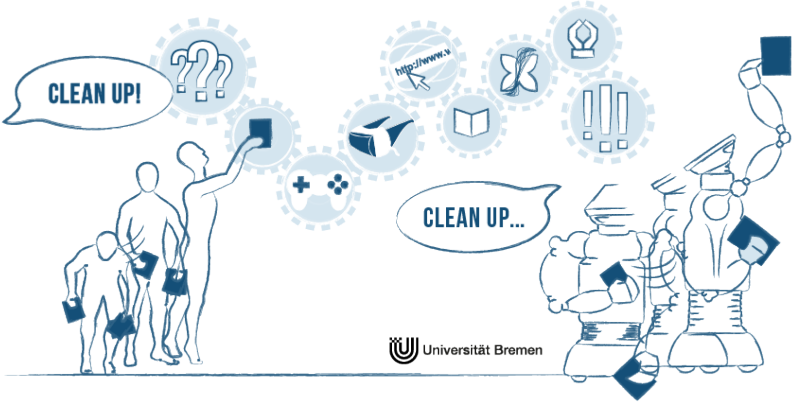
EASE - EVERYDAY ACTIVITY SCIENCE AND ENGINEERING

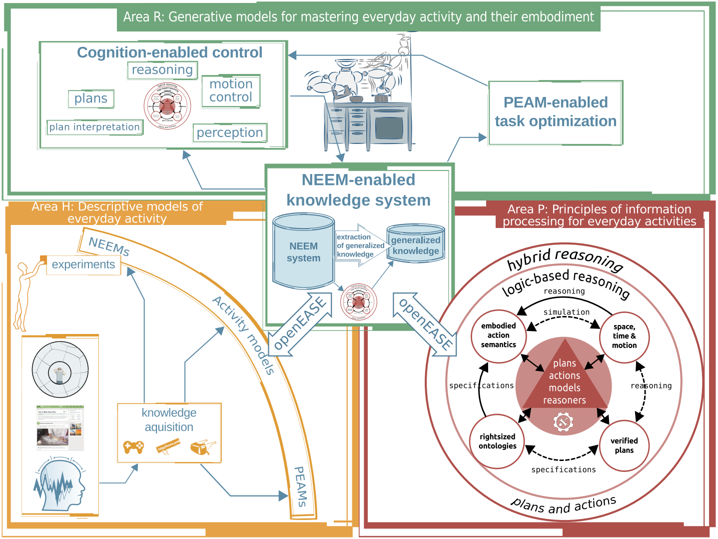
Tanja Schultz
John Bateman
Gordon Cheng
Hagen Langer

Discovering and Exploiting the „Manifolds“
of Human Problem-Solving for Robots



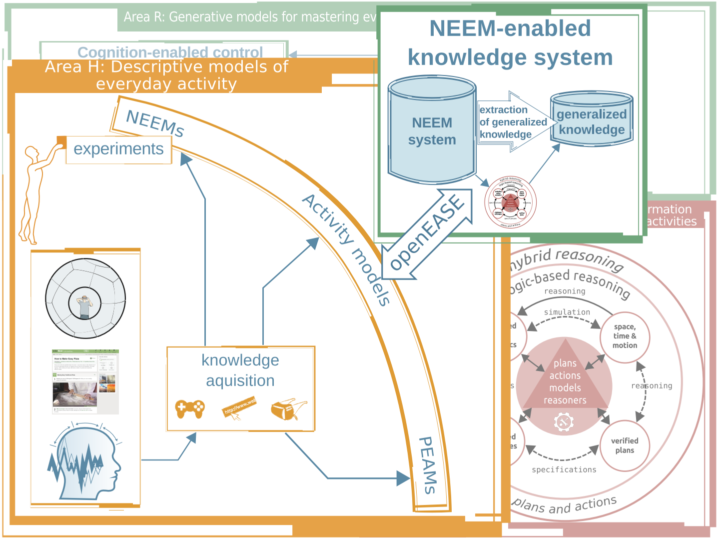
Universität Bremen

Overview



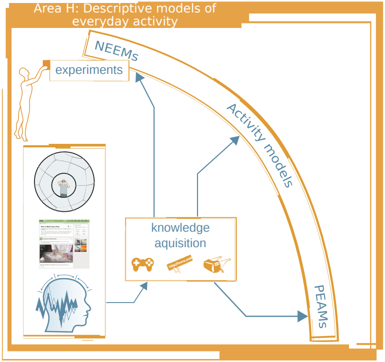
RA H RA P RA R

Research Area H



RA H: Role in EASE

- Acquire data and knowledge of humans performing everyday activities (EA)
- Design novel sensorimotor intervention paradigms
- Interpret and explicate underspecified instructions → NEEMs
- Derive hierarchically structured representations of EA → PEAMs



RA H: Objectives and Measures of Success

Goal: Understand how people perform so flexibly even vaguely formulated everyday activity tasks

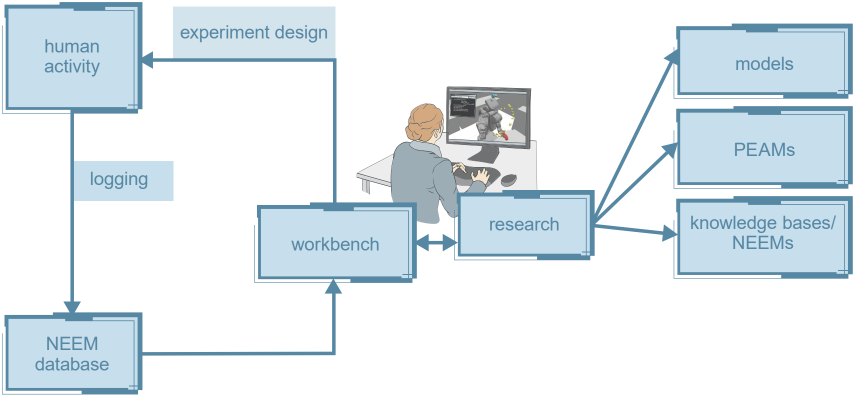
Objectives:

- Acquire and interpret high-volume multimodal data of human everyday activities
- Design sensorimotor intervention paradigm in virtual reality
- Disambiguate vaguely formulated instructions by mining and serious games
- Learn and apply descriptive and causal models of everyday activities

Measures of success:

- Answer queries based on the learned activity models
- Provide Pragmatic everyday activity manifolds (PEAMs)

