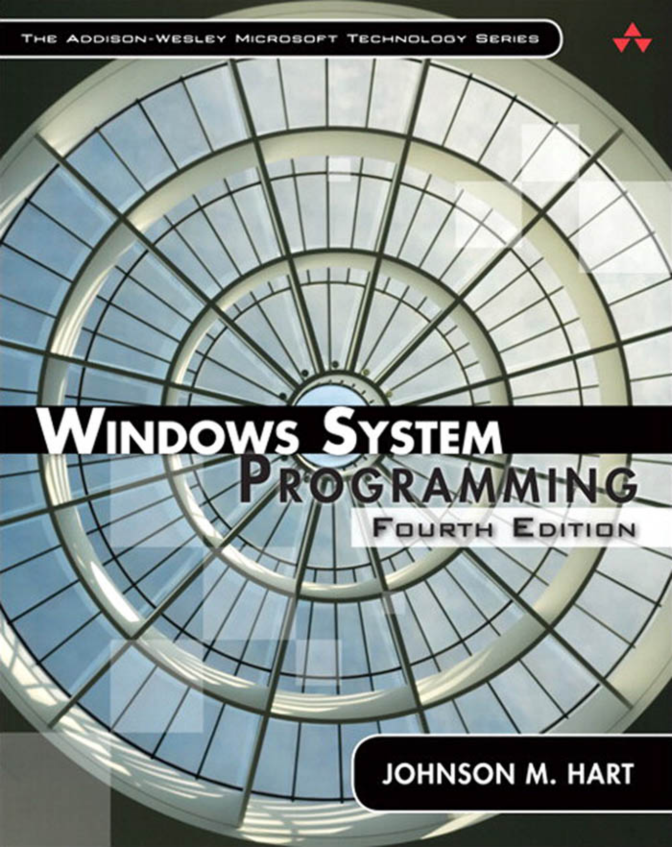
THE ADDISON-WESLEY MICROSOFT TECHNOLOGY SERIES



WINDOWS SYSTEM PROGRAMMING

FOURTH EDITION

JOHNSON M. HART

The publisher offers excellent discounts on this book when ordered in quantity for bulk purchases or special sales, which may include electronic versions and/or custom covers and content particular to your business, training goals, marketing focus, and branding interests. For more information, please contact:

U.S. Corporate and Government Sales
(800) 382-3419
corpsales@pearsontechgroup.com

For sales outside of the U.S., please contact:

International Sales
international@pearsoned.com

Visit us on the Web: informit.com/aw

Library of Congress Cataloging-in-Publication Data
Hart, Johnson M.
Windows system programming / Johnson M. Hart.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-321-65774-9 (hardback : alk. paper)
1. Application software—Development. 2. Microsoft Windows (Computer file). 3. Application program interfaces (Computer software). I. Title.

QA76.76.A65H373 2010
005.3—dc22

2009046939

ISBN-13: 978-0-321-65774-9
ISBN-10: 0-321-65774-8
Text printed in the United States on recycled paper at Courier in Westford, Massachusetts.
First printing, February 2010

Preface

This book describes application development using the Microsoft Windows Application Programming Interface (API), concentrating on the core system services, including the file system, process and thread management, interprocess communication, network programming, and synchronization. The examples concentrate on realistic scenarios, and in many cases they're based on real applications I've encountered in practice.

The Win32/Win64 API, or the Windows API, is supported by Microsoft's family of 32-bit and 64-bit operating systems; versions currently supported and widely used include Windows 7, XP, Vista, Server 2003, Server 2008, and CE. Older Windows family members include Windows 2000, NT, Me, 98, and 95; these systems are obsolete, but many topics in this book still apply to these older systems.

The Windows API is an important factor for application development, frequently replacing the POSIX API (supported by UNIX and Linux) as the preferred API for applications targeted at desktop, server, and embedded systems now and for the indefinite future. Many programmers, regardless of experience level, need to learn the Windows API quickly, and this book is designed for them to do so.

Objectives and Approach

The objectives I've set for the book are to explain what Windows is, show how to use it in realistic situations, and do so as quickly as possible without burdening you with unnecessary detail. This book is not a reference guide, but it explains the central features of the most important functions and shows how to use them together in practical programming situations. Equipped with this knowledge, you will be able to use the comprehensive Microsoft reference documentation to explore details, advanced options, and the more obscure functions as requirements or interests dictate. I have found the Windows API easy to learn using this approach and have greatly enjoyed developing Windows programs, despite occasional frustration. This enthusiasm will show through at times, as it should. This does not mean that I feel that Windows is necessarily better than other operating system (OS) APIs, but it certainly has many attractive features and improves significantly with each major new release.

Many Windows books spend a great deal of time explaining how processes, virtual memory, interprocess communication, and preemptive scheduling work without showing how to use them in realistic situations. A programmer experienced in UNIX, Linux, IBM MVS, or another OS will be familiar with these concepts and will be impatient to find out how they are implemented in Windows. Most Windows books also spend a great deal of space on the important topic of user interface programming. This book intentionally avoids the user interface, beyond discussing simple character-based console I/O, in the interest of concentrating on the important core features.

I've taken the point of view that Windows is just an OS API, providing a well-understood set of features. Many programmers, regardless of experience level, need to learn Windows quickly. Furthermore, understanding the Windows API is invaluable background for programmers developing for the Microsoft .NET Framework.

The Windows systems, when compared with other systems, have good, bad, and average features and quality. Recent releases (Windows 7, Vista, Server 2008) provide new features, such as condition variables, that both improve performance and simplify programming. The purpose of this book is to show how to use those features efficiently and in realistic situations to develop practical, high-quality, and high-performance applications.

Audience

I've enjoyed receiving valuable input, ideas, and feedback from readers in all areas of the target audience, which includes:

- Anyone who wants to learn about Windows application development quickly, regardless of previous experience.
- Programmers and software engineers who want to port existing Linux or UNIX (the POSIX API) applications to Windows. Frequently, the source code must continue to support POSIX; that is, source code portability is a requirement. The book frequently compares Windows, POSIX, and standard C library functions and programming models.
- Developers starting new projects who are not constrained by the need to port existing code. Many aspects of program design and implementation are covered, and Windows functions are used to create useful applications and to solve common programming problems.
- Application architects and designers who need to understand Windows capabilities and principles.
- Programmers using COM and the .NET Framework, who will find much of the information here helpful in understanding topics such as dynamic link libraries (DLLs), thread usage and models, interfaces, and synchronization.
- Computer science students at the upper-class undergraduate or beginning graduate level in courses covering systems programming or application devel-

opment. This book will also be useful to those who are learning multithreaded programming or need to build networked applications. This book would be a useful complementary text to a classic book such as *Advanced Programming in the UNIX Environment* (by W. Richard Stevens and Stephen A. Rago) so that students could compare Windows and UNIX. Students in OS courses will find this book to be a useful supplement because it illustrates how a commercially important OS provides essential functionality.

The only other assumption, implicit in all the others, is a knowledge of C or C++ programming.

Windows Progress Since the Previous Editions

The first edition of this book, titled *Win32 System Programming,* was published in 1997 and was updated with the second edition (2000) and the third edition (2004). Much has changed, and much has stayed the same since these previous editions, and Windows has been part of ongoing, rapid progress in computing technology. The outstanding factors to me that explain the fourth edition changes are the following:

- The Windows API is extremely stable. Programs written in 1997 continue to run on the latest Windows releases, and Windows skills learned now or even years ago will be valuable for decades to come.
- Nonetheless, the API has expanded, and there are new features and functions that are useful and sometimes mandatory. Three examples of many that come to mind and have been important in my work are (1) the ability to work easily with large files and large, 64-bit address spaces, (2) thread pools, and (3) the new condition variables that efficiently solve an important synchronization problem.
- Windows scales from phones to handheld and embedded devices to laptops and desktop systems and up to the largest servers.
- Windows has grown and scaled from the modest resources required in 1997 (16MB of RAM and 250MB of free disk space!) to operate efficiently on systems orders of magnitude larger and faster but often cheaper.
- 64-bit systems, multicore processors, and large file systems are common, and our application programs must be able to exploit these systems. Frequently, the programs must also continue to run on 32-bit systems.

Changes in the Fourth Edition

This fourth edition presents extensive new material along with updates and reorganization to keep up with recent progress and:

- Covers important new features in Windows 7, Vista, and Server 2008.
- Demonstrates example program operation and performance with screenshots.
- Describes and illustrates techniques to assure that relevant applications scale to run on 64-bit systems and can use large files. Enhancements throughout the book address this issue.
- Eliminates discussion of Windows 95, 98, and Me (the "Windows 9x" family), as well as NT and other obsolete systems. Program examples freely exploit features supported only in current Windows versions.
- Provides enhanced coverage of threads, synchronization, and parallelism, including performance, scalability, and reliability considerations.
- Emphasizes the important role and new features of Windows servers running high-performance, scalable, multithreaded applications.
- Studies performance implications of different program designs, especially in file access and multithreaded applications with synchronization and parallel programs running on multicore systems.
- Addresses source code portability to assure operation on Windows, Linux, and UNIX systems. Appendix B is enhanced from the previous versions to help those who need to build code, usually for server applications, that will run on multiple target platforms.
- Incorporates large quantities of excellent reader and reviewer feedback to fix defects, improve explanations, improve the organization, and address numerous details, large and small.

Organization

Chapters are organized topically so that the features required in even a single-threaded application are covered first, followed by process and thread management features, and finally network programming in a multithreaded environment. This organization allows you to advance logically from file systems to memory management and file mapping, and then to processes, threads, and synchronization, followed by interprocess and network communication and security. This organization also allows the examples to evolve in a natural way, much as a developer might create a simple prototype and then add additional capability. The advanced features, such as asynchronous I/O and security, appear last.

Within each chapter, after introducing the functionality area, such as process management or memory-mapped files, we discuss important Windows functions and their relationships in detail. Illustrative examples follow. Within the text, only essential program segments are listed; complete projects, programs, include files, utility functions, and documentation are on the book's Web site (www.jmhartsoftware.com). Throughout, we identify those features supported only by current Windows versions. Each chapter suggests related additional reading and gives some exercises. Many exercises address interesting and important issues that did not fit within the normal text, and others suggest ways for you to explore advanced or specialized topics.

Chapter 1 is a high-level introduction to the Windows OS family and Windows. A simple example program shows the basic elements of Windows programming style and lays the foundation for more advanced Windows features. Win64 compatibility issues are introduced in Chapter 1 and are included throughout the book.

Chapters 2 and 3 deal with file systems, console I/O, file locking, and directory management. Unicode, the extended character set used by Windows, is also introduced in Chapter 2. Examples include sequential and direct file processing, directory traversal, and management. Chapter 3 ends with a discussion of registry management programming, which is analogous in many ways to file and directory management.

Chapter 4 introduces Windows exception handling, including Structured Exception Handling (SEH), which is used extensively throughout the book. By introducing it early, we can use SEH throughout and simplify some programming tasks and improve quality. Vectored exception handling is also described.

Chapter 5 treats Windows memory management and shows how to use memory-mapped files both to simplify programming and to improve performance. This chapter also covers DLLs. An example compares memory-mapped file access performance and scalability to normal file I/O on both 32-bit and 64-bit systems.

Chapter 6 introduces Windows processes, process management, and simple process synchronization. Chapter 7 then describes thread management in similar terms and introduces parallelism to exploit multiprocessor systems. Examples in each chapter show the many benefits of using threads and processes, including program simplicity and performance.

Chapters 8, 9, and 10 give an extended, in-depth treatment of Windows thread synchronization, thread pools, and performance considerations. These topics are complex, and the chapters use extended examples and well-understood models to help you obtain the programming and performance benefits of threads while avoiding the numerous pitfalls. New material covers new functionality along with performance and scalability issues, which are important when building server-based applications, including those that will run on multiprocessor systems.

Chapters 11 and 12 are concerned with interprocess and interthread communication and networking. Chapter 11 concentrates on the features that are properly part of Windows—namely, anonymous pipes, named pipes, and mailslots. Chapter 12 discusses Windows Sockets, which allow interoperability with non-Windows systems using industry-standard protocols, primarily TCP/IP. Windows Sockets, while not strictly part of the Windows API, provide for network and Internet communication and interoperability, and the subject matter is consistent with the rest of the book. A multithreaded client/server system illustrates how to use interprocess communication along with threads.

Chapter 13 describes how Windows allows server applications, such as the ones created in Chapters 11 and 12, to be converted to Windows Services that can be managed as background servers. Some small programming changes will turn the servers into services.

