# Parallel Models

Different ways to exploit parallelism

# Reusing this material

# Outline

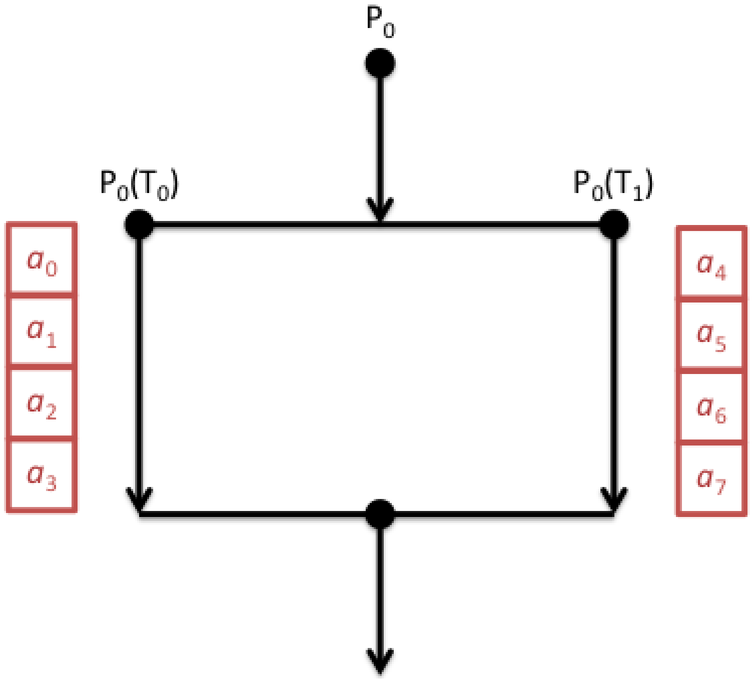
- Shared-Variables Parallelism
  - threads
  - shared-memory architectures
- Message-Passing Parallelism
  - processes
  - distributed-memory architectures
- Practicalities
  - usage on real HPC architectures

# 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

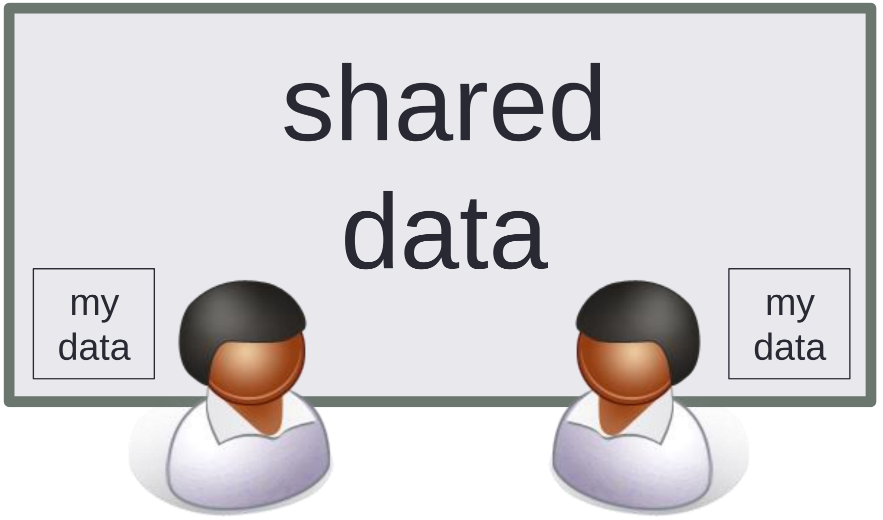


# Analogy

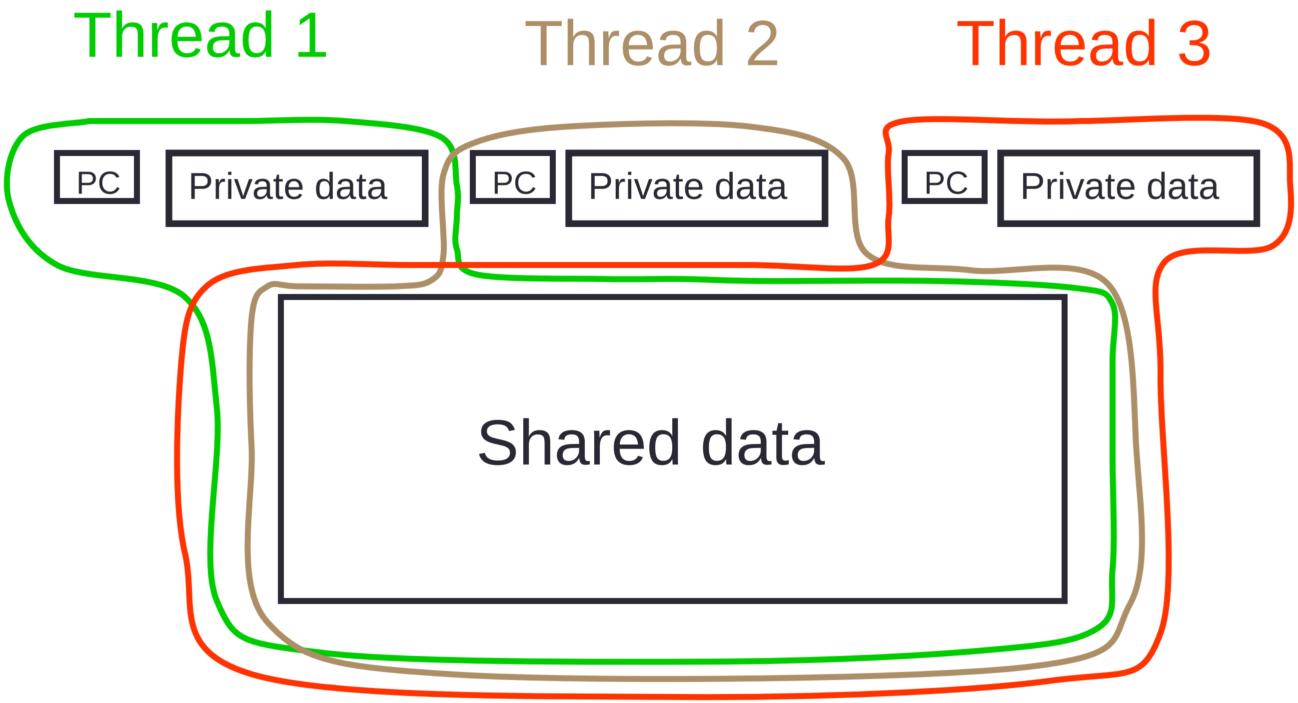
- One very large whiteboard in a two-person office
  - the shared memory
- Two people working on the same problem
  - the threads running on different cores attached to the memory

