Production Design in 3D Computer Animation: Multipurpose and Polymorphic Stages for Efficient Production Frameworks

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A special thank you
to my adviser Professor Mike Dawney, and to my project consultant Dr Anastasia Dimitra.

Disclaimer

The views expressed in this document are mine and are not necessarily the views of my supervisory team, examiners or Middlesex University.

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Glossary

2D Graphics: Flat digital images.

3D Graphics: Objects in digital space that usually appear to have volume.

Acting areas: The places on a stage where characters can be positioned. Supernumerary actors such as background spectators may be outside the acting area.

Aesthetics: From the Greek word αίσθηση - feeling. In this project I explain how certain Mise-en-scène choices can support narratives in film sequences. Control over film elements enables causing emotional responses to viewers such as in thrilling or moving films.

Atmospheric Effects: Spatial effects such as fog, dust, and fire.

Bitmap: A digital image that comprises of square pixels. Digital cameras and image scanners commonly capture bitmap data.

Bump mapping: A technique in 3D computer graphics that enables simulating low relief on smooth surfaces. Bump map images indicate how light affects different areas of a surface and can make it appear to have indentations.

Camera motions: truck (the camera moves sideways), **dolly** (the camera moves in or out).

Camera tilt: The camera is tilted upwards or downwards in **low angle shots** and **high angle shots.**

Displacement mapping: A technique in 3D computer graphics for converting a bitmap into a polygon surface with geometrical relief.

DOF: Depth of field refers to lens focusing in photography. A shallow depth of field can make objects at certain distances from the camera appear blurred.

FOV: Field of view refers to the angle of view. A wide field of view can be achieved with a wide photographic lens.

Global illumination technologies can simulate **physical lighting** by taking into account how photons are emitted from a light source and how they react to objects. The computational process involves calculating the trajectory of photons as they bounce off of surfaces or as they pass through transparent or translucent objects.

Keyframes: Keyframes can contain data concerning attributes such as space coordinates of an object. An object can have two keyframes that are positioned on different points of the timeline, each containing different space coordinates so as to enable the computer to automatically calculate in-between animation frames. Other animated attributes that can be changed with keyframes include the colour and intensity of a light.

Lighting technologies: 3D objects can appear to be illuminated with the use different computational methods.

LOD: Level of detail usually refers to the amount of detail in a 3D model and its textures. Although Low LOD can be appropriate for objects without a prominent position in the frame, a close-up shot may look as if the object has poorly defined geometry and texture.

Look-at system: The orientation of an object with a look-at controller depends on the positioning of another object. The object with the look-at controller can keep facing another moving object similar to how an eyeball rotates when the eye is focused on a moving object.

Materials: The properties of materials enable us to control the appearance of 3D surfaces such as the colour and the shininess of surfaces. Advanced material systems enable specifying how transparent objects refract light such as diamonds which have a different index of refraction than glass.

Mise-en-scène: (French) refers to placing things on a stage.

Modular: We can assemble a 3D object out of smaller parts called modules.

Multipurpose: Something that can cover multiple needs. This project deals with multipurpose stages that provide diverse shot compositions from different acting areas.

Polygonal modelling: 3D shapes can be made out of polygonal surfaces that comprise of faces, edges, and vertices. We can reshape a model by repositioning vertices.

Polymorphic: Something that can take different forms. The elements of a polymorphic stage can be repositioned to give the appearance of different places.

Rendering: The conversion of 3D graphics such as textured meshes into the bitmap images that are film frames.

Shading: A 3D wireframe can be shown as a surface. Shading will make the material react to lighting so that it appears as metal, plastic, cloth etc.

Shadow mapping is a technique that enables a light to cast shadows while typically consuming considerably fewer computational resources compared to ray traced shadows or to indirect illumination. The Shadow mapping process involves projecting a bitmap from where a spot light is located. The projected image acts as a mask that indicates the areas of 3D surfaces that are in the shadow.

Shot: When we press record on a camera we are capturing a continuous video clip that can be called a shot.

Stepped keyframe: A type of keyframe that can make an object abruptly change position at a point in the animation timeline. Stepped keyframes enabled changing the positioning of scenic elements at the moment between consecutive shots in animation sequences.

Texture mapping: Bitmaps enable controlling the appearance of 3D surfaces. For example, we can use a picture of a brick wall to make a plane appear to be made of bricks.

Toon Shading: Enables making 3D surfaces appear as if they are made with ink and paint when rendered.

Test Rendering (in computer animation): The process of creating image previews to evaluate the effect of implemented actions on the product. Testing trials can be part of multiple cycles that consist of previewing, assessing, and refining. Testing can be focused on improving specific elements such as lighting, texturing, framing, or animation.

Abstract

The potential to enhance production efficiency in computer animated films was explored holistically by designing multipurpose stages for two films.

Certain cases demonstrate static stages with stationary scenic elements that are laid out according to ground plans with multiple acting spaces which share a common background theme. The multiple case study also deals with dynamic stage elements which enable differentiating the mise-en-scène for varied shot compositions. Specific object repositioning systems enable managing a limited number of scenic elements in order to increase the usefulness of stages. Reusable objects that internally comprise of modular elements are shown for their ability to reappear reassembled and differentiated at different moments during a sequence. Productivity advantages deriving from reusable stage objects include reduced modelling workload, and limited computational loads due to the restricted amount of stage geometry. Computational optimisations facilitate working with an economical technical infrastructure as they enable reducing latencies deriving from the execution of digital processes.

Making films with a reduced number of stages enables working with a limited number of project files and with a less fragmented workflow. A stages that enables managing multiple scenes on a lengthy animation timeline can provide a centralised overview of production progress. The presented stage design rationales are not restricted to specific visual themes or styles as their operation does not rely on surface colours. For example, systems demonstrated within the salt lake stage are most likely applicable in an alternative arctic environment theme with similarly shaped geological features. Moreover, the presented multipurpose stages enabled making scenes that feature types of travelling actions commonly found in animated films such as running, driving, and flying.

The outcomes guide designers through organisational and creative options that enable realising respectable computer animated films with optimal use of production resources.

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Chapter 1: Introduction

The research problem

Stages, in computer animation films, are seen as systems that have an impact on production economy. Although films comprise of a mixture of tasks concerning multiple design disciplines, the explanatory analysis of data focuses on how multipurpose stages can be designed so as to achieve enhanced production efficiency.

I explored the subject by making narrative computer animated films which were the source of primary holistic data. The resulting stage layouts and management systems enable framing common types of action in various environmental themes. Consequently, the presented techniques can potentially be adopted by other designers and be applied in a range of unique production scenarios.

Research project distinctiveness/originality

Narrative films customarily portray stories in original ways. However, the originality of a product does not mean that the production methods are also unique. For example, one stage system can support making differently themed environments with a common mise-en-scène, for example the framing of a traveling actions viewed from a tracking camera.

Each studied case is a presentation of a separate system that enabled covering specific actions from certain camera angles. The visual theme of each stage relies on the appearance of surfaces which can be differentiated. The information in this project is more concerned with how objects are managed and less with decisions regarding shapes and colours as the point is not to show how to replicate a visual style.

A traveling action can comprise of potentially different subjects and environments such as bicycles, cars or horses within forests or cityscapes. The information presented in cases of stages that enabled making walking scenes within forests can be applied for displaying similar actions in cities.

A scenic element management system enables handling objects that vary in theme. For example, background surfaces depicting a mountainside and a skyscraper could be handled in a similar way. In practice, a stage system can host both a walking character on a forest path and on a pavement. This would entail differentiating the appearance of surfaces such as a background wall of trees, a dirt path and shrubs in the forest would respectively appear as a building wall, pavement tiles and dustbins in the city.

The categories of actions covered in this project include traveling in the form of running, driving, flying and walking; dialogues and action scenes with a ranging number of characters while sitting, standing or traveling provides examples of commonly applied framing practices.

Efficient production frameworks which are built around multipurpose stages have been implemented before I started this project. Although animation films in general offer observable clues regarding how their stages could have been made, relying on this data source would provide fragmentary information. The primary data in this project offers a clear understanding of how design choices affect production.

The collective knowledge in this project comprises of common industry practices and of new systems such as ones that enable managing dynamic modular scenic elements.

Multipurpose stages are demonstrated for their role in project management and, ultimately, for enabling the creation of high-quality products at reduced costs.

Fundamental terms - working definitions

Single-purpose stage: A stage built for documenting a single type of character action such as for a dialogue scene, or camera action such as for an establishing shot.

Multipurpose stage: A stage that can host two or more significantly different points of view. Inclusive versatile stages can provide enhanced production efficiency as they enable displaying different backgrounds, thus enabling the creation of sequences with diverse shots without excessive project file fragmentation.

Polymorphic stage: I have introduced this term to refer to a type of multipurpose stage that dynamically changes in form to meet the needs of different shots. Polymorphic stages contain modular scenic elements which can be repositioned so as to provide different frame compositions for consecutive shots that may appear to be located in different environments.

Homogeneous modular elements enable providing diverse appearances of a themed environment. Reusable and flexible scenic elements can reduce the amount of stage geometry and thus enable limiting the requirements on computational resources.

The purpose of this project

This project is based on the assumption that productivity can be enhanced by the design of stages that provide multiple acting spaces and framing options.

Several design approaches are presented which have enabled the economical production of computer animation films.

Although the design of versatile stages is not new, there is little theoretical documentation on the subject. Upon close observation of computer animation films it is possible to notice multipurpose stages being used. However, the available data on such cases, in the form of interviews, articles and commentaries is often superficial. The multiple case study took advantage of a primary source of data which enabled identifying causal relationships between certain practices and their effects on production efficiency. The presented cases deal with the rationale of planning choices and provide a retrospective analysis of the resulting products.

Attention was given to 3D asset management and optimisation so as to minimise negative effects on productivity deriving from delayed executions of digital processes.

Methods for reducing stage geometry were documented during the course of designing and implementing multipurpose stages. The potential of repositioning scenic elements for achieving increased scenic optimisation was explored by designing systems that progressively provided knowledge on ways to take advantage of moveable objects.

The exploration of uses for moveable stage objects led to developing the polymorphic stage design process that aims to exploit dynamic modular elements. Polymorphic stages can dramatically change in form so as to adapt to the framing needs of different shots.

Polymorphic stages takes advantage of a combination of known modular design practices and of the ability to change the positioning of 3D stage elements between shots with keyframes.

The polymorphic stage rationale is demonstrated with a case that features modular mountain elements that, in varied arrangements, create the appearance of different landscapes. This system derived from primary research and is considered to be innovative. However, possible previous implementation of similar systems cannot be ruled out as efficient production practices can be guarded as trade secrets

Project outline

In 2003 I designed an inclusive stage, for a 3D computer animated TV commercial that contained eight separate environments. This setup enabled implementing efficient production progress review cycles through the ability to observe eight film sections of the film at once. The setup also provided immediate access for editing any part of the sequence.

The multiple case study relies on holistic data gathered from designing and working with new multipurpose stages. The concurrent observation of inclusive stages and end products, in the form of films featuring a number of locations, enabled identifying the conditions that affect production efficiency.

Multipurpose stage design was an integral part of production planning. The form of each stage, in the multiple case study was determined with top-view drawings. However, the implementation process, with 3D computer graphics, consisted of cycles of evaluation and progressive refining.

The data concerns production planning, stage development, and end products. Stage plans that cover a range of production scenarios, were developed into 3D computer environments, and the visual output of each stage was progressively refined.

The presented systems make use of common tools found in multiple computer animation applications. The findings are concerned with a mind-set that affects decision-making regarding the form of the stage, and the rationale of optimisation systems. The execution process, the optimisation measures, and consequently how the tools are used differently is driven by planned production strategies. The explanatory analysis of data is focused on how systems work rather than on the reasoning behind the shapes and colours of scenic elements. The outcomes this way enable the reader to broadly adopt the presented practices without being limited to applying specific visual styles.

Research Questions

The main purpose of this project was to obtain new knowledge regarding the design of multipurpose stages. Primary data from my past animation projects suggested that combining multiple environments in the space of one 3D project file can simplify production management, and facilitate certain production tasks.

The following preliminary research question provided direction to this research project:

- Based on the researcher's professional experiences: How did multipurpose stage design affect productivity during the making of the TV advertisement INFOTE-GBN (2003)?

Two types of multipurpose stages enabled addressing multiple and diverse shots efficiently in 2003. Observations from previous uses of multipurpose stage systems resulted in propositions that were the basis for initiating a targeted exploration of the subject.

The exploratory research phase of this research project aimed to answer the following questions:

- How can multipurpose stage design benefit computer animated film production?
- What limitations are observed when working with multipurpose stages?

During the explanatory phase I addressed:

- How can optimised 3D graphics in multipurpose stages benefit production efficiency?

The presented cases revolve around how certain multipurpose stage systems enabled achieving the results seen in two films. The analysis provides inferences concerning the implementation of certain design rationales in different production scenarios.

A concern throughout this research project was the sensible allocation of computational resources. Computer animation productions often consume vast amounts of processing power. Multipurpose stages can have increased computational requirements due to the presence of different environments on a stage that are likely comprised of a larger number of scenic elements. This project explains how I was able to contain all the production requirements within a limited computational capacity. The presentation of stages addresses 3D graphics optimisation through embedded stage systems that enable optimal display of scenic elements.

Project background

Introduction

My previous experience in making multipurpose stages formed the foundation for expanding my understanding of the subject by making new stages that affect production efficiency in different computer animation scenarios.

TV advertisements that deal with promotional communication may concern the immediate announcement of the availability of products such as a new car that is ahead of competition. Apart from tight production timeframes, low production costs can also be key for producers and clients to reach an agreement.

A TV commercial that I undertook in 2003 involved such a challenging concept that made it difficult to deliver the film on time or with profit unless I had an efficient production plan.

My experience in real-time 3D applications and visualisation provided an understanding of how objects can be purposefully positioned to create views of terrains and buildings with optimised 3D graphics.

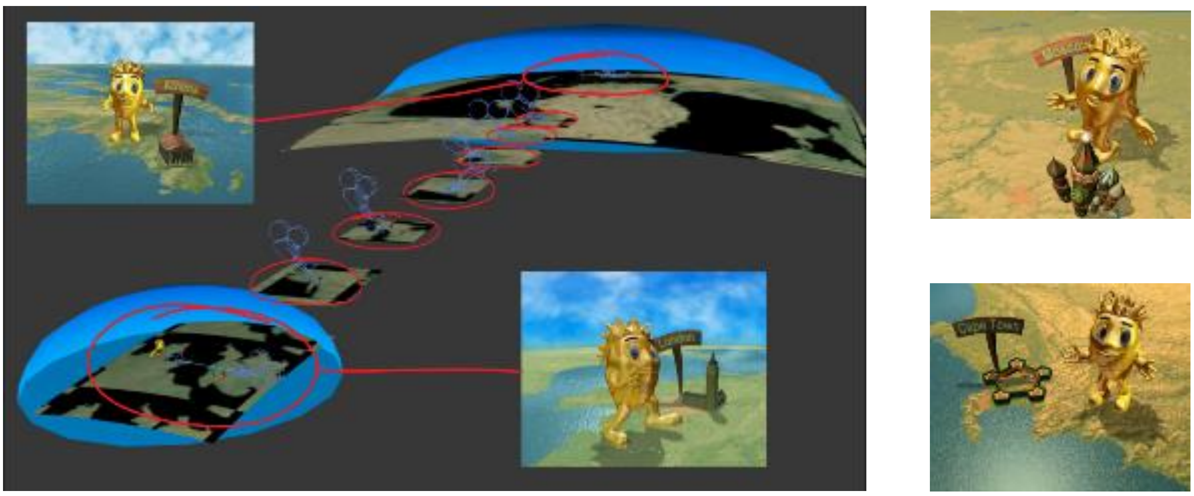
Multipurpose stage retrospect – Case: GBN – Infote (2003) TV advert

In 2003 I was commissioned to make a TV commercial which promoted directory services of Infote S.A which at that time was owned by Hellenic Telecommunications Organisation S.A. (OTE).

The production framework enabled me to compose shots of multiple environments that exist on two multipurpose stages. The ability to work on multiple shots with a single 3D project file enabled me to:

- Alter the lighting and rendering style of multiple shots en masse with one common setup.
- Export sequential shots of different environments with sole render jobs.
- Directly manage 3D assets within a reduced number of project files.

Multipurpose stages enabled making adjustments that affected multiple shots at once, thus reducing production costs compared to the alternative of having separate stages for every presented environment.



Stage and screenshots from TV Advertisement: GBN – Infote (2003)

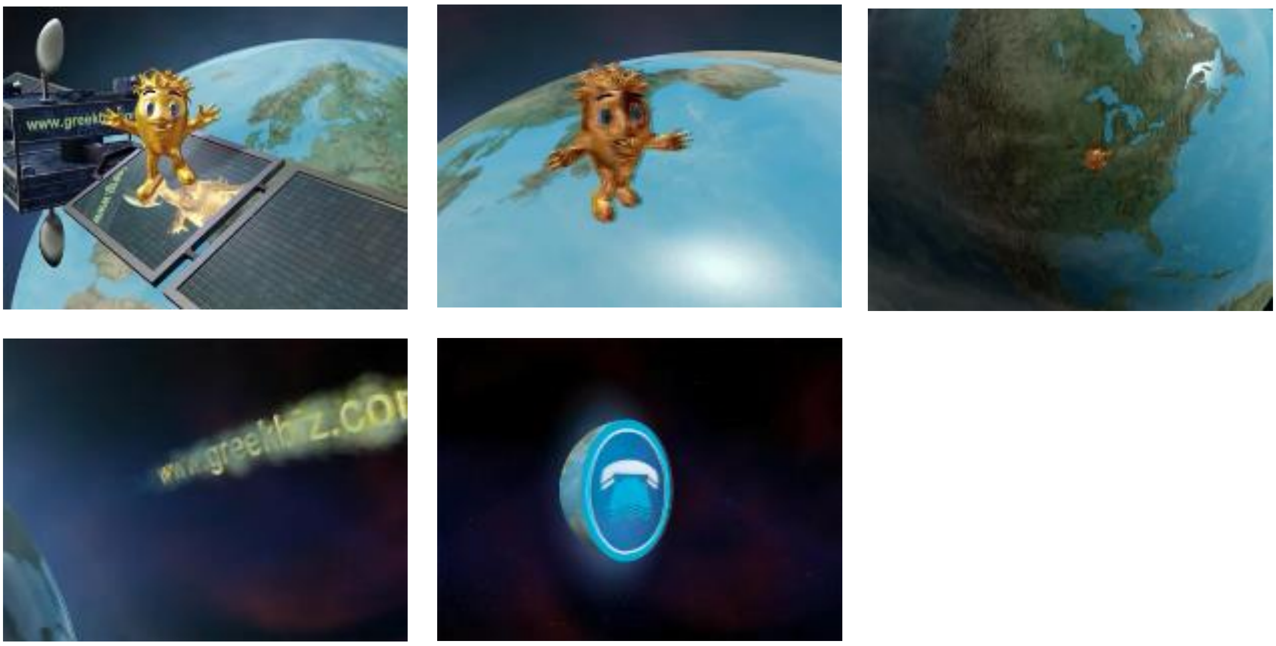
One stage enabled making a character appear to visiting eight separate geographic locations. The size of each patch of terrain coincides with the boundaries of the frame of each shot. The size of the texture maps of each ground surface was optimised for the output video resolution. As such, the stage to provide well defined surfaces without requiring excessive computational resources. Two sky domes in the first and last patches of land enabled me to include the horizon in the frame. The remaining six sites required smaller areas of land to fill the frame due to the camera being placed at higher angles.

Although the coexistence of separate environments added computational weight to the stage, this approach provided improved project management and increased productivity.

The second stage was used for covering the action from space in five shots that feature the same background elements of a terrestrial globe and a starry backdrop.

Having shots with common background objects enabled having a stage with a limited total number of scenic elements that had a positive effect on computational demands.

A recurring subject in the multiple case study concerns the ability to manage a limited number of scenic objects which feature as parts of different environments.



GBN – Infote (2003). Screenshots from 2nd stage.

In practice, the case indicates that multipurpose stages can provide cost effective revision cycles stemming from the remarks of directors, clients and producers. Such remarks could concern changes in lighting and textures as well the appearance of a character who could be made to wear an accessory once with changes being automatically applied to a series of shots.

After the having delivered the film, the client requested on a Friday an additional version in which the mascot was replaced by a flying logo. The client received the additional film version on the Monday that followed as the task mainly consisted of replacing the character in only two stages, followed by two 3D rendering assignments.

Real-time 3D environments retrospect

In the early 2000s I made environments for real-time 3D games. My B.A. (hons) research project involved designing and developing an action game level situated in an underground village near a river of lava with three walking characters. I also made 3D environments, characters and vehicles for interactive web applications and games for Digital Publications S.A. in Greece (subsidiary of Space Hellas S.A.). 3D web games had to have small file sizes so as to enable downloading the content with dialup connections within reasonable times.

The experience in making lightweight 3D objects with high visual impact enabled me to make optimal use of geometry and texture maps while making the animated films that are presented in this project. Optimal use of computational resources can limit hardware and infrastructure requirements and uncontrolled processing power consumption can slow down operations.

Scenography for films and level design have similarities as both often feature avatars and cameras moving through 3D environments. However, levels for racing or action games often feature terrains that allow the camera to continuously travel over large areas, whereas stages may only have to give the impression of an environment from specific viewpoints.

Real-time 3D graphics technologies

Technological improvements over time have enabled displaying 3D graphics with improved technical quality. Videogame developers are able to make applications that can display impressive 3D graphics in real-time on gaming devices. Although game engines are not commonly used for making animated films, the general principles of geometry, textures and cameras are common in both industries.

The quality of real-time 3D lighting on contemporary gaming consoles is lower than what can be expected from tools that enable making pre-rendered photorealistic architectural visualisation.

Global illumination is a computationally intensive process that enables simulating how light rays bounce off of surfaces. The use of global illumination is still hard to justify on the limited processing power of gaming devices. However, parallel computing enables professionals to access processing power on a wholly different order of magnitude. A single shelf on a computer rack that holds ten graphics processing units can complete rendering tasks significantly faster than a workstation. The processing power of a rack can be scaled up linearly by adding computing devices.

Certain professional 3D graphics applications enable rendering a scene with global illumination on graphics processing units that are similar to those used in gaming computers. Most scenes in Agrinoui (2015) were rendered on a small scale parallel computing system with two graphics cards at a rate of approximately one frame per two minutes. During the production of Agrinoui preview rendering of sequences was made at a quarter of the final image quality at half a minute per frame.

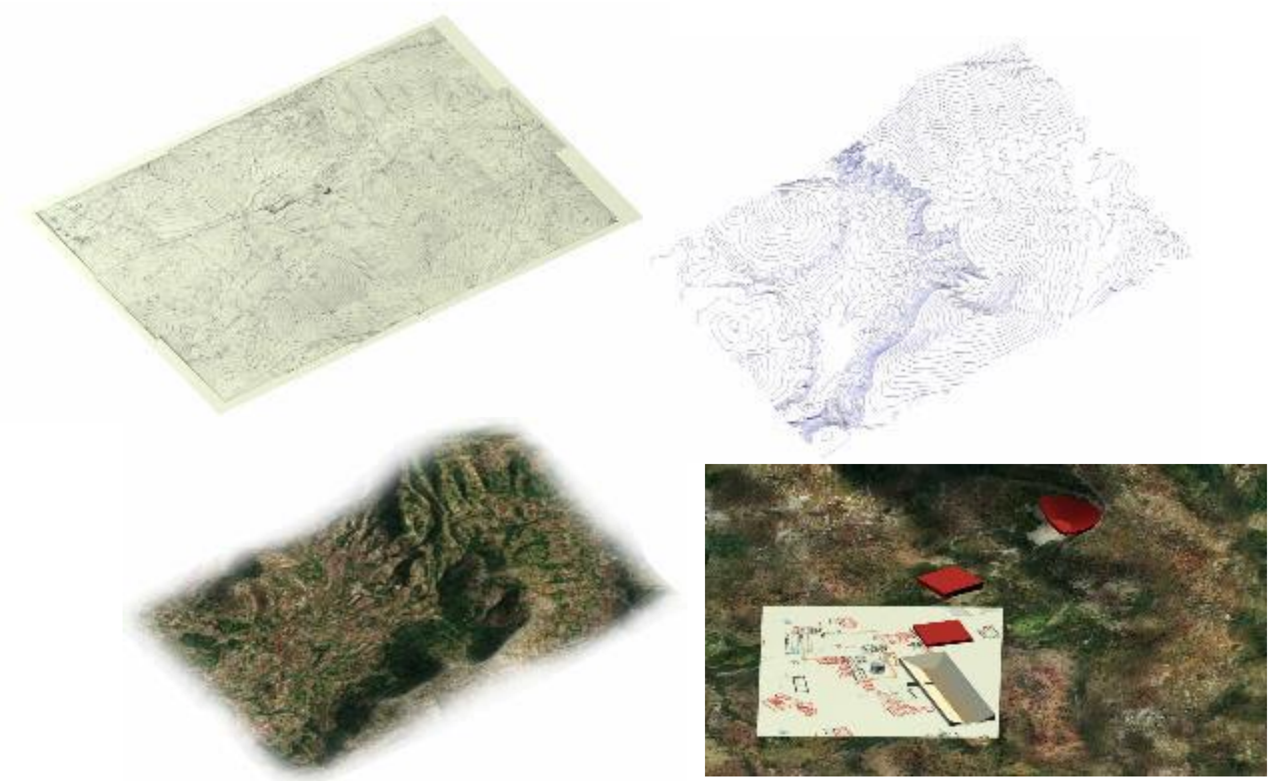
The processing power required to render film previews in real-time would be equal to approximately 1500 graphics cards from 2014. The ever improving efficiency in hardware and software tools consequently leads to a constant drop in the size and the cost of such installations.

I believe that productivity advantages can be found, especially for creators of animated TV series, with the ability to review the progress made with high image quality while making edits on the spot, and by being able to export film sequences with minimal delays.

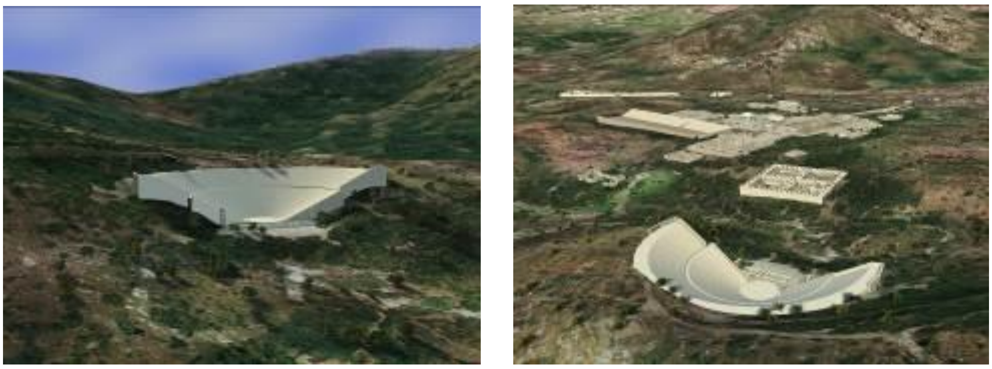
Visualisation retrospect

In 2006 I undertook a visualisation project for the Greek ministry of culture. I started making the 3D representation of ancient Epidavros by scanning detailed topographic maps.

I proceeded with converting the contours into terrain elevations and I edited aerial photos to make the texture. I then used archaeological architectural documents and maps for making models of ancient buildings and for positioning them on the terrain.



Images from the making of the visualisation of ancient Epidavros (2006)



Screenshots from the flythrough presentation of the ancient city of Epidavros (2006)

The visualisation project offered a high level of accuracy of positioned objects enabling scientific observations. However, a film stage may not need to have a high level of accuracy as perspective views make it hard to measure distances or to perceive small variations in object sizes.

Although a digital film set can have the form of a realistic terrain, most sets do not need to appear correctly from all angles as films normally have specific framing needs. A set that is designed for framing specific shots, can have a terrain topology that would look unreasonable from other viewpoints. Working with known camera positions enables assigning increased detail in areas that need it most such as foreground objects that occupy a large area of the frame. Conversely surfaces, such as the back side of a hill, that are not visible to the camera can be omitted.

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Chapter 2: Terms of reference/objectives

Introduction

Scenic design is one of several disciplines that together enable making computer animated films.

Howard defines scenography as:

> *"the seamless synthesis of space, text, research, art, actors, directors and spectators that contributes to an original creation." "Scenography is always incomplete until the performer steps into the playing space and engages the audience".* (Howard, 2002)

Stage design is studied in practice as an integral part of computer animation projects which consist of the combination of multiple media and of sequences of different locations which are edited together to form a film.

In the following review we will see information relevant to the research subject that stem from common practices in new media as well as from non-digital production methods.

Although this project is concerned with making digital stages, the planning process entails thinking about issues beyond the technical scope of 3D computer graphics such as an understanding of how the positioning of flat or 3D shapes in space affect frame composition.

Systems developed by pioneers such as Lotte Reiniger, Fleischer Studios, Disney Studios and Charlie Chaplin Studios in the early 20th century are relevant as traditional methods can be transported into virtual space. References to analogue systems enable thinking about 3D graphics beyond the scope of digital tools but in terms of perception of space projected on a flat screen.

A historical retrospect addresses technological milestones as 3D graphics evolved over the years, indicating both steady fundamental principles as well as achievements that took place when innovative production methods and improved production tools were introduced.

The review also addresses common practice in the fields of preproduction for computer animated films as well as production pipeline, modular design, image quality and 2D-3D mixed media techniques.

Examples of 3D environments of notable feature films and TV series provide supportive information that connects contemporary practices in the film industry with this project.

Review of relevant literature and practice.

The literature review contains information regarding the practice of making 3D environments for computer animated films within the context of art and design disciplines that are connected to the research subject.

The review refers to non-digital filmmaking techniques that create an enhanced perception of depth in the image which can be replicated with computer graphics. On the one hand, knowledge on how forced perspective works enabled me to limit the size of the stages that are studied in this project. On the other hand, the ability to generate graphical perspective with flat scenic elements enabled me to make cost-effective 3D objects.

Examples of art direction, mise en scéne, and editing in live action and animated films are examined for their ability to communicate story concepts. This project contains case studies that explain how certain stages provided visual outputs that support the communicational needs of scripts. Stage design decisions, within the larger context of productions, are normally affected by the need to support a common concept that is shared with other departments such as music and character animation.

I have explored the practice of making stages that contain more than one acting area, and that provide multiple options for camera placement. Stages that can host multiple actions can be used for making longer animation sequences.

A historical review of the evolution of 3D computer graphics shows how they started being used in effects scenes for live action films in the seventies, and how fully computer-generated productions appeared in the early nineties.

The dramatic improvement of hardware and software over the years enabled me to work towards achieving productivity gains by working in a different way. I took advantage of the enhanced processing power of workstations to come up with a streamlined production approach that enables reducing the number of stages needed to make a film. Stages that can host action in multiple locations offer project management advantages such as the ability to make long animation sequences with few project files.

This review highlights 3D asset management and optimisation practices that positively affect productivity in animated films and video games. I was able to increase production efficiency by creating computationally light scenic elements that were shown multiple times within the films that are presented in the multiple case study.

The perception of depth in analogue animation systems

Techniques developed in the early 20th century provide an enhanced sense of depth to the animated picture and are still relevant today.

Lotte Reiniger developed a system gave a sense of moving through space. The system consisted of a rostrum camera and layers of semi-transparent images that could move independently from each other.

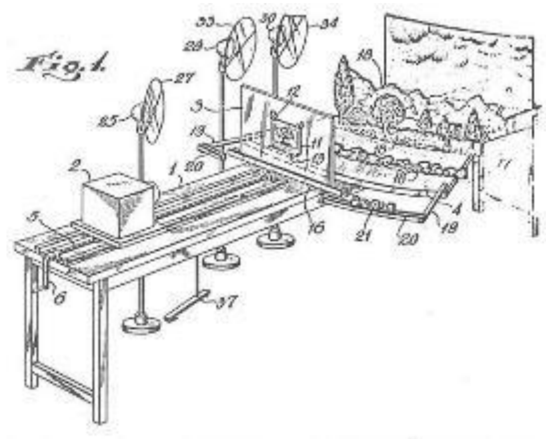
In the following scene the horseman flies through painted layers of clouds that move across the frame at different speeds to create a motion parallax effect that simulates camera motion.

Adventures of Prince Achmed (1926)

More sophisticated systems based on the same principles were developed in the years that followed such as the Multiplane Camera system that was used in popular Disney studios productions since 1937.

Walt Disney presents the Multiplane Camera used in Bambi (1942)
from Disneyland (TV Series), Episode: Tricks of Our Trade (1957)

Stereoptical systems developed in the 1930s included three-dimensional scenic elements to provide an enhanced sense of volume.



Technical drawing of a Setback system (1934) at the Fleischer Studios.

The above setup enables the camera to approach the subject by performing a dolly movement. The Setback combines 3D scenic objects with a 2D layer of animated characters in the foreground and a flat image as a backdrop.

Differentiated versions of the Setback system enabled making sequences with diverse subjects and camera motions. In the next example the camera appears to track sideways.

Film: Little Swee'Pea (1936)

As the camera follows the subject, the 3d models of buildings have an enhanced sense of volume that distinguishes the Setback from the Multiplane Camera system. Both aforementioned systems provide an enhanced sense of depth by creating a motion parallax effect.

The principles of analogue systems can be transferred into 3D computer graphics. Several systems presented in the multiple case study rely on single-sided surfaces that face the camera and explain how 2D and 3D elements can be combined within in digital space with computer graphics. The scenery in my films was generally designed to appear correctly only from the point of view of the camera. Production efficiency was enhanced by not creating the side of objects facing away from the camera. The benefits include having a speedier modelling process and faster processing speeds. Although flat scenic elements can limit camera movement, my films present design solutions that enable a range of camera motions.

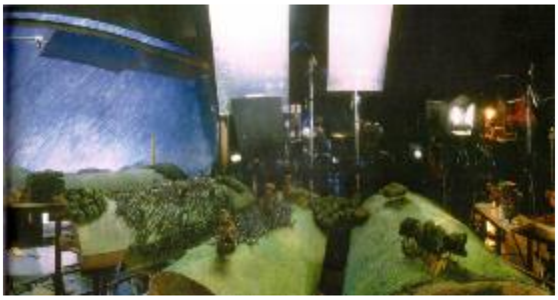
Stop motion animation

Stop motion involves the positioning of physical objects on a stage that is often at table height. The Aardman book of 3D Animation reveals how sets were created for several of their film and television projects:

> *"Outdoor sets are generally bigger and more difficult because you have different layers from front to back, and this all takes up a lot more space than a room [interior] set".*
> (Lord and Sibley, 1999)

In stop motion animation, it is often necessary to make environments appear larger than what they really are. The ability to make a horizon appear distant while using a limited amount of stage space has been a concern for this research project.

Film: Wat's Pig (1996)



3D set for stop motion animation at Aardman studios. Lord, P. & Sibley, B. (1999)

This stage covers the needs one view and the colour of distant layer of mountains are less saturated to provide a sense of atmospheric perspective. The sense of depth is enhanced by giving a limited motion to the camera. The form of the outdoor set influenced how I approached the design of the savannah stage for Struthio (2011) (see chapter 4, page 111).

Stop motion animation and 3D computer animation stages share the same principles in terms of occupying 3D space and camera positioning. I was intrigued by how separate semi-cylinders could look as landscapes in still shots, and by how they appear during pedestal camera motions. I explored with computer graphics the potential of making land surfaces with separate terrain elements for the use in stages with multiple acting areas and usable points of view.

Concept art and using 2D film projection means for presenting 3D worlds

Film: The prince of Egypt (1998)

A 2D painting can convey perception of depth by incorporating graphical and atmospheric perspective, and lighting can further enhance the perception of separation between objects.

Layered objects with different colour schemes can provide sense of separation between them. The sense of depth can be further increased with chiaroscuro effects that provide contrast between lit and shaded areas.

Dutch Painter Piet Mondrian stated:

> *"Observing sea, sky and stars, I sought to indicate their plastic function through a multiplicity of crossing verticals and horizontals. Impressed by the vastness of Nature, I was trying to express its expansion, rest and unity."* (Moszynska, 1990)

Mondrian made a note in his sketchbook around 1911 stating:

> *"The surface of things gives enjoyment, their interiority gives life."* (Seuphor, 1964)

Although a landscape can appear to be realistic, interiority can be interpreted as how a concept is communicated in ways that cause emotions. For example overcast weather could make a battlefield appear sorrowful, but flowers and birds could make it feel hopeful. In films the appearance of surfaces act as a visual communication medium that can amplify the effectiveness of storytelling. Other film elements that help communicating the concept of a scene include acting and music.

Claude Monet said:

> *"Landscape is only an impression, its appearance changing at every moment."* (Met, 2009)

The haystacks series of 25 paintings concern a study of the appearance of the same subject under different lighting conditions, varying weather conditions and seasons.

This research project deals with showing certain stages on separate occasions with different lighting conditions. Lighting can differentiate the appearance of an environment and can be an economical way for providing visual diversity to a film.

In the following part of an analysis of painting choices of notable painters, the writer provides examples of several styles such as Hyper-realism or simplified stylisation.

> *"Looking at paintings, especially, emphasises that there are many different ways in which to express the same things. These different expressions are what begin to create 'style'."* (Demers, 2001)

The multiple case study deals with two films with individual styles. The style of surfaces remained consistent throughout the duration of each film. The common style of different stages enabled cost effective shared use of scenic elements such as trees and clouds that reappeared in different scenes.

Ansel Adams on expression in photography:

> *"I know some photographs that are extraordinary in their power and conviction, but it is difficult in photography to overcome the superficial power or subject; the concept and statement must be quite convincing in themselves to win over a dramatic and compelling subject situation."* (Adams, 1996)

Concept art for films are planning documents that affect the visual communication of a scene through purposeful combinations of shapes and colours which complement more direct storytelling tools such as dialogue and the actions of characters. The appearance of an environment can not only affect the mood of a scene, it can also direct the attention of the viewer to points of interest that can be illuminated in order to stand out.

Jeremy Birn instructs on cinematic principles which include composition, staging and lighting in digital productions. He noted on layout:

> *"Good composition and staging are key ingredients in any compelling professional image. In effect, they act as subtle cues from the director, helping guide a viewer's eye. Composition and staging are governed by a set of artistic rules and cinematic conventions that you can apply in 3D graphics when adjusting your camera, lights, layout, and animation."* (Birn, 2006)

It has been noted that:

> *"The director's job is to make it all work. I have three rules: 1. Be simple. 2. Be clear 3. Put everything where you can see it".* (Williams, 2009)

Stage objects that do not serve the concept or the story can unnecessarily draw the attention of the viewer, for example, an irrelevant red mailbox on a pedestrian. Indiscreet visual effects can also distract viewers who could lose their immersion into the story due to being drawn into thinking how the film was made.

Production efficiency – reuse of assets

Production efficiency can be enhanced by the reuse of elements which can be redisplayed in different parts of a film.

Charles-Émile Reynaud invented the "Théâtre Optique" film system which enabled animated images of characters to be projected onto a separate still backdrop image.

The following two frames from the film Pauvre Pierrot feature the same drawing of a character that reappears in reverse.

Film: Pauvre Pierrot (1892)

Traditional cel animation, like the Théâtre Optique, operates on the principle of superimposing layers of animated drawings. In cel animation the background images are usually still paintings which can be stored and reused in separate scenes.

Similarly, when a stop motion animation stage is dismantled, the scenic elements can be stored to be reused or repurposed for another set. Moreover, theatrical flat scenery, which was used in passed plays, can be repainted and used again in different productions.

The films in this case study contain objects that appear multiple times. The discrete reuse of available assets can increase production efficiency. This project presents how the reappearance of scenic objects can be made unnoticeable to the audience by changing certain properties of an object prior to being displayed again.

Side notes:

Cel animation enables using a set of drawings for displaying repetitive character action cycles such as walking. The same drawings of facial poses can be shown multiple times for displaying talking action.

Groups of cells which display frequently used actions can be stored in an order which enables locating them for reuse in more than one scenes.

The reuse of objects can also be found in stop motion animation substitution techniques which involve replacement of entire puppets or their parts.

Scenography Fundamentals

A statement in The Cambridge Introduction to Scenography:

> *"Scenography is not simply concerned with creating and presenting images to an audience; it is concerned with audience reception and engagement. It is a sensory as well as an intellectual experience, emotional as well as rational."* (McKinney and Butterworth, 2009)

Modernist scenographer pioneer Adolphe Appia advocated three elements as fundamental to creating a unified and effective mise en scene:

> *"1, Dynamic and three-dimensional movements by actors. 2, Perpendicular scenery. 3, Using depth and the horizontal dynamics of the performance space."* (Brockett, 1994)

About theatrical scenic design:

> *"Any variation of shape, structure or design does not alter the fact that we have to have something vaguely horizontal for people to stand on and something sort of vertical behind them to create a believable environment to tell our stories."* (Napoli and Gloman, 2006)

The most common building blocks for theatrical stages are horizontal platforms and vertical backings, drops and flats which are usually painted surfaces that help define a setting.

The multiple case study features the application of common principles regarding artistic unity and management of performance space on digital 3D stages. The speedy positioning of moveable flat panels on a theatrical stage can occur during a short pause between acts. I explored a similar approach to handling scenic elements with 3D computer graphics for composing different shots. This project demonstrates a dynamic type of digital stage in which scenic blocks instantly change position when the camera cuts to different points of view.

A custom-made façade can obtain a unique appearance at a significantly lower cost compared to making utilitarian buildings. Moveable flat scenic elements enable a set to be constructed within a limited timeframe, and offer options for repurposing and storage.

Similar to the use of façades in film and theatrical flats which are usually faced towards the audience, I also placed single sided digital surfaces so as to create a spatial impression only from the camera's point of view.

Scenography: Common practice

Forced perspective

Stage objects can appear to be larger than the space they actually occupy. Perspective manipulation has enabled making practical effects shots with miniature models such as exploding buildings. One advantage of tangible scale models is reduced construction costs. Moreover, the smaller scale can be decisive for the feasibility of animated effects shots such as busting dams or battling spaceships. Such scale models can be designed to fit within the internal space of a studio that provides controlled weather and lighting conditions. These advantages, however, do not apply in digital 3D stages. The stages in the multiple case study made use of forced perspective to avoid technical and management difficulties that stem from working with excessively large 3D environments.

The following pressed perspective example shows that a building can appear to be larger, when it is seen from the ground level, by making the windows of higher floors smaller.

Documentary TV series: Modern Marvels episode: Walt Disney World (2005)

Digital backgrounds: Methods for parallax effects

In contemporary productions, the Multiplane Camera effect can be replicated digitally with the use of compositing software. The process is in both cases involves animating independent layers of images.

In the following example, the 2D layers of waves have independent motion. The sense of perspective has been created by making the distant waves smaller.

Film: The History of the Devil (2007)

Referring to post-production, it has been noted:

> *"Matte painting for the moving camera: Correct perspective has to be carefully built into matte paintings to create a convincing illusion of depth."* (Kelly, 2000)

Video compositing enables making separate image layers move sideways at different speeds to recreate a tracking shot that focuses on a travelling subject. In contrast, a motionless 3D stage can host traveling cameras to create shots with motion parallax.

A horizontal terrain surface can be useful for placing vertical planes depicting trees. Although the positioning of 2D images in space involves a simpler process compared to making 3D models, flat surfaces can limit the range of camera motions due to the risk of revealing the lack of inherent object volume.

The following example contains a ground surface and upright images of mountains, trees, and buildings.

Film: Thrive: What On Earth Will It Take (2011)

Digital backgrounds and compositing

In many cases the area of a stage where characters are positioned can be handled separately from the background. Compositing techniques enable merging foreground and background elements to form a single image.

A 2D painted backdrop with a fixed perspective can limit the range of camera positions. Such limitations can be overcome by making additional matte paintings according to the framing of each shot. As backdrops are usually combined with a foreground image it is important that both elements have matching perspective and lighting.

Digital painting and photo editing tools enable working with layers of images; each group of layers may depict an object such as a tree or a building façade. The cost of creating additional views of an environment can be reduced by repurposing elements such as a copied tree that can become part of multiple backdrops.

Image layers can also be combined within compositing software that enables applying motion independently to obtain motion parallax by simulating the analogue multiplane camera system. Although compositing techniques enable making shots featuring camera movement, a stack of multiple layers on the compositing timeline can be challenging to manage. As such, the amount of work associated to creating individual shots makes extensive use of compositing difficult to justify in the production of TV series.

The multiple case study deals with 3D stages that can host moving cameras enabling the output of single-layered image sequences. When a multipurpose 3D stage is used for producing several minutes of film, it can become an economical alternative to compositing individual shots of only last a few seconds.

3D environments - Mixed media

A digital 3D stage can comprise of both painted planes and 3D objects. The 3D buildings in the following crane shot maintain correct perspective throughout the shot. This is witnessed by observing how the appearance of the sides of box shaped structures changes during a tracking shot.

The change in internal perspective is less noticeable when objects are further away. Therefore, background objects such as distant houses and mountains can be painted planes which can be made with fewer workhours.

Film: Elena and the secret of Avalor (2016)

The multiple case study features examples of simplified background scenic elements that provide adequate image quality without devoting excessive production resources.

Anaglyph flat surfaces in 3D Computer Animation

The following example demonstrates an artistic choice of purposefully making scenic elements appear flat. The mat surface in the trees makes them seem soft, and the subtle chequered texture pattern gives a fabric-like appearance to the material. Moreover, the shallow depth of the foliage elements and their smooth edges makes them look more like seat cushions than leaves. The pastel green colours and uncomplicated branch shapes support the composition of a safe and joyful background that does not detract the viewer's attention from the action.

Animated series: *Doc McStuffins* (2012) Episode: A bad case of the Pricklethorns

I have explored the use of relief-surface objects with different styles. In my film Struthio (2011), several elements such as trees and clouds had shallow cross sections and smooth surfaces that enabled defining silhouettes strongly against the background.

The evolution of 3D computer animation

Throughout the years, since the seventies, computer artists have worked within the limited capabilities of available 3D animation tools.

One of the early uses of 3D computer graphics was for displaying wireframes that could show an animated perspective view of made with lines in space.

Star Wars (1977)

The ability to make 3D shaded surfaces opened up the potential for 3D graphics to be used for depicting a considerable range of effects.

Looker (1981)

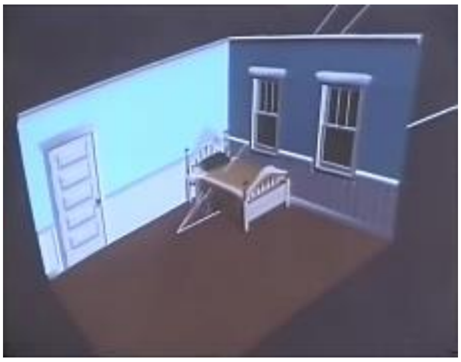
Each episode in the Quarxs computer animated TV series has a duration of under 3 minutes. The photorealistic 3D graphics were achieved with the application of texture maps on surfaces, with the use of shadow-casting lights, and by simulating reflections on objects such as mirrors and teaspoons. The principles of polygonal models, texture maps and cameras are still relevant. 3D computer graphics became a medium that utilised common mise-en-scène fundamentals regarding the positioning of cameras, lights, objects and subjects on a stage.

Quarxs (1991) Episode: Elasto Fragmentoplast

ReBoot (1994) Episode: The Tearing

The episodes of ReBoot (1994) have a running time of 23 minutes and features choreographed anthropomorphic characters, through the use of bone systems, thus enabling a common framing compositions that was familiar from live action films.

Toy story (1995) was the first entirely computer generated 3D animation feature film. The concept of the film encouraged the application of relatively fast shading processes for the plastic surfaces of toys. The Flintstones (1994) is a live action film with effects scenes that included realistic fur. Despite the handling of fur textures requiring more intensive digital processes compared to plastic, the 1994 production focused its computational resources towards processing only one object in a small portion of the film. The effect is of a masked layer of a 3D furry animal which was superimposed over live action footage.



A stage of Andy's room in: Toy Story (1995)
Image from: The Story Behind Toy Story (1999)

The Flintstones (1994)
Live action footage combined with a computer animated character.

The Matrix (1999). Combined use of live action footage and 3D graphics.

Layers of Computer graphics effects can be both superimposed over live action footage, and they can form underlying background images. The bullet-time effects shot from The Matrix combines live-action footage of Keanu Reeves with a realistic digital background. Camera tracking techniques enabled the real and virtual cameras to have matched motions.

The creation of the 3D rooftop differs from the discipline of architecture and architectural visualisation in that the 3D stage does not need to have geometry under the terrace floor to create the impression of the actor standing on top of a tall building.

3D computer graphics – Working within hardware/software limitations

Introduction

The advent of new technologies has given access to gigantic amounts of computational power compared to what filmmakers had in the nineties. Yet, 3D scene optimisation practices from a few decades ago are still relevant as computational resources are finite.

Image quality in Computer-generated imagery (CGI)

Production teams of animated TV series normally create more hours of content compared to the creators of feature length animated films. The following example demonstrates differences in image quality between the two types of animation productions. A notable difference between films and series is the rate at which content is made as the TV show production team will normally output multiple hours of content each year. The advent of more advanced tools has enabled incorporating increasingly computationally demanding rendering tasks such as physical lighting in recent TV series.

Feature film:
Mickey's Twice Upon a Christmas (2004)

Mickey Mouse Clubhouse – Episode:
Daisy in the Sky (2006)

The pictured above film that was released in 2004 has more natural lighting, more defined textures and atmospheric effects such as snowflakes and lens flares compared to the TV show that first aired in 2006. The screenshot from the animated series appears to have lower quality shadows and materials. The Mickey Mouse Clubhouse TV series aired between 2006 and 2016. Within this decade the advances in knowledge and technology enabled the production company to incorporate improved lighting and rendering quality in a similarly themed TV series that debuted in 2017. Mickey and the Roadster Racers (2017) has lighting characteristics comparable to Mickey's Twice Upon a Christmas (2004) which is an important accomplishment when releasing multiple episodes each year.

Mickey and the Roadster Racers - Episode: Race for the rigatoni ribbon (2017)

The following are some of the computationally-heavy processes that provide increased technical quality in the appearance of surfaces.

- Detail in geometry, for example a tree with dense branches and independent leaves.
- Thick soft surfaces which are made of hair, fur or grass.
- Physical lighting systems: Simulation of how light bounces on surfaces.
- Volumetric effects such as atmospheric dust.
- Raytracing: Simulation of reflective, refractive, translucent objects and caustic effects.

The increased technical image quality in recent 3D computer animated series can make individual screenshots difficult to discern from animated feature films. However, an observation of an entire season of TV episodes may reveal the same environment being featured in both pleasant and troublesome times. A general-use stage with neutral lighting will normally be less effective than customised environments in communicating the individual feelings found in different story contexts.

Setting up systems exclusively for individual shots can be hard to justify for making TV episodes with limitations in production timeframe and budget. For example, production resources would offer better value if they were allocated towards setting up systems for effects, such as rain, that appear in multiple scenes rather than just in a single shot. The practice of customising lighting for individual scenes is not, in itself, a source of increased computational stress. However, omitting the step of relighting stages for different scenes results in shortening the production pipeline, and thereby in reducing the required work hours.

The practice of reusing 3D elements stored in asset libraries (see chapter 2, page 56) does not automatically result in sacrificed quality and is not exclusively connected to TV series as the exact same objects can appear in multiple scenes of theatrically released feature films and in their sequels.

Ideally, sacrifices aiming to save significant amounts of production resources will have a minimal effect on quality. An example choice that could significantly reduce the needed computational infrastructure would be to render a show at 720P resolution instead of 1080P. As many TV networks do not broadcast in higher resolutions, the difference in image quality would largely be imperceptible.

Taking advantage of the strengths of tools within a limited computational envelope

The observation of computer animated films alone does not provide quantitative data regarding the used computational power.

Video games offer measurable information regarding the quantity of processing power required to display 3D computer graphics because we can inspect devices to observe hardware usage and achieved frame rates.

Optimisation of 3D graphics for real-time applications can be decisive for achieving satisfactory frame-rates. The gaming devices in the early nineties had significant restrictions in the ability to process multiple 3D surfaces simultaneously. Some 3D games of that era made extensive use of flat surfaces depicting images of objects as planes are faster to process compared to 3D models with additional geometry. Although 3D games have evolved tremendously since the nineties, the fundamental elements of real-time 3D computer graphics are still relevant.

Ultima Underworld: The Stygian Abyss (March, 1992) *Blue Sky Productions*
The screenshots display a textured staircase and a cuboid door

Ultima Underworld (1992) is indicative of real-time 3D graphics capabilities in 1992 games. It can be observed that the enemies and most objects consist of 2D images that face the camera. The game contains textured 3D geometry for walls, inclined floors, and box-shaped objects for doors. Cuboid shapes have only six faces and are less computationally demanding than 3D characters that would have required more complex geometry and therefore more capable gaming hardware.

Shortly after Ultima Underworld, Wolfenstein 3D (1992) was released that had fewer system requirements because of a game engine that made selective use of computer graphics capabilities. The limitations of the levels included corridors having walls intersecting at only 90-degree angles, the flat floor and ceiling appearing as solid colours, and the hero not being able to jump. One solution that helped reduce computational needs was the use of 2D sliding doors that could better hide their lack of volume compared to rotating doors.

Wolfenstein 3D (May, 1992) *id Software*
The screenshots contain a 2D animated character and a planar sliding door

The multiple case study presents limitations, benefits, and management systems for using textured single-sided surfaces facing the camera. Mixed use of 2D and 3D objects can limit the amount of computational operations required to display graphics in real-time viewports as well as for rendering frames.

Computational resource management in computer animated films

Case: Ralph Breaks The Internet (2018)

A common concern, even in film productions with substantial production budgets, is the computational optimisation of 3D environments.

Ernest Petti, technical supervisor of Ralph Breaks The Internet (2018) talked at the 2018 Siggraph Production Session: Wreck-It Ralph 2: Visualizing the Internet, about the creation of extremely detailed buildings that were laid out for a cityscape preview. He explains that test rendering a cityscape that comprised of high resolution buildings was not possible at first due to the amount of geometry and the lack of memory optimisations.

Combination of buildings shown at Siggraph on 14/8/2018

> *"After the creative work was initially established and we did some layout tests to see if we liked how it looked flying through these buildings we decided to do our first full render test […] and so we kicked off the test on our Hyperion renderer and the test never came back [due to the overwhelming computational load] so we knew we had some [optimisation] work to do there. And it's basically the sheer amount of geometry that's being dealt with for all the different types of buildings and their detail was something that wasn't going to brute force its way. […] we had to get a little more intelligent […] to basically reduce the memory to a point where it could be handleable, renderable and art-directable." "[The scene pictured below] was renderable in a reasonable amount of time".* (Petti, 2018)

Ralph Breaks the Internet (2018) Screenshots displaying optimised cityscapes

Components of detailed building

Material variants for different building looks

The high-resolution buildings comprise of detailed elements such as exterior signs and interior surfaces that are visible through the glazing. Differentiated materials gave various appearances to a base building model. Several differentiated versions of base models in the presented cases were made economically (see chapter 4, pp 132-133).

An asset library (see chapter 2, page 56) with detailed buildings that are viewable from all directions can enable composing new stages quickly with existing resources.

The excessive detail in objects can often be easily reduced for shots where the subject appears small or blurry for reducing computational loads. This can be approached by deleting smaller elements, especially from the sides of buildings that are not shown in the frame, and by reducing texture map resolutions. Moreover, manual methods and automated tools enable reducing the number of vertices in curved shapes.

Case: 9 (2009)

In his article, published in the Animation Practice, Process & Production journal, Matthew Teevan, head of production at Starz Animation, provides an overview of the production workflow for the animated feature 9 (2009). The following excerpt indicates connections between the creation of stage layouts, camera positioning, and optimised 3D assets.

> *"In relation to a lot of design and layout much of this work is done in 2D – it is drawn, Photoshopped, painted – and we build as many of the assets in advance before we get into shot and sequence production. We decided to geometry-optimize as many of the assets as we could, which means that we could adjust the shape and view of something to make it look different, so that within any one shot we could save on rendering. There was so much rubble, for example, we merely rendered a few pieces then optimized placement and shooting issues. This meant going to layout as early as possible and using as much pre-visualization as possible to facilitate trajectories and rendered elements. If the camera was placed in a certain position we could judge very early what was going to be seen and what would be less seen, and plan what was required accordingly."* (Teevan, 2011)

It is common practice to avoid having redundant geometry on a stage as this would increase computational demands without benefiting the rendered image. Optimised 3D assets were especially important in the showcased multipurpose stages because, by design, they can include spaces that are not shown in all of the hosted scenes. A notable example from the Salt Lake stage is the tunnel (see chapter 4, page 161) which is shown only in the last ten seconds of a four-minute sequence. The tunnel comprises of a computationally light repeated wall pattern, and an undemanding lighting rig (see chapter 4, page 209) which was activated only when the camera entered the tunnel. The inclusion of the tunnel on the Salt Lake stage would not have been justified if its weight had adversely affected productivity.

The reduction of modelling work is another topic that is addressed in the multiple-case study. Matthew has shared how he was able to reduce the modelling workload in 9 (2009)

> *"We had to do a burned-out car, too, so we repurposed some footage from a movie called Everyone's Hero (Colin Brady, USA/Canada, 2006) which featured lots of 1930s cars. We retextured it, of course, and did a lot of visual distressing, and that served our purpose well, and it serves as a good example of using extant or previous acquisitions and assets. Reusing materials by turning it around and shooting from a different angle was also another strategy."* (Teevan, 2011)

A notable example of repurposed assets is the Pyramidal setup of multiple planes that I had made in 2007 which appears in Struthio (2011) as part of the Book stage (see chapter 4, page 107). Additionally, the sky textures from the aforementioned system were adapted to create the skies in Agrinoui (2015) (see chapter 4, page 206).

Matthew Teevan mentioned in his article the practice of reusing existing objects in different contexts by displaying them from different angles. This topic was explored with the use of dynamic systems that comprise of modular elements in a range of applications including mountainscapes (see chapter 4, pp. 172-176), and within static environments such as the forest stage (see chapter 4, pp. 127-129).

Computational weight of digital 3D models

Video game consumers are generally aware that upgrading to newer generations of computers, tablets or game consoles will enable watching real-time 3D content with improved image quality. PC Video games often allow the user to lower graphics quality settings to increase the frame rate on slower machines. And conversely, users can apply settings for increased image detail so as to take advantage of more advanced hardware.

Graphics settings panel in video game: Half-Life 2 (2004)

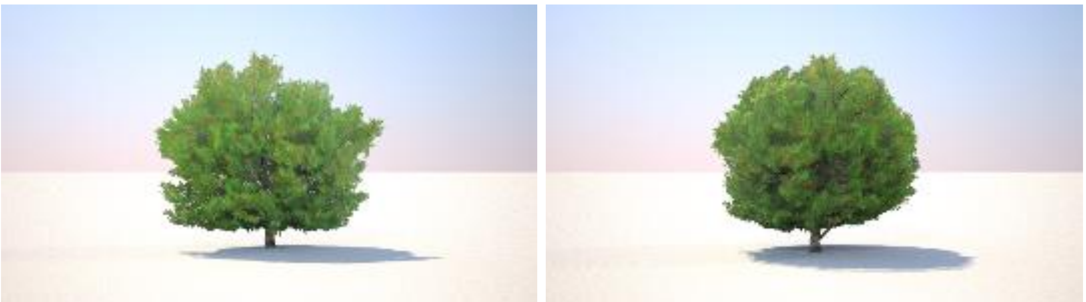
Faster processors and more RAM generally enable the real-time display of more polygons and texture maps regardless of application and operating system. Consequently, the productivity of 3D content creators can be affected by potent hardware as it provides real-time visual feedback of more detailed and more numerous 3D objects.

Case in point

The following example illustrates how increased object detail generates computational loads in computer animated films.

The 3D model of a tree shown in Agrinoui (2015) provides measureable data concerning polygon count and texture map size which are properties commonly found in professional computer graphics applications with polygonal modelling tools.

Appropriate adjustment of the level of detail (LOD) of objects based on how they will appear within the frame can result in avoiding wasting production resources. Excessive detail would create increased computational requirements, and insufficient detail would lower image quality.



Versions of a tree model with low LOD (Left) and high LOD (right)

The following table indicates how the different LODs affect computational weight in order to highlight the benefits of using lighter versions of models when they won't have a prominent place in the frame. For example, distant and out of focus objects can have reduced detail without affecting the image quality of the film.

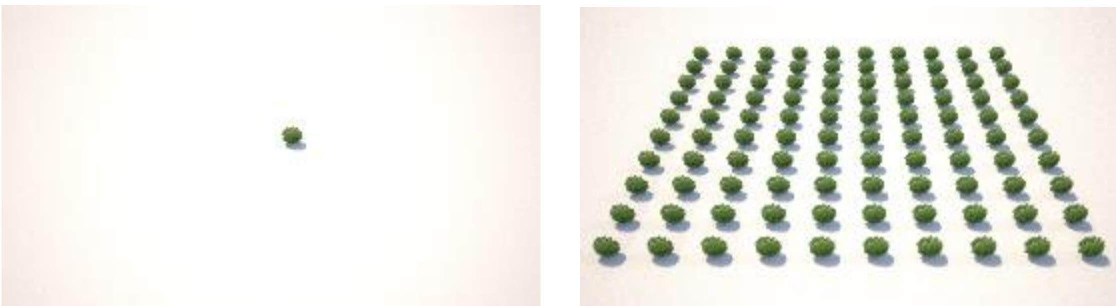
Table: Characteristics and computational weight of tree versions with low and high LOD.

	Uncompressed 3D Project File size	Dependencies: Diffuse, Bump, and Opacity Maps. Uncompressed File size:	Texture map resolution	Tree geometry resolution	Full HD image Render time
Scene with one **low-LOD** tree.	0,86MB	Total: 5MB	1024x 1024 pixels	Vertices: 69 Faces: 89	16''
Scene with one **high-LOD** tree.	2,37MB	Total: 80MB	4096x 4096 pixels	Vertices: 18.555 Faces: 8.362	29''

The rendering time of the high-LOD model took almost double the amount of time compared to the low-LOD model. The rendering times indicate that increasing the detail of foliage can significantly increase production costs.

Although there are significant differences in the amount of texture size and the amount of polygons, I was able to work on each model individually without noticeable system lag. Indicatively, even the high resolution model could be displayed in a shaded viewport at around 120 frames per second. However, the computational strain of stages with multiple objects can cause the frame rate to drop significantly.

The next example shows how a computer can be stressed when numerous objects are displayed simultaneously. For this purpose, I have copied the model and positioned 100 trees in a square grid arrangement.



Wide view: Rendered frames with a single tree, and with 100 trees.

Table: Computational weight comparative data of two sets of objects.

	Uncompressed 3D Project File size	Dependencies: Diffuse, Bump, and Opacity Maps. Uncompressed File size:	Texture map resolution	Tree geometry resolution	Full HD image Render time
Scene with 100 independent (copied) **low-LOD** trees	4,35MB	Total: 5MB	1024x 1024 pixels	Vertices: 6.900 Faces: 8.900	30’’
Scene with 100 independent (copied) **high-LOD** trees	154,06MB	Total: 80MB	4096x 4096 pixels	Vertices: 185.5500 Faces: 836.200	59’’

The file sizes indicate a link between the amount of geometry and the amount of stored data. A steep rise of data can noticeably slow down certain processes. Indicatively, the viewport refresh rate for navigating the scene with a single high LOD tree fell from 120 frames per second to under 15 FPS with 100 trees. Additionally, the rendering process for the wide view with a single high LOD tree took 12’’, and 59’’ for 100 high-LOD trees.

