Parallel Models

Different ways to exploit parallelism

Reusing this material

Outline

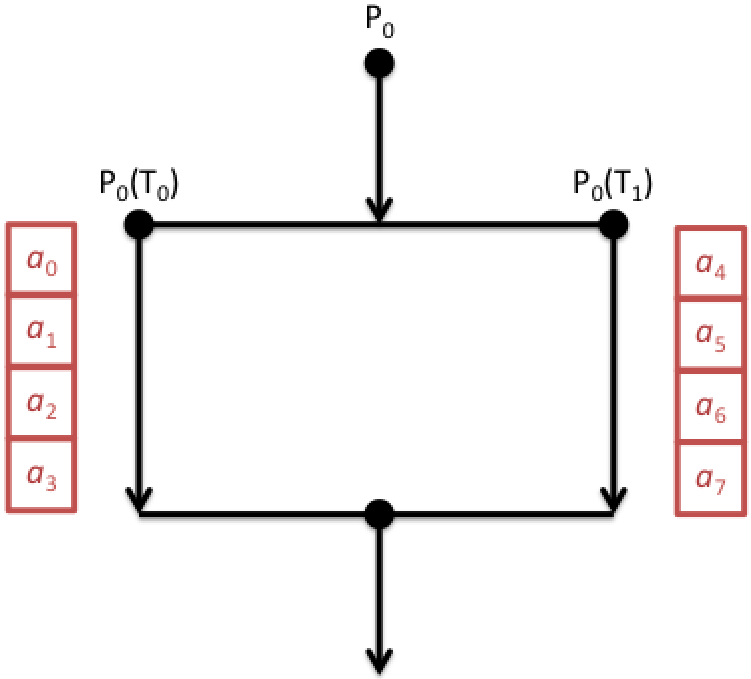
- Shared-Variables Parallelism
  - threads
  - shared-memory architectures
- Message-Passing Parallelism
  - processes
  - distributed-memory architectures
- Practicalities
  - usage on real HPC architectures

Shared Variables

Threads-based parallelism

Shared-memory concepts

- Have already covered basic concepts
  - threads can all see data of parent process
  - can run on different cores
  - potential for parallel speedup

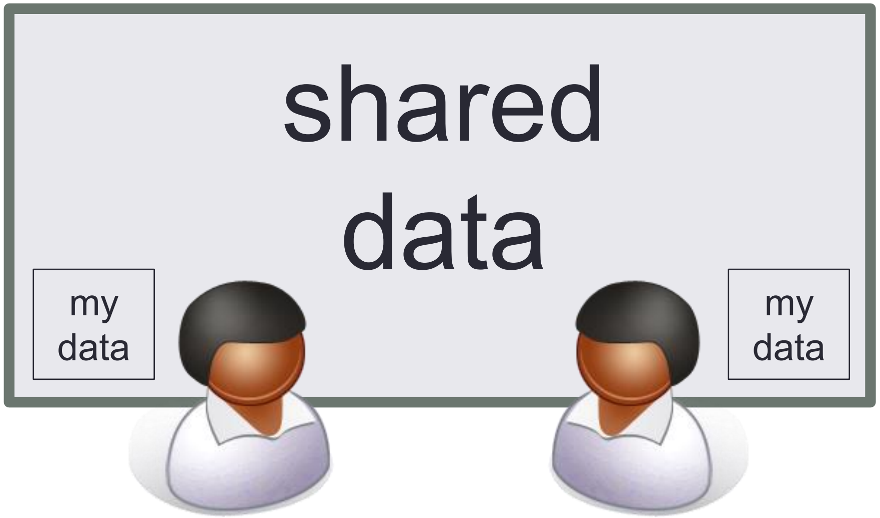


Analogy

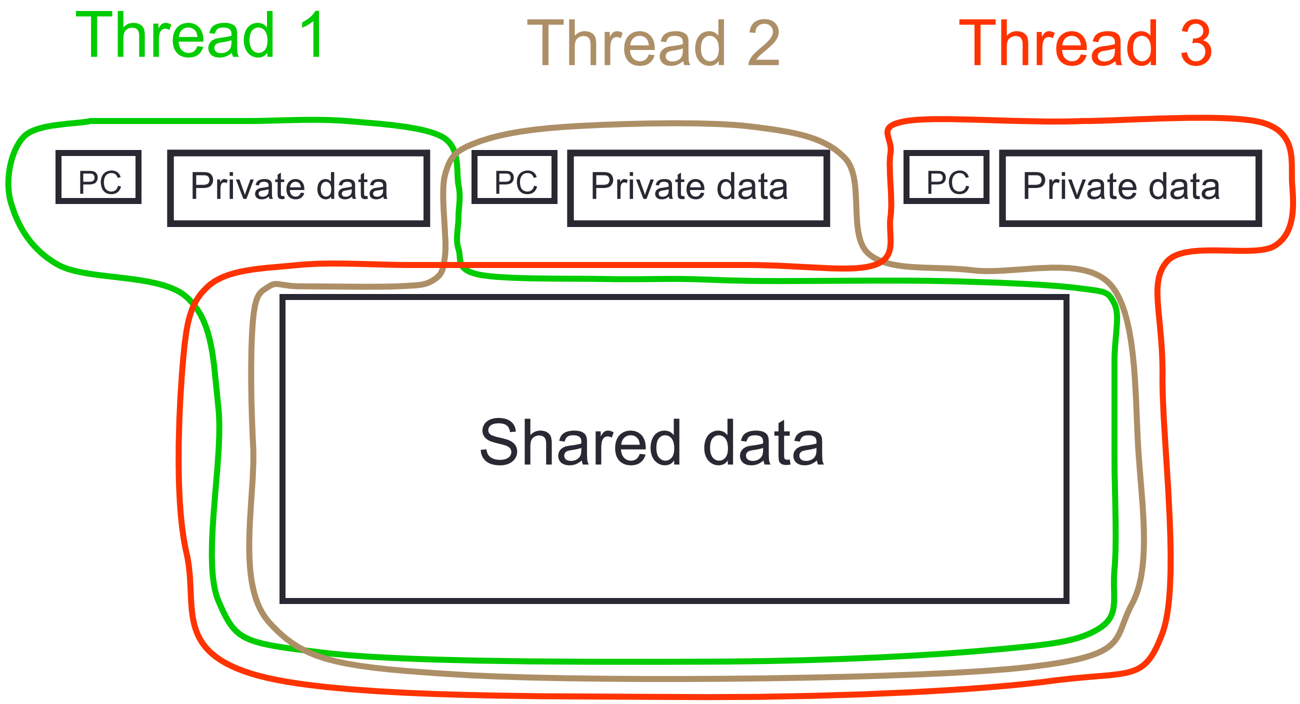
- One very large whiteboard in a two-person office
  - the shared memory
- Two people working on the same problem
  - the threads running on different cores attached to the memory

