

Dual Device User Interface Design: PDAs and Interactive Television

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ABSTRACT

Computing environments which involve many interacting devices are a challenge for system and user interface designers. A prototype of a multiple-device application consisting of a personal digital assistant (PDA) that operates in conjunction with interactive television (ITV) was developed from user requirements for a real estate information service. The application is used both as a stand-alone service and in conjunction with a television. Users interact exclusively with the PDA. The television responds to PDA output and is used for the presentation of visual images and videos. In this paper the application is described and user interface design issues that arise in the context of multiple device systems are discussed.

Keywords: Personal digital assistants (PDA), interactive television (ITV), ubiquitous computing, mobile computing, multiple devices.

DESIGNING FOR MULTIPLE DEVICES

Future computing environments are likely to involve a combination of specialized personal devices that interact with each other. This will form a new class of systems in which multiple coordinated computing devices are used in various configurations at different times and places to achieve a task. Such systems, often referred as "ubiquitous computing" [4,8], support greater mobility and take advantage of the strengths of different specialized devices that are available at a particular time or place. Multiple device systems, and the concept of "ubiquitous computing," offer many new design challenges to the field of human-computer interaction.

The concept of multiple interacting devices is not new; however, in most cases the interaction is one-way and takes the form of a controlling device paired with a controlled device. Some examples include a television remote control

in which input to the controller device causes the controlled device to change channels, modify volume, etc.; an electronic phone directory and dialer which emits tones that control the behavior of a telephone switch; or a stereo component system in which several independent, interacting devices send information to each other. Interestingly, Brown, Buxton, & Murtagh [2] observe that a multiple-device metaphor is used in a wide variety of computing applications which are not really multiple devices, e.g. the "Control Panel" for adjusting an application's or device's parameters.

In all of these cases, the particular devices that can interact are predetermined and the range of possible interactions is limited. We are interested in the design issues that arise when considering multiple computing devices, each of which is capable of carrying out a broad range of interactive applications, which might be combined in many different ways.

Our group has recently developed a prototype of real estate information service that uses a personal digital assistant (PDA) and a television that is part of an interactive television (ITV) services network. A PDA is a hand-held, mobile computing device that has built-in infrared and serial communications capabilities and which is designed to interact with other devices. PDAs are already used as remote controllers for televisions, however the power of PDAs will be most evident when they go beyond the role of a controlling device and are used as a companion computing device. A likely use for PDAs in the future is to interact with cable television services and networked computer systems as a companion device.

The primary goal of the PDA-ITV project was to investigate the design and use of this example of a multiple-device system. We hoped to support mobile users with the PDA, take advantage of the high-quality display capabilities of a television, and utilize the resources of a broadband information network. In this paper we describe the prototype and highlight several of the design challenges that arose.

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CHI 96 Vancouver, BC Canada
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Design Challenges

HCI researchers have emphasized the importance of understanding how the design space for user interfaces is influenced by characteristics of input and output devices [3,6] and how these characteristics interact with task characteristics [5]. Multiple coordinated computing systems are a new class of systems that complicates the understanding of both users' tasks and input and output characteristics of the system.

Design constraints are more fluid in a multiple-device system for several reasons. First, there are several devices which differ in their input and output characteristics, and differing combinations of devices have novel input-output characteristics. Second, the user may accomplish different parts of a task using different devices, and task characteristics can change depending on the particular device combination that is available. Third, input and output are confounded, with the output to one device (e.g. a touchscreen) becoming the input to another (e.g. a television).

We identified several general questions that arise in the context of designing for multiple-device systems. These include:

- How can a multiple device application be designed so that it is useful both as an ensemble and in individual parts?
- How can several information technologies be used in combination to support users' task goals?
- On which device(s) should each output be located, since devices differ in their display capabilities?
- On which device(s) should each input control be located, since devices differ in their input capabilities?
- When should input on one device control output on the other, and how is this "distributed control" accomplished?
- How can several information technologies be coordinated over space and time to avoid confusing users?

