Parallel programming

Programming the memory models

- Shared memory: all processors share the same address space
  - OpenMP: directives-based programming
  - PGAS languages (UPC, Titanium, X10)
- Distributed memory: every processor has its own address space
  - MPI: Message Passing Interface

Ideal vs Practice

- Shared memory (or SMP: Symmetric MultiProcessor) is easy to program (OpenMP) but hard to build
  - bus-based systems can become saturated
  - large, fast (high bandwidth, low latency) crossbars are expensive
  - cache-coherency is hard to maintain at scale

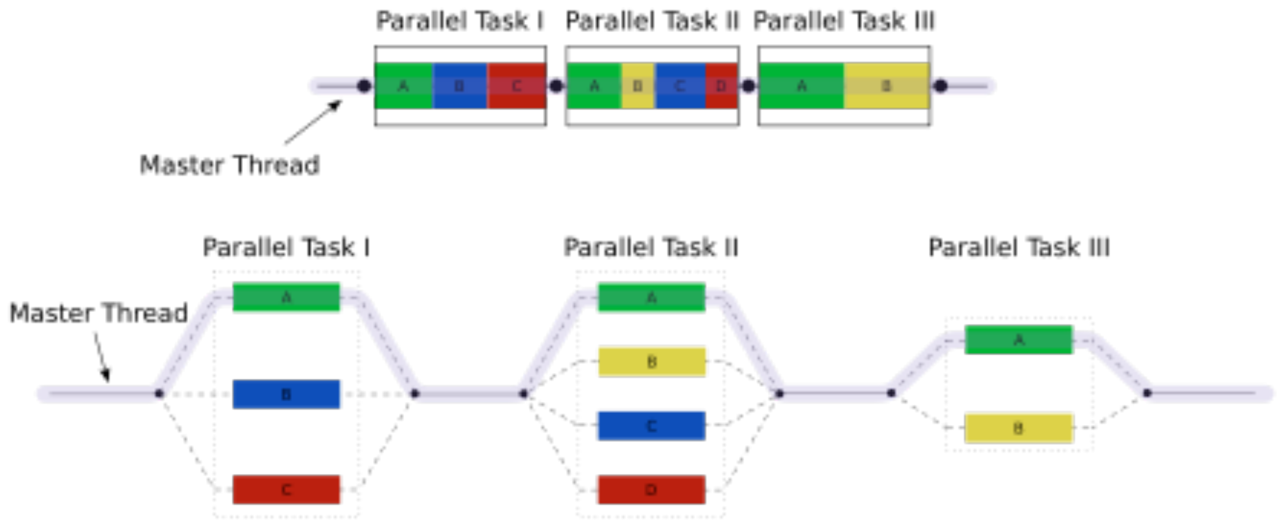
Ideal vs Practice

- Distributed memory is easy to build (bunch of PCs, ethernet) but hard to program (MPI)
  - You have to spell it all out
  - interconnects have higher latency, so data is not immediately there
  - makes parallel algorithm development and programming harder

Programmer's view vs Hard reality

- It is possible for distributed hardware to act like shared
- Middle layer: programmatic, OS, hardware support
- New machines: SGI UV, Cray Gemini

Shared memory programming in OpenMP



- Shared memory.
- Various issues: critical regions, binding, thread overhead

Thread programming

- Threads have shared address space (unlike processes)
- Great for parallel processing on shared memory
- Ex: quad-core => use 4 threads (8 with HT)
- OpenMP declares parallel tasks, the threads execute them in some order (shared memory essential!)
- Obvious example: loop iterations can be parallel

OpenMP programming

- "pragma"-based: directives to the compiler

```
#pragma omp parallel default(none) \
             shared(n,x,y) private(i)
{
 #pragma omp for
   for (i=0; i<n; i++)
       x[i] += y[i];
} /*-- End of parallel region --*/
```

clauses

```
!$omp parallel default(none)      &
!$omp shared(n,x,y) private(i)
!$omp do
      do i = 1, n
         x(i) = x(i) + y(i)
      end do
!$omp end do
!$omp end parallel
```

