An Introduction into Parallelization

Part I - Concepts, Terminology & Models

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Outline

1. Concepts and Terminology
   - Amdahl's Law
   - Granularity
   - Scalability
   - Complexity

2. Parallel Programming Models
   - Recap: Computer Architectures
   - Single-Instruction Multiple-Data (SIMD)
   - Shared memory without threads
   - Shared memory with Multithreading

Concepts and Terminology

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CPU/Processor/Core while technically nowadays each CPU/processor hosts more than one core, we use this terms interchangeably

Node A 'standalone' unit consisting of its own CPUs, memory (& storage).

Process/Task logically discrete section of computational work - typically a program or program-like set of instructions that is executed by a processor

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Massively Parallel Refers to the hardware that comprises a given parallel system - having many processing elements (the meaning of "many" keeps increasing)

Embarrassingly Parallel Solving many similar, but independent tasks simultaneously; little to no need for coordination between the tasks

Concepts and Terminology (cont.)

Wall(-clock) time "physical" time (i.e. time measured on a stopwatch)

Throughput amount of (sub)tasks/data processed per (wall) time unit

Latency (wall time) delay between invoking the operation and getting the response (e.g. finishing a task)

Observed speed-up ratio between wall time of serial and parallelized code

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CPU time time a process spent running on CPUs (with each used CPU adding to it)

Parallel overhead Additional amount of (CPU/wall) time/resources required to run parallelized code (e.g. start-up time and memory usage of framework, data comm., synchronization)

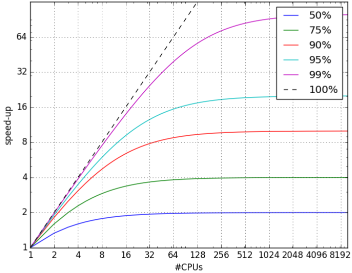
Concepts and Terminology - Amdahl's Law

- theoretical speedup in *latency* S_{latency} of execution of task with fixed workload:

Amdahl's law

$$S_{\text{latency}} = \frac{1}{(1-p) + \frac{p}{s}}$$

p is parallelizable fraction of code
s its speed-up



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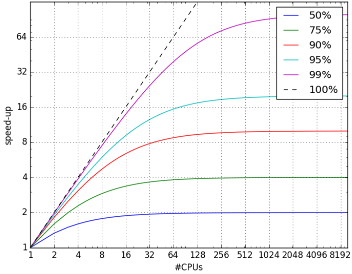
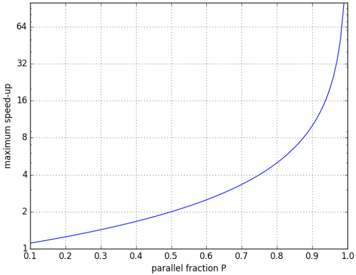
- From this follows

$$\lim_{s \to \infty} S_{\text{latency}} = \frac{1}{1-p}$$

i.e. never speeds up more than the inverse serial fraction of code





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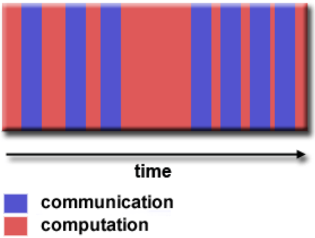

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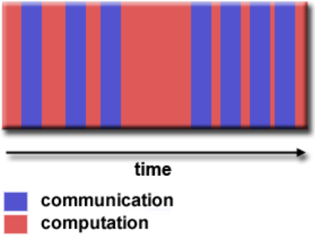

