



# **Windows 10 System Programming**

## **Part 1**

**Pavel Yosifovich**

# Windows 10 System Programming, Part 1

Pavel Yosifovich

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# Contents

<b>Introduction . . . . .</b>	<b>1</b>
Who Should Read This Book . . . . .	1
What You Should Know to Use This Book . . . . .	1
Sample Code . . . . .	1
<b>Chapter 1: Foundations . . . . .</b>	<b>2</b>
Windows Architecture Overview . . . . .	2
Processes . . . . .	2
Dynamic Link Libraries . . . . .	2
Virtual Memory . . . . .	2
Threads . . . . .	2
General System Architecture . . . . .	2
Windows Application Development . . . . .	3
Your First Application . . . . .	3
Working with Strings . . . . .	3
Strings in the C/C++ Runtime . . . . .	3
String Output Parameters . . . . .	3
Safe String Functions . . . . .	3
32-bit vs. 64-bit Development . . . . .	3
Coding Conventions . . . . .	4
C++ Usage . . . . .	4
Handling API Errors . . . . .	4
Defining Custom Error Codes . . . . .	4
The Windows Version . . . . .	4
Getting the Windows Version . . . . .	4
Exercises . . . . .	4
Summary . . . . .	5
<b>Chapter 2: Objects and Handles . . . . .</b>	<b>6</b>
Kernel Objects . . . . .	6
Running a Single Instance Process . . . . .	9

## CONTENTS

Handles . . . . .	12
Pseudo Handles . . . . .	12
RAII for Handles . . . . .	12
Using WIL . . . . .	12
Creating Objects . . . . .	13
Object Names . . . . .	13
Sharing Kernel Objects . . . . .	13
Sharing by Name . . . . .	13
Sharing by Handle Duplication . . . . .	13
Private Object Namespaces . . . . .	13
Bonus: WIL Wrappers for Private Namespaces . . . . .	13
Other Objects and Handles . . . . .	14
User Objects . . . . .	14
GDI Objects . . . . .	15
Summary . . . . .	15
<b>Chapter 3: Processes . . . . .</b>	<b>16</b>
Process Basics . . . . .	16
Processes in Process Explorer . . . . .	16
Process Creation . . . . .	16
The main Functions . . . . .	16
Process Environment Variables . . . . .	16
Creating Processes . . . . .	16
Handle Inheritance . . . . .	17
Process Drive Directories . . . . .	17
Process (and Thread) Attributes . . . . .	17
Protected and PPL Processes . . . . .	17
UWP Processes . . . . .	17
Minimal and Pico Processes . . . . .	17
Process Termination . . . . .	17
Enumerating Processes . . . . .	17
Using EnumProcesses . . . . .	18
Using the Toolhelp Functions . . . . .	18
Using the WTS Functions . . . . .	18
Using the Native API . . . . .	18
Exercises . . . . .	18
Summary . . . . .	18
<b>Chapter 4: Jobs . . . . .</b>	<b>19</b>
Introduction to Jobs . . . . .	19
Creating Jobs . . . . .	19

Nested Jobs . . . . .	19
Querying Job Information . . . . .	19
Job Accounting Information . . . . .	19
Querying for Job Process List . . . . .	19
Setting Job Limits . . . . .	20
CPU Rate Limit . . . . .	20
User Interface Limits . . . . .	20
Job Notifications . . . . .	20
Silos . . . . .	20
Exercises . . . . .	20
Summary . . . . .	20
<b>Chapter 5: Threads Basics . . . . .</b>	<b>21</b>
Introduction . . . . .	21
Sockets, Cores, and Logical Processors . . . . .	21
Creating and Managing Threads . . . . .	21
The Primes Counter Application . . . . .	21
Running Primes Counter . . . . .	21
Terminating Threads . . . . .	21
A Thread's Stack . . . . .	22
A Thread's Name . . . . .	22
What About the C++ Standard Library? . . . . .	22
Exercises . . . . .	22
Summary . . . . .	22
<b>Chapter 6: Thread Scheduling . . . . .</b>	<b>23</b>
Priorities . . . . .	23
Scheduling Basics . . . . .	23
Single CPU Scheduling . . . . .	23
The Quantum . . . . .	23
Processor Groups . . . . .	23
Multiprocessor Scheduling . . . . .	23
Affinity . . . . .	24
CPU Sets vs. Hard Affinity . . . . .	24
System CPU Sets . . . . .	24
Revised Scheduling Algorithm . . . . .	24
Observing Scheduling . . . . .	24
General Scheduling . . . . .	25
Hard Affinity . . . . .	25
CPU Sets . . . . .	25
Background Mode . . . . .	25

