SAGE: Scalable Adaptive Graphics Environment
Persistent Visualization and Collaboration Services for Global Cyberinfrastructure

Maxine D. Brown, Jason Leigh, Luc Renambot, Sungwon Nam,
Ratko Jagodic, Hyejung Hur, Lance Long, Byungil Jeong

***Abstract*—SAGE, the Scalable Adaptive Graphics Environment, is high-performance graphics middleware that provides distributed teams of researchers with the ability to interact with one another and with their data using display-rich global cyberinfrastructure that consists of ultra-resolution tiled display walls and high-performance computing resources connected over optical networks. Over 50 sites worldwide – universities, research institutions and companies – have already adopted SAGE to drive their ultra-resolution displays.**

***Index Terms*—Collaborative work, Cyberinfrastructure, Distributed computing, Visualization.**

I. Introduction

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 tiled display walls driven by computer clusters and interconnected over multi-gigabit optical networks.

Cyberinfrastructure – including supercomputers, data stores, large-scale instruments, global networks and sensornets – is capable of generating and disseminating petabytes, and ultimately exabytes, of data, and researchers are now grappling with ways to best manage the scale and complexity of their data. This is propelling the worldwide adoption of tiled display walls, which enable the creation of *cyber-mashups,* or juxtapositions, of data visualizations, enabling greater insight. What is needed is a globally integrated collaborative work environment to better facilitate data analysis and productivity.

SAGE is cross-platform, open-source middleware that enables users worldwide to have such 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.

EVL's *Cyber-Commons,* an EVL term for a technology-enhanced meeting room that supports local and distance collaboration and promotes group-oriented problem solving, outfitted with a tiled display wall running SAGE and 20Gbps of networking. As shown in Fig. 1, Cyber-Commons is used to teach UIC Computer Science courses in *Visualization and Visual Analytics, Video Game Design, Scientific Visualization,* and *Virtual Reality,* as well as a Physics graduate seminar. The *Video Game Design* class is taught remotely with Louisiana State University; the Physics seminar is taught remotely with CERN and Los Alamos National Laboratory.

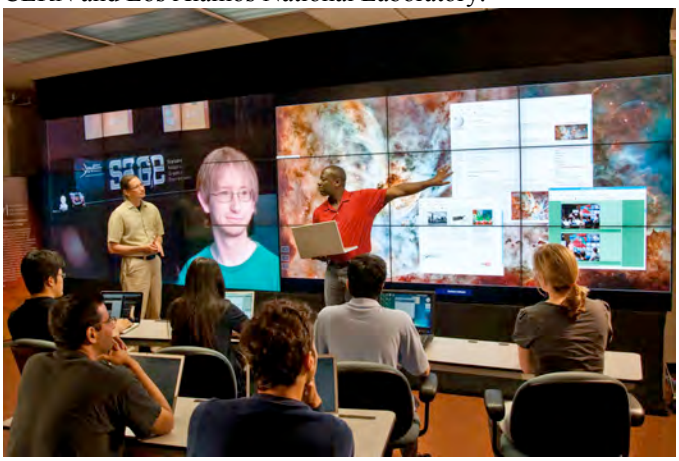


Fig. 1. EVL Professor Johnson uses the Cyber-Commons space to teach the computer science course *Visualization and Visual Analytics*.

II. Background

SAGE is an outgrowth of the NSF-funded OptIPuter[1] project. The initial design of tiled display walls, ultimately adopted by the OptIPuter project and named *OptIPortals*, was based on a 2002 NSF award to EVL for *LambdaVision*[2], a 100-Megapixel tiled display. As SAGE was designed to

Manuscript received February 16, 2010. This work is supported in part by the U.S. National Science Foundation under grant 0943559.

Maxine D. Brown is with the University of Illinois at Chicago (UIC) Electronic Visualization Laboratory (EVL), Chicago, IL 60607-7053 USA (phone: 312-996-3002; fax: 312-413-7585; e-mail: maxine@uic.edu).

J. Leigh, L. Renambot, S. Nam, R. Jagodic, H. Hur and L. Long are with UIC/EVL, Chicago, IL 60607-7053 USA (e-mail: spiff, renambot, snam5, rjagod1, hhur2, llong4 @uic.edu).

Byungil Jeong was with UIC/EVL. He is now with the Texas Advanced Computing Center (TACC), University of Texas, Austin, TX 78758 USA (email: bijeong@tacc.utexas.edu)

[1] NSF Information Technology Research (ITR) award OCI-0225642, October 2002-September 2009 funded OptIPuter. Larry Smarr (UCSD) was principal investigator (PI), Jason Leigh and Tom DeFanti (UIC) and Mark Ellisman and Phil Papadopoulos (UCSD) were co-PIs, and Maxine Brown (UIC) was project manager.

[2] Jason Leigh (UIC), PI, received NSF CNS-0420477, September 2004 – August 2008, for LambdaVision.

stream high-resolution images and animations over optical networks, EVL prototyped network-based transport protocols and prefetching algorithms over optical networks accessible via StarLight, using circuits that are part of Global Lambda Integrated Facility (GLIF) fabric.

