Chapter 4: Threads

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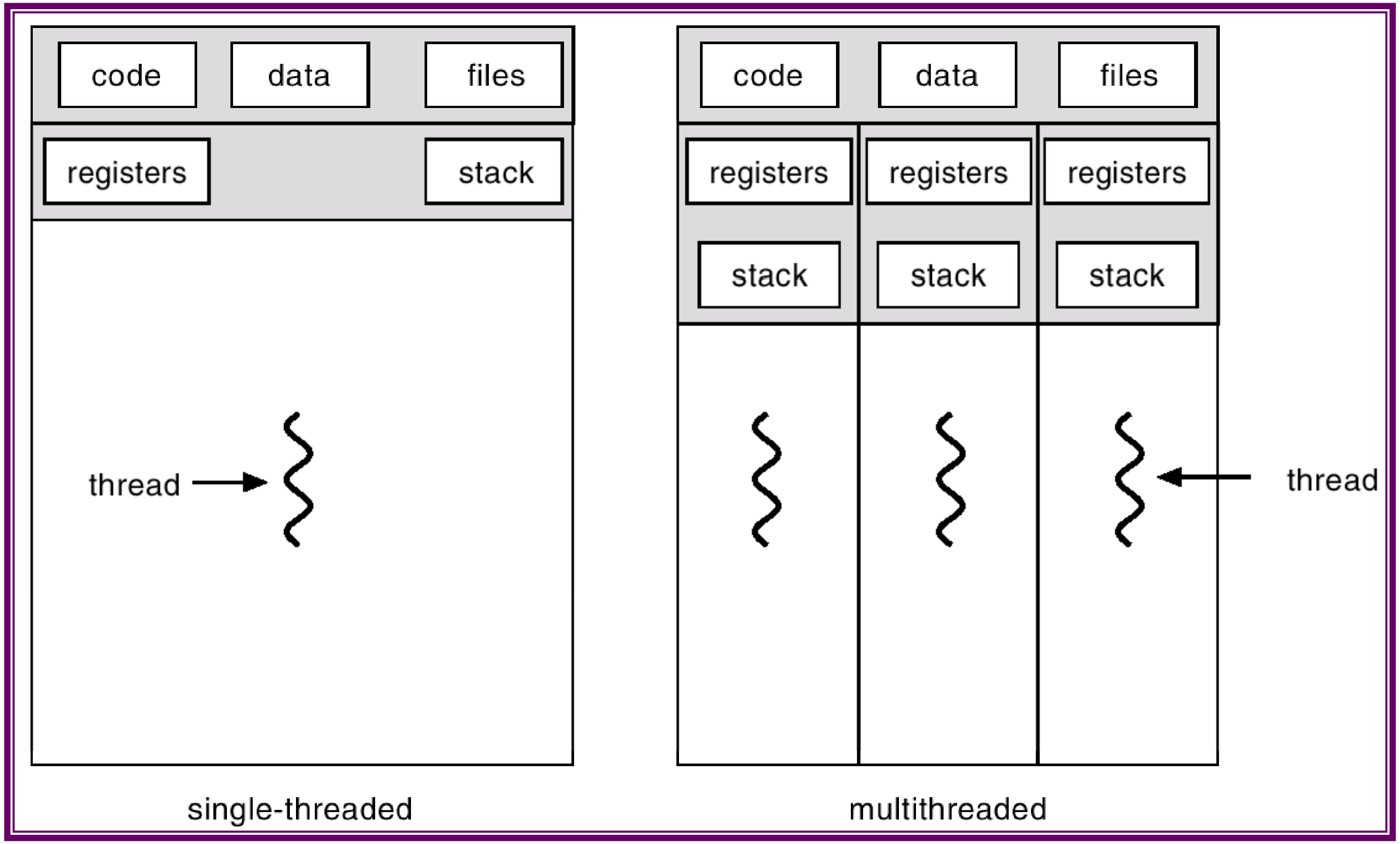
Chapter 4: Threads

- Overview
- Multithreading Models
- Thread Libraries
- Threading Issues
- Operating System Examples

What is a thread?

- A *thread*, also known as *lightweight process* (LWP), is a basic unit of CPU execution.
- A thread has a thread ID, a program counter, a register set, and a stack. Thus, it is similar to a process has.
- However, a thread *shares* with other threads in the *same* process its code section, data section, and other OS resources (*e.g.*, files and signals).
- A process, or heavyweight process, has a *single* thread of control.

Single and Multithreaded Processes

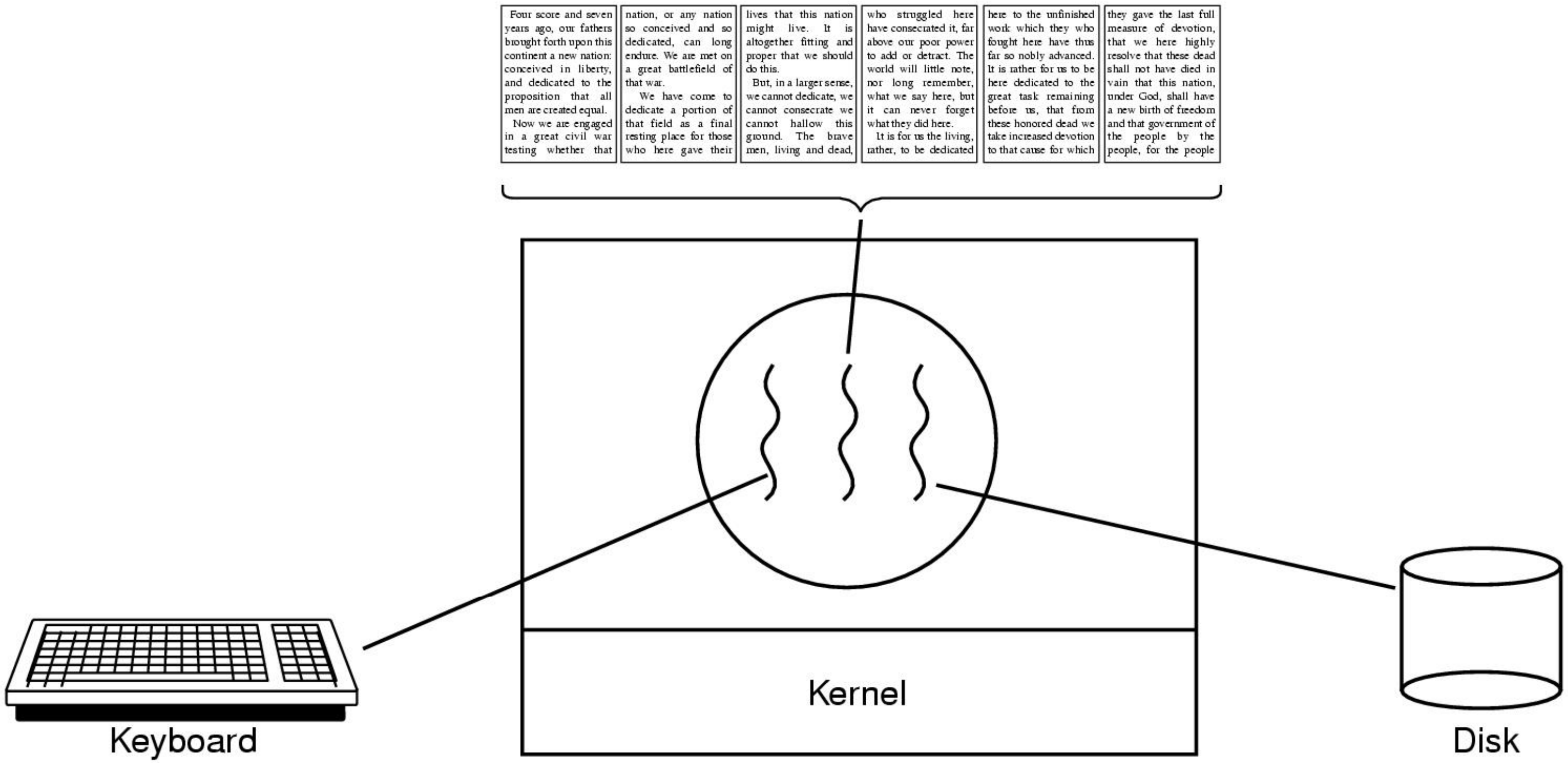


- Threads in a same process are tightly coupled or loosely coupled?

