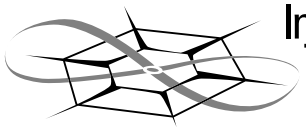
The University of Kansas



Information and Telecommunication Technology Center

Technical Report

The Ambient Computational Environments Architecture for Reliable, Secure, and Pervasive Computing

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Abstract

During the past few years, the technology world has become more and more geared towards the next generation of Internet connectivity. How to integrate a myriad of devices and technologies into one easily accessible network of user-friendly computational resource became the next challenge.

The ACE - Ambient Computational Environments - architecture aims at high-scale and seamless integration of services (which can be defined as user applications or programs) and devices within a secure network and onto a robust framework. This architecture also allows for easy introduction of new services and devices, enabling the environment to adapt to new technologies and user needs. Such environments allow users to interact with it and to access computational resources from anywhere at the touch of a button or with a spoken command. The ACE infrastructure consists mainly of ACE service daemons, which are the building blocks of ACE services. These daemons, along with a secure, reliable, and persistent state storage comprise the basis of the ACE system architecture.

This study is intended to outline the architecture of the ACE project, to illustrate the usefulness of ACE and its applications, and obtain some insight from other similar projects in academia and businesses as to how feasible and worthwhile the ACE approach is.

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Chapter 1

Introduction

In today's world more and more people talk about the next step in Internet accessibility. Terms such as pervasive computing, wireless Internet access, and everywhere computing [1][2] are heard. The concept of having computational resources available to anyone, anywhere, at the touch of a button or the utterance of a spoken command has been in the minds of many researchers and developers throughout universities and businesses alike. The consumer world is also constantly being bombarded with more and more gadgets and new software for PCs and workstations in order to "facilitate" our lives when, in actuality, their sheer numbers make us all the more confused. It would be advantageous to free ourselves of our cellular phones, pagers, electronic agendas, the files we have on our office PCs, and the tiny pieces of data that scattered everywhere in our attempt to organize our lives and have it all readily available at our fingertips and in one place. To do so, we must create an all-encompassing and ubiquitous/pervasive computational environment that allows "computers… …to enter the human world rather than the other way around." [3]. That is, computers should adapt to our needs and make it easy to access our information and tools from any given location and to invisibly provide distributed and readily available computational power to its users [4]. This concept led to the birth and development of the Ambient Computational Environments project at the

Information and Telecommunication Technology Center at the University of Kansas [5].

ACE, as it is referred to, and its structure is an intricate system of services all interconnected via a large computer network to provide a wide range of capabilities to its clients and users. These services must coexist and work together seamlessly to provide a long-lived and robust environment where users can access computational resources on demand.

In order for these services to provide such invisible integration of capabilities within a highly complex system it becomes necessary to develop a very modular and flexible service infrastructure. Here, an outline and a detailed description of the top-level view of the entire ACE service architecture shall be given. This document covers the basic infrastructure of the ACE system, the types of services it can and should provide, and how all these services interact to accomplish their tasks and serve ACE users. This document is intended to be an all encompassing bird's eye view description of ACE and its architecture.

This architecture is divided into many unique application and design areas, all of which shall be discussed in this paper. These main areas are as follows: **ACE users and human interaction** with widespread service accessibility (including user work contexts); **ACE service daemon infrastructure**; **ACE security and authentication**; **basic ACE framework services**; **ACE user applications** (including some legacy apps), and **persistent store**.

All of the design elements that shall be discussed here have either already been implemented and tested or are currently under development. At the conclusion of this paper, some scenarios shall be presented, some insight shall be given into related projects, and suggestions and improvements for future ACE work shall be presented.

So, before continuing and further delving into the ACE architecture, some terminology and concepts must be defined and discussed.

1.1 ACE Services and ACE Users

What exactly is the concept of an ACE service? An ACE service is any computational, data access, or multimedia resource provided by an ACE to an ACE user or another ACE service. Examples of this would be PTZ – Pan Tilt Zoom camera controls, data storage or general-purpose applications, user identification readers, etc. Note that unlike many other similar projects [6][7] ACE considers all capabilities and resources made available to end consumers to be ACE services. Exactly how these services are designed and how they interact shall be further discussed later. So who are the end consumers of these services?

They are the ACE users. ACE users can be separated into two main categories: human users and non-human users. Non-human users are high-level applications that utilize ACE services on their own to provide automation within an

ACE. Examples of this would be video monitoring systems, personnel tracking systems, etc.

The bulk of ACE system usage shall come from human users. These shall be the focus of this paper. Furthermore, from now on, ACE users shall strictly refer to human users.

Human users are the ones who shall be accessing an ACE environment given proper identification and calling on ACE services to command devices and utilize the ACE distributed computing power.

1.2 Human Interaction Within ACE

ACE users can utilize an ACE in various and unlimited ways. It all depends on the services that are defined within a specific ACE and how these are interconnected to provide specific functionality.

ACE users can interact with an ACE through various different ACE enabled devices. In order for a device to be ACE enabled, it must have low-level interface software developed for it so that ACE services may communicate with them and provide ACE users with access to their capabilities. Such devices include PTZ (Pan-Tilt-Zoom) cameras, projectors, identification devices such as fingerprint scanners and iButton readers [12], etc. Other devices such as notebooks, picturebooks, PDAs (Personal Digital Assistants), and workstations simply serve as networked access

points to the ACE network. These devices can be placed throughout an ACE within conference rooms, offices, hallways, and even automobiles.

FIGURE 1: EXAMPLES OF ACE INTERACTION DEVICES.

User interaction isn't limited to the devices mentioned above. Many forms of interaction with an ACE shall come from high-level programs and GUIs (Graphical User Interfaces) intended to accept ACE user commands, interpret these commands, and call on other ACE services to execute them.

Below is a picture of one of the graphical user interfaces already implemented and working within our current version of ACE. This GUI is an example of how users may access an ACE and control devices and services available.

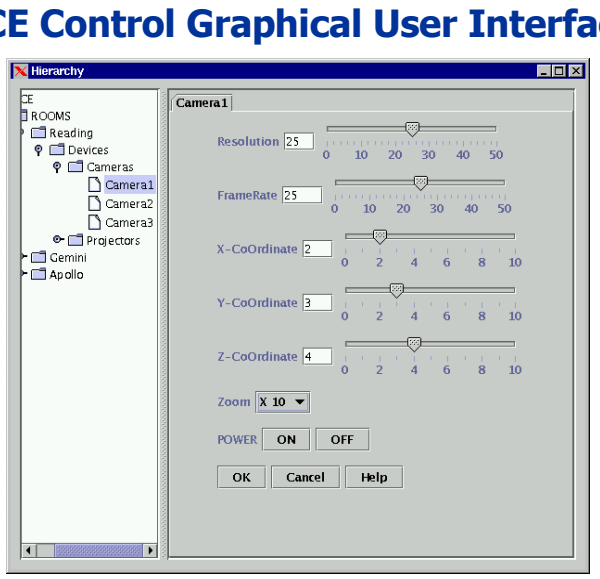

FIGURE 2: AN EXAMPLE OF AN ACE SERVICE CONTROL GUI.

On the left side, available ACE services and devices are listed in a hierarchical tree fashion based on their location within ACE (e.g. specific rooms in a building). By selecting a service or device on the left side, the appropriate parameter controls are displayed to the right. The example seen in the GUI above is for the PTZ camera. Notice that the right side allows the user to control parameters such as x, y, and z spatial coordinates of where the camera is pointed at, the resolution and frame rate of image capturing, zoom factor, and also provides an on/off button to switch the camera on and off.

Examples of other user interaction software are voice recognition systems, voice command interpreters, computer speech synthesis systems, device control

graphical interfaces, face and gesture recognition systems, sound triangulation systems, user locators and trackers, audio and video streaming, telephone over IP systems, etc.

All these devices and software services are integrated into the ACE architecture and infrastructure (which shall be further discussed below) and thus can easily communicate with each other and form a seamless network of services.

FIGURE 3: SOME OTHER ACE USER INTERACTION DEVICES (DSC IBUTTON [12], SONY FIU [14], COMPAQ IPAC [15], SONY VAIO NOTEBOOKS [16], SONY VAIO PICTUREBOOKS [17]).

1.3 ACE User Workspaces

Another significant form of access that an ACE provides for its users is a user workspace. An ACE user workspace is a virtual computational space/environment that a user may utilize to run his/her applications and access the ACE network. This virtual space is defined physically as the graphical space on a terminal or workstation screen where a user's file space can be accessed, applications and programs can be executed, and computational power utilized.

A user may have more than one instance of a workspace defined for him/herself. In each workspace the user may run different programs while accessing the same user file space.

In an ACE, a user may identify him/herself via an ACE identification device in order to have his/her active workspace brought up on demand independent of where the user is within the environment. Through his/her active workspace, the user may bring up necessary files and run desired applications. Then, upon leaving or logging off from a certain access location within an ACE, the workspace and its current state are maintained. The user can then pick up where he/she left off at another access point at a later time.

In a sense, a workspace is a virtual version of a user's personal desktop computer. The difference is that it has no physical dimensions. Therefore it may be taken immediately to an access location where the user is and utilized on demand.

Chapter 2

ACE Service Daemon Infrastructure

As mentioned before, an ACE service can be any capability provided by ACE whether this be data processing, data input, data storage, data transmission, device control, network access, etc. In order to provide ACE users with a wide range of distributed services and as part of the ACE requirements of modularity and flexibility, it became obvious that ACE in itself would not be a single all knowing omnipotent computational entity that controlled all sub-environments within a single ACE. In fact, the concept of ACE required much the opposite style of computing where small, independent, and distributed systems work together to endow ACE with its unique capabilities. These simple systems can then come together like building blocks or lego pieces to provide more complex functionalities, output, and/or behavior.

This reasoning led to the design of a basic ACE service daemon that is responsible for performing a single, unique, and well defined function within the ACE infrastructure. Thus, different and specialized daemons comprise the building blocks of the ACE world. These are the independent pieces that work together to provide a variety of more complex services/capabilities within ACE.

These unique services/daemons act as independent entities with unique capabilities and can serve as both consumers and producers of services to any other

service. They must communicate with each other in a common all encompassing language that can be easily decomposed and interpreted for issuing commands and transmitting data. The diagram below depicts this concept.

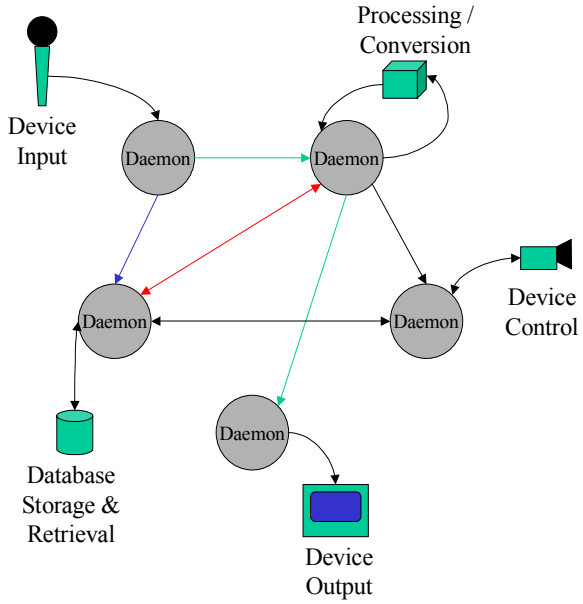

FIGURE 4: HOW ACE SERVICE DAEMONS INTERACT TO PROVIDE COMPLEX CAPABILITIES AND COMPUTATION.

