CSCI [4|6]730
Operating Systems

Threads

Chapter 2: Threads: Questions

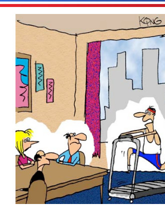
- How is a thread different from a process?
- Why are threads useful?
- How can POSIX threads be useful?
- What are user-level and kernel-level threads?
- What are problems with threads?

Course Philosophy

- **Textbook / Course difference**
  - » **Threads**
  - » **Scheduling**
  - » **Synchronization**
  - » **Interrupt (I/O)**
- **Practice/Practical Considerations**
- **Incremental Programming (HW)**

Review: What is a Process?

A process is a program in execution…



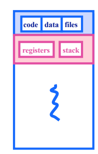
A thread have

(1) an execution stream and

(2) a context

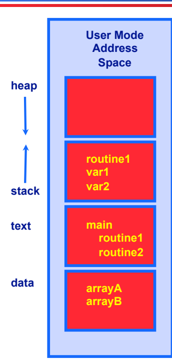
- **Execution stream**
  - » **stream of instructions**
  - » **sequential sequence of instructions**
  - » **“thread” of control**
- **Process ‘context’ (seen picture of this already)**
  - » **Everything needed to run (restart) the process …**
  - » **Registers**
    - – **program counter, stack pointer, general purpose…**
  - » **Address space**
    - – **Everything the process can access in memory**
    - – **Heap, stack, code**

Running on a thread



Review: What Makes up a Process?

- **Program code (text)**
- **Data**
  - » **global variables**
  - » **heap (dynamically allocated memory)**
- **Process stack**
  - » **function parameters**
  - » **return addresses**
  - » **local variables and functions**
- **OS Resources**
- **Registers**
  - » **program counter, stack pointer**



address space are the shared resources of a(ll) thread(s) in a program

What are are problem’s with Processes?

- **How do processes (*independent* memory space) *communicate*?**
  - » **Not really that simple (seen it, tried it – and you have too):**
    - – **Message passing (send and receive)**
    - – **Shared Memory: Set up a shared memory area (easier)?**
- **Problems:**
  - » **Overhead: Both methods add some kernel overhead lowering performance**
  - » **Complicated: IPC is not really that ‘natural’**
    - – **increases the complexity of your code**

Processes versus Threads

Solution: A thread is a "lightweight process" (LWP)

- An execution stream that shares an address space
  - » Overcome data flow over a file descriptor
  - » Overcome setting up `tighter memory' space
- Multiple threads within a single process

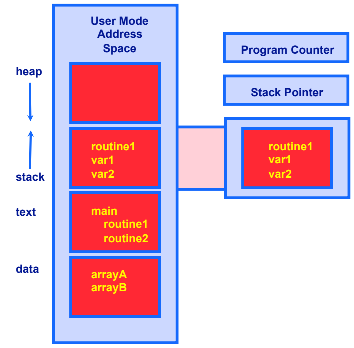
```
main()
   {
   i = 55;
   fork();
   // what is i
```

Examples:

- Two processes (copies of each other) examining memory address `0xffe84264` see different values (i.e., different contents)
  - » same frame of reference
- Two threads examining memory address `0xffe84264` see same value (i.e., same contents)
- Illustrate: i-threading.c, i-forking.c

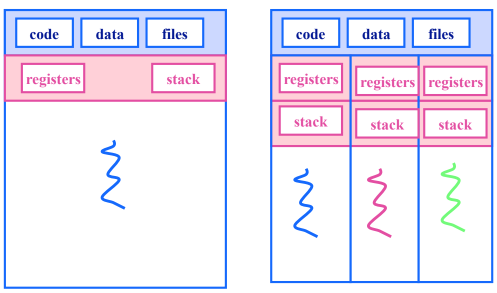
What Makes up a Thread?

- Own stack (necessary?)
- Own registers (necessary?)
  - » Own program counter
  - » Own stack pointer
- State (running, sleeping)
- Signal mask



address space are the shared resources of a(ll) thread(s) in a program

Single and Multithreaded Process



Why Support Threads?

