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Windows 95/NT System Programming

Interprocess Communication

Main Topics

- Shared Memory and Synchronization Techniques
  - Mutex Objects
  - Signals and semaphores
  - Critical Sections
  - Deadlock
- Pipes
  - Anonymous Pipes and Named Pipes
  - Reading and Writing Pipes

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Wait Functions

- Win32 `wait` functions enable a thread to block its own execution
  - return when conditions specified in *wait* are satisfied
  - include timeout interval and handles to one or more synchronization objects

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Wait Functions

- *WaitForSingleObject*
- *WaitForSingleObjectEx* (alertable wait)
- *WaitForMultipleObjects*
- *WaitForMultipleObjectsEx*
- *MsgWaitForMultipleObjects* (can return when specified type of input is available)

Synchronization Object Overview

- A `synchronization object` is an object whose handle can be specified in wait function to coordinate the execution of multiple threads
- Objects used exclusively for synchronization
  - event
  - mutex
  - semaphore
- Other synchronization objects:
  - change notification, console input, process, thread

Mutex Objects

- Signaled when not owned by any thread, non-signaled when owned by thread
- Only one thread at a time can own a mutex
- Created using `CreateMutex`
  - other threads with handle to mutex can own mutex object
- Thread obtains ownership by specifying object handle in `OpenMutex` wait function
- Release using `ReleaseMutex` function

Mutex Objects (cont'd)

```
One thread calls *CreateMutex*
Pass mutex handles to other cooperating threads
loop forever
        *WaitForSingleObject*
        ... critical section ...
        *ReleaseMutex*
end loop
```

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Synchronization Example: Using Named Objects & Mutex

```
HANDLE hMutex;
DWORD dwErr;
hMutex = CreateMutex ( NULL,        /* no security descriptor */
        FALSE,                      /* mutex not owned */
        “DatabaseMutex”);           /* object name */
if (hMutex == NULL)
        printf (“CreateMutex error: %d\n”, GetLastError() );
else
        if (GetLastError() == ERROR_ALREADY_EXISTS)
                printf (“CreateMutex opened existing mutex\n”);
        else
                printf(“CreateMutex created new mutex\n”);
```

One process creates mutex object

Another process opens handle to existing mutex

```
HANDLE hMutex;
hMutex = OpenMutex (MUTEX_ALL_ACCESS,
        FALSE,    /* handle not inheritable */
        “DatabaseMutex”);
if (hMutex == NULL)
        printf (“OpenMutex error: %d\n”, GetLastError() );
```

Synchronization Example: Using Named Objects & Mutex

```
dwWaitResult = WaitForSingleObject (hMutex, 5000L);  /* 5-second timeout */
switch (dwWaitResult) {
        case WAIT_OBJECT_0:                          /* obtained mutex ownership */
                try {
                        ... write to database ...
                }
                finally {
                        if (!ReleaseMutex (hMutex)) {      /* release mutex ownership */
                                ... error handling ...
                        }
                        break;
        case WAIT_TIMEOUT:
                return FALSE;
        case WAIT_ABANDONED:           /* got ownership of abandoned mutex object */
                return FALSE;
}
```

Critical Section Objects

- Similar to mutex objects, but can be used only by threads of the same process
  - faster than mutex objects
- Can be owned by only one thread at a time
- Must declare `CRITICAL_SECTION` variable and initialize using `InitializeCriticalSection`
- Thread use `EnterCriticalSection` to request ownership and `LeaveCriticalSection` to release ownership
- Use `DeleteCriticalSection` to release system resources

Semaphore Objects

- Limits number of concurrent accesses to a shared resource
- Create using `CreateSemaphore`
- Other threads can open handle to existing semaphore object using `OpenSemaphore`
  - semaphore count decreases by one
- Use `ReleaseSemaphore` to increase semaphore count

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Synchronization Example: Using Semaphore Objects

```
HANDLE hSemaphore;
LONG cMax = 10;
hSemaphore = CreateSemaphore (NULL,      /* no security attributes */
        cMax,            /* initial count */
        cMax,            /* maximum count */
        NULL);           /* unnamed semaphore */
if (hSemaphore == NULL)
        ... check for error ...
```

Create semaphore

Before accessing shared resource

```
DWORD dwWaitResult;
dwWaitResult = WaitForSingleObject (hSemaphore, 0L);
switch (dwWaitResult) {
        case WAIT_OBJECT_0:
                ... semaphore signalled ...
                break;
        case WAIT_TIMEOUT:
                ... semaphore nonsignalled ...
                break;
}
```

Synchronization Example: Using Semaphore Objects (cont'd)

```
if (!ReleaseSemaphore (
      hSemaphore,      /* semaphore handle */
      1,               /* increase count by one */
      NULL) ) {        /* not interested in previous count */
      ... handle error ...
}
```

