A Resources Model for Distributed Sensemaking

Simon Attfield
Interaction Design Centre, Faculty of Science and Technology, Middlesex University, London NW44BT.
S.Attfield@mdx.ac.uk

Bob Fields
Interaction Design Centre, Faculty of Science and Technology, Middlesex University, London NW44BT.
B.Fields@mdx.ac.uk
+44 (0)20 8411 2272
https://orcid.org/0000-0003-1117-1844

Chris Baber
School of Engineering, University of Birmingham, Birmingham. B15 2TT UK
C.Baber@bham.ac.uk
https://orcid.org/0000-0002-1830-2272

Abstract

In the field of Naturalistic Decision Making, the Data-Frame Model (DFM) has proven to be a popular and useful way of thinking about sensemaking. DFM provides a parsimonious account of how 'sensemakers' interact with the data in their environment in order to make sense of what is happening. In this paper, however, we argue that it is useful to elaborate DFM in several ways. We begin by arguing for the idea of sensemaking as a quest for coherence, an idea that we see as entirely consistent with the DFM. We then present some examples of sensemaking studies and use these to motivate a Distributed Resources Model of Sensemaking. This model uses the notion of resources for action, as resources that can be flexibly drawn upon in both choosing courses of action and accounting for the actions of oneself and of others (as opposed to prescriptions or mechanisms that determine behaviour in any strict way). It describes resources involved in sensemaking in terms of three domains: Knowledge and Beliefs, Values and Goals, and Action. Knowledge and beliefs are concerned with how things are; Values and Goals are concerned with how things are desired to be; and Action provides the means for redressing the gap. Central to the model is the idea that these resources can be distributed across a cognitive work system across actors and representational media. Hence, it aims to provide a framework for analysing sensemaking as Distributed Cognition.

Keywords: Sensemaking; Data-Frame Model; Distributed Cognition;

1. Introduction

Weick (1995) described sensemaking as a process of finding meaning from information. Starbuck and Milliken (1988) proposed that when people make sense of stimuli they do so by placing it into a framework which allows them to comprehend, understand, explain, attribute, extrapolate and predict. While several theories and models of sensemaking have been proposed (*e.g.*, Dervin, 1983; Pirolli and Card, 2005; Russell et al. 1993; Weick, 1995), the theory that has gained most traction in the Naturalistic Decision Making (NDM) community is the Data-Frame Model (DFM) (Klein, Philips, Rall & Peluso, 2007; Klein, Moon and Hoffman, 2006a & b). At its most basic, DFM proposes that 'data' (information from the world) can be made sense of through the application of an appropriate 'frame' (knowledge structure). The 'frame' can be elaborated or modified to accommodate new 'data'. In this manner, DFM regards sensemaking as an ongoing, dynamic interplay between data and frame. DFM provides a basis for explaining notable phenomena of sensemaking, such as the ability to comprehend a situation based on a small number of cues or 'anchors'; the fact that an interpretation of a situation extends beyond these anchors to create expectations that can either be satisfied or violated; the fact that people sometimes hold on to interpretations in the face of apparently conflicting information; and that sometimes people experience a radical reassessment of what they believe is true.

By reflecting on DFM in the light of our own studies of sensemaking, we have noted some ways in which we think it might be usefully developed. Whilst part of the attraction of DFM lies in its elegance, we believe that there are tensions that arise in its application and some incomplete areas can be addressed.

More specifically, in this paper, we build on the arguments presented in Attfield and Baber (2017) and elaborate DFM in five ways:

1. The concept of 'frame' in DFM seems to conflate the idea of generic beliefs and specific beliefs. We propose a separation of these is useful. This involves a clarification of the notion of 'frame';
2. DFM seems to imply (but is not committed to) the idea that sensemaking can be understood as the application of a single frame. We make the case that people make sense of situations through the application of multiple frames;
3. DFM says little about the role of 'values' in sensemaking. We develop the case that values, and their translation into goals (as described, for example, by Cognitive Work Analysis) play a central role in sensemaking;
4. DFM implies that 'sensemaking' is a cognitive act, and that the product of this action could be represented as a verbalisable statement. We suggest that, in some cases, 'sense' could be represented by an action, and this could be difficult to verbalise. This involves clarification of what constitutes the product of a sensemaking process;
5. DFM could be interpreted as model of 'cognition in the head'. Contrary to this, sensemaking is often best understood as distributed physically, socially and over time. In relation to this we show how abstract information resources can used by a distributed cognitive system.

This development of the DFM parallels other developments and discussions that have taken place in this journal and elsewhere in the human factors literature. For instance, the debate around the value and validity of 'situation awareness' as a theoretical construct (Carsten and Vanderhaegen, 2015) revolves partly around whether to focus on the properties of components (including human ones) of a system, or on collective properties and behaviours of the system as whole (Salmon, Walker, & Stanton, 2015). Similar proposals (e.g. Marti 2000) for an expanded 'unit of analysis' in understanding complex activity systems in context have been key influence on the model presented here.

2. Sensemaking: A Quest for Coherence

We begin by looking at the concept of sensemaking and developing the idea that sensemaking is a quest for coherence between ideas at different levels of abstraction. We take our lead from the approach of Ordinary Language Philosophy (or 'Oxford Philosophy'). Ordinary Language Philosophy, a form of Analytic Philosophy, argues for the resolution of philosophical problems through the analysis of everyday language as the arbiter of meaning; *meaning*, in ordinary language philosophy, *is use*. To ask, "What is sensemaking?", then, is to ask, "how is the word 'sensemaking' used?" (Attfield and Baber, 2017).

Although the word 'sensemaking' is not part of common usage, we can look at what people mean when they say something does or doesn't. Brooks (2009), for example, relays a discussion between Marie Curie, Hendrik Lorentz and Albert Einstein about how radioactive materials apparently defy the laws of conservation of energy and momentum. Brooks explains that, "Radioactivity was an anomaly; it didn't *make sense*. The problem was eventually solved by the birth of quantum theory". Here we understand the initial problem as an apparent lack of coherence between beliefs about phenomena at two different levels of abstraction - the behaviour of radioactivity versus the (more abstract) laws of the conservation of energy and momentum. We can also assume that this lack of coherence was resolved once quantum theory was introduced.

Next, a thought experiment - imagine you have a friend who you have learned enjoys visiting museums - he visits many, talks about them often, and keeps museum guides on a dedicated bookshelf. However, on a trip to a different city you see him turn down a visit to a local museum announcing that it doesn't sound very interesting. This behaviour does not *make sense* to you, at least, not in the light of your impression of your friend as a museum enthusiast. Here, your impression plays a similar role to 'the laws of the conservation of energy and momentum' in the radioactive materials example, and his behaviour plays a similar role to the behaviour of 'radioactivity' - they seem mutually incompatible. Again, the problem is one of coherence between beliefs at different levels of description. At one level is a theory and at the other is an observation of behaviour which seems inconsistent with it. We are likely to say that the behaviour doesn't 'make sense'. Then you realise, or are informed, that your friend is actually only interested in natural history museums, and the offer related to a cultural museum. With this, coherence is resumed and his behaviour can be said to 'make sense'... but notably because the theory changed, not the behaviour.

From such examples we might be inclined to conclude that sensemaking is about coherence between descriptions of how the world is, expressed at different levels of abstraction, between high-level theory or assessment and data, and of addressing matters when coherence seem lacking. But the question of coherence and things making sense can be extended beyond descriptions of how the world is. During the recent soccer World Cup, England faced a match that they could afford to lose without being kicked out of the competition. The match following that, however, was critical for staying in. Ahead of the first match, one BBC article argued that it would therefore "make sense" to rest some of the key players. Again, sensemaking is about coherence - playing certain players may or may not 'make sense' given the longer-term goal of winning the competition. Sensemaking, can be about whether one or more actions are consistent with one or more higher-level objectives. The higher-level objective provides the frame into which an action may of may not fit. The same idea can also be applied to questions of ethics and law. It may be said that an individual ethical judgement does not 'make sense' given a commitment to a more abstract but conflicting ethical principle, or that a legal judgement does not 'make sense' if it conflicts with a prevailing (and more general) law.

