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# Extreme Collaboration

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Design is an activity that benefits greatly from face-to-face interaction. There are good reasons in fact for collocating designers in the same room environment. Requirements can be dynamic, and being in the same room provides all with immediate information on how the requirements have changed, or conversely, enables people to question requirements immediately. Being collocated in the same environment enables each person to access whoever they need at the moment to get relevant information. The group benefits by having multiple members keep track of changes and catch errors before they escalate. Continual communication among designers is necessary to solve problems, discuss alternatives, and question assumptions as soon as the need arises. The communication needs to keep pace with the speed of the design activity, and face-to-face work is so far the best way to enable this.

The trend of having people design face-to-face is exemplified in *warroom* environments. In warrooms, teams work together synchronously in all phases of the project--they do not just meet for status reviews. Some results suggest that warroom environments can lead to increased productivity—far beyond what one might expect. In a study of collocated software development teams, Teasley et al. (2000) found these teams to produce double the amount compared to a company baseline. Team members used flipcharts, whiteboards, and individual workstations to support their work. Similar increased productivity was reported with managers, designers, and sales teams in warrooms (Covi et al., 1998). Initial studies are indicating that paired programmers who work side-by-side are making fewer errors and may be more productive than when working alone (Williams and Kessler, 2000).

Here I describe a unique kind of "warroom" environment where people work closely together using a variety of computer technologies. I term this type of design activity *extreme collaboration* to refer to working within an electronic and social environment that maximizes communication and information flow. This study attempts to answer an important question relevant for computer-supported cooperative work: how can physical collocation and technology together enable a team to produce a complex space mission design in a remarkably short time?

## The warroom for designing space mission proposals

NASA’s Jet Propulsion Laboratory (JPL), provides NASA-wide aid in planning missions, ranging from the ocean to deep space exploration. In April 1995, the Advanced Projects Design Team, known as Team X, was formed to serve as internal consultants to NASA in designing new space mission proposals, e.g. the Mars Probe. The goal of Team X was to improve the speed and quality of a mission proposal through a combination of a permanent team of diverse experts and an electronic meeting room environment. The design proposal defines all aspects of a space mission: how the science requirements will be fulfilled, which telecommunications devices to use, how much power and propulsion is needed, what information will be transmitted back to earth, and so on. Team X accomplishes this complex task, completing a design proposal, generally in three sessions of three hours each, within a week (with some pre and post work).

Team X is composed of sixteen members who are engineers with expertise in a particular subsystem for space mission design, such as power, thermal, or telecommunications systems. There is also a team leader. Most engineers have been members of Team X for at least two years. The engineers work together in a room using multiple technologies: public displays, databases of past space mission equipment and measures, an orbit visualization program, a configuration graphics program, and a publish-subscribe system of networked spreadsheets, all of which function to facilitate the spread of information in the environment. Figure 1 shows an actual session of Team X.

It is difficult to judge the accuracy of a Team X design proposal, as it can take years before a space mission is completed, but some verifications suggest that the quality is high. A model of the Team X output predicted the final cost of seven actual completed space missions within 5%. An independent verification done by a customer was within 10% of the Team X estimate, which for a complex space mission is extremely reliable. Team X maintains a steady stream of customers.

Fieldwork and interviews conducted at the Team X site focused on the team members‘ interaction and use of technology in their work context. Over a period of 3 months, thirteen different space mission designs were observed, from requirement specification to completion. Each mission ranged from one to three sessions per week, of three hours or slightly more per session. The observer interacted with all team members, and in addition, in-depth interviews were conducted with Team X members, the team leader, a long-time customer, and the developer of the software tool used by the team.

## Networks that operate in the warroom

*Everyone has a piece of this information. It's all spread out and I'm trying to find out where it lives.*

How does a team of 16 members work so efficiently that they can create a design proposal for an entire space mission, from launch, to orbit, to landing, in nine hours? The key answer is that the design activity involves both a unique nd complex interplay of human and electronic networks. First, the engineers contact each other in order to discuss specific pieces of information. Simultaneously, another kind of networking occurs that is not visible to the casual observer: information is passed around electronically using a publish/subscribe system of spreadsheets that are linked together. Both human and electronic networks are closely intertwined. Together, they function to provide more access to information than what face-to-face interaction alone would provide.

