EveryWare Lab

Data Management for Mobile and Pervasive Computing

# *Ontology-based context-aware activity recognition*

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EveryWare Lab

Data Management for Mobile and Pervasive Computing

- Context representation and reasoning
- Data privacy in location based services
- Assistive technologies on mobile devices


Spin-off: [EveryWare Technologies srl]

# Outline

- Motivation
- Ontology-based activity recognition
- Handling uncertainty
- Hybrid data- and knowledge-driven methods
- Experiments
- Research challenges



# Motivation

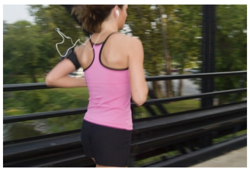
# Which activities?

- Human activity recognition is about detecting:
  - Physical activities
  - Activities of daily living (ADL)
  - Social interactions



# What for?

- Ubiquitous computing
- **Health-care**
- Recognition of critical events
- Training
- Homeland security






# Based on what data?

- More invasive technologies
  - Camera, Microphone, Observers
- Less invasive technologies
  - Wearable sensors (smartwatch, smartphone, medical devices, …)
  - Environmental sensors (position, time, temperature, object use, door openings, …)
  - **Knowledge about the subject, the environment, the possible activities**

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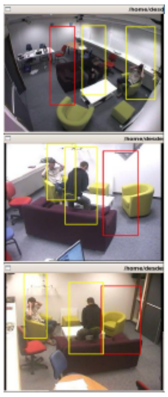
# How?
# Statistical (data-driven) methods



- Based on the use of sound, image and scene recognition software
- Based on machine learning techniques and data coming from different sensors
  - Accelerometers
  - Body-worn sensors
  - Environmental sensors
  - RFID (objects' use)
  - …

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## How?
## Symbolic (knowledge-driven) methods

- Human activities can be (imprecisely) formally described
- Given the description of a general activity (e.g., *giving a class*) an instance of that activity can be recognized from a set of facts (e.g., *20 students in classroom C1*, *Prof. Brown in C1*, *Prof. Brown using the blackboard, ...*) by firing some rules or by other reasoning mechanism



## Why context/knowledge?

- Monitoring an anonymous professor ...
  - events from sensor readings :
    - reclining position (unchanged)
    - right arm reaching head (once every 2-3 minutes, span > 30min)
  - ARS can't find a good match

Sick in bed taking his hand periodically to the forehead for a headache?

# Why context/knowledge?

- Add context:
  - it is Wed Sep 18, 3pm
  - his calendar says 'At DemAAL summerschool'

Revised guess:
- using microphone to ask questions in a seminar? (confidence low ...)



# Why context/knowledge?

- Add context/data: picture posted on FB with timestamp Wed Sep 17 12:00

# Why context/knowledge?

- use knowledge
  - load classifiers/descriptions for possible activities on the beach
  - use profile information (possibly with personal data mining)



# Why context/knowledge?

- New activity candidate
  - relaxing and drinking beer on the beach (instead of improving his presentation)

# How to use knowledge: the DL approach

- Description Logics (DL)
  - have a well-defined semantics
  - provide complete reasoning
  - are supported by optimized reasoning tools
- DLs are the underlying logics of OWL *ontology language*
- A domain is modeled by classes, individuals, and complex relationships among them
  - giving a class := the actor is a teacher,
    the actor's current location is a classroom,
    at least 5 students are in the classroom, and
    the actor is writing on a blackboard



# DL Basics

- Terminologic Part (TBox)
  - A collection of concepts characterizing the domain (e.g., classes of activities, classes of context elements, types of actors/objects involved)
- Assertional Part (ABox)
  - A collection of facts about concrete instances in the application domain (e.g., specific objects, actors, locations observed)

The TBox is often referred as *ontology*
TBox + ABox make the *knowledge base*

# DL syntax

DL syntax and semantics of $\mathcal{ALC}$-concept descriptions and the corresponding OWL syntax.

