CS 220: Introduction to Parallel Computing

Message Passing Interface (MPI)

Lecture 13

Today's Schedule

- Parallel Computing Background
- Diving in: MPI
- The Jetson cluster

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Parallel Computing (1/2)

- Now that we're all C masters, we can move on to the good stuff: parallelism
- Specifically, we'll be looking at distributed memory systems for the next section of the course
- In these systems, we have a few different elements:
  - Physical machines
  - Processors
  - Processor cores

Parallel Computing (2/2)

- Parallel computing can be summed up with a simple motto:
    - “Divide and conquer”
- Let’s take a problem, break it into smaller pieces, and then have multiple cores/processors/machines work on it all at once
- Challenge: getting all these processors to work together

Approaches

- We can use several different strategies to parallelize applications
- The first approach we'll examine in this class is MPI
  - Message Passing Interface
- MPI has a lot of functionality, but at its core is based on a very simple idea:
  - **Running multiple copies of your program**
    - (Sometimes even across multiple computers)

Architectures

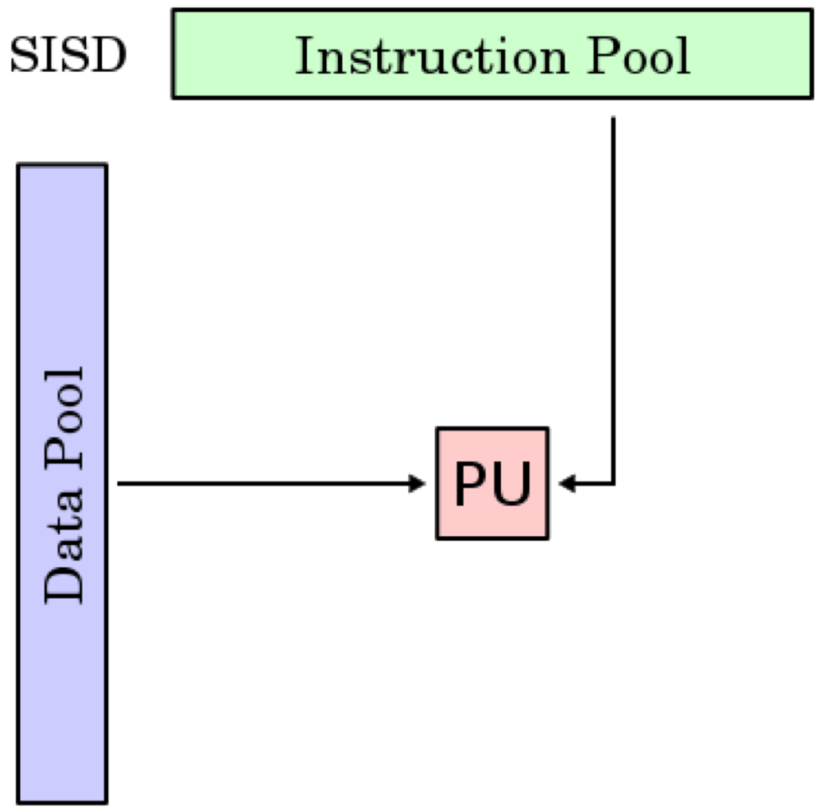
- Before we dive in, we need to take a look at the hardware architectures behind parallel systems
- There are several types:
  - SISD, SIMD, MISD, MIMD
- These classifications were proposed by Michael J. Flynn in 1966
  - ***Flynn's Taxonomy***
- See: https://en.wikipedia.org/wiki/Flynn%27s_taxonomy

Flynn’s Taxonomy: Breakdown

- Each architecture is composed of three elements
- PUs – processing units / processing elements
- The instruction pool
  - Your program, translated to machine code
- The data pool
  - The data you’re working with

SISD

- Single instruction, single data
  - One CPU, one core, one thread (uniprocessor)
  - One pool of memory
  - One thing at a time!
- PCs up until 2010 or so



