Operating Systems: Threads and Concurrency

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Acknowledgements: Material based on the textbook Operating Systems Concepts (Chapter 4)

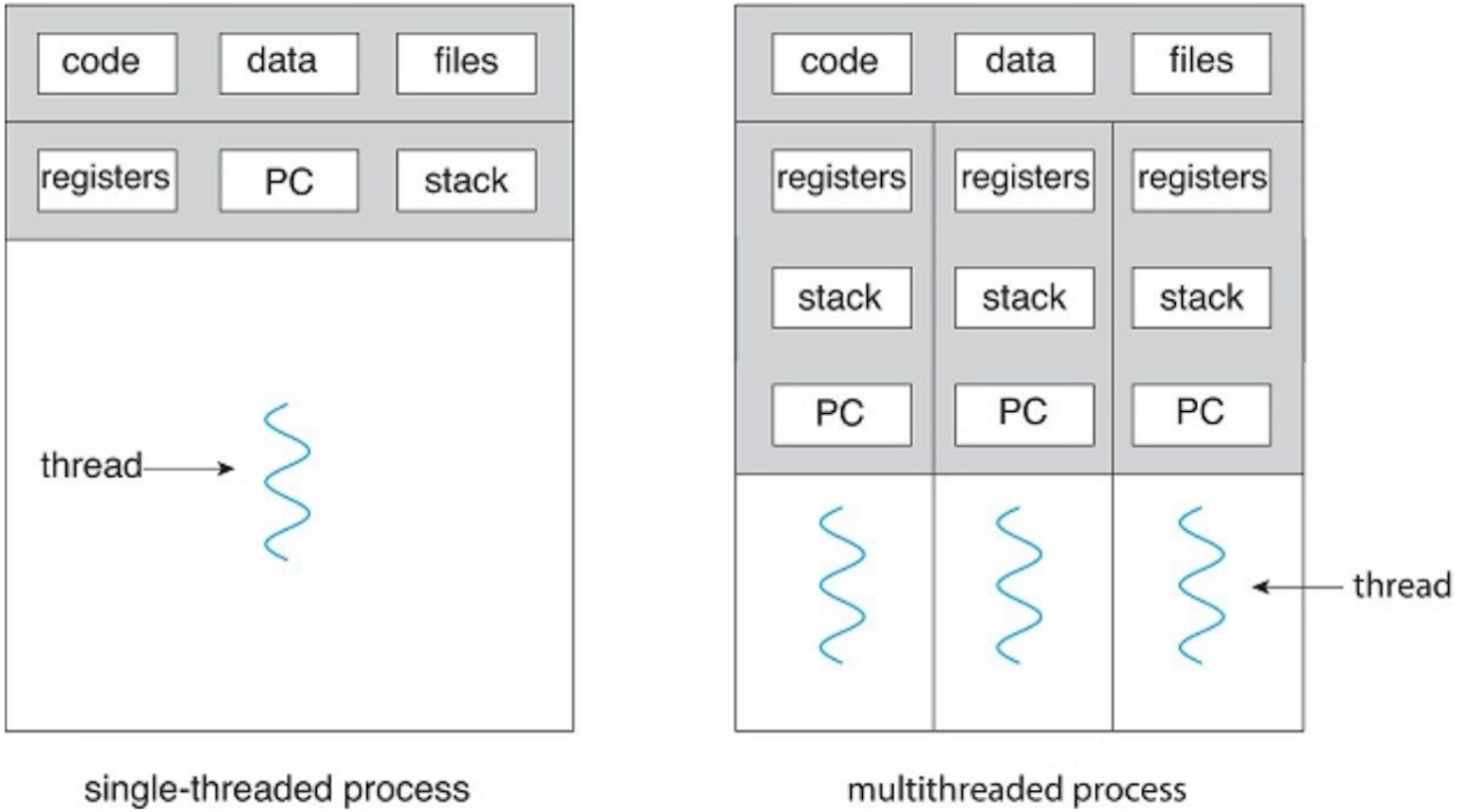
Threads

- A traditional process has a single thread of control.
- **Multi-threaded applications** have multiple threads within a single process.
- When the operating system supports threads, a **thread** is a basic unit of CPU utilization.
- Process creation is many times heavy-weight while thread creation is light-weight.