| constructor name | DL syntax | semantics | OWL syntax |
|---|---|---|---|
| negation | $\neg C$ | $\Delta \setminus C^{\mathcal{I}}$ | complementOf |
| conjunction | $C \sqcap D$ | $C^{\mathcal{I}} \cap D^{\mathcal{I}}$ | intersectionOf |
| disjunction | $C \sqcup D$ | $C^{\mathcal{I}} \cup D^{\mathcal{I}}$ | unionOf |
| existential restriction | $\exists r.C$ | $\{x \in \Delta \mid \exists y : (x, y) \in r^{\mathcal{I}} \wedge y \in C^{\mathcal{I}}\}$ | someValuesFrom |
| value restriction | $\forall r.C$ | $\{x \in \Delta \mid \forall y : (x, y) \in r^{\mathcal{I}} \rightarrow y \in C^{\mathcal{I}}\}$ | allValuesFrom |

From [T. Springer et al, JAISE 2009]

$$\texttt{Mother} \equiv \texttt{Person} \sqcap \texttt{Female} \sqcap \exists \texttt{has-child.Person}$$

```
Person(Alice)
Female(Alice)
has-child(Alice, Marc)
```



# Higher expressivity with OWL2

$$\texttt{TeaParty} \sqsubseteq \texttt{SocialActivity} \sqcap \forall \texttt{hasTimeExtent.Afternoon} \sqcap \forall \texttt{hasActor.}(\texttt{Person} \sqcap \exists \texttt{hasCurrentPosture.Seated} \sqcap \exists \texttt{hasCurrentActivity.Sipping} \sqcap \exists \texttt{hasCurrentLocation.}\big(\texttt{LivingRoom} \sqcap \geq 2\, \texttt{contains.TeaCup} \sqcap \forall \texttt{hasSoundSensor.}(\texttt{MeasuredSoundDb} \leq 35[\texttt{int}])\big)\big),$$

$$\texttt{LivesInBuilding} \circ \texttt{HomeBuildingOf} \,\dot{\sqsubseteq}\, \texttt{NextDoorNeighbor}$$

# DL reasoning

- TBox inconsistency, concept subsumption, classification, equivalence
- Realization
  - Example: Given an ABox context instance description find the most specific class of activities it belongs to
- Class and conjunctive queries
  - Examples:
    - find (in ABox) all instances of the activity "having_Tea"
    - find (in ABox) all objects that have been used in the kitchen in the last 2 hours

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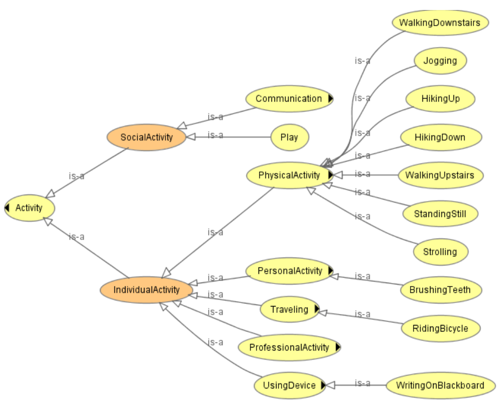
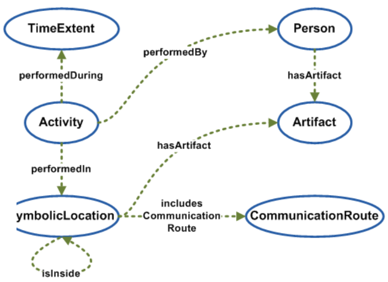
# Activity Ontology example

- OWL-DL ontology




| Class | Descendants |
|---|---|
| Activity | 35 |
| Artifact | 43 |
| CommunicationRoute | 14 |
| Person | 4 |
| SymbolicLocation | 30 |
| TimeExtent | 11 |

