Introduction and Research Background

Joachim Hertzberg

Osnabrück University
and DFKI Robotics Innovation Center

UNIVERSITÄT OSNABRÜCK

Overview

1. Osnabrück, its University, and DFKI
2. Research in Plan-Based Robot Control

   ****** Lunch Break ******

3. Application-Oriented Research:

   Agricultural Robotics

4. Plan of (my part of) the SAI seminar

1. Osnabrück, its University, and DFKI
2. Research in Plan-Based Robot Control

   ****** Lunch Break ******

3. Application-Oriented Research:

   Agricultural Robotics

4. Plan of (my part of) the SAI seminar

Osnabrück

- Population: 160,000
  (larger area ≈ 500,000)
- Founded: ≈ 800
- Economy (area):
  - Trade
  - Logistics
  - Food Industry
  - Healthcare
  - Metal Processing
  - Cars (VW)
  - Agricultural Machines

Osnabrück University

UOS Profile

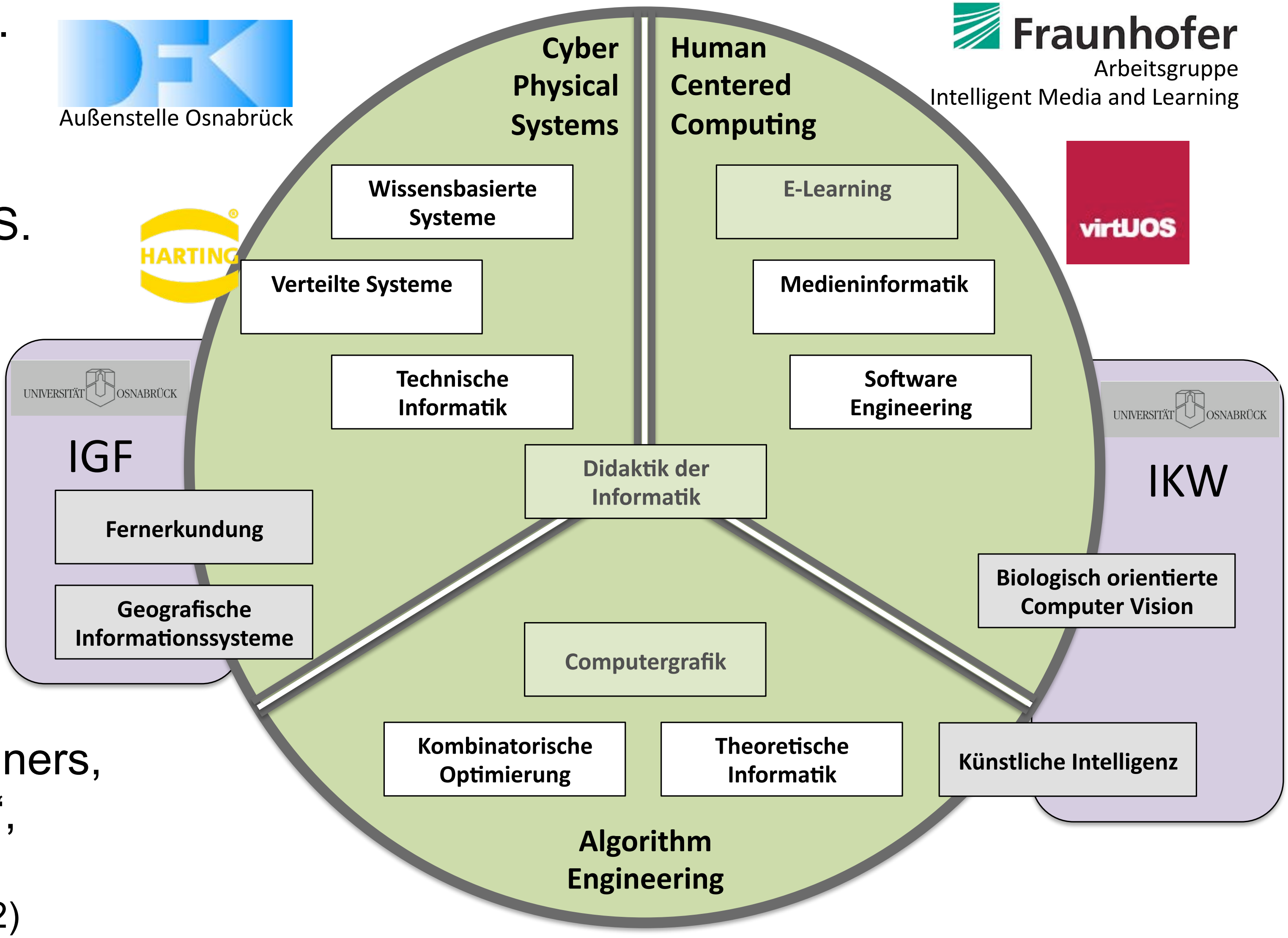
- operational since 1974
- original profile: humanities & teacher education
- recent profile (some elements):
  - interdisciplinary institutes (Cognitive Science, Environmental Syst. Rsch., International Studies, …)
  - teacher education
- Research foci
  - 1 rsch. cluster (DFG), Biology
  - 4 grad. coll. (e.g., Cog. Sci.)

Size

- ≤ 12,000 students
- 1680 staff (≥ 200 profs)
- ≈ 118 Mio € budget (2013)
- no medicine,
  no engineering

Institute of Computer Science

- Bachelor C.S.
- Master C.S
- Dr. rer. nat.
- B.-2-Subj. C.S.
- Teacher's Master
- "Imports"
  - Cog.Sci.
  - Math
  - Physics
  - Economy
  - …
- ca. 120 beginners, plus „imports“, per year (capita, Fall 2012)

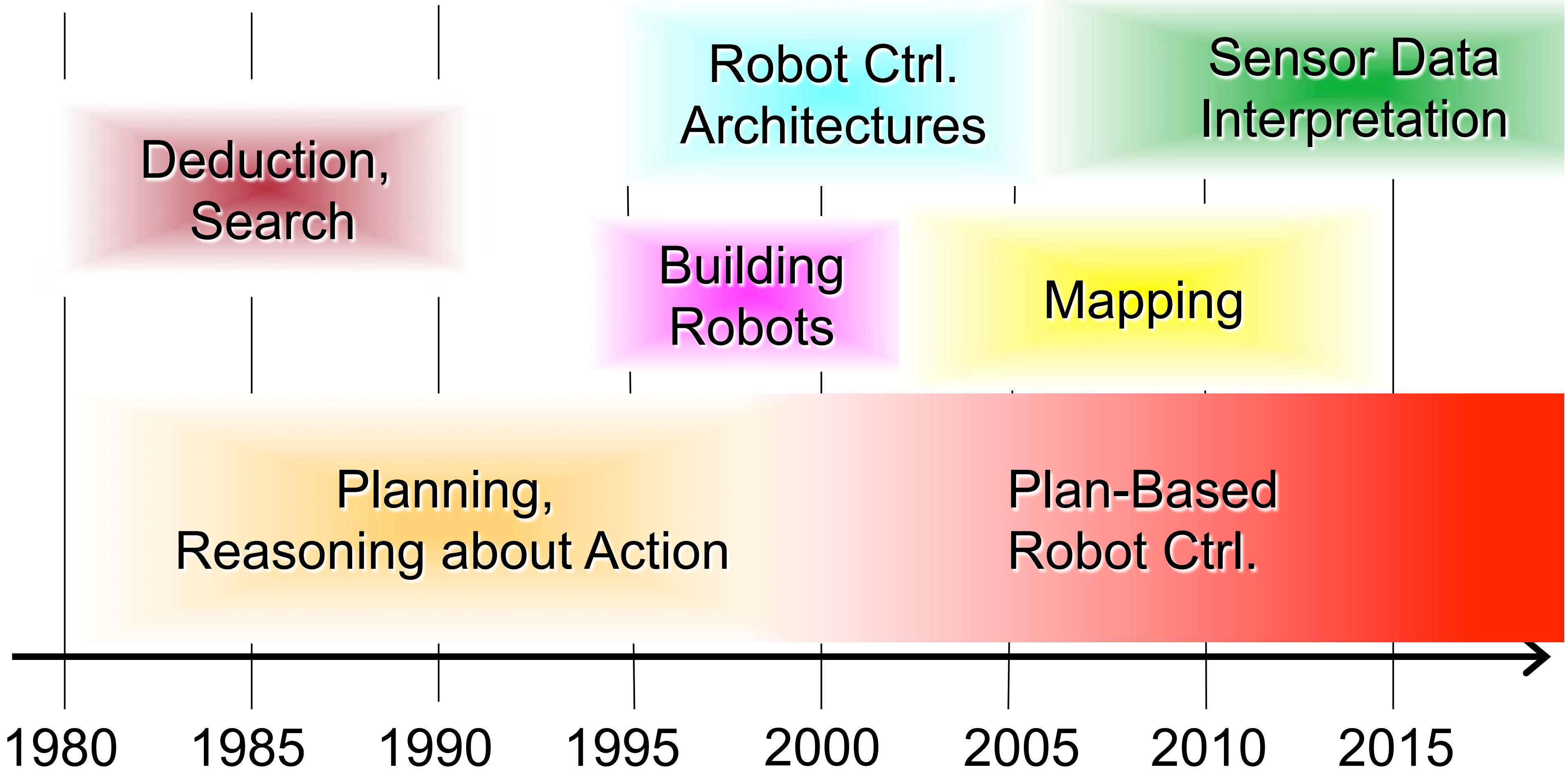


DFKI in Osnabrück

- Osnabrück Branch (of DFKI Robotics Innovation Center) founded in 2011
- Research topic: Plan-based robot control
- Chief application domain: Agricultural robotics
- More about that after lunch!

My Long-Term Research Agenda

How does long-term purposeful behavior work?



