Applied Artificial Intelligence, 19:881–904

ISSN: 0883-9514 print/1087-6545 online
DOI: 10.1080/08839510500234750

Taylor & Francis
Taylor & Francis Group

COLLABORATION IN THE SEMANTIC GRID: A BASIS FOR e-LEARNING

Kevin R. Page, Danius T. Michaelides, David C. De Roure, and Nigel R. Shadbolt □ *ECS, University of Southampton, Southampton, UK*

Yun-Heh Chen-Burger, Jeff Dalton, Stephen Potter, and Austin Tate □ *AIAI, University of Edinburgh, Edinburgh, UK*

Simon J. Buckingham Shum, Marc Eisenstadt, Michelle Bachler, and Jiri Komzak □ *KMI, The Open University, Milton Keynes, UK*

□ *The CoAKTinG project aims to advance the state of the art in collaborative mediated spaces for the Semantic Grid. This paper presents an overview of the hypertext and knowledge-based tools that have been deployed to augment exiting collaborative environments, and the ontology that is used to exchange structure, promote enhanced process tracking, and aid navigation of resources before, after, and during a collaboration. While the primary focus of the project has been supporting e-Science, this paper also explores the similarities and application of CoAKTinG technologies as part of a human-centered design approach to e-Learning.*

This work is funded by the UK Engineering and Physical Sciences Research Council under grant number GR/R85143/01, in association with the Advanced Knowledge Technologies (AKT) Interdisciplinary Research Collaboration (IRC), also sponsored by EPSRC under grant number GR/N15764/01. The AKT IRC research partners and sponsors are authorized to reproduce and distribute reprints and online copies for their purposes notwithstanding any copyright annotation hereon. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of other parties.

We are grateful to members of the CombeChem team for their assistance with the case study: Jeremy Frey, Gareth Hughes, Hugo Mills, monica schraefel, and Graham Smith. CombeChem is also funded by the EPSRC under grant number GR/R67729/01. We are also grateful to our collaborators in NASA's Work Systems Design and Evaluation group, the Mars Society, and the Remote Science Team of MDRS Crew Rotation 29, especially Bill Clancey and Maarten Sierhuis (Mobile Agents Projects) and Shannon Rupert (RST Lead).

Since February 2004, work on BuddySpace has been supported by the European Community under the Innovation Society Technologies (IST) program of the 6th Framework Programme for RTD (project ELeGI, contract IST-002205). The consideration of CoAKTinG in the e-Learning context has also come about through the ELeGI project and we are grateful to Hugh Davis for his assistance in this regard. This document does not represent the opinion of the European Community, and the European Community is not responsible for any use that might be made of data appearing therein.

Address correspondence to Kevin R. Page, Intelligence, Agents, Multimedia Group, School of Electronics and Computer Science, University of Southampton, Highfield, Southampton, SO17 1BJ, United Kingdom. E-mail: krp@ecs.soton.ac.uk

The CoAKTinG (Collaborative Advanced Knowledge Technologies in the Grid) project[1] aims to advance the state of the art in collaborative mediated spaces for distributed e-Science through the novel application of advanced knowledge technologies. It comprises four tools: instant messaging and presence notification (BuddySpace), graphical meeting and group memory capture (Compendium), intelligent "to-do" lists (Process Panels), and meeting capture and replay. These are integrated into existing collaborative environments (such as the Access Grid[2]), and through use of a shared ontology to exchange structure, promote enhanced process tracking and navigation of resources before, after and during a meeting.

THE SEMANTIC GRID, COLLABORATION, AND LEARNING

While the grid is often thought of in terms of providing a distributed system of high-performance computing resources, this is only one aspect required when supporting successful use of Grid computing. The Grid must also provide structured access to the wealth of data produced and held within it, and an environment within which the collaborative processes of investigation can occur—be it meetings between researchers, or shared access to experiments.

Grid computing came about as a way of harnessing computational resources—supercomputers and clusters—to help achieve new scientific result. Grid middleware facilitates the routine interaction of computational and data resources. This traditional "fat iron and big pipes" view has evolved considerably to a contemporary definition of Grid computing in terms of dynamic virtual organizations (Foster et al. 2001):

> "The real and specific problem that underlies the Grid concept is coordinated resource sharing and problem solving in dynamic, multi-institutional virtual organizations. The sharing that we are concerned with is not primarily file exchange bur rather direct access to computers, software, data, and other resources, as is required by a range of collaborative problem-solving and resource brokering strategies emerging in industry, science, and engineering."

People are a key part of this, and we can now see the Grid as a composite of computational grid, data grid, and collaborative grid functionalities.

This vision of the Grid is closely related to that of the Semantic Web, which is also, fundamentally, about "joining things up." The value of applying Semantic Web technologies to the information and knowledge in Grid applications is apparent, and there has been increasing recognition that Semantic Web technologies are useful not just *on* the Grid infrastructure but also *within* it, providing the means to describe resources and services, and composing them in virtual organizations. The former—working with knowledge in the application domain—is often described as "Knowledge Grid," whereas the focus on semantics as part of the Grid machinery is key to the "Semantic Grid" vision (Goble et al. 2004). The use of Semantic Web technologies to integrate the tools described in this paper brings together this notion of Semantic Grid with the Collaborative Grid.

It is this facet of collaboration, in particular, which CoAKTinG addresses. Collaboration as an activity can be seen as a resource in itself, which with the right tools can be used to enhance and aid future collaboration and work. Each of the CoAKTinG tools can be thought of as extracting *structure* from the collaboration process. The full record of any collaboration (e.g., a video recording of a meeting) is *rich in detail*, but to be useful we must extract resources which are *rich in structure*. In essence, this is a process of creating structured knowledge from information, and we must be able to share and re-use the knowledge amongst tools and agents in the Grid—the Semantic Grid.

The issues involved in collaboration are not unique to science; we believe that the techniques and tools employed by CoAKTinG have useful applications in e-Learning as well. As a case in point, an experimental-based collaborative learning paradigm has recently been adopted by the European Learning Grid Infrastructure project (Allison et al. 2003), and includes several CoAKTinG components at its core. In the last section, we elaborate on how CoAKTinG can be applied in the e-Learning context.

CoAKTinG Tools

BuddySpace

BuddySpace (Eisenstadt et al. 2003; Vogiazou et al. 2005) is an Instant Messaging environment (based on the Jabber protocol) with both client and server functionality extended to enhance presence awareness. Specifically, it introduces automatic roster ("buddy list") construction and intelligent service discovery on the server, and the graphical visualization of people and their presence states on an image, geographical, or conceptual map, as can be seen in Figure 1. This allows for multiple views of collaborative workgroups and the immediacy or at a glance nature gives users a snapshot of a virtual organization. This is critical in modern learning organizations: We know from Whitelock (Whitelock et al. 2000) that presence awareness increases emotional well-being, and from Nardi et al. (2002) that users benefit from knowing who else is around via presence and messaging tools. In a meeting, the instant message capabilities of BuddySpace naturally provide a "backchannel" to the meeting, for example, conveying URLs of documents discussed or as a non-disrupting