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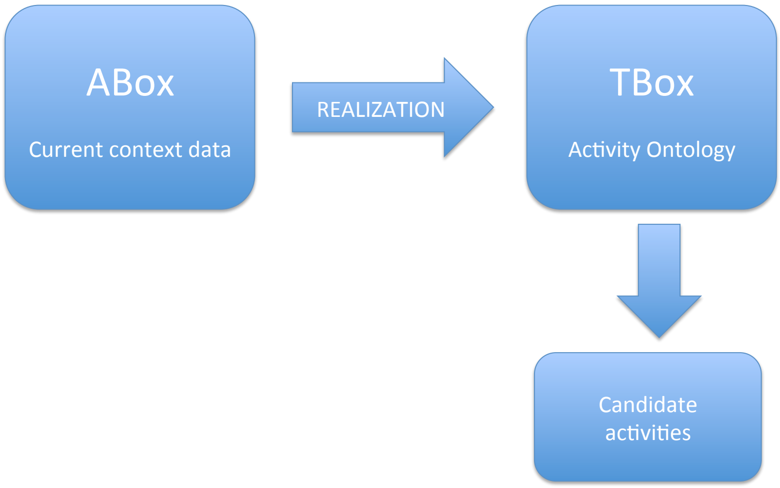
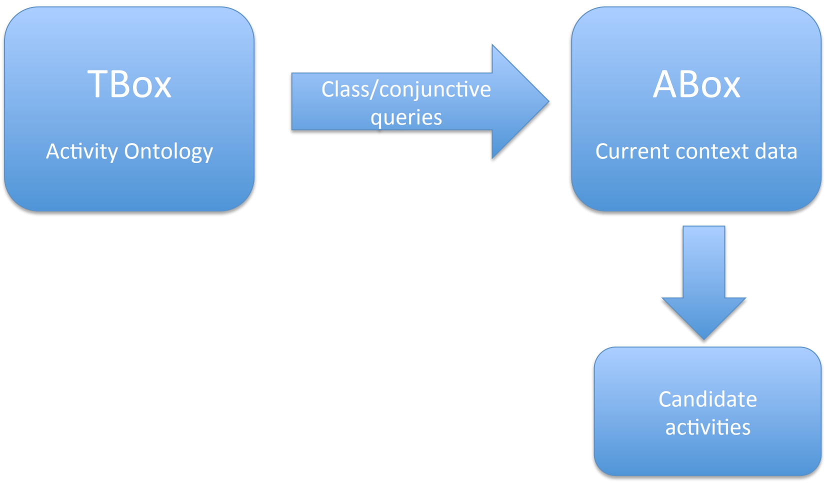
## Basic recognition methods with DLs






## Basic recognition methods with DLs



# Example of ontological reasoning

- "Can activity *A* be executed in context *C*?"
  - Add an assertion stating that an instance of *A* is performed in an instance of *C*
  - Perform consistency checking to detect whether the execution *A* is consistent with *C*

$\mathtt{BrushingTeeth} \sqsubseteq \mathtt{PersonalActivity} \sqcap \forall \mathtt{performedIn}.(\exists \mathtt{hasArtifact.Sink}) \sqcap \ldots$

$\mathtt{RestRoom} \sqsubseteq \mathtt{Room} \sqcap \exists \mathtt{hasArtifact.Sink} \sqcap \ldots$

$\mathtt{LivingRoom} \sqsubseteq \mathtt{Room} \sqcap \neg \exists \mathtt{hasArtifact.WaterFixture} \sqcap \ldots$

$\mathtt{BrushingTeeth(CURR\_ACT); RestRoom(CURR\_LOC\_1); LivingRoom(CURR\_LOC\_2)}$

