

An Introduction into Parallelization

Part II - Design

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Outline

1 Parallel Programming Models (cont.)

- Recap: Computer Architectures
- Distributed Parallelism with Message Passing
- Hybrid Models

2 Designing Parallel Programs

- Understand your problem and tools
- Partitioning - Domain vs functional decomposition
- Data Dependence / Race conditions
- Synchronization
- Communication
- Load balancing
- I/O
- Performance Analysis & Tuning
- Conclusions / tl;dr



Parallel Programming Models



THREE LEVELS OF PARALLEL PROGRAMMING



VECTORIZATION



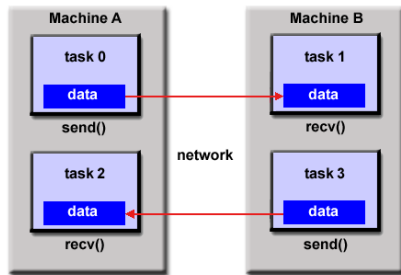
MULTITHREADING



**DISTRIBUTED
PARALLELISM**

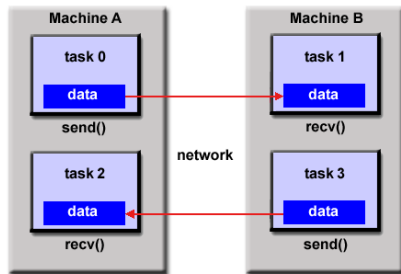
Distributed Parallelism with Message Passing

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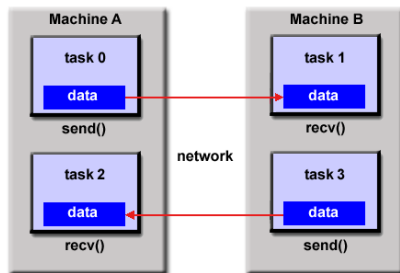
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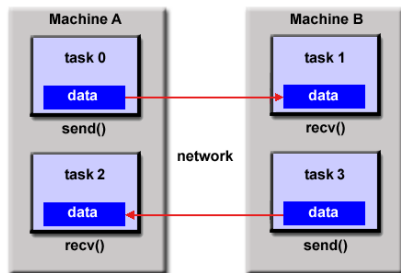
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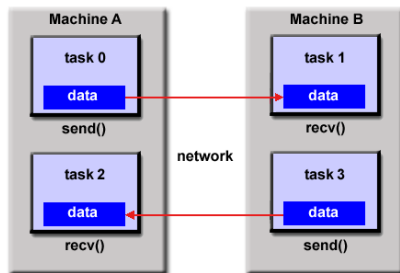
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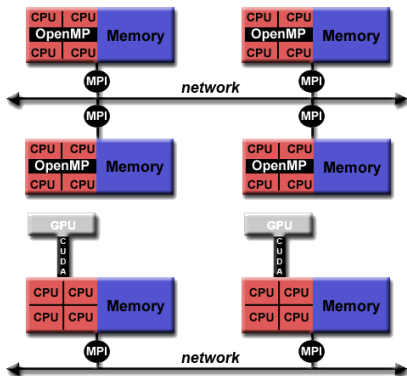
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- The message system can also be used to synchronize processes
- *MPI* is the “de facto” standard



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)

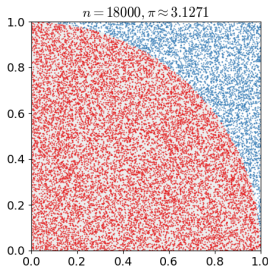


Designing Parallel Programs



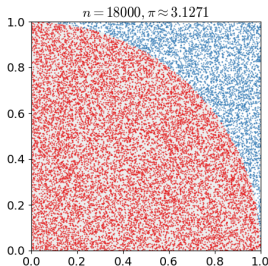
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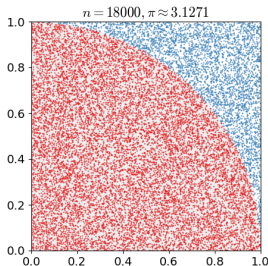


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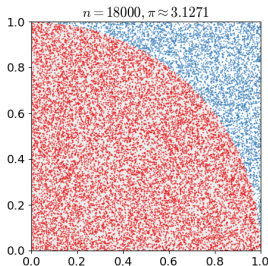
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- Consider replacing your algorithms with equivalent ones better suited for parallelism

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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)



Partitioning - Domain decomposition

- In this type of partitioning, the data associated with a problem is decomposed. Each parallel task then works on a portion of the data.