OpenMP programming

- Handling of private and shared data

```
      sum = 0.0
!$omp parallel default(none) &
!$omp shared(n,x) private(i)
!$omp do reduction (+:sum)
      do i = 1, n
         sum = sum + x(i)
      end do
!$omp end do
!$omp end parallel
      print *,sum
```

Variable SUM is a shared variable

Now that threads have come up…

- Your typical core can handle one thread (two with HT)
- `Context switching’ is expensive
- GPU handles many threads with ease, in fact relies on it
- => GPU is even more SIMD than you already realized

On to Distributed Memory

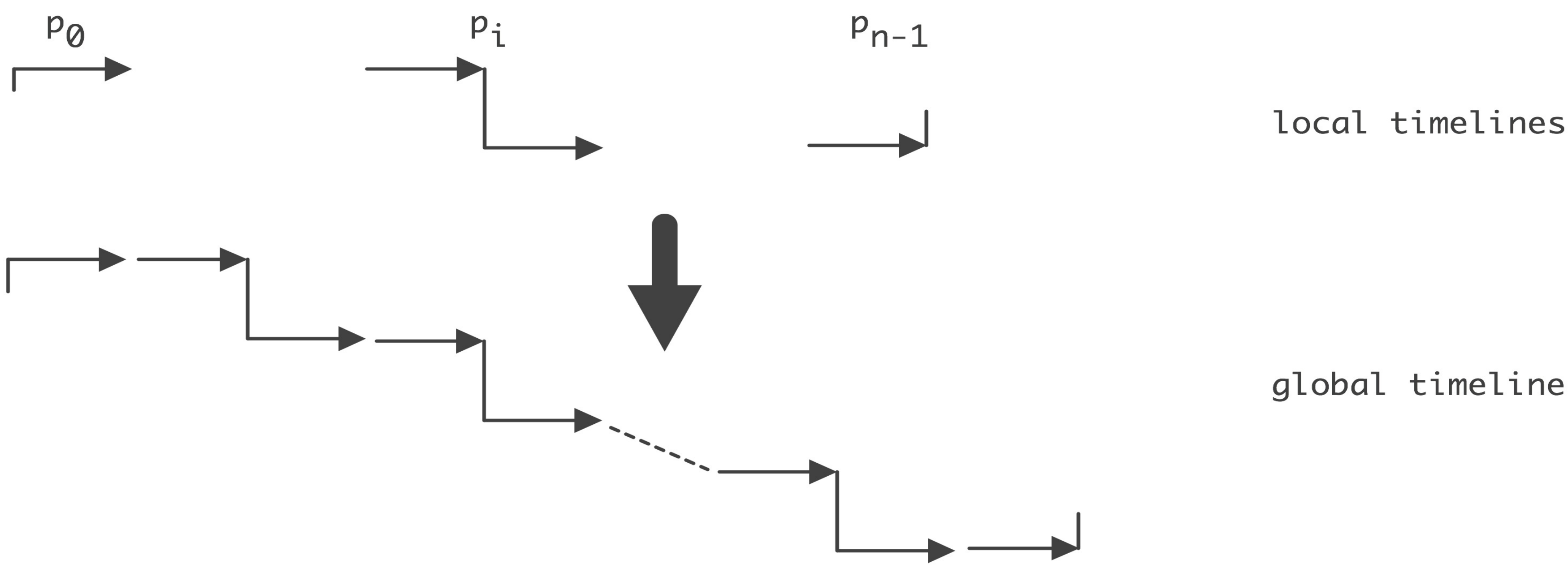
Parallel algorithms vs parallel programming

- Example: two arrays *x* and *y*; *n* processors; p_i stores x_i and y_i
- Algorithm: $y_i := y_i + x_{i-1}$
- Global description:
  - Processors 0..n-2 send their *x* element to the right
  - Processors 1..n-1 receive an *x* element from the left
  - Add the received number to their *y* element

