IQ-Wall: An Open Standard for Tiled Video Walls that Balances Flexibility, Usability, Performance, and Cost

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Abstract: Tiled video walls are engaging, useful, and pervasive in our everyday environment. They can be especially attractive to higher education institutions looking to spur innovation in teaching, research, and collaboration. However, if not thoughtfully designed, video walls can be expensive, difficult to maintain, and provide only limited functionality. Indiana University has been working with video walls for more than 10 years, using them in a variety of settings to support faculty, staff, and students in a broad range of research, education, community engagement, and creative activities. This experience has led to the development of an open hardware and software standard for video walls that provides flexibility, usability, maintainability, and the lowest possible costs while still maintaining good performance and high visual quality. In this paper, we share the motivations and technical details behind this open standard, as well as the lessons learned in building and supporting tiled video walls as multi-purpose displays.

Motivation

We see video walls in airports, shopping malls, athletic venues, museums, corporate lobbies, broadcasting studios, and universities. Their uses are broad and their impacts, significant. Digital signage is perhaps the most straight-forward and common use of video walls, but they are effective as multi-window command-and-control canvases, interactive ultra-resolution data visualization and analysis displays, and sophisticated collaborative environments to support research and active learning. The large physical size of video walls supports multi-user collaboration and creates a sense of visual immersion. The high resolution of video walls facilitates detailed analysis and the aggregation and juxtapositioning of a variety of information. The vivid colors of modern flat-panel video walls allow for authentic visual simulations and creative experiences in a variety of physical spaces and lighting conditions. Yet, in spite of these advantages and diverse possibilities, many video walls are installed for a limited purpose and/or suffer from unnecessary integration costs that ultimately limit their utilization, impact, and potential for wider deployment.

Indiana University (IU) installed its first tiled video wall in 2004, utilizing relatively expensive high-end components and a professional audio/video integrator. This system generated broad interest among the University's faculty, staff, and students for uses varying from research visualization to collaborative presentations to artistic creations. This success spurred staff from IU's Advanced Visualization Laboratory (AVL) to explore lower cost and technologically simpler options as a means to enable the deployment of additional video walls to have even greater impact on the University's core missions. This work led to development of an open specification for video walls, dubbed the "IQ-Wall", which can be implemented by most educational technology teams with relatively modest budgets. To date, AVL has designed and built nine walls around this standard. The IQ-Wall is intended to be used by a variety of disciplines in a variety of situations. It strikes a balance between cutting-edge technology, good performance, and cost. We assert that institutions interested in purchasing a vendor-integrated video wall or other advanced display solution should consider implementing their own IQ-Wall.

This paper summarizes the technical and social issues related to creating and deploying an IQ-Wall. We begin with an overview of tiled video wall technologies and our broader IQ initiative. We detail the most important components of the IQ-Wall system and summarize our installations and lessons learned. We conclude by discussing empirically-derived use cases and the IQ-Wall value proposition.

Overview of Tiled Video Wall Technology

Display Technologies

Robert Simpson provides an overview of the display technologies used for video walls, noting that video walls first emerged in the early 1980s (Simpson, 2009). These systems began as a simple tiling of CRT monitors but suffered from poor color consistency and large gaps between the monitors which formed the single aggregate image.

The first major advance in display technology was the video wall cube. Cubes are self-contained, projection-based display units that have very thin bezels, thereby minimizing the gap between cubes and enhancing the view of the entire image. Special filters in front of the projection unit maximize contrast and color uniformity while minimizing bright spots. Cubes are designed for 24/7 operations and were initially intended for use in command and control environments. Disadvantages of cubes include their initial cost, large footprint and required maintenance.

Around the same time as projection cubes were becoming popular, a number of academic research groups began building video walls using commodity DLP or LCD projectors (Green, 1999; Li, 2000). These installations typically used a single flexible screen material and had the advantage of no gaps in the image. Moreover, the cost per commodity projector was typically 5-10 times less than the equivalent professional-grade projection cube. The disadvantages were that the projectors had to be very precisely aligned to make the image appear continuous; commodity projectors were also difficult to color-balance and suffered from hot-spots.

