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UWIN – UNIX* for Windows

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Abstract

This paper describes an effort of trying to build a UNIX interface layer on top of the Windows NT^[1] and Windows 95^[2] operating system. The goal was to build an open environment rich enough to be both a good development environment and a suitable execution environment.

The result of this effort is a set of libraries, headers, and utilities that we collectively refer to as UWIN. UWIN contains nearly all the X/Open Release 4^[3] headers, interfaces, and commands. An earlier paper on porting to Windows NT^[4], describes alternative porting strategies and presents some performance results for UWIN. In this paper we discuss some of the design decisions behind UWIN and some of the results so far as well as some of the remaining challenges.

1. INTRODUCTION

The marketplace has dictated the need for software applications to work on a variety of operating system platforms. Yet, maintaining separate source code versions and development environments creates additional expense and requires more programmer training.

The Software Engineering Research department at AT&T Labs writes and distributes several widely used development tools and reusable libraries that are portable across virtually all UNIX platforms.^[5] To enhance reuse of these tools and libraries, we wanted to make them available on systems running Windows NT and/or Windows 95. We did not want to spend the cost needed to support multiple versions of these libraries, and we wanted to minimize the amount of conditionally compiled code.

One way to lower this cost is to use a middleware layer that hides the differences among the operating systems. The problem with this approach is that it forces one to program to a non-standard, and often proprietary, interface. In addition, it often limits one to the least common denominator of features of the different operating systems.

An alternative is to build a middleware layer based on existing standards. This has been the approach followed by IBM with the introduction of OpenEdition^[6] for the MVS operating system, URL <http://www.s390.ibm.com/products/oe>. OpenEdition is X/Open compliant so that a large collection of existing software can be transported at little cost.

Windows NT is an operating system developed by Microsoft to fill the needs of the high-end market. It is a layered architecture, designed from the ground up, built around a microkernel that is similar to Mach.^[7] One or more *subsystems* can reside on top of the microkernel which gives Windows NT the ability to run different logical operating systems simultaneously. For example, the OS/2 subsystem allows OS/2 applications to run on Windows NT. The most important subsystem that runs on Windows NT is the WIN32 subsystem. The WIN32 subsystem runs all applications that are written to the WIN32 Application Programming Interface (API)^[8]. The API for the WIN32 subsystem is also provided with Windows 95, although not all of the functions are implemented. In most instances binaries compiled for Windows NT that use the WIN32 API will also run on Windows 95.

The POSIX subsystem allows applications that are strictly conforming to the IEEE POSIX 1003.1 operating system standard^[9] to run on Windows NT. Since the POSIX standard contains most of the

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standard UNIX system call interface, many UNIX utilities are simple to port to any POSIX system. Because most of our tools require only the POSIX interface, we thought that it would be sufficient to port them to the POSIX subsystem of Windows NT. Unfortunately, this is not a viable alternative for most applications. Microsoft has made the POSIX subsystem as useless as possible by making it a closed system. There is no way to access functionality outside of the 1990 POSIX 1003.1 standard from within the POSIX subsystem, either at the library level or at the command level. Thus, it is impossible to invoke the Microsoft C compiler from within the POSIX subsystem. Softway System, Inc., URL <http://www.softway.com>, has an agreement with Microsoft to enhance the POSIX subsystem. Softway claims that they will open up the POSIX subsystem so that it can access WIN32 applications. They have built the OpenNT product with this enhanced subsystem. However, it is still not possible to mix UNIX API calls and WIN32 calls in a single application. A final drawback to this approach is that the POSIX subsystem is not available for Windows 95.

We investigated alternative strategies that would allow us to run programs on both UNIX and Windows NT based systems. After looking at all the alternatives, we decided to write our own library that would make porting to Windows NT and Windows 95 easy. We spent three months putting together the basic framework and getting some tools working. Realizing that the task was larger than a one person project, we contracted a small development team of 2 or 3 to do portions of the library, packaging, and documentation. This paper discusses the implementation of our POSIX library and current status. Version 1.2 of UWIN has been freely available in binary form for non-commercial use on the internet from the web site <http://www.research.att.com/sw/tools/uwin>. Version 1.3, described here, should be available from this site by the time of this conference.

2. GOALS

We wanted our software to work with Windows 3.1, Windows 95, and Windows NT. A summer student wrote a POSIX library for Windows 3.1 and we were able to port a number of our tools. However, the limited capabilities of Windows 3.1 made it a less than desirable platform. We instead focused our goals on Windows NT and Windows 95. We decided to use only the WIN32 API for our library so that the library would work on Windows 95 and

so that all WIN32 interfaces would be available to applications.

Initially, our goal was to provide the IEEE POSIX.1 interface with a library. This would be sufficient to run `ksh` and about eighty utilities that we had written. It soon became obvious that this wasn't enough for many applications. Most real programs use facilities that are not part of this standard such as sockets and/or IPC.

