5. Threads

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Contents

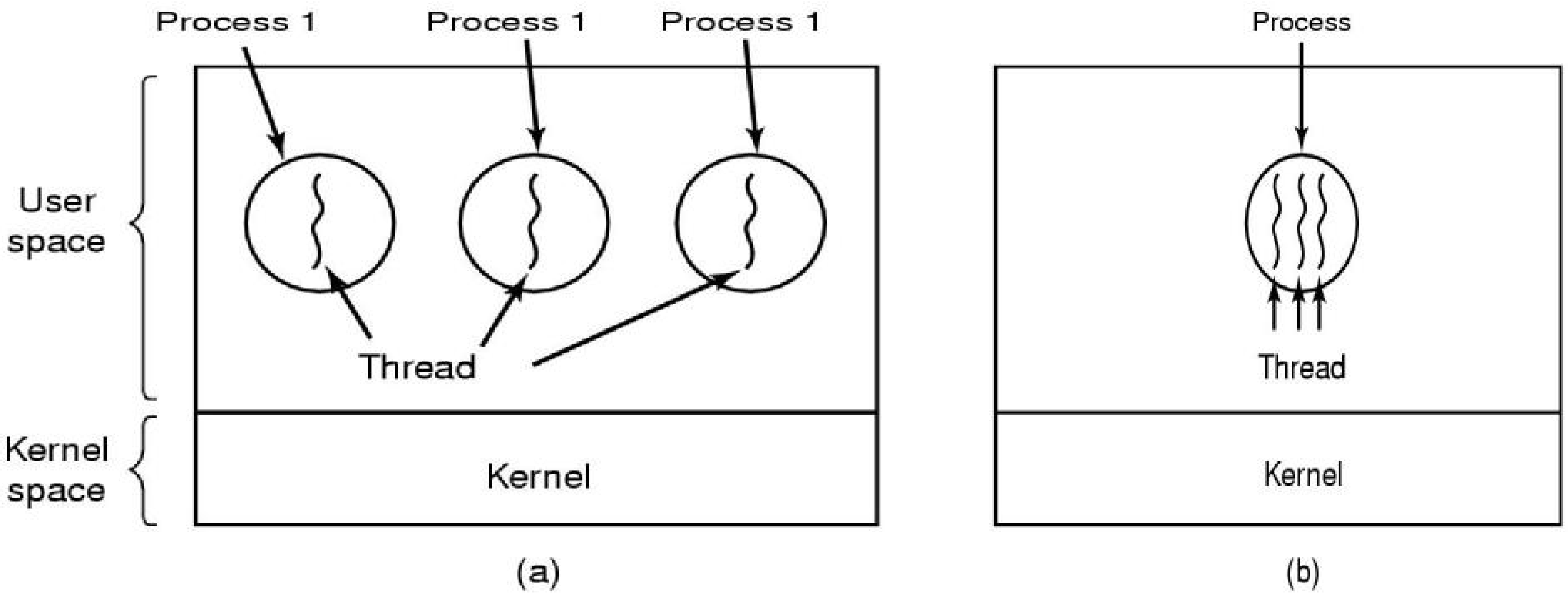
Processes

- Heavy-weight
  - A process includes many things:
    - An address space (all the code and data pages)
    - OS resources (e.g., open files) and accounting info.
    - Hardware execution state (PC, SP, registers, etc.)
  - Creating a new process is costly because all of the data structures must be allocated and initialized
    - Linux: over 100 fields in task_struct
      (excluding page tables, etc.)
  - Inter-process communication is costly, since it must usually go through the OS
    - Overhead of system calls and copying data