1. Osnabrück, its University, and DFKI

2. **Research in Plan-Based Robot Control**

   ****** Lunch Break ******

   2.1 Issues & Challenges
   2.2 Interpreting 3D Point Clouds
   2.3 Plan-Based Control

3. Application-Oriented

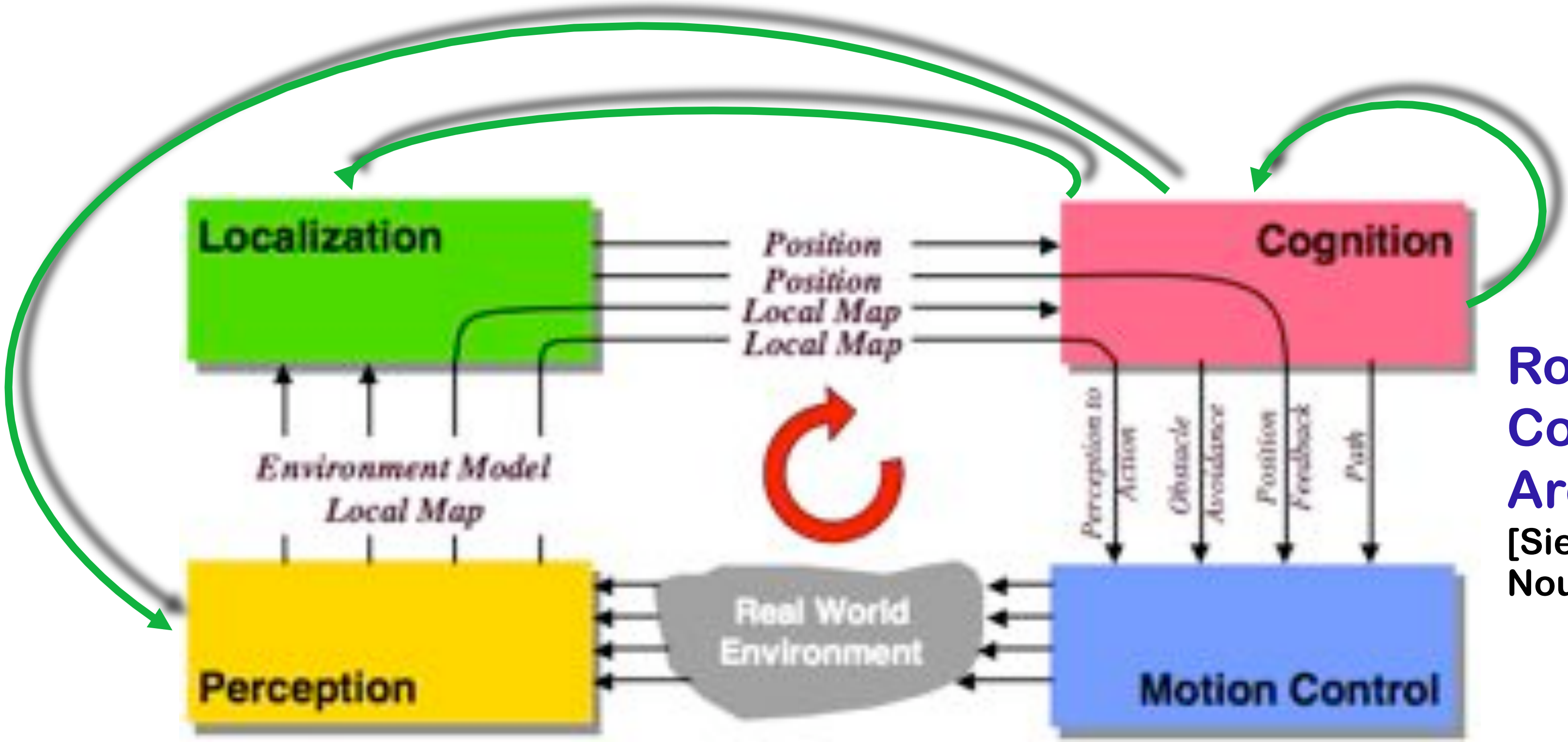
   Agricultural Robotics

4. Plan of (my part of) the SAI seminar

2.1 Issues & Challenges

2.2 Interpreting 3D Point Clouds
2.3 Plan-Based Control

Really Closing the Loop

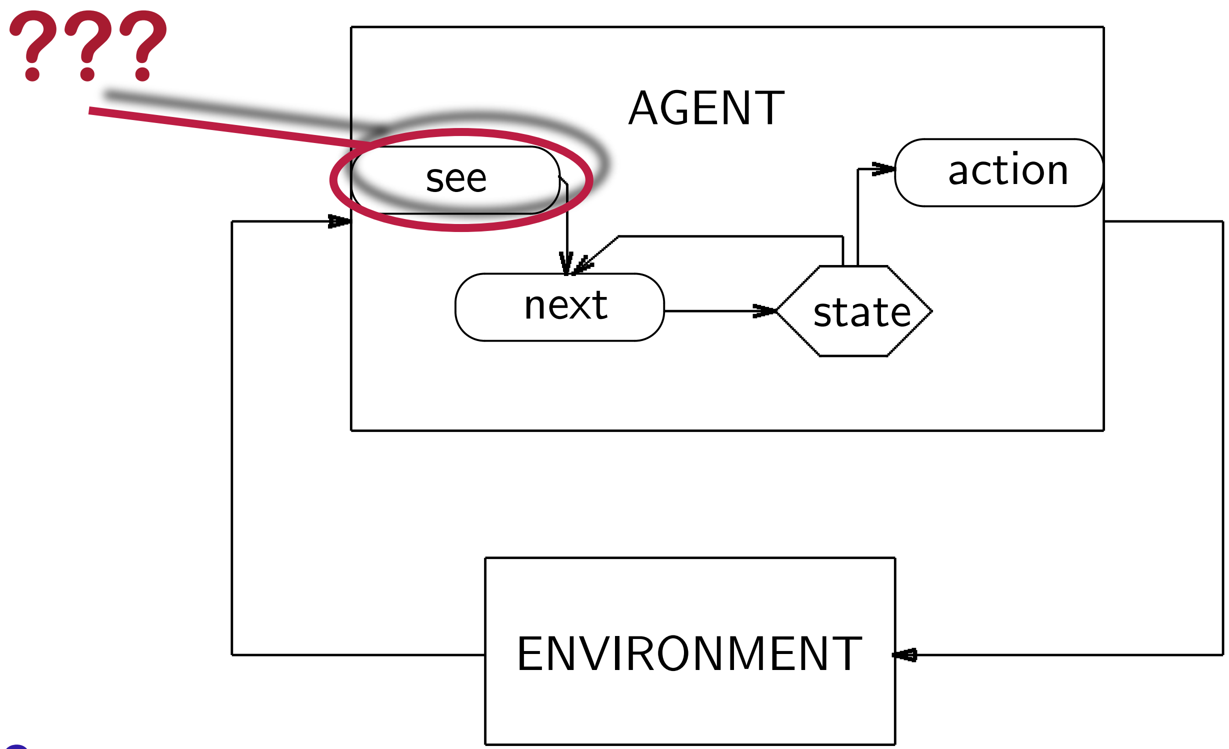


Robot Control Architecture
[Siegwart/ Nourbakhsh 2004]

Examples

- “If you see a sink and a tiled floor, then this is no conference room!”
- „If you are in the kitchen, you should see an oven!“

Plan Execution Monitoring



Agent Architecture
[Beierle/ Kern-Isberner 2008]

Issue

- Plan execution monitoring: Tell *success* case from *nominal* case from *failure* case from *retry* case from …
- …see next slide

Sensor Data Interpretation

Example: How many chairs?

[AG Bülthoff,
MPI Biol. Kybernetik]

Sensor data interpretation includes top-down reasoning!

… and overall:

- Handle temporal, changing, partially obsolete and/or wrong KBs/Belief Bases
- Handle huge KBs, of which only a small part is relevant for given planning/perception problem
  - Tell (potentially) relevant from (apparently) irrelevant KB parts
- Solve “object anchoring” problem (not to mention symbol grounding)

2.1 Issues & Challenges

2.2 Interpreting 3D Point Clouds

2.3 Plan-Based Control

The Problem

- **Given**: 3D sensor environment point cloud model
  …as by 3D laser scanner, ToF camera, Kinect, …
  …typically registered from several scans (automatic)

- **Given**: CAD model of some object/type
  …as by provider, Google 3D Warehouse, …
- **Given**: model of geometric constituents of object
  …as handcrafted (now) or gained from CAD model (future)
- **Find**: object occurrences in data

Why Care?

- Semantic mapping (mapping with objects + ontology)
- Data reduction (point sub-clouds ➜ geometric primitives)
- Fill up occlusions (perceive true 3D in “2.5D” sensor data)
- Applications! (map sensed reality to nominal CAD)
  - Robotic mapping
  - Facility management
  - ➜ Plant engineering


(Own) References

- M. Günther, T. Wiemann, S. Albrecht, J. Hertzberg.
  Building Semantic Object Maps from Sparse and Noisy 3D Data.
  Proc. IROS-2013

- T. Wiemann, K. Lingemann, J.Hertzberg.
  Automatic Map Creation for Environment Modelling in Robotic Simulators.
  Proc. 27th Eur. Conf. Modelling and Simulation (ECMS-2013)

- T. Wiemann, K. Lingemann, A. Nüchter, J. Hertzberg.
  A Toolkit for Automatic Generation of Polygonal Maps – Las Vegas Reconstruction.
  Proc. 7th German Conf. on Robotics (ROBOTIK-2012)

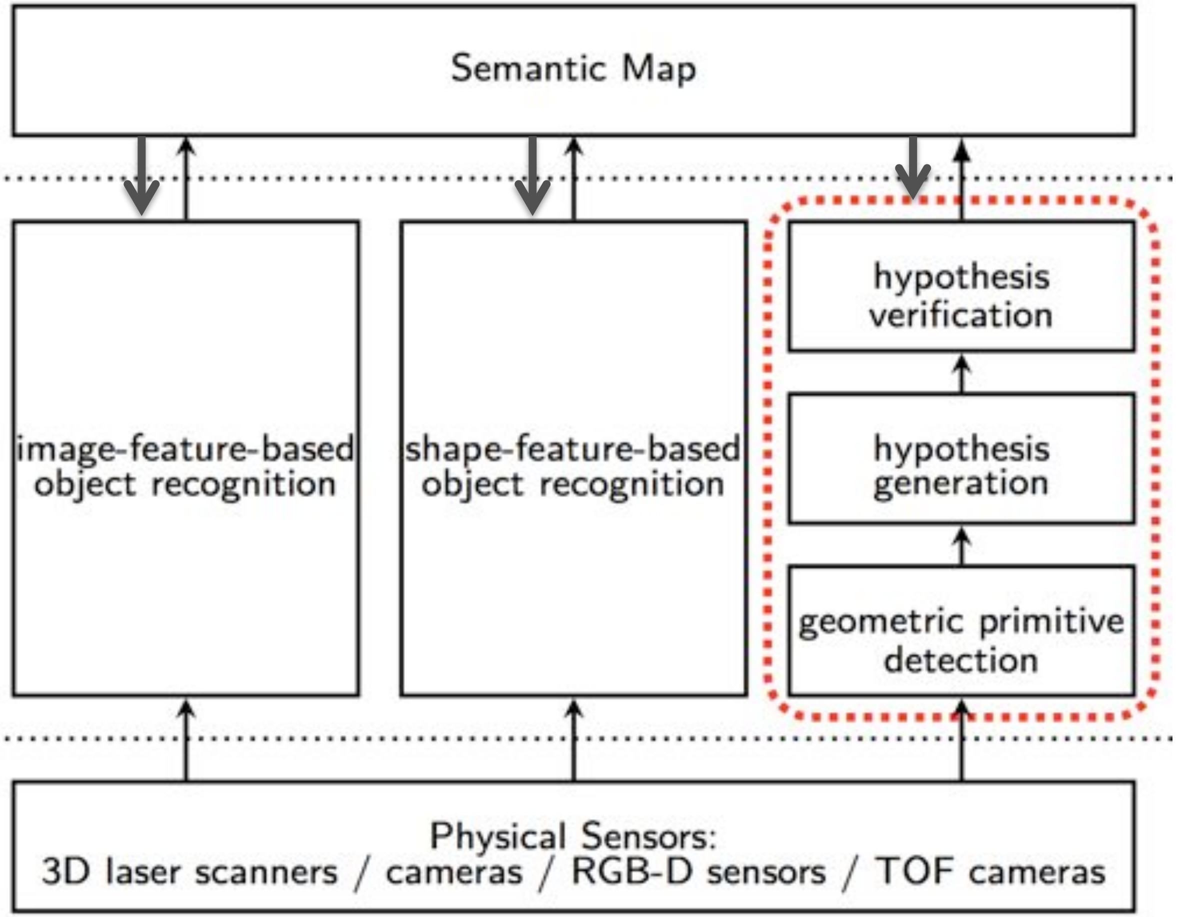
- M. Günther, T. Wiemann, S. Albrecht, J. Hertzberg.
  Model-based object recognition from 3D laser data.
  Proc. 34th Annual German Conference on AI (KI-2011)

- **LVR: http://www.las-vegas.uni-osnabrueck.de/**

- **3DTK: http://slam6d.sourceforge.net/**

Architecture Context

Other object recognition methods may/should co-exist!



