國立交通大學建築研究所

碩士論文

環室觸發—可重設的環室個人設計環境架構

Ambient Trigger: An Interface Framework for Evoking Ambient Reconfiguration in Personal Design Environment

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ABSTRACT

The process of designing in a personal design environment (PDE) often encounters interruption. Due to the lack of an automatic reconfigurable framework, such interruption often shifts the designer's focus from designing to dealing with new situations. In this paper, we propose a novel interface framework called Ambient Trigger (AT), for the instant and easy switching of PDE into an appropriate state to support encountered situations without much user intervention. With the AT Interface framework, designer could realize a multifunctional and reconfigurable personal design environment. Such environment enables its user to easily reconfigure his/her ambient environment with simply an embodied action toward mediated objects. To verify the framework, a test-bed environment is designed and implemented during the research. Four scenario examples were presented for demonstrating usage of AT. In conclusion, AT has shown its differences as well as possibilities in advancing ambient environment for further investigation.

Keywords: Ambient, Trigger, Reconfiguration, Responsive Environment, Personal Design Environment, Embodied Interaction, Ambient Intelligence.

環室觸發—可重設的環室個人設計環境架構

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摘　　　要

對設計者而言，在實體的個人設計環境中做設計，經常需要和周遭的人、事、物、環境互動而中斷設計過程。這些中斷經常造成設計者注意力轉移，或甚至得放下手邊進行中的工作以便處理新的狀況。本研究提出一個介面架構－環室觸發 (Ambient Trigger) 以回應此問題。

透過環室觸發架構，設計者可以建構一個較不易分散注意力、可立即重塑的個人設計環境。這樣的環境可讓使用者輕易地透過體現的動作 (embodied action)，來達到觸發環室元件重新設定以支援某項特定的設計活動。本研究透過設計與實作一個實體個人設計環境，來測試和檢驗這個環室觸發架構，並以四個劇本描述環室觸發環境的使用情境。本研究總結並討論了環室觸發架構的差異性，及其對於進一步發展環室媒介環境的幾項可能性。

關鍵字：環室、觸發、互動式空間、個人設計環境、人機互動、環境智能

誌　　謝

這本論文的完成，首先要感謝我的指導教授張登文，在我碩士研究生涯予我專業的訓練和提攜，教導我何謂願景，何謂一個好研究。謝謝口試委員：成大資訊建築研究室鄭泰昇教授、銘傳空間媒體研究室梁容輝教授，以及 Ofram 的執行長 Tristan d'Estrée Sterk 等，在口試中所提出的批判及建議，讓我瞭解到跨領域研究上，仍有許多需要我深入思量與探究之課題。

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謝謝家琳前前後後給予研究上的幫忙，也謝謝妳一路上的陪伴，時時刻刻給我鼓勵及鞭策，讓我的論文寫作過程更加難忘。

誠摯感謝《轉法輪》作者李洪志先生，研一下的時候讀過一遍《轉法輪》，從此讓我從此透徹人生的目的和意義，擁有更多的智慧和胸襟去完成我的碩士論文研究與包容我身邊的一切事情，不致於在高壓下失控造業，心性比以前提高了不少。能夠從眾多邪說歪理中求得正法，眞的是『朝聞道，夕可死』矣。

2006/7/19

鼎翰　于家中

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INTRODUCTION

The process of designing in a *personal design environment* (PDE) often encounters interruption. Due to the lack of an automatic reconfigurable framework, such interruption often shifts the designer's focus from designing to dealing with new situations. In this paper, we propose a novel interface framework for the instant and easy switching of PDE into an appropriate state to support encountered situations without much user intervention. The research background, problem, goals, methods and scope, and the thesis structures are presented in this chapter.

1.1 BACKGROUND

The background of this research originates from the joint aspects of PDE and ambient technology. Ambient function has played a crucial part in aiding personal design practice. Due to the advances of ambient technology, ambient has become a way for designing creative environments that help work and foster communication. In this section we have a glimpse of how PDE has evolved to Ambient PDE.

1.1.1 Personal Design Environment

Traditional design setting is often comprised of different purposeful spaces/rooms for different activities. It is common to carry out a design activity in a specific environment. For example, designer would do design work in a private PDE, and have a group discussion in a conference room. PDE, also called *personal workspace* (Firlik, 2005) has been for decades an essential type of space which is commonly seen in a typical design studio.

Personal is a general term. When referring to PDE, we often indicate a static physical space comprised of elements such as partitions, desks, or chairs, for an individual design practice for working. It is not unusual for designers to do their designing in their PDE, for designing is a highly attentive task and needs to be dealt with full concentration. Even after group collaborations, the designer returns to his office cubicle (i.e. PDE). Though there is no one uniform pattern of work practice in a PDE, it is evident that there is a dialectical relation between the designer and his PDE (Dave, 2003).

Fig 1-1: Traditional studio with PDEs (*after* Dave, 2003).

In their PDE, designers tend to customize their ambient setting and strategically arrange spatial elements in different proximities or in easily accessible ways to better help their designs. For example, the designer would put a material book aside in case he might need to choose materials, so when needed, he can reach for them quickly. Separated designers would also seat themselves closer to form a social awareness and foster collaboration, and, when needed, it is would be easier for them to initiate a discussion without looking for each other or setting up any facilities. It is also common to see designers augment their partitions with notes, documents, or sketches for easier managing information. It is a fact that ambient settings, when appropriately arranged, could provide designers with significant design support or benefits. A great amount of different types of PDEs were developed under such an urge to increase variations of design fashion, such as Steelcase's Personal Harbor (Hamilton et al., 1996), Dilbert's Ultimate Cubicle (Adams, 2001), and IBM's BlueSpace (Chou et al., 2001). All these new PDEs exploit spatial elements to better support work and emphasize on personalization as well as flexible customizability.

Fig 1-2: Dilbert's Ultimate Cubicle (*after* IDEO[1]).

1.1.2 Ambient Environment

One of the above trends regarding designing spaces to be more user-centric and flexible is the urge to have an ambient environment. Ambient environment is a kind of architectural space that exploits ambient functionality and human spatial perception to help human activity. As information technologies were introduced into the architectural environment, ambient functionality was enhanced and extended. It is believed that the future spaces are likely to be filled with interactive surfaces and interact with human via foreground/background awareness and other natural, multiple modalities (Norman, 1999; Weiser, 1991).

Various works were developed with similar ambient approaches by integrating digital mechanisms into spatial physical elements. Examples of such are Media Spaces (Bly et al., 1993), a system that integrates multiple media and connects distant places and groups of people together, Ambient Displays (Wisneski et al., 1998), an artifact that displays information for background awareness (Fig 1-3),

[1] IDEO, http://www.ideo.com

Tangible Interfaces (Ishii and Ullmer, 1997), which projects digital information on the physical environment for intuitive interaction with users, and Roomware, which sees room as modular spaces for docking digital components (Fig 1-4) (Streitz et al., 1999). These technologies transform spatial elements into interactive spaces, and aids designers in different aspects, such as providing social awareness (Gross, 2003; Prante et al., 2003) or providing instant design media (Chen and Chang, 2005). Furthermore, they can be customized or arranged freely to fit personal usage or preferences.

Fig 1-3: A PDE with a customized ambient display aside (*after* Ambient Device[2]).

These environmentally-integrated ambient elements, though designed for different purposes, embrace a shared characteristic, which Weiser and Brown noted as Calm Technology (Weiser and Brown, 1996), "*What is in the periphery at one moment may in the next moment come to be at the center of our attention and so be crucial.*" The aim of Calm Technology is to provide information in the periphery which can be easily perceived by moving one's attention from the center to the periphery, and back, without overburdening.

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[2] Ambient Devices , http://www.ambientdevices.com

Fig 1-4: Roomware components (*after* fraunhofer IPSI[3]).

1.1.3 Ambient Personal Design Environment

Properly arranging and integrating ambient media into a space creates a newly ambient PDE which helps design activity to be carried out more fluently and seamlessly with the aid of ambient functions (Chen and Chang, 2005; Chou et al., 2001). Each spatial element, such as a building block, contributes to the whole construct of ambient support, and designer uses his multiple sensors and modalities freely to interact with the digital information that surrounds the environment as a way to advance a design activity (Fig 1-5).

Based on the study of precedents, we can summarize key ideas that form the basis of the *ambient personal design environment*, which can also be viewed in general design guidelines as:

Foreground and Background: Ambient mediated environments attune the designer's perception, and can be divided into foreground and background (Wisneski et al., 1998), or, say, periphery and center (Weiser and Brown, 1996). Foreground channel is where designer's focus is on, and the background is where the designer's awareness is, without disturbing the foreground tasks.

***Calm*:** Interactive media are embedded or integrated into the environment, which is blended into user's background unobtrusively.

[3] Fraunhofer IPSI, http://www.ipsi.fraunhofer.de

Cooperative: Each ambient element provides partial functional support for an activity. They work cooperatively to form an ambient support as a whole, and do not interfere with each other.

***Context Specific*:** The ambient elements are targeted at a particular design context or activity.

***Customization*:** Ambient elements can be tailored towards the user's need, in terms of what functions or forms they provide, and how they can be easily managed and used as environmental resources.

These characteristics make the ambient environment more personalized in the way of environment interaction, and proactively serve the user's needs. An example of Ambient PDE is shown in Figure 1-5. In Figure 1-5, the user is having a collaborative sketch over a projection on the table, while at background he is aware of the remote status via a light matrix display aside. This customized calm setting is arranged for a remote collaboration context, and the display as well as the table projection act cooperatively to form remote collaboration support.

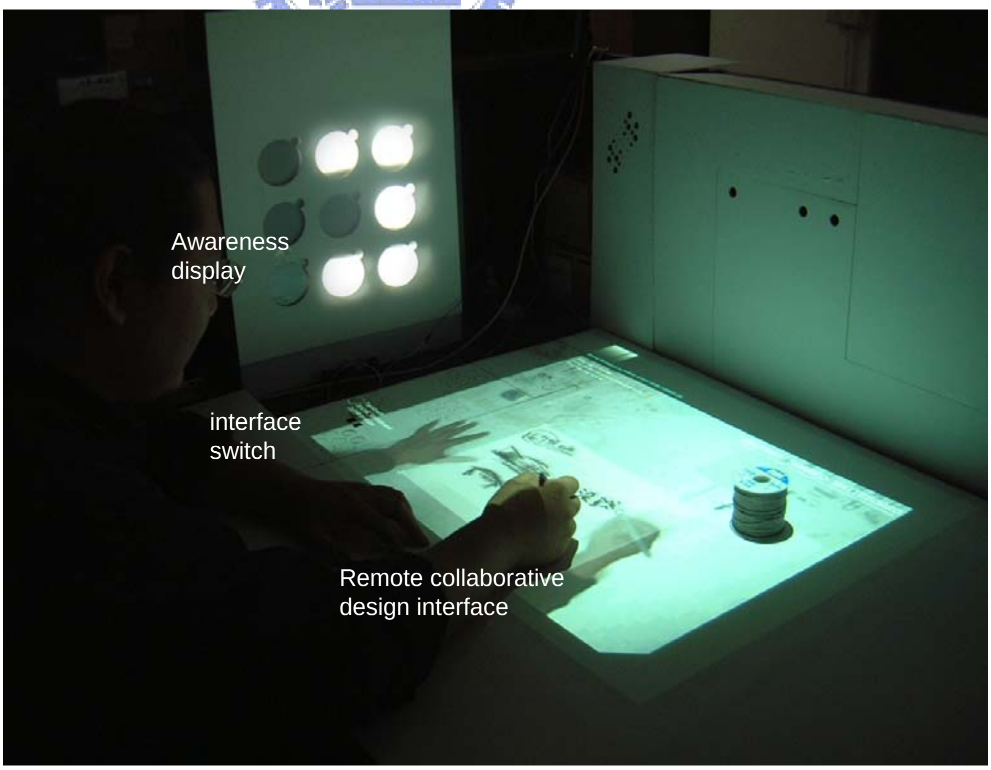


Fig 1-5: An example of an Ambient PDE

1.2 THE PROBLEM

The process of designing in a PDE often encounters interruption. Such interruption could be the designer’s sudden thoughts, encountering other colleagues, or receiving a phone call during the designing. This often shifts the designer’s focus from designing to dealing with the new situation (Jett and George, 2003; Miyata and Norman, 1986). However, due to the lack of an automatic reconfigurable framework, such a context shift sometimes distracts the designers by requiring them to stop their foreground tasks to prepare the essential devices needed to set up for the appropriate environment. How can an ambient PDE be reconfigured from A to B easily and instantly as shown in Figure 1-6? What is the framework and process needed to evoke the ambient setting reconfiguration?

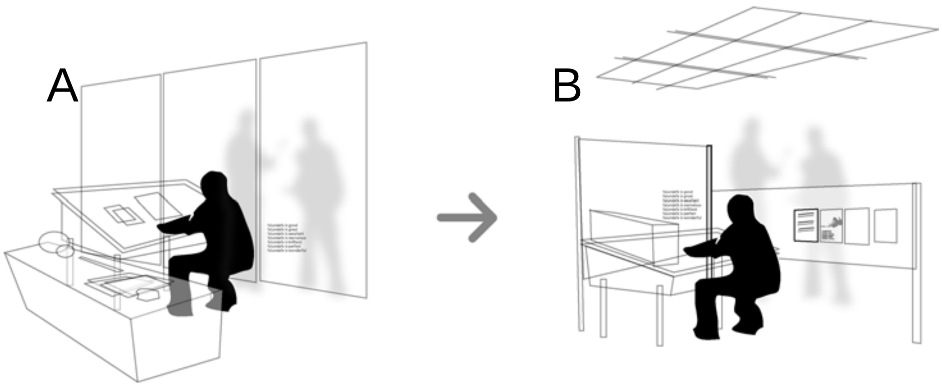


Fig 1-6: How can one reconfigure an ambient PDE from A to B instantly and easily?

Whilst PDE has become more and more ambient-functioning, it is evident that we need more flexibility on ambient settings to fit different needs while designing in a PDE. If we take the dynamic nature of design into account, the design of ambient PDE should also be dynamic and reconfigurable immediately, which means it should be capable of supporting the user’s evolving needs during a design process.

1.3 AIMS AND SCOPE

According to the problem stated above, the goal of this research is thus to propose a framework for automatic ambient reconfiguration in an ambient PDE.

One of the major goals for the framework is to minimize distractions caused by reconfiguring ambient functionality in ambient PDEs. We decided to eliminate extraordinary user intervention, to mediate the configuration process by preset customized computation and automation strategy, and to represent the changed environment in an ambient way. Configuration in this sense is seen by triggering a series of specified actions with parameters, which results in different ambient mediated environmental settings. We call these approaches "Ambient Triggers (ATs)". In this paper, we define the AT framework and its design principles, as well as explore the possibility of ATs. Overall, major objectives in the list below can be achieved.

1) A conceptual definition of ATs
2) A framework for ATs that reconfigures the ambient mediated PDE.
3) A set of design principles for AT interface
4) An environmental prototype system for the reification of the AT framework and the design principles.

The scope of the research focuses on *ambient environment*, *ambient technology* which multiplexes ambient intelligence and ubiquitous computing technology, and *personal design activity*. The research is primarily built in the lines of the *ambient environment*, arguing for a feasible framework for ambient reconfiguration. It is important to note that the purpose of this research is not to create a new PDE, but to provide a new perspective to the design and integration of ambient mediated PDEs.

1.4 METHODS AND STEPS

The problem of the research is built in the lines of the ambient environment. After reviewing relevant work in ambient environment, we oriented our research and further investigated the interface design issue and analyzed characteristics for an ambient trigger user interface. We conduct design experiments to gain insights as to frame a hypothetical framework as well as framework design principles for the research. Furthermore, by implementing the framework, the design principles and computability of the framework is refined and tested.

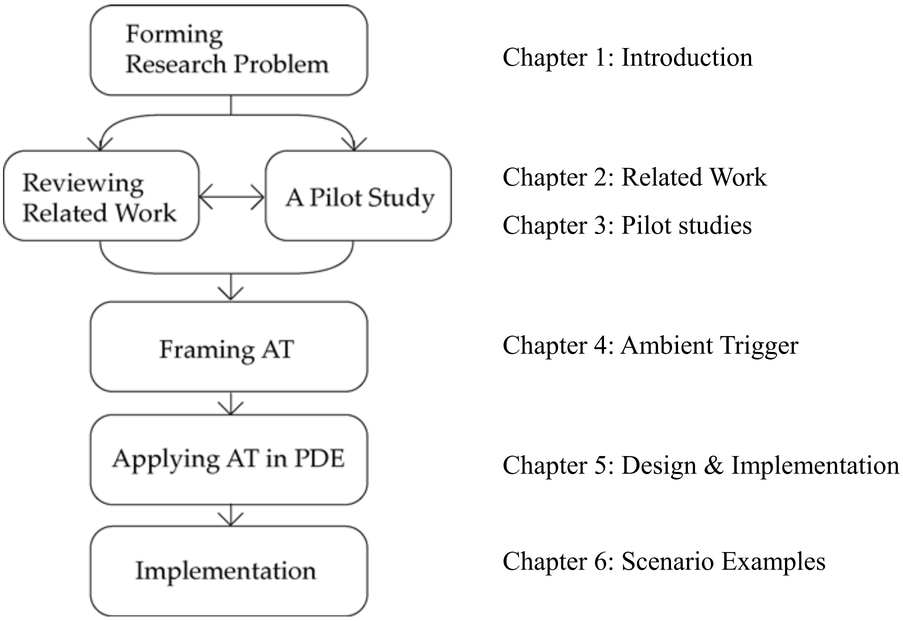


Fig 1-7: Methodology of the research.

The research step is depicted in Figure 1-7. First, we reviewed relevant frameworks and projects in domains related to ambient environment. Second, with lessons learned from reviews, we conducted design experiments as pilot studies to explore the interface design principles and framework feasibility for evoking ambient reconfiguration. Third, together with lessons learned from reviews and the pilot studies, we proposed the *Ambient Trigger*, a computational model specific for reconfiguring ambient settings in an ambient environment. Fourth, we constructed a test-bed environmental setting with applications to be tested on a planned scenario. And last, we reifed the AT framework and the proposed design principles by going through scenario examples, and made a conceptual comparison with a case that evokes ambient reconfiguration via various media.

1.5 STRUCTURE OF THE THESIS

The thesis is organized as follows:

Chapter 1: INTRODUCTION introduces the research background, problem, goals, methods and steps, scope, and the structure of the thesis.

Chapter 2: RELATED WORK reviews related frameworks and projects in terms of the ambient environment, with a focus on reconfigurability.

Chapter 3: PILOT STUDIES presents three ambient environment design cases: Ambient Window, InfoRiver Table, and Walls from World, for experimenting on interfaces to evoke ambient reconfiguration.

Chapter 4: AMBIENT TRIGGER gives an introduction to the idea of AT, with its characteristics, framework, components, mechanisms, and workflow elaborated.

Chapter 5: DESIGN AND IMPLEMENTATION reports the design and implementation process of a test-bed environment for verifying AT.

Chapter 6: SCENARIOS AND REIFICATION shows scenario examples of AT, and makes a comparison of the triggering steps between using AT interface and using various interactive ambient elements.

Chapter 7: DISCUSSION AND CONCLUSION discusses the research results, its drawbacks, benefits, and possible implications in the advancing ambient environment. The chapter concludes with research significance and suggestion for future directions.

2

RELATED WORK

In this chapter we review related work regarding the notion of ambient reconfiguration. The criteria for searching the relevant work are described in 2.1. We review related frameworks in 2.2, related projects in 2.3, and summarize lessons learned in 2.4. In 2.5, we suggest pilot studies to consolidate the assumption for an ambient reconfiguration triggering interface.

2.1 CRITERIA FOR SEARCHING

The purpose for reviewing related work is to situate our research into a broader research context, to gain insights from previous researches and to find a way for further investigation. To focus on the notion of ambient reconfiguration, we strategically derived two major issues regarding ambient reconfiguration. The first issue is on how a designer evokes ambient reconfiguration and how ambient elements react to the designer's request (i.e. ambient interface). The second issue is on how a system engine computes for the user's request and how it controls the reactions of the environment (i.e. reconfiguration process) (Fig 2-1).

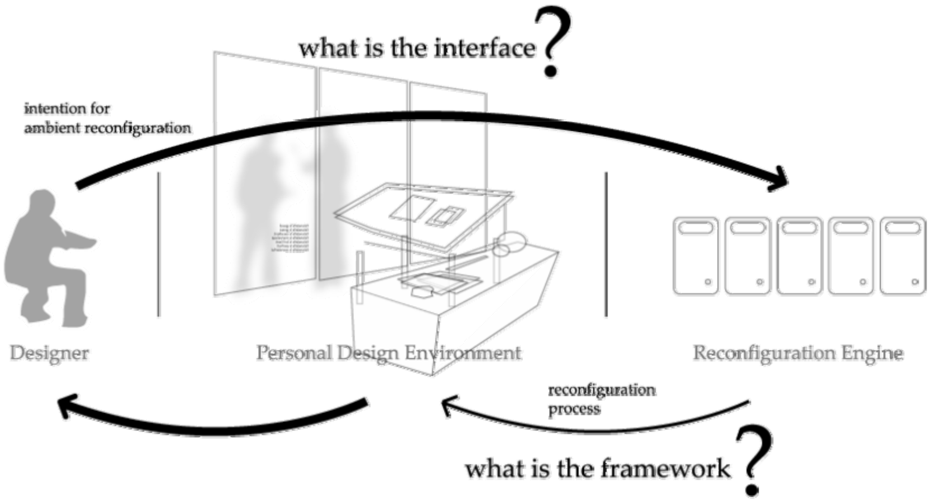


Fig 2-1: Derived two major issues for strategic review.

Based on the above two main issues, the review aims to grasp the ideas on what the interface and the framework could be like. We decided to review related projects from an ambient interface view and to review frameworks from a reconfiguration process view. The criteria for the selection of frameworks are described below:

1) The notion of automatic reconfiguration refers to the capability of space to perform different functions when the user requests it. As a result, the work should have at least a three-step triggering process (i.e. user *input*, *process*, and *output*).
2) The *output* of the framework should be spatial and should make environmental changes.
3) Since ambient characteristics are crucial components in our research, the work should be able to collocate with ambient or ubiquitous computing technology.

And for projects, the work to be reviewed should reflect upon:

1) characteristics of the ambient environment,
2) the (partial) change of an environment,
3) the easiness on the user evoking ambient interaction, and
4) the capability of transforming ambient elements into different forms/functions.

2.2 RECONFIGURATIVE FRAMEWORKS

In this section, we select frameworks showing spatial reconfigurability and having more relevance to ambient environments among different domains such as ambient intelligence (Aarts, 2004), ubiquitous computing (Weiser, 1991), and responsive architecture (Bullivant, 2005; Sterk, 2003). Conceptual, representational, and computational frameworks are reviewed. We describe each as follows.

2.2.1 Hybridized Control Model

(Sterk, 2003) proposed an extensible model for controlling responsive architecture, which can be used as a fundamental concept to describe reconfigurable ambient environments. It is a simple model which consists of three parts (Fig 2-2):

1) ***User input:*** which offers users the means to control and interact with the building;
2) ***A building structure:*** which has a responsive capability that enables it to directly respond to environmental loads, and
3) ***Spatial responses:*** which is used to control the partitioning or services for activity inside spaces.

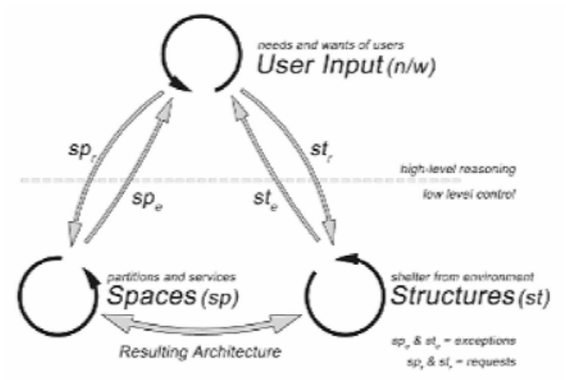


Fig 2-2: A hybridized control model for responsive architecture (*after* Sterk, 2003).

2.2.2 Frameworks of Context Awareness

In general, the context is the circumstance of “who is in where, doing what, how, and for what”. In an ambient intelligence (Marzano and Aarts, 2003) viewpoint, objects and services need to be aware of the state of their surroundings at any given moment. It is a fundamental technology used to achieve a user-centric intelligent environment. There are many ways to describe or structure contexts. For example, (Oh and Woo, 2004) proposed a unified model to format and integrate contexts into the structure of 5W1H (Why, Who, When, Where, Which, and How).

