Parallel Communication Architectures

Different Types of Architecture

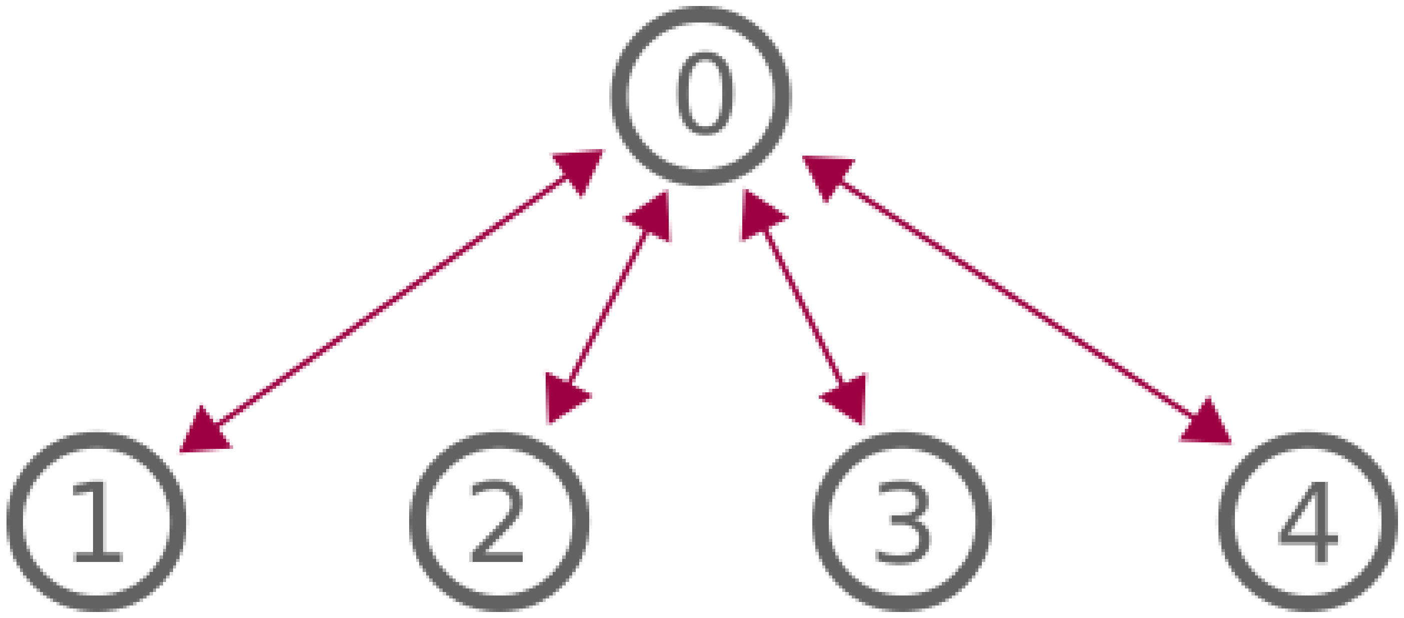
- As MPI simply provides the communication tools, it does not dictate the parallel architecture that will be used

Two main types of architecture

- Master/Slave
  - A master node controls the other nodes
  - …people are looking to change the name, but no agreement on replacement
    - Proposals include Master/Minion, Main/Secondary, or Primary/Replica
- Peer to Peer
  - All nodes are equivalent to one anther

Master/Slave

- What is a Master-Slave architecture?
    - All communications go through a master node that controls a set of nodes that do tasks for it



Master/Slave

- Advantages:
  - Often relatively straightforward to implement
  - A single process has access to all the data
- Disadvantages:
  - Scalability issues as communications into the master can become a bottleneck

Master/Slave

When might you consider using a master/slave architecture:

- Trivially parallel problems
    - Problems with sub-tasks that can be carried out completely independently
    - Master farms out the problems to all the slave nodes and waits for the answers to come back

