Cloud Computing
CS 15-319

Programming Models- Part I

Lecture 4, Jan 25, 2012

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Today…

- Last 3 sessions
  - Administrivia and Introduction to Cloud Computing
  - Introduction to Cloud Computing and Cloud Software Stack
  - Course Project and Amazon AWS
- Today's session
  - Programming Models – *Part I*
- Announcement:
  - Project update is due today

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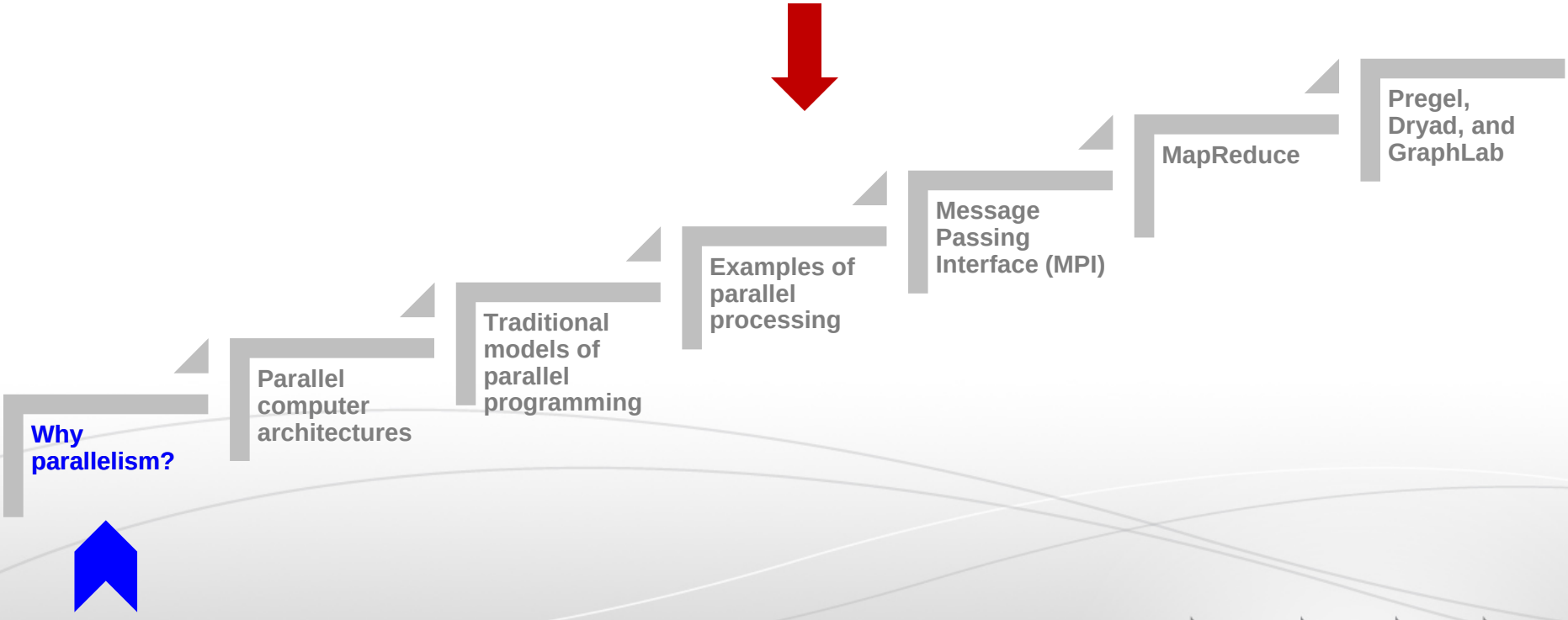
Objectives

Discussion on Programming Models



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Amdahl's Law

- We parallelize our programs in order to run them faster
- How much faster will a parallel program run?
  - Suppose that the sequential execution of a program takes T_1 time units and the parallel execution on p processors takes T_p time units
  - Suppose that out of the entire execution of the program, s fraction of it is not parallelizable while $1-s$ fraction is parallelizable
  - Then the speedup (***Amdahl's formula***):

$$\frac{T_1}{T_p} = \frac{T_1}{(T_1 \times s + T_1 \times \frac{1-s}{p})} = \frac{1}{s + \frac{1-s}{p}}$$

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Amdahl's Law: An Example

- Suppose that 80% of you program can be parallelized and that you use 4 processors to run your parallel version of the program

- The speedup you can get according to Amdahl is:

$$\frac{1}{s+\frac{1-s}{p}} = \frac{1}{0.2+\frac{0.8}{4}} = 2.5 \text{ times}$$

- Although you use 4 processors you cannot get a speedup more than 2.5 times (or 40% of the serial running time)

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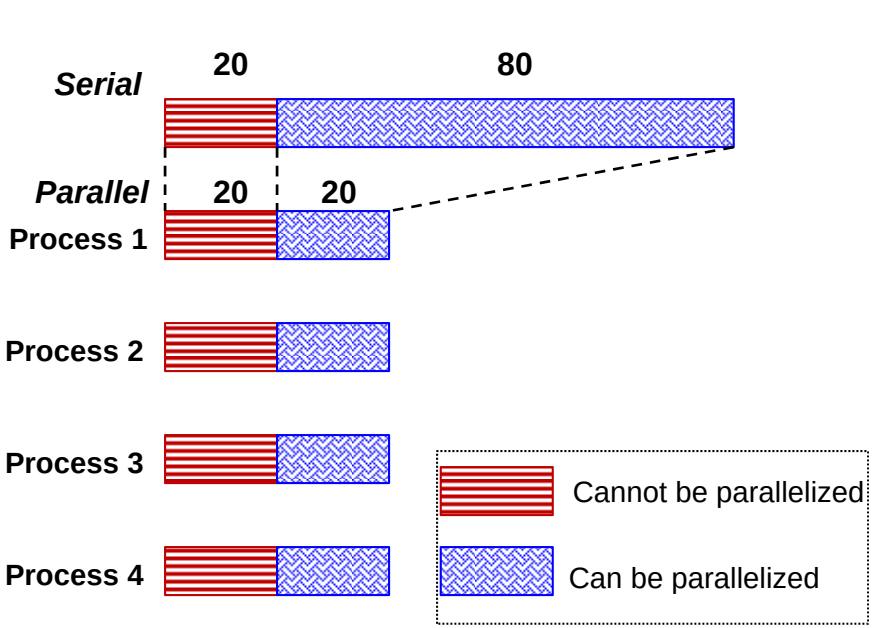
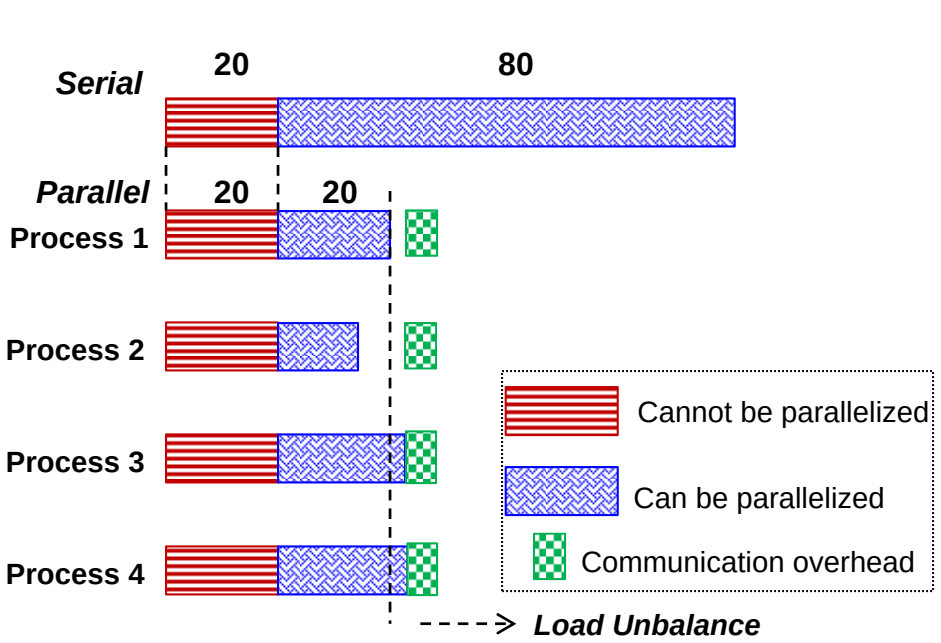
Real Vs. Actual Cases

- Amdahl's argument is too simplified to be applied to real cases
- When we run a parallel program, there are a communication overhead and a workload imbalance among processes in general



1. Parallel Speed-up: An Ideal Case



2. Parallel Speed-up: An Actual Case

Guidelines

- In order to efficiently benefit from parallelization, we ought to follow these guidelines:

1. Maximize the fraction of our program that can be parallelized
2. Balance the workload of parallel processes
3. Minimize the time spent for communication