Hence, a central issue for sensemaking is whether there is apparent coherence, or consistency, in ideas within a domain expressed at different levels of description or abstraction. And to the extent that ideas at one level can be inconsistent with ideas at the another, so ideas at one level can be inferred from ideas at the another. Problems of sensemaking are rather like, if not identical to the problem of the hermeneutic loop, in which interpretation of parts (of a text) depend upon interpretation of the whole (of a text) and vice versa (Schmidt, 2016).

3. Examples

In this section, we present some observations about sensemaking drawn from some previous studies by the authors. These lay ground for (and to some extent preview) the theoretical ideas we develop in section 4. The studies include a study of a Military Signals Intelligence (SigInt) training exercise reported by Attfield et al.

(2015) and Wheat et al. (2016) and a study of Crime Scene Examination reported by Smith et al. (2008), Baber (2009 & 2010) and Baber & Butler (2016). Some other studies will be discussed in passing.

3.1 Military Signals Intelligence (SigInt)

Attfield et al. (2015) and Wheat et al. (2016) report a military Signals Intelligence (SigInt) training exercise in which Analysts were tasked with assessing the identity and location of opposing military units based on intercepted radio communications. The exercise was based on a simulated, enemy beach landing. The Analyst's task in this exercise was to work as part of an intelligence cell (figure 1). Interceptors (left) were radio operators who intercept radio broadcasts and sent information about these, such as the direction of origin and message content, to the Direction Finder. The Direction Finder used information from multiple Interceptors to triangulate locations and compile 'Tactical Tip-Off' (TTO) reports for the analyst. These reports includes the location information, radio frequencies of the communications and the call signs used, as well as selected message excerpts. The job of the analyst was to use this information to construct a build 'situation picture' and provide periodic summary reports about it to a Supervisor. Figure 1 shows this forward direction of information and also shows how articulated priorities for what to look for propagated back.

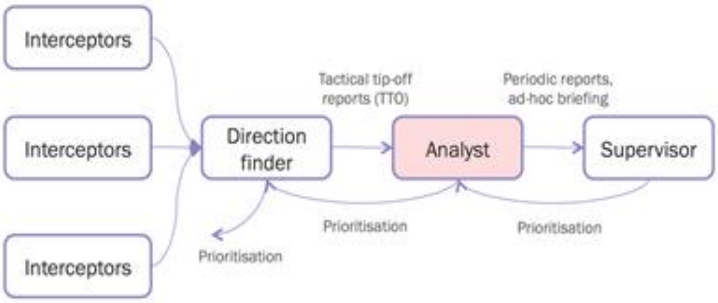
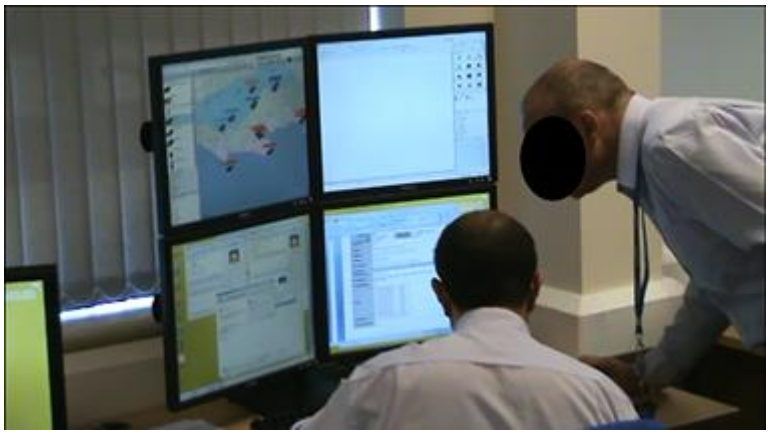


Figure 1. *The analyst's role in the context of other roles within an intelligence 'cell'.*

Attfield et al. (2015) and Wheat et al. (2016) focussed their analysis on the Analyst role. The Analyst had four displays (see Figure 2). The software included the EW Training & Mission Support Tool (EWMST)[1] (top left) where the analyst recorded and maintained a map of assets in the field; IBM i2 Analyst's Notebook (top right) where the analysts created a network graph showing inferred command structure relationships between assets; a chat tool and Microsoft Word (bottom left) where the analyst received and viewed reports from the Direction Finder, and Microsoft Word (bottom right) where the analyst created reports for the Supervisor.



[1] EWMST is proprietary software developed by MASS Consultants Ltd (UK).

Figure 2. *The Analyst's workstation - shows the Analyst (sitting) and the Supervisor (standing).*

The analysts also had a set of printed materials. These included:

- 'Radio Equipment Table' linking different radio types with their frequency ranges, modes (e.g. FM/AM), level of command, role and general remarks;
- 'Radio Procedures Call Signs Table' linking call sign formats to level of command and some general remarks;
- Equipment lists showing what equipment different groups typically have;
- Area maps;
- An Order of Battle (ORBAT) describing the command structure of an opposing military group, including information about personnel and equipment at different levels.

The job of the analyst was to use reports from the Direction Finder and information from the printed materials to draw conclusions about an opposing force. When a report arrived, the analyst would use positional information to plot the communicating entities on the map. They would then, (1) compare the frequency of communication shown in the report with the ranges shown in paper Radio Equipment Table, striking through the radios that couldn't have made the communication; (2) compare the call signs in the report with the forms in the Radio Procedures Call Signs Table, striking through forms that could be eliminated. Since both tables linked to information about level of command, this provided the analyst with a shortlist of possible levels of command of the communicating sub-network - sometimes just one.

The analyst would then return to the report for further clues. Message information that could be interpreted as relating to specific kinds of equipment could then be combined with the Order of Battle and level of command information to infer the identity of a specific military unit. Through this process, and related processes of elimination, the analysts were able to associate each call sign with a unit.

Something we draw attention to initially from this example is that, although the Analyst's job within the cell is what we might consider an archetypal sensemaking role involving interpreting, explaining and predicting etc., we can also view the cell as a whole as a sensemaking system. Interceptors act as sensors, seeking information and passing it on; the Direction Finder uses this to interpret position, and filter other information and pass it on; the Analysts then uses this and reference information to draw further inferences and form an integrated situation picture. The Analyst then passes selected conclusions to the supervisor, and this leads to information gathering priorities which are propagated back to guide collection. Hence, the sense that is made determines where attention is focussed and what is seen.

We also draw attention to the role played by external artefacts at the Analyst's workstation, some of which are shared within the system, some of which are not. The situation picture that the analyst creates is captured in the map and reports to the Supervisor. It is a product of inferences made using situation specific information (data) captured in reports and chat with the Direction Finder and more generic information about the use of a types of radio and call signs and also the expected structure of the opposing army. The paper artefacts can be seen as the embodiment in physical form of a collection of generic and quite long-term frames. For example, the radios table captures properties of military radios, such as the fact that they operate on a particular range of frequencies and are used for certain types of communication within the command structure. More specialised constraints represent the way the generic frame may be instantiated with information about the particular types of radio that may be in use in the current situation. For instance, a particular type of radio may operate in the 1.25-4.5MHz frequency range, and be used for either FM or AM communications between Regiment and Battalion.

