Supporting Tool for Cooperative Work Analysis Based on Distributed Cognition

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Abstract: This paper aims to use a distributed cognition-inspired approach in an analysis of how teams work. The intention is to extract tacit knowledge from observations of a cognitive system which can be derived from the identification of information trajectories and the grouping of agent actions/activities into specific abstract processes. For this purpose, we have developed a tool to support analysis from a distributed cognitive perspective, and we present a prototype of the tool for assisting analysis of cooperative work here. This work is part of a study into the applicability of distributed cognition to cooperative tasks, with the objective of developing a systematic framework to represent relevant knowledge and expertise.

Keywords: Cooperative Work Analysis, Cognitive Process Analysis, Task Analysis Tool, Knowledge Management

1. INTRODUCTION

Cooperation plays a key role in group or team work to accomplish a task successfully. In particular, it is a critical factor in establishing good relationships between human partners and artefact systems working as a team or group. In other words, it plays a critical part in developing good cooperative working, and should be considered in the design of systems.

It is expected that good team cooperation can contribute to greater efficiency, reduced workload and error prevention in a work environment. Team cooperation processes, however, are not yet well understood because they consist of complex processes. We therefore need to understand the details of basic functions of tasks in a system in order to design more reliable interfaces and training programmes for cooperative work.

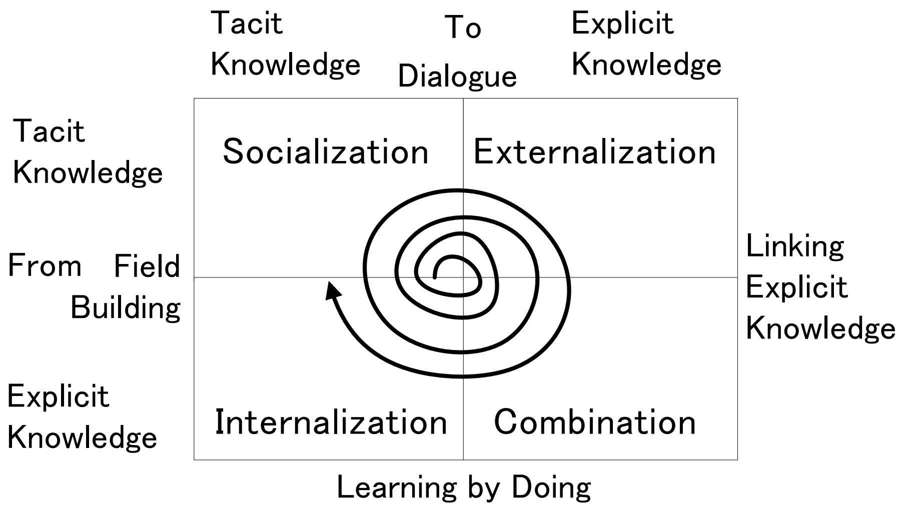
To improve cooperation in work, it is necessary to analyse functional elements during a system design process in order to understand the functions themselves. We believe that distributed cognition[1] is an effective approach for understanding the interactions between agents (humans or artefacts) in a system that involves collaborative work. In this research, we attempted to apply a method based on distributed cognition to analyse the activity that takes place in cooperative work. Distributed cognition analysis makes explicit the dependencies between human actors and artefacts by examining the transformation and propagation of information through various forms of representation. We propose a prototype tool to support the analysis of cooperative work based on distributed cognition to formalise the basic knowledge of workers in order to facilitate the understanding of knowledge structures and logical relationships.

2. KNOWLEDGE MANAGEMENT FOR COLLABORATIVE WORK

It is not easy to acquire the knowledge needed for complex collaborative work as a team. Codifying and managing knowledge can assist in effective knowledge acquisition. However, explicit knowledge is only part of the whole. Thus, we need to consider what knowledge is tacit and what knowledge is explicit in work as a team.

