An introduction to parallel programming

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Definitions

- Parallel computing
  - Partition computation across different compute engines

- Distributed computing
  - Paritition computation across different machines

Same principle, more general

Outline

- Introduction to "traditional" programming
  - Writing code
  - Operating systems
  - …
- Why do we need parallel programming?
  - Focus on programming shared memory
- Different ways of parallel programming
  - PThreads
  - OpenMP
  - MPI?
  - GPU/accelerators programming

As a side…

- A bit of computer architecture
  - We will understand why…
  - Focus on shared memory systems
- A bit of algorithms
  - We will understand why…
- A bit of performance analysis
  - Which is our ultimate goal!
  - Being able to identify bottlenecks

Programming basics

Take-aways

- Programming basics
  - Variables
  - Functions
  - Loops
- Programming stacks
  - BSP
  - Operating systems
  - Runtimes
- Computer architectures
  - Computing domains
  - Single processor/multiple processors
  - From single- to multi- to many- core

Why do we need parallel computing?

Increase performance of our machines

› Scale-up

- Solve a "bigger" problem in the same time

› Scale-out

- Solve the same problem in less time

Yes but..

- Why (highly) parallel machines…

- …and not faster single-core machines?

The answer #1 - Money

The answer #2 – the "hot" one

Moore's law

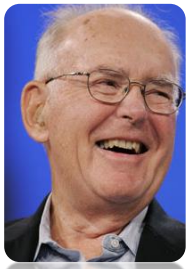
› "The number of transistors that we can pack in a given die area doubles every 18 months"

Dennard's scaling

› "performance per watt of computing is growing exponentially at roughly the same rate"

The answer #2 – the "hot" one

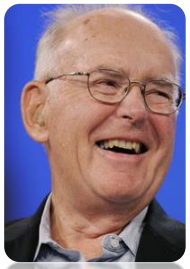
- SoC design paradigm



- Gordon Moore
  - His law is still valid, but…

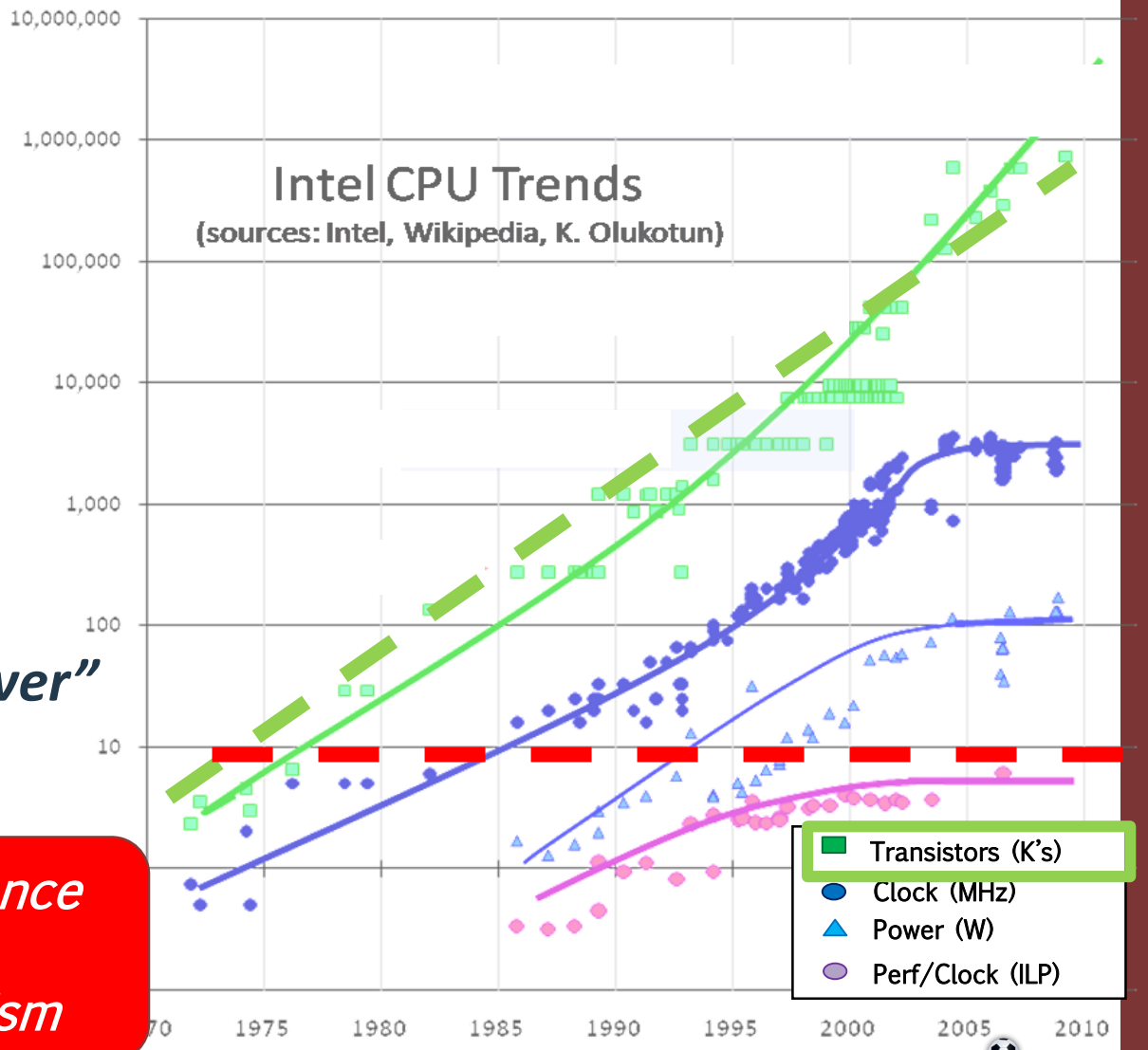
The answer #2 – the "hot" one

- SoC design paradigm

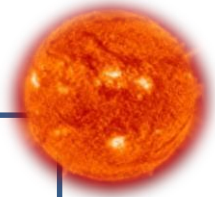


- Gordon Moore
  - His law is still valid, but…
- ***"The free lunch is over"***
  - **Herb Sutter, *2005***

Performance → parallelism



In other words…



Surface of the sun

Rocket nozzle

Nuclear Reactor

Projection

Modern computers

First PCs

The explosion of web

Summer temperature

1970 1980 1990 2000 2010 2020

Hot plate

Instead of going faster..

- ..(go faster but through) parallelism!

