Building Blocks

Operating Systems, Processes, Threads

Reusing this material

Outline

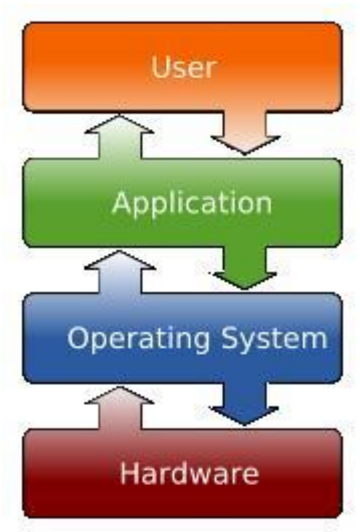
- What does an Operating System (OS) do?
  - OS types in HPC
  - The Command Line
- Processes
- Threads
  - Threads on accelerators
- OS performance optimisation
  - Why is the OS bad for performance?
  - Approaches to improving OS performance

Operating Systems

What do they do? Which ones are used for HPC?

Operating System (OS)

- The OS is responsible for orchestrating access to the hardware by applications.
  - Which applications are running at any one time?
  - How is the memory allocated and de-allocated?
  - How is the file-system accessed?
  - Who has authority to access which resources?
- Running applications are controlled through the concepts of *processes* and *threads.*
  - an applications / program is a single process…
  - …which may have multiple threads



OS's for HPC

- HPC systems have always used Unix
  - vendors (DEC, SUN, Cray, IBM, SGI, …) all wrote their own version
- Now dominated by Linux (of various flavours)
  - Most HPC vendors modify a commercial Linux distro (RedHat or SUSe) and tailor to their own system.
  - Many commodity clusters run a free Linux distro (CentOS is particularly popular).
- All systems in the top500 now use Linux
  - IBM used their own AIX Unix until around 2017

The Command Line

- HPC sector is dominated by Linux
- Interaction almost always through Linux command line.
  - e.g. which two files or folders are taking up the most space?

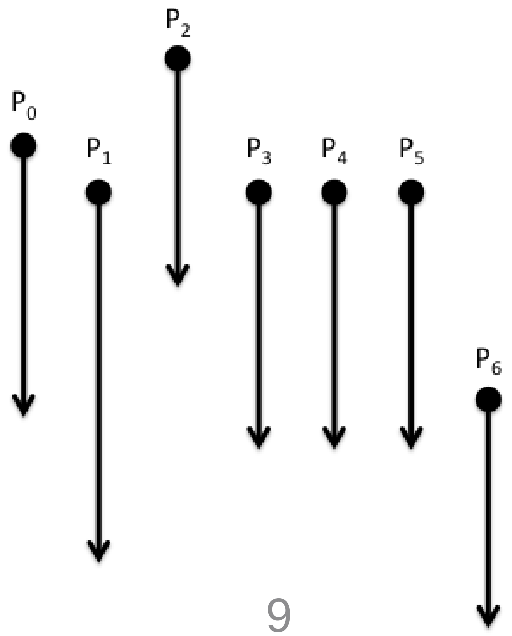
```
user@hpcsystem> du -sm * | sort -n | tail -2
```

  - often a reasonably large barrier to new people adopting HPC.
- For any serious use of HPC you will have to learn to use the command line.
  - often also useful for using command line on your own laptop/PC
- Should also learn basic operation of in-terminal text editor
  - vi/vim is generally available
  - emacs is another popular choice

Processes

Processes

- Each application is a separate *process* in the OS
  - a process has its own memory space which is not accessible by other running process.
  - processes are ring-fenced from each other: if web browser crashes, it can’t scribble over document stored in the memory your word processor
- Each process is scheduled to run by the OS



OS and multicore

- "*Multicore parallelism – manually specified by the user*"
  - what's the use of a multicore laptop if I run non-parallel code?

- OS's have *always* scheduled multiple processes
  - regularly check which process is running
  - give another process a chance to run for a while
  - rapid process switching gives *illusion* applications run concurrently even on a single core

- With a multicore processor
  - multiple processes can *really* run at the same time

Process Scheduling

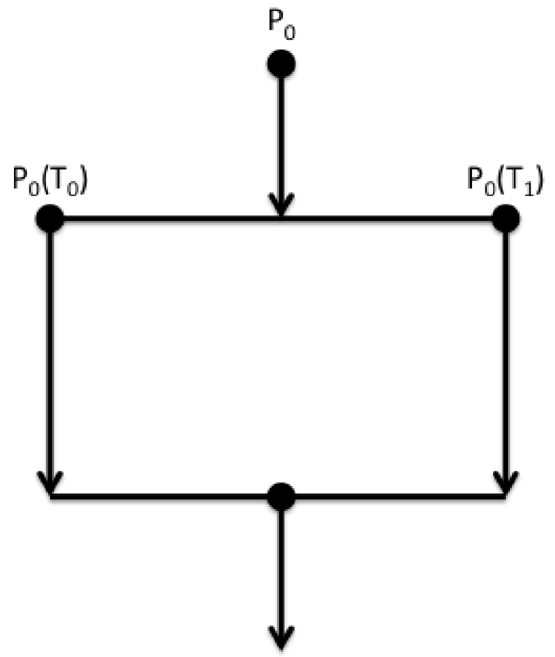
- The OS has responsibility for interrupting a process and granting the core to another process
  - Which process is selected is determined by the *scheduling policy*
  - Interrupt happens at regular intervals (every 0.01 seconds is typical)
  - Process selected should have processing work to do
- On a quad core processor, OS schedules 4 processes at once
- Some hardware supports multiple processes per core
  - Known as *Symmetric Multi-threading* (SMT)
  - Usually appears to the OS as an additional core to use for scheduling
- Process scheduling can be a hindrance to performance
  - in HPC, typically want a single user process per core

Threads

Sharing memory

Threads

- For many applications each process has a single *thread*…
  - … but a single process can contain multiple threads
  - each thread is like a child process contained *within* parent process



Threads (cont.)

