Knowledge in Artificial Intelligence

VU VRIJE UNIVERSITEIT AMSTERDAM

Knowledge Engineering for Hybrid Intelligence

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Who are we

- Research : Hybrid Intelligence, Knowledge Graphs, Explainability
- Applications : Hybrid Intelligence, KR-driven robots, Scientific Discovery
- More : mother of 2, drove to Mongolia, loves mountain sports

https://kmitd.github.io/ilaria/

This tutorial

What will you get out?

- have a structured way of designing and analysing your HI scenario(s)
- based on KE methodologies
- decompose your HI scenarios in standardised tasks
- prepare for comparison and reuse

This tutorial

1. Part 1 : Introduction (14:00-15:00)
    - Introduction to Knowledge Engineering, CommonKADS
    - Introduction to the HIKE framework
2. Part 2 : Structuring you HI scenario (15:00-16:30)
    - Introduction to UML notations
    - (Hands-on 1.1) Fill the ontology table
    - (Hands-on 1.2) Design a UML workflow of the your HI scenario
3. Part 3 : Measuring the HIness of your scenario (16:30-18:00)
    - Introduction to the HIness measures
    - (Hands-on) Measuring the HIness of your own scenario

Part 1
Introduction

Problem and Motivation

HI is an **emerging field**

- Hybrid Intelligence (NL), Humane-AI network (EU), Human-AI co-evolution (FI) …
- HHAI Conference, Human-centred AI workshops

Working definition

- AI to **enhance** human capabilities (as others tools do)
- AI to ~~replace~~ **collaborate with** humans (complementarity, synergy)

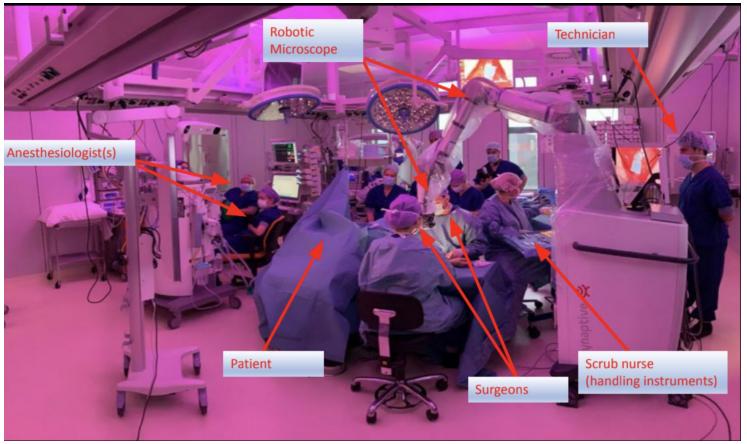
Problem and Motivation

A practical HI example : the **micro-surgeon**

- A coupled system (human-machine) learning high quality task performance in a (micro)surgical environment

Tasks

- human has an ***incentive*** to teach the robot
- the robot ***learns*** from the human experience
- the robot ***asks*** when in doubt/ for permission
- the robot ***defers*** to the human



Successful surgical procedure → successful patient outcome

Problem and Motivation

Lacks **formal, systematic representation** of the hybrid complex interaction

- which interactions ? which knowledge ?
- which tasks and methods ?
- which datasets ?

What for?

- efficient development of new HI scenarios
- comparison / reuse of concepts (design patterns) across applications

→ we need a **method** to design the knowledge & tasks involved in HI interactions

Research Hypothesis

Knowledge Engineering (CommonKADS) can help formally describe HI systems:

- identify and standardize tasks and knowledge
- support design with reusable and interoperable design blocks
- toward a characterization of HI

Questions

1. Classical KE to **characterize** modern HI applications?
2. Which are the common, typical **components** in HI applications ?
3. Can we **measure the HI-ness** of an application?

Knowledge Engineering? (KE)

('80s) The process of eliciting, structuring, formalising, implementing information involved in a knowledge-intensive processes, in order to construct a program that can perform a difficult task adequately

