EECS 3221
Operating System Fundamentals

No. 3

Thread

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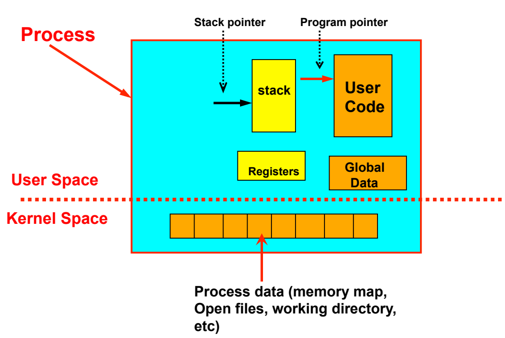
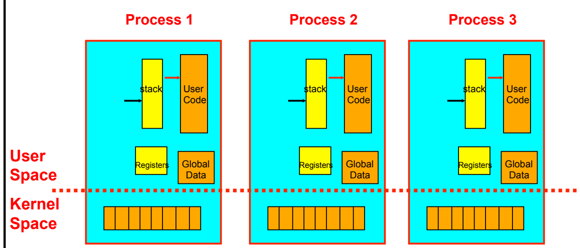
Thread Concept

- What is thread?
- Difference between a process and a thread

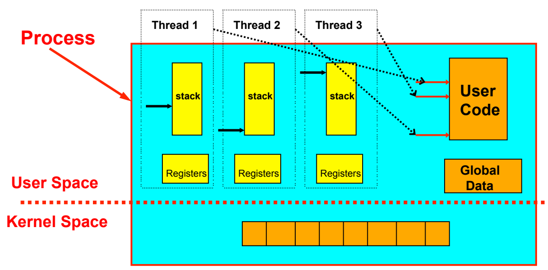
One single-threaded Process



Multiple single-threaded Process



One multi-threaded Process



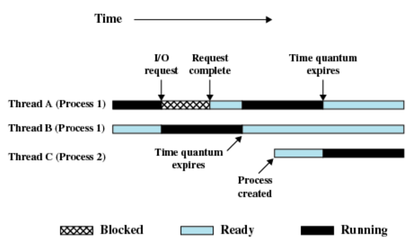
Process vs. Thread

- Traditional process contains a single stream of control.
  (one process can do one thing at a time)
- Multithreaded process: contains several different streams of control. Each stream is called a thread of this process.
  (multithreaded process can do multiple jobs simultaneously)
- A multi-threaded process contains several threads.
- All threads in a process share:
  - Code section & data section
  - OS resources (memory map, open devices, accounting, etc.)
- Each thread includes:
  - A thread ID
  - A program counter (PC)
  - A register set
  - A stack & stack pointer

Comparison

- One single-threaded process:
  - can do one thing at a time
- Multiple single-threaded processes:
  - can do many things at the same time
- One multi-threaded process
  - Also can do many things at the same time
- Why multiple thread??
  - Multi-threaded process requires less OS resources (memory)
  - More efficient for OS to handle threads than processes

Multithreading



Multithreading Example on a Uniprocessor

Benefits to use threads

- Threads occupy less memory than processes.
- Takes less time to create a new thread than a process.
- Less time to terminate a thread than a process.
- Less time to switch context between two threads within the same process.
- Since threads within the same process share memory and files, they can communicate with each other without invoking the kernel.

Thread-safe or Reentrant code

- To be thread safe, the program must be reentrant:
  - Program never modifies itself.
  - Each function calling keeps track of its own progress.
  - No use of static/global data.
  - No use of non-reentrant functions or routines.

Non-reentrant C code

```
int delta;

int diff (int x, int y)
{
    delta = y - x;
    if (delta < 0) delta = -delta;
    return delta;
}
```

Reentrant C code

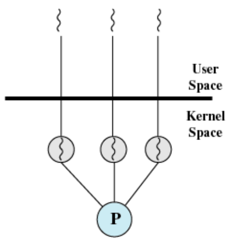
```
int diff (int x, int y)
{
    int delta;

    delta = y - x;
    if (delta < 0) delta = -delta;
    return delta;
}
```

Kernel Threads

- Kernel threads are supported directly by OS kernel.
- The kernel performs thread creation, scheduling, and management in the kernel space.
- Slow to maintain (need system calls to kernel space).
- Each kernel thread can run totally independently:
  - One thread blocks, the kernel will schedule another thread to run.
  - Several kernel threads can run in parallel if many CPU's are available.
  - OS to support kernel thread:
    - Windows NT/2000/XP
    - Solaris 2
    - Linux

Directly Use Kernel Threads

- For each user task, make system call to create a kernel thread.