As a general concept of knowledge management, there is “tacit knowledge” and “explicit knowledge”. Tacit knowledge is individual knowledge which is personal and context-specific. Such knowledge is difficult to formalise and communicate concisely to others. On the other hand, explicit knowledge can be represented by a formal, logical, systematic language. Such knowledge can be transmitted to others easily[2]. Polanyi stated that "*human beings acquire knowledge by actively creating organizing their own experiences*." Given this idea, knowledge that can be represented by systematic language or symbols is a part of overall knowledge. Tacit and explicit knowledge are subjective while explicit knowledge is objective. Nonaka and Takeuchi[3] say of tacit and explicit knowledge that "*the dynamic model of knowledge creation is anchored to a critical assumption that human knowledge is created and expanded through social interaction between tacit knowledge and explicit knowledge*," and that the process, called "knowledge conversion", is cyclical and mutual.

Figure 1. Knowledge conversion, and the knowledge spiral (Nonaka & Takeuchi, [2])



Knowledge conversion forms a process of transformation called the "knowledge spiral", shown in Figure 1. This cycle is a dynamic process in the organisation of activity. One purpose of codifying a systematic structure of knowledge is to assist the transformation processes of these modes of knowledge in order to formalise the knowledge of team members performing complex collaborative work.

It is important to analyse the relationships between work processes and to understand the specific content of tacit knowledge or explicit knowledge.

Cooperative workers require special knowledge and skills for carrying out their specific operations. If the acquisition of technical skills and special knowledge is required to obtain good performance from a system that includes humans, there should be a formal, systematic, and codified training programme in which logical thinking, experience and skills are combined. By formalizing theory and experiences, the knowledge conversion process can thereby proceed smoothly and efficiently. The framework should enable the efficient organization and acquisition of special knowledge and skills by assisting the process of knowledge conversion, such as tacit knowledge creation or the acquisition of explicit knowledge.

In complex collaborative work, team workers first learn about conventional rules and technical regulations from manuals and other literature. They then acquire basic knowledge of and skills for controlling operations through iterative simulator training. After that, they learn the specific rules, technical regulations, and orders for the environment in which they will actually carry out operations. They finally qualify after acquiring through training the knowledge and skills needed for performing operations at the working positions where they will work.

When dealing with configurations or work, the components of knowledge are separated. One component is explicit knowledge, such as information that can be described in a document. The other is tacit knowledge, including information which is difficult to describe in systematic written language (such as information on visual, auditory, and situational awareness) but is easier to understand.

3. DISTRIBUTED COGNITION ANALYSIS

How can we perfom analysis to acquire or capture knowledge such as that found in complex processes in the real world?

3.1. Methodology

Distributed cognition can be effective in analysing cooperative work from the cognitive process perspective. Distributed cognition is a methodological framework by which cognitive processes that span multiple actors mediated by technology can be analysed [4]. Distributed cognition analysis makes explicit the dependencies between human actors and artefacts by examining the transformation and propagation of information through various forms of representations. As such, the 'knowledge' can be represented in terms of interactions in context, which lends itself to further analysis. The management of team knowledge and hence the retention of knowledge, is through changes in distributed cognition induced by the introduction of new systems, personnel, and norms.

Distributed cognition is based on the idea that the notion of cognition can be applied to an ensemble of distributed individuals and artefacts, rather than confined to an individual [5]. The interaction of individuals, with different levels of knowledge and skills, and artefacts within a system allows them to come together as a single resource achieving its assigned task. The concepts applied in cognition are the same as in distributed cognition, but are directed at the interactions between a number of individuals and technological devices, or "agents". These agents are humans or artefacts that are capable of assisting or directly carrying out information processing in some way. For example, a piece of paper can be considered an agent due to its ability to retain information, offloading cognitive demands from a human agent.

Cognitive systems can be described using different units of analysis, allowing some systems to subsume others. This enables the examination of different interacting elements: from an individual with a single set of tools, to groups of individuals interacting with each other and a number of tools [6]. Information is represented by media in a cognitive system, including internal representations (individuals' memory) and external representations. The cognitive activities within a system are viewed as computations, which are enabled through the propagation and/or transformation of the representational state of information between agents, across different media. These propagations form traceable information trajectories from the initial input to the system to its final output. Assuming that these trajectories form stable patterns, an observable and changeable "cognitive architecture" is uncovered. In short, the focus in distributed-cognition is on how information is represented, transformed and distributed across individuals and representational media. The key benefit of adopting a distributed cognition approach is that the information processing within a system of interacting individuals and artefacts becomes directly observable. Through observation, a greater understanding of the information processing can be gained, potentially leading to a more effective system design. This ability to observe information processing differs from the traditional perspective on cognition, which can only infer it.

