

Parallel Models

Different ways to exploit parallelism



Reusing this material



This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.

http://creativecommons.org/licenses/by-nc-sa/4.0/deed.en_US

This means you are free to copy and redistribute the material and adapt and build on the material under the following terms: You must give appropriate credit, provide a link to the license and indicate if changes were made. If you adapt or build on the material you must distribute your work under the same license as the original.

Note that this presentation contains images owned by others. Please seek their permission before reusing these images.

Outline

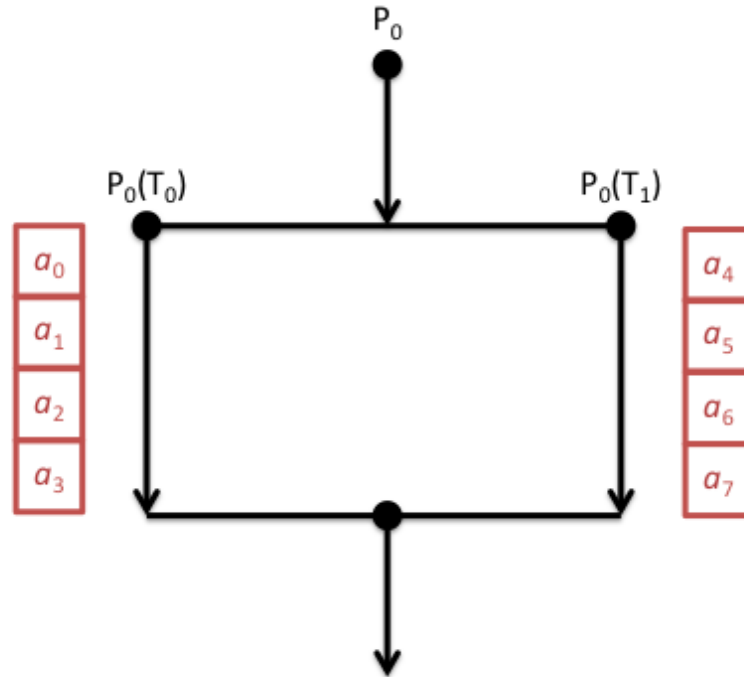
- Shared-Variables Parallelism
 - threads
 - shared-memory architectures
- Message-Passing Parallelism
 - processes
 - distributed-memory architectures
- Practicalities
 - usage on real HPC architectures

