Tracking with Multiple Sensors

Martin Wagner

Lehrstuhl für Angewandte Softwaretechnik
Institut für Informatik
Technische Universität München
martin.wagner@in.tum.de

Overview

- Problem Statement
- Approach
- Formal Model
- Distributed Implementation
- Handling Mobile Setups
- Demo Application: Ubiquitous SHEEP
- Conclusions & Future Work

Research Areas

Augmented Reality (AR)

1. Combines real and virtual objects in real environment
2. Runs interactively, and in real time
3. Registers real and virtual objects in three dimensions

[Azuma 1997]

Ubiquitous Computing (Ubicomp)

- Magnitude of computers for every user, stationary and mobile
- Computing infrastructure becomes invisible in user's lives
- Key feature: *context awareness* leading to *implicit interaction*

[Weiser 1991, Schilit 1994]

Problem Statement

Provide abstraction from location sensors

- Concurrent access by multiple applications
- Transparent handling of sensor access and fusion
- Support requirements from AR (e.g. performance, accuracy) and Ubicomp (e.g. scalability, sensor diversity)
- Support dynamic changes in availability of sensors

AR in Intelligent Environments

- AR applications extend their range of operation
  - Mobile AR
  - Powerful wearable devices
- Ubicomp applications extend their immersivity
  - “Natural” interaction benefits from accurate location information
- Combining tracking requirements from ubicomp *and* AR allows to use AR interaction in ubiquitous environments

Enhancing AR Tracking Technology

- No single sensor is perfect for all AR applications
  - Sensor fusion gains attention
  - Reusable solutions required
- Tracking technologies tend to build upon each other
  - Initialization problem for natural feature tracking
  - Stabilize results of absolute by relative tracker

Overview

- Problem Statement
- Approach
- Formal Model
- Distributed Implementation
- Handling Mobile Setups
- Demo Application: Ubiquitous SHEEP
- Conclusions & Future Work

Approach

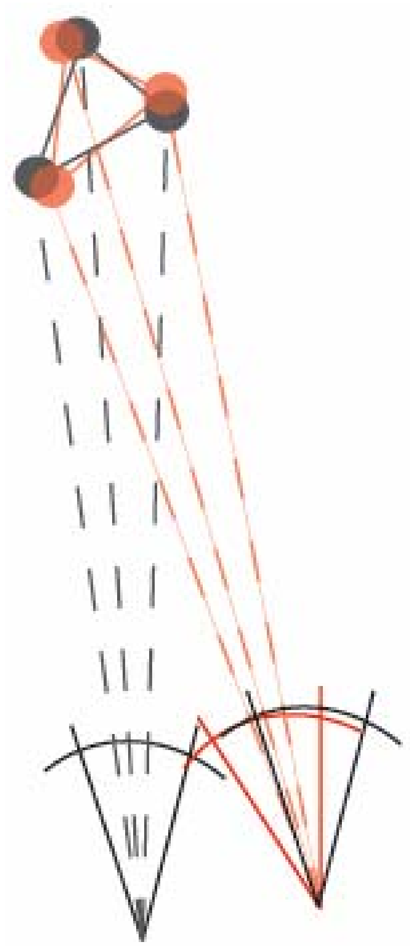
1. Analyze existing applications, location sensors and multi-sensor fusion systems from AR and Ubicomp
2. Define abstract formalism supporting arbitrary sensor networks
3. Design distributed implementation concept bringing formalism to real problems
4. Implement prototypical middleware
5. Define and implement architecture allowing to integrate mobile sensor setups at run time