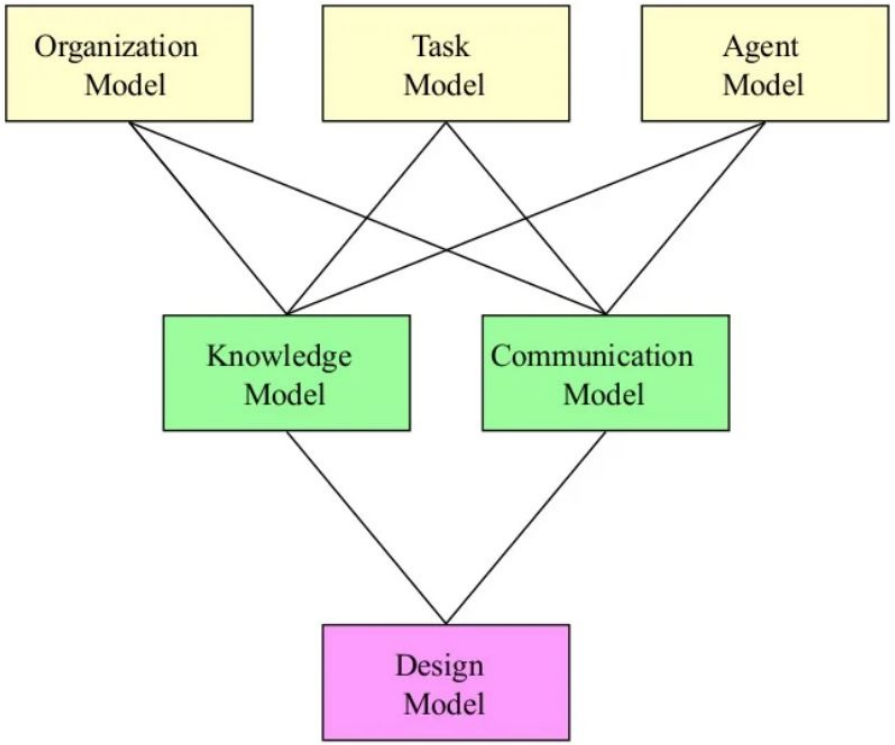
KE allows to:

- describe **tasks and roles** in knowledge-intensive processes
- give a basic organisation of knowledge (roles, tasks)
- model design components
- **standardise and reuse** knowledge across applications

A KE methodology: CommonKADS

Engineer a system's **behavior**, its application **domain**, and the **organization** behind it.

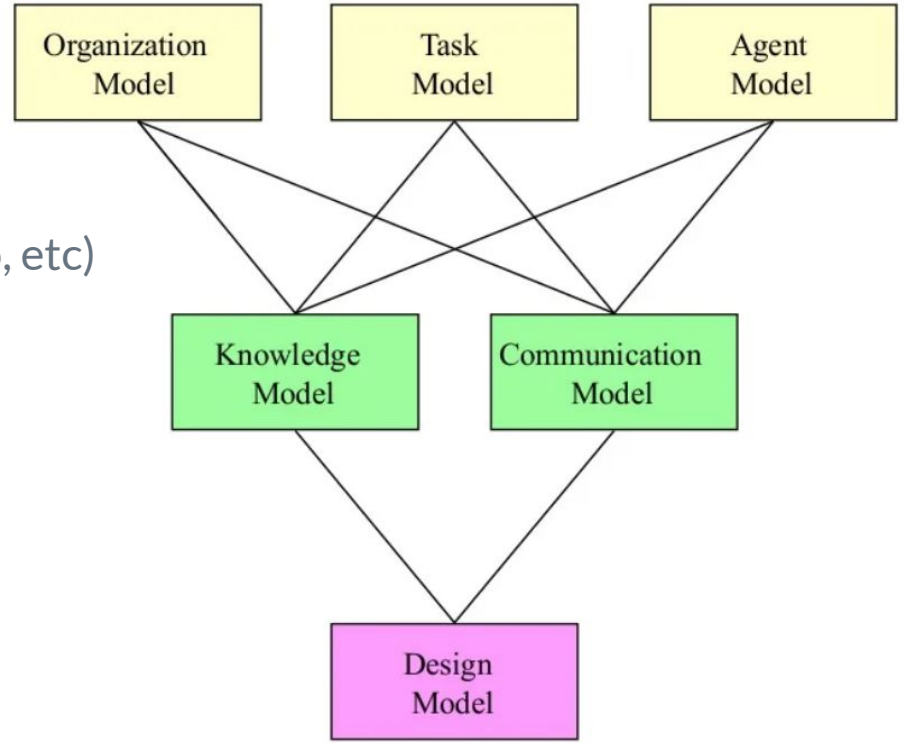
A series of **design models** serving as requirement specification to implement a KB-system



Principles of CommonKADS

Back to our **micro-surgeon**

- **OM** : analysis of the hospital setting
- **TM** : layout of the microsurgery task (i/o, etc)
- **AM** : characteristics of the agents (competences, legibility, authority)
- **KM** : knowledge used in the surgery
- **CM** : transactions between agents
- **DM** : technical specification



Basic CommonKADS Terminology

Domain

- some area of interest
- *banking, food industry, car manufacturing*

Task

- something that needs to be done by an agent
- *monitor a process, create a plan, analyze deviant behavior*