Chapter 14 shows how to perform asynchronous I/O using overlapped I/O with events and completion routines. You can achieve much the same thing with threads, so examples compare the different solutions for simplicity and performance. In particular, as of Windows Vista, completion routines provide very good performance. The closely related I/O completion ports are useful for some scalable multithreaded servers, so this feature is illustrated with the server programs from earlier chapters. The final topic is waitable timers, which require concepts introduced earlier in the chapter.

Chapter 15 briefly explains Windows object security, showing, in an example, how to emulate UNIX-style file permissions. Additional examples shows how to secure processes, threads, and named pipes. Security upgrades can then be applied to the earlier examples as appropriate.

There are three appendixes. Appendix A describes the example code that you can download from the book's Web site (www.jmhartsoftware.com). Appendix B shows how to create source code that can also be built to run on POSIX (Linux and UNIX) systems; this requirement is common with server applications and organizations that need to support systems other than just Windows. Appendix C compares the performance of alternative implementations of some of the text examples so that you can gauge the trade-offs between Windows features, both basic and advanced.

UNIX and C Library Notes and Tables

Within the text at appropriate points, we contrast Windows style and functionality with the comparable POSIX (UNIX and Linux) and ANSI Standard C library features. Appendix B reviews source code portability and also contains a table listing these comparable functions. This information is included for two principal reasons:

- Many people are familiar with UNIX or Linux and are interested in the comparisons between the two systems. If you don't have a UNIX/Linux background, feel free to skip those paragraphs in the text, which are indented and set in a smaller font.
- Source code portability is important to many developers and organizations.

Examples

The examples are designed to:

- Illustrate common, representative, and useful applications of the Windows functions.
- Correspond to real programming situations encountered in program development, consulting, and training. Some of my clients and course participants have used the code examples as the bases for their own systems. During consulting activities, I frequently encounter code that is similar to that used in the examples, and on several occasions I have seen code taken directly or modified from previous editions. (Feel free to do so yourself; an acknowledgment in your documentation would be greatly appreciated.) Frequently, this code occurs as part of COM, .NET, or C++ objects. The examples, subject to time and space constraints, are "real-world" examples and solve "real-world" problems.
- Emphasize how the functions actually behave and interact, which is not always as you might first expect after reading the documentation. Throughout this book, the text and the examples concentrate on interactions between functions rather than on the functions themselves.
- Grow and expand, both adding new capability to a previous solution in a natural manner and exploring alternative implementation techniques.
- Implement UNIX/Linux commands, such as `ls`, `touch`, `chmod`, and `sort`, showing the Windows functions in a familiar context while creating a useful set of utilities.[1] Different implementations of the same command also give us

---

[1] Several commercial and open source products provide complete sets of UNIX/Linux utilities; there is no intent to supplement them. These examples, although useful, are primarily intended to illustrate Windows usage. Anyone unfamiliar with UNIX or Linux should not, however, have any difficulty understanding the programs or their functionality.

an easy way to compare performance benefits available with advanced Windows features. Appendix C contains the performance test results.

Examples in the early chapters are usually short, but the later chapters present longer examples when appropriate.

Exercises at the end of each chapter suggest alternative designs, subjects for investigation, and additional functionality that is important but beyond the book's scope. Some exercises are easy, and a few are very challenging. Frequently, clearly labeled defective solutions are provided, because fixing the bugs is an excellent way to sharpen skills.

All examples have been debugged and tested under Windows 7, Vista, Server 2008, XP, and earlier systems. Testing included 32-bit and 64-bit versions. All programs were also tested on both single-processor and multiprocessor systems using as many as 16 processors. The client/server applications have been tested using multiple clients simultaneously interacting with a server. Nonetheless, there is no guarantee or assurance of program correctness, completeness, or fitness for any purpose. Undoubtedly, even the simplest examples contain defects or will fail under some conditions; such is the fate of nearly all software. I will, however, gratefully appreciate any messages regarding program defects—and, better still, fixes, and I'll post this information on the book's Web site so that everyone will benefit.

The Web Site

The book's Web site (www.jmhartsoftware.com) contains a downloadable *Examples* file with complete code and projects for all the book's examples, a number of exercise solutions, alternative implementations, instructions, and performance evaluation tests. This material will be updated periodically to include new material and corrections.

The Web site also contains book errata, along with additional examples, reader contributions, additional explanations, and much more. The site also contains PowerPoint slides that can be used for noncommercial instructional purposes. I've used these slides numerous times in professional training courses, and they are also suitable for college courses.

The material will be updated as required when defects are fixed and as new input is received. If you encounter any difficulties with the programs or any material in the book, check these locations first because there may already be a fix or explanation. If that does not answer your question, feel free to send e-mail to `jmh_assoc@hotmail.com` or `jmhart62@gmail.com`.

Acknowledgments

Numerous people have provided assistance, advice, and encouragement during the fourth edition's preparation, and readers have provided many important ideas and corrections. The Web site acknowledges the significant contributions that have found their way into the fourth edition, and the first three editions acknowledge earlier valuable contributions. See the Web site for a complete list.

Three reviewers deserve the highest possible praise and thanks for their incisive comments, patience, excellent suggestions, and deep expertise. Chris Sells, Jason Beres, and especially Raymond Chen made contributions that improved the book immeasurably. To the best of my ability, I've revised the text to address their points and invaluable input.

Numerous friends and colleagues also deserve a note of special thanks; I've learned a lot from them over the years, and many of their ideas have found their way into the book in one way or another. They've also been generous in providing access to test systems. In particular, I'd like to thank my friends at Sierra Atlantic, Cilk Arts (now part of Intel), Vault USA, and Rimes Technologies.

Anne H. Smith, the compositor, used her skill, persistence, and patience to prepare this new edition for publication; the book simply would not have been possible without her assistance. Anne and her husband, Kerry, also have generously tested the sample programs on their equipment.

The staff at Addison-Wesley exhibited the professionalism and expertise that make an author's work a pleasure. Joan Murray, the editor, and Karen Gettman, the editor-in-chief, worked with the project from the beginning making sure that no barriers got in the way and assuring that hardly any schedules slipped. Olivia Basegio, the editorial assistant, managed the process throughout, and John Fuller and Elizabeth Ryan from production made the production process seem almost simple. Anna Popick, the project editor, guided the final editing steps and schedule. Carol Lallier and Lori Newhouse, the copy editor and proofreader, made valuable contributions to the book's readability and consistency.

Johnson (John) M. Hart
jmhart62@gmail.com
December, 2009

CHAPTER

6 Process Management

A process contains its own independent virtual address space with both code and data, protected from other processes. Each process, in turn, contains one or more independently executing *threads*. A thread running within a process can execute application code, create new threads, create new independent processes, and manage communication and synchronization among the threads.

By creating and managing processes, applications can have multiple, concurrent tasks processing files, performing computations, or communicating with other networked systems. It is even possible to improve application performance by exploiting multiple CPU processors.

This chapter explains the basics of process management and also introduces the basic synchronization operations and wait functions that will be important throughout the rest of the book.

Windows Processes and Threads

Every process contains one or more threads, and the Windows thread is the basic executable unit; see the next chapter for a threads introduction. Threads are scheduled on the basis of the usual factors: availability of resources such as CPUs and physical memory, priority, fairness, and so on. Windows has long supported multiprocessor systems, so threads can be allocated to separate processors within a computer.

From the programmer's perspective, each Windows process includes resources such as the following components:

- One or more threads.
- A virtual address space that is distinct from other processes' address spaces. Note that shared memory-mapped files share physical memory, but the sharing processes will probably use different virtual addresses to access the mapped file.

- One or more code segments, including code in DLLs.
- One or more data segments containing global variables.
- Environment strings with environment variable information, such as the current search path.
- The process heap.
- Resources such as open handles and other heaps.

Each thread in a process shares code, global variables, environment strings, and resources. Each thread is independently scheduled, and a thread has the following elements:

- A stack for procedure calls, interrupts, exception handlers, and automatic storage.
- Thread Local Storage (TLS)—An arraylike collection of pointers giving each thread the ability to allocate storage to create its own unique data environment.
- An argument on the stack, from the creating thread, which is usually unique for each thread.
- A context structure, maintained by the kernel, with machine register values.

Figure 6–1 shows a process with several threads. This figure is schematic and does not indicate actual memory addresses, nor is it drawn to scale.

This chapter shows how to work with processes consisting of a single thread. Chapter 7 shows how to use multiple threads.

Note: Figure 6–1 is a high-level overview from the programmer's perspective. There are numerous technical and implementation details, and interested readers can find out more in Russinovich, Solomon, and Ionescu, *Windows Internals: Including Windows Server 2008 and Windows Vista*.

A UNIX process is comparable to a Windows process.

Threads, in the form of POSIX Pthreads, are now nearly universally available and used in UNIX and Linux. Pthreads provides features similar to Windows threads, although Windows provides a broader collection of functions.

Vendors and others have provided various thread implementations for many years; they are not a new concept. Pthreads is, however, the most widely used standard, and proprietary implementations are long obsolete. There is an open source Pthreads library for Windows.

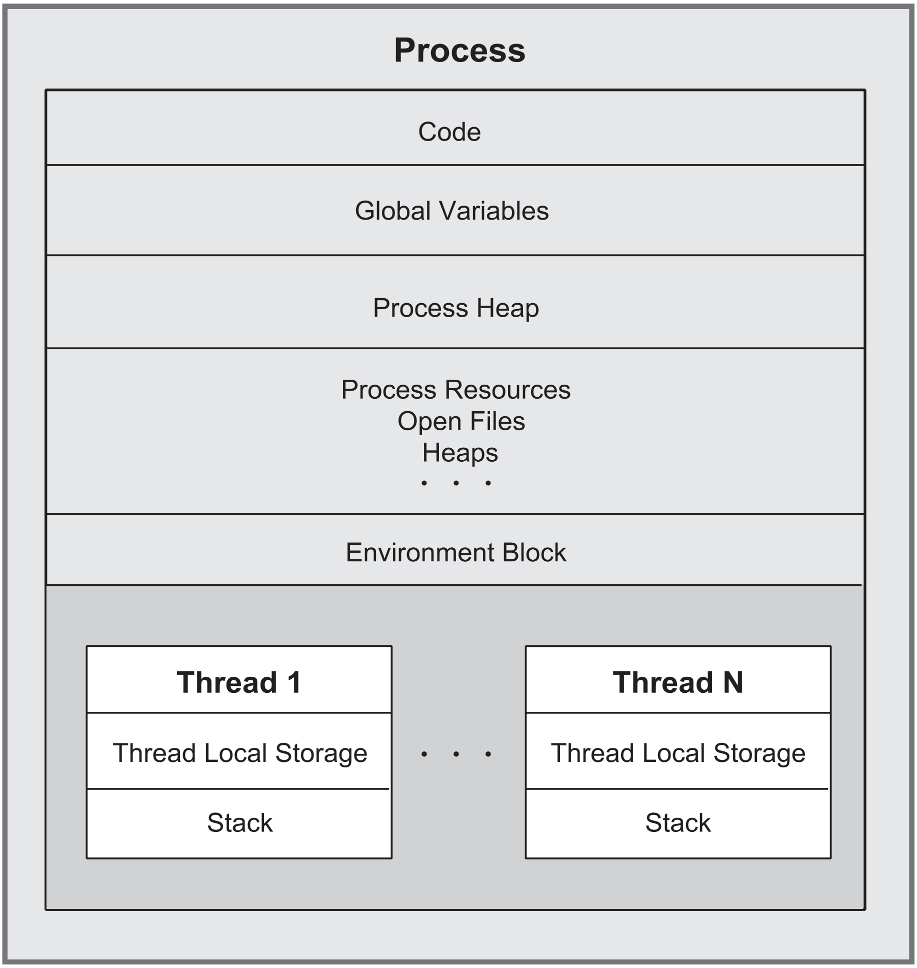


Figure 6–1 A Process and Its Threads

Process Creation

The fundamental Windows process management function is `CreateProcess`, which creates a process with a single thread. Specify the name of an executable program file as part of the `CreateProcess` call.

It is common to speak of *parent* and *child* processes, but Windows does not actually maintain these relationships. It is simply convenient to refer to the process that creates a child process as the parent.

`CreateProcess` has 10 parameters to support its flexibility and power. Initially, it is simplest to use default values. Just as with `CreateFile`, it is appropriate to explain all the `CreateProcess` parameters. Related functions are then easier to understand.