Shared Variables

Threads-based parallelism

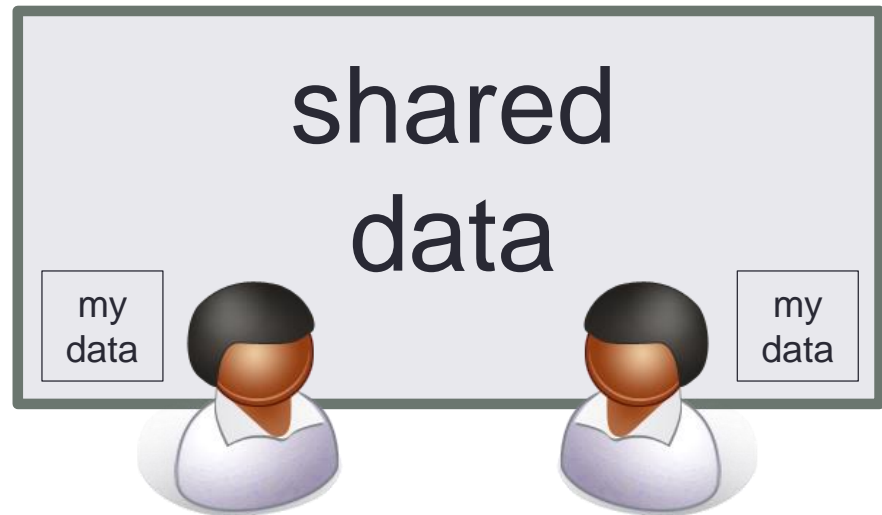
Shared-memory concepts

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

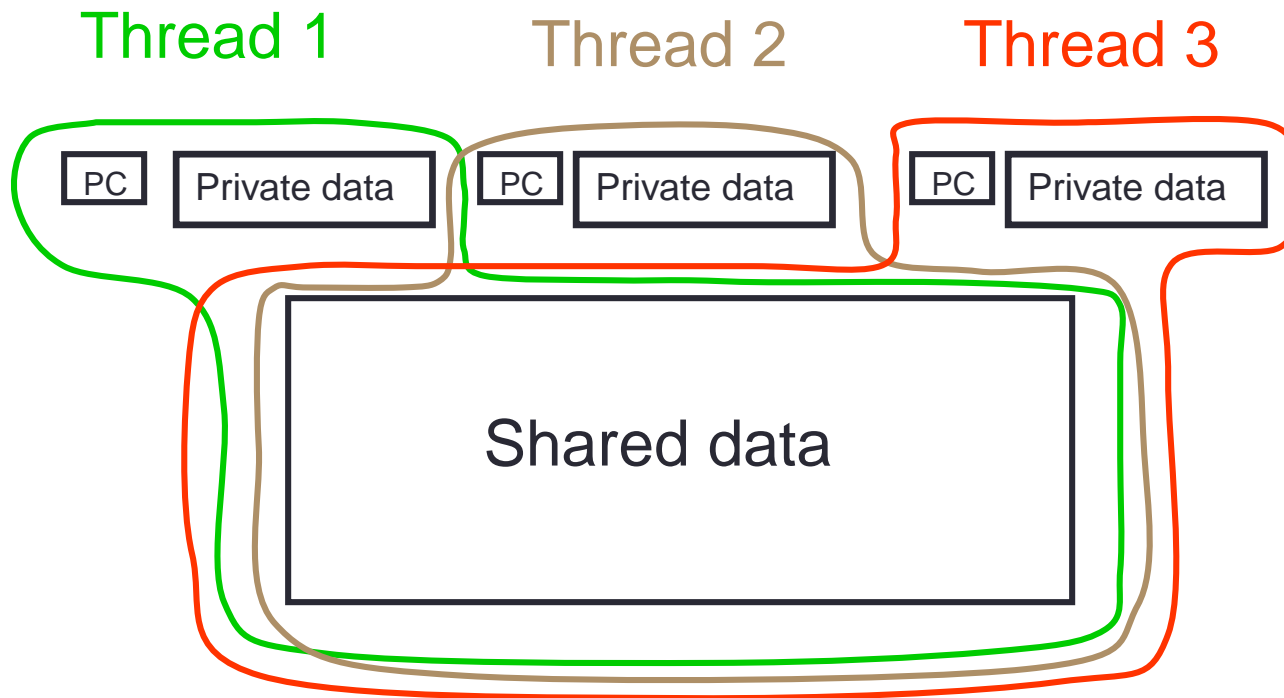


Analogy

- 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 Communication

Thread 1

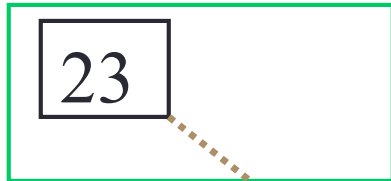
Thread 2

Program

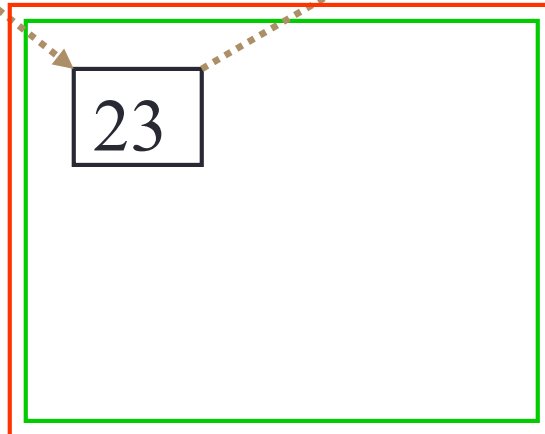
```
mya=23  
a=mya
```

```
mya=a+1
```

Private
data



