WEARABLE CINEMA/WEARABLE CITY: bridging physical and virtual spaces through wearable computing

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Abstract
Wearable computing provides a means to transform the architecture and the space surrounding us into a memory device and a storytelling agent. We assembled a wearable computer specifically aimed to the purpose of mapping architecture into an experience comparable to that of watching a movie *from inside the movie set*, or being immersed in an information city whose constructions are made of words, pictures, and living bits. The wearable is outfitted with a private eye which shows video and graphics superimposed on the user's real-surround view. It uses real-time computer vision techniques for location finding and object recognition. We describe two applications. *Wearable City* is the mobile version of a 3D WWW browser we created called "City of News." It grows an urban-like information landscape by fetching information from the web, and facilitates the recollection of information by creating associations of information with geography. *Wearable Cinema* extends the previous system to generate an interactive audio-visual narration driven by the physical path of the wearer in a museum space.

Introduction

A short time and technological leap separates today's thin laptops from Walkman-sized computers which can be easily carried around by individuals at all time of day. Such small computers, accompanied by a high-resolution private eye for display, and an input device, are already reshaping our technological landscape as they allow us to wear technology just as an element of our everyday clothing. Yet the consequences of offering an uninterrupted connection to the Internet, a TV and/or computer-monitor embedded in the glasses, as well as a variety of input, sensing, and recording devices constantly active and attached to our body, is likely to determine a profound impact in the way we perceive and relate to the world. Together and in addition to our five senses we will soon have access to an additional dimension which will make us see, remember, access information, monitor our health and time schedule, communicate, in ways which we hadn't thought possible before. Starner [Starner, 1997], Pentland [Pentland, 1996], and Mann [Mann, 1997], describe early work in wearable computing and anticipate some future trends.

Our work is based on the assumption that the surrounding architecture should be seen not just as a trigger for the sensors of the wearable to acknowledge our presence in a specific location and prompt us with relevant information. While this is certainly useful in a variety of occasions, these are more likely to occur while executing specific tasks such as device repair, brokerage, or training. We believe that in order for any kind of information to be presented to us in a way which is not fragmented or disruptive of our current activities, for it to become a part of our cognitive space, and be remembered and integrated with the flow of our mental activities, we need to be able to map, directly or by analogy, some of the real-world architecture back into the wearable display.

Our contribution is to show that, in addition to and beyond the technological effort necessary to assemble the hardware and optimize our software for real time sensing and 3d graphics augmentation, we need to build a display environment, a tailored information landscape, which helps people construct a cognitive map to organize, sort, classify, remember, integrate, the variety of textual or visual information presented. In accomplishing this task, we have been inspired by the existing literature in the field of spatial orientation, from a cognitive psychology perspective.

A "survey" type of space representation led us to create a wearable 3d web browser called *Wearable City* which dynamically builds an urban-like information space based on a starting city map. A procedural spatial representation of type "route" inspired the construction of *Wearable Cinema*, a visual and auditory museum guide, which unfolds an interactive documentary driven by the path of the visitor in the museum space.

In the following paragraphs we provide some background on the literature on spatial orientation which shaped our approach. We show how our knowledge of space can be used not only to find our bearings, but also to memorize and organize information, using space as a memory device or technique. As a foundation for the visual and auditory storytelling work developed in Wearable Cinema, we then illustrate how historically, architecture does actually embed a narration, and provide a few examples. Finally, we describe Wearable City and Wearable Cinema, as well as the wearable computer and sensing which host these applications, and draw conclusions based on our experience with the public using these devices.

Spatial Orientation and Cognitive Maps

Psychologists call the acquisition of spatial knowledge "cognitive mapping process." Golledge [Golledge, 1992] described this process as leading to the formation of an internal representation of space, which is indispensable to allow interaction with the external world. The term "cognitive map" was introduced to refer to this internal representation [Downs and Stea, 1973]. During the past decade psychologists and philosophers have been involved in a long debate aimed at establishing if people build internal representations of space as a mental image [Kosslyn, 1980], or as verbal propositions which syntactically describe space [Couclelis, 1988], or as a set of connected representations of a different nature [Kuipers, 1982], or if there is any mental representations at all, but instead only symbolic associations [Pylyshin, 1981].

