Activity Recognition in Smart Homes

The 11th International Conference on Information Integration and Web-based Applications & Services

The 7th International Conference on Advances in Mobile Computing & Multimedia

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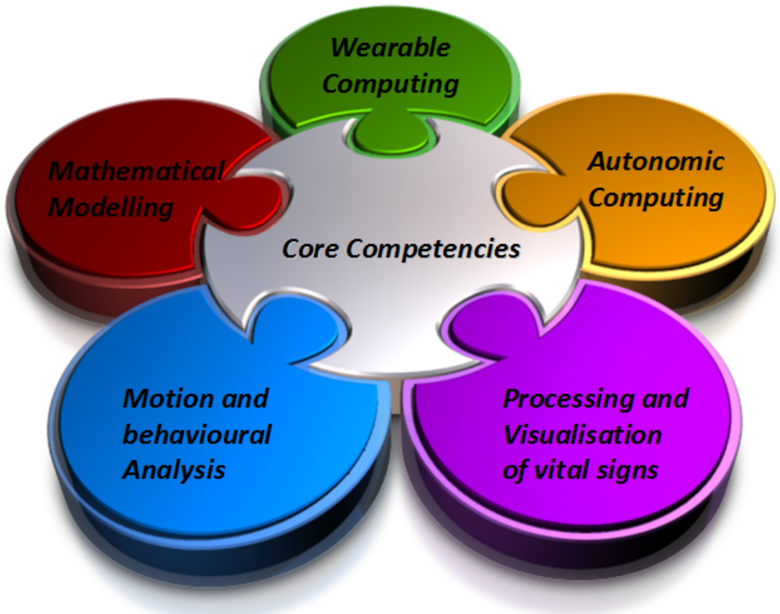
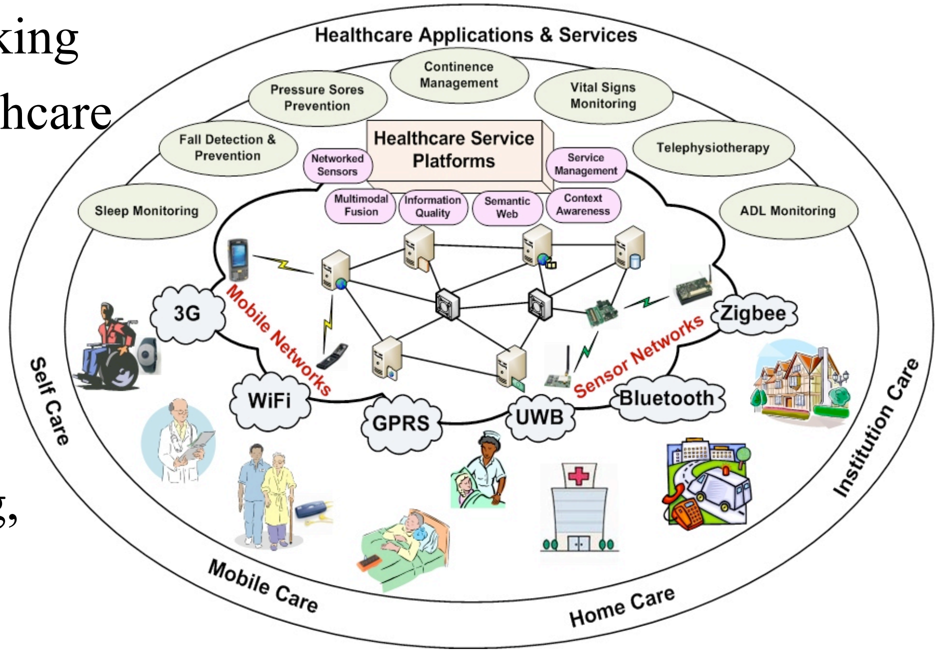
Dr. Luke L. Chen

- Research Institute of Computer Science, University of Ulster
  - One of two Universities in Northern Ireland
  - Ranked 15th for research power out of 81 UK Universities in 2008 RAE
- Intelligent Environment Research Group
  - Multiple research themes
  - Both theoretical and applied
  - Focus on AAL, assistive technologies
- Research expertise
  - AI, esp. intelligent agent
  - Knowledge and semantic technologies
  - Their applications, e.g., semantic services, Grid, data integration, etc.



Dr. Jit Biswas, I^{2}R

- Institute for Infocomm Research (I^{2}R), A*STAR, Singapore
  - Research Institute under Agency for Science, Technology and Research
  - Leading in Information Communications and Media, in South East Asia
- Role in Matrix: Networking Protocols Dept. & Healthcare Program
  - Core strength in Wireless Sensor Networking
  - Strong collaborative applications in Healthcare
- Research expertise
  - Wireless Sensor Networking
  - Information Quality based Resource Mgt
  - Healthcare application and services involving pattern recognition, data mining, integrated systems approach



The Program

- Introduction to the Tutorial
  - The context
  - The schedule
- Data-driven activity recognition
- Knowledge-driven activity recognition
- Discussion

An Emerging Ageing Society

- A worldwide demographic change
  - Ageing population is increasing in an unprecedented rate
  - 80+ is the fastest growing age group.
- Social and healthcare crisis
  - Prevalence of physical, sensory deficiency and cognitive decline
  - Already overstretched social and healthcare resources
  - Increased resource needs outpace resource investment
- Demand on new models for social and healthcare delivery with affordable costs

Converging Trends

- Pervasive sensing infrastructure
  - Low cost, low power, high performance sensors, e.g., RFID, wireless motes, etc.
  - Communication protocols, standards
- Advances in core computer science
  - Artificial intelligence techniques – ambient intelligence
    - e.g., algorithms for probabilistic reasoning and machine learning, such as Bayesian networks, Stochastic sampling, etc
  - Knowledge technologies
  - Semantic technologies
- Ambient Assisted Living (AAL)
  - Support independent living for the elderly and disabled
  - Improve health care – Ageing in place, intervention and prevention

Smart Homes (SH)

- A specific realisation of AAL

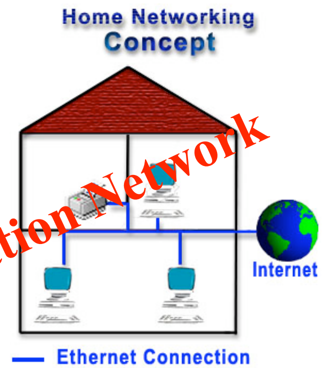
  Smart homes are augmented residential environments equipped with sensors, actuators and devices, inhabited by the elderly or disables, operated by professionals and health services

- The purpose and aspirations

  To enhance and improve quality of life, prolong stay at home with technology-enabled assistance

Sensors

Actuator



Communication Network

Control Interfaces

The Challenge

Given the real-time data streams from multiple sensors in multiple formats

- Infer an inhabitant's location, action and activities
- Predict what the inhabitant's will do
  - Provide just-in-time context-aware activity assistance
- Detect behavior patterns and/or behavior anomaly
  - Support intervention and prevention before serious health problems happen
  - Opportunities for learning
- Activity recognition is key

Activity Recognition

- Based on the types of sensor data
  - Vision-based
  - Non-vision-based
    - Wearable sensors
    - Object-attached sensors
- Based on the way data are analysed
  - Data-driven approaches
    - Probabilistic reasoning and machine learning, e.g., Bayesian networks, Stochastic sampling, etc.
  - Knowledge-driven approaches
    - Formal knowledge modelling, representation and reasoning, e.g., logics, ontologies, etc.

The Central Issues

- Modeling Activities of Daily Living (ADLs)
  - From sensor data
    - Data-driven approaches
  - By engineering commonsense domain knowledge
    - Knowledge-driven approaches
  - By mining textual descriptions
    - Information

- Tracking and predicting a user's activities
- Recognizing user errors and needs
  - Toward proactive assistive technology

Activity Recognition

The Data-driven Approach

By Dr. Jit Biswas

Activity Recognition

The Knowledge-driven Approach

By Dr. Liming Chen

Ontology-based Activity Recognition (O-BAR)

- Generic knowledge-driven approaches
- Ontologies and their use for activity recognition
- Ontology-based activity recognition
- A case study walk-through
- Implementation and demo

Knowledge-driven Approach

- Capture and engineer domain knowledge
- Create formal ADL models
- Represent both ADL models and sensor data using a formal knowledge representation formalism
- Map activity recognition, prediction and assistance to inference and reasoning, e.g., induction, deduction and abduction

Existing Methods

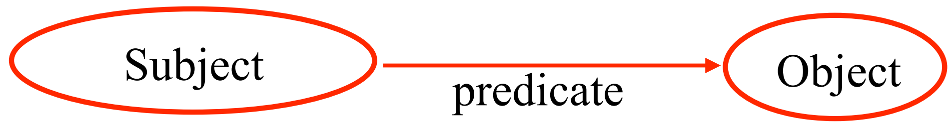
- Process based activity modelling
  - Using logical knowledge representation formalisms
    - Situation theory, key-hole planning (Kauz, 1991; Wobke, 2002)
    - Event calculus (IJARM, Chen et al. 2008)
    - Description Logic + lattice theory (Bouchard et al. 2006)
    - Temporal reasoning and action theory (Augusto, 2004; Chua, 2009)
- State based activity modelling
  - Mining textual descriptions (Tapia, 2006)
  - Ontological modelling and reasoning (Akdemir et al. 2008; Yamada et al. 2007; Chen & Nugent 2009)

Ontologies

- Definition
  - An explicit specification of various conceptualisations in a problem domain
  - A vocabulary for the specifications and representation of the generic concepts, attributes, relations and axioms of a domain
- In essence, an approach to knowledge modelling
  - Provide a homogeneous view over heterogeneous data sources, thus enabling seamless integration, interoperability and sharing
  - Enable a higher level of automation based on the machine understandable content
  - Facilitate reasoning and inference for knowledge (pattern) discovery and advanced intelligent applications.

