Mechanism for Optimizing the Reasoning for Activity Recognition: Application for Ambient Assisted Living for Elderly People

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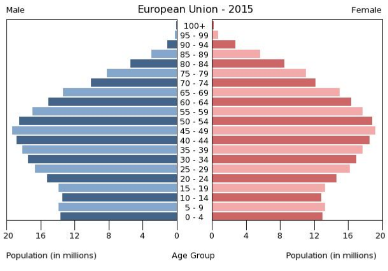
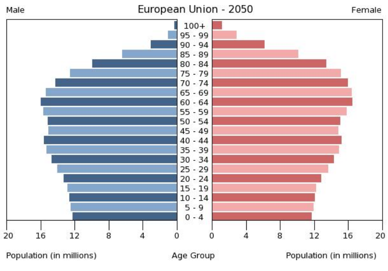
An Ageing Population



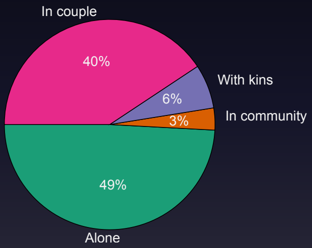
Population pyramids in Europe — 2015



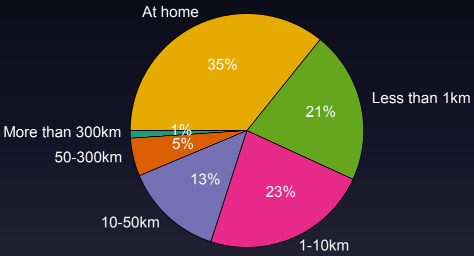
Population pyramids in Europe — 2050

An Ageing Population

Study performed in 2014, with 120 elderly people and their caregivers[1].



Person living with elderly people



Distance separating elderly people from their caregiver

1 Mounir Mokhtari, Romain Endelin, Hamdi Aloulou, and Thibaut Tiberghien. "Measuring the impact of ICTs on the quality of life of ageing people with mild dementia". In: ICOST 2014. Springer, 2014, pp. 103–109.

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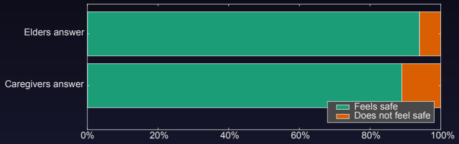

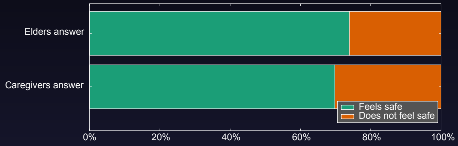

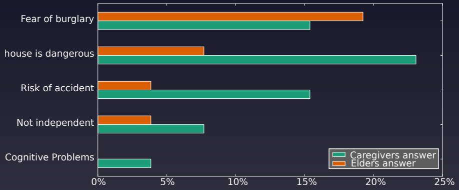

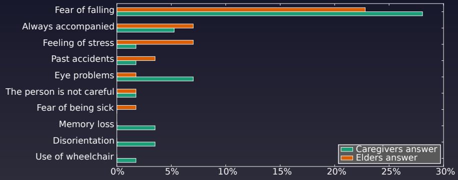

Feeling of security inside elderly people's house

Feeling of security outside elderly people's house

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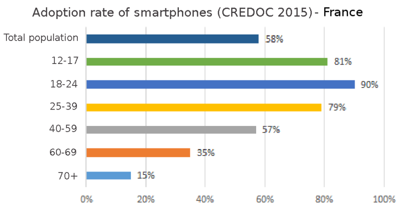
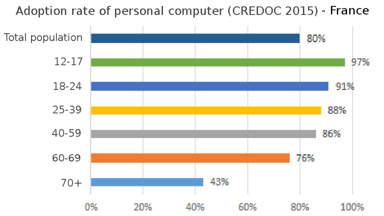
Adoption of New Technologies





- Causes of non-adoption from elderly people:
  - Learning curve;
  - Lack of habits;
  - Do not see the interest;
  - Systems are not designed with elderly people in mind.

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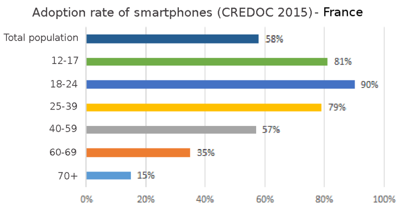

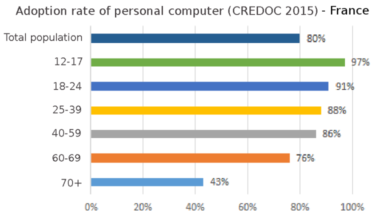

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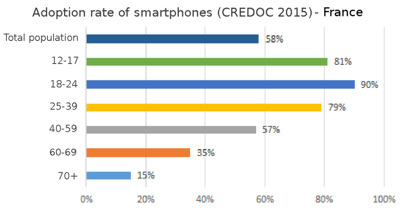

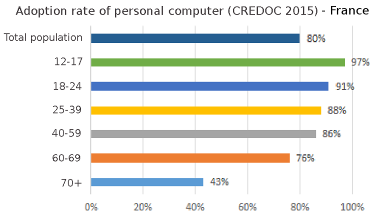

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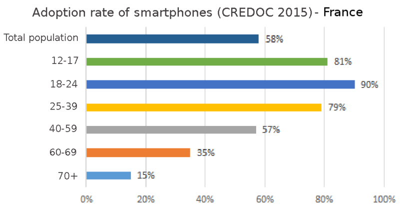