Many researchers in this field today agree with the mental image hypothesis. Most relevant however to our investigation are the studies which explain the processes by which spatial knowledge is acquired. Inspired by the developmental studies of Jean Piaget [1948], Siegel and White [Siegel and White, 1975] describe the cognitive mapping process as a sequence of three phases: identification of landmarks, a procedural route knowledge, formed when traveling between two landmarks, and a structural survey knowledge, which is equivalent to inferring a map. Landmarks are reference points, often individual buildings that are distinctive and recognizable. Routes are the channels along which we move around, such as streets, roads, alleys, or even rivers and railway lines. Survey knowledge allows understanding of how different reference points are connected, what are the routes between them, distance evaluation, and alternative path finding. This work has been refined by Golledge [Golledge, 1992] who stressed the importance of landmarks as organizers which cluster spatial information around familiar places, such as the workplace, the house, the school, etc.

The research of urban designers focusing on spatial orientation is also aligned with the work of the above mentioned psychologists. Appleyard [1969] studied the role of buildings as landmarks in big cities, on the basis of their visibility and social significance. He also classified cities according to the survey representation that experimental subjects would provide. Perhaps most influential is the work of Kevin Lynch [Lynch, 1960]. Lynch identifies five elements to be essential in the construction of the cognitive map of an urban environment: paths, edges, districts, nodes, and landmarks. Through his analysis of the constitutive elements of the image of the city, he has not only transmitted a lesson to urban designers, but also to the virtual reality designers of our generation.

While windows as a desk-top metaphor screen is the most common appearance of operating systems for desktop computers today, *we envision future computing environments in which the information display is organized according to a spatial metaphor*. We provided an early example with City of News [Sparacino, 1997], a 3D web browser which is currently being transformed into an operating system front end. We believe it is essential for wearable computers which select and filter a large information flow coming from the Internet, to present us with data in a structured and integrated fashion, together with the other human senses. The particular display environment we have chosen for our applications is one which grows from the spatial orientation literature we briefly described, and is organized around landmarks, routes, and maps. It is designed to favor the recollection of information, and create a sense of seamless "immersion" in the augmented reality set provided in the private eye display of the wearable, by creating spatial handles to data, such as memory palaces, memory theaters, and memory cities.

Memory Palaces, Memory Theaters, Memory Cities

Mnemonics techniques based on associating information to a location in space are at least as old as at least 500 BC. In the ancient Greece it was common to use a familiar itinerary, including its landmarks such as temples, theaters, columns, statues, houses, as placeholders for things to remember. Ancient roman rhetoricians used a variety of images and location based mnemonics techniques to memorize their speeches. The recollection of information through spatial associations leverages from our familiarity with the places where we live and operate, and the natural easiness we have in remembering the location of the hundreds of objets in our house, workplace, neighborhood, city. This easiness contrasts with our scarce ability to memorize things like poems, mathematical formulas, or sometimes the details of a story we read in the newspaper or the Internet. This can be explained by the fact that, as shown in the previous paragraph, our spatial memory is structured: we cluster spatial information around landmarks, we recall sequential routes, and infer survey maps.

Throughout antiquity until the seventeenth century, scholars have emphasized the importance of these techniques, especially since at the time neither books nor certainly computers, which are the physical support of our long-term memory, were easily available. We have found three of these location-based techniques to be relevant to our objective of building an information landscape tailored to a wearable computer display.

