# Parallel Programming Concepts

# Programming Models

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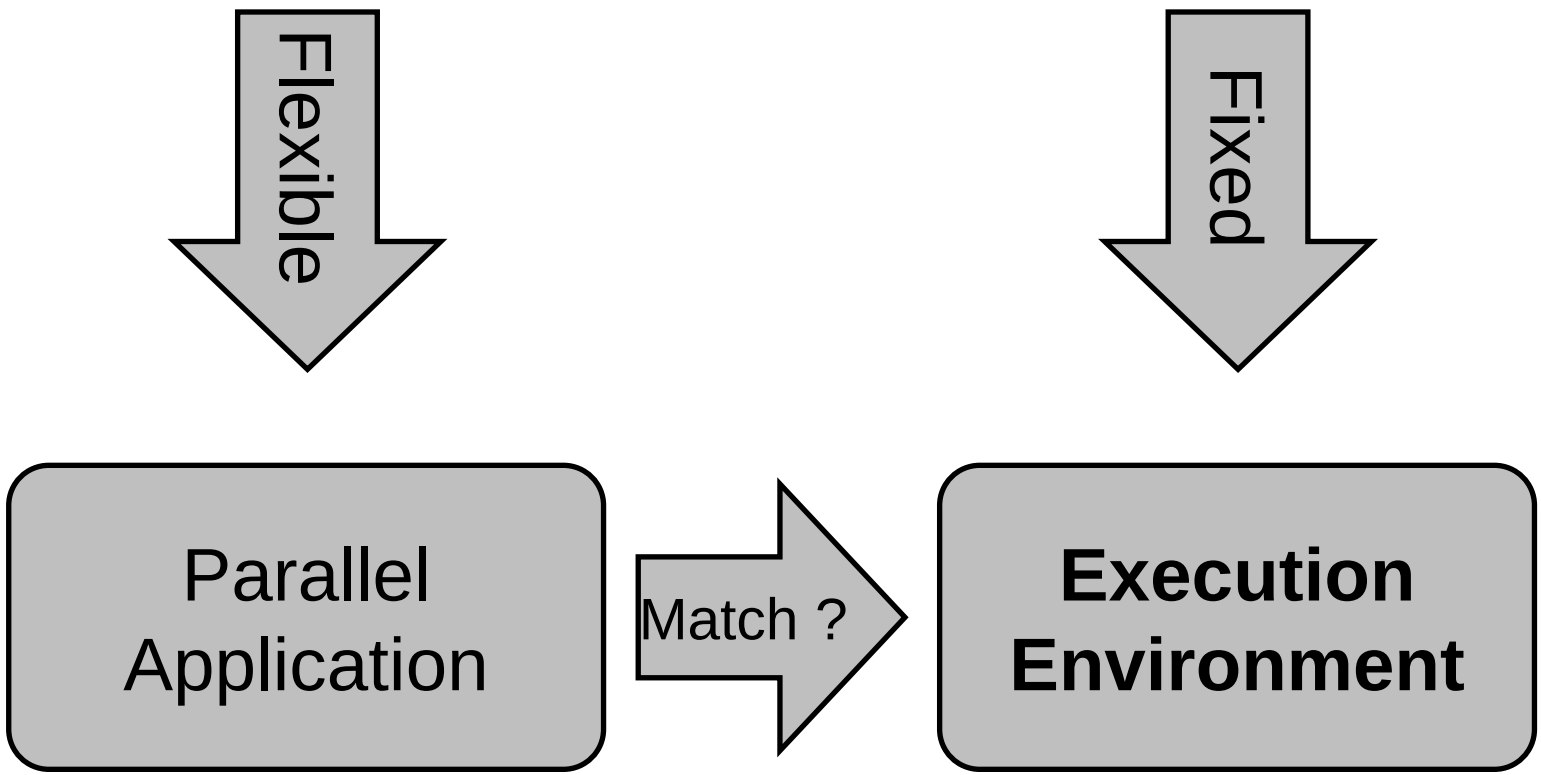
*Sources:*