Methodology applied in RA H



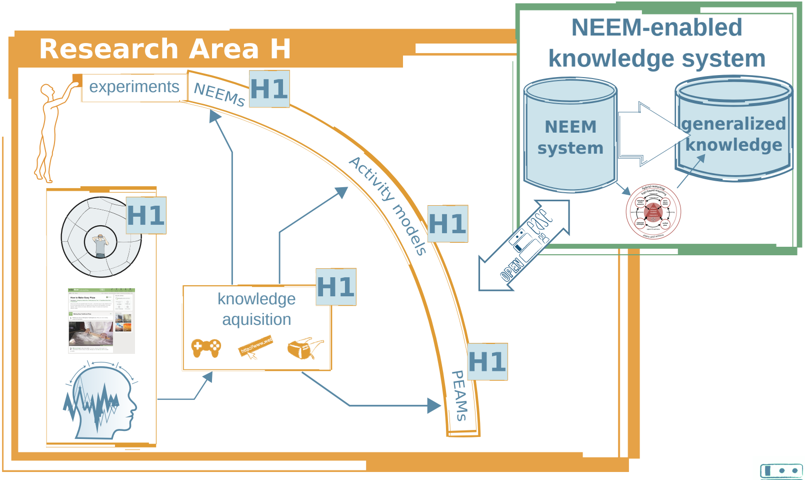
Subproject H01:

Acquiring activity models by situating people in virtual environments

Schill

Zachmann

Zetzsche



H01 Scientific Goals and Proposed Solution

Scientific Goals:

- Gain insights into mechanisms of sensory and motor control of humans
- Make the flexibility of human sensorimotor behavior available to robotics applications

Major Challenge:

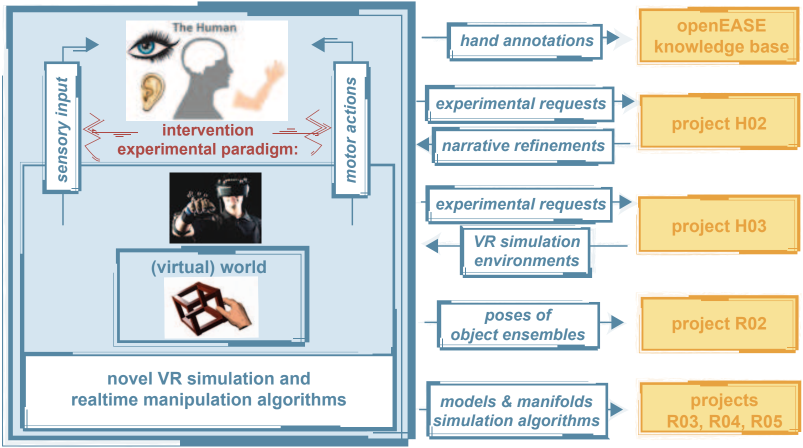
- Human voluntary actions are predominantly based on unconscious and automatic cognitive mechanisms, thus are difficult to investigate

Proposed Solution:

- Create novel experimental methodologies and impossible configurations in Virtual Reality
- Develop novel algorithms for physically-based simulations of manipulation activity

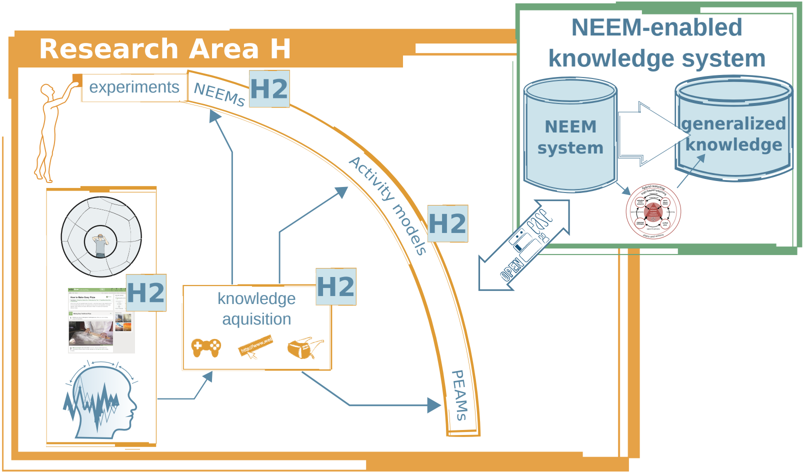
H01 Approach

H01 workbench for openEASE



Subproject H02:

Mining and explicating instructions for everyday activities



H02 Scientific Goals and Proposed Solution

Scientific Goals:

Investigate methods for obtaining knowledge about EA through mining instructions and explicating them using serious games

- Recognize underspecifications in instructions
- Explicate them using formal lexical and spatial knowledge
- Understand how humans disambiguate the underspecified instructions
- Motivate users to contribute their pragmatic knowledge

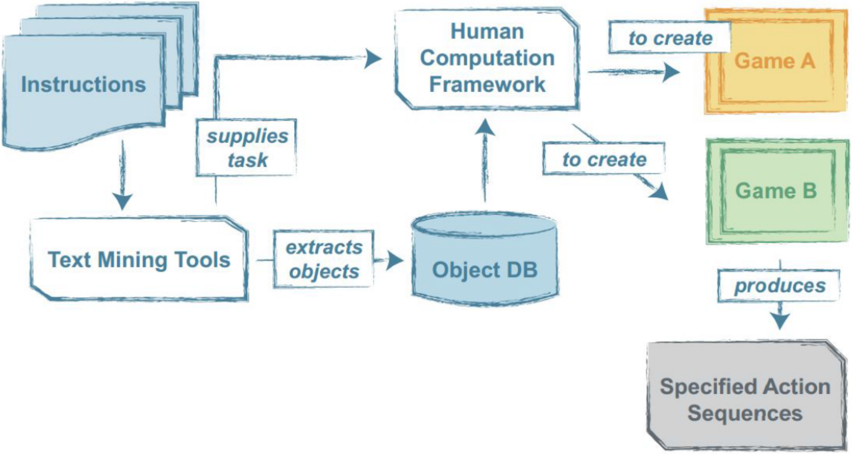
Major Challenge:

- Instructions are created *by* humans *for* humans and are thus underspecified

Proposed Solution:

- Combine text mining and human computation to efficiently generate high-quality NEEMs via game design

H02 Approach



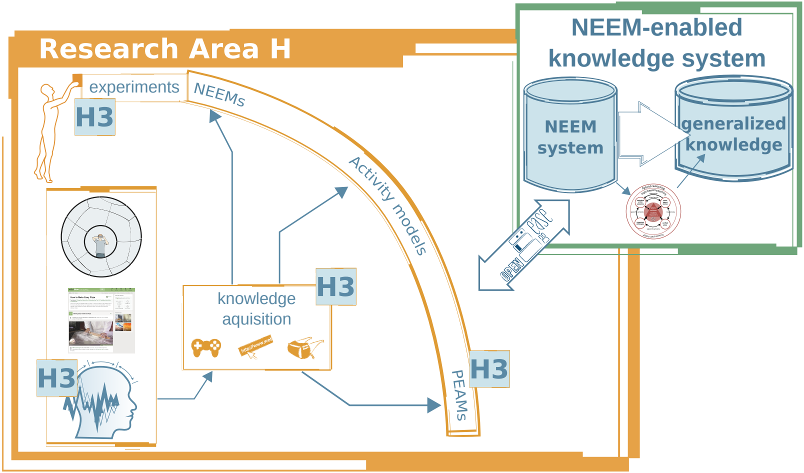
Subproject H03:

Natural activity statistics


Schill


Schultz


Herrmann



H03 Scientific Goals and Proposed Solution

Scientific goals:

Detect PEAMs via collection, annotation, analysis and interpretation of complex human EA

Major challenge:

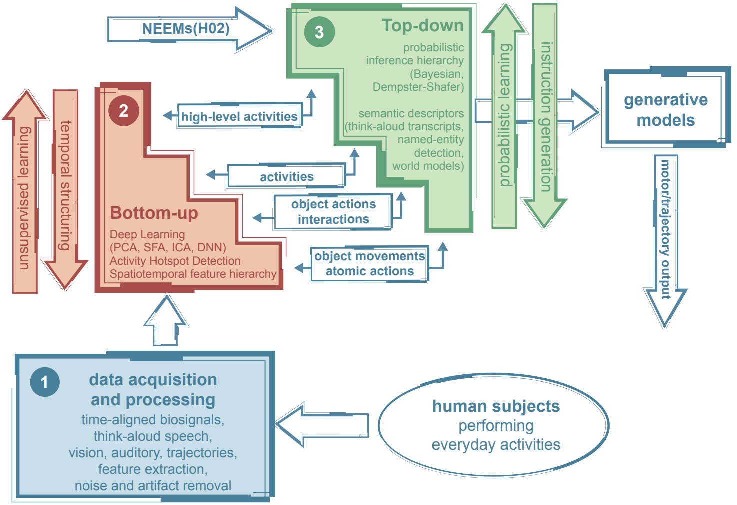
Find representations of human everyday activity data which ...

- are of lower dimensionality than the original data
- assign a hierarchical temporal structure decomposed into general units
- contain semantic descriptors related to the recorded activities
- allows the generation of instructions for performing PEAMs

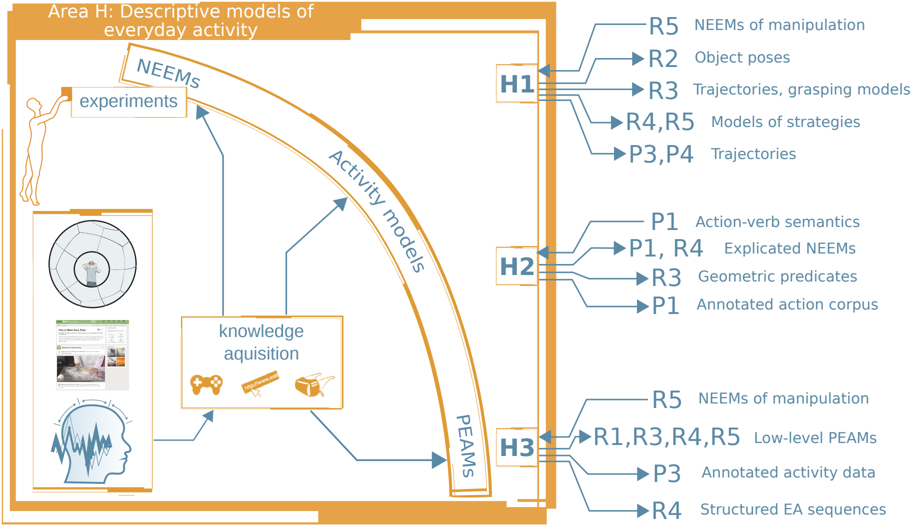
Proposed solution:

- Acquire high-dimensional data of human everyday activities
- Perform multi-level combination of bottom-up and top-down approaches to provide generative model

H03 Approach



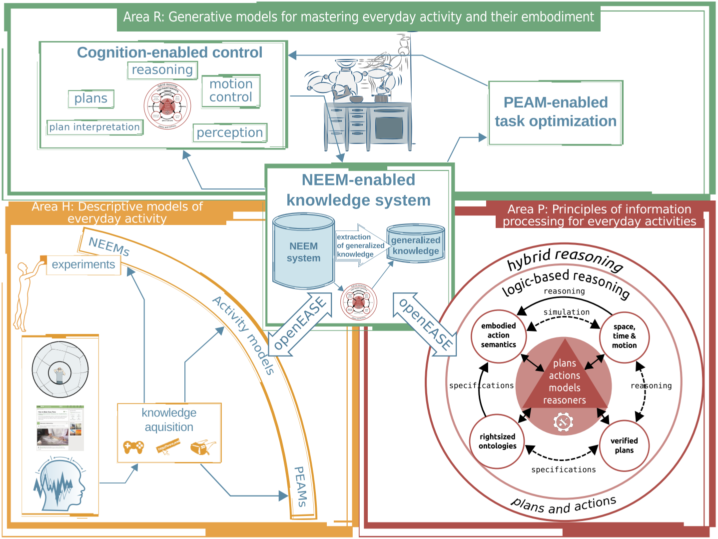
Interrelationships with EASE



The 'EASE factor': what participation in EASE adds

- Each of the H-projects draws on a strong foundation of SOA research
- The embedding of multimodal data, knowledge and models of human activities into robotics applications allows robots to approach humans' capabilities to flexibly perform vaguely formulated EA
- In return the explicit robotic models of activities and embodied perception provide a realistic testable grounding
- This feedback loop can only be established in tight collaboration within EASE

Overview



Area R: Generative models for mastering everyday activity and their embodiment
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reasoning
motion control
plans
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PEAM-enabled task optimization
NEEM-enabled knowledge system
NEEM system
extraction of generalized knowledge
generalized knowledge
openEASE
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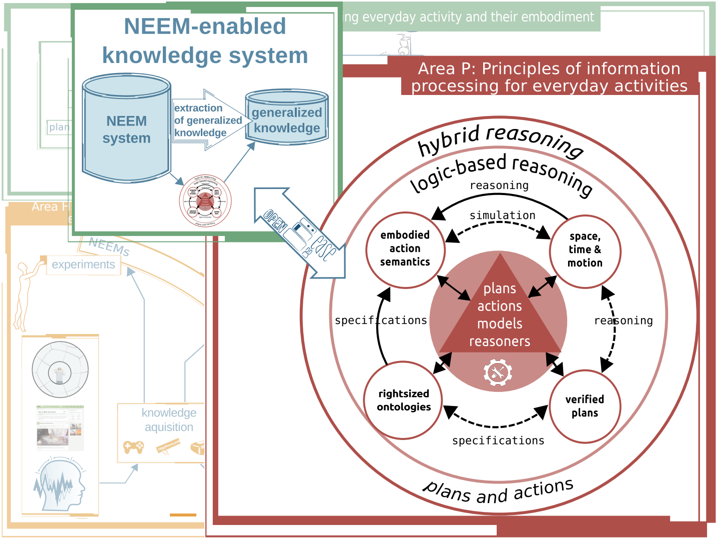
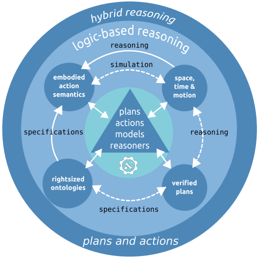
Area H: Descriptive models of everyday activity
NEEMs
experiments
Activity models
knowledge aquisition
PEAMs
Area P: Principles of information processing for everyday activities
hybrid reasoning
logic-based reasoning
reasoning
simulation
embodied action semantics
space, time & motion
plans actions models reasoners
specifications
reasoning
rightsized ontologies
verified plans
specifications
plans and actions