2.1 The ACE Service Daemon

Each service and/or device within an ACE is controlled directly by a unique instance of an ACE service daemon. This daemon is responsible for being an intermediary between the service/device control platform and the client wishing to

utilize the service/device. Note here that when a reference is made to a "client" within an ACE that may refer to any kind of entity attempting to communicate and/or request services from an ACE daemon. Such an entity may be a simple client program or yet another ACE service daemon.

The daemon provides a structure for encrypted and certified socket communications, service registration, and lease renewal (all of which shall be discussed later). With this framework in place, implementing a service daemon and along with all its necessary functions and command language semantic definitions (based on an ACE command language - explained later) becomes a simple, standard, and modular task. As services are implemented these can then be made to talk to one another and provide services to one another. Thus building a complex system of ACE services becomes a matter of simply defining functions and proper interface commands between such services.

Each ACE daemon runs on its own thread of execution and thus is an independent entity and may be run on separate machines spread throughout an ACE network. Furthermore, each machine/computing system in an ACE may have one or more ACE service daemons running within it, each providing a specific service.

2.1.1 Daemon Design

The statement made earlier about each daemon running on its own thread of execution is true to a certain extent. It is true in that each daemon becomes a single and independent entity as far as executing code and providing services.

In fact, each daemon consists of four threads that continuously run to endow the ACE service daemon with its communication and service rendering capabilities. These threads are the main thread, the command thread, the data thread, and the control thread. The command thread is the only one created on a per connection basis. Therefore a daemon may have more than one command thread running.

Each of these threads work independently of each other when communicating with other daemons and when providing services. This is done in order to take advantage of concurrency within multiprocessor machines running these daemons and to separate communications from control and data streaming capabilities required of an ACE daemon.

The main thread is responsible for initializing the daemon upon startup (service registration, KeyNote authentication, etc) and managing the other threads. The command thread handles the creation of socket communications between a client and the service daemon itself and listens on the incoming connection for commands. The data thread is responsible for handling any data stream operations over a UDP channel. The control thread handles the execution of commands sent in through the command thread and to service notifications if necessary.

All communications between these threads are carried out over message queues that trigger actions as these messages are sent from one thread to another.

From this setup, ACE daemons become very independent and highly efficient shells that serve as the basis for ACE services. As services are performed or commands executed, more messages can be received, and others may be sent out, all independent of each other and concurrently.

2.2 ACE Service Command Language

As previously stated, the services within ACE share a common control language. This language is used by the ACE daemons to communicate both data and service commands to each other.

The structure of this command language is based on the simple command and arguments construction much like that seen in a regular Unix environment and contains a few simple data types. Below is the syntactic definition of the ACE command language.

```
<CMND> := <CMNDNAME><space>[<ARGLIST>];
<CMNDNAME> := <WORD>
<ARGLIST> := | <ARGUMENT> | <ARGUMENT><space><ARGLIST> |
             <ARGUMENT>',''<ARGLIST>
<ARGUMENT> := <ARGNAME>'='<ARGVALUE>
<ARGVALUE> := <INTEGER> | <FLOAT> | <WORD> | <STRING> |
          <VECTOR> | <ARRAY>
```

```
<INTEGER> := <any integer valued number>

<FLOAT> := <any real valued number>

<WORD> := <contiguous alphanumeric & underscore>;

<STRING> := <WORD> | "<contiguous printable characters>"

<VECTOR> := {[<INTEGER>]',’…} | {[<FLOAT>]',’…} |

        {[<WORD>]',’…} | {[<STRING>]',’…}

<ARRAY> := {<VECTOR_LIST>}

<VECTOR_LIST> := <VECTOR> | <VECTOR>','<VECTOR_LIST>
```

For each unique daemon implementation, a set of command and argument semantics must be defined, within the basic language structure, and tailored to fit the specific capabilities of that service daemon. That is, for each daemon that is implemented for a specific service there must also have been defined for it the commands that it'll understand, execute, and return (return commands are used to reply on the status of the attempted command such as successful or failed) and the arguments that go along with those commands.

All this syntactic and semantic content is stored within a basic ACE service command data structure used by ACE clients and daemons. This object that is used for containing and communicating ACE commands is called the `ACECmdLine` object. Every command that is to be issued to an ACE service is first built as an `ACECmdLine` object. This object is then converted into a string by the issuing client/daemon and is then transmitted over the network to the receiving side. Once

received, this string is used to construct an exact copy of the `ACECmdLine` object by means of the ACE Command Parser. This parser, built uniquely for the ACE project service daemons, checks the incoming string for syntactic and semantic correctness (against those parameters defined within the receiving daemon/service) and the new `ACECmdLine` object is constructed. Once this is done, the recipient may access the transmitted content of the command in order to perform its task. The diagram below depicts this process.

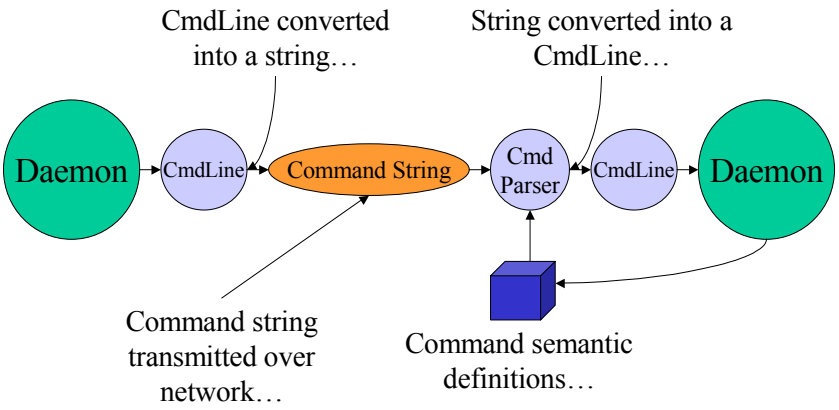

FIGURE 5: HOW ACE COMMANDS ARE BUILT, TRANSMITTED, AND INTERPRETED FOR ACE DAEMON COMMUNICATIONS.

As can be seen, providing ACE with a unique and simple command language allows for a very lightweight form of communication between services and clients. A

form of communication that is much more lightweight than utilizing something like RMI.

2.3 ACE Service Daemon Hierarchy & Service Implementation

Another significant aspect of the ACE daemon infrastructure is its modularity and ease of integration into the existing architecture.

The basic service daemon is primarily composed of three modules: the daemon itself (implementation), the service's command semantics, and the command interface to that daemon. Each daemon command interface provides the means by which users and other services access and command service daemons through the network.

The service daemon itself is what executes the commands it receives, operating on data, performing calculations, or serving as yet another interface to something like a database or GUI.

The service semantics define the ACE commands and arguments to those commands that are valid and understandable by the service daemon. These semantics are used in the construction and parsing of service commands that are transmitted from one daemon or client to another as was seen in the section 5.2 above.

Finally, the command interface is what provides users and client programs the means by which to execute or request services from service daemons. These

interfaces are arranged in a hierarchical manner. In this way, child nodes inherit methods, characteristics, and actions from the parent nodes. This inheritance is achieved through the Java API utilized to create our daemon infrastructure. With this structure, it is easy to develop different services and integrate them into the current infrastructure. Additionally, with this type of inheritance structure, child nodes can be developed to be like their parent nodes but with additional functionalities.

As can be seen from the hierarchy diagram below (Figure 6), all services inherit from a basic service daemon. These are then divided into more types of services (only database and device are illustrated here). These in turn define other child database and device control services. Finally, the device control services can be further specialized for specific models of PTZ cameras and projectors.

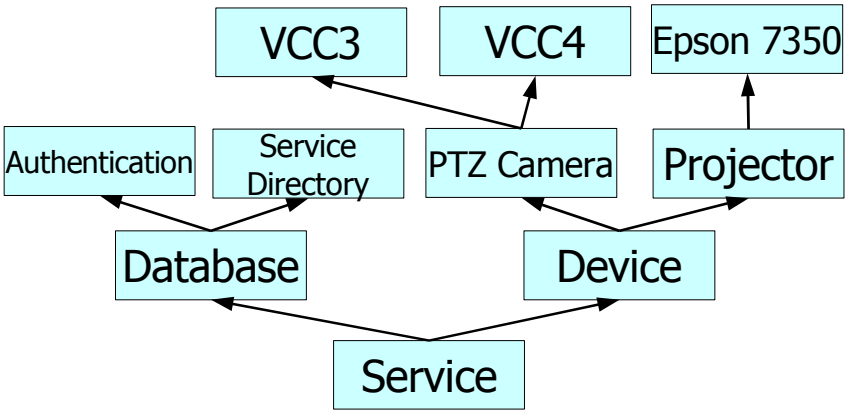

FIGURE 6: A PART OF THE ACE SERVICE DAEMON HIERARCHY.

With this infrastructure, new services can be brought online quickly and painlessly. Device and service specific portions of new services to be added are isolated to prevent complete re-coding of service daemon specific framework. Also, changes to the service designs and to their commands can be easily made and propagated to all child services.

Another advantage of this modular daemon design is that the underlying details of the service implementation are completely hidden from the client and its programmer. All that needs to be known is the command interface to the service and how to utilize it to obtain the capabilities needed.

2.4 Service Discovery – ACE Service Directory

If so many different and unique services can be made available within the ACE infrastructure, how does one service find another? With services distributed throughout the environment it becomes necessary to provide other services and clients with the ability to quickly find and connect to desired daemons for specific needs. ACE needs to provide services with this capability. A capability similar to a DNS in which a central location or server can be queried for finding specific machines within a network. ACE needs to supply services with the proper information for finding other services within the ACE network.

Within this daemon infrastructure it became sensible to make such lookup and discovery ability yet another service provided by an ACE daemon. This service is

called the ACE Service Directory – ASD. It serves as a central listing or directory of services currently available and running within the ACE environment. Any and all ACE services currently active automatically register themselves with the ASD service (the location of which is known to all ACE daemons) so that other services and clients know that it is active and available.

Registered services also automatically remove themselves from the ASD registry upon shutdown by properly informing the ASD service of their removal.

Furthermore, if services become inactive due to programming errors or system crashes, the ASD removes those services from its listing so that other services don't waste time and resources attempting to connect to a defunct ACE service. The simple mechanism that has been implemented to do so is to create service leases within the ASD. Upon registration with the ASD, each ACE service is given a lease time for which they'll be allowed to remain within the ASD listing. If a registered service fails to renew its service lease with the ASD upon lease time expiration, this service shall automatically be removed from the ASD. In order to remain in the ASD, services must periodically issue service lease renewals with the ASD so that they may remain registered within it. This mechanism accounts for the system failures mentioned earlier whereby daemons that become inactive due to malfunction are automatically removed from the ASD once their service lease expires.

The next diagram (figure 7) demonstrates how the ASD is used.