Model-based object recognition

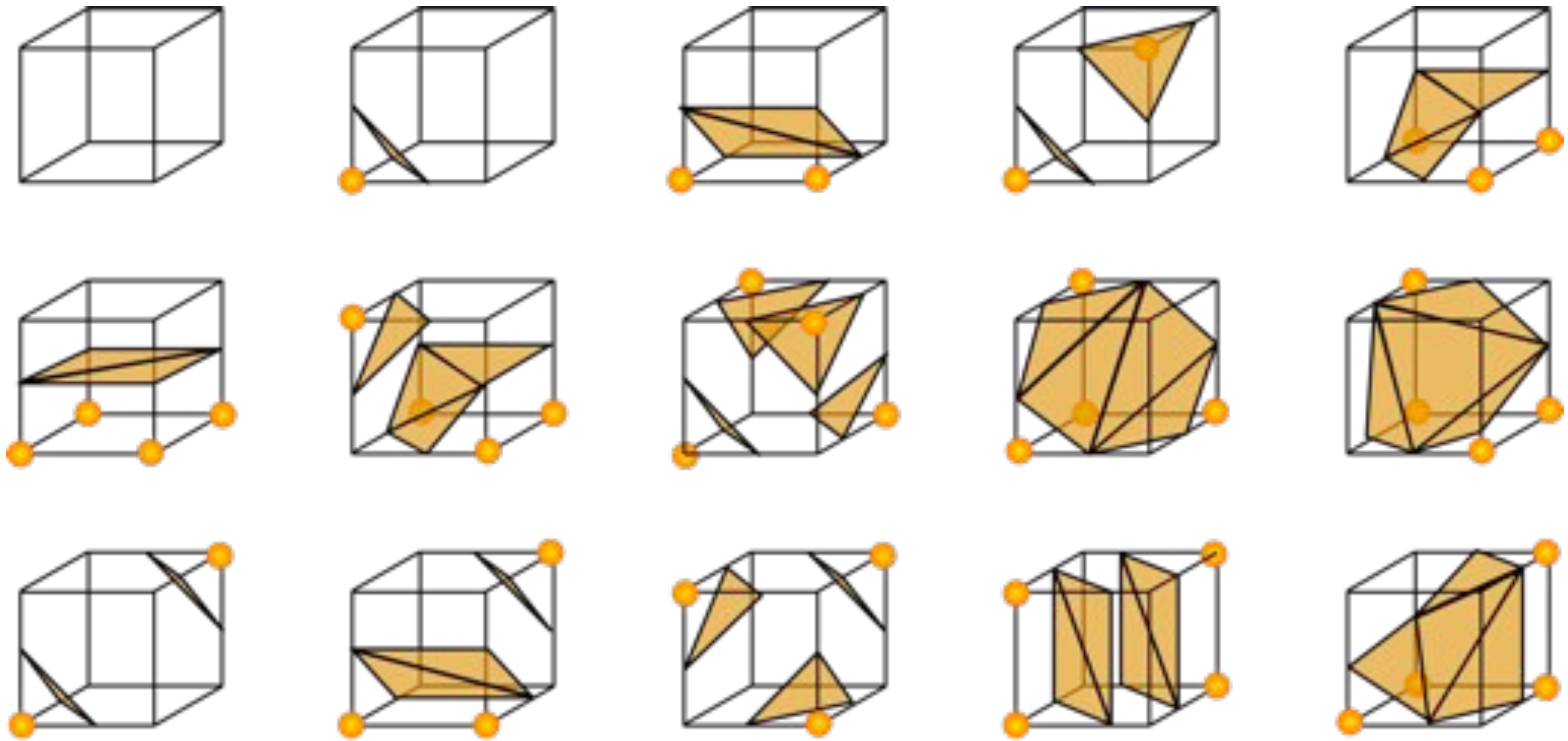
Step I: Detect Geometric Primitives

- Detect primitives (plane, cylinder, sphere) from point normals in dense sub-clouds
- Furniture: restrict to **planar patches** (orientation-independent!)

- Generate triangle mesh by optimized marching cubes implementation
- Region growing along homogeneous triangle normals

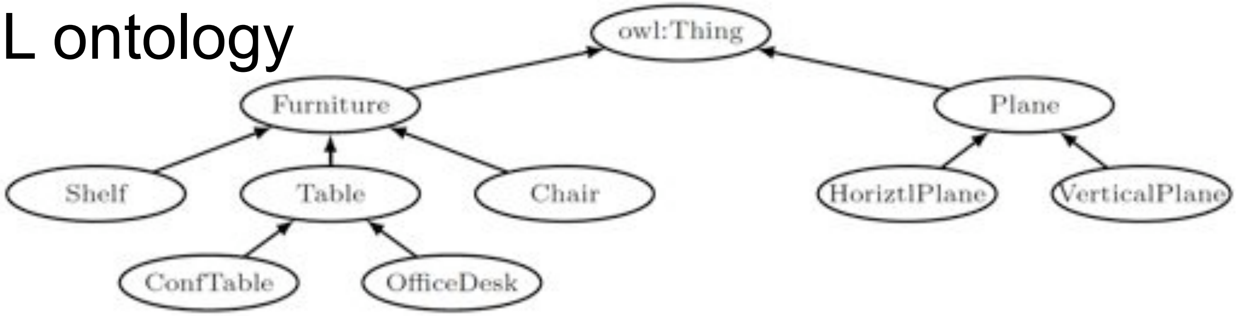
Marching Cubes …

… is a std. algorithm from CG for turning
voxel-oriented representation into polygonal representation



Step II: Generate Object Hypotheses

- … based on OWL-DL ontology



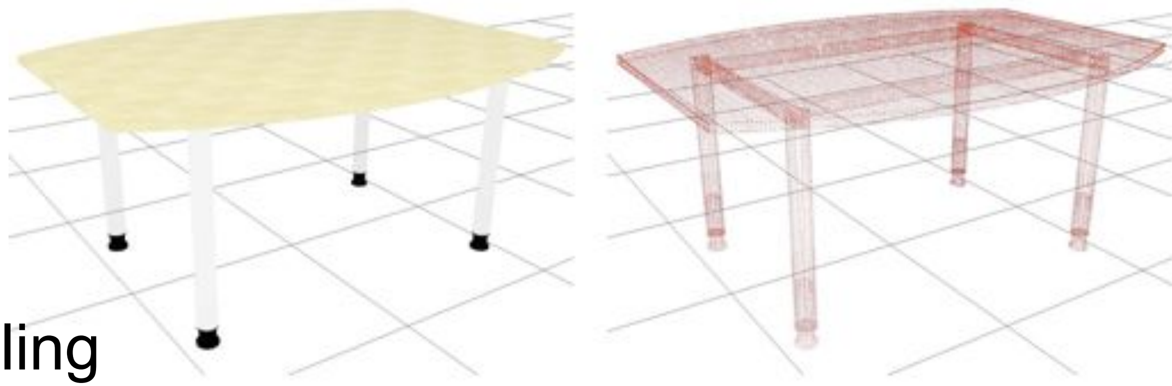
- Check relations based on sensor data (size, spatial relations), combine SWRL rules with ontology

$$Table(?p) \leftarrow HorizontalPlane(?p) \wedge hasSize(?p,?s) \wedge$$
$$swrlb:greaterThan(?s,1.0) \wedge hasPosY(?p,?h) \wedge$$
$$swrlb:greaterThan(?h,0.65) \wedge swrlb:lessThan(?h,0.85)$$

- Calculate object pose hypothesis (surface normals, PCA, …)

Step III: Verify Object Hypotheses

Basic Idea



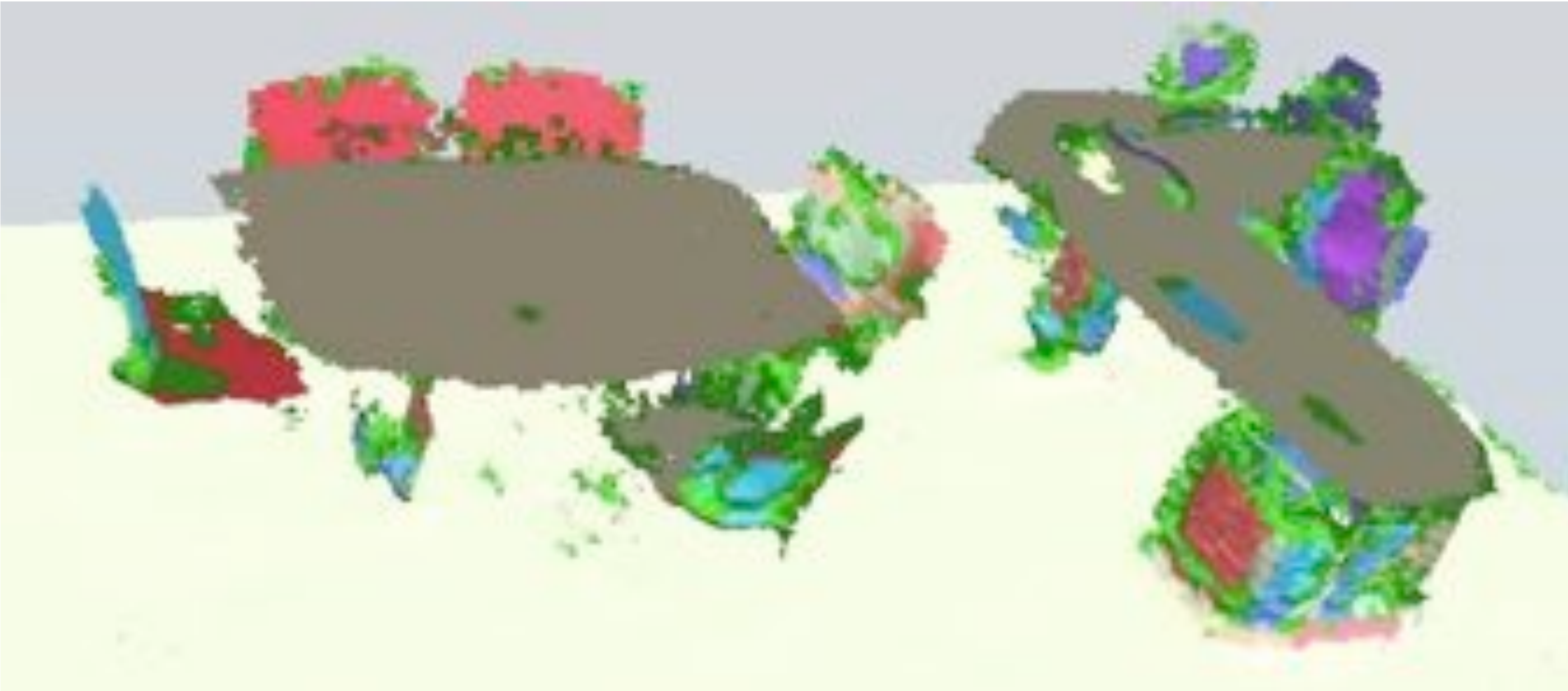
- Sample CAD model into 3D point cloud
- Register model sampling with sensed 3D point cloud at hypothetical pose, using ICP
- Accept object hypothesis if matching error below threshold

Modification (ignore errors from scanning/sampling difference)