The 100 high-LOD trees require almost double the amount of rendering time compared to the 100 simpler models. The render time difference is not proportional to the difference in polygon numbers because many of the calculations concern other processes such as simulated physical lighting.

The replication of this experiment with different software would probably yield varied results concerning rendering times and file sizes. However, these succinct comparative examples aim to plainly indicate a causal relationship between two variables of data. As the amount of geometry and texture map resolution increases, so will computational demands in terms of the quantity of processing calculations, occupied RAM, and hard drive space.

Most 3D applications provide the option to make Instanced copies of objects in which case the geometrical data of an object is recorded once and all the instances refer to that singular piece of data. I observed how instanced geometry enables reducing the amount of data in a project file by replacing the copied high-LOD trees with 100 instances of the same model. The uncompressed file size with 100 instanced high-LOD trees was reduced to 3,47MB from the 154,06MB file that contained the geometrical data of every individual copied tree. I also observed that the computer graphics application utilised 716MB of system memory when it loaded the scene with instanced High-LOD models, whereas loading the file with the High-LOD copied trees occupied 1.215 MB RAM.

The adjustment of the level of detail in 3D models relative to their size in the frame is common practice in the fields of video games and computer animated films. The significance of optimised models becomes clear by taking into account that digital environments commonly comprise of multiple elements that collectively can create a challenging load.

The multipurpose stages presented in this project feature objects with different LOD as well as instanced copies of modular scenic elements that further reduced computational demands of animated sequences.

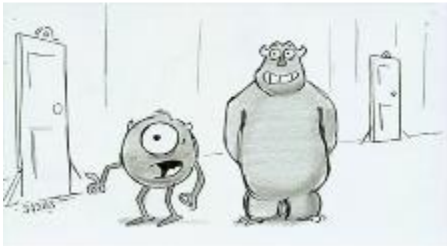
Contemporary digital stage design - Common practice

Stage Design during development and preproduction

It has been stated that:

> *"[Digital directing] involves vision, planning and a knowledge of key cinematic principles."*
> (Ablan, 2002)

The storyboard and the 3D previs enable the creators to define framing and timing for each shot before entering the production phase. Prior to making a 3D animatic a film project can be separated by each location described in the script, and top view sketches can indicate the shape of the stage. The top view plans can be blocked out with 3D Visualisation to test the mise en scène with undetailed 3D objects and cameras. A draft 3D stage enables a low-cost trial and error visual approach to develop the choreography and to adjust the form of a stage.




Images from Storyreel and Layout from Disney-Pixar film: Monsters Inc. (2001)

Stage elements can surround an acting space so as to enable covering dialogue scenes with reverse angles. Moreover, as the background extends beyond the field of view, it enables making framing adjustments over the course of the production.


Film: Monsters Inc. (2001)

Draft 3D graphics can be made with a relatively low polygon count and without computationally demanding lighting. The low processing load enables displaying the 3D previs in real-time which is key for making on-the-fly framing and timing adjustments.

Multiple sets for a town in The Grinch (2018)

Karen Moltenbrey, editor-in-chief of CGW magazine presented how The Grinch (2018) was made in a 6-page article that includes descriptions provided by some of the film's creators. The article was published in the 4th quarterly edition of CGW in 2018, and provides information about the layout of a town that was separated into independent sets of smaller locations.

> *"[Within] Whoville are many smaller but more intricate indoor and outdoor sets."*
> (Moltenbrey, 2018)

The complexity of managing multiple separate stages, instead of working with one multipurpose stage, for a travelling sequence through town has a negative effect on production timeframes and costs. However, this approach can be justified because creators can focus their attention and computational resources to a single purpose.


Left: Establishing shot of Whoville in The Grinch (2018).
Right: Frame from one of the smaller sets displaying life inside the town.

One of the directors of The Grinch (2018), Yarrow Cheney, explained that the layout of the town Whoville provided numerous views of different areas that were shown during travelling actions.

> *"We know every location — where Cindy-Lou's house is compared to the town square, compared to the entrance to the city and the Who Foods Market. […] If you wanted to, you could actually build a real-life Whoville and it would make sense as a town."*
> (Moltenbrey, 2018)

Computer Graphics Supervisor, Bruno Chauffard, explains properties of 3D structures in Whoville:

> *"Each house and store has a specific shape, which was never straight, and that influenced every sub-element such as windows, balconies, and doors."* (Moltenbrey, 2018)

3D models with flat surfaces and straight edges need significantly less geometry compared to curvy shapes. The computational demands of numerous models with complex geometry can justify separating a town into smaller locations so as to improve the speed of computational operations.

Karen Moltenbrey explains how the elements of a homogeneous architectural style were handled:

> *"The crew managed to build a library of elements that they could slightly reshape and adapt to dress the different buildings. Once the buildings were assembled, the artists could procedurally regenerate the textures to fit the new shapes they had created."* (Moltenbrey, 2018)

A library with 3D architectural elements can facilitate the assembly of multiple stages with different layouts of similarly themed buildings. The process involves choosing and placing objects in a 3D environment from the library and enables making stages that only contain necessary objects. For example, deleting redundant stage objects can be done knowing that they can be recovered from the library.

Aesthetic judgment

Having a description of what an environment aims to communicate enables making purposeful decisions such as whether to use low or high key lighting, cold, warm, or saturated colour schemes, and shapes that can be dangerously angular or curvy and soft.

One of the directors of the Grinch (2018), Scott Mosier describes how the appearance of scenic elements enabled making Whoville have a specific look and feel:

> *"[…] the artists transformed from line drawings of a handful of snow-covered houses into a brightly-colored, three-dimensional city with teetering, swerving buildings of Seussian style. The Whos are welcoming and warm, so their town needed to reflect this in the shapes and textures of their homes, shops, and vehicles"* (Moltenbrey, 2018)

The curvy architectural style of houses was chosen to reflect the community in Whoville. However, the uninviting Mt. Crumpit has sharp angles that are fitting for the home of the Grinch as they reflect his unpleasant personality.

Multiple environments on one stage

Having two environments on one stage can be justified when a camera needs to show both in one shot. Such stages enable the camera to follow action from one room to another or to be pointed towards an open window.

In the following scene the room happens to be empty because Andy is moving to another house. Having a low amount of geometry in one space can limit its computational load so as to enable creating coexisting areas that would occupy the remaining available computational envelope.

Dolly in shot from Toy Story (1995)

Stages for multiple TV episodes

A central residential location

Stages for series are, in many cases, open to suit the needs of unforeseen purposes. The sets are often designed without available scripts of future episodes, therefore, it makes sense to incorporate a range of options regarding the positioning of cameras and characters.

The layout of the main character's home can have provisions for a kitchen, a living room, and a garden even if the first episode does not explore all the spaces. Storyboard artists, directors and writers can have spatial awareness by referring to the top-view plan of the complete home. The floor plan enables understanding what kinds of shots are feasible without dramatic interventions on the shape of a stage that will feature in multiple episodes.

Many actions in *Masha and the Bear* take place in and around this house in a forest.

Animated series: *Masha and the Bear (*2010)

An inclusive stage that can host a range of actions for the needs of a multiple episodes will likely not be optimised for the views of each individual scene. However, the stage can be optimised for a scene by deleting objects that will not appear in the sequence. The process can be approached by treating the full-fledged house as a master environment. The stage of each new episode can start by opening a copy of the master environment, followed by adapting it to the unique needs at hand. The adaptation could involve deleting objects that never enter the frame during a sequence, or adding objects that only feature in one episode, such as an outdoor trampoline.

A stage containing both a living room and a kitchen would not have the lowest possible computational load for handling and rendering individual still shots. However, the convenience of directly operating on multiple cameras within one environment can be key for obtaining an efficient production framework that aims at a high yield of episodes.

Environments of wide areas - A city

When the stories of an animated series are located in one city, opportunities may rise to use a set in more than one episode or to reassemble parts of sets to make differentiated cityscapes.

The stories in the animation series Miraculous: Tales of Ladybug & Cat Noir take place in Paris. Developing an asset library of Parisian urban architecture can facilitate making diverse stages with the use of modular elements such as tileable parapets or cornices for building façades.

Miraculous: Tales of Ladybug & Cat Noir (2015)

Stages for single TV episodes

In animated series where the locations are not constant, stages can be made specifically for the needs of single episodes. The TV series Max Adventures: Atlantos 2 features diverse environments as each episode shows a section of a long journey.

Custom production frameworks can enable coping with the demand for additional environments for subsequent episodes by strengthening the department that is responsible for 3D environments.

Max Adventures: Atlantos 2 (2016)

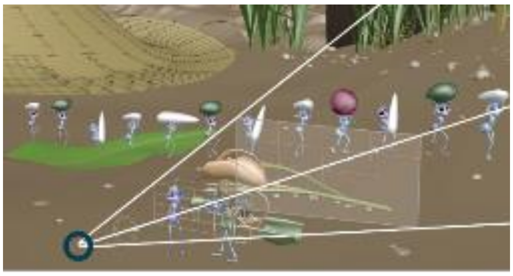
Increased needs for new 3D environments can also be found in The Little Prince (2010) TV series in which each story takes place on a different planet. Each double episode entailed making new environments for different planets as well as the creation of new characters who inhabit it.

Le petit Prince - Episode: La planète du temps (2010)

Stages for a single camera angle

A set that is specifically made for a still shot can benefit from having scenic objects positioned outside the field of view. Some of the reasons that could justify extending the size of a stage beyond the frame of the camera include:

- Having objects wait outside the frame until they need to appear. Background motion can be practically managed by having objects such as a cloud or a train entering and exiting the frame.
- It enables framing adjustments and limited camera movement.
- It can provide realistic ambient lighting, shadows, as well as convincing reflections of the environment.



Science behind Pixar (2015)

Screenshot: A Bug's Life (1998)

Although the stage in the above example enables showing the subject from different angles, it serves to indicate how supernumerary characters, in this specific shot, start walking outside the frame before they enter. Inside the droplet of the telescope we see reflections of the surrounding environment, including the sky outside the frame. The reflections can be made by surrounding the stage with a low-resolution textured dome or with surfaces that roughly resemble the environment as reflected images often appear unsharp.

When physical lighting is used, the lack of surfaces for the light to bounce on can affect the lighting of the scene. Surfaces outside the frame that act similarly to light reflectors in photography enable bouncing the light back into the scene. Similarly, objects outside the frame can cast shadows in it.

Environments that appear to be different from reverse camera angles

Some racing games such as Live for Speed (2003) have race tracks that can be driven in both directions. Enabling a circuit to be driven in clockwise and counter clockwise directions offers an economical way for adding a diversified racing challenge. Despite both challenges having the same visual theme, driving in the reverse direction can make the topography seem unfamiliar.

The same chicane shown from different angles. Live for Speed (2003)

Armed with the knowledge that a location can be shown from opposite directions without easily being recognised as the same, I designed a forest path on a stage for Struthio (2011) that is traversed in both directions. Despite the same location being shown in separate scenes, the reverse viewing angles enabled suggesting that the action takes place in different areas of a jungle.

3D computer graphics – Common practice

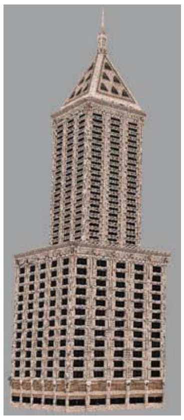
Efficient 3D asset usage in animated TV series

TV series that have a consistent theme can have the production pipeline shortened by reshowing the same objects in each episode. The repeated use of 3D assets is not limited to a single environment as the same trees can be copied and shown in different areas of a large park. Moreover, clusters of objects can comprise of multiple copies of objects such as trees, clouds, and grass strands.

Reusing props: Modular design in 3D Computer Animation

By designing models with modular properties we can significantly reduce the amount of work associated to making different versions of larger objects that comprise of copied components.

The following images demonstrate how a few modules can be arranged to make differently shaped buildings. Additionally, a window can be repeated many times to cover large areas of the façade of a building.



Source: McKinley, M (2010) *Maya Studio Projects – Game environments and props*, Wiley Publishing.inc – Cybex, USA

The author of the book explains:

> *"With modular modeling, you can create a system of modules (also called tinker toys by certain aspects of the industry) to create practically any environmental structure. You could*

create a modular system of dungeons for a game with a medieval theme, a modular street system to go along with the city, or modular spans to create bridges of any length.” (McKinley, 2010)

The multiple case study includes the presentation of a stage in which a vehicle travels across a mountainous terrain. Mountain modules were rearranged so as to create the perception of different landscapes.

Organising and reusing props: Asset libraries

*Jungle junction (*2012) - Introduction Sequence

This frame from the introduction sequence in the TV series *Jungle junction* (2012), contains objects that are displayed throughout the animated series. In such cases, it makes sense to develop a process that enables composing new stages out of a collection of prefabricated objects that are stored in an asset library.

The multiple case study contains stages that featured the process of importing scenic elements from an asset library for assembling differentiated 3D environments.

LOD in close ups (Level of Detail)

Animated series: Mickey Mouse Clubhouse (2010). Episode: Daisy’s Grasshopper

Although the tree in the above example looks detailed in the wide shot, it appears to lack detail when the camera moves closer to the branches. This problem could have been handled by making a model or a texture that would provide a more defined surface for the close-up shot.

Demanding corrective actions that concern a handful of seconds within an entire episode can be hard to justify within a short production timeframe. Apart from the additional creation of new models and textures, the inclusion of highly detailed models can slow down the computer's responsiveness and rendering speed. Although a close up shot can be handled as a separate 3D scene, this would add a layer of complexity to production management. With looming deadlines, the improvement of individual shots can have a low priority or it could be dealt with practical and imperfect solutions such as by applying a mesh smoothing algorithm.

Assigning appropriate LOD to objects

The creation of objects with excessive detail leads to wasted production resources whereas too low detail will affect image quality.

An inspection of previsualization images enables distinguishing prominent objects in the frame that will require more detailed textures and geometry. Also important is the identification of elements that can be simplistic possibly because the distance of an object from the camera can make it appear small or out of focus.

In many cases an establishing shot may contain something that needs to be shown again in a close-up shot. This can be approached by making an additional, more detailed, version of an object or even a new stage.

Distant and close-up views of a flower in the proboscis. *Horton hears a Who! (2008)*

Using an icosahedron to portray a sphere can be acceptable if the vertices are not discernible. With a similar logic, as we approach a plane with a bitmap texture the image will become pixelated or blurry. The line between LOD and image quality is not always clear. Certain material properties can be adjusted that affect the quality of surfaces such as shininess, translucency, bas relief, how the surroundings are reflected as well as how light is refracted as it passes through an object. The quality of cel shaded materials is affected by properties such as the level of simulated ink outline quality.

Quality settings that can be found in atmospheric effects tools include the detail in the flames of a fire. Similarly, properties that affect the detail of shadows on the ground can be found in certain types of lights. Deciding how much detail is appropriate for a complex situation can be made through the visual inspection of test-rendered images. For example viewing a shot with motion blur could enable judging whether the potential lack of detail in a subject is perceptible.

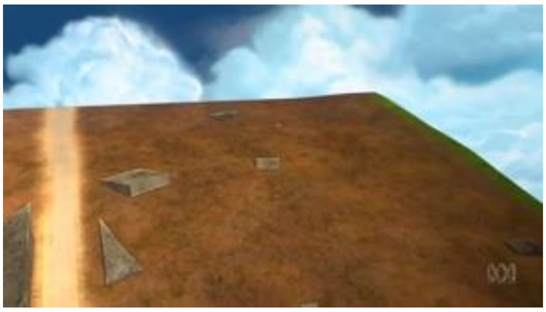
When dealing with non-realistic image elements such as imaginary furry flowers or anthropomorphic animals there can be a wide spectrum of acceptable levels of detail. The thickness and length of each hair of an elephant's eyebrows and their density are properties that can largely depend on desired character traits or film style.

Part of this project is concerned with making versions of trees with low and high LOD primarily for positioning them at different distances from the camera. The non-realistic style of trees enabled working with reduced geometrical detail compared to a photorealistic approach. Moreover, the omission of tree surfaces that are not visible to the camera further reduced the computational weight of 3D models.

Tiling and scale of texture maps

The appearance of 3D surfaces can be significantly affected by the use of 2D images called texture maps. It is common practice to cover a surface with repetitions of an image in a process called tiling. For example, a picture of one brick can be repeated many times so as to cover the surface of a box thus making it appear as a brick wall.

A concern for making stages that appear to have a correct scale in both establishing and close-up shots is that the appearance of the ground can be very different when we see it from a distance. If we applied an image of a square meter of soil over a flat surface it could appear nicely if the subject of the frame was a flowering plant. However if the camera pulled back so as to fill the view with a square kilometre, the appearance of a million tiled images would be problematic.



TV series: *Le Petit Prince. Episode: La planète de Géhom* (2010)

Tiling is an economical way for covering a large with a texture. However, natural surfaces such as grass or dirt are less forgiving compared to bricks or floor tiles. The repetitive tiling effect in the first screenshot makes the ground of a cube shaped planet appear unnatural. As the camera gains altitude, in the second screenshot, a different texture map solved the problem of visible tiling. However, the second texture also feels unnatural and inconsistent because it resembles dirt being seen from eyelevel.

I have observed how the appearance of terrain surfaces change when we look at different area sizes. I captured the following photos and used them as reference for making ground surfaces for Agrinoui (2015). The first picture was taken at shoulder height and the second is a distant mountainside. By understanding the nature of materials and by respecting their scale I was able to make ground surfaces that appear correctly from a wide range of distances.

Dirt, Nicosia, 25-12-2014

Troodos Mountains, 14-8-2011

Operating on multiple versions of a stage

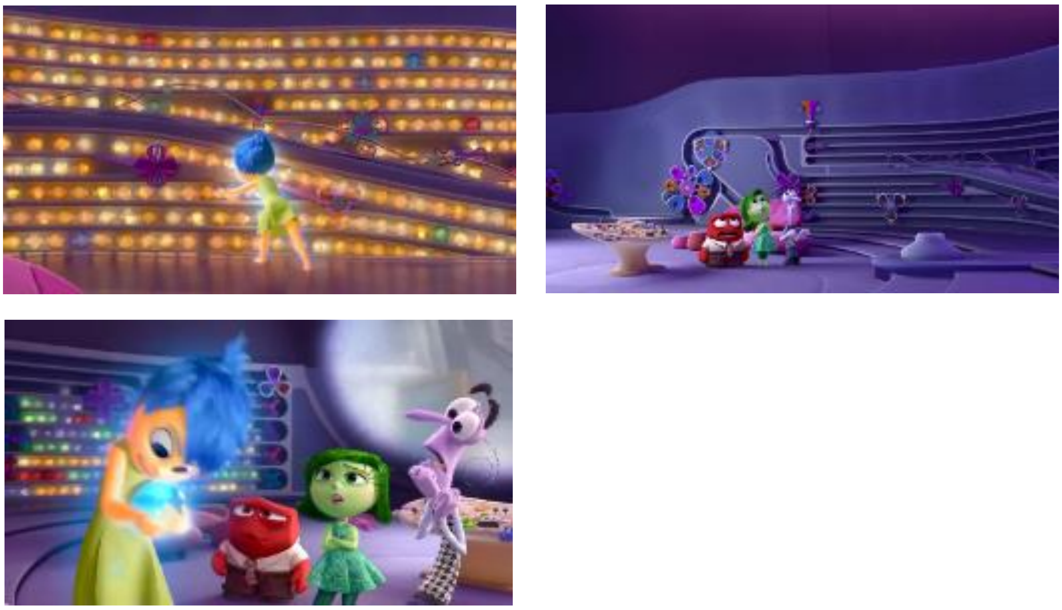
In contrast to animated series where achieving high production rates is key, a customised image output tends to be prioritised in animation feature films.

The pictures from the film Inside Out (2015) display a control room that is in the brain of a major character. The room is shown in diverse circumstances as a large part of the story takes place there.

The low-resolution model of this environment enabled the previsualization of sequences with multiple camera positions. The models in the previs can act as foundation or reference material for developing the more detailed and textured objects that will appear in the final image.

Behind the scenes - Inside Out (2015)

Even though the following screenshots are from within the same environment, the lighting and the contents of each frame vary substantially. An option that enables creators to focus on obtaining an appropriate look and feel for each scene is to handle the environments as separate projects. Each stage would start with the same shelve structure and the positioning of different ornaments and lighting setup could be made with different project files.



Inside Out (2015)

Both screenshots in the following example have a similar framing but different lighting and effects.

Inside Out (2015)

The question of whether two scenes should be handled separately on duplicate stages or with a single stage project file can be answered by weighing the potential productivity benefits and computational demands of each scenario. A stage with conditions such as the dark scene (right image) with one character and a limited number of light sources would require significantly fewer data if it did not include the additional elements seen in the screenshot on the left. Handling the two scenes as separate projects would facilitate two character animation teams to work in parallel.

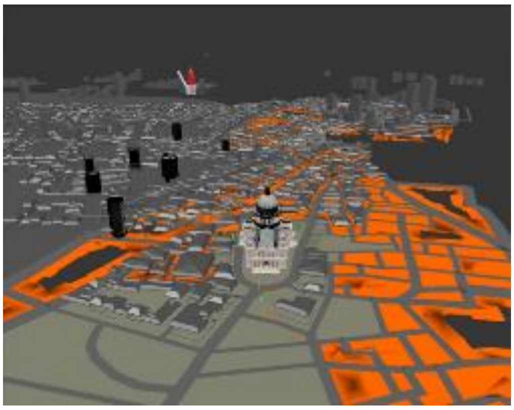
The multiple case study features a stage with dynamically changing sky colours that give a sense of different times of the day for separate scenes. A change in lighting conditions is a relatively economical way to make visually diverse scenes with one stage. 3D projects with a lengthy timeline enable artists to work with a linear workflow on each shot progressively as tasks for setting up the project file, such as synchronising the voice track, need to be assigned once.

Large environments – Cities. Stage Design Case: Cars 2

The director of Cars 2 (2011) had this to say about how the city environments of the film were designed.

> *"The detail of these sets, it's like cities, it's like full cities"* (Lasseter, 2011)
> Source: Behind the scenes at Pixar with John Lasseter & the makers of Cars 2 (2011)

A fast-paced action sequence of a car chase can be composed of a considerable amount of shots which are positioned over a long distance of roads.



3D environment of London made for: Cars 2 (2011)
Source: Khan Academy Documentary: Pixar in a Box (2015)

A primitive model of a city enables a workstation to provide direct control over the composition and flow of successive shots during previsualization which is a preview of what will be shown on film.

The animatic shows the elements that need to be visible within frame. Objects that are obscured by nearby buildings would not need to be modelled for the final sequence. However, in some cases rough shapes of objects outside the frame enable providing more realistic ambient lighting, shadows and reflections.

Previs from Cars 2 (2011) Source: Khan Academy Documentary: Pixar in a Box (2015)

Once the animatic is ready choices can be made to separate the 3D environment of the city into sections which will cover the specific needs of each shot.

In the pictured chase scene from cars 2 we have three consecutive shots. At first we have a wide establishing shot of the cityscape which includes hundreds of buildings that are not within the frame of subsequent shots.

Having separate stages for shots with significantly different scenic needs enables optimal use of geometry. Additionally, handling each shot independently provides organizational choices for having more people work simultaneously on different parts of a sequence.

Cars 2 (2011)

Modular design in Cars2 (2011)

Modular design enabled a streamlined modelling process for the numerous buildings.

The image on the left shows the pieces that make up certain building façades in the film Cars 2. The same pieces of walls and windows, arranged differently, can be used to make additional diversified buildings.

Khan Academy Documentary: Pixar in a Box (2015)

Differentiating the appearance of scenic elements

Screenshots of game courses: Forest, Night, Storm, Desert, Marsh, and Snow.
Lotus Turbo Challenge 2 (1991) *Magnetic Fields*

Videogames often comprise of levels that have a differentiated appearance while relying on the same game engine. Each course in Lotus Turbo Challenge 2 (1991) has a different set of images for background mountains and skies, as well as for roadside objects such as trees and signposts. The colours of the road surfaces are adapted to the conditions of each environment. Roadside objects and distant mountains comprise of 2D bitmaps with transparency masks. The objects can acquire different styles as technically their appearance relies on replaceable photos or digital paintings. The brown and white trees in the Marsh and Snow courses have similar outlines and foliage shapes which indicates that they are recoloured versions of the same tree.

I played the game as a teenager and remember noticing that the visually diverse courses made each level feel fresh, it also motivated completing courses in anticipation to see the next one. The urge was comparable to reading fiction, or watching a film, and being eager to see how the plot unfolds.

Connection to multiple case study
A seasonal change can add diversity to the scenes of a film as it does to the levels of a game. For example, the texture map colours of the deciduous trees in Agrinoui (2015) and Struthio (2011) can be altered from green to orange to signify autumn.

Apart from seasonal changes, textures of terrain features can be repainted to obtain diversified environments. For example, the salt lake stage from Agrinoui (2015) could be made to look like an arctic landscape by changing the colours of surfaces without affecting the underlying systems. The hypothetical icy landscape could have the ground surface repainted to resemble glacial ice, the distant mountains could be made to appear as snow covered slopes, and the clear sky as overcast.

I saved production resources by changing the colours of stage assets that were shown under different conditions. Specifically, the textures of sky and cloud objects were adapted for use in daytime, evening, and night-time scenes on separate stages.

Other methods that enabled me to show a stage at different times of the day include the creation of dedicated 3D lighting rigs and post-production colour grading.

The repurposing of stages by changing the appearance of surface skins while keeping the functionality of underlying systems enables saving costs.

Aesthetic Judgement: Communicating concepts via scenery and film editing

A clear film purpose can guide creators purposefully form each visual and audible element so that collectively a common concept is communicated. The style of a motion picture cannot be fully appreciated by looking at the shapes and colours of still frames as time based media consists of changing elements that create an impression over the course of the film.

Films can still communicate while missing major components such as scenery or characters. Character action can occur against a plain white background, and a completely black screen does not prevent a narrator from describing a situation. Even without sound a well-timed silent pause, by cutting a film to black, can improve concept comprehension.

One of the pauses in Memento (2000)

Screenshot from The Blair Witch Project (1999)

By looking at film elements as vehicles of communication rather than a means for demonstrating beautiful pictures, it is observable that the composition of aesthetically pleasing shots can be harmful for horror scenes. The Blair Witch Project (1999) was recorded with inexpensive media by relatively inexperienced camera operators within dark environments often lit by flashlights and on-camera lights. Although the resulting image was in many cases grainy, unfocused, shaking and poorly framed, it was ideal for supporting the central idea of the film. The use of high-end cameras, lighting rigs, and the inclusion of popular actors could have prevented achieving a sense of authenticity.

The Pride Rock. Lion King (1994)

The Pride Rock in the Lion King is shown in a thriving era under the rule of Mufasa and in a time of despair due to the devastation brought by King Scar. The unsaturated colours helped make the land appear dry and lifeless. The incoming dark clouds and the sharp-edged silhouettes of leafless trees are consistent with the expansion of hyena territory which was once limited to the elephant graveyard.

Elephant graveyard. Lion King (1994)

The inhospitable living space of hyenas describes their sinister personalities. Their environment does not become peaceful in the film just like the hyenas themselves are consistently menacing. The elephant bones enclose the visitors with sharp unwelcoming shapes, and danger seems to lurk in the fog and shadows.

The examples highlight the ability of scenography to support the intended feeling of a scene which can be described with a few words in the script such as dark scary and isolated or bright welcoming and hopeful. A clear goal enables creating a fitting style for each scene. A sorrowful and tense disaster scene can be supported by appropriate shapes, colours, lights, camera movement, acting, editing, sound effects and music.

Saving Private Ryan (1998). Scene: Invasion of Normandy
The shots display the action from the perspective of fighters over and underwater

The audio and visual elements of the battle scene work together to transfer the chaotic struggle, danger, confusion and human loss.

When the American soldiers approach Omaha beach we closely follow their actions with handheld panning cameras and a fast editing pace. The energetic shouting actors are surrounded by explosions, gunfire, smoke, water waves, and cloudy weather. During the battle we are transferred to an underwater scene and see parallel action with less noise and slower motions that include visible bullet trajectories. While underwater we see an intense use of red colour of blood in contrast with the blue water giving a few seconds for the audience to understand the death of one person before we return above sea-level where human casualties occur at a much faster rate. Subjective shots position the audience within the combat and enables people to empathise with a dire situation.

End scene. Fight Club (1999)

The final scene in the Fight Club features several explosions and collapsing buildings. The destruction is juxtaposed with two characters calmly watching the spectacle. The motionless camera and the soundtrack isolates the distressed outside world and enables the scene to focus on the relieved protagonist whose inner struggles have come to an end.

Although both the battle scene from Saving Private Ryan (1998) and the building demolition in Fight Club (1999) contain explosions, they create opposite emotions as one builds tension and the other brings peace to the main character. Both cases indicate that the concept of a story is a major factor in determining how actions will be presented.

Home of the Once-ler as it appears when he is introduced, and
at the end of the film The Lorax (2012)

A home can reflect the current inner world if its inhabitant. In the film Lorax (2012) the Once-ler lives on a land that he regrets to have destroyed. His house, is introduced with a low-angle frame under a thundering sky. The dark appearance of the house is consistent with how lonely and depressed the occupant felt at that time.

The Once-ler's optimistic outlook is manifested in the ending scene featuring the house with a blue sky, rounded hilltops, puffy clouds and warm sunlight. This example shows how an object can be presented as cheerful or dangerous depending on the occasion.

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Chapter 3: Methodology

Summary

This chapter explains the methodological approach to this research project which concerns the exploration of multipurpose stage design within the production of two short animation films *Struthio* (2011) and *Agrinoui* (2015).

The films acted as test platforms for multipurpose stages which were designed for obtaining efficient production workflows. The outcomes are connected with achieving high levels of image quality while maintaining aesthetic control within manageable frameworks.

The main part of the multiple case study consists of an explanatory retrospective analysis of inclusive stage systems which were tested within the complexities found in actual production conditions.

The data presented with a summative case study approach originates from conducting primary research with visual exploration methods and visualisation tools.

The multiple case study examines the forms of multipurpose stages which were designed to enable operating on multiple, diverse and long scenes. The management process of modular scenic elements which enabled optimal use of 3D assets is also showcased.

The literature review contains information about common practice in scenography with analogue and digital media. Digital 3D space shares common mise-en-scène principles with live action and stop motion productions as films generally have a common cinematic language.

Introduction

Although multipurpose stages have provided enhanced production efficiency in past computer animation films, there is little documentation on this matter. I therefore assume that the practice of making efficient stage systems primarily relies on the resourcefulness of creatives. This project aims to attain a comprehensive understanding about how multipurpose stages can effectively address the needs of a range of production scenarios.

Two enlightening multipurpose stages which I made in 2003 formed a steppingstone for starting this project. My practical involvement with the research subject has provided a good overall understanding of how productivity can be affected by stage design.

Primary research enabled me to investigate the subject by designing, implementing and observing several forms of multipurpose stages. The analysis of multiple cases of real-world production scenarios has provided holistic sets of evidence which support the resulting generalisations.

Operational Definitions

A descriptive presentation concerns 3 primary subjects. The following list defines tasks associated with planning, artistic choices, and technical considerations of the project.

Planning deals with

- Creating planning material, with the provision of combining multiple environments on one stage. Namely, concept art, storyboards, top view drawings and 3D previsualisation.
- Previsualisation through blocking out stages with low-resolution models.
- Creation of a 19-minute previs which enables instant editing access to any part of the film with real-time 3D graphics.
- Providing a smooth transition from the planning to the production phase.

Creating the impression of an environment deals with

- Foreseeing the resulting 2D compositions from all the scene’s camera angles when designing a 3D stage.
- The impression of 3-Dimensionality within objects through the use of image projections on relief surfaces.
- Developing curved panoramic painted surfaces that surround the stage.
- Forming the shapes of objects so that the composition creates forced perspective illusions and motion parallax effects.
- Applying custom colours to objects for conveying a sense of atmospheric perspective to a scene, as an alternative to using simulated fog effects.

Scenic optimisation

- Reduction of number of models present on stage can be achieved by reshowing certain objects in different contexts. Modular design enables showing objects repeatedly in a scene without appearing to be identical. A dense forest can be made by using instanced geometry of a handful of different trees. Similarly, numerous shapes of clouds can be made out of a cluster of basic cloud objects by changing their relative position.
- Customised scene optimizations which decrease computational requirements enabled achieving increased rendering speeds and improved responsiveness of real-time 3D graphics. I applied different levels of detail to geometry according to the proximity and scale of objects in relation to the point of view.

Multipurpose stages are concerned with the development of custom efficient production systems that address unique production needs. Stage that can display different environments enabled the creation of long sequences with few project files. Having fewer stages caused reduced fragmentation in the production pipeline compared having multiple stages with a single environment.

Unified 3D environments have enabled a team to work simultaneously on environmental and character animation improvements. The workflow featured shared progress review cycles that enabled making observations on global improvements.

Aesthetic judgment in computer animated films

The word aesthetic derives from “αίσθηση” which means sensation or perception in Greek.

The choice of colours, shapes and motion in a scene can convey feelings that support communicating story concepts.

Wassilly Kandinsky in his book *On the Spiritual in Art* dealt with the effect of colour.

> *“When you let your eye stray over a palette covered with colours, two main results are produced: The first is a purely physical effect when the eye itself is enchanted by beauty and the multiple delight of colour. The observer is pleased. He experiences a pleasure similar to that enjoyed by an epicure in tasting a delicacy. The eye is stimulated as the tongue is titillated by a spicy dish. Or it is refreshed and soothed as a finger touching ice.”*
> (Kandinsky, 2004)

Gorge Maestri explains in [Digital] Character Animation 2 that being informed about a subject enables making purposeful appearance decisions.

> *“When designing a character, you first need to know a bit about him or her. Is the character young or old, short or tall? Is the character the hero or the villain? […] aggressive or meek? All these criteria, plus many more, will factor into the designs of your characters.”*
> (Maestri, 2001)

The sensations conveyed by 3D animation sequences are affected by visual choices in the fields of lighting, textures, shapes, frame composition, camera movement, choreography, camera motion, as well as the timing of shots. Aesthetic judgements in this project are occasionally made to indicate how the appearance of environments reflect the mood of a scene or the emotional state of characters. The presented rationale of visual communication in certain scenes provides general awareness regarding artistic considerations that are often part of scenic design.

Visual perception and depth perception

I took advantage of the limited perception of space when it is displayed on a flat screen from selected angles. Observing the image from a specific viewpoint enables realizing that many surfaces are not visible, either because they are obscured by objects in front of them or because they face away from the camera.

Opaque scenic objects that are hollow or without backside surfaces may adequately serve the frame composition from certain camera aspects. Similarly, when the horizon is obscured by a building, we can omit the creation of more distant background elements such as mountains. Moreover, we can redisplay objects within different contexts. For example, we can have the same taxi cab passing by a in the background multiple times without disturbing the viewer’s immersive film experience.

The awareness of the limited perception of flat film images enabled making digital 3D environments that offer enhanced production efficiency.

- When scenic objects comprise only of the surfaces that face the camera the time required to make them can be reduced and their computational weight limited. For example, the terrace or the back side of a building may not be needed if they are not shown in the film.
- Motion parallax can be created with planes that are positioned at different distances from a moving camera. Planes in space can be seen from limited points of view that are consistent with the composition needs of a film shot.
- Different viewing angles of an environment can appear as separate locations under certain conditions. Fewer stages may need to be built if they can indicate different locations.

- Forced perspective enables limiting the size of stages.
- The number of scenic elements on a stage can be limited by repositioning and redisplaying objects in different shot compositions.
- Scenic elements do not need to surround the acting space if the camera does not need to provide reverse angle views.

Research methods

The purpose of this project is to increase our understanding in regards to inclusive 3D stages that can efficiently cater to the needs of different scenes.

I approached the subject with exploratory and explanatory research phases which involved becoming actively engaged with a new design logic that led to the creation of films. The data gathered during the making of Agrinoui (2015) and Struthio (2011) is presented within a multiple case study.

Formative research was supported by observations regarding a computer animated TV advertisement that I made in 2003 (see chapter 1, pp 21-22). The ad features two multipurpose stages that offered enhanced productivity because they enabled working on actions that needed different backgrounds. The eight 3D environments that were on one stage enabled making a character appear to visit eight countries without having a segmented workflow. In practical terms, the underlying systems of the two stages cover very specific production needs that are not useful in most production scenarios. However, this experience enabled me to start this project knowing that multipurpose stages can reduce production costs. What I did not know were circumstances that would enable multipurpose stages to provide enhanced production efficiency.

The advertisement provided primary information degrading the underlying theory of the research subject. The two films, Agrinoui (2015) and Struthio (2011), that were produced during this research project enabled me to try new multipurpose stage arrangements and to collect data that provided a better understanding of multipurpose stage design applications.

Gill and Johnson point out a usual practice in research design:

> *"[Here it is important to remember that] the researcher, through developing his/her research design, is usually trying to test hypotheses generated from a theory, through data collection, in order to see whether or not the theory survives those attempts at falsifying or disproving it."* (Gill & Johnson, 2010)

I designed stages that progressively took better advantage of dynamic modular elements. Cycles of action and reflection resulted in ultimately developing a polymorphic stage that enabled creating multiple landscapes by repositioning scenic elements such as mountain sides.

A comprehensive description of the main role of qualitative research in my project, is as follows:

> *"Qualitative research has as its goal an understanding of the nature of phenomena, and is not necessarily interested in assessing the magnitude and distribution of phenomena (i.e., quantifying it). Participant observation is just one of a number of methods that are employed to achieve this kind of understanding."* (De Walt, 2001)

Exploratory research consisted of planning and developing multipurpose stages that were used for the production of two films. Participant observation enabled me to interpret the data that is presented in the form of an explanatory multiple case study.

The following description explains how participant observation enables acquiring new knowledge:

> *"In participant observation, the investigator is not a passive observer but actively engages in the research context to come to know about it."* (DePoy & Gitlin, 2011)

During the exploratory phase I made animated films that involved carrying out common tasks related to development and preproduction such as scriptwriting, drawing of storyboards, concept art, and top view sketches, as well as time-based 2D and 3D previsualisation. The rationale of each multipurpose stage was documented with top-view drawings. 3D previsualisation enabled obtaining preliminary data regarding feasibility, limitations, and advantages of planned systems.

A pertinent description of visual exploration is as follows:

> *"Visual exploration is a method of primary research most commonly used by designers for solving problems of form and communication. Studies during this phase can include multiple variations of color, imagery, typography, and structure. Beginning with a series of thumbnail sketches and concluding with a realized prototype, this process is used to vet out the most viable graphic solution. The process of visual exploration forces creative to move beyond initial concepts, often resulting in unique and innovative solutions."* (Visocky O'Grady, 2006)

Computer graphics enable studying and refining a 3D system during the planning phase of a film production. Visualisation is explained as follows:

> *"Visualization is a rapid prototyping tool that designers use to make concepts easily understood. Visualization techniques help designers examine form, concepts, or even usability. Whether executed on paper or rendered in a three-dimensional modelling program, visualization helps make abstract ideas into concrete tangible objects."* (Visocky O'Grady, 2006)

The presented stages started off as ideas that were visually explored prior to being developed into refined working systems that enabled making computer animated films.

After having determined the shapes and inner workings of interconnected 3D environments I proceeded with implementation. During the film production I used notes to document important aspects which later became part of the retrospective analysis.

The importance of field notes is explained below:

> *"For case studies, your own field notes are likely to be the most common component of a database. These notes take a variety of forms. The notes may be a result of your interviews, observations, or document analysis."* (Yin, 2014)

The planning and implementation tools that were used in making films with multipurpose stages are familiar to many computer animators. Thus, the presented multipurpose and polymorphic stage design rationales can be adopted by practitioners who are willing to use their tools differently.

Exploratory research enabled extracting new holistic data about the design and operation of multipurpose stage systems and case study enabled information analysis and reporting.

A description of the case study research method:

> *"A case study is an empirical inquiry that investigates a contemporary phenomenon (the "case") in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident."* (Yin R, 2014)

I have investigated several uses for multipurpose stages by designing inclusive stages for different production scenarios. The investigation of multiple cases provided converging data from different sources. The usefulness of this approach is indicated below:

> *"Case studies can cover multiple cases and then draw a single set of "cross-case" conclusions."* (Yin, 2014)

Two groups of cases stem from the production of two films. I first made Struthio (2011) for which I designed and developed different types of multipurpose stages (see chapter 4, pp 101-136). The initial findings provided knowledge that influenced the way I designed additional stages with multiple acting spaces for Agrinoui (2015) (see chapter 4, pp 138-214). The progressively gained experience enabled me to investigate the use of dynamic modular scenic elements which ultimately led to making a polymorphic stage that features transforming environments.

The two films have a different approach in film direction and make use of different lighting, texturing and rendering technologies. This indicates that multipurpose stages are not connected to any specific visual style. However, iterative development was dominant during the making of the presented stages and systems. The widely used cyclic process approach is described in the next subchapter.

Iterative design in the production pipeline

During the production of two animated films, I primarily used common tools that are available in most professional 2D and 3D computer graphics software. A major part of the implementation process was the progressive addition of improvements which occurred in cycles. The repeating process of review and implementation of corrective actions resulted in constructing refined products.

The logic of iterative design is as follows:

> *"Iterative design is based on a cycle of prototyping, testing, and refining. In iterative design, testing the project in some way-whether through focus groups, user tests, personas, or other methods-generates data to compare successive evolutions or "iterations"."* (Visocky O'Grady, 2006)

Iterative design is commonly integrated within several parts of the computer animation process which collectively form the steps of a production pipeline. The completion of an individual part can undergo a series of improvement cycles which follow the aforementioned iterative process principle.

Pipelines do not always have a fixed configuration as each film has unique requirements. The production pipelines for the studied cases have significant differences. Indicatively, the pipeline for Struthio (2011) was shorter than in Agrinoui (2015) because of the lack of dialogues which eliminated the need for voice recording and lip-synching. Moreover, the extensive use of Cel shading in the 2011 film necessitated a considerably limited amount of work concerning texture painting and UV mapping. The following table shows comparable sections of the pipeline diagram that highlight the aforementioned difference.

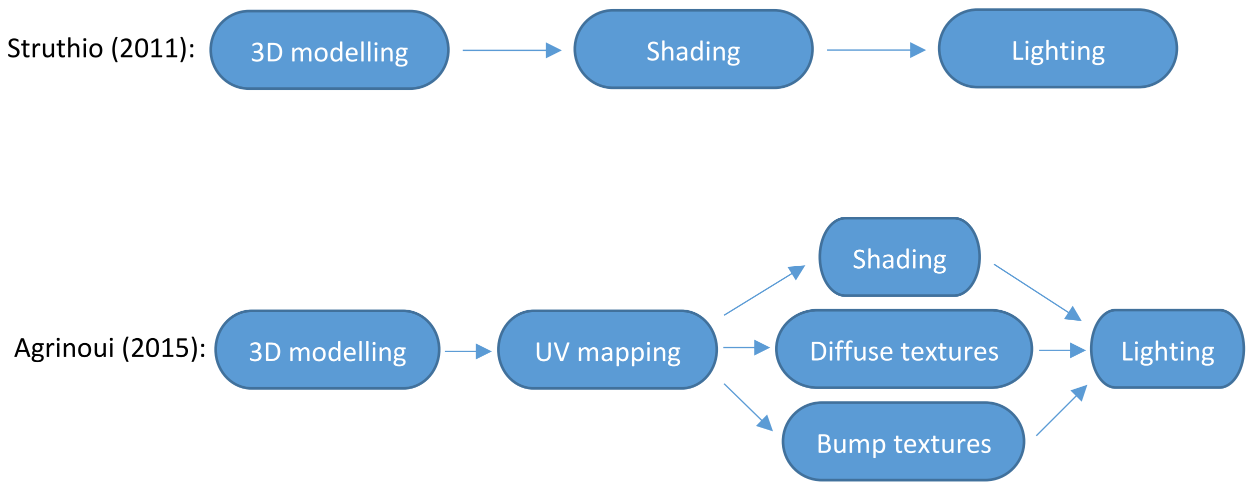


Table: Certain pipeline differences between two films

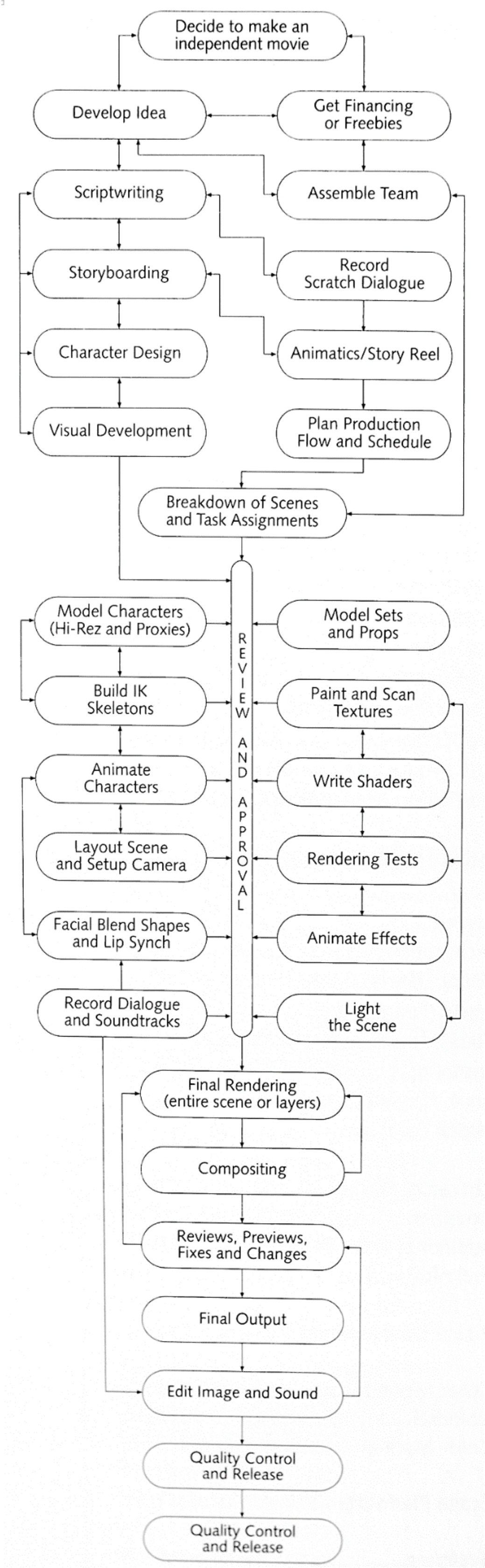


Table: Generic production flowchart (Kerlow, 2002)

In the film industry, the compartmentalised steps in the production pipeline are commonly assigned to separate teams. Team coordination can provide a smooth workflow and a timely exchange of interconnected parts. Timeframe charts facilitate defining not only the order by which tasks will take place, but also the time window for starting and completing each task. Such documents provide an organisational overview that indicates, for example, that scriptwriting precedes storyboarding, and that the dates on which the storyboard team is expected to be called to service.

The generic flowchart on the left provides an overview of interconnected production tasks.

"This presents a possible production flow for a small team working on an independent computer-animated short." (Kerlow, 2002)

Iterative improvements can be applied in numerous elements in the form of performing cycles that consist of progress reviews and of applying improvements up until the part is cleared to be used in conjunction with other steps in the pipeline. The application of iterative improvements through review cycles is indicated in the table as "Review and Approval" and encompasses numerous production tasks.
The role of revisions in computer animation was also underlined by Mark Dhrami who was head of production financing at Gaumont Animation when he talked about production pipelines at the 2014 Cartoon conference in Toulouse, France. It was indicated that a series of planning steps can lead to obtaining refined visual guides before making high-quality characters, backgrounds and props with 3D computer graphics. Dhrami also indicated that cycles of revising and editing can be applied to tasks such as layout, modeling, rigging, and rendering:

"Retakes and approvals" (Dhrami, 2014)

Cycles consisting of trials and the assessment of preview images enabled the gradual improvement of multiple aspects in Agrinoui (2015) and Struthio (2011). The feedback from test rendering enabled making lighting adjustments (See chapter 4, page 146).

The following diagram shows a part of the common workflow for adjusting the daylight lighting rigs in Agrinoui (2015).

Review cycle after having set up an initial Lighting rig **Subsequent cycle**

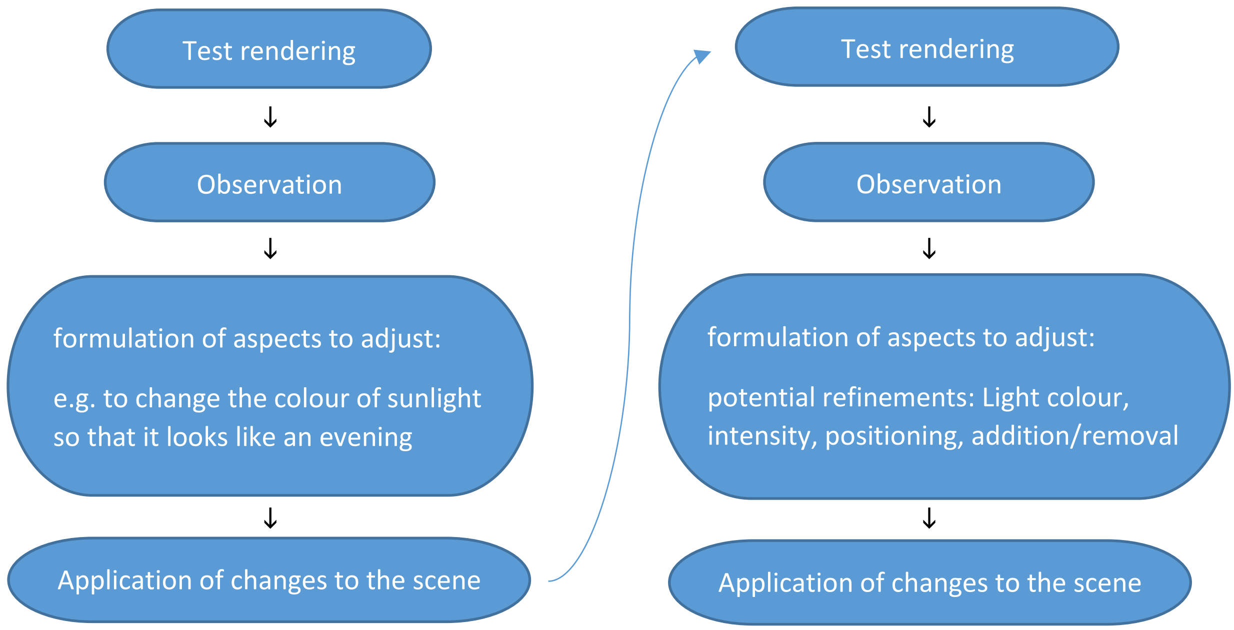


Table: Revision cycles. The precise remarks that emerge from progress inspection are not predictable.

The number of revision cycles was not predetermined due to the inability to foresee the editing remarks of subsequent progress reviews. Due to the unstructured nature of the process, there was no perceived advantage of preparing planning diagrams such as the above. It was regarded as sufficient to estimate the amount of work needed based on observing the stage layout, combined with prior experience with the process of setting up lights and the subsequent fine-tuning of their properties. During project budgeting and forecasting, it is sensible to take into account the likelihood of unforeseen technical setbacks which could consume time to troubleshoot.

There was a common technical approach regarding lighting and rendering the exterior daylight scenes of Agrinoui (2021). The line of action was decided upon evaluating costs and benefits. This kind of evaluation also occurred later as part of formulating the corrective actions within each revision cycle. For example, the justification for adding light sources would normally entail evaluating the effect of new lights on the image output as well as on rendering times.

Test rendering during the making of Struthio (2011) and Agrinoui (2015) served a dual purpose. One objective of testing was to progressively refine the appearance of the elements within the frame. The other aspect dealt with testing and improving technical matters such as computational optimization and asset management. The purpose of most of the systems that are presented in chapter 4 concern making landscapes that appear detailed with economical use of production resources. Although the use of such systems is not noticeable in the end products, they enabled limiting the number of required workhours as well as the amount of equipment for digital processing. A stage can simultaneously host multiple dynamic systems for simultaneously displaying elements such as groundcover (see chapter 4, pp 197-203), and forests that comprise of a limited number of trees (see chapter 4, pp 157-158). The development of the aforementioned dynamic systems were crucial steps that led to a major project finding. Polymorphic stage design concerns the ability to compose different environments out of a limited number of modular scenic objects (see chapter 4, pp 172-177).

Progressive improvements during the preproduction phase

Common preproduction actions can provide conditions for testing story concepts and stage layouts without the use of 3D computer graphics. Drawn storyboard frames can be rejected and redrawn, and top-view plans can be adjusted in conjunction with 3D previsualisation (see chapter 4, pp 159-161).

The initial top-view drawings for the stages of Agrinoui (2015) provided a very general view of the layout concepts (see chapter 4, page 127). The initial stage design concepts remained stable throughout the development phases. The subsequent revisions were mostly concerned with refining the mise-en-scène rather than making fundamental changes. The sizes of objects were determined to a significant degree during 3D previsualisation (see chapter 4, page 149). A substantial change was carried out on an exceptional occasion during the production phase (see chapter 4, pp 173-174).

Deleted scenes are oftentimes disclosed in the form of animatics by filmmakers in behind-the-scenes documentaries. The review of storyboarded sections can result in the decision to omit entire scenes (see chapter 4, page 160). Even when a script has been deemed suitable, visualised planning documents provide additional feedback that enable affirming or reassessing the effectiveness or even the necessity of scenes. The removal, the replacement or the editing of questionable scenes at a later time in the production pipeline is normally expected to come at higher costs because fleshing out details can consume significant amounts of resources.

The following graph shows that stage layouts were drawn and evolved from an early phase of the creation of Agrinoui (2015) and Struthio (2011).

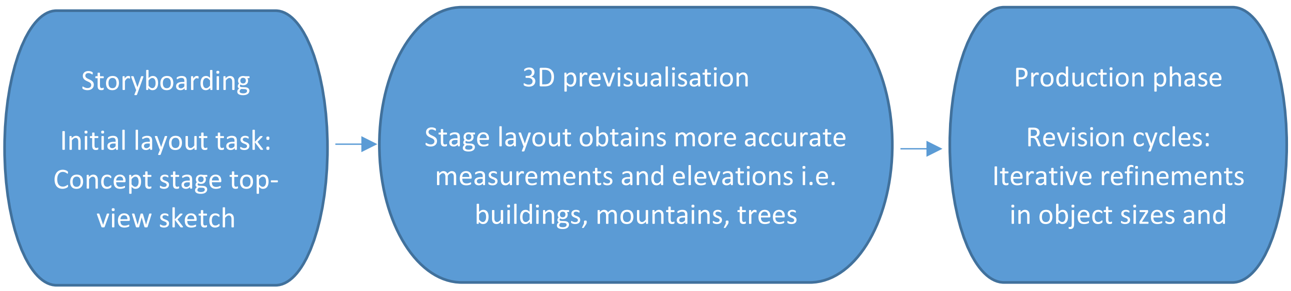


Table: Evolution of stage layout at different production phases

Progressive improvements during the production phase

The diagrams on page 73 indicate that computer animation pipelines can vary from production to production. However, the general modus operandi supports testing and gradually developing custom technical systems and new images.

Computational optimisation is a common concern in computer animation and a combination of measures can be applied. Angelos Rouvas explained that special efforts were made to reduce the computational load of a 3D environment (see chapter 4, pp 97-99).

> *"The technical team needed many findings to be able to open this set on a computer. It is of high architectural precision and detail... so very heavy."* (Rouvas, 2019)

A commonly practiced optimisation measure for reducing the computational weight of a 3D environment is the removal of surfaces and details that are not noticeable within the frame.

> *"We have left [out] a lot of detail since the script does not require close-up shots of every part of the monument."* (Rouvas, 2019)

The removal of elements that create computational loads is commonly practiced especially when there is redundant detail that does not significantly affect the final image. Matthew Teevan explained that the efforts in optimising geometry saved time in later steps of the production pipeline (see chapter 2, page 45).

> *"We decided to geometry-optimize as many of the assets as we could […] so that within any one shot we could save on rendering."* (Teevan, 2011)

Matthew went on to explain that knowing the camera positioning helped to determine the appropriate amount of detail for the objects that are shown in the frame.

> *"If the camera was placed in a certain position we could judge very early what was going to be seen and what would be less seen, and plan what was required accordingly."* (Teevan, 2011)

Production pipelines typically facilitate testing and revising. The element of testing and refining was vital during the development of several systems and of diverse stage layouts presented in chapter 4.

The layouts of different multipurpose stages can vary dramatically even if they have similar design rationales. If we compare the mouse nest stage (see chapter 4, page 98) with the savanna (see chapter 4, page 112) we will see remarkable similarities in the design reasoning. Both stages have multiple acting spaces and they featured in several film sequences. However, the visual results are considerably different as one consists of a small-scale interior space while the other has exterior surroundings. The visual differences are accentuated by the contrasting approach in lighting, rendering, and shading. This comparison highlights the versatility of the underlying principles in designing multipurpose stages.

Production Phase: Trial and error for applying gradual improvements

The previously displayed production flowchart (see chapter 2, page 73) indicates task modules that are interconnected with the prominent intermediate element "Review and Approval". The series of steps for completing each pipeline task in the production phase commonly involves working towards covering documented goals in concept art and technical plans. The process commonly involves progressively adding refined elements that are regularly evaluated for their effectiveness. For example, at the onset of developing the lighting rig, several lighting technologies could be evaluated for their expected effect on production costs, image quality and storytelling. Thereafter the common progressive steps include positioning light sources on the stage where they can be tested, and adjusted. A sensible set of steps for making a daylight lighting rig for exterior environments is presented in the book Digital Lighting and Rendering:

> *"You can create a simple outdoor lighting setup by adding three elements to your scene: direct sunlight; soft fill light representing light from the sky; and indirect light, simulating light that has bounced off of surfaces in your environment. When you put these three elements together, you can simulate outdoor light at any time of day."* (Birn, 2014)

It is clarified that there are several approaches for creating skylight:

> *"You can simulate sky illumination in three alternative ways in modern software: You can simulate the sky with an array of lights coming from different directions instead of using dome lights; you can use a unified sun and sky shader that is available in many programs; or you can use image-based lighting to illuminate the whole scene with a High Dynamic Range Image (HDRI)."* (Birn, 2014)

The procedure for making a lighting rig entails placing different types of light sources and adjusting properties such as intensity and colour.

The progressive refinement of the lighting rig involves cycles of applying adjustments that affect the aesthetics such as intensity and colour and reviewing the rendered outcome:

> *"The shadows from the sun are the most important shadows in an outdoor scene. Be sure to adjust and test-render the sun shadows, and make sure you like their shape and direction, before you move on to add any other lights."* (Birn, 2014)

Refined technical optimisations or workarounds can lead to increased shadow quality at reduced rendering times. The following example is indicative of how a specific lighting setup can be made more efficient

> *"Stretching a depth map over too broad an area can cause it to lose accuracy. If you want to work efficiently with depth maps in cases like this, sometimes you must represent the sun with an array of spotlights, and each must provide light and shadows to one region of the scene. Using multiple depth maps, each with a reasonable resolution such as 1024 or 2048, is usually more efficient than cranking up the depth map resolution above 4096 or 8192."* (Birn, 2014)

Comparative tests were made during the creation of Struthio (2011) and Agrinoui (2015) for the gradual improvement of the lighting, the models, and the textures of 3D environments. A fast-paced method for progressively refining shapes, colours, and lights involved comparing preview images that were rendered before and after an adjustment was made. The simultaneous display of the two images enabled identifying the effect of recent actions by comparing the differences. Changes that had a positive impact were frequently followed by additional trials in the same direction so as to obtain optimal settings or more suitable shapes and colours. At the same time, digital tools are forgiving when actions yield unfavourable results and undo commands could conveniently revert the scene into a previous state. An illustrative example of how revision cycles progressively affected the layout of mountains and their appearance within the frame can be found in the section about the making of the mountain roads stage (see chapter 4, pp 174-175).

The revision cycles that enabled adjusting the layout of the savanna stage during the production phase (see chapter 4, page 112) took into consideration the refined positioning of cameras and involved periodically studying rendered previews of animated sequences. Some review cycles addressed shaping the height of background mountains as their shape affected the composition of the frame. Other revisions dealt with studying the frame contents so as to remove sections of objects that were not visible in order to reduce 3D geometry. This process resulted in cutting a glaring gap in the surrounding mountains. This rationale was also applied to the river which stops flowing where it exits the frame at a point just outside the field of view in the corresponding scene. The removal of stage objects that are not visible from certain camera angles is commonly practiced in the industry and serves as a measure for limiting computational loads (see chapter 2, page 44 and 54).

The appropriate amount of detail in objects that are within the frame varies from case to case (see chapter 2, page 57). Apart from removing redundant geometry, there were numerous occasions where geometrical detail was in progressive steps, for example, certain review cycles concerned adjusting the shape of the edge of the river, and the addition of geometry in key places to improve its appearance (see chapter 4, page 114).

Cases where the amount of geometry is too high for the purpose of an object can result from importing 3D models from an asset library into the stage file (see chapter 2, page 56). After placing high resolution models on a stage, a purposeful set of revision cycles can address identifying and removing excessive details from objects that appear inconspicuous within the frame. Creators of Ralph Breaks The Internet (2018) shared their experience of having composed a cityscape that comprised of high-resolution buildings. A targeted reduction of detail was necessary for their hardware to carry out the rendering process (see chapter 2, page 44).

Design improvements that are carried over from production to production

Visual improvements are often noticeable by comparing objects, in films or video games, that reappear in sequels. This is because systems that were used in the first version of a production can be reused, adapted or improved so as to take advantage of more recent technologies. Updated systems can also be evolved so as to cover needs that did not exist in the earlier work. Objects that reappear in subsequent instalments may need to be shown differently such as in a wet condition.

Matthew Teevan explained how the model of a 1930's car that was shown in Everyone's Hero (2006) was repurposed to be displayed as a destroyed car in the film 9 (2009) (see chapter 2, pp 45-46).

> *"We retextured it, of course, and did a lot of visual distressing […]"* (Teevan, 2011)

Changing the appearance of preexisting surfaces can bring down costs that are associated with modelling, UV mapping, as well as with planning and research concerning the shape of the object.

The reuse of 3D assets does not always need to be made discreetly as characters and their homes may reappear in separate productions. However, the redisplay of objects, even within the same film, can be made unnoticeable to the viewer. This subject was addressed extensively in this project.

> *"Reusing materials by turning it around and shooting from a different angle was also another strategy."* (Teevan, 2011)

Two productions can rely on similar underlying technical structures that are capable of different visual outputs as indicated in the literature review (see chapter 2, page 62). The use of shared design rationales can be observed in the presented cases. The following example illustrates how knowledge in a specific area grew by reapplying successfully implemented technical concepts that were adapted to the particularities of additional 3D environments. The savannah stage (see chapter 4, page 112) and the racetrack stage (see chapter 4, page 151) have background setups that comprise of rows of mountains with a semi-circular shape when viewed from above. However, the later version featured an additional system (see chapter 4, page 152) which enabled the camera to be oriented towards directions that cover 360 degrees of view. Another subject that was revisited in several cases concerned scenic objects that are shaped as ribbons for diverse uses. Ribbon-like elements enabled filling stage areas efficiently with vegetation (see chapter 4, page 131), forests (see chapter 4, page 120), and mountain sides (see chapter 4, page 177).

Interview about common practice

Production efficiency is a common goal among filmmakers regardless of technique or budget. I have identified examples of versatile stages being used in computer animation projects of the multitalented film director Angelos Rouvas who provided useful details (see chapter 4, pp 97-99).

A film director can consult with a scenographer and a computer graphics technical director in order to plan an efficient production framework. An informed overview enables planning a film while being aware of how certain shots will affect requirements in talent, infrastructure and timeframe. Alternatively, directors who are also technically savvy scenic designers are often able to directly draw the shape of a multipurpose stage that satisfies their creative vision, and that provides high production efficiency.