Per process items	**Per thread items**
Address space	Program counter
Global variables	Registers
Open files	Stack
Child processes	State
Pending alarms	
Signals and signal handlers	
Accounting information	

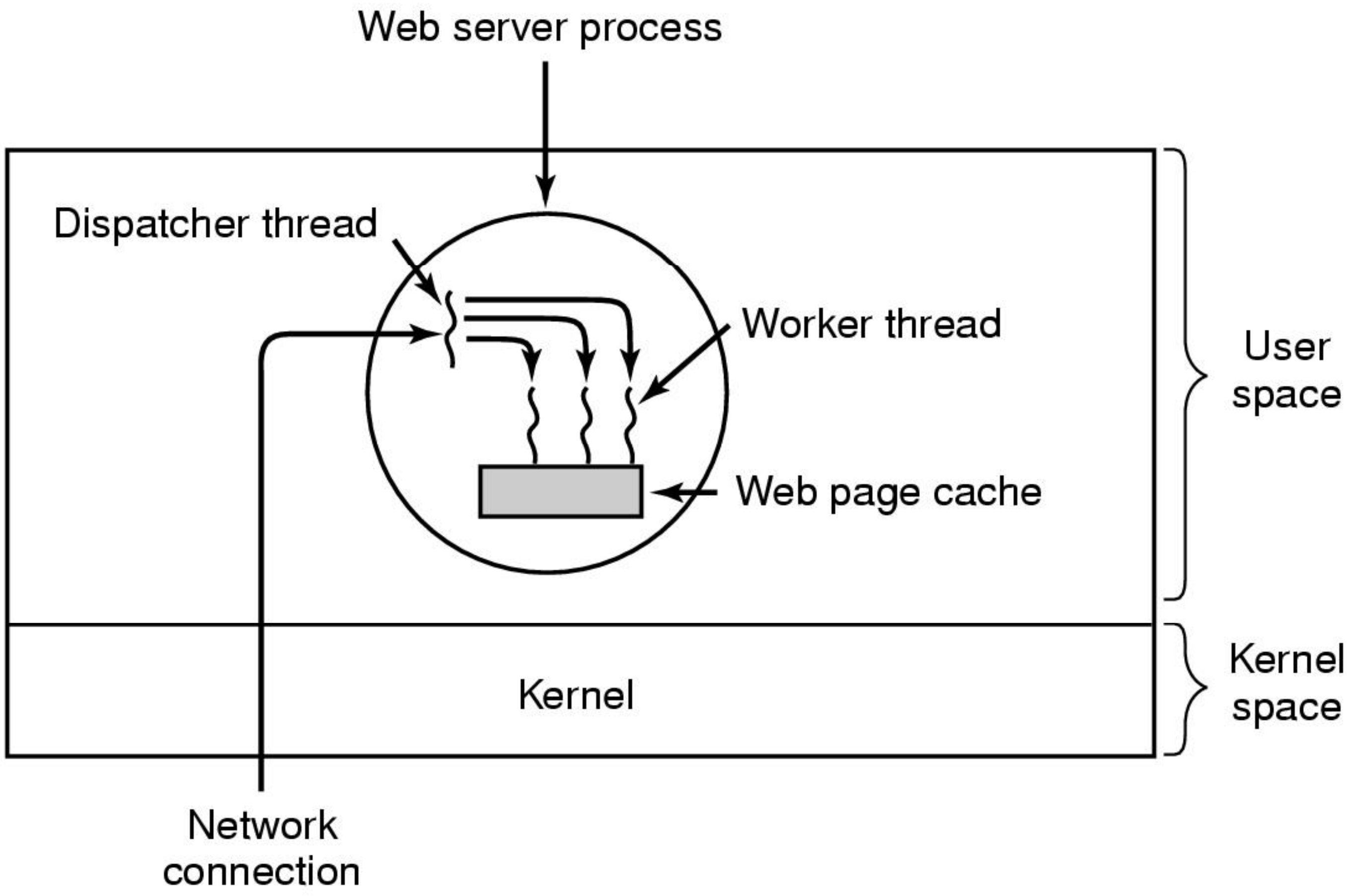
- Items shared by all threads in a process
- Items private to each thread

Thread Usage (1)



A word processor with three threads

Thread Usage (2)



A multithreaded Web server

Thread Usage (3)

```
while (TRUE) {
  get_next_request(&buf);
  handoff_work(&buf);
}
```

(a)

```
while (TRUE) {
  wait_for_work(&buf)
  look_for_page_in_cache(&buf, &page);
  if (page_not_in_cache(&page)
       read_page_from_disk(&buf, &page);
  return_page(&page);
}
```

(b)

- Rough outline of code for previous slide
  - (a) Dispatcher thread
  - (b) Worker thread
  - Note: A Event-Driven Framework

Benefits

- Responsiveness
- Resource Sharing
- Economy
- Utilization of MP Architectures

Benefits (cont.)

- Process fork() vs. pthread_create()

Platform	fork()			pthread_create()		
	real	user	sys	real	user	sys
AMD 2.4 GHz Opteron (8cpus/node)	41.07	60.08	9.01	0.66	0.19	0.43
IBM 1.9 GHz POWER5 p5-575 (8cpus/node)	64.24	30.78	27.68	1.75	0.69	1.10
IBM 1.5 GHz POWER4 (8cpus/node)	104.05	48.64	47.21	2.01	1.00	1.52
INTEL 2.4 GHz Xeon (2 cpus/node)	54.95	1.54	20.78	1.64	0.67	0.90
INTEL 1.4 GHz Itanium2 (4 cpus/node)	54.54	1.07	22.22	2.03	1.26	0.67

http://www.cnblogs.com/mywolrd/archive/2009/02/04/1930708.html

Different Ways to Implement Concurrency

- Process (notes: Process Control Block in OS Kernel)
- Light-weight Process and Kernel Threads
- User Threads
- Fibers

Lower Cost in Context Switching

User Threads

- Thread management done by user-level threads library
  - Context switching of threads in the same process is done in user mode

- Examples

  - POSIX *Pthreads*

  - Mach *C-threads*

  - Solaris UI-*threads*

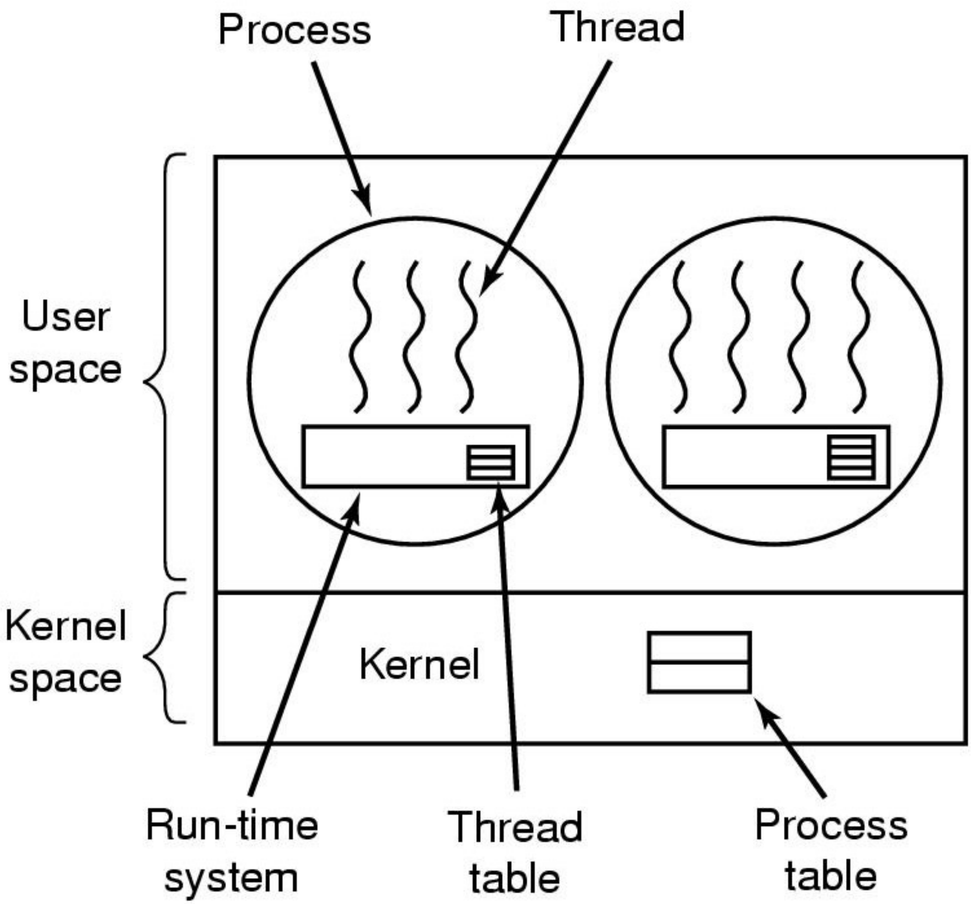
http://www.yolinux.com/TUTORIALS/LinuxTutorialPosixThreads.html#CREATIONTERMINATION

User Threads (Cont.)

- User threads are supported at the user level. The kernel is not aware of user threads.
- A library provides all support for thread creation, termination, joining, and scheduling.
- There is no kernel intervention, and, hence, user threads are usually more efficient.

- Unfortunately, since the kernel only recognizes the containing process (of the threads), *if one thread is blocked, each other threads of the same process are also blocked* since the containing process is blocked.
- Can be mitigated by asynchronous I/O.

