Current Trends on the Application of Ontologies in Information Fusion

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5th International Seminar on New Issues in Artificial Intelligence

Universidad Carlos III de Madrid

GIAA

1. **Information Fusion**
2. Ontologies
3. Ontology-based IF applications
4. Present and future research

Definition

*"theories and methods to effectively **combine data** from **multiple sensors** and **related information** to achieve **more specific inferences** than could be achieved by using a single, independent sensor."*

(Liggins, Hall and Llinas, 2009)

Applications

Military applications

- Automatic target recognition
- Autonomous vehicles guidance
- Remote sensing
- Battlefield surveillance
- Support to decision-making

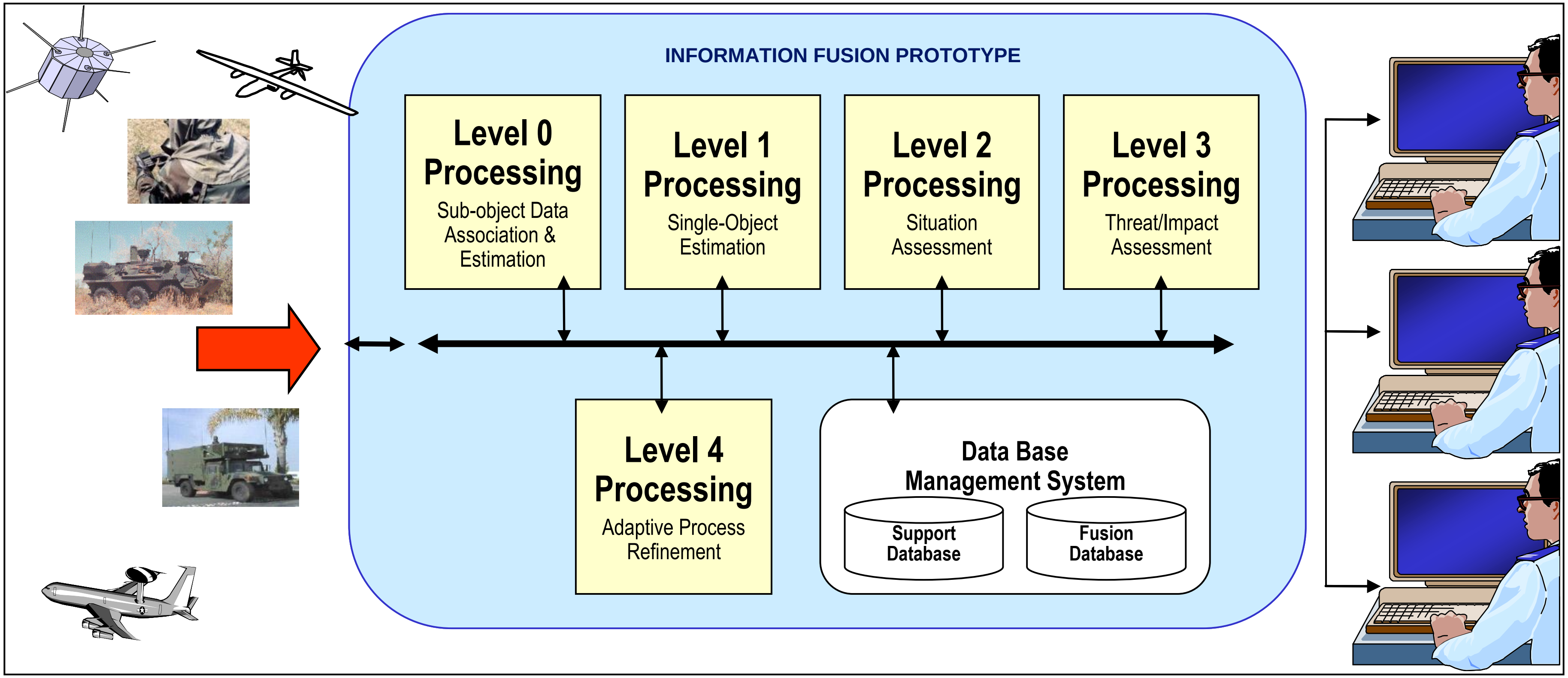
Security and surveillance

- Intrusion detection
- Video-vigilance
- Threat recognition
- Network security

Other applications

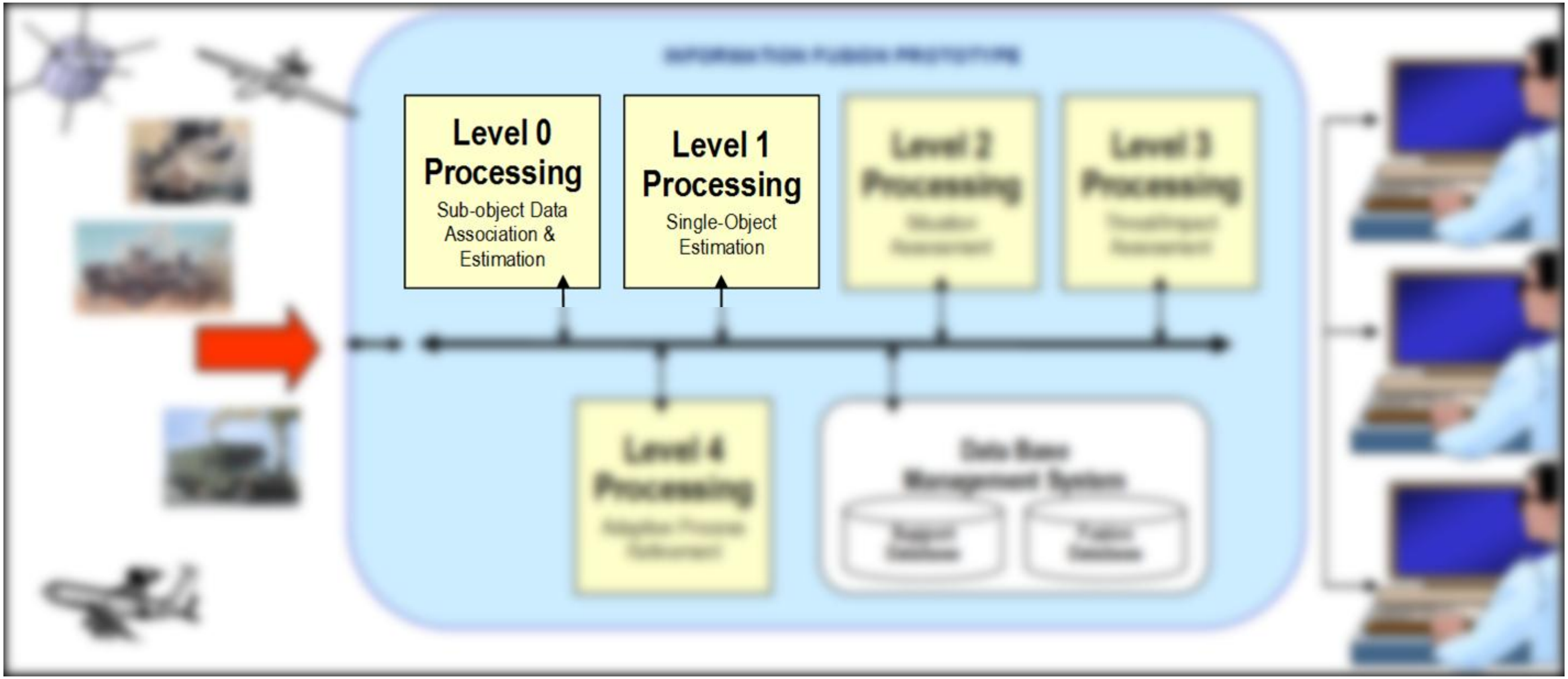
- Transportation
- Traffic control systems
- Bio-medical applications
- etc.