3.2. Domain Field

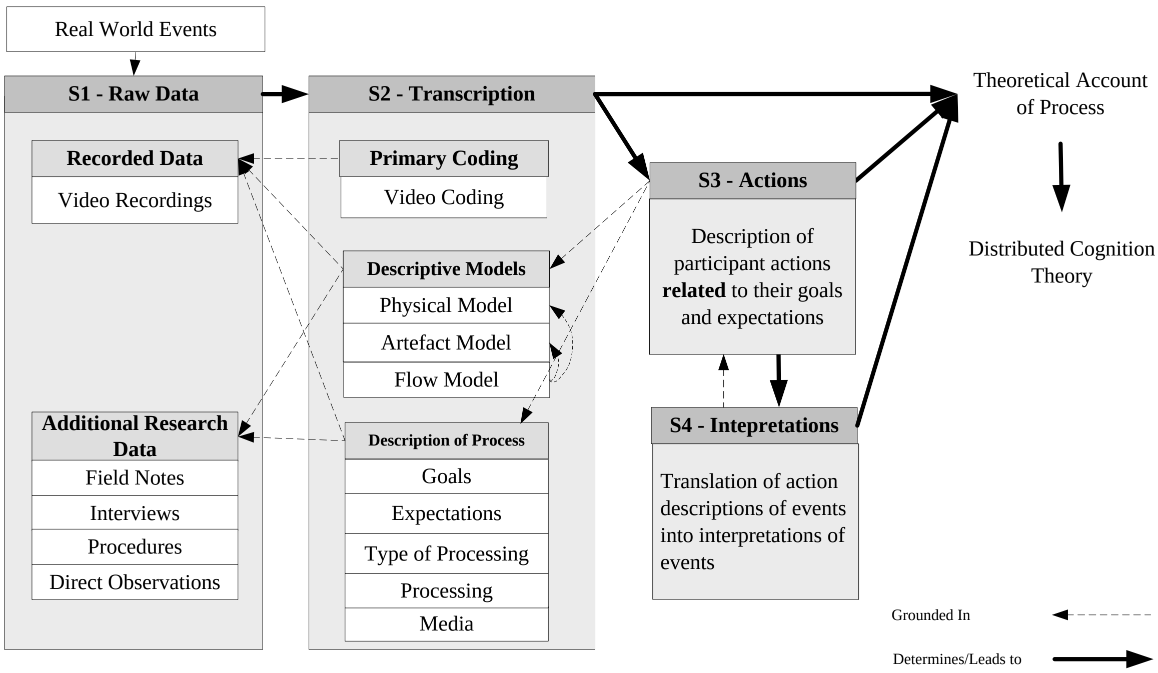
To verify the functions of our prototype collaborative work analysis tool, we use Air Traffic Control (ATC) work as a case study of collaborative work. As our research background, we have attempted to analyse the operation of a team of air traffic controllers (ATCOs) carrying out ATC work. To design technical systems to support operations, it is necessary to understand the roles and character of Air Traffic Controllers as system users. However, it is difficult for system designers and developers to understand the contents of an air traffic controller's work as knowledge due to it being highly specialised knowledge which is applied in complex tasks performed as a team. To understand these kinds of knowledge and skills such as tacit knowledge, we need to analyse and model structures of objective work. In order to design and develop more reliable systems, we need to understand details of the basic functions of the whole system of operations, including those of the controllers.

4. PROTOTYPE TOOL FOR COLLABORATIVE WORK ANALYSIS

4.1. Description of Knowledge

It is difficult for a trainee to learn the knowledge of cooperative work such as ATC work. This is because the working processes of cooperative operations are complex and performed by a team working as an organization. Codifying and managing that knowledge can assist learning it effectively. However, it is considered that explicit knowledge is only expressed as a part of the entire knowledge. This section will discuss the definition and representation of knowledge. Figure 2 shows details of a framework for extracting knowledge of cooperative work based on the distributed cognition analysis of observations of the work [7].

