ECE459: Programming for Performance Winter 2015

Lecture 4 — January 12, 2015

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Multicore Processors

As I've alluded to earlier, multicore processors came about because clock speeds just aren't going up anymore. We'll discuss technical details today.

Each processor *core* executes instructions; a processor with more than one core can therefore simultaneously execute multiple (unrelated) instructions.

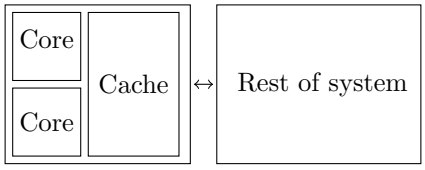
Chips and cores. Multiprocessor (usually SMP, or symmetric multiprocessor) systems have been around for a while. Such systems contain more than one CPU. We can count the number of CPUs by physically looking at the board; each CPU is a discrete physical thing.

Cores, on the other hand, are harder to count. In fact, they look just like distinct CPUs to the operating system:

```
plam@plym:~/courses/p4p/lectures$ cat /proc/cpuinfo
processor : 0
vendor_id : GenuineIntel
cpu family : 6
model : 23
model name : Pentium(R) Dual-Core  CPU      E6300  @ 2.80GHz
...
processor : 1
vendor_id : GenuineIntel
cpu family : 6
model : 23
model name : Pentium(R) Dual-Core  CPU      E6300  @ 2.80GHz
```

If you actually opened my computer, though, you'd only find one chip. The chip is pretending to have two *virtual CPUs*, and the operating system can schedule work on each of these CPUs. In general, you can't look at the chip and figure out how many cores it contains.

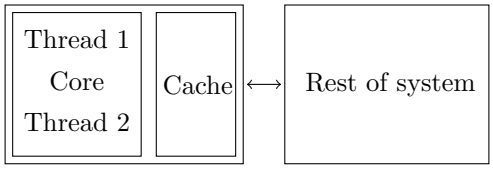
Hardware Designs for Multicores. In terms of the hardware design, cores might share a cache, as in this picture:



(credit: *Multicore Application Programming*, p. 5)

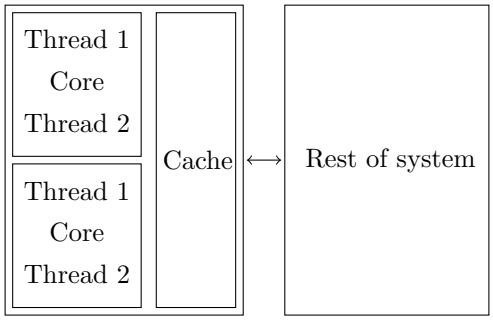
This above Symmetric Multithreading (SMP) design is especially good for the 1:1 threading model. In this case, the design of the cores don't need to change much, but they still need to communicate with each other and the rest of the system.

Or, we can have a design that works well for the N:1 model:



One would expect that executing two threads on one core might mean that each thread would run more slowly. It depends on the instruction mix. If the threads are trying to access the same resource, then each thread would run more slowly. If they're doing different things, there's potential for speedup.

Finally, it's possible to both use multiple cores and put multiple threads onto one core, as in the M:N model:



Here we have four hardware threads; pairs of threads share hardware resources. One example of a processor which supports chip multi-threading (CMT) is the UltraSPARC T2, which has 8 cores, each of which supports 8 threads. All of the cores share a common level 2 cache.

Non-SMP systems. The designs we've seen above have been more or less SMP designs; all of the cores are mostly alike. A very non-Smp system is the Cell, which contains a PowerPC main core (the PPE) and 7 Synergistic Processing Elements (SPEs), which are small vector computers.

Non-Uniform Memory Access. In SMP systems, all CPUs have approximately the same access time for resources (subject to cache misses). There are also NUMA, or Non-Uniform Memory Access, systems out there. In that case, CPUs can access different resources at different speeds. (Resources goes beyond just memory).

In this case, the operating system should schedule tasks on CPUs which can access resources faster. Since memory is commonly the bottleneck, each CPU has its own memory bank.

Using CMT effectively. Typically, a CPU will expose its hardware threads using virtual CPUs. In current hardware designs, each of the hardware threads has the same performance.

However, performance varies depending on context. In the above example, two threads running on the same core will most probably run more slowly than two threads running on separate cores,

since they'd contend for the same core's resources. Task switches between cores (or CPUs!) are also slow, as they may involve reloading caches.

Solaris "processor sets" enable that operating system to assign processes to specific virtual CPUs, while Linux's "affinity" keeps a process running on the same virtual CPU. Both of these features reduce the number of task switches, and processor sets can help reduce resource contention, along with Solaris's locality groups[1]

Processes versus Threads

The first design decision that you need to solve when parallelizing programs is whether you should use threads or processes.

- Threads are basically light-weight processes which piggy-back on processes' address space.

Traditionally (pre-Linux 2.6) you had to use `fork` (for processes) and `clone` (for threads). But `clone` is not POSIX compliant, and its man page says that it's Linux-specific—FreeBSD uses `rfork()`. (POSIX is the standard for Unix-like operating systems).

When processes are better. `fork` is safer and more secure than threads.

1. Each process has its own virtual address space:
   - Memory pages are not copied, they are copy-on-write. Therefore, processes use less memory than you would expect.
2. Buffer overruns or other security holes do not expose other processes.
3. If a process crashes, the others can continue.

Example: In the Chrome browser, each tab is a separate process. Scott McCloud explained this: `http://uncivilsociety.org/2008/09/google-chrome-comic-by-scott-m.html`.

When threads are better. Threads are easier and faster.

1. Interprocess communication (IPC) is more complicated and slower than interthread communication; must use operating system utilities (pipes, semaphores, shared memory, etc) instead of thread library (or just memory reads and writes).
2. Processes have much higher startup, shutdown and synchronization costs than threads.
3. Pthreads fix the issues of `clone` and provide a uniform interface for most systems. (You'll work with them in Assignment 1.)

[1] Gove suggests that locality groups help reduce contention for core resources, but they seem to help more with memory.

How to choose? If your application is like this:

- mostly independent tasks, with little or no communication;
- task startup and shutdown costs are negligible compared to overall runtime; and
- want to be safer against bugs and security holes,

then processes are the way to go. If it's the opposite of this, then use threads.

For performance reasons, along with ease and consistency across systems, we'll use threads. We will describe both Pthreads and C++ 11 threads, in particular.

Overhead of Processes vs Threads. The common wisdom is that processes are expensive, threads are cheap. Let's verify this with a benchmark on a laptop (included in the live-coding directory) which creates and destroys 50,000 threads:

```
jon@riker examples master % time ./create_fork
0.18s user 4.14s system 34% cpu 12.484 total
jon@riker examples master % time ./create_pthread
0.73s user 1.29s system 107% cpu 1.887 total
```

Clearly Pthreads incur much lower overhead than `fork`. Pthreads offer a speedup of 6.5 over processes in terms of startup and teardown costs.