Note first that the function does not return a `HANDLE`; rather, two separate handles, one each for the process and the thread, are returned in a structure specified in the call. `CreateProcess` creates a new process with a single *primary* thread (which might create additional threads). The example programs are always very careful to close both of these handles when they are no longer needed in order to avoid resource leaks; a common defect is to neglect to close the thread handle. Closing a thread handle, for instance, does not terminate the thread; the `CloseHandle` function only deletes the reference to the thread within the process that called `CreateProcess`.

```
BOOL CreateProcess (
   LPCTSTR lpApplicationName,
   LPTSTR lpCommandLine,
   LPSECURITY_ATTRIBUTES lpsaProcess,
   LPSECURITY_ATTRIBUTES lpsaThread,
   BOOL bInheritHandles,
   DWORD dwCreationFlags,
   LPVOID lpEnvironment,
   LPCTSTR lpCurDir,
   LPSTARTUPINFO lpStartupInfo,
   LPPROCESS_INFORMATION lpProcInfo)
```

Return: `TRUE` only if the process and thread are successfully created.

Parameters

Some parameters require extensive explanations in the following sections, and many are illustrated in the program examples.

`lpApplicationName` and `lpCommandLine` (this is an `LPTSTR` and not an `LPCTSTR`) together specify the executable program and the command line arguments, as explained in the next section.

`lpsaProcess` and `lpsaThread` point to the process and thread security attribute structures. `NULL` values imply default security and will be used until Chapter 15, which covers Windows security.

bInheritHandles indicates whether the new process inherits copies of the calling process's inheritable open handles (files, mappings, and so on). Inherited handles have the same attributes as the originals and are discussed in detail in a later section.

dwCreationFlags combines several flags, including the following.

- CREATE_SUSPENDED indicates that the primary thread is in a suspended state and will run only when the program calls ResumeThread.
- DETACHED_PROCESS and CREATE_NEW_CONSOLE are mutually exclusive; don't set both. The first flag creates a process without a console, and the second flag gives the new process a console of its own. If neither flag is set, the process inherits the parent's console.
- CREATE_UNICODE_ENVIRONMENT should be set if UNICODE is defined.
- CREATE_NEW_PROCESS_GROUP specifies that the new process is the root of a new process group. All processes in a group receive a console control signal (Ctrl-c or Ctrl-break) if they all share the same console. Console control handlers were described in Chapter 4 and illustrated in Program 4–5. These process groups have limited similarities to UNIX process groups and are described later in the "Generating Console Control Events" section.

Several of the flags control the priority of the new process's threads. The possible values are explained in more detail at the end of Chapter 7. For now, just use the parent's priority (specify nothing) or NORMAL_PRIORITY_CLASS.

lpEnvironment points to an environment block for the new process. If NULL, the process uses the parent's environment. The environment block contains name and value strings, such as the search path.

lpCurDir specifies the drive and directory for the new process. If NULL, the parent's working directory is used.

lpStartupInfo is complex and specifies the main window appearance and standard device handles for the new process. We'll use two principal techniques to set the start up information. Programs 6–1, 6–2, 6–3, and others show the proper sequence of operations, which can be confusing.

- Use the parent's information, which is obtained from GetStartupInfo.
- First, clear the associated STARTUPINFO structure before calling CreateProcess, and then specify the standard input, output, and error handles by setting the STARTUPINFO standard handler fields (hStdInput, hStdOutput, and hStdError). For this to be effective, also set another STARTUPINFO member, dwFlags, to STARTF_USESTDHANDLES, and set all the handles that the child process will require. Be certain that the handles are inheritable and that

the CreateProcess bInheritHandles flag is set. The "Inheritable Handles" subsection gives more information.

lpProcInfo specifies the structure for containing the returned process, thread handles, and identification. The PROCESS_INFORMATION structure is as follows:

```
typedef struct _PROCESS_INFORMATION {
   HANDLE hProcess;
   HANDLE hThread;
   DWORD dwProcessId;
   DWORD dwThreadId;
} PROCESS_INFORMATION;
```

Why do processes and threads need handles in addition to IDs? The ID is unique to the object for its entire lifetime and in all processes, although the ID is invalid when the process or thread is destroyed and the ID may be reused. On the other hand, a given process may have several handles, each having distinct attributes, such as security access. For this reason, some process management functions require IDs, and others require handles. Furthermore, process handles are required for the general-purpose, handle-based functions. Examples include the wait functions discussed later in this chapter, which allow waiting on handles for several different object types, including processes. Just as with file handles, process and thread handles should be closed when no longer required.

Note: The new process obtains environment, working directory, and other information from the CreateProcess call. Once this call is complete, any changes in the parent will not be reflected in the child process. For example, the parent might change its working directory after the CreateProcess call, but the child process working directory will not be affected unless the child changes its own working directory. The two processes are entirely independent.

The UNIX/Linux and Windows process models are considerably different. First, Windows has no equivalent to the UNIX fork function, which makes a copy of the parent, including the parent's data space, heap, and stack. fork is difficult to emulate exactly in Windows, and while this may seem to be a limitation, fork is also difficult to use in a multithreaded UNIX program because there are numerous problems with creating an exact replica of a multithreaded program with exact copies of all threads and synchronization objects, especially on a multiprocessor computer. Therefore, fork, by itself, is not really appropriate in any multithreaded application.

`CreateProcess` is, however, similar to the common UNIX sequence of successive calls to `fork` and `execl` (or one of five other `exec` functions). In contrast to Windows, the search directories in UNIX are determined entirely by the `PATH` environment variable.

As previously mentioned, Windows does not maintain parent-child relationships among processes. Thus, a child process will continue to run after the creating parent process terminates. Furthermore, there are no UNIX-style process groups in Windows. There is, however, a limited form of process group that specifies all the processes to receive a console control event.

Windows processes are identified both by handles and by process IDs, whereas UNIX has no process handles.

Specifying the Executable Image and the Command Line

Either `lpApplicationName` or `lpCommandLine` specifies the executable image name. Usually, only `lpCommandLine` is specified, with `lpApplicationName` being `NULL`. Nonetheless, there are detailed rules for `lpApplicationName`.

- If `lpApplicationName` is not `NULL`, it specifies the executable module. Specify the full path and file name, or use a partial name and the current drive and directory will be used; there is no additional searching. Include the file extension, such as `.EXE` or `.BAT`, in the name. This is not a command line, and it should not be enclosed with quotation marks.
- If the `lpApplicationName` string is `NULL`, the first white-space-delimited token in `lpCommandLine` is the program name. If the name does not contain a full directory path, the search sequence is as follows:

  1. The directory of the current process's image
  2. The current directory
  3. The Windows system directory, which can be retrieved with `GetSystemDirectory`
  4. The Windows directory, which is retrievable with `GetWindowsDirectory`
  5. The directories as specified in the environment variable `PATH`

The new process can obtain the command line using the usual `argv` mechanism, or it can invoke `GetCommandLine` to obtain the command line as a single string.

Notice that the command line is not a constant string. A program could modify its arguments, although it is advisable to make any changes in a copy of the argument string.

It is not necessary to build the new process with the same UNICODE definition as that of the parent process. All combinations are possible. Using `_tmain` as described in Chapter 2 is helpful in developing code for either Unicode or ASCII operation.

Inheritable Handles

Frequently, a child process requires access to an object referenced by a handle in the parent; if this handle is inheritable, the child can receive a copy of the parent's open handle. The standard input and output handles are frequently shared with the child in this way, and Program 6-1 is the first of several examples. To make a handle inheritable so that a child receives and can use a copy requires several steps.

- The `bInheritHandles` flag on the `CreateProcess` call determines whether the child process will inherit copies of the inheritable handles of open files, processes, and so on. The flag can be regarded as a master switch applying to all handles.
- It is also necessary to make an individual handle inheritable, which is not the default. To create an inheritable handle, use a `SECURITY_ATTRIBUTES` structure at creation time or duplicate an existing handle.
- The `SECURITY_ATTRIBUTES` structure has a flag, `bInheritHandle`, that should be set to `TRUE`. Also, set `nLength` to `sizeof (SECURITY_ATTRIBUTES)`.

The following code segment shows how to create an inheritable file or other handle. In this example, the security descriptor within the security attributes structure is `NULL`; Chapter 15 shows how to include a security descriptor.

```
HANDLE h1, h2, h3;
SECURITY_ATTRIBUTES sa =
    {sizeof(SECURITY_ATTRIBUTES), NULL, TRUE };
...
h1 = CreateFile (..., &sa, ... ); /* Inheritable. */
h2 = CreateFile (..., NULL, ... ); /* Not inheritable. */
h3 = CreateFile (..., &sa, ...);
    /* Inheritable. You can reuse sa. */
```

A child process still needs to know the value of an inheritable handle, so the parent needs to communicate handle values to the child using an interprocess communication (IPC) mechanism or by assigning the handle to standard I/O in the `STARTUPINFO` structure, as in the next example (Program 6–1) and in several additional examples throughout the book. This is generally the preferred

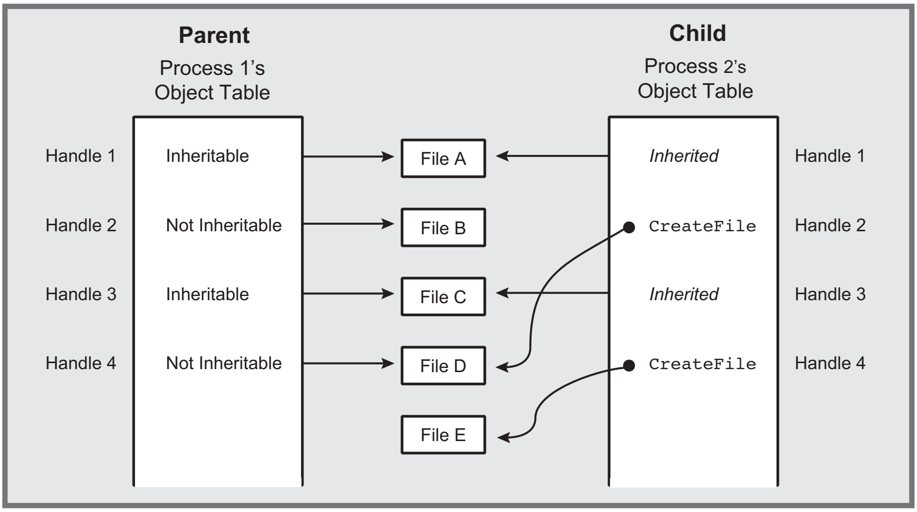


Figure 6–2 Process Handle Tables

technique because it allows I/O redirection in a standard way and no changes are needed in the child program.

Alternatively, nonfile handles and handles that are not used to redirect standard I/O can be converted to text and placed in a command line or in an environment variable. This approach is valid if the handle is inheritable because both parent and child processes identify the handle with the same handle value. Exercise 6–2 suggests how to demonstrate this, and a solution is presented in the *Examples* file.

The inherited handles are distinct copies. Therefore, a parent and child might be accessing the same file using different file pointers. Furthermore, each of the two processes can and should close its own handle.

Figure 6–2 shows how two processes can have distinct handle tables with two distinct handles associated with the same file or other object. Process 1 is the parent, and Process 2 is the child. The handles will have identical values in both processes if the child's handle has been inherited, as is the case with Handles 1 and 3.

On the other hand, the handle values may be distinct. For example, there are two handles for File D, where Process 2 obtained a handle by calling `CreateFile` rather than by inheritance. Also, as is the case with Files B and E, one process may have a handle to an object while the other does not. This would be the case when the child process creates the handle. Finally, while not shown in the figure, a process can have multiple handles to refer to the same object.

Process Identities

A process can obtain the identity and handle of a new child process from the `PROCESS_INFORMATION` structure. Closing the child handle does not, of course, destroy the child process; it destroys only the parent's access to the child. A pair of functions obtain current process identification.

```
HANDLE GetCurrentProcess (VOID)

DWORD GetCurrentProcessId (VOID)
```

`GetCurrentProcess` actually returns a *pseudohandle* and is not inheritable. This value can be used whenever a process needs its own handle. You create a real process handle from a process ID, including the one returned by `GetCurrentProcessId`, by using the `OpenProcess` function. As is the case with all sharable objects, the open call will fail if you do not have sufficient security rights.

```
HANDLE OpenProcess (
   DWORD dwDesiredAccess,
   BOOL bInheritHandle,
   DWORD dwProcessId)
```

Return: A process handle, or `NULL` on failure.

Parameters

`dwDesiredAccess` determines the handle's access to the process. Some of the values are as follows.

