Parallel Programming Concepts

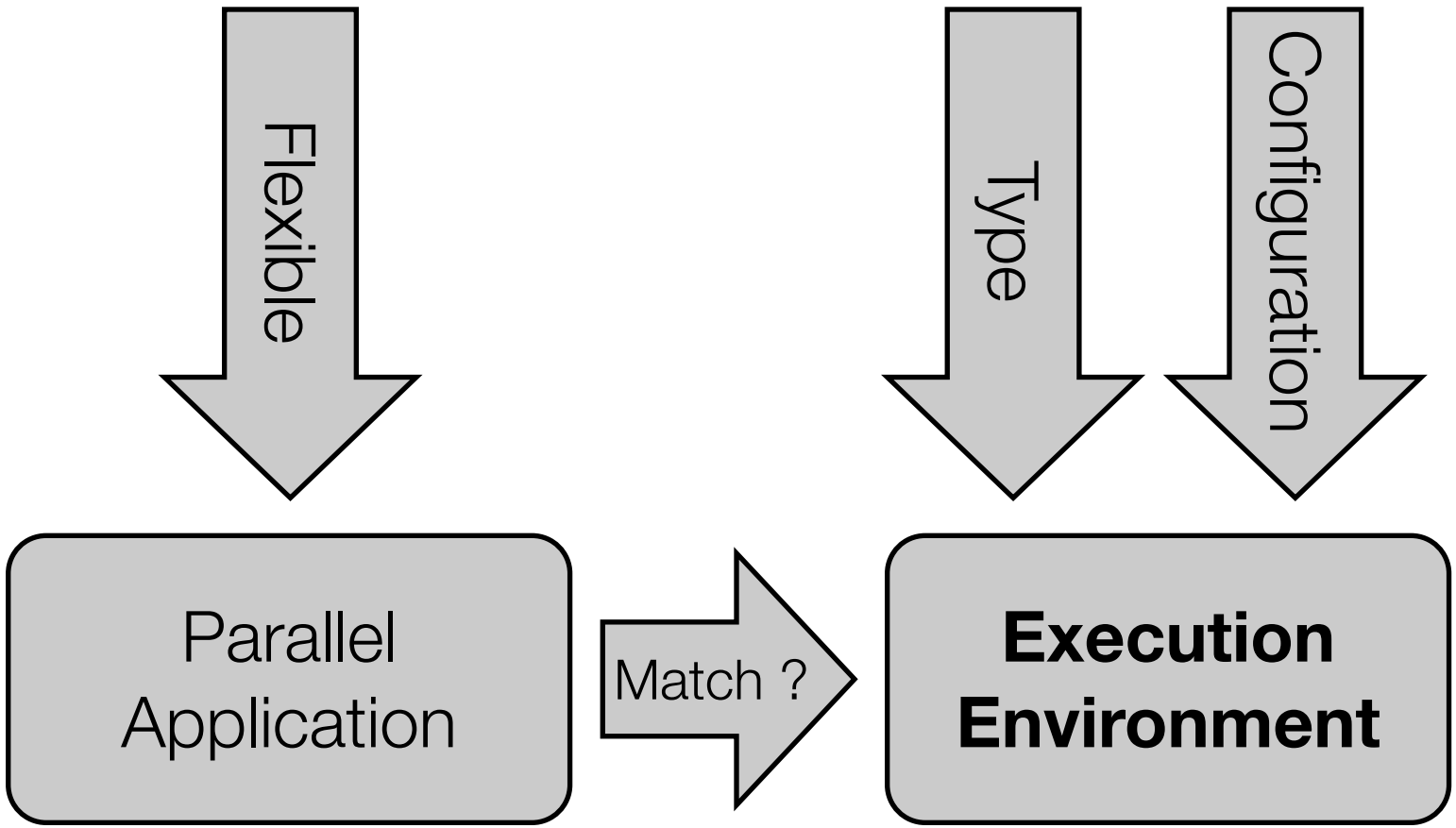
Programming Models

Peter Tröger

Sources:

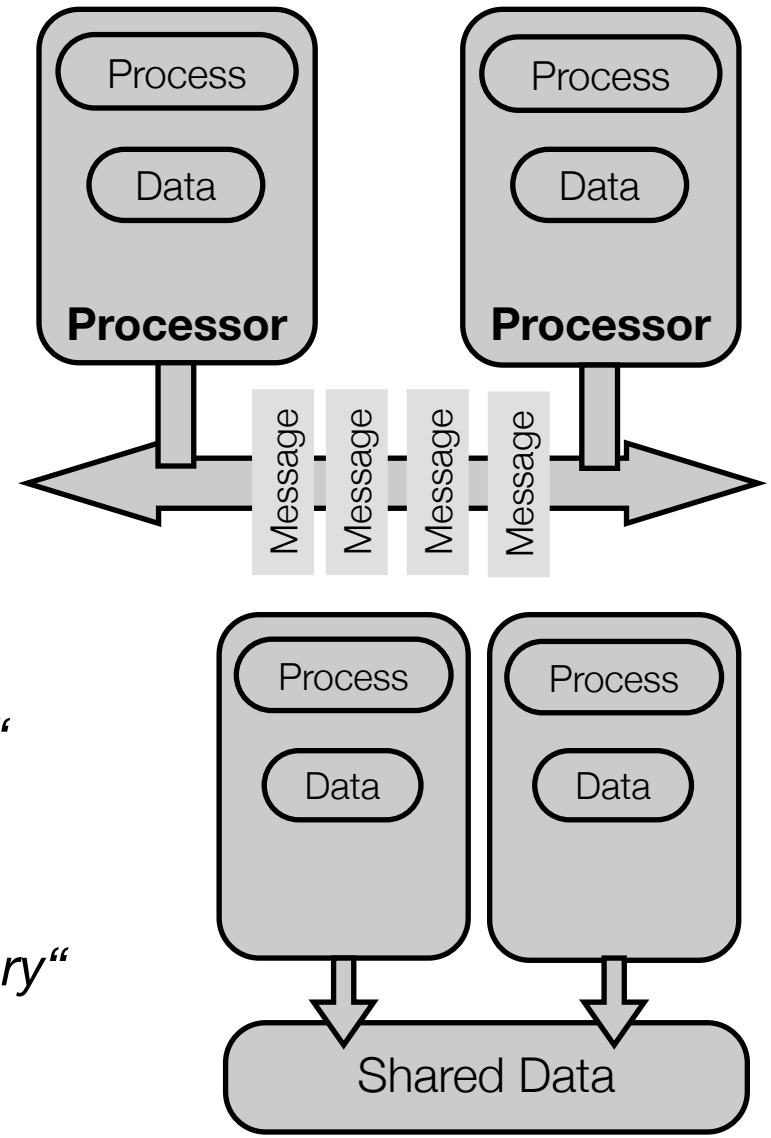
Clay Breshears: The Art of Concurrency
Blaise Barney: Introduction to Parallel Computing

