EveryWare Lab
Data Management for Mobile and Pervasive Computing

Towards the Combination of Statistical and Symbolic Techniques for Activity Recognition

Daniele Riboni

EveryWare Lab, University of Milano
http://everywarelab.dico.unimi.it/

Outline

- Introduction
- Statistical techniques
- Symbolic techniques
- Towards a hybrid framework
- Conclusions

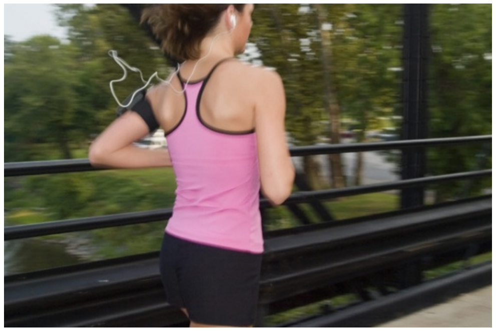
Introduction

- Human activity recognition is about detecting:
  - Actions / gestures
  - Physical /ADL activities
  - Interactions

- Based on:
  - Sensor data
  - Object use
  - Location

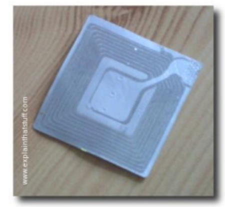
Applications

- Pervasive computing
- Health-care
- Recognition of critical events
- Training
- Homeland security

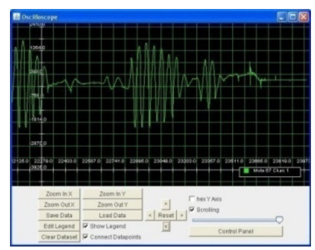


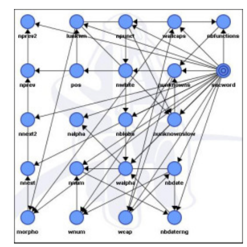
Activity-awareness

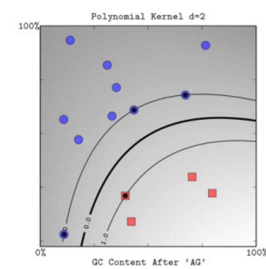
- Sensing



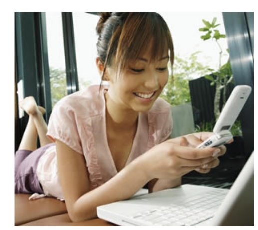
- Modeling/reasoning







- Adaptation /decision making



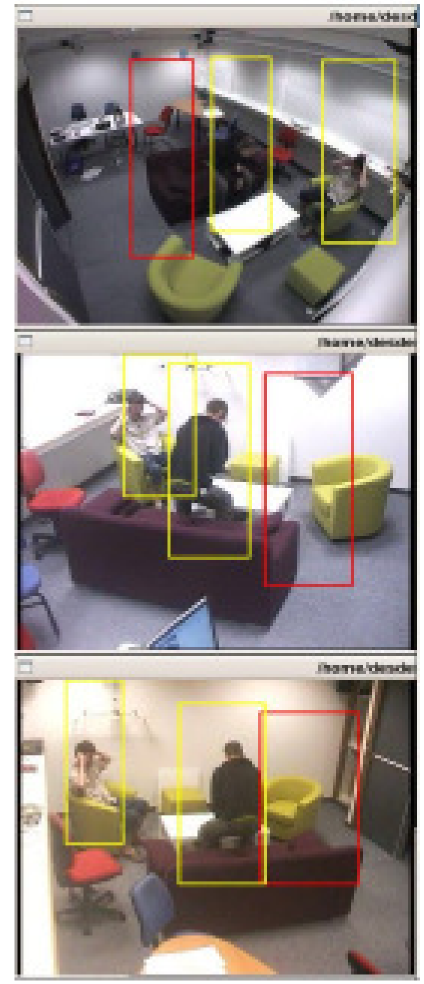
Issues

- Accurate recognition of complex activities and interactions
- Dynamic sensor configurations
- Scalability
- Obtrusiveness
- Privacy