Threads in Single and Multithreaded Processes

- Each thread consists of:
  1. Thread ID,
  2. Program Counter,
  3. Set of registers
  4. Stack
- However, they share other components of the process such as code, data, and files

Threads in Single and Multithreaded Processes



single-threaded process

multithreaded process

Multi-threading examples

- Editing word document
  - One thread can interpret the key strokes.
  - Second thread display images.
  - Third thread checks spelling and grammar.
  - Fourth thread does periodic automatic backups of the file being edited.
- Most operating system kernels are multi-threaded.
  - Many threads operate in the kernel process, where each thread performs a specific task.
    - Managing devices
    - Managing memory
    - Interrupt handling, etc.

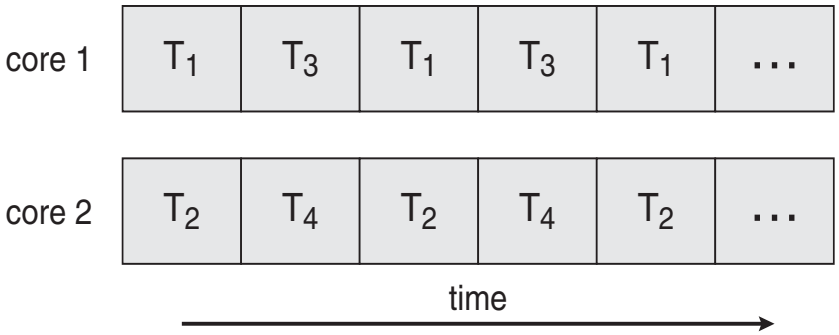
Advantages

- **Responsiveness –** may allow continued execution if part of process is blocked, especially important for user interfaces
- **Resource Sharing –** threads share resources by default.
  - Resource sharing is easier between threads than processes
- **Economy –** cheaper than process creation, thread switching lower overhead than context switching
- **Scalability –** a single process can take advantage of multiprocessor architectures
- Threads enable **concurrent programming** and, on multiple processor systems, true **parallelism**.

Parallelism

Parallelism implies a system can perform more than one task simultaneously

Parallelism on a multi core system

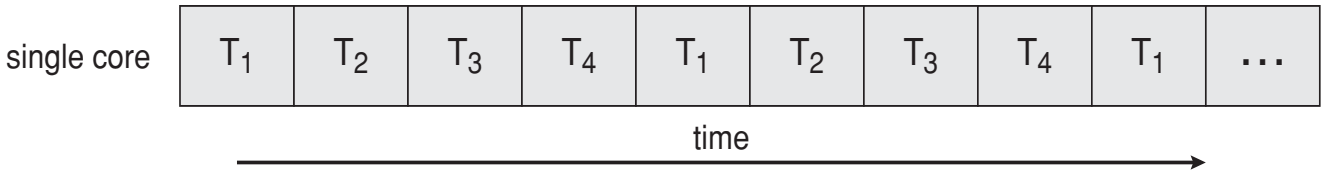


Concurrency

Concurrency supports more than one task making progress

- Single processor/core, scheduler provides concurrency

Concurrent execution on a single-core system:



It is possible to have concurrency without parallelism?

