STCI: OptIPlanet Cyber-Mashup

Persistent Visualization and Collaboration Services for Global Cyber Infrastructure

NSF Award OCI-0943559

www.sagecommons.org



Annual Report September 1, 2009 – August 31, 2010
Submitted October 4, 2010

Jason Leigh, Maxine Brown, Andrew Johnson, Luc Renambot
Electronic Visualization Laboratory
University of Illinois at Chicago
851 S. Morgan St., Room 1120
Chicago, IL 60607-7053
spiff@uic.edu

Table of Contents

1. Participants 3
   1.A. Primary Personnel 3
   1.B. Other Organizations That Have Been Involved as Partners 3
   1.C. Other Collaborators or Contacts 4
2. Activities and Findings 6
   2.A. Research Activities 6
      2.A.1. Overview 6
      2.A.2. SAGE User Community 6
         2.A.2.1. SAGE Sites 6
         2.A.2.2. SAGE Website Statistics 7
      2.A.3. SAGE Improvements for the Past Year 12
         2.A.3.1. SAGE Code Releases 12
         2.A.3.2. Cyber-Mashup Authoring 12
         2.A.3.3. Cyber-Mashup Editing and Interactivity 13
         2.A.3.4. Enhanced Scalable Streaming 18
      2.A.4. Cyber-Mashup Collaboration Service 20
      2.A.5. Education, Outreach and Broader Participation 20
         2.A.5.1. SAGE on YouTube 20
         2.A.5.2. SAGE Press Releases 20
         2.A.5.3. SAGE in the Classroom 21
         2.A.5.4. SAGE Outreach 22
         2.A.5.5. SAGE Technical Demonstrations and Presentations 23
   2.B. Research Findings 29
      2.B.1. Cyber-Mashup Authoring 29
      2.B.2. Cyber-Mashup Editing and Interactivity 29
      2.B.3. Enhanced Scalable Streaming 30
      2.B.4. SAGE in the Classroom 31
   2.C. Research Training and Development 32
   2.D. Outreach Activities 32
3. Publications and Products 33
   3.A. Journal Publications 33
   3.B. Books / Publications 33
   3.C. Internet Dissemination 33
   3.D. Other Specific Products 33
4. Contributions 34
   4.A. Contributions within Discipline 34
   4.B. Contributions to Other Disciplines 34
   4.C. Contributions to Human Resource Development 34
   4.D. Contributions to Resources for Research and Education 34
   4.E. Contributions Beyond Science and Engineering 35
5. Conference Proceedings 36
6. Special Requirements 37
   6.A. Objectives and Scope 37
   6.B. Special Reporting Requirements 37
   6.C. Animals, Biohazards, Human Subjects 37

1. Participants

1.A. Primary Personnel

Participant's Name(s)	Project Role(s)	>160 Hours/Yr
Jason Leigh	Principal Investigator	Yes
Maxine Brown	Co-Principal Investigator	Yes
Andy Johnson	Co-Principal Investigator	Yes
Luc Renambot	Co-Principal Investigator	Yes
Lance Long	Senior Personnel	Yes
Ratko Jagodic	Graduate Student	Yes
Hyejung Hur	Graduate Student	Yes
HeeJoo Kim	Graduate Student	Yes
Viktor Mateevitsi	Graduate Student	Yes
Sungwon Nam	Graduate Student	Yes

1.B. Other Organizations That Have Been Involved as Partners

King Abdullah University of Science and Technology (KAUST)
King Abdullah University of Science and Technology (KAUST) <www.kaust.edu.sa/> is an international graduate-level research university located in Thuwal, on the Red Sea in the Kingdom of Saudi Arabia. KAUST was inaugurated in September 2009 by King Abdullah, whose dream for more than 30 years has been to build a university dedicated to inspiring a new age of scientific achievement that will impact Saudi Arabia, the region and the world. To foster its growth, KAUST Global Collaborative Research (GCR) established Special Academic Partnerships (SP) with select institutions across the world to rapidly develop key laboratories and facilities on campus and initiate world-class research and programs in coordination with KAUST faculty. Through these Special Partnerships and other GCR Programs, KAUST has launched an active global research and education network geared towards solving challenging scientific and technological issues.

Sharp Laboratories of America
Sharp Laboratories of America (SLA) <www.sharplabs.com> is Sharp Corporation's first and only US-based research and development laboratory, focusing on the trends, technology issues, and product demands of North American markets in order to develop technologies to match. SLA sees a market for high-resolution interactive display systems in research laboratories and homes in the foreseeable future, and partners with the UIC Electronic Visualization Laboratory to learn how today's early adopters are using this technology.

Texas Advanced Computing Center
Texas Advanced Computing Center (TACC), University of Texas at Austin <www.tacc.utexas.edu>, enables discoveries that advance science and society through the application of advanced computing technologies. To fulfill this mission, TACC staff members assist research teams in properly employing the systems, software, and expertise necessary to foster educational innovation and to provide a greater societal impact. To support the world-class research, TACC provides advanced visualization resources and consulting services, including Stallion, one of the highest resolution tiled display walls in the world, and Longhorn, a very large hardware accelerated, remote, interactive visualization cluster. In late 2008, TACC hired EVL graduate Byungil Jeong, who received his PhD for SAGE and SAGE Visualcasting. TACC encourages Jeong to work with EVL on SAGE development.

1.C. Other Collaborators or Contacts

The SAGE User Community currently consists of ~58 major research and education institutions worldwide that use SAGE and contribute to its development. Those institutions are:

AUSTRALIA
AARNet www.aarnet.edu.au
Australian National University http://information.anu.edu.au/daisy/infoservices/2085.html
CSIRO Discovery Centre http://research.ict.csiro.au/research/labs/information-engineering/ie-lab-projects/optiportal
CSIRO Information and Communication Technologies, Marsfield www.csiro.au/resources/CSIROvision.html
Monash University – Caulfield http://messagelab.monash.edu.au/Infrastructure/OptiPortal
Monash University – Clayton http://messagelab.monash.edu.au/Infrastructure/OptiPortal
University of Melbourne www.unimelb.edu.au/
University of Queensland http://www.vislab.uq.edu.au/research/optiputer/

CANADA
Ciena Networks, Canada www.ciena.org
Simon Fraser University www.sfu.ca

CHINA
Chinese Academy of Sciences, Computer Network Information Center http://english.cnic.cn

CZECH REPUBLIC
Masaryk University, Laboratory of Advanced Networking Technologies (2 systems) www.sitola.cz/sitola/index.en.html

GERMANY
Braunschweig University of Technology, Institute of Computer and Network Engineering, Germany www.ida.ing.tu-bs.de

INDIA
Monsanto Research Centre (Bangalore) www.monsantoindia.com/monsanto/layout/researchcentre

JAPAN
Knowledge Graphics Technologies (KGT), Inc. www.kgt.co.jp
Kyoto University www.kyoto-u.ac.jp/en
National Institute of Advanced Industrial Science and Technology (AIST) www.aist.go.jp/index_en.html
National Institute of Information and Communications Technology, Koganei, Japan www.nict.go.jp/index.html
Osaka University, CyberMedia Center www.osaka-u.ac.jp/eng

KOREA
Gwangju Institute of Science and Technology (GIST) http://netmedia.gist.ac.kr
Korea Institute of Science and Technology Information (KISTI) www.ksc.re.kr/eng/index.htm

MEXICO
Ensenada Center for Scientific Research and Higher Education (CICESE) www.cicese.edu.mx

NETHERLANDS
SARA Computing & Networking Services www.sara.nl/index_eng.html
University of Amsterdam, System and Network Engineering Research Group www.science.uva.nl/research/sne
University of Amsterdam, e-BioScience Laboratory www.micro-array.nl/ibu.html

NEW ZEALAND
Victoria University of Wellington http://ecs.victoria.ac.nz/EResearch/OptIPortal

RUSSIA
Russian Academy of Sciences, Science and Innovation Center
www.chernogolovka.org/eng_content/show_index.php
Russian Academy of Sciences, Space Research Institute http://arc.iki.rssi.ru/eng

SAUDI ARABIA
King Abdullah University for Science and Technology (KAUST) www.kaust.edu.sa

TAIWAN
National Center for High-performance Computing (NCHC) www.nchc.org.tw/en

UNITED STATES
Adler Planetarium & Astronomy Museum www.adlerplanetarium.org
Argonne National Laboratory, Center for Nanoscale Materials http://nano.anl.gov
Argonne National Laboratory, Transportation Research and Analysis Computing Center
www.anl.gov/TRACC
Calit2/University of California, Irvine www.calit2.net/about/info/uci
Calit2/University of California, San Diego www.calit2.net
Calit2/University of California, San Diego (SAGE Wall) http://ivl.calit2.net/wiki/index.php/Infrastructure
Calit2/University of California, San Diego (OptIPortable) www.calit2.net
Calit2/University of California, San Diego (Rocks/CAMERA) www.calit2.net
Florida International University, Center for Internet Augmented Research & Assessment www.fiu.edu
Louisiana State University, Center for Computation and Technology www.cct.lsu.edu
NASA Goddard Space Flight Center, Space Visualization Studio http://svs.gsfc.nasa.gov
Northwestern University, International Center for Advanced Internet Research
www.it.northwestern.edu/about/departments/icair/index.html
Purdue University, Envision Center for Data Perceptualization www.envision.purdue.edu
Rincon Research Corporation www.rincon.com
Sharp Laboratories of America www.sharplabs.com
Texas A&M University, Computer Science www.cs.tamu.edu
UCSD-National Center for Microscopy and Imaging Research www.ncmir.ucsd.edu
UCSD-Scripps Institution of Oceanography www.sio.ucsd.edu
University of Hawaii, Center for Microbial Oceanography: Research and Education
http://cmore.soest.hawaii.edu
University of Illinois at Chicago, Electronic Visualization Laboratory (Cyber-Commons)
www.evl.uic.edu/core.php?mod=4&type=1&indi=379
University of Illinois at Chicago, Electronic Visualization Laboratory (LambdaVision)
www.evl.uic.edu/lambdavision
University of Illinois at Urbana-Champaign/National Center for Supercomputing Applications
www.ncsa.uiuc.edu
University of Michigan, Department of Atmospheric, Oceanic & Space Sciences
http://aoss.engin.umich.edu
University of Michigan, Digital Media Commons www.dc.umich.edu/dmc/
University of Michigan, School of Information www.si.umich.edu
University of Texas at Austin, Texas Advanced Computing Center
www.tacc.utexas.edu/resources/visualization/
University of Washington www.washington.edu
US Geological Survey (USGS) National Center for Earth Resources Observation and Science
http://edc.usgs.gov

2. Activities and Findings

2.A. Research Activities

2.A.1. Overview

SAGE and tiled display walls are creating a global collaborative visualization environment that allows virtual teams of researchers to manage the scale and complexity of their data and work with one another. SAGE is an outgrowth of the NSF-funded OptIPuter project (award #OCI-0225642, October 1, 2002 – September 30, 2009). This STCI enables the principal investigators to transition SAGE from a research prototype to a hardened technology, nurture the growth of the SAGE User Community, and create new open services for visualization and collaboration utilizing shared cyberinfrastructure.

Today's scientists tackle issues of global priority, such as the environment, geoscience, bioscience, disaster response, and the physical nature of the universe, to name a few. Scientists need the ability to view ultra-resolution images and/or create "cyber-mashups," or juxtapositions of information – a critical component of data analysis –to gain more holistic views and insight regarding complex issues, and make more informed observations and discoveries. For example, geoscientists study aerial and satellite maps (e.g., 365K x 365K pixels) and neurobiologists study electron microscope images (e.g., 4K x 4K pixels).

SAGE is a graphics streaming architecture that enables users to interactively access, display and share a variety of data-intensive information, in a variety of resolutions and formats, from multiple sources, with the same ease that the Web affords for accessing lower-resolution objects today. This requires 21st-century "personal computers;" that is, tiled display walls driven by computer clusters and interconnected over multi-gigabit optical networks.

SAGE is cross-platform, open-source middleware that enables users worldwide to have a common operating environment, or framework, to access, stream and juxtapose data objects – whether digital cinema animations, high-resolution images, high-definition video-teleconferencing, presentation slides, documents, spreadsheets or laptop screens – on one or more tiled display walls. SAGE's network-centered architecture allows collaborators to simultaneously run various applications (such as 3D rendering, remote desktop, video streams and 2D maps) on local or remote clusters, and share them by streaming the pixels of each application over ultra-high-speed networks to large tiled displays.

2.A.2. SAGE User Community

2.A.2.1. SAGE Sites

Prior to this STCI award, there were ~43 known groups using SAGE. In Year 1 of this award, we now have ~58 international sites, which are documented on the SAGE website <www.sagecommons.org>.



While the following list is as up-to-date as we have, our users continue to build and deploy tiled display walls at their institutions, so the number of SAGE sites continues to grow. If an institution has more than one SAGE wall, the number of walls is noted in parentheses after the institution's name.