The most recent innovation in display technologies for video walls has been the flat panel. Modern flat panel monitors are relatively inexpensive, easy to install and configure, align nicely when tiled, have good color calibration options, and are easy and cost-effective to repair or replace.

Image Generators: Compute & Software

While the displays themselves are obviously vital to the video wall, so too are the computing hardware and software that manage and display the visual content. Video wall processors are specialized units capable of ingesting a combination of video (e.g., DVD, Blu-Ray players) and computer sources, and then compositing and distributing those sources across a tiled array of displays. Processors commonly rely on proprietary software interfaces that offer scaling and control mechanisms and have ability to move individual sources around on the larger display as if they were windows within a desktop GUI (RGB Spectrum, 2015; Jupiter, 2015). Video wall processors are good at ingesting and managing external sources but suffer from an inability to allow native applications to access the full resolution of the collective display while still maintaining interactive performance (defined as a minimum of 30 frames per second).

With the advent of powerful, commodity graphics cards in the early 2000's, academic research groups began driving tiled displays using a cluster of display computers where each computer was connected to one or two of the individual monitors making up the video wall. This afforded users the opportunity to access all available pixels while offering interactive performance. Problems with this approach were software and content distribution across the cluster and synchronization of the display frames. Special software, such as WireGL (Humphreys, 2001) and Chromium (Humphreys, 2002) were developed to alleviate this concern, but configuration and maintenance of a computer cluster proved non-trivial for most users, and many pre-existing off-the-shelf software applications were not capable of running in such a clustered environment.

Graphics card manufacturers eventually began to offer cards with multiple video outputs and built-in synchronization mechanisms. These cards could be installed in standard desktop computers running Microsoft Windows (that would support commercial, off-the-shelf software) and had configurations for managing small video walls with a limited number of tiles. In 2009, the AVL built its first tiled video wall using a desktop PC computer configured with an NVidia Quadro Plex with four video outputs (NVIDIA, 2015). A key to this prototype was the utilization of Matrox TripleHead2Go video splitters which allowed each video output from the Quadro Plex to drive three displays at full resolution; thus, our 4-output PC effectively became a 12-display system. This configuration was the first instance of what we would eventually label an ultra-resolution or "UltraRes" PC. The UltraRes PC eliminates the need for cluster-aware software, and nearly every commercial and open source package can run at full resolution with no modification.

IQ Initiative

The IQ-Wall is one of five systems born from an Indiana University-led initiative called the IQ project. The IQ project aims to create and deploy advanced visualization systems and interfaces which are relatively inexpensive, interactive, and immersive (Wernert, 2012). All IQ systems attempt to lower the technological barriers to entry and democratize access to advanced visualization technologies as a means to increase the breadth and depth of utilization. IQ systems strike a balance between low cost and professional quality as well as between good performance, ease of use, and ease of maintenance. These designs are open and meant to be shared and improved upon by the community. Once systems are deployed to a location on campus, site staff are encouraged to collect and share usage data and insights. These insights are fed back into the design process and used to improve the next iteration.

In addition to the IQ-Wall, other IQ systems include: the IQ-Station—an interface and display for virtual reality and immersive visualization; the IQ-Table—a portable multi-touch aware horizontal 55" diagonal table display; the IQ-Tilt—a multi-touch aware 94" diagonal 2x2 tiled display that elegantly converts from a horizontal table position to a vertical orientation; the IQ-Force—a haptic display featuring virtual and physical co-location (UITS, 2015).

IQ-Wall System

Display

IQ-Walls can be constructed with any matching slim-bezel digital televisions or monitors. Early versions of the IQ-Wall at IU used Samsung monitors, but we transitioned exclusively to Planar monitors in 2014. Planar (2015) offers professional quality monitors with a distributed hardware architecture. The monitors themselves contain minimal electronics and connect to a Planar controller module using a shielded Cat6 cable that carries video and control signals, and to a Planar power module using a low-voltage power cable. These external modules are housed in an equipment rack that can be located up to 200' away in an A/V closet without special video extension. This arrangement allows for cooler and quieter operation in the room housing the display. We use HD resolution monitors with thin or ultra-thin bezels. One model also supports passive stereoscopic 3D viewing. The Planar controllers also have built-in video signal ingestion and can accommodate a limited number of wired external video sources.