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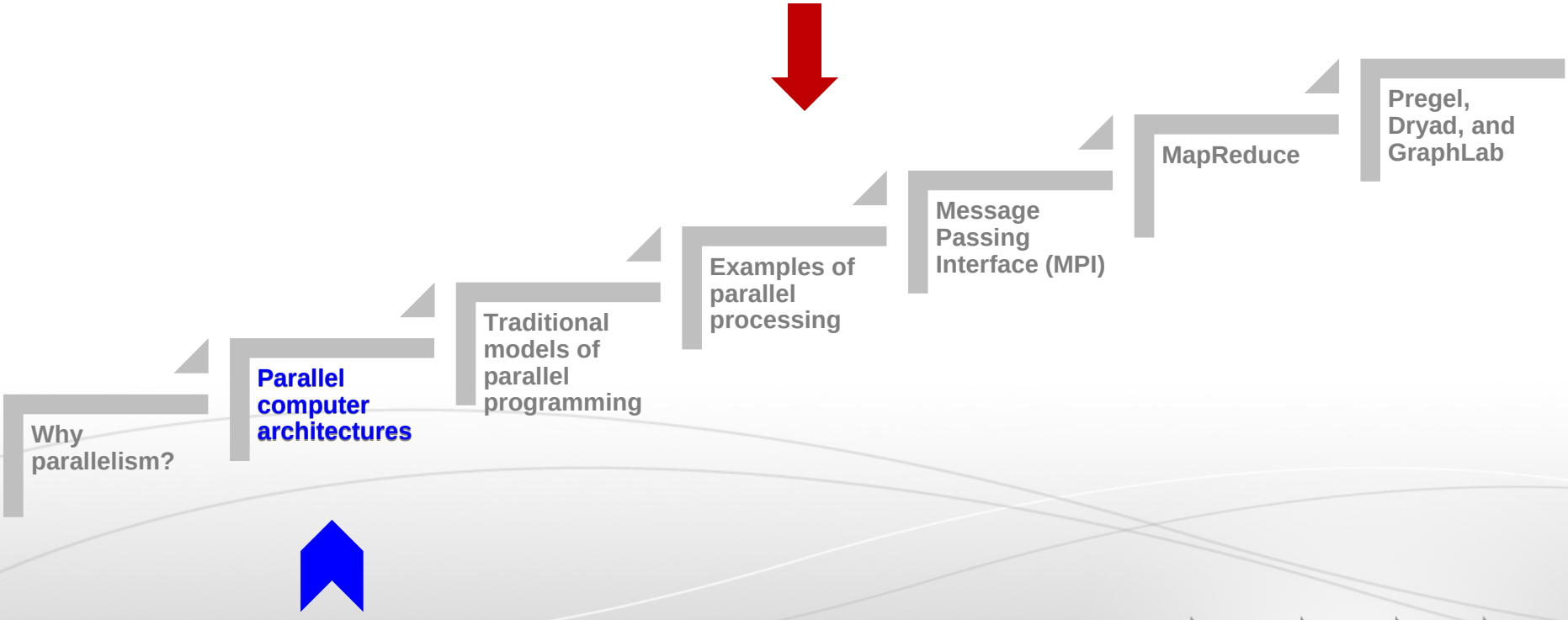

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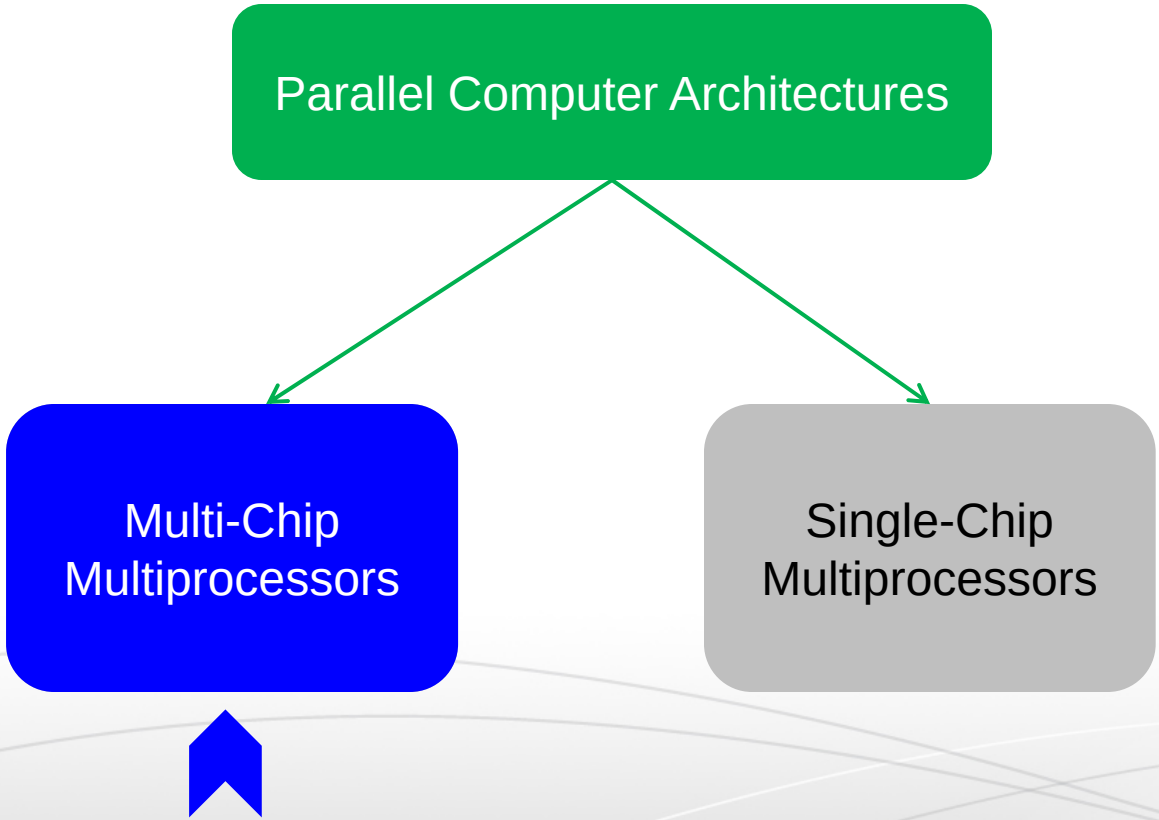
Parallel Computer Architectures



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Multi-Chip Multiprocessors

- We can categorize the architecture of multi-chip multiprocessor computers in terms of two aspects:
  - Whether the memory is physically centralized or distributed
  - Whether or not the address space is shared

Memory		Address Space	
		Shared	**Individual**
	Centralized	SMP (Symmetric Multiprocessor)/UMA (Uniform Memory Access) Architecture	N/A
	Distributed	Distributed Shared Memory (DSM)/NUMA (Non-Uniform Memory Access) Architecture	MPP (Massively Parallel Processors)/UMA Architecture

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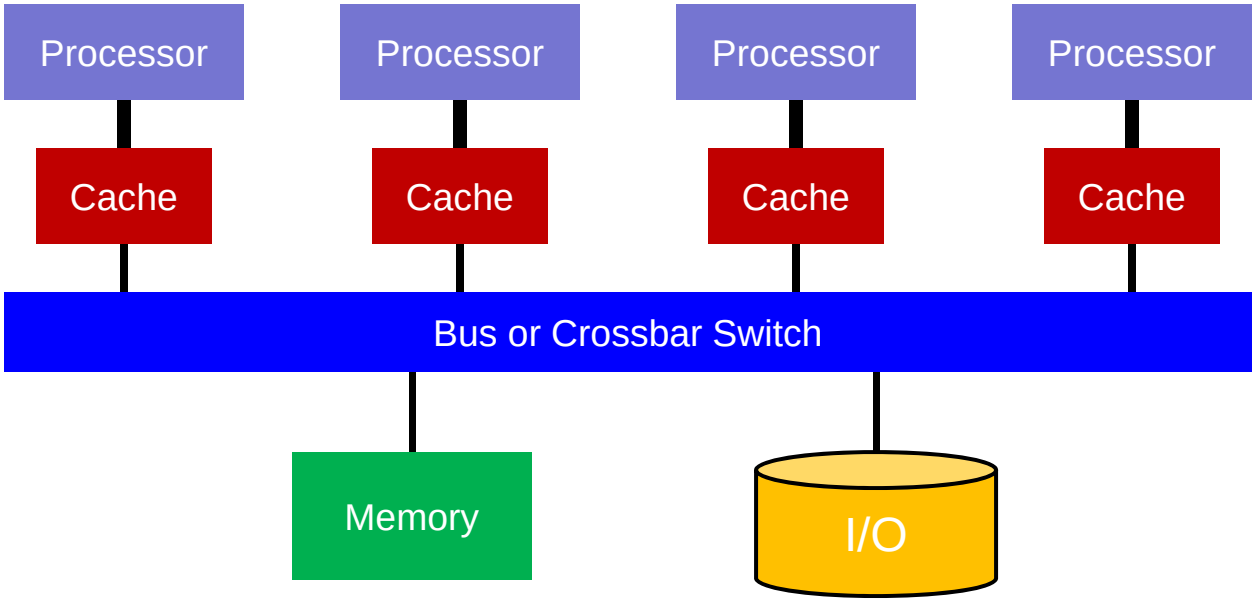
Symmetric Multiprocessors