We needed to provide a character based terminal interface so that curses based applications such as `vi` could run. After the initial set of utilities was running, we wanted to get several socket based tools working. Several projects at AT&T that became interested in using our libraries, required the System V IPC facilities. The `S` graphics system^[10] and `ksh-93`^[11] required runtime dynamic linking. As the project progressed, the need for privileged users, such as `root` on UNIX systems, surfaced. We decided that it was important to have `setuid` and `setgid` capabilities. It soon became clear that we needed full UNIX functionality and we set our goal on X/Open Release 4 conformance.

We needed to have a complete set of UNIX development tools since we didn't want to get into the business of rewriting makefiles or changing build scripts. Most code written at AT&T, including our own, uses `nmake`^[12], (no relation to the Microsoft `nmake`), but we also wanted to be able to support other make variants. We didn't want to do manual configuration on tools that have automatic configuration scripts.

A second measure of completeness is the degree to which all the system services can be accessed through the UNIX API. Our goal was to be able to perform as many of the Windows NT tasks as possible via traditional UNIX commands. For example, it should be possible to reboot the system when logged in through a telnet session by calling the UNIX shutdown program. We should also be able to access the Windows registry database with standard UNIX utilities such as `grep`.

One important goal that we had from the beginning was to not require WIN32 specific changes to the source to get it to compile and execute. The reason for this is that we wanted to be able to compile and execute UNIX programs without having to understand their semantics. In addition we wanted to limit the number of new interfaces functions and environments variables that we had to add to use our library. It is difficult to manage more than one or

two environment variables when installing a new package.

Another goal that we had was to provide a robust set of utilities with minimal overhead. If utilities written to the X/Open API were noticeably slower than the same utilities written to the native WIN32 API, then they were likely to be rewritten making our library unnecessary in the long run.

A final and important goal was interoperability with the native Windows NT system. Integration with the native system not only meant that we could use headers and libraries from the native system, but that we could pass environment variables and open file descriptors to commands written with the native system. There couldn't be two unrelated sets of user ids and separate passwords. If write permission were disabled from the UNIX system, then there should be no way to write the file using facilities in the native system and vice versa.

We have not as yet achieved all of our goals, but we think that we are close. The rest of the paper will discuss some of the issues we needed to deal with and our solutions.

3. PROBLEMS TO SOLVE

The following problems need to be understood and dealt with in porting applications to Windows NT. These are some of the issues that need to be addressed by POSIX library implementations. Section 6 describes how UWIN solved most of these problems.

3.1 Windows NT File Systems

Windows NT supports three different file systems, called FAT, HPFS, and NTFS. FAT, which stands for File Access Table, is the Windows 95 file system. It is similar to the DOS file system except that it allows long file names. There is no distinction between upper and lower case although the case is preserved. HPFS, which stands for High Performance File System, was designed for OS/2. NTFS, the native NT File System, is similar to the Berkeley file system.^[13] It allows long file names (up to 255 characters) and supports both upper and lower case characters. It stores file names as 16 bit Unicode names.

The file system namespace in Win32 is hierarchical as it is in UNIX and DOS. A pathname can be separated by either a / or a \. Like DOS, and unlike UNIX, disk drives are specified as a colon terminated prefix to the path name, so that the

pathname `c:\home\dgk` names the file in directory `\home\dgk` on drive `c:`. Many UNIX utilities expect only / separated names, and expect a leading / for absolute pathnames. They also expect multiple /'s to be treated as a single separator.

Even though NTFS supports case sensitivity for file names, the WIN32 API has no support for case sensitivity for directories and minimal support for case sensitivity for files, limited to a `FILE_FLAG_POSIX_SEMANTICS` creation flag for the `CreateFile()` function. Certain characters such as *, ?, >, |, :, ", and \, cannot be used in filenames created or accessed with the WIN32 API. The names, `aux`, `com1`, `com2`, `nul`, and filenames consisting of these names followed by any suffix, cannot be created or accessed in any directory through the WIN32 API.

Because Windows 95 doesn't support execute permission on files, it uses the `.exe` suffix to decide whether a file is an executable. Windows NT doesn't require this suffix, but some NT utilities, such as the DOS command interpreter, require the `.exe` suffix.

3.2 Line Delimiters

Windows NT uses the DOS convention of a two character sequence `<cr><n1>` to signify the end of each line in a text file. UNIX uses a single `<n1>` to signify end of line. The result is that file processing is more complex than it is with UNIX. There are separate modes for opening a file as text and binary with the Microsoft C library. Binary mode treats the file as a sequence of bytes. Text mode strips off each `<cr>` in front of each new-line as the file is read, and inserts a `<cr>` in front of each `<n1>` as the file is written. Because the number of characters read doesn't indicate the physical position of the underlying file, programs that keep track of characters read and use `lseek()` are likely to not work in text mode. Fortunately, many programs that run on Windows NT do not require the `<cr>` in front of each `<n1>` in order to work. This difference turned out to be less of a problem that we had originally expected.

3.3 Handles vs. file descriptors

The WIN32 API uses *handles* for almost all objects such as files, pipes, sockets, processes, and events, and most handles can be *duped* within a process or across process boundaries. Handles can be inherited from parent processes. Handles are analogous to file descriptors except that they are unordered, so that a per process table is needed to maintain the ordering.