Shared
data

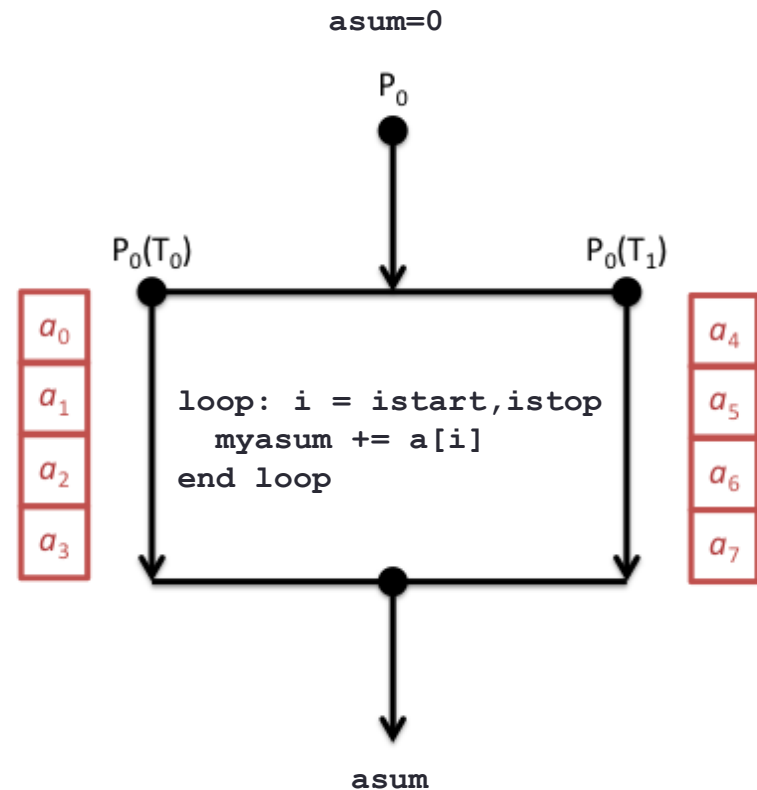


Synchronisation

- 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

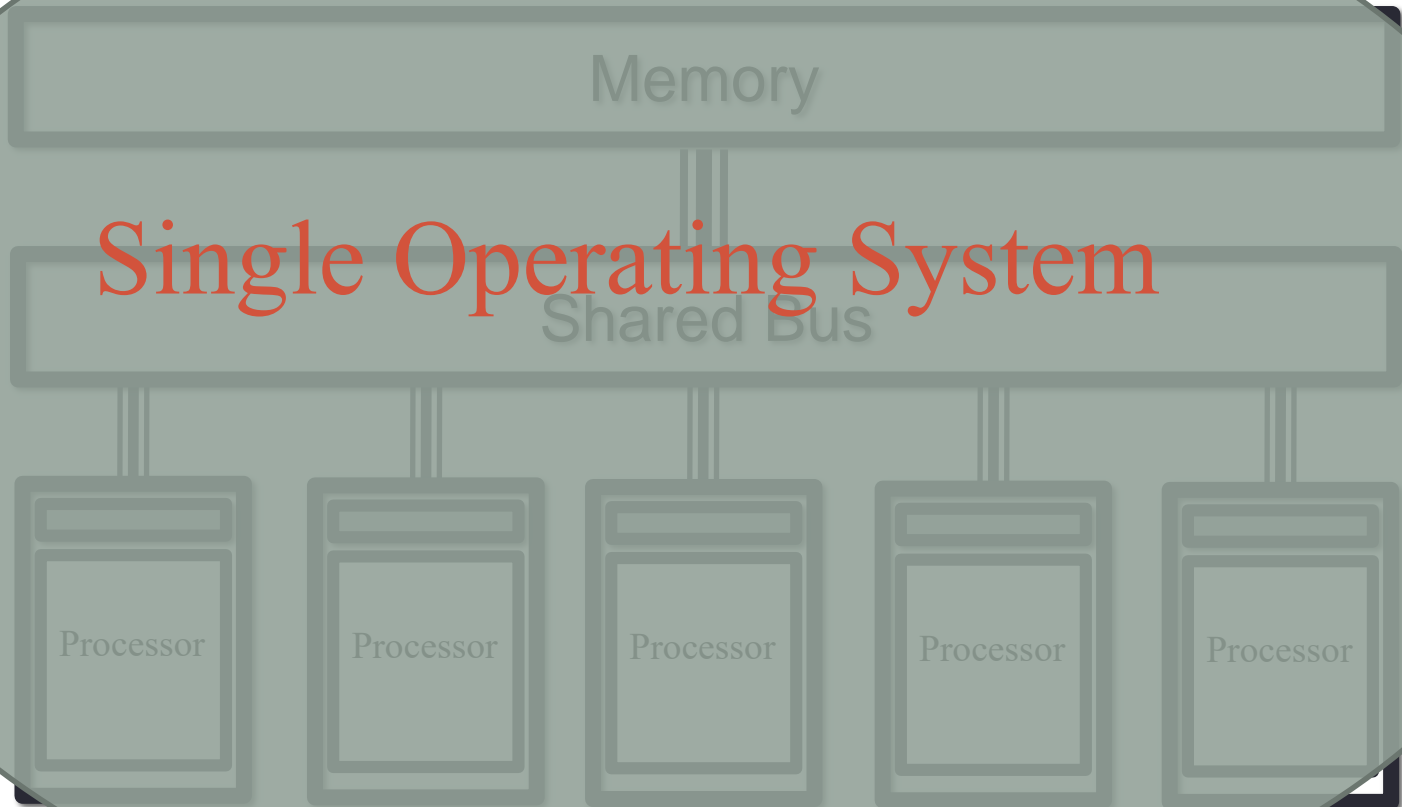
- Computing $asum = a_0 + a_1 + \dots + a_7$
 - shared:
 - main array: **a [8]**
 - result: **asum**
 - private:
 - loop counter: **i**
 - loop limits: **istart, istop**
 - local sum: **myasum**
 - synchronisation:
 - thread0: **asum += myasum**
 - barrier
 - thread1: **asum += myasum**



