Abstract – This paper proposes a novel model of information related to virtual collaboration, the Information Pyramid of Virtual Collaboration. It encompasses information about objects and actions that make up action patterns at different levels of granularity. Information at these levels ranges from fine-grained system events to entire work processes. Information items at a given level of the Information Pyramid are transformed to information items on the next-higher level. The information model makes it possible to abstract from fine-grained events to large-scale work activities; it also makes it possible to drill down from larger-scale activities to their constituent smaller-scale activities. Captured information about virtual collaboration provides awareness information to others; it may also be reused when performing the same or similar work activities.

Keywords: Action patterns, collaborative work, information model, ontology, teleworking.

1 Introduction

Virtual collaboration, understood to mean the collaboration of teams across boundaries of space and time and aided by information and communication technology, has become increasingly common in recent years [8]. Team members now tend to be more and more geographically distributed, and thus many organizations are relying on the ability to bring together people for joint work in a virtual space that only exists within the computer, without having to bring the people involved together in a traditional face-to-face setting.

While there are benefits to be gained from virtual collaboration, there are however also challenges raised by this mode of working. Among these is the difficulty of knowing what is, and has been, “going on” during the virtual collaboration. Unlike collaboration in a traditional face-to-face setting, collaboration in the virtual lacks many of the sensory cues which inform members of the collaboration, as well as others in close proximity, of the content and progress of work being performed. Whereas members of a traditional team may overhear and oversee what other team members nearby are working on, providing valuable information to guide their own actions, members of a virtual team lack this information.

Systems through which virtual collaboration is conducted, designated here as collaboration systems, usually offer information on the actions of others through the provision of awareness information [4, 5]. In most cases, however, awareness information is relatively fine-grained, consisting of up-to-the-second streams of events of other’s actions. Moreover, it usually focuses on presently performed actions, and rarely includes the history of past actions. While there have been numerous contributions on awareness in the literature since the first papers on this topic appeared in the early 1990s, there is no comprehensive model of awareness information covering both dynamic aspects (answering questions such as “what happened?”) and static ones (answering questions such as “what was involved?”), as well as spanning different scales of collaborative activity, from minute single-user actions to large multi-person work processes.

This paper proposes a novel integrated information model of virtual collaboration that aims to address this shortcoming, and thereby to provide the basis for creating more comprehensive awareness support than current collaboration systems offer. The following sections introduce the model, present an example of the application of the model to information from a particular collaboration system, and discuss the application of the model to a given collaboration system.

2 The Information Pyramid of Virtual Collaboration

The Information Pyramid of Virtual Collaboration ("Information Pyramid" for short) is an information model capturing essential aspects of virtual collaboration. Before explaining the model itself, first some elementary concepts are introduced.

2.1 Elementary concepts

Virtual collaboration involves people working together on a common task or process. Their work often revolves around artefacts, which are the products of their joint efforts and are typically documents, drawings, and the like. To enable their joint work it is necessary for collaborators to communicate with each other, and for this purpose communication channels are used. A communication channel is a facility of computer-mediated communication; examples include dis-
discussion forums, electronic mail, text chat, and audio-video conferencing.

Virtual collaboration takes place in collaboration spaces, which are defined as follows:

A collaboration space is a virtual space which provides the opportunity for bringing together people, artefacts, and communication channels for individual or joint activity.

Collaboration spaces are provided by collaboration systems, which are defined as follows:

A collaboration system is a software system which supports virtual collaboration through the provision of collaboration spaces.

Examples of actual collaboration systems that match this definition include BSCW [1], TEAMROOMS [9], and LIVENET [6].

Virtual collaboration consists of the performance of actions in collaboration spaces, involving objects. An example is posting a discussion statement to an electronic discussion forum. The act of posting constitutes the action, whereas both the discussion statement and the discussion forum constitute objects. Objects are defined as follows:

An object is a static entity provided and maintained by a collaboration system.

Examples of objects are: collaboration spaces, people, documents, communication channels, etc. Collaboration systems may support annotations and versioning, in which case each annotation or new version is a separate object that is related to an existing object through the action that created it. Actions are defined as follows:

An action is a function or operation that can be performed in a collaboration system.