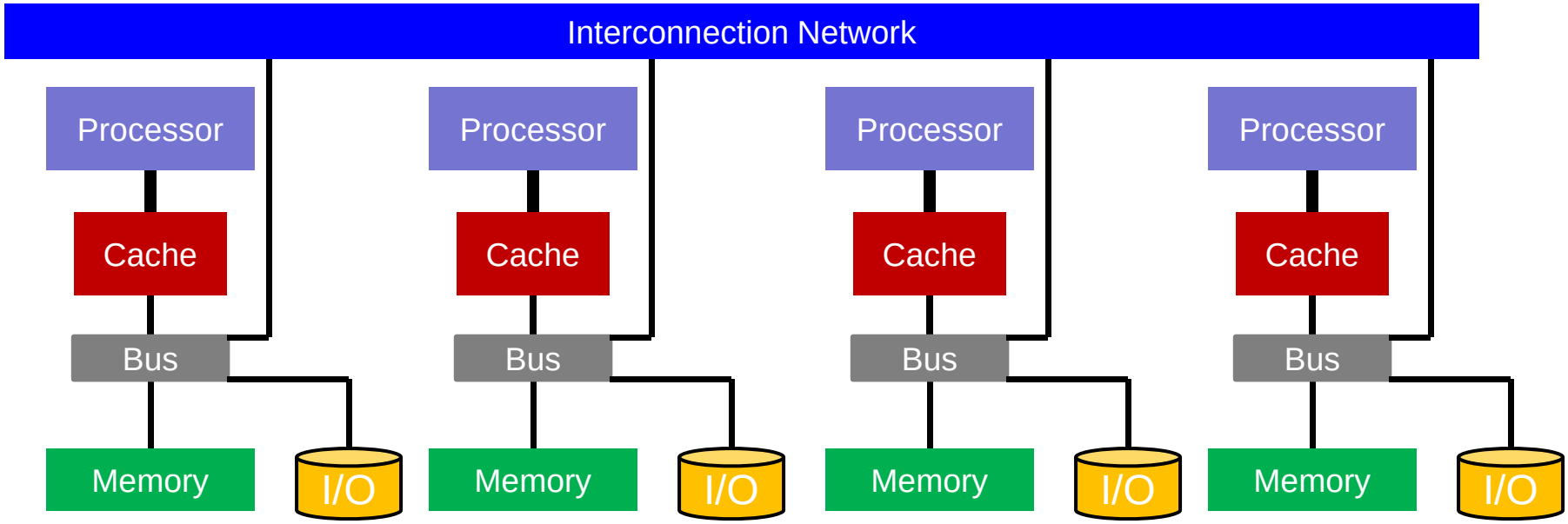
- A system with Symmetric Multiprocessors (SMP) architecture uses a shared memory that can be accessed equally from all processors



- Usually, a single OS controls the SMP system

Massively Parallel Processors

- A system with a Massively Parallel Processors (MPP) architecture consists of nodes with each having its own processor, memory and I/O subsystem



- Typically, an independent OS runs at each node

Distributed Shared Memory

- A Distributed Shared Memory (DSM) system is typically built on a similar hardware model as MPP
- DSM provides a shared address space to applications using a hardware/software directory-based coherence protocol
- The memory latency varies according to whether the memory is accessed directly (a local access) or through the interconnect (a remote access) (hence, NUMA)
- As in a SMP system, typically a single OS controls a DSM system

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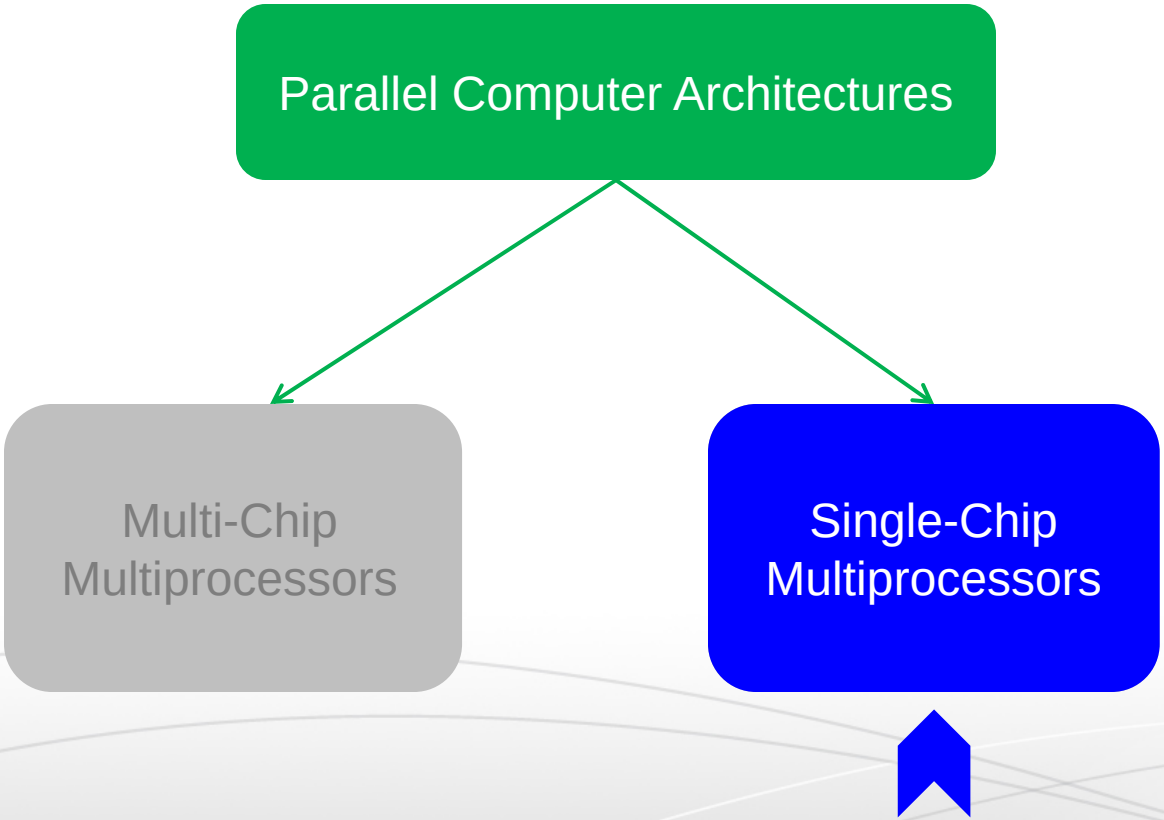
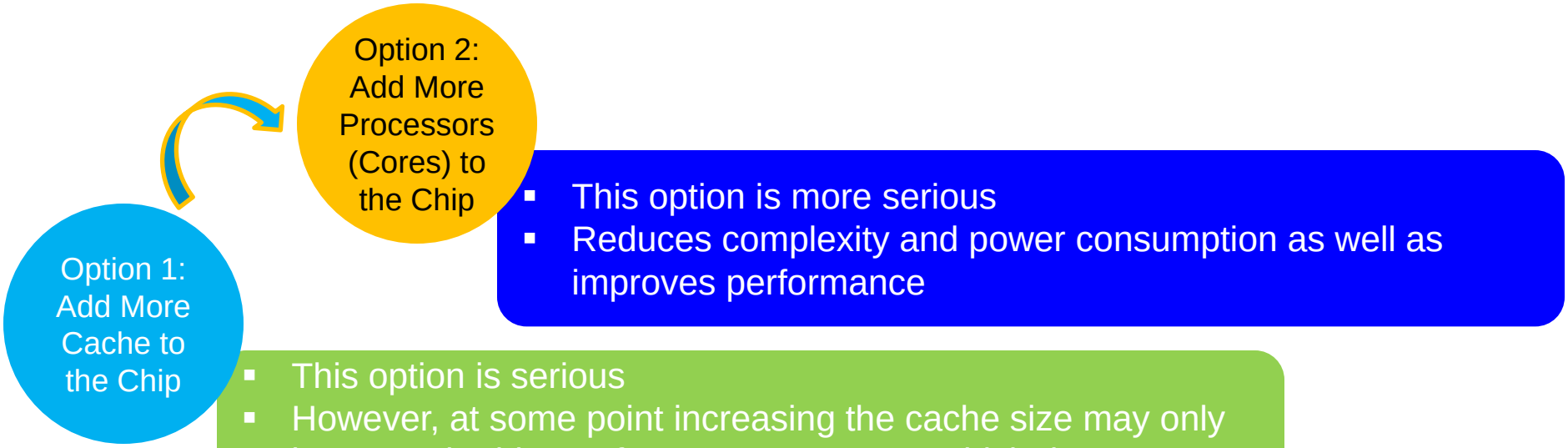
Parallel Computer Architectures



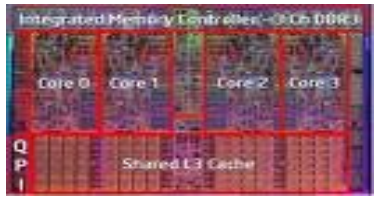
Moore's Law

- As chip manufacturing technology improves, transistors are getting smaller and smaller and it is possible to put more of them on a chip
- This empirical observation is often called Moore's Law (# of transistors doubles every 18 to 24 months)
- An obvious question is: "What do we do with all these transistors"?

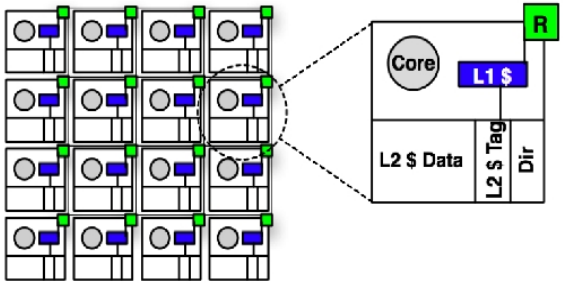


Chip Multiprocessors

- The outcome is a single-chip multiprocessor referred to as Chip Multiprocessor (CMP)



- CMP is currently considered the architecture of choice
- Cores in a CMP might be coupled either tightly or loosely
  - Cores may or may not share caches
  - Cores may implement a message passing or a shared memory inter-core communication method
- Common CMP interconnects (referred to as Network-on-Chips or NoCs) include bus, ring, 2D mesh, and crossbar



- CMPs could be homogeneous or heterogeneous:
  - Homogeneous CMPs include only identical cores
  - Heterogeneous CMPs have cores which are not identical