The display mounting structure can be free-standing, and even movable (for smaller IQ-Walls), or it can be permanently mounted to a reinforced building wall. Weight can be substantial so careful planning is critical. Articulating wall mounts have been used to allow IQ-Walls to be curved and dynamically adjusted. (See Figure 3.) For wider configurations, the curve improves the visibility of all parts of the display, especially when working up close. Optional hardware components include audio input and output devices, multi-touch capabilities, spatial tracking systems (for virtual reality or other advanced interfaces such as gestures), dedicated videoconferencing systems and cameras, and advanced control systems (e.g. a Crestron or AMX controller).

Compute

The UltraRes PC is the component that separates an IQ-Wall from many other tiled video wall solutions. It is critical to achieving our goal of supporting a broad and diverse user population. The UltraRes PC enables high-end scientific and information visualization, rich visual simulation experiences, and high fidelity multi-window collaborative sessions on a single computer. Our latest UltraRes PC configuration utilizes a workstation class computer with dual 8-core processors, 128 GB memory, 1 TB hard drive, and a standard keyboard/mouse for input. Graphics are provided through an NVIDIA Quadro GPU that fits inside the workstation (in contrast to the Quadro Plex, used for the first generation of IQ-Wall, which was an external graphics unit requiring dedicated power and additional cables). Monitor synchronization is implemented using NVIDIA Mosaic Mode (enabled on the Quadro GPU).

A limitation of the UltraRes PC is its inability to properly ingest and manipulate external video sources. To accommodate this, we provide a limited number of wired connections that feed directly into the Planar controller. Additionally, we have a wireless open-source software solution (described in the next subsection). This combination of the UltraRes PC, wired connections into the Planar controller, and open-source software is considerably less expensive than a traditional video wall processor and has the advantage of being able to accommodate interactive, ultra-resolution viewing and analysis.

Software

The UltraRes PC runs the Microsoft Windows operating system which provides a familiar interface for the vast majority of users. Moreover, this means that IQ-Walls support a wide variety of off-the-shelf software. This is a tremendous advantage over previous generations of advanced visualization facilities which required specialized software and perhaps even dedicated operators. Commonly used and supported software include: office productivity suites, tools for scientific visualization, ultra-resolution infographic and image viewing, visual analytics, 3D model viewing and manipulation, virtual reality and visual simulation, video playback, Google Earth and Google Maps, and modern web browsers. In addition to off-the-shelf applications, our group has developed specialized applications that take advantage of the unique capabilities of the IQ-Wall. For example, we created an application that allows a group to view 32 spherical data sets at once with a centered and larger highlighted data set. This application compliments our Science on a Sphere display (Science, 2015). (See Figure 1.)

The IQ-Wall Screensaver is an IU-developed application which runs whenever a user logs out of the IQ-Wall system. This is the foundation for supporting digital signage on IQ-Walls. The application is essentially the open source Chromium web browser modified to run as a screensaver in fullscreen mode. The screensaver loads content from a curated list of websites and media galleries and displays them in containers of various sizes that align with the tiles of the IQ-Wall. (See Figure 2.) A configuration file is provided so that the local IQ-Wall administrator can specify the content to load and the sizes of the containers. Layouts are chosen randomly at specified intervals so that content always appears fresh, somewhat unique, and interesting to viewers.

In lieu of an expensive video processor unit or wired connections to user laptops, IQ-Walls run SAGE2 (Marrinan, 2014). SAGE2 is an open-source collaboration tool built by the Electronic Visualization Lab at University of Illinois at Chicago specifically for large, ultra-resolution tiled displays (such as IQ-Walls). SAGE2 runs entirely on modern web technology. A local user starts a SAGE2 session on the IQ-Wall, then collaborators can use the Chrome browser on their personal computers, laptops, or mobile devices to wirelessly connect to the IQ-Wall and share content. Users can choose whether to share an individual application or their entire desktop. Using SAGE2, the IQ-Wall can accommodate an unlimited number of collaborators. Everyone can see, move and resize each other's shared windows.