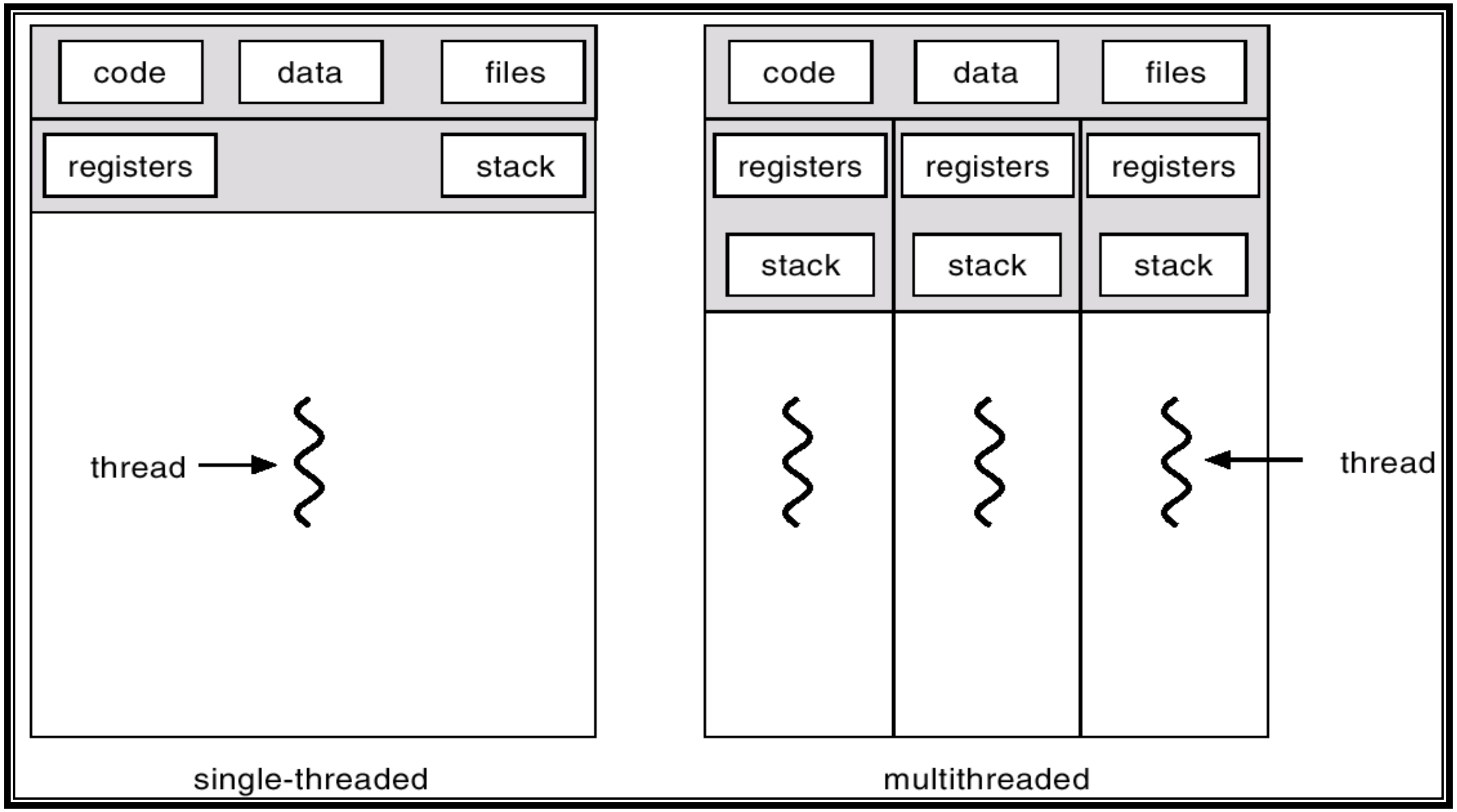
Thread Concept: Key Idea

- Separate the concept of a process from its execution state
  - Process: address space, resources, other general process attributes (e.g., privileges)
  - Execution state: PC, SP, registers, etc.
  - This execution state is usually called
    - a thread of control,
    - a thread, or
    - a lightweight process (LWP)

Thread Concept: Key Idea (Cont'd)



Single and Multithreaded Processes



What is a Thread?

- A *thread* (or *lightweight process*) is a basic unit of CPU utilization; it consists of:
  - program counter
  - register set
  - stack space

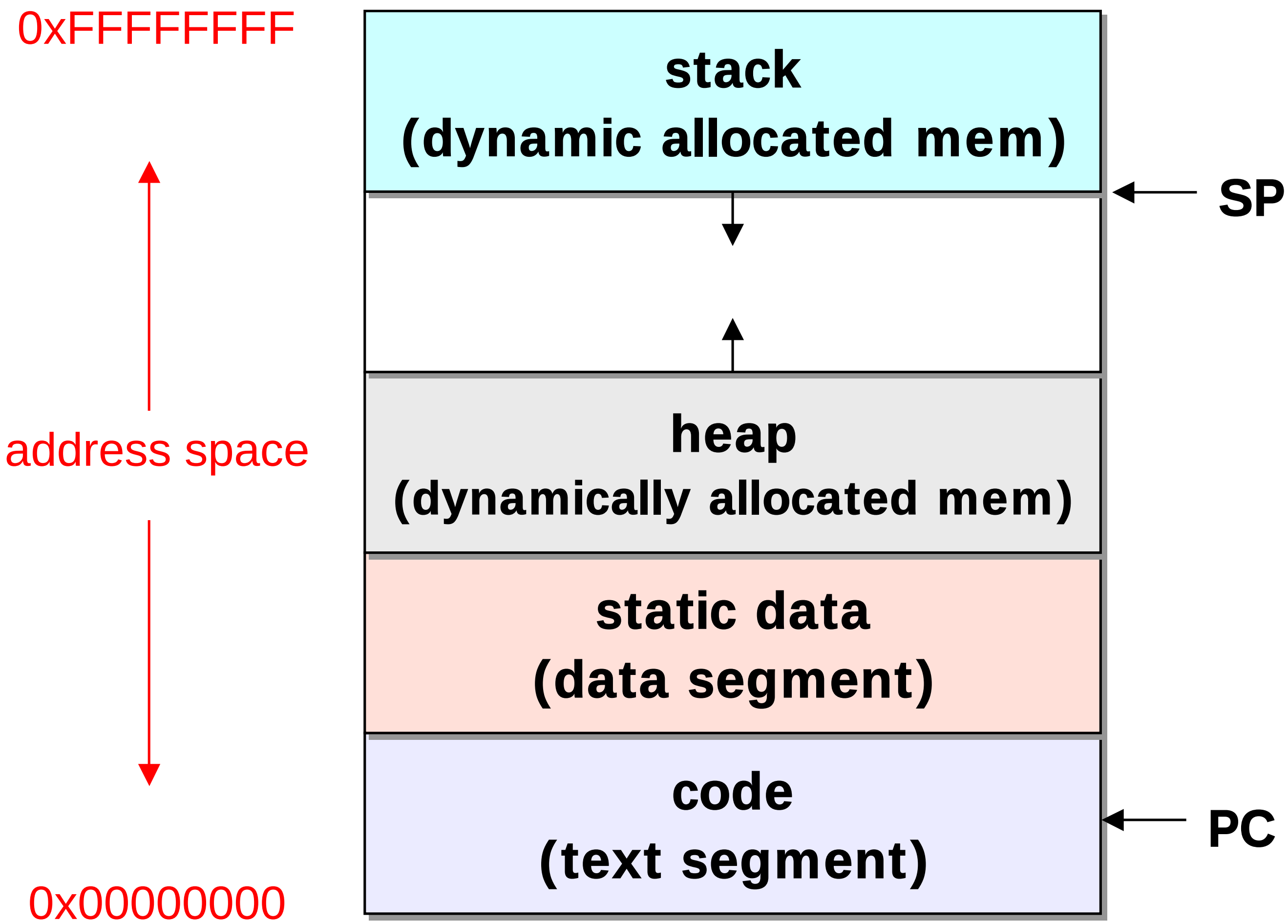
- A thread shares with its peer threads its:
  - code section
  - data section
  - operating-system resources
  - collectively known as a *task* or process

