Distributed Working Pictures

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Abstract: Small co-located teams can share 'Common Operating Pictures' to enable high levels of cooperation and backup amongst the team members. However, when teams are large or distributed across poor communications networks, sharing operating pictures with all members of the team can consume so much communication resource and individual attention that it reduces the team's effectiveness in accomplishing its task.

This paper introduces the costs and benefits of distributing picture components, and ways of encouraging the communications to be appropriate and useful: to build sufficiently good common pictures amongst suitable team members for them to function. It follows that a 'single picture of the truth' is rarely desirable even when technically possible, and this paper shows why that is so.

Building suitably distributed, shared and incomplete pictures requires sophisticated evaluation and management of information - information that may be real world observations or assessments of them. Understanding how such information needs are expressed and fulfilled in distributed teams should transfer across several information management and information exploitation disciplines.

Key terms: Distributed Cognition, Situation Awareness, Tactical Pictures, Single Picture of the Truth, Common Pictures, Local Operations Pictures

1 Introduction

Coordinating large teams to carry out complicated tasks requires sharing understanding of the situation, but trying to tell everyone involved everything about the task is not always desirable, even when it is possible. Indeed, trying to tell everyone everything everywhere is obviously impossible, whether desirable or not.

So to improve the performance of extended collaborating teams, we need to understand where the edges of interested groups, physical constraints and suitable subjects interact to find out what needs to be shared with whom ('just enough') and what structures and languages can reduce cognitive and communication loads while maintaining good coordination. The trade-offs between and alignments of good coordination, cognitive loads, distraction, informed decision making, resilience, framing, comfort, short-term success, long-term persistence, and so on are not straightforward. There are likely to be many local Goldilocks states ('not too cold, not too hot; just right') across multi-dimension trade-off surfaces. Acceptable trade-offs depend highly on the working environment, team and task.

This paper argues that this evaluation is necessary (that attempting, for example, to share a 'single picture of the truth' is usually undesirable) and suggests a framework for that evaluation. It starts in section 2 by describing some working environments in order to give the reader some examples of what drives the information systems. In section 3 it introduces fairly well established models of shared team awareness of those environments. Section 4 goes on to list costs and benefits of sharing information, section 5 uses these to show that there are 'natural' extents of any particular working picture, and section 6 suggests ways of pushing these extents further out.

2 Example Working Environments

The work that produced this paper uses three case studies to represent a broad range of distributed collaboration environments: expert engineering collaborations, academic 'scrum' research, and military ground operations.

Military operations are a usefully 'extreme' working environment to study: communications are poor, intermittent and fragile, time constraints are hard and tight, outcome stakes are high, stress and emotions are strong, consequences are ethically fraught, evidence is sparse, unreliable [Hill 2010] and drowned in clutter, knowledge sets are complex, and supporting systems are stripped-down yet mission- and safety-critical. This extreme environment helps to expose issues that can be significant in office environments but are masked by other effects.

Unlike some other operations that are somewhat similar – such as fire-fighting – military operations have opponent teams. Teams that compete and conflict with other teams not only collaborate and cooperate within and between themselves, but attempt to do so better (in some way) than their opponents: they will attempt to 'get inside the opponent's decision cycles', to disrupt the opponent's awareness of the situation, and to protect against opponent attempts to disrupt their own. There may also be some merit in attempting to persuade opponents to compete instead of conflict, and to collaborate rather than compete.

To reduce space, we focus in this paper on military examples that are readily differentiated from each other, can be represented by reasonably simple information models, and importantly are widely recognised due to the long-standing popularity of war films, newspaper articles and books.

2.1 In the Field (or Building...)

Soldiers in the field must spend their time observing the environment around them, looking for cues and clues for an enemy that is deliberately attempting to reduce them. The environment is often unfamiliar, the area not previously seen, and the detail heavily cluttered and three dimensional.

To understand this, consider for a moment your office or your house. Where are your immediate colleagues, or your neighbours? How would you describe the way to the bathroom, or where to find an item in the kitchen? Extend that to a small group of eight or so people strung out through adjacent rooms and consider where they are, how to get them, how to communicate with them, how to point out something specific outside the building. Directions and reference points depend heavily on obstacles, obvious common features, lines of sight, and the relative positions of the team members in the reference frames we mentally build to navigate, rather than a flat map.

2.2 Tactical Command

Mid-level commanders (who command from thirty to several hundred men) coordinate arrangements of people (actual and desired) and tend to model the situation as a 'birds eye' top-down view, like a map, analysed and interpreted as routes and barriers and fields of fire and areas of influence and so on. A civilian equivalent might be to use a satellite navigator in the car, or on foot.