- Determine model/data correspondence according to filled/ empty voxel bins

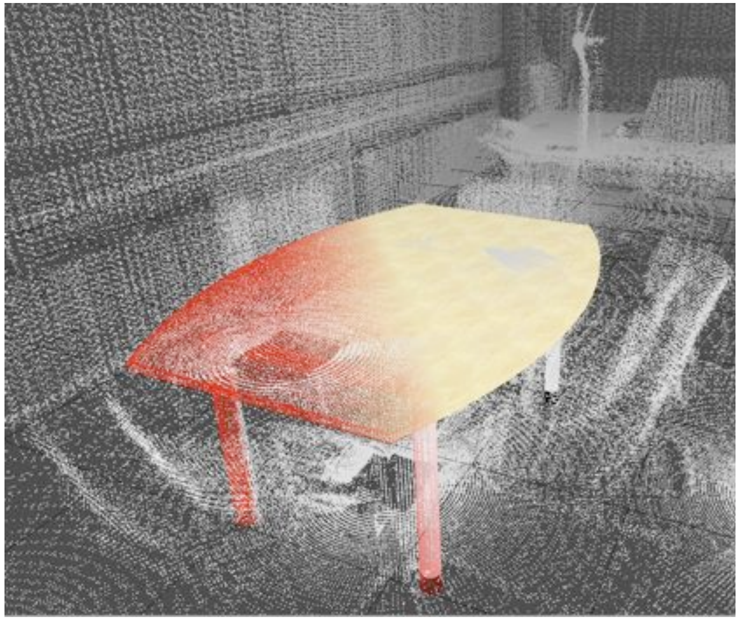
Example: 3D Point Cloud Data

Example: Primitives & Hypotheses

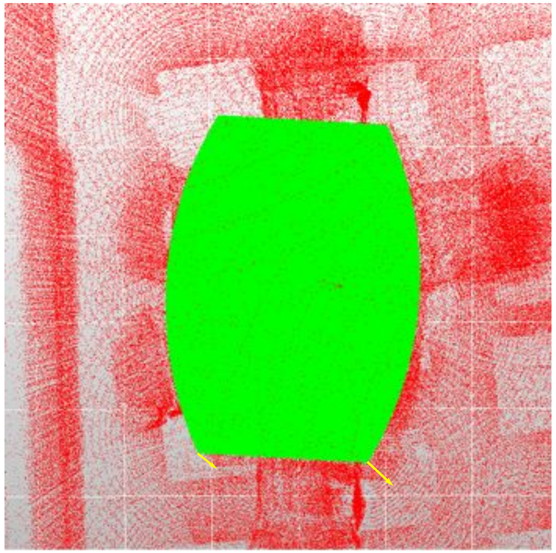


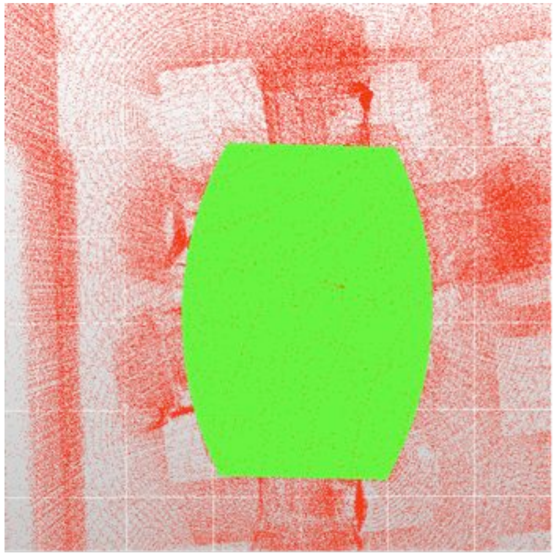
- Plane patches from triangle mesh (neighboring triangles with like normals)
- Non-planar surfaces in green
- Table(top) hypotheses in grey

Example: Verification



Verify table object and pose by ICP matching of point sampling at hypothetical pose





Corresponding CAD table top before and after ICP matching

Example: Results

Animation

Issues in Sensor Data Interpretation

- Abduce **potential aggregates** from detected objects plus DL domain model
- **Reinterpret** objects
- **Substitute sensor data** (occlusions) by reasoning
- Generate **expectations**

[Neumann & Möller, 2006]

2.1 Issues & Challenges

2.2 Interpreting 3D Point Clouds

2.3 Plan-Based Control

Robot Planning

The plan *is that part of the robot's program,*
whose future execution the robot reasons about explicitly.
[D. McDermott, 1992]

- Dates back to STRIPS/SHAKEY tradition in AI (1960/70s)
- Various benefits for robot ctrl: Performance optimization (time, robustness), HRI/RRI, software engineering
- Plan just <u>one</u> source of information for robot ctrl (<u>hybrid</u> arch.s)
- Plan format may vary; notion of planning may differ from classical view ("adapting library plan stubs")

☛ Robot plans are short. Autonomous execution matters!

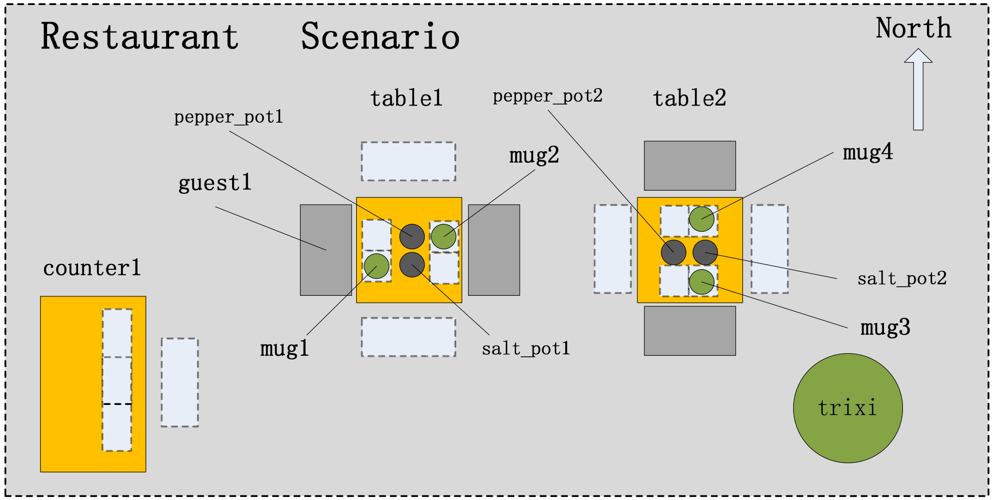
☛ Needs hybridization with space, time & resource reasoning

☛ Needs object anchoring & action grounding!

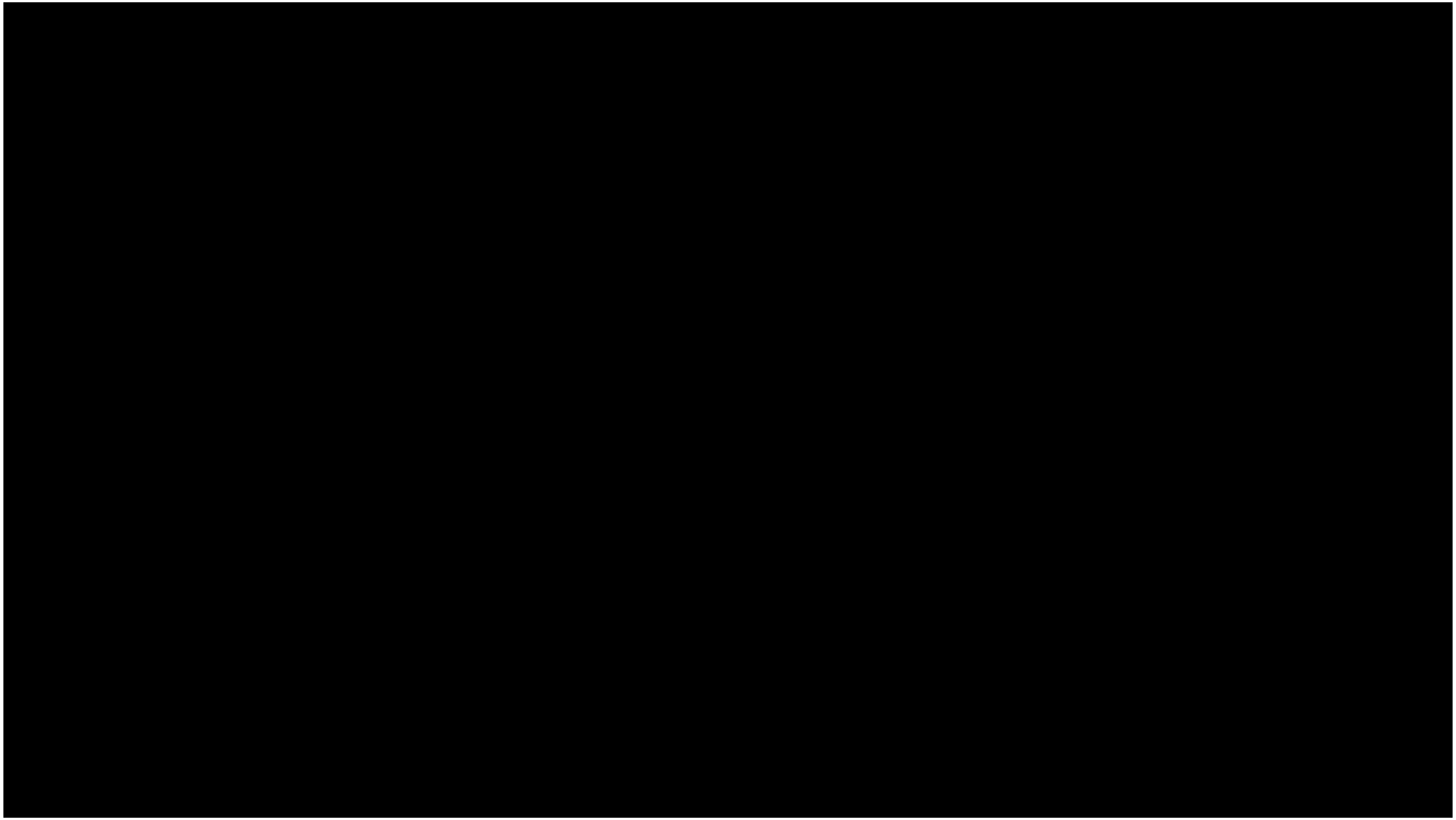
☛ Needs to cope with irrelevant, outdated & wrong facts!