The Parallel Programming Problem



Execution Environment

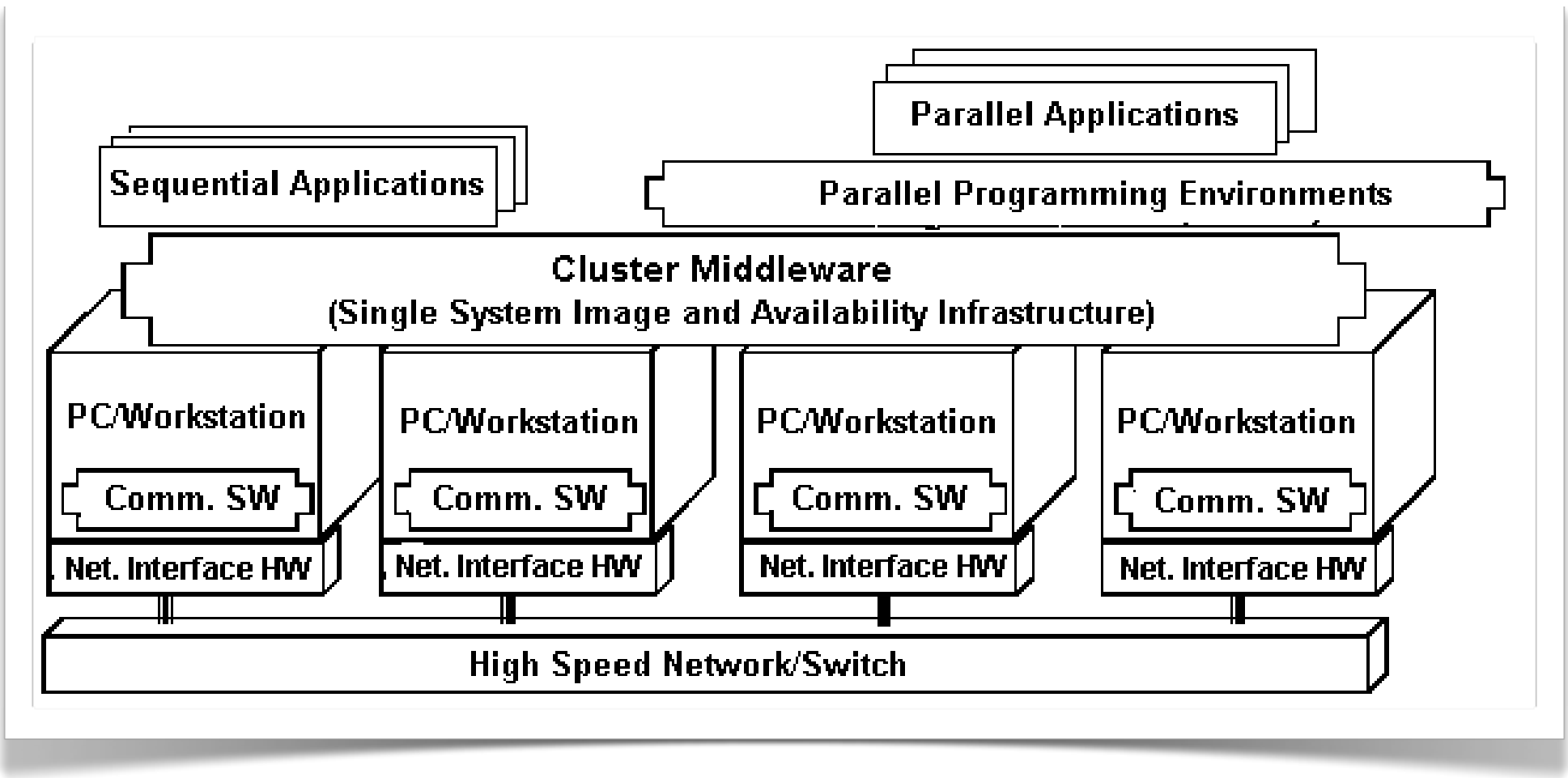
- Execution environments can be distinguished in two classes
  - „*Shared memory*“: SMP hardware, distributed shared memory, virtual runtime environments, ...
  - *„Shared nothing“*: Hardware clusters, massively parallel HPC, grid computing, processor interconnect, Hadoop, ...
- Pfister: *„shared memory“*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