Implementing Threads in User Space



A user-level threads package

Kernel Threads

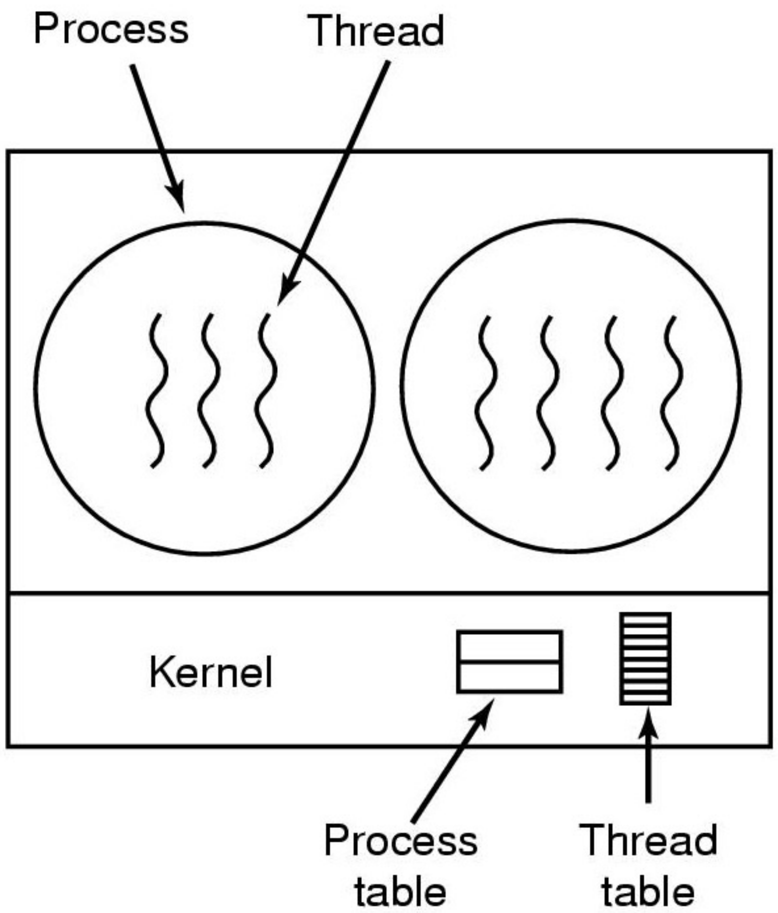
- Supported by the Kernel

- Examples
  - Windows 95/98/NT/2000
  - Solaris
  - Tru64 UNIX
  - BeOS
  - Linux

Kernel Threads (Cont.)

- Kernel threads are directly supported by the kernel. The kernel does thread creation, termination, joining, and scheduling in kernel space.
- Kernel threads are usually slower than the user threads.
- However, *blocking one thread will not cause other threads of the same process to block*. The kernel simply runs other threads.
- In a multiprocessor environment, the kernel can schedule threads on different processors

Implementing Threads in the Kernel



A threads package managed by the kernel (Note: POSIX *Pthreads* library support also the creation of kernel threads)

http://www.yolinux.com/TUTORIALS/LinuxTutorialPosixThreads.html

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- Java Threads
- Windows Threads API
- Pthreads

Multithreading Models

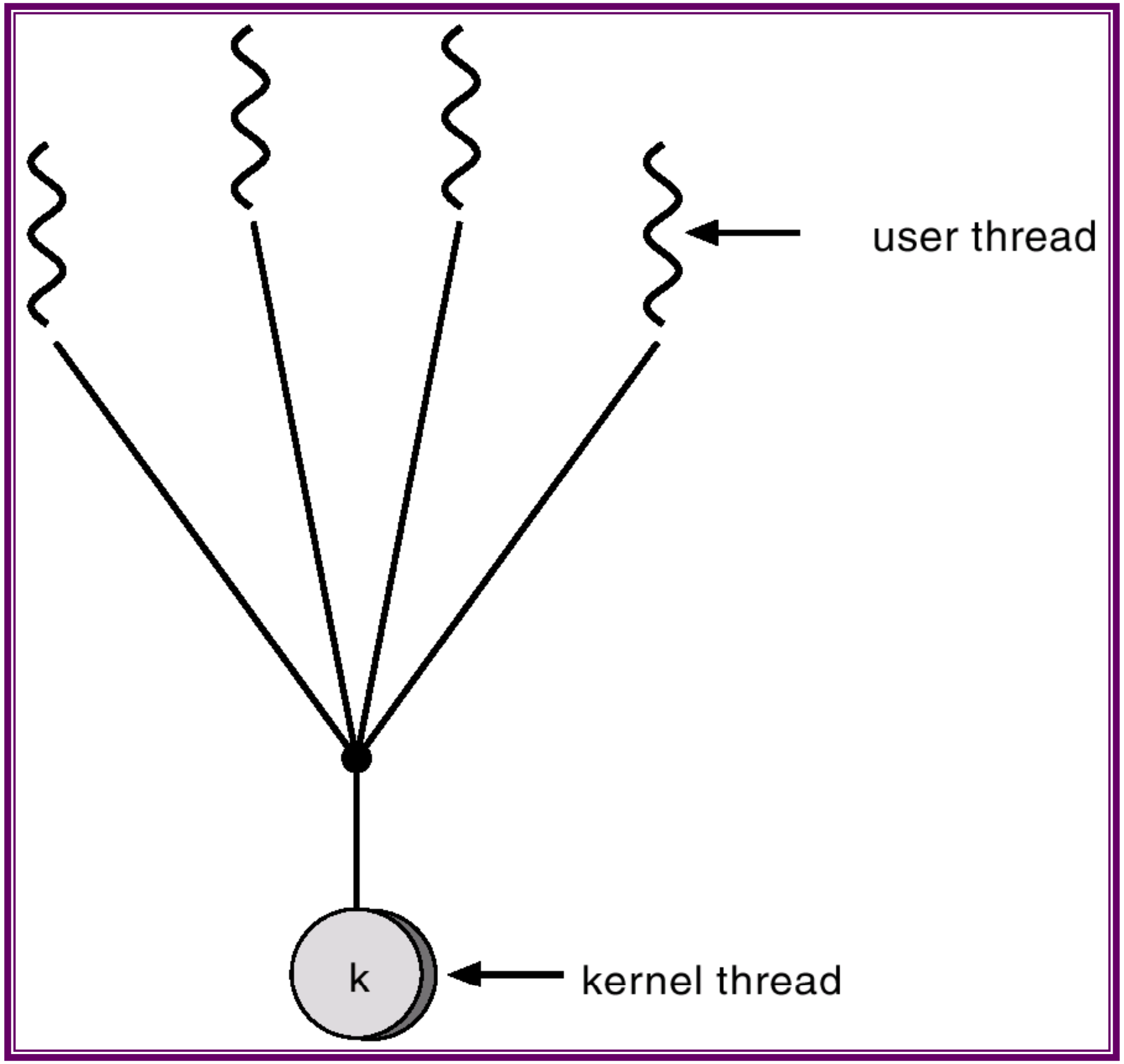
- Many-to-One
- One-to-One
- Many-to-Many

Many-to-One

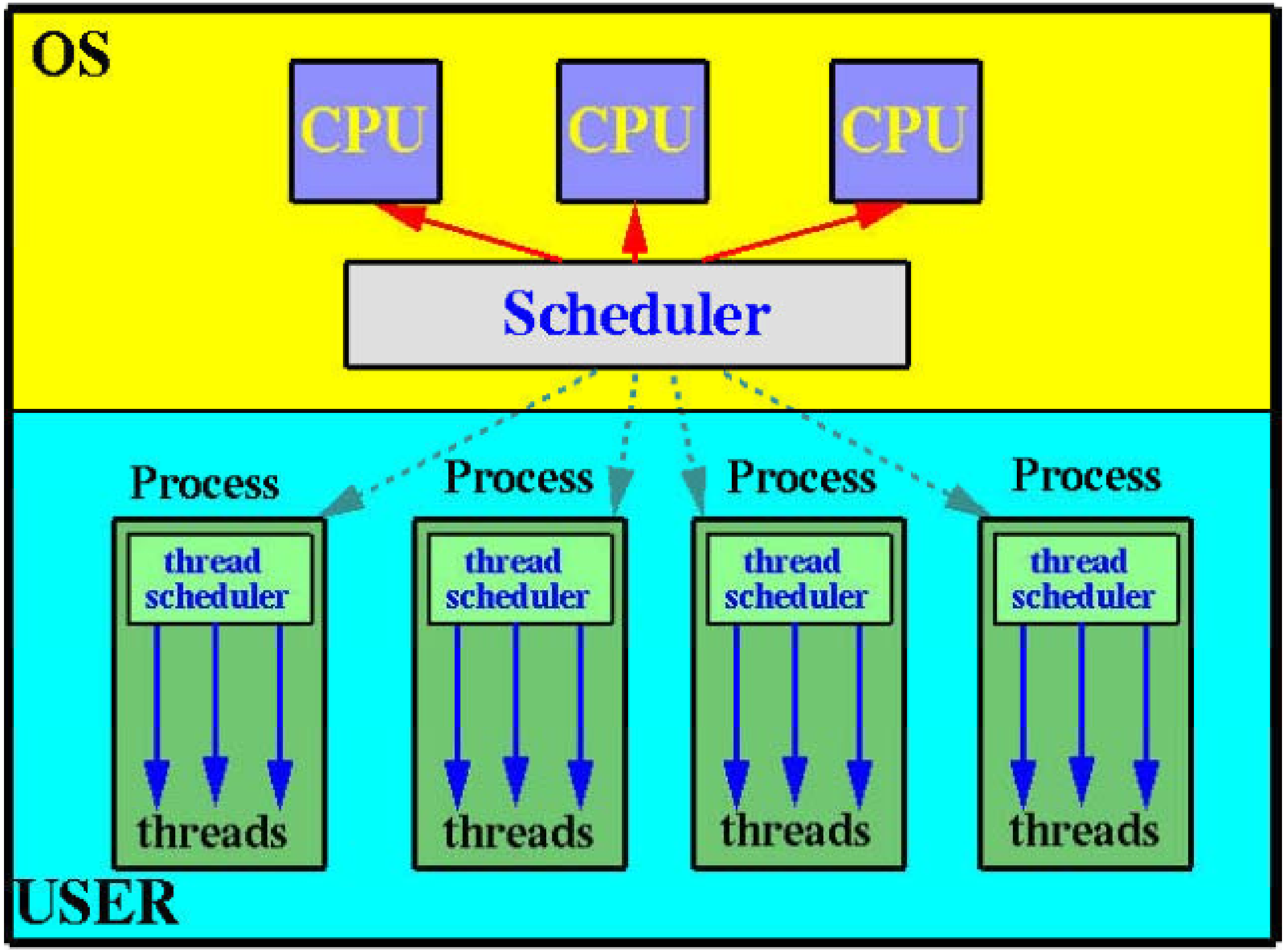
- Many user-level threads mapped to single kernel thread.