Running Example: RACE

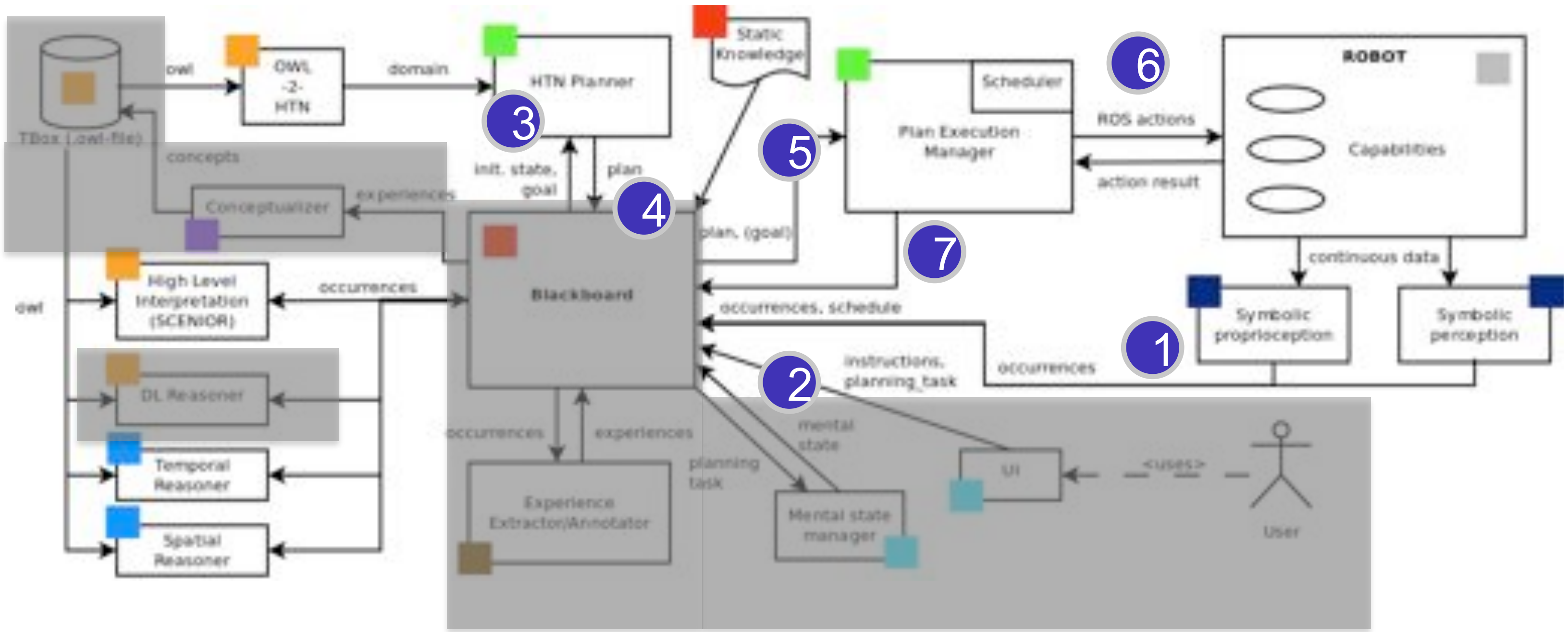
- <u>R</u>obustness by <u>A</u>utonomous <u>C</u>ompetence <u>E</u>nhancement
- Univ.s Aveiro, Hamburg (coord.), Leeds, Örebro, Osnabrück
- EU 7th FP, 12/2012–11/2014
- **Research Topic**: Learning from (own) robot experiences
- Osnabrück part: Plan-based robot control
- **http://project-race.eu/**



How to Serve a Coffee



Control Flow



HTN Planning

- ROS node for (J)SHOP2
- World state is extracted from the Blackboard

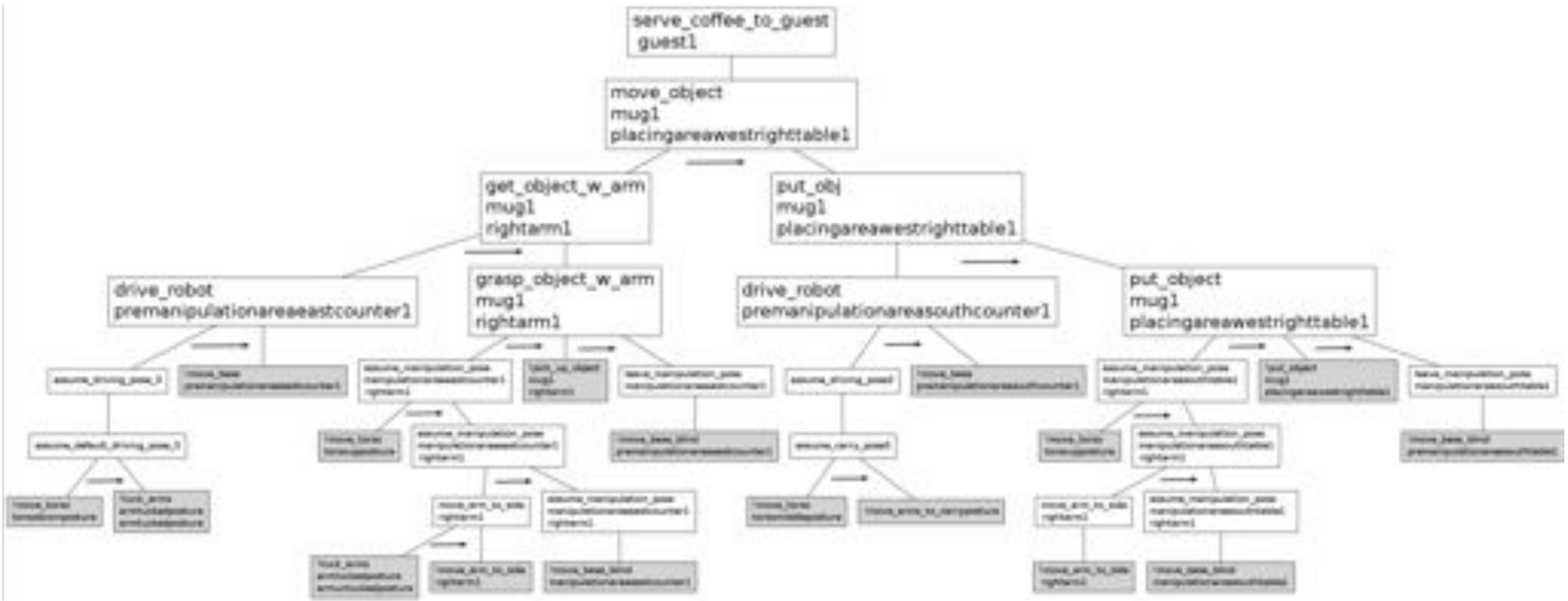
Class_Instance:	[RobotAt, robotAt1]
Starttime:	[50, 50]
Endtime:	[0, 0]
Properties:	
- [hasObject, Robot, trixi]	
- [hasArea, Area, floorAreaTamsRestaurant1]	

→ (RobotAt trixi floorAreaTamsRestaurant1)

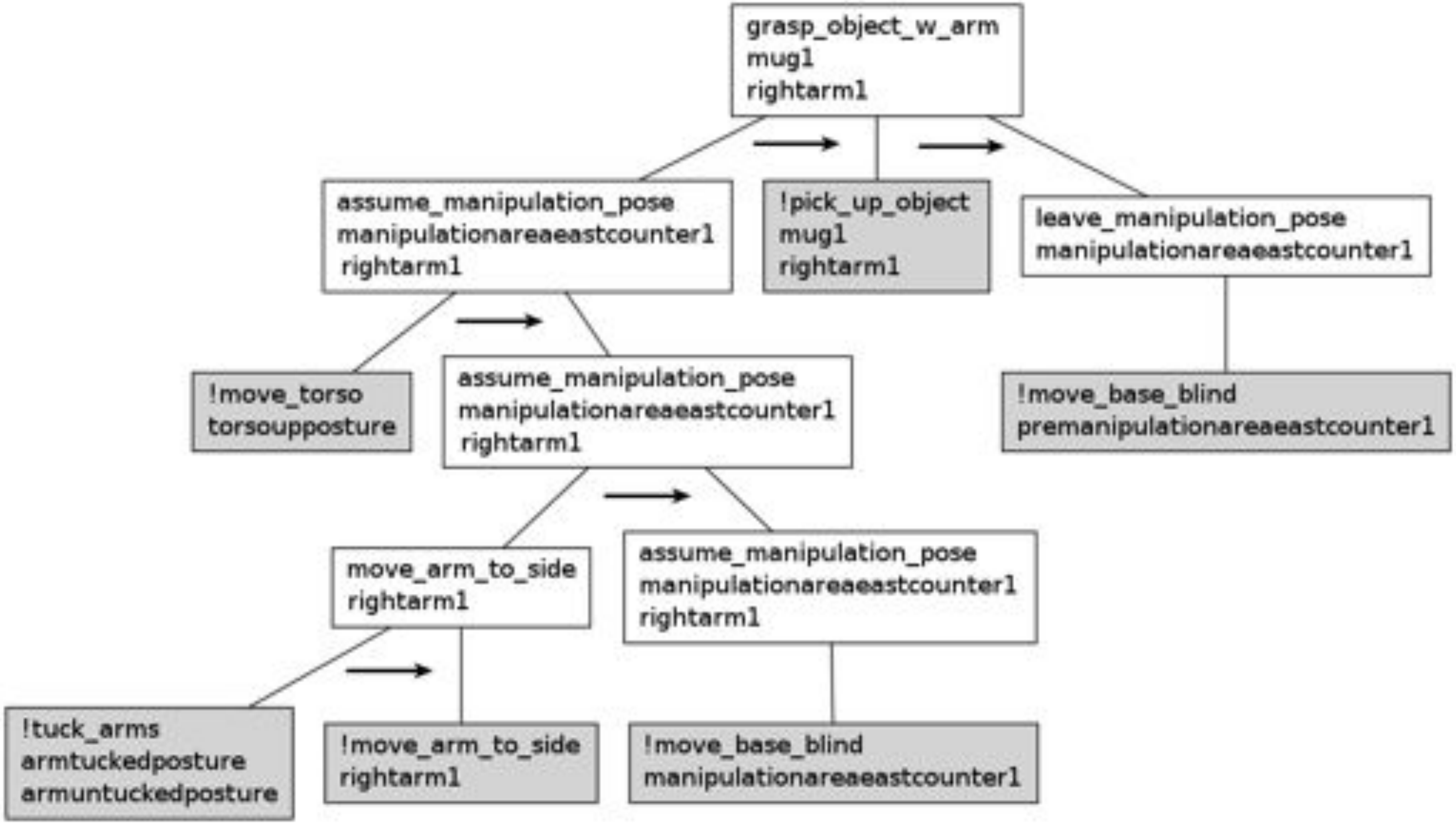
Class_Instance:	[On, on1]
Starttime:	[10, 10]
Endtime:	[0, 0]
Properties:	
- [hasPhysicalEntity, PhysicalEntity, mug1]	
- [hasArea, Area, placingAreaEastLeftCounter1]	

→ (On mug1 placingAreaEastLeftCounter1)

HTN (STN) Task serve_coffee_to_guest



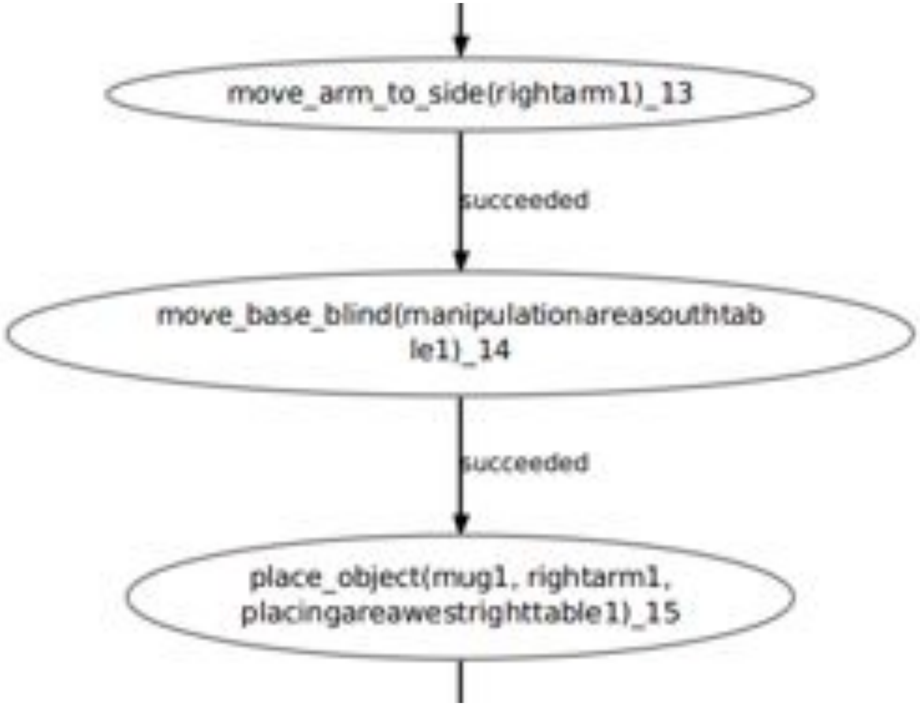
HTN (STN) Subtask grasp_object



Plan Execution with SMACH

- Plan is transferred to a SMACH state machine and executed
- 1 to 1 to 1 mapping from operators to states to robot capabilities (atomic actions)

