Collaboration Technologies and Their Use

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Effective collaboration happens when the tools needed are available and used appropriately by the collaborators. In this section, we first review the **kinds of technologies** that have been effective in supporting distributed work, with different kinds of work benefiting from different constellations of technologies. Our framework follows closely that of (Sarma, Redmiles et al. 2010), listing technologies as **communication, coordination,** and **information repositories**, adding significant aspects of the **computational environment** (See Table 1). Although we may mention specific technologies, the point is not to recommend a specific current technology, because they will quickly be replaced with newer versions. We rather wish to emphasize the types of technology that are useful and why. Then we follow it with an **analytic scheme** to guide people to choose the right constellation for the work.

Table 1. Classification of technologies to support distance work.

Communication Tools	**Information Repositories**
Email and texting	**Computational Infrastructure**
Voice and video conferencing	System architecture
Chat, forums, blogs and wikis	The network
Virtual worlds	Large scale computation
Coordination Tools	Human computation
Shared calendars	
Awareness tools	
Meeting support	
Large visual displays	
Workflow and resource scheduling	

1 Kinds of collaboration technologies

Communication Tools

Email and texting. Email is ubiquitous. It has been characterized by many as the first successful collaboration technology (Sproull and Kiesler 1991; Satzinger and Olfman 1992; Grudin 1994)

(Whittaker, Bellotti et al. 2005). One of the cornerstones of its success is that today it is device or application independent; and with attachments, it is a way to share almost anything the recipient can read. As happens with other technologies, people use it for things other than the original intent. People use it for managing time, reminding them of things to do, and keeping track of steps in a workflow (Mackay 1989; Carley and Wendt 1991; Whittaker and Sidner 1996; Whittaker, Bellotti et al. 2005). Because it was not designed for these purposes, it doesn't support these tasks very well, although gmail's recent attempt to glean "tasks" from email is a step in this direction. People develop ad hoc workarounds (usually involving paper) to do things like keeping track of who has responded to a request sent to many people

Instant Messaging (IM), sharing primarily simple text messages with another person or even a group, has made significant inroads into organizations. In some cases it has replaced the use of email, phone, and even face-to-face (Muller, Raven et al. 2003; Cameron and Webster 2005). There is evidence that it is sometimes used for complex work discussions, not just simple back and forth about mundane issues (Isaacs, Walendowski et al. 2002). It is also used effectively for quick questions, scheduling, organizing social interactions, and keeping in touch with others (Nardi, Whittaker et al. 2000).

Except for the attachments (which can include elaborate drawings, figures and video clips), all of these so far are text based, and even thin text in the abbreviated world of texting. Text remains an impoverished medium compared to the tones and facial/body expressions possible when face-to-face.

Conferencing tools: Voice and Video.

There are a myriad of opportunities to communicate beyond text in today's world, and many are used heavily. The telephone trumps text in being able to convey tone and to have immediacy of response. In fact, delays caused by technical interruptions of voice and video transmission are highly disruptive to conversational flow because of the importance of pauses in turn taking (e.g., (Johnstone 1995).

Many people have telephones these days from which they can teleconference, at least on a small scale. Organizations often provide services for larger scale audio "bridges" for conference calls. Key to the smooth execution of these calls is whether the phones have "full duplex" or "half duplex" transmissions. Half duplex lines are capable of transmitting only one direction at a time.

Since natural conversations often include "backchannels," the "uh huh," "hmms," etc. that convey whether the recipient is agreeing, understanding, or not, when using a half duplex line, these are silenced. As a consequence, often the speaker will talk longer than necessary, not sure if the recipient has understood yet or not (Doherty-Sneedon, Anderson et al. 1997). Additionally, conversational turn taking is often signaled by an utterance from the one who wants to take the turn while the current speaker is speaking (Duncan 1972). These are entirely cut out in a half duplex line, creating awkward competitions for who will speak next.

While tone of voice can add meaning to the words said, facial expressions and body language add another layer. In large meetings, video helps convey who is present without an explicit roll call, and by eye contact and expression, conveys who is paying attention. But there is an emotional component as well. Many report the extra "presence" someone has when they are connected by video (Bradner and Mark 2001). Not only can one see the people, but also the situation or context they are witnessing. For example, it is easier to understand the tone of a meeting where participants seem to be eager to wrap it up when an increasingly heavy snowstorm is visible out the window.