- Used on systems that do not support kernel threads.

Many-to-One Model



Many-to-One Model (Cont.)

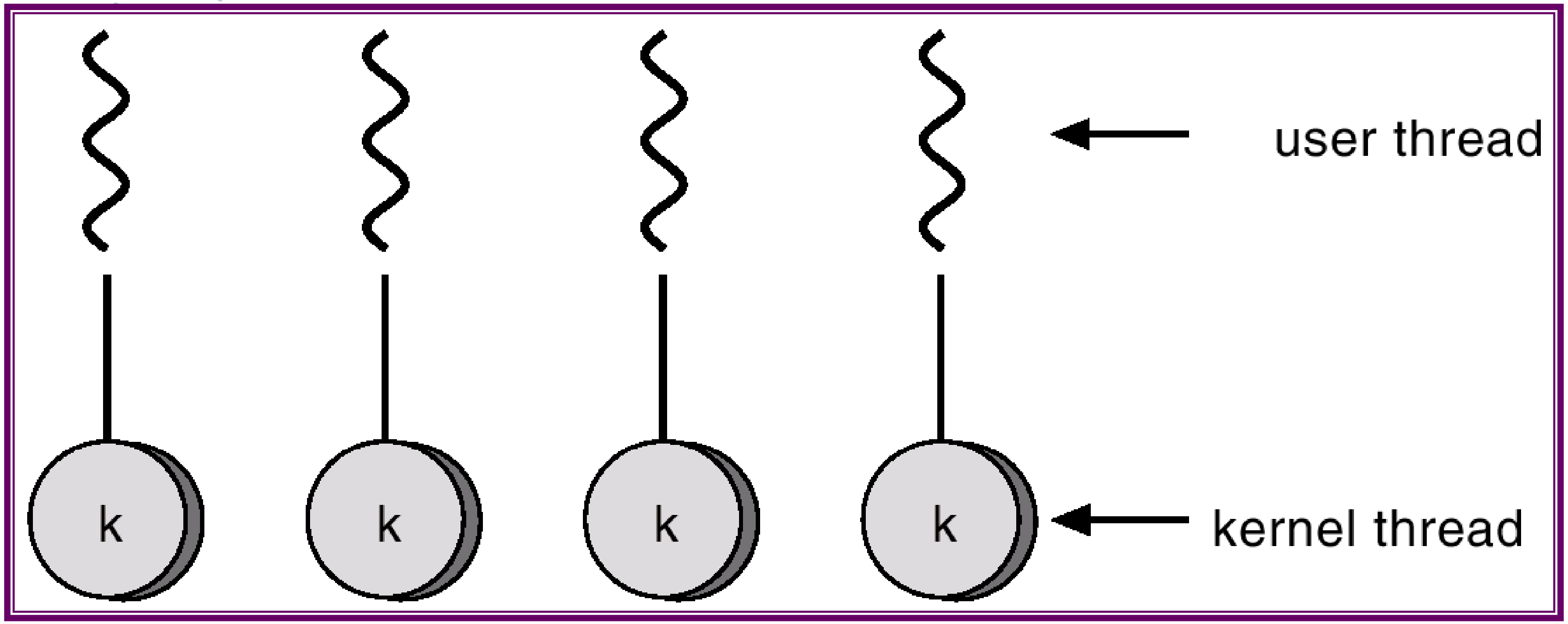


One-to-One

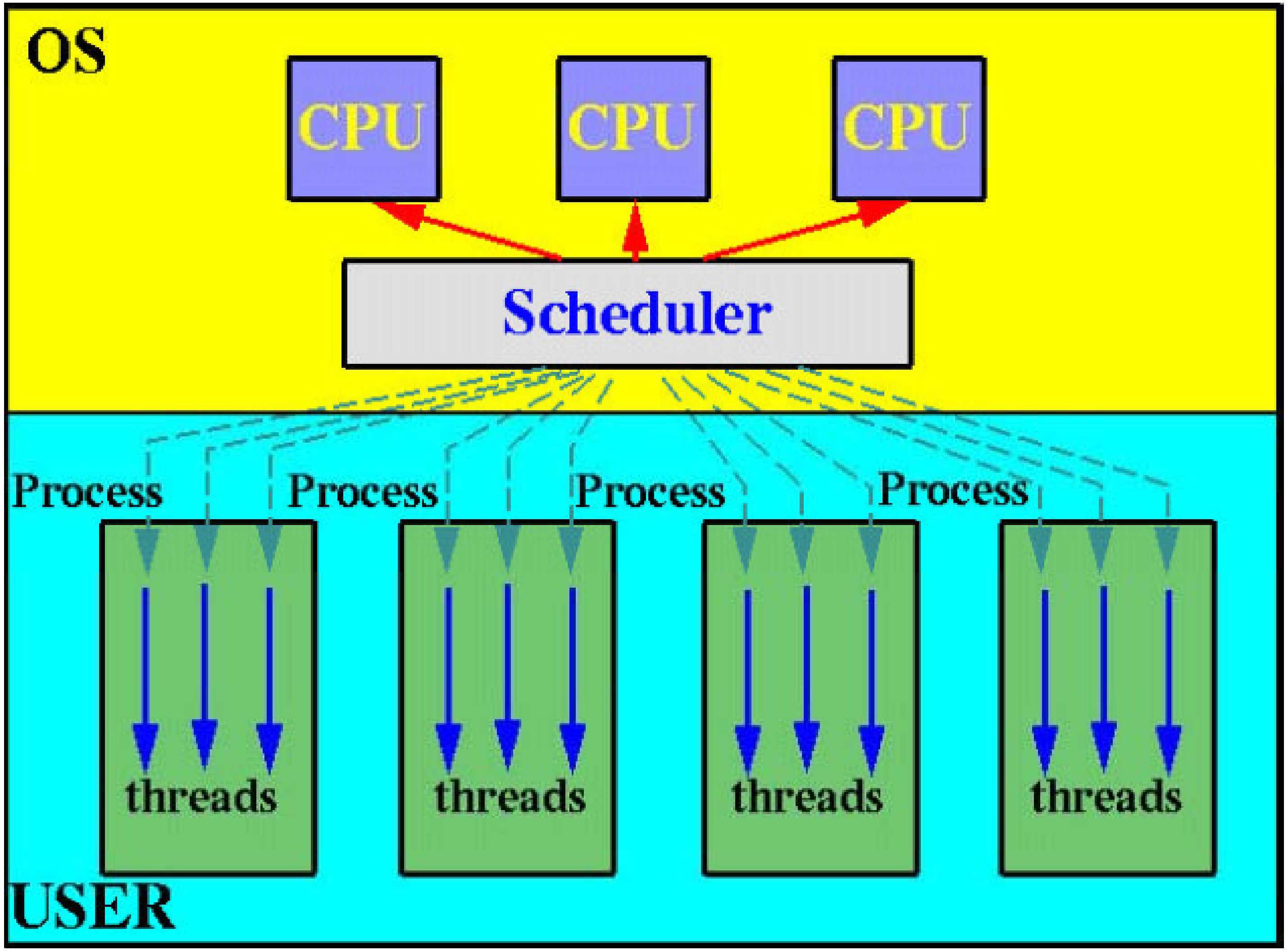
- Each user-level thread maps to kernel thread.