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

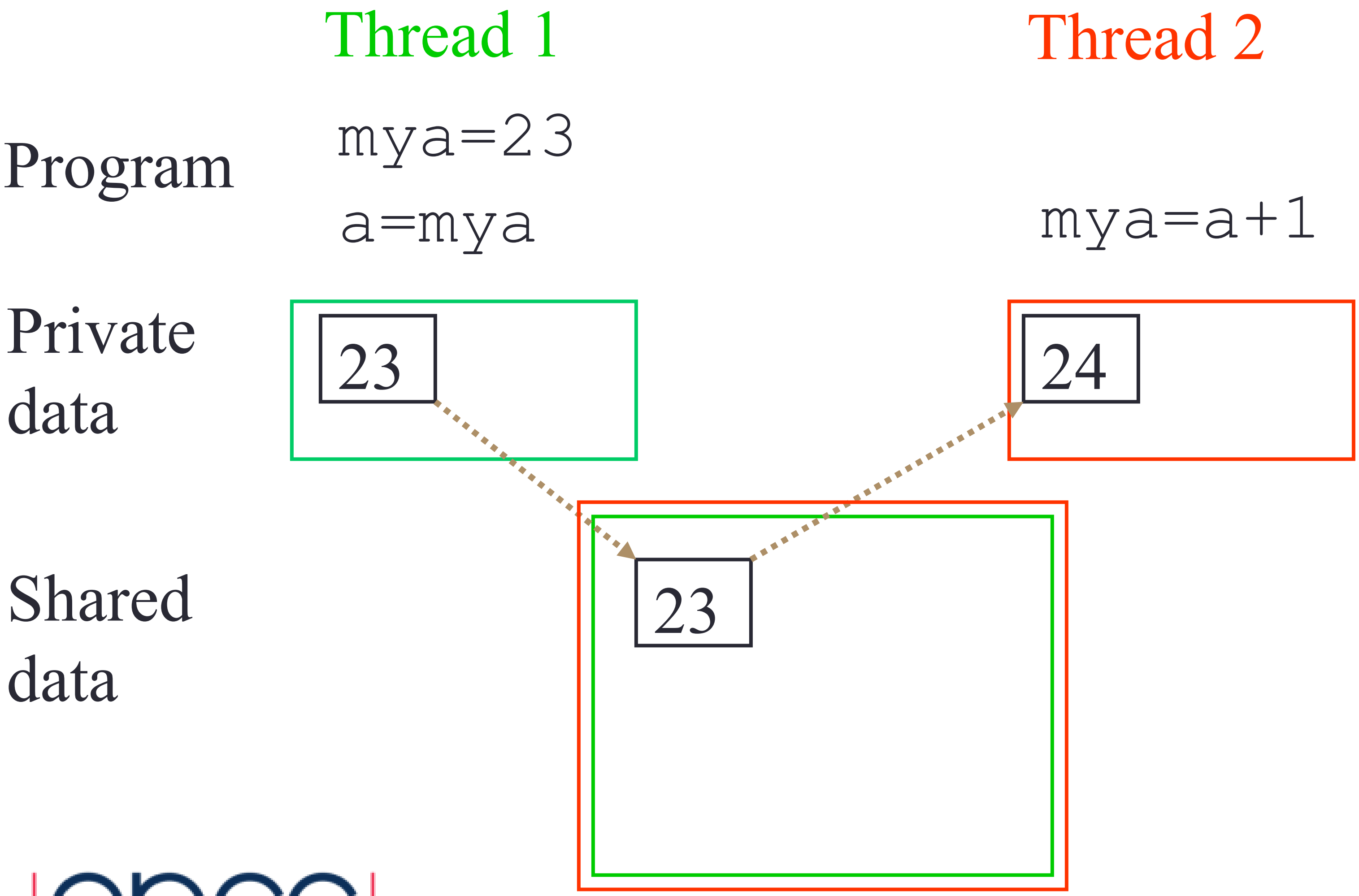
- Also need *private* data



# Threads


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

# Thread Communication

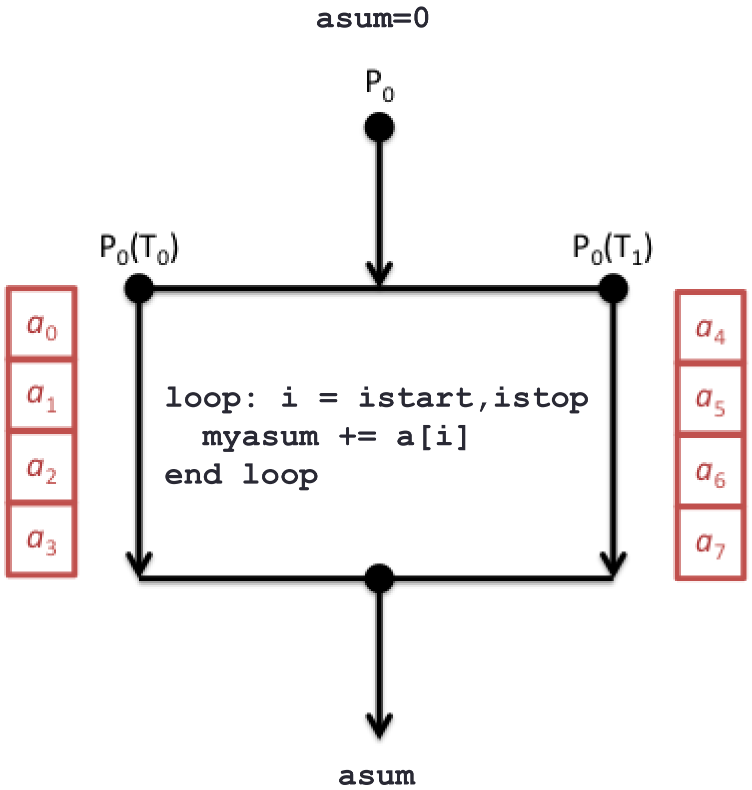


# Synchronisation

- 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 = $a_0$+ $a_1$ + … $a_7$**
  - 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