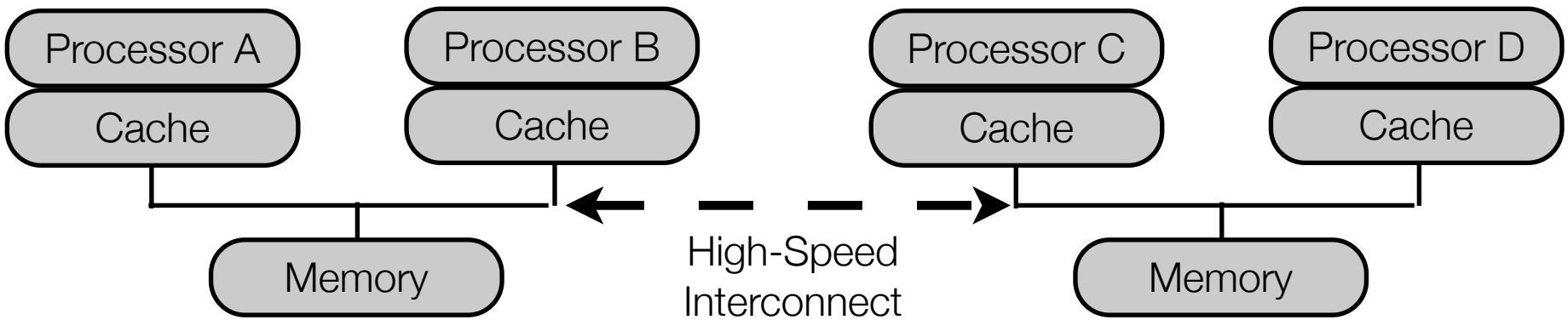
Shared Memory

- 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



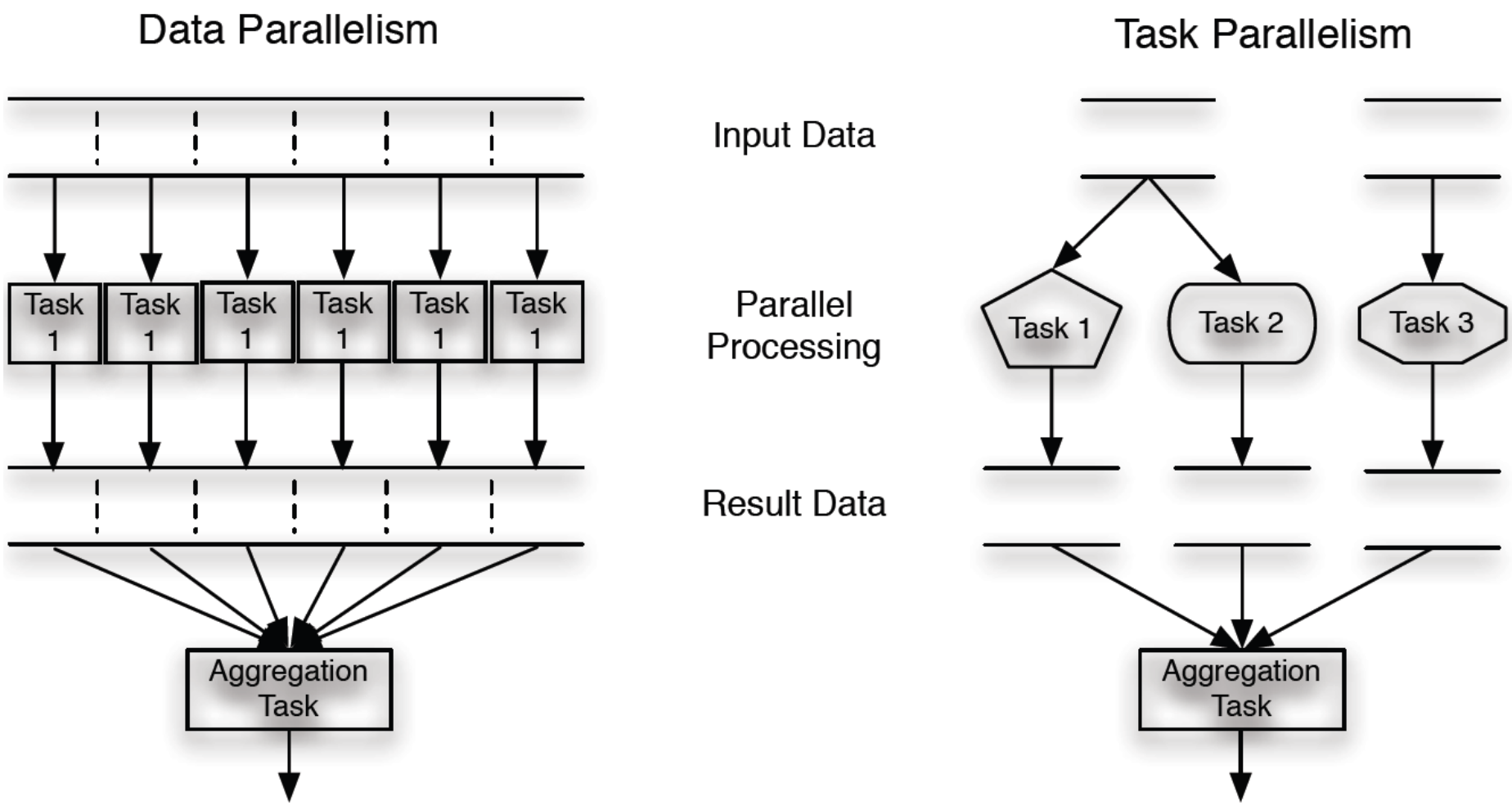
Hybrid Environments



Execution Environment

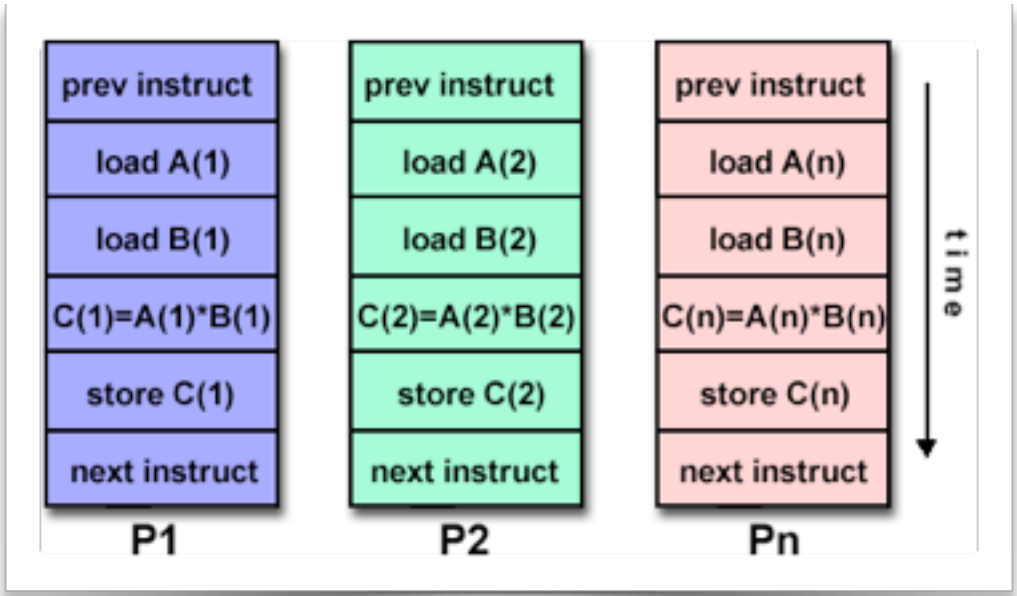
- Hardware / software execution environment with *„shared memory“* resp. *„shared nothing“* is optimized for specific workload
  - *„task parallel“*
    - Different operations being performed at the same time
    - Might originate from the same or different programs
  - *„data parallel“*
    - Parallel 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