There are three phases in the workflow cycle of context awareness (Aarts and Roovers, 2003):

1) ***Perceiving the environment:*** the first step is to collect information about the environment and turn it into a useful form with sensor technology or smart sensors.
2) ***Classifying and analyzing the data:*** the second step is to use the information provided by sensors to determine the state of the environment as a whole based on the model of context.
3) ***Interpreting the context and taking action:*** The last step is, based on the environmental context the system has perceived, to use high-level knowledge to decide what the system should do.

2.2.3 Implicit HCI Framework

iHCI (Implicit Human-Computer Interaction) is a conceptual model which takes context into account as implicit input and has influence on the environment by implicit output (Fig 2-3) (Schmidt, 2000). It is most suitable for systems where the the user should not be distracted from the main task in the physical spatial context. This model is widely applicable for specific domains, such as proactive applications, adaptive UIs, user interruptions, communication applications, resource management, and the generation of metadata.

(Schmidt, 2004) gave a formal definition of *implicit input* and *implicit output*:

Implicit Input: Implicit input pertains to the actions and behaviors of humans, which are done to achieve a goal and are not primarily regarded as interaction with a computer, but captured, recognized, and interpreted by a computer system as input.

Implicit Output: Output of a computer that is not directly related to an explicit input and which is seamlessly integrated with the environment and the task of the user.

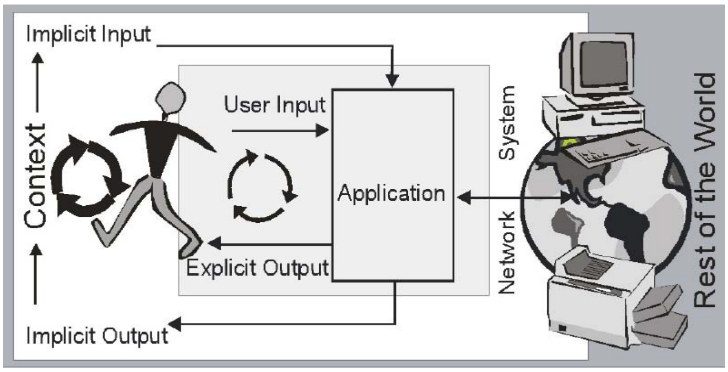


Fig 2-3: Implicit human-computer interaction model (*after* Schmidt, 2004).

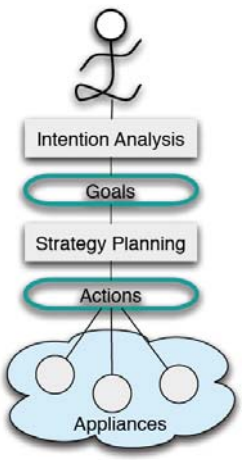
2.2.4 Workflow Cycle of Ambient Intelligence

(Hellenschmidt and Wichert, 2005) proposed three major steps for the workflow cycle of an ambient intelligence system:

Awareness: The environment and the objects within the environment should be aware of the user's current situation, his interaction condition with the environment, his personal condition, and the possible condition he should be adapted to.

Intention Analysis: The environment must infer the user's intention based on the situation it is aware of, and respond with possible cooperative or proactive support to the user.

Strategy Planning and Execution: The environment should transform the user intention it inferred into an adaptation strategy which the environment and environmental objects can provide.



Such an interaction cycle can be generalized and termed as 'Goal-based Interaction' (Heider and Kirste, 2002), as shown in Fig 2-4. Goal-based interaction requires two functionalities: *Intention Analysis*, interpreting user interactions and environmental contexts into concrete goals, and *Strategy Planning*, which maps goals to device operations (Hellenschmidt and Wichert, 2005).

Fig 2-4: Principle of goal-based interaction (*after* Heider & Kirste, 2005).

2.2.5 Framework for Project Aura

The pervasiveness of computers frees users from being bound to specific desktop computers. Based on such a concept, project Aura (Sousa and Garlan, 2002) tries to create a distraction-free computing environment with ubiquitously available computational resources. Users in a ubiquitous computing environment can bind and compose their own task context and release them at any physical service hot-spot. The computer-supported task thus becomes a personal aura which surrounds people, provides personalized settings, and requires no configuration efforts for switching among different computational platforms or environments.

2.2.6 SODAPOP

SODAPOP (Self-Organizing Data-flow Architectures supPorting Ontology-based problem decomPosition), is a middleware for simplifying the framework integration process among smart objects (Hellenschmidt and Kirste, 2004). Its objective is to make the environment observe and analyze the user's goal, and combines appropriate components with environmental resources into a unifying system automatically in real-time according to the analyzed data. The integration has two aspects: 1) ***Components integration:*** the pattern matching in the system level. For example, attaching an input device to the ensemble's interaction event bus; 2) ***Operational Integration:*** The mapping of interface operations with metaphorical relation. For example, connecting a CD player into a CD recorder could be embodied as "Copy" (Hellenschmidt and Kirste, 2004).

2.2.7 Framework for VICOM and PER2

Inspired by Antonio Damasio's Human Conscience Model (Damasio, 2000), (Marchesotti et al., 2005) designed a flexible architecture the for user to interact with ambient intelligence environments (Fig 2-5). This model is comprised of a few mapped parts: a) *Eso-Sensors* for sensing external contextual data, b) *Endo-Sensors* for sensing internal status, and c) *Self Kernel*, which connect to *Autobiographical Memory* (i.e. short-term memory) and *Autobiographical Self* (i.e. long-term memory). This neurobiologically-inspired model is the basis of the artificial analysis and decision core, allowing the system to acquire and manage a deeper understanding of context information. The flexibility of the architecture is issued in three aspects: context-awareness, multimodal communication, and user-centered adaptive interaction. The proposed design employs a rule-based adaptation module where acquired contextual knowledge about the environment and the user is represented in terms of concepts and facts and are exploited to personalize the multimodal feedback for the user (Stefano et al., 2005).

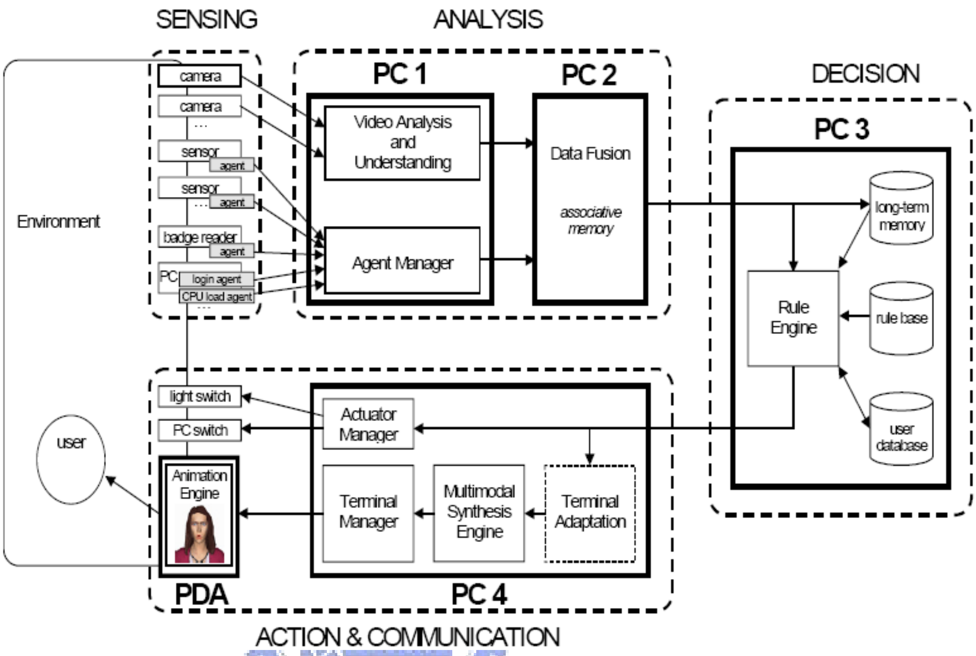


Fig 2-5: Framework for VICOM and PER2 (*after* Stefano et al., 2005)

2.2.8 Summary

In this section we have reviewed representational as well as computational frameworks which could be generally applied to describe a triggering mechanism with sufficient reconfigurability.

Though not developed specifically for ambient reconfiguration purpose, each framework has provided us with insights for developing an ambient reconfigurable framework. Mainly, the Hybridized Control Model (Sterk, 2003) has framed a general and fundamental framework for approaching ambient reconfiguration. Frameworks of Context Awareness (Aarts and Roovers, 2003; Marzano and Aarts, 2003; Oh and Woo, 2004) have illustrated the computational workflow mapping to spatial contexts. Implicit HCI frameworks (Schmidt, 2000) have suggested implicit interaction as a less distractive way for the user to interact with a physical system.

The workflow cycle of ambient intelligence (Heider and Kirste, 2002; Hellenschmidt and Wichert, 2005) have suggested a goal-based type of interaction, which point out that the need for ambient interactive services is based on the user's intention. Aura (Sousa and Garlan, 2002), a work that approaches distraction-free interaction by providing users with ubiquitously accessible platforms, has suggested automatic configuration of spaces without the user's explicit configuring process. SODAPOP (Hellenschmidt and Kirste, 2004; Hellenschmidt and Kirste, 2004) suggested that different combinations of operations or objects refer to different interactive contexts, and the framework of VICOM and PER2 (Marchesotti et al., 2005) (Stefano et al., 2005) have provided us with a flexible and intelligent model that is suitable for achieving ambient reconfiguration technologically. Some processing techniques in terms of contextual data acquisition and categorizations were also learned.

To gain a whole view on the research problem and to understand the practicability as well as feasibility in terms of ambient reconfiguration, the next section reviews related projects that evoke ambient reconfiguration from an interface perspective.

2.2 AMBIENT ENVIRONMENTS

In the previous section, we reviewed related frameworks that imply the feasibility for achieving automatic ambient reconfiguration. The goal for reviewing related ambient environments is to understand the role of interface in evoking ambient reconfiguration, and how the user's intention for ambient reconfiguration is being interfaced. In this section, we review related projects from research labs worldwide that show or imply the practicability and possibilities of ambient reconfiguration with user control.

2.2.1 Nebula

Nebula (Marzano and Aarts, 2003) is an interactive projection system designed to enrich the experience of going to bed, sleeping, and waking up (Fig 2-6). By simply placing pebble-encompassing specific interactive content into the bed bag, a correspondent ceiling interactive projection will be triggered, and the user can manipulate it by adjusting their sleeping positions and by interacting with their partner while in bed. Though it is not designed for design work or relatively formal tasks, it shows potential of environmental adaptation via light-weight human intervention.

Fig 2-6: Nebula with reconfigurable ceiling projection (*after* Royal Philips Electronics website[4]).

2.2.2 Visual Interaction Platform

Visual Interaction Platform (VIP) (Aliakseyeu et al., 2001) is an augmented reality design application combined with the WIMP interface. The physical setting of VIP

4 http://www.design.philips.com/about/design/section-13534/index.html

mainly constitutes of two spaces: an action-perception space for design work, and a communication space as a supplement (Fig 2-7 left). VIP has a range of 2D/3D navigation and manipulation support via mediated objects, such as hand writing, sketching, and the tracking of physical objects (Fig 2-7 right). VIP is a working prototype that integrates the function needed for the early stage of design, and combines both benefits of the WIMP interface and natural artifact-mediated interaction. With VIP, the designer can freely choose the interaction style that best fits his needs when performing specific operations. However, though VIP has shown its reconfigurability in various tasks such as switching mediated objects for different operations, it is mainly designed as a fixated supporting tool only in the early stages of design, and does not adapt to other design activities.

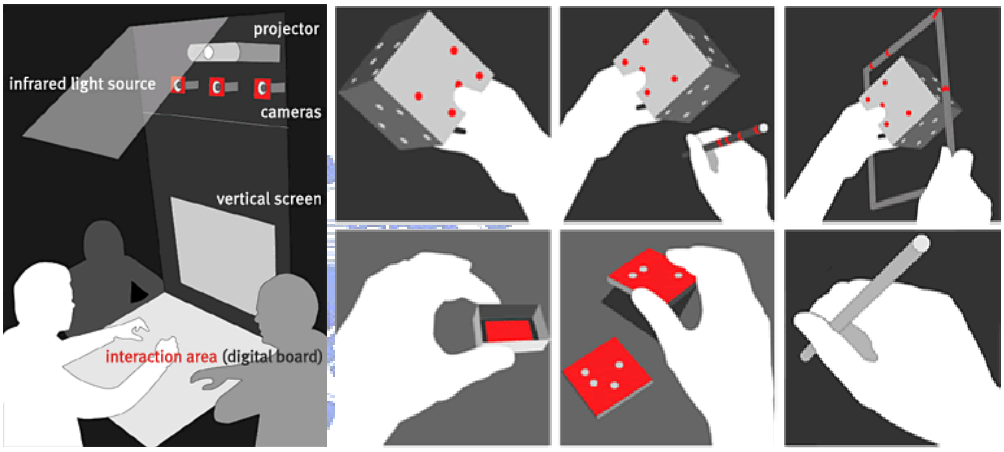


Fig 2-7: Spatial arrangement of VIP (left), and different mediated objects for interacting with VIP (right) (*after* VIP website[5]).

2.2.3 Ambient Agoras

The major goal for project Ambient Agoras (Prante et al., 2004) is to transform the physical envelop of a work environment into a social architectural space which supports informal communication, collaboration, and social awareness within the organization. The result of the project—Hello.Wall (Prante et al., 2003), is an example artifact as a social catalyst that fosters both local and remote collaboration within a larger organization (Fig 2-8).

It contains three different interaction states: *Ambient*, *Notification*, and *Interaction*, and is activated by user proximity to it (Fig 2-9). When a user keeps his distance from the Hello.Wall, it appears to be an atmospheric decorative ambient display.

[5] Visual Interaction Platform at Industrial Design Eindhoven, http://www.vip.id.tue.nl

But when the user steps closer, the ambient display starts to serve an informative role and notifies the user if there are any private messages for him. One more step closer, the user can explicitly interact with it, such as view or leave a message to others via a borrowed display—ViewPort. In some views, by measuring the user's proximity, the Hello.Wall can be seen as adaptive to the three kinds of different social activities. Measuring the proximity to reconfigure the function of Hello.Wall is comprehensible and acceptable by users in this case. However, they may not be suitable for manifestation for design activity adaptation.

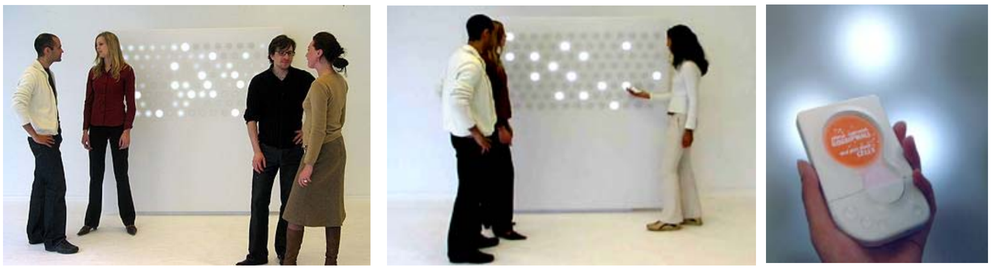


Fig 2-8: Informal communication around Hello.Wall (left). Interacting with Hello.Wall with ViewPort (middle). ViewPort in detail (right) (*after* Ambient Agoras[6]).

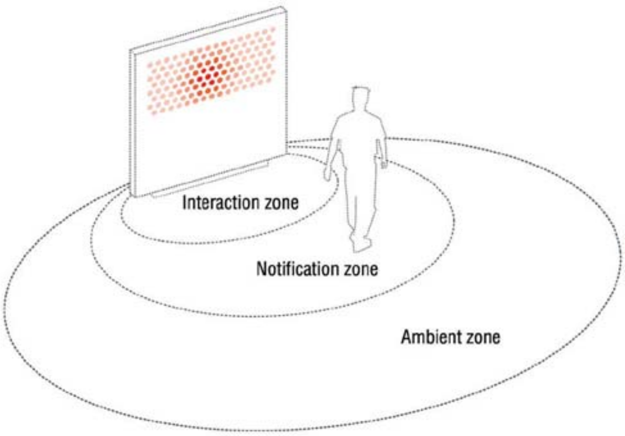


Fig 2-9: Ambient Agoras with three interaction states (*after* Ambient Agoras).

2.2.4 Interactive Public Ambient Display

Similar to Hello.Wall mentioned above, Interactive Public Ambient Display (Vogel and Balakrishnan, 2004) is another interactive ambient display consisting of four levels of interaction states: *ambient display*, *implicit interaction*, *subtle interaction*,

[6] The Disappearing Computer Initiative - AMBIENT AGORAS, http://www.ambient-agoras.org

and *personal interaction* (Fig 2-10 left). Also determined and triggered by user proximity to the display, it offers different user interaction modalities and different contents, judging by the user's distance to the display. The right of Figure 2-10 shows the user interacting with Interactive Public Ambient Display.

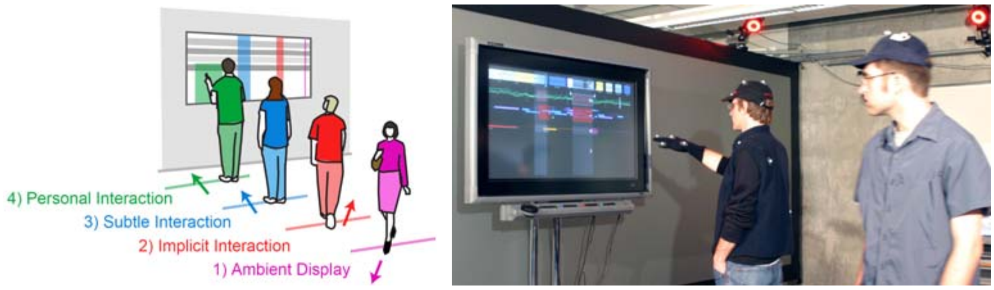


Fig 2-10: An Interactive Public Ambient Display with four interaction states (left), and a user interacting with Interactive Public Ambient Display (right).

2.2.5 Muscle Reconfigured

Muscle Reconfigured (Biloria and Oosterhuis, 2005), as real-time responsive spatial envelop installation, envisions space as a network of nodes which constantly exchange information and behaves as a collective whole to attain spatial reconfigurations (Fig 2-11). It reconfigures its shape to adapt to human ergonomics or behaviors. The prototype has successfully made space reconfigurable, but it is reconfigured to be more adapted to human ergonomics or behaviors instead of design activity.

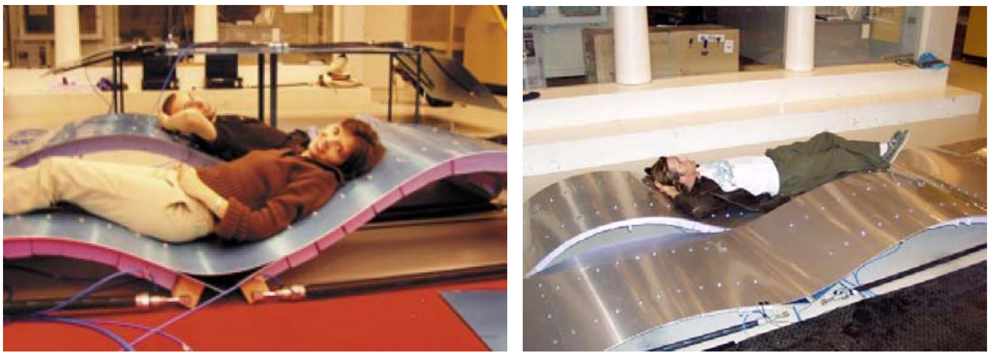


Fig 2-11: Muscle Reconfigured (*after* HRG, TUDelft[7]).

[7] Hyperbody Research Group at TU Delft, http://www.protospace.bk.tudelft.nl

2.2.6 Impromptu

Impromptu (Beigl et al., 2004) is a concept and system for instant creation of ad-hoc pervasive computing environments. By introducing different everyday objects tagged as Smart-Its Particles into the environment, they are aware of each other, configure themselves to correspondent functions, and cooperatively forms a spatial support, without users having to set-up, configure, maintain, or administer such environments by themselves. Impromptu could be adaptive to different situations when different tagged object are present in the environment. However, this means the adaptation is constrained with the objects, and every time the adaptation is needed, extraordinary user intervention is required, which may annoy the user.

2.2.7 U-Texture

U-Texture (Kohtake et al., 2005) is a topology-aware building panel which allows the user to composite it into different 3D shapes to form specific functional smart objects (Fig 2-12) such as ambient walls, collaborative tables, smart stands, or smart shelves. U-Texture is able to recognize the entire structure and functioning automatically (Fig 2-13). Such topology-aware adaptation is an intuitive way to trigger specific adaptation strategies; however, the composition itself needs user foreground intervention and lacks immediacy, which may distract the user, whose goal and focus of interest should be on another thing.

Fig 2-12: A modular building panel for U-Texture (*after* UbiLab[8]).

Fig 2-13: Smart Table, Smart Shelf, Smart Wall, and Smart Stand (*after* Kohtake et al, 2005).

[8] http://www.ubi-lab.org/u-texture

2.2.8 Animated Work Environment

Animated Work Environment (AWE) (Green et al., 2005) is a concept of the future work environment interior embedded with intelligent components that adapt to a range of work needs and situations over time. The configuration and functionality of the environment is user-controllable over a WIMP interface on the work surface with preset programs (Fig 2-14). A user can reconfigure the whole space into different purposeful spaces simply via buttons or toggles. However, AWE appears to be a conceptual idea only and the practicability and feasibility is still under evaluation.

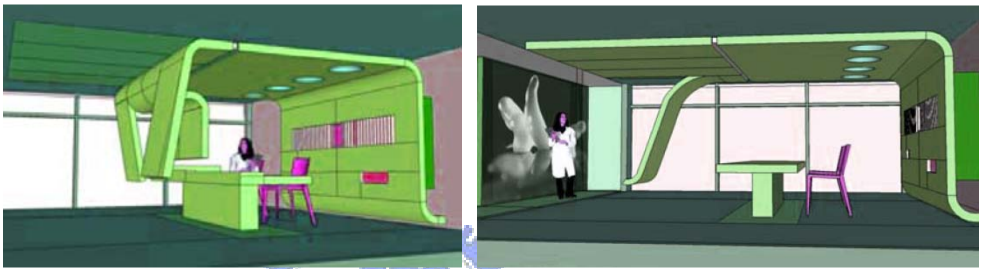


Fig 2-14: AWE in *Composing* mode (left); AWE in *Presenting* mode (right) (*after* Green et al, 2005).

2.2.9 Turntroller

Turntroller (Suzuki et al., 2005) is a device for controlling appliances around the environment simply via a "Turn" operation (Fig 2-16). It is composed of two columnar knobs. The back side knob is used for selecting the appliance to control and the front side knob is used for actually controlling it (Fig 2-15). Turntroller provides users with an easily way to reconfigure the ambiance in any place.

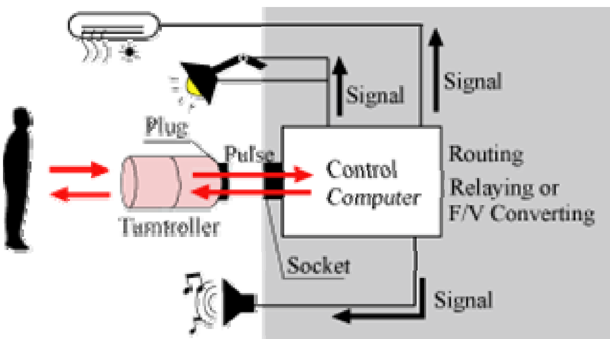


Fig 2-15: The system architecture of the Turntroller (*after* Turntroller[9]).

[9] http://www.turntroller.com

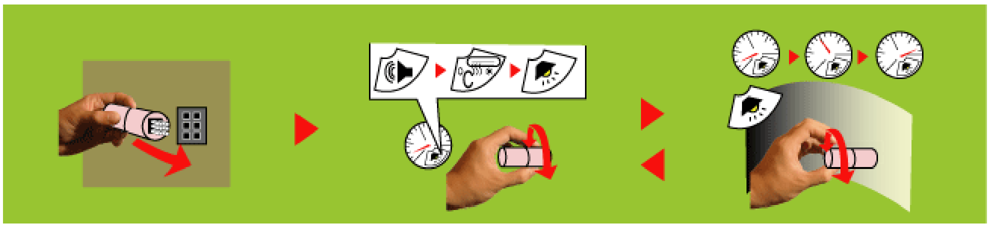


Fig 2-16: A diagram describing the usage of Turntroller (*after* Turntroller).

