An Introduction into Parallelization

Multithreading and Multiprocessing for Beginners

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Outline

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

Thread part of the computational work of a process that is executed in parallel on an additional processor

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

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

Concepts and Terminology (cont.)

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

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

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

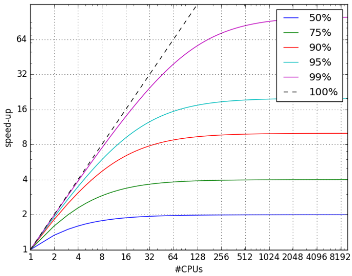
Concepts and Terminology - Amdahl's Law

- 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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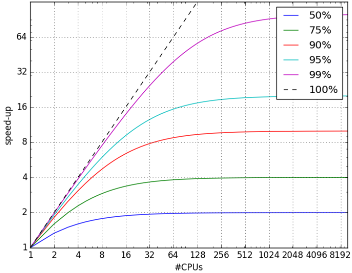
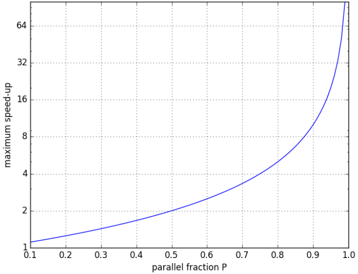
- From this follows

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

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





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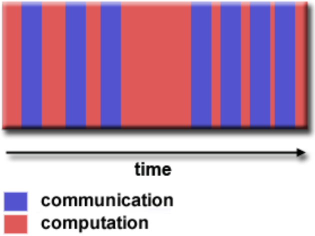

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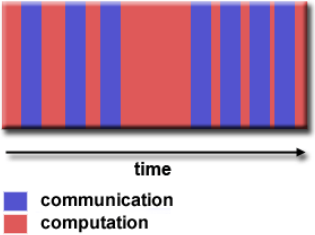
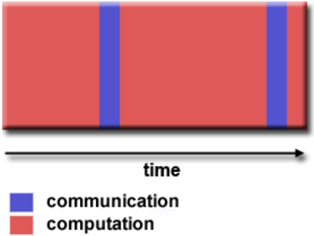
  coarse-grained: less frequent comm.; lower communication costs, but potentially poorer load balancing





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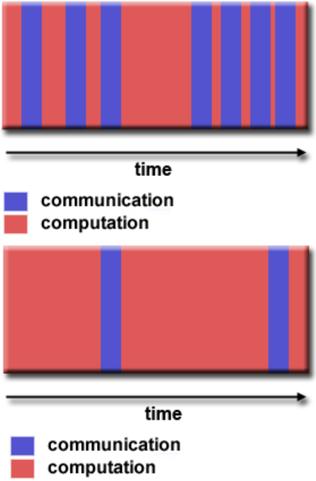
- best choice dependents on circumstances



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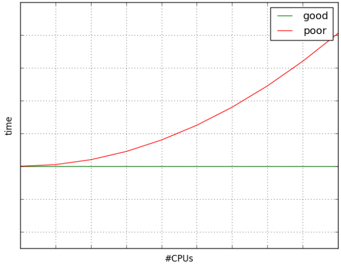

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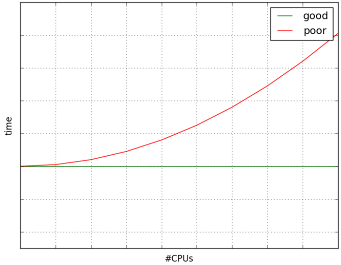

