Do you know what I know? Situational Awareness and Scientific Teamwork in Collaborative Environments

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Abstract

Scientific experimentation in the molecular biology domain is highly dynamic and requires expertise from diverse disciplines, such as molecular biology, statistics, bioinformatics and mathematics. Scientists are confronted with new technological developments and bioinformatics tools when analyzing and interpreting vast amounts of data from their experiments. In our project, we investigate the face-to-face collaboration of multidisciplinary scientific teams. Our aim is to identify requirements and to design and evaluate new interaction concepts to support scientific teams in future collaborative environments.

This paper presents an on-going work on the support of co-located scientific team collaboration in a real world context. In particular, we focus on situational awareness: being aware of what is happening around you, and on group creativity. These are essential for successful team collaboration. After presenting an overview of the studies on team creativity and situational awareness support, we describe the collaborative environment for scientific teams in a molecular biology context. We also report our results of an empirical case study translated into user requirements for support of multidisciplinary collaboration of scientific teams, as well as our findings on the situational awareness support in collaborative environments. Finally, we present our multi-level approach for practical case studies with multidisciplinary scientific teams. These studies bring new insights into how the new computing technology affects teamwork and contribute to the development of novel concepts for collaborative environments.

Keywords: Co-located collaboration, situational awareness, creativity, teamwork, collaborative environment, scientific teams

1 INTRODUCTION

Evolving technologies in molecular biology are producing vast amounts of data. Scientists experimenting in this discipline are confronted with the problem of applying methods from different disciplines, such as statistical, mathematical and machine learning techniques, when analyzing and interpreting their data. In addition, integration of the results with information from heterogeneous information sources is a difficult part of their experiments analysis. Nowadays, molecular biologists daily retrieve data from many large, often publicly available databases and have to analyze them while interpreting their own results. Such databases often have complex web interfaces which are too difficult for inexperienced users such as biologists (Kulyk and Wassink, 2006).

An important research area in molecular biology is *omics* experimentation deals with "omes": large or complete arrays of cell components, such as the genome (all genes) and the proteome (all proteins). For example, studies that encompass the whole genome are in general referred to as *"genomics"* studies, and studies that examine the expression level of all mRNAs (messenger RNA, which directs the synthesis of proteins) in a given cell population are called *"transcriptomics"*.

Omics experimentation has two tightly coupled aspects: the *wet-lab* part and the *dry-lab* or *in-silico* part. The wet lab refers to concrete experiments on real cells or their components, often using high-throughput techniques that may generate up to a million datapoints per experiment. The dry lab refers to quality control, analysis, and interpretation of the wet-lab data. Dry-lab activities are all performed using the computer.

Current *omics* experimentation in molecular biology, such as needed in, for example, drug discovery and cancer research, is a complex, highly dynamic and multidisciplinary task that requires teamwork (Rauwerda et al., 2006; van der Vet et al., 2007). Project success in teams often depends upon team coordination and creative thinking. Diversity of expertise in teams has a positive impact on creative problem solving (Coughlan and Johnson, 2006; Shalley and Gilson, 2004).

The majority of the reported studies on team coordination support is centred on distributed collaboration and has been conducted in laboratories with mainly students performing predefined tasks (Carroll et al., 2006). The focus of our research is on *co-located collaboration* of *teams* working on joint projects in *real* work environments. This work is a part of a user interfaces and visualisation project within BioRange, devoted to the user-centred design and evaluation of visualisations and enriched interactions in order to enhance the exploration of bioinformatics resources by multidisciplinary teams of scientists (van der Vet et al., 2007). BioRange is a large national project of the Netherlands Bioinformatics Centre (NBIC) that supports bioinformatics development in the Netherlands.