SAGE User Sites 2010

Australia
- AARNet
- Australian National University
- CSIRO Discovery Center
- CSIRO Information and Communication Technologies, Marsfield
- Monash University – Caulfield
- Monash University – Clayton
- University of Melbourne
- University of Queensland

Canada
- Ciena Networks
- Simon Fraser University

China
- Chinese Academy of Sciences, Computer Network Information Center

Czech Republic
- Masaryk University, Laboratory of Advanced Networking Technologies (2)

Germany
- Braunschweig University of Technology, Institute of Computer and Network Engineering

India
- Monsanto Research Centre

Japan
- Knowledge Graphics Technologies (KGT), Inc.
- Kyoto University
- National Institute of Advanced Industrial Science and Technology (AIST)
- National Institute of Information and Communications Technology (NICT), Koganei, Japan
- Osaka University, CyberMedia Center

Korea
- Gwangju Institute of Science and Technology (GIST)
- Korea Institute of Science and Technology Information (KISTI)

Mexico
- Ensenada Center for Scientific Research and Higher Education (CICESE)

Netherlands
- SARA Computing & Networking Services
- University of Amsterdam, System and Network Engineering Research Group
- University of Amsterdam, e-BioScience Laboratory

New Zealand
- Victoria University of Wellington

Russia
- Russian Academy of Sciences, Science and Innovation Center
- Russian Academy of Sciences, Space Research Institute

Saudi Arabia
- King Abdullah University for Science and Technology (KAUST)

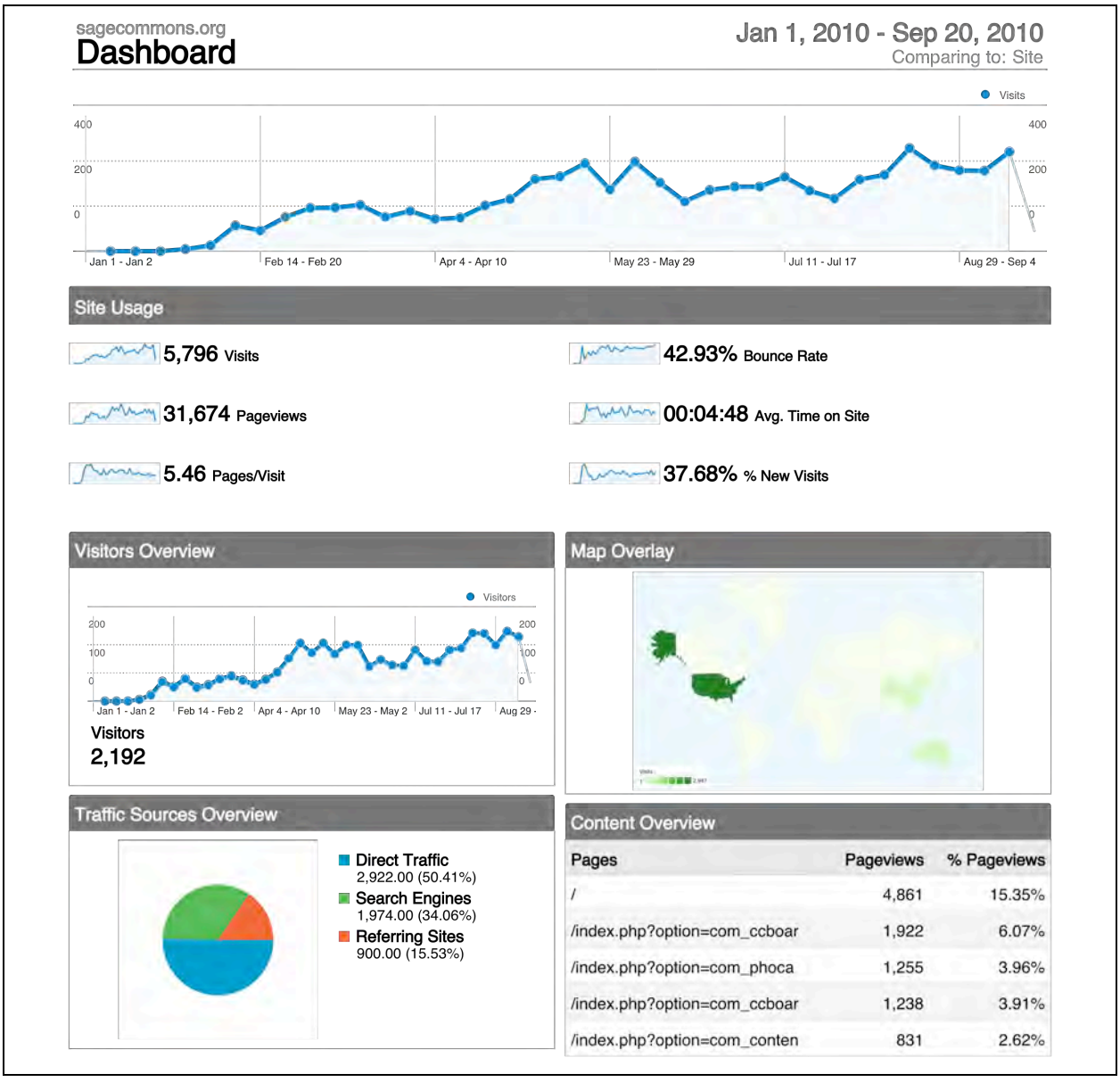
Taiwan
- National Center for High-performance Computing (NCHC)

United States
- Adler Planetarium & Astronomy Museum
- Argonne National Laboratory, Center for Nanoscale Materials
- Argonne National Laboratory, Transportation Research and Analysis Computing Center
- Calit2/Univ. of California, Irvine
- Calit2/Univ. of California, San Diego (4)
- Florida International University, Center for Internet Augmented Research & Assessment (CIARA)
- Louisiana State University, Center for Computation and Technology
- NASA Goddard Space Flight Center, Space Visualization Studio
- Northwestern University, International Center for Advanced Internet Research (iCAIR)
- Purdue University, Envision Center for Data Perceptualization
- Rincon Research Corporation
- Sharp Laboratories of America
- Texas A&M University, Computer Science
- UCSD-National Center for Microscopy and Imaging Research
- UCSD-Scripps Institution of Oceanography
- University of Hawaii, Center for Microbial Oceanography: Research and Education
- University of Illinois at Chicago, Electronic Visualization Lab (2)
- University of Illinois at Urbana-Champaign/National Center for Supercomputing Applications
- University of Michigan-Department of Atmospheric, Oceanic & Space Sciences
- University of Michigan, Digital Media Commons
- University of Michigan, School of Information
- University of Texas at Austin, Texas Advanced Computing Center (TACC)
- University of Washington
- US Geological Survey (USGS) Earth Resources Observation and Science

2.A.2.2. SAGE Website Statistics

The SAGE website has general information, user locations, new versions of SAGE open-source software and a Forum on which users can post announcements or technical questions for discussion.

Below are *Google Analytics* graphs of the weekly increase in traffic on the SAGE website for the period January 1 – September 20, 2010.

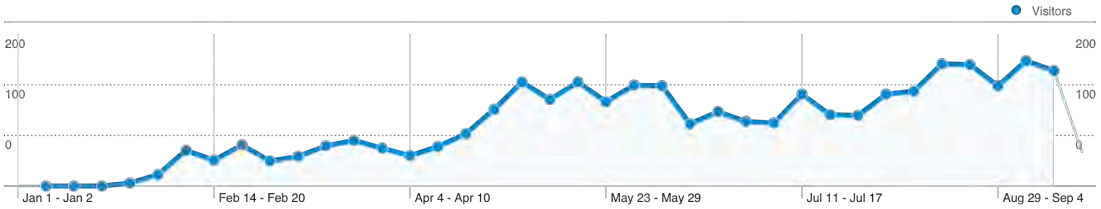

sagecommons.org
Dashboard
Jan 1, 2010 - Sep 20, 2010
Comparing to: Site
Visits
400
200
0
Jan 1 - Jan 2
Feb 14 - Feb 20
Apr 4 - Apr 10
May 23 - May 29
Jul 11 - Jul 17
Aug 29 - Sep 4
Site Usage
5,796 Visits
42.93% Bounce Rate
31,674 Pageviews
00:04:48 Avg. Time on Site
5.46 Pages/Visit
37.68% % New Visits
Visitors Overview
Visitors
200
100
0
Jan 1 - Jan 2
Feb 14 - Feb 2
Apr 4 - Apr 10
May 23 - May 2
Jul 11 - Jul 17
Aug 29 -
Visitors
2,192
Map Overlay
Traffic Sources Overview
Direct Traffic
2,922.00 (50.41%)
Search Engines
1,974.00 (34.06%)
Referring Sites
900.00 (15.53%)
Content Overview
Pages
Pageviews
% Pageviews
/
4,861
15.35%
/index.php?option=com_ccboar
1,922
6.07%
/index.php?option=com_phoca
1,255
3.96%
/index.php?option=com_ccboar
1,238
3.91%
/index.php?option=com_conten
831
2.62%

sagecommons.org

Visitors Overview

Jan 1, 2010 - Sep 20, 2010

Comparing to: Site



2,192 people visited this site

5,796 Visits

2,192 Absolute Unique Visitors

31,674 Pageviews

5.46 Average Pageviews

00:04:48 Time on Site

42.93% Bounce Rate

37.68% New Visits

Technical Profile

Browser	Visits	% visits
Firefox	2,810	48.48%
Chrome	1,063	18.34%
Safari	1,003	17.31%
Internet Explorer	764	13.18%
Opera	77	1.33%

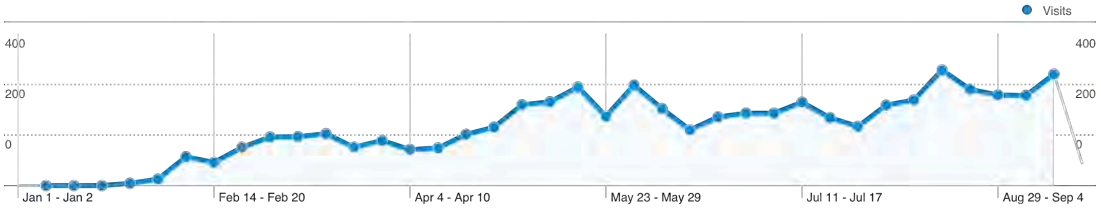
Connection Speed	Visits	% visits
T1	2,962	51.10%
Unknown	1,266	21.84%
DSL	856	14.77%
Cable	668	11.53%
Dialup	41	0.71%

sagecommons.org

Traffic Sources Overview

Jan 1, 2010 - Sep 20, 2010

Comparing to: Site



All traffic sources sent a total of 5,796 visits

50.41% Direct Traffic

15.53% Referring Sites

34.06% Search Engines



Direct Traffic
2,922.00 (50.41%)

Search Engines
1,974.00 (34.06%)

Referring Sites
900.00 (15.53%)

Top Traffic Sources

Sources	Visits	% visits
(direct) ((none))	2,922	50.41%
google (organic)	1,932	33.33%
evl.uic.edu (referral)	639	11.02%
renambot.lakephoto.org	60	1.04%
facebook.com (referral)	25	0.43%

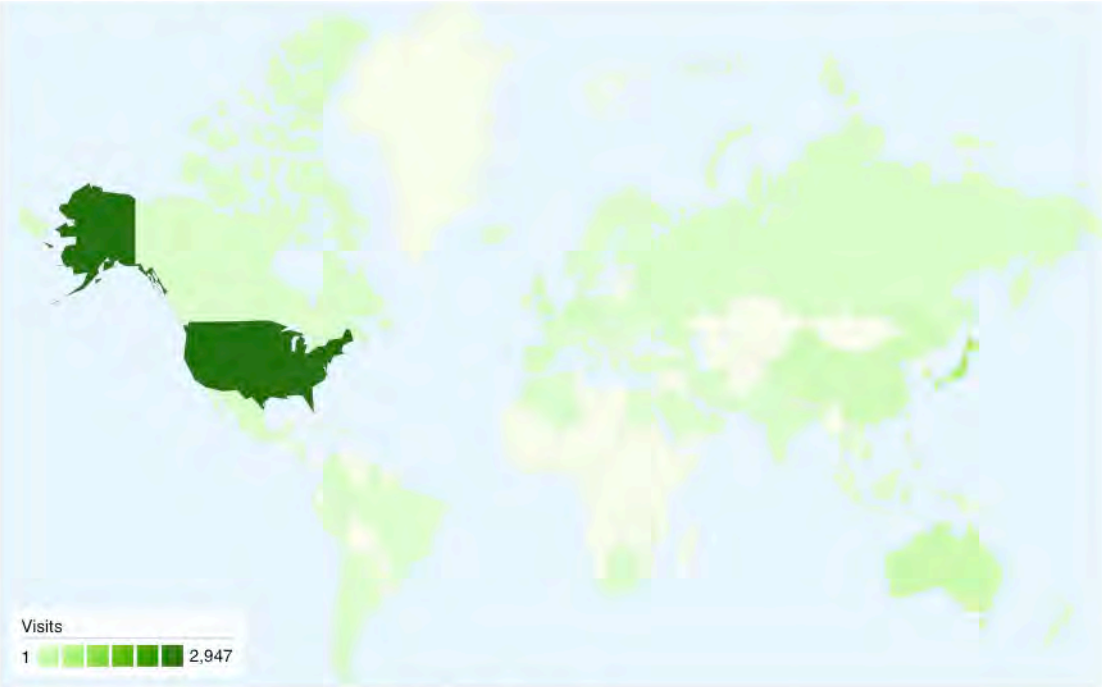
Keywords	Visits	% visits
sage commons	219	11.09%
sage evl	180	9.12%
sagecommons	167	8.46%
evl sage	132	6.69%
scalable adaptive graphics	110	5.57%

