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A Pattern-supported Parallelization Approach

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Outline

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- Parallel Design Patterns
- Pattern-supported Parallelization Approach
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  - Pattern Catalogue
- Case study: Unmanned Aerial Vehicle
- Summary

Motivation

- Multicore and manycore CPUs in embedded systems
- Goals:
  - Faster execution of a workload
  - Concurrent execution of multiple tasks
  - Shorter reaction times
  - Energy savings because of lower clock frequency

→ **Need for parallel applications**

- But, especially for embedded systems:
  - Much legacy code
  - Limited development resources
  - Complicated testing and debugging

Parallel Design Patterns

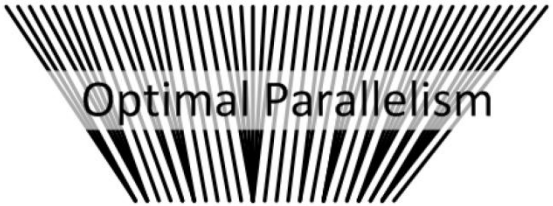
- Design Patterns
  - Idea initially in architecture
  - Recurring problems → best practice solutions
  - Transfer to software engineering
  - Mainly object oriented design, see “Gang of four”
  - Standardized description: Pattern Catalogue

- Parallel design patterns
  - Extended concept: design patterns providing parallelism
  - Tradeoff: flexibility in design vs. development effort

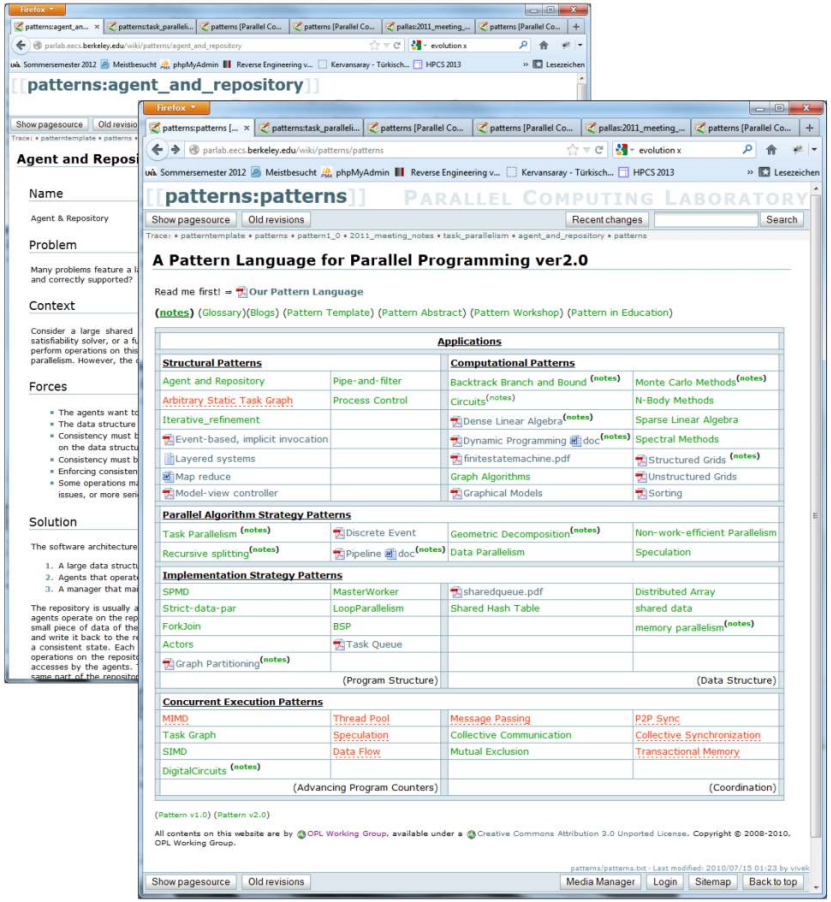
Pattern-supported Parallelization Approach

- **Starting point:**
  - Sequential program (“legacy code”)
  - Pattern Catalogue with parallel design patterns
- **Phase 1: Targeting Maximum Parallelism**
  - Create model to reveal parallelism
  - Model consisting of sequential parts and parallel design patterns
  - Platform independent

- **Phase 2: Targeting Optimal Parallelism**
  - Agglomeration of nodes, definition of parameters
  - Creation of threads and mapping onto target architecture
  - Platform dependent