THE PDA-ITV APPLICATION

The domain of real estate information is information-rich, requires considerable database browsing, involves comparison of multiple selection criteria, and benefits greatly from multimedia presentation formats. It is a domain which traditionally requires the intervention of a human agent to mediate search and help in decision making. It also requires home buyers to be present in the new location and to spend considerable time traveling to homes and neighborhoods for a first-time look. A service that reduces any of these requirements would be highly valuable.

The prototype real estate information system was developed using data from interviews and participatory design sessions with potential users. The requirements gathering, design sessions, and development activities were all influenced by the fact that our system utilized more than one device.

The application architecture is illustrated in Figure 1. A user interacts with a PDA using the touchscreen. A PDA

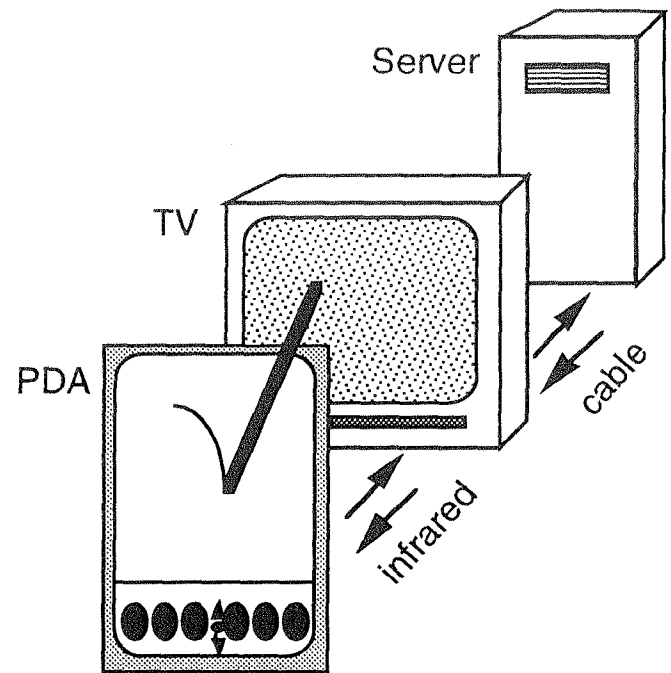


Figure 1. The user interacts with a hand-held PDA using a stylus to tap or write on a touchscreen. The PDA and a server interact with a television using a settop box with infrared and cable I/O.

communicates with an ITV service through a television settop box. Communication between the PDA and the settop box uses wireless infrared technology. The settop box communicates with a server through a cable system. Communication is bi-directional between the device pairs. This enables complex user-system interactions. For example, a user can perform an action on the PDA which is received by the settop box, which then downloads data from the server, which can then be displayed on the television and/or transmitted back to the PDA.

We refer to this situation as a *dual-device* system since there are only two devices "visible" to the user: the PDA and the television. Here we discuss only the behavior of the PDA and television.

USER REQUIREMENTS

To inform our design of the PDA-ITV system, we conducted two user studies: a task analysis and a participatory design study.

Task Analysis

Four people who had bought a house within the last 5 years were asked to select three to five houses in an assigned price range from a traditional paper real estate catalogue with photos and text. Participants supplied verbal protocols as they searched for suitable homes. After identifying a set of homes, participants summarized their strategy and discussed what they did and did not like about doing the selection task with the paper catalogue. Finally, they described their

Task Structure	Search for a set of homes	Serial access to homes	Individual home browsing
PDA Screens		House Selection Screen	House Information Screen

Table 1. The task structure derived from user studies, and PDA screens developed for two of the tasks.

vision of a "magic catalogue" that would do the task in the manner that they wanted it done.

We identified a task structure composed of three phases: searching for candidate homes, serially accessing homes for inspection, and opportunistically exploring the information available about a particular home (top row of Table 1). Although the phases must occur in this order, an earlier phase can always be returned to directly from a later phase. We assumed that our overall design task was to support this task structure.