sagecommons.org

Map Overlay

Jan 1, 2010 - Sep 20, 2010

Comparing to: Site



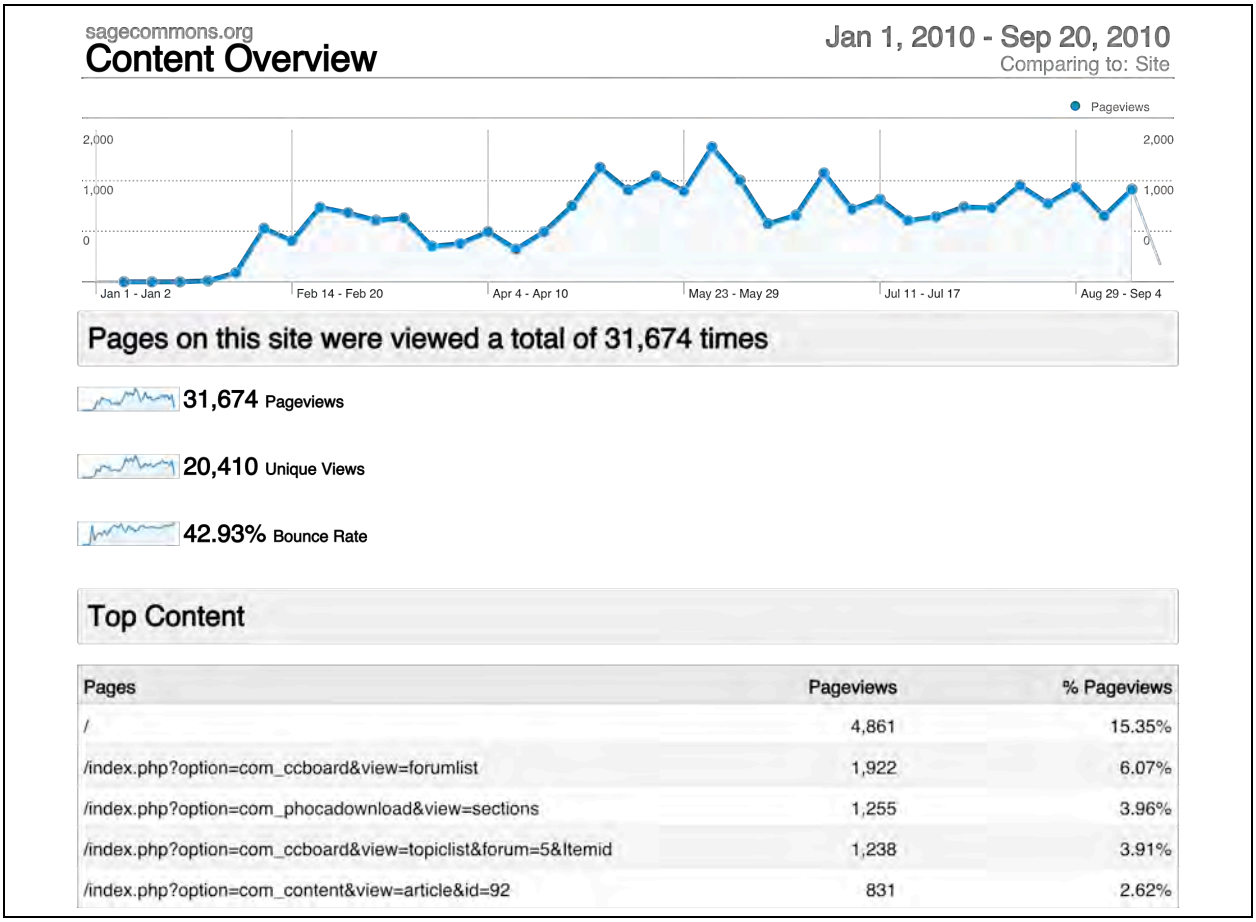
5,796 visits came from 69 countries/territories

Site Usage

Visits	Pages/Visit	Avg. Time on Site	% New Visits	Bounce Rate
5,796	5.46	00:04:48	37.77%	42.93%
% of Site Total: 100.00%	Site Avg: 5.46 (0.00%)	Site Avg: 00:04:48 (0.00%)	Site Avg: 37.68% (0.23%)	Site Avg: 42.93% (0.00%)

Country/Territory	Visits	Pages/Visit	Avg. Time on Site	% New Visits	Bounce Rate
United States	2,947	5.61	00:04:53	32.17%	41.16%
Japan	736	4.95	00:03:56	34.78%	43.34%
Australia	274	8.18	00:07:12	33.21%	26.28%
Vietnam	195	5.79	00:06:40	14.36%	49.74%
China	190	5.41	00:04:49	56.84%	52.11%
South Korea	181	6.74	00:06:58	45.86%	21.55%
United Kingdom	180	3.52	00:02:24	66.11%	63.33%
Netherlands	132	5.93	00:04:24	29.55%	30.30%
Germany	113	7.03	00:06:21	51.33%	38.05%
Spain	101	6.75	00:06:08	27.72%	32.67%

1 - 10 of 69



2.A.3. SAGE Improvements for the Past Year

2.A.3.1. SAGE Code Releases

There are two versions of SAGE available for download from the SAGE website. SAGE "classic" (the open-source version) and SAGE "advanced" (with the new Graphical User Interface available as Linux binaries). SAGE's overall performance has been improved such that more content and higher-resolution content can be shown simultaneously, user interaction is faster, and new physical interaction devices have been integrated. There has also been significant improvement in desktop sharing performance.

2.A.3.2. Cyber-Mashup Authoring

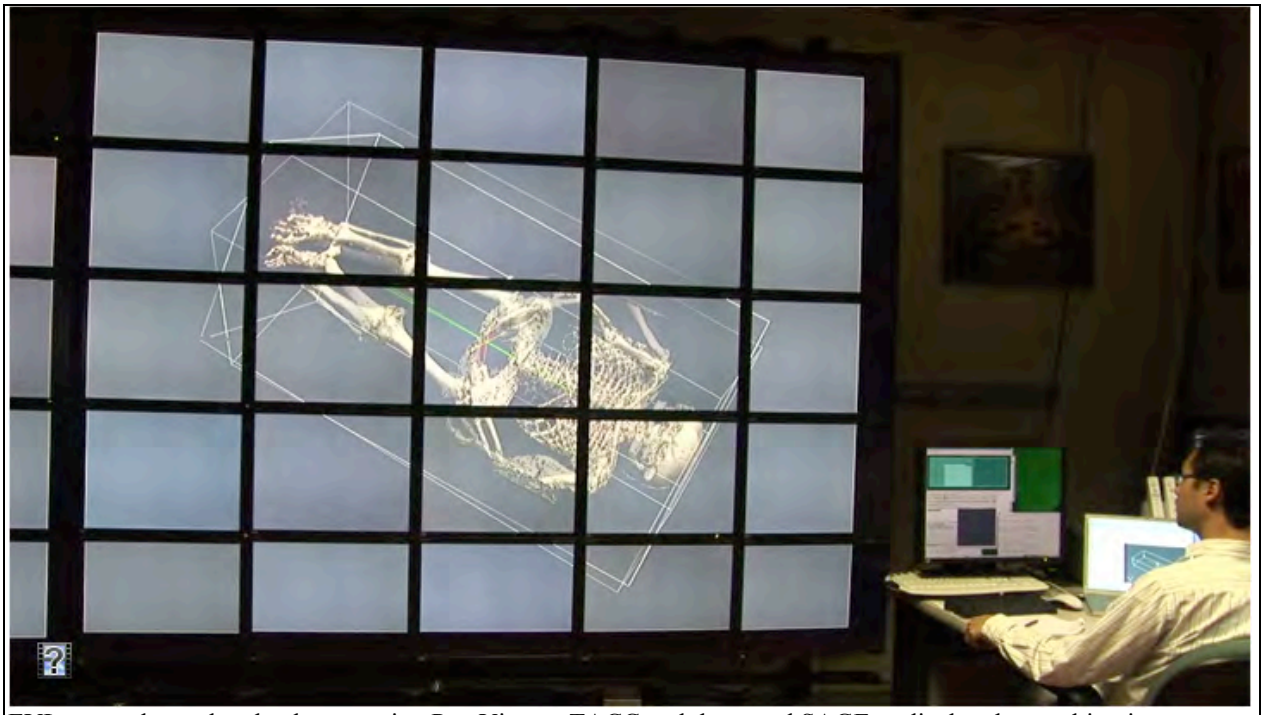
To create a Cyber-Mashup on a tiled display wall, a user deals with numerous data sources (images, graphs, video, simulation results, 3D content, spreadsheets, etc.) that can be stored on a personal computer, at a laboratory, on campus, or nationally or internationally. SAGE has several new techniques to enable users to more easily access and retrieve diverse datasets for visual exploration, analysis and/or presentation.

Support for Large-Scale Data Visualization Tools

Users wanted SAGE to be more closely tied to supercomputing, such as TeraGrid and Blue Waters. In the first year, we integrated SAGE with ParaView <www.paraview.org>, a widely used, data analysis and visualization application based on the Visualization Tool Kit or VTK. Data exploration can be done interactively or programmatically using ParaView's batch processing capabilities.

ParaView is an extensible, open source, multi-platform application for visualizing large datasets. Typically ParaView is used to render stored datasets and the resulting pixel streams are assembled and

sent to a scientist's desktop. With SAGE, the rendering cluster uses SAIL to synchronize and send parallel streams and to a tiled wall configuration.



EVL remotely rendered a dataset using ParaView at TACC and then used SAGE to display the resulting image on our tiled display.

2.A.3.3. Cyber-Mashup Editing and Interactivity

To make tiled display walls easier to use, SAGE must provide automated assistance for users to organize information, especially as the quantity of content grows, and create user interfaces that enable both legacy applications as well as newly developed applications to properly scale their interfaces depending on the size and resolution of the display walls.

Scalable Content Organization

As the available size and resolution of a tiled display wall increases, users tend to put more and more information up, such that it becomes more difficult and tedious to organize it into meaningful arrangements. Each time new media is put on the display, all the windows have to be manually moved and resized for direct comparison. To deal with this issue content organization, we developed several *layout management features* to more easily organize multiple windows on the display[1].

- We created automatic tiling templates that lay out windows in one of several grid patterns while trying to utilize the available space as much as possible.
- Independent of a display's resolution, there are times when there is more content than one can comfortably fit. For such cases we created a *minimize* feature where windows can be minimized and recalled in the future.
- We added the ability to select multiple windows and manipulate them simultaneously (e.g., move, resize, maximize, minimize).
- To better manage large amounts of content, we created a tool to easily browse and show a large

[1] EVL has worked with the Collaboratory for Research on Electronic Work (CREW) at University of Michigan's School of Information to leverage their knowledge of group work in project rooms and shared displays in this effort.

number of multimedia files by taking advantage of a tiled display's high resolution (shown below).



The media browser, developed using SAGE widgets, enables users to easily display and search multimedia files.

Enhanced Support for Interactivity

To enable interaction *within* existing (closed/proprietary) applications and to provide a more complete set of tools to build user interfaces into applications that take advantage of the SAGE API, we started developing a direct interaction layer into SAGE ***to enable concurrent multi-user interaction with multiple remote applications displayed across tiled display walls.***

Before the development of a direct interaction layer, the SAGE User Interface was limited to a cross-platform desktop-based interface. Every user ran a copy of the interface on his laptop and connected to the tiled display to perform basic window manipulations (resize and move) and to start and stop applications. Additionally, each user could show his laptop screen on the wall through a VNC plug-in or drag-and-drop multimedia files.

Based on our own experiences and the feedback from the current SAGE User Community, we developed the following important direct interaction system *design goals.* (Results are described in Section 2.B: Research Findings.)

- **Distributed –** SAGE's interaction system needs to display user interface elements across any number of displays driven by any number of machines. Additionally, application interfaces should be visible on remote displays without the application being aware of SAGE's rendering-display separation. Similarly, any physical interaction device should be able to control any remote application without being concerned with its rendering location.
- **Scalable –** Since users have displays of different sizes and resolutions, the interaction system needs to automatically adapt to the target display size and resolution, from both a visibility and usability perspective. For example, physical interaction devices should adapt their speed and sensitivity (control-display gain) and interactive objects should adjust their size so they are visible and the devices can easily interact with them**.**
- **Multi-user –** Because large tiled display walls are well suited for collaborative work, SAGE must support concurrent multi-user interaction. This interaction could be on the same display or even within the same application. Moreover, the applications themselves should be unaware of how many

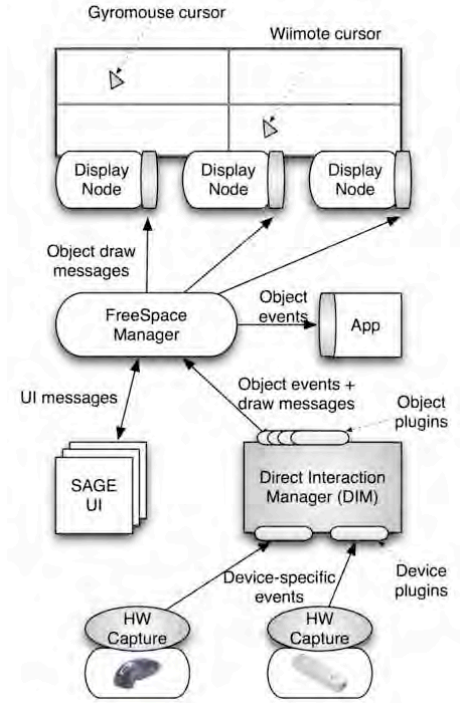
devices are currently interacting with its user interface.