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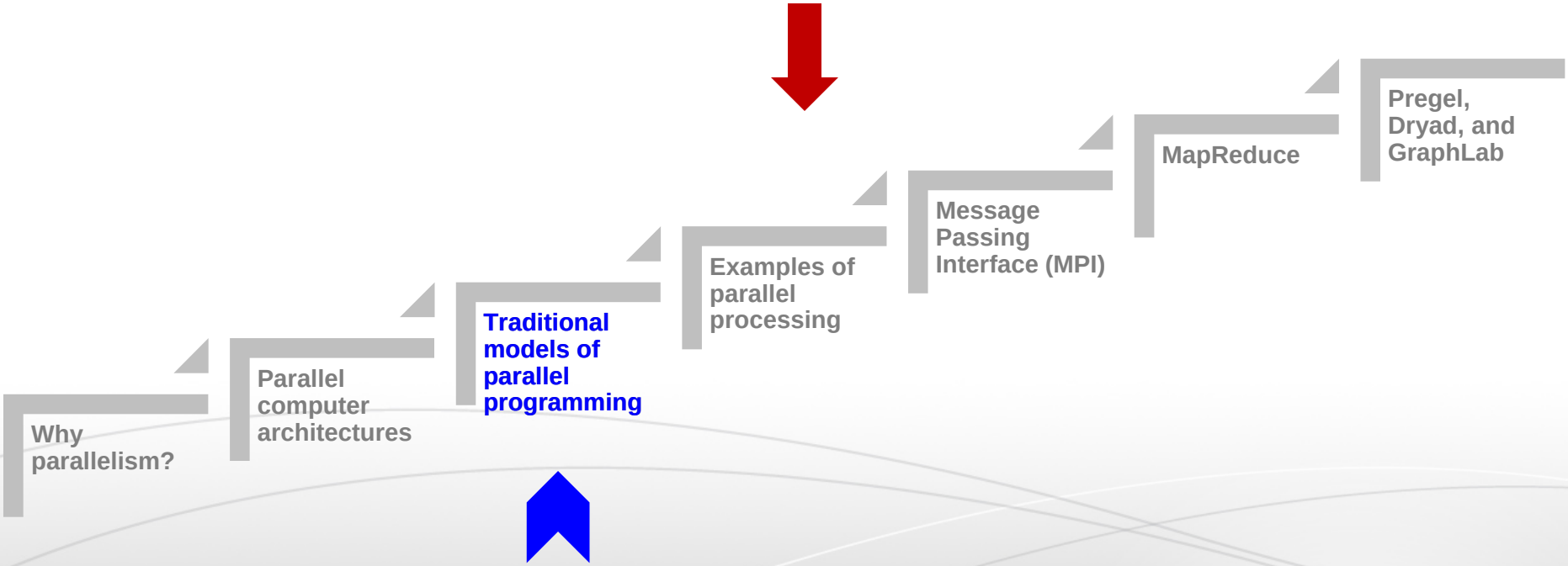

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Models of Parallel Programming

- What is a parallel programming model?
  - A programming model is an abstraction provided by the hardware to programmers
  - It determines how easily programmers can specify their algorithms into parallel unit of computations (i.e., tasks) that the hardware understands
  - It determines how efficiently parallel tasks can be executed on the hardware
- Main Goal: utilize all the processors of the underlying architecture (e.g., SMP, MPP, CMP) and minimize the elapsed time of your program

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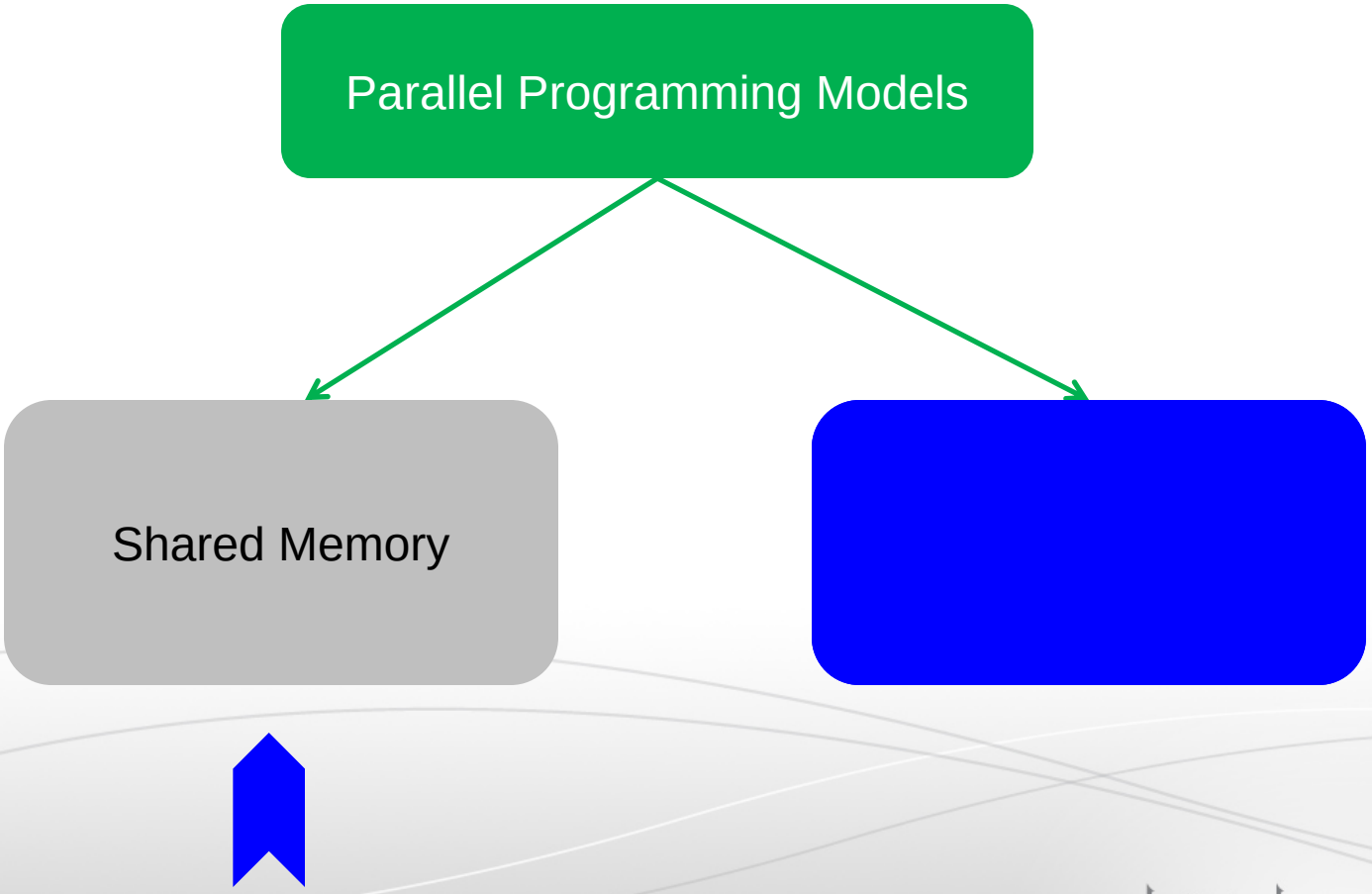
Traditional Parallel Programming Models



Shared Memory Model

- In the shared memory programming model, the abstraction is that parallel tasks can access any location of the memory
- Parallel tasks can communicate through reading and writing common memory locations
- This is similar to threads from a single process which share a single address space
- Multi-threaded programs (e.g., OpenMP programs) are the best fit with shared memory programming model

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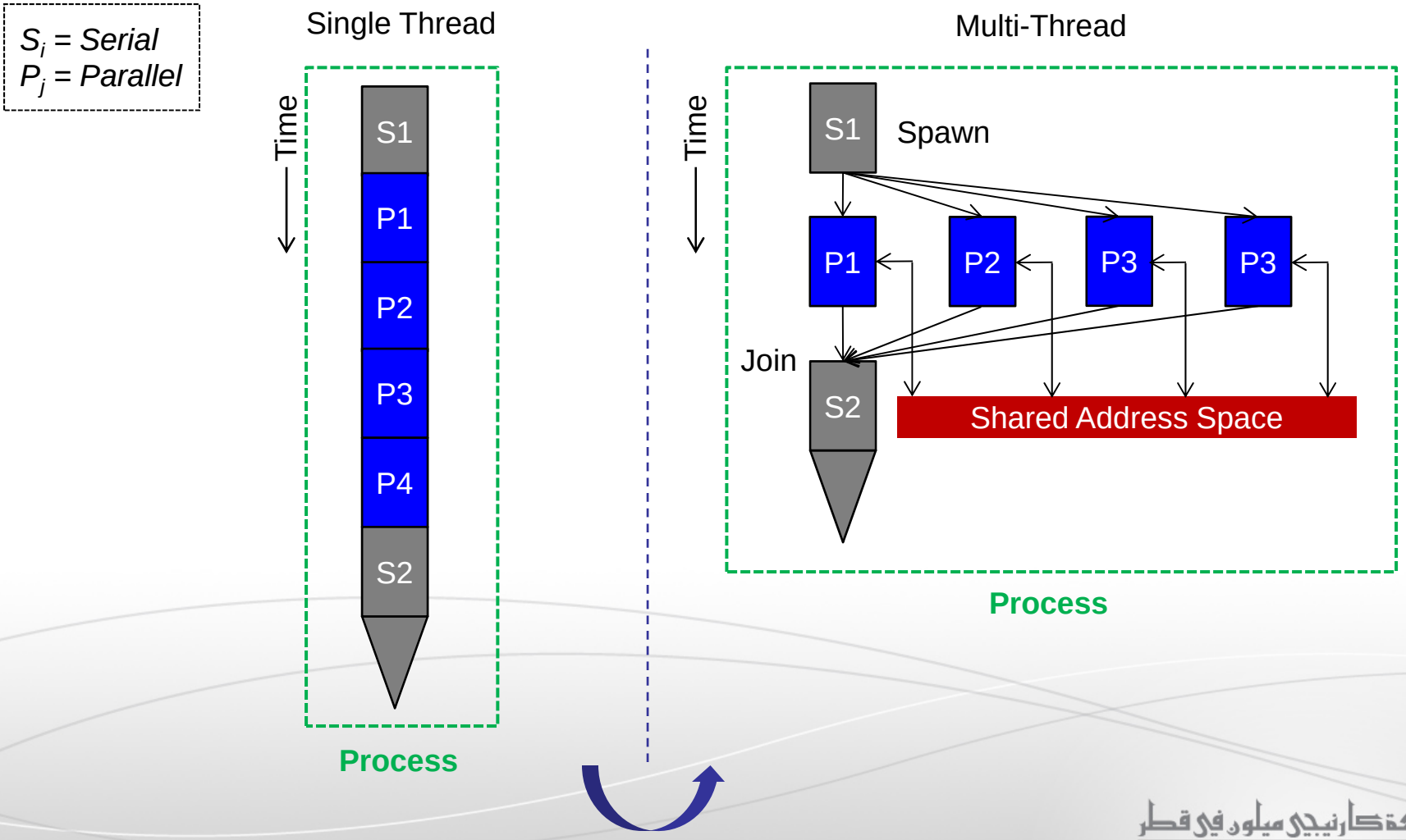
Shared Memory Model