Participatory Design

Four new people who had bought a house within the last five years participated in a cooperative design exercise. With the help of a facilitator, the participants designed a paper version of an information system for browsing and selecting real estate using a PDA and a television.

Participants began by giving a general description of how they wanted the system to look and behave. Next they specified the design by creating a house shopping scenario. Participants created representations of their input controls and output displays on two pads of paper, one representing the television screen and the other the PDA. Successive pages showed changes in appearance.

All participants placed input controls on the PDA. They all utilized the touchscreen capabilities and created maps, icons, buttons, and other controls for the PDA. Even when menus were displayed on the television screen, a companion representation was used on the PDA for selection.

The participants clearly expected the information on the television to be coordinated with the information on the PDA. If a selection on the PDA resulted in the display of information about a particular house on the television, for example, the PDA touchscreen would also be updated. This is quite different from a traditional remote control which clearly does not change its characteristics in response to what it is controlling. We adopted several of the participants' ideas for coordinating the PDA and television in the prototype.

PROTOTYPE DESCRIPTION

A prototype was developed using Newton® MessagePads for the PDAs and a Macintosh® to simulate the interactive video service. The system fully supports the user scenarios

described here, although it does not currently utilize an extensive real estate database.

Our design of the prototype interface had three aims: 1) to support users' task goals 2) to exploit users' major design ideas, and 3) to explore the design constraints of interacting devices. Participants suggested using the touch screen to display informative graphics such as a map or floor plan. Direct manipulation on the graphic displayed on the touch screen was used to control the television display. From this suggestion, we derived two of our design themes: 1) coordinated graphic displays on the PDA touch screen and television screen, and 2) direct manipulation on a PDA touch screen.

We decided that it was appropriate to have a separate PDA screen for each phase of the task analysis. The prototype supports the house selection and house information browsing components of the task analysis (Table 1 and Figure 2). We have not yet implemented the initial search phase. Consistent with the users' practice of moving between phases, navigation buttons allow users to go back to any previous screen.

During the house inspection phase, users wanted a variety of types of information in several categories. They also wanted to control the display of information from the PDA. We supported this by creating buttons for six types of house information on the House Inspection PDA screen. The buttons can be selected in any order to browse the information.

In the following sections, the House Selection screen and House Inspection screen are described in detail.

House Selection

The result of initial search is a set of candidate homes displayed on the *House Selection Screen* of the PDA and on the television (left portion of Figure 2). The homes are presented in the form of a map on the PDA and a mosaic of pictures on the television. The map includes the major roads for the area and the locations of the homes. Note that this combination display is useful for the "catalogue shopping" phase when a home buyer wants to see what the homes look like. Without the television, the PDA is still useful as a map which can be used to drive to different house locations.

From the *House Selection Screen*, the user may return to the earlier search phase by pressing the "Search" button at the bottom of the screen. If the user wishes to see details about a house, he or she taps on the appropriate house on the PDA map.

House Information Browsing

When a user selects a house on the *House Selection Screen*, the PDA displays a *House Information Screen* with a text description of the house, and the television (if present) displays a large view of the home (right portion of Figure 2). A low-resolution view of the house can also be

