Just Scratching the Surface, the Long Road to Effective Cross-Display Interaction

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Abstract

There are five issues that face designers of systems that support cross-surface interactions “in the wild.” These present unique challenges to successfully deploying multiple displays that fully exploit surface technologies and the rich interactions they afford: (1) the form factor of a display often determines its appropriate role in a multi-surface environment; (2) placement rules, replication, and presentation format for content that is shared across surfaces can have complex semantics that need careful design to be effective; (3) the physical and logical topology of linked surfaces impacts how cross-surface interaction will be controlled; (4) the rapid convergence of computer graphics, computer vision, and haptic input and output are opening up vast new possibilities that were only imaginable a few years ago; and (5) the desire to make these new technologies accessible to a widely diverse set of stakeholders makes all of the issues that much more challenging. We illustrate our discussion through examples drawn from our own work supporting collaborative urban design for sustainable cities.

Author Keywords

Charrette; collaboration; content sharing; form factor; interaction design; interdisciplinary; public engagement; stakeholder; surface; sustainability; urban design; user-centered design; visualization.

Figure 1: UD Co-Spaces: a multi-display collaborative environment where urban design stakeholders can simultaneously interact with multiple surfaces.

Figure 2: UD Co-Spaces supports 2D maps on a tabletop coordinated with 3D views on the wall

Figure 3: Google Earth is used to embed a proposed sustainable design into an existing urban context.

ACM Classification Keywords
H.5.2-3. [Information Interfaces and Presentation]: User Interfaces, Group and Organization Interfaces

Introduction
As the title of this position paper suggests, we believe that despite multiple decades of research and experience with surface computing, we have only just begun to understand what can be accomplished using multiple surfaces that are used in concert with each other. The particular issues that we focus on are those that arise from cross-display interaction. This does not mean that there are not equally important challenges for single-surface interaction. There are. But our interest is in identifying areas in which substantial progress can be made in the next few years.

The opportunities provided by computing environments with multiple display surfaces bring with them a number of challenges. Weiser first elaborated a vision of computational agents embedded in everyday settings that is now variously known as ubiquitous computing, pervasive computing, and smart environments [11]. More than a decade ago, researchers at Stanford developed the iRoom to demonstrate how a heterogeneous collection of displays could inter-operate to support seamless interactions across the displays [8]. Since then, there has been much research activity exploring collaboration on single and multiple tabletop displays for a variety of application domains.

Our own work has focused on urban design where we have studied how a multi-display environment centered on an interactive multi-user tabletop display that we call UD Co-Spaces (Fig. 1) can support the public charrette process that is commonly used by planners [2, 5].

Our main goals were: (a) engaging different groups of stakeholders to actively interact with design options, (b) fostering collaboration and co-creation of urban design through the use of touch-based interaction and surface technology, and (c) enabling stakeholders to understand consequences of their choices using simple visual encodings that connect sustainability indicators to urban form.

There has already been a lot of interest in using interactive surfaces in the context of urban planning. The archetype tabletop system for urban design was URP [9], developed by Ishii and his colleagues at the MIT Media Lab and subsequently extended to incorporate aspects of mixed reality [1, 4]. Later, Wagner et al. [10] developed a mixed-reality system for urban planning using both tabletop and wall displays with physical objects on the table. The physical objects are only used as tokens instead of being actual scale models of buildings, as in Ishii's Luminous Table [4]. These applications are more like presentation tools for previously developed urban designs, with little support for actual interactive design activities such as those that take place in brainstorming sessions when civic engagement with a wide range of stakeholders is important.

More recent tools such as ETH's ValueLab [3] bring together large interactive displays and visualizations to facilitate public participation in the planning of mega-cities – what Halatsch et al. refer to as "Future Cities." ValueLab uses GIS data and visualization software to simulate design choices. Maquil et al. developed ColorTable [6], an interactive round table to facilitate communication between diverse stakeholders. ColorTable utilises a tangible user interface and tokens placed on the table to represent design elements, such as buildings or streets. It uses a physical map augmented with 2D images and 3D objects to lend the design area more realism. A perspective view of the design is provided by a projected image on a wall display.

