ICTP
The Abdus Salam
International Centre
for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

Basic Principles of Parallelism

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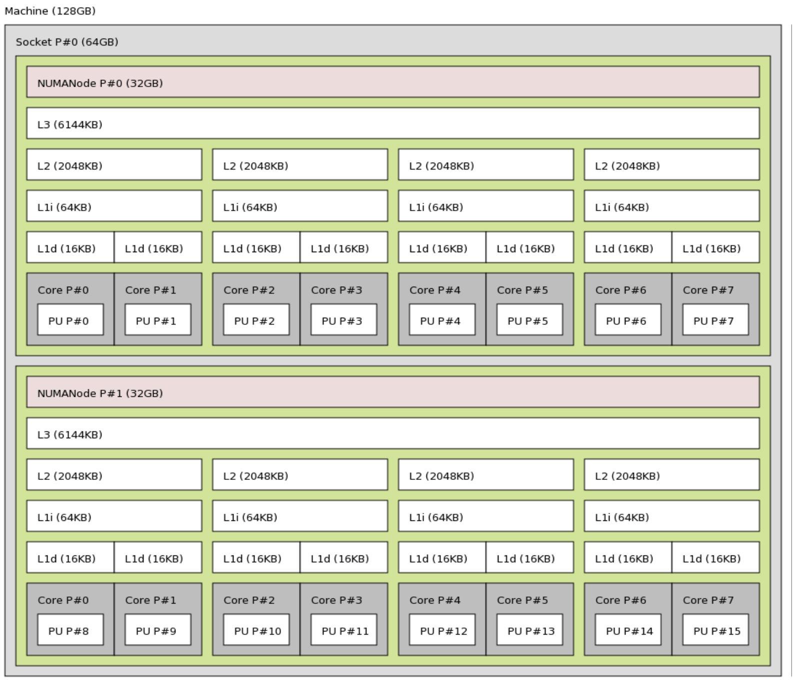
Why Parallel Programming

- Solve larger problems
- Run memory demanding codes
- Solve problems with greater speed
- Today?!
    - Processing of massive amount of data
    - Inescapable to exploit modern CPU systems

Modern CPUs Models



Machine (128GB)

Socket P#0 (64GB)

NUMANode P#0 (32GB)

L3 (6144KB)

L2 (2048KB) L2 (2048KB) L2 (2048KB) L2 (2048KB)

L1i (64KB) L1i (64KB) L1i (64KB) L1i (64KB)

L1d (16KB) L1d (16KB) L1d (16KB) L1d (16KB) L1d (16KB) L1d (16KB) L1d (16KB) L1d (16KB)

Core P#0 PU P#0 | Core P#1 PU P#1 | Core P#2 PU P#2 | Core P#3 PU P#3 | Core P#4 PU P#4 | Core P#5 PU P#5 | Core P#6 PU P#6 | Core P#7 PU P#7

NUMANode P#1 (32GB)

L3 (6144KB)

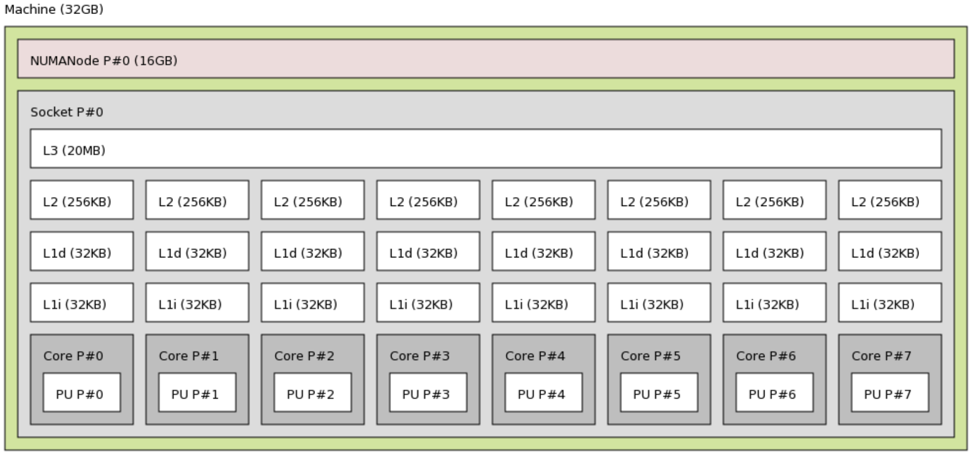
L2 (2048KB) L2 (2048KB) L2 (2048KB) L2 (2048KB)

L1i (64KB) L1i (64KB) L1i (64KB) L1i (64KB)

L1d (16KB) L1d (16KB) L1d (16KB) L1d (16KB) L1d (16KB) L1d (16KB) L1d (16KB) L1d (16KB)

Core P#0 PU P#8 | Core P#1 PU P#9 | Core P#2 PU P#10 | Core P#3 PU P#11 | Core P#4 PU P#12 | Core P#5 PU P#13 | Core P#6 PU P#14 | Core P#7 PU P#15

The AMD Opteron 6380 Abu Dhabi 2.5GHz



Machine (32GB)

NUMANode P#0 (16GB)

Socket P#0

L3 (20MB)

L2 (256KB) L2 (256KB) L2 (256KB) L2 (256KB) L2 (256KB) L2 (256KB) L2 (256KB) L2 (256KB)

L1d (32KB) L1d (32KB) L1d (32KB) L1d (32KB) L1d (32KB) L1d (32KB) L1d (32KB) L1d (32KB)

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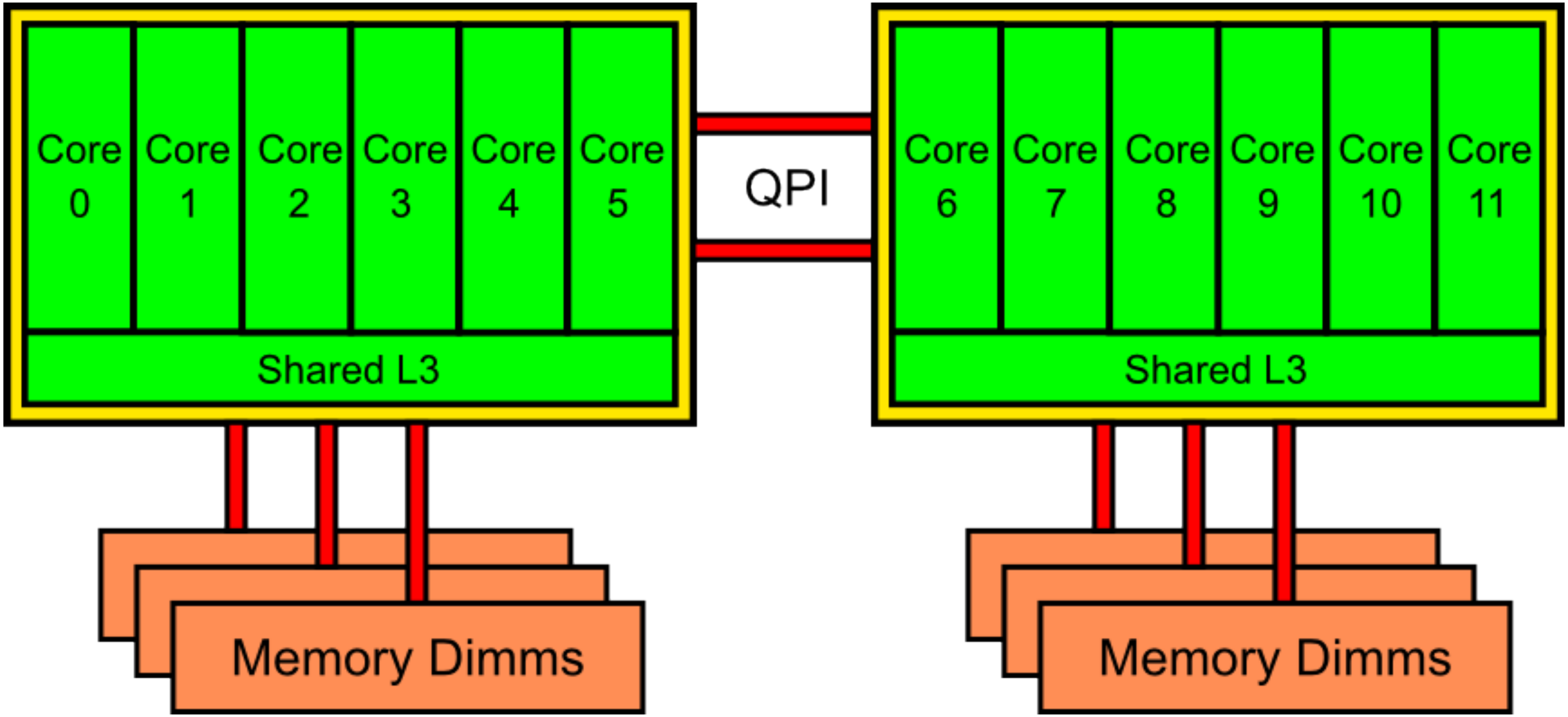
Core P#0 PU P#0 | Core P#1 PU P#1 | Core P#2 PU P#2 | Core P#3 PU P#3 | Core P#4 PU P#4 | Core P#5 PU P#5 | Core P#6 PU P#6 | Core P#7 PU P#7