Problem #1

- New computer architectures
- At least, three architectural templates

Problem #2

- Need to efficiently program them
- HPC already has this problem!

The problem

- Programmers must know a bit of the architecture!
- To make parallelization effective
- "Let's run this on a GPU. It certainly goes faster" (cit.)

The Big problem

- Effectively programming in parallel is difficult

Brian Kernighan (1942-)
- Researcher, theory of informatics
- Co-authored UNIX and AWK
- Wrote "The C Programming Language" book

"Everyone knows that debugging is twice as hard as writing a program in the first place.

So if you're as clever as you can be when you write it, how will you ever debug it?"

I am *really* sorry guys..

- I will give you code…
  - ..but first I need to give you some maths…
    - …and then, some architectual principles

Amdahl's Law

Amdahl's law

- A sequential program that takes 100 sec to exec
- Only 95% can run in parallel (it's a lot)
- And.. you are an extremely good programmer, and you have a machine with 1billion cores, so that part takes 0 sec
- So,

$$T_{par} = 100_{sec} - 95_{sec} = 5_{sec}$$

$$Speedup = \frac{100_{sec}}{5_{sec}} = 20x$$

…20x, on one billion cores!!!

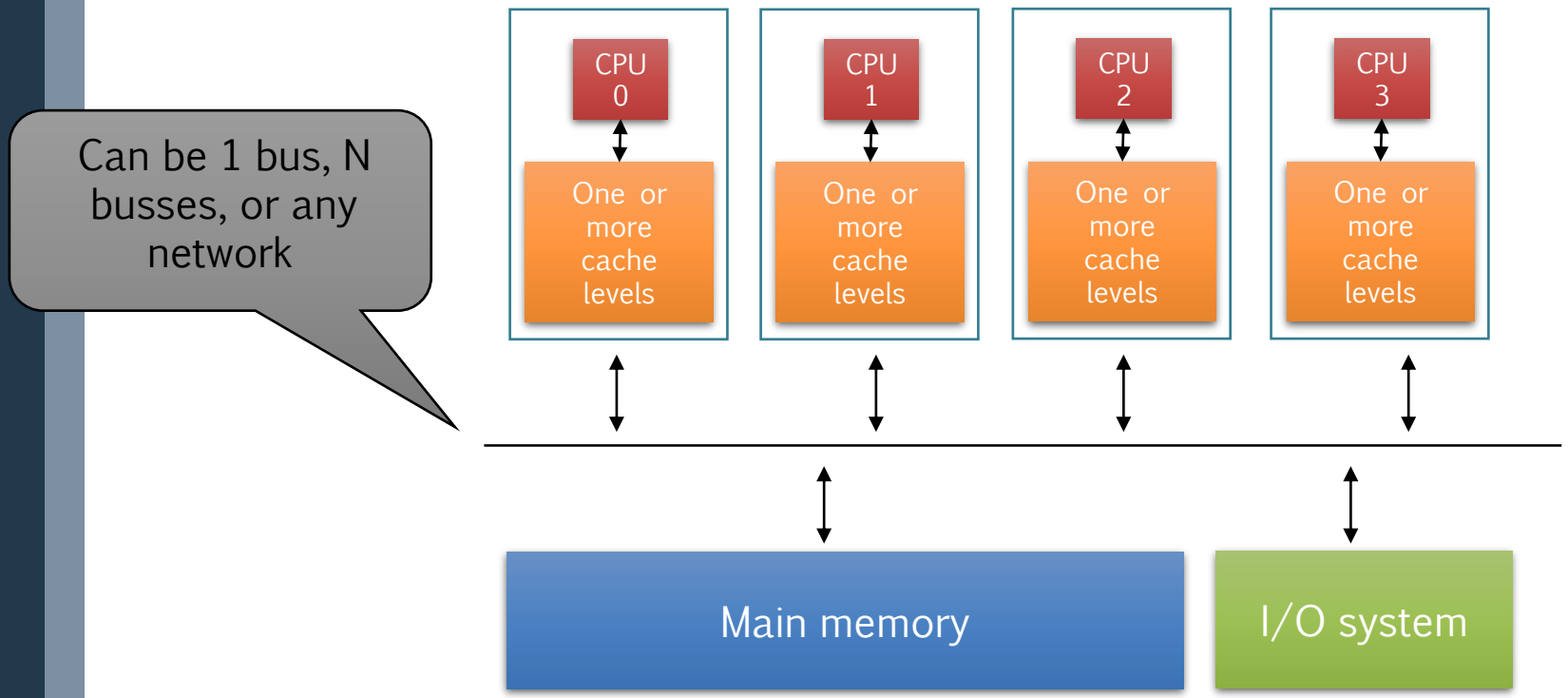
Computer architecture

Step-by-step

1. "Traditional" multi-cores
   - Typically, shared-memory
   - Max 8-16 cores
   - This laptop
2. Many-cores
   - GPUs but not only
   - Heterogeneous architectures
3. More advanced stuff
   - Field-programmable Gate Arrays
   - Neural Networks

