What is a Parallel Architecture?

A parallel computer is a collection of processing elements that cooperate to solve large problems fast.

Some broad issues:

- Resource Allocation:
  - How many processing elements (PEs)?
  - How powerful are the PEs?
  - How much memory?
- Data access, Communication and Synchronization
  - How do the PEs cooperate and communicate?
  - How are data transmitted between PEs?
  - What are the abstractions and primitives for cooperation?
- Performance and Scalability
  - How does a design translate into performance?
  - How does it scale?

Issues in Multiprocessors

Which **programming model for interprocessor communication**

- shared memory
  - regular loads & stores
  - SGI UV, Intel Core i3, i5, i7, AMD Opteron “Bulldozer”, Sun SPARC T4, ARM Cortex A5, Nvidia Tegra 3
- message passing
  - can directly access only private address space
  - explicit sends & receives for shared data
  - IBM BlueGene/Q, Cray XE6, Fujitsu K Computer, Intel Paragon

Shared Memory vs. Message Passing

Shared memory

- + simple parallel programming model
    - global shared address space
    - not worry about data locality ***but***
        - *get better performance when program for data placement*
        - *lower latency when data is local*
            - ***but*** can do data placement if it is crucial, but don't have to
    - hardware maintains data coherence & threads synchronize to order processor's accesses to shared data
    - like uniprocessor code so parallelizing by programmer or compiler is easier

⇒ can focus on program semantics, not inter-processor communication or data layout

Shared Memory vs. Message Passing

Shared memory

- + low latency (no message passing software) ***but***
    - *overlap of communication & computation*
    - *latency-hiding techniques can be applied to message passing machines*
- + higher bandwidth for small transfers ***but***
    - *usually the only choice*

Shared Memory vs. Message Passing

Message passing

- + abstraction in the programming model encapsulates the communication costs ***but***
  - *overheads: copying, buffer management, protection*
  - *additional language constructs*
  - *need to program for nearest neighbor communication*
- + no coherency hardware
- + good throughput on large transfers ***but***
  - *what about small transfers?*
- + more scalable (memory latency for uniform memory doesn't scale with the number of processors) ***but***
  - *large-scale SM has distributed memory also*
    - ***hah!*** so you're going to adopt the message-passing model?

Shared Memory vs. Message Passing

Why there was a debate

- little experimental data
- not separate implementation from programming model
- can emulate one paradigm with the other
  - MP on SM machine
    message buffers in local (to each processor) memory
    copy messages by ld/st between buffers
  - SM on MP machine
    ld/st becomes a message copy
    sloooooooooow

Who won?

Issues in Multiprocessors

Which **execution model**

- control parallel
  - identify & synchronize different asynchronous threads
- data parallel
  - same operation on different parts of the shared data space
- dataflow (later)

Issues in Multiprocessors

How to **express error-free parallelism** (hardest problem)

- language support
  - HPF, ZPL
- runtime library constructs to support threads
  - coarse-grain, explicitly parallel C programs
- automatic (compiler) thread creation
  - implicitly parallel C & Fortran programs, e.g., SUIF & PTRANS compilers
- HW & compiler support for maintaining correctness (today's efforts)

Flynn's Taxonomy

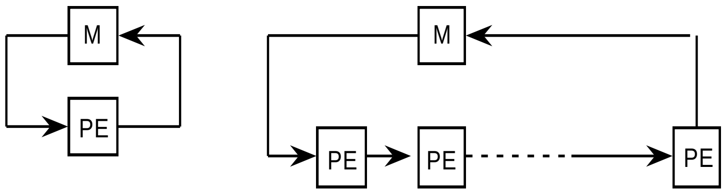
Classifies computers by control & data streams

Single Instruction, Single Data (SISD) (single-context uniprocessor)	Single Instruction, Multiple Data (SIMD) (single PC: Vector, GPUs, CM-2)
Multiple Instruction, Single Data (MISD) (systolic arrays, streaming processors)	Multiple Instruction, Multiple Data MIMD (Clusters, SMP servers)

Systolic Architectures

Replace single processor with array of regular (or specialized) processing elements

Orchestrate data flow for high throughput with less memory access



Important Issues

- the programming model debate for inter-processor communication
- Flynn’s taxonomy