- **Physical Interaction Device Independence –** Even though the mouse is the de-facto standard for desktop systems, in most cases the mouse is inappropriate for tiled display walls because it confines the user to a surface. It is therefore necessary to easily integrate new devices into SAGE without requiring changes to the applications or to the display interface. Furthermore, depending on display size, resolution and room configuration, some devices may be more appropriate than others.

Direct Interaction Manager (DIM)

DIM is the core of the new SAGE interaction system, and contains the following components: *Device Manager* to manage physical interaction devices, *Event Manager* to deliver device events to appropriate interactive objects, and *Overlay Manager,* which manages the drawing of objects on the display.

- **Device Manager –** The Device Manager manages physical interaction devices, performs event handling for events from the devices, manages the logic and drawing of objects and delivers events to applications. To allow multi-user interaction, it accepts events from multiple devices through a network interface. If multiple devices are used in a system, especially if they are of different types, they are typically connected to multiple computers that receive their events (e.g., a special machine for the camera tracker), which necessitates network-based communication. A simple Hardware Capture component contains plug-ins for each device, and captures device-specific events, which are then delivered to the Device Manager. To provide robust service, the Device Manager dynamically adds new devices and removes old ones if they fail or disconnect, enabling users to freely join and leave a space as they please.

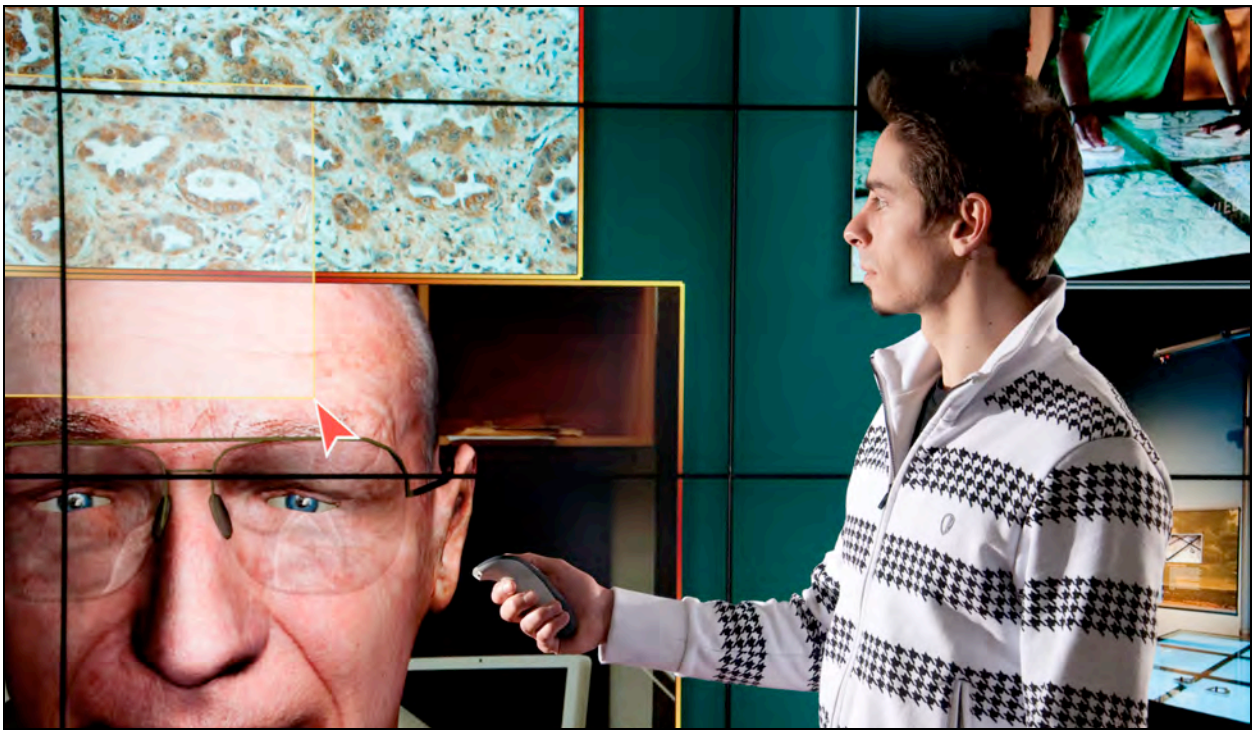


Direct Interaction Manager integrated with SAGE. The components in shaded gray are all a part of the DIM.

- **Event Manager –** All device-specific events are converted to a generic set of events, which therefore allows heterogeneous devices to interact with the display equally. As some devices are more powerful than others, they can generate a larger subset of generic events. These generic events are put in an event queue where the Event Manager processes them in order, trying to find an appropriate event handler for each. An event handler is the base class for any interactive object that wants to receive events. There is also an event handler for every application, which will deliver interaction events to the actual application, whether it is local or remote (for instance, a dragging event can be delivered to a map application). Since the applications can be freely resized and repositioned on the display, all the event coordinates are normalized before being sent to the applications, as they are unaware of their own window position and size. While an event handler processes an event, the Event Manager will lock it in order to prevent competition from different devices (e.g., if a button is held down or something is being dragged). However, no such restrictions are imposed between different event handlers, which allows for true multi-user interaction.
- **Overlay Manager –** The term *overlay* refers to any visible object on the display. Therefore, if an event handler is visible, it is also an overlay. Overlays are actually drawn by the plug-ins, which are loaded by the Display Nodes. As event handlers receive events, they issue drawing commands that the Overlay Manager then delivers to the appropriate plug-in on each Display Node.

SAGE Widgets

With the introduction of DIM, SAGE had a functional, though very limited, interface. It was possible to move and resize application windows and forward simple events, such as pan, zoom or click, to an application. As there is no one single device that best interacts with tiled display walls, we designed SAGE to use a variety of devices, even though they might generate different events. EVL integrated several mid-air devices into the SAGE Widget Framework; notably, the Gyromouse, joysticks, trackballs, 6 degree-of-freedom magnetic trackers and the Nintendo Wiimote.



While each device has advantages and disadvantages, the Nintendo Wiimote would seem to be the preferred device because it's inexpensive, intuitive and easy to set up. However, because the Wiimote was developed with home TV screens in mind, it doesn't scale very well to large high-resolution displays. Therefore, EVL designed and developed a new tracking algorithm that improves Wiimote accuracy without requiring any changes to the hardware itself.

However, there was not a way for the application to present a user interface on a remote display, short of drawing it manually into its own application buffer that is streamed to SAGE. Consequently, we developed a unified widget framework, which allows all applications, and the display itself, to use the same set of widgets without dealing with the event handling, the drawing, the interaction devices being used, or the distributed nature of the environment. Currently, several basic widgets have been implemented: buttons, icons, menus, labels, thumbnails, panels and sizers.

- **Integration with DIM –** The widget framework is compatible with the DIM architecture. Each widget is an event handler (it can act on device events) and an overlay (it can be drawn on the display). It is extensible, and new widget types can be through a plug-in architecture similar to the device plug-ins. This means that the DIM event handler plug-in describes the logic of each widget and the overlay plug-in on each Display Node describes the drawing for that widget. The Event Manager then handles the proper routing of events from devices to event handlers and the Overlay Manager handles the routing of drawing commands from the event handlers to the proper overlay plug-in on the Display Node.

- **Widget Creation and Widget Types –** Even though DIM manages all widgets, events and devices, widgets can be created by DIM or by an application through a simple API that is similar to a desktop-based widget framework (e.g., Qt, wxWidgets, etc). When requested by DIM, widgets are automatically labeled as *global widgets*, and typically used to interact with the display itself (e.g., the "Start" button, icons on the desktop, or taskbar). All global widgets are resized relative to the display, and can be positioned relative to the display or "attached" to an application and therefore positioned relative to the application window (e.g. close and maximize buttons for each window).



Application widgets are scaled relative to the application window (player controls) while global widgets are scaled relative to the display size (maximize and close buttons).

  Widgets created by the application are labeled *application widgets*, and are strictly used for the API. Therefore, all the application widgets are positioned and resized relative to the application window on the display in order to keep their interface consistent with the designer's intentions. Widget parameters (e.g. size, position, label) are set using the API, which then creates an XML description of the widget. This XML description represents the widget in the network communication between DIM, the application, and the Display Node. Entities that create the widgets can also register callbacks to receive widget events when they take place (e.g. button click, menu selection). These events will be automatically delivered to the appropriate event callback even if the widget was created by an application running on a distant rendering cluster.

SAGE Pointer

The old SAGE user interface was too cumbersome and full-featured for casual use, but providing all users with a Gyromouse seemed impractical. Given that most people bring a laptop to meetings, we created a minimal desktop application called Sage Pointer that enables users to directly control the SAGE display from their laptop, share multimedia files and share their desktop on the display.

SAGE, Touch Screens and User Gestures



In May 2010, EVL installed a touch screen over its Cyber-Commons tiled display wall. While EVL began

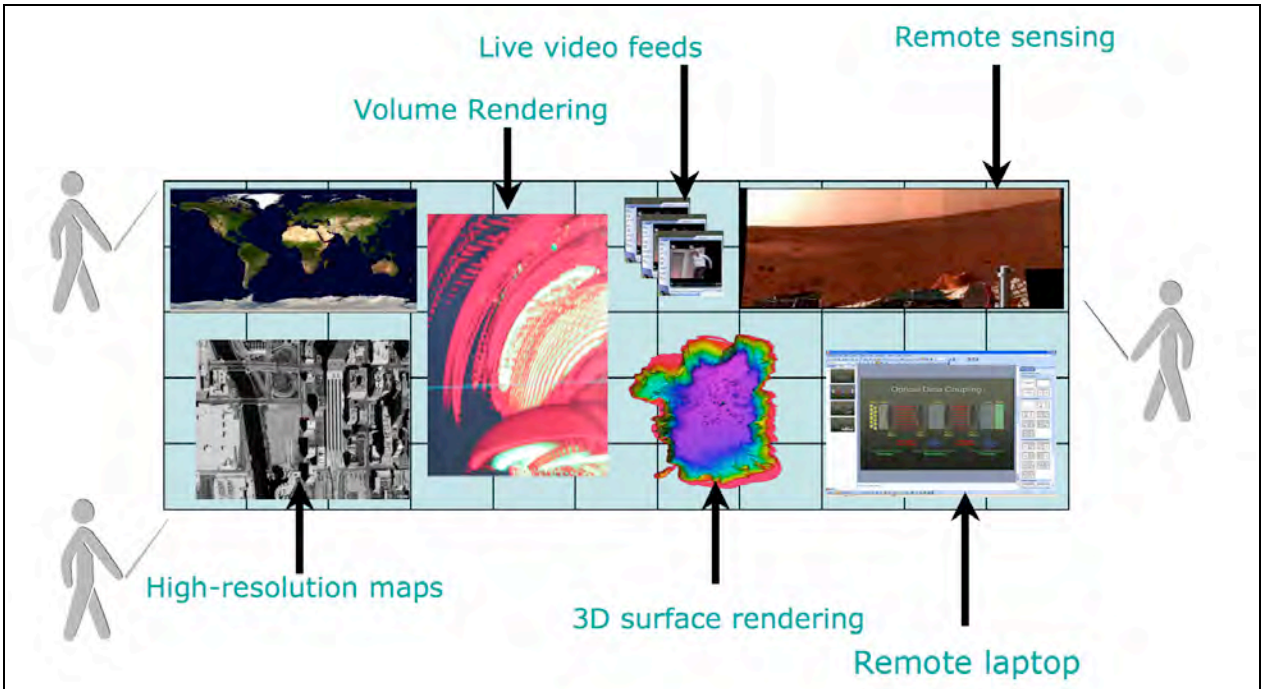
to integrate touch-screen input with SAGE, several EVL undergraduate students used the Processing programming language to develop applications for the wall. In addition, EVL began to develop a multi-user gesture recognition interface for the EVL Cyber-Commons wall so that multiple users can simultaneously interact with the display using multi-finger gestures; this is not yet integrated into SAGE.

2.A.3.4. Enhanced Scalable Streaming

Scalable Stream Synchronization

To display a continuous image on a tiled display, all the tiles that constitute an application window need to be synchronously updated. This is especially important for moving images, such as animations. In SAGE, the synchronization mechanism previously consisted of a simple network barrier and an application's image was synchronized *independent* of other applications, which resulted in visual artifacts and failed to scale as the number of applications being displayed on the wall increases.

Over the past year, SAGE was improved so it can ***seamlessly display multiple applications*** on a tiled display wall. There are three requirements for seamless frame synchronization on tiled display walls: data synchronization, swap buffer synchronization, and gen-lock synchronization (the vertical refresh cycles of the displays).