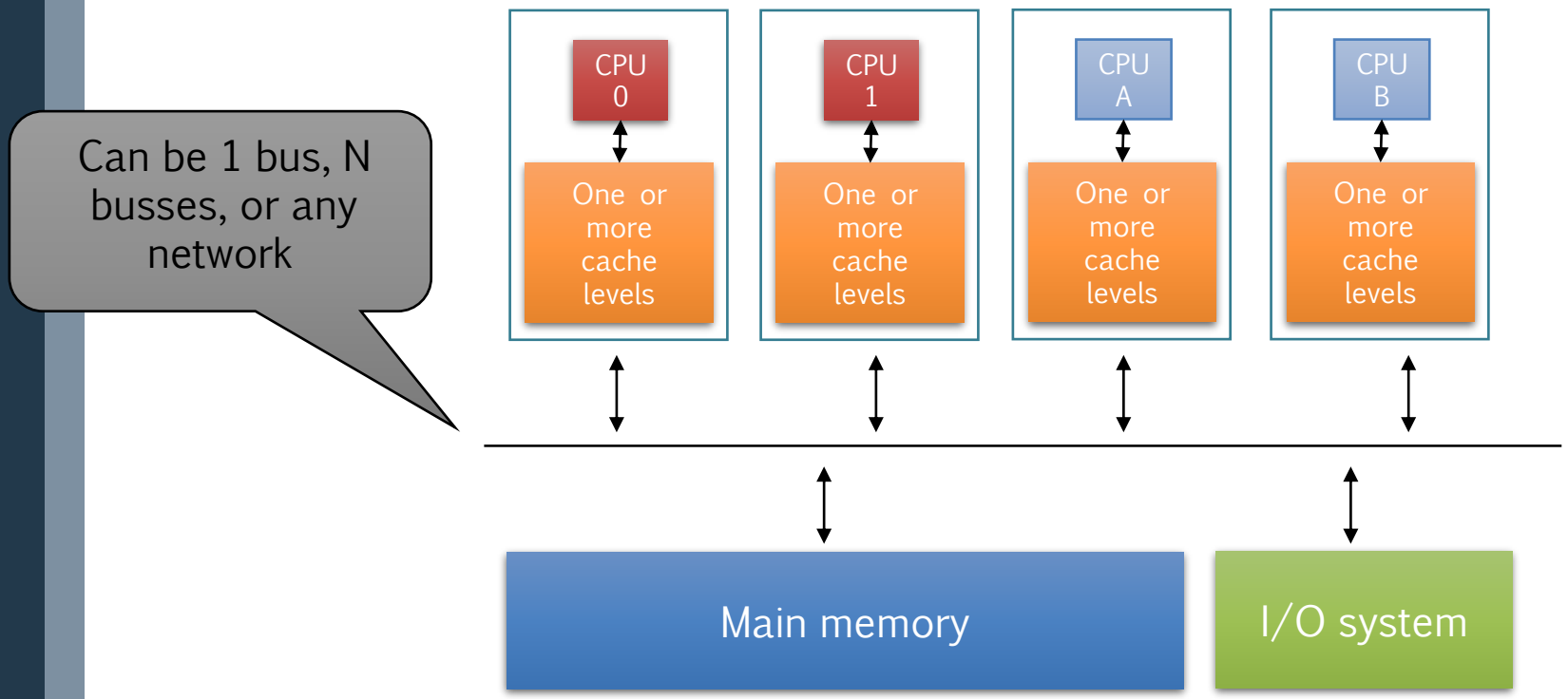
Symmetric multi-processing

- Memory: centralized with bus interconnect, I/O
- Typically, multi-core (sub)systems
  - Examples: Sun Enterprise 6000, SGI Challenge, Intel (this laptop)



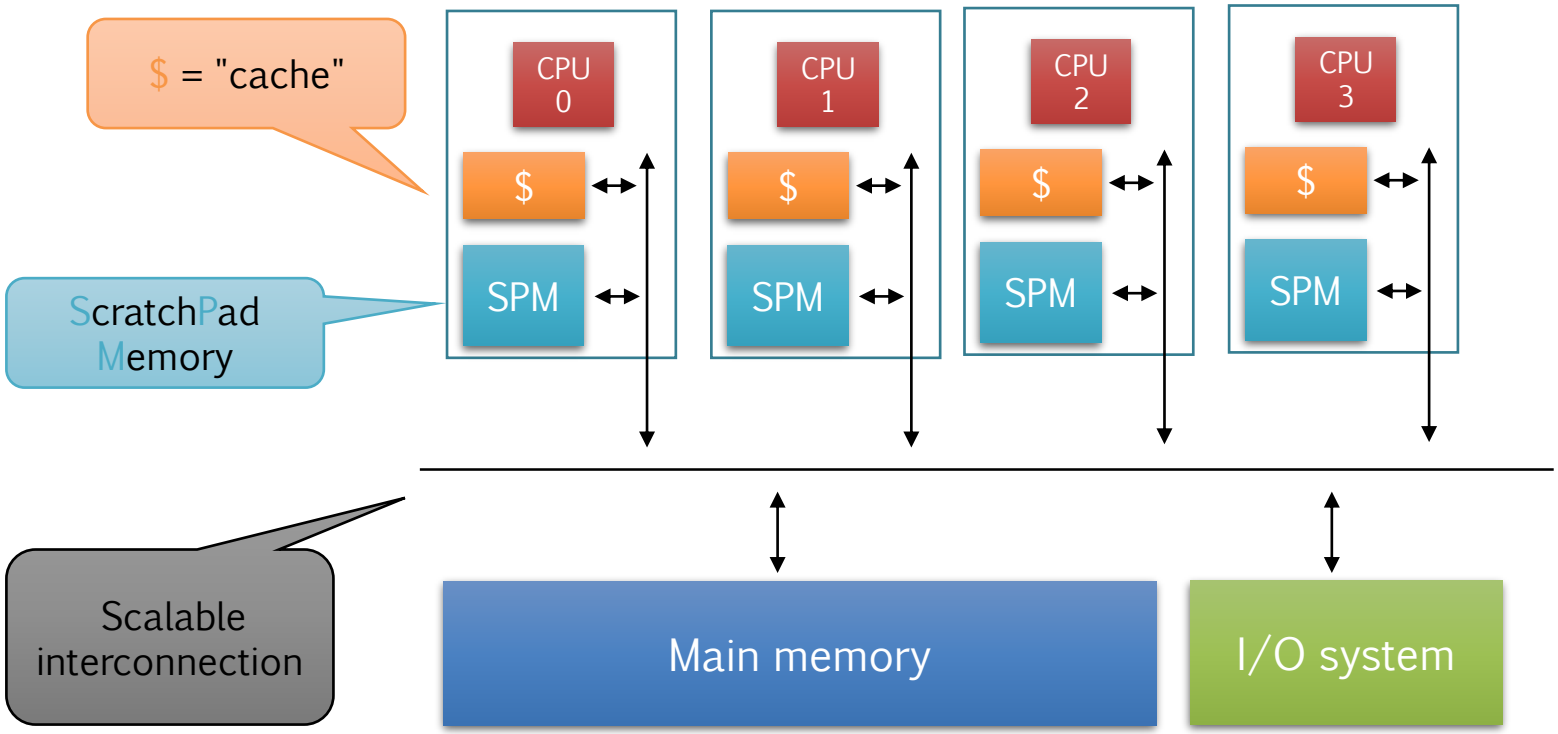
Asymmetric multi-processing

- Memory: centralized with uniform access time (UMA) and bus interconnect, I/O
- Typically, multi-core (sub)systems
  - Examples: ARM Big.LITTLE, NVIDIA Tegra X2 (Drive PX)



