Enabling Distributed Collaboration among Heterogeneous Devices

Richard Skarbez
University of North Carolina at Chapel Hill
Department of Computer Science
skarbez@cs.unc.edu

Mary C. Whitton
University of North Carolina at Chapel Hill
Department of Computer Science
whitton@cs.unc.edu

ABSTRACT

In this paper we describe a new class of collaborative scientific applications that incorporate heterogeneous devices, such as shared supercomputing or visualization resources, personal computers, and mobile devices, present some classes of collaboration tasks that could profitably make use an application infrastructure that connects heterogeneous devices, and identify some particular applications that fall into these classes. We also describe in greater detail one potential application, natural science field research that employs sensor networks. We also discuss some of the problems that need to be addressed in building an application that allows such heterogeneous device collaboration and some benefits to digital science that could be realized by building collaborative applications in this fashion.

Author Keywords

Distributed collaboration, collaborative science, mobile devices, visualization, human-computer interaction.

ACM Classification Keywords

H5.3. [Information interfaces and presentation (e.g., HCI)]: Group and Organization Interfaces---collaborative computing.

INTRODUCTION

The “big shared resource” (BSR) has long been an important part of scientific research. In the past, this may have been a large-scale telescope or a particle accelerator. Today, it could be any of these traditional devices augmented with computer control, or it might be a supercomputer or a sophisticated visualization environment, such as a dome or a CAVE. Regardless of type, BSRs are generally expensive, are difficult to install and maintain, require specialized expertise to operate, and are often physically distant from researchers and scientists who would like to use them. Enabling collaboration using the BSR has been achieved by networked interfaces or bringing all collaborators to the BSR’s location. This is expensive, inconvenient, and inefficient. Today, virtually every scientist has access to a personal desktop or laptop computer, and there have been efforts to enable researchers to do collaborative science using desktop computers, including the Collaborative nanoManipulator (CnM) [1], a networked interface for controlling an atomic force microscope which also served as a platform for analysis of distributed collaboration. Projects such as that one address some of the collaboration difficulties discussed above.

Scientists today have access to increasingly powerful mobile devices. These devices are available, relatively cheap, and network-enabled. Many “smartphones” possess sufficient audio/video and computing capabilities to run fairly heavyweight applications such as computer games or video players, or, potentially, scientific applications. That said, these devices still lag far behind desktop computers or workstations in terms of processing power, display size, network bandwidth and user interface sophistication.

An application infrastructure that connects these different classes of devices (BSRs, PCs, and mobile devices) and enables collaborations among their users would benefit distributed science. In the remainder of this position paper, we present some potential benefits of such an infrastructure, applications where such technology would benefit scientific research, and discuss some problems that need to be addressed and ideas for building such an infrastructure.

POTENTIAL BENEFITS

A collaboratory based around a BSR would naturally benefit from allowing users on less-capable devices to interact with the BSR, or other users of the BSR, over the network. There are some problems of collaboration that could be directly addressed with such technology, and there are some types of collaborative activities that would benefit more clearly than others.

The primary problem with BSRs is that they are not easily accessible. Allowing remote access on commodity computers or mobile devices would help to alleviate this

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problem. This is particularly true in time-sensitive situations, where it may be impractical or impossible for all collaborators to be in the same place.

In addition, extending the collaboration to include remote users makes it easier to accomplish iterative refinement in the sciences, by closing the distance (real or metaphorical) between experiment and analysis. For example, consider the fields of archaeology and cultural heritage preservation. Virtual environments (VEs) are being used as tools in these fields. (There is an annual symposium at IEEE VAST on the topic.) However, field research is still an essential part of study. By bringing mobile users into the collaboration, researchers examining a virtual model of a site in a CAVE can directly indicate to the mobile user an area of interest, and she can examine the location in person, and immediately send back measurements or pictures that can be incorporated into the model seen in the BSR.

A similar situation can be imagined in the physical sciences: Researchers analyzing the results of an experiment (possibly an on-going experiment) in a dome display can identify interesting features to a remote user who is controlling the instrument, and he can then modify the experiment or take additional measurements that can be incorporated into the data and visualization.