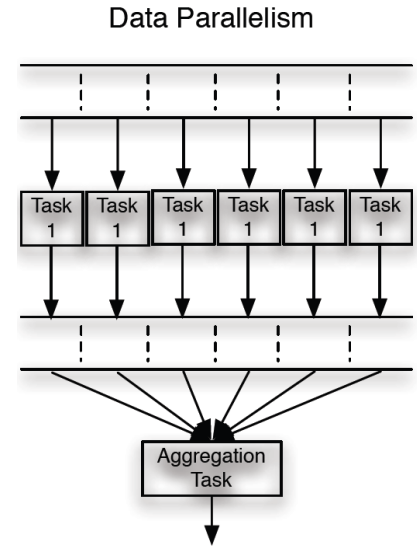


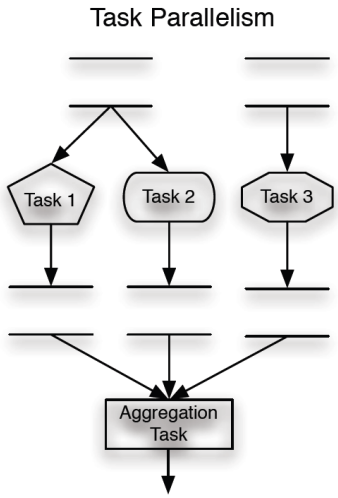
Execution Environment

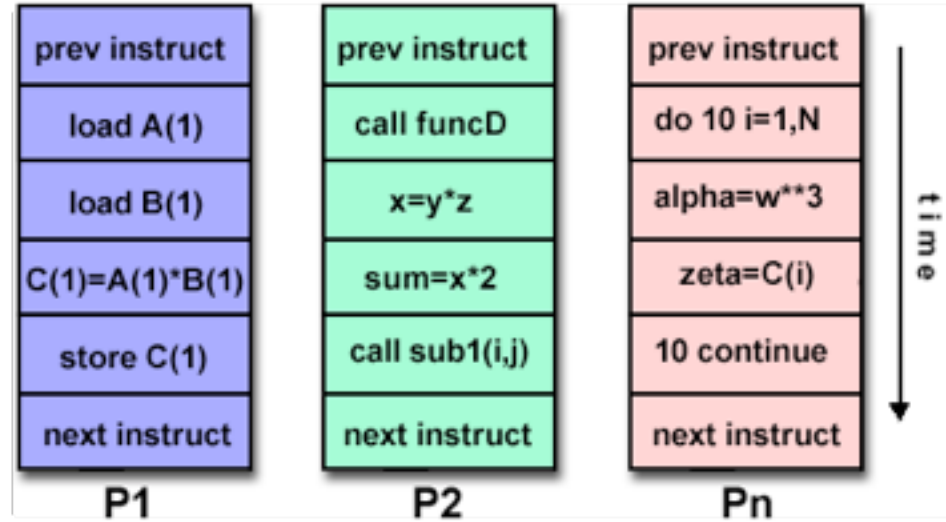
(C) Blaise Barney



Single Instruction, Multiple Data (SIMD)