2.3 Logistics Support

Enabling the immediate task of destroying the enemy's will to fight are the support services that provide the fighting command with the food, water, ammunition and other equipment required to carry out that task, and services such as casualty evacuation and medical care.

This working environment is concerned with stuff: where it is, how much of it there is, what it is, how quickly it is consumed, what's available to move it, and so on.

2.4 Specialist

Overlaid on the above 'fighting' command are various special interests. Signallers for example are responsible for maintaining the communication networks, and so have to share with each other their awareness of radio frequency overlaps, ranges, available equipment, encryptions, callsigns and so on.

3 Understanding the Environment

The above section describes some of the different people who are attempting to collaborate with each other, both inside their groups and across them, and the environments they operate it. This section briefly describes models to represent how they understand their environments and communicate them to each other.

Considerable work is going into how we understand the world around us [eg Endsley 1995] in order to inform our decision making [eg Klein 1999]. Our interest here is in the *distribution* of that understanding, recognised as currently insufficiently studied [eg Salmon 2010].

For the purpose of this paper, we simplify this down into three components:

- An individual's *situation awareness*. This is our understanding – a mental model - of what is going on in the real world. In practice this cannot be an objective model; it is necessarily a conceptual approximation and includes our limited understanding of how the world works, what we would like it to be, and actions that might bring that about [Endsley 1995].

It is built out of experience of the world (including training exercises), information conveyed directly from others (such as brief descriptions), and 'pictures' often aggregated from several sources.

- Communicated *information.* Information informs: it modifies in some way the worldview of the informed. It contributes to the individual's situation awareness.
- A shared *picture.* This is an assembly of information that acts as a reference model of particular aspects of the world, such as a map overlaid with symbols showing the location of friendly and enemy units, or a link diagram showing the relationships between personalities in the local area [eg Checkland 1981, Stanton 2010]. It might be used to hold a reference for the operator alone – an externalised piece of situation awareness – but is commonly used to communicate situation awareness from one operator to another.

The interpretation of the picture therefore is vital to common team awareness; it has to be assimilated quickly (to avoid losing tempo), easily (to avoid consuming attention or encourage mistakes) and unambiguously (to avoid translating into the wrong SA). The interpretation need not *persist* in the mind if the external picture (such as a map) can be referred to easily and reliably.

Similarly, and for similar reasons, it should be quick and easy to create and communicate, with suitable support (training, procedures and equipment) to make it easy and unambiguous. Ambiguity, where each party can interpret a different picture from the same communication, can have devastating effects on the military when for example applying lethal force against the wrong targets.

4 Language, Dialect & Scripts

The above section outlined very briefly some ways of modelling collaborative understanding, and here we consider the mechanisms by which we share that understanding.

Conveying a particular picture, or part of one, can be by several mechanisms. For example a voiced phrase ("Enemy: right of road, third telegraph pole, at base") might also be represented as a symbol on a map. The semantics of this voice description and symbol are the same and possibly use the same language construction (grammatical relationships of location, time, motion, capability, intent, interaction and so on), but represented by different scripts.

The different *forms* of picture and information exchange depend on the type of working environment, and there are different *instances* of them depending on the task. For example, field troops typically use the *form* of specific voiced phrases to exchange enemy locations, while mid-level commanders use map symbols and coordinates.

A particular enemy location – an *instance* – might be shared by both those field troops in contact with them, and their mid-level commanders. That is, an *instance* of a particular picture may be represented and passed by several *forms* of pictures.

However the different forms necessarily constrain and enable the passing of information in different ways: for example maps with symbols can provide a fast visual snapshot, from which we can rapidly extract patterns. It is a suitable medium on which to collect and aggregate individual reports to show an overall picture.

Similarly therefore, a *form* of a picture may represent and pass several *instances* of pictures.

The picture may also be conveyed by dialogue, for example to confirm intelligent receipt (paraphrasing rather than a simple acknowledgement), or perhaps to develop understanding about what information is required and what is available. Typically information in counter insurgency operations is less straightforward than the 'enemy location and capability' information in fighting operations. The details themselves include more complex interactions ("Mr Ahmed is trading poppies for guns") and have to carry labels about where it came from and how this affects the detail ("so says Mr Mohammad, who's brother is Mr Ahmed's rival in coffee farming").

The information or dialogue must be in a commonly understood specific language (so meaning is established accurately and unambiguously), concise (to reduce the load on the mechanism of conveying), related to the environment (so conveyed information relates to the right situation) and timely (so that it's not too late to use).