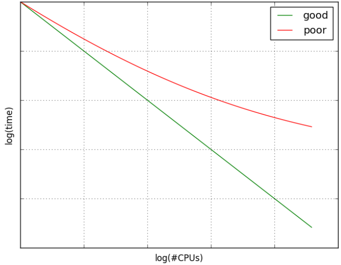

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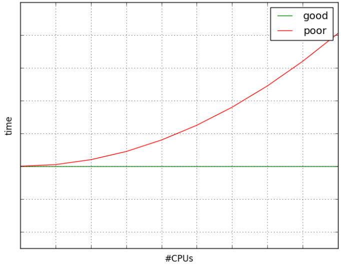
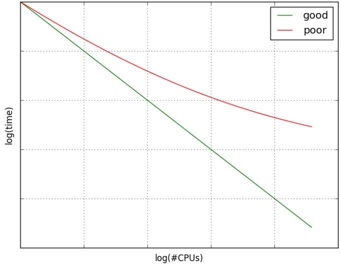


Factors affecting scalability:

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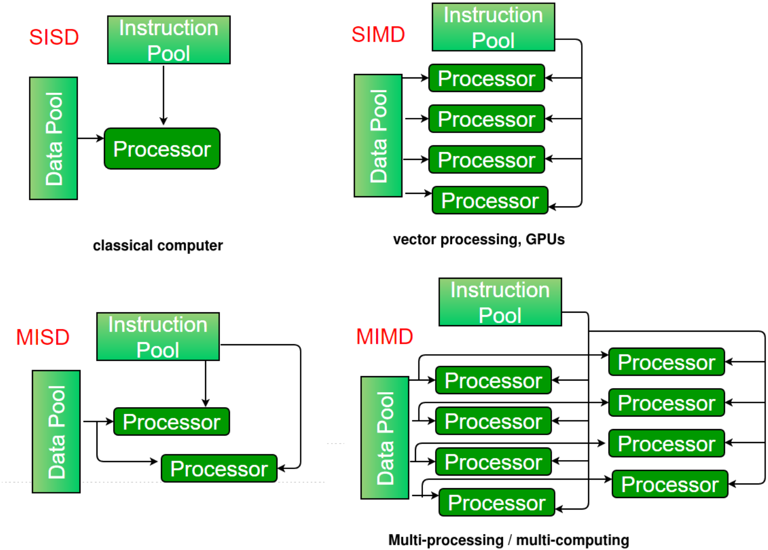
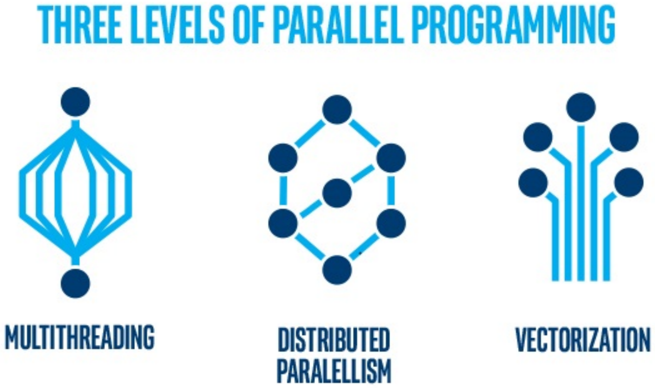
You have to find a trade-off between development time and runtime. Make sure the development of a speed-up does not cost you more time/resources than it saves you in the end!

Parallel Programming Models

Recap: Computer Architectures - Flynn's taxonomy



Parallel Programming Models - Overview



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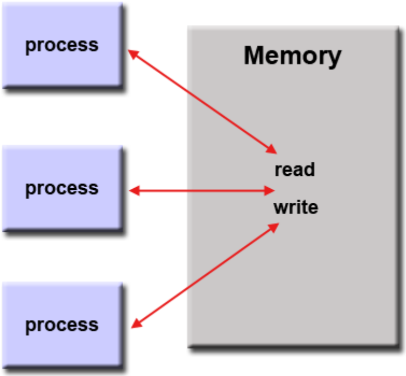
Scalar version	Vectorized version

