Processes - Part II

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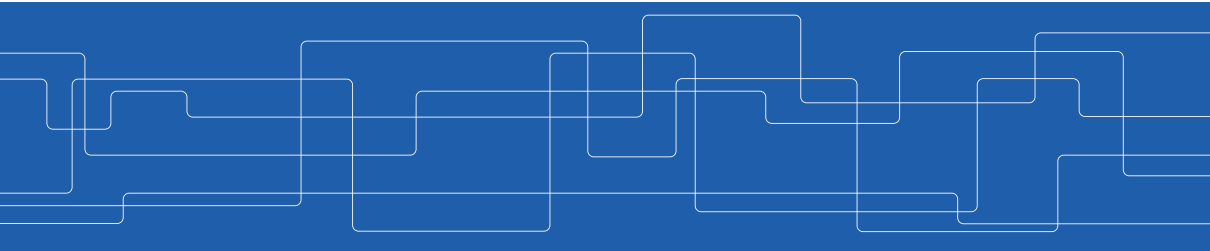
2022



Threads

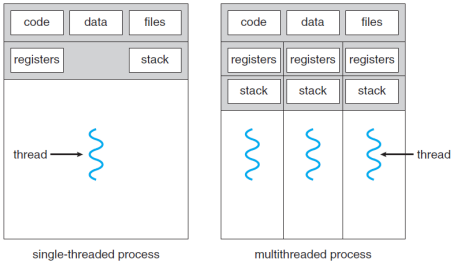
Thread

A basic unit of CPU utilization.

https://tinyurl.com/e8crhtne

Threads (1/2)

- A traditional process: has a single thread.



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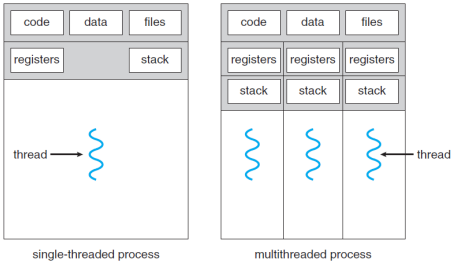
- Multiple threads in a process: performing more than one task at a time.



Threads (1/2)

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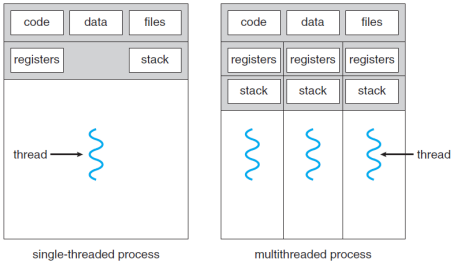
- Multiple threads in a process: performing more than one task at a time.
- Threads in a process share code section, data section, and other OS resources, e.g., open files.

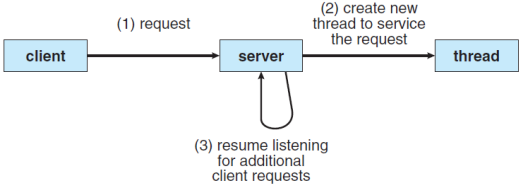


Threads (2/2)

- Multiple tasks of an application can be implemented by separate threads.
  - Update display
  - Fetch data
  - Spell checking
  - Answer a network request

Threads - Example

- Multi-threaded web-server architecture



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- Economy: thread switching has lower overhead than context switching.
- Scalability: process can take advantage of multiprocessor architectures.

Multi-core Programming

Multi-core Systems

- Users need more computing performance: single-CPU → multi-CPU

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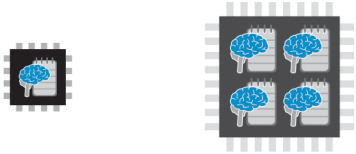

- Multi-threaded programming
  - Improves concurrency and more efficient use of multiple cores.

Concurrency vs. Parallelism (1/2)

- Concurrency: supporting more than one task by allowing all the tasks to make progress.

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  - A scheduler providing concurrency.