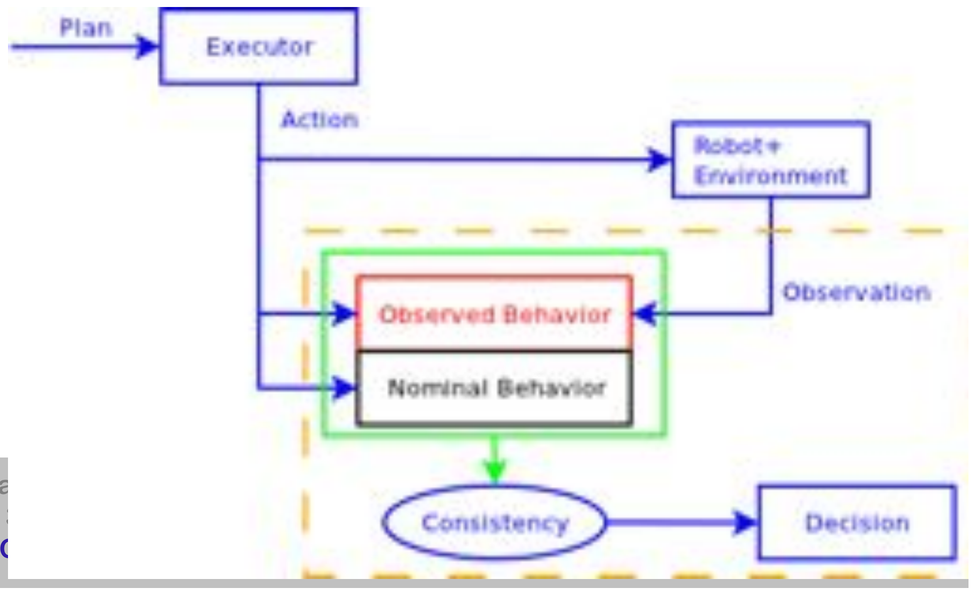
```
(!move_arm_to_side
   rightarm1)

(!move_base_blind
 manipulationareasouthtable1)

(!place_object
   mug1
   rightarm1
   placingareawestrighttable1)
```



- Failed plan can be reinserted into the Blackboard, which invokes re-planning (or “failing upward” in plan hierarchy)

“Consistency-Based” Execution Monitoring

- In RACE, Execution Monitoring can leverage rich knowledge
  - spatial (e.g., correct placement of objects w.r.t. each other)
  - temporal (e.g., coffee gets cold after 5 minutes)
  - causal (e.g., gripper is not closed while holding cup)
  - ontological (e.g., functional zones)
  - resource (e.g., do not exceed max weight of tray)
- How to assess consistency of observed behavior w.r.t. rich knowledge?
- Towards consistency-based execution monitoring
  - infer courses of actions and changes in the environment based on inconsistencies in different types of knowledge



The need for Hybrid Planning

- Space, time, and “causation” (action dependencies) interact in plan-based robot control
  – Clutter on the table influences the best serving position,
    which influences the best grasp and the arm trajectory and the arm to use – left, right,
    which influences the arm to pick up an object with on the way,
    which influences that part of the path and the time,
    which influences …
- Separating different planning realms leads to suboptimal and inflexible plans
- Integrating them creates complexity;
  luckily, robot plans are short
- Current path in RACE: build a hierarchical planner in terms of the Meta-CSP framework (F. Pecora, Örebro)

1. Osnabrück, its University, and DFKI
2. Research in Plan-Based Robot Control

   ****** Lunch Break ******

3. Application-Oriented Research:

   Agricultural Robotics

4. Plan of (my part of) the SAI seminar

1. Osnabrück, its University, and DFKI

2. Research in Plan-Based Robot Control

   ****** Lunch Break ******

3. **Application-Oriented Research:**

   Agricultural Robotics

4. Plan of (my part of) the SAI seminar

3.1 What is DFKI?
3.2 Robots Gone Farming

3.1 What is DFKI?

3.2 Robots Gone Farming

DFKI

The **German Research Center for Artificial Intelligence** (German: *Deutsches Forschungszentrum für Künstliche Intelligenz, DFKI*) is one of the world's largest **nonprofit contract research institutes** in the field of innovative software technology **based on AI methods**.

The Pentagon of Innovation

DFKI Figures

- 414 staff scientists (384 full time equiv.)
- 39,5 Mio. € turnover in 2012
- Turnover per scientist > 100 T€
- average age: 36
  (comparison: Fraunhofer Society: 43)
- Additional 285 sc. assistants (171/full t. equiv.), additional freelancers
- 699 staff
- 171 running projects

The Funding Model of DFKI

15 Mio €
Competitive Contracts from Industry, Government Agencies, European Union

Three Thirds Model

Financial Corridor	Proposals reviewed by Advisory Board
3,9 Mio €	Industrial Shareholders
3,9 Mio €	States: Bremen / Rheinland-Pfalz / Saarland / Niedersachsen
3,9 Mio €	BMBF

The Private Shareholders of DFKI GmbH

Deutsche Telekom

intel

HARTING

JOHN DEERE

VSE RWE GROUP

software AG

SAP

Microsoft Deutschland GmbH

EMPOLIS INFORMATION MANAGEMENT

KIBG

Fraunhofer

Saarland

Rheinland-Pfalz

DFKI

Bremen

Deutsche Post

DAIMLER

BMW Group

ASTRIUM AN EADS COMPANY

CLAAS

RICOH

Deutsche Messe AG Hannover · Germany

UNIVERSITÄT DES SAARLANDES

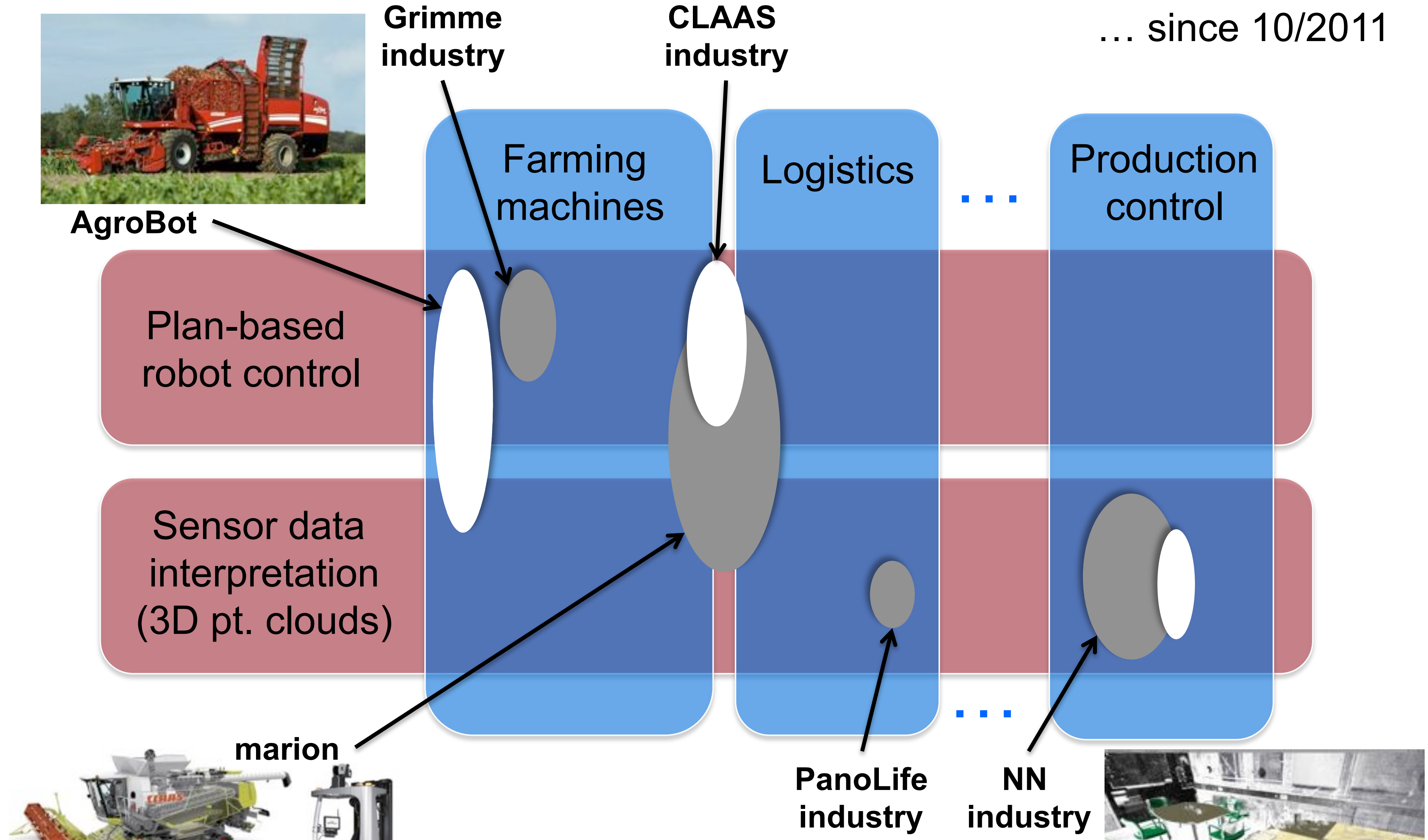
Universität Bremen

TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

Research Units and Groups

- Innovative Factory Systems
- Embedded Intelligence
- Agents and Simulated Reality
- Safe Cognitive Systems
- Institute for Business Informatics at DFKI
- Robotics Innovation Center
- DFKI-RIC Branch OS
- Intelligent User Interfaces
- Language Technology
- Augmented Reality
- Knowledge Management