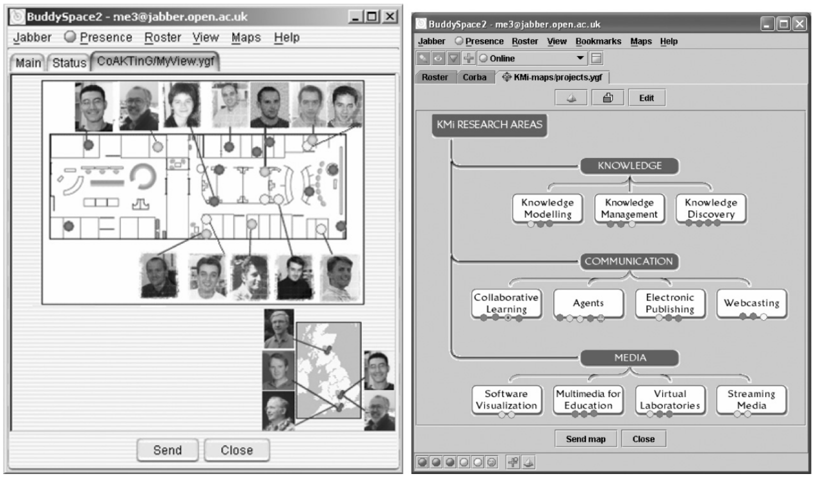

FIGURE 1 BuddySpace showing a virtual organization and presence indicators: (a) with live/clickable presence dots superimposed on geographical and office locations, and (b) with the office dots superimposed on a conceptual map depicting KMi's research themes as generated from an underlying ontology.

communication. For distributed meetings, such Access Grid meetings, the presence of individuals gives an extra indication of co-location (especially if the videoconferencing technology is failing). The back-channel can also be used for meeting control tasks, such as queueing of speakers and voting on issues. For meeting capture purposes, logs of the channel conversations are made. Individual messages are timestamped and possibly examined to see if they control meeting specific messages.

In an e-learning context, BuddySpace leverages the overwhelming power of social cohesiveness that can be brought about by knowledge of the presence and location of others in both real and virtual spaces, in the style argued persuasively by Rheingold (2002). We know also from the work of Reffell and Eklund (2002) that this kind of presence awareness is used by students to locate resources, for quick exchange of information and to organize meetings either online or face-to-face. Indeed we argue that enhanced presence is much more than just "messaging" and "maps." In particular, we aim to provide tools that enable us to express the entire situated context of the learner, which is clearly a lot more than just "location X" and "online" or "offline." The learner's current state of mind, including goals, plans, and intentions, must be understood, as well as the way this connects with ongoing activities and devices accessible to the learner. As these are made explicit, plausible inferences can be drawn about what the leaner wants and needs to know, and this gives us an important foot in the door for addressing the problem of delivering the right knowledge to the right people in the right place at the right time. So far, this notion of "right knowledge" has been nothing more than a knowledge management slogan, but our belief is that enhanced presence capabilities, embedded in the entire CoAKTinG toolset, can make this dream a reality.

Compendium

Compendium is a hypermedia software tool for publishing issue-based *dialogue maps*, concept networks which structure issues, ideas, and arguments in a discussion, linked as required to background multimedia documents and Internet resources. Compendium is best thought of as a knowledge management environment for supporting personal/group deliberations and memory, combining hypermedia, modeling, and mapping skills (Conklin et al. 2001).

Figure 2 shows an extract from a dialogue map created over several meetings, both face-to-face and virtual (as part of the NASA Mars exploration field trial described later). In this example (Clancey et al. 2005), co-located geologists at a desert site (a Mars simulation) arranged rock sample photos for analysis. Colleagues (simulating a support team back on Earth) reviewed this on the Internet and raised queries, linking them into the map as new *questions, ideas,* and *arguments.* The Mars crew then responded (highlighted nodes). In other maps, discussions include links to voice annotations and Web data sets. Compendium provides a shared visual focus on the contributions as they are made (particularly useful in the absence of other shared visual referents in virtual meetings), and a group

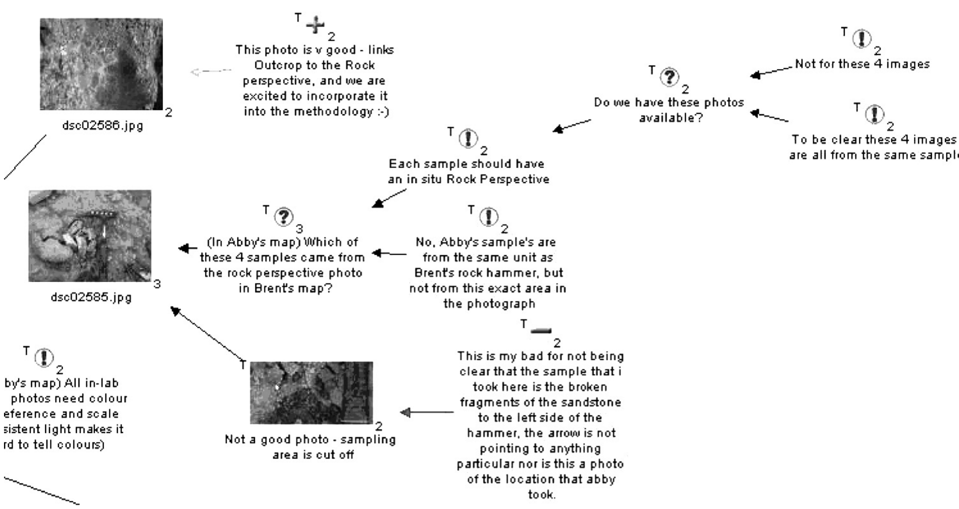

FIGURE 2 A dialogue map created in the Compendium software tool, illustrating its capabilities for integrating media resources with analysis and argumentation from different stakeholders in both conventional and virtual meetings (see text for details).

validated memory of how contributions connect: the dialogue map becomes the group's evolving, shared picture of their problem.

To date, Compendium has been used in the following range of ways:

- By a facilitator in real time to map the structure of synchronous meeting discussions, both co-located and online (Conklin et al. 2001; Selvin and Buckingham Shum 2002; Papadopoulos 2004).
- By an online forum moderator to summarize asynchronous discussion threads.
- As a generic entity-relationship mapping tool for modeling problems, with end-user customizable visual notations.
- As a personal or group knowledge management tool (Conklin 2003; Selvin and Buckingham-Shum 2005).

The content of maps may be driven entirely by what participants raise as issues, or at the other extreme, discussion can be driven by working through predefined *issue templates*, which specify the issues to be tackled, and possibly the options available and the criteria by which they should be judged. The approach can be particularly powerful by blending free-form and predefined maps. In all these cases, maps are created by people as an aid to thinking. However, maps can also be automatically generated and read by an interoperable computer system that knows how to write/read issue templates (e.g., Clancey et al. [2005]). The maps then provide hypertext functionality for navigating and linking data elements, and can be combined with any of these modes of use.

Compendium is a semantic, visual hypertext system, providing several ways to manage the connections between ideas: drawing *graphical links* between nodes (showing different kinds of connection in a given context); *transclusion* (tracking occurrence of the same node across different contexts); *metadata tagging* (enabling harvesting of nodes with common attributes across different contexts); and *catalogues* (managing libraries of nodes and template structures).

In our experience, Compendium introduces a distinctive element to the design space of knowledge technologies, namely, making meetings into true events for group knowledge creation that leave a *trace*—a structured, collectively owned, searchable group memory that is generated in real time as a product of a meeting. Effective, on-the-fly construction of knowledge resources does not come for free—the lower the effort invested at the capture stage (e.g., simply video recording all meetings, or taking conventional minutes), the more work is required for collective reuse and computational support. Naturally, we want quality knowledge resources for minimal effort, and while smart analysis technologies will continue to push the boundaries, there are pragmatic factors to consider: what is possible *now*? Compendium tackles the capture bottleneck that any knowledge construction effort must confront, by investing effort in real time quality capture by a facilitator and mediated and validated by those at the meeting.