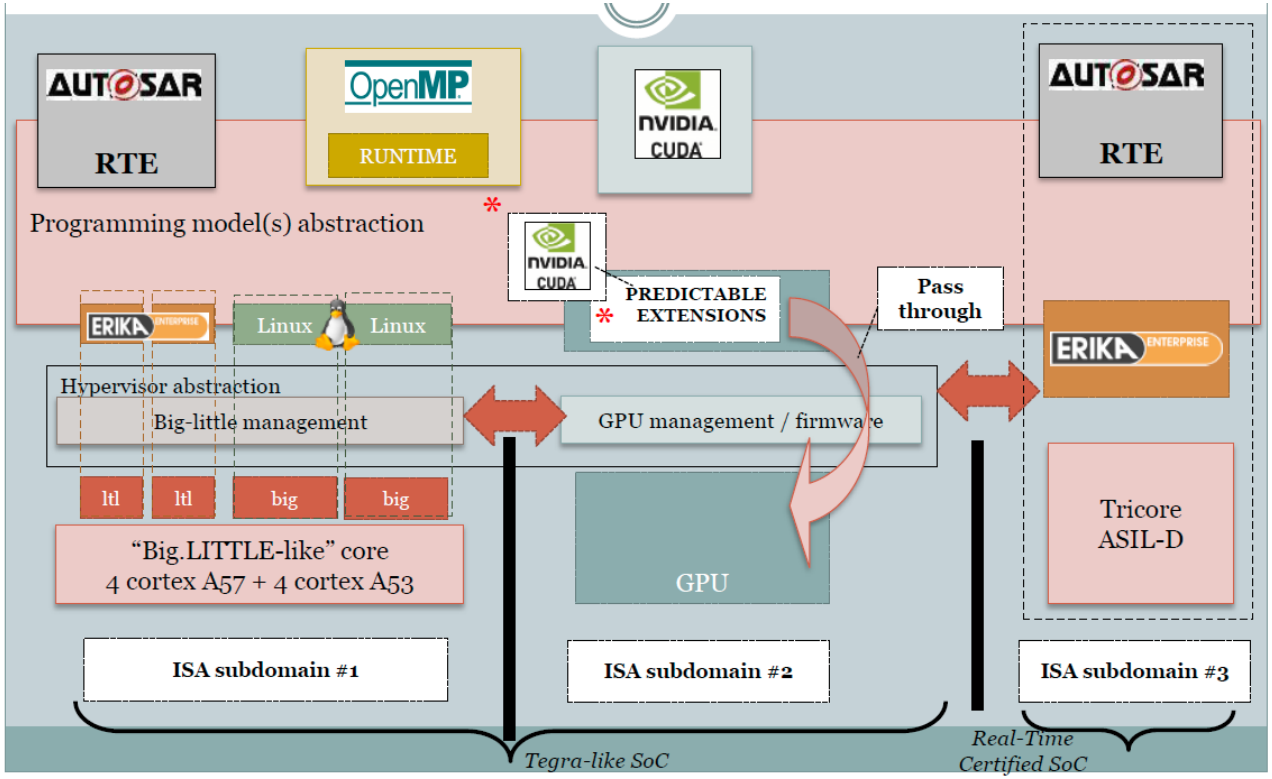
SMP – distributed shared memory

- Non-Uniform Access Time - NUMA
- Scalable interconnect
  - Typically, many cores
  - Examples: embedded accelerators, GPUs



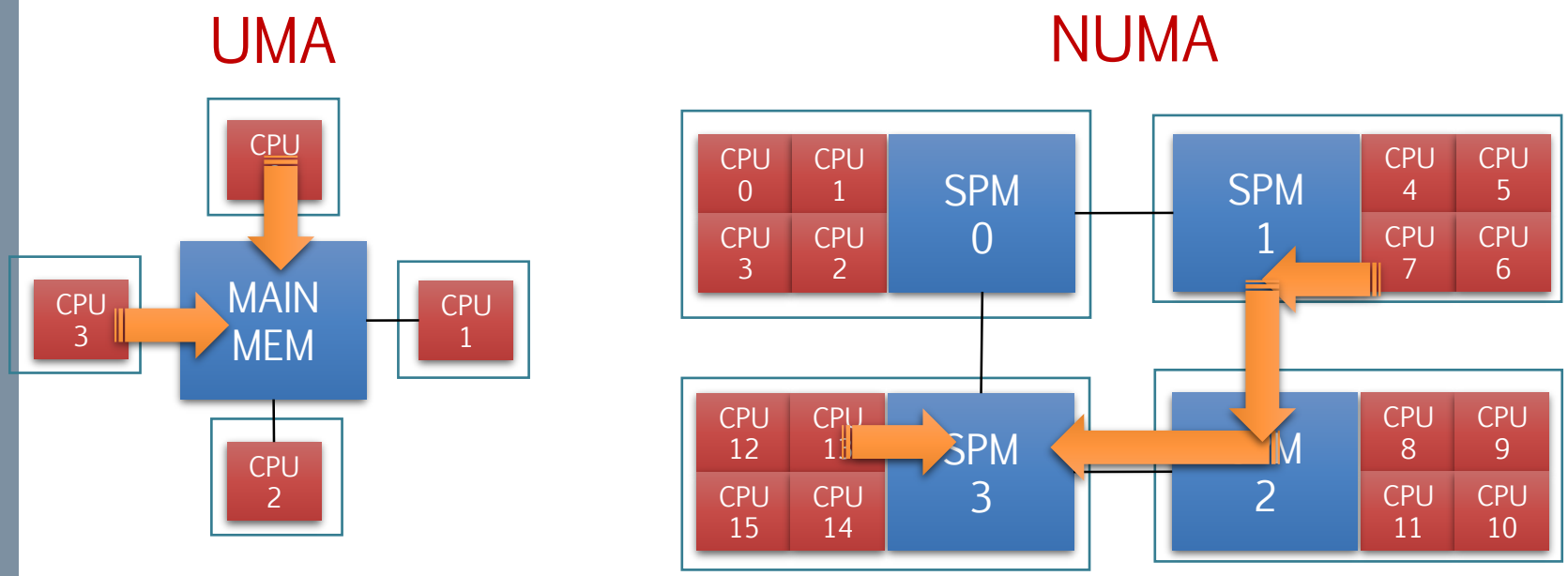
Go complex: NVIDIA's Tegra

- Complex heterogeneous system
  - 3 ISAs
  - 2 subdomains
  - Shmem between Big.SUPER host and GP-GPU



UMA vs. NUMA

- Shared mem: every thread can access every memory item
  - (Not considering security issues…)
- Uniform Memory Access (UMA) vs Non-Uniform Memory Access (NUMA)
  - Different access time for accessing different memory spaces