- `SYNCHRONIZE`—This flag enables processes to wait for the process to terminate using the wait functions described later in this chapter.
- `PROCESS_ALL_ACCESS`—All the access flags are set.
- `PROCESS_TERMINATE`—It is possible to terminate the process with the `TerminateProcess` function.
- `PROCESS_QUERY_INFORMATION`—The handle can be used by `GetExitCodeProcess` and `GetPriorityClass` to obtain process information.

bInheritHandle specifies whether the new process handle is inheritable. dwProcessId is the identifier of the process to be opened, and the returned process handle will reference this process.

Finally, a running process can determine the full pathname of the executable used to run it with GetModuleFileName or GetModuleFileNameEx, using a NULL value for the hModule parameter. A call with a non-null hModule value will return the DLL's file name, not that of the .EXE file that uses the DLL.

Duplicating Handles

The parent and child processes may require different access to an object identified by a handle that the child inherits. A process may also need a real, inheritable process handle—rather than the pseudohandle produced by GetCurrentProcess—for use by a child process. To address this issue, the parent process can create a duplicate handle with the desired access and inheritability. Here is the function to duplicate handles:

```
BOOL DuplicateHandle (
   HANDLE hSourceProcessHandle,
   HANDLE hSourceHandle,
   HANDLE hTargetProcessHandle,
   LPHANDLE lphTargetHandle,
   DWORD dwDesiredAccess,
   BOOL bInheritHandle,
   DWORD dwOptions)
```

Upon completion, lphTargetHandle receives a copy of the original handle, hSourceHandle. hSourceHandle is a handle in the process indicated by hSourceProcessHandle and must have PROCESS_DUP_HANDLE access; DuplicateHandle will fail if the source handle does not exist in the source process. The new handle, which is pointed to by lphTargetHandle, is valid in the target process, hTargetProcessHandle. Note that three processes are involved, including the calling process. Frequently, these target and source processes are the calling process, and the handle is obtained from GetCurrentProcess. Also notice that it is possible, but generally not advisable, to create a handle in another process; if you do this, you then need a mechanism for informing the other process of the new handle's identity.

DuplicateHandle can be used for any handle type.

If `dwDesiredAccess` is not overridden by `DUPLICATE_SAME_ACCESS` in `dwOptions`, it has many possible values (see MSDN).

`dwOptions` is any combination of two flags.

- `DUPLICATE_CLOSE_SOURCE` causes the source handle to be closed and can be specified if the source handle is no longer useful. This option also assures that the reference count to the underlying file (or other object) remains constant.
- `DUPLICATE_SAME_ACCESS` uses the access rights of the duplicated handle, and `dwDesiredAccess` is ignored.

Reminder: The Windows kernel maintains a reference count for all objects; this count represents the number of distinct handles referring to the object. This count is not available to the application program. An object cannot be destroyed (e.g., deleting a file) until the last handle is closed and the reference count becomes zero. Inherited and duplicate handles are both distinct from the original handles and are represented in the reference count. Program 6–1, later in the chapter, uses inheritable handles.

Next, we learn how to determine whether a process has terminated.

Exiting and Terminating a Process

After a process has finished its work, the process (actually, a thread running in the process) can call `ExitProcess` with an exit code.

```
VOID ExitProcess (UINT uExitCode)
```

This function does not return. Rather, the calling process and all its threads terminate. Termination handlers are ignored, but there will be detach calls to `DllMain` (see Chapter 5). The exit code is associated with the process. A `return` from the main program, with a return value, will have the same effect as calling `ExitProcess` with the return value as the exit code.

Another process can use `GetExitCodeProcess` to determine the exit code.

```
BOOL GetExitCodeProcess (
   HANDLE hProcess,
   LPDWORD lpExitCode)
```

The process identified by `hProcess` must have `PROCESS_QUERY_INFORMATION` access (see `OpenProcess`, discussed earlier). `lpExitCode` points to the `DWORD` that receives the value. One possible value is `STILL_ACTIVE`, meaning that the process has not terminated.

Finally, one process can terminate another process if the handle has `PROCESS_TERMINATE` access. The terminating function also specifies the exit code.

```
BOOL TerminateProcess (
   HANDLE hProcess,
   UINT uExitCode)
```

Caution: Before exiting from a process, be certain to free all resources that might be shared with other processes. In particular, the synchronization resources of Chapter 8 (mutexes, semaphores, and events) must be treated carefully. SEH (Chapter 4) can be helpful in this regard, and the `ExitProcess` call can be in the handler. However, `__finally` and `__except` handlers are *not* executed when `ExitProcess` is called, so it is not a good idea to exit from inside a program. `TerminateProcess` is especially risky because the terminated process will not have an opportunity to execute its SEH or DLL `DllMain` functions. Console control handlers (Chapter 4 and later in this chapter) are a limited alternative, allowing one process to send a signal to another process, which can then shut itself down cleanly.

Program 6–3 shows a technique whereby processes cooperate. One process sends a shutdown request to a second process, which proceeds to perform an orderly shutdown.

UNIX processes have a process ID, or `pid`, comparable to the Windows process ID. `getpid` is similar to `GetCurrentProcessId`, but there are no Windows equivalents to `getppid` and `getgpid` because Windows has no process parents or UNIX-like groups.

Conversely, UNIX does not have process handles, so it has no functions comparable to `GetCurrentProcess` or `OpenProcess`.

UNIX allows open file descriptors to be used after an `exec` if the file descriptor does not have the `close-on-exec` flag set. This applies only to file descriptors, which are then comparable to inheritable file handles.

UNIX `exit`, actually in the C library, is similar to `ExitProcess`; to terminate another process, signal it with `SIGKILL`.

Waiting for a Process to Terminate

The simplest, and most limited, method to synchronize with another process is to wait for that process to complete. The general-purpose Windows wait functions introduced here have several interesting features.

- The functions can wait for many different types of objects; process handles are just the first use of the wait functions.
- The functions can wait for a single process, the first of several specified processes, or all processes in a collection to complete.
- There is an optional time-out period.

The two general-purpose wait functions wait for synchronization objects to become *signaled*. The system sets a process handle, for example, to the signaled state when the process terminates or is terminated. The wait functions, which will get lots of future use, are as follows:

```
DWORD WaitForSingleObject (
   HANDLE hObject,
   DWORD dwMilliseconds)
```

```
DWORD WaitForMultipleObjects (
   DWORD nCount,
   CONST HANDLE *lpHandles,
   BOOL fWaitAll,
   DWORD dwMilliseconds)
```

Return: The cause of the wait completion, or `0XFFFFFFFF` for an error (use `GetLastError` for more information).

Specify either a single process handle (hObject) or an array of distinct object handles in the array referenced by lpHandles. nCount, the size of the array, should not exceed MAXIMUM_WAIT_OBJECTS (defined as 64 in winnt.h).

dwMilliseconds is the time-out period in milliseconds. A value of 0 means that the function returns immediately after testing the state of the specified objects, thus allowing a program to poll for process termination. Use INFINITE for no time-out to wait until a process terminates.

fWaitAll, a parameter of the second function, specifies (if TRUE) that it is necessary to wait for all processes, rather than only one, to terminate.

The possible successful return values for this function are as follows.

- WAIT_OBJECT_0 means that the handle is signaled in the case of WaitForSingleObject or all nCount objects are simultaneously signaled in the special case of WaitForMultipleObjects with fWaitAll set to TRUE.
- WAIT_OBJECT_0+n, where 0 ≤ n < nCount. Subtract WAIT_OBJECT_0 from the return value to determine which process terminated when waiting for any of a collection of processes to terminate. If several handles are signaled, the returned value is the minimum of the signaled handle indices. WAIT_ABANDONED_0 is a possible base value when using mutex handles; see Chapter 8.
- WAIT_TIMEOUT indicates that the time-out period elapsed before the wait could be satisfied by signaled handle(s).
- WAIT_FAILED indicates that the call failed; for example, the handle may not have SYNCHRONIZE access.
- WAIT_ABANDONED_0 is not possible with processes. This value is discussed in Chapter 8 along with mutex handles.

Determine the exit code of a process using GetExitCodeProcess, as described in the preceding section.

Environment Blocks and Strings

Figure 6–1 includes the process environment block. The environment block contains a sequence of strings of the form

```
Name = Value
```

```
DWORD GetEnvironmentVariable (
   LPCTSTR lpName,
   LPTSTR lpValue,
   DWORD cchValue)

BOOL SetEnvironmentVariable (
   LPCTSTR lpName,
   LPCTSTR lpValue)
```

Each environment string, being a string, is `NULL`-terminated, and the entire block of strings is itself `NULL`-terminated. `PATH` is one example of a commonly used environment variable.

To pass the parent's environment to a child process, set `lpEnvironment` to `NULL` in the `CreateProcess` call. Any process, in turn, can interrogate or modify its environment variables or add new environment variables to the block.

The two functions used to get and set variables are as follows:

`lpName` is the variable name. On setting a value, the variable is added to the block if it does not exist and if the value is not `NULL`. If, on the other hand, the value is `NULL`, the variable is removed from the block. The "=" character cannot appear in an environment variable name, since it's used as a separator.

There are additional requirements. Most importantly, the environment block strings must be sorted alphabetically by name (case-insensitive, Unicode order). See MSDN for more details.

`GetEnvironmentVariable` returns the length of the value string, or `0` on failure. If the `lpValue` buffer is not long enough, as indicated by `cchValue`, then the return value is the number of characters actually required to hold the complete string. Recall that `GetCurrentDirectory` (Chapter 2) uses a similar mechanism.

Process Security

Normally, `CreateProcess` gives `PROCESS_ALL_ACCESS` rights. There are, however, several specific rights, including `PROCESS_QUERY_INFORMATION`, `CREATE_PROCESS`, `PROCESS_TERMINATE`, `PROCESS_SET_INFORMATION`, `DUPLICATE_HANDLE`, and `CREATE_THREAD`. In particular, it can be useful to limit `PROCESS_TERMINATE` rights to the parent process given the frequently mentioned dangers of terminating a running process. Chapter 15 describes security attributes for processes and other objects.

UNIX waits for process termination using `wait` and `waitpid`, but there are no time-outs even though `waitpid` can poll (there is a nonblocking option). These functions wait only for child processes, and there is no equivalent to the multiple wait on a collection of processes, although it is possible to wait for all processes in a process group. One slight difference is that the exit code is returned with `wait` and `waitpid`, so there is no need for a separate function equivalent to `GetExitCodeProcess`.

UNIX also supports environment strings similar to those in Windows. `getenv` (in the C library) has the same functionality as `GetEnvironmentVariable` except that the programmer must be sure to have a sufficiently large buffer. `putenv`, `setenv`, and `unsetenv` (not in the C library) are different ways to add, change, and remove variables and their values, with functionality equivalent to `SetEnvironmentVariable`.

Example: Parallel Pattern Searching

Now is the time to put Windows processes to the test. This example, `grepMP`, creates processes to search for patterns in files, one process per search file. The simple pattern search program is modeled after the UNIX `grep` utility, although the technique would apply to any program that uses standard output. The search program should be regarded as a black box and is simply an executable program to be controlled by a parent process; however, the project and executable (`grep.exe`) are in the *Examples* file.

The command line to the program is of the form

```
grepMP pattern F1 F2 ... FN
```

The program, Program 6–1, performs the following processing:

- Each input file, `F1` to `FN`, is searched using a separate process running the same executable. The program creates a command line of the form `grep` *`pattern`* `FK`.
- The temporary file handle, specified to be inheritable, is assigned to the `hStdOutput` field in the new process's start-up information structure.
- Using `WaitForMultipleObjects`, the program waits for all search processes to complete.
- As soon as all searches are complete, the results (temporary files) are displayed in order, one at a time. A process to execute the `cat` utility (Program 2–3) outputs the temporary file.
- `WaitForMultipleObjects` is limited to `MAXIMUM_WAIT_OBJECTS` (64) handles, so the program calls it multiple times.
- The program uses the `grep` process exit code to determine whether a specific process detected the pattern.