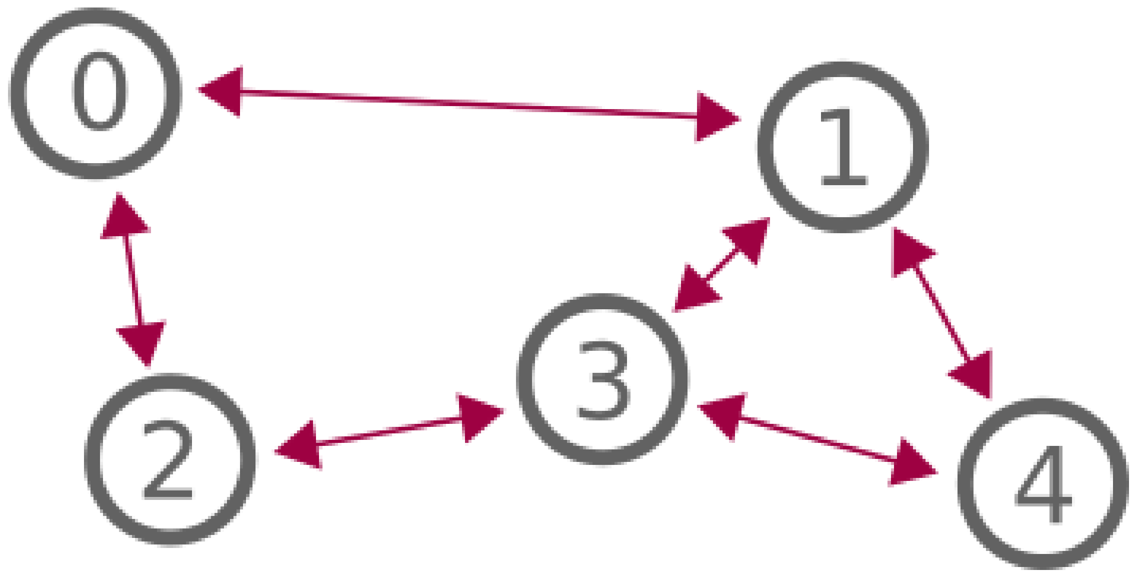
- Problems where data from all the nodes need to be collated
    - Information note just exchanged between nodes but needs to be combined
    - Might form part of an otherwise peer-to-peer architecture – see hybrid architectures

Master/Slave

- Types of communications to be used –
  - A Master/Slave architecture will usually rely heavily on collective communications
    - This will spread some of the communication load away from the master node
  - Scatter/Gather or Scatter/Reduce the usual communication methods
  - Can use non-blocking point to point if you wish to respond to individual slave nodes as they complete
    - Send new data to a node without waiting for all the nodes to complete

Peer to Peer

- What is a Peer to Peer architecture?
  - Every process has equal precedent and communicates directly with the other process (or, more usually, a subset of them)



Peer to Peer

- Advantages
    - Very good for problems that are strongly coupled, especially if each node needs to only communicate with a subset of neighbours
    - Good scalability as the amount of communication into a particular node will only be a weak function of the network size if the number of neighbours is system size independent
        - Often the case in, for instance, domain decomposition problems

- Disadvantages
    - Often harder to code as no node is in charge of the system
    - Typically, no node will know the entire solution
        - Need to post-process results from different nodes

Peer to Peer

- Types of communications to be used –
  - Will mostly be reliant on non-blocking point to point communications - MPI_Isend and MPI_Irecv
  - Most appropriate choice if nodes only communicate with a subset of the other nodes and these sets of communications are fully interlinked
  - May sometimes need to communicate data between all the nodes (e.g. obtaining a single timestep when using a dynamic timestep)
    - MPI_Allgather or MPI_Allreduce most appropriate

Hybrid Architectures

- It is not required that a program stick religiously to single communication architecture
- An example of where a hybrid architecture is appropriate might be domain decomposition with dynamic load balancing
    - The main calculation loop is most efficiently done using peer-to-peer communications as each process only needs to communicate with the processes responsible for the neighbouring domains
    - For dynamic load balancing each processes needs to calculate their own computational and communication load, but this information needs to be collated at a single process in order for a new domain distribution to be calculated and distributed – a master slave type communication arrangement