The richness of voice and video, however, can create barriers to people who are from different cultures. The expected pause structures in conversation are different in the Western and Eastern cultures, often creating miscues. Because Westerners are used to a shorter pause structure than Easterners, they will dominate the conversation (Ulijn 1995). Easterners, expecting a longer pause between utterances, pauses which convey respect, find the Westerners rude; Westerners interpret Easterners' silence as their having nothing to say. Similarly, when video shows facial expressions and eye contact information, because those features are interpreted differently in different cultures, people again may make wrong attributions of interest and consent.

The video connection has to be physically arranged to achieve a good sense of presence. Eye contact and gaze awareness are key linguistic and social mediators of communication (Kendon 1967; Argyle and Cook 1976). In video, as in real life, people tend to focus on the face of the person they are talking with, and attempt to make eye contact by looking at the eyes of the person. Unfortunately, to appear to make eye contact over video requires the person to look not at the projected eyes of the remote person but at the camera. Therefore, to convey eye contact, extra effort needs to be expended to move the video of the remote person as close to the camera as possible; on many of today's big screen monitors with the camera on top, this translates to as high as possible. Without this careful adjustment, the camera conveys a sideways glance or the top of a person's head, which are interpreted as disinterest (Grayson and Monk 2003).

Conversations are often accompanied by gestures referring to an object, a document, data, or a visualization. The popular, simple way to do this is to send all participants slide decks and to direct the changing from one to the other by "next slide." But there are more sophisticated tools like GoToMeeting, Google Hangout, and Skype screen sharing that allow someone to share their desktop or a particular window with others, allowing them to control what others are looking at and being able to focus attention by using the mouse/pointer.

Chat Rooms, Blogs, Forums, and Wikis.

Longer conversations from larger numbers of people are usually accomplished through chat rooms, blogs, forums and wikis. Chats are nearly real-time, whereas blogs, forums and wikis have a longer time between contributions. When used for distributed science, all are typically restricted to a designated work group rather than being public.

Space physicists in UARC and SPARC (Upper Atmospheric Research Collaboratory and Space Physics and Aeronomy Research Collaboratory) used chats extensively to converse during their "campaigns," particular periods where the sun's activity impacted the upper atmosphere. The chats, being automatically recorded, allowed people to "read in" to the conversation (scrolling back and reading what had been happening), helping them "catch up" even though their time zone differences disallowed them from participating fully in real-time. The conversations were comparable to those held face-to-face (McDaniel 1996).

Wikis similarly are free-for-all conversations, but are even less structured in formatting. Forums are typically set up for discussion threads, whereas wikis can take any form whatsoever. In the BIRN collaboratory (Biomedical Informatics Research Collaboratory), wikis were used extensively to share test protocols, tips and FAQs, and announcements of the availability of new software tools and articles of interest (Olson, Ellisman et al. 2008).

Twitter and Facebook have seen high adoption in the public sphere, but at this point, it is unclear where they have been adopted in the world of distributed science.

Virtual Worlds

Virtual worlds are graphical, 3-D representations of physical spaces, and have drawn considerable attention from both industry and academia (Bainbridge 2007). They allow a person to experience a realistic environment, usually through an avatar. They can explore the space, manipulate objects, and, when networked together, can interact with other people's avatars. Recently, MICA (Meta-Institute for Computational Astrophysics) is a collaboratory based exclusively in virtual worlds. They provide professional seminars, popular lectures and other public outreach events in Second Life[1] (Djorgovski, Hut et al. 2010).

Such simulations of real worlds have been in common use for training in the military for a long time (Johnson and Valente 2009). And multiplayer games such as World of Warcraft[2] have allowed for a wide range of playful interactions, though (Brown and Thomas 2006) speculated that real leadership skills might be learned in a game like this that involves extensive quests involving substantial numbers of players. Virtual worlds have been used for a variety of other application domains, including health care (Boulos, Hetherington et al. 2007), software engineering (Koehne and Redmiles 2012), and education (Wankel and Hinrichs 2011).