- Examples
  - Windows 95/98/NT/2000
  - OS/2

One-to-one Model



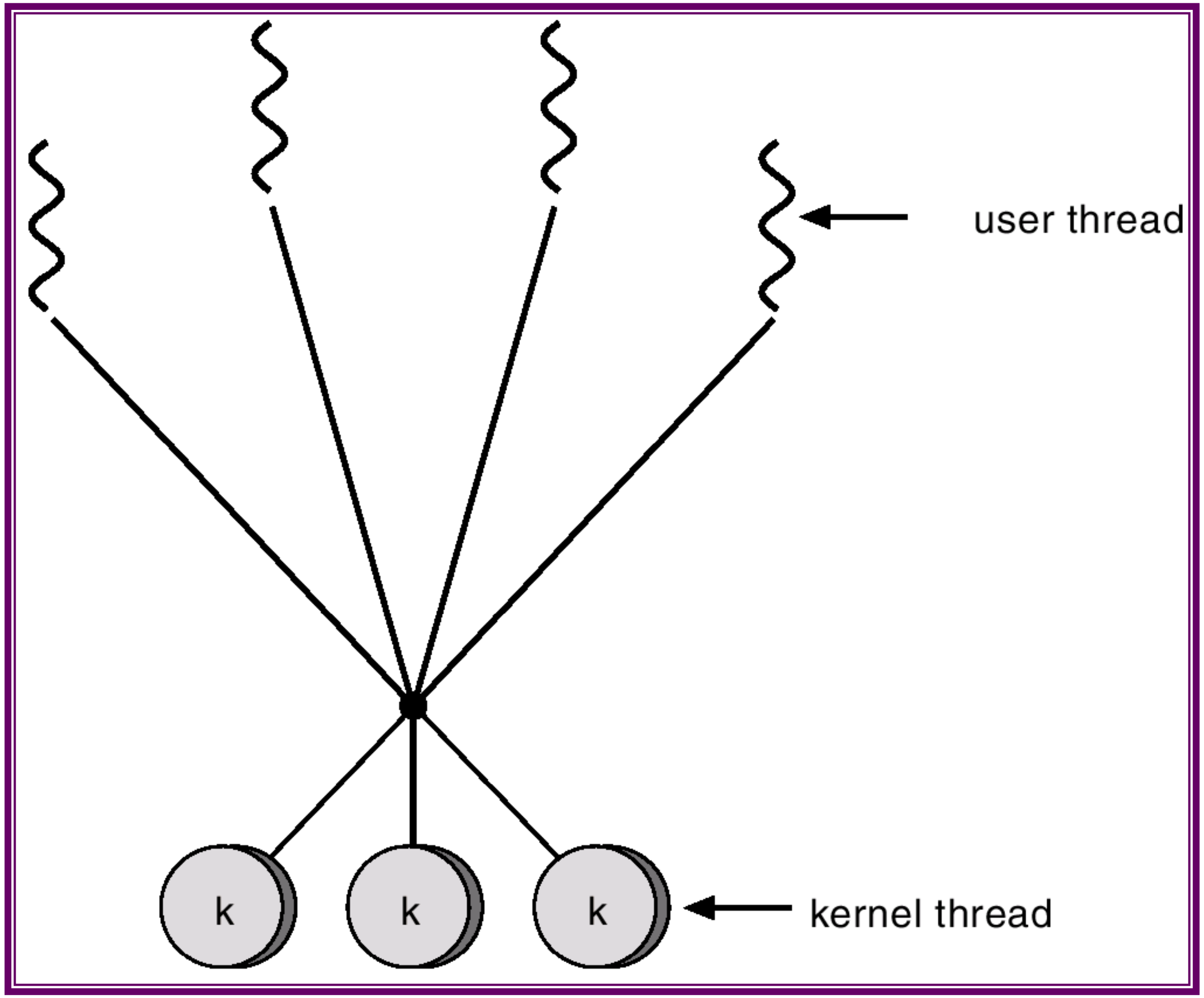
One-to-one Model (Cont.)



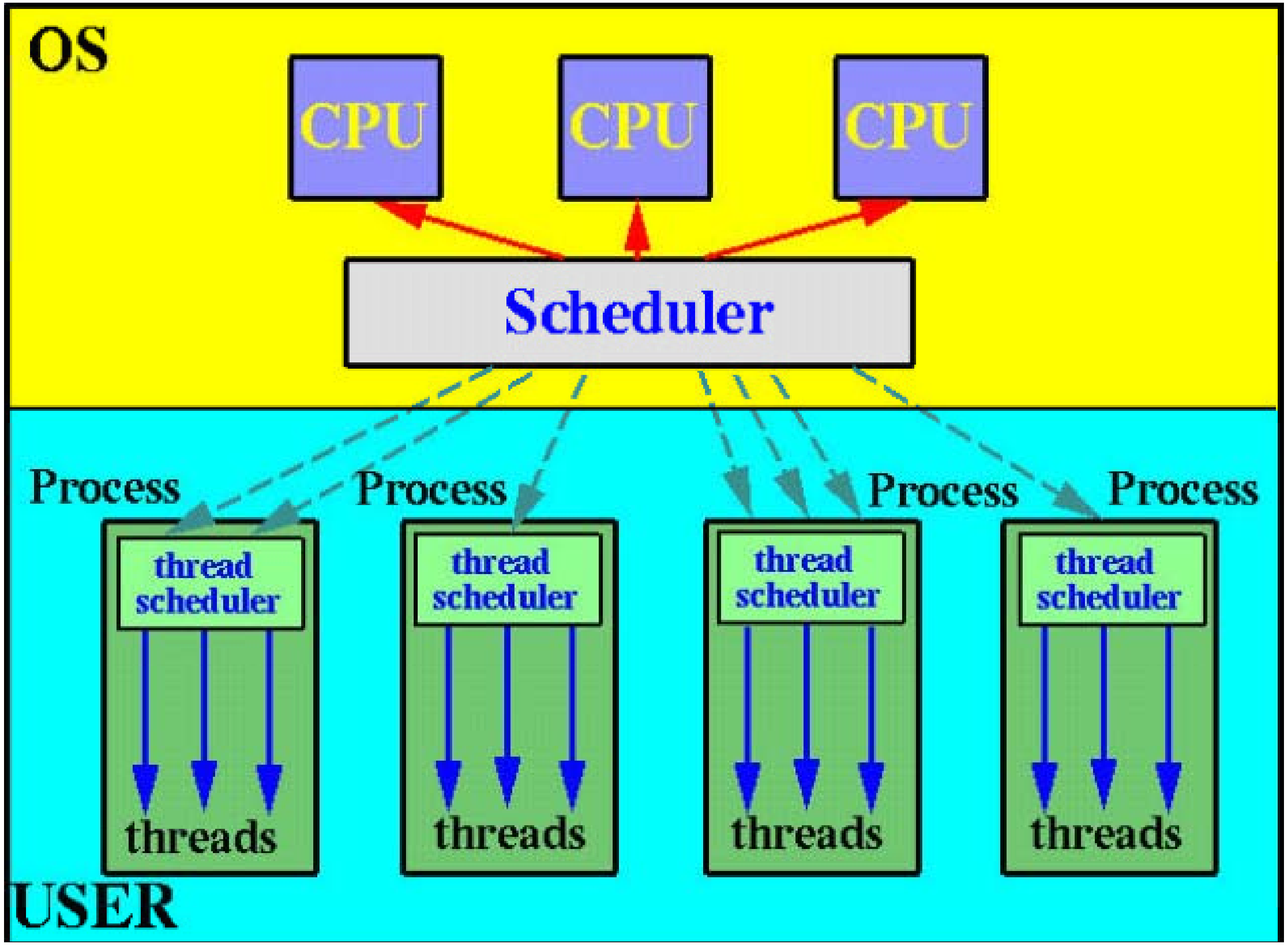
Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads.
- Allows the operating system to create a sufficient number of kernel threads.
- Solaris 2
- Windows NT/2000 with the *ThreadFiber* package

Many-to-Many Model



Many-to-Many Model (Cont.)



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Threading Issues

- Semantics of fork() and exec() system calls.
- Thread cancellation.
- Signal handling
- Thread pools
- Thread specific data
- Scheduler Activations

Semantics of fork() and exec()

- Does **fork()** duplicate only the calling thread or all threads?
- In a Pthreads-compliant implementation, the fork call always creates a new child process with a single thread, regardless of how many threads its parent may have had at the time of the call.
- Furthermore, the child's thread is a replica of the thread in the parent that called fork

Thread Cancellation

- Terminating a thread before it has finished
- Two general approaches:
  - **Asynchronous cancellation** terminates the target thread immediately
  - **Deferred cancellation** allows the target thread to periodically check if it should be cancelled
    - ✓ The point a thread can terminate itself is a ***cancellation point*.**

Thread Cancellation (Cont.)

- With asynchronous cancellation, if the target thread owns some system-wide resources, the system may not be able to reclaim all recourses
- With deferred cancellation, the target thread determines the time to terminate itself. Reclaiming resources is not a problem.
- Most systems implement asynchronous cancellation for processes (e.g., use the kill system call) and threads.
- Pthread supports deferred cancellation.