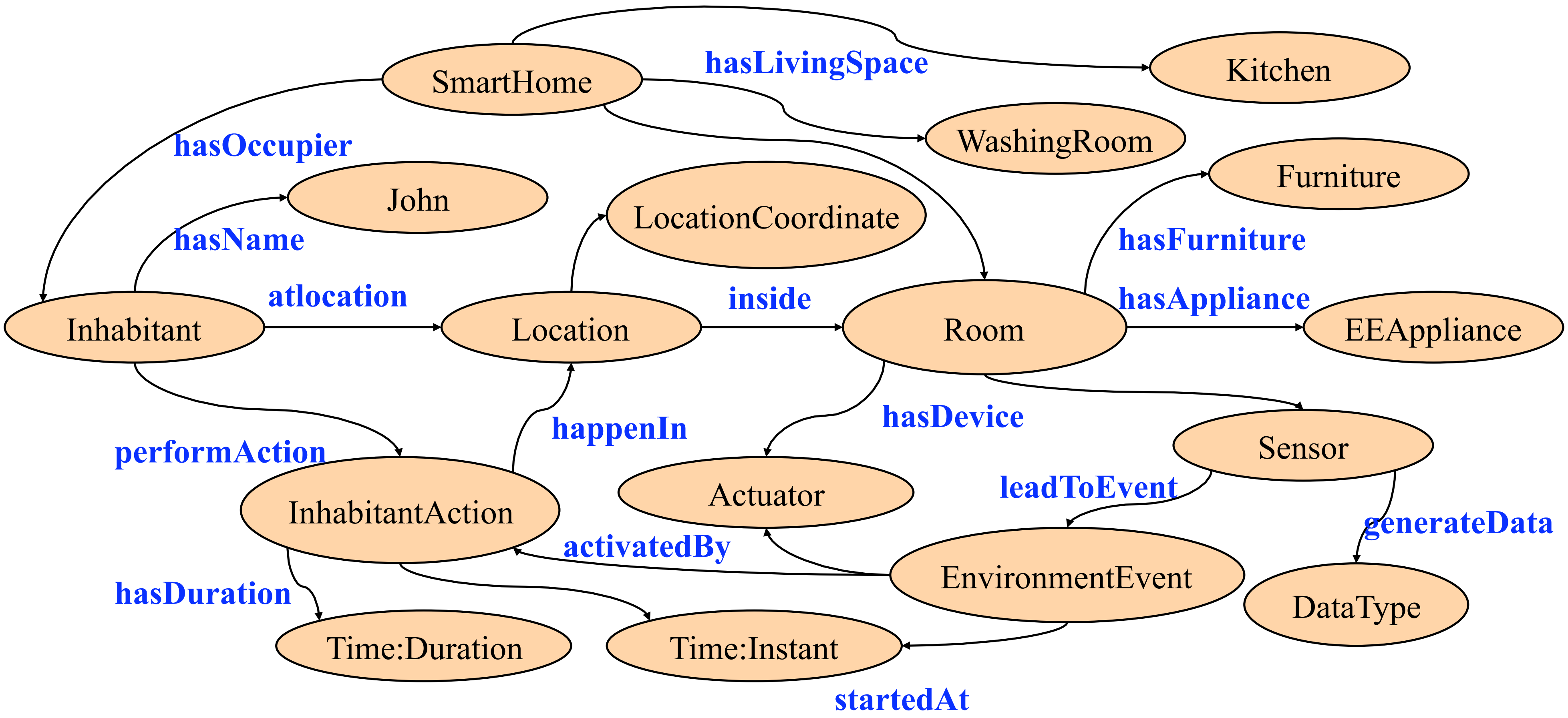
Ontology Languages

- Define and represent ontologies
  - A set of modelling primitives for describing classes, properties and individuals
  - A set of axioms and entailment rules for inferring relationships and supporting reasoning
- RDFS and OWL
  - RDFS - A graphical data model



  - OWL – extended RDFS with three species compliant with DL

Example: Ontological Context Representation



Current Use of Ontologies

For vision based activity recognition

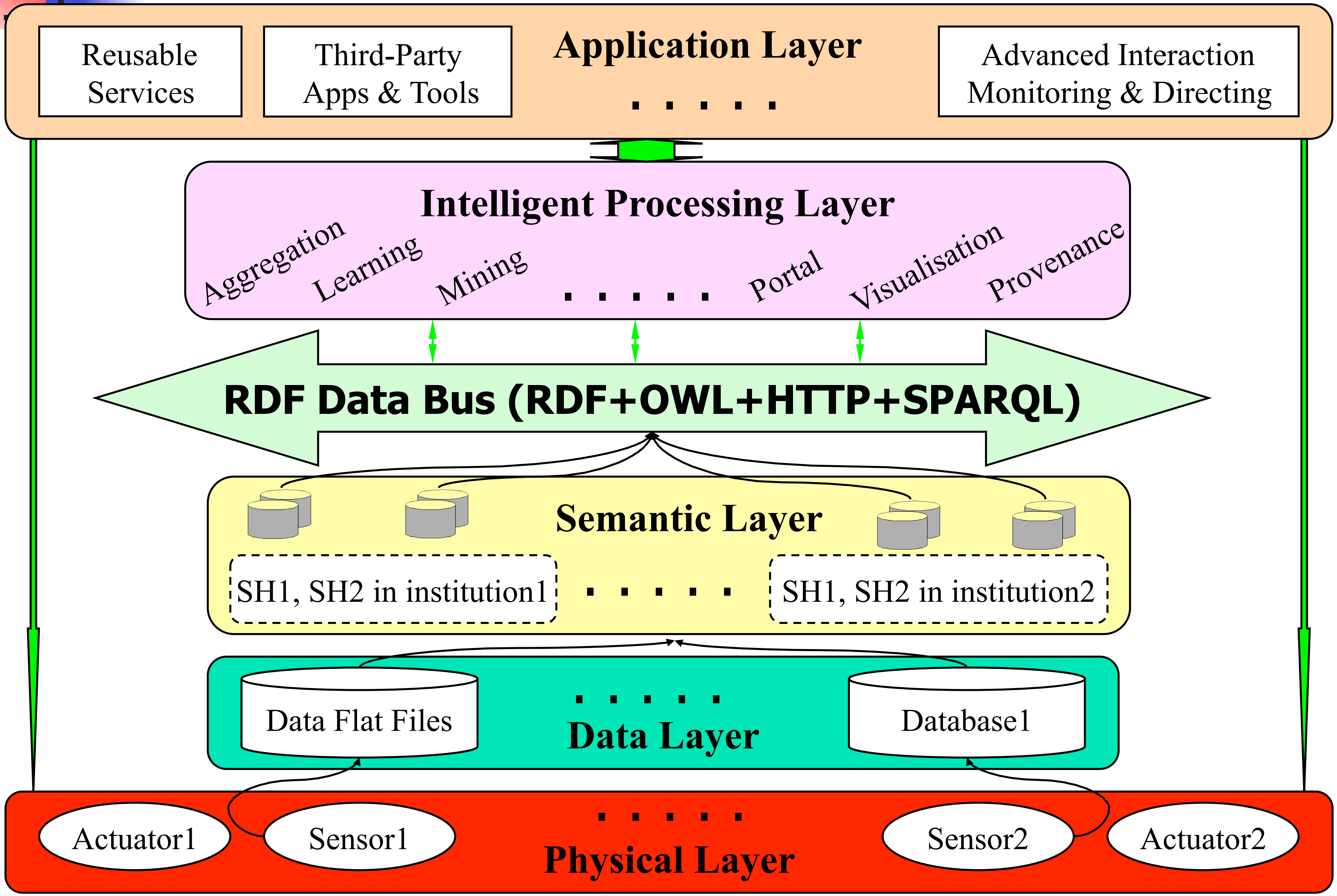
- Specifying common terms for activity definition (a set of rules)
  - An ontology for analyzing social interaction in nursing homes (Chen, 2004)
  - Ontolgoies for the classification of meeting videos (Hakeem, 2004)
  - Monitor activities in a bank setting (Georis, 2004)
  - An initiative to define ontologies for six domains of video surveillance
  - A video event ontology and representation language (Hobbs, 2004)
- Activity recognition is performed using individually preferred algorithms
  - such as rule-based systems (Hakeem, 2004) and finite-state machines (Akdemir, 2008)

Current Use of Ontologies

For sensor based activity recognition

- Modelling incompleteness and multiple representations of terms
  - E.g., object ontologies from WordNet (Tapia, 2006); Ontologies of things (Yamada et al. 2007)
- Activity recognition is performed using probabilistic and/or statistical algorithms
- Ontology-centric design for middleware and system – addressing interoperability, e.g., (Latfi, 2007; Michael, 2007)
- The Semantic Smart Home concept (Chen 2009)
  - leverage the full potentials of semantic technologies in the whole lifecycle of assistive living

Semantic Smart Home

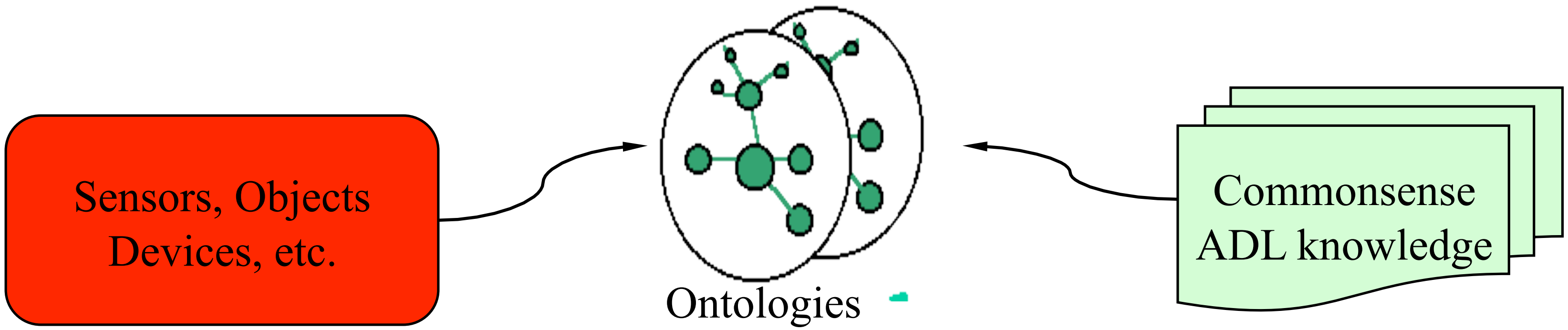


O-BAR Rationale

- Ontological context modelling
  - Ontologies - sensors, objects, time, environment states, etc.
  - Data fusion
- Ontological activity modelling
  - Not only describing activities using common terms
  - But also describing interrelationships between activities as well as activities and objects
- Semantic reasoning
  - Activity recognition
  - Activity learning
  - Activity assistance