- All threads in a process have access to the same memory
  - the memory of the parent process
- Threads are a useful programming model pre-dating multicore
  - e.g. a computer game (a process) creates asynchronous threads
    - one thread controls the spaceship
    - another controls the missile
    - another deals with keyboard input
    - …
  - but all threads update the same game memory, e.g. the screen

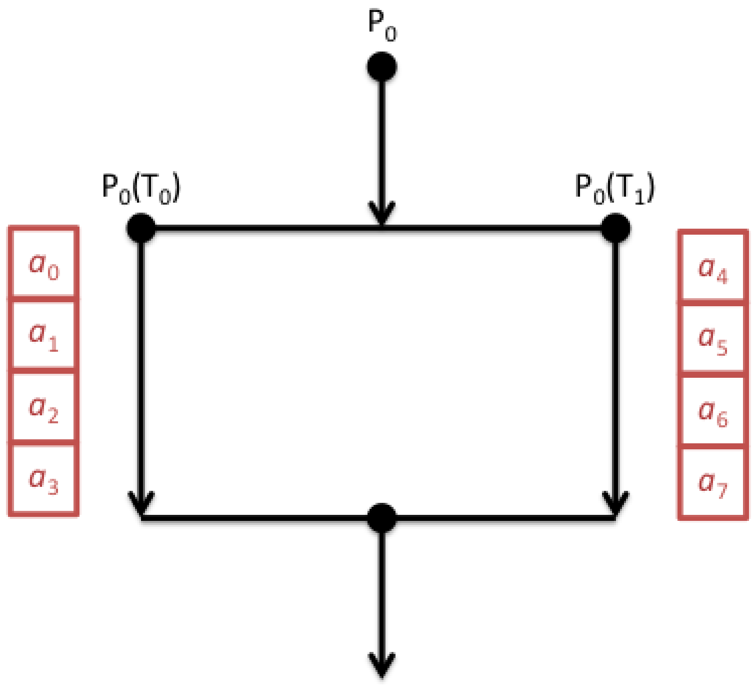
- OS scheduling policy is aware of threads
  - ensures all of the game operations progress
  - switching between threads usually quicker than between processes

Threads and multicore

- With multiple cores
  - multiple threads can operate at the same time on the same data to speed up applications
- Cannot scale beyond the number of cores managed by the operating system
  - to share memory, threads must belong to the same parent process
- In HPC terms cannot scale beyond a single *node*
  - using multiple nodes requires multiple processes
  - this requires inter-process communication – see later

Shared-memory concepts

- Process has an array of size eight
  - each thread operates on half the data; potential for 2x speedup



Threads and Accelerators

- The Accelerator programming model generally requires a huge number of threads to provide efficient usage
  - Oversubscription of the accelerator by threads is encouraged
  - Hardware supports fast switching of execution of threads
    - switch off a thread when it is waiting for data from memory
    - switch on a thread that is ready to do computation
    - try and hide memory latency
  - As GPGPUs can have 1000's of computing elements, oversubscription can be difficult!
- Threading is becoming more and more important on modern HPC machines

OS Optimisation

How do vendors get performance?

Different Compute node OS

- Interactive (front-end) nodes usually run a full OS
  - You interact with these directly and-so the OS provides a full suite of tools and functionality that you would expect
- Compute nodes often run an optimised OS to improve performance
  - A greatly stripped down system with the bare minimum functionality required to run codes
  - As you don't interact directly with the compute nodes then they just need to support the execution of codes
  - Example is Cray's Compute Node Linux which is based on SUSE Linux (Enterprise)

OS Optimisations

- Remove features that are not needed (e.g. USB support)
  - The best optimization is not to have it in the first place!
- Restrict scheduling flexibility and increase interrupt period
  - To avoid interrupting user programs
- Bind processes and threads to specific cores
- Remove support for virtual memory (paging)
  - Which provides the illusion of more RAM than is physically available by writing out to disk. However this is very slow and hence avoided with HPC.
  - Therefore the amount of RAM present is a strict memory limit that you can’t go beyond

Summary

Summary

- OS orchestrates access to hardware resources by software
  - HPC sector dominated by Linux
  - Access via command line rather than GUI
- Each running application is a separate process
  - Has its own memory space and can be scheduled by OS
  - Usually placed on a particular core and not moved
- Running applications can have one or more threads
  - Threads share memory and OS switching is faster than for processes
- OS Optimisation
  - Remove unnecessary features
  - Increase user-level control of placement