Developing Collaboration Awareness Support from a Cognitive Perspective

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Abstract

This paper discusses collaboration awareness from a cognitive perspective. Several models of the cognitive process are reviewed to distill awareness drivers that, when regarded in the collaboration context, set up a comprehensive view of collaboration awareness. Our major research goal is developing collaboration awareness support taking into consideration the need to provide awareness about the group but also the need to preserve cognitive load. The selected case study involved brainstorming. We developed a brainstorming tool having a collaboration awareness component that automatically balances the parallel production of ideas and the cognitive stimulation of users by reading the others' ideas. This balance is based on a set of heuristics regarding task switching and cognitive load. The experimental results indicate the component increased the production of ideas by 9.6%, while giving users 54.7% more time to type ideas without being interrupted. These results suggest the collaboration awareness component could effectively balance individual and group work. These results contribute to improve awareness support in collaboration technology.

1. Introduction

We regard collaboration awareness as a continuous cognitive process that helps managing the contents of a shared task and the social relations necessary to achieve the task goals through collaboration [1]. Supporting collaboration awareness is one of the most distinguishing challenges associated with collaboration technology development [2-4]. The main reason is quite straightforward to discern: it aims to compensate the relative inefficiencies of remote communication channels. When compared with the face-to-face scenarios, remote collaboration tends to lack richness and generate equivocality and ambiguity [5]. Since collaboration awareness support offers cues about who is present in a group, the actions performed by the group members, and where they are located, moving, looking, doing, etc., it may indeed compensate the missing features [3].

It is also unsurprising that we find several toolkit components fostering the integration of collaboration awareness support in software platforms. Some notable examples may be found in MAUI [6], GroupKit [7] and Rendezvous [8]. These toolkit components are important to prop up a rapid deployment of collaboration technology in organizations.

But we have to carefully regard these collaboration awareness components to understand if they may effectively accomplish their goals. For instance, awareness may depend on group size, the type of tasks being accomplished and the demands of the situation. We may also consider that under certain circumstances these components may contribute to cognitive problems such as information overload, stress and human error [9]. We thus envision the development of collaboration awareness components capable to handle the challenges posed by cognitive constraints and the working context, responding with flexibility to the environmental conditions.

More precisely, our main research goal is supporting collaboration awareness taking not only into account the cues about what the group is doing but also the cognitive issues that may arise from dealing with large amounts of information and fluid contexts.

From a more practical viewpoint, the challenge we report in this paper concerns how to balance individual and collaborative work, considering that the extremes may be detrimental to productivity: the former because it may lead to digression and conflict, the later because it may cause poverty of attention [10].

In this paper we review some cognitive models with the purpose to develop a comprehensive outlook of the cognitive issues behind awareness. This is accomplished in Section 2. We proceed in Section 3 with a discussion of the implications to awareness brought by the collaboration context. In Section 4 we propose a set of components supporting collaboration awareness. In particular, we propose a component capable to control the delivery of awareness information. Section 5 presents an implementation of awareness control in brainstorming. We also present

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evaluation data obtained from laboratory experiments. Section 6 discusses some limitations of this work. Section 7 briefly refers some related work. We close the paper with a summary of the obtained results and some concluding remarks.

2. Overview

The Feedback Model is a primary concept in systems thinking [11] and a natural candidate to start our overview of cognitive models. The Feedback Model regards humans operating a system with the intent to reach a reference output, which is achieved by approximation, comparing the obtained outputs with the reference. This offers a very simplified view of human behavior, but nevertheless serves to explain some typical behavioral patterns such as undershooting and damping. Based on this model, we may conceive awareness as the ability to perceive and act upon feedback information.

The Human Information Processor Model [12] also applies a systems view to human behavior, regarding humans as machines where stimuli ignite perceptual activities, followed by cognitive and motor activities, which in turn originate new stimuli. Again, awareness is based on continuous information feedback.

This model has been highly influential, the reason why many other models tend to reflect its cyclic view, with most differences centered on the cognitive task. For instance, the Reference Model of Cognition [13, 14] extends the cognitive component with interpretation and planning components. The Step Ladder Model [15] also extends the cognitive component with identification, interpretation, task definition and planning components.

The Contextual Control Model [16] adds disturbances to the cycle, which are fundamental to understand human cognition facing the unexpected. Raising the preoccupation with understanding cognitive failures, we find the Model of Fallible Machine [17]. This model highlights the impact of heuristics such as similarity matching and frequency gambling in erroneous behavior. This model regards awareness as a combination of perception and information retrieval [14].

Two cognitive views that depart away from the perceptual-cognitive-motor mechanics are the Sensemaking Model and the Model of Knowledge Creation. The Sensemaking Model [18] seeks to understand how humans and organizations deal with information according to their mindsets.

Ecological changes are similar to the stimuli, events and disturbances defined by other models. Humans enact the perception of ecological changes using their commitment and interpretation mindsets. Some cues are selected and made intelligible according to known patterns of behavior and may lead to decisions and actions. Others are simply discarded. Inline with the Model of Fallible Machine, feedback is insufficient to understand how humans and organizations respond to events. This understanding requires inquiring about experience and knowledge.