My conversation with Angelos Rouvas concerned the potential of multipurpose stages. His analysis of how he dealt with two animation projects came from the standpoint of a director who knows how to take advantage of multipurpose stages in favour of obtaining increased production efficiency.

One common concern of Angelos and me in making a multipurpose stages is achieving a number of compelling shots so as to cover the needs of long film segments without losing the audience’s interest. Another common concern is in making computationally light 3D environments that enable making films economically, and with a quality that would make them desirable by film festivals, distributors, viewing platforms, and audiences.

Research project composition

Outline of preliminary phase: formative research:

- Review of knowledge concerning multipurpose stage design. Study of a computer animation projects that incorporates multipurpose stage design. Formulation of theoretical propositions.
- Review of common practice.
- Formulation of research objectives.

A retrospective observation of primary data that was collected during a computer animation TV advertisement in 2003 enabled me to establish that multipurpose stages can offer significant productivity advantages. The primary objective was to obtain a better understanding of designing stages that can display multiple environments, and thereby offer enhanced production efficiency.

Outline of exploratory phase: Holistic data extraction:

- Planning of film projects that contain multipurpose stages.
- Design and implementation of static inclusive multipurpose stages as part of the film production process. Static multipurpose stages have multiple acting spaces, they can show multiple environments, and they rely on scenic objects that stay still.
- Exploration of dynamic repositioning of small modular scenic elements. Changing the location of objects to frame different shots provided optimised use of stage objects and an overall reduction of on-stage objects. Repositioning the elements of clusters of trees and clouds enabled showing them multiple times as differentiated objects.
- Exploration of dynamic multipurpose stage design in which large scenic elements of hills and mountains are repositioned between shots to create the appearance of diverse terrain morphologies. A polymorphic stage can display a large number of 3D environments without increased computational demands due to the repurposing of major building blocks that already are on the stage.
- A database that comprises of field notes and progress files of the film projects was maintained throughout the exploratory part of the research project.

During this phase I made separate stages that cover the needs of different animation sequences. The iterative design process led to obtaining refined production systems that collectively provided a productive workflow with low computational latency and professional image quality.

Outline of explanatory phase: Analysis of data - Multiple case study:

- Separation of data into comprehensive categories.
- Explanation the purpose of each stage.
- Analytical presentation of how each stage system was made.
- Report on how scenic optimisations affected production efficiency.
- Observations on the parallel workflow of two 3D computer graphics artists.
- Observations on incorporating modular design within multipurpose stages.
- Generalised inferences about polymorphic stage design.

The analysis of collective data provided a thorough understanding of how multipurpose stage design can be practiced with positive outcomes in regards to overall production efficiency.

Preliminary phase

The preparatory study consisted of collecting information about prior achievements in the field of research and of reviewing past cases. Samples from animated films have been gathered to showcase several types of 3D and 2D environments. The exploration identifies the forms of stages and shapes of scenic elements in relation to the visual results seen in notable animated feature films, that prioritise image quality, and in animated series with a high production rate.

Animated Series provided insight regarding resource management that enables making a considerable number of episodes in a short amount of time. The research reveals certain limitations in directing choices that can be imposed, and compromises in image quality that provide improved production efficiency. I explored the relationship between the appearance of surfaces in relation to their substance. I documented how certain scenic elements for live-action films serve a purpose of appearance such as flat building façade that is not useable as an actual building. The findings inspired me to explore the creation of scenic elements that look right from a limited few points of view and that can be made and managed more economically compared to objects that can be seen from all angles.

I observed previous practices of handling various terrain morphologies and stage structures. I increased my awareness regarding the management of 3D asset libraries that facilitate access to repeatedly used objects for preparing separate scenes. I learned about procedures that facilitate reusing props such as modular design which can be used for assembling numerous different constructions with the use of a few basic building blocks. Model management can be catalytic for economically building 3D environments in terms of work hours and computational resources.

The review of literature and of past cases (see chapter 2, pp 28-62) enabled me to specify the goals of this project. The fundamental theory derived from a TV production that I made in 2003 which relied on two stages to create numerous shots.

Gill and Johnson explain the importance of initiating research design with a theory:

> *"[Here it is important to remember that] the researcher, through developing his/her research design, is usually trying to test hypotheses generated from a theory, through data collection, in order to see whether or not the theory survives those attempts at falsifying or disproving it."* (Gill & Johnson, 2010)

The preparatory work enabled me to lay a path that ultimately led to a deep understanding of how specific actions can assist in making professional productions with limited budgets or timeframes.

Exploratory phase

The applicability of multipurpose stages was tested within production conditions that involve interconnections of 3D environments with other processes such as character animation. The holistic research approach enabled the observation of multipurpose stages during the planning and development phases of two computer animation films.

Computer animation films consist of the combination of media which are comprised of smaller pieces of work. As such, I was able to see stage design within the complexities of complete productions. Choices regarding the form of 3D environments and mise-en-scène can be documented in storyboards, concept art, top-view sketches, and 3D previsualisation. During development and preproduction we can decide on matters such as the general size and shape of the acting spaces as well as the timing of shots and choreography.

Finer adjustments can be added during the production phase where the 3D surfaces that will be shown in the film are developed, along with lighting.

Both films Agrinoui (2015) and Struthio (2011) acted as platforms for trying out new practices that led to the development of refined production systems. In order to reach fully developed systems the film project went through a 3D production pipeline which is common practice for making computer animated films. Upon the assembly of scenery and characters, I commenced iterative improvement cycles that enabled to progressively refine film elements by periodically reviewing the production progress.

The following string of actions transformed ideas into products. The shape and functionality of my stages was conceptualised and documented during development and preproduction with descriptive storyboards and draft sketches of top view plans. The concepts were tested by digitally blocking the stages out with undetailed geometry thus forming the basis for previsualisation that contained choreography, timing and framing data. The film production phase contained the development of more detailed 3D environments based on the descriptions of the 3D stage layouts. Progressive improvements were applied on the scenic elements through performing periodic cycles of review which were followed by the subsequent implementation of adjustments.

I took special measures for making optimal use of 3D assets and I implemented management systems that kept computing performance at levels that ensured a productive workflow.

Scenic optimisation enabled keeping the number of stage elements low. Object optimisation enabled depicting detailed objects with relatively low computational demands. Special systems enabled streamlining repetitive tasks such as ensuring that the facades of numerous objects face towards the camera in multiple shots. To lower the geometry of objects I made extensive use of single-sided surfaces in order to provide a detailed appearance of objects such as trees as long as the normal side faces the camera.

The appearance of the environments evolved in incremental steps during the production phase until satisfactory image results were achieved. The workflow consisted of cycles of rendering previews of each sequence. Each preview video enabled me to observe and make notes about improvement tasks that would be implemented during the next work session. The recognition of the resulting films by jury members of international film festivals are indicative of the overall quality of Struthio (2011) and Agrinoui (2015).

Film planning

At the onset of the production of Agrinoui (2015) and Struthio (2011) I was confronted with fundamental development and preproduction issues that included defining visual themes, the framing of each shot, and planning for technical implementation.

The observation of the appearance of atmospheric phaenomena and of actual locations provided awareness of the visual properties of objects that would appear in my films. I photographed landscapes and their elements such as hillsides and clusters of trees from different distances. This primary source of data acted as visual reference that enabled me to make stages that take up a limited amount of space. Forced perspective enabled me to make the horizon in vast mountainscapes appear to be distant when actually background objects such as the sun and clouds were in relatively close proximity to the acting spaces.

Uses of imaging in studies are described here:

> *"Imaging, including both still photography and video, is another data-recording strategy that is being increasingly used in naturalistic inquiry. Imaging is particularly useful in studies that focus on environmental elements, interactions between individuals, and person–environment activity, as well as when observations of both nonverbal and verbal behaviors are the focus of the research study."* (DePoy & Gitlin, 2011)

Visual exploration was conducted by preparing storyboards, concept art and top view plan sketches. The process of trying concepts, forms, and colours enabled me to formulate and document decisions in visual material that was later used as reference during the production phase.

Animatics enabled me to previews the films and to adjust the framing and timing of each shot. The planning material provided information about the number and type of objects that need to be developed.

The 3D previsualisation of Agrinoui contained low resolution draft 3D environments and provided feedback regarding the practicality of the shape of each stage. I used the layout of the 3D previs as a foundation during production to progressively replace the low detailed geometry with high quality objects.

Technical trials enabled developing the non-photorealistic cel shaded appearance of Struthio (2011). The painterly appearance of surfaces in Agrinoui (2015) was also developed during early trials where I standardised a texture map editing approach that was applied on most surfaces to obtain a consistent visual style.

The planning steps:

- Scriptwriting and storyboard drawing were critical for deciding the storyline and for describing each shot. Strategic adjustments to the script can positively affect production efficiency.
- Top view concept drawings of the stages provided information about how the placement of elements would affect frame composition. They also enabled calculating the overall scenic requirements.
- The 2D animatics were a sequential presentation of the storyboard sketches of Struthio (2011) and Agrinoui (2015). Animatics were essential to visualise the flow of the stories and enabled adjusting the timing of each shot.
- The 3D animatics enabled placing cameras and proxy objects, and provided visualised tests of how the stage concepts work in three dimensions by providing a spatial awareness that was not present in storyboards.
- The 3D animatic of *Agrinoui* (2015) incorporated all the stages of the film within one working file. This enabled previewing the entire film in real time. The setup provided instant access to any part of the film for adjusting blocking, framing and timing.
- Field work took place to produce reference photographic material of real objects and environments. The pictures were used for observation and as a basis for creating texture maps for 3D surfaces.
- A technical research of tools gave insight regarding production needs and expectations.

Sampling

The stages in this project enabled using a common cinematic language which can communicate stories in ways that feel natural to the audience. Moreover, the stages host representative types of actions that are commonly shown in films. For example a scene may start with a wide establishing shot; a dialogue can be covered with over-the-shoulder framing; and a moving camera trucking shot can follow travelling actions such as walking, running, driving and flying.

The locations of the 3D environments deal mostly with outdoor spaces that contain natural and manmade elements. Wide open external environments include a salt lake, a savannah, a beach and mountains; areas that feel more confined include a road tunnel and a stadium passageway as well as forest paths. Areas with architectural elements include buildings around a race track, an ancient temple, a bridge as well as pavements and streets with straight and winding sections.

The underlying systems of the presented stages can support environments with diversified themes by altering the appearance of surface skins. For example, the horse racetrack could be transformed into a running track; the ancient temple could be transformed into a cathedral; and the salt lake into an ice covered lake.

Although the research outcomes can be used as a paradigm for making stages with a similar layout, the multiple case study explains multipurpose stage design as a philosophy that can be adapted to address the unique production needs of new films.

The underlying polymorphic stage design rationale that relies on shifting modular scenic elements can be transferred to create types of environments that are not presented here. Elements that can be handled as modules of larger objects can be found in the identical windows of building facades, the seats inside a bus, a train or an airplane, the bedroom layout in a cruise ship or a hotel floor, supermarket aisles, and restaurant dining tables. Polymorphic stage design theory, can be applied to make a transforming floor of an office building that features moveable furniture and walls. Such a stage could host scenes in what appears to be different floors of a building.

Explanatory Phase - Data analysis

The multiple case study method enabled the retrospective analysis of data that was collected during the exploratory phase of this project. Stage design is evaluated as an interconnected element that affects several steps in the production pipeline. On the one hand explanatory research enabled documenting how certain multipurpose stage systems were designed and how they were managed within film projects. On the other hand the collective information of the reported cases enabled reaching generalised inferences. The conclusions can have implications for other film projects as the studied productions depict types of actions and landscapes that are commonly shown in films.

Kothari explains the case study method:

> *"It is a method of study in depth rather than breadth. The case study places more emphasis on the full analysis of a limited number of events or conditions and their interrelations. The case study deals with the processes that take place and their interrelationship. Thus, case study is essentially an intensive investigation of the particular unit under consideration. The object of the case study method is to locate the factors that account for the behaviour patterns of the given unit as an integrated totality."*
>
> *"In respect of the case study method an effort is made to know the mutual inter-relationship of causal factors."* (Kothari, 2004)

The making of animated films consists of a broad range of tasks. However, the data which is presented concerns only the subjects that are connected to the research subject. This focused approach provided a deep understanding of how multipurpose and polymorphic stage design can affect production efficiency.

Yin explains that the researcher can have an active role on the studied phenomena:

> *"Participant-observation is a special mode of observation in which you are not merely a passive observer. Instead, you may assume a variety of roles within a fieldwork situation and may actually participate in the actions being studied"* (Yin, 2014)

Primary research was a reliable source of information. Obtaining meaningful data from other production companies could lead to inconclusive results. Although many companies release behind-the-scenes documentaries and commentaries that explain how certain films were made, the contained data is often superficial as these productions are often targeted towards consumers rather than experienced filmmakers who would likely appreciate more in-depth information.

Sekaran explains the difficulty of obtaining useful data from third parties.

> *"Authentic case studies are difficult to find because many companies prefer to guard them as proprietary data."* (Sekaran, 2003)

I kept notes of my observations during the production of the two films which took place during the development of the research project. These notes contained the reasoning behind certain systems, and about progressive updates of work during film development.
While making the films I frequently compared the results of actions by visually assessing images that were made with a trial and error approach. A typical example of this process is picking the best option after observing two similar images that were made with a slightly differentiated object colour or shape. The awareness of the path that led to the resulting products is essential for understanding the production process.

Jackson explains the contents of analytical notes:

> *"[Analytical notes] involve interpretation, or inferences on your part, in other words, judgements or conclusions drawn about what is being observed based on contextual information."* (Jackson 2010)

Once I had completed the first film I reflected on my noted observations in preparation for the second film. My initial experience on working with multipurpose stages was key for designing diversified and new systems for Agrinoui (2015).

The philosophy of shifting scenic objects evolved with gradual steps until I made a transforming stage that displayed multiple landscapes by rearranging mountain modules.

The case study method enabled me to process the data gathered during the production of two films. Having a collective overview of the dataset enabled me to make a retrospective analysis and to reach conclusions.

Thomas offers a pertinent description of the case study method:

> *"Case studies are analyses of persons, events, decisions, periods, projects, policies, institutions, or other systems that are studied holistically by one or more methods. The case that is the subject of the inquiry will be an instance of a class of phenomena that provides an analytical frame — an object — within which the study is conducted and which the case illuminates and explicates"* (Thomas, 2011)

The actualisation of complete products provided a profound awareness of the interconnections between multipurpose stages and other parts of a production.

Kothari's explanation supports the rationale of my research methodology.

> *"In brief, we can say that case study method is a form of qualitative analysis wherein careful and complete observation of an individual or a situation or an institution is done; efforts are made to study each and every aspect of the concerning unit in minute details and then from case data generalisations inferences are drawn."* (Kothari, 2004)

I present the research outcomes by providing descriptions of how each multipurpose stage has enabled working on multiple scenes.

Each case contains a description of the purpose of a stage and the reasoning behind its shape. I also explain key areas in the production pipeline such as the purposeful three dimensional form of scenic elements, how they were organised as 3D assets, and I present practical systems that enabled handling stage elements. I provide information that concerns production workflow that includes cooperative teamwork that enabled achieving parallel progress in character animation and in scenic work. Having multiple people work simultaneously on a scene has implications concerning production timeframes. The overall information provides an understanding of how each stage was designed, developed and managed as a whole.

Sekaran explains descriptive studies:

> *"A descriptive study is undertaken in order to ascertain and be able to describe the characteristics of the variables of interest in a situation."*
>
> *"Descriptive studies are also undertaken to understand the characteristics of organizations that follow certain common practices."* (Sekaran, 2003)

This project explains how the optimisation of 3D graphics and the optimal use of scenic objects had a positive effect on production efficiency by enabling a speedy completion of simple tasks such as file-saves and limited computational demands for editing 3D graphics and for rendering long sequences. Furthermore, the case reports contain descriptions regarding the limitations of camera movement and frame composition in relation to the activity of the subjects within each stage system.

The creation of two films provided a wealth of data that I separated into essential categories so as to methodically address each research objective.

Kothari explains the importance of organising data:

> *"Classification: Most research studies result in a large volume of raw data which must be reduced into homogeneous groups if we are to get meaningful relationships. This fact necessitates classification of data which happens to be the process of arranging data in groups or classes on the basis of common characteristics."* (Kothari, 2004)

Each of the studied cases deals with a separate 3D stage. The analysis of each stage consists of subjects that describe the purpose and explain how the objectives were met. The reports are accompanied by images of the creation process and frames of the final products. Each case has sections that address film planning, optimisation, implementation and observation of the resulting product. The planning section comprises of a review of storyboard, animatic and top-view drawings. The optimisation section deals with maximizing the potential of tools and work-hours. The implementation and observation sections provide an analysis of how each stage operates in relation to the appearance of the films.

The collective overview of the sum of cases enabled me to provide a set of outcomes that concern meaningful multipurpose stage design and implementation practices.

O'Grady explains Summative research:

> *"[…] summative research [is] used to frame and decipher the outcome of an investigative process. It confirms that the original hypothesis is correct or illustrates that it is flawed."* (O'Grady, 2009)

Teamwork - Participants and data

Films are normally comprised of separate pieces of work that are connected to different branches of knowledge.

The invited specialists who participated in making my films were not involved with stage design and development. However, the stage is an area that character animators come in touch with to gain an understanding of the shape of the acting area and its surroundings.

Although I made notes on multipurpose stage design concepts during the scriptwriting process, I did not feel the need to explain the rationale to my collaborators. While I was writing the scripts the process of choosing locations was affected by their potential to provide appropriate conditions for testing the research propositions.

When I asked for expert advice on the initial version of the script of Agrinoui (2015) it never occurred that the choice of locations compromised the quality of storytelling even though achieving a convenient production process had affected the decision-making process. Writers can be made aware of potential limitations in environment choices for a range of reasons including there being already a framework in place that was used for making previous episodes of a TV series.

Planning documents in the form of a script, concept art, a storyboard and an animatic were useful for communicating the production needs of Agrinoui (2015) with visual artists, the casting team, the sound designers and the voice actors. The music composers in both Agrinoui (2015) and Struthio (2011) started working towards the end of the production when the film already had audio effects and nearly finished visuals.

The voice track enabled me to edit the sequences with accurate timing when I made the 3D previsualisation of Agrinoui (2015). The previs offered a coarse description of the choreography, the shapes of stages and the scenic elements that needed to be developed in more detail. The planning material was useful for communicating the production needs with the collaborating 3D computer artist. Sakis Kaleas undertook the tasks of character-rigging, character animation, the development of a 3D model of a vehicle, providing technical advice on lighting and rendering as well as implementing particle systems, volumetric effects and physics simulation.

The organisational structure had a provision for collaborating 3D artists as it enabled the simultaneous work on 3D environments and animation. The framework provided solutions for file sharing, as well as for periodically combining characters with stages for the creation of film previews.

Each preview cycle gave visual feedback that enabled assessing the progress on both animation and scenic work. Frequent progress reviews enabled the effective identification, annotation and communication of improvement actions. Cycles consisting of a progress review, implementation of improvements, and rendering a preview sequence enabled focusing our efforts on specific tasks. Applying improvements iteratively reduced the chances of working towards a wrong direction and having to delete large parts of our work as corrective operations. Improvement tasks mainly concerned the addition of definition to scenic objects and to motions by carrying out actions of progressive refinement.

The proxy environments from the 3D previs offered a comprehensive understanding to the character animator of the size of the project before he undertook the job as the previs indicated the framing of each shot and the intended character actions (see chapter 4, pp 142-146).

The lightweight 3D environments from preproduction were ideal for hosting character animation operations because they provided the limits of acting spaces as well as the cameras whose framing enabled focusing animation tasks to visible areas. As a result, character animation project files did not have to load or display computationally heavy background objects. Respectively, project files that were used for developing the scenery contained the low-resolution proxy characters from the 3D animatic, and not the detailed characters, resulting in limiting the computational demands during scenic improvements. The use of low resolution geometry provided a responsive computational workspace both 3D artists to have during the real-time 3D creative process. The high resolution characters and stages were periodically merged to create preview sequences.

The fact that computer graphics in Struthio (2011) were handled by a single person, myself, did not intrinsically shorten the production pipeline. However, the revision cycles did not entail the communication of instructions or the sharing of file updates with collaborators. Being in charge of both directing and of implementation enabled me to make speedy improvement cycles as progress reviews contained efficient and achievable technical solutions which I could immediately implement.

Struthio (2011) showed clearly how multipurpose stage design could incorporate different environments and provide productivity advantages. Thus, Struthio (2011) constituted a decisive step for initiating the more technically demanding team project Agrinoui (2015).

Case Study - Interview

Interviews were a corroborative source of information concerning the general practice of designing multipurpose stages as well as the effective teamwork during the production of Agrinoui (2015).

Computer animation film director Angelos Rouvas shared his view about creating stages that serve multiple purposes in a discussion about his experience with the subject in two of his productions (see chapter 4, pp 97-99).

A film's production timeframe can be shortened with a corresponding increase in people and infrastructure. To assure the effective collaboration of team members the production framework can take advantage of provisions that support unobstructed and even synergistic workflows.

The production framework of Agrinoui (2015) enabled two 3D artists to work simultaneously on each scene. Two artists working in synergy achieved a productivity increase that was greater than if they worked on separate scenes. The synchronised collaboration provided enhanced efficiency during revision cycles. As a director, my periodic review of progress was based on observing one preview sequence at a time that displayed the animated characters within the environment that would be shown in the film. The periodic observations about applying improvements concerned the image as a whole as I made simultaneous notes on the motion of characters and the appearance of 3D environments. The efficiency of the revision process was also supported by the fact that each single preview rendering job provided a long preview sequence that included the updated progress in both animation and scenery.

The interview is part of the multiple case study and concerns the documentation of the view of Sakis Kaleas (see chapter 4, pp 212-214) who made character rigs, character animation as well as atmospheric and physics effects for Agrinoui (2015).

Yin explains how short interviews can be part of the case study method:

> *"The case study relies on many of the same techniques as a history, but it adds two sources of evidence not usually available as part of the historian's repertoire: direct observation of the events being studied and interviews of the persons involved in the events."* (Yin R, 2015)
>
> *"A major purpose of [a one-hour] interview might simply be to corroborate certain findings that you already think have been established."* (Yin R, 2015)

The interview offers the opportunity to explain how a serial pipeline would be less advantageous, compared to the implemented parallel process, as separate cycles of observation and implementation sessions would need to take place to address image and motion improvements.

Another discussion topic is the organisational structure for project file sharing. An advantageous effect of multipurpose stages which host long sequences is the overall reduced number of project files. Furthermore, a reduction in character animation projects reduces the times needed to prepare the conditions of setting up separate scenes.

The interview highlights the usefulness of 3D previsualisation regarding the documentation and communication of stage layouts and choreography which acted as templates during production.

During production I had the backup plan option to divide large stages into smaller areas if the productivity advantage was lost due to unforeseen computational demands. The character animator had a similar option and took advantage of separating extremely long sequences into shorter sections for practical reasons. Even so, the streamlined character animation workflow took advantage of operating on long sequences.

Although unified stages may require more time to plan, compared to having multiple single-purpose stages, the amount of resources saved during film production as a whole can be substantial.

The streamlined character animation setups that were applied in Agrinoui (2015) and Struthio (2011) have prospects for use in animated series. In subsequent episodes the models of main characters and scenic elements can be reset into their default position. Thus, limiting the work of making new scenes of in the same environment to animating new actions.

Devising technical concepts

Technical systems were developed for film productions, and are therefore largely seen as a means to an end. The multifaceted concerns of film creators are highlighted in an interview published in 2011 in the Animation Practice, Process & Production journal. Shane Acker, director of the short film 9 (2005) and of its 2009 feature length adaptation, explains how his broad knowledge background enabled him to design post-apocalyptic environments featuring destroyed buildings.

> *"Being a designer and architect, I have an interest in how things come together and connect, and how they fall apart, and I wanted to create a really tactile, believable world, which demonstrated this."* (Wells, 2011)

The presented systems stared as ideas that mainly concerned the layout of versatile stages, the usability of scenic objects for reducing the amount of work, as well as the optimisation systems for limiting computational loads. Concepts were deemed suitable for further development if they had the potential to support the narrative, and to provide productivity advantages.

Conceiving primary ideas mostly occurred at unscheduled moments and involved simultaneously taking into account storytelling/communicational, artistic/aesthetic, and technical/management aspects. Ideas consisted of potential routes of action along with predictions of possible outcomes.

Although the thinking process, during the development phases of film productions, resulted in documenting fundamental plans, its contextual framework is complex, and varied depending on the specifics of each case. The cases are linked by the common goal of exploring multipurpose stage design rationales through practice.

Per Galle, in his article "Elements of a shared theory of science for design" builds upon previously formulated design definitions to provide clarified explanations of research and design concepts.

> *"In a more recent book on the theory of science of engineering, Clausen et al. formulated the following definition, which might very well apply to other design professions: 'Design is to be understood as an organized preparation and completion of a deliberate but creative course of development, in order to create new products, processes and systems' (2009: 216, my translation)."* (Galle, 2018)

Galle explains that the design process is evolved with the acquisition of new knowledge:

> *"Sargent beautifully describes the impermanence in a context of engineering. He explains how new design projects constantly create a need for un-anticipated combinations of knowledge; […] As he concludes, '[i]t could be that the only thing common to all design is the intention to produce something useful. That does not mean that design theory and methodology research ends, it means that it is unending' (Sargent 1994: 400)."* (Galle, 2018)

The exploration path in this project was not predetermined and it was adapted to create new applications and forms for static and dynamic stage systems that had shown to be effective. As experience grew, new stages incorporated more sizeable spaces for running and driving actions. The collective group of systems that was designed for each stage acted as a functional prototype and as a knowledge source that influenced the development of additional types of dynamic floors, lights, and modular elements. The progressively expanded knowledge on dynamic elements led to making a stage that relies on moveable mountains for composing numerous landscapes.

Galle continues by providing a definition:

"Practice: to employ one's knowledge in action (particularly everyday routine action, often professional).

Such action obviously leaves experience in its wake, which gives rise to knowledge by acquaintance (Section 3.2). So knowledge breeds new knowledge through practice, gradually and through mutual interchange." (Galle, 2018)

My knowledge regarding common practices was combined with personal work experience and a general awareness of the capabilities of digital tools. The knowledge background enabled me to intuitively foresee, without a computer, the potential outcome of hypothetical systems. For example, figuring out ways to reduce stage geometry with dynamic cloud modules (see chapter 4, pp 193-194) was made by mentally exploring applications that are based on established modular design theory. Descriptive notes of system concepts directed the initial steps in the realisation phase which were incorporated into film production pipelines. Ultimately, established systems such as those found in trees (see chapter 4, pp 153-158) were subsequently used in shrubs. The creation of visually differentiated elements occurred at a relatively fast pace because it involved following an already familiar step-by step creation process.

Common preproduction practices were suitable for developing the mise-en-scène. Ideas of stage layouts with multiple acting spaces were noted as top view plans. Stage shapes were further explored with storyboard drawings that took into account the spatial awareness of stage layout, as well as the positioning of cameras and characters. Thereafter, digital 3D visualisation enabled adjusting stage blocking for a refined framing of shots. Some ideas, such as the initial book layout approach (see chapter 4, page 106) underwent substantial changes until they were adequately evolved for the films.

In favour of conciseness the presented data is focused on explaining finalised systems. However, selective observations from the exploratory trial and error process provide insight about how certain concerns, and errors were handled. For example, unforeseen technical issues emerged from mispositioned stages in relation to the origin coordinates (see chapter 4, pp 212-214).

Limitations

Although multipurpose stage design has been thoroughly studied, the project findings have not been tested on large scale production scenarios.

Small scale productions form a suitable platform for trying new design methods as it reduces the risk of possible damages. The lack of stakeholders who could impose working with traditional methods facilitates taking unconventional routes. When I made the Mountain Roads polymorphic stage I based the concept of transforming stages on a theory without having seen something similar being implemented. Thus, I was not absolutely positive that the quality of the resulting landscapes would have met the target. Commencing such an endeavour in a large-budget production without assured success would probably increase the stakes and consequently bring resistance from backers.

Custom production frameworks can potentially enable coordinated large teams to work simultaneously on computer animation projects with multipurpose stages. A challenge with producing animated TV series concerns making every episode within a short amount of time. I have successfully implemented a parallelised production framework on a small scale. As such, the data does not concern the management of large production teams.

File referencing technologies would probably enable multiple animators to work efficiently on the same long sequence of a multipurpose stage. A computer animation project file can rely on externally referenced objects that are being saved in separate project files of different artists. During animation operations the computer of one artist accesses the project files of other artists over a network to provide a live combined view of the team's progress. The complexity of maintaining an active link between project files can be disadvantageous especially in cases where we must reactivate stored project files to potentially re-edit a scene that was made in the past.

The rendering requirements of the presented cases were relatively low. In my opinion multipurpose stages can take advantage of high-end rendering systems, such as render-farms, to either increase productivity, with near real-time rendered image sequences, or to increase image quality by including additional computationally intensive effects.

Despite the limitations, I have offered notable multipurpose stage design paradigms and theory that can be incorporated in large-scale productions by knowledgeable teams who can build custom production frameworks around their unique needs and infrastructure.

Computer animation productions can have storylines that vary greatly. A story can be adapted to take advantage of multipurpose stages by making adjustments to the locations found in the script. However, a deep analysis of how scriptwriting affects production efficiency would not be particularly helpful as multipurpose stage design is not exclusive to narrative film. For example, documentaries and visualisation projects can also potentially benefit from multipurpose stages. Therefore, multipurpose stage theory can be seen as a basis that, combined with the ingenuity of creators, can lead to new forms of stages.

Alternative research methods

At the onset of this project I considered conducting experiments as a primary research method. I intended to compare different multipurpose stage design and implementation strategies to identifying the most effective practices.

According to Griffith:

> *"In the scientific method, an experiment is an empirical method that arbitrates between competing models or hypotheses. [...] Experimentation is also used to test existing theories or new hypotheses in order to support them or disprove them."* (Griffith, 2001)

My experiments would have taken place within a round generic stage shape. 3D environments built for this purpose would have enabled a comparative analysis between versions of stages with changes in key variables.

Multipurpose stage systems affect so many areas of a film that it would have been difficult to assess the effectiveness of production design by conducting controlled experiments which would have generated data in isolation from real production conditions.

A comparative analysis of the results of experiments would have yielded detailed in-depth knowledge as they would have been focused on the effect of specific variables. Although experiments can be useful for refining established knowledge, they would not have been suitable for illuminating a new field extensively in width.

Yin explains that experiments can take place in both laboratory and field settings:

> *"Experiments are done when an investigator can manipulate behavior directly, precisely, and systematically. This can occur in a laboratory setting, in which an experiment may focus on one or two isolated variables (and presumes that the laboratory environment can "control" for all the remaining variables beyond the scope of interest), or it can be done in a field setting, where the term field (or social) experiment has emerged to cover research where investigators "treat" whole groups of people in different ways, such as providing them with different kinds of vouchers to purchase services (Boruch & Foley, 2000)."* (Yin R, 2014)

A disadvantage of experiments within a laboratory setting would be the limited usefulness of outcomes primarily due to the inability of a generic type of stage to cater to the unique needs of typical films. Furthermore, the isolation from creating a whole marketable product would provide an incomplete understanding of the subject. Although experiments can take place in field settings, they would have negatively affected film production progress. The experiments would require resources to be devoted towards the comparison of methods through the pursuit of creating comparable stages. Instead, I incorporated multipurpose stage design in two films and, as is commonly practiced, I progressively made improvements to the films. During this process I noted useful observations and after the films were finished, I made a retrospective analysis of evidence.

The multiple case study is concerned with the analysis of purposefully differentiated custom stages that host multiple scenes within holistic film production scenarios. The presented multipurpose stages contain representative examples of commonly used environmental themes, character actions and camera positioning to cover dialogue and travelling actions as well as establishing shots which are common elements of visual storytelling.

Seeing how multipurpose stages have been used to create films that contain familiar types of action and camera usage can encourage practitioners to consider implementing the presented production methods.

Measuring the effectiveness of multipurpose stages

The results of a comparative analysis between films with and without multipurpose stages would not yield reliable results due to the difficulty in finding a comparable contemporary film with similar quality characteristics and satisfactory data concerning production methods and costs. Judging film budgets can offer misleading impressions as production expenses are greatly affected by elements that are not relevant to the research subject.

The benefits of multipurpose stages are presented with a descriptive analysis of achievements. The most prominent benefits of multipurpose stages concern practicality. Operating on one stage reduces the amount of tasks needed to be made compared to having a fragmented project. Although I did not quantify the amount of workhours saved with multipurpose stages, I explain how they offer a reduced workload compared to having multiple independent stages with a single acting space.

Incorporating multipurpose stage design into the planning process requires additional planning which, among other things, may involve reviewing the script in an effort to identify chances for combining two or more environments in the space of one stage. This process is followed by visualisation trials with tools such as top-view plans and 3D previsualisation.

The advantages of multipurpose stages are in the streamlined production framework. When a stage can host longer sequences certain tasks need to be repeated fewer times, and project management benefits from a simplified file structure.

Scenic optimisations for Agrinoui (2015) contributed to reducing the computational needs to a point where the use of a render farm would not make economic sense.

Overall production requirements for making animated feature length films can be further reduced due to enhanced efficiency associated with scaling up and mass production. For example a five-fold increase in film duration would probably require a less than equal increase in the numbers of 3D characters and scenic objects.

Agrinoui (2015) is a pilot TV episode. Consecutive episodes could be made with fewer production resources by reusing the environments, the characters as well as the lighting and rendering systems that were developed for the pilot episode. A further increase in production efficiency can be achieved by placing systems for handling repetitive tasks. For example a facial motion capture system can be configured once and be used in separate motion recording sessions for applying grimaces and synchronised lip movement with speech.

The project at this point in time

A natural concern for research subjects that deal with digital technology is whether the outcomes will still be relevant after a few decades. Another question is why technology, in its current state, is now mature for production teams to take advantage of the research outcomes.

Technological developments occur at a fast rate. While certain 3D computer graphics procedures have significantly changed over the years, others have not. This project does not rely on rapidly evolving technologies that concern lighting, rendering, and animation. The creation of multipurpose stages mostly depends on the use of polygonal models, texture maps, and keyframes that 3D artists have been able to manipulate for decades in productions such as Toy Story (1995).

The computational power of 1995 workstations limited the ability to make stages with multiple acting spaces and views, unless the detail was significantly reduced. Essentially, many types of multipurpose stages would not have enabled producing professional results. Most of the presented stage concepts take advantage of today's RAM and processors ability to load more texture maps, and handle more geometry.

Although I made a production with multipurpose stages in 2003, it featured 3D environments with a relatively low polygon count and only one character in them. My more recent practice can better support the use of multipurpose stages as viable production methods as the end film products contain well defined 3D environments, multiple characters and have substantial durations.

The multipurpose stage design process can take advantage of the designer's understanding of what can be technically achieved as he can predict situations where a stage could become overwhelmingly computationally demanding. Another useful ability if for the designer to make decisions regarding the locations in the film as changes to the environments described in the script can result in significantly reduced production costs. The development of an implementation strategy during pre-production is key for potentially improving productivity. During the malleable planning phase, adapted changes can be made regarding interconnected aspects of narrative, style approach and technical implementation.

Filmmakers often weigh in practicality of execution within their decision making process. Through experience I have found that a director can take advantage of the strengths of production resources, such as available specialised workforce and infrastructure, to choose an efficient execution process at an early phase.

Regarding the evolution of technology, at the current rate of hardware and software improvement, we can confidently predict that the next generations of tools will enable making films with more detailed 3D graphics without increased equipment costs. I expect technological progress to open new doors for exploiting multipurpose stage design. In my view, the fundamental design and workflow rationale that is presented in this project is expected to remain relevant for the foreseeable future.

Chapter 4: Project activity and findings

Interview

Introduction

Making computer animated films with few but large stages does not necessarily lead to economically beneficial production solutions. The following interview addresses situations where multipurpose stages had both a positive and a questionable impact on production efficiency.

The amount of detail in objects relative to their size within the frame

My adviser Dr Anastasia Dimitra introduced me to the notable work of Angelos Rouvas. Angelos is the director of “Mentor” an ambitious production which was unfortunately halted in October 2018.

This film contains a stage which provided both a general view of the acropolis as well as a close-up view of the pediment of the Parthenon.

First teaser: Mentor (2018)

Angelos Rouvas provided details about the scenic optimisation approach in a personal interview which took place in May, 2019. The following extracts are translated from Greek.

> *“On the Acropolis and especially on the Parthenon several of the metopes are images and not relief [flat surfaces which provide the impression of relief through the use of image maps]. We have left [out] a lot of detail since the script does not require close-up shots of every part of the monument. So everything is based on the process of breaking down the script into shots or the storyboard as well as on the capabilities of your technical equipment.”*

This dual-purpose environment was optimised by selectively assigning more geometrical detail to objects that are shown within the frame of close-up shots.

Angelos explained that despite the optimisation measures, the stage still demanded significant computational resources.

> *“The technical team needed many findings to be able to open this set on a computer. It is of high architectural precision and detail ... so very heavy...”*

The gains of having a multipurpose stage instead of two separate stages are not clear.

> *"Unfortunately, I cannot tell you exactly if this option was right for the production as a whole because unfortunately it was not materialized."*

It is known that the optimisation measures were not able to reduce the processing times to comfortable levels with the hardware available at the time.

> *"However, with the equipment I had for making the pilot, there was a considerable delay in opening the scenes containing the Acropolis monuments. They were big files and very heavy."*

This example highlights three key factors. Firstly, that despite the technical challenges, there are significant motives for making stages that can cover different framing needs. Secondly, that the gains in productivity can be compromised by slow digital processing. Lastly, that scenic optimisation based on the points of view is common practice (for information on assigning appropriate LOD to objects see chapter 2, page 55).

The multiple case study in this project shares details about how the shapes and systems of certain stages have provided diverse viewing angles as well as details about the optimisation measures which enabled an unobstructed workflow. Several cases contain a wide establishing shot followed by shots that focus on smaller areas which have increased detail to support the close-up views.

Interview: A stage with multiple acting spaces

This section deals with a versatile stage that was made before this project started and that contains multiple acting spaces for efficiently making long sequences with diverse framing needs.

The film The Little Mouse who Wanted to Touch a Star (2007) starts with an exploratory moving shot through the nest of two mice. Angelos Rouvas, co-director of the film, confirmed that the nest appears in approximately four minutes of the film and that the stage enabled framing shots of different parts of the room for covering separate actions.

The three main acting spaces of the stage are within the region of an armchair, of a bed, and in the hallway. The stage was also used for composing close-up shots of such as that of a newspaper.

Screenshots from the stage of the nest in the film:
The Little Mouse who Wanted to Touch a Star (2007)

I asked Angelos Rouvas to confirm if this was a multipurpose stage and for a comment on its overall effect on production economy.

> *"Yes, I confirm that it was a set with dozens of small items. Of course it was not as heavy as the rock of the Acropolis with its monuments and sculptures [appearing in the 2018 teaser of film Mentor]. Clearly it [the multipurpose stage] saved time and money."*

This shows that productivity advantages, under certain circumstances, can be obtained from stages that can host different camera angles. This example also highlights that it is permissible for multipurpose stages to contain large amounts of geometry so as to cover the needs of separate views as long as the computational delays do not significantly affect productivity.

The internal space meant that the scenic elements had to have a relatively high amount of detail as the framing was made with cameras at close proximity.

> *"The setting, as a small hole in the wall, did not allow for very distant shots in less detail [such as the distant buildings in the establishing shot of the Acropolis in the 2018 teaser of film Mentor]. Everything was clear."*

Multipurpose stages generally require more computational power compared to single-purpose stages. However, the scenic optimisation strategies for the multipurpose stages that are presented in this project can significantly decrease hardware requirements. The films in the multiple case study were made with the minimum anticipated equipment expenses as all the processes, including rendering at comfortable speeds could be assigned to a single workstation.

Multiple case study

Introduction

The cases that are presented here concern making computer animation films efficiently with stages being the central part of the analysed production frameworks.

The analysis of two short films focuses on stages that serve multiple purposes and provides explanations of how certain subsystems affect workflow. Agrinoui (2015) and Struthio (2011) are two pilot episodes that have a combined play time of approximately 26 minutes. Working with small production teams and with unhurried production timeframes enabled me to develop stage solutions with full awareness of why the film elements have a certain form and how they are interconnected. Struthio (2011) was made with four 3D stages and Agrinoui (2015) was made with seven stages. Each stage can be seen as an independent project that enables creating a couple minutes of film. Theoretically, the separation of a TV episode into sections that follow the rationale of the presented stages would enable individual teams of artists to work in parallel to create multiple episodes in a year. The multiple case study deals with the presentation of stages that were developed serially within a small-scale production framework that featured animating the elements of one shot at a time. I estimate that the presented knowledge regarding multipurpose stage practices provide a route for designing a scaled up production line that could provide a linear increase in yield of episodes through parallelisation of tasks with a larger workforce and infrastructure. Regardless of the potential industrial uses for the presented knowledge, the data in this project explains how standalone animation films can be made with limited workforce and equipment.

The presentation of case data features a demonstration of plans, custom systems and achievements for each multipurpose stage separately. However, the analysis of systems enabled collecting homogeneous data from multiple cases so as to make comprehensive observations and to make generalised inferences regarding production efficiency as a whole. Certain universal topics deal with making and managing optimised 3D assets, with organised teamwork, with the automation of processes, and with creating environments that can host multiple points of view.

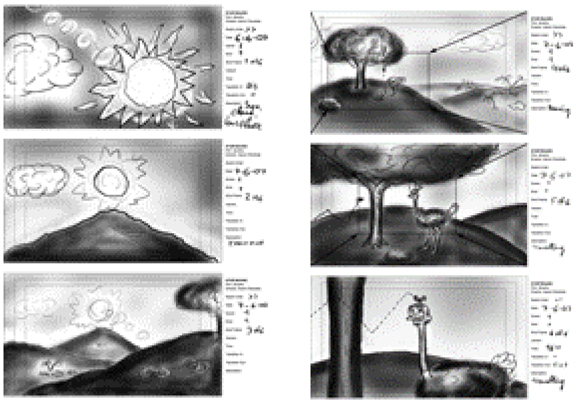
Film: Struthio (2011)

Film information

Computer Animation Film with play time of 6’ 38”.
Release date: October 2, 2011
Premiere: Cyprus International Film Festival (CYIFF) 2011.

Film Planning

The planning documents of ‘Struthio’ enabled me to specify the framing of each shot which was vital for shaping the 3D stages.



Storyboard frames from the savannah scene in Struthio (2011)

The sketches above provide key scenic design information concerning framing and topography for an establishing crane shot in a savannah environment.

Concept art for the savannah stage

2D painted concept art enabled specifying a style with refined colours and shapes.

I used the planning documents as a guide for making 3D models of scenic elements such as trees, hills and clouds. Having a general understanding of the aimed style provided focus and reduced the chances of unexpected setbacks during tasks that concern modelling, lighting and texturing.

The Savannah stage was used to make scenes that take place in three different areas.

Screenshot from Struthio (2011)

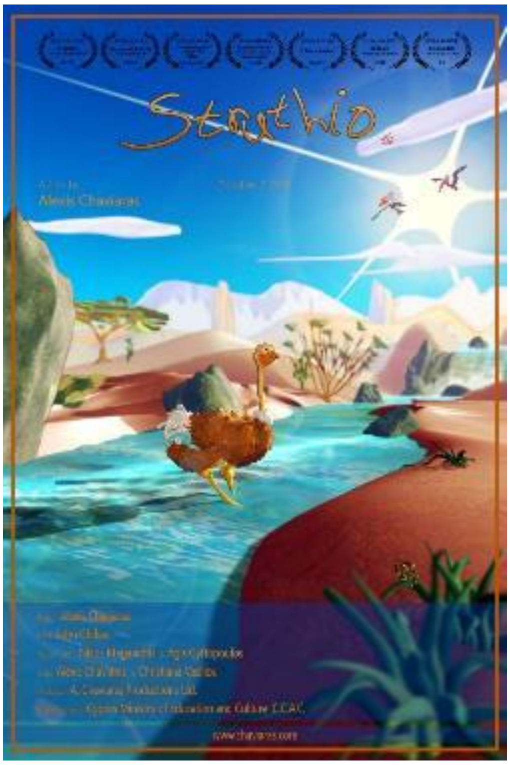
Four multipurpose stages were made for Struthio (2011).

The “Savannah” stage that features three acting areas. One with a river, one with a hill, and one with a dry valley.

The “Book” stage features a book that opens to reveal an immersive illustration in which the camera dives. Its purpose is to bridge the outside world of a reader with the world of the story within the book during the intro and outro sequences.

The “Flight” stage enabled long camera motions over the savannah and the jungle.

The “Jungle” stage provided different settings for running scenes.



Film Poster: Struthio (2011)

Revisiting locations

Struthio (2011) provides a sense of increased visual diversity by shifting between locations that are revisited under different conditions. For example a hill is shown with daylight and at night.

By interchangeably displaying locations of the savannah and the jungle the film provides a feeling of continuous travelling activity. Diversified views of two environmental themes created a sense of visiting multiple areas with a small number of stages.

A contrasting example would be the fairy tale of Little Red Riding Hood in which the story does not show the same location twice. The script would start at the house of the girl, followed by her journey through the woods and it would end up at the house of the grandmother.

Breakdown of the timeline by location

The order in which the environments of Struthio (2011) appear in the film is as follows. The "stage" column indicates that a few stages hosted multiple scenes. The sample screenshots offer an indication of the visual diversity in shots from each stage.

Time in film (min:sec)	**Scene/location**	**Stage**	**Screenshot**
0:11	Book opens.	Book	
0:28	Dive into illustration with multiple planes.	Book	
0:40	Ostrich meets fly at the hill.	Savannah	
1:07	Female ostrich eats at the dry valley.	Savannah	

1:25	Ostrich sleeps at the hill.	Savannah	
1:39	Ostrich wakes up at the hill.	Savannah	
1:57	Inside the mind of the ostrich.	2D animation (insert)	
2:03	Ostrich has devised a plan at the hill.	Savannah	
2:10	Ostrich goes to the elephant.	Jungle	
2:42	Ostrich goes to the Snake.	Jungle	
3:17	Exotic flying birds.	Flight	
3:19	Ostrich launch.	Jungle	
3:25	Ostrich gains altitude at the dry valley.	Savannah	

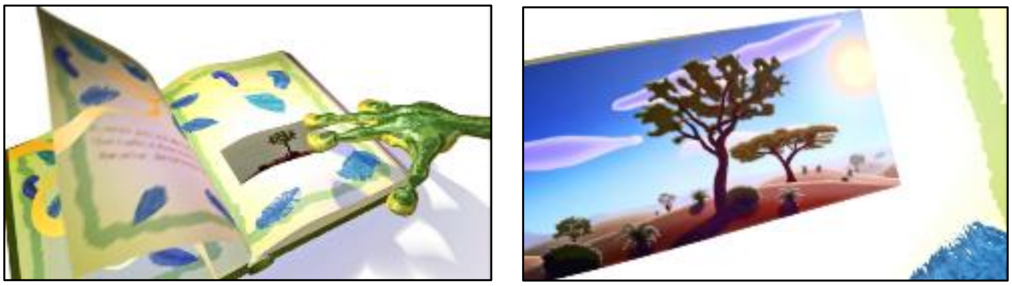
3:32	Ostrich flies over trees.	Flight	
3:59	Ostrich lands at the elephant area.	Jungle	
4:17	Ostrich goes to the spiderweb.	Jungle	
3:31	Ostrich comes out of the river.	Savanna	
4:45	General meeting on the hill.	Savannah	
5:42	The camera goes out of the book.	Book	
5:53	End credits - illustration with multiple planes.	Book	

Case: “Book” stage

Introduction (concept)

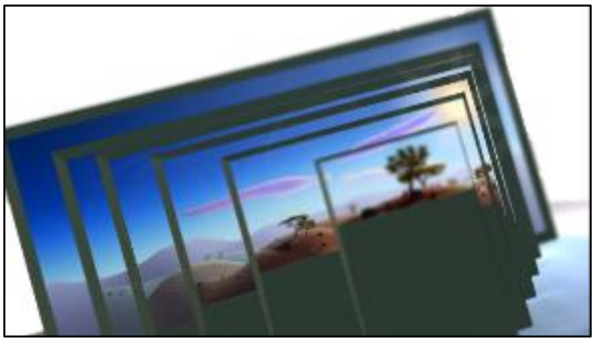
This stage has two environments that are shown simultaneously in a fashion that resembles a common situation of a camera passing from an internal to an external space through an opening.

The introductory scene of Struthio (2011) shows a book that opens to reveal a 3D illustration that comprises of image layers positioned at different distances from the camera. The camera dives into the illustration to signify our immersion into the story. The dive acts as a progressive transition involving different visual styles that separate two worlds.



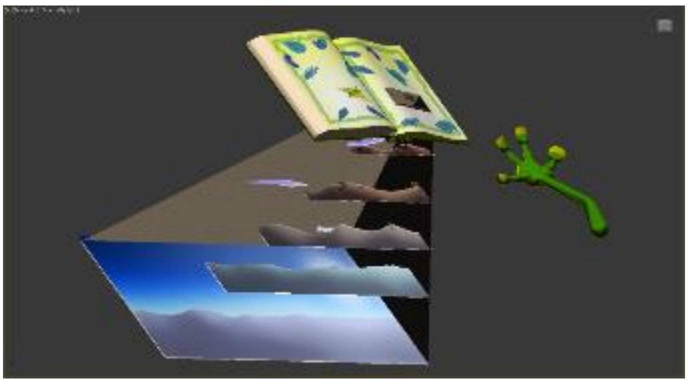
Screenshots from Struthio (2011)

Stage rationale (shape)



Rendered frame from rejected Stage concept

My initial idea for combining the book with the multiple planes was to position them vertically on a book page. After testing this configuration I rejected it due to the distracting structure and because I wanted a more immersive action as we entered into the story.



The final “Book” stage from a 3D viewport.

The final stage has the plane configuration positioned through a hole in the book which enabled a more effective “diving” camera motion.

The book does not lay flat on a horizontal surface; it is rotated upward by 45 degrees. This change enabled me to smoothly operate a two-node target camera while it was performing a vertical dive into the illustration. 3D Cameras that are controlled by separately positioning the point of view and the target point can acquire an undesired roll angle when pointed vertically.

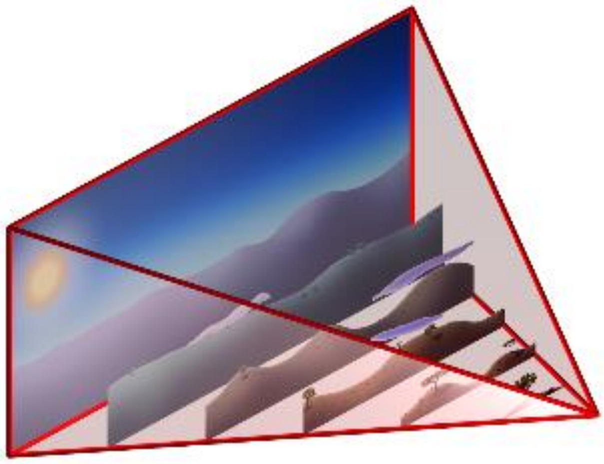
> *Technical note: When the two control nodes coincide on the horizontal axes we no longer have data regarding the desired upward direction. As a result the gimbal lock effect occurs and the camera rolls uncontrollably.*

There is often more than one solution for overcoming technical difficulties with 3D graphics. An alternative solution to the gimbal lock would be to make a special camera rig.

Rationale of stage form

The practice of positioning images at different distances from the camera, and the coexistence of 2D with 3D elements can be seen in analogue systems that are mentioned in the review of relevant literature and practice (see chapter 2, pp 29-30).

I made the pictured Pyramidal setup of multiple planes in 2007 as part of a research project for my M.A. in Design (Middlesex University). The pyramidal shape enables the camera to change its field of view as it travels inside the system.



Painted layers in pyramidal positioning (2007)

Narrow and wide fields of view from inside the system.

The book stage is a combination of the pyramidal system of the painted planes combined with the 3D book. The system as a whole enabled moving the camera in both locations in one take.

Benefits of multiple planes

The benefits of having multiple flat surfaces include the immediacy in having high quality visual feedback with low cost equipment. The 3D geometrical data of planes is minimal and the simple materials rely on texture maps for transparency and colour images, known as diffuse maps, which contain all the visual detail.

The pyramidal setup of multiple planes has limited computational requirements for real-time viewport navigation as well as during the rendering process which is not charged with calculating shadows. A Laptop from 2006 with 2GB RAM was able to load 3 pyramid systems simultaneously and render them in 1080P. A 2D artist does not need special technical skills to paint separate planes as most professional bitmap editing software enables working with separate image layers.

The motion parallax effect can alternatively be achieved with 2D video editing software by stacking multiple images and moving each layer horizontally or vertically at different speeds. Certain methods for achieving parallax effects with digital tools are explained in the review of relevant literature and practice (see chapter 2, pp 36-37).

Compared to the use of compositing techniques that entail moving multiple images, the 3D system has notable advantages. A 3D environment only needs the camera to move to create a fly-through shot with motion parallax, depth of field, and simulated lens flares as well as volumetric effects such as fire or fog. Moreover, the space between planes enables adding animated 3D objects such as the flying birds and text that feature in the title sequence at the end of Struthio (2011).

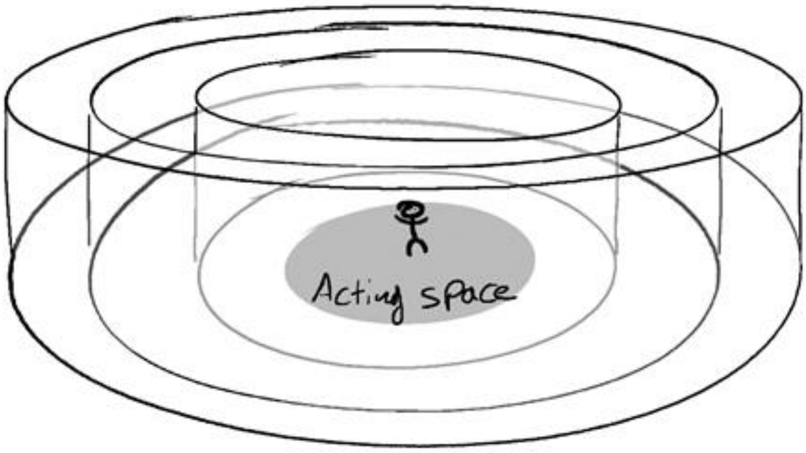
Limitations of multiple planes

Although the pyramidal setup effectively provides a sense of depth, the planes themselves can be noticeably flat when the camera makes motions such as panning and trucking. Another restriction concerns the lack of a floor to support the choreography of 3D walking characters as the ground is depicted on vertical planes. Furthermore, the limited useable angles of view would not practically enable covering a dialogue with over-the-shoulder shots.

The knowledge gained from the pyramidal setup was essential for later developing a system that features multiple relief surfaces, instead of planes, facing the camera. The setup was placed in the background to give room in the foreground for a horizontal ground for 3D characters to stand on (see chapter 4, pp 178-180).

Circular Solution for more camera angles

A solution that enables turning the camera in opposite directions is pictured below.



Concept illustration: Bent background image layers surround the acting space.

In the above system, the camera can perform panning and pedestal motions. However, a trucking motion would quickly result in viewing the inner “ring” surface from an unnaturally steep angle. Performing a long truck motion is possible by having a subject in front of a motionless camera while the rings are rotated around the centre of the stage at different speeds.

I designed a stage variant with multiple layers of curved surfaces with a ninety-degree bend (see chapter 4, pp 119-120).

A horizontal surface in the centre receives shadows which enhance the viewer’s understanding of where 3D objects and characters are situated in relation to the ground.

Circular stage implementation

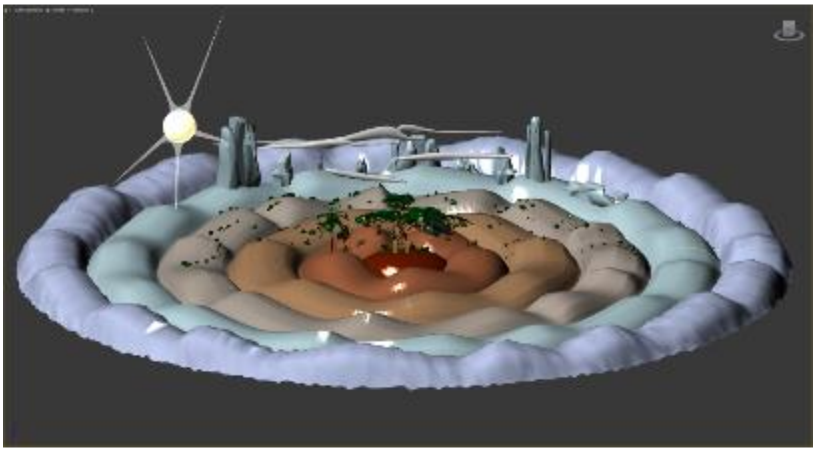
I tested the circular stage form concept as a precursory trial for the savannah stage. Instead of using the painted texture maps of the pyramidal system with multiple planes, I made concentric rings of mountains out of 3D geometry. The 3D background models were able to better match the style of the characters. The homogeneous appearance derived from universally applying materials with similar texture shading.

Main characters provided visual style reference.

I designed four characters, prior to making the savannah stage. The form and textures of the characters was used as reference for developing a visually consistent style for the environment.

The savannah stage depicts a differently styled version of the environment shown with the multiple planes in the introduction scene of Struthio (2011). The silhouettes of hills and trees are refined shapes of those visualised in the storyboard and concept art.

A benefit of having 3D models as hills, instead of flat images of hills, is that their volume becomes noticeable when the camera moves. For example an upward pedestal camera motion would gradually reveal more ground surface whereas a 2D painting of a hill seen from a moving camera would gradually obtain a distorted perspective revealing that it is a vertical flat surface. The use of semi-cylindrical terrain modules is not new (see chapter 2, page 31).



3D Stage with a 360 degree field of view

The rows of hills resemble concentric rings that surround the acting space in the centre. The experimental circular shape of the stage enabled me to explore possible camera motions within the central acting area. Although the camera can move vertically, the hills and the horizon will appear distorted at points of view that are higher than the tallest tree.

Despite the confined acting space and the camera positioning limitations, a stage with a 360 degrees of view can be versatile as actions can be covered with reverse angles. Versatile stages can be valuable for animated series as the ability to shoot a range of actions facilitates covering the needs of unwritten scripts of future episodes.

A character's running of flying motion can be covered by a simulated trucking shot. The flying effect can be executed by having an immobile camera and subject, e.g. a car, placed inside the acting space and by rotating the stage rings around the centre. By rotating inner rings faster than the outer ones the trees near us will traverse the frame faster than the distant mountains. The resulting motion parallax effect resembles looking out of a moving train.

Image: Panoramic view from the centre of the stage at different camera directions.

The atmospheric perspective was created by applying a different colour to each layer of hills. The concept paintings also featured different tints for depicting distant objects.

> *Technical notes: With 3D graphics atmospheric perspective can be applied with a fog effect which uses z-depth data to change the colours of distant objects. However, manual colour selection offers more creative control. For example the fog effect would provide less saturated colours to the sky. Moreover, Image post processing effects such as volume fog normally need to be applied separately to each frame of an animation sequence. This process can induce a noticeable feedback lag which is compounded when rendering multiple animation frames.*

Forced perspective

Although the horizon, in the film, appears to be several kilometres away from us, the round stage occupies a significantly smaller area.

Round 3D Stage concept (isometric view)

View from the stage centre

I applied forced perspective by making distant objects physically smaller. For example, even though the rock formation [in red circles] is in close proximity to the centre of the stage, it appears distant and tall from the centre of the stage. The actual size of the rock is comparable to the tree [in yellow circles]. The general rationale of forced perspective is explained in the review of relevant literature and practice (see chapter 2, page 36).

One benefit of stages with a limited area is practical viewport navigation due to the shorter panning and zooming operations needed to change our view of different objects. Another advantage of small 3D environments is the enhanced precision of space coordinates. Technical limitations make it challenging for positioning objects with millimetre accuracy when the 3D environment covers an extremely large area.

Although the round stage provided an appropriate appearance for the film, it only had the topographic features to cover the needs of one of three needed savannah locations.

Case: "Savannah" stage

Stage development Phase 2 – Shape adaptation

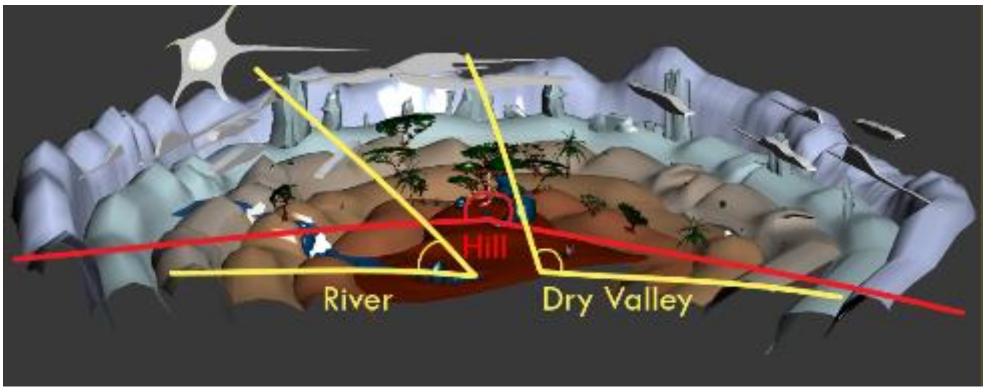
After having established the style of the savannah with a hill surrounded by hills in a circular arrangement. I adapted the shape of the stage to host more scenes by including a river and a dry valley. After studying the storyboard I realised that the stage did not have to be fully surrounded by mountains to frame the shots. By removing a large section of mountains, the new multipurpose stage contained less geometry than the circular version.

"Savannah" stage.

The multipurpose stage has three main locations, indicated with yellow cameras, from where action is visible in the six circled areas.

Respective film screenshots of river, hill, and dry valley areas.

Although the distances between the acting areas of the hill, the river, and the dry valley are small, they appear to be disconnected in the film.



"Savannah" stage. The lines indicate the camera coverage limits for each location.

Although the actions that occur on the hill are covered with camera angles that cover the entire stage, the foreground of the river and valley areas do not enter the frame.

As a result, the views from hill, river, and valley share common background elements without this fact being noticeable.


The view from the hill and the view from the river with the same background tree.

Despite the overlapping background views, the lack of noticeable repetitive patterns gives the impression that the locations are farther apart. The camera, in the above images, from two different positions, is pointed towards the same direction. The hill being at a higher elevation provides a different view of the terrain which contains the same mountain slopes and the same tree.

View from hill

View from valley

The camera, in the above frames, was directed towards the right edge of the stage. The positioning of the camera at different locations and altitudes made the topography look different despite the frames containing shared elements.

Although the shapes of the trees and hills are the same, a change in the sun's position has affected their colours, thereby assisting in making the locations appear to be different.

Benefits

The savannah stage demonstrates the ability to create the appearance of more than one locations with a minimal increase in scenic elements as the addition of the valley and the river areas to the central hill only required a few new objects in the foreground.

The limited computational demands of the optimised multipurpose stage enabled me to animate the characters directly in it without significant lag in real-time editing and file saves. Working on character animation and on scenery within the same project file offered practicality in a one-person production framework as it enabled having high quality visual feedback of the environment while animating. The workflow of enabled me to review and edit animation sequences as a whole as it offered the ability to immediately perform single-pass test renderings containing all the image elements shown in the film. Progress reviews were followed by applying immediate edits on both scenery and character animation within one project file. This approach is not ideal within a team-work approach where the environmental editing and character animation could be handled independently as was the case with another presented framework (see chapter 4, pp 142-144).