Figure 1: Custom Science on a Sphere display software running on an IQ-Wall as part of a public exhibit.

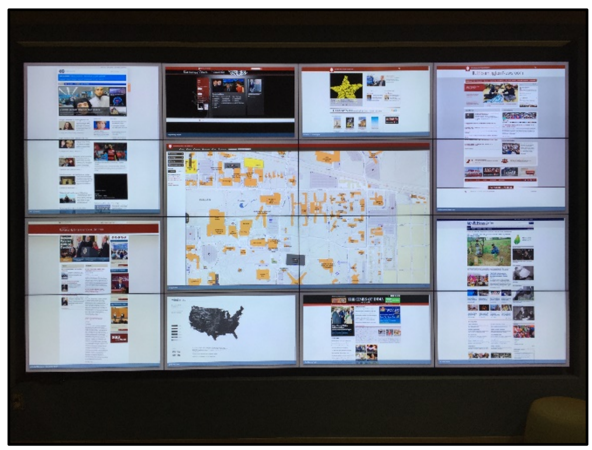

Figure 2: The IQ-Wall screensaver application displaying multiple web pages and a campus map.

Summary of IU Installations

We have built nine IQ-Walls over the past six years. All of these are located on the Indiana University Bloomington campus. Their primary tasks vary greatly, but include some combination of research, teaching, public relations, exhibits, informal collaboration in a public space, and command-and-control operations. Table 1 provides a summary of the tile configuration, total resolution (in megapixels) and physical size for each installation.

Observations and Recommendations

Hardware costs and the time required to design and install an IQ-Wall have both decreased significantly with subsequent installations, allowing us to deploy IQ-Walls more inexpensively and more rapidly. While walls can be configured at any reasonable width and height, an IQ-Wall with an equal number of rows and columns will properly maintain the HD aspect ratio, which offers advantages when working with standard HD or 4K media and presentation formats. At the same time, such "n x n" configurations abound in malls, airports, and television studios and often suffer from looking too "standard". As an alternative, consider wider or curved installations that may suggest an "advanced" or novel installation. The initial impression and positive perception of your facility is critical to its utilization.

Select spaces for a tiled wall that are visible and, if at all possible, open to the public. Our three IQ-Walls that are situated in public spaces have higher utilization from a more diverse audience than those installed in dedicated research, teaching, and operations spaces. At IU, IQ-Walls are configured to allow anyone who has physical access to the Wall and a University computing ID to login to the system using centrally-managed Microsoft Active Directory Service credentials. Removing the requirement to request access or create an account has been a foundation of this initiative's recent success and growth. On the flip side, organizations or building managers may want to restrict usage scenarios on public displays. This is understandable and should be discussed prior to the installation. Finally, do not assume what people know, their comfort level, or willingness to try your new display. We recommend conducting public trainings and workshops as often as possible.

Location	***Primary Purpose***	***Tile Config***	***Total Resolution***	***Size***
Mathers Museum of World Culture, 2009	Teaching, Exhibits	3 x 4	4098 x 3072 (12.5 MP)	10' x 8'
School of Informatics & Computing, 2010	Research	3 x 3	4098 x 2304 (9.5 MP)	10' x 6'
Cyberinfrastructure Building, 2011	Public Space, Research	6 x 4	10080 x 4200 (42 MP)	24' x 9'
Global Research Network Operations Center, 2011	Operations	6 x 2	11520 x 2160 (25 MP)	24' x 4.5'
Social Science Research Commons, 2012	Research, Presentations	2 x 2	1920 x 1080 (2.1 MP, scaled up 2x)	8' x 4.5'
Wells Library Scholars Commons, 2014	Public Space, Research	4 x 4	5464 x 3072 (17 MP)	13.5' x 8'
Indiana University Foundation, 2015	Public Relations	3 x 3	1920 x 1080 (2.1 MP, scaled up 3x)	10' x 6'
Global & International Studies Building, 2015	Public Space, Presentations	4 x 4	7680 x 4320 (34 MP)	13.5' x 8'
Indiana University Data Center, 2015	Operations	8 x 2	15360 x 2160 (34 MP)	27' x 4'

Table 1: IQ-Walls on the IU Bloomington campus.