Typically the languages and dialects are developed through training, realistic exercises and experience, and so evolve appropriately. Rearranging organisations or re-tasking may require redeveloping the languages used to share awareness during task execution.

The relationship between meaning, shared language, grammars, symbologies, intent and information in this environment could benefit from further exploration. There may be scope for a universal (or at least widespread) battle language, expressed in different forms depending on the task, environment and available communications technology.

5 Sharing is not free

While we might argue that shared knowledge across a team can – personality conflicts, goal incompatibility, judgement failure and so on aside – improve team effectiveness, ensuring that knowledge is in place and up to date is not free.

5.1 Informing costs bandwidth

When communication has used up all the available bandwidth, it stops or delays other communication. Anyone familiar with press-to-talk radios, or trying to send a mobile-phone text at new year, will be familiar with the problems of such overloads.

Available bandwidth in military, police, emergency and similar working environments varies considerably. Radio communications are typically contended, low bandwidth, and intermittent, but when patrols come in to base they have access to rich information sets such as maps and direct dialogue with commanders and other patrollers. The detailed information exchanges and picture assembly are therefore done at base, with only relevant updates passed on by radio.

5.2 Informing costs weight (or mobility)

Remote communications requires communications equipment, and the longer, richer and farther the communication the more equipment is required. Batteries are a significant load on the foot soldier, and carrying more batteries means carrying less other equipment, or suffering performance degradation with consequent effects on mission capability. Ultimately, running out of power results in lost communications altogether.

It is tempting therefore for command nodes to become static; deploy generators, fix antennas to make communications more reliable, set up offices to manage information more easily and comfortably, and so on. Given the intent of forward armed forces might be summarised as “find, fix and finish”, succumbing to this temptation essentially self-finds and self-fixes the headquarters.

5.3 Informing costs security

Communication can be overheard. Voice and poorly encrypted tactical radio nets are noticeably vulnerable. Even if the content is not understood, the transmission itself can identify position and sometimes unit and capability. Signals may be recorded and decoded ‘offline’ to reveal working practices and standard procedures. Radio silence is commonly applied to avoid such, thus blocking communication.

In counter insurgency operations, where the threat from Improvised Explosive Devices (IEDs) is common, jammers are sometimes used to interfere with some device trigger mechanisms, and these in turn interfere with radios. Turning jammers off or moving out of range of them in order to communicate removes a layer of security.

5.4 Informing, and being informed, costs attention

It takes time to transmit any data, and this is time not spent doing. If that data informs – that is, it changes the informed’s world view – then it also takes time to assimilate. The more of it there is, the longer it takes to transmit, understand, and adjust the world view.

This can become a significant impact on the cognitive load of both the informer and the informed. While informing, neither are doing or planning [Kramer].

5.5 Informing Obscures: Clutter

While informing can distract (see below) it also obscures. Verbal communications can prevent other verbal communications from being heard, radio messages block other radio operators from using the channel, and it is common for symbols on maps to become so cluttered that it becomes difficult to distinguish them from each other, and in particular to distinguish the important ones from the less important ones.

5.6 Distraction by detail

More information is not necessarily better information; when detail is made easily available it can become a distraction from harder to process but still vital information [Yes Minister 1980]. Similarly, easily measurable and available detail may not be useful detail [Adler 2008]. As UAVs became common in theatre so did the video that they were streaming back, and anecdotally this rich and immediate 'Kill TV' tended to distract staff supporting command posts.

5.7 Distraction from detail

More information is still not necessarily better information; when too many information feeds are being handled, it becomes necessary to 'skim' them in order to keep the situation awareness up to date, and so to be able to plan and respond more quickly and usefully than the enemy. Timeliness can therefore be at the expense of missing important details.

5.8 Distributing cognition

Adding suitable experts to the picture constructions can be a benefit by reducing the load on the commander, by interpreting and combining several picture feeds into fewer, larger-grained feeds. However this also adds an extra layer of separation between the commander and the source, and can lead to several extra 'hops' between distributed peers that disconnect pictures.

6 Natural Picture Extents

The trade-offs between the above costs and benefits of sharing information lead to some 'obvious' markers that suggest the extent to which either *form* or *instance* of pictures apply across an organisation.

For example, the different environments described in section 2 above suggest different forms due to the constraints: voice and relative position descriptions for frontline soldiers, and map symbols for mid-level commanders. Overlapping areas and boundaries between them become translation points, so junior commanders have to translate the situation around them into global reference frames for their commanders, and vice versa for their subordinates.

