Operating Systems

05. Threads

Paul Krzyzanowski
Rutgers University
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Thread of execution

Single sequence of instructions
- Pointed to by the program counter (PC)
- Executed by the processor

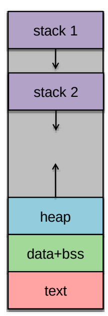
Conventional programming model & OS structure:
- Single threaded
- One process = one thread

Multi-threaded model

A thread is a subset of a process:
- A process contains one or more kernel threads

Share memory and open files
- BUT:
  separate program counter, registers, and stack
- Shared memory includes the heap and global/static data
- No memory protection among the threads

Preemptive multitasking:
- Operating system preempts & schedules threads



Sharing

Threads share:
- Text segment (instructions)
- Data segment (static and global data)
- BSS segment (uninitialized data)
- Open file descriptors
- Signals
- Current working directory
- User and group IDs

Threads do not share:
- Thread ID
- Saved registers, stack pointer, instruction pointer
- Stack (local variables, temporary variables, return addresses)
- Signal mask
- Priority (scheduling information)

Why is this good?

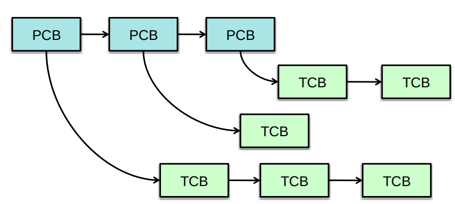
Threads are more efficient
- Much less overhead to create: no need to create new copy of memory space, file descriptors, etc.

Sharing memory is easy (automatic)
- No need to figure out inter-process communication mechanisms

Take advantage of multiple CPUs – just like processes
- Program scales with increasing # of CPUs
- Take advantage of multiple cores

Implementation

Process info (Process Control Block) contains one or more Thread Control Blocks (TCB):
- Thread ID
- Saved registers
- Other per-thread info (signal mask, scheduling parameters)



Scheduling

A thread-aware operating system scheduler schedules *threads*, not *processes*

– A process is just a container for one or more threads

Scheduling Challenges

Scheduler has to realize:

- Context switch among threads of different processes is more expensive
  – Flush cache memory (or have memory with process tags)
  – Flush virtual memory TLB (or have tagged TLB)
  – Replace page table pointer in memory management unit
- CPU Affinity
  – Rescheduling threads onto a different CPU is more expensive
  – The CPU's cache may have memory used by the thread cached
  – *Try to reschedule the thread onto the same processor on which it last ran*

Process vs. Thread context switch

A thread switch within the same process is not a full context switch
– the address space (memory map) does not get switched

```
linux/arch/i386/kernel/process.c:

/* Re-load page tables for a new address space */
{
    unsigned long new_cr3 = next->tss.cr3;
    if (new_cr3 != prev->tss.cr3)
        asm volatile("movl %0,%%cr3": :"r" (new_cr3));
}
```

This statement tests if the new task has the same memory map as the current one. If so, we're switching threads and will not run the instruction to switch the memory mapping tables

Multi-threaded programming patterns

Single task thread
– Do a specific job and then release the thread

Worker threads
– Specific task for each worker thread
– Dispatch task to the thread that handles it

Thread pools
– Create a pool of threads *a priori*
– Use an existing thread to perform a task; wait if no threads available
– Common model for servers

Kernel-level threads vs. User-level threads

Kernel-level
– Threads supported by operating system
– OS handles scheduling, creation, synchronization

User-level
– Library with code for creation, termination, scheduling
– Kernel sees one execution context: one process
– May or may not be preemptive

User-level threads

Advantages
– Low-cost: user level operations that do not require switching to the kernel
– Scheduling algorithms can be replaced easily & custom to app
– Greater portability

Disadvantages
– If a thread is blocked, all threads for the process are blocked
  - Every system call needs an asynchronous counterpart
– Cannot take advantage of multiprocessing

You can have both

User-level thread library on top of multiple kernel threads

1:1 – kernel threads only
(1 user thread = 1 kernel thread

N:1 – user threads only
(*N* user threads on *1* kernel thread/process)