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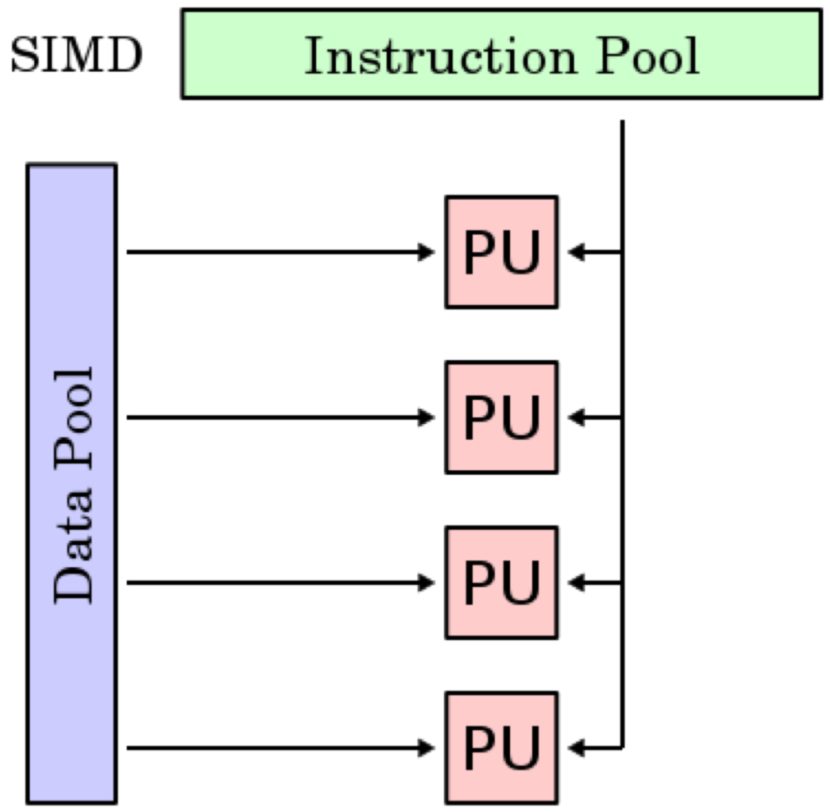
SIMD

- Single instruction, multiple data stream
- Each PU executes the same instructions on a different piece of the data
- Great for highly-parallel workloads (GPUs)



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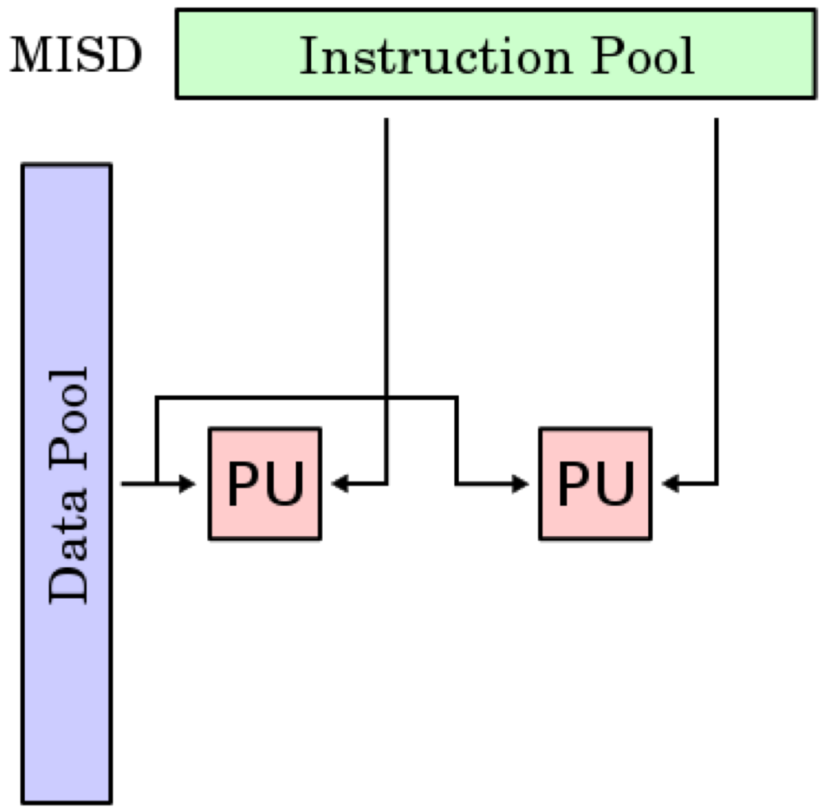
MISD

- Multiple instruction, single data
- More uncommon
- Here, the data is fed to multiple PUs
- Each PU executes the same instructions
- Then the results are compared
  - Fault tolerance