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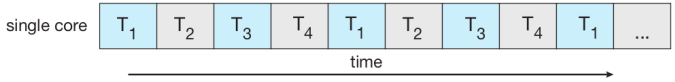
- Concurrent execution on a single-core system.



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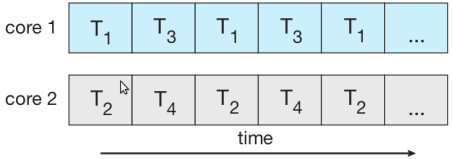
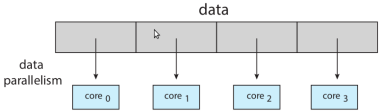


Types of Parallelism

- Data parallelism
  - Distributes subsets of the same data across multiple cores, same operation on each.



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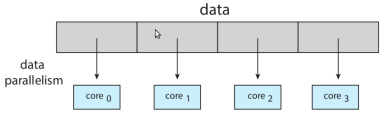
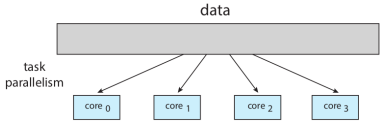


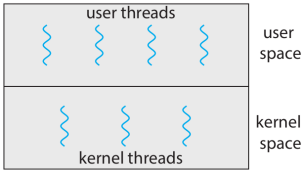
- Task parallelism
  - Distributes threads across cores, each thread performing unique operation.



Multi-threading Models

User Threads and Kernel Threads

- User threads: managed by user-level threads library.
- Kernel threads: supported by the Kernel.



User Threads and Kernel Threads

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  - Three primary thread libraries:
  - POSIX pthreads
  - Windows threads
  - Java threads
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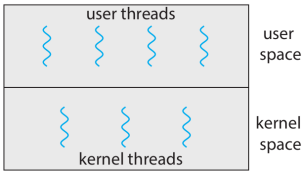
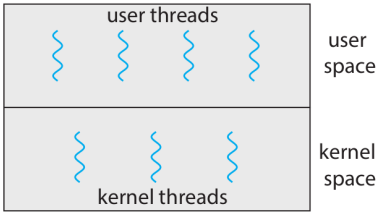


Multi-Threading Models

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



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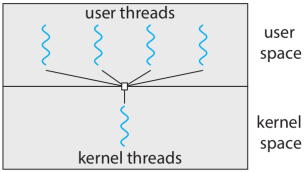

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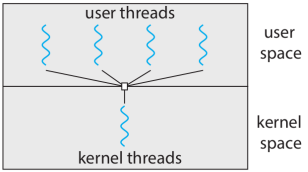

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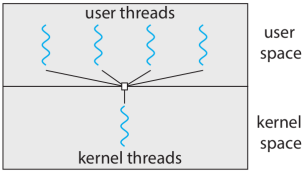

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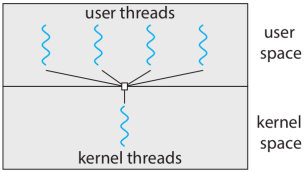
- Few systems currently use this model.
  - Solaris green threads
  - GNU portable threads



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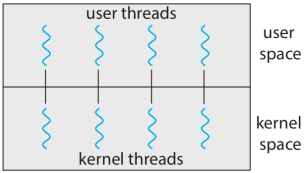

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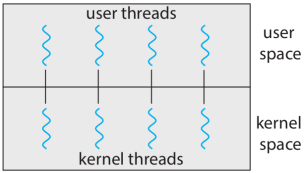

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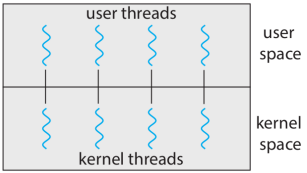

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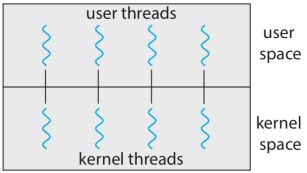