While these early research investigations are similar to ours

Figure 4: Discussions among stakeholders naturally flow back and forth between the multiple surfaces.

Figure 5: Sustainability indicators provide feedback to stakeholders through infographics-style widgets.

Figure 6: Indicators on an auxiliary wall display help stakeholders track progress toward their sustainabilty goals.

in the sense that they utilised multiple displays in conjunction with collaborative tabletops for urban planing, our efforts focused on providing familiar visualization and interaction techniques, accessibility, and fast and early feedback to encourage broad-based public engagement. Our assumption that ubiquitous experience with personal computers, hand-held smart phones, and tablets has created a level of sophistication in the general public that implies that gestures such as zoom and pinch will be familiar to many people was definitely borne out in our evaluations of this approach [5].

In this position paper we reflect on our experience to date and we share some of the insights that we gathered through many years of observing different iteration of UD Co-Spaces in use with different broad range of users (singles, families, youth, older adults) with a range of computer savvy from novices to experts. We believe that the insights we gained are worth considering when building future multi-display systems even for different application domains and collaborative tasks. We have structured the rest of the paper around the discussion of five key issues that we would like to bring to the attention of the cross-surface interactions community.

1. Form Factors Matter – A Lot!

The size, aspect ratio, orientation, and location (relative to viewers) of a display implies certain affordances that are different for each combination of these factors. Examples are text, which needs to be readable and thus a vertical orientation is preferred), and maps (which traditionally can be used from multiple viewpoints and thus are appropriate for horizontal orientations. Size matters at a number of scales, one being when the size is larger than a person can reach across (for a horizontal display) or reach up to (for a vertical display).

While other researchers have also investigated the importance of the spatial parameters of displays [7], in our studies with UD Co-Spaces we learned how different form factors can affect users' experience, interactions and engagement. For example, the biggest problem with the initial prototype for UD Co-Spaces was limited screen real estate. Display size was not enough for robust design exercises (*size matters*). In the second iteration, we used a bigger tabletop display and we added a 3D view (Fig. 2). Proposed buildings are viewed in context using Google Earth (Fig. 3) to facilitate discussion of the urban landscape (Fig. 4).

Content can dictate form factors when choosing a surface. The natural up-down orientation of the 3D view of a landscape and of the indicator "widgets" (Fig. 5) we designed was more appropriate for a vertical display (*orientation matters*). After our initial design we decided to move the indicators from the tabletop to the wall display (Fig. 6) to free up valuable space on the tabletop, but later we learned that it created a new display real estate problem: indicators took space on the wall that was better be used for 3D. We learned that the location of indicators affected engagement: users were so much engaged with the tabletop that they neglected the indicator metrics on the wall (*location relative to the viewer matters*). We addressed these issues in the third iteration of our system by adding personal hand-held devices to control the 3D view on the wall and to view the indicator widgets (Fig. 7), thus freeing up the wall display for 3D while also encouraging more interaction with the sustainability indicators.

2. Content Sharing and Collaboration Patterns

A similarly range of concerns relates to how display content is shared across or on surfaces, some correlated with size (small surfaces are difficult to share, very large surfaces are easy to share), but in some cases the issues are more

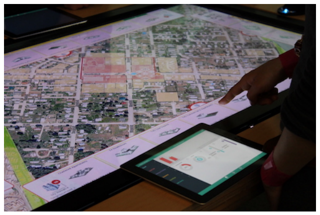

Figure 7: UD Co-Spaces integrates tabletop, wall, and personal hand-held surfaces.

Figure 8: Hand-held surfaces provide personal "scratch space" to set targets for indicators.

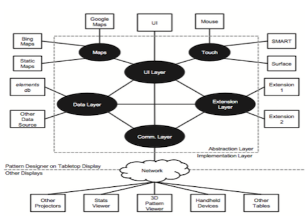

Figure 9: UD Co-Spaces uses a message-based protocol to link loosely coupled applications – perhaps running on multiple computers that are connected across a network.

about privacy, personal 'working space' or who has the right to determine the content of the display (or a portion of the display).