3.2 Crime Scene Examination

Contrary to its portrayal in popular entertainment, the examination of a crime scene is separate activity from determining 'whodunit'. The Crime Scene Examiner, or Scene of Crimes Officer (SOCO), samples the crime scene in a methodical manner to recover items which could (subject to additional forensic analysis) become evidence in a criminal investigation. As an approximate description of the criminal investigation process, a

'victim' reports a crime and (if appropriate) a SOCO visits the scene and recovers items which are then passed to an Exhibit Manager who logs these and passes them (if appropriate) to a Forensic Scientist for analysis who then produces a report for the Senior Investigating Officer who then combines this evidence with other evidence to build a case which then is passed to the Criminal Standards Authority and (if they believe there is a case to answer) this is presented at Court. In other words, and like the SigInt analyst, the activity of the SOCO is part of a much larger investigation activity or sensemaking system; in this case one that often involves 'teams' which form and disband on an ad hoc basis (Smith et al., 2008). Like the SigInt cell, each part involves different interpretation and analysis activity (Baber, 2010). While the description is UK-centric, other countries follow a similar process, and the main point to note is how far removed SOCO activity can be from the 'investigation'.

However, the role of the SOCO is perhaps more analogous to the Interceptors in the SigInt cell. Ideally, the SOCO would recover items in as objective a manner as possible – this means not only making sure that the items are not contaminated but also making sure that the selection of items is not based on preconceptions of who might have committed the crime (in order to ensure that potential bias is minimised). In other words, sensemaking is restricted at this point so as not to bias interpretation further up the chain. However, anticipating the sensemaking process beyond information gathering is important. As Baber and Butler (2016) show, a characteristic difference between trainee and experienced SOCOs is the ability to appreciate how a given item might be forensically examined, and the use of this understanding to support their decisions in evidence recovery. From this brief overview, one can see that the 'sensemaking' in criminal investigation involves many different actors and it involves several different types of material (and also the same material could have different roles in the investigation, e.g., recovered item, item to be subjected to scientific study, item as evidence, item as contested evidence). In this way, material serves as resources for action for different people in the investigation (Baber et al., 2009). In order for DFM to accommodate the distributed nature of this process, and to explain how material can serve as resources for action, it needs to be elaborated.

The role of the SOCO is to *make visible* material which might otherwise be hidden, e.g., through dusting for prints or swabbing for DNA, and preserving material in a transportable form, e.g., using plaster to cast footwear marks on the ground or sticky tape to lift fingerprints from a dusted surface or photographs to record toolwear marks. In this respect, the SOCO is seeking resources as well as responding to them. In a sense, the job of the SOCO is to select an appropriate focus for activity and then convert from one form of resource to another. This is illustrated by table 1.

Baber et al. (2009) apply the concepts of the Distributed Information Resources model in order to produce a more detailed understanding of the interplay between the actions of the Crime Scene Examiner and elements of the physical and informational environment of the crime scene. Wright et al. (2000) identify a number of potential information resources that form part of Baber et al.'s analysis, including State, Goal, History, Plan and Action Possibility. The vocabulary of resources, allows the Crime Scene Examination activity to be viewed in terms of what resources are present and are used, and how they are used to allow Examination activities to take place.

For example, the state of the crime scene acts as a resource in several ways. Most obviously, a visual inspection of the scene itself yields important *state* information about objects and evidence that may be immediately present. Other aspects of the scene may suggest the *possibility* of further actions that may be carried out. For instance, the presence of appropriate surfaces at the scene may suggest to the analyst the possibility of dusting for fingerprints, which may transform the scene so as to reveal yet more information about the state of the scene.

The *history* of activity that this analyst and others have engaged in may also provide a resource for action. For instance, the analyst may recall similar scenes from other investigations. Sequences of action that have proved useful previously, or which are part of a standard procedure or a known technique may serve as *plans*, made available to the Examiner if they are externally represented (e.g. as written procedures) or internally represented (e.g. as a result of training).

Table 1: *Resources used in Crime Scene Examination [from Baber et al., 2009]*

Focus	***State***	***Goal***	***History***	***Plan***	***Possibility***
Environment	Visual inspection	Retrieve objects / evidence	Recall similar scene	Follow Procedure	Objects and surfaces hold evidence

Surface	Visual inspection or chemical treatment	Search scene, perform analysis, make recording	Recall likely surfaces to check	Apply technique	Surfaces hold fingerprints, DNA, fibres etc.
Object	Visual inspection	Search scene, collect objects, make recording	Recall likely objects	Collect and record	Contain evidence or serve as evidence
Sample	Chemical treatment	Search scene, collect samples, make recording	Database of samples	Analyse and record	Evidence can be obtained from sample
Results	Results produced by analysis	Results in the form of graphs and numbers	Database of results	Record and interpret	Results can be interpreted probabilistically
Individual	Identified by specific features	Match results to features	Database of features	Compare	Match can be interpreted probabilistically
Report	Collation of material	Produce coherent case	Updating of collection	Compile results etc.	A case can be made on the basis of the evidence

An artefact such as the Crime Scene Report, may serve as a paper representation of a goal resource, by indicating the different types on information that are to be collected, and therefore the different types of activity that can be engaged in to collect this information. If the structure of the report is used to structure and sequence the activities of the Examiner, then the report template can be regarded as a plan resource as it is used to determine what investigative actions are to be carried out, and in what order.

The process of resource translation means that the SOCO ought to focus primarily on the recovery (and subsequent forensic examination) process, rather than on speculating as to who made the marks or why the marks were made. Furthermore, as noted previously, the SOCO recovers material with the intention of passing these on to other experts for further analysis. As with the Crime Scene Report, the recovered material becomes a potential resource for other people in the criminal investigation process.

From the perspective afforded by the resources for sensemaking model, operations in the data-frame space can be seem as uses or manipulations of artefacts that are the physical embodiment of resources. For instance, 'elaborating a frame' can involve filling in the slots of a template. If the frame is physically represented, this becomes a physical, rather than purely mental operation, as is the case when the SOCO complete parts of the Crime Scene Report. It is not so much that the Report aids the SOCO's mental elaboration of an internally represented frame, but rather that the report is the frame, and writing text into blank spaces is its elaboration.

4. A Distributed Resources Model for Sensemaking

In this section we describe the Distributed Resources model for sensemaking. This will involve enumerating and discussing resources that play a role in sensemaking. We use the word 'resource' in the same way as Wright, Fields & Harrison (1996 & 2000) who adopted this idea from Suchman (1987). Suchman used the idea to describe the role of plans, not as prescriptions or mechanisms that determine behaviour in any strict way, but as resources that can be flexibly drawn upon in both choosing courses of action and accounting for the actions of oneself and of others. Wright, Fields & Harrison (1996 & 2000) referred to such resources as 'abstract information structures'. This essentially separates the question of *what* is represented (i.e. the information content) from *how* and *where* it is represented and in what medium. This is significant since it enables

descriptions of Distributed Cognition (Hutchins, 1995 a, b), in which the representations involved in cognitive processes are seen not as located in the heads of individuals, but distributed across a wider cognitive system.

Processes and the representations on which they operate on can be seen as distributed in several ways, including *socially*, between a number of participants, *physically*, across internal mental states and external physical artefacts. Wright et al.'s (1996, 2000) 'resources model', a distributed cognition model of human-computer interaction, identifies a collection of types of 'abstract information structures' (including plans, goals, states, action possibilities, action history, and action-effect mappings) that can serve as resources for action in that context. Representations of such abstract structures will, in a given scenario, be distributed in a variety of ways across available physical media. The media in which information resources may be embodied have specific affordances and support particular manipulations and transformations. For instance, a planned sequence of actions can be represented physically in the form of a paper checklist, or as an on-screen list of actions to be performed. Alternatively, it may be represented in the mind of a participant as the steps of a task to be carried out. In common with the Resources model for Human Computer Interaction, we provide a framework through which a kind of Distributed Cognition can be described and analysed - in this case, Sensemaking. In doing so we elaborate and extend on the description provided by DFM.

