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Application of the NCSA Habanero Tool for Collaboration on Structural Integrity Assessments

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Manuscript Completed: August 1998

Date Published: November 1998

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Prepared for

Division of Engineering Technology

Office of Nuclear Regulatory Research

U.S. Nuclear Regulatory Commission

Washington, DC 20555-0001

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Abstract

The Habanero software was developed by the National Center for Supercomputing Applications at the University of Illinois, Urbana-Champaign, as a framework for the collaborative sharing of Java applications. The Habanero tool performs distributed communication of single-user, computer software interactions to a multiuser collaborative environment. An investigation was conducted to evaluate the capabilities of the Habanero tool in providing an Internet-based collaborative framework for researchers located at different sites and operating on different workstations. These collaborative sessions focused on the sharing of test data and analysis results from materials engineering areas (i.e., fracture mechanics and structural integrity evaluations) related to reactor pressure vessel safety research sponsored by the U. S. Nuclear Regulatory Commission. This report defines collaborative-system requirements for engineering applications and provides an overview of collaborative systems studied within the project. The installation, application, and detailed evaluation of the performance of the Habanero collaborative tool are discussed. The capabilities of the Habanero tool are compared to those of another commercially available collaborative product. Recommendations are given for future work in collaborative communications.

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Acronyms

API	Applications Programming Interface
AWT	Application Windowing Toolkit
COTS	commercial off-the-shelf
FTP	File Transfer Protocol
GIF	Graphics Interchange Format
HP	Hewlett Packard
ILS	Internet Locator Service
ISDN	Integrated Digital Services Network
ITU	International Telecommunications Union
JDK	Java Development Kit
JEST	Java Extensible Server Technology
JPEG	Joint Photographic Experts Group
JSDT	Java Shared Data Toolkit
LAN	Local Area Network
MC	Multipoint Controller
MCU	Multipoint Control Unix
MPEG	Moving Picture Experts Group
NCSA	National Center for Supercomputing Applications
NRC	Nuclear Regulatory Commission
OEM	original equipment manufacturer
ORNL	Oak Ridge National Laboratory
PC	personal computer
PNG	Portable Network Graphic
PNNL	Pacific Northwest National Laboratory
POTS	plain old telephone service
RPV	reactor pressure vessel
RTP	Real-Time Protocol
SGI	Silicon Graphics Incorporated
TCP/IP	Transmission Control Protocol / Internet Protocol
TIFF	Tagged Image File Format
UDP	User Datagram Protocol
UI	user interface
UIUC	University of Illinois, Urbana-Champaign
WWWFC	World-Wide Web Federal Consortium

Acknowledgments

The authors acknowledge the support and encouragement provided by M. E. Mayfield of the U. S. Nuclear Regulatory Commission in formulating and achieving the objectives of the project.

The support of staff at the National Center for Supercomputer Applications, University of Illinois, Urbana-Champaign, Illinois, is gratefully acknowledged. In particular, the authors wish to thank A. Suvaiala for her important contribution to Chap. 4.

At Oak Ridge National Laboratory, the assistance provided by P. T. Williams and A. S. Kimsey of the Computational Physics and Engineering Division is acknowledged.

1 Introduction

The Nuclear Regulatory Commission (NRC), as a member federal agency in the World-Wide Web Federal Consortium (WWWFC), is supporting development of Internet-based software at the National Center for Supercomputing Applications (NCSA) at the University of Illinois, Urbana-Champaign (UIUC). NCSA has developed the Habanero tool as a framework for the collaborative sharing of Java applications. The Habanero tool performs distributed communication of single-user, computer software interactions to a multiuser collaborative environment. At present, Habanero is a research project intended to provide a proof of principle for a platform-independent, Java-based collaborative system.

The objective of the NRC-sponsored project described herein was to evaluate capabilities of the Habanero tool in providing an Internet-based collaborative framework for researchers located at different sites and operating on different workstations. The focus of these collaborative sessions was on the sharing of test data and analysis results from materials engineering areas (i.e., fracture mechanics and structural integrity evaluations) related to NRC-sponsored reactor pressure vessel (RPV) safety research. The project was managed by the Oak Ridge National Laboratory (ORNL), with the Department of Civil Engineering at UIUC, providing major technical support as a subcontractor to ORNL.

This report provides an overview of collaborative systems studied within the project, including typical software components, technical definitions and considerations, and a selected list of available commercial and research collaborative systems. The collaborative-system requirements deemed critical to engineering analyses are discussed. This is followed by a description of the installation, application, and detailed evaluation of the performance of the Habanero collaborative tool that was carried out collectively by NRC, UIUC, and ORNL as part of this project. The capabilities of the Habanero research tool are compared to those of a currently available commercial collaborative product. Finally, conclusions and some recommendations for future work in collaborative communications are included.

2 Collaboration Systems Overview

2.1 Collaboration Software Components

Collaboration systems generally consist of server and client software programs for starting, joining, ending, and managing a real-time conference over a communication medium such as the Internet. In addition, the following collaboration tools are typically available to conference participants via the client and/or server software:

- A. Data conferencing capabilities allow sharing of data between conference participants.
 - 1. Shared Whiteboard tools provide a common area where conference participants can share graphic image data and annotate images using a drawing toolkit.
 - 2. Shared clipboard capabilities allow the users to cut, paste, copy to/from a common clipboard.
 - 3. Application sharing capabilities allow conference participants to view and manipulate applications jointly.
 - 4. File transfer capabilities allow conference participants to exchange files during the collaborative session without the need for additional software [i.e., File Transfer Protocol (FTP) programs].
- B. Audio conferencing allows conference participants to share voice conversations in real-time using a microphone and speakers.
- C. Video conferencing allows conference participants with video cameras to exchange periodically updated video images with each other.

2.2 Multipoint Conference Models

A multipoint conference is a collaborative session between two or more participants. The scheme used to route conference data between the participants is identified as the multipoint conference model. The two most common models are the decentralized multipoint conference and the centralized multipoint conference.¹

2.2.1 Decentralized Model

The decentralized multipoint conference model is the more simplistic of the two common models because it does not require use of a server machine. Instead, each participant's machine sends data to every other machine in the conference. One of the participant machines, usually the one that initiated the conference, acts as the Multipoint Controller (MC) and may perform some server-type functions. The disadvantage of this model is that as more conference participants are added, network traffic and bandwidth used increases exponentially, resulting in slower performance. The amount of bandwidth used by each machine increases by $n + 1$ where n is the number of participants. Thus, the decentralized model is suitable only for small numbers of conference participants.