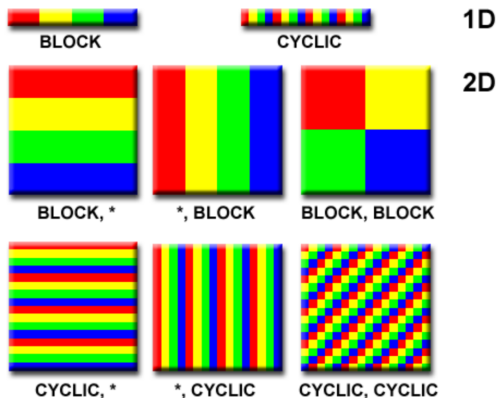
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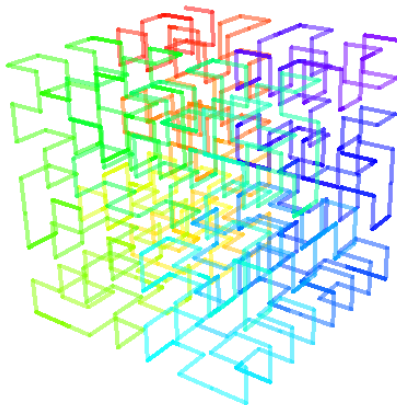
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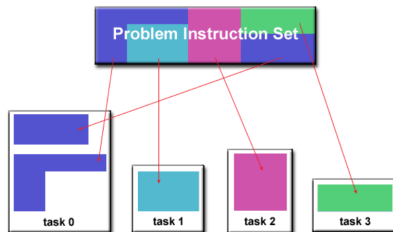
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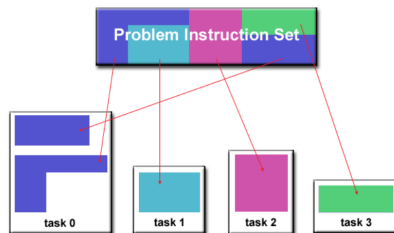
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- implemented e.g. in master/slave paradigm (see exercises)

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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



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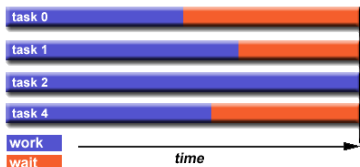
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 - ▶ Point-to-Point vs. collective communications



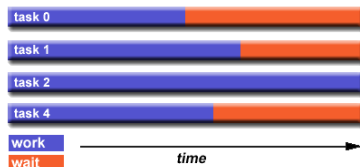
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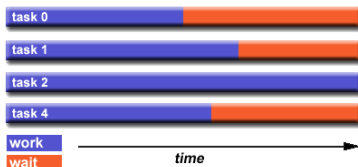
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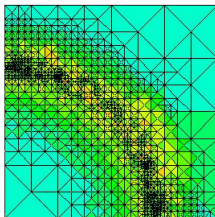
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- requires well-balanced workload distribution between processors
- difficult in heterogeneous, dynamic problem sets with incomplete information about the actual workload



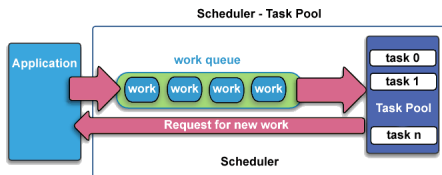
Load balancing (cont.)

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



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- more on this on Day 3!



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- profilers do **NOT** tell you **HOW** to optimize your code, they merely tell you **WHERE** to (potentially) do so for the best yield.