Priority Boosts . . . . .	25
Completing I/O Operations . . . . .	25
Foreground Process . . . . .	25
GUI Thread Wakeup . . . . .	25
Starvation Avoidance . . . . .	26
Other Aspects of Scheduling . . . . .	26
Suspend and Resume . . . . .	26
Suspending and Resuming a Process . . . . .	26
Sleeping and Yielding . . . . .	26
Summary . . . . .	26
<b>Chapter 7: Thread Synchronization (Intra-Process) . . . . .</b>	<b>27</b>
Synchronization Basics . . . . .	27
Atomic Operations . . . . .	27
The Simple Increment Application . . . . .	27
The Interlocked Family of Functions . . . . .	27
Critical Sections . . . . .	27
Locks and RAII . . . . .	28
Deadlocks . . . . .	28
The MD5 Calculator Application . . . . .	28
Calculating MD5 Hash . . . . .	28
The Hash Cache . . . . .	28
Image Loads Notifications . . . . .	28
Event Parsing . . . . .	28
Putting it All Together . . . . .	29
Reader Writer Locks . . . . .	29
RAII Wrappers . . . . .	29
MD5 Calculator 2 . . . . .	29
Condition Variables . . . . .	29
The Queue Demo Application . . . . .	29
Waiting on Address . . . . .	29
Synchronization Barriers . . . . .	30
What About the C++ Standard Library? . . . . .	30
Exercises . . . . .	30
Summary . . . . .	30
<b>Chapter 8: Thread Synchronization (Inter-Process) . . . . .</b>	<b>31</b>
Dispatcher Objects . . . . .	31
Succeeding a Wait . . . . .	31
The Mutex . . . . .	31
The Mutex Demo Application . . . . .	31

Abandoned Mutex . . . . .	31
The Semaphore . . . . .	32
The Queue Demo Application . . . . .	32
The Event . . . . .	32
Working with Events . . . . .	32
The Waitable Timer . . . . .	32
Other Wait Functions . . . . .	32
Waiting in Alertable State . . . . .	32
Waiting on GUI Threads . . . . .	33
Waiting for an Idle GUI Thread . . . . .	33
Signaling and Waiting Atomically . . . . .	33
Exercises . . . . .	33
Summary . . . . .	33
<b>Chapter 9: Thread Pools . . . . .</b>	<b>34</b>
Why Use a Thread Pool? . . . . .	34
Thread Pool Work Callbacks . . . . .	34
The Simple Work Application . . . . .	34
Controlling a Work Item . . . . .	34
The MD5 Calculator Application . . . . .	34
Thread Pool Wait Callbacks . . . . .	34
Thread Pool Timer Callbacks . . . . .	35
The Simple Timer Sample . . . . .	35
Thread Pool I/O Callbacks . . . . .	35
Thread Pool Instance Operations . . . . .	35
The Callback Environment . . . . .	35
Private Thread Pools . . . . .	35
Cleanup Groups . . . . .	35
Exercises . . . . .	36
Summary . . . . .	36
<b>Chapter 10: Advanced Threading . . . . .</b>	<b>37</b>
Thread Local Storage . . . . .	37
Dynamic TLS . . . . .	37
Static TLS . . . . .	37
Remote Threads . . . . .	37
The <i>Breakin</i> Application . . . . .	37
Thread Enumeration . . . . .	37
The <i>thlist</i> Application . . . . .	38
Caches and Cache Lines . . . . .	38
Wait Chain Traversal . . . . .	38