Awareness is therefore an ambiguous construction based on the present and the past, which clearly departs away from the information-processing cycle. Another important conceptual change to consider is that selection and retention occur at the organizational level, which emphasizes awareness as a collective function.

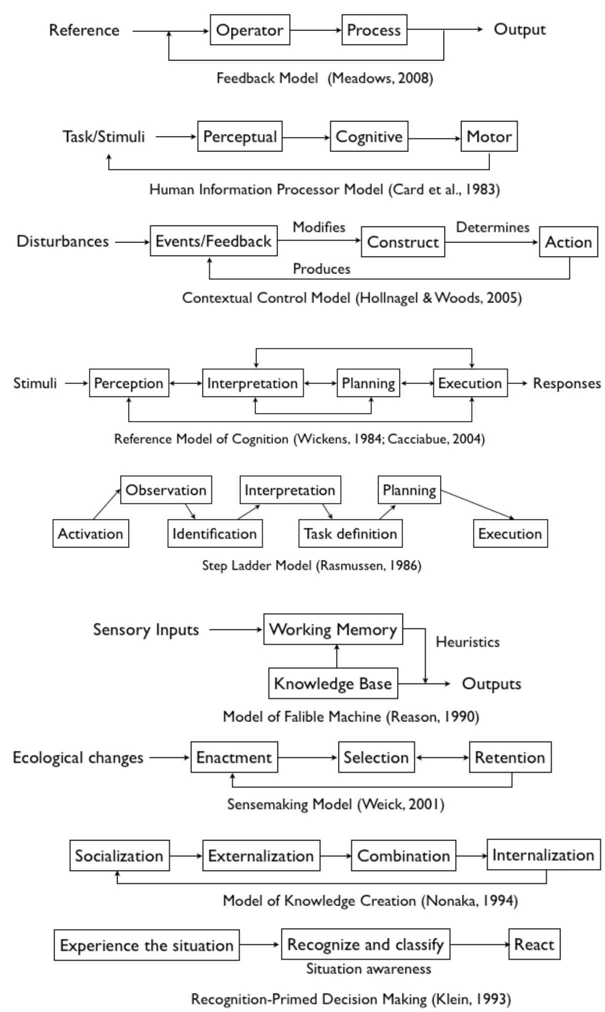

Figure 1. Models of the cognitive process

The Model of Knowledge Creation [19] seeks to understand how humans utilize their tacit and explicit knowledge. Knowledge is transformed from tacit (in the mind) to explicit (in the world) through a cycle of data socialization, externalization, combination and internalization. One interesting aspect of this model is that it highlights the differences between individual (internalization and externalization) and group (socialization and combination) functions.

The Recognition Primed Decision Making (RPDM) [20] introduces a naturalistic perspective over the cognitive process [21]. It distinguishes itself by trying to understand how time pressure, uncertainty, ill-defined goals, personal stakes and other factors affect cognition. RPDM is important to explain human behavior in critical contexts demanding emergency response. Instead of trying to rationalize the cognitive process, in the line of normative approaches [22, 23], RPDM emphasizes three fundamental cognitive functions: experiencing the situation, recognizing and classifying events, and reacting to events. This model brings forward the notion of situation awareness as the capacity to apprehend expectancies, cues, goals and actions in a context of unfolding events. One significant difference to other models is that awareness becomes intrinsically associated with action, not only perception and cognition.

In Figure 1 we present a visual representation of the various models that were reviewed. It should be noted that this list is necessarily incomplete, since many variations of these models exist (especially of the Human Information Processor Model); and, of course, these representations do not convey the whole richness of the referenced models.

Nevertheless, this overview highlights that awareness requires a constant interplay between four main drivers found in the reviewed cognitive models (Figure 2): (1) attending the ongoing events through perception, interpretation, internalization, etc; (2) utilizing knowledge, experience and commitment; (3) applying heuristics and mindsets to facilitate information processing; and (4) maintaining the information flows through retention, socialization, externalization, etc.

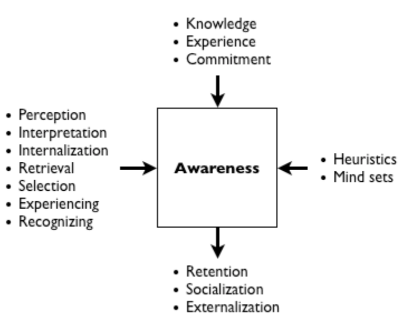

Figure 2. Awareness drivers

3. Complexity Brought by Collaboration

We will now consider the additional complexity brought by collaboration awareness. We start by observing that people working in a group must attend to an increasing number of events than working individually. Everything being equal, the new events come from the other group members. They are necessary to externalize knowledge, socialize, coordinate activities and share individual progresses toward the common goals. The cognitive effort necessary to process these events may grow exponentially with the size of the group and may quickly outweigh the benefits of collaboration, a situation that has been captured in Brooks' Law: adding manpower to a late project makes it later [24].

Besides the increasing quantity of events, collaboration also involves attending multiple information sources. This multiplicity of sources is known to contribute more than the rate of events to degrade human performance, as people tend to sample fewer sources when under stress [25].