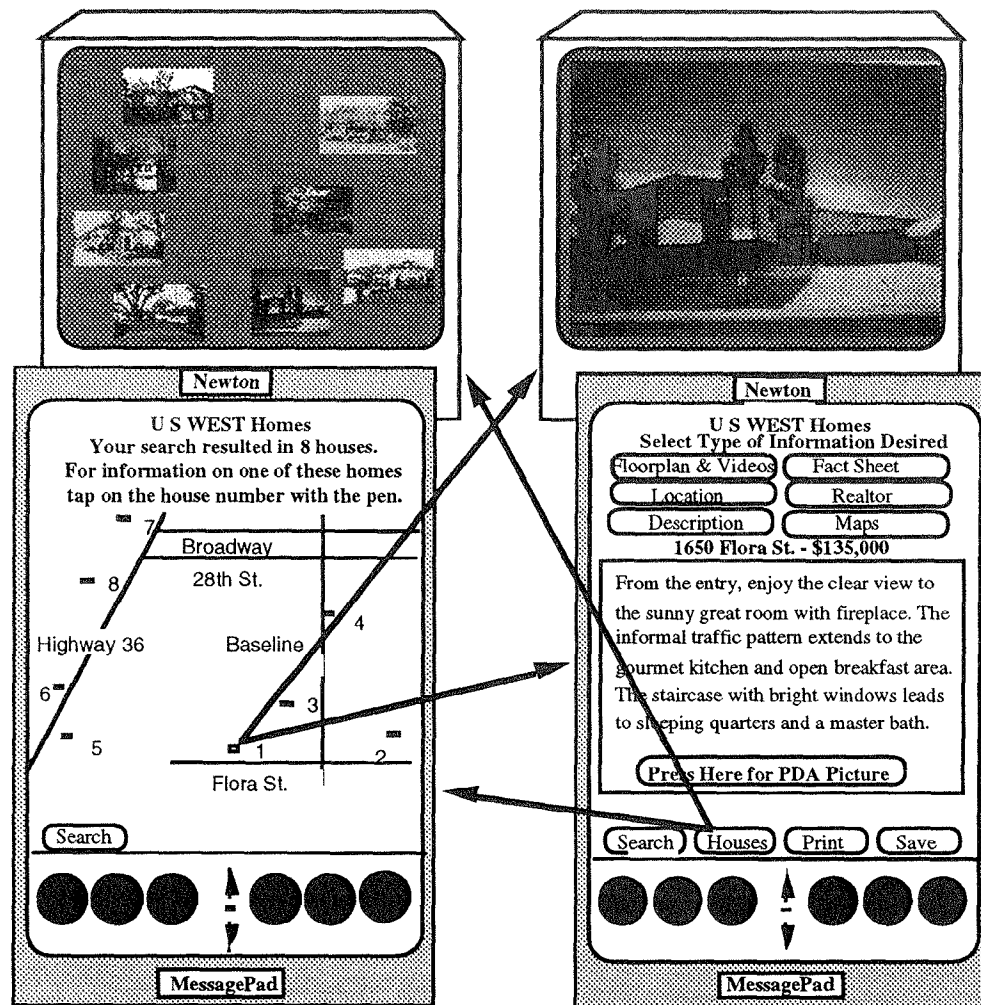


Figure 2. On the left is the PDA *House Selection Screen* (foreground) and accompanying mosaic of house pictures on the television (background). Touching a house on the PDA results in display of the PDA *House Information Screen* (right foreground) and accompanying picture of the house on the television (right background). Pressing "Houses" on the PDA returns the user to House Browsing. (Note that all figures in this paper represent actual prototype screens. Photographs of the prototype screens did not show sufficient detail.)

presented on the PDA screen. The PDA image, which appears as an overlay of the text, is useful if a television is not available. A "Houses" button will return the user to the House Selection state. The "Search" button remains available to initiate a new search. "Print" and "Save" buttons are available at the bottom of the screen to create more permanent records of the information about the house being inspected.

The *House Information Screen* contains six house information buttons at the top and an information box in the center. The six information buttons provide access to various categories of information about the selected house. This information appears in the information box and may have accompanying information on the television screen.

Location

When a user presses the "Location" button, plain text describing the location is displayed in the information

window. A picture of the street is shown on the television, if available. A "Play" button on the PDA allows users to see a "walking tour" of the street.

Description

When the "Description" button is pressed, plain text describing the home is displayed in the information window. This description corresponds to the "advertising" description that typically appears in printed catalogues or newspapers. A front view of the home is shown on the television. This is the initial state of the system when a user leaves the house selection screen (see Figure 2).

