Abstract Rendering of Human Activity in a Dynamic Distributed Learning Environment

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ABSTRACT

Contemporary distributed enterprises present challenges in terms of demonstrating community activity awareness and coherence across individuals and teams in collaborating networks. *Building with a Memory* is an experiential media system that captures and represents human activity in a distributed workplace over time. The system senses and analyzes movement in two workspaces in a mixed-use building with the results rendered in an informative ambient display in the building entryway. We describe the design and development of the system, together with insights from two studies of the installation and promising future directions.

Categories and Subject Descriptors: J.5 [Computer Applications]: Arts and Humanities – *fine arts*.

General Terms: Algorithms, Design, Human Factors.

Keywords: Memory, motion tracking, ambient presence.

1. INTRODUCTION

Within distributed organizations, building and maintaining mutual awareness across individuals is vital to ensure the development of a strong sense of communal achievement. For enterprises employing adaptable spaces, the activity dynamics of employees must be generally understood by the entire community to inform efficient collaboration. Such challenges provide opportunities for the development of technical, social and environmental responses aimed at increasing community awareness and understanding.

Prior responses to these challenges have addressed the awareness shortfall, ranging from artistic interventions (Jeremijenko's *"Live Wire*") [12], to more utilitarian solutions [13]. Informed by insights from these works and others, our research examines the mediated cultivation of community activity awareness in a dynamic, distributed learning environment.

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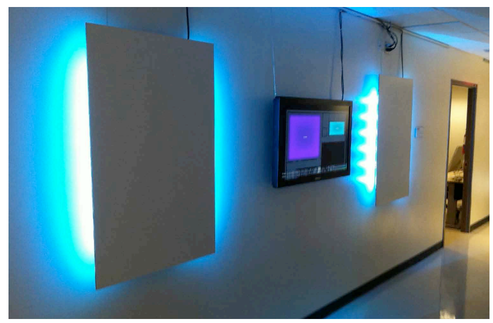

Figure 1: The dynamic light panels and video display of the *Building with a Memory* system

We present *Building with a Memory*, an experiential media system [11] that uses a network of sensors and output devices to capture and represent the history of human activity across related spaces. The system analyzes and renders both the current level of physical activity in the sensed spaces, and that same activity contextualized over time, through colored lighting and a video display.

The system is distributed across three spaces (two sensed and one for display) in a multi-use university building that is evolving into a hub for the host academic unit and surrounding campus communities. This well-trafficked location provides an ideal setting for observing, analyzing and rendering emergent human activity. Our system aims to present meaningful value for regular, occasional and one-off building visitors, without compromising individual privacy. To do so, the system understands human activity as an aggregation characterizing the large-scale dynamics in the two sensed spaces, where no one individual is directly identifiable. Analysis of this activity is visually represented on a panel display and two variable-color, lighting fixtures The visual representation plays automatically, providing a straightforward entry point for new visitors while also encouraging repeated *unfocused* or low-effort engagement by familiar workers [6].

The work described in this paper builds extensively on an earlier prototype detailed in [3] with significant technical, conceptual and aesthetic improvements. New technical contributions include a networked architecture with an extensible API, sensing in multiple spaces and refined mappings of activity to feedback.

2. RELATED WORK

In crafting *Building with a Memory*, we draw on several areas of inquiry. Within the workplace context, research into the ambient representation of presence and activity has produced novel installations from both academic and commercial entities. Within the visual realm, the role of light and color in conveying meaning about human activity reveals a historical record of traditional, digital and interactive artistic explorations that serve to situate and direct our work. The works of Mark Rothko, Hans Hofmann, Moris Louis and Barnett Newman inspire the aesthetic of our system's light panel display while James Turrell and Olafur Ericsson inspired our use of light field schemas.

2.1 Artistic Exploration of Human Movement

There is a rich history of interactive art exploring the sensing and representation of human activity in space, either explicitly or implicitly (Utterback's *Aurora Organ* or *Abundance*; Snibbe's *You are Here*; Rokeby's *San Marco Flow*; Viegas' *Artifacts of the Presence Era*). These pieces explore a variety of dynamics in terms of the relationship between sensed activity, archiving, and reflection. In works like *Impossible Geographies* [5], *Motion Traces*, and *Abundance*, users' actions map directly to feedback. In *San Marco Flow* and *You are Here*, the sensed space is separate from, or larger than, the feedback space. As a result, those sensed may be unaware of their participation. These works also vary in their representation of the history of human activity. *You are Here, San Marco Flow* and *Abundance* represent individual activity directly; *Aurora Organ* and *Impossible Geographies* represent activity abstractly.