The memory palace is the most ancient memory organizer. It is based on the fact that we all easily remember the layout and sequence of the rooms in our house, as well as the location of the objects and furniture they contain. The memory palace can be a real or imaginary place, it can be a famous architecture, or a fantasy place, and can be adapted to our learning goals. Things to remember can be transformed in images, signs, symbols, or sculptures and placed inside the memory palace to trigger the correct associations. Magritte's "Les valeurs personnelles" [Figure 1] (Personal Values, 1952) provides a visual example of this technique showing a fantastic association between objects and place.

The memory theater was designed by Camillo (1480-1544) as a horseshoe shaped theater, and a hierarchical architecture containing universal ideas represented by statues. By mapping the architecture of the theater to the architecture of knowledge he was hoping to achieve an understanding of the entire universe. His theater was conceived not only as a system encompassing and leading to encyclopedic knowledge, but also as a method to find and generate new ideas.

The memory city: [Figure 2] Camillo's memory theater inspired the philosopher Campanella (1568-1639) to imagine a utopian "sun-city" which embeds in its architecture – gardens, houses, city-walls – all knowledge and keys to knowledge. Its districts correspond to fundamental disciplines, such that navigating through the city would correspond to a learning path through a huge library where the architecture takes the place of the books.

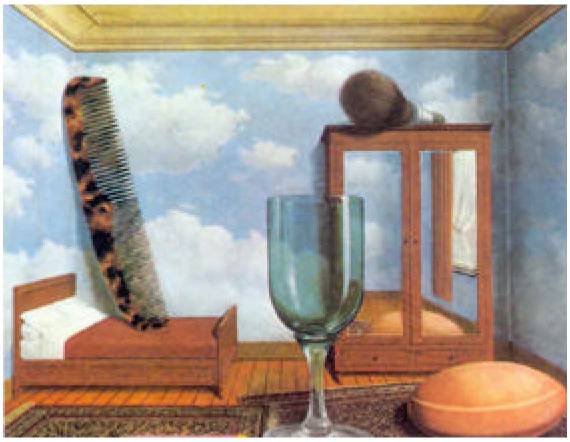

Figure 1. Magritte's "Les Valeurs Personnelles" as example of fantastic associations between objects and place.

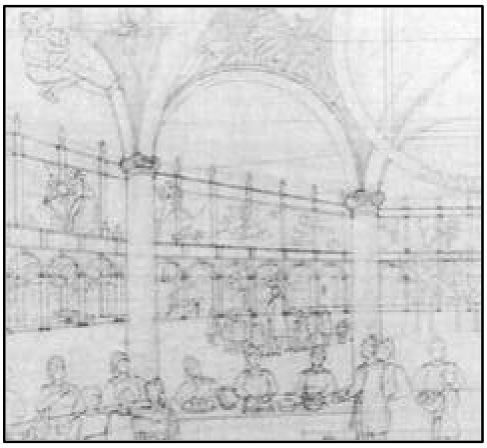

Figure 2. Campanella's utopian "Citta' del Sole" reconstructed by A. Magnaghi and A. Casaloni. Source: [Firpo, 1997]

By analyzing these architectural memory devices we see the emergence of an ambition to build a place – real or imaginary – which is at the same time a universal library, a museum, and a theater. Yet today there is already a place which acts as the universal library, and aspiring for more: it's the World Wide Web. Our task has been to provide a structuring means which integrates web information into our cognitive map of familiar places. We have built a memory city, within which we can orient ourselves according to the spatial abilities we described in the previous paragraph, while we navigate in real space and observe the outside world through the augmented reality display of the wearable computer. We use this Internet memory city as our perceptual anchor which bridges and associates the real and the virtual. We called it: Wearable City.