In this paper, we present on-going work on the support of scientific team collaboration in the context of molecular biology *omics* experimentation. In particular, we focus on group creativity and situational awareness since they play an essential role in successful team's collaboration. Situational awareness concerns "knowing what is going on", basically being aware of what is happening around you and having a shared understanding of the information. *Situational awareness* can be generally defined as (Endsley, 1995, p.36):

> *The perception of the elements of the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*

Endsley (1995) suggests that situational awareness can be achieved by linking an objective state of the world to its mental analogue on **three levels**:

- Level 1: **Perception** of the elements in the environment within a volume of space;
- Level 2: **Comprehension** of their meaning;
- Level 3: **Projection** of their status in the near future.

In our research, we define *situational awareness* as the process of identifying the source and nature of the problem, comprehending multiple visualisations and a context (Figure 2), observing various changes in the environment, seeing what team members do and have done and keeping track of the work progress. We investigate the following research questions: What does situational awareness mean in scientific team collaboration? How can we support situational awareness in collaborative environments? How will new computing technology influence scientists' work, team collaboration and creative thinking in practice? How can we design technology that supports scientists' tasks and to get them to interact in a collaborative environment with prolonged involvement? After presenting an overview of the state-of-the-art on team creativity and team coordination support, we describe the collaborative environment for scientific teams in molecular biology context, and how to support situation awareness. We also report our conceptual results together with the results of an empirical case study that included contextual interviews, observations and questionnaires in different sub-domains of bioinformatics. Finally, we present our approach for practical case studies with molecular biology teams followed by conclusions and discussion.

2 SUPPORTING CREATIVITY AND TEAM COORDINATION

Presence of various expertise and levels of experience in a team is important for creative thinking and reasoning (Dunbar, 1995; Shalley and Gilson, 2004). There have been a series of studies investigating *group creativity* processes in real world situations. However, the tasks used in these studies did not address scientific teams. Yet, creativity and creative thinking theory can be applied just as much in science as in design (Johnson and Carruthers, 2006). A recent empirical study by Johnson and Carruthers provides a good overview of the relevant theories on creative processes. Results of this work are requirements for software tools to support specific creative tasks (Johnson and Carruthers, 2006).

Other empirical studies, although conducted in real work environments, focus only on team coordination. For instance, Manser et al. (2006) investigate coordination needs of cardiac anaesthesia teams in an operating room environment. The result of their study is a conceptual framework for the analysis of multidisciplinary team collaboration in complex work environments. A qualitative study by Wilson et al. (2006) reports the impact of a shared display on small group work in a medical setting.

Recent studies have also stated that people first need to understand the context in order to understand the existing situation and reach shared understanding in a team (Carroll et al., 2006; Varakin et al., 2004) (See Figure 2). As user-centred designers, we first need to analyse the actual context in which the computing technology will be deployed. Understanding of the actual context will help us to design technology that supports scientists in their primary task at hand, and thus leads them to collaborate and interact in a collaborative environment with prolonged involvement. It will also help us to find out how new computing technology in collaborative environments will influence scientists' work, team collaboration and creative thinking (Hallnass and Redstrom, 2002).

Molecular biology in general is a highly visual discipline (Campbell and Heyer, 2006). Visualisations play a large role in the analysis and interpretation of *omics* experiments (van der Vet et al., 2007) (See Figure 1). In the next section we discuss how visualisations can support group discussions and we introduce the collaborative environment for scientific teams. We argue that situational awareness can be supported in such environments by making changes in visualisations and relations between multiple visualisations easily noticeable and by means of attentive and proactive interfaces.

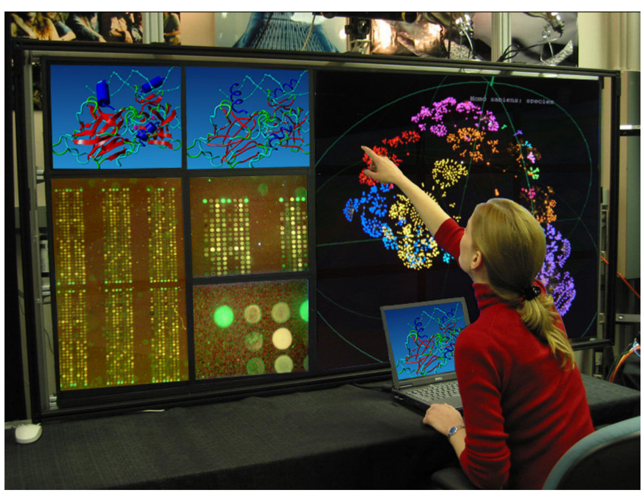

Figure 1: A scenario in which a life scientist is interacting with multiple visualisations.