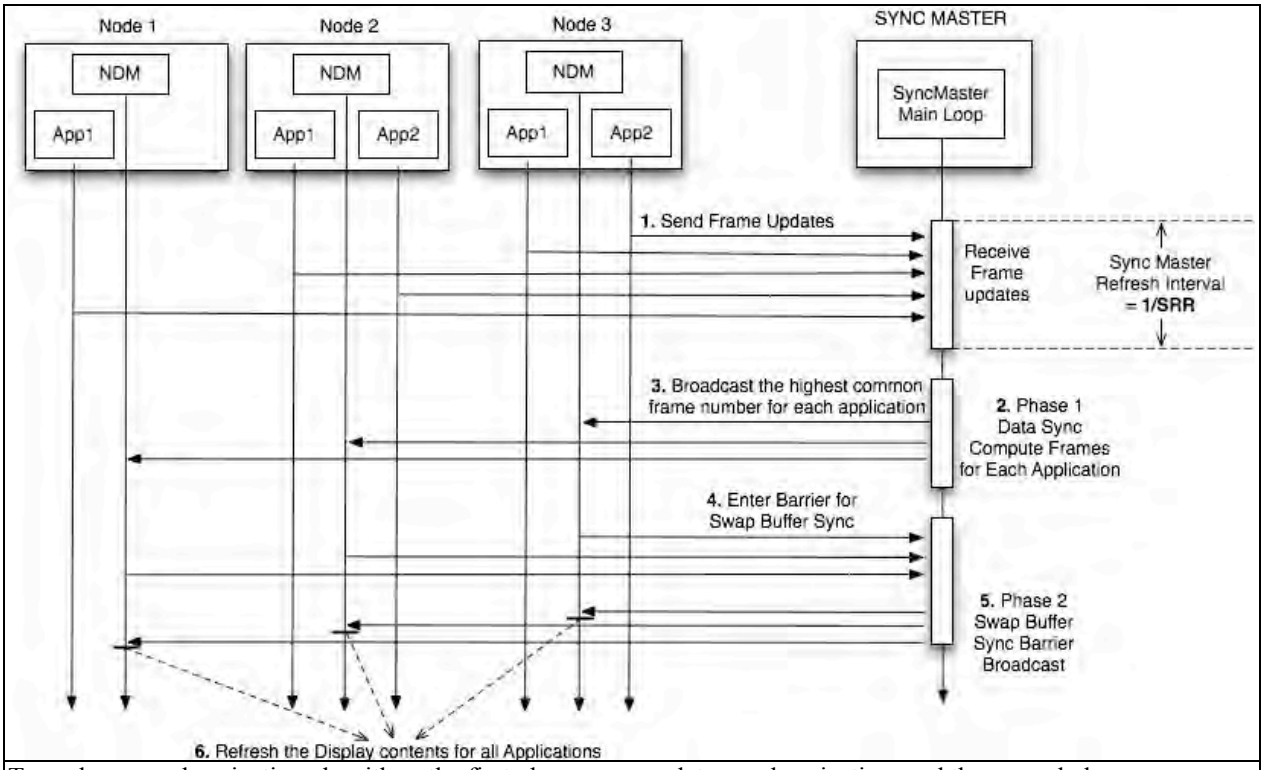


In SAGE, while a compute cluster drives the individual displays, it merely acts as a lightweight client that receives pixels from remote rendering resources, such as visualization clusters or supercomputers. To display a continuous image on a tiled display, all the tiles that constitute an application window need to be synchronously updated. SAGE was improved to synchronize *multiple* applications so they update at the same time.

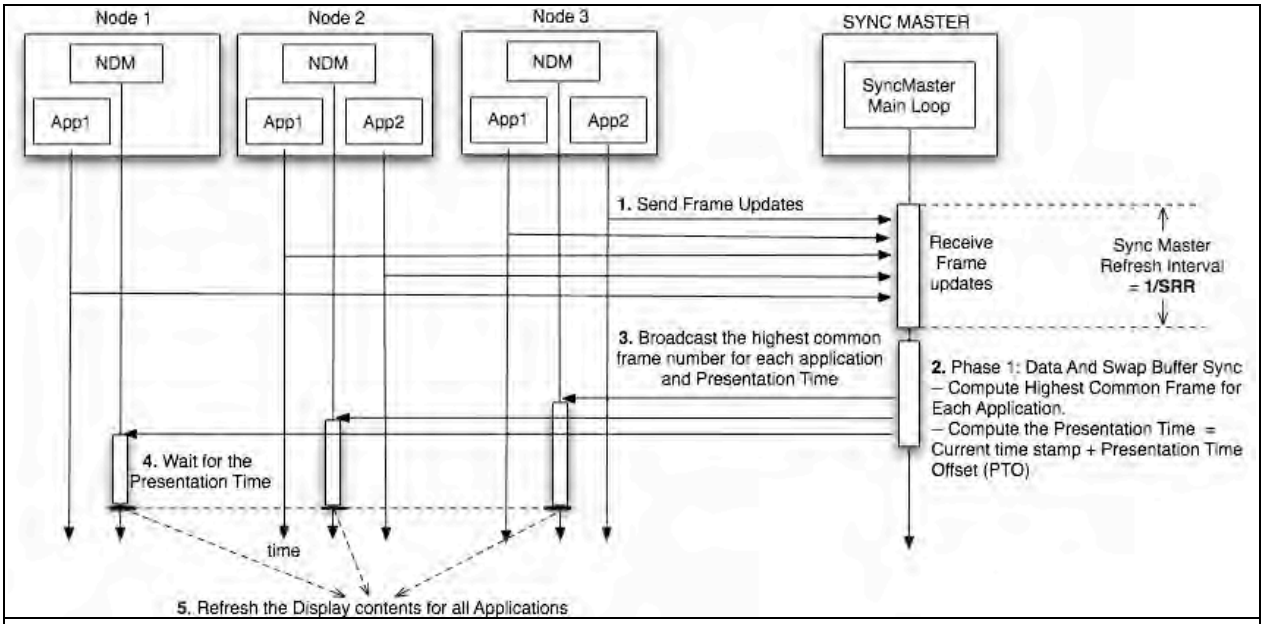
We developed a *two-phase synchronization algorithm* that (a) scales better when multiple applications are running, and (b) improves inter-tile synchronization. We also developed a *one-phase algorithm* that provides more accurate results but uses Windows' Network Time Protocol (NTP*)* and consumes more CPU cycles.

In these new approaches, data synchronization is achieved using a single global synchronization master instead of a separate data synchronization manager for each application. In both algorithms, the global synchronization manager provides data synchronization. Whereas the two-phase algorithm achieves swap buffer synchronization with a network barrier after the data synchronization phase, the one-phase

algorithm uses NTP synchronized clocks on each node. The two-phase algorithm is more applicable to diverse high-resolution tiled-display systems, while the one-phase approach yields higher synchronization but has a limited number of target systems since it requires NTP support and is more CPU-intensive.



Two-phase synchronization algorithm: the first phase ensures data synchronization, and the second phase ensures swap buffer synchronization using a network barrier.



One-phase synchronization: the first phase ensures data synchronization, and the synchronized swap buffer is ensured by making each node wait until presentation time instead of using a centralized network barrier at the SYNC MASTER.

Reliable Low-Latency Streaming

SAGE streams data from multiple remote sources over optical networks for simultaneous display on a tiled display wall. Critical requirements for data streaming include low-jitter and high-performance. SAGE currently provides the option of using the TCP protocol for reliable data streaming and UDP for unreliable data streaming. The two algorithms described in the previous section assume reliable delivery of frames, namely, that the image frame data not be lost or dropped in any of the display nodes. EVL is currently investigating synchronization techniques to handle unreliable data streaming.

2.A.4. Cyber-Mashup Collaboration Service

To support distance collaboration, EVL is implementing a low-end VNC capability to enable multimedia sharing across multiple, distributed SAGE walls.

SAGE Visualcasting is being enhanced to share very-high-resolution images (as well as animations).

2.A.5. Education, Outreach and Broader Participation

2.A.5.1. SAGE on YouTube

EVL's YouTube station features several SAGE-related videos.

SAGE and ParaView integration <www.youtube.com/evltube#p/a/u/1/yjdy0UXrEro>
Graphical User Interfaces <www.youtube.com/evltube#p/a/u/2/Xi0elpyO1Kw>
Inter-tile synchronization method <www.youtube.com/evltube#p/a/u/0/yJqFbNJcvtM>

Partner David Abramson at Monash University in Australia also has a YouTube video showing SAGE:

Supercomputing and research productivity <www.youtube.com/watch?v=S-L65xbtMVA>

2.A.5.2. SAGE Press Releases

SAGE has appeared in the news:

UCSD Researchers Receive NSF Award to Support Data-Intensive Applications for Advanced Networks, July 26, 2010, <www.calit2.net/newsroom/release.php?id=1715>

Sharp's Digital Signage Session Tops off Display Week, June 1, 2010, <http://displaydaily.com/2010/06/01/sharps-digital-signage-session-topps-off-display-week/>

SARA's participation at WCIT2010, May 25, 2010, <www.sara.nl/news/recent/20100531/WCIT2010_eng.html>

Interactive Learning: Classroom Wall Opens to the World, May 18, 2010, <http://news.medill.northwestern.edu/chicago/news.aspx?id=164805>

A Room With A View, February 1, 2010, <www.edtechmag.com/higher/january-february-2010/a-room-with-a-view.html>

Multimedia Systems 2010, February 2010, <www.sagecommons.org/index.php?option=com_content&view=article&id=69:multimedia-systems-2010&catid=1:latest-news&Itemid=50>

AARNet, University of Queensland and Queensland Cyber Infrastructure Foundation Launch Australia's First Visualcasting Exchange, February 11, 2010, <www.sagecommons.org/index.php?option=com_content&view=article&id=80:aarnet-university-of-queensland-and-queensland-cyber-infrastructure-foundation-launch-australias-first-visualcasting-exchange&catid=1:latest-news&Itemid=50>

APAN Claims Domestic and World Firsts, February 11, 2010, <www.aarnet.edu.au/News/2010/02/11/APAN-claims-domestic-and-world-firsts.aspx>

CineGrid International Workshop 2009, December 6-9, 2009, <www.sagecommons.org/index.php?option=com_content&view=article&id=68:cinegrid-international-workshop-2009&catid=1:latest-news&Itemid=50>

SAGE Highlights @ SC09, November 17, 2009, <www.sagecommons.org/index.php?option=com_content&view=article&id=67:cinegrid-international-workshop-2009-12609-12909&catid=1:latest-news&Itemid=50>

Ultra-high-speed, made ultra-easy, October 14, 2009, <www.uic.edu/htbin/cgiwrap/bin/uicnews/articledetail.cgi?id=13580>

NSF STCI Proposal Awarded to UIC/EVL, August 18, 2009, <www.sagecommons.org/index.php?option=com_content&view=article&id=45:joomla-community-portal&catid=1:latest-news&Itemid=50>

2.A.5.3. SAGE in the Classroom

A Cyber-Commons is a technology-enhanced meeting room on a university campus that supports local and distance collaboration and promotes group-oriented problem solving in formal and informal situations. Cyber-Commons' goal is to help students learn how to collaborate within a university and among universities – to solve problems within a discipline and among multiple disciplines. The components of the Cyber-Commons can be altered and enhanced as needed to build the right-sized space with the right amount of local computing power and the right amount of networking to match local needs.

EVL supports and uses its Cyber-Commons for classroom instruction for undergraduate, Masters and PhD students. SAGE encourages the creation of cyber-mashups – it is used to turn the entire wall into a unified frame buffer onto which content from multiple sources, including distributed clusters, can be streamed, and allows multiple co-located or remote users to interact simultaneously by adding and manipulating content on the wall, and interacting with other participants through high-definition video.

Multiple users can interact with the wall simultaneously by walking up to it and touching it (enabled by the touch screen overlay) to move windows, add content from a media library, or organize content. Other users can simultaneously drag and drop content onto the wall from their laptop, or control remote pointers on the wall. Another can draw on a Wacom tablet that is streamed to the screen as a blackboard. Content includes image files, movie files, Microsoft Office files, and streaming desktops through VNC. Groups can form and re-form on the wall and divide the wall space up among multiple concurrent tasks. The current state of the wall can be saved, and older states can be re-loaded at later times.

Since the summer of 2009, when the Cyber-Commons wall was installed, ***10 different UIC courses have been taught by six different instructors in the new Cyber-Commons:*** CS 376 Practicum in Computer Science Presentations; CS 426 Video Game Design and Programming, with half of the class attending from Louisiana State; CS 491 Visualization and Visual Analytics; CS 526 GPU Programming; CS 527 Computer Animation; CS 586 Data and Web Semantics; CS 594 Computational Biology, with a live link to Princeton; Physics 594 Parts 1 and 2 - Hunt for the Quark Gluon Plasma, with remote lectures from Los Alamos and CERN; and Art and Design 508 Advanced Electronic Visualization and Critique. There are also regularly scheduled research meetings, seminars, and videoconference calls that take place in the Cyber-Commons several times a week.



The UIC Visualization and Visual Analytics class compares various representations of the same dataset



UIC Visual Analytics students present projects and simultaneously view and compare other solutions



The UIC Physics class listens to a remote presentation from Los Alamos

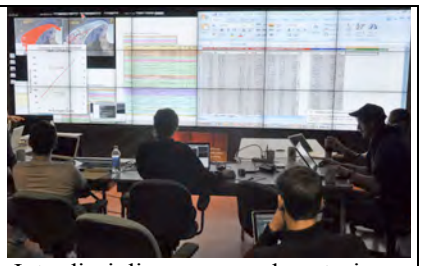
We have also seen and encouraged ad-hoc use of the Cyber-Commons outside of regularly scheduled classes and meetings. Groups of students in the Visual Analytics course and the Video Game Design course use the space to brainstorm different ideas using the Wacom tablet on the wall as a whiteboard. Groups of graduate students discuss ideas for their research and upload related journal papers onto the wall from their laptops. Groups of PhD students studying for the qualifying exam display multiple exams and their answers along with related web pages on the wall for discussion.