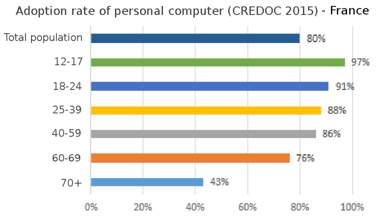

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Pervasive Computing

Definition

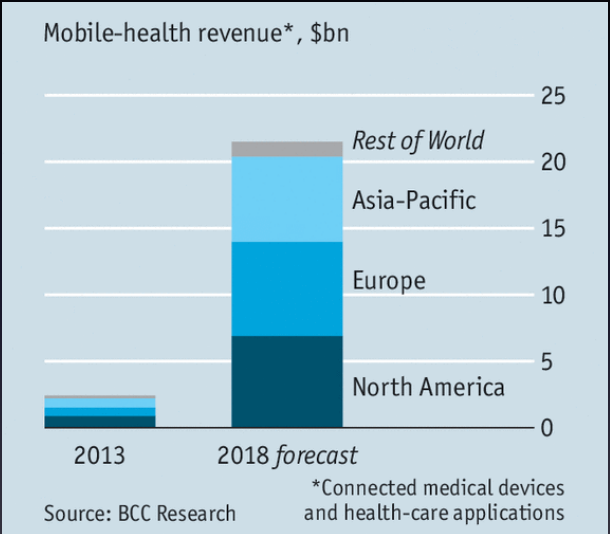
"The age of calm technology, when technology recedes into the background of our lives"

Mark Weiser, 1991

The Benefits of Pervasive Computing:

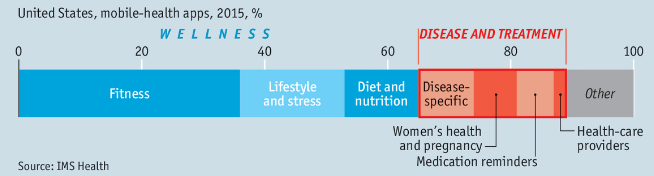
- Reduced learning curve;
- Adapted for people with disabilities;
- Customized interactions for each users.

Opportunity — eHealth



The growth of Mobile Health

Opportunity — eHealth



Mobile Health — From Well-Being to Disease Treatments

Ambient Assisted Living

- Large number of existing implementations;
  - Only a handful of them have real world usage[2].

Recommended focus areas:[2]

- Design methodologies;
- Security;
- User experience;
- Usability;
- Accuracy.

Existing solutions:

- UniversAAL;
- OpenAAL;
- OpenHAB;
- CASAS;
- DOMUS;
- …

2 Mukhtiar Memon, Stefan Rahr Wagner, Christian Fischer Pedersen et al. "Ambient assisted living healthcare frameworks, platforms, standards, and quality attributes". In: Sensors 14.3 (2014), pp. 4312–4341

Context

The team — PAWM International

- Top-down approach:
  - Focus on practical applications;
  - *Pull* challenges from the use-case.

Initial situation

- UbiSMART V2, a modular framework for Ambient Assisted Living[3];
- A Semantic-based Reasoning for Activity Recognition[4].

3 Hamdi Aloulou. “Framework for ambient assistive living: handling dynamism and uncertainty in real time semantic services provisioning”. PhD thesis. Evry, Institut National des Télécommunications, 2014

4 Thibaut Tiberghien. “Strategies for context reasoning in assistive livings for the elderly”. PhD thesis. Evry, Institut National des Télécommunications, 2013

Outline

Use-Case: Moving Towards a Real and Scalable Deployment

Saint-Vincent-de-Paul, Nursing Home, ***Occagnes, FRANCE***

The Deployment

- **Starting:** September 2013
    - Active until today
- Nursing home
    - 5 rooms deployed
- Individual houses
    - Up to 3 individual deployed

Chaire Quality of Life. Mutuelle Générale; AG2R La Mondiale.
VHP Interactive.

Scientific Challenges

- A framework for Ambient-Assisted Living:
  - From *proof-of-concept* to *production-ready* implementation;
- Qualify and improve Activity Recognition.

Outline

UbiSMART — Challenges

- ➡ A framework for Ambient-Assisted Living:
  - Simplify the installation process;
  - Seamlessly extend to multiple deployments;
  - Design for the end-users;
- Qualify and improve Activity Recognition.

UbiSMART — Challenges

- ➡ A framework for Ambient-Assisted Living:
  - Simplify the installation process:
    - Install a gateway within the house;
    - Define a right set of sensors;
    - Communicate with the server;
    - Maintain the system.
  - Seamlessly extend to multiple deployments;
  - Design for the end-users;
- Qualify and improve Activity Recognition.

UbiSMART — Challenges

- ➡ A framework for Ambient-Assisted Living:
  - Simplify the installation process;
  - Seamlessly extend to multiple deployments:
    - Automatic configuration of the gateway;
    - Monitoring;
    - Improve performances;
  - Design for the end-users;
- Qualify and improve Activity Recognition.

UbiSMART — Challenges

- ➡ A framework for Ambient-Assisted Living:
  - Simplify the installation process;
  - Seamlessly extend to multiple deployments;
  - Design for the end-users:
    - User-Friendly services.
    - Secured access for the users;
- Qualify and improve Activity Recognition.