- How do they collaborate?
  - working together
  - but not interfering

- Also need *private* data



Threads

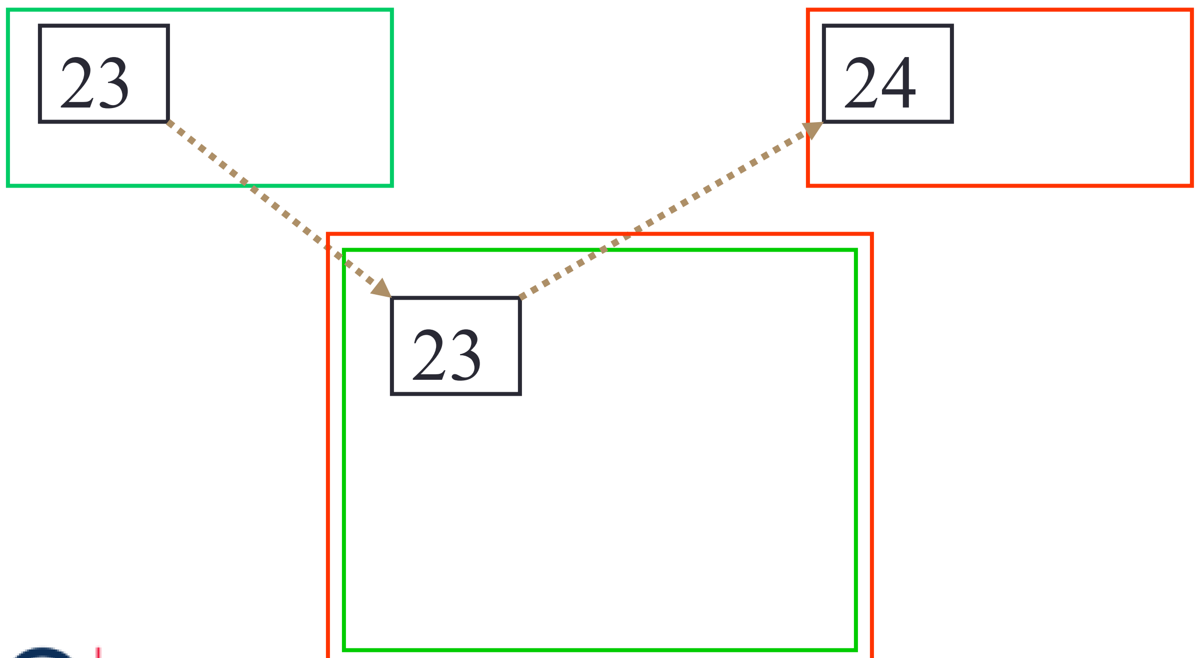

Thread 1
Thread 2
Thread 3
PC
Private data
PC
Private data
PC
Private data
Shared data

Thread Communication

	Thread 1	Thread 2
Program	`mya=23` `a=mya`	`mya=a+1`

Private data

Shared data

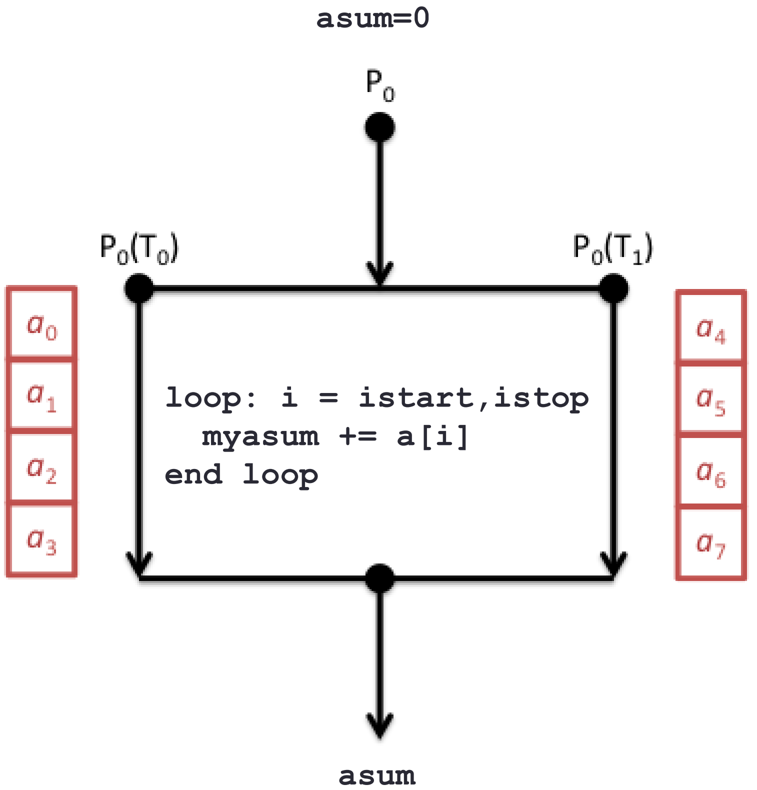


Synchronisation

- Synchronisation crucial for shared variables approach
  - thread 2's code must execute *after* thread 1
- Most commonly use global barrier synchronisation
  - other mechanisms such as locks also available
- Writing parallel codes relatively straightforward
  - access shared data as and when its needed
- Getting correct code can be difficult!

Specific example

- Computing **$asum = a_0 + a_1 + \ldots a_7$**
  - shared:
    - main array: **`a[8]`**
    - result: **`asum`**
  - private:
    - loop counter: **`i`**
    - loop limits: **`istart, istop`**
    - local sum: **`myasum`**
  - synchronisation:
    - thread0: **`asum += myasum`**
    - barrier
    - thread1: **`asum += myasum`**