(b) Pure kernel-level

Example of Kernel Thread: Linux Thread

- Linux kernel support kernel threads, system call *clone().*
- *fork()* creates a new process
  - Create a new memory space for new process
  - Copy from the address space of the calling process
- *clone()* simulates *fork(),* but
  - It does not create new memory space.
  - The new process shares the same address space of the original process.
  - → two processes sharing the same memory space. (something like thread)

Linux Thread

- Linux use `clone()` to create kernel threads.

```
#include <sched.h>
 int clone(int (*fn)(void *), void
  *child_stack, int flags, void *arg);
```

fn: starting function
child_stack: stack memory space for child thread.
flags: what to share.
for thread creation:
flags = CLONE_FS | CLOSE_VM | CLONE_SIGHAND | CLONE_FILES
arg: arguments to pass.

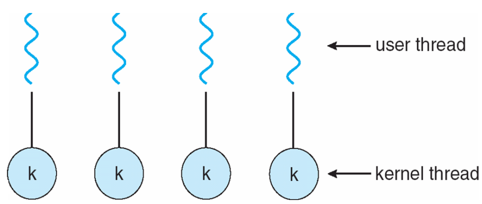
User Thread

- User thread: supported above the kernel and implemented by a thread library in user space.
  - The library supports thread creation, scheduling, management in user space.
  - User threads are fast to create and manage (no need to make a system call to trap to the kernel).
  - User threads for better compatibility across OS platforms.
  - User threads save kernel resources.
- Problems with user threads:
  - The kernel is not aware of the existence of users threads.
  - User thread must be mapped to the kernel to execute in CPU.
- Examples: POSIX Threads (Pthreads), Java Threads, Win32 Threads, Solaris UI-threads

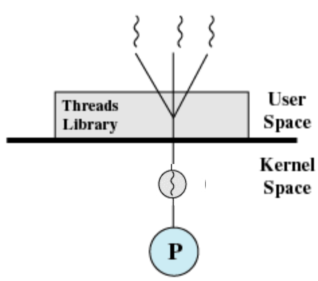
Three Models for User Thread

- One-to-One mapping
- Many-to-One Mapping
- Many-to-Many Mapping

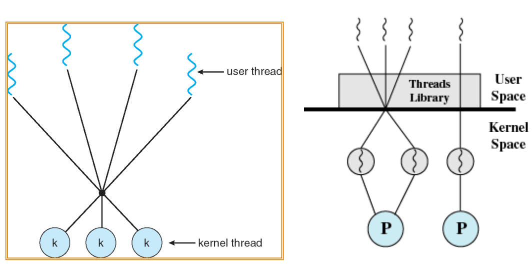
One-to-One Mapping



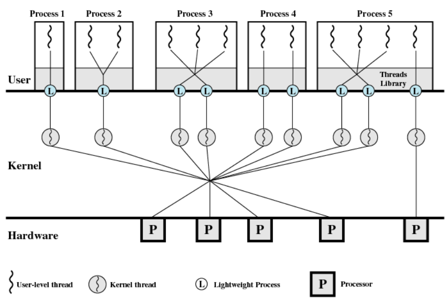
Many-to-One Mapping



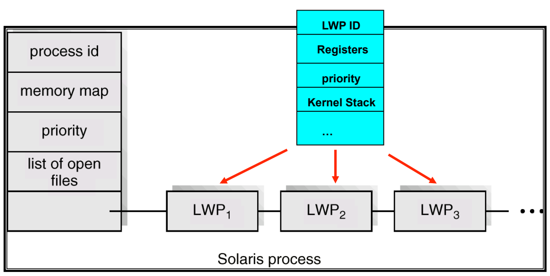
Combined Model: many-to-many mapping



Solaris Threads



Thread data structure in Solaris



Threading Issues

- *fork()* and *exec()* implementation
  - One thread calls *exec()*, it will replace the entire process.
  - One thread in a process call *fork()*, it duplicates all threads in the process or just one calling thread.
- Thread cancellation: terminating a thread before it finishes.
  - Asynchronous cancellation
  - Deferred cancellation
- Unix Signal Handling
  - 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