Research Area P



RA P: Role in EASE

- provide foundations for the **formalisation** of, and **reasoning** about, everyday activities
- establish **principles** for the required information representation and processing
- provide *ontologies, reasoners, and semantic specifications* mediating NEEMs and PEAMs
- interface to *hybrid reasoning* in research area R via shared query architecture



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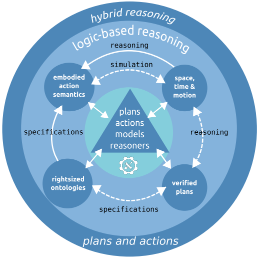

Intuition & Ambition

Several independent perspectives (human activities, robotics, formalisation) now pursuing similar approaches, requirements and solutions at multiple levels: it is time to leverage off this situation to achieve a **new level of performance** – EASE makes this possible.

RA P: Objectives and Measures of Success

Goal: design, realize, and evaluate a new logic-based knowledge representation and processing infrastructure for achieving mastery of everyday activities

Objectives:

- Defining **models**, **knowledge structures**, and **reasoners** necessary for NEEMs
- Achieving **flexible levels** of qualitative abstraction that optimise reasoning by exploiting PEAMs using a **spectrum of formal languages**
- Formalizing the **plans and their properties** necessary for mastering everyday activities

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Measures of success:

- growing repertoire of **formalised queries** relying directly on enhanced reasoning capabilities
- demonstrated **principles** of knowledge representation and processing, derived and validated for all knowledge areas required

Starting Points: Three $\mathcal{P}$erspectives

Addressing:

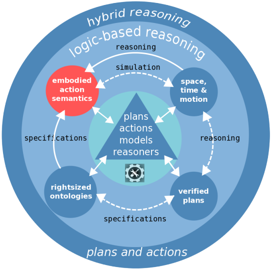
- P-projects individually and with respect to the international state of the art
- P-projects in relation to one another and in relation to the EASE CRC as a whole
- The added value of performing the P-projects within the context of EASE: what is the difference?

Subproject P01:

Embodied semantics for the language of action and change


Bateman


Malaka



Premise and SoA:

- Language understanding demands abstract, qualitative, embodied simulation
- but this is known not to be 'complete' simulation! – how to restrict?
- existing approaches limited in scale, in embodied realization, and formalisation

Challenges:

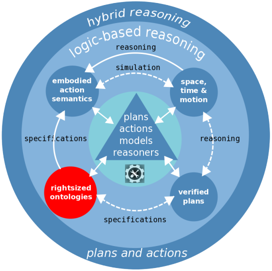
- to achieve a combination of simulation and qualitative formal semantics for **embodied semantics**

Subproject P02:

Rightsizing ontologies

Lutz

Bateman



Premise and SoA:

- Intelligent everyday behavior requires substantial knowledge (Cyc, etc.)
- existing technology for ontology reasoning *unable to cater for the demands of reasoning* in performing everyday activities adequately

Challenges:

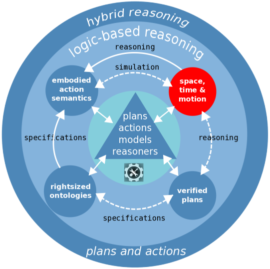
- to bridge between expressive languages for KR and lightweight languages for efficient reasoning **in a principled fashion**

Subproject P03:

Spatial reasoning in everyday activity


Bhatt


Schultheis



Premise and SoA:

- Human-level performance requires cognitively-motivated spatiotemporal formalisations

Challenges:

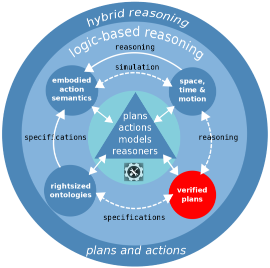
- to deliver methods, algorithms and tools for commonsense representation and reasoning about **space and motion**
- to direct action-based problem solving using computational models **leveraging off the environment**

Subproject P04:

Formalizations and properties of plans

Drechsler

Grosse



Premise and SoA:

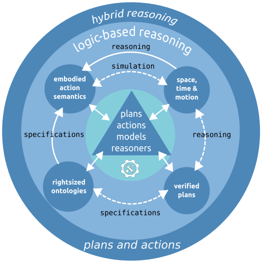
- Substantial properties of plans can be formally specified and verified for behavior prior to execution
- existing approaches restricted by scale and flexibility of ‘everyday’ scenarios

Challenges:

- to create efficient reasoning tools for verifying formal properties of robot plans: **offline, online, on-the-fly**
- to provide improvements in **error-handling and scalablity**

P-projects: interrelationships **within** P

- The P-projects can be seen collectively as solving a **portfolio of formalisation** challenges essential for gaining control of the central reasoning tasks involved in modeling and performing activities *intelligently*
- The projects constitute a **logic-based** and **closely interacting** network of research activities, thereby maximising synergies and added-value of re-use



P: a complete unified scenario

Instruction: "And better make sure everyone gets something to drink"

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P01 Underspecified embodied ‘linguistic’ semantics:

- context: at home, setting table for guests
- resolution of activities, underspecified people, objects and actions
- qualitative actions on objects: simulation semantics

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P02 Background knowledge and ontology:

- household, dining room, table, plates, knives, forks
- drinks $\Rightarrow$ activities: containers, glasses
- rightsized for effective reasoning

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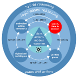

P03 Activities, space and motion:

- commonsense spatial representation and reasoning: getting the robot to the table, drinks to the table, teabags out of the box
- building on situated activities and bottom-up sensor (RGB-D) data
- declarative query-answering about space and change

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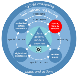

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P04 Activities and plans: Verification

- take the glasses and drinks to the table and set them out
- plan verification: is the plan formally correct?
- passing on verified plans to robot
- potential on-the-fly hindrances and correction

P: a complete unified scenario: **major impacts**

P01 Underspecified embodied 'linguistic' semantics:

▷ linguistics, qualitative embodied semantics

P02 Background knowledge and ontology:

▷ formal specifications, KR and ontology

P03 Activities, space and motion:

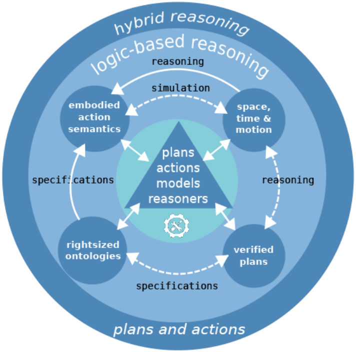
▷ KR, commonsense reasoning, spatial reasoning

P04 Activities and plans: Verification

▷ plan verification in open scenarios

P-Projects: interrelationships within EASE: overview

Tightly coupled, interleaved and interacting with the H and R areas...