<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>

Parallel Programming Models - Shared memory without Threads

- simplest parallel programming model



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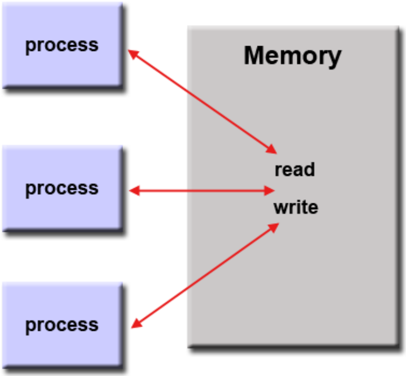

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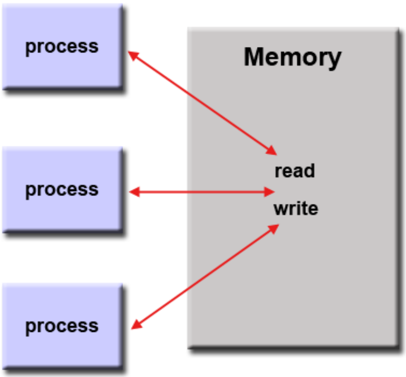

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- processes share common address space
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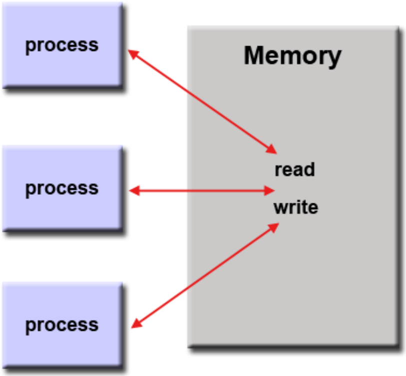
- while not very common in use, e.g. POSIX standards provide API, UNIX provides shared memory segments



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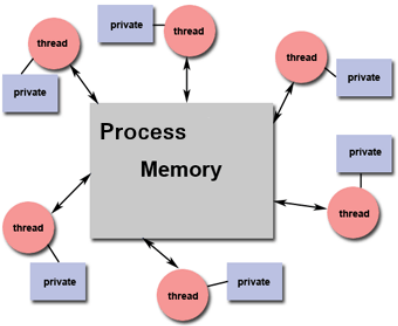

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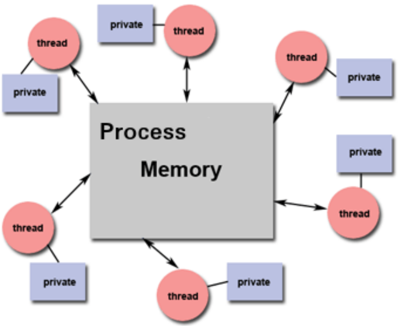

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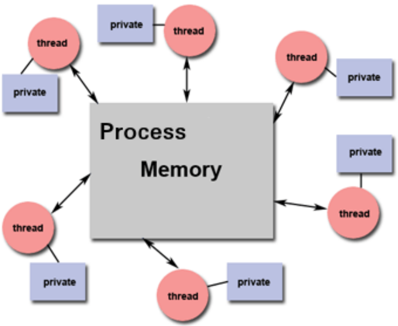

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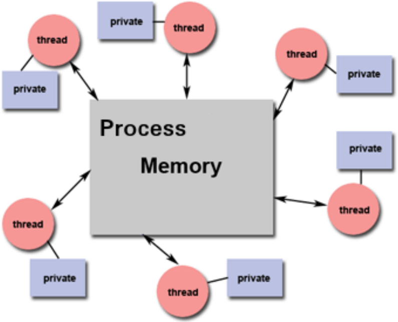
- Each thread has local data, but also, shares the entire resources of its parent process i.e. saves replicating a program's resources for each thread ("light weight").