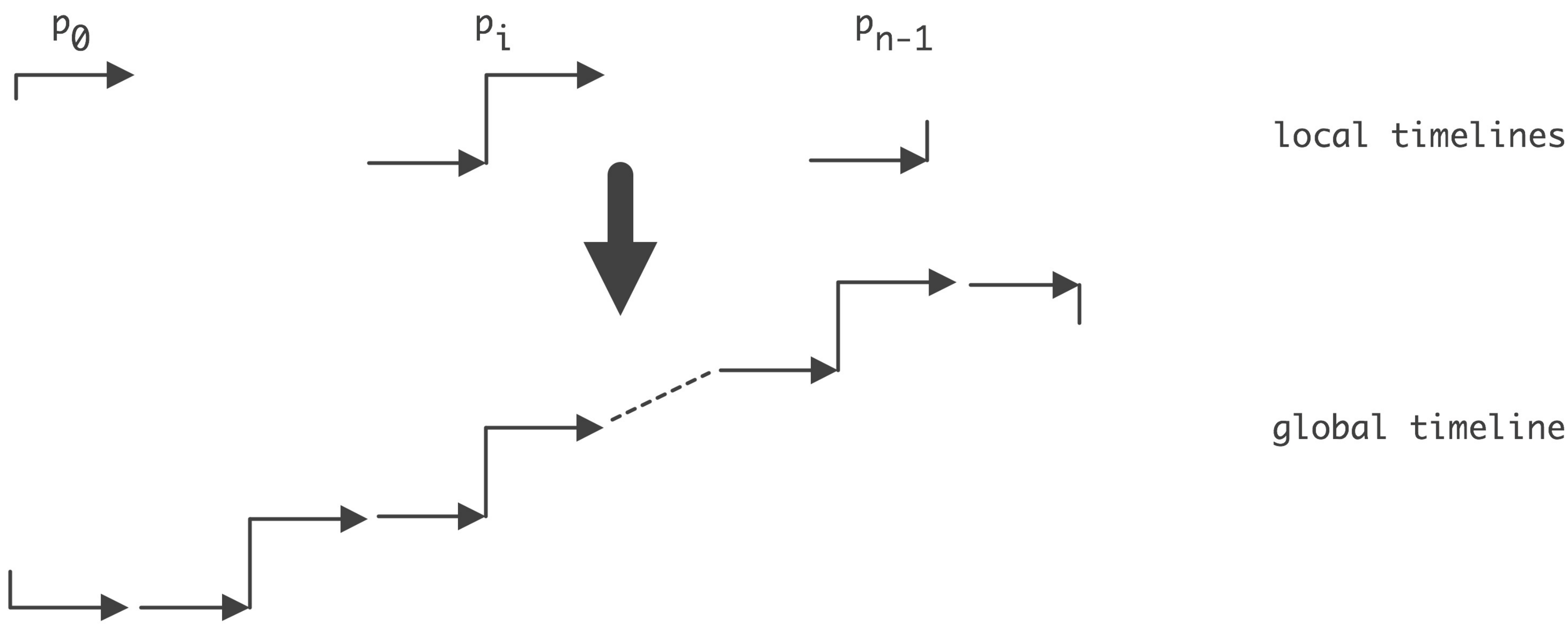
Local implementations

- One implementation:
  - If my number >0: receive a *x* element, add it to my *y* element
  - If my number <*n-1*: send my *x* element to the right
- Other implementation
  - If my number <*n-1*: send my *x* element to the right
  - If my number >0: receive a *x* element, add it to my *y* element