After accessing shared resource, release semaphore

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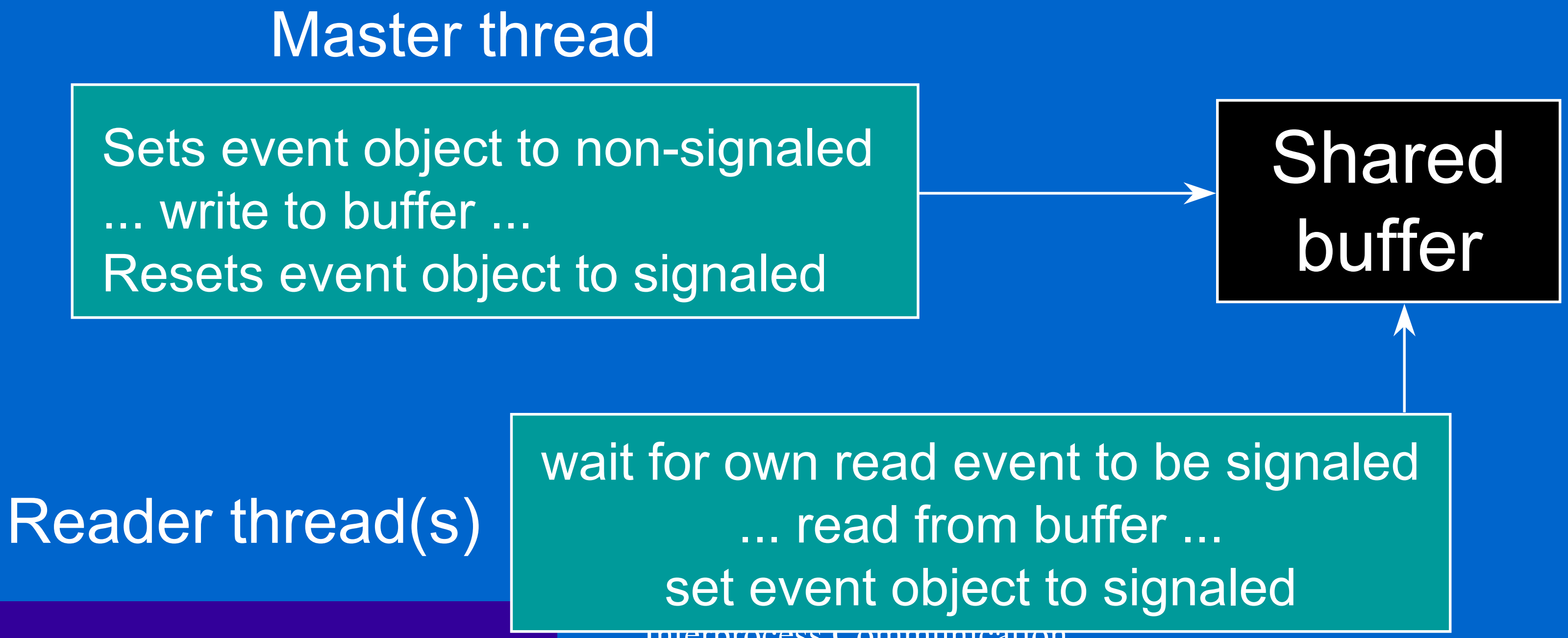
Event Objects

- Useful for signaling thread when a particular event has occurred
- State can be either signaled or non-signaled
- Create using `CreateEvent`
- Other threads can open a handle to existing event object using `OpenEvent`
- Use `PulseEvent` function to set event object's state to signaled and then reset it to non-signaled after releasing appropriate number of wait threads

Example: Using Event Objects

- Event objects used to prevent several threads from reading from shared memory buffer while master thread is writing to it


Master thread
Sets event object to non-signaled
... write to buffer ...
Resets event object to signaled
Shared buffer
Reader thread(s)
wait for own read event to be signaled
... read from buffer ...
set event object to signaled

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Using Event Objects: Master Thread

```
#define NUMTHREADS 4
HANDLE hGlobalWriteEvent;
void CreateEventsAndThreads (void) {
            HANDLE hReadEvents [NumThreads], hThread;
            DWORD i, IDThread;
            if ((hGlobalWriteEvent = CreateEvent (NULL, TRUE, TRUE, “WriteEvent”)) == NULL)
                        /* error exit */
            /* Create multiple threads and auto-reset event object for each thread */
            for (i=1; i<=NUMTHREADS; i++) {
                        hReadEvents[i] = CreateEvent (NULL, FALSE, TRUE, NULL) ;
                  if (hReadEvents[i] == NULL) {
                 /* error exit */
                  }
                  hThread = CreateThread(NULL, 0,
                     (LPTHREAD_START_ROUTINE) ThreadFunction,
                     &hReadEvents[i], /* pass event handle  */
                     0, &IDThread);
                  if (hThread == NULL) {
                 /* error exit */
                  }
            }
}
```