Many handles, such as pipe, process, and event handles, have a synchronize attribute, and a process can wait for a change of state on any or all of an array of handles. Unfortunately, socket handles do not have this attribute. One of the few novel features of WIN32 is the ability to create a handle for a directory with the synchronize attribute. This handle changes state when any files under that directory change. This is how multiple views of a directory can be updated correctly in the presence of change.

3.4 Inconsistent Interfaces

The WIN32 API handle interface is often inconsistent. Failures from functions that return handles return either 0 or -1 depending on the function. The `CloseHandle()` function does not work with directory handles. The WIN32 API is also inconsistent with respect to calls that take pathname arguments and calls that take handles. Some functions require the pathname and others require the handle. In some instances, both calls exist, but they behave a little differently.

The WIN32 API is also inconsistent with respect to reporting errors when commands fail. Many commands return a boolean value for success or failure and the exit code for failure can be found by calling `GetLastError()`. However, a number of commands return the exit code with 0 indicating success.

3.5 Chop Sticks Only

The WIN32 subsystem does not have an equivalent for `fork()` or an equivalent for the `exec*()` family. There is a single primitive, named `CreateProcess()` that takes 10 arguments, yet still cannot perform the simple operation of overlaying the current process with a new program as `execve()` requires.

3.6 Parent/Child Relationships

The WIN32 subsystem does not support parent/child relationships between processes. The process that calls `CreateProcess()` can be thought of as the parent, but there is no way for a child to determine its parent. Most resources, such as files and processes, have handles that can be inherited by child processes and passed to unrelated processes. Any process can wait for another process to complete if it has an open handle to that process. There is a limited concept of process group that affects the distribution of keyboard signals, and a process can be placed in a new group at startup or can inherit the

group of the parent process. There is no way to get or set the process group of an existing process.

3.7 Signals

The WIN32 API provides a structured mechanism for exception handling. Also, signals generated from within a process are supported by the API. However, signals generated by another process have no direct method of implementation. In addition to being able to interrupt processing at any point, a signal handler might perform a `longjmp` and never return.

3.8 Ids and Permissions

Windows NT uses *subject identifiers* to identify users and groups. A subject identifier consists of an array of numbers that identify the administrative authority and sub-authorities associated with a given user. A UNIX user or group id is a single number that uniquely identifies a user or group only within a single system. Information about users is kept in the a registry database which is accessible via the WIN32 API and the LAN manager API.

Windows NT uses an *access control list*, ACL, on each file or object to control the access of the file or object for each user. UNIX uses a set of permission bits associated with the three classes of users; the owner of the object, the group that the object belongs to, and everyone else. While it is possible to construct an access control list that more or less corresponds to a given UNIX permission, it is not always possible to represent a given access control list with UNIX permissions.

Windows NT has separate permissions for writing a file, deleting a file, and for changing the permission on a file. The write bit on UNIX systems determines all three. Thus, it is possible to encounter files that have partial write capability.

UNIX processes have real and effective user and group id's that control access to resources. Windows NT assigns each process a *security token* that defines the set of privileges that it has. UNIX systems use `setuid/setgid` to delegate privileges to processes. Windows NT uses a technique called *impersonation* to carry out commands on behalf of a given user. There is no user that has unlimited privileges as the *root* user does with UNIX. Instead the special privileges of root have been broken apart into separate privileges that can be given to one or more users. One of the biggest challenges we faced was providing the UNIX model of `setuid/setgid` on top of the WIN 32 interface.

The implementation of WIN32 for Windows 95 does not support the NT security model and calls return a *not implemented* error.

3.9 Terminal Interface

Windows NT and Windows 95 allow each character based application to be associated with a *console* which is similar to an *xterm* window. Consoles support echo and no echo mode, and line at a time or character at a time input mode, but lack many of the other features of the POSIX *termios* interface. There is no support for processing escape sequences that are sent to the console window. In echo mode, characters are echoed to the console when a read call is pending, not while they are typed. There are separate console handles for reading from the keyboard and writing to the screen.

3.10 Special Files

The WIN32 API supports unnamed pipes with the UNIX semantics. Named pipes are also supported but have different semantics than fifos and occupy a separate name space. There is no */dev* directory to name special files such as */dev/tty* and */dev/null*. The WIN32 does support special names of the form *\\.\PhysicalDrive* for disk drives and tape drive devices.

Windows NT supports hard links to files, but there is no WIN32 API call to create these links. They do not support symbolic links in the file system directly, but on Windows 95 and on Windows NT 4.0, the file browser does support *short cuts* which are very similar to symbolic links.

3.11 Shared libraries

The WIN32 API supports the linking of shared libraries at program invocation and at run time. The libraries are called dynamically linked libraries or DLL's and are represented by two separate files. One file provides the interface and is needed at compile time to satisfy external references. The second file contains the implementation as is needed at run time.