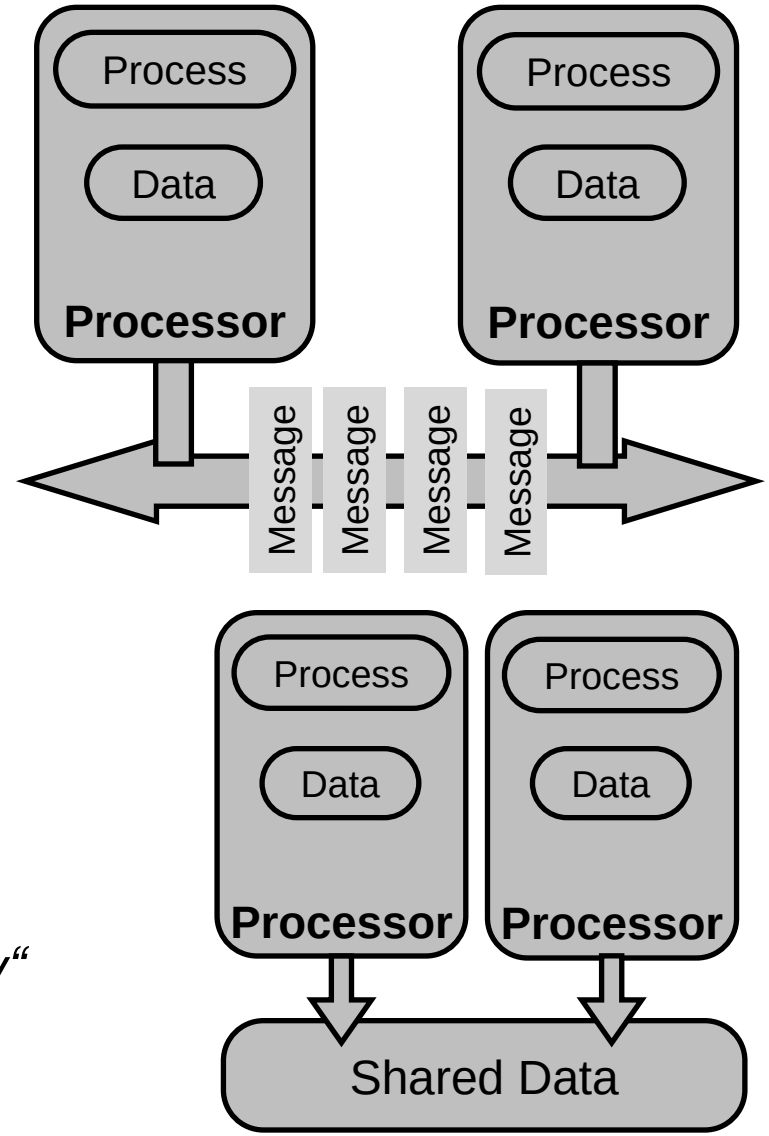
*Clay Breshears: The Art of Concurrency*
*Blaise Barney: Introduction to Parallel Computing*