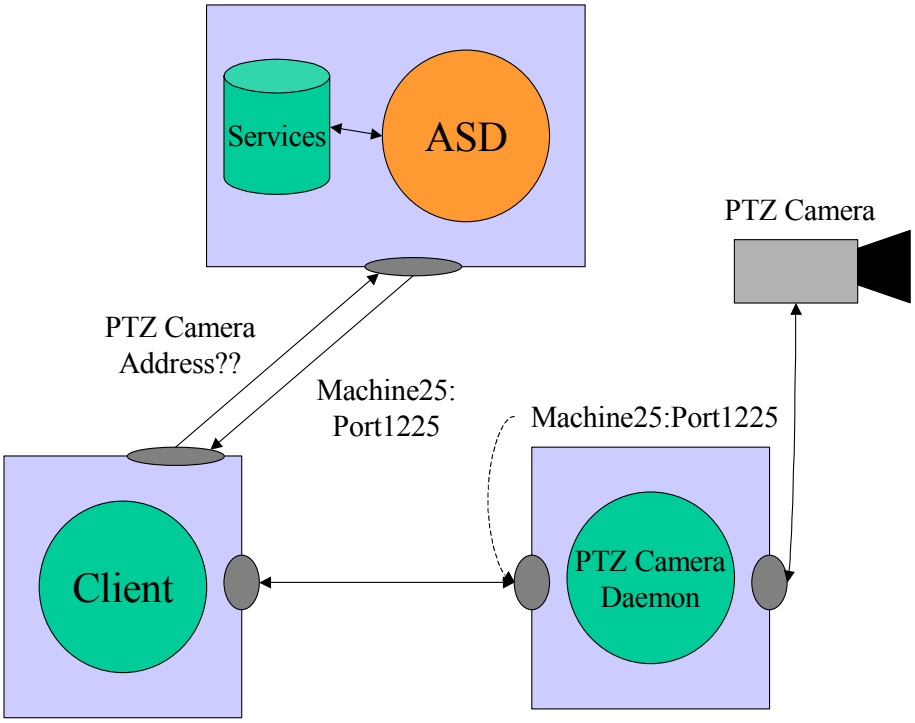

FIGURE 7: AN EXAMPLE OF HOW SERVICES INTERACT WITH THE ASD FOR SERVICE LOOKUP.

Here a client program wishes to communicate with a PTZ Camera service. By knowing the fixed socket location of the ASD, the program inquires if there are any PTZ camera services available and if so, where. The ASD looks up its database of currently active services and finds a PTZ camera service available and responds with the machine and port address of that service. Once the reply is received, the client program opens a socket connection to the service at the address specified by the ASD and begins controlling the camera at that location via ACE commands to the PTZ camera daemon.

2.5 ACE Daemon Notifications

Another important component of an ACE service are notification commands. The basic ACE daemon has incorporated within it the capability of notifying interested parties (other services) of specific commands that have been issued and executed.

This capability is what is called "ACE service notifications" and it is inherent in all ACE daemons within the Service level (see section 5.3 above). Simply put, all ACE daemons have notification commands semantically and syntactically defined for them (i.e. within the ACE command language). These commands allow ACE services to keep a running list of all other ACE commands that are being "listened" for and all the ACE services that are to be notified when such commands are executed.

For instance, let's say that an ACE PTZ camera daemon is running within an ACE conference room. Also, consider a basic requirement that whenever a new person identifies him/herself at the door, that the camera point towards the door in order to visualize the new user walking into the room.

In order for this to occur, a user identification daemon (that controls the identification of users at specific ID devices) must notify the camera daemon that a new user has been positively identified at the room door and is walking in. This prompts the camera to turn towards the door and visualize the user.

The diagram below (Figure 8) depicts the details of this concept.

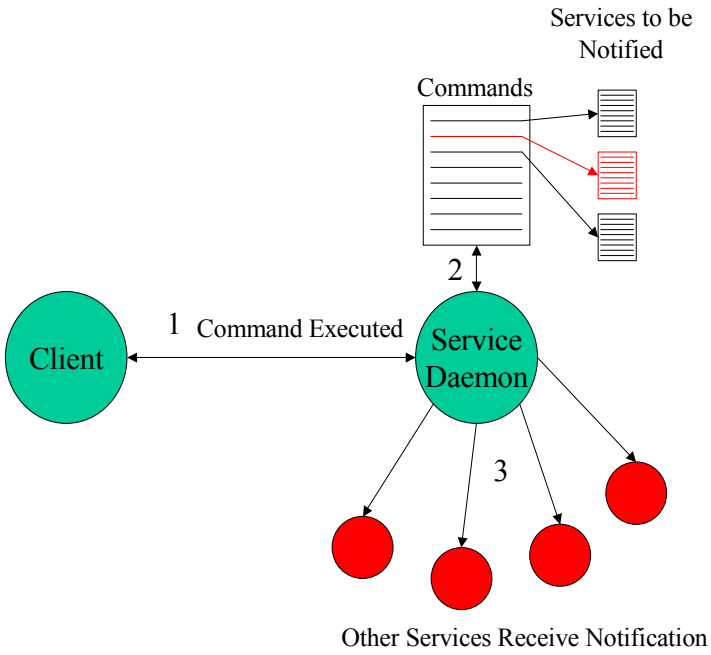

FIGURE 8: ACE SERVICE NOTIFICATIONS – AN INHERENT ASPECT/CAPABILITY OF ACE SERVICE DAEMONS. SERVICES KEEP RUNNING LISTS OF WHICH SERVICES TO NOTIFY WHEN CERTAIN COMMANDS HAVE BEEN EXECUTED BY THE DAEMON.

Above a client connects to a "Service Daemon" and issues an ACE command (1). This daemon then looks up its list of commands to see if the command issued is a command that prompts a notification and if so, which existing services need to be notified for this command (2). Once the services that require a notification are looked up by the daemon, the appropriate methods in those other services are invoked thus

effectively notifying these services that a specific command has been executed for the service daemon at hand (3).

What exactly does it mean to receive a notification and have appropriate methods invoked? Furthermore, how do services get added to the notification list to begin with? When a service deems it necessary to be notified of a specific command (call this the notified service) within some other service (call this the notifying service), they issue an "addNotification" command to the notifying service either at startup or later. This effectively adds the method name of the command interface object (as seen in section 5.3 above) of the notified service to the list of services to notify. Once a command is executed within the notifying service, all appropriate command interfaces of services to be notified are referenced and the listed interface methods are invoked on those services. This is what it means to receive a notification.

This capability is very useful for ACE services in that these can now react to changes in the environment and appropriately respond to user actions and adapt to environment activity, crashes, and conflicts simply by notifying each other of such changes.

2.6 Daemon Startup

Before each unique ACE daemon may start performing the service it was intended to provide, it must go through a set of simple yet necessary initialization

steps within ACE to establish itself with its surroundings, register itself, and record its existence.

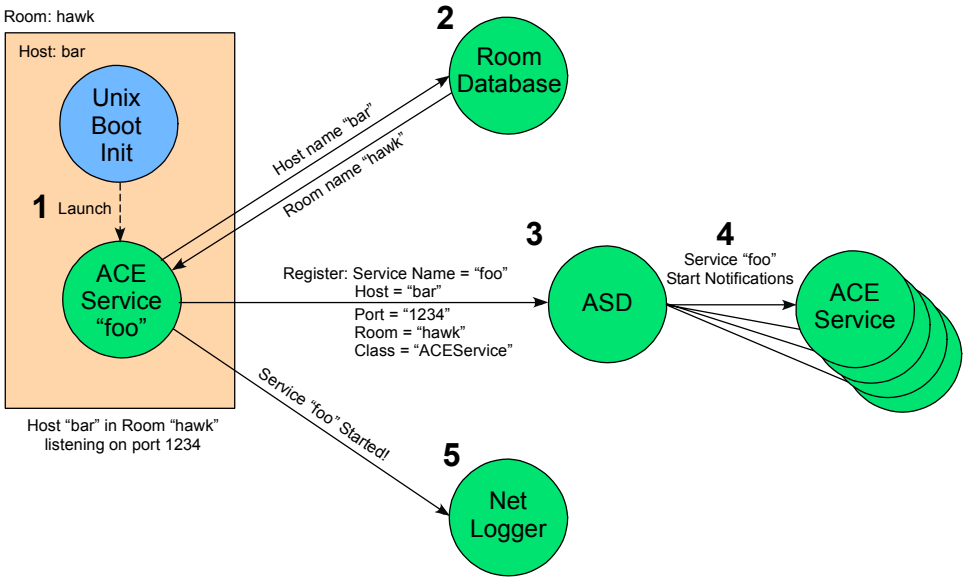

FIGURE 9: A STEP-BY-STEP PROCESS THAT ALL ACE DAEMONS GO THROUGH TO INITIALIZE THEMSELVES INTO AN ACE.

Consider the diagram above. Upon booting, the Unix machine "bar" automatically launches the ACE service "foo" (1). The first immediate step the service "foo" takes after initializing itself and its socket connection on port 1234 is to contact the ACE Room Database service (discussed later) in order to establish its location and surroundings and to place itself in the room database as one of the available services in room "hawk" (2). Next, the service contacts the ASD on a known socket and registers its information there so that other services in ACE are able to find it (3). This registration may trigger notifications to other ACE services (if any are awaiting notifications on it) that this new service "foo" is now running and

available (4). Finally, “foo” contacts the net logging service to register for historical purposes that the service “foo” has started on host “bar” (5).

Once these steps are complete, the service can now begin performing the actions it was programmed to do.

Chapter 3

ACE Security and Authentication

In this section, ACE security measures shall be discussed. These are necessary to make ACE a network where only valid users with proper permissions may run applications, access files, and transmit information in a secure fashion.

3.1 ACE Communications

As with any network environment, the communication framework must provide a means of relaying information from point A to point B in a secure manner.

The security mechanism that has been incorporated into the ACE service infrastructure in order to make sure that the communication between services and clients is secure from eavesdroppers and unauthorized entities is the use of SSL

All ACE communications from one service to another is encrypted using SSL (Secure Socket Layer) encryption. All the service commands using the ACE command language and all data transferred between ACE services are encrypted in this fashion at the socket level.

3.2 ACE Service Access and Authentication

Within an ACE network ACE users must be given access to underlying network and also be registered with ACE in order to access and utilize ACE services. In order to be properly identified within an ACE the user must first access an ACE user identification device such as a fingerprint scanner, an iButton reader, or a badge reader. Once this is done and the user has been identified, he/she may access the services within an ACE. Unfortunately, being a valid ACE user does not get a user far if he/she doesn't have valid permissions.

In ACE, both users and services are restricted in the use of other services and what commands may be issued. For this purpose, the KeyNote trust management system [8] has been integrated into the ACE service infrastructure. Both users and services shall have credentials and assertions defined for what can and can't be done within an ACE. These credentials control what commands can be issued, what services can be accessed, what connections can be made, for how long services can be utilized, how much of computing resources may be consumed, etc.

Below is an example of how ACE services verify permissions for a simple ACE service.

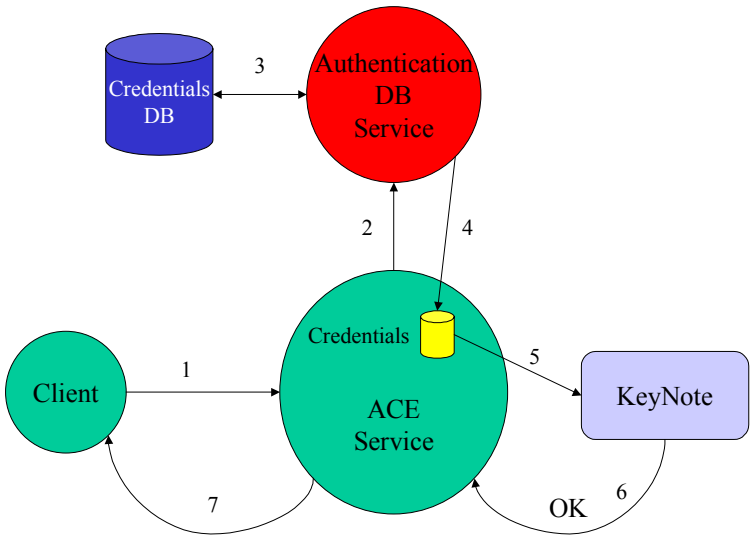

FIGURE 10: A DEPICTION OF HOW THE ACE SERVICE INFRASTRUCTURE WORKS WITH AN AUTHENTICATION DATABASE SERVICE TO STORE AND MANAGE KEYNOTE CREDENTIALS AND ASSERTIONS IN ORDER TO VERIFY USER PERMISSIONS AND SYSTEM ACCESS TO ACE SERVICES AND INFORMATION.