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Personal contribution of this thesis
In close collaboration with other researchers of the team
Work mostly carried by other researchers of the team

UbiSMART — Challenges

- ➡ A framework for Ambient-Assisted Living:
  - Simplify the installation process:
    - Install a gateway within the house; $\Longleftarrow$
    - Define a right set of sensors; $\Longleftarrow$
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    - Monitoring;
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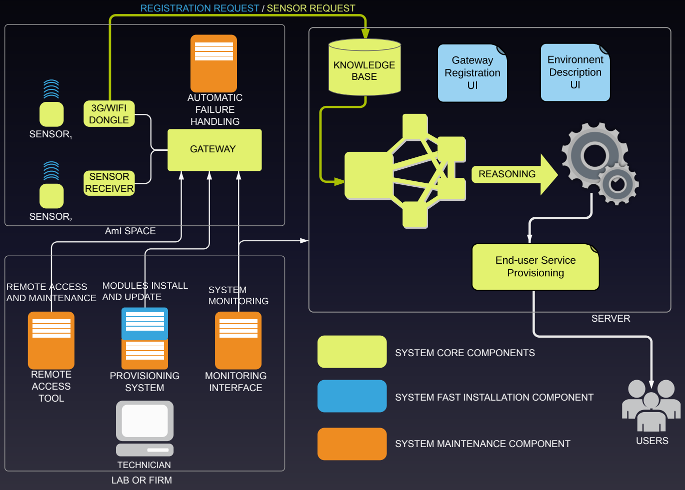
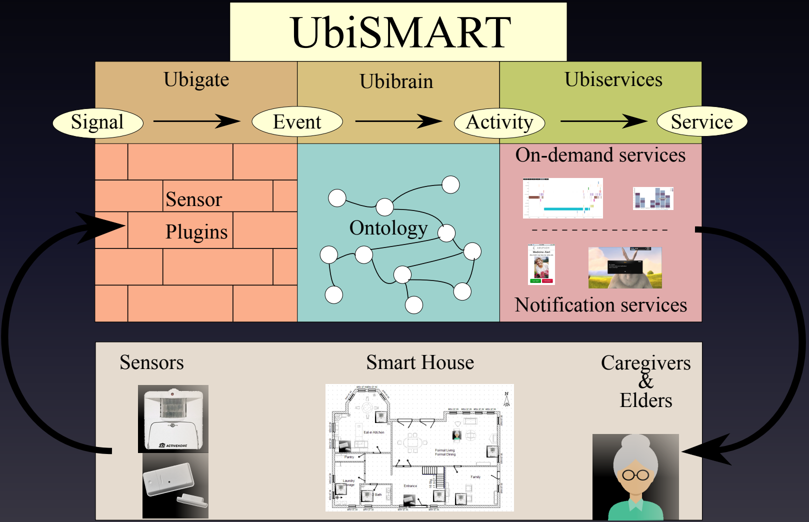
Response to the challenges



Deployment in a house

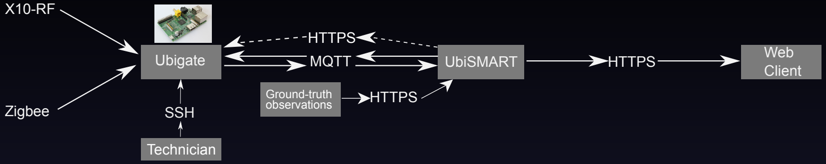
The New UbiSMART Framework



Improvements over the previous UbiSMART

	UbiSMART V2	**UbiSMART V3**
Language	Java	Javascript
Framework	OSGi	NodeJS/Express
Environment	Command-Line	Web-Application
Paradigm	Service-Oriented Architecture	Model/View/Controller
Modularity	Service-based	Plugin-based
Reasoner	✓	✓
Sensor events	✓	✓
Service delivery	~	✓
User interface	✗	✓
Encryption	✗	✓
Multiple houses	✗	✓
User privileges	✗	✓
Data persistence	✗	✓
Semantic Plug&Play	✗	✓

Communication Protocols



Roles:

- MQTT:
  - **Sensor events;**
  - Sensor discovery;
  - Service delivery;
  - Monitoring;
  - Configuration.
- HTTPS:
  - Gateway discovery;
  - Ground-truth observations.
- SSH:
  - Provisioning;
  - Maintenance.

MQTT messages:

- Topic:

```
house/1/marmitek/sensor/A1
```

- Payload:

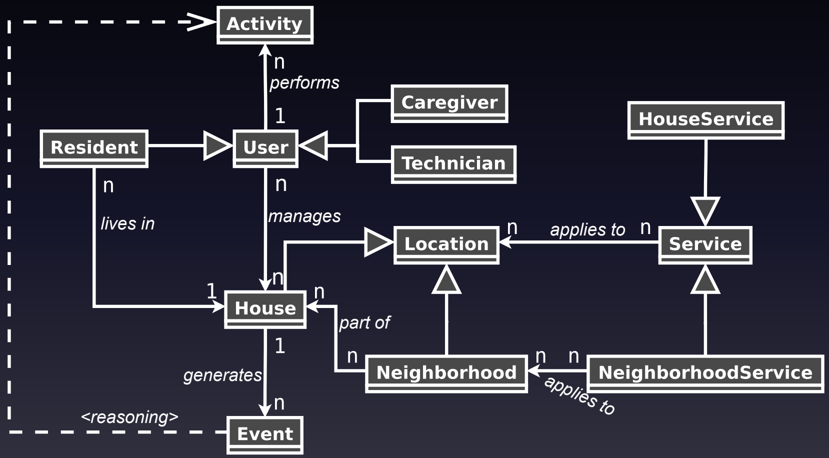

```
{
  "date": "2016-05-17T09:06:00.116+02:00",
  "house": 1,
  "sensor": "A1",
  "value": "off"
}
```