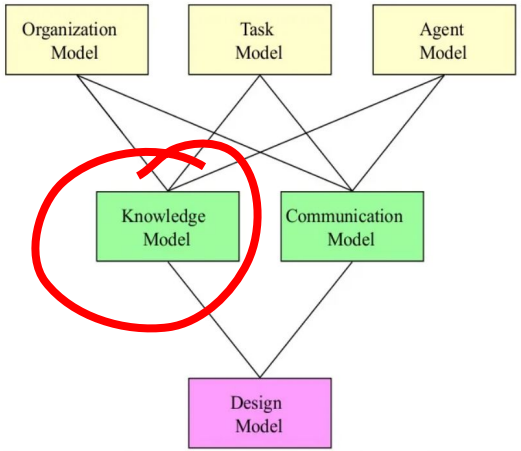
Agent

- the executor of a task in a domain
- *a human, some software*

HIKE : A Knowledge Model for HI

Idea

- Let's **engineer knowledge** in HI scenarios
- Build a HI "knowledge model" : describe knowledge components (agents,roles, tasks) for a HI process
- Validate through **commonalities/differences** of different Hybrid Intelligence scenarios



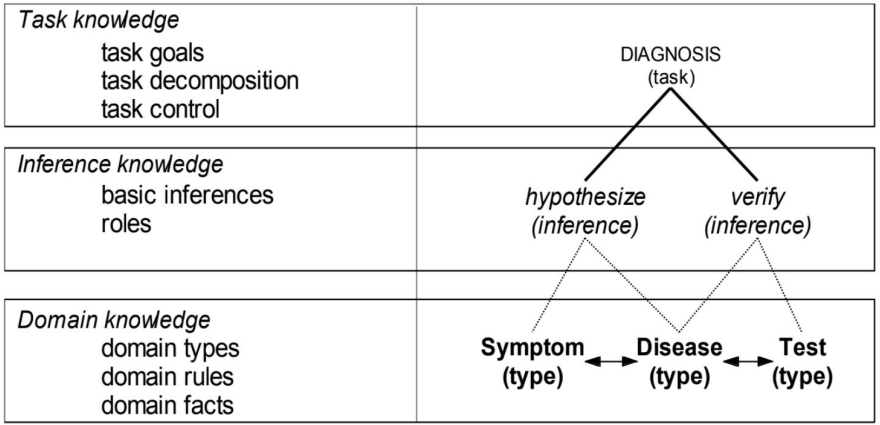
Original Knowledge Model

1. **Task Layer**

   which problem- solving sub-tasks + input, output and goal
2. **Inference Layer**

   primitive reasoning steps combined in sub-tasks
3. **Domain knowledge Layer**

   domain-specific knowledge to execute inference (classes and relationships)



*Knowledge Model in a **medical application***

Hybrid Intelligence Knowledge Model (HIKE)

Goal : create a Knowledge Model for HI applications

Define:

1. **HI Task Layer** : which HI tasks, subtasks and goal(s) of an application?
2. **HI Inference Layer** : which primitive functions can be combined into HI sub-tasks?
3. **HI Domain Layer** : which domain-specific knowledge is needed to execute inferences?

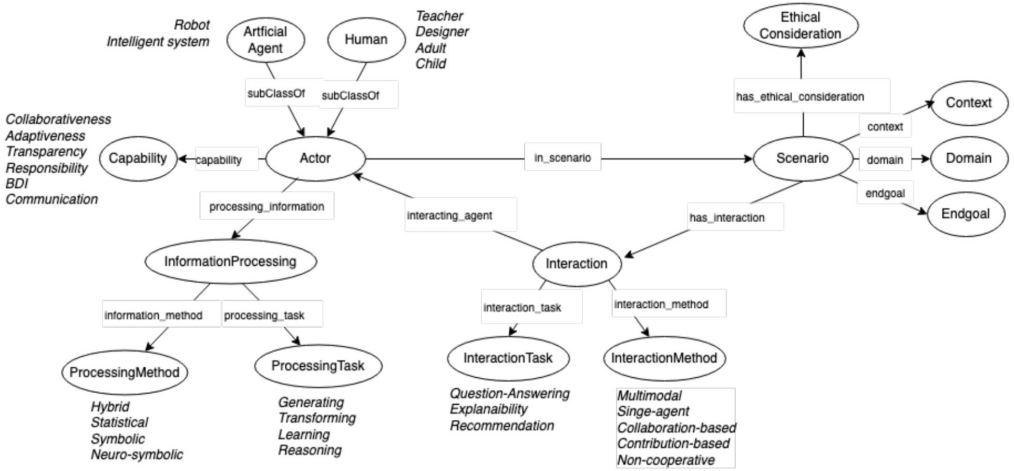
We call this Knowledge Model **HIKE**

HIKE : Domain Layer

Terminology is scenario-dependent

Abstract classes and relationships:

- **actors** (characteristics, capabilities)
- **interactions** (methods, tasks)
- **scenarios** (context, endgoal, ethical considerations)



indicating the **knowledge role** in the application

HIKE : Tasks and Inference Layer

Describe the tasks hierarchically (= **task decomposition**)

Original CommonKADS

- analytic tasks

  diagnosis, monitoring, classification

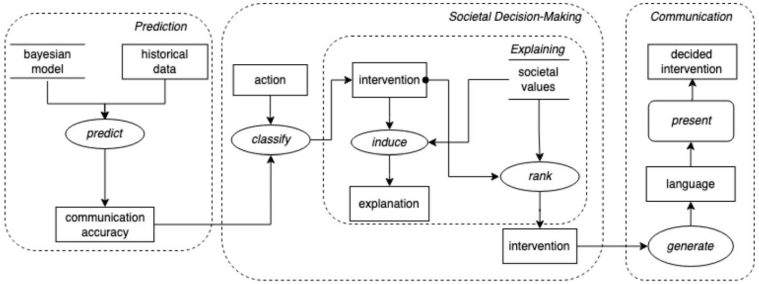
- synthetic tasks

  scheduling, planning, designing

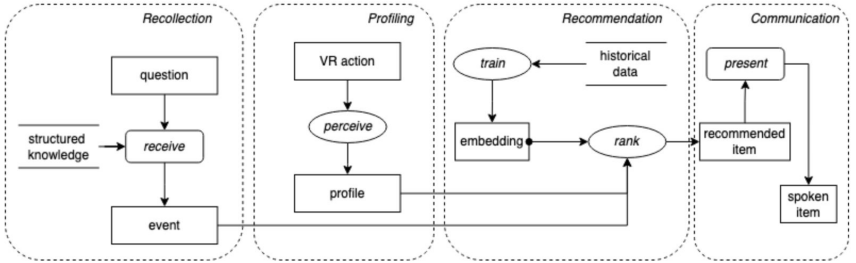
Recognition	Training, Classification ·		
Prediction	Regression	Training, Predicting	
Reasoning	Inference	Induction, Abduction, Deduction	
Action	Cognitive	Attention	Monitor, Orienting, Sustained
		Memory	Recollect, Short-term, Sensory
		Perception	Vestibular, Olfaction, Audition, Touch, Vision
		Decision Making	Individual, Societal, Debiasing
		Knowledge-aid	Mental Models, Team Role Allocation, Creativity
	Physical	Movement	Body Part Mvt., Translation

Additional HI : Reuse from the literature

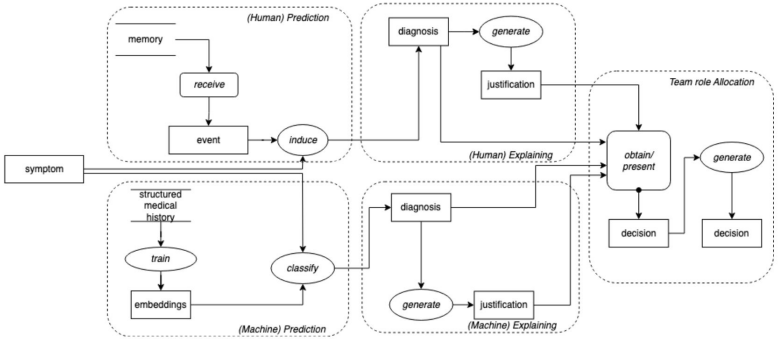
Using HIKE to characterise HI scenarios



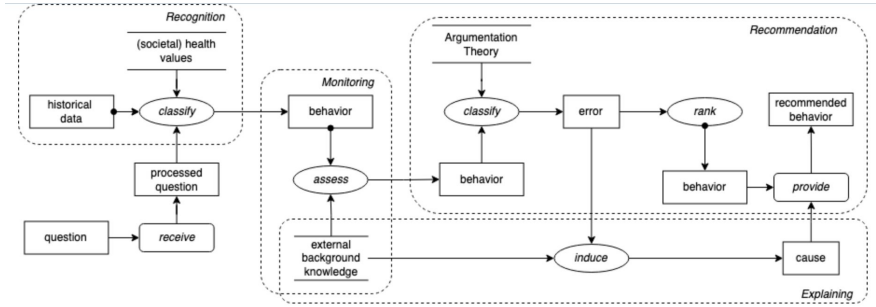
(S3) Collective Decisions in Law and Economics



(S4) Educational Recommenders with Narratives



(S5) Knowledge Graphs for Machine Intelligence



(S6) Co-learning Buildings

HIKE : Comparison of scenarios

Classical KE tasks

- Monitoring, Prediction, Classification

Importance of **symbols**

- Ontologies, KGs
- Input for subsymbolic tasks
- Rise of neuro-symbolic applications