There are some restrictions on DLL's that are not found on UNIX system shared library implementations. One restriction is that you cannot override a function called by a DLL by providing your own version of the function. Thus, supplying your own *malloc()* and *free()* functions will not override the calls to *malloc()* and *free()* made by other DLL's. Secondly, the library can only contain pointers to data, not data itself. Thus, making a symbol such as *errno* part of a DLL is

impossible. Even making symbols such as *stdin* point to data in a DLL invites trouble since it is not possible to compile code that uses

```
static FILE *myfile = stdin;
```

3.12 Compilers and libraries

Microsoft sells the Visual C/C++ compiler for Windows NT and Windows 95. This compiler has both a graphical and command line interface. Microsoft also sells a software developers kit (SDK) that contains tools, including the Microsoft *nmake*. The compiler and linker use a different set of flags than standard UNIX compilers, and C files produce *.obj* files by default, rather than *.o* files. Fortunately, the linker can handle both *.obj* and *.o* files. The linker has options to choose a starting address and to specify whether the application is a console application, a GUI application, a POSIX application, or a dynamically linked library.

3.13 Environment Variables

The WIN32 API supports the creation and export of environment variables in much the same way that UNIX systems do. Some environment variables, such as *PATH* are used by both WIN32 and by UNIX, yet have different formats. UNIX uses a : separated list of pathnames; WIN32 uses a ; separated list.

4. UWIN DESIGN AND IMPLEMENTATION

We started work on writing our own POSIX library at the beginning of 1995 after being dissatisfied with the existing commercial products. We were able to put together a useful subset of functions in about 3 months. However, to be successful, it was necessary to provide as complete a package as possible. The library needed to handle console and serial line support, sockets, UNIX permissions, and other commonly used mechanisms such as memory mapping, IPC, and dynamic linking. In addition, to be useful, the libraries had to be documented and supported. This put the scope of the project outside of the reach of a small research department such as ours.

We subcontracted some of the development to Wipro in India to help complete this project. We jointly designed the terminal interface and the group in India implemented it. They also worked on completing the sockets library. They packaged the software for installation and are providing documentation. This section describes the UWIN implementation and how we solved many of the

problems described in Section 4.

4.1 UWIN Architecture

The current implementation of UWIN consists of two dynamically linked libraries named `posix.dll` and `ast52.dll` that more or less implement the functions documented respectively in section 2 and section 3 of UNIX manuals. In addition, a server process named UMS runs as Administrator (the closest thing to `root`). UMS generates security tokens for `setuid/setgid` programs as needed. It also is responsible for keeping the `/etc/passwd` and `/etc/group` files consistent with the registry database. The Architecture for UWIN is illustrated in Figure 1. The UMS server does not exist for Windows 95.

The `posix.dll` library maintains an open file table that is shared by all the currently active UNIX processes in a memory mapped region. This region is writable by all processes so that an ill-behaved process could affect another process. Even though all processes have read and write access to the shared segment, secure access to kernel objects in Windows NT is not compromised by this model because a process must have access rights to an object to use it; knowing its address or value doesn't give additional access rights. Some initial measurements indicated that the alternative of having a server process update the shared memory region, would have had a performance penalty that we did not believe was worth the cost. However, this is an area for future investigation.

The open file table is an array of structures of type `Pfd_t` as illustrated in Table 1.

Pfd_t	
long	refcount
int	oflag
char	type
short	extra

TABLE 1. File Table Structure

The `refcount` field is used to keep track of free entries in this table. The `Win32 InterlockedIncrement()` and `InterlockedDecrement()` functions are used to maintain this count so that concurrent access by different processes will work correctly. The `oflag` field stores the open flags for the file. The `type` field indicates what type of file, regular, pipe, socket, or special file. The function that is used read from

or to write to the file depend on the value of `type`. For certain types, the `extra` field stores an index into a type-specific table that stores additional information about this file.

The `posix.dll` library also maintains a per process structure, `Pproc_t`. The per process structure contains information required by UNIX processes that is not required by Win32 processes such as parent process id, process group id, signal masks, and process state as illustrated in Table 2.

Like the open file table, the process table maintains a reference count so that process slots can be allocated without creating a critical region. The meaning of most of the fields in the process structure can be deduced by its name. The `Psig_t` structure contains the bit mask for ignored, blocked and pending signals. When the first child process is invoked by a process, a thread is created that waits for this and subsequent processes to complete. The `waitevent` field contains an event this thread also waits on so that additional children can be added to the list of children to wait for.

Pproc_t	
long	refcount
HANDLE	proc,thread
HANDLE	sigevent
HANDLE	waitevent
HANDLE	etok,rtok
ulong	ntpid
pid_t	pid,ppid,pgrp,sid
id_t	uid,gid
Psig_t	siginfo
mode_t	umask
ulong	alarmremain
int	flags
time_t	cutime,cstime
Pprocfd_t	fdtab[OPEN_MAX]

TABLE 2. Process Table Structure

The process structure contains an array of up to `OPEN_MAX` structures of type `Pprocfd_t` that is indexed by file descriptor. The `Pprocfd_t` structure contains the close-on-exec bit, the index of the file in the open file table, and the corresponding handle or handles as illustrated in Table 3.