JDL model



The JDL Functional Model of the Information Fusion Process.
Adapted from (Liggins, Hall, & Llinas, 2009)

Low-Level Information Fusion



Level 0 processing (Sub-object refinement)

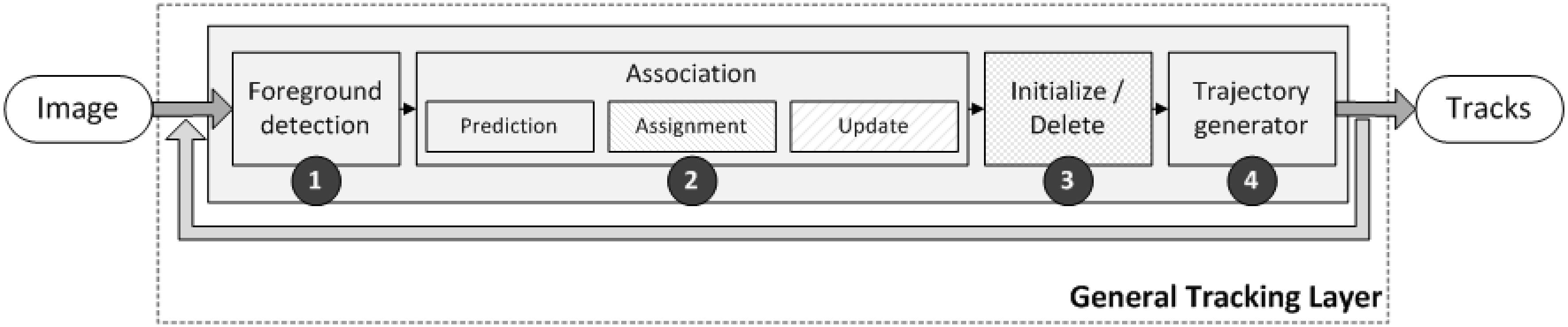
Methods to estimate the existence and features of structures of interest that may be discernible before the declaration of a named entity can realized

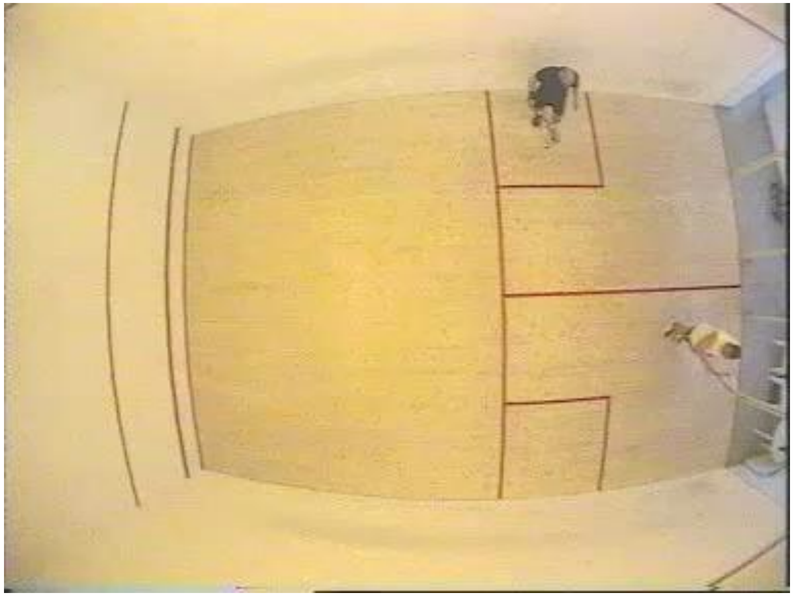
Image segmentation

Level 1 processing (Object refinement)

Processes to combine locational, parametric, and identity information to achieve refined representations of individual objects or entities

Time history of the kinematic property of an object –tracking





http://www.youtube.com/user/GIAAUC3M/videos

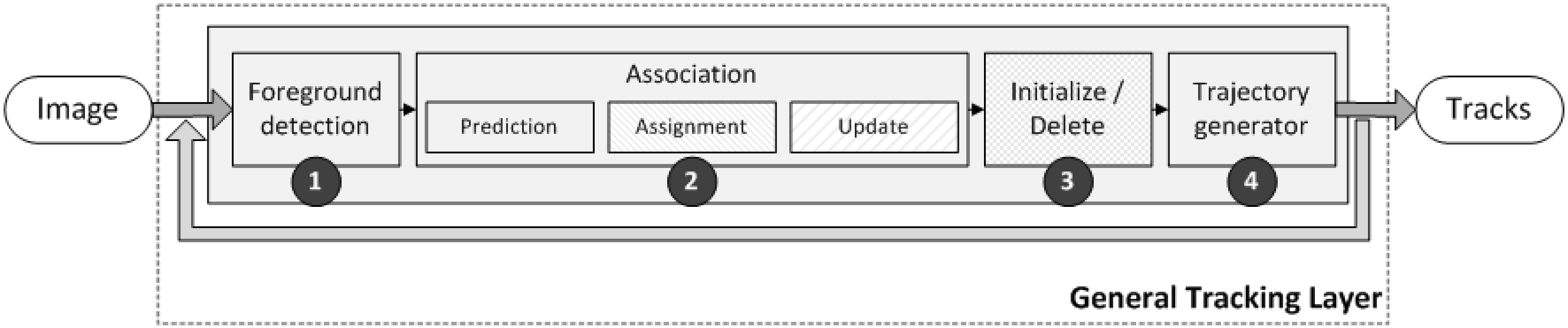
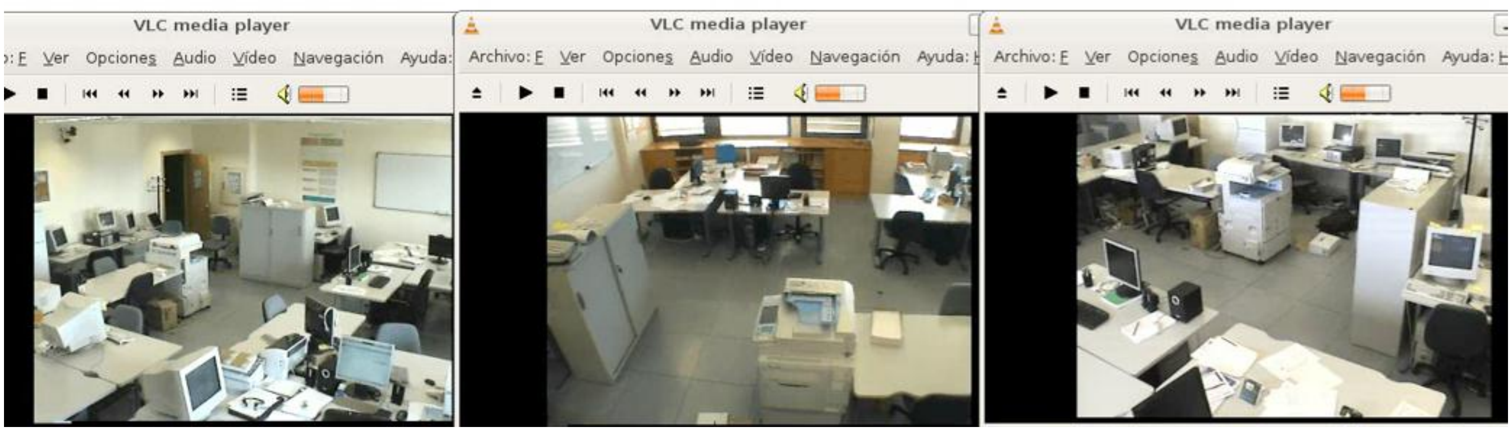