I-X Process Panels

The aim of the I-X research program (Tate et al. 2002) is to create an enabling environment for mixed-initiative (i.e., involving both human and computer agents) synthesis tasks. The definition of a "synthesis task," as it is considered here, is general enough to embrace tasks as diverse as designing an aircraft engine, devising a marketing strategy, and writing a joint report. Such tasks occur regularly in organizations and usually require some degree of creativity, something that is difficult to emulate on computer. (This is not to say that computers do not have a role to play in the task, for instance, in simulating design concepts.)

I-X draws on (and is a natural successor to) several decades of AI experience in planning, scheduling, and, more recently, process, workflow, and activity management. Born of this experience, and lying at the conceptual heart of the program, is a unifying upper ontology for a shared representation of a synthesis task, whatever the precise nature of the task or its domain may be. This conceptualization, the ⟨I-N-C-A⟩ ontology (Tate 2003), is based on the notion of both the processes governing and the products emerging from the task being composed of abstract "nodes" related by a series of constraints, and about which issues are cyclically generated and resolved so as to refine the set of nodes and their relationships. This model allows flexibility in the extent and nature of the formalization of the representation. So, while an informal approach to representing, say, constraints might suffice when coordinating joint memorandum-writing activities ("finish by next Friday"), a more formal scheme might be imposed for a design task where precision is required or automated constraint-solver agents are to be invoked ("has-orientation (fin-9102, horizontal)"). As well as encouraging a well-founded encapsulation of the task, the model also provides the basis for a systems architecture and communication framework, allowing the concrete realization of I-X systems.

For a user, the principal interface to the I-X technologies is through a *process panel*. Panels present to users the current state of the collaboration from their individual perspectives, and allows them to decompose activities, refine elements of the plan, delegate issues, invoke the automated agents, etc., all serving to move the overall task toward completion. Libraries of standard operating procedures can be accessed to provide model plans for archetypal activities. In addition to this activity management engine, the panel gives users access to domain-editing and planning tools, visualizations of the collaboration space and agent-relationship editors (Figure 3).

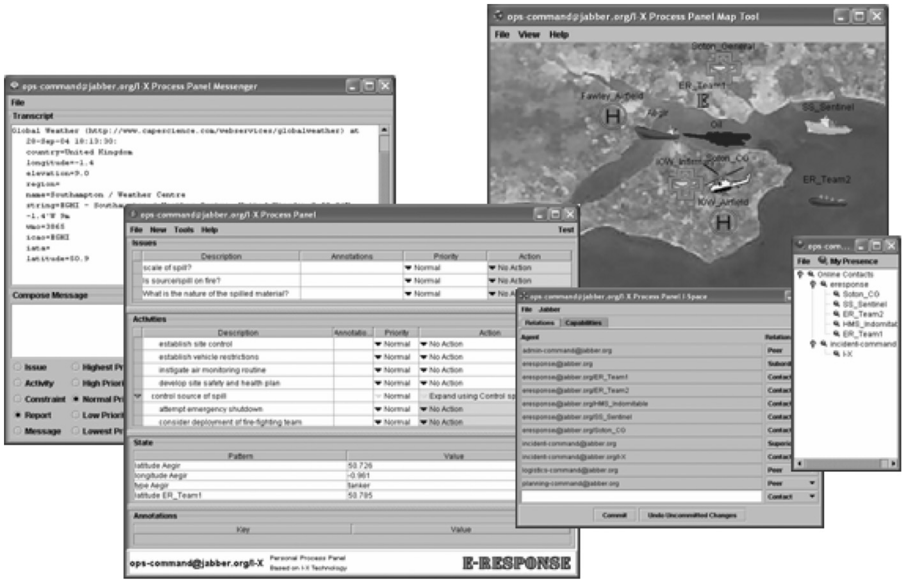

FIGURE 3 An I-X process panel, and its accompanying tools, shown engaged in coordinating the response to a simulated environmental emergency.

In the context of CoAKTinG, I-X has the role of activity management and guidance. In practice, this can range from assisting users to establish videoconferencing channels, through structuring periodic administrative meetings, to encouraging laboratory best practice. A Jabber communications layer allows for presence status, issues arising, emerging constraints, etc., to be shared with the other tools, thereby providing an integrated collaborative environment.

MEETING REPLAY

Once a meeting has taken place, it can be useful to revisit the ideas and topics discussed. Traditionally, formal minutes are taken to record the salient points, but often these are too brief to be more than a simple memory aid. In the typical CoAKTinG scenario (such as an Access Grid node), full audio and video logs are available, but conversely these are too verbose to be of practical use. We require the ability to select high-level points of reference from the meeting, then zoom in to view detailed records, e.g., a user sees from Compendium notes that a decision was made, but to understand the subtle reasoning behind that outcome wishes to view the video of discussion between participants.

Each meeting is described using RDF conforming to an OWL meeting ontology; this represents resources such as: the meeting time, location, attendees, audio/video recordings, any presentations given (and associated Web viewable versions), and argumentation annotation from Compendium. The "Event/has-sub-event" structure held within the RDF is mapped onto a more conventional timeline, which is automatically published using HTML and Javascript on a Web site (Figure 4). The user can navigate the meeting using the video timeline, or jump to a different point in the meeting by selecting a particular event, such as a slide being presented, or a Compendium node being created. By using the shared AKT reference ontology, we can also link to further information about resources held in other knowledge bases, e.g., when a person is referenced we link to information about them in the populated AKT triple store. We populate the timeline with any temporally annotated information about the meeting that would aid the user in navigation.

In CoAKTinG, we have experimented with annotating the timeline in terms of:

- Agenda item
- Slide exhibits
- Compendium node
- Speaker identification
- I-X activity (action item) creation
- BuddySpace chat

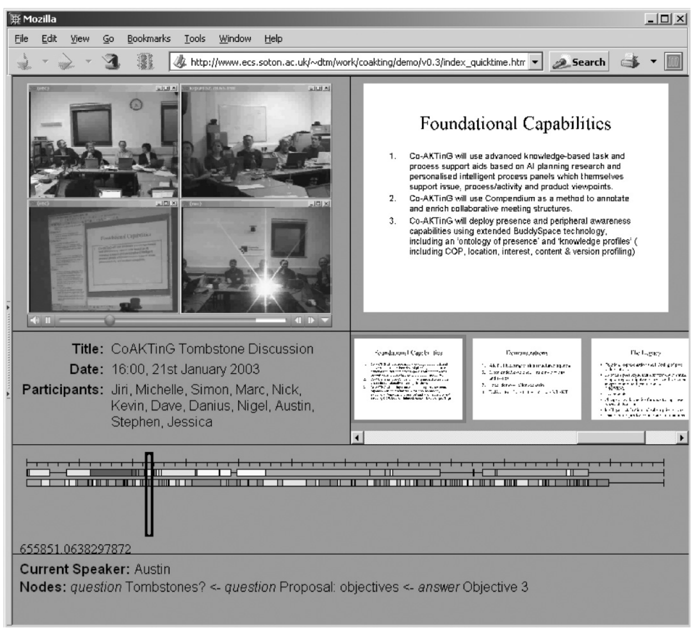

FIGURE 4 The meeting replay tool.