Reductions

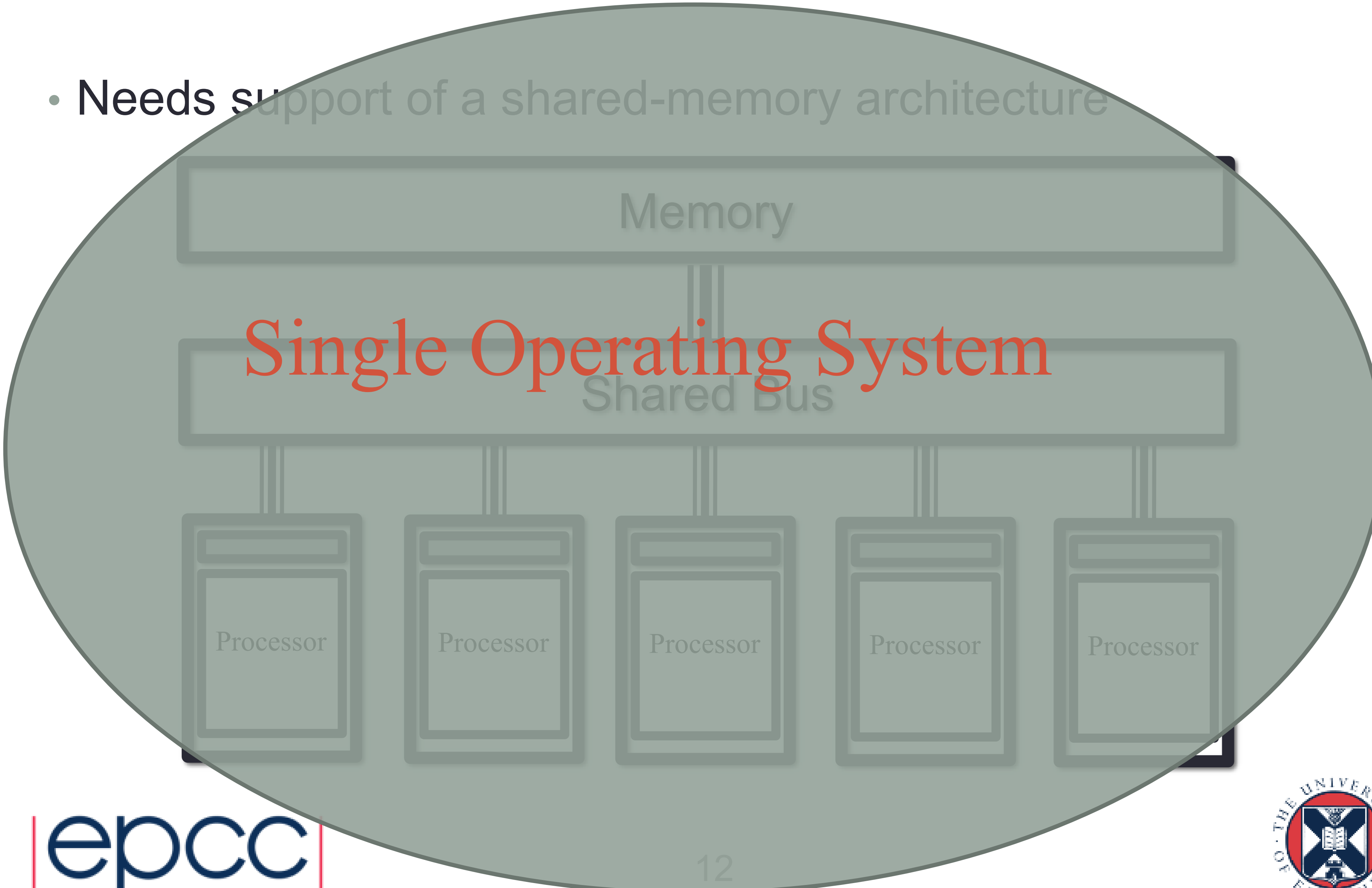
- A *reduction* produces a single value from associative operations such as addition, multiplication, max, min, and, or.

```
asum = 0;
for (i=0; i < n; i++)
    asum += a[i];
```

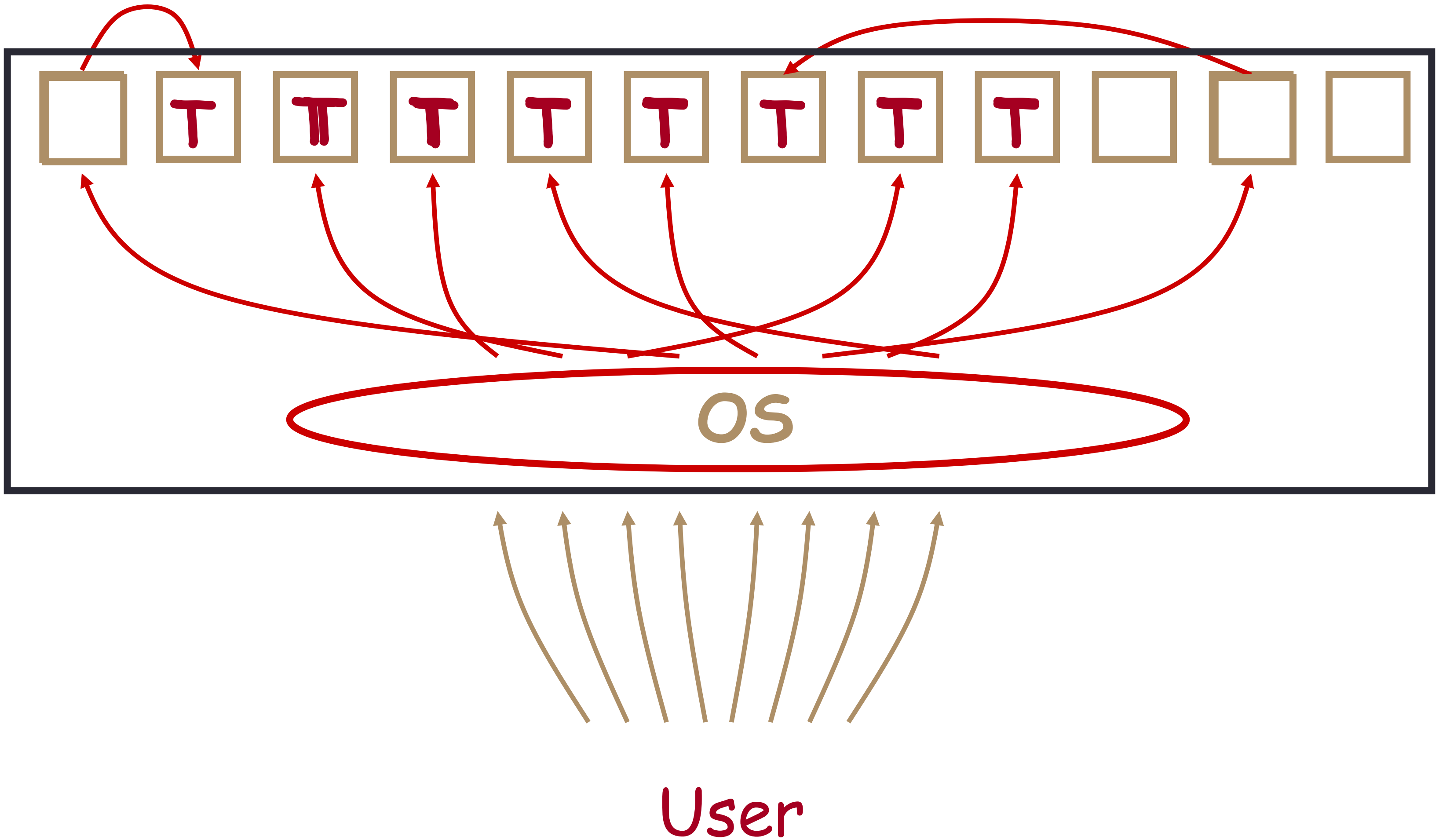
- Only one thread at a time updating **`asum`** removes all parallelism
  - each thread accumulates own private copy; copies reduced to give final result.
  - if the number of operations is much larger than the number of threads, most of the operations can proceed in parallel
- Want common patterns like this to be automated
  - **not** programmed by hand as in previous slide