Shared Memory Example

```
for (i=0; i<8; i++)
  a[i] = b[i] + c[i];
sum = 0;
for (i=0; i<8; i++)
  if (a[i] > 0)
    sum = sum + a[i];
Print sum;
```

Sequential

```
begin parallel // spawn a child thread
private int start_iter, end_iter, i;
shared int local_iter=4, sum=0;
shared double sum=0.0, a[], b[], c[];
shared lock_type mylock;

start_iter = getid() * local_iter;
end_iter = start_iter + local_iter;
for (i=start_iter; i<end_iter; i++)
  a[i] = b[i] + c[i];
barrier;

for (i=start_iter; i<end_iter; i++)
  if (a[i] > 0) {
    lock(mylock);
      sum = sum + a[i];
    unlock(mylock);
  }
barrier;     // necessary

end parallel // kill the child thread
Print sum;
```

Parallel

Why Locks?

- Unfortunately, threads in a shared memory model need to synchronize
- This is usually achieved through mutual exclusion
- Mutual exclusion requires that when there are multiple threads, only one thread is allowed to write to a shared memory location (or the critical section) at any time
- How to guarantee mutual exclusion in a critical section?
  - Typically, a lock can be implemented

```
//In a high level language
void lock (int *lockvar) {
  wh
  *l
}
void
  *lockvar = 0;
}
```

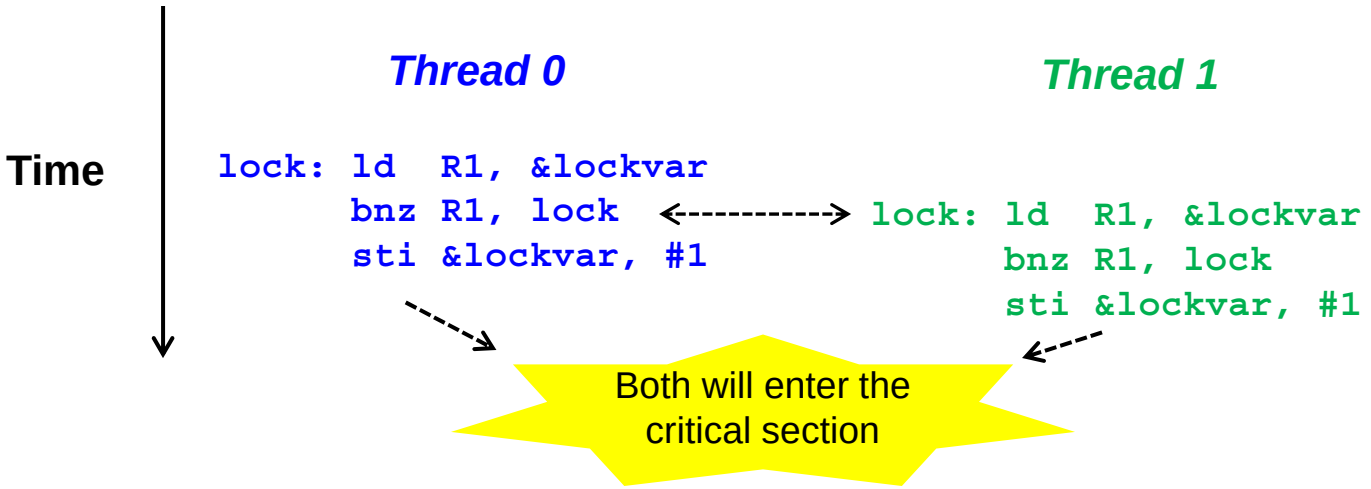
In machine language, it looks like this:

```
unlock: st   &lockvar, #0
        ret
```

Is this Enough/Correct?

The Synchronization Problem

- Let us check if this works:



- The execution of **ld**, **bnz**, and **sti** is not atomic (or indivisible)
  - Several threads may be executing them at the same time
- This allows several threads to enter the critical section simultaneously

The Peterson's Algorithm

- To solve this problem, let us consider a software solution referred to as the Peterson's Algorithm [Tanenbaum, 1992]

```
int turn;
int interested[n];  // initialized to 0

void lock (int process, int lvar) {     // process is 0 or 1
  int other = 1 - process;
  interested[process] = TRUE;
  turn = process;
  while (turn == process && interested[other] == TRUE) {} ;
}
// Post: turn != process or interested[other] == FALSE

void unlock (int process, int lvar) {
  interested[process] = FALSE;
}
```

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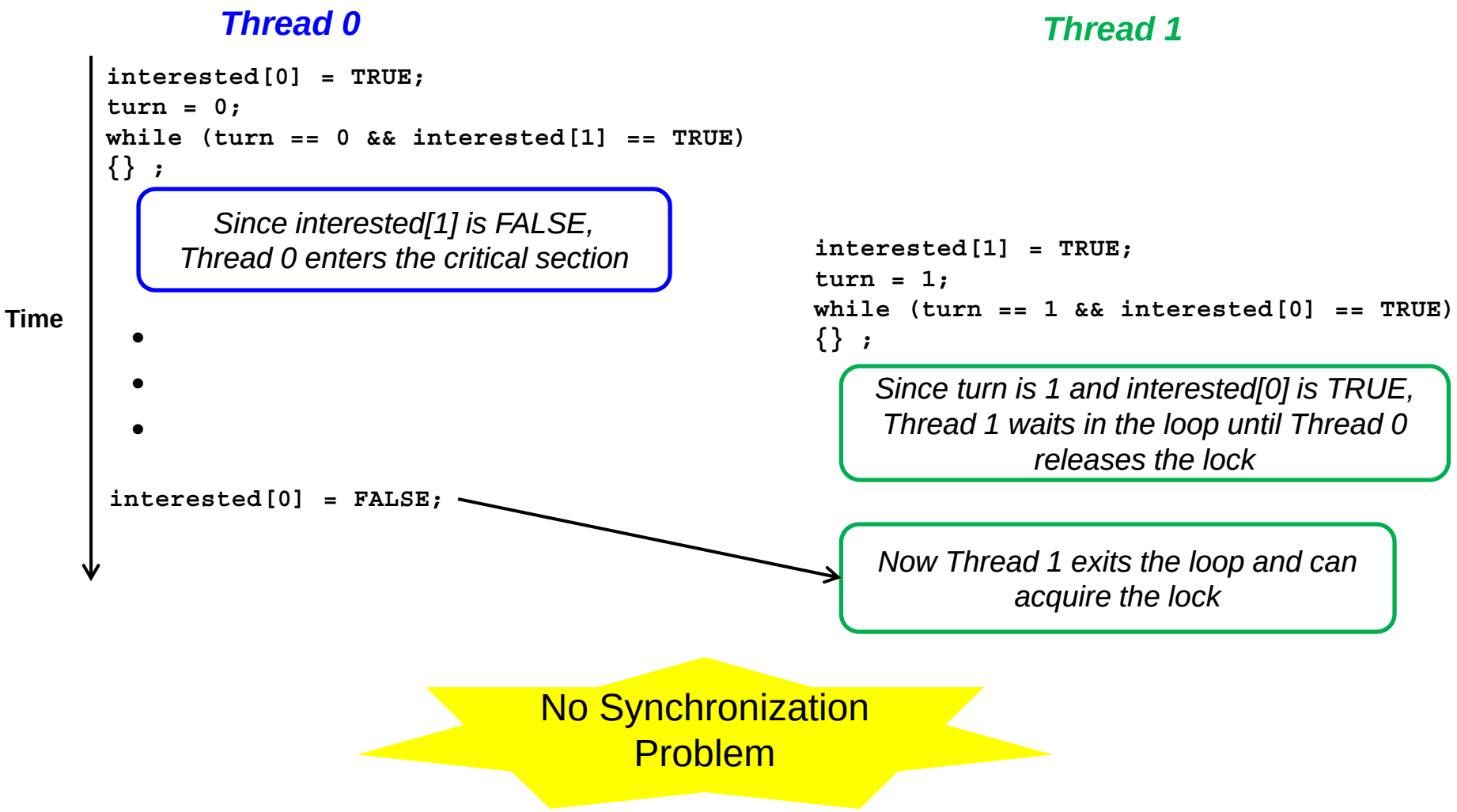
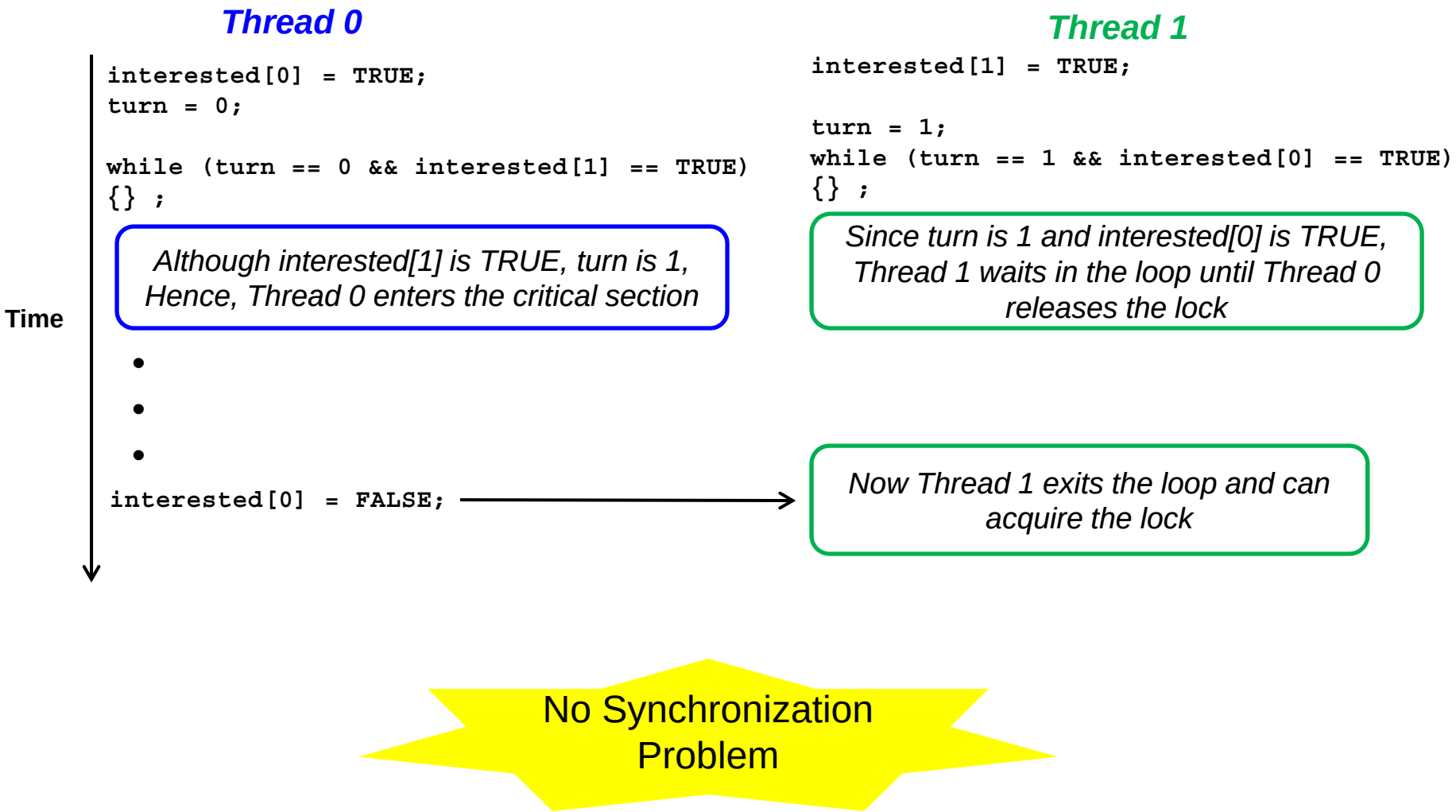
No Race



