COSC 420: High Perf. Computing

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Course Policies

- See web page for most info: resources, schedule, due dates, etc.
- Highlights of course structure
  - Largely project/program based
  - Two midterms, one final
    - May not be standard exam format, TBD

Strategies for success

- University policy: 1 credit = 4 hours work outside lecture
- Keep documentation open and nearby
- Talk to friends, others in class. Hang out in the lab
- Care for your physical being! Eat, sleep, and rest appropriately.
- Spaced repetition is shown to be **vastly** superior to “cramming”

Bonus point opportunities

- You may receive up to 5% total bonus on your final grade by participating in voluntary professional development and community service. Examples include:
  - Gull Week (Sept 9 – 19)
  - GullCode (MATH/COSC club)
  - Game Jam (SU Indies club)
  - Volunteer work
  - See me for further approval...

Course Goals

- Recap of the focus of COSC 320
  - Design advanced algorithms and structures
  - Prove asymptotic complexity, ignore “constant” and “small” overhead
- Contrast with this course
  - Still working with advanced DS and Algorithms
  - Now, be concerned with reducing the extra computational overhead, possibly with specialized hardware

Course structure

- Assignments will largely consist of 5-7 short term projects
  - … but there will still be some math to do and turn in
  - There will be some hardware components, system configuration, etc.
- Minimal programming guidance given in class, mostly theory and problem solving techniques
- Presentations are likely, TBD

Programming Tools

- With a focus on implementation, focus on using specific software environment/toolchain
  - C language (yay!) with some Python later
- Still working on a GNU/Linux environment
  - Be familiar with command-line tools!
- Will eventually use multi-node setups to run software

High-Performance Tools

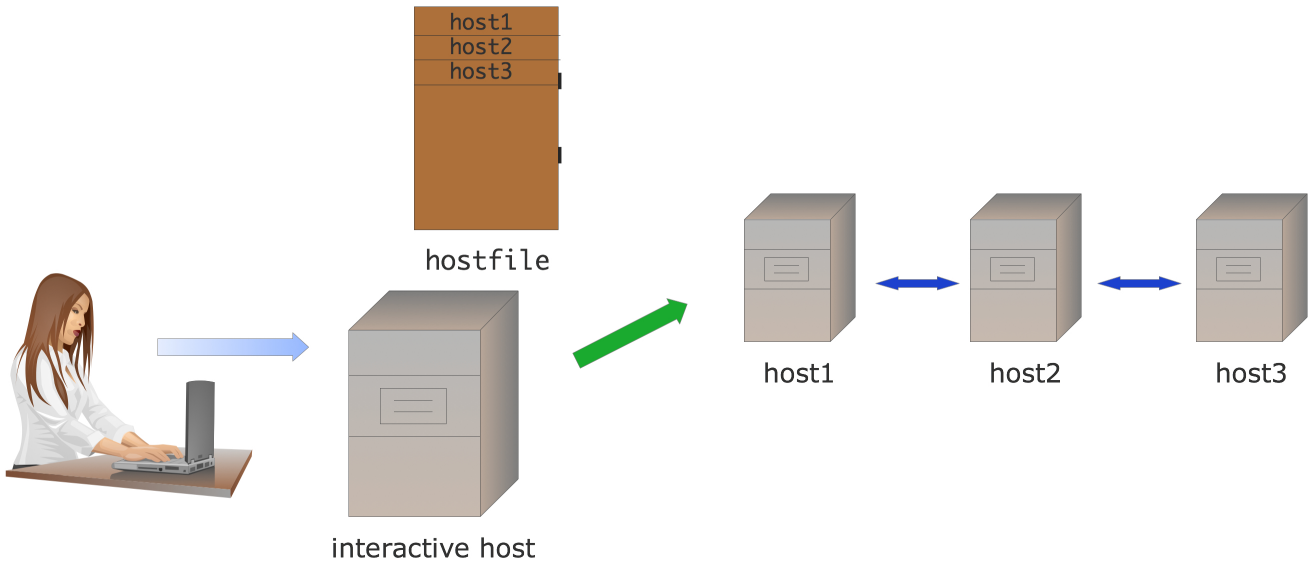
- Distributed memory
  - Multiple independent processes on multiple compute nodes (but which commonly communicate or use shared memory storage)
  - MPI Library – message passing interface
    - Allows one to easily run programs in parallel with communication constructs
      - Not always free/cheap!
    - Also has bindings for Fortran and Python (C++ bindings are deprecated)