Examples of actions are: creating a collaboration space, entering a collaboration space, creating a document, reading a document, sending a message to another user, etc.

Actions as defined here are independent of objects. However, almost every action involves objects, as the example above showed. To fully describe an action therefore requires inclusion of context information. Action context is defined as follows:

An action context is the set of information identifying the subject, referent, and location of an action.

Subject refers to the action performer (a human user of the collaboration system, or a computational entity); referent is that which is being acted upon (such as a discussion forum); and location is the virtual place where the action occurs.

A given action may occur in many different action contexts. For example, the action of posting a discussion statement to a bulletin board could be performed by different subjects (users); have different referents (discussion forums); and be performed in different locations (collaboration spaces). Collections of similar actions can be generalized into action patterns, defined as follows:

An action pattern is a pattern describing an action together with a particular action context.

Here, pattern is understood to mean a “structure existing within a body of data.”

Given these definitions of elementary concepts, the Information Pyramid can now be introduced.

2.2 The Information Pyramid

The Information Pyramid consists of information about objects and actions, and their combination into specific action patterns, related to virtual collaboration. It is made up of six levels, as depicted in Fig. 1.

At the bottom of the Information Pyramid is the most small-scale, detailed information, whereas at the top is the most large-scale, abstract information. This is expressed in the shape and colour of the figure. The shape of the figure suggests that the amount of information at higher levels is smaller, as it constitutes a higher level of abstraction. The different colours suggest that information at higher levels is denser than that at lower levels, in the sense that each unit of higher-level information corresponds to several units of lower-level information. From bottom up, the different levels contain following information:

1. Infrastructure level: This is the level of the underlying software infrastructure running “below” the collaboration system itself. In the case of a web-based collaboration system, for instance, the underlying infrastructure is a web server. At this level, objects are recorded in the files under the control of the underlying system. Actions are typically recorded as events occurring in the software infrastructure, such as web server access requests recorded in a web server log, or records in the transaction log of a database management system, in the case where a collaboration system operates on top of such
a system. Action patterns at this level correspond to events in the software infrastructure.

2. **System level**: This is the level of the collaboration system itself, through which collaboration is carried out. Records of objects at this level are contained in the application data of the collaboration system, typically residing in files or database tables. Actions are the commands issued to the collaboration system. Collaboration systems are typically structured as client-server systems, where multiple clients are served by one server. In this case, clients send service requests to a server, which then performs the requested actions. Records of such service requests, such as in a server log, constitute records of actions at this level. This information is of a larger scale than the corresponding information on the infrastructure level, so a single object or action on the system level usually corresponds to multiple objects or actions on the infrastructure level. Action patterns at this level correspond to operations performed by the collaboration system.

3. **User level**: This is the level on which individual users operate. These users perform actions on objects residing in collaboration spaces. Objects at this level are the collaboration spaces and other objects contained in them, whereas actions at this level are the operations performed by users, such as opening a document for reading. Objects at this level are often abstractions of corresponding objects at the system level. Likewise, actions at this level often correspond to multiple actions on the system level: i.e., a single action performed by the user may involve several system-level actions. Action patterns at this level correspond to operations performed by a single user.

4. **Collaboration level**: At this level, multiple users work in collaboration with each other. Objects at this level, as on the user level, are the collaboration spaces and other objects contained in them, whereas actions at this level are the operations performed by multiple users. Thus whereas objects at this level mostly correspond closely to those at the user level, actions are abstractions of multiple user-level actions. Action patterns at this level correspond to operations performed by groups of users.

5. **Task level**: At this level, larger-scale activity involving several lower-level actions takes place. Objects at this level are groupings of multiple lower-level objects, whereas actions at this level are the tasks performed by multiple users. These tasks consist of certain combinations of actions and objects from lower levels. Action patterns at this level correspond to tasks performed by groups of users.

6. **Process level**: At this, the highest level of the Information Pyramid, collections of tasks are performed by groups of users. These constitute work processes, i.e. collections of related tasks. Objects at this level are combinations of multiple lower-level objects involved in the process. Actions at this level are collections of task-level actions. Action patterns at this level correspond to processes performed by groups of users.