Group members must also explicitly manage the trade-offs between doing individual work and attending to the group, considering in particular the cognitive effort associated with externalization and socialization. This work fragmentation has been estimated to occur in 57% of the tasks of information workers and may become detrimental due to the stress in maintaining awareness and extra cognitive costs when resuming work [26].

Furthermore, we also observe that people working in a group often recognize the others' information needs. This induces proactive actions to disseminate information. The capacity to consider the others' information needs has been recognized a main component of awareness [27].

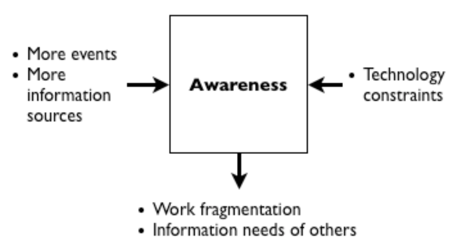

Figure 3. Collaboration awareness drivers

In all these circumstances, cognition is more likely exposed to situations where relevant events are discarded or quickly forgotten, increasing stress levels, confusions and errors, among other problems [28]. In fact, there is a growing body of evidence showing that memory failures regarding tasks yet to be performed are becoming a significant problem for information workers, leading people to devise countermeasures such as emailing reminders to themselves [29]. To complicate these matters even further, we should also consider the constraints brought by collaboration technology [3]. Thus the set of influences presented in Figure 2 should be complemented with the additional influences derived from collaboration that are summarized in Figure 3.

4. Supporting Collaboration Awareness

Our main research problem is how to effectively support collaboration awareness while considering the previously described influences. Our approach is founded on the perspective that awareness is a continuous cycle of cognitive activities encompassing perception, knowledge, heuristics, retention and the other drivers summarized in Figure 2.

This cycle of cognitive activities is fundamentally supported by actions, events and feedback. For instance, the decision to shutdown a system is followed by an action (e.g., push the button), followed by feedback information (gauge goes to zero) supporting the cognitive activity that confirms the action was accomplished. But this cycle may also be supported by feedforward [30]: the computer interface may generate an event (e.g., an alarm), perceived by the user, who may decide to act upon it (shutting down the system).

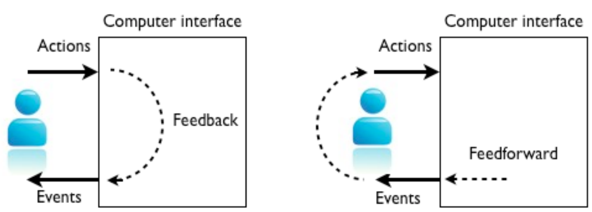

Figure 4. Feedback and feedforward

Feedback and feedforward are illustrated in Figure 4. Of course this view may be applied to collaboration [31]. We just have to consider multiple feedback/feedforward cycles established between each user and a shared computer interface. The shared computer interface allows spanning the actions and events across multiple users.

But this view does not incorporate the collaboration awareness drivers summarized in Figure 3. In order to fully consider collaboration, we must bring forward the concept of feedthrough (Figure 5) [32]: feedthrough is like feedback, but multiplexed to other users. Feedthrough supports multiple information sources, bringing information about the other's actions to individual users. Feedthrough also contributes to perceive the information needs of others, based on the recognition of what the others are doing.

Feedthrough is also critically related with work fragmentation, considering it is the basis to articulate individual and group strategies. And finally, feedthrough is also responsible for conveying many cues necessary to overcome the limitations of remote collaboration, especially considering who belongs to the group and what they are doing.

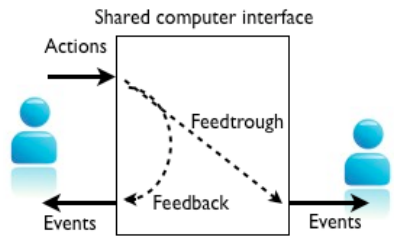

Figure 5. Feedthrough

We should now analyze in more detail the shared computer interface. We start by introducing two important awareness components: the awareness input filter and multiplexer, and the awareness output filter.

The awareness input filter and multiplexer is specialized in processing the users' actions that contribute to generate feedthrough. The level of processing may range from a simplistic approach consisting of multiplexing feedback to the other users, towards more sophisticated functionality, such as controlling the granularity and timing of feedback information that is multiplexed to the other users [2].

The awareness output filter is responsible for delivering feedthrough to the users. Again, the delivery may consider various levels of sophistication. The more simplistic ones may simply reproduce feedback information, while the most complex ones may consider how to summarize the events, avoiding cognitive overload and attention problems.

Since we are considering various levels of control over awareness production and delivery, it is quite reasonable to define a mechanism to actively manage collaboration awareness. For that purpose, we define the awareness-coupling device.

Conceptually, the awareness-coupling device controls the behavior of the awareness input and output filters. Two types of control are considered: controlling awareness at the origin, for instance specifying what, how and when the individual actions should be reported to the others; and controlling awareness at the destination, e.g. discarding some less-important events. We may also consider two control levels: autonomous, when the awareness-coupling device controls awareness solely based on actions and events; and mixed, when the users are allowed to explicitly control or configure the device.