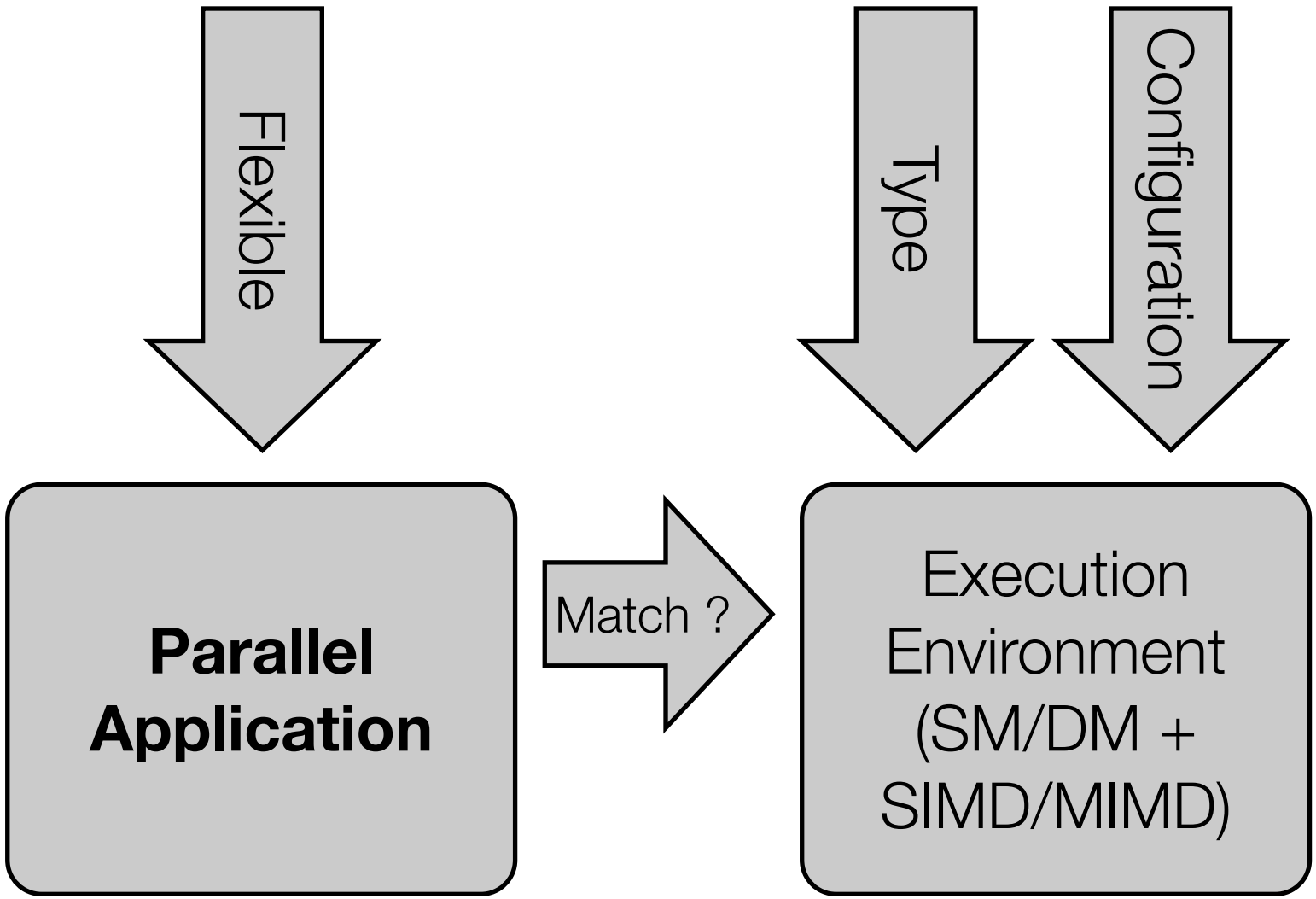
Multiple Instruction, Multiple Data (MIMD)