HI-specific tasks

- **Creative tasks** : Explaining, Communication
- **Interaction**: Team-role Allocation, Negotiation, Societal DM
- **Multimodality**

Part 2 Structuring HI Scenarios

Practical HI example: the Virtual Museum tour guide

- A virtual agent accompanies a visitor in a VR exhibition
  - Theory of Mind, Collaboration, Trust
- *Agent* :
  - stores information about paintings+user
  - recommends art objects, answers questions
- *User*
  - **interacts** through VR for a personalised experience

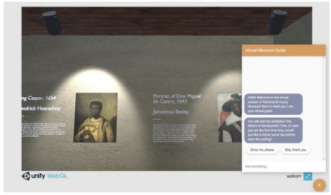


Figure 2. Interface of the virtual guide in web-based virtual museum

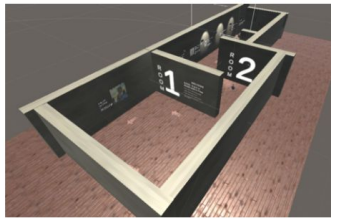
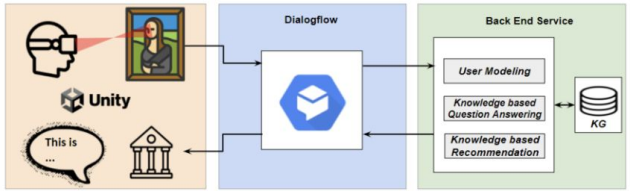


Figure 3. Two rooms in the virtual museum.



How to apply HIKE?

1. Define a few scenarios (what does your application do?)
2. Define the application's **domain layer**
    - Create an ontology of main concepts and relationships
    - Map the concepts to the HI ontology
3. Define the application **task and inference layers**
    - List the tasks and subtasks hierarchically
    - List the input and output for each task
4. Create a **task decomposition**
    - Link tasks and inputs/outputs sequentially

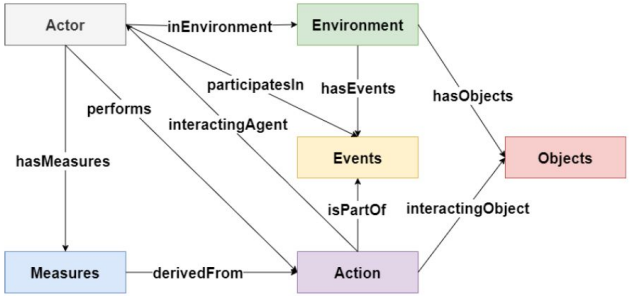
1. Define a few scenarios

Example from the VR application

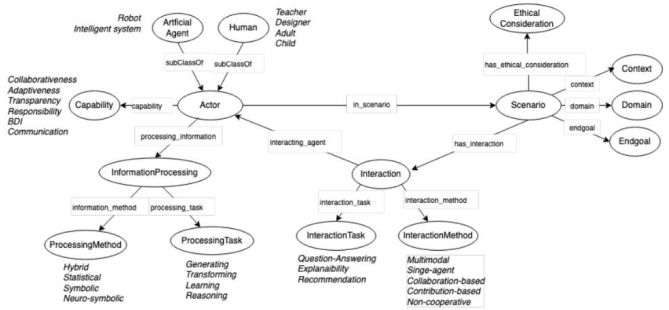
- S1. **Multimodal Interactions.** *The agent captures Sarah's gaze, facial expressions, and speech inputs, employing multimodal analysis and reasoning to understand her interests. Based on the interpreted multimodal inputs, the agent dynamically tailors its interaction (e.g. highlighting specific objects in the painting to guide visual attention or encourage hand grabbing, offering additional cultural background, recommending related paintings)*
- S2. **Real-time Understanding of User States**. T*he agent employs Theory of Mind to assess Sarah's beliefs, intentions, and emotion, adjusting its responses dynamically*
- S3. **Memory Integration for Personalisation**. T*he agent recalls Sarah's preferences and integrates them with information from previous users to enhance the exhibition experience.*

