Future Generation Computer Systems 54 (2016) 296–305

Contents lists available at ScienceDirect

Future Generation Computer Systems

journal homepage: www.elsevier.com/locate/fgcs

SAGE2: A collaboration portal for scalable resolution displays

Luc Renambot [a], Thomas Marrinan [a], Jillian Aurisano [a], Arthur Nishimoto [a], Victor Mateevitsi [a], Krishna Bharadwaj [a], Lance Long [a], Andy Johnson [a], Maxine Brown [a], Jason Leigh [b,*]

[a] Electronic Visualization Laboratory, Computer Science Department, University of Illinois at Chicago, United States

[b] Laboratory for Advanced Visualizations and Applications, Department of Information and Computer Sciences, University of Hawaiʻi at Mānoa, United States

ARTICLE INFO

Article history:
Received 30 April 2014
Received in revised form
7 April 2015
Available online 16 June 2015

Keywords:
Scalable Resolution Display Environments
Window manager
Web-based
Collaboration
Multi-user interaction
Large-scale displays
Application development

ABSTRACT

In this paper, we present SAGE2, a software framework that enables local and remote collaboration on Scalable Resolution Display Environments (SRDE). An SRDE can be any configuration of displays, ranging from a single monitor to a wall of tiled flat-panel displays. SAGE2 creates a seamless ultra-high resolution desktop across the SRDE. Users can wirelessly connect to the SRDE with their own devices in order to interact with the system. Many users can simultaneously utilize a drag-and-drop interface to transfer local documents and show them on the SRDE, use a mouse pointer and keyboard to interact with existing content that is on the SRDE and share their screen so that it is viewable to all. SAGE2 can be used in many configurations and is able to support many communities working with various types of media and high-resolution content, from research meetings to creative session to education.

SAGE2 is browser-based, utilizing a web server to host content, WebSockets for message passing and HTML with JavaScript for rendering and interaction. Recent web developments, with the emergence of HTML5, have allowed browsers to use advanced rendering techniques without requiring plug-ins (canvas drawing, WebGL 3D rendering, native video player, etc.). One major benefit of browser-based software is that there are no installation requirements for users and it is inherently cross-platform. A user simply needs a web browser on the device he/she wishes to use as an interaction tool for the SRDE. This lowers considerably the barrier of entry to engage in meaningful collaboration sessions.

1. Introduction

Today, scientific data is collected, stored and analyzed digitally. Scientific phenomena are observed with new types of digital instruments, sensors and robotic autonomous vehicles capable of collecting data at ever-increasing resolutions. Natural phenomena from global weather systems to chemical reactions at the atomic level can now be simulated inside supercomputers, generating massive volumes of scientific data. These troves of data are invaluable to scientists as they explore the raw information and evidence needed for new insights and discoveries. However, making those insights is an increasingly complicated task, as the scale and complexity of data continue to grow at unprecedented rates. Since big data problems frequently require the combined efforts of many individuals from disparate fields, the next generation of visualization and interaction environments will need to enable collaboration and group work.

To deal with the scale and complexity of data, the *2007 DOE Visualization and Knowledge Discovery workshop report* [1] and the *2008 NSF Building Effective Virtual Organizations workshop report* [2] recognized that new modalities for accessing more visual information were necessary and described SRDEs as the type of environments that is crucial for next-generation collaborative cyber-enabled exploration. Furthermore, there is now conclusive evidence that large-scale display environments enable collaboration and significantly amplify the way users make sense of large-scale and complex data [3–11].

One software system that has addressed these issues is SAGE, the Scalable Adaptive Graphics Environment [12–15]. SAGE, in

* Corresponding author.
E-mail addresses: renambot@uic.edu (L. Renambot), thomas.j.marrinan@gmail.com (T. Marrinan), jillian.aurisano@gmail.com (J. Aurisano), arthur.nishimoto@gmail.com (A. Nishimoto), mvictoras@gmail.com (V. Mateevitsi), krishnaknbharadwaj@gmail.com (K. Bharadwaj), long.lance@gmail.com (L. Long), ajohnson@uic.edu (A. Johnson), maxine@uic.edu (M. Brown), leighj@hawaii.edu (J. Leigh).

http://dx.doi.org/10.1016/j.future.2015.05.014
0167-739X/

Fig. 1. Co-located collaborative session using SAGE2. Left—photo of ten users interacting with an SRDE tiled wall. Right—snapshot of a single user connected to SAGE UI, which provides interaction methods and a visual representation of the SRDE.

conjunction with SRDEs, represents a new type of "digital lens"—a high-resolution display that can effectively visualize large amounts of data in a collaborative environment. SAGE is an open-source middleware that provides users with a common operating environment, or framework, to access, display and share a variety of data-intensive information. The software allows each user to create a pointer on the SRDE by using their own personal device, or to directly approach the SRDE and interact through a multi-touch interface. In this manner, multiple users can simultaneously add and interact with content. SAGE utilizes pixel streaming over high-speed networks to display content ranging from high definition images and videos to PDF documents and laptop screens. While SAGE is being used to drive over 100 SRDEs around the world, its architecture was based on a monolithic software stack that made it increasingly difficult to integrate new capabilities as user requirements grew.