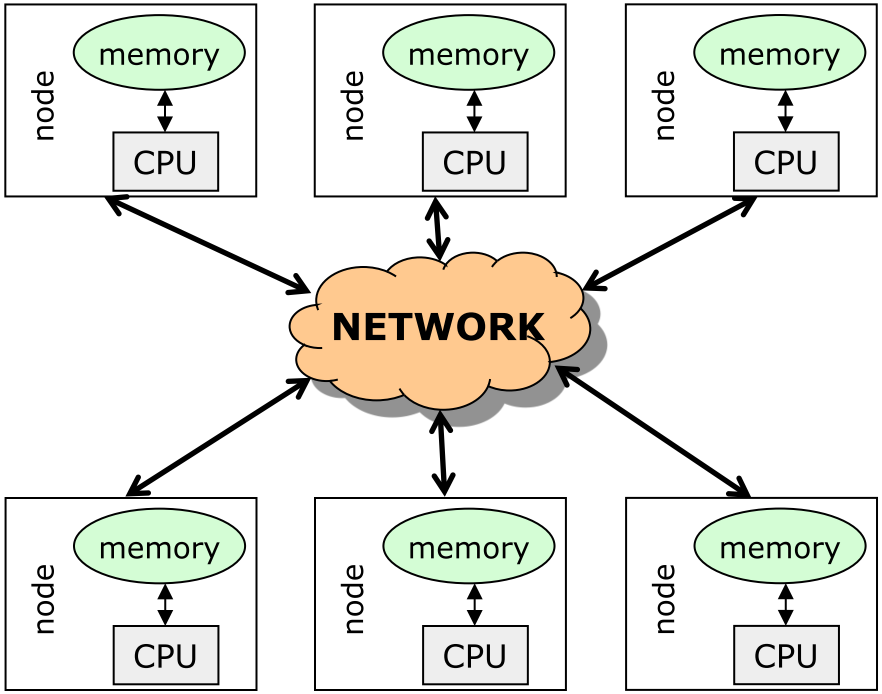
The Intel Xeon E5-2665 Sandy Bridge-EP 2.4GHz

Multiple Socket CPUs

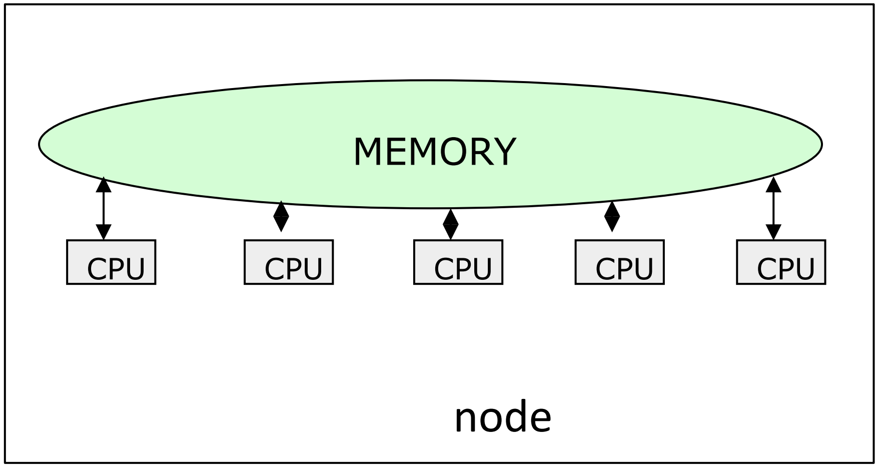


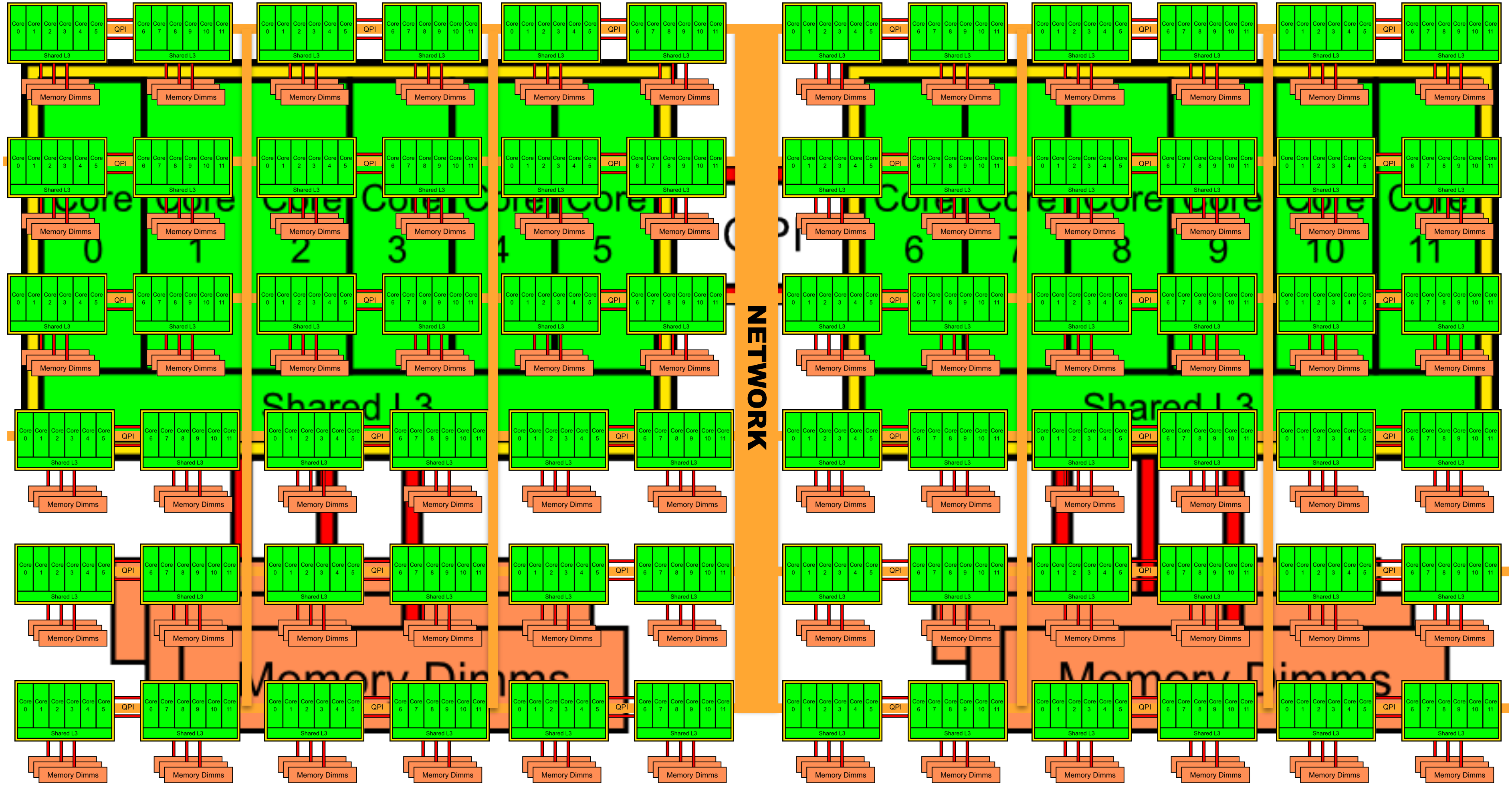
Parallel Architectures

- Distributed Memory

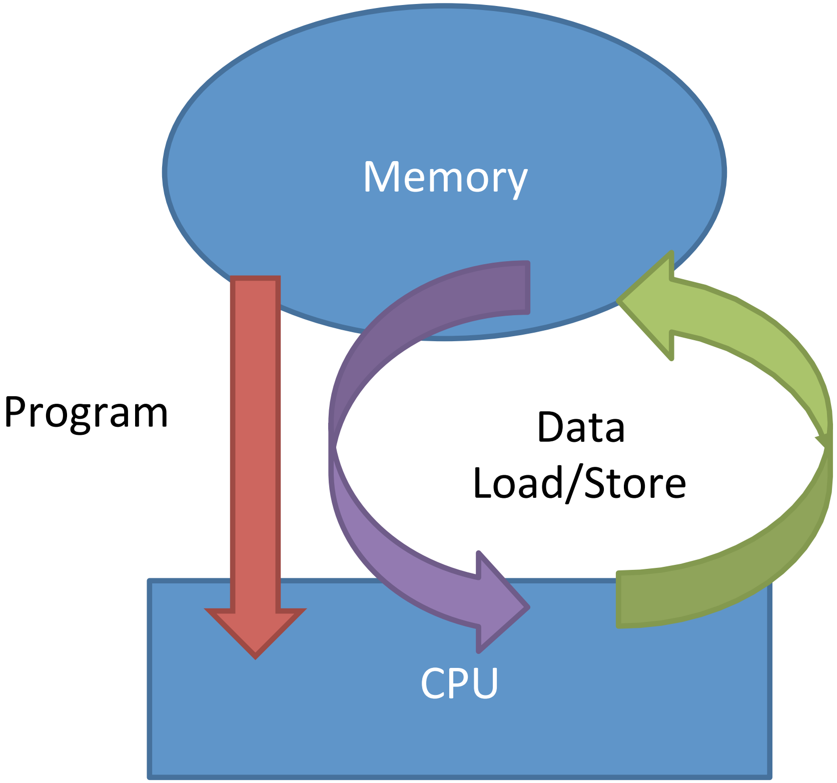


- Shared Memory

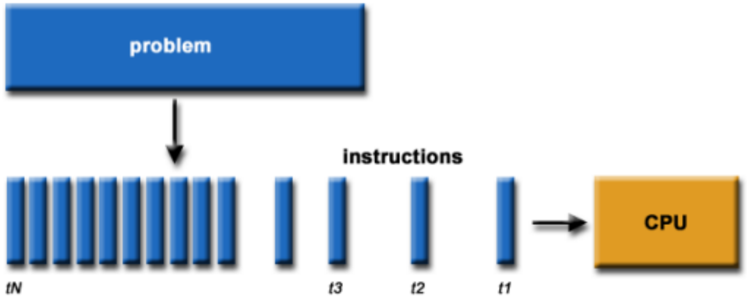



Core 0
Core 1
Core 2
Core 3
Core 4
Core 5
Core 6
Core 7
Core 8
Core 9
Core 10
Core 11
QPI
Shared L3
Memory Dimms
NETWORK