2.2.10 Instant Collaboration Environment

Instant Collaboration Environment (ICE) (Chen and Chang, 2005) is a project investigating how a designer can reconfigure his PDE into a remote collaborative environment to have "Clearboard"-like (Ishii et al., 1994) or "Media Space"-like (Bly et al., 1993) ambient settings (Fig 2-17). Users within ICE can easily collaborate with remote colleagues simply by pressing buttons to immediately trigger the environment into a desired collaborative setting (Fig 2-18). However, according to our observation and experiences, when users request remote collaboration, they cease for a few seconds to seek the correct buttons to press. As a result, buttons appear not to be an ideal choice for an unobtrusive trigger interface.

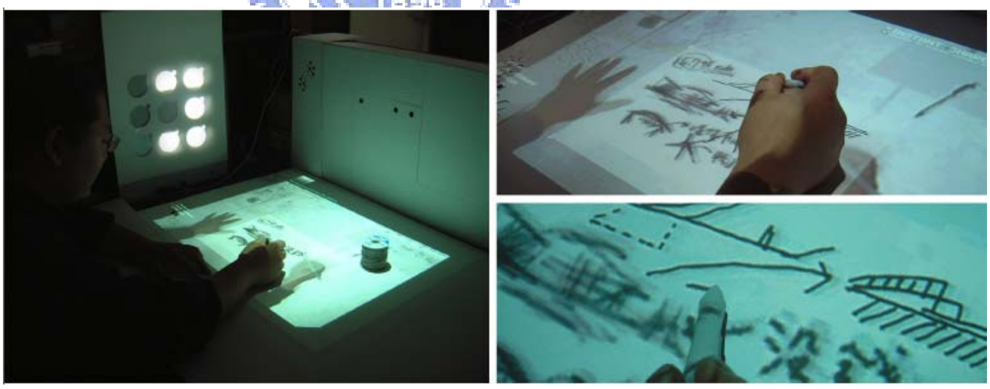


Fig 2-17: Remote collaboration with "Clearboard"-like interface in an ICE.

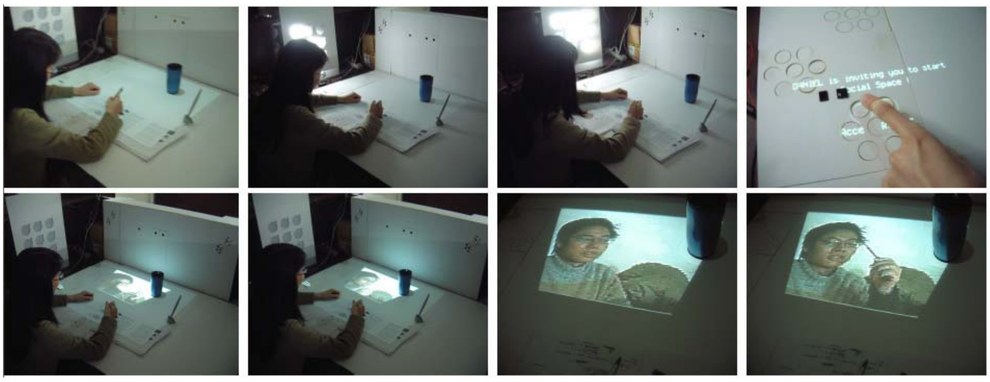


Fig 2-18: A user initiates a "Media Space"-like collaboration in an ICE.

2.2.11 Summary

The works mentioned above show a variety of feedback elements, from spatial envelop, artifacts, appliances to interactive surfaces. It also shows a variety of ways to evoke ambient interactions by evoking them via controllers, implicit inputs, the composing of different elements or embodied actions toward an artifact.

Interaction techniques such as controller devices, gesture controls, or tangible inputs have been investigated as approaches for users requesting ambient settings to tailor to different needs. One can use a universal remote controller to switch the state of an appliance and connect each of them to form cooperative services. Because design is dynamic in nature and requires different design support for different purposes at times via controllers or techniques, the environment should be triggered to reconfigure into different kinds of ambient mediated support immediately.

Interaction techniques for triggering ambient reconfiguration and reconfigured ambient elements are summarized into a chart in Table 2-1. The related projects have shown possible techniques for achieving ambient reconfiguration, which we discuss in the following section.

Table 2-1: Lists of related projects.

No	Project Name	Techniques for Evoking AR	Feedback Elements
1	VIP (2001)	Placing new artifact into the work space	A table with a front surface
2	Nebula (2001)	Putting Pebbles into baggage	Ceiling and a bed
3	Ambient Agoras (2003)	Body approaching the wall	A Wall
4	Impromptu (2004)	Attaching Smart-It particles to everyday artifacts	Everyday artifacts
5	Interactive Public Ambient Display (2004)	Body approaching the display	Ambient display
6	Works from HRG (2004)	Movements or sounds	Spatial envelop
7	U-Texture (2005)	Composing into artifacts	Everyday artifacts
8	AWE (2005)	Pressing buttons and toggles	Spatial envelop and everyday artifacts
9	Turntroller (2005)	Rotating the knob	Environmental appliances
10	ICE (2005)	Pressing buttons	A table with a front surface and an embedded ambient artifact

2.3 SUMMARY OF REVIEW

In this chapter we reviewed relevant frameworks that feed back users with environmental changes, and projects investigating into the ways user evoking ambient environment changes. The differences of our proposed framework in related work are elaborated in 2.3.1, and the lessons learned from related work are summarized in 2.3.2.

2.3.1 Research Positioning

Our proposed framework for the thesis differs from related frameworks and projects in some aspects. Our proposed framework is designed specifically for the user to evoke ambient reconfiguration, while other frameworks are either too general, or focus on different specific use cases. And most of related projects reviewed are also for some specific context of use or focus on the controller itself, and few of them investigate into the idea of ambient reconfiguration. In a word, our proposed framework is specifically designed for ambient reconfiguration.

2.3.2 Lessons Learned

With the review of the related work, we were inspired, and gained some insights on an ambient reconfiguration framework. Lessons learned are summarized below.

Input, Analysis, Decide, and Output

From relevant frameworks, it is found that a framework for an ambient reconfiguration should at least have a user *input*, contextual *analysis*, *decision-making*, and multiple *outputs* in the workflow. The framework derives user *input* by inferring about the user's intention of reconfiguring the ambient setting, *analyzing* it with other relevant factors, *deciding* for output strategy, and then triggering multiple correspondent *outputs* to form a new ambient setting.

User Intention, Object, and Environment

From related projects, it is found that an object plays a crucial role in interfacing with the user's intention and the ambient settings. It is also found that the ambient environment is the composition of different objects. Since the object can be an artifact, spatial enclosure, or ambient element, the relation among user, object, and the ambient environment closely interplays with each other.

Techniques in Deriving User Intention

Before proceeding to ambient reconfiguration, finding out how to derive the user's intention as a user input is crucial to the framework. *Context awareness and inference* is a technique for evoking system reconfiguration to adapt to a situational context. Different from the user's explicit control of the trigger method, *context awareness* achieves system reconfiguration by proactively observing and inferring the spatial context without the user's explicit intervention. It can be incorporated with implicit input, which is a distraction-free way of interfacing with the user's intention. By adopting context-aware technology, spatially integrated media in PDE can be further made to be context sensitive and to automatically capture the user's intents, observe user behaviors or overall spatial context, and eventually proactively offer just-in-time ambient support to the users.

2.4 TOWARD A FRAMEWORK FOR AMBIENT RECONFIGURATION

Though there are controlling or interaction techniques for users to reconfigure ambient settings in a unified fashion, most of them distract users by shifting their attention from tasks to the control interface. *Context awareness* appeared to be potential technologies that could solve this problem. However, context-aware techniques rely too much on the accurate inference of contextual data which make them unreliable for highly attentive work like personal design activities. Therefore, user input as well as contextual data to analyze and determine the consequences should be both considered within an ambient reconfiguration process.

We have found that some trigger interfacing approaches are obviously obtrusive, such as interfaces that require users to explicitly command or give inputs. Nevertheless, some have shown their potential as an unobtrusive method to trigger ambient settings such as embodying the user to take natural actions and the like. There are already some technologies available that could be used for such kinds of less distractive triggers. However, it is not clear what the unobtrusive trigger interface should be designed in the context of the ambient environment. To further investigate on interface requirements for triggering ambient reconfiguration, we conducted a pilot experiment on a few design cases in the next chapter in the hopes of summarizing conceptual frameworks and design principles.

3

PILOT STUDIES

In this chapter we explore interface methods for triggering ambient reconfiguration. By going through three iterative design experiments, we analyze and apply the user's natural interaction to conduct design experiments with the guidance of ambient environment requirements. During the process, design principles for ambient trigger interfaces, possible computational trigger mechanisms, and technologies for prototyping ambient environments were experimented on and learned from. In 3.1, we briefly introduce the purpose and methods for the pilot studies. From 3.2 to 3.4, we go through each of the design cases in detail, and summarize the design principles in 3.5.

3.1 EXPERIMENTAL DESIGN

In pilot studies, we aimed at exploring the trigger mechanism for ambient reconfiguration and interface characteristics in an ambient environment. By observing everyday experiences, we found that users interact with environments with bodily actions or behaviors, like, for example, *stepping on* the floor, *sitting on* the chair, or *looking out of* the window. We believe such implicit actions are naturally distraction-free (Schmidt, 2004), and could be rich resources as actuators to evoke changes in an ambient environment in an intuitive way.

Based on the above assumption, we tried to conduct three iterative design experiments with a focus on the trigger mechanisms and techniques in the hopes of empirically summarizing conceptual frameworks as well as design principles. During a subject called Special Topics in Computational Design, at the Graduate School of Computational Design, NYUST[10], three design experiments on ambient environment prototype were conducted as part of an experiment for Ambient Triggers. Different purposes or design premises were set to explore different aspects of interface and interaction techniques. They are *Ambient Window*, *InfoRiver Table and InfoCapsule*, and *Walls from World*. Students were asked to conduct experiments with references to the reconfiguration workflow learned from related works, and were taught the concepts of implicit input and context-aware computing. And because the object is critical, students were encouraged to investigate the characteristics of everyday objects and human behavior and the ways of manipulating it.

The works described below were done in the lines of ambient environment, which has characteristics summarized as *foreground and background, cooperative, calm, context specific,* and *customization* (Aarts, 2004; Gross, 2003; Weiser and Brown, 1996; Wisneski et al., 1998). To realize the environment, interface technologies as well as design principles which aimed at improving interaction between human and physical space to become more natural and intuitive were studied and tried out (Maglio et al., 2000; Oviatt, 2002; Podlaseck et al., 2003; Ullmer and Ishii, 2001; Vertegaal, 2003), and were implemented with the physical computing approach (Igoe and O'Sullivan, 2004). The physical computing approach is a quick and dirty approach for the rapid prototyping and examining of the feasibility of interactive concepts using low costs and easily available sensors and actuator technologies.

3.2 AMBIENT WINDOW

3.2.1 Conception

The first design work is Ambient Window. It is an experiment on how inhabitants' behaviors, especially implicit actions, can have an influence on their living environment to create a more relaxing atmosphere.

In this project, we treat the window as an atmosphere catalyst. It provides ambient feelings that have an influence on a user's behavior and, in reverse, the users'

[10] National Yunlin University of Science and Technology, Taiwan

implicit action would also have influences on the environment which eventually would change the atmosphere calmly. Ambient Window is a virtual projection window that tries to re-create influential ambient feelings and enlarge this characteristic in a basement context, which has no window to the outside.

3.2.2 Interaction Design

According to the concept described above, the interaction design of this project primarily focuses on the creation of an atmospherical feeling via implicit interaction with the Ambient Window. We have designed three implicit interactive triggers, as shown in Table 3-1 and Fig 3-1. When a user appears around the Ambient Window, the projection on the Window will be activated with darkened light. When the user is seated on the sofa, the light will be brightened. Then, when a seated user acts largely, the blue bird in the projection will fly away in response to the user's actions.

Table 3-1: Interaction techniques with Ambient Window

Implicit Input	Implicit Output
A user approaches the Ambient Window	Ambient Window projects darker ambient light
A user sit on the sofa behind the Ambient Window	1. Ambient Window projects brighter ambient light 2. The coffee machine starts to make coffee
User's interaction behind the Ambient Window become more drastic	Blue birds on the projection of Ambient Window flies away

Fig 3-1: A user approaches the Ambient Window with dark ambient light (left). Three people seated behind the Ambient Window with bright ambient light (middle). The interaction between the people implicitly changes the projection content of the Ambient Window (right).

3.2.3 Implementation

The three interactive trigger scenarios were achieved by embedding sensor technologies into the environment, including switches under the sofa for detecting people sitting, and a webcam for detecting the user's level of bodily movement. Actuations include ambient light, a coffee machine, and the Ambient Window projection. The transformation of sensor signals from analogue into digital format for computation and vice versa is achieved via a K28 chip connected to a PC. The implementation framework of the Ambient Window is illustrated as Fig 3-2.

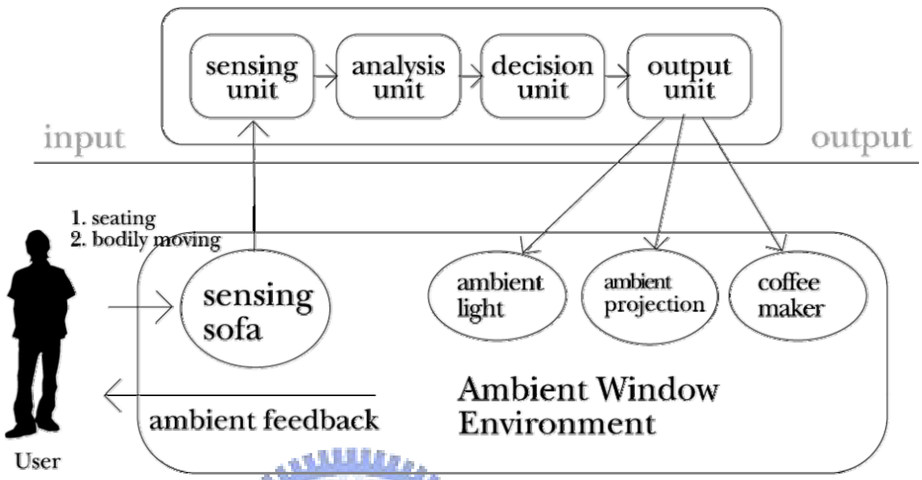


Fig 3-2: The implementation framework of the Ambient Window.

The selected behavior towards the sofa (i.e. seating and bodily movement) will be detected as implicit input to the sensing unit of the system. After analyzing and deciding the output strategy, the system will trigger the appropriate correspondent ambient elements (i.e. ambient light, projection, and coffee maker). These ambient elements will form an ambient feedback to the user's awareness.

3.2.4 Findings

From this experiment we found that implicit behavior could potentially have an influence on the whole spatial context, and result in enticing different user behaviors or interactions between the user and the environment. When the user's awareness changes in his surrounding, he recognizes and then attends to it for intervention. Whether the user will ignore it depends on his own will. For example, the coffee smell as an incentive to users for to have a cup of coffee when coffee has been made, or the bird on the Ambient Window projection would raise the user's attention and curiosity, but their existence won't disrupt what user is focusing on doing at hand, and user is free to decide whether to attend to them or not (Fig 3-3). During our trial, we also found that ambient changes could form new triggers that could induce users to interact with them, and this may in turn trigger other ambient changes. For example, when the user sees a sofa, it might induce him to be seated. And after being seated, the projected blue bird would induce the user to touch it, and this will evoke the next trigger. This supports the assumption that the ‘trigger’ is the fundamental construct which fosters user interacting with the environment. With this ‘trigger’, the environmental could be changed iteratively.

Fig 3-3: The presence of the bluebird on the Ambient Window projection makes the user feel like to touching it (left). The coffee was made after a user sat, and evoked the user to intervene with it (right).

3.3 INFORIVER

3.3.1 Conception

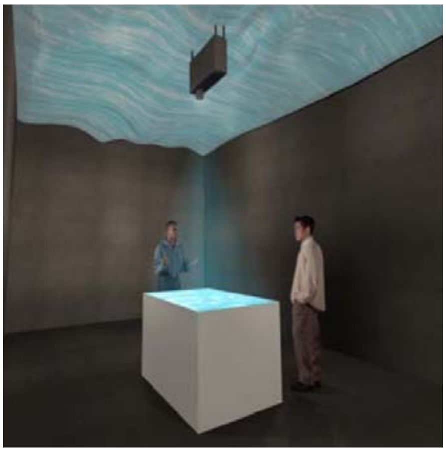


Fig 3-4: Physical installation of the InfoRiver.

In this project, we aimed at experimenting on how users can manipulate digital information in a natural way with the aid of metaphor and metaphorical mediated objects. A conceptual sketch of the physical installation of the work investigating on this issue is shown in Figure 3-4. This work contains two interactive artifacts: the InfoRiver Table and the InfoCapsule. We envisioned the world layered with a fluid interface in a river-like form with floating digital information (including text, images, and sound data), and users living in such a world can grasp any digital information encountered, or can share information onto it. The InfoRiver Table is the proof-of-concept idea, as an example of an everyday artifact with a fluid interface. And the InfoCapsule, in such a context, is a personal container that users carry around the environment to grasp, store, share, and manipulate digital information over the InfoRiver. By combining the InfoRiver Table and the InfoCapsule, this project tries to argue that some simple tasks can be naturally accomplished with the appropriate involvement and metaphorical design of mediated objects.

3.3.2 Interaction Design

We augmented digital projections of information and dynamic river flow images over a conventional table as an experimental prototype to test the InfoRiver concept (Fig 3-4). A capsule-like artifact was selected and designed to be a manipulative object which could be separated into two pieces, top and bottom, to interact with the InfoRiver Table (Fig 3-5). Metaphorically, the capsule has been envisioned as a magical container which contains various magical stuffs, as we can see from many comic books such as in “Dragon Ball”[11].

To make mapping comprehensible to the user, we illuminated metaphorical visual elements such as “harbor” and “riverside” areas along the edges of a table surface. The “harbor” is the area for exporting and importing digital information, and the “riverside” is envisioned as the area for viewing the full content of the grasped digital information. Dragging digital information onto the geographical elements will cause the corresponding trigger. Modes for user interacting with InfoRiver Table via InfoCapsule are summarized in Table 3-2.

Table 3-2: Interaction Techniques of InfoCapsule with InfoRiver

Action with InfoCapsule	Outcome
Put the top piece of InfoCapsule on the “harbor”	The digital information previously contained in the InfoCapsule floats out into the InfoRiver
Put the bottom piece of InfoCapsule with concave face downward over the InfoRiver to grasp and move digital information	The digital information was dragged and moves with the InfoCapsule
Drag any digital information to the “riverside”, with concave face downward Bottom piece	The digital information is enlarged and the full content is shown
Use the concave face downward bottom piece to drag any digital information to the “harbor”	The digital information was saved into the InfoCapsule

[11] *Dragon Ball* is a Janpanese manga series by Akira Toriyama.

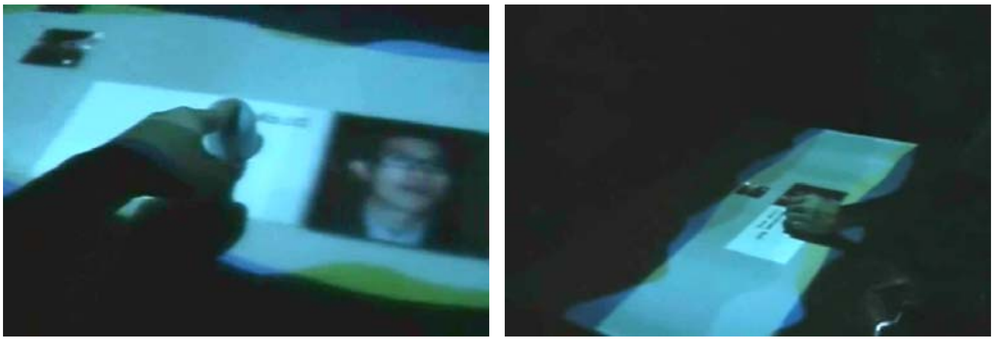


Fig 3-5: The user grasping information over the InfoRiver Table with the top piece of the InfoCapsule.

3.3.3 Implementation

The system architecture of the InfoRiver Table is shown in Figure 3-5. The table artifact was embedded with an RFID reader to detect and retrieve personal stored digital information. The digital information were stored and managed in a database server. A webcam is also embedded into the table artifact to track the position of the LED light. When the user hovers the bottom piece of the InfoCapsule over the table surface, the webcam tracks the LED light to know the moving location of the bottom piece of InfoCapsule. After acquiring the sensing data from the user's manipulations of the InfoCapsule, the system analyzes and decides on the output strategy. The triggered ambient projection and position tracking components form an ambient feedback to the user.

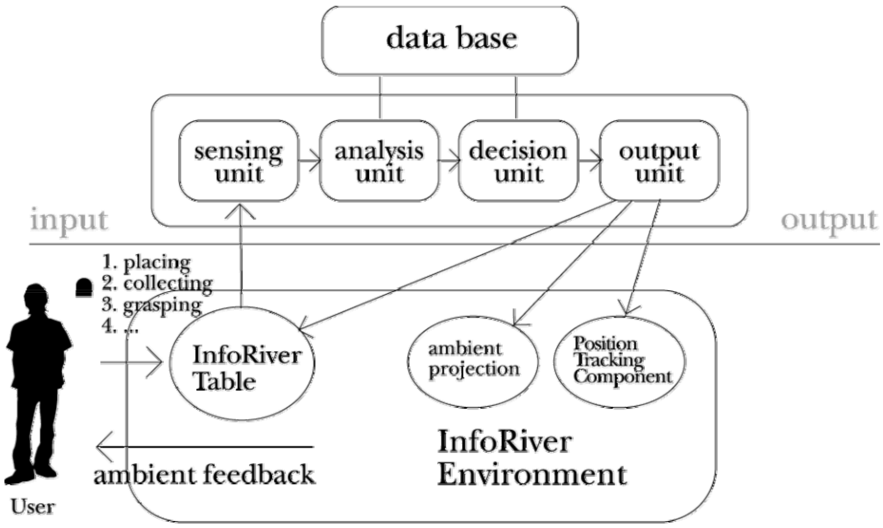


Fig 3-6: The system architecture of the InfoRiver.

The InfoCapsule is composed of an LED, a mercury switch and a mercury battery, a pressure switch and a RFID tag (Fig 3-7). With the proper mechanical design, the LED can be switched on/off with the embodied action when coupled with user behavior, and thus interaction states of the InfoCapsule could be identifiable to the system simply via the LED light tracking.

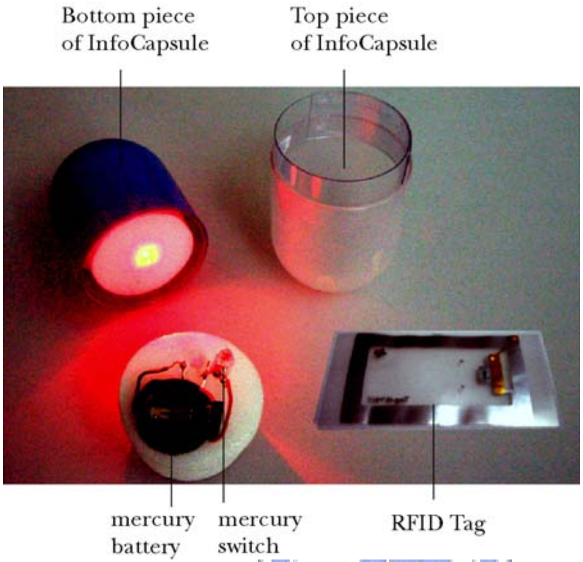


Fig 3-7: The composition of an InfoCapsule.

3.3.4 Findings

In the InfoRiver Table and InfoCapsule design experiment we have found that mediated objects could expand the user's interactive modalities by augmenting the object with different states and usages. By exploiting the unique form and interface, the mediated object could be more tailored to the user's style and can be provided with higher personalized support. Novel manipulative techniques which were not in the original usage of the mediated object make the user capable of doing things which were not intended to be accomplished with the same objects. With little training, such manipulative techniques could also be intuitive to users.

In the InfoRiver project, we used "river" and things relevant to river as metaphors, like the riverside, harbor, and so on. This suggests that a comprehensible mapping between a user action and the mediated object, as well as the things being triggered, is required. Also, The InfoCapsule represents not only a trigger object, but an interface to manipulate digital information over InfoRiver Table. This suggests that the object used to trigger the interaction could be directly used as the controller interface for the interaction.