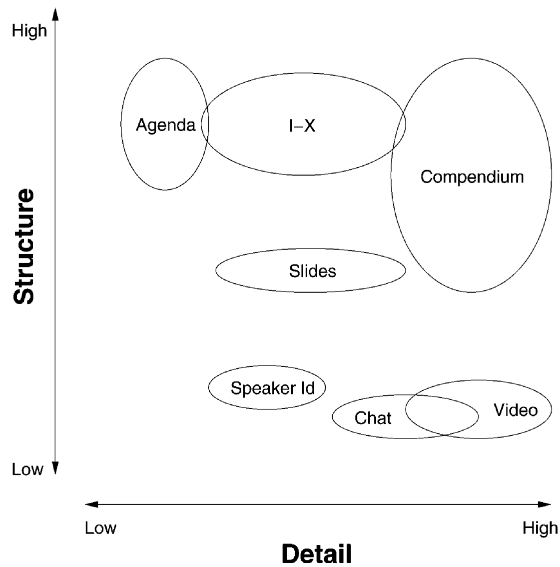

FIGURE 5 Meeting detail and structure of recorded sources.

By providing all available information, we hope to cater for the many activities and contexts of the user, in a seamful (Chalmers et al. 2003) manner.

We can categorize the information presented in the entire meeting replay in terms of the dimensions structured and detailed, as shown in Figure 5. Video, for example, is high in detail, in that it captures the entire audio and visuals of the meeting. Structurally, it is relatively low, since although there is implicit structure (image frames and audio samples), these do not directly contribute to navigating the structure of the meeting. Video processing could be applied to segment the video into scenes but structurally this would not provide much more than speaker identification. The agenda, conversely, is high in meeting structure, but relatively low in the details. Compendium captures a moderate level of detail in a highly structured representation.

ONTOLOGY

The Advanced Knowledge Technologies (AKT) project, with which CoAKTinG is affiliated, has developed a reference ontology[3] to describe the domain of computer science research in the United Kingdom, exemplified by the CS AKTive Space semantic Web application. Within this domain, its vocabulary is able to express relationships between entities such as individuals, projects, activities, locations, documents, and publications. For purposes of capturing meeting specific information, the reference ontology is already suitable for encapsulating:

- The meeting event itself
- Meeting attendees
- Projects that are the subject matter of the meeting
- Documents associated with the meeting, including multimedia

For activities such as meetings, which we wish to index and navigate temporally, the way in which the ontology represents time is of particular relevance. The reference ontology contains the notion of an *event*, which is a *temporal-thing* that can define a duration, start and end times, a location, and *agents* involved in the event. More importantly, each event can express a *has-sub-event* relationship with any number of other events, and it is with this property that we build up our temporal meeting structure. Within the ontology there are also many event subclasses, such as *giving-a talk*, *sending-an-email*, *book-publishing*, and *meeting-taking-place*.

While the reference ontology provides a foundation for describing meeting related resources, the CoAKTinG meeting ontology (Figure 6) extends the OWL version of AKT reference ontology to better encompass concepts needed to represent collaborative spaces and activities, including:

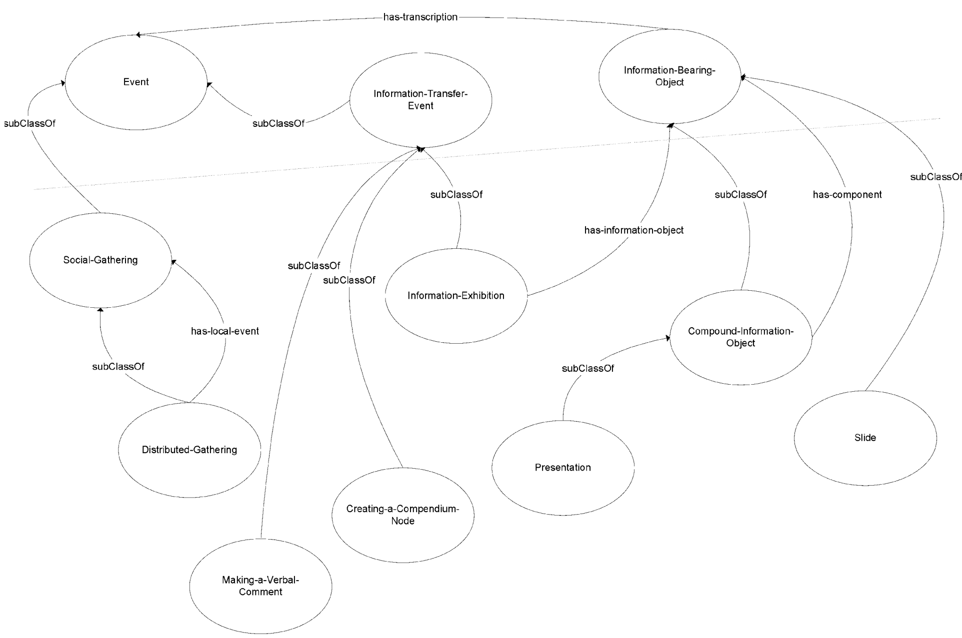

FIGURE 6 A simplified representation of the meeting ontology.

- Time properties sufficient for multimedia synchronization.
- Distributed gatherings to represent meetings that simultaneously take place in several spaces, both real and virtual.
- Exhibition of information bearing objects, e.g., showing a slide as part of a presentation.
- Compound information objects, e.g., to describe a presentation consisting of several multimedia documents.
- Rendering of information objects, e.g., JPEG image of a slide.
- Transcription of events, e.g., a video recording of a presentation, minutes of a meeting.
- Annotation of events, e.g., making a verbal comment, creating a Compendium node.

When a meeting takes place we mark up the event with metadata—details such as those listed—to build a structured description of the activities that occur. Through use of an ontology shared and understood by several different tools, we can lower the workload needed to provide usable and useful structure.

CASE STUDIES

CombeChem – Grid-enabled Combinatorial Chemistry

The CombeChem project aims to enhance structure property correlation and prediction by increasing the amount of knowledge about materials via synthesis and analysis of large compound libraries. This entails a complete end-to-end connection between the laboratory bench and the intellectual chemical knowledge that is published as a result of the investigation; necessitating that all steps in the process are enhanced by a suitable digital environment. Automation of the measurement and analysis is required in order to do this efficiently and reliably while ensuring that wide dissemination of the information occurs together with all the necessary associated background (raw) data that is needed to specify the provenance of the material. CombeChem has achieved many parts of this ambitious program, e.g., the smart laboratory,[4] Grid-enabled instrumentation, data tracking for analysis, methodology for publication@source, process and role-based security, and high throughput computation.

The CoAKTinG tools provide support for the e-Science process in CombeChem and they also enable the digitization of missing links in the processing chain that form part of the typical collaborative scientific processes that we are attempting to enhance using the Grid infrastructure: support of the experimental process, tracking and awareness of people and machine states, capturing of the discussions about data as well as the traditional metadata, and enriched metadata regarding these components to support interlinking.

The BuddySpace systems can be adapted to show and track the interactions between the staff and equipment using the National Crystallographic Service (NCS), providing information to their users about the state of the service. Compendium provides the harness to ensure more adequate capture of the discussions in analysis, while process panels provide the means to initiate and track key tasks and issues. Additionally the ideas from CoAKTinG provide different techniques to achieve the necessary multi-user interaction in real time over the network and give CombeChem the opportunity to implement the video interaction collaboration part of CombeChem using event based ontologies to annotate real-time streaming media and content.

These various components are valuable complements to CombeChem individually but jointly are even more powerful. For example, process panels can exploit the presence information derived from BuddySpace with respect to instrument status and operator availability to offer more informed task delegation options. This completes the chain of digital support and capture, maximizing the potential for re-use of the digital information in support of the scientific process.