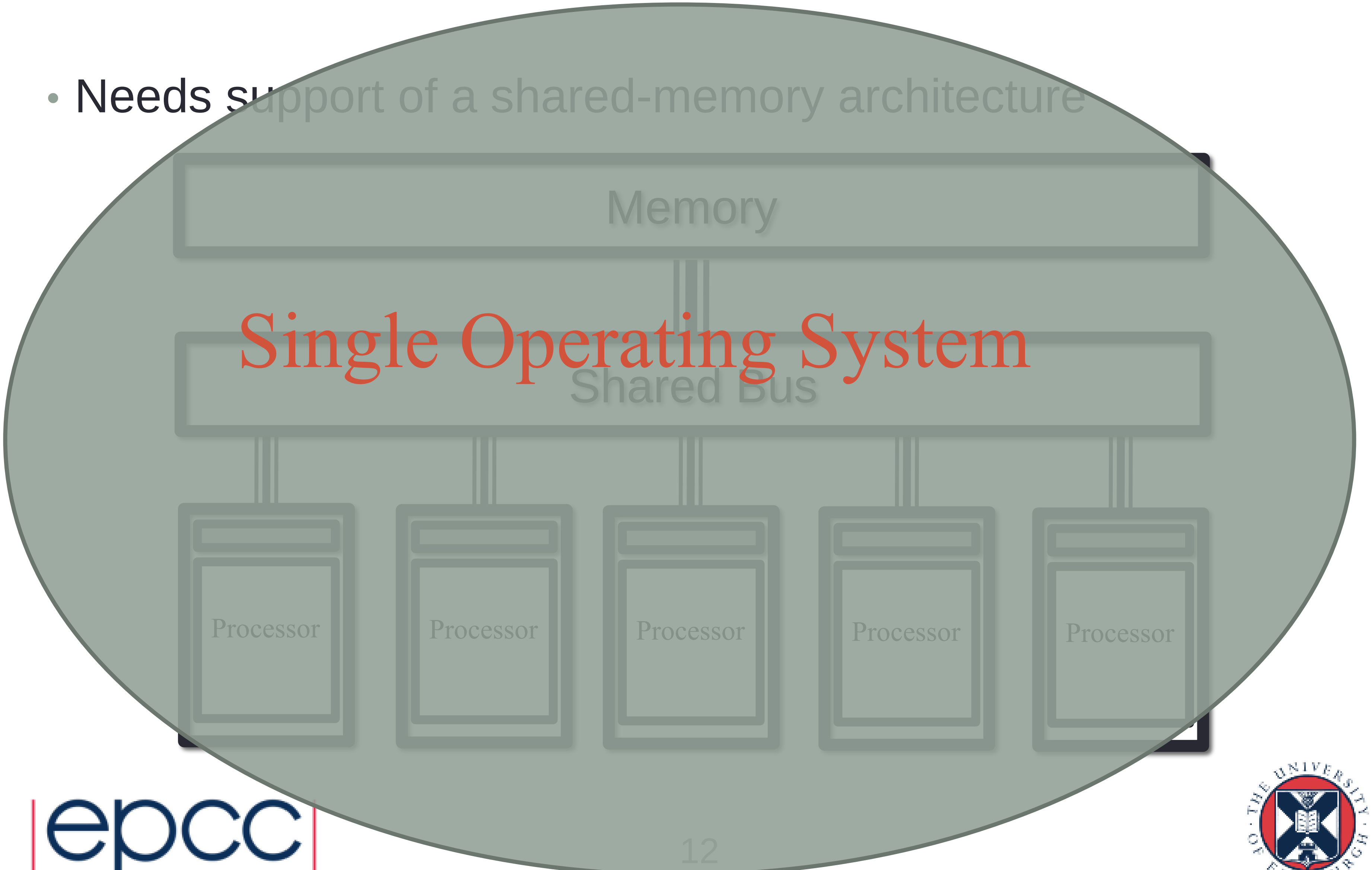
- A *reduction* produces a single value from associative operations such as addition, multiplication, max, min, and, or.

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

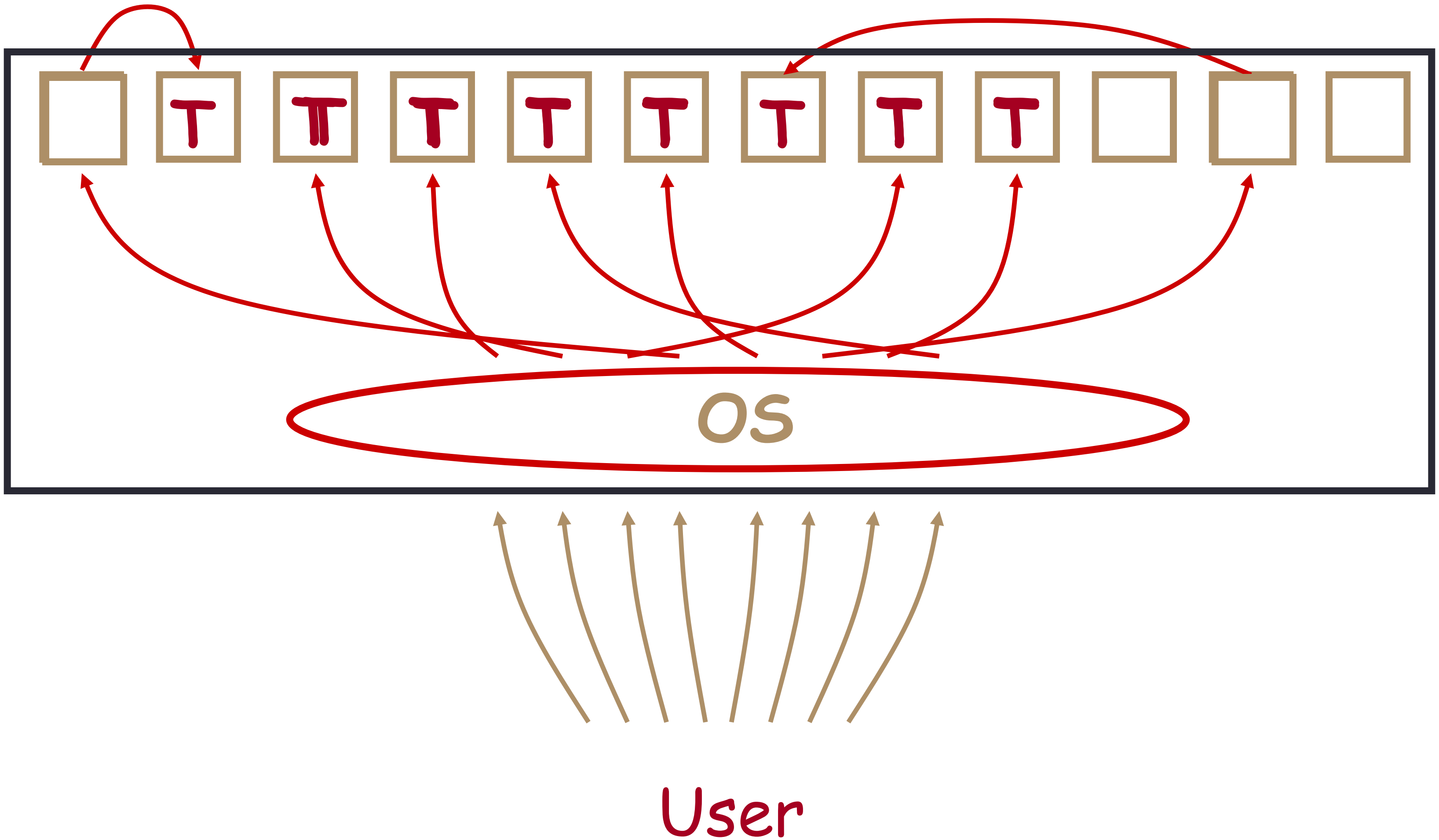
- Only one thread at a time updating **`asum`** removes all parallelism
  - each thread accumulates own private copy; copies reduced to give final result.
  - if the number of operations is much larger than the number of threads, most of the operations can proceed in parallel
- Want common patterns like 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