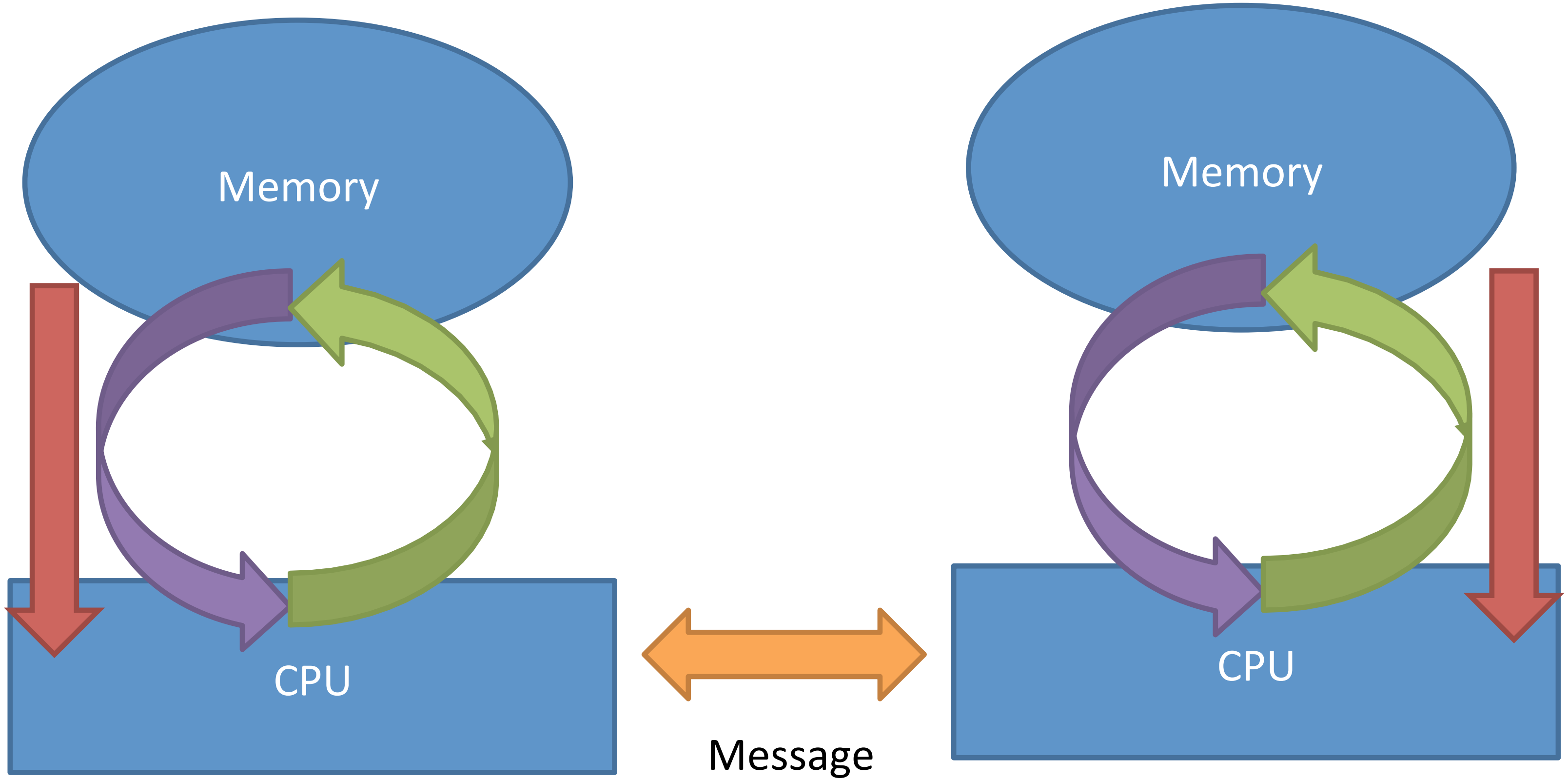
Serial Programming



A problem is broken into a discrete series of instructions.
Instructions are executed one after another.
Only one instruction may execute at any moment in time.



Parallel Programming



Logical Machine Organization

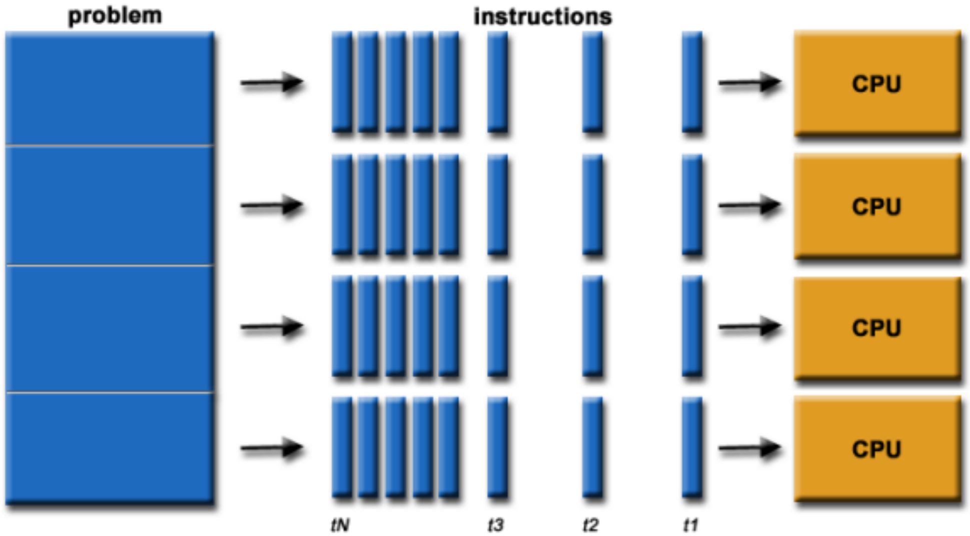
- Developers can have a different view of the hardware architecture due to the abstraction of the logical organization (how access to memory).
- It is easy to logically partition a Shared Memory system as a Distributed Memory system.
- The opposite is not trivial.

Design of Parallel Algorithm /1

- A serial algorithm is a sequence of basic steps for solving a given problem using a single serial computer
- Similarly, a parallel algorithm is a set of instruction that describe how to solve a given problem using multiple (>=1) parallel processors
- The parallelism add the dimension of concurrency. Designer must define a set of steps that can be executed simultaneously!!!

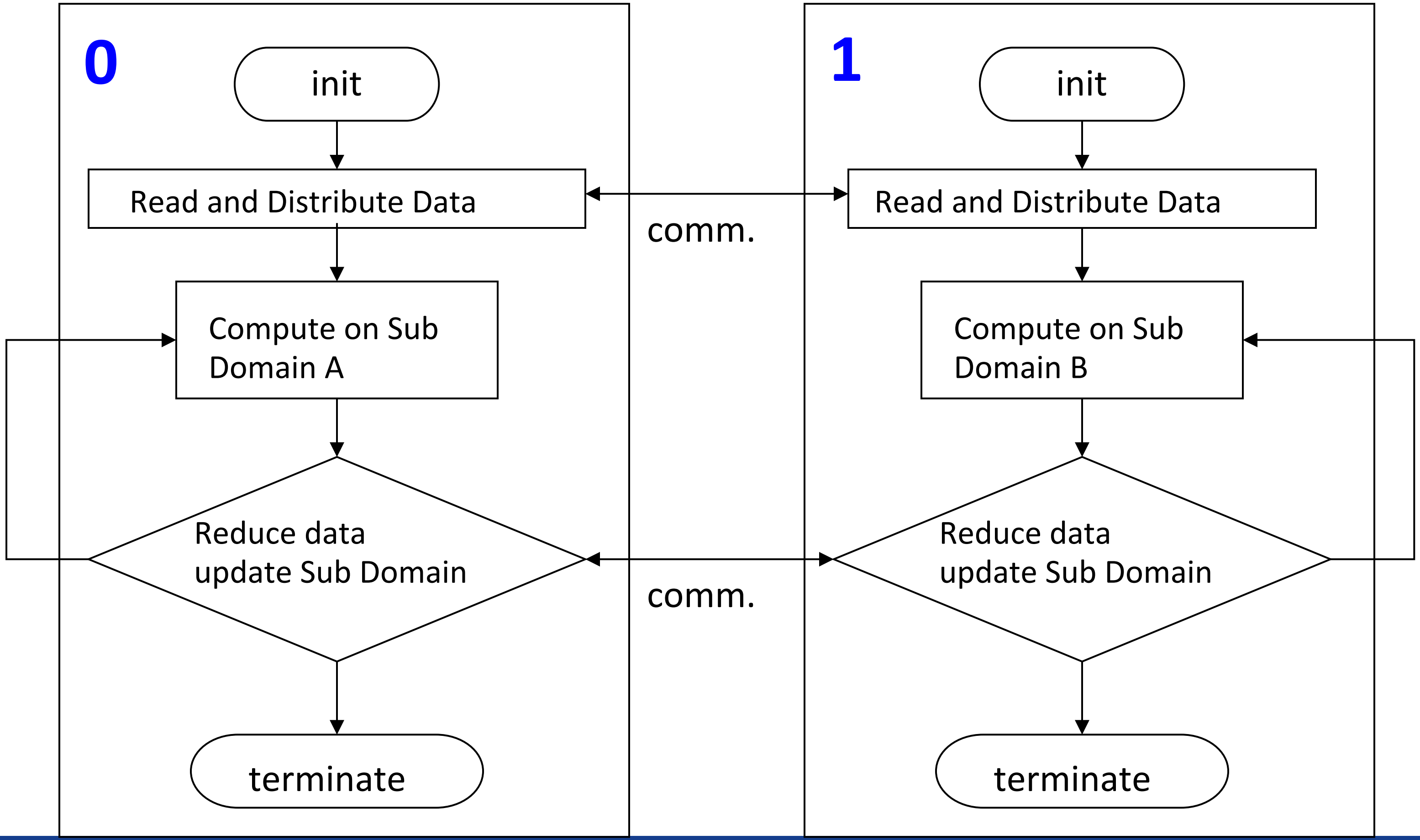
Concurrency

The first step in developing a parallel algorithm is to decompose the problem into tasks that can be executed concurrently