Figure 2. The framework of distributed cognition analysis

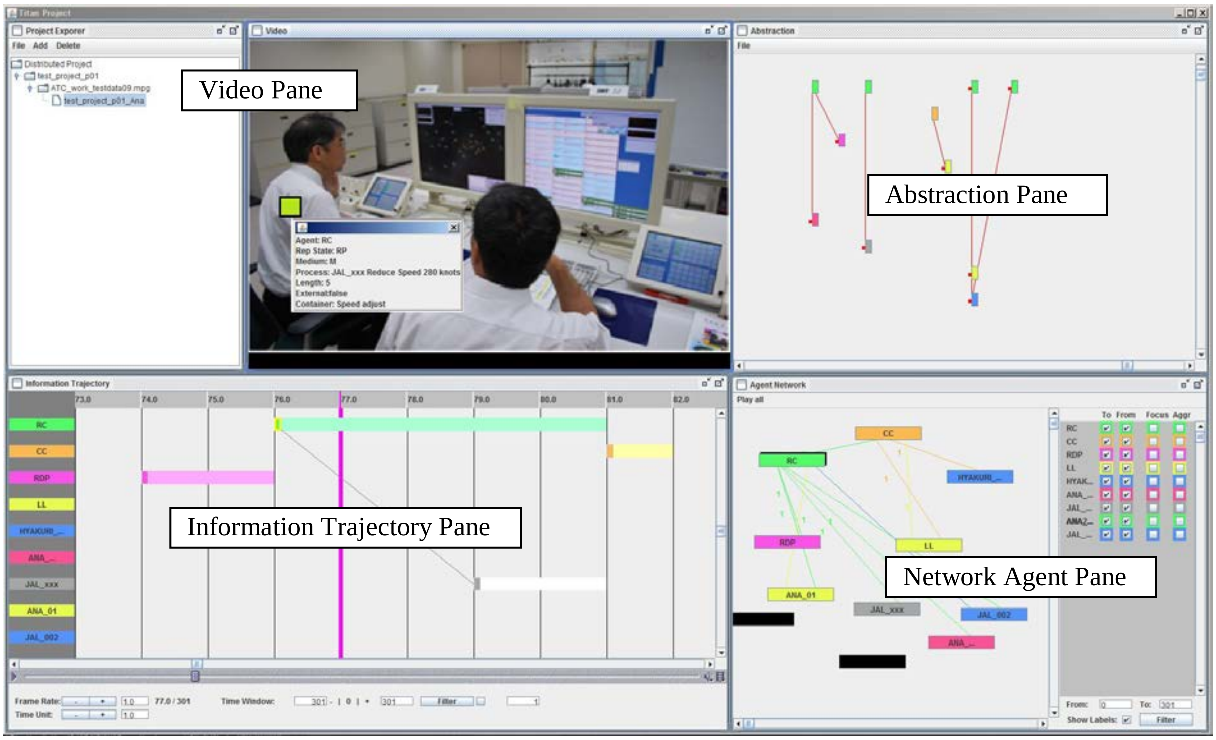


Real-world events that occur during the execution of cooperative work are captured by researchers as video and audio recordings (which are considered the focus of the analysis) and additional data in the form of field notes, interviews, procedures and direct observations. Acquiring representations of real-world events in these forms (shown as S1 – Raw Data in the figure) is the first stage of the analysis. The second stage involves a secondary representation of real-world events, this time in the form of transcriptions (S2 – Transcription). There are several forms of representation at this stage. Raw video data can be coded, identifying agents and representational states of information. These chosen codes are grounded, or verified, by additional data sources such as interviews or field notes. Physical and artefact models can be formed, possibly informed by, or during, the video coding. These models describe the physical aspects of the system which affect cognition, and the artefacts and representations that are intrinsic to information processing. These models are also grounded in the raw data representations of real-world events. The third stage (S3 – Actions) is a representation of real-world events in terms of agent actions, goals and expectations. It is at this point that agents are related to one another, with a direction/trajectory of propagation or translation of information. When assigning actions to specific agents, they are grounded in a description of the processes which are occurring. This can be in terms of the type of processing which occurs, the media involved, and the goals and expectations of the agent. These attributes are in turn grounded in data collected by the researchers. As trajectories/relationships between agents are identified, a flow model is formed which describes how information is propagated through the system. The final representation of real-world events is when descriptions of actions are interpreted into events (S4 – Interpretations). Each stage of representation is a theoretical account of cognition in the system. When all these representations are combined, a distributed cognition theory explaining the cognition of the system is formed.