Data Input

Input — Sensor events

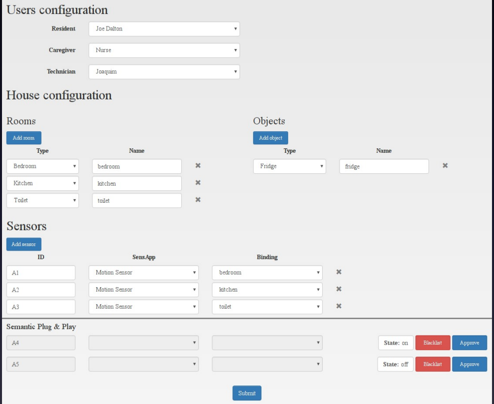
date,	house,	sensor,	value
2014-09-23 13:33:00.000000,	1,	A1,	on
2014-09-23 13:33:00.000000,	2,	A1,	on
2014-09-23 13:37:00.000000,	3,	A1,	on
2014-09-23 13:44:40.000000,	5,	C2,	On
2014-09-23 14:05:36.000000,	3,	a819880,	normal
2014-09-23 14:05:42.000000,	5,	C2,	On
2014-09-23 14:05:49.000000,	5,	C2,	On
2014-09-23 14:05:53.000000,	3,	a819880,	alert
2014-09-23 14:05:55.000000,	3,	a819880,	normal
2014-09-23 14:05:57.000000,	3,	a819880,	alert
2014-09-23 14:05:59.000000,	3,	a819880,	normal
2014-09-23 14:06:07.000000,	3,	a819880,	alert
2014-09-23 14:06:10.000000,	3,	a819880,	normal
2014-09-23 14:06:15.000000,	3,	a819880,	alert
2014-09-23 14:06:32.000000,	5,	C1,	On
2014-09-23 14:06:36.000000,	3,	a819880,	normal
2014-09-23 14:06:37.000000,	3,	a819880,	alert
2014-09-23 14:06:38.000000,	3,	a819880,	alert
2014-09-23 14:07:00.000000,	3,	A1,	On
2014-09-23 14:07:06.000000,	3,	A1,	On

UbiSMART Model



Most of the credit for development go to Dr. Thibaut Tiberghien and Mr Joaquim Bellmunt Montoya.

Semantic Plug&Play

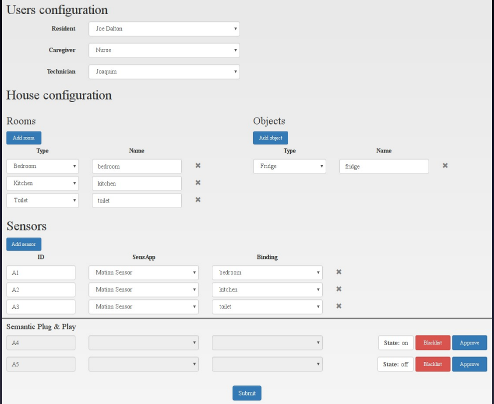


House declaration — Homedesc

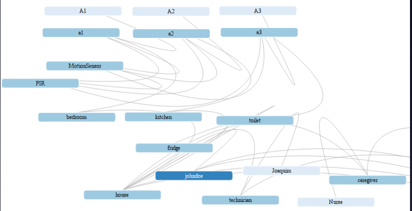
```
hom:johndoe rdf:type qol:Resident.
hom:johndoe qol:residentOf hom:house.
hom:johndoe qol:id "4"^^xsd:integer.
hom:johndoe qol:name "Joe Dalton"^^xsd:string.
hom:caregiver rdf:type qol:Caregiver.
hom:caregiver qol:caregiverOf hom:house.
hom:caregiver qol:id "5"^^xsd:integer.
hom:caregiver qol:name "Nurse"^^xsd:string.
hom:technician rdf:type qol:Technician.
hom:technician qol:technicianOf hom:house.
hom:technician qol:id "3"^^xsd:integer.
hom:technician qol:name "Joaquim"^^xsd:string.
hom:bedroom rdf:type qol:Bedroom.
hom:bedroom qol:partOf hom:house.
hom:kitchen rdf:type qol:Kitchen.
hom:kitchen qol:partOf hom:house.
hom:toilet rdf:type qol:Toilet.
hom:toilet qol:partOf hom:house.
hom:fridge rdf:type qol:Fridge.
hom:fridge qol:locatedIn hom:house.
hom:a1 rdf:type hom:MotionSensor.
hom:a1 qol:id "A1"^^xsd:string.
hom:a1 qol:deployedIn hom:bedroom.
hom:a2 rdf:type hom:MotionSensor.
hom:a2 qol:id "A2"^^xsd:string.
hom:a2 qol:deployedIn hom:kitchen.
hom:a3 rdf:type hom:MotionSensor.
hom:a3 qol:id "A3"^^xsd:string.
hom:a3 qol:deployedIn hom:toilet.
```