Given the number of SAGE early adopters, listed in Table 1, NSF recently awarded EVL a three-year grant to transition SAGE from a transformative research prototype to a hardened technology that provides production-quality, community-driven open services for persistent visualization and collaboration, to make global cyberinfrastructure accessible to broader communities of scientists and students.

III. SAGE AND VISUALCASTING

When users use large-scale displays connected to optical networks, they want to seamlessly move information from one part of a display or room to another. This requires an intelligent software system, cluster and high-bandwidth local network to correctly route image data at interactive speeds. Furthermore, multicasting to support distance collaboration in these environments is an extremely challenging problem, both for the network and for the computer end systems that assemble the multicasted data streams; hence, the development of SAGE's Visualcasting capability.

SAGE serves as a window manager, allowing users to move, resize, and overlap windows as easily as on standard desktop computers. SAGE has standard collaboration desktop tools, such as image viewer, video player, and desktop sharing capabilities, enabling participants to resize, pan, zoom and move through the data. The SAGE user interface reliably supports the scaling and movement of any window on the SAGE display, while providing the user with performance monitoring for post-mortem analysis (frame rates, bandwidth for rendering and display nodes) using the NetLogger file format. New interaction devices and user interface controls that augment the windows environment are currently being integrated into SAGE, as shown in Fig. 2.



Fig. 2. New interaction devices and user interface controls are currently being integrated into SAGE, in support of persistent collaboration.

SAGE supports visualization at multi-ten-Megapixel resolution with interactive frame rates using gigabit local-area networks. SAGE is scalable in terms of the amount of visualization data and the visualization resolution. SAGE addresses the heterogeneity problem by decoupling graphics rendering from graphics displays so that visualization applications developed on various environments can easily migrate into SAGE by streaming their pixels into the virtual frame buffer. The output of arbitrary *MxN* pixel rendering cluster nodes can be dynamically routed to *XxY* pixel display screens, permitting user-definable layouts on the display. The dynamic pixel-routing capability of SAGE allows users to freely move and resize each application's imagery over the tiled displays in run time, tightly synchronizing the multiple visualization streams to form a single stream. Users can simultaneously run multiple visualization applications in the SAGE framework without losing dynamic pixel-routing capability, while using selectable network protocols adapted for each application; e.g., UDP for video streaming, TCP for large image data, and LambdaStream for rendered animations.

SAGE Visualcasting supports global collaboration by enabling two or more users to share application content, sending multi-gigabit streams as required. Connected, participating end-point sites form a virtual laboratory, as Visualcasting enables everyone to see the same content at the same time. Endpoints can be of any size and configuration, varying from a single high-resolution monitor to room-sized display walls. SAGE enables each site to maintain control of the layout (position, size, overlapping) of its displays. Visualcasting lets users select what information they want to send, and to whom. Several Visualcasting trials are illustrated in Fig. 3 and Fig. 4.

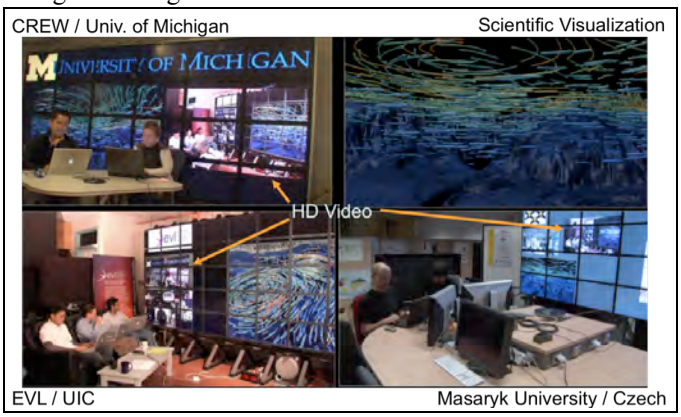


Fig. 3. SAGE Visualcasting collaboration at SC08 with remote participants from EVL, University of Michigan and Masaryk University.

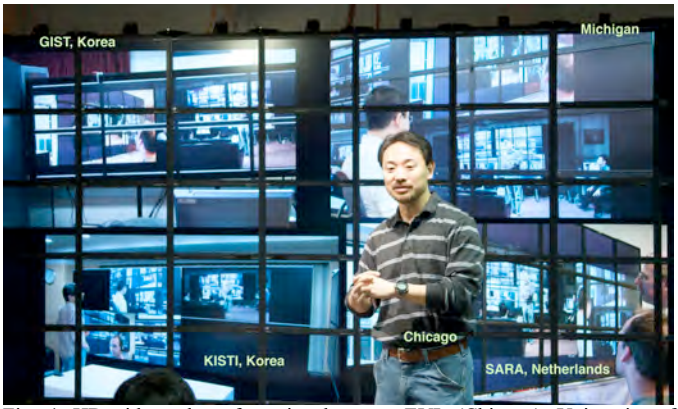


Fig. 4. HD video teleconferencing between EVL (Chicago), University of Michigan (Ann Arbor, upper-right), SARA (Amsterdam, lower-right), Gwangju Institute of Science and Technology (GIST – Korea, upper-left) and KISTI (Korea, lower-left) using SAGE Visualcasting.