4.2. Tool for Information Trajectory Analysis (TITAN) and Structure Overview

We developed TITAN as a prototype tool to support distributed cognition analysis based on video data, The tool is shown in Figure 3 [7]. To use TITAN, a user first clicks in the Video Pane on a location in the Raw Data video frame which he identifies a point of interest. An identifier, in the form of a coloured shape, appears at the clicked point in the video frame and indicates an occurrence of a representational state. As a part of the Transcription process, the user identifies the agent which is related to the representational state. Annotations can be made for a number of representational state identifiers, which may have different agents. In this manner, the tool supports direct annotation of the video Raw Data to indicate the physical and temporal locations of an event, process, agent or representational state transformation. Here, an agent can be human or non-human, distinguished by different colours. As the video is played, rewound or fast forwarded, the representational state identifiers appear at their given coordinates.

Figure 3. Overview of TITAN



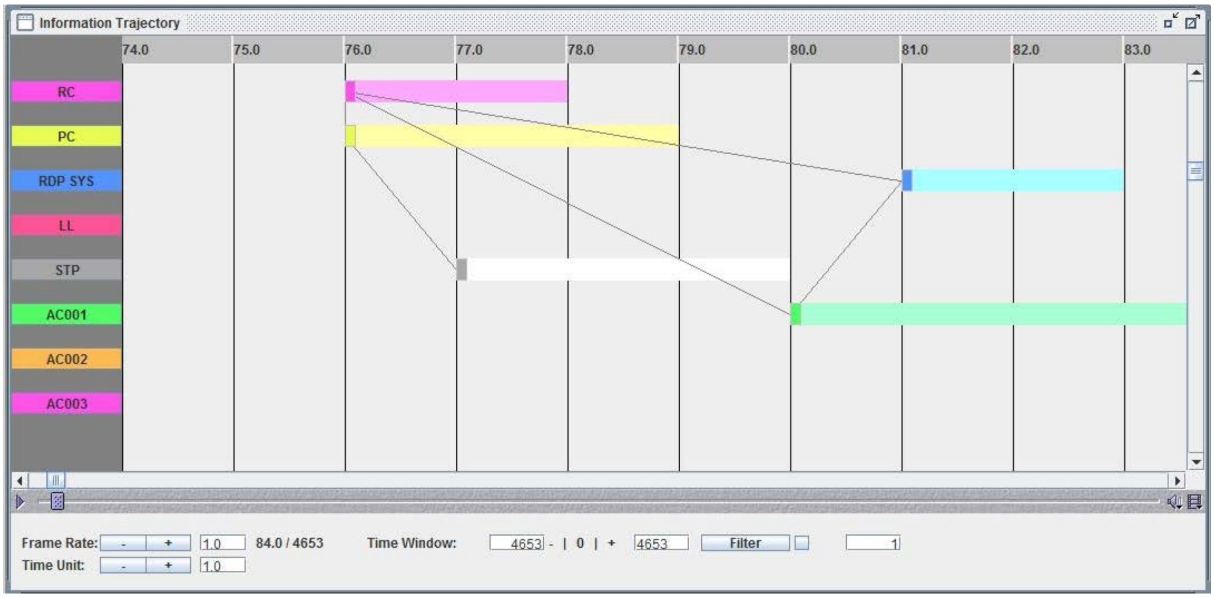
The next stage of the analysis involves generating representations of real-world events which describe the actions, goals and expectations of agents. One way of presenting this is by displaying each representational state and its corresponding agent on a time history graph using the raw video as the time reference, as shown in the Rep-State Trajectory Pane in the figure. Representational states shown in their timeline positions can be connected using lines to indicate a transformation or propagation from one state to another. This, then, shows how representational states are related to one another, at which point further transcription may take place to describe these relations as actions or events. What emerges at this point in the analysis is a flow model that describes how information propagates through the cognitive system.