# The Parallel Programming Problem



# Execution Environment

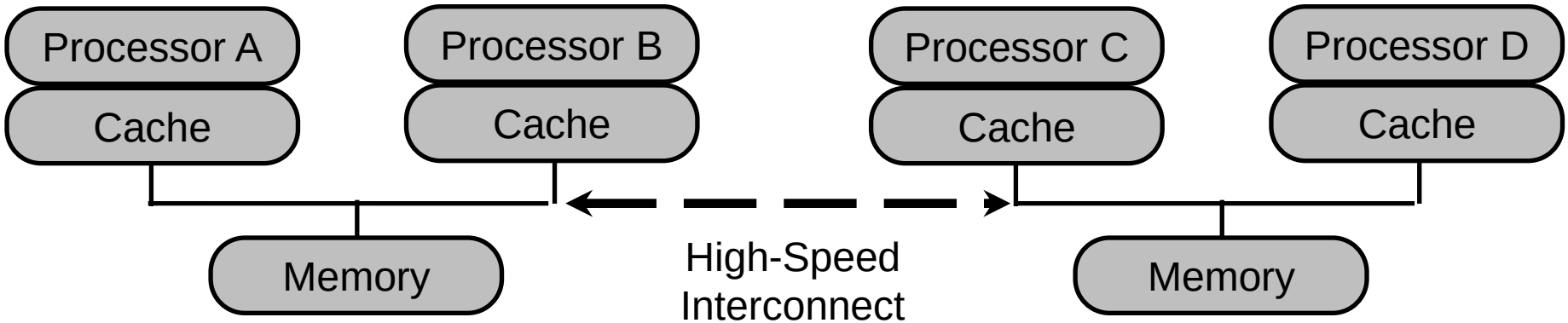
- Execution environments can be distinguished in two classes
  - „*Shared memory*“: SMP hardware, distributed shared memory, virtual runtime environments, ...
  - *„Shared nothing“*: Hardware clusters, massively parallel HPC, grid computing, processor interconnect, Hadoop, ...
- Pfister: *„shared memory“* vs. *„distributed memory“*
- Foster: *„multiprocessor“* vs. *„multicomputer“*
- Tanenbaum: *„shared memory“ vs. „private memory“*
- Environment can be either hardware or software

