

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)



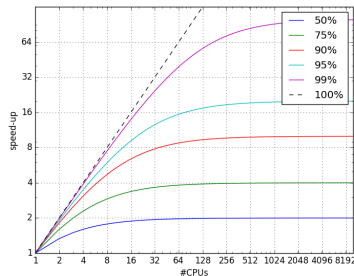
Concepts and Terminology - Amdahl's Law

- 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
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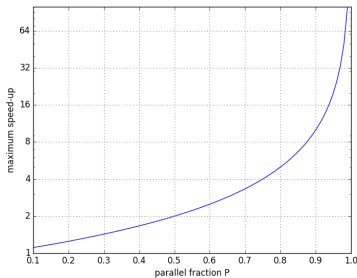
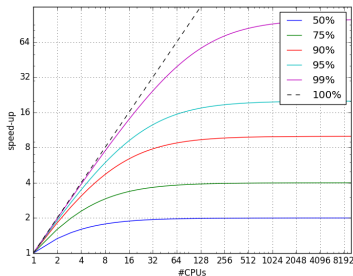
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- From this follows

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

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



Concepts and Terminology - Granularity

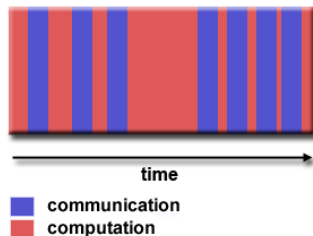
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Concepts and Terminology - Granularity

- Computation / Communication Ratio

fine-grained frequent communication; facilitates e.g. load balancing, comes with overhead costs

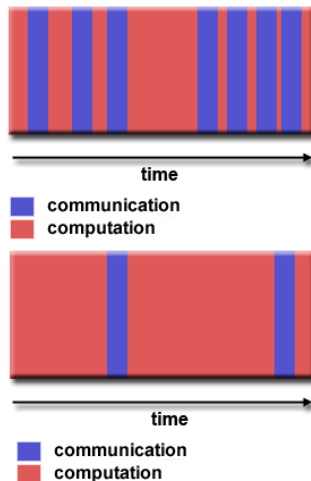


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lower communication costs, but potentially poorer load balancing



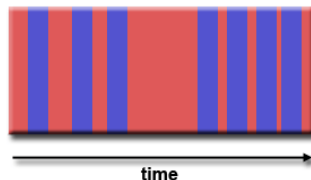
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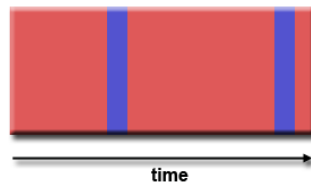
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- best choice depends on circumstances



■ communication
■ computation



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Concepts and Terminology - Scalability

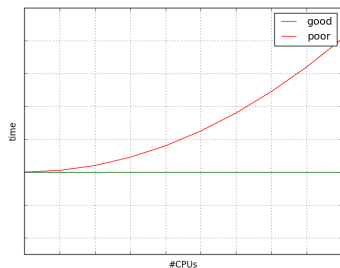
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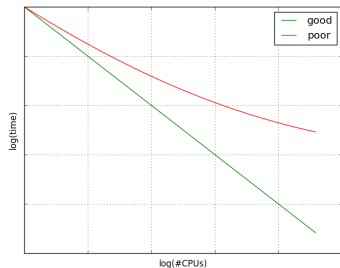
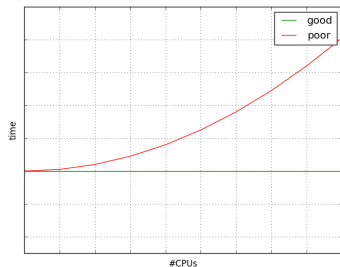


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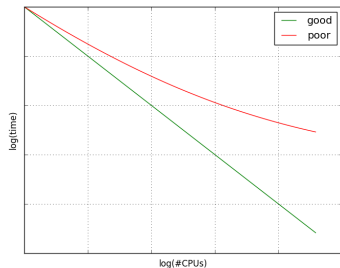
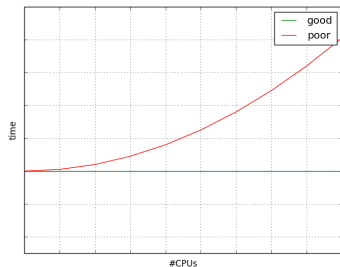
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Factors affecting scalability:

- 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



Concepts and Terminology - Cost of Complexity

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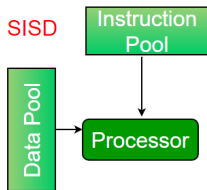
- Design
- Coding
- Debugging
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You have to find a trade-off between development time and runtime. Make sure the development of a speed-up does not cost you more time/resources than it saves you in the end!