Finally, the design and evaluation of collaborative applications for heterogeneous devices, including mobile devices, have not been the subject of much study. We believe that research in these areas would yield productive insights into the nature of distributed collaboration, scientific or otherwise.

POTENTIAL APPLICATIONS

One benefit of enabling heterogeneous device collaboration is that data-gathering and analysis can be more tightly coupled. That said, it is true that many collaborative tasks are either primarily real-time (multiple parties working to gather data, run an experiment, or perform a complicated task), or primarily post-experiment (multiple parties participating in data analysis, or designing the next experiment). This distinction can also be used to classify BSRs. Traditional scientific instruments are most often used in real-time in the conducting of experiments. Visualization tools such as CAVEs, domes, display walls, etc. are used primarily for post-experiment analysis. Supercomputers can be used in both ways, depending on the nature of the task.

Another useful distinction is whether the collaboration is being directed by a user or users local to the BSR, or by a remote user. To clarify, we use directing to mean guiding the direction of the science. For example, consultation is listed as a remote task in Table 1, even though local users may very well have initiated the action.

	Real-Time	**Post-Experiment**
Local Direction	Direction / Doing and monitoring	Directed data gathering
Remote Direction	Consultation	Evaluation / Planning

Table 1. Collaborative scientific tasks grouped by the location of the expert and the timing of the task

In a distributed collaboration where the direction is local to the BSR and the task is real-time, an expert can be using the BSR for display and directing the remote user in performance of a difficult task, as in 3D Medical Consultation [2]. Also, the task can be divided among multiple users, where an expert is controlling the equipment and one or more other users are observing the data being generated, or controlling other aspects of the experiment. The archaeological task discussed in the previous section is an example of the case where the direction is local to the BSR and the task is post-experiment. The case where the direction is remote and the task is real-time is a consulting task; an example would be a remote medical consultation. Finally, the case where the direction is remote and the task is post-experiment could be a situation where a remote expert reviews the performance of a task with the personnel who were involved, discusses changes, and plans future work.

USE CASE - SENSOR NETWORKS

An example might help to illustrate the utility of this idea. Consider the use of sensor networks for field research in the natural sciences, e.g. monitoring animal populations. Such a sensor network could generate a huge amount of data, which would be transmitted to and stored in some central facility. The behavior of the sensor network itself could easily be monitored and managed from a variety of devices, including mobile devices and regular desktop computers.

The captured sensor data could be visualized in a CAVE, where one or multiple researchers could analyze the results. These researchers might find something of interest in the data, and could communicate that directly to a field researcher on-site with a mobile device, guiding the user to the particular item of interest. The field researcher could then make adjustments to the sensor behavior using his mobile device, and capture pictures or video which could be transmitted directly back to the central facility and displayed to the researchers in the CAVE. They could then immediately determine additional actions to be taken or form hypotheses about the data, which could be sent back to the on-site researcher (along with any relevant data) to get her opinion, and so on.

In addition, the field researcher could access the BSR from her mobile device in order to make use of its more powerful computational resources, allowing her to do productive analysis work from the field.

APPROACH

There are many problems that need to be addressed for such a heterogeneous collaboration infrastructure to be deployed and used successfully. These problems can be grouped into four categories: data management and communication, visualization, human-computer interaction, and collaboration support. Our research interests are primarily in visualization and user interaction techniques for collaborative applications on mobile devices, and so that will be the focus of the discussion.

An analogy may help to clarify many of the points below. Consider lakes as data, pipes of different sizes representing network bandwidth, and computing devices as buckets that can do something with the water. A computational BSR has a large bucket (advanced visualization hardware, powerful computational resources, large data storage) that needs to be filled from a small pipe from a small lake (the data sent from the mobile device). Meanwhile, the mobile device has a much smaller bucket (small display, less computational power, etc.), fed by a small pipe from a large lake (the data generated by the BSR). Because of this inherent resource asymmetry, we as researchers must develop visualization and computer-human interaction techniques that can overcome these differences and enable effective collaboration.