Live HD video broadcast of robotic surgeries for the Clinical Robotic Surgery Association (CRSA) (2009)



The NCSA Virtual School's Many-Core Processor class was streamed to EVL's Cyber-Commons classroom (2009)



Interdisciplinary researchers trying to analyze and integrate various types of geophysical sensor data simultaneously (2010)

EVL, in cooperation with the UIC Communications department, has been conducting initial surveys of students using Cyber-Commons. Their overall reaction has been very positive. The students liked seeing related information on the screen, compared to more common multimedia classrooms, and believe that they are learning more. Instructors accustomed to teaching in lecture halls with multiple blackboards, however, have found the single Wacom tablet doesn't give enough space to work out large problems. No one has reported any adverse side effects (headaches, tired eyes, etc). We are continuing these studies.

EVL has also been advising KISTI (Korean Institute of Science and Technology Information), who is collaborating with Seoul National University with funding by the Korean Ministry of Education, Science, and Technology, on how to deploy 40 networked tiled display walls based on our Cyber-Commons model around Korea in the next three years, with seven to be deployed in 2011.

2.A.5.4. SAGE Outreach

EVL does numerous education and outreach demonstrations to assist UIC with recruitment, retentio, and professional development efforts. EVL faculty and students both demonstrate SAGE and use SAGE to give EVL overview presentations in the Cyber-Commons room.

July 22, 2010. A group of teachers and college-eligible African American male high school juniors visited UIC to learn more about its programs. As several students expressed interest in studying computer science, the group visited EVL and got demos and tours.



July 21, 2010. EVL's Andy Johnson gave a presentation to 30 math and science high-school teachers from four midwestern states, who toured EVL as part of a two-week intensive University of Illinois Summer Training Institute (STI), a continuing education program offered by the Illinois Project Lead The Way (PLTW) initiative.



July 9, 2010. EVL's Andy Johnson gave a presentation to 20 students from the Chicago State University Minority Engineering program using EVL's Cyber-Commons display and SAGE.

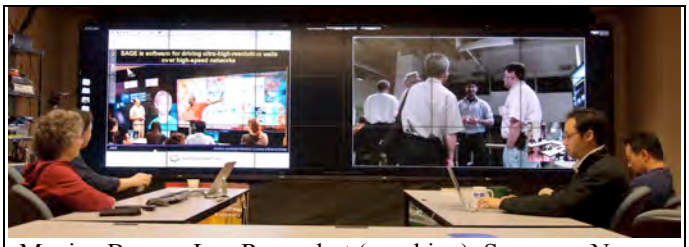


June 21-23, 2010. Maxine Brown attended the NSF Broader Impacts for Research and Discovery Summit (BIRDS) in Washington DC. This summit was intended to develop guidance materials for the NSF CISE/OCI research community on how to integrate activities that address the NSF broader impacts review criteria into their research. Working groups met to discuss and document current/future broader impact activities and ways in which infrastructure can be established to make it easier for NSF investigators to improve the broader impacts of their work <http://toilers.mines.edu/BIRDS/index.html>.

June 18, 2010. On June 18, 2010, EVL hosted a teacher and several of his students from Chicago's Austin Polytechnic High School as part of the University of Illinois Affiliate Project Lead The Way (PLTW) program. This PLTW trip was organized by Dr. Wally Goncharoff of the UIC College of Engineering. After the tour and discussions, the teacher sent an email to Goncharoff saying, "...the effect of your tour on their imaginations and positive conception of UIC cannot be overstated."



June 9-10, 2010. The GreenLight Minority-Serving Institutions Cyberinfrastructure Coalition (MSI-CIEC) Workshop, held at Calit2/UCSD, focused on the Calit2 NSF-funded GreenLight project on the first day, and focused on OptIPortals the second day. Demos featured a remote SAGE presentation and demo by EVL's Luc Renambot to attendees in the Calit2 Virtulab in San Diego.



Maxine Brown, Luc Renambot (speaking), Sungwon Nam and Jason Leigh participated remotely from EVL/UIC in the MSI-CIEC Workshop. Renambot's Powerpoint presentation appears on the left side of the screen. MSI-CIEC attendees who listened to the presentation and asked questions appear right-most display window. (Photo: Lance Long)

April 30, 2010. EVL hosted 23 journalism students from Northwestern University's Medill School. Their professor, Donna Leff, takes her students to visit a variety of places, with the goal of having the students write articles about subjects they find interesting. This visit subsequently resulted in a story about EVL's unique and advanced classroom, and particularly how UIC physicist David Hofman uses it to teach with colleagues from remote locations <http://news.medill.northwestern.edu/chicago/news.aspx?id=164805>.

April 5, 2010. The UIC Dept of Earth & Environmental Sciences (EaES) and the WISEST (Women in Science and Engineering System Transformation) program invited Dr. Maria Zuber, head of MIT's Dept of Earth, Atmospheric and Planetary Sciences, to UIC for 2 presentations. She met with Maxine Brown for breakfast and then toured EVL and saw demos of our latest technologies.

February 15, 2010. EVL hosted several UIC recruiting efforts – notably the CS Open House and UIC Engineering Week.

2.A.5.5. SAGE Technical Demonstrations and Presentations

November 13-19, 2010. EVL is holding a SAGE Birds-of-a-Feather at SC10 on Tuesday, November 16,

12:15-1:15pm <http://sc10.supercomputing.org/schedule/event_detail.php?evid=bof121>. In addition, EVL will do SAGE demonstrations in the KAUST booth and will assist SARA with their SAGE demo in the Dutch Research booth.

October 13-14, 2010. EVL is working with colleagues at SARA on a major end-to-end data streaming demonstration they are doing for the GLIF 2010 meeting in October. SARA plans to stream ultra-high-resolution scientific visualization animations over the SURFnet 40Gbps light path between SARA and CERN. They plan to repeat this 40Gbps demo between StarLight (Chicago) and the SC10 conference (New Orleans) in November. SAGE bottlenecks have been encountered and EVL is helping trouble shoot.

September 14, 2010. Larry Smarr visited the NSF Science & Technology Center for Microbial Oceanography: Research and Education (C-MORE) at University of Hawaii, where they expressed interest in being more aggressive SAGE users and using SAGE to better collaborate with C-MORE partners at MIT and University of Washington. (EVL will follow up.)

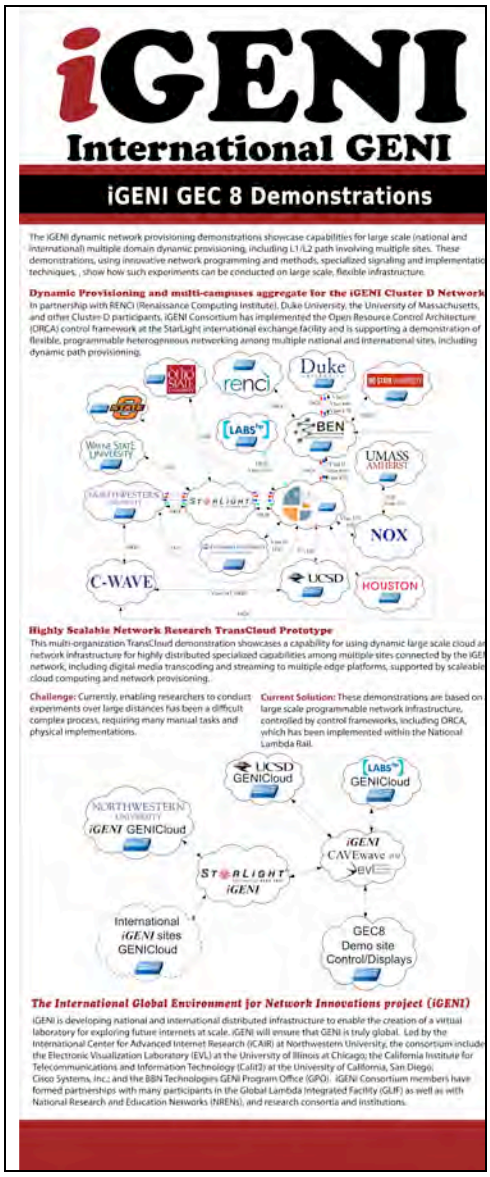
August 11-12, 2010. Jason Leigh visited Seoul National University and KISTI in Korea. At both locations, he gave the presentation "Global Cyber-Commons: Supporting Global Collaborative Research, Development, and Education in Cyber-Infrastructure-Enhanced Environments." In the next three years, the Korean government wants to construct and operate ~40 persistent Cyber-Commons-like collaboration nodes for education and research, all running SAGE. Jason met with Jysoo Lee, head of the KISTI Supercomputer Center, to discuss system architecture, software, and content.

August 4, 2010. EVL decommissioned its LambdaVision tiled display wall. LambdaVision, funded in 2004 with an NSF MRI grant, was (at its time) an ultra-high-resolution visualization and networking instrument to support collaboration among co-located and remote experts who wanted to access and interact with ultra-high-resolution imagery. The NSF OptIPuter project adopted LambdaVision and its precursor, GeoWall-2; subsequently, the term *OptIPortal* was used to describe all LambdaVision-type displays. OptIPuter funded the initial research and development of SAGE. EVL's LambdaVision has been replaced by the Cyber-Commons tiled display wall, so this instrument was dismantled and given to several campus groups (ACM student chapter, computer science department, etc.). Below, EVL faculty, staff and students took a group photograph in honor of the occasion.



July 26-29, 2010. Luc Renambot attended Rice University's Center for Scalable Application Development Software (CScADS) Scientific Data and Analytics for Petascale Computing Workshop in Snowbird, UT, and gave a presentation on SAGE.

July 20, 2010. Northwestern University (Joe Mambretti, principal investigator), Calit2 (Tom DeFanti) and EVL (Maxine Brown) are principals of "iGENI," the international Global Environment for Network Innovations (GENI), which is an NSF-funded project and part of the overall NSF GENI program. On July 20, 2010, Northwestern, Calit2 and EVL collaborated on a major iGENI demo that utilized SAGE for the 8th GENI Engineering Conference (GEC 8), held at Calit2/UCSD. One aspect of this demo focused on dynamic network provisioning integrated with cloud computing to support transcoding for digital media. Using SAGE, digital media content was streamed from Chicago to Calit2's SAGEwall.



This iGENI demo is a prototype of a demo being prepared with partners HP Labs and Ericsson for a GEC 9 VIP event in Washington DC in November 2010. The full demonstration will involve: (a) digital media transcoding, (b) for multiple edge platforms (e.g., smart phones, tablets, computers, tile displays, standard displays), (c) supported by scalable cloud clusters, (d) based on a fabric of dynamically provisioned network L1/L2 paths. Due to logistic (and other) reasons, transcoding for GEC8 was limited to small edge platforms and not high-definition streams; however, L1/L2 network provisioning to support high-end digital streams was shown at GEC 8 to convey the overall concept. Transcoding for HD will be shown at GEC 9. SAGE will be the client used for the full demonstration at GEC 9, when the transcoding capability will be extended to a wider range of platforms. The goal is to create a cloud-based platform that can transcode to random devices (versus having separate services for each device).

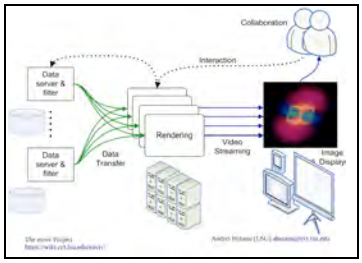
Northwestern University established Eucalyptus clouds on clusters at HP Labs, Northwestern, and UCSD's CS department, interconnected with vLANs. These three interconnected clouds have been implemented as scalable compute resources supporting the transcoding.

July 15, 2010. Michael Stanton, Director of Innovation of RNP (Brazilian National Research and Education Network), had previously introduced Brazilian colleagues to SAGE software and tiled display systems; however, this was his first trip to Chicago and he took the opportunity to visit StarLight and EVL, to better understand our technologies and activities so that he can better identify researchers in Brazil to be collaborators.

July 7, 2010. Sachin Deshpande and others at Sharp Laboratories of America (SLA), an EVL partner, gave the presentation "Technologies and Applications for Large-Sized High Resolution Tiled-Display Systems" at SLA offices in Camas, WA, at the July meeting of the Pacific Northwest Chapter of the Society for Information Display (SID).



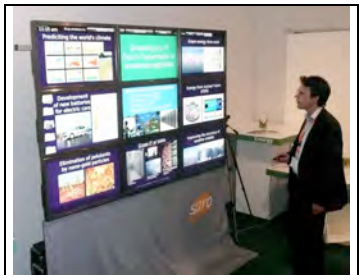
EAVIV Testbed (ongoing): EAVIV is a research testbed for experimenting with distributed visualization scenarios on high-speed networks. Louisiana State University (LSU), National Center for Supercomputing Applications and Masaryk University (Czech Republic) are deplying it. It will support the development and testing of applications that distribute computing, storage and visualization tasks and take advantage of dynamically provisioned optical networks and services. SAGE will be used to stream images from remote rendering machines. LSU gets NSF EAGER funding.



June 9, 2010. On June 10 in Japan (June 9 in the US), a major event in Osaka to promote it as the Knowledge Capital of Japan featured SAGE Visualcasting demonstrations. Participants included NICT/Osaka University's VisLab in Japan, NCHC and NTUT in Taiwan, University of Queensland in Australia, and Calit2 in the US. EVL remotely operated the SAGE Wall at Calit2.



May 25-27, 2010. SARA supercomputer center in The Netherlands did a major SAGE demonstration for the WCIT World Congress on ICT (SARA booth shown in photo), showcasing applications developed in-house as well as by its users and guests. SARA focused on projects that related to "Greening by IT". On top of static images, SARA ran movies and applications, using SAGE to maximize various windows when they wanted the audience to focus on that particular content. EVL provided tech support prior to the event.