## CONTENTS

The Deadlock Detector Application . . . . .	38
Asynchronous WCT Sessions . . . . .	38
User Mode Scheduling . . . . .	38
Init Once Initialization . . . . .	38
Debugging Multithreaded Applications . . . . .	39
Breakpoints . . . . .	39
Parallel Stacks . . . . .	39
Parallel Watch . . . . .	39
Thread Names . . . . .	39
Exercises . . . . .	39
Summary . . . . .	39
<b>Chapter 11: File and Device I/O . . . . .</b>	<b>40</b>
The I/O System . . . . .	40
The CreateFile Function . . . . .	40
Working with Symbolic Links . . . . .	40
Path Length . . . . .	40
Directories . . . . .	40
Files . . . . .	40
Setting File Information . . . . .	41
Synchronous I/O . . . . .	41
Asynchronous I/O . . . . .	41
ReadFileEx and WriteFileEx . . . . .	41
Manually Queued APC . . . . .	41
I/O Completion Ports . . . . .	41
The <i>Bulk Copy</i> Application . . . . .	41
Using the Thread Pool for I/O Completion . . . . .	42
The <i>Bulk Copy 2</i> Application . . . . .	42
I/O Cancellation . . . . .	42
Devices . . . . .	42
Pipes and Mailslots . . . . .	42
Pipes . . . . .	42
Transactional NTFS . . . . .	42
File Search and Enumeration . . . . .	43
NTFS Streams . . . . .	43
Summary . . . . .	43
<b>Chapter 12: Memory Management Fundamentals . . . . .</b>	<b>44</b>
Basic Concepts . . . . .	44
Process Address Space . . . . .	44
Page States . . . . .	44



## CONTENTS

Address Space Layout . . . . .	44
32-bit Systems . . . . .	44
64-bit Systems . . . . .	44
Address Space Usage . . . . .	45
Memory Counters . . . . .	45
Process Memory Counters . . . . .	45
Process Memory Map . . . . .	45
Page Protection . . . . .	45
Enumerating Address Space Regions . . . . .	45
The <i>Simple VMMMap</i> Application . . . . .	45
More Address Space Information . . . . .	46
Sharing Memory . . . . .	46
Page Files . . . . .	46
WOW64 . . . . .	46
WOW64 Redirections . . . . .	46
Virtual Address Translation . . . . .	46
Summary . . . . .	46

# Introduction

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# Chapter 1: Foundations

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# Chapter 2: Objects and Handles

Windows is an object-based operating system, exposing various types of objects (usually referred to as *kernel Objects*), that provide the bulk of the functionality in Windows. Example object types are processes, threads and files. In this chapter we'll discuss the general theory related to kernel objects without too much details of any specific object type. The following chapters will go into details of many of these types.

---

In this chapter:

- Kernel Objects
  - Handles
  - Creating Objects
  - Object Names
  - Sharing Kernel Objects
  - Private Object Namespaces
- 

## Kernel Objects

The Windows kernel exposes various types of objects for use by user-mode processes, the kernel itself and kernel-mode drivers. Instances of these types are data structures in system (kernel) space, created and managed by the Object Manager (part of the Executive) when requested to do so by user or kernel code. kernel objects are reference counted, so only when the last reference to the object is released will the object be destroyed and freed from memory.

There are quite a few object types supported by the Windows kernel. To get a peek, run the *WinObj* tool from *Sysinternals* (elevated) and locate the *ObjectTypes* directory. Figure 2-1 shows what this looks like. These types can be cataloged based on their visibility and usage:

- Types that are exported to user-mode via the Windows API. Examples: mutex, semaphore, file, process, thread, timer. This book discusses many of these object types.

- Types that are not exported to user mode, but are documented in the *Windows Driver Kit* (WDK) for use by device driver writers. Examples: device, driver, callback.
- Types that are not documented even in the WDK (at least at the time of writing). These object types are for use by the kernel itself only. Examples: partition, keyed event, core messaging.