3 SCIENTIFIC VISUALISATIONS AND SITUATIONAL AWARENESS IN COLLABORATIVE ENVIRONMENTS

Until recently, most of the studies in scientific visualisations mainly address the design of integrated software visualisation tools, with "single user - single visualisation" interaction. However, as a study on collaborative scientific visualisations illustrates (Li et al., 2005), the picture becomes more complex in situations where groups of users will be interacting with multiple visualisations and communicating with each other at the same time. In genomics research, there is a strong need for visualising the large genomics datasets during multidisciplinary collaborative discussions for comparing and sharing data among scientists (Li et al., 2005). Designing visualisations for multiple use to enhance exploration of heterogeneous information is a new challenge in cooperative work.

Work on collaborative environments and group support has been reported in a number of studies. Depending on the aspect one wants to emphasise, such an environment is often called by different names: for example, collaborative interactive environment (Borchers, 2006), multiple display environments (Huang, 2006; Rogers and Lindley, 2004), ubiquitous computing room (Brad et al., 2002), collaborative control room (Li et al., 2005), among many others. Many of these environments use visualisations on large displays to support group discussions (Borchers, 2006; Huang, 2006; Rogers and Lindley, 2004).

Much of this work is relevant but has to be adapted to the specific needs of the multidisciplinary teams in *omics* experimentation: molecular biologists, microarray experts, bioinformaticians, and statisticians. The practitioners of the various disciplines involved in our research bring with them a rich and often implicit background knowledge, as was found for scientists in general by Dunbar (1995).

The *e*-BioLab environment is a collaborative environment that aims to facilitate multidisciplinary teams during project meetings on molecular biology experiments, with an initial focus on microarray experiments (Rauwerda et al., 2006). The goal of a microarray experiment is to simultaneously examine the expression level of all genes of a specific organism, in a cell type in a specific growth or stress condition. Microarray technology is currently one of the most important methods in genomics and is usually applied to unravel complex cellular mechanisms or discover transcriptomics (see the introduction) biomarkers: genes whose expression profile can be used for diagnostic purposes or to monitor and predict cellular processes (Stekel, 2003).

Figure 2: Scientists interacting with microarray visualisations using multiple displays in *e*-BioLab, MicroArray Department/Integrative Bioinformatics Unit, University of Amsterdam.

In interpreting a microarray experiment in the e-BioLab, both results of the experiment itself and of statistical data analysis can be displayed in the form of visualisations on the large display, as in the example on Figure 2. In this way, team members can assess an entire microarray experiment. Moreover, in a multidisciplinary setup a large high-resolution display connected to online genomics resources can be used to construct models of biological mechanisms, thus enhancing *omics* experimentation and interpretation of the results. The largest tiled display is split into a number of displays (See Figure 1, 2). The visualisations on the various parts of the display are obviously related in the sense that they refer to the same experiment, but currently it is not always evident what the precise relation is. To prevent users from getting lost and to support situational awareness, visual aids will have to bring the relations between the various subscreens and changes in visualisations more in focus of attention.

Multiple visualisations can be closely related, and therefore a change in a visualisation on one display will have to be related to visualisations on other displays in a manner pioneered by the Spotfire[1] system. In our case, however, the situation is more complex. For example, in microarray experimentation a statistician needs to establish confidence intervals and statistical power of an analysis. However, only molecular biologists and microarray experts can assess whether it is experimentally possible in the wet-lab to increase statistical power or to avoid confounding by choosing a different experimental setup.