The model is shown in figure 3. The processes of DFM are represented at the centre. We connect these to three resource domains[2]: Knowledge and Belief, Values and Goals, and Action (we will argue that DFM is predominantly concerned with Knowledge and Belief). We also include the 'situation' to suggest that the sensemaker could work from the 'situation' *per se* or from a 'representation' (meaning something constructed from data coming from the situation…), and that working from either situation or representation evokes different opportunities for action.

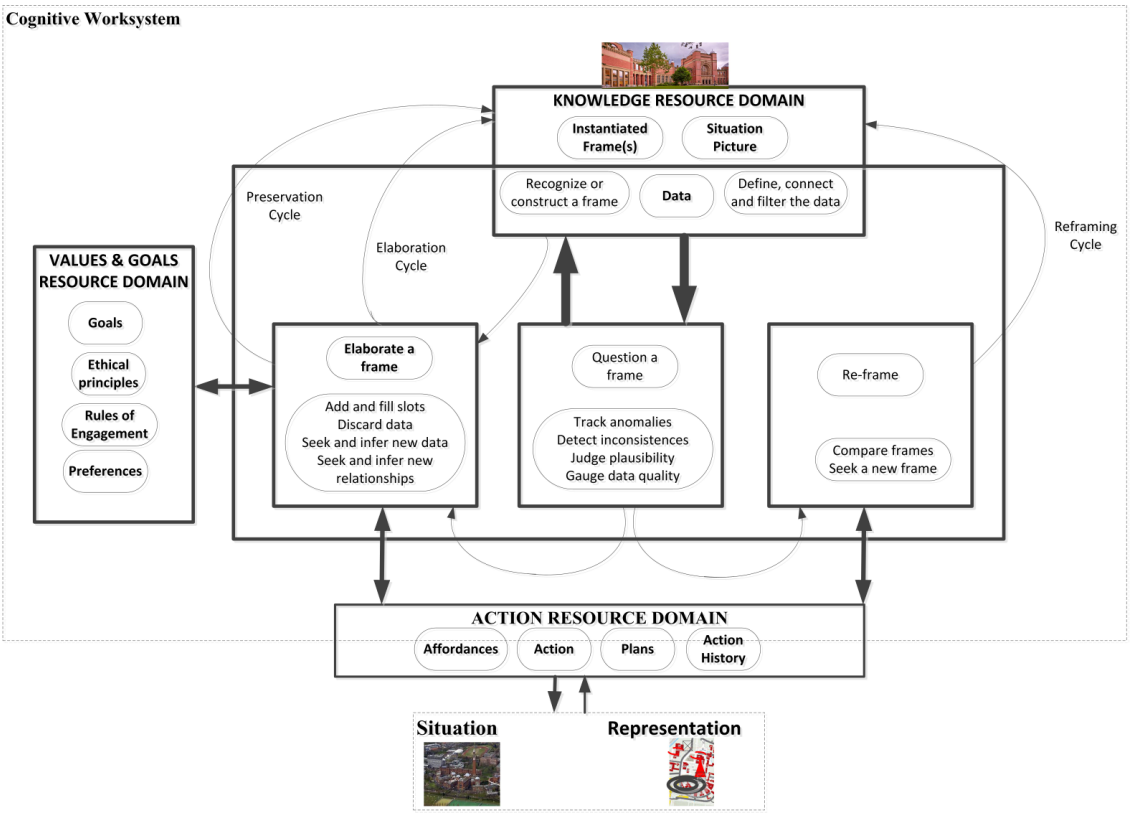


Figure 3. *A Resources Model for Distributed Sensemaking*

[2] We use 'domain' here to mean a taxonomically bounded set of things.

In the following sections we describe the resources in each domain.

4.1 Knowledge and Belief

Frames and their Instantiations

The idea of a 'frame' in sensemaking is the idea of a structuring or orienting concept that captures or accommodates some lower-level, more detailed ideas or phenomena. A frame is a way of looking at something which both offers cognitive economy and from which we can derive expectations and surprise (Blandford & Attfield, 2010). In discussing 'frames' we make a distinction between frames as generic concepts and their instantiation in an given assessment, a distinction that we believe is less clear in descriptions of the DFM. Attention to this distinction is drawn by the external representation of frames within paper tables used by the SigInt analyst which describe generic radio and call sign types that might be encountered, and in the initially blank Crime Report form used by the SOCO. The work of the SigInt Analyst (or of the Distributed Cognitive System as a whole) involves eliminating possible generic frames that are candidate explanations of what's going on. The more data that is gained, the closer the analysis is to a unique identification of the frame that is specific to the current situation. The incoming report about an intercept represents a set of data specific to the current situation. The combination of these two sets of beliefs: generic frames and data, can produce a third belief structure: instantiated frames. Partially or completely instantiated frames are a key element of an emerging 'situation picture'. As generic frames are selected and then instantiated with available data, the situation picture is further enriched by the addition of detail and structure. In understanding the process of sensemaking here, it is useful to see these representations of generic and instantiated frames as complementary resources that allow sensemaking actions to take place: they may be orientated to and used in a flexible way that shapes and influences the sensemaking activity, but need not determine in any strong way the action that unfolds.

The visual form of a table affords this kind of combination: look-up operations (e.g. of the frequency of an intercepted radio communication), producing a new belief (which radios match the incoming frequency) in the form of the selection of some frames (those radios that match) and the rejection of others (the ones that don't). The affordances of the medium of paper (or of some sorts of editable electronic representation) allow this new belief to be represented directly: e.g. by crossing out (or deleting, in the case of an electronic representation) rows in the table that don't match, narrowing down the possible candidate frames that may be relevant to the current situation.

When, for example, the SigInt Analyst crosses out rows in a Radio Equipment Table using data received as part of a TTO report from the Direction Finder, the relevant generic frame is partially instantiated, by strengthening the constraints on what is believed to be going on in the current situation. And the situation picture is made more specific by eliminating certain possible interpretations of the available data. If the Analyst were to receive data about a communication on a frequency not covered by a row in the Radio Equipment Table, this could be detected, again by a relatively simple visual comparison between the relevant part of the incoming TTO report and the relevant column of the table. The recognition of such an anomaly could lead to a number of possible sensemaking steps, for instance the retrieval of an alternative frame (perhaps one that treated the intercepted communication as non-military, on non-standard in some other way), or the modification of the current frame, represented with physical annotation.

Our examples also highlight some of the key features of a Distributed Cognition understanding of the situation: resources are distributed around the cognitive work system in a number of ways. Frames are represented not (only) in the head, but in the collection of artefacts, such as paper tables or computer screens that are also a part of the system. A further form of distribution is evident in the way that the Radio Equipment Table represents the accumulation, possibly over a long period of time of the work of potentially many people outside of the current situation. The expression, in rows of the table, of constraints on how slots of the Military Radio frame may be instantiated is one example of how cognitive work at an earlier stage has 'pre-computed' results that are needed in the current analytic situation.