- A traditional or *heavyweight* process is equal to a task with one thread

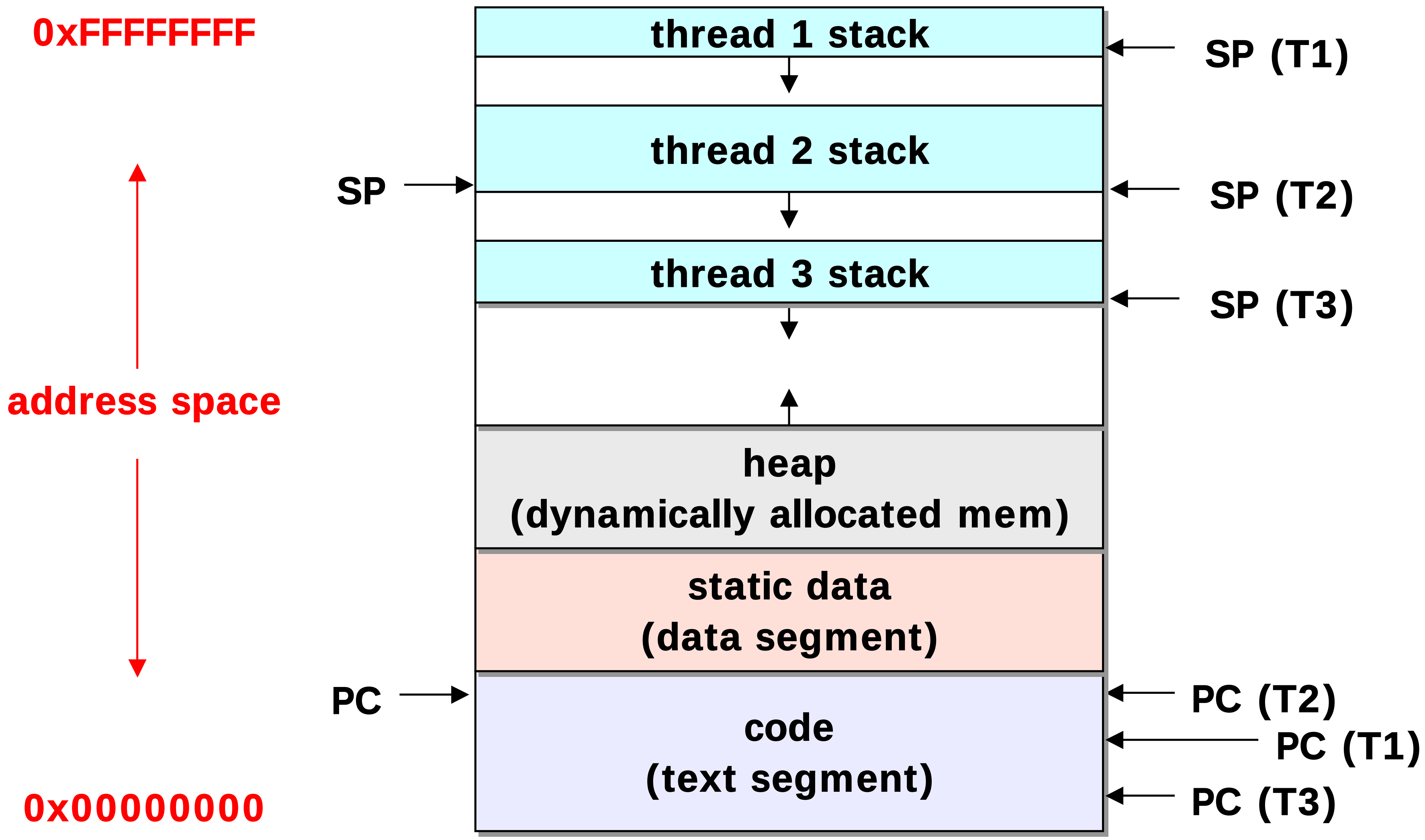
Process vs. Thread

- Processes vs. Threads
  - A thread is bound to a single process
  - A process, however, can have multiple threads
  - Sharing data between threads is cheap: all see the same address space
  - Threads become the unit of scheduling
  - Processes are now containers in which threads execute
  - Processes become static, threads are the dynamic entities

Process Address Space



Address Space with Threads



Concurrent Servers: Processes

- Web server example
  - Using fork() to create new processes to handle requests in parallel is overkill for such a simple task.

```
While (1) {
    int sock = accept();
    if ((pid = fork()) == 0) {
        /* Handle client request */
    } else {
        /* Close socket */
    }
}
```