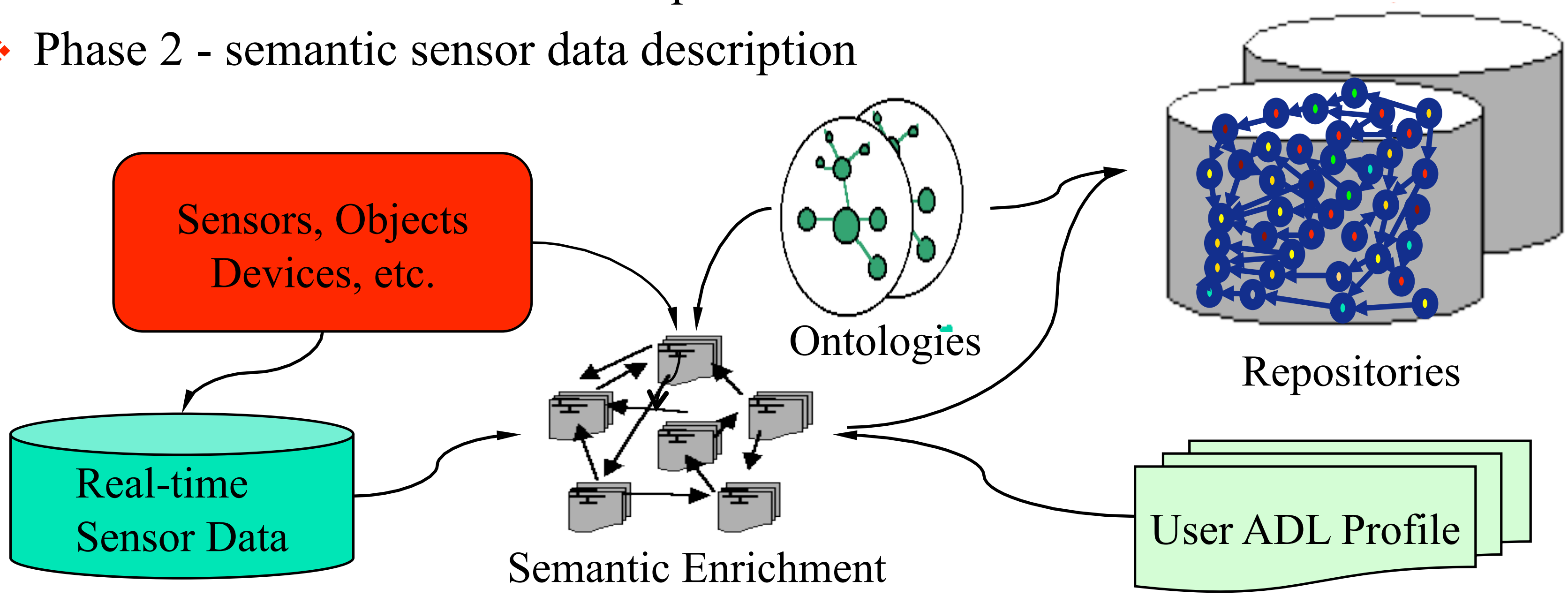
O-BAR Methodology: Ontological Modelling

- Domain analysis and knowledge acquisition
  - Entity identification, e.g., sensors, objects, devices, …
  - Activity characterisation
- Ontology construction
  - Context ontologies, inc. time ontologies, ..
  - Activity ontologies



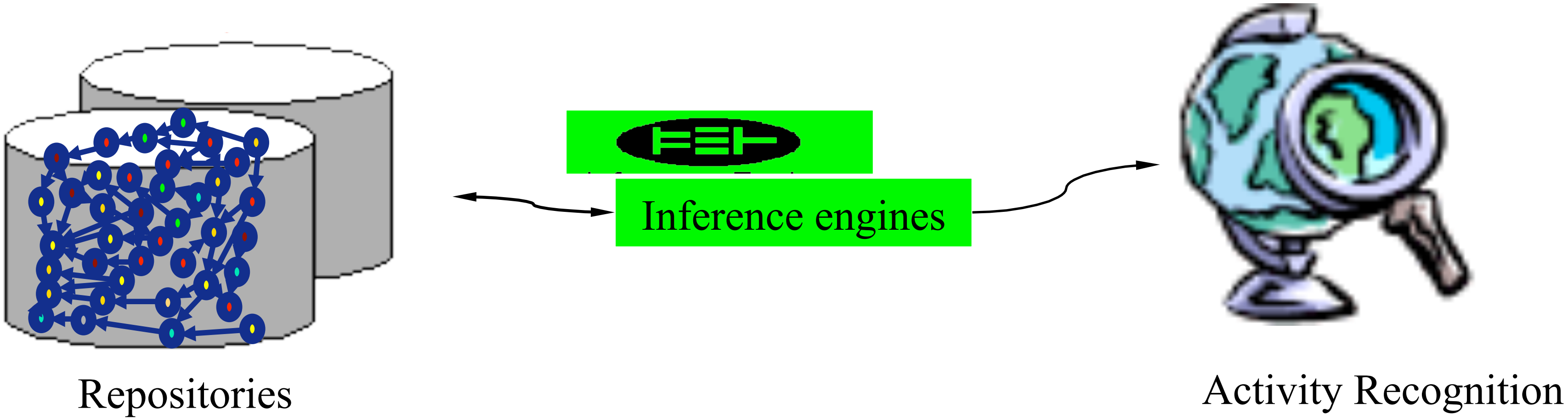
O-BAR Methodology: Semantic Repository

- User activity (ADL) profiles
  - Customised semantic activity descriptions for individuals
- Two phase semantic metadata generation
  - Phase 1 – semantic sensor description
  - Phase 2 - semantic sensor data description



O-BAR Methodology: Activity Recognition

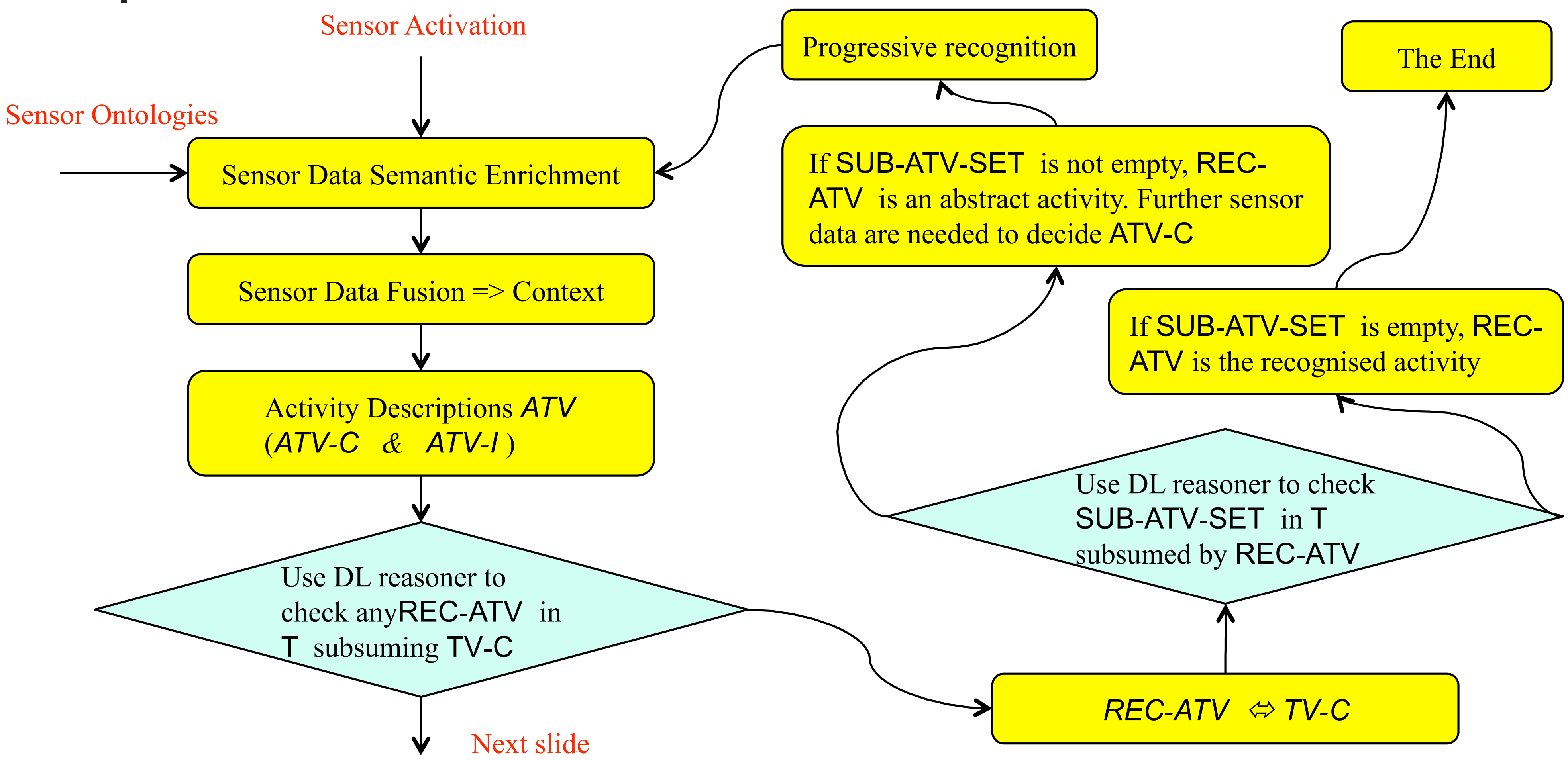
- Equivalent to concept classification
  - Given a SH semantic repository KR(T, A), with a set of terminological axioms T and a set of assertional axioms A
  - Given a context at a specific time with a set of sensor readings linking to objects that form part of an activity description
  - Performed by DL subsumption reasoning