Pattern Catalogue

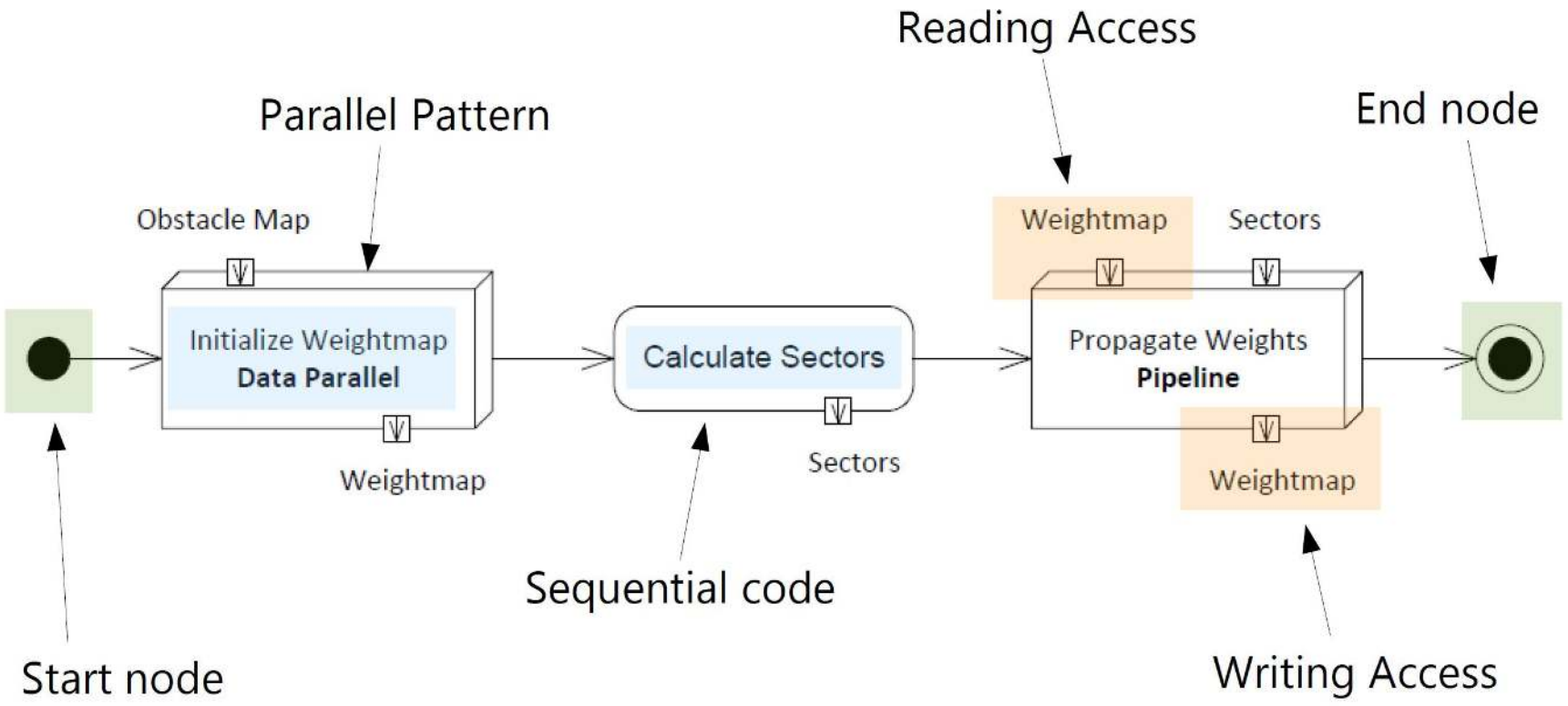


- The Pattern Catalogue:
  - Basis for parallelization
  - Contains all allowed parallel design patterns
  - Description according to meta-pattern
  - Description is textual, no reference implementations
  - Implementation examples are optional
  - Grows over time
- Example: “Our Pattern Language”
  - http://parlab.eecs.berkeley.edu/wiki/patterns/patterns
  - Organized in multiple layers