Hardware

- Needs support of a shared-memory architecture



Thread Placement: Shared Memory



Threads in HPC

- Threads existed before parallel computers
  - Designed for *concurrency*
  - Many more threads running than physical cores
    - scheduled / descheduled as and when needed

- For parallel computing
  - Typically run a single thread per core
  - Want them all to run all the time

- OS optimisations
  - Place threads on selected cores
  - Stop them from migrating

Practicalities

- Threading can only operate within a single node
  - Each node is a shared-memory computer (e.g. 24 cores on ARCHER)
  - Controlled by a single operating system
- Simple parallelisation
  - Speed up a serial program using threads
  - Run an independent program per node (e.g. a simple task farm)
- More complicated
  - Use multiple processes (e.g. message-passing – next)
  - On ARCHER: could run one process per node, 24 threads per process
    - or 2 procs per node / 12 threads per process or 4 / 6 ...

Threads: Summary

- Shared blackboard a good analogy for thread parallelism
- Requires a shared-memory architecture
  - in HPC terms, cannot scale beyond a single node

- Threads operate independently on the shared data
  - need to ensure they don't interfere; synchronisation is crucial

- Threading in HPC usually uses OpenMP directives
  - supports common parallel patterns
  - e.g. loop limits computed by the compiler
  - e.g. summing values across threads done automatically

Message Passing

Process-based parallelism

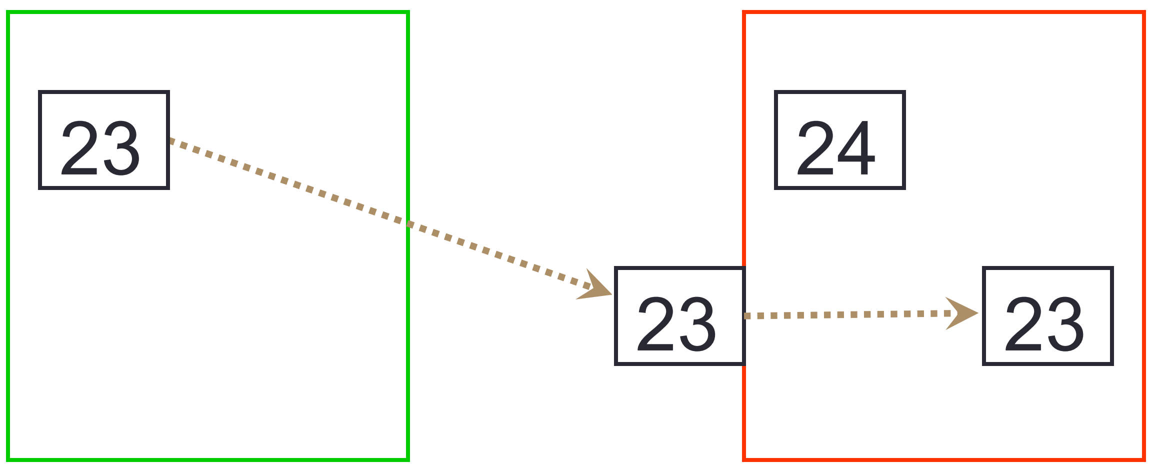
Analogy

- Two whiteboards in different single-person offices
  - the distributed memory
- Two people working on the same problem
  - the processes on different nodes attached to the interconnect
- How do they collaborate?
  - to work on single problem
- Explicit communication
  - e.g. by telephone
  - no shared data

Process communication

	Process 1	Process 2
Program	`a=23` `Send(2,a)`	`Recv(1,b)` `a=b+1`

Data



Synchronisation

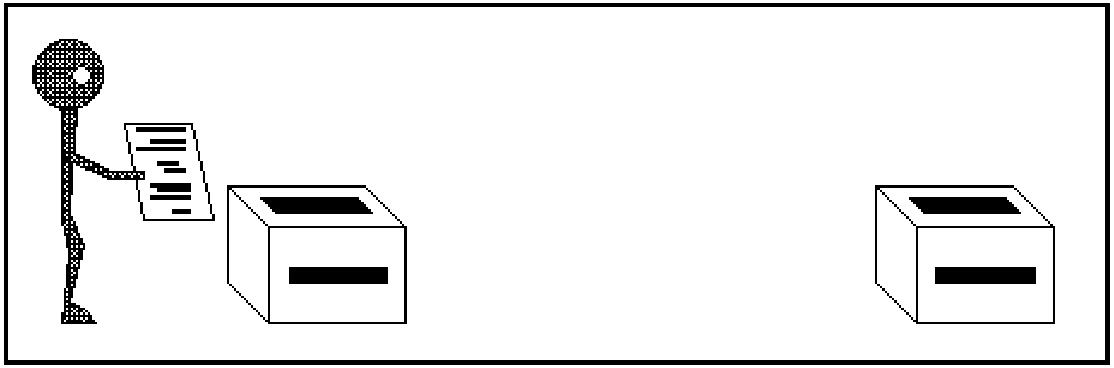
- Synchronisation is automatic in message-passing
  - the messages do it for you
- Make a phone call …
  - … wait until the receiver picks up
- Receive a phone call
  - … wait until the phone rings
- No danger of corrupting someone else's data
  - no shared blackboard

Communication modes

- Sending a message can either be synchronous or asynchronous
- A synchronous send is not completed until the message has started to be received
- An asynchronous send completes as soon as the message has gone
- Receives are usually synchronous - the receiving process must wait until the message arrives