- *Divide large task across several cooperative threads*
- Multi-threaded task has many performance benefits

- Examples:
  - » Web Server: create threads to:
    - Get network message from client
    - Get URL data from disk
    - Compose response
    - Send a response
  - » Word processor: create threads to:
    - Display graphics
    - Read keystrokes from users
    - Perform spelling and grammar checking in background

Why Support Threads?

- Divide large task across several cooperative threads
- *Multi-threaded task has many performance benefits*

- Adapt to slow devices
  - » One thread waits for device while other threads computes
- Defer work
  - » One thread performs non-critical work in the background, when idle
- Parallelism
  - » Each thread runs simultaneously on a multiprocessor

Why Threads instead of a Processes?

- Advantages of Threads:
  - » Thread operations cheaper than corresponding process operations
    - In terms of: Creation, termination, (context) switching
  - » IPC cheap through shared memory
    - No need to invoke kernel to communicate between threads
- Disadvantages of Threads:
  - » True Concurrent programming is a challenge (what does this mean? True concurrency?)
  - » Synchronization between threads needed to use shared variables (more on this later – this is HARD).

Why are Threads Challenging? pthread1 Example: Output?

```
main()
{
   pthread_t t1, t2;
   char *msg1 = "Thread 1"; char *msg2 = "Thread 2";
   int ret1, ret2;
   ret1 = pthread_create( &t1, NULL, print_fn, (void *)msg1 );
   ret2 = pthread_create( &t2, NULL, print_fn, (void *)msg2 );
   if( ret1 || ret2 )
   {
     fprintf(stderr, "ERROR: pthread_created failed.\n");
     exit(1);
   }
   pthread_join( t1, NULL );
   pthread_join( t2, NULL );
   printf( "Thread 1 and thread 2 complete.\n" );
}
void print_fn(void *ptr)
{
   printf("%s\n", (char *)ptr);
}
```


Why are Threads Challenging?

- Example: Transfer `$50.00` between two accounts and output the total balance of the accounts:

  `M` = Balance in Maria's account (begin `$100`)
  `T` = Balance in Tucker's account (begin `$50`)
  `B` = Total balance

- Tasks:

```
T = 50, M = 100
M = M - $50.00
T = T + $50.00
B = M + T
```

Idea: on distributing the tasks:
(1) One thread debits and credits
(2) Another Totals
Does that work

Why are Threads Challenging?

- Tasks:

```
T = 50, M = 100
M = M - $50.00   } One thread debits
T = T + $50.00   } & credits
B = M + T        } One thread totals
```

`M = M - $50.00`	`M = M - $50.00`	`B = M + T`
`T = T + $50.00`	`B = M + T`	`M = M - $50.00`
`B = M + T`	`T = T + $50.00`	`T = T + $50.00`
`B = $150`	`B = $100`	`B = $150`

Common Programming Models

- Manager/worker
  - » Single manager handles input and assigns work to the worker threads
- Producer/consumer
  - » Multiple producer threads create data (or work) that is handled by one of the multiple consumer threads
- Pipeline
  - » Task is divided into series of subtasks, each of which is handled in series by a different thread

Thread Support

- Three approaches to provide thread support
  - » User-level threads
  - » Kernel-level threads
  - » Hybrid of User-level and Kernel-level threads

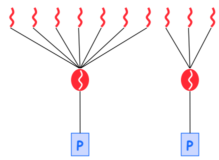
Latencies

- Comparing user-level threads, kernel threads, and processes.
- Null fork: the time to create, schedule, execute, and complete the entity that invokes the null procedure (overhead of creating a thread)
- Signal-Wait: the time for an entity to signal a waiting entity and then wait on a condition (overhead of synchronization)

Procedure call = 7 us Kernel Trap = 17 us	User Level Threads	Kernel Level Threads	Processes
Null fork	34	948	11,300
Signal-wait	37	441	1,840

User-Level Threads

- Many-to-one thread mapping
  - » Implemented by user-level runtime libraries
    - – Create, schedule, synchronize threads at user-level
  - » OS is not aware of user-level threads
    - – OS thinks each process contains only a single thread of control