TABLE 1
SAGE USER COMMUNITY – JANUARY 2010

AUSTRALIA
- AARNet
- Monash University - Caulfield
- Monash University - Clayton
- University of Melbourne
- University of Queensland

CANADA
- Nortel Networks, Canada
- Simon Fraser University

CHINA
- Chinese Academy of Sciences, Computer Network Information Center

CZECH REPUBLIC
- Masaryk University, Advanced Networking Technologies Lab (2)

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

JAPAN
- Knowledge Graphics Technology, Inc.
- Kyoto University
- National Institute of Advanced Industrial Science and Technology (AIST)
- National Institute of Information and Communications Technology (NICT) - Otemachi
- Osaka University

KOREA
- Gwangju Institute of Science and Technology (GIST), Networked Media Laboratory
- Korea Institute of Science and Technology Information (KISTI)

MEXICO
- Ensenada Center for Scientific Research and Higher Education

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

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, Transportation Research and Analysis Computing Center
- Calit2, University of California, Irvine
- Calit2, University of California, San Diego (3)
- Florida International University, Center for Internet Augmented Research & Assessment
- Louisiana State University, Center for Computation and Technology
- NASA Goddard Space Flight Center, Space Visualization Studio
- Northwestern University, International Center for Advanced Internet Research
- Purdue University, Envision Center
- Rincon Research Corporation
- Sharp Laboratories of America
- Texas A&M University, Computer Science & Engineering
- 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/ Provost's Virtual Space Interaction Testbed
- University of Texas at Austin, Texas Advanced Computing Center
- University of Washington
- US Geological Survey (USGS), National Center for Earth Resources Observation and Science

REFERENCES

[1] SAGE: www.sagecommons.org

[2] Byungil Jeong, Jason Leigh, Andrew Johnson, Luc Renambot, Maxine Brown, Ratko Jagodic, Sungwon Nam, and Hyejung Hur, "Ultrascale Collaborative Visualization Using Display-Rich Global Cyberinfrastructure," IEEE Computer Graphics & Applications, 2010, accepted for publication.

[3] B. Jeong, "Visualcasting: scalable real-time image distribution in ultra-high resolution display environments," PhD Dissertation, Computer Science, University of Illinois at Chicago, 2009

[4] G. Pieper, T.A. DeFanti, Q. Liu, M. Katz, P. Papadopoulos, J. Keefe, G. Hidley, G. Dawe, I. Kaufman, B. Glogowski, K. Doerr, J.P. Schulze, F. Kuester, P. Otto, R. Rao, L. Smarr, J. Leigh, L. Renambot, A. Verlo, L. Long, M. Brown, D. Sandin, V. Vishwanath, R. Kooima, J. Girado, B. Jeong, "Visualizing Science: The OptIPuter Project," SciDAC Review, Issue 12, Spring 2009, IOP Publishing in association with Argonne National Laboratory, for the US Department of Energy, Office of Science, pp. 32-41.

[5] Luc Renambot, Byungil Jeong, Hyejung Hur, Andrew Johnson, Jason Leigh, "Enabling high resolution collaborative visualization in display rich virtual organizations," Future Generation Computer Systems, Volume 25, Issue 2, February 2009, pp. 161-168.

[6] T.A. DeFanti, J. Leigh, L. Renambot, B. Jeong, A. Verlo, L. Long, M. Brown, D. Sandin, V. Vishwanath, Q. Liu, M.J. Katz, P. Papadopoulos, J.P. Keefe, G.R. Hidley, G.L. Dawe, I. Kaufman, B. Glogowski, K.-U. Doerr, R. Singh, J. Girado, J.P. Schulze, F. Kuester, L. Smarr, "The OptIPortal, a scalable visualization, storage, and computing interface device for the OptIPuter," Future Generation Computer Systems, Volume 25, Issue 2, February 2009, pp. 114-123.

[7] J. Leigh, A. Johnson, L. Renambot, "Advances in Computer Displays," (chapter), Advances in Computers, Vol. 77, Elsevier/Morgan Kaufman, July 13, 2009.

[8] Jason Leigh and Maxine D. Brown, "Cyber-commons: merging real and virtual worlds," Communications of the ACM, Volume 51, Issue 1, January 2008, pp. 82-85

[9] B. Jeong, L. Renambot, R. Jagodic, R. Singh, J. Aguilera, A. Johnson, J. Leigh, "High-performance dynamic graphics streaming for Scalable Adaptive Graphics Environment," Proceedings of SC06, Nov. 2006.

[10] L.L. Smarr, A. A. Chien, T. DeFanti, J. Leigh, and P. M. Papadopoulos, "The OptIPuter," Communications of the ACM, Volume 46, Issue 11, pp. 58-67, November 2003.