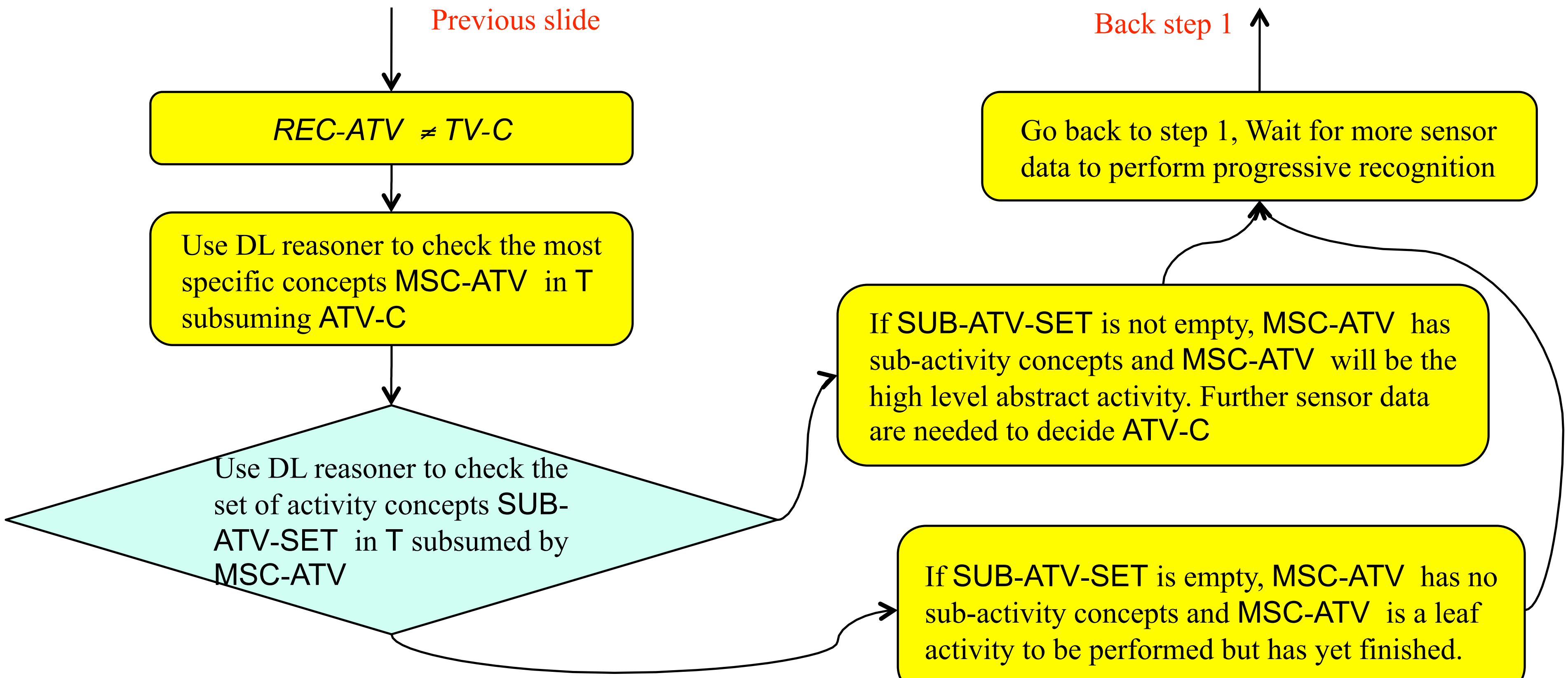
Theoretical Subsumption Algorithm in DL

- Structured subsumption algorithm
  - A1 u … u A*m* u 8 R1. C1 u … u 8 R*n*. C*n*
  - B1u … u B*k* u 8S1. D1 u … u 8 S*l*. D*l*
  - A & B classes, S & R properties, C & D descriptions
- C v D (C subsume D)
  - For all *i*, 1 ≤ *i* ≤ *k*, there exists *j*, 1 ≤ *j* ≤ *m* such that B*i* = A*j*
  - For all *i*, 1 ≤ *I* ≤ *l*, there exists *j*, 1 ≤ *j* ≤ *n* such that S*i* = R*j* and C*j* v D*i*
- More complex one based on tableau algorithm

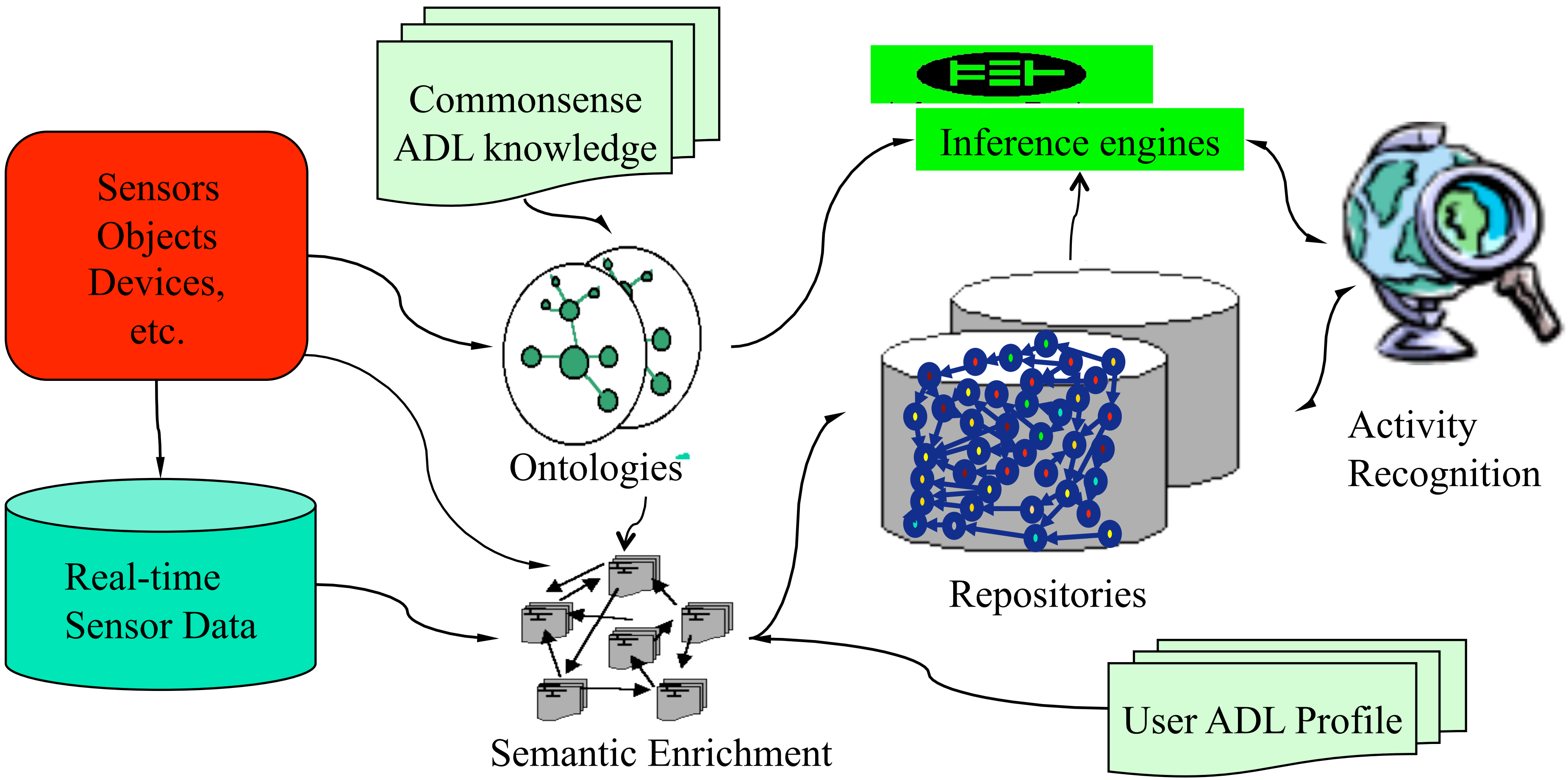
Algorithm Mapped to Activity Recognition



Algorithm Mapped to Activity Recognition

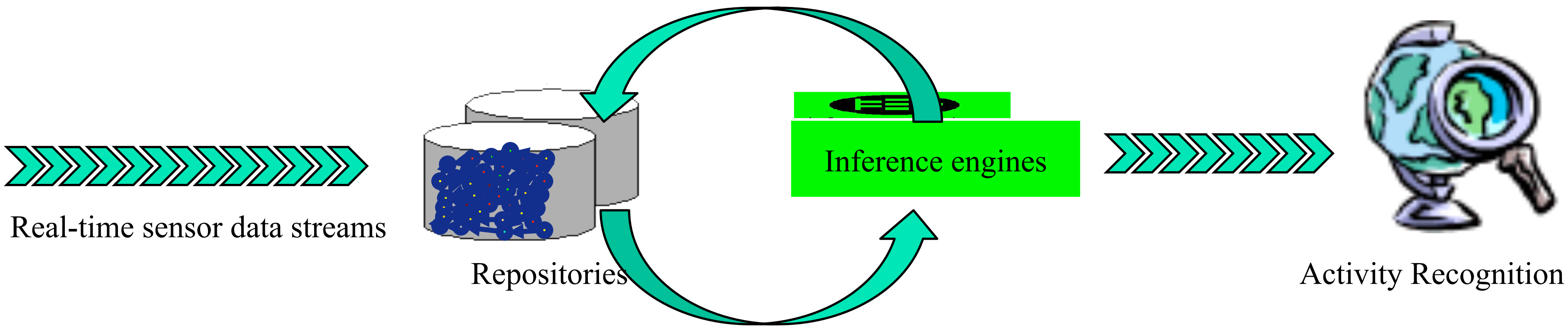


O-BAR Lifecycle



O-BAR Features

- No requirements for large dataset to learn and test activity models
- Support incremental progressive activity recognition
  - An activity unfolds in a timeline
  - Each time new sensor data become available (or every 20 seconds)
  - New context will be used to perform recognition

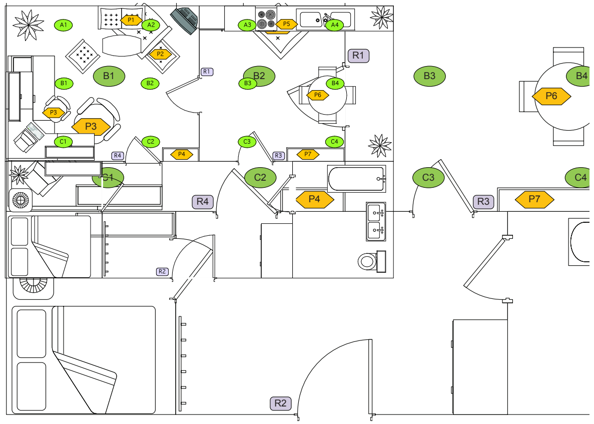


O-BAR Features

- Organic activity model evolution
  - Ontological activity modelling creates the "seed" ADL models
  - Using learning to extract new patterns and improve the models
- Activity priority / importance modelling
  - Discriminating parallel activities
- Enable activity assistance at two levels of abstraction
  - Course-grained activity assistance
    - Perform reasoning against conceptual activity models (Tbox)
  - Fine-grained activity assistance
    - Perform reasoning against activity instances (Abox)
- Activity specific sliding window
  - Dynamically change the sliding window to adapt to the activities