3.4 WALLS FROM WORLD

3.4.1 Conception

This project is an examination of the idea of transforming everyday spatial elements into functional objects for both background awareness and foreground interaction. The concept of the Walls from World envisions the wall, instead of merely being a spatial enclosure, as an artifact for remote asynchronous communication. The idea comes from the conduction of the concrete wall, where sounds could be transferred from one side to the opposite side. Such a characteristic implies implicit and indirect communication, and sometimes people exploit such characteristics in everyday life such as eavesdropping on neighbors or conveying speech via concrete walls. We emphasize on such characteristic and see the wall as a communicative media for verbal exchanges. In this work, the wall is also seen as a container for storing messages and gossips. Any messages left on the wall could be transferred and received by other people on the other side approaches the wall at the time. Even when one does not appear to be at spot at the moment, he doesn't miss any gossips or messages from distant spaces "behind the wall".

3.4.2 Interaction Design

The Walls from World includes three contextual state designs coupled and evoked with different user behaviors (Fig 3-8). They are the *Ambient*, *Nofitication*, and *Intervention* states. We define the three interaction states of the wall as follows:

Ambient state: This is when the Wall contains no messages from the remote. At this state, the Wall remains calm.

Notification state: The system changes to the Notification state at the moment messages from the remote Wall are received. At this state, the Wall will change its projection (e.g. a projected flower blooming, or the movement of a painting) to unobtrusively notify the user (Fig 3-9).

Intervention state: The system changes to the Intervention state when the user approaches the wall. In this state the user could talk to the wall to record speech, or snuggle close with his ears to the wall to listen to messages left from remote space.

Fig 3-8: The Wall in Ambient state (left). The Wall in Notification state (middle). The Wall in Intervention state (right).

Table 3-3 shows an example of the three interaction states with their detailed trigger process. The Intervention state, which activates the speaking and recording mechanisms of the wall, automatically switches on when the user stands within 1 meter to the Wall (Fig 3-10). A user can speak while standing close to the Wall and the system will record and save what user says. To listen to speeches left from a remote Wall, a user can snuggle close with ears to the Wall. The sound of the speech will repeat until the user departs 1 meter away from the wall for more than 5 seconds.

Table 3-3: Interaction Techniques for Walls from World

Interaction State	Description of The State	Behavior	Results
Ambient	The Wall stays calm with ambient projection		
Notification	The ambient projection changes to notify the user	User aware of the changes and knows there are messages from a remote Wall	
Intervention		The user approaches the Wall to listen to the messages	The system recognizes which position the user stands on
Intervention		The user listens with ear close to the wall	The speaker plays messages
Intervention		The user speaks with face close to the Wall	The recorder starts to record the user's speech
Intervention		User departing the wall	Stops recording after 5 seconds silence, and the system changes back to Ambient state

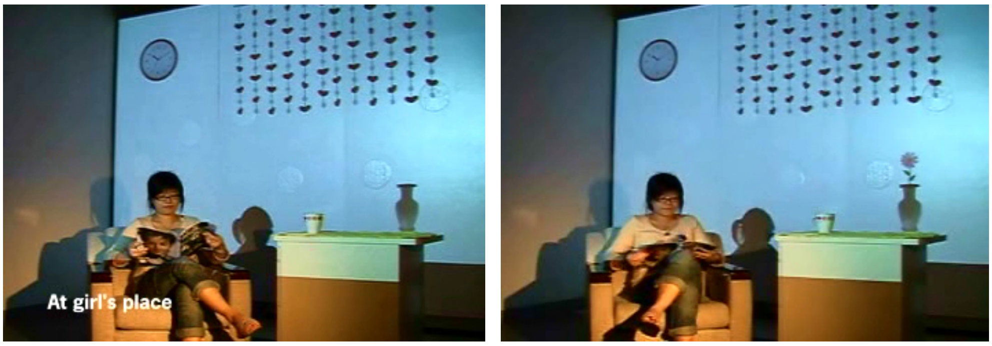


Fig 3-9: The Wall in Ambient state (left). The Wall in Notification state (right).

Fig 3-10: A user listening to messages (left) and speaking to the Wall to leave messages (right).

3.4.3 Implementation

The interactive wall artifact is realized by embedding an array of microphones and speakers into a wood-made wall coated with a layer of plastic material. A switch sensor array is also embedded on the floor beneath the wall to detect the user's presence when he is close to the wall. A chip called the IO9624 is used to transform switch sensor signals into digital form and is computed in a Visual Basic written program. The program then outputs the results to Director MX to perform the recording or playing of sound tasks depending on the interaction state, then sends the signals remotely through the Internet, and correspondently changes the ambient projection on the wall. After receiving the signal, the remote wall will switch to the correspondent state and perform the correspondent actions. The implementation framework is illustrated in Fig 3-11.

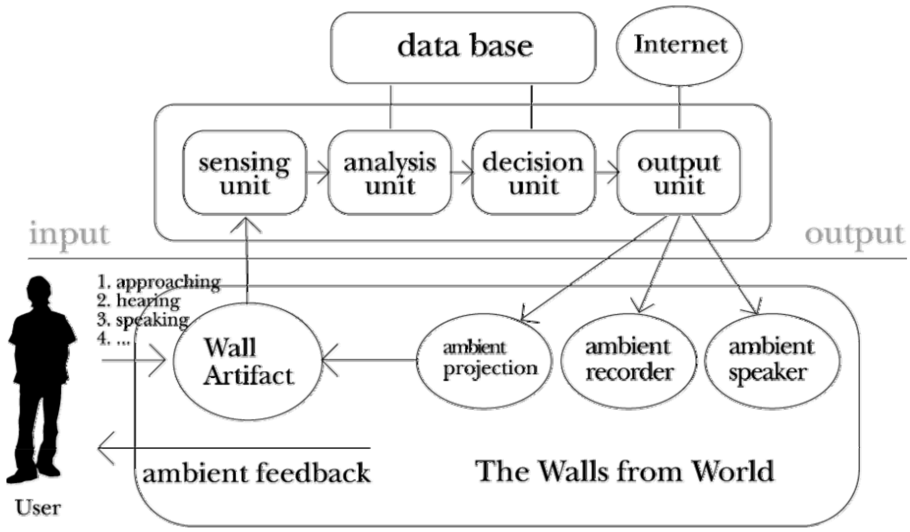


Fig 3-11: The implementation framework for Walls from World.

3.4.4 Findings

From the work, Walls from World, we have learned that with proper mapping, spatial elements can be immediately reconfigured into different states for both implicit and explicit interactions. By exploiting behaviors specifically made towards an artifact, it is possible to create new manipulative behavior and transform an artifact into a different functional object. Furthermore, by embodying natural continuous behaviors such as triggers to switch an object interaction state, the transition between different interaction states can be made to be more consistent and fluent.

3.5 FRAMEWORK DESIGN PRINCIPLES

From the above design experiments, it has been shown that each work has its similarity and uniqueness. It has also been shown that a building block of each work has a trigger mechanism to evoke environmental interactions, and whether these trigger methods and processes are found to be less distractive is the key to success. In order to extract and summarize key characteristics of a less distractive trigger as design principle, we tried to identify characteristics that we believe shape or partially contribute to such ‘less distractive’ features. These characteristics are summarized empirically for the designing of ambient reconfiguration trigger interfaces. The summarized design principles with relations to the role of input/feedback are shown as Table 3-4. And Table 3-5 shows each characteristic with its comparison with the three projects.

Table 3-4: Framework design principles

input/feedback	Characteristic	Description
input	Embodying Natural Behavior	The ambient interactivity trigger should make use of user's natural behavior in a given context. Such everyday behaviors or skills are easy to achieve, especially ones that can be achieved while the user's foreground is occupied.
input	Representative	The mediated object should be representative in evoking ambient interactivity. For example, a pen represents a sketch activity, and could be used as a trigger to evoke ambient support for sketch activity.
Input/feedback	Consistency	Following representative, the mediated object should be used or interacted directly after evoking ambient interactive for consistency.
input	Comprehensible in Mapping	The mapping between user action and the mediated object involved to evoke ambient interactivity should be comprehensible to the user.
input	Uniqueness	The user action to evoke ambient interactivity should be carefully selected for uniqueness. It should be specific and unambiguous, and will carry the same contextual or perceived meaning over time.
input	Single Light-weight Action	The ambient interactivity trigger should be light-weight and take no more than one step of the behavioral action of users.
feedback	Awareness Feedback	The system should provide consistent awareness feedback for users in order to let the user to be easily aware the status of the interaction, which should be incentive to foster further user interaction with system.
feedback	Immediacy and Fluidity	The ambient interactivity should be immediate but fluid. It is important to find a balance between the immediacy and fluidity for a consistent sense of interaction with system to occur.

Table 3-5: A Comparison of the three projects in terms of ambient characteristics

Characteristic	Ambient Window	InfoRiver Table	Walls from World
Embodying Natural Behavior	√	√	√
Representative		√	
Consistency		√	√
Comprehensible in Mapping		√	√
Uniqueness		√	√
Single Light-weight Action	√	√	√
Awareness Feedback	√	√	√
Immediacy and Fluidity	√	√	√

3.6 SUMMARY

In this chapter, we have explored and summarized trigger mechanisms which evoke environmental interaction in an ambient mediated environment. By investigating three design cases of an ambient environment (i.e. *Ambient Window*, *InfoRiver*

Table and InfoCapsule, and *Walls from World*), we were able to experiment on ambient technologies for a feasible trigger interface, and have glimpsed the outline of an interface framework, and have learned about the prototyping techniques as well. Lessons learned from the design cases in terms of characteristics of ATs, including *embodying natural behavior*, *representative*, *consistency*, *comprehensible in mapping*, *uniqueness*, *single action*, *awareness feedback*, and *immediacy and fluidity*, were identified as framework design principles.

Along with lessons learned from here and Chapter 2, in the next chapter we formulate an interface framework specific for evoking ambient reconfiguration in an ambient PDE.

4

AMBIENT TRIGGER

From the previous pilot design experiments, we have identified trigger mechanisms and their framework design principles for evoking ambient interaction in an ambient environment. Along with the combination of lessons learned and the analysis of PDE, in this chapter we formulate the interface framework called *Ambient Trigger* (AT). The concepts, analyses, framework descriptions, as well as components structures of ATs are elaborated.

4.1 CONCEPTION

The idea of ambient reconfiguration indicates the rearrangement of ambient support setting that results in the contextual switching of a design activity. In the ambient environment, elements involving design activity switching are: *human*, *ambient setting*, design *media*, and *operation*. In a personal design point of view, the human, other than the designer himself, and media that is not key to a design activity, can be seen as ambient elements to an individual designer. Therefore, the relationships were reframed simply into a designer with his personal ambient setting.

In combination with lessons learned from the pilot studies, we enforce the role of object to trigger the switching of ambient setting and propose an interface framework called Ambient Trigger.

Ambient Trigger (AT) is a framework for evoking ambient reconfiguration in an ambient mediated environment, and can be further divided into *AT Interface* and *AT System*. AT System is the computational mechanism for controlling and switching the status of ambient elements, and AT Interface is the user interface used to evoke environmental interaction. AT Interface could be further divided into *AT Object* and *AT Actions* (Fig 4-1).

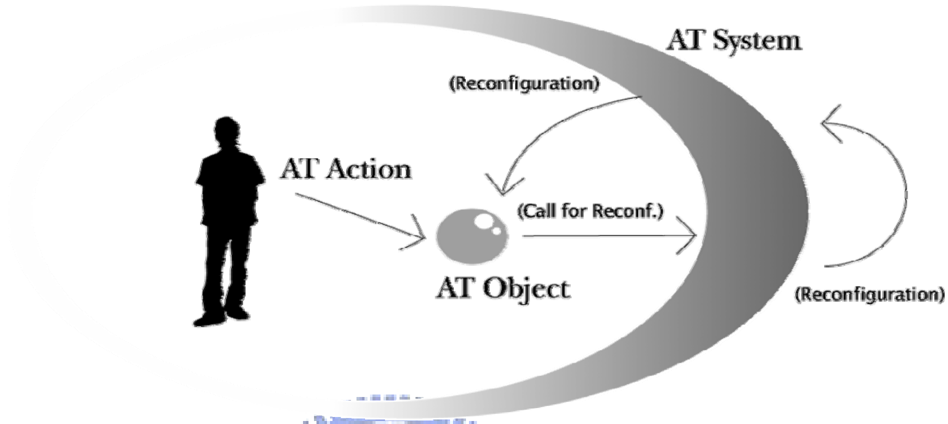


Fig 4-1: The conceptual diagram for the Ambient Trigger process.

The definitions for AT Object and AT Action are as follows:

AT Object is the mediated object coupled with embodied single action to achieve ambient reconfiguration in an ambient mediated environment. Mediated objects could be everyday objects or specially designed artifacts.

AT Action is everyday behavior or natural human skills coupled with an AT Object to evoke environmental interaction.

The ambient feedback and the triggering method reflect upon the ambient characteristics analyzed in the previous chapter.

4.2 INTERACTION SPACE TYPES

Aside from a conceptual definition of an Ambient Trigger, for incorporations within a PDE context to achieve our goal, we need to observe and analyze how designers conduct personal design activities in relation to their PDE. After observations in design schools and architecture agencies on how designers use their PDE to carry out design activities, we have found some common settings composed of crucial elements, settings such as a *designer*, *colleagues*, *peripheral resources*, *design media*, and *tasks*. For the interaction and interweaving of each of these elements, three fundamental types of interaction spaces were identified. They are *Task Space*, *Communication Space*, and *Awareness Space*.

4.2.1 Task Space

Design tasks are often carried out in a task space which might be shaped, and is based on a large desk or table surface. This is where designers commonly focus their attention on during a design process. The Task Space might contain some sub-task spaces within it, and might be arranged in a style for the designer to conveniently manage and switch among them. Designers deal with tasks in various ways depending on the content or goals of their tasks. Mostly they are mediated by some artifacts such as a pen and paper, model materials, or other design tools.

4.2.2 Communication Space

Communication Space is where the designer and his colleagues communicate, where social interaction or informal collaboration take place. The communication is multi-modal, which involves speech, facial expressions, or gestures, and sometimes involves design media with a shared task between communicators. The designer would dynamically borrow large surfaces or spaces for communication with shared tasks if there is not enough space available.

4.2.3 Awareness Space

Awareness Space is the designer’s background perceptive channel so he can be aware or so he can access peripheral resources. Peripheral resources range from dynamic fluid informative things such as passers-by and their talks, to static artifacts such as tools or books on the shelves. The designer interacts with Awareness Space mainly with their background awareness, and dynamically attends to or accesses them when needed.

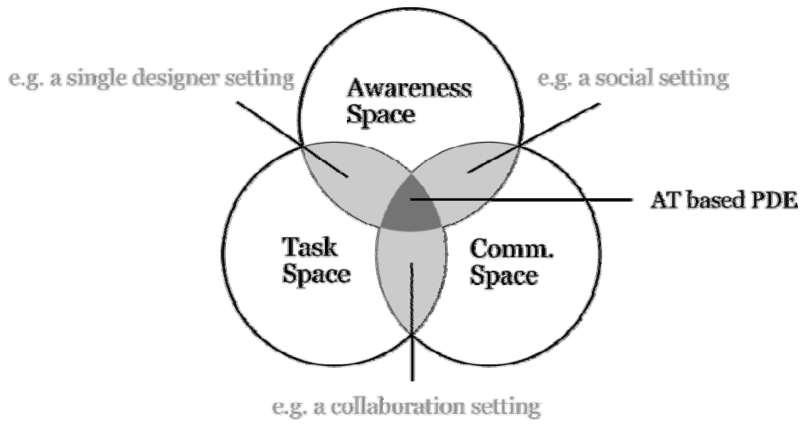


Fig 4-2: Intersection of the three interaction space types

The intersections and blends of these interaction spaces form different design activities (Fig 4-2). For example, an overlap between Awareness Space and Task Space forms an essential single-user design environment, an overlap between Awareness Space and Communication Space forms a social environment, and an overlap between Task Space and Communication Space forms a collaborative design environment.

4.3 AMBIENT TRIGGER FRAMEWORK

A trigger could be seen to be composed of three parts: input, process, and output. As a premise to achieve our research goal, the output part should be made up of interactive ambient elements which form an ambient mediated environment which interacts with its users. The process part includes four main units: *sensing*, *analyzing*, *decision-making*, and *output*. It should be incorporated with a set of rules or knowledge that can help decide the appropriate output strategy. And for the input part, a less distractive trigger interface (i.e. AT Object) for users should be embodied for evoking ambient reconfiguration. The overall structure of the AT framework is illustrated in Figure 4-3.

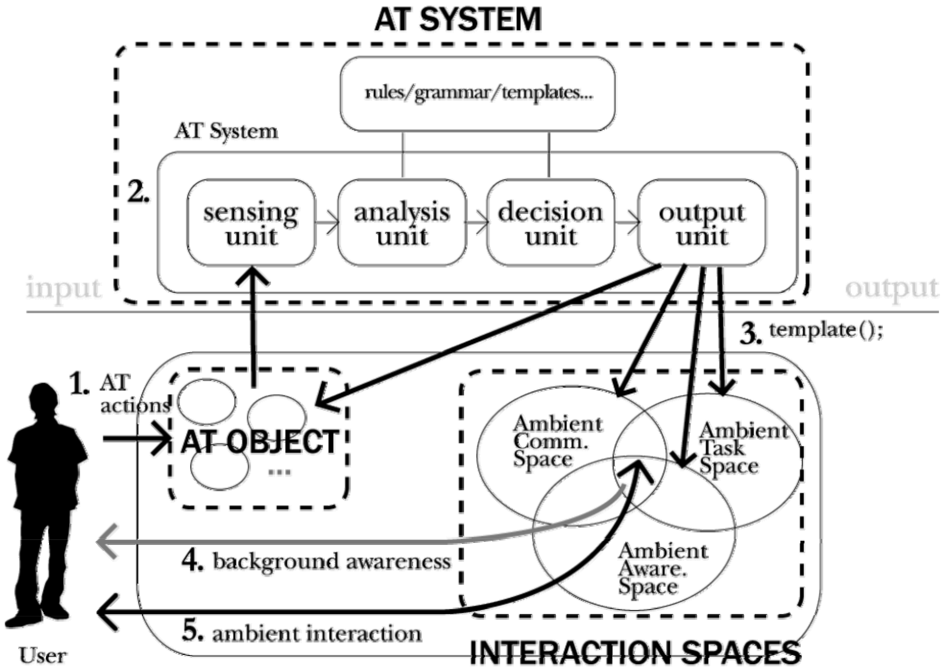


Fig 4-3: Framework for Ambient Trigger in a PDE

The framework is composed of different entities interacting with each other. The components, as well as the system workflow of Ambient Triggers, are elaborated in 4.4 and 4.5.

4.4 COMPONENTS

The AT Framework is comprised of the following key components: *Interaction Spaces*, *AT Object*, and the *AT System*.

4.4.1 Interaction Spaces

Interaction Spaces (i.e. Ambient Communication Space, Ambient Task Space, and Ambient Awareness Space) are interactive input/output channels that augment spatial elements with spatial interface technologies such as Tangible Interfaces (Ishii and Ullmer, 1997; Ullmer and Ishii, 2001), Attentive Interfaces (Maglio et al., 2000; Vertegaal, 2003), Multimodal Interfaces (Oviatt, 2002), or the combination of each. They provide methods for user communication or interaction with the space in a more natural way, acquiring environmental or contextual conditions and forming different design activity supports as well as user-preferred ambiance.

4.4.2 AT Object

AT Object is an everyday mediated object or specially designed artifact coupled with everyday behavior or natural human skills to evoke environmental interaction. The principle of AT Object is to use the user's behavior as implicit input to the system, while making the user focus on his foreground tasks. Mediated objects could be made into design media to directly interact with the ambient mediated design environment after reconfiguring environment interaction.

4.4.3 AT System

AT System is the core processing unit comprises of Sensing Unit, Analysis Unit, Decision Unit, and an Output Unit. How the user interacts or manipulates AT Object will be detected and perceived by the system, and analyzed with a preset knowledge or a set of rules. After the analysis, the AT system will then decide on an actuation strategy that best interprets the current context and can then activate correspondent spatial I/O elements to form ambient support to its users. The resulting environment will be an ambient environment that specifically supports a design activity and interacts with the user spatially. The Ambient Trigger System could be connected to a set of rules, rule-base, or distributed knowledge so as to inference the actuation strategy.

4.5 WORKFLOW

The framework is initiated with the user carrying out AT actions as a means to request ambient reconfiguration. The way for an AT system to achieve ambient reconfiguration is to activate correspondent interaction spaces. These spaces cooperatively act as a whole to form the ambient environment, and to interact with the users via foreground and background interaction. Assigning different purposeful spatially integrated I/O interfaces with associated activities supports each specific design task in these interaction spaces. In sum, the workflow of an ambient reconfiguration with an Ambient Trigger is within 5 steps (Fig 4-3):

1) Detecting AT Actions.
2) AT Actions are being processed with AT System.
3) The appropriate output strategy is selected, and the correspondent templates to

interaction spaces as well as the AT object is then applied.

4) The evoked ambient setting frames the background awareness to the designer.

5) The ambient trigger process ends. The user interacts with the evoked ambient elements.

4.6 SUMMARY

In this chapter, we have presented the AT, a framework for evoking ambient reconfiguration in an ambient environment. Three interaction space types in terms of designers interacting with their PDEs were identified and integrated into the AT framework. The framework is composed of three key components: AT Object, AT System, and Interaction Spaces, and is initiated with AT Actions, which the user acts towards, manipulates, and interacts with the AT Object. To verify the AT Framework, the design and implementation of a physical test-bed environment is presented in the next chapter.

5

DESIGN & IMPLEMENTATION

To verify the applicability and feasibility of the framework, we designed and implemented a reconfigurable ambient PDE with the AT framework. We physically constructed a test-bed environment and designed a few AT objects as well as ambient applications in the test-bed as a way to verify the AT framework. In this chapter, we present physical design, interaction design, and application design for the test-bed environment, as well as the implementation of its system architecture and components.

5.1 DESIGN MANIFESTO

To verify the framework, assumptions were made in order to develop the design manifesto for implementation and verification. It is envisioned that, first, the future of the everyday environment is embedded with unobtrusive computing devices that can help human activity with foreground and background interaction. Second, the future of the PDE is modularly designed for Ambient Triggers, suitable for anyone, and ubiquitously accessible. Third, the future of the designer is that he will have to carry a portable device that contains his personal information as well as design media to evoke the personalization of the modular PDE.

Based on the above assumptions, the design of the test-bed is targeted to design a modular PDE with enough physical settings and a suitcase containing AT Objects and personal information as an everyday portable artifact for future designers.

5.2 OVERVIEW OF THE TEST-BED ENVIRONMENT

To verify the framework as well as framework design principles of AT, we designed and implemented a test-bed environment prototype, which is multifunctional and can be evoked for different interaction states with AT Objects (Fig 5-1). The test-bed environment also contains applications with the cooperative and networked services offered by intersecting three interaction spaces. Applications were delivered to user via the mixed environmental elements, including a table surface, a partition, and other peripheries.

Fig 5-1: An overview of the test-bed environment prototype.

Three kinds of AT Objects for evoking different interaction states of the environment were implemented: *Designer's Suitcase*, *Ambient Pen* and *Colleague Surrogate*. We discuss them in 5.2. Aside from this, to focus on the AT framework test on ambient reconfiguration, we used a quick AR approach (Podlaseck et al.,

2003) by illuminating projections onto the existing PDE physical settings. The test applications as different states of the environment we have that were implemented include: *Personal Design Ambience*, *Ambient Sketch Space*, *Distantly Bonded Spaces*, and *Pen-based Media Space Environment*. Each supports targeted design activities as well as different mediated object embodiments (Fig 5-2). We discuss them in 5.4.

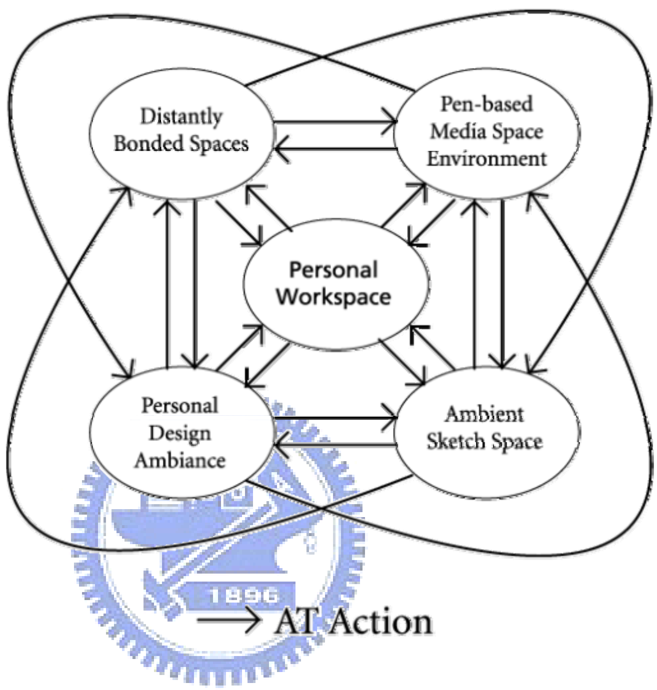


Fig 5-2: Triggering a non-interactive personal workspace into different preset interactive states.