Fact Sheet

When a user presses the "Fact Sheet" button, plain text with technical details about the home is displayed in the information window. This text contains specifics like number of bedrooms, square footage, date of construction, type of heating, etc. that would appear on a typical detailed

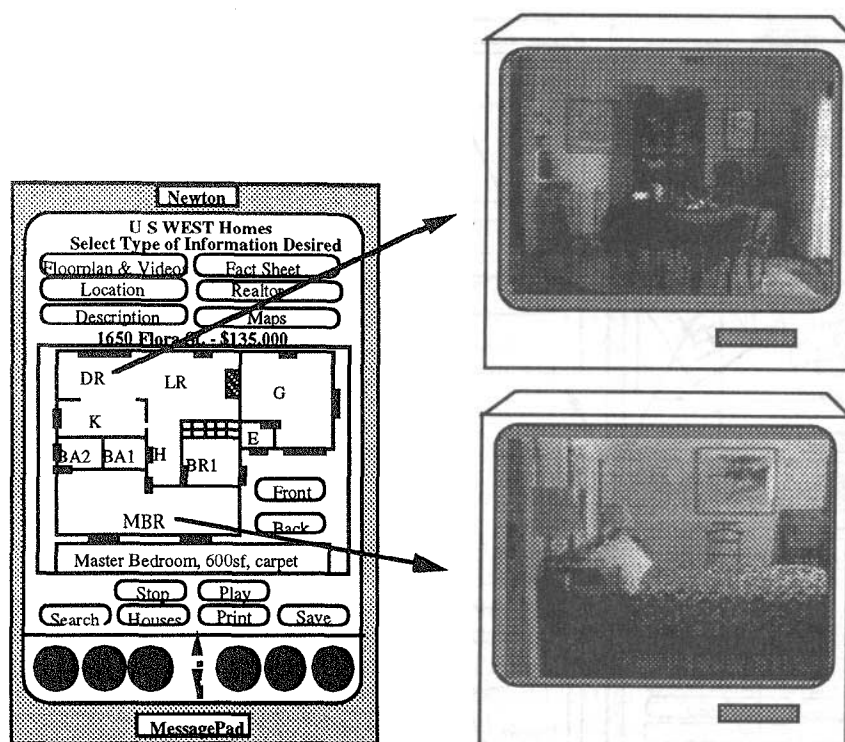


Figure 3. Pressing the "Floorplan and Videos" button results in display of a floorplan on the PDA. Touching a room causes a text description of the room to appear on the PDA and a picture of the room to appear on the television. Pressing the "Play" button shows a room walkthrough on the television.

fact sheet from a commercial listing service. A picture of the home is shown on the television.

Realtor

When a user presses the "Realtor" button, plain text giving background information about the realtor is displayed in the information window. The Realtor's picture appears on the television. A "Play" button on the PDA results in the display of a video of the realtor describing him/herself and the house. A button on the PDA can be pressed to show a low-resolution picture of the realtor on the PDA in case a television is not available.

Floorplan & Videos

When a user presses the "Floorplans & Videos" button, a floorplan of the currently selected house appears in the information window (Figure 3). When a room is touched with the stylus, information about the room (e.g. square footage, flooring type) appears in a text window on the PDA. In addition, if the user is using a television, touching a room causes the display of an image of the room on the television screen. "Play" and "Stop" video control buttons appear on the PDA screen when a floor plan is being studied. When the "Play" button is pressed, a video showing the entire room is presented on the television. Thus, the user can use the PDA to control a video walkthrough of the house. "Back" and "Front" buttons are also shown on the PDA, and pressing one of

these yields either a front or back view of the home on the television.

If a television is not available, the floorplan presentation on the PDA is still useful as a stand-alone application. Users could navigate through a house and learn details about each room by taking the PDA with them on a real walkthrough, for example.

Maps

When a user presses the "Maps" button, several map icons are displayed in the information window of the PDA (Figure 4). The buttons are labeled with different types of maps, for example "RTD" (the local bus system), "Schools," "Civic," etc. The television shows a detailed map of the region. When a user presses one of the map types on the PDA, the PDA information screen shows a very general schematic of the appropriate map with important locations identified. The more detailed map on the television shows a highlight of the selected map component. For example, when "Civic" is selected, a map of main roads is shown on the PDA with locations like the Library and Police Station indicated. These landmarks are also highlighted on the television's detailed map.