An advantage of multipurpose stages is that style adjustments can affect several scenes at once. Adjustments of textures, lights, camera, and render settings can globally affect the appearance of all the scenes that take place on the stage. If I developed the three locations as independent stages, the process could have been slowed down by having to track the changes made for adjusting lights and textures of one environment, and by applying the updated settings to the other two stages to ensure consistent image quality.

Although a consistent lighting and texture style between scenes was desired, there are several options for differentiating the appearance of a scene if needed. Adaptive lighting enables changing the lighting of a specific shot by activating a different lighting rig on the first frame of the shot triggered by keyframes on the timeline (see chapter 4, page 209). Another option for altering the colours of a specific shot in a sequence is with video editing software. The colours of the night scene in Struthio (2011) resulted from a process that is generally known as “day for night” and involved decreasing brightness levels of images with daylight, increasing the contrast, and limiting the colour range to shades of blue.

Colour graded night scene.

Optimisation

One issue of stage optimisation concerned the adaptation of its shape to the framing needs of the film which resulted in removing large areas of terrain. Another area of optimisation concerned assigning optimal amounts of detail to scenic elements. The rationale of assigning appropriate levels of detail is explained in the review of relevant literature and practice (see chapter 2, page 57).

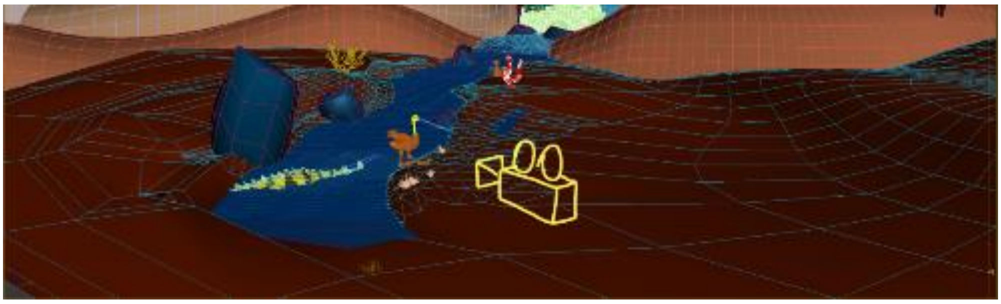


Image of viewport with edged faces indicating the areas with more dense geometry.

The level of detail in the geometry was made by considering the position of the camera. In the above example the parts of the river banks which have a significant presence within the frame are more densely defined.

Savannah Terrain Modelling

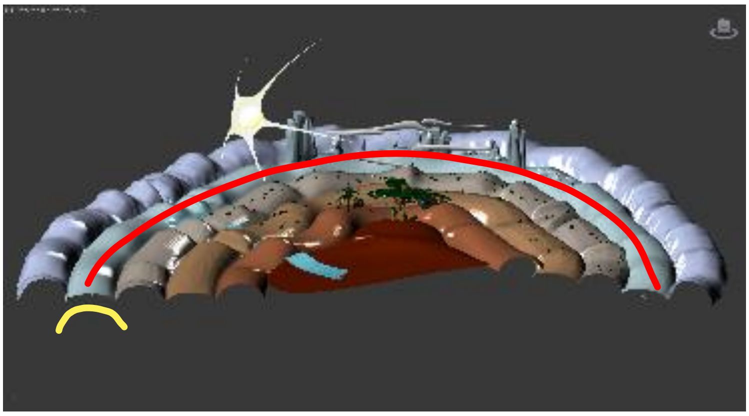
The first step in adapting the form of the stage to the needs of the film was to widen the shape of the foreground terrain surface to include the areas of hill, river, and valley. I positioned the cameras and developed the choreography directly on the semi-circular stage.


Image from work-in-progess


Screenshot from Struthio (2011)

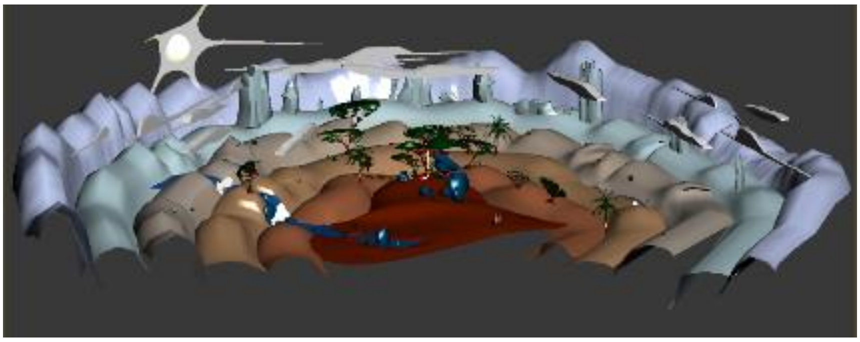
The image on the left indicates the placed proxy character objects on the stage to act out the choreography for previsualising the framing of each shot.

After having positioned the cameras I removed the portions of mountains that never entered the field of view.


Savannah: Initial formation of semi-circular stage

I used the “lofting” modelling technique, which enables making models out of two lines, for shaping each row of mountains. I made an arc shape for the cross-section of the semi-tubular hills, indicated with yellow line, and a line that describes the path of the mountain range, indicated in red. This modelling technique enabled me to adjust the shape of each ring and the height of the mountains. The omission of surfaces that were hidden from the view of the camera resulted in a reduced amount of generated geometry. This optimisation step facilitated keeping the computational demands of the stage at levels that did not cause significant lag in common activities such as viewport navigation and file saving.

After having shaped the stage in a way that served the framing of every shot I positioned the detailed versions of characters and animate them. The animation process required several cycles of revisions that entailed periodically making rendered animation previews. During these steps I progressively made refined adjustments to the lights and to the shape of the terrain.



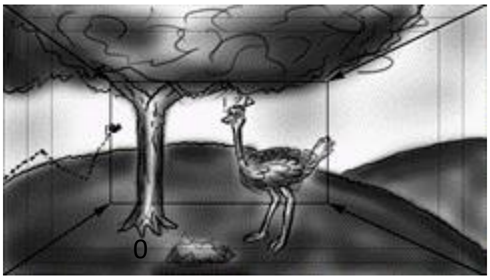
Final form of savannah stage.

During the revision cycles I progressively adjusted the shapes of mountains, the river and waterfall. I also added or adapted the positioning of trees, bushes, rocks and clouds after reviewing the composition of each shot.

Struthio (2011) Screenshot. Example of unplanned terrain change

During the production phase I decided to change the framing of the close-up shot of the crocodile. The new frame revealed a void in the background. I covered the gap by pulling the edges of the mountains to the right. The added terrain looks like a flat landmass in the film and it did not affect the appearance of other shots.

Savannah stage - Progress history



Storyboard frame

2D Concept art

Frame from 3D round concept stage

Frame from animation preview with character proxy

Film screenshot

The storyboard was key to adapting the round concept stage to the needs of Struthio (2011). The storyboard frames provided vital information for drawing a top view stage plan that included three acting areas, and indicated the camera positions.

Although a previs is commonly made with coarse geometry, I directly adapted the geometry of the concept stage to block the stage shape as the modelling method was practical and flexible, and it enabled making computationally light geometry. The previs was made with a stage that was at an advanced development phase which hosted proxy characters for specifying subject positioning and framing.

The production process continued with importing the high quality characters on the stage who were then animated over several work sessions with intermediate observations of rendered previews of the animation sequence at hand. The assessment of each preview video resulted in noting areas of improvement in both animation and scenery. In the subsequent work session I would act upon the identified improvements such as the tree in the above images which clearly went through several shape revisions.

I found that the making simultaneous progress on both the animation and the stage tasks reduced the total number of revision cycles. This provided increased productivity and multiple chances for identifying and rectifying problems. I used a similar approach of making simultaneous progress in developing 3D environments and character animation within a team of artists in Agrinoui (2015) which is presented in the corresponding case analysis (see chapter 4, page 138).

By not using intensive computational processes I was able to handle and render all 3D objects at a reasonable pace with cost effective equipment. The ability to contain all processes within one workstation PC from 2010 offers secondary cost benefits such as reduced IT work associated with managing a network of render nodes and reduced electricity consumption. The savings on infrastructure and production running costs can have a compounding effect on limiting the expenses of a scaled-up TV series.

Case inferences

Combining multiple acting spaces on one stage with the common savannah theme enabled working on a different sequences from one 3D project file, and affected productivity in the following ways:

- Fewer stages meant simplified project file structure.
- Edits affecting the appearance of surfaces were globally applied on all scenes.
- Although the characters appeared in different scenes, the process of importing characters on the stage occurred once.

The productivity benefits from multipurpose stages can be weakened by increased computational demands that slow down operations. The computational resource requirements were increased by a limited amount with the addition of acting spaces because of:

- Each location on the stage utilised the same background elements. Therefore, each location exclusively featured only a few foreground objects.

Technical optimisation measures enabled maintaining a productive workflow.

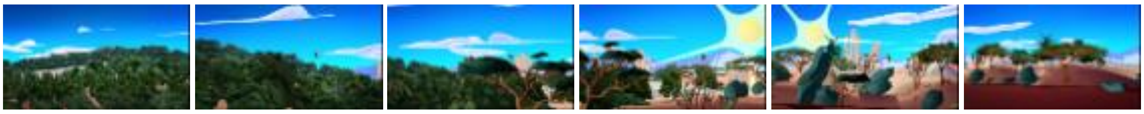
- Avoidance of computationally demanding effects such as furry materials and physical lights.
- Render trials enabled tuning the settings of lights and toon shaders so as to reduce the use of computational processes that didn't meaningfully affect image quality, thus providing improved rendering speeds.
- The removal of terrain sections that did not enter the frame reduced the amount of stage geometry.
- Providing an appropriate amount of detail according to how objects appear within the frame. For example faraway trees that occupied a small portion of the frame needed less geometrical detail than the trees in the foreground.
- Atmospheric perspective was built into the objects. By assigning bluer tints to distant mountains I avoided the need for applying fog effects that would consume computational resources.

The initial development of a concept 3D environment enabled me to working directly with the high-quality stage for previsualising the choreography. The convenient terrain modelling methods enabled skipping the creation of a low-resolution proxy environment that is typical for previs projects. My approach does not challenge established previs practices, as it was based on previously prepared groundwork. However, previsualisation work was facilitated by the use of modelling methods that enabled me to conveniently adjust the shape of the ground, as well as to optimise the geometry so that it would not have excessive computational requirements.

This case indicates how the design of multipurpose stages in combination with optimisation measures can provide enhanced production efficiency without noticeably sacrificing image quality in the process.

Case: “Flight” stage

Introduction - Repurposed stage concept



Panoramic view - Screenshots from sweeping crane shot

The flying scene takes place over the savannah and the jungle, and starts with a long tracking shot followed by more shots with camera movement over a forest.

I took advantage of the flexible terrain modelling approach from the savannah stage to reshape the terrain for the needs of the flight scene.

The storyboard indicated an ostrich flying fast at a low altitude above trees. I worked on a copy of the savannah stage for altering its shape and add enough distance for the travelling action. Repurposing the savannah stage saved a significant amount of time due to the reuse of the established lighting and rendering setup and because of the reduced need for new models and textures.

Stage shape and optimisation measures

3D trees can comprise of large amounts of geometry as they can have multiple branches with numerous leaves. A 3D forest consisting of hundreds of trees is bound to have considerable computational demands. However, surfaces that depict images of whole trees can be made with significantly less geometry.

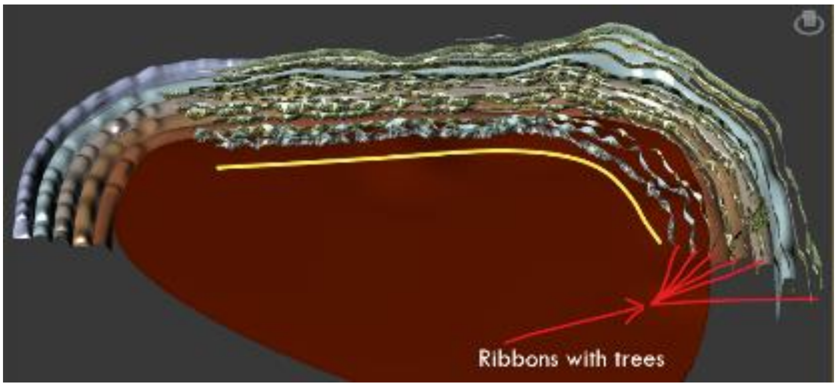
A lightweight system was made to display a dense forest which is a variant of several systems that are presented in this project featuring single sided textured surfaces. The “flight” stage contains long ribbon-like surfaces that depict arrays of trees. The form of the presented stages largely depended on the compositional needs of shots, and the “flight” stage is no exception as the arrangement enabled hosting cameras that follow specific travelling actions.

Examples of how flat textured layers can be positioned in space to create an enhanced sense of depth can be found in the review of relevant literature and practice (see chapter 2, pp 35-37).

The textures are composed of tiled maps in which an image section of forest is repeated several times across the surface of each ribbon.

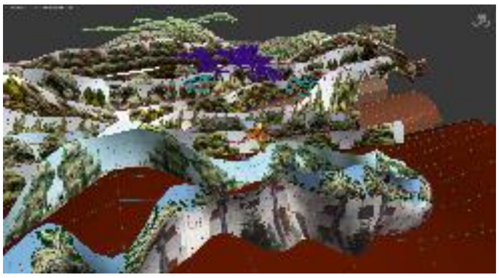
The ribbon surfaces are bent vertically at multiple places to shape mountain ridges. The shape of the hilly terrain was adjusted by controlling the bending of multiple rows of trees. A canyon, for example could be made by pointing multiple rows of ribbons downwards at common point of their width. The ripple distortion on ribbons on their horizontal axes made the repetitive pattern of texture maps less noticeable and made the positioning of trees appear random and natural.

The camera maintained the sense of topographical relief best when it was kept at a low altitude and pointed towards the horizon.



“Flight” stage

The long ribbons [indicated with yellow line] enable long sideways camera trucking movements and the curve enables panning motions. Thirteen layers of trees [indicated with red lines] enabled the camera to dolly in and out over the trees.



Viewport image

Film screenshot

The tree surfaces are placed at different distances from the camera and are oriented facing it at all times.

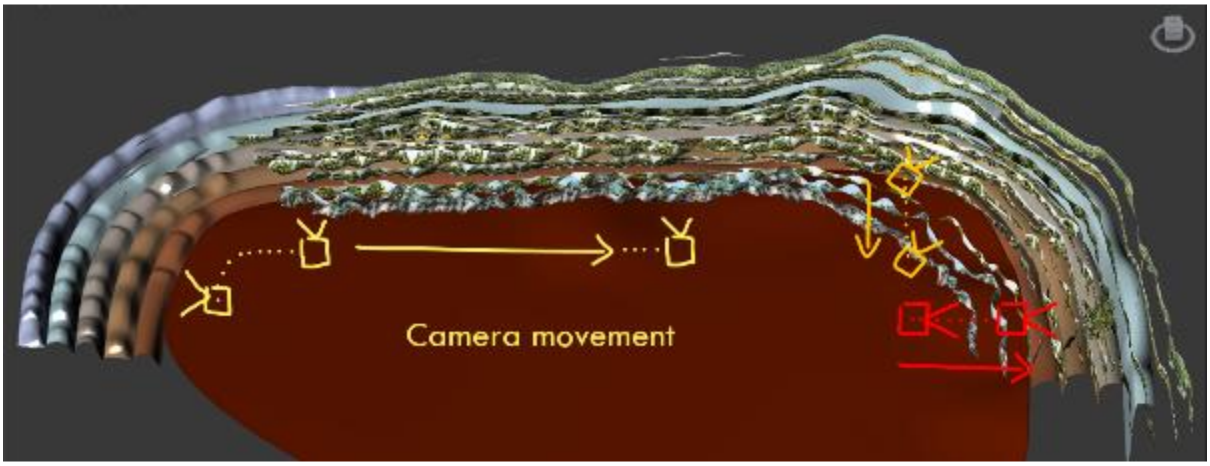
Having observed the real-life appearance of trees at different distances from the point of view, I applied the knowledge to make ribbons with purposefully different textures to give the impression of a vast forest within a limited space. The general rationale of forced perspective is explained in the review of relevant literature and practice (see chapter 2, page 36).

Instead of scattering trees of equal size across a large area, I strategically positioned images of trees with different sizes and colour tints to create forced perspective and atmospheric perspective effects.

The large trees that are closer to the camera have saturated colours. At half the distance toward the horizon the ribbons depict clusters of trees which form walls of trees (see chapter 4, pp 122-124). The scale of trees changes progressively on each layer up to the outer ribbon where we can no longer distinguish individual trees as all we see is a dense tree-lined hillside. Atmospheric perspective was embedded into the colour of textures were progressively bluer and less saturated as the distance from the camera increased.

As with most stages with forced perspective, if the camera comes too close to the outer layers of trees, the illusion that suggests they are several kilometres away is lost.

Camera movements



"Flight" stage with camera trajectories

The curves in the mountains enabled the camera to pan and the straight was used for a tracking motion. The camera's trajectories are indicated with the yellow, orange, and red lines.

The camera motion indicated in orange occurs within an area where the layers of trees bend. This area enables the camera to perform dolly and panning motions simultaneously as long as the surfaces with trees keep facing the camera. The flight stage overcomes the FOV limitation of the system with multiple planes in the "book" stage (see chapter 4, page 107) which severely limited camera motions such as panning. The flight stage also overcomes the camera trucking limitation of the circular stage form which provided little room for moving the camera (see chapter 4, pp 109-110).

On the right side of the stage the layers of mountains and trees are further apart to provide room for the camera to perform dolly movements [marked in red] without reaching the outer layers of trees as this would prevent the horizon from appearing to be distant.

The concept of using ribons is unsuitable for an interactive fly-through types of applications due to the limited viewing angles of trees. However, working within the limitations of camera positioning and angles, it is possible to plan animation sequences, with pan, dolly and truck camera movements with good framing compositions.

I would advise for storyboard artists to be made aware of the limitations of stage systems with layered ribbon surfaces which can only be shown from limited angles. Knowing the limitations of certain techniques enables 2D artists to suggest efficient camera movements and to discuss possible stage layouts.

If the storyboard was drawn without the artist being aware of the stage design process, it may be possible to later edit and adapt any unpractical camera movements. Essensially, reconsidering the execution of challenging shots can lead to increased usefulness of a multipurpose stage.

For example a storyboard frame with a non-crucial high-angle shot that is not compatible with the flight stage concept could be reconsidered during the stage design phase so as to tell the story with an alternative and applicable shot.

Tree texture maps

Foreground array of trees

The process of making the texture maps for the ribbons started by capturing reference photos of trees at different distances. The following examples show commonly practiced procedures for converting photos into tileable texture maps.

Foreground trees: Captured photo, and processed diffuse texture map

An important step in transforming the photos into texture maps is a process called masking. The mask [indicated in red] is data that defines which areas of the ribbon are transparent.

Photographic material can be used for making realistic environmental elements. However I needed a painterly style that could better fit with the non-photorealistically shaded 3D objects of the scene. I applied paint brush strokes over the tree with a graphics tablet for stylisation.

Each ribbon of trees displays the same image multiple times side-by-side – a function called tilling. The repetition pattern of the tree includes alternated horizontally flipped trees. Seeing two mirrored images in the film makes it harder to notice they are exact duplicates.

The awareness of the factors that make objects appear differently depending on their distance from the camera, enables artists to directly apply appropriate features such as atmospheric perspective without relying on digital fog effects or on photographic references (see chapter 2, page 32).

Preview rendering

While making the texture maps of trees, I assigned the materials on ribbons on the stage. The process involved frequently rendering the animation sequence to obtain visual feedback of how the trees would look in the fast paced scene with motion blur and focus blur. The previews were used for determining if the style of the texture maps could blend with the other objects, and for specifying the total number of ribbons and textures needed to achieve the intended effect. Previews were also observed for noticeable repetition patterns due to the presence of copied objects. Corrective actions for when two or more trees appeared too similar would be to cut the ribbon and position a plane with a differentiated tree to stop the repetitive pattern in the array.

A production efficiency sweet spot was reached as the forest was comprised of the least amount of different trees while the view over the forest extended far into the distance.

Reuse of scenic elements

The reuse of a limited amount of scenic objects provides enhanced production efficiency and is a recurring subject in this project. The ideal number depends on the specifics of the case at hand. On the one hand I knew that the camera would travel long distances which meant that large arrays of trees would need to cross the frame. On the other hand several factors made it hard to notice the existence of multiple copies of the same tree.

Depending on how each scot is framed, a shallow depth of field can draw the viewer's attention to the performance of characters leaving the foreground out of focus. Motion blur caused by moving cameras, in certain shots, further prevented paying attention to individual trees in the foreground. Another distracting factor is fast editing cuts that don't provide much time to observe the scenery. Fourthly, the wavy distortion of the textured ribbons makes the repeated tree images look different. In addition to that, by flipping every second tree image horizontally, the viewers have even more difficulty in identifying similarities between trees standing next to each other.

Screenshot of a tracking shot featuring multiple instances of the same tee.

The trees [circled in red] don't appear to be the same, especially considering that they cross the screen in less than a second.

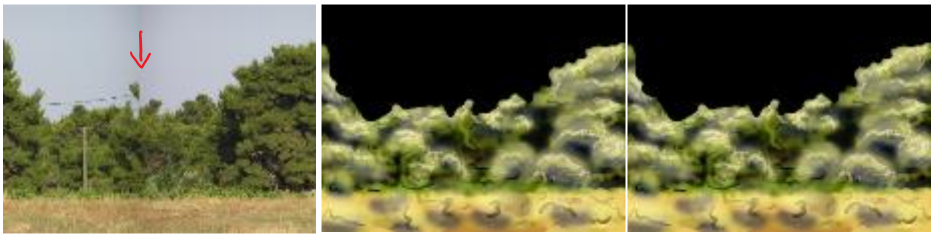
Performing adjustments to the positioning of objects would have been diffucult If I relied on the realtime visual feedback of viewports. Rendered video previews were key for assessing how shots with fast camera movement would appear in the film. The computationally light workload of the textured ribbons anabled previewing animated sequences with fewer CPU operations.

It can be hard to assess how scenic changes affect the film with delayed visual feedback. I frequently made observations by comparing versions of rendered frames before and after applying a change. One such comparison was used for determining the effectiveness of horizontally flipping alternating trees for making the presence of copied elements more discrete.

Middle ground and background arrays of trees

The trees that are between the horizon and the foreground were more likely to appear sharp in the film. One reason for this is that when the trees and the action of characters are situated at the same distance from the camera, they share the same focal plane. Moreover, the sideways tracking motion of the camera causes objects in the middle ground move slower across the frame, compared to foreground objects, making them visible for more time with less motion blur.

One example of a tileable map for trees being positioned at a distance of around 100 meters from the camera is shown in the pictures.

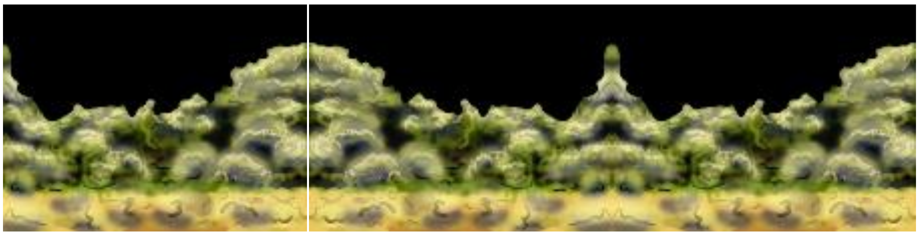


Middle ground trees processing

I took the initial photo of trees that form a thick body of foliage from a distance of approximately 200 meters with the sun being behind me.

I used image editing to make the picture seamlessly tileable. This process involved offsetting the image to the side to reveal the seam. I edited the seam, indicated with the red arrow, to make it indistinguishable. The resulting tileable image could be copied and placed side by side without noticing any vertical borders in the foliage.

I applied digital paint strokes over the picture to provide an appearance that fits the style of the film.



Example of horizontal tiling. Every second image repetition is mirrored.

The fact that the same image is displayed multiple times became less noticeable when I flipped the map horizontally after each repetition effectively doubling the width of the outline of trees. This process can make a distracting mirror effect in the areas where the images meet which was generally not noticeable in the fast paced flight scene. However, conscious decisions can be made to allow technical imperfections in favour of reducing production expenses (see chapter 2, page 58).

The trees in the photograph that was used as a basis for the texture map were illuminated with the sun being behind the camera. The even illumination did not create undesirable sideway shadows which would make the horizontally mirrored map appear to be illuminated from another direction. Trial and error is a powerful way to determine whether inconsistent lighting can be acceptable in practice. Similarly, making rows of different pictures of trees look as a cohesive forest took revision cycles of test renderings followed by applying refined edits regarding the colours and shapes within texture maps, as well as regarding the shaping and positioning of ribbons.

For the trees in the background I took pictures of distant mountainsides covered with trees and used them as a basis for making tillable maps that were assigned to long strips that were shaped to appear as mountain ridges. The difference in the scale of trees between the inner and outer ribbons on the stage provided the feeling of a distant horizon without the horizon being far from the camera. Instead of having similarly sized trees and let perspective determine how large the stage should be, I made the background objects smaller and used forced perspective to reduce the area of the landscape (see chapter 2, page 36).

Foreground for close-up shot

Screenshot of flight scene with 3D tree model

The flight scene concludes with the character crashing into a 3D tree model as an image map would not provide sufficient detail for this shot.

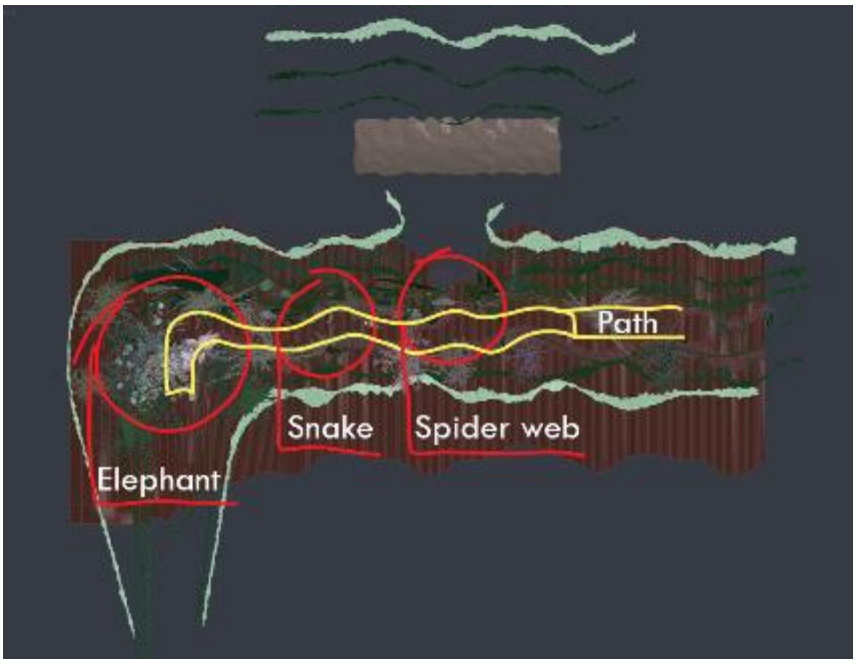
The thickness and denseness of the 3D branches was customised to the framing needs of one shot. The geometry of each leaf is low as their shape relies on the opacity map (mask) of one leaf material which was based on a photo that I captured of a broadleaf tree. I spread copies of the leaf along the branches at different angles.

The ability to cover an area with instances of the same object has several benefits. It primarily reduces the time to make 3D assets. It simplifies the process of positioning the objects, and it can significantly reduce computational requirements as the data that describes the shape and the colour of instanced geometry can be loaded once regardless of the number of times the identical objects appear (see chapter 2, page 49).

Case: "Jungle" stage

Introduction - Overview

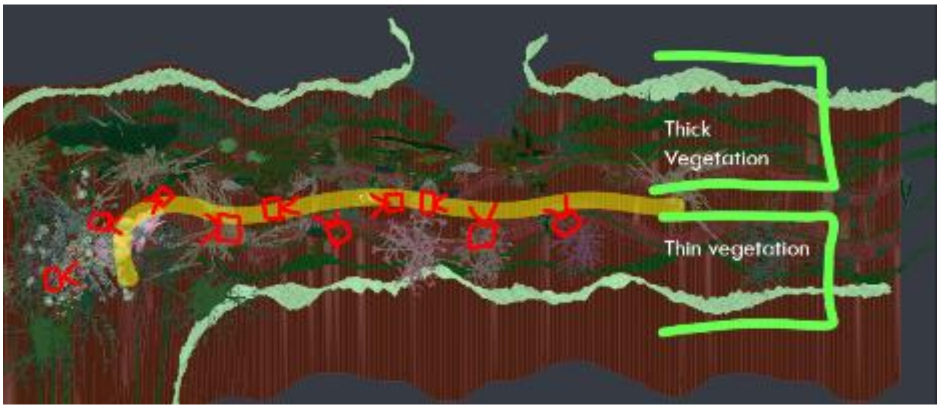
The stage has four acting areas that are located on a forest path. Although the locations are situated within close proximity to each other, the stage provides a sense of visiting more remote areas.



Top view of stage

Film screenshots in areas along the path

The areas that host an elephant, a snake and a spider web are connected with a path that was traversed in both directions.



Top view of acting space and surrounding areas.

The yellow line indicates the acting space and the red cameras represent the used points of view. One side of the path has more models of plants than the other as the camera never turns directly towards the side with thin vegetation indicated in green.

The camera positions and orientations, indicated in red, provide fields of view containing multiple layers of vegetation that give the impression of a deep and dense forest.

The areas with less vegetation become only partially visible in the side of the frame when the camera is pointed towards the direction of the path. The fact that the camera does not need a 360 field of view made it possible to have fewer plants in certain areas, and to keep the computational requirements of the stage at levels that would not induce lag that would significantly hinder productivity on a workstation from 2010.

One of the benefits of designing a stage that can host multiple camera angles with optimal amounts of scenic elements is that fewer resources need to be allocated towards making 3D models. Moreover, a reduced amount of scenic objects positively affects the complexity of asset management systems, it reduces the delays in computational processes, and it enables a film to be made with fewer multipurpose stages.

One view to signify different locations - Example 1

The jungle stage hosts scenes in three main areas that have overlapping sections. The snake scene involves running across the path and some shots take place in an area where another scene, involving a spider web, also takes place. The two areas were not meant to appear close to each other in the film. Therefore, the viewers had to not realise that he they see the same background.


Screenshots from the snake scene and the spider web scene.
Respective times in film (min:sec): 3:03, 4:20.

The pictured shots show the same area of the stage from approximately the same point of view. The main differentiating factor in the shots is that the spider web sequence was flipped horizontally with a simple video editing command.

A consideration before mirroring the frame is to avoid having objects such as lettering which will not appear correctly when inverted. It was also important for the character not to have noticeable asymmetric features. Although the hair of the ostrich is asymmetrical it is practically impossible to notice the reverse hairdo in some shots.

Another consideration prior to mirroring shots is to avoid showing recognisable landmarks as the point of mirroring the image is to give the impression of two different places. The mirrored scene includes a recognisable spider web which was hidden in the other scene.

The homogeneous look of jungle comprises of organic shapes that do not draw attention to specific objects. Therefore, displaying the same unmemorable objects within different contexts can go unnoticed.

One view to signify different locations - Example 2


Screenshots with similar framing from different scenes.
Respective times in Struthio (2015) (min:sec): 2:12, 2:50.

Both the elephant scene and the snake scene momentarily display the same area of the path as the first scene involved a running action that made the camera travel through the location of the snake.

It is difficult for the viewers to notice that they have seen the location twice primarily due to the difficulty to identify a repeating pattern. It is worth noting that the action is fast paced and that the lighting in the two shots is slightly different. However, this example aims to show the importance of context in the story which is expected to have continuity.

The following example highlights that the shape of the stage is disconnected from what we want the audience to perceive. Let us say that the story needs us to travel through four corridors and to take a right turn after each one.


Screenshots from The Shining (1980)

It is expected for hotel buildings to have corridors that are similarly decorated. Therefore, it would be possible to cover all filming needs by repeatedly traveling through one corridor by cutting each shot after having travelled a straight section and entered a corner. Viewing the four shots consecutively we can give the impression of completing a round of the building. If needed, each corridor can look different by changing some features prior to every take such as paintings on the walls.

In the following example in the first scene I hid the snake that is seen hanging on a tree the second time we visited the location.

Screenshots from Struthio (2015).
The same area presented as different locations. Respective times in film (min:sec): 2:10, 3:14.

The camera in both shots is positioned near the “elephant” location and points in the same direction. However, the two images look different primarily due to the first shot having a wider field of view with the lens focused towards the background. The second shot has tighter framing and focuses on at a relatively small distance from the camera.

Having differentiated the lens settings reduced the risk of viewers noticing that they are repeatedly watching the same location. Being able to use the same views more than once enhanced efficiency as there was no need to compose an additional environment or to make more 3D models. The cost of unnecessary models would have extended beyond that of the work hours dedicated to making them as the low number of 3D assets resulted in lower computational latency, and it provided a simpler and more manageable stage.

Models of the jungle stage

Introduction

It is achievable to make scenes with high visual impact and with limited resources such as work hours and equipment. Choices regarding which few impactful objects will be made as well as the modelling approach can lead to reduced production costs. This section shows the economical building process of the jungle stage.

I made two types of objects. The ribbons acted as dense and coarse layers of low-resolution vegetation that fill large areas with greenery while giving an enhanced sense of depth. Individual 3D models of trees, flowers, and bushes helped define the forest with more understandable plant shapes. The hybrid combination of two types of objects provided an overall detailed impression of a jungle without requiring excessive modelling efforts and with a reasonably low polygon count.

Model creation and management

Models of trees and plants were made separately from the stage in a project file that acted as an asset library. Plants were progressively imported into the stage project file where their position was determined according to framing composition.

Several large 3D objects were created directly on the stage as they needed to be shaped after the acting spaces. Such objects include the terrain as well as the shrubs surrounding the path which consisted of ribbons that had to follow the contour of the acting areas. Occasionally the stage space was used to create refined smaller objects such as flowers because of the immediacy of seeing the shot composition. Such objects, when finalised, were exported to the asset library for storage.

Organised storage for 3D assets can be invaluable in productions such as animated series in which the library provides access to objects that can be imported into multiple stages. The use of asset libraries is commonly practiced (see chapter 2, page 56).

Although the jungle stage project file contains the data of trees and flowers, its organisational structure is not ideal for 3D asset storage. Once a few plants become part of a stage they may be copied, scattered or deleted making it difficult to track objects. A stage can contain hundreds of copies of the base plants, whereas a 3D asset library can provide direct access to the unique master objects.

Ribbons as vegetation

Although the use of multiple planes or ribbons can limit the useable area for camera positioning, ribbons have shown how versatile they can be in the form presented in the flight stage (see chapter 4, pp 119-121). The flight stage required limited production resources to build and manage, and it provided useful camera angles.

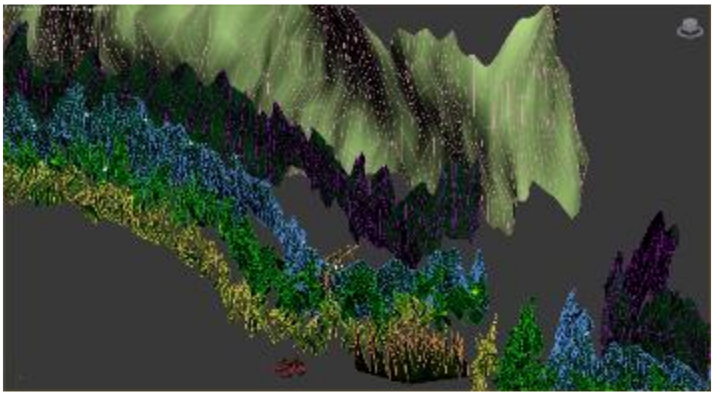
Although the jungle has a different environmental context which operates on a smaller scale, it uses a similar rationale for arranging layers of surfaces that span the entire length of the forest path.

A differentiating factor of the jungle ribbons is that they don’t use image maps of plants but rather rely on their 3D shape to provide a general sense of vegetation near the acting spaces.

The jungle stage was designed for the camera to stay approximately within the area of the path and at a height that is close to the eye level of the main character. The camera can pan sideways without going over the ribbons, and has limited ability to perform pedestal motions.

The ribbons provide an enhanced sense of image depth even though they are not spread out far from the path. Atmospheric perspective provides the sense of looking deep into the forest and is achieved through the progressively lighter and less saturated colours in ribbons that are farther from the camera.

The nearest ribbon to the path resembles a wavy picket fence. All layers of ribbons have bending distortions to appear more natural-looking. The layers of greenery near the back are made visible by being taller. The distant ribbons are made with fewer polygons as the detail would be lost due to being out of focus and because they did not need to draw attention. The outside ribbon acts as a wall that blocks our view and reduces the need for having objects beyond that distance.



High angle view of stage indicating the positioning of 5 ribbons. Film screenshot.

The system of jagged ribbons cannot stand on its own as its vague resemblance with foliage is not sufficiently defined for being shown with the intended framing. For this reason better defined models of independent plants were added to create a forest appearance with more diverse shapes and colours of plants.

The significance of an optimised stage

Production costs can be positively affected by avoiding making scenic elements with excessive detail, and by reducing the number of stage objects. Lowering the geometry of a stage can lead to reduced computational loads, whereas working with fewer 3D objects can reduce modelling requirements and can facilitate stage management.

The computational requirements of the optimised jungle stage enabled me to handle stage development, character animation and rendering within one 3D project file. The ability to handle multiple tasks without interconnected 3D project files provided immediacy in completing tasks such as performing quick preview render jobs that enabled seeing a fully composed image with a single command.

During the creation of a previs, apart from seeing which objects come within the frame we can also take note of how much area of the frame they take up, as they may only be partially visible (see chapter 4, page 133). Scenarios in which making only a part of a larger object is, for example when the frame of the shot needs to contain a shop window without the rest of the building, but also when there are obstacles that obstruct the view or that make the appearance of an object unclear. Moreover, objects that are seen through a dirty window or through pouring rain may require less detail. Lighting can also reduce the clarity of an object's appearance, for example if a bright source of light, such as the sun, is behind our subject we might be looking at its dark silhouette with lens flares further reducing clarity.

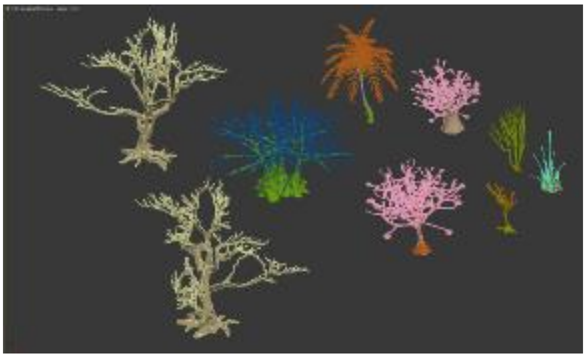
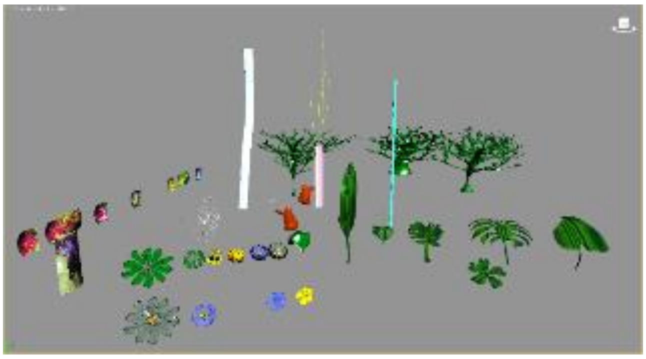
Scenic elements in the flight stage were economically made by taking into account image blurriness caused by camera motion and by knowing that the detail of objects that are beyond the focal plane may not be visible as they will be out of focus (see chapter 4, page 123).

Development and preproduction material such as storyboards, top-view plans and 3D previsualisation enable estimating the appropriate level of detail for geometry and textures of objects before starting stage development. The subject of assigning appropriate amounts of detail is addressed in another case (see chapter 4, page 156).

A homogeneous environmental element that is comprised of similar objects can make use of instanced copies. Scattering multiple copies of a blade of grass on a patch of ground can be much faster to implement compared to model it out of unique strands of grass.

Geometry instancing can be used for visualising subjects that have repetitive elements such as the leaves of trees. In practice, changes in the shape of one of multiple instanced windows of a building will be automatically applied on all copies. The reduced computational load of instanced geometry has been addressed in the review of literature and practice (see chapter 2, page 49).

Models of stage - 3D models of plants

Library of independent 3D models of plants and trees.

I managed the prototypes of individual 3d plants within a separate 3D scene which functioned as an asset library.

I reduced the modelling requirements and increased production efficiency by showing the same objects multiple times in the film. Moreover, modular design enabled making group entities that seam complex while comprising of copies of a few basic building blocks (see chapter 2, page 55).

The same tree bent tree trunk can appear as a different object when seen from a different angle. This is the primary reason for being able to make a forest out of a relatively small number of models of trees, leaves and flowers.

For different types of leaves and flowers I made one basic model which I modified into different shapes and colours with simple procedures. Similarly, many trees are differentiated versions of the same base object. The ability to reduce the amount of production resources that go into the modelling process through quick differentiation techniques, or by composing objects out of modules affects production costs.

Optimisation by cropped geometry

The view from the cameras on the stage was useful for adjusting the mise-en-scène. However, seeing how certain objects extend outside the frame enabled making optimal use of geometry.

Since many trees did not have to wholly fit within the frame, I was able to determine which sections of trees would be needed.

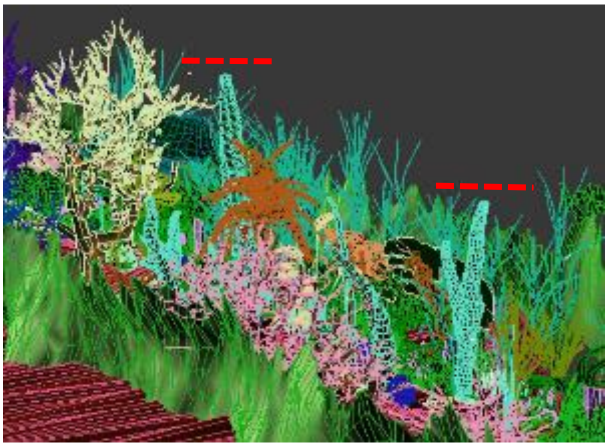
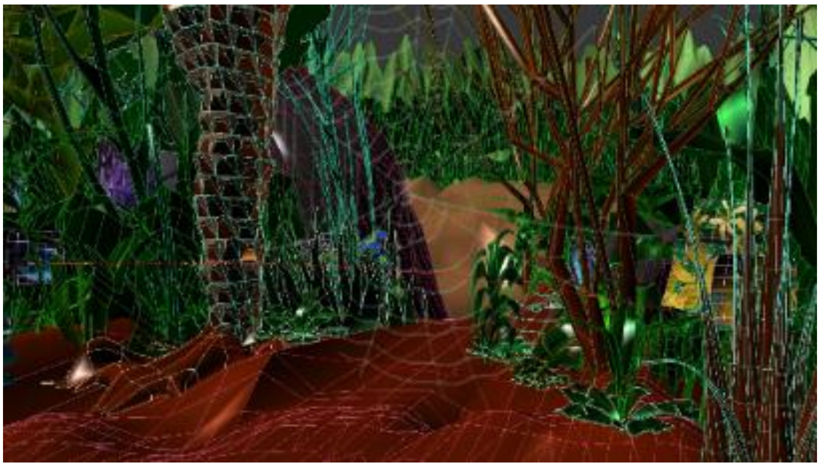


Image of stage indicating tree trunks cut at certain heights

By avoiding to include geometry that is not directly visible, the stage contained only meaningful geometry. An example of how objects that are outside our field of view affect the final image can be found in the review of relevant literature and practice (see chapter 2, page 54).

The lack of tree foliage over the jungle affected lighting in that the scene lacked shadows that would be expected when sunlight passes through the canopy. I positioned Cucoloris objects (a.k.a. cookies) over the trees to create adjustable areas of shade. Cookies gave the impression of being surrounded by tall and dense trees, and consumed little computational power compared to including fully modelled trees on the stage.

Importing models into the jungle stage



Stage enriched with models of plants in real-time 3D viewport

When the cameras were placed on the stage and the shape of the path and ribbon system had been set. I imported the trees and plants from the asset library into the jungle stage. The positioning of objects was made while observing the framing composition through the known camera angles with real-time 3D visual feedback.

In order to fill the length of the path with vegetation I positioned copies of plants in areas where the coarse background vegetation lacked detail.

I made certain copies of plants look different by changing basic attributes such as their scale, their rotation, their lighting and their colour. Having variations in the objects made the repetitive patterns less observable to the viewer. The differentiated copies of objects made the jungle stage appear to have more diverse plants and trees than the limited number of objects in the asset library.

Screenshots indicating copies of the same object.
Times in Struthio (2011): 2:14, 2:59, 2:32, 3:00

The above images indicate copies of a plant discretely blend with the greenery. When watching the film the repeated use of the plant is virtually unnoticeable as the shape of such objects is lost within the green background and because the attention is drawn towards the actions of the characters.

Even if the similarity between copies was noticeable it would still appear natural as people expect plants of a species to look similar. The process of positioning copies of plants had a considerable impact on the appearance of the film for the resources spent.

Summation of the jungle stage

This case is a paradigm for efficient production methods that act on two levels. On one level I presented how the background greenery was economically made. On another level I have shown how a stage that is small and light on computational demands can give the impression of visiting multiple locations. The scenes were carefully choreographed to make optimum use of the acting spaces along a trail.

Through this case I explained how we can repeatedly present the same background as part of different locations. Once I established where the scene is situated, for example, near the tree with the snake, I was then able to add generic views of the jungle that were also presented in scenes of other locations. Although each of the three main areas have identifiable elements such as a passageway that crosses the path, the areas ceased being recognisable under the following conditions:

- when an object such as the spider web became hidden
- when the frame of the sot was flipped horizontally
- when the field of view changed (i.e. the same location was shown with a wide angle a telephoto view)
- When the focus of attention was the character in combination with a fast editing pace.

A condition that enabled a stage area to be presented as a different location, is that both locations needed to share the same theme. It is best if the environment that is presented within different contexts does not contain memorable objects such as the Eifel tower which would create a powerful impression. If the viewers can recognise a location by its specific objects, they may also find that the presented locations do not match the intentions in the script.

Essentially, the background provides the general environmental context such as hospital corridors which can be expected to have a similar appearance whether we are on the third or the fourth floor. Other examples of environments that may look similar in different locations include a sewer system of a city, a prison cell, hotel rooms, office cubicles, parts of school buildings, and railway tracks in mining tunnels. I took advantage of the homogeneous appearance of a dense forest to present it as a backdrop for different locations.

A notable example of how an environment can appear to be different from reverse camera angles can be found in the review of relevant literature and practice (see chapter 2, page 55).

Technical notes on instanced models

Most 3D software packages can take advantage of copied objects by storing the model's data once irrespective of how many times it is shown in the scene. This process reduces memory usage and can keep computational performance at levels that have little effect on productivity. Although there are variations between 3D software tools, widely used terms for making duplicates of objects which are loaded once in a 3D scene are "instances" and "references".

Examples of how instanced copies of objects affect the computational load of a scene can be found in the review of relevant literature and practice (see chapter 2, pp 47-49).

Film Struthio (2011) recapitulation

Within Struthio I explored the design and implementation of stages that can cover the needs of multiple scenes. The stages differ in form, in theme, in the types of objects they contain, and in the types of actions that they host which are covered with moving cameras.

I explored the use of groups of single sided painted planes, relief surfaces, and ribbons that incorporate forced perspective. I have shown that such objects can be made economically and that they can have a significant impact on image quality. I have showcased hybrid systems that combine single sided surfaces with 3D models that are viewable from all sides. I have also shown how the camera can be managed within such systems as there are limitations regarding possible viewing angles.

The jungle stage, which has a versatile trail on a small amount of space, served to explore how to increase the usability of an environment by making an area appear as different locations in separate scenes. The savannah stage enabled explaining how different acting spaces could share a common background. The book stage hosts two diverse environments and the flight stage enabled covering traveling actions over a forest landscape with computationally light trees.

I have explained ways for reducing the 3D modelling workload and how certain conditions can affect the needed level of detail of scenic elements. Optimised 3D assets and rendering systems reduced processing requirements to a point where it was practical to work on stage development and character animation within the same project file.

The project files were used for exporting long animation preview sequences with minimal post-processing needs with a single render command. Fast processing times in combination with no need for video compositing can be critical for the production of lengthy content such as animated series.

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Multiple case study: Agrinoui (2015)

Overview

Poster of Agrinoui (2015)

Agrinoui has a play time of 19 minutes and 40 seconds, and premiered on October 20, 2015 at the Rialto Theatre in Limassol, Cyprus.

Agrinoui (2015), just as Struthio (2011) acted as a platform for designing multipurpose stages. The stages hosted multiple characters that performed diverse types of actions within new environmental themes that enabled extracting complementary data. The fact that the more recent film made use of different lighting and texturing technologies indicates that the findings of this project are not limited to the use of specific rendering engines or particular visual styles. However, rendering setups that aim to provide more realistic images may consume considerably more computational resources to execute processes that simulate the physical properties of materials and lights.

The stages presented hence forward incorporate systems that enable the dynamic repositioning of scenic elements. Moveable scenery enabled me to make stages that provide increased visual diversity with reduced amounts of geometry which in turn enabled making the film with fewer stages.

My initial trials concerned applying dynamic properties to secondary objects that do not define the acting spaces nor did they affect the shapes of terrains and buildings. In these cases I reused groups of objects such as clouds and trees by repeatedly repositioning them within the frame of different shots as a measure to make optimal use of computational resources.

The exploration advanced with the development of a type of dynamic system, called polymorphic stage, which is designed to take different forms. Major scenic objects such as mountains were rearranged at different points on the timeline to display different landscapes.

The holistic research project looks into multipurpose stages as being an integral part of the production framework that enables the coordinated work of a team of 3D computer artists. The production framework of Agrinoui (2015) enabled performing simultaneous operations on character animation and stage development. Productivity was enhanced by the synchronised film preview cycles which enabled periodically reviewing the collective team progress.

Coordinated production pipelinelines with either small or large teams of artists working in synergy can lead to a scaled up output rate with reduced workhours. Optimised multipurpose stage systems can further reduce production costs by enabling working uninterruptedly on long sequences with a low number of project files that have limited computational requirements.

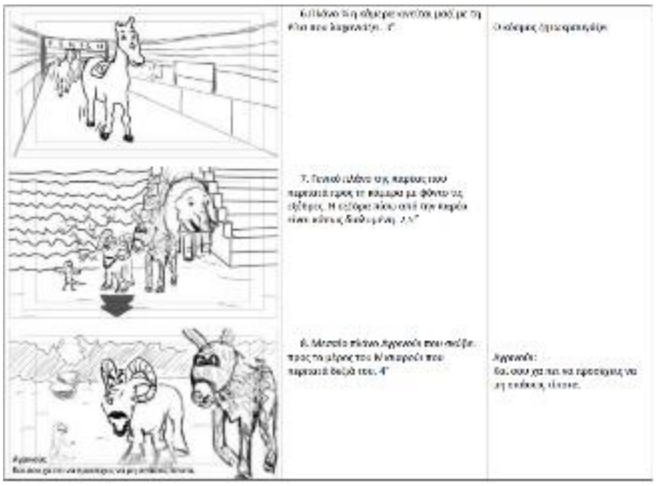
The importance of production efficiency is particularly evident in animated TV series where considerable production rates can be found for making episodes with consistent quality.

The optimisation measures of 3D assets in Agrinoui (2015) went beyond known processes for adjusting the level of detail (see chapter 2, pp 56-57). I further explored the potential uses of single sided surfaces that were presented in Struthio (2011) cases. Relief surfaces that face the camera can appear to have great detail and volume even when they are actually hollow façades. Although such surfaces can limit camera movements, as they lack geometry on their side, back and top views, I am presenting how I managed several types of moving shots.

Development and preproduction in Agrinoui (2015)

The writing process involved visualising scenes with storyboard drawings, and receiving input from other writers. The storyboard and the leica reel were tools that facilitated re-evaluating the storyline and led to the removal of non-essential scenes and to refinement of dialogues and of the flow of shots.

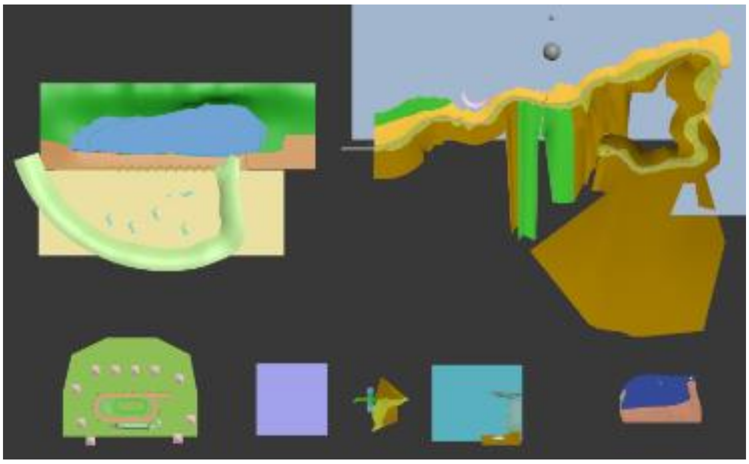
The cost of trying out how a scene would look like by preparing visualisation documents is often justifiable even if the scene does not make into production as a flexible planning phase enables making adjustments that will improve the film experience. The fact that film producers often disclose leica reels of deleted scenes reinforces that planning documents can be regarded as tools for making revisions and not merely as a way to note production tasks.



Storyboard page from the final scene of Agrinoui (2015)

While I was making the storyboard I also visualised, with top-view sketches, the shape of the stage and the positioning of cameras and characters that would provide the intended framing. The spatial awareness enabled me to factor in practical issues of acting spaces and camera positions. Incorporating stage design at this early phase enabled reducing production costs by making framing decisions that favour a practical execution process.

The 3D animatic enabled me to test how each stage concept can provide the desired framing. During the 3D visualisation process I refined the placement of scenic objects, characters and cameras. This process provided framing feedback in real-time which enabled me to directly adjust the shapes of the stages.



Top view of all seven stages in the 3D animatic project file

The 3D previzualisation process required one 3D project file which included all the seven stages of the film. This approach had the advantages of being able to preview and edit the previs in real-time, and export the entire video file with a single rendering command.

> *Side note: The editing process of animation films is commonly made at the beginning of a production. The editing of a live action film is different in that it normally takes place during post production and involves adjusting the timing of shots once the ideal takes have been selected.*

The low-resolution geometry within the 3D previz file made it possible to work without noticeable lag in the viewports while having the proxy objects of seven stages visible.

During the production phase I used the proxy stages as a reference guide for placing high resolution scenic elements. However, I broke down the film into seven sections, resulting in separate groups of project files for each stage. The seven project sections consisted of the scenes that took place on the separate stages of the racetrack, the flight over Cyprus, the salt lake, the mountain roads, the beach, the forest, and the temple of Apollo.

In hindsight I would now position each blocked out stage near the digital space centre as defined by the origin which is situated at XYZ coordinates with zero values. Instead, I had positioned each draft stage next to one another without having foreseen the problems with accuracy that would later be encountered with the character animation tools as explained in the interview section with character animator Sakis Kaleas (see chapter 4, page 212).

Common timeline for leica reel, audio, 3D animation, and video editing

The timing of each shot was roughly estimated in the storyboard and it was progressively refined with the leica reel and with the previs that featured the recorded dialogue audio tracks. The voice actors had limited visual feedback during the recording sessions as they only had the storyboard as reference.

The leica reel consisted of the storyboard frames being presented sequentially. At this phase I started a video editing project which had a reference video timeline that was consistently used throughout the filmmaking project. The video editing timeline was used for mixing the sounds and, as the project progressed, I replaced the storyboard frames with 3D previsualisation. Ultimately, I overlaid 3D animation preview sequences which were frequently updated during the revision and improvement cycles. The video editing file provided the master timeline which was synchronised with the timelines of the 3D computer animation files.

The synchronised timelines enabled me to do things such as export revised audio tracks from the video editing file which would be compatible with any 3D animation project file. Having synchronised voice tracks enables animating the characters and applying precise movement to lips.

The fact that any audio track, that spanned the duration of the whole film, had compatible timing with all the 3D animation files had a positive effect on productivity. Having a single voice track for all animation tasks provided a simple audio management structure.

During the production phase 3D environments and character animation were handled with separate project files. Having a common timeline enabled merging the characters and environments to make a synchronised video sequence that contained all the visual elements. The merging process occurred each time I rendered a preview image sequence.

The timeline of the video editing file had a provision for transitions that would prevent disrupting the synchronised timelines of audio, video and 3D animation.

Screenshots from Agrinoui (2015) indicating a change of scenes with a wipe transition

The film has 12 transitions between video clips in the form of cross dissolves and wipes. During such transitions there are a few seconds where two video clips overlap. Applying these transitions would shorten the duration of the film, thereby causing the loss of voice synchronisation between the video editing and the 3D animation timelines.

My way for keeping the editing and animation timelines compatible with each other was to apply the 12 transitions in the video editing project file towards the end of the production just before sending the film to the audio effects specialists and the music composer. At that point the voice tracks were unlikely to change. However, the marked transitions on the timeline made it possible to manually restore synchronisation between the video editing and computer animation project if needed. Restored synchronisation would be useful in the event of having to rerecord dialogue lines and to synchronise the lips of characters to the new voice track.

Production pipeline of Agrinoui (2015)

Introduction

The production pipeline for computer animation films comprises of several steps that are handled sequentially such as model shaping, followed by texturing. Each step can be completed faster with parallelisation in which, for example, the modelling workload is handled by multiple artists, each being responsible for creating separate objects that can be categorised into props, characters, and scenery.

Although the production timeframe can be shortened by having two 3D modellers work in parallel, the total amount of work hours is not directly affected by the size of the team as one artist can theoretically handle the same workload in twice the amount of time.

3D generalists with the capacity to undertake multiple tasks such as modelling, texturing, lighting, and animation, can make short films within small production teams.

The computer animation team of Agrinoui (2015)

The term “production pipeline” suggests that certain tasks occur sequentially. A reasonable linear order would be to draw a concept of a character, to model it, then to make the textures, followed by making a bone rig and then giving motion.

It is possible to establish a parallel workflow that offers enhanced efficiency through synergy. The collaborative production framework of Agrinoui shows how different production departments can achieve increased productivity through synergy.

The two production elements that were approached in tandem were character animation and stage development. Apart from a preview of the film, the 3D previsualisation process provided an editable 3D computer graphics file that formed the basis for superimposing the high-quality scenic elements and characters.

3D previsualisation

Animator Sakis Kaleas gave motion to the characters while I worked separately on the environments.

High quality Characters and animation

High quality environment

Productivity levels when animating characters can drop significantly if the animator does not have real-time visual feedback of mesh transformations. Character animation project files would be slow to work with if they contained detailed scenic elements. This was also true regarding the work on 3D environments which benefited from the absence of the computationally demanding characters.

By aligning the positioning of characters and of scenic objects to the space coordinates established with the previz it became possible to combine the high quality characters with the detailed scenery.

Animated characters merged with high quality environment

Characters and scenery were frequently united for creating preview videos. Each review cycle concerned the progress in both character animation and 3D environments. The periodic review of a high quality image composite enabled me to make informed observations regarding the next animation tasks as well as further work on the appearance of the stage.

If the work on character animation and on 3D environments had occurred at different times, I would roughly estimate that I have would have had to perform twice the number of progress reviews. The development of the two production components in isolation could have created problems that would have been observable only by ultimately putting them together.

Communication

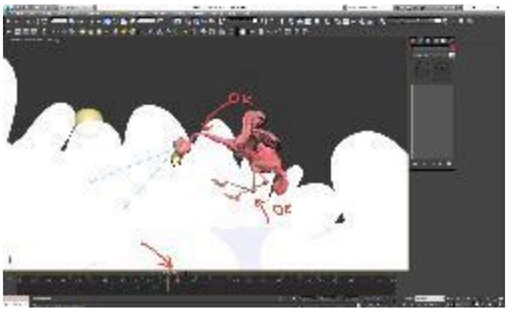
The medium of communication between character animator and director varied as we used phone calls, video calls that enabled remotely displaying the contents of one’s screen in real-time, emails, and file sharing over the web. Although we operated in different countries the reliable digital communication technologies enabled having a smooth workflow.

Although I often provided lists of observations to the character animator after each revision, I found useful the process of capturing a screenshot, from our shared preview animation video, and add handwritten notes on top of the image.

The images underneath display a sample of review notes taken at different revision sessions which formed the iterative improvement cycles. These specific messages aimed at progressively refining the motion and posture of the flying bird.

Review notes on 19-11-2014 and on 22-12-2014

On a few occasions I captured an image of the computer screen displaying graphics within the 3D software. This enabled communicating lists of settings or issues with skinning and bone systems.



Screenshot of 3D graphics software interface

The superimposed handwritten technical notes on the screenshot above facilitated explaining the cause of a skin problem with the character bone rig. The timeline in the bottom shows at which moment the observed issues take place.

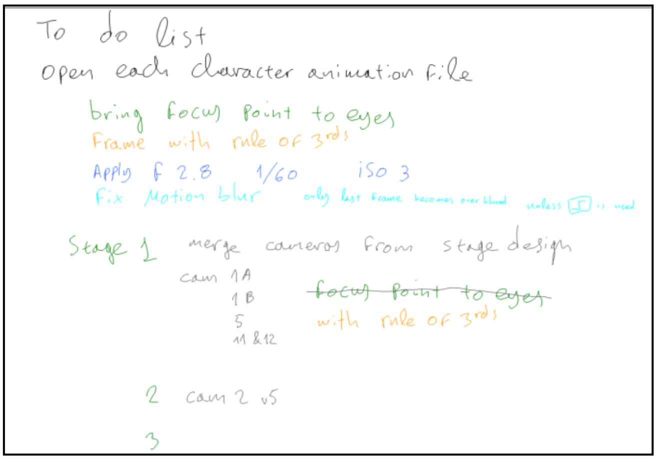
The drawn lines enable communicating a pose more effectively than descriptive text. The picture filenames contained the frame number which enables locating the exact moment on the timeline of the 3D software.

Screenshot of rendered preview within the detailed environment.
The two drawn lines indicate a preferred neck bending.

I periodically merged the animated character with the high quality environment to make high-quality preview videos for global progress assessments. With an output rate of one frame per minute, the preview rendering process of a 30 second preview clip would take 12 hours to complete on one workstation. The high quality preview video was shared with the character animator who also acted as technical consultant, who frequently provided important technical advice on a range of matters such as lighting, physics, and atmospheric effects.

I used each preview video to note observations that concerned our next steps in applying improvements in both animation and 3D environments. Separate notes about scenic improvements were addressed towards myself since I had multiple production roles including director and computer artist.

If I had to manage a larger team of 3D artists the process of observing progress would have been similar and I would have used similar means of communication. If separate artists were responsible for models, textures, and the other production pipeline tasks, I would have provided individualised feedback notes on a regular basis.



Sample Notes of 16-8-2015. This work session towards the end of the production concerned tweaking exposure settings as well as the framing of each shot in relation to where the eyes of the characters had ended up being positioned.

I consulted my notes during my computer graphics work sessions. The notes served as checklists of tasks which I could methodically go through. I was able to foresee the workload of each day and to focus on separate steps rather than becoming overwhelmed by the size of the project.