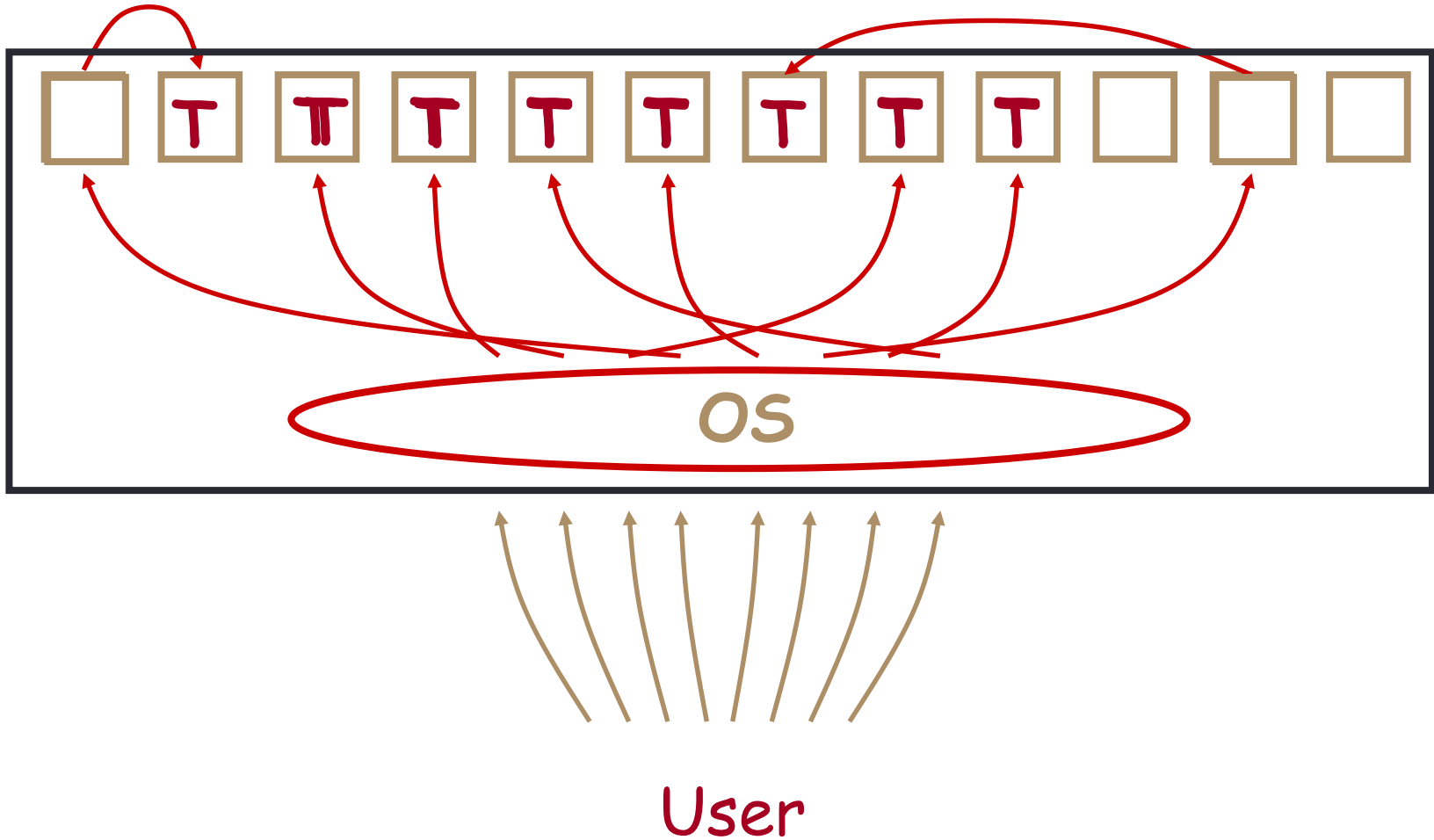
Hardware

- Needs support of a shared-memory architecture

Single Operating System



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

Program

Process 1

`a=23`

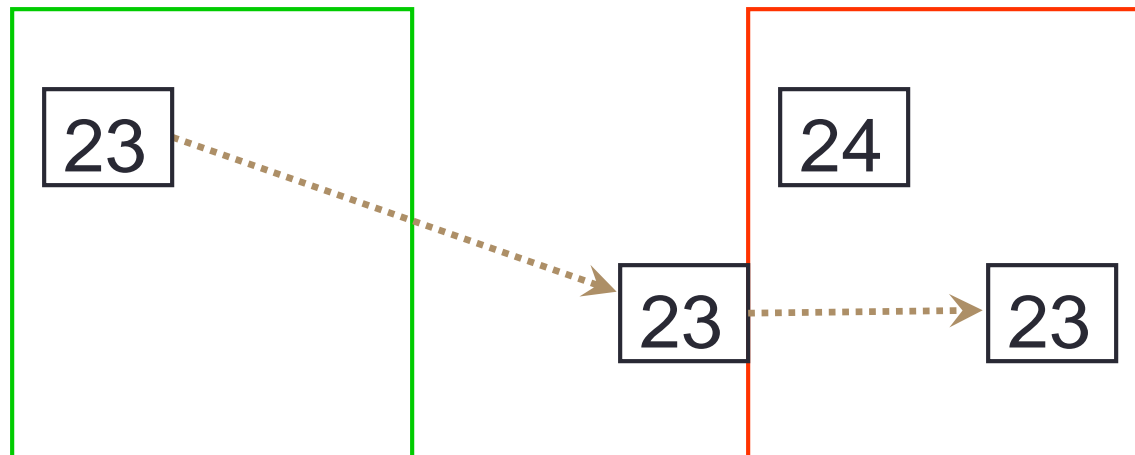
`Send (2, a)`

Process 2

`Recv (1, b)`

`a=b+1`

Data



Synchronisation

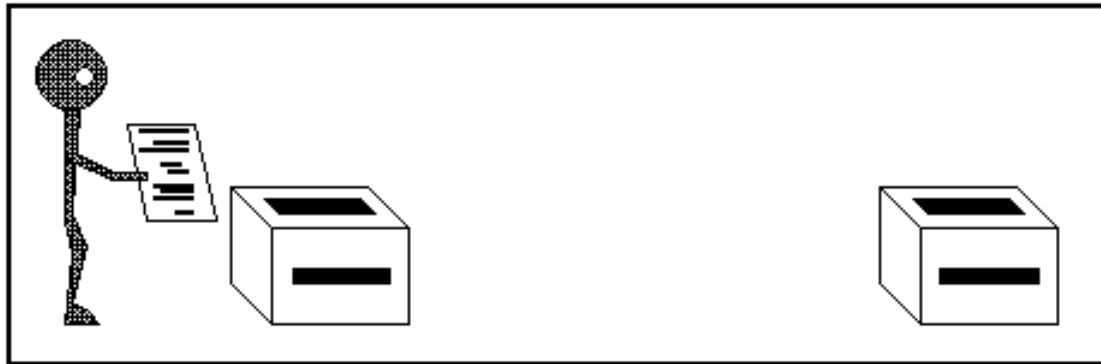
- Synchronisation is automatic in message-passing
 - the messages do it for you
- Make a phone call ...
 - ... wait until the receiver picks up
- Receive a phone call
 - ... wait until the phone rings
- No danger of corrupting someone else's data
 - no shared blackboard