Activity and Pattern Diagram

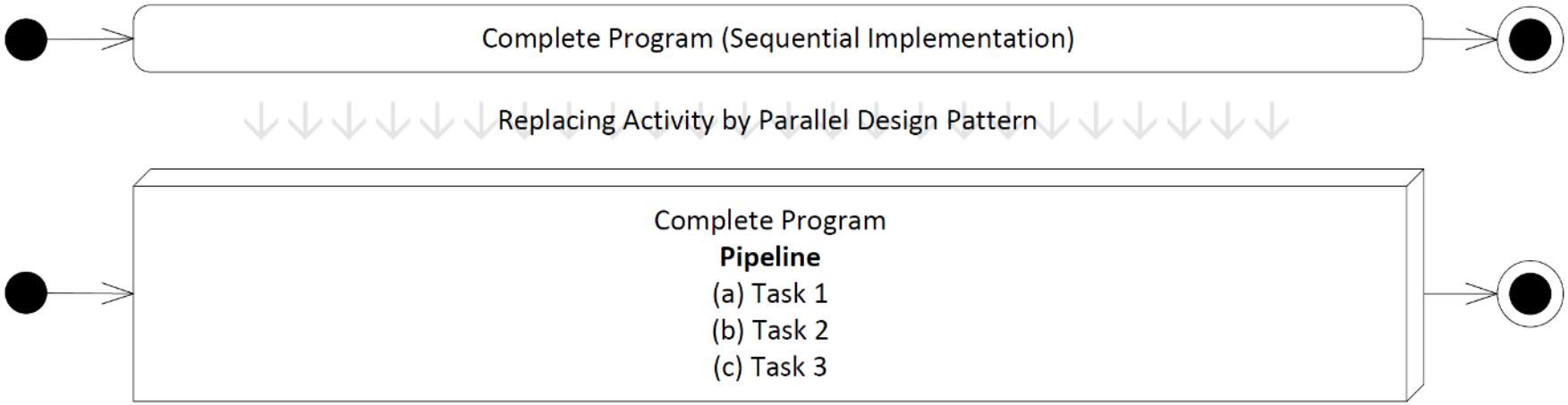
- Extension of UML2 Activity Diagram:
  - *Parallel design pattern* is new node type similar to activity
  - Activities: either sequential or encapsulate APD
  - Parallel design patterns: Multiple activities in parallel
- Patterns are only way to introduce parallelism
- Advantages over inventing a new notation:
  - Well known, easy to understand, tools exist
  - Support for dependencies, branches, and nesting

Activity and Pattern Diagram



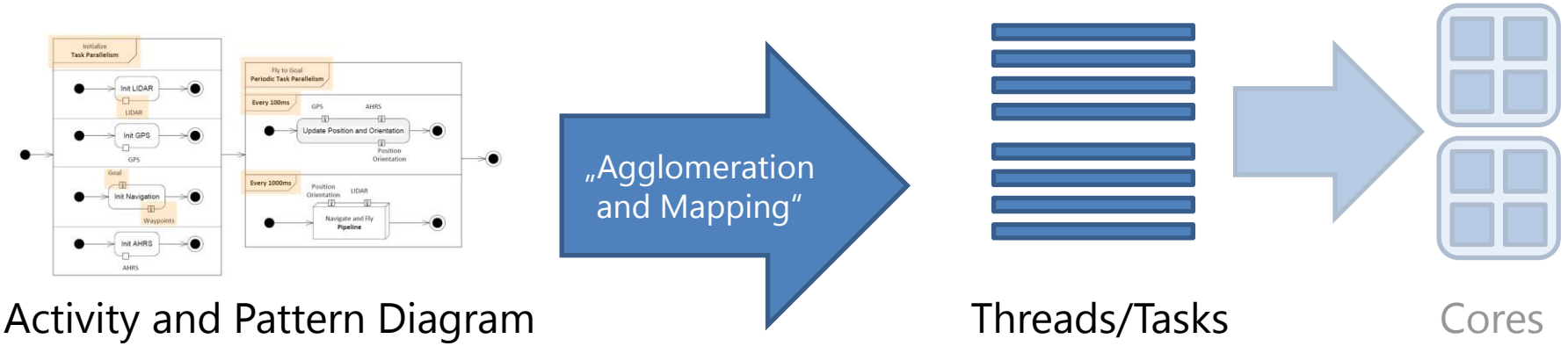
Pattern-supported Parallelization Approach: Phase 1