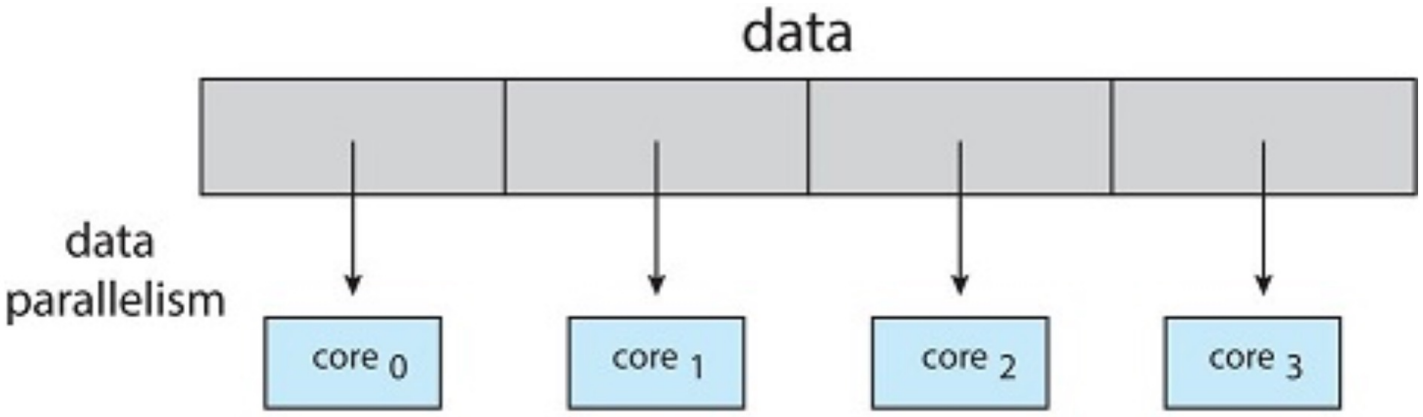
Multicore Programming

- **Multicore** or **multiprocessor** systems puts pressure on programmers, challenges include:
  - **Dividing activities:** Identifying tasks in the application that can be performed concurrently.
  - **Balance:** Evaluate if the tasks coded to run concurrently provide same or more value than the overhead of thread creation.
  - **Data splitting:** Preventing threads from interfering with each other.
  - **Data dependency:** Tasks need to be synchronized if data is shared.
  - **Testing and debugging:** Challenging as the race conditions become difficult to identify.
    - Race condition results when several threads try to access and modify the same data concurrently

Multicore Programming (Cont.)

Two types of parallelism: Data and Task parallelism

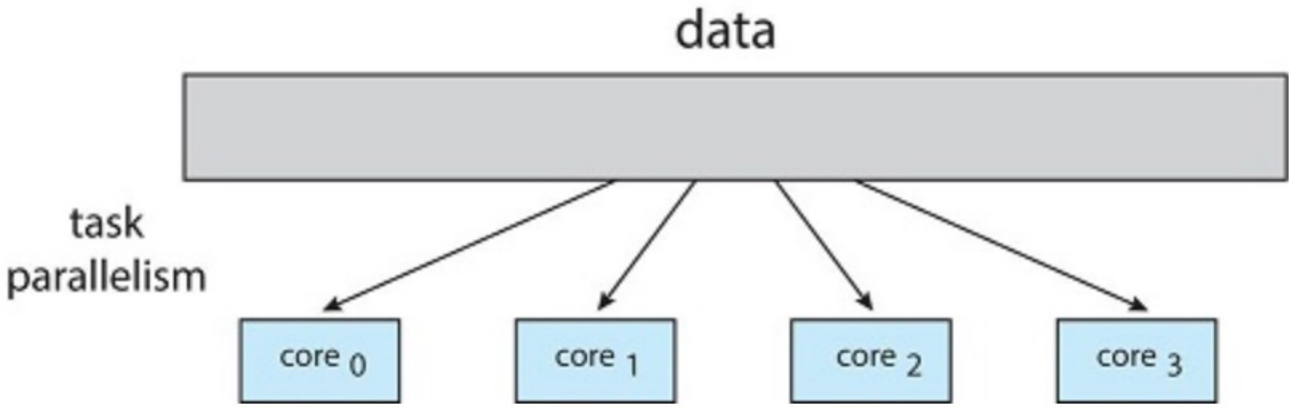
- **Data parallelism:** distributes subsets of the same data across multiple cores, same operation on each subsets



- Example: Adding numbers 1 to N, where N is large. The set is divided into number of cores and the same computation is performed on each set.