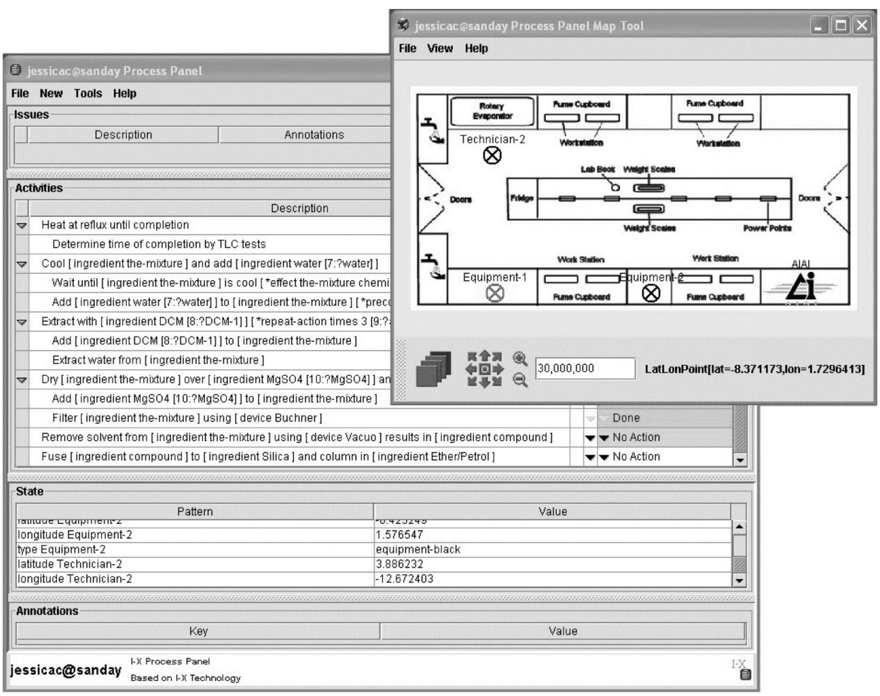

FIGURE 7 I-X process panel configured for e-Chemists.

Here we illustrate one particular aspect of the deep integration—the application of the process panel tool to the laboratory, building on the process capture work of CombeChem's Smart Tea team. Figure 7 shows a screen capture of an I-X process panel and its map tool, resulting from our initial experiment. The map tool depicts a real chemistry lab where both fixed and mobile entities are represented. The positions of mobile entities such as movable equipment and technicians are updated automatically through the (world) state subpanel. By sharing information with BuddySpace, (dynamic) properties of devices are also described in the same panel. At this particular point in time, it shows Technician-2 is in front of the rotary evaporator and about to carry out the subprocess "Remove solvent from the-mixture using Vacuo results in Compound," having completed the previous steps in this process. In our investigation, the process decomposition facility of the I-X activity sub-panel supports views of different levels of abstraction that fits nicely with different chemists' (and labs') practice. Activities, issues, annotations, and constraints may be recorded directly or via Compendium where in-depth discussion has taken place. Static and dynamic process editing provide great flexibility as processes are modifiable at run-time in response to unexpected changes. The ability to store, retrieve, and refine process models is important in the chemistry domain where existing processes are constantly reviewed and modified to discover or synthesize new chemical compounds. This facility alone makes I-X a valuable back-end component for integration with the existing CombeChem Grid.

Scientific Exploration on Mars

As part of long-term research into manned Mars missions, NASA's Work Systems Design and Evaluation group conducts annual field trials of its agent-based software and robots at the Mars Society's Desert Research Station (MDRS) in Utah, USA. As a part of the 2004 trial, several CoAKTinG tools were used to support the collaboration that occurs between the astronauts on Mars and the distributed groups of support scientists on Earth (known as the Remote Science Team (RST) and, in this particular case, specialists in geology).

The role of the RST is to analyze the data collected by the astronauts during their extra-vehicular activities (EVAs) on the planet surface, and the subsequent debrief at the Mars base (which is videotaped to provide a detail-rich recording). Throughout the EVA semantically annotated data is collected using the NASA agent robots. Communication delays between Earth and Mars mean that the usual means of collaboration of at a distance, such as real-time conversations and the sharing of computer screens, are impractical. This is further complicated by the international composition of the RST, who will be collaborating across many time zones.

During their debrief, the astronauts use Compendium as a dialogue mapping tool to capture the structure of the meeting. This is sent back to Earth, along with the video recording, where the CoAKTinG ontology is used as a mediator to produce a meeting replay.

This replay is then viewed by the distributed members of the RST, in conjunction with the Compendium map of the debrief. When the RST meets virtually, any one member can take navigational control of the Replay so as to highlight relevant sections to the other RST members. The RST meeting itself is also captured using Compendium, and the map is sent back to Mars with the RST analysis; this is used to plan for the next EVA. Throughout the mission, and especially during their meetings, the virtual community of the RST is support by BuddySpace.

APPLICABILITY TO e-LEARNING

Learning is clearly about a lot more than collaboration but, on the other hand, it is evident upon a moment's reflection that peer interaction is involved in a very large number of learning experiences throughout one's life, and the Computer Supported Cooperative Learning (CSCL) community has built strongly upon this concept for many years (Hiltz 1994; Hooper 1992). Our challenge is to harness the best of breed collaboration capabilities that we have created within the CoAKTinG project, and understand the way these can be leveraged for greatest e-Learning effectiveness. Toward this end, we have been motivated by one of the most influential theories in European higher education of the past twenty years, namely the Conversational Framework of Laurillard (Laurillard et al. 2000; Laurillard 1993). Laurillard argues that learning can be viewed as a series of teacher-learner conversations taking place at multiple levels of abstraction. As summarized in Laurillard (1993):

> "At the most general level of description, the learning process is characterised as a 'conversation' between teacher and student operating on two levels, discursive and interactive, the two levels being linked by the twin processes of adaptation and reflection."

As Britain and Liber (2000) observe, Laurillard's Conversational Framework serves as an excellent starting point for evaluating modern virtual learning environments (VLEs). They argue that any VLE can be analyzed in terms of how well it supports discourse, whether it is adaptable, and how well it supports interaction and reflection. These dimensions of discourse, adaptation, interaction, and reflection play precisely to the very strengths of the CoAKTinG toolset, which by its very nature supports all four: discourse is at the heart of all of the components, adaptation is built in because the tools are completely domain-agnostic, and interaction and reflection are the very essence of Compendium's concept mapping and the CoAKTinG replay tool.

e-Learning Theory and Practice Illustrated via Compendium Usage

As a specific instance of the conversational framework mentioned previously, Compendium uses an approach called conversational modeling (Selvin 1999). Conversational modeling extends the technique developed by Jeff Conklin termed Dialogue Mapping, which in turn derives from the formative public policy planning work of Horst Rittel (Rittel and Webber 1973). Rittel characterized the concept of "wicked problems," which can only be solved by all stakeholders striving to define the problem and being willing to explore issues dialogically, in what he termed argumentative design, which focuses attention on asking good questions that clarify the available options, and the strengths and weaknesses of each. Such problems are typical of complex, applied dilemmas of the sort commonly used in teaching assignments to test students' ability to apply, or derive, abstract ideas to/from concrete scenarios.

In learning contexts, issue-maps of this sort can be used in several ways to summarize:

- Background information about a complex issue to be tackled.
- Evidence as it is gathered and how it pertains to issues under debate.
- Contributions to online discussion forums as a visual precis.