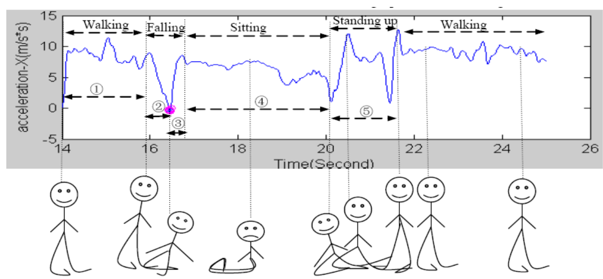
O-BAR Case Study

- Activity monitoring, activity recognition and assistance at SERG in University of Ulster



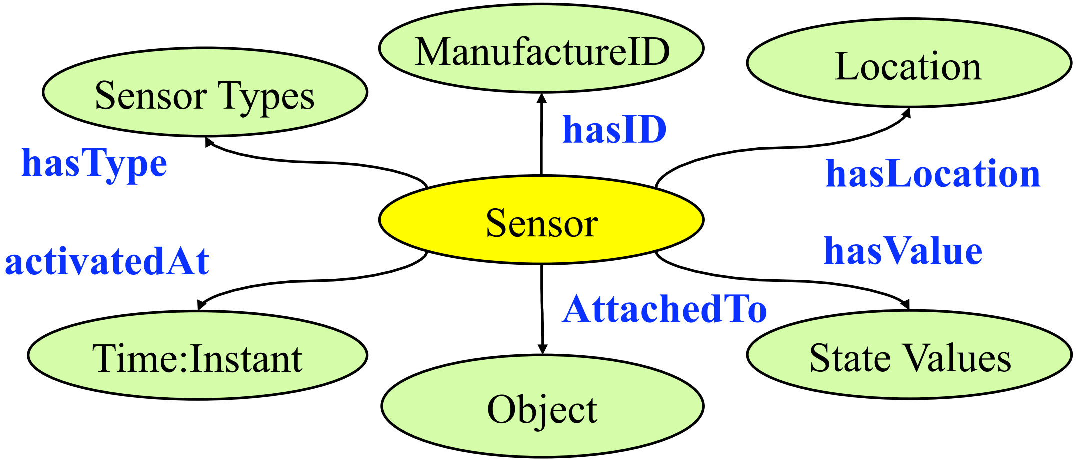
Sensor based interaction tracking and recognition

Wearable Devices and activity monitoring

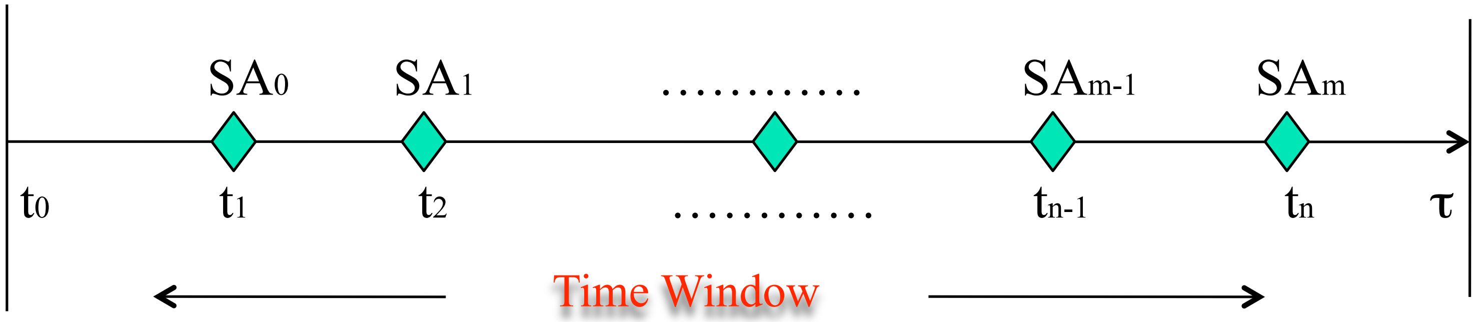


Semantic Context Modelling

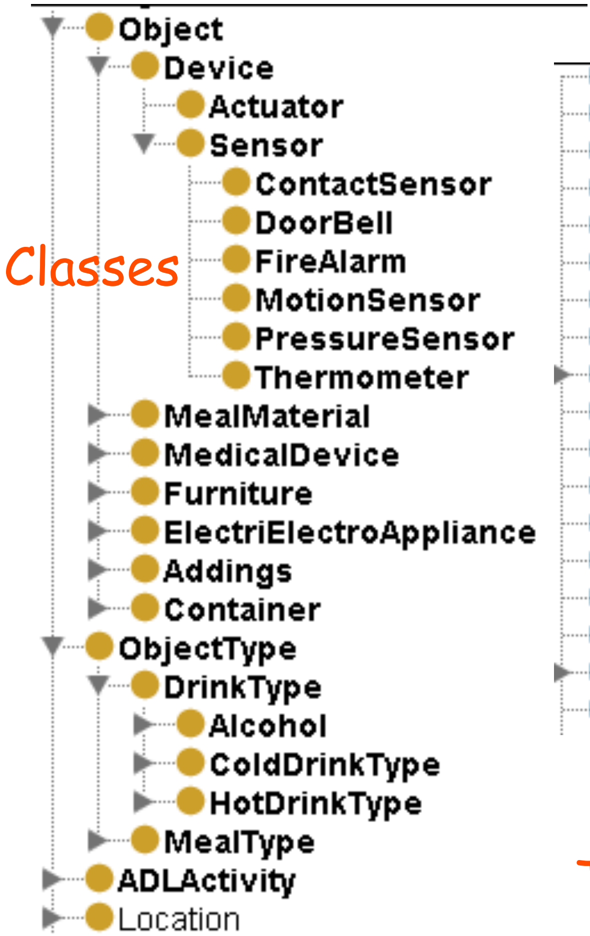
- Object (Equipment/Device/Appliance)
- Location (Environment/space)
- Temporal information

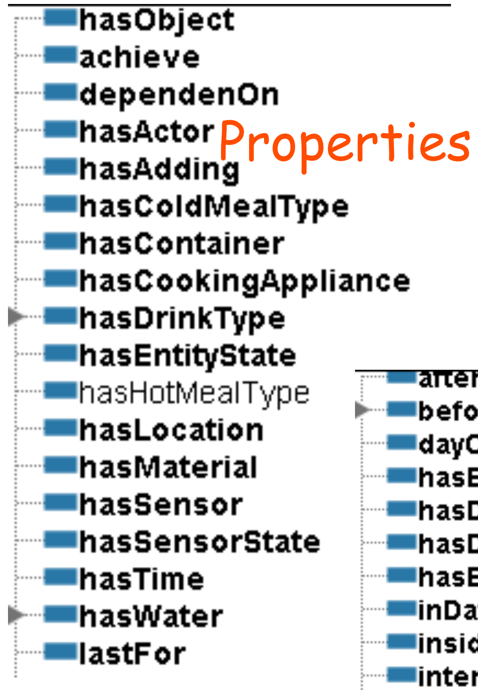


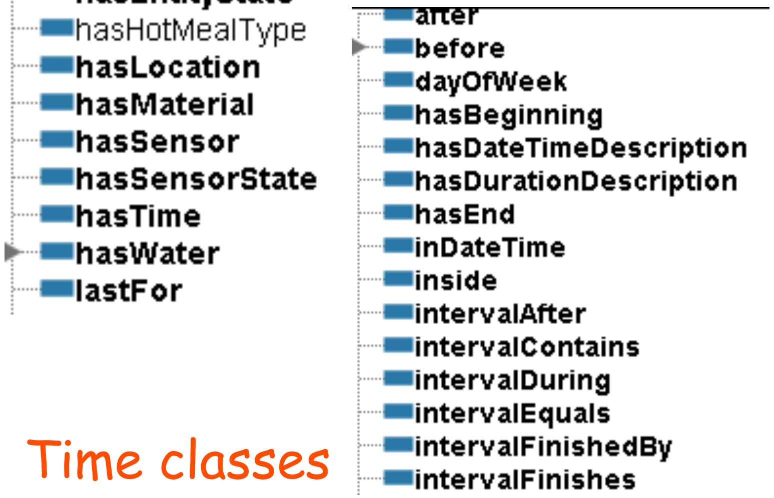
Context at τ => $SSD_0 \cup SSD_1 \cup \ldots \cup SSD_{m-1} \cup SSD_m$



Sensor Ontologies





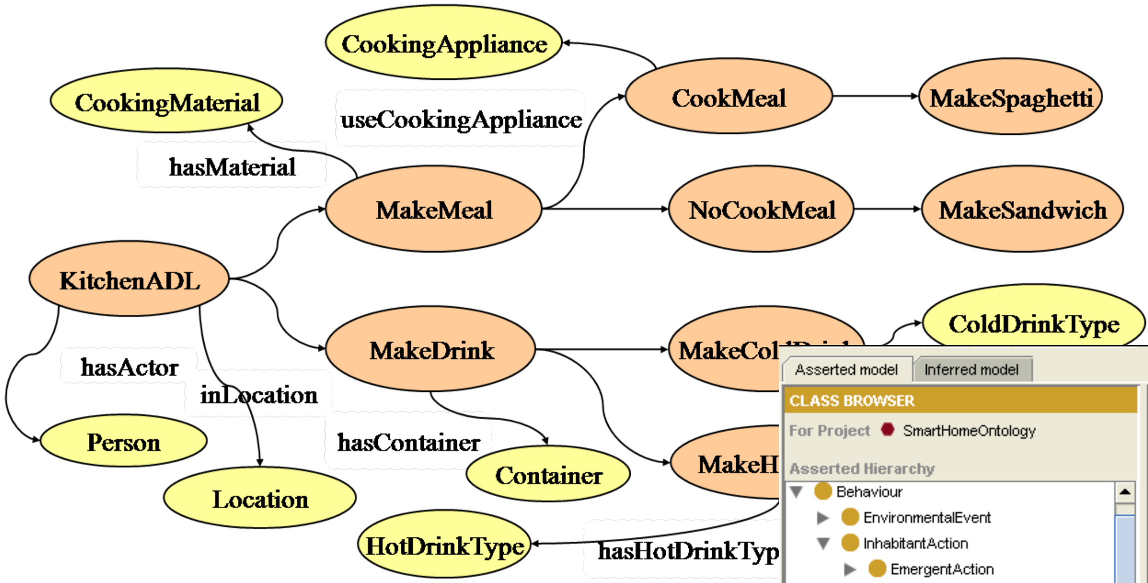


- Protégé ontology editor
- Import W3C Time ontology
- Potential for using current medical data ontologies