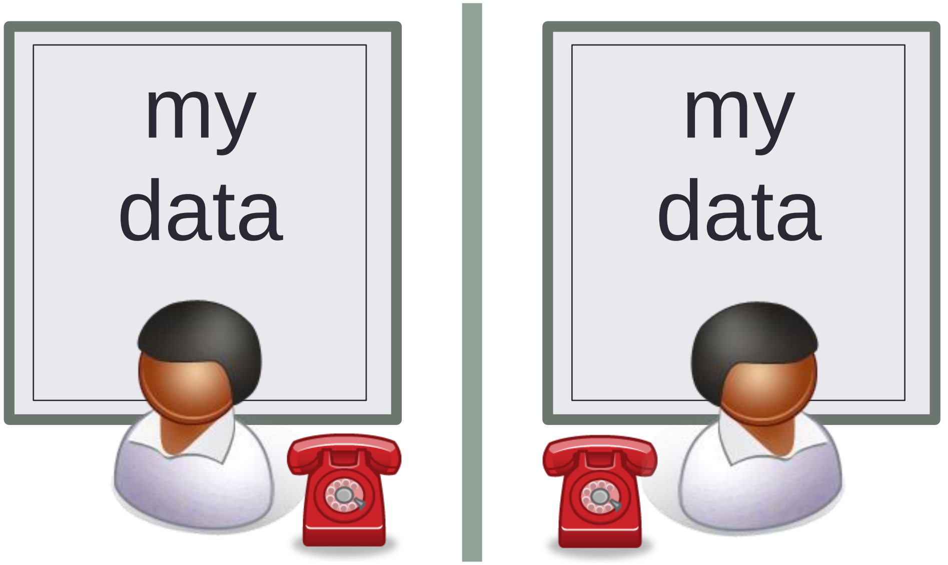
- Threading in HPC usually uses OpenMP directives
  - supports common parallel patterns
  - e.g. loop limits computed by the compiler
  - e.g. summing values across threads done automatically

# Message Passing

Process-based parallelism

# Analogy

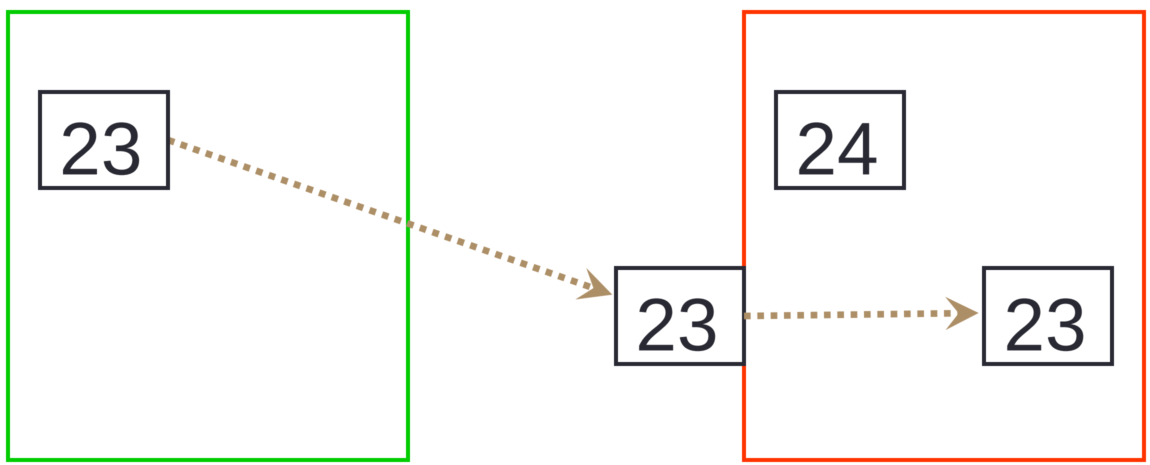
- Two whiteboards in different single-person offices
  - the distributed memory
- Two people working on the same problem
  - the processes on different nodes attached to the interconnect
- How do they collaborate?
  - to work on single problem
- Explicit communication
  - e.g. by telephone
  - no shared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



# Process communication

| | Process 1 | Process 2 |
| --- | --- | --- |
| Program | `a=23`<br>`Send(2,a)` | `Recv(1,b)`<br>`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