DFKI Osnabrück Branch



3.1 What is DFKI?

3.2 Robots Gone Farming

Example Projects: SmartBot, marion

Sugar Beet Harvester MAXTRON, Grimme

Robotic Solutions for Agriculture, Ship Building, and SME Production

Funding: EU Interreg

Partners (some): Amazone, DFKI, Grimme, HS OS

Combine Harvester LEXION, Tractor XERION, CLAAS

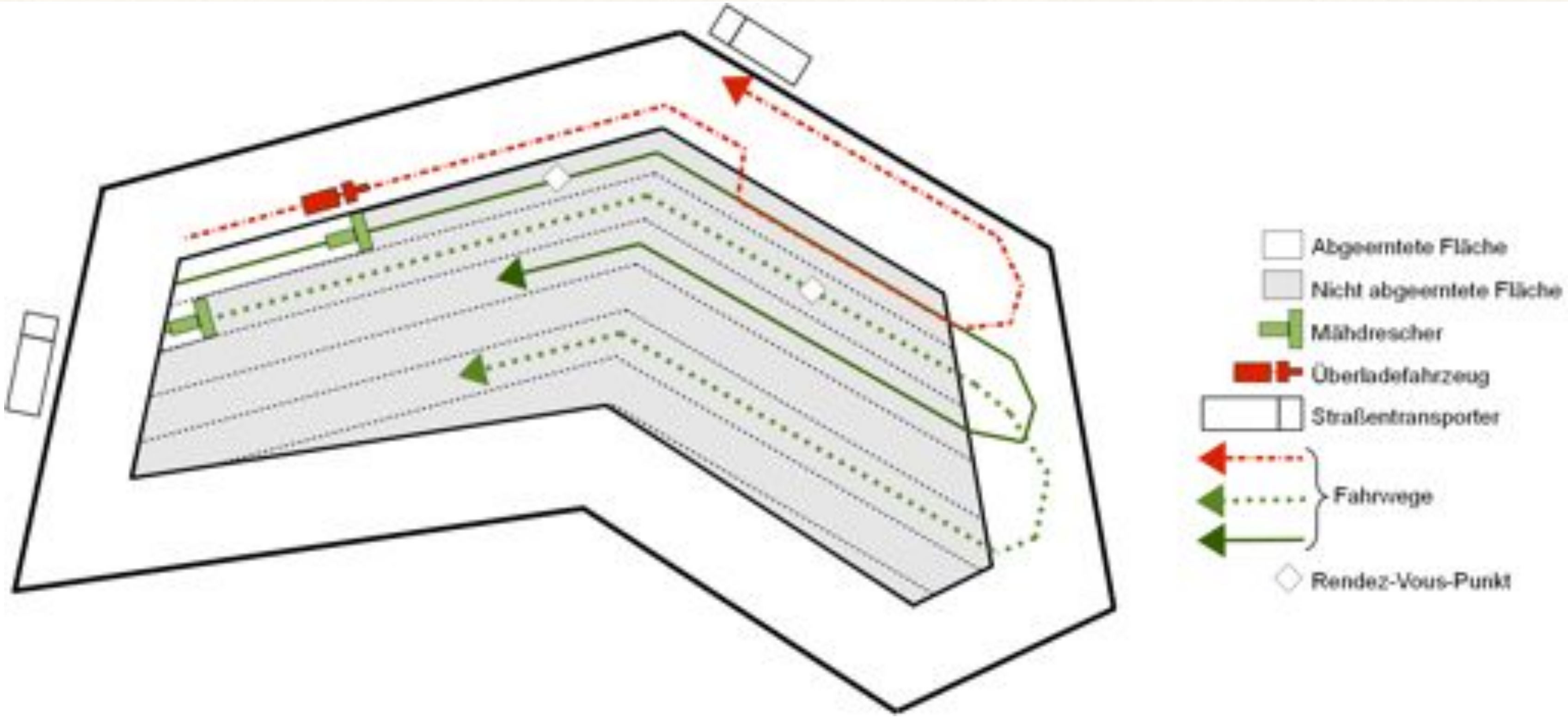
Mobile, autonomous, co-operative robots in complex value creation chains

Funding: Fed. Min. Economy (BMWI)

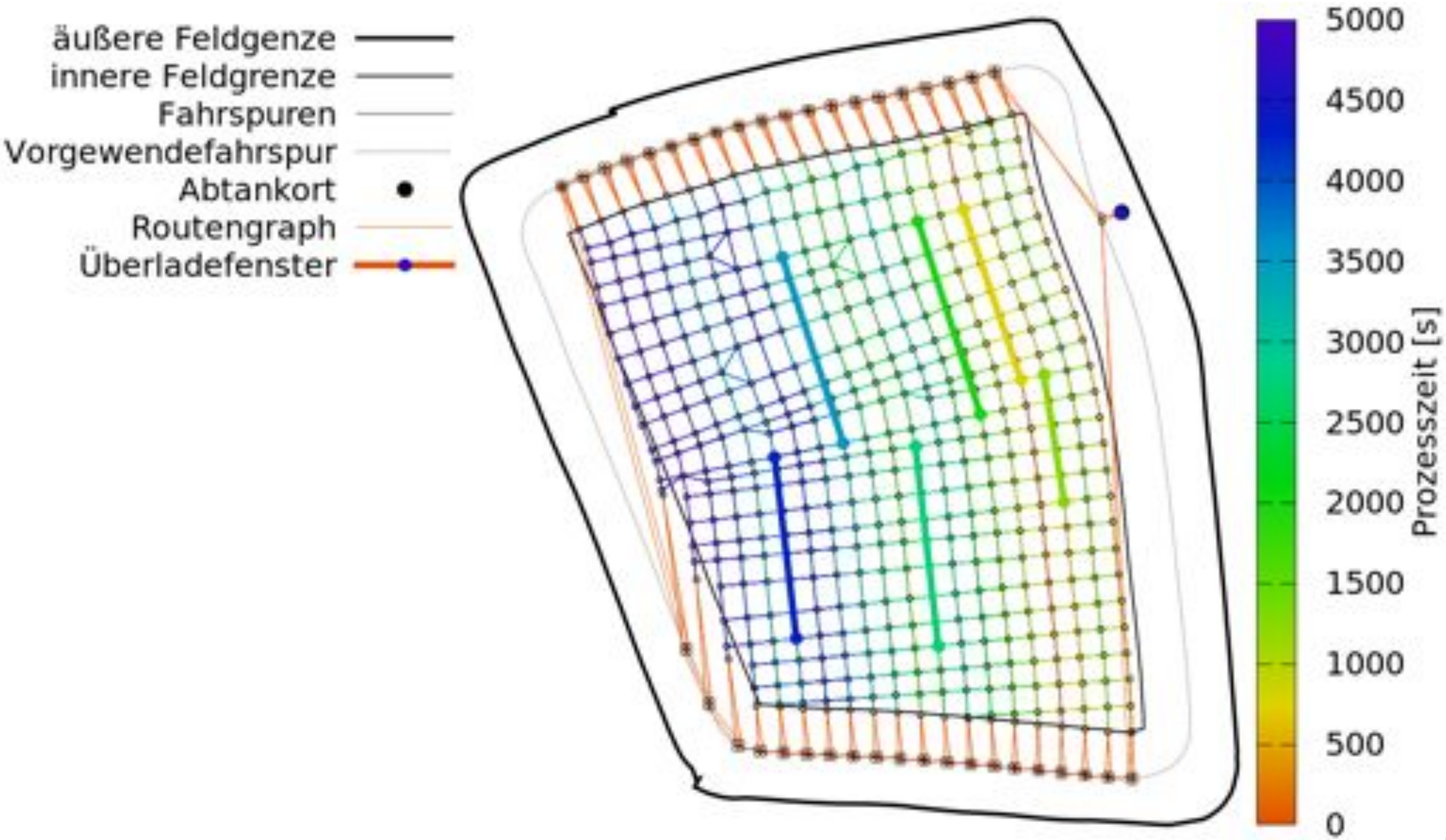
Partner: CLAAS, DFKI, STILL, ATOS

(ended 12/2013)