High-Performance Tools

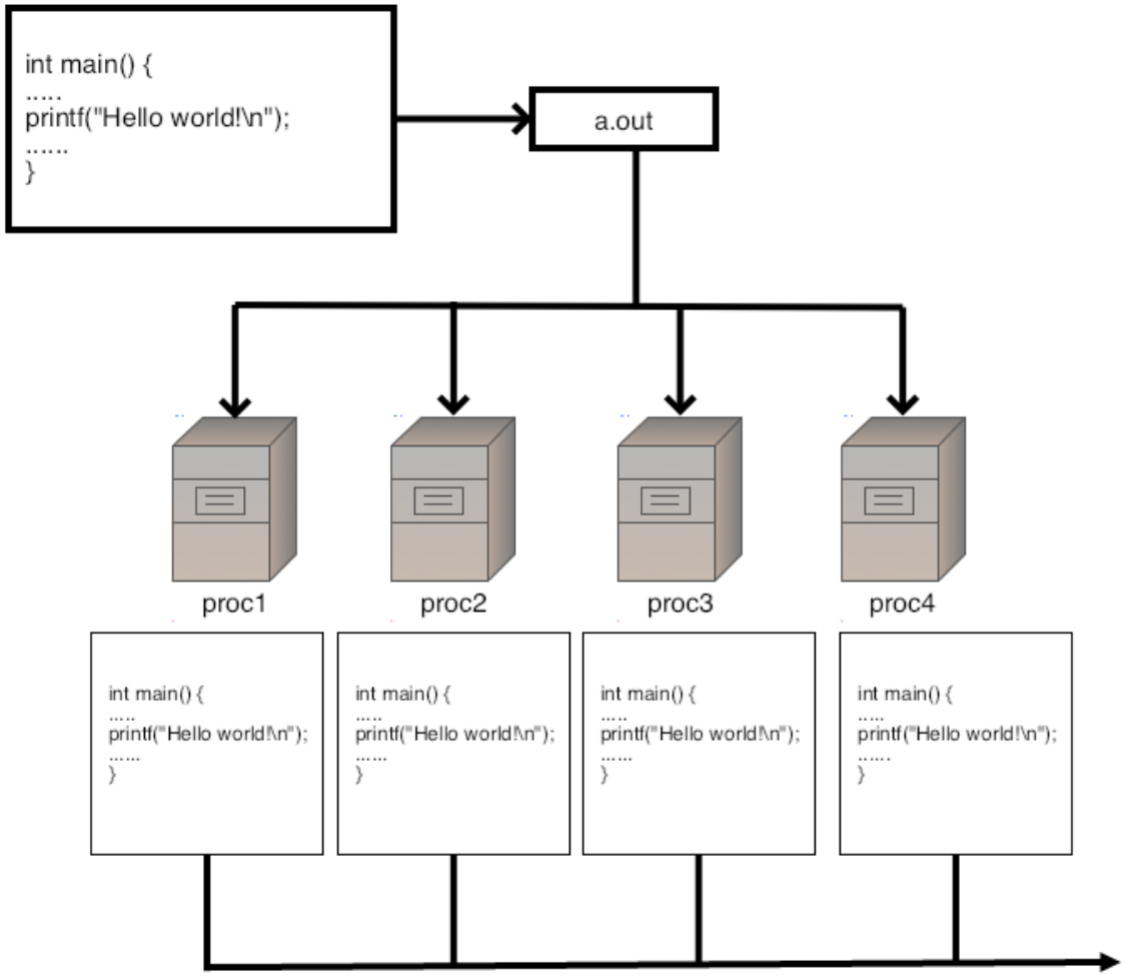
- Shared memory
  - Multiple programs that share the same memory pool during execution
    - No communication overhead!
    - Need to manage race conditions (ouch)
    - Executable can be run in a standard way
  - OpenMP (multiprocessing) library
    - Provided through compiler tools, not separate library routines
  - MPI can also support shared memory (later)

Getting Started: Using MPI

- Install the “openmpi” and “openmpi-devel” packages
- You may need to add the paths to mpicc and mpiexec to your “PATH” environment variable



SPMD


int main() {
.....
printf("Hello world!\n");
.....
}
a.out
proc1
proc2
proc3
proc4
int main() {
.....
printf("Hello world!\n");
.....
}
int main() {
.....
printf("Hello world!\n");
.....
}
int main() {
.....
printf("Hello world!\n");
.....
}
int main() {
.....
printf("Hello world!\n");
.....
}

“Hello, world!”

```
#include<stdio.h>

int main(){
  printf(“Hello, world!\n”);
  return 0;
}

# Run program with: mpiexec -n 5 ./a.out
```

What happened?