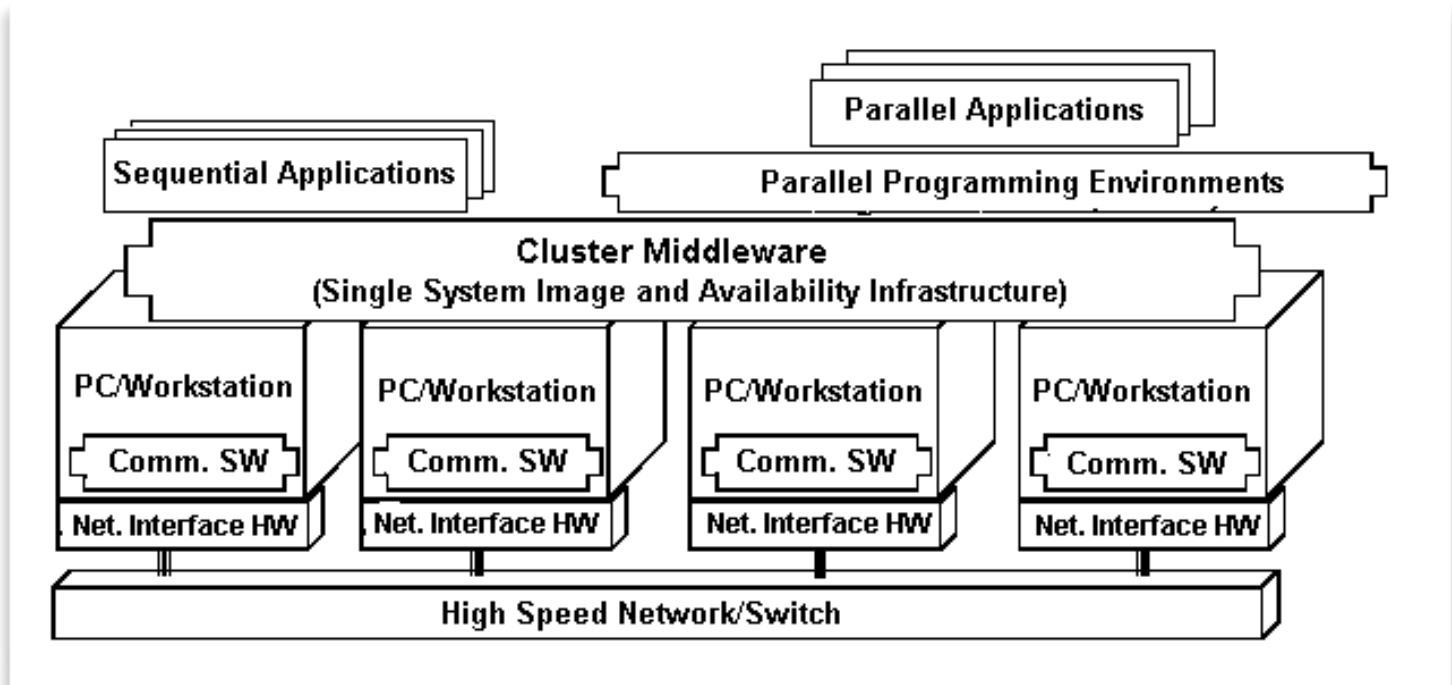


# Shared Memory

- All processors act independently, access the same global address space
- Changes in one memory location are visible for all others
- **Uniform memory access (UMA) system**
  - Equal load and store access for all processors to all memory
  - Default approach for majority of SMP systems in the past
- **Non-uniform memory access (NUMA) system**
  - Delay on memory access according to the accessed region
  - Typically realized by processor interconnection network and local memories
  - Cache-coherent NUMA (CC-NUMA), completely implemented in hardware
  - About to become standard approach with recent X86 chips