A broad categorization of levels in the Information Pyramid is shown by the labels on the left hand side of Fig. 1: micro level, meso level, and macro level. This categorization is centered on the user level, for it is here that the actual actions performed by users of the collaboration system take place. This level is designated as the **meso level** in this categorization. At levels below the meso level, multiple smaller-scale operations corresponding to each user action occur, thus the designation **micro level**. At levels above the meso level are aggregations of individual user actions into multi-user actions, tasks, and processes, thus the designation **macro level**.

### 3 Example

To illustrate the levels of the Information Pyramid, an example of action patterns on different levels is presented below. The example is based on data obtained from the LIVENET collaboration system. As the main source of information in LIVENET is on the system level, the example illustrates patterns of virtual collaboration starting from that level up to the process level. The example is related to a specific virtual collaboration process, concerned with product concept development, and shows action patterns of parts of that same process at different levels of the Information Pyramid up to the process level where the process as a whole is shown. The example is intended to illustrate the different information at different levels of the Information Pyramid, and their correspondence across levels.

#### 3.1 LIVENET

LIVENET is a collaboration system developed at the University of Technology, Sydney [6]. It supports mainly asynchronous collaboration of distributed groups of people, i.e. different-time, different-place interactions. A central server is accessed across the network, most commonly through a web interface (an example of which is shown in Fig. 2).

LIVENET provides collaboration spaces called **workspaces**. These can be populated with a number of different types of objects such as documents, discussion forums, tools, and message channels, all tied together through a configurable governance structure. Across workspaces, most of these objects can be shared. For each workspace, any number of **roles** can be defined, and users can be added to a workspace as **participants** occupying roles. The same user can have different roles in different workspaces, but can only occupy one role in each workspace.

#### 3.2 EMOO diagrams

To represent essential aspects of action patterns, a graphical notation called **EMOO diagrams** (extended MOO diagrams) is used. The notation is based on the MOO diagram-
Finally, multiple EMOO diagrams can be combined into a single EMOO meta diagram that shows the relationships in terms of artefact flows between individual EMOO diagrams. An example of this is shown later on in this paper, in Fig. 7 (b).

### 3.3 LIVENET action patterns

Examples of action patterns obtained from the LIVENET collaboration system are shown below, from the system level up to the process level.

#### 3.3.1 System level

In the LIVENET system, actions performed by the LIVENET server are recorded in a server log. Each log entry records the action performed by the LIVENET client, context information including subject, referent and location, and any other attributes of the action that may be supplied. An extract taken from the LIVENET log for a system-level action is shown below (note that identifying information, such as actual user and group names, have been changed in this record to preserve the anonymity of the users involved):

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This record consists of several fields separated by vertical bars: action number, timestamp, session number, workgroup, workspace, workspace owner, user, role, action, and four action parameters. It represents an add_statement action (an action for posting a statement in a discussion forum). It was issued in session 4325 from within workgroup Group3, in workspace Prepare-Report owned by John.Smith. The action was performed by the user Mary.Lamb, taking the role of Writer in the given workspace.

This add_statement action is part of a sequence of other actions which are logically related. In the case of posting a statement to a discussion forum, the LIVENET system performs a sequence of three system-level actions: first a get_block_tree action (an action for retrieving a list of statements posted in a discussion forum), followed by the add_statement action above, followed by yet another get_block_tree action. EMOO diagrams of action patterns involving these three system-level actions are shown in Fig. 3.

#### 3.3.2 User level

A user-level action in LIVENET is an action performed by a single user. Examples of this include: opening a document, entering a workspace, posting a discussion statement, etc. User-level actions and action patterns are not logged in LIVENET, thus they can only be derived from corresponding system-level actions and action patterns. This derivation process is briefly discussed in the following section; here an example of a derived user-level action pattern is presented.

The three system-level action patterns shown above correspond to a single user-level action pattern, that of posting a new statement to a discussion forum. That is, whenever this...
sequence of action patterns occurs, and provided that all three action patterns have the same action context (subject, referents, location), it can be transformed to a single user-level action pattern, in this case the action pattern Post-Discussion-Statement. This is shown in the EMOO diagram of Fig. 4. It shows that the subject Writer (a multi-subject) is connected with the discussion forum Discuss Report through a posting action (shown by the arrow pointing from the subject to the discussion forum).

