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THE EMBEDDED WINDOW TOOLKIT
Porting Java's AWT to an Embedded System

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1 Introduction

The Java language has features that make it preferable to C/C++ for many application domains. It is therefore desirable to use this language for many types of applications, including the development of certain small embedded systems. One aspect of Java that makes it desirable is the inclusion of a portable windowing library called the Abstract Window Toolkit (AWT). The AWT was designed to facilitate the construction of graphical user interfaces on various windowing platforms.

Many common embedded systems have a limited amount of memory in comparison to a desktop computer. Very often the embedded system has a rather low resolution liquid crystal display (LCD). The complete AWT is not practical for these systems as it has many more features than required, resulting in an unnecessarily large memory footprint. The AWT is intended for systems with a pointer, like a mouse, and multiple, overlapping windows. Many simple embedded systems have no need of these features. Recently, Sun Microsystems has introduced Personal Java, which includes a subset of the AWT. Personal Java reduces both the memory footprint and the complexity of the AWT, but still has many more features then are needed for a simple embedded system. The main question addressed by this thesis is how small, in terms of both code and required memory, can a usable subset of the AWT be made?

Java is a superior language because it draws together many concepts previously found desirable in other, older languages. For example, it uses the simple clean syntax of the C language for ordinary statements. The syntax of C is widely known, and is famous

for being so concise and powerful. The Java syntax for invoking an object's methods is also borrowed from C++. One advantage to this similarity is reducing the time required for learning the Java language for someone familiar with C++.

Java has support for multi-threading contained in the standard library. It also has the keyword `synchronized` to tell the compiler that a procedure cannot be started while another `synchronized` procedure of the same object is executing. Multithreading is a very useful feature for building embedded systems. Very often, it is necessary to have more than one process executing simultaneously, for example, it would be desirable to scan the keyboard while measuring some sensors and updating the display. Using Java, each of these tasks can be written as a separate thread and the task switching handled by the language. Multithreading is available using C/C++ or assembly language, however it is an attribute of the operating system and the programming interface varies on different platforms. With Java, since the multithreading is built into the language and standard libraries, the programming interface is consistent on all platforms.

Another important advantage of Java is it's automatic memory management. The "garbage collection" type of memory management was pioneered in the LISP language. It is a big advantage to the programmer since it removes the potential errors associated with having to de-allocate memory. There are two forms of this problem, the memory leak and the dangling pointer. In a memory leak, the programmer allocates memory, however the programmer never deallocates memory. This can cause the memory requirements of a program to grow until it exceeds the capacity of the system at which point the program will fail. The dangling pointer is the opposite problem. Memory is deallocated before all

references to that memory are removed. This memory may be reallocated for a second use, which makes the data referred to by the first pointer invalid.

In the context of an embedded system, garbage collection is somewhat of a limitation since many garbage collection schemes require the system to shut down temporarily while the garbage collector runs. This means that real-time systems could not be built using Java. However, this is not a limitation of the language but its implementation. New garbage collection schemes using hardware assisted techniques appear to make real-time Java systems possible [NIL94]. The choice of using a garbage collection system is a trade off between the need to have an embedded system that can have reliable software easily created for it versus writing the entire system in assembly language or C. Using a low-level language like assembly would create a smaller, faster application but at a greater cost in terms of development effort. For many complex applications the advantages of automatic memory allocation outweigh the disadvantages.

Java also has built-in exception handling. While exceptions have been added to C++, their use is optional. Unfortunately, this means that many programmers will not use them. In Java, the use of exceptions is mandatory. A programmer cannot use a function that might throw an exception unless they provide a mechanism for handling that exception or explicitly declare the exception will be passed up the call chain. In an embedded system, this is a useful requirement, since it is widely believed this technique increases the reliability of the software. Unhandled exceptions will generally cause an embedded system to crash.

The networking capability of Java is a useful feature when building an embedded system that is connected to a network. While this is technically not a feature of the language, rather a feature of its libraries, it is important that the networking interfaces are well developed and defined. While networking interfaces are clearly defined for many operating systems, including them in Java makes the interface platform independent, which is a definite advantage to the programmer who needs only learn the interface once.

The Java virtual machine uses run-time linking, something that is also a feature of LISP. This feature allows an application to execute code that was not available at the time the application started execution. This has many applications in an embedded system. One example is the UCSC JavaCam servlet [MCD98]. This system uses run time linking to allow code to be loaded into an embedded system across a network. The code that is loaded over the network into the embedded system is known as a servlet. The JavaCam servlet is required to use a predefined interface to communicate locally with the embedded system in order to control the camera settings and capture images. It is free however, to communicate back over the network with the client system that supplied the servlet in any format that the client wishes. This run time linking is an advantage over C/C++, since C/C++ is linked prior to execution either at compile time or at the time the application is loaded into memory.

One of the most important features of Java is its portability. Since Java runs on a virtual machine, the binary code is identical across various platforms. It might seem that portability would be useless in an embedded system since the software for an embedded system is typically run from a read only memory. There are, however, a couple of

advantages to having the object code portable. The main advantage is involved in providing updates to the operating software. Many embedded systems use some type of "flash" memory for storing the program code. While many embedded systems do not provide any means of updating this code (e.g. microwave ovens, telephones) many other more complex ones do have the ability to update. If Java is used, it is possible that the same update package could work on embedded systems using different hardware. This could be an advantage when the hardware platform is changed during the product lifetime. Only one version of the Java object files would need to be maintained and distributed for all hardware platforms.

A second advantage of Java's portability is during the development process of the embedded system. The identical object files that are to be used in the embedded system may be run in a simulation environment on any platform that supports the Java virtual machine. This yields two advantages. During the design process, rapid prototypes of the product can be developed and shared across a network without distributing any source code. This allows an untrusted user to interact with the design using their favorite computer platform. The second advantage is that as the product is being coded, the object files that will be used in the final hardware can be tested without requiring the tester to have any actual system hardware.

2 Overview of the AWT

In order to write a useful application, it is necessary to have a user interface. Java includes a basic toolkit called the AWT for building platform independent graphical user

interfaces (GUI's). The goal of the AWT design was to provide a set of classes that represent the most commonly used window objects and provide versions of them for all common windowing environments. Sun Microsystems' version of the AWT currently supports Windows, Macintosh, and X-Windows. The AWT supports a pointing device, overlapping windows, variable width fonts, and multiple depth color graphics.

There are many ways to implement a platform independent windowing library. The technique that the AWT designers used was to make a set of wrapper classes that interface to the native windowing system of the computer system. This means the native window manager "look and feel" is retained, since the AWT window objects are actually native window objects.

There are multiple layers in the AWT classes. First there is a group of window objects that are identical across all the platforms. These classes are all derived from the `Component` class and represent objects and/or controls that can be displayed. These component objects have a one to one mapping to wrapper classes. The wrapper classes are called peers and are different for each platform. Finally, a toolkit class, also unique for each platform, has the job of connecting the platform independent component classes to the platform dependent peer classes. The next section describes the working of the AWT peer system in greater detail.

While the toolkit and the peer classes must be implemented differently on the various hardware platforms (much in the same way that the virtual machine is different), this is transparent to the Java programmer. The Java programmer requests a window with

a button on it, and this is produced by the system independent of what computer platform is being used.

The AWT was defined as a lowest common denominator of the many popular window systems. Only window objects that existed on all platforms were included. Therefore, it contains a subset of the features available on the different platforms. However, compared to the very simple requirements of many embedded systems, it is still too complex.