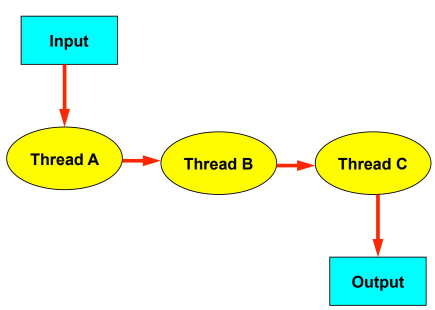
Thread Pools

- Create a number of threads at process start-up, place them into a pool, where they sit and wait for work.
- When the process receives a request, it awakens a thread from the pool, and serves the request immediately.
- Once the thread completes, it returns to the pool.
- If the pool contains no available thread, the process waits until one becomes free.
- Benefits of thread pools:
  - Faster to service a request.
  - Thread pool limits the total number of threads in system (no overload).

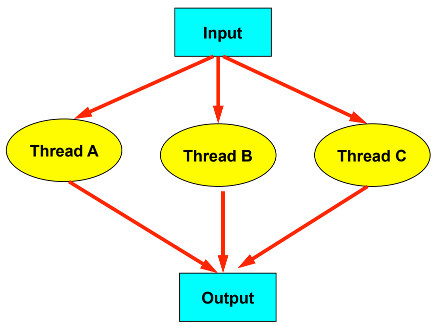
Three Models to use Threads

- Pipeline
  - Assembly line: each thread repeatedly performs the same operation on a sequence of data sets, passing each result to another thread for next step.
- Work Crew
  - Each thread performs an operation on its own data independently, then combine all results to get the final.
- Client/Server
  - A client contacts with an independent server for each job.

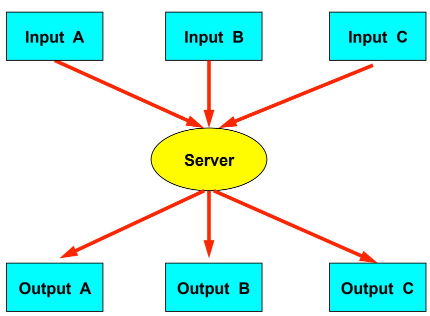
Pipeline



Work Crew



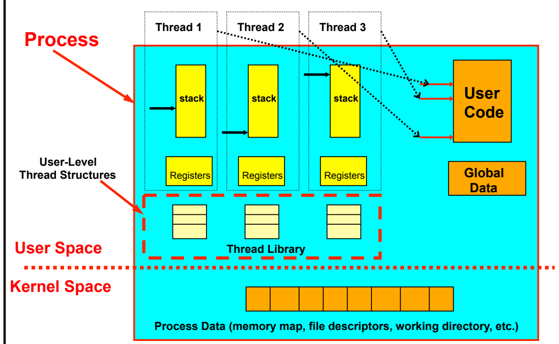
Client/Server



User Threads: Pthreads

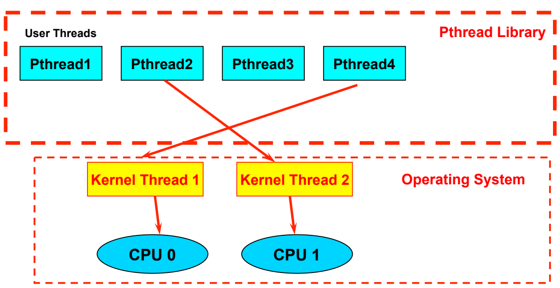
- A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization.
- API specifies behavior of the thread library, implementation is up to development of the library.
- Common in UNIX operating systems (Solaris, Linux, Mac OS X).

Multi-threaded Process in Pthreads



Multithread programming

- User thread vs. kernel thread
- Multithreaded programming with POSIX thread (Pthread)



POSIX Thread (1)

- Thread creation and termination:

```
#include <pthread.h>

pthread_create(pthread_t *thread, const pthread_attr_t
        *attr, void *(*start) (void *), void *argv) ;

        pthread_exit(void *value_ptr) ;
```

POSIX thread(2)

- Wait for another thread to terminate

pthread_join(pthread_t thread, void **value_ptr) ;

- Cancellation

pthread_cancel(pthread_t thread) ;

- Others

pthread_self(void) ;
pthread_detach(pthread_t thread) ;
pthread_attr_init(pthread_attr_t *attr) ;

Example 1: thread.c

- Example: thread.c (How to use pthread)
- Two threads:
  - *main*() thread
  - *runner*() thread

Example 2: alarm.c

- Example 1: alarm.c (no process/thread)
- Example 2: alarm_fork.c (multiple process)
- Example 3: alarm_thread.c (multiple thread)