Coordination Support

A class of technologies exist to support collaborators in finding a time to work synchronously, and a second set of technologies to support the coordination during the time together. Calendars and awareness mechanisms are in the first set; formal and informal meeting support tools fall in the second set. Workflow systems coordinate asynchronous work across different players, and complicated systems support scheduling of shared high-end equipment.

Shared Calendars.

Although the original introduction of group calendars was met with resistance, many organizations have seen value in their use (Grudin 1994; Grudin and Palen 1995). Calendars support the coordination of meetings, finding a time when the important participants are available.

Calendars are also used as a tool to display and/or read availability. When colleagues do not respond to requests in their usual timely way, one can view their calendar to discover whether

1 www.secondlife.com

2 us.battle.net/wow/

they are out of town or in a meeting. The information also allows one to plan when to contact a person (e.g., an "ambush" after a meeting in order to get a signature). And of course this can be particularly valuable for geographically dispersed colleagues who are in different timezones, reminding people of where the workdays overlap and where they do not.

Awareness Tools

When people are collocated, there are a number of ways they learn whether others are available. In real life, open doors allow assessment of activity; noting that a colleague is not in the office but that their briefcase and coat are still there suggests the promise of return. Bumping into colleagues in the hall allows brief exchange of information. All of this is available without the explicit intention or actions of the people involved. When people are remote, these cues are missing and the act of making cues available takes effort.

Today awareness information is conveyed in the status indicators of Instant Messaging (IM) systems. With IM, the user has control over what status indicator to convey to others, but it comes at the cost of remembering to set it and actually setting it. The cost of receiving the status setting, however, is very low. Many IM clients list the person's chosen colleagues who agree to be monitored, and their status is typically listed in iconic form on the edge of the screen.

IM indicates the user's current state, from which one can infer whether they can be interrupted, but not exactly what they are working on. In the domain of software engineering, a key form of advancement in science, where coordination of detailed efforts is of primary importance but the work nearly invisible, developers have created and widely adopted various system to "check out and check in" portions of the code they are working on. For example, *Assembla*[3] is a collection of tools to track open issues and who is working on them, plus a code repository where code is assigned to a person to work on, the time during which others are locked from editing. These kinds of coordination tools are powerful, but not widely adapted to domains other than software engineering.

A more general system that notes what people have been or are working on in a shared document appears in Google Docs. The names of others who are currently editing the document are shown at the top of the document, their cursors with their names in a flag is shown where they are working now, and their listing of past revisions, a listing of who did what (with authors'

3 https://www.assembla.com/home

contributions highlighted in different colors) indicate what has been changed. These various symbols and colors provide awareness of who is doing what, and who did what if more than one person is working on the document either at the same time or asynchronously.

Meeting Support

Coordination support for meetings, whether they are face-to-face or remote, comes in two flavors: formal and informal. The 1990s saw a lot of effort in Group Decision Support Systems (GDSS), where participants were led by a meeting facilitator through a number of computer-based activities to generate ideas, evaluate them in a variety of ways, do stakeholder analysis, prioritize alternatives, etc. (Nunamaker, Dennis et al. 1991; Nunamaker, Briggs et al. 1996/97). But these systems fell into disuse because of their management overhead and cost.

Informal meeting support tools typically take the form of a simple projected interactive medium, such as a Word outline or a Google Doc. The outline lists the agenda items as the highest level in the outline; during the meeting a scribe takes notes that everyone can view and implicitly vet. As agenda items are completed, the outline format allows the item to be collapsed, implicitly giving a visual sense of progress. Those applications that allow multiple people to author the shared document, like Google Apps, are even more powerful in these settings. When there is a single scribe, that person typically is so busy that they are barred from contributing to the conversation. When there are multiple authors "live," when one scribe talks, others can take over seamlessly to enter notes on what they are saying. Additionally, these note taking tools have been used very effectively in teams that have people for whom English is not their native language. The real-time visible note-taking is akin to "closed captioning" of the meeting.

Large visual displays

A third type of coordination support is a combination of awareness (typically of a situation rather than people and their work) and rich information visualization. Large complex displays that allow monitoring of a complex device like a nuclear power plant or the nationwide communication network, serve both as shared information and sources of awareness when people are collocated (See Figure 2).