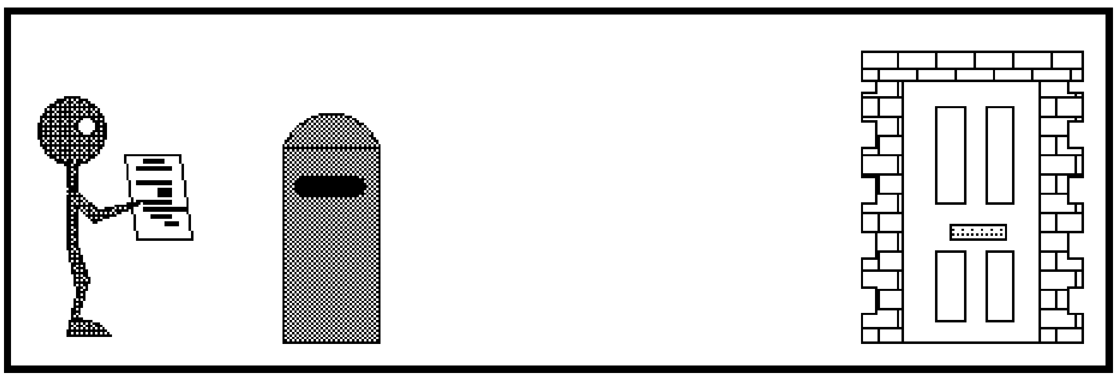
Synchronous send

- Analogy with faxing a letter.
- Know when letter has started to be received.



Asynchronous send

- Analogy with posting a letter.
- Only know when letter has been posted, not when it has been received.



Point-to-Point Communications

- We have considered two processes
  - one sender
  - one receiver

- This is called point-to-point communication
  - simplest form of message passing
  - relies on matching send and receive

- Close analogy to sending personal emails

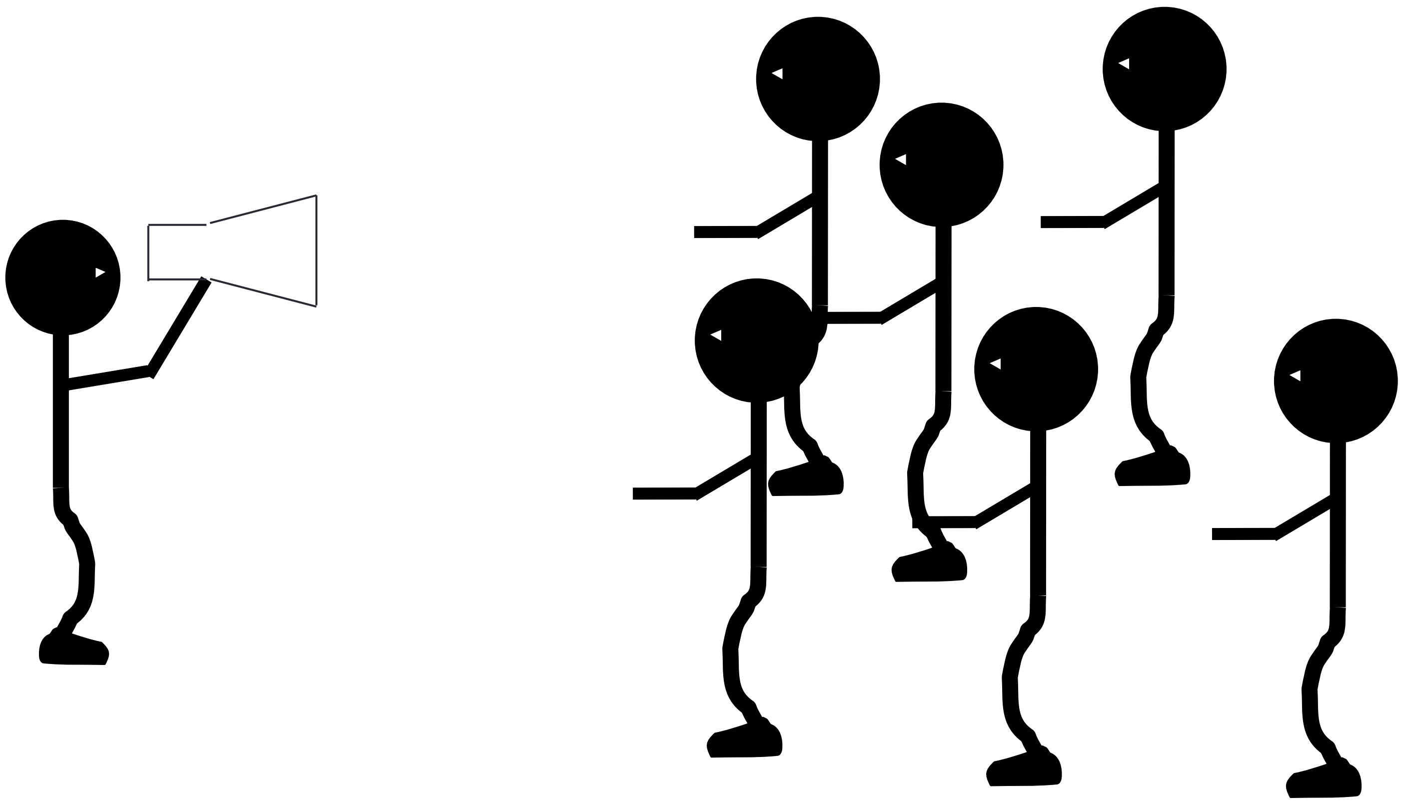
Message Passing: Collective communications