2.2.2 Centralized Model

In contrast, the centralized model requires use of a server machine. Each participant's machine sends data to a central conferencing server known as the Multipoint Control Unit (MCU). The MCU then serializes the data from all participants (i.e., puts the data in the correct time sequence) and sends the data to each of the participants. Because each machine only connects to MCU and not to every other machine, the amount of bandwidth used by the centralized model does not increase drastically with the number of participants. Hence, the centralized model is more scalable, and thus faster and more suitable, for larger numbers of participants than is the decentralized mode.

Collaboration

2.3 Collaborative Application Sharing

Collaborative applications may be either "collaboration-aware" or "collaboration-unaware."² Collaboration-aware applications are those originally written for use by multiple users in a collaboration environment. Collaboration-unaware applications are those originally written for single users, but later made to work in a collaboration environment. In some collaboration environments, the application must be modified to work collaboratively. In other collaboration environments, the runtime environment is modified to make the application work collaboratively.

The two common methods for sharing applications are display broadcasting and event broadcasting; each has advantages and disadvantages. Most commercial off-the-shelf (COTS) conferencing systems use display broadcasting because it is easier to implement and is generally recognized as a proven technology. Most research initiatives on collaboration systems at universities and laboratories use event broadcasting for application sharing.

2.3.1 Display Broadcasting

In display broadcasting, only one computer in the collaboration conference runs a single instance of the application. The display from this application is broadcast to all other participants in the conference. User data from conference participants are returned to the single-application instance for processing, and any resulting changes made to the display are rebroadcast to all participants. The display broadcasting is controlled by a MCU server for centralized conference models and by the user machine on which the application is running for decentralized models.

The advantage of display broadcasting is that the shared application only needs to exist on one of the user's machines. This is a significant advantage when only one participant owns a copy of an expensive COTS application. Also, many collaboration-unaware applications can be shared by display broadcasting without modification to the application, again a big advantage when sharing COTS applications.

The disadvantage of display broadcasting is that significant network bandwidth is used for broadcasting the entire display of the application to each participant. Thus, for complicated graphics displays to large numbers of participants, display broadcasting may be too slow.

2.3.2 Event Broadcasting

In event broadcasting, each computer in the collaboration conference runs a copy of the application. Only the event states are broadcast to other conference participants. The event broadcasting method requires that the application environment on each machine be identical. Thus, most collaborative systems using event broadcasting are Java based.

Event broadcasting requires much less network bandwidth than display broadcasting because only the event states are broadcast rather than the whole display. Event broadcasting thus requires less network traffic and may be faster than display broadcasting. However, the Java environment itself can be slow and may negate the speed advantage.

A major disadvantage of event broadcasting is that every participant must have access to a copy of the application to be shared. Also, many collaboration-unaware applications require modification for event broadcasting to be viable. For freely available applications, this disadvantage may not be a big problem. However, these requirements would make sharing of most COTS applications either impossible or very expensive.

2.4 Collaborative Conferencing Standards

Conferencing standards are set by the International Telecommunications Union (ITU).^{3, 4} Separate conferencing standards are defined for the following transport media:

- Integrated Digital Services Network (ISDN)
- Local Area Network (LAN)
- Plain Old Telephone Service (POTS)
- Internet

Each conferencing standard includes one or more standards for data, audio, and video. The data conferencing standard is the same for all transport media, while the audio and video conferencing standards vary for the different transport media. The audio and video standards include compression and decompression algorithms, called codecs, optimized for the bandwidth and speed of the transport media.

The ITU H.323 conferencing standard for the Internet and LAN is subdivided into various components. The Internet audio standard is G.723, and the video standard is H.263. The LAN conferencing standard includes the same audio and video standards as those for the Internet, plus a few additional choices.

For both the Internet and LAN, the data conferencing standard is T.120 and includes the T.122, T.123, T.124, and T.125 standards for establishing and joining conferences; the T.126 standard for Whiteboards; the T.127 standard for file transfer; and the T.128 standard for application sharing. The T.128 standard uses display broadcasting to implement application sharing.

2.5 Transport Protocols

The following transport protocols are used in collaborative systems for transmitting various types of data across the Internet:

- Transmission Control Protocol/Internet Protocol (TCP/IP) is a reliable transport protocol for error-free transmission of data. Data packets are sequenced by the receiving computer to preserve correct ordering. TCP/IP is the recommended transport protocol for data conferencing where data losses are intolerable. However, it is not recommended for real-time audio/video because the data checking can result in slower transmission.
- With the User Datagram Protocol (UDP), maintaining data flow takes precedence over data reliability. Packets are dropped (lost) if data transmission cannot keep up with real-time. UDP is recommended for audio/video transport but not for data conferencing.
- The Real-Time Protocol (RTP) is similar to UDP, but it contains a sequence number so that data packets can be ordered in sequence and a time-stamp so that audio and video can be synchronized. These features make RTP useful in mixing audio data from multiple conference participants.

2.6 Survey of Available Collaborative Systems

The number of collaborative conferencing systems is rapidly expanding. They range from early systems using the Unix X-Windows environment, to currently available commercial products supporting the ITU standards, and to current Java-based research projects.

Collaboration

2.6.1 X-Windows Collaboration Systems

Many of the early collaboration conferencing systems were developed for the Unix X-Windows environment in the early to mid-1990s. These systems make use of the X-Windows client/server networked architecture that easily allows multiple distributed X-displays. A partial list of X-Windows-based collaboration systems is followed by the developing agency:⁵

1. Mpower [Hewlett Packard (HP)]
2. ShowMe (Sun Microsystems)
3. Argo (Digital Equipment Incorporated)
4. TeamConference (Spectragraphics)
5. XTV (Old Dominion University and University of North Carolina)
6. XMX (Brown University)
7. Collage (NCSA)

2.6.2 ITU Standards-Compliant Collaboration Systems

Many of the currently available commercial collaboration systems partially or fully support the ITU H.232 conferencing standard and thus use the display broadcasting model for sharing applications. These products are mostly available for the Windows 95/NT operating system on personal computers (PCs). One product, Microsoft NetMeeting, is available at no cost. Most of the other products allow partial or full interactivity with NetMeeting. Application sharing can be accomplished between an Apple Macintosh using the Timbuktu software and a PC using the NetMeeting software. Application sharing can be accomplished between Unix machines running the DC-Share software and PCs running the NetMeeting software. However, DC-Share is currently only sold to original equipment manufacturers (OEMs) and large corporations. The following is a partial list of commercial products supporting the ITU conferencing standards:

1. Microsoft NetMeeting
2. Netscape Conference
3. Intel ProShare
4. Farallon Timbuktu
5. Data Connection DC-Share

2.6.3 Java-Based Collaboration Systems

Current research in collaborative systems is mostly focused on event broadcasting systems based on the Java programming language. They include systems based on sharing Java applications (Habanero), sharing Java applets (TANGO), and replacing the Java Application Windowing Toolkit (AWT) with a collaborative version (Java Collaborator Toolset). Also, the developers of the Java programming language have released an "unofficial" toolkit, the Java Shared Data Toolkit (JSDT), for use in developing collaborative software. The following is a partial list of Java-based collaboration systems followed by the research organization or developer:^{3, 4, 6}

1. Habanero (NCSA and UIUC) (uses Java Applications)
2. TANGO⁷ (Syracuse University) (Web-based, i.e., uses Java Applets)
3. DISCIPLE (Rutgers University)
4. Promondia (Erlangen University)
5. UARC (Michigan University)

6. Java Collaborator Toolset (Old Dominion University) (uses customized Java AWT)
7. Infospheres (Caltech)
8. Java Extensible Server Technology⁸ (JEST) (Syracuse University)
9. JSDT (JavaSoft)

3 Collaboration Requirements

The most important requirement for using a collaborative tool in engineering applications is the ability to present information and data in a visual format. This information comes from a variety of sources, including photographs of materials characterization specimens, laboratory test specimens, and experimental rigs; graphical displays of measured laboratory data and of analysis results obtained from two- and three-dimensional (2- and 3-D) computational models (finite-element and finite-difference); overhead presentations; and written reports. Tools that can easily and seamlessly allow the researcher to convey this visual information are imperative. Some examples of commercial software programs used at ORNL to generate visual information include Abaqus Post, MSC Patran, Adobe Photoshop, ClarisDraw, KaleidaGraph, Microsoft Word, and Microsoft PowerPoint. The UIUC researchers use these in addition to the UIUC-developed graphics program LOGOS.

3.1 Simple Collaborative Environment User Interface

A collaborative framework must be simple to use for researchers who are not computer professionals. Installation by a researcher with average familiarity with computers and the Internet should be straightforward.

3.2 Application Sharing

The most convenient way to present engineering analyses in a collaborative environment is to utilize methods of sharing computer applications that are normally used in these analyses. Two types of application sharing are desirable:

- Share an application such that other participants can see the application, but the other participants do not direct execution of the application.
- Share an application such that the other participants can see the application and can execute any functionality of the application.

3.3 Whiteboard

Another useful method of sharing results of engineering analyses is through a Whiteboard. A Whiteboard is a screen window that displays static images. Whiteboards generally have a set of tools for manipulating and annotating the images. The following Whiteboard tools would be useful:

1. Import images from files [MPEG, Joint Photographic Experts Group (JPEG), Tagged Image File Format (TIFF), Graphics Interchange Format (GIF), and PNG formats].
2. Save images to files (MPEG, JPEG, TIFF, GIF, PNG formats).
3. Screen capture a selected area of user's display into Whiteboard.
4. Annotate images using a set of drawing tools.
5. Copy, cut, paste, and delete images and/or annotations.
6. Point to features in the image.
7. Zoom image size larger or smaller.
8. Move image on screen in any direction.
9. Display multiple images on the same screen.
10. Display multiple images on different screen pages.

Collaboration Requirements

3.4 Document Editor

In engineering applications, numerous reports and documents describing the results of tests and analyses are generated. A collaborative document editor would allow the papers to be reviewed and edited in a very timely manner without the need for lengthy faxes or time-consuming mail. A collaborative document editor must be able to handle integrated equations, figures, images, and tables that engineering reports are likely to contain.

3.5 Text Chat

A Text chat tool is useful for sending short written messages back and forth between conference participants. This tool proves useful if there are problems with voice communications.

3.6 Audio Chat

The most efficient way for collaborators to discuss shared visual results is through verbal communication. Handheld telephone sets tie up one hand that may be needed for the keyboard. In addition, they only allow one person at a collaboration site to speak or listen at a time. These problems can be solved through the use of speakerphones, but the sound can be distorted and difficult for everyone to hear. An Audio chat tool, which sends audio signals over the Internet, is a possible alternative to telephones and would not incur long distance phone charges. The Audio chat tool needs to provide fully duplexed, synchronous communications between multiple conference participants. Half-duplexed, walkie-talkie audio capabilities are not conducive to discussing engineering analyses.

3.7 Video

Real-time video is generally used in collaborative frameworks to view the other participants in a conference. Current application requirements may not justify the extra video bandwidth needed for this purpose. However, real-time video could be useful in viewing, for example, fracture surfaces of test specimens, although still photographs from a digital camera might also be sufficient.

3.8 Two-Dimensional Graphics

The 2-D X-Y style graphs are used extensively in engineering applications to communicate experimental and numerical data. The 2-D graphs are typically produced using the software packages KaleidaGraph at ORNL and LOGOS at UIUC. A collaborative system must be able to share these 2-D graphs.

3.9 Three-Dimensional Graphics

The results of finite-element computations are analyzed using the 3-D graphics programs Abaqus Post at ORNL and PATRAN at UIUC. A collaborative system must be capable of sharing the results of these 3-D graphics analyses.

3.10 File Transfer

While files can usually be transferred by electronic mail (e-mail) or an FTP program outside of the collaborative framework, having a file transfer tool in the collaborative framework would be a convenience. Files do not always transmit by e-mail correctly or may be blocked by the e-mail host because of size or security constraints. Using an FTP program to transfer files would require *separate* transfers to each participant in the conference by the owner of the file. Also, some sites may not allow FTP transfers.

3.11 Session Recording

A session recording capability could be used to document a collaborative conference for later review by the conference participants or by parties that could not be present.

4 Habanero Collaborative Tool

The description of the Habanero tool given in this section was drawn primarily from NCSA sources.

4.1 Structure

The NCSA Habanero tool is a software framework that facilitates the development of software for synchronous communication over the Internet. It also provides an environment for creating and participating in collaborative sessions and applying a suite of tools that use the framework and demonstrate many of its capabilities. Habanero supports any number of users that the network traffic can handle.

Habanero's implementation in Java allows a single source code base to be used on all hardware platforms that support Java(TM). Thus, collaborative sessions between participants using different hardware platforms, such as PCs and Unix workstations, are possible. The cross-platform synchronization of arbitrary tool types is made possible by sharing Java objects using the Habanero Application Programming Interface (API). Habanero works by replicating software tools or applications across clients and then sharing all state changes in those applications. The Habanero framework provides state and event synchronization for the application's multiple copies. When a new client joins a session, information is sent about which applications are running in that session. Each application then sends enough information to allow new clients to completely replicate the important state being shared by the existing copies of that application. Habanero ensures that all clients experience the same state and change events in the same order, which results in applications appearing the same to all clients.