In this example, a client wishes to execute a command on an ACE service (1). The ACE service recognizes that a command is about to be executed by a specific client and goes on to request the available KeyNote credentials and assertions for this command and for this specific client from the Authentication Database Service (2). This service serves as an interface to the storage and access of credentials and assertions to other ACE services wishing to verify client trust. The Authentication DB service looks up the necessary information from the database (3) and returns the requested information to the ACE service (4). The ACE service then forwards this

information to the KeyNote trust management system (5), which verifies that the provided credentials and assertions are valid for this type of client and action. Then either an OK or a NOT OK is replied back to the ACE service as to the validity of the client's permissions. In this case, the OK is given (6) and the ACE service performs the command requested by the client and returns the result of the executed command to the client (7). Had a NOT OK been given, the ACE service would refuse to execute the requested command replying that the client did not have valid permissions for the attempted command.

Chapter 4

Basic ACE Services

With the basic concept of ACE and the main daemon framework in place, basic ACE services that interact with one another and provide a basis for other higher-level services to be built upon can be constructed.

In this section, some of the basic services that have already been implemented shall be presented. These services work together to provide ACE with the accessibility, robustness, and distributiveness that are the main goals behind an Ambient Computational Environment concept. These services work together to provide the following ACE capabilities: virtual user workspaces, user registration, identification, and authentication, service discovery, data conversion and distribution, and network logging.

One of these services has already been seen – the ASD – since this was necessary to understand the basic service discovery within the daemon infrastructure. Now, some of the other services that provide the basis for the capabilities mentioned above shall be examined.

4.1 HRM – Host Resource Monitor

The host resource monitor service provides computational and network resource status on a single host (the same host this service runs on). The HRM provides this information in one of two possible ways. It may supply this information via notification commands (section 5.5 above) to services that request to be notified or it may be queried for specific information by other services/clients.

Some of the information that is reported by the HRM to requesting services include host CPU load, CPU speed (in bogomips), network traffic load, total and available memory, and disk storage capabilities and size.

This service shall work in unison with other services to provide ACE with its distributed and service robustness qualities (detailed in sections to come).

4.2 SRM – System Resource Monitor

The system resource monitor provides much the same kind of information as the HRM service but is different in that it serves as the resource monitor for all the machines running in an ACE environment. As described above, it communicates with all HRMs below it in order to monitor all computing resources at a system wide level thus allowing for uniform allocation and distribution of ACE system resources. It also serves as the resource allocation interface between clients wishing to run applications within ACE and single hosts executing these applications.

The following diagram shows this relationship.

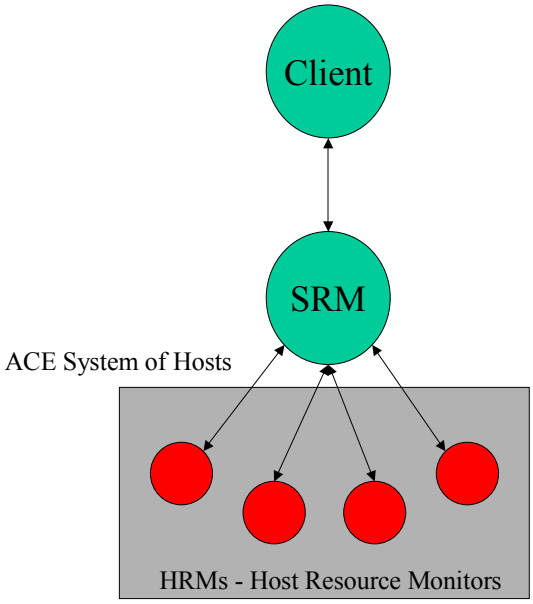

FIGURE 11: HOW HRM'S WORK TOGETHER WITH A LOCAL NETWORK LEVEL SRM TO PROVIDE CLIENTS WITH INVISIBLE DISTRIBUTION OF COMPUTATIONAL RESOURCES.

4.3 HAL – Host Application Launcher

The Host Application Launcher (HAL) is responsible for running/launching any type of application on specific hosts. If a client wishes to run a certain program or application on a host, it must first connect to the HAL and request that a specific application be launched. The HAL then simply runs the requested program on a selected host utilizing the host's local resources.

4.4 SAL – System Application Launcher

The System Application Launcher or SAL is responsible for running a specific program or application within an ACE local network. Much like an SRM communicates with one or more HRMs below it to distribute computational resources, the SAL delegates the responsibility of launching applications within an ACE to its underlying HALs. Like an HRM, a HAL also resides locally on the host it launches applications on.

If an ACE client wishes to run a specific application, it requests that that be done to the SAL. The SAL then finds an appropriate HAL to launch the application (randomly or by resource allocation by communicating with the SRM) and delegates that responsibility to that chosen HAL. The HAL then runs the requested application locally on its host.

4.5 WSS – Workspace Server

Another important ACE service is called the Workspace Server. This ACE service is responsible for creating and removing user workspaces as these get created and closed by users. It is also responsible for naming and keeping track of instances of these workspaces that are created for specific users.

Remember from section 4 above, that a user workspace is a virtual area where the user runs his/her programs and accesses his/her information. Also remember that

a user may have more than one user workspace running, thus it becomes necessary to manage these workspaces for each individual ACE user.

An example of how this service works to provide users with virtual workspaces shall be given in section 10 below where most of these services shall be integrated into some typical ACE usage scenarios.

4.6 ACE ID Monitor Service

This service has the unique job of receiving user identification notifications (refer to section 5.5 for daemon notifications) from ACE identification devices (such as a fingerprint scanner service) and initiating the appropriate actions to account for a positive or negative identification notification.

For instance, let's say a user wants to have his/her workspace show up on the screen of an access station after identifying him/herself via a fingerprint scanner. The user presses his/her fingerprint to the scanner and is positively identified. The identification device service sends a positive user identification notification to the ID monitor. This in turn causes the ID monitor to call the workspace server to start up a workspace viewer on the access station's screen. If the user is not identified as a valid user, the ID monitor can then call the appropriate services to deal with that situation (e.g. if one wants to get extreme, call the FBI alerting service and notify them of an intruder that must be arrested immediately).

4.7 AUD – ACE User Database Service

In order for any person to interact with an ACE he or she must be a valid ACE user. What does this mean? It means that the person is not only a registered user within the local computer network but also a user registered within ACE. In order to register a user with ACE, the user must register basic information such as username, password, full name, identification number (e.g. iButton #, fingerprint scan data, etc), and public key (hence the reason why the user must be a valid user within the LAN) with an ACE user management service. This service should manage users and their information so that other services may or may not grant access to people wishing to utilize ACE. Such a service must communicate with yet another service called the ACE User Database.

This service is simply an ACE interface to a database of valid ACE users and their pertinent information. The AUD takes insertion and selection query requests from other authorized ACE services to lookup and modify the database of ACE users. Access to this service and the user information is not limited to an ACE user manager but to all other authorized ACE services that wish to find out some information about a user or users they interact with.

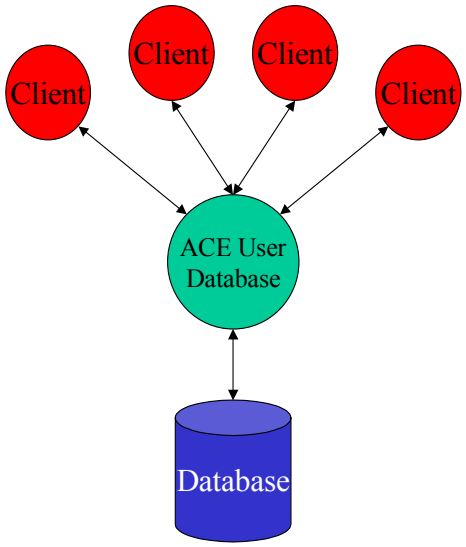

FIGURE 12: AN ACE USER DATABASE SERVES AS AN INTERFACE FOR SERVICES WISHING TO STORE AND/OR ACCESS USER IDENTIFICATION INFORMATION FROM THE DATABASE.

4.8 ACE FIU – Fingerprint Identification Unit

This service is a simple controller interface for the Sony fingerprint identification unit model FIU-001/500 [13]. This service communicates directly to the FIU, loading its tables of known fingerprints, querying it for identification of user fingerprints, and serving as an interface to other ACE services wishing to identify someone and/or receive identification notifications.

So, in other words, the FIU service has been implemented to identify ACE users via their fingerprints serving as an interface to the Sony FIU device.

4.9 ACE IButton Reader Service

The IButton service is yet another user identification service that simply interfaces to the IButton reader [12]. The IButton is a simple solid-state memory device that stores a unique serial number (see figure 3 above). When associated with a user, it may be used as an identification device. This ACE service serves to read these numbers from the IButton reader, identify users based on known users and their serial numbers stored in the AUD, and interface to other ACE services wishing to identify someone and/or receive identification notifications.

4.10 ACE Authorization Database Service

This service, much like the AUD, is a database interface service that stores user and client service authorization assertions. This service is utilized by ACE services to lookup certificate assertions for users and other services attempting to execute specific commands within ACE. These assertions are passed onto KeyNote, which is used to determine if a proper assertion or chain of assertions are present thus giving the client permission to perform specific actions.

This service was already introduced and exemplified as part of section 6.2 above.

4.11 ACE Room Database Service

In order for ACE services to be spatially aware of their surroundings and also have some knowledge of where they reside within an ACE, their location information (along with other data) is kept within an ACE Room Database service. This service is responsible for storing and supplying services with information such as building names, room names, names of services located within specific rooms, physical location of these services in the room, physical dimensions of the room (for modeling and logistical purposes), etc. For instance, for a user to control a camera daemon and tell it to move to a specific position within the room, the camera needs to be spatially aware of its environment. That is, it needs to know where it is located with respect to locations and other objects within the room so that it may establish a 3D coordinate system for referencing the room space. Furthermore, services need to know what other services are in the room so that they may provide users with capabilities at specific locations within an ACE.

4.12 ACE Converter Service

The ACE Converter service is basically what it states it is. It performs data conversion from one format to another. For example, if video information was being transferred from a camera in the ACE to a file managing system (that is, some video information was being recorded onto disk) some kind of format conversion (or compression) should be applied before this data can be stored. In order to do so, an ACE converter is placed in between the video capture service and the file storage service. It takes the raw video stream from the camera, converts it to a format such as MPEG, and sends it to the file manager service for storage.

This service isn't limited to this type of conversion. It is capable of converting from one format to another from a set of known formats. The diagram of this simple example is shown below.

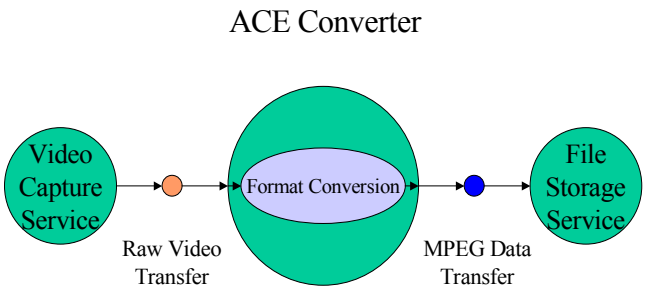

FIGURE 13: AN EXAMPLE OF HOW A VIDEO STREAM IS SENT THROUGH AN ACE CONVERTER SERVICE FOR FORMAT CONVERSION BEFORE DATA STORAGE/USAGE.