- Single Program Multiple Data (SPMD)
  - One executable gets copied between multiple nodes (-n 5)
  - Each node runs the *exact same* program!
    - This means, if you want different nodes to behave differently, we will need some tools for introspection
- We won't worry about the analogous MPMD structure

Using MPI F’real

- Compile with MPI library
  - `#include<mpi.h>`
  - Use `mpicc` or `gcc -I/path/to/mpi.h`
- MUST CALL
  - `int MPI_Init(int *argc, int ***argv)`
  - `int MPI_Finalize()`

Other Important Tools

- Type: `MPI_Comm`
  - Represents the “MPI communicator”
- int MPI_Abort(MPI_Comm, int)
  - Aborts and returns an error code
- Object: MPI_INFO_ENV
  - key/value pairs for `mpiexec` options

More tools

- `int MPI_Get_processor_name(char *name, int *resultlen)`
  - Places name in the provided buffer
  - Length of name in second param
  - “name” param must be length at least MPI_MAX_PROCESSOR_NAME

Managing Processes

- The group of processes is the “communicator”
  - MPI_COMM_WORLD is a predefined communicator, but you can have more
- MPI_Comm_size() – total size of the comm
- MPI_Comm_rank() – the rank of the current process within the communicator
- Both above take MPI_Comm and int*
  - Result stored in the second param

More MPI Interface

- MPI_Get_processor_name – retrieves the node name
  - Takes char* to store and int* for the length
  - MPI_MAX_PROCESSOR_NAME is a constant defining the largest name possible

Using these tools for parallelism

- We want to “distribute” the labor of a task
- But, according to the above, every process is identical!
- … not really, they each know their own rank
- So we use the rank to determine who does which work

Lab Task 1

- (See posted instructions for more detail)
- Given a (probably large) number, N, determine if it is prime or composite
  - Brute force, for now
  - How? Discuss!
- Once we know how many tasks must be done, we can use MPI to distribute them evenly across the nodes

Hardware Parallelism

- Take into account various hardware architectures
  - CPU
  - FPU
    - Takes heavy advantage of “pipeline” methodology
  - GPU

Pipelines

- Focus on floating point operations (FLOPS)
- Stages of a floating point operation
  - Decode instruction, find data locations
  - Fetch data into registers
  - Align exponents
  - Do the operation
  - Normalize result
  - Store

Pipelines

- Supposing each stage has dedicated hardware
- The second instruction can begin decoding once the first one has begun fetching
- The third can be decoded while the second is fetched and first is aligned
- Etc...

Pipeline speedup

- Total time for n operations without pipeline is
  - t(n) = n * l * t
  - Number of instructions is n
  - Number of stages is l
  - Cycle time is t
- We say the “rate” is n/t(n)
  - So without pipeline, 1/(l*t)
- With pipeline, t(n) = ?

Pipeline speedup

- With pipeline, t(n) = (s + l + n-1)*t
  - S is the “startup time” of the pipeline to distribute data as necessary
  - Written sometimes as t(n) = [n + $n_{1/2}$]*t
- Consider limit of the rate for each as n goes to infinity
  - With pipeline, has a dependence on n
  - Becomes “l times” faster!
- To get to this case, consider the rate with $n_{1/2}$ instructions...

Pipeline in action

- Consider vectors/arrays a, b, c and the two following loops:
- ```
  For(i)
    a[i] = b[i] + c[i]
  ```
- ```
  For(i)
    a[i+1] = a[i]*b[i] + c[i]
  ```
- Can we speed up the second, despite dependence?

Other hardware parallelism

- Multiple-issue: independent instructions that can happen at the same time
- Branch prediction: compiler can “guess” which branch of a conditional will happen
- Out-of-order execution: instructions rearranged by compiler
- Prefetching: speculatively request data before it is explicitly used

Memory Hierarchy

- Main considerations
  - Location, distance from CPU/FPU/GPU
  - Buses: wires that transfer data between different memories
  - Latency
  - Bandwidth

Memory Hierarchy