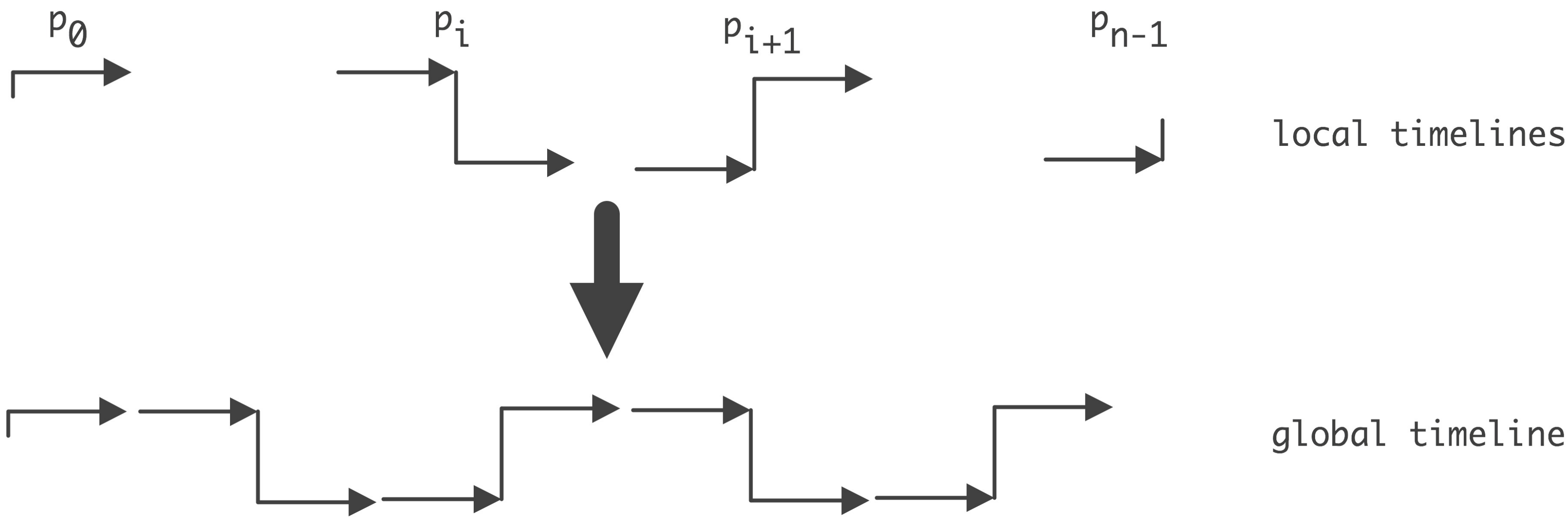
- One implementation:
  - If my number >0: receive a *x* element, add it to my *y* element
  - If my number <*n-1*: send my *x* element to the right



- Other implementation
  - If my number <*n-1*: send my *x* element to the right
  - If my number >0: receive a *x* element, add it to my *y* element



- Better implementation
  - If my number odd: receive then send
  - If my number even: send then receive



Blocking operations

- Send & recv operations are *blocking*: a send does not finished until the message is actually received
- Parallel operation becomes sequentialized; in a ring even loads to *deadlock*

Non-Blocking operations

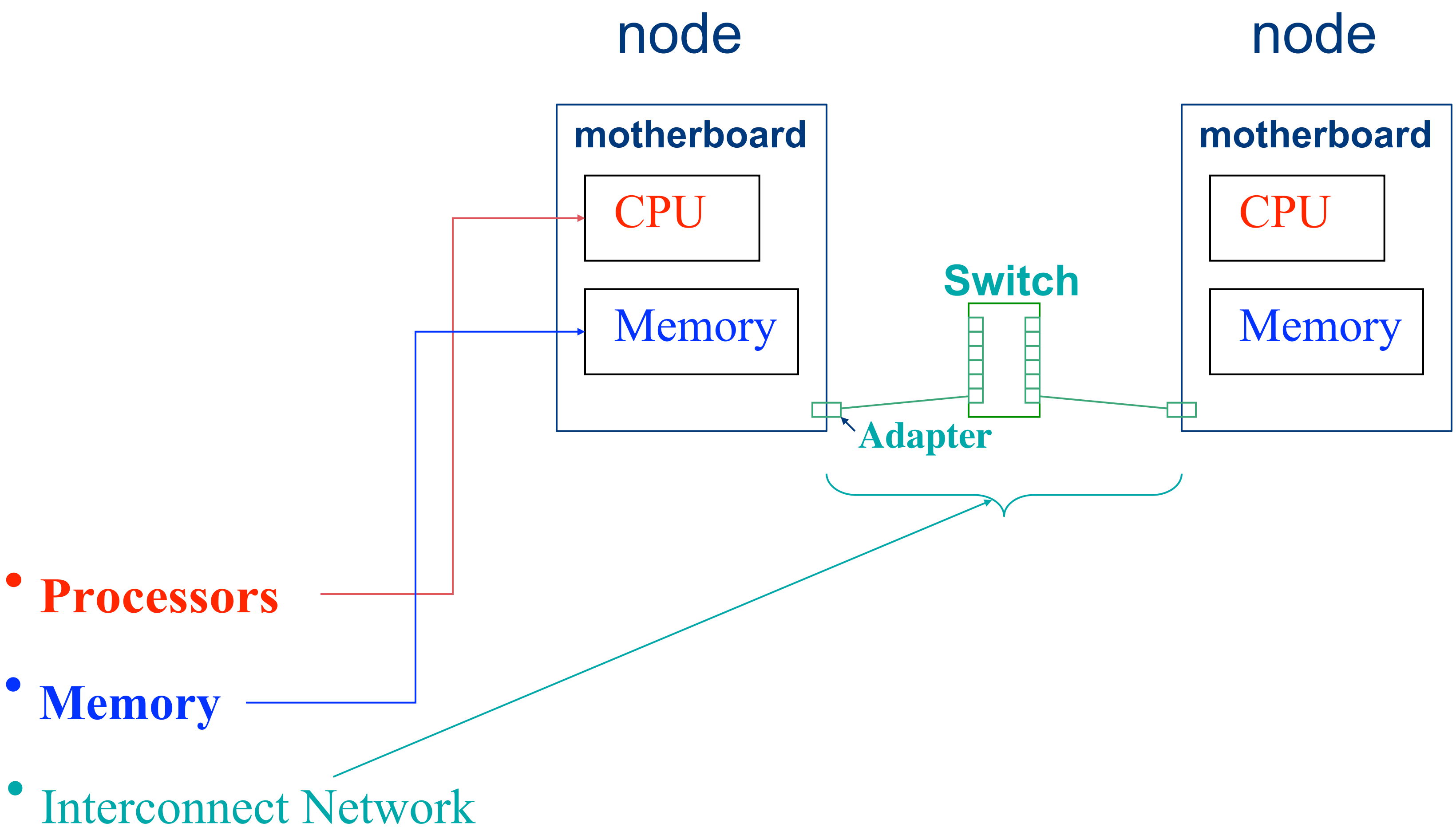
- Non-blocking send & recv:
  - Give a buffer to the system to send from / recv into
  - Continue with next instruction
  - Check for completion later