With Team X members, the social groundwork for communicating (see Nardi and Whittaker, 2001) has already been laid through several years of working together in the same room. As a result, introductory remarks are seldom necessary to preface communication, or establish a context. The context is visible through the activity in the room, and the information on the linked spreadsheets. Team X members freely approach each other during design work directly asking for help and information, or contributing advice.

During the design, different parts of the human network are connected. The Team X members have been referred to as "gunslingers", alert and ready to shoot from the hip when a problem arises. As soon as they discover that their expertise is needed to solve a problem, they go to where the problem lies. They may go to a group discussing the problem, to the customer with a question, or even to the public display which visually shows an error. Others may join them. Or, they may stay in their seats and call out a quick answer. Team X members continually move back and forth between individual subsystem work, small group work, and orchestrated entire team work.

What triggers Team X members to group together is that they continually monitor information in the room both visually and aurally. Similar types of monitoring have been observed in control room environments where actors closely interact (Suchman, 1996, Heath and Luff, 1992; Bentley et al., 1992). The Team X environment differs from these in that there are far more people and sources of information to monitor: sidebar (small group) conversations, public conversations, public displays (which may display the orbit visualization and spacecraft design), the team spreadsheet, the team leader, the customer, the neighbor's screen, and one's own spreadsheet. Each source provides a piece of the whole picture, i.e. the state of the mission design. As one engineer described, he keeps one part of his hearing always tuned into what's happening in the room. This ability to attend to conversations in the room while conducting their own work (or even being part of another conversation in parallel) seems to characterize all Team X members.

Figure 1. The Team X warroom environment. The engineering subsystems are Cost, Thermal, Power, Structures, Configuration Graphics, Systems, Telecom Hardware, Propulsion, Ground Systems, Telecom Systems, Mission Design, ACS, CDS, Instruments, Science, and Programmatics.

The cocktail party phenomenon (Cherry, 1953), i.e. when one attends to specific words in a noisy environment, has often been observed in the warroom, when keywords are spoken aloud that are relevant for a subsystem. Hearing their subsystem names (e.g. Power, Propulsion) also attracts their attention, which suggests that Team X members are extremely involved in their roles.

## The interdependencies in the network

How do the Team X engineers select which information to monitor in this noisy environment? In their own words, the team members described that through long experience, they developed “maps” of their own interdependencies, i.e. their role in the network. Such a “map” refers to an internal model of who one is most likely to get information from, and who is most likely to receive the information that one produces. The engineers know approximately what order the information builds upon other information. For example, Telecom Systems needs information from CDS, ACS, and Ground Systems for calculations. Any change of a CDS calculation affects the Telecom result. These interdependencies refer to both the computer and human-mediated information flow. The observer found the individual "maps" to be consistent among the team members. The newest member, nine months with the team, claimed that it took him three months to develop a basic map of his own interdependencies in the overall network, and he is still learning.

What adds to the complexity of learning interdependencies is that the network is not static; engineers must also take into account when they need, and do not need, to interact with another. Having internalized a map of interdependencies helps team members focus their monitoring on individuals whose interaction is most likely to affect them. Thus, this knowledge may help reduce information overload by limiting the networking options in this environment.

## The electronic-network in the warroom

Along with human networking, information is passed around electronically in the warroom environment. The team uses a simple publish-subscribe system of networked spreadsheets to exchange results, mostly equipment descriptions and calculations. The publish-subscribe technology creates a flexible electronic network: team members can publish information when they are ready, and subscribe to information when they need it (if it is available). For a space mission proposal, input parameters can range from 11 up to 519 per subsystem, with a median of 76 per person. These results represent just the "tip of the iceberg", since there can be thousands of underlying calculations and 10-20 sidebar conversations that lie behind the production of a single result.

The electronic network provides the raw data; the engineers process the data through their human networking. The two networks are highly interdependent. Hearing that a result is ready, by monitoring the room conversation can lead an engineer to subscribe to this result. On the other hand, results that one subscribes to using the spreadsheet technology can trigger that individual to form a sidebar conversation to discuss the data.