We see the following reasons for maintaining a distinction between frames and their instantiations:

- Characterizing the nature of expertise is of interest in areas such as naturalistic decision making. In relation to sensemaking expertise is domain specific relating to a sensemakers 'repertoire' of frames. Such a repertoire makes little sense without the notion of generalisable frames. In the SigInt and SOCO example, externalised generic frames form part of and expand this repertoire and so augment expertise;
- Elaborating a frame is described as extending a frame by either adding or filling slots (Klein et al., (2007). We contend that these are different kinds of elaboration. In adding slots a generic concept is made more specific through additional features (the difference between the idea of a 'dog' and of a 'border collie'). In filling slots, a situation picture is made more complete;
- Although a way of learning about generic concepts may be the experience of instances (there are other forms of learning of course), and a way of learning about specific instances may involve the application of generic concepts, knowledge of one is not the same as knowledge of the other. We may know (roughly) what a pyroclastic lava flow is and yet never experience one;
- For the researcher interested in analysing and designing for sensemaking as distributed cognition, this distinction creates the opportunity to observe, discuss and design for generic frames as embodied within external artefacts (e.g. a pre-flight checklist) and their transformation into instantiated frames (e.g. a pre-flight checklist completed immediately prior to such-and-such flight);

Situation Pictures, Multiple Frames

There may be many situations in which sensemaking can be usefully characterised as the application of a single frame. However, a further reason for being clear about the distinction between frames and their instantiations is the observation that a situation picture can be thought of as drawing on multiple frames. In our experience of studying sensemaking tasks in intelligence analysis, investigative journalism, crime analysis, and e-discovery, assessments of a prevailing situation can emerge over time and be complex.

The SigInt example above is a case in point - Wheat, Attfield and Fields (2016) tracked how inferences emerge over time through the combination of incoming reports and information in paper tables as 'inference trajectories' (figure 4). What these show is how resources representing generic concepts (frames) and specific pieces of information (data) combine to support an evolving situation picture - in this case represented within an Intelligence Summary (IntSum, figure 4, furthest right).

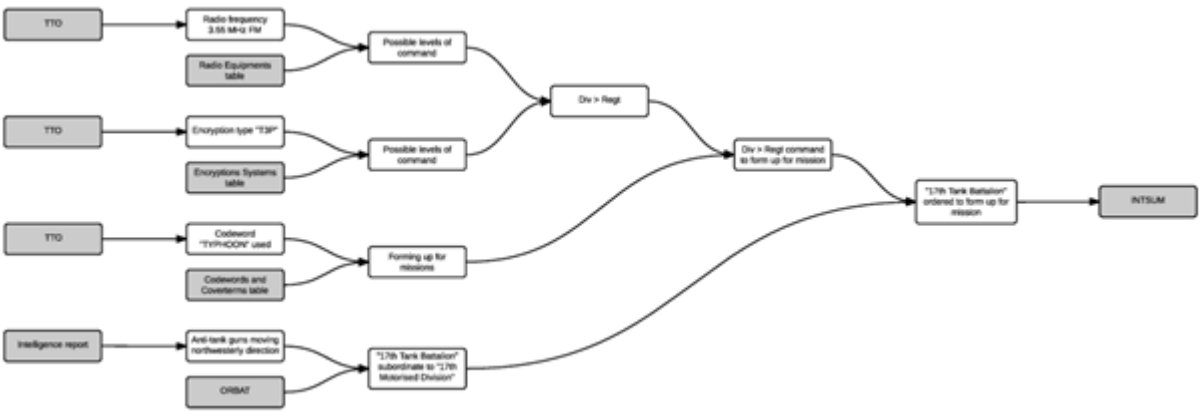


Figure 4: *An Inference Trajectory from Wheat, Attfield and Fields (2016) showing the evolution of a situation picture based on resources representing generic concepts (frames) and specific piece of information (data).*

A similar analysis was performed by Kodagoda and Wong (2016) who reported findings from interviews with police criminal intelligence analysts in the form of an 'inference decomposition chart', showing the way in which beliefs and associated uncertainty propagate through an evolving analysis.

Kodagoda et al. (2016) also conducted a study to better understand how participants conducted an intelligence related sensemaking task. Participants were asked to use a novel visualisation tool which allowed them to search for and sort academic articles. Their task was to draw conclusions about who were the influential authors in a given academic field. Think-aloud protocols taken from participants using the system showed that in drawing conclusions about authors, participants made assessments about individual publications using features such as citation count. At least two frames seemed to be in play, an 'influential paper' frame, which captures ideas about what it means for a paper to be influential, and an 'influential author' frame which captures ideas about what it means for an author to be influential - assessments of one supporting assessments of the other.

Also, in a study of lawyers conducting regulatory investigations, Attfield & Blandford (2011) described how the lawyers constructed large and detailed chronologies of activity within an organisation under investigation. The construction of the chronologies was based primarily on email communications and exploited background knowledge (*i.e.* generic frames) at different levels of scale, ranging from the typical pattern of activity on long-term contracts to individual meetings in restaurants. Consistent with Pennington and Hastie's (1991) Story Model of juror decision making and Wagenaar, Van Koppen and Crombag's (1993) theory of anchored narratives, these narratives typically featured multiple episodes, each constructed from the combination of evidence and generalised background knowledge at different levels of detail.

Finally, in a study into how a group of police crime analysts used external representation, Selvaraj et al. (2016) described how the analysts structured their assessments in terms of 'think-steps', which were generic, extensible conceptual templates that decomposed a crime based on its type (e.g. 'human trafficking') into sub-elements that the analyst could focus on (e.g. recruiting, transport, housing, work, medical care and finance).

Assessments of complex situations can themselves be complex and operate at different levels of description. In work on intelligence analysis Baber *et al*., (2015; 2016), suggested that analysts tend to alternate between broad and narrow focus, *i.e*., looking at several topics and then narrowing to a smaller number. Similar effects have been observed by Elm *et al*. (2005) and Roth *et al.* (2010). For this paper, the argument is that the broad/narrow focus represents effort toward the development of an assessment. And, that while it is sometimes possible that a situation might be usefully described in terms of a single, overarching frame (e.g. 'murder', 'bid rigging', 'insider trading'), the construction of such assessments typically involves the application of multiple frames at different levels of granularity. The picture we are left with is of stratified assessments which 'make sense' or otherwise in virtue of coherence across multiple levels of description.

4.2 Values and Goals

Values are the reason that sense is made, such as improving a patient's health, reducing crime or simply the intrinsic pleasure of making sense of something. Whereas *knowledge and beliefs* are concerned with how things *are* (or are believed to be), *values and goals* concern how things are desired to be, or ought to be. We use the term *values* to refer to both *ethical principles* and *subjective interests*. Values provide sensemaking with its forward momentum, influencing both the need for sense and the kind of sense that is needed. We include *goals* in this category as the lower level expression or manifestation of these bound to a given situation.

Significant values may include the terms of reference of an analysis, an organisational mission statement, or the hippocratic oath. Like resources of knowledge and belief, their representation can be distributed socially and physically in an extended cognitive work system. Values of this kind may be primarily represented internally, by individual actors – for instance the SOCO will typically understand, through training and experience, the importance of securing a crime scene, even if no external representation of this value exists among the artefacts present at the scene. An organisation's mission statement may, on the other hand, be represented in a physical artefact such as an intranet or website page.

Theories of sensemaking tend not to engage with the role of values and interests in depth. Where DFM perhaps most clearly discusses this is in relation to the different kinds of cues that people with different interests may notice, driven by the different kinds of assessment they want to make. For example, Klein et al. (2007), point out that a fire-ground commander, an arson investigator, and an insurance agent will be aware of different cues and cue patterns in the same house fire, since the commander will want to determine the intensity of the fire and its risk to crew members, the arson investigator will be interested in the colour of the smoke for signs of accelerants, and the insurance investigator will be interested in the extent of damage in order to judge what parts of the house can be recovered.

Values can motivate sensemaking that allows for their translation into goals. Attfield and Dowell (2002) reported a study of journalists at a national British newspaper who started the day by browsing the newswires and local newspapers. The journalists said that they did this looking for opportunities for story angles, motivated by values of reporting news that is at once *original* (at a national newspaper level), *newsworthy* and *true*. Once found, and agreed with the editor, an assignment idea would enable the journalists to translate these values into some lower-level goal that was achievable (i.e. writing a particular article). According to Vakkari (2001), when such a focus is constructed, thoughts about the task become clearer and more structured, and the sensemaker has a problem that might be solved. Hence, sensemaking itself can reveal opportunities. As Suchman (1987) argued, people frequently walk into situations without plans or even goals. We argue that equipped with values, making sense of the situation they walk into can enable them to convert values or interests into purposeful action.