- Goal: Reveal sufficient parallelism for any platform as Activity and Pattern Diagram (APD)
- Start with single activity, repeatedly apply two operations:
  a) **Replacement:** apply parallel design pattern
  b) **Splitting:** decompose into multiple activities



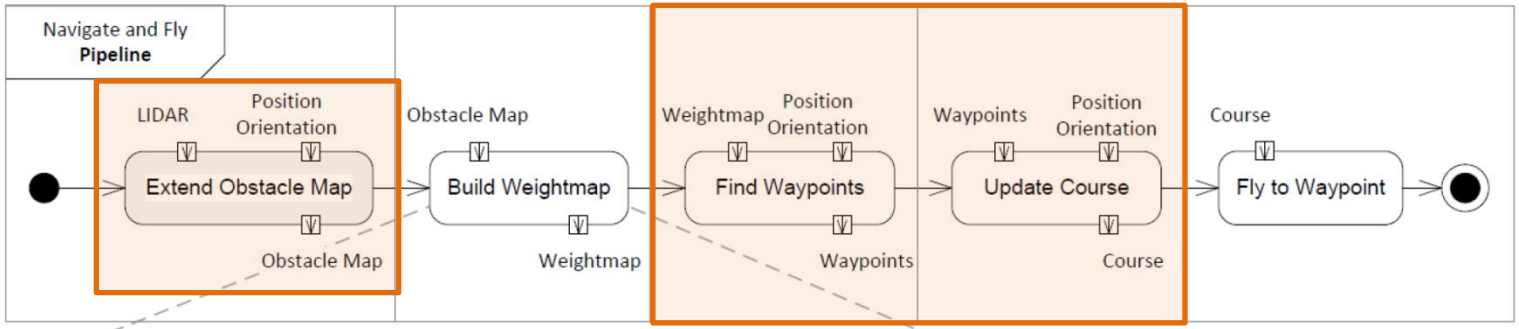
Pattern-supported Parallelization Approach: Phase 2

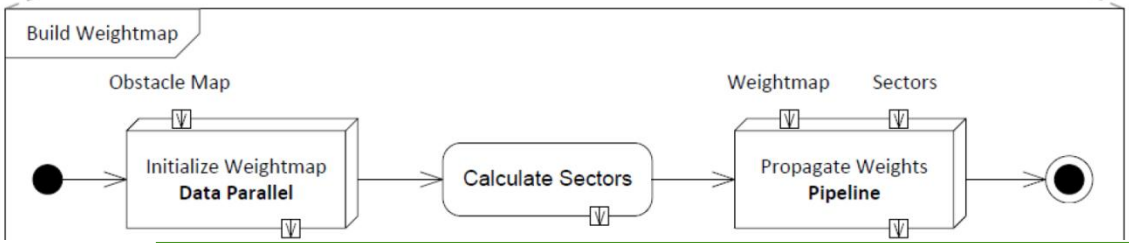
- Transition from maximum to optimal parallelism by agglomeration
- Similar to optimization problem:
  - Global Objective: reduce execution time, energy consumption, …
  - Execution time influenced by e.g. communication/ computation ratio, cost for synchronization, etc.
  - Side conditions: number of available cores/threads; dependencies (control, data, timing), etc.



Pattern-supported Parallelization Approach: Phase 2

- Agglomeration is…
  - **Replacing a parallel design pattern** by an activity, e.g., replacing pipeline by activity → Reduction of parallelism
  - **Joining elements** of parallel design pattern, e.g., multiple pipeline stages to single one → Reduction of overhead
  - **Defining parameters**, e.g., concurrent workers for data parallelism → Tailoring design patterns to target platform