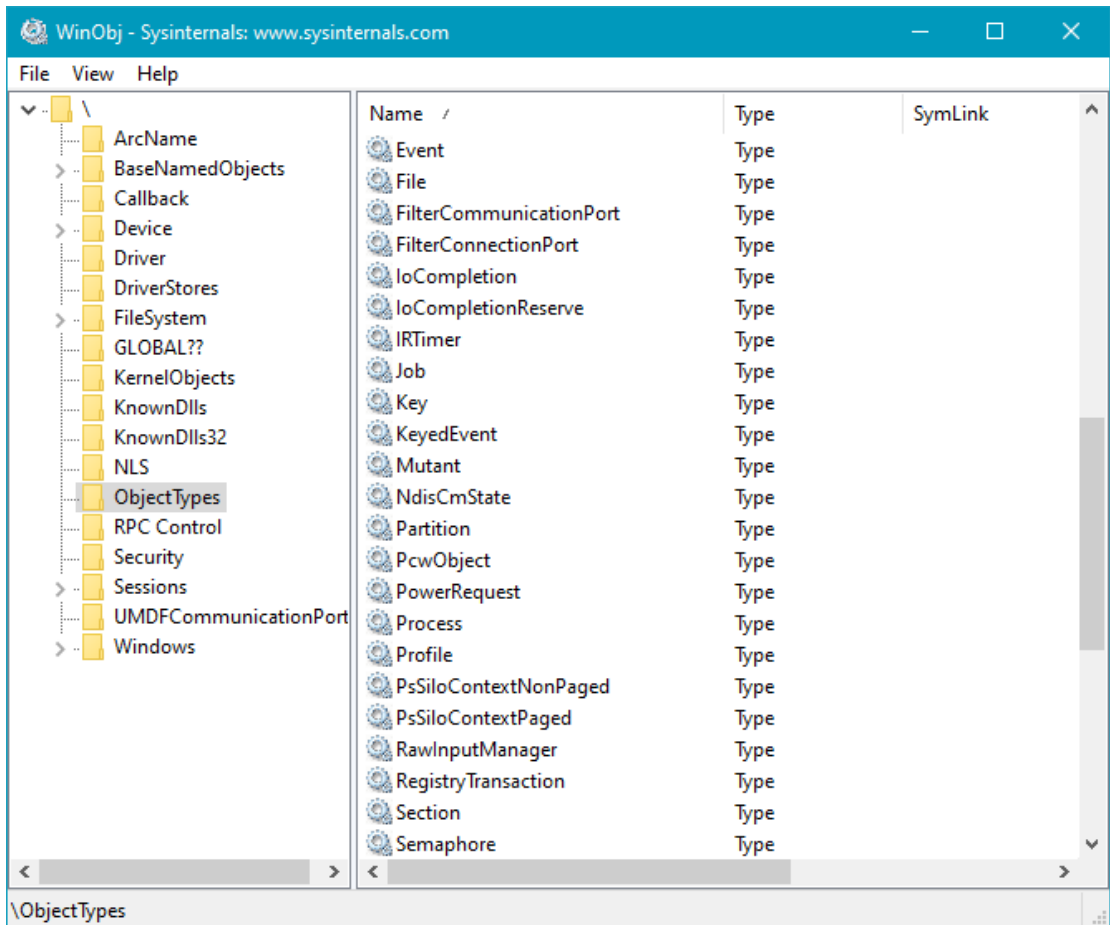


Figure 2-1: Object types

The main attributes of a kernel object are depicted in figure 2-2.