Multicore Programming (Cont.)

- **Task parallelism** – distributing threads across cores, each thread performing unique operation.



- Example: Windows word document example (Slide# 4)

Amdahl's Law

- Identifies performance gains from adding additional cores to an application that has both serial and parallel components
- *S* is serial portion
- *N* processing cores

$$speedup \leq \frac{1}{S + \frac{(1-S)}{N}}$$

- If an application is 75% parallel and hence 25% serial (S=0.25 in formula).
  - moving from 1 to 2 cores results in speedup of 1.6 times

Amdahl's Law Contd..

- Notice that as $N \rightarrow \infty$, speedup approaches 1 / *S.*
- According to the law, adding more # of processes after a certain number has no effect on speedup!
- Some suggest formula does not account for hardware performance, therefore ceases to apply when N → ∞

User threads and Kernel threads: Relationship

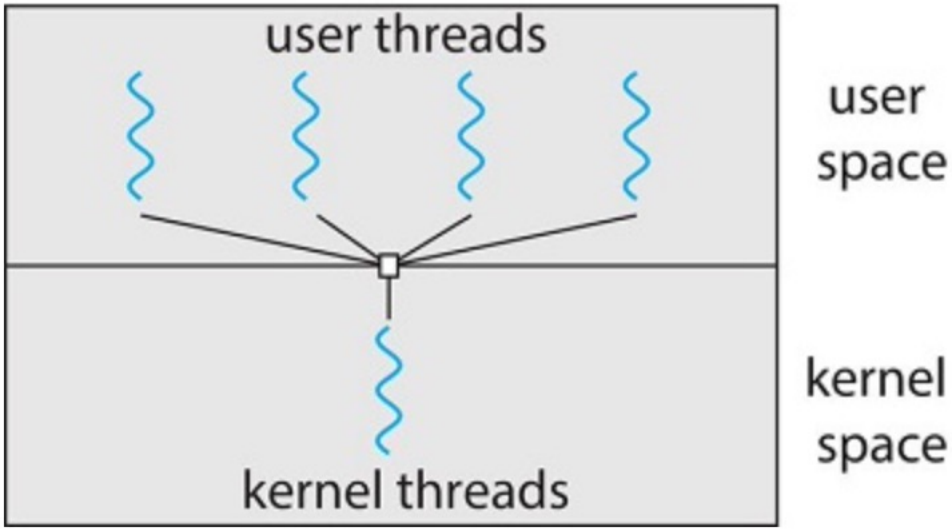
- A relationship must exist between kernel and user level threads
  - When the kernel is loaded several kernel level threads are created to support its functioning.
  - A user program can create threads
  - However, the OS must provide support to schedule and execute them on the CPU.
  - OS provides support to a thread or a process by assigning kernel thread(s).
  - This depends on the multithreading model adopted by the OS.

Multithreading Models

- Below are the multithreading models adopted by OS
  - Many-to-One
  - One-to-One
  - Many-to-Many