The `posix.dll` library implements the `malloc()`, `realloc()`, and `free()` interface using the `Vmalloc` library written by Kiem-Phong

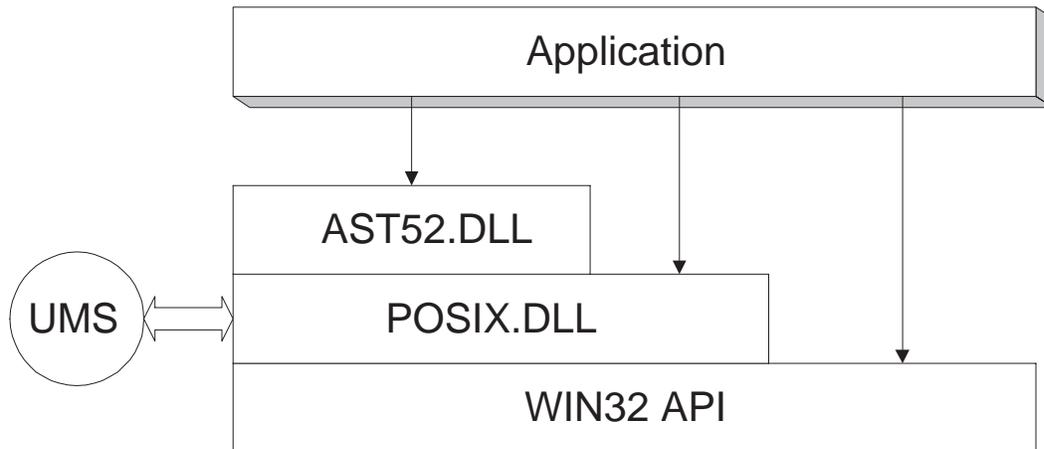


Figure 1. – UWIN Architecture

Vo^[14]. The `Vmalloc` library provides an interface to walk over all memory segments that are allocated which is needed for the `fork()` implementation described later.

Pproc_t	
short	index
char	close_exec
HANDLE	primary
HANDLE	secondary

TABLE 3. Process file structure

The `asta52.dll` library provides a portable application programming interface that is used by all of our utilities. The interface to this library is named `libast.a`, for compatibility with its name on UNIX systems. The 52 is used to indicate that it is version 5.2 of this library, the latest version number on UNIX systems. `libast.a` provides C library functions that are not present on all systems so that application code doesn't require `#ifdefs` to handle system dependencies. `libast.a` is built using the `iffe` command^[15] to feature test the host system and determine what interfaces do not exist in the native system.

`libast.a` relies on the Microsoft C library for much of the ANSI-C functionality. The most significant exception to this, other than `malloc()` which is provided by `posix.dll`, is the `stdio`

library. `libast.a` provides its own version of the `stdio` library based on calls to `Sfio`^[16]. The `Sfio` library makes calls to `posix.dll` rather than making direct calls to the WIN32 API as the Microsoft C library does so that pathnames are correctly mapped.

The use of `Sfio` also provides a simple solution to the `<cr><nl>` problem. When a file is explicitly opened for reading as a text file, an `Sfio discipline` for `read()` and `lseek()` can be inserted on the stream to change all `<cr><nl>` sequences are to `<nl>`. The `lseek()` discipline uses logical offsets so that the removal of `<cr>` characters is transparent. We did not provide a discipline to change `<nl>` to `<cr><nl>` since we discovered that most Windows 95 and Windows NT utilities worked without the `<cr>s`. The `<cr>s` could be inserted by a filter such as `sed` if required.

4.2 Files

The `posix.dll` library performs the mapping between handles and file descriptors. Usually, each file descriptor has one handle associated with it. In some cases, two handles may be associated with a file descriptor. An example of this is a console that is open for reading and writing which uses separate handles for reading and writing.

The `posix.dll` library handles the mapping between UNIX pathnames and WIN32 pathnames. Many UNIX programs assume that pathnames that

do not begin with a / are relative pathnames. In addition, only / is recognized as a delimiter. There is only a single root directory; the operation of changing to another drive does not change the root directory. The `posix.dll` library maps all file names it encounters. If the file name begins with a / and the first component is a single letter, then this letter is taken as the drive letter. Thus, the UNIX filename `/d/bin/date` gets translated to `d:\bin\date`. The file name mapping routine also recognizes special file names such as `/dev/tty` and `/dev/null`. A / not followed by a drive letter is mapped to the drive that UWIN has been installed on so that programs that embed absolute pathnames for files in `/bin`, `/tmp`, `/dev`, and `/etc` work without modification. The file name mapping also solves the problem caused by the WIN32 interface special treatment of the names, `aux`, `com1`, `com2`, `nul`, and filenames consisting of these names followed by any suffix,

Version 1.3 of UWIN adds support for Universal Naming Conversion (UNC) naming. UNC uses names of the form `//hostname/filename` to access files on a given host. In addition, Version 1.3 adds the name `/sys` as a way of naming the system directory. This makes it easier to write shell scripts that are portable across windows machines.

Finally, the path search algorithm was modified to look for `.exe` and `.bat` suffixes.

One problem introduced by the pathname mapping is that passing file name arguments to native NT utilities is more difficult since it understands DOS style names, not UNIX names. A library routine was added to return a DOS name given a UNIX name.

The `posix.dll` library pathname mapping function also takes care of exact case matching on file systems that require it. One of the most troublesome aspects of the WIN32 API is its lack of support for pathname case distinction. It is not uncommon to have files named `Makefile` and `makefile` in the same directory in UNIX. UWIN handles case distinction by calling the WIN32 `CreateFile()` function both with and without the `FILE_FLAG_POSIX_SEMANTICS` function. If they compare equal, it executes the function internally, otherwise it spawns a POSIX subsystem process to carry out the task.