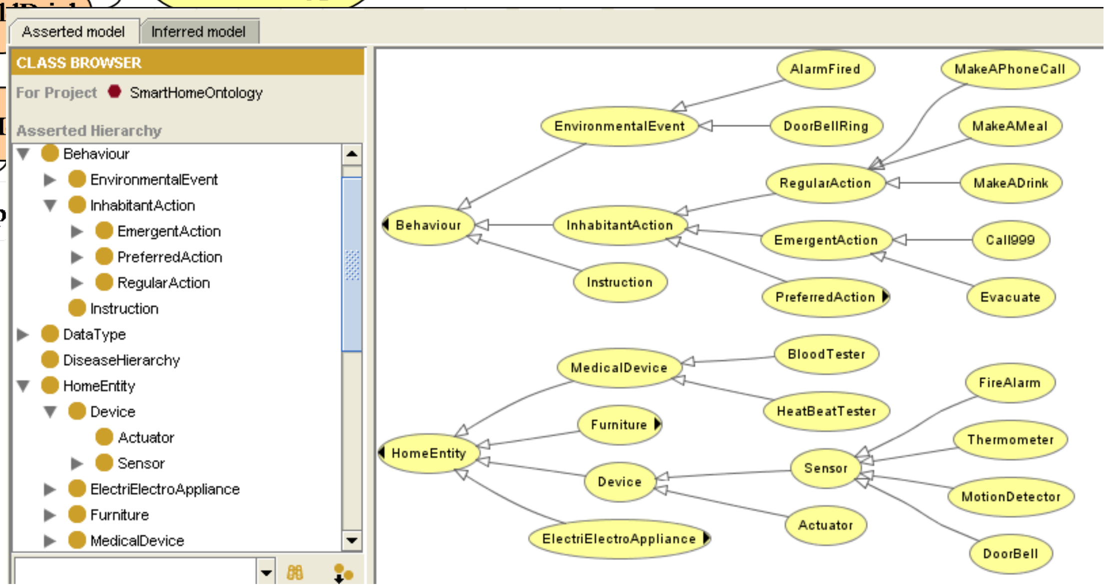
Activity Modelling

- A process model
  - A sequence of situations
  - Emphasis on sequential order
- A descriptive model
  - Characterised by a number of properties
  - Emphasis on states
- Ontological activity modelling
  - Explicitly specify relationships between objects and activities
  - Build a hierarchical structure to encode the interrelations between activities
  - There are usually a “is a” and “part of” relationships

Informal and Formal ADL Models



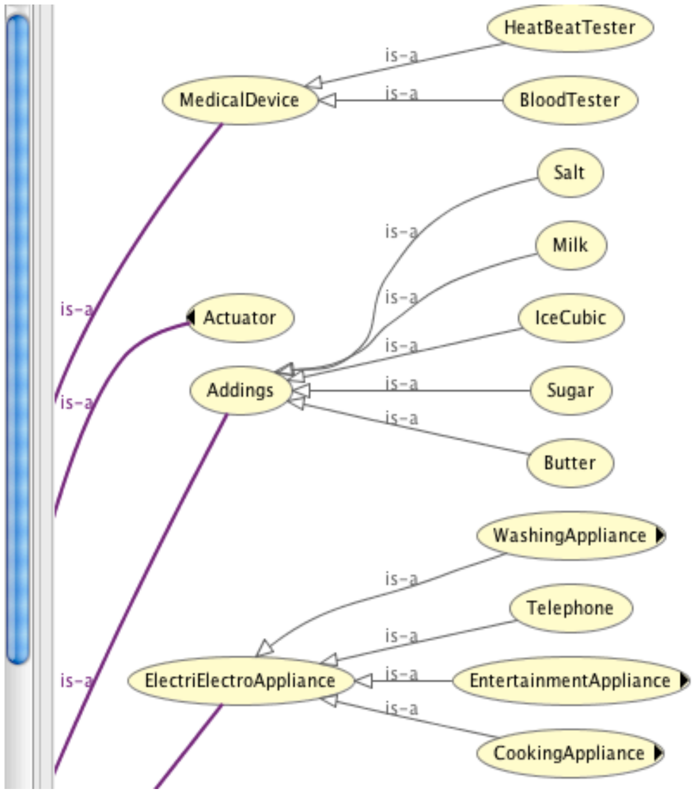
Graphical ADL representation



ADL ontologies

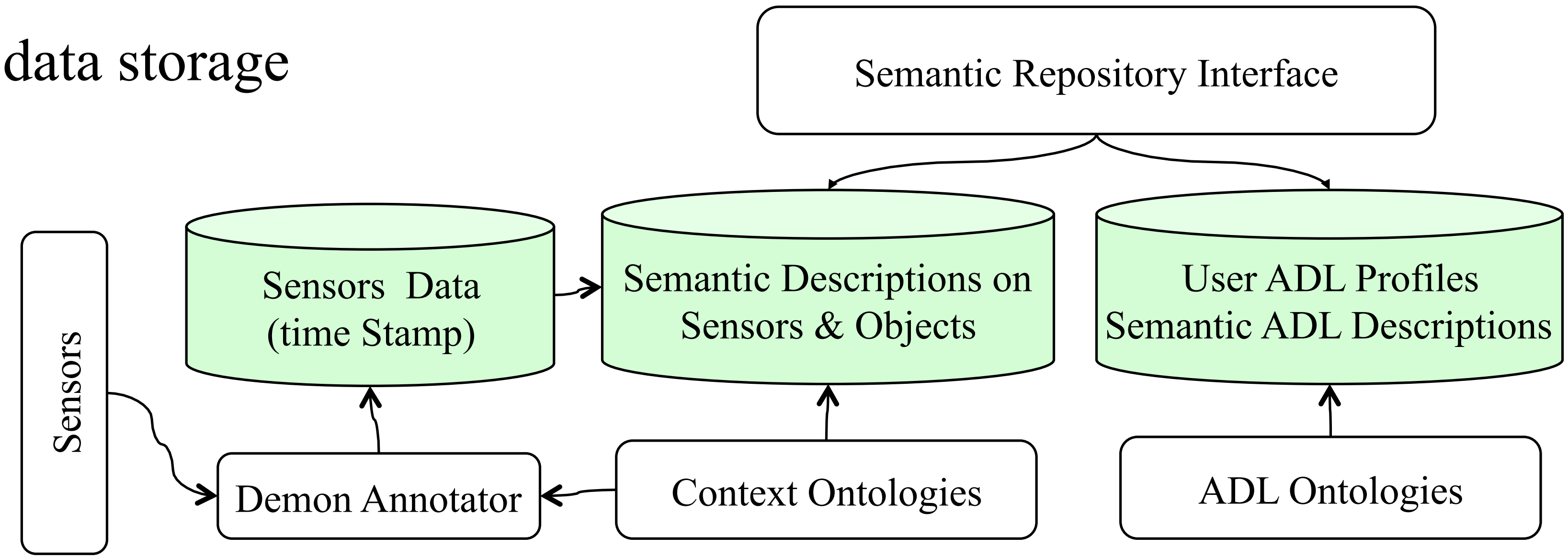
An Example: MakeDrink ADL Class

- Linking context ontologies to ADL ontologies



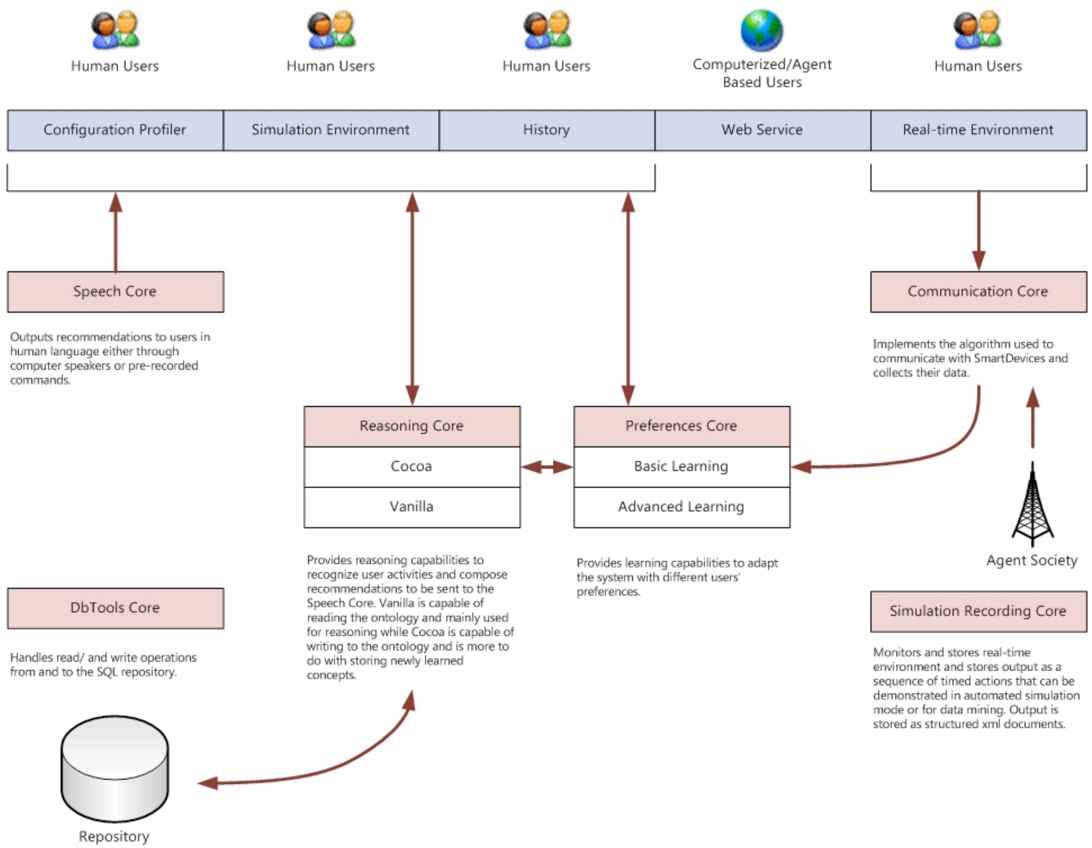
Semantic Data Creation and Storage

- Two-phase approach for creating semantic data
  - Manual annotation for sensors, devices, objects and user ADL profiles
  - Light-weight demon-style annotator for real-time sensor data
- Two mechanisms for data storage