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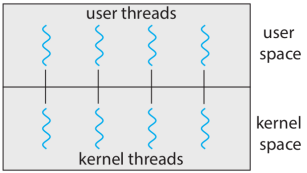
- Examples:
  - Windows
  - Linux



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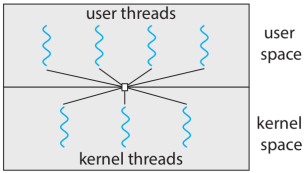

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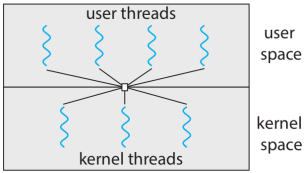
- Allows many user-level threads to be mapped to many kernel threads.
- Allows the OS to create a sufficient number of kernel threads.



Many-to-Many Model

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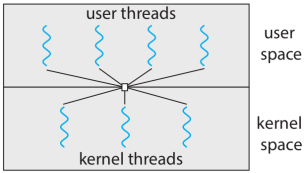
- Allows the OS to create a sufficient number of kernel threads.
- Examples:
  - Windows with the ThreadFiber package
  - Otherwise not very common



Thread Libraries

Thread Libraries (1/2)

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- Two primary ways of implementing:
  - Library entirely in user-space.
  - Kernel-level library supported by the OS.

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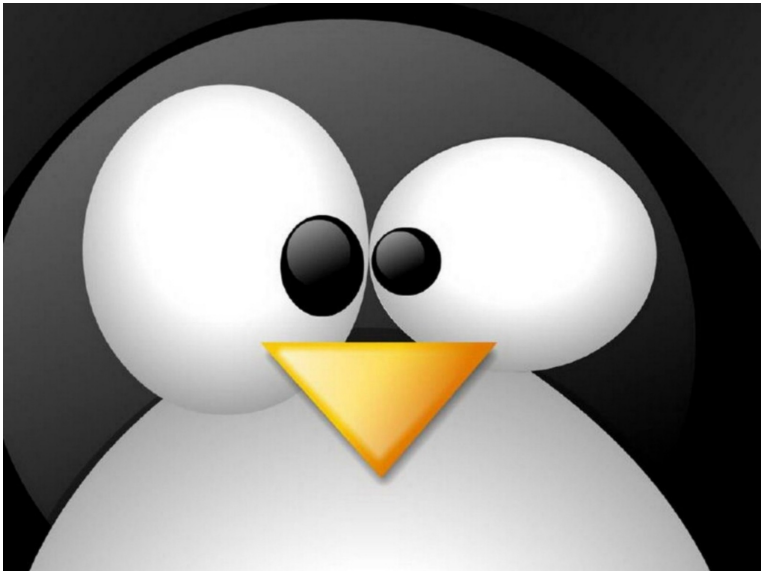
- Java thread
  - Uses a thread library available on the host system.



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- API specifies behavior of the thread library, implementation is up to development of the library.
- Common in UNIX OSs, e.g., Solaris, Linux, Mac OS X

Thread ID

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- The PID is assigned by the Linux kernel, and TID is assigned in the Pthread library.
- Represented by `pthread_t`.
- Obtaining a TID at runtime:

```
#include <pthread.h>

pthread_t pthread_self(void);
```

Creating Threads

- `pthread_create()` defines and launches a new thread.

```
#include <pthread.h>

int pthread_create(pthread_t *thread, const pthread_attr_t *attr,
  void *(*start_routine)(void *), void *arg);
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- `start_routine` has the following signature:

```
void *start_thread(void *arg);
```

Terminating Threads

- Terminating yourself by calling `pthread_exit()`.