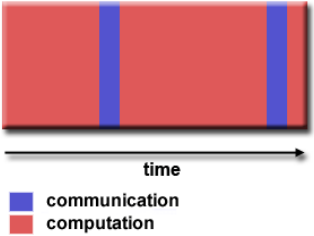

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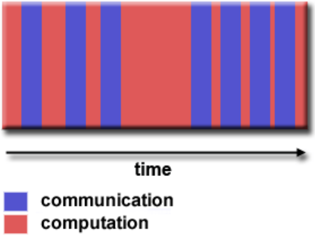
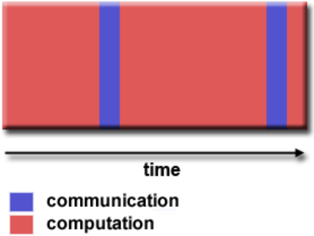
- best choice dependents on circumstances





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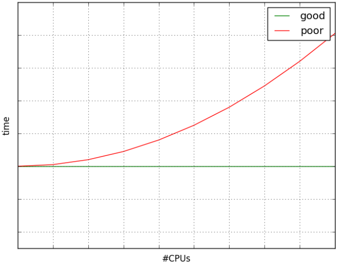

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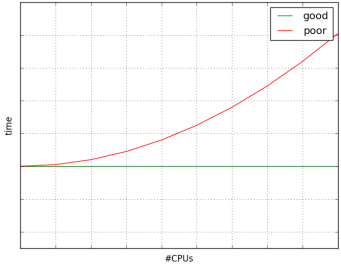

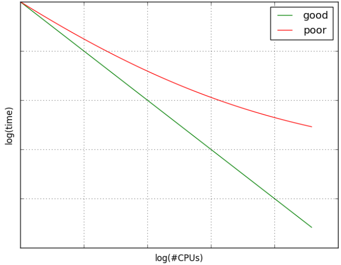

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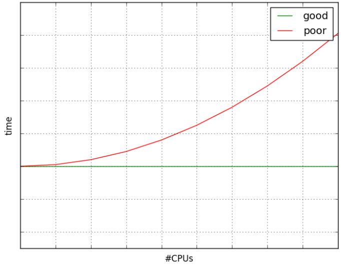
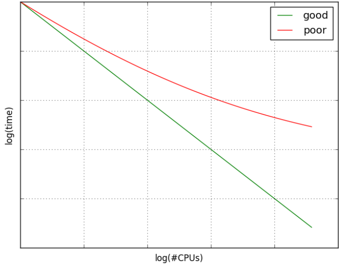


Factors affecting scalability:

- I/O bandwidth (for RAM, storage and communication)
- imperfect/impossible load balancing
- overhead on comm. (e.g. exchange of padding around domain)
- limitations of parallel support libraries / parallel overhead



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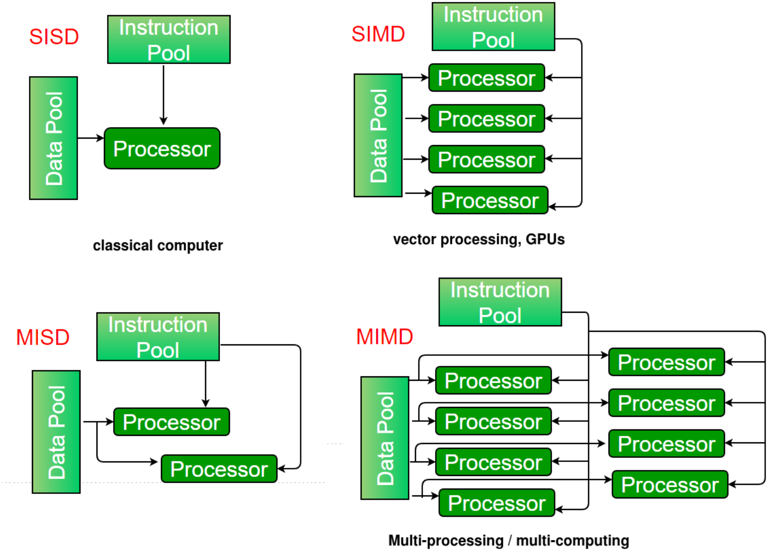
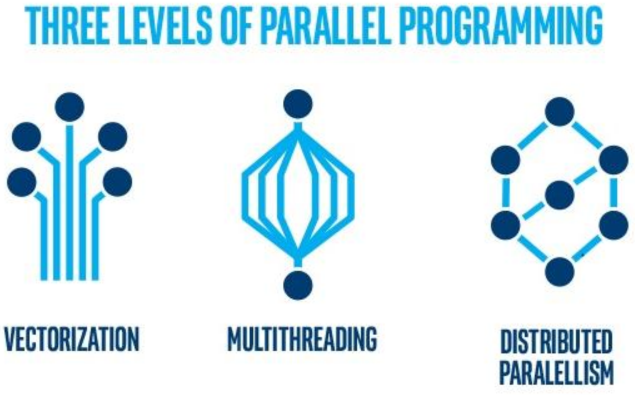
You have to find a trade-off between development time and runtime. Make sure the development of a speed-up does not cost you more time/resources than it saves you in the end!