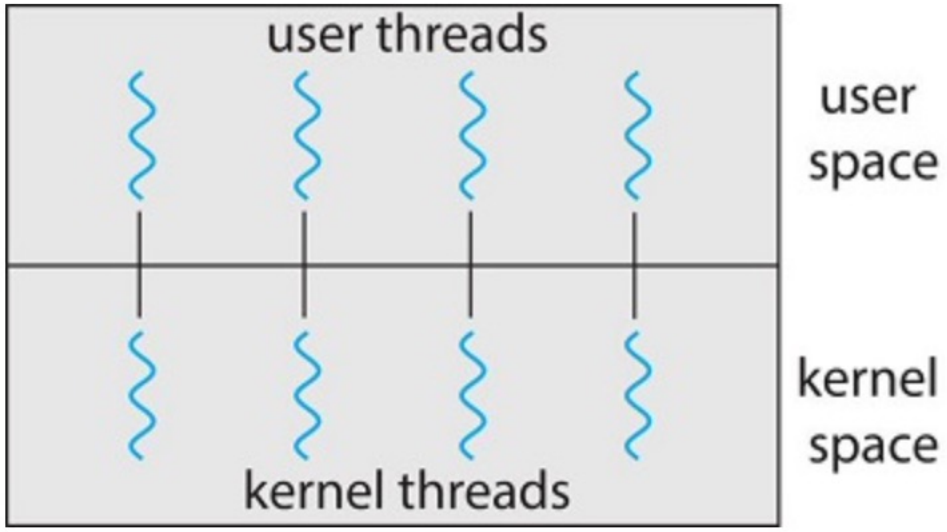
Many-to-One

- All user-level thread(s) created by the process mapped to single kernel thread
- Thread management handled by the **thread library in user space** - very efficient.
- One thread blocking causes all threads to block
- Multiple threads may not run in parallel on multicore system because only one one kernel thread exists to support them.
- Few systems currently use this model
- Examples OS (implemented it in past):
  - **Solaris Green Threads**
  - **GNU Portable Threads**



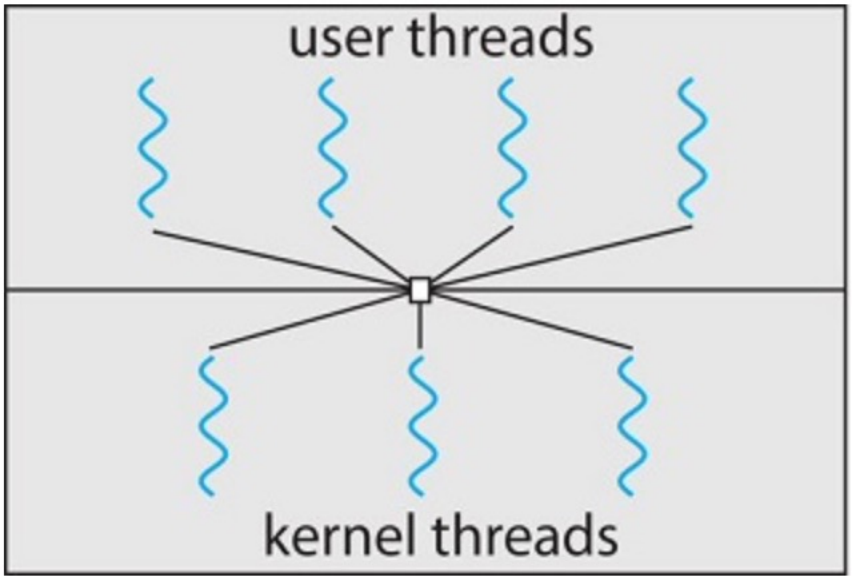
One-to-One

- Each user-level thread is mapped to a kernel thread.
- Creating a user-level thread creates a kernel thread to mange it
- More concurrency than many-to-one but has max. overhead.
- Number of threads per process sometimes restricted due to overhead
- Examples: Windows, Linux, Solaris 9 and later



