Visual Exploration of Communication in Command and Control

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Abstract

Communication is a central activity in command and control. However, analysing communication using linear transcription of large amounts of sequential data is tedious and time consuming. This paper describes an alternative approach to communication analysis based on visual exploration of abstract representations of communication. It introduces a visualisation technique based on the Attribute Explorer. The technique was implemented in a visualisation component embedded in a framework for coordinated presentation of temporal data. It is demonstrated using authentic communication data from a military exercise and a rescue operation.

1. Introduction

Communication is crucial in distributed, safety-critical human activities, such as fire fighting, law enforcement, and military operations, where units operate at separate locations under hazardous conditions to achieve common goals. Commanders, team leaders, and specialists must exchange plans, procedures, reports, and orders to coordinate and synchronise their efforts. Not only are such messages vital to ensure a successful outcome of an operation, but they also provide an observable trace of how key actors have perceived the emerging situation and what decisions they have made. Therefore, recording and analysing communication from multiple channels are important means of gaining insight into the processes involved in command and control (C2).

A major problem with communication analysis and other process-tracing methods [19] is that they can generate huge amounts of data. Another problem is that analysis of audio data based on transcription is time-consuming and tedious [3]. Fisher and Sanderson [6] observed that the time required to analyse a recorded sequence could be many times longer than the sequence itself. But they also indicated a potential solution to the problem based on visualisation of abstract representations of audio data. The key idea in the approach is to store digitised audio data and postpone any transcription or replay of the data until it is absolutely required. Instead, the analyst interacts with an abstract representation of the sequential audio data through a graphical user interface that supports navigation based on speech patterns or annotated keywords and provides random access to any audio sequence of interest. A similar approach underlies the multimedia analysis tool DIVA [8] that includes representations of multiple synchronised multimedia streams accessible through a graphical user interface.

This paper combines an abstract representation of communication with an exploratory visualisation interface. Communication is recorded as digitised audio data or as electronic messages, and each message exchange is represented as an abstract link with information about sender, receiver, time point, duration, and classification [16]. Visualisation and exploration take place at the level of abstract links. The problem of formulating—or even knowing—relevant questions suggests that queries should be dynamic in the sense that the results of interactions are immediately visible [13]. Obtaining zero hits or too many hits when searching and browsing large data sets is another well-known problem [15]. As communication analysis includes exploratory tasks, we need a clear view of the context to navigate among the data. Providing dynamic queries alone does not solve this problem. We also need hints on where and how to adjust the queries to manage the hits [14]. These requirements prompted us to base our tool for communication analysis on the Attribute Explorer [15, 14].

Using authentic data from a military training exercise and a rescue operation exercise we show how the extended Attribute Explorer helps answering ubiquitous C2 questions, such as what an actor said to another actor in a specified time interval. But more important, we demonstrate how the visualisation supports discovering unanticipated communication patterns and helps detecting anomalies in the underlying link data [18]. The software tool was implemented as a plug-in component for the MIND visualisation framework [10, 9].

The next section briefly introduces C2 and describes the role of communication in C2. Then follows a short description of the MIND visualisation framework. After those preliminaries we review the Attribute Explorer and describe how our extension facilitates the analysis of communication in C2. A discussion and our conclusions complete the paper.

2. Communication in command and control

Pigeau and McCann [11] provided a general definition of C2 that focuses on its role in a distributed activity: "The establishment of common intent to achieve coordinated action" (p. 165). They further distinguished between intent that is publicly communicated (explicit intent) and intent that is assumed from the cultural, organisational, and individual context (implicit intent). Shattuck and Woods [12] linked this definition of C2 to the role of a communication process as a conveyor of plans, procedures, specifications of degree of control, and reports on system status between supervisors and actors in a hierarchical, distributed organisation. In particular they discussed the inherent conflict between maximising a supervisor's degree of control and enabling local actors to respond to rapid changes in the environment. Flin [5] reported that not having a complete picture of an emerging situation was a major source of stress for fire commanders. In essence, this issue concerns what must be communicated, before and during a mission, and what can be managed at a local level guided by what has been communicated and what can be inferred from the context.