2. Define the application's domain layer

1. Create an ontology of main concepts and relationships



2. Take the HI ontology of knowledge roles



3. Map the concepts to the HI ontology

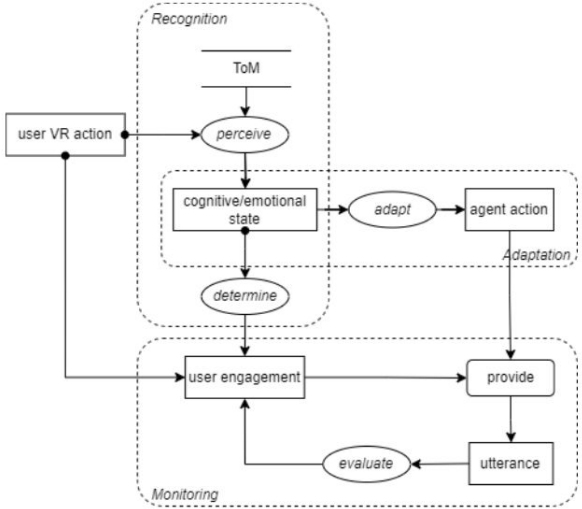
	hi:EndGoal	hi:ProcessingMethod	hi:ProcessingTask
S1	Multimodal Interaction	Multimodal Analysis & Neurosymbolic	Reasoning
S2	Real-time State Understanding	Theory of Mind	Generate
S3	Memory Integration	Symbolic techniques	Transform
S4	Perception Building	Multimodal Analysis & Theory of Mind	Learning
S5	Explainability	Statistical techniques	Generate
S6	Collaborative Pursuit of Goals	Reinforcement Learning	Learning, Generate

3. Define the application's task and inference layers

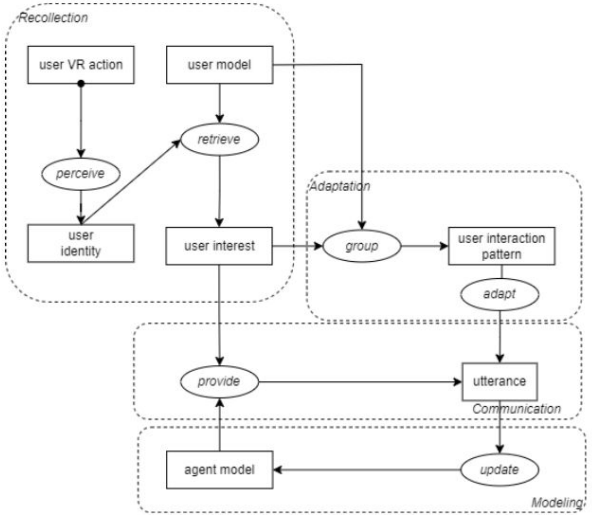
1. Define coarse-grained tasks
   - E.g. `Recognition` of user's mood, `Prediction` of the next painting to recommend, `Reasoning` over user interests, `Action` (cognitive actions based on ToM, Physical actions such as gaze or movements)
2. Decompose the tasks into smaller, fine-grained sub-tasks hierarchically
   - E.g. classical KE : `abstract`, `select`, `transform` certain data
   - KE transfer functions for communications (`obtain`, `receive`, `present`, `provide` data)
   - VR-specific inferences : `perceive` through a VR headset or `interact` with virtual objects
3. Link the leaves at the lowest level (primitive processes or inferences) to the terms of the ontology (the inputs and outputs of such processes)
   - E.g. static inputs (e.g. the cultural heritage Knowledge Graph, a room in the VR exhibition)
   - E.g. dynamic inputs (e.g. an explanation to the user, user's gaze, etc.)

4. Create a Task Decomposition

Link your inferences in a workflow. Cluster your inferences in high-level tasks.



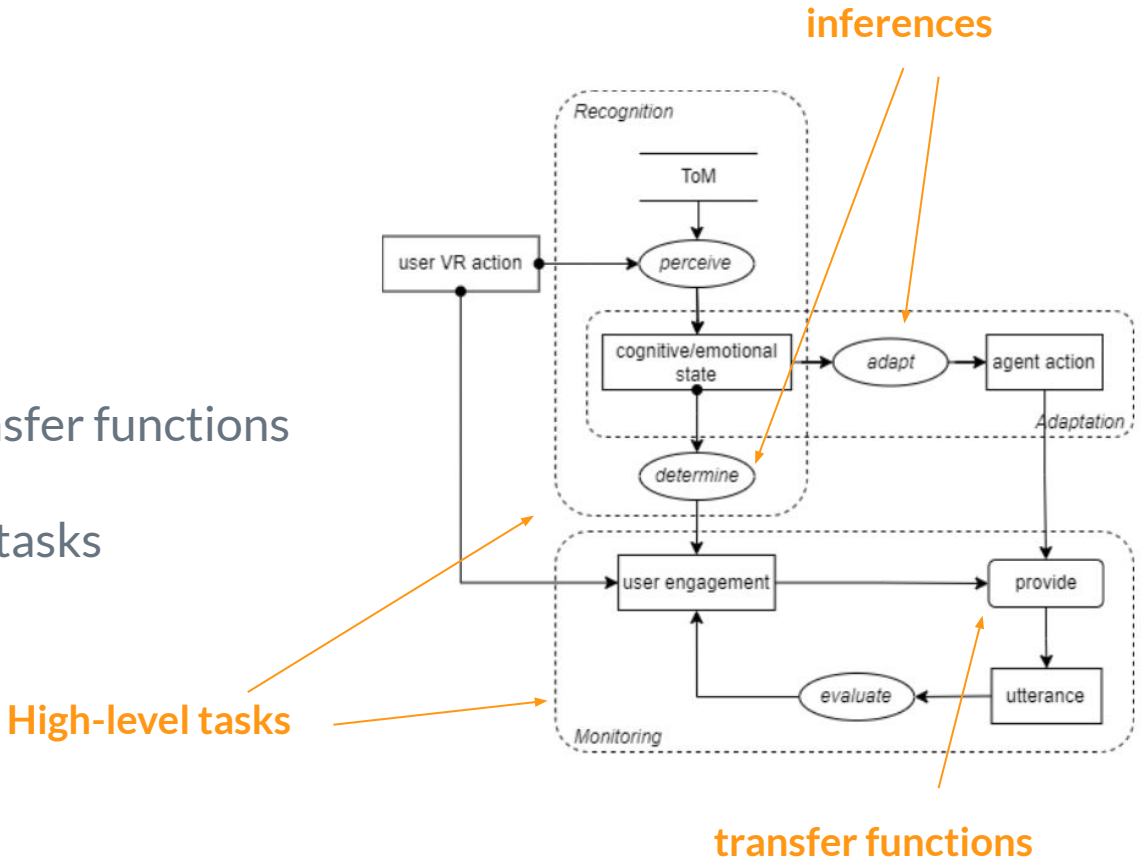
S2. Real-time Understanding of User States.