5.3 AMBIENT TRIGGER INTERFACE DESIGN

The physical interface design of Ambient Triggers for evoking ambient reconfiguration involves the design of AT Object and AT Action.

5.3.1 Ambient Trigger Objects Design

It has been shown that design media or mediated objects were used not only for mediating design activity, but also for defining and triggering the design activity (Gay and Hembrooke, 2004). As a result, we designed three kinds of AT objects for evoking different states in the physical test-bed environment: *Designer's Suitcase*, *Ambient Pen*, and *Colleague Surrogates*. They were used to mediate and interact with different test applications. We intentionally exploited the physical constraints by putting Ambient Pen, Colleague Surrogates and other AT objects into Designer's Suitcase (Fig 5-3). This way, all the mediated objects required to interact with the environment could be collected and managed easily as a whole, as depicted in Figure 5-2. Moreover, we designed a docking platform on the table surface for the Designer's Suitcase, as an initial trigger point to evoke a PDE ambient interaction.

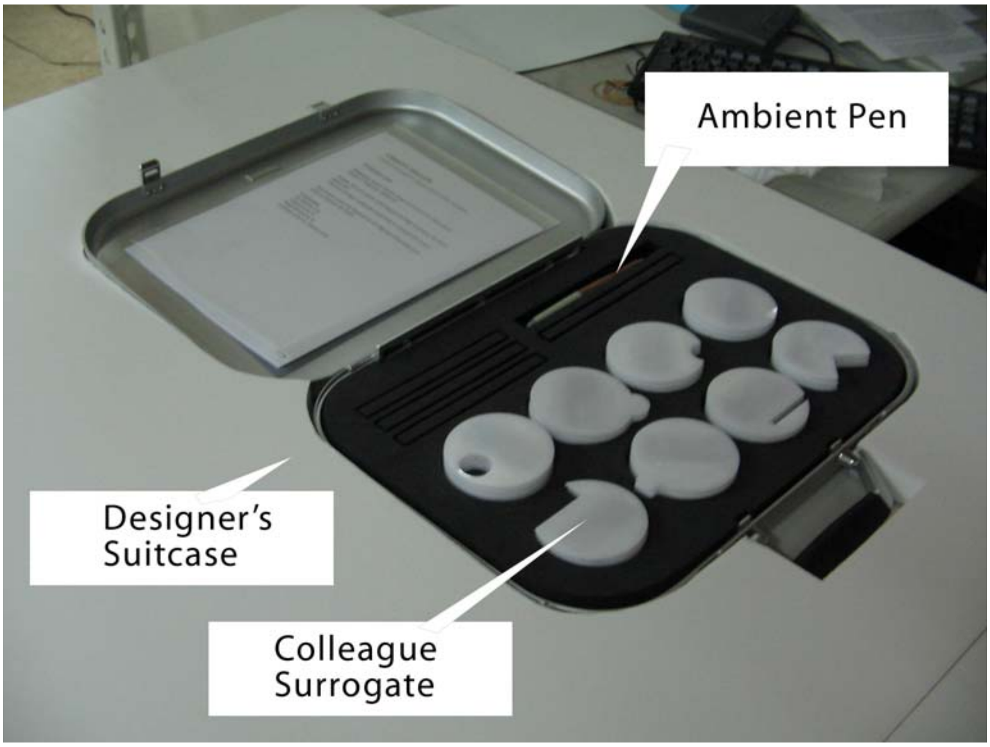


Fig 5-3: The design of Designer's Suitcase constraining AT Objects.

The conceptual design for each AT object was illustrated as follows:

Designer's Suitcase

Suitcases are often used by businessman carrying important documents and perhaps some frequently used goods. A suitcase is not only a container for managing important personal materials; it could also be seen as an identity for that person. We envisioned the Designer's Suitcase a personal suitcase containing mediated objects needed for interacting with an Ambient Mediated PDE, as well as an embodied interface that can be used to ambient trigger environmental personalization. The form of the Designer's Suitcase is shown in Figure 5-4.

Fig 5-4: The appearance of Designer's Suitcase.

Colleague Surrogates

A surrogate is something representing someone when he is absent. Colleague Surrogates are physical artifacts envisioned as substitution for remote colleagues who cannot be present and cannot be interacted with at the same place. Each Colleague Surrogate represents different remote colleagues, and each are used to trigger a remote collaboration environment with the specified colleague. An example prototype of Colleague Surrogate is shown in Figure 5-5.

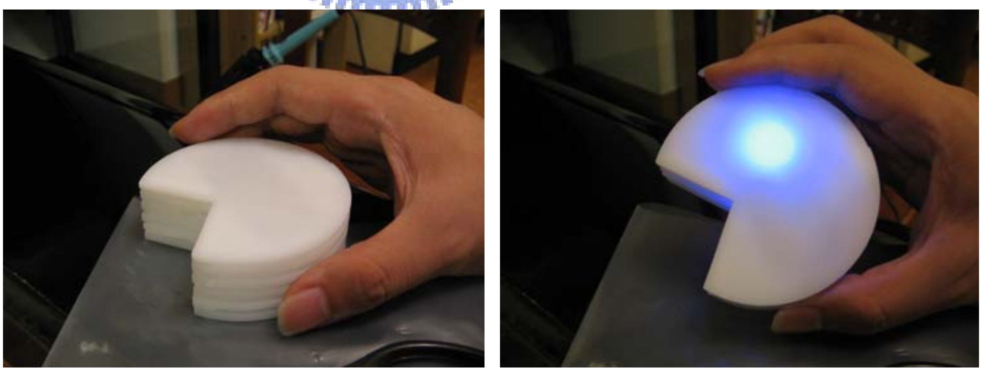


Fig 5-5: The appearance of Colleague Surrogate.

Ambient Pen

A pen is a fundamental design media, as using a pen to sketch, draw, and write is an essential skill for most of designers. The Ambient Pen is a pen that could ambiently trigger some pen-based design activities, and can evoke ambient responsive visualizations (Fig 5-6). We were not trying to change or envision the pen as something unique, but to augment it with a digitally enhanced service.

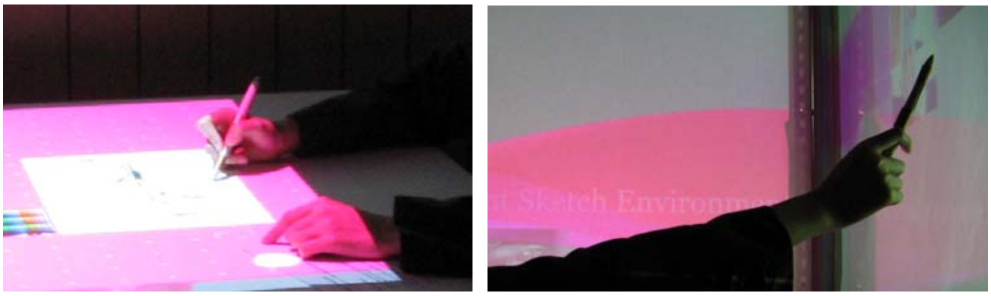


Fig 5-6: The appearance of Ambient Pen.

5.3.2 Ambient Trigger Embodiments

Table 5-1: Elaboration of Fundamental AT interaction

AT Interaction in Non-interactive State	Evoked States
Put the *Designer's Suitcase* onto the modular docking platform with it open	Personal Design Ambience
Take out only the *Colleague Surrogate* from the Designer's Suitcase in the modular docking platform, and place it on the Task Space.	Distantly Bonded Spaces
Take out only the *Ambient Pen* from the Designer's Suitcase in the modular docking platform	Ambient Sketch Space
Take out both *Ambient Pen* and *Colleague Surrogate* from the Designer's Suitcase in the modular docking platform	Pen-based Media Space Environment

Concerned with how mediated objects can be embodied, we followed framework design principles and chose behaviors of *placing on* and *taking off* AT objects as concrete cues for ambient triggering. The reason for us to choose these behaviors is that we see that the placement of the object is sometimes the initial point to carry out an activity, and the taking away the object sometimes means the termination of an activity. We specify the system to evoke different interaction states by the user *placing them on* or *taking them off* different AT objects. The fundamental Ambient Trigger embodiment design is summarized in Table 5-1, and the overall AT embodiment design is elaborated in Figure 5-7 and Table 5-2.

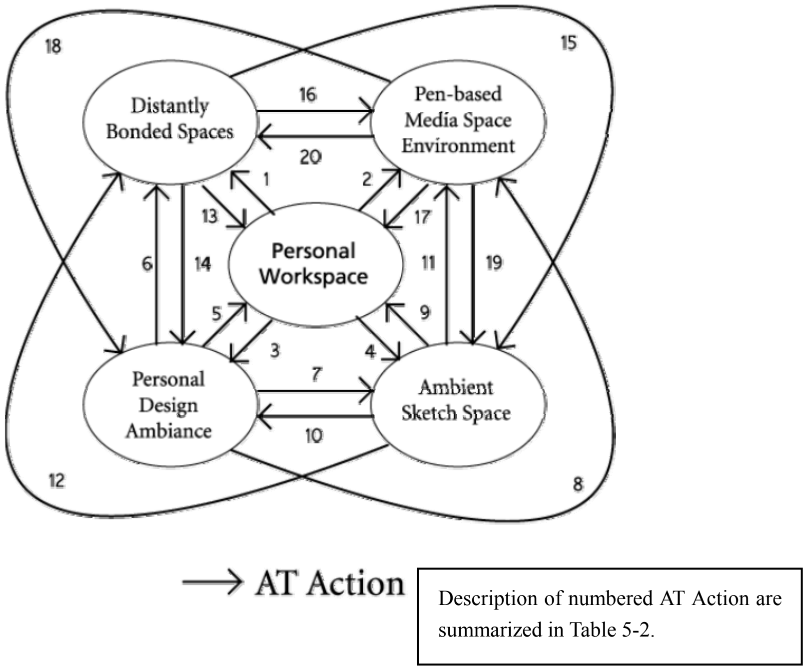


Fig 5-7: Triggering environment with different AT Action.

Table 5-2: List of AT Actions in our implemented framework

No.	Original State	AT Action towards AT Object	Evoked States
1	Non-interactive Personal Workspace	Placing on Designer's Suitcase + Taking out Colleague Surrogate	Distantly Bonded Space
2	Non-interactive Personal Workspace	Placing on Designer's Suitcase + Taking out Ambient Pen + Taking out Colleague Surrogate	Pen-based Media Space Environment
3	Non-interactive Personal Workspace	Placing on Designer's Suitcase	Personal Design Ambience
4	Non-interactive Personal Workspace	Placing on Designer's Suitcase + Taking out Ambient Pen	Ambient Sketch Space
5	Personal Design Ambience	Taking out Designer's Suitcase	Non-interactive
6	Personal Design Ambience	Taking out Colleague Surrogate	Distantly Bonded Space
7	Personal Design Ambience	Taking out Ambient Pen	Ambient Sketch Space
8	Personal Design Ambience	Taking out Ambient Pen + Taking out Colleague Surrogate	Pen-based Media Space Environment
9	Ambient Sketch Space	Taking out Designer's Suitcase	Non-interactive
10	Ambient Sketch Space	Putting back Ambient Pen	Personal Design Ambience
11	Ambient Sketch Space	Taking out Colleague Surrogate	Pen-based Media Space Environment
12	Ambient Sketch Space	Putting back Ambient Pen + Taking out Colleague Surrogate	Distantly Bonded Space
13	Distantly Bonded Space	Taking out Designer's Suitcase	Non-interactive
14	Distantly Bonded Space	Putting back Colleague Surrogate	Personal Design Ambience
15	Distantly Bonded Space	Putting back Colleague Surrogate + Taking out Ambient Pen	Ambient Sketch Space

16	Distantly Bonded Space	Taking out Ambient Pen	Pen-based Media Space Environment
17	Pen-based Media Space Environment	Taking out Designer's Suitcase	Non-interactive
18	Pen-based Media Space Environment	Putting back Ambient Pen + Putting back Colleague Surrogate	Personal Design Ambience
19	Pen-based Media Space Environment	Putting back Colleague Surrogate	Ambient Sketch Space
20	Pen-based Media Space Environment	Putting back Ambient Pen	Distantly Bonded Space

5.4 AMBIENT SETTING DESIGN FOR APPLICATIONS

The goal of designing applications within our framework is to validate the reconfigurability of different interaction states and the practicability of the framework. However, application development appears to be another huge research topic and is out of our research scope. In this paper we designed immediate applications without formal usability evaluations. The test applications we preset include *Personal Design Ambience*, *Distantly Bonded Space*, *Ambient Sketch Space*, and *Pen-based Media Space Environment*. The ambient elements supporting a particular design context were arranged in positions that are in accordance with their importance. The major interactive interface was positioned on the table surface, other useful or relevant elements were positioned in front of the table, and the elements with minor importance were placed on the partition wall beside the user. The ambient setting design for each application is depicted as follows.

5.4.1 Non-interactive

The test-bed environment is non-interactive while there is no AT interaction detected (Figure 5-8). When the user docks the Designer's Suitcase on the docking platform on the table surface and then opens it, the environment switches to the Personal Design Ambience state. By taking out different AT Objects (i.e. Ambient Pen, Colleague Surrogate, and so on), the environment could then be switched to different interaction states.

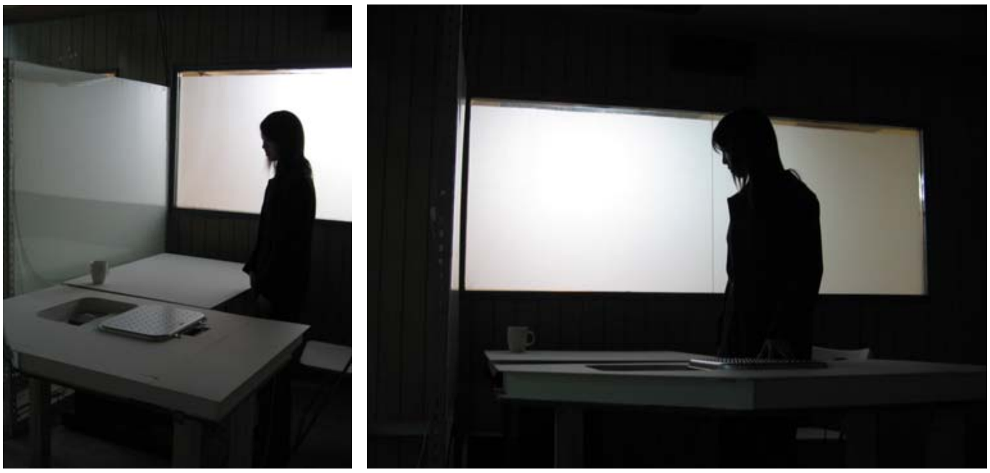


Fig 5-8: The test-bed environment in non-interactive state.

5.4.2 Personal Design Ambience

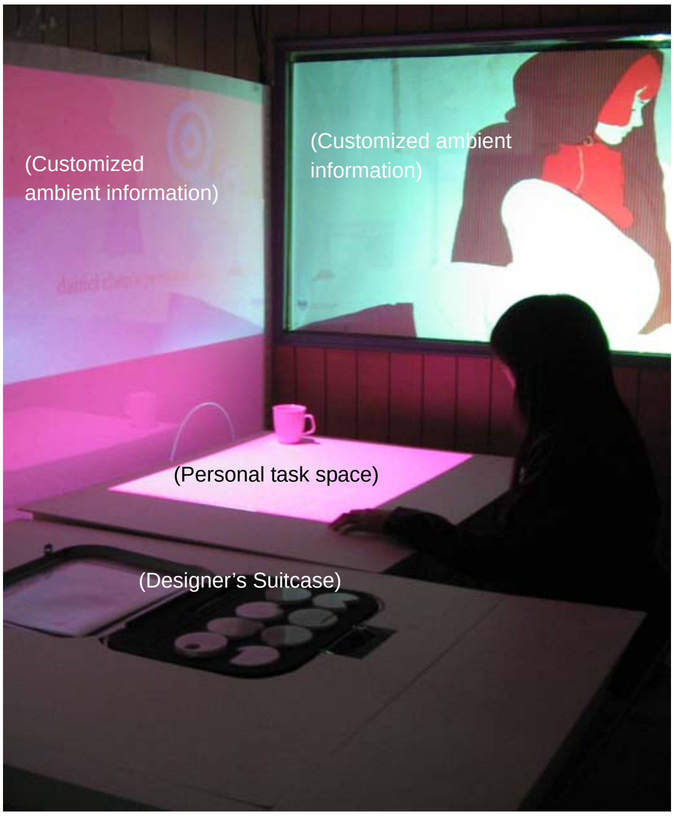


Fig 5-9: An overview of Personal Design Ambience Setting.

The Personal Design Ambience state is ambient-triggered by user placing Designer’s Suitcase (with it open) onto the modular docking platform on the table surface we intentionally designed to fit the form of the Suitcase. In this Personal Design Ambience interaction state, the environmentally-surrounded spatial elements can be projected customized information or preferred ambience, as an Awareness Space provides personalized awareness to the designer. An overview of Personal Design Ambience is shown in Figure 5-9.

5.4.3 Ambient Sketch Space

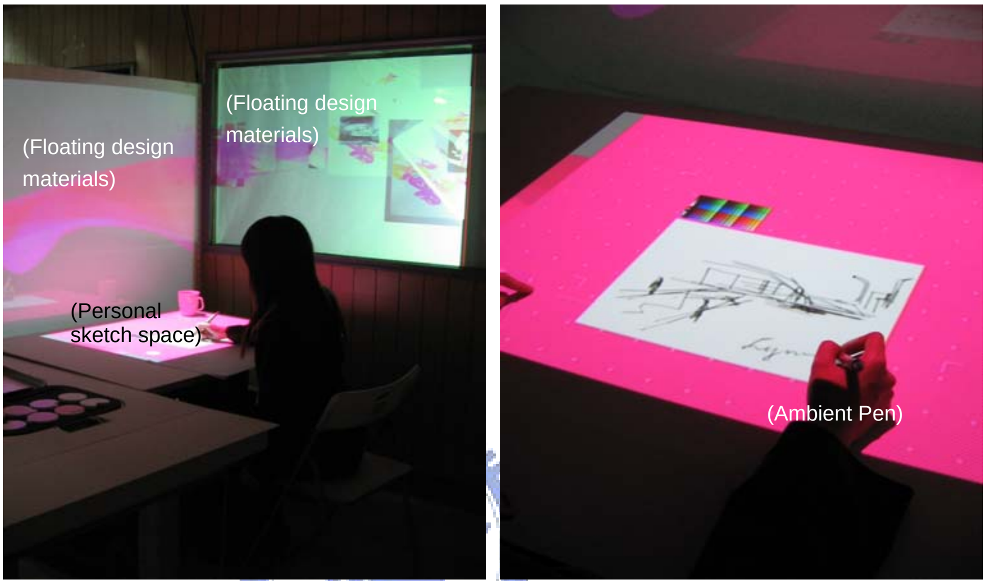


Fig 5-10: An overview of Ambient Sketch Space Setting

The *Ambient Sketch Space* is ambient triggered by taking out the *Ambient Pen* directly from the Designer's Suitcase. The *Ambient Sketch Space* interaction space contains foreground pen-based interactions within a personal task space, and the background interaction happens with a peripheral space floating the design materials. The purpose for floating the design materials is to aid the designer in doing design with inspiring visual works and ideas in an unobtrusive way. They are documents, drawings, pictures, and photos that can be retrieved from a database. An overview of the Ambient Sketch Space is shown in Figure 5-10.

5.4.4 Distantly Bonded Spaces

The urge for *Distantly Bonded Spaces* state is based on the previous two application scenarios. Designer could choose who to bond with by placing different *Colleague Surrogates*, which represent some specific remote colleague, onto the table surface. Once it has been placed, the remote colleague's real-time image will be projected onto the front partition for Media Space (Bly et al., 1993) communication. The peripheral spatial elements will show the social awareness information of the other unbonded colleagues as an indication and catalyst to foster group collaboration. Primarily, the *Distantly Bonded Spaces* is used for Media Space communication, but with different design media involved, the communication could be reformed or augmented with various channels and modalities. For example, the designer could take out Ambient Pen for pen-based media space collaboration. Therefore, we also developed an example of this as shown in the next section. An overview of a Distantly Bonded Space is shown in Figure 5-11.

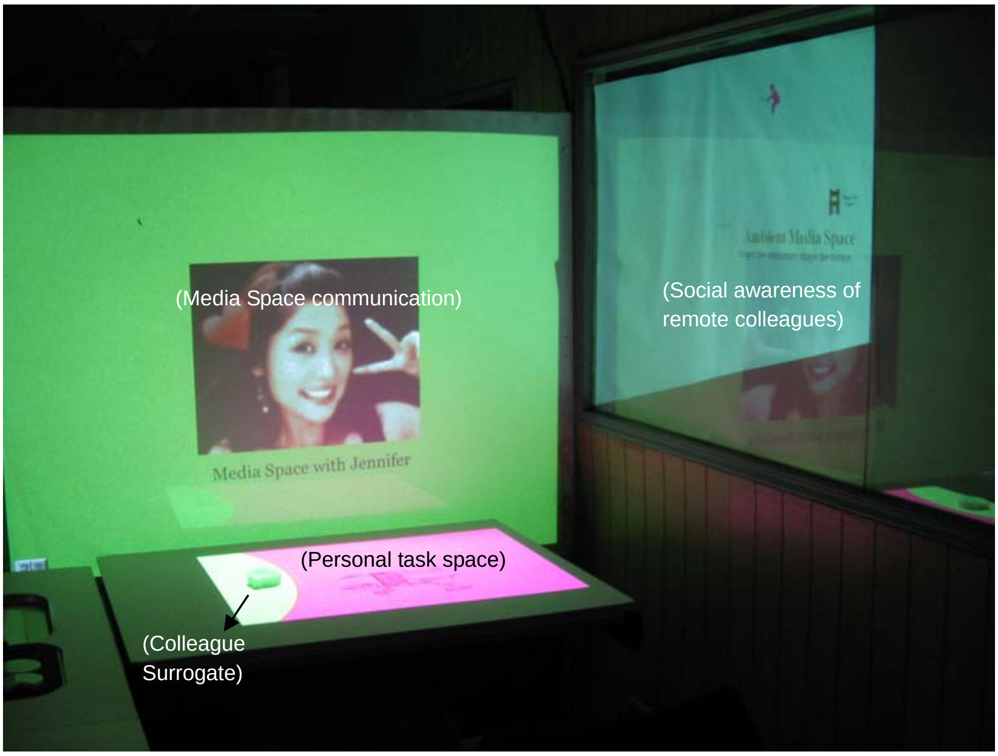


Fig 5-11: An overview of Distantly Bonded Space Setting

5.4.5 Pen-based Media Space Environment

Different combinations of spatial objects may sometimes refer to different interactive context as to create new spatial settings. For example, a colleague involved in a personal design context may transform that personal design context into a collaborative design context. In our application, we also want to validate such feature. Therefore, we have exploited the combinational use of *Ambient Pen* and *Colleague Surrogate* to evoke a *Pen-based Media Space Environment* as an example. The Pen-based Media Space Environment is composed of a shared sketch space for a remote collaborative sketch in real time, while a Media Space is for video-conference style communication, and social awareness information is for displaying the periphery status of remote colleagues. An overview of a Pen-based Media Space Environment is shown in Figure 5-12.