The pedagogical design of software for scaffolding student argumentation is an established theme in CSCL research, with a workshop dedicated to this issue (Buckingham Shum 2000) and the recent book, *Arguing to Learn,* consolidating results to date and proposing a framework for understanding the relationship between learning and argumentation (Andriessen et al. 2003). Argument mapping as a specific form of representational support is also finding application in diverse domains, from specifically academic learning and research, to reflective learning and the negotiation of meaning in work settings confronting wicked problems (Kirschner et al. 2003). The key lesson from CSCL argumentation research with school and university students is, arguably, that simply giving students argument mapping tools is not usually successful. Critical additional factors that must be co-designed into an exercise designed to promote learning are the task, the group configuration, and the expertise of the students. Often, students do not produce particularly elegant argument maps, but in a collaborative setting, the task of constructing them provokes verbal deliberations that reflect the kinds of critical, reflective cognition that one wants to instill (Kanselaar et al. 2003).

Compendium is often used as a means of gathering together diverse resources into a common place, for organization and analysis. Teachers, students, or researchers can use Compendium's maps to drag and drop multimedia resources onto a map (Figure 8). At a more advanced stage in course design, learning resources (whether formal learning objects or otherwise) can be sequenced using Compendium as a visual planning aid.

Open University Ph.D. students are using Compendium as a visual database for managing their literature reviews, and as way to refine their research questions, and Compendium is used to support virtual supervision of e-Ph.D. students (Figure 9).[5]

Whilst meetings are central in almost all organizational life, in an e-Learning context they may range from being irrelevant (if students have chosen self-paced e-Learning precisely to avoid having to be in the same virtual place at the same time), to being invaluable (where online meetings may be the richest form of synchronous contact and support amongst students and tutors). If teamworking is part of a course, then hybrid forms of collaboration may be explicitly encouraged to develop teamworking skills. The traditional "learning/research" or "student/scientist" boundaries are

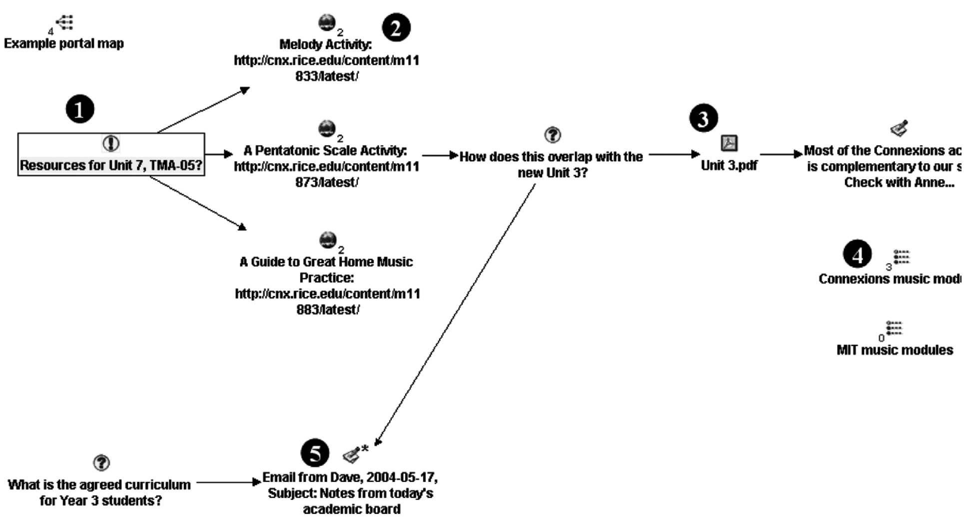

FIGURE 8 Example use of Compendium by an instructional designer to organize issues, ideas, and resources from diverse sources: (1) The key problem to be addressed is framed as a question; (2) open courseware resources are dropped from a Web browser onto the map; (3) an existing course Unit 3 is added in response to the issue about one of the Web resources; (4) a catalogue of resources is created; and (5) a relevant e-mail is linked to as a response to two different questions.

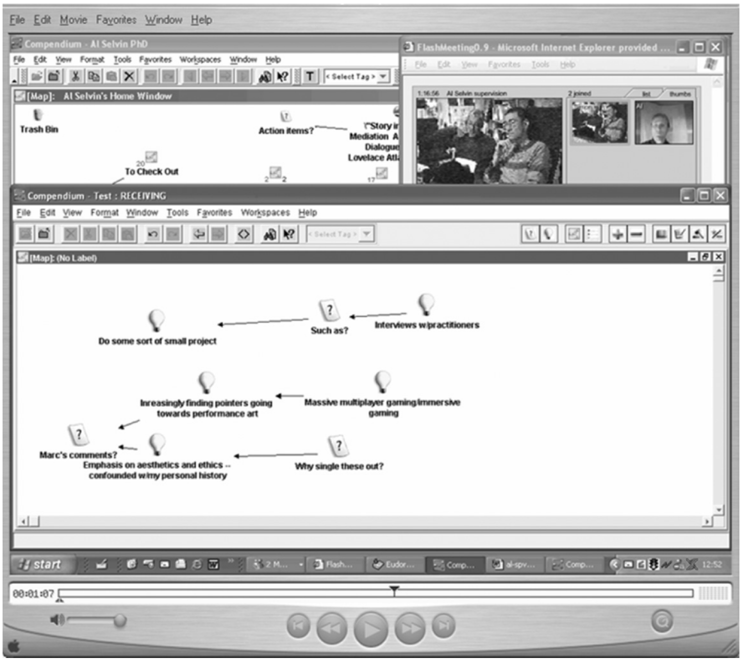

FIGURE 9 Mapping issues, ideas, and arguments in shared Compendium during e-Ph.D. supervision at the Open University. If the meeting is screen recorded, the digital movie of the evolving dialogue maps provides a visual index that can be skimmed. This was an early low tech way to test ideas that fed into the semantic navigation functionality afforded by the integrated Compendium meeting replay tool.

in fact blurred, in that e-Science, the context in which CoAKTinG operated, requires very similar hybrid modes of engagement ranging from individual through to collective sensemaking. The motivation behind Compendium is to support this sensemaking activity spectrum by constructing a representation of the problem space that is coherent (structured using IBIS/conversational modeling), agreed (constructed in response to, and visible to, all stakeholders), and persistent (a hypermedia group memory), with other relevant media resources embedded in this conceptual Web. Space precludes more detailed discussion of Compendium's use in learning contexts, examples of which can be found in Carr (2003) for teaching legal argumentation skills, and Selvin and Buckingham-Shum (2005) for its use to support literature analysis and research planning.

I-X for Task Oriented e-Learning

Administration tasks—the planning and coordination necessary for efficient management and delivery of e-Learning—are a straightforward match for the methods supported by I-X. In addition, I-X technology can be used to assist directly in the learning process. The effective teaching of non-trivial synthesis tasks—those concerned with the design or production of artifacts—has been recognised to be extremely difficult (Simon 1999). This is because the successful performance of such a task will typically draw heavily on experience, and experience is, of course, the very thing that students lack. In many cases, the best that teachers can aim to achieve is the transfer of the scientific or analytical body of knowledge that underpins the task, in the hope that this will equip their students to go on to acquire the necessary experience through practice.