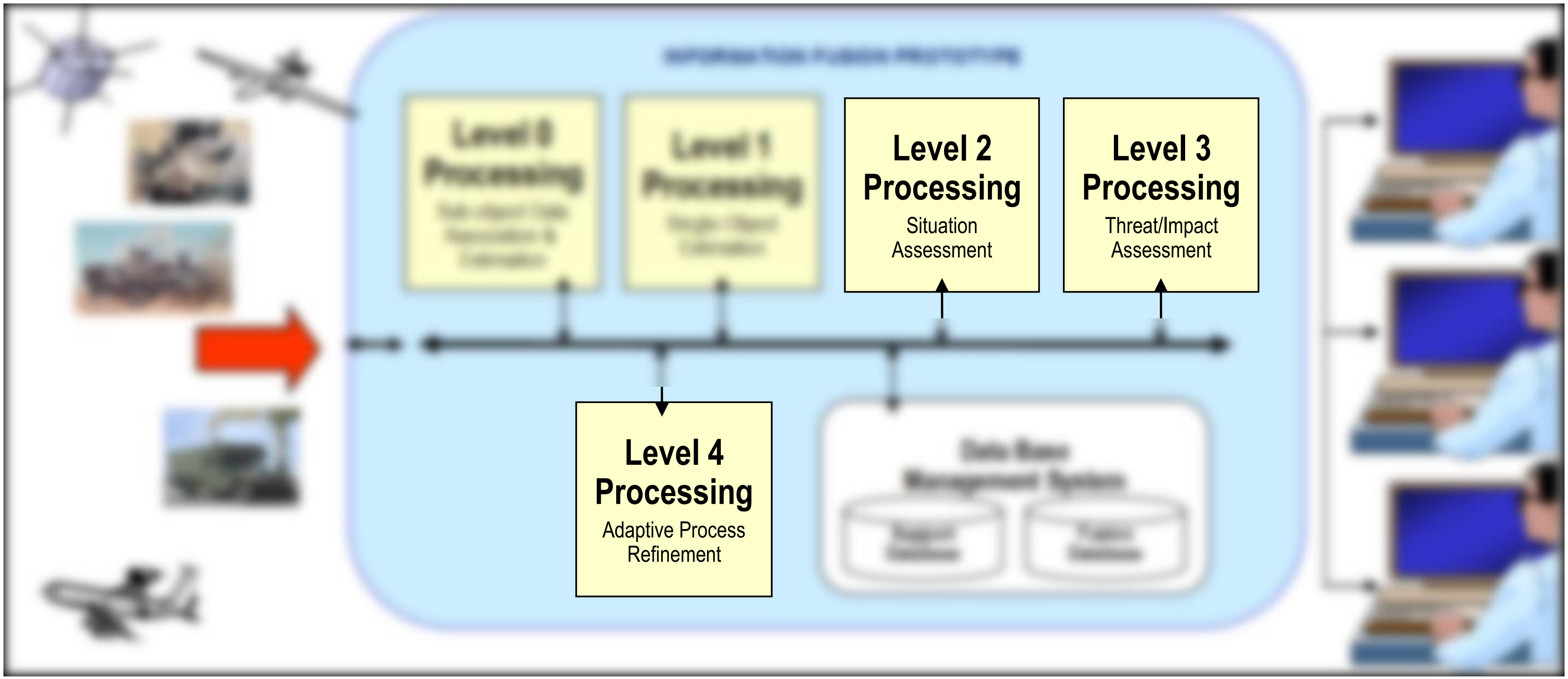
Image
Foreground detection
Association
Prediction
Assignment
Update
Initialize / Delete
Trajectory generator
Tracks
1
2
3
4
General Tracking Layer


REBAJAS

```
ede@f3d3:~/workspace/csa/src/bin$ ./run
```



High-Level Information Fusion



Level 2 processing (Situation Understanding)

Develops a description of current relationships among objects and events in the context of their environment

People in a meeting

Level 3 processing (Threat Refinement)

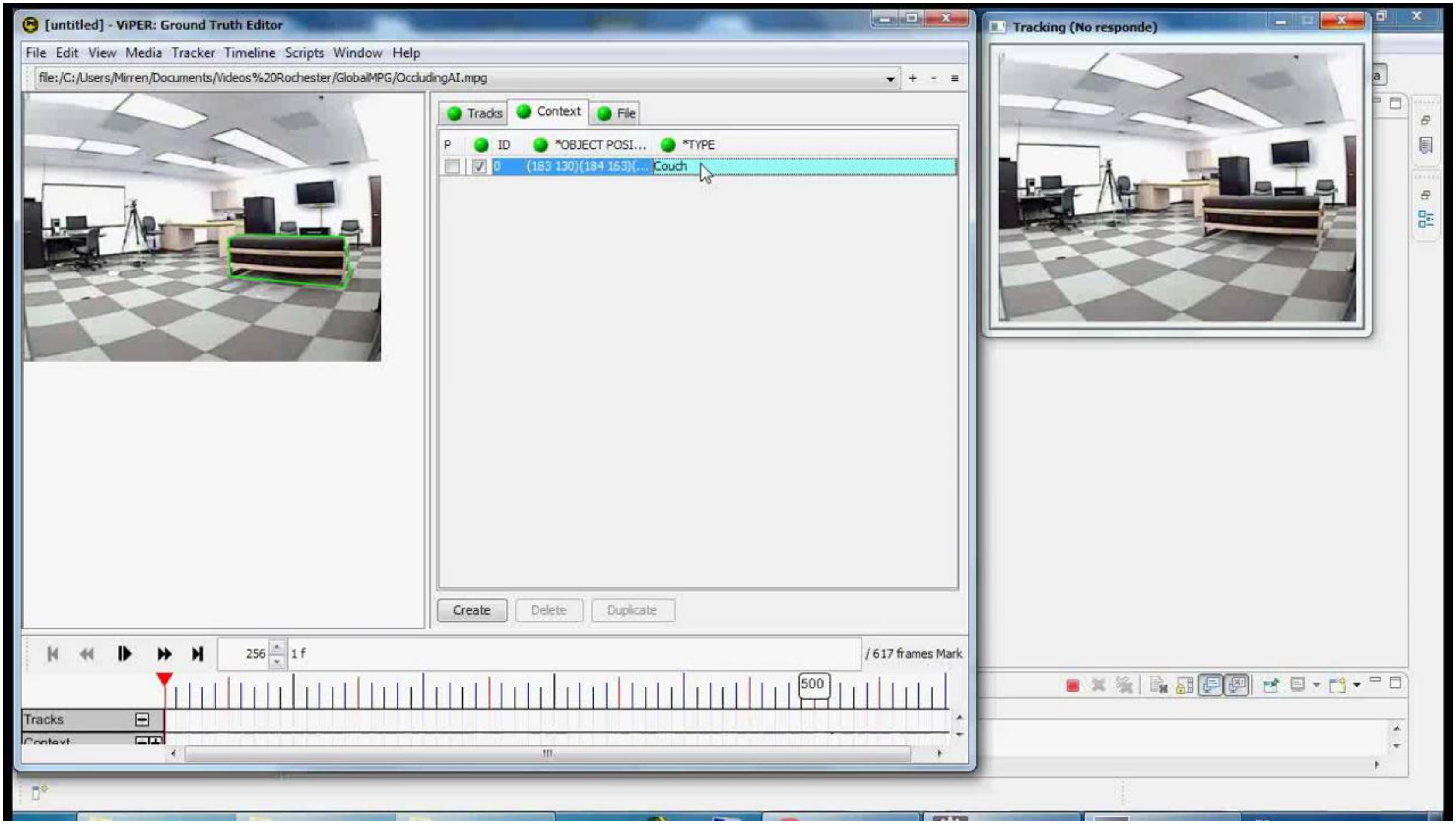
Identification and assess special situations that relate to some type of threatening or critical world states

Dropping a bag

Level 4 processing (Process Refinement)

Meta-process: detect, evaluate and act to improve the overall fusion process

Zoom camera to focus on dropped bag


[untitled] - ViPER: Ground Truth Editor
File Edit View Media Tracker Timeline Scripts Window Help
file:/C:/Users/Mirren/Documents/Videos%20Rochester/GlobalMPG/OccludingAI.mpg
Tracks
Context
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ID
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(183 130)(184 163)(...
Couch
Create
Delete
Duplicate
256
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/ 617 frames Mark
500
Tracks
Tracking (No responde)

Limitations of classical approaches

High-Level Information Fusion (HLIF) – Levels 2-4

- ***Understand*** the scene
- ***Evaluate*** threats
- Support ***decision making***