S3. Memory Integration for Personalisation.

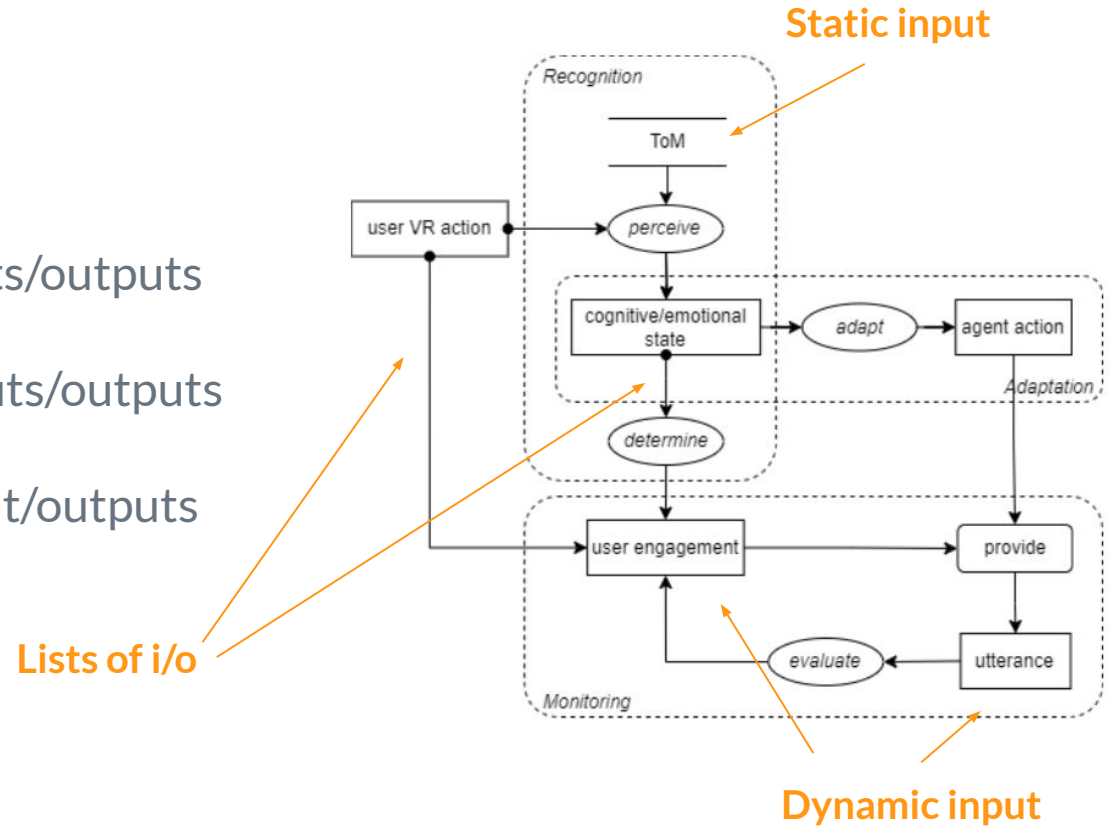
UML Notation

- Ovals = inferences
- Rounded rectangles = transfer functions
- Dashed boxes = high-level tasks



UML Notation

- Full squares = dynamic inputs/outputs
- Horizontal lines = static inputs/outputs
- Dotted arrows = lists of input/outputs



Your turn now

- Choose an HI application/scenario
- Follow the steps in slides 23-26
- End of this session :
  - *at least* have a scenario, an ontology, a list of processes
  - 5 mins general discussion

Short of ideas ?