Actually, we find many instances of awareness-coupling devices in current collaboration technology:

- Viewports control awareness at the outputs by restricting the physical areas of interest [2]. They are mixed devices, since the users may operate them.
- Radar views also control awareness at the outputs by reducing the information granularity [2]. They are autonomous, as they do not require user intervention.
- Telepointers control awareness at the inputs by allowing one user to control the remote display of a pointing device [3]. They are mixed devices.
- Private/shared spaces control awareness at the inputs by defining what data may be distributed to others and what data remains private. They are autonomous.
- Group activity filters control awareness at the outputs. They are mixed devices, as the users can configure them.

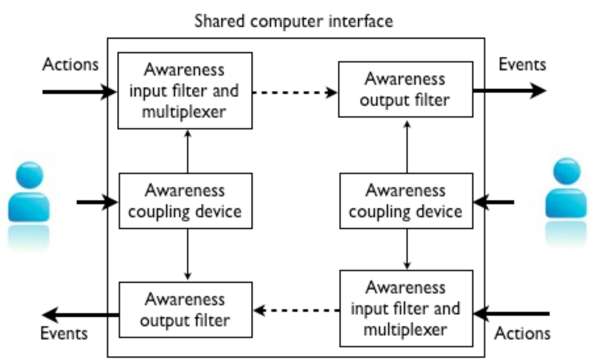

Figure 6. Coupling device

Figure 6 summarizes our view of collaboration awareness support. In the next section we will describe the implementation of a collaborative tool based on this view.

5. Brainstorming Tool

The main problem discussed in this paper is that collaboration technology must balance the need to maintain collaboration awareness with the need to preserve individual activities. Too much awareness information may result in difficulties managing task switching, memory losses, stress, cognitive overload, errors, etc. Too little collaboration awareness promotes digression, repetition, conflict, and lack of stimulus, socialization and ideas.

Brainstorming is a collaborative task where the individual production of ideas has to be balanced with attention to the others' ideas, the reason why this task was selected for our research. The rules of brainstorming [33] encourage the participants to produce as many ideas as possible, because quantity is wanted; and to rely on cognitive stimulation by glimpsing the others' ideas. But clearly some balance should be attempted when designing collaboration awareness support so that production and stimulation do not conflict with each other. The ABTool presented in this section aimed exactly to study how to balance these tasks.

Regarding the production task, one of the positive effects of synchronous brainstorming is supporting parallel work. The users may develop ideas in parallel, which reduces production blocking and improves the group's productivity expressed by the raw quantity of ideas generated by the group [34, 35].

Cognitive stimulation is more challenging however: as the number of ideas increases, for example, because the group is inspired and the group size is large, the users may become distracted by awareness information and ultimately be unable to divide their attention between producing ideas and glimpsing the others' ideas. This effect may explain why some experiments with brainstorming have been equivocal [35].

The ABTool implements a mechanism we designate opportunity seeker. The opportunity seeker manages information about the others' ideas and delivers those ideas to the users based upon criteria that try to optimize collaboration awareness.

The opportunity seeker is an awareness-coupling device. The feedthrough information consists of ideas input by each user.

The ideas input in the ABTool are multiplexed to the several users but are not immediately delivered to them. Instead, they are stored in buffers and only delivered at a time and in a quantity that is controlled by the opportunity seeker according to a set of criteria:

- Delivering too many ideas may become distracting, reducing the capacity to effectively attend to the group.
- Delivering too few ideas may give the wrong impression about what the group is doing.
- The user activities are divided between acting upon the computer interface to write ideas and attending to the group, reading the others' ideas.
- The best opportunities for raising attention occur at the boundaries between tasks [36].

The main research hypothesis was: the control of awareness information supported by the opportunity seeker will improve productivity, measured as the overall number of ideas generated by the group.

The major practical challenge regarding the ABTool design was adapting the collaboration awareness framework to the concrete aspects of synchronous brainstorming. As previously said, the opportunity seeker leverages the alternation between two tasks: production and stimulation. To alternate between these tasks, the opportunity seeker must determine their boundaries.

We adopted an empirical approach to determine these boundaries. We asked two groups of five volunteers to participate in synchronous brainstorming sessions using the ABTool with the opportunity seeker inactive (supplying immediate feedthrough). Beyond the interaction with ABTool, no other communication was allowed.

We then recorded three types of events: (a) key presses while typing ideas; (b) the moments when the users submitted ideas to the group; and (c) the instants when feedthrough was delivered to the user's computer displays.

From the collected data we learned that: (1) users usually do not stop typing when they receive feedthrough; (2) users typically pause after putting forward an idea; and (3) there are numerous periods of time with no typing activity. Based upon these observations, we decided that the task boundaries would be settled when a user submits an idea. The opportunity to deliver awareness information would therefore occur immediately after a user submits an idea.

In addition, considering the periods of typing inactivity, we decided to incorporate a timeout in the opportunity seeker, delivering buffered awareness information if no task boundary was detected after 10 seconds of inactivity. In Figure 7 we illustrate the ABTool functionality when the opportunity seeker is active.

