Multiprocessors connected by a network

- Restrictions of the bus architecture: high bandwidth, low latency and long length are incompatible
- Shared memory (single address space) vs. multiple private memories
- Centralized memory vs. distributed memory (physically distributed single address space)
Parallel programming by message passing

Summing 100000 numbers by 100 processors

• The processor containing 100000 numbers sends subsets of 1000 to the others.

• Each processor individually sums the 1000 numbers:

```c
sum=0;
for (i=0; i<1000; i++) sum=sum+A1[i];
```

• Adding the 100 partial sums (send(Pr,Val), receive()):

```c
half=100;
limit=100;
repeat
    half=(half+1)/2;
    if (Pn>= half && Pn <limit) send (Pn-half, sum)
        if (Pn< limit/2+1) sum=sum+receive()
    limit=half;
until (half==1);
```
Distributed memory communication

- Explicit communication: *send* and *receive* instead of *load* and *store*
- *Shared virtual memory*: adding a software layer on top of sends and receives to provide a single address space
- Cache coherency (snooping does not work): *directories*. A single directory contains information for each block of memory: which caches have copies of the block, whether it is dirty etc.
- When there is a write to a shared block the *directory controller* sends messages to each processor that has a copy of the block.
Memory allocation (single address space)

- The programmer or the compiler allocates data to the processor that is likely to use it.
- **Cache-only memory**: Add a second level of coherence to the main memory for every processor: moving blocks of memory between the processors.

![Diagram]

**a.**

**b.**
Cost, performance, and cost/performance
Clusters

- A network (LAN) of loosely coupled machines
- Drawbacks:
  - High cost of administering
  - Slow connection through the I/O bus;
  - Division of memory
- Hybrid clusters (clustered shared memory)
Network topology

- **Network cost:** number of switches, number of links on a switch, width (bits) of a link, length of links
- Performance metrics:
  - *Total network bandwidth* (best case)
  - *Bisection bandwidth* (worst case)
- Topologies:
  - **Fully connected network**
  - **Ring**
  - **Multistage networks**

![Diagram of network topologies](image-url)