The final stage of the analysis involves creating a representation whereby actions are interpreted and given meaning. A window called the Abstraction Pane displays each representational state and its relationships with other representational states. The user can then group states together, producing a new identifier which contains those states. This identifier is labelled as a specific process, procedure or event. This can be carried out not only for representational states identified in the cognitive system, but for containers as well. This enables a process of abstraction, where very detailed representational states can be represented as abstract processes. This is another aspect of the flow model, allowing users to observe the cognitive system in as much or as little detail as they wish.

4.3. Information Trajectory Pane

To help users absorb the information in the Trajectory Pane, shown in Figure 4, a filter function allows time width of the displayed area to be changed as the "current time" in the trajectory pane moves with the displayed frame time of the raw video. By default, the Trajectory Pane shows the entire length of the video, allowing users to see what is going to come next. When filtered, the timeline expands to show only a certain number of seconds, which may help users better appreciate what is happening in different sections of the playback. Furthermore, to allows users to more easily observe events before or after the current time, the "current time" point in the Trajectory Pane can be moved from its default position at the left of the timeline to the middle or to the right of the display.

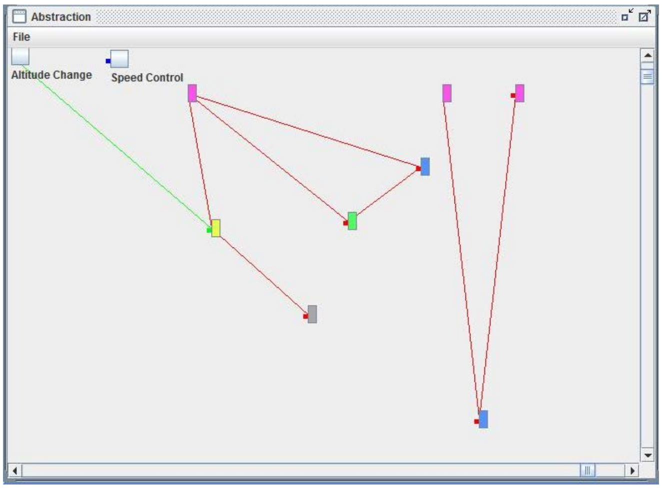
Figure 4. Information trajectory pane in TITAN



4.4. Abstraction pane

After an analysis is completed, there will be a significant number of representational states and relationships. Manipulating these individually can be laborious, so the Abstraction Pane allows a number of representational states and containers (which are grouped within the same container) to be selected and moved as a single unit. This can be seen in Figure 5, in which the block of four representational states are moved to the top right of the screen while still retaining their structure.
Another feature is a method of opening and closing containers. When a container is opened, a button is placed at the top left of the screen (for closing the container). This layout was chosen as it was reminiscent of an open window on an operating system's graphical user interface. When the button is clicked, the container is closed. Additional editing features allow changing container attributes.

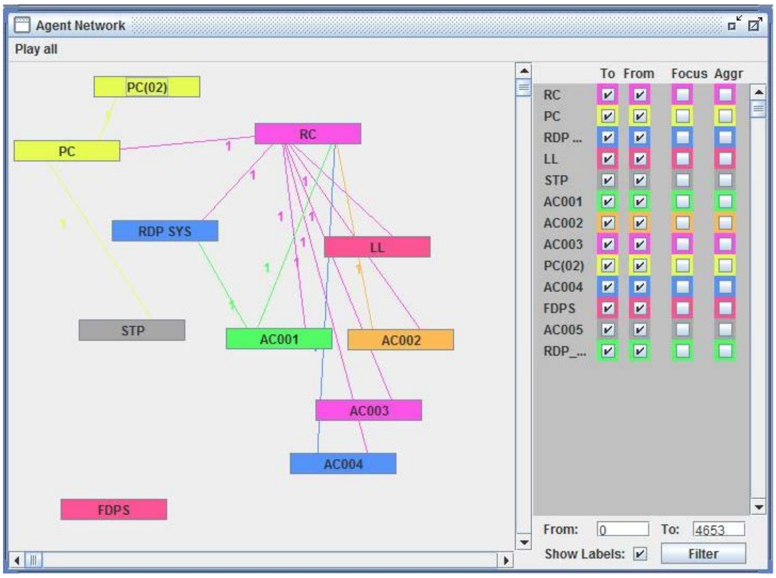
Figure 5. Groups of representational states as a single unit in abstraction pane