4.13 ACE Distribution Service

Yet another low-level data transfer service available in ACE is the ACE Distribution Service. This daemon takes in an input data stream and a set of known destination services and forwards this data onto a set of one or more other services that request that data.

Below is an example of a distribution daemon working to supply a set of ACE services with a video stream from a video capture service.

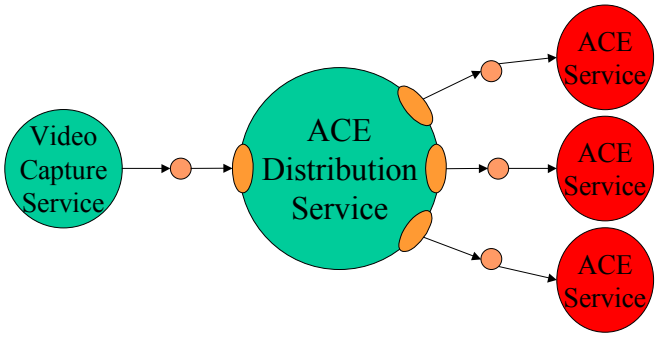

FIGURE 14: A DEPICTION OF AN ACE DISTRIBUTION SERVICE FORWARDS DATA FROM ONE SOURCE TO ONE OR MORE ACE SERVICES.

4.14 ACE Network Logger Service

Last but not least is the ACE Network Logger. This service is used mainly for security and debugging purposes within the ACE system. This service simply stores service activity information within a set of logging files. This is used mainly to record what kinds of activities are present within an ACE system and to serve as a history so that, if necessary, system administrators can investigate them for security holes or system bugs. An example of this would be an attempt of an invalid user to log into the system. If an unknown user attempts to log into the system an invalid identification error message along with pertinent details would be sent to the ACE Network Logger for recording (via ACE notifications). If this persisted (more than one attempt in different days) proper action could be taken to prevent the user for tampering with the system.

4.15 A High-Level Service Example

Suppose a high-level audio system needs to be built. It is needed to connect the audio signals of two remote sites/rooms and also include the output of a local ACE service (as audio output) so that audio conferencing could be performed. Furthermore, the conversation that is taking place needs to be recorded. A two-way audio stream connection in between the two sites is to be constructed. It needs to be

free of feedback and allow other local ACE services to pick up on possible voice commands to the local ACE by users in the rooms.

Consider the setup in figure 15 of the following basic ACE services:

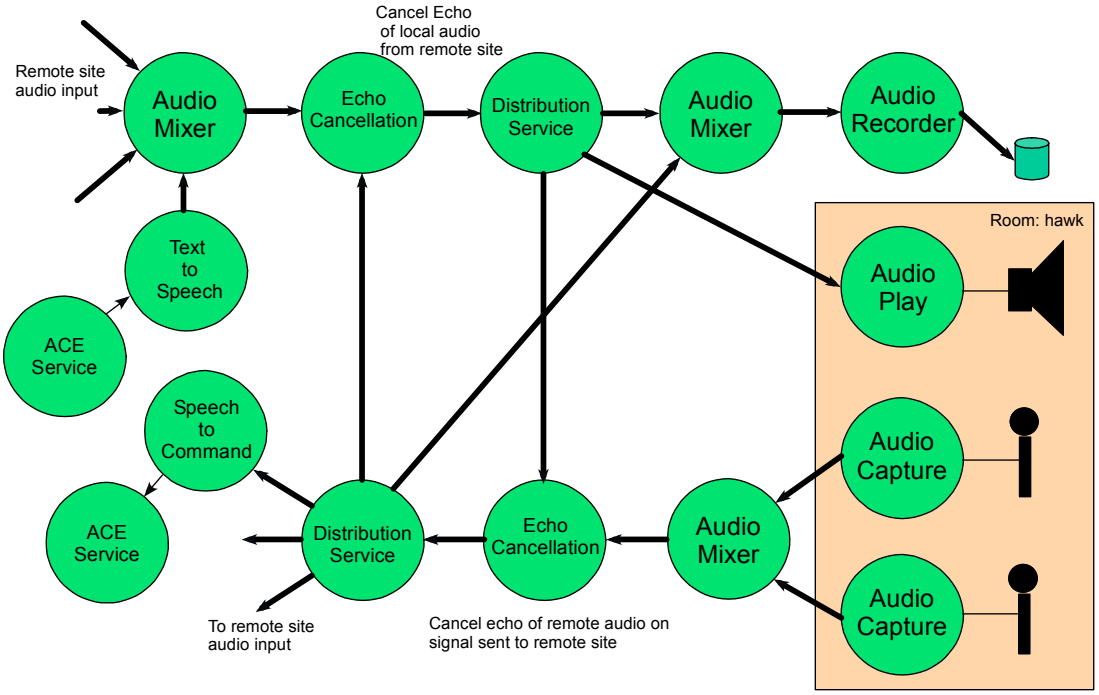

FIGURE 15: AN EXAMPLE OF HOW BASIC ACE SERVICES CAN BE COMBINED TO PERFORM HIGH-LEVEL AUDIO STREAMING, CONFERENCING, COMMANDING, AND RECORDING.

1) *Audio Mixer*

Combines multiple audio signals into one audio signal/stream.

2) *Text-to-Speech*

Converts text messages into an audible voice signal.

3) *Echo Cancellation*

Removes redundant audio signals (with an arbitrary amount of delay) from an input audio signal.

4) *Distribution Service*

Distributes a given signal/stream to a set of known ACE services wishing to receive the data.

5) *Audio Recorder*

Records on hard media a given input audio stream.

6) *Audio Play*

Plays an input audio signal on an output device such as a speaker.

7) *Audio Capture*

Captures an audio signal from a microphone and digitizes it so that it may be streamed across the network.

8) *Speech-to-Command*

Analyses an input audio signal for specific voice commands and converts them, if any, to a specific and well-known ACE service command message.

From the diagram above, it is clearly visible how audio mixer services along with distribution services can create a two-way audio stream allowing two-way communications in between the sites.

Also, echo cancellation services may receive both audio signals from both directions in order to correct for audio feedback.

An audio recording service connected to the distribution service allows the entire conferencing conversation to be recorded for historical purposes.

Finally, text-to-speech and speech-to-command services can be placed at the ends of the communications streams in order to provide ACE users with an interactive interface to commanding and receiving responses from local active ACE services.

Chapter 5

ACE User Applications

As has just been demonstrated, with the basic ACE services in place, other high-level services can then be constructed to provide users and administrators with easier access to the environment. These applications include user-friendly graphical interfaces to devices and services, legacy applications integrated with ACE, general purpose, communications, and data transfer applications, and administrative applications used to register users, delegate authority, and control ACE specific data.

In section 3, an example of a graphical user interface for controlling devices and services within ACE was demonstrated. Other legacy applications are also used in ACE. These applications were integrated and/or modified to be part of ACE. Some of these applications include VNC (Virtual Network Computing) from AT&T labs [9] and Gnome O-Phone [10]. Finally, some other ACE built applications have been included in the ACE system to utilize ACE resources and capabilities. These include audio & video capture and camera and projector control services.

Before delving into these applications, how these applications can be run within ACE (temporary, restart, and robust execution) must first be examined.

5.1 Temporary Applications

Within ACE any general-purpose application that is run on a user workspace or on an ACE machine is considered a temporary application. This is mainly due to the fact that such applications are not vital applications for the existence and operation of an ACE.

Examples of such applications are word processors, Internet browsers, office utilities, etc. These applications are allowed to crash and it is irrelevant to the ACE system as a whole whether or not these applications are executed again.

5.2 Restart Applications

Restart applications are those that need to be running within ACE in order for proper execution of ACE services but are allowed to crash or stop running for a small interval of time and must then be restarted.

Examples of such applications can be a user's default workspace, an ACE camera control service, the network logger (even though some activity information is lost), etc.

For this reason, these applications must be closely watched by other ACE services in order to make sure they are up and running and be restarted in case of a crash. Such a service has not yet been implemented but the ACE infrastructure makes this possible and easy to do. Notifications can be utilized to alert such watcher services of closed applications and can also work in conjunction with the ASD and the WSS to make sure such restart applications are up and running.

This type of service is the next step in our current development of ACE to ensure that applications that need to be up are always up and that they are restarted in case of a crash.

5.3 Robust Applications

Robust ACE applications are those that are extremely vital to the proper execution of ACE services and functioning of the system as a whole. Such applications must not be allowed to crash, can be moved from one host to another with minimal to no interruption of service, or have a backup redundant instance of the application ready to take over in case it does stop running.

Such applications are ACE user management applications (that register and identify users and distribute authorization), services such as the ASD and AUD, the workspace server, etc. If any of these applications die for a long period of time the consequences could be a partial to complete halt of ACE itself.

A basis for maintaining robustness of applications within ACE, as for restart applications, has also not been fully implemented in our current version of ACE. This endeavor is a complex one and must be developed closely with the work being done within the persistent store. This is also in its initial stage and further developments are still to come.

5.4 VNC & ACE User Workspaces

For a good part of this paper, the concept of user workspaces and how these are managed and utilized were discussed but no thought was given to what actually generates and controls a user's workspace. This is where VNC (Virtual Network Computing) from AT&T labs comes in [6].

This legacy application was taken, and its use slightly modified to fit the ACE infrastructure. VNC is used to emulate user workspaces and redirect them to appropriate ACE access points around the network.

VNC works in a client-server fashion. The VNC server as it is called, is responsible for actually housing or running the user's workspace, maintaining all state information, and accepting input and output to the workspace when it is being viewed/utilized by a user. The VNC client, or VNC viewer as it is called, is simply a client program that runs remotely on a simple network access point and connects to the VNC server. The server then redirects all I/O to that client/viewer thus allowing the user to remotely see and command his/her workspace that is running at the server location. Of course that in order for someone to access a workspace (i.e. run the VNC viewer) he/she must provide the proper user password to the VNC server so that proper access can be given. VNC also allows the user to have more than one running workspace at the VNC server. This way a user may have multiple workspaces for running different applications.

The diagram below shows a simple schematic of how VNC works by redirecting I/O to remote machine viewers.

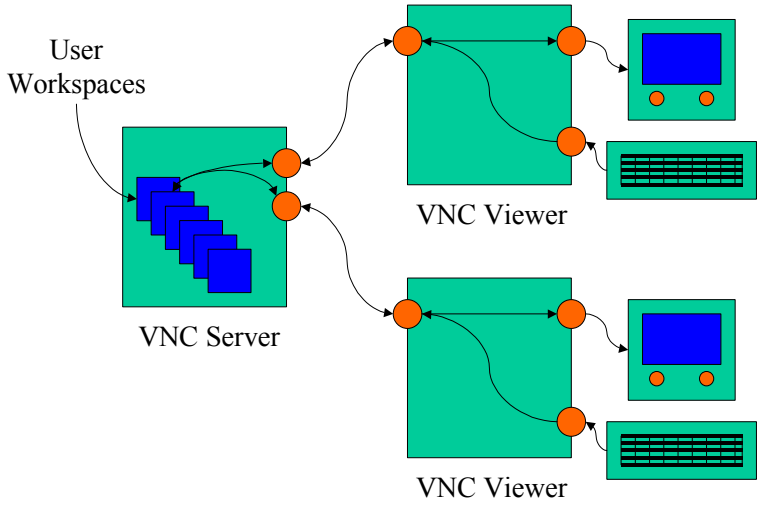

FIGURE 16: HOW VNC WORKS TO PROVIDE VIRTUAL USER WORKSPACE ACCESS FROM REMOTE ACCESS POINTS AROUND THE NETWORK WHILE RUNNING ON A SEPARATE HOST MACHINE.