Process-based parallelism

Collective Communications

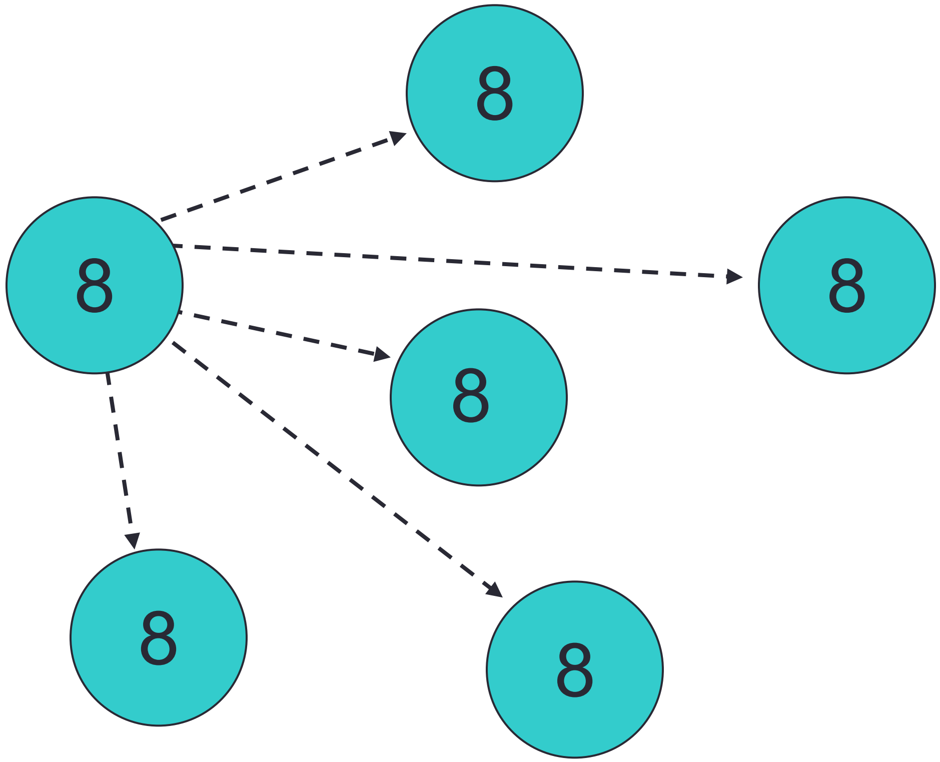
- A simple message communicates between two processes
- There are many instances where communication between groups of processes is required
- Can be built from simple messages, but often implemented separately, for efficiency