# Shared Nothing

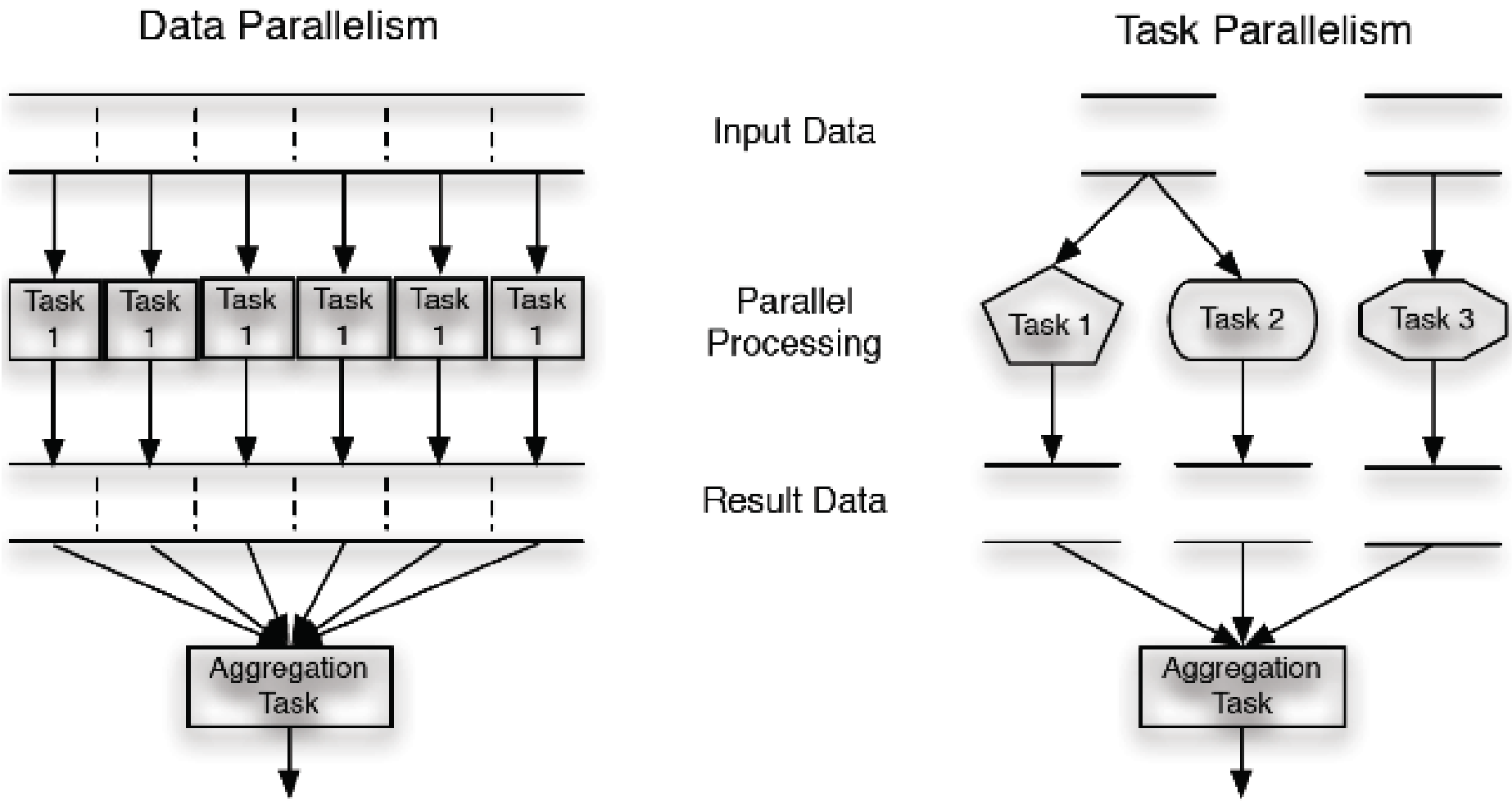


# Execution Environment

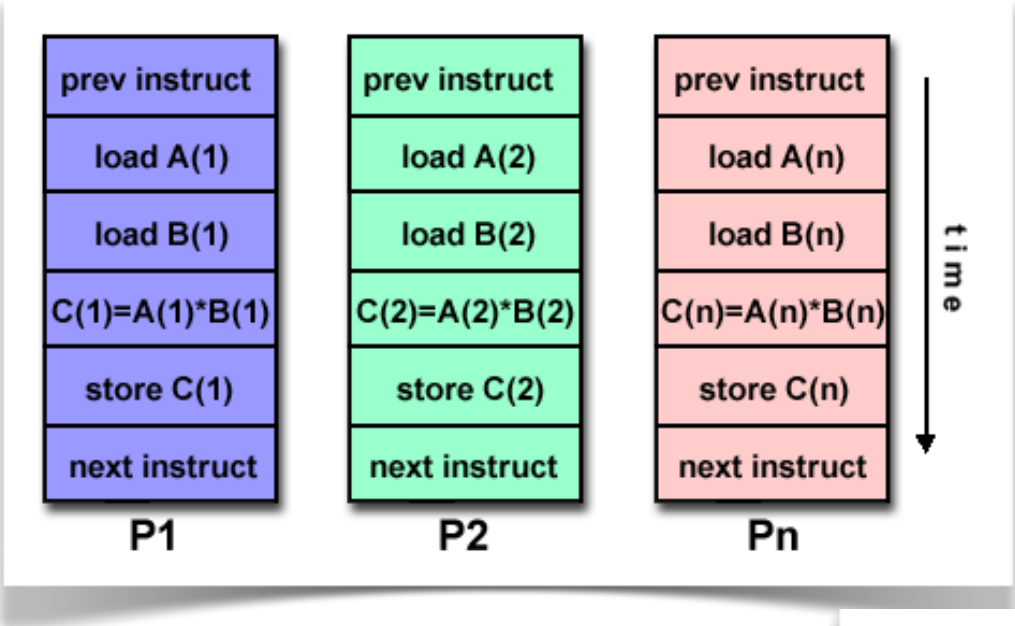
- Hardware / software execution environment with *„shared memory“* resp. *„shared nothing“* is optimized for specific workload
  - *„task parallel“*
    - Different operations being performed at the same time
    - Might originate from the same or different programs
  - *„data parallel“*
    - Parallel execution of the same operation on disjoint data sets
- Maps directly to SIMD / MIMD, orthogonal to memory semantics
- Sometimes also *„flow parallelism“* added
  - Overlapping work on data stream (pipelines, assembly line model)