Concurrent Servers: Threads

- Using threads
  - We can create a new thread for each request

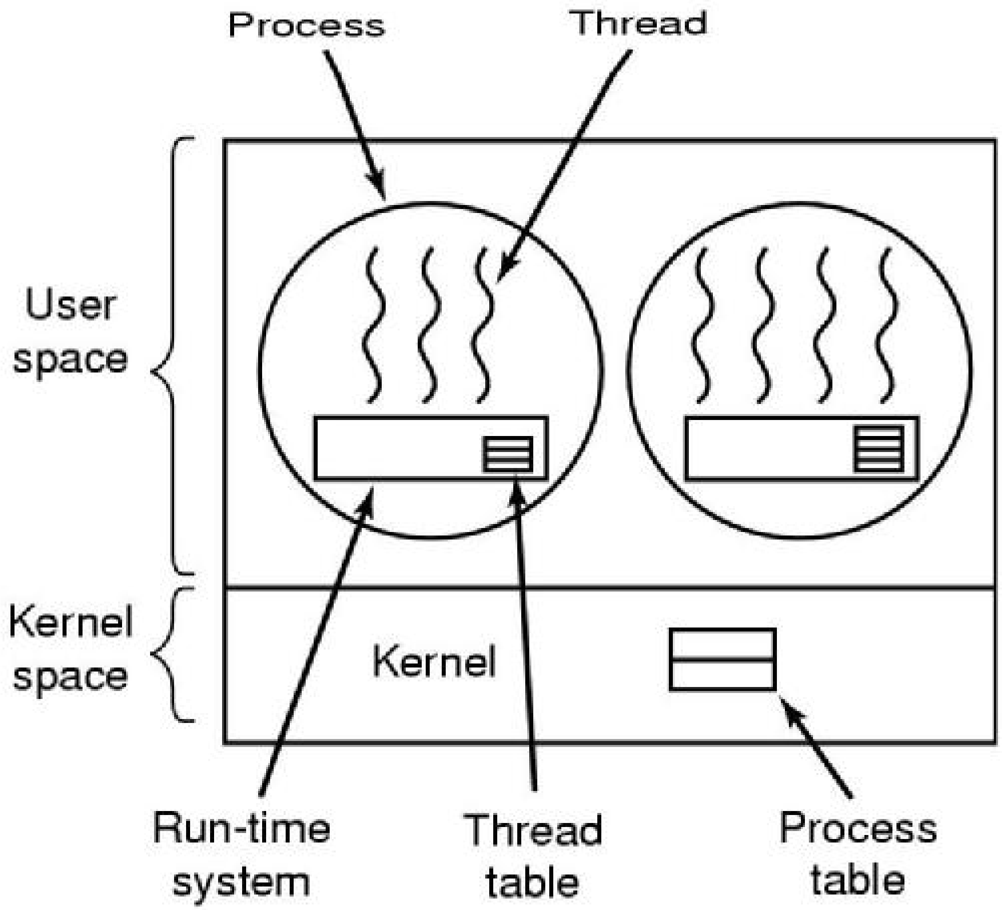
```
webserver ()
{
    While (1) {
        int sock = accept();
        thread_fork (handle_request, sock);
    }
}
handle_request (int sock)
{
    /* Process request */
    close (sock);
}
```

Benefits

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

User Threads

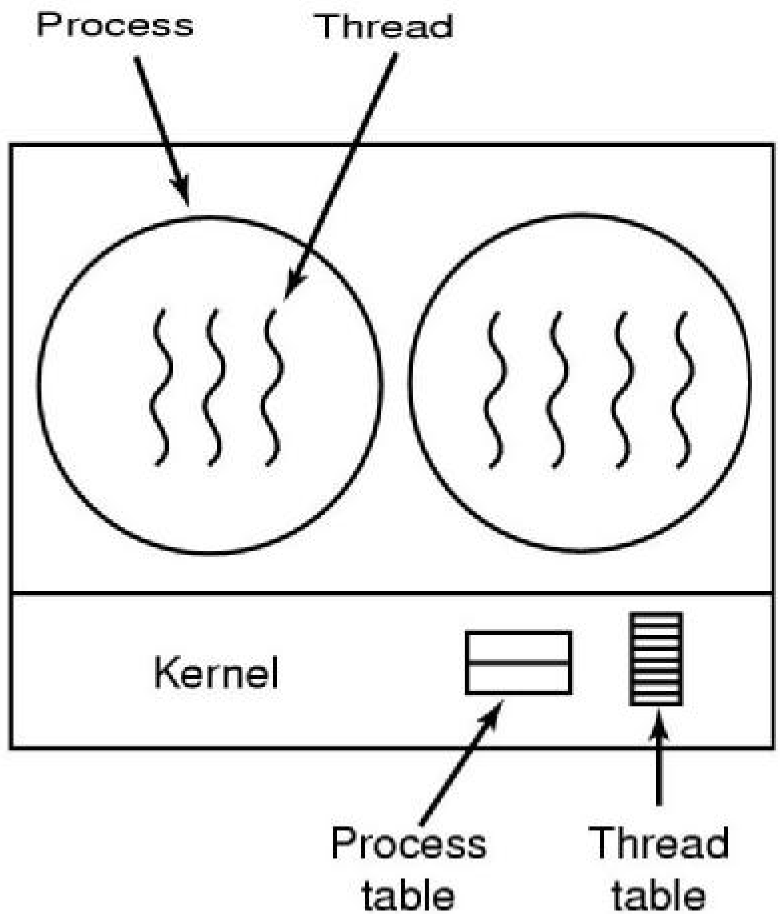
- Thread management done by user-level threads library
- Examples
  - POSIX *Pthreads*
  - Mach *C-threads*
  - Solaris *threads*



Kernel Threads

- Supported by the Kernel
  - thread creation and management requires system calls

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



User-level Threads vs. Kernel-level Threads

- User-level threads
  - The user-level threads library implements thread operations
  - They are small and fast
  - User-level threads are invisible to the OS
  - OS may make poor decisions
    - e.g. blocking I/O
  - Thread scheduling
    - Non-preemptive scheduling: yield()
    - Preemptive scheduling: timer through signal
- Kernel-level threads
  - All thread operations are implemented in the kernel
  - The OS schedules all of the threads in a system
  - Kernel threads are cheaper than processes
  - They can still be too expensive