VNC usage was slightly modified for ACE. As seen before, the WSS is responsible for managing user workspaces. It creates them, names them based on whose workspace it is and where it is running, and deletes them when needed. It must also verify user VNC passwords so that only valid users may see and access their running workspaces. The normal execution of a VNC viewer requires that the user input his/her password directly to VNC. Unfortunately, within ACE, the VNC

sessions are managed and controlled by the WSS. For this purpose, the VNC password files were directly accessed and modified by the WSS when new workspaces were created and when users accessed their workspaces from remote access points. This guaranteed that the password verification by VNC was made invisible to the normal ACE user. Simply by being a valid ACE user and properly identifying him/herself with one of the ACE identification devices/services (e.g. FIU unit), the user is allowed to access his/her workspaces via the WSS and VNC.

As was mentioned before, more insight shall be given to ACE workspaces and how these are run with the examples in section 10 below.

5.5 O-Phone & ACE Communications

Another open source, legacy application incorporated into ACE is called the O-Phone. This application enables full-duplex telephone communication over IP. Thus allowing users to call each other and even external phones from their workspaces. This frees up the user from having to be near a phone to make a call. If a valid ACE user is near an access point, he/she can bring up a workspace and make a phone call.

No major modifications were done to this application in order to incorporate it in ACE. It was merely adapted to work properly with our local network and can thus be run from any user workspace as a regular system application. No ACE GUI has

yet been developed for this application for ease with ACE usage. Creating an ACE GUI for this type of application is next in current ACE developments.

Chapter 6

ACE Persistent Store

For ACE to be deemed the robust and long-lived user environment for both data and running applications, a method of securely storing and retrieving data and application state information and guaranteeing their persistence needs to exist. For this reason it became necessary to develop persistent store structure and service for ACE.

The initial conceptual framework entails the use of three completely redundant and interconnected cluster of server systems.

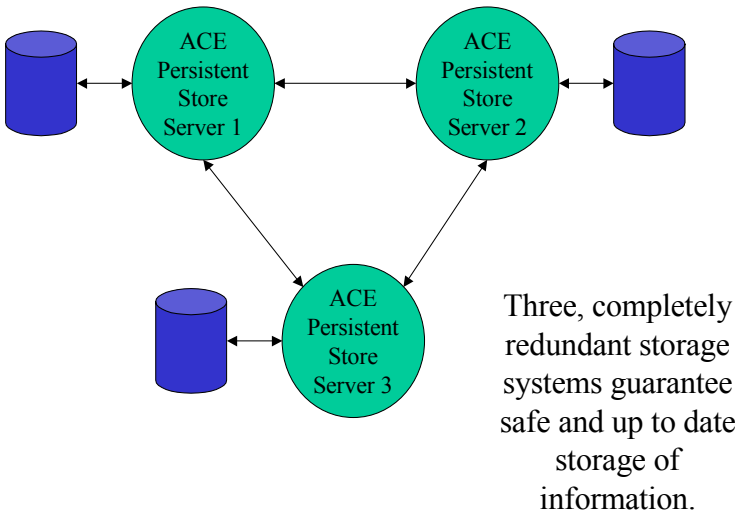

FIGURE 17: THE FIRST CONCEPTUAL FRAMEWORK OF HOW A CLUSTER OF THREE PERSISTENT STORE SERVERS SHALL WORK TOGETHER TO PROVIDE REDUNDANT AND ROBUST STORAGE OF ACE SERVICE AND APPLICATION STATE, PROVIDING THE FOUNDATION FOR ACE ROBUST APPLICATIONS AND SERVICES.

The three storage systems above perform constant data synchronization in order to ensure that the same exact data is stored within each of their individual storage areas.

If for any reason, one or two of the servers fail or crash, ACE services may still access the stored information within them. Furthermore, by having three separate storage servers, it is possible to remove potential bottlenecks of many ACE services attempting to access information on a single storage server at the same time.

ACE utilizes this redundant storage systems in order to safely maintain and always have available all the user, service, and configuration information necessary to make ACE a robust architecture on which services and applications can run and be recovered.

Although this may seem to be a unique and completely different component of the ACE architecture, it is simply another service within ACE. This service utilizes the framework depicted above to provide robust and secure state information for other services and clients within ACE so that if user workspaces, applications, and robust services fail, they can quickly be recovered to their last known state. This type of service utilizes a straightforward object-oriented namespace approach to storing application and program state information and forms the basis for supporting restart and robust applications as seen in sections 8.2 and 8.3 above.

Initially, development of this persistent store service framework was intended to include M-VIA (Modular Virtual Interface Architecture) [11] as its network cluster communications interface. This idea has currently been abandoned and other routes are currently being investigated.

Chapter 7

ACE Scenarios

After touching on the ACE architecture and the main design components that work together to make ACE a robust and interconnected framework of services, some ACE scenarios can now be developed. These scenarios shall illustrate how the pieces described above fit together to supply a coherent set of services and capabilities. All of these scenarios have already been attempted and have successfully run in the current version of ACE.

7.1 Scenario 1 – New User & User Workspace

John Doe is a new employee at ACECo. After getting settled in and getting to know his new work environment he presents himself to the system administrator to have a new ACE user account established for himself.

The administrator obtains from him all the pertinent information and creates a new Unix user account for John. Then, he adds this new user as a new ACE user as well. Utilizing a simple GUI, the administrator inserts John and his new account information into the user database via the AUD service. His fingerprint is scanned and added as well. As John is being added as a new user, the GUI also communicates with the Workspace Server. The WSS verifies that this is a new user by checking that

the user information within the AUD is empty. This prompts the WSS to create a new VNC server session (i.e. the user's default workspace) for John. To do so, the WSS requests from the SAL that a new VNC session for user John be started somewhere. The System Application Launcher works in conjunction with the HAL, SRM, and HRM to create a new default workspace for John. First, the SAL inquires with the SRM to find out which machine in the ACE network is most suitable (has the most free resources or is best for a given application) for running the VNC server application. The SAL has this information with it from the regular communications it holds with all the HRMs in the network to obtain host resource information. Once a suitable host has been selected, the SAL requests from the HAL on the selected host to launch a VNC server application as the default workspace for user John. Figure 18 below shows the connections between the services for a better understanding of these steps.

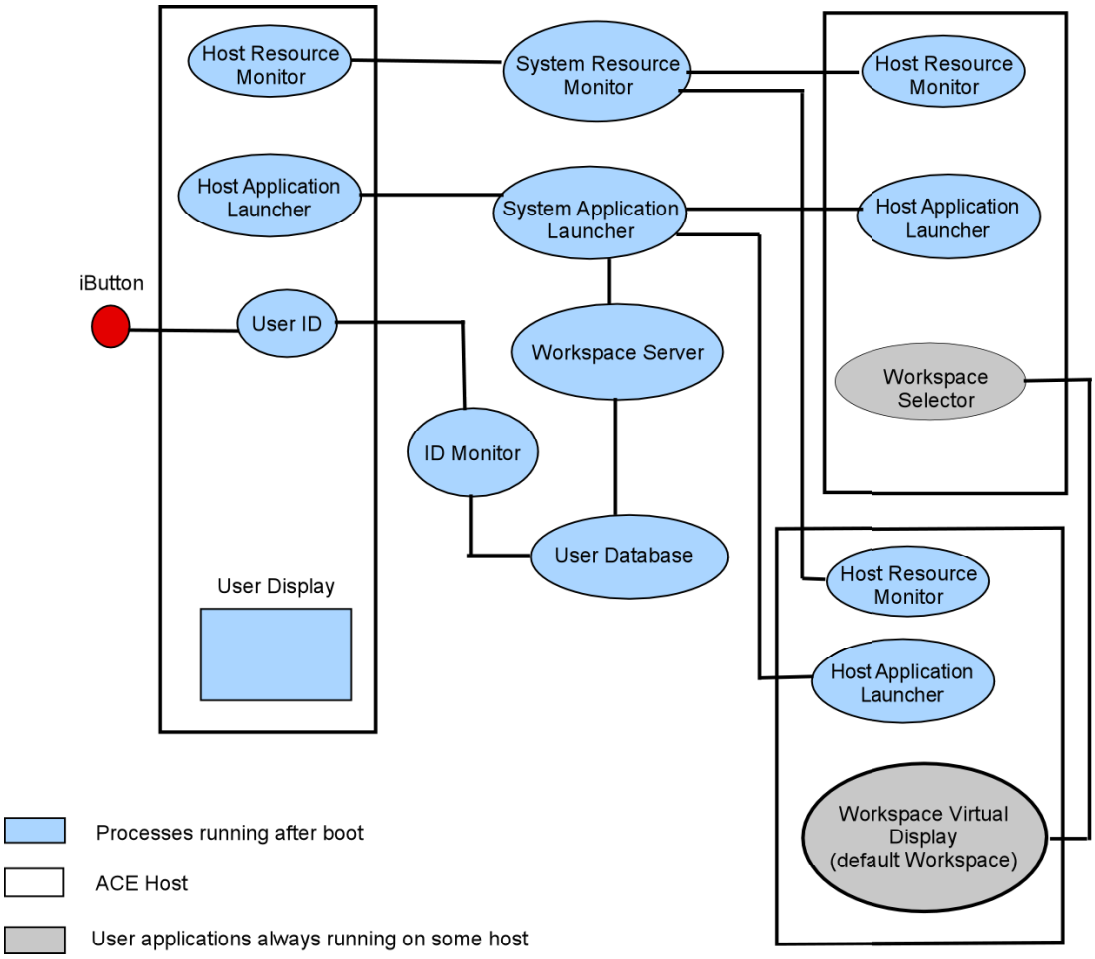

FIGURE 18: A DIAGRAM OF HOW ALL ACE SERVICES ARE INTERCONNECTED TO PROVIDE ACE USERS WITH IDENTIFICATION CAPABILITIES AND USER WORKSPACES.

With this being done, John now has a default workspace constantly running on the selected host.

7.2 Scenario 2 – User Identification

John is to give his presentation in the ACE conference room in 30 minutes. In order to prepare for his presentation he goes to the conference room and identifies himself at the podium computer by pressing his thumb to the fingerprint scanner next to it. As soon as this is done, the user ID daemon, which constantly polls the FIU (Fingerprint Scanning Unit) daemon, requests from the FIU that the user be verified. In John's case, he is a valid ACE user and is thus positively identified. This causes the ACE User ID service to send out a notification that user 'John Doe' has been identified at the ACE conference room to the ID Monitor service. The ID Monitor service then updates John's current location with the AUD. At this point John Doe has been successfully identified and other services can now be invoked.

7.3 Scenario 3 – User Workspace

Once John Does has been successfully identified, the ID Monitor service is responsible for communicating with the Workspace Server so that the user's workspace can be brought up to the user's current access point.

The WSS invokes the SAL to start a VNC viewer session at John's current location (which was obtained from the ID Monitor) so that his default workspace may be brought up. The SAL then invokes the HAL on John's current host. This in turn starts John's VNC viewer application so that he may access his default user

workspace. Effectively, John's workspace pops up on his screen at the conference room podium and he goes on to access his presentation files and setup his speech. Diagram 19 below shows the entire process from user identification to displaying the user workspace. The red circle on the left labeled FIU is where the user would identify him/herself.