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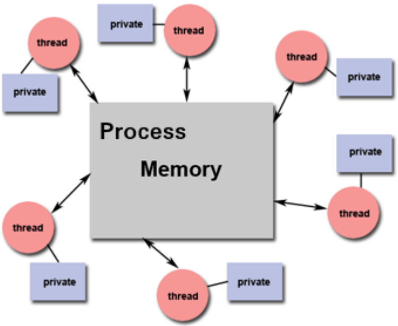

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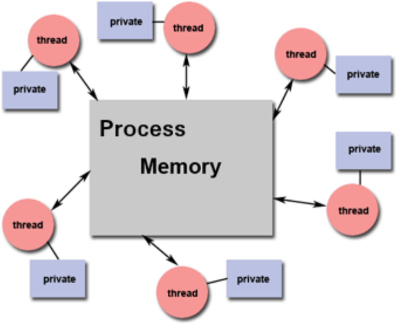

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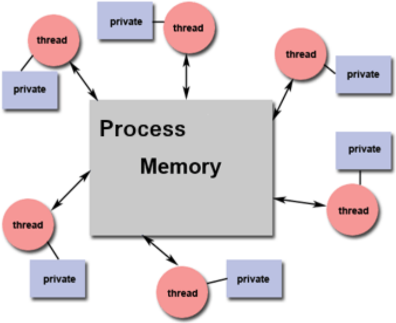

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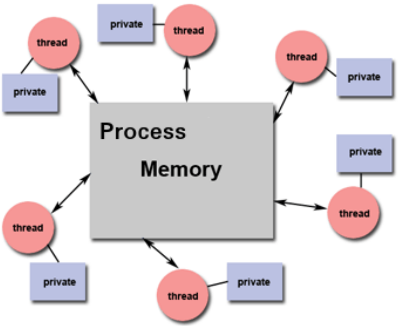
- We will focus on two standards: **OpenMP** & **POSIX Threads**



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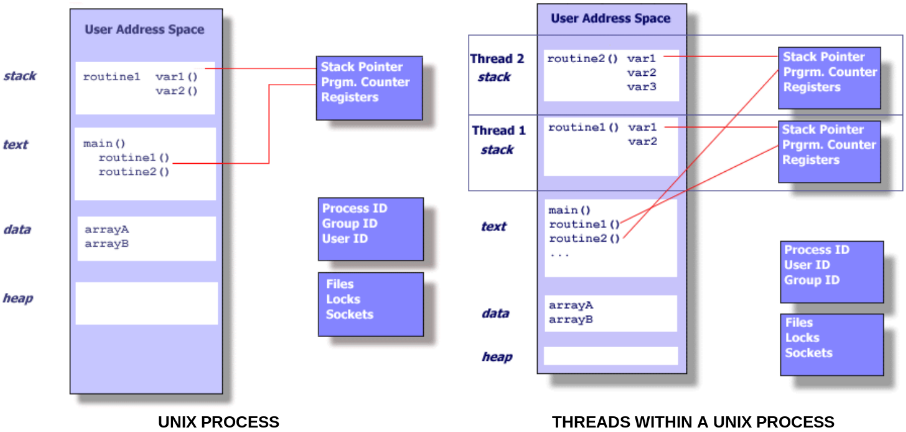

Distributed Parallelism with Message Passing

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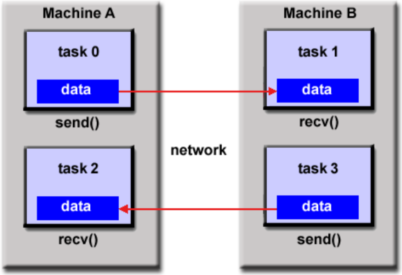

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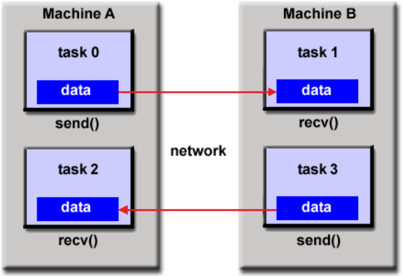