$\mathtt{performedIn(CURR\_ACT, CURR\_LOC\_2);\ isABoxConsistent()}$

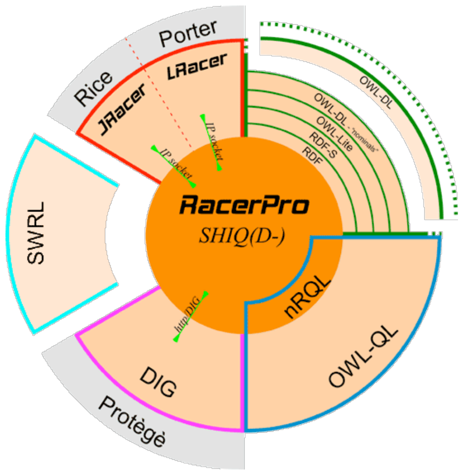


# Ontology Tools

protégé

Fact++

Pellet



# Drawbacks of existing techniques

- Statistical (data-driven):
  - Scalability
    - with the number of sensors and candidate activities
  - Adaptability
    - change in sensors, position, orientation, environment requires expensive re-training and reconfiguration
  - hard for complex activities
- Symbolic (knowledge-driven):
  - Not well suited to the recognition of low-level activities
  - difficult knowledge engineering task
  - Expressiveness and efficiency issues



# Evolution of statistical methods

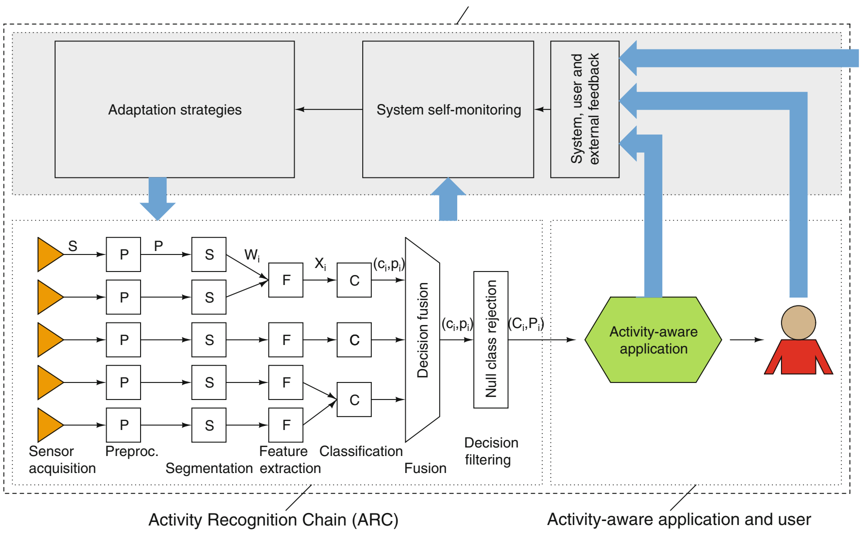
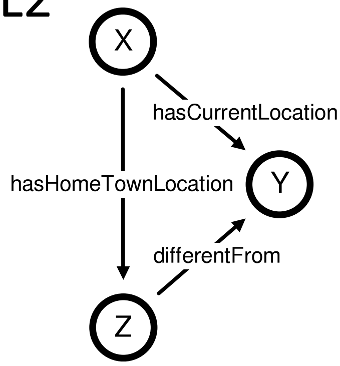



Figure from [D. Roggen et al, JAIHC 2013]

# Limits of OWL2

- Expressiveness
  - Tree model property
  - Lack of rules support
  - time
  - uncertainty




$$\forall X \forall Y \forall Z\ (\texttt{Person}(X) \land \texttt{Location}(Y) \land \texttt{Location}(Z) \land \texttt{hasCurrentLocation}(X, Y) \land \texttt{hasHomeTownLocation}(X, Z) \land \texttt{differentFrom}(Z, Y) \rightarrow \texttt{hasCurrentActivity}(X, \texttt{traveling}))$$



# Augmenting ontological reasoning with rules

- Two approaches
  - tightly coupled: a unified language for rules and ontologies
    - Example: OWL+SWRL
    - Drawback: easy to end up with undecidable logics
  - Loosely coupled: rule-based and ontological reasoning are executed separately
    - Drawback: limited reasoning capabilities (no feedback)

# Handling uncertainty

**Context information**

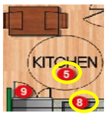
▪Sensors 5, 8 are in the kitchen ***(user's location)***