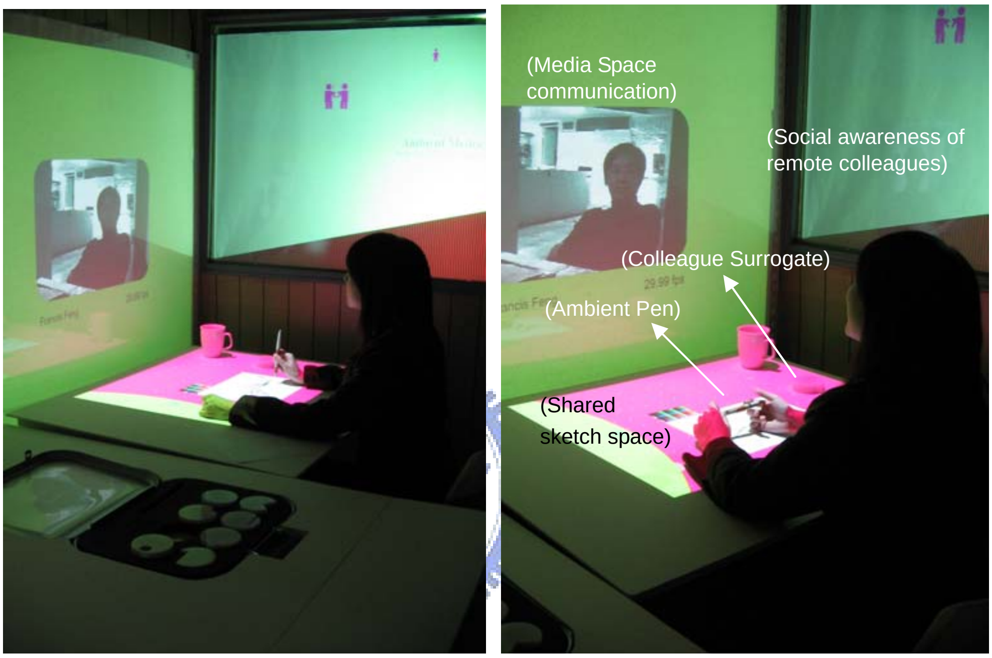


Fig 5-12: An overview of Pen-based Media Space Environment.

5.5 SYSTEM ARCHITECTURE

To realize the above ambient settings as well as interaction modalities, we have implemented our system in an AT framework. The architecture of the system we have implemented is shown as Fig 5-13. The system components and workflow are detailed in 5.4.1 and 5.4.2.

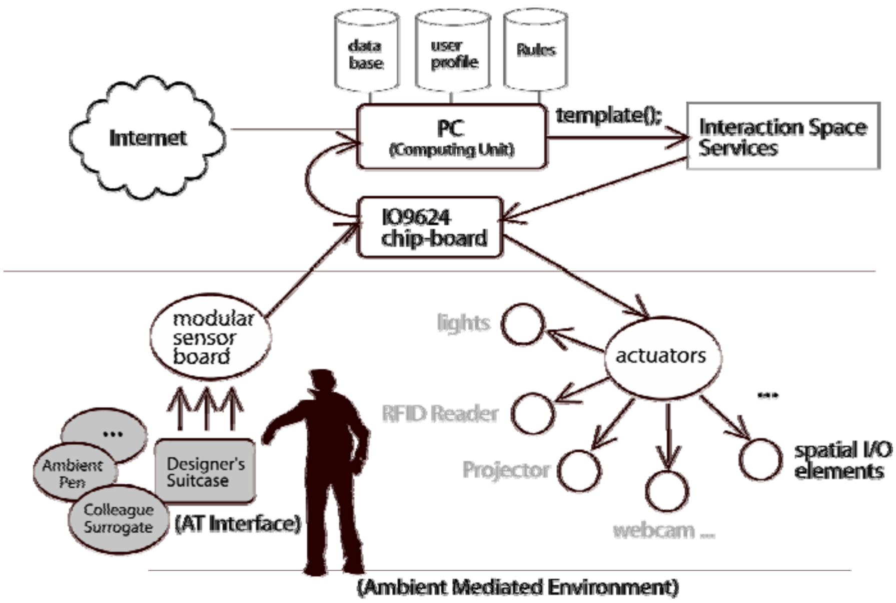


Fig 5-13: The implemented architecture of the test-bed environment.

5.5.1 System Components

Our implemented test-bed environment is comprised of key components as follows:

a) ***AT Interface:*** AT Interfaces are mediated objects (i.e. Designer's Suitcase, Ambient Pen, and Colleague Surrogate) used by the user to initiate an Ambient Trigger process. The interaction states between user and the mediated objects are sensed by Modular Sensor Board connected to the Computing Unit (i.e. PC). **b)** ***IO9624 Chip-Board:*** IO9624 Chip-Board is a processing board specific for AD/DA conversion. It connects to the Modular Sensor Board to sense real-world signals and connects to a set of actuators to control the switch for ambient elements. **c)** ***Modular Sensor Board:*** Sensors are for capturing, collecting, and measuring spatial conditions in terms of user intent, overall interaction status, or environmental changes. In our case we focus on capturing the user's behavior in terms of the AT interface. **d)** ***Actuators:*** Actuators are used to control the switch or adjustments of embedded artifacts or appliances used to form spatial I/O settings (i.e. interactive ambient elements) such as lights, air conditioners, projectors, RFID reader, or motors. **e)** ***Computing Unit:*** Computers are used to process sensor data and are used to control the activation and deactivation of interactive ambient elements. Computers are connected to a set of bases to record interaction context, rules for system decision on output strategy, and user profiles to be retrieved to personalize the environment. **f)** ***Interaction Space Services:*** Interaction Space

Services, including *Communication Space Service*, *Awareness Space Service*, and *Task Space Service* are analyzed interactional spaces providing partial ambient interaction support. Each of them listens to the Computing Unit in terms of how to act cooperatively to form an environmental support as a whole.

5.5.2 System Workflow

The system is initiated by the user's embodied interaction with an AT interface (i.e. *Designer's Suitcase*). When the modular sensor board detects the interaction, it sends the sensor data to the PC for further analysis. For example, the modular sensor board signals the PC when it detects that the Ambient Pen is picked out of the Suitcase. We connect the IO9624[12] chip-board with a modular sensor board as middleware to collect the sensor data. The chip-board is also connected to actuators to control the switch of interactive ambient elements.

The program controlling IO9624 chip-board is written in Visual Basic, and communicates with other application programs via OCX, such as flash.ocx for communicating with Shockwave Flash. The Modular Sensor Board, an array of pins embedded on a docking platform on table, which connects to the Designer's Suitcase when put on, detects whether objects inside the Suitcase have been taken out or put back, and then signals the changes to the PC.

After receiving the data, the PC will determine the correspondent output strategy according to a set of predefined rules, algorithms, and the user profile. At the same time, the PC is connected to the Internet to retrieve more data or to make a remote connection. The determined strategy will then be sent Interaction Space Service (i.e. Communication Space Service, Awareness Space Service, and Task Space Service) for correspondent functions, and each Interaction Space Service will further actuate the correspondent spatial outputs (i.e. projections, lights, speakers, and/or interactive appliances). By doing so, an ambient mediated environment for the specific design support can be formed. The detailed function description for each component is depicted in the next section.

[12] IO9624 is a chip-board developed by Allpeople Automation Inc. in Taiwan.

5.6 PHYSICAL CONSTRUCTION

The test-bed environment is physically constructed in a 4 × 5 × 2.6 (h) cubic meter area proximate to a wall in the author's home basement. The overall spatial configuration is illustrated in Fig 5-14. We hand-made an ordinary working table and placed a partition in front of it to enclose the test-bed environment. The equipments and devices components, such as RFID Reader, camera sensors, and modular sensor board, used in each test interaction state were embedded into the environment in advance (Fig 5-15). Multiple projectors are used to illuminate ambient imagery over the spatial envelop to provide spatial visual interface and awareness feedback with users.

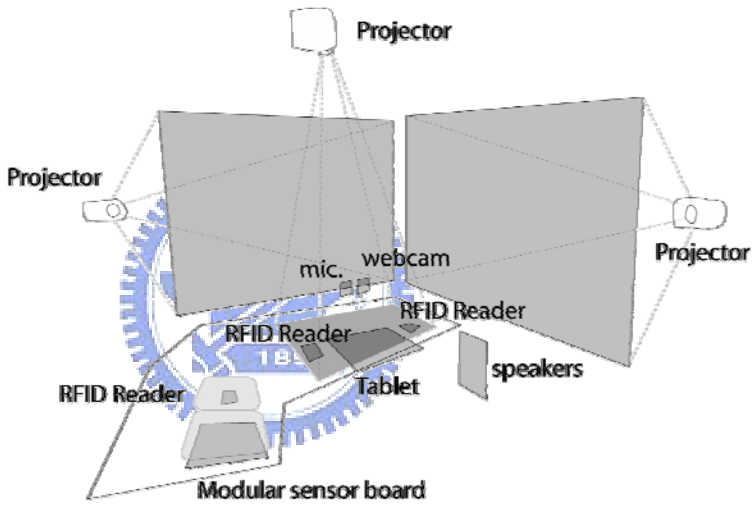


Fig 5-14: The overall view of spatial arrangement of pre-embedded components.

Fig 5-15: Components embedded beneath the table surface (left: a tablet, and right: a RFID reader).

A key component to sense Ambient Trigger interaction is the Modular Sensor Board. The Modular Sensor Board is an array of pins, which can be connected rightly to fit into the Designer's Suitcase through arrays of holes on the back surface and touch the AT Objects inside of the Suitcase (Fig 5-16). By systematically detecting the status of each pin, it could infer which AT Objects inside the Suitcase is being picked. The Modular Sensor Board is embedded beneath a docking platform on the side of the table surface. The docking platform is designed to fit the form and size of the Designer's Suitcase. By doing this, the user can place the Designer's Suitcase onto the docking platform, accurately position-fitting the pins to the holes on the Suitcase surface.

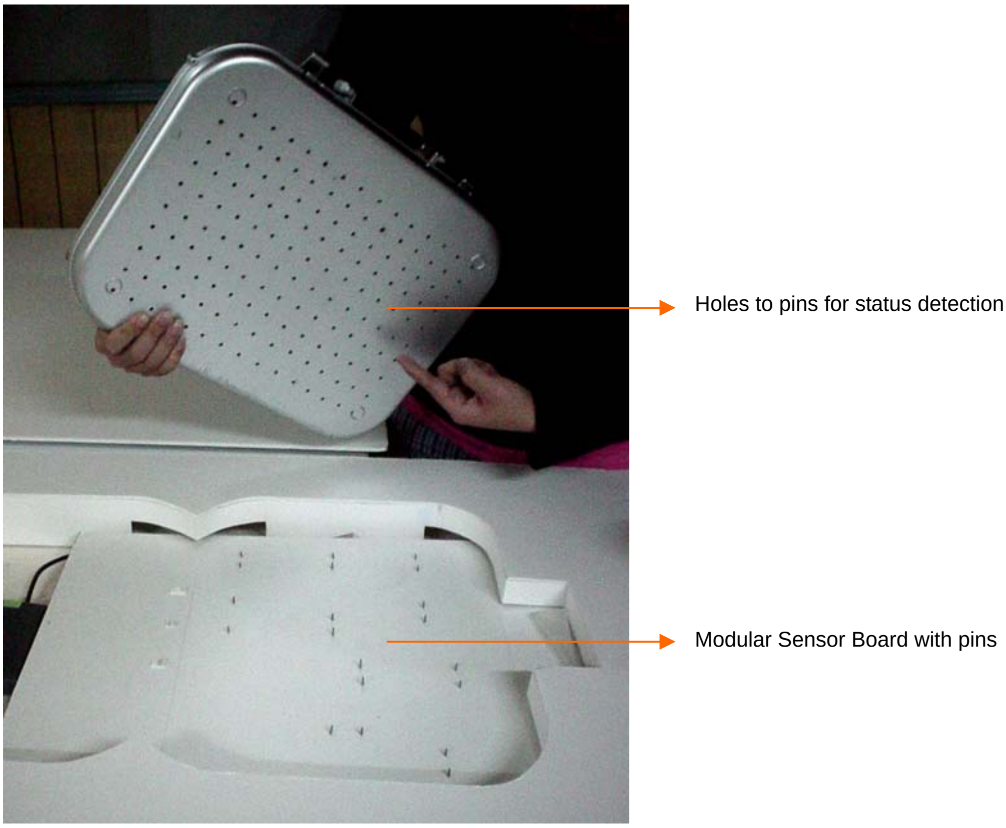


Fig 5-16: Pins to the holes on the Suitcase envelop.

In order to detect whether the Designer's Suitcase has been opened after putting it onto the docking platform, an RFID Reader is embedded beneath to detect whether the front case, which embedded with an RFID Tag, is approaching. The Reader is able to detect the Tag within less than a 3 cm distance. As a result, it can detect when the front case is being opened to extend (i.e. with Tag close to within 3 cm of the Reader) (Fig 5-17).

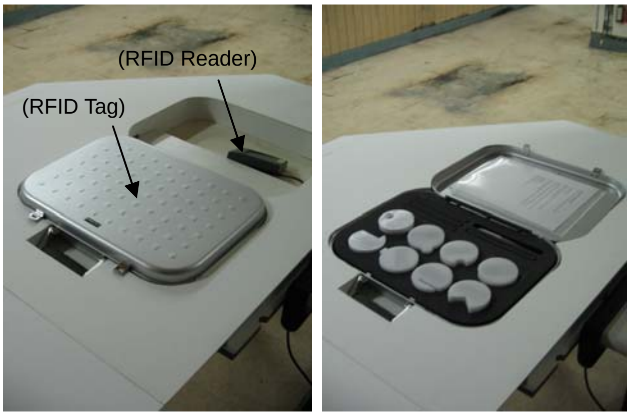
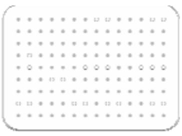
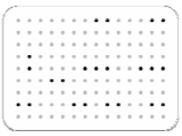
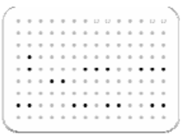
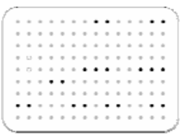
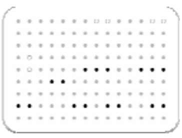


Fig 5-17: The RFID Tag embedded in the front case surface, and the RFID Reader under the concave (left). The Tag can be detected by the Reader when the Suitcase is opened to extend (right).

The Modular Sensor Board with pins for connecting to the Designer's Suitcase detects the status changes of each pin to infer the AT Actions in real time. The different pin-status diagram with descriptions in terms of the ambient triggered environment state is illustrated in Table 5-3.

Table 5-3: Examples of different pin status

Pin status diagram	Description	Ambient Triggered Environment
	*Designer's Suitcase* is not on the docking platform (i.e. disconnected to the pins on the Modular Sensor Board)	None
	*Designer's Suitcase* is put onto the docking platform (i.e. connected to the pins on Modular Sensor Board)	Personal Design Ambience
	Ambient Pen is taken out of the Designer's Suitcase	Ambient Sketch Space
	Colleague Surrogate is taken out of the Designer's Suitcase	Distantly Bonded Spaces
	Ambient Pen and Colleague Surrogate are taken out of the Designer's Suitcase	Pen-based Media Space Environment

* The black circles in Pin status diagram means that pin is touched with some AT Object. We use this as a technique to infer the AT Actions.

5.7 SUMMARY

In this chapter, we designed and implemented a test-bed prototypical environment to validate the feasibility and the computability of the framework. The applications we have implemented include *Personal Design Ambience*, *Ambient Sketch Space*, *Distantly Bonded Spaces*, and *Pen-based Media Space Environment*. Each application was triggered by specific AT Objects, including *Designer's Suitcase*, *Ambient Pen*, and/or *Colleague Surrogate*. We physically constructed a test-bed environment for verification. The concept, ambient setting, construction process, system architecture, and components for the test-bed environment were elaborated.

In the next chapter, we'll show scenario examples and evaluate a comparison for reifying the AT framework.

6

SCENARIOS AND REIFICATION

In this chapter, we present example AT interactions in our implemented test-bed environment by scenarios. Four main scenarios were planned sequentially and tested empirically. Aside from this, we were concerned on whether the AT Interface is different from a non-mediated approach to ambient reconfiguration, and we also made a comparison of evoking ambient reconfiguration using ATs and various interactive ambient elements as reification of the framework.

6.1 SCENARIO EXAMPLES

In order to verify the practicability and demonstrate the usage of the AT framework, we present example AT interactions with our implemented test-bed environment with scenarios. Four main scenarios were planned sequentially and tested empirically. They are designer-evoking Personal Design Ambience, Ambient Sketch Space, Distantly Bonded Space, and Pen-based Media Space Environment. Each is depicted as follows:

6.1.1 Scenario 1: Personal Design Ambience

Lynne is a young female architectural designer. Today, early in the morning, when she woke up, she was reminded that she needed to finish a sketch before meeting her clients later today. She goes to her design studio with her Designer's Suitcase.

After her arrival at the personal design environment in the design studio, she places her Designer's Suitcase into a docking platform on the table surface. When Lynne opens the Suitcase, the environment recognizes that she is going to work, and initiates a Personal Design Ambience state specific for Lynne's preference. Floating images and texts that remind Lynne of items yet to be accomplished are floating around the partition and wall.

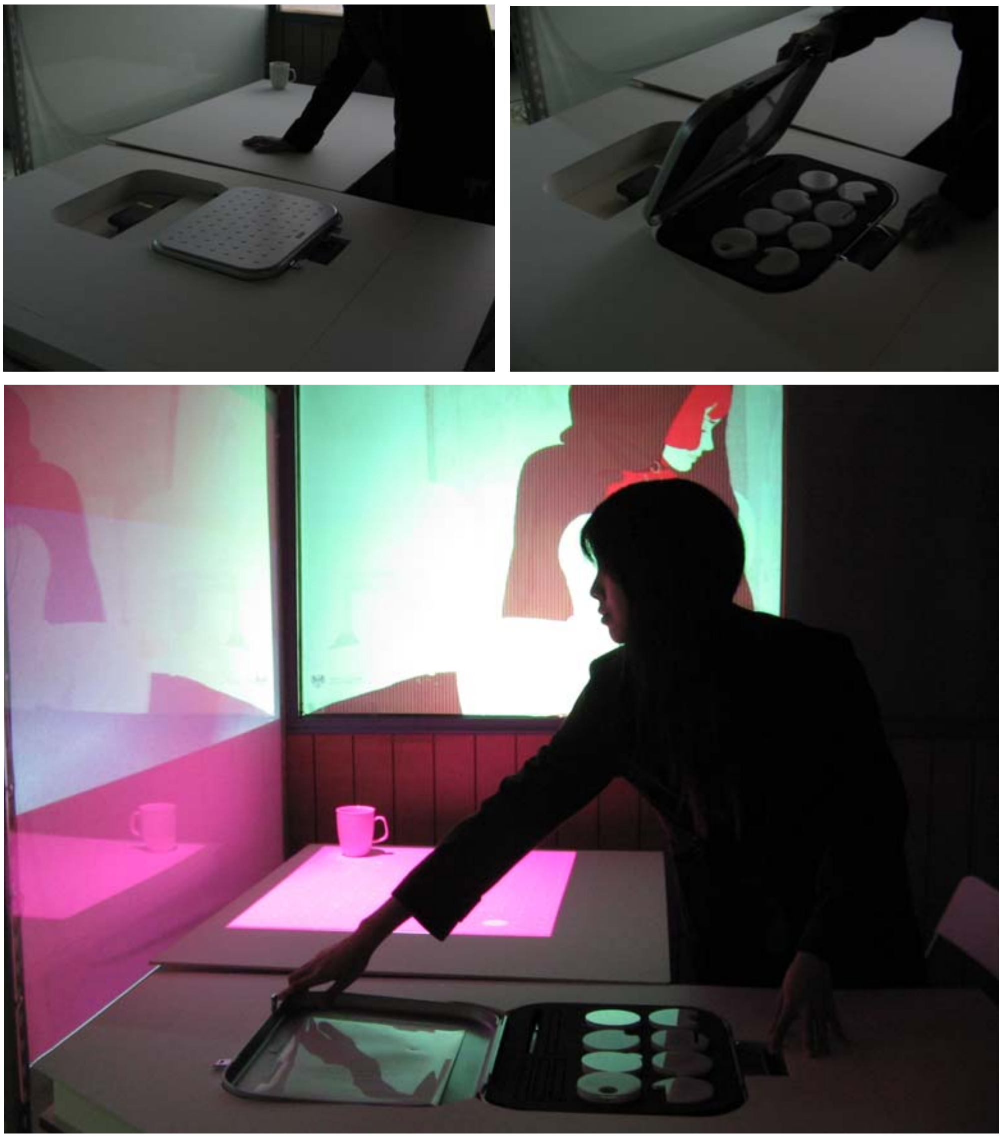


Fig 6-1: The environment is personalized when the user opens the Designer's Suitcase.

The Figure 6-1 shows the AT interaction of the designer evoking a non-interactive environment into her Personal Design Ambience. Figure 6-2 shows the system architecture. Lynne's docking and opening the Designer's Suitcase is detected by the AT system in the environment. After its analysis and decision-making, the system applies the correspondent template, which projects Lynne's ambient information on the partition and the wall. Lynne is aware of this, and the interactive projections have made Lynne capable of interacting with the ambient information. Table 6-1 summarizes the AT Interaction of the above scenario.

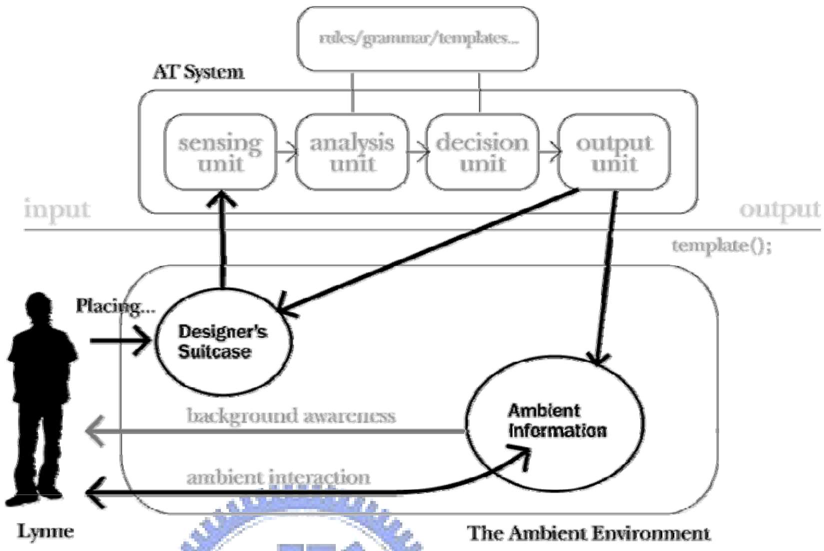


Fig 6-2: The diagram of evoking Personal Design Ambience.

Table 6-1: Ambient Trigger in Personal Design Ambience scenario

AT Action towards AT Object	Evoked Interaction State	(Evoked/Switched) Interaction Spaces	Evoked Interactive Components / Spatial Response
Placing Designer's Suitcase into a docking platform on the table surface	Personal Design Ambience	Awareness Space	Projections of floating images and texts on the spatial elements

6.1.2 Scenario 2: Ambient Sketch Space

After glimpsing items she needs to work with, Lynne decides to finish the sketch. So she takes out an Ambient Pen from the Designer's Suitcase. Meanwhile, the whole ambient mediated environment reconfigures to an Ambient Sketch Space state to provide Lynne with sketch activity support. A drawing space emerges on the table, and a few design materials and references shared by other colleagues are floating on the wall. Lynne starts her sketch by drawing on the table surface, at times inspired by the information floating on the wall.