In our work, we provided personal working spaces on iPads (Fig. 8), where users could access, customize, interact and learn about the sustainability indicators. This not only allowed some personal explorations, but also allowed more parallelism where group worked on a loose collaboration style, or formed sub-groups that allowed them to work on the task in parallel. The same notion was true about the 3D view. We observed that some group members became specialized with one of the display content and interaction types, which enabled groups to go forward with collective effort. In terms of sharing, we observed that some expert users projected their iPad screens on the wall to share and discuss the indicators with another group member.

3. Physical and Logical Surface Connectivity

An entirely separate set of issues is how multiple displays can be connected, either physically or logically. Work (mostly by others) about how content or workflow moves from screen to screen includes extended desktop models and the iRoom [8] where a mouse cursor moves off one display onto another in a seamless manner that depends on the topological connections between the displays vs. what we do in UD Co-Spaces where personal handheld displays control shared wall displays through a logical connection that is independent of display topology.

With multiple wall displays there is opportunity to coordinate their content in various ways. One feature we support in the UD Co-Spaces system is having two or more 3D wall displays whose viewing parameters are synchronized. One example is three large displays each located on a different wall of a rectangular room. The 3D view of the display in the middle can be controlled from the tabletop (using the widget we designed for this) or from an iPad (using our custom app). The displays on each side have the same "look-at" point (the position on the ground plane where the virtual camera is looking) but their headings (direction from the look-at point to a virtual camera) each differ by 90 degrees.

As the middle display moves through the scene the two side displays show orthogonal views. In testing this feature we found that the display on the left should show a view from the right, and the display on the right a view from the left – at first counter-intuitive but upon reflection we realized that our paradigm was that each display is looking at the exact-same point on the ground plane, so the left-is-left and right-is-right mapping to screens that is used in a flight simulator is not really appropriate for visualizing a 3D urban design.

Important issues include how two or more displays come into these relationships. In the iRoom [8], displays are static in their physical locations, so the room 'knows' the topological relationships, but in the newest version of the iPad controller we need to tell it which display it is controlling or that it is controlling multiple displays at the same time. The same holds when an iPad acquires ownership of an indicator widget. We have not yet developed a full framework for this, but we have thought about the interaction sequences necessary for an iPad to select a display or an indicator, similar to how a PC running Windows selects one of multiple external displays when setting up an extended desktop. There could be multiple similar indicators so it would be important to be able to identify which instance is being modified among those that are displayed publicly.

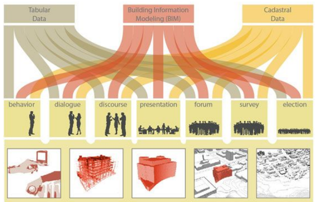

Figure 10: UD Co-Spaces is part of an on-going exploration of digital tools for sustainable urban design.

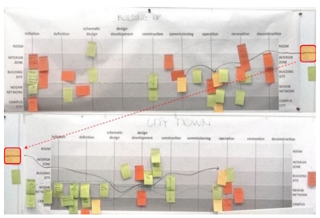

Figure 11: Existing paper-based charrettes "flow" content across surfaces as in this photo of two adjacent bulletin boards with a timeline and Post-it ® notes.

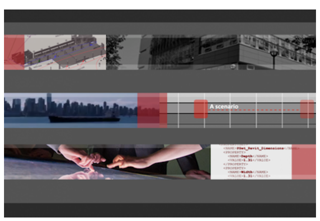

Figure 12: Urban design uses a variety of representations and visualizations within the charrette process that can be mimicked and improved using digital surfaces.

4. Rapidly Converging Technologies

A fourth issue is the convergence of computer vision and computer graphics, so that interactive surfaces in the future can be expected to be both displays and sensors that are able to see what is in front of them and use that information not just for things like gestural input but also to figure out where all of the other displays – and the people – are located within the room.

Some devices will be only one or the other (display or sensor), but more and more (like the iPad) they will have both capabilities. For example, an iPad could work much like the original 3D viewing widget did on the tabletop, but this time using vision (on the iPad) to determine the look-at point on the table and the heading and even the elevation and range by figuring out the POV parameters by matching what the iPad camera sees with what the tabletop is known to be displaying – and perhaps adding some "fiducial" information to assist the human who is trying to position the 3D camera for a wall display.