2.1 How the AWT Peers Work

Java's AWT uses a system of peers. A peer is a wrapper for a native windowing system object. A peer acts as a stand-in for a native window object. For example, when you create a **`Button`**, you also create a **`ButtonPeer`**. The **`ButtonPeer`** calls the native window system and requests that a button be displayed on the screen.

A one to one correspondence exists between the peers and the native window objects. For every AWT component, a peer is automatically created. It is interesting to note that the peer is not created at the same time as the AWT component, but rather when the **`addNotify`** method of the AWT component is called. The **`addNotify`** method can be called explicitly, but more often it is called implicitly when the AWT object is displayed.

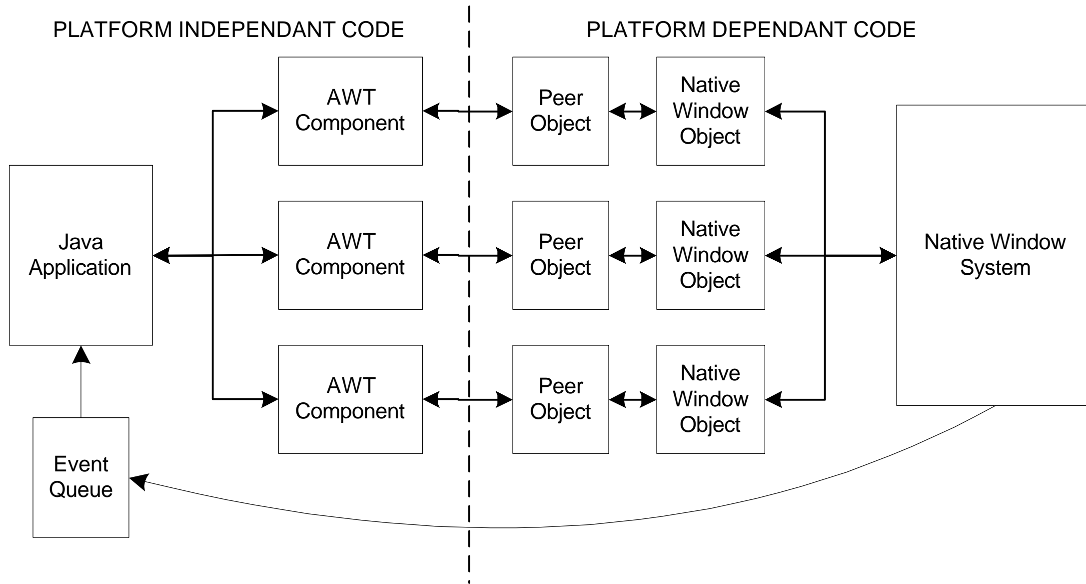

Figure 1. AWT Peer Model

The programmer using the AWT never actually needs to know about peers. They work using the AWT components. When the program begins to run, the AWT components used by the programmer are constructed. This, in turn, causes the platform specific peers to be constructed. Most of the components' procedures simply call the peer object, and the peer object in turn calls the native window system. While this layering no doubt pays a price in efficiency, it provides a benefit in making the AWT easier to port to new platforms.

2.2 The AWT Toolkit Class

The platform dependant code in the AWT is isolated effectively from the AWT classes that make up the programmer API. The platform dependant code consists of two

areas, the **`Toolkit`** class and the peer classes. The toolkit class is an abstract class that is extended by each different implementation of the AWT. In my project, this class was also made runnable and contains the event handler as a separate thread. In the Win95/NT version of the toolkit, two additional classes, **`EventQueue`** and **`EventDispatch`** are used. The bulk of the Toolkit class contains methods of the following form:

```
protected ButtonPeer createButton(Button target)
 {
      return new EwtButtonPeer( target );
 }
```

Figure 2. Toolkit Class Calls Peer Constructor

This code is called by the constructor of **`Button`**. Its job is to make a native implementation of the desired component, a **`Button`** in this instance. Note that the actual AWT button is passed in as a parameter, and the toolkit specific peer is returned. This allows double linking of the objects - the **`Button`** keeps a reference to the native peer, and the native peer keeps a reference to the AWT button component it "works" for.

2.3 Walk through

One way to explain how the AWT works is to walk through a very simple application and examine what objects are created and what methods are called. The test program is shown below in Figure 3. The sample program makes a frame and places a button in it. The walk through analysis of this program will be limited to the most important AWT method calls. A complete trace of the method entry and exits, using the trace method option of the JVM (-tm) resulted in a file containing over forty thousand

lines of method calls and returns. The approach used here has the goal of explaining the relationship between the platform independent AWT classes and the platform dependent peer classes.

```
import java.awt.*;
public class trivial
{
    static Frame f;
    static Button b;

    public static void main( String argv[] )
    {
        b  = new Button( "Button" );
        b.setBounds( 5, 25, 100, 35 );

        f = new Frame();
        f.setLayout( null );
        f.add( b );
        f.setSize( 110, 65);
        f.show();
    }
}
```

Figure 3. AWT Walkthrough Example

The following list explains some of the methods that are called during the execution of the above code.

1. Constructor for **`Button`**: The first line in the main method calls the constructor for button. This in turn calls the constructor for **`Component`**, since **`Button`** is extended from **`Component`**.

2. **`b.setBounds()`**: The call to set the bounds of the **`Button`** is handled in the part of the **`Button`** object inherited from **`Component`**.

3. Constructor for `Frame`: Making a new `Frame` calls the constructors for `Frame`, `Window`, `Container`, and `Component` in that order.

4. `f.setLayout()`: Setting the layout manager to null is handled in the `Container` part of the `Frame`.

5. `f.add()`: The call to add the button to the frame is handled in the `Container` part of the `Frame`.

6. `f.setSize()`: The `setSize` call is handled in the `Component` part of the `Frame`.

Note that up to this point no platform dependent code has been invoked. All the methods are part of the AWT code that is common to all platforms. Now, when the program requests that the frame be displayed, by calling it's `show()` method, the platform dependent code begins.

7. `f.show()`: The show call is handled in the `Window` part of the `Frame`. This method checks to see if the parent's peer is null – if it is null, which is true in this example, the `addNotify` method of the parent, `Frame.addNotify()` is called.

8. `Frame.addNotify()`: This method makes a peer. The name of the toolkit class is obtained from the `System.Properties`, and that platform dependent toolkit's `createFrame()` method is called with `this` passed as a parameter.

9. `WToolkit.createFrame()`: The `createFrame` method returns a new platform dependent frame peer. Toolkit has a static initializer as well as a constructor. The static initializer loads the `WINAWT.DLL` library. In the constructor, three additional

threads are started. These threads are called `AWT_Windows`, `AWT_EventQueue`, and `ScreenUpdater`.

10. Constructor for `WFramePeer`: The `WFramePeer` extends `WWindowPeer`, which extends `WPanelPeer`, which extends `WCanvasPeer`, which extends `WComponentPeer`. For this reason, the constructors of all these objects are called in sequence. Inside these methods, calls to the native windowing code allow the peer objects to communicate with the native window objects.

3 Overview of Existing Embedded Java Solutions

Sun Microsystems has several flavors of Java intended for systems smaller than a personal computer. However, it appears that none of these match the characteristics of the EWT. Either the systems have no support for the AWT or they support much more of it than the EWT does. A brief discussion of each of these platforms appears below.