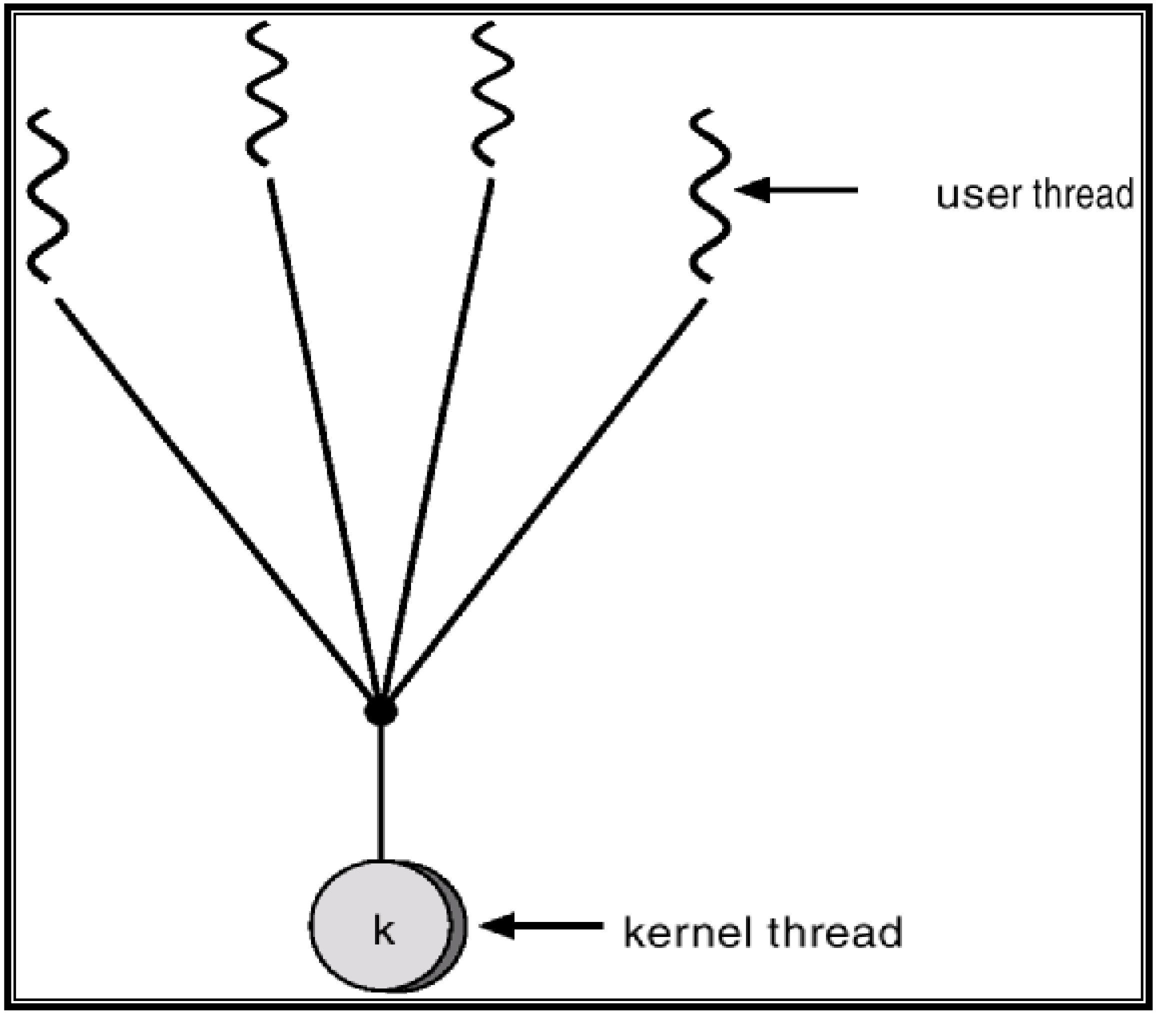
Multithreading Models

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

Many-to-One

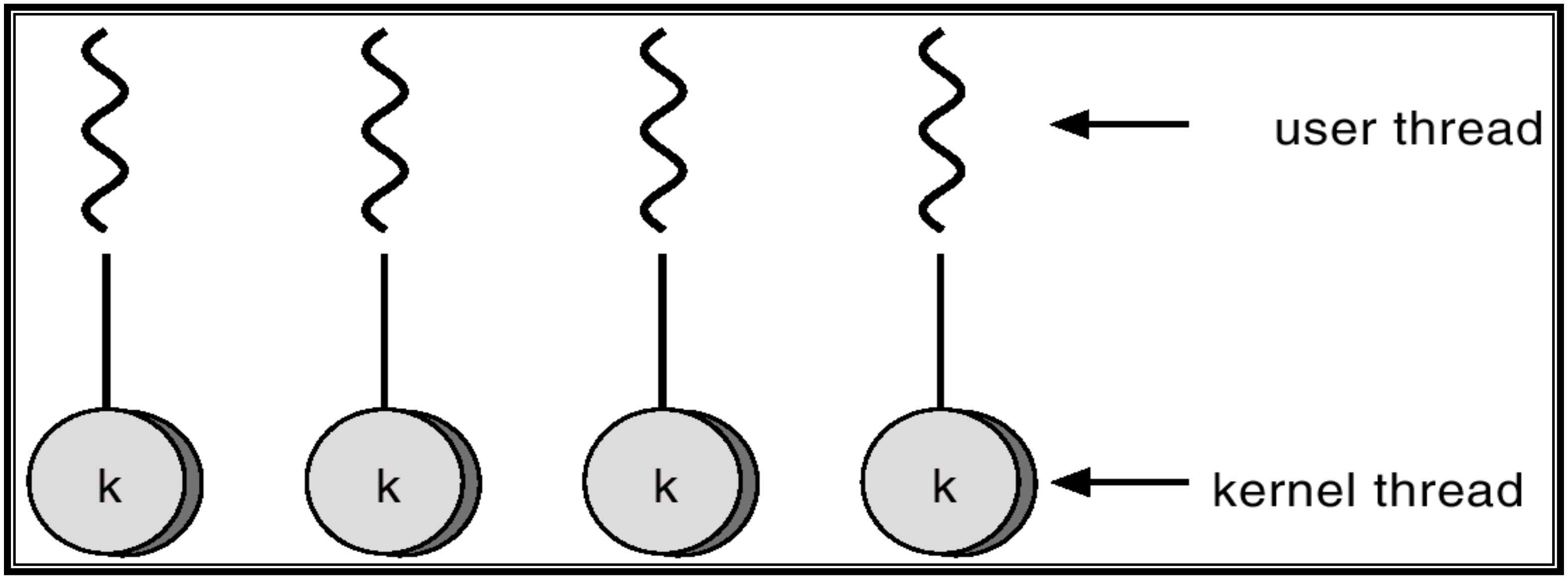
- Many user-level threads mapped to single kernel thread