**Background knowledge**

▪The subject ***can not*** be present in two rooms at the same time

▪Cleaning the kitchen ***usually*** takes place after eating

**Sensors-derived data**



What is the **most probable** activity under these **constraints?**

**Certain axioms (facts)**

**Uncertain axioms**



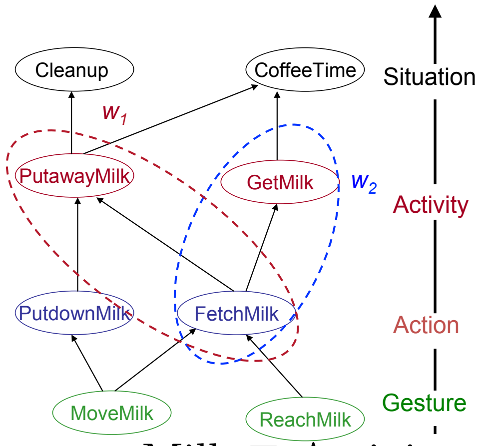
# Using Log-linear DLs

- **Input**: DL *axioms* with **and** without *weights*
- **Output**: A most probable consistent ontology
- **Method**: *Probabilistic* approach to ontological reasoning

  **Maximize:** Sum of *weights*
  **Subject to:** Constraints ensuring *Consistency* of ontology
- **Tool**: Elog Reasoner

[Helaui et al, Ubicomp 2013]

# Example of weighted axioms




$$w_1: \text{PutawayMilk} \sqsupseteq \text{Activity} \sqcap \exists\, \text{hasActor}.(\text{Person} \sqcap \exists\, \text{hasAction}.\text{FetchMilk})$$



# Hybrid methods

## Towards a hybrid framework

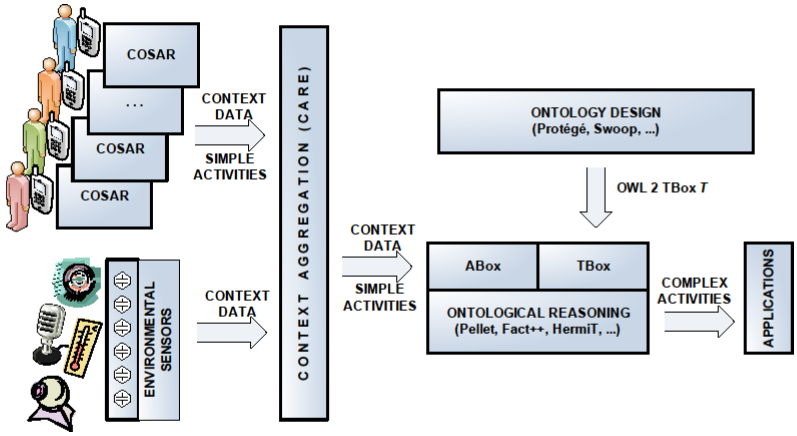
- Overall goal: *coupling symbolic and statistical methods to get the best of the two worlds*
- Research issues:
  - Devising a *hybrid intelligent system*
  - Defining a *common ontology* for activities and context data
  - *Flexibility*
  - *Efficiency*



## Different hybrid approaches

1. Ontology used only as a common "vocabulary" for context and activities + possibly for recognition goals guidance
2. Knowledge-driven recognition applied as a second stage after data-driven methods
3. Knowledge-driven methods intertwined with data-driven methods

# Hybrid approach 2

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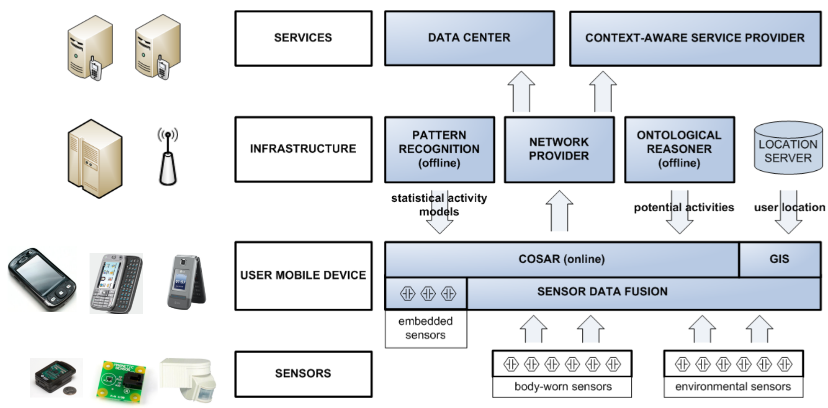
# Hybrid approach 3