Parallel Performance

Assessing the Performance of Parallel Code

Two main measures of performance:

- Speedup ratio:
  - How many times quicker the code is in parallel relative to the serial code

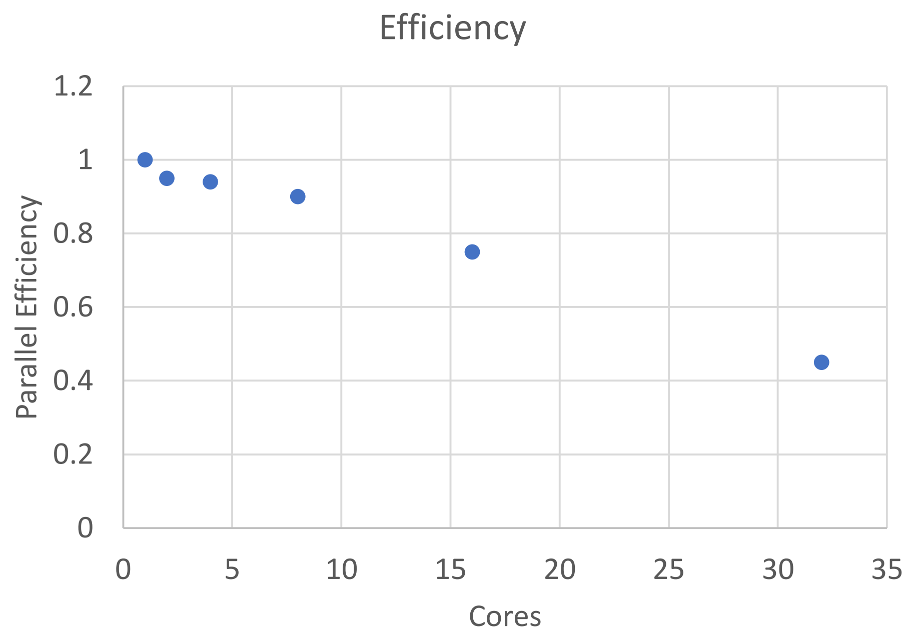
$$S = \frac{T_1}{T_N}$$

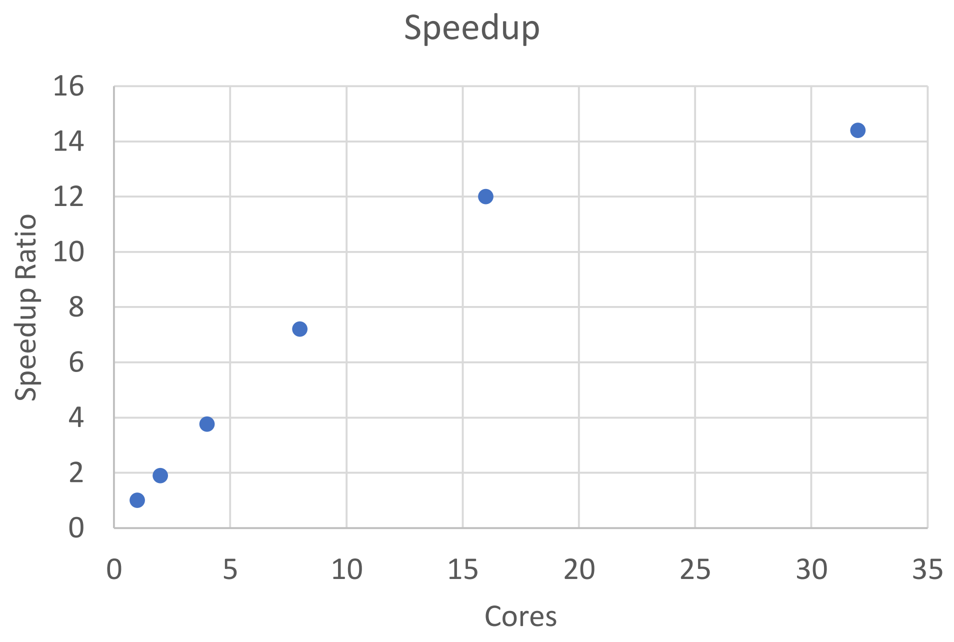
- Parallel Efficiency
  - How fast is the code relative to an ideal speedup

