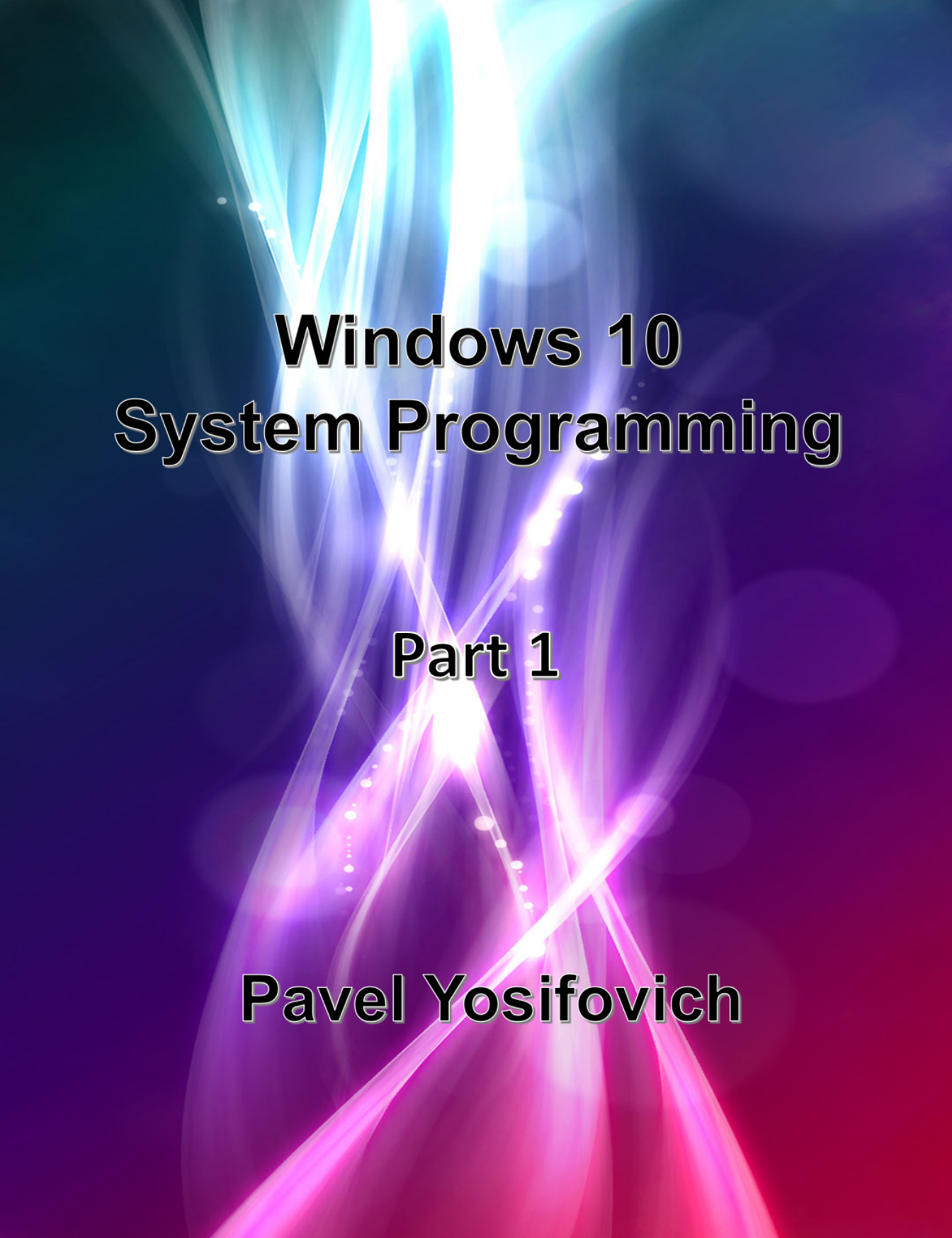
Windows 10
System Programming
Part 1
Pavel Yosifovich

Windows 10 System Programming, Part 1

Pavel Yosifovich

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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.