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# Hybrid approach 3: example

- Statistical technique applied over ontology-based selected candidates
- Temporal smoothing based on a sliding window

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Garden** | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| **HospitalBuilding** | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| **Kitchen** | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| **Laboratory** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| **LivingRoom** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **Meadow** | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| **RestRoom** | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **UrbanArea** | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| **Wood** | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |

*Columns:* **1=brushingTeeth; 2=hikingUp; 3=hikingDown; 4=ridingBycicle; 5=jogging; 6=standingStill; 7=strolling; 8=walkingDownstairs; 9=walkingUpstairs; 10=writingOnBlackboard**

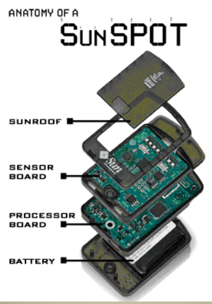


# Datasets and Experiments

# COSAR Experimental setup

[Riboni-Bettini, PUC 2011]

- Data acquired from a GPS receiver and two *Sun SPOTs*
  - Programmable in Java
    - Fully capable JME CLDC 1.1 Java VM
  - 180 MHz 32 bit processor, 512K RAM/4M flash memory, IEEE 802.15.4 radio
  - http://www.sunspotworld.com
- 5-hours activity data collected by 6 volunteers
- 10 activities






# COSAR Experimental results

(a) Evaluation of statistical classifiers

| Classifier | Accuracy |
|---|---|
| Bayesian Network | 72.95% |
| C4.5 Decision Tree | 66.23% |
| Multiclass Logistic Regression | 80.21% |
| Naive Bayes | 68.55% |
| SVM | 71.81% |

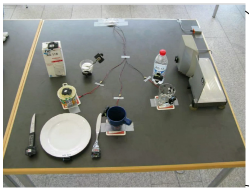
(b) Overall accuracy

| Classifier | Accuracy |
|---|---|
| statistical | 80.21% |
| statistical-voted | 84.72% |
| COSAR | 89.20% |
| COSAR-voted | 93.44% |

(c) Error reduction

| versus → | statistical | statistical-voted | COSAR |
|---|---|---|---|
| statistical-voted | 22.79% | | |
| COSAR | 45.43% | 29.32% | |
| COSAR-voted | 66.85% | 57.07% | 39.26% |

# Ongoing experiments with Log-linear DL and the Opportunity Dataset



**72 sensors of 10 modalities**
**12 subjects**



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http://www.opportunity-project.eu

# The SECURE project


- *Intelligent System for Early Diagnosis and Follow-up at Home*
- Partners: Health Telematic company, ICT service provider, Hospital institution specialised on dementia, EveryWare lab
- monitoring 3-10 patients in their homes, non intrusive sensors

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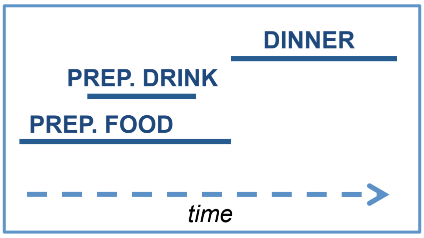
# Research Challenges



# Research challenges

- Integration of **temporal reasoning** (qualitative and/or quantitative)
  - Among other existing work see [Meditskos et al. COMOREA 2013, Riboni et al. COMOREA 2011]



# Research challenges

- Devising smart techniques to increase efficiency of ontological reasoning (while dealing with uncertainty and time)
- Recognizing concurrent and interleaved activities (possibly with multiple actors)
- Devising adaptive techniques



# Research challenges

Enriching context data collection to enhance activity recognition and prediction by mining *Small Data*
See Deborah Estrin's TEDMED talk (http://tedmed.com/)

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*Thanks for your attention*