Wearable City

The City

Wearable City is the mobile version of a 3D WWW browser we created, called "City of News." City of News [Sparacino, 1997] fetches and displays URLs so as to form skyscrapers and alleys of text and images which users can visit as if they were exploring an urban landscape of information [Figures 3,4]. The system is given a map of a known city at start. When browsing, the text and images from web pages are remapped into the facades of the virtual buildings growing from their footprint on the city map. The City is organized in districts, which provide territorial regrouping of urban activities. Similarly to some major contemporary cities, there is a financial district, an entertainment district, and a shopping district. One could think of these districts as urban quarters associated to the different conceptual areas of one of the many currently available search engines on the Internet. An early version of this research provided other functional groupings by creating a mapping between modern newspaper layout and city planning, hence the name "City of News" for this project.

To date we have grown cities of news from maps of Boston, New York, Stuttgart in Germany, the SIGGRAPH 99 floor map, and a few imaginary locations. The 3D browser operates in three stages. At start, the system analyzes the geometry of the given city map, and saves it in memory. Then, when browsing, a parser fetches all the data from the target URL, using a TCP/IP socket, and extracts all the available page layout information. The parser recognizes a large set of HTML tags and builds a meta-representation of the page which contains the text and image data in one field, and its formatting information in the associated field. This meta-representation is passed on to the graphical engine. The engine maps the text and images into graphics and textures, and reformats this information according to the real estate available from the assigned location on the map. The location is chosen automatically by an order defined on the map, or manually by the user who makes a meaningful association with the given architecture. The software is written in Open Inventor and C++, and runs under the Linux operating system. A wireless network connection ensures a constant link to the WWW within its range.

We showed an early version of Wearable City at the SIGGRAPH 99 Millennium Motel demonstration floor [Sparacino, 1999a] [Figure 9]. A large number of people tried the system during the one week long exhibit, and expressed considerable interest and curiosity.

Figures 3,4: City of News, a 3D web browser which dynamically builds an urban landscape of information.

The Wearable
The wearable is a jacket which has an embedded CPU, a sensing system for location identification, high-resolution color display head mounted display glasses, and a touch sensitive threaded keypad as input [Figure 5]. The jacket is a commercial denim long-sleeved jacket, decorated with an illuminated pattern on the back, as embellishment.

In order to run high-end graphics on the wearable in 3D, we have chosen to use an off-the-shelf CPU rather than a custom-made one. We selected a Toshiba Pentium II, 366 MHz ultra-thin laptop, detached the LCD screen, and all unnecessary parts to minimize its weight. We designed a custom lining to attach the CPU to the jacket, internally, on the back. We also added two side pockets to the lining to carry the display's batteries and other devices when necessary.

The input system is a reduced keyboard [Figure 6], sewn on one sleeve, and made with touch sensitive conductive thread. The keyboard is designed for general use with wearables, and contains as keys the 0-9 numbers and symbols representing VCR controls, which can all be easily remapped for use in a variety of applications.

The display is a commercial lightweight SVGA color head mounted glasses [Figure 7], sold as non-see-through for immersive viewing. We modified the display for augmented reality applications by manually removing all the electronics from one eye [Figure 8]. When wearing the display, after a few seconds of adaptation, the user's brain assembles the world's image of one eye with the display's image seen by the other eye, into a fused augmented reality viewing.

The location system is made by a network of tiny infrared devices which transmit a location identification code to the receiver worn by the user and attached to the jacket. The transmitters are approximately coin-sized, and are powered by small lithium batteries which last for about a week. They are built around a PIC microcontroller and their signal can be detected as far as about 14 feet away within a cone range of approximately thirty degrees.

Figure 5. Wearable computer: jacket and display.

Figure 6. Touch sensitive keypad.

Figure 7. SVGA color headmounted diplay screen, with a view of the SIGGRAPH 99 Wearable City demo.

Figure 8. Modified SONY SVGA color glasstron display, which is see-through on one eye.

Figure 9. Browsing using a “memory map”. The wearable plays movie clips interactively according to the wearer’s path at SIGGRAPH 99’s Millennium Motel.