4.3 fork/exec

The `fork()` system call was implemented by creating a new process with the same startup information as the current process. Before executing

`main()`, it copies the data and stack of the parent process into itself. Handles that were closed when the new process was created are duplicated into the new process. The `exec*()` family of functions was much harder to implement. The problem is that there is no way to overlay the calling process. Some commercial products have the current process wait for the child process to complete and then exit. There are two problems with this approach. First, a process that `execs` repeatedly will fill up the process table. More importantly, resources from the parent process are not released. Our method causes the child process to be reparented to the grandparent and the process that calls `exec*()` to exit. The process id returned by the `getpid()` function will be the process id of the process that invoked the `exec*()` function. In other cases, it will be the same process id as the WIN32 uses. To prevent that process id from being used again by WIN32, a handle to the process is kept by the grandparent process.

Even though we implemented `fork()` and the `exec*()` family of functions, our code rarely uses them. Because the `CreateProcess()` function doesn't have an overlay flag, two processes need to be created in order to do both `fork()` and `exec*()`. `libast` provides a `spawn*()` family of functions that combines the functionality of `fork()/exec*()` on systems that don't have the `spawn*()` family. All functions in `libast` that create processes such as `system()` and `popen()` are programmed with this interface. On most UNIX systems, the `spawn*()` family is written using `fork()` or `vfork()` and `exec*()`. We implemented `spawn*()` in our `posix.dll` library to call `CreateProcess()` directly.

The `CreateProcess()` function has the ability to specify information and startup options that cannot be specified with `fork()` and `exec()`. The Version 1.3 of UWIN supplies a function `uwin_spawn()` that takes an argument that contains additional information for `CreateProcess()`. This should make it unnecessary for an application to call `CreateProcess()` directly.

4.4 Signals

Signals are handled by having each process run a thread that waits on an event. To send a signal to a process, the bit corresponding to the given signal number is set in the receiving process's process block, and then its signal thread event is set. The signal thread then wakes up and looks for signals. It is important for the signal handler to be executed in

the primary thread of the process, since the handler may contain a `longjmp()` out of the handler function. Prior to calling `main()`, an exception filter is added to the primary thread that checks for signals. The signal thread does this by suspending the primary thread raising an exception that will activate the exception filter of the primary thread, and then resuming the primary thread.

4.5 Terminals

The POSIX `termios` interface is implemented by creating two threads; one for processing keyboard input events, and the other for processing output events and escape sequences. These threads are connected to the read and write file descriptors of the process by pipes. The same architecture is used for socket based terminals and serial I/O lines. Initially, these threads run in the process that created the console and make it the controlling terminal. These threads service all processes that share the controlling terminal. New threads will be created if the process that owns the threads terminates and another process is sharing the console. When a process is created, these threads are suspended and the console handles are passed down to the child. This enables a native application to run with its standard input and output as console handles. If the application has been linked with the `posix.dll`, then these threads are resumed before `main()` is called so that UNIX style terminal processing takes place. The result is that UNIX processes will echo characters as they are typed and respond to special keys specified by `stty`, whereas native WIN32 applications will only echo characters when they are read and will use Control-C as the interrupt character.

4.6 Ids and Permissions

Permissions for files are only available on Windows NT. Calls to get a set permissions return *not implemented* errors on Windows 95. Creating a Windows NT ACL that closely corresponds to UNIX permissions isn't very difficult. The ACL needs three entries; one for owner, one for group, and one that represents the group that contains all users. Windows NT allows separate permission to delete a file and to change its security attribute. These permissions are give to the owner of a file. The UNIX `umask()` command sets the default ACL so that native applications that are run by UWIN will create files with UNIX type permissions.

Mapping of subject identifiers to and from user and group ids is more complex. UWIN maintains a table

of subject identifier prefixes, and constructs the user id and group id by a combination of the index in this table and the last component of the subject identifier. The number of subject identifier prefixes that are likely to be encountered on a given machine is much smaller than the number of accounts so that this table is easier to maintain.

4.7 Special files and Links

Special files such as fifos and symbolic links require `stat()` information that is not kept by the NT or FAT file systems. Also, the file system does not store the `setuid` and `setgid` permission bits. With the NT file system, this extra information has been stored by using a poorly documented feature called *multiple data streams* that allows a file to have multiple individually named parts. A separate data stream is created to hold additional information about the file. The `SYSTEM` attribute is put on any file or directory that has an additional data stream so that they can be identified quickly with minimal overhead during pathname mapping.

Using multiple data streams requires the NT file system. On other file systems, fifos and symbolic links are implemented by storing the information in the file itself. The `setuid`, `setgid` functionality is not supported on these file systems.

UWIN treats Windows 95 and Windows NT 4.0 *short cuts* as if they were symbolic links. However, these links can be created with any of the UWIN interfaces. This was done by reverse engineering the format of a short cut file and finding where the pathname of the file that it referred to was stored.