Purely **numerical techniques** are **insufficient**

- Cognitive abilities
- Complex and unpredictable world situations
- **Context information (CI)**

Definitions of CI

Dey and Abowd (2001):

"Any information (either implicit or explicit) that can be used to characterize the situation of an entity"

Henricksen (2003):

"The context of a task is the set of circumstances surrounding it that are potentially of relevance to its completion"

Kandefer and Shapiro (2008):

"The structured set of ***variable, external constraints*** *to some (natural or artificial) cognitive process that* ***influences the behavior*** *of that process in the agent(s) under consideration"*

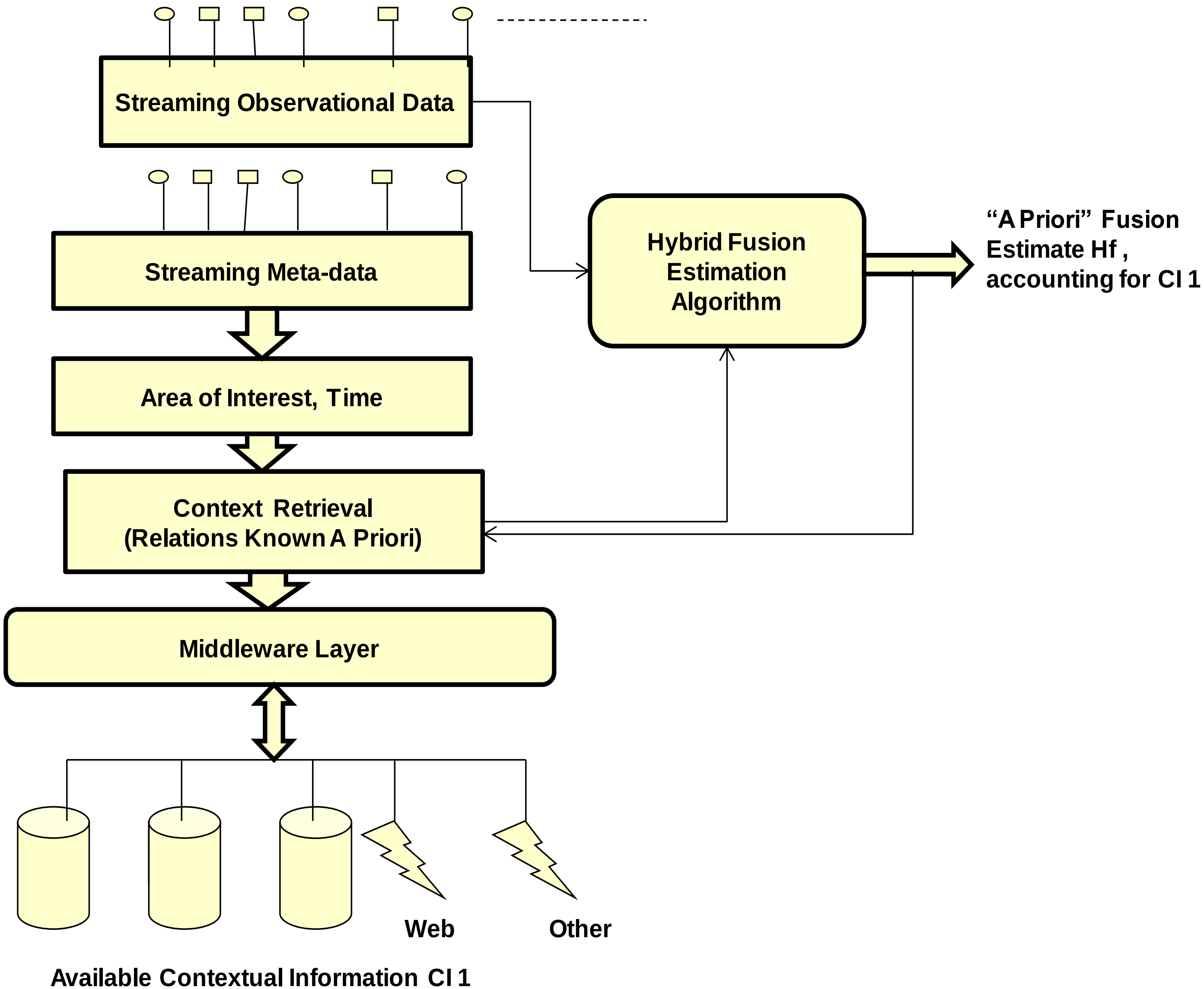
A priori framework

Accounts for the effect on situational estimation of that CI that is known **at design time (“a priori”)**

This CI should be easily **incorporated to the fusion procedures** (*hard-wired*)

It produces hybrid fusion methods, maybe numerical/symbolical

J. Gómez-Romero, J. García, M.A. Patricio, J.M. Molina & J. Llinas. *High-Level Information Fusion in Visual Sensor Networks*. In Visual Information Processing in Wireless Sensor Networks. IGI Global, 2012.


Streaming Observational Data
Streaming Meta-data
Area of Interest, Time
Context Retrieval
(Relations Known A Priori)
Middleware Layer
Hybrid Fusion
Estimation
Algorithm
“A Priori” Fusion
Estimate Hf ,
accounting for CI 1
Web
Other
Available Contextual Information CI 1

A posteriori framework

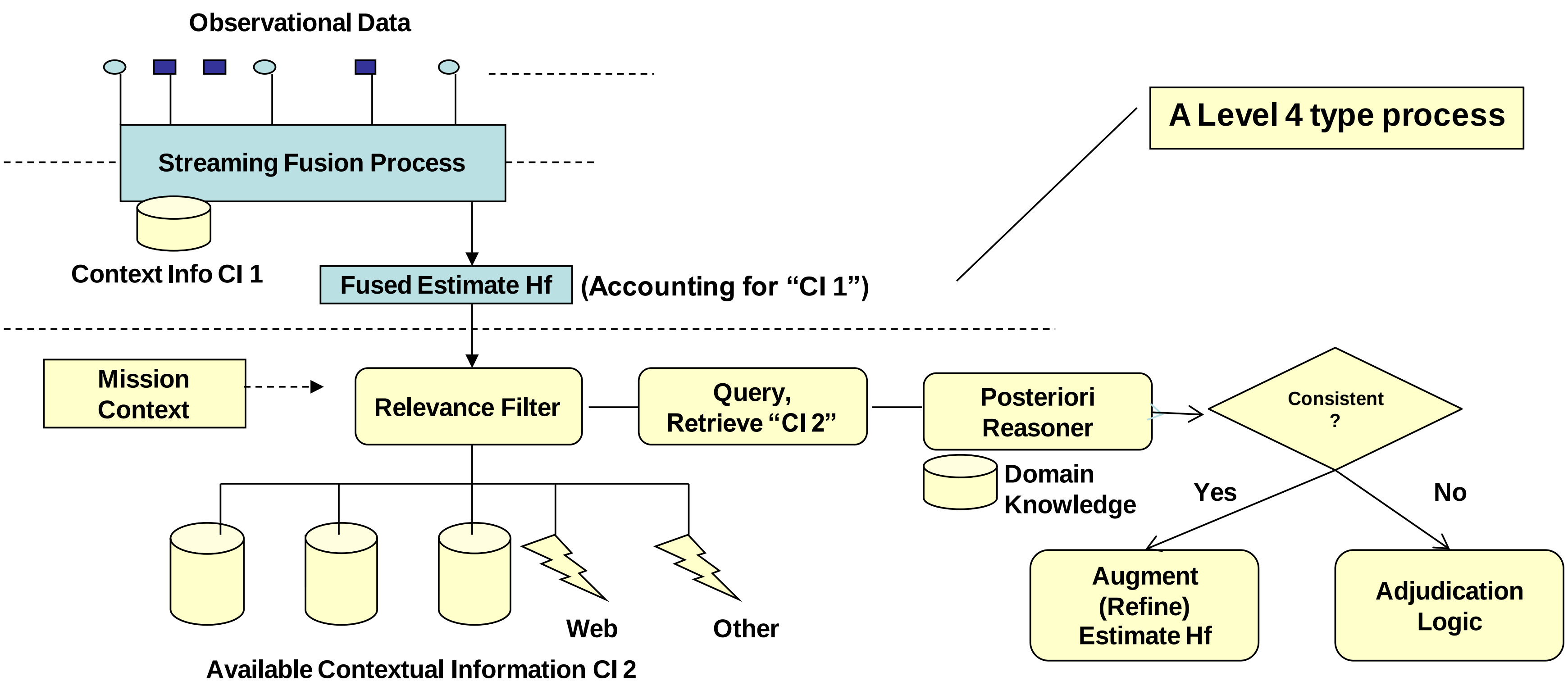
Sometimes, the **integration** of all CI in the IF algorithm / system **is not possible**:

All relevant CI may not be known or available at system/algorithm design time

CI may not be of a type that was integrated into the system/algorithm at design time and so may not be able to be easily integrated in the situation estimation process

CI exploitation is an **additional process** that performs several tasks:

- Retrieval of relevant CI from available sources
- Consistency checking (fusion hypothesis and relevant CI)
- Augmentation, embellishment of fused results
- Supporting of possible L4 adaptive operations


Observational Data
Streaming Fusion Process
Context Info CI 1
Fused Estimate Hf
(Accounting for "CI 1")
A Level 4 type process
Mission Context
Relevance Filter
Query, Retrieve "CI 2"
Posteriori Reasoner
Consistent ?
Domain Knowledge
Yes
No
Augment (Refine) Estimate Hf
Adjudication Logic
Web
Other
Available Contextual Information CI 2

CI exploitation requires flexible and dynamic

Situation model · Context model

Symbolic formalisms to represent and reason with abstract information

Ontologies >>>

1. Information Fusion
2. **Ontologies**
3. Ontology-based IF applications
4. Present and future research

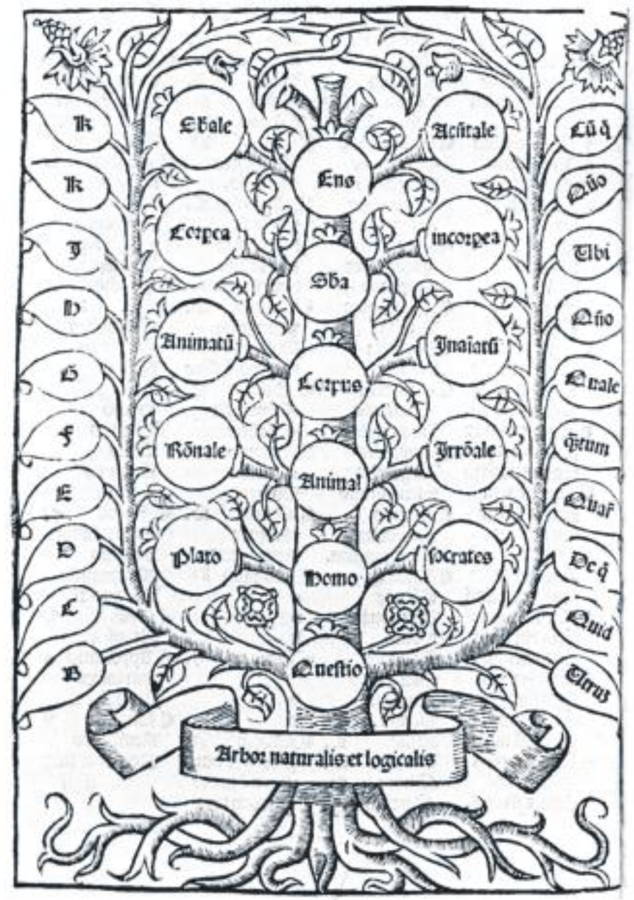
Ontologies in Philosophy

Ontology *(phil.)*

Study of part-of relationships and entity dependencies

Ontology as a science analyzes the features of possible things, and the categories in which they can be included

M. Bunge. *Treatise on Basic Philosophy, vol. 3. Ontology I: The Furniture of the World*. Springer, 1977



Tree of Science (R. Lull)
[J.F. Sowa. *Knowledge Representation: Logical, Philosophical, and Computational Foundations*, 2000]

Ontologies in Computer Science

ontology

Rigorous and exhaustive conceptual schema, focused on a certain domain and designed to facilitate information communication and reuse among different computational systems

An ontology is a formal, explicit specification of a shared conceptualization

R. Studer, V.R. Benjamins & D. Fensel. *Knowledge engineering: principles and methods*. In: Data Knowledge Engineering 25.1-2 (1998). Pp. 161–197

Thomas R. Gruber. *A translation approach to portable ontology specifications*. In: Knowledge Acquisition 5.2 (1993). Pp. 199–220

P. Borst, H. Akkermans & J. Top. *Engineering ontologies*. In: International Journal of Human-Computer Studies 46.2-3 (1997). Pp. 365–406

An **ontology** is an agreed representation that describes the objects of a domain in a logic-based language that can be automatically processed

Advantages of using ontologies in IF

- **Interpretability**
  - High level symbolic description
- **Interoperability**
  - Agreed representation of fusion information
- **Scalability**
  - Promote extension and reuse
- **Formal**
  - Reasoning with logic-based formalisms
- **Tools**
  - Standard languages, reasoning engines, programming interfaces, …

The Big Bang Theory © CBS

(01’20’’) Siri – Active Ontologies to support human tasks

Representation primitives

> Agnostic w.r.t. representation languages

…but usually, a Description Logic (DL) is used OWL 2 ≈ $\mathcal{SROIQ}$

ontologies = **Semantic Networks** + **Description Logics**

M. Krötzsch, F. Simancik & I. Horrocks. *A Description Logic Primer*. arXiv:1201.4089v1.

Elements

Concepts (classes, types)

Set of entities of the domain with common features

Unary FOL predicates

Instances (individuals)

Entities belonging to a concept

FOL constants

Relationships (properties, roles)

Binary associations between individuals or individuals and basic datatype values (integers, stringes, etc.)

FOL binary predicates

Axioms

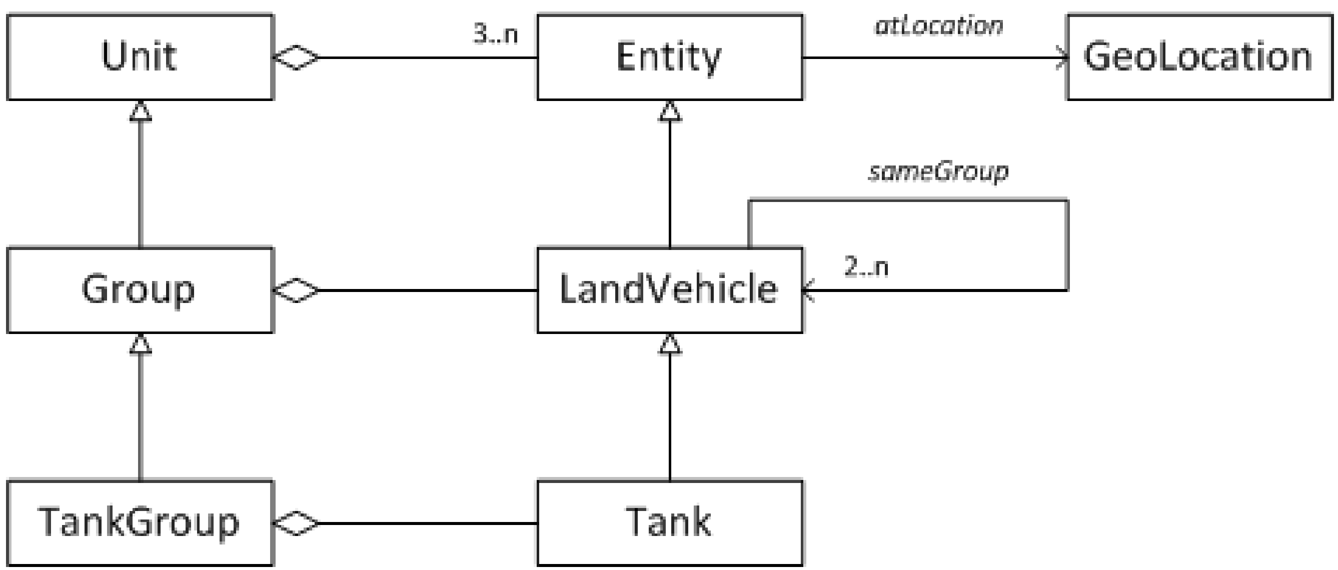
Restrictions that define the features of concepts, instances and relations