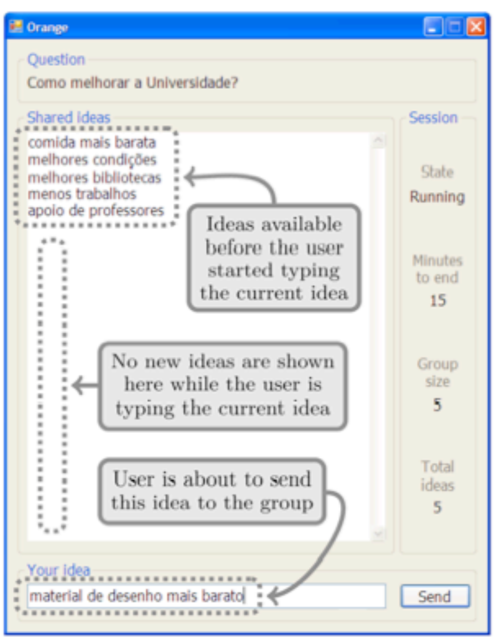

Figure 7. ABTool

The ABTool was then evaluated with laboratory experiments. The experiments involved 11 groups of 5 people, for a total of 55 participants. Most of the participants were undergraduate students. A self-assessment of typing experience with computers revealed that 86% of the participants were skilled, thus avoiding influences in typing speed. The experiments were done in a laboratory room using identical hardware and software. Speaking was strictly forbidden to simulate a distributed work environment and to mitigate extraneous influences. Each computer ran mouse and keyboard logging software. The participants completed practice and test tasks consisting of short brainstorming sessions. A more detailed report of these experiments is presented elsewhere [37].

The practice task allowed the participants to get familiar with brainstorming in general and ABTool in particular. A question was given and then participants were asked to generate as many ideas as possible by typing on the keyboard and reading other users' ideas on the computer display.

A repeated measures design was adopted for the experiments. Each group was exposed to two treatment conditions (opportunity seeker active and inactive). Four different brainstorming questions were randomly assigned to the groups. The obtained results show that the groups produced an average of 9.6% more ideas per session when the opportunity seeker was active[1].

We also conducted a post-hoc analysis of the collected mouse/keystroke events to understand the performance differences. We measured the time taken to write an idea, the time between delivering ideas and restarting typing new ideas, the number of characters per idea and the time between consecutive idea deliveries. The obtained results show the opportunity seeker reduced awareness events by an average of 44.1%. This difference is because the opportunity seeker outputs 1.9 ideas on average (standard deviation is 1.2) to the users, instead of outputting one idea at a time.

As a consequence, the users had on average 54.7% more time to think about and type an idea without being interrupted by awareness events. These results suggest the opportunity seeker could actually balance individual and group work, serving as an effective awareness-coupling device.

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[1] The Wilcoxon signed-ranks test revealed a 3.7% probability of chance explaining the differences. The Wilcoxon signed-ranks test also revealed there was no bias introduced by more popular questions or a learning effect caused by the repeated measures design.

6. Discussion

We note that our experiments have some key compromises and limitations. Within the most important ones we might include:

- Brainstorming is one particular task type within a large set of collaborative tasks ranging from ideation to discussion, decision-making, problem solving, negotiating etc. It may thus be impossible to extrapolate the measured productivity gains to other tasks types.
- The productivity measure that was adopted may not be the best one. Alternatives to measuring the raw number of ideas would be, for instance, measuring unique ideas and measuring good ideas. In particular, the last one requires adopting a qualitative approach instead of the quantitative approach we adopted to analyze the results.
- Brainstorming has a flimsy relationship with collaboration awareness, because the dependence on awareness information only occurs when a user has drawn out of ideas. We also note the brainstorming participants are not dependent on each other. The others stimulate them, which is different.
- The opportunity seeker is based upon several empirical decisions that may affect the obtained results. Overall, more experiments seem necessary.
- The major contributions of collaboration technology are obtained at strategic levels considering, for instance, decision-making, learning and conflict management. On the one hand, the cognitive view seems to address marginal concerns. On the other hand, a 9.6% performance improvement also seems negligible.

Although we do not conceal the importance of these arguments, we nevertheless would like to point out that our main goals with this experiment were not centered on improving brainstorming but instead study awareness support. Of course the opportunity seeker was tailored to brainstorming and we cannot extrapolate its particular functionality to other collaborative contexts.

The main point is the ABTool design improved because we considered the cognitive aspects of collaboration awareness. The adopted awareness framework points towards adjusting awareness events using an awareness-coupling device, and the device proved effective in our case study. Although we may not extrapolate the specific functionality of the opportunity seeker, we extrapolate its importance to other collaborative contexts, especially the ones where interaction with the shared computer is paramount (e.g., immersive environments, geocollaboration).

We understand the productivity measure that was adopted may be challenging. For instance, we realize that in our particular case moving the work balance towards the individual task by not distracting the user while writing an idea may lead to repeated ideas. Also, producing more ideas may not necessarily conduct to more distinct ideas or even more innovative ideas. But this is a specific problem of brainstorming. On the contrary, finding the optimal balance between attending to the group and working individually is a more generic problem, and our experiments show that it can be tackled in the design stage.

We conjecture that awareness-coupling devices might contribute to fine-tune collaborative technology to the specific working contexts. The case study demonstrates this tuning.