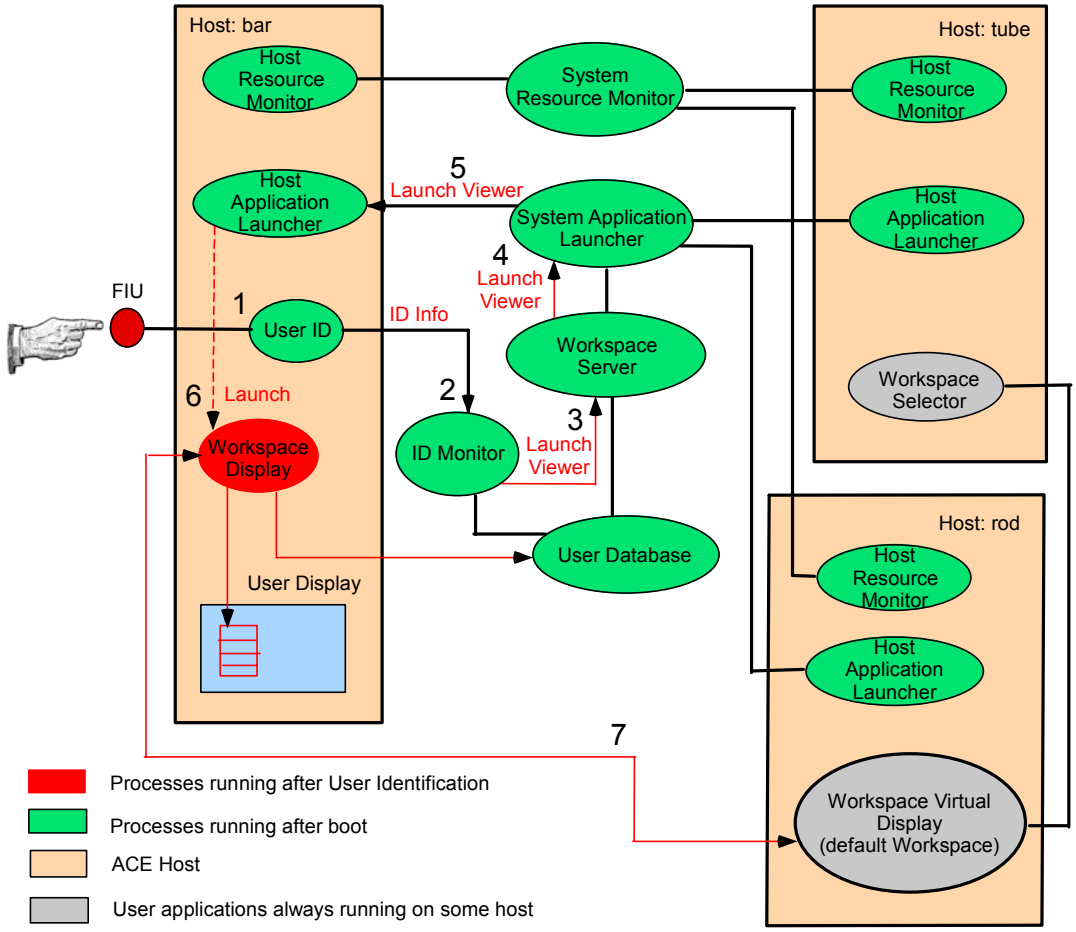

FIGURE 19: THE STEPS EXECUTED BY AN ACE TO VERIFY A USER AND DISPLAY THE USER'S WORKSPACE AT HIS/HER ACCESS LOCATION.

7.4 Scenario 4 – Multiple User Workspaces

Can a user have more than one workspace? The answer is yes. ACE users are not limited to a single workspace (as has been mentioned earlier). The default workspace is created for all users so that he/she may have at least one valid and working workspace through which to access the network and its resources.

In creating new workspaces, the same basic ACE services are utilized to launch, maintain, and display the running workspaces. The only significant difference is that now users are presented with a workspace selector when a user identifies him/herself (figure 19 above). This selector works in conjunction with the WSS to find and display a workspace selected by the user.

Let's say that John has been working on his presentation from a separate workspace that is not his default workspace. So now, John has 2 valid running workspaces. As soon as he identifies himself a small workspace selector GUI pops up on the access point screen showing him a list of all workspaces running and available. He selects the secondary workspace he owns and that causes the WSS to attempt to launch the viewer of this workspace. It communicates with the SAL to do so.

Soon enough, John's secondary workspace is up and visible on the podium access point and John continues to setup his presentation.

7.5 Scenario 5 – ACE Services & Devices

One last thing needs to be done before John can get his presentation ready to go. He must turn on the projector and set the camera to point towards the podium. Using his workspace, he starts the ACE device GUI. This GUI communicates with the ACE Room Database service to find out what devices are present within the room, where they are, and what current settings they have.

John selects the projector from a graphical representation of these devices. This pops up another screen that shows the different controls that can be set for the projector. He uses it to turn the projector on and to output the workspace to the screen. This effectively causes the GUI program to communicate with the projector daemon and send appropriate messages to execute John's commands. Then, he selects the camera output to stream to the projector as a picture in picture output. Finally, he selects the camera and uses it to control the camera and pan, tilt, and zoom it towards the podium.

All of these commands performed by John are fundamentally simple daemon-to-daemon communications that are used to execute actions. Client and daemons automatically find each other via the ASD and communicate with each other to obtain and supply the proper information to perform a given task. The next stage in development for ACE is to have all the above described commands be given by voice and gestures.

John is now ready to give his presentation.

Chapter 8

Related Work

As was previously stated, the work being done here is one among many other research projects currently being developed to create the next generation of widely accessible and robust Internet applications and services. Next, a brief analysis is made on the main aspects of some of these other projects in order to gain insight into their principal differences so that possible improvements can be included in future ACE developments.

The projects analyzed here have been chosen due to their similarity to ACE, how complimentary their work is to that developed for ACE, and how insightful they are to future ACE solutions.

8.1 UC Berkeley – Ninja Project

At the Computer Science department at UC Berkeley, important work has been done in the area of next generation Internet based applications and devices. This work is called the Ninja project [6].

The main focus of Ninja is that of the seamless integration of services and devices that work together automatically to provide high-level services to its users

within a robust and long-lived cluster of workstations and accessed easily over the Internet.

The Ninja architecture [18] consists primarily of four components: bases, units, active proxies, and paths.

- Bases are clusters of workstations that serve as the computing basis for service execution and state information storage.
- Units are the numerous different devices that are to be integrated into the Ninja next generation Internet concept (e.g. PDA's, cellular phone, pagers, sensors, etc).
- Active Proxies are transformational elements or interfaces to the units allowing them to be integrated with the Ninja service architecture.
- Paths are abstractions to the concept of composing more complex services from a set of interconnected lower-level services, thus creating a conduit or path through which data can be streamed through from service to service, providing clients with unique and complex capabilities.

Ninja is very similar to ACE in many aspects. Like ACE, Ninja focuses on the concept of easily accessible and reliable network of services (whether those be applications or devices). Within ACE, the ASD is the service responsible for service registration and is where services and clients go to find other services. In Ninja, that similar service is called the SDS – Service Discovery Service. The bases in Ninja provide services and applications with persistent state information in case of crashes

and system failures in much the same way that our persistent store architecture saves the same state information via redundant server systems. Like ACE, the Ninja architecture also facilitates for the integration of various heterogeneous devices ("units") and services within the network. Finally, the concept of creating modular and simple services and composing them into "paths" [19] to generate high-level and complex functionality is also the same within ACE.

Ninja on the other hand has some differences that are worthwhile examining.

First, Ninja's active proxies are unique interfaces to user devices called units. These proxies effectively translate the information to and from these units so that proper unit to service communication can take place. In the ACE world, such translation is built in to the ACE service that is specifically built to control and intermediate for unique devices. The currently implemented interfaces for the devices in ACE are built in C and utilize a Java wrapper that allows JNI calls to service methods. Effectively, ACE devices are fully integrated ACE services. At the service level, no distinction is made between software-driven and device rendered ACE services.

Another main difference found is that in Ninja, service communication is done primarily via object serialization and RMI. As was previously discussed, ACE utilizes a unique ACE language constructed for ACE services and a language parser to interpret messages sent from one service to another. This approach makes ACE communications much more lightweight than that of Ninja's bytecode transmissions, which may be large depending on the service being rendered.

As previously stated, Ninja's bases are clusters of workstations that are utilized for computation and storage. Unlike ACE, Ninja groups these bases together and all services execute on these clusters and communicate to devices via the Internet or local area network. ACE, on the other hand, attempts to distribute its computing power. Regular workstations spread throughout the environment may execute ACE services. This not only reduces network traffic to local devices (devices that are physically close to the workstation providing the service) but also makes response times to these local services much more efficient.

Finally, Ninja attempts to fully automate the construction of high-level services via their path concept and the use of XML descriptors accessed via the SDS and XSet services [19]. This idea of Automatic Path Creation (or APC for short) has no equivalent within ACE. Current developments in ACE call upon programmers to hard code what services to look for when specific complex capabilities are needed. In ACE, services cannot do that for themselves. They can of course connect to each other and work together to provide complex services, but currently they cannot determine on their own what services are needed to provide specific high-level functions.

Ninja has come a long way in developing an infrastructure for ubiquitous computing and further examination into their work may prove very useful for improvements in the ACE architecture.

8.2 MIT – Oxygen Project

Another significant project developed at the Laboratory of Computer Science and the Artificial Intelligence Laboratory at MIT is project Oxygen. This multimillion-dollar project aims at adapting computers to the human world making it easy for humans to interact with computers by visual cues and voice commands. Oxygen attempts to make access to computational power pervasive and natural to anyone. Furthermore, they envision making computers intelligent enough to interpret and adapt to the needs of human users. Oxygen enables people "to do more by doing less." [20].

Oxygen's goals are to create an environment where computing is pervasive (found everywhere), embedded (sensing and affecting our world), nomadic (where users and computation are free to move about), and eternal (always present, never shutting down nor rebooting).

The main framework of Oxygen is built upon the notion of three important components. The handheld H21 computers, the built in wall computers E21s (or enviro21s as they are called), and the active and self adapting network N21 that interconnects these computational units [7][21].

The H21s, or Handy 21s, are all-encompassing handheld devices that can change from a wireless Internet connection to a pager, to an AM/FM radio, to a walkie-talkie, TV, cellular phone, etc. It also contains a display, camera, IR connector and radio antenna. It is low power, low bandwidth, with limited

computational capabilities, and mostly software driven. The H21s are the universal interfaces of users to the Oxygen world.

The E21s are computers built into the rooms and environments that provide users with access to higher computational power and bandwidth. These E21s can communicate with the H21s for remote access and may directly control devices such as phones, faxes, sensors, cameras, and microphones.

Finally, the decentralized networks called N21s provide adaptive network topologies that react to changes in the network, in the devices connected to them, and to changing conditions such as congestion, errors, and varied traffic. They also allow for automatic resource and location discovery without manual system administration and do all of the above in a secure and authenticated fashion. Although not explicitly detailed, it is likely that an Active Networks approach may be taken for this purpose.

Oxygen envisions a world where web bots, computer secretaries, and task automation in conjunction with a state-of-the-art speech recognition system allows users to naturally converse with computers and obtain what they need from them. By saying things like "Turn up the heat every morning at 7am" or "Find me the presentation Maggie gave me two days ago" computers shall understand the commands, interpret them, and make inferences based on users' preferences and histories to obtain exactly what they asked for. Again, the end goal: "doing more by doing less."