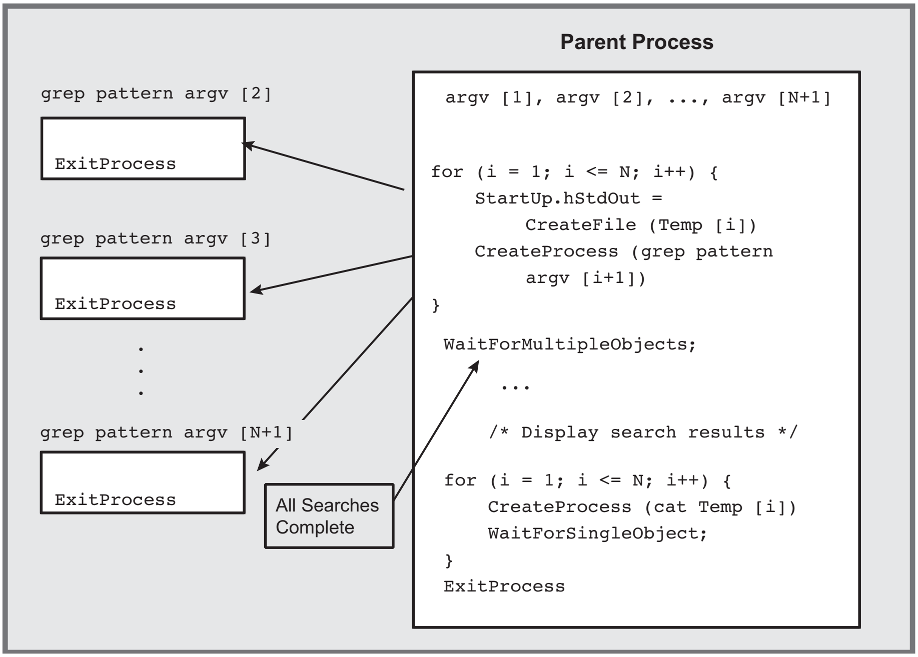


Figure 6–3 File Searching Using Multiple Processes

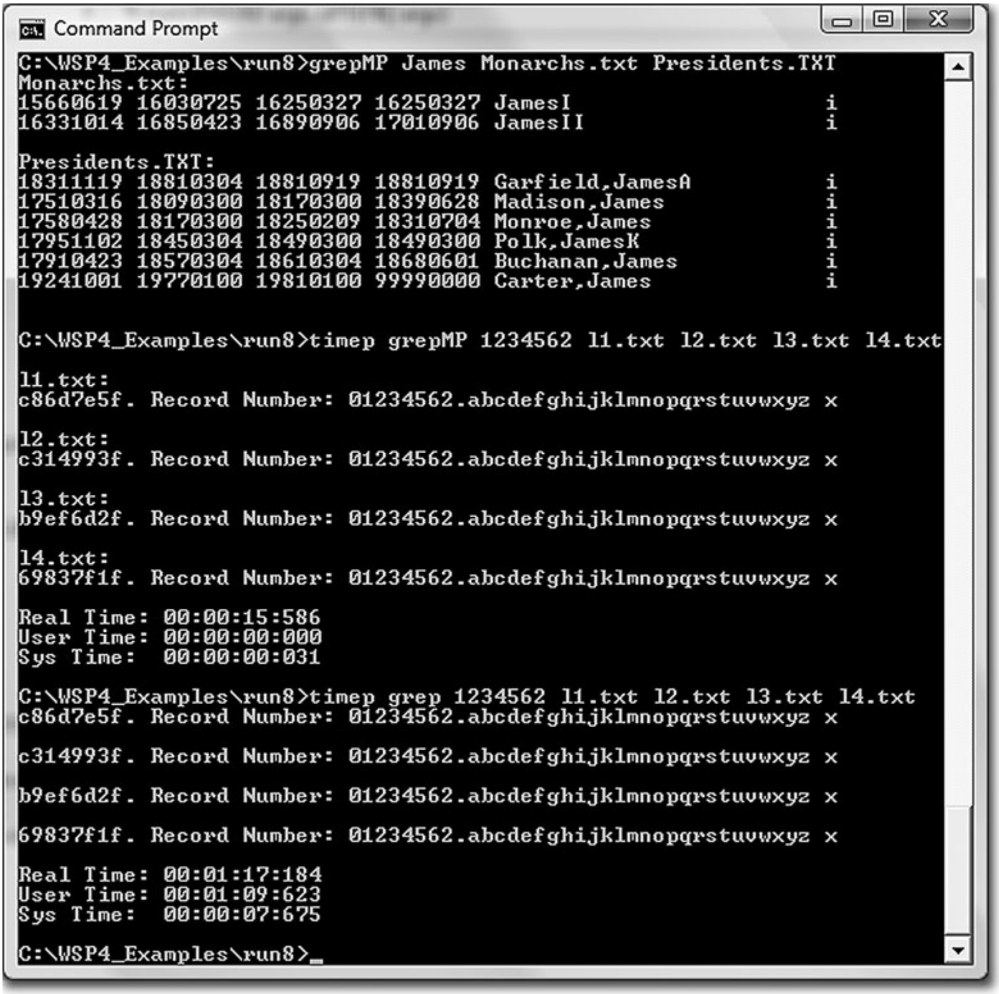
Figure 6–3 shows the processing performed by Program 6–1, and Run 6–1 shows program execution and timing results.

Program 6–1 `grepMP`: Parallel Searching

```
/* Chapter 6. grepMP. */
/* Multiple process version of grep command. */

#include "Everything.h"
int _tmain (DWORD argc, LPTSTR argv[])
/* Create a separate process to search each file on the
   command line. Each process is given a temporary file,
   in the current directory, to receive the results. */
{
   HANDLE hTempFile;
   SECURITY_ATTRIBUTES stdOutSA = /* SA for inheritable handle. */
         {sizeof (SECURITY_ATTRIBUTES), NULL, TRUE};
   TCHAR commandLine[MAX_PATH + 100];
   STARTUPINFO startUpSearch, startUp;
   PROCESS_INFORMATION processInfo;
```

```
DWORD iProc, exitCode, dwCreationFlags = 0;
HANDLE *hProc; /* Pointer to an array of proc handles. */
typedef struct {TCHAR tempFile[MAX_PATH];} PROCFILE;
PROCFILE *procFile; /* Pointer to array of temp file names. */

GetStartupInfo (&startUpSearch);
GetStartupInfo (&startUp);
procFile = malloc ((argc - 2) * sizeof (PROCFILE));
hProc = malloc ((argc - 2) * sizeof (HANDLE));

/* Create a separate "grep" process for each file. */
for (iProc = 0; iProc < argc - 2; iProc++) {
   _stprintf (commandLine, _T ("grep \"%s\" \"%s\""),
         argv[1], argv[iProc + 2]);
   GetTempFileName (_T ("."), _T ("gtm"), 0,
         procFile[iProc].tempFile); /* For search results. */
   hTempFile = /* This handle is inheritable */
      CreateFile (procFile[iProc].tempFile,
         GENERIC_WRITE,
         FILE_SHARE_READ | FILE_SHARE_WRITE, &stdOutSA,
         CREATE_ALWAYS, FILE_ATTRIBUTE_NORMAL, NULL);
   startUpSearch.dwFlags = STARTF_USESTDHANDLES;
   startUpSearch.hStdOutput = hTempFile;
   startUpSearch.hStdError = hTempFile;
   startUpSearch.hStdInput = GetStdHandle (STD_INPUT_HANDLE);

   /* Create a process to execute the command line. */
   CreateProcess (NULL, commandLine, NULL, NULL, TRUE,
      dwCreationFlags, NULL, NULL, &startUpSearch, &processInfo);
   /* Close unwanted handles. */
   CloseHandle (hTempFile); CloseHandle (processInfo.hThread);
   hProc[iProc] = processInfo.hProcess;
}

/* Processes are all running. Wait for them to complete. */
for (iProc = 0; iProc < argc - 2; iProc += MAXIMUM_WAIT_OBJECTS)
   WaitForMultipleObjects ( /* Allows a large # of processes */
         min (MAXIMUM_WAIT_OBJECTS, argc - 2 - iProc),
         &hProc[iProc], TRUE, INFINITE);
/* Result files sent to std output using "cat." */
for (iProc = 0; iProc < argc - 2; iProc++) {
   if (GetExitCodeProcess(hProc[iProc], &exitCode) && exitCode==0)
   {
      /* Pattern was detected -- List results. */
      if (argc > 3) _tprintf (_T ("%s:\n"), argv[iProc + 2]);
      _stprintf (commandLine, _T ("cat \"%s\""),
            procFile[iProc].tempFile);
      CreateProcess (NULL, commandLine, NULL, NULL, TRUE,
         dwCreationFlags, NULL, NULL, &startUp, &processInfo);
      WaitForSingleObject (processInfo.hProcess, INFINITE);
```

```
            CloseHandle (processInfo.hProcess);
            CloseHandle (processInfo.hThread);
        }

        CloseHandle (hProc[iProc]);
        DeleteFile (procFile[iProc].tempFile);
    }
    free (procFile);
    free (hProc);
    return 0;
}
```



Run 6–1 `grepMP`: Parallel Searching

Run 6–1 shows `grepMP` execution for large and small files, and the run contrasts sequential `grep` execution with parallel `grepMP` execution to perform the same task. The test computer has four processors; a single or dual processor computer will give different timing results. Notes after the run explain the test operation and results.

Run 6–1 uses files and obtains results as follows:

- The small file test searches two *Examples* files, `Presidents.txt` and `Monarchs.txt`, which contain names of U.S. presidents and English monarchs, along with their dates of birth, death, and term in office. The "i" at the right end of each line is a visual cue and has no other meaning. The same is true of the "x" at the end of the `randfile`-generated files.
- The large file test searches four `randfile`-generated files, each with 10 million 64-byte records. The search is for a specific record number (`1234562`), and each file has a different random key (the first 8 bytes).
- `grepMP` is more than four times faster than four sequential `grep` executions (Real Time is 15 seconds compared to 77 seconds), so the multiple processes gain even more performance than expected, despite the process creation overhead.
- `timep` is Program 6–2, the next example. Notice, however, that the `grepMP` system time is zero, as the time applies to `grepMP` itself, not the grep processes that it creates.

Processes in a Multiprocessor Environment

In Program 6–1, the processes and their primary (and only) threads run almost totally independently of one another. The only dependence is created at the end of the parent process as it waits for all the processes to complete so that the output files can be processed sequentially. Therefore, the Windows scheduler can and will run the process threads concurrently on the separate processors of a multiprocessor computer. As Run 6–1 shows, this can result in substantial performance improvement when performance is measured as elapsed time to execute the program, and no explicit program actions are required to get the performance improvement.

The performance improvement is not linear in terms of the number of processors due to overhead costs and the need to output the results sequentially. Nonetheless, the improvements are worthwhile and result automatically as a consequence of the program design, which delegates independent computational tasks to independent processes.

It is possible, however, to constrain the processes to specific processors if you wish to be sure that other processors are free to be allocated to other critical tasks.

This can be accomplished using the processor affinity mask (see Chapter 9) for a process or thread.

Finally, it is possible to create independent threads within a process, and these threads will also be scheduled on separate processors. Chapter 7 describes threads and related performance issues.

Process Execution Times

You can determine the amount of time that a process has consumed (elapsed, kernel, and user times) using the `GetProcessTimes` function.

```
BOOL GetProcessTimes (
   HANDLE hProcess,
   LPFILETIME lpCreationTime,
   LPFILETIME lpExitTime,
   LPFILETIME lpKernelTime,
   LPFILETIME lpUserTime)
```

The process handle can refer to a process that is still running or to one that has terminated. Elapsed time can be computed by subtracting the creation time from the exit time, as shown in the next example. The `FILETIME` type is a 64-bit item; create a union with a `LARGE_INTEGER` to perform the subtraction.

Chapter 3's `lsW` example showed how to convert and display file times, although the kernel and user times are elapsed times rather than calendar times.

`GetThreadTimes` is similar and requires a thread handle for a parameter.

Example: Process Execution Times

The next example (Program 6–2) implements the familiar `timep` (time print) utility that is similar to the UNIX `time` command (`time` is supported by the Windows command prompt, so a different name is appropriate). `timep` prints elapsed (or real), user, and system times.

This program uses `GetCommandLine`, a Windows function that returns the complete command line as a single string rather than individual `argv` strings.

The program also uses a utility function, `SkipArg`, to scan the command line and skip past the executable name. `SkipArg` is in the *Examples* file.