One approach to representing such stratification is the Abstraction Hierarchy (AH) in Cognitive Work Analysis (Vicente, 1999; Jenkins et al., 2008). The Abstraction Hierarchy represents the idea that a 'system' seeks to achieve an overall purposive function. The system achieves this purpose in spite of constraints under which it operates. These constraints can be expressed in terms of competing objectives that contribute to the overall purpose. In the Abstraction Hierarchy, these constraints are termed Abstract Functions, and can be considered as expressions of the outcomes that the system values. The Abstract Functions in AH could be thought of as problems that can be solved, and so have stopping conditions.

In the North x Southwest Intelligence Challenge (Baber et al., 2016), for example, a value could be 'follow the money' (meaning that the approach to dealing with this challenge would be to focus on the flow of money between individuals), and another value could be 'interrupt drug smuggling' (meaning that the approach would be to focus on the routes that smuggling operations might take) – each of these values imply different ideas of what constitutes useful data and useful sense. We adopt this terminology and concept to propose that the selection of a frame can be influenced by values in terms of which activity is performed. Figure 5 shows an AH for the SOCO example. In this AH, there are six Abstract Functions which provide constraints, cues and opportunities for performing the work.

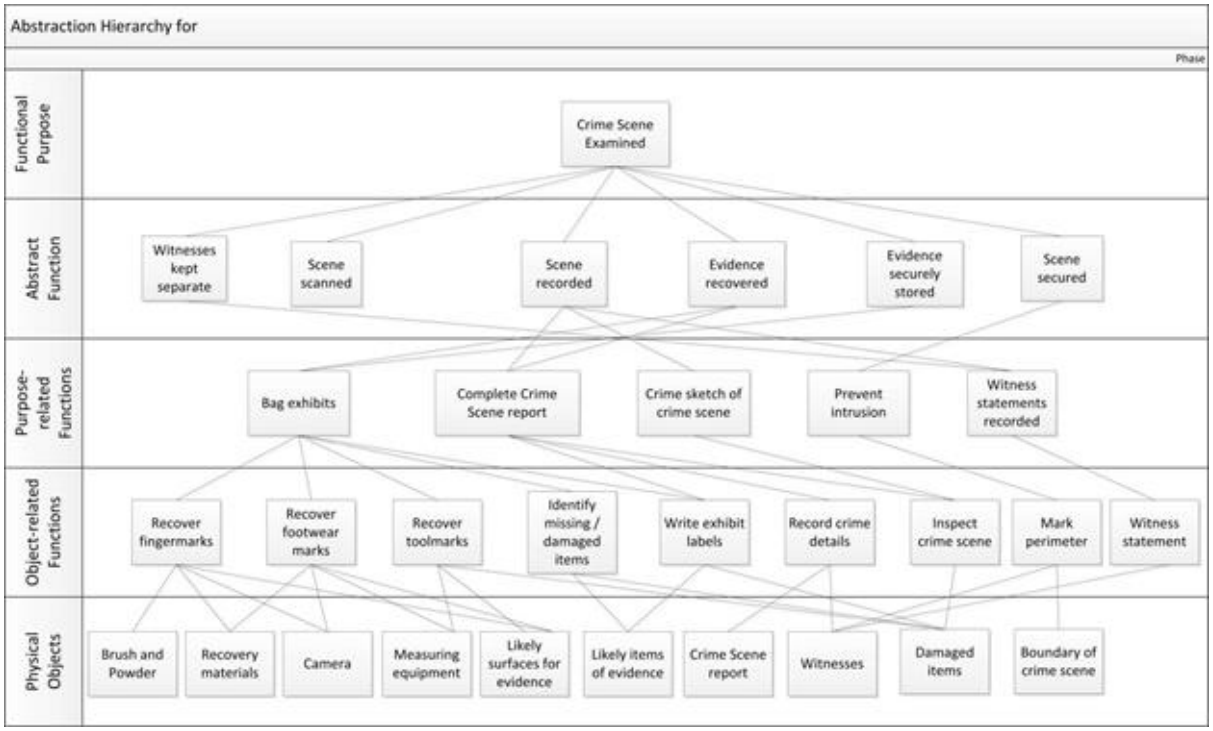


Figure 5: *Abstraction Hierarchy for Crime Scene Examination*

Depending on the nature of the crime, the priority given to each of the Abstract Functions might vary. However, the overriding 'value' is to ensure that anything recovered from the scene has not been contaminated (by other people walking across the scene, by evidence being placed next to other material, by errors made by the SOCO etc.) and provides a record of recovered material. The emphasis on this 'value' could be one reason why Baber and Butler (2010) found that experienced SOCO's concentrated on 'recoverable' evidence and spent less time considering the *modus operandi* of the criminal. What is apparent is that few, if any of the Abstract Functions in figure 5 could be considered as a 'frame' *per se*. Rather, these represent higher-level, guiding principles that would influence the manner in which a frame might be created or applied.

In order to address the question of how 'Values' might influence sensemaking, one could begin with an Abstraction Hierarchy (as shown in figure 5). This would highlight which Values the sensemaker needs to consider, and how these make influence their selection of 'frames'. By exploring how the sensemaker relates their actions to the higher-level objectives and constraints that the Abstract Functions indicate, we can also explore how changes in the situation picture influence, and are influenced by, these. For example, the SOCO could be attending a particularly busy crime scene in which there are Police officers, journalists, paramedics, all seeking access to the scene. In this case, the need to ensure 'evidence securely stored' (i.e., not contaminated by other materials) could conflict with 'scene secured' (i.e., with multiple persons accessing the scene). This could result in either closer guarding of the perimeter (to prevent access) or additional collection of material (from all people who have entered the scene) in order to control for contamination. One way of exploring the management of such conflicts would be to explore, through interviews using Critical Decision Method, how the person would recognise and respond to them. In this way, one can consider how Values compete and how these have a bearing of the ways in which frames become instantiated.

4.3 Action

The result of sensemaking is not only the production of 'sense' (or the cycling through of the sensemaking process to refine 'sense') but also action. We use the term action to refer to the performance of a physical task (such as speak to a colleague, search for more data, pick up an object, delete an item of a table of radio frequencies), or to the performance of a cognitive task (such as decide to look for more information, formulate a

verbal description of the 'sense'). The inclusion of physical tasks suggests what de Jaegher and di Paolo (2007) call 'participatory sensemaking'. In this, sensemaking is enactive, in that it arises when people perform an action that is appropriate to a given context. For example, two people ballroom dancing and responding to each other's movement need to make 'sense' of each other's movement, but this need not be something that could be put into words (Baber et al., 2015). For the SOCO, one way in that 'sense' could be a form of participatory sensemaking comes from performing a particular, well-practised activity. For example, dusting for fingermarks involves several actions that can be coordinated, from 'twizzling' the brush between thumb and forefinger, to holding a torch to shine across the mark, to applying sticky tape to lift the mark. Each of these seemingly innocuous and 'non-cognitive' actions can be modified to adapt to a given context, such that there is a synergy between acting and looking, e.g., twizzling the brush with the one hand, while holding the neck of a wine bottle and rotating it to catch the light from a torch to look for different prints.

By highlighting the enactive nature of sensemaking, de Jaegher and di Paolo (2007) show that making sense is not solely a matter of 'knowing what' but also of 'knowing how'. Duffy *et al*. (2015) use this distinction to argue that sensemaking involves a combination of semantic and pragmatic 'sense'. In this, 'semantic' sense is the meaning that can be assigned to an instantiated frame in the context of the situation picture, and 'pragmatic' sense combines knowing which action could be performed and knowing which information source could be consulted next. The information source could be another person or it could be something in the environment, such as the tables used in SigInt. This means that sensemaking can also relate to the ways in which the person makes use of available resources for action.