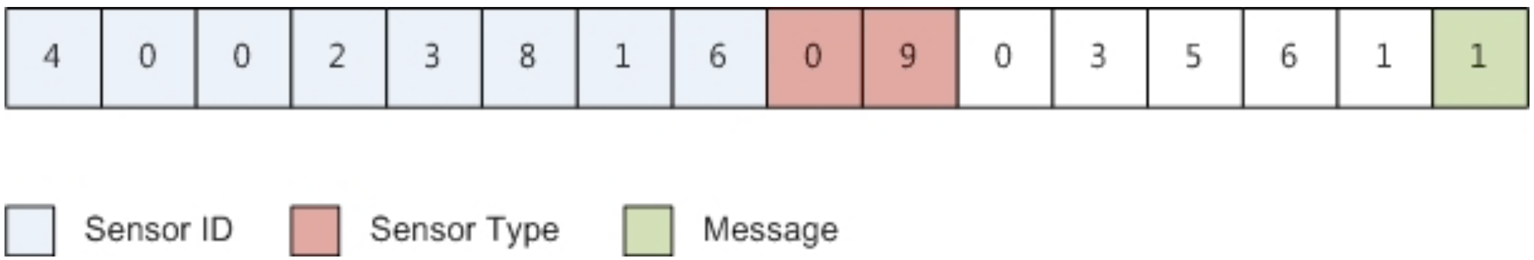
Implementation Architecture

- Reasoning core
- Preferences (adaptive learning) core
- DB Tools
- Communication core
- Speech core
- User Interface tools



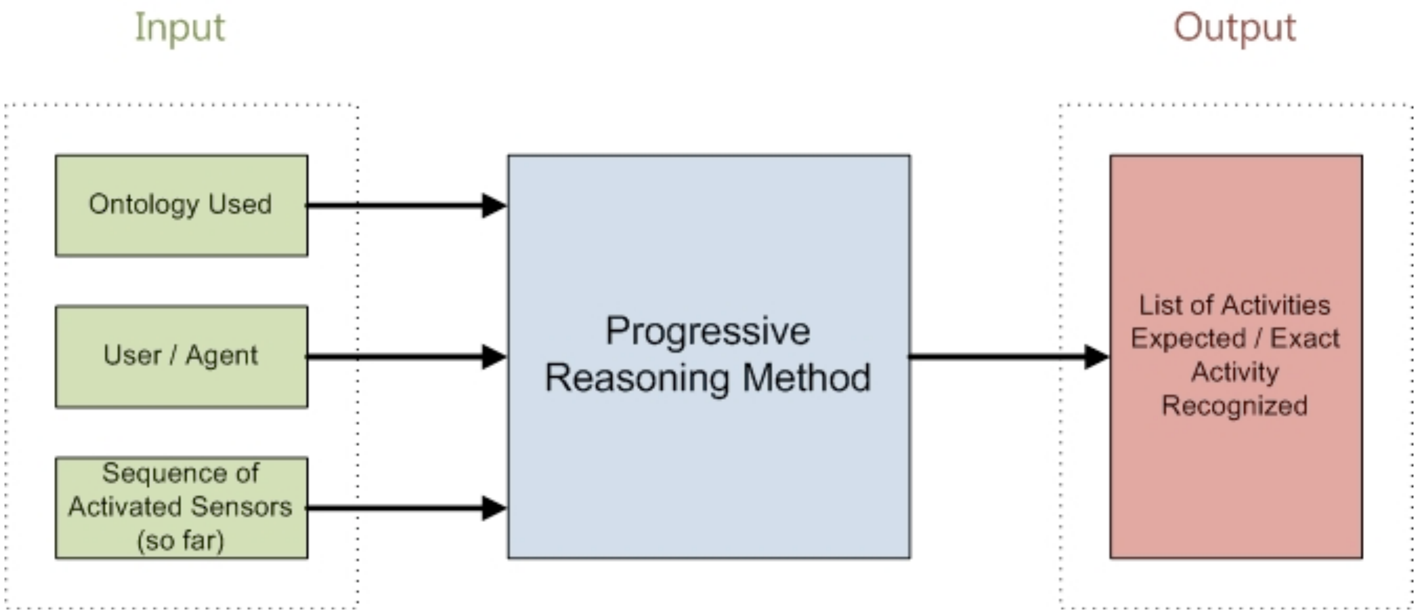
Communication Core

- Provide a physical-digital interface gateway
  - Sensor data collection
  - Sensor data transformation
- Sensor data semantic enrichment
  - Using sensor ontologies
- Archive the semantic sensor data



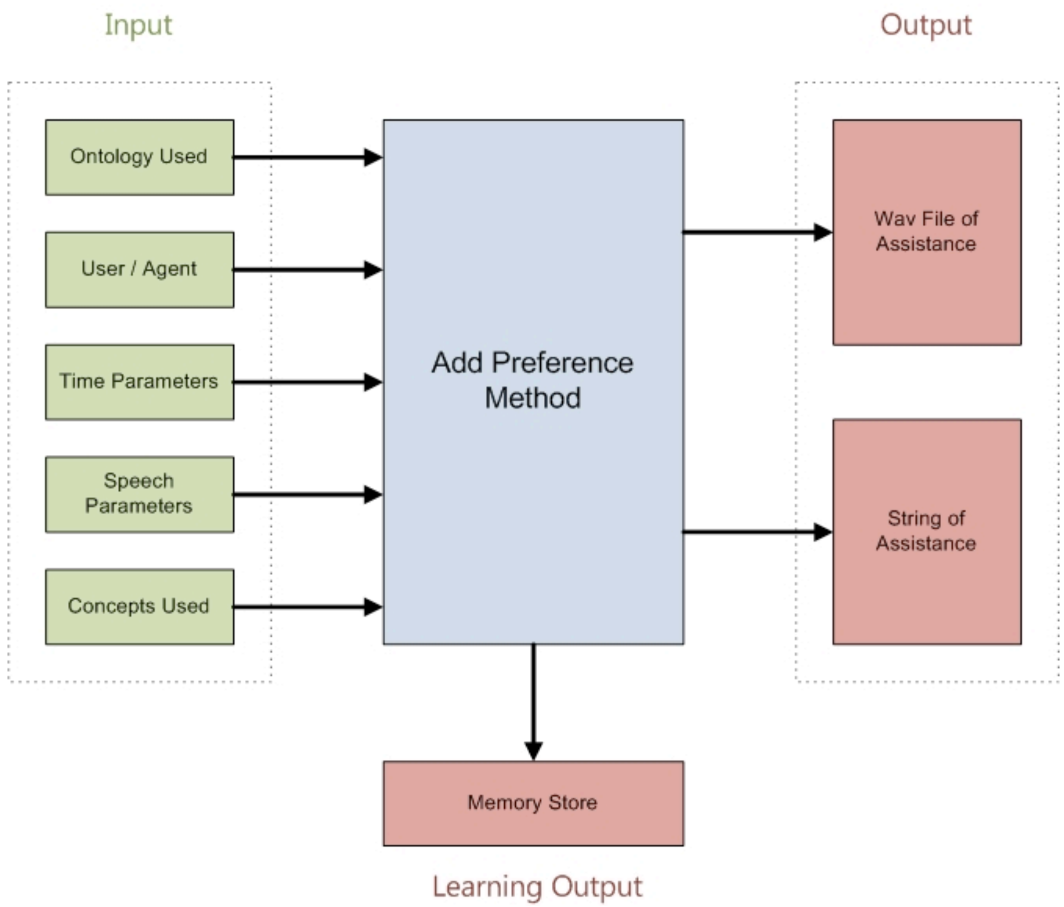
Reasoning Core - Vanilla

- Perform progressive activity recognition by implementing the recursive subsumption reasoning



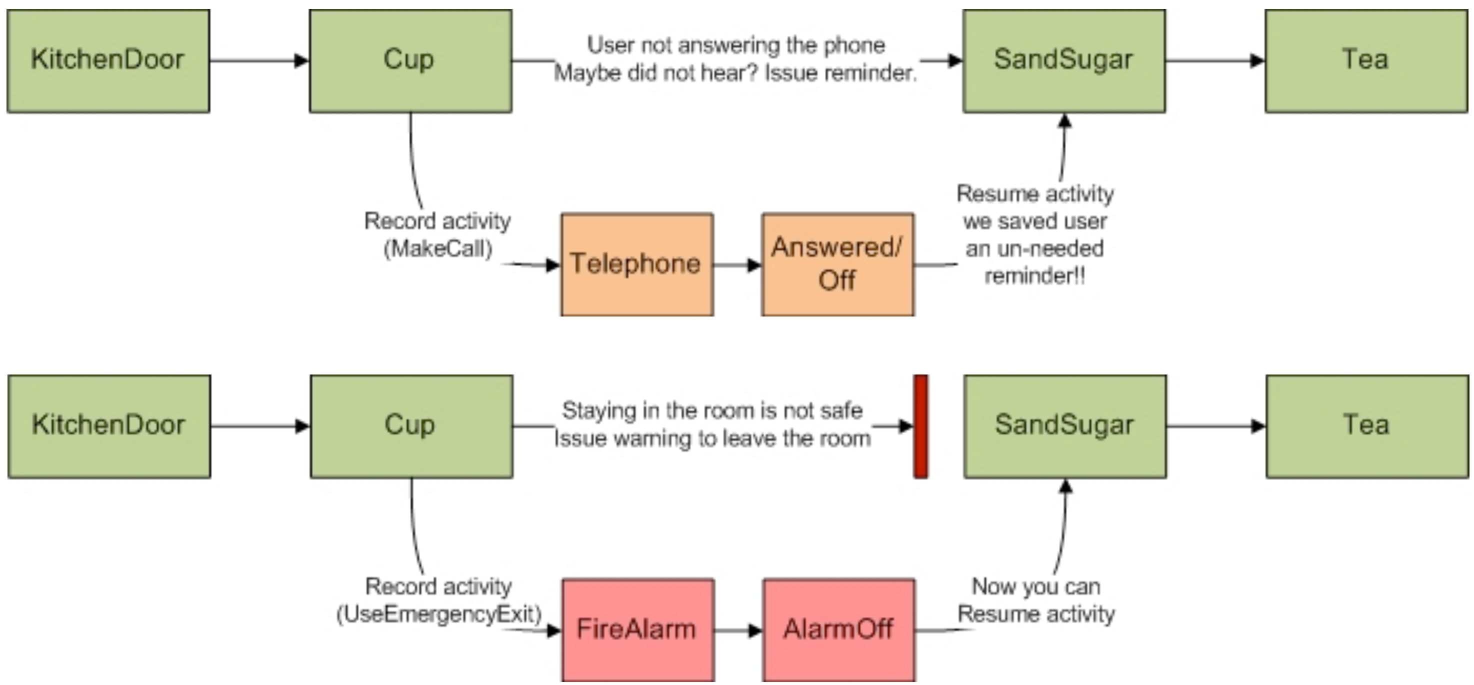
Reasoning Core - Cocoa

- Activity assistance
  - Setting up activity duration & urgency
  - Visual and vocal
  - Synthetic or pre-recorded
- Learning preferences
  - Basic learning
    - User's specific ADL profiles
  - Advanced learning
    - New activity classes
  - Manual specification