5. Diversity of Stakeholders

Matching the interaction techniques to the stakeholders is perhaps the most significant challenge when working in the wild because the range of stakeholders is large and often there is no opportunity to know who they will be until the system is actually deployed in use. The trade-off between creating sophisticated interactions to enable more personal exploration vs. keeping it simple for engaging lay people is ever present. As we noted at the outset, our hunch that stakeholders today are more savvy about touch surface technology turned out to be right. It is a pretty good bet that this will continue to be the case so that interactive surfaces for specific application domains can rely on a certain base level of expertise within many members of the public. But there will almost certainly always be a need to ensure that no segment of the stakeholders is disenfranchised by the choice of technology for a system.

Current Prototype

The most recent iteration of our system, UD Co-Spaces, uses a loosely coupled set of applications that communicate with each other through a whiteboard-style messaging system (Fig. 9).

The main application runs on a multi-touch tabletop display. The application has a database of urban forms (buildings, parks, and other structures) called *cases* that can be moved onto the background urban landscape to create a *pattern*.

The application supports abstractions that can be bound to various servers for displaying maps (Bing, Google Maps, or a static map), interpreting multi-touch gestures on a number of commercial tabletop displays (Microsoft Surface, PQ Labs, or Smart Technologies), and providing 3D visualization of the cases in a pattern in context (Cesium or Google Earth).

Handheld devices (iPads) communicate via WiFi to proxy applications that serve as forwarding agents to the messaging system that integrates services on the handheld devices with services on the tabletop. So, for example, swiping gestures on an iPad can move the point of interest in the 3D view on the wall display by sending incremental changes to a forwarding agent that then uses the messaging service to broadcast the updates to the viewpoint information to the application that uses Google Earth to render the 3D scene.

The tabletop application continuously re-calculates the values of *indicators* that serve as *metrics* for assessing the quality of an urban design pattern in terms of sustainability goals. The new values are broadcast, using the messaging

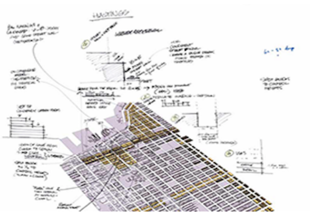

Figure 13: Integration of stakeholders' comments, notes, and calculations with geographic data is common in the charette process and is easily supported and enhanced with digital surfaces.

Figure 14: Urban design charrettes that support stakeholders in envisioning future sustainable neighborhoods who traditionally use non-interactive surfaces. UD Co-Spaces can support traditional workflows as well as offering enhanced features available with digital cross-surface surfaces interaction.

system. A separate application shows widgets with visualizations of the indicators on the wall display, or on applications running on the iPads that are notified by the forwarding agents when new indicator values are calculated.

When cases are added, removed, or moved to new locations on the tabletop, the tabletop application broadcasts these changes which are then used to update the Google Earth renderer.

Conclusion

Our work with UD Co-Spaces is part of a larger research project (Fig. 10). We have only just begun to understand what can be accomplished using multiple interactive surfaces. There is much yet to understand. This can only be achieved through sustained experimentation and testing via real applications in the wild. This can be a very challenging, cumbersome, imperfect and resource-intensive applied research model. One needs deep application domain expertise and strong collaborators, a context within which the application matters, and real-life participants willing to experiment while they are trying to accomplish something else – plus there is a need for "just in time" technical and programming expertise if the research questions we have identified (the five issues that we discussed) are to be pursued effectively.

The existing charrette approach to urban design already uses large surfaces where content flows from one surface to the next (Fig. 11), and a variety of representations ranging from highly realistic to abstract schematics are employed to understand the consequences of design choices (Fig. 12) as well as integration of textual comments, notes, and calculations with the geographic information for proposed urban designs (Fig. 13). The exciting challenge is to move from the non-interactive surfaces that are the norm (Fig. 14) to fully interactive cross-surface environments.

One area of future research could be examining how to reduce the overhead and increase the iteration speed associated with conducting research in the wild. We are still developing a robust infrastructure in which we are able to generate and "swap out" options fairly quickly to explore new ideas. It would be very useful if such an infrastructure could be independent of the core application domain content – in our case urban design – so that the issues could be more easily tackled in a variety of application domains to get a broader understanding of each of the five issues.

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