- A problem is broken into discrete parts that can be solved concurrently
- Each part is further broken down to a series of instructions
- Instructions from each part execute simultaneously on different processors
- An overall control / coordination mechanism is used

What is a Parallel Program



Design of Parallel Algorithm /2

- Identify portions of the work that can be performed concurrently
- Mapping the concurrent pieces of work onto multiple processes running in parallel
- Distributing the input, output and intermediate data associated within the program
- Managing accesses to data shared by multiple processors
- Synchronizing the processors at various stages of the parallel program execution

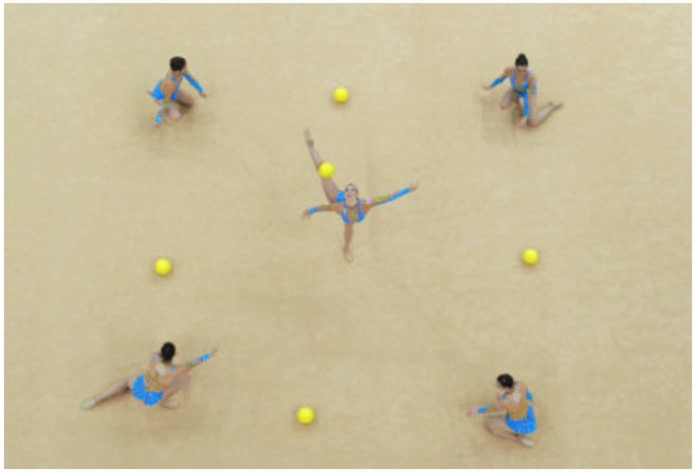
Type of Parallelism

- **Functional (or task) parallelism**: different people are performing different task at the same time

- **Data Parallelism**: different people are performing the same task, but on different equivalent and independent objects

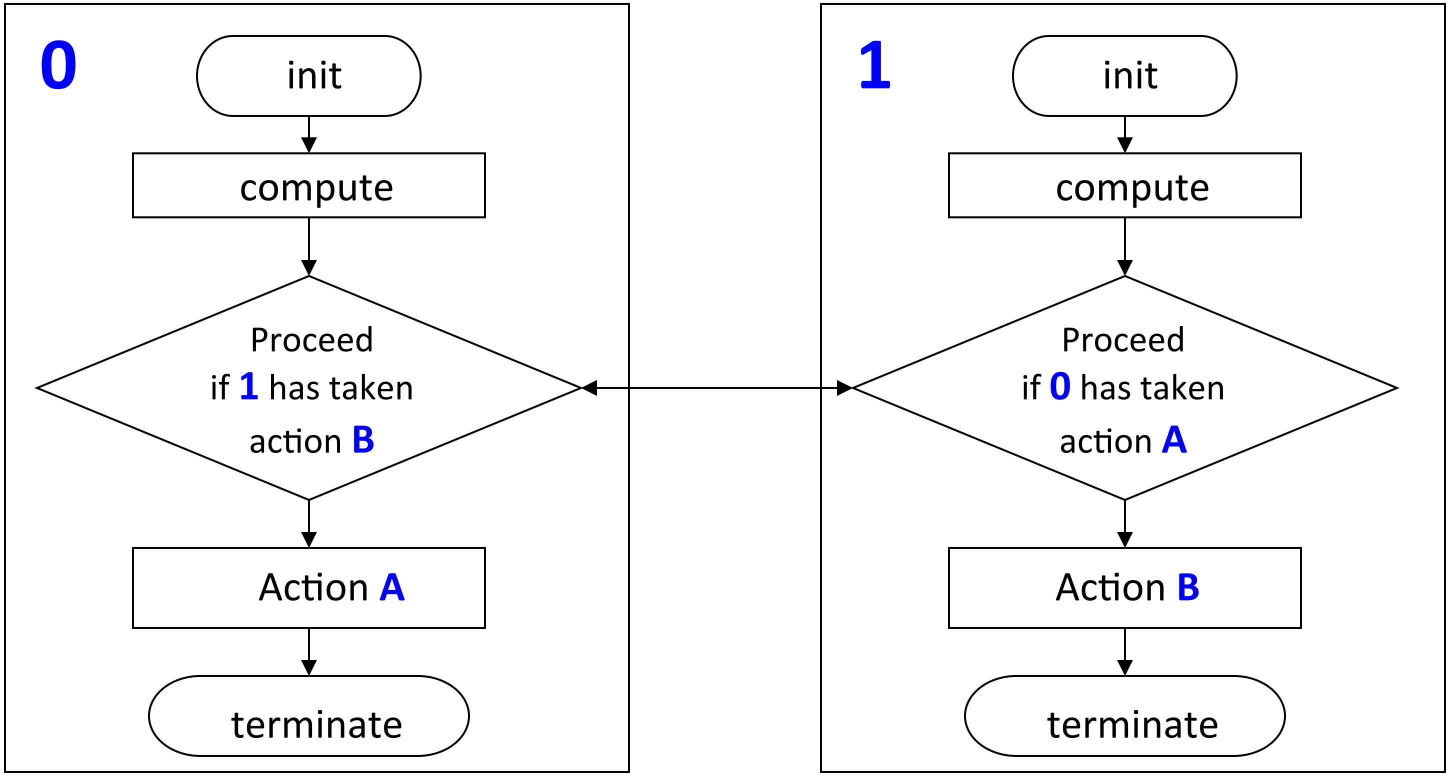
Process Interactions

- The effective speed-up obtained by the parallelization depend by the amount of overhead we introduce making the algorithm parallel
- There are mainly two key sources of overhead:
    1. Time spent in inter-process interactions (**communication**)
    2. Time some process may spent being idle (**synchronization**)

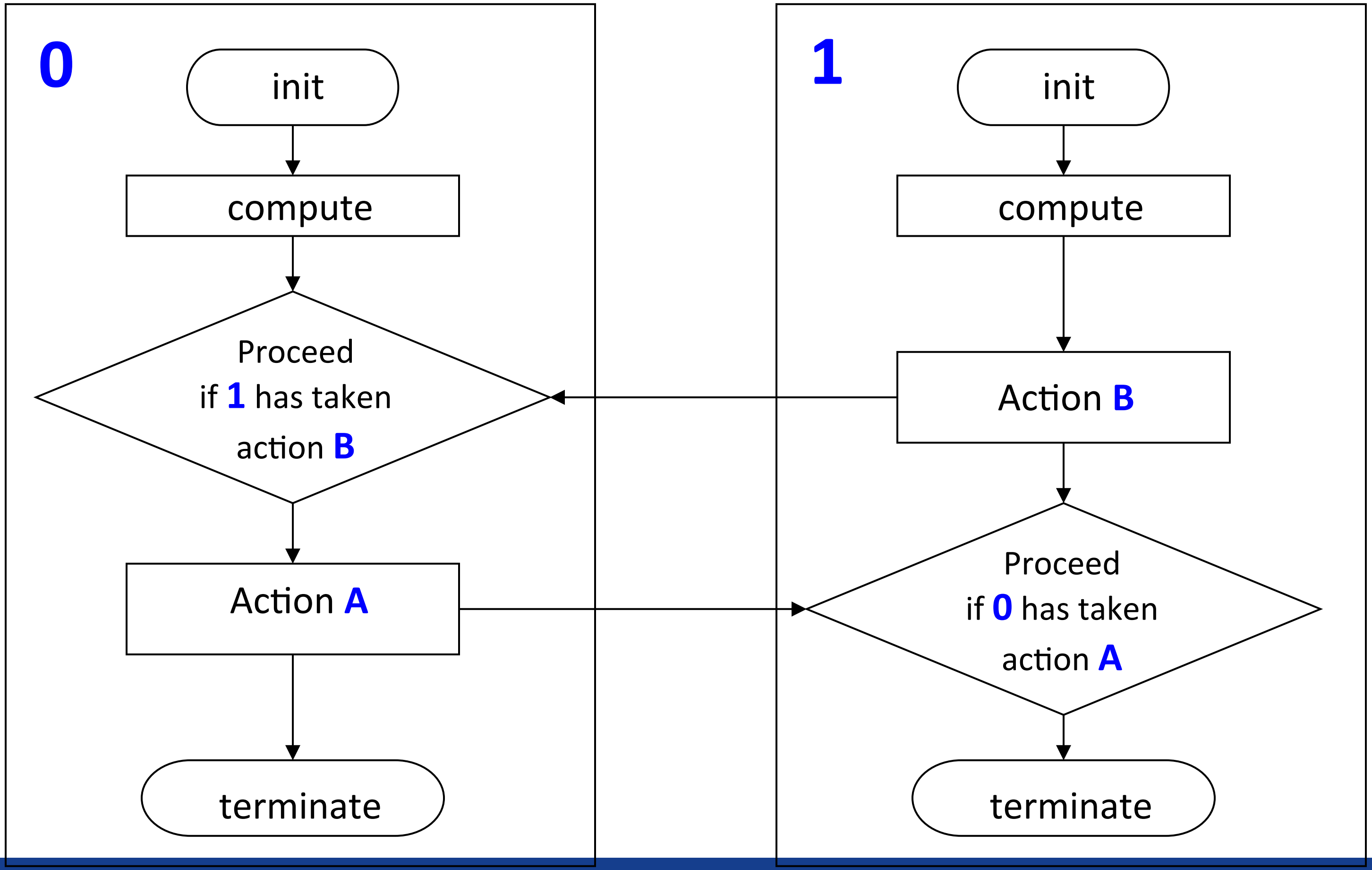


DEADLOCK

- occurs when 2^+ processes are blocked and each is waiting for the other to progress.