When an item like a landmark or bus stop is touched on the PDA, an address appears on the PDA and a narration, if available, appears on the television. The user re-touches the "Maps" button to see another map.

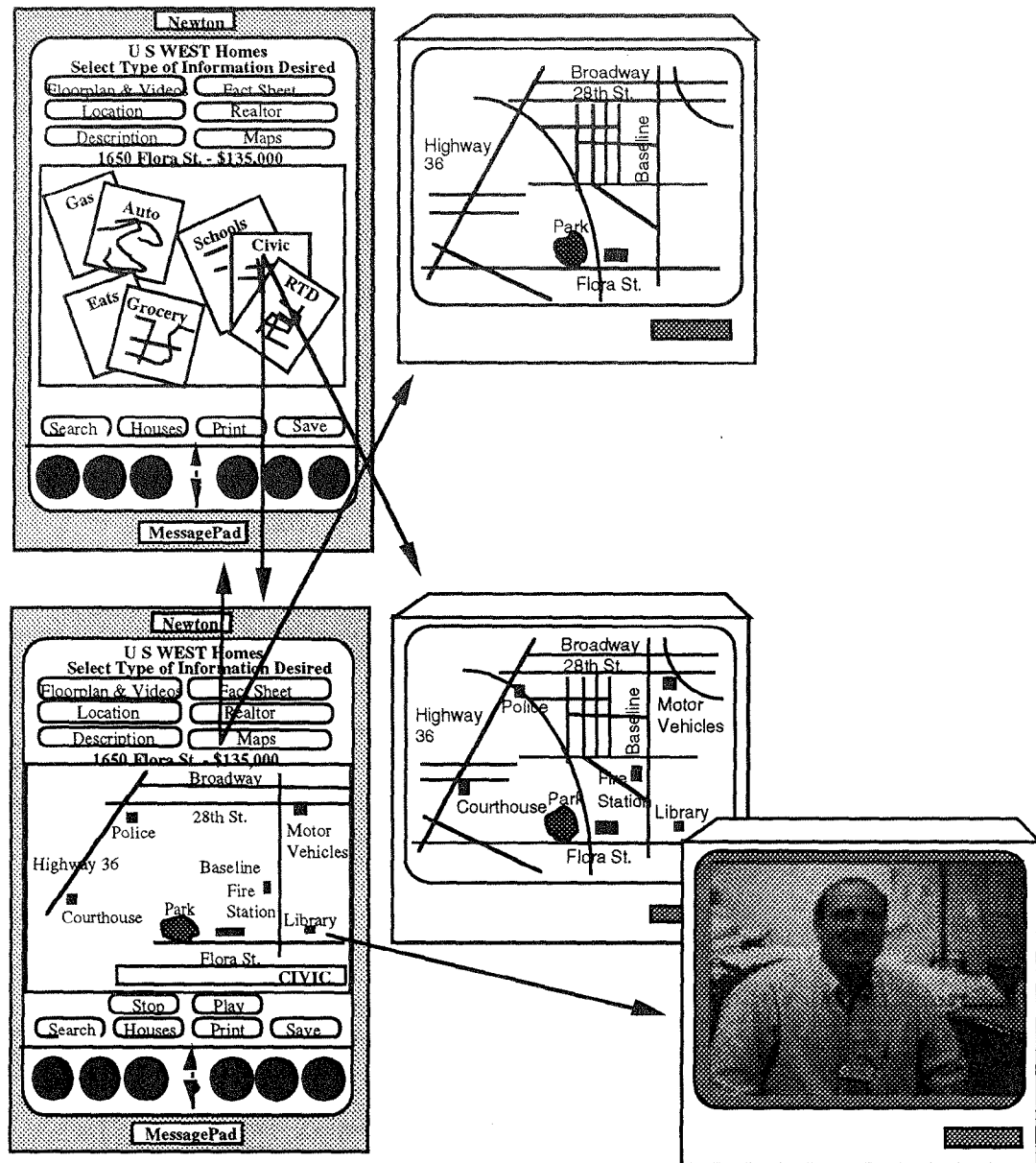


Figure 4. Pressing the "Maps" button results in a set of map icons on the PDA and a detailed regional map on the television (top PDA-TV pair). Tapping a map causes a schematic map of the area with locations of the chosen type to appear on the PDA and, in more detail, on the television (bottom PDA-TV pair). Tapping a location on the PDA causes a narrative to play on the television (bottom right) and an address to appear in a pop-up on the PDA (not shown).

Without a television, the maps can be used to navigate to different locations or simply learn about the neighborhood. With the television, the user gains a visual feel for the neighborhood and can gather considerable information about each of the establishments.

EXAMPLE TASK WALKTHROUGH

The following scenario describes how a prospective home buyer might use the PDA-ITV system. First, the buyer would use the PDA to access a home information service on their television. The buyer could be located anywhere with respect to their final destination (in fact, this service would be most useful to buyers who were far from their

ultimate destination). The buyer would use the PDA to send search information (such as price range and location) to the information provider who, in turn, would download data about a set of candidate houses to the PDA. The candidate houses would appear on the PDA in the *House Selection Screen* and on the television as shown in the left portion of Figure 2.

The buyer could glance at the houses on the television and decide whether to begin a new search (if all of the houses looked like the wrong style, for example) or inspect some in detail. If a new search was desired, then the "Search" button at the bottom of the PDA screen is available.

The user may next wish to look at the details for a small number of candidate houses. By touching a house with the stylus, the user is taken directly to a description of the house on the *House Information Screen* and is shown a close up of the house on the television (right portion of Figure 2). By moving back and forth between these screens, the buyer simulates browsing the advertising section of a newspaper or real estate booklet.

Once a few candidates have been selected for serious consideration, the buyer might next begin examining the maps (Figure 4) to see where the candidate houses are located. Houses far from neighborhood schools or in undesirable locations could be rejected. After narrowing the search to a very few houses, the buyer might take video walkthroughs of each one (Figure 3). Finally, the buyer would use the "Realtor" button to get contact information about the realtor.