The most profound technologies are those that disappear

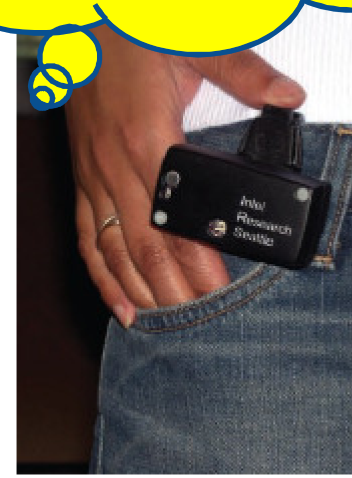
Statistical techniques

- Use of sound, image and scene recognition software
  - N. Oliver *et al*.: Layered Representations for Human Activity Recognition. In: Proc. of ICMI-02
  - O. Brdiczka *et al*.: Learning Situation Models for Providing Context-Aware Services. In: Proc. of HCI 2007
  - …
- Pros:
  - Effective for smart home/office applications
- Cons:
  - Limited to confined environments
  - Subject to privacy concerns



Statistical techniques

The alarm clock,
alerted by Sal's
restless rolling
before waking, …



- Based on body-worn sensors and on machine learning techniques
- From multiple locations to multi-modal activity recognition:
  - e.g., T. Choudhury *et al*.: The Mobile Sensing Platform: An Embedded Activity Recognition System. In: *IEEE Perv. Comp. 7(2)*, 2008
- Pros:
  - Non-obtrusive, embeddable in portable devices
- Cons:
  - Restricted to a limited number of activities

Statistical techniques

- Surrounding environment, objects' use, and accelerometer data
  - S. Wang *et al.*: Common Sense Based Joint Training of Human Activity Recognizers. In: Proc. of IJCAI-07.
  - M. Stikic *et al.*: ADL Recognition Based on the Combination of RFID and Accelerometer Sensing. In: Proc. of Pervasive Health 2008

- Pros: very effective for recognizing ADL

- Cons: it is unlikely that in a near future all of the objects in our environment will be tagged

Symbolic techniques

Meetings consist of several people spending time in the same room

- Symbolic techniques are well-suited for recognizing complex activities
  - Expressing constraints and relationships among context data
- A language is needed to formally define activities
- Need to handle uncertainty
- Several different conditions can be stated to determine the same activity
- Recognition relies on simpler observations
  - giving a class := the actor is a teacher,
    the actor's current location is a classroom,
    some students are in the classroom, and
    the actor is writing on a blackboard

S.W. Loke: Six ways to tell if you are in a meeting, CoMoRea'06

Symbolic techniques

- Various symbolic formalisms have been investigated to handle activities (and context)
- Description logics (DL) have emerged because:
  - They provide complete reasoning
  - They are supported by optimized reasoning tools
- DL allow *ontologies* to be defined
  - A domain is modeled by classes, individuals, and complex relationships among them
  - The language of choice is generally OWL-DL

Symbolic techniques

- Expressivity: OWL-DL lacks important operators
  - Property composition:

$$\texttt{isColleagueOf} \equiv \texttt{isEmployedBy} \circ \texttt{isEmployerOf}$$

  - Role-value maps:

$$\texttt{Person} \sqcap (\texttt{hasCurrentLocation} = \texttt{hasWorkLocation})$$

- OWL-2 promises to overcome some limitations of OWL-DL while retaining decidability
  - B. Motik *et al.* : OWL 2 Web Ontology Language: Structural Specification and Functional-Style Syntax. W3C Working Draft. 02 December 2008

Symbolic techniques

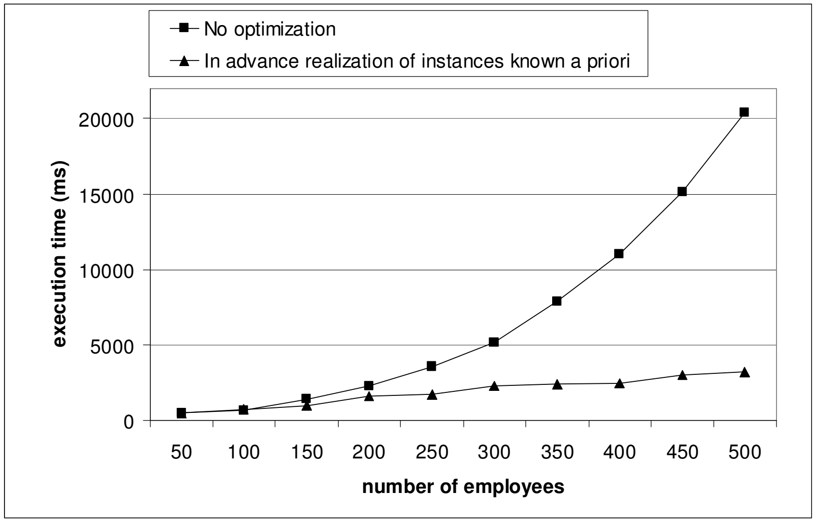
How can we recognize "spontaneous urgent meetings"?