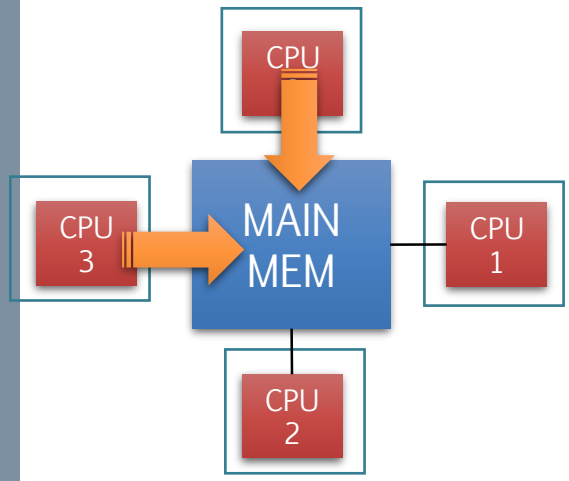
UMA vs. NUMA

- Shar
  - (
- Unif
  - D

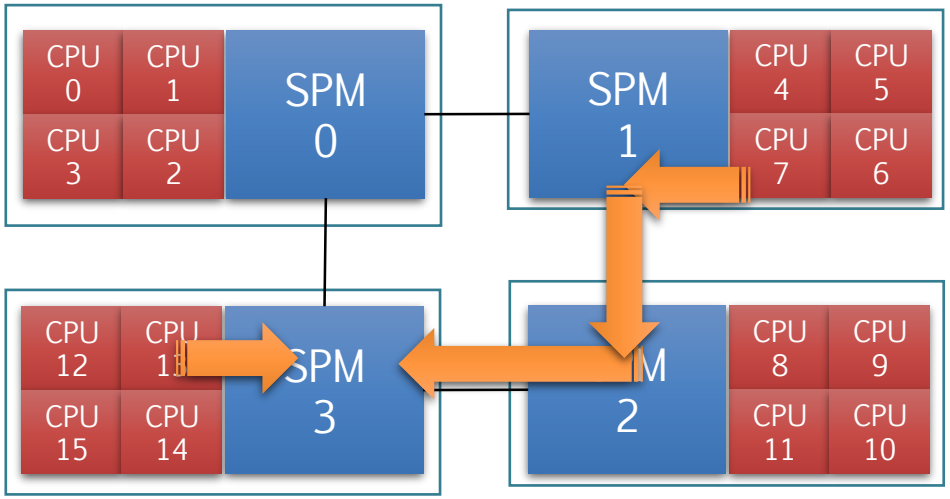
(NUMA)

	MEM0	MEM1	MEM2	MEM3
CPU0…3	0 clock	10 clock	20 clock	10 clock
CPU4…7	10 clock	0 clock	10 clock	20 clock
CPU8…11	20 clock	10 clock	0 clock	10 clock
CPU12..15	10 clock	20 clock	10 clock	00 clock

UMA



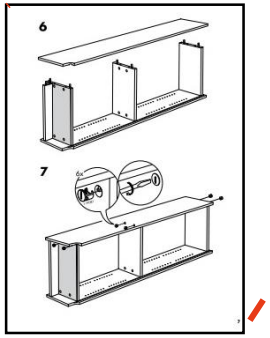
NUMA

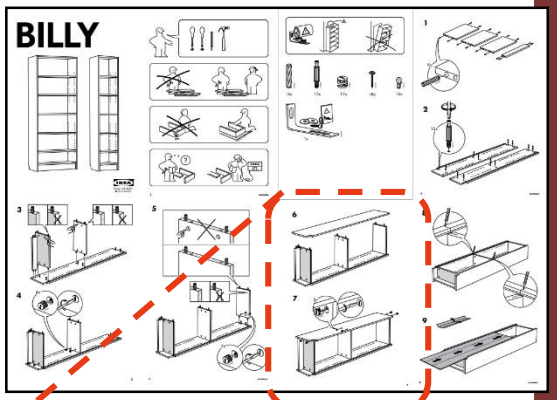


Some definitions

What is…

- ..a core?
  - An electronic circuit to execute instruction (=> programs)
- …a program?
  - The implementation of an algorithm
- …a process?
  - A program that is executing
- …a thread?
  - A unit of execution (of a process)
- ..a task?
  - A unit of work (of a program)





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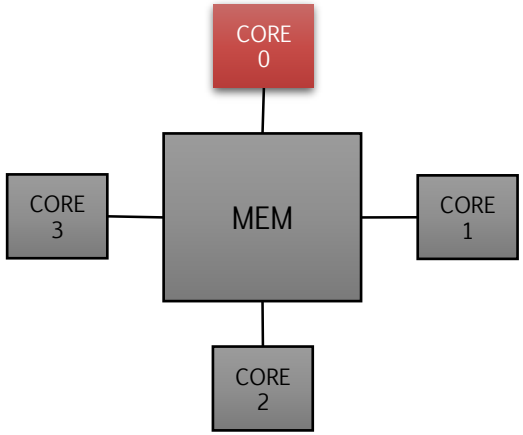

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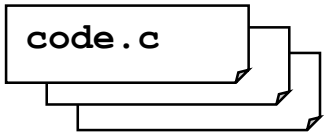

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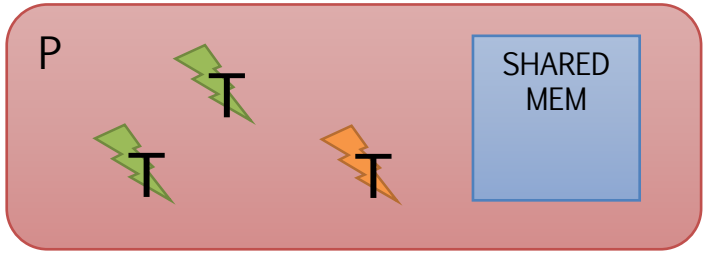
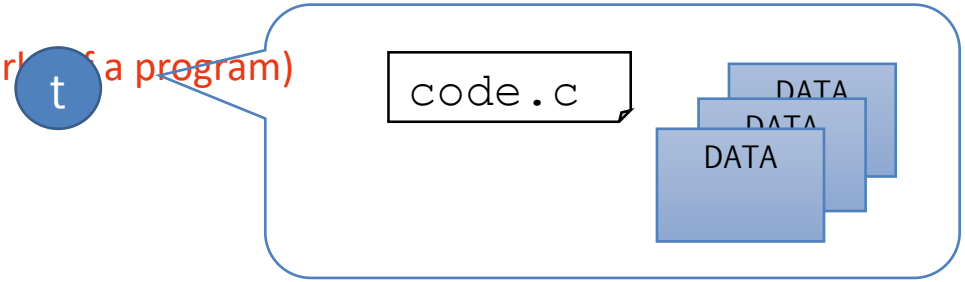
  - A program that is executing



- …a thread?
  - A unit of execution (of a process)

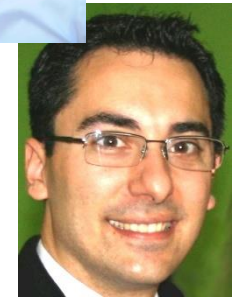
- ..a task?
  - A unit of work (of a program)



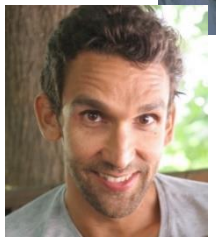
What is a task?