$$E = \frac{T_1}{N\,T_N} = \frac{S}{N}$$

Speedup and Parallel Efficiency

- Parallel efficiency will usually drop as the number of cores used increases
  - It is possible to have super-linear speedup (efficiencies greater than one), but quite rare and will usually be caused by smaller tasks having more efficient cache usage





Amdahl’s Law

- Based on the idea that part of the solution is in parallel and part is in serial
  - f is the fraction of the code that has been parallelised
    - The fraction of the code based on execution time
  - Assumes that the parallel portion has an efficiency of 1

$$T_N = (1-f)T_1 + \frac{f}{N}T_1 = T_1\left(1-f+\frac{f}{N}\right)$$

$$S = \frac{1}{1-f+\frac{f}{N}} \qquad E = \frac{1}{N(1+f)-f}$$

- This implies that the speedup can never be greater than $\frac{1}{1-f}$ irrespective of the number of cores used

Communication and Parallel Efficiency

- In distributed memory codes, most of the calculations are in parallel
  - Amdahl’s law is less applicable
  - Inefficiency often comes from the relative amount of time spent transferring data (or waiting for communications) relative to the amount of time spend doing calculations

$$T_{Total} = T_{Calculate} + T_{Communicate}$$

- If we assume that the problem is of size P and that we can perfectly decompose the problem then

$$T_{Calculate} \propto \frac{P}{N}$$

- The communications are often associated with the “edges” of the data

$$T_{Communicate} \propto \left(\frac{P}{N}\right)^{n}$$

- Where n will typically be between zero and one and will often depend on the dimensionality of the data

Communication and Parallel Efficiency

- We can combine these to estimate how speedup and parallel efficiency might be expected to change with problem size and the number of cores used
  - Note that these are just approximations, but can be used to get a feel for the expected trends

$$E \approx \frac{1}{1 + kP^{n-1}N^{1-n}}$$

  - Where k is problem specific and is related to the relative cost of communication and computation
- Given that $0 < n < 1$ this equation implies that:
  - For a given problem size, P, the efficiency drops as N increases
  - It also implies that bigger problems will have a higher efficiency when using the same number of cores

Domain Decomposition
Efficiency of domain decomposition

- If we assume a constant resolution then, for a 3D system, computational time will be roughly proportional to the volume of a domain and communication to the surface area of the domain (volume of the domain raised to the power 2/3)
  - In 2D system the equivalent is the computational time varying with the area of the domain and the communications with the perimeter of the domain

For domain decomposition $n \approx \frac{d-1}{d}$

$$E_{3D} \approx \frac{1}{1 + k\left(\frac{V}{N}\right)^{-\frac{1}{3}}}$$

$$E_{2D} \approx \frac{1}{1 + k\left(\frac{V}{N}\right)^{-\frac{1}{2}}}$$

A note on parallel efficiency

- It is virtually always more efficient to have tasks carried out in parallel relative to being data parallel
  - E.g. if you have 10 large simulations to complete, have parallel code to carry out the simulations and have 100 cores available to you:
  - Two main options:
    - Carry out each of the simulations on 100 cores, doing this for each of the 10 simulations
    - Carry out all 10 simulations at the same time, each using 10 cores.

  - The second option is typically the best one
    - The parallel efficiency of carrying out the individual simulations drops as the number of cores increase
    - The exception to this heuristic will be when some of the simulations to be carried out are computationally much more expensive than others