To analyse communication in C2 we thus need to consider both the messages sent between various actors and the situation in which they were sent. Examples of important issues in the operational context are:

- **Actors:** What individuals and teams are involved and what is their status?
- **Organisation:** How are individuals and teams organised in units and how is the chain of command defined?
- **Communication:** What means of communication exist and how does the communication structure relate to the chain of command?
- **Tasks:** What tasks have actors been assigned?
- **Location:** Where are the actors?
- **Activity:** What are the actors doing?
- **Coordination:** What activities need to be coordinated to ensure effective, efficient, and safe operations?
- **Time:** Are there deadlines and when do activities have to commence and cease?
- **Artefacts:** What is the status of communication systems and other tools for C2 and how are they used?
- **Environment:** What does the terrain look like and what is the weather like?

Although communication analysis can provide crucial information pertaining to those issues, other means of process data are required as well, for example log files from C2 systems, log files from positioning devices, and video recordings from command posts [16]. Compiling process data and combining them with verbal reports provided by participants enable the construction of behavioural protocols [19] to address cognitive aspects of communication in C2.

3. The MIND visualisation framework

The need to handle large amounts of data pertaining to diverse aspects of command and control in distributed operations motivated our development of the MIND visualisation framework [10, 9]. MIND uses data collected in a real operation to construct a time-synchronised, discrete-event representation of the course of events of the operation. The resulting model can be presented in a visualisation tool that supports time-based navigation and animation using multiple views. MIND includes a component model that enables the development and deployment of customised models and visualisations to meet the requirements of different domains, research questions, and target audiences. Examples of visualisation views deployed with MIND are:

- **Map view:** Presents the time-dependent location of actors using symbols in customisable maps
- **Photograph view:** Displays time-stamped and annotated digital photographs of actors at work
- **Video view:** Displays time-stamped video sequences of activities in the operation
- **Audio sequence view:** Provides random access to time-stamped audio data from various communication networks
- **Communication link view:** Presents audio data represented both as communication links and audio sequences
- **Dynamic timeline:** Shows an overview of selected events to support temporal navigation
- **Document view:** Displays written information, for example plans, standard operating procedures, and orders

So far, MIND has been used to support training and evaluation in the military domain [7, 1] and in the public safety sector [10, 4]. It has also been used to support research on airborne mine detection in Croatia.

4. Exploring the Attribute Explorer

The Attribute Explorer [15] is an interactive visualisation tool that employs the concept of linked histograms. It provides one histogram for each dimension (or attribute) of the data, where the height of each bar corresponds to the number of data elements that fall under that interval. By changing the limits in one dimension the corresponding hits are updated (or 'brushed') in the other dimensions. Elements filled in a contrasting colour represent full hits, that is, they satisfy all constraints in all dimensions. Shades of grey—from black to white—represent the number of dimensions failed. An element is coloured black if it fails in one dimension only and white if it fails in all. For each dimension added to the data set, there is an additional constraint that can be violated. Thus the number of colours required equals the number of dimensions of the data.

The Attribute Explorer supports central tasks in visual exploration of communication by meeting the following three requirements:

- **The need to answer known questions:** It accepts well-defined, absolute restrictions on each dimension, which subsumes pre-defined queries.
- **The need for exploration:** It encourages exploration by enabling dynamic interaction with every dimension and presenting immediate visual feedback.
- **The need for context:** It provides a view of the context at all times as the colour-coded histograms give hints on where to relax constraints to get hits and where to impose restrictions to narrow the solution space.

5. Extending the Attribute Explorer

Before we can explore communication visually using the extended Attribute Explorer we need to convert the data recorded to an abstract representation. A commonly used method for evaluation of communication is link analysis, which accounts for frequencies of interactions between humans, machines or their combinations [2]. Extended Link Analysis [16, 1] extends basic link analysis to address communication in C2 by adding time stamps and message classifications to links. The communication links constructed include the following attributes:

- **Sender:** The actor in a communication network that initiated the communication
- **Receiver(s):** The actor(s) in a communication network to whom the message was addressed
- **Classification:** A hierarchical set of categories, allowing both detailed classifications and summary classifications
- **Start time:** The time when the communication was initiated
- **Total length:** The total length of the communication sequence

In addition, a link may have an optional text annotation that includes a key word or a short summary. These attributes cover several of the operational issues listed in Section 2.

