A Pattern-supported Parallelization Approach

Ralf Jahr, Mike Gerdes, Theo Ungerer

University of Augsburg, Germany

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Outline

- Motivation
- Parallel Design Patterns
- Pattern-supported Parallelization Approach
  - Two phases
  - Activity and Pattern Diagram
  - 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

Parallelization Approach

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

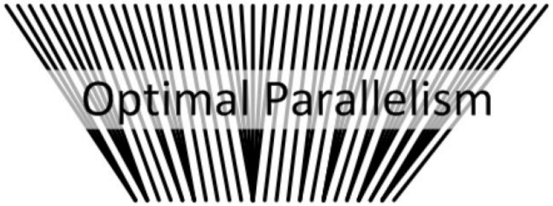
- Parallel design patterns
  - Extended concept: design patterns providing parallelism
  - Tradeoff: flexibility in design vs. development effort

Pattern-supported Parallelization Approach

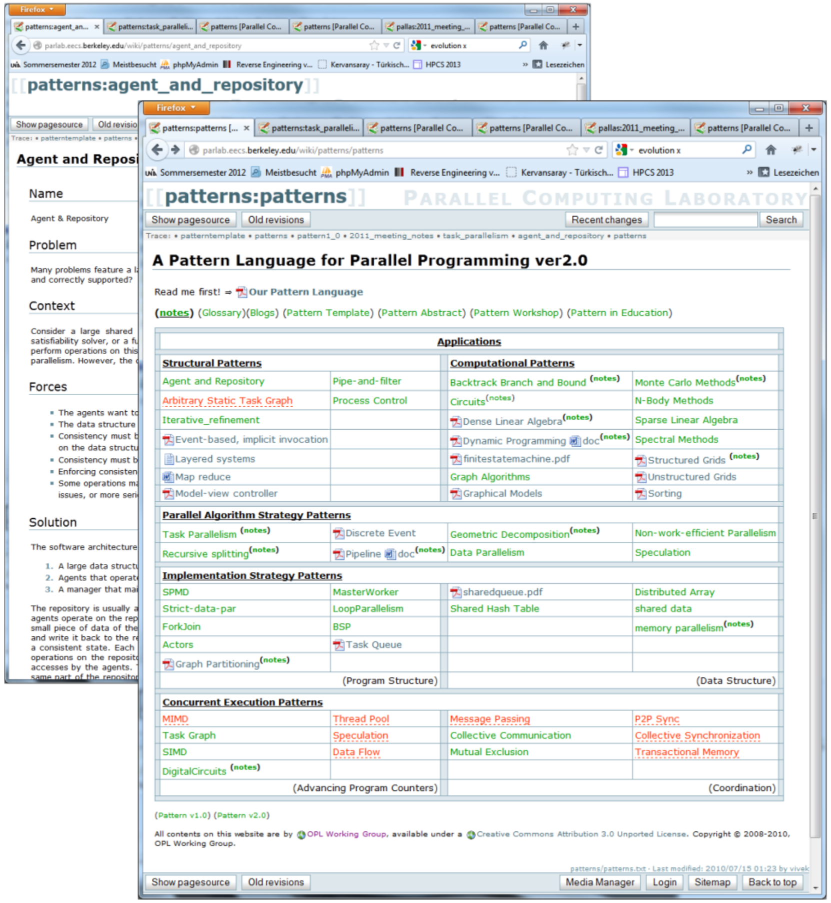
- **Starting point:**
  - Sequential program (“legacy code”)
  - Pattern Catalogue with parallel design patterns
- **Phase 1: Targeting Maximum Parallelism**
  - Create model to reveal parallelism
  - Model consisting of sequential parts and parallel design patterns
  - Platform independent

Maximum Parallelism

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



Pattern Catalogue



patterns:agent_and_repository

Agent and Reposi

Name

Agent & Repository

Problem

Context

Forces

Solution

patterns:patterns

PARALLEL COMPUTING LABORATORY

Trace: • patterntemplate • patterns • pattern1_0 • 2011_meeting_notes • task_parallelism • agent_and_repository • patterns

A Pattern Language for Parallel Programming ver2.0

Read me first! ⇒ Our Pattern Language

(notes) (Glossary)(Blogs) (Pattern Template) (Pattern Abstract) (Pattern Workshop) (Pattern in Education)