Narrative Architecture

While architecture provides a powerful memory and organizing device, nevertheless people experience their lives as a narrative. All the mnemonics techniques we previously described provide a “virtual set” in which the mind creates images with micro-stories associated to them. The famous neurologist Luria cites the exemplary case of Serasevskij, a man with a prodigious memory, who could recall long mathematical formulas he did not understand, or entire passages of a book. Serasevskij was a “normal” individual under all other aspects of intelligence. His technique consisted in an extraordinary ability to imagine a compelling story involving the symbols representing the sequence of objects to be remembered. Amongst cognitive psychologists, Jerome Bruner stressed the importance of story, as the means which structures our perception and communication [Bruner, 1990]. He reminded us that thinking cannot be reduced to mere information processing and sorting into categories. For Bruner, narrative is our main instrument of making-meaning, the embodiment of culture, communication, and education.

Architecture and narrative are certainly not disjoint, and the history of architecture offers innumerable examples of places which embed and narrate a story through their spatial layout and décor. To explain the theoretical premises of our next application, Wearable City, we illustrate in this paragraph a few examples of narrative architecture. By doing so we show how we can see our path through space as generator of a flexible and interactive story, as an Arianna’s thread in the *logos* of architecture.

The Greek Temple, fifth century BC [Figure 10]
The temple is the place where the people gather in the occasion of religious feasts. It merges with the natural landscape through the ratio of its geometric forms. Its fulcrum is not the internal cell which contains the simulacrum of divinity, but the external arcade, where the rituals would take place in front of the gathered people. It is characterized by a balance of horizontal and vertical, full and empty, and has a rectangular plan.

Rome, Mausoleum of Santa Costanza, first half of fourth century [Figure 11]
It is the place where early Christians would assemble. The round plan and the sober décor reflect the spiritual harmony and purity the community seeks. The round forms separate the internal space from all external. The light converges towards the altar in the center, and tends to transform the entire space in light which symbolizes the supernatural.

Modena, The Dome, eleventh century [Figure 12]
At this time the church is a more complex and functional organism. It is not a space of contemplation but a space for life. It has a Latin cross plan and three levels: the crypt, the central nave with the aisles, and a presbytery. A rich variety of decorations narrate not only sacral themes but also allegories, symbols, tales, and proverbs.

Florence, Church of San Lorenzo, by Brunelleschi, fifteenth century [Figure 13]
A church with a Latin cross design, derived from traditional models, disciplined by the mathematical proportions, which was Brunelleschi’s major contribution to Renaissance architecture. In opposition to

the medieval spirituality, his architecture reflects a rational approach to reality, for which knowing an object is equivalent to knowing its shape, geometry, and material appearance.

Rome, Church of Sant' Ivo alla Sapienza, by Borromini, seventeenth century [Figure 14]
Borromini realizes a complex scheme in which he applies the geometrical rules to the whole and to the parts at the same time, rather than privileging one or the other or considering them in sequence. His baroque architecture is guided by a formal design, which has its own autonomous validity and is untied from the traditional philosophical and historical symbols attached to form.