Similarly, specialist tasks tend to evolve specific concise phrases and terms for activities within those tasks that are useless or misunderstood elsewhere. For example, the word 'repeat' is used in British Army radio communications with the very specific meaning of repeating the last artillery fire mission, and so should not be used to request the repetition of, say, a voice message.

The aggregation and reduced detail of picture *instance* as it is conveyed is largely limited by the communications mechanisms at the lower operations levels. Training and experience provide expertise for small teams to trade distraction against the need to keep peers and commanders informed.

Shared culture provides common bonding and frequently common references for communicating, and vice versa [eg Kirke 2009, Kirke 2004]. This culture might come from the soldiers' backgrounds, and recruiting regiments from common geographic areas provides a somewhat similar starting point. As teams work together they tend to evolve their own culture which, along with the bonding that is vital to this line of work, promotes tight concise understanding within the team but makes more difficult to collaborate with unfamiliar teams. The British Army therefore imposes some of its own common culture by drill, and enforces cross-team culture by combined training, but on the other hand encourages strong hierarchical competitive tribalism to support team cohesion under stressful circumstances.

Some parts of pictures are deliberately not universally shared to maintain secrecy, such as the locations of special forces. However to ensure that they do not get fired upon when other troops are

operating in their area, this location information must still be connect up with fire missions (or vice versa). Limiting the view of friendly locations however can be one contribution amongst many [Reason 2000] to fratricide, or ‘friendly fire’, as occurred in 1982 in the Falklands conflict when one special forces patrol attacked another.

By contrast, some parts of pictures are deliberately shared further than immediately necessary, in case circumstances change and they must quickly contribute. All-informed nets allow commanders to eavesdrop on their peers, so that they can keep up with what is going on around them without having to have that information relayed via the headquarters (and so consume extra communication resources).

Similarly, pictures are aggregated through chains of command so that commanders can understand the context and activities of particular events to inform their wider interactions and collaborations.

7 Extending pictures

The above 'natural' extents of forms and instances can sometimes be bridged or extended to reduce the translations between them.

For example, technology can bypass the load on attention by automatically ‘reporting’ and translating certain information, such as the locations of friendly units using GPS. Automatic encryption, frequency hopping and queuing reduces the effort in communicating and improves reliability.

This means that more detailed pictures can be built, and in turn we can expect increased load on attention. Technology can help here too, by providing displays that can be customised and filtered so that the viewer can focus (by removing clutter) on particular aspects of the picture.

Automatic universal broadcast of some picture information however reduces the resilience of the information systems to attack. For example, if locations of all friendly units are ubiquitous across the organisation’s information systems, then a penetration *anywhere* in that system can expose the locations of all units.

This must be balanced against the benefits of improved coordination at the ‘edges’ of the organisation where the hierarchical command structures can leave significant communication gaps between units close to each other on the ground. Neighbouring front-line units can be close to each other geographically but remote in both command and communication hops.

Most pictures however only need to be partially ‘extended’, by aggregating and combining them into different pictures appropriate to the extended part of the organisation, or indeed beyond the organisation to collaborators. Some of these can be automatic, such as bundling up locations of individual units into one approximate location. Some are reasonably straightforward, such as using liaison officers to act as ‘gateways’ between collaborating organisations with different cultural and working practices. Some are more complex, such as planning and assembling intelligence, which tends to force staff to resort to slow and ambiguous natural language to convey these pictures. Research into supporting these complex picture distributions could improve their timeliness and reduce their ambiguity.

Defining the extent of a picture instance or form is not an exercise in isolation. It impacts on, and is impacted by, the tasks required, the structures of the organisation, the skills of the individuals, equipment available, and the operating environment. Changing the structure of parts of the organisation, for example by delegating mission responsibility to remote commanders, can radically affect the extents to which pictures need to be communicated.

8 Conclusion

In summary, pictures are used to support the shared situation awareness that is vital to good team coordination. Conveying a picture is not free however, and the consequences of blindly or automatically conveying detailed pictures are not always beneficial. In particular, attempting to build single universal pictures across large organisations can heavily distract individuals from their tasks, create vulnerabilities to exposure, increase the logistics load, reduce the agility of the organisation to locally adapt to changing picture needs, and offers little practical benefit.

It can be tempting to assume that improving information technology will solve problems with information sharing; we hope we have shown that in some circumstances more communications technology does not only not improve situation awareness but can detract from it. By describing

characteristics about information sharing, information managers and exploiters can make a more informed decision about the suitable extent and form to which that information should be shared and aggregated.

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