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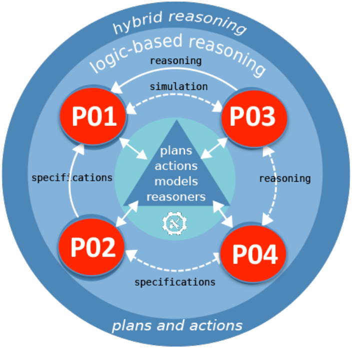

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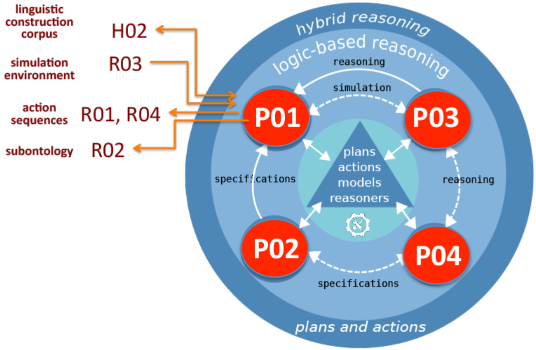

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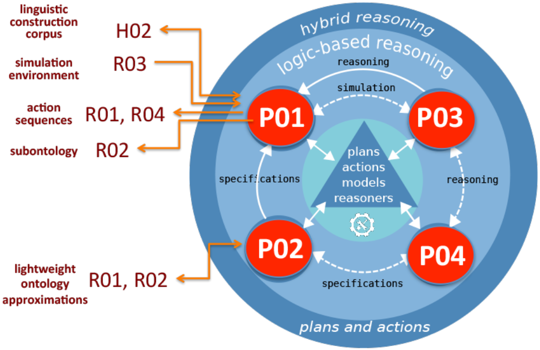

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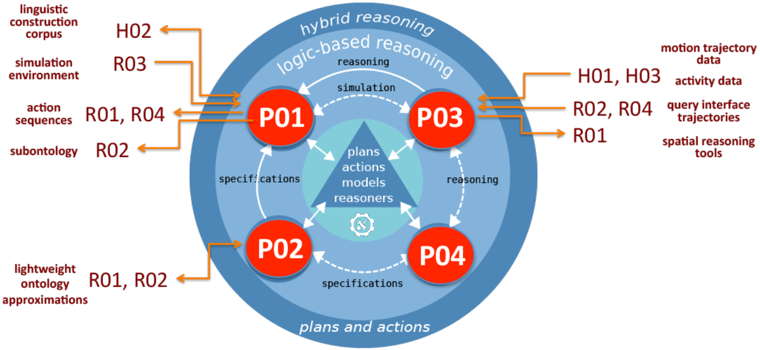

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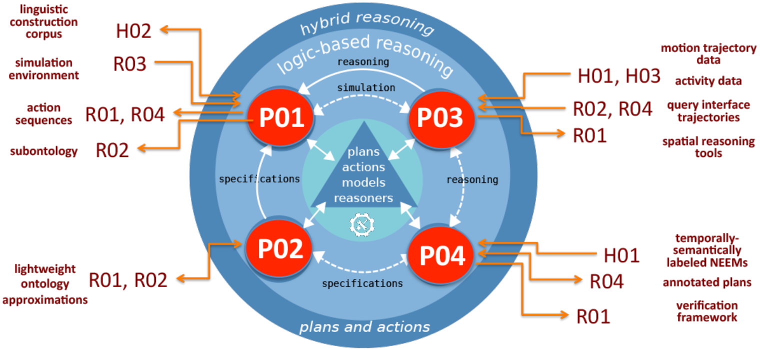

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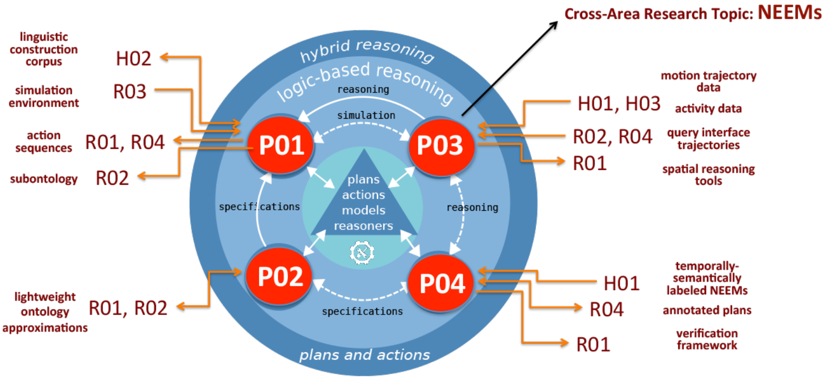


The best of three worlds...

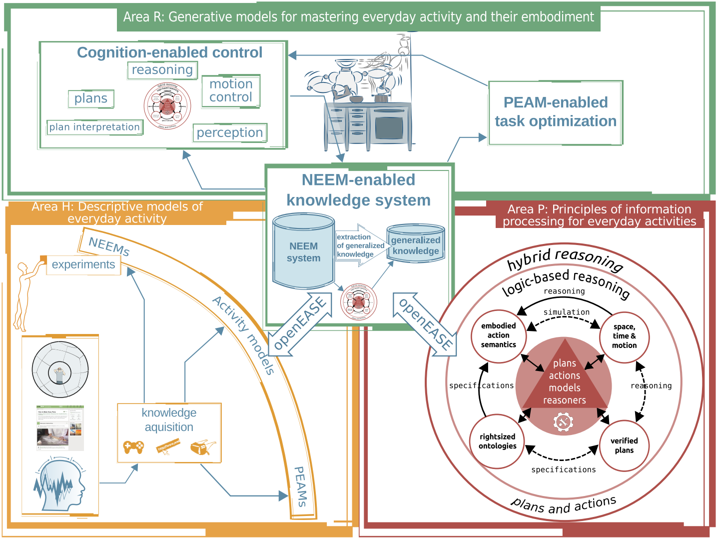
- Direct empirical data (behavioral, perceptual, movement) from situated performance of everyday activities from the H-area
- Realistic grounding in explicit robotic models of activities and embodied perception in the R-area – often building on substantial implemented previous work
- Formalisation of knowledge and reasoning at varying levels of qualitative abstraction: refining results from H and producing testable models for R

All managed via the openEASE exchange architecture

The ‘EASE factor’: what participation in EASE adds

- Each of the P-projects explores ground-breaking research tasks **already internationally at the state-of-the-art** or beyond
- Drawing on this foundation, embedding within the EASE scenario and framework provides an unprecedented opportunity for taking those research tasks to the next level: **anchoring both in empirical data and in robotic embodiments**
- This **multiple feedback loop** is precisely what has been missing in more isolated research directions hitherto
- **Long-term interdisciplinary perspectives** opened up for sustained results advancing the forefront of international research in each of the areas addressed and documented in leading journals and conferences

