CS 5204
Operating Systems
Lecture 5

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Announcements

- Project/survey paper handout on Wednesday

Motivation

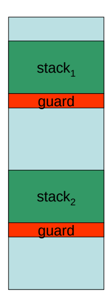
- Q: Is Lauer/Needham relevant to current systems?
- Which model should we pick for which application – both are available on current systems
- Must understand implementation trade-offs on contemporary systems
  - In addition to programming model trade-offs

Implementing Threads

- Issues:
  - Who maintains thread state/stack space?
  - How are threads mapped onto CPUs?
  - How is coordination/synchronization implemented?
  - How do threads interact with I/O?
  - How do threads interact with existing APIs such as signals?
  - How do threads interact with language runtimes (e.g., GCs)?
  - How do terminate threads safely?

Managing Stack Space

- Stacks require continuous virtual address space
  - virtual address space fragmentation (example 32-bit Linux)
- What size should stack have?
  - How to detect stack overflow?
  - Ignore vs. software vs. hardware
- Related: how to implement
  - Get local thread id “pthread_self()”
  - Thread-local Storage (TLS)



Nonpreemptive Threads

- Aka Coroutines
  - CPU switches at well-defined points (“yield”, or synchronization points: “lock”, “wait”)
  - Low context-switch cost - similar to procedure call
- Advantages
  - Can make integrating garbage collection easier
  - Can allow for very fine-grained resource control (Capriccio)
  - Can be implemented w/o kernel support

Nonpreemptive Threads (cont'd)

- Disadvantages:
  - Can increase latency
  - Hard to extend to multiprocessor machines
  - Makes termination of uncooperative threads hard (why?)
- Note: using nonpreemptive threads does not negate need for locks – why?

Preemptive Threads

- CPU can switch at any time
  - Higher context switch cost: more state to save
- Advantages
  - Allows for quasi-parallelism (latency benefits)
- Disadvantages
  - Requires kernel support
  - Can make scheduling & GC control harder

Example: x86

- Nonpreemptive = C calling conventions:
  - Caller-saved: eax, ecx, edx + floating point
  - Callee-saved: ebx, esi, edi, esp
    - ebp, eip for a jmpbuf size of 6*4 = 24 bytes
- Preemptive = save entire state
  - All registers + 108 bytes for floating point context
- Note: context switch cost = save/restore state cost + scheduling overhead + lost locality cost

On Termination

- If you terminate a thread, how will you clean up if you have to terminate it?
- Strategies:
  - Avoid shared state where possible
  - Disable termination
  - Use cleanup handlers try/finally, pthread_cleanup

```
Queue q1, q2; // shared
thread_body() {
  while (!done) {
    Packet p = q1.dequeue();
    q2.enqueue(p);
  }
}
```


User-level Threads (aka 1:N)

- Kernel sees one thread per process
- Scheduling + synchronization done in user-space
  - Potentially fast context switches
  - fast locks (if nonpreemptive!)
- Threads are lightweight

User-level Threads (cont'd)

- Drawbacks:
  - I/O blocks entire process
  - Often nonpreemptive (although can be advantage)
  - Both of these can be remedied with signals
    - Virtual timers for preemption
    - Asynchronous I/O signals
    - This is expensive and often fragile
  - Not multiprocessor capable

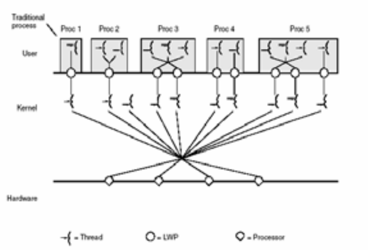
Kernel-level Threads (aka 1:1)

- Kernel manages threads
- I/O blocks only current thread
- Context switch requires kernel trap
  - Synchronization may require kernel traps as well
- OS timer interrupts provides preemption, kernel scheduler schedules threads
  - Allows for use of SMPs

M:N Model

- Implemented in Solaris
  - Implementation for Linux in NGTL
- Idea:
  - Create small number M of LWPs ("light-weight processes") onto which (larger number) N of user-level threads are being scheduled
  - Only create LWP if all LWPs are currently blocked; time out unused LWPs

Lightweight Processes (M:N)



Source: *Multithreading in the Solaris Operating Environment*, Sun 2002

Drawbacks of M:N model

- Solaris discarded LWPs
  - Linux never introduced them (NPTL won over NGTL)
- Why:
  - Automatic concurrency control hard
    - How many LWPs should be allocated?
  - Experience showed limited gain from faster context switches in user mode
  - _schedlock contention
  - Signal implementation difficult
    - Needed manager thread for asynchronous signals

Linux NPTL

- Recent 1:1 model
- Enabled by kernel changes:
  - Introduction of task groups in kernel (e.g. exit_group)
  - scalable scheduling facilities O(1) scheduler
- Fast-path synchronization in user-mode
  - Futex (Fast Userspace Mutex) – avoids need to enter kernel for common case
  - FUTEX_WAIT/FUTEX_WAKE

Outlook

- 1996 talk by John Ousterhout: "Why threads are a bad idea"
  - Threads are hard to program (synchronization, deadlock)
  - Threads break abstractions
  - Threads are hard to make fast
  - Threads aren't well-supported
- Conclusion: use threads only when their power is needed, for true CPU concurrency – else use single-threaded event-based model
- SEDA & Capriccio (and others) followed

Summary

- Implementation issues:
  - Stack management
  - Preemptive vs. nonpreemptive
    - “cooperative multitasking”
  - User-level vs Kernel-level models
  - I/O management & signal implementation