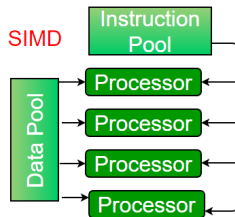
Parallel Programming Models



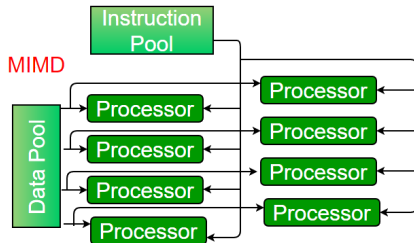
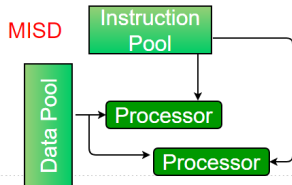
Recap: Computer Architectures - Flynn's taxonomy



classical computer



vector processing, GPUs



Multi-processing / multi-computing



THREE LEVELS OF PARALLEL PROGRAMMING



VECTORIZATION



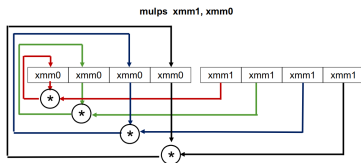
MULTITHREADING



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PARALLELISM**

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

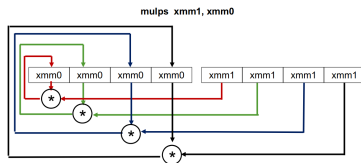
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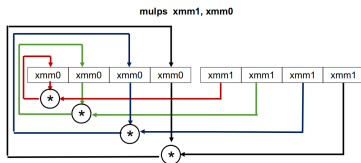
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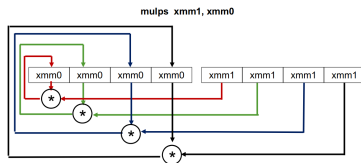
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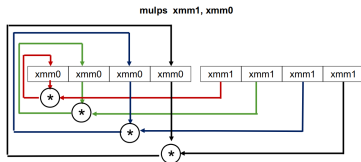
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What to consider when using these extensions:

- 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



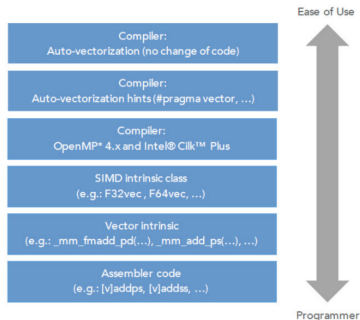
Parallel Programming Models - SIMD / Vectorization

Scalar version	Vectorized version
<pre>int A[], B[], C[]; ... for(i=0; i<n; i++) { a = A[i]; b = B[i]; c = a+b; C[i] = c; }</pre>	<pre>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 */ }</pre>



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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)



Parallel Programming Models - SIMD / Vectorization

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Non 'Straight line' code :

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

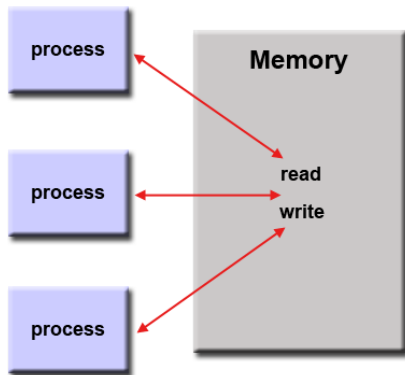


Parallel Programming Models - SIMT / GPUs



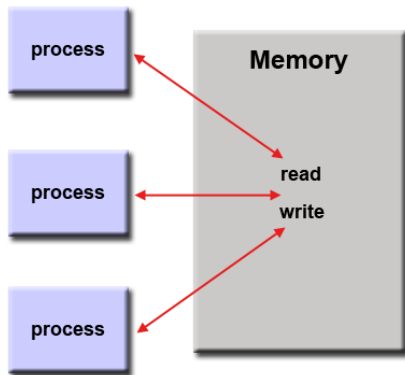
Parallel Programming Models - Shared memory without Threads

- simplest parallel programming model



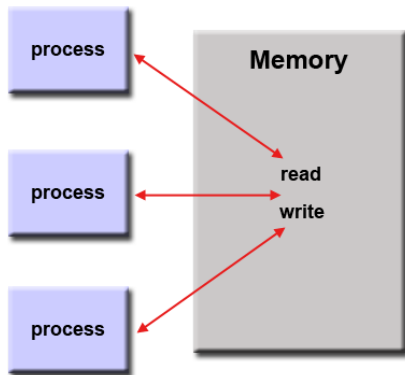
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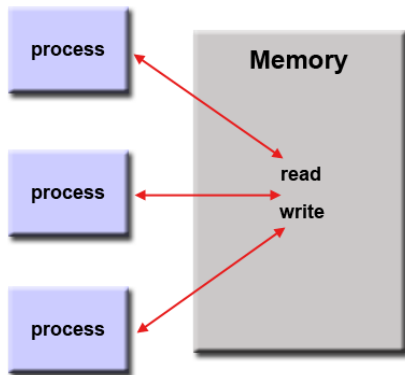
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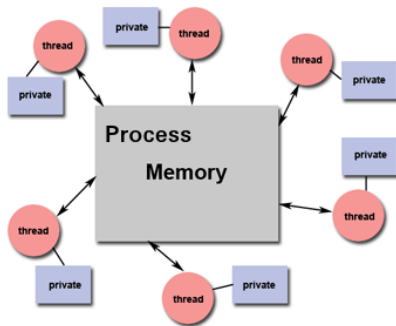
Parallel Programming Models - Shared memory without Threads