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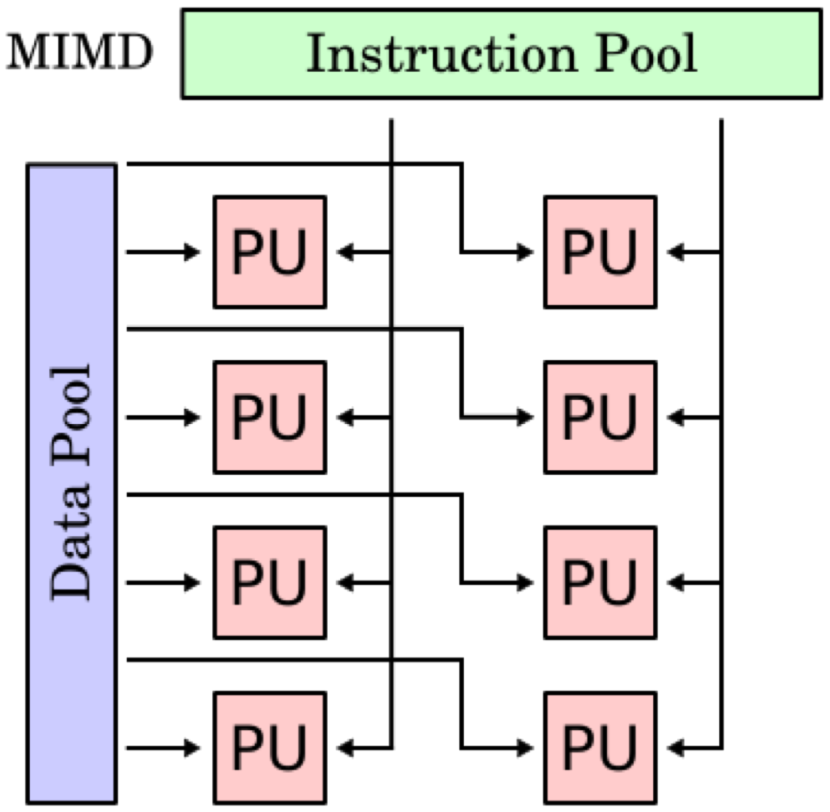
MIMD

- Multiple instruction, multiple data
- Nodes work independently
- Multi-core PCs, distributed systems
- Our focus in this class



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Amdahl's Law [1/2]

- In the best case scenario, doubling the number of cores will halve your execution time
- In practice, this is difficult
  - There is **overhead** associated with parallelism
- Amdahl's law puts a bound on potential speedup:

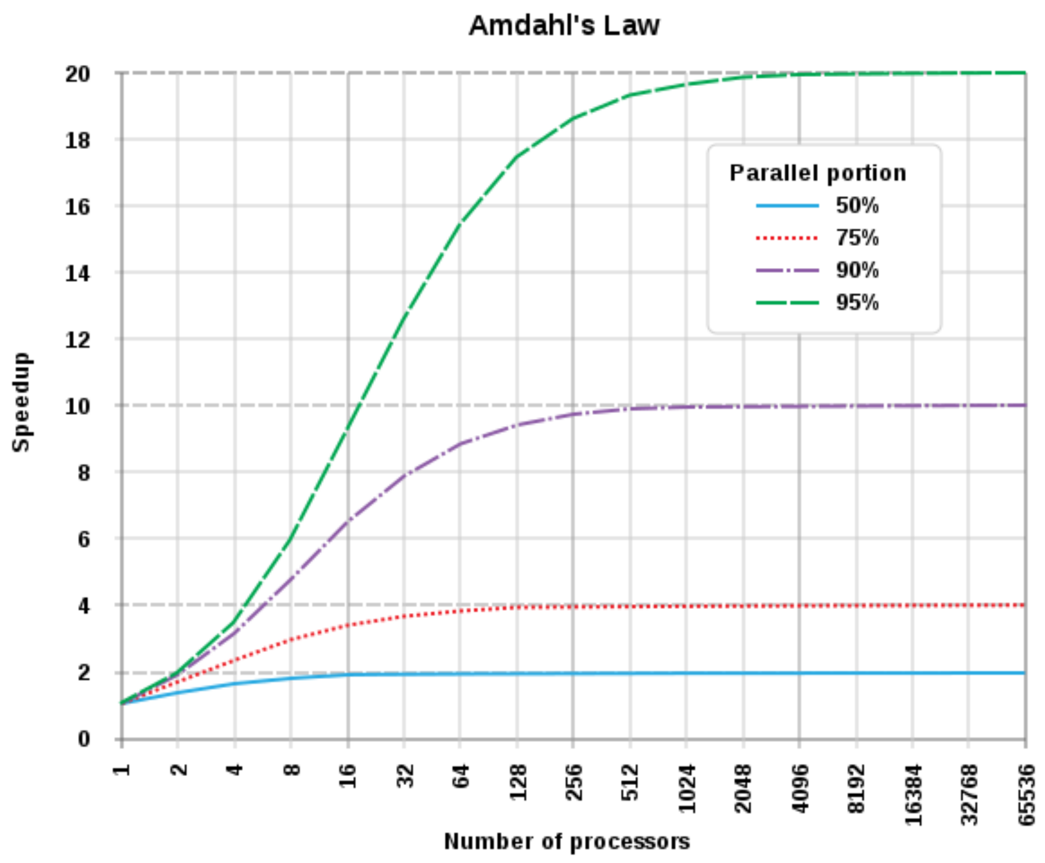
$$S_N = \frac{1}{(1-P) + \frac{P}{N}}$$

S – speedup

P – parallelizable portion

N – number of PUs

Amdahl's Law [2/2]