4.2 Description of Current Capabilities

Habanero provides a collaborative environment that enables each participant to create, join, leave, and browse sessions. As described by NCSA, the Habanero framework and its user interface (UI) support the following functions:

- Multiple sessions. A participant can collaborate in several different sessions concurrently.
- Extension of the set of collaborative applications. Applications can be added to the Habanero environment.
- Detailed information about a session such as its name, schedule, agenda, and who is allowed to participate. It also supports anonymity of the participants in the session if desired.
- A preconfigured session launch facility that allows users to describe a session once and save this information for later reuse.
- A notification mechanism to invite participants to join an on-line session. This system supports both synchronous (a window pops up on the invited person's display) and asynchronous notification (an e-mail message).
- User roles. The initiator of a session has a specific role in defining the characteristics of a session by determining the group of collaborators allowed to join that session. The initiator also defines the notification process and the authentication mechanism. Participants can play roles such as active participant, passive observer, or other roles described by specific tools.
- Awareness of others. The Habanero UI shows the current participants, where they are located, how active they are, and which participant used each tool last.
- Multilanguage support. The Habanero UI supports displays in French, Spanish, and English. Multilanguage support for each collaborative tool is left to its own developers.
- Security features such as access control and authentication.
- Capture and replay of sessions. Each user can capture an entire session or a partial session and replay it later in single user mode.

Habanero

The current distribution of Habanero contains various applications and tools that were developed mainly to illustrate the framework potential and to facilitate the design and implementation of collaborative software. Tools of general interest distributed with Habanero 2.0 are the Whiteboard, the Audio chat tool, the Chat tool, and the Voting tool. Other tools, such as Lattice (a crystallographic tool) and the upcoming collaborative LOGOS, were developed by various organizations within the scientific community.

4.3 Installation of the Habanero System

The Habanero 2.0 system runs virtually on any platform that supports a Java implementation compatible with the Java Development Kit (JDK) version 1.1.5. However, because Java implementations are very new, they sometimes contain minor "bugs" that can cause problems.

Currently, Habanero has been tested and works well on Microsoft Windows95, Microsoft WindowsNT 4.0 or higher, and Sun Solaris 2.6 or higher. Habanero also works on SGI-IRIX, HP-UX, and MacOS, with minor window sizing and repainting bugs that come from the native implementations of Java on those platforms.

All Habanero tools developed in Java will run on all the above platforms. Tools that were developed in other languages, like C, C++, or Fortran, will run only on the platforms on which they were compiled. For example, the Audio chat tool runs only on Windows95, WindowsNT, and Solaris.

In general, minimum platform requirements for Habanero are the same as the minimum requirements for the Java implementation on that platform. Minimum requirements for an IBM-PC compatible machine running Windows is a 486 processor and at least 32 MB of memory. All platforms must have a Java Virtual Machine (VM) installed to run Habanero.

Installation details can be found at <http://www.ncsa.uiuc.edu/SDG/Software/Habanero/Release/index.html>, the NCSA Habanero Web site. Habanero installation involves downloading the class files from the Web site, changing the CLASSPATH environment variable to point to the Habanero files, and copying the habanero/rsc directory to the user's home directory. After modifying the *user.props* file to point to the current directories, Habanero is ready to start. An InstallShield executable automates this installation process on Windows95 and WindowsNT platforms.

5 Performance Evaluation of Habanero

5.1 Simple Collaborative Environment User Interface

Habanero has a simple interface for starting a collaborative session. One of the participants initiates the conference by running the Habanero server executable and then the Habanero client executable. Both programs display a DOS window for error messages and other system messages. The conference initiator then defines a session by entering the session name, server IP address, and port number in the Habanero Session Definition/Off-Line client window as shown in Fig. 1. The other conference participants then run the Habanero client executable and enter the same session definition information. Session definitions can be saved and reused.

When connection to the conference is successful, the Habanero Session/On-Line window, shown in Fig. 2, is displayed. Available collaborative applications are listed under the file folder tree as shown in Fig. 3. The Whiteboard, Audio chat, Text chat, and Text Editor tools are located under the Tools subfolder of the Demo folder. Double clicking on a tool icon starts the tool application.

The buttons to the right of the file folder tree extend the Session/On-Line window to display additional information as shown in Fig. 3. Additional information options include session information, list of active applications, list of participants, location map of participants, session notification list, and session security information.

A few minor problems were noted with the Habanero user interface:

1. The vertical scroll bars in the Habanero Session/On-Line window do not function properly.
2. In the Habanero Session/On-Line window, the pop-up tool tips for the Leave Session, Record Session, Save Session Definition, and Open Mailer buttons only work if the mouse cursor is dragged from the surrounding background area onto the button. The tool tips do not work if the mouse cursor is dragged from one button to the next.
3. The Port number text box on the Session Definition/Off-Line and Session/On-Line windows is too small to completely display four-digit port numbers as shown in Figs. 2 and 3.

Figure 1 Habanero Session Definition window

Figure 2 Habanero Session On-line window

Figure 3 Habanero Notification List window

4. Many of the message screens have windows that are too small on some PCs. The full text message cannot be read, and the buttons cannot be pressed without first resizing the window.
5. Screen refresh times were sometimes slow.

5.2 Application Sharing

For Habanero to share an application among conference participants, a copy of the application must exist as a Habanero client for each participant. Habanero replicates all important state information of the application to each Habanero client. The application appears the same to each participant because Habanero ensures that all clients see the same state and change events and see them in the same time order. For example, when a participant draws a line on the Whiteboard, the information about this line is sent to the Whiteboard clients of all the other collaborators. Each collaborator's Whiteboard client then draws the same line.

Most Habanero tools developed in the Java programming language will run on any platform that supports Habanero. Java applications that call system-specific libraries will only run on the platforms that support those library calls. Habanero tools developed in other languages, such as C, C++, or Fortran, will only run on the platforms for which they have been compiled. Moreover, these client applications must be modified, sometimes significantly, to operate within a Java environment.

Performance

The Habanero Developers API documentation details special considerations that the programmer must be aware of when writing new Java Habanero application tools or adapting previously written programs. Attention must be paid to the architecture of the program code. In particular, the recognition of user events, such as a key press or mouse click, and the actions that are performed in response to user events, such as drawing text or lines on the Whiteboard, must be separated in the application code.

Habanero applications can be developed by any interested party and included as a tool in the Habanero tools directory. A Habanero Conversion Wizard is provided to facilitate converting previously written Java applets into Habanero tools. Many applications written in other programming languages can also be incorporated into Habanero by wrapping the program in a Java layer.

The Habanero application sharing mechanism does facilitate sharing of COTS programs. To share a COTS program in Habanero, the programmer must obtain the source code for the program, and the program must meet the requirements for Java wrapping. Obtaining a COTS source code generally involves signing license agreements and paying royalty fees.