The I-X technology can assist in this move from theory to practice in a number of ways. First, the underlying (generic) synthesis model encourages a methodical representation of and approach to any task, involving cycles of issue-raising, exploration of alternatives, issue resolution/activity formulation, and activity performance. Secondly, the domain editing tools promote the formalization, storage, and later reuse of activity plans that are found to be successful. Thirdly, the availability of shared standard operating procedures, tried-and-tested plans for typical tasks, gives the user ready access to an existing body of expertise. The use of these procedures, and their modification to the expediencies of the current task, allow the user to develop their own expertise in the task. Taken together, these features of I-X aim to encourage novice users to develop their own expertise whilst performing tasks within the context of a distributed virtual environment of shared resources, support agents, and other users of various levels of proficiency.

The Social Dimension of e-Learning

Even the best computer-supported collaboration tools can yield disappointing results in the field with real learners, as an extensive analysis of the literature by Kreijns et al. (2002) has persuasively argued. Kreijns et al. argue that the missing link concerns social interactions: All too often the social psychological dimension is typically ignored (they claim), and it is simply assumed that social interactions will automatically occur even without explicit (e-Learning environment) scaffolding to help make this happen. A strength of CoAKTinG's underlying enhanced presence approach is that it provides, via the BuddySpace component, the very type of social-affordance scaffolding that Kreijns et al. propose, in particular, peripheral social/presence awareness and impromptu "off-task" interactivity, and thereby addresses a key missing link within many e-Learning environments.

But are these ideas borne out in practice? At the time of writing, BuddySpace has been downloaded by about 30,000 users, ranging from hobbyists to universities and corporate clients looking for enterprise-wide deployment of a custom messaging platform. The biggest long-term use, highly appropriate for studies of e-Learning, comes from our colleagues within the Open University, and from Open University students taking specific courses, particularly in foreign languages, that have opted to deploy BuddySpace as a community building tool. We analyzed just over 1000 discussion forum messages of students enrolled in a single Open University foreign language course, and found that nearly 20% of the messages in the first month of the course where highly location-centric, along the lines of "is there anyone here from Manchester?" This suggested to us that location-centric displays would be both motivating to the users and also suitable for large-scale visualization: precisely the cornerstones of the BuddySpace user interface.

We "drilled down" to observe these and several dozen "cohort" students in detail, and sent questionnaires to 15 long-term (>6 months) BuddySpace users. From an analysis of the questionnaires (Vogiazou et al. 2005), it was apparent that automatically generated groups and enhanced state information (online, away, low attention, online-but-elsewhere) were perceived as the most beneficial and most frequently-used feature of BuddySpace. Indeed, the enhanced states are an immediate benefit of deploying the AKT reference ontology to represent presence information. The second main result of the questionnaire analysis was that BuddySpace maps, personal rosters, and group rosters engender a strong sense of community belonging (we asked our long-term users to rate the extent of "group belongingness" engendered by a sample of twenty activities, events, and physical artifacts in the workplace, using a 7-point Likert scale (from $-3 =$ "very negatively: not only do I not feel a part of this group, I feel very negatively about it" to $+3 =$ "very positively: I associate very positively with this group"). These twenty items ranged from corporate logos and political rallies (intended to provide a baseline for strong belongingness) to BuddySpace-specific items such as dots on maps, presented to the users in a randomized order. Importantly for us, the items "appear as dot on an office map," "appear as a dot with thumbnail photo on an office map," "membership of automatically-generated list," and "membership of self-created buddy list" all ranked within the top five items, rivaled only in "belongingness-power" by the feeling instilled by seeing one's corporate logo in a newspaper ad! This is a strong endorsement of the notion of "feel-good factor" in crowd identity, which was one of the motivating factors of this work, and nicely fills the gap highlighted by (Kreijns et al. 2002).

In addition to distinguishing between educational and social psychological dimensions, Kreijns et al. are also passionate about the importance of task-related vs. non-task-related learning activities. The CoAKTinG toolset addresses this concern too: the I-X process panels are a straightforward medium for specifying task-centric learning goals and outcomes, whereas the non-task-related activities fall out of the Compendium, replay, and BuddySpace-centric interactions. This is not to say that CoAKTinG provides a silver bullet for e-Learning. On the contrary, the literature suggests that there is no silver bullet, and it is interesting note that for both the important and well-understood aspects of collaborative learning, and also the more poorly understood but well-argued implicit and social aspects, the CoAKTinG toolset, without having been designed as an "e-Learning platform" already addresses many of the most central concerns.

e-Learning and the Grid

How, then, does the Grid fit into the picture? The original Grid promise was to provide unlimited computational resources on demand to match projected computational needs via a kind of generic "service matchmaking." Out of this original vision has emerged an extended notion of *arbitrary resource provision,* including not only CPU-intensive resources, but also data resources, intelligent agent resources, and even human *tutorial* and *mentoring* resources as-and-when appropriate. This generic resource-on-demand model lies at the heart of the European Learning Grid Infrastructure project (ELeGI [Allison et al. 2003]), and fits very nicely with the CoAKTinG approach, which itself aims to provide generic service-level support for the type of collaboration-intensive activities we have described. In essence, there are many similarities in supporting the collaborations involved in e-Science and e-Learning; indeed this is one of the reasons why the (Semantic) Grid is a suitable approach to the human centered design of e-Learning. It is a short step from the remote experiments and collaborations of CombeChem and Mars exploration to virtual teaching laboratories and experimentation—the interactions, conversations, and enhanced presence which are key to Learning Grids and virtual communities.

In closing, we summarize where the CoAKTinG tools (and if not specific tools, the concepts underlying them) can be transposed into the Learning Grid:

- BuddySpace, with its notions of enhanced presence and communication, can be used to create a virtual community consisting the individual students and teachers, and provide the often-ignored "social affordance scaffolding."
- Compendium can be used to capture collective thinking within a learning group that is physically distributed, and used to plan, structure, and access other learning resources, thereby providing critical interactive and reflective machinery for the learner.

- I-X process panels can be used to plan and structure learning tasks, goals, and experiments, and provides a mechanism for tracking issues and tasks when part of a collaboration, thereby proving critical task-level support.
- The use of a shared semantic ontology amongst the tools provides a sum greater than the parts. Structured metadata from the various tools can be combined with new material to create further services such as the relay tool, which can be used to review results from collaborative experiments and tasks, thereby augmenting the all-important adaptive and reflective components so critical to current and future e-Learning environments.

CONCLUSIONS

This paper has introduced the tools that have been developed by the CoAKTinG project and identified how they are typically used in meetings, and in support of collaborative science in the Semantic Grid. It has also shown how they are being being explored in scenarios such as Combe-Chem and future Mars exploration, and how this experience can be applied to the construction of a Learning Grid, within the context of a human-centered design approach to e-Learning.

We have provided an example of the use of Semantic Web technologies to integrate this set of tools as to support the collaborative grid. These tools provide a platform for future work, and there is much to be done, for example, we are not yet making full use of the capabilities to incorporate domain-specific ontologies, nor of reasoning. There are also some important engineering challenges in the management of the recorded metadata to facilitate replay. We have not addressed issues of security, digital rights management, and consent for release of metadata, all of which are clearly important in virtual organizations. While some of the individual tools and underlying approaches have been proved in an educational setting, we lack practical experience of using the integrated CoAKTinG toolset as a learning environment. All of these would be exercised through a case study in e-Learning.

In our work, we have assumed that the people in the virtual organization have already been identified. Our current work includes the application of Semantic Web technologies to help with the initial identification of the members of the virtual organization, for example, by identification of communities of practice from Semantic Web representations of bibliographic data. We are also considering the integration of further tools, such as a portal based on a MUD that has been developed in an adjacent project. In other activities, we are capturing additional event data as people interact through the use of pervasive computing technologies.