This paper presents the prototype for the next generation of SAGE, called SAGE2 for Scalable Amplified Group Environment. SAGE2 is a lightweight web-based middleware that runs in a browser. Along with the salient features of SAGE, SAGE2 (depicted in Fig. 1) aims to expand upon SAGE's collaborative framework to support interaction with a wider variety of content and enable a richer set of input modes for multiple users. Web-based applications and JavaScript programming are becoming increasingly popular and when coupled with strong application development support, we believe that SAGE2 will attract a large community of developers for multi-user, high-resolution applications. HTML5 allows a browser to be used as a powerful rendering middleware. SAGE2 exploits this factor to transform a browser into an active environment capable of supporting diverse media content and advanced 2D and 3D visualizations. Additionally, SAGE2 becomes inherently cross-platform and requires no installation beyond having an up-to-date browser. Since web-based data portals and visualization tools are widely used for collaborative research in industry and academia, SAGE2 is capable of supporting a large array of collaborative research activities.

2. Related work

Scientific visualization on SRDEs takes advantage of parallel rendering frameworks. The "Distributed Graphics System" [16] was an early system for rendering content to tiled displays. A Silicon Graphics Onyx2 with eight R10000 processors drove the tiled display; multiple networked client applications could connect and share the display space at once. WireGL [17] is a sort-first parallel renderer with a parallel interface that distributes the rendering primitives to a cluster of nodes. WireGL does support scalable display sizes, however only a single application can drive the tiled display. Influenced by WireGL, Chromium [18] is a framework for interactive rendering on clusters, which uses OpenGL to move geometry across the network. Existing OpenGL desktop applications can be ported to work on a cluster by utilizing Chromium, with only a few modifications. Equalizer [19] is an OpenGL parallel rendering system that supports scalable display environments. Using physical and logical abstraction, applications can run on a single or multiple displays.

OmegaLib [20,21] is a middleware that uses Equalizer for parallel rendering and provides the tools to develop immersive 2D–3D applications for flexible systems ranging from tiled display walls to CAVE environments. OmegaLib also offers event handling that supports multiple heterogeneous devices. Cross Platform Cluster Graphics Library (CGLX) [22] is an OpenGL graphics framework for distributed, high performance visualization systems. CGLX allows users to easily develop new or adapt existing OpenGL desktop applications for visualization clusters such as tiled displays and multi-projector systems. CGLX supports collaboration through multiple multi-touch devices. Input events are synchronized with the display environment and scene information is streamed to the mobile device [23].

In many disciplines, collating data from various sources and juxtaposing content becomes an important task. In these scenarios, scalable window managers that support multi-user interaction are utilized to give SRDEs the appearance of one seamless desktop. The Distributed Multihead X [24,25] is a parallel X11 server. A traditional window manager (like KDE or Gnome) needs to run on top of DMX to fully utilize its capabilities. DMX acts as an X11 proxy server that accepts server connections, therefore allowing the construction of scalable display environments. CubIT [26] is a multi-user presentation and collaboration framework designed for the large-scale projector and multi-touch LCD walls of The Cube exhibition and learning facility. Using either web-based or iOS interfaces, users are able to upload and manage multimedia content to the wall. The Python/Kivy multi-touch interface enables drag and drop interaction allowing moving, scaling and sharing of content across the shared canvas or between users. LACOME [27,28] is a multi-user collaborative system that supports multi-user screen sharing through VNC. Participants can connect to the LACOME server using the standard VNC protocol, share their screen on a large display and interact with the other screens by moving them around. DisplayCluster [29] closely resembles the original SAGE, as it provides a windowing system for multimedia content across SRDEs. While claiming improved performance over SAGE, it relies purely on pixel streaming whereas SAGE2 can additionally take advantage of native distributed rendering.

Co-located and remote collaboration has been greatly affected by the advancement of web-based technologies. The web is being increasingly used to collaborate in a variety of scenarios such as teaching, corporate meetings and manufacturing. Binary