On a visit to the location, the buyer and realtor could take the PDA with them and use the "Maps" screen to navigate to the locations of candidate houses. Once at a house, the "Floorplan" screen would be used to find a house's rooms.

This scenario shows that a prospective buyer could learn a considerable amount about a home and a neighborhood before visiting the new location. The buyer could come to the realtor with several pre-selections. The scenario also shows the use of the system both in a dual-device situation and as a mobile, stand-alone PDA application (using data downloaded through the cable television system). In addition to the advantages of current online real estate systems and interactive home finding services [1,9], the PDA-ITV system enables mobility, multi-user information sharing, greater presentation control, and the ability to use the service in the multiple contexts of house selection.

DESIGN GUIDELINES

From our experience in prototyping the PDA-ITV real estate information service, we developed several design guidelines for use in multiple-device situations. The guidelines result from an interaction of the constraints provided by devices, tasks, types of information, and user goals. Since they are "guidelines," and not rules, they will not always apply; however, they can guide designers in reasoning about multiple-device systems. The guidelines address many of the questions posed at the beginning of the paper.

- *Distribute information across the appropriate devices.*

Information devices differ in their strengths. For example, a television is appropriate for pictures, videos, and audio output. PDAs are appropriate for display of text and some graphics such as simple maps or icons. An important part of our user requirements gathering was to capture information on which devices users might want to use for different information. We then placed graphical and

schematic information on the PDA and detailed images and videos on the television (cf. [2]).

- *Combine devices so that the ensemble provides more than each independent device.*

Value is added if applications on two (or more) devices are cooperative and complementary to each other. For example, a map on a PDA and pictures of houses on a television are useful in themselves. However, if the map on the PDA can be used to navigate through house pictures, then the combined application is more useful than either stand-alone application.