5.3 Whiteboard

The Habanero Whiteboard consists of an image display area and a drawing toolbar as shown in Figs. 4 and 5. In addition to drawing tool buttons, the drawing toolbar contains buttons for manipulating the position of images.

5.3.1 Import Images From Files

Habanero can only import images from files created using the public domain TIFF or JPEG image formats. Other image formats are not imported because they are proprietary and would require paying for a license.

Among the graphics programs frequently used at ORNL, only Adobe Photoshop can save images as TIFF or JPEG files. To use images from ClarisDraw or KaleidaGraph in Habanero, the image must first be saved as a PICT file. The PICT file can then be read into Photoshop and saved as a TIFF or JPEG file. To use PostScript images in Habanero, the Unix shareware program XV can be used to convert image formats to TIFF or JPEG. This requires an inconvenient file transfer to and from the Unix machine.

5.3.2 Save Images to Files

Habanero has a file-save option for saving Whiteboard images in either the TIFF or JPEG formats. Annotations drawn on the image are saved with the image.

5.3.3 Screen-Capture Selected Area of User's Display into Whiteboard

Habanero cannot capture screen images for display in the Whiteboard. NCSA has no current plans to write a screen-capture tool for Habanero, because the level of effort involved in writing such a tool would be large.

Pacific Northwest National Laboratory (PNNL) required 2 years to develop a screen-capture tool in C++. PNNL is trying to incorporate this tool into Habanero either by modifying the C++ code or by porting the code to Java. However, the PNNL screen-capture tool would be a separate tool from the Whiteboard and would not be integrated into the Whiteboard. This tool might be ready for distribution by mid-1998, but there are no guarantees.

Figure 4 Habanero Whiteboard

Figure 5 Habanero Whiteboard with multiple images

As a work-around for the lack of an integrated screen-capture tool in Habanero, a separate screen-capture program can be used if it will save images in TIFF or JPEG. The Unix shareware image manipulation program XV, which has a built-in screen capture tool, was used to function in this mode. To capture screens on a PC, XV was run in a X-Windows server on the PC. Screen captures were also accomplished with the Netscape Conference Whiteboard tool that will save images in JPEG and TIFF formats. The Habanero Whiteboard was able to read and display these files.

5.3.4 Annotate Images Using a Set of Drawing Tools

Habanero contains an adequate set of drawing tools. These tools allow any participant to draw circles, squares, straight lines, free-form lines, text, and crossbars in any color on the image. However, the thickness of the drawing lines cannot be specified.

The function of some drawing tool buttons is not immediately obvious to a new user. Modifying Habanero to display a help message in the status bar of the Whiteboard window would make the button function more obvious.

The drawing tools are located in a horizontal toolbar at the bottom of the image area by default. This toolbar takes up considerable window area that obstructs the viewing of large images. However, the drawing toolbar can be undocked to a separate window and resized. When resized horizontally, the toolbar's icons are moved closer together. When resized smaller than some minimum width, the toolbar becomes unusable. When resized vertically, the toolbar's icons are not repositioned, and a large blank space below the icons is the result.

5.3.5 Copy, Cut, Paste, and Delete Images and Annotations

Habanero does not have a copy, cut, or paste function. However, Habanero provides a menu bar option called *Clear*, which deletes images and annotations. Three options are provided on the *Clear* menu: *Clear Plots* deletes annotations on the Whiteboard, *Clear Images* clears all images read into the Whiteboard, and *Clear Everything* deletes all images and annotations. Individual images and annotations can be deleted one at a time by using the delete button on the drawing toolbar. There is no way to undo a deletion on the Habanero Whiteboard.

5.3.6 Point-to Features in the Image

Habanero does not currently have a pointer tool that a participant could use to point to features on an image. As a work-around, any participant can construct a static free-form arrow with the drawing tools.

5.3.7 Zoom Image Size Larger or Smaller

Habanero does not currently have a zoom image capability, and there are no plans to add this function.

5.3.8 Move Image on Screen in any Direction

Images on the Habanero Whiteboard can be moved in any direction by clicking on the twelfth Whiteboard tool and then grabbing and dragging the image with the mouse.

5.3.9 Display Multiple Images on Same Screen

Habanero is able to read in multiple image files. The images are stacked on top of each other in a single Whiteboard window. If the image on top is smaller than the underlying images, the underlying images appear in the background. Clicking on the tenth Whiteboard tool button and then clicking on an image places that image on the bottom of the stack. Clicking on the ninth Whiteboard tool button and then clicking on an underlying image places that image on top of the stack. The image on top may need to be moved first to expose a section of the underlying image. If the images are small enough, they can be repositioned to prevent overlapping.

5.3.10 Display Multiple Images One at a Time on Different Screen Pages

Habanero only has one Whiteboard screen, so multiple images cannot be placed on separate screen pages. There are no plans to add this function to Habanero. However, multiple Whiteboard tools can be opened.

5.4 Document Editor

The Habanero Text Editor, shown in Fig. 6, works competently as a simple text editor. However, it will not handle equations, figures, tables, or any of the special formatting functions supported by full-featured document editors. This is a serious drawback and makes the Habanero Text Editor minimally useful.

There are no plans to incorporate a full-featured editor into Habanero. Currently available document editors that would fulfill this need are all commercial codes. Incorporating a commercial editor into Habanero would require having access to the source code so that it could be wrapped in Java. Such code access would require paying royalty fees. Writing a full-featured document editor would be very costly and time-consuming.

5.5 Text Chat

The Habanero Text chat tool, shown in Fig. 7, works well and is easy to use. Any participant can input a line of text to be displayed in the chat window of all participants. Each line of text in the chat window is preceded by the author's name. A participant can specify a new name, clear all text in the chat window, and start logging text sent to the chat window.

5.6 Audio Chat

The Habanero Audio chat tool, shown in Fig. 8, only works in a half-duplex walkie-talkie type mode. Only one person can talk at a time. When a participant wants to talk, the "raise hand" button is pressed in the Audio chat tool, and the request is

Figure 6 Habanero Text Editor

Figure 7 Habanero Text chat window

Figure 8 Habanero Audio chat window

put on a list. When the current speaker relinquishes control by toggling the microphone button off, the next person on the list toggles the microphone button on and starts talking. This mode of conversation was found to be cumbersome and less preferable than using speakerphones. A full-duplex Audio chat with true multiway conversation capabilities would be much better.

5.7 Video

Habanero does not have real-time video collaboration capabilities. However, Habanero has a video player tool that will play prerecorded video files.