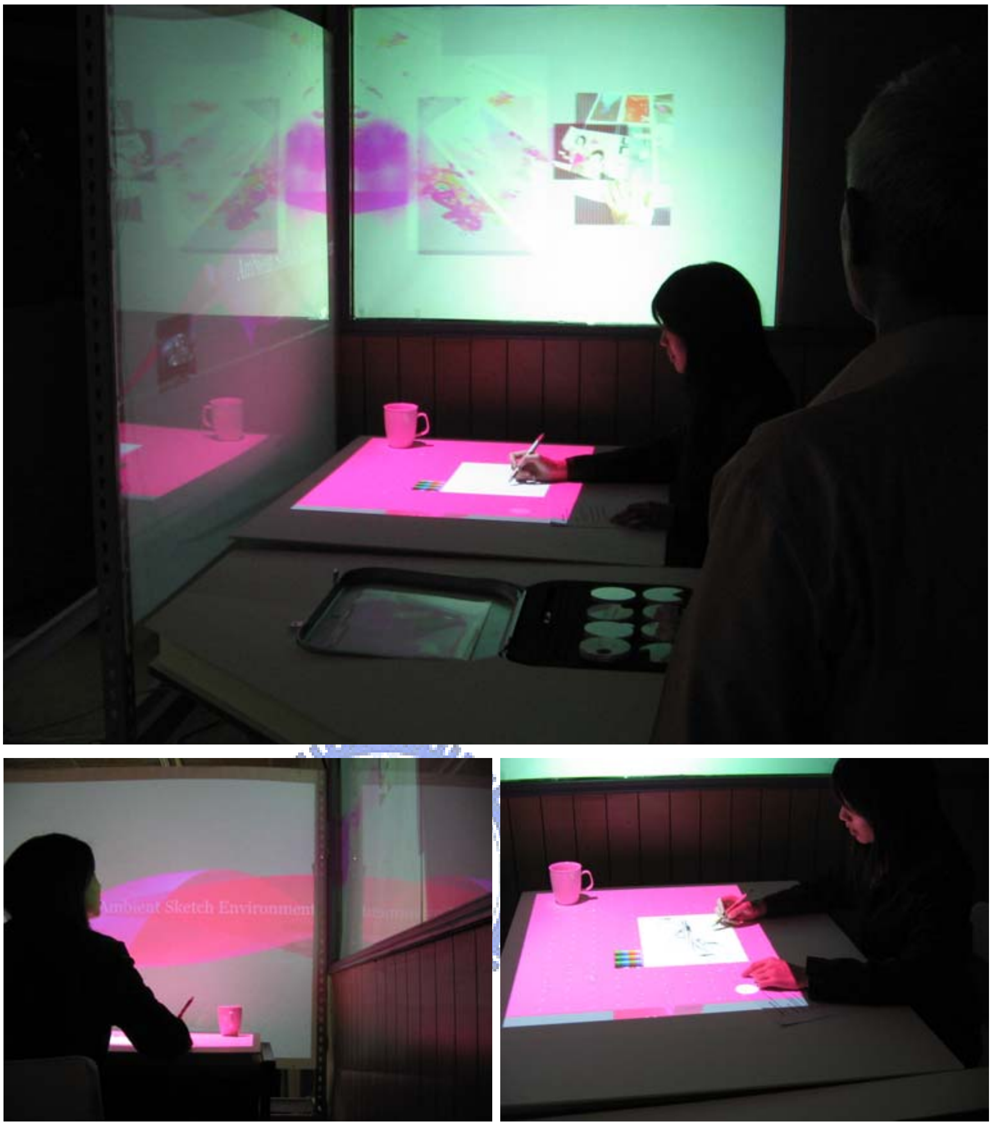


Fig 6-3: User sketches in the PDE in Ambient Sketch Space state.

Lynne's taking of the Ambient Pen out from the Designer's Suitcase was detected by the AT system in the environment. After its analysis and decision-making, the system applied the correspondent template that projected design materials and references on the partition and the wall, graphical interfaces on the table surface, and activated the tablet embedded beneath the table. Lynne was aware of this, and the interactive projections and the Ambient Pen made Lynne capable of interacting with these ambient interfaces. Figure 6-3 shows how Lynne interacts within the Ambient Sketch Space, where she sketches on the projected surface and is aware of the information projected on the wall. Figure 6-4 shows the system architecture. Table 6-2 summarizes the AT Interaction of the above scenario.

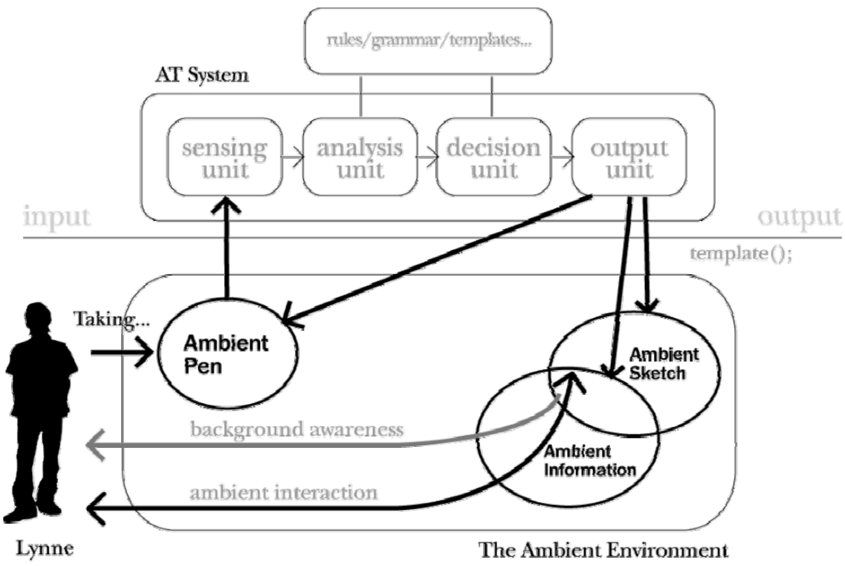


Fig 6-4: The diagram of evoking Ambient Sketch Space.

Table 6-2: Ambient Trigger in Ambient Sketch Space scenario

AT Action towards AT Object	Evoked Interaction State	(Evoked/Switched) Interaction Spaces	Evoked Interactive Components / Spatial Response
Taking out the Ambient Pen from the Designer's Suitcase	Ambient Sketch Space	Task Space	Projection of Embedded Tablet module set
		Awareness Space	Projection of design materials and references

6.1.3 Scenario 3: Distantly Bonded Space

After sketching for a while, Lynne feels that she wants to talk to Jennifer about another project that she invited Lynne to participate in yesterday. So, Lynne puts back the Ambient Pen, takes out the Colleague Surrogate which represents Jennifer, and puts it on a light spot area of the table surface. At the same time, her environment informs Jennifer of an invitation. The environment immediately reconfigures into a Distantly Bonded Space state in which the Media Space with Jennifer's real-time image is projected on the surface in front of the table, and an iconic representation of all other remote colleagues floating on the peripheral wall. Lynne then talks directly to Jennifer via the projected Media Space, while keeps a background awareness with other remote colleagues.

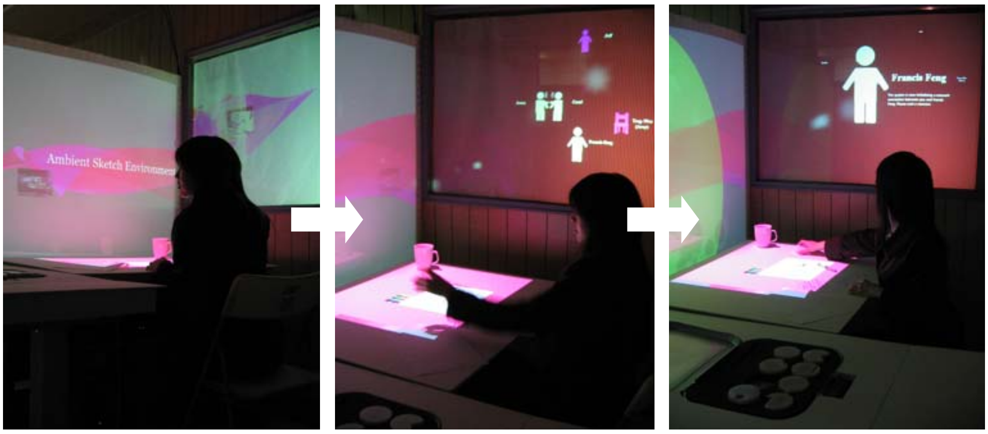


Fig 6-5: User evokes Distantly Bonded Spaces state with Colleague Surrogate

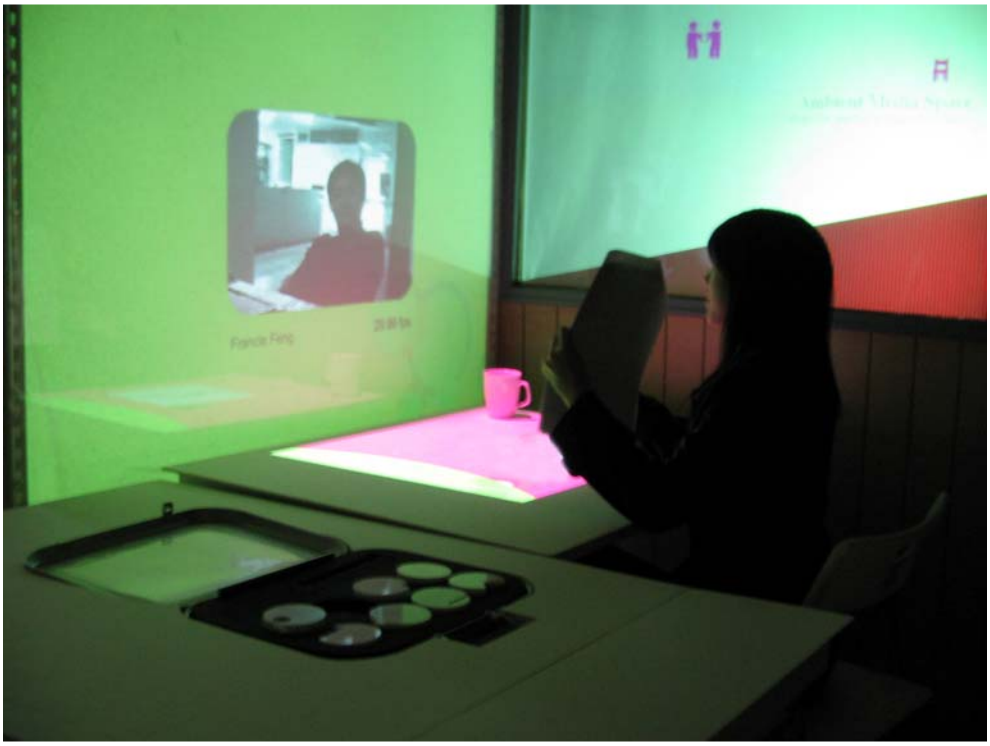


Fig 6-6: User remote collaboration via Media Space.

Lynne's putting the Ambient Pen back into the Designer's Suitcase caused the environment to restore itself to its Personal Design Ambience state, switching the projected information and deactivating the functioning of the embedded tablet. After that, Lynne's taking the Colleague Surrogate out from Designer's Suitcase was detected by the AT system in the environment. After its analysis and decision-making, the system applied the correspondent template that initiated a remote connection (Chen and Chang, 2005). Figure 6-5 shows the process of Lynne initiating and connecting remotely using Colleague Surrogate.

After connection was successfully made, the system projected a real-time streaming Media Space on the wall, with social awareness information on the partition, and activated the embedded microphone and speakers needed for Media Space communication. Lynne was aware of this, and the Media Space and social awareness projection made Lynne capable of interacting with and become aware of remote colleagues over the ambient interfaces. Figure 6-6 shows Lynne interacting with the remote colleague via a Media Space projection in the Distantly Bonded Space state. Figure 6-7 shows the system architecture. Table 6-3 summarizes the AT interaction of the above scenario.

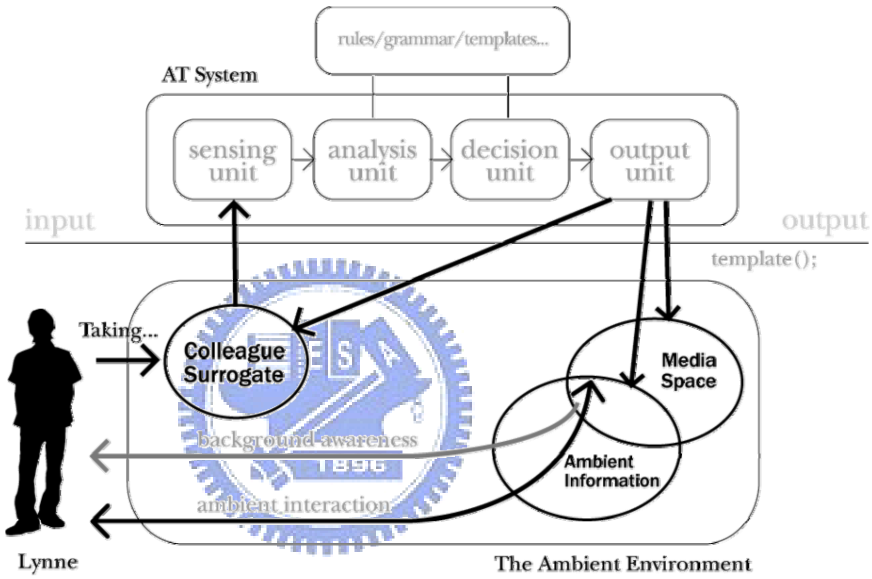


Fig 6-7: The diagram of evoking Distantly Bonded Space.

Table 6-3: Ambient Trigger in Distantly Bonded Spaces scenario

AT Action towards AT Object	Evoked Interaction State	(Evoked/Switched) Interaction Spaces	Evoked Interactive Components / Spatial Response
Putting the Ambient Pen back to the Designer's Suitcase	Personal Design Ambience	Awareness Space	Projections of floating images and texts on the spatial elements
Taking out the Remote Colleague Surrogate which represents Jennifer	Distantly Bonded Space	Communication Space	Projection of Jennifer's real-time image, activates embedded speakers and a microphone
		Awareness Space	Projection of remote colleague with status indication

6.1.4 Scenario 4: Pen-based Media Space Environment

After they talk for a while, Lynne comes asks Jennifer to check out the sketch she previously worked on. Lynne takes out an Ambient Pen from the Designer's Suitcase. This time, the previous sketch and drawing space emerge on Lynne's table surface and also on Jennifer's. Thus, both Task Spaces connect in real-time, so Lynne can directly share and modify her sketch with Jennifer, at the same time communicating over Communication Space via the surface in front of the table.

Fig 6-8: An overview of the Environment in a Pen-based Media Space Environment.

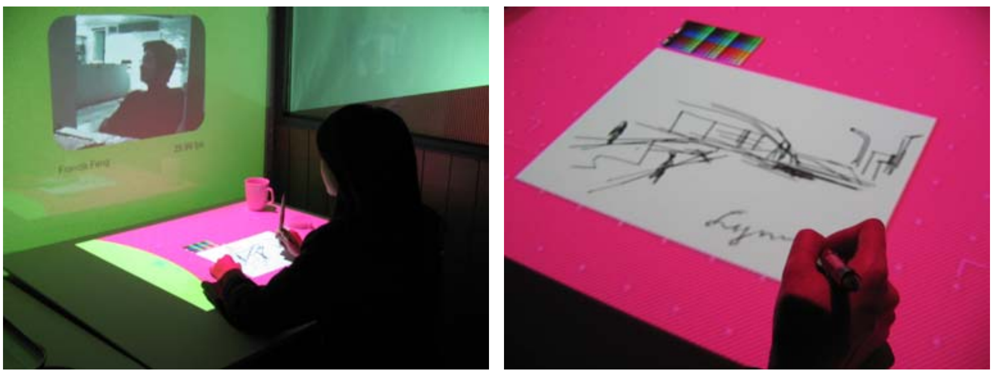


Fig 6-9: Partial view of the Environment in a Pen-based Media Space Environment state.

Lynne's taking of the Ambient Pen out from the Designer's Suitcase was detected by the AT system in the environment. After its analysis and decision-making, the system applied the correspondent template that activated the tablet embedded beneath the table, projected graphical interfaces on the table surface, and connected it with the remote space. Lynne was aware of this, and the Media Space and Ambient Pen made Lynne capable of communicating with remote colleague with drawings as well as vocal communication over these ambient interfaces. Figures 6-8 and 6-9 show how Lynne interacts within the Pen-based Media Space Environment with a projected Media Space as well as a projected sketching surface. Figure 6-10 shows the system architecture. Table 6-4 summarizes the AT interaction of the above scenario.

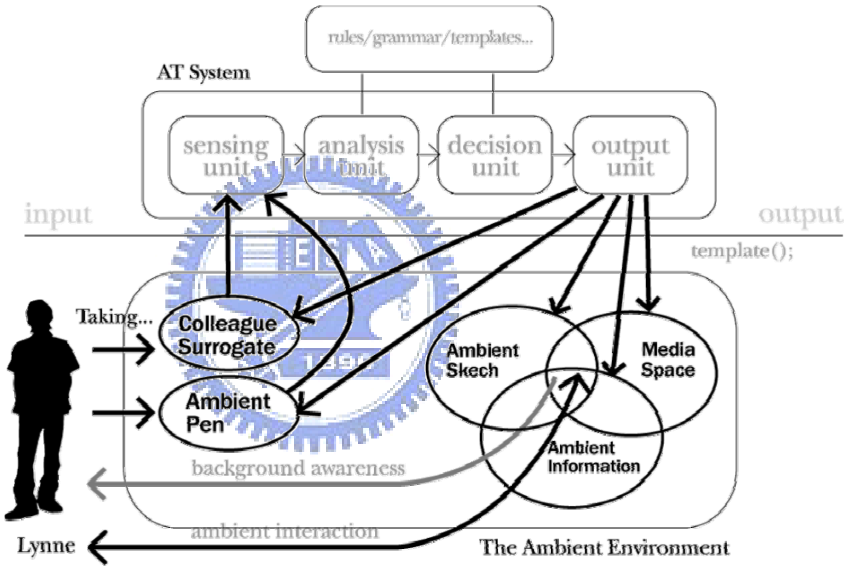


Fig 6-10: The diagram of evoking a Pen-based Media Space Collaboration.

Table 6-4: Ambient Trigger in Pen-based Media Space Environment scenario

AT actions	Resulting State	(Evoked/Switched) Interactional Spaces	Evoked Interactive Components / Spatial Response
Taking out the Ambient Pen from the Designer's Suitcase	Pen-based Media Space Environment	Communication Space	Projection of Jennifer's real-time image, activates embedded speakers and a microphone
		Awareness Space	Projection of remote colleague with status indication
		Task Space	Projection of Embedded Tablet module set

6.2 A COMPARISON

One of the major concerns of the research is whether the AT framework shows any differences in evoking ambient reconfiguration. A basic way to verify this is by making a comparison. A comparison in terms of the user evoking an ambient reconfiguration by embodied behavior is illustrated in Table 6-5.

Table 6-5: Comparison of feedback between an AT and a non-mediated Environment

Embodied Behavior	Feedback in AT Environment	Feedback in Non-mediated Environment
Docking the Designer's Suitcase onto table platform	Feedback with Personalized Design Ambience state	The environment remains impersonalized
Taking out the Ambient Pen from the Designer's Suitcase	Feedback with Ambient Sketch Space state	Feedback with no sketch facility
Taking out the Colleague Surrogate from the Designer's Suitcase	Feedback with Distantly Bonded Space state	The environment remains unbonded
Taking out both the Ambient Pen and the Colleague Surrogate from the Designer's Suitcase	Feedback with Media Space-based Environment state	Feedback with no sketch facility, space remains unbonded

Because AT objects are particularly designed, whose users are assumed to be trained and have an understanding of the consequences of AT, the resulting environment is as expected. The AT PDE feedback had environmental changes, while in a non-mediated PDE had no feedback. This closes a loop in an interactive process, which will needs the user to prepare, arrange, and set up the environment instead, which also means more distractions in a design process.

Aside from the above comparison, we compared the process of ambient reconfiguration using AT and using various interactive ambient elements. The comparison of each process is shown in Table 6-6.

Table 6-6: Comparison between using AT versus using various media

Using AT	Mediated by	Using various interactive ambient elements	Mediated by
Prepare the mediated objects or design media needed	User	Prepare the mediated objects or design media needed	User
Prepare the interactive ambient elements needed	System	Prepare the interactive ambient elements needed	User

Arrange the interactive ambient elements into the appropriate position	System	Arrange the interactive ambient elements into the appropriate position	User
Electronically set up and connect each interactive ambient element	System	Electronically set up and connect each interactive ambient element	User
Start the application	System	Start the application	System

The key difference between using AT and using various spatial media for an ambient reconfiguration is the level of user involvement and intervention. The ambient reconfiguration mediated by AT only requires the user to prepare the mediated objects or design media (i.e. AT objects) needed, and the system will then trigger the correspondent procedure without user intervention. While in the case of using various spatial media, the user needs to set up all the components for an ambient reconfiguration. Though the user needs to preset preference settings to evoke a personalized ambient reconfiguration, this is assumed to do be done only once, and after, ambient trigger would be applied every time.

6.3 SUMMARY

As scenario examples show, we have successfully combined various applications into one ambient mediated environment to trigger or switch to when needed. By nearly-simple embodied actions (i.e. picking up or placing something), the user can easily evoke an Ambient Trigger process. We also compared the ways of spatial reconfiguring using AT with using various interactive ambient elements. The comparison showed the differences between using AT and using various interactive ambient elements. We discuss the advantages, drawbacks, implications, and limitations of these results in the next chapter.

7

DISCUSSION & CONCLUSION

With previous heuristically verification of the AT framework, in this chapter we discuss its results, interesting issues found during the implementation and verification, and conclude this thesis with research contributions, limitations, and suggestions for future directions.

7.1 GENERAL DISCUSSION

The main idea for AT is to see human behavior towards some specific object as an initial trigger to evoke ambient reconfiguring for different design activities. Our scenario example has demonstrated how the user can change the functional as well as metaphorical support of the ambient environment by simply switching AT Objects. Though the design and implementation of the framework appeared to be only one example, we have found some issues interesting to discuss.

7.1.1 Reconfigurability of AT

The reconfigurability of AT is based on a single actuation. By mass actuations, it is possible to transform the spatial setting totally. However, such actuation-based reconfiguration is also limited by its nature. We found it difficult to actuate functional mechanisms without appropriate presetting and pre-positioning. For example, we pre-embedded the tablet beneath the table surface and activated/de-activated it with ambient reconfiguration. Such a presetting approach is practicable and feasible, but may limit the flexibility and extensibility of an AT environment. Another limitation of the reconfigurability of the AT is due to the nature of physical form. The physical form of an object or space is static and complex, which lacks the flexibility to be changed.

To extend the flexibility of the AT environment in the future, we suggest trying other flexible actuation technologies or intelligent materials that can be self-reconfigurable to dynamically fit into different spatial contexts.

7.1.2. The Selection of AT Embodiment

Our selection of AT embodiment is based on our observations. According to our framework design principles, the AT action should be natural, unique, and carried within a single action. However, it happened that at many times it is difficult to select a representational behavior to be embodied as an AT action. This is because some activities are ambiguous and can’t be easily judged or distinguished in appearance. We tried to approach this problem by introducing new objects into the environment. We created new meaning and new metaphors to the object, but kept to the nature of the manipulation of an object. We have found this a good way because only little training is needed to make the user understand the usage of AT Objects such as these.

7.1.3 Recursiveness of AT

The AT is recursive in essence. The reconfigured ambient environment motivates a user to perform actions, which could be captured to trigger a correspondent reconfiguration. For example, the changed environment showing the remote colleague status could foster the contact between two designers, thus motivate the designers to contact and further collaborate with each other. In this sense, how the environment could feedback with implications or suggests to next design activities should be well addressed. Also, in our test application, we deliberately kept the background awareness unchanged when the environment was restored, as a way to remind the user what he has previously done and to motivate his next actions. We think reminders, as well as showing traces of the design process is also important to user awareness, so that he wouldn’t get lost in the process, and so he could orient the design process more effectively.

7.1.4 Sequences of AT

The same ambient trigger (but with different sequential order) indicates different design activity contexts. This would also affect how a user would respond to and help evolve his environment. For example, taking an Ambient Pen before or after initiating Media Space collaboration indicates a totally different scenario of context of use. Therefore, to design a spatial application for AT means that it also needs to define the contextual relations between former and later applications to be triggered. Incorporating this to take the design process with different AT sequences as a whole will make the environment very complex. But it is important to note that there is no need to build up all the scenarios of context of use, but only to build some according to a limited pattern of personal design practices, which is enough to accomplish a better personal design support.

7.1.5 The Nature of the Actuation

During the test, we have found that how the actuation is triggered is a key to success. We used techniques from motion pictures, such as the gradual blending of ambient imagery, as ways to switch environmental appearances, indicating functional change. Slowly dissolving of the periphery into another ambient setting makes the user aware but not distract by it. In contrast, we made the foreground interactive ambient element dissolving and switching more obvious to inform the users, and we made them quicker to make the user attend to it without waiting too long. Though to this end we do not know to what degree of immediacy and fluidity could be counted as a distraction-free reconfiguration process, it is obvious that the user should not be distracted by the reconfiguration process.

7.1.6 Physical Space Constraints

How the physical environment is partitioned will help define how they form an internal space for supporting a specific activity. Our implemented system tied the representation of interaction spaces with spatial settings, such as tying Awareness Space to the Wall, Communication Space to the Front Partition, and the Task Space to the Table Surface. Such boundaries have made spatial elements static and inflexible, and probably may pose ergonomic and cognitive problems to the environment. But if we can actuate physically partition reconfiguration, they may release more constraints of physical environment to better support the user with cognition and ergonomics. And, by reconfiguring physical partitioning, we may form richer kinds of internal spaces for different support activities.