We propose that this distinction between applying or acting-out a frame can be readily understood through the lens of Rasmussen's (1983) levels of activity. So, this enactive sensemaking could be understood as skill-based activity, in which the person has some well-practised behaviour which applies to the context. The relationship between behaviour and context constitutes a form of 'frame' (albeit one that might not be directly or easily verbalised). Where there might be more than one option for a skill-based response, the lack of coherence felt by the sensemaker could be resolved through rule-based activity. In this case, the 'frame' would involve extracting those features of the context that relate to each action, and then selecting the most appropriate action. Again, it is not obvious that this selection requires verbal justification as it could be performed equally well through a feedback loop in which the context is checked, and then additional information sought to select one action over another. Only in cases where there is no obvious actions to perform (when skill-based or rule-based activity are not possible) does the sensemaker engage in explicit frame management through knowledge-based activity.

The domain of Action focuses on transformation. We include in this domain *affordances for action*, *plans*, and *action history*. Affordances for action are action possibilities available to the sensemaker at a given time. For example, the SigInt analyst's paper tables afford striking items through with a pen or pencil and this in turn is taken to represent and record the elimination of possible interpretations of the prevailing situation given some received data. Similarly the computerised map affords actions that make it suitable for representing a geographical view of a prevailing situation. For the SOCO, the crime report form affords recording observations that will act as data for a wider sensemaking system.

Given the ordered list of items on the paper tables, these also present the analyst with an optional plan that they typically follow. According to this plan, the analyst starts at the top of the table and considers each generic frame in turn, striking through those that can be eliminated, with the net effect of narrowing one aspect of the situation picture. A plan gives structure to multiple actions. The SOCO might use the crime report template as a plan but they typically 'walk the scene' and complete the form afterwards. Here, the crime scene itself gives structure to the plan, ensuring that everything is covered and nothing is repeated. The plan might equally be an internalised procedure. One advantage of an externally represented plan with affordances for indicating progress is that as it is used it automatically becomes its own history, indicating which actions have been followed and in what order.

4.4 A Summary of Resources

In this section, we summarise the resources we have identified so far organised into the domains of *Knowledge and Belief*, *Value and Interest*, and *Action* (Table 2). Again, we reiterate that in distributed sensemaking these resources can be represented 'in the head' of one actor, across multiple actors, or across multiple external artefacts.

Table 2: *Defining Spaces in the Resources for Sensemaking Model*

Knowledge and Belief

Generic frames – a library of generic 'template' belief structures about how the world tends to work or tends to be that constitute 'background knowledge'. It can be a repertoire of understandings and can support inferences about a prevailing situation which are based on data but which extend beyond the data. It creates expectations which can act as the bridge between data as cues and beliefs about a situation. But as much as background knowledge enables interpretation it can also limit or bias towards what has been experienced before or what is expected.

Data – incoming information from the surrounding world (e.g. 'evidence' in the Crime Scene), or from other, related cognitive work systems (e.g. the TTO reports produced by the Direction Finder and passed on to the Signals Intelligence Analyst) can also serve as a resource (for instance, triggering the selection of generic frames that may relate to incoming data). Data could be partitioned or classified according to several criteria, or the processes it is involved in. For example, data (objects) may be responsive to a given search or not, un-reviewed/reviewed, considered relevant/not relevant or relevant to a given topic/issue.

Instantiated Frame – a representation that stands for some aspect of a prevailing situation of interest (or a situation in its entirety) where the situation is what is being made sense of. An instantiated frame arises when data enables selection from amongst a set of generic frames *i.e.* the application of background knowledge.

Situation Picture – the combined sense that has been made of a prevailing situation relevant to some set of values or interests. It is a situation-specific belief structure (*i.e.* a set of interconnected beliefs) which may be complex with many parts and may be articulated at different levels of description. As a belief structure it or its parts may be maintained with different degrees of subjective commitment, conviction or certainty. Similarly, a set of multiple and mutually exclusive alternative frames may be represented. Theories and hypotheses are describable in these terms.

Values and Goals

Values – values understood as having an ethical mandate and/or values understood as abstract expressions of the interests of an agent or organisation. Values both shape and constrain the kind of sense that is made, as well as constrain the kind of sense that is useful to make. Values (or 'abstract functions' to use the terminology of the Abstraction Hierarchy) such as 'securing the scene' or 'witnesses should be kept separate' are specific to the activity at hand, while others, such as the mission statement intended to capture common values in an organisation, may be much more general, encompassing many of the activities in a large enterprise.

Goal – Goals serve as representations of desired states that allow an actor to choose actions or plans to address values. Goals have can be achieved by meeting their stopping conditions and hence are more or less transitory. Values, on the other hand, tend to continue from situation to situation without stopping conditions. The sense made in a situation can enable the translation of values into goals and hence situated action.

Action

Affordances – possibilities for action within the environment and representational artefacts;

Plans – projected and potentially re-usable sequences of action.

Action History – the actions already performed. On a very short time scale, knowing what has just been done can guide the next step.

Action history and plan are complementary resources, with the former representing actions that have happened already, and the latter a projection of actions that will happen in the future. This complementarity can be usefully exploited in the design of representational artefacts. For instance, a paper checklist or written procedure can indicate planned actions; as items are checked off, they become part of the representation of action history.

5 Conclusion

The central argument of this paper has been that DFM could usefully be elaborated. We have presented some empirical examples and argued for the development of a conceptual framework that covers the domains of knowledge and belief, values and interests and action. We propose, first, that the data-frame relationship exists through the application of an instantiated frame. This arises when a situation-specific belief can be applied to the available 'data' in the situation. Prior to interpreting the data available in a situation, the sensemaker could be said to hold a generic belief, *i.e.*, a belief that could apply to 'situations like this' rather than to this specific situation. An initial step in sensemaking is to instantiate the belief in order to create a usable frame. From this, DFM then explains how the instantiated frame is worked with in combination with the interpretation of available data.

The interpretation of available data, however, is only one action open to the sensemaker. Other actions could include searching for new data, requesting data from a colleague, or acting on the world. We propose that actions on the world will indicate sensemaking in that a request for information could suggest that coherence is still being sought, while physical action could suggest that 'sense' has been made sufficiently to enable a course of action to be selected. In this respect, the link between sensemaking-as-action and Recognition Primed Decision Making (Klein et al., 1986) should be clear. Furthermore, the instantiation of a frame will involve the person making use of available resources – and these could include the embodiment through artefacts or communication with other people, or the Values that the sensemaker brings to the situation. Thus, the selection of beliefs (and their instantiation as frames) implies the sensemaker is pursuing a particular set of values. We have proposed that *some* of these values could be captured in the Abstract Functions of CWA (although we accept that there will be values that are not so easily quantified).

6 References

Attfield, S. and Baber, C. (2017) Elaborating the frames of data-frame theory, *13th International conference on Naturalistic Decision Making*, 25-32.

Attfield, S. and Dowell, J. (2002) Information seeking and use by newspaper journalists. *Journal of documentation*, *59*(2), pp.187-204.

Attfield, S., Fields, B., Wheat, A., Hutton, R., Nixon, J., Leggatt, A. and Blackford, H. (2015) Distributed sensemaking: A case study of military analysis. Proceedings of 12th International Conference on Naturalistic Decision Making, 9-12 June 2015, McLean, VA.

Baber, C. and Butler, M., (2012) Expertise in Crime Scene Examination: comparing search strategies of expert and novice Crime Scene Examiners in simulated crime scenes, *Human Factors, 54,* 413-424.