5.8 Two-Dimensional Graphics

NCSA is currently working on incorporating UIUC's LOGOS 2-D graphics program into Habanero. LOGOS is a Fortran-77 program that drives X-Windows output on Unix machines. On Windows 95/NT, LOGOS uses the simple window graphics capabilities provided in Fortran libraries. NCSA has developed a JAVA wrapper for LOGOS that enables collaborative execution of LOGOS. Each participant executes a native port of LOGOS on their computer (Windows 95/NT, Sun, SGI, and HP).

5.9 Three-Dimensional Graphics

Currently, there are no 3-D graphics tools for Habanero.

5.10 File Transfer

There is no generic file transfer tool in Habanero.

5.11 Session Recording

Any conference participant can record the Habanero session by clicking the Session Record button on the Session Definition/Off-Line window and entering a save file name. The recorded session can be played back later with the separate Habanero Replay Editor program.

6 Evaluation of Alternative Collaboration Tools

As noted in the previous section, Habanero fails to meet several of the major performance criteria for a production-quality collaborative framework described in Chap. 2. To evaluate the feasibility of those performance criteria, ORNL conducted a market survey of other collaborative frameworks. Several collaborative frameworks were identified that work with Windows NT/95 PCs. One of these, Microsoft NetMeeting, was chosen for a more in-depth evaluation because it is available as a free download from the Microsoft Web site. NetMeeting has Whiteboard and Text chat tools and supports application sharing, file transfers, and two-way audio/video.

Two additional commercial products were also briefly evaluated. The DataBeam Meeting Tools software, available for about \$40, is an add-on presentation and Whiteboard client tool that works in conjunction with NetMeeting. The Netscape Conference has Whiteboard and Text chat tools, supports collaborative Web browsing, file transfers, and two-way audio, but it does not support general application sharing or video. While the evaluation focuses on NetMeeting, significant differences between NetMeeting and Meeting Tools or Conference are noted.

NetMeeting can use either the centralized or decentralized multipoint conference model. The centralized model requires the addition of a commercial MCU software program running on a server machine. These MCU server programs, which vary in price from about \$250 to \$40,000, were not tested in this evaluation. The number of conference participants in the centralized model is limited by the specifications of the MCU program. In the decentralized model, NetMeeting has no inherent limit on the number of conference participants, but it experiences dramatic performance degradation with more than 20 participants. Netscape Conference appears to be limited to two-way collaboration.

NetMeeting provides several methods for connecting to conference participants. Connections can be made through an Internet Locator Service (ILS) or by entering the network host or IP addresses of conference participants. Public ILS servers that anyone can use to make NetMeeting connections are available from Microsoft and several other companies. Any site can also set up its own ILS server on a PC running the Windows NT 4.0 Server. The ILS software can be downloaded at no cost from Microsoft. Netscape Conference also makes connections either through a Netscape Directory Locator Service (DLS) server or directly through IP addresses.

NetMeeting conforms to the T.120 industry standard for data collaboration, except for the T.126 standard for Whiteboards. The NetMeeting Whiteboard was written before the T.126 standard was adapted by the ITU. NetMeeting also conforms to the H.323 industry standard for video/audio collaboration. This conformance to industry standards allows NetMeeting to work with various third-party client and server programs. This flexibility is advantageous because each of the third-party applications has different strengths and weaknesses. NetMeeting tends to have better developed tools for data collaboration and less developed tools for audio/video collaboration than many of the third-party applications. However, Meeting Tools has more sophisticated Whiteboard capabilities than NetMeeting. Also, the third-party MCU server programs tend to have better security features and enhanced audio/video mixing capabilities.

6.1 Simple Collaborative Environment User Interface

NetMeeting was tested in a decentralized multipoint mode, that is, without the use of a third-party MCU. Connections to conference participants were initiated using the public ILS servers provided by Microsoft. By default, NetMeeting is configured to automatically log into one of the Microsoft ILS servers on startup. Occasionally, difficulties were experienced in making connections through the public Microsoft ILS servers, probably because of the heavy load on these machines.

Evaluation

The NetMeeting client application startup window is geared toward making Internet calls or connections as shown in Figs. 9 and 10. By default, the NetMeeting window displays a directory of all parties logged into the selected ILS server, including the person's e-mail address, name, city, state, and audio/video capability. On the default Microsoft ILS servers, this directory can be rather long.

A customized list of *SpeedDial* numbers can be generated for parties called frequently. The *SpeedDial* menubar item contains a selection for adding new *SpeedDial* entries as well as a list of all *SpeedDial* entries. Clicking the *SpeedDial* icon on the left of the NetMeeting screen will display in the NetMeeting window a list of *SpeedDial* e-mail addresses along with the log-in status of the party as shown in Fig. 9. When connecting directly via IP addresses, the *SpeedDial* list displays the IP address rather than the e-mail address of users. No name is associated with either the e-mail address or IP address on the *SpeedDial* list. This was the most significant drawback found with NetMeeting's user interface.

A connection is made by double clicking on a *SpeedDial* address in *SpeedDial* window or selecting one from the *SpeedDial* menubar item. A confirmation message is displayed to the contacted party for acceptance or rejection of the connection. After a connection is established, the NetMeeting displays the *Current Call* window as shown in Fig. 10. Information on the *Current Call* window does include the name of connected parties.

Netscape Conference program has more simplistic, easier to use interface than NetMeeting. Up to six *Speed Dial* buttons can be customized with a participant's name. Conference also includes an address book in which names, e-mail addresses, etc., can be entered. A two-way conference can be initiated by clicking a *Speed Dial* button or highlighting a name in the address book and clicking the *Call* button.

Figure 9 NetMeeting SpeedDial window

Figure 10 NetMeeting Current Call window

6.2 Application Sharing

NetMeeting was able to share *all* Windows NT/95 applications that were tested within the project. Figure 11 shows NetMeeting sharing Abaqus Post, the 3-D graphics postprocessor used in ORNL's fracture mechanics simulations. In addition, applications running on a Unix workstation could be shared by first displaying the application on Windows NT/95 with an X-Windows server (e.g., Hummingbird's eXceed, Digital's eXcursion, or White Pine's Exodus). NetMeeting allows sharing in two modes: (1) other participants can view the application but cannot interact with the application, and (2) other participants can see and interact with the application. This works correctly even for shared X-Windows that drive Unix applications.

Netscape Conference supports collaborative Web browsing using the Netscape Web browser. Conference does not support generic application sharing.

6.3 Whiteboard

The NetMeeting Whiteboard tool is shown in Fig. 12 with an annotated Abaqus Post image.