N:M – hybrid threading
(*N* user threads on *M* kernel threads)

pthreads: POSIX Threads

- POSIX.1c, Threads extensions (IEEE Std 1003.1c-1995)
  - Defines API for managing threads
- Linux: native POSIX Thread Library
- Also on Solaris, Mac OS X, NetBSD, FreeBSD
- API library on top of Win32

Using POSIX Threads

Create a thread

```
pthread_t t;
pthread_create(&t, NULL, func, arg)
```

- Create new thread *t*
- Start executing function *func(arg)*

Join two threads (wait for thread *t* to terminate)

```
void *ret_val;
pthread_join(t, &ret_val);
```

- Thread *t* exits via *return* or *pthread_exit*

No parent/child relationship among threads!

- Any one thread may wait (join) on another thread

A different approach to threads

- Threads force a highly-shared model
  - Memory map, signals, open files, current directory, etc. all shared
- Processes force a non-shared model
  - Separate memory, open files, etc.
- What if we allow the user to specify what is shared when a new process is created?
  - Then we don't need threads since processes can share all memory if they want to … and open files … and anything else

Linux threads

- Linux has no concept of a thread
- All threads implemented as standard processes
  - No special scheduling semantics
  - All processes defined in the kernel by `task_struct`
- Support thread-like behavior via *clone* system call
  - Designed to implement threads
  - A process can control what gets shared with a new process
  - Based on Plan 9's *rfork* system call

Linux *clone()* system call

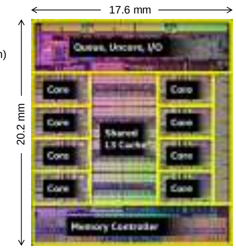
- Clone a process, like *fork,* but:
  - Specify function that the child will run (with argument)
    - Child terminates when the function returns
  - Specify location of the stack for the child
  - Specify what's shared:
    - Share memory (otherwise memory writes use new memory)
    - Share open file descriptor table
    - Share the same parent
    - Share root directory, current directory, and permissions mask
    - Share namespace (mount points creating a directory hierarchy)
    - Share signals
    - *And more…*
- Used by pthreads

Threading in hardware

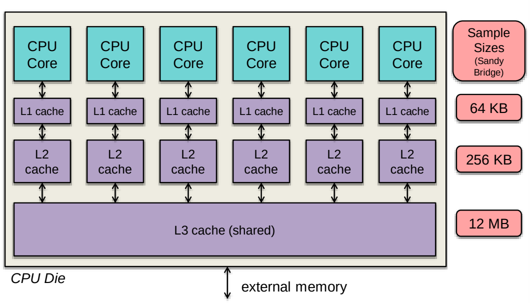
- Hyper-Threading (HT) vs. Multi-core vs. Multi-processor
- One core = One CPU
- Hyper-Threading
  - One physical core *appears* to have multiple processors
    - Looks like multiple CPUs to the OS
    - Separate registers & execution state
  - Multiple threads run but compete for execution unit
  - Events in the pipeline switch between the streams
  - Threads do not have to belong to the same process
    - But the processors share the same cache
    - Performance can degrade if two threads compete for the cache
  - Works well with instruction streams that have large memory latencies

Example CPU

- Intel® Core™ i7-5960X Extreme Edition (Haswell-E)
- 3.0 GHz up to 3.5 GHz (Turbo)
- 2.6B 22 nm Tri-Gate 3-D transistors
- 8 cores; 16 threads
- Per-Core caches:
  - 512 KB L1 cache (128 KB data; 128 KB instruction)
  - 2 MB L2 cache
- 20 MB shared L3 cache



Multi-core architecture



Stepping on each other

- Threads share the same data
- Mutual exclusion is critical
- Allow a thread be the only one to grab a critical section
  - Others who want it go to sleep

```
pthread_mutex_t = m = PTHREAD_MUTEX_INITIALIZER;
    ...
pthread_mutex_lock(&m);
/* modify shared data */
pthread_mutex_unlock(&m);
```


The End