Execution Environment Examples

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

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

The Parallel Programming Problem



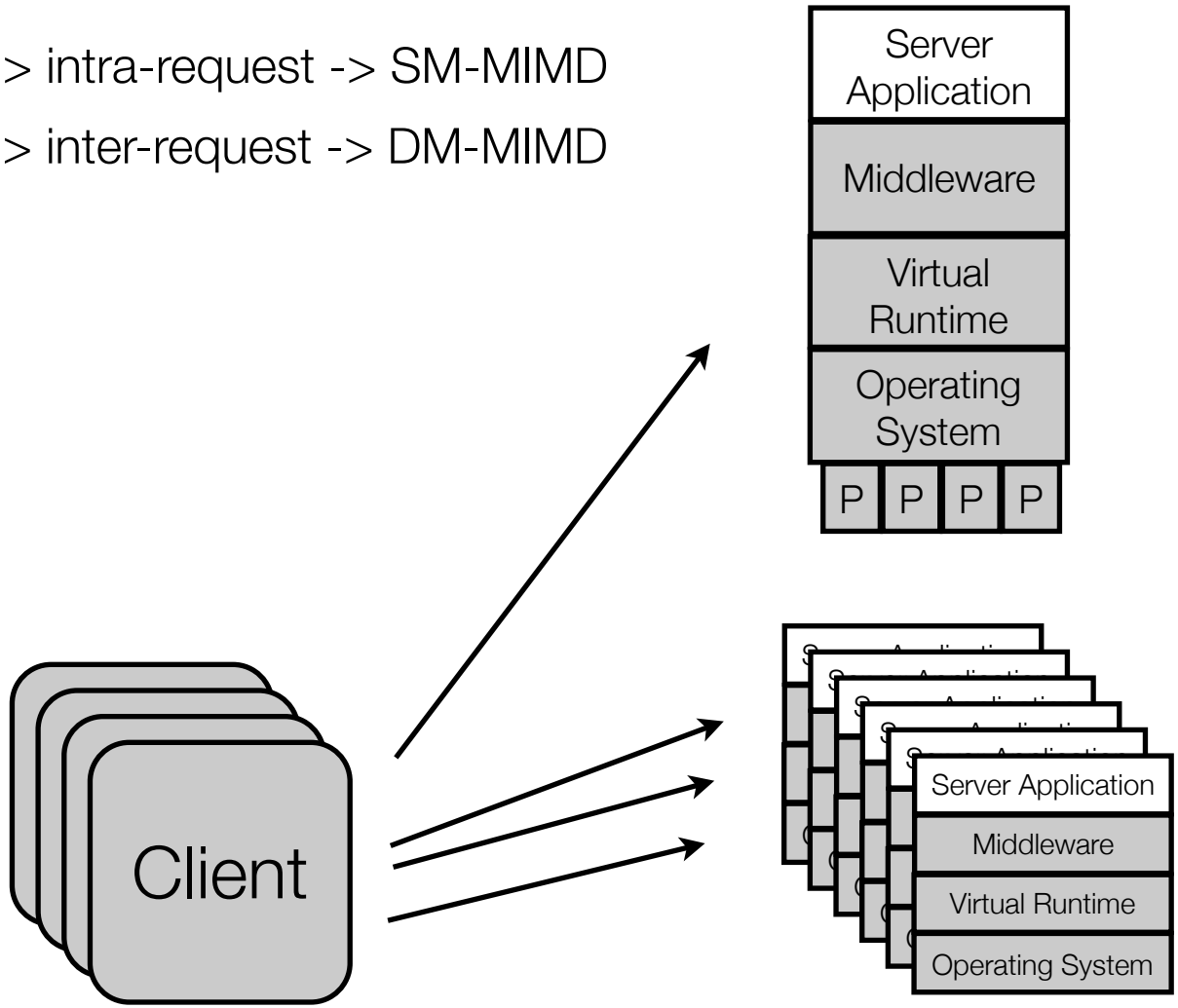
Parallel Application

- 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

Speedup -> intra-request -> SM-MIMD

Scaleup -> inter-request -> DM-MIMD



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

From Multi-Tasking to Implicit Parallelism

- Imperative multi-tasking fails to solve concurrency issues
  - At each statement, developer must decide semantically upon locks to ensure correct data access and data modification
  - For each method call, one must reason about locks being held (deadlock)
  - Locks are not fixed at compile time, new might be created during run time
  - Additional locks might remove race conditions, but also add new deadlocks
  - -> Tackle the problem from a completely different direction
- **Declarative / implicit parallelism** instead of imperative programming
- **Message passing** instead of shared memory as concurrency base

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
- Classification
  - **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 languages and libraries

Parallel Programming Languages

- Programming languages contain of syntax and standard library
  - Example: C + libc, Python + class library
  - Allows adding parallel programming support to sequential languages
- Often languages implement more than one parallel programming model
- Languages are often categorized by their feasibility for a particular execution environment - *„data-parallel languages“* vs. *„task-parallel languages“*
- Most algorithmic problems obviousely match to one kind of execution environment: *„data-parallel problem“* vs. *„task-parallel problem“*

Multi-Tasking	PThreads, OpenMP, OpenCL, Linda, Cilk, ...
Message Passing	MPI, PVM, CSP Channels, Actors, ...
Implicit Parallelism	Map/Reduce, PLINQ, HPF, Lisp, Fortress, ...
Mixed Approaches	Ada, Scala, Clojure, Erlang, X10, ...