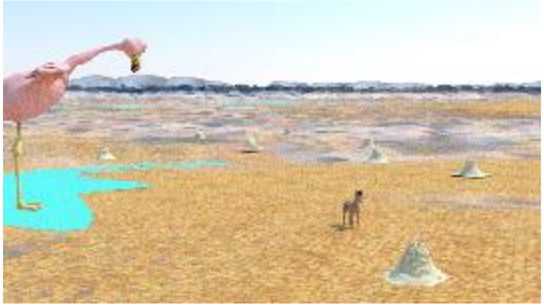
Stage development - workflow

Stage development still preview (20-5-2015)

Film screenshot

During stage development I often rendered still frames to make on-the-spot adjustments to the lighting system and to scenic objects. Rendering a still frame would normally take less than a minute and occurred multiple times during the day. Hardware processing power affects the speed at which render jobs are completed. However, a 3D scene that is not optimised, in terms of level of detail, texturing, lighting, and rendering, can be so computationally demanding that any advantages of having superior computers are quickly negated.

Animatic (28-6-2014)



Stage development still preview render (23-5-2015)

Film screenshot (20-10-2015)

The screenshot from the stage development phase indicates how elements from the previs such as the lake and the proxy characters were used as reference points.

Although the proxy characters did not have moving limbs, their position provided visual reference regarding framing and relative scale that facilitated adjusting the sizes of objects. For example, observing the size of the characters in relation to the environment was a factor for choosing a height for the piles of salt as well as the denseness of the salt lake floor texture. Although I used real size measurements, I also referred to the rendered frame to make refined scale adjustments based on visual feedback.

Computational resource management

Film productions usually start with a budget that states the allocation of resources such as the amount intended for the acquisition of equipment. Regardless of available processing power, computational resource management enables incorporating the highest permissible technical attributes of image quality without undermining the productivity of computer animators.

A slow computer can complete demanding tasks if we give it enough time. Working with computationally demanding computer graphics can induce numerous short delays during a work session which can add up to a significant amount of wasted work hours. Furthermore, having the workflow frequently paused can potentially affect mental concentration and cause further productivity loss.

In general terms I find it preferable to perform “save file” operations in less than ten seconds and to render high quality preview still images in under a minute. Processes that need to occur in real time include navigating through a 3D environment which can be made comfortably a rate of 10 frames per second. However, real-time 3D character animation is ideally displayed at film frame rate i.e. 24 FPS. A computer can be kept responsive by throttling certain processes. If, for example, characters are displayed at a low viewport frame rate, hiding some secondary elements can positively affect refresh rates.

In cases where the available computational envelope becomes excessively strained due to processing numerous animated characters it could be possible to compensate by reducing the use of other demanding elements such as the amount of geometry dedicated to scenery. The racetrack stage in Agrinoui (2015) hosted 13 animated characters and included particle systems that took up a significant part of the computational envelope. The challenge was to make a stage that would not provide an inferior visual quality compared to other scenes of the film that displayed fewer characters.

In order to keep a responsive workspace I devoted a limited portion of computational resources to the scenic elements of the racetrack stage. I designed dynamic repositioning systems that restricted the amount of 3D geometry dedicated to trees, small plants, and background Mountains.

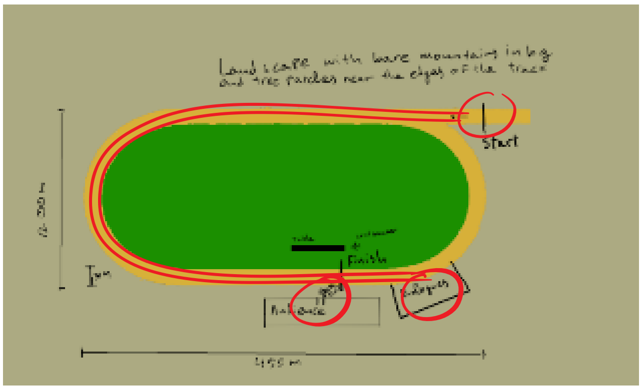
Another stage featuring a winding road with sea and mountainscapes enabled me to devote more computational resources for environmental elements because it needed to host significantly fewer characters compared to the racetrack stage.

Agrinoui Stage: Racetrack

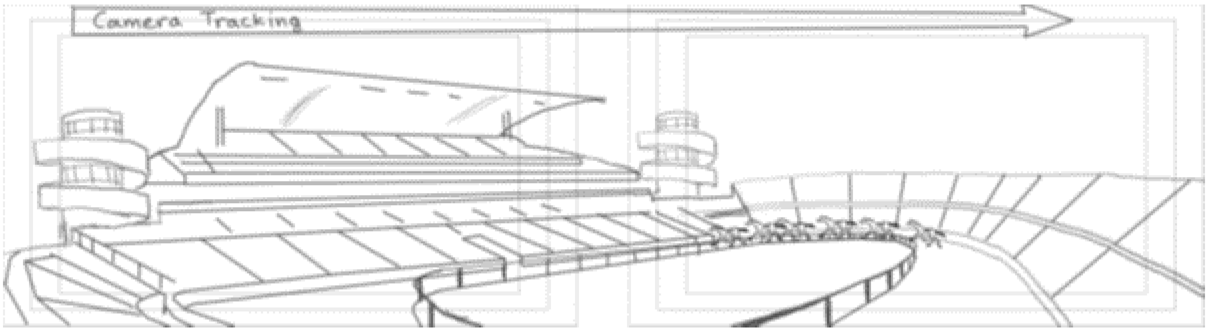
Planning

The racetrack is a versatile stage that hosts dialogue scenes and races. The stage includes the entire length of the course, the grandstand, and a terrain that provides a surrounding view of distant mountains.

I created the shot list bearing in mind the size specifications of actual racetracks. Having prior knowledge of the main features of the stage enabled me to draw the storyboard frames with confidence that the shots would be realisable.



Top view concept drawing indicates the shape of the stage and acting areas in red



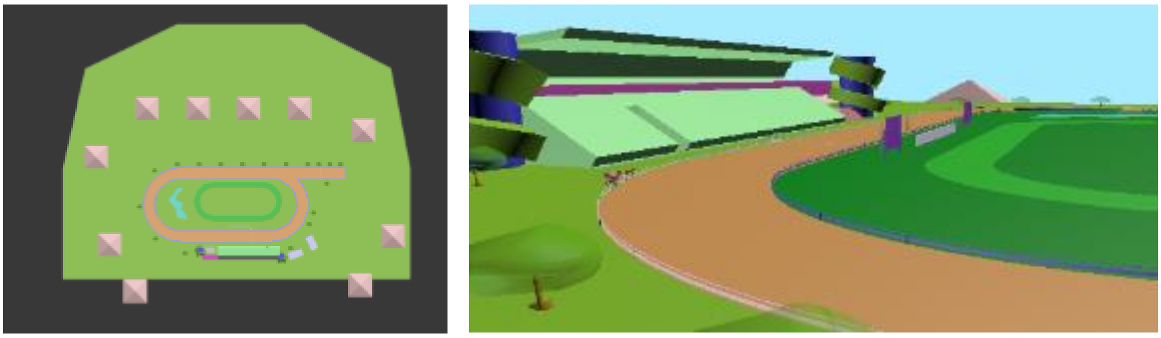
Storyboard panel

I drew the racetrack in the storyboard with a landmark structure that resembles the form of an existing football stadium. Although the surrounding enclosure would omit the need for a distant horizon, the numerous spectator seats would still require a significant amount of geometrical detail.

Although the film contains several landmarks of Cyprus, upon reviewing the storyboard I decided to omit the G.S.P. stadium and designed a new environment that I considered to be more suitable.

Comparative concept art for deciding on the racetrack surroundings

Concept art enabled me to visualise different background choices. Ultimately both the wall of trees and surrounding spectator seats were rejected in favour of a less obstructed view that reaches distant mountains in the horizon. I tried a racetrack concept with open-space in 3D previsualisation and decided to pursue this direction. The revision of planning material enables us to make refined improvements with considerably lower costs compared to creating and rejecting high quality 3D environments.



Top view of stage of 3D previsualisation and Screenshot

The 3D Animatic, contained the general form of the stage which acted as a guide for creating and positioning high quality 3D objects. The framing of each shot enabled me to make decisions on the ideal properties of scenic elements including their appropriate level of detail.

Race track stage – Vital optimisation

Acting spaces make up a significant area of the stage. The entire length of the running course hosted horse races and two areas at ground level near the spectator seats hosted dialogue scenes.

Acting area on the course, another at an access gate of the grandstand near the finish line, and another at a passage where horses can exit at a turn of the track

Panoramic view of the race track

The inclusion of a complete racetrack on the stage enabled following the action linearly as the timeline used in the 3D software shows the shots in the same succession as they appear in the film. The 3D software enabled the camera to instantly change its point of view and field of view for making multiple successive shots.

Several optimisation measures enabled me to make the stage with a limited amount of geometry. Having a lightweight stage was vital for handling computationally demanding files that contained thirteen animated characters and for rendering long scenes.

Without optimisation measures I would have had difficulty including the entire racetrack on one multipurpose stage which was decisive for working uninterruptedly on complete scenes. Although heavier 3D scenes can be managed by separating the stage into smaller sections, solutions of fragmenting project files would distance us from the multipurpose stage design (see next section for a hypothetical fragmentation example). The design rationale deals with making a balanced stage that combines versatility and good visual quality without causing computational delays that significantly obstruct productivity.

The making of intricate animated effects shots can involve rendering certain elements in separate passes that are later stacked as layers of video in a compositing application. Although working on separate video layers enables making minute image adjustments, the time-consuming process would be inconsistent with the aim of making long sequences efficiently.

The race track stage features in 5 minutes and 48 seconds of the film which translates in over 8000 frames. By rendering the film as a single layer of video I facilitated the previewing process, I simplified the video clip file structure, and I saved money on storage that would better cope with editing multiple layers of video.

The single pass rendering system of Agrinoui (2015) enabled me to also create a stereoscopic version of the film at low cost because the process involved a small amount of compositing work.

Hypothetical fragmentation of racetrack stage

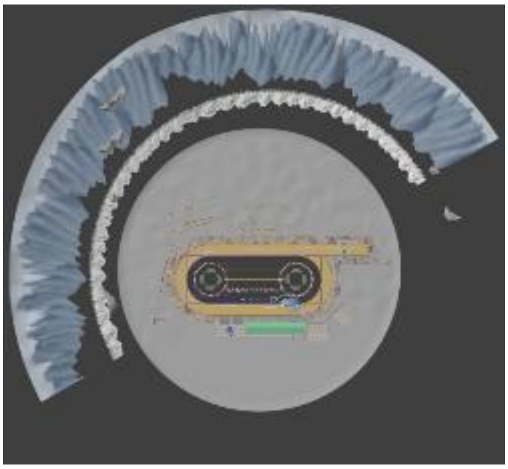
If the racetrack stage was excessively computationally demanding, it could have been separated into multiple areas. For example, each of the two dialogue areas could be an independent stage. The prospect of dividing the running area of the track into sections would cause significant disadvantages concerning the creation of an establishing shot and because of losing the ability to review shot continuity of racing scenes in real-time viewports. Unlike the multipurpose stage, a three-stage solution would not display the shots in the order they appear in the film. This would require additional work for synchronising the voice tracks to the 3D scenes.

Managing multiple racetrack themed stages could cause inconsistencies such as in the appearance of the sky and lighting that were progressively developed (see chapter 4, page 146). The process of tracking and updating changes in the appearance of shared scenic elements is an additional task in the pipeline that was not necessary with the implemented race track stage. Such additional steps in the production workflow can add up to numerous work hours considering the repetitive nature of cycles consisting of progress reviews and implementation of improvements.

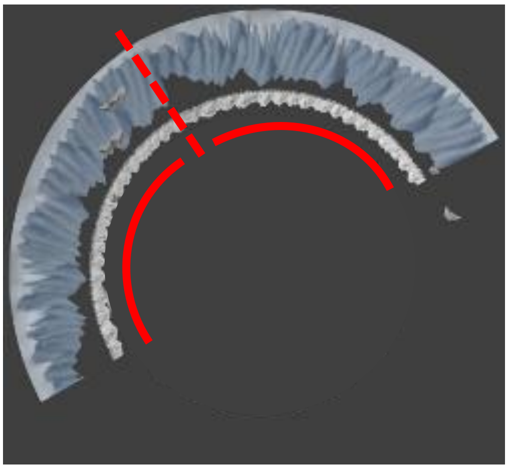
The length of animation sequences that take place on a stage, affects the time needed for the production team to complete operations that are connected to that stage. The reduction of processing time for frequently used file commands, for space navigation, for object manipulation and for frame rendering by even small amounts, has a compound effect on overall production speed.

This project focuses on the alternative to dividing a computationally demanding stages which is to optimise the effectiveness of scenic objects. This project goes beyond assigning appropriate amounts of detail (see chapter 2, pp 56-57) and presents systems that can reduce stage geometry by repositioning modular scenic objects.

Race track stage – Layers of mountains



Top view of 3D stage in final form



The mountains are tileable quadrants

The layers of mountains comprise of single sided relief surfaces facing the centre of the stage. Although the mountains appear to extend far beyond the horizon, they are in fact positioned in close proximity to the racetrack. To make the mountains appear to be distant, I incorporated forced perspective by having significantly smaller than true-to-scale mountains. The blue tint in the mountain textures simulated the effect of looking through a long distance of atmosphere. This approach was also used in the savannah stage (see chapter 4, page 111).

> *Technical notes: A fog simulation effect, which takes into account the distance from the camera to an object can be used to simulate atmospheric perspective. However, the effect would have had a negative effect on computational demands as it needs to be applied each time a frame is rendered.*

Simulated fog can reduce colour contrast of distant objects which corresponds to how an atmosphere actually affects the appearance of colours. I purposefully diverged from the restricting physically correct colour palette that would have resulted from fog simulation by manually selecting the colours of distant surfaces. The digitally painted texture maps of mountains have a blue hue with a higher than natural brightness contrast as actual mountains would have appeared duller. Similarly, I handpicked the sky colours so as to create a frame that contains an unnaturally vibrant range of colours. The use of forced perspective and selective colour palette came with restrictions concerning the useable area for camera positioning.

> *Technical note: Forced perspective enabled having a compact stage which reduced the risk of running into technical limitations associated with accuracy in space coordinates. By having the horizon within a short distance from the acting spaces, the stage occupied a limited area which facilitated the precise positioning of the feet of a small lizard that touched surfaces of scenic elements.*

System for reduced geometry – Dynamic Semi-circular mountains

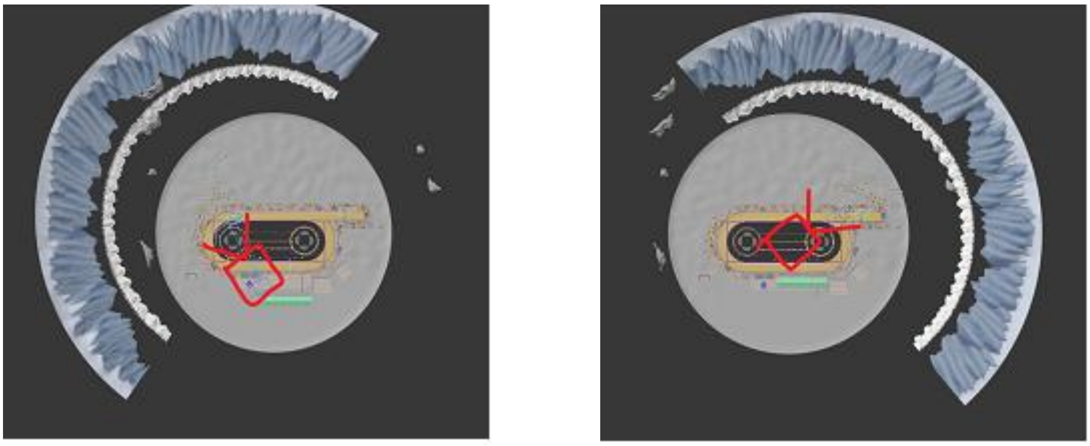
Two layers of mountains in the background comprised of bent surfaces that partially surrounded the racetrack covering a 180-degree field of view from the centre of the stage.

Whenever a shot required the camera to be pointed towards the direction with the background void I would reposition the semi-circular mountains within the frame. This process was reasonably fast to carry out as I only had to scrub the timeline to the initial frame of a shot, and to rotate the mountains so that they cover any gaps in the horizon. No exact rotation was required for positioning the mountains within the frame due to their homogeneous appearance throughout their length.

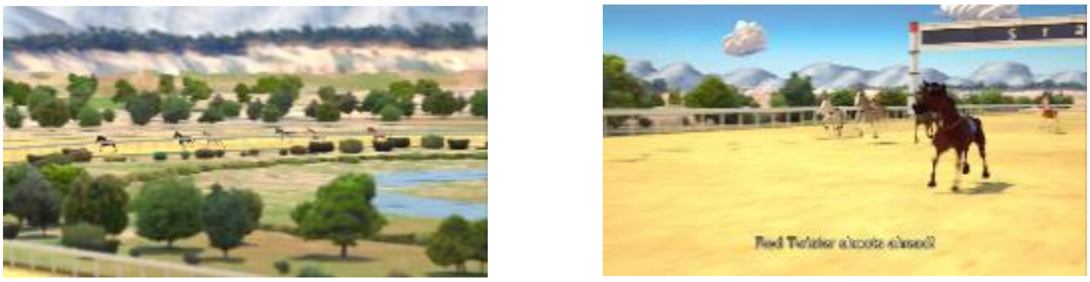
Animation keyframes stored the data regarding the moment at which the mountains should appear at specified orientations.

> *Technical note: Keyframes in computer animation enable storing parameters such as space coordinates. Animation can occur when two keyframes at different points on the timeline have different values. For example to make a 3d object travel from point A to point B we need two keyframes, each one containing the object coordinates at the start and end of the animation. Animation software enables adjusting how the frames between two keyframes will be automatically interpolated as keyframe data enables controlling advanced properties such as acceleration. However, in-between frames can be omitted as keyframes with stepped tangents enable objects to be instantaneously repositioned.*

The mountains, in my case, did not need to appear to be moving, therefore I used instantaneous repositioning between shots for the mountains as well as for the cameras.



Top views of stage with camera [indicated in red] pointed in different directions



Screenshots from Agrinoui (2015) displaying the respective views in the film

The top view of the stage reveals that I only created areas of background terrain that are visible to the camera.

The texturing and modelling process was made faster by making quadrants of mountain objects which were placed side-by-side without having a visible seam at the connection point (see image on previous page). The tileable texture maps and the instaced copies of quadrant objects required fewer system resources compared to a potential single-object semicircular mountain range.

I had the option to completely surround the stage with a continuous mountain range by adding copies of the quadrant objects. Compared to the alternative of encircling the racetrack with mountains, the repositioning system enabled me to cut the amount of mountain geometry in half, thereby reducing the computational load of the stage.

Models of trees

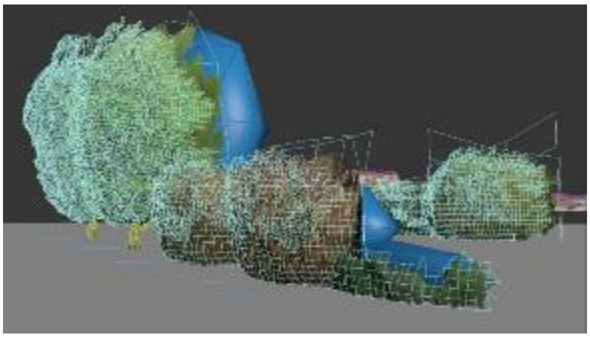
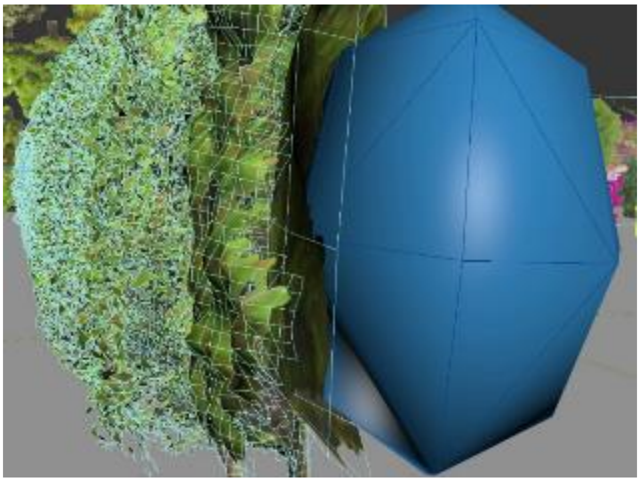


Image of models stored in the asset library of Agrinoui (2015)

Trees and shrubs comprise of single sided relief surfaces that are shaped as spherical domes. The normal side needed to face towards the general direction of the camera to avoid revealing that the sides are missing. However, the bent shape of the tree and surface relief in the foliage makes it appear to have volume which is especially noticeable in shots with camera motion that are shown in Agrinoui (2015).



1 2 3 4

Layers of high LOD tree (side view)

1. The outer layer comprises of small disconnected polygonal faces that resemble independent floating leaves which are laid out in the shape of a spherical cap.

2. The second layer is a relief that has elevations that resemble bulges of foliage. Depressions were made in the shaded areas of the texture map.

3. The third layer comprises of a low polygon surface that displays the texture map in reverse, mirrored horizontally. This surface provided additional thickness and made the outline appear more natural when the camera performed tracking motions.

4. Although the blue object was invisible to the camera, it purposely blocked light which made the tree cast a sizable shadow. Without the fourth element, the tree would create an unnaturally thin shadow when lit from the side.

An actual tree comprises of numerous branches and leaves that would have required a tremendous amount of geometry to replicate requiring significant amounts of computational resources. Instead of recreating shapes of actual tree elements, I made surfaces that carried the image of a tree. The texture maps provide the visual appearance of the tree and the geometry was shaped to improve how the object reacts to light and how it appears through moving cameras.

A breakdown of how the elements of the high LOD tree affect the image is presented below.

The outer foliage layer enhances thickness and outline:

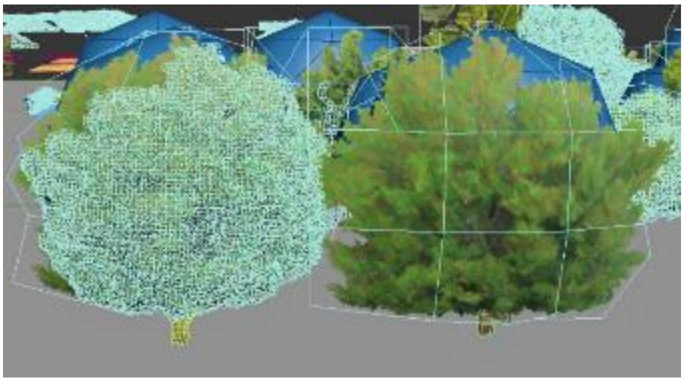
Bumps provide uneven relief surface:

Curvature: bright and shaded areas, and tree appears to have volume when camera moves:

Shadows on the ground have controllable size:

Screenshot of Agrinoui (2015).
The plants face towards the camera which performs a dolly out movement.

Levels of detail (LOD) - Working with large numbers of objects



Two versions of a tree with different LOD

The differences between the two trees are practically indiscernible when they take up a small area of the frame. To make the low LOD version I removed the two outer layers of geometry that contained more detailed relief. The rationale for choosing to display the version of an object with an appropriate amount of detail is described in the review of relevant literature and practice (see chapter 2, page 57).

Low resolution trees were normally positioned at longer distances from the camera compared to the high LOD versions. Details such as independent leaves are not discernible when a tree is shown out of focus or when it occupies a small area of the frame. Other conditions that prevent details to be observable include night-time lighting conditions, fog, rain as well as blurriness caused by fast camera motion. By studying the conditions of each shot in the previs, I understood which areas would be appropriate for positioning the low LOD versions of objects. The reduced use of high LOD objects was one of the measures for making optimal use of computational resources that effectively enabled having an increased amount of scenic elements on a sizeable stage.

The benefits of model optimisation have a compound effect when displaying large numbers of identical objects. An example in the review of relevant literature and practice indicates the differences in the amount of geometrical data when we have multiple copies of objects with low LOD compared to high LOD (see chapter 2, pp 48-49).

Seen in isolation, a low resolution 3D model of a spectator consisting of less than 1000 polygons has objectively limited computational requirements. However, if the spectator seats were filled with such models the stage would have required significantly more computational power than necessary.

The spectators on the racetrack stage comprise of planes that depict persons. The thousand fold reduction in the amount of polygons for the spectator system reduced the time needed to execute repetitive tasks such as saving files or rendering frames.

Screenshot from Agrinoui (2015)

The above framing enabled me to determine the appropriate amount of detail required for each spectator. In this shot, the camera focuses on the audience and the screen area occupied of individual spectators is measureable in terms of pixel resolution.

Efficient 3D modelling – Modules of structures

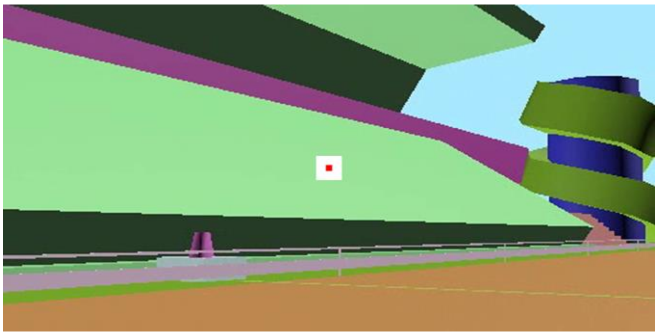
Manmade structures often contain multiple instances of the same element. A building with identical windows can be visualised by making one model of a window followed by arranging copies of the model to assemble a façade.

Other copied building blocks on the racetrack stage can be seen on the roof of the stands and the 28 flag poles. Great numbers of copied objects are the spectator seats and the posts that support railings.

The stage contains several pairs of columns that hold loudspeakers, screens, and signboards. The modelling process took advantage of having initially made one column which was then edited to make diversified versions. Another example of conveniently diversifying the appearance of copies of an object is can be seen above the spectators in the roof elements which have alternating colours.

Technical note: Instance copy is a term for a common option in computer graphics software for linking duplicate objects to a single set of data. Instance copies of thousands of spectator seats that referred to the data of a single model, resulted in an optimised file size. Unlinked copies of thousands of objects would have created an individual set of data for each object and would have significantly increased file size (see chapter 2, page 49).

Assigning an appropriate LOD



Screenshot from 3D previsualisation of Agrinoui (2015)

Previsualization enables determining how much screen area will be occupied by an object. The red square in the centre of the image has a horizontal size equal to one hundredth of the width of the frame.

The area of the red square can be translated into an amount of pixels if we know the resolution of the film. In a 2K resolution frame, the red square would be approximately 20x20 pixels which is useful for assigning a fitting amount of detail to seats and spectators on the grandstand of the racetrack.

The storyboard may indicate conditions that reduce the sharpness of displayed objects. A further reduction of level of detail can be justified if an object will appear blurred because of being out of focus or due to camera motion. The storyboard may provide information about atmospheric conditions, about lights and effects that reduce how clear the objects will be displayed.

Storyboard frame and screenshots with blurry elements in Agrinoui (2015)

In practice, it was difficult to identify objects that could be made with reduced detail after reviewing storyboard frames for shots with focus blur or motion blur. Only few of the 75 shots that were composed on the versatile racetrack stage had significant camera motion. The ability to render technically correct frames with high depth of field enabled me to choose the amount of bokeh at a later progress reviewing phase with rendered results. For example, for the third frame, with the legible start sign, I had planned for the lens to be focused further away knowing that the amount of blur would be specified after the evaluation of test renderings. When I observed the preview of the animated shot I found that the motion of the running horses effectively drew the attention to the action which was a factor that prompted me to choose a deep depth of field.

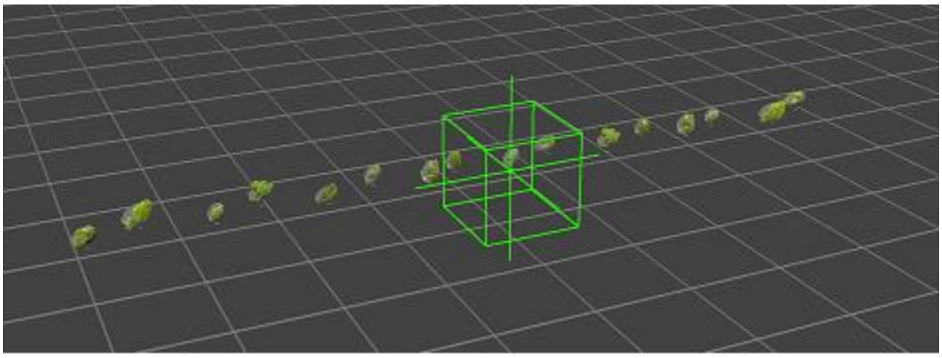
Once the stage optimisations could ensure a productive workflow, any further achievement towards decreasing computational demands would not have significantly lowered production costs.

It would have been possible to achieve faster execution of computational tasks without multipurpose stages. However, the advantage of multipurpose stages primarily lies in reducing the workload of 3D artists. For example, if individual shots were handled with isolated project files, the computational load could have been reduced by deleting the objects that were not visible in the frame (see chapter 2, page 54). However, the resulting complex file structure would have impeded project management, and frequently occurring tasks would have become cumbersome such as rendering a preview of a whole scene.

The racetrack stage enabled managing 75 shots and operating on long animation sequences with a limited number of project files. The objective of optimisation was to have sustainable performance levels that facilitated the efficient handling of large groups of shots.

Management of trees on stage

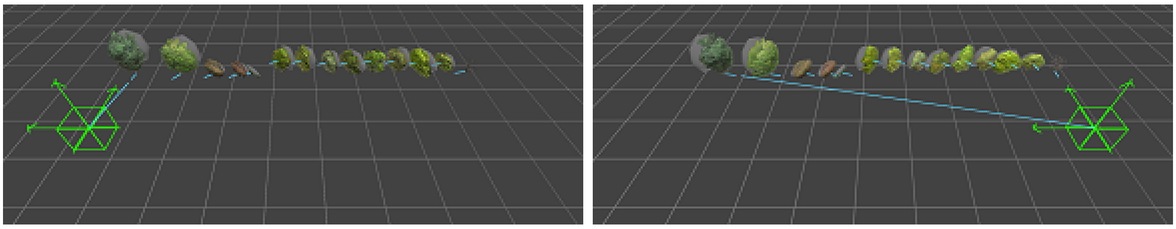
The racetrack contained a large number of trees that had to change positioning between shots. Repositioning each tree independently would have been time consuming. Therefore I made groups trees with a linear layout which enabled moving 16 trees at once.



The trees were linked to a master helper object which enabled moving the trees as a group

The trees had to be rotated to face the camera each time it acquired different positions for separate shots.

An automated process enabled a large number of trees to be rotated towards the direction of one dedicated helper object. The object was positioned close to the camera before each shot.



As the green object is repositioned, the trees point automatically towards it

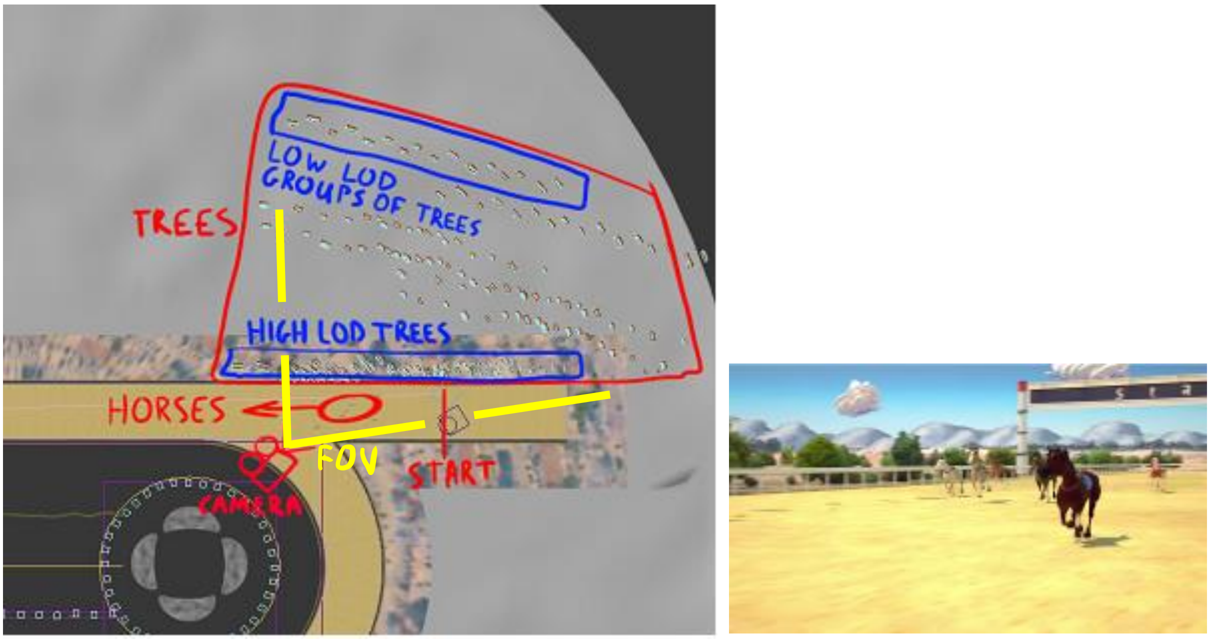
The look-at function is known as a way to control the aiming of the eyes of a character.

The linear layout of the tree group enabled obsructing the view in the background with a few rows of trees. Such shallow walls of trees aimed to create the impression of a sizeable forest behind it without necessitating additional geometry.

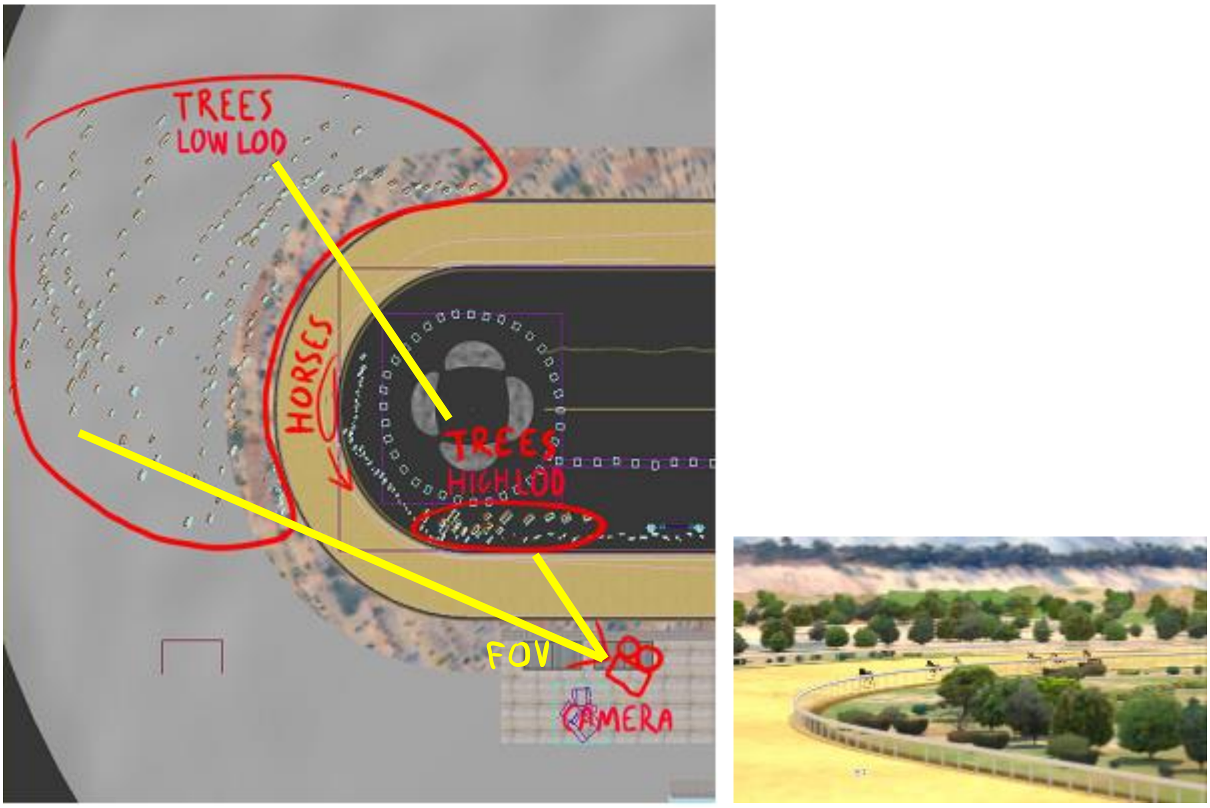
Dynamic System for reduced geometry on stage – Tree repositioning within FOV

The film gives the impression that the racetrack is surrounded by a significantly larger amount of trees than are actually on the stage.

Like the mountains, the trees also changed positions between shots depending on the orientation of the camera.



Top view of the racetrack stage at time (min:sec) 0:42 with respective film screenshot



Top view of the racetrack stage at time (min:sec) 1:00 with respective film screenshot

The top view of the stage shows how the same groups of trees were repositioned within the field of view of two different shots.

Planning revisions

Visualisation documents

Storyboard sketches indicate the flow of shots and how a scene is communicated as a whole. Concept art paintings focus on individual views and enable giving refined shapes and colours to elements. During the creation of planning material I considered alternative surroundings for the horse. The observation of comparable paintings convinced me to replace the road, that was described in the initial script and storyboard, with a plain dry salt lake.

In another instance, planning material enabled me to reassess the impact of a scene to the story.

Concept art and storyboard frames of a deleted scene

I chose to remove the dialogue between flamingos in the water as it provided context for a secondary character without progressing the story.

Although the removal of a storyboarded scene may seem counterintuitive, this choice led to a more concise film. With this in mind, exploring scenes during preproduction without being certain that they will eventually be shown in the film, can lead to presenting a story in a more refined way. A producer that chooses to replace film sections after reviewing the storyboard probably aims to improve the experience of the audience, and in doing so he essentially allocates production resources towards areas that demonstrably matter most.

Scenes may also be deleted if the total length of the storyboard exceeds the intended duration of the project such as TV episodes with standardised running times.

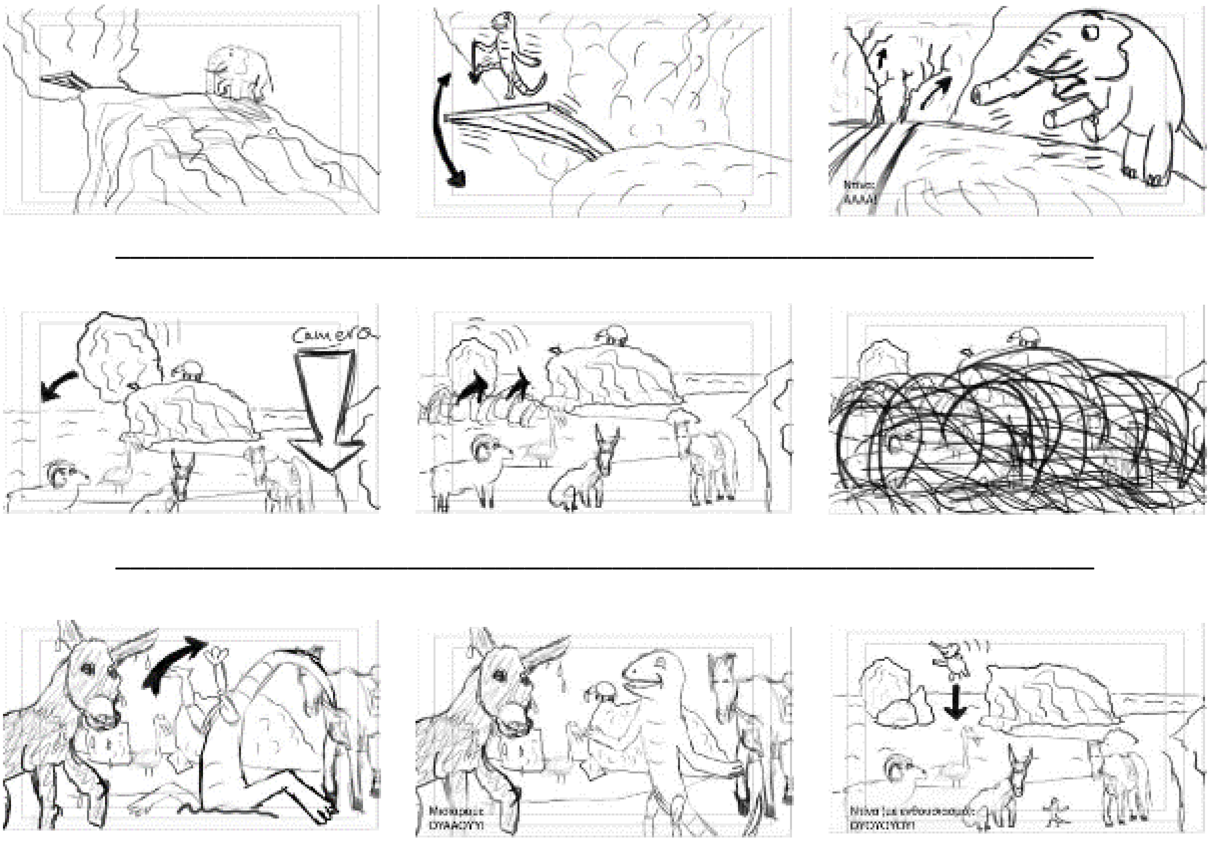
A different ground for deleting a scene could be the level of difficulty to create it. I deleted a scene in which a giant wave had to hit the beach making several characters wet.

The water effects would have required considerable effort to realise. I would have proceeded making the scene if it had a deeper purpose beyond comic relief. Hence, I could not justify the additional cost for making a scene that was not essential.

The following relevant example indicates that the cost of a film can be lowered by identifying demanding shots and by questioning their necessity. The process, of looking for alternatives may result in making an equally interesting film more economically.

This indirect way for increasing production efficiency focuses on avoiding costly scenes. The horse races had a significantly larger cost to set up compared to the abandoned plan of making the big wave effect. However, the races were more economical because they had a duration of two minutes whereas the big wave would cover only a few seconds of film.

Concept art



Storyboard frames of a deleted scene

The underlying comical message of the deleted scene was a fictional explanation of how the rock formation of Petra tou Romiou came to be which was irrelevant to the issues the protagonist faced.

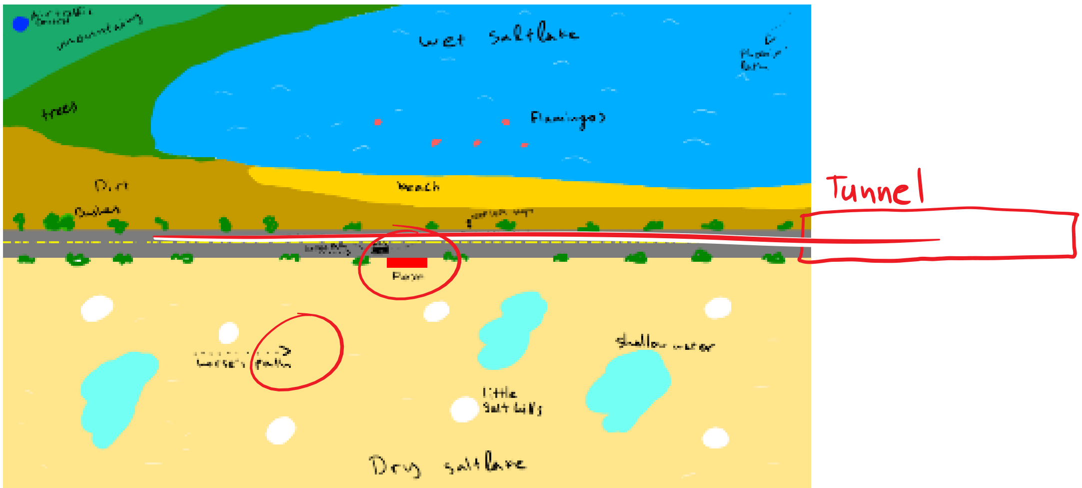
Agrinoui Stage: Salt lake

The salt lake stage has three acting areas.

Screenshots of the three scenes that take place on the stage and time (min:sec) in film.

The walk: 2:13 to 3:23 | Bus stop: 3:24 to 5:00 | Bus ride: 5:01 to 6:11

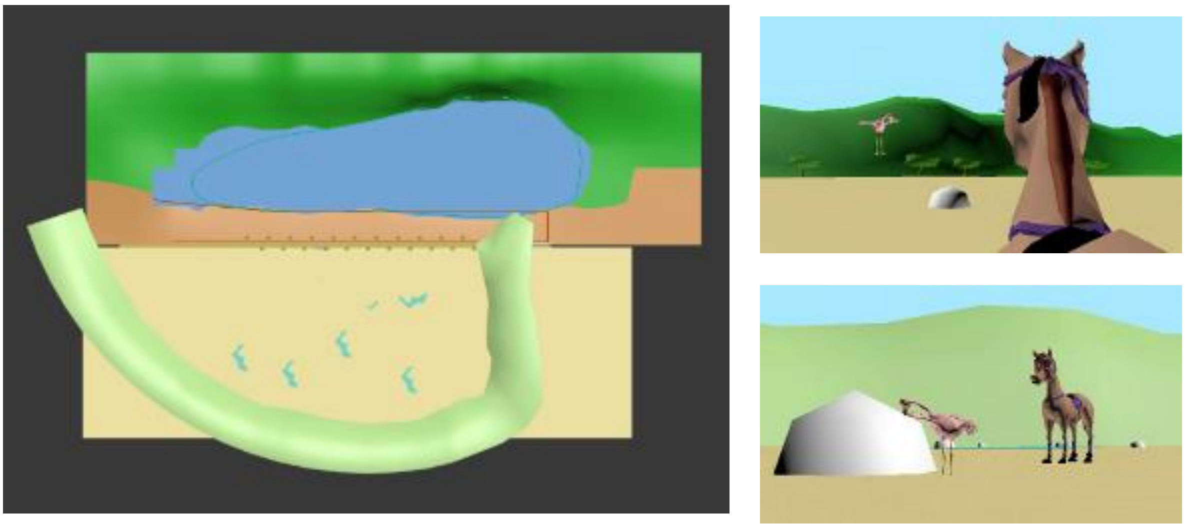
The storyboard provided awareness about the types of shots needed for the three scenes. With this knowledge I drew a top view of the stage that combined the environments of a dry lake and a wet lake which were separated by a straight road that had a bus stop and a tunnel.



The Top view concept drawing preceded making the 3D previs (red lines indicate acting spaces)

The salt lake stage hosted 3 distinct but consecutive scenes in the film. As such, the four-minute timeline of the stage project file enabled displaying the shots in the order they appear in the film.

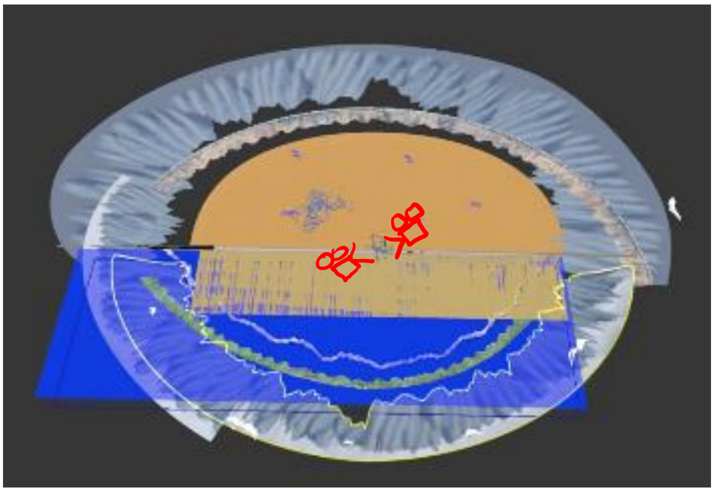
The concept top view drawing lacks the surrounding mountains as it focuses on the position of acting spaces and key terrain elements.



Top view of stage in previs and screenshots from a camera pointed in different directions

During the making of the 3D previs I blocked out the two sections of surrounding mountains with different approaches. A single-piece terrain surface under the wet lake extended towards the horizon where it formed the shapes of mountains. Whereas the dry lake had a separate surface that intersects the flat ground acting as a façade of a mountain range indicated in light green. After considering both options I chose to encircle the stage with separate mountain objects.

I imported the rows of mountains from the racetrack stages and altered their height and colour. The mountains over the dry lake were lower than those behind the wet lake. The repurposing and differentiation of the 3D assets saved production resources as it reduced modelling work.



Birds eye view of stage as seen through a real-time 3D viewport

The inherent forced perspective and atmospheric perspective of the mountains enabled the stage to look spacious within a limited area. The seemingly vast dry lake enhanced the feeling of loneliness for the main character.

Reverse angle shots at the bus stop show both sides of the road

The coexistence of the three stage areas was necessary for the bus stop scene which is situated near the road in the middle of the stage and features the camera being directed towards both the dry and the wet lakes. However, some scenes needed to display a limited part of the scenery. When the camera enters the road tunnel for approximately ten seconds, the salt lake did not need to be visible. Most 3D programmes enable temporarily hiding groups of objects. Hiding the objects outside the tunnel made certain computational tasks quicker. Similarly, the walking scene was limited to the dry lake area. As such, the road, the wet lake, and the tunnel did not need to be visible during that scene.

The process of placing the four-minute voice track on the animation timeline of the stage took place once. If I had worked on the 3 environments with separate project files it would have taken more time to prepare the additional audio tracks and to ensure they are synchronised across the video editing, the character animation, and the stage project files.

A long journey on a short road

To make the bus travel a longer distance than the length of the road on the stage, I made it repeatedly pass from the same areas.

I repositioned the bus to the beginning of the route after each cut transition during the dialogue scene on the bus.

The image explains how the bus covered a longer distance than the length of the road

When the camera comes close the edge of the stage, it approaches the mountains which have an unnaturally small scale due to forced perspective. Seeing the mountains from a short distance had to be avoided due to the introduction of distortions in perspective.

Localised detail for close-up shots and less detail for wide shots

Two similar looking objects that are shown from different distances may need different amounts of detail (see chapter 2, page 57).

The surface of the salt lake contains a patch with detailed relief which was positioned underneath the characters. The terrain that extends beyond the acting space is a horizontal plane. Similarly the hill of salt within the acting area contains more geometry compared to the similar looking hills in the background. Another relevant example is found on the pavement that has a portion with dense geometry just for the areas that are approached by the camera. The more distant tiles were once again flat and their rough appearance relied on textures.

> *Technical note: Normal and bump maps affect how light reacts to surfaces and provide the impression of low relief without displacing geometry.*

The reflective wet lake seen from above is a flat shape that is positioned approximately one centimetre above the ground. The practice of creating an impression of volume with planes was especially popular in the first 3D games because of the low amount of geometry that required reduced computational power to be displayed (see chapter 2, page 46).

Screenshots from Agrinoui (2015)

The Screenshots in the left feature large flat ground surfaces whereas the low relief in the right-side images is made with displaced geometric deformations.

Dynamic floor of dry lake - High level of detail near a moving camera

Screenshot of backward tracking shot with detailed ground

A square section of ground surface with detailed geometric relief is present in the pictured dialogue scene, and covers more than the width of the frame but drops off after a few meters in front of the camera. In the screenshot, the low resolution flat ground starts approximately at the heap of salt and extends towards the horizon.

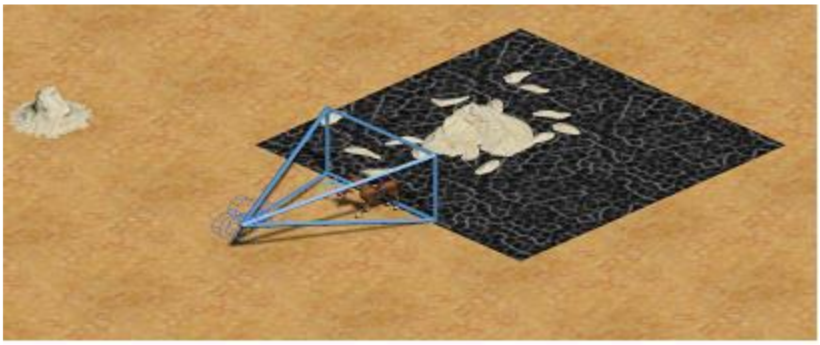
The ground section with geometrical relief is positioned a few millimetres above the low LOD plane that extends towards the horizon. The tiled textures of both surfaces are aligned, therefore, the edge of the detailed object provides a seamless connection with the low resolution ground.

Two characters cover a significant distance as they walk on the dry lake. The backward motion of the camera revealed a large area of ground that would have required a large amount of geometry if it had geometric relief.

I developed a system that enabled the detailed patch to follow the camera during the long tracking motion. The aim was to continually have the detailed object be within the bottom of the frame as that part of the ground was closest to the camera.

The detailed patch was tileable which meant that it was possible to position two of these objects side by side without having a noticeable seam. Instead of covering a large area with multiple copies of the object, I instantaneously repositioned the patch at key moments during the motion of the camera over the salt flats. Each new position of the patch was aligned with the tile pattern of the underlying low resolution ground.

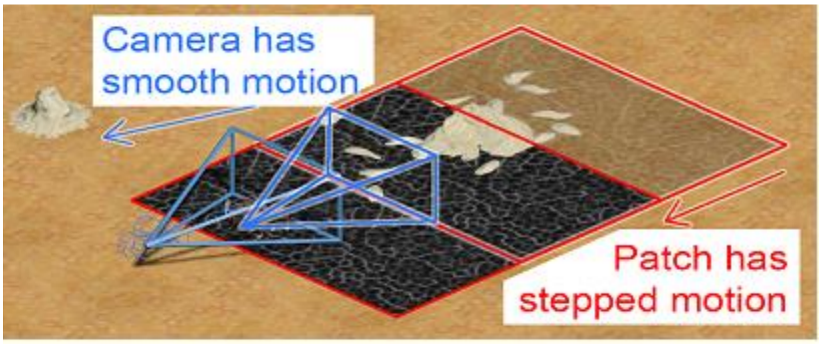
The system enabled giving the appearance of a large area having a detailed surface by repeatedly showing a small sized ground object. If I had covered the entire acting space with the relief surface, the excessive amounts of geometry would have added a computational load that could have had a negative impact on productivity if the computer became less responsive.



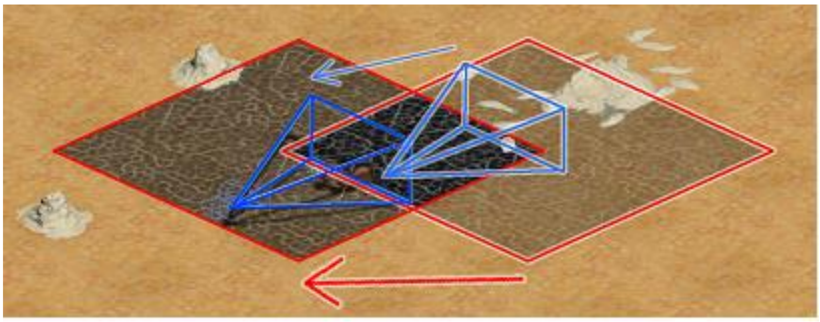
Bird’s eye view of the area where the camera follows two walking characters

The blue pyramidal shape corresponds to the field of view of the camera, and indicates that the high LOD ground patch, indicated in black covers the lower edge of the frame.

As the camera moves backwards, and the ground with low LOD is about to enter the frame, the patch snaps into a new position under the camera.



The detailed patch of ground follows the motion of the camera



The patch is repositioned in diagonal and vertical directions as the camera moves steadily

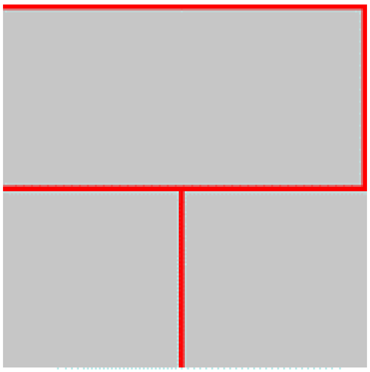
The trajectory of the camera did not have to be aligned with the motion of the patch. Although the patch has to be moved at distances that are equal to the length of the tileable pattern, it can be moved vertically diagonally and horizontally. As such, the system enables the camera to move in any direction.

The instantaneous repositioning of the patch does not produce distracting flickering and provides a constant appearance of detailed ground throughout the shot. The High LOD surface has rough protrusions that near the edges gradually diminish. The seam where the edges of the square meet the large ground surface is indiscernible because both surfaces are flat at that area.

Object repositioning system with aligned tiling explained

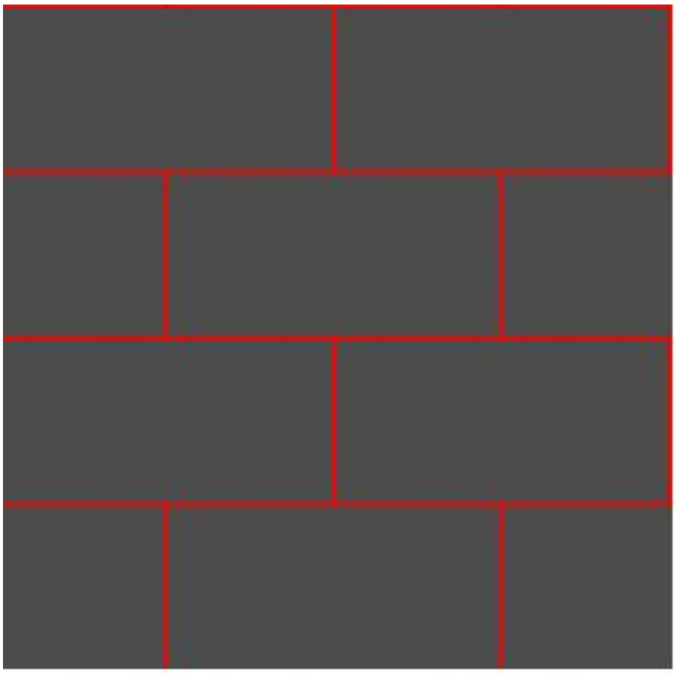
A floor that is covered with square ceramic tiles can be replicated with computer graphics by repetition of one tile multiple times. Tileable objects can offer enhanced production efficiency as only a fraction of a large object needs to be made.

The following square image can offer the repeating brick wall pattern.



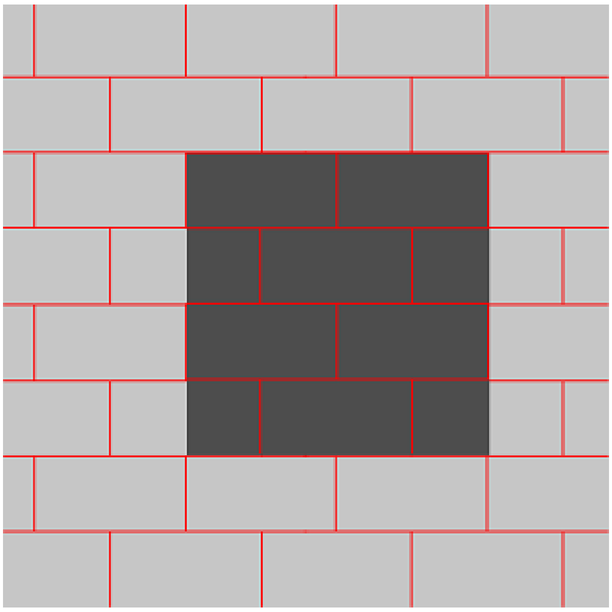
Tileable map

Four copies of the image map set next to each other produce the following image.

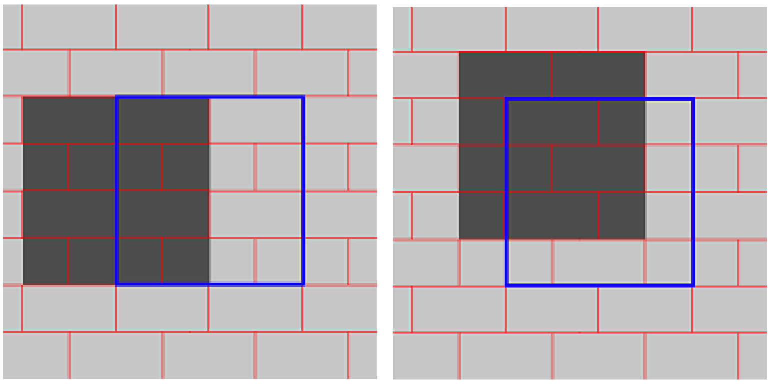


Map repeated twice horizontally and vertically

The 2x2 image map [dark square] represents the high-LOD embossed object which is laid over a separate larger low LOD flat surface [indicated with light gray]. The low resolution object would appear indiscernible from the small object from a certain distance because the textures share the same alignment.



The dark grey square represents the detailed ground patch on the saltlake.
Light gray areas represent ground with low LOD



The high LOD square can move in increments vertically and diagonally

The overlapping repositioning choices for the patch in eight directions enable it to be constantly under freely moving characters that are followed by a travelling camera.

How much the camera can come close to the ground depends on the amount of detail in the high LOD surface. As the camera gains altitude all four edges of the patch come into the field of view. However, at this distance, the surface with low LOD has enough detail to display the ground with the identical quality of the detailed patch.

Appointing a size for the width of the detailed patch primarily depends on ensuring that its edges will not be noticeable when they enter the sides of the field of view. Having a shallow depth of field enables reducing the length of the patch as geometrical relief is redundant beyond a certain distance where the far edge would appear blurry.

Agrinoui Stage: Mountain Roads with coastline

Introduction

The stage with the winding roads takes a large amount of space as it needed to host several road trip scenes. A technical challenge that arose during development and preproduction was to design a stage capable of displaying multiple landscapes while keeping the computational demands at levels that would not impede productivity.

Prior to designing the stage with transforming landscapes, I had already developed several optimisation systems that concerned the repositioning of scenic elements during animation sequences. Such dynamic systems include the trees on the racetrack that reappeared in different areas, and the patch of ground on the salt lake that followed a moving camera to provide a detailed foreground.

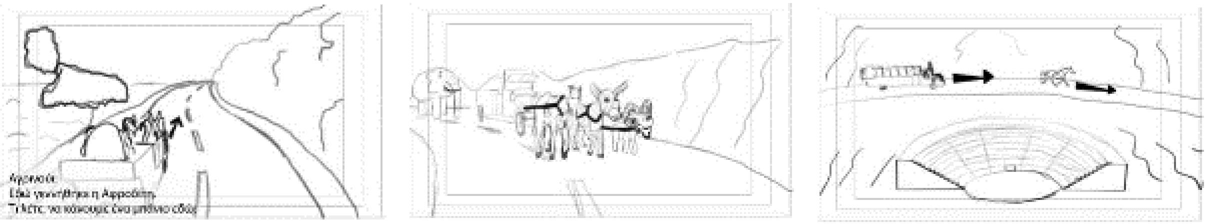
The mountain-roads stage served as a platform for further exploring practical applications for dynamic scenic elements. The stage enabled following the action in several bus journeys on a winding road which follows a coastline and enters a region surrounded by mountains.

The screenshots indicate the diversity in terrain views from one stage

The polymorphic stage makes use of known modular design principles (see chapter 2, page 55) as a basis for a system that enables managing dynamic scenic elements. A system of moveable mountain surfaces enabled making several arrangements that provided the appearance of different landscapes. The form of the set changes at key points of the timeline to enable framing establishing shots, and covering travelling scenes with dialogues.

The reuse of scenic elements enabled the transformable stage to have a relatively low total amount of geometry.