- *Information content strongly determines display format, which should be mapped to the appropriate device(s).*

An analysis of materials currently used in real estate sales showed several types of information. The most basic information about real estate is textual, consisting of descriptions of houses' features and realtors' contact data. Pictures are very important and are typically the next step beyond text in house advertisements. Real estate offices also provide house pictures. Videos are also sometimes available. Later in the buying process, maps become important. Thus the nature of the information strongly biased where we wanted to place it. High resolution image information went on the television while textual and schematic information went on the PDA. In the case of the maps, an interactive schematic map with main streets only was displayed on the PDA, while a more detailed map or neighborhood scene was displayed on the television.

- *User tasks influence which device is appropriate for particular types of information.*

Users need different types of information for different tasks. For example, we discovered that real estate buyers wish to perform an initial search without much effort. They are happy to view pictures and read descriptions in one location, at home or in a realtor's office for example. Thus we could provide information relevant to this activity on the television. Map and neighborhood information, on the other hand, is desired once buyers begin traveling to homes. Thus, this information must be represented on the mobile PDA.

- *Device coordination is critical. Be sure that the information on different devices is coordinated, consistent, and up to date.*

All devices should be dealing with the same task, and a device should never be left in an old state. For example, a user may view a house on the television screen but then begin to read the description for a new house on the PDA. If a picture of the old house remains on the television there is potential for confusion.

- *Combine the coordinated information guideline with the appropriate device guideline.*

Information about the same thing can be presented in more than one way. For example, information about a room can be conveyed in a picture, a text description, and a floorplan graphic. It is often desirable to display different types of information simultaneously on the same devices. Multiple representations allow systems to take advantage of the ability of users to manipulate one type of representation and see changes in another. For example, navigation through a house video is controlled on a schematic floorplan displayed on a PDA.

DISCUSSION

The PDA-ITV real estate prototype provides a multimedia information retrieval and browsing application that operates both as a stand-alone device and in conjunction with television images and videos. The design of this system was derived by combining user requirements analyses, participatory design outcomes, and guidelines for multiple device systems.

All control components and text information were placed on the hand-held device. Enough information was included on the PDA to enable users to perform some aspects of all the subtasks. Information on the television enhanced the ability of users to do the tasks, but it was not required.

PDA-augmented systems could support many different kinds of activities. For example, it is easy to imagine that a user might want to contact a realtor through the PDA (a communications application), use the PDA to calculate mortgage payments or apply for a loan analysis (financial services applications), or get instructions for how to get to an address from a current location (a transportation application that might even use global positioning data). In fact, future computing applications will involve a plethora of specialized devices.

While our initial prototype focused on the home buyer as a primary user, several other potential users would be involved in the use and support of a real system. A house seller might be interested in listing their home and need to arrange for the appropriate data to be gathered (e.g. video) and published. Real estate agents would become involved both using the system on behalf of their buyers and arranging for sellers to publish their house information. Information providers would become involved in the storage, maintenance, and delivery of the material.

Multiple-device applications complicate the problem of matching the capabilities of devices to users' tasks [5,7]. They also greatly complicate any attempt to produce a taxonomy of devices [3,6] since their usage patterns change through time and vary depending on their combination (e.g. is exploring a floorplan on a stand-alone PDA different from using the same PDA application to control a video walkthrough?). There are many new challenges and issues

for user interface designers when they begin to think about multiple device environments. Our goal in this paper was to begin exploring some of these issues in the context of a dual-device system and to identify some principles for multiple-device user interface design.

ACKNOWLEDGMENTS

Newton and Macintosh are trademarks of Apple Computer, Inc. registered in the U.S.A. and other countries.

The authors would like to acknowledge the contributions of our colleagues: Mike King, Monica Marics, Michael Muller, Carrie Rudman, Patricia Somers, Lynn Streeter, and Scott Wolff; and a visiting colleague: Scott Hudson.

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