LUND UNIVERSITY

HPC2N, UmU

Parallel programming
Shared and distributed Memory

Joachim Hein
LUNARC & Centre of Mathematical Sciences
Lund University

Pedro Ojeda May
HPC2N
Umeå University

LUND UNIVERSITY

INTRODUCTION TO PARALLEL COMPUTING

Lund University

Why parallel programming?

- Improve computational speed
  - Get faster time to solution
  - Larger, hopefully more realistic problem
- Divide problem into subtasks
  - Assign subtasks to different CPUs → parallel computing
- Parallel computing is presently the **only** game in town to get more performance
  - CPUs do not get faster (stuck around 3 GHz for years)

Example

- Calculate large sum:

$$\sum_{n=1}^{40000} a_n$$

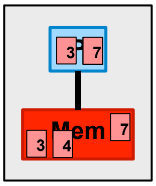
- Split into four sums, use a different processor for each:

$$\sum_{n=1}^{10000} a_n \quad \sum_{n=10001}^{20000} a_n \quad \sum_{n=20001}^{30000} a_n \quad \sum_{n=30001}^{40000} a_n$$

- In the end: four partial results and need to make into one!

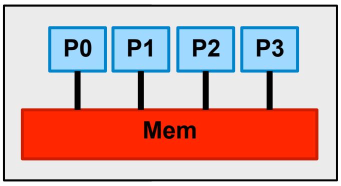
Serial programming

- We want to do a long calculation
- Pencil & Paper to slow ☹
- Take a computer
  - Write a program in C, Fortran, ...
  - Run the program
- What happens when the program runs?
  - Processor reads data from memory
  - Processes these data
  - Writes result back to memory
  - Write final result to disk
- What can we do if that is still too slow ???



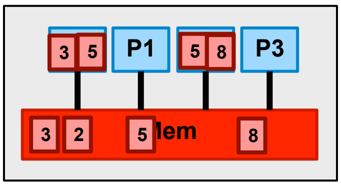
Parallel programming

- Take more than one processor
- Partition the entire calculation into independent parts
- Assign one or more of these parts to each processor
- Should be faster now!
- But normally the parts are **not** fully independent
- Dealing with these data dependencies is a key challenge in parallel computing



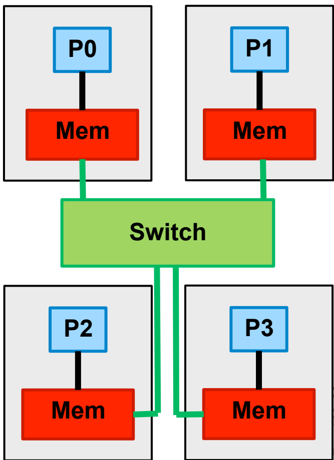
Shared Memory Architecture

- Several processing elements manipulate the same, shared memory space
- Easy to move data between processors
  - Write result to shared memory
  - Read on different processor
- Care is needed regarding order:
  - P0 needs to write before P2 can read
- Read/write to shared memory has typically higher cost than manipulating registers/cache



Distributed memory machine

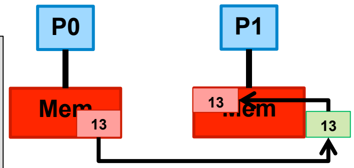
- Several independent computers (typically referred to as: nodes)
- With interconnect network
- Separate program, called *task*, on each processor
- Each has its private data
- Typically explicit message passing
- Processes:
  - Send data into the network
  - Receive data from the network
  - They can not just use it



Double sided point-to-point communication

- Most basic form of communication in message passing:

Program on P0:	Program on P1:
`a = 13`	
`send(a,1)`	
	`recv(b,0)`
	`c = c + b`



Discussion

MESSAGE PASSING
SHARED MEMORY

Message passing

- Programmer explicitly distributes and exchanges data
- Data transfer by "**value**" – explicit data copy
- Entire program typically needs updating in "one go"
- Suitable for large variety of architectures
  - Includes shared memory
  - Required for largest super-computers
- Work by programmer typically benefits performance
  - Good memory locality (Cache & CC-NUMA)
- Access to vast amounts of memory (TB of RAM)
- Typical problems encountered:
  - Segmentation faults
  - Dead lock

Lund University

Shared memory programming

- Typically less demanding on the programmer
- Possible to work "incremental"
- Allows for more algorithms to be implemented
  - Replicated data situations
  - Unstructured data distributions
- Requires shared memory architecture
  - e.g.: Multicore, SMP, CC-Numa
- Limited in core count
- Typical problems encountered:
  - Data races ➔ wrong results, often non-deterministic
  - Memory locality problems ➔ bad performance

Lund University

Hybrid: Message passing & shared memory

- All contemporary distributed memory machines use shared memory machines as basics building blocks (nodes):
  - Can ignore: use message passing between **and** within the nodes
  - Can use shared memory techniques inside the node and use message passing
- Danger of picking up the disadvantages of both:
  - Complexity of message passing programming
  - Performance penalty of shared memory programming
- Advantages in situations with:
  - Large memory required by each message passing task
  - Expensive/complex data redistributions
  - Can help with network congestion and latency

A simple performance model

AMDAHLS LAW
OF PARALLEL COMPUTING

Parallel speed-up and efficiency

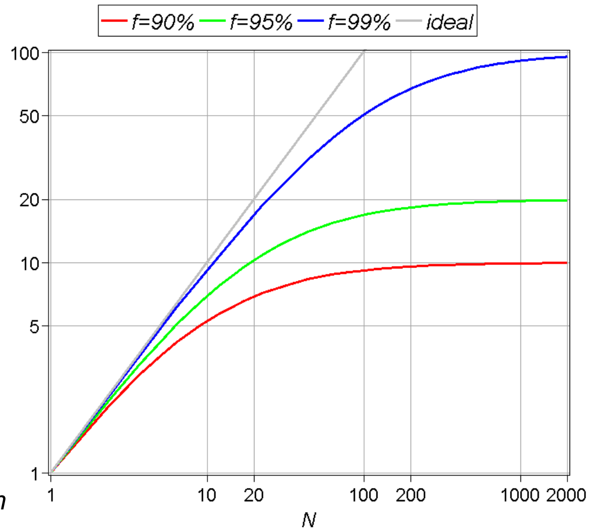
- Faster time to solution is the key aim of parallel computing
  t_1 : time to solution using 1 processor
  t_N : time to solution using N processors
- Parallel speed-up: $$S(N) = \frac{t_1}{t_N}$$
- Parallel efficiency: $$E(N) = \frac{t_1}{N \cdot t_N}$$
- Naïve performance expectation: $E(N) = 100\%$

Simple performance model: Amdahl's law for parallel programs

- Consider a program takes time t_1 in serial (on 1 processor)
- A fraction $f < 1$ can be parallelised efficiently on N processors
  - Time spend on the parallel part: $f\, t_1 / N$
  - Time spend on the serial, remaining part: $(1-f)\, t_1$
  - Total time on parallel code: $t_N = (1-f + f/N) t_1$
- Speed up: $$\frac{t_1}{t_N} = \frac{1}{1 - f\left(1 - \frac{1}{N}\right)}$$

Amdahl's law

- Speed-up limited to: $1/(1 - f)$
- 50% of max speed-up: $N_{50} \approx 1/(1 - f)$
- Not much point in running beyond $\approx\mathbf{2}N_{50}$
- ***Fall-out:*** *Serial parts in computational kernel can not be tolerated*



Summary

- Parallel computing offers faster time to solution
- Basic ideas behind
  - Shared memory programming
  - Message passing programming
  - Hybrid programming
- Discussed the impact of remaining serial parts

Lund University