Monitoring information in the room has helped the team recover from software errors. For example, links to the shared spreadsheet can be broken if new items are typed in. The results are not published. The team leader had just been in a sidebar discussing the item, and when he did not see the result get published, he immediately informed the engineer, who did not realize the link was broken. Yet a new item that is not publicly discussed can result in a broken link that goes unnoticed.

## Facilitating the network: the team leader

The team leader facilitates the social and electronic networks by continually monitoring all subsystems. He calls out for team members to publish when he knows others need it, and to subscribe to information that he knows has been published. These observations strongly suggest that he has internalized a complete map of the interdependencies of the team, over his five years of experience with the team. The leader changes the public displays to show specific data to support conversations that he hears, e.g. a spacecraft image when he hears a discussion on the spacecraft design.

The team leader keeps the team on track. For example, once he was able to lower the cost estimate for probes from 20 to three million. Although information spreads verbally around the room, the leader is the trigger that transforms separate discussions of errors into an entire group discussion. He defines when a problem becomes a "crisis". For example, he has announced to the team to change the space mission design mid-way through a session. However, it can take three announcements until the entire team responds to a major change. This again argues that the engineers are selectively attending to information, as they respond less fast to a comment that is not directed specifically to them.

## Networking within the physical space

Each subsystem is mapped to a specific location in the room, i.e. individual workstations. Groups form by people walking over to another, by remaining in one's seat and talking to a neighbor, or even speaking across the room. At any point in time people can be: at their workstations (performing calculations or waiting for results), in a sidebar (solving a problem), at the public display (solving a problem concerning information on that display), or gathered at the customer's table (likely discussing requirements with the customer). The position of each team member in the room provides a cue as to what might be happening with their respective subsystem in terms of the design.

Activity is always related to a location (Kendon, 1990). With Team X, an engineer's activity is related to a part of the room which has people and/or technology that the engineer is concerned with. A person's activity at any point in time is visible to all in the room. Thus, where an engineer is at any point in time conveys information about that specific subsystem. The physical arrangement of the entire group at any point in time cues everyone in the room as to the state of the human network, which in turn conveys information about the state of the design.

Seeing people huddled around the mission orbit on the public display communicates that there is a concern with the orbit. Overhearing keywords in this conversation can provide an engineer with a fairly good idea of what the problem is about. The physical collocation of the team makes their human networking visible. The electronic networking is less visible, although it can be inferred by knowing the interdependencies, and seeing what information one has already received from the linked spreadsheets.

# The limitations of designing in a warroom

The Team X environment cannot work for everyone, nor can it work for all design tasks. First, certain personalities are needed to be able to work in such a public environment. Most work is visible (except intermediate calculations), especially mistakes. Second, a person must be extremely flexible. Former team members who could not adapt to such an unstructured environment did not last in the team. Third, a person must be able to withstand the stress of the noise and the time pressure. Yet despite the noise, one must be able to continually monitor.

Almost all members report being mentally tired at the end of a session. Yet results from a questionnaire administered to the team showed their mean satisfaction working in the environment to be 9.4 (sd=.9), on a scale of 1 to 10 (high). One engineer reported the experience to be exhausting, but thrilling, as in riding a roller coaster. One must be able to enjoy problem-solving in such a social atmosphere.

A warroom environment is designed for teams where the tasks are highly interdependent, but also when relationships between actors are very dynamic. When work is less interdependent and ad hoc, then there is less of a need to participate in others' intermediate results, and the presence of others may be distracting.

Extreme collaboration involves a delicate balance between an electronic and social network. How to adjust the information flow between networks in still an open question. Automating the flow of more information may relieve stress that is reported as a problem by many team members. Yet automating may reduce the potential for human networking; questioning assumptions, challenging values, and discussing options is a crucial aspect of designing. On the other hand, it may free up time for more human networking.

Future research needs to address how much social and task information people actually are capable of utilizing when designing. This knowledge would prove valuable for designing new technologies that can better support the networking that is an integral part of design.

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