Data Management and Communication

Scientific applications often involve large datasets. Mobile devices, in general, have limited memory, limited computational resources, and limited—as well as inconsistent—network connectivity. Applications that allow mobile users to interact with large datasets should provide them the option of working with portions of the dataset or a "lower-resolution" representation of the data in order to minimize storage, bandwidth, and power requirements. Simply generating a coarser sampling of the data is problematic for scientific applications, since doing so can eliminate important high-frequency detail, or create artifacts that are not in the underlying data. Developing or identifying a way of generating multi-scale representations of data while preserving "important" features is a crucial step in developing this collaboration infrastructure.

Also, sufficient data should be stored locally to allow the mobile user to continue working in cases of poor or nonexistent network connectivity. Finally, there may be significant network latency in such a collaborative application; this must be taken into account in the design of the application.

Visualization

CAVEs, large-scale display walls, and head-mounted displays are now in use in many facilities. Even low-end desktop computers generally have displays with greater than one megapixel resolution. Meanwhile, mobile devices have displays of less than 4" in size with resolutions of 480x320 or less. Furthermore, mobile devices have less rendering capability than desktop machines or workstations, and high-quality rendering often comes at the expense of decreased battery life.

Applications tailored to mobile devices must account for the greatly decreased field of view and screen real-estate available to users of these devices; at the same time, they should take advantage of some of their unique characteristics, such as improved resolution (in terms of pixels per inch) and ease of repositioning. Such applications should also recognize the fact that their users will frequently be operating in situations where they need to preserve battery life; they should provide users with the option of "gracefully degrading" the visualization quality in order to minimize power usage.

Human-Computer Interaction

Mobile devices employ non-traditional input techniques such as touch- or pen-based input. In addition, input modalities are not consistent across mobile devices: some have keyboards, and some do not; some have touchscreens, and others do not; some allow pen-based input, and some do not; and so on. These devices also often have many input modalities that have not been fully explored for or were not applicable to desktop computers; these include cameras, GPS units, and accelerometers.

Application developers for mobile devices should be aware of these differences, and should design interfaces that take advantage of mobile devices' unique characteristics rather than attempting to mimic the interfaces of desktop computers or advanced visualization facilities. We need to develop a body of knowledge about usability and interface effectiveness for scientific applications so that application developers can make informed design choices.

Collaboration Support

These ideas are focused on how an application should be designed so that the mobile user can interact with users on desktop computers, or users in advanced visualization environments. Note that we are not talking about other sociological factors that come into play in collaborative scenarios, such as situational awareness; we are focusing only on the technological aspect of how people would work together in an environment of heterogeneous resources.

Users on mobile devices see a very different data rendering and user interface than users of more capable devices. There are differences in display size and resolution. In addition, the mobile user may be interacting with a more coarsely sampled version of the dataset, or may be viewing the data as a non-photorealistic rendering that may be better suited to the limitations of the mobile hardware. As a result, the particular presentations that each user sees may be very different. Effective collaboration, however, often requires that users are looking at the same thing, or at least similar enough representations that the elements that are important for the science under discussion are visible to all parties. They need to be able to refer to common landmarks. The differing representations must be "connected" such that users of both can effectively communicate about the data.

Given what was discussed earlier, it is likely that an application designed for a mobile device and a "partner" application designed for a desktop computer, or a CAVE, will have different user interface techniques and affordances, different renderings, and possibly different underlying data (in the sense that the mobile user might have a coarser sampling of the data or some such). If the mobile user performs some manipulation of the dataset, or wants to draw his collaborators attention to some feature of the data, he must be able to know that his collaborators receive and understand that message, and that it is correctly mapped onto their representation of the data. The converse should hold true as well. The problem here is identifying the intent of a user working with one representation of the data, and communicating that intent to another user working with a different representation.

CONCLUSION

Our intentions in this position paper were to identify some problems common to distributed scientific collaboration, and to point toward a new collaboration paradigm incorporating heterogeneous devices that could help resolve these difficulties. Big shared resources are essential to many scientific pursuits, not only in experimentation but also increasingly in analysis, in the forms of visualization facilities. Allowing both co-located and remote users to observe or control these BSRs from a range of heterogeneous devices could increase the productivity of existing collaboratories, or make possible collaborations that were previously unfeasible. As our particular research interest is in enabling collaboration between users of BSRs and users of mobile devices, we then pointed out some of the difficulties inherent in developing scientific applications for mobile devices, and some design rules that might ease some of these difficulties.

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