Oxygen's basic conceptual framework is very different from that of ACE. Much of Oxygen's foundation is heavily based on the N21s and their adaptive and

automatic nature and on the H21s and E21s flexibility and computational power. They centralize this power to these two units and rely on the N21 network to be intelligent enough to efficiently interconnect them and adapt to changes in the environment.

ACE is not limited to only a couple of devices and does not attempt to make an all-encompassing handheld. Rather, ACE attempts to base computational power to heterogeneous systems distributed throughout the network. It also maintains the responsibility of supplying services, adapting to changes, and doing so in a secure manner to service daemons running on these machines. Oxygen depends on the versatility and power of the H21s and E21s to provide any and all services and that of the N21s to provide them with adaptive and ubiquitous access to these services. This is not to say that Oxygen's approach is wrong, on the contrary, it is a novel and unique approach but their sole dependency on the H21s and E21s may become limiting in the future. On the other hand, the development of a self-organizing and intelligent network that creates collaborative regions among Oxygen users, although a complex task, may prove to be a very useful and powerful foundation.

8.3 IBM Corporation – WebSphere

Within the past few years, IBM Corporation has been working on a new way to facilitate the integration of home and business devices to the Internet. At IBM's Pervasive Advanced Technology Laboratory in Austin, Texas, researchers have

created a complete working prototype of the future home, kitchen, and automobile. They have created an environment where all devices within it are directly connected to the Internet and all have their own unique URLs. Users can locally or remotely control these devices by simply logging onto the Internet [22].

Behind all of this is IBM's WebSphere Everyplace Server. This server is an integrated software platform providing applications and devices with integration, connectivity to the Internet, and with a realm of services ranging from security and authentication, device and subscriber management, content transformation, and data synchronization to messaging systems [23]. This platform aims at simplifying connectivity and large-scale device integration for current enterprises and service and content providers.

It also allows authenticated web-enabled applications and devices to connect to it via third-party or their own wireless gateway and utilize their services. This is a Java based software platform and utilizes HTTP as its main connectivity protocol to third-party gateways and wireless devices. Authentication is also carried out over HTTP [24].

The basic network and communications framework of this project greatly differs from that of ACE in its communications protocol and in that it attempts to centralize device and applications integration and control to a main server or cluster of servers that oversee all connections and users. Although this approach has proven scalable through simulations [23] it may not be appropriate or viable for small-scale purposes and environments. Furthermore, it lends itself to dependency on IBM

developers to extend its capabilities and include new services, making it impossible for outside developers to create and integrate their own services. Also, this framework does not manage device state information and expects the outside devices and applications to handle their own state persistence.

Although this platform is an attempt at simple and large-scale integration of Internet applications and devices and has a very different architecture, it is rich in ideas and possibilities as far as services and potential applications of pervasive computing are concerned. New developments within IBM's WebSphere may become very useful to future ACE developments and in extending its concepts.

8.4 Sun Microsystems – Jini

Another important development in this area was made by Sun Microsystems – the Jini technology [25]. The main idea behind Jini is that its very simple framework gives developers the freedom to create network-enabled services that may be implemented in either software or hardware.

Jini is built upon Sun's own Java interface and utilizes Java's RMI (Remote Method Invocation) and object serialization for clients to utilize services over the network.

The basic Jini framework consists of network services, clients, and a lookup service for finding other services on the network [26][27]. A multicast mechanism is used to find the lookup service either for service registration or for other service

lookups. Network services wishing to be registered with the lookup service or "join" the network of services must first find the lookup service via a multicast message and register their interface attributes (what methods they can execute) with it. Clients wishing to "discover" services also utilize a multicast mechanism to find the lookup service and then query the lookup service for specific well-known service method interface attributes. Once a service is found, a service proxy is passed onto the client and the service is rendered directly to the client via RMI.

Jini also allows for service leasing within the lookup service and for an event driven model allowing other services to be notified of specific events in the network. Furthermore, Jini utilizes its own implementation of ACL's and principals for trust management within the network.

At first glance Jini contains many elements that are similar to those developed within ACE – a lookup service, service discovery, service lease times, event notifications, freedom of service development for software and hardware applications, a service/client duality allowing services to become clients and utilize other services, and the ability to utilize non-Java services via Java interfaces.

Although the above-mentioned characteristics are very advantageous to the development of ACE, the decision was made not to use Jini within the ACE architecture due to some of its non-desirable traits. Jini is still at its very early stages and desirable devices and software interfaces for basic services have not yet been released. Also, as Jini is licensed under the Sun Community Source License [28] that poses as an obstacle for future code modification and redistribution for developments

such as potential mobile sockets currently being investigated for ACE. Finally, Jini utilizes its own trust management implementation thus the utilization of the KeyNote Trust Management system (which is very desirable for our applications) becomes difficult or impractical.

Therefore, although Jini provides a very flexible and simple architecture for ACE-like capabilities, it is still very new and also restrictive as far as security, modification, and redistribution are concerned.

Chapter 9

Improvements & Future Work

The ACE project was started early in the spring of 2000 and although much development work has been done to lay its foundations – the main daemon infrastructure, and the basic ACE framework services – much design and implementation work remains to be done.

Currently, the main challenge for development of ACE deals with creating a robust and reliable system of services that can detect and recover from failures and is scalable to serve hundreds and even thousands of users. This task is composed of many different research areas. First and foremost, a service structure must be created to detect and handle system and service crashes, quickly identifying failures and re-initializing restart and robust applications and services. Secondly, research and development of mobile sockets must be integrated with the current ACE service infrastructure to handle downed ACE services allowing clients to quickly resume their tasks with other service instances and to ensure service mobility. Thirdly, continued work must be done to implement and integrate a persistent store mechanism within the service daemon framework to ensure that state information is maintained for robust services and applications. Also, the authentication capabilities of KeyNote's credentials within ACE must be extended to allow for more flexible authentication criteria (which is limited at its current implementation). Finally,

significant amount of testing must be done to ensure the scalability of the system and that ACE can fulfill the concept of a long-lived system. Central services such as the ASD, AUD, WSS, etc must be fully tested for large communication loads, persistence, and extended execution time.

If ACE succeeds in becoming the long-lived, reliable, robust, secure, and widely accessible system that it is envisioned to be, then further developments can be made in the areas of speech recognition, natural language analysis, gesture and face recognition, audio triangulation, personnel tracking, multi-modal user interaction, multi-format data streaming, real-time written and spoken language translation, task automation (e.g. properly executing the command "print this out to the nearest printer"), and creation of intelligent devices and applications such as adaptive camera systems (i.e. automatic control of image quality), automatic climate control systems, lighting control systems, personal virtual administrative assistants, etc.

It may also be advantageous to further investigate and integrate some concepts taken from other projects such as Ninja and WebSphere into ACE. Some of these concepts include Ninjas's Automatic Path Creation with XML and IBM's user interaction devices and modalities such as ACE enabled cars, coffee makers, digital art, entertainment systems, etc.

Chapter 10

Contributions & Innovations

ACE, its architecture, and its implementation have been made possible by the contributions of many professors, students, and staff alike. Many of the components that have been here presented were created by individual and group efforts of the ACE development team, including my own.

Additionally, ACE itself presents researchers and developers with some unique and innovative design components that are important and worthwhile considering.

10.1 ACE's Innovations

The ACE architecture presents many advantages and qualities that make it a flexible, robust, and lightweight system. It is also a system in which the development of new applications and services are made easy and fast. Some of these qualities and design approaches are unique within the world of the next generation Internet and significant to point out.

Some of these unique qualities include:

- A modular service daemon structure, making the integration and development of new and heterogeneous services and technologies simple for developers.

- An ACE service daemon hierarchy that makes the development and alteration of service elements effortless. A service hierarchy unique within the realm of pervasive computing.
- An ACE command language and its corresponding parser (developed explicitly for ACE and geared towards service communications) that allow for very lightweight service-to-service communications. A construct unseen in any other pervasive computing project and with the potential of making ACE a competitive architecture efficiency-wise.
- An architecture that aims at open source development unlike many similar projects that have developed their own proprietary code and utilized licensed and restricted applications. ACE has integrated a variety of open source applications with its architecture and aims at open redistribution objectifying unrestricted development and improvement of its architecture and services. An approach that may prove advantageous for allowing ACE and its original ideas to improve and percolate through to the Internet of the next generation.

These unique qualities make ACE a novel system and provides singular contributions to the work currently being done in the area of pervasive computing.

10.2 Personal Contributions

The ACE effort includes some of my own personal work. Listed below are some of my main contributions to the ACE effort along with references to pertinent internal ACE documentation.

1. Assisted in the design of and completely documented the ACE command language.

   (Internal Documentation File Names: ACELanguageReqs.doc, ACELanguageSpecs.doc, ACECommandObjectSpecs.doc)

2. Design, documentation, and implementation of the ACE command language parser.

   (Internal Documentation File Names: ACEParserDesign.doc, ACEParserEnumTypesDesign.doc, ACEParserCmdArgExtentSpecs.doc, ACEParserSpecifications.doc)

3. Design, documentation, and implementation of the ACE Service Directory.

   (Internal Documentation File Names: ACEServiceDirectorySpecs.doc, ACEServiceAttributesSpecs.doc, ACEServiceClassHierarchySpecs.doc, ACEServiceDirectoryDatabaseDesign.doc, ACEServiceDirectoryDesign.doc,)

4. Design, documentation, and implementation of the ACE User Database service.

(Internal Documentation File Names: ACEUserDatabaseServiceRequirements.doc, ACEUserDatabaseDBDesign.doc, ACEUserDatabaseServiceDesign.doc, ACEUserAttributesSpecs.doc, ACEUserDatabaseServiceSpecifications.doc)

5. Development and documentation of a standardized script for regression testing of ACE services.

   (Internal Documentation File Names: ACECodeDebugRequirements.doc, ACERegressionTestingRequirements.doc, ACEErrorConventionSpecs.doc, ACETraceSpecifications.doc)

6. Working directly within the ACE architecture development team contributed with ideas, suggestions, and solutions in brainstorming sessions as the ACE architecture grew and took shape.

Chapter 11

Conclusions

In this paper many aspects of the ACE architecture have been examined. These aspects included ACE users and how humans interact with the environment, the basic daemon framework and its capabilities, security and authentication within ACE, user applications and legacy systems incorporated into ACE, and the base ACE services implemented and currently under development. Basic scenarios depicting the interaction of users and ACE systems were covered and current developments by other corporations and universities in the area have been discussed.

Clearly ACE has many unique advantages. Its modular service daemon structure and hierarchy simplifies service development and allow for flexible higher-level service construction. The daemon's built in notifications capabilities allow for desired event-driven models. The daemon's multithreaded nature allows services and the underlying system to take advantage of execution concurrency. Finally, the ACE user workspaces approach is a good compromise between the well-known desktop PC's and the full virtual data and services integration of the future.

It is clear from the ACE architecture, its novel capabilities, its advantages, and from the work done in other similar projects that ACE and its daemon framework not only have potential to become the envisioned pervasive and robust system but to also be a flexible, modular, and easily adaptable platform on which to develop new

services and capabilities. Moreover, it is also an architecture that allows developers the freedom to expand its capabilities and applications in any imaginable way. ACE has become a very worthwhile infrastructure on which to build. At its current state, ACE begs continued exploration, experimentation, and improvement.

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