0
init
compute
Proceed if 1 has taken action B
Action A
terminate
1
init
compute
Proceed if 0 has taken action A
Action B
terminate

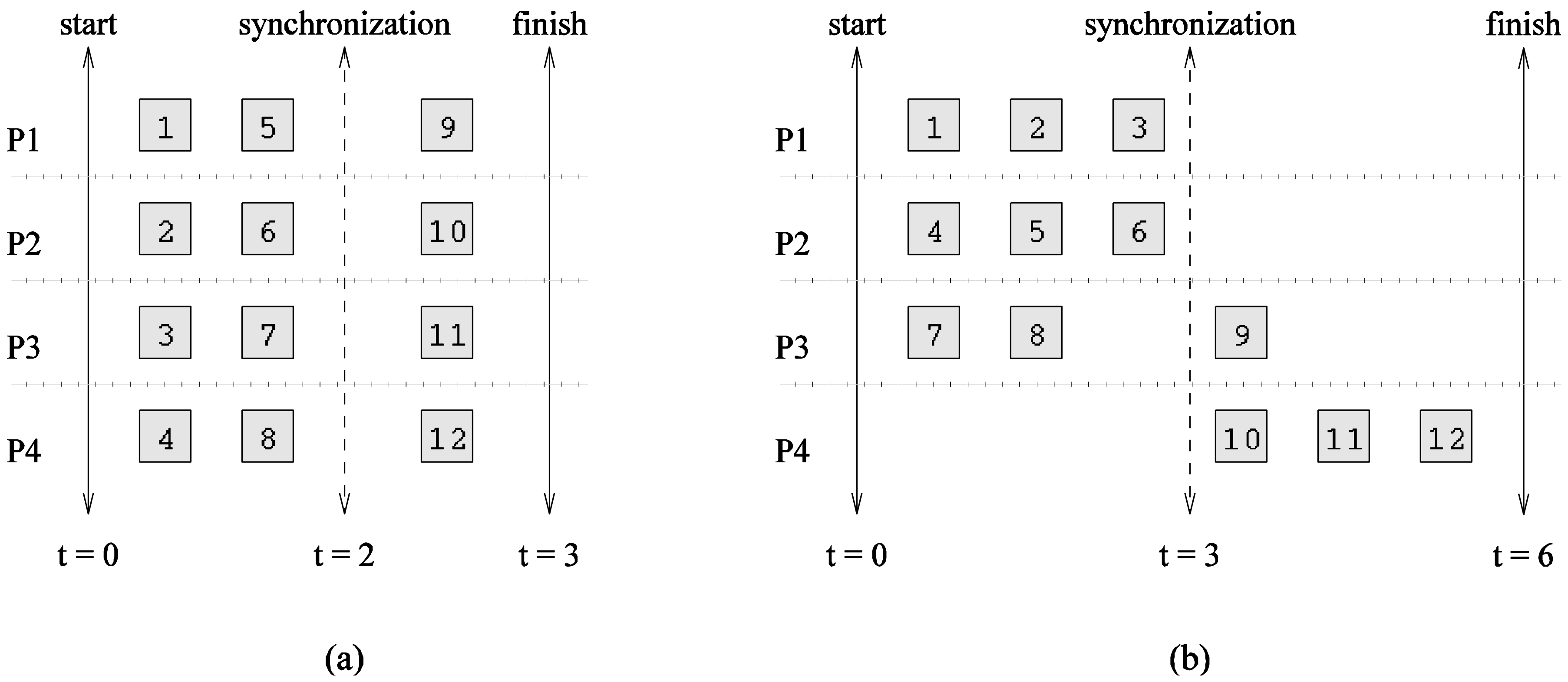
Avoiding DEADLOCK


0
init
compute
Proceed if 1 has taken action B
Action A
terminate
1
init
compute
Action B
Proceed if 0 has taken action A
terminate

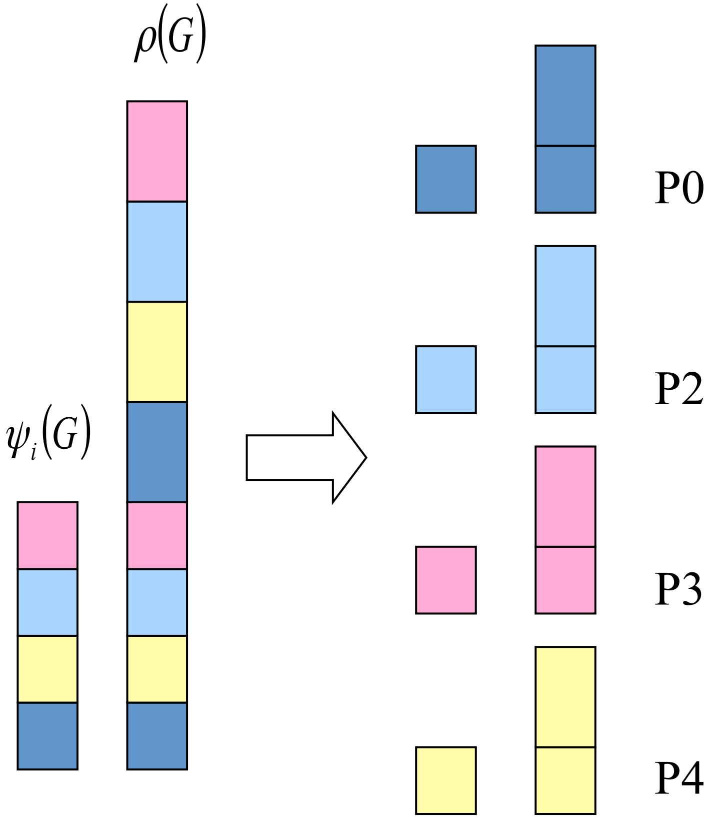
Load Balancing

- Equally divide the work among the available resource: processors, memory, network bandwidth, I/O, ...
- This is usually a simple task for the problem decomposition model
- It is a difficult task for the functional decomposition model