7.1.7 Physical Design Techniques

One purpose of Ambient Trigger is to freely evoke ambient reconfiguration with embodied action whenever the user requests. However, it is difficult to find a universal behavior that is both context-independent and is able to carry out actions free of distractions. We tried to probe this problem with a modularizing approach, and applied some shape or material design techniques to compensate with each other. We have intentionally designed a modular concave to evoke the designer's natural responses to the use of everyday environment by putting the Designer's Suitcase on the concave to initiate ambient reconfiguration. Such strategy means that the AT Interface is not merely used to design mediated objects, but also to design the environment to be coupled with. Thus, how objects and the environment could be naturally carried out in pairs could become a means, and our exploited modular design method has shown potential to incorporate this.

7.1.8 Summary

Characteristics in terms of AT and some of interesting issues found during our research have been presented. We believe the issues discussed above would benefit and provide insights for future researches. In the next section, we try to summarize some possible impacts and implications to design.

7.2 POSSIBILITIES

A few possible impacts to design as well as implications to designing interactive space have emerged. We discuss each below.

7.2.1 Beyond Ambient State Switch

The way of the AT object evoking ambient reconfiguration is similar to that of a switch controller. However, it differs from the switch controller in many aspects, such as AT object being passively carried out with natural behavior or action rather than by pressing or toggling a solid interface, and the AT object could be used more than just to simply switch control. It can be used as a design media for the user to interact with spatial applications and environmental resources. Combining AT objects with interfaces for design interaction may also suggest new design paradigm in terms of interactive environment design, which may lead to redesigning user behavior with objects, and may enrich and inaugurate affordances of everyday artifacts.

7.2.2 Design Element

The AT could be seen as a design element directly arranged and interacted with. For example, the arrangements and material projection of spatial settings could be immediately spatialized and adjusted via natural interaction. Such an instant and interesting way of using AT could be further applied to spatial ambiance design and interior design simulations.

7.2.3 Personal Design Space Carrier

The design and implementation of the Designer's Suitcase implied that personal design setting is carried by the user. And when needed, it is possible to extract the PDE to any place that has an AT platform. This is in accord with what William Mitchell envisioned as "Attentive Architecture" (Mitchell, 2002), implying a new work type and new design pattern for designing the design environment.

7.2.4 Continuous Interaction Experience

From the view of PDE, it is found that past researches, while focusing on seamless interaction, don't take the continuity between two design activity supports into consideration when designing PDE. The definition of AT and its framework may contribute toward this problem and fill the gap in between two spatial applications by providing a distraction-free way of jumping from one spatial application to another. By switching spatial applications that naturally interact with users, it is possible to achieve both a continuous and seamless interaction experience in ambient mediated PDE. Moreover, we believe such a consistent experience could be easily reproduced in other kinds of computing-enhanced environments, such as UbiComp-based, Smart, or Intelligent Environments.

7.2.5 Form Follows Design Activity

Though the technologies doing ambient reconfiguration were limited in our implementation and still various technologies are yet to be tested and experimented, our implementation showed its reconfigurability by evoking actuators to act a series of actions. Actuators can be connected to many electronically driven things. For example, by incorporating kinetic structures such as actuated tensegrity structures (Sterk, 2003) into the design of AT environment, it is possible for the user to evoke physically responsive architecture. This implies the possibility of making space adapt to design activity with Ambient Triggers. AT action, which represents the rules and strategies of an ambient reconfiguration, can be united to make the spatial settings follow the spatial design activity being carried out. By properly customizing and fully implementing the AT framework, a form that complies with design activity could likely be created.

7.2.6 Evolving Ambient Environment

In the Ambient World (i.e. Ambient Display, Ambient Environment, or Ambient Intelligence), ATs could be extended as mechanisms for an evolving ambient mediated environment. The implementation of our framework has suggested that ATs could be used to evoke and change the knowledge, algorithm, or rule bases of spatial interactive elements. Furthermore, the knowledge, algorithm, or rule base of the trigger itself can also be replaced or changed as well, and in turn can create new methods for AT. In this way, AT could be an activator to move the space to evolve.

7.2.7 Summary

A few possible implications and impacts to design have been presented. To sum up, ATs have not only shown possibilities in design, but also in advanced design environments and ambient environments.

7.3 CONCLUSION

The thesis is situated along the lines of the ambient environment and is aimed at aiding the change of ambient support in personal design activities to be less distractive. Pilot design experiments were conducted to help form the foundation for AT framework and design principles. To verify the computability of the proposed framework as well as the AT interface design principles, a few test applications were developed and implemented as scenario examples. Finally, the paper compared the framework with ambient reconfiguration using various spatial media, and presented scenario examples of the usage of AT. This thesis has shown differences in the AT framework, as well as its computability and possibilities. In overall, this thesis:

1) developed and proposed an AT framework,
2) designed principles for AT Interface, and
3) implemented an AT system for evoking distraction-free ambient reconfiguration.

We believe the AT framework can be applied not only to the PDE, but to different types of ambient environments. It is important to note that AT is not aimed at replacing current design paradigms, but at proposing a way to help designers focus more on his design task while interacting with ambient interfaces fluently and dynamically. We believe that, when fully implemented, the AT framework could be helpful for designers doing design.

7.3.1 Research Limitations

There are limitations to our research. First, we know that user evaluation is an important aspect for interactive systems; however, we did not conduct user evaluation due to our research scope. Second, our system focuses on ambient mediated environment and is limited by all kinds of physical constraints. It is also out of the research scope of developing a real reconfigurable environment which physically and kinetically moves.

7.3.2 Future Directions

For future development, we are interested in and looking forward to seeing further investigation into the following issues:

Spatial Applications Specific for AT Environments

One challenge in designing ambient trigger applications is to find out what is specifically needed to support and what the alternatives are. Taking our implemented test cases, for example. We borrowed concepts from a previous work on the social awareness theory regarding ambient displays (Chen and Chang, 2005; Gross, 2003; Prante et al., 2003) and applied them directly into our test application design. We believe that it is interesting to develop the spatial applications exploited characteristics of AT, which can make the spatial settings respond and adapt to design activities.

User Evaluation

As stated in our research limitation, user evaluation is an important aspect in the verification of an interactive system as well as in the environment. As a result, a formal study on usability techniques such as scenario-based evaluation or focused group interviews should be conducted in the future.

Implementing the Alternative Physical Design Approach

As stated in the research limitations discussion, physical constraints have limited the flexibility of ATs. Such problems could be approached with different physical design strategies such as kinetic design or modular design. Therefore, we should experiment with different physical design methods in the hopes that we can gain more understanding of the principles of AT environment design.

Triggers Not Caused By Human

Spatial relevant conditions (such as humidity, temperature, or time) have affected people's everyday lives. There is also a great possibility of integrating spatial condition changes as triggers to evoke ambient reconfiguration. In the future we would also like to investigate on this issue and integrated it into the AT framework for improvement and refinement.

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Terminology

Along the thesis, many terms as well as jargons have been used. In order not to distract the reader, we clarify each term below:

Ambient Environment. Ambient Environment is the architectural space embedded with ambient interfaces that interact with human via foreground or background awareness.

Trigger. Trigger is the action upon the system that starts the use case/event which sometimes is a series of actions, and causes something to happen.

Ambient Trigger (AT). Ambient Trigger is an interface framework for evoking ambient reconfiguration. The framework is composed of AT Object, AT System, and spatial I/O elements.

AT Object. AT Object is the mediated artifact coupled with embodied behavior for evoking ambient reconfiguration.

Designer's Suitcase. Designer's Suitcase is an AT Object used to trigger personalization in an AT environment.

Ambient Pen. Ambient Pen is an AT Object for evoking the Ambient Sketch state in an AT environment.

Colleague Surrogate. Colleague Surrogate is an ambient device representing some remote colleague identity, and is used to trigger instant connection with the remote colleague by evoking the Distantly Bonded state in an AT environment.

Appendix

The core processing code for the test-bed environment is written in Microsoft Visual Basic 6 with Flash.ocx, a middleware to integrate Shockwave Flash Object into Visual Basic Components, and run on a Windows 2000 Server OS and AMD Athlon™ XP 2500+ with 1G Ram computing unit. It contains 3 Forms (.frm) and 2 Modules (.bas) as follows.

1. FormA (PCFormA.frm)

```
Dim k As Long
Dim InputData As String
Private Declare Sub Sleep Lib "kernel32" (ByVal dwMilliseconds As Long)
Dim bb As Integer
Dim bExit As Boolean
Dim SS As Integer
Dim tName As String
Dim tNameLab As String
Dim OpNow As Integer
Dim VoiceStatus As Boolean
Dim ThinkStatus As Boolean
Dim Real_ThinkStatus As Boolean
Dim RemotePresence As Boolean
Dim Op1Status As Boolean
Dim Op2Status As Boolean
Dim Op3Status As Boolean
Dim bListening As Boolean
Dim already_aware As String
Dim current_slice As String

Private Sub wsserver_ConnectionRequest(ByVal requestID As Long)
    Dim frmNew As New frmServer
    lRequestID = requestID
    Load frmNew
End Sub

Private Sub wsserver_Error(ByVal Number As Integer, Description As String, ByVal Scode As Long, ByVal Source As String,
ByVal HelpFile As String, ByVal HelpContext As Long, CancelDisplay As Boolean)
    MsgBox "Error : " & vbCrLf & Description
End Sub
Private Sub Timer1_Timer()

Text1.Text = MSComm_RFID.Input
Text2.Text = MSComm_RFID2.Input
Text3.Text = MSComm_RFID3.Input

If Text1.Text = "  s01A0  ME0070000184A91F6  8" Then
If RemoteText.Text <> 1 Then
RemoteText.Text = "1"
    tName = "designer1"
    tNameLab = "go"
    swfObj.TGotoLabel tName, tNameLab
    swfObj.TPlay (tName)
    IO9624.Timer2.Enabled = True

frmServer.ws.SendData "wallpaper_periphery"
```

```
End If
End If

If Text2.Text = "  s01A0  ME0070000184A8CF4  i" Then 'Jennifer Surrogate Activated!
If RemoteText2.Text <> 2 Then

If already_aware = "2" Then
RemoteText2.Text = "2"
    tName = "ani_065"
    tNameLab = "go"
    swfObj.TGotoLabel tName, tNameLab
    swfObj.TPlay (tName)
    IO9624.Timer2.Enabled = True
frmServer.ws.SendData "inviting_jennifer"
already_aware = "0"

End If

End If
End If


If Text3.Text = "  s01A0  ME0070000184A8CF4  i" Then

If RemoteText2.Text = "0" Then '////////////////////////////// Starts to aware Jennifer.
   If already_aware = "0" Then
   frmServer.ws.SendData "aware_jennifer"
    already_aware = "1"
   End If
End If

If RemoteText2.Text = "2" Then   '////////////////////////////// Terminate Jennifer Surrogate!
    If RemoteText3.Text <> 3 Then
    RemoteText3.Text = "3"

    tName = "ani_065"
    tNameLab = "end"
swfObj.SetVariable "end_status", "0"
RemoteText2.Text = "0" 're-activate RFID2

    swfObj.TGotoLabel tName, tNameLab
    swfObj.TPlay (tName)
    IO9624.Timer2.Enabled = True
frmServer.ws.SendData "terminating_jennifer"

End If
End If
End If

If Text1.Text = "" Then
    If RemoteText.Text = "1" Then
    tName = "designer1"
    tNameLab = "end"
    swfObj.TGotoLabel tName, tNameLab
    swfObj.TPlay (tName)
    IO9624.Timer2.Enabled = False
    frmServer.ws.SendData "fade_out"
End If

RemoteText.Text = "0"
RemoteText2.Text = "0"
RemoteText3.Text = "0"
End If

If Text3.Text = "" Then
If already_aware = "1" Then
already_aware = "2"
frmServer.ws.SendData "cancel_jennifer"
```

```
'RemoteText2.Text = "X"
RemoteText3.Text = "0"
End If
End If

End Sub
Private Sub Form_Load()
    bListening = True
    cmdListen_Click

already_aware = "0"

'RFID for Suitcase
MSComm_RFID.CommPort = 15
MSComm_RFID.Settings = "9600,N,8,1"
MSComm_RFID.InputLen = 512
MSComm_RFID.InBufferSize = 512
MSComm_RFID.InputMode = comInputModeText
MSComm_RFID.PortOpen = True

swfObj.Movie = App.Path & "\" & "projection_A.swf"

'RFID2 for Requesting Remote Collaboration
MSComm_RFID2.CommPort = 14
MSComm_RFID2.Settings = "9600,N,8,1"
MSComm_RFID2.InputLen = 512
MSComm_RFID2.InBufferSize = 512
MSComm_RFID2.InputMode = comInputModeText
MSComm_RFID2.PortOpen = True

'RFID3 for optional in Remote Collaboration
MSComm_RFID3.CommPort = 16
MSComm_RFID3.Settings = "9600,N,8,1"
MSComm_RFID3.InputLen = 512
MSComm_RFID3.InBufferSize = 512
MSComm_RFID3.InputMode = comInputModeText
MSComm_RFID3.PortOpen = True

IO9624.Timer1.Enabled = False

For i = 0 To 255
  IO9624.Address.AddItem i
Next

'open com1
If IO9624.Option1.Value = True Then
  IO9624.MSComm1.CommPort = 1
Else
  IO9624.MSComm1.CommPort = 2
End If
IO9624.MSComm1.Settings = "9600,N,8,1"
IO9624.MSComm1.InputLen = 512
IO9624.MSComm1.InBufferSize = 512
IO9624.MSComm1.InputMode = comInputModeBinary
IO9624.MSComm1.PortOpen = True

'Activate Timer1
IO9624.Timer1.Interval = 100
IO9624.Timer1.Enabled = True
IO9624.Timer2.Interval = 60
IO9624.Timer2.Enabled = False

End Sub
Private Sub cmdListen_Click()
    Dim frmTarget As frmServer
    bListening = Not bListening
    If Not bListening Then
        wsserver.LocalPort = 1024
        wsserver.Listen
```

```
    Else
        For Each frmTarget In colOpenForms
            Unload frmTarget
            Set frmTarget = Nothing
        Next frmTarget
        wsserver.Close

    End If
End Sub
```

2. FrmServer (frmServer_Lynne.frm)

```
Dim iConnNum As Integer
Private Declare Function AVIO_OUT_LPT1 Lib "AVIO.dll" (ByVal PortData As Integer) As Integer
Public userID As String
Public posX As Integer
Public posY As Integer
Dim logStatus As Boolean
Private Declare Sub Sleep Lib "kernel32" (ByVal dwMilliseconds As Long)


Private Sub ws_DataArrival(ByVal bytesTotal As Long)

Dim strData As String
ws.GetData strData
Form1.Text1.Text = strData

If strData = "WeiRuIn" Then
    Form1.MSComm1.Output = "WeiRuIn"
End If

End Sub
Sub MsgS(sMsg As String)
    lstServer.AddItem sMsg
    lstServer.ListIndex = lstServer.ListCount - 1
End Sub
Private Sub Form_Load()
    Dim frmTarget As frmServer
    lConn = lConn + 1
    iConnNum = lConn
    colOpenForms.Add Me

    ws.Accept lRequestID
End Sub
Private Sub Form_Unload(Cancel As Integer)
    Dim iTemp As Integer
    ws.Close
    DoEvents
    For iTemp = 1 To colOpenForms.Count
        If colOpenForms.Item(iTemp).hWnd = Me.hWnd Then
            colOpenForms.Remove iTemp
            Exit For
        End If
    Next iTemp
End Sub
Private Sub ws_Close()
    Dim strData As String
    Unload Me
End Sub

Private Sub LOOP_Click()

bExit = False
While Not bExit
    bb = &H1
    AVIO_OUT_LPT1 (bb)
```

```
        Call delays
DoEvents
        bb = &H2
        AVIO_OUT_LPT1 (bb)
          Call delays
DoEvents
        bb = &H4
        AVIO_OUT_LPT1 (bb)
        Call delays
DoEvents
        bb = &H8
        AVIO_OUT_LPT1 (bb)
        Call delays
DoEvents
        bb = &H10
        AVIO_OUT_LPT1 (bb)
        Call delays
DoEvents
        bb = &H20
        AVIO_OUT_LPT1 (bb)
        Call delays
DoEvents
        bb = &H40
        AVIO_OUT_LPT1 (bb)
        Call delays
DoEvents
        bb = &H80
        AVIO_OUT_LPT1 (bb)
        Call delays
DoEvents
Wend
End Sub

Private Sub stop_Click()

bExit = True
bb = 0
End Sub

Private Sub delays()
Dim ii, jj, kk
For ii = ii To 65000
For jj = jj To 60000
For kk = kk To 60000
i = ii + jj + kk
Next kk
Next jj
Next ii
End Sub
```

3. IO9624 (IO9624.frm)

```
Private Sub Command1_Click(Index As Integer)

If Command1(Index).Caption = "On" Then
  MSComm1.Output = Chr(1)
  MSComm1.Output = Chr(Address.Text)
  MSComm1.Output = Chr(Index + 1)
  MSComm1.Output = Chr(0)
  MSComm1.Output = Chr(0)
  Command1(Index).Caption = "Off"
Else
  MSComm1.Output = Chr(1)
  MSComm1.Output = Chr(Address.Text)
  MSComm1.Output = Chr(Index + 1)
  MSComm1.Output = Chr(1)
```

```
  MSComm1.Output = Chr(0)
  Command1(Index).Caption = "On"
End If

End Sub
Private Sub Form_Load()

Text1.Text = "0"
Text2.Text = "0"
Text3.Text = "0"
Text4.Text = "0"
Text5.Text = "0"
Text6.Text = "0"
Text7.Text = "0"
Text8.Text = "0"
Text9.Text = "0"

End Sub

Private Sub Timer1_Timer()
Dim port(95) As String
Dim bbb As Variant
Dim aaa() As Byte
Dim i As Integer
Dim portA As String
Dim portB As String
Dim portC As String
Dim portD As String
Dim portE As String
Dim portF As String
Dim portG As String
Dim portH As String
Dim portI As String
Dim portJ As String
Dim portK As String
Dim portL As String

MSComm1.InputLen = 512
bbb = MSComm1.Input

Sleep (10)

MSComm1.Output = Chr(1)
MSComm1.Output = Chr(Address.Text)
MSComm1.Output = Chr(30)
MSComm1.Output = Chr(0)
MSComm1.Output = Chr(0)

timedelay = 0

Do
timedelay = timedelay + 1
Sleep (1)
If timedelay = 300 Then
  timedelay = 0
  Exit Sub
End If
Loop Until MSComm1.InBufferCount >= 15

MSComm1.InputLen = 15
bbb = MSComm1.Input
aaa = bbb

If aaa(0) <> 4 Then
  Exit Sub
ElseIf aaa(1) <> 13 Then
  Exit Sub
ElseIf aaa(2) <> Val(Address.Text) Then
  Exit Sub
```

```
End If

portA = ChangeBin(aaa(3))
portB = ChangeBin(aaa(4))
portC = ChangeBin(aaa(5))
portD = ChangeBin(aaa(6))
portE = ChangeBin(aaa(7))
portF = ChangeBin(aaa(8))
portG = ChangeBin(aaa(9))
portH = ChangeBin(aaa(10))
portI = ChangeBin(aaa(11))
portJ = ChangeBin(aaa(12))
portK = ChangeBin(aaa(13))
portL = ChangeBin(aaa(14))

For i = 1 To 8
 port(i - 1) = Mid(portA, i, 1)
Next i
For i = 9 To 16
 port(i - 1) = Mid(portB, i - 8, 1)
Next i
For i = 17 To 24
 port(i - 1) = Mid(portC, i - 16, 1)
Next i
For i = 25 To 32
 port(i - 1) = Mid(portD, i - 24, 1)
Next i
For i = 33 To 40
 port(i - 1) = Mid(portE, i - 32, 1)
Next i
For i = 41 To 48
 port(i - 1) = Mid(portF, i - 40, 1)
Next i
For i = 49 To 56
 port(i - 1) = Mid(portG, i - 48, 1)
Next i
For i = 57 To 64
 port(i - 1) = Mid(portH, i - 56, 1)
Next i
For i = 65 To 72
 port(i - 1) = Mid(portI, i - 64, 1)
Next i
For i = 73 To 80
 port(i - 1) = Mid(portJ, i - 72, 1)
Next i
For i = 81 To 88
 port(i - 1) = Mid(portK, i - 80, 1)
Next i
For i = 89 To 96
 port(i - 1) = Mid(portL, i - 88, 1)
Next i


For i = 0 To 95
 IO9624.instate(i) = port(i)
Next

End Sub

Private Function ChangeBin(X As Byte)
 Dim i As Long, bin As String

    For i = 0 To 7
        If X And (2 ^ i) Then       ' Use the logical "AND" operator.
            bin = bin + "1"
        Else
            bin = bin + "0"
        End If
    Next
```

```
    ChangeBin = bin
End Function

Private Sub instate_Change(Index As Integer)

 If instate(Index).Text = 1 Then
  IO9624.instate(Index).BackColor = &HFF00&
 End If

 If instate(Index).Text = 0 Then
   IO9624.instate(Index).BackColor = &HFF&
 End If
End Sub

Private Sub Timer2_Timer()

'//////////////////////////////////////////////////////////////////////////////////////////
'////////////////////////////////// take out Ambient Pen ////////////////////////////////
'//////////////////////////////////////////////////////////////////////////////////////////

If instate(63).Text = 1 Then

        If Text1.Text = "0" Then

        Text1.Text = "1"
        tName = "ani_063"
        tNameLab = "go"
        FormA.swfObj.TGotoLabel tName, tNameLab
        FormA.swfObj.TPlay (tName)

        FormA.swfObj.TStopPlay "designer1"

        frmServer.ws.SendData "sketch_periphery"

        End If
End If

'//////////////////////////////////////////////////////////////////////////////////////////
'////////////////////////////////// put back Ambient Pen ////////////////////////////////
'//////////////////////////////////////////////////////////////////////////////////////////

If instate(63).Text = 0 Then
    If Text1.Text = "1" Then
        tName = "ani_063"
        tNameLab = "end"
        FormA.swfObj.TGotoLabel tName, tNameLab
        FormA.swfObj.TPlay (tName)
        Text1.Text = "0"
    End If
End If

If instate(64).Text = 1 Then
        If Text2.Text = "0" Then

        Text2.Text = "1"
        tName = "ani_064"
        tNameLab = "go"
        FormA.swfObj.TGotoLabel tName, tNameLab
        FormA.swfObj.TPlay (tName)
        End If

        If Text1.Text = "1" Then
        If Text12.Text <> "1" Then
       Text12.Text = "1" 'ambient pen + colleague surrogate no.1
        tName = "ani_c1"
        tNameLab = "go"
        FormA.swfObj.TGotoLabel tName, tNameLab
        FormA.swfObj.TPlay (tName)
        End If
```

```
            End If
            End If


If instate(64).Text = 0 Then
      If Text2.Text = "1" Then
            tName = "ani_064"
            tNameLab = "end"
            FormA.swfObj.TGotoLabel tName, tNameLab
            FormA.swfObj.TPlay (tName)
            Text2.Text = "0"
      End If
      If Text1.Text = 1 Or Text2.Text = 1 Then
      If Text12.Text = "1" Then
            tName = "ani_c1"
            tNameLab = "end"
            FormA.swfObj.TGotoLabel tName, tNameLab
            FormA.swfObj.TPlay (tName)
      Text12.Text = "0"
      End If

      End If

End If

'/////////////////////////////////////////////////////////////////////////////////////////
'/////////////////////////////////// take out Colleague Surrogate //////////////////////////
'/////////////////////////////////////////////////////////////////////////////////////////

If instate(65).Text = 1 Then
            If Text3.Text = "0" Then

            Text3.Text = "1"

            tName = "ani_065"
            tNameLab = "init"
            FormA.swfObj.TGotoLabel tName, tNameLab
            FormA.swfObj.TPlay (tName)

frmServer.ws.SendData "colleague_periphery"

End If
End If

'/////////////////////////////////////////////////////////////////////////////////////////
'/////////////////////////////////// put back Colleague Surrogate //////////////////////////
'/////////////////////////////////////////////////////////////////////////////////////////

If instate(65).Text = 0 Then
            If Text3.Text = "1" Then

FormA.RemoteText2.Text = "0"
FormA.RemoteText3.Text = "0"

            Text3.Text = "0"
            tName = "ani_065"
            tNameLab = "close_init"
            FormA.swfObj.TGotoLabel tName, tNameLab
            FormA.swfObj.TPlay (tName)
End If
End If

End Sub
```

4. modDec (modDec.bas)

```
Option Explicit

Public lConn As Long
Public lRequestID As Long
Public colOpenForms As New Collection
```

5. modFunc (modFunc.bas)

```
Option Explicit

Sub sendMsg(sMsg As String)
    Dim frmTarget As frmServer
    For Each frmTarget In colOpenForms
        frmTarget.ws.SendData sMsg
        DoEvents
    Next frmTarget
End Sub
```