Applications			
Structural Patterns		**Computational Patterns**	
Agent and Repository	Pipe-and-filter	Backtrack Branch and Bound (notes)	Monte Carlo Methods(notes)
Arbitrary Static Task Graph	Process Control	Circuits(notes)	N-Body Methods
Iterative_refinement		Dense Linear Algebra(notes)	Sparse Linear Algebra
Event-based, implicit invocation		Dynamic Programming doc(notes)	Spectral Methods
Layered systems		finitestatemachine.pdf	Structured Grids (notes)
Map reduce		Graph Algorithms	Unstructured Grids
Model-view controller		Graphical Models	Sorting
Parallel Algorithm Strategy Patterns			
Task Parallelism (notes)	Discrete Event	Geometric Decomposition(notes)	Non-work-efficient Parallelism
Recursive splitting(notes)	Pipeline doc(notes)	Data Parallelism	Speculation
Implementation Strategy Patterns			
SPMD	MasterWorker	sharedqueue.pdf	Distributed Array
Strict-data-par	LoopParallelism	Shared Hash Table	shared data
ForkJoin	BSP		memory parallelism(notes)
Actors	Task Queue		
Graph Partitioning(notes)			
	(Program Structure)		(Data Structure)
Concurrent Execution Patterns			
MIMD	Thread Pool	Message Passing	P2P Sync
Task Graph	Speculation	Collective Communication	Collective Synchronization
SIMD	Data Flow	Mutual Exclusion	Transactional Memory
DigitalCircuits (notes)			
	(Advancing Program Counters)		(Coordination)

(Pattern v1.0) (Pattern v2.0)

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patterns/patterns.txt · Last modified: 2010/07/15 01:23 by vivek

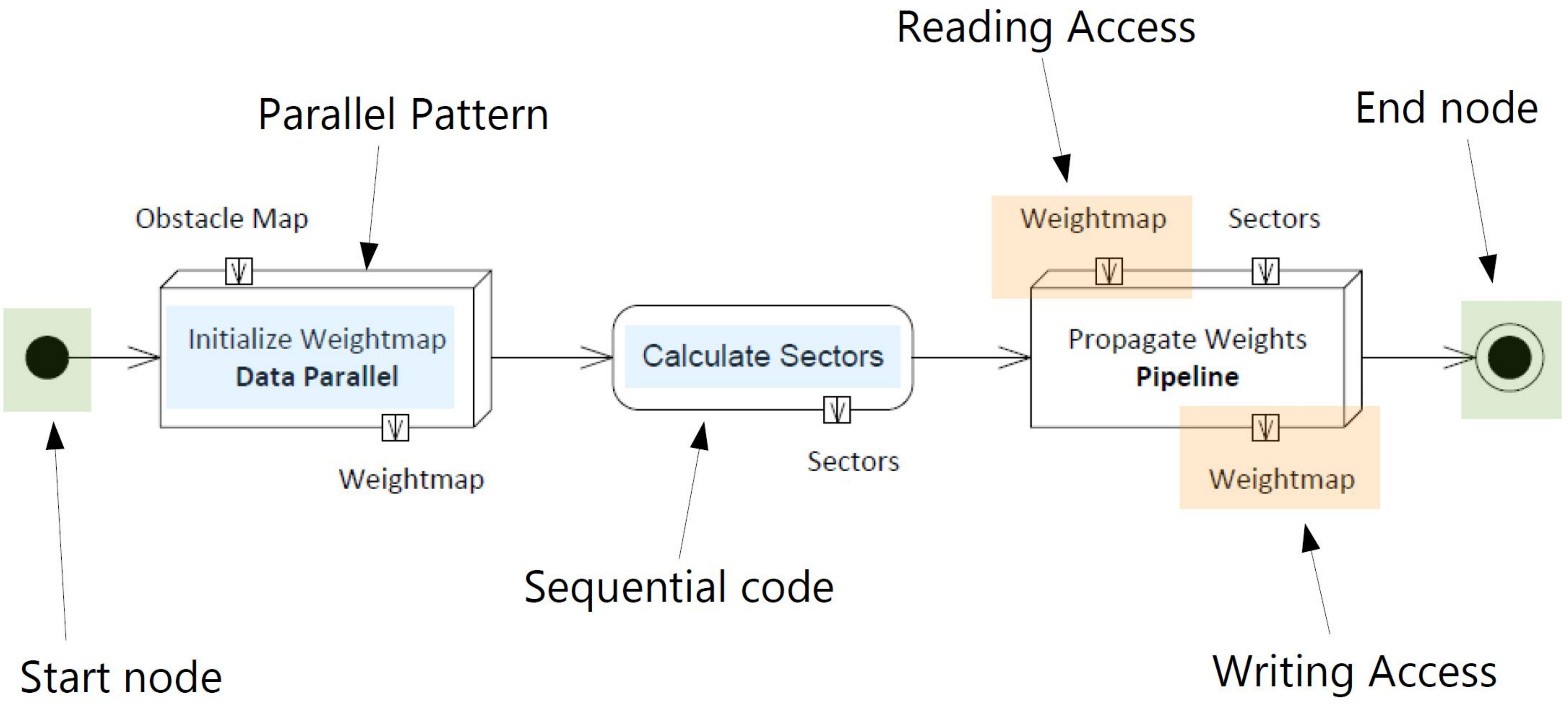
- The Pattern Catalogue:
  - Basis for parallelization
  - Contains all allowed parallel design patterns
  - Description according to meta-pattern
  - Description is textual, no reference implementations
  - Implementation examples are optional
  - Grows over time