P-SOCRATES

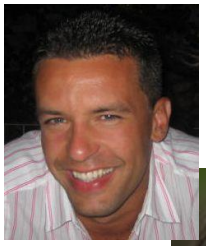
OpenMP task



Operating System task



Real-time task



Symmetric multi-processing

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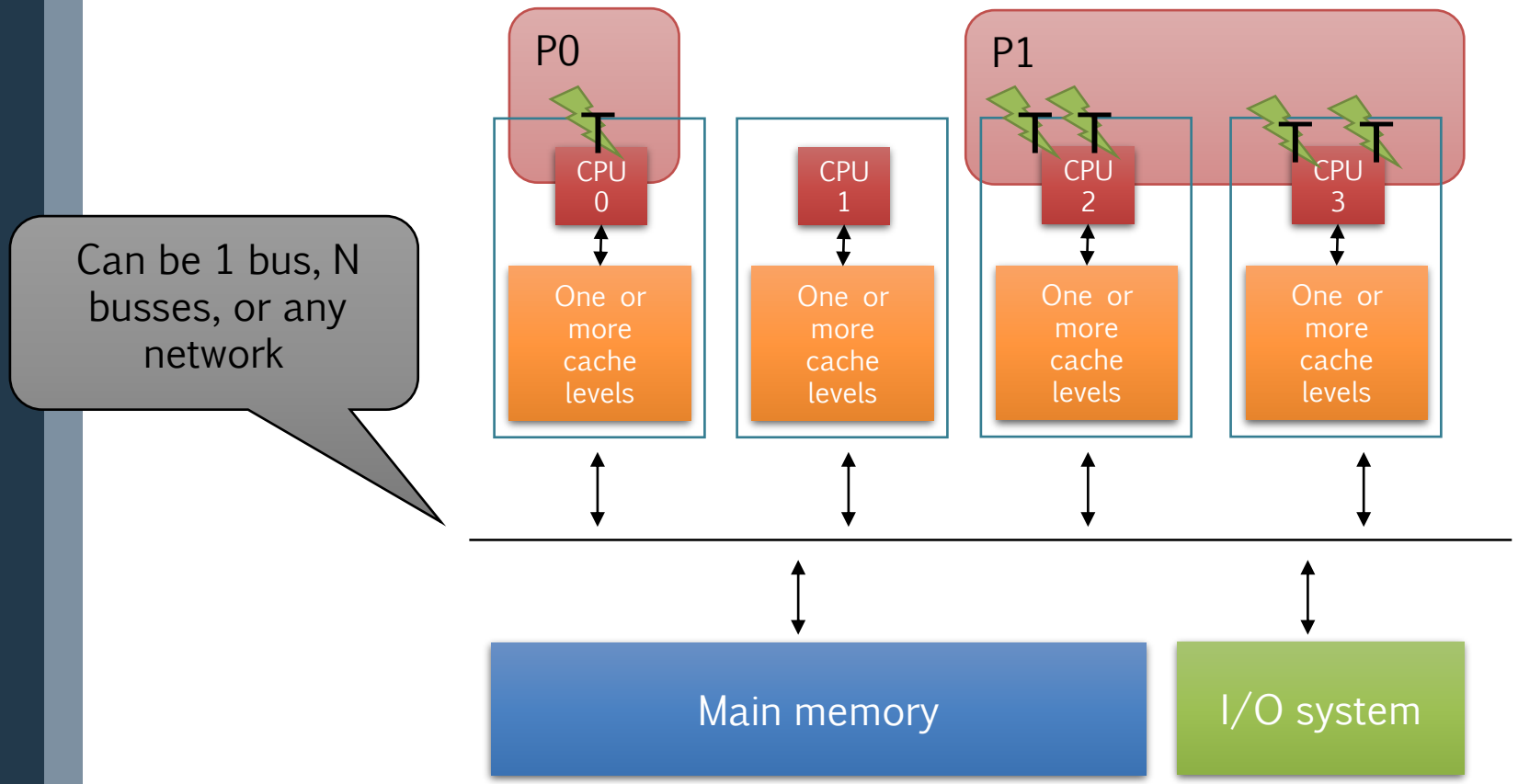
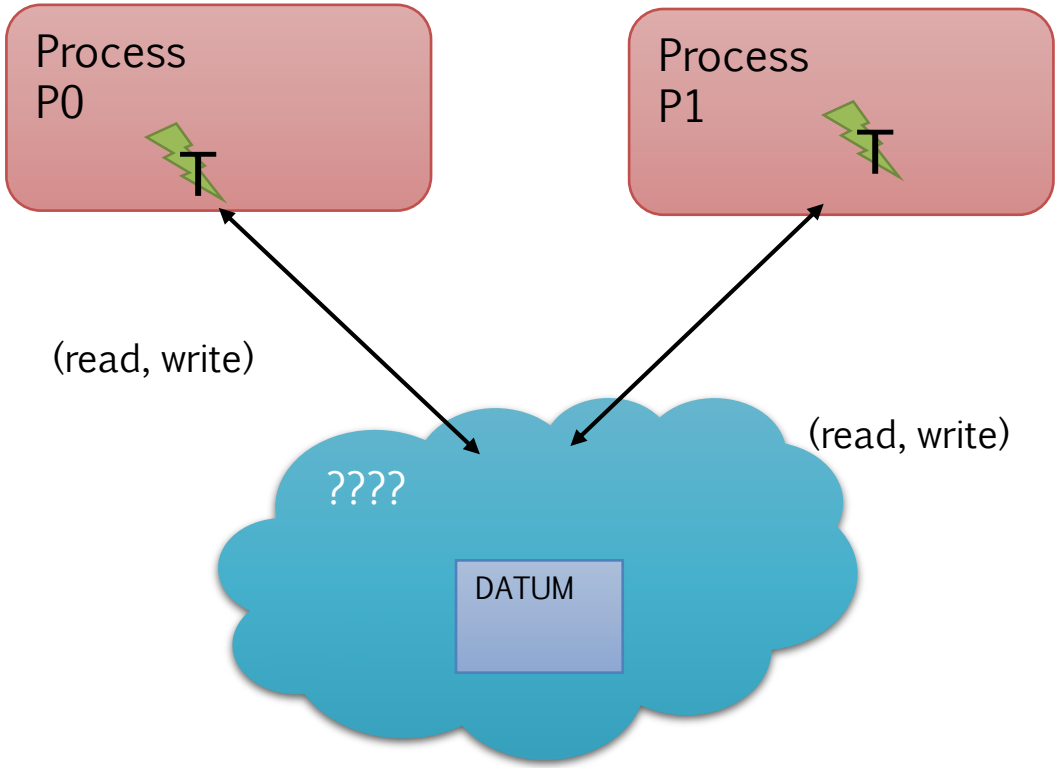
  - Examples: Sun Enterprise 6000, SGI Challenge, Intel (this laptop)