Master Thread (cont'd)

```
VOID WriteToBuffer(VOID) {
DWORD dwWaitResult, i;
if (! ResetEvent(hGlobalWriteEvent) ) {
     /* error exit */
}
dwWaitResult = WaitForMultipleObjects(
     NUMTHREADS, hReadEvents, TRUE, INFINITE);
switch (dwWaitResult) {
    case WAIT_OBJECT_0:
        .
        . /* Write to shared buffer */
        .
        break;
    default:
        printf("Wait error: %d\n", GetLastError());
        ExitProcess(0);
}
```

Master Thread (cont'd)

```
if (! SetEvent(hGlobalWriteEvent) ) {
        /* error exit */
}
for(i = 1; i <= NUMTHREADS; i++)
    if (! SetEvent(hReadEvents[i]) ) {
            /* error exit */
    }
}
```

Event Example: Reader Threads

```
VOID ThreadFunction(LPVOID lpParam) {
DWORD dwWaitResult, i;
HANDLE hEvents[2];

hEvents[0] = (HANDLE) *lpParam;  /* thread's read event */
hEvents[1] = hGlobalWriteEvent;
dwWaitResult = WaitForMultipleObjects(
        2,          /* number of handles in array   */
        hEvents,    /* array of event handles       */
        TRUE,       /* wait till all are signaled   */
        INFINITE);  /* indefinite wait              */
switch (dwWaitResult) {
case WAIT_OBJECT_0:
        /* … Read from the shared buffer … */
        break;
    /* An error occurred. */
    default:
         printf("Wait error: %d\n", GetLastError());
         ExitThread(0);
}
if (! SetEvent(hEvents[0]) ) {
         /* error exit */
}
}
```

Interprocess Synchronization

- Multiple processes can have handles of same mutex, semaphore, or event object for IPC
- Processes can share object handles using named objects
- Child process created by `CreateProcess` can inherit handle of mutex, event, or semaphore object if `SECURITY_ATTRIBUTES` structure enables inheritance

Duplicating Handles

- `DuplicateHandle` function creates a duplicate handle that can be used by another specified process
  - creating process must pass handle to other process using interprocess communication

Overlapped I/O

- Win32 API can do synchronous and asynchronous I/O
- Synchronous I/O:
  - returns only when I/O completes
- Asynchronous (overlapped) I/O:
  - returns as soon as the call is issued
  - process is signaled when I/O completes
  - good for time-consuming I/O

Pipes

- A pipe is a communication conduit with two ends
  - a process with a handle to one end can communicate with a process having a handle to the other end
- Can be:
  - one-way: one end read-only; other end write-only
  - two-way: both ends of the pipe can read or write
- Can be anonymous (unnamed) or named

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Anonymous Pipes

- Unnamed, one-way pipe that transfers data between related processes
  - parent and child process
  - two child processes of the same parent
- Used for local communication only
- Use `CreatePipe` to create an anonymous pipe with two handles
  - read handle
  - write handle
- After creating pipe, pass one end to another process; usually through inheritance

Anonymous Pipes (cont'd)

- Parent must communicate handle value to child:
  - Parent specifies pipe handle to `SetStdHandle` before creating child
  - Child uses `GetStdHandle` to retrieve handle value when it starts up
- Standard handles are
  - standard input
  - standard output
  - standard error

Reading From Anonymous Pipes

- To read from a pipe, use read handle in call to `ReadFile` function
- `ReadFile` returns when
  - an error occurs
  - when the specified number of bytes has been read
  - when the write end of the pipe is closed

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Writing To Anonymous Pipes

- To write to a pipe, use write handle in call to `WriteFile`
- `WriteFile` returns when
  - an error occurs
  - when the specified number of bytes has been written
  - when the read end of the pipe is closed
- If pipe's buffer is full and there are still bytes to write, `WriteFile` does not return until some other process or thread reads from pipe, making more buffer space available

Asynchronous I/O On Pipes

- Asynchronous (overlapped) I/O not supported for anonymous pipes
  - cannot use `ReadFileEx` and `WriteFileEx`
  - overlapped parameter to `ReadFile` and `WriteFile` ignored

Redirecting Standard Output of Child to Pipe

- Call `GetStdHandle` to get current standard output handle
- Call `CreatePipe` to create anonymous pipe
- Call `SetStdHandle` to set standard output to write handle of pipe
- Call `CreateProcess` to create child process which inherits handles from parent
  - child process use `GetStdHandle` to retrieve handles
- Call `CloseHandle` to close parent's handle to write end of pipe
- Call `ReadFile` function to read from pipe
  - parent reads data written to standard output by child process

Wait Functions

- `WaitForSingleObject`
  - returns when state of specified object is signaled or when timeout elapses
- `WaitForMultipleObjects`
  - returns when state of one of specified objects is signaled or when timeout elapses
- `WaitForSingleObjectEx`, `WaitForMultipleObjectsEx`
  - similar to first two, but can perform alertable wait when `fAlertable` parameter is `TRUE`
    - functions return when `ReadFileEx` or `WriteFileEx` completion routine is queued for execution