4.5. Agent Network Pane

The other output of the tool is an agent network analysis, which is displayed in an Agent Network Pane as shown in Figure 6. This view allows the user to explore the relationships between agents based on a social network analysis approach. Each unique agent and the relationships with its corresponding representational states are identified, producing a network. A line between two agents indicates a relationship between them (based on an interaction through propagation or transformation of representational state). The direction of the relationship is represented by the colour of the line – the agent of the same colour is where the influence is FROM. The thickness of the line and a numerical annotation indicate the number of interactions between the agents. This helps to identify important interactions in the cognitive system. Relationships can be viewed individually, where the number of times a specific agent interacts with another is recorded, or aggregated, where the total number of interactions between agents is recorded. Filters may also be applied whereby a time period within the video is specified and only interactions within that time frame are displayed. It is also possible to "focus" on an agent, where only the interactions between the selected agent and all other agents are considered. This allows the user to perform a more detailed analysis to identify critical agents in the system.

Figure 6. Agent network pane



Another feature of this pane is the ability to construct a video sequence of all of the relationships currently in view. The Video Pane will display the sequence by automatically jumping between points in the video. This feature works with all the filters described above, and so will literally play video clips only of those relationships which are visible to the user. Similarly to the Abstraction pane, agents can be grouped together and labelled as a group of agents, whereupon the lines representing the interactions between all agents and the new group of agents are recalculated. The utility of this feature of TITAN depends on the unit of analysis; for example, ATCOs often use a significant number of flight strips in their work, but if observed individually the ATCOs interact relatively infrequently with each flight strip. Grouping ATCOs together reveals the true importance of flight strips in cooperative work to be revealed.

4.6. External document

TITAN has an external document link function that allows representational states and containers in the Abstraction Pane to be linked to specific areas of text in external documents. These functions could provide a point of view which is a correspondence relationship between the text in an external document and actual procedure. There are also likely to be a number of containers or representational states that reference the same text, as well as to a number of texts that refer to the same representational state, and these one-to-one, one-to-many and many-to-many relationships need to be captured effectively. This function allows the network of knowledge between the documents to be codified as explicit knowledge and the analysed data to be codified as tacit knowledge.
These output data are useful in understanding or codification to lean specialized skills or knowledge. TITAN could be used in a training programme to present the analysed tacit knowledge, allowing trainees to select a specific process involved in their role and observe, through video recordings, how the process is handled "in the wild". The first step toward achieving this goal is to link containers and representational states identified in TITAN to an external document outlining the processes involved. To link a representational state or container to a process in an external document, a user "picks up" and drags the representational state or container from the Abstraction Pane and releases it on the corresponding process of interest in the external document.

5. CONCLUSION

We have introduced the idea of an actual technique to understand cooperative work in the real world. Moreover, we showed a prototype tool for assisting analysis of collaborative work to manage knowledge from a distributed cognitive perspective. Our development tool based on distributed cognition can be used to support the identification and introduction of new technologies to improve the information processing in systems. As a case study, we used TITAN for analyzing team work such as air traffic controllers' work. Distributed cognition is a useful perspective to adopt when analysing the interaction between groups of individuals and artefacts. However, the approach generates significant levels of data, which require a substantial amount of time to analyse. We will continue to improve functions for supporting analysis such as usability, additional view points and so on, and to evaluate the validity of those functions as a future work.

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