Overview

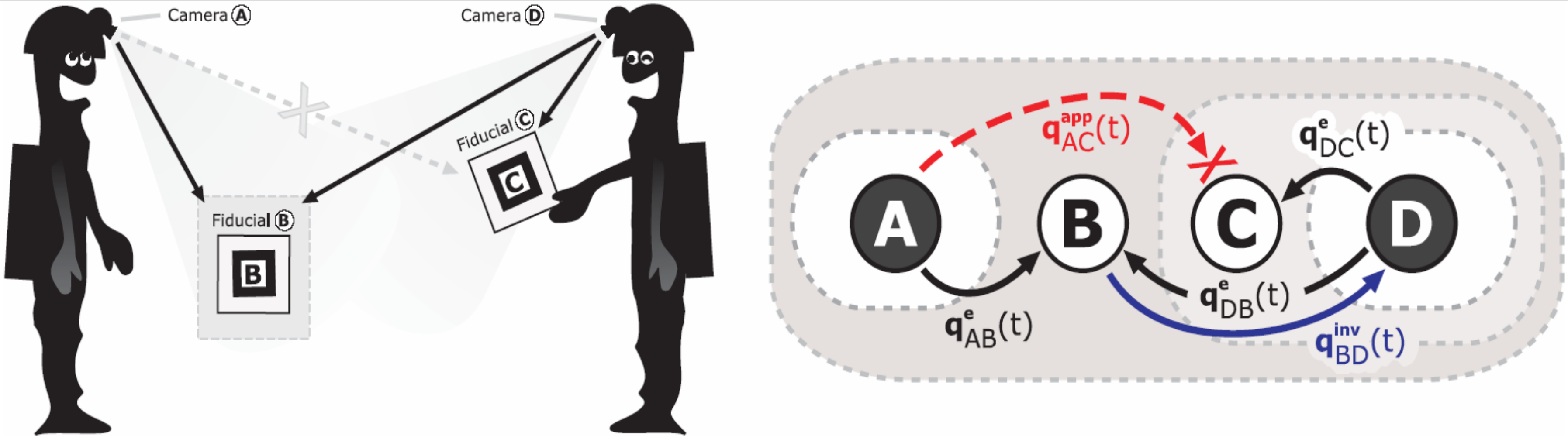
- Problem Statement
- Approach
- Formal Model
- Distributed Implementation
- Handling Mobile Setups
- Demo Application: Ubiquitous SHEEP
- Conclusions & Future Work

Formal Model: Challenges

- Non-trivial inversion of spatial relationships
- Timing issues: measurements made at discrete points in time, demand for estimates in continuous time
- Should map onto real implementation without too many restrictive assumptions
- For this purpose: handle dynamic changes in availability of spatial relationships



Formal Model



- Approach: directed ***spatial relationship graph***
  - Describe spatial relationships as functions of time
  - Functions yield estimates of spatial relationship characterised by attributes
- Generic inference mechanism:
  1. Find shortest path in SR graph (according to application defined criteria based on attributes)
  2. Set up run time data flow graph according to shortest path

Overview

- Problem Statement
- Approach
- Formal Model
- Distributed Implementation
- Handling Mobile Setups
- Demo Application: Ubiquitous SHEEP
- Conclusions & Future Work

Why Peer to Peer Implementation?

- Allow ad-hoc connections of mobile setups
  - Use stationary equipment for mobile users' applications
  - Use mobile users' equipment (e.g. cameras, accelerometers) for stationary infrastructure and applications
- Make mobile setup self-contained
  - Mobile users should access spatial relationships without stationary infrastructure
- No single point of failure
  - Important for safety critical applications

Distributed Implementation

- Concept based on fully distributed label correcting shortest path algorithm
- Two-phase setup:
  1. Find shortest path and set up corresponding data flow network
  2. Transform run time spatial data within this efficient network
- Simulation shows feasibility of approach for small setups
- Prototype implementation based on DWARF AR framework
- Sensors and run time data flow modeled as set of *services*
- Demonstration setup combining stationary ART dTrack system with mobile ARToolkit vision-based tracker

Overview

- Problem Statement
- Approach
- Formal Model
- Distributed Implementation
- Handling Mobile Setups
- Demo Application: Ubiquitous SHEEP
- Conclusions & Future Work