The complexity of multiple displays showing often complex visualisations can, as mentioned earlier, be reduced by employing attentive and proactive interfaces (Crowley, 2006). Such interfaces have to anticipate the context and provide an appropriate feedback without distracting the user from their main task. An example of such interfaces for awareness and collaboration support is a persuasive displays environment designed by Mitsubishi Research Lab (Dietz et al., 2004). Such environments can also include *peripheral awareness displays*: systems that reside in the user's environment within the periphery of user's attention (Plaue et al., 2004). These ubiquitous computing services provide feedback on the periphery of user's attention. The feedback is generated on the basis of multimodal cues sensed by the sensors embedded in the environment (Iqbal et al., 2005). The evaluation of such awareness interfaces focuses on effectiveness and *unobtrusiveness*: the ability of visual representation to communicate information at a glance without overloading the user (Plaue et al., 2004; Kulyk et al., 2006) We will elaborate on this in the next section.

4 OUR APPROACH AND RESULTS

The support of multidisciplinary scientific teams in collaborative environments is centrally addressed within our BioRange project. As in any user-centred approach, user studies and task analysis are a core activity in our research (Bartlett and Toms, 2005; Homa et al., 2004; van Welie and van der Veer, 2003). Contextual observations and interviews are conducted to find out how such collaboration takes place in daily work practices between biologists, bioinformaticians, and biomedical researchers and how we can support them (Kulyk and Wassink, 2006). The results of our studies demonstrate that multidisciplinary collaboration is essential in molecular biology and bioinformatics. Visualisations of experimental and biological data are used for discussing the experimental results and for assessing the progress of an experiment. Scientists expect they will profit from multiple visualisations in a collaborative environment. At the same time, they point out the danger of overwhelming the viewer with too much information. They strongly prefer to collaborate face-to-face. This is also confirmed in studies for other user groups (McCowan et al., 2003; Nijholt et al., 2006; Rienks et al., 2006) and for scientific teams (Dunbar, 1995). The results of our exploratory study have been translated into requirements for support of collaboration and multidisciplinary teamwork in bioinformatics, as well as into profile descriptions of novices, experts and scientific teams (Kulyk and Wassink, 2006).

In order to identify the key aspects and user requirements for the collaboration support in the context of a scientific collaborative environment, we also perform an extensive task analysis of the current microarray experimentation practice, based on contextual interviews and observations (van Welie and van der Veer, 2003). Use case scenarios for empirical studies in microarray experiments are provided by our project partners (Rauwerda et al., 2006). Scientists from various disciplines: molecular biologists, microarray experts, bioinformaticians and statisticians closely collaborate during such experiments. In particular, we aim to build a detailed task model of mi-

[1] http://www.spotfire.com, last visited May 30, 2007

croarray experiments. A task model of the current work situation describing phases of a microarray experiment is currently being validated with domain experts.

As the literature confirms, creativity in scientific collaboration can be supported by providing an *appropriate environment* and a *context* (Coughlan and Johnson, 2006). However, introducing a new environment and new technologies, as for example presenting multiple visualisations on a large display (see Figure 1,2), may increase scientist's cognitive load and influence the way project team members collaborate (Varakin et al., 2004). Awareness information in such shared workspace environment is always required to coordinate team activities (Dourish and Bellotti, 1992). We believe that *situational awareness* is a very important aspect of co-located team collaboration in complex environments, as other research confirms (Manser et al., 2006) (see section 2). Especially in the multidisciplinary settings, situational awareness information is affected by individual team members abilities, their interaction with other team members, and the environments in which they collaborate (Bolstad et al., 2005). It is essential to provide situational awareness support in collaborative environments in order to support team's coordination needs and creative problem solving.