Creating links requires extraction of senders and receivers, and classification of message contents. For computer-based communication, for example e-mail, links can be generated semi-automatically using logging tools. However, to process recorded audio data substantial manual work is required.

Spence and Tweedie [15] discussed both ordinal and categorical attributes, but all the application examples presented concerned data sets with numerical attributes [14]. In our case the attributes are of different types—categorical, hierarchical, ordinal—and they may be both discrete and continuous. For such attributes, range-based selection is not sufficient. Instead, a user must be able to select and deselect elements independently. Furthermore, some of the attributes of a communication link need not have mutually exclusive ranges of values. Communication links may specify several receivers for one message, which forces the same underlying data to be represented at several places in the histogram. Similarly, a communication link may include multiple message classifications. Another characteristic is the temporal dimension of the data set: Communication is distributed over time and will therefore add an underlying source of dynamism into the exploration.

6. Application examples

To demonstrate the benefits of using the extended Attribute Explorer, we examine radio communication from two field exercises. In the first exercise a joint multi-agency rescue force responded to a mass-casualty underground train derailment in Stockholm [17]. The other exercise involved manoeuvre warfare with a mechanised battalion in northern Sweden.

First, we demonstrate how the Attribute Explorer helps us find the answers to predefined queries. One example of such a query is to ask for all communication sequences initiated by a particular actor. In the Attribute Explorer there is a straightforward way of conducting this non-exploratory task by imposing restrictions on the attributes of the data set. Figure 1 illustrates this use where one staff member (police unit 9770) has been selected in the 'sender dimension' leaving all other dimensions minimised. The hits represent every sequence initiated by unit 9770 and they are listed below the histogram. From this list, it is possible to replay the audio message of selected communication links and to synchronise the other views in the MIND visualisation framework with the links. The time stamp of the selected communication link is used as the target time point for temporal navigation in the framework. The contents of the views are updated to reflect the state at that time. Figure 2 depicts a map view of the incident area showing the current state of all involved units at the point of time derived from such an interaction with the Attribute Explorer.

In exploratory tasks, for example when studying movements and activities of military units, an analyst may seek to answer why a unit suddenly interrupted its activities or turned and headed for another direction. Figure 3 illustrates such an example that involves the military unit DX. Selecting the unit in focus (DX) as receiver, choosing the classification category 'order' (which includes three different subcategories: preliminary order, short order, and full order), and specifying a time span covering the last hour, produce a view where the hits correspond to all orders given to the unit in the specified time frame. Replaying these orders (or maybe just by looking at their textual annotations) may reveal the reason for the unit's behaviour.

In both these examples queries formulated in a data base language could have produced the same end result. But we would not have been invited to notice the additional contextual information. For example, we see in Figure 3 that DX never received a full order, neither in nor outside the selected time interval. We conclude this from the fact that the 'full order' classification elements are coloured grey, which means that they violate constraints in more than one dimension. However, we notice that DX did receive orders some hours before (the

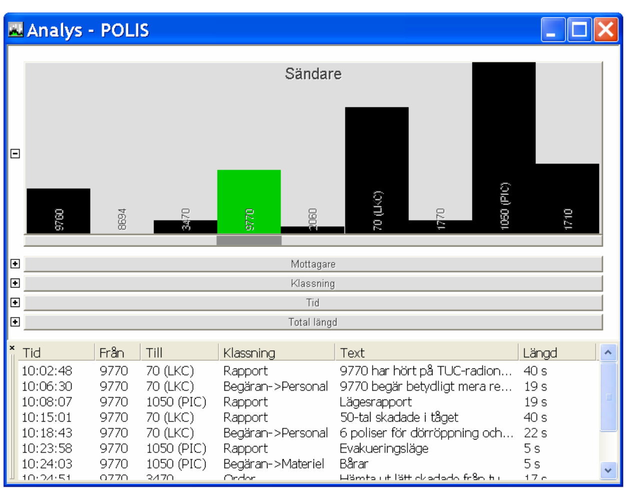

Figure 1. An example of a simple query using only one dimension, sender (*sändare*), of the Attribute Explorer: Police unit 9770 is selected in the sender dimension and all communication initiated by 9770 is shown in the list.