Signal Handling

- Signals are used in UNIX systems to notify a process that a particular event has occurred
- All signals follow the same pattern:
  1. Signal is generated by particular event
  2. Signal is delivered to a process
  3. Signal is handled
- A **signal handler** is used to process signals

Signal Handling (Cont.)

- Options:
  - Deliver the signal to the thread to which the signal applies
  - Deliver the signal to every thread in the process
  - Deliver the signal to certain threads in the process
  - Assign a specific thread to receive all signals for the process

Thread Pools

- Create a number of threads in a pool where they await work
- Advantages:
  - Usually slightly faster to service a request with an existing thread than create a new thread
  - Allows the number of threads in the application(s) to be bound to the size of the pool

Thread Specific Data

- Allows each thread to have its own copy of data
- Useful when you do not have control over the thread creation process (i.e., when using a thread pool)
- Pthreads library supports thread specific data

https://en.wikipedia.org/wiki/Thread-local_storage#Pthreads_implementation

Scheduler Activations

- Both M:M and Two-level models require communication to maintain the appropriate number of kernel threads allocated to the application
- Scheduler activations provide **upcalls** - a communication mechanism from the kernel to the thread library
- This communication allows an application to maintain the correct number kernel threads

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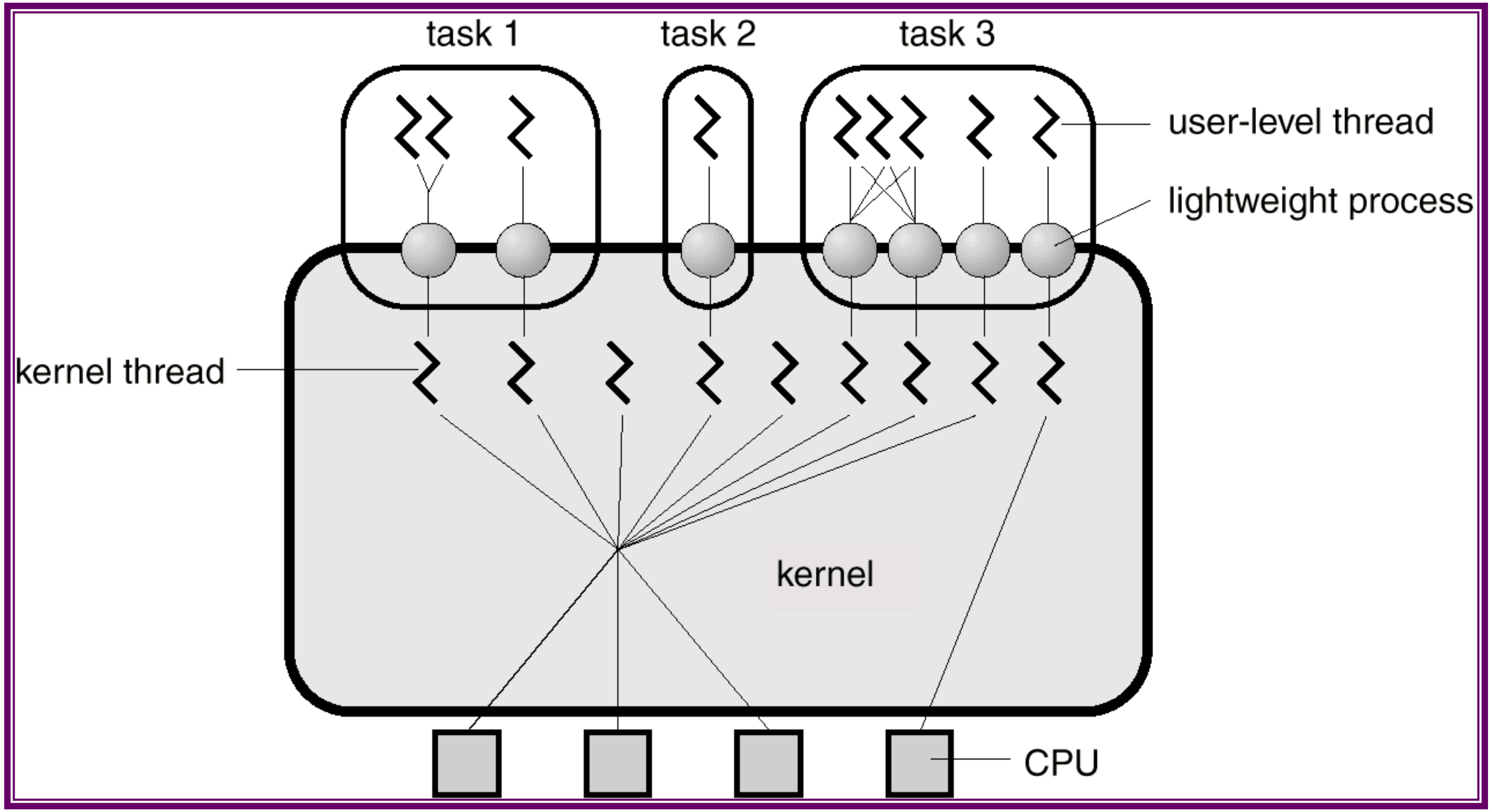
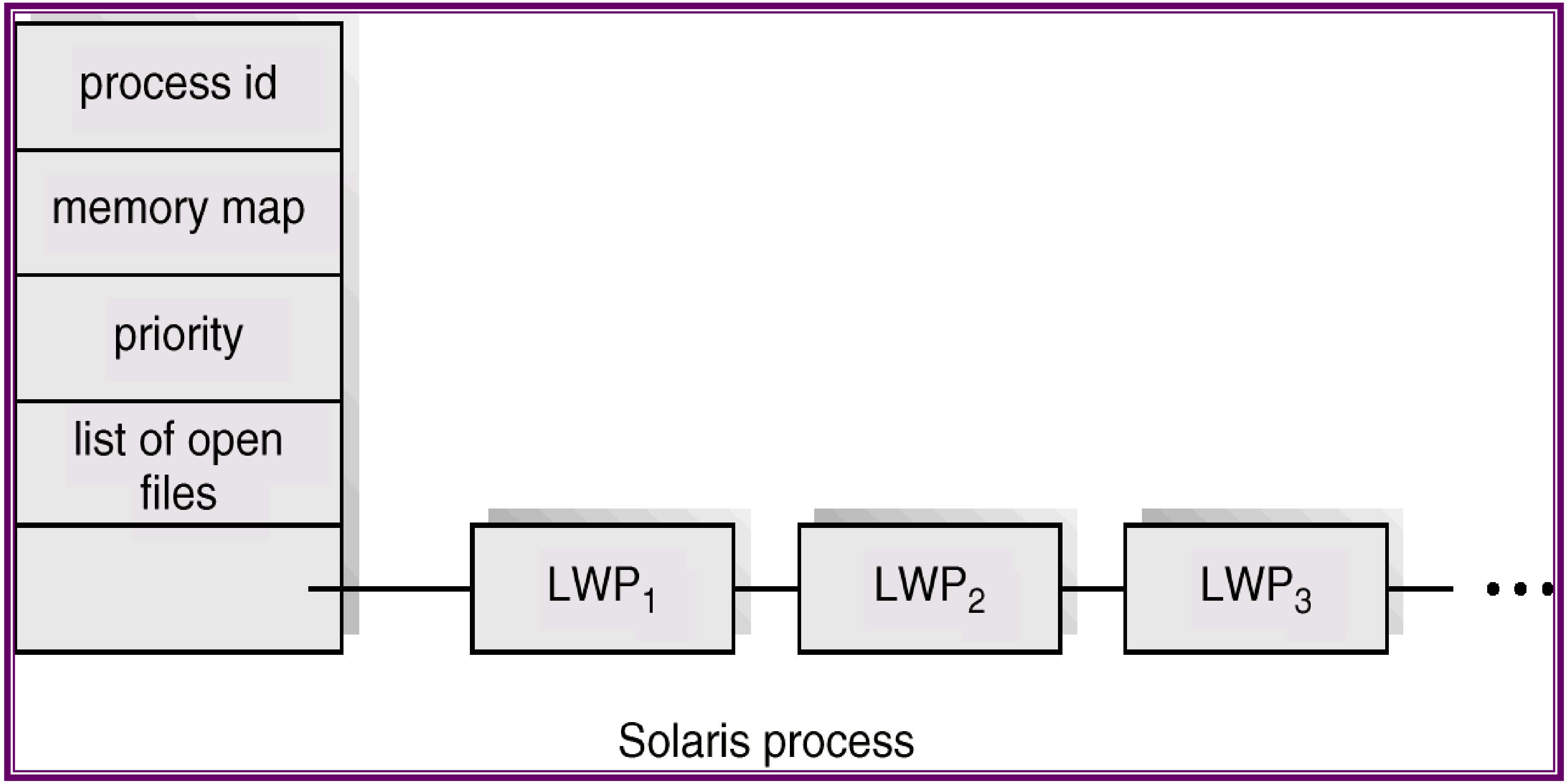
Solaris 2 Threads