3.1 Java Card

The smallest Java systems are built to the JavaCard specification. These systems are intended for "SmartCard" technology. SmartCards are typically single chip devices, intended to be placed on a plastic card the size of a credit card. The typical target applications are storing and retrieving information, although some applications have been written that will execute on the smart card, notably cryptographic applications.

The Java Card API contains four packages that are specifically tailored to the requirements of a smart card. Minimum hardware requirements are specified at 16 Kbytes ROM and 512 bytes of RAM.

The Java Card specification does not include any of the AWT classes. Many of the core Java classes and packages are also omitted. For example, the specification does not allow garbage collection, dynamic class loading, threads, or floating-point numbers.

3.2 Embedded Java

The next step up from the JavaCard specification is the Embedded Java application environment. Embedded Java targets industrial controllers, automotive, printers, and low-end telephones.

Minimum hardware requirements are specified at 512K ROM and 512K RAM. This size seems to most closely fit with the NS486 development board. The development board is sold with 1 Mbyte DRAM and 256 Kbytes of flash EPROM. Note that the UCSC project increased the size of the ROM to 1 Mbyte and also typically stores the Java bytecode on a PCMCIA card, at least for development work.

The Embedded Java specification does not require any of the AWT classes. It does allow for subsets of the AWT to be included. This is essentially what the EWT is, a version of the Embedded Java specification. At the time that work on EWT was begun, the Embedded Java specification was not released.

3.3 Personal Java

One step below the complete Java system, Personal Java is designed for set-top boxes, real-time operating systems, telephones with graphic displays, Internet television systems, and car navigation systems.

The minimum hardware requirements are specified at 2 Mbytes of ROM, and 1 Mbyte of RAM.

The Personal Java specification includes a subset of the AWT classes, known as the Personal AWT. The Personal AWT is a subset of the AWT, much like the EWT. The Personal AWT modifies the `Component`, `Dialog`, `Frame`, `PopupMenu`, and `Window` classes.

In addition, the following classes are made optional: `CheckboxMenuItem`, `FileDialog`, `Menu`, `MenuBar`, `MenuShortcut`, `MenuShortcut`, and `Scrollbar`.

Even with these modifications, the Personal AWT is still more complicated then would be required for many embedded system user interfaces.

3.4 Solutions from Companies other than Sun

One alternative to the AWT is being offered by NewMonics. It is called Minimal Window Toolkit or MWT[NEW96]. While MWT claims to be minimal, the EWT is much smaller, although also much less functional. In addition, MWT is dependent on the use of the Metagraphics graphics libraries. On NewMonics web site the size of the MWT including the native libraries is given as 458 Kbytes. They also compare their software to the AWT on Win95/NT platform. In order to do this they estimate the native method footprint by adding the sizes of `awt.dll`, `user32.dll`, `gdi32.dll`, and the corresponding VGA driver `dll` file. The size of the native methods is placed at 690 Kbytes.

I tried to examine the sizes of these files on my system and found the `awt.dll` file in the `jdk1.0.2/bin` directory. The size of this file was 152 Kbytes. In the jdk1.1.6 directory I could not find an `awt.dll` file. Probably, this file has been replaced by a file named `msawt.dll`. In the later version of the AWT, the file size has predictably increased to 224 Kbytes.

4 EWT - the Embedded Window Toolkit

The EWT, or embedded window toolkit, is a set of Java classes and native code that implements a subset of the AWT. It is written to run on the NS486 development system using a low-resolution black and white LCD display. Programs written for the EWT will also run on any Java platform that supports the AWT with a minor modification to the program. The required modification concerns the selection of font type. In EWT there are only two statically defined fixed size fonts. AWT has a complex lookup method to attempt to match fonts on various platforms. The EWT is designed as a research tool to test how much memory is required to have a toolkit which acts, at least for a couple of classes, exactly like the AWT.

The design of the EWT was motivated by the desire to add a hardware user interface to an application running on the UCSC Java Nanokernel [MON97]. While the NS486 contains special hardware to support an LCD panel, there is no software support for graphics or text.

4.1 User Interfaces on Embedded Systems

Embedded systems come in all sizes and levels of complexity. Microprocessors today are embedded in everything from a wristwatch to a jetliner. One common thread between embedded systems is the need to communicate to a human. A popular way an embedded system communicates with a user is through a visual interface. A wide set of visual user interfaces for embedded systems make use of an LCD. The LCD is common because they are relatively inexpensive, require little power, and can be small in physical size. In complex embedded systems, the resolution of the display approaches that of a

typical computer system display. In the majority of embedded systems the display resolution is much less.

While Java would be an excellent solution for programming in many of these smaller embedded systems, it is clear that fully implementing the AWT wouldn't be at all practical or useful. However, implementing a subset of the AWT would allow portability of the object code, a useful advantage already discussed above.

The question then arises: just how small can a useful subset of the AWT be made, and what differences are there between an AWT designed for small embedded systems versus the complete AWT supplied for a personal computer?

4.2 Requirements for EWT

The design of EWT was based on building a user interface for a greenhouse environmental controller. This was envisioned as a device that would allow control of some equipment such as heaters, fans, and misters while monitoring, temperature, humidity, and light levels.

While network connection and control of this device would be a big advantage, it was desired to be able to operate the device without a network connection. Therefore, a user interface was required that was local to the embedded system. The example mechanical interface imagined and then coded in a simulation as a test for this project consisted of eight devices. There are four keys under the display, and a rotary scroll knob with two keys below it. The two keys are labeled "ENTER" and "EXIT". The four keys below the display are used to navigate through a series of menus using labels that change above the keys. The rotary scroll knob is used to change a numeric value, or select from a

list. From the standpoint of a user concerned with entering numeric values (as in temperature set points in an environmental control) this is a practical and simple to use interface.

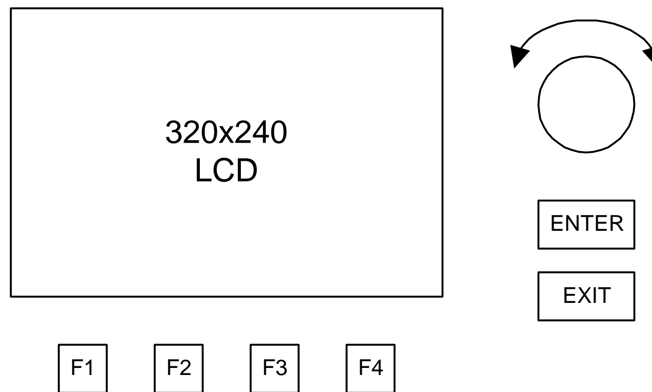

Figure 4. Proposed Embedded User Interface

The current implementation of EWT supports only one Frame at a time. There is no support for overlapping windows. Given the resolution of the LCD, and the desire for minimum complexity, this seems like a reasonable choice. Probably the most basic AWT component is “Label”, which simply displays text at a given location. In order to respond to user input, a “Button” was also implemented. With these two simple components a small application can be constructed. The choice of implementing these two components was made because the goal was to implement a subset of AWT as small as possible that still would allow creation of a useful application.

4.3 Three Options for EWT

There are several ways to implement a user interface on the NS486 as a Java library. One choice was to ignore the AWT and design a specialized library optimized for

the LCD. Another choice is to follow the model of the AWT, but ignore the peer system. The alternative that was chosen was to treat EWT as a partial port of the AWT peers to the NS486 platform.