May 23-28, 2010. The 2010 Society for Information Display (SID) Symposium, held in Seattle, Washington, held a "Digital Signage" session in which Sachin Deshpande from Sharp Laboratories of America (SLA) (second from right in photo) participated. He talked about EVL SAGE advanced graphical user interface research, which SLA is funding. SLA is interested in issues of multiple simultaneous users (what Deshpande calls "advanced user interaction") on tiled display walls, producing new display and audio technologies.



March 3-4, 2010. Luc Renambot at EVL and Joe Keefe at Calit2/UCSD demonstrated SAGE at the PRAGMA 18 Workshop (Pacific Rim Applications and Grid Middleware Assembly), held at UCSD. San Diego. EVL streamed data from a storage server at StarLight to the SAGE Wall at Calit2. In particular, EVL streamed an animation of Mt. Hood, Oregon, created by PRAGMA member and SAGE user AIST (National Institute of Advanced Industrial Science and Technology) of Japan. EVL and Calit2 were connected via Polycom (output directed to the tiled wall) so the two groups could talk to one another.



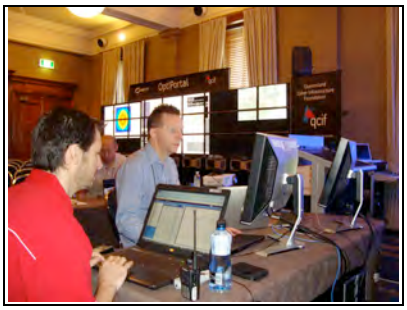
PRAGMA 18. AIST participants stand in front of the Calit2 SAGE Wall with their data of Mt. Hood, Oregon.



Calit2 SAGE Wall. The Polycom image from EVL is shown in the upper left.

February 22-23, 2010. Sungwon Nam presented the paper "Multiapplication, Intertile Synchronization on Ultra-High-Resolution Display Walls," by Sungwon Nam, Sachin Deshpande, Venkatram Vishwanath, Byungil Jeong, Luc Renambot, and Jason Leigh at the ACM Multimedia Systems 2010 Conference in Scottsdale, AZ.

February 8-11, 2010. University of Queensland (Brisbane, Australia), University of Melbourne (Victoria, Australia), Gwangju Institute of Science and Technology (GIST) (Korea) and TACC at University of Texas, Austin, in the US participated in a SAGE Visualcasting demo at APAN29 (the Asia-Pacific Area Network 29th conference, in Sydney, Australia). The photo shows the University of Queensland setup at the APAN29 conference site.



February 7-9, 2010. EVL (Jason Leigh, Luc Renambot, Ratko Jagodic, Sungwon Nam, Maxine Brown) participated in ON*VECTOR Photonics Conference, held at Calit2/UCSD in San Diego. Jagodic participated in the CSCW panel (shown in photo) and gave the presentation "Improving SAGE Capabilities for Computer Supported Cooperative Work (CSCW)," explaining his new SAGE user-interaction schemes. Nam participated in demonstrations of SAGE and multi-rail aware, high-performance, flexible data transfer applications using TLAN technologies.

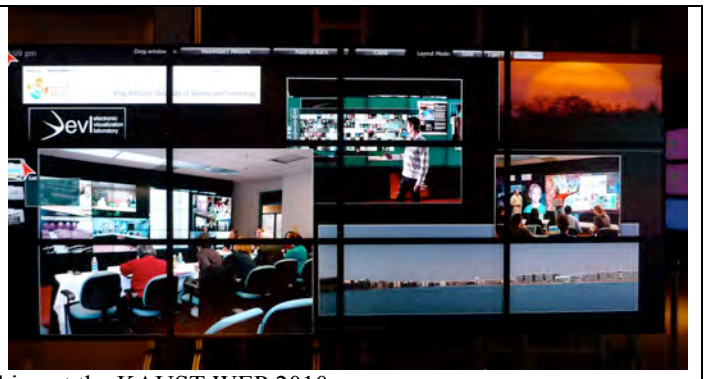


*ON*VECTOR (Optical Networked Virtual Environments for Collaborative Trans-Oceanic Research) is a joint project of NTT Network Innovation Laboratories, Keio University's Institute for Digital Media and Content, the University of Tokyo's Morikawa Laboratory, the University of Illinois at Chicago's (UIC) Electronic Visualization Laboratory (EVL), and Calit2/UCSD, and managed by Pacific Interface Inc.*

February 1, 2010. Dr. Jason English of the Monsanto Research Centre in Bangalore, India, visited EVL to learn more about SAGE and tiled display walls. Subsequently, Monsanto bought a tiled wall, paid for EVLers Lance Long and Luc Renambot to visit Bangalore to set up the wall and teach locals about SAGE. They are now in the process of using SAGE and want to further collaborate with EVL on application development.

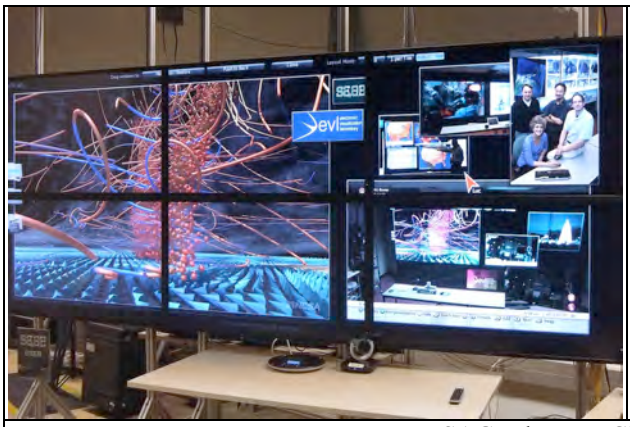
January 30-February 3, 2010. Luc Renambot participated in the King Abdullah University for Science and Technology (KAUST) Winter Enrichment Program (WEP), Saudi Arabia, and taught the course "Streaming Televisualization (SAGE)" with Greg Wickham of KAUST.




Luc Renambot teaching at the KAUST WEP 2010.

January 27-29, 2010. Jason Leigh attended the NSF Strategic Technologies for CyberInfrastructure STCI and Software Development for CI (SDCI) PI Meeting in Arlington, VA on January 28-29, and participated in a poster session to showcase SAGE. Sungwon Nam attended the January 27th NMI Build and Test infrastructure Workshop.

December 6-9, 2009. EVL (Jason Leigh, Luc Renambot) organized SAGE demos at the CineGrid Workshop, held at Calit2/UCSD. Maxine Brown, Sungwon Nam and Ratko Jagodic participated remotely from Chicago via SAGE video teleconferencing. In addition, Leigh and Renambot gave the presentation "Building CineGrid Nodes Using SAGE OptIPortals – The Path Forward" during the Workshop.



SAGE demo at CineGrid Workshop.



November 16-20, 2009. EVL (Jason Leigh, Luc Renambot, Sungwon Nam, Ratko Jagodic, Maxine Brown) held the SC09 Birds-of-a-Feather (BOF) session "Next Generation Scalable Adaptive Graphics Environment (SAGE) for Global Collaboration" <http://scyourway.supercomputing.org/conference/view/bof195>. This BOF discussed next-generation SAGE development by its global user community. The agenda and Powerpoint presentations are online at <www.sagecommons.org/index.php?option=com_content&view=article&id=91:pragma18&catid=1:latest-news&Itemid=50>. Also, Sungwon Nam gave the SAGE presentation "Remote Visualization of Large Scale Data for Ultra-High Resolution Display Environment," at the 2009 Workshop on Ultra-Scale Visualization <http://vis.cs.ucdavis.edu/Ultravis09>, also held at SC09.

2.B. Research Findings

2.B.1. Cyber-Mashup Authoring

Support for Large-Scale Data Visualization Tools

SAGE now supports ParaView. EVL is now looking for potential users to see how it performs.

2.B.2. Cyber-Mashup Editing and Interactivity

Scalable Content Organization

SAGE is heavily utilized in the UIC CS Visualization and Visual Analytics course, which gives EVL an opportunity to observe faculty and students using SAGE's GUI in order to develop more robust tools and techniques that are intuitive and appropriate.

Enhanced Support for Interactivity

The design of SAGE's direct interaction layer meets our goals of *enabling concurrent multi-user interaction with multiple remote applications* displayed across tiled display walls. The new SAGE Direct Interaction Manager (DIM) has the following design attributes:

- **Distributed –** By decoupling the widget logic, drawing and creation, we achieved a truly distributed widget framework. Widgets can be seamlessly drawn across any number of displays driven by any number of Display Nodes. Applications located on distant rendering resources can present their user interface on any display by requesting widgets and receiving events over the network all without ever being aware of this separation. This separation means that we can develop new interaction techniques that are more appropriate for the large tiled display walls without requiring any modifications to the applications themselves. For example, as display resolution dramatically increases, target acquisition becomes much more difficult. One approach is to dynamically resize targets as cursors get near, which is something we were able to easily implement without changing any of the applications.
- **Scalability –** During startup, DIM first collects information about the display environment and calculates the appropriate widget scale factor to adjust for usability (ease of clicking on a target with a physical interaction device) and visibility (font size visible on the display). To provide truly scalable drawing, we use dynamically resizable vector fonts and large raster images that are typically scaled down to reduce aliasing. It would be straightforward to add support for vector images as well. Since we assume that applications are rendered remotely, we cannot assume that every image used in the application interface is already present on the display side. Therefore, the API automatically embeds necessary images in the XML widget description, which is then delivered to the Display Nodes for drawing. This gives application developers freedom to design custom interfaces.
- **Multi-user –** We designed DIM to support multiple interaction devices while giving each device a separate cursor. Additionally, while rules exist to prevent multiple devices from interacting with one widget at the same time, no such rules are enforced between widgets; hence multiple users can interact with different widgets simultaneously, even within the same application.
- **Physical Interaction Device Independence –** As previously mentioned, it is possible that new physical interaction devices will be introduced that perform better on large tiled display walls. New devices can be added to SAGE by simply providing a plug-in that describes the conversion between device-specific events and generic sets of events. By using the generic set of events and removing the specifics of each device, we can treat all of them equally for event handling purposes.

Since we have the capability to integrate new devices easily, we experimented with various off-the-shelf devices such as joysticks, a Gyromouse, trackpads, 6 degree-of-freedom tracked wand, and the Wiimote. Although each device has strengths and weaknesses, the Gyromouse seems to be the most suitable. It is inexpensive, readily available, can be used simultaneously, allows users to be mobile in front of the

display, and doesn't require an elaborate setup. Even though it has a slight learning curve associated with it, users quickly became comfortable using it, and it remains the preferred device. However, since the Gyromouse is inherently affected by hand jitter, it may be somewhat difficult to acquire smaller targets, especially on larger displays, as the accuracy of the device has to be traded for speed.

Initially, the Gyromouse was used to move application windows by clicking and dragging a small area at the bottom and top of the window to mimic the behavior of desktop operating systems. However, by allowing the Gyromouse to drag a window to new locations by clicking anywhere within the window, moving windows became significantly faster and easier, and users were encouraged to experiment more with the layout. Similarly, windows can be resized by dragging any of the four corners; however, after using a mouse wheel to "zoom" a window in and out, we noticed it became the preferred method, and encouraged users to experiment with different window sizes more often.

SAGE Pointer

Using a global hot key, users can capture their desktop's mouse pointer and a new pointer is created on the SAGE display that is controlled by the laptop's track pad. This gives users the same ability to manipulate widgets and applications on the display as if they were using a Gyromouse. Since new devices (i.e., pointers) can be added to DIM dynamically, users can casually switch back and forth between controlling their laptop and controlling the SAGE display.

SAGE, Touch Screens and User Gestures

EVL continues to make improvements to make SAGE more robust and consistent, and therefore more appropriate for touch interaction.

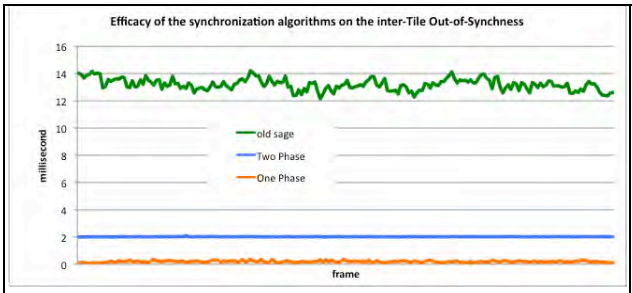
2.B.3. Enhanced Scalable Streaming

Scalable Stream Synchronization

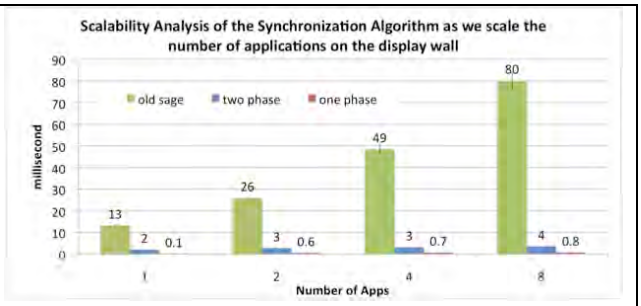
Using the *two-phase synchronization algorithm*, both scalability (i.e., the number of applications) and inter-tile frame synchronization achieved up to 100-fold improvements over existing SAGE mechanisms. The *one-phase algorithm* achieved a 10-fold improvement over the two-phase, and up to 90-fold improvement over the original approach. This research was published in the paper "Multi-Application Inter-Tile Synchronization on Ultra-High-Resolution Display Walls," and presented at the Multimedia Systems 2010 conference.