# Execution Environment

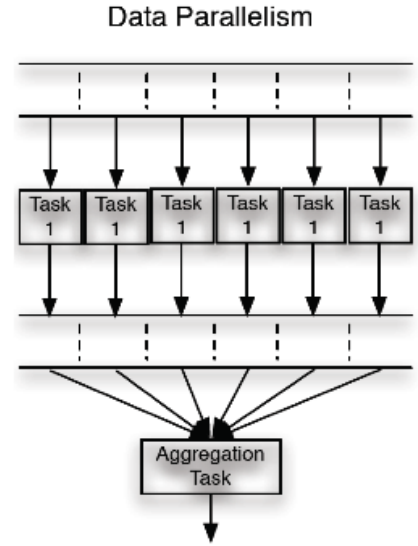


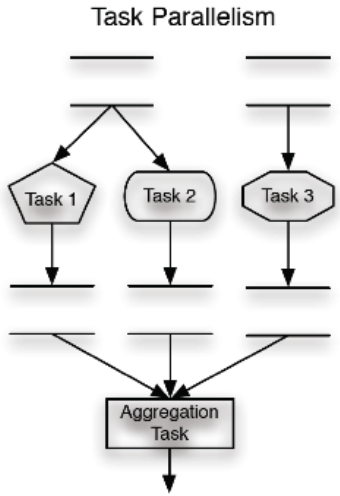
# Execution Environment

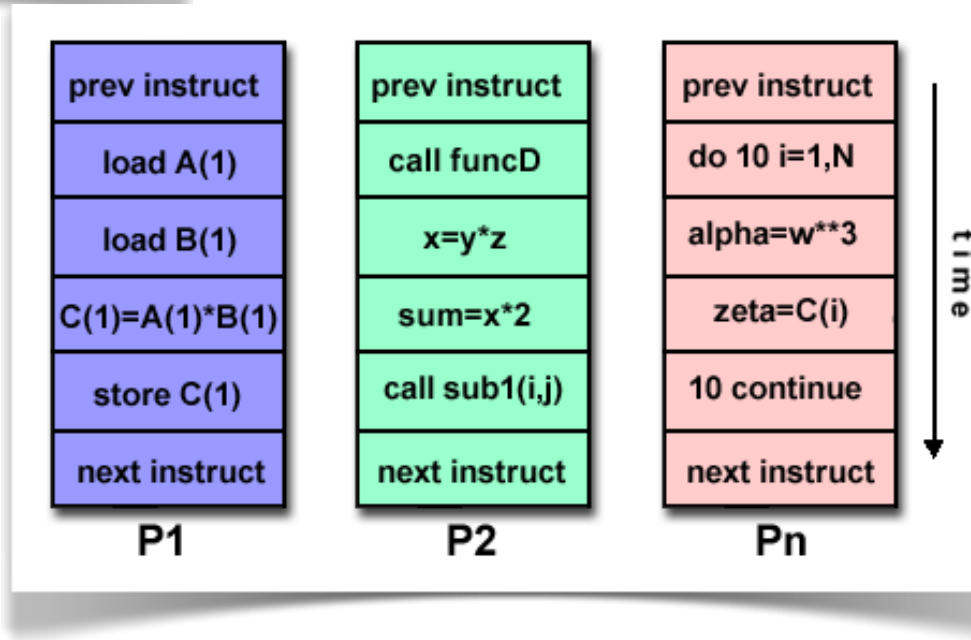
(C) Blaise Barney




**Single Instruction, Multiple Data (SIMD)**



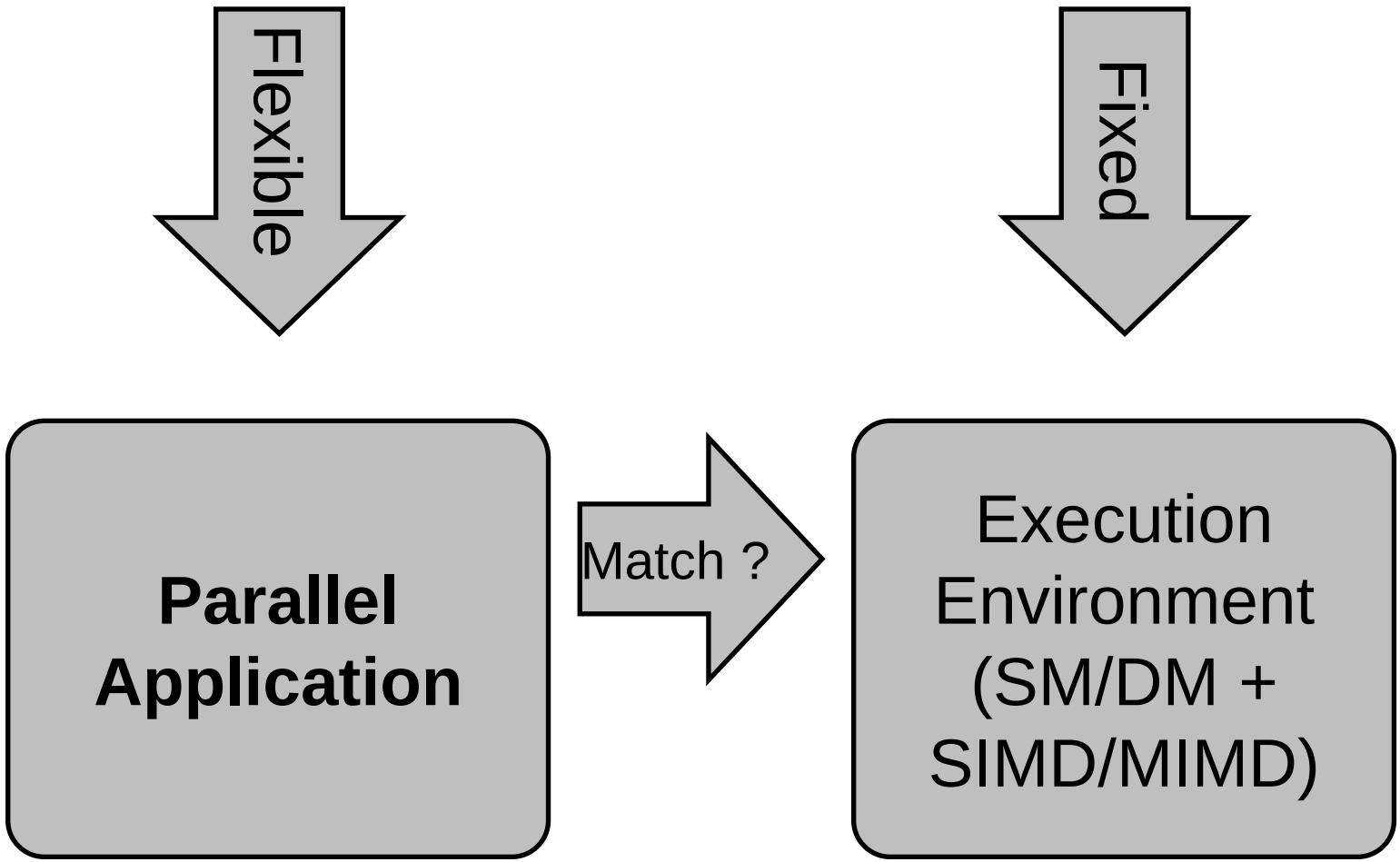

**Multiple Instruction, Multiple Data (MIMD)**

# Execution Environment Examples

| | Data Parallel / SIMD | Task Parallel / MIMD |
|---|---|---|
| Shared Memory (SM) | *SM-SIMD*<br>GPU, Cell, SSE, AltiVec<br>Vector processor<br>... | *SM-MIMD*<br>ManyCore/SMP system<br>... |
| Shared Nothing / Distributed Memory (DM) | *DM-SIMD*<br><br>processor-array systems<br>Hadoop<br>... | *DM-MIMD*<br><br>cluster systems<br>MPP systems<br><br>... |

- Note:
  Task-parallel execution environments are easily also usable as data-parallel execution environment, but not optimized for it