4.3.1 Non-AWT Solution

The choice to ignore the AWT would have created a set of Java objects that were optimized for the LCD requirements and available keys. In an embedded system like a copier or greenhouse environmental control system, the menu and user input design can be very specialized. The components of the AWT are intended for a full "QWERTY" keyboard, mouse, and multi-window high-resolution display. Design of the interface from the ground up would result in a more natural choice of software objects to represent the interface objects. A disadvantage of this approach is that the interface objects must be created from scratch. Also, the application code will not run on other Java platforms without additional work porting the custom interface objects.

4.3.2 AWT Solution without Peers

If the peer model was not used, the basic components of AWT would have been directly implemented as platform dependent objects. The goal of platform independence could still be realized, since the Java application code has no knowledge of the peer objects, therefore the same code that works on a Windows platform could work on the EWT.

Following the AWT system without using the peer model has the disadvantage that there is no way to guarantee compatibility without extensive testing. Additionally, using

the AWT peer system means the existing AWT non-peer code, which is publicly distributed by Sun, could be used without modification.

4.3.3 AWT Solution using peers?

The source code of the AWT components is publicly distributed and is identical across different platforms. Using the peer concept, it was possible to reuse the existing Java AWT component code, unmodified. The extra layer of the peer classes enforces platform independence, which makes using the peers desirable even at the cost of a larger memory footprint. The peer classes enforce platform independence because the components that an application interacts with represent identical code on all platforms. There is, unfortunately, no guarantee that the peer classes provide the same underlying *behavior* on all platforms.

Designing the EWT to be a subset of AWT has additional advantages. The application code can run on the embedded system or directly on a PC that supports Java. It can be run on any Embedded Java that supports the AWT. If the EWT had been written to reflect the input controls available on the embedded system, then the EWT code would also need to be available on the PC system.

4.4 A Button is not a Key

An interesting problem arose when implementing the example application using the EWT. The user interface contains four buttons that act as labels for four actual mechanical keys located under the display. This is intended to function as a menu system. The labels of the keys change depending on the location in the menu structure.

The EWT is designed to work from keypad input. There is no support for a pointing device such as a mouse. This leads to some problems in compatibility with the AWT. Most of the AWT components are designed to be operated with a mouse. The easy way to operate a button using the AWT is simply to click on it with a mouse. The only other way to operate the button is to change the focus to the button, possibly by using the tab key, and then press the enter key. There is no way to map a single keystroke to a button press without adding additional code in the application. The newest beta release of the AWT, in version 1.2, supports menu shortcut keys. Unfortunately, the shortcut keys apply to pull down menus and not buttons.

The example application implements this type of button in a very roundabout way. In fact, we experimented with two different approaches to this problem. The numeric keys 1 through 4 are used to simulate four keys that would be placed under the LCD in both solutions.

The initial approach was to have a key press generate a mouse event at a specific location on the window. Each of the number keys would be assigned a specific location, at which to trigger the mouse event. The thought was that the active button at that particular location of the display would then be triggered. Unfortunately, these mouse events do not trickle down from the container to the contained component. In other words, a `MouseEvent` on a component gets passed up to the container (in our case, a Frame) that holds the button, but a `MouseEvent` on a container does not get passed down to the components held in the container. In order to make this work we were forced to add a lot of code to the keyboard event handler. When the system saw a number key

between 1 and 4 pressed, it would search all visible components in order to determine which button occupied the location that was associated with the keyboard event. The search was made by calling the **`contains()`** method of each visible component in the container to see if the coordinate associated with the number key was inside the component. This technique works because the only components found at the button locations are buttons. If other components might occupy these locations, a further test for the type **`Button`** would be required. Finally, an **`ActionEvent`** corresponding to the button object that we have singled out is created and then dispatched to the event queue.

A second solution was to keep a table that associates the four keys with the different buttons. When a menu is removed and another one made active, this table must be updated to reflect the new buttons that are now associated with the keys. The advantage is that when a key is pressed, the **`ActionEvent`** for the correct button is immediately available from the table, with no search or validation required.

A solution similar to one of the above is necessary in order to be compatible with the existing AWT. If we did not attempt to implement the AWT **`Button`**, we would be free to come up with our own, very specialized structure that would describe the user interface more directly. For example, the four button menus might motivate a hierarchical menu structure, similar to the AWT **`Menu`** structure, except the number of **`MenuItems`** would be fixed, and the means of activation would be simple **`KeyEvents`**.

4.5 The EWT Peers

The current implementation of the EWT provides the following peer classes:

`EwtButtonPeer`

EwtComponentPeer

EwtContainerPeer

EwtFramePeer

EwtLabelPeer

EwtWindowPeer

An interesting difference between a typical implementation of the AWT and the EWT is that in the case of the EWT, there is no underlying window system. Instead of simply passing calls down to the native window system, as is the case in a typical AWT port, the peers of the EWT actually do the work of drawing text and lines necessary to build the simple components supported by the EWT.

The lack of native window code may be less efficient, since the native window code is usually written at a low level and fine tuned for efficiency, but it demonstrates that most of the platform dependent code required for porting the AWT may be written in Java.

4.6 An EWT Port to Win95/NT

In addition to implementing the EWT on the target system, simulation code was developed for Win95/NT. This allowed testing the EWT code without having to program it into the NS486 board, a time consuming process. The simulation consisted of replacing the native method calls to the Java Nanokernel with calls to a Windows DLL that simulated the behavior of the native methods. A useful by product of this, was that the size of Java code that made up the EWT could be directly compared to the standard AWT provided for Win95/NT. The required native methods are described in detail in section 6.1 below.

5 UCSC Embedded Systems Development Platform

The EWT was developed as a component of the Embedded Systems Lab development platform. The development platform consists of hardware and software. The hardware includes a National Semiconductor development board, a host PC with a serial port connection, and an LCD and LCD adapter board. The software consists of the Java Nanokernel, a Java compiler, a C compiler, linker and debugger, and various custom built utilities.

5.1 NS486 Development Board

The National NS486 development board is a complete self-contained embedded system with many attributes. It has a 25 MHz NS486 CPU chip. The required clocks and reset circuitry for the CPU are included. There is a 256 Kbyte flash memory, which was upgraded by UCSC to 1 Mbyte. The system boot code is contained in this chip. A DRAM socket is included for main system memory, in which UCSC has installed a 4 Mbyte DRAM module. A PCMCIA socket is also provided on the development board. UCSC has installed a battery backed memory card in this location, and a simple file system is included in the Java Nanokernel that allows classes to be loaded from the memory on this card.

Further attributes of the NS486 evaluation board are two serial ports, a bi-directional parallel port, and a real time clock.

Finally, there is a PC/104 expansion interface. This interface is extremely popular in the embedded systems market. It is functionally identical to the ISA buss, the buss at the heart of the original IBM PC. The only difference is the connector type. Instead of using the gold finger card edge connector, PC/104 uses the more reliable (and smaller)

0.025-inch square pin and socket system. UCSC has installed a commercially available Ethernet card in the PC/104 socket on the evaluation board.

5.2 The Java Nanokernel System Software

The software environment that the EWT was implemented on was developed by several UCSC graduate students. The Java Nanokernel is a very small “soft” real-time operating system, specifically designed to support the Java virtual machine. The source code for JN consists of only about 2000 lines of C code. There is much more that is included in the Nanokernel system. This includes a TCP/IP stack modified from the publicly available KA9Q. A simple file system is also included. The file system is a single directory system, although since the forward slash character is allowed in the file name, it is able to mimic the directory structures required for the Java package structure. Further parts of the system are a fairly complete suite of tests that are executed from a simple menu system using a VT100 terminal. Finally, the system has a command line interpreter which is used to start execution of a Java class file and a modified Java virtual machine.