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Message Passing Interface

- Message passing is the most common paradigm for programming distributed memory systems
- Processors coordinate their activities by sending messages to each other across the network
  - Infiniband
  - Ethernet
- Message Passing Interface, or just **MPI**, gives us C functions to do this

Ranks

- With MPI, we won’t just be running a single program anymore
  - Now, we’ll deal with multiple processes
- These processes are identified by nonnegative integer ranks
- If there are p processes, the processes will have ranks 0, 1, 2, … , p – 1

Installing MPI

- On Linux, it’s as easy as installing the **openmpi** group of packages:
  - apt-get install openmpi-bin openmpi-common libopenmpi*
- Newer Macs don’t come with MPI already installed, so you will need a 3rd party package manager:
  - Homebrew (http://brew.sh), MacPorts
  - Then install **openmpi**
- Windows: cygwin **openmpi** package is ***buggy***

Compiling MPI Applications

- To compile your MPI code, you'll need a new command:
  - mpicc
- This is just a **wrapper** around gcc or whatever compiler you have on your system
  - Sets up compilation with the correct libraries and options

Running MPI Applications

- You can't just run **a.out** or whatever your executable is called
- Instead, you'll need to use an MPI launcher:
  - orterun -n 4 ./a.out
    (will run **a.out** with four processes)
  - mpiexec -n 4 ./a.out
    (exactly the same thing!)
  - mpiexec -n 4 --hostfile=jets.txt ./a.out
    (runs on multiple machines)

Hello World

- As usual, we need to write a “hello world” application as our first step!
- In MPI, we can print out some more information: the hostname of the machine, its rank, and the total number of processes
- Let’s try this out…

MPI_Init()

- Needs to be run before you do anything else
- You can pass in NULL for both of its arguments, or you can pass in the argc and argv command line arguments
  - If you do that, it'll remove any orterun/mpiexec/mpirun-related stuff from the command line

MPI Communicators

- You might've notice MPI_COMM_WORLD in the example
- This is the global communicator group
- You can create groups of processes to coordinate your distributed applications
  - For instance, maybe one group will work on the upper-left corner of an image

Helpful Functions

```
/* Total number of processes in this MPI communicator */
int comm_sz;
MPI_Comm_size(MPI_COMM_WORLD, &comm_sz);

/* Get the rank of this processor */
int rank;
MPI_Comm_rank(MPI_COMM_WORLD, &rank);

/* Get the host name of this processor */
char hostname[MPI_MAX_PROCESSOR_NAME];
int name_sz;
MPI_Get_processor_name(hostname, &name_sz);
```

Cleaning Up

- At the end of your MPI program you must call:

```
      MPI_Finalize();
```

- This cleans up all the MPI state information that was being held while your program ran
- Finishes all pending communications
- After calling this, executing any MPI function will raise an error

MPI: Summing Up

- At a basic level, all MPI does is clone your process and run it multiple times
- Without any special intervention, the processes will all just do the same thing
- However, we can **branch** based on process ranks to organize processing activities and communicate