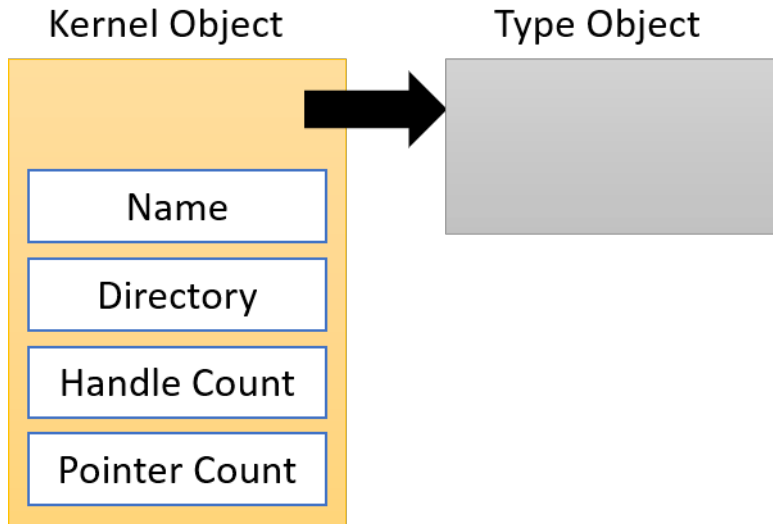


Figure 2-2: Kernel Object Attributes

Since kernel objects reside in system space, they cannot be accessed directly from user mode. Applications must use an indirect mechanism to access kernel objects, known as handles. Handles provide at least the following benefits:

- Any change in the object type's data structure in a future Windows release will not affect any client.
- Access to the object can be controlled through security access checks.
- Handles are private to a process, so having a handle to a particular object in one process means nothing in another process context.

Kernel objects are reference counted. The Object Manager maintains a handle count and a pointer count, the sum of which is the total reference count for an object (direct pointers can be obtained from kernel mode). Once an object used by a user mode client is no longer needed, the client code should close the handle used to access the object by calling `CloseHandle`. From that point on, the code should consider the handle to be invalid. Trying to access the object through the closed handle will fail, with `GetLastError` returning `ERROR_INVALID_HANDLE` (6). The client does not know, in the general case, whether the object has been destroyed or not. The Object Manager will delete the object if its reference drops to zero.

Handle values are multiples of 4, where the first valid handle is 4; Zero is never a valid handle value. This scheme does not change on 64 bit systems.

A handle is logically an index to an array of entries in a handle table maintained on a process by process basis, that points logically to a kernel object residing in system space. There are various `Create*` and `Open*` functions to create/open objects and retrieve back handles to these objects.

If the object cannot be created or opened, the returned handle is in most cases `NULL` (0). One notable exception to this rule is the `CreateFile` function that returns `INVALID_HANDLE_VALUE` (-1) if it fails.

For example, the `CreateMutex` function allows creating a new mutex or opening a mutex by name (depending whether the mutex with that name exists). If successful, the function returns a handle to the mutex. A return value of zero means an invalid handle (and a function call failure). The `OpenMutex` function, on the other hand, tries to open a handle to a named mutex. If the mutex with that name does not exist, the function fails.

If the function succeeds and a name was provided, the returned handle can be to a new mutex or to an existing mutex with that name. The code can check this by calling `GetLastError` and comparing the result to `ERROR_ALREADY_EXISTS`. If it is, then it's not a new object, but rather another handle to an existing object. This is one of those rare cases where `GetLastError` can be called even if the API in question succeeded.

## Running a Single Instance Process

One fairly well-known usage for the `ERROR_ALREADY_EXISTS` case is limiting an executable to have a single process instance. Normally, if you double-click an executable in Explorer, a new process is spawned based on that executable. If you repeat this operation, another process is created based on the same executable. What if you wanted to prevent the second process from launching, or at least have it shut down if it detects another process instance with the same executable already running.

The trick is using some named kernel object (a mutex is usually employed, although any named object type can be used instead), where an object with a particular name is created. If the object already exists, there must be another instance already running, so the process can shut down (possibly notifying its sibling of that fact).

The *SingleInstance* demo application demonstrates how this can be achieved. It's a dialog-based application built with WTL. Figure 2-3 shows what this application looks like running. If you try launching more instances of this application, you'll find that the first window logs messages coming from the new process instance that then exits.