MPI: message passing

- Message Passing Interface: library for explicit communication
- Point-to-point and collective communication
- Blocking semantics, buffering
- Looks harder than it is

```
if(myid == 0)
 {
   printf("WE have %d processors\n", numprocs);
   for(i=1;i<numprocs;i++)
   {
     sprintf(buff, "Hello %d", i);
     MPI_Send(buff, 128, MPI_CHAR,
             i, 0, MPI_COMM_WORLD);
   }
   for(i=1;i<numprocs;i++)
   {
     MPI_Recv(buff, 128, MPI_CHAR,
              i, 0, MPI_COMM_WORLD, &stat);
     printf("%s\n", buff);
   }
 }
 else
 {
   MPI_Recv(buff, 128, MPI_CHAR,
            0, 0, MPI_COMM_WORLD, &stat);
   sprintf(idstr, " Processor %d ", myid);
   strcat(buff, idstr);
   strcat(buff, "reporting for duty\n");
   MPI_Send(buff, 128, MPI_CHAR, 0, 0, MPI_COMM_WORLD);
 }
```

Basic Anatomy of a Server/Desktop/ Laptop/Cluster-node



RAID

- Was: Redundant Array of Inexpensive Disks
- Now: Redundant Array of Independent Disks
- Multiple disk drives working together to:
  - increase capacity of a single logical volume
  - increase performance
  - improve reliability/add fault tolerance
- 1 Server with RAIDed disks can provide disk access to multiple nodes with NFS

Parallel Filesystems

- Use multiple servers together to aggregate disks
  - utilizes RAIDed disks
  - improved performance
  - even higher capacities
  - may use high-performance network
- Vendors/Products
  - CFS/Lustre
  - IBM/GPFS
  - IBRIX/IBRIXFusion
  - RedHat/GFS
  - ...

Summary

- Why so much parallel talk?
  - Every computer is a parallel computer now
  - Good serial computing skills central to good parallel computing
  - Cluster and MPP nodes are largely like desktops and laptops
    - Processing units: CPUs, FPUs, GPUs
    - Memory hierarchies: Registers, Caches, Main memory
    - Internal Interconnect: Buses and Switch-based networks
  - Clusters and MPPs built via fancy connections.