Program 6–2 `timep`: Process Times

```
/* Chapter 6. timep. */

#include "Everything.h"
int _tmain (int argc, LPTSTR argv[])
{
   STARTUPINFO startUp;
   PROCESS_INFORMATION procInfo;
   union { /* Structure required for file time arithmetic. */
      LONGLONG li;
      FILETIME ft;
   } createTime, exitTime, elapsedTime;
   FILETIME kernelTime, userTime;
   SYSTEMTIME elTiSys, keTiSys, usTiSys, startTimeSys;
   LPTSTR targv = SkipArg (GetCommandLine ());
   HANDLE hProc;

   GetStartupInfo (&startUp);
   GetSystemTime (&startTimeSys);

   /* Execute the command line; wait for process to complete. */
   CreateProcess (NULL, targv, NULL, NULL, TRUE,
         NORMAL_PRIORITY_CLASS, NULL, NULL, &startUp, &procInfo);
   hProc = procInfo.hProcess;
   WaitForSingleObject (hProc, INFINITE);

   GetProcessTimes (hProc, &createTime.ft,
         &exitTime.ft, &kernelTime, &userTime);
   elapsedTime.li = exitTime.li - createTime.li;
   FileTimeToSystemTime (&elapsedTime.ft, &elTiSys);
   FileTimeToSystemTime (&kernelTime, &keTiSys);
   FileTimeToSystemTime (&userTime, &usTiSys);
   _tprintf (_T ("Real Time: %02d:%02d:%02d:%03d\n"),
         elTiSys.wHour, elTiSys.wMinute, elTiSys.wSecond,
         elTiSys.wMilliseconds);
   _tprintf (_T ("User Time: %02d:%02d:%02d:%03d\n"),
         usTiSys.wHour, usTiSys.wMinute, usTiSys.wSecond,
         usTiSys.wMilliseconds);
   _tprintf (_T ("Sys Time: %02d:%02d:%02d:%03d\n"),
         keTiSys.wHour, keTiSys.wMinute, keTiSys.wSecond,
         keTiSys.wMilliseconds);

   CloseHandle (procInfo.hThread); CloseHandle (procInfo.hProcess);
   CloseHandle (hProc);
   return 0;
}
```

Using the `timep` Command

`timep` was useful to compare different programming solutions, such as the various Caesar cipher (`cci`) and sorting utilities, including `cci` (Program 2–3) and `sortMM` (Program 5–5). Appendix C summarizes and briefly analyzes some additional results, and there are other examples throughout the book.

Notice that measuring a program such as `grepMP` (Program 6–1) gives kernel and user times only for the parent process. Job objects, described near the end of this chapter, allow you to collect information on a collection of processes. Run 6–1 and Appendix C show that, on a multiprocessor computer, performance can improve as the separate processes, or more accurately, threads, run on different processors. There can also be performance gains if the files are on different physical drives. On the other hand, you cannot always count on such performance gains; for example, there might be resource contention or disk thrashing that could impact performance negatively.

Generating Console Control Events

Terminating a process can cause problems because the terminated process cannot clean up. SEH does not help because there is no general method for one process to cause an exception in another.[1] Console control events, however, allow one process to send a console control signal, or event, to another process in certain limited circumstances. Program 4–5 illustrated how a process can set up a handler to catch such a signal, and the handler could generate an exception. In that example, the user generated a signal from the user interface.

It is possible, then, for a process to generate a signal event in another specified process or set of processes. Recall the `CreateProcess` creation flag value, `CREATE_NEW_PROCESS_GROUP`. If this flag is set, the new process ID identifies a group of processes, and the new process is the *root* of the group. All new processes created by the parent are in this new group until another `CreateProcess` call uses the `CREATE_NEW_PROCESS_GROUP` flag.

One process can generate a `CTRL_C_EVENT` or `CTRL_BREAK_EVENT` in a specified process group, identifying the group with the root process ID. The target processes must have the same console as that of the process generating the event. In particular, the calling process cannot be created with its own console (using the `CREATE_NEW_CONSOLE` or `DETACHED_PROCESS` flag).

[1] Chapter 10 shows an indirect way for one thread to cause an exception in another thread, and the same technique is applicable between threads in different processes.

```
BOOL GenerateConsoleCtrlEvent (
   DWORD dwCtrlEvent,
   DWORD dwProcessGroup)
```

The first parameter, then, must be one of either `CTRL_C_EVENT` or `CTRL_BREAK_EVENT`. The second parameter identifies the process group.

Example: Simple Job Management

UNIX shells provide commands to execute processes in the background and to obtain their current status. This section develops a simple "job shell"[2] with a similar set of commands. The commands are as follows.

- `jobbg` uses the remaining part of the command line as the command for a new process, or *job,* but the `jobbg` command returns immediately rather than waiting for the new process to complete. The new process is optionally given its own console, or is *detached,* so that it has no console at all. Using a new console avoids console contention with `jobbg` and other jobs. This approach is similar to running a UNIX command with the `&` option at the end.
- `jobs` lists the current active jobs, giving the job numbers and process IDs. This is similar to the UNIX command of the same name.
- `kill` terminates a job. This implementation uses the `TerminateProcess` function, which, as previously stated, does not provide a clean shutdown. There is also an option to send a console control signal.

It is straightforward to create additional commands for operations such as suspending and resuming existing jobs.

Because the shell, which maintains the job list, may terminate, the shell employs a user-specific shared file to contain the process IDs, the command, and related information. In this way, the shell can restart and the job list will still be intact. Furthermore, several shells can run concurrently. You could place this information in the registry rather than in a temporary file (see Exercise 6–9).

Concurrency issues will arise. Several processes, running from separate command prompts, might perform job control simultaneously. The job management functions use file locking (Chapter 3) on the job list file so that a user can invoke

[2] Do not confuse these "jobs" with the Windows job objects described later. The jobs here are managed entirely from the programs developed in this section.

job management from separate shells or processes. Also, Exercise 6–8 identifies a defect caused by job id reuse and suggests a fix.

The full program in the *Examples* file has a number of additional features, not shown in the listings, such as the ability to take command input from a file. `JobShell` will be the basis for a more general "service shell" in Chapter 13 (Program 13–3). Windows services are background processes, usually servers, that can be controlled with start, stop, pause, and other commands.

Creating a Background Job

Program 6–3 is the job shell that prompts the user for one of three commands and then carries out the command. This program uses a collection of job management functions, which are shown in Programs 6–4, 6–5, and 6–6. Run 6–6 then demonstrates how to use the `JobShell` system.

Program 6–3 `JobShell`: Create, List, and Kill Background Jobs

```
/* Chapter 6. */
/* JobShell.c -- job management commands:
   jobbg -- Run a job in the background.
   jobs -- List all background jobs.
   kill -- Terminate a specified job of job family.
         There is an option to generate a console control signal. */

#include "Everything.h"
#include "JobMgt.h"

int _tmain (int argc, LPTSTR argv[])
{
   BOOL exitFlag = FALSE;
   TCHAR command[MAX_COMMAND_LINE], *pc;
   DWORD i, localArgc; /* Local argc. */
   TCHAR argstr[MAX_ARG][MAX_COMMAND_LINE];
   LPTSTR pArgs[MAX_ARG];

   for (i = 0; i < MAX_ARG; i++) pArgs[i] = argstr[i];
   /* Prompt user, read command, and execute it. */
   _tprintf (_T ("Windows Job Management\n"));
   while (!exitFlag) {
      _tprintf (_T ("%s"), _T ("JM$"));
      _fgetts (command, MAX_COMMAND_LINE, stdin);
      pc = strchr (command, '\n');
      *pc = '\0';
      /* Parse the input to obtain command line for new job. */
      GetArgs (command, &localArgc, pArgs); /* See Appendix A. */
      CharLower (argstr[0]);
```

```
      if (_tcscmp (argstr[0], _T ("jobbg")) == 0) {
         Jobbg (localArgc, pArgs, command);
      }
      else if (_tcscmp (argstr[0], _T ("jobs")) == 0) {
         Jobs (localArgc, pArgs, command);
      }
      else if (_tcscmp (argstr[0], _T ("kill")) == 0) {
         Kill (localArgc, pArgs, command);
      }
      else if (_tcscmp (argstr[0], _T ("quit")) == 0) {
         exitFlag = TRUE;
      }
      else _tprintf (_T ("Illegal command. Try again\n"));
   }
   return 0;
}

/* jobbg [options] command-line [Options are mutually exclusive]
      -c: Give the new process a console.
      -d: The new process is detached, with no console.
      If neither is set, the process shares console with jobbg. */
int Jobbg (int argc, LPTSTR argv[], LPTSTR command)
{
   DWORD fCreate;
   LONG jobNumber;
   BOOL flags[2];
   STARTUPINFO startUp;
   PROCESS_INFORMATION processInfo;
   LPTSTR targv = SkipArg (command);

   GetStartupInfo (&startUp);
   Options (argc, argv, _T ("cd"), &flags[0], &flags[1], NULL);
      /* Skip over the option field as well, if it exists. */
   if (argv[1][0] == '-') targv = SkipArg (targv);

   fCreate = flags[0] ? CREATE_NEW_CONSOLE :
         flags[1] ? DETACHED_PROCESS : 0;

      /* Create job/thread suspended. Resume once job entered. */
   CreateProcess (NULL, targv, NULL, NULL, TRUE,
         fCreate | CREATE_SUSPENDED | CREATE_NEW_PROCESS_GROUP,
         NULL, NULL, &startUp, &processInfo);
      /* Create a job number and enter the process ID and handle
         into the job "data base." */

   jobNumber = GetJobNumber (&processInfo, targv); /* See JobMgt.h */
   if (jobNumber >= 0)
      ResumeThread (processInfo.hThread);
   else {
      TerminateProcess (processInfo.hProcess, 3);
```

```
        CloseHandle (processInfo.hProcess);
        ReportError (_T ("Error: No room in job list."), 0, FALSE);
        return 5;
    }
    CloseHandle (processInfo.hThread);
    CloseHandle (processInfo.hProcess);
    _tprintf (_T (" [%d] %d\n"), jobNumber, processInfo.dwProcessId);
    return 0;
}

/* jobs: List all running or stopped jobs. */
int Jobs (int argc, LPTSTR argv[], LPTSTR command)
{
    if (!DisplayJobs ()) return 1; /* See job mgmt functions. */
    return 0;
}

/* kill [options] jobNumber
    -b Generate a Ctrl-Break
    -c Generate a Ctrl-C
        Otherwise, terminate the process. */
int Kill (int argc, LPTSTR argv[], LPTSTR command)
{
    DWORD ProcessId, jobNumber, iJobNo;
    HANDLE hProcess;
    BOOL cntrlC, cntrlB;

    iJobNo =
        Options (argc, argv, _T ("bc"), &cntrlB, &cntrlC, NULL);

    /* Find the process ID associated with this job. */
    jobNumber = _ttoi (argv[iJobNo]);
    ProcessId = FindProcessId (jobNumber); /* See job mgmt. */
    hProcess = OpenProcess (PROCESS_TERMINATE, FALSE, ProcessId);
    if (hProcess == NULL) { /* Process ID may not be in use. */
        ReportError (_T ("Process already terminated.\n"), 0, FALSE);
        return 2;
    }
    if (cntrlB)
        GenerateConsoleCtrlEvent (CTRL_BREAK_EVENT, ProcessId);
    else if (cntrlC)
        GenerateConsoleCtrlEvent (CTRL_C_EVENT, ProcessId);
    else
        TerminateProcess (hProcess, JM_EXIT_CODE);
    WaitForSingleObject (hProcess, 5000);
    CloseHandle (hProcess);
    _tprintf (_T ("Job [%d] terminated or timed out\n"), jobNumber);
    return 0;
}
```

Notice how the `jobbg` command creates the process in the suspended state and then calls the job management function, `GetJobNumber` (Program 6–4), to get a new job number and to register the job and its associated process. If the job cannot be registered for any reason, the job's process is terminated immediately. Normally, the job number is generated correctly, and the primary thread is resumed and allowed to run.

Getting a Job Number

The next three programs show three individual job management functions. These functions are all included in a single source file, `JobMgt.c`.

The first, Program 6–4, shows the `GetJobNumber` function. Notice the use of file locking with a completion handler to unlock the file. This technique protects against exceptions and inadvertent transfers around the unlock call. Such a transfer might be inserted accidentally during code maintenance even if the original program is correct. Also notice how the record past the end of the file is locked in the event that the file needs to be expanded with a new record.

There's also a subtle defect in this function; a code comment identifies it, and Exercise 6–8 suggests a fix.