We also understand that other task types might involve a stronger dependence on collaboration awareness. Brainstorming is a divergent task and convergent tasks typically demand more awareness information. Contexts like emergency management also entail more dependence on collaboration awareness. But in general collaboration is a mix of convergent and divergent work.

We showed that divergent work might benefit from awareness management. We consider that further experiments should be accomplished to assess the impact of awareness management in convergent situations.

Regarding the several empirical decisions that were taken when designing the awareness-coupling device, we see them as necessary. The opportunity seeker does not deliver more than 10 ideas at once and the timeout period for delivering feedthrough is 10 seconds. We could have considered experimenting other values, but that would have increased the complexity of the experimental design beyond what would be feasible. Collaborative experiments are very challenging and some tradeoffs are almost mandatory.

And finally we should discuss the impact of the proposed approach. The cognitive perspective is necessarily focused on small-scale design problems such as mental memory usage, user-interface optimization and avoidance of slips, lapses and errors. Most of these problems emerge in critical fields such as air traffic control, piloting, supervisory control of industrial processes, etc. The development of collaborative technology seems to be more focused on large-scale concerns, typically related with organizational goals. This includes application areas such as business process management, calendaring, organizational memory, conflict management, and support to decision and negotiation processes.

Nevertheless, as collaboration technology becomes more pervasive in organizations, we foresee the increasing dependence on collaborative technology to support critical functions. For instance, the resilience engineering trend [38] posits increasing collaboration to augment flexibility and resistance when facing unexpected events and emergency situations. Under these demanding conditions, collaborative technology design will have to face cognitive issues [39, 40]. We thus expect a significant increase of the importance given to the design issues discussed in this paper as collaboration technology becomes more prevailing in organizations.

7. Related Work

This work has many affinities with research on Attentive User Interfaces (AUI) [41, 42]. A prime motivation for AUI is dealing with attention problems and interruptions when interacting with computers. AUI rely upon specialized input/output devices to manage human attention. Examples include using eye-trackers to detect eye-gaze and body orientation [43], and physiological sensors to detect mental workload [44].

Although most research on AUI is directed towards single-user interfaces, some experiments have already been done with multiuser interfaces. Two notable cases are GAZE [45] and GAZE-2 [46], which use eye-trackers placed in front of the users to support a video conferencing system that gives the impression the group members are looking at the current speaker. This is accomplished by using the eye-tracking information to adjust auditory and visual feedthrough. The eyeView [47] meeting system also manipulates the audio and video channels to emphasize who is the current speaker. Beyond these cases with video conferencing tools, we are not aware of other experiments with collaboration technology.

The specific functionality of the awareness-coupling device has naturally many relationships with research on collaboration awareness. Significant cases include the Virtual School [48], which experimented a notification system for collaboration awareness. JAMM [49] provides flexible collaboration awareness support by filtering feedthrough information, although it lacks user tailorability. Gutwin and Greenberg [50] have done extensive research in collaboration awareness, considering in particular coupling management. But the focus has been centered on increasing awareness, not balancing it. Schmidt [51] provides an historical review of awareness, pointing out the subtleties of the involved cognitive phenomena, especially considering attention. Carrol et al. [4] also provide a thorough review of collaboration awareness with a particular focus on mental models, emphasizing the importance of articulating work with awareness.

8. Conclusions

This paper reviewed several models of the cognitive process. These models highlight awareness as cyclic information processing helping to perceive and act upon feedback information. This seems to involve a variety of cognitive functions such as perception, enactment, interpretation and selection. Furthermore, several theories posit that awareness is also based on experience, knowledge and action.

Collaboration awareness brings this complex view towards an even more demanding context. Collaboration is not only based on feedback (and feedforward). New information flows are necessary to model multiple information sources, others' information needs, work fragmentation and technological constraints. We thus have to multiplex feedback towards the group in the form of what has been designated feedthrough.

Having demonstrated the need to model feedthrough, we discussed the importance of managing awareness production and delivery. This discussion resulted in a conceptualization of the shared computer interface as the composition of three components: (1) awareness input filter and multiplexer; (2) awareness output filter; and (3) awareness-coupling device.

The awareness input filter and multiplexer is responsible for processing the actions from one user, filtering those actions according to various criteria such as level of detail and timing, and multiplexing cues about those actions to other users. The awareness output filter is responsible for delivering to one user the cues about the actions produced by the other users. This delivery may also be subject to several filtering criteria, such as level of detail, interest and timing. The awareness-coupling device allows specifying the levels of detail necessary to balance collaboration awareness. It may operate autonomously or support user interaction and configuration.

We then discussed a particular implementation of the awareness-coupling device. The specific case regards the implementation of a brainstorming tool. We regarded brainstorming as a combination of two main tasks: individual production of ideas and attention to the others' ideas. Brainstorming thus brings forward the crux of the collaboration awareness design problem: too little collaboration awareness leads to digression and lack of stimulus, while too much collaboration awareness brings cognitive overload.

The awareness-coupling device exactly aims at balancing collaboration awareness. In the studied case, it was implemented by what we designate opportunity seeker, an automatic mechanism that, based on the users' keystrokes attempts to deliver the others' ideas at the exact moments where they may have more impact. The experimental results demonstrate the capability of the opportunity seeker to balance individual and group work, giving in particular more time to work individually.

