Operating Systems Design
5. Threads

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Thread of execution

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

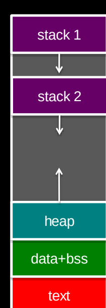
Conventional programming model & OS structure:
- Single threaded
- One process = one thread

Multi-threaded model

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?

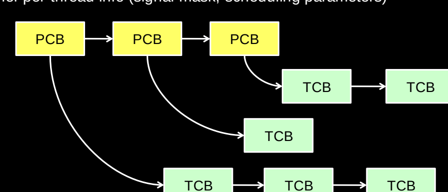
Threads are more efficient
- Much less overhead to create: no need to create new copy of memory space, file descriptors, etc.

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 threaded-aware operating system scheduler schedules *threads*, not *processes*

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

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
- Scheduling threads onto a different CPU is more expensive

Process vs. Thread context switch

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

/* Re-load page tables */
{
    unsigned long new_cr3 = next->tss.cr3;
    if (new_cr3 !=3D prev->tss.cr3)
        asm volatile("movl %0,%%cr3": :"r" (new_cr3));
}
```

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

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

N:1 – pure 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 (as of 2.6 kernel)
- 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:

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

- Wait for thread *t* to terminate (via *return* or *pthread_exit*)

No parent/child relationship!

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

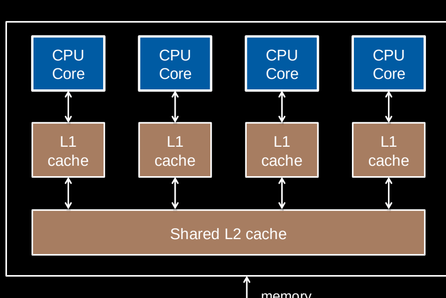
Linux *clone()* system call

- 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 the same parent
    - Share root directory, current directory, and permissions mask
    - Share open file descriptor table
    - Share namespace (mount points creating a directory hierarchy)
    - Share signals
    - Share memory (otherwise memory writes use new memory)
    - *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
  - 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
  - Works well with instruction streams that have large memory latencies

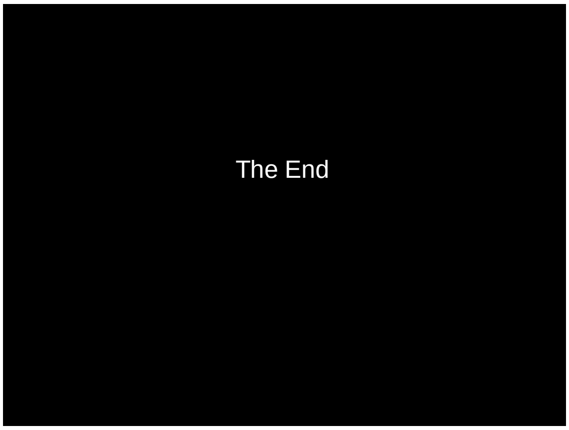
Multi-core architecture



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