Program 6–4 `JobMgt`: Creating New Job Information

```
/* Job management utility function. */

#include "Everything.h"
#include "JobMgt.h" /* Listed in Appendix A. */
void GetJobMgtFileName (LPTSTR);
LONG GetJobNumber (PROCESS_INFORMATION *pProcessInfo,
       LPCTSTR command)

/* Create a job number for the new process, and enter
   the new process information into the job database. */
{
   HANDLE hJobData, hProcess;
   JM_JOB jobRecord;
   DWORD jobNumber = 0, nXfer, exitCode, fileSizeLow, fileSizeHigh;
   TCHAR jobMgtFileName[MAX_PATH];
   OVERLAPPED regionStart;

   if (!GetJobMgtFileName (jobMgtFileName)) return -1;
                /* Produces "\tmp\UserName.JobMgt" */
   hJobData = CreateFile (jobMgtFileName,
          GENERIC_READ | GENERIC_WRITE,
          FILE_SHARE_READ | FILE_SHARE_WRITE,
          NULL, OPEN_ALWAYS, FILE_ATTRIBUTE_NORMAL, NULL);
```

```
    if (hJobData == INVALID_HANDLE_VALUE) return -1;

    /* Lock the entire file plus one possible new
       record for exclusive access. */
    regionStart.Offset = 0;
    regionStart.OffsetHigh = 0;
    regionStart.hEvent = (HANDLE)0;

    /* Find file size: GetFileSizeEx is an alternative */
    fileSizeLow = GetFileSize (hJobData, &fileSizeHigh);
    LockFileEx (hJobData, LOCKFILE_EXCLUSIVE_LOCK,
          0, fileSizeLow + SJM_JOB, 0, &regionStart);

    __try {
       /* Read records to find empty slot. */
       /* See text comments and Exercise 6-8 regarding a potential
          defect (and fix) caused by process ID reuse. */
       while (ReadFile (hJobData, &jobRecord, SJM_JOB, &nXfer, NULL)
             && (nXfer > 0)) {
          if (jobRecord.ProcessId == 0) break;
          hProcess = OpenProcess(PROCESS_ALL_ACCESS,
                FALSE, jobRecord.ProcessId);
          if (hProcess == NULL) break;
          if (GetExitCodeProcess (hProcess, &exitCode)
                && (exitCode != STILL_ACTIVE)) break;
          jobNumber++;
       }

       /* Either an empty slot has been found, or we are at end
          of file and need to create a new one. */
       if (nXfer != 0) /* Not at end of file. Back up. */
          SetFilePointer (hJobData, -(LONG)SJM_JOB,
                NULL, FILE_CURRENT);
       jobRecord.ProcessId = pProcessInfo->dwProcessId;
       _tcsnccpy (jobRecord.commandLine, command, MAX_PATH);
       WriteFile (hJobData, &jobRecord, SJM_JOB, &nXfer, NULL);
    } /* End try. */

    __finally {
       UnlockFileEx (hJobData, 0, fileSizeLow + SJM_JOB, 0,
             &regionStart);
       CloseHandle (hJobData);
    }
    return jobNumber + 1;
}
```

Listing Background Jobs

Program 6–5 shows the `DisplayJobs` job management function.

Program 6–5 `JobMgt`: Displaying Active Jobs

```
BOOL DisplayJobs (void)

/* Scan the job database file, reporting job status. */
{
   HANDLE hJobData, hProcess;
   JM_JOB jobRecord;
   DWORD jobNumber = 0, nXfer, exitCode, fileSizeLow, fileSizeHigh;
   TCHAR jobMgtFileName[MAX_PATH];
   OVERLAPPED regionStart;

   GetJobMgtFileName (jobMgtFileName);
   hJobData = CreateFile (jobMgtFileName,
         GENERIC_READ | GENERIC_WRITE,
         FILE_SHARE_READ | FILE_SHARE_WRITE,
         NULL, OPEN_EXISTING, FILE_ATTRIBUTE_NORMAL, NULL);

   regionStart.Offset = 0;
   regionStart.OffsetHigh = 0;
   regionStart.hEvent = (HANDLE)0;

   /* Demonstration: GetFileSize instead of GetFileSizeEx */
   fileSizeLow = GetFileSize (hJobData, &fileSizeHigh);
   LockFileEx (hJobData, LOCKFILE_EXCLUSIVE_LOCK,
         0, fileSizeLow, fileSizeHigh, &regionStart);

   __try {
   while (ReadFile (hJobData, &jobRecord, SJM_JOB, &nXfer, NULL)
         && (nXfer > 0)){
      jobNumber++;
      if (jobRecord.ProcessId == 0)
         continue;
      hProcess = OpenProcess (PROCESS_ALL_ACCESS, FALSE,
            jobRecord.ProcessId);
      if (hProcess != NULL)
         GetExitCodeProcess (hProcess, &exitCode);
      _tprintf (_T (" [%d] "), jobNumber);
      if (hProcess == NULL)
         _tprintf (_T (" Done"));
      else if (exitCode != STILL_ACTIVE)
         _tprintf (_T ("+ Done"));
      else _tprintf (_T (" "));
      _tprintf (_T (" %s\n"), jobRecord.commandLine);
```

```
      /* Remove processes that are no longer in system. */
      if (hProcess == NULL) { /* Back up one record. */
         SetFilePointer (hJobData, -(LONG)nXfer,
               NULL, FILE_CURRENT);
         jobRecord.ProcessId = 0;
         WriteFile (hJobData, &jobRecord, SJM_JOB, &nXfer, NULL);
      }
   } /* End of while. */
   } /* End of __try. */

   __finally {
      UnlockFileEx (hJobData, 0, fileSizeLow, fileSizeHigh,
                  &regionStart);
      CloseHandle (hJobData);
   }

   return TRUE;
}
```

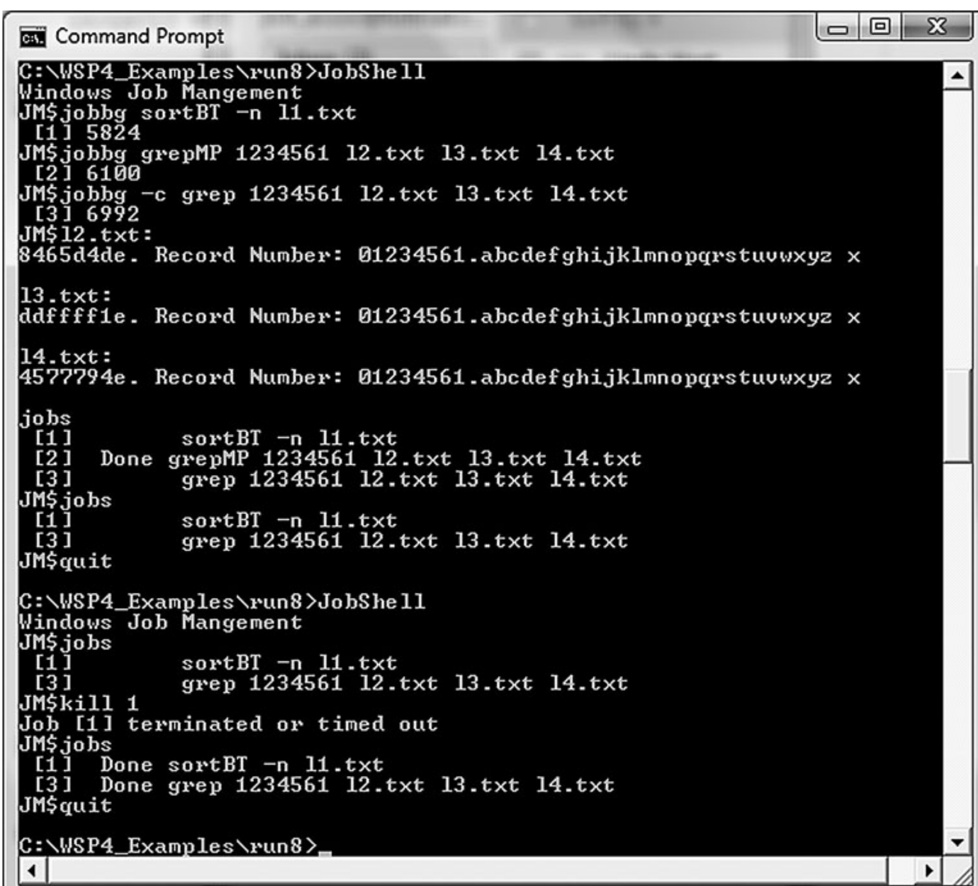
Finding a Job in the Job List File

Program 6–6 shows the final job management function, `FindProcessId`, which obtains the process ID of a specified job number. The process ID, in turn, can be used by the calling program to obtain a handle and other process status information.

Program 6–6 `JobMgt`: Getting the Process ID from a Job Number

```
DWORD FindProcessId (DWORD jobNumber)

/* Obtain the process ID of the specified job number. */
{
   HANDLE hJobData;
   JM_JOB jobRecord;
   DWORD nXfer;
   TCHAR jobMgtFileName[MAX_PATH];
   OVERLAPPED regionStart;

   /* Open the job management file. */
   GetJobMgtFileName (jobMgtFileName);

   hJobData = CreateFile (jobMgtFileName, GENERIC_READ,
         FILE_SHARE_READ | FILE_SHARE_WRITE,
         NULL, OPEN_EXISTING, FILE_ATTRIBUTE_NORMAL, NULL);
   if (hJobData == INVALID_HANDLE_VALUE) return 0;
```

```
    /* Position to the entry for the specified job number.
     * The full program assures that jobNumber is in range. */
    SetFilePointer (hJobData, SJM_JOB * (jobNumber - 1),
          NULL, FILE_BEGIN);

    /* Lock and read the record. */
    regionStart.Offset = SJM_JOB * (jobNumber - 1);
    regionStart.OffsetHigh = 0; /* Assume a "short" file. */
    regionStart.hEvent = (HANDLE)0;
    LockFileEx (hJobData, 0, 0, SJM_JOB, 0, &regionStart);
    ReadFile (hJobData, &jobRecord, SJM_JOB, &nXfer, NULL);
    UnlockFileEx (hJobData, 0, SJM_JOB, 0, &regionStart);
    CloseHandle (hJobData);
    return jobRecord.ProcessId;
}
```



```
Command Prompt
C:\WSP4_Examples\run8>JobShell
Windows Job Mangement
JM$jobbg sortBT -n l1.txt
 [1] 5824
JM$jobbg grepMP 1234561 l2.txt l3.txt l4.txt
 [2] 6100
JM$jobbg -c grep 1234561 l2.txt l3.txt l4.txt
 [3] 6992
JM$l2.txt:
8465d4de. Record Number: 01234561.abcdefghijklmnopqrstuvwxyz x

l3.txt:
ddffff1e. Record Number: 01234561.abcdefghijklmnopqrstuvwxyz x

l4.txt:
4577794e. Record Number: 01234561.abcdefghijklmnopqrstuvwxyz x

jobs
 [1]         sortBT -n l1.txt
 [2]   Done grepMP 1234561 l2.txt l3.txt l4.txt
 [3]         grep 1234561 l2.txt l3.txt l4.txt
JM$jobs
 [1]         sortBT -n l1.txt
 [3]         grep 1234561 l2.txt l3.txt l4.txt
JM$quit

C:\WSP4_Examples\run8>JobShell
Windows Job Mangement
JM$jobs
 [1]         sortBT -n l1.txt
 [3]         grep 1234561 l2.txt l3.txt l4.txt
JM$kill 1
Job [1] terminated or timed out
JM$jobs
 [1]   Done sortBT -n l1.txt
 [3]   Done grep 1234561 l2.txt l3.txt l4.txt
JM$quit

C:\WSP4_Examples\run8>_
```

Run 6–6 `JobShell`: Managing Multiple Processes

Run 6–6 shows the job shell managing several jobs using `grep`, `grepMP`, and `sortBT` (Chapter 5). Notes on Run 6–6 include:

- This run uses the same four 640MB files (`l1.txt`, etc.) as Run 6–1.
- You can quit and reenter `JobShell` and see the same jobs.
- A "Done" job is listed only once.
- The `grep` job uses the `-c` option, so the results appear in a separate console (not shown in the screenshot).
- `JobShell` and the `grepMP` job contend for the main console, so some output can overlap, although the problem does not occur in this example.

Job Objects

You can collect processes together into *job objects* where the processes can be controlled together, and you can specify resource limits for all the job object member processes and maintain accounting information.

The first step is to create an empty job object with `CreateJobObject`, which takes two arguments, a name and security attributes, and returns a job object handle. There is also an `OpenJobObject` function to use with a named object. `CloseHandle` destroys the job object.

`AssignProcessToJobObject` simply adds a process specified by a process handle to a job object; there are just two parameters. A process cannot be a member of more than one job, so `AssignProcessToJobObject` fails if the process associated with the handle is already a member of some job. A process that is added to a job inherits all the limits associated with the job and adds its accounting information to the job, such as the processor time used.

By default, a new child process created by a process in the job will also belong to the job unless the `CREATE_BREAKAWAY_FROM_JOB` flag is specified in the `dwCreationFlags` argument to `CreateProcess`.