Development and preproduction



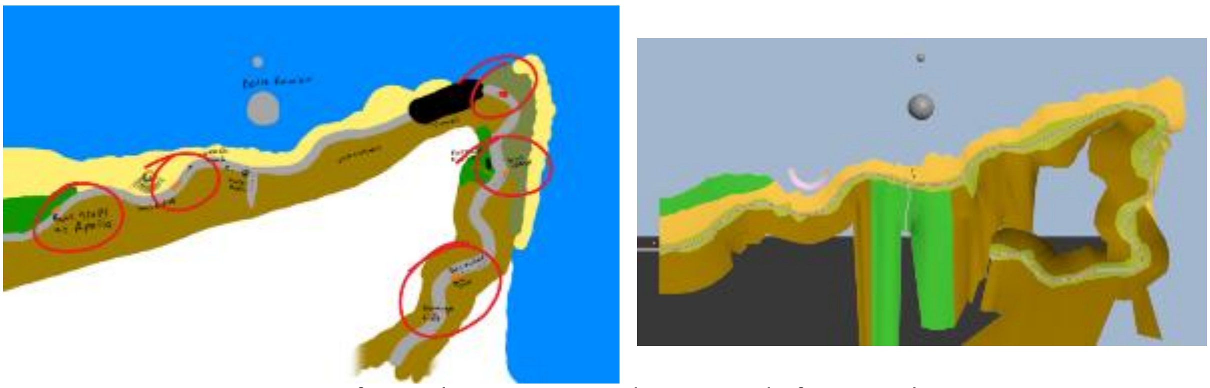
The storyboard frames indicate the locations that are visited during the road trip

I drew storyboard scenes of the road trips without knowing whether the inclusion of all the featured environments on one stage would lead to improved productivity.

It was not crucial for the production to contain all the vistas on one stage as I could have addressed the needs of each environment with separate 3D project files. However, the fact that the environments shared a common theme was a decisive factor for pursuing the idea of including multiple locations on one stage.

Concept art provided a visual guideline. The 3D previs contained a rough shape of the stage

3D previsualisation provided the positioning guidelines for the production phase as the blocked out layout was used for overlaying the high quality scenic elements and animated characters. The scenes that take place on the winding road, amount to two minutes and forty seconds of the film.



Top views of stage layout concept drawing and of previsualisation

The top view stage concept drawing indicates, in red, the locations where different actions occur. The 2D shape of the road was transferred into the 3D previsualisation file. I proceeded with forming a rough draft stage where I specified the elevation of the road in relation to the mountains, and the sea level.

Screenshots from previsualisation and film

The images indicate how the shape of the stage and the positioning of viewpoints in the previs were transferred in the production phase where the low geometry terrain model was replaced by more detailed shapes and the framing refined.

The challenges

I had to create multiple environments on one stage that would appear dissimilar despite having a common theme of mountains and shorelines. Also, the produced images had to have a consistent image quality with the rest of the film. Finally, the stage should provide a productive workflow within the same computational envelope available for the rest of the film.

I had to develop dynamic modular systems that enabled making visually diverse terrains with a limited amount of scenic objects. The objective was to create the impression of a landscape from the camera's point of view without aiming to create a physically correct topography.

One workstation had to promptly handle everyday tasks such as loading, saving and navigating through the stage in real-time 3D. The rendering process on one PC took approximately two minutes per frame with high quality settings and thirty seconds with draft quality.

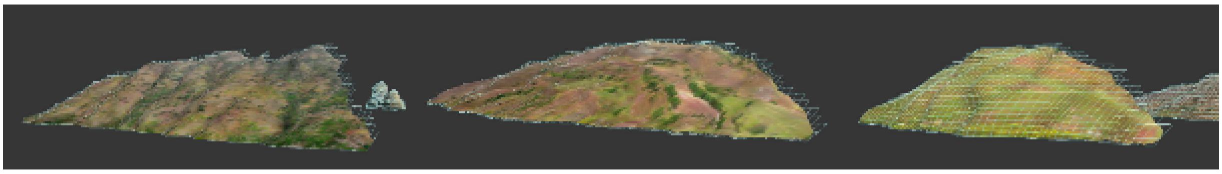
A provision was in place to enable splitting the stage into four parts if the stage became too computationally demanding. Ultimately, the stage remained undivided as the optimisation measures enabled having a productive workflow as well outputting sequences that consistently met the intended level of visual quality.

Polymorphic stage design

The mountain roads stage has a winding road with a fixed shape that passes through mountainous landscapes that alter in appearance between scenes and for special compositional needs of individual shots.

The design process which I call polymorphic stage design makes use of scenic module repositioning to dramatically transform the areas that surround the acting space.

This type of stage uses object repositioning not only for computational optimisation as seen in cases such as the racetrack (see chapter 4, page 158), but also as a means to alter the composition of viewpoints. The diverse landscapes that surround the acting areas were made by rearranging modular elements that depict hills and mountains.



Samples of mountain modules in the asset library

The mountainsides comprise of independent low poly relief surfaces that can be seen from limited angles. The 3D surfaces comprise of a low polygon count that vaguely resemble the shapes of mountainsides without having assigned materials. The 3D shapes obtained a suitable mountainlike appearance with the use of texture maps responsible for the detailed colours and bumps, as well as for the masked outlines that define the ridges. The flat edge at the bottom of the modules enables them to be perfectly aligned with the flat stage floor.

For the texture maps I captured photos of mountains which vary in shape, size and surface material from different distances. The photos were then digitally processed to create diffuse, opacity, and bump maps that provided colour, outlines, and roughness respectively.

Screenshots from Agrinoui (2015) indicating the reuse of a mountainside module

Although mountain modules become part of different landscapes, it is difficult for the viewer to notice the repeated use. Each landscape comprises of a different arrangement of overlapping objects that create unique mountain ridges.

The modules do not contain shapes or colours that stand out so as to avoid creating recognisable patterns. Distinctive landmarks such as a red tower or a steep ravine would confuse the viewer if they were shown in separate locations.

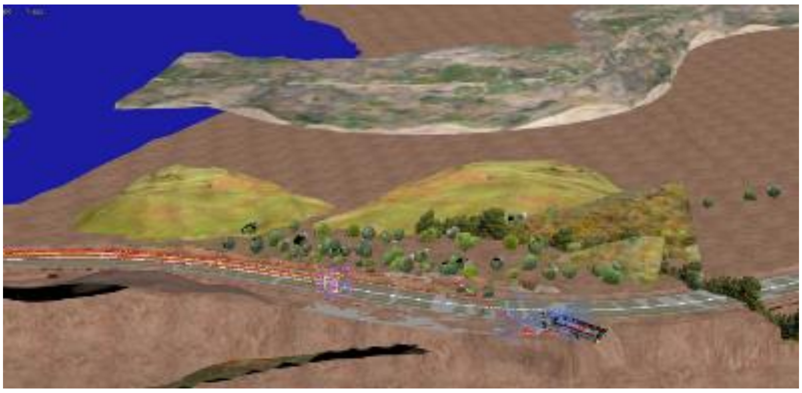
The face of each mountain module was deformed with a push-pull paint modelling process that creates indentations in areas indicated with the pointing device. These indentations create shaded areas depending on the position of the light source. A mountainside, such as the one pictured above, that is featured in two locations can appear to be different if the digital sun illuminates it from different directions as the shadows will be differently shaped. Another factor that diversifies the appearance of a mountainside is how it faces the camera. A slight rotation so that the mountain does not directly face the camera or a tilt would create a different ridge shape in the frame.

The ability to show the same mountain surfaces in separate locations resulted a reduced modelling workload. Another advantage of the lowered number of objects on stage, was the responsive real-time 3D viewports which enabled having all the scenic objects visible while scrolling through the whole timeline.

The camera view was essential for assembling a landscape out of modules. The choice for positioning hills and mountains was made by seeing how the modules occupy space within the 2D film frame. The objective was to make environments that appear correctly from specific points of view, rather than have a physically correct terrain. The bird's eye view of the stage is indicative of how the illusion falls apart when the camera moves outside its designated area.

Rejected mountain composition

Revised composition



Viewport displaying the stage area where the vehicle went off road

The light green hills in the centre of the viewport are mirrored duplicate objects. By flipping one hill horizontally, a longer homogeneous ground formation was made that has less noticeable repeating patterns. The same mountain modules were repositioned elsewhere as part of another landscape.

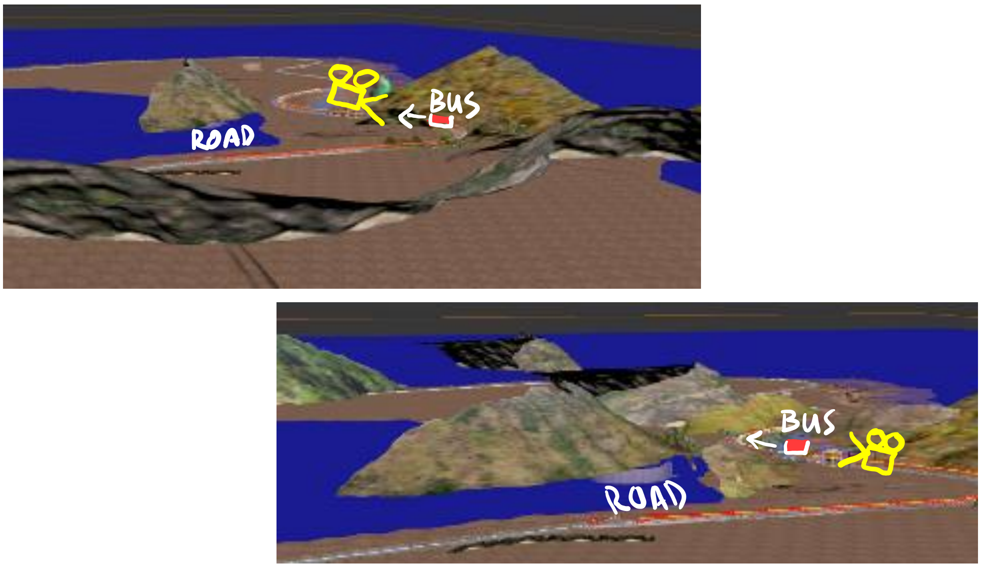
Light green hills reappear in the scene with the roadtrip to the temple of Apollo

Stage development

The bendy road consisted of a horizontal flat surface with an asphalt material that was placed over a flat ground with a soil texture. The appearance of supposed slopes comes from actions such as having a vehicle with a loose handbrake roll downhill. The flatness at the side of the road was disguised by overlaying plants and rough surfaces of dirt. From a technical standpoint, flat surfaces compared to hilly terrains require less geometry and simplify the animation process due to aligning animated objects with one common ground altitude.

Preview images of two consecutive shots during stage development

Respective images of evolved stage (film screenshots)



Birds eye views of the stage corresponding to the left and right screenshots (above)

I progressively added detail on the blocked out layout from the previs starting by creating the immovable stage elements of the coastline and the road.

I made and stored the models of mountain sides in a separate 3D asset library project file which provided organised access to scenic objects (see chapter 4, page 179). Then I imported the mountain modules and arranged them to create the environment for the first road trip.

The above screenshots are indicative of the iterative design process during which observation of rendered preview images enabled determining corrective actions. When I started arranging the mountains for the scene where the bus rolls downhill, it became evident that more modules were required to adequately diversify the appearance of the landscape in relation other to road locations. The film screenshots indicate how the morphology was altered after the observation of the preview images prompted me to add more mountain modules.

The viewport images of the stage indicate how the mountain objects instantaneously changed position between the two consecutive shots to form different background compositions. The data concerning the positioning of scenic objects is stored in keyframes with stepped tangents. The time-based dynamic system uses the timeline to apply different stage forms at specified points in time.

In the first viewport image, the camera is targeted in towards the right side of the stage to frame the landscape in that direction. In the second image, the mountains have been repositioned in the opposite direction so that they become visible in the reverse angle shot.

Once I had determined the positions of mountains, I placed smaller objects such as trees and rocks at the side of the road which add detail and hide the flatness of the terrain. Review cycles enabled trying out different mountain arrangements and to refine the lighting.

Repositioning and rescaling of rocks

Reference photo: Petra tou Romiou, Cyprus

I captured a photo of a landmark with a rock formation and used it to create texture maps.

Texture colour (diffuse map with transparency)

Although the rocks depicted a known landmark in the film, the rocks were shown on several other occasions in the film.

Screenshots of scenes that feature repositioned rocks

These images indicate the rock modules being shown in several locations with diversified positions and scale. At scenes where the rocks appear at the side of the road their size is approximately one tenth that of what they have near the coast line. The choice to reduce rock sizes was made after testing to ensure that the rocks would have a fitting appearance as an unrealistic scale can make objects seem unnatural (see chapter 2, page 58).

The first sea stack resembles the Petra tou Romiou landmark primarily because of the matching rock formation. However the rocks become unfamiliar when the deconstructed modules have significantly differentiated layouts.

Ribbons with tillable maps

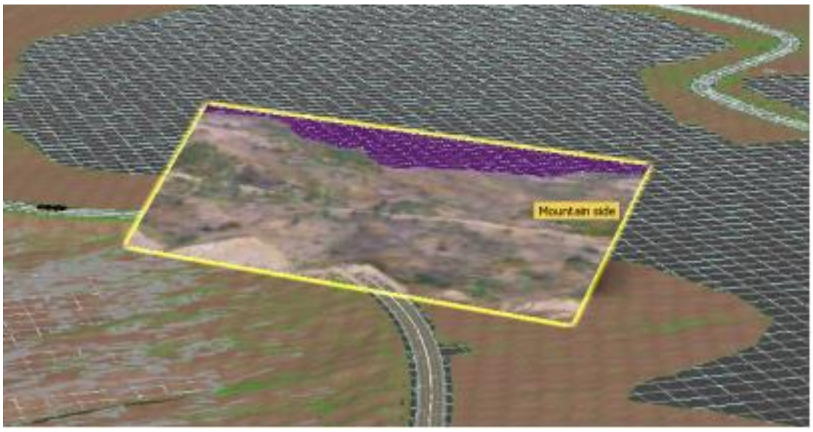
The road traveling scenes needed long stretches of hills next to the road. I started making this object by preparing a texture. I used the following photo as reference which I had captured in 2006 for my collection of images and textures.

Reference photo: Alona, Cyprus

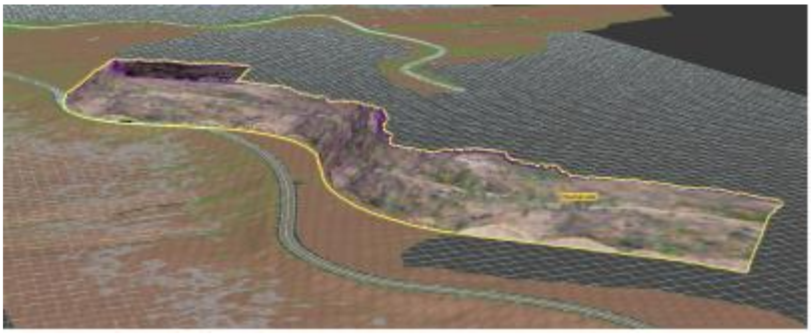
By positioning myself at an elevated position, the mountain surface is almost perpendicular to the camera. By having the sun behind me the mountainside does not have shadows that emphasize terrain protrusions. The shadows on the digital 3D surface were created by the relief and the 3D lighting system.

The road builders had carved chunks of rock out of the mountain, creating triangular features.

Tileable texture map



Texture assigned to inclined plane



3D viewport displaying the ribbon next to the road

I digitally sculpted indentations on the surface including the triangular sidehill cuts. When I elongated the relief surface, multiple horizontal repetitions of the seamless texture covered the ribbon. I applied bends to the hillside to suit the shape of the road.

Variations of elongated surfaces can be seen on the racetrack stage (see page 151) which contains bent strips of mountains in the background; on the jungle stage (see page 131) which contains ribbons that resemble vegetation spanning the length of a path; and on the flight stage where the ribbons of trees (see page 120) enabled the camera to follow the action over considerable distances.

Such ribbons can fill long stretches of background with few objects that require limited computational resources.

Film screenshots featuring the ribbon

Multiple surfaces setup

Several layouts have been presented in this project that feature rows of surfaces that are perpendicular to the point of view.

The following mountain setup is a variation of the pyramidal setup of multiple planes that was part of the “Book” stage in Struthio (2011) (see chapter 4, pp 106-107).

Film screenshot

Alternatively, since the camera did not need to perform large movements, the distant mountain range in the screenshot could have been made with a flat backdrop image (see chapter 2, page 32).

I made a multiple surface system that was economically made. The process involved deconstructing a landscape image into separate mountain elements which were applied on 3D surfaces to make individual mountainsides that were positioned at different distances from the camera.

The system provided motion parallax to shots with a moving camera and the stereoscopic 3D view of this location creates further separation of distant objects.

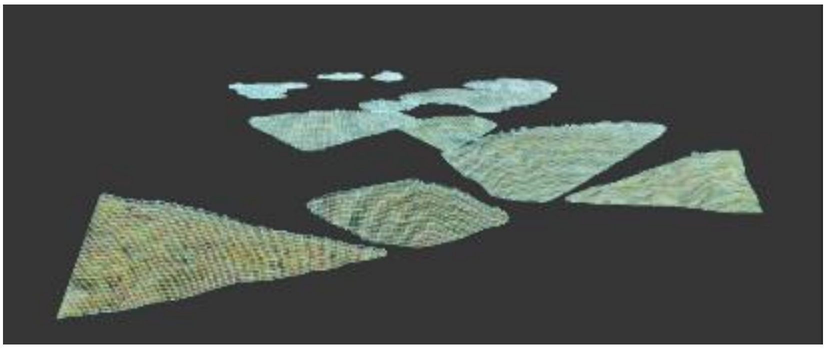
> *Note: Having objects at different distances from the camera enables adjusting the depth of field and applying volumetric effects such as fog. Furthermore, action can be placed between mountains such as that of flying birds.*

In 2010 I had captured a wide high-resolution photo of a hilly terrain which I saved in my collection of images and textures.

Panoramic stitched photo of mountains in Neos Voutzas, Attica Greece

Diffuse texture map (blue areas indicate transparency)

I deconstructed the image by spreading out the hillsides and leaving some space between them. The shape of the mask created the appearance of detailed ridges. The inclusion of several mountains within one texture map simplified keeping track of the layout as well as file management becaouse the diffuse map featured on one material that was assigned to all the 3D objects shown in the following image.

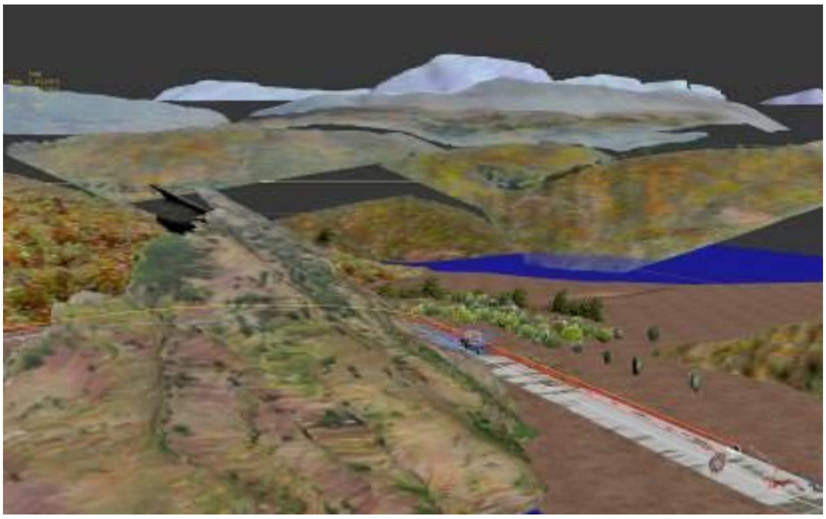


3D Viewport: Bird's-eye view of system in asset library

Each slanted hillside element was positioned at different distances from the camera. When the camera is within permissible limits and at a low altitude, the shapes of the modules appear to fit together and without any visible gaps.

3D Viewport: Low view of system

The 3D mountain view appears to have the same layout as the diffuse texture map in the front view. I made the pieces overlap slightly, in the front view, so as to enable limited camera movements at low heights.



3D Viewport displaying the system on the stage

The system with multiple illustrated planes in the “book” stage (see chapter 4, pp 106-107) was different in that the vertical planes made it difficult to integrate standing characters. It would also be difficult to create a matching 3D terrain because of the need to replicate the style of the planes which included fixed painted shadows. Moreover, the pyramidal system took considerably more time for painting the separate layers compared to the relief surfaces in the Mountain Roads stage which all rely on a single diffuse map.

The 3D mountain modules visually blend with the horizontal ground where the characters can walk. The style of the modules was compatible with other stage elements because of the general use of relief surfaces that had materials with matching shaders and textures, and because of a lighting rig that simultaneously affected the mountains and foreground objects.

A similarity between the system featuring planes and the one with relief mountain surfaces is that the texture colours of distant mountains create atmospheric perspective (see chapter 2, page 32). Moreover, the smaller scale of distant objects creates forced perspective (see chapter 2, page 36) that reduces the needed occupied space.

Both the pyramidal and the modular mountain systems provided motion parallax in shots with a moving camera. However, a difference between the two design approaches is that individual bent relief surfaces can appear to have volume as the camera moves.

Mountain modules create motion parallax effect in shot with pedestal camera movement

Shot with dolly camera movement

The reference photo was processed to extract the contained outline shapes of mountains. The photo also provided the colour scheme of harmoniously coexisting hillsides that included the effect of atmospheric perspective. Having the atmospheric perspective embedded within the texture, eliminated the need for volumetric fog simulation.

Dynamic system for high LOD roadside embankment

The uneven embankments at the sides of the roads are relief surfaces that are positioned near the camera. The stage would require a considerably large amount of computational resources if the entire length of the road was surrounded by such dense geometry.

I created strips of detailed roadside dirt that were dynamically repositioned within the field of view of separate shots.

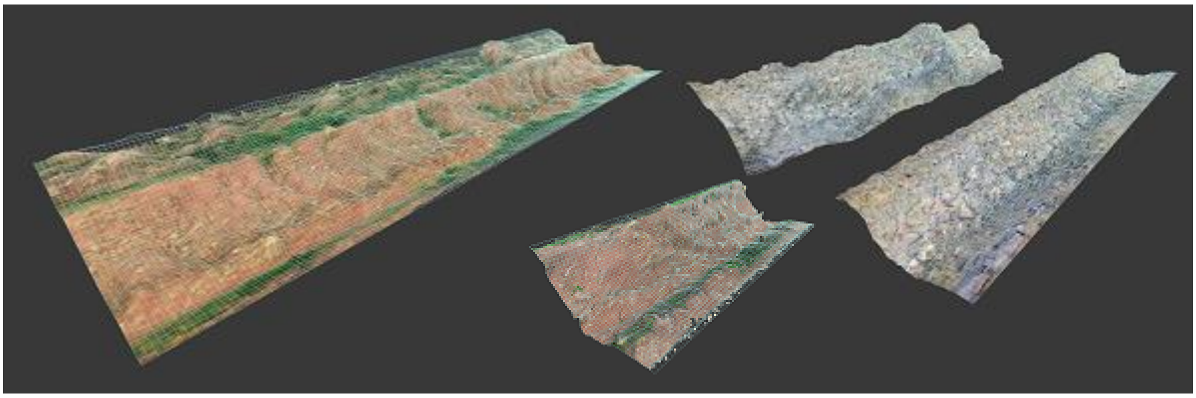
Film screenshot. Detailed roadside dirt

The strips were laid over the low level-of-detail fixed ground surface which formed the coastline and spanned the entire length of the road.

The strips of dirt had a tileable texture map which enabled the surface to be lengthened to cover a significant distance.

Horizontally tileable texture map

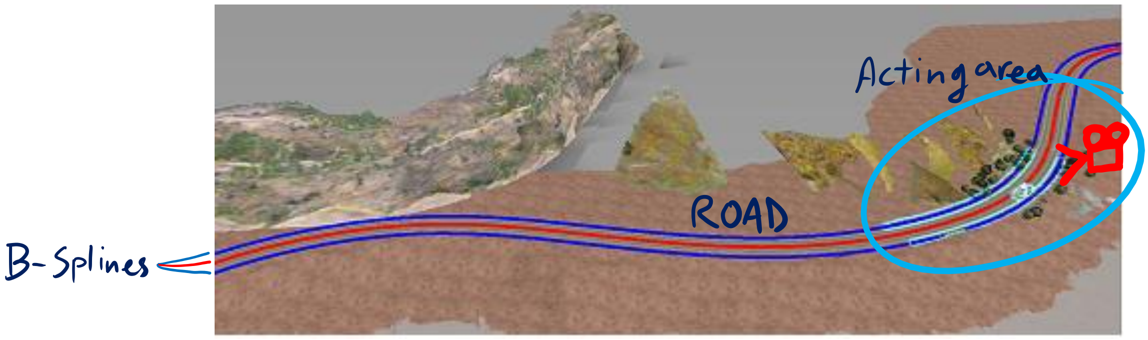
After applying the texture to a 3D surface I made indentations with the push-pull shaping technique to add roughness.



Images of tileable roadside strips in the asset library

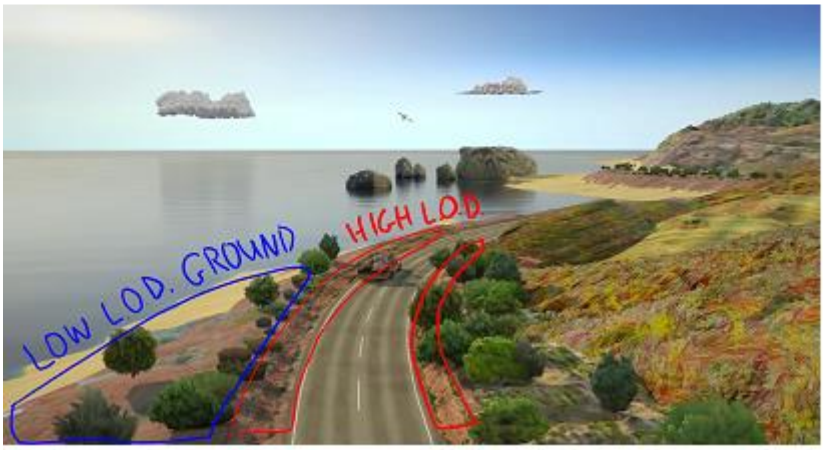
I created additional ground models with different materials for increased diversity.

The planar road has a constant width and was made with the lofting technique in which the tarmac follows the shape of a curved line (see red line in next image). The outline shape of the road (indicated in blue) was used for placing the strips of roadside ground which automatically followed the bends of the road.



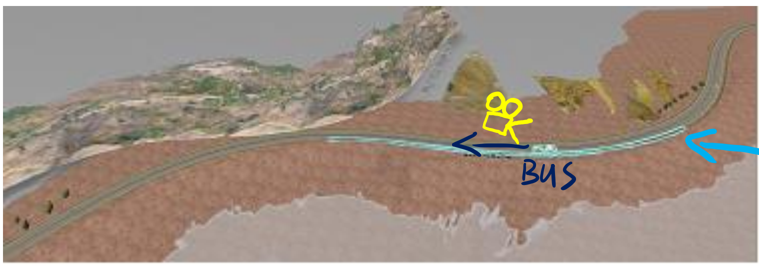
3D Viewport displaying the bus in the first shot of a trip

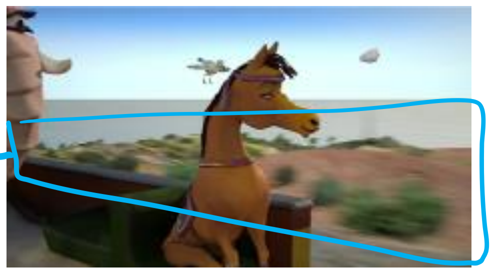
The sequence starts with an elevated view. For this shot I placed roadside embankments on both sides of the road. The viewport image is indicative of the stage layout featuring a concentration of elements within the field of view.



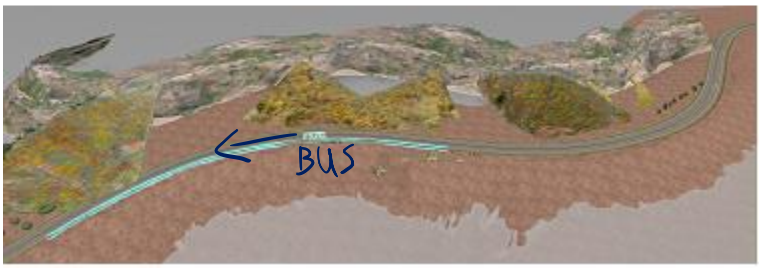
Film screenshot - Embankment strips indicated with red

The frame in the subsequent shots in the travel sequence contains only one side of the road. The strips of dirt are positioned on the visible side of the road. As the vehicle covers a significant distance, the roadside embankment is instantaneously repositioned further down the road.





Film screenshot



3D viewport displaying the repositioned embankment according to the position of the vehicle

Agrinoui Stage: Forest

Planning

The objective of this stage was to have a group of characters walk along a forest path.

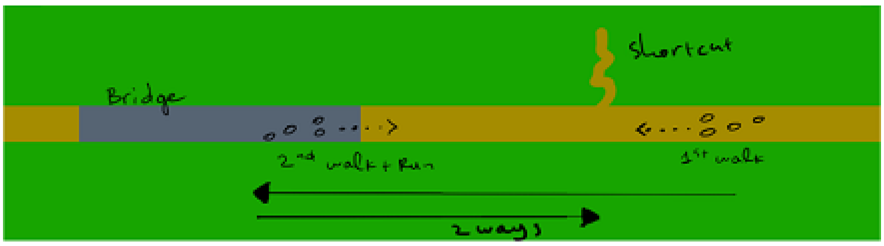
Agrinoui (2015) Storyboard frames

I took advantage of my prior experience from making a footpath for Struthio (2011) (see chapter 4, page 126). However, the newer stage had different needs and made use of dynamic stage elements.

Screenshots featuring a path from the jungle in Struthio (2011) and the forest in Agrinoui (2015)

The form of the Jungle stage remains static for the three scenes that take place there. The length of the path appears to be longer than the size of the stage because it is not obvious that the lead character passes from the same areas multiple times.

The making of the forest stage involved making top view drawings to define the shape of the stage and the choreography of the scene. The characters had to walk on a dirt path, then they had to cross over a Stonebridge and thereafter they needed to continue on the dirt path up to a junction.



Rejected top view forest stage concept

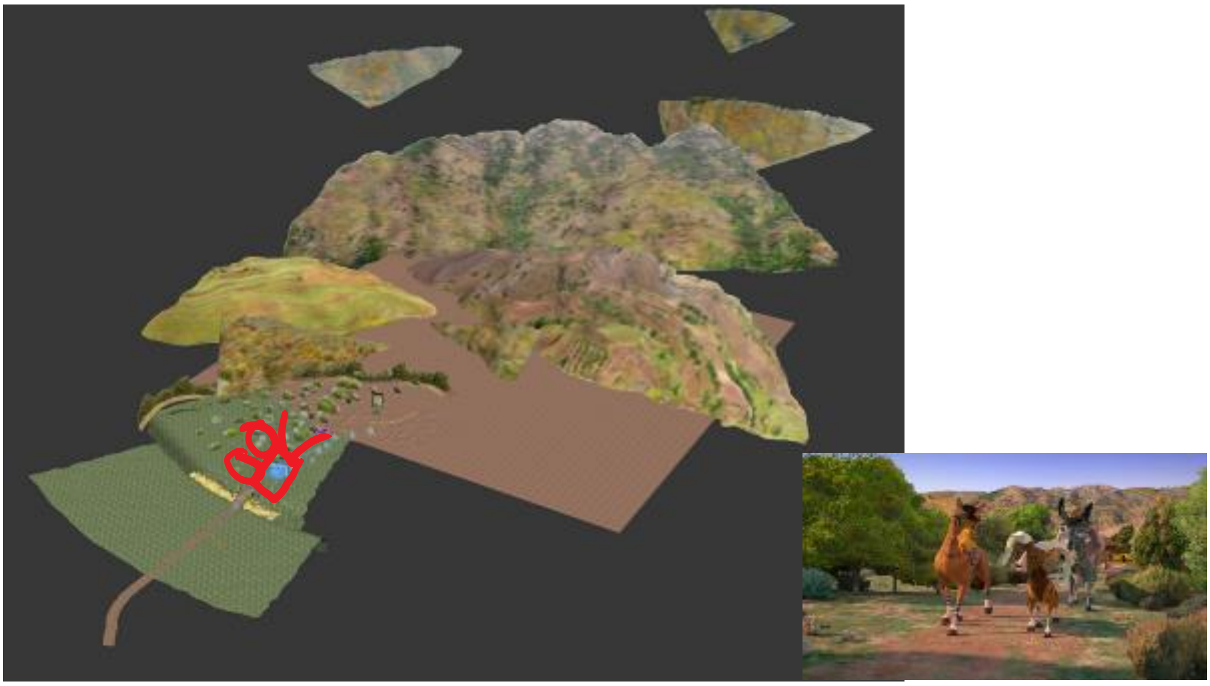
I initially contemplated making a short path that would have required travelling both ways to cover the walking distance shown in the forest scene. In this hypothetical scenario, the fists shot of the walk would be up to the bridge. The second section of the scene would be made by turning the characters around and walk towards the starting point. With appropriate lighting and camera positioning, the film would have given the impression that the group has not changed direction. The rationale of this type of stage is seen in Struthio (2011) and aims at making the most of stage with a limited size.

I had no need to limit the distance of the path as the size of the stage was far from reaching any technical limitations. Therefore, I decided to create the entire length of the path and to have the characters walk in one direction. A longer stage would have required more plants at each side of the path if the scenic objects were static. By adapting the tree repositioning system that was initially developed for the racetrack stage (see chapter 4, page 158), I managed to make the forest stage with a limited amount of objects.

Selected top view forest stage concept

The forest stage layout features an elongated path for a group of characters to continuously walk in the same direction.

Scenic object repositioning for pointing the camera in different directions



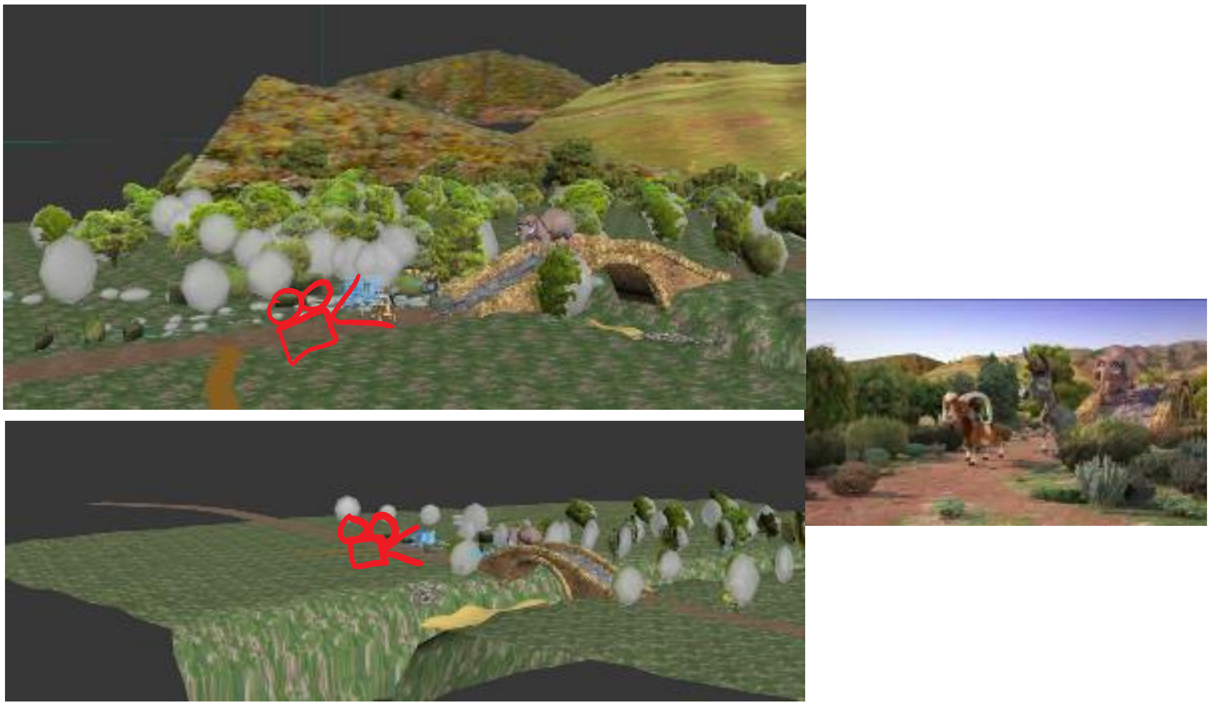
3D viewport: Stage form in first shot and film screenshot

Notice in the viewport how the moveable scenic elements such as mountains and trees are gathered in front of the camera.

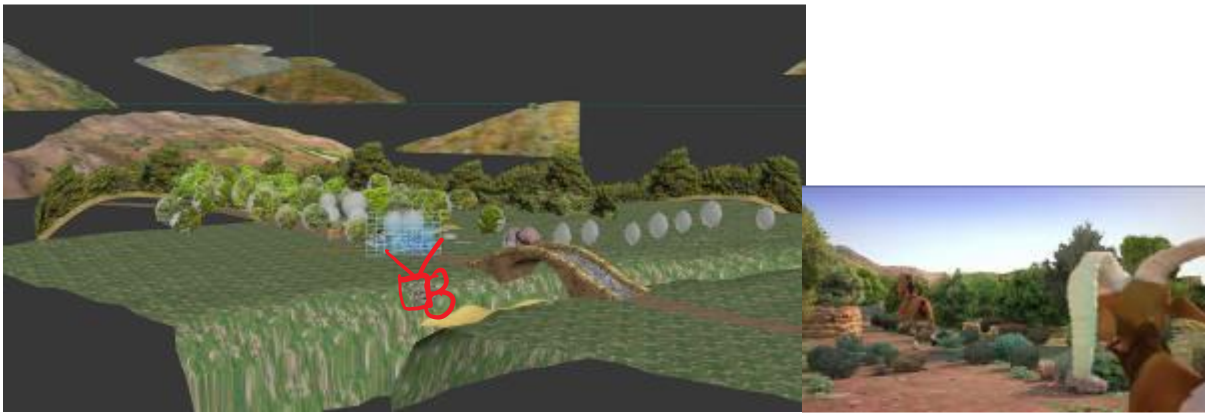
The dynamic stage elements are initially gathered on one side of the river and face the camera. When the characters walk on the bridge, the elements are repositioned to frame the shot of the river (see next image).

Stage view of form and corresponding shot of the river

When the characters reach the other side of the river two reverse angle shots of the path are shown:



The viewports show the positioning of objects and the corresponding view towards the bridge

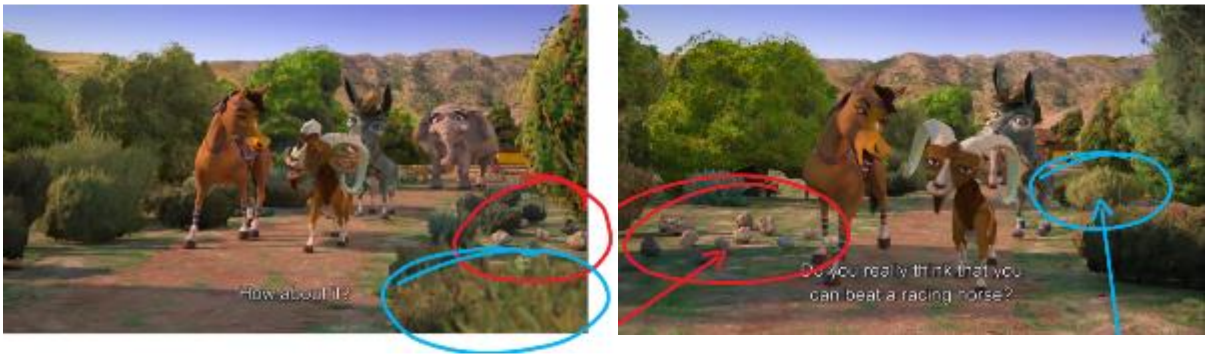


The dynamic elements are repositioned for the reverse angle shot

The viewport screen capture bellow shows how the trees and mountains are instantly repositioned on the other side of the bridge to frame the next shot.

Scenic object repositioning in continuous shot

The walk starts with a lengthy dolly out shot. As the camera recedes, the trees occupy less and less space in the frame as additional trees shrubs and rocks enter from the sides. Each time a large plant enters the frame, it obstructs the view of objects behind it. Objects that become out of sight are repositioned at the sides of the path behind the camera in order to reenter the frame as the camera continues moving backwards.



Film screenshots of dolly out camera motion. Time in film: 14:02 and 14:10

The stones, marked in red, were initially placed on the right side of the path. As the camera travelled backwards, the stones gradually became hidden behind the shrubs, marked in blue, in front of them. At that moment the stones were instantaneously repositioned next to the camera at the left side of the path and subsequently re-entered the frame as the camera continued its course.

This is a variation of dynamic systems that enable reducing the amount of geometry on stage that are presented in this project. This example demonstrated how object repositioning can be applied during a dolly out shot. Objects can be repositioned within other types of shots as well (see chapter 4, page 194-195).

Dynamic module assembly and deconstruction

At one point in the forest sequence, the characters cross a stone bridge which consists of an assembly of elements.

In the shots where the bridge is not within the frame, disassembled bridge parts can be seen scattered near the path as indistinct structures and ruins.

Film screenshot featuring the whole bridge at time 14:20 in Agrinoui (2015)

Screenshots displaying parts of the bridge at times 13:55 and 14:39

Marked in red are the stone modules that are instantly repositioned to form the bridge configuration during the river crossing. When the characters reach the other side of the river, the bridge is separated once more and its parts form structures that resemble wells, stone benches and ruined walls.

This example shows how elements of artificial structures can be reassembled to form different shapes. The subject of dynamic module assembly is found in other parts of this project where explanations can be found about the advantages of reducing the number of scenic objects (see chapter 4, pp 193-197).

Agrinoui Stage: Night at the beach

3D structures for wide shots

Frames from the storyboard and previsualisation featuring background buildings

The "Beach" stage was designed to create dialogue scenes in a relatively small acting space. The small camera motions did not create noticeable motion parallax within distant buildings. Although the buildings could have comprised of painted planes, I chose to create 3-dimentional objects.

I had the option to include moving crane shots in the film to present the 3D castle and lighthouse. However, as the purpose of the surroundings was to create an ambience, I did not want the audience to focus their attention on the buildings. Regardless of the shots that were included in the film, the review addresses the economical creation of a castle that can be shown with a dolly shot from limited angles with a LOD suitable for filling the frame with the object.

The Paphos castle - Vertical Images adapted to perspective

If we observed a box shaped corner building from the middle of a street intersection, we would notice only two primary vertical surfaces that intersect at a 90 degree angle within our field of view. To recreate that view with 3D graphics we would not have to make the sides of the building that are hidden from view.

To make such a scenic element efficiently, I was not concerned with surfaces, such as the roof and the backside walls, which are not visible to the camera.

The Paphos castle from different points of view and lighting conditions.

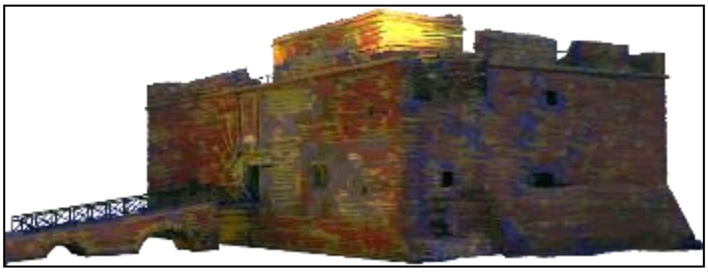
I captured the photos during separate visits between 2007 and 2010 for my photographic collection.

Before making the 3D shape, I studied the shape of the castle and how it appears under different lighting conditions and from different angles.

Prior to making the castle I had made several types of 3D models that comprised of single sided textured surfaces (see chapter 4, pp 151-154, and 178-180). The base photos of the diffuse texture maps of trees and mountainsides were generally captured under flat lighting conditions (see chapter 4, page 176) and relied on the lights in the 3D scene to obtain highlights and to cast shadows.

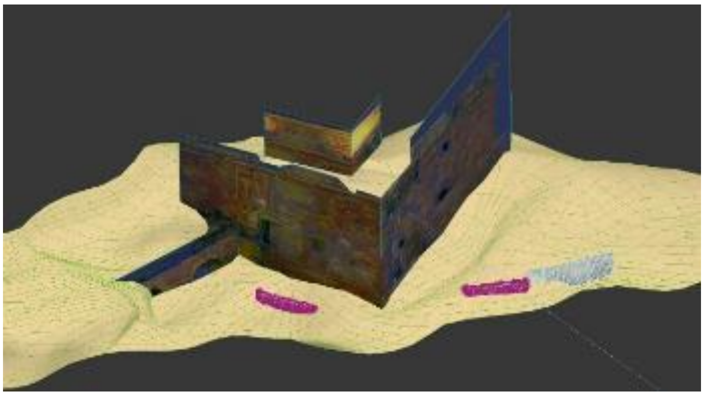
The base photo of the castle texture was captured when it was illuminated by artificial lights and the sky during twilight. The resulting diffuse texture had baked-in lights and shadows, and simplified the process of lighting the 3D scene.

One approach for making a 3D castle would have been to use two pictures displaying each of the adjacent walls head-on. The modelling process would have involved making separate texture maps of the two sides of the building which would then be applied on planes that form a corner edge. I shortened the creation time by using only one photo as a foundation (see first image above) in which the castle has 45-degree angle to the point of view.



Castle texture map with opacity mask that defines the outline

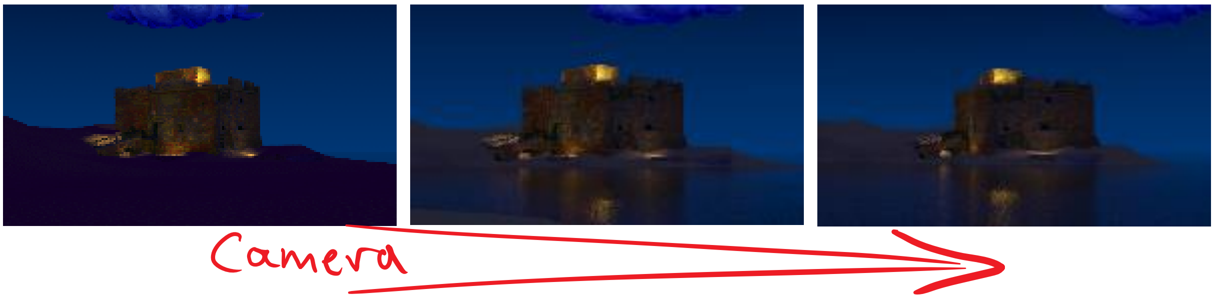
The intrinsic perspective in the picture was compatible with the view from the campfire area on the beach stage. Although the 3D shape of the castle consists of two cuboids and a bridge, only five planar surfaces are visible to the camera. The orientation of the planes corresponds to that of the actual castle.



Birds-eye view of the Castle scenic object

To make the sides of the large walls I applied the material with the diffuse map to a plane to which I made a crease at the corner where they intersect. Then I repeated the process for the walls on the upper floor level. The positioning of the surfaces involved making refined transformations to achieve a natural looking perspective from the intended viewing area.

The visual inspection of rendered images showed that the textured planes contained adequate detail for filling the frame with the castle and for performing trucking shot at a low height.



The perspective castle looks natural throughout the left to right trucking shot.
The shot was not used in Agrinoui (2015).

This modelling method can be applied for making different types of cuboid structures, and if it is lit from behind by a digital sunlight, it can cast shadows with a realistic shape on the ground. If the light was shining on the castle from the side, the shape of the shadow on the ground would not correspond to the depicted building due to the lack of a terrace to block the light. To fix the problem I would add a box in the area occupied by the castle with roughly the size of the structure. Although the box would be unrenderable, its render settings would make it able to cast shadows. Shadow casting objects were used for enlarging the shadows of hollow trees (see chapter 4, page 153).

In a daylight scene or with a closer view the castle we would probably need to add details such as geometric indentations for windows and doors. The recessed features would have provided improved perspective and shadows in such areas.

Most single sided objects in Agrinoui (2015) have a surface that needs to face the camera at approximately less than 20 degree angles. The castle is different in that it provides a wider area for the camera to move horizontally, and because of creating notable motion parallax. The practice of keeping the perspective of 3D buildings appear correctly during truck shots is not new (see chapter 2, page 38).

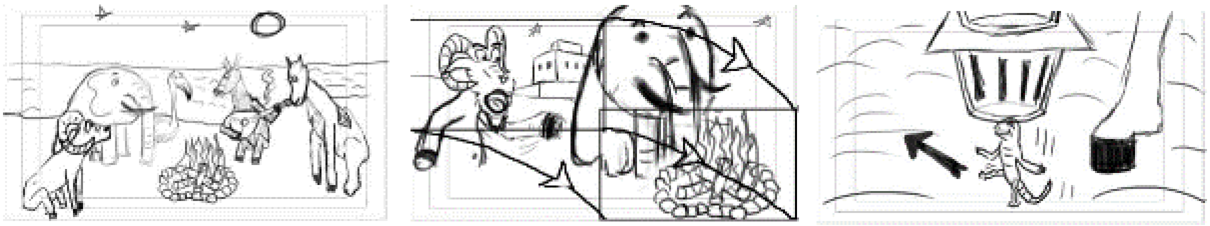
Compared to the use of a textured plane, the 3D castle can host volumetric effects such as a fire between two walls on the terrace. Moreover, a 3D castle can be better presented with stereo imaging. A 2D castle object would have limitations such as the inability to focus the lens on the terrace room with intention to cause focus blur on the walls in front of it.

The process of making of 3D models of popular structures entails measuring and recreating the parts that make it recognisable. I saved considerable time by using the base photo of the Paphos castle as it did not involve creating geometry with precise size.

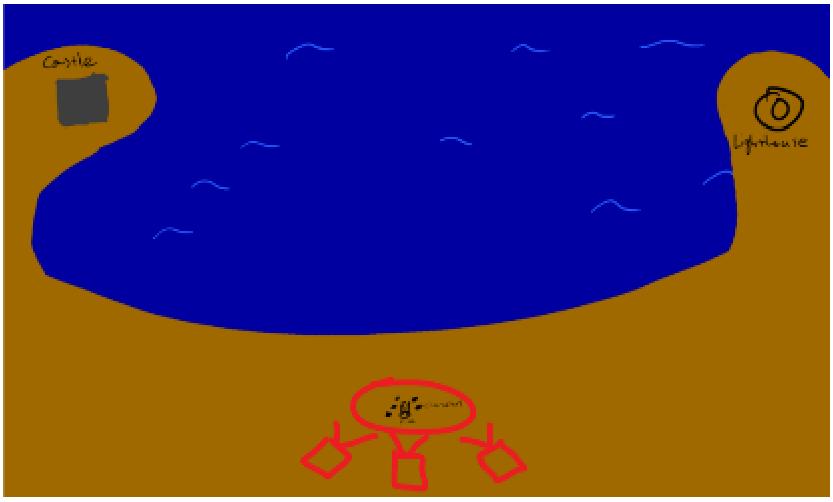
By keeping the highlights from the floodlights within the texture map of the castle, I was able to reduce the number of light sources on the beach stage. A limitation of this approach is that it can be difficult to change lighting conditions. Crucially, I only needed to show the castle with unchanged lighting.

The simple modelling approach enabled me achieve high image quality with limited computational resources and work hours.

Dynamic floor with relief - high level of detail with limited geometry



Storyboard frames



Top view concept drawing of the Beach stage

The action on the beach was limited to one place. The storyboard indicated that the camera had to approach the sand to show a dancing lizard, so I knew early on that the sand should have detail.

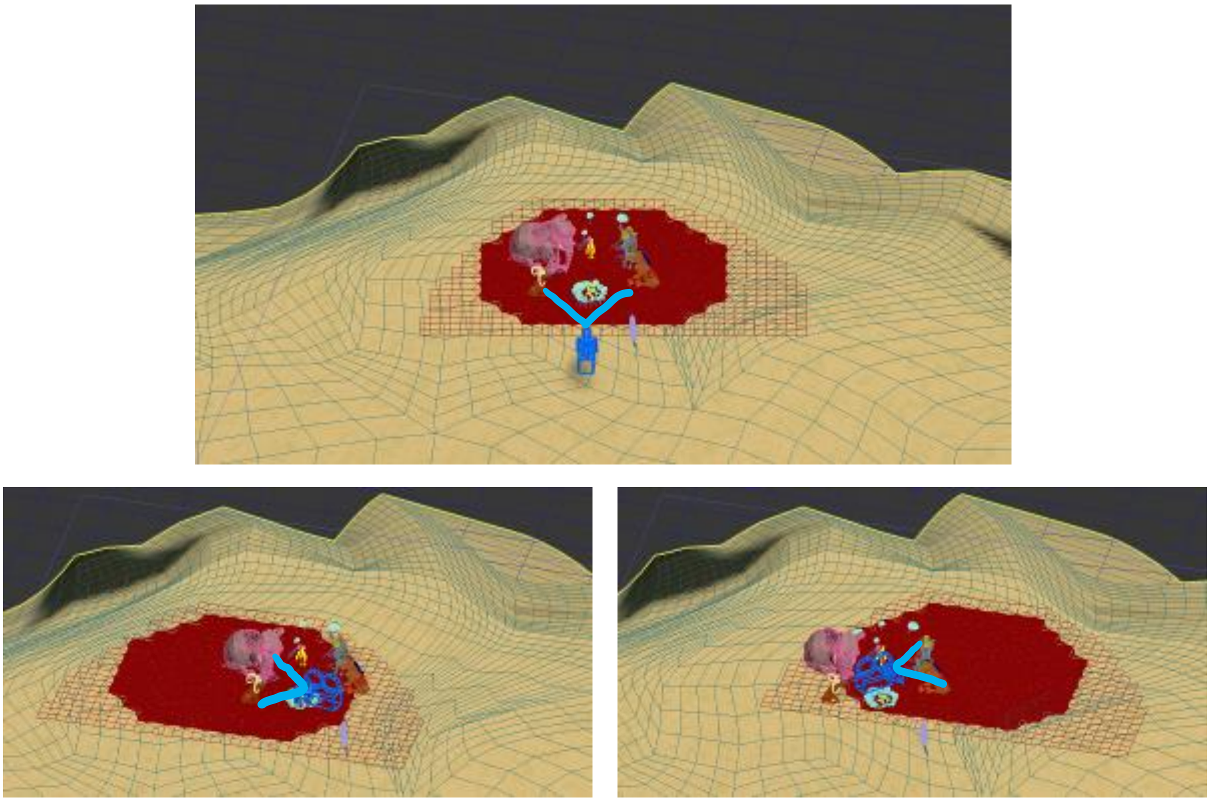
The beach stage has a simplified version of the dynamic ground patch repositioning system that was used on the salt-lake stage (see chapter 4, pp 165-166). The sand around the campfire has displacements with dense geometry. The repositioning system enabled making the sequence with a reduced area of detailed ground.

The high level-of-detail patch was repositioned in front of the camera for each shot in which the camera was pointed in different directions.

As the beach scenes do not have long travelling motions, such as the walking scene on the aforementioned salt lake stage, the sand patch did not have to be repositioned during a shot. As such, the sand model did not have to be tileable which facilitated the modelling process. Moreover, the fact that the patch did not need to be positioned with accuracy, sped up the task of repositioning it between shots.

The positioning of the patch in front of the camera was straightforward as the process consisted of creating a stepped keyframe while moving the surface somewhere with improved frame coverage. The placement of the patch did not have to be exact as it was not affected by its position in the previous or next shot.

First three shots of the beach sequence



Viewports display the acting area and ground patch positioning, in red,
and the camera in blue that provided framing of shots respectively.

The night scene does not make the best use of the system due to the limited acting area. A scenario in which the patch would have had a bigger impact on reducing stage geometry would be if there were more than one acting spaces in which case the moveable patch would be utilised to display larger areas of beach sand.

Agrinoui (2015) - Stage Systems

This section demonstrates alternative uses for systems that have been presented in this project. The examples provide supportive data for the effectiveness and applicability of systems.

The stages “Phoenix Flight”, and “Temple of Apollo” have relatively simple configurations regarding the acting spaces. The two stages have environments that were significantly less computationally demanding compared to some other stages in Agrinoui (2015). Optimal use of computational resources was not mission-critical for the stages that contained only one environment. However, optimisation systems, such as modular repositioning, enabled having reduced numbers of objects on stage which provided increased speeds in handling and rendering 3D graphics.

Dynamic module assembly and deconstruction – Clouds, trees, structures

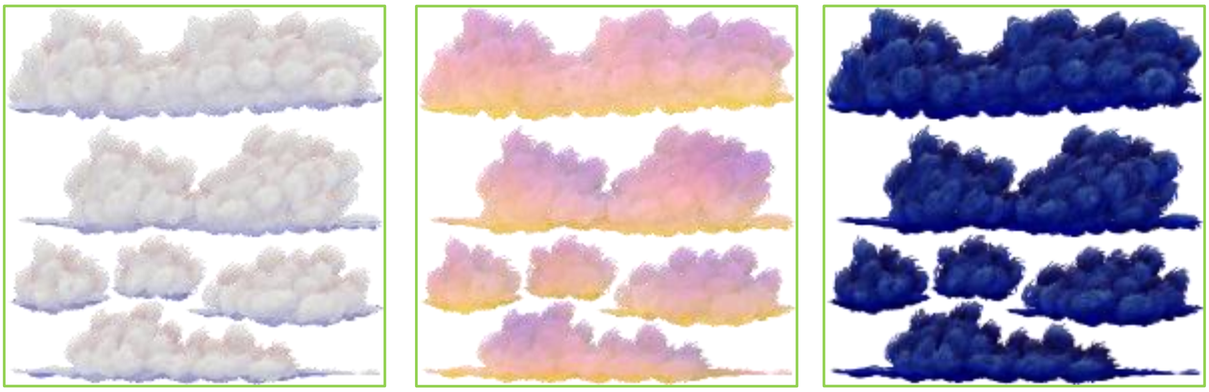
The bridge on the forest stage (see chapter 4, pp 186-187) comprises of a combination of separate components that can take different forms for the display of different structures in consecutive shots.

Other examples of differentiating the layout of modules include rocks formations (see chapter 4, pp 175-176), and the mountains (see chapter 4, page 172) that enabled making different landscapes.

The following examples involve the use of modules to create different cloud formations, differently shaped clusters of trees as well as differenttiated archaeological structures

The next scene features a flamingo flying through clouds while it approaches an island.

Planning material for flight scene in Agrinoui (2015)



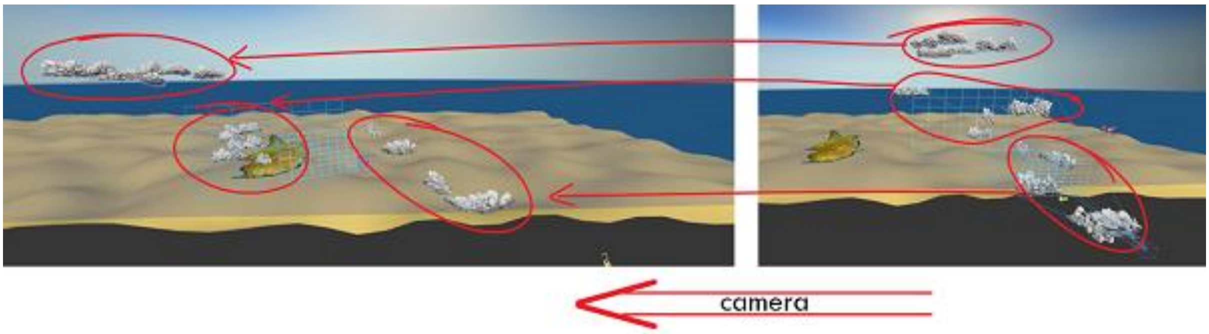
Three sets of cumulus cloud texture maps

Throughout the film Agrinoui (2015) we see six basic cloud shapes. I made three versions of the cloud texture map with different colours for the daylight, evening and night scenes.

The subject of differentiating the appearance of scenic elements has been addressed in the review of relevant literature and practice (see chapter 2, page 62).

The six cloud modules were occasionally combined to form larger bodies of clouds with a unified outline. The overlapping objects in the following image indicate that it is possible to create a significant variety of shapes by rearranging the modules within the view.

Film screenshot



Birds-eye view of Flight stage. Time in film: 1:56 (right image) and 2:08 (left image)

The images above indicate the instantaneous repositioning of clouds during a shot with a moving camera. Once a cloud exits the frame it is repositioned and shown again giving the impression that the sky has more clouds than the number of objects on the stage.

Respective film screenshots at times 1:56 and 2:08

Object repositioning enabled the limited number of elements on the stage, and module rearrangement made the shapes of clouds appear to be different when they re-enter the frame as clusters.

Film screenshot at the temple of Apollo

Clusters of clouds that offer diversified and unique outlines can comprise of a small number of modules. The unique cloud shapes in the image above were made by positioning pairs of the smaller clouds closely together.

The same logic can be seen in scenes with clusters of trees. An aerial shot with camera movement on the racetrack stage displays groups of objects that appear twice with different formations.

Screenshots of initial and ending frames of a shot

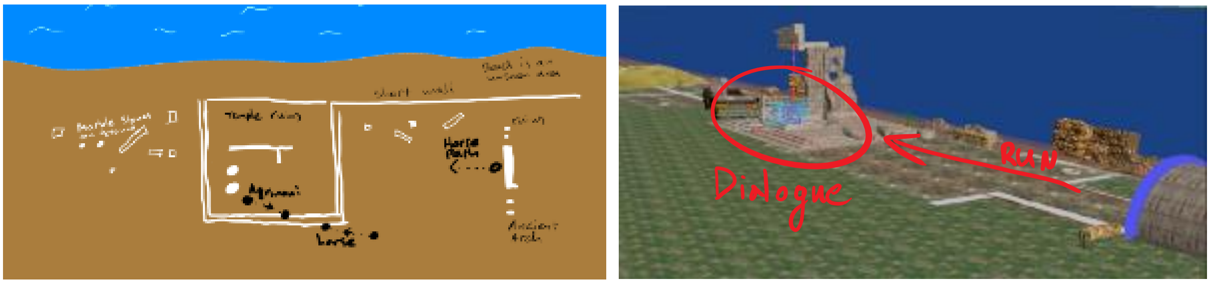
As the camera moves and the trees, indicated in red, go outside the field of view, they are repositioned towards the right side of the track and reappear in frame. This gave the impression of there being more objects without loading the stage with excessive amounts of geometry.

Even though a limited number of trees had been modelled, the clusters of trees form unique outlines that provide diverse appearances making it difficult to notice repetitive patterns. Moreover, as trees and clouds are not the point of interest in the film it becomes harder to notice that they are shown in multiple scenes.

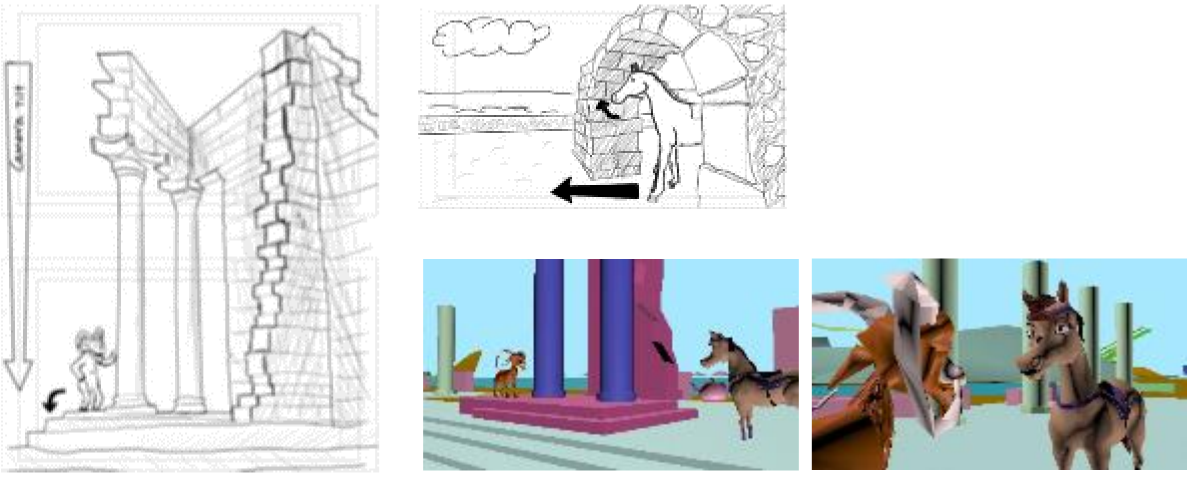
Other examples are also presented in this project concerning the repositioning of scenic objects during a continuous shot with different types of camera motion (see chapter 4, pp 165-166, and page 186). The common concept was to take objects once they stopped being visible and to reposition them so that they re-enter the frame as the camera still moves.