Integrating Mobile Setups at Run Time

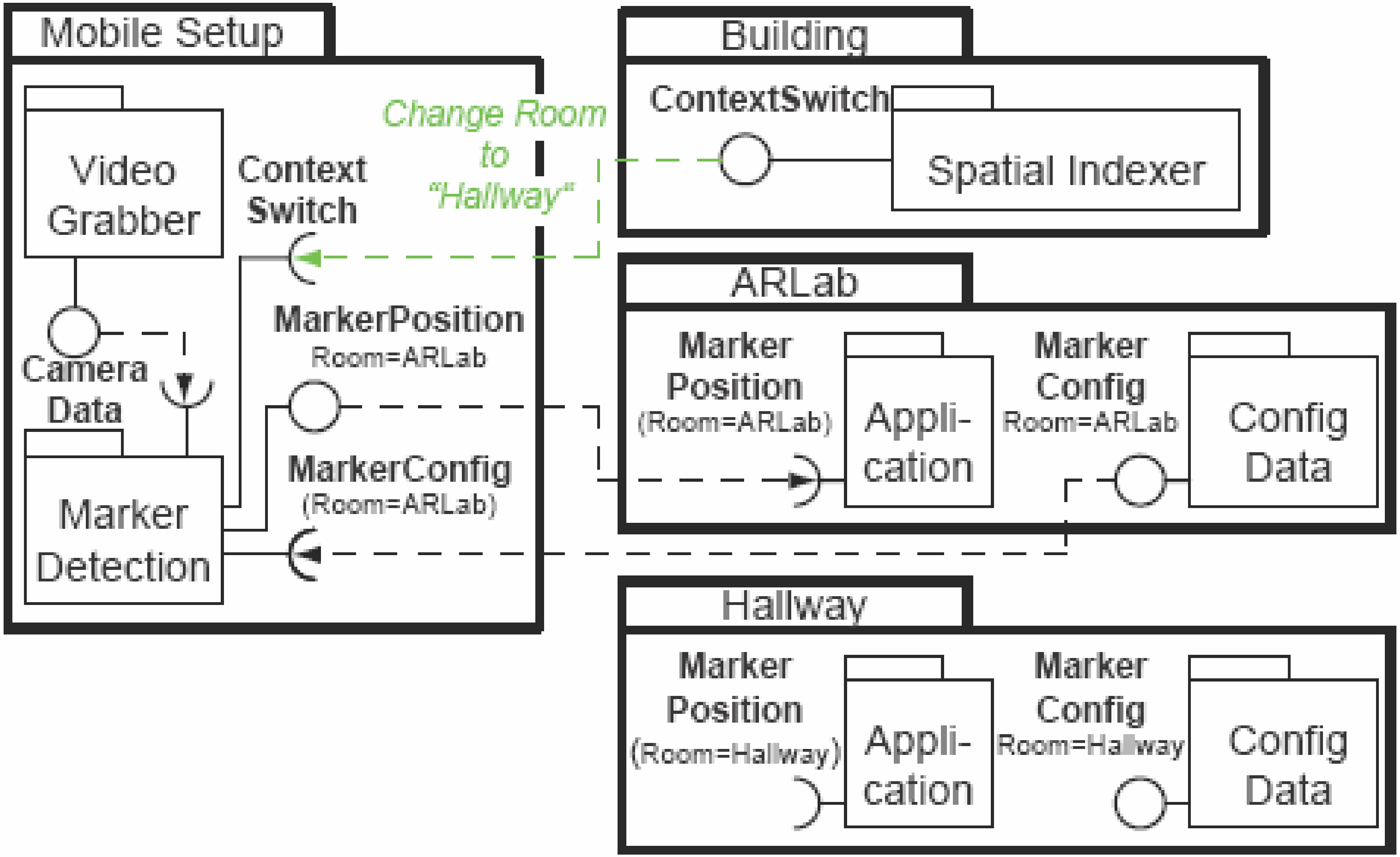
Situation:

- Formalism and distributed implementation assume all relevant objects have unique ID
- Especially vision-based sensors work via template matching, in unknown environments they have to be initialized with situation specific templates

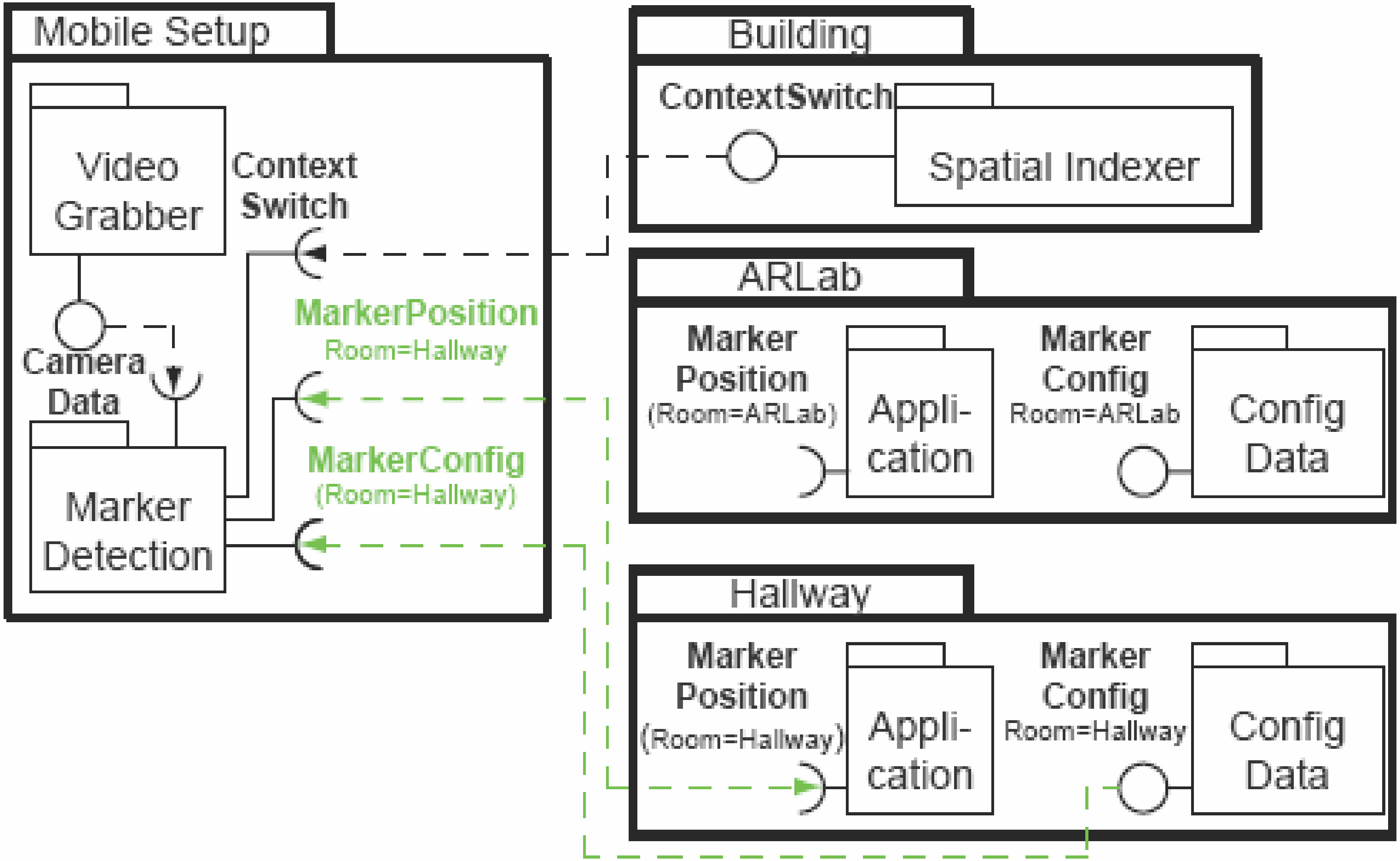
Proposed Architecture:

- Concept: distribute configuration information along spatial entities (rooms, buildings etc.)
- Employ DWARF service location facilities to configure mobile components in context-aware fashion

Example: Moving from Lab to Hallway



Example: Moving from Lab to Hallway

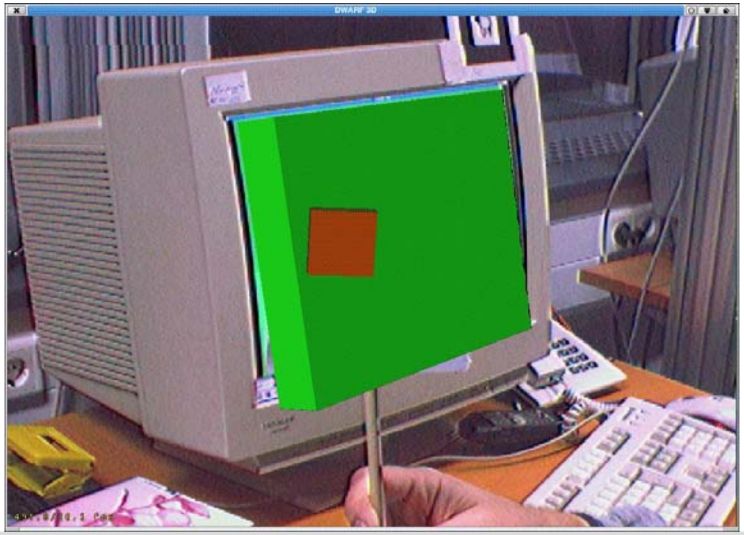


Overview

- Problem Statement
- Approach
- Formal Model
- Distributed Implementation
- Handling Mobile Setups
- Demo Application: Ubiquitous SHEEP
- Conclusions & Future Work

Ubiquitous SHEEP

- Integrated demo application bringing all discussed concepts together
- Game-playing scenario: user can carry around and color virtual sheep
- Tracking setup modeled with formalism
- Configuration of mobile setup and sheep application logic uses mobile configuration architecture



Overview

- Problem Statement
- Approach
- Formal Model
- Distributed Implementation
- Handling Mobile Setups
- Demo Application: Ubiquitous SHEEP
- Conclusions & Future Work

Conclusions

- Applying formalism to real-world AR applications is feasible
- Proposed implementation restricts formalism's expressiveness only marginally in real applications
- Context-aware configuration architecture allows to segregate syntactic sensor information from semantic context information

Future Work

- Extend formalism to incorporate low quality sensors (e.g. accelerometers) and advanced generic sensor fusion schemes
- Define hierarchy of spatial relationships to reduce the search space for inferences
- Find application areas for highly dynamic multi-sensor setups

Thank you.

Any questions?