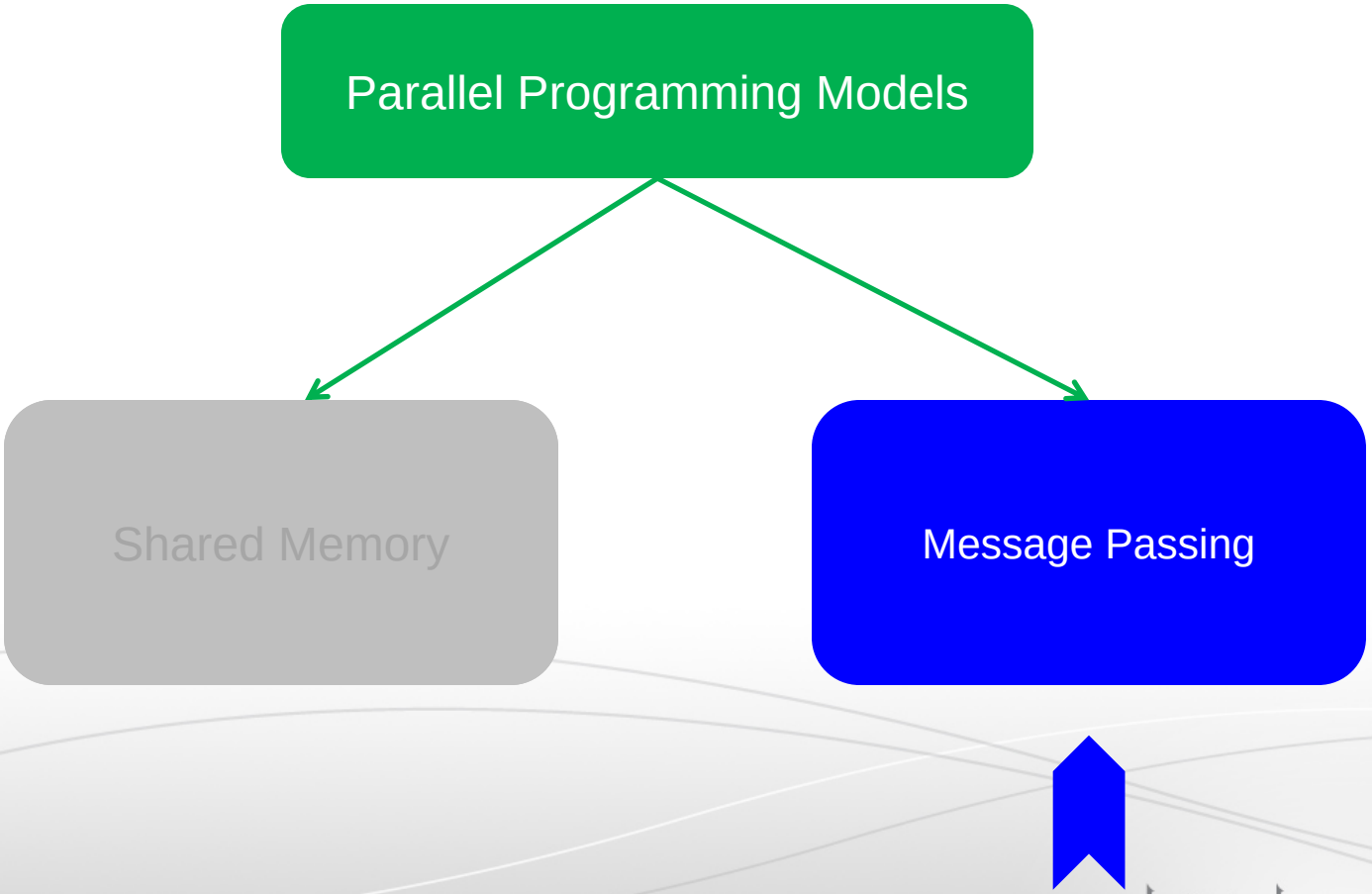
No Synchronization Problem

With Race



No Synchronization Problem

Traditional Parallel Programming Models



Message Passing Model

- In message passing, parallel tasks have their own local memories
- One task cannot access another task's memory
- Hence, to communicate data they have to rely on explicit messages sent to each other
- This is similar to the abstraction of processes which do not share an address space
- Message Passing Interface (MPI) programs are the best fit with the message passing programming model

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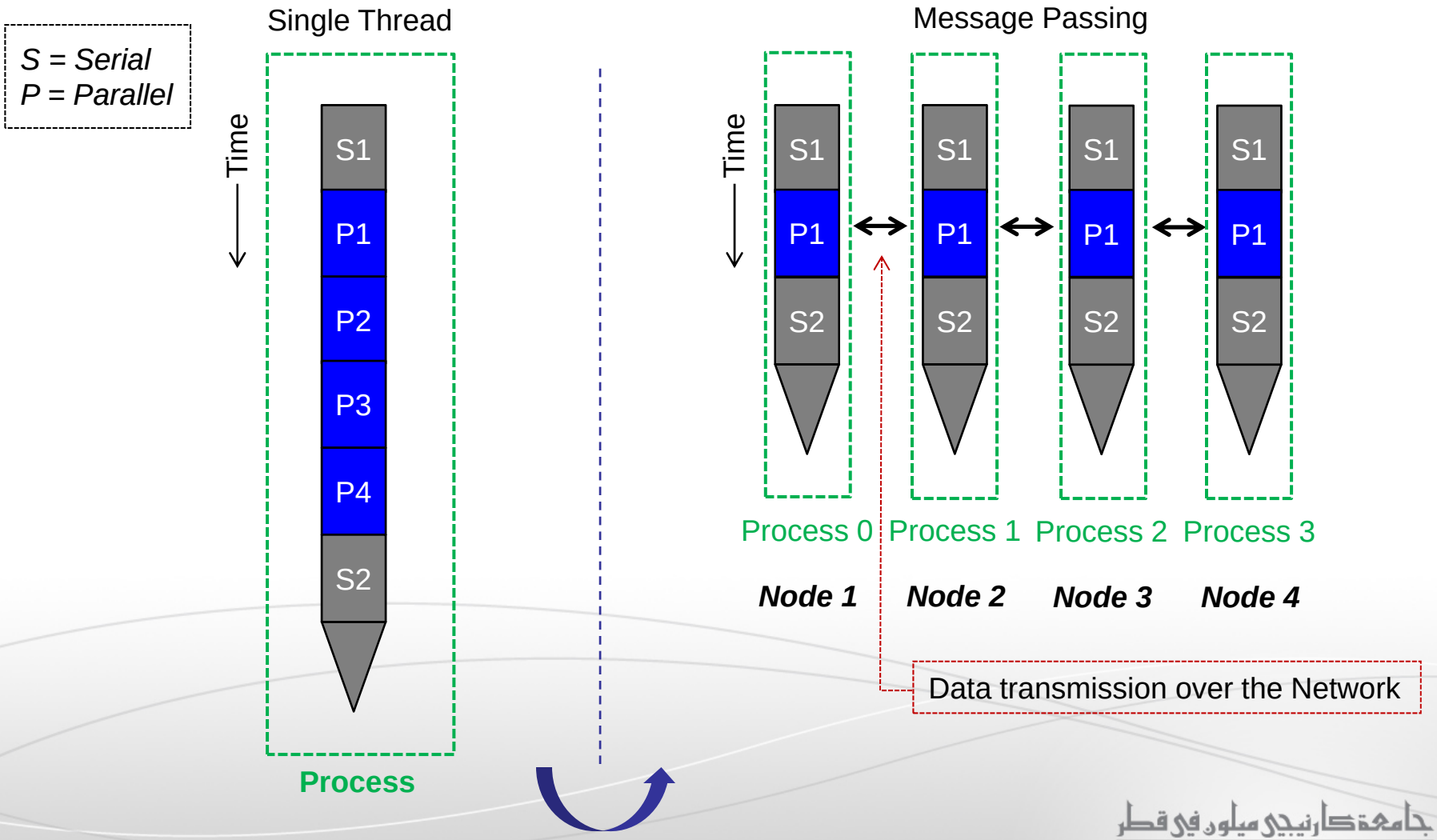
Message Passing Model