5.3 Overview of LCD Hardware

Liquid Crystal Displays work by applying an alternating voltage across a special fluid. When the fluid is placed in this electric field, the liquid acts as a light polarizer. By placing a polarizing filter between the viewer and the liquid, the amount of light transmitted to the viewer can be controlled by controlling the applied voltage.

There are two basic types of LCD’s which are typically used in embedded systems. These are known as character and graphic LCD’s. The character LCD’s are generally custom made for the application and have individual segments which are fabricated in the

shape of a number segment or a special symbol, such as a low battery symbol. Graphic LCD's are simply arrays of rectangular pixels in which software is used to generate characters and symbols.

Graphic LCD's also come in two different classes. Some use a specialized controller that has it's own memory. When a pixel is written once to the controller, the controller stores it in its memory and the pixel remains on the display until it is overwritten. In this type of display, the controller continually refreshes the LCD from its local memory. The other type of LCD system does not require separate memory. This system is analogous to a raster scan video monitor. In this system, data for the entire display must be continuously written to the LCD, at a rate rapid enough so the display doesn't flicker. While this system creates much more overhead on the processor, it is superior when rapid changes to the displayed image are needed, since the image is generally contained in high-speed system memory. The NS486 contains a special LCD controller designed to generate this type of scan line data output from system memory.

The NS486 uses the on chip DMA controller to transfer data from a frame buffer allocated in DRAM to the LCD controller. The frame buffer is an array of bytes statically allocated in the operating system code. The array is organized as follows: first there is a section of 32 bytes called a Gray-scale Look Up Table (GLUT). The GLUT provides factors that map the 4 gray scale levels to different modulation values. The GLUT values remained unchanged from the National demonstration code. The next 19200 bytes contains the pixel data. The pixel data is two bits per pixel and as usual, is organized as a scan line. The dimensions of the display determine the size of the array. The display is

320 by 240 and there are 4 pixels per byte. The built in LCD controller includes a timing generator and a FIFO which synchronizes with the DMA controller which sends the contents of the frame buffer in a burst that is repeated approximately 70 times a second.

5.4 Hardware Modifications

In order to connect the LCD to the NS486 development board a special interface circuit board was required. The NS486 provides 4 LCD data lines and 3 LCD clocks. The clocks include a frame signal, used to signal the start of a frame, a data latch, and a data shift clock. The data lines output four different scan lines simultaneously.

Unfortunately, there are other required signals that are not supplied directly by the NS486 chip. There is a display off signal which is generated using a NOR gate. Also an interlacing signal is required – this signal may be generated by using a flip-flop to divide the frame clock by two.

Additional power supplies are also required. The LCD has a florescent backlight. This backlight requires a high AC voltage, approximately 170VAC. A DC to AC inverter supplies this voltage. The LCD also requires a –25VDC bias voltage. This voltage is generated by a small switching power supply, fabricated on the circuit board. Finally, a potentiometer is required to adjust the contrast voltage.

The required circuitry was built on a small wire wrap prototype board and mounted in a case along with the display. A bill of materials and a schematic of the circuit board is found in the appendix. The design of the circuit was based on a paper by Michael Draeger[DRA97].

6 Measuring the size of the AWT

Measuring the size of the AWT is not difficult, the problem comes when comparing this size to the EWT. The AWT uses the native window system to do much of the work. In contrast to this, the EWT runs on a platform that has no native window system. The EWT has a very minimal amount of native methods, less than 100 lines of C source code. This interface, as discussed below in section 6.1, includes only five methods. In contrast, the size of the Windows graphics library is enormous. An estimate of the size of the Windows native code can be made by adding the size of some of the required Windows DLL files, however, this is only a very rough estimate. It is likely that the actual memory footprint is much larger than the estimate created by examining the DLL sizes, since this does not include any of the fonts, which are held in many separate files.

6.1 Measurement Experiment

A very small port of the AWT was made for the NS486 system. A 320 by 240 pixel display was connected as described in the documentation for the development board. The Java Nanokernel was modified to provide some basic support for the LCD. This required addition of the following functions:

`USHORT LCD_Start( void )` – The **`LCD_Start`** function initializes the LCD controller hardware and the DMA hardware. A DMA request is generated by the LCD controller approximately every 14 milliseconds. This request causes data to be transferred from the frame buffer in system memory to the LCD controller. A FIFO in the controller allows data to leave the controller at a constant rate, even though the DMA transfer may be somewhat sporadic.

`USHORT LCD_Stop( void )` – The `LCD_Stop` function disables the DMA transfer and shuts down the LCD controller..

`void LCD_drawImage( LCD_IMAGE im, int x, int y )` – The `LCD_drawImage` function takes an image structure and an x and y coordinate. Then it copies the image data to the frame buffer located in main memory. The copy places the top left corner of the image at the x and y location of the frame buffer. The `LCD_drawImage` clips any portions of the image that extend beyond the coordinates of the frame buffer.

`void LCD_drawLine( int x1, int y1, int x2, int y2 )` – The `LCD_drawLine` function draws a line between any two points in the frame buffer. If the line extends beyond the coordinates of the frame buffer it is clipped.

`char GetChar( void )` – This function is used to read a key press from the serial port of the NS486. It is blocking, i.e. it does not return until a key press is received. This function is not technically part of the EWT, but was required because the capability of reading a single character from `stdin` in the JavaNanokernel system relies on changing the mode of the input stream from cooked to raw. For portability reasons to the WinNT platform, a function existing in the JavaNanokernel, `uart_rcv_c()` was used. This fuction is equivalent to the WinNT `getch()` which retrieves a single character from the keyboard.

Note that the `LCD_IMAGE` data type is an array of `char` containing a raster format image along with two `int`s that give the x and y dimensions. The `LCD_drawImage`

function simply copies this array to the appropriate part of the frame buffer, overwriting whatever is present in the buffer at that location.

The functions discussed above were implemented in C, as is the Java Nanokernel system. Java wrapper functions called **drawLine**, **drawImage**, and **makeWindow** were written to make these functions accesible from Java. The **makeWindow** function simply uses the **LCD_Start** function. In addition, two fonts were created. These fonts were implemented as static arrays of images. A **drawString** method was written that would sequentially call **drawImage** to display a string.

A simple **ButtonPeer** was implemented that used the **drawString** and **drawLine** to draw a button on the display. Finally a mock application was written. The application is a mock up of what might be required to implement a greenhouse environmental controller. There is a menu of four buttons across the bottom of the LCD, and they allow the display of three different measurement parameters, as well as the selection of a different set of menu buttons.

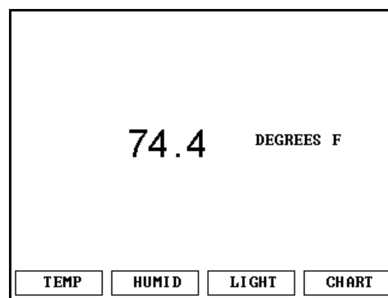

Figure 5. Main Menu of Example Application

6.2 Relative comparison Results

The size of the Java classes which were required to execute the above was measured using the "–v" switch on the Java virtual machine. When the virtual machine is started with this switch, it sends to standard error the name of each class as it is loaded. Two lists were made, one using the EWT version on WinNT and a second one using the normal AWT on WinNT. Both of these lists were made with version 1.1.6 of the virtual machine and class files. The lists were then filtered to remove any classes that were not either part of the `java/awt` package, part of the `sun/awt` package, or part of the `ucsc/ewt` package. By removing the classes not associated with the AWT or EWT, differences between the size of the toolkits should be more dramatic. The lists were the sorted alphabetically, and arranged in a spreadsheet such that identical classes were placed on the same row. The size of each class was then entered and totals obtained for both.