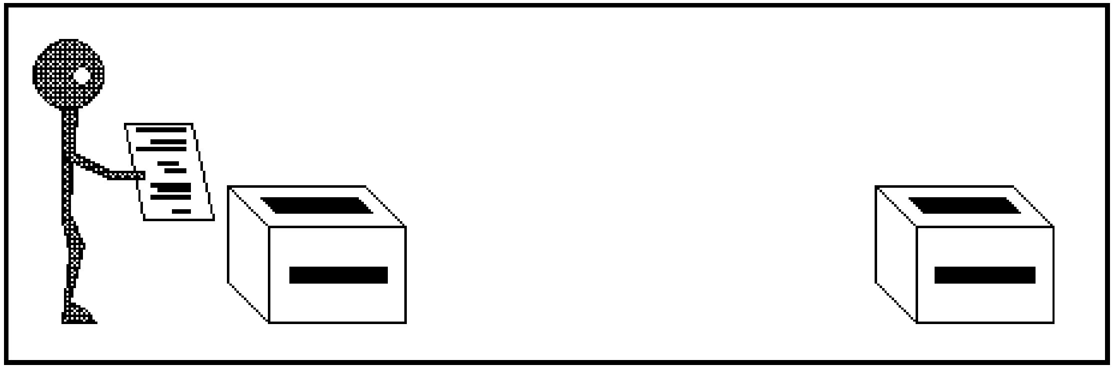
- No danger of corrupting someone else's data
  - no shared blackboard

# 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

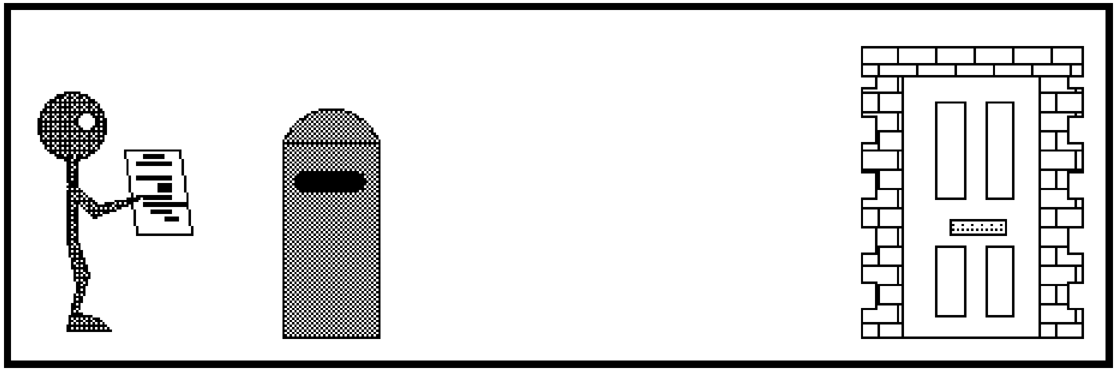
# Synchronous send

- 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

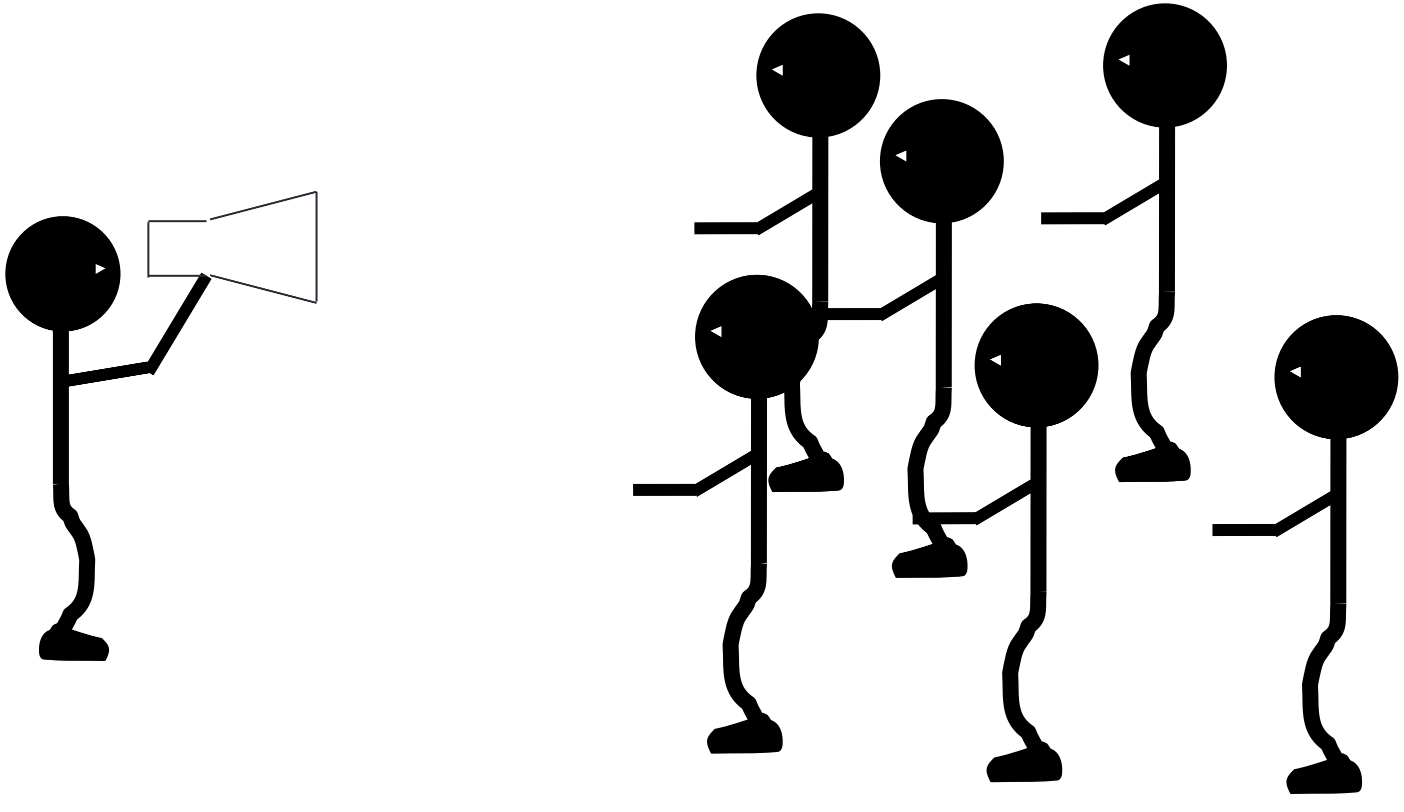
# Message Passing: Collective communications