Figure 2. Large visual display for the Fermi Nuclear plant. *Alexander Cohn, Times. File Photo.*

A similar sort of display is used in distributed science. For example, scientists involved in monitoring the upper atmosphere, noting the trace of activity from sun storms and the concomitant disturbances in the upper atmosphere, first created a coordinated view of their sensing instruments. Over time, they co-developed an integrated rendition of what was actually happening, a view of the earth from above, side-by-side with what the theories said should be happening. This visual juxtaposition of theory and data allowed the rapid discovery of both conformance and dis-confirmations of data with theory, speeding the science (See Figure 3).

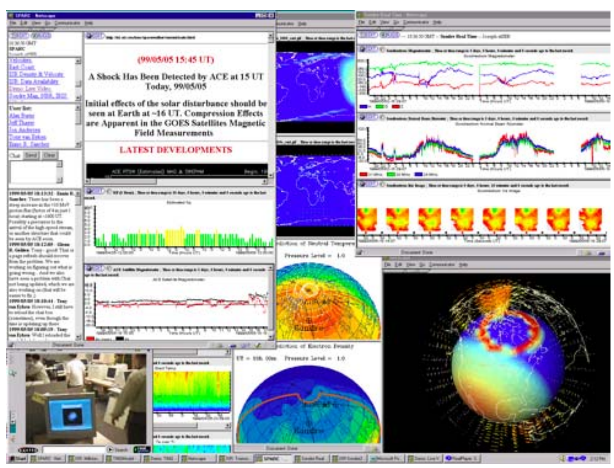

Figure 3. Visual display for coordinating data and theory in Upper Atmospheric science.

While the commercial world continues to produce larger and larger high resolution displays at lower and lower costs, for some very specialized purposes wall-sized displays have been created by tiling together large numbers of displays. The Hiperwall, developed at the University of California, Irvine, and subsequently spun off as a commercial wall-size display, is a good example. See Figure 4 for an example.

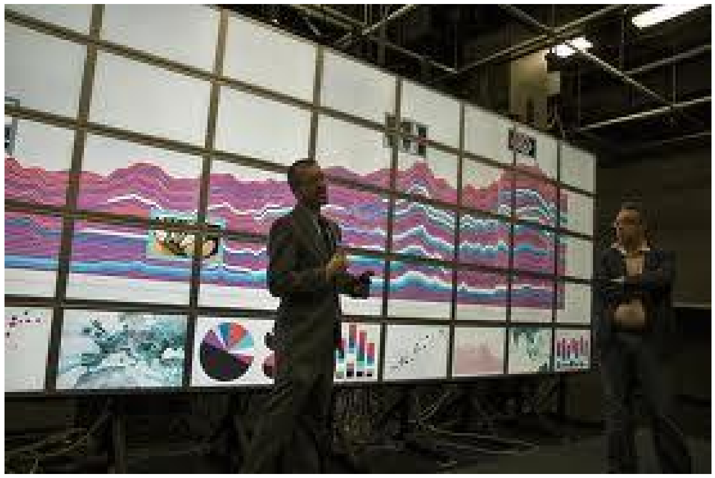

Figure 4. The Hiperwall.

Workflow and Resource Scheduling

A number of routine tasks that require input/approval from a number of people benefit from a structured digital workflow system. For example, the process of applying for a job involves a number of people: the candidate, the people who send recommendation support, the evaluators, and a manager who orchestrates the final decision, which is then communicated to the candidate, and when successful, the human resources department. A number of efficient online systems handle just this type of flow. A very successful workflow system supports the National Science Foundation grant submission, review, discussion, and decision making process, notifying the appropriate players in the process at the appropriate time, giving them the tools and information they need, recording their actions, and sending the process on to the next in line. Although the rigidity of these system can sometimes prevent their adoption, a number of such systems have succeeded (Grinter 2000).

In some research endeavors, especially in the hard sciences where the expense of a large piece of equipment necessitates researchers sharing it, systems have been put in place to schedule time on the equipment. Some clever systems have been created with the joint goals of being fair to those requesting time and to maximize the use of the equipment. Bidding mechanisms have been explored to optimize various aspects of the complicated allocation problem (Chen 2010). Various kinds of auctions have been tested to both create an equitable distribution of time and to prevent people from "gaming" the system (Chen and Sonmez 2006).