Overview



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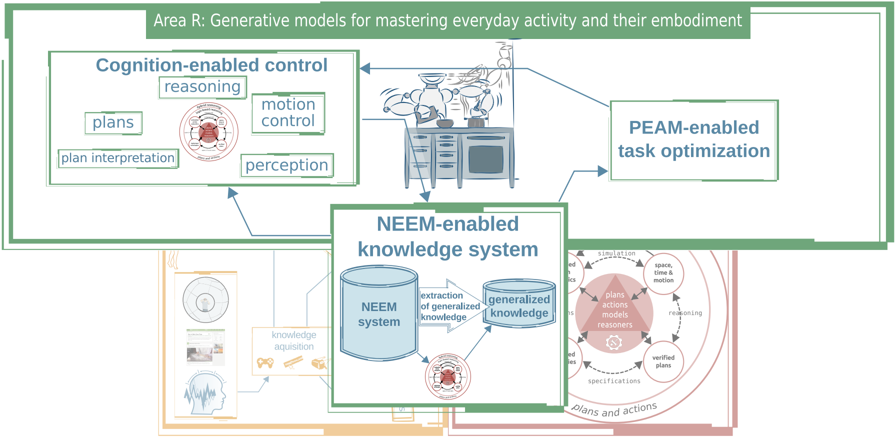
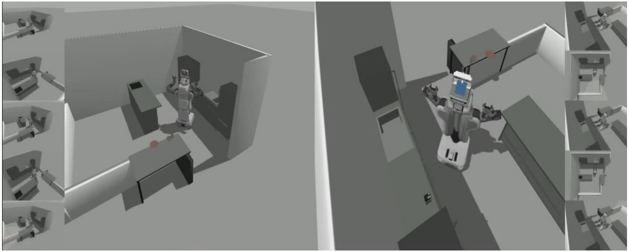
Research Area R



RA R: Role in EASE

- Acquire **commonsense and naive physics** knowledge from multiple demonstrations
- Provide **robust perception** systems through background knowledge and NEEMs
- Establish principles to autonomously **learn simulation models** from real-world NEEMs
- Design **generic robot plans** through exploitation of regularities of everyday activity



RA R: Objectives and Measures of Success

Goal: investigate and construct the EASE control framework including perception, learning, reasoning and planning mechanisms

Objectives: realize the

- NEEM-based knowledge system
- perception-based and simulation-based reasoning mechanisms
- plan-based control framework

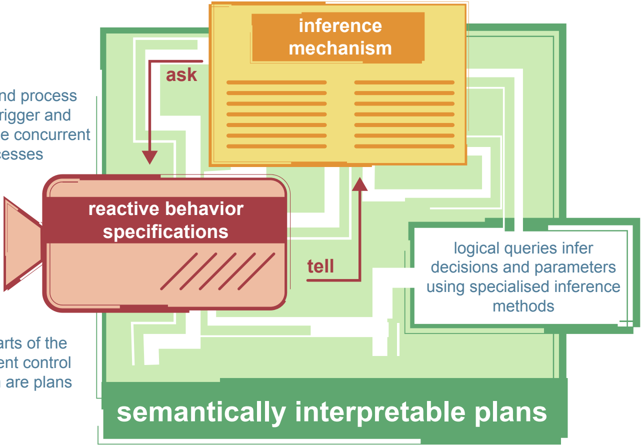
Measures of success:

- benchmark queries to test the cognitive capabilities
- performance increase
- autonomy in adaptation of generic plans

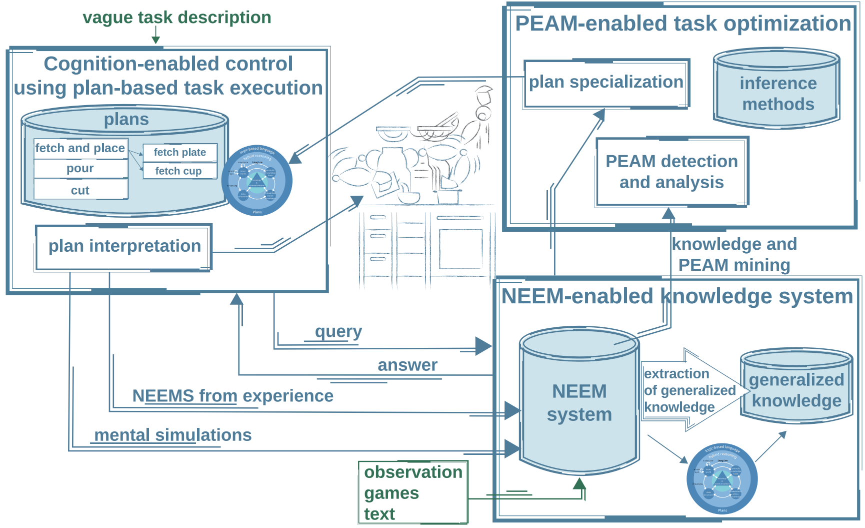
Starting points - Embodying plan execution

sensor and process events trigger and synchronize concurrent processes

large parts of the concurrent control program are plans



Methodology applied in Area R

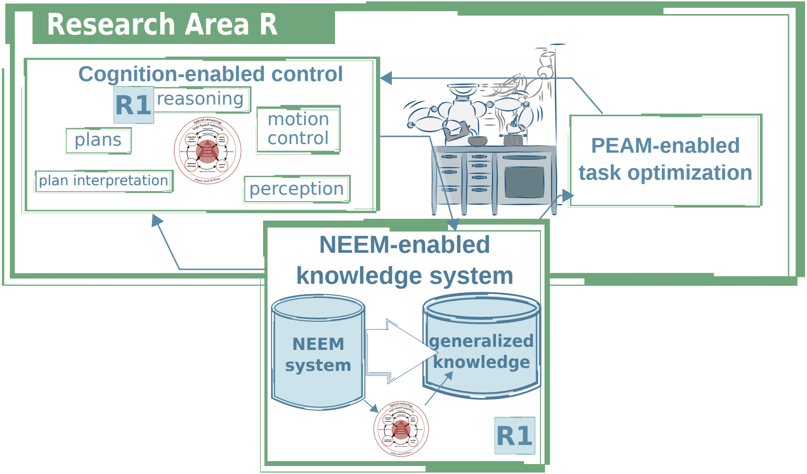


Subproject R01

NEEM-based embodied knowledge system


Beetz


Cheng



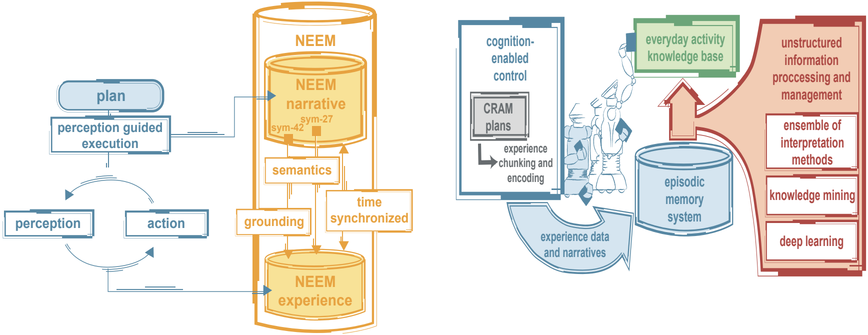
R01 Scientific Goals

- **Development** of an embodied **knowledge** acquisition, representation, and management **framework**.
  - artificial episodic memories indexed through **symbolic narratives**
  - **declarative knowledge** subsystems for everyday activity knowledge
  - experience analytics subsystem to **extract commonsense and naive physics** knowledge
- Investigation of a physically embodied **query answering service** for knowledge completion.