REFERENCES

Allison, C., S. Cerri, M. Gaeta, P. Ritrovato, and S. Salerno. 2003. Human learning as a global challenge: European learning grid infrastructure. In *Global Peace Through the Global University System*, eds. T. Varis, T. Utsumi, and W. Klemm, Hämeenlinn: University of Tampere, pages 465–488.

Andriesssen, J., M. Baker, and D. Suthers. 2003. *Arguing to Learn: Confronting Cognitions in Computer-Supported Collaborative Learning Environments*. Dordrecht: Kluwer.

Britain, S. and O. Liber. 2000. A framework for the pedagogical evaluation of virtual learning environments (JTAP Report 041). http://www.jisc.ac.uk/jtap/htm/jtap-041.html.

Buckingham-Shum, S. 2000. Workshop report: Computer-supported collaborative argumentation for learning communities. *ACM SIGWEB Newsletter* 9(1):27–30.

Carr, C. 2003. Using computer supported argument visualization to teach legal argumentation. In: *Visualizing Argumentation: Software Tools for Collaborative and Educational Sense-Making*, eds. P. A. Kirschner, S. J. Buckingham Shum, and C. S. Carr. London: Springer-Verlag.

Chalmers, M., I. MacColl, and M. Bell. 2003. Seamful design: Showing the seams in wearable computing. In: *Proceedings of IEE Eurowearable 2003*, pages 11–172, Birmingham, UK.

Clancey, W., M. Sierhuis, R. Alena, D. Berrios, J. Dowding, J. Graham, K. Tyree, R. Hirsh, W. Garry, A. Semple, S. Buckingham Shum, N. Shadbolt, and S. Rupert. 2005. Automating CapCom using mobile agents and robotic assistants. In *Proceedings of 1st AIAA Space Exploration Conference*, Orlando, FL. Available on CD "AIAA Meeting Papers on Disc," Reston, VA.

Conklin, J. 2003. Dialog mapping: Reflections on an industrial strength case study. In: *Visualizing Argumentation: Software Tools for Collaborative and Educational Sense-Making*, eds. P. A. Kirschner, S. J. Buckingham Shum, and C. S. Carr. London: Springer-Verlag.

Conklin, J., A. Selvin, S. Buckingham Shum, and M. Sierhuis. 2001. Facilitated hypertext for collective sensemaking: 15 years on from gIBIS. In *Proceedings The Twelfth ACM Conference on Hypertext and Hypermedia (Hypertext '01)*, Århu, Denmark (aarhus), pages 123–124.

Eisenstadt, M., J. Komzak, and M. Dzbor. 2003. Instant messaging + maps = powerful tools for distance learning. In: *Proceesings of TelEduc03*.

Foster, I., C. Kesselman, and S. Tuecke. 2001. The anatomy of the grid: Enabling scalable virtual organizations. *International Journal of Supercomputer Applications* 15(3).

Goble, C., D. De Roure, N. Shadbolt, and A. Fernandes. 2004. Enhancing services and applications with knowledge and semantics. In *The Grid 2: Blueprint for a New Computing Infrastructure* (2nd edition), eds. C. Kesselman and I. Foster, San Francisco, CA: Morgan-Kaufmann, pages 431–458.

Hiltz, S. 1994. *The Virtual Classroom: Learning without Limits Via Computer Networks*. Norwood, NJ: Ablex.

Hooper, S. 1992. Cooperative learning and computer-based instruction. *Educational Technology, Research* 24(3):307–333.

Kanselaar, G., G. Erkens, J. Andriessen, M. Prangsma, A. Veerman, and J. Jaspers. 2003. Designing argumentation tools for collaborative learning. In *Visualizing Argumentation: Software Tools for Collaborative and Educational Sense-Making*, Springer-Verlag.

Kirschner, P., S. Buckingham Shum, and C. Carr. 2003. *Visualizing Argumentation: Software Tools for Collaborative and Educational Sense-Making*. London: Springer-Verlag.

Kreijns, C., P. Kirschner, and W. Jochems. 2002. The sociability of computer-supported collaborative learning environments. *Educational Technology and Society* 5(1).

Laurillard, D. 1993. *Rethinking University Teaching*. London: Routledge Falmer.

Laurillard, D., M. Stratfold, R. Luckin, L. Plowman, and J. Taylor. 2000. Affordances for learning in a non-linear narrative medium. *Interactive Media in Education* 2000(2).

Nardi, B. A., S. Whittaker, E. Isaacs, M. Creech, J. Johnson, and J. Hainsworth. 2002. Integrating communication and information through contactmap. *Communications of the ACM* 45(4):89–95.

Papadopoulos, N. 2004. *Conflict Cartography: A Methodology Designed to Support the Efficient and Effective Resolution of Complex, Multi-Stakeholder Conflicts* (white paper). http://www.compendiuminstitute.org/compendium/papers/conflictcartography42.03.pdf.

Reffell, J. and S. Eklund. 2002. *Instant messaging in Project-Based Learning*. Berkeley: University of California.

Rheingold, H. 2002. *Smart Mobs: The Next Social Revolution*. Cambridge, MA: Perseus.

Rittel, H. and M. Webber. 1973. Dilemmas in a general theory of planning. *Policy Sciences* 4:155–159.

Selvin, A. 1999. Supporting collaborative analysis and design with hypertext functionality. *Journal of Digital Information* 1(4).

Selvin, A. and S. Buckingham Shum. 2002. Rapid knowledge construction: A case study in corporate contingency planning using collaborative hypermedia. *Knowledge and Process Management* 9(2): 119–128.

Selvin, A. M. and S. J. Buckingham Shum. 2005. Hypermedia as a productivity tool for doctoral research. *New Review of Hypermedia and Multimedia (Special Issue on Scholarly Hypermedia)* 11(1):91–101.

Simon, H. A. 1999. *The Sciences of the Artifical.* Cambridge, MA: The MIT Press.

Tate, A. 2003. ⟨I-N-C-A⟩: An ontology for mixed-initiative synthesis tasks. In *Proceedings of the Workshop on Mixed-Initiative Intelligent Systems (MIIS) at the International Joint Conference on Artificial Intelligence (IJCAI-03)*, Acapulco, Mexico, pages 125–130.

Tate, A., J. Dalton, and J. J. Stade. 2002. I-P^2-Intelligent process panels to support coalition operations. In *Proceedings of the Second International Conference on Knowledge Systems for Coalition Operations (KSCO-2002)*, Toulouse, France, pages 184–190.

Vogiazou, Y., M. Eisenstadt, M. Dzbor, and J. Komzak. 2005. From buddyspace to cititag: Large-scale symbolic presence for community building and spontaneous play. In *Proceedings of the ACM Symposium on Applied Computing*, Santa Fe, NM, pages 1600–1606.

Whitelock, D., D. M. Romano, A. Jelfs, and P. Brna. 2000. Perfect presence: What does that mean for the design of virtual learning environments? *Education and Information Technology* 5(5):227–289.

NOTES

1. http://www.aktors.org/coakting/
2. http://www.accessgrid.org/
3. http://www.aktors.org/omtology/
4. http://smarttea.org/
5. The Memetic project (http://www.memetic-vre.net/) is now integrating CoAKTinG's Compendium and the meeting replay tools into the access grid collaboration environment. Other collaboration tools for e-learning/e-research are detailed on the e-Ph.D. project (http://www.kmi.open.ac.uk/projects/e-phd/).