Ontology output

Semantic Plug&Play

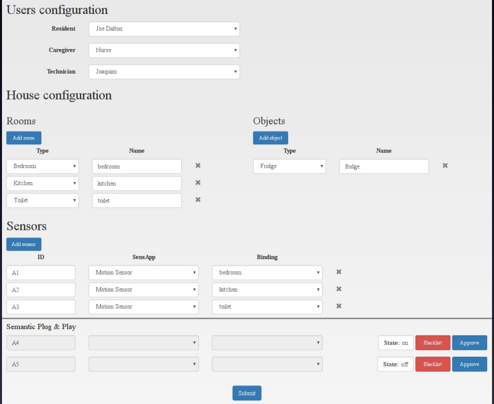


House declaration — Homedesc



Ontology visualization

Semantic Plug&Play



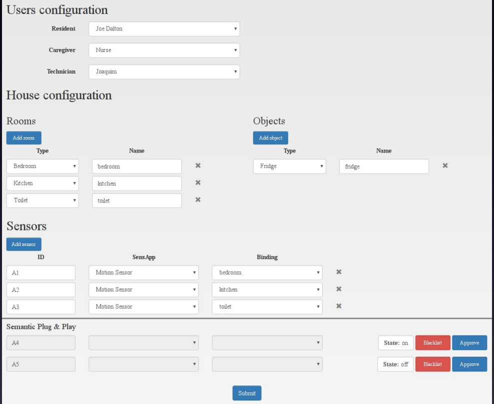
House declaration — Homedesc


```
{
 "houses":[
  {
   "id":1,
   "sensors":[
    {
     "id":"A1",
     "binding":"bedroom",
     "bindingType":"Room"
    },
    {
     "id":"A2",
     "binding":"kitchen",
     "bindingType":"Room"
    },
    {
     "id":"A3",
     "binding":"toilet",
     "bindingType":"Room"
    }
   ]
  }
 ],
 "blacklist":[

 ]
}
```


Gateway output

Semantic Plug&Play



House declaration — Homedesc

Benefits

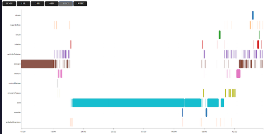
- The deployment can be performed by a non-technician;
- Ontologies are specific per-house.

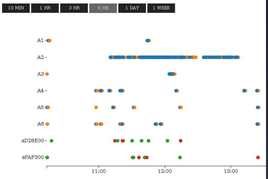
Semantic Plug&Play

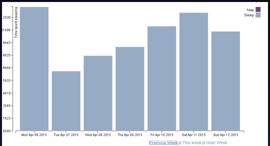
Demo…

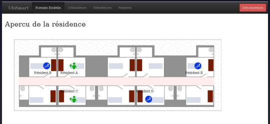
UbiSMART Service Provisioning

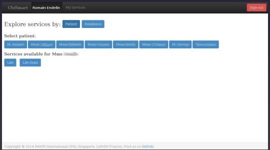
Use case — Visualizing activities

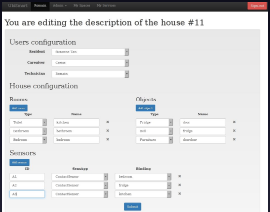


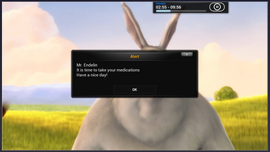












Validation — Installation

	Without our approach	**With our approach**
Background Work	1h	1h
Active Work	45min	5min
Installer	Expert	Non-Expert
Deployment Time	4h	20min
Installer	Expert	Non-Expert
Upgrade process	5-20min per gateway	0

Validation — Maintenance

- Improvement on the maintenance process
  - Daily Maintenance Duration = $N \times (D + R \times (1 - A) \times T)$
  - Expected Downtime = $C + (1 - A) \times T$

	Without our approach	**With our approach**
Daily Maintenance Duration	2h 5min	15min
Downtime	12 hours	6 minutes

Validation — Maintenance

- Improvement on the maintenance process
  - Daily Maintenance Duration = $N \times (D + R \times (1 - A) \times T)$
  - Expected Downtime = $C + (1 - A) \times T$
- Where:
  - A: The probability that a house can be fixed automatically after a failure;
  - T: The time required to manually fix a house;
  - N: The number of deployed houses;
  - D: The expected duration until a faulty house is noticed.
  - R: The daily probability of having a failure in a house;
  - C: The time required to check one house;

	Without our approach	**With our approach**
A	0	0.8
T	30min	
N	50 houses	
D	12h	10 sec
R	0.05	
C	1min	0min
Daily Maintenance Duration	2h 5min	15min
Downtime	12 hours	6 minutes

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Outcome: A Framework for Ambient Assisted Living[5,6]

Person	Start of deployment	End of deployment	Events	Activities inferred
Resident 1	23 Sep 2014	14 Mar 2015	29,194	6,491
Resident 2	15 Mar 2015	26 Aug 2015	34,680	10,101
Resident 3	28 Aug 2015	Ongoing	5,210	1,243
Resident 4	23 Sep 2014	06 Aug 2015	63,715	12,897
Resident 5	07 Aug 2015	Ongoing	2,891	428
Resident 6	23 Sep 2014	Ongoing	85,231	15,946
Resident 7	23 Sep 2014	Ongoing	44,102	10,332
Resident 8	25 Sep 2014	03 Jun 2015	10,576	2,673
Resident 9	04 Jun 2015	Ongoing	23,536	1,636
House 1	24 Sep 2014	02 Jan 2016	160,275	22,604
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Amount of data obtained in our deployment

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Outcome: A Framework for Ambient Assisted Living[5,6]

Person	Start of deployment	End of deployment	Events	Activities inferred
Resident 1	23 Sep 2014	14 Mar 2015	29,194	6,491
Resident 2	15 Mar 2015	26 Aug 2015	34,680	10,101
Resident 3	28 Aug 2015	Ongoing	5,210	1,243
Resident 4	23 Sep 2014	06 Aug 2015	63,715	12,897
Resident 5	07 Aug 2015	Ongoing	2,891	428
Resident 6	23 Sep 2014	Ongoing	85,231	15,946
Resident 7	23 Sep 2014	Ongoing	44,102	10,332
Resident 8	25 Sep 2014	03 Jun 2015	10,576	2,673
Resident 9	04 Jun 2015	Ongoing	23,536	1,636
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Outline

Activity Recognition — Challenges

- ✓ A framework for Ambient-Assisted Living;
- ➡ Qualify and improve Activity Recognition:
  - Perform Activity Recognition;
  - Qualify the reasoning;
  - Make the reasoning more accurate;
  - Facilitate prototyping;
  - Include a learning process.