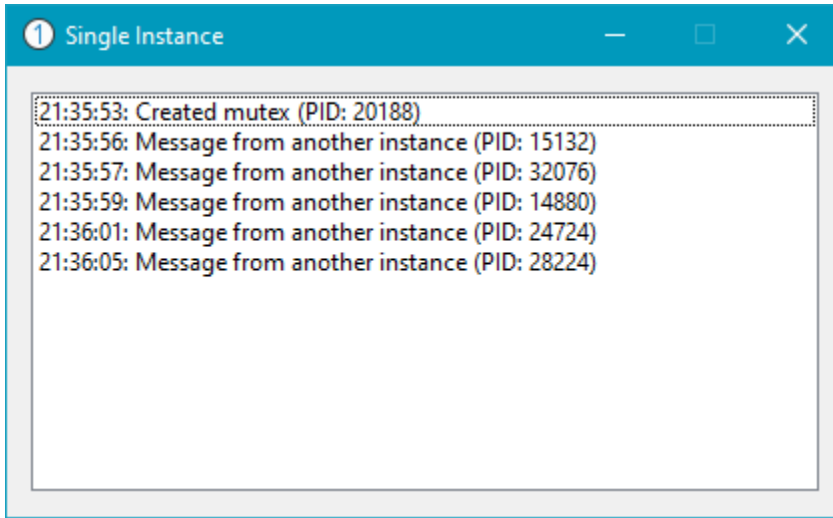


Figure 2-3: The Single Instance application

In the `WinMain` function, we create the mutex first. If this fails, then something is very wrong and we bail out.

```
HANDLE hMutex = ::CreateMutex(nullptr, FALSE, L"SingleInstanceMutex");
if (!hMutex) {
    CString text;
    text.Format(L"Failed to create mutex (Error: %d)", ::GetLastError());
    ::MessageBox(nullptr, text, L"Single Instance", MB_OK);
    return 0;
}
```

Failure to create the mutex should be extremely rare. The most likely scenario for failure is that another kernel object (which is not a mutex) with that same name already exists.

Now that we get a proper handle to the mutex, the only question is whether the mutex was actually created or we received another handle to an existing mutex (presumably created by a previous instance of this executable):

```
if (::GetLastError() == ERROR_ALREADY_EXISTS) {
    NotifyOtherInstance();
    return 0;
}
```

If the object existed prior to the `CreateMutex` call, then we call a helper function that sends some message to the existing instances and exits. Here is `NotifyOtherInstance`:

```

#define WM_NOTIFY_INSTANCE (WM_USER + 100)

void NotifyOtherInstance() {
    auto hWnd = ::FindWindow(nullptr, L"Single Instance");
    if (!hWnd) {
        ::MessageBox(nullptr, L"Failed to locate other instance window",
            L"Single Instance", MB_OK);
        return;
    }

    ::PostMessage(hWnd, WM_NOTIFY_INSTANCE, ::GetCurrentProcessId(), 0);
    ::ShowWindow(hWnd, SW_NORMAL);
    ::SetForegroundWindow(hWnd);
}

```

The function searches for the existing window with the `FindWindow` function and uses the window caption as the search criteria. This is not ideal in the general case, but it's good enough for this sample.

Once the window is located, we send a custom message to the window with the current process ID as an argument. This shows up in the dialog's list box.

The final piece of the puzzle is handling the `WM_NOTIFY_INSTANCE` message by the dialog. In WTL, window messages are mapped to functions using macros. The message map of the dialog class (`CMainDlg`) in *MainDlg.h* is repeated here:

```

BEGIN_MSG_MAP(CMainDlg)
    MESSAGE_HANDLER(WM_NOTIFY_INSTANCE, OnNotifyInstance)
    MESSAGE_HANDLER(WM_INITDIALOG, OnInitDialog)
    COMMAND_ID_HANDLER(IDCANCEL, OnCancel)
END_MSG_MAP()

```

The custom message is mapped to the `OnNotifyInstance` member function, implemented like so:

```

LRESULT CMainDlg::OnNotifyInstance(UINT, WPARAM wParam, LPARAM, BOOL &) {
    CString text;
    text.Format(L"Message from another instance (PID: %d)", wParam);

    AddText(text);
    return 0;
}

```

The process ID is extracted from the `wParam` parameter and some text is added to the list box with the `AddText` helper function:

```

void CMainDlg::AddText(PCWSTR text) {
    CTime dt = CTime::GetCurrentTime();
    m_List.AddString(dt.Format(L"%T") + L": " + text);
}

```

`m_List` is of type `CListBox`, a WTL wrapper for a Windows list box control.