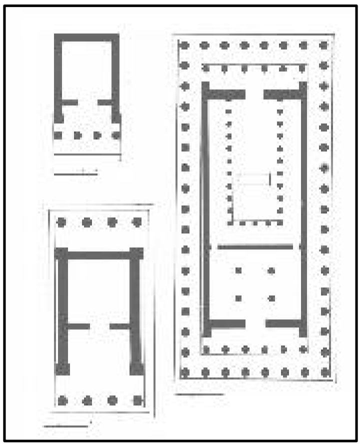

Figure 10. Greek Temples

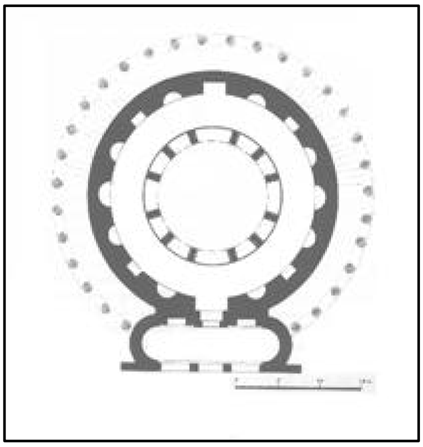

Figure 11. Rome, Mausoleum of Santa Costanza

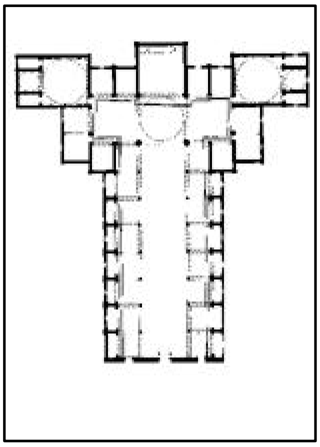

Figure 13. Florence, Church of San Lorenzo

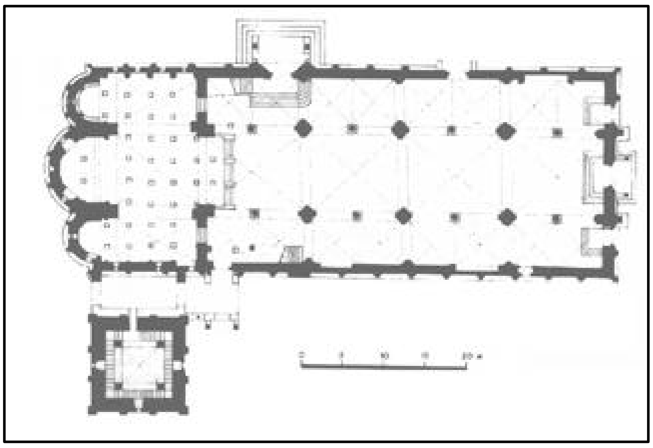

Figure 12. Modena, The Dome

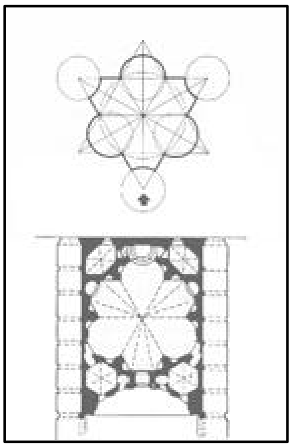

Figure 14. Rome, Church of Sant' Ivo alla Sapienza.

These examples show architecture's historical longing to narrate and become narrative through its forms. By looking at the sequence of plans shown in figures 10-14 we understand how a rectangle, a circle, a cross, or other more complex figures, transmit a message through the centuries. This message is a story about how people through times relate to life, nature, and spirituality. Our work hypothesis for our second application is that by wearing a small computer able to articulate a visual and auditory narrative in its private eye display, we can accomplish architecture's dream to transform itself into narrative. We have chosen to develop our research in a museum, which we transform into a universal library and a living memory theater when we wander in it with a wearable computer. The geometrical constraints imposed by the museum's architecture – the helicoidal sequential path at Wright's Guggenheim, or the pyramidal path of Le Corbusier's project for the Museum of Human Knowledge – condition our path and influence the content orchestration.

Wearable Cinema

The Cinema

We envision and work towards making the museum visit indistinguishable from watching a movie – or a theater play. This movie is slightly different from the ones we are accustomed to: it unfolds a story for us as we wander around the museum space, but is as engaging and immersive as traditional movies. Interactive movies have been a largely explored topic of research in multimedia and entertainment since the last decade. Davenport did early work which influenced this research field [Davenport, 1991, 1993]. Yet many problems such as the type of input device, the choice of breakpoints for interaction, and the fragmented and therefore non-immersive experience which results from interaction, are still unsolved. In some cases, a multi-threaded plot appears unjustified and unsatisfactory, especially for fiction, as people expect to see a "meaningful conclusion" – the moral of the story – and a well edited visual narrative, which are both hard to do interactively.