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

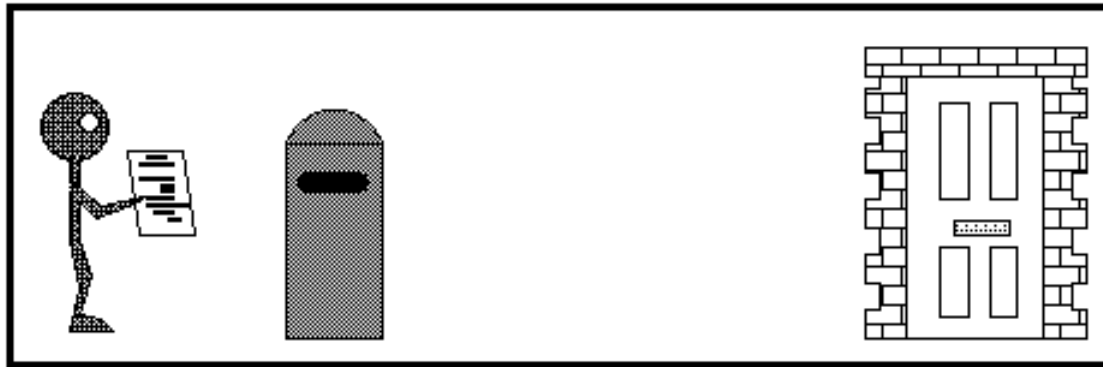
Synchronous send

- 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

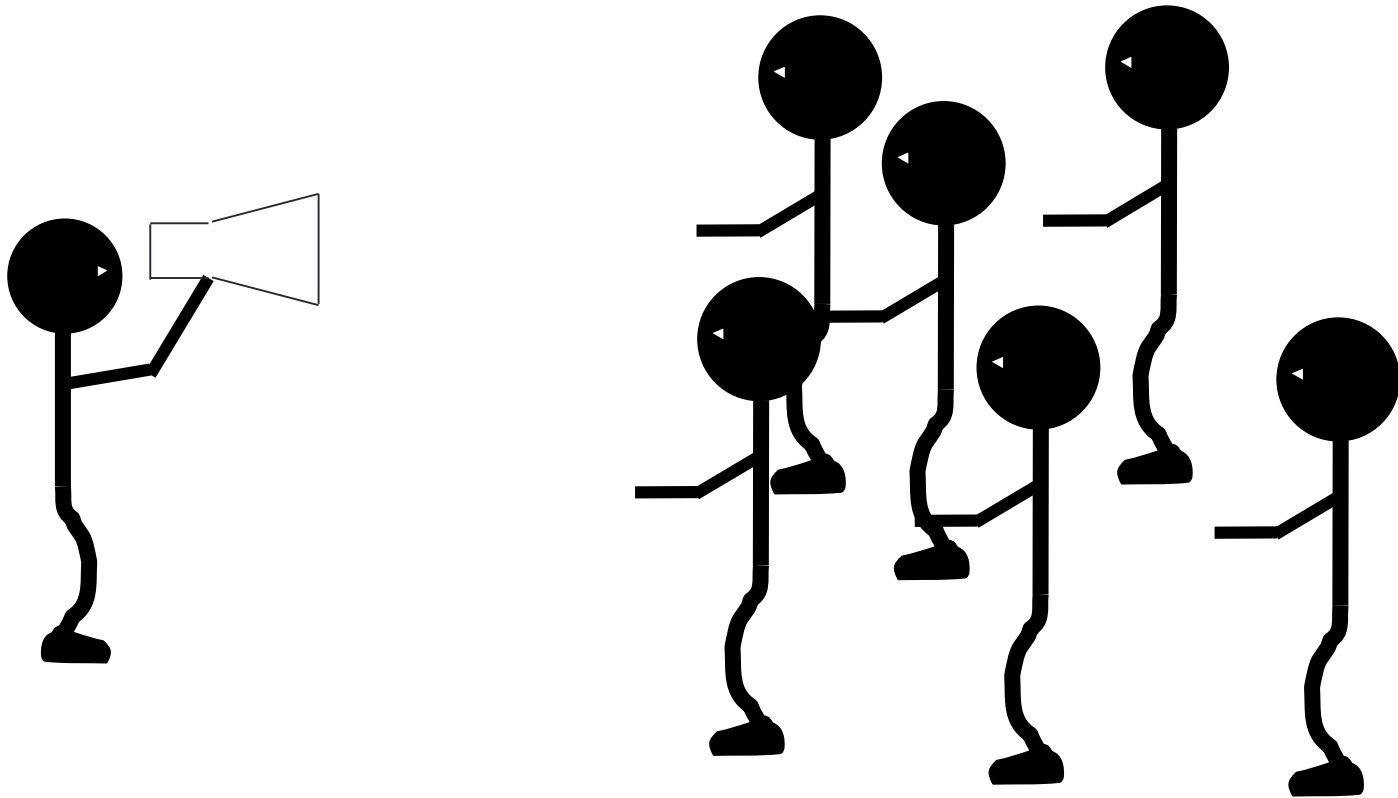
Message Passing: Collective communications