- OWL-DL coupled with rule-based reasoning
  - H. Chen *et al.*: Semantic Web in the Context Broker Architecture. Proc. of PerCom 2004
  - X.H. Wang *et al.*: Ontology based context modeling and reasoning using OWL. CoMoRea'04
  - A. Agostini *et al.*: Loosely Coupling Ontological Reasoning with an Efficient Middleware for Context-awareness. Proc. of MobiQuitous 2005

- Fact-based models
  - J. Indulska *et al.*: Towards a Standards-Based Autonomic Context Management System. Proc. of PerCom 2008

OWL-based techniques

- Even without expressive constructors, reasoning with OWL-DL is expensive
  - Ontological reasoning should be performed offline on powerful machines
  - Some optimizations can help:
    - A. Agostini *et al.*: A performance evaluation of ontology-based context reasoning. CoMoRea'07.



Drawbacks of existing techniques

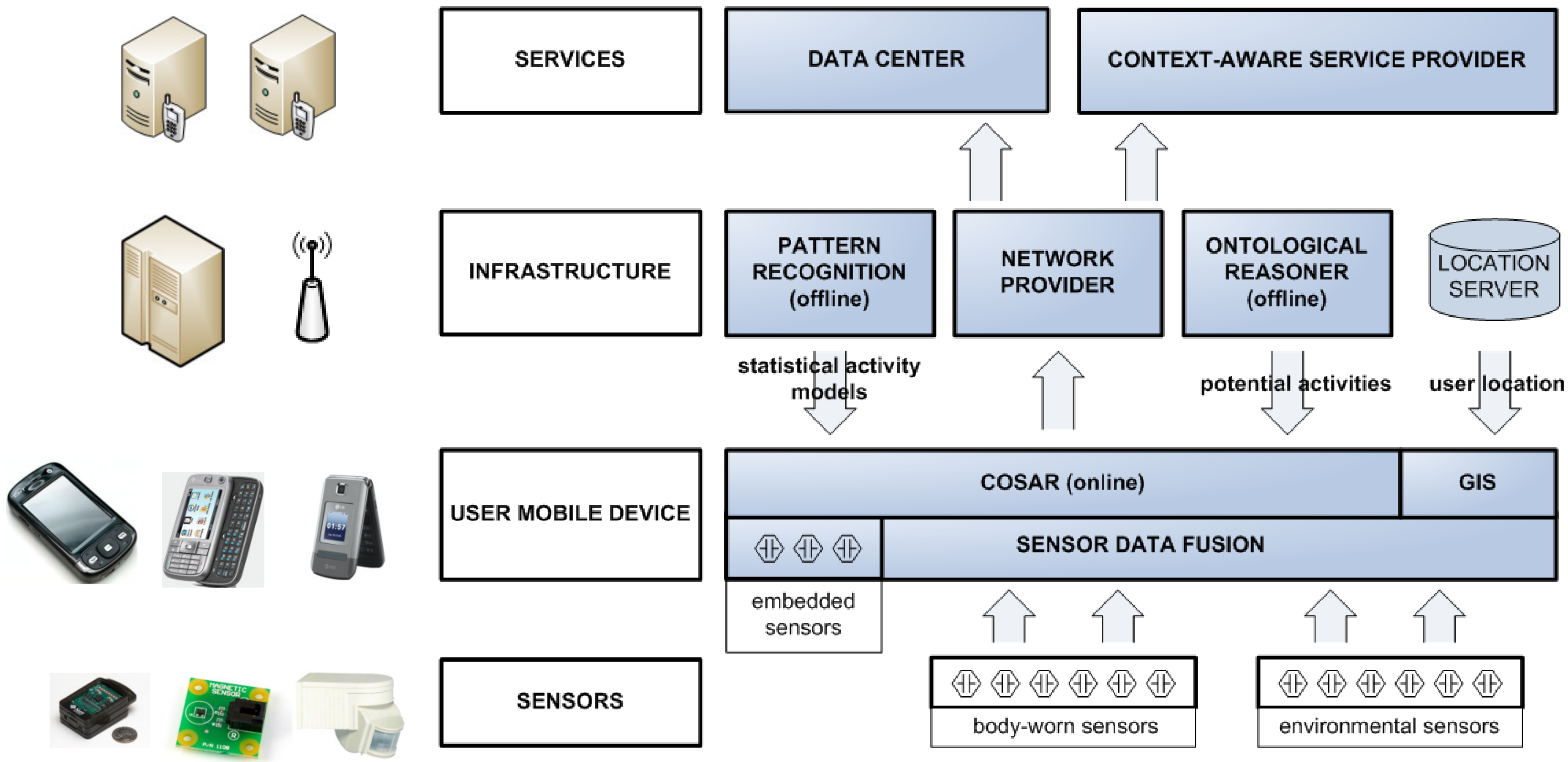
- Statistical:
  - Recognition of complex activities
  - Static assumptions about sensors configurations
  - Scalability
  - (in some cases) Practicality and privacy issues
- Symbolic:
  - Cannot recognize basic physical activities and observations
  - (in some cases) Expressiveness and efficiency issues; do not handle uncertainty and fuzzyness