# The Parallel Programming Problem

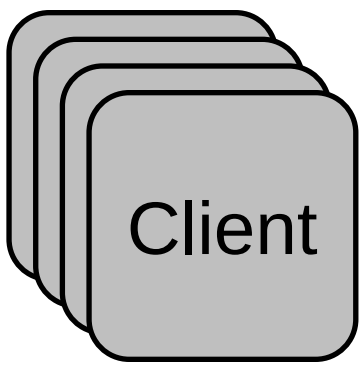


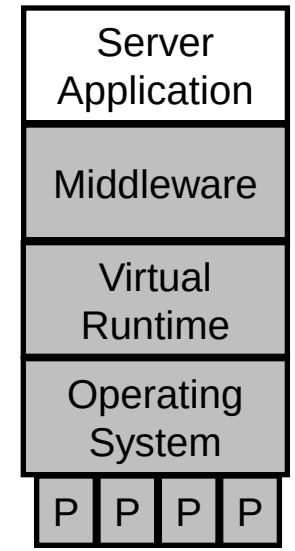
# Parallel Application

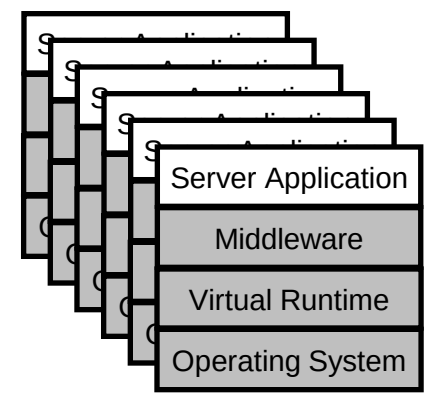
- Motivation for porting your application:
- **Linear speedup**
  - n times more resources lead to n times less time for solving the same task
- **Linear scaleup**
  - n times more resources solve an n times larger problem in the same time
- Goal depends on the application, examples:
  - Transaction processing usually heads for **throughput** (scalability)
  - Decision support system usually heads for better **response time** (speed)
- ‚Parallel application‘ is a widely used term

# Example: Server-Side Parallelism

| | Scaleup | Speedup |
|---|---|---|
| SM-MIMD | (Inter) | Intra |
| DM-MIMD | Inter | (Intra) |




**Intra-request parallelism**
for response time
-> speedup

**Inter-request parallelism**
for throughput
-> scaleup

# Parallel Application

- Parallel application execution
  - Supported to have two or more actions executing *simultaneously*
  - Demands execution environment
- Parallelization can be coarse-grained or fine-grained
  - Decision of algorithm design and / or configuration
- Proposal for this course (this is debatable)
  - **coarse-grained** == **inter-request parallelism** (think Apache)
  - **fine-grained** == **intra-request parallelism** (think multithreading)
  - Interpret single application start as one ‚request‘
- How to formulate our parallel application ? We need a **programming paradigm**.

# Programming Paradigm

- Programming paradigm: coding convention or standard
  - Something a majority of people agrees upon
- Parallel programming is one of these paradigms
  - Other examples: declarative, constraint-based, structured, object-oriented
- Each paradigm can be realized by a set of programming models
  - Programming model: *„set of rules for a game“* [Almasi, Gottlieb]
  - Point where execution environment and application meet
  - Programming models for parallel programming:

    **Multi-Tasking, Message Passing, Implicit Parallelism**

# Programming Models

- High-level view of the application on it‘s execution environment
- Intended as contract - if you follow the rules, scalability should be achievable
- Decouples software and execution environment architecture development
- **Multi-Tasking:** Typically used for SM-MIMD execution environments, recently also relevant for SM-SIMD environments
- **Message Passing:** Typically used for DM-MIMD execution environments
- **Implicit Parallelism:** globally useful, since mapping is implicit
- No enforcement, different mappings are possible
- Programming models are implemented by programming languages / libraries

# Parallel Programming Languages

- Often languages implement more than one parallel programming model
- Programming languages contain of syntax and standard library
  - Example: C + libc,  Python + class library
  - Allows adding parallel programming support to sequential languages
- **Multi-Tasking:** pthreads, OpenCL, Linda, Ada, Cilk, PGAS, ...
- **Message Passing:** MPI, PVM, CSP channels, actors ...
- **Implicit Parallelism:** Map/Reduce, PLINQ, HPF, Lisp, Fortress ...
- **Mixed stuff**: OpenMP & Co., Scala, Erlang, X10, Clojure...
- Languages are often categorized by their feasibility for a particular execution environment - *„data-parallel languages“* vs. *„task-parallel languages“*