Process-based parallelism

Collective Communications

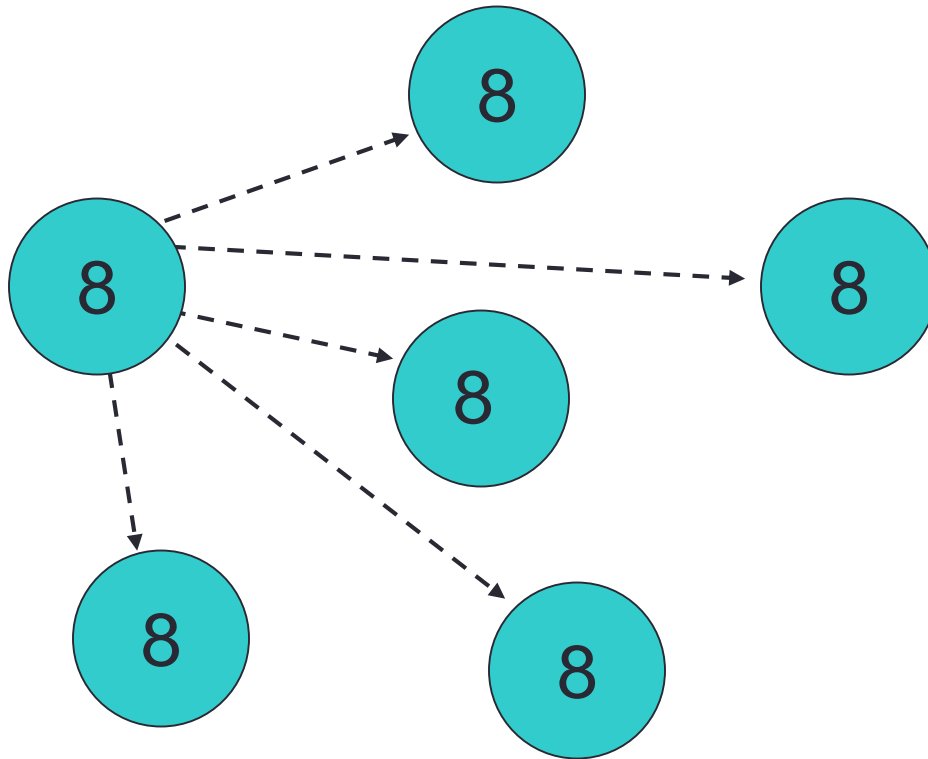
- A simple message communicates between two processes
- There are many instances where communication between groups of processes is required
- Can be built from simple messages, but often implemented separately, for efficiency