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
  - *Efficiency*
  - *Flexibility*
  - Enforcing *privacy*

Towards a hybrid framework

- Overall framework



Towards a hybrid framework: symbolic technique

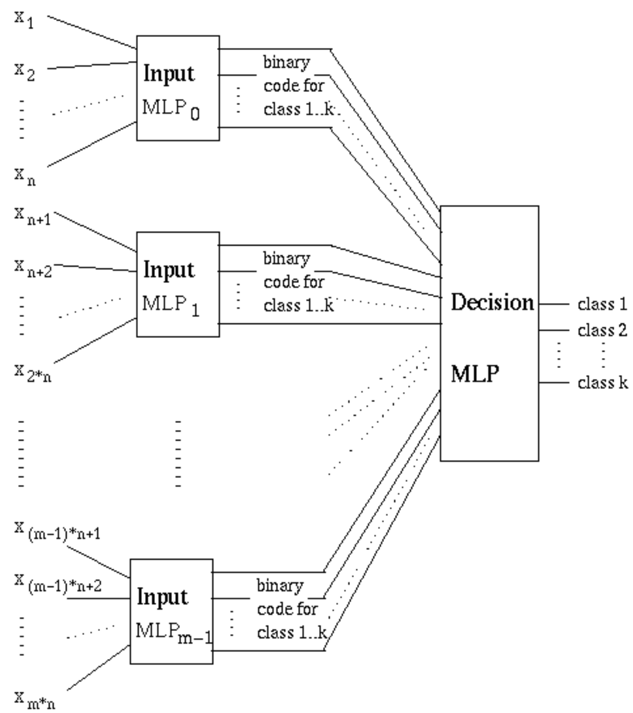
- Language requirements:
  - Sufficient expressiveness
  - Decidability
  - Support for uncertainty and/or fuzzyness
  - Interoperability with OWL

- A candidate: *fuzzyDL*
  - Developed at ISTI-CNR
  - Includes expressive contructors
  - An optimized reasoner is actively maintained
  - Compatible with OWL-Lite

Towards a hybrid framework: statistical technique

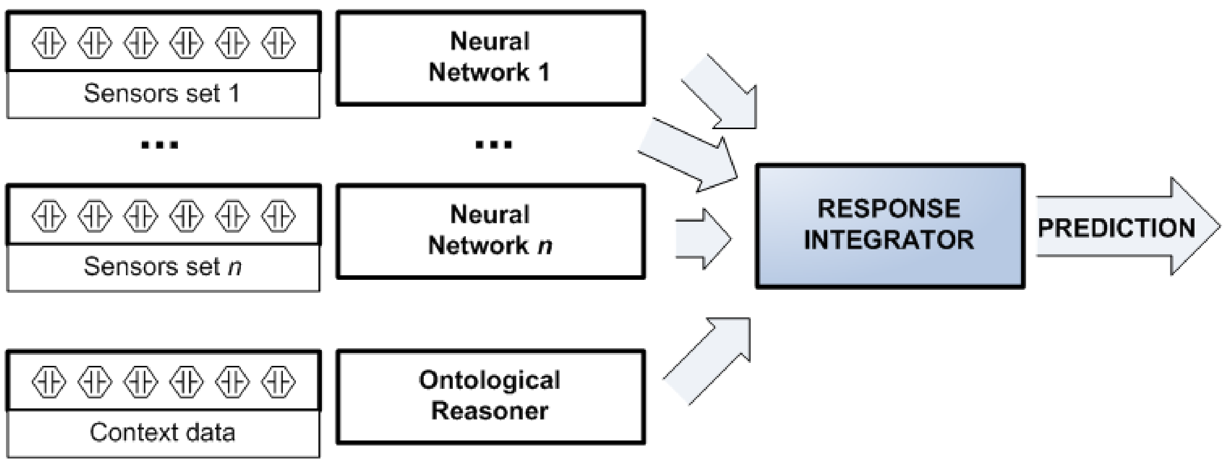
- Requirements:
  - Good recognition performance
  - Run-time efficiency
  - Modularity