Note that whereas the EMOO diagram of Fig. 4 resembles that at the centre of Fig. 3, it is important to keep in mind that the EMOO diagram of Fig. 4 represents an action pattern that forms an aggregation of all three action patterns represented by the three EMOO diagrams of Fig. 3.

### 3.3.3 Collaboration level

A collaboration-level action in LIVENET is an action performed by a group of users. A collaboration-level action pattern corresponds to a collection of user-level action patterns with a (partially) shared action context. The part of the action context that is shared may be location (actions taking place in spacial proximity, where the space is understood to be virtual), or some object being affected by the action pattern (a document jointly worked on; a discussion forum where a joint discussion takes place; etc.).

To continue the earlier example, a group of user-level action patterns within the shared context of a given discussion forum (the action’s referent) together constitute the collaboration-level action pattern Group-Discussion. It corresponds to a number of user-level action patterns related to the given discussion forum. In the case of LIVENET, the user-level action patterns which contribute to the Group-Discussion action pattern include Post-Discussion-Statement (posting a statement) and Open-Discussion-Statement (reading a statement).

Fig. 5 (b) shows an EMOO diagram of the collaboration-level action pattern Group-Discussion presented in this example. It shows that two subjects are involved in the discussion (of which Writer is a multi-subject). Both of the subjects have read and post access to the discussion forum, which thus forms an aggregation of several individual Open-Discussion-Statement and Post-Discussion-Statement user-level action patterns. Part (a) of the figure shows the four individual user-level action patterns that are aggregated into the collaboration-level action pattern Group-Discussion.

### 3.3.4 Task level

A task-level action in LIVENET is a larger-scale activity (compared to a collaboration-level action) and is performed by a group of users. A task-level action pattern corresponds to the combination of two or more collaboration-level action patterns.

An example of a task is that of joint report preparation. This is an activity which involves several collaboration-level actions: it may start out with a discussion of the format and structure of the required report, followed by individual document preparation work. This may then lead to document sharing and review, before integrating the separate report pieces into the whole report document.

In terms of the action patterns involved, this task may consist of a combination of Group-Discussion, Document-Sharing, and Document-Preparation collaboration-level action patterns. They are combined through the subjects involved in those action patterns, linking the collaboration-level action patterns together into the Final-Report-Preparation task-level action pattern. An EMOO diagram of this action pattern, combining the earlier Group-Discussion action pattern from Fig. 5 (b) with a Document-Sharing and a Document-Preparation action pattern, is shown in Fig. 6 (b), whereas part (a) of the figure shows the constituent collaboration-level action patterns. Here the Document-Sharing collaboration-level action pattern involves both the Coordinator and Writer subjects, and is mediated through the Report-Parts artefact (a multi-artefact, with one artefact for each report part). Artefact access within the Document-Sharing collaboration-level action pattern differs between the two subjects: whereas the Writer subject has both read
and write access, the Coordinator subject has only read access. Lastly, the Final-Report artefact constitutes the task's final outcome, and is produced by the Coordinator subject through the Document-Preparation action pattern.

### 3.3.5 Process level

A process-level action is the largest-scale activity in the Information Pyramid, and is performed by a group of users. A process-level action pattern consists of a number of task-level action patterns.

Following on from the example of joint report preparation, this task may be part of a process concerned with developing concepts for new products. The whole process may consist of several tasks, including: brainstorming ideas for new products, market study, financial analysis, development of a selected product concept, and finally preparation of a report with the results of the individual tasks.

In terms of the action patterns involved, the process in this example combines the five task-level action patterns Product-Brainstorming, Market-Study, Financial-Analysis, Concept-Development, and Final-Report-Preparation (which was already shown above). Each of these task-level action patterns takes place in its own collaboration space and involves a number of subjects, communication channels and artefacts. All subjects are involved in more than one task-level action pattern, as are most of the artefacts. EMOO diagrams of these five task-level action patterns are shown in Fig. 7 (a). Together these task-level action patterns constitute the process-level action pattern Product-Concept-Development, shown in the form of an EMOO meta diagram in Fig. 7 (b).