Solaris Process



Windows XP Threads

- Implements the one-to-one mapping.
- Each thread contains

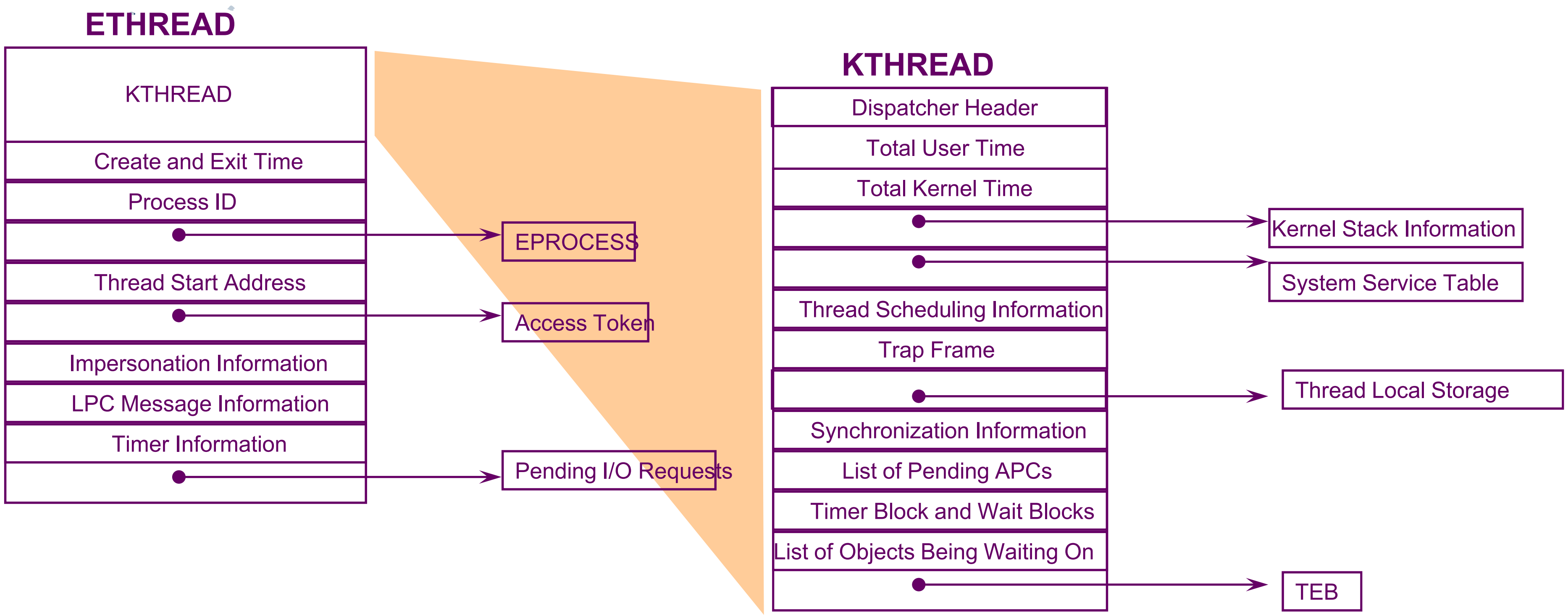
  - a thread id

  - register set

  - separate user and kernel stacks

  - private data storage area

Thread Block



Linux Threads (not POSIX pthreads Library)

- Linux refers to them as *tasks* rather than *threads*.
- Thread creation is done through clone() system call.
- Clone() allows a child task to share the address space of the parent task (process)

- What is the difference between fork() and clone()?

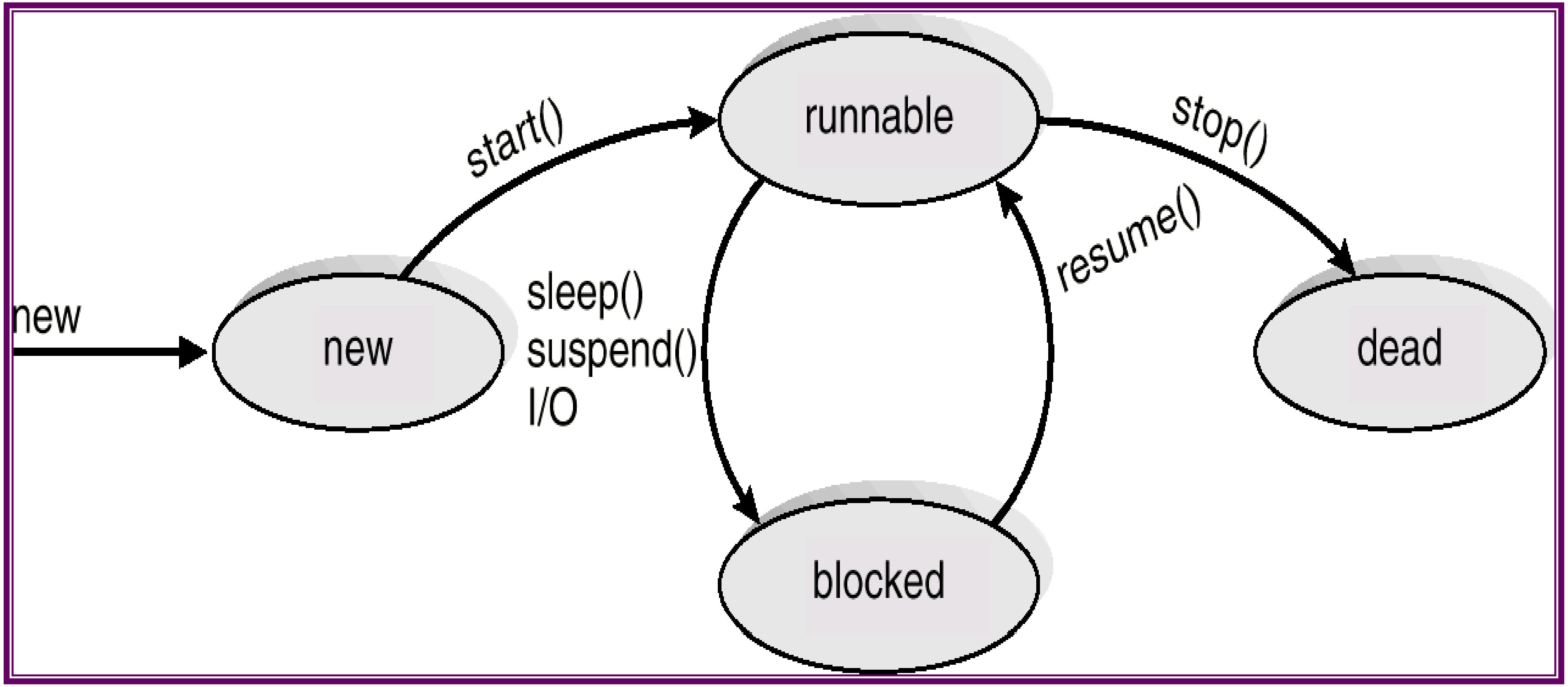
  http://linux.die.net/man/2/clone

  http://www.ibm.com/developerworks/cn/linux/kernel/l-thread/

Java Threads

- Java threads may be created by:
  - Extending Thread class
  - Implementing the Runnable interface
- Java threads are managed by the JVM.

Java Thread States



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Pthreads

- a POSIX standard (IEEE 1003.1c) API for thread creation and synchronization.
- API specifies behavior of the thread library, implementation is up to development of the library.
- Common in UNIX operating systems.

pthread_create

int pthread_create(tid, attr, function, arg);

- pthread_t * tid
  - handle or ID of created thread
- const pthread_attr_t *attr
  - attributes of thread to be created
- void *(*function) (void*)
  - function to be mapped to thread
- void *arg
  - single argument to function
- Integer return value for error code

pthread_create explained

- spawn a thread running the function
- thread handle returned via pthread_t structure
  - specify *NULL* to use default attributes
- single argument sent to function
  - If no argument to function, specify *NULL*
- check error codes!