The use of modules also enabled making the Temple of Apollo stage with a reduced number of objects.

The scene at the ancient temple opens with a track left camera movement parallel to a running horse. The horse reaches an area with a central structure where a dialogue occurs.

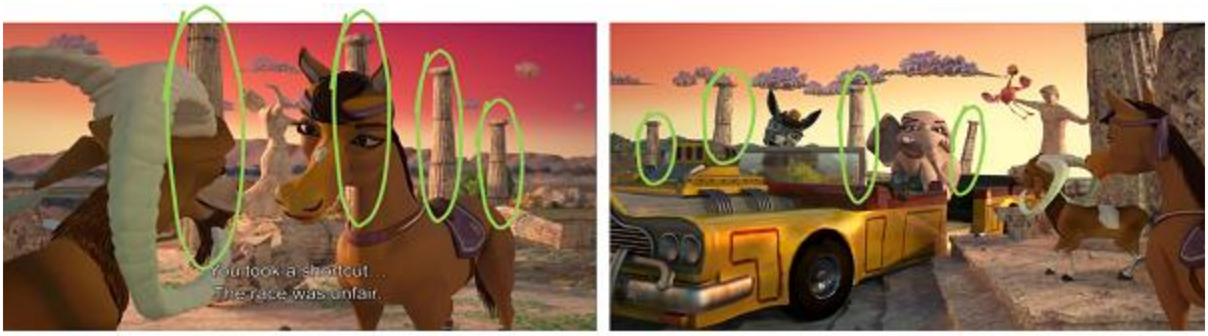


Top view concept drawing and viewport with the acting space of the Temple of Apollo stage



Storyboard frames, and previsualisation screenshots

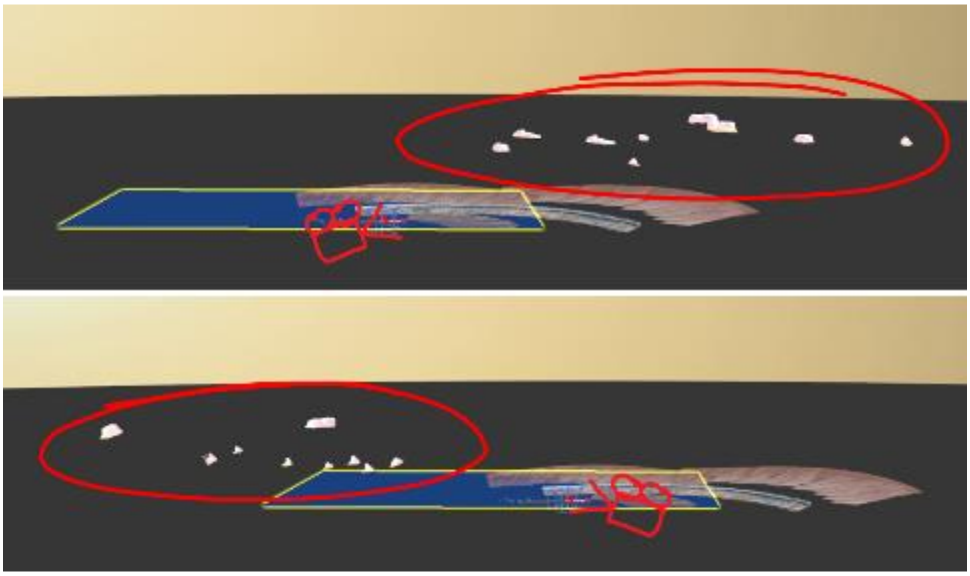
The following example shows how four ancient columns were repositioned in consecutive reverse angle shots to give the impression of having two ancient structures on either side of the central building.



Reverse angle shots from the Temple-of-Apollo scene

The coordinates of the columns in both shots are stored within keyframes. If the scene contained numerous alternating over-the-shoulder shots, the positioning data could be retrieved to create the framing of a previously composed shot. The columns and the camera could assume previous positions by copying their keyframes into new points of the timeline.

The clouds were also repositioned for framing the reverse shots.



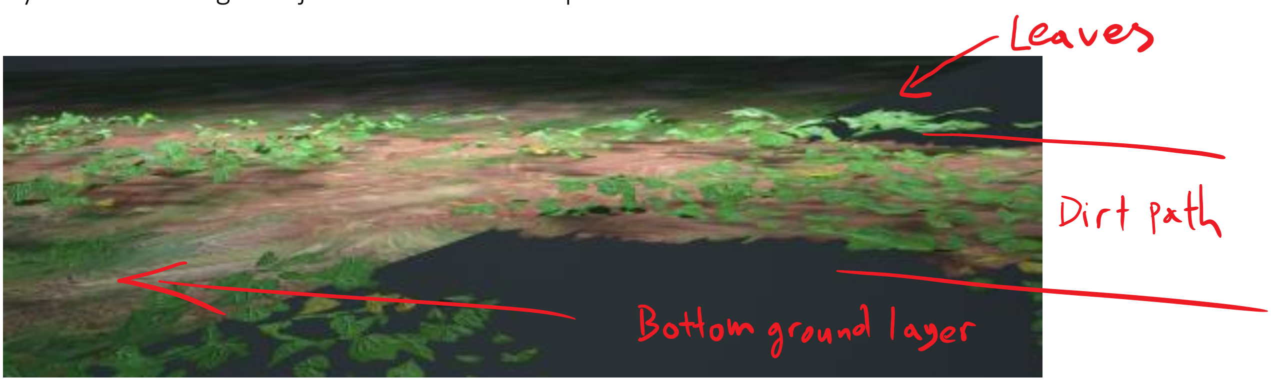
Wide view of stage shows the position of clouds for the different shots

Although the temple of Apollo stage has only 9 cloud objects, the sequence gives the impression that the sky has three times as many.

The static proxy stage for the previsualisation process included all 13 columns that appear in the film. Having the key stage elements in their correct place enabled me to focus on adjusting the shape of the stage. The dynamic repositioning systems were implemented during stage development phase where a closer observation revealed the number of columns and clouds necessary for the sequence.

The ability to reduce the number of objects on a stage by using dynamic modular scenic objects has a ripple effect in reducing production costs. The direct benefit of altering the shape of an object by repositioning its components is a reduction of the workload of artists. The indirect effect of having fewer scenic elements on a stage is the reduction of computational loads which is key for making versatile multipurpose stages that provide productivity advantages.

Dynamic low-height objects – Groundcover plants with medium LOD



Close-up image of forest floor layers

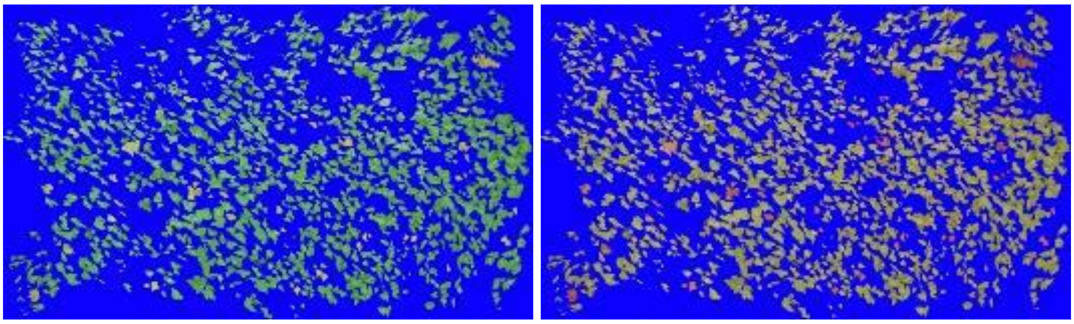
The forest floor consists of three objects that have little distance between them.

The bottom layer is a flat surface with a texture map that depicts dirt with scattered areas of grass.

The middle layer forms the forest path which is also flat and is positioned less than a centimetre above the first one. The rough edges of the dirt path rely on an opacity texture map which makes the object blend with the greener ground that surrounds it. Although I could have made one mixed material that contained both ground textures, the separate path surface provided a practical way for positioning and bending the path on the forest floor.

The upper layer is a rough surface that depicts low vegetation. The leaves are single sided, and float a few centimetres above the ground. I did not need a system for making the leaves face the camera as they appeared correctly from all directions provided that the point of view was more than one metre above the ground.

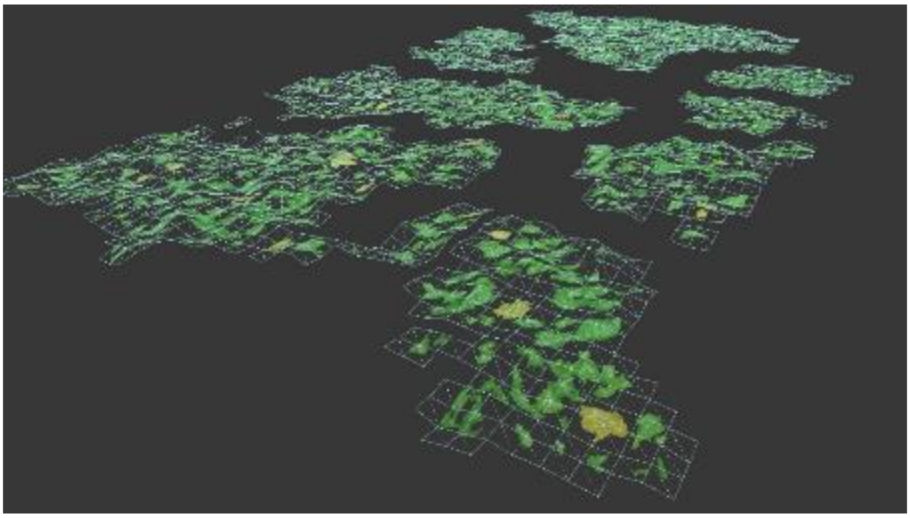
Reference photo, Cyprus 2014



Edited groundcover diffuse maps with differentiated colours
transparency indicated in blue

The version with green leaves was used on the forest stage and at the temple of Apollo, whereas a version with a colour adjustment were used as dry leaves on the sunny racetrack stage.

Screenshots featuring groundcover on the right side of the frames.



Model: Low polygon wavy surface

The low vegetation has a moderate amount of detail which makes it unsuitable for close-up shots of, for instance, a lizard. The leaf material was applied on a low polygon surface with faces at random angles. The 3D model of the leaves was separated into sections that were spread out to reveal areas of underlying dirt in the gaps.

The texture made the object appear detailed and the bumpy geometry made the leaves appear uneven. The 3D model was simple as I did not create geometry for individual leaves and for plant stems. The outline data for the leaves was stored in the image mask which describes the areas of the material that are opaque or transparent.

Details such as stems would not have been visible in the forest scene as I knew that the camera remained at a distance of over one metre from the dirt. Therefore choosing to make redundant geometrical details would have been a waste of work hours and computational resources.

Lighting for texture maps

One benefit of capturing my own reference images is that the first-hand observation of the surrounding environment can provide a better understanding of the conditions that make a surface appear a certain way.

When I captured the wild groundcover plants, on the previous page, I was in a humid and shaded part of a forest, in a summer midday, not far from a river. The empty water bottle in the picture provided a sense of scale. Supportive information encourages making realistic combinations of environmental elements. For example, having green mosses on treeless dry land could appear unreasonable.

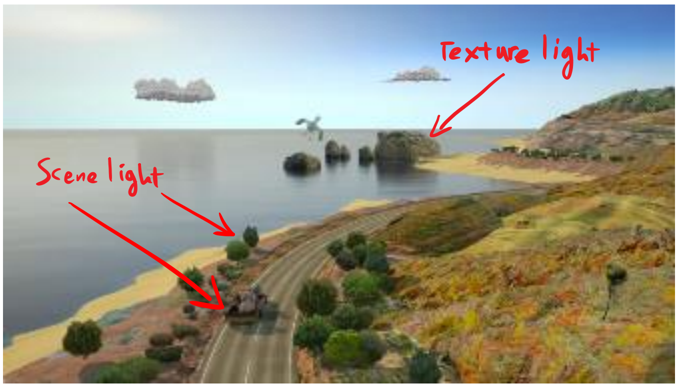
Other advantages of capturing photos include choosing the point of view. In the case of the groundcover, the subject needed to be perpendicular to the camera. I looked for a shady area as direct sunlight that passed through several openings in canopy created undesirable bright patches on the forest floor.

My stages comprise of combined scenic components that appear consistent because of being mindful of texture map qualities such as the colour temperature of base photos and whether they were captured under soft or hard light. Observing the subject on the screen of the camera with a neutral white balance and an awareness of light source qualities can provide a better understanding of the colour palette.

Whereas the observation of third-party pictures may have incomplete information regarding the lighting conditions, and unknown colour enhancement processes may provide misleading colour saturation and brightness contrast.

Most of the photos that I captured for making the textures in Agrinoui had even lighting conditions (see chapter 4, page 176) as intense shadows within the diffuse map could make an object appear peculiar in relation to other objects whose shading relied on the digital lights of a scene. However, the diffuse texture map of Petra tou Romiou (see chapter 4, page 175) has shaded parts that made the rocks look more 3-dimensional.

Ideally, the digital sun should illuminate the rocks from a common direction to match the 2D shading of the rock's texture. However, during stage development, I chose to position the sun in the opposite direction. Despite lighting not being visually consistent, I found that the rocks were effective at drawing the viewer's attention without creating undesirable distractions.



Screenshot from Agrinoui (2015) – The shading of the landmark rocks made it stand out

Although my decision is not commonly practiced, it is useful to see why it is generally advisable to use textures that do not have embedded shadows and highlights.

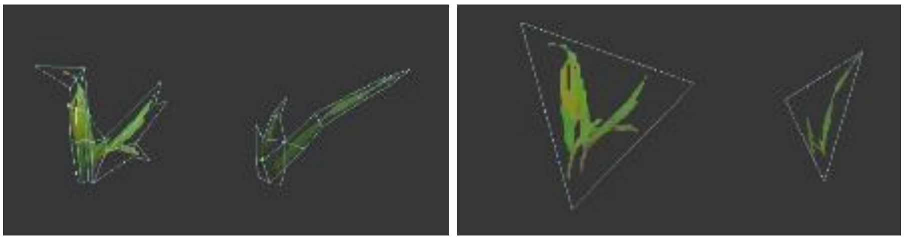
Placing a 3D object with a diffuse texture map that was photographed during a cloudless afternoon, next to an object with a map that was captured in overcast weather could result in an inhomogeneous combination due to incompatibilities in colour temperature, and in lighting qualities such as the direction of light and light softness. The hue of one object would probably lean towards orange and the other would be bluer with softer shadows. Colour correction in image editing enables making the colours of two images of trees compatible. However, it can be more difficult to edit out harsh shadows from direct sunlight that illuminates, for example, the side of a tree or a rock.

Dynamic low-height objects – Groundcover plants with high LOD

It has been established with the 3D castle (see chapter 4, pp 188-190) that texture maps can make simple geometrical shapes appear to have volume and detail.

3D graphics applications enable adjusting several material properties with bitmap texture maps. The material of the small plants comprises of 3 images that control colour, opacity and roughness of 3D surfaces with low polygon counts.

- The diffuse maps are images that are responsible for the base colour of the object.
- The opacity maps enabled me to mask the outlines provided detailed contours to the leaves and stems.
- The bump map provided a low relief appearance.



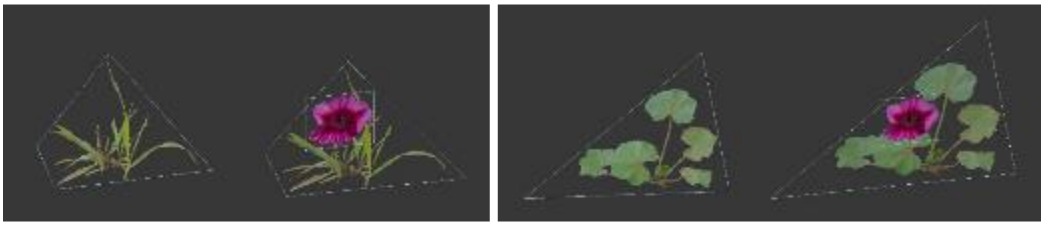
Viewport images with edged faces display two versions of grass modules with different LOD

The grass stems with more polygons were designed to be positioned closer to the camera compared to the plants that comprise of a single triangular face.

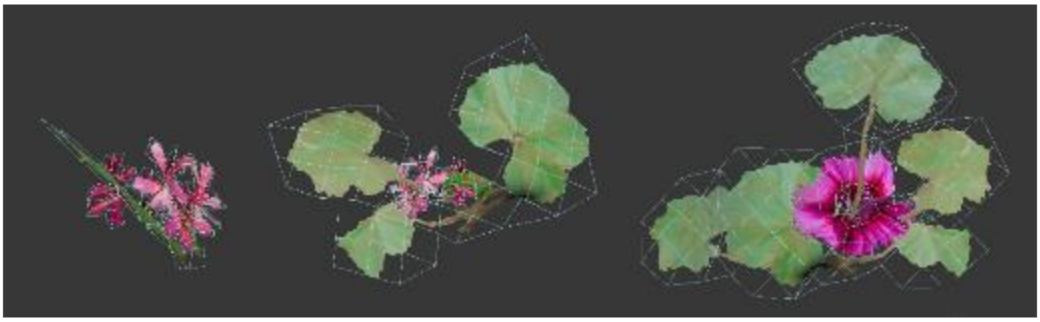
Screenshot with high-LOD version of texture-based plant

Recreating the above plant without an opacity image map would have required a significant amount of computationally demanding polygons for tracing the outline of each leaf.

Modular plants enabled me to create diversified versions of plants by superimposing surfaces that depicted images of flowers.

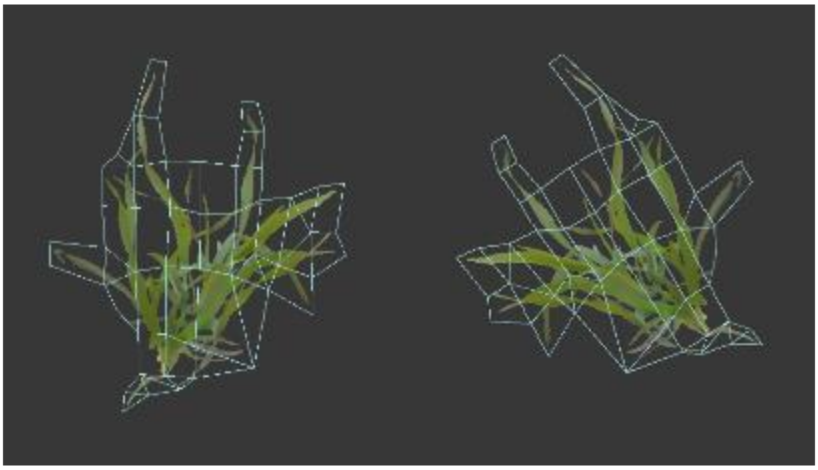


Viewport image displays low LOD plants with and without a flower



High LOD combinations of modules with additional diversified plants

I reduced the modelling workload by presenting the same models differently. Modular plants could be diversified by making various plant-flower combinations.



The copy of the grass module was flipped horizontally,
and was rotated 30 degrees counter clockwise.

A copied object can appear to be different by applying free-form deformations or by changing its hue. Such changes can be applied very fast compared to making a new model.

Group plant wedge system

A concentrated positioning of plants in front of the camera reduced the number of unutilised objects that remained outside of the frame.

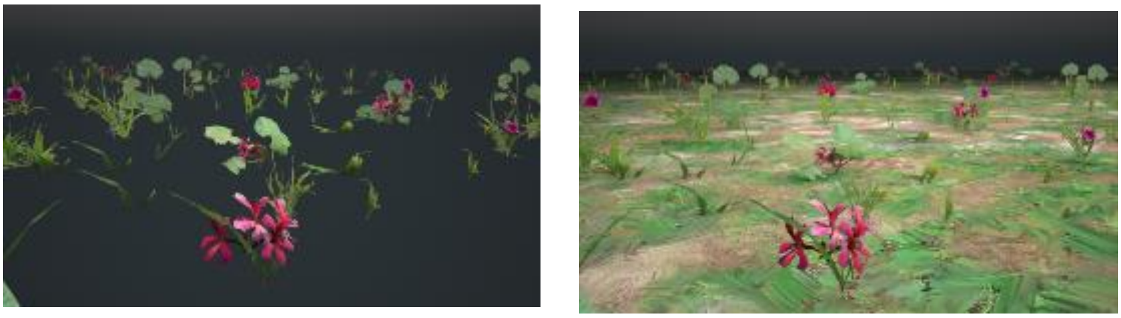
I attached the plants on a wedge shaped horizontal plane that could cover a camera's field of view.

The wedge controlled the positioning of the whole group of plants. I placed the pivot point of the wedge under the area where the camera would be positioned. This point is indicated with a sphere in the viewport images and all the plants are facing towards the camera area.

Viewport images with the wedge shaped plant area being rotated around the pivot point

I would place the wedge's pivot point approximately underneath the camera and I would have rotated it towards the direction that the camera was pointing.

I manually positioned the wedge within the field of view and I repeated the process for subsequent shots.



Viewport images of plants and ground surface

The ground beneath the plants had to be flat to enable easy alignment. The wedge helper object was coplanar to the ground and was invisible in the rendered frame.

Film screenshots featuring the same group of plants in different orientations

The purpose of the wedge system is to reduce the number of plants on the stage and to ensure that the single-sided surfaces of plants face the camera.

A major advantage of the wedge is that it is simple to implement and to explain how it is operated to co-workers. Other advantages of the wedge system is that it uses models of plants that have limited demands on work hours and on computational resources. The fact that the wedge was used in different acting spaces of the racetack stage, indicates that the system is versatile as it can generally be positioned on horizontal flat ground surfaces.

> *Technical note: The wedge system can be adapted for use on uneven grounds. One way to approach this would be with a space warp object that deforms the shapes of objects that enter its area of influence. A spacewarp with a box shaped free-form deformation (FFD) can make elevations to a horizontal mesh for a hilly ground surface. By making the same spacewarp affect the shape of the wedge system, the plants would conform to the shape of the terrain even when they are repositioned.*

Ground surface superimpositions that offer enhanced production efficiency

Before making ground surfaces such as low-height plants, bumpy beach sand and salt lake surfaces, I gained an understanding of the physical properties of the objects, I observed how they react to light and how they appear as a flat picture.

Water can appear transparent or reflective depending on the circumstances. The ponds in Agrinoui (2015) did not have depth and I did not devote resources into making lake bottoms.

Screenshots featuring reflective planar lakes on top of flat ground surfaces

The water plane floats less than a centimetre above ground level. The appearance of the water surface depends on the sky and the reflected objects.

> *Technical note: Reflections can appear on planar surfaces with a flat mirror process that is significantly faster to process than ray tracing methods which are better suited for making reflective curvy surfaces such as a silver teapot.*

The lake surface was made by shaping a closed spline that was converted into a flat mesh. The modelling processes of most presented single sided scenic elements is not technically challenging and can be carried out by moderately experienced 3D artists or by seeking guidance in manuals of professional 3D graphics applications.

Although there are more advanced techniques for making 3D objects, the ability to make impactful background objects with a few simple steps can save work hours. Moreover, the modest computational requirements of simple flat reflective objects were small compared to the alternative of simulating transparent volumes of water that can refract light.

This example is indicative of the thought process of a designer who uses the combined awareness of digital tools and of the visual impact of elements in a framed composition. I had predicted that additional effects such as light diffraction would not have offered a significant improvement in the appearance of the ponds. Focusing on how objects appear in the frame rather than on replicating redundant physical properties is key for devising ways to efficiently make scenic objects with basic computer graphics tools.

Universal assets

I saved production resources by showing the same scenic elements in multiple parts of the film.

Screenshot from the temple of Apollo scene

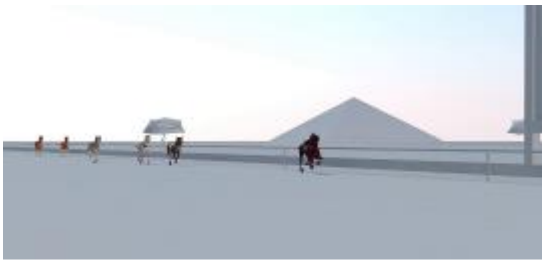
In the above screenshot there are several elements that were used throughout the film. The arch model and stone surfaces were used on the forest bridge; the background mountains can be seen in the racetrack and salt lake scenes; the dirt under the trees was at the sides of the mountainous road; and the same models of clouds, trees and shrubs are shown throughout the film.

Dynamic sky colour system - Sky cylinder

The colour of the sky can depend on lighting tools that simulate light being emitted from the entire sky dome. Another common approach is to surround the stage with a light blue hemisphere that enables framing extreme low angle shots (see chapter 1, page 21).

The problem that I found with simulated skies and painted sky domes was the limited range of colours within the frame that contains a limited section of the background. Although a hemisphere that surrounds the stage can have a range of colours that spans from light shades in the horizon to dark shades at the top, only a small portion of sky is visible within the frame. As a result, the camera would only capture a limited amount of sky colours at any time.

I designed a dynamic system that gave a vibrant and rich range of colours to the sky within the frame. The system had a provision for conveniently adjusting size of the sky backdrop to the framing of different shots.

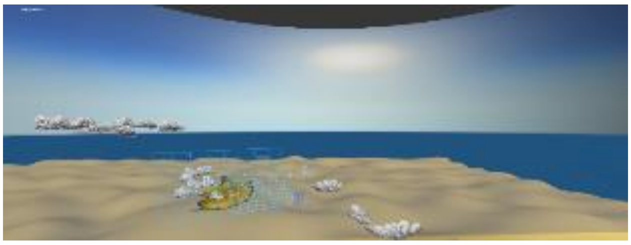


Rejected skylight simulation

Manually coloured sky cylinder

I was not concerned with how the sky looked outside the boundaries of the frame, nor did I need physically accurate sky colours or lighting. I wanted to control the colour gradations of the sky which in combination with a custom lighting rig could provide an appropriate mood to each scene.

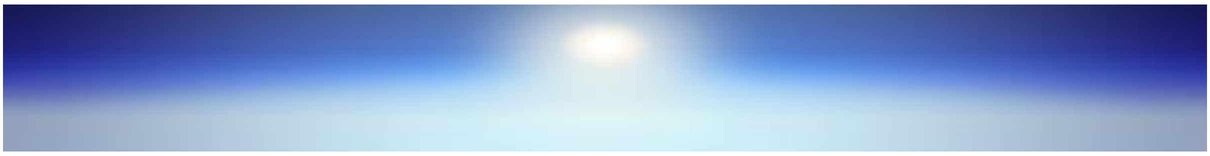
Screenshot featuring a sky with a vibrant colour scheme



Viewport displaying the upper edge of a cylindrical sky

The stages in Agrinoui (2015) were surrounded by the inner wall of a cylinder that had one of four colour schemes for scenes that take place at different times of the day. The circular top of the cylinder was redundant as it was not supposed to enter the frame.

The diffuse image map of the sky materials had a very wide aspect ratio that enabled the image to be wrapped around the circumference of the cylinder.



Sky image map for morning and afternoon scenes

Sky image map with sunset

Part of my M.A. in Design research project at Middlesex University (2007) concerned a study on sky lighting properties under different conditions. In 2007 I digitally painted a landscape that later became part of the introduction scene (see chapter 4, pp 106-107), and of the end credits of Struthio (2011).

Digital painting (2007)

The sky texture maps for Agrinoui (2015) derived from the 2007 project. The editing process involved elongating the sky backdrops and applying them to cylindrical shapes that surrounded the stages.

By changing the height and orientation of the cylinder I was able to control which area of the sky would be in the frame.

Left: Film Screenshots of shot with tilt down camera action. Right: Stage from 3D viewport

The low angle shot required the sky object to have an increased height so as to prevent the cylinder cap from entering the frame. The viewport screenshots indicate how the size of the sky was adapted to the framing of different shots.

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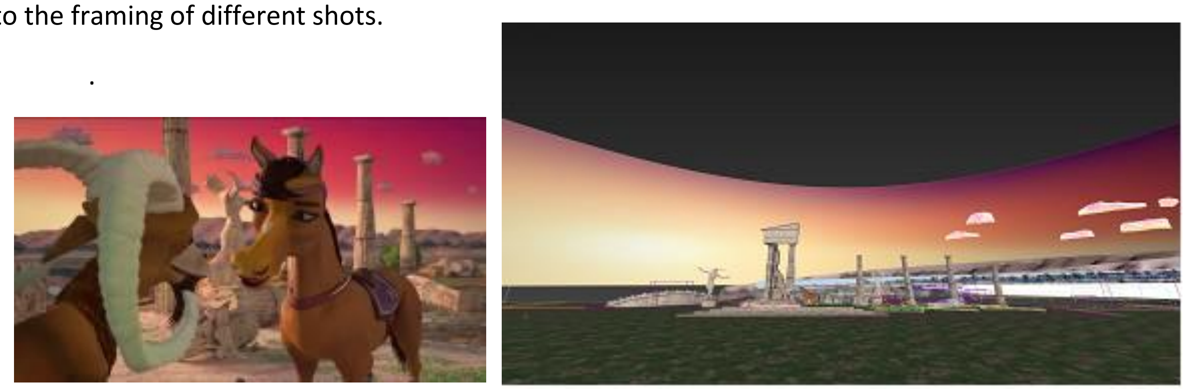


Screenshot with a smaller portion of the sky in the frame.
The viewport shows the lowered height of the sky cylinder

By shortening the cylinder in the second shot, the sky in the frame acquired a wider colour gamut.

Optimised Lighting/rendering

Agrinoui (2015) made use of physical lighting simulation systems, whereas Struthio (2011) made use of point lights with shadow projection. Despite having used different rendering systems, both lighting approaches went through optimisation processes in order to avoid assigning more than the necessary processing resources.

One of the lighting optimisation measures in Struthio (2011) concerned using a limited number of light sources. Comparative testing of types of lights enabled me to choose methods that provided a fitting look without wasting computational resources. Direct sunlight was recreated with a computationally fast combination of a spotlight that projected a sharp shadow map. I achieved fast rendering by not using heavier lighting types such as area lights with ray traced shadows or global illumination with simulated physical lighting. Only the sunlight would cast shadows and these were targeted towards a limited area in the foreground of each scene.

Agrinoui (2015) made use of a computationally demanding types of physical lighting. The process for optimising the lighting rig was similar to the one followed for the 2011 production as multiple rendering tests were conducted to come up with optimal settings. However, the adjustments for setting up the physical lighting system concerned different types of settings.

Reaching an appropriate lighting quality without devoting an excessive volume of computational processing, involved using the least amount of light sources, adjusting the area size of each light source and the amount of emitted photons, as well as the number of times photons would bounce off of surfaces.

The volume of computational processing devoted to rendering each frame was that of a workstation, from the production year of the produced films, working for approximately two minutes. Although limiting rendering time has a negative impact on image quality aspects such as lighting, processing limits are important for production frameworks with a high output rate such as a TV series.

Most of the scenes in my films were rendered in a single pass. Although an elaborate effects scene can comprise of stacked video layers of objects and superimposed effects, the time-consuming workflow for compositing each shot is not consistent with the streamlined postproduction process needed for the high quantity output needed for TV series.

By keeping superimposed effects such as dust and lens flares to a minimum, I had significant benefits in productivity. On the one hand the uncomplicated single layer of rendered sequences provided a more direct way to preview the progress while the animated content was made. On the other hand, it enabled remastering Agrinoui (2015) in stereoscopic 3D with minimal effort. Moreover, having 1 layer of video to edit meant that storage space requirements were limited and that tasks such as exporting the film were made relatively fast.

Multipurpose stages enabled me to preview long sequences and one of the tasks during the improvement cycles was to adjust lighting and exposure for multiple shots. The consistent rendered output made it unnecessary to colour correct shots independently during post production.

Adaptive lighting

The racetrack stage was used in night, evening and daytime scenes. The change from day to evening lighting involved using stepped keyframes to change the positioning of the lights in the sky and to change the colour of the lights.

The night scene required a different lighting rig as the main light source were artificial lights insteas of the sun. Stepped keyframes were used to disable the sunlight and to enable the floodlights for the night scene.

Screenshots of the racetrack with different light settings enabled

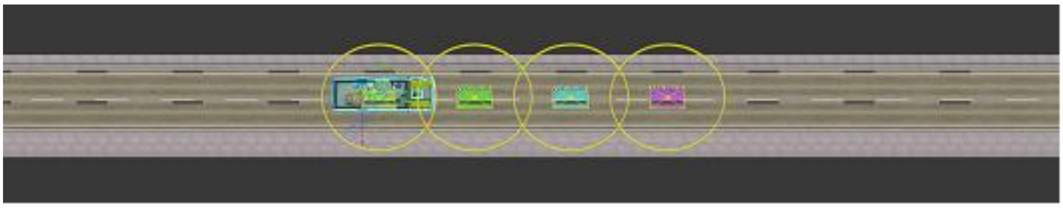
Lighting repositioning system

The bus travels on the salt lake stage within a road tunnel that has twelve light fixtures.

Film screenshots display the friends between overhead lights (left) and under a light (right)

Twelve physical light sources would have significantly slowed down the rendering process. I therefore created a moveable lighting rig that consisted of four lights which followed the travelling action.

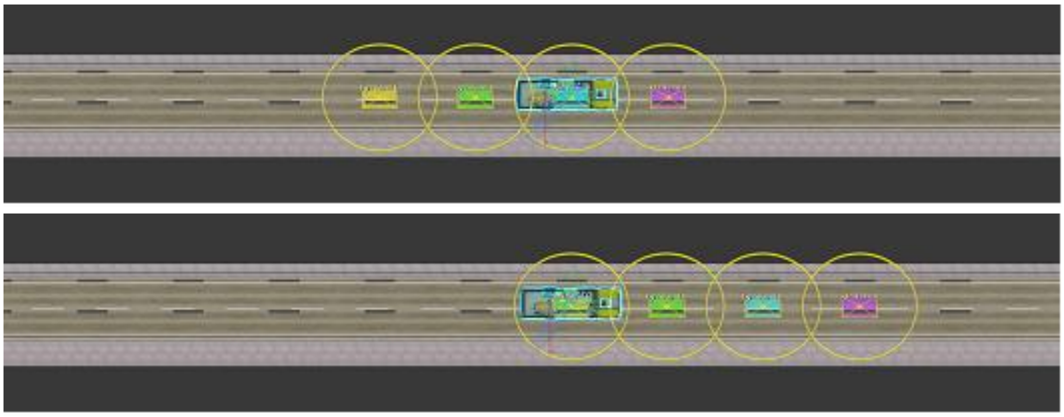
The system takes advantage of how the intensity of light is reduced as the distance from the source increases. The intensity of the overhead lights is reduced to zero at a distance of five meters from the source. The area affected by the lights is indicated by the yellow circles in the top view of the road.



Top view of the bus moving within the tunnel

As the bus moves forward and gets past a light, we leave its sphere of influence and that light no longer affects the contents of the frame.

As the bus enters the sphere of influence of the last light, the entire array of lights instantaneously moves forward a distance of two times the space between lights.



Top view screenshots before and after the lights have shifted

The aligned repositioning of lights ensures that the lights above the bus are in the same place when the change occurs and as a result there is no noticeable lighting difference in the film. The lights are shifted four times during the tunnel sequence.

The order of appearance of environments

The sequence of events and the order of appearance of environments in Agrinoui (2015) is as follows.

The film starts with a horse race in which Olympia performs badly and has an altercation with her father. The music for this scene was composed to highlight the troubling situation.

The next scene introduces a silly flamingo flying merrily in the sky over the Mediterranean Sea. The insertion of the joyful scene provided an antithesis between two sad scenes and hints that the story has colourful characters.

The salt lake scene starts with Olympia being disappointed as she reflects on her defeat on a barren land.

A picturesque coastal road was in the background when Olympia boarded a bus with new friends and she later lets herself have a good time by boarding on a picturesque.

As night falls the friends show compassion towards Olympia and encourage her to keep trying before they start singing around the warm campfire on a calm beach.

Olympia had certain obstacles to overcome that would gradually change how she saw herself. The challenge in the mountains that concerned the will to work hard found Olympia pulling a bus uphill towards a remote garage. Another challenge was for her to be patient and understanding even when she was right in a dispute. Sure enough, Olympia quickly got over having been tricked into believing the bus had broken down.

During the relaxing stroll through a green forest and over a scenic bridge Olympia has gained a positive mindset and is challenged to run as fast as she can towards the temple of Apollo.

When Olympia ran along the picturesque seaside in the golden evening light she understood how much she likes running and ultimately gathered the courage to choose going back to racing.

The film ends with two scenes at the racetrack which is presented consecutively as an unwelcoming and as an exciting place through differentiated framing and lighting.

The sightseeing trip reflected the transformative inner journey of Olympia who became more confident and provided justification for visiting multiple purposefully selected locations.

Teamwork in Agrinoui (2015) - Interview

Character animator Sakis Kaleas shared his experience on the production of Agrinoui (2015) in a retrospective interview provided on 16-10-2019 with certain clarifying answers provided on 18-11-2020. The interview aims to shed light onto how the workflow of animation departments can be affected by multipurpose stage design rationales.

The production framework of Agrinoui (2015) had provisions for communicating updates of revision cycles between team members, and for sharing project files over the web as the collaboration took place from a distance.

Question: Agrinoui was made with only 7 stages. How did animating characters for long sequences affect productivity?

> **Sakis Kaleas:** *It has its pros and its cons, working with characters in a setup scene you can easily justify the personalities according to the scenery and have a clear set to work for. However due to the restrictions of the world coordinates it was many times too difficult to express myself in the animation because of the characters being so far away from the origin of the world which is the XYZ:000 was making even the smallest move hard to accomplish.*

Note on troubleshooting incident: Some stages were positioned more than a kilometre from the origin (zero coordinates) during preproduction. The decision stemmed from having the blocked out stages positioned side-by-side in a layout that provided a practical project overview during film previsualisation. As the distance from the origin increases, it becomes more possible to encounter problems regarding the accuracy in object positioning. Indeed, we later realised in the production phase that the character rigs were not responding as expected at certain distances from the origin.

The resolution of this problem would have been easy if, during preproduction, I had ensured that the character rigs had an effective master control that would enable repositioning animated characters during production. Another measure would have been to simply reposition each stage closer to the origin prior to starting the production phase. Although, having one timeline for the 20-minute real-time 3D previs was useful, it did not necessitate having to spread out all the stages for a side-by-side overview. I had the option to have all seven stages occupy the same space near the origin from the start, while retaining the ability to previsualise the entire film with one 3D project file. The procedure would have involved grouping the elements of each stage into separate layers that can be hidden or displayed by switching a visibility option button.

Question: Was it useful for you to have the real-time 3D film preview material contained within one project file?

> **Sakis Kaleas:** *That was the most useful part of the whole production, having a clear timeline with all sets and scenes in a previz animatic.*

Question: Although we worked in different countries we were able to communicate and share files over the internet. Would we collaborate better if our offices were in close proximity?

> **Sakis Kaleas:** *Always the "close proximity" can be a benefit but I think this has also to do with the people involved, we found a great way to communicate and solve problems and also add directed corrections to each animated scene by only using the net. This is also a milestone of Agrinoui, the professionalism of the team.*

Question: The production framework of Agrinoui involved periodically obtaining a high-quality rendered preview of the sequence we were simultaneously working on. Did the preview videos provide a clear, immediate and mutual understanding of our progress? Did it help defining and communicating our next steps?

Sakis Kaleas: *Yes, it did help to identify areas to improve and to communicate the next steps.*

Question: You animated the characters within the low-res environment geometry (see chapter 4, page 143) of the previs which indicated the boundaries of the acting spaces and provided an understanding of the mise en scene. Did the exclusion of detailed scenic objects keep your computer responsive enough so as to not significantly inhibit your productivity while animating the characters?

Sakis Kaleas: *Yes of course, this is the way to do it anyway!*

Question: Would it have been useful for you to be able to see a high-quality environment in real-time 3D, instead of low resolution geometry, during the character animation process?

Sakis Kaleas: *That could be helpful only if the props were really close with the characters and an interaction could appear but… as long as it was written in the script! So having proxy environment is the way to go so the animation flow wouldn't be interrupted.*

Question: The mountain-roads stage features a level road at a constant elevation which enabled making a scene with the bus seemingly being pulled uphill and a scene where it looks like it rolls downhill. Is having a level road helpful to for the animation process?

Sakis Kaleas: *it could be, but it is not of a great importance because that's the animator's job, to provide the proper physics in any scene no matter if they are true or false. The final result is making the audience believe on what they see.*

Question: Was it beneficial, to handle the animation of 13 characters in the 2-minute final sequence of Agrinoui (2015) within one 3D project file?

Sakis Kaleas: *One file was necessary to make sure of the interaction between the characters.*

Context for the next questions: The stage design approach in Agrinoui (2015) offered productivity advantages during the making and handling of scenic elements that enabled composing different backgrounds. Another advantage is the convenience of assigning single preview rendering jobs for long film sections. Project management also benefited from having few but lengthy character animation files. The next questions aim to shed light on potential advantages or disadvantages that the character animation department can have by managing and working on project files that contain long (e.g. 2-minute) animation timelines compared to working with more files with shorter (e.g. 30'') timelines.

Question: You have experience in animating multiple characters for lengthy scenes. Beyond which timeline duration would you expect to see a significant decrease in the productivity of an artist animating a scene with 10 characters?

Sakis Kaleas: *I would say that lengthy scenes in general can be the reason for a decreased productivity if their purpose is to be filled with complex animation such as action scenes or dancing or martial arts. The reason behind that is because the further you progress into the timeline the more complicated it becomes, so it's getting harder and harder with each animation sequence to be completed.*

Question: Would the answer be different if the film sequence contained only five characters that just performed simple walking and talking actions?

Sakis Kaleas: *The answer wouldn't be the same, now we talk about simple walking animation, which also gets complicated as we progress in the timeline but not in the same way. Simple, it can't get out of control compared with an action scene. However, I prefer to make animations in a decent amount of frames so I can give more details and do more movement analysis. Now, the decent cannot actually be defined, but it can be less than 800 frames, anything beyond that starts to complicate things.*

Notes on animating lengthy character animation sequences. Defining the ideal length of a character animation timeline depends on factors such as:

- The number and the complexity of rigs. Agrinoui (2015) contains multiple animated quadrupeds which can be challenging to animate compared to simpler bipeds.
- The complexity of choreographies and the quality of expression.
- An animator with years of experience in creating walk cycles and facial animation is less likely to be overwhelmed by managing longer timelines. Even so, an animator can become more accustomed with the tasks at hand by studying the multipurpose stage rationale and technical advice annotations.
- A two-minute timeline can be separated into four 30-second sections. Under certain conditions, animation work in any one section can be made in isolation from other scenes that are situated at other chronological portions of the shared timeline within the same 3D project file. For example, the relatively simple character rigs in Struthio (2011) enabled resetting the animated elements by purposefully adding keyfames at the first frame of each scene. Working on a two-and-a-half minute timeline did not noticeably restrict character animation productivity. On the contrary, concentrating operations in a reduced number of project files offered increased practicality as it provided project management advantages such as having a practical production overview, and it reduced the workload of tasks such as setting up new scenes and preview rendering assignments.

Question: Let's assume you are the animation director of the potential TV series with the style of Agrinoui (2015), and the total amount of workhours is fixed for a team of between 1 and 20 character animators. How large would the animation team have to be before potentially encountering significant project management difficulties?

> **Sakis Kaleas:** *well, the larger the team the better! But that always depends on the budget, so my thoughts about it would be to have a single Animator dealing with max 2 character so he would be able to apply the personality of each in a good way, and also there should be a good differentiation on the roles of the animators, to character, environment, vfx.*

Question: Into approximately how many sections would you divide the 20-minute episode timeline for effective progress supervision and project file management?

> **Sakis Kaleas:** *The sections would be as many as the scenes of the episode written in the script, for example if the script contains 12 scenes then 12 should be the sections divided to. Then, each of the Sections could be again divided into smaller timelines for the reasons I explained [i.e. incorporating demanding choreographies or well defined character personalities]. Complex scenes [are better managed with] smaller timelines, normal scenes [have] no limitation in the timeline. Last but not least if there is scene similarity then probably 2 scenes could be merged into 1, for faster production.*

Review of film appearance in the studied cases

Introduction

This research project primarily deals with the productivity advantages of multipurpose stages. Several stages were designed, developed and used in the production of two films which enabled collecting holistic data. The following review concerns how the films communicate certain concepts cinematically and contains explanations about how the contents of the frame and the succession of shots have supported storytelling. The review provides complementary data to the presented stage systems in the form of explanations of the concepts that motivated the mise-en-scène.

The films Agrinoui (2015) and Struthio (2011) provide indicative examples of how the stage systems can be used. The findings are applicable in a wide range of film genres and storylines because the systems operate independently from the shapes and colours that appear in the film. For example, altering the appearance and the size of the scenic elements on the oval horse racetrack stage in Agrinoui (2015) can make it suitable for hosting other sports. Conversions could make the stage look like a track and field stadium or an automobile racing circuit. The camera angles in the fictional racing scenes in Agrinoui (2015) are indicative of how scenes with running athletes can be captured. In a documentary film, the oval stage rationale could be the basis for recreating a visualised middle-distance track event of the 1896 Summer Olympics.

Editing and frame composition in calm and tense scenes

A film can provoke contrasting feelings. Emotional scenes may contain an affectionate parent, a grieving figure, or a romantic couple. Lively scenes can display a practical joke or a festive atmosphere. Other times, a scene can build suspense in anticipation of showing the solution to a mystery, the result of a race, or the outcome of a fight.

A film sequence can more clearly convey targeted emotions by having supporting shapes and colours within the frame combined with deliberate choices in camera angles, camera motion, and editing pace (see chapter2, pp 63-65).

Editing

The night scene at the beach (see chapter 4, pp 188-192) in Agrinoui (2015) contains a conspiracy discussion during which the campfire had been extinguished and made the acting space void of warm light. The blue light from the night sky and the large dark areas in the frame created a sinister setting that was fitting for the dialogue. Immediately after the secret conversation the film shows a contrasting idyllic cape with a sunny cloudless blue sky with round shaped mountains, sandy beaches and without significant shadow areas that could have suggested danger. The daytime scene starts with a carefree journey that does not foretell the problems laying ahead.

Juxtaposed consecutive scenes with three different moods in Agrinoui (2015)

Scene fades to black. The transition into the night scene signifies that the fly did not stop annoying the ostrich for hours in Struthio (2011)

In Struthio (2011) I ended a day scene on the savannah stage (see chapter 4, pp 112-118) by fading to black for one second to signify passage of time during which the ostrich's predicament had not changed. The common element in the day and night scenes is the motion of the fly which appears as a flying dot. The black screen between the scenes indicates that the fly had been following the ostrich throughout the day and into the night.

Lighting

A hill is shown at night, evening and morning scenes in Struthio (2011)

The cold colours and the hard-edged dark shadows in the night scene on the savannah stage reflect the troubled feelings of the ostrich near his unwelcoming home.

Although the evening and morning scenes feature a vibrant blue sky, the dark surfaces in the frame are supportive of the stressful situations that the ostrich living there needs to go through. The strong back lighting causes stark contrast between the dark outlines of rocks and plants, against the brighter terrain and sky.

The ostrich is generally confused and this feeling is supported by having of multiple shapes in the background such as trees, rocks, and clouds. Sharp edges such as the pointed rays of the sun add tension, as do the vertical cliffs in the distant mountains.

The sun in the morning and evening scenes is deliberately positioned behind the central hill of the savannah stage. Despite the astronomically incorrect orientation of the sun, it mattered more that the scenes provided a sense of unease that foreshadowed unpleasant situations.

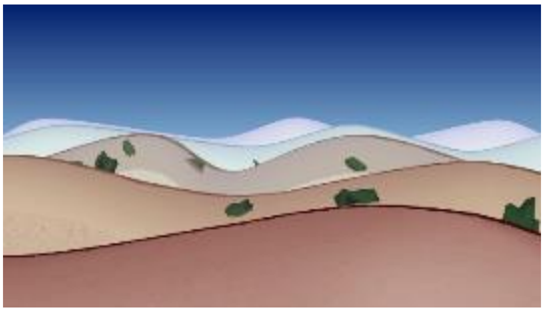


Image from precursory tests for developing the savannah stage. The sun is behind the camera

Several elements contribute to bringing out calmer feelings in the preliminary test image. The low overall number of objects provides a simpler composition. The smooth curves and textures of the hilly surfaces lack harsh edges and shadows that could signify or hide danger.

The savannah stage went on to receive trees and a river to make the environment appear more hospitable and less like a deadly desert.

Screenshot of the more hospitable home place of the female ostrich

The female ostrich appears to lead a calm and optimistic life as her head faces the sun, and the background is less cluttered than that of the troubled male ostrich. The palm tree suggests happiness and the berry bush in front of her symbolises abundance.

The similarities in the appearance of the terrain at the homes of both ostriches indicates that the locations belong to the same wider area. However, the adjusted mise-en-scène enabled each location to communicate the inner world of its resident.

Customised laws of nature

The shape of the trunk of the tree on the hill where the ostrich lives is symbolic of his unstable life as the thin branches also signify instability. Three trees in Struthio (2011) are shown to bounce back upright upon impact without breaking, similarly, the ostrich does not become physically harmed as he falls into them. The comedic immortality of the protagonist is intended to make the audience less worried about his safety, and more fascinated with the outcome of the clashes. The rubber physics apply only in the world of the story within the book (see chapter 4, page 106). At the end of the film, as we leave the world of the ostrich, we are back in the world of the book reader which is where the fly is ultimately killed. The demise of the fly brings closure to the story as we know that whatever happens next with the ostrich's looming threatening confrontations inside the book, he will be safe.

Final scene in Struthio (2011)

At the end of Struthio, the protagonist is confronted consecutively with several angry animals and insects. The scene shows the ostrich having no control over the onrush and before he knew it he was surrounded and confused.

The dizzying chaos was supported by shots from moving cameras with a fast editing pace. Although the tight framing focused on one action at a time, the composition contained multiple shapes that created tension. The busy framing during the climax is not meant to be seen as still images out of context. A vital element of the scene is the juxtaposition of the complex world of the ostrich with the simple world of the reader that are consecutively shown in the continuous final shot.

The turning point of the scene is when the ostrich becomes overwhelmed by his adversaries after which tension is reduced by pulling the camera back and into the world of the book reader where he is shown as an illustration.

The calmer outside world has a plain white background, a simpler frame layout, a lowered number of characters, and is shown with a lengthy shot that lowers the pace.

As the page turns the characters on the savannah become hidden. Only the annoying fly manages to get out of the book and becomes smashed by the tongue of the frog reader signifying story closure. Rather than cutting the film to black I kept on reducing tension by having the camera slowly dive into another illustration of an idyllic savannah landscape that featured birds flying into the sunset while displaying rolling credits.


From complexity to simplicity: Frames before and after the climax in Struthio (2011)

The environment with the book acts as a buffer that separates the imaginary world, where no one can die, from the calm outside world that we see at the beginning and at the end of the film. The three steps that gradually introduce the viewer to the plot start with the book that shows where the story is situated. After immersing into the book we successively meet the main character and then we are presented with his problem.

The moral of the story lies in how messy situations can occur by trying to solve problems recklessly. The story being about ignoring the source of a problem justifies cutting the story short of showing how the ostrich resolved the discord with the annoyed animals that were angered because of how he dealt with the problem. Another reason for leaving an unresolved situation is to instil the desire to see more because the film acts as a pilot production that can be used as the basis for a larger production.

The final race in Agrinoui (2015)

The editing pace in the final race in Agrinoui (2015) brings energy to the scene, the cheering spectators add excitement and the blue sky does not portend trouble. The steady camera motion and the fixed framing provided a reassuring sense that Olympia is in her element.

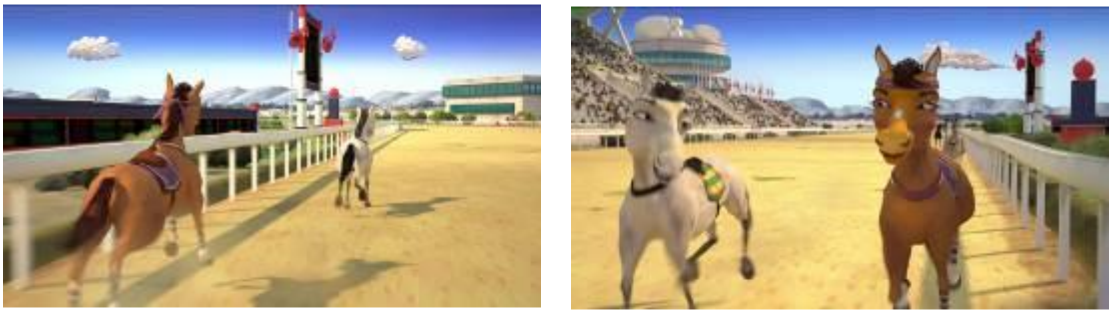
The stable shot highlights the concentrated efforts of the protagonist

The succession of shots, the framing as well as the timing were specified by taking into account the need to communicate the importance of trying one's best regardless of the performance of others. The concept meant that running was not about winning, not about escaping danger, and not about an epic achievement. In this scene the horse Olympia is already feeling fulfilled and runs confidently without stress against friendly competitors. The intended feelings were supported by smooth camera motions. During the truck and dolly shots, where the camera is following the racers, the frame composition remains constant as Olympia, and the lines created by the horizon and the top rails remain in the same area of the frame.

If the editing was too fast and with shaking camera motion then the race could have gotten an undesirable element of stressful struggle as if the result of the race was of utter importance or as if Olympia was fearfully running for her life. Notable scenes featuring slow motion running can be found in the film Chariots of Fire (1981). Slow motion shots of Olympia could have made overtaking actions appear to be heroic and essential. However, I did not want to overemphasize overtakes as that would not be consistent with the underlying concept of persistence being more important than winning this particular race.

Shots with camera following the action with constant frame composition in Agrinoui (2015)

The climax of the race occurs before the horses reach the final straight of the track. However, I wanted this part of the race to focus on Olympia having found her lost passion for running. When the horses reach the final straight, the scene becomes more focused on Olympia having overcome her inner obstacles. During the final stretch we are no longer hearing the announcer or the spectators talking and the inspiring music supports the spiritual rather than the physical struggle.



Left: Closely following the action before the finish line
Right: Friendly glances between opponents right after finishing the race

Although Olympia finished second, she looked satisfied fresh and optimistic, and offered a genuine smile to her opponent who had just finished ahead of her.

Once the film established that being second did not prevent satisfaction, a twist in the plot makes Olympia the winner. The film ends without showing the friends celebrate victory as winning was not the point of the story.

My script had concise and direct descriptions such as the weather, the location, the action, and the dialogue. However having a deeper understanding of underlying meanings was key for making purposeful directing decisions.

The rolling bus scene

Shot designed to build tension. Agrinoui (2015)

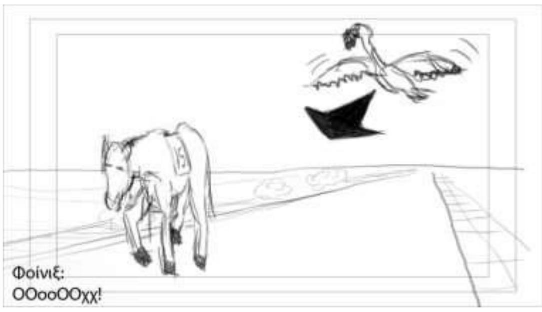
The positioning of the moving camera added suspense in the scene where the bus rolls backwards. Placing the camera at a low height and in close proximity to the bus increased the sense of speed, and the feeling of danger was created by having the tyres roll into a ditch with off-road obstacles passing underneath the camera.

The backlighting, the textures, and the frame composition further increase tension through the rough surfaces on the side of the road and with the metallic elements such as the grill of the vehicle.

Although I intended to build anticipation for an imminent accident, the upbeat music and the blue sky do not foreshadow a catastrophe, as the bus later stops without falling off a cliff.

Salt lake stroll

The salt lake scene begins with Olympia the horse walking alone.



Drawing from initial storyboard (26-10-2011)   Concept painting made on 8-10-2012

The location of the walk was a road in the first version of the script as well as in the initial storyboard. Upon reviewing the previsualised scene I assessed the effectiveness of the environment at evoking feelings that are consistent with a lonely and heartbroken character that is reflecting on her life decisions.

Revised concept painting made on 10-10-2012   Film screenshot Agrinoui (2015)

I replaced the road with a vast rough dry ground during a concept art revision. The lack of manmade structures gave an enhanced sense of solitude and the lack of a path or a road that would lead someplace supports her search for direction and purpose in life.

The horse is an important element in the frame that carries weight in the composition and provides context. If the horse was missing, the purpose of the shot and the psychological effects would have been lost. Moreover, if I had addressed the painting as being merely a landscape, the missing horse would have created an empty space that could have provoked the addition of unnecessary objects to make a pleasing composition. Although the facial characteristics of the painted horse were not accurate, the painting enabled specifying an effective composition that prevented positioning redundant objects that could have adversely affected the communication of the story. The environment had to be unthreatening as Olympia meets an optimistic flamingo who makes her feel less sad after a friendly conversation.

Making a new friend on the Salt lake. Agrinoui (2015)

The calm feelings on the salt lake are supported by uncomplicated frame compositions. Elements that induce calmness are the flat ground and the thin horizon line. The heaps of salt do not appear threatening as they are lower than the eyelevel of the horse, they are white and they lack sharp edges. If the background contained tall sharp mountains, and the foreground was rocky with pointy shrubs the setting could look more adventurous or more dangerous.

A calm-inducing element is the cloudless soft-coloured sky which does not have the sun within the frame. A visible bright sun could have suggested extreme heat and undesirable brightness contrast. The shallow lakes of water indicate that the conditions are not uncomfortably dry.

The ground has soft colours and lacks the potentially distracting strongly shaped dark shadows in the concept paintings that aimed to reflect the troubled mind of Olympia. Furthermore, I could not justify having indiscrete shadows as they could set expectations for a negative development which would not be fitting for the introduction of the friendly flamingo in the following shot.

The subtle camera motion and long takes, during the stroll of the flamingo with the horse, provided a reassuringly calm pace that brought the focus on a new friendship being made.

The beach at night

The beach environment was chosen specifically as a fitting backdrop for a calm and meaningful dialogue about the horse's life choices.

The relaxed and welcome atmosphere is supported by the friends sitting down around an illuminating and warm campfire. The colour scheme separates the foreground that is lit from a warm light source from the background that is dimly lit by the high colour temperature night sky making distant surfaces dark blue. The dark areas outside the friendly circle isolates the friends from the outside world. However, the picturesque surroundings and the bright moon support the overall sense of being in a comfortable and safe place. The clues that indicate the lack of strong wind include the calm sea, the slow movement of the clouds, and the undisturbed fire flames. Audible gusts of wind could disrupt the conversation and introduce discomfort from flustering hair and the erratic motion of the campfire flames.

On either end of the beach and at equal distances from the campfire there are unthreatening structures that provide a sense of balance and connection to the outside world. The castle is illuminated as a tourist landmark that symbolises resilience and stability through its wide stable form and its stone material that withstood centuries of wear and tear. The stone tower of the lighthouse symbolises safety, dependability and guidance as it is meant to assist travelling ships.

The stages in this multiple case study started as empty spaces therefore the scenic elements were purposefully shaped, coloured and positioned to provide a fitting ambience and frame composition.

Although I critically observe the composition in the films that I watch, casual viewers do not need to be consciously aware of how backgrounds affect the perception of scenes nor are they expected to be aware of every symbolism used. In fact becoming aware of how a film was made prevents us from immersing ourselves into the cinematic experience.

Watching a film for a second time, after knowing the plot can reveal clues to the viewer and decode meanings on a different level. For example, one might notice that the moon is not perfectly round and make a philosophical associations about the value of imperfections.

Waning gibbous moon and origami-shaped boat. Agrinoui (2015)

The cheerful slow-moving origami shaped fishing boat adds life to the background discretely. A tall ship with lights would have created a needless distraction and a warship would have introduced a threat. Quantity also mattered as additional boats would have made the sea unpleasantly crowded and distracting.

The forest

Forest scene. Agrinoui (2015)

The choice of a calm location supported relieving the tension that was built up in previous scenes. Olympia leaves her troubles behind in the forest and her mood becomes playful with Agrinoui.

Greenery, the river, and the clear sky support an optimistic outlook. The discussion among friends during a stroll is covered with long takes and with smooth camera motion to provide a relaxed mood. The bridge crossing symbolizes Olympia leaving the past behind as she is seen enjoying running again for the first time after her disappointing race at the beginning of the film.

The Temple of Apollo

Temple of Apollo scene. Agrinoui (2015)

A friendly race between Olympia and Agrinoui ends at a picturesque archaeological site. Ancient buildings often have an imposing architecture due to the tall columns and a ceiling height suitable for giants.

Hard-edged structure elements and free standing vertical stone columns can make an environment feel stressful. However, within the context of the film the ruins are part of a touristic site that is supported by the view of the sea and the calming light of the golden hour.

Environments can psychologically affect characters in several ways. For example a rollercoaster can cause excitement or fear. A flower on a grave can help express how a mourning character feels after having lost a loved one. A candlelit dinner table enables highlighting subtle facial expressions in a romantic scene.

The stage of the ancient temple of Apollo acts as an enjoyable picturesque backdrop for the characters who are not distracted by the architecture because they feel comfortable in it. This comfort is expressed with acts such as running, jumping, and driving over the ruins. The characters not being concerned about where they are enabled the dialogue to focus on the deeper troubles of the protagonist.

Differentiated lighting can transform the temple of Apollo from being welcoming into being frightening. The stage can host a horror scene by having a frightened character walk slowly under a night sky while pointing a torch with a narrow beam of light on different parts of ruins in anticipation of a sudden dangerous confrontation.

Details such as vegetation have contributed to having a friendly atmosphere. The statues in the background are not missing parts and have Greek folk dance poses. The positive atmosphere supported the concept of predisposing Olympia to think constructively rather than to intensify a dispute, in the beginning of her dialogue, which could damage here friendship.

The scene ends with a bus driver arriving and stopping at the dialogue area on an ancient platform. Although the action is a nudge towards how some Cypriots park their cars on pedestrians, the friendly romp is primarily meant to highlight the joyful mood of the group. The mood enabled getting directly to the point of the dialogue as the scene ends with asking the key question of whether Olympia will race at the track.

Night at the racetrack

The night before the final race in Agrinoui (2015)

Olympia had a hurdle to overcome before competing in the final race as she had to confront her father over having quit racing in the first scene. The setting of the daughter-father conversation is at the empty racetrack at night-time, and foreshadows a negative outcome as the father explains why Olympia is unfit for participating in the race. Although Olympia seemingly tries in vain to convince her father to let her compete, a plot twist occurs in the scene that follows where Olympia is shown participating in the race.

The night scene starts with Olympia entering from a gate with her father standing at the entrance. The positioning of Olympia between two walls and behind a barrier that separates her from the track symbolises that if she wanted to race she had to first regain the support of the gatekeeper whom she had abandoned. Other elements that made the position of Olympia seem unfavourable include the missing cheering crowds, the moonless sky, the dark stadium screen and columns that block the view of the sky as well as the railings and shrubs that obstruct access to the racetrack.