- Example: “Our Pattern Language”
  - http://parlab.eecs.berkeley.edu/wiki/patterns/patterns
  - Organized in multiple layers

Activity and Pattern Diagram

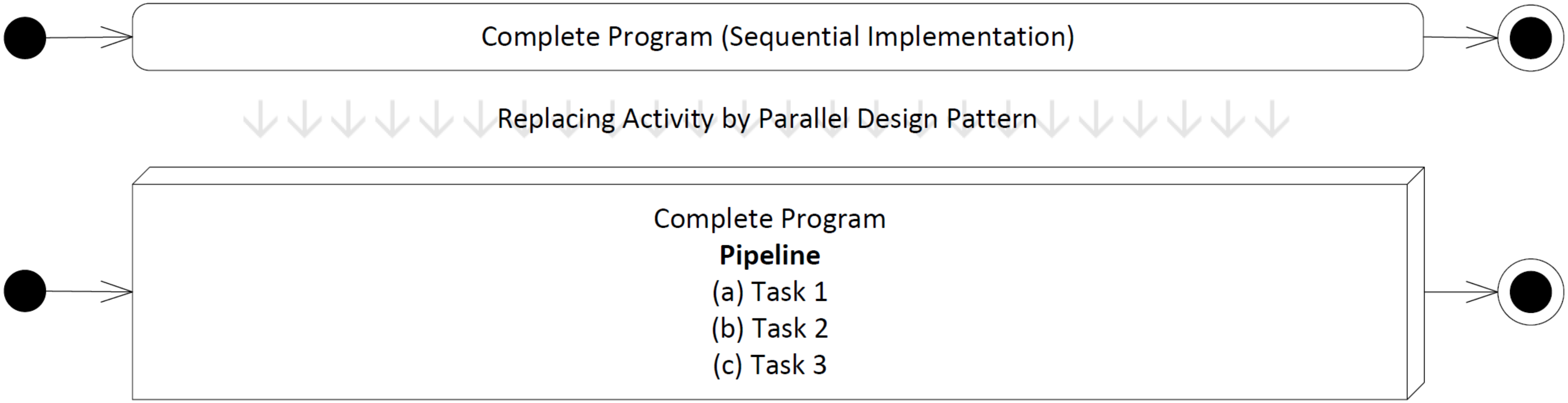
- Extension of UML2 Activity Diagram:
  - *Parallel design pattern* is new node type similar to activity
  - Activities: either sequential or encapsulate APD
  - Parallel design patterns: Multiple activities in parallel
- Patterns are only way to introduce parallelism
- Advantages over inventing a new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