## Handles

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## Pseudo Handles

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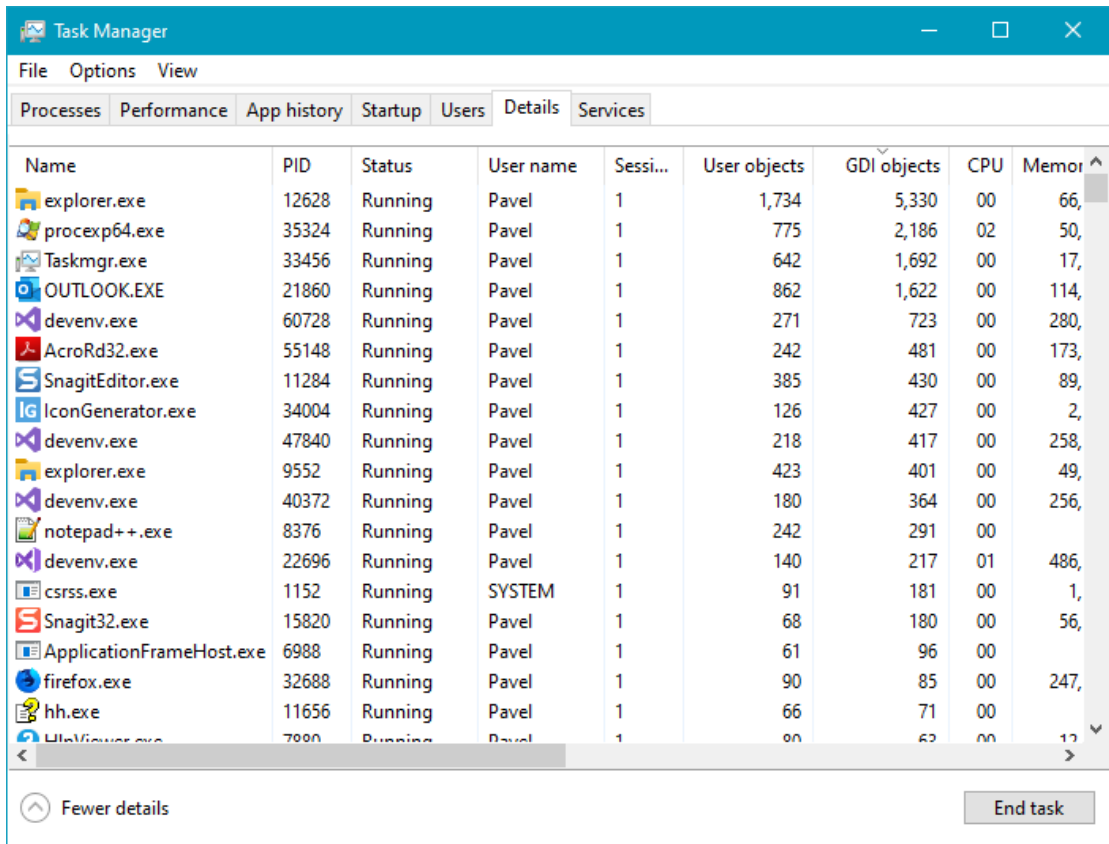
### Bonus: WIL Wrappers for Private Namespaces

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## Other Objects and Handles

Kernel objects are interesting in the context of system programming, and are the focus of this book. There are other common objects used in Windows, namely user objects and GDI objects. The following is a brief description of these objects and handles to such objects.

*Task Manager* can show the number of such objects for each process by adding the *User Objects* and *GDI Objects* columns, as shown in figure 2-21.