Parallel Programming Models

Recap: Computer Architectures - Flynn's taxonomy

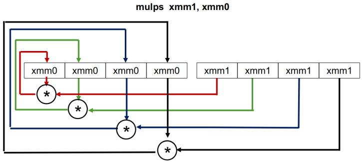


Parallel Programming Models - Overview



Recap: Processor - Supplementary instruction sets (SIMD/Vectorization)

Processors provide special hardware extensions to perform certain operations faster/more efficiently:



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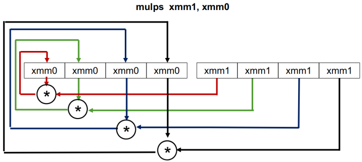

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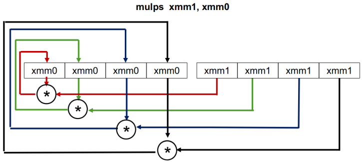

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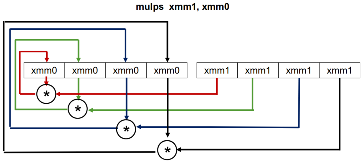

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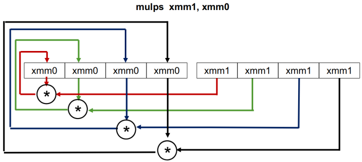

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What to consider when using these extensions:

- **users** try to compile code newest instruction set supported by the CPU you are planning to run on
- **coders** try to organize code in a way to make best use of SIMD

Parallel Programming Models - SIMD / Vectorization

Scalar version	Vectorized version

`int A[], B[], C[];`
`...`
`for(i=0; i<n; i++) {`
`  a = A[i];`
`  b = B[i];`
`  c = a+b;`
`  C[i] = c;`
`}`
	`int A[], B[], C[];`
	`...`
	`/* vectorized loop */`
	`for(i=0; i<n; i+=vf) {`
	`  va = A[i..i+vf[;`
	`  vb = B[i..i+vf[;`
	`  vc = padd(va, vb);`
	`  C[i..i+vf[ = vc;`
	`}`
	`/* epilogue */`
	`for( ; i<n; i++) {`
	`  /* remaining iterations */`
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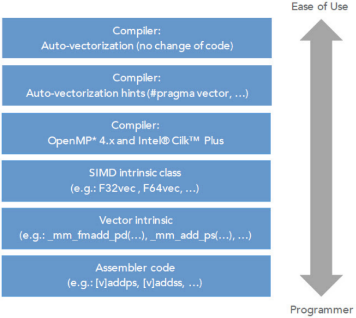

- various ways of using vectorization:
  - automatic optimization by compiler (-O2 and higher)
  - assisted auto-vectorization using special statements
  - explicit vectorization (cf. OpenMP SIMD, ASM)