Broadcast: one to all communication



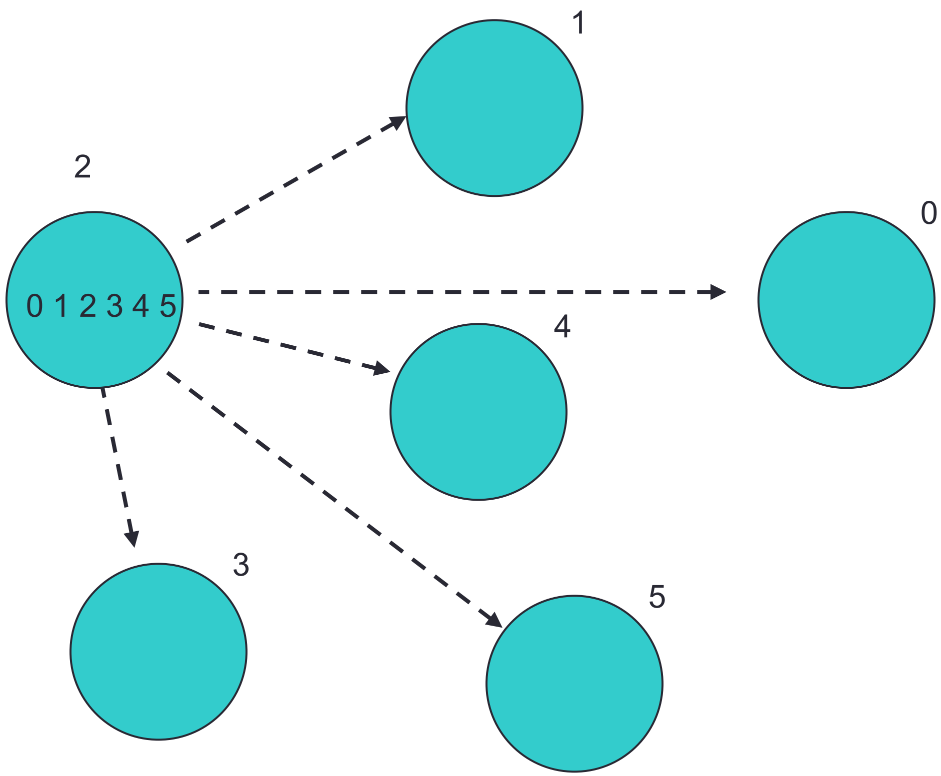
Broadcast

- From one process to all others



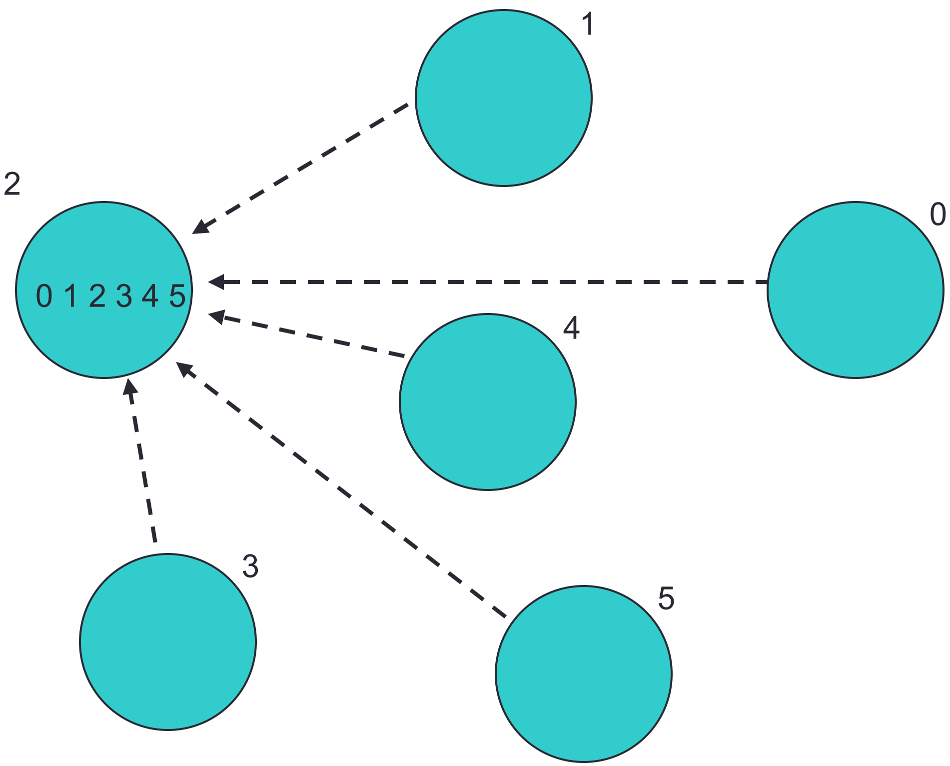
Scatter

- Information scattered to many processes



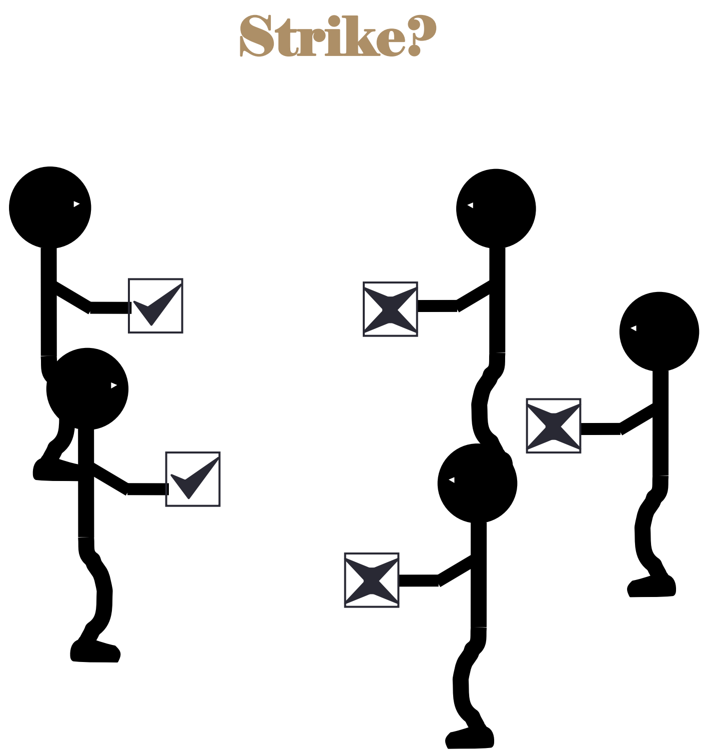
Gather

- Information gathered onto one process



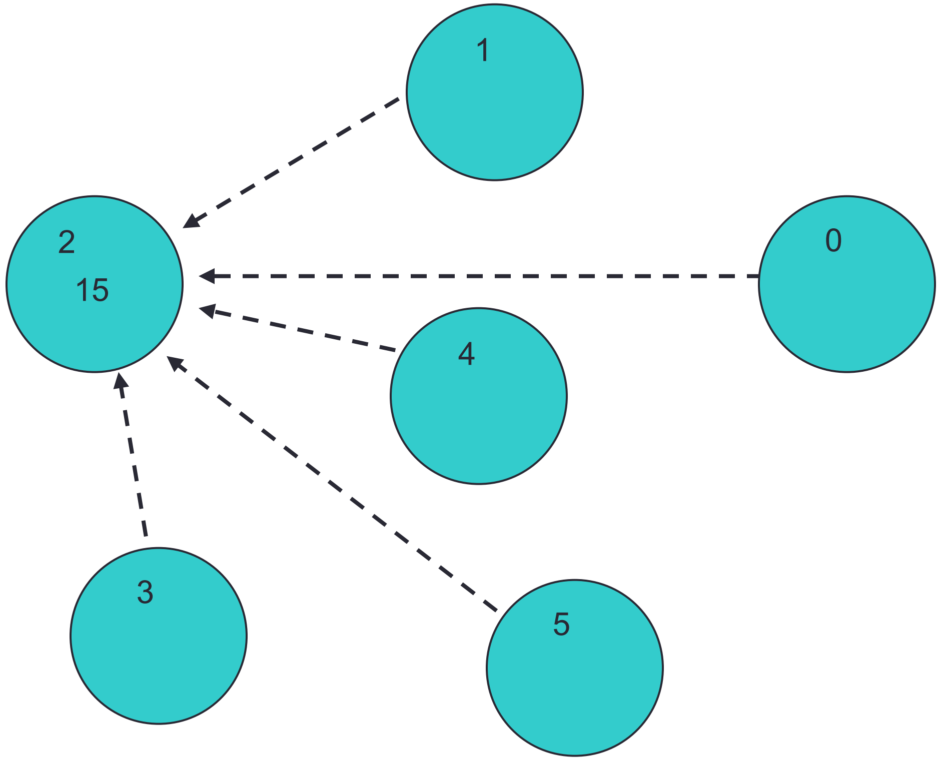
Reduction Operations

- Combine data from several processes to form a single result

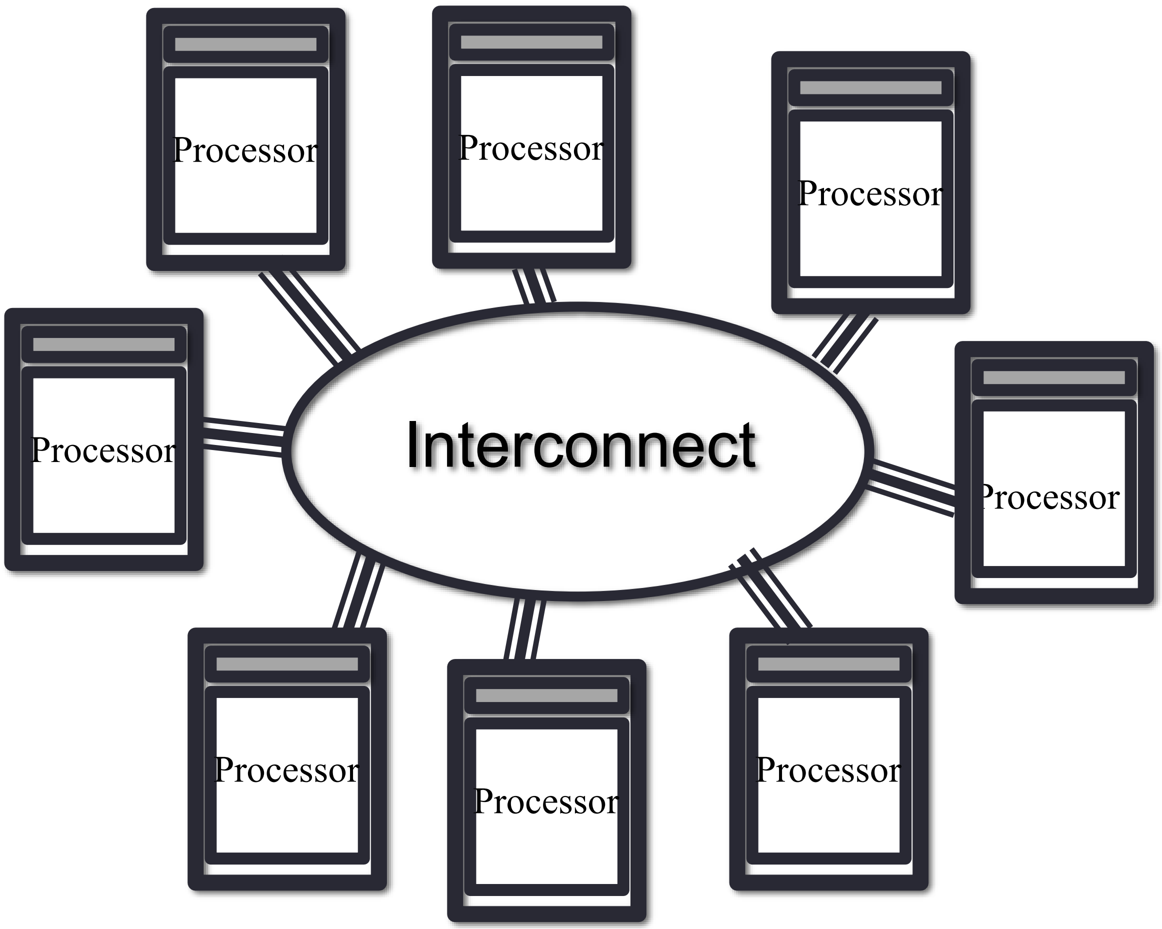


Reduction

- Form a global sum, product, max, min, etc.



Hardware



- Natural map to distributed-memory
  - one process per processor-core
  - messages go over the interconnect, between nodes/OS's

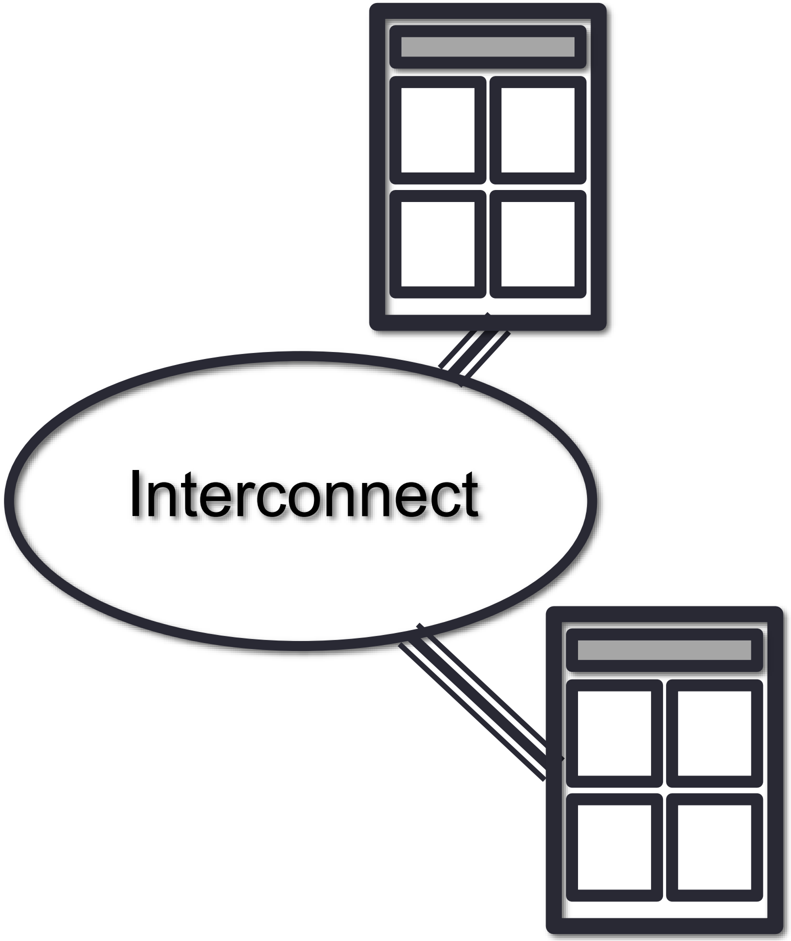
Processes: Summary

- Processes cannot share memory
  - ring-fenced from each other
  - analogous to white boards in separate offices
- Communication requires explicit *messages*
  - analogous to making a phone call, sending an email, …
  - synchronisation is done by the messages
- Almost exclusively use Message-Passing Interface
  - MPI is a library of function calls / subroutines

Practicalities