Fifos are implemented by using WIN32 named pipes. A name is selected based on the creation date of the fifo file. Only the first reader and the first writer on the fifo create and connect to the named pipe. All other instances duplicate the handle of either the reader or the writer. This way all writers to a fifo use the same handle as required by fifo semantics.

A POSIX subsystem command is also invoked to create hard links since there is no WIN32 API function to do this. Hard links fail for files in the FAT file system.

4.8 Sockets

Sockets are implemented as a layer on top of `WINSOCK`, the Microsoft API for BSD sockets. Most functions were straight forward to implement. The `select()` function proved more difficult than we had anticipated because socket handles could not be used for synchronization, and because the

Microsoft `select()` call only worked with socket handles. The `posix.dll select()` function allows different types of file descriptors to be waited for.

Our first implementation of `select()` created a separate thread that used the Microsoft `select()` to wait for socket handles, and created an event for the main thread to add to the list of handles to wait for. Our second implementation used a library routine to convert input/output events on sockets to windows messages and then waited for both windows messages and handle events simultaneously. This method had the added advantages that it was possible to implement `SIGIO` and that it was easy to add a pseudo file device named `/dev/windows` that could be used to listen for windows messages. Adding this pseudo device made it possible to use the UNIX implementation of `tccl` to port `tksh`^[17] applications to Windows NT.

4.9 Invocation

When UWIN invokes a process, it does not know whether the process is a UWIN process or a native process. It modifies the `PATH` variable so that it uses the ; separated DOS format. It also passes open files in the same manner that the Microsoft C library does so that programs that are compiled with this library should correctly inherit open files from UWIN programs. The initialization function also sees whether a security token has been placed in its address space by the UMS server, and if so, it impersonates this token.

The POSIX library has an initialization routine that sets up file descriptors and assigns the controlling terminal starting the terminal emulation threads as required. The `posix.lib` library also supplies a `WinMain()` function that is called when the program begins. This function initializes the `stdin`, `stdout`, and `stderr` functions and then calls a `posix.dll` function passing the address of another `posix.lib` function that actually invokes `main()`. The `posix.dll` function starts up the signal thread and sets the exception filter for signal processing as described above. The reason for this complexity is so that UNIX programs will start with the correct environment, and so that `argv[0]` will have UNIX syntax without the trailing `.exe` since many programs use `argv[0]`. Much of the complexity occurs inside the `posix.dll` part because programs do not require recompilation when changes are added there.

The current version of UWIN provides partial support for files larger than two gigabytes. The underlying NTFS file system supports 64 bit file offsets. However, the size of `off_t` is stored as a 32 bit integer because some programs would otherwise break. The type `off64_t` is defined and the functions `ftruncate64()`, `lseek64()`, and `truncate64()` have been implemented. The current `stat` structure actually fills in a 64 bit file size, but only the low 32 bits are accessible. The current version of `Sfio` supports 64 bit file offsets, but this option has not as of yet been enabled.

5. CURRENT STATUS

At the time of this writing, most interfaces required by the X/Open Release 4 standard have been written and work as described in the standard. The X/Open standard requires full ANSI C functionality as well. In addition, interfaces for the `curses` library, the `sockets` library, and the `dynamic linking library`, are also working.

A C/C++ compiler wrapper has been written that calls either the Microsoft Visual C/C++ 2.x, 4.x or 5.x compiler. This compiler supports the most commonly used UNIX conventions and implicitly sets default include files and libraries. In addition it has an added hook for specifying native compiler and linker options. Applications compiled with our `cc` command can be debugged with native debuggers such as the Visual C/C++ debugger. Several auto configuration programs use the output of the C preprocessor to probe the features of the system. The output format of the Microsoft C compiler caused some of the configuration programs to fail. To overcome this, a filter is inserted when running the compiler to generate preprocessor output so that existing configuration programs work. Our compiler wrapper can be invoked as `cc` for ANSI-C compilation, as `CC` for C++ compilation, and as `pcc` to build POSIX subsystem applications.

Our compiler wrapper follows the normal UNIX defaults for suffixes rather than using the Microsoft conventions; `.o`'s rather than `.obj`'s. The `.exe` suffix is not required for Windows NT since it uses permission bits to distinguish executables. However, since we also want binaries to run on Windows 95, the `.exe` suffix is added to the name of the output file if no suffix is supplied when the compiler is invoked as `cc` or `CC`.

The tools have been enhanced to make building dynamically linked libraries easier. The `ar` command has been extended with an option to

generate an export file from a definition file (.def). The `ld` command has a flag to build dynamically linked libraries.

The latest version of `ksh`, `ksh-93` was ported. The implementation supports all features of `ksh-93` including job control and dynamic linking of built-in commands at run time. While no changes to the code should have been necessary, changes were made to `ksh` specifically for NT. The hostname mapping attribute, `typeset -H`, which has no effect on UNIX systems, was modified to call the `posix.dll` function that returns the WIN32 pathname corresponding to a given UNIX pathname. The ability to do case insensitive matching for file expansion was also added. A compile time option to allow `<cr><nl>` in place of `<nl>` was added to the shell grammar to avoid the overhead of text file processing.