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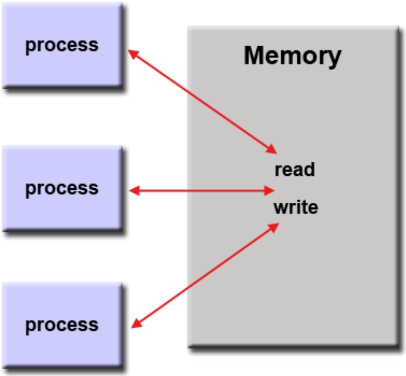
  Non 'Straight line' code :

```
for (i=1; i<CalcEnd(); i++) {
    if (DoJump()) i+= CalcJump();
    C[i] = A[i]+B[i];
}
```

Parallel Programming Models - Shared memory without Threads

- simplest parallel programming model



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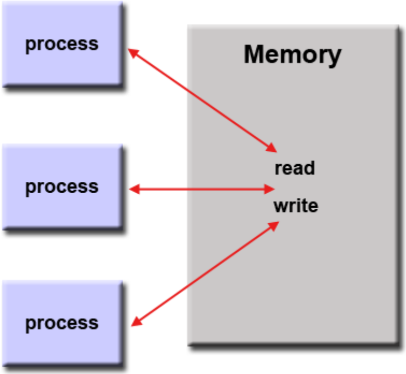

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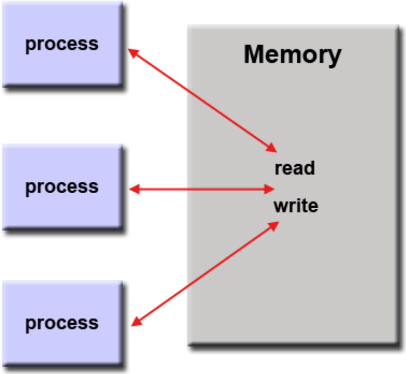

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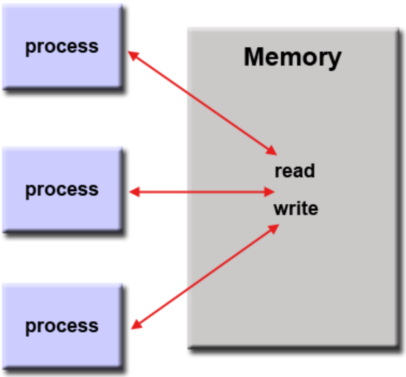
- processes share common address space
- access to shared memory has to be controlled to prevent race conditions and deadlocks (see later)
- while not very common in use, e.g. POSIX standards provide API, UNIX provides shared memory segments



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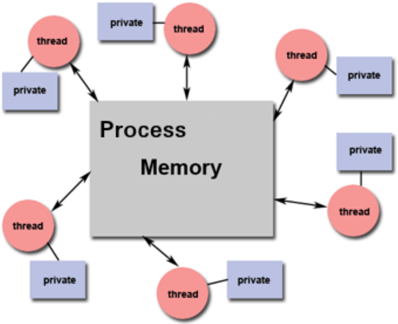

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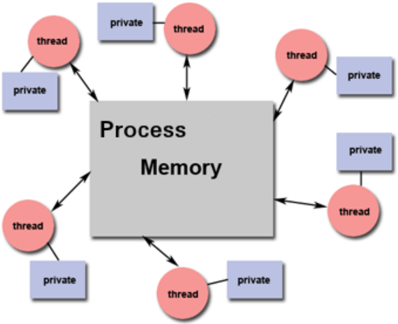

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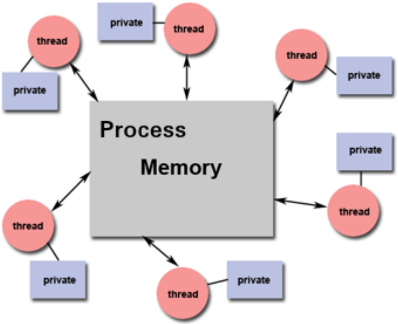