- Here's some applications to choose from

  https://github.com/kmitd/HI-CommonKADS
- Or use the microsurgeon use-case (slides on github)

Remember the Terminology

Domain

- some area of interest
- *banking, food industry, car manufacturing*

Task

- something that needs to be done by an agent
- *monitor a process, create a plan, analyze deviant behavior*

Agent

- the executor of a task in a domain
- *a human, some software*

Discussion hands-on/1

- ...

Part 3
Measuring Hlness

Measuring HI-ness

Steps:

1. Take your scenarios
2. Make a list of the tasks in a Table
3. Mark classical KE vs HI-specific tasks
4. Describe weak/sdtrong level of collaboration toward the same goal
5. HI-ness : the % of “Strong” HI level

S*	Task	Task Description	HI Task	HI Level	HI-ness
S1	Modeling	Storing user VR multimodal actions, user interest, agent actions, and communication style of the agent		Weak	20%
	Recognition	Determining user interest based on VR action and updating the user model	✓	Weak	
	Recommendation	Selecting agent actions based on agent and user models	✓	Strong	
	Communication	Providing knowledge to the user	✓✓	Weak	
	Monitoring	Evaluating user interest based on current user actions after providing knowledge		Weak	
S2	Recognition	Determining the user’s cognitive state through Theory of Mind techniques	✓	Weak	33%
	Adaptation	Adapting agent actions based on recognized user state	✓✓	Strong	
	Monitoring	Evaluating user engagement based on current actions after providing knowledge		Weak	
S3	Recollection	Recollecting information about the user, such as interests, previous interactions	✓	Strong	50%
	Adaptation	Adapting agent utterances based on collective patterns of users stored in memory	✓✓	Strong	
	Communication	Providing knowledge to the user	✓✓	Weak	
	Modeling	Storing agent actions		Weak	

List of tasks in a Table

1. Describe each task qualitatively
   - *Monitoring : storing user VR multimodal actions…*
   - *Communication : providing knowledge to the user*
   - …

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	Communication	Providing knowledge to the user	✓✓	Weak	
	Modeling	Storing agent actions		Weak	

Marking HI Tasks

1. HI-specific tasks as ✓✓
   - Communication, Adaptation, Perception, Collaborative Decision Making)
2. Open-ended KE tasks as ✓
   - Recollection, Recognition, Recommendation
3. Classical CommonKADS tasks : no checkmark
   - Monitoring, Modeling

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	Communication	Providing knowledge to the user	✓✓	Weak	
	Modeling	Storing agent actions		Weak	

Marking HI level

Weak HI task :

Involves a mixed team with little collaboration toward the same goal

- *(S1, S2) Recognition of user information*
- *(S1, S3) Modelling or retrieval of single agent information*

Mark : **Weak**

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	Communication	Providing knowledge to the user	✓✓	Weak	
	Modeling	Storing agent actions		Weak	

Marking HI level

Strong HI task :

the team actually creates **synergy**

- *(S1) Action Recommendation based on user and agent model*
- *(S2,S3) Dynamic Adaptation based on user states and collective patterns in memory*

Mark : **Strong**

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	Communication	Providing knowledge to the user	✓✓	Weak	
	Modeling	Storing agent actions		Weak	

Establishing HI-ness

Count the amount of Strong HI tasks wrt the total number of tasks

- *(S1) 1/5 = 20%*
- *(S2) 1/3 = 33%*
- *(S3) 2/4 = 50%*

NB: you can **increase the HIness** by redefining your task!

(S6) Recognition: Strengthen the role of the user by using different methods (MTurks, explicit user-based models, etc.).

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	Adaptation	Adapting agent utterances based on collective patterns of users stored in memory	✓✓	Strong	
	Communication	Providing knowledge to the user	✓✓	Weak	
	Modeling	Storing agent actions		Weak	

Your turn now

- Take your HI application/scenario and task decompositions
- Follow the steps in slides 32-38
- Try improving your HIness!
- End of this session :
  - *at least* have a 1 task decomposition and its HI-ness !
  - 5 mins discussion

Short of ideas ?

- Here's some applications to choose from https://github.com/kmitd/HI-CommonKADS
- Or use the microsurgeon use-case (slides on github)

Discussion hands-on/2

- ...

Conclusions

Summary

HIKE :

- helps describe knowledge and tasks in HI scenarios
- identifies common design components for HI scenarios
- Allows to **measure HI-ness** of an application

What's next?

- Help us standardising HI design

Thanks!

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