Use Cases

We present five distinct use cases based on our empirical observations and conversations with users. Each demonstrates a key functionality of the IQ-Wall. In practice, multiple use cases can be, and often are, employed within a single IQ-Wall session. A session can have many users, and those users can be physically present at the IQ-Wall or they may join through video conferencing and remote screen sharing technologies. Real-time collaborations between IQ-Wall installations are becoming more common as the technology proliferates and the user base grows.

Advanced Visualization - Ultra-Resolution and Stereoscopic 3D

A key capability of the IQ-Wall is its ability to facilitate advanced visualization and analysis scenarios well beyond what is commonly available on desktop systems. Ultra-resolution viewing refers to the ability to access the full resolution of the display, often ranging from eight to 24 times the resolution of a typical desktop monitor. Ultra-resolution visualization is especially helpful for research groups analyzing information-rich visualizations or high-fidelity images. (See Figure 3.) The size and resolution of the IQ-Wall allows the examination of details within the context of the entire data set without resorting to zoom and pan operations. Stereoscopic 3D viewing is commonly used for scientific visualization applications, screening stereoscopic 3D movies or interacting with visual simulation applications. The 3D capability is useful in comprehending complex spatial forms or renderings, and for increasing the sense of presence and immersion within a simulation.

Simultaneous Multi-Window Viewing

In this scenario, users rely on the size and resolution of the IQ-Wall to juxtapose multiple windows, applications, or media elements. Items being shown can include documents or spreadsheets, interactive visualizations, computer programs, webpages, images, videos, or windows that facilitate video conferencing. The key here is to display lots of related information from different sources or applications at the same time. This is a popular use of an IQ-Wall that is simply not possible with a traditional desktop monitor. Windows can originate from either the UltraRes PC or from external video sources that are ingested and displayed on the IQ-Wall. (Figure 6 demonstrates this use case for operations control.)

Figure 3: A 24-tile curved IQ-Wall being used for ultra-resolution visualization and analysis of network data.

Figure 4: Three-dimensional art showcase using the stereoscopic 3D capability of this IQ-Wall.

Figure 5: A presenter using a 3x4 IQ-Wall located in an on-campus museum.

Figure 6: The 12-tile IQ-Wall located in the Global Research Network Operations Center.

Creative Display

The combination of ultra-resolution, physical size, brightness, color uniformity, and optional features such as spatial tracking and stereoscopic 3D afford a novel and creative canvas for modern digital artists. (See Figure 4.) Faculty and students have used our IQ-Walls to create rich visual simulations and interactive virtual environments. The large field-of-view and exceptional visual quality of the IQ-Wall offers higher fidelity and detail than other virtual reality devices. It also has the benefit of accommodating group viewing and innovative gesture-based input. The IQ-Wall has been utilized for student portfolio reviews and exhibitions.

Presentation

Presentations are popular and well supported on the IQ-Wall. The IQ-Wall is large and bright enough to accommodate traditional formal group presentations while simultaneously being able to support ultra-resolution and/or stereoscopic 3D presentations. The presenter can use a presentation clicker and speak to an audience physically located in the room. By adding video conferencing capabilities, the presenter gains the ability to share their content with a remote audience. The presenter can use the UltraRes PC or can connect and display their own external video source (e.g. a laptop). Powerpoint is the most commonly used software for this case and scales well on the IQ-Wall (See Figure 5). Innovative presentation tools such as Prezi (Prezi, 2015) gain additional impact and context with the size and resolution of the IQ-Wall.

Digital Signage and Display

The digital signage use case is simple, but valuable, and features passive viewing of digital content. Preferably, users would provide custom content that makes use of the full resolution of the display, but our screensaver software can aggregate multiple, standard resolution sources to achieve full resolution. In this mode, the IQ-Wall is essentially locked down and interaction is generally not allowed. This is an unmanned mode of operation, referred to as the "attract" mode, which is enabled whenever the IQ-Wall is not actively being used. This attract mode is primarily used for public relations, information dissemination, and to spark interest and curiosity among people walking by or loitering in the vicinity.