Many-to-Many Model

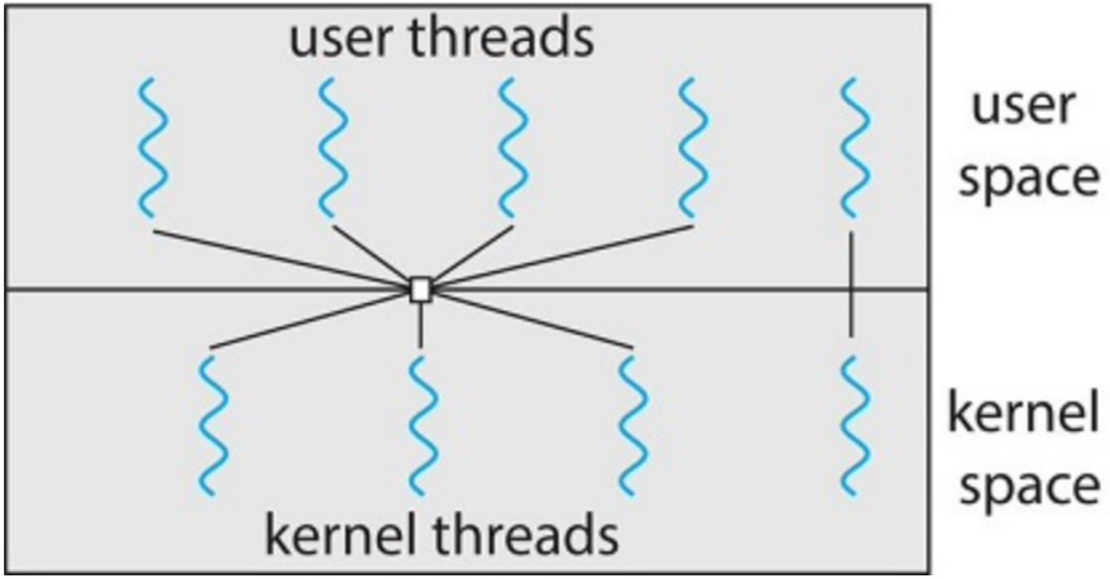
- Allows many user level threads to be mapped to an equal or smaller no. of kernel threads.
- Users have no restrictions on the number of threads created.



- Blocking kernel system calls does not block the entire process
- Processes (with threads) can be split across multiple processors.
- Individual processes may be allocated variable numbers of kernel threads, depending on the number of CPUs present and other factors.
- Examples: Solaris prior to version 9

Two-level Model (variation of Many-to-many)

- Similar to many to many model, except that it allows a user thread to be **bound** to kernel thread
  - Solaris 8 and earlier



User Threads and Kernel Threads

- **User level threads** - management done by user-level threads library in user space. These threads are put by programmers into there programs.
- **Kernel level threads** – managed by the Kernel in kernel space.
- Virtually all general purpose operating systems have thread support:
  - E.g., Windows , Solaris, Linux, Tru64 UNIX, Mac OS X

Thread Libraries

- **Thread library** provides programmer with API for creating and managing threads
- Two primary ways of implementing
  - **Library entirely in user space**: Involves API functions implemented solely within user space, with no kernel support
  - **Kernel-level library supported by the OS**: Involves system calls and requires a kernel with thread library support.

Thread Libraries Cont.

There are three main thread libraries in use today:

- **POSIX Pthreads** - may be provided as either a user or kernel library, as an extension to the POSIX standard.
- **Win32 threads** - provided as a kernel-level library on Windows systems.
- **Java threads** - Since Java generally runs on a Java Virtual Machine, the implementation of threads is based upon whatever OS and hardware the JVM is running on, i.e. either Pthreads or Win32 threads depending on the system.

Pthreads

- May be provided either as user-level or kernel-level
- Pthreads, is a POSIX standard API for thread creation and synchronization
  - Specification **not** implementation
- API specifies behavior of the thread library, implementation is up to development of the library
- Common in UNIX operating systems (Solaris, Linux, Mac OS X)
- On Linux, pthread library implements the 1:1 model
- Function names start with “pthread_”

Pthreads

- To be able to create threads in your C program you need to include the `pthread.h` header file.
- Each thread has a unique thread ID. To create thread IDs for your threads in your program you should use the `pthread_t` data type.
- Thread attributes should be created/modified using `pthread_attr_t` data structure.
- Declare and code the function in which the thread begins control. For an example see the `runner()` function on the next slide.
- To create threads, use `pthread_create()` function and pass in the necessary parameters.
- For the parent thread to output the sum after all summing threads have exited, it is important that you use the `pthread_join()` function.
- How does the `pthread_join()` function work?

Pthreads Example

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

#include <stdlib.h>

int sum; /* this data is shared by the thread(s) */
void *runner(void *param); /* threads call this function */

int main(int argc, char *argv[])
{
  pthread_t tid;  /* the thread identifier */
  pthread_attr_t attr; /* set of thread attributes */

  /* set the default attributes of the thread */
 pthread_attr_init(&attr);
  /* create the thread */
  pthread_create(&tid, &attr, runner, argv[1]);
  /* wait for the thread to exit */
  pthread_join(tid,NULL);

  printf("sum = %d\n",sum);
}
```

Pthreads Example (Cont.)