..start simple…

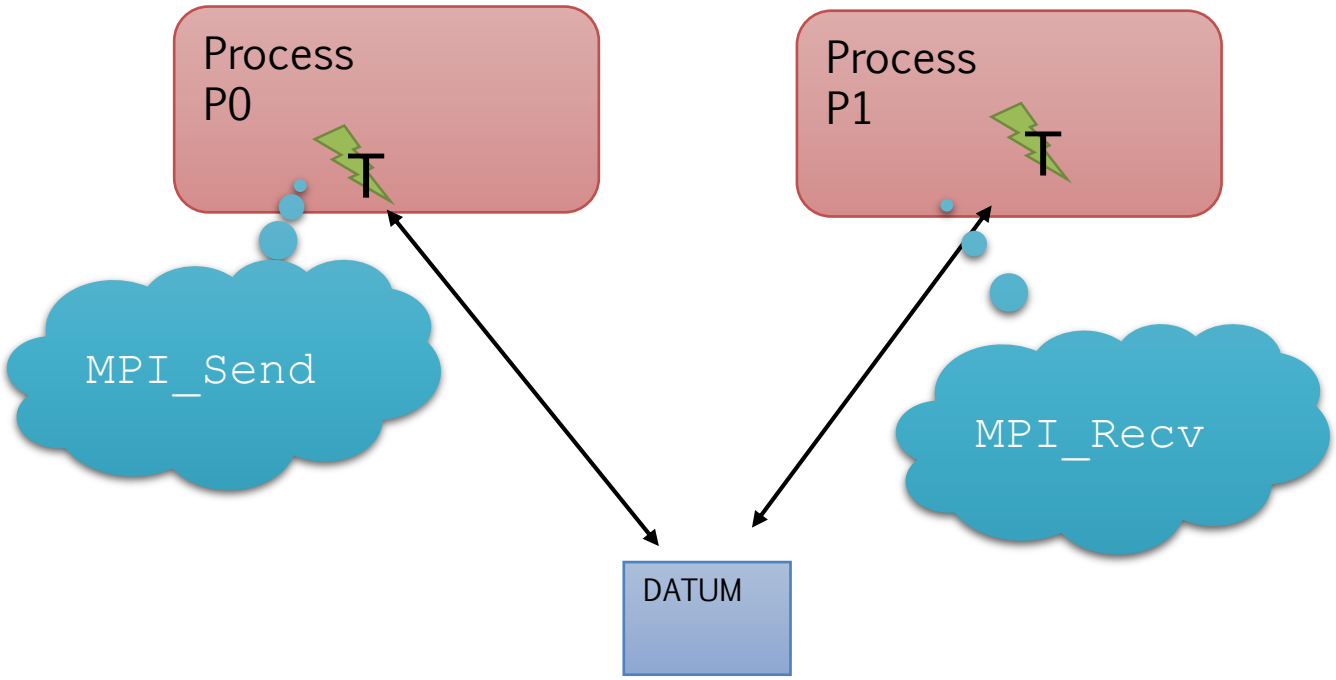
Something you're used to..