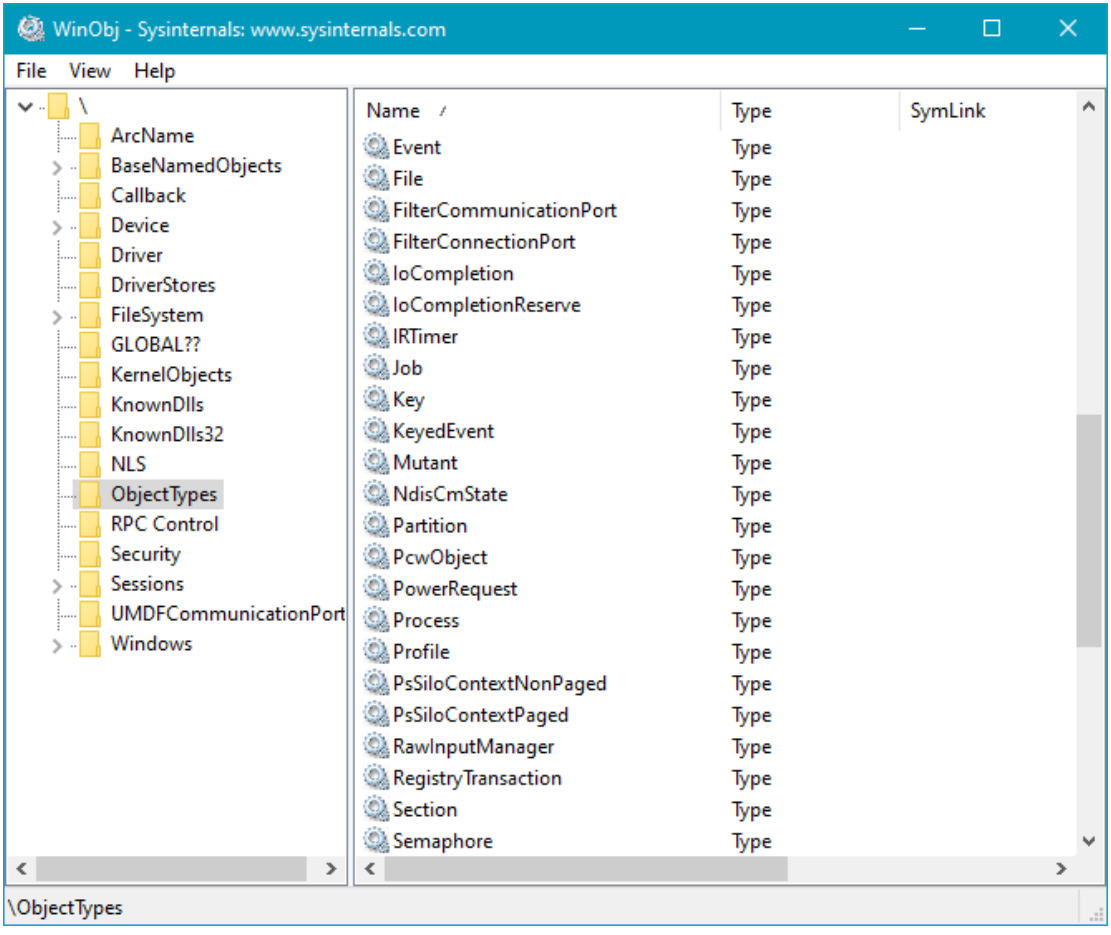

Figure 2-1: Object types

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

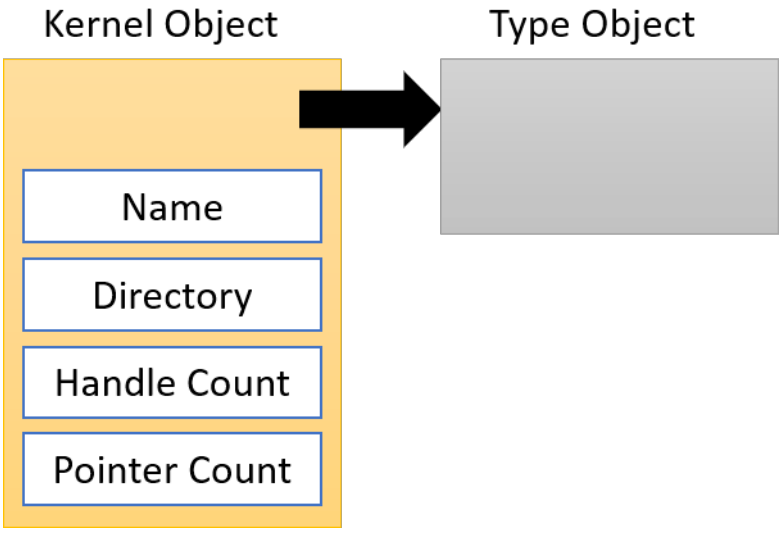

Figure 2-2: Kernel Object Attributes

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_EXIST` 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.