Message Passing Example

```
for (i=0; i<8; i++)
  a[i] = b[i] + c[i];
sum = 0;
for (i=0; i<8; i++)
  if (a[i] > 0)
    sum = sum + a[i];
Print sum;
```

Sequential

```
id = getpid();
local_iter = 4;
start_iter = id * local_iter;
end_iter = start_iter + local_iter;

if (id == 0)
  send_msg (P1, b[4..7], c[4..7]);
else
  re

for
  a[

local_sum = 0;
for (i=start_iter; i<end_iter; i++)
  if (a[i] > 0)
    local_sum = local_sum + a[i];
if (id == 0) {
  recv_msg (P1, &local_sum1);
  sum = local_sum + local_sum1;
  Print sum;
}
else
  send_msg (P0, local_sum);
```

No Mutual Exclusion is Required!

Parallel

Shared Memory Vs. Message Passing

- Comparison between shared memory and message passing programming models:

Aspect	Shared Memory	Message Passing
Communication	Implicit (via loads/stores)	Explicit Messages
Synchronization	Explicit	Implicit (Via Messages)
Hardware Support	Typically Required	None
Development Effort	Lower	Higher
Tuning Effort	Higher	Lower

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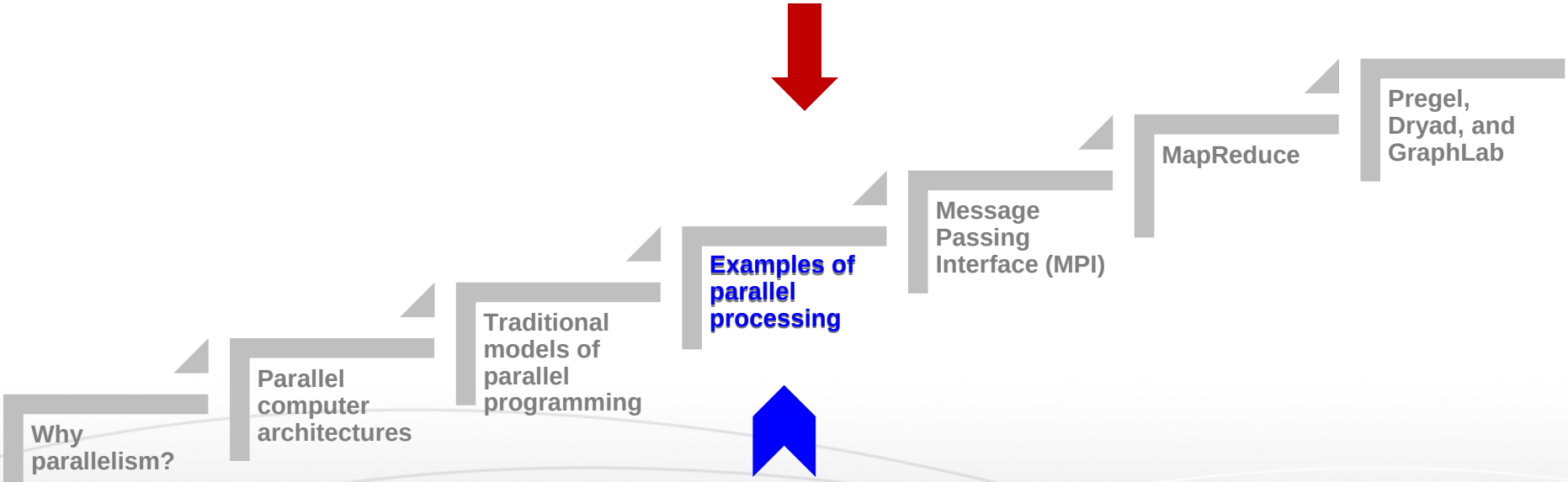

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SPMD and MPMD

- When we run multiple processes with message-passing, there are further categorizations regarding how many *different* programs are cooperating in parallel execution

- We distinguish between two models:

  1. Single Program Multiple Data (**SPMD**) model

  2. Multiple Programs Multiple Data (**MPMP**) model

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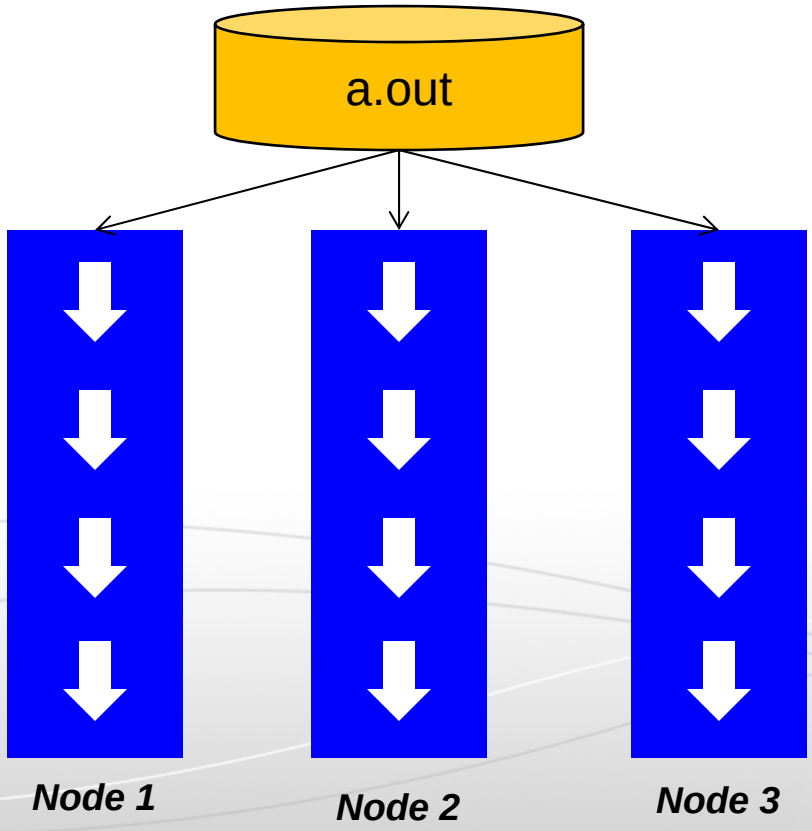
SPMD

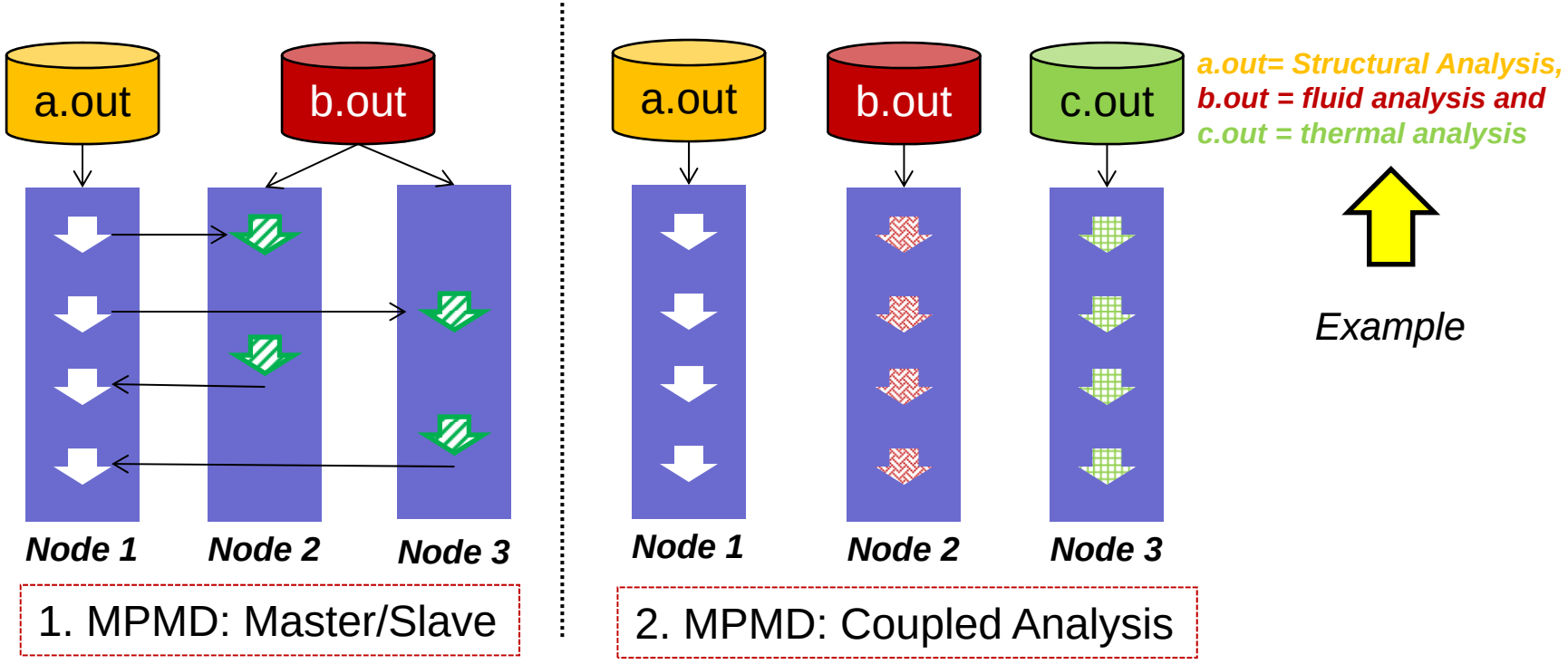
- In the SPMD model, there is only one program and each process uses the same executable working on different sets of data