- Used on systems that do not support kernel threads



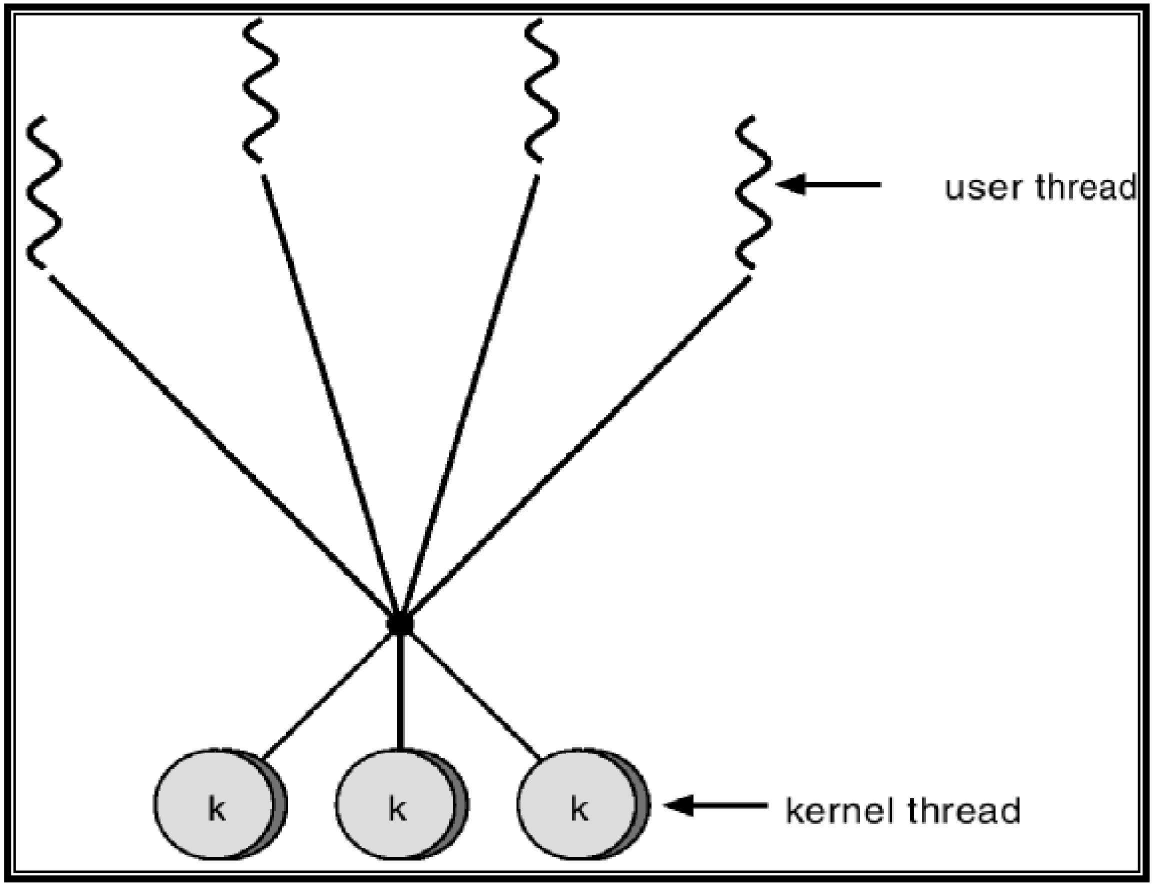
One-to-One

- Each user-level thread maps to kernel thread
- Examples
  - Windows 95/98/NT/2000
  - OS/2



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



Threading Issues

- Semantics of fork() and exec() system calls
  - Two versions of fork()
- Thread cancellation
  - Asynchronous cancellation
  - Deferred cancellation
- Signal handling
  - To the thread to which the signal applies
  - To every thread in the process
  - To certain threads in the process
  - Assign a specific thread to receive all signals for the process
- Thread pools
  - Create a number of threads at process startup
- Thread specific data

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

Threads Interface

- POSIX-style threads
  - Pthreads
  - DCE threads (early version of Pthreads)
  - Unix International (UI) threads (Solaris threads)
    - Sun Solaris 2, SCO Unixware 2

- Microsoft-style threads
  - Win32 threads
    - Microsoft Windows 98/NT/2000/XP
  - OS/2 threads
    - IBM OS/2

Pthreads

- Thread creation/termination

```
int pthread_create (pthread_t *tid,
                    pthread_attr_t *attr,
                    void *(start_routine)(void *),
                    void *arg);
```

```
void pthread_exit   (void *retval);
```

```
int pthread_join     (pthread_t tid,
                      void **thread_return);
```

Pthreads (Cont'd)

- Mutexes

```
int pthread_mutex_init
                        (pthread_mutex_t *mutex,
                         const pthread_mutexattr_t *mattr);
```

```
void pthread_mutex_destroy
                        (pthread_mutex_t *mutex);
```

```
void pthread_mutex_lock
                        (pthread_mutex_t *mutex);
```

```
void pthread_mutex_unlock
                        (pthread_mutex_t *mutex);
```