Finally, you can specify control limits on the processes in a job using `SetInformationJobObject`.

```
BOOL SetInformationJobObject (
   HANDLE hJob,
   JOBOBJECTINFOCLASS JobObjectInformationClass,
   LPVOID lpJobObjectInformation,
   DWORD cbJobObjectInformationLength)
```

- `hJob` is a handle for an existing job object.
- `JobObjectInformationClass` specifies the information class for the limits you wish to set. There are five values; `JobObjectBasicLimitInformation` is one value and is used to specify information such as the total and per-process time limits, working set size limits,[3] limits on the number of active processes, priority, and processor affinity (the processors of a multiprocessor computer that can be used by threads in the job processes).
- `lpJobObjectInformation` points to the actual information required by the preceding parameter. There is a different structure for each class.
- `JOBOBJECT_BASIC_ACCOUNTING_INFORMATION` allows you to get the total time (user, kernel, and elapsed) of the processes in a job.
- `JOB_OBJECT_LIMIT_KILL_ON_JOB_CLOSE` will terminate all processes in the job object when you close the last handle referring to the object.
- The last parameter is the length of the preceding structure.

`QueryJobInformationObject` obtains the current limits. Other information classes impose limits on the user interface, I/O completion ports (see Chapter 14), security, and job termination.

Example: Using Job Objects

Program 6–7, `JobObjectShell`, illustrates using job objects to limit process execution time and to obtain user time statistics. `JobObjectShell` is a simple extension of `JobShell` that adds a command line time limit argument, in seconds. This limit applies to every process that `JobObjectShell` manages.

When you list the running processes, you will also see the total number of processes and the total user time on a four-processor computer.

Caution: The term “job” is used two ways here, which is confusing. First, the program uses Windows job objects to monitor all the individual processes. Then, borrowing some UNIX terminology, the program also regards each managed process to be a “job.”

First, we’ll modify the usual order and show Run 6–7, which runs the command:

```
JobObjectShell 60
```

[3] The working set is the set of virtual address space pages that the OS determines must be loaded in memory before any thread in the process is ready to run. This subject is covered in most OS texts.

to limit each process to a minute. The example then runs to shell commands:

```
timep grep 1234561 l2.txt l3.txt l4.txt
timep grepMP 1234561 l2.txt l3.txt l4.txt
```

as in Run 6–6. Note how the `jobs` command counts the processes that `timep` creates as well as those that `grepMP` creates to search the files, resulting in seven processes total. There is also a lot of contention for the console, mixing output from several processes, so you might want to run this example with the `-c` option.

There are also a few unexpected results, which are described for further investigation in Exercise 6–12.

Program 6–7 gives the `JobObjectShell` listing; it's an extension of `JobShell` (Program 6–3), so the listing is shortened to show the new code. There are

```
Command Prompt
C:\WSP4_Examples\run8>JobObjectShell 60
Windows Job Mangement with Windows Job Object.
JM$jobbg timep grep 1234561 l2.txt l3.txt l4.txt
 [1] 6616
JM$jobbg timep grepMP 1234561 l2.txt l3.txt l4.txt
 [2] 5524
JM$jobs
 [1]        timep grep 1234561 l2.txt l3.txt l4.txt
 [2]        timep grepMP 1234561 l2.txt l3.txt l4.txt
Total Processes: 7, Active: 7, Terminated: 0.
User time all processes: 25.000
JM$8465d4de. Record Number: 01234561.abcdefghijklmnopqrstuvwxyz x

l2.txt:
8465d4de. Record Number: 01234561.abcdefghijklmnopqrstuvwxyz x

l3.txt:
ddffff1e. Record Number: 01234561.abcdefghijklmnopqrstuvwxyz x

l4.txt:
4577794e. Record Number: 01234561.abcdefghijklmnopqrstuvwxyz x

Real Time: 00:00:14:336
User Time: 00:00:00:000
Sys Time:  00:00:00:109
ddffff1e. Record Number: 01234561.abcdefghijklmnopqrstuvwxyz x

4577794e. Record Number: 01234561.abcdefghijklmnopqrstuvwxyz x

Real Time: 00:00:53:133
User Time: 00:00:48:765
Sys Time:  00:00:04:180
jobs
 [1]  Done timep grep 1234561 l2.txt l3.txt l4.txt
 [2]  Done timep grepMP 1234561 l2.txt l3.txt l4.txt
Total Processes: 10, Active: 0, Terminated: 0.
User time all processes: 862.000
JM$quit

C:\WSP4_Examples\run8>
```

Run 6–7 `JobObjectShell`: Monitoring Processes with a Job Object some deviations from the MSDN documentation, which are described in Exercise 6–12 for investigation.

Program 6–7 `JobObjectShell`: Monitoring Processes with a Job Object

```
/* Chapter 6 */
/* JobObjectShell.c JobShell extension
   Enhances JobShell with a time limit on each process.
   The process time limit (seconds) is argv[1] (if present)
      0 or omitted means no process time limit
*/

#include "Everything.h"
#include "JobManagement.h"

#define MILLION 1000000
HANDLE hJobObject = NULL;

JOBOBJECT_BASIC_LIMIT_INFORMATION basicLimits =
         {0, 0, JOB_OBJECT_LIMIT_PROCESS_TIME};

int _tmain (int argc, LPTSTR argv[])
{
   LARGE_INTEGER processTimeLimit;
   . . .
   hJobObject = NULL;
   processTimeLimit.QuadPart = 0;
   if (argc >= 2) processTimeLimit.QuadPart = atoi(argv[1]);
   basicLimits.PerProcessUserTimeLimit.QuadPart =
      processTimeLimit.QuadPart * 10 * MILLION;

   hJobObject = CreateJobObject(NULL, NULL);
   SetInformationJobObject(hJobObject,
      JobObjectBasicLimitInformation, &basicLimits,
      sizeof(JOBOBJECT_BASIC_LIMIT_INFORMATION));
   . . .
   /* Process commands. Call Jobbg, Jobs, etc. - listed below */
   CloseHandle (hJobObject);

   return 0;
}

/* Jobbg: Execute a command line in the background, put
   the job identity in the user's job file, and exit.
*/
int Jobbg (int argc, LPTSTR argv[], LPTSTR command)
{
   /* Execute the command line (targv) and store the job id,
      the process id, and the handle in the jobs file. */
```

```
   DWORD fCreate;
   LONG jobNumber;
   BOOL flags[2];

   STARTUPINFO startUp;
   PROCESS_INFORMATION processInfo;
   LPTSTR targv = SkipArg (command);

   GetStartupInfo (&startUp);

      /* Determine the options. */
   Options (argc, argv, _T ("cd"), &flags[0], &flags[1], NULL);

      /* Skip over the option field as well, if it exists. */
   if (argv[1][0] == '-')
      targv = SkipArg (targv);

   fCreate = flags[0] ? CREATE_NEW_CONSOLE : flags[1] ?
         DETACHED_PROCESS : 0;

   /* Create the job/thread suspended.
      Resume it once the job is entered properly. */
   CreateProcess (NULL, targv, NULL, NULL, TRUE,
         fCreate | CREATE_SUSPENDED | CREATE_NEW_PROCESS_GROUP,
         NULL, NULL, &startUp, &processInfo);

   AssignProcessToJobObject(hJobObject, processInfo.hProcess);

   jobNumber = GetJobNumber (&processInfo, targv);
   if (jobNumber >= 0)
      ResumeThread (processInfo.hThread);
   else {
      TerminateProcess (processInfo.hProcess, 3);
      CloseHandle (processInfo.hThread);
      CloseHandle (processInfo.hProcess);
      return 5;
   }

   CloseHandle (processInfo.hThread);
   CloseHandle (processInfo.hProcess);
   _tprintf (_T (" [%d] %d\n"), jobNumber, processInfo.dwProcessId);
   return 0;
}

/* Jobs: List all running or stopped jobs that have
   been created by this user under job management;
   that is, have been started with the jobbg command.
   List summary process count and user time information.
*/
```

```
int Jobs (int argc, LPTSTR argv[], LPTSTR command)
{
   JOBOBJECT_BASIC_ACCOUNTING_INFORMATION BasicInfo;

   DisplayJobs (); /* Not job objects, but jobbg created processes */

   /* Dispaly the job object information */
   QueryInformationJobObject(hJobObject,
      JobObjectBasicAccountingInformation, &BasicInfo,
      sizeof(JOBOBJECT_BASIC_ACCOUNTING_INFORMATION), NULL);
   _tprintf (_T("Total Processes: %d, Active: %d, Terminated: %d.\n"),
      BasicInfo.TotalProcesses, BasicInfo.ActiveProcesses,
      BasicInfo.TotalTerminatedProcesses);
   _tprintf (_T("User time all processes: %d.%03d\n"),
      BasicInfo.TotalUserTime.QuadPart / MILLION,
      (BasicInfo.TotalUserTime.QuadPart % MILLION) / 10000);

   return 0;
}
```

Summary

Windows provides a straightforward mechanism for managing processes and synchronizing their execution. Examples have shown how to manage the parallel execution of multiple processes and how to obtain information about execution times. Windows does not maintain a parent-child relationship among processes, so the programmer must manage this information if it is required, although job objects provide a convenient way to group processes.

Looking Ahead

Threads, which are independent units of execution within a process, are described in the next chapter. Thread management is similar in some ways to process management, and there are exit codes, termination, and waiting on thread handles. To illustrate this similarity, `grepMP` (Program 6–1) is reimplemented with threads in Chapter 7's first example program.

Chapter 8 then introduces synchronization, which coordinates operation between threads in the same or different processes.

Exercises

6–1. Extend Program 6–1 (`grepMP`) so that it accepts command line options and not just the pattern.

6–2. Rather than pass the temporary file name to the child process in Program 6–1, convert the inheritable file handle to a `DWORD` (a `HANDLE` requires 4 bytes in Win32; investigate the Win64 `HANDLE` size) and then to a character string. Pass this string to the child process on the command line. The child process, in turn, must convert the character string back to a handle value to use for output. The `catHA.c` and `grepHA.c` programs in the *Examples* file illustrate this technique. Is this technique advisable, or is it poor practice, in your opinion?

6–3. Program 6–1 waits for all processes to complete before listing the results. It is impossible to determine the order in which the processes actually complete within the current program. Modify the program so that it can also determine the termination order. *Hint:* Modify the call to `WaitForMultipleObjects` so that it returns after each individual process terminates. An alternative would be to sort by the process termination times.

6–4. The temporary files in Program 6–1 must be deleted explicitly. Can you use `FILE_FLAG_DELETE_ON_CLOSE` when creating the temporary files so that deletion is not required?

6–5. Determine any `grepMP` performance advantages (compared with sequential execution) on different multiprocessor systems or when the files are on separate or network drives. Appendix C presents some partial results, as does Run 6–1.

6–6. Can you find a way to collect the user and kernel time required by `grepMP`? It may be necessary to modify `grepMP` to use job objects.

6–7. Enhance the `DisplayJobs` function (Program 6–5) so that it reports the exit code of any completed job. Also, give the times (elapsed, kernel, and user) used so far by all jobs.

6–8. The job management functions have a defect that is difficult to fix. Suppose that a job is killed and the executive reuses its process ID before the process ID is removed from the job management file. There could be an `OpenProcess` on the process ID that now refers to a totally different process. The fix requires creating a helper process that holds duplicated handles for every created process so that the ID will not be reused. Another technique would be to include the process start time in the job management file. This time should be the same as the process start time of the process obtained from the process ID. *Note:* Process IDs will be reused quickly. UNIX, however, increments a counter to get a new process ID, and IDs will repeat only after the 32-bit counter wraps around. Therefore, Windows programs cannot assume that IDs will not, for all practical purposes, be reused.

6–9. Modify `JobShell` so that job information is maintained in the registry rather than in a temporary file.

6–10. Enhance `JobShell` so that the `jobs` command will include a count of the number of handles that each job is using. *Hint:* Use `GetProcessHandleCount` (see MSDN).

6–11. `Jobbg` (in the `JobShell` listing) currently terminates a process if there is no room in the table for a new entry. Enhance the program to reserve a table location before creating the process, so as to avoid `TerminateProcess`.

6–12. `JobObjectShell` exhibits several anomalies and defects. Investigate and fix or explain them, if possible.

- Run 6–7 shows seven total processes, all active, after the first two jobs are started. This value is correct (do you agree?). After the jobs terminate, there are now 10 processes, none of which are active. Is this a bug (if so, is the bug in the program or in Windows?), or is the number correct?
- Program 6–7 shows plausible user time results in seconds (do you agree?). It obtains these results by dividing the total user time by 1,000,000, implying that the time is returned in microseconds. MSDN, however, says that the time is in 100 ns units, so the division should be by 10,000,000. Investigate. Is MSDN wrong?
- Does the limit on process time actually work, and is the program implemented correctly? `sortBT` (Program 5–1) is a time-consuming program for experimentation.

Index

R

S