Process-based parallelism

# Collective Communications

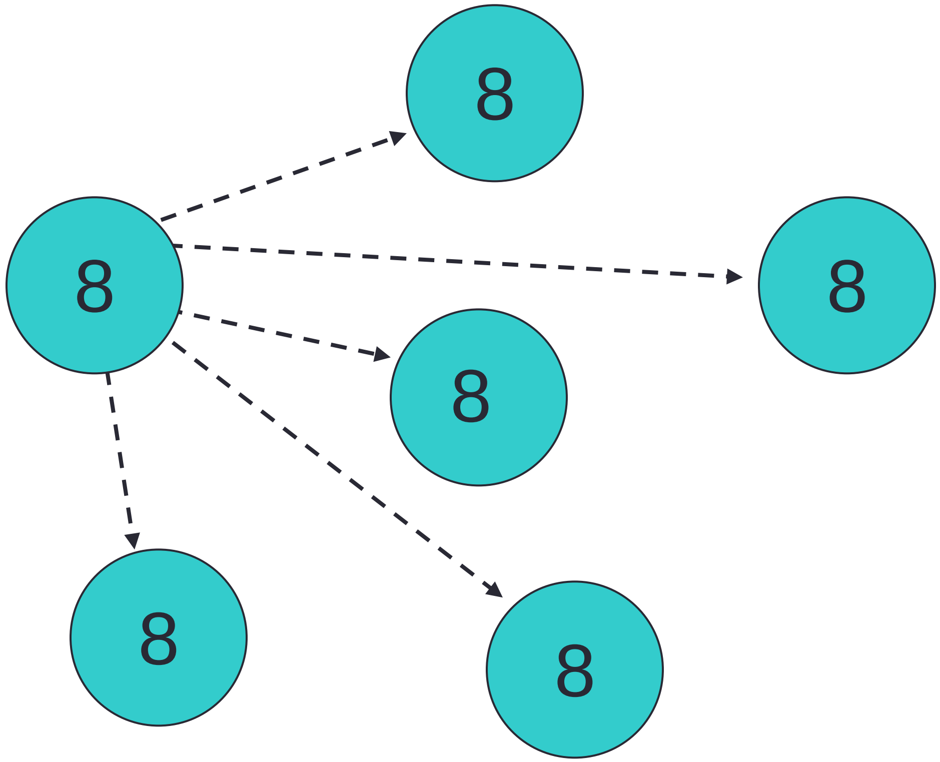
- A simple message communicates between two processes
- There are many instances where communication between groups of processes is required
- Can be built from simple messages, but often implemented separately, for efficiency