FOL formulas

Curso *Modelado, Simulación y Optimización de Sistemas.*

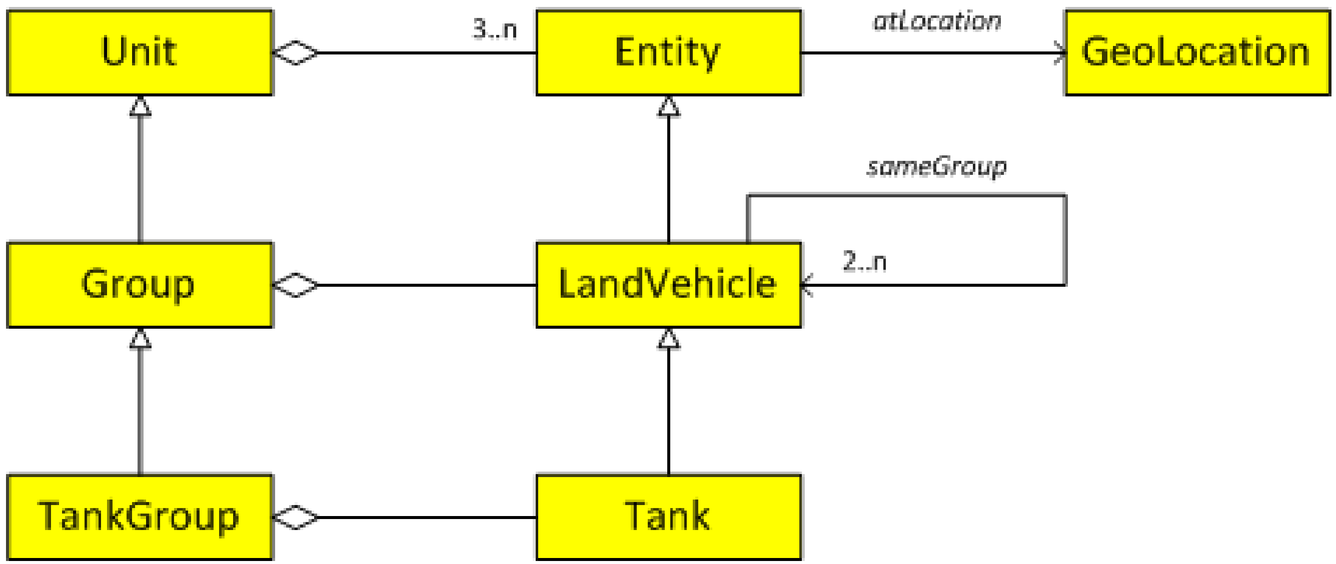
Representation primitives

adapted from (Kokar, 2010 – Workshop at Fusion Conference 2010)



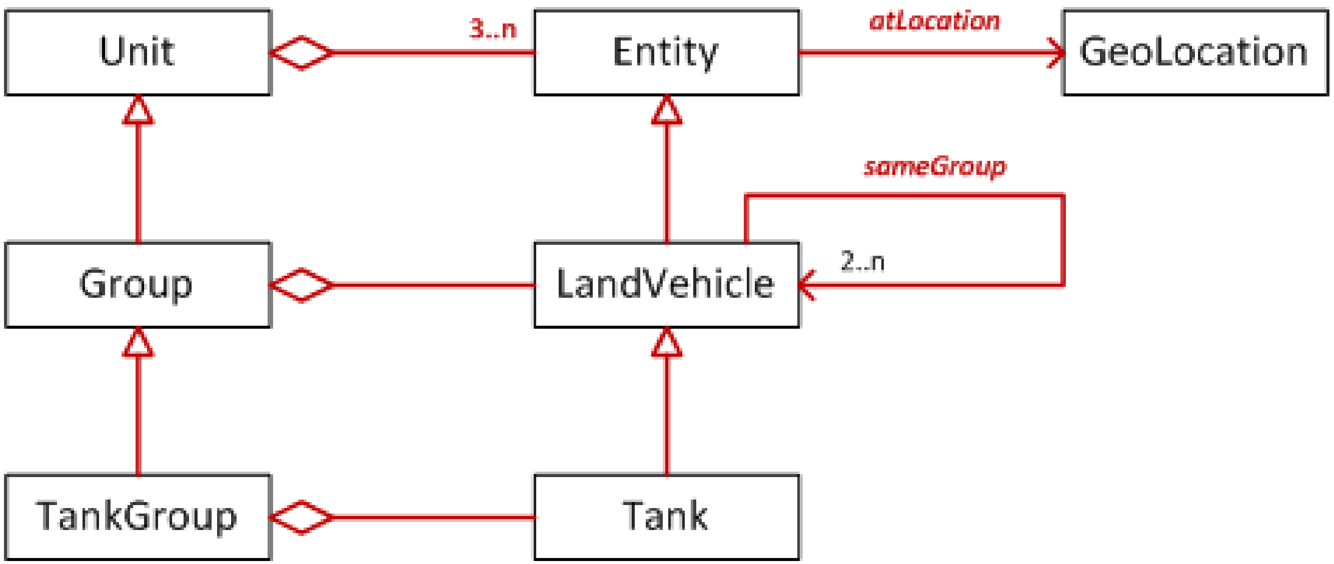
M. Kokar, C.J. Matheus, K. Baclawski. *Ontology-based situation awareness*. *In: Information Fusion, 10* (2009). Pp. 83-98