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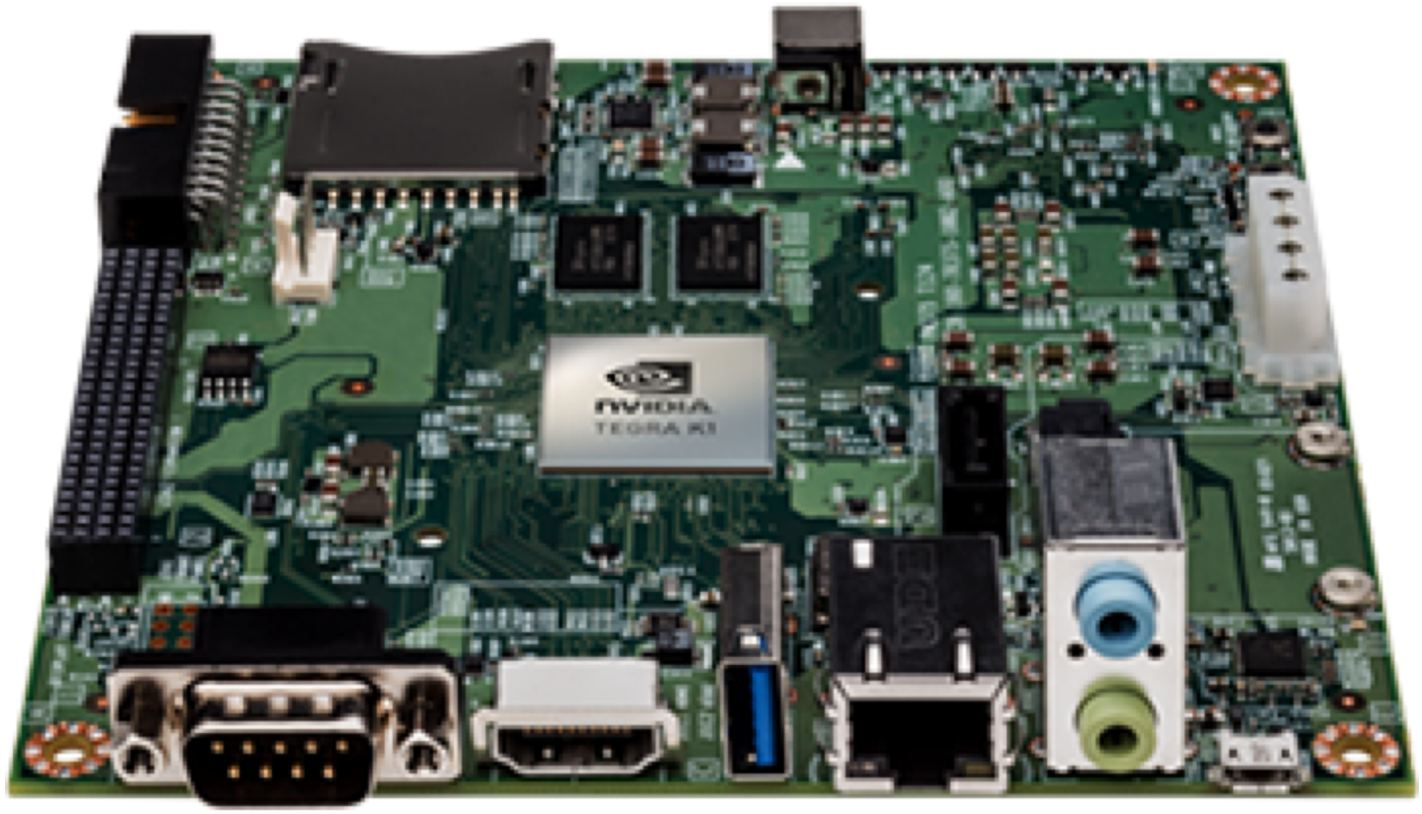
The Jetsons

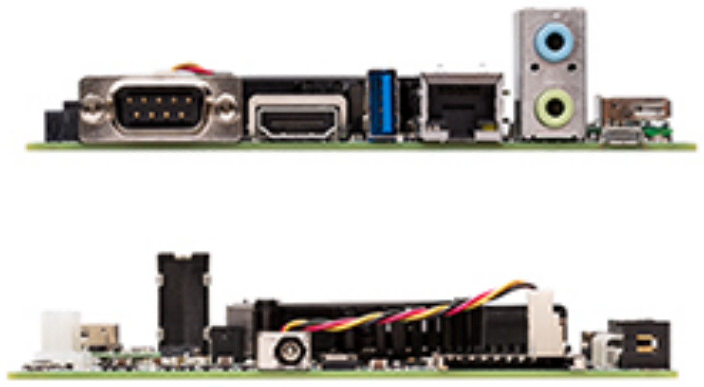
- We have 24 NVIDIA Jetson **TK1** machines
- These are ARM-based boards for parallel computing and GPU programming using NVIDIA CUDA
- Hardware:
  - Quad-core ARM CPU
  - NVIDIA Kepler GPU with 192 CUDA Cores
  - 2 GB Memory

Jetson TK1



Jetson TK1

- Somewhat like a Raspberry Pi on steroids
- We'll use this cluster for the rest of the semester
  - (Including GPU programming)



Accessing the Jets

- To reach the jet machines, you will need to use **ssh**
  - You may have done this in previous courses
- Furthermore, you will need **passwordless** ssh set up in order to effectively use MPI
- This allows MPI to distribute your program across multiple servers

Cooling Your Jets

- To get on the Jetson machines, you first need to log into **stargate.cs.usfca.edu**
- Then ssh to:
  - jet01
  - jet02
  - …
  - jet24