Pthreads (Cont'd)

- Condition variables

```
int pthread_cond_init
                    (pthread_cond_t *cond,
                     const pthread_condattr_t *cattr);
```

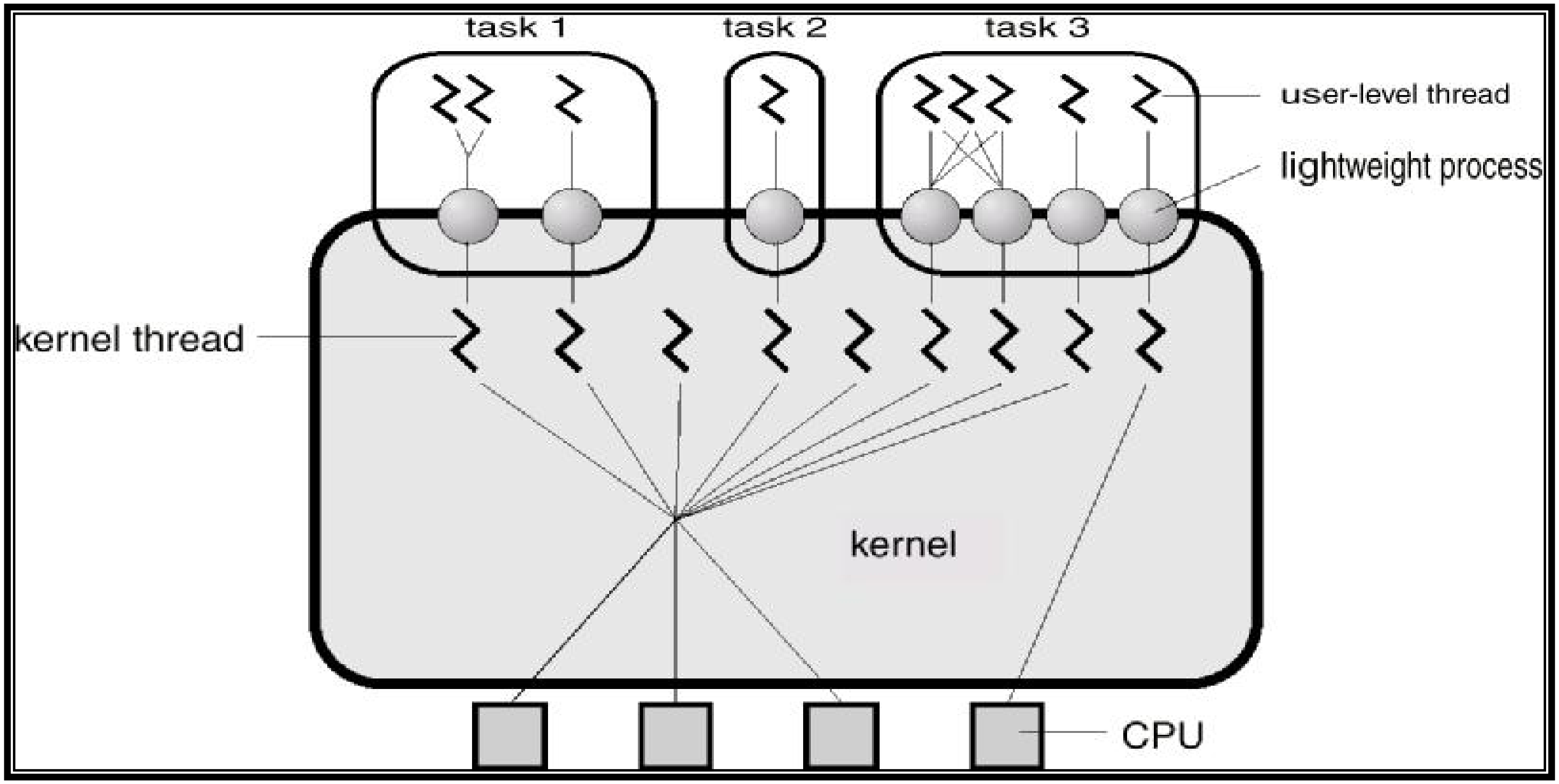
```
void pthread_cond_destroy
                    (pthread_cond_t *cond);
```

```
void pthread_cond_wait
                    (pthread_cond_t *cond,
                     pthread_mutex_t *mutex);
```

```
void pthread_cond_signal
                    (pthread_cond_t *cond);
```

```
void pthread_cond_broadcast
                    (pthread_cond_t *cond);
```