How we use the parallel models

Practicalities

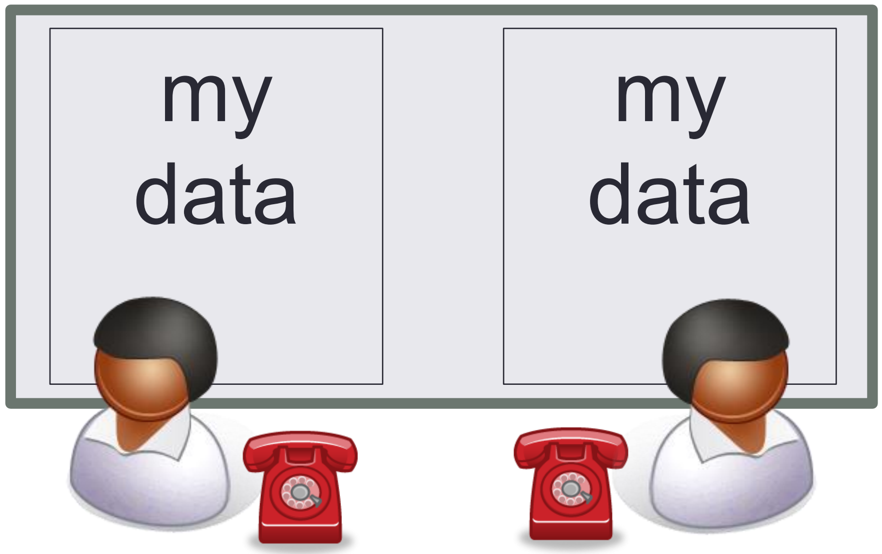


- 8-core machine might only have 2 nodes
  - how do we run MPI on a real HPC machine?
- Mostly ignore architecture
  - pretend we have single-core nodes
  - one MPI process per processor-core
  - e.g. run 8 processes on the 2 nodes
- Messages between processor-cores on the same node are fast
  - but remember they also share access to the network

Message Passing on Shared Memory

- Run one process per core
  - don't directly exploit shared memory
  - analogy is phoning your office mate
  - actually works well in practice!

- Message-passing programs run by a special job launcher
  - user specifies #copies
  - some control over allocation to nodes



Summary

Summary

- Shared-variables parallelism
  - uses threads
  - requires shared-memory machine
  - easy to implement but limited scalability
  - in HPC, done using OpenMP compilers

- Distributed memory
  - uses processes
  - can run on any machine: messages can go over the interconnect
  - harder to implement but better scalability
  - on HPC, done using the MPI library