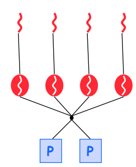
- Advantages
  - » Does not require OS support; Portable
  - » Can tune scheduling policy to meet application (user level) demands
  - » Lower overhead thread operations since no system calls
- Disadvantages
  - » Cannot leverage multiprocessors (no true parallelism)
  - » Entire process blocks when one thread blocks

Blocked UL Threads: Jacketing

- Avoids 'blocking' on system calls that block (e.g., I/O)
- Solution:
  - » Instead of calling a blocking system call call an application level I/O jacket routine (a nonblocking call)
  - » Jacket routine provides code that determines whether I/O device is busy or available (idle).
  - » Busy:
    - – Thread enters the ready state and passes control to another thread
    - – Control returns to thread it retries
  - » Idle:
    - – Thread is allowed to make system call.

Kernel-Level Threads

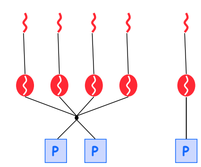
- One-to-one thread mapping
  - » OS provides each user-level thread with a kernel thread
  - » Each kernel thread scheduled independently
  - » Thread operations (creation, scheduling, synchronization) performed by OS



- Advantages
  - » Each kernel-level thread can run in parallel on a multiprocessor
  - » When one thread blocks, other threads from process can be scheduled
- Disadvantages
  - » Higher overhead for thread operations
  - » OS must scale well with increasing number of threads

Two-Level Model

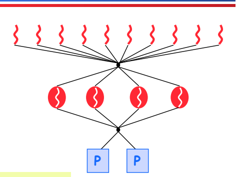
- one-one & (strict) many-to-many
  - » OS provides each user-level thread with a kernel thread
  - » Supports both bound an unbound threads
    - – Bound threads - permanently bound to a single kernel level thread
    - – Unbound threads may move to other kernel threads



- Advantages
  - » Flexible, best of two worlds
- Disadvantages
  - » More complicated

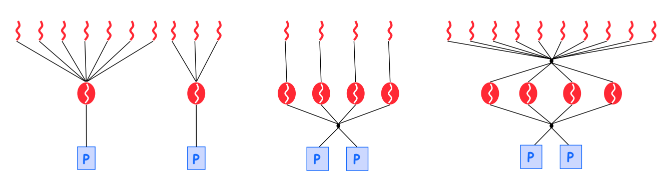
Hybrid of Kernel & User -Level Threads

- m - n thread mapping (many to many)
  - » Application creates m threads
  - » OS provides *pool* of n kernel threads
  - » Few user-level threads mapped to each kernel-level thread



- Advantages
  - » Can get best of user-level and kernel-level implementations
  - » Works well given many short-lived user threads mapped to constant-size pool
- Disadvantages
  - » Complicated…
  - » How to select mappings?
  - » How to determine the best number of kernel threads?
    - – User specified
    - – OS dynamically adjusts number depending on system load

Thread Models



- Kernel Level: Windows 95/98/NT/2000, Solaris, Linux
- User Level: POSIX Pthreads, Mach, C-threads, Solaris threads
- Hybrids: IRIX, HP-UX, True 64 UNIX, Older Solaris models

Threading Issues: fork() & exec()

- fork()
  - Duplicate all threads?
  - Duplicate only the thread that performs the fork
  - Resulting new process is single threaded?
  - -> solution provide two different forks
- exec()
  - Replaces the process - including all threads?
  - If exec is after fork then replacing all threads is unnecessary.

Threading Issues: Cancellation

- Example 1: User pushes top button on a web browsers - while other threads are images (one thread per image).
- Example 2: Several threads concurrently searches data base and one thread finds target data.
- Asynchronous Cancellation: Immediate (OS need to reclaim resources)
- Deferred Cancellation: Thread terminates it self when notices it is scheduled for termination.

Threading Issues: Threads and Signals

- Problem: To which thread should OS deliver signal?
- Option 1: Require sender to specify thread ID (instead of process id)
  - Sender may not know about individual threads
- Option 2: OS picks destination thread
  - POSIX: Each thread has signal mask (disable specified signals)
  - OS delivers signal to all threads without signal masked
  - Application determines which thread is most appropriate for handing signal
- Synchronous - delivered to the same process that caused the signal
- Asynchronous - event is external to running process.