- simplest parallel programming model
- 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



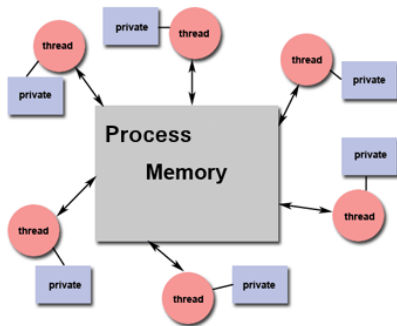
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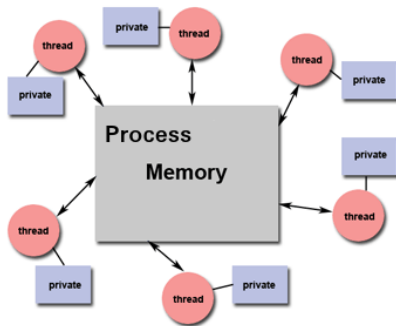
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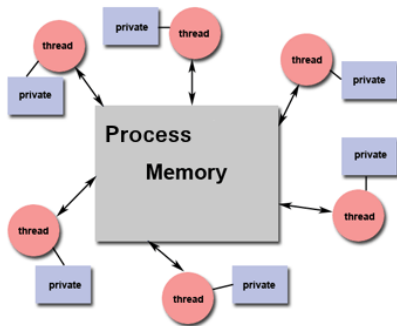
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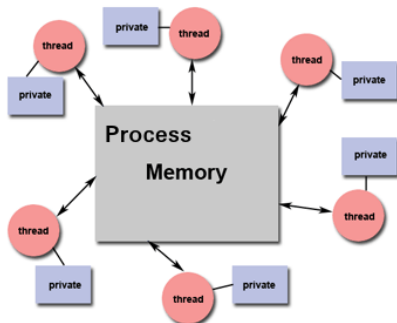
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- Each thread has local data, but also, shares the entire resources of its parent process i.e. saves replicating a program's resources for each thread ("light weight").



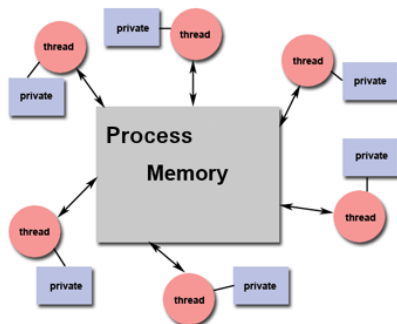
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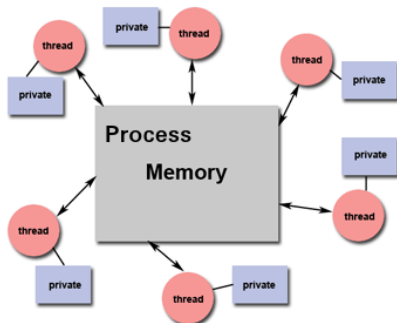
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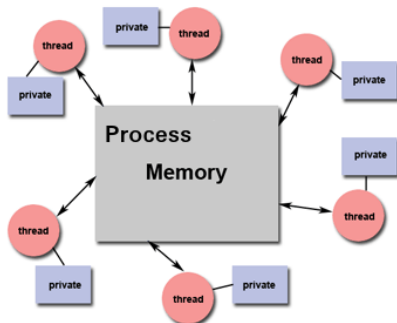
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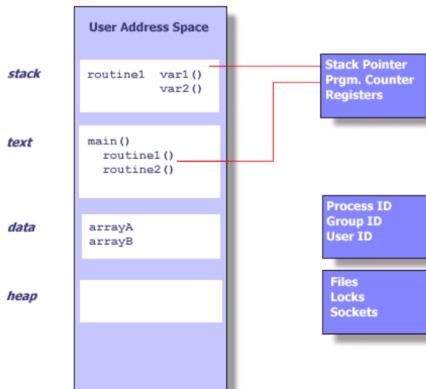


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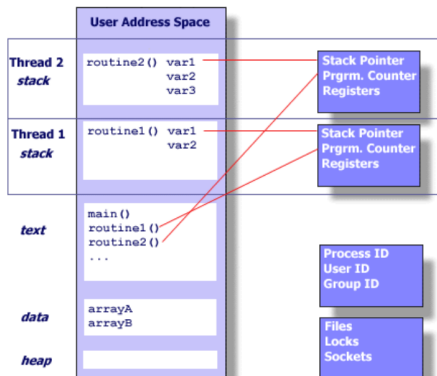
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- We will focus on two standards:
OpenMP & POSIX Threads



Parallel Programming Models - Shared memory with Multithreading (cont.)



UNIX PROCESS



THREADS WITHIN A UNIX PROCESS



To be continued ...