```c
#include <pthread.h>

void pthread_exit(void *retval);
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#include <pthread.h>

void pthread_exit(void *retval);
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- Terminating others by calling `pthread_cancel()`.

```
#include <pthread.h>

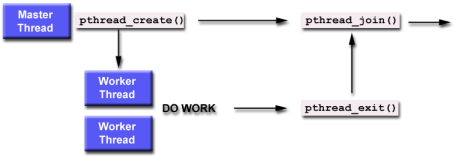
int pthread_cancel(pthread_t thread);
```

Joining and Detaching Threads

- Joining allows one thread to block while waiting for the termination of another.

```c
#include <pthread.h>

int pthread_join(pthread_t thread, void **retval);
int pthread_detach(pthread_t thread);
```



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Joining and Detaching Threads

- Joining allows one thread to block while waiting for the termination of another.
- You use join if you care about what value the thread returns when it is done, and use detach if you do not.

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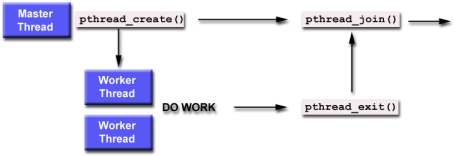

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A Threading Example

```c
void *start_thread(void *message) {
  printf("%s\n", (const char *)message);
  return message;
}

int main(void) {
  pthread_t thread11, thread2;
  const char *message1 = "Thread 1";
  const char *message2 = "Thread 2";

  // Create two threads, each with a different message.
  pthread_create(&thread1, NULL, start_thread, (void *)message1);
  pthread_create(&thread2, NULL, start_thread, (void *)message2);

  // Wait for the threads to exit.
  pthread_join(thread1, NULL);
  pthread_join(thread2, NULL);

  return 0;
}
```

Implicit Threading

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- Four methods explored:
  - Thread Pools
  - Fork-Join
  - OpenMP
  - Grand Central Dispatch

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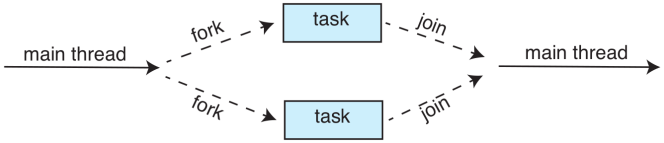
- Create a number of threads in a pool where they await work.
- Usually slightly faster to service a request with an existing thread than create a new thread.
- Allows the number of threads in the application(s) to be bound to the size of the pool.

Fork-Join (1/2)

- Multiple threads (tasks) are forked, and then joined.



Fork-Join (2/2)

```
Task(problem)
   if problem is small enough
      solve the problem directly
   else
      subtask1 = fork(new Task(subset of problem))
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      result1 = join(subtask1)
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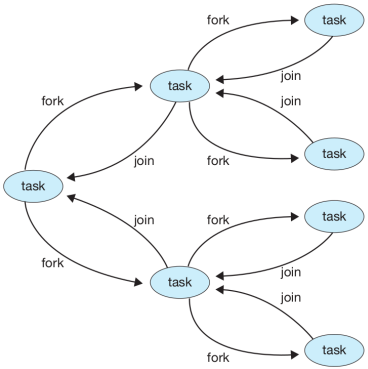

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- Identifies parallel regions: blocks of code that can run in parallel.
- `#pragma omp parallel`: create as many threads as there are cores.
- `#pragma omp parallel for`: run for loop in parallel.

OpenMP (2/2)

```c
#include <omp.h>
#include <stdio.h>

int main(int argc, char *argv[]) {

  /* sequential code */

  #pragma omp parallel
  {
    printf("I am a parallel region.");
  }

  /* sequential code */

  return 0;
}
```

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```
dispatch_queue_t queue = dispatch_get_global_queue(DISPATCH QUEUE PRIORITY DEFAULT, 0);

dispatch_async(queue, ^{ printf("I am a block."); });
```

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- Thread-Local Storage (TLS)

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- `exec()` usually works as normal: replace the entire process, including all threads.

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  - Assign a specific thread to receive all signals for the process.

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- Two general approaches:
  - Asynchronous cancellation terminates the target thread immediately.
  - Deferred cancellation allows the target thread to periodically check if it should be cancelled.

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  - TLS visible across function invocations.

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Questions?

Acknowledgements

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