Representation primitives

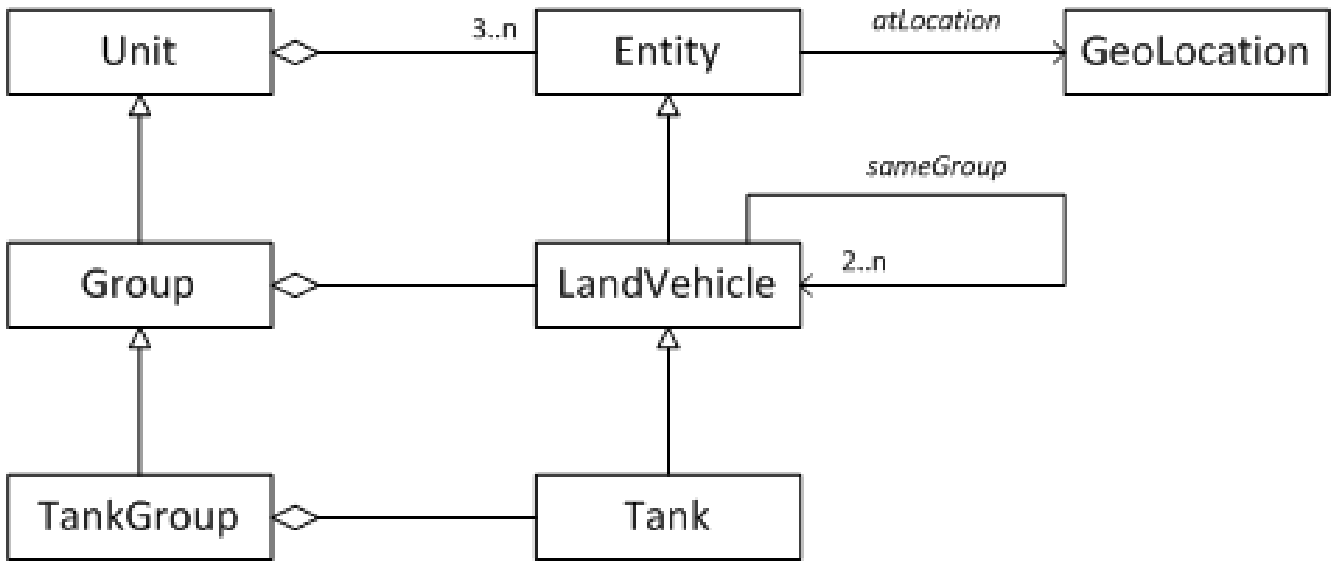


Concepts

Representation primitives



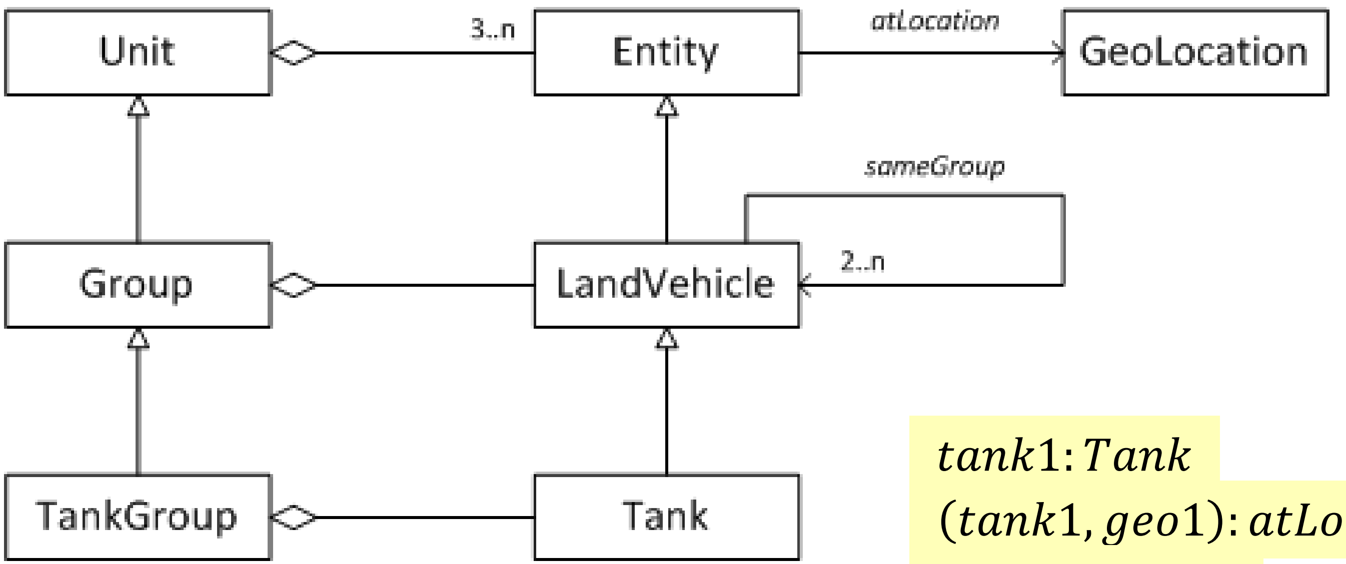
Relations



$$Tank \sqsubseteq LandVehicle \sqcap \geq 1 hasEquipment.TankGun$$

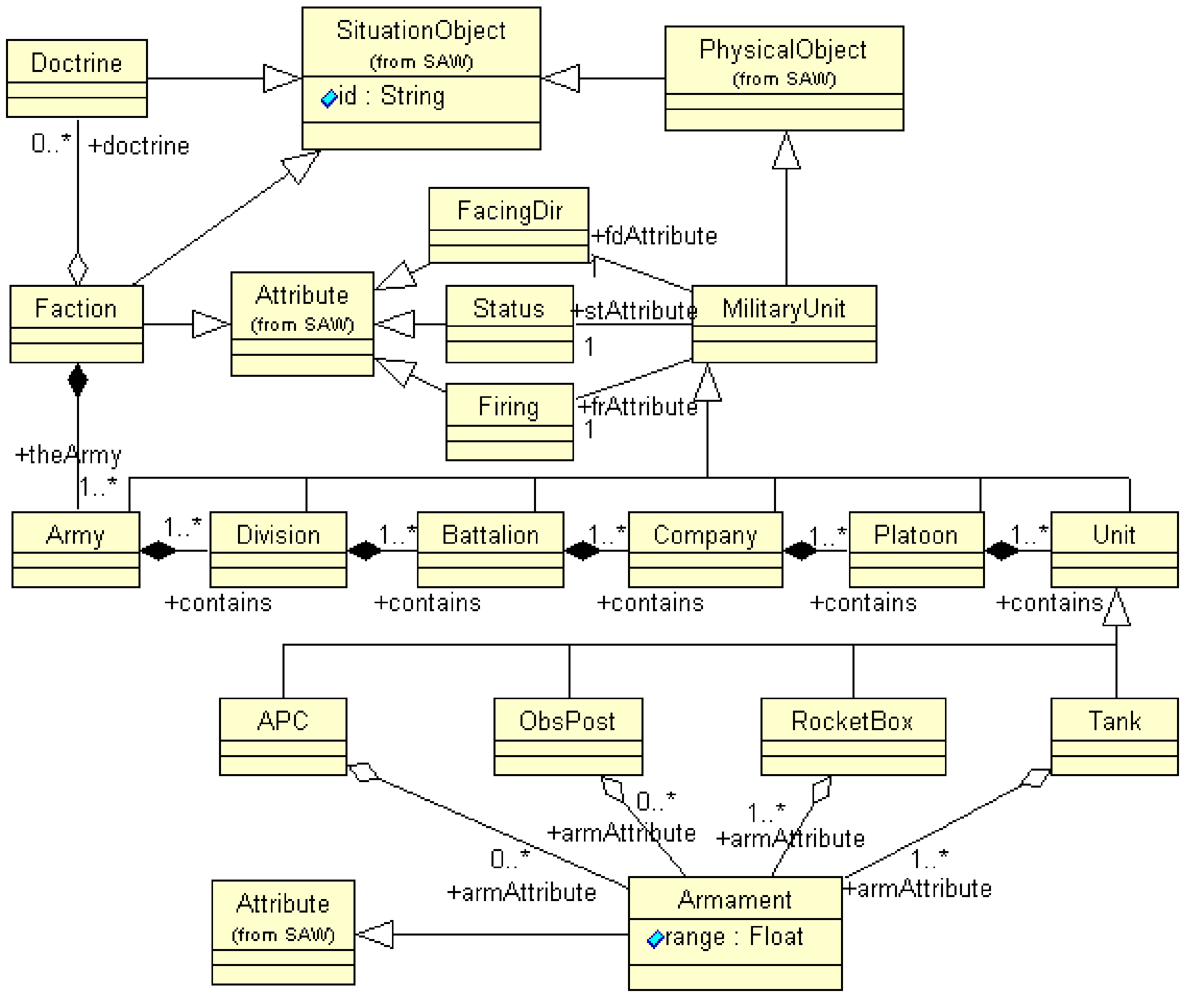
Axioms (concepts)

Representation primitives



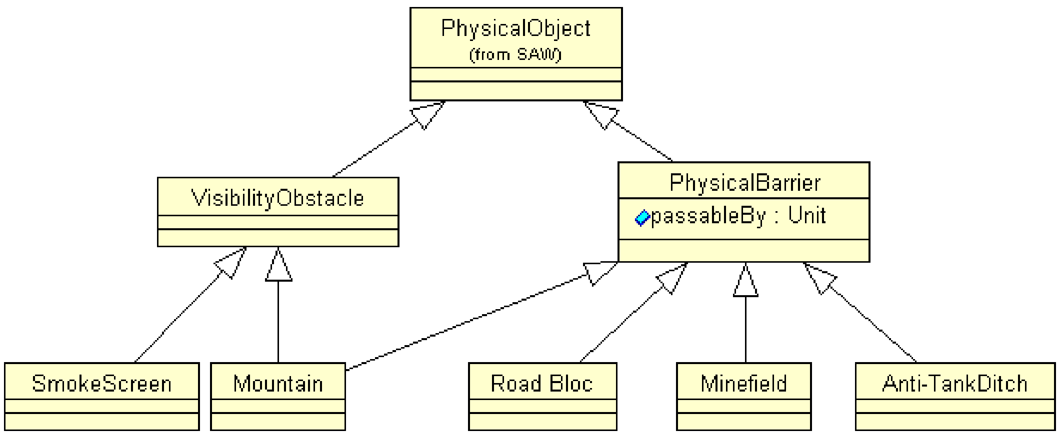
$tank1: Tank$
$(tank1, geo1): atLocation$
$(geo1, 12.1): x$
$(geo1, -8.7\ ): y$