- Multiple processes
- That communicate via shared data



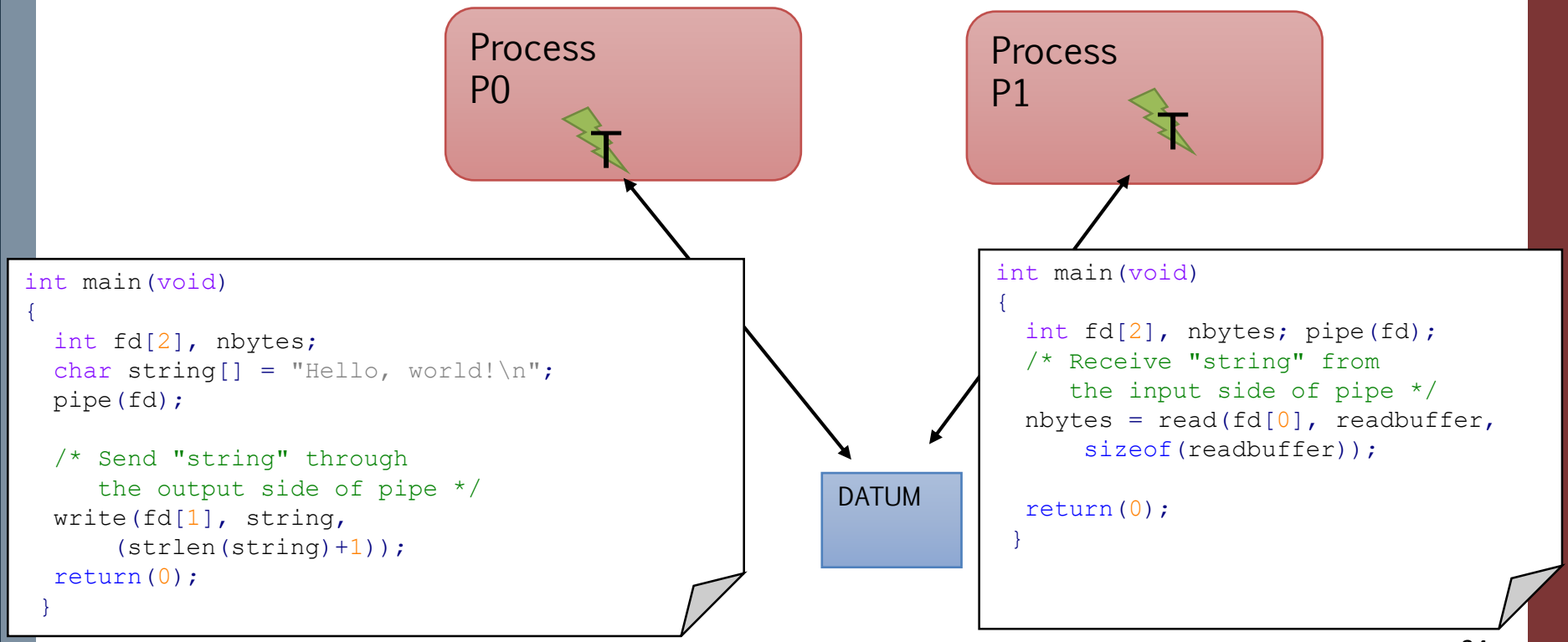
Howto #1 - MPI

- Multiple processes
- That communicate via shared data



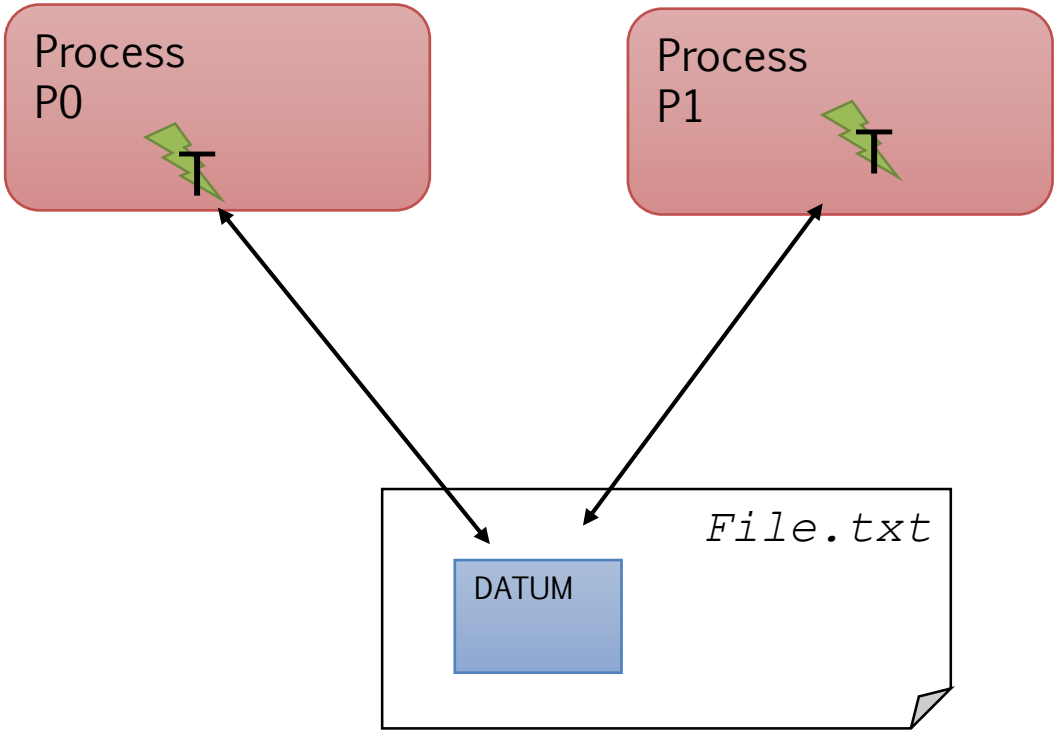
Howto #2 – UNIX pipes

- Multiple processes
- That communicate via shared data



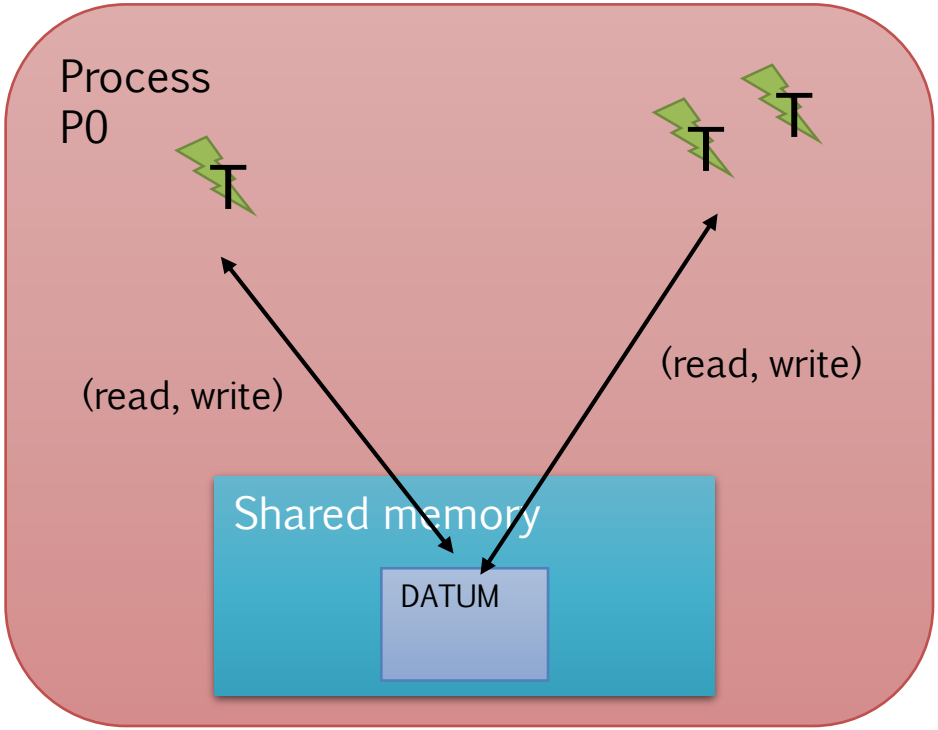
Howto #3 – Files

- Multiple processes
- That communicate via shared data



Shared memory

- Coherence problem
  - Memory consistency issue
  - Data races
- Can share data ptrs
  - Ease-to-use



References

- "Calcolo parallelo" website
  - http://hipert.unimore.it/people/paolob/pub/PhD/index.html
- My contacts
  - paolo.burgio@unimore.it
  - http://hipert.mat.unimore.it/people/paolob/
- Useful links
- A "small blog"
  - http://www.google.com