AWT		EWT	
.\ghewt.class	5064	.\ghewt.class	5064
Java/awt/AWTError.class	315	Java/awt/AWTError.class	315
java/awt/AWTEvent.class	4614	Java/awt/AWTEvent.class	4614
java/awt/AWTEventMulticaster.class	7286	Java/awt/AWTEventMulticaster.class	7286
java/awt/BorderLayout.class	5166	Java/awt/BorderLayout.class	5166
java/awt/Button.class	3409	Java/awt/Button.class	3409
java/awt/Color.class	4924		
java/awt/Component$NativeInLightFixer.clas s	2593	Java/awt/Component$NativeInLightFixer.clas s	2593
java/awt/Component.class	25832	Java/awt/Component.class	25832
java/awt/Container.class	14389	Java/awt/Container.class	14389
java/awt/Cursor.class	1459	Java/awt/Cursor.class	1459
java/awt/event/ActionListener.class	286	Java/awt/event/ActionListener.class	286
java/awt/event/AdjustmentListener.class	305	Java/awt/event/AdjustmentListener.class	305
java/awt/event/ComponentEvent.class	1555	Java/awt/event/ComponentEvent.class	1555
java/awt/event/ComponentListener.class	372	Java/awt/event/ComponentListener.class	372
java/awt/event/ContainerEvent.class	1386	Java/awt/event/ContainerEvent.class	1386

java/awt/event/ContainerListener.class	321	Java/awt/event/ContainerListener.class	321
java/awt/event/FocusListener.class	299	Java/awt/event/FocusListener.class	299
java/awt/event/InputEvent.class	1213	Java/awt/event/InputEvent.class	1213
java/awt/event/ItemListener.class	281	Java/awt/event/ItemListener.class	281
		Java/awt/event/KeyEvent.class	9332
java/awt/event/KeyListener.class	313	Java/awt/event/KeyListener.class	313
java/awt/event/MouseEvent.class	2071		
java/awt/event/MouseListener.class	372	Java/awt/event/MouseListener.class	372
java/awt/event/MouseMotionListener.class	313	Java/awt/event/MouseMotionListener.class	313
java/awt/event/PaintEvent.class	1284		
java/awt/event/TextListener.class	281	Java/awt/event/TextListener.class	281
java/awt/event/WindowEvent.class	1201		
java/awt/event/WindowListener.class	438	Java/awt/event/WindowListener.class	438
java/awt/EventDispatchThread.class	1625		
java/awt/EventQueue.class	2704	Java/awt/EventQueue.class	2704
java/awt/EventQueueItem.class	493		
java/awt/FocusManager.class	2475	Java/awt/FocusManager.class	2475
java/awt/Font.class	3809	Java/awt/Font.class	3809
java/awt/Frame.class	5651	Java/awt/Frame.class	5651
		Java/awt/Graphics.class	3685
		Java/awt/Image.class	1382
java/awt/image/ImageObserver.class	493	Java/awt/image/ImageObserver.class	493
java/awt/Insets.class	1391		
java/awt/Label.class	1634	Java/awt/Label.class	1634
java/awt/LayoutManager.class	473	Java/awt/LayoutManager.class	473
java/awt/LayoutManager2.class	504	Java/awt/LayoutManager2.class	504
java/awt/LightweightDispatcher.class	3951	Java/awt/LightweightDispatcher.class	3951
java/awt/Menu.class	5275	Java/awt/Menu.class	5275
java/awt/MenuComponent.class	3034	Java/awt/MenuComponent.class	3034
java/awt/MenuContainer.class	333	Java/awt/MenuContainer.class	333
java/awt/MenuItem.class	5453	Java/awt/MenuItem.class	5453
java/awt/peer/ActiveEvent.class	213		
java/awt/peer/ButtonPeer.class	3409	Java/awt/peer/ButtonPeer.class	3409
java/awt/peer/CanvasPeer.class	221		
java/awt/peer/ComponentPeer.class	1364	Java/awt/peer/ComponentPeer.class	1364
java/awt/peer/ContainerPeer.class	338	Java/awt/peer/ContainerPeer.class	338
java/awt/peer/FontPeer.class	182		
java/awt/peer/FramePeer.class	379	Java/awt/peer/FramePeer.class	379
java/awt/peer/LabelPeer.class	291	Java/awt/peer/LabelPeer.class	291
java/awt/peer/LightweightPeer.class	2654	Java/awt/peer/LightweightPeer.class	2654
java/awt/peer/PanelPeer.class	219		

java/awt/peer/WindowPeer.class	262	Java/awt/peer/WindowPeer.class	262
java/awt/PopupMenu.class	2020	Java/awt/PopupMenu.class	2020
java/awt/Rectangle.class	4242	Java/awt/Rectangle.class	4242
java/awt/Shape.class	216	Java/awt/Shape.class	216
java/awt/Toolkit.class	5336	Java/awt/Toolkit.class	5336
java/awt/Window.class	7815	Java/awt/Window.class	7815
sun/awt/CharToByteSymbol.class	2197		
sun/awt/DrawingSurface.class	253		
sun/awt/EmbeddedFrame.class	1184		
sun/awt/FontDescriptor.class	640		
sun/awt/im/InputContext.class	2012		
sun/awt/im/InputMethodContext.class	278		
sun/awt/PlatformFont.class	6430		
sun/awt/SunToolkit.class	3809		
sun/awt/UpdateClient.class	231		
sun/awt/windows/CharToByteWingDings.class	1628		
sun/awt/windows/WButtonPeer.class	1535	.\ucsc\ewt\EwtButtonPeer.class	1655
sun/awt/windows/WCanvasPeer.class	1345		
		.\ucsc\ewt\EwtContainerPeer.class	1238
sun/awt/windows/WColor.class	604		
sun/awt/windows/WComponentPeer.class	7271	.\ucsc\ewt\EwtComponentPeer.class	3767
sun/awt/windows/WDefaultFontCharset.class	499		
sun/awt/windows/WFontPeer.class	2017	.\ucsc\ewt\EwtFont.class	986
sun/awt/windows/WFramePeer.class	2145	.\ucsc\ewt\EwtFramePeer.class	1215
		.\ucsc\ewt\EwtImage.class	1622
sun/awt/windows/WLabelPeer.class	1535	.\ucsc\ewt\EwtLabelPeer.class	1521
sun/awt/windows/WObjectPeer.class	553		
sun/awt/windows/WPanelPeer.class	1284		
sun/awt/windows/WToolkit.class	9399	.\ucsc\ewt\WillsAWT.class	8343
sun/awt/windows/WWindowPeer.class	2662	.\ucsc\ewt\EwtWindowPeer.class	626
		.\ucsc\ewt\NativeGraphics.class	780
		.\ucsc\ewt\LCDGraphics.class	4065
		.\ucsc\ewt\EwtFont$Digits.class	7407
		.\ucsc\ewt\EwtFont$SansSerif.class	9459
TOTAL FOR AWT	205312	**TOTAL FOR EWT**	199060
		EWT IS WHAT PERCENT OF AWT?	97.0%

Figure 6. Java Byte Code for AWT versus EWT

7 Conclusions

The result that the class sizes of the two systems were almost identical was not surprising. The very simple EWT required almost the same amount of object code as the vastly more complex AWT. The reason that they are so similar in size is because only parts of the AWT that were needed were including in the list. The list shows only classes that are loaded by the run time system. In Java, a class that is declared but not used is not loaded. Since the application has identical requirements, whether using AWT or EWT, the required classes have a similar size.