The above example has illustrated the different levels of the Information Pyramid of Virtual Collaboration, from the system level up to the process level, showing instances of action patterns at each of these levels. The example showed that action patterns on a given level (with the exception of the lowest level) are aggregations of action patterns on the level below. Thus an instance of a higher-level action pattern corresponds to multiple instances of lower-level action patterns. In this way there is a chain of correspondences of action patterns from the lowest level to the highest level of the Information Pyramid. In the case of the above example, the chain of corresponding action patterns across levels is shown in Fig. 8. It shows the correspondence of two action patterns on the system level (add_statement and get_block_tree) to the user-level action pattern Post-Discussion-Statement (the correspondence being represented...
Figure 7: EMOO diagrams of five task-level action patterns and EMOO meta diagram of the corresponding process-level action pattern Product-Concept-Development.

4 Application

The above section has illustrated the Information Pyramid through a comprehensive example of information related to virtual collaboration. The present section outlines how the Information Pyramid can be applied to a given collaboration system. This requires two things:

1. Information about virtual collaboration on at least one level of the Information Pyramid.

   The source for this information is usually the set of log files and databases under the control of the collaboration system. In cases where a collaboration system does not maintain such information, such support has to be added to the system. The information thus collected constitutes the base level of the Information Pyramid for the given collaboration system, meaning it is the lowest level in the Information Pyramid at which information is available. For instance, if a collaboration system records system-level actions and objects (as in the case of LIVENET presented above), then the system level becomes the base level of that collaboration system’s Information Pyramid. However, it is also possible for a given collaboration system to collect information on more than one level of the Information Pyramid. In this case, the lowest one of these becomes the base level.

2. Specifications of transformations of information to higher levels.

   Information on the levels above the base level of the Information Pyramid can be derived from those at lower levels through transformations, such as aggregations. This is achieved through initial specification of a model of each level of the Information Pyramid, in terms of its constituent information items (objects, actions, action patterns), in the form of an ontology of the given collaboration system. This is followed by the specification of the transformations that produce an information...
item from one or more information items on the level below it. All these specifications become part of an ontology that covers all levels of the Information Pyramid from the base level up, and the transformations between them.

Once an ontology of a given collaboration system’s information items and transformations has been specified, it can be implemented. An example of an ontology-centred framework integrating information extraction, derivation, and retention from collaboration systems was earlier proposed [2]. Applying this framework to collaboration systems creates a rich information source about the virtual collaboration carried out through them. This information makes it possible for those engaged in the collaboration to become informed about the work of others at the level of granularity that they are interested in: either to see the overview of an entire work process, or to drill down into individual tasks, or collaborative activities of only parts of tasks, or individual activities, or even of the micro-level events that the collaboration system generates when these activities are being performed. When retained, it also provides a valuable source of information to those not directly involved, but with an interest, in the virtual work, such as to management.

The availability of information on virtual collaboration, in the form of action patterns, also opens the potential for future reuse. Action patterns that have been derived from base-level information can be retained for future retrieval in situations when a similar action pattern is needed. For example, an action pattern for carrying out product concept development (the example given in the previous section) can be instantiated in a collaboration system by automatically creating its collaboration spaces and populating them with the required objects, as described in [3].

5 Conclusion

The popularity of virtual collaboration is likely to remain, and indeed to increase, in the foreseeable future. Knowing what happens during virtual collaboration is essential to effective virtual work, and this is aided by the awareness information provided by collaboration systems. However, currently awareness information is often limited to the “here-and-now”, and usually consists of fine-grained records of detailed activity. This paper has proposed an information model of virtual collaboration that offers a more comprehensive view of virtual collaboration than those of previous contributions. Based on this information model, support can be added to collaboration systems to provide additional awareness information that can be of value in a number of situations, including for knowing what has happened in the past, as well as for obtaining an abstract view of a set of activities. Besides its usefulness to the collaborators themselves, this can be of value, for example, in getting newly joined co-workers “up to speed” by reviewing the activities of a project since its beginning, or to inform superiors of the recent progress of work. It may also enable the collection of action patterns of actual work processes that can later be instantiated by those who need to perform similar work. Through the enhanced provision of awareness information as described here, collaboration systems have the potential for making virtual collaboration somewhat less challenging than it presently is.

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