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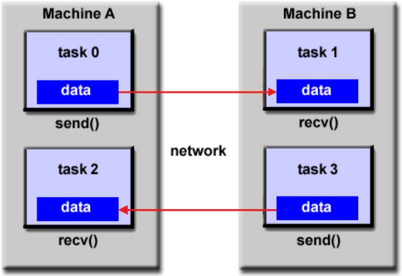

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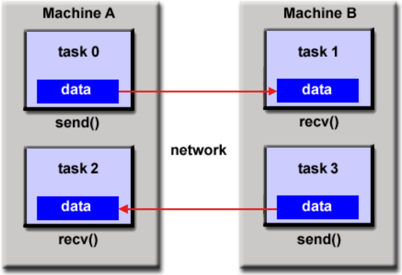

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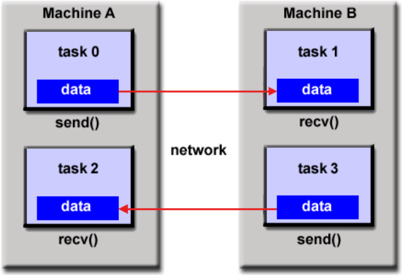
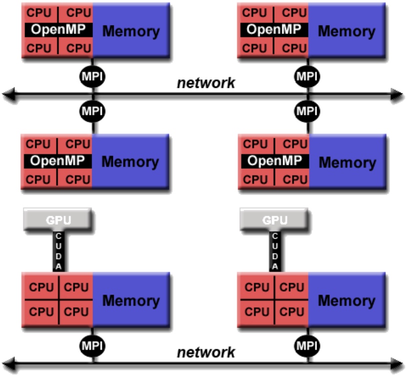
- *MPI* is the "de facto" standard



Hybrid Models

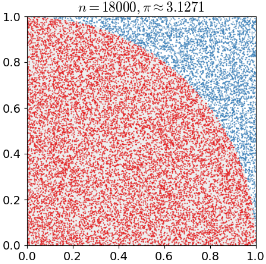
- Allows to make best use of locally shared memory or hardware, while still allowing for a good scalability across multiple nodes
- Comes with a significant increase in complexity/costs
- certain incompatibilities between libraries may exist (e.g. lack of thread-safety of MPI library)



Designing Parallel Programs

Understand your problem (!)

- some problems can be easily parallelized e.g. calculation of π by Monte-Carlo sampling



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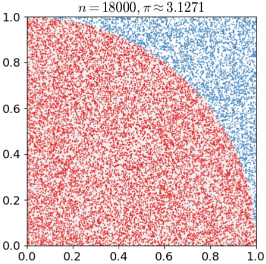

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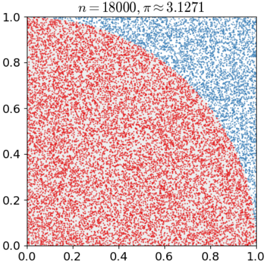

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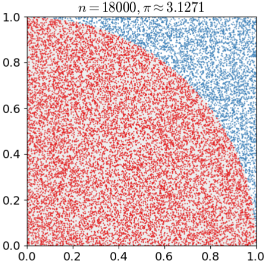

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- Identify inhibitors to parallelism: data-dependencies, I/O bottlenecks
- Consider replacing your algorithms with equivalent ones better suited for parallelism

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- make use of hardware optimization (e.g. vectorization, optimized libraries like MKL)
- identify hotspots in your program, i.e. routines where program spends lots of time in and check for improvement in parallelism ($\rightarrow$Amdahl's Law/Scaling)

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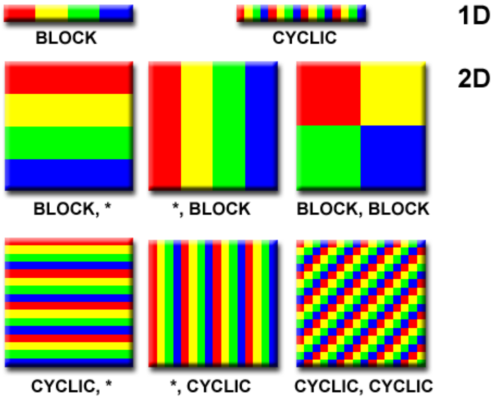