About 175 UNIX tools have been ported to Windows NT, the vast majority required no changes. Common software development tools such as `yacc`, `lex`, `make` and `nmake` have also been ported. Most of the utilities are versions that we have written at AT&T over the last ten years and are easily portable to all UNIX platforms. Other utilities, such as `make`, `bc`, and `gzip` we compiled from the GNU source using `autoconfig` to generate headers and makefiles. The `yacc` and `less` utilities and the new `vi` program were ported from freely available BSD source code. In most cases, no changes were made to the original source code.

The X Windows code has two parts, the client and the server. The server had already been ported to Windows NT and Windows 95 by commercial vendors and there was no need to build UWIN version for it. In addition, the server is often running on a UNIX host. The most difficult part of porting the X Windows client code was the fact that it had `#ifdefs` for WIN32 that selected native WIN32 calls, bypassing the UWIN calls. Once this was straightened out, the compilation was straightforward.

6. UNSOLVED PROBLEMS

It would be nice to say that all of UNIX could be implemented with WIN32, but this isn't the case. One problem, which is an artifact of using the the WIN32 API rather than the POSIX subsystem, is that there is no way to create or access a file whose name ends in `.'. '`, even by using the `FILE_FLAG_POSIX_SEMANTICS` flag with `CreateFile()`.

A second problem is that the way authentication works in Windows NT differs from that on UNIX systems. On UNIX systems, the password is encrypted and compared to the encrypted password in the user accounts database. On Windows NT, a function that takes the user name and password is called, and this function returns a *token* that can be used to define the access privileges of a process. Since there was no access to the encrypted passwords with WIN32, we had to make changes to programs such as `ftp` that require authentication or programs such as `telnetd` that need to create processes on behalf of the user.

A third problem for which we were not able to find a satisfactory solution was how to `fchmod()` a file whose handle was opened with read permission only. If the handle was opened by another process the name is not known, so a separate open is not possible. One solution would be to always try opening the file with permission to change the mode. The problem with this solution is that the open will fail for any file that is not owned by the user opening the file, and a second open attempt would be required. This would practically double the time needed to open a file for opening a readonly only, which we felt was unacceptable.

We encountered a number of problems relating to concurrency restrictions that do not occur on UNIX systems. For example, if a file was memory mapped, an attempt to open it for truncation would fail. We could not find a way around this problem so we had to change the `vi` code that we were using to not use memory mapping. We are unable to change the access permissions of a dynamically linked library that is in use. We are also unable to rename a directory any other process has this directory, or a subdirectory as its current working directory. In Windows 95, we are unable to move or rename files that are open, even when these have been opened for maximum sharing.

Finally, we encountered numerous problems with the permission system. We were unable to add a new group to an existing process. It is often difficult or impossible to map access control lists to UNIX permissions in a meaningful way.

7. FUTURE WORK

We currently are using the Microsoft Developers Studio debugger. Unfortunately, this requires us to be logged in on the console. We often have several users logged onto a single NT workstation and only one user at a time can use this debugger. In

addition, the debugger can't be used when logged in from home via a telnet session. We hope to write the nub for the deet debugger^[18] so that it can be used as a command line and/or graphical debugger.

In addition, we are trying to decide how to port the *n* dimensional file system, *n*-DFS^[19], to Windows NT. *n*-DFS provides a mechanism to add file system services such as viewpathing and versioning. The difficulty in porting *n*-DFS is that it must also capture native WIN32 API calls to provide a transparent interface.

We would like to add support for asynchronous I/O as defined by the POSIX realtime standard^[20]. Unfortunately, unlike the POSIX API, the WIN32 API requires that you make the decision about whether the I/O is synchronous or asynchronous when the file is opened as well as when it is read. A file opened for synchronous reads cannot be read asynchronously, and a file opened for asynchronous reads cannot be read synchronously. This makes it impossible to use asynchronous I/O on a file that has been redirected by the shell.

The current version of UWIN does not handle many of the internationalization issues well. The current implementation has been compiled for ASCII rather than UNICODE. We plan to use UFT8 encoding of UNICODE for the system call interface, and to convert to UNICODE on the NT file system. This way we do not need to build separate binaries for UNICODE.

Another issue worth investigating is whether it is possible to run Linux binaries under UWIN. This would only make sense for dynamically linked programs.

Finally there are some WIN32 interfaces that could be handled through the file system interface such as the Windows NT registry and the clipboard.

8. CONCLUSIONS

There appear to be few if any technical reasons to move from UNIX to Windows NT. The performance of Linux exceeds that of NT 4.0 and Linux appears to be more reliable. However, if you want to or need to move an application to Windows 95 or Windows NT, we believe the POSIX library we developed to be superior to any of the existing commercial libraries.

The code for the `posix.dll` library is fairly small, about 15K lines including the terminal emulator. This library runs in the WIN32 subsystem using the

WIN32 API and runs under Windows 95 as well.

The UWIN binaries are freely available for non-commercial use from the web site <http://www.research.att.com/sw/tools/uwin>. We hope that this will encourage contributions of applications that have been built with UWIN. Licenses for commercial use of UWIN are available from Global Technologies, Ltd., <http://www.gtlinc.com>.

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