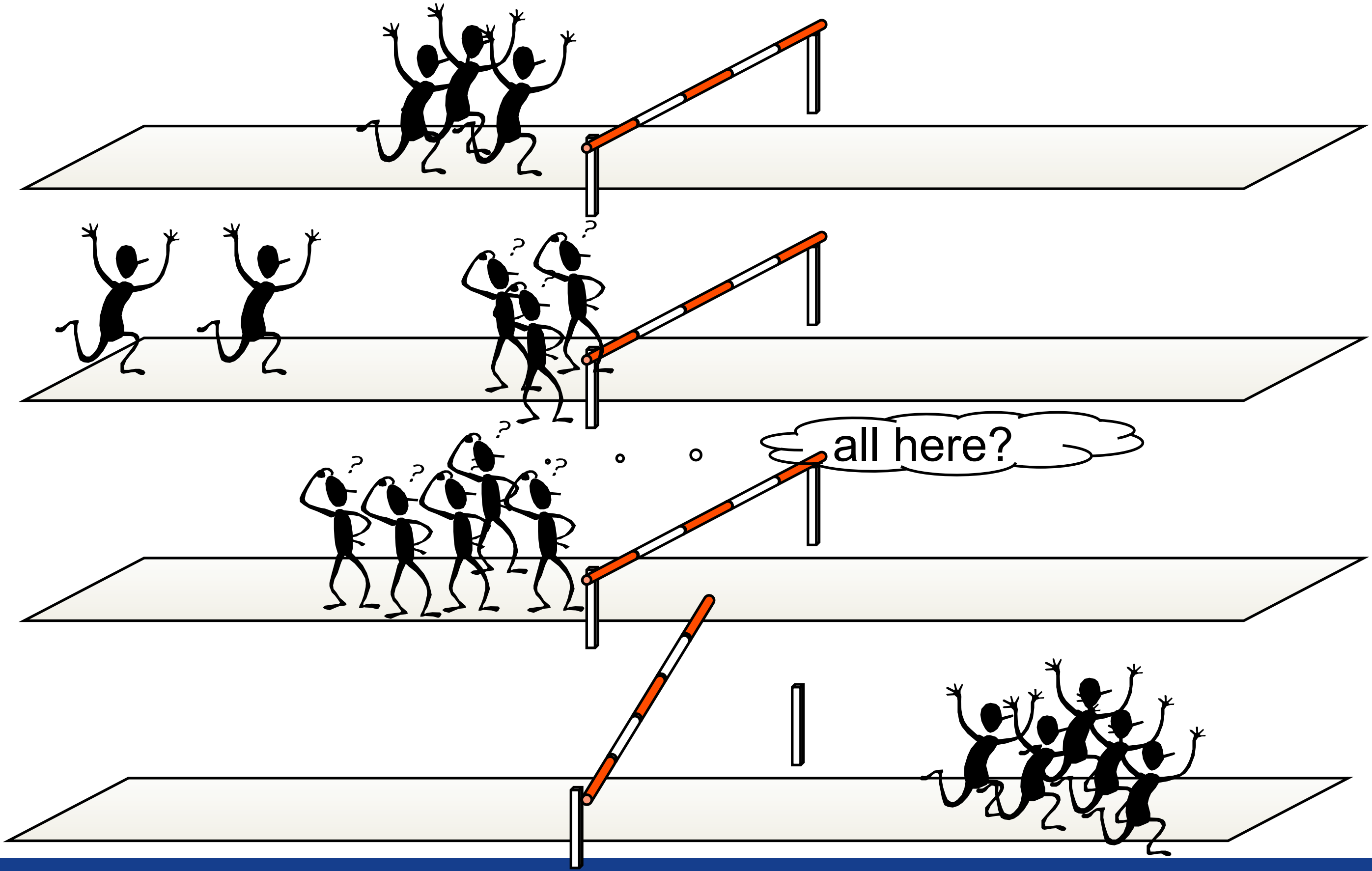
Mapping and Synchronization



Reciprocal Space distribution

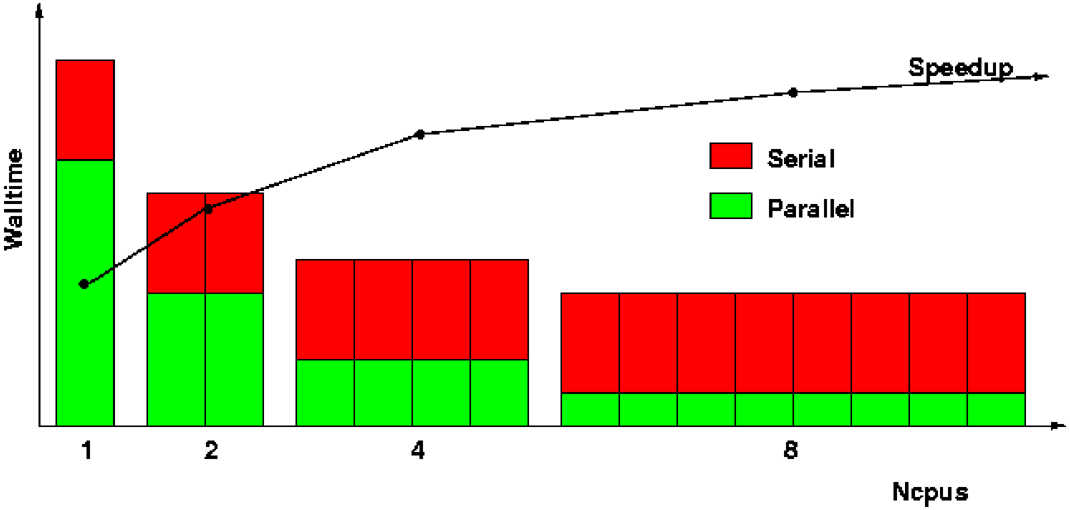


Effect of load-unbalancing



Amdahl's law

In a massively parallel context, an upper limit for the scalability of parallel applications is determined by the fraction of the overall execution time spent in non-scalable operations (Amdahl's law).



maximum speedup tends to
$1 / (1 - P)$
P= parallel fraction

1000000 core

$P = 0.999999$

serial fraction= 0.000001

Minimizing Communication

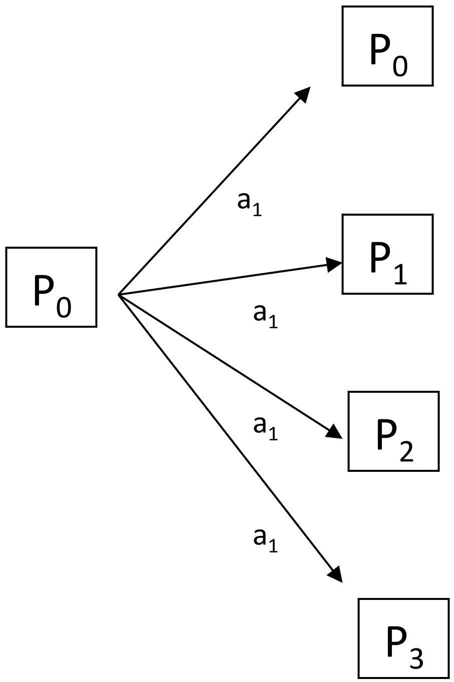
- When possible reduce the communication events:
  - Group lots of small communications into large one
  - Eliminate synchronizations as much as possible. Each synchronization level off the performance to that of the slowest process

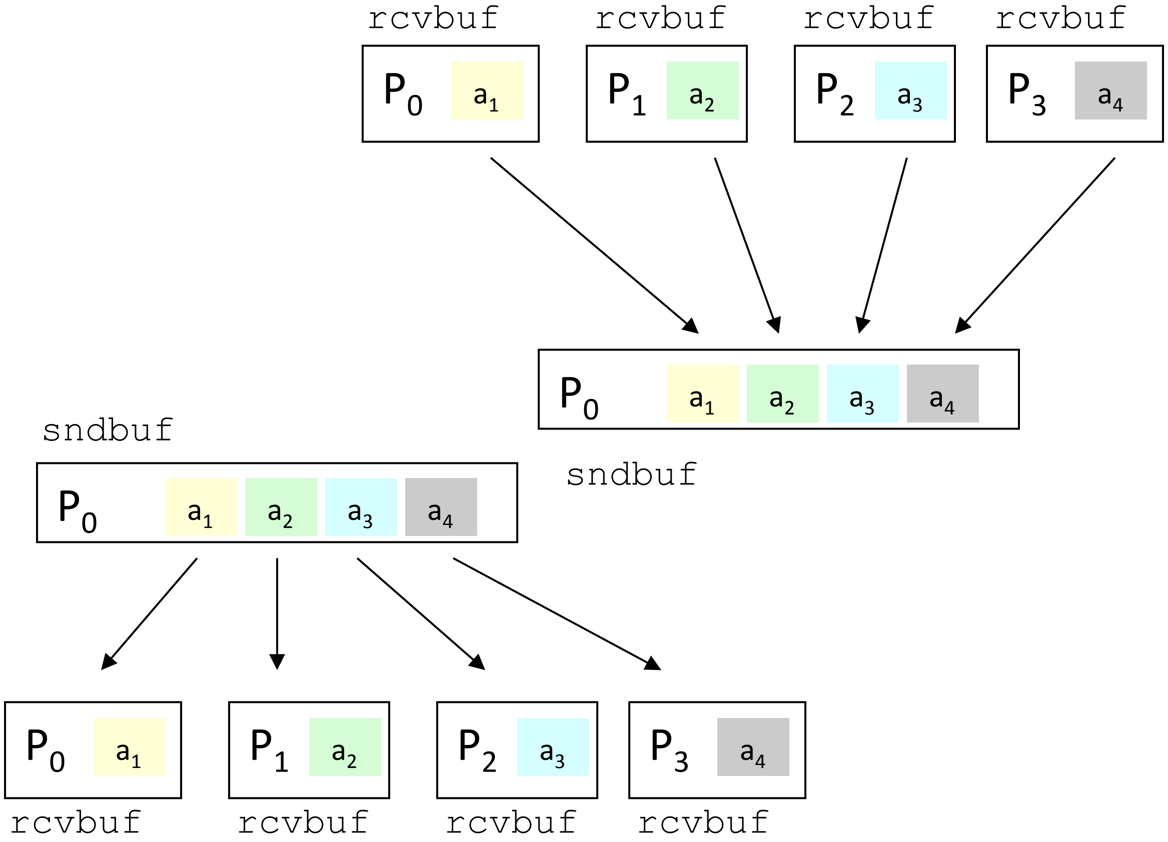
Overlap Communication and Computation

- When possible code your program in such a way that processes continue to do useful work while communicating
- This is usually a non trivial task and is afforded in the very last phase of parallelization.
- A successful implementation can bring a relevant improvement