Activity and Pattern Diagram



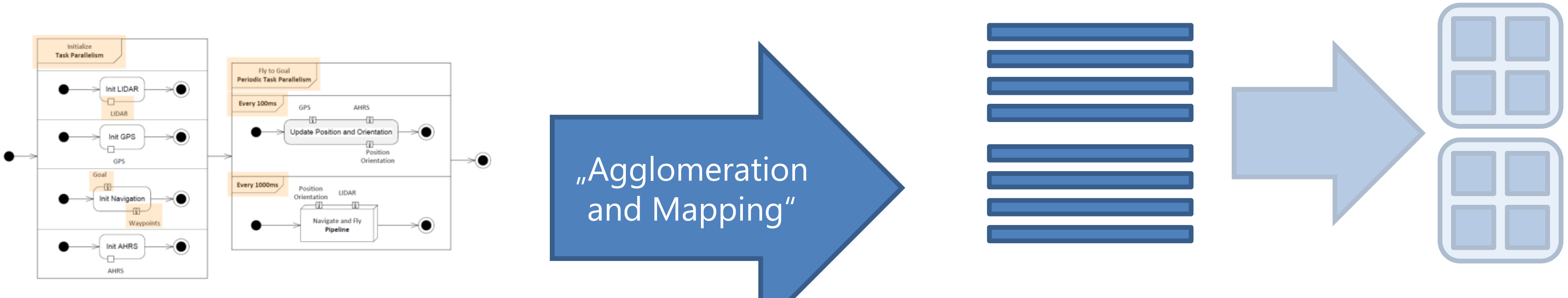
Pattern-supported Parallelization Approach: Phase 1

- 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


Complete Program (Sequential Implementation)
Replacing Activity by Parallel Design Pattern
Complete Program
Pipeline
(a) Task 1
(b) Task 2
(c) Task 3

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.