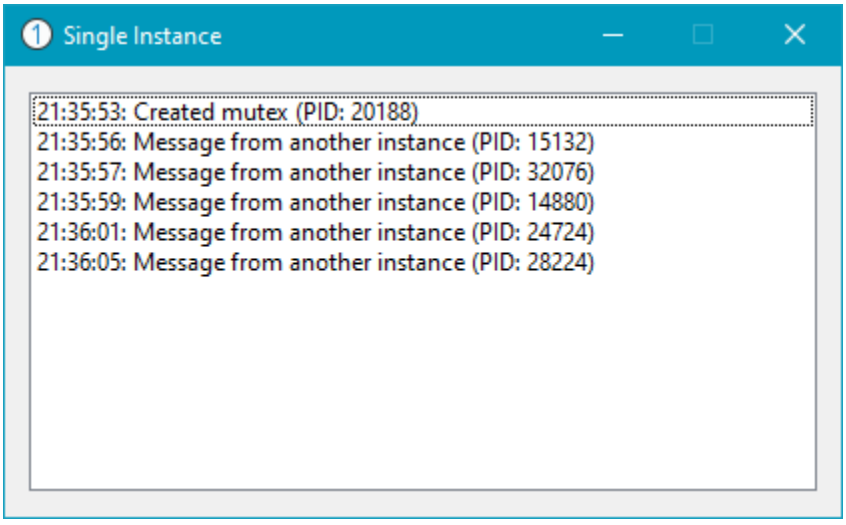

Figure 2-3: The Single Instance application

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.

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Creating Objects

Object Names

Sharing Kernel Objects

Sharing by Name

Sharing by Handle Duplication

Private Object Namespaces

Bonus: WIL Wrappers for Private Namespaces

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.

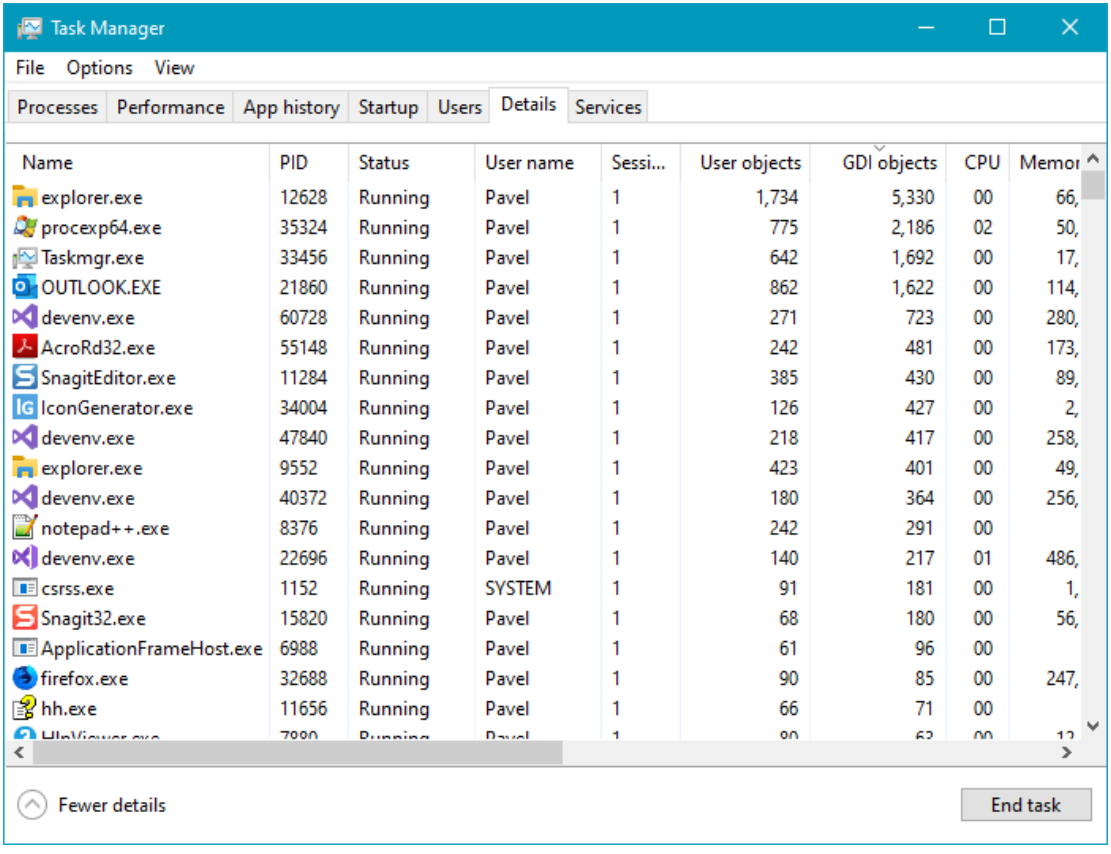

Figure 2-21: User and GDI object count

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.

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