Considering the contributions of this research, we highlight two major outcomes: the opportunity seeker and the conceptualization of collaboration awareness. The former proposes a novel type of awareness component that departs away from the simple view that more awareness information is necessary to support group work. Instead, it points towards a more considerate perspective where balance is necessary to avoid cognitive overload.

The later brings forward a conceptual framework composed from various cognitive models having complementary perspectives over awareness. The proposed conceptualization highlights a rich collection of awareness drivers organized in four main categories: (1) related with the perception of events; (2) associated with knowledge utilization; (3) considering the need to apply heuristics to understand events; and (4) taking into account the retention of awareness information.

Regarding future work, we are now experimenting a new opportunity seeker to manage events coming from Twitter in collaborative settings, considering in particular collaborative software development. Tweeter is becoming increasingly popular but poses significant challenges to collaboration because of the potential high number of events the users may be requested to attend.

9. Acknowledgments

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10. References

[1] P. Leinonen, S. Jarvela, and P. Hakkinnen, "Conceptualizing the Awareness of Collaboration: A Qualitative Study of a Global Virtual Team," *Computer Supported Cooperative Work,* vol. 14, pp. 302-322, 2005.

[2] C. Gutwin and S. Greenberg, "The effects of workspace awareness support on the usability of real-time distributed groupware," *ACM Transactions on Computer-Human Interaction,* vol. 6, pp. 243-281, 1999.

[3] C. Gutwin and S. Greenberg, "A Descriptive Framework of Workspace Awareness for Real-Time Groupware," *Computer Supported Cooperative Work,* vol. 11, pp. 411-446, 2002.

[4] J. Carroll, M. Rosson, G. Convertino, and C. Ganoe, "Awareness and teamwork in computer-supported collaborations," *Interacting with Computers,* vol. 18, pp. 21-46, 2006.

[5] R. Daft and R. Lengel, "Organizational information requirements, media richness and structural design," *Management Science,* vol. 32, pp. 554-571, 1986.

[6] J. Hill and C. Gutwin, "The MAUI toolkit: Groupware widgets for group awareness," *Computer Supported Cooperative Work,* vol. 13, pp. 539-571, 2004.

[7] M. Roseman and G. S., "Building real-time groupware with GroupKit, a groupware toolkit," *ACM Transactions on Computer-Human Interaction,* vol. 3, pp. 66-106, 1996.

[8] R. Hill, T. Brinck, S. Rohall, J. Patterson, and W. Wilner, "The Rendezvous architecture and language for constructing multiuser applications," *ACM Transactions on Computer-Human Interaction,* vol. 1, pp. 81-125, 1994.

[9] F. Redmill and J. Rajan, *Human factors in Safety-Critical Systems*. Oxford, UK: Butterworth Heinemann, 1997.

[10] H. Simon, "Designing organizations for an information-rich world," in *Computers, communication, and the public interest* Baltimore, MD: Johns Hopkins University Press, 1971, pp. 37-72.

[11] D. Meadows, *Thinking in Systems*. UK: Earthscan, 2009.

[12] S. Card, T. Moran, and A. Newell, *The Psychology of Human-Computer Interaction*. Hillsdale, NJ: Lawrance Elrbaum, 1983.

[13] C. Wickens, *Engineering Psychology and Human Performance*. Columbus, OH: Charles Merrill, 1984.

[14] P. Cacciabue, *Guide to Applying Human Factors Methods*. London: Springer, 2004.

[15] J. Rasmussen, *Information Processes and Human-Computer Interaction. An Approach to Cognitive Engineering*. Oxford: North Holland, 1986.

[16] E. Hollnagel and D. Woods, *Joint Cognitive Systems: Foundations of Cognitive Systems Engineering*: CRC Press, 2005.

[17] J. Reason, *Human Error*. Cambridge, UK: Cambridge University Press, 1990.

[18] K. Weick, *Making Sense of The Organization*. Oxford, UK: Blackwell, 2001.

[19] I. Nonaka, "The knowledge-creating company," *Harvard Business Review,* pp. 96-104, 1991.

[20] G. Klein, "A recognition-primed decision (RPD) model of rapid decision making," in *Decision making in action: Models and methods*, G. Klein, J. Orasanu, R. Calderwood, and C. Zsambok, Eds. Norwood, CT: Ablex, 1993.

[21] R. Lipshitz, G. Klein, and J. Orasanu, "Taking Stock of Naturalistic Decision Making," *Journal of Behavioral Decision Making,* vol. 14, pp. 331-352, 2001.

[22] H. Simon, *Administrative behavior: A study of decision-making processes in administrative organizations (4th edition)*. New York: Free Press, 1997.