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Existing before the beginning of this thesis
Personal contribution of this thesis
Beyond this thesis' scope

Activity Recognition — Introduction

- **Purpose:** Accurately recognize the user's activity, in order for the system to provide an adequate reaction.
- **Input:** A sequence of sensor events.
- **Method:** Divided between two approaches:

Data-driven

- Powerful computations, using machine-learning methods.

Knowledge-driven

- Ontological representation of knowledge.

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Knowledge-driven

- Ontological representation of knowledge.

Choosing knowledge-driven methods:

- Does not require datasets;
- Specific to each user;
- Adapted for complex-systems.

UbiSMART's Original Reasoning Engine

- Using ontological models:
  - Semantic web technologies;
  - N3 formalism;
  - Euler Rule Engine.
- Includes both *model* and *reasoning*:

Model

```
hom:resident_a a :Resident ;
    :detectedIn hom:outside ;
    :name "A" ;
    :residentIn hom:house_a .
hom:sensor_bedroomMotion a :MotionSensor ;
    :deployedIn hom:room_bedroom ;
    :id "Bedroom Motion"@en .
hom:sensor_mainDoorSensor a :ContactSensor ;
    :attachedTo hom:door_bedroom-outside ;
    :id "Main Door Sensor"@en .
```

Reasoning

```
{
  ?u qol:detectedIn ?r.
  ?r a qol:Livingroom.
  ?r qol:motionMeasured ?m.
  ?m math:notLessThan 2
} => {
  hom:watchtv :getScore 7.
}.
```

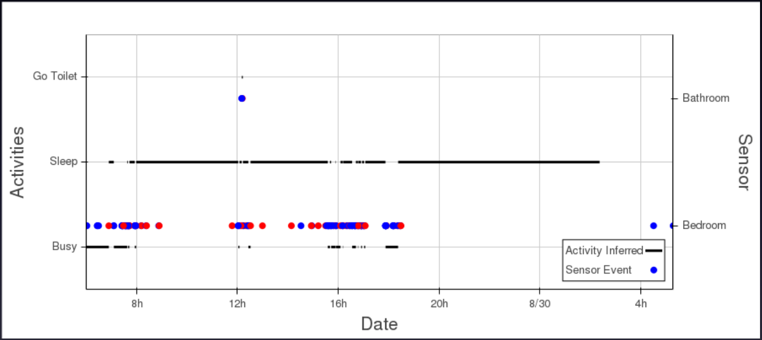
Problems Observed

- Faulty inference due to a **poorly defined rule**;
- Reasoner trying to be **too fine-grained**;
- Reasoner being **too coarse-grained**.

Outline

Problems Observed — 1/2

- ➡ Faulty inference due to a poorly defined rule:



- Reasoner trying to be too fine-grained;
- Reasoner being too coarse-grained.

Making Rules Less Error-Prone

Rules Factory

- Going from this…

```
{?u qol:detectedIn ?r. ?r a qol:Outside. hom:clock qol:hasValue ?t.
  ?t func:hours-from-dateTime ?h.
  ?h math:notLessThan 22. ?h math:lessThan 7
} => {hom:runAway :getScore 9}.
{?u qol:detectedIn ?o. ?o a qol:Outside. ?u qol:inRoomFor ?d.
?d math:notLessThan 18000
} => {hom:runAway :getScore 9}.
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- …to that:

```
[{
   "name": "Run away",
   "conditions": {
      "hour_of_the_day": [22, 7],
      "detected_in": {"room": "room:Outside"},
      "min_duration": "5min"
   }
}]
```

Making Rules Less Error-Prone

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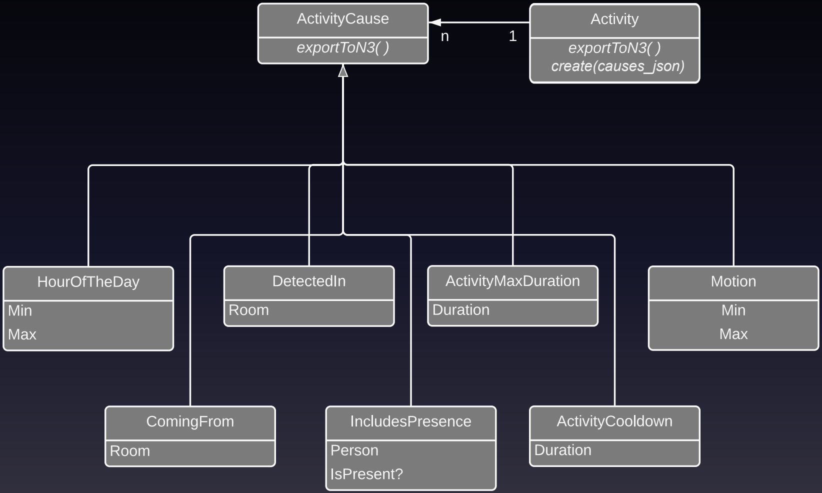
```

Benefits:

- More standardized;
- Reduced redundancy;
- Errors are raised on compilation, not execution.