Broadcast: one to all communication



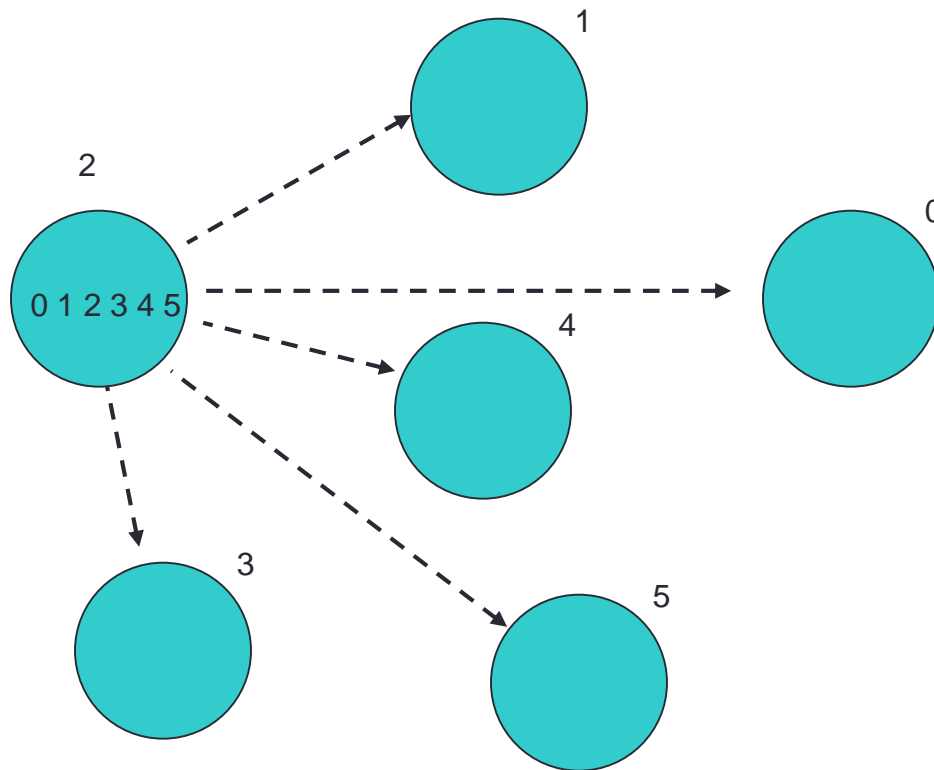
Broadcast

- From one process to all others



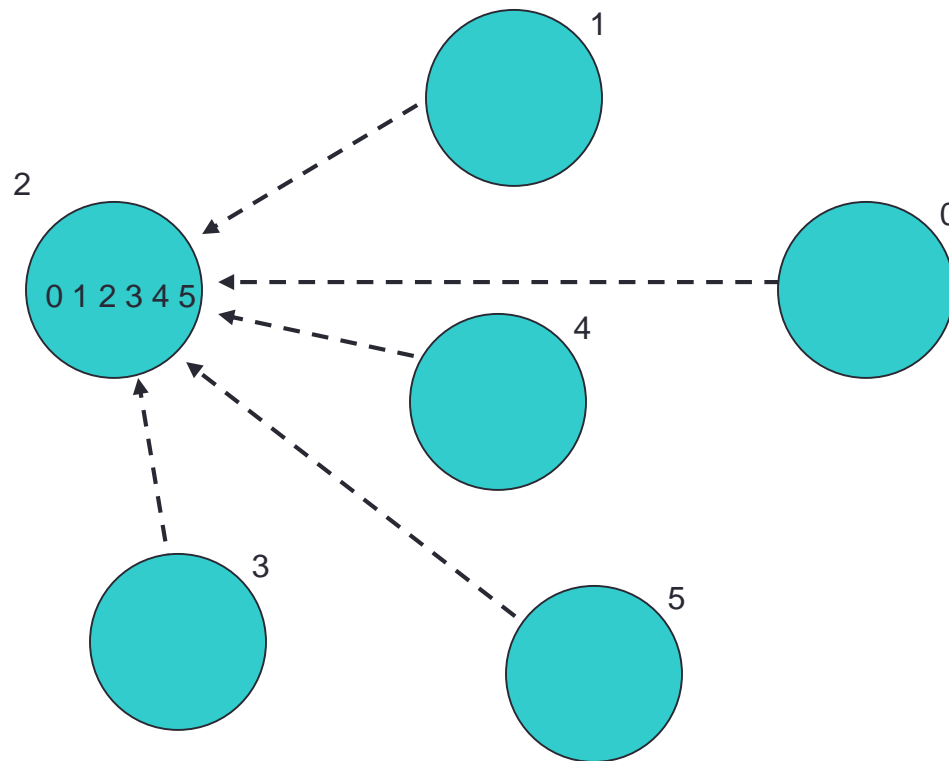
Scatter

- Information scattered to many processes



Gather

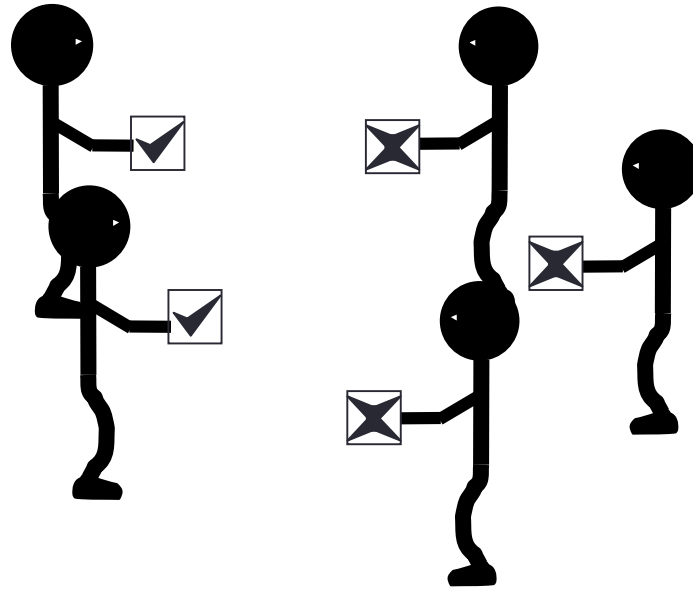
- Information gathered onto one process



Reduction Operations

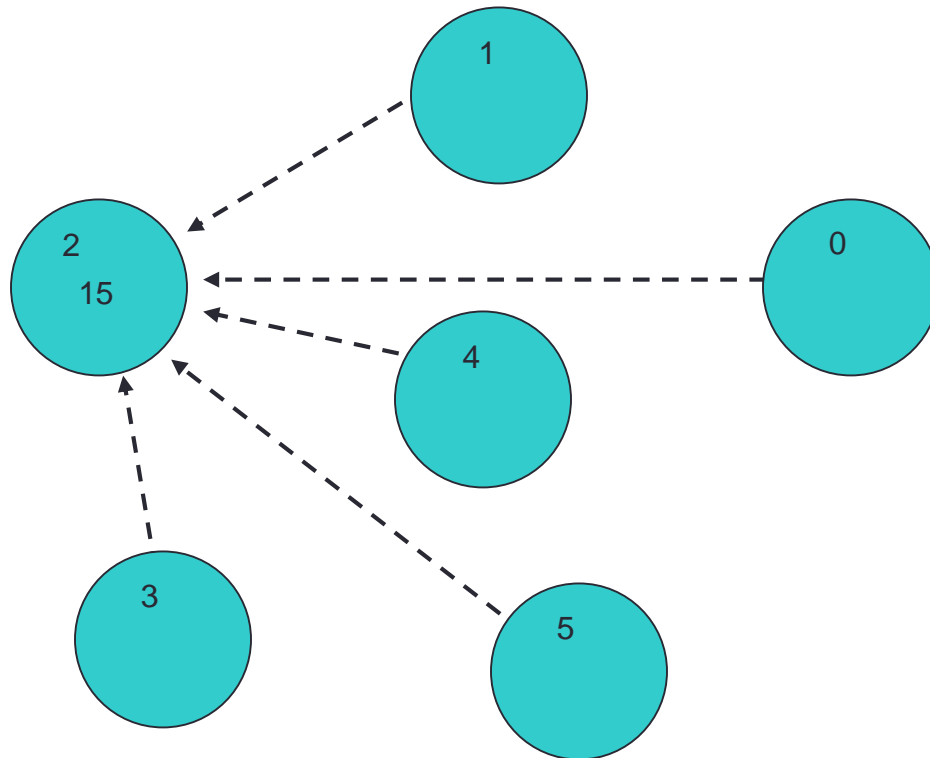
- Combine data from several processes to form a single result

Strike?