Figure 2. One of the views in MIND that can be synchronised to the Attribute Explorer: This view shows involved units (police and fire department vehicles, ambulances etc.) on a photographic map of the incident area.

black elements in the time dimension area). Furthermore, we see that DX did not receive any other types of messages during the selected hour, because all elements in unselected classification categories fail in at least one other dimension (see Figure 3).

Exploring a scenario in the Attribute Explorer may result in the discovery of relevant facts without any pronounced question to begin with. For example, when we examine the messages sent from the battalion staff to the subordinate companies in the battalion exercise, we find a period of nearly two hours where no communication was initiated. Figure 4 shows a view where a time interval including that period has been selected. The first hit in the selection represents an order that instructed the company TJ to carry out their task. Presuming that TJ conducted that task, the next step is to inspect communication initiated by TJ during this activity. By limiting the sender dimension to only include TJ, by restricting the receiver dimension to include only the supervisors of TJ in the battalion staff, and by selecting the classification dimension to 'reports', we see how TJ continuously reported its progress (see Figure 5). The reports are immediately accessible in the list of hits (as in Figure 1), allowing the original communication to be reviewed and replayed. The example view in Figure 5 gives other hints as well: TJ did not report to anyone else than its supervisors (no black elements outside the limits). Moreover, TJ reported enemy status (as indicated by the small black element to the right). By looking at the length dimension as well (minimised in the figure) we discover that all reports were short, except for one that was considerably longer. Selecting that link leads us to a concluding summary report of the company's progress. These examples demonstrate the exploratory use of the visualisation tool for analysing communication.

What about finding problems in the underlying data? Using the length dimension to select unusually short messages from the military exercise, we find that they typically are flawed in some way (e.g. lost connections and poor audio quality) and usually classified as 'other'. Adding a classification for incomplete transmissions would make it possible to relate communication problems to other aspects of an operation. Furthermore, it is easy to detect communication links pertaining to orders that (by mistakes in the link analysis) point in the wrong direction. If a commander receives an order from a subordinate unit there will be an isolated green element in the explorer view that stands out. Once spotted, the corresponding communication link can be adjusted to convey the correct information.

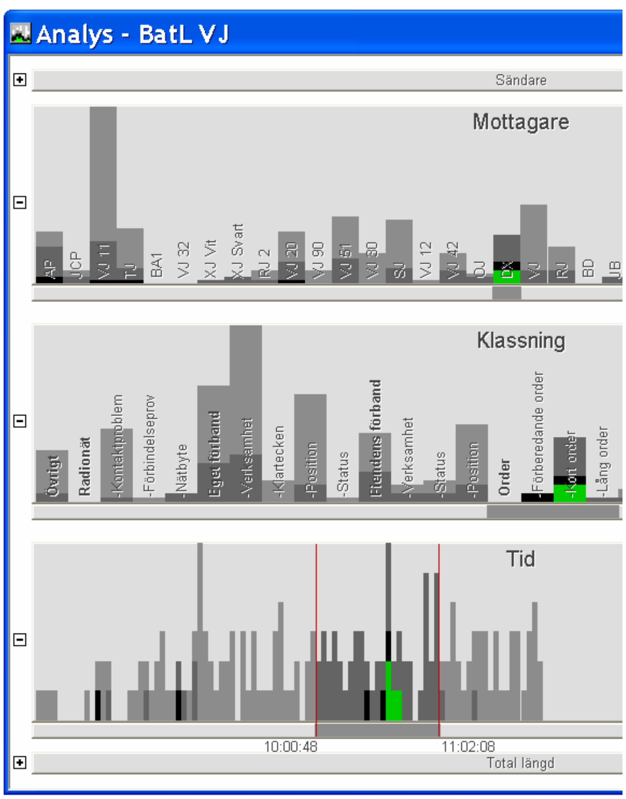

Figure 3. This view shows the use of three dimensions, receiver (*mottagare*), classification (*klassning*) and time (*tid*), to find the most recent orders given to military unit DX. The selection in the classification dimension comprises order (*order*), preliminary (*förberedande*) order, short (*kort*) order and full (*lång*) order.