Making Rules Less Error-Prone



Rules Factory — The model

Knot — A Prototyping Framework

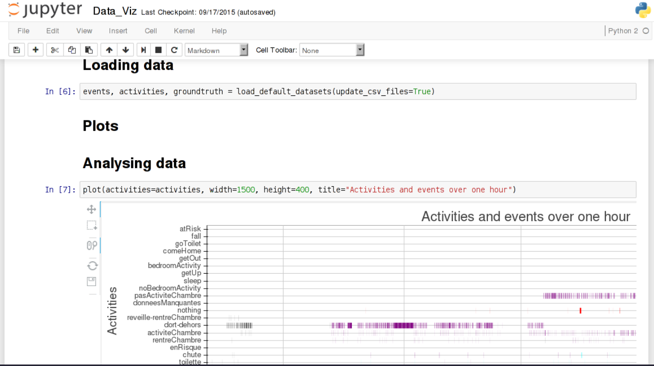
A brief overview…

- *Rules factory* & houses factory;
- Modular *reasoning engine*;
    - Tracing changes in the ontology;
- Data *preprocessing*;
- Data *visualization*;
- Realistic data generation;

Benefits

- Faster prototyping cycles;
- All-in-one environment;
- Rules can be exported into N3 format.

Knot — A Prototyping Framework

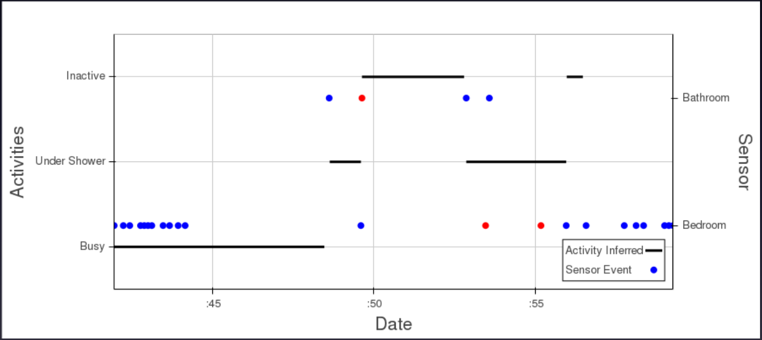


Knot's Integrated Development Environment

Outline

Problems Observed — 2/2

- ✓ Faulty inference due to a poorly defined rule;
- ➡ Reasoner trying to be too fine-grained:



- ➡ Reasoner being too coarse-grained;

Problems Observed — 2/2

- ✓ Faulty inference due to a poorly defined rule;
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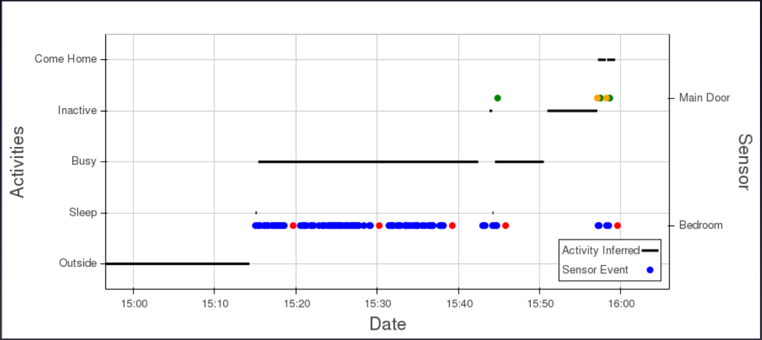
- ➡ Reasoner being too coarse-grained:



Introducing Hierarchical Activities

You could be *“in the kitchen”*, *“cooking”* AND *“cooking pasta”*, at the same time.

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- Activities
  - Kitchen Activity
    - Eat Meal
    - Cook Meal
  - Activity in Bathroom
    - Go Toilet
    - Hygiene
  - Living Room Activity
    - Read Book
    - Watch TV
  - Bedroom Activity
  - Sleep
  - Outside
  - Come Home

Representation

```
:cookMeal a :Activity ;
   rdfs:label "Cook Meal"@en ;
   :generalizes :cookPasta .
:cookPasta a :Activity ;
   rdfs:label "Cook Pasta"@en ;
   :specializes :cookMeal .
```

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```

- A prerequisite for the proposed method of improving accuracy.

Introducing Granularity and Accuracy

- Precision :
  - *The amount of details attached to an activity.*
- Accuracy;
  - *The confidence of having a correct inference.*

- Given a hierarchy of activities,
  a child activity is always **more fine-grained** and **less accurate** than its parent.

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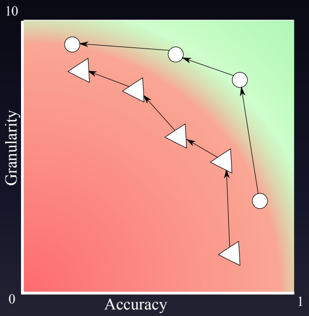

- Given a hierarchy of activities,
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Measuring the Accuracy of an Activity

1. Observe the ground-truth, from a real deployment;
2. Simulate the activities in a living lab.

Measuring the Accuracy of an Activity

1. Observe the ground-truth, from a real deployment:
   - $P(A = a|I = a)$:
     - *"is the person really doing a, when the reasoner says a?"*

$$P(A = a|I = i) = \frac{|a \cap i| \sum_{X \in I} duration(X)}{|A \cap I| \sum_{x \in i} duration(x)} \tag{1}$$

where:

$|A \cap I|$:observations made while inferring an activity

$|a \cap i|$:occurrences when i is inferred and a is observed

$\sum_{x \in i} duration(x)$: total duration when i is inferred

$\sum_{X \in I} duration(X)$: total duration covered by our inferences

2. Simulate the activities in a living lab.

Measuring the Accuracy of an Activity

1. Observe the ground-truth, from a real deployment;
2. Simulate the activities in a living lab:

$$P(A = a | I = i) = \frac{|a \cap i| X}{|A \cap I| x} \tag{2}$$

where:

$|A \cap I|$:observations made while inferring an activity

$|a \cap i|$:occurrences when i is inferred and a is observed

x: occurrences when i is inferred

X: total number of inferences

A More Effective Method For Activity Recognition

- Looking for the activity with the best balance of accuracy and granularity.
  1. Assign a score to each activity, based on its accuracy and granularity.

$$Score(a) = \left(accuracy\ (a)^{A} \times (0.1 \times granularity\ (a))^{G}\right)^{\frac{1}{A \times G}} \tag{3}$$

Where:

A is the weight given to Accuracy

G is the weight given to Granularity

The 0.1 factor is used to normalize Granularity as a [0, 1] value

  2. When several activities are inferred at once, Select the activity with the highest score.

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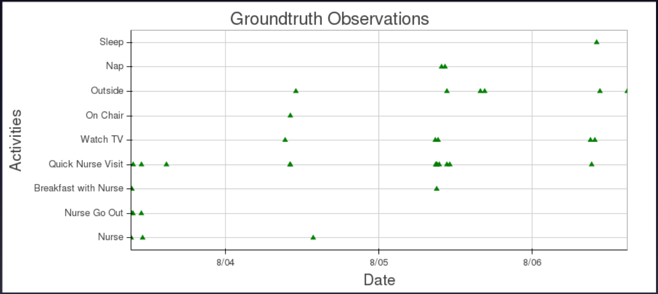
Remark: *The application of this method is reasoner-agnostic*

Outline

Validation — Observing Ground-Truth

- 465 observations in nursing home, over 10 days.



Validation — Introducing Metrics

- $T(A)$ — Measured accuracy of the reasoning
- $\bar{A}(activities)$ — Average value of accuracy
- $\bar{G}(activities)$ — Average value of granularity
- $\bar{S}(activities)$ — Average value of score

Validation — Introducing Metrics

- $T(A)$ — Measured accuracy of the reasoning:

$$T(A) = \frac{|\{groundtruth(a) = inferred(a) | a \in A\}|}{|groundtruth(A) \cap inferred(A)|} \qquad (4)$$

- $\bar{A}(activities)$ — Average value of accuracy
- $\bar{G}(activities)$ — Average value of granularity
- $\bar{S}(activities)$ — Average value of score

Validation — Introducing Metrics

- $T(A)$ — Measured accuracy of the reasoning
- $\bar{A}(activities)$ — Average value of accuracy:

$$\bar{A}(activities) = \frac{\sum\limits_{a \in activities} (accuracy\,(a) \times duration\,(a))}{\sum\limits_{a \in activities} duration\,(a)} \tag{5}$$

- $\bar{G}(activities)$ — Average value of granularity
- $\bar{S}(activities)$ — Average value of score

Validation — Introducing Metrics

- $T(A)$ — Measured accuracy of the reasoning
- $\bar{A}(activities)$ — Average value of accuracy
- $\bar{G}(activities)$ — Average value of granularity:

$$\bar{G}(activities) = \frac{\sum\limits_{a \in activities} (granularity\,(a) \times duration\,(a))}{\sum\limits_{a \in activities} duration\,(a)} \tag{6}$$

- $\bar{S}(activities)$ — Average value of score

Validation — Introducing Metrics

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- $\bar{A}(activities)$ — Average value of accuracy
- $\bar{G}(activities)$ — Average value of granularity
- $\bar{S}(activities)$ — Average value of score:

$$\bar{S}(activities) = \frac{\sum\limits_{a \in activities} (score(a) \times duration(a))}{\sum\limits_{a \in activities} duration(a)} \tag{7}$$

Validation — Results

- **48%** improvement of measured accuracy;
  - **38%** loss in granularity.

Sample	A	P	Total Measured Accuracy $T(A)$	Average Accuracy $\bar{A}$	Average Granularity $\bar{G}$	Average Score $\bar{S}$
Before calibration	*3*	*1*	63.4%	55.5%	6.75	56.9%
After calibration			93.8%	89.4%	4.15	73.4%
Before calibration	*1*	*1*	63.4%	67.3%	5.56	59%
After calibration			66.7%	55.5%	5.82	60.7%

Results with $(A = 3, G = 1)$ and $(A = 1, G = 1)$, before and after the calibration

Outline

Conclusion

Contributions:

- *UbiSMART*, a framework for Ambient Assisted Living:
  - User-friendly services;
  - Simplified setup, can be carried by a non-technician;
  - Automatic configuration per-house.
- A novel method to infer activities with an adequate granularity and accuracy;
- A prototyping engine for activity recognition.
  - Including a *"rules factory"*
- And also…
  - An algorithm to filter multi-user situations;
  - Two methods to detect inconsistencies in a rule engine.

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Conclusion

Validations:

- A year of deployment in several real-world environment;
  - Including more than 300,000 recorded sensor events.
- Part of the “Chaire Quality of Life” and “VHP interactive” projects;
- Foundation for the *City4Age* Horizon2020 European project.

Perspectives

- Remaining challenges towards industrial large-scale deployment:
  - More accurate activity recognition;
  - More powerful service delivery:
    - Upcoming PhD thesis of Joaquim Bellmunt Montoya.
  - More adequate selection of sensors:
    - Upcoming PhD thesis of Ibrahim Sadek.
  - Improve performances for the reasoning engine.
- Opportunities:
  - Tracking the long-term evolution of elderly people's health;
    - Upcoming PhD thesis of Firas Kaddachi.
  - Towards smart-cities.

Thank you very much for your attention.

Any questions?