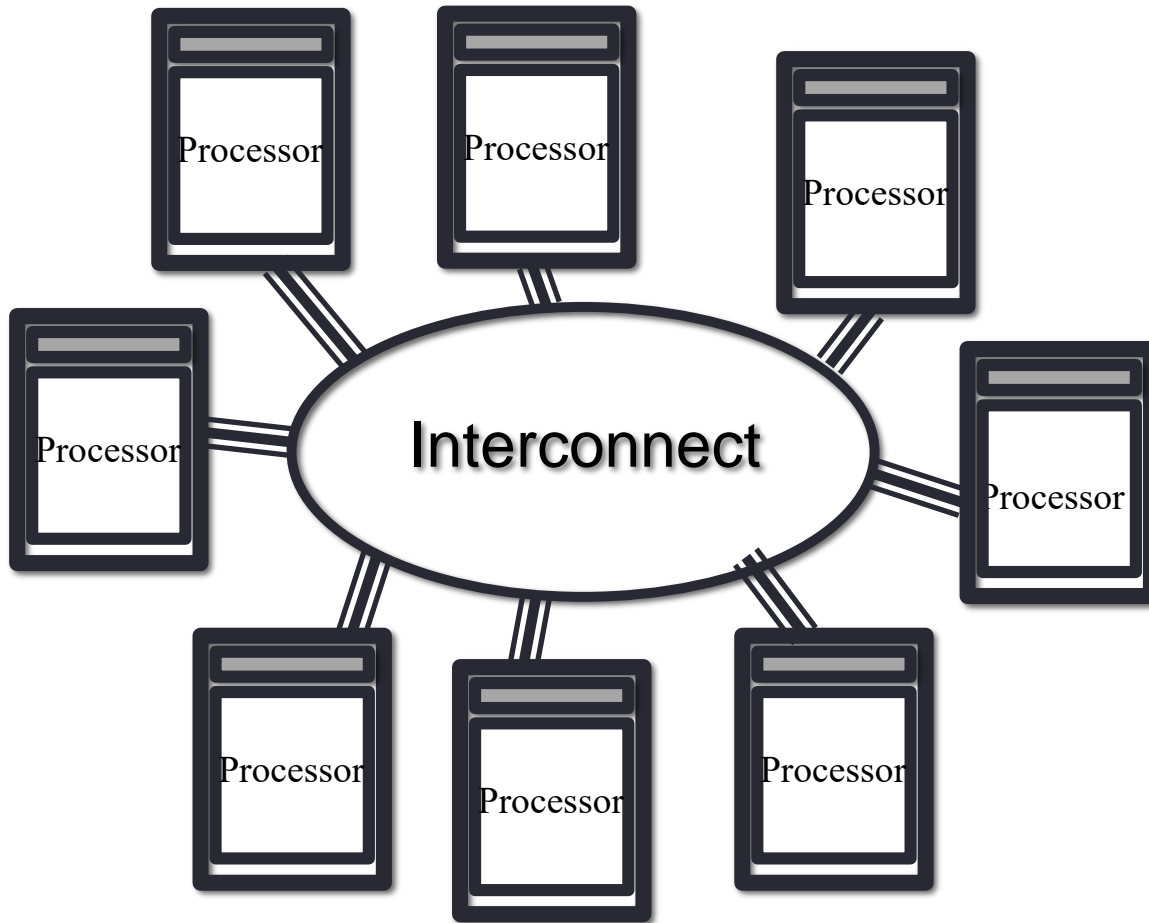


Reduction

- 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

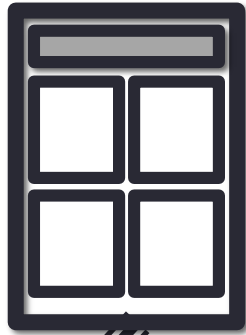
Processes: Summary

- 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



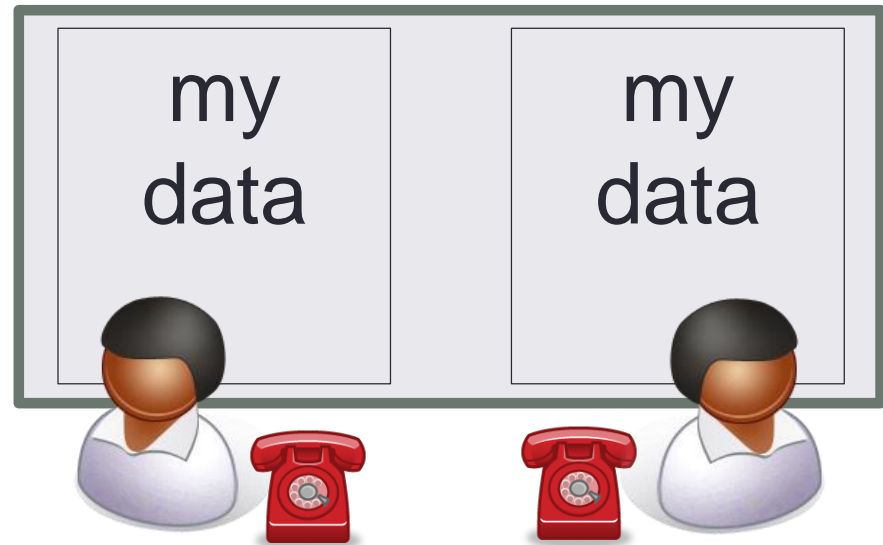
Interconnect



- 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