The final race, on the following day, occurs on the same racetrack stage with differentiated lighting. The bright blue sky combined with the excited crowd, the enthusiastic commentator, and the encouraging music provided a dramatic mood shift. The subject of differentiating a stage has been addressed in the review of relevant literature and practice (see chapter 2, pp 59-60).

Permissible errors

Although technically we can specify the appropriate amount of detail (see chapter 4, page 156), determining whether certain visual errors can be left in a film may not be as clear-cut. Factors that affect whether to leave uncorrected errors in a film include budget/time constraints, and how noticeable a problem is which can be a matter of subjective judgement.

The stage development process largely involves dealing with applying improvements to visual issues. Whether a problem is of major importance or not may depend on its location within the frame.

Screenshot of a frame that includes oddly shaped shadow

The large plant, in the above shot casts an unnatural shadow. I chose not to devote time towards finding the cause and a fix for the problem because the attention of the audience is drawn towards the face of a talking character, which makes the error on the ground hard to notice.

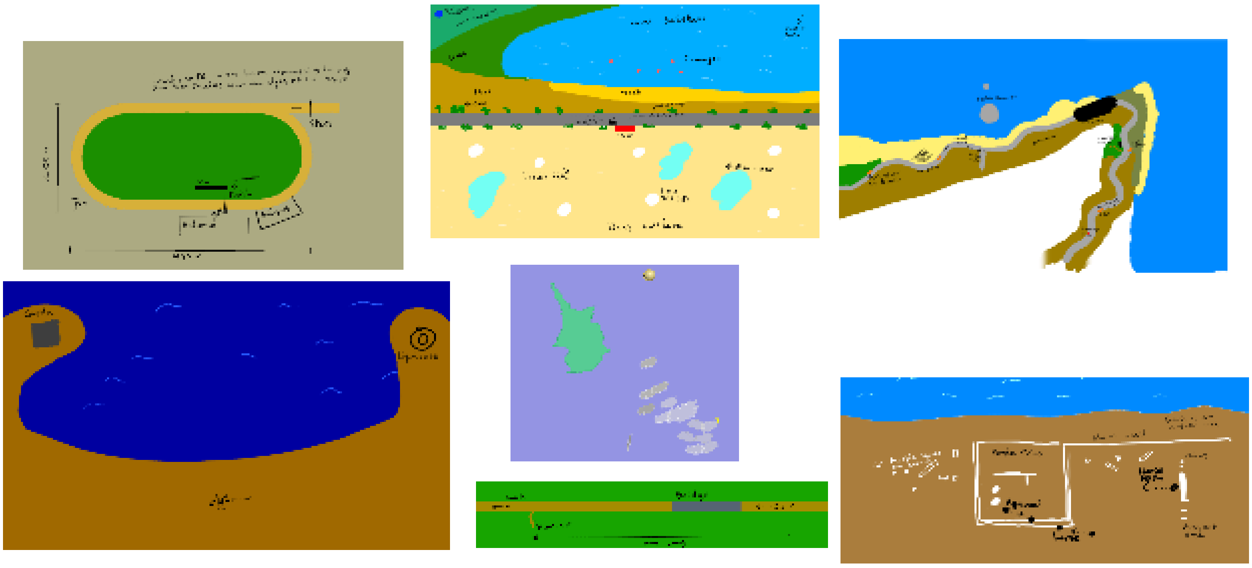
In another case, a lighting error was near the centre of the frame (see chapter 4, page 200). The decision to leave imperfections in the film can save production resources. However, if the errors are noticeable we risk affecting the suspension of disbelief in viewers.

Multiple Case Study – summation

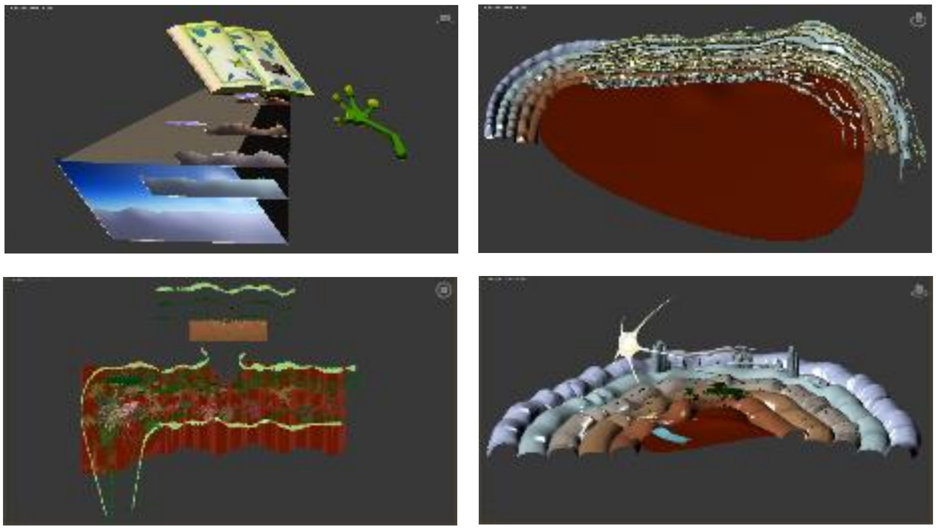
I have explored how stages with multiple acting spaces can host diverse scenes. The shape of a static multipurpose stage mostly remains the same throughout the animation sequence.

Dynamic Systems that rely on the repositioning of 3D modules between shots have enabled making larger multipurpose stages with a limited number of scenic elements.

The following drawings and viewport screenshots are the top views of the stages that were made during this research project.



Top views of the seven stages in Agrinoui (2015): Racetrack, Salt lake, Mountain roads, Beach, Flight, Forest, and Temple of Apollo



Top views of the 3D stages in Struthio (2011): Book, Flight, Jungle, and Savannah

The peak of this project was the making of a dynamic stage in which modular mountain elements transform the appearance of the terrain. The changes in the form of the stage enabled having a diverse mise-en-scène in different scenes that take place on mountain roads in Agrinoui (2015).

I propose Polymorphic Stage Design to be the term by which we refer to the creation of dynamic stages that can take different forms through the repositioning of modular elements. The rearrangement of modules that collectively form larger objects can provide differentiated compositions.

The production methods that are presented can enhance the efficiency of small teams but can also be applied in making animated series and feature films. Agrinoui, has the length of a full TV episode, and its production framework enabled team members to work simultaneously on character animation and stage development of a scene.

I have presented how the stages provided a streamlined workflow through the ability to work on multiple scenes with few project files. The limited number of stages, and the ability to render long sequences with minimal video post processing requirements facilitated the creation of a stereoscopic 3D version of Agrinoui (2015).

Agrinoui (2015) Anaglyph 3D screenshot

Thickness of lines and paintbrush strokes

We can capture a full shot and a close-up photographic image of a real tree and expect both pictures to be detailed, as the wide shot can contain thousands of leaves and the view of a single leaf can make individual veins distinguishable. However, when the camera approaches small parts of a painted tree, details such as leaves will likely be displayed as coarse brush strokes because of the finite amount of detail.

The flower in the wide shot has fewer petals.
Little Furry (2016). Episode: Yeti blues

The decision can be subjective regarding whether or not to have a constant stroke width in different types of shots. The above screenshots indicates that separate elements can be handled differently. The close-up shot of the flower in the above example has a flower with more petals compared with the wide shot. By not increasing the outline thickness of the flower, it was possible to add detail such as the stem and stamens which would not have room for internal colour with wider outlines.

Conversely, although the line width of the flower has remained the same in both shots, the white hand comprises of thicker lines in the close-up shot. From a technical standpoint, both the hand and the flower are acceptable as no noticeable image distortions are introduced in the closeup shot such as pixelated elements or visible vertex edges in curves that should appear smooth.

Several scenic objects in Struthio (2011) have simulated ink outlines stemming from toon shaders. The process of defining which objects would be given outlines was affected by a personal understanding of using lines, shapes and colours, as well as from the needs of a scene because adding outlines to a distant object could place unnecessary emphasis to it.

To set the outline width, I compared test rendered frames and selected the preferable version. I proceeded by setting up a system for the automatic change of outline widths based on the distance of an object from the camera.

Outlines of rocks have the same thickness despite the FOV change. Struthio (2011)

Considerations of object scaling were also part of the creation of Agrinoui (2015) which makes use of painted texture maps whose brushstrokes can appear too big when the camera approaches certain surfaces.

Full size diffuse texture map of mountain range

Cropped image of mountain texture

The painted mountains contain brushstrokes that are normally unsuitable for being displayed in close-up shots. In shots with narrow FOV the mountains were shown out of focus, and as the blurriness hid the coarse brushstrokes, there was no there was no question of replacing the object with a more defined version (see chapter 4, page 152).

Project findings

Advantages of a different design approach

Films can be seen as an assembly of the collective sum of scenes that can be addressed as individual subprojects within a production. The number of stages a film is often connected to the number of different acting spaces.

Instead of partitioning a film into the number of acting spaces, I included on a stage multiple locations that share a common environmental theme. A stage with multiple locations can cater to a larger number of shots which can offer the following advantages.

The primary effect incorporating inclusive stages in a production is the reduction in the number of project files, required to make a film. The number of 3D assets is reduced when multiple locations become part of one stage as grouping locations by theme enables displaying the same background elements from different acting spaces.

Most 3D graphics projects use an interlinked file system which connects 3D geometry with files such as texture maps. A reduced number of stages can provide a more manageable project file system as fewer file connections would be needed for making a film.

The rearrangement of groups of 3D Modules made them appear transformed as they were shown in different scenes. A significant amount of resources can be saved by showing the same 3D assets in different scenes as it can reduce the modelling requirements, it can simplify asset management, and it can reduce the computational requirements of a stage.

The inclusive stages presented in the multiple case study enabled working efficiently on long sequences. During the making of Struthio (2011), and Agrinoui (2015) frequent cycles occurred in which improvements were applied iteratively. Each revision cycle had have three phases which started by rendering a preview of the sequence, followed by identifying the areas that needed attention, and ended with the execution of improvement tasks. As the length of a sequence increases, the total number of revision cycles needed to make a film is reduced

A significant amount of work-hours was saved by the reduced number of review cycles as the preparation of each preview rendering assignment involved manual procedures. Furthermore, as each assessment cycle addressed long sequences, it resulted in more observations that enabled artists to work with longer intervals on implementing improvements before receiving updated feedback.

Static stages such as the Savannah (see chapter 4, page 112) have a fixed form which enables us to see different locations by changing the position of the camera. The Mountain Roads is a dynamic stage that can provide additional views by repositioning scenic elements (see chapter 4, page 169).

Static multipurpose stages

Static stages can have multiple locations within a shared environment. In these cases it is the camera that changes position while the scenic elements remain still. I have explored the possibility of having the same background visible from two locations that have a different terrain morphology near the camera.

I have also explored the conditions under which the same environment can be presented multiple times and appear each time as being a different location.

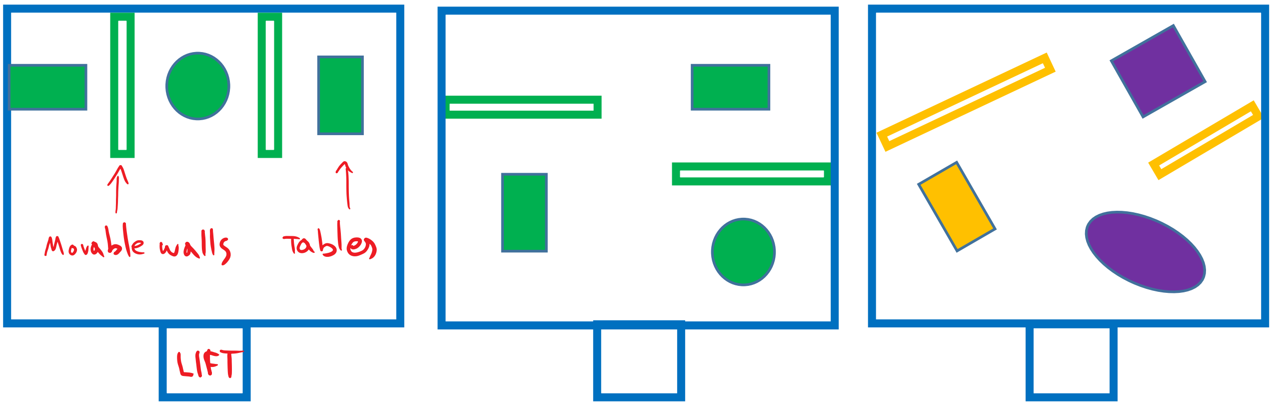
The Savannah stage (see chapter 4, page 112) consists of acting spaces that are located on the same ground surface, thus enabling wide camera panning motions that were useful for creating an establishing shot. However, static stages can consist of unconnected sections (see chapter 1, page21) with the purpose of enhancing productivity.

Dynamic multipurpose stages (Polymorphic stages)

Modular scenic elements enabled changing the appearance of certain stage locations.

Polymorphic stages take advantage of the homogeneous characteristics of a shared environmental theme between two or more locations. Scenic elements, such a mountainsides can act as modules that when rearranged to provide the appearance of different landscapes. The nine images presented in the polymorphic stage case study (see chapter 4, page 169), correspond to shots that belong to a timeline that spans approximately four minutes. Each stage configuration was stored in keyframes that were positioned on the timeline of the 3D project to coincide with the first frame of the corresponding shot.

The following representative example illustrates how a dynamic polymorphic stage can operate. A stage that has the form of an office space can be used to portray different office floors within a building. In this scenario each floor is differentiated by changing the arrangement of the same dividing walls and furniture such as desks and chairs. A number of stage arrangements can be stored within keyframes which contain the position and orientation data of the dynamic objects. Any of the stored stage arrangements can be retrieved by placing its corresponding keyframes on the desired frame on the timeline.



Top view floor concept drawing of transformable office space

The first two layouts represent a rearrangement of object on the stage floor. The third layout is indicative of the possibilities of changing additional properties of the objects. Keyframes can store changes in the shape such as a non-uniform scale as well as changes in the material such as the diffuse colour.

A stepped keyframe can instantly change the shape with practical object distortions such as bend, twist, and squash. Lighting properties such as intensity and colour can also be changed. Changes in the positioning and the properties of lights enabled displaying the race track stage in daytime and evening scenes (see chapter 4, page 209).

Types of multipurpose stages

- A stage with independent environments: The stage contains separate areas which comprise of elements that exclusively appear on each respective environment. An example in which no scenic element appears in more than one environment is presented in the introductory chapter (see chapter 1, page 21). This setup streamlined the procedure for assigning rendering tasks; for managing sequences with several shots; it simplified asset management; and it enabled handling character animation on 8 locations from within one 3D project file. A negative characteristic of this approach is that the unified 3D scene will consume more computational resources compared to addressing each 3D environment as a separate project.
- Shared background: A stage with several acting areas which share a common background such as the Savannah stage (see chapter 4, page 112). Separate scenes can take place in different areas of the stage. The background can comprise of elements that are visible from multiple locations if the camera points in the same direction on the horizon. Compared to having isolated environments, this type of stage offers improved scenic optimisation as the same stage elements can be shown on multiple occasions.
- Alternative appearance: A stage with a single environment such as a path in the jungle (see chapter 4, pp 126-129) can be presented in different ways so as to imply the existence of different locations. Environments that comprise of homogeneous elements can make the audience think the traveling action occurs in changing locations when in fact the camera remains in the same area. For example we may not need to build the entire route if we need show movement through the corridors of a hospital since they may look similar. In which case we can show travelling through a certain section multiple times and imply that the camera has moved to other parts of the building.
- Dynamic: Stages can have moveable scenic elements that can be repositioned for different shots. The purpose of moveable objects in the Race Track stage (see chapter 4, page 152) was to reduce the number of stage elements thereby reducing the computational load of the stage.
- Polymorphic: Modular scenic elements can be assembled differently to create diverse stage layouts. Polymorphic stages serve several purposes as presented in the Mountain Roads case (see chapter 4, page 172) which shows how the layout of mountains changed for creating different landscapes. The reuse of a limited number of mountain modules helps to avoid wasting significant amounts of computational power, and it helps reduce amount of work to make the 3D models. Moreover, the efficient production system enabled managing and rendering long sequences with few project files. Therefore, although modular dynamic objects require careful planning, they can pay dividends during the production of the film.

Efficient production workflow

This project provides explanations regarding the combination of actions that enabled making two films efficiently.

Main characteristics of the efficient production systems:

- Inconspicuous display of the same stage elements on multiple occasions in films.
  - Static background elements that are shown from different locations. A notable example is the salt lake stage (see chapter 4, pp 161-162).

    - The context of a scene can make the same acting space be perceived as a different location as indicated in the case of the Jungle stage (see chapter 4, pp 127-129).
    - The appearance of objects can be conveniently diversified with colour and lighting changes, and with transformational changes such as rotation, scale or a horizontal flip.

- Single sided and flat stage components required limited effort to create and had limited computational requirements as long as they were shown from specific distances and angles. Notable examples include is the creation of
    - trees and shrubs (see chapter 4, pp 153-154)
    - Plants (see chapter 4, pp 201-203)
    - Ground cover (see chapter 4, pp 197-199)
    - Semi-circular mountains (see chapter 4, page 151-152)
    - Roadside dirt (see chapter 4, page 181)
    - Buildings (see chapter 4, pp 188-190)
    - Mountain modules (see chapter 4, page 172)

- Asset library system
    - Computationally lightweight 3D assets enabled the development of library systems that could display numerous environmental scenic elements simultaneously in real-time. (see chapter 4, page 132)
    - The single library system for environmental elements provided instantaneous access to scenic objects for them to be imported onto stages.
    - The library project files acted as a workplace for developing 3D models. This further simplified 3D object access and file management (see chapter 4, page 153).

- Systems for managing groups of single sided objects such as trees and small plants.
    - Automation of the orientation of 3D assets enabled multiple objects to face the camera with a single Look-at control (see chapter 4, page 157).
    - Wedge system for ground objects within the field of view (see chapter 4, page 203).
    - Versions of objects with a low LOD were normally positioned at longer distances from the camera (see chapter 4, page 154).

- The total number of 3D stages was reduced by including two or more locations. A notable example is the Savannah stage (see chapter 4, page 112).
    - The low total number of stages enabled working with fewer project files.
    - Large stages enabled each revision cycle to contain observations that concern long sequences, which led to each work session to address more improvements.

- Team work was feasible by enabling simultaneous operation on the stages and on character animation. (see chapter 4, pp 212-214)
    - A practical procedure for merging the separate animation and stage work was beneficial as this task needed to be performed periodically for rendering single-pass preview videos.

    - Working on character animation without the presence of detailed scenic objects and vice versa provided a more responsive workspace in terms of managing computational resources.

- Multiple planning documents were made for the Mountain Roads stage (see chapter 4, pp 170-171). Planning material such as top view stage drawings and 3D previs enabled
    - Developing stage form concepts economically with rough quality
    - Having worked out a stage form that can cover the compositional needs of all the shots in a sequence before the production phase during which fundamental changes can be more timeconsuming.
    - Avoid the deletion of a scene during the production phase. Having edited the entire film with previsualised material reduces the chances of later finding that a scene does not work out as expected.

- A series of computational optimisation measures enabled rendering preview sequences at a speed that did not reduce productivity, and with limited computer requirements. The optimisation of 3D graphics extends beyond applying no more detail than necessary to 3D models (see chapter 2, pp 56-57) as it also includes specifying settings for lighting, materials, and the rendering setup. The mindful distribution of computational resources towards making the surfaces obtain the quality seen in Struthio (2011), and Agrinoui (2015) enabled having frequent, economical and speedy review cycles of each sequence.
  The development of film preview systems took advantage of
    - a technical research of tools during development and preproduction of the two films which enabled making informed decisions about allocating production resources.
    - a study concerning the required properties of objects that enter the frame of each shot by taking into account conditions such as depth of field as focus blur can enable reducing the level of detail in certain areas.

  The choice of tools and how they are used can vary greatly between productions. The presentation of how specific software operates falls beyond the scope of this research project. However, the processes that are presented can be performed in most professional 3D computer animation software packages.

- Repositioning of dynamic modular scenic elements
    - The information regarding the position, rotation and scale of moveable scenic elements was stored in Keyframes (see chapter 4, page 152)
    - Modular objects that act as clusters of trees or clouds when positioned closely together can be rearranged to form different outline shapes (see chapter 4, pp 194-195).
    - Groups of modular elements can be rearranged to appear as different types of structures such as a bridge that transforms into old walls for the needs of different shots (see chapter 4, pp 186-187).

  Dynamic systems enabled
    - changing the stage layout to compose different landscapes (see chapter 4, page 174)
    - Positioning background objects within the field of view of different shots for reducing the amount of geometry on the stage (see chapter 4, page 152)
    - Creating the appearance of a large area of detailed ground with the use of a moveable patch (see chapter 4, pp 165-168)

- Development process for efficiently making multiple versions of scenic elements (see chapter 2, page 62).
    - Standardised procedures enabled creating diverse versions of trees, mountainsides, and sky backdrops (see chapter 4, page 206). The common modelling and texturing approach enabled making additional versions of objects significantly faster than the first one.

Writing for multipurpose stages

The choice of locations, when writing a script, has a direct impact on the cost of film production.

Although production resources can be reduced by limiting the number of environments as well as of action scenes, this project looks at less obvious factors that affect costs.

Instead of trying to limit the number of locations, I have limited the number of environment themes. During the writing process of Struthio (2011) I chose to place actions in different savannah locations (see chapter 4, page 112). The common savannah environment was key for making a stage with three acting spaces that have a shared background.

A writer that is not aware of how the shared background theme affects stage design, could come up with more expensive locations. If instead of the shared savannah, one of the scenes had to take place in a small village, then the village would probably have to be made on a separate stage. A production becomes more fragmented as stages are added.

A script that is written without trying to choose locations with a common theme can be adapted so as to create suitable conditions for multipurpose stages. I have found that the choice of location does not always affect the action that may be driven by the inner motives of a character. Therefore, changing the location for a short scene, for example of someone joyfully walking his dog, from a beach to a forest that already features in another scene in the film, may not significantly alter the meaning of the scene, but it can reduce production costs.

The rewriting process could start by distinguishing the scenes that are not tightly connected to certain places. At this point the writer, the stage designer and the director can look for ways to combine two or more environments, with common characteristics, aiming to create single multipurpose stages. Here is an easter egg ✋.

Making a script highly compatible with multipurpose stage design can be decisive for greenlighting animation projects with a limited budget. The rewriting process could start with a re-evaluation of the purpose of each location in relation to the story. Scenes that are connected to specific locations may have to be substantially altered so that the edited storyline can be told with fewer environmental themes but possibly with more locations. Numerous locations can be made economically by reusing scenic objects with the commonly practiced use of 3D asset libraries (see chapter 2, page 56). However, the methods that are explained in the multiple case study mainly concern the ability to make films more economically by making fewer stages that can host longer animation sequences because of incorporating multiple acting spaces.

The scripts of Agrinoui (2015) and Struthio (2011) influenced the stage design approach as knowing the framing needs of each sequence was key for purposefully shaping the stage. However, since multipurpose stages can host a range of actions and camera positions, they can be reused for creating additional content. For example, a stage that enables creating a scene consisting of an establishing shot and over-the-shoulder shots of two flamingos having a friendly dialogue, can also provide similarly framed shots for showing a heated argument between two emus.

Chapter 5: Conclusions and recommendations

Introduction

This research project started with knowledge, from previous professional experience, indicating that multipurpose stages can provide productivity advantages when making computer animated films. This project enabled me to explore the conditions that would make a stage with multiple acting spaces a better choice over having multiple independent stages. During the exploratory research I designed and developed stages that could host diverse types of actions on different locations. The explanatory part of this project includes an extensive commentary on how certain products were made.

The production workflow benefits that were identified in the studied cases stemmed from the ability to work on multiple animation scenes with one stage. The ability to work on large sequences provided a streamlined process for making progress reviews as well as for the implementation of animation and scenic improvements. Working on large animation sections can improve the productivity of the director as he can communicate more issues with each progress review cycle. Moreover, it enables the stage developer to work with fewer and less fragmented project files. Moreover, it enables the character animator to animate continuous sections of the film with visual feedback over the flow of an entire scene. Finally, the ability to assign rendering jobs that span the duration of an entire scene can save work hours because of the fewer times that rendering tasks are initiated over the course of the production.

The effectiveness of multipurpose stages can be compromised by poorly managed computational resources. By combining several 3D environments on one stage, we are bound to increase the number of 3D objects, and thereby also computational loads compared to working on multiple stages independently. However, the presented optimisation measures enable limiting the adverse computational effects of having a stage with multiple locations.

Inclusive stages in films and TV series

Multipurpose stages that cover the needs of multiple scenes can be integrated in films with various durations, budget sizes and technical specifications.

The ability to efficiently make films with reduced resources enables small teams to make lengthy films, whereas productions with higher budgets can choose to distribute costs savings towards other areas such as talent recruitment.

The racetrack stage (see chapter 4, pp 148-149) hosted two races and four dialogue scenes. This indicates that TV episodes can take advantage of multipurpose stages as they can be reused within different story contexts.

Agrinoui (2015), with a play-time of 19 minutes 40 seconds, can be seen as a pilot episode for an animated series, with subsequent episodes being cheaper to produce due to the reuse of the models, textures, rigs as well as lighting and rendering setup which have already been developed.

Agrinoui also has the potential to become a feature-length film adaptation. Although a 100-minute feature film could need five times the number of stages used in Agrinoui, economy of scale suggests that the amount of necessary production resources would be less than fivefold. Making a feature film that takes advantage of established guidelines from a proof-of-concept short would have reduced requirements in developing additional art as new stages would follow a common line. Similarly, for making additional stages, time would be saved while carrying out lighting, texturing and modelling tasks by reusing or adapting pre-existing material such as 3D assets, lighting rigs as well as established map painting procedures.

Multipurpose stages are normally designed to cover the needs of multiple scenes in commonly themed locations. A stage under the described conditions will not cease to offer productivity benefits if it contains objects that are not shown in all the scenes. The savannah stage (see chapter 4, page 112) contains foreground elements of three locations that are not displayed in every scene. Moreover, objects that are composed of modules can take the form of different objects as indicated in the example where the elements of a bridge were rearranged to resemble old ruins and walls shown in other shots (see chapter 4, pp 186-187).

Production efficiency is generally desirable regardless of the amount of available resources and thus multipurpose stage practices are not limited to low-budget or small-scale productions.

Optimised Inclusive stages

A major criterion for making 3D objects without excessive computational requirements is to avoid adding detail that will not be registered in the rendered frame (see chapter 2, page 57).

The appropriate LOD of an object can be defined with precision (see chapter 4, page 156) by measuring its presence within the frame. However, the direct observation of test renderings enable comparing how a change in a setting affects the image and rendering speed. Such tests can help determining things such as the point where lighting settings can provide shadows with acceptable quality in order to avoid devoting computational resources towards rendering unnoticeable effects.

An object on a multipurpose stage can have a significant presence within the frame of one shot, and in the next shot the object may cover a small area of the frame. The appropriate level of detail of objects on the presented stages was generally determined by observing the shot in which an object became most conspicuous within the frame.

The same fly was used in both wide and close-up shots of the scene

In wide shots the fly could have been made with a black dodecahedron. However, since the fly model was already on the stage I used that one consrantly because of a few reasons. Firstly, a higher than necessary LOD would not reduce image quality in wide shots. Additionally, an increasw in the number of animated objects would have led to managing more objects and consequently a more complex workflow. Finally, a comparative test render with the fly hidden indicated an insignificant performance reduction in processes such as real-time graphics display within viewports and rendering speed which meant that the use of a substitute low LOD fly model would not have noticeably improved productivity.

The detail in objects that is were not visible in a specific shot was generally not deemed redundant if it was shown in other parts of the sequence. The intention with computational optimisations was not to achieve instant execution of common tasks but to rather have a reasonable speed for commands such as a file save that can arguably take up to five seconds without noticeably affecting productivity. Performance sacrifices can be justified because of the streamlined workflow attained with multipurpose stages. If computational delays become substantial, such as a project file taking half a minute to save, the productivity benefits of multipurpose stages can be negated (see chapter 4, pp 97-98).

> *Technical note: An inclusive stage may contain groups of objects which are not shown in every scene it hosts. Processes that involve disabling lights or hiding groups of scenic objects enables the computer to display only the objects that need to remain visible in any given scene, thus reducing possible lag in viewports. The use of instanced 3D assets such as textured models enables having multiple copies of objects with a limited load on system memory (see chapter 2, page 49).*

Static multipurpose stages

A stage can contain acting spaces in different locations. These locations can be connected as they may belong to a common larger space such the presented racetrack stage from Agrinoui (2015) which contains a long running area and three acting spaces for standing characters (see chapter 4, page 148). Alternatively, the distance between two acting areas may not be clear in the film. Cases such as the Savannah stage (see chapter 4, page 112) and the salt lake stage (see chapter 4, page 161) that were used in Struthio (2011) and Agrinoui (2015) respectively have acting areas that seem to have a considerable distance between them in the film without their positions on the stage being far apart from each other.

A common method for having a reduced number of scenic elements in the aforementioned cases was through showing the same background elements from the different acting spaces.

The savannah stage has three locations with a distinctly different terrain in the foreground. The common background elements that are visible from the three locations are distant mountains, trees, as well as the sky with the sun and clouds. Interestingly, the topography of the background appears differently from each acting space because the distance between the three locations provides different points of view over the 3D terrain. As a result the stage with the common background enabled having three diverse locations with a shared savannah theme.

The theme relies on the appearance of the surfaces which can be altered to obtain different environments (see chapter 2, page 62).

Usefulness of modular design

A common practice in computer graphics to display duplicate copies of artificial objects that are expected to have a similar appearance such as the lampposts on a street or the balconies on a building. As mentioned in the review of relevant literature and practice (see chapter 2, page 55), modular design is known to be used for composing differently shaped buildings out of copies of a handful of pieces.

Groups of modular scenic objects enabled controlling the shape of a larger element. One example concerns the shape of large clouds in Agrinoui (2015) that can be changed by individually moving the parts of it is made up of. Similarly, tree formations of patches of trees, in the same film, were changed by altering the relative positioning of separate trees (see chapter 4, pp 194-195).

Another example deals with architectural elements on the stage with the temple of Apollo in Agrinoui (2015), which enabled displaying different layout versions of ancient structures and ruins. A repositioned group of ancient columns enabled displaying different archaeological sites with changed layouts on either ends of the stage in separate shots (see chapter 4, page 196).

The polymorphic approach enables conserving the amount of geometry on a stage by repositioning the same elements and by presenting them as different objects at different points in a film.

Multipurpose stages with dynamic minor modular scenic elements

I have presented management systems that enable reducing the number of objects on a stage based on the repositioning of scenic objects between shots. Minor stage objects such as trees and rocks whose purpose is to enrich the terrain can be relocated for the compositional needs of different shots (see chapter 4, pp 175-176).

Having trees in areas that are not within the field of view of the camera can create unnecessary and potentially avoidable computational loads. Repositioning systems enabled reducing the number of objects such as trees and clouds on a stage by making them reappear in front of the camera in different shot compositions (see chapter 4, page 158).

Multiple objects could be repositioned in groups, such as patches of trees, so that they can be placed faster within the frame of each shot composition. Scenic elements with a single normal side may need to be facing the camera head on. A procedure that entails specifying a point in space can make multiple objects automatically rotate to face the camera (see chapter 4, page 157).

Polymorphic stages (transforming stages)

Before designing a stage that can take different forms I had established how the modular elements of a larger object can be rearranged to appear as a different objects at specified moments on the timeline. The knowledge gained from making repositioning systems that formed differently shaped structures as well as clusters of trees and clouds provided the foundations for trying a new stage design approach.

Polymorphic stages are designed around the use of dynamic modules and enable making dramatic environmental transformations by rearranging major scenic elements. The presented polymorphic stage enabled composing different landscapes by rearranging mountain modules (see chapter 4, page 172). The module creation process involved photographing and observing mountainous terrains from ground level, followed by digitally deconstructing the view into separate landmasses which were turned into individual single sided 3D modular components. The modules comprised of layers of convex relief surfaces that depict the sides of mountains. The combined modules created the appearance of landscapes from specific viewpoints from which overlapping mountains could be shown that stretch far into the horizon.

The layers of mountainsides had to face towards the general direction of the camera to be displayed properly. As such, viewing the stage from above revealed gaps between modules and the lack of a unified terrain. Despite the limitations in creating high angle views, the versatile system enabled me to compose views from altitudes similar to the height of the tallest mountains.

Elevated landscape shots of polymorphic stage

The shape-changing stage enabled creating seven landscapes that surrounded the acting locations of road trip scenes. Different landscape themes can be achieved by changing the appearance of modules. Modules with differentiated textures and shapes can enable creating desert, underwater or snow covered landscapes while using the same principles explained in the relevant case study.

Polymorphic stage design affects productivity in the following ways:

- Efficient use of computational resources is achieved by having a low number of reusable modular elements on a stage.
- 3D modelling requirements can be reduced as modular elements can be assembled to form different shapes.
- The ability to limit the number of models leads to a simplified library management of 3D assets and texture maps of scenic elements.
- Handling a single stage for multiple sequences reduced the required number of project files for stage development and character animation. Every time a new stage is made certain tasks need to take place such as setting up the lighting rig, the rendering settings, and the placement of characters.
- A stage that can host long sequences can provide an unfragmented workflow that enhances productivity for direction, stage development, character animation, and rendering tasks. At the onset of each revision cycle, long preview sequences can be created by initiating a single render job. Thereafter, the review process enables identifying a considerable amount of areas of improvement. The cycle is completed with the uninterrupted implementation of improvements by artists who have an overview of a significant section of the film.

Writing for polymorphic stages

As a writer and a production designer of computer animated productions, I normally write or edit scripts while giving attention simultaneously towards being effective at what the project communicates as well as towards how the project can be efficiently implemented. Knowing how a scene can be realised enables me to adapt my writing to take advantage of cost-effective production practices.

Scriptwriters can adapt their work to fit within certain guidelines. For example a script can be written in compliance with a fixed TV episode format in terms of duration, locations, and characters. In this context a writer can be made aware of the broader polymorphic stage design rationale, to that he can avoid wording certain actions in ways that would prevent a sequence from being contained on one stage.

For example, if a story concerns the lives of office workers in a two storeys of a building, the writer could consult with the stage designer about the possible types of office spaces that can be made on one stage. It may be easier for a transformable stage that can display office rooms and corridors to take the form of a conference room, rather than that of a balcony overlooking a busy street.

Stage awareness can help writers avoid placing actions in areas that would entail making additional non-vital exclusive stages. A vital establishing shot that may need to be made independently could be that of the exterior of an office building that is followed by scenes inside the building.

It is difficult to justify making a stage that enables framing very dissimilar internal and external shots as the different subjects may not be easily composed out of the same scenic objects. The more a stage becomes loaded with objects, the more complicated stage management becomes and increased computational resources will be needed.

I saw significant productivity benefits by avoiding to divide stages into separate project files. A prime example is the mountain roads stage (see chapter 4, page 169) that could display numerous landscapes, which were the connecting visual theme, while offering an unobstructed workflow as it enabled working seamlessly on more than four minutes of film with few project files. I took advantage of the common theme in all the presented landscapes by using the same 3D models of roads and mountains to create different stage compositions.

Polymorphic stage design rationale: Working with limitations, and extensions in practice

A common characteristic in the presented stages is that they have designated areas for camera positioning and limitations regarding camera orientation and field of view (FOV). If the cameras were positioned outside the limits, the resulting images could have problematic perspective, objects with insufficient detail, and areas that are void of objects.

A stage may not offer a 360 degree view nor a high angle view of an acting space. However, the ability to frame specifically planned shots can enable covering the action in a fulfilling way that does feel as if there was a missing view.

A hypothetical example will demonstrate how a polymorphic stage can be built around a story that takes place in an external urban environment. The following story contains two office buildings which provide the desired shared visual theme and thus are fitting for designing a system that can take advantage of modular scenic elements.

> Two office buildings of competing companies owned by antagonising brothers are on opposite sides of a road. The owner of one company approaches his workplace on foot and notices a surprising banner hanging on the building across the street.

While making the shot-list we have the option to limit shot framing to views that only display one building at a time. In this case, we can make one polymorphic building that will shape-shift for different shots to make it appear as if there are two buildings on location. Buildings can be made out of an assembly of modules (see chapter 2, page 55).

The sequence could start with a wide establishing shot of a building with its owner walking on the pedestrian. The second shot is a close up of the person’s face as he turns his head towards the other side of the road, and drops his jaw as he reads the announcement of a competing product. Lastly, a subjective wide shot of the competitors' building across the street.

The building that is initially on one side of the road, becomes transformed and repositioned on the other side of the road for the final shot. The shapes of buildings can be diversified by repositioning modules such as windows on the façade, resulting in one version being a short and wide structure, and the other being tall and narrow.

Top view stage layout of urban road concept

Although, this stage could seem to be limiting in terms of framing choices, the sequence communicates the story effectively. This is because the system was purposefully designed to only provide the framing needed for a particular scene. The existence of a road system, outside the FOV, with junctions and building blocks is insinuated by showing narrow sections of a pavement and road in the frame composition of each building. The addition of a subjective shot of a vehicle driver, indicated with a red camera in the top view, would entail having a view that includes the road's vanishing point and additional buildings. Such a shot would dramatically increase the number of objects needed on the stage and the time needed to produce the sequence.

In general practice, the framing described storyboards enables evaluating production needs as the sketches indicate the visible surfaces. A study of storyboard frames provides an understanding of the parts of objects that do not need to be on the stage. If the external view of a building only exposes its front face, then making surfaces that are hidden from view would not be justifiable. Other parts that would not need to be made include internal structural elements that support a building, such as beams, pillars, and foundation. The stage designer's mind-set differs from that of architects and structural engineers as stage objects only need to appear functional on screen.

The aforementioned example shows on a small scale how polymorphic stage design can be incorporated within the development and preproduction workflow as stage plans can be drawn concurrently with storyboards. On a larger scale, the stage could have an area that extends two or three building blocks. Such a stage could enable displaying numerous different traveling scenes by using the rationale of the Mountain Roads stage (see chapter 4, page 172). Compared to the mountain theme, the urban theme would make use dynamic structural modules, instead of mountainsides, that would enable transforming the buildings for composing different cityscapes.

Elements, such as traffic lights, cars, pedestrians, trashcans, and signs can potentially be repositioned unchanged to reappear in different areas of the route of a driving scene. The same objects featured in multiple locations in Agrinoui (2015) (see chapter 4, pp 175-176).

Polymorphic stage design enables making diverse environments in the same space with a small number of modular 3D models and with a streamlined workflow.

Scenic elements in multipurpose stages in practice

A production plan enables foreseeing how the computer animation process will be implemented. It is normal for the pipeline to be shaped around meeting specific image objectives by exploiting a combination of available resources that is unique for each animation project.

Keeping 3D elements on a stage that do not serve a purpose can have a negative impact on productivity. Redundant objects can complicate scene handling, and can put a strain on hardware which can slow down loading, editing and rendering operations. A known solution to dealing with objects that do not have a place on a stage is to store them in an external 3D asset library (see chapter 2, page 56).

The presented stages occasionally contain objects that are only shown briefly. The water surface of the river appears for only four seconds in the following shot which is part of a 58-second scene.

Agrinoui (2015)

Although the water adds to the computational demands of the stage, its existence was justified because the total computational weight of the stage was not obstructing productivity, and because making a separate stage exclusively for this shot would have added a layer of complexity in terms of project management.

The reasoning behind this decision touches the core of multipurpose stage design which connects efficiency with a low total number of stages. Consequently, while one additional stage may not constitute a notable difference in the grand scale of a production, the practice of adding a stage for every panoramic view in a film could result in a significantly more complex project structure.

The seven in total stages in the film Agrinoui (2015) enabled streamlining the iterative design process of review and improvement cycles. The low number of stages enabled rendering long sequences and thus the film required a low number of render jobs for both previewing purposes, and for the final output of the sequences. The making of the stereoscopic 3D version of Agrinoui benefited in particular from the ability to render the entire film by assigning a limited number of rendering tasks.

Multipurpose stages that contain objects such as the aforementioned river water are at a disadvantage compared to having exclusive stages for each separate location in terms of rendering and handling speeds. However, the negative effects of having objects that are briefly displayed can be minimized by using known methods for optimising 3D computer graphics, and by implementing systems based on the demonstrated cases that have provided an unobstructed workflow with limited hardware costs.

Polymorphic stage design research extensions

Shape changing stages enable creating diversified commonly themed environments. I have demonstrated how modular mountain elements can form different landscapes, and I presume that there are undiscovered applications for moveable modular elements.

The presented polymorphic stage features mountainous roads (see chapter 4, page 169), and is based on a system that, as evidence suggests, would remain operational if we changed the landscape theme by altering the appearance of scenic surfaces (see chapter 2, page 62). In my opinion the differentiation of the appearance of modules would enable making underwater or even extra-terrestrial environments with predictable outcomes, namely multiple landscapes with camera positioning restrictions as explained in the case study.

Further research could increase our understanding of how transforming stages can be used in the industry by revealing additional types of modular scenic systems.

Conducting research in the field of multipurpose stages is most meaningful when it concerns creating products with contemporary industry quality standards. However, this could make comprehensive research projects costly as computer animated TV series are often made with considerable production budgets.

The costs associated with research for designing innovative modular production systems can be justified as polymorphic stages enable reducing production costs by providing efficient production frameworks. Incorporating such research projects within the production of independent animated films has certain advantages. Primarily, a researcher that has the role of executive producer in a small scale production will have more freedom to adjust the production framework compared to directors who work for major studios that operate with already established production pipelines. Moreover, workers at major studios are normally required to sign non-disclosure agreements which essentially prohibit sharing inside information.

Further exploration of polymorphic stage design could involve trying the use of dynamic modular systems in stages that enable displaying different subjects in ways that were not covered in this project.

If we used the design rationale of the Mountain Roads stage (see chapter 5, page 169) to make a similarly versatile stage with city roads we could work in the following direction. A stage could be based on the urban road concept (see chapter 5, page 242), but have a road that spans the length of three building blocks. Modular structures of buildings (see chapter 2, page 55) could be repositioned at different points on the timeline to form diverse cityscapes for both traveling and dialogue scenes. Specifically, such a stage could enable displaying actions of following a travelling vehicle through seemingly different city areas, and of dialogues between walking pedestrians in front of detailed shop windows.

Polymorphic stages use sets of modular elements that can be repositioned to transform the shape of a location as long as each new environment is similarly themed. Examples of internal environments with shared themes include prison cells, hotel rooms, classrooms, and hospital corridors. Such types of stages can take advantage of the documented observations (see chapter 4, pp 127-129) on making the same location appear as if it is a different place.

A previously mentioned concept polymorphic stage features different floors of an office building and takes advantage of dynamic scenic elements (see chapter 4, page 231).

Polymorphic stages in relation to level design

The case study that concerns the stage with a mountainous winding road explains a design approach that is similar to drawing a car racetrack for a racing game. Planning involved drawing a top view of a long road with bends that marked several spots where different scenes would take place.

The map provided a visual reference for the positioning of actions in physically different locations.

The levels of videogames can contain complex street networks. Traditionally, 3D videogame levels are made in full by the developer who can position multiple instanced copies (see chapter 2, page 49) of objects, such as streetlights, on different roads. 3D game engines commonly use an automated system that makes visible only the objects that come within the field of view of the camera. Thus, game engines enable the hardware to process only the 3D objects that the gamer needs to see.

Polymorphic stages are different in that they entail managing a reduced number of objects. For example, a stage with interconnecting roads could make use of a small number of street lights that would be visible in one shot. The group of streetlights would take a different position in accordance with the framing of each subsequent shot.

A major difference between a game level and a polymorphic stage is in that the stage developer can work with objects that have significantly more detail than the level designer working within the same computational envelope. If we increase the amount 3D geometry that is displayed on the developers screen, at some point lag will be introduced that can negatively impact productivity.

As a level design researcher and practitioner I find useful to be able to simultaneously see all the contents of a level while working on it in the graphics application.

3D models for games are generally made with fewer polygons compared to models that are made for films. As such the display of a hundred 3D trees for games within the viewport of a 3D application could have a similar computational load as a single tree for film due to detailed features such as individual branches and leaves. Therefore stages for animated films can have fewer objects visible within the viewport compared to game levels. The presented Mountain roads stage enabled having all the stage elements simultaneously visible in the viewport because the dynamic repositioning systems lowered the total number of 3D objects (see chapter 4, pp 172-176).

There are connections between certain top-view layouts of my stages and level design practices. For example, the layout of the mountain roads and the horse racetrack stages could resemble that of racing games as the environments feature a long route and a complete racing circuit respectively. Modular repositioning techniques enable working with fewer but more detailed objects on the stage, compared to game levels without requiring significantly different computational resources.

Polymorphic stage layout for internal and external spaces

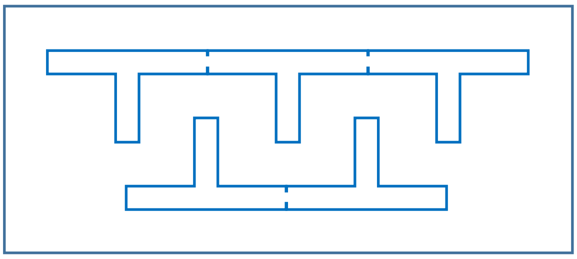
The width of roads and pavements in Agrinoui (2015) had realistic dimensions. Knowing the size and the shape of the ground where the characters will be moving enabled me to establish the exact shapes of acting areas with floor plans.

I used the dimensions of actual racetracks to create the layout of the racetrack stage. Establishing the shapes of foreground spaces preceded addressing the layout of surrounding environmental elements.

The top view plan of the Mountain Roads stage was a map of a winding road with notes concerning the position where each scene takes place on that road. The entire layout was blocked out with low resolution 3D geometry for making the previs which provided a practical visual overview of how the key locations are interconnected. The blocked out stage acted as a guide for overlaying the more detailed dynamic mountain modules and for changing their position depending on the framing of different shots (see chapter 4, page 170-172).

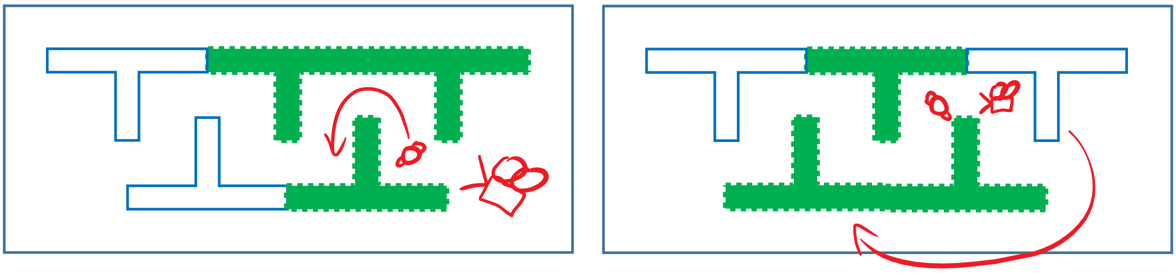
The following example explains how the design approach can be adapted to different kinds of environments.

A map can refer to the paths in a hedge maze that would enable a polymorphic stage to host sequences of people trying to find their way out. The floor plan visually inform us about where each action takes place. One benefit of containing the entire traversed path on one stage is the avoidance of continuity errors such as having a consistent sun orientation between shots.



Top view layout of a garden labyrinth

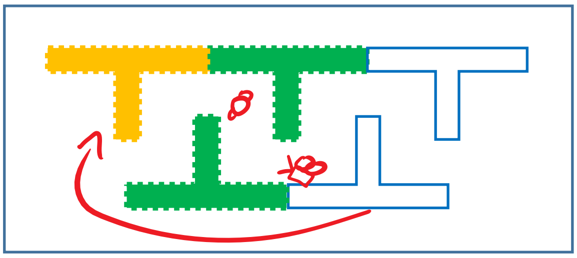
The layout indicates the possible positions for the detailed dynamic modules that would be laid over the stage frame during the production phase. As with the Mountain Roads stage, the hedge maze can be made with low resolution geometry for a full previsualization overview.



The blocked out stage acts as a guide for positioning the
detailed modules (green) within the FOV

Once the upper right module exits the frame, as the camera travels through the maze, it is repositioned to be presented again as walls that are further down the path.

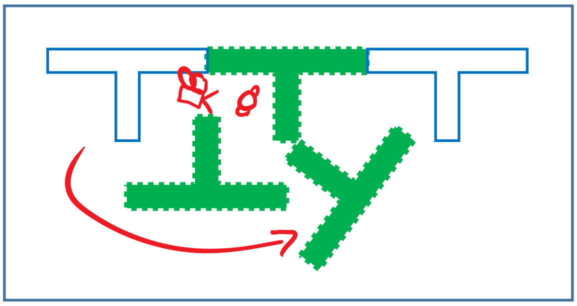
This use of module repositioning serves to reduce the amount of geometry on stage. However, a characteristic of polymorphic stages is that they can make locations look different.



Module repositioning and differentiation

A module can obtain a different appearance by altering certain properties that are saved within a keyframe (see chapter 4, page 231). The colours of the vertical green hedges can be changed to appear withered (see chapter 4, page 198).

Another way for differentiating the appearance of a location is by changing the topography.



The module takes a position that changes the layout

The action in the image above is of the person turning around and realising that the pathway behind him has changed revealing a new exit.

This knowledge can be applied for creating layouts with interconnected or isolated spaces. The hedge maze for example could be ten times larger and it could host scenes of two persons wandering in different locations of the stage.

Internal spaces can vary in shape and theme as stages can depict concert halls, cinema complexes, hotels, caves, dungeons, prisons, schools, etc. The above example indicates a general approach for drawing top views featuring corridors and rooms. For example, the camera could follow a person walking out of a hotel room into the corridor and then into another room in a continuous shot. The entire first room can be moved to the location of the second room during the time that the camera is in the corridor. The room can be altered so that it appears to be different (see chapter 4, page 231).

3D graphics optimisation

The level of detail of 3D objects can be adapted according to their relative size in the frame. For example, a flower could be seen as a coloured dot from the perspective of a brachiosaurus, but more detail would be needed for a subjective shot of a bee approaching the flower (see chapter 2, page 57). A flower with individual petals within the frame of a subjective shot from a brachiosaurus would probably not cause a substantial computational load. However, covering the large ground area within the field of view of the brachiosaurus with thousands of plants can make the project file prohibitively heavy.

Prudent use of processing power does not necessarily affect productivity. For example if we had to superimpose a 3D basketball over wide shots of live footage, the ball could have more detail than necessary without noticeably slowing down computational processes on workstations that are capable of handling higher workloads in real-time. However, this project is different in that it addresses making long sequences with multiple 3D objects. Therefore, optimisation measures were key to avoid creating overwhelming computational loads that would have adverse effects on productivity and/or on hardware costs (see chapter 4, pp 97-98). My general approach towards making 3D models was to assign just the amount of detail needed which was determined by studying the shot in which each object would appear most prominently within the frame (see chapter 5, page 138).

Objects that appear in large numbers, such as groundcover plants, can demand a significant amount of computational resources. Therefore, I took special care to make plants with appropriate levels of detail relative to their distance from the camera (see chapter 4, pp 197-199). Another method for minimising the amount of plants, was to have them concentrated in within the field of view and by repositioning a group of plants in front of the camera for different shots (see chapter 4, page 203).

Being aware of the visual properties of 3D objects compared to planes that display images of objects, enabled me to selectively make specific elements with low computational requirements and with a suitable appearance. I made hollow objects that are viewable from limited angles, such as a castle that lacks a redundant roof and backside walls (see chapter 4, pp 188-190). Planes that depict plants offer significant savings in the amount of geometry used compared to models featuring individual leaves. Compounding benefits in processing speed can be found with the use of textured planes when the number of objects on the stage is increased (see chapter 4, page 201).

The level of detail of a 3D object usually concerns the polygon count, and the number of pixels in texture maps. System memory can only store a finite number of texture maps and high resolution image maps will occupy a proportionally large percentage of RAM (see chapter 2, pp 47-49). For the creation of Agrinoui (2015) I had a decent amount of RAM, yet I monitored texture resolution and memory usage. If the stages had used unreasonably high amounts of texture map resolution, the computer would not have been able to effectively load or render the project. Excessive texture map resolution can result from applying a picture to an object without considering the area size of the frame that it will occupy (see chapter 4, page 156).

A reflexive account about the films in the multiple case study

A characteristic of independently produced films is the significant amount of control and flexibility that the person in charge has over decisions regarding the creative and technical approach. Major studios are different in that a team of directors needs to be coordinated to collectively address matters such as art, technical implementation, and layout. It is complicated for a major studio to start working with an innovative production approach because of risking incompatibilities stemming from changing how the different departments operate and collaborate with each other.

The production systems that are presented in the multiple case study took advantage of experience gathered from previously designed multipurpose stages. The supportive prior knowledge enabled me to progressively design more advanced systems leading to the development of the polymorphic Mountain Roads stage. My design approach involved little risk of failure due to the thorough planning process for each new multipurpose stage which enabled having reliable expectations of how new systems would operate.

The film Struthio (2011) had a relatively simple workflow which did not necessitate recording voice tracks and synchronising action to audio. Animated short films that do not contain dialogue can be appealing to a global audience due to the lack of language barriers. The cost for having dialogue includes cast, crew, recording facilities and, for global distribution, translation, dubbing, subtitling.

I was responsible for both directing and implementation in Struthio (2011) and thus the cycles of progress reviews and implementation of edits were made in a direct way as having full awareness of each problem meant that I would approach each situation only once to obtain the desired result.

Managing a small production team within a wide timeframe during the creation of Agrinoui (2015) enabled me to be highly aware of every part of the process. The presented knowledge can be applied in production frameworks with a larger workforce for higher yields of animated scenes. The tasks for developing each of the presented stages and its associated animated scenes were handled separately in sequential order. A parallelised production framework would enable handling multiple tasks at the same time.

Both films were made as pilot episodes and are being commercially distributed as short films. I am currently involved with collaborative projects that have benefited from the project findings in ways that cannot be reported without disclosing confidential information. It is common practice for producers to safeguard data about the business and production plans of unreleased projects. Sensitive information include the premise of a TV series, the episode format, storylines, character descriptions, budget analysis, workforce, infrastructure, market research analysis, production pipeline, timeframe, release date, distribution strategy, cast, characters, title of series, and stakeholder identities.

Pilot animation episodes commonly provide the aesthetic and technical foundation, and serve as a guide for making additional characters and scenic elements with matching styles economically. Once a step-by-step process has been established for making one tree, which provides the guidelines for the style and for the technical approach, the creation of additional trees can be made substantially faster, and with a consistent appearance. Once a group of different types of trees has been created, they can be copied and differentiated relatively quickly by applying shape and colour distortions (see chapter 2, page 62).

The production of a pilot episode enables establishing several guidelines for subsequent episodes, ranging from scriptwriting and the timing of scenes, to defining the limits regarding the types of actions that can be shown, and camera positioning.

The preparatory work for making marketable films and TV programmes normally includes understanding how the anticipated product serves the target audience, the formulation of a budget and a production timeframe, as well as securing funds and making distribution arrangements. The existence of a pilot episode enables seeing how the audience relates to it, it helps build stakeholder confidence. Moreover, the technical groundwork combined with the known amount of work hours needed to complete certain production tasks enables reliably calculating the production resources needed for planning a scaled-up production.

Multipurpose stages enable handling scenes with a continuous workflow that is advantageous for making lengthy scenes with good value for money. The ability to demonstrate that an animation project can be made economically is a factor that helps persuade potential investors to support the project. Systems that enable reducing production costs without sacrificing quality can assist in limiting investment risk as the recuperation of initial capital can be made sooner or it can limit the damages of potentially poor sales. Hence, efficient production frameworks, such as the ones presented in the multiple case study, work favourably towards finding support and greenlighting animation projects.

Technological developments that occurred since the premieres of Struthio (2011) and Agrinoui (2015) have led to the availability of improved software as well as to more economical and powerful hardware. Access to cheaper processing power can be utilised as a way to reduce production costs, or as a way to improve technical image quality by incorporating computationally demanding elements such as grass and fur or by increasing video resolution. I am not aware of any recent technological developments having the potential to invalidate the value or usefulness of the presented multipurpose stage systems.

Answered research questions

This project sheds light onto how stages can be designed so as to achieve enhanced production efficiency during the creation of computer animated films. Stage systems with multiple acting spaces were showcased for their ability to provide streamlined production workflows and simplified project file structures. The multiple case study addressed two main questions.

- What are the advantages and limitations of working with different types of multipurpose stages?
- How do the systems for optimised use of 3D elements work in the presented multipurpose stages, and how do they affect productivity?

The holistic primary data was gathered while making stages designed to provide increased productivity, and observations of end products provided a full understanding of how certain practices affected the creation of computer animated films. 3D environments with multiple acting spaces enable making long sequences with a low number of stages. Consequently, multipurpose stages make productions less fragmented and provide immediacy in handling several production tasks.

Particular attention was paid to avoid having computational tasks take too long to complete as that would have caused increased production costs either due to the need for additional computational resources, or due to the reduced productivity of 3D artists.

I documented how different types of multipurpose stages provide diverse camera angles with a limited number of 3D objects.

- Some of the presented stages, such as the Savannah stage, feature different foreground acting spaces that have a shared view of background elements such as mountains.
- The Jungle stage features a path that is traversed multiple times. The same area was shown for making scenes that appear to take place in different locations.
- The Mountain Roads stage relies on dynamic modular mountain elements to create diverse landscape compositions for different scenes.

Scenic elements consisting only of surfaces facing the camera consumed limited computational resources due to the lack of backside geometry. Stage systems facilitated the repositioning of objects so that they could be shown multiple times with different camera angles.

The general layouts of the presented stages were determined during development and preproduction along with the camera angles and choreography. Planning documents concerning the compositional needs of each shot enabled designing stages that would not contain unnecessary geometry in order to avoid needlessly creating computational loads.

The major demonstrated systems are:

- Dynamic floor patches enabled constantly having detailed ground surfaces and small plants near a travelling camera.
- Dynamic scenic elements enabled reducing the amount of geometry on stages by repositioning modular objects, such as clouds, within the field of view of different shots.
- Groups of objects, such as single sided trees could be repositioned and rotated en masse to face the camera in different shots.
- Scenic elements with forced perspective enabled fitting 3D environments with seemingly distant horizons within a limited space. Large distances between objects in digital space can affect the precision by which objects are positioned in the foreground, e.g. the feet of a lizard touching the ground (see chapter 4, page 111).

Who can benefit from the presented design approaches

I am reasonably certain that the following groups can take advantage of the presented multipurpose stage design rationales, as well as of the presented optimisation and management systems.

- Advanced computer animation students who already know how to make presentable visuals, can take advantage of multipurpose stages to increase the length of their student projects.

- TV episodes can become less costly by incorporating a reduced number of manageable stages in the production pipeline. Agrinoui (2015) was made with 7 stages. By extension, Types of productions that can achieve reduced production costs include feature films, TV advertisements, and music videoclips. Although additional research is needed, a field that could benefit from multipurpose stages is mixed media film productions featuring digital environments that surround live action footage.

- Potential investors can be drawn by production proposals that are supported by efficient frameworks.

- Detailed technical studies enable formulating production budgets with relative precision through calculating the required amount of work and infrastructure. Knowing details about the technical approach of filmmaking reduces the chances of major setbacks due to unpredicted technical obstacles.

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Appendix 1: Evidence of achievement

Products (Films)

Agrinoui (2015), A. Chaviaras Productions Ltd, Nicosia, Cyprus.
Film available at: https://vimeo.com/155865171 Password: solfami
Trailer: https://vimeo.com/183638370

Struthio (2011), A. Chaviaras Productions Ltd, Nicosia, Cyprus.
Film available at: https://vimeo.com/73512119 Password: solfami
Trailer: https://vimeo.com/255794142

Infote - Greek Business Network (2003), A. Chaviaras Productions - Silver Images, Athens, Greece.
Film available at: https://vimeo.com/283106612/e3e9e8d8f4

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Appendix 2 References

Filmography

A Bug's Life (1998) Walt Disney Pictures, Pixar Animation Studios, United States.

Adventures of Prince Achmed (1926) Lotte Reiniger, Germany.

Behind the scenes at Pixar with John Lasseter & the makers of Cars 2 (2011) Holy Moly Entertainment Ltd, United States.

Cars 2 (2011) Walt Disney Pictures, Pixar Animation Studios, United States.

Disneyland (TV Series), Ep: *Tricks of Our Trade* (1957) Walt Disney Productions, United States.

Doc McStuffins (TV Series), Ep: A bad case of the Pricklethorns (2012) Walt Disney Studios Home Entertainment, Burbank, California, United States.

Elena and the secret of Avalor (2016) Disney Television Animation, United States.

Fight Club (1999) Fox 2000 Pictures and Coproducers, United States.

First teaser: *Mentor* (2018) Boo Productions, Greece

Horton hears a Who! (2008) Blue Sky Studios, 20th Century Fox Animation, United States.

Inside Out (2015) Walt Disney Studios Motion Pictures, United States.

Jake and the Neverland Pirates: Battle For The Book! (2015) DVD, Walt Disney Studios Home Entertainment, Burbank, California, United States.

Jungle junction (TV series), Ep: *Zooter's Surprise Delivery* (2012) Walt Disney Studios Home Entertainment - Spider Eye Productions, United States, United Kingdom.

Le petit Prince (TV series), Ep: *La planète du temps* (2010) Method Animation and Coproducers, France, Switzerland.

Les Triplettes de Belleville (2003) Les Armateurs and Coproducers, France, Belgium, Canada, United Kingdom.

Lion King (1994) Walt Disney Pictures, United States.

Little Furry (2018) Dupuis Audiovisuel, Piwi+, Belvision, RTBF – OUFtivi, Ketnet, Dargaud Media, France.

Little Swee'Pea (1936) Fleischer Studios, United States.

Looker (1981) The Ladd Company, United States.

Masha and the Bear - Hide & Seek (2010) Animaccord Animation Studio, Moscow, Russia.

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Memento (2000) Summit Entertainment, Team Todd, United States.

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Mickey Mouse Clubhouse (TV series) Ep: *Daisy's Grasshopper* (2010), Disney Television Animation, United States.

Mickey Mouse Clubhouse (TV series), Ep: *Daisy in the Sky* (2006) Disney Television Animation, US.

Mickey Mouse Clubhouse: Mickey's Great Outdoors (2011) Walt Disney Studios Home Entertainment, Burbank, California, United States.

Mickey's Twice Upon a Christmas (2004) DisneyToon Studios and Coproducers, United States.

Miraculous: Tales of Ladybug & Cat Noir (TV series), Ep: *Climatika* (2015) Zagtoon and Coproducers, France, Italy, South Korea, Japan.

Modern Marvels (TV series), Ep: *Walt Disney World* (2005) Jupiter Entertainment, United States.

Monsters Inc. (2001) Walt Disney Pictures, Pixar Animation Studios, United States.

Pauvre Pierrot (1892) Charles-Émile Reynaud, France.

Pixar in a Box (2015) Pixar Animation Studios, Khan Academy, United States.

Quarxs (TV series), Ep: *Elasto Fragmentoplast* (1991) Canal+, France.

Ralph Breaks the Internet (2018) Walt Disney Animation Studios, United States.

ReBoot (TV series), Ep: *The Tearing* (1994) Mainframe Entertainment and Coproducers, Canada.

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The Grinch (2018) Universal Pictures / Illumination, California, United States

The History of the Devil (2007) Seirbhis nam Meadhanan Gàidhlig and Coproducers, Australia.

The Little Mouse who Wanted to Touch a Star (2007) ERT, Time Lapse Pictures, Greece

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