- Candidate technique: modular neural networks



Towards a hybrid framework: hybrid intelligent system

- Modular hybrid system
  - Composed of separate neural and symbolic units
  - Binding provided by the common ontology
    - each neural output node corresponds to an activity concept
  - Results combined by a *response integrator*



Towards a hybrid framework: response integration

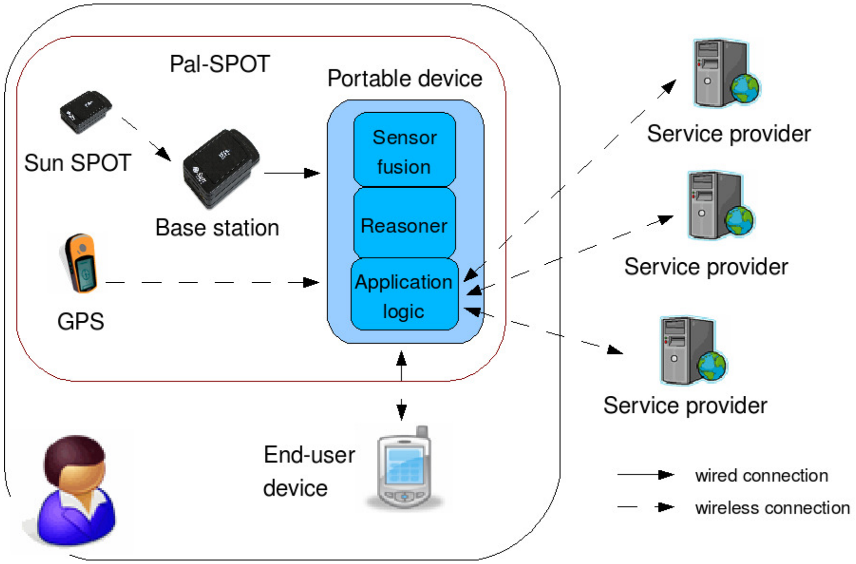
- Reasoning units:
  - Symbolic unit: provides fuzzy results
  - Statistical units: provide uncertain results

- Integration can be based on fuzzy integrals:
  - Non-linear function defined w.r.t. fuzzy measures (e.g., the $g\lambda$-fuzzy measure of Sugeno)
  - Other techniques may be investigated

Pal-SPOT project

- *http://everywarelab.dico.unimi.it/palspot*

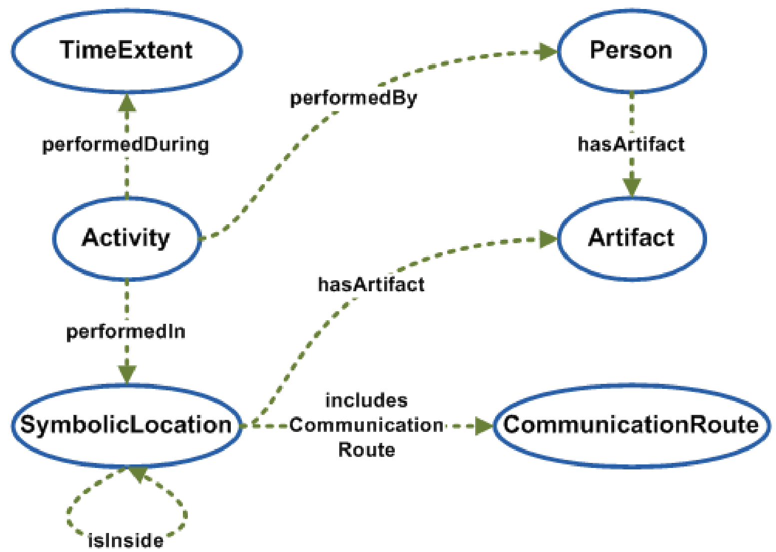
- Goal: integration of statistical reasoning with an existing middleware for context-awareness based on symbolic reasoning
  - C. Bettini *et al.*: Efficient Profile Aggregation and Policy Evaluation in a Middleware for Adaptive Mobile Applications. Journal of Pervasive and Mobile Computing 4(5)