R01 Approach

Collecting NEEMs and learning generalized knowledge from NEEMs

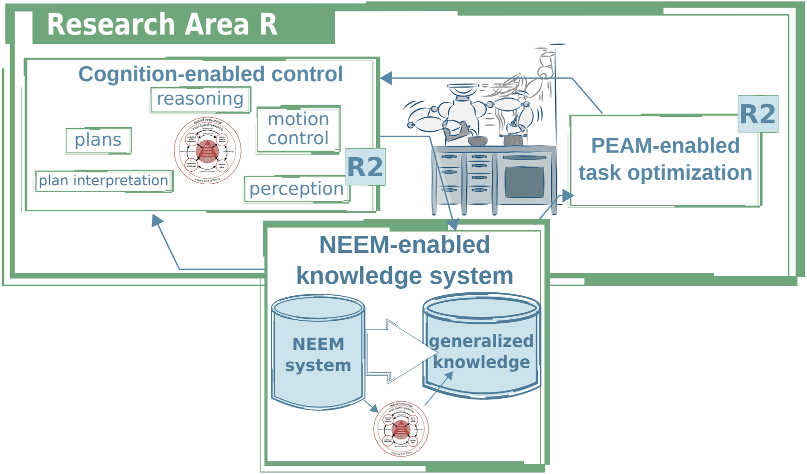
- **Acquire memories** of activities from human and robot performances – from observations, simulations, mental simulations, etc.
- Extract **generalized** everyday activity **knowledge**.



Subproject R02

Multi-cue perception based on background knowledge

Frese



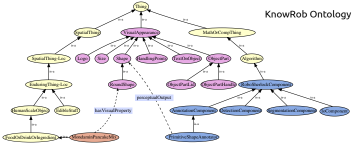
R02 Scientific Goals

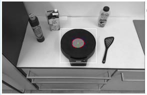
- 3D-object **localization** in, e.g. cupboards and dishwasher
- Extreme **occlusion**
- Utilize **background** knowledge and memory to foster recognition
- "PEAM of objects inside containers"

R02 Approach

- Comprehensive Bayesian model of relevant cues and phenomena – geometric depth, edges, color, **reflections**
- **Inference** Algorithm for this combination
- Integration with **RoboSherlock** (UIMA) framework

```
(detect (an object
        (name handle)
        (location kitchen_sink)))
```





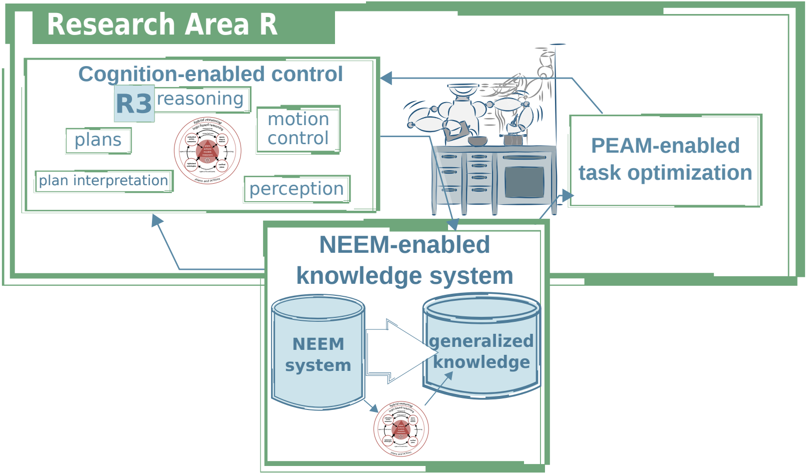
```
(detect (an object
  (location on (object PancakeMaker))
  (shape flat)
  (color yellow)
  (name Pancake)))
```

Subproject R03

Embodied simulation-enabled reasoning

Zachmann

Beetz

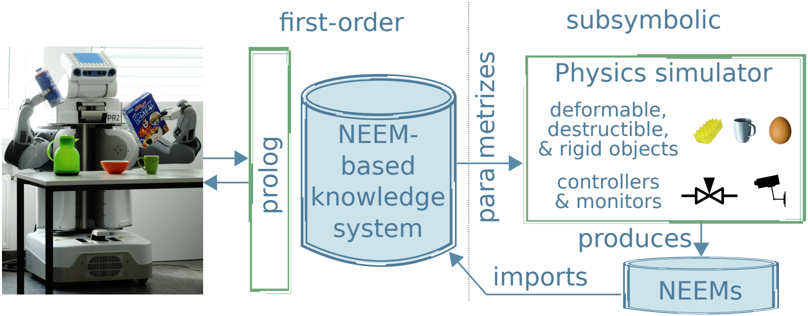


R03 Scientific Goals

- **Simulation-enabled** reasoning engine for robots
- Integration of simulation-enabled **reasoning** into the **perception-action** loops of the robots
- Simulations for **naive physics and commonsense reasoning**
- **Learning** simulation models from NEEMs

R03 Approach

Develop a qualitative **inference method** to reason about actions and their effects based on the **mental simulation-based** predictions.