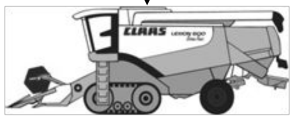
Corn Harvesting Scenario



Route Planning



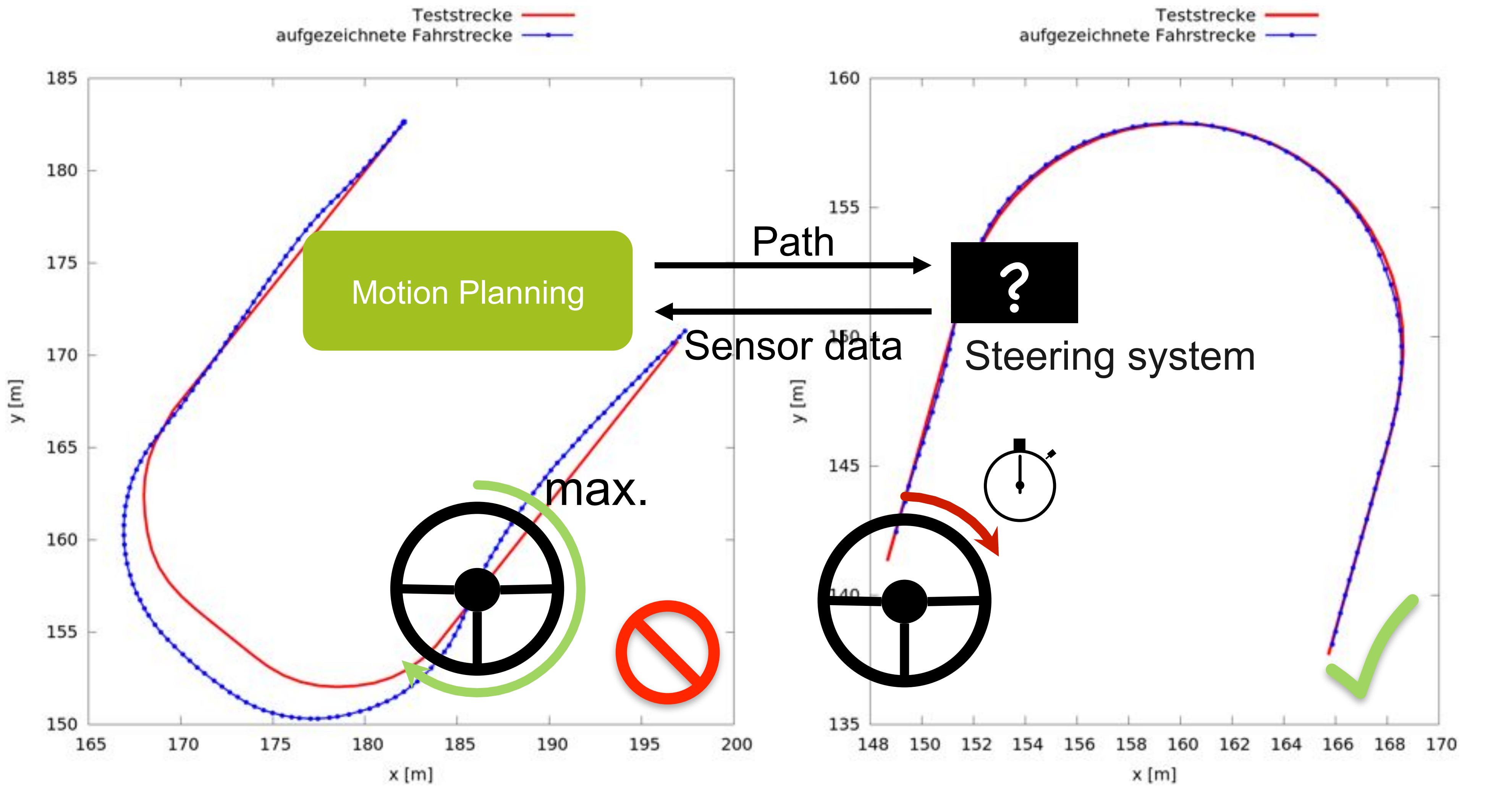
Motion Planning, Structure

- Motion Planning
  - 

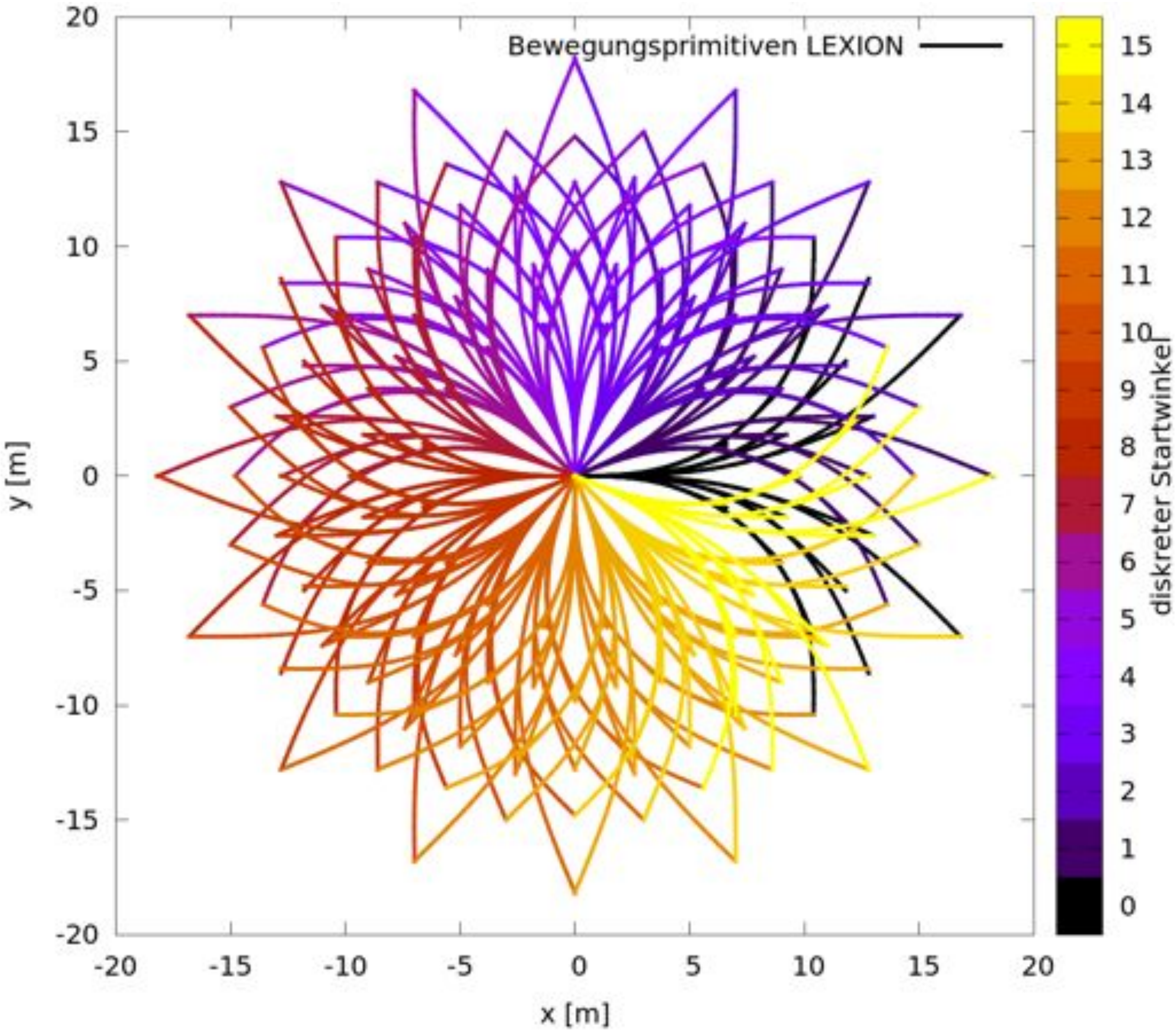
    Harvester
    - Approximate nominal path
    - SBPL lattice planner[2]
  - 

    Tractor
    - Graph search
      - Approximate nominal path
      - SBPL lattice planner[2]

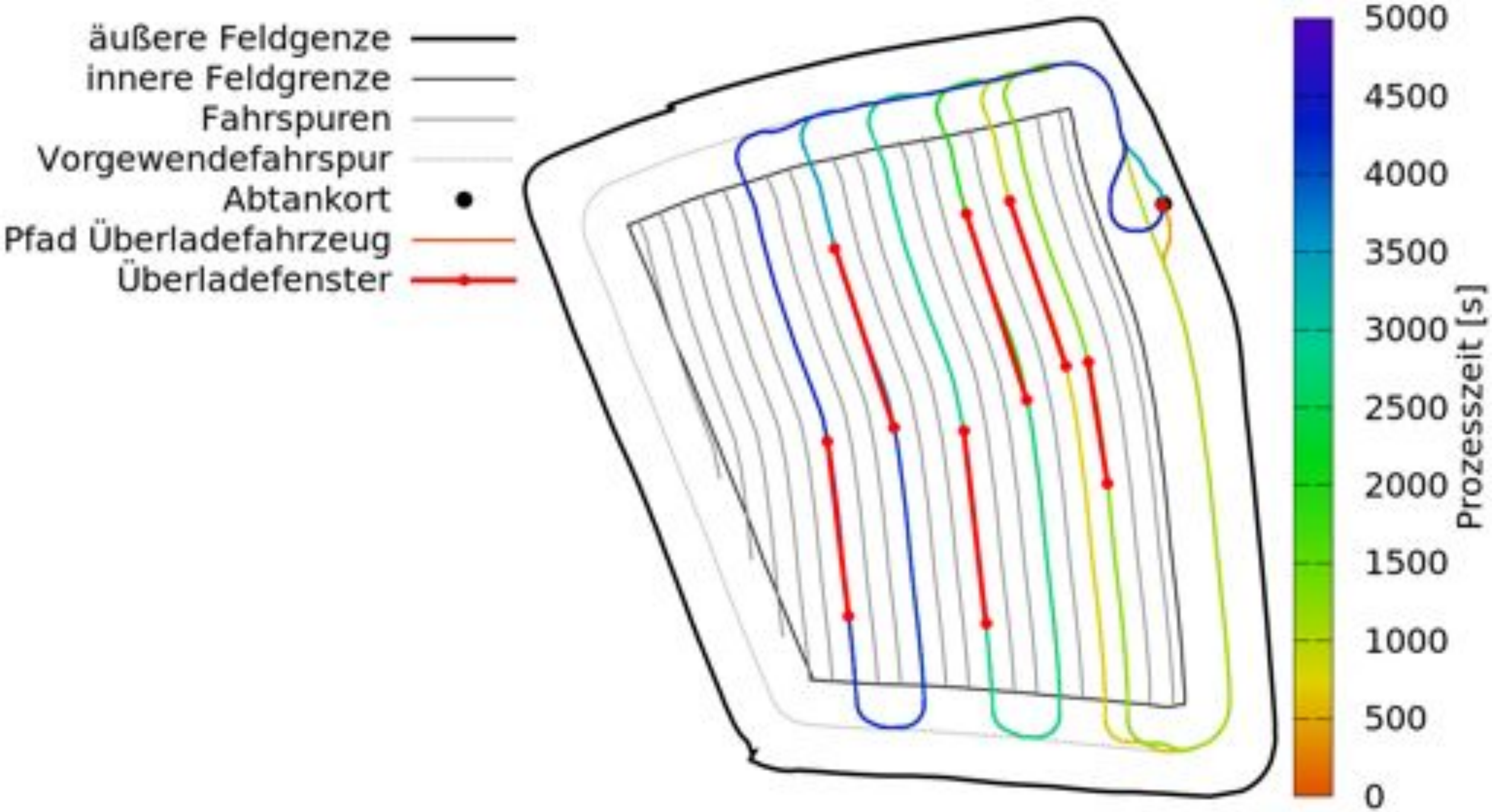
Determine Machine Parameters



Motion Primitives

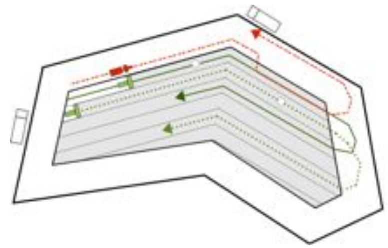


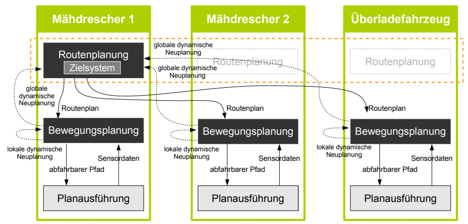
Motion Planning

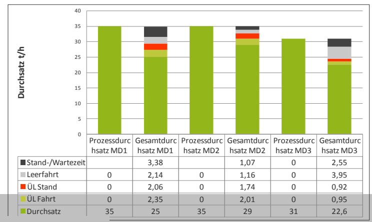


The Big Story

- Machine Throughput keeps increasing
- Logistics becomes a limiting factor
- Planning needed for complete process chain
- “marion” was about developing a prototype for a dynamical planning system for corn harvesting
- Process agents get coordinated better
- Unlock hidden productivity potential
- “marion” results are now being developed towards products as financed by CLAAS







	Prozessdurchsatz MD1	Gesamtdurchsatz MD1	Prozessdurchsatz MD2	Gesamtdurchsatz MD2	Prozessdurchsatz MD3	Gesamtdurchsatz MD3
Stand-/Wartezeit		3,38		1,07	0	2,55
Leerfahrt	0	2,14	0	1,16	0	3,95
ÜL Stand	0	2,06	0	1,74	0	0,92
ÜL Fahrt	0	2,35	0	2,01	0	0,95
Durchsatz	35	25	35	29	31	22,6

1. Osnabrück, its University, and DFKI

2. Research in Plan-Based Robot Control

   ****** Lunch Break ******

3. Application-Oriented Research:

   Agricultural Robotics

4. **Plan of (my part of) the SAI seminar**

Seminar Sessions

- **All sessions**:
  (1) Presentation by myself; lunch break;
  (2) discuss paper from literature (which all(!) have read)
- **For (2)**: 2 students lead through the paper discussion
- All papers online on the Seminar Web page
  (plus **http://www.inf.uos.de/hertzberg/sai14-jh.html**)

- **March 14th**: Semantic Mapping
- **March 21st**: Object Anchoring and Symbol Grounding
- **April 4th**: Approaches to Plan-Based Robot Control
- **April 14th**(!!): "Service Robotics"

Exams

- Three options for passing:
  - Lead the discussion in a session (pair of 2 students)
  - Oral discussion (30’) about the seminar topics with me (pair of 2)
  - Hand in an essay (ca. 10 pages) summarizing one of the seminar papers (1 student)
  - **Deadlines**:
    - Oral discussions: By May 25th
    - Essays: Hand in by May 16th
    - After that: Grading is “fail”

- Volunteers for next Friday’s paper?
  N. Blodow & al.: Autonomous Semantic Mapping for Robots Performing Everyday Manipulation Tasks in Kitchen Environments. Proc IROS-2011

Thanks …

- … to the the KBS group staff
  - Sven Albrecht
  - Martin Günther
  - Thomas Schüler
  - Jochen Sprickerhof
  - Sebastian Stock
  - Thomas Wiemann
  - … and students

… for your time!

- … to the DFKI OS staff
  - Kai Lingemann
  - Stefan Scheuren
  - Stephan Stiene
  - Astrid Ullrich
  - … and students