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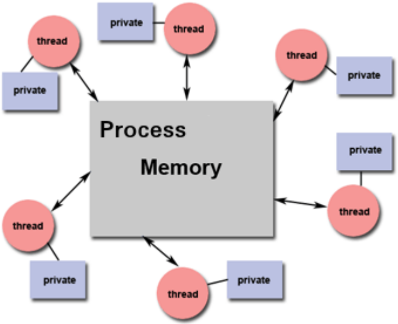
- Each thread has local data, but also, shares the entire resources of its parent process i.e. saves replicating a program's resources for each thread ("light weight").



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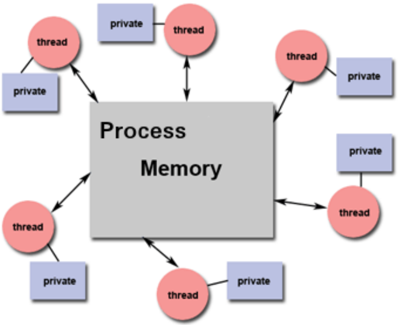

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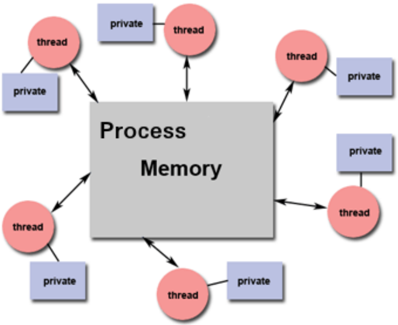

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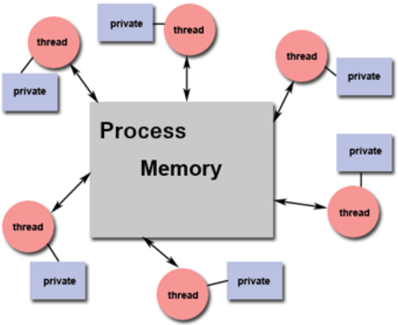

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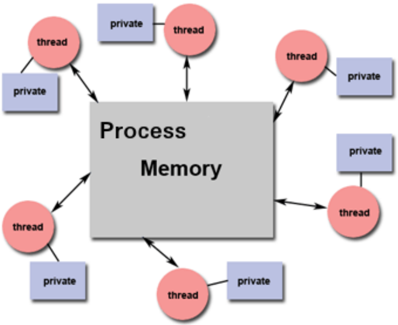
- We will focus on two standards: **OpenMP** & **POSIX Threads**



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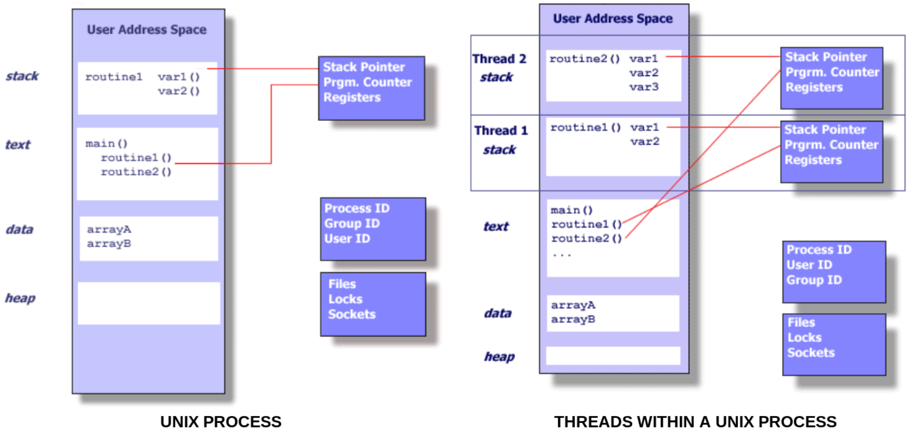

To be continued ...