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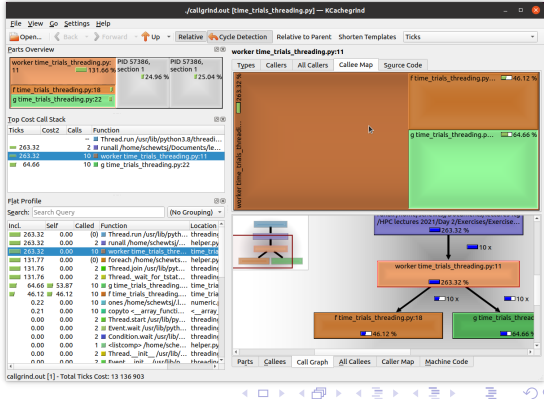
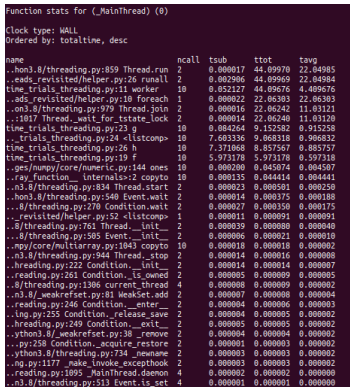
```
Function stats for (.MainThread) (0)
Clock type: WALL
Ordered by: totaltime, desc

name                                ncall      tsub      ttot      tavg
..hon3.8/threading.py:859 Thread.run 2      0.000017  44.09970  22.04985
..ads_revisited/helper.py:26 runall 2      0.002986  44.09969  22.04984
time_trials_threading.py:11 worker 10     0.052127  44.09676  4.409676
..ads_revisited/helper.py:10 foreach 1      0.000022  22.06303  22.06303
..on3.8/threading.py:979 Thread.join 2      0.000016  22.06242  11.03121
...1017 Thread_wait_for_tstate_lock 2      0.000014  22.06240  11.03120
time_trials_threading.py:23 g       10     0.084264  9.152582  0.915258
..trials_threading.py:24 _listcomp_ 10     7.603336  9.068318  0.906832
time_trials_threading.py:26 h       10     7.371068  8.857567  0.885757
time_trials_threading.py:19 f       10     5.973178  5.973178  0.597318
..ges/numpy/core/numeric.py:144 ones 10     0.000200  0.045074  0.004507
..ray.function _internals>:2 copyto 10     0.000135  0.044414  0.004441
..n3.8/threading.py:834 Thread.start 2      0.000023  0.000501  0.000250
..hon3.8/threading.py:540 Event.wait 2      0.000014  0.000375  0.000188
..8/threading.py:270 Condition.wait 2      0.000027  0.000350  0.000175
..revisited/helper.py:52 _listcomp_ 1      0.000011  0.000091  0.000091
..8/threading.py:761 Thread._init_ 2      0.000039  0.000080  0.000040
..8/threading.py:505 Event._init_ 2      0.000006  0.000021  0.000010
..mpy/core/multiarray.py:1043 copyto 10     0.000018  0.000018  0.000002
..n3.8/threading.py:944 Thread._stop 2      0.000014  0.000016  0.000008
..hreading.py:222 Condition._init_ 2      0.000014  0.000014  0.000007
..reading.py:261 Condition._is_owned 2      0.000005  0.000009  0.000005
..8/threading.py:1306 _current_thread 4      0.000008  0.000009  0.000002
..n3.8/_weakrefset.py:81 WeakSet.add 2      0.000007  0.000008  0.000004
..reading.py:246 Condition._enter_ 2      0.000004  0.000006  0.000003
..ing.py:255 Condition._release_save 2      0.000004  0.000005  0.000002
..hreading.py:249 Condition._exit_ 2      0.000005  0.000005  0.000002
..ython3.8/_weakrefset.py:38 _remove 2      0.000004  0.000004  0.000002
...py:258 Condition._acquire_restore 2      0.000001  0.000003  0.000002
..ython3.8/threading.py:734 _newname 2      0.000003  0.000003  0.000002
..np.py:1177 _make_invoke_excpthook 2      0.000003  0.000003  0.000002
..reading.py:1095 _MainThread.daemon 4      0.000002  0.000002  0.000000
..n3.8/threading.py:513 Event.is_set 4      0.000001  0.000001  0.000000
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- often, there are already “low-hanging fruits” in the serial code (reduction of I/O, amount of function calls, object conversions, etc.); demands in-depth knowledge of how things work “under the hood”.
- tools like profilers can help you to identify what to optimize, but you still need the knowledge on how to do this.