[23] H. Simon, "Decision Making and Problem Solving," *INTERFACES,* vol. 17, pp. 11-31, 1987.
[24] F. Brooks, *The Mythical Man Month*. Reading, MA: Addison-Wesley, 1975.
[25] M. Sanders and E. McCormick., *Human factors in engineering and design*. New York, NY: McGraw-Hill, 1992.
[26] G. Mark, V. Gonzalez, and J. Harris, "No task left behind? examining the structure of fragmented work," in *CHI'05: Proceedings of the SIGCHI conference on Human factors in computing systems*, Portland, OR, 2005, pp. 321-330.
[27] M. Endsley, "Toward a theory of situation awareness in dynamic systems," *Human Factors,* vol. 31, pp. 32-64, 1995.
[28] M. Eppler and J. Mengis, "The concept of information overload: A review of literature from organization science, accounting, marketing, MIS, and related disciplines," *The Information Society,* vol. 20, pp. 325-344, 2004.
[29] M. Czerwinski, E. Horvitz, and S. Wilhite, "A diary study of task switching and interruptions," in *CHI'04: Proceedings of the SIGCHI conference on Human factors in computing systems*, Vienna, Austria, 2004, pp. 175-182.
[30] S. Wensveen, J. Djajadiningrat, and C. Overbeeke, "Interaction frogger: a design framework to couple action and function through feedback and feedforward," in *Proceedings of the 2004 conference on Designing interactive systems*, Cambridge, MA, 2004, pp. 177-184.
[31] D. Kieras and T. Santoro, "Computational GOMS modeling of a complex team task: Lessons learned," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, Vienna, Austria, 2004, pp. 97-104.
[32] J. Hill and C. Gutwin, "Awareness Support in a Groupware Widget Toolkit," in *Proceedings of the 2003 international ACM SIGGROUP conference on Supporting group work*, Sanibel Island, Florida, 2003, pp. 258-267.
[33] A. Osborn, *Applied imagination*. New York: Charles Scribner's Sons, 1963.
[34] R. Gallupe, L. Bastianutti, and W. Cooper, "Unblocking brainstorms," *Journal of Applied Psychology,* vol. 7, pp. 137-142, 1991.
[35] A. Pinsonneault, H. Barki, R. Gallupe, and N. Hoppen, "Electronic brainstorming: the illusion of productivity," *Information Systems Research,* vol. 10, pp. 110-133, 1999.
[36] B. Bailey and J. Konstan, "On the need for attention-aware systems: Measuring effects of interruption on task performance, error rate, and affective state," *Computers in Human Behavior,* vol. 22, pp. 685-708, 2006.
[37] A. Ferreira, P. Antunes, and V. Herskovic, "Improving Group Attention: An Experiment with Synchronous Brainstorming," *Group Decision and Negotiation,* forthcoming.
[38] E. Hollnagel, D. Woods, and N. Levenson, *Resilience Engineering: Concepts and Precepts*. Hampshire, England: Hashgate, 2006.
[39] E. Hollnagel and D. Woods, *Joint Cognitive Systems: Introduction to Cognitive Systems Engineering*. Boca Raton, FL: CRC Press, 2005.
[40] D. Woods and E. Hollnagel, *Joint Cognitive Systems: Patterns in Cognitive Systems Engineering*. Boca Raton, FL: CRC Press, 2006.
[41] R. Vertegaal, "Attentive user interfaces: Introduction," *Communications of the ACM,* vol. 46, pp. 30-33, 2003.
[42] C. Roda and J. Thomas, "Attention aware systems: Introduction to special issue," *Computers in Human Behavior,* vol. 22, pp. 555-556, 2006.
[43] R. Vertegaal, J. Shell, D. Chen, and A. Mamuji, "Designing for augmented attention: Towards a framework for attentive user interfaces," *Computers in Human Behavior,* vol. 22, pp. 771-789, 2006.
[44] C. Wickens and J. McCarley, *Applied Attention Theory*. Boca Raton, FL: CRC Press, 2008.
[45] R. Vertegaal, "The GAZE groupware system: Mediating joint attention in multiparty communication and collaboration," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, Pittsburgh, PA, 1999, pp. 294-301.
[46] R. Vertegaal, I. Weevers, C. Sohn, and C. Cheung, "GAZE-2: Conveying eye contact in group video conferencing using eye-controlled camera direction," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, Ft. Lauderdale, FL, 2003, pp. 521-528.
[47] T. Jenkin, J. McGeachie, D. Fono, and R. Vertegaal, "eyeView: Focus+context views for large group video conferences," in *CHI'05: Extended abstracts on Human factors in computing systems*, Portland, OR, 2005, pp. 1497-1500.
[48] J. Carroll, D. Neale, P. Isenhour, M. Rosson, and D. Mccrickard, "Notification and awareness: synchronizing task-oriented collaborative activity," *International Journal of Human-Computer Studies,* vol. 58, pp. 605-632, 2003.
[49] J. Begole, M. Rosson, and C. Shaffer, "Flexible Collaboration Transparency: Supporting Worker Independence in Replicated Application-Sharing Systems," *ACM Transactions on Computer-Human Interaction,* vol. 6, pp. 95-132, 1999.
[50] C. Gutwin and S. Greenberg, "The importance of awareness for team cognition in distributed collaboration," in *Team Cognition: Understanding the Factors That Drive Process and Performance*, E. Salas, S. Fiore, and J. Cannon-Bowers, Eds.: APA Press, 2004, pp. 177-201.
[51] K. Schmidt, "The Problem with 'Awareness'," *Computer Supported Cooperative Work,* vol. 11, pp. 285-298, 2002.