The differences in size appear in the platform dependent code. The sun/awt classes are somewhat larger that their simpler ucsc/ewt classes. The EWT fonts are implemented as images and therefore require support for images.

One result that seems surprising is that many classes are loaded which have no purpose. The EWT has no **`Menu`**, no **`LayoutManager`** and yet these classes are loaded. It should be possible to remove these classes and thereby reduce the memory footprint of the EWT by modifying the non peer classes.

Another reason for the large size of the EWT is the inclusion of fonts. As previously discussed, the EWT stored fonts as Java Images. This is not at all efficient. The **`Image`** classes were required by the EWT implementation, while they were not required for the AWT. The size of the font classes is also very inefficient. For example,

the `EwtFont$SansSerif.class` required 9459 bytes. The data contained within was 55 images that were 8 by 10 pixels. A C language array could pack this into 550 bytes. Part of the reason for the increased size is that the images were stored in an array of 128 images, which requires a pointer table.

Despite the similarity between the sizes of the class files, we are not achieving a fair comparison. As discussed above, the EWT requires almost no native graphics support, much different from the AWT. If we add in the native methods used by both systems, it is apparent the EWT is much smaller.

AWT		EWT	
msawt.dll	224256	Jn_lcd.o	8036
user32.dll	44544		
gdi32.dll	131072		
Vga.drv	52064		
Java Classes	205312		199060
Total AWT	657248	Total EWT	207096
		EWT % of AWT	31.5%

Figure 7. Size Comparison Including Native Code

The size of the EWT seems much more reasonable when the native code is included. This size fits well within the Embedded Java requirements of 512K ROM. Thus it has been shown that an AWT compatible subset, tailored to the needs of a small embedded system, can be built without the need for the embedded system to have a native windowing system.

8 Appendixes

8.1 Bill Of Materials

LCD ADAPTER FOR NS486SXF EVAL BOARD Revised: October 11, 1998

wholt@cse.ucsc.edu Revision: A

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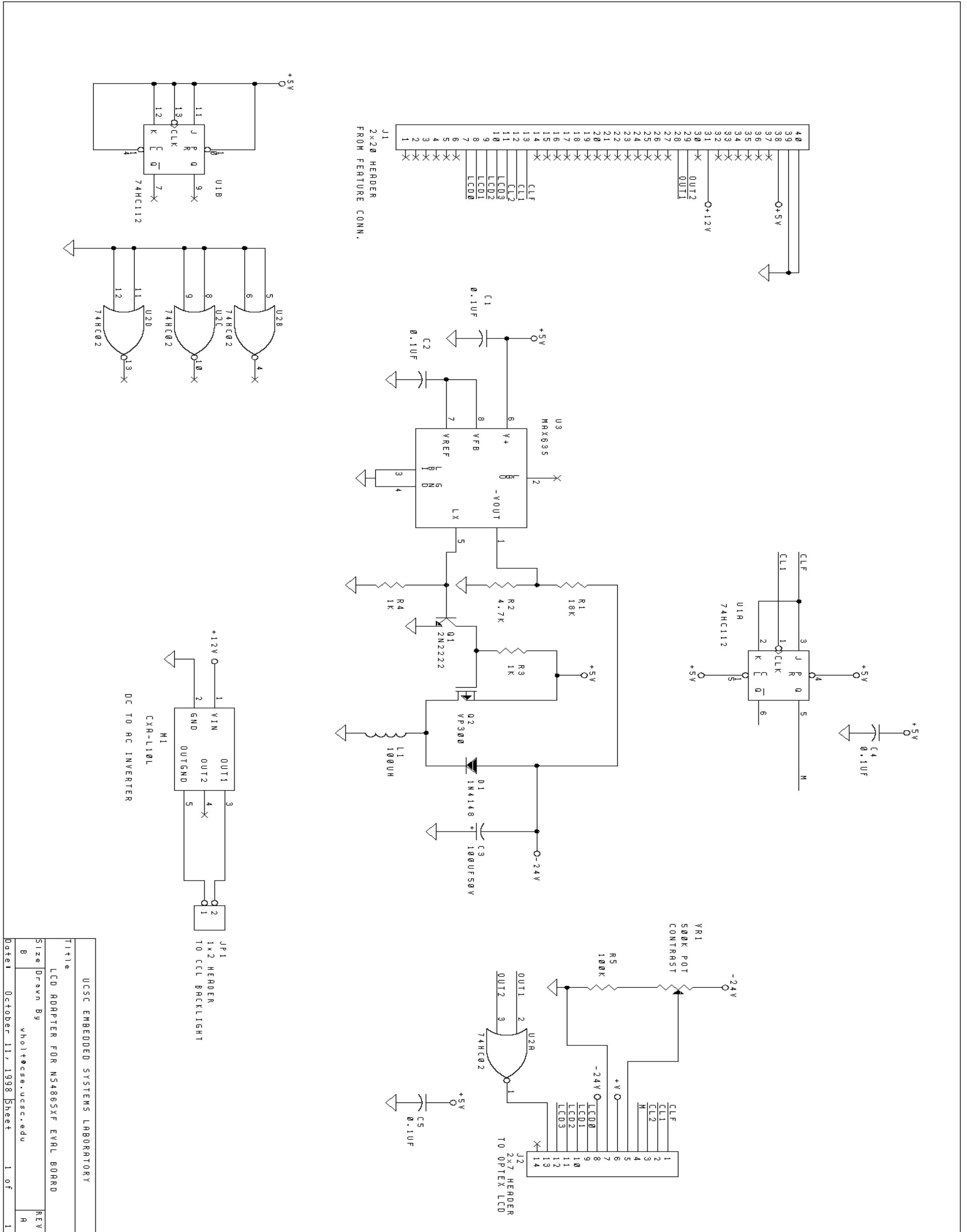
Item	Quantity	Reference	Part	Digi-Key
1	4	C1,C2,C4,C5	0.1UF	P4924-ND
2	1	C3	100UF50V	P1353-ND
3	1	D1	1N4148	1N4148-ND
4	1	JP1	1x2 HEADER	
5	1	J1	2x20 HEADER	
6	1	J2	2x7 HEADER	
7	1	L1	100UH	M5820-ND
8	1	M1	CXA-L10L	73-1007-ND
9	1	Q1	2N2222	ZTX-651-ND
10	1	Q2	VP300	ZVP2106A-ND
11	1	R1	18K	18KQBK-ND
12	1	R2	4.7K	4.7KQBK-ND
13	2	R3,R4	1K	1.0KQBK-ND
14	1	R5	100K	100KQBK-ND
15	1	U1	74HC112	MM74HC112N-ND
16	1	U2	74HC02	MM74HC02N-ND
17	1	U3	MAX635	MAX635CPA-ND
18	1	VR1	500K POT	3310C-1-504-ND