Name	PID	Status	User name	Sessi...	User objects	GDI objects	CPU	Memor
explorer.exe	12628	Running	Pavel	1	1,734	5,330	00	66,
procexp64.exe	35324	Running	Pavel	1	775	2,186	02	50,
Taskmgr.exe	33456	Running	Pavel	1	642	1,692	00	17,
OUTLOOK.EXE	21860	Running	Pavel	1	862	1,622	00	114,
devenv.exe	60728	Running	Pavel	1	271	723	00	280,
AcroRd32.exe	55148	Running	Pavel	1	242	481	00	173,
SnagitEditor.exe	11284	Running	Pavel	1	385	430	00	89,
IconGenerator.exe	34004	Running	Pavel	1	126	427	00	2,
devenv.exe	47840	Running	Pavel	1	218	417	00	258,
explorer.exe	9552	Running	Pavel	1	423	401	00	49,
devenv.exe	40372	Running	Pavel	1	180	364	00	256,
notepad++.exe	8376	Running	Pavel	1	242	291	00	
devenv.exe	22696	Running	Pavel	1	140	217	01	486,
csrss.exe	1152	Running	SYSTEM	1	91	181	00	1,
Snagit32.exe	15820	Running	Pavel	1	68	180	00	56,
ApplicationFrameHost.exe	6988	Running	Pavel	1	61	96	00	
firefox.exe	32688	Running	Pavel	1	90	85	00	247,
hh.exe	11656	Running	Pavel	1	66	71	00	
UlaView.exe	7890	Running	Pavel	1	90	62	00	12,

Figure 2-21: User and GDI object count

## User Objects

User objects are Windows (HWND), Menus (HMENU) and hooks (HHOOK). Handles to these objects have the following attributes:

- No reference counting. The first caller that destroys a user object - it's gone.

- Handle values are scoped under a Window Station. A Window Station contains a clipboard, desktops and atom table. This means handles to these objects can be passed freely among all applications sharing a desktop, for instance.

The terms Window Station and desktop will be discussed later in this book. Atom tables will not, as these are related to the UI subsystem in Windows, which is not the focus of this book.

## GDI Objects

The *Graphics Device Interface* (GDI) is the original graphics API in Windows and is still used today, even though there are richer and better APIs (Direct2D for example). Example GDI objects: device context (HDC), pen (HPEN), brush (HBRUSH), bitmap (HBITMAP) and others. Here are their attributes:

- No reference counting.
- Handles are valid only in the process in which they are created.
- Cannot be shared between processes.

## Summary

In this chapter, we looked at kernel objects and the ways they can be accessed and shared by using handles. We did not look at any specific object type too closely, as these will be discussed in other chapters in more detail. In the next chapter, we'll delve into the most well-known of all kernel objects - the process.



# Chapter 3: Processes

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## Processes in Process Explorer

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## Process Creation

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## The main Functions

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## Creating Processes

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## Using EnumProcesses

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## Using the WTS Functions

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## Using the Native API

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## Creating and Managing Threads

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## The Primes Counter Application

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## Terminating Threads

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## A Thread's Name

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# Chapter 6: Thread Scheduling

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## Affinity

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## Ideal Processor

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## Suspend and Resume

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## Suspending and Resuming a Process

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# Chapter 8: Thread Synchronization (Inter-Process)

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## Abandoned Mutex

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## Working with Events

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## Other Wait Functions

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## Asynchronous I/O

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## Using the Thread Pool for I/O Completion

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## The *Bulk Copy 2* Application

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## Transactional NTFS

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## File Search and Enumeration

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## NTFS Streams

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## Summary

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# Chapter 12: Memory Management Fundamentals

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## Basic Concepts

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## Process Address Space

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## Page States

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## Address Space Layout

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## 32-bit Systems

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## 64-bit Systems

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## Address Space Usage

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## Memory Counters

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## Process Memory Counters

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## Process Memory Map

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## Page Protection

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## Enumerating Address Space Regions

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## The *Simple VMMap* Application

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## More Address Space Information

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## Sharing Memory

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## Page Files

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## WOW64

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## WOW64 Redirections

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## Virtual Address Translation

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## Summary

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