Other research involves semi-public workspace displays that present visualizations meaningful primarily to 'insiders' [10]. These projects range from pragmatically functional to deliberately abstract. We seek to balance between these two poles and to render activity for familiar insiders and visitors.

2.2 Activity through Optical Flow

Computer vision offers a multitude of techniques for analyzing and understanding human activity, including blob tracking, face recognition, and gesture recognition [1,7]. These methods are often used to identify people rather than protect their privacy. We aim instead to understand activity at a much coarser granularity – to record general levels of activity rather than individual actions.

Optical flow is regularly used as input to more complex algorithms, such as Support Vector Machines [2,9]. We use raw optical flow data because it provides coarse measures of activity, but cannot be used to identify individuals. This maintains privacy, while still extracting information. This low-complexity method also makes it easier to move toward low cost sensor nodes.

3. SYSTEM OVERVIEW

Building with a Memory captures information about human activity, through fixed video sensors. A central server receives and archives this data and provides an API for feedback devices to access both current and historical activity. The activity is analyzed and rendered through a situated flat panel display and variable-color, indirect lighting fixtures (see Figure 2).

3.1 Sensing

Each sensor node includes a computer connected to a wide-angle USB video camera. Our application captures video at a resolution of 320x240 at three frames per second. The application performs Lucas-Kanade optical flow analysis to extract motion vectors and streams them to the archival server via TCP/IP. The choice of frame-rate provides a balance between capturing movement and minimizing server and network load. Raw video is not saved or transmitted, thus protecting the anonymity of individuals in the space and further reducing bandwidth and storage requirements.

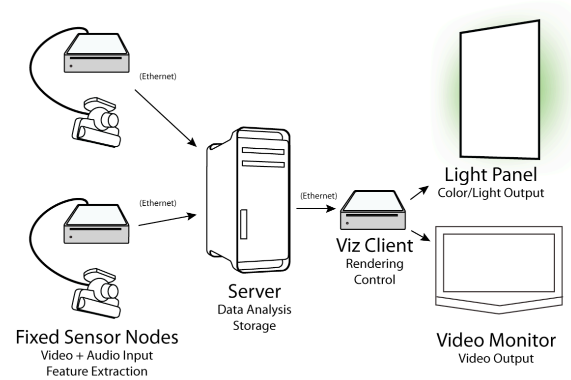

Figure 2: The architecture of the installation.

3.2 Archival

The archival server receives the data from the sensor nodes and saves it to disk, with the prior ten minutes of activity kept in memory. The server can provide the current or historical data for any room, either in terms of raw or normalized magnitudes. The system averages the total optical flow magnitude from the last 90 frames, implementing a low-pass filter to emphasize macro-scale patterns rather than local spikes. We select the sum of the magnitude of optical flow vectors for each frame as the primary feature for our visualization since it provides a direction-invariant metric. The server archives all optical flow vectors for each frame allowing for additional features to be calculated in the future.

3.3 Feedback

Building with a Memory provides feedback through a video display and LED lighting. All feedback shares a common color mapping based on the conventions used in heat-maps [4], weather maps (as in www.weather.com) and television shows displaying thermal cameras, making it familiar to observers in a Western cultural context (Figure 4).

The video display renders the previous week's activity both as a line-graph and on a floor plan contextualizing the sensed spaces in the building (Figure 3). A playback head automatically scrubs across the historical data, highlighting an hour-wide window. The average activity level for the window is represented in the color of the room on the floor plan. The video display also shows the current activity level of each sensed space to the right of the line graphs, updating every ten seconds. This update rate minimizes network traffic and discourages people from manipulating the visualization by intentionally moving around in the space.

The LED light panels (Figure 5) located to each side of the display, present the average of current activity levels. The light panels use 12 clusters of red, green and blue Philips LEDs to wash the walls surrounding the installation with color. This provides an ambient indication of the building's current activity level.

Each light panel contains an XBee 802.15 radio, an Arduino Pro microcontroller, and three LED driver boards (see Figure 5). Each LED is individually addressable, allowing for the development of complex patterns of color. Passive cooling is used to avoid adding cooling fans that would detract from the ambiance of the piece.

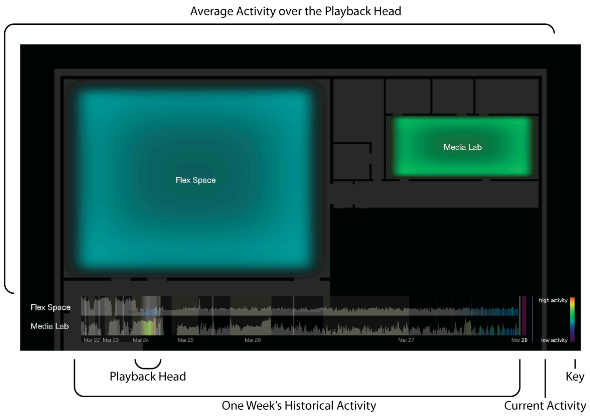

Figure 3: The on-screen visualization.