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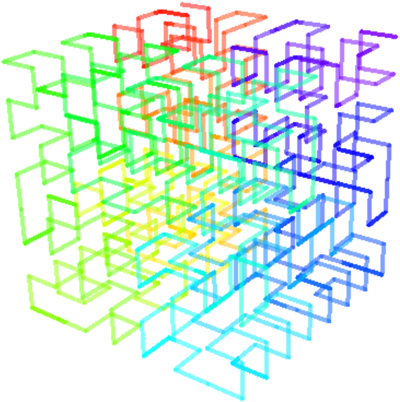

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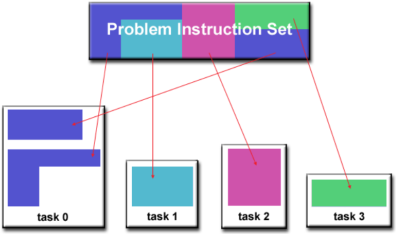
- Tasks/threads then specialize in doing specific parts of the overall work:



Partitioning - functional decomposition

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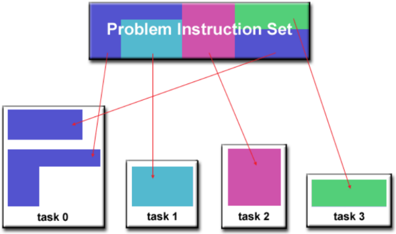

- implemented e.g. in master/slave paradigm (see exercises)

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- This can also cause a so called race condition:

Thread 1	Thread 2		Integer value
			0
read value		←	0
increase value			0
write back		→	1
	read value	←	1
	increase value		1
	write back	→	2

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- ... or to synchronize the calculations of processes (using barriers) for communication to exchange results or to redistribute the workload

Communication

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  - Point-to-Point vs. collective communications

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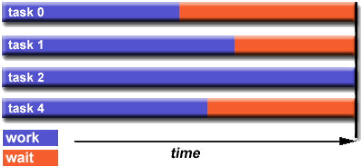
- Load balancing needed to ensure that processors are optimally i.e. minimizing idle times at synchronization points



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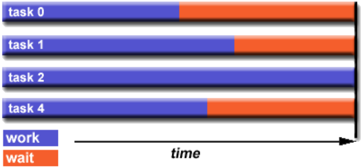

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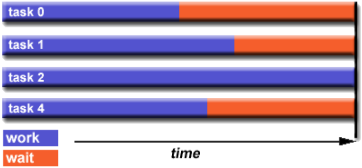
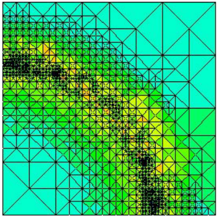


- requires well-balanced workload distribution between processors
- difficult in heterogeneous, dynamic problem sets with incomplete information about the actual workload



Load balancing (cont.)

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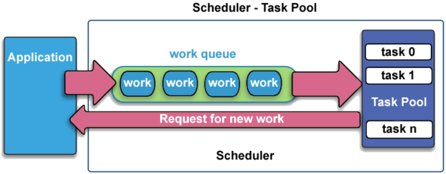
- alternatively, use asynchronous approach with scheduler-task pool with smaller workload packages



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- more on this tomorrow!

Performance Analysis & Tuning

- Analyzing and tuning parallel program performance can be much more challenging than for serial programs as interactions between tasks result in very complex dynamics
- Unfortunately, covering this topic in any detail would go beyond the scope of this introduction to parallel program.
- There are a number of excellent tools for this task: e.g. Intel VTune Amplifier and Intel Trace Analyzer