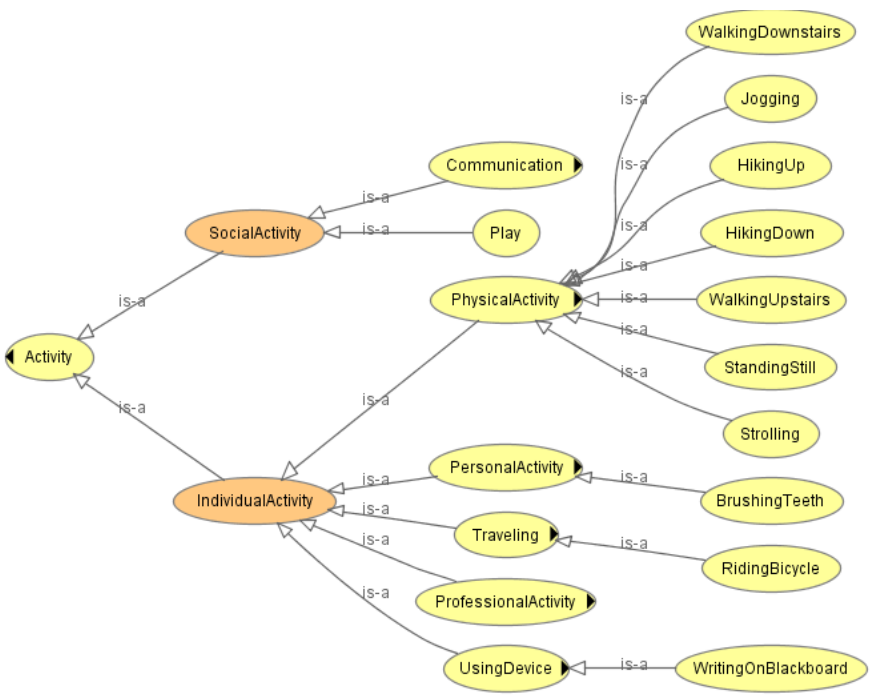


- Partially supported by a grant from *Sun Microsystems*

Preliminary implementation: symbolic technique

- Traditional (non-fuzzy) ontology: OWL-DL





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

Preliminary implementation: symbolic technique

- Ontological reasoning: crisp technique
- 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*

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

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

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

```
BrushingTeeth(CURR_ACT);RestRoom(CURR_LOC_1);LivingRoom(CURR_LOC_2)
performedIn(CURR_ACT,CURR_LOC_1); isABoxConsistent()
```

Preliminary implementation: machine learning technique

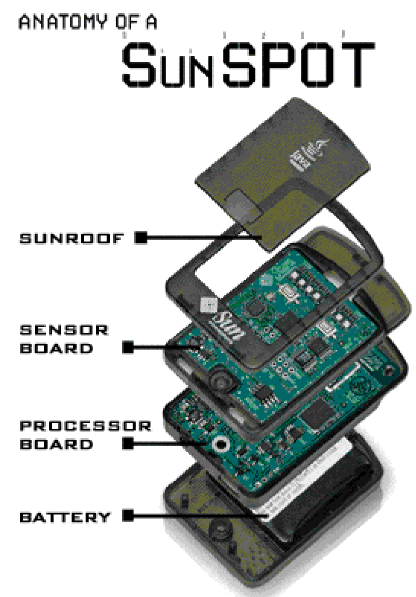
- Various techniques have been tried (NN, NB, SVM, MLR, ...)
- Temporal smoothing based on a sliding window
- Response integration is based on the matrix obtained from the symbolic reasoner:

	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

Experimental setup

- 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

Preliminary implementation

- 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%

Open issues and future work

- Coping with dynamic sensors configurations
- Automatically deriving fuzzy assertions
- Recognizing concurrent and interleaved activities
- Preserving users' privacy
- Devising effective activity-aware applications

Acknowledgments

- Thanks to:
  - Claudio Bettini for useful comments on the hybrid reasoning technique
  - The volunteers that collaborated to the collection of data used in the experiments
- EveryWare Lab
  - http://everywarelab.dico.unimi.it/