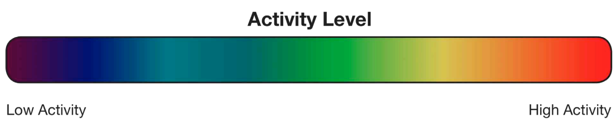

Figure 4: The color mapping is defined as a linear gradient in HSL color space.

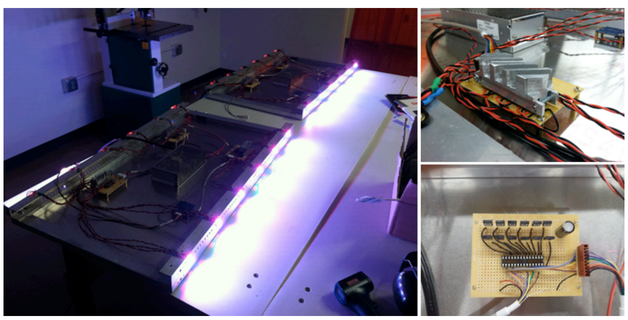

Figure 5: Light panel construction

4. EVALUATION METHODOLOGY

Evaluating this type of system formally presents many challenges. The system includes both novel and standard approaches in terms of design, engineering, aesthetics and implementation. Due to this overlap, we consider the taxonomy of technical/quantitative analysis and aesthetic/qualitative evaluations proposed in [8]. We are interested in whether the data reveals meaningful patterns of activity, and community understanding of, the installation.

Building with a Memory was installed in February 2011. Sensors were installed in a computer lab (*Media Lab*) and a lecture / performance space (*Flex Space*). The feedback was located in the entry hallway (see Figure 6).

4.1 Activity Pattern Analysis

We focus on two time periods: an open house that took place in February 2011 and a normal week of activity during March 2011. For both of these periods we can detect identifiable events such as lectures, dance performances and class changes.

Accurately capturing events in large environments can be challenging due to restricted space for camera placement. In both spaces, cameras were placed in ceiling corners. The cameras could not be mounted overhead due to low ceilings and obstructions. This caused activity in those corners to register a greater optical flow magnitude than activity in the opposite corner. The magnitudes were normalized with respect to each individual room to compensate for differences in room size.

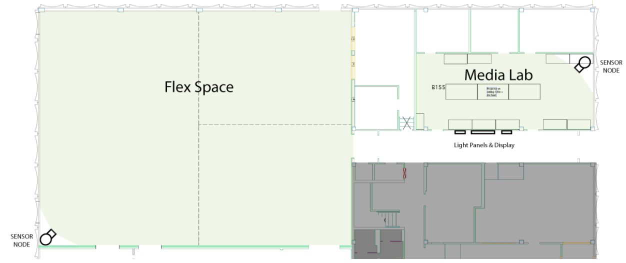

Figure 6: Floor plan of the building in which the sensing nodes and visualization are installed. Light shading indicates camera sensor fields of view.

The data was first down-sampled using a windowing technique. Anything under the noise floor was removed. To smooth the data, a 10-frame window was moved across the data, with a 5-frame overlap between successive windows. For each window, the minimum value was used to remove the influence of the large spikes due to switching the lights in the space on or off. If the minimum value was below the noise floor, implying missing data, the mean of the magnitude was used instead. This technique provides us with less noisy data that is more easily analyzed.

4.2 User study

Through surveys, we evaluated the installation's impact on stakeholders' knowledge of activity in the building. Participants recruited from the community were asked to describe their use of the building's facilities and to estimate the level of activity in the building for the week prior to interacting with the installation. They were also asked about their interest in a direct measure of building activity. A week later, after interacting with the installation, participants were asked to complete the survey again. This allowed changes in awareness promoted by the installation to be subjectively measured. Participants were asked whether they found the installation distracting or informational and whether they would like to be provided with the information on a website or through a mobile application.

5. RESULTS

Informal feedback was received throughout the month the project was displayed. The general response was positive. Administrative leaders in several university departments expressed a desire to integrate the system into workspaces they managed. Viewers were attracted to the form of the installation and to the ideas expressed. Several spectators commented that the installation's feedback could be used to understand activity such as water/power use.