Information Repositories

When people are collaborating, whether collocated or remote, shared information needs to be organized and managed. The model of informally collaborating by sending people edited documents as attachments is common but fraught with challenges. All kinds of issues of version control and meshing of changes loom. A better solution is to have a place where the single document resides, a shared file, with all the authors having access. Many universities and large corporations provide such service as a matter of course; others do not. CTools, originally built as a learning management system headquartered at the University of Michigan, was found to be additionally useful as a project based shared file system. Administrators could assign read/write permissions to people for various documents and folders. In some cases, change were made directly to the documents; in other cases, the collaborators made heavy use of version control, at the minimum through elaborate files names on copies.

Recognizing this difficulty, some large software solutions were generated. Microsoft, for example, offers Sharepoint, an integrated set of tools selected for use in a particular collaboration. It includes collections of websites, collaboration tools, information management (including tagging documents for permissions, types, and automatic content sorting). It also allows search over all the contents.

A more recent foray into shared editing and file management, but with a more fluid form, is Google Apps. The applications within Google Apps (documents, presentations, spreadsheets, forms, and drawings) each can be shared with others or placed into a folder, called a "collection," which can be shared. Each user of the document can put it in a folder of their choosing for their own view, allowing them to embody their own organization. This set of features gives the users a lot of flexibility, but without vetted "best practices," many are doing it badly. And people are still confused by the "cloud" (Voida, Olson et al. 2013).

Those who share data rather than documents have an additional set of challenges. If data are being collected by a set of people, they have to agree, at the outset, what constitutes good quality data. Many scientific collaboratories have goals that include sharing data across sites. For example, in an early Biomedical Informatics Research Network (BIRN), they believed that progress on understanding schizophrenia would benefit from having a larger sample size of MRI images of patients, both with and without schizophrenia, doing various cognitive tasks while being imaged. A great deal of effort was spent in ensuring that the tasks that the patients performed were standardized, and that the various imaging machines were calibrated. In other scientific collaboratories, great care was given to developing a shared ontology of medical terms so that patient data could be aggregated from different locations and from different medical specialties, each of which had their own vocabularies (Olson, Ellisman et al. 2008).

In some areas of science, key to the recording and vetting of information is the laboratory notebook. In many domains, the researcher keeps a personal record of their activities each day, including tests they ran, information they gathered, and things they noticed. It was important to sign and date each entry to record important discoveries, often feeding into patent applications. In some large scientific collaborations, they noted the value of being able to store and share these notebooks. They built an electronic notebook. One developed at the Pacific Northwest National Labs, the Electronic Laboratory Notebook (ELN) was so well designed that it was used heavily throughout the labs, and adopted by other collaboratories even in different domains (Myers 2008).

Aspects of the Computational Infrastructure

The System Architecture

Many scientific collaborations have no choice as to how to architect their systems. The large scale computation is either local or on a private grid of secure machines, and the data, often large, are stored on their own massive servers.

Today scientists who have no need for storing or computing on massive data have a choice whether to purchase applications for installation on their machines or to opt for computing and storage "in the cloud." If one chooses to work in the cloud, connectivity is important if collaborative access in real-time is required. Many cloud-based applications offer some level of off-line activity, though then the availability of up-to-date version control is lost. A more serious concern for some is security. There is resistance to cloud computing in the medical world, military contractors, police and fire departments, certain government agencies, and others who are sensitive to information loss. While advocates of cloud computing often rebut such concerns, they nonetheless exist.

One interesting consequence of these different architectures is that each architectural choice creates its own behavioral consequences. When the applications and documents are on private machines, the mode of collaboration is hand-off, serial revision: documents are revised with "tracking changes" on and sent to the author-editor, who in turn can choose to accept each or not. The power resides in whoever the collective has made editor. In contrast, where the document and application resides "in the cloud," there is an implied place where those designated as editors can go to make changes. In this model, each edit appears as if accepted; the document is changed. Others can view the revision history and undo the changes, but at least at present a reversion to an earlier version undoes *all* changes, not just one at a time. Neither model in its current form is ideal.

