

- Clusters are loosely coupled
- Network of independent computers
 - Each has private memory and OS
 - Connected using I/O system
 - E.g., Ethernet/switch, Internet
- Suitable for applications with independent tasks
 - Web servers, databases, simulations, ...
- High availability, scalable, affordable

- SMPs
 - Processors are identical
 - Controlled by a single operating system
 - Cost to administer is about the same as a uniprocessor
 - Communicate via memory bus
 - More difficult to scale
 - Higher cost to purchase

- Clusters

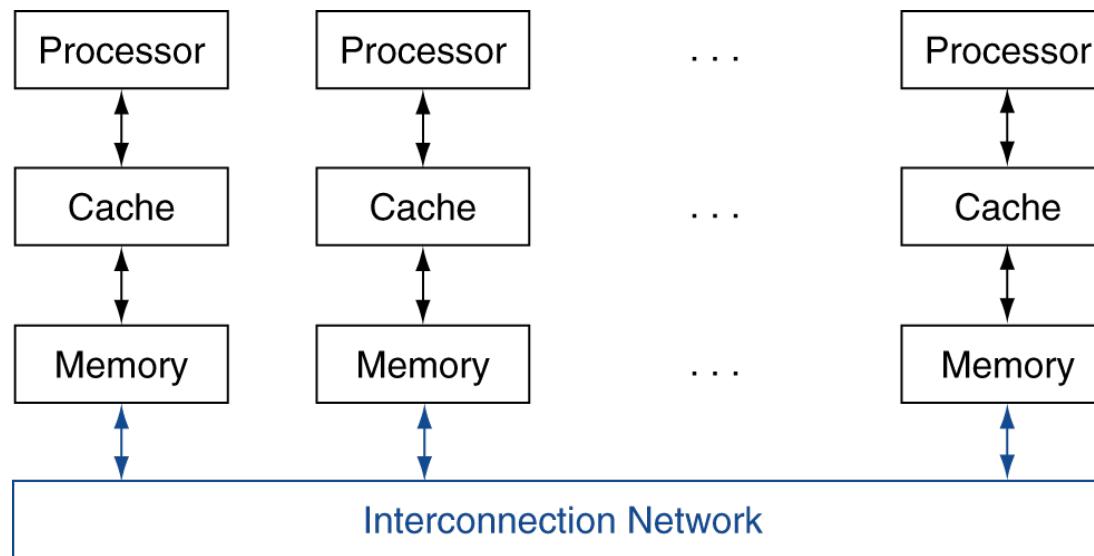
- Each node is a complete computer
- Nodes can employ different processors
- Cost to administer N-node system is about the same as for N separate computer systems
- Communicate via I/O bus at a slower rate
- Easier to scale
- Nodes may be low cost COTS (commodity off the shelf) computers

- Identical commodity-grade computers networked into a LAN
- Originally referred to a computer built in 1994 by Thomas Sterling and Donald Becker at NASA
- Normally use a unix-like operating system
- One server node and one or more client nodes connected via ethernet

Beowulf Cluster



- Each processor has private physical address space
- Hardware sends/receives messages between processors



- Sum 100,000 on 100 processors
- First distribute 1000 numbers to each
 - The do partial sums

```
sum = 0;  
for (i = 0; i<1000; i = i + 1)  
    sum = sum + AN[i];
```

- Reduction
 - Half the processors send, other half receive and add
 - Then $\frac{1}{4}$ send, & $\frac{1}{4}$ receive and add, ...
 - Send/receive also provide synchronization
 - Assumes send/receive take similar time to addition

- Given send() and receive() operations

```
limit = 100; half = 100; /* 100 processors */
repeat
    half = (half+1)/2; /* send vs. receive
                           dividing line */
    if (Pn >= half && Pn < limit)
        send(Pn - half, sum);
    if (Pn < (limit/2))
        sum = sum + receive();
    limit = half; /* upper limit of senders */
until (half == 1); /* exit with final sum */
```