The museum context provides a great platform of experimentation for interactive documentaries, as the interactive input is "naturally" and seamlessly provided by the visitor's path inside its aisles. Therefore it does not require pauses, breakpoints, or loops in the content presentation. Some museums – especially those which have large collections of artwork, like paintings, sculptures, and manufactured objects – already use audiovisual material to give viewers some background and a coherent narrative of the works they are about to see or that they have just seen. In some cases, they provide audio-tours with headphones along the exhibit. In others, they dedicate sections of the exhibit to the projection of short audiovisual documentaries about the displayed material. Often, these movies that show artwork together with a description of their creation and other historical material about the author and his times, are even more compelling than the exhibition itself. The reason is that the documentary has a narration, the visuals are well orchestrated and come with music and dialogues. The viewer is then offered a more unified and coherent narration than in the fragmented experience of the visit. A visit to a museum demands, as a matter of fact, a certain amount of effort, knowledge, concentration, and guidance, for the public to leave with a consistent and connected view of the material presented.

It is therefore logical to fuse together the audiovisual documentary which illustrates and extends an exhibit, with the visitor's path inside that exhibit, using a wearable computer. We create a new type of experience which makes the visit indistinguishable from seeing a movie from inside the movie set. This immersive experience cannot be achieved by a simple associative coupling between inputs and outputs. It requires a "perceptive layer" which constantly monitors the input and creates an output having a model of the user, its goals, as well as an "understanding" of the content itself, the logical connection amongst the parts, and their emotional impact on the user. We previously described perceptive media modeling in [Sparacino, 1999b].

Our current work transforms our research lab into a museum space. We have gathered a variety of historical footage and authored an interactive presentation for a wearable computer using a Wearable City 3D graphics presentation to situate the user in the space. The audiovisual presentation of the footage and its description are authored using Macromedia's Flash authoring environment. A perceptive media modeling of the content unfolds the wearable cinema as the visitor walks around the space, and the camera attached to the wearable recognizes its presence in specific locations or relevant objects.

Oliver [Oliver, URL] developed a wearable computer with a visual input as a visual memory aid for a variety of tasks, including medical, training, or education. This system allows recording small chunks of video and associates them with triggering objects. When the objects are seen again at a later moment, the video is played back. Wearable Cinema differs from the previous application in many ways. Its scope is to create a cinematic experience and to situate it within the containing architecture. Its focus is in content orchestration, and to carefully construct an immersive experience guided by the perception of the senses of the wearable, using perceptive media modeling. As opposed to the cited application, Wearable Cinema is not a simulation running on a desktop computer connected to a head mounted display. It actually runs on a wearable, which was especially designed for it, and the computer vision runs in real time on the wearable CPU.

The Wearable

The main distinctive characteristic of this setup is that it uses real time computer vision as input for easier and faster location finding. This has the additional advantage that no time needs to be spent distributing the infrared location emitters around the space, and substituting the batteries when necessary. A quick training on the locations or objects to recognize is the only setup needed for the computer vision system at start.

The wearable is made by two sandwiched CPUs [Figure 15]. One is dedicated to processing the input and the other to produce the output shown on the wearable display. We use a thin ungeared Pentium II Toshiba laptop, stripped down to its motherboard, connected to a super-thin Sony VAIO Pentium II on a local net. The Toshiba runs the Linux OS and is used for the real time computer vision sensing. The VAIO runs the Microsoft Windows 98 OS and uses a combination of Flash animations and Open Inventor 3D graphics to generate the cinematic experience.

These two very thin and lightweight computers are hosted inside a stylized backpack. The wearable is connected to a small wide-angle camera worn on the user's shoulder, and to a high resolution SVGA display.