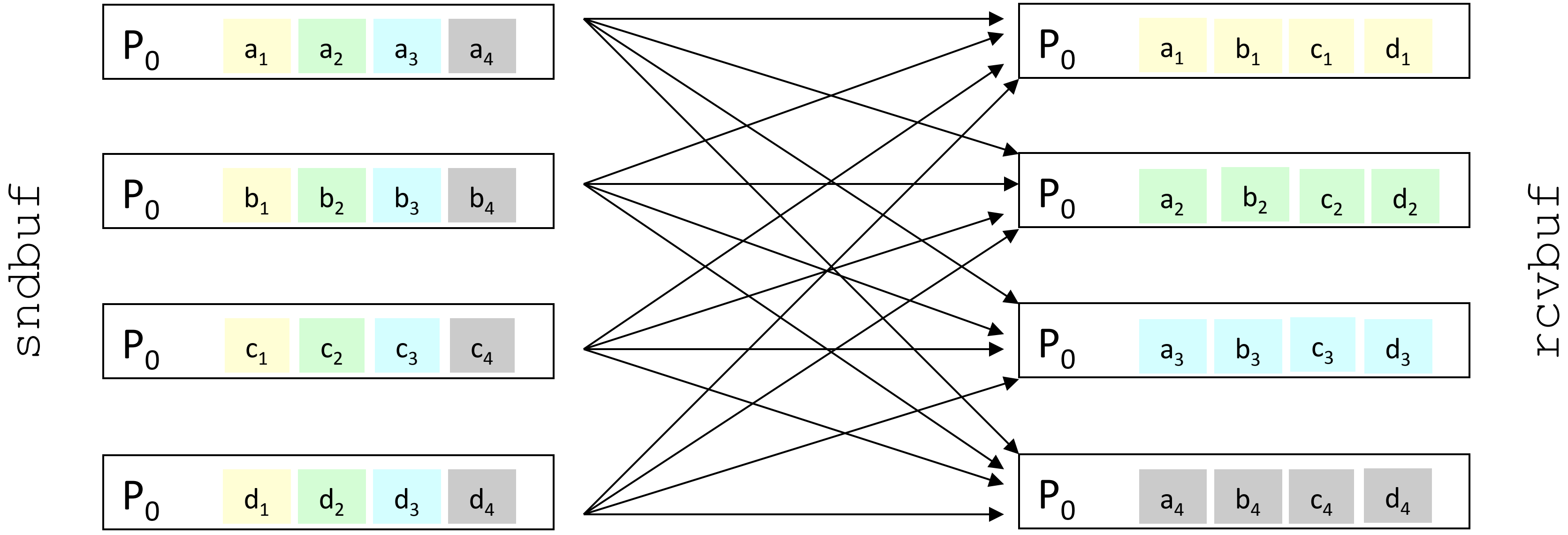
Scatter/Gather

Broadcast





All to all



sndbuf

P_0 a_1 a_2 a_3 a_4

P_0 b_1 b_2 b_3 b_4

P_0 c_1 c_2 c_3 c_4

P_0 d_1 d_2 d_3 d_4

rcvbuf

P_0 a_1 b_1 c_1 d_1

P_0 a_2 b_2 c_2 d_2

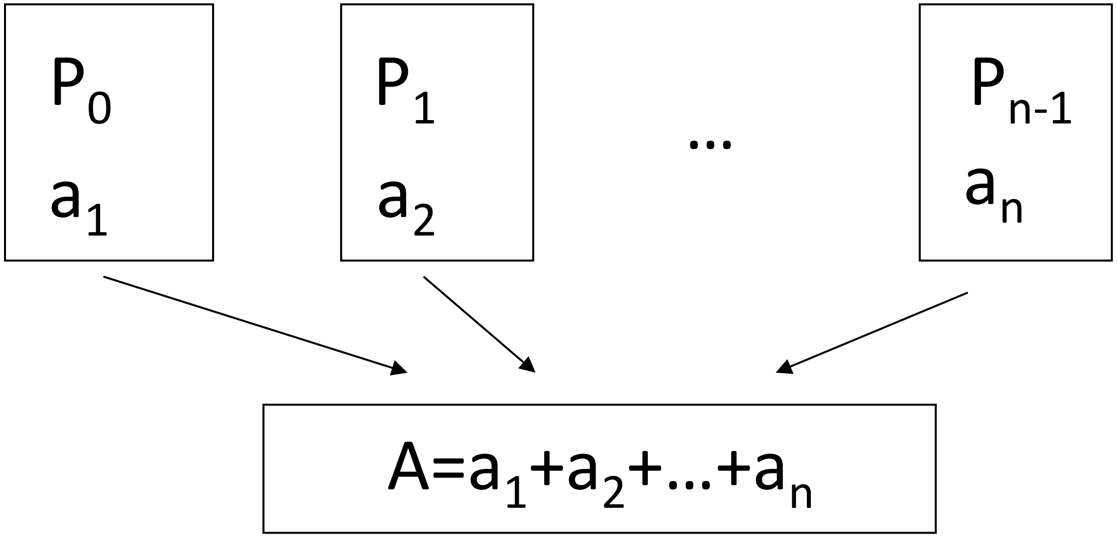
P_0 a_3 b_3 c_3 d_3

P_0 a_4 b_4 c_4 d_4

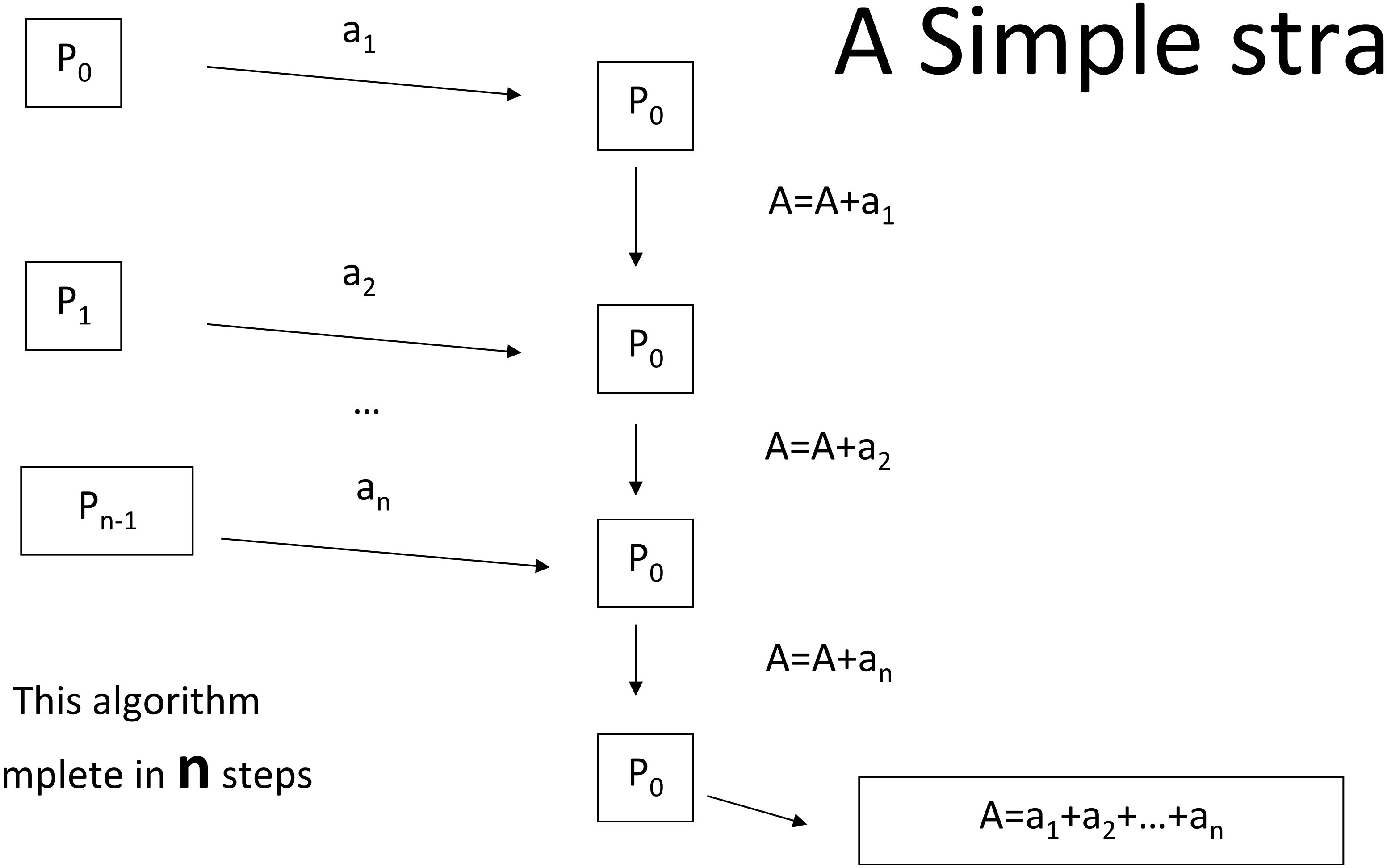
Very useful to implement data transposition

Reduction

- Reduction: sum up the partial results of different process (maybe the most common parallel operation required in a parallel program)



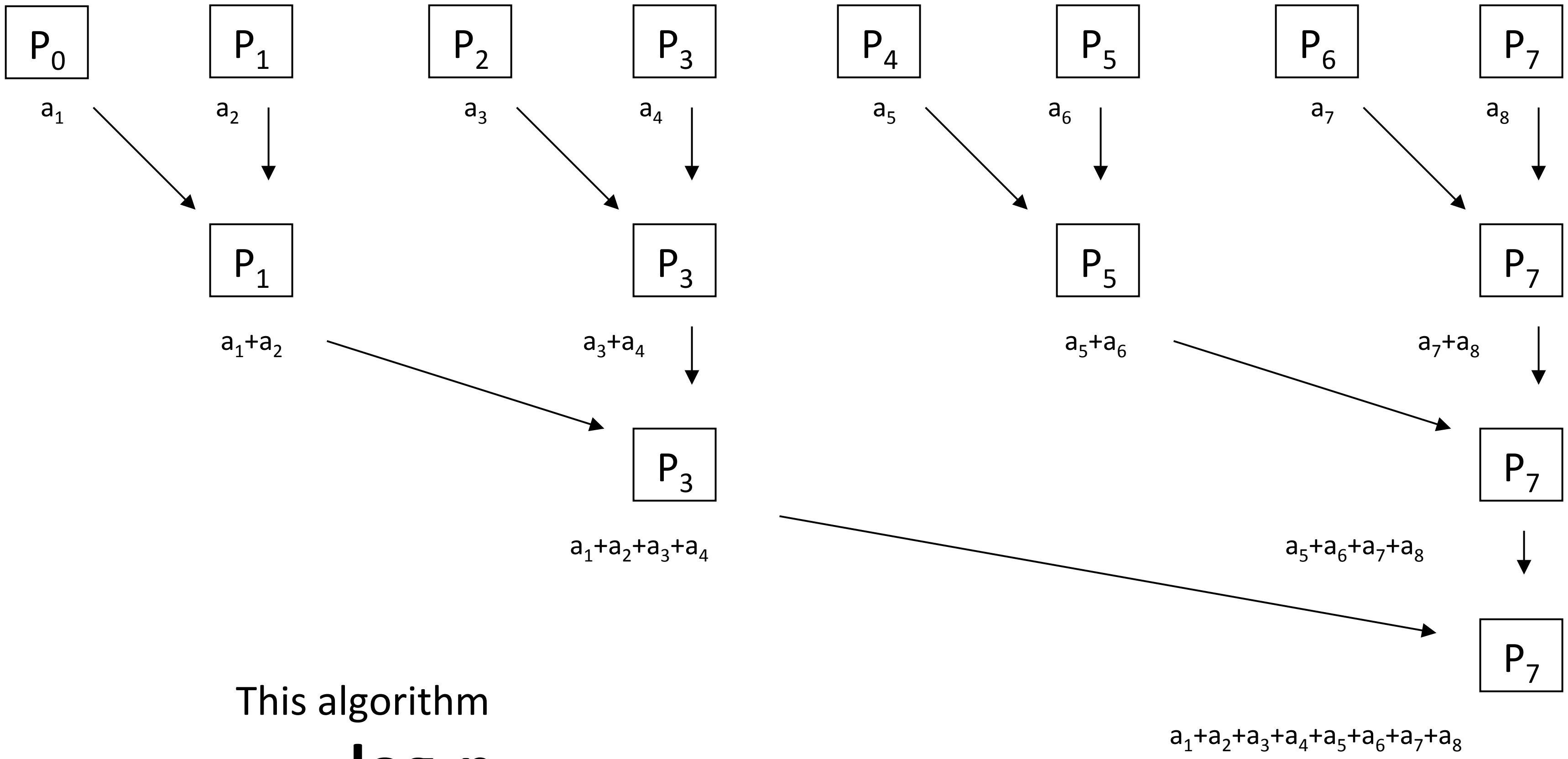
A Simple strategy



This algorithm

complete in **n** steps

Binary Tree



This algorithm

complete in $\mathbf{\log_2 n}$ steps

Binary Tree

- Finding the right partner:

	Sender	Receiver
Step 1	`MOD(myid,2)=0`	`MOD(myid,2)=1`
Step 2	`MOD(myid,4)=1`	`MOD(myid,4)=3`
Step 3	`MOD(myid,8)=3`	`MOD(myid,8)=7`
…		
Step n	`MOD(myid,2**n)=`	`MOD(myid,2**n)=`
	`2**(n-1)-1`	`2**n-1`

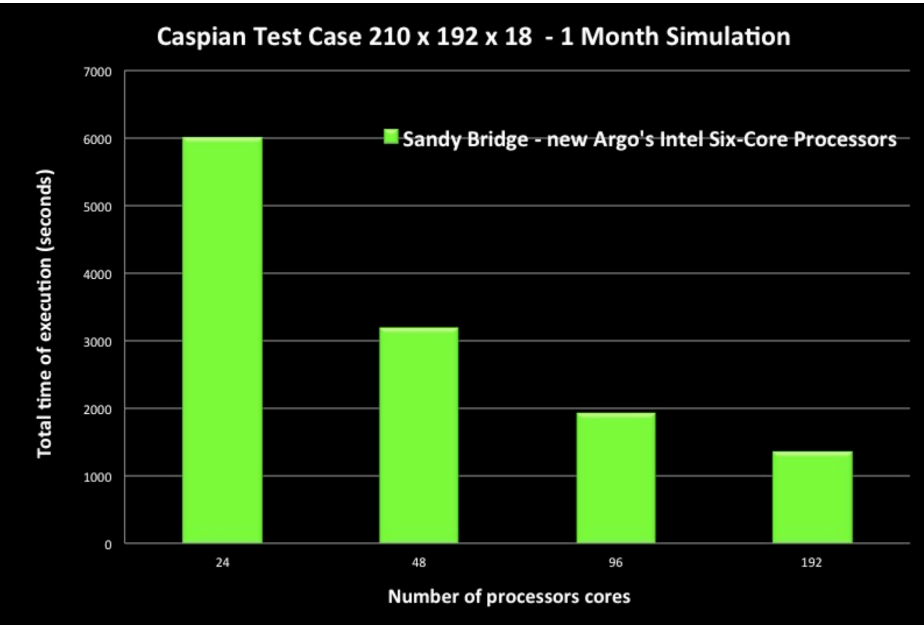
- `myid:` processor index

How do we evaluate the improvement?

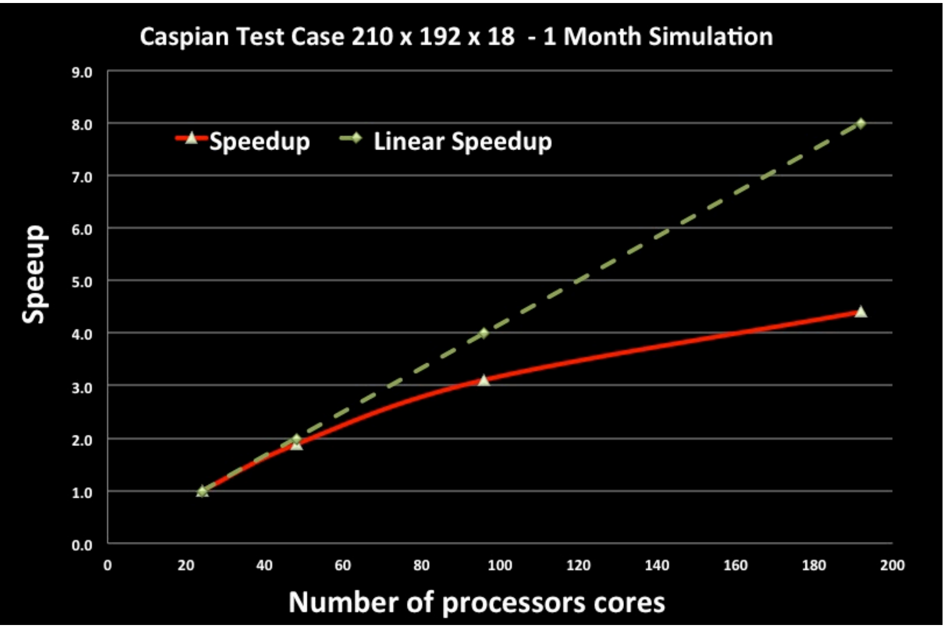
- We want estimate the amount of the introduced overhead => $T_o = n_{pes} T_P - T_S$
- But to quantify the improvement we use the term **Speedup**:

$$S_P = \frac{T_S}{T_P}$$

Speedup



Caspian Test Case 210 x 192 x 18 - 1 Month Simulation



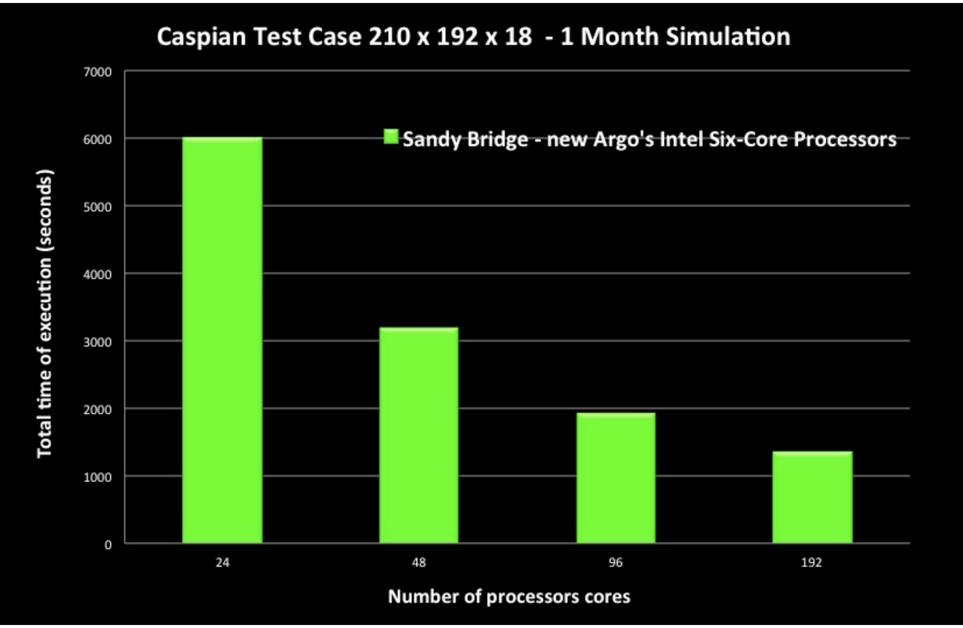
Caspian Test Case 210 x 192 x 18 - 1 Month Simulation

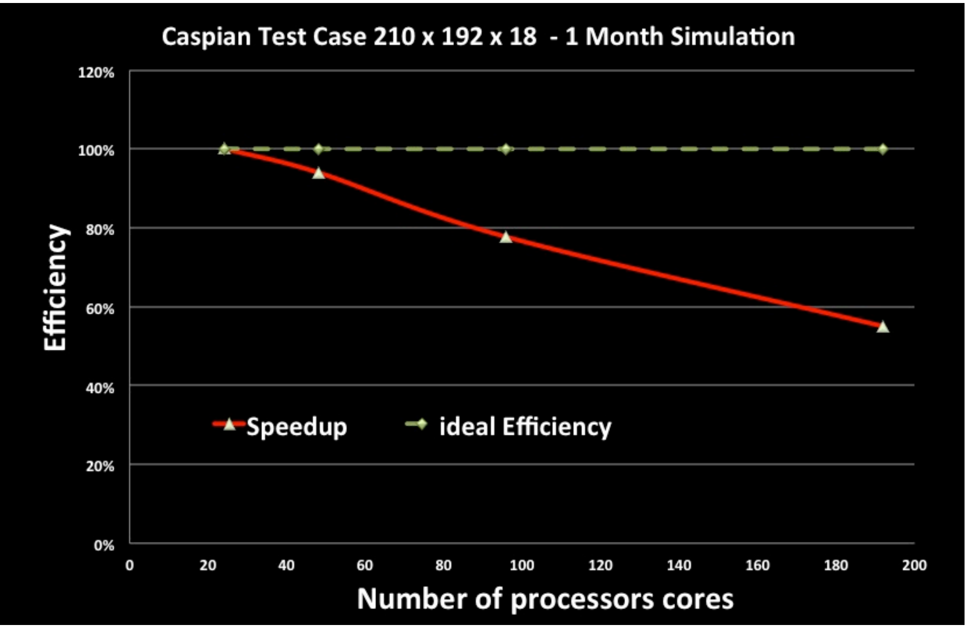
Efficiency

- Only embarrassing parallel algorithm can obtain an ideal Speedup
- The **Efficiency** is a measure of the fraction of time for which a processing element is usefully employed:

$$E_P = \frac{S_P}{p}$$

Efficiency


Caspian Test Case 210 x 192 x 18 - 1 Month Simulation
Total time of execution (seconds)
7000
6000
5000
4000
3000
2000
1000
0
Sandy Bridge - new Argo's Intel Six-Core Processors
24
48
96
192
Number of processors cores


Caspian Test Case 210 x 192 x 18 - 1 Month Simulation
Efficiency
120%
100%
80%
60%
40%
20%
0%
Speedup
ideal Efficiency
0
20
40
60
80
100
120
140
160
180
200
Number of processors cores

Thanks for your attention!!