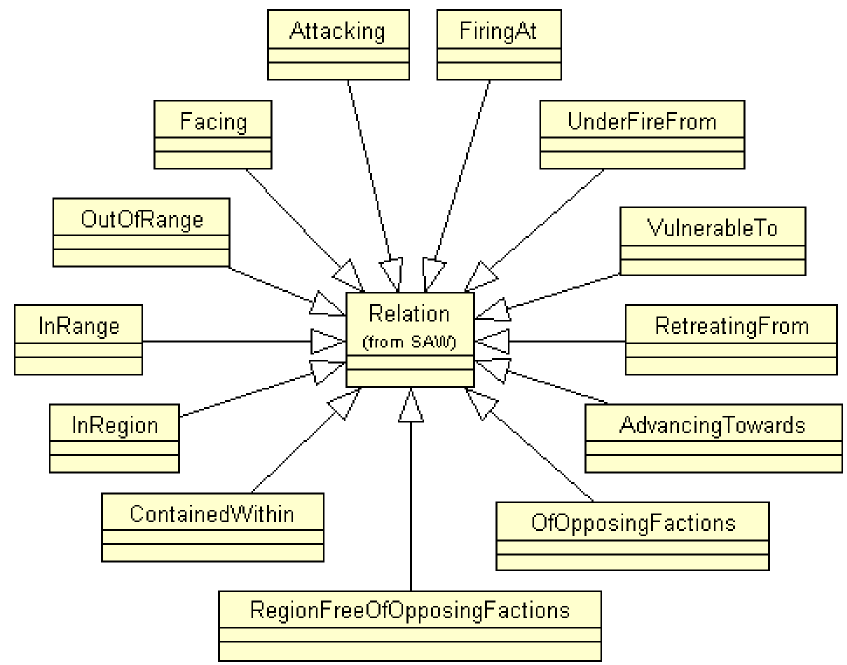
Axioms (instances)



The Battlefield ontology (excerpt)
Adapted from (Matheus, Kokar & Backawski, 2003)

Battlefield Ontology





Automatic procedure to obtain **implicit** axioms **from explicit** axioms (*entailment*)

- Modus ponens: $\langle A, A \rightarrow B \rangle \vDash \langle B \rangle$
  - Resolution in propositional logic

Tableaux algorithms

- Reasoning algorithms for DLs
- Complete and decidable
- Implemented by inference engines (RACER, Pellet)
- Theoretical efficiency is not very good, but worst cases are infrequent
- The more expressive is the DL, the less efficient is the associated reasoning procedure

Reasoning tasks

Satisfiability / consistency

An axiom is satisfiable if it is not a contradiction to the remaining axioms

Subsumption

A (super-) concept includes a (sub-) concept

Equivalence

Two concepts include the same instances

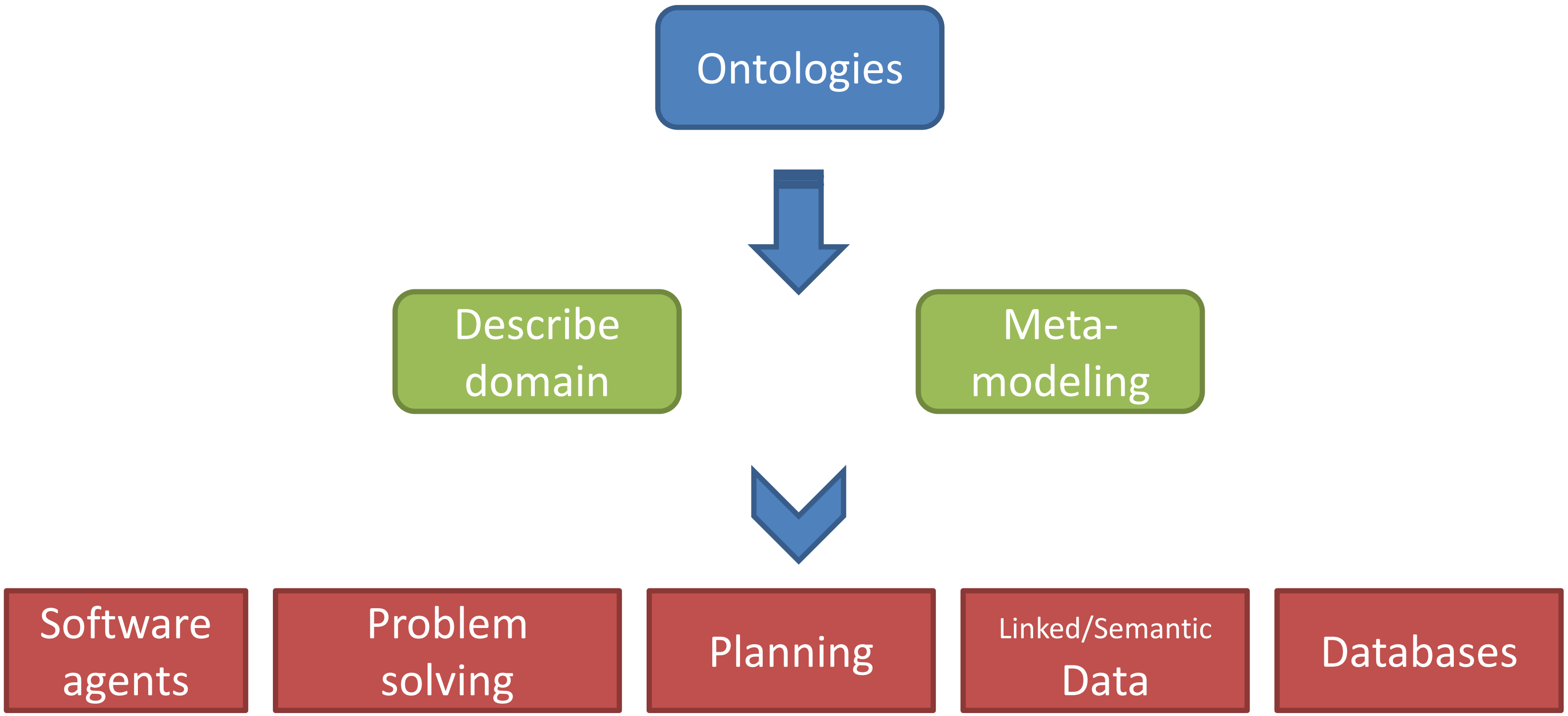
Disjointness

Two concepts do not have any common instance

Instance checking

An instance belongs to a class

Ontologies are integrated into the fusion process!



1. Information Fusion
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3. **Ontology-based IF applications**
4. Present and future research

Third-generation surveillance systems

- Large number of cameras
- Geographical spread of resources
- Many monitoring points

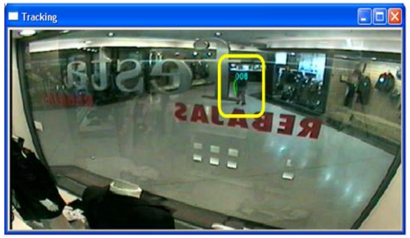
Objective

To achieve a high degree of understanding of the scene from multiple observations to barely require operator attention while cutting component costs

From PETS2002 ftp://ftp.pets.rdg.ac.uk/pub/PETS2002

In: J. Gómez-Romero, M.A. Patricio, J. García & J.M. Molina. *Context-based reasoning using ontologies to adapt visual tracking in surveillance*. In: Proceedings of the 6th IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS ’09) (2009). Pp. 226-232