On the basis of our current findings from conceptual studies and requirements analysis, we are performing a series of practical case studies. We are conducting a series of real-life observations during the project discussions of multidisciplinary scientific teams in the *e*-BioLab (Rauwerda et al., 2006; van der Vet et al., 2007). Our aim is to get insight into how the new technology affects teamwork, and to contribute to the development of novel concepts to support co-located group creativity and situational awareness in a scientific collaborative environment. In particular, we are investigating the effect of the large display visualizations on both individual and team situational awareness. We are also evaluating new designs to enhance the awareness by making relations and changes between different visualizations more explicit. For instance, during the project meeting relevant visualizations on a tiled display will be highlighted and the other ones will become faded. In this way, a presenter can draw the attention of the other team members to visualizations relevant to the expertise of particular scientists (Figure 2). In addition, a notification about the annotations made on visualizations is essential to make all team members aware of the changes. We are using multiple data collection techniques during the case study: systematic direct observations, screen capturing and video recording of molecular biology teams during their project discussions. Video recordings from several angles together with capturing multiple displays enables us to analyse several ongoing interactions simultaneously.

The complexity of the processes involving both communication in the team and the use of the collaborative environment requires the combination of the methodological approach to support situational awareness in co-located team collaboration and the practical method to capture and analyse the dynamics of technology-mediated interactions in the environment. The nature of the interfaces as well as physical characteristics and affordances of the environment define the way in which interactions occur (Fruchter and Cavallin, 2006). Therefore our approach for data analysis includes the combination of behaviour, interaction and environment analysis. In addition to the objective analysis, post-interviews and questionnaires will be carried out to obtain subjective judgments of the team members on, among other aspects, group satisfaction, situational awareness and distraction from primary task (Kulyk et al., 2006). The three dimensions of situational awareness described above will be used in designing a questionnaire. We are adapting the computational model of *shared situation awareness* (Bolstad et al., 2005) to the context of our case studies. This model uses the Situation Awareness Global Assessment Technique (SAGAT) - an objective measure of situation awareness based on work of Endsley (1995).

By applying several user study techniques and a multi-level method for data analysis we can define interaction patterns: ways in which team members interact with each other and the environment. Thus we iteratively improve the design of the e-BioLab, as well as construct a framework for evaluation of how new technology, such as multiple large display visualisations, influence scientists' work and team collaboration.

5 CONCLUSION AND DISCUSSION

A new wave of advanced visualisation environments, such as collaborative interactive environments (Borchers, 2006), multiple display environments (Huang, 2006; Rogers and Lindley, 2004) and our collaborative scientific environment (van der Vet et al., 2007) requires new methods of design and evaluation in order to adequately address all aspects of collaborative work. In this paper, we presented the on-going research on the support of co-located team collaboration in the context of molecular biology *omics* experimentation. We described state-of-the-art studies on team coordination and creativity support. Furthermore, we discussed how visualisations can support group discussions and described the collaborative environment for scientific teams in a molecular biology context. As a result we showed that situational awareness is of a crucial importance in co-located team collaboration. We argued that situational awareness can be supported in such environments by bringing changes and relations between multiple visualisations more in focus of attention and by means of attentive and proactive interfaces. We also reported our results of an empirical case study and domain analysis translated into user requirements for support of multi-disciplinary collaboration of scientific teams. At the end we presented the multi-level approach for analysing the technology-mediated interaction in collaborative environment, taking into account important issues of situational awareness and group work. Practical case studies bring new insights into how computing technology affects teamwork and contribute to the development of novel concepts for scientific collaborative environments. This work will also contribute to understanding of how scientists of various levels of expertise and backgrounds interact with new technologies in collaborative environments.

The expected results of this research are: (a) a conceptual framework for studying situational awareness in co-located collaboration of multidisciplinary teams, (b) requirements and guidelines for collaborative designs based on the analysed results of practical case studies, (c) a new genre of technologies to support situational awareness of teams in collaborative environments. This work aims to inform the theory and practice of human computer interaction and design for collaboration support.

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