Pattern-supported Parallelization Approach: Phase 2

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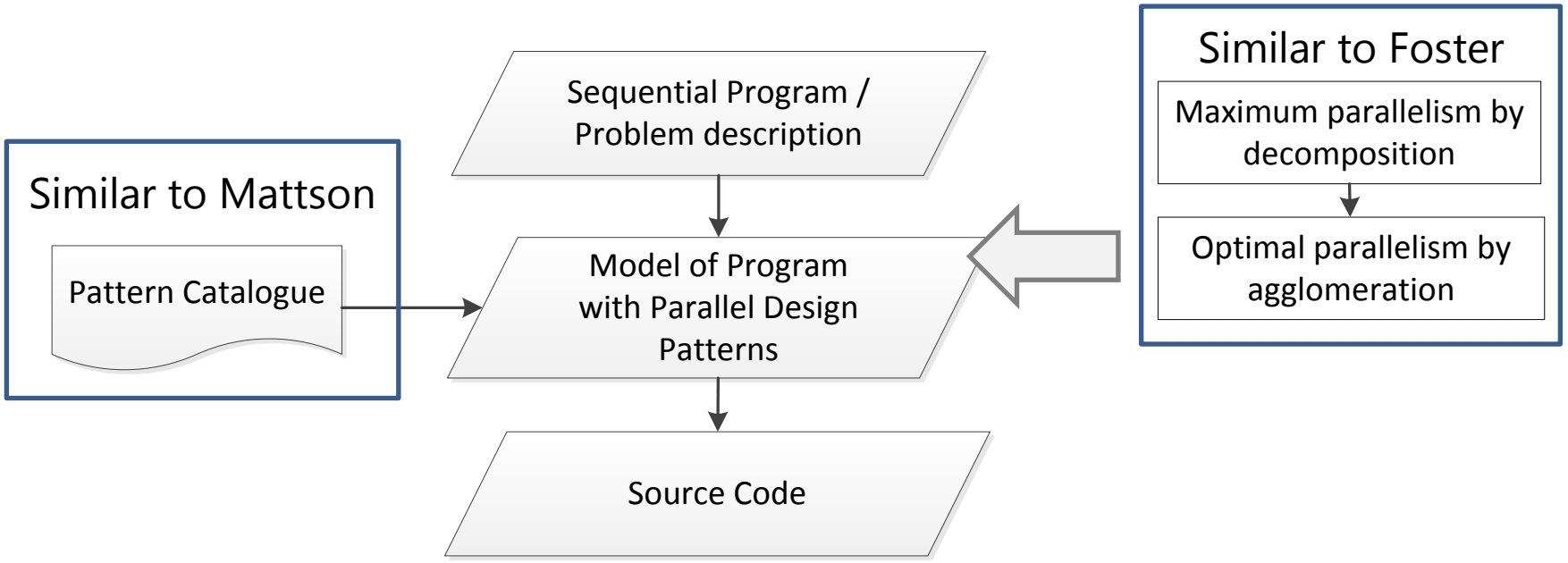
- Mapping
  - Find optimal mapping between code (APD) and threads/tasks and cores/clusters
  - Trade-off between optimal use of resources vs. parallelism
  - Not in focus of parallelization, different research area
- Objectives for parallelization process
  - Speedup/rough approximation of speedup
  - Resource usage
  - Energy consumption
  - Implementation effort (e.g. number of patterns)
- If necessary: iterative application of process!

Pattern-supported Parallelization Approach



- Manual process with clear methodology
- Fast modelling of parallelism with Activity and Pattern Diagram; derived from UML2
- Pattern Catalogue
  - Easier implementation of parallel program
  - Higher Documentation Quality
- Algorithmic skeletons for reduced implementation effort

Example & Work in Progress: Unmanned Aerial Vehicle (UAV)

http://www.oberwelzdesign.com/en/project/quadcopter01

The Software

- Autonomous flight over terrain
  - Obstacle detection
  - Automatic path planning (Laplace operator)
- Assumptions:
  - Sequential software exists
- Overview of the software:
  - Initialize system
  - Loop until goal is reached:
    - Determine position
    - Mark obstacles
    - Plan path
    - Set course

Parallelization

- Phase 1
  - Goal: Expose parallelism
  - Finished, see paper
  - Six instances of parallel design patterns
- Phase 2
  - Goal: Tailor parallelism to target platform
  - But: work in progress, no target platform yet defined
  - Approximated speedup based on profiling: 7.8
    - → Enough parallelism for 2 to 6 cores
    - → Further work necessary for 8+ cores

Summary

- Pattern-supported parallelization approach
  - Two phases:
    - Reveal parallelism: architecture independent
    - Agglomerate and map: architecture dependent
  - Only **parallel design patterns** to introduce parallelism
  - Parallel design patterns are described in **Pattern Catalogue**
  - Supporting structure: **Activity and Pattern Diagram**, similar to UML2 Activity Diagram
  - Limited effort for parallelization and implementation of parallel program
- Future work:
  - Tool support for parallelization, especially Phase 2
  - Extend parallelization process for hard real-time systems
  - More case studies, different platforms → gain knowledge