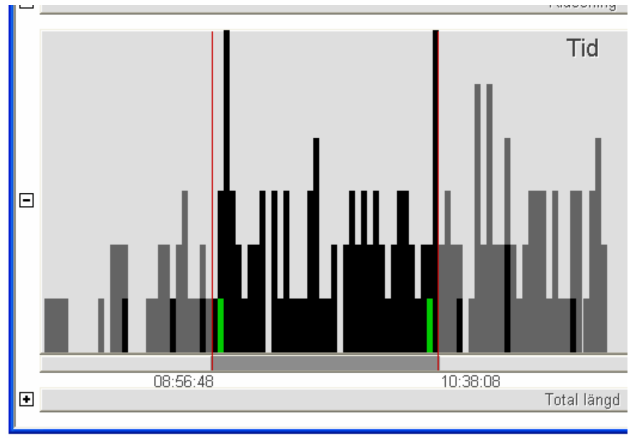

Figure 4. This view shows received messages for the company TJ during a period of time. The first message is a direct order and leads us to look closer on how TJ will carry out this order.

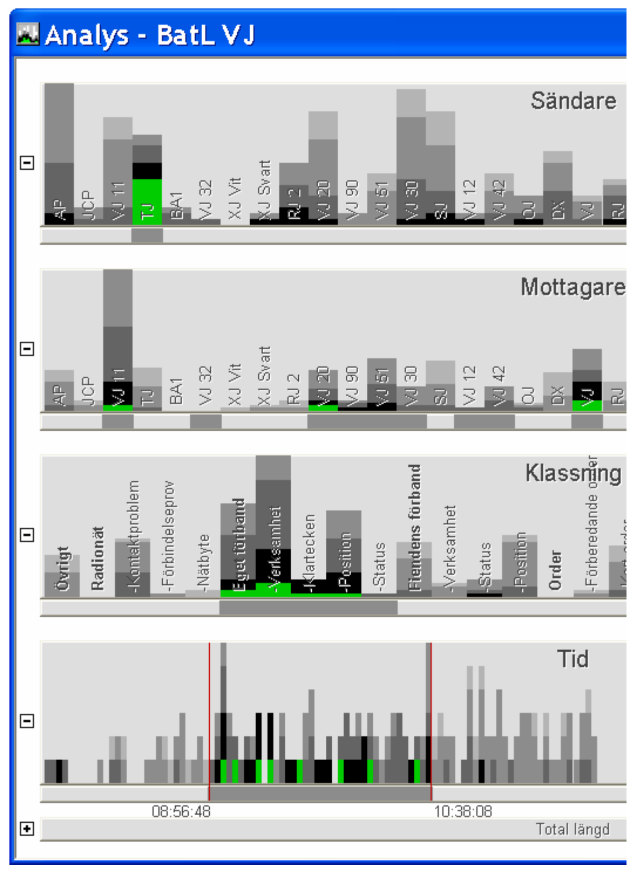

Figure 5. By selecting appropriate limits on the sender (*sändare*), receiver (*mottagare*), classification (*klassning*), and time (*tid*) dimension we see how the company TJ regularly reports to its supervising officers.

7. Conclusion and future work

Our goal was to develop a tool that can support the analysis of communication in command and control. In the short time the prototype has been available for C2 system analysts within the MIND research group, it has already been welcomed as a helpful tool not only to answer ubiquitous questions pertaining to communication in C2, but also to explore patterns and relations in communication data. The combination of link analysis and a visual representation based on the principles of the Attribute Explorer provides new possibilities for explorative communication data analysis in the C2 domain. These possibilities fill gaps in the MIND framework–a research tool under constant development–and shed light on further development issues for the framework as a whole, where more powerful coordination possibilities among different views is one example.

More research is needed in the area to evaluate the usefulness of the technique. However, formal evaluations of the Attribute Explorer in order to compare it to other techniques could be hard to get ecologically relevant. The exploratory nature of the Attribute Explorer and the complex nature of communication and C2 make this task non-trivial. However, to get an improved understanding of the usefulness, the implemented tool will be delivered to and used by analysts outside the MIND research group as well, contributing to a deeper insight.

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