These are two entirely different modes of collaborating in terms of workflow. Often collaborators tacitly make the decision about who has the power to make changes, who can merely comment, and who has the final say in accepting the changes proposed. The existence of these two models present additional challenges to the users who are involved in collaborations of both kinds. They have to remember where something is stored, how to find it, and who has the power to decide on edits in each case, a situation we call "thunder in the cloud" (Voida, Olson et al. 2013).

The Network

Underlying all collaboration technologies is the network. Simply put, the bandwidth has to be sufficient for the kind of work to be done. Most of the developed world has adequate bandwidth for ordinary tasks, including video. Specialized needs that require large amounts of bandwidth will require specialized network infrastructure. Many of the large scientific projects have had to build high performance networks to handle the volume of data that comes from their instruments as well as specialized computing to garner enough resources to do the computation on that mass of data. For example, the ATLAS detector at CERN produces 23 petabytes[4] of raw data per second. This enormous data flow is reduced by a series of software routines that ends up storing about 100 megabytes of data per second, which yields about a petabyte of data each year. It requires special infrastructure to deal with data flows like this.

Large Scale Computational Resources

In many areas of endeavor, such as advanced scientific research or data mining in business, large scale computational resources are needed. Certain high-end centers, such as the National Center

[4] A petabyte is 10^{15} bytes. 10^3 = kilobyte, 10^6 = megabyte, 10^9 = gigabyte, 10^{12} = terabyte.

for Atmospheric Research (NCAR), in Boulder, Colorado, have traditionally developed their advanced computational resources in-house. But organizations such as the National Science Foundation (NSF), realizing that there is a need for advanced computing in many areas they serve, have supported the building of infrastructures to support advanced computation. The historically important supercomputer centers are one manifestation of this. Not only have high-end computational resources been developed, but associated high speed networking to support access to these facilities have emerged as well. A particularly noteworthy example of advanced infrastructure to support such needs is the Grid, as sophisticated computational infrastructure that is widely used (Foster and Kesselman 2004). A more recent example is the NanoHub[5], a special computational infrastructure for nanoscience and nanotechnology.

Human Computation

There is also a tradition of using human capabilities aggregated over large numbers to achieve important computational outcomes. One of the earliest examples of socially organized human computation concerned the calculation of the return of Halley's comet, carried out by three people in 1757 (Grier 2005). However, this phenomenon has experienced a recent renaissance under the rubrics of crowdsourcing (Howe 2008; Doan, Ramakrishnan et al. 2011), collective intelligence (Malone, Laubacher et al. 2010), the wisdom of crowds (Surowiecki 2005), and citizen science (Bonney, Cooper et al. 2009; Hand 2010). The core idea is that in many interesting domains gathering together the small inputs of a large number of individuals ("micro tasks") can lead to results that can be as high in quality as judgments by experts and done in a fraction of the time.

2 Deciding what constellation of technologies a particular collaboration needs

In sum, collaborations typically need technologies to support **communication** and the sharing of the objects about which conversation takes place. Technologies are needed to **coordinate** the conversations, both to find times to converse and to coordinate around the objects. The objects, **information** and/or data, need to be managed: collected to exacting standards, managed, and made accessible.

[5] nanoHUB.org

Which technologies are chosen for a collaboration can have an impact on the success of the collaboration. In listing the technologies, above, we noted a number of features that affect how they are used, with choices at almost every juncture. Here, we gather the features of the technology, highlighting the choices available that impact behavior.

In short, the features that are important include:

- the speed of response, impacting conversation and immediacy of data understanding
- the size of the message/data or how much computation is required, impacting required computation and networking
- security, impacting choices about architecture
- privacy, again, impacting choices about architecture
- accessibility, impacting who can easily get access
- the richness of what is transmitted, impacting conversation and data understanding
- the ease of use, impacting adoption
- context information, impacting coordination across sites
- cost, impacting what can be accomplished
- compatibility with other things used, impacting adoption

3 Conclusions

Choosing the appropriate suite of technologies to support collaboration is not easy. The sets of features of each drive how they are each going to be used; the technology often dictates social configurations of use. Although we have not provided a decision tree of questions, answers of which would point to the "right" set of technologies, we have provided a listing of classes of collaboration technologies, a listing of the key features of these technologies that should be carefully considered in the choice of one's particular use. It is important to consider all facets of collaboration at a distance: Communication, coordination, information repositories, and computational infrastructure.

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