Solaris 2 Threads

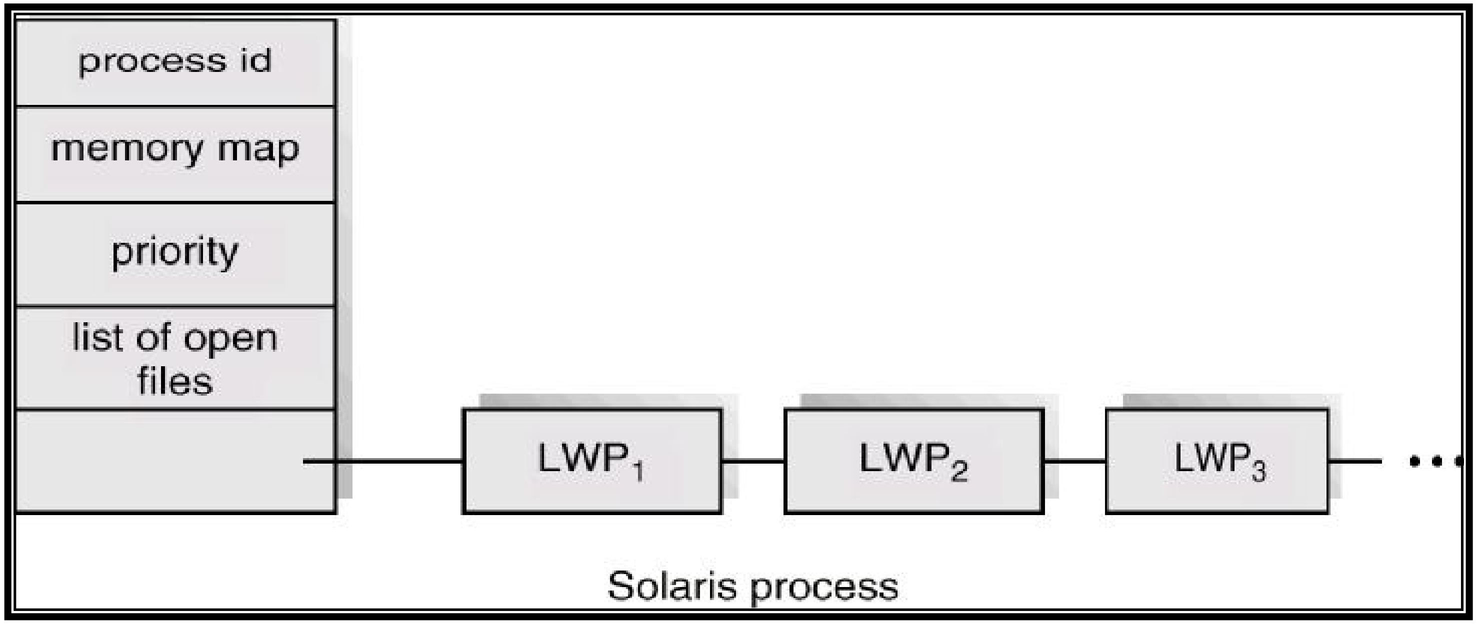


Solaris 2 Threads

- LWP (Lightweight Process)
  - A virtual CPU for executing code or system calls
  - Each process contains at least one LWP
  - Each LWP is connected to exactly one kernel-level thread
  - Each LWP is separately dispatched by the kernel, may
    - perform independent system calls
    - incur independent page faults
    - run in parallel on a multiprocessor, etc.
  - The thread library dynamically adjusts the number of LWPs in the pool to ensure the best performance for the application
  - It also “ages” LWPs and deletes them when they are unused for a long time.
  - An LWP is a kernel data structure

- *For implementing many-to-many model*

Solaris Process



Windows 2000 Threads

- Implements the one-to-one mapping

- Each thread contains
  - a thread id
  - register set
  - separate user and kernel stacks
  - private data storage area

- Cf) Fibers
  - Fibers are often called “lightweight” threads
  - Fibers are invisible to the kernel
  - Fibers provide a functionality of the many-to-many model

Linux Threads

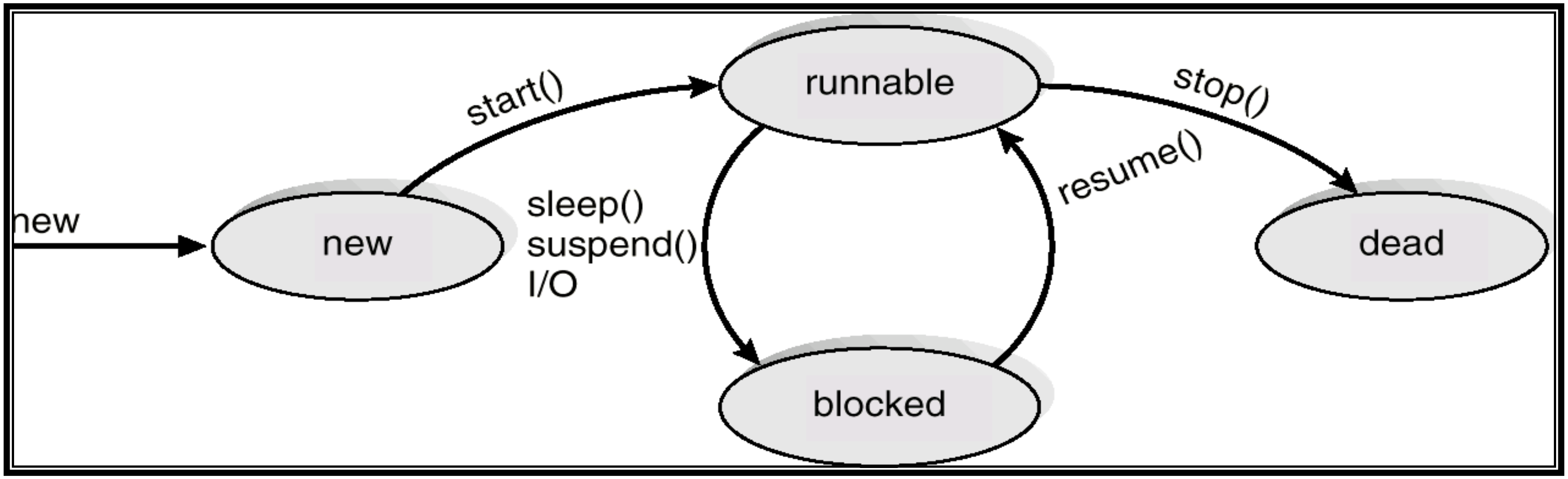
- Linux refers to them as *tasks* rather than *threads*
- Thread creation is done through clone() system call
- Clone() allows a child task to share the address space of the parent task (process)
- *So, there exist POSIX compatibility problems*
- *Approaches for POSIX compliance*
  - Linux 2.4 introduces a concept of “thread groups”
  - NPTL (Native POSIX Threading Library) – by RedHat
    - 1:1 model
  - NGPT (Next Generation POSIX Threading) – by IBM
    - M:N model

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



Threads Design Space