„Agglomeration and Mapping“

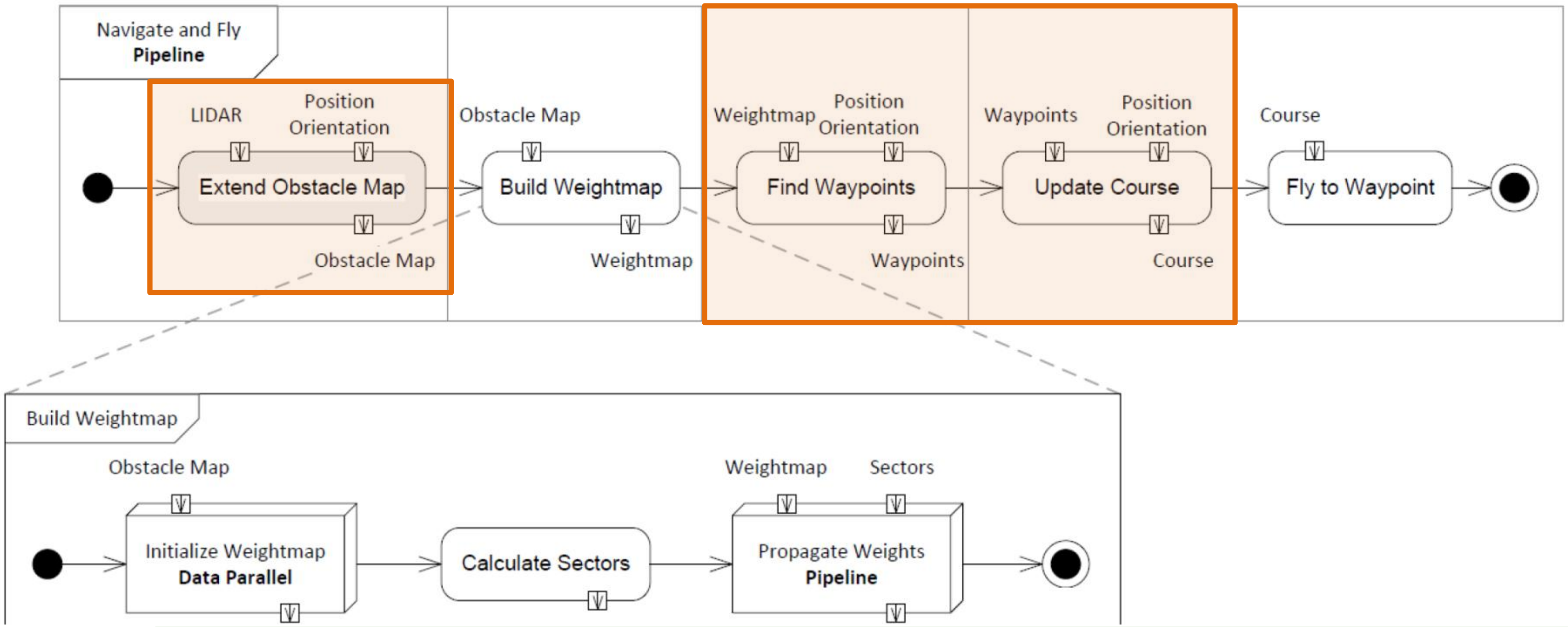
Activity and Pattern Diagram

Threads/Tasks

Cores

Pattern-supported Parallelization Approach: Phase 2

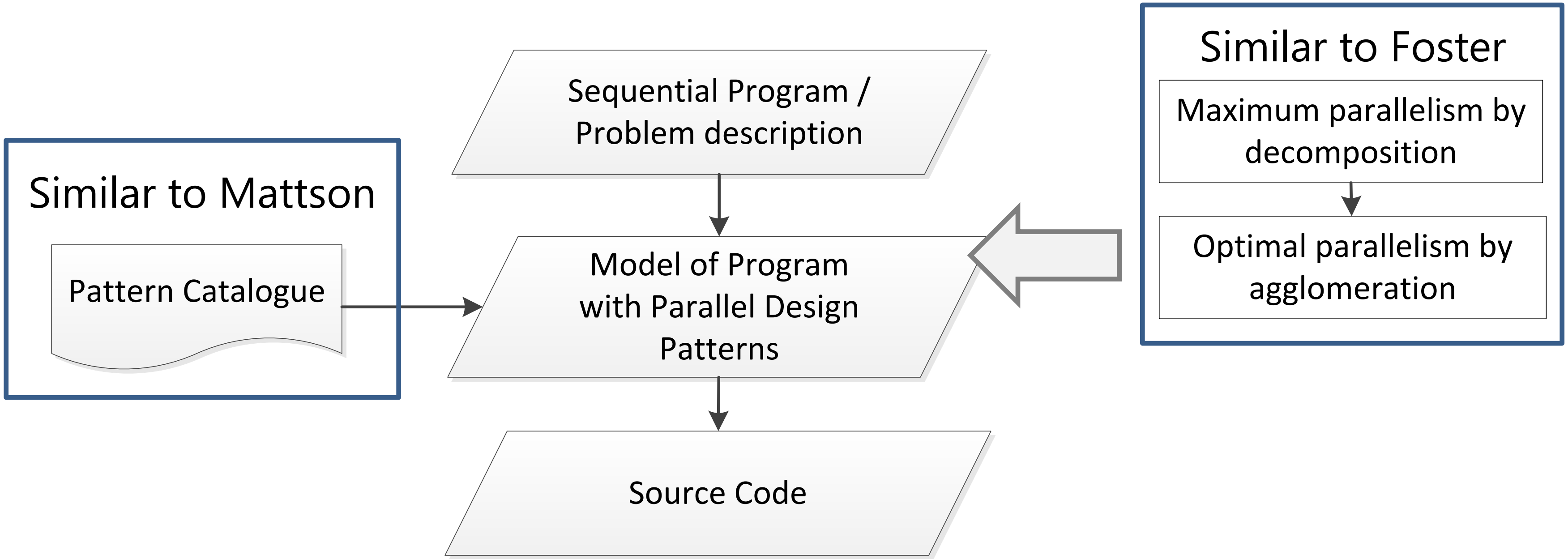
- Agglomeration is…
  - **Replacing a parallel design pattern** by an activity, e.g., replacing pipeline by activity → Reduction of parallelism
  - **Joining elements** of parallel design pattern, e.g., multiple pipeline stages to single one → Reduction of overhead
  - **Defining parameters**, e.g.,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



Pattern-supported Parallelization Approach: Phase 2

- 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


Similar to Mattson
Pattern Catalogue
Sequential Program / Problem description
Model of Program with Parallel Design Patterns
Source Code
Similar to Foster
Maximum parallelism by decomposition
Optimal parallelism by agglomeration

- 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