# Broadcast: one to all communication



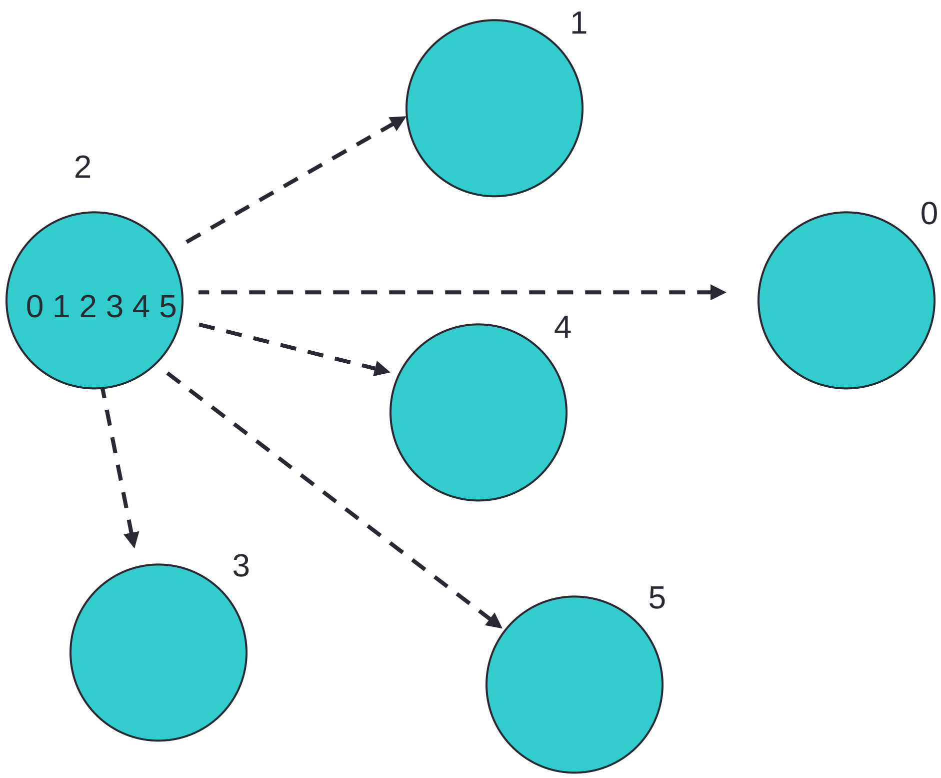
# Broadcast

- From one process to all others



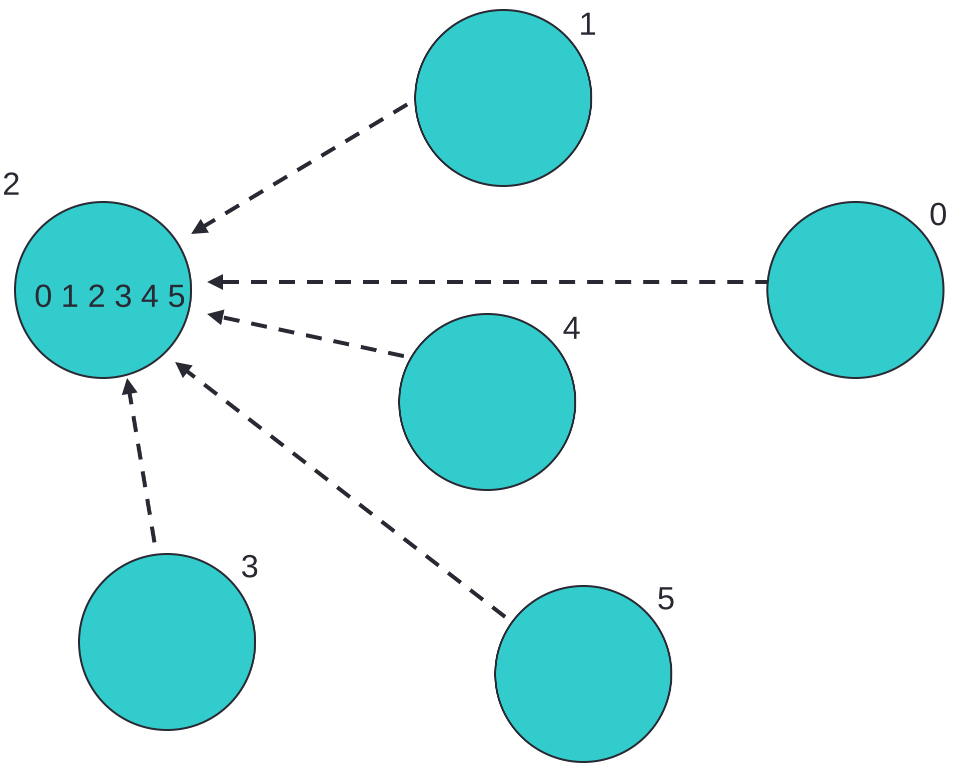
# Scatter

- Information scattered to many processes



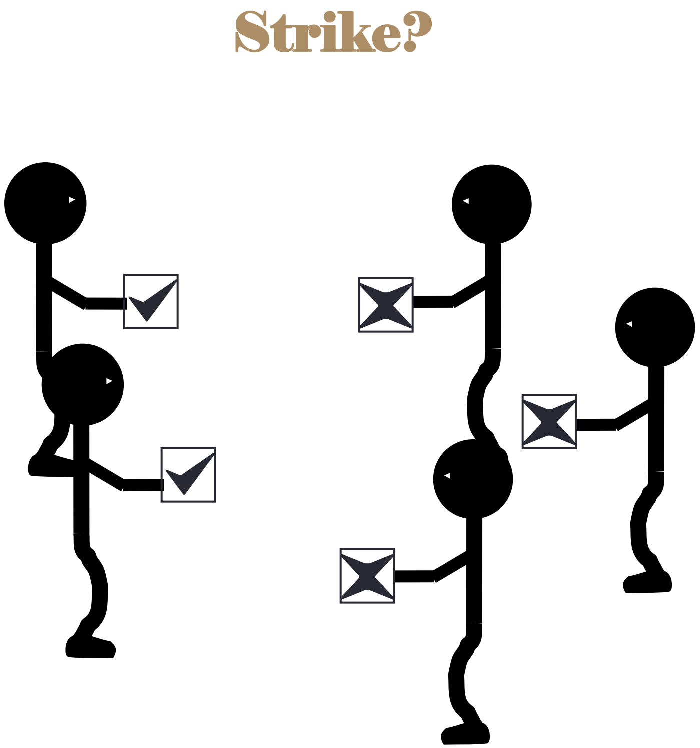
# Gather

- Information gathered onto one process



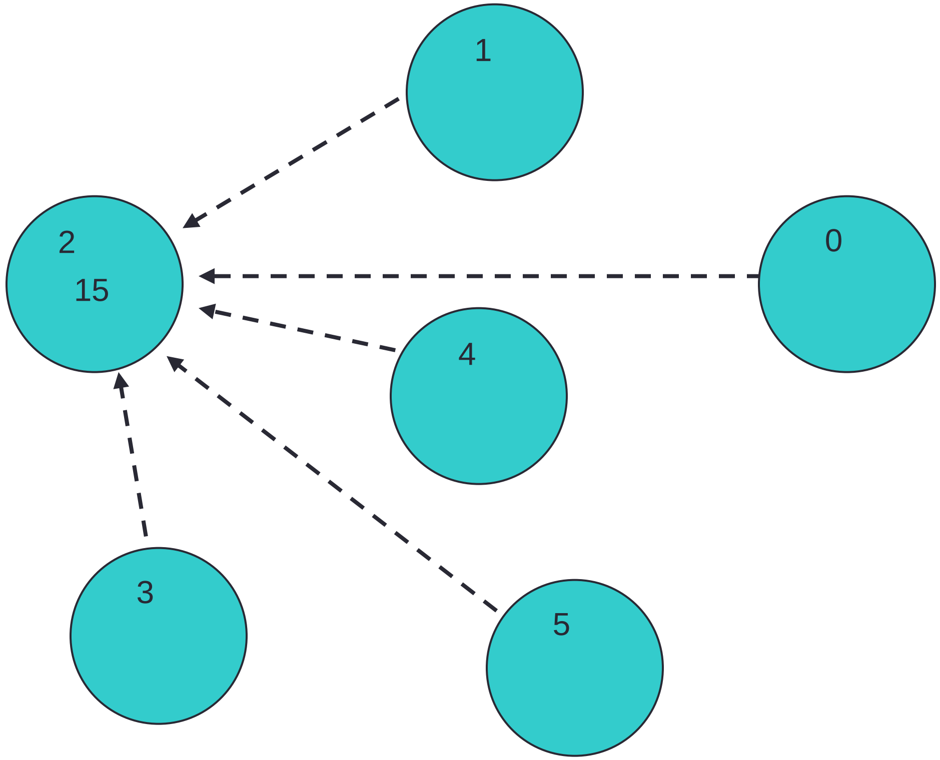