Other Thread Issues

- Creating thread is costly…
- No bound of number of threads…

Thread Pools

- Create a number of threads in a pool where a number of threads await work
- Advantages:
  - Usually slightly faster to service a request with an existing thread than waiting to create a new thread
  - Allows the number of threads in the application(s) to be bound to the size of the pool
- The number of threads can be set heuristically based on the hardware and can even be dynamically adjusted taking into account user statistics.

IPC: Shared Memory

- Processes
  - Each process has private address space
  - Explicitly set up shared memory segment within each address space
- Threads
  - Always share address space (use heap for shared data)
- Advantages
  - Fast and easy to share data
- Disadvantages
  - Must *synchronize* data accesses; error prone (later)

IPC: Message Passing

- Message passing most commonly used between processes
  - » Explicitly pass data between sender (src) + receiver (destination)
  - » Example: Unix pipes
- Advantages:
  - » Makes sharing explicit
  - » Improves modularity (narrow interface)
  - » Does not require trust between sender and receiver
- Disadvantages:
  - » Performance overhead to copy messages
- Issues:
  - » How to name source and destination?
    - – One process, set of processes, or mailbox (port)
  - » Does sending process wait (I.e., block) for receiver?
    - – Blocking: Slows down sender
    - – Non-blocking: Requires buffering between sender and receiver

IPC: Signals

- Signal
  - » Software interrupt that notifies a process of an event
  - » Examples: SIGFPE, SIGKILL, SIGUSR1, SIGSTOP, SIGCONT
- What happens when a signal is received?
  - » Catch: Specify signal handler to be called
  - » Ignore: Rely on OS default action
    - – Example: Abort, memory dump, suspend or resume process
  - » Mask: Block signal so it is not delivered
    - – May be temporary (while handling signal of same type)
- Disadvantage
  - » Does not specify any data to be exchanged
  - » Complex semantics with threads

Old Quiz

1. What resources (context) within a process are shared between threads?
   - » (5) Address space
2. What resources (context) cannot be shared among threads within the same process?
   - » (3) A thread need: (3) Own stack and (5) registers [missing one -2]
3. What happens to other threads within the same process when a thread reads from disk?
   - » (5) Blocks (3) if user level (2)
4. Name a user level thread package?
   - » (5) P-threads (posix threads)
5. Do Java threads use kernel or user level threads (Justify your answer)?
   1. (4) 3 for a guess (4) for correct

Scheduler Activations Notes (Open Slot)

- Provides better OS support for user level threading
  - » Dynamic adjustment of number of kernel level threads to user level threads:
    - – E.g. Two level and the m:n thread models need to maintain appropriate ratios
  - » Key Idea: Kernel notifies thread scheduler of all kernel events via upcalls

Scheduler Activations

- Use an intermediate data structure between user/kernel level threads.
- Details: User level threads run and are scheduled (by the user level scheduler) on 'virtual processor'
  - » A data structure or light-weigh process (LWP) that is between the kernel thread and the user thread.
  - » Each LWP is attached to a kernel thread and kernel threads are what the OS schedules to run on physical processors.

Scheduler Activations

- An application may require any number of LWPs to run efficiently.
  - » Example: A CPU-bound application on a single processor.
    - – Needs only one LWP.
  - » Example: An I/O-bound application
    - – May need many LWPs- one for each concurrent blocking system since if there are not enough LWPs, the unassigned threads must wait for one of the LWPs to return from the kernel.

Scheduler Activations

- Why not a user level thread scheduler that spawns a kernel thread for blocking operations?
  - Forget spawning, use a pool of kernel threads.
  - But how do we know if an operation will block?
    - read might block, or data might be in page cache.
    - Any memory reference might cause a page fault to disk.
- Scheduler Activations
- Kernel tells user when a thread is going to block, via an **upcall**.
  - Kernel can provide a kernel thread to run the user-level upcall handler (or preempt user thread).
  - User-level scheduler suspends blocking thread and can give back kernel thread it was running on.

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