5.1 Activity Pattern Analysis Results

We first consider the building opening celebration. The event included periods in which guests explored numerous interactive installations, listened to speeches, and observed dance and laptop music performances. The Media Lab contained one exhibit. Half of the Flex Space was configured as an auditorium, while the other half contained interactive exhibits. We focus on the Flex Space, where most of the evening's events occurred (Figure 7). We can determine from the graph that the dance performance and the laptop orchestra's entrance into the space generated substantial activity levels. At other points, people moved between the spaces engaging with exhibits, generating constant levels of activity.

Our second example looks at the activity of a typical week in the building. Figure 8 depicts activity in the Flex Space throughout one week in March 2011. This data demonstrates very different patterns of activity from the Open House event. The Flex space is currently used as a lecture hall on Tuesdays and Thursdays. The

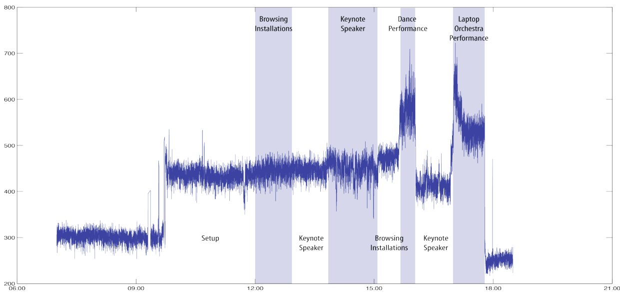

Figure 7: Flex space activity during the open house.

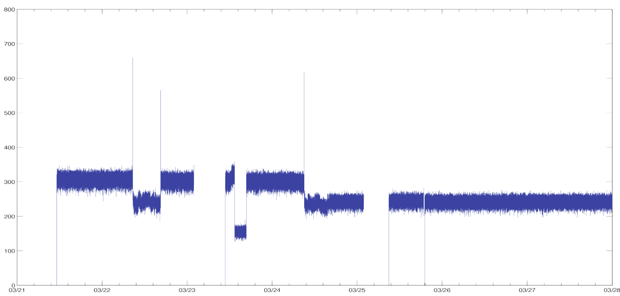

Figure 8: Flex space over one week in March 2011.

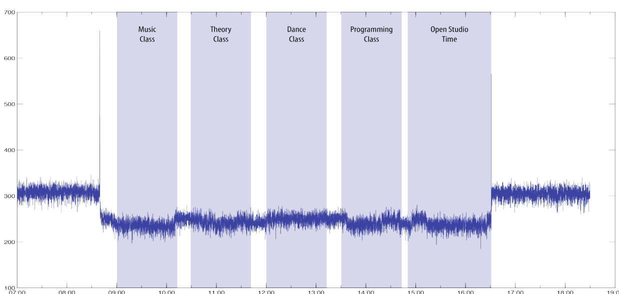

Figure 9: Flex space on Tuesday of the week in March (7 am to 6:30 pm).

periodicity of these activities is visible, including heightened levels of activity during the dance related classes (see Figure 9). This space is relatively unused the rest of the week. The Media Lab is not displayed as the activity in that space is unremarkable.

5.2 User Study Results

Our pre-survey revealed surprising attitudes towards the workspaces. Twelve community members responded to the survey, including faculty, staff, and students. Although the number of survey respondents was limited, several observations can still be made. Of those surveyed, most were interested in activities in the Media Lab and wanted to know when they could enter to use the computers or socialize, pointing to the Media Lab as the primary locus for community activity. Interest was divided between spaces for staff and faculty who monitor both locations.

Based on the survey, community members assumed that the Media Lab space was active at night, even though it is closed and locked after 8pm. In general, the Media Lab was perceived to be more active than it actually is, and more active than the Flex Space. This reveals a bias in how the spaces are programmed.

In the post-survey, participants reported interest in seeing the system expanded to other spaces in the building, including a fabrication and electronics lab. Respondents spent about a minute looking at the display, indicating minimal attention was required to make sense of the design. They felt the installation was not distracting, and were not concerned with the presence of cameras.

6. FUTURE WORK

The *Building with a Memory* system presents many opportunities for continued research. These include the development of additional sensing techniques and the roll out of new interfaces tailored for smart-phone access. Along the aesthetic dimension, the mappings of human activity to color may need to be rethought based on the addition of new sensors (both static and mobile) and new sensing modalities. These changes must be considered in terms of their contribution to the local community.

In the near future, we intend to deploy a mobile application that allows stakeholders to browse activity levels of the sensed spaces at various levels of granularity. Given our survey results, we would also like to add sensors to additional workspaces.

Future sensing advances include integrating our optical-flow system into more complex human-motion tracking algorithms, such as blob tracking or dynamic background subtraction, which could more precisely localize individuals. We are investigating the integration of acoustic feature detection into the sensor nodes to classify types of activity in the space.

7. ACKNOWLEDGMENTS

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