```
/* The thread will execute in this function */
void *runner(void *param)
{
  int i, upper = atoi(param);
  sum = 0;

  for (i = 1; i <= upper; i++)
    sum += i;

  pthread_exit(0);
}
```

Pthreads Code for Joining 10 Threads

```
#define NUM THREADS 10

/* an array of threads to be joined upon */
pthread_t workers[NUM_THREADS];

for (int i = 0; i < NUM_THREADS; i++)
  pthread_join(workers[i], NULL);
```

Question

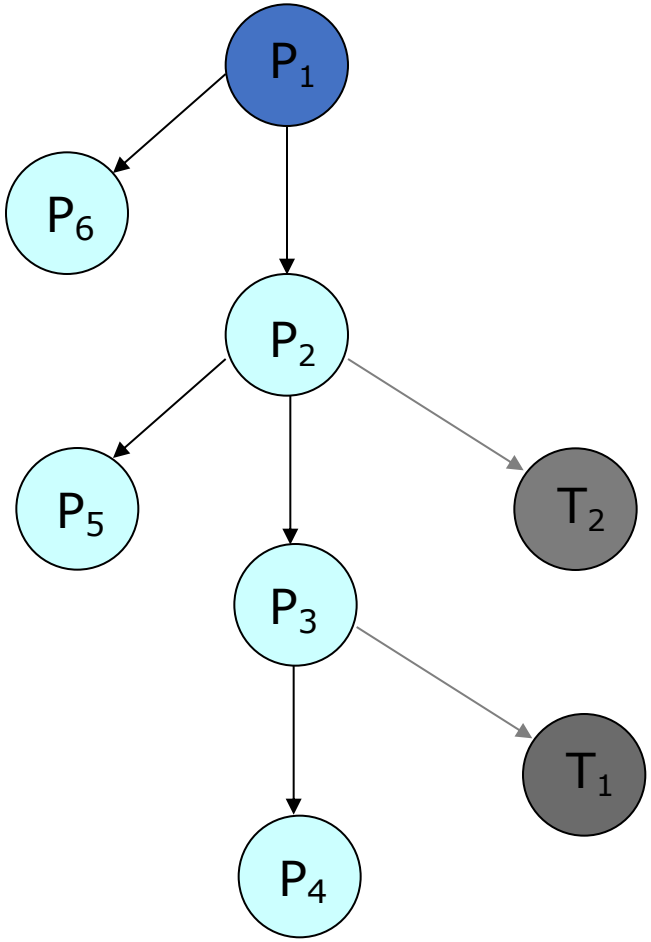
```
int main()
{
        pid_t pid;
        pid = fork();
        if (pid == 0) { /* child process */
                fork();
                thread_create( . . .);
        }
        fork();
        return 0;
}
```

How many unique processes are created?

How many unique threads are created by `thread_create( . . .)`?

Draw the process and thread tree.

Process and thread tree for question in slide 4.24



Linux Threads

- Linux treats processes and threads the same.
- Linux refers to them as ***tasks*** rather than ***threads***
- Thread creation as discussed here can be achieved through **`clone()`** system call by setting appropriate flags (enables behaviors) in the system call.

flag	meaning
CLONE_FS	File-system information is shared.
CLONE_VM	The same memory space is shared.
CLONE_SIGHAND	Signal handlers are shared.
CLONE_FILES	The set of open files is shared.

- clone() is better than fork() as it offers fine grained control in creating the child process and allows a child task to share the address space of the parent task (process)

Implicit Threading

- In **Implicit Threading**, creation and management of threads done by compilers and run-time libraries rather than programmers
- Three methods explored
  - Thread Pools
  - OpenMP
  - Grand Central Dispatch