MPMD

- The MPMD model uses different programs for different processes, but the processes collaborate to solve the same problem

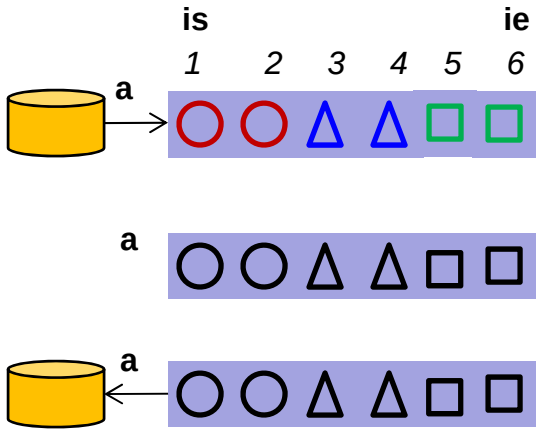
- MPMD has two styles, the *master/worker* and the *coupled analysis*



An Example

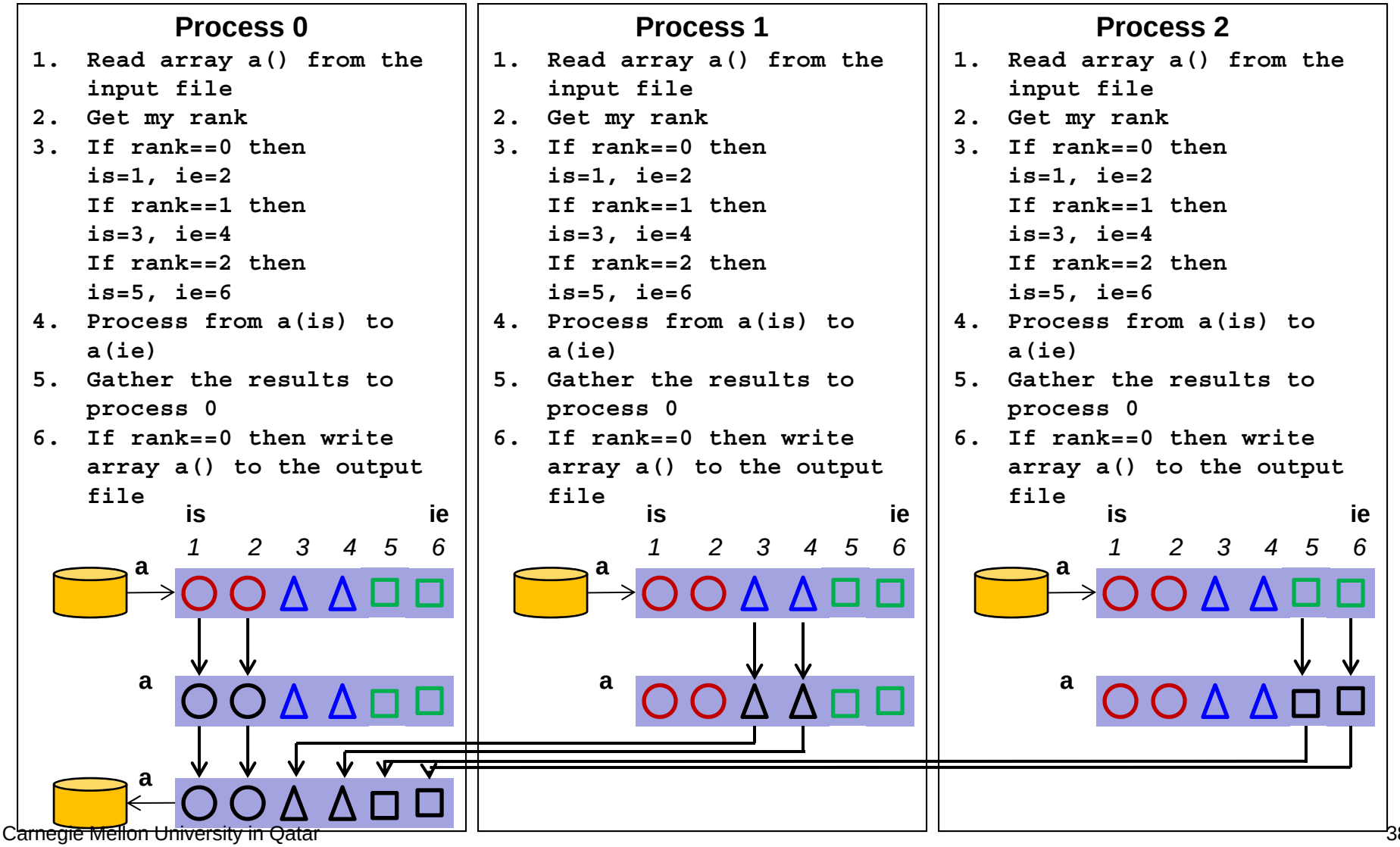
A Sequential Program

```
1. Read array a() from the input file
2. Set is=1 and ie=6  //is = index start and ie = index end
3. Process from a(is) to a(ie)
4. Write array a() to the output file
```



- Colored shapes indicate the initial values of the elements
- Black shapes indicate the values after they are processed

An Example



Concluding Remarks

- To summarize, keep the following 3 points in mind:
  - The purpose of parallelization is to reduce the time spent for computation
  - Ideally, the parallel program is *p* times faster than the sequential program, where *p* is the number of processes involved in the parallel execution, *but this is not always achievable*
  - Message-passing is the tool to consolidate what parallelization has separated. It should not be regarded as the parallelization itself

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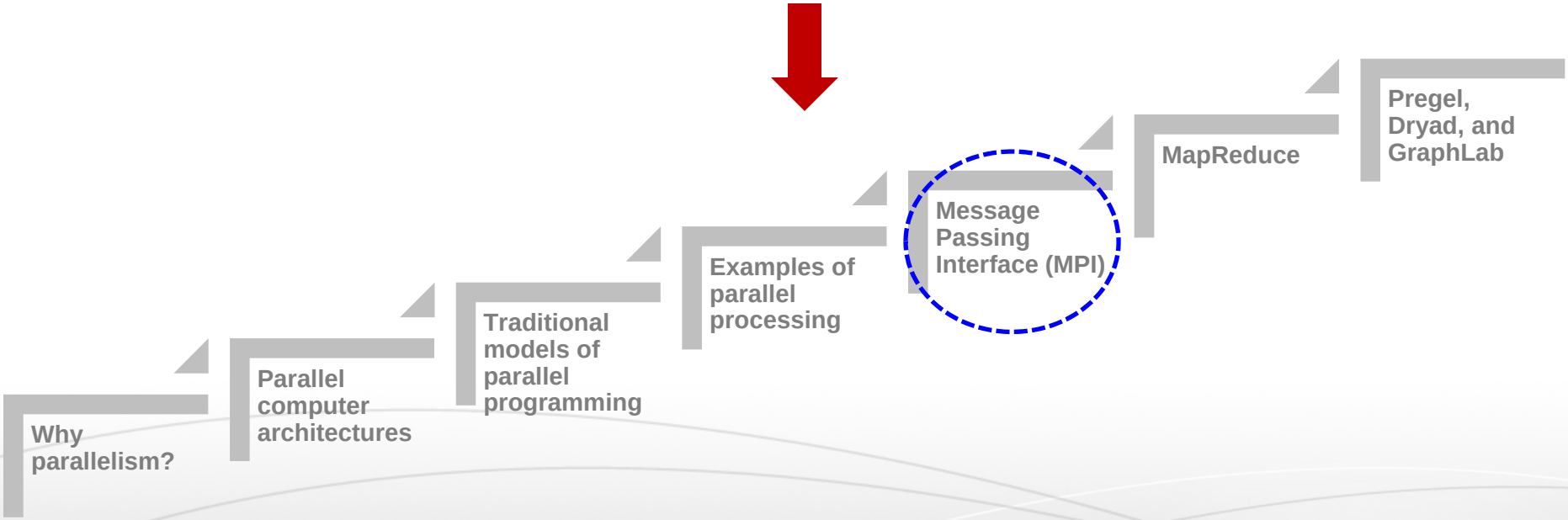
Next Class

Discussion on Programming Models



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