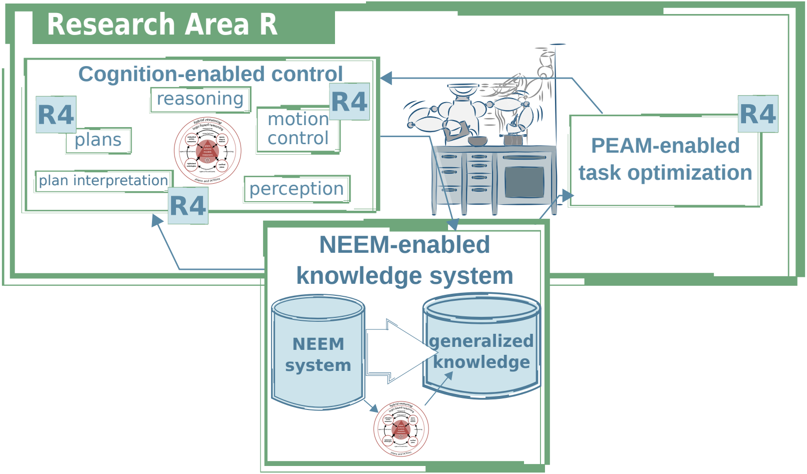


Subproject R04

Specializing and optimizing generic robot plans

Beetz

Albu-Schäffer



R04 Scientific Goals

- Use PEAMs to improve task performance of generic robot plans for particular task contexts
- Consider plans as executable and modifiable behavior specification subject to reasoning
  - **Plans as subjects of learning**: Analyze plans and NEEMs to detect flaws and opportunities
  - **Plans as high-performance inference engines**: Learn query-specific knowledge bases
  - **Plans as interpreters of vague action descriptions**: Specify actions using desired effects

R04 Approach

A generalized action plan for pouring

def-plan pour (⟨**theme**⟩ : (some stuff)
⟨**source**⟩ : (an object
(type container)
(contains ⟨**theme**⟩))
⟨**dest**⟩ : (a location))

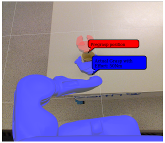
begin

1. reach(⟨**source**⟩)
2. lift(⟨**source**⟩) (a location (above ⟨**dest**⟩))
3. tilt(⟨**source**⟩)
   until (amount (some stuff (at ⟨**dest**⟩))
   $\geq$ (amount ⟨**theme**⟩))

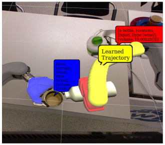
end

Groundings

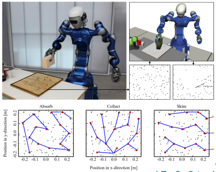
`reach:`



`tilt:`



`wipe:`

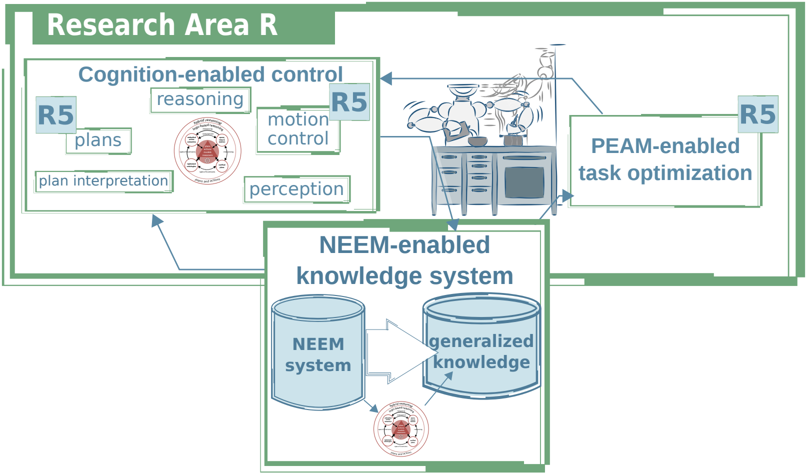


Subproject R05

Episodic memory for everyday manual activities


Ritter


Beetz



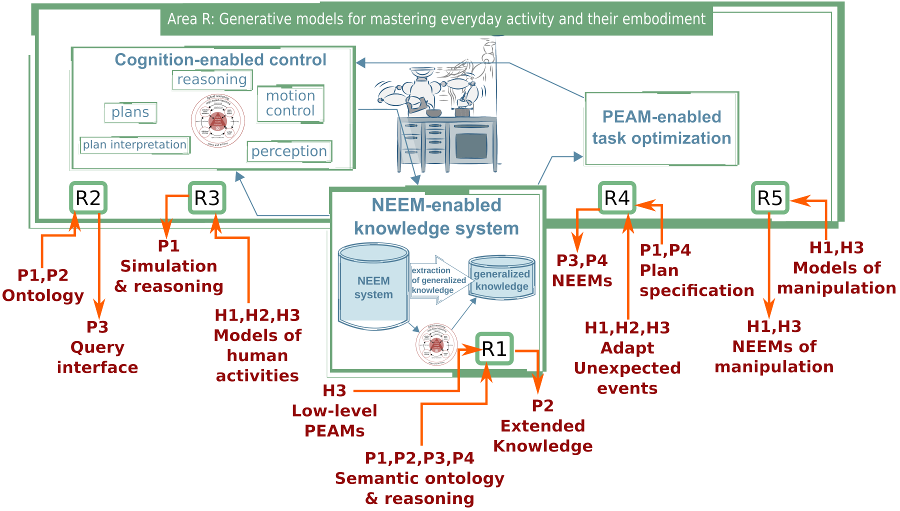
R05 Scientific Goals

- NEEM-based information processing and control models for **hand manipulation actions**
- Link semantic and procedural knowledge representations via NEEMs in order to **scale to large numbers of action patterns**
- Use of NEEMs and episode mirroring to **accelerate learning novel hand manipulation** skills from very few example episodes

R05 Approach

- Exploration informed by NEEMs
- NEEMs as link between **semantic and procedural memories**
- Exploitation of **grasp synergies** (PEAM)

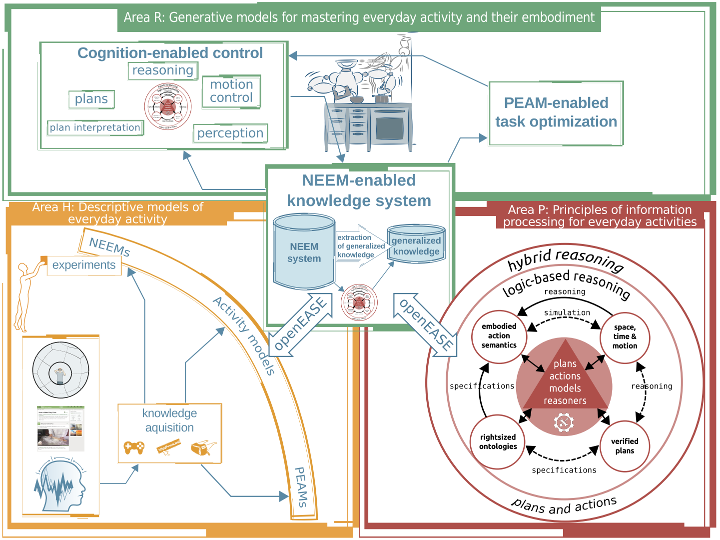
R-Projects: interrelationships within EASE: overview



The ‘EASE factor’: what participation in EASE adds

- **Boosting information processing** for robots by exploiting episodic memory systems
- **NEEM memory system**: compression, management, retrieval that includes commonsense and naive physics knowledge
- **Rapidly learn** from few examples using NEEMs and episode mirroring
- Optimize **generic robot plans** through exploitation of regularities of everyday activity
- The robot will be knowledge about **what it did**, how it **behave**, what **happened**, what it **saw**, etc.

Overview



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