The computer vision system uses a combination of color histograms and shape analysis to identify objects or locations. Segmentation of regions to analyze is achieved by gaussian modeling of the target color, as in Wren [Wren, 1997]. Shape analysis is based on contour extraction and calculation of centralized moments on the contour points. The connection between the input and output software is done using the RPC protocol. The vision program runs as a server and communicates the result of its processing to a Java client through RPC. On the other CPU a Java server broadcasts this information to the Flash program via Javascript. The Open Inventor graphics connects to the vision program on the other CPU directly with RPC.

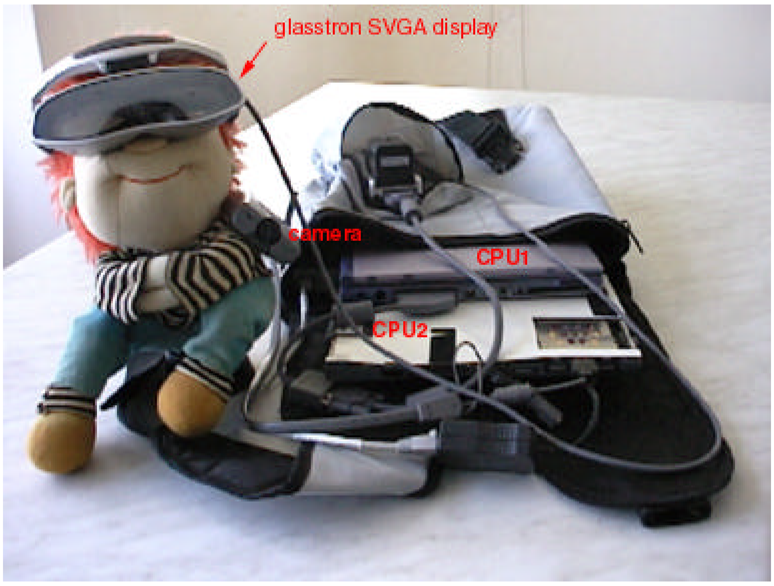

Figure 15. Wearable Cinema setup, showing the backpack, the two CPUs, the camera, and the lightweight color SVGA glasstron display.

Conclusions

We described two research projects which transform the surrounding real space architecture into a graphical memory device and a video-based storytelling agent, using purposely designed wearable computers. For *Wearable City*, we have been inspired and guided by the literature in the field of spatial orientation from a cognitive psychology perspective, as well as urban planning and mnemonics. We showed how, by designing 3D space as a memory city organized around reference landmarks and grouped in functional districts, we construct a tailored information landscape which helps the wearer build a cognitive map of the information flow on the wearable display. *Wearable Cinema* creates an immersive audio-visual cinematic narration guided by the path of the wearer in the museum space. By using real time computer vision techniques for object recognition and location identification it provides a bridge between the real and the virtual inside the augmented reality display of the wearable, and accomplishes architecture's historical dream to transform itself in narrative.

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We are grateful to Thad Starner who was a technical consultant and who fostered these projects since their conception a few years ago. Thad also adapted SONY's SVGA glasstron to be see-through by removing the electronics from one eye. Rich DeVaul and Ari Benbasat designed the infrared emitter/transmitter system used in Wearable City. Christopher Wren provided technical assistance and glue code for the same project. Emily Hui did a product design study for the lining for the wearable jacket, by making a careful exam of heat dispersion and weight balance. Rehmi Post, Maggie Orth, Chris Metcalfe, Pamela Mukerji, and Peter Russo worked on the conductive-thread-based keypad of the jacket. Josh Weaver and Dana Kirsch provided precious help in demonstrating Wearable City at SIGGRAPH. Brian Noble wrote the LINUX drivers used for the Wearable Cinema input camera. Bill Dirks wrote video4linux, used for image acquisition under LINUX . Rob Kaybee from Georgia Tech helped with the drivers installation. Amandeep Loomba and Dave Berger did all the necessary LINUX system administration work. Tracie Lee authored Macromedia Flash animations. Thomas Minka was a technical consultant for the computer vision work of Wearable Cinema.

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