Value Proposition

There are four primary costs in installing and operating an IQ-Wall: (1) hardware costs, (2) design and installation costs, (3) system maintenance costs, and (4) user support costs. The hardware costs are the most variable and are dependent on the size of the wall, the additional features and capabilities of the displays (e.g. stereoscopic, bezel size), and the additional hardware features and capabilities of the system (e.g. touch, spatial tracking, video conferencing, etc.) While the hardware cost isn't always directly proportional to the number of tiles, it can be used to provide a useful estimate. In the past six years, we have seen the cost of the core of an IQ-Wall system (inclusive of displays, mounting hardware, UltraRes PC, and cabling) drop from an average of $6,500 per tile to roughly $5,000 per tile.

The cost of staff time required to design and install a system has dropped even more, ranging from over 300 hours for the initial research and development phase for our first IQ-Wall system in 2009, to an average of just over 60 hours per system for the three IQ-Walls installed in 2015. This trend is not surprising as we gain experience and are able to use similar or identical components. These efficiencies allow us to realize substantial cost savings to our university and non-affiliated partners, especially when compared to the cost of vendor-integrated solutions, which can be more than twice the cost of an internally integrated IQ-Wall.

The IQ-Wall has minimal maintenance costs and, with adequate support staff, requires no vendor maintenance contracts. There are no projector bulbs to replace, and the individual components are expected to last for anywhere from 6-10 years. The UltraRes PC is serviceable using standard and readily available computer parts, and should be upgraded regularly to keep pace with the demands of software and data-intensive users. (We do recommend purchasing one or two additional monitors in lieu of an extended hardware contract. Having spare parts on hand eliminates the need to find funding in a crunch and allows local support staff to do a quick swap should a monitor unexpectedly fail.)

The fact that the UltraRes PC runs a current and standard version of Microsoft Windows allows us to leverage the time and expertise of the IT support staff in the departments and schools where the IQ-Walls are installed. These staff members maintain the system image and software installations as part of their normal duties. The UltraRes PC and Windows are also the key to helping AVL staff support a very large number of users. Since no application development or customization is required, users can readily bring the software tools they are already familiar with to their sessions on the IQ-Wall. Staff effort is dedicated to basic user training and consultation on process enhancements offered by the IQ-Wall.

While the cost avoidance is readily quantified, the return on investment can be more difficult to measure. We have recently begun to be more systematic about collecting utilization data. For example, for the two publically accessible IQ-Walls built within the last year, we have recorded 316 distinct user sessions. This, of course, does not take into account the number of collaborators (local and remote) who participate in the session but are not officially logged into the system. Moreover, when located in public spaces (such as building lobbies), the IQ-Wall can also be used for digital signage, community events, and information sharing. The value of these activities is difficult to quantify but has clear benefits and helps to increase the sense of community and association among university members.

Conclusion

To sum up, the IQ-Wall is an open and cost-effective specification for creating video walls that offers flexible design options and lowers barriers to use and support by operating on the Windows platform. It is a visualization technology that is broadly applicable to a variety of disciplines and usage scenarios. After nine deployments at Indiana University over six years, the staff has reduced the cost per tile (equipment cost plus labor to install) and become adept at installing the technology in expanding arenas. User uptake has grown with more IQ-Walls in public spaces. These users take advantage of the ultra-resolution to facilitate collaboration, creative expression, enhance presentations, and offer a passive signage mode that still delivers dynamic content. By joining in this open collaboration, other institutions that are interested in installing video walls can leverage our experience to save time and money while jump-starting their efforts. (Idaho National Labs and Missouri University of Science and Technology have already installed IQ-Walls, and we are actively advising the University of Illinois Engineering Library on an installation.)

We are committed to growing the community of IQ-Wall users. We have plans to deploy additional IQ-Walls at Indiana University Bloomington as well as other IU campuses, including multiple planned deployments for our Indianapolis campus. We are working with our learning technologies group to scale out the IQ-Wall standard to classrooms and formal educational settings. We will also continue to increase the quantity and depth of our IQ-Wall trainings and workshops and continue to share the IQ-Wall standard and help organizations outside of IU realize new deployments.

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