Figure 11 NetMeeting application sharing of the Abaqus Postprocessor

Figure 12 NetMeeting Whiteboard with screen-captured image and annotations

Evaluation

6.3.1 Import Images From Files

NetMeeting will only read files with the NetMeeting Whiteboard-specific WHT format. The authors have not seen any other applications that use this format. However, this is not considered to be a major problem because NetMeeting can incorporate images from other programs either through screen-captures or through the clipboard copy and paste functionality.

The DataBeam Meeting Tools software can import image files of various formats. Netscape Conference can open Bitmap, GIF, TIFF, and JPEG files.

6.3.2 Save Images to Files

Any participant in a NetMeeting session can save the Whiteboard images to a file with the WHT format. All images and annotations on all pages of the Whiteboard are saved. Images cannot be saved to other image file formats such as JPEG or TIFF.

The DataBeam Meeting Tools software can only save images in a Meeting Tools specific file format. Netscape Conference can save annotated images in Bitmap, TIFF, and JPEG files.

6.3.3 Screen-Capture Selected Area of User's Display into Whiteboard

The NetMeeting Whiteboard supports two types of screen captures. In *Select Window* screen-capturing, an entire window is captured by clicking anywhere in the desired window. In *Select Area* screen-capturing, any rectangular area on the screen is captured by dragging the mouse to select the area.

NetMeeting can also copy images to and paste images from the standard Windows 95/NT clipboard. This provides another means of capturing screen images.

The authors also found the Whiteboard screen-capture tools to be very useful outside of conferencing applications. All of the NetMeeting and Habanero figures in this paper, except Fig. 12, were produced using the NetMeeting Whiteboard's screen-capture tools. The NetMeeting Whiteboard could not be used to capture an image of itself, so the Netscape Conference Whiteboard was used to capture Fig. 12. Selected Whiteboard images were copied and then pasted into this document using the transparent Windows clipboard.

6.3.4 Annotate the Image Using a Set of Drawing Tools

NetMeeting has drawing tools that include the ability to draw text, free-form lines, straight lines, rectangles, and ellipses in any selected color. Rectangles and ellipses can be colored outlines or color-filled solids. NetMeeting also has a highlight tool that colors a see-through line. Four width sizes can be selected for all lines and outline shapes. The color and line width of selected annotations can also be changed after the annotations have been created. Also, annotations can be grabbed and moved to another position on the Whiteboard.

6.3.5 Copy, Cut, Paste, and Delete Images and/or Annotations

The NetMeeting Whiteboard allows selection of images and/or annotations either individually, as a group, or all at once. Selected images and/or annotations can then be copied, cut, pasted, or deleted. The copy, cut, and paste functions use the Windows clipboard. Therefore, a paste can be made either to the same Whiteboard page, to a different Whiteboard page, or to another windows application that uses the windows clipboard. In addition, a copy from another Windows application can be

pasted into the NetMeeting Whiteboard. The last cut or deletion can be undone. However, no undo features exist for copies and pastes.

6.3.6 Point-to Features in the Image

The NetMeeting Whiteboard has a pointer tool that is shaped like a hand with a pointed finger. The pointer can be moved about the Whiteboard screen by grabbing it with the mouse and dragging it to the desired location. The pointer can be toggled off.

6.3.7 Zoom Image Size Larger or Smaller

NetMeeting Whiteboard images can be zoomed (enlarged) by a factor of 4. This corresponds to doubling the height and width of the image. The image size can be toggled between its original size and this fixed zoom size. The image size cannot be reduced in the Whiteboard.

The DataBeam Meeting Tools software supports variable-sized zooms for both enlargements and reductions in image size. Netscape Conference supports three levels of enlargement and reduction zooms.

6.3.8 Move Image On Screen in any Direction

Images can be moved on the Whiteboard screen in any direction in NetMeeting.

6.3.9 Display Multiple Images on Same Screen

Multiple images can be displayed on the NetMeeting Whiteboard screen.

6.3.10 Display Multiple Images One at a Time on Different Screen Pages

Additional pages can be added to the NetMeeting Whiteboard. Forward and backward buttons are used to go from one page to the next.

DataBeam's Meeting Tools also supports multiple Whiteboard pages. However, the Netscape Conference Whiteboard only supports one page.

6.4 Document Editor

NetMeeting does not have an incorporated document editor. However, NetMeeting can share various text and document editors in collaborative mode. The authors tested Microsoft Word and Interleaf and were able to collaboratively edit a document with equations and figures. In addition, images could be copied from the Whiteboard and pasted into the Microsoft Word document. The Emacs editor was also tested with NetMeeting and worked well in collaborative mode.

6.5 Text Chat

The NetMeeting Text chat tool, shown in Fig. 13, works well and is easy to use. Any participant can input a line of text to be displayed in the chat window of all participants. Each line of text in the chat window is preceded by the author's name. A participant can specify a new name, clear all text in the chat window, and start logging text sent to the chat window.

Figure 13 NetMeeting Text chat window

6.6 Audio Chat

The Audio chat tool in NetMeeting will only work between two participants at a time. It does however, work in full-duplex mode. Several NetMeeting-compatible MCU conference servers have or are developing multipoint, full-duplex audio capabilities.

6.7 Video

NetMeeting allows real-time video collaboration, but only between two participants at a time. Several NetMeeting-compatible MCU conference servers have multipoint video capabilities.

6.8 Two-Dimensional Graphics

NetMeeting does not have an incorporated 2-D graphics program. However, NetMeeting can share various 2-D graphics programs. The authors tested LOGOS running on a Windows 95 PC and found that it works in collaborative sharing mode. Also, Tecplot running on a Unix workstation was tested by displaying the program on a Windows 95 PC using the X-Windows server Exodus. Tecplot works very well in the NetMeeting collaborative sharing mode.

6.9 Three-Dimensional Graphics

NetMeeting does not have an incorporated 3-D graphics program. However, NetMeeting can share various 3-D graphics programs. A small OpenGL 3-D graphics demonstration program written in Visual C++ for Windows was tested in the NetMeeting collaborative sharing mode. All conference participants were able to push the application buttons to make the 3-D object rotate, zoom, etc. The commercial Abaqus Post 3-D graphics program used to evaluate the results of Abaqus finite-element analyses was also tested. All conference participants were able to type in Abaqus Post commands and use the mouse to interactively rotate the graphics object.

6.10 File Transfer

NetMeeting participants are able to send files to other participants and receive files from other participants. In NetMeeting tests, the authors were able to send the NRC participant a Microsoft Word file that would not transfer correctly through the e-mail system.

6.11 Session Recording

NetMeeting does not have an option for recording a collaborative session. However, several NetMeeting-compatible MCU conference servers do have session recording capabilities.