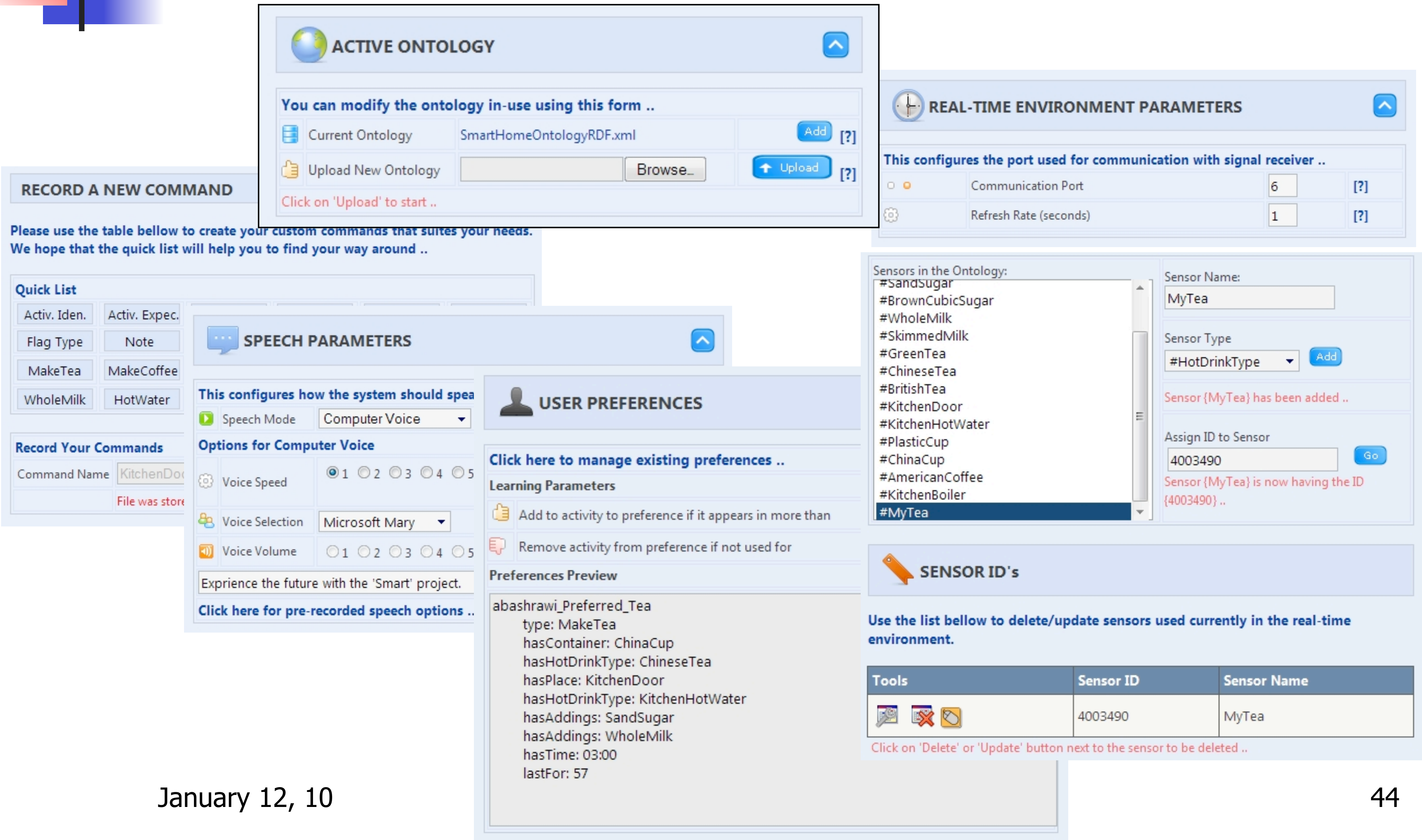


Parallel Activity Recognition & Assistance

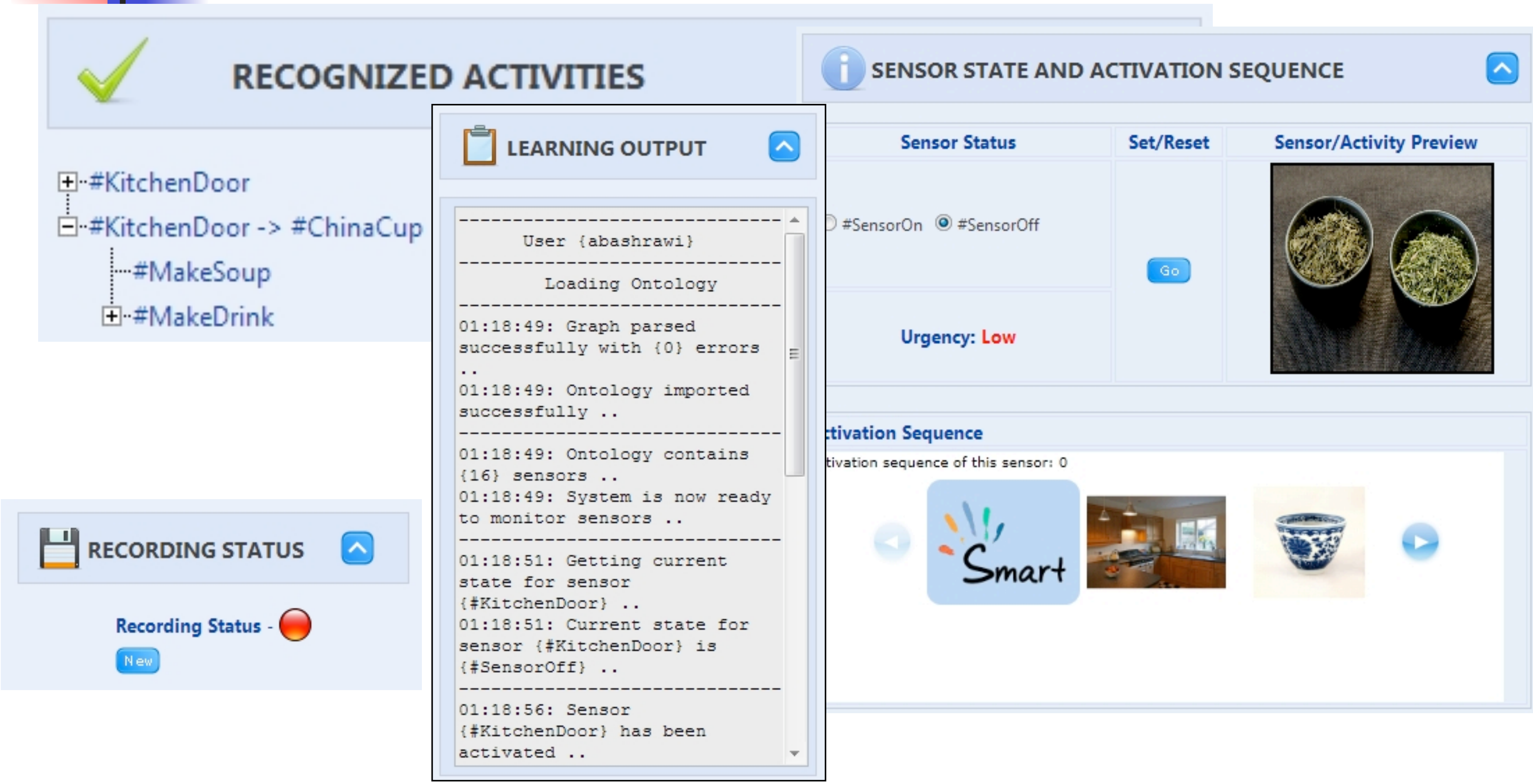
- Specify a hierarchy of importance for activities
- Provide assistance in terms of urgency



User Interface Tools: System Configuration



User Interface Tools: Presentation



System Demonstration

Conclusions

- With abundant domain knowledge on ADL, knowledge-driven approach, in particular, O-BAR, provides a number of advantages:
  - Easy to get started – everyone knows how they perform an activity
  - State based modelling and reasoning is more robust - there is no fixed sequences for an activity, esp. for ADLs
  - Support incremental progressive activity recognition
  - Able to discriminate importance and urgency of activities through semantic descriptions
  - Support course-grained and fine-grained activity assistance
- O-BAR is still in its infancy
  - Large-scale experimenting - more use scenarios and sensor types
  - Real world use case study
  - A number of open issues – the future work

Future Research Directions

- A hybrid activity modelling approach
  - Create a “seed” activity model from knowledge-driven approach
  - Evolve activity models through data-driven approach
- Enhance O-BAR with process knowledge
  - Incorporate procedural activity knowledge, e.g. order, sequence
  - Use rule-based constraints
- Combine subsumption classification with temporal reasoning
  - Enable explicit temporal processing supporting just-in-time assistance
- Handle data uncertainty and incompleteness
  - Extend description logic with fuzzy logics or possibility theories

Thank you!

Questions?

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