8.2 Schematic



8.3 Mock Application Source Code

```
import ucsc.ewt.*;
import java.awt.*;
import java.awt.event.*;
import java.util.*;

public class ghewt extends Frame
    implements ActionListener, KeyListener
{
    //these rectangles outline the menu buttons, the reading value,
    // and units display
    static Rectangle f1= new Rectangle(   4, 216, 72, 20 );
    static Rectangle f2= new Rectangle(  84, 216, 72, 20 );
    static Rectangle f3= new Rectangle( 164, 216, 72, 20 );
    static Rectangle f4= new Rectangle( 244, 216, 72, 20 );
    static Rectangle d = new Rectangle(  20, 60, 200, 100 );
    static Rectangle u = new Rectangle( 220, 100, 100, 30 );

    //menu A
    static Button temp, humid, light, chart;
    //menu B
    static Button hour, day, week, back;

    static Label tempValue, humidValue, lightValue;
    static Label tempUnits, humidUnits, lightUnits;

    static ghewt lcd;

    //keeps track of which menu is active
    static Button menu_key[ ]= new Button[4];

    public ghewt()
    {
        super( "An LCD SIMULATION" );
// the next section is to force the toolkit to EWT
//    only necessary to use the Win95/98/NT version of EWT
        Properties theProps;
        theProps = System.getProperties();
//comment out this line to use normal AWT
//        theProps.put( "awt.toolkit", "ucsc.ewt.WillsAWT" );
        System.setProperties( theProps );
        System.out.println( theProps );
    }

    public static void main( String argv[] )
    {
        lcd = new ghewt();
//Comment out one of the following two lines
        Font digits = new Font( "Helvetica", Font.PLAIN, 72 );
//        Font digits = EwtFont.EwtDigits;

        lcd.setLayout( null );

        // build the menus
```

```
temp  = new Button( " TEMP " );
temp.setBounds( f1 );
humid = new Button( "HUMID" );
humid.setBounds( f2 );
light = new Button( "LIGHT" );
light.setBounds( f3 );
chart = new Button( "CHART" );
chart.setBounds( f4 );
hour = new Button( " HOUR " );
hour.setBounds( f1 );
day = new Button( "  DAY  " );
day.setBounds( f2 );
week = new Button( " WEEK " );
week.setBounds( f3 );
back = new Button( " BACK " );
back.setBounds( f4 );

// so the action events we make on the buttons
// get passed back up to the frame
temp.addActionListener( lcd );
humid.addActionListener( lcd );
light.addActionListener( lcd );
chart.addActionListener( lcd );
hour.addActionListener( lcd );
day.addActionListener( lcd );
week.addActionListener( lcd );
back.addActionListener( lcd );

// this next section is only important for AWT
temp.addKeyListener( lcd );
humid.addKeyListener( lcd );
light.addKeyListener( lcd );
chart.addKeyListener( lcd );
hour.addKeyListener( lcd );
day.addKeyListener( lcd );
week.addKeyListener( lcd );
back.addKeyListener( lcd );

// only need this for EWT
lcd.addKeyListener( lcd );

// make some fake data to display
tempValue= new Label( " 74.4" );
tempValue.setFont( digits );
tempValue.setBounds( d );
humidValue= new Label( " 62.9" );
humidValue.setFont( digits );
humidValue.setBounds( d );
lightValue= new Label( "574.4" );
lightValue.setFont( digits );
lightValue.setBounds( d );
tempUnits= new Label( "DEGREES F" );
tempUnits.setBounds( u );
humidUnits= new Label( " PERCENT " );
humidUnits.setBounds( u );
lightUnits= new Label( "  LUMENS " );
```

```
        lightUnits.setBounds( u );

        // add them to the display
        lcd.add( temp );
        lcd.add( humid );
        lcd.add( light );
        lcd.add( chart );
        lcd.add( hour );
        lcd.add( day );
        lcd.add( week );
        lcd.add( back );
        lcd.add( tempValue );
        lcd.add( humidValue );
        lcd.add( lightValue );
        lcd.add( tempUnits );
        lcd.add( humidUnits );
        lcd.add( lightUnits );

        // make the menu active
        menu_key[0] = temp;
        menu_key[1] = humid;
        menu_key[2] = light;
        menu_key[3] = chart;

        // make everything but the active invisible
        hour.setVisible( false );
        day.setVisible( false );
        week.setVisible( false );
        back.setVisible( false );
        humidValue.setVisible( false );
        lightValue.setVisible( false );
        humidUnits.setVisible( false );
        lightUnits.setVisible( false );

        lcd.setSize( 320, 240 );
        lcd.show();
    }
    public void actionPerformed( ActionEvent e )
    {
        if ( e.getSource().equals( temp ) )
        {
            tempValue.setVisible( true );
            humidValue.setVisible( false );
            lightValue.setVisible( false );
            tempUnits.setVisible( true );
            humidUnits.setVisible( false );
            lightUnits.setVisible( false );
            lcd.repaint();
        }
        else
        if ( e.getSource().equals( humid ) )
        {
            tempValue.setVisible( false );
            humidValue.setVisible( true );
            lightValue.setVisible( false );
            tempUnits.setVisible( false );
```

```
    humidUnits.setVisible( true );
    lightUnits.setVisible( false );
    lcd.repaint();
}
else
if ( e.getSource().equals( light ) )
{
    tempValue.setVisible( false );
    humidValue.setVisible( false );
    lightValue.setVisible( true );
    tempUnits.setVisible( false );
    humidUnits.setVisible( false );
    lightUnits.setVisible( true );
    lcd.repaint();
}
else
if ( e.getSource().equals( chart ) )
{
    temp.setVisible( false );
    humid.setVisible( false );
    light.setVisible( false );
    chart.setVisible( false );
    tempValue.setVisible( false );
    humidValue.setVisible( false );
    lightValue.setVisible( false );
    tempUnits.setVisible( false );
    humidUnits.setVisible( false );
    lightUnits.setVisible( false );
    hour.setVisible( true );
    day.setVisible( true );
    week.setVisible( true );
    back.setVisible( true );

    menu_key[0]= hour;
    menu_key[1]= day;
    menu_key[2]= week;
    menu_key[3]= back;

    lcd.repaint();
}
else
if ( e.getSource().equals( back ) )
{
    hour.setVisible( false );
    day.setVisible( false );
    week.setVisible( false );
    back.setVisible( false );
    temp.setVisible( true );
    humid.setVisible( true );
    light.setVisible( true );
    chart.setVisible( true );
    tempValue.setVisible( true );
    tempUnits.setVisible( true );

    menu_key[0] = temp;
    menu_key[1] = humid;
```

```
            menu_key[2] = light;
            menu_key[3] = chart;

            lcd.repaint();
        }
    }

    public void keyTyped( KeyEvent e )
    {
        Component temp;
        int x= -10 , y= -10;

        switch( e.getKeyChar() )
        {
            case '1':
                temp= menu_key[0];
                break;
            case '2':
                temp= menu_key[1];
                break;
            case '3':
                temp= menu_key[2];
                break;
            case '4':
                temp= menu_key[3];
                break;
            default:
                temp= null;
        }
        if ( null != temp )
        {
            temp.dispatchEvent(
            new ActionEvent( temp,
                             ActionEvent.ACTION_PERFORMED, null ));
        }
    }

    public void keyPressed( KeyEvent e )
    {
    }
    public void keyReleased( KeyEvent e )
    {
    }
}
```

9 References

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