7 Assessment of Collaboration Tools

Habanero has a few advantages over NetMeeting. The Java-based Habanero software was designed to be platform-independent and runs on Windows PCs, Unix workstations, and Macintoshes. However, the Java language remains *insufficiently robust to allow true platform independence* for all of Habanero's tools. For example, the Audio chat tool is very much platform-dependent. While NetMeeting only runs on Windows 95/NT PCs, the authors do not see this as a major hindrance given the general availability of PCs. Also, NetMeeting-compatible products for Unix and Macintosh platforms are in development. Farallon's recently released Timbuktu Pro for the Macintosh allows sharing of applications with PCs running NetMeeting. Data Connection has announced the availability of the Unix DC-Share suite of data-conferencing components that are interoperable with NetMeeting on PCs. However, DC-Share is currently only sold to OEMs and large corporate end-users.

NetMeeting has several advantages over Habanero. The NetMeeting Whiteboard is more fully developed and has essential features that the Habanero Whiteboard lacks. DataBeam's Meeting Tools software, used in conjunction with NetMeeting, supports even more Whiteboard and presentation capabilities lacking in Habanero. NetMeeting has a file transfer tool, which Habanero does not have. While NetMeeting does not have a session recording capability and its full-duplex Audio chat is limited to two parties, other commercially available NetMeeting-compatible MCU servers have or are developing these capabilities. Habanero has a session recording capability, but its Audio chat is only half-duplex and thus not likely to be used.

By far, the most significant advantage of NetMeeting over Habanero is the very general application sharing capabilities of NetMeeting. NetMeeting allows collaborative sharing of any application that displays on a PC *without any modifications* to the program code. This includes programs executing on PCs and programs executing on Unix workstations and displayed on a PC through a standard X-Windows server. Habanero can only share applications that have been incorporated into the Habanero framework by wrapping the source code in a Java layer. While NCSA provides a Conversion Wizard tool for facilitating this process, it may still be a time-consuming and costly process to convert previously written codes for application sharing in Habanero. Also, the license fees associated with obtaining source code for commercial applications may be prohibitive.

While the application sharing capabilities of NetMeeting are currently more applicable to the needs of sharing engineering analyses than those of Habanero, the technical advances in application sharing present in Habanero and other Java-based collaborative research projects should be recognized. NetMeeting uses display broadcasting for application sharing, while Habanero uses event broadcasting. Display broadcasting uses considerably more network bandwidth than event broadcasting. This will become an increasingly important consideration as the level of network traffic increases with increasing numbers of users. Continued research in event broadcasting technologies is important for this reason.

The authors believe that development of methods for sharing applications using event broadcasting without the necessity of modifying the application's code is an important area for future research. Syracuse University's Java-based TANGO collaborative framework, which runs in a Web browser, has made some progress in this area. *Sharing Agents* are used to share Microsoft Word, Excel, PowerPoint, and Visual C++, although only one application can be shared at a time. Sharing other PC applications requires updates to the Sharing Agent configuration file and the Windows registry.

8 Conclusions and Recommendations for Future Development

At this point in time, collaboration tools based on display broadcasting technologies are more fully developed than tools based on the Java-based event broadcasting technologies. In particular, the Whiteboard tools and application sharing capabilities of NetMeeting are more fully developed than those of Habanero. Thus, the authors recommend using NetMeeting rather than Habanero for sharing engineering analyses through collaborative conferences. Furthermore, the authors make the following recommendations for follow-on work:

- organization of a pilot collaborative network that includes NRC contractors and associated NRC technical monitors engaged in RPV and piping integrity research;
- installation of Microsoft's ILS software on a Windows NT server at a selected NRC-contractor site to support the pilot collaborative network; this server would be used in place of the publicly available Microsoft ILS servers;
- evaluation of commercially available, NetMeeting-compatible MCU server software programs installed on a Windows NT server; this includes evaluation of bandwidth consumption, security features, and full-duplex, multiparty audio capabilities;
- further evaluation of commercially available, NetMeeting-compatible data sharing tools;
- development of user convenience tools; this may include user interface tools for organizing the various tasks involved in collaboratively sharing engineering analyses and/or smart help tools to assist the engineer in efficiently using the best set of available collaborative tools for the task; and
- evaluation of the pilot network based on trial collaborative sessions conducted over a 12-month period.

Currently, the NetMeeting tool does not meet requirements for full-duplex, multiparty audio; consequently, more work must be done to achieve this goal. Various commercially available NetMeeting-compatible MCU servers can be evaluated to determine if their audio capabilities are adequate. Also, headsets, microphones, and speakers with echo cancellation need to be evaluated to determine if they improve the audio quality. If the third-party MCU option is not viable, then the use of telephone conferencing equipment could be evaluated in conjunction with NetMeeting.

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BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER
(Assigned by NRC, Add Vol., Supp., Rev.,
and Addendum Numbers, if any.)

NUREG/CR-5570
ORNLT/M-13674

2. TITLE AND SUBTITLE

Application of the NCSA Habanero Tool for Collaboration on
Structural Integrity Assessments

3. DATE REPORT PUBLISHED

MONTH	YEAR
November	1998

4. FIN OR GRANT NUMBER

W6735

5. AUTHOR(S)

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6. TYPE OF REPORT

Technical

7. PERIOD COVERED (Inclusive Dates)

8/1/96 - 8/30/98

8. PERFORMING ORGANIZATION - NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

Oak Ridge National Laboratory
Oak Ridge, TN 37831-6283

University of Illinois at Urbana-Champaign
205 North Matthews
Urbana, IL 61801

9. SPONSORING ORGANIZATION - NAME AND ADDRESS (If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)

Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES

S.N.M. Malik, NRC Project Manager

11. ABSTRACT (200 words or less)

The Habanero software was developed by the National Center for Supercomputing Applications at the University of Illinois, Urbana-Champaign, as a framework for the collaborative sharing of Java applications. The Habanero tool performs distributed communication of single-user, computer software interactions to a multiuser collaborative environment. An investigation was conducted to evaluate the capabilities of the Habanero tool in providing an Internet-based collaborative framework for researchers located at different sites and operating on different workstations. These collaborative sessions focused on the sharing of test data and analysis results from materials engineering areas (i.e., fracture mechanics and structural integrity evaluations) related to reactor pressure vessel safety research sponsored by the U.S. Nuclear Regulatory Commission. This report defines collaborative-system requirements for engineering applications and provides an overview of collaborative systems within the project. The installation, application, and detailed evaluation of the performance of the Habanero collaborative tool are compared to those of another commercially available collaborative product. Recommendations are given for future work in collaborative communications.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

collaborative tools, Habanero tool, Java applications, multiuser collaboration

13. AVAILABILITY STATEMENT

unlimited

14. SECURITY CLASSIFICATION

(This Page)

unclassified

(This Report)

unclassified

15. NUMBER OF PAGES

16. PRICE