For a single application, the graph below (left image) compares swap buffer completion time differences. The new synchronization algorithms achieve very low swap buffer variance compared to SAGE's original frame synchronization method, which results in better inter-tile frame synchronization. The high variance in the old method is because SAGE lacks swap buffer synchronization. We observed swap buffer completion time variances for 1,000 consecutive frames. The completion time difference of swap buffer among the various nodes in the original approach was around 12–14 ms, which caused viewers to visually perceive tearing in the application image on the display wall. The swap buffer completion time variance in the two-phase algorithm was higher than that of the one-phase algorithm because of the barrier latency in the second phase of the two-phase algorithm. However, both the two-phase and one-phase algorithms achieved inter-tile frame synchronization and exhibit a visually seamless display across the wall.

For multiple applications, the graph below (right image) shows that the algorithm scales as the number of applications is increased. SAGE's original per-application synchronization approach failed to sustain acceptable synchronization jitter with an increasing number of applications, whereas both the two-phase and the one-phase algorithms ensured tight frame synchronization despite an increasing number of applications. This was due to the single global synchronization master for all applications. Though minor increments of the swap buffer completion time difference were incurred by the increased system overhead on the display nodes as we increased the number of applications, this result still satisfied very tight frame synchronization tolerance.



Inter-tile swap buffer completion time difference (out-of-sync time) for a single application.



Inter-tile swap buffer completion time difference (out-of-sync time) with increasing number of applications.

Stereoscopic tiled display walls, such as Varrier, StarCAVE, and the soon-to-be developed NG-CAVE, are used for interactive and immersive 3D visualizations. Such applications require support for a high frame rate, up to 120 fps, to achieve interactivity. A frame synchronization scheme for these applications must be able to *achieve tight synchronization, regardless of an application's frame rate.* Though current 3D display systems are designed to view single applications, we anticipate viewing multiple applications in the future. Thus, we evaluated the performance of the synchronization algorithms as we scaled the frame rate of an animation, displayed across an entire 28-node tiled display wall, from 30 fps to 120 fps. The two new algorithms were sustained the target frame rate with minimal deviation. The old SAGE algorithm sustained the target frame rate up to 60 fps but failed to sustain it at 120 fps.

In addition to sustaining high frame rates, a good synchronization mechanism should *sustain the frame rates as more applications are launched* on a tiled display wall. To test this, we increased the number of applications streaming to the display wall and evaluated the impact of the synchronization mechanisms on the aggregate achievable frame rate. The old SAGE synchronization mechanism was able to sustain the frame rate only up to four applications and showed a 25% drop for 8 applications. In contrast, both the two-phase and the one-phase algorithms scaled as the number of applications increased.

Another key requirement of a good synchronization mechanism is the ability to *scale with the number of display nodes* as the number of display nodes and associated tiled display size increases. In the case of the two-phase algorithm, we observed minor increments in the inter-tile swap buffer completion time difference as we scaled the number of nodes, though the 2ms difference was too short for a user to notice any asynchrony between tiles. The one-phase algorithm achieved the tightest synchronization (~0.02ms), primarily because of the synchronized clocks and high-resolution hardware timers for displaying the frame as close as possible to the presentation time. In this test, both new algorithms showed much more improved scalability over the old approach.

Reliable Low-Latency Streaming

EVL is currently investigating synchronization techniques to handle unreliable data streaming.

2.B.4. SAGE in the Classroom

Several classes are being taught in our Cyber-Commons room using SAGE. The Computer Science's *Visual Analytics* class, taught by Professor Andy Johnson, teaches various visualization techniques through existing visualization examples. Johnson's lecture notes are displayed using a web browser and various images and videos, relevant to the lecture, are displayed using SAGE. SAGE enables many high-resolution images, which illustrate different visualizations of the same dataset, to be simultaneously compared. At the end of the class, the students were asked to complete a survey about their classroom experience; 80% felt that they were learning significantly more in this classroom space than they would have in a more traditional classroom equipped with whiteboards and a single projector, given their ability to compare multiple visualizations simultaneously, which is not possible in a traditional classroom.

2.C. Research Training and Development

NSF's many CI initiatives are amassing terabytes to petabytes of data, and will soon reach exabytes. EVL's SAGE efforts will enable users to connect visualization pipelines running on supercomputers, data storage systems and/or instruments to ultra-resolution tiled display walls.

In addition to advancing Computer Science, this project will help advance knowledge and understanding in the domain sciences, by providing faculty, staff and students with a means to manage the scale and complexity in their data with an intuitive environment for controlling cyberinfrastructure-enabled resources.

Those involved in this project extend outside the boundaries of UIC, given EVL's other collaborators -- on campus, nationally (museums, NCSA Great Lakes Consortium for Petascale Computing partners, DOE/SciDAC partners), and internationally (via StarLight, PRAGMA and GLIF). All the people working on display-related projects are involved in furthering research; either in their respective disciplines or by helping us better understand the limitations and future directions of our activities. It is clearly our students who benefit most, and are in high demand by the commercial sector for jobs in R&D when they graduate.

Also, making SAGE open-source has enabled greater participation by industry partners, including Monsanto, Sharp Laboratories of America, Rincon, Ciena and Microsoft Research. They want to understand their future customers, so are working with EVL to prototype ideas and solutions.

2.D. Outreach Activities

For detailed information, see Section 2.A.5: Education, Outreach and Broader Participation

EVL is committed to diversity and deems it central to its programs, projects, and activities, and provides research assistantships to graduate students, support for Research Experiences for Undergraduates (REUs), and mentoring programs for high-school students from the Illinois Math and Science Academy. Also, EVL faculty uses the technologies and tools it develops in the classroom, helping train the next-generation workforce.

EVL participates in major computer science conferences and workshops (e.g., ACM/IEEE Supercomputing [SC] and PRAGMA), networking conferences and workshops (e.g., PFLDnet, GLIF), and domain-science conferences (e.g., TeraGrid, AGU). EVL disseminates information via its website, YouTube, conference presentations, journal articles, and media promotion. EVL also actively works with museums, another outlet for broad dissemination; we currently work closely with Adler Planetarium in Chicago and the Science Museum of Minnesota.

EVL attracts a disproportionately higher number of underrepresented students than other CS departments because of its joint program with the Art & Design Department, and its many collaborations with humanities, engineering, medicine and science. UIC has a higher percentage of Latino and African-American students than any Big 10 university and ranks 44th (of over 2,000 universities) in the number of BA degrees awarded to Latinos and African-Americans. At the graduate level, UIC is ranked 26th in MA degrees awarded to Latinos and African-Americans.

In addition, EVL is very active in UIC College of Engineering and Computer Science recruitment and minority outreach activities, and does demonstrations and presentations for the annual Engineering Open House, "Bring Your Daughters to Work" day, the Society of Women Engineers (SWE), and the Association for Computing Machinery (ACM) student chapter, among others.

3. Publications and Products

3.A. Journal Publications

Ratko Jagodic, Luc Renambot, Andrew Johnson, Jason Leigh, Sachin Deshpande, "Enabling Multi-User Interaction in Large High-Resolution Distributed Environments," Future Generation Computer Systems (special issue on CineGrid, Cees de Laat, editor), Elsevier, accepted for publication

Beongil Jeong, Jason Leigh, Andy Johnson, Luc Renambot, Maxine Brown, Ratko Jagodic, Sungwon Nam, Hyejung Hur, "Ultrascale Collaborative Visualization Using a Display-Rich Global Cyberinfrastructure," IEEE Computer Graphics and Applications, Vol. 30, No. 3, pp. 71-83, May/June 2010, doi:10.1109/MCG.2010.45

3.B. Books / Publications

3.C. Internet Dissemination

www.sagecommons.org

3.D. Other Specific Products

Other than the information reported here, we have not developed any other specific product of significance.

4. Contributions

4.A. Contributions within Discipline

Since 2002, EVL has been conducting research in the use of high-performance remote rendering and streaming as a possible solution to the large-scale data visualization problem. This approach performs the "heavy lifting" of accessing, filtering and visualizing the data, using NSF cyberinfrastructure investments in the TeraGrid, high-speed national networks (such as National LambdaRail and Internet2), and relies on instruments, such as the Cyber-Commons and SAGE, to view the results.

SAGE development opens up new opportunities in computer science research at the intersection of large-scale data visualization, human-computer interaction, virtual reality, and high-speed networking. In addition, SAGE is being used to support several classes and seminars taught in the Computer Science, Art and Design, and Physics departments.

4.B. Contributions to Other Disciplines

Coping with complexity and scale in data is a problem that spans all of e-science. The Nation's cyberinfrastructure initiatives are amassing terabytes to petabytes of data, which will soon reach exabytes. When NCSA Blue Waters comes online, the only way to access it will be over networks. SAGE can provide scientists with a conduit into visualizing petascale computations.

Today, ultra-resolution display environments are fast becoming the "lenses" of virtual "microscopes" and "telescopes," enabling researchers to observe the data in cyberinfrastructure repositories. Using SAGE, scientists can create visualization pipelines from multiple sources -- whether supercomputers, data storage systems and/or instruments (such as high-definition cameras), as well as laptop screens and the Web -- to access and share a variety of information, in a variety of resolutions and formats, and create giant cyber-mashups. These "electronic posterboards" enable users to access up-to-date, related sets of information and simultaneously display them, to quickly see context as well as details and make more informed and timely decisions. This is unprecedented and heretofore not available, and will have a profound and transformative effect on data visualization, data exploration and collaboration, making cyberinfrastructure more accessible to end systems and to end users, both in the laboratory and in the classroom.

4.C. Contributions to Human Resource Development

Tiled display walls and SAGE are enabling technologies that will transform to the way today's scientists and future scientists manage large-scale and complex data so that they can more rapidly discover the underlying causes and solve problems of national priority, such as global climate change, or homeland security. We firmly believe that we need to give scientists and students better technologies in the laboratory and classroom than they currently have at home. At EVL, SAGE and tiled display walls provide a community resource openly accessible to our faculty and students, where they gather, meet, study, and work. In addition, EVL employs graduate and undergraduate students to help build the technologies, and our faculty uses it in the classroom, helping train the next-generation workforce.

4.D. Contributions to Resources for Research and Education

Our Nation already invests in network-connected, middleware-enabled cyberinfrastructure to generate and disseminate petabytes (ultimately exabytes) of data among researchers worldwide. What is missing, however, is a globally integrated collaborative work environment to facilitate data analysis and high productivity. The SAGE User Community believes SAGE and tiled display walls can fulfill that need, and is already using these technologies to such diverse disciplines as: geoscience, homeland security, bioscience, cosmology, atmospheric science, chemistry, computer science, medicine and art.

A few groups already use SAGE and tiled display walls in the classroom, giving the next-generation workforce access to these advanced technologies. And, industry is starting to partner with visualization and networking researchers to better understand and ultimately commercialize these technologies. Providing a production-quality SAGE will make cyberinfrastructure more accessible to broader communities of scientists and students, and help maintain US leadership in high-performance computing.

4.E. Contributions Beyond Science and Engineering

A "cyber-mashup," or juxtapositions of information, is a transformative high-productivity tool. It is a critical component of data analysis, enabling people to gain more holistic views and insight regarding complex issues, and make more informed observations and discoveries. SAGE leverages low-cost scalable thin-client PC clusters to enable end users to interactively access remote visualization data objects from shared cyberinfrastructure, as easily as the Web makes access to remote lower-resolution images today.

Technology costs have dropped to the point that adoption of these once-considered high-end technologies is now affordable. EVL actively works with museums; EVL currently works with Adler Planetarium in Chicago and the Science Museum of Minnesota, who use our tools and technologies in their educational displays to educate the general public.

In addition, EVL has a number of industry research groups interested in SAGE and tiled display walls; notably, Monsanto, Sharp Laboratories of America, Rincon, Ciena and Microsoft Research. EVL's prior visualization systems, including the CAVE, ImmersaDesk, and GeoWall, created new hardware and software companies and new jobs for Americans, to build and/or use these systems in research institutions and companies.

5. Conference Proceedings

NSF FastLane wants published papers. Instructions state: If you are unable to locate your Conference Proceeding citation using the search below, you may manually add your Conference Proceedings in the "Books or Other One-Time Publication" tab under Publications and Products.

S. Nam, S. Deshpande, V. Vishwanath, B. Jeong, L. Renambot, J. Leigh, “Multi-Application Inter-Tile Synchronization on Ultra-High-Resolution Display Walls,” ACM Multimedia Systems 2010, Scottsdale, Arizona, February 22-23, 2010

Sungwon Nam, Luc Renambot, Andrew Johnson, Jason Leigh, Byungil Jeong, Kelly Gaither, “Remote Visualization of Large Scale Data for Ultra-High Resolution Display Environment” (presentation), 2009 Workshop on Ultra-Scale Visualization, SC09, Portland, November 16, 2009 <http://vis.cs.ucdavis.edu/Ultravis09/slides/SC09_ultravis_NAM.pdf>

6. Special Requirements

6.A. Objectives and Scope

A brief summary of the work to be performed during the next year of support if changed from the original proposal.
Our scope of work has not changed.

6.B. Special Reporting Requirements

Do special terms and conditions of your award require you to report any specific information that you have not yet reported?
No.

6.C. Animals, Biohazards, Human Subjects

Has there been any significant change in animal care and use, biohazards, or use of human subjects from what was originally approved (or approved later)?
No.