Baber, C., Smith, P., Butler, M., Cross, J. and Hunter, J., (2009) Mobile technology for crime scene examination, *International Journal of Human-Computer Studies, 67,* 464-474

Baber, C., Attfield, S., Conway, G., Rooney, C. and Kodagoda, N. (2016) Collaborative sensemaking during Intelligence Analysis exercises, *International Journal of Human Computer Studies, 86,* 94-108.

Baber, C., Chen, X. and Howes, A. (2015) (Very) rapid decision making: framing or filtering? *12th International Conference on Naturalistic Decision Making,*

Baber, C. (2010) Distributed Cognition at the Crime Scene, *AI & Society, 25*, 423-432.

Baber, C. and McMaster, R. (2016) *Grasping the Moment: sensemaking in response to routine incidents and major emergencies,* Avebury: Ashgate

Blandford, A., & Attfield, S. (2010). Interacting with information. *Synthesis Lectures on Human-Centered Informatics*, *3*(1), 1-99.

Brooks, M. (2010) 13 Things that Don't Make Sense: The Most Intriguing Scientific Mysteries of Our Time. Profile Books.

Carsten, O., and Vanderhaegen, F. (2015). Situation awareness: Valid or fallacious? *Cognition, Technology & Work*, *17*(2), 157–158. https://doi.org/10.1007/s10111-015-0319-1.

De Jaegher, H., & Di Paolo, E. (2007) Participatory Sense-Making: An enactive approach to social cognition, *Phenomenology and the Cognitive Sciences*, 6, 485-507.

Dervin, B. (1983) *An overview of sense-making research: Concepts, methods, and results to date*. Paper presented at the annual meeting of the International Communication Association, Dallas, TX, May. [On-line]. Available: http://communication.sbs.ohio-state.edu/sense-making/art/artdervin83.html.

Duffy, T., Baber, C. and Stanton, N.A. (2013) Measuring collaborative sensemaking, *Proceedings of the 10th International ISCRAM conference,* 561-565

Ellis, D. and Haugan, M. (1997) Modelling the information seeking patterns of engineers and research scientists in an industrial environment. *Journal of documentation*, *53*(4), 384-403.

Elm, W., Potter, S., Tittle, J., Woods, D., Grossman, J. and Patterson, E. (2005) Finding decision support requirements for effective intelligence analysis tools, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Sage CA: Los Angeles, CA: SAGE Publications. pp. 297-301.

Feltovich, P. J., Johnson, P. E., Moller, J. H., and Swanson, D. B. (1984) LCS: The role and development of medical knowledge in diagnostic expertise. In W. J. Clancey & E. H. Shortliffe (Eds.), Readings in medical artificial intelligence: The first decade (pp. 275–319). Reading, MA: Addison-Wesley.

Hutchins, E. (1995a) *Cognition in the Wild*. MIT Press.

Hutchins, E. (1995b) How a cockpit remembers its speeds. *Cognitive Science*, *19*(3), 265–288.

Jenkins, D.P., Stanton, N.A., Salmon, P.M. and Walker, G.H. (2008) *Cognitive Work Analysis: coping with complexity,* Aldershot: Ashgate.

Klein, G.A., Calderwood, R. and Clinton-Cirocco, A. (1986) Rapid decision making on the fire ground. In *Proceedings of the Human Factors Society Annual Meeting,* Sage CA: Los Angeles, CA: SAGE Publications, 576-580.

Klein, G., Phillips, J.K., Rall, E.L. and Peluso, D.A. (2007) A data-frame theory of sensemaking. In *Expertise out of context: Proceedings of the sixth international conference on naturalistic decision making* (pp. 113-155). New York, NY, USA: Lawrence Erlbaum.

Klein, G., Moon, B., & Hoffman, R. R. (2006a) Making sense of sensemaking 1: Alternative perspectives. *IEEE Intelligent Systems, 21(4),* 70-73.

Klein, G., Moon, B., & Hoffman, R. R. (2006b) Making sense of sensemaking 2: A macrocognitive model. *IEEE Intelligent systems, 21(5),* 88-92.

Kodagoda, N., Attfield, S., Wong, B.L., Rooney, C. and Choudhury, S. (2013) Using interactive visual reasoning to support sense-making: Implications for design. Visualization and Computer Graphics, IEEE Transactions on, 19(12), pp.2217-2226.

McMaster, R., Baber, C. and Duffy, T. (2012) The role of artefacts in Police Emergency response sensemaking, *Proceedings of the 9th International ISCRAM conference,*

Pennington, N., & Hastie, R. (1991). A cognitive theory of juror decision making: The story model. *Cardozo L. Rev.*, *13*, 519.

Piaget, J., & Cook, M. (1952) The origins of intelligence in children. New York: International Universities Press.

Piaget, J. (2013) The construction of reality in the child (Vol. 82). Routledge.

Pirolli, P. and Card, S. (2005) The sensemaking process and leverage points for analyst technology as identified through cognitive task analysis. In *Proceedings of international conference on intelligence analysis*, pp. 2-4.

Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics*, SMC-13(3), 257–266. https://doi.org/10.1109/TSMC.1983.6313160.

Roth, E.M., Pfautz, J.D., Mahoney, S.M., Powell, G.M., Carlson, E.C., Guarino, S.L., Fichtl, T.C. and Potter, S.S. (2010) Framing and contextualizing information requests: Problem formulation as part of the intelligence analysis process, *Journal of Cognitive Engineering and Decision Making*, *4*, 210-239.

Russell, D.M., Stefik, M.J., Pirolli, P. and Card, S.K. (1993) The cost structure of sensemaking. In *Proceedings of the INTERACT'93 and CHI'93 conference on Human factors in computing systems* (pp. 269-276). ACM.

Salmon, P. M., Walker, G. H., and Stanton, N. A. (2015). Broken components versus broken systems: why it is systems not people that lose situation awareness. *Cognition, Technology & Work*, *17*(2), 179–183. https://doi.org/10.1007/s10111-015-0324-4.

Schmidt, L.K. (2006) Understanding Hermeneutics. Acumen, Stocksfield, UK.

Smith, P.A., Baber, C., Hunter, J. and Butler, M. (2008) Measuring team skills in crime scene examination: exploring ad hoc teams, *Ergonomics*, *51*, 1463-1488.

Starbuck, W. H., & Milliken, F. J. (1988). Executives' perceptual filters: What they notice and how they make sense. In Executive Effect: Concepts and Methods for Studying Top Managers, ed. D. Hambrick. Greenwich, Conn: JAI Press (pp. 35–65).

Suchman, L.A. (1987) *Plans and situated actions: The problem of human-machine communication*. Cambridge University Press.

Vakkari, P. (2001) A theory of the task-based information retrieval process: a summary and generalisation of a longitudinal study. Journal of Documentation, 57(1), pp. 44-60.

Vicente, K.J. (1999) *Cognitive Work Analysis: towards safe, productive and healthy computer-based work*, Mahwah, NJ: LEA.

Wagenaar, W. A., Van Koppen, P. J., & Crombag, H. F. (1993). *Anchored narratives: The psychology of criminal evidence*. St Martin's Press.

Weick, K.E. (1995) *Sensemaking in organizations* (Vol. 3). Sage.

Wheat, A., Attfield, S. and Fields, B. (2016) Developing a model of distributed sensemaking: a case study of military analysis. *Informatics*, 3, 1.

Wright, P. C., Fields, B., & Harrison, M. D. (1996) Distributed information resources: A new approach to interaction modelling. In *Proceedings of ECCE8: Eighth European Conference on Cognitive Ergonomics* (pp. 10–13).

Wright, P. C., Fields, R. E., & Harrison, M. D. (2000) Analyzing human-computer interaction as distributed cognition: the resources model. *Human-Computer Interaction*, *15*(1), 1–41.