# Reduction Operations

- Combine data from several processes to form a single result

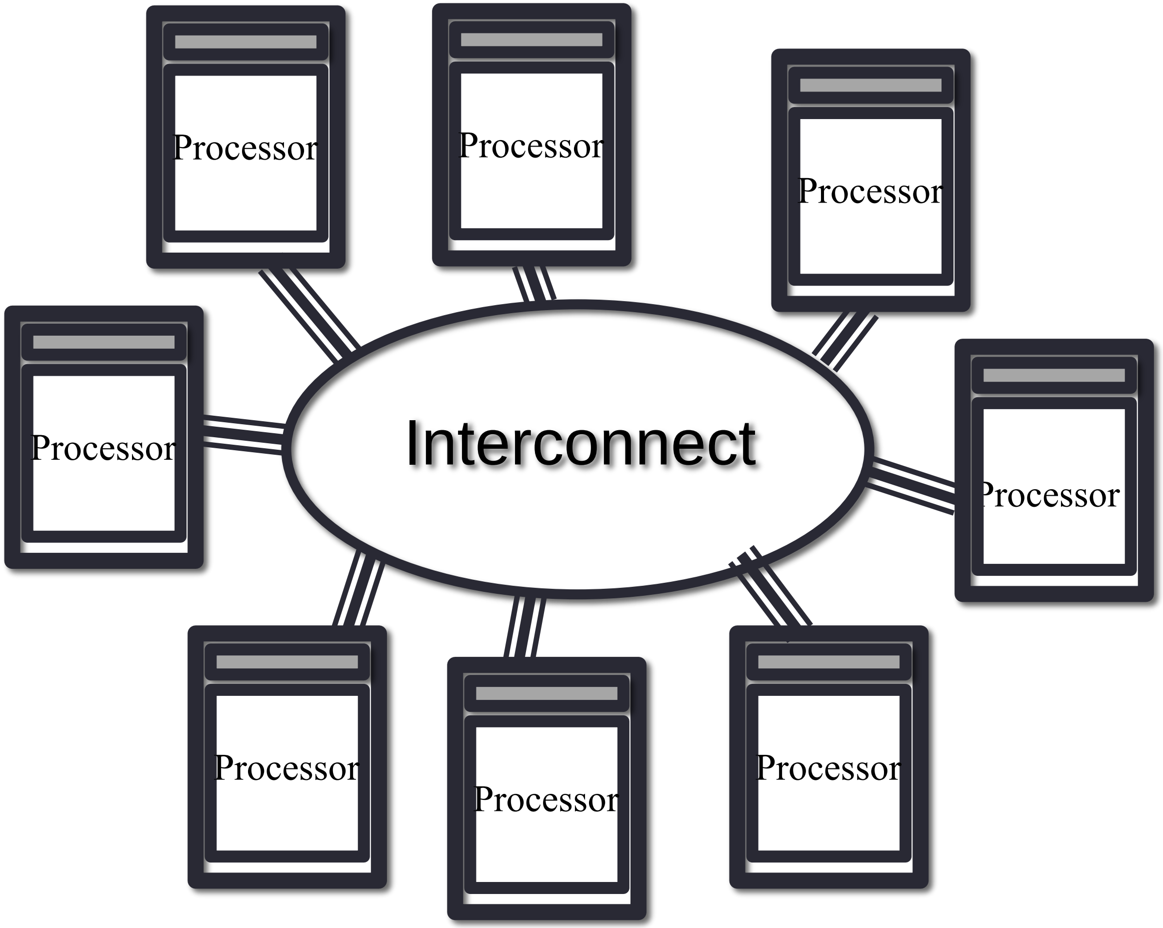


# Reduction

- 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

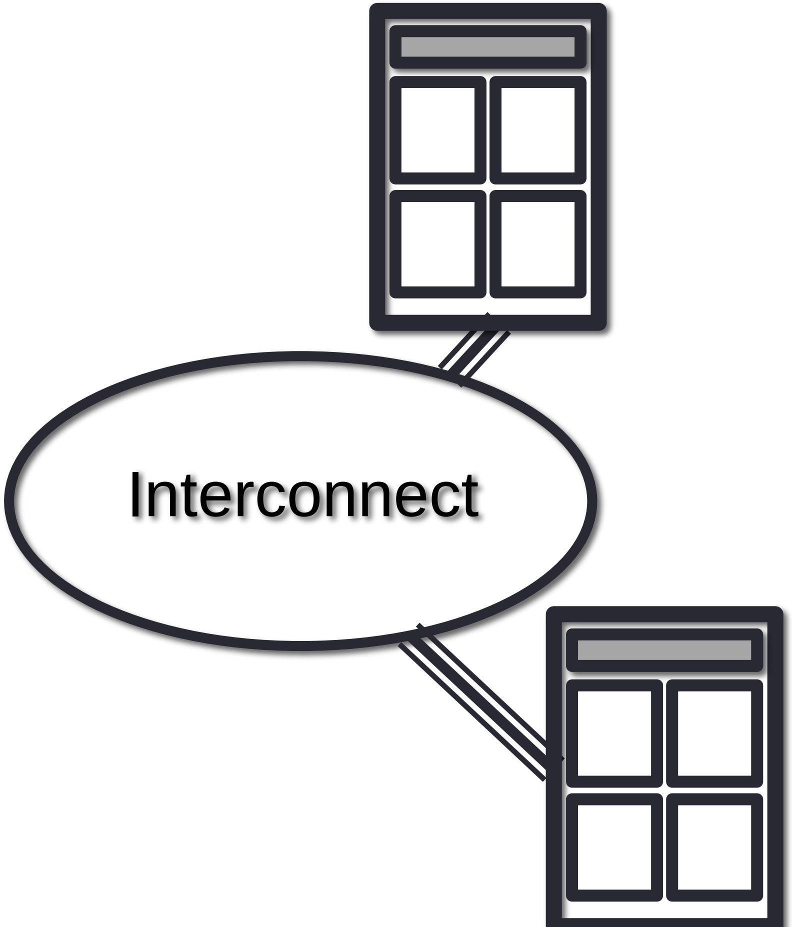
# Processes: Summary

- 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

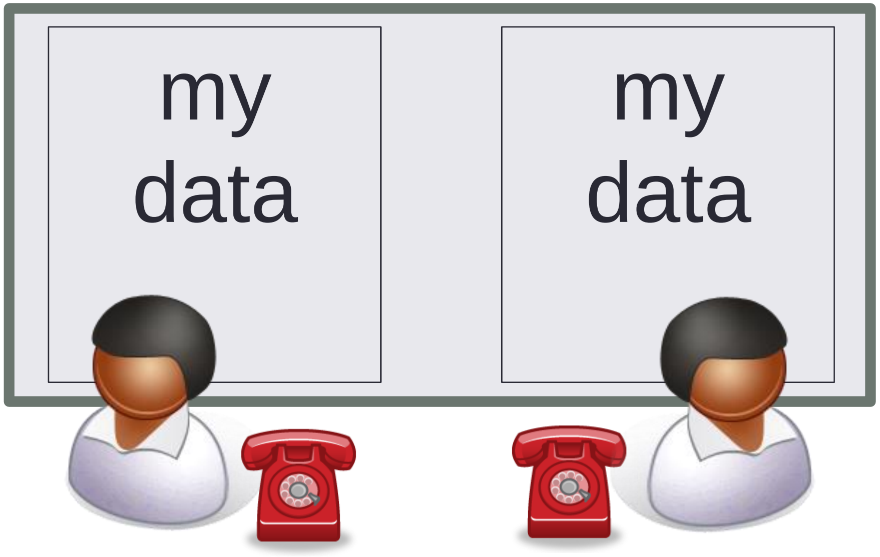
# Practicalities




- 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