EAGAIN – insufficient resources to create thread

EINVAL – invalid attribute

Threads states

- pthread threads have two states
  - joinable and detached
- threads are joinable by default
  - Resources are kept until *pthread_join*
  - can be reset with attribute or API call
- detached thread can not be joined
  - resources can be reclaimed at termination
  - cannot reset to be *joinable*

Waiting for a thread

int pthread_join(tid, val_ptr);

- pthread_t *tid
  - handle of joinable thread
- void **val_ptr
  - exit value returned by joined thread

pthread_join explained

calling thread waits for the thread with handle tid to terminate

- only one thread can be joined
- thread must be joinable

exit value is returned from joined thread

- Type returned is (void *)
- use NULL if no return value expected

ESRCH –thread not found

EINVAL – thread not joinable

Example: Multiple threads

```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>

void *print_msg_function( void *ptr );

main()
{
    pthread_t thread1, thread2;
    const char *msg1 = "Thread 1";
    const char *msg2 = "Thread 2";
    int  iret1, iret2;
```

Example: Multiple threads

```
iret1 = pthread_create( &thread1, NULL,
                        print_msg_function, (void*) msg1);
if(iret1) {
    fprintf(stderr,"Error - pthread_create() return code:
%d\n",iret1);
    exit(EXIT_FAILURE);
}

iret2 = pthread_create( &thread2, NULL,
                        print_msg_function, (void*) msg2);
if(iret2) {
    fprintf(stderr,"Error - pthread_create() return code:
%d\n",iret2);
    exit(EXIT_FAILURE);
}
```

Example: Multiple threads

```
    printf("pthread_create() for thread 1 returns: %d\n",iret1);
    printf("pthread_create() for thread 2 returns: %d\n",iret2);

    pthread_join( thread1, NULL);
    pthread_join( thread2, NULL);
    printf(“main thread exit”);
    exit(EXIT_SUCCESS);
}

void *print_msg_function( void *ptr )  {
    char *msg;
    msg = (char *) ptr;
    printf("%s \n", msg);
}
```

Example: Multiple threads

Main Thread	Thread1	Thread2
pthread_create(&thread1);		
pthread_create(&thread2);		
printf("pthread_create() for thread 1”);		
printf("pthread_create() for thread 2”);		
	printf(“Thread 1 \n“);	
		printf(“Thread 2 \n“);
pthread_join(thread1);		
pthread_join(thread2); printf(“main thread exit”);		

Example: Multiple threads

Main Thread	Thread1	Thread2
pthread_create(&thread1);		
	printf(“Thread 1 \n“);	
pthread_create(&thread2);		
printf("pthread_create() for thread 1”);		
printf("pthread_create() for thread 2”);		
		printf(“Thread 2 \n“);
pthread_join(thread1);		
pthread_join(thread2); printf(“main thread exit”);		

Example: Multiple threads

Main Thread	Thread1	Thread2
pthread_create(&thread1);		
pthread_create(&thread2);		
		printf(“Thread 2 \n“);
printf("pthread_create() for thread 1”);		
printf("pthread_create() for thread 2”);		
	printf(“Thread 1 \n“);	
pthread_join(thread1);		
pthread_join(thread2); printf(“main thread exit”);		

Example: Multiple threads

Main Thread	Thread1	Thread2
pthread_create(&thread1);		
pthread_create(&thread2);		
		printf(“Thread 2 \n“);
	printf(“Thread 1 \n“);	
printf("pthread_create() for thread 1”);		
printf("pthread_create() for thread 2”);		
pthread_join(thread1);		
pthread_join(thread2); printf(“main thread exit”);		

Thread Termination

- void pthread_exit(void *status);
  - terminate the current thread
- int pthread_cancel(pthread_t thread);
  - the thread to be cancelled may:
    - ✓ignore the request
    - ✓terminated immediately (Asynchronous cancellation)
    - ✓deferred terminated (Deferred cancellation)
- int pthread_kill(pthread_t thread, int sig);

Deferred Cancellation

- int pthread_setcancelstate(int state, int *oldstate);
  - set the calling thread's cancelability stat
  - PTHREAD_CANCEL_ENABLE
  - PTHREAD_CANCEL_DISABLE
- int pthread_setcanceltype(int type, int *oldtype)
  - PTHREAD_CANCEL_ASYNCHROUS
  - PTHREAD_CANCEL_DEFERRED
- void pthread_testcancel(void);
  - create a cancellation point in the calling thread.

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Windows Thread APIs

- CreateThread
- ExitThread
- TerminateThread
- GetExitCodeThread

- GetCurrentThreadId - returns global ID
- GetCurrentThread - returns handle
- SuspendThread/ResumeThread
- GetThreadTimes

Windows API Thread Creation

```
HANDLE CreateThread (
    LPSECURITY_ATTRIBUTES lpsa,
    DWORD cbStack,
    LPTHREAD_START_ROUTINE lpStartAddr,
    LPVOID lpvThreadParm,
    DWORD fdwCreate,
    LPDWORD lpIDThread)
```

cbStack == 0: thread‘s stack size defaults to primary thread‘s size

- lpstartAddr points to function declared as
  `DWORD WINAPI ThreadFunc(LPVOID)`
- lpvThreadParm is 32-bit argument
- LPIDThread points to DWORD that receives thread ID non-NULL pointer !

Windows API Thread Termination

```
VOID ExitThread( DWORD devExitCode )
```

- When the last thread in a process terminates, the process itself terminates

```
BOOL GetExitCodeThread (
    HANDLE hThread, LPDWORD lpdwExitCode)
```

- Returns exit code or STILL_ACTIVE

Suspending and Resuming Threads

- Each thread has suspend count
- Can only execute if suspend count == 0
- Thread can be created in suspended state

```
DWORD ResumeThread (HANDLE hThread)
DWORD SuspendThread(HANDLE hThread)
```

- Both functions return suspend count or 0xFFFFFFFF on failure

Example: Thread Creation

```
#include <stdio.h>
#include <windows.h>


DWORD WINAPI helloFunc(LPVOID arg ) {
        printf(“Hello Thread\n”);
        return 0;
}


main() {
        HANDLE hThread =
                CreateThread(NULL, 0, helloFunc,
                        NULL, 0, NULL );
        }
```

What’s Wrong?

Example Explained

- Main thread is process
- When process goes, all threads go
- Need some methods of waiting for a thread to finish

Waiting for Windows* Thread

```
#include <stdio.h>
#include <windows.h>
BOOL thrdDone = FALSE;
DWORD WINAPI helloFunc(LPVOID arg ) {
        printf("Hello Thread\n");
        return 0;
}

main() {
        HANDLE hThrea
                Create
                    NULL, 0, NULL );
        }
```

thrdDone = TRUE;

Not a good idea!

while (!thrdDone);

Waiting for a Thread

Wait for one object (thread)

```
DWORD WaitForSingleObject(
      HANDLE hHandle,
      DWORD dwMilliseconds );
```

Calling thread waits (blocks) until

- Time expires
  - Return code used to indicate this
- Thread exits (handle is signaled)
  - Use **INFINITE** to wait until thread termination

Does not use CPU cycles

Waiting for Many Threads

Wait for up to 64 objects (threads)

```
DWORD WaitForMultipleObjects(
      DWORD nCount,
      CONST HANDLE *lpHandles, // array
      BOOL fWaitAll, // wait for one or all
      DWORD dwMilliseconds)
```

Wait for all: `fWaitAll==TRUE`

Wait for any: `fWaitAll==FALSE`

- Return value is first array index found

Notes on WaitFor* Functions

- Handle as parameter
- Used for different types of objects
- Kernel objects have two states
  - Signaled
  - Non-signaled
- Behavior is defined by object referred to by handle
  - Thread: signaled means terminated

Example: Waiting for multiple threads

```
#include <stdio.h>
#include <windows.h>
const int numThreads = 4;

DWORD WINAPI helloFunc(LPVOID arg ) {
  printf(“Hello Thread\n”);
  return 0; }

main() {
  HANDLE hThread[numThreads];
  for (int i = 0; i < numThreads; i++)
    hThread[i] =
      CreateThread(NULL, 0, helloFunc, NULL, 0, NULL );
  WaitForMultipleObjects(numThreads, hThread,
                                             TRUE, INFINITE);

}
```

Example: HelloThreads

- Modify the previous example code to print out
  - appropriate "Hello Thread"message
  - Unique thread number
    - ✓use for-loop variable of CreateThread loop
- Sample output:

```
Hello from Thread #0
Hello from Thread #1
Hello from Thread #2
Hello from Thread #3
```

What’s Wrong?

```
DWORD WINAPI threadFunc(LPVOID pArg) {
  int* p = (int*)pArg;
  int myNum = *p;
  printf( “Thread number %d\n”, myNum);
}
. . .
// from main():
for (int i = 0; i < numThreads; i++) {
  hThread[i] =
     CreateThread(NULL, 0, threadFunc, &i, 0, NULL);
}
```

What is printed for myNum?

Hello Threads Timeline

Time	*main*	*Thread 0*	*Thread 1*
T_0	i = 0	---	----
T_1	create(&i)	---	---
T_2	i++ (i == 1)	launch	---
T_3	create(&i)	p = pArg	---
T_4	i++ (i == 2)	myNum = *p myNum = 2	launch
T_5	wait	print(2)	p = pArg
T_6	wait	exit	myNum = *p myNum = 2

Race Conditions

- Concurrent access of same variable by multiple threads
  - Read/Write conflict
  - Write/Write conflict
- Most common error in concurrent programs
- May not be apparent at all times
- How to avoid data races?
  - Local storage
  - Control shared access with critical regions

Hello Thread: Local Storage solution

```
DWORD WINAPI threadFunc(LPVOID pArg)
{
  int myNum = *((int*)pArg);
  printf( "Thread number %d\n", myNum);
}
. . .

// from main():
for (int i = 0; i < numThreads; i++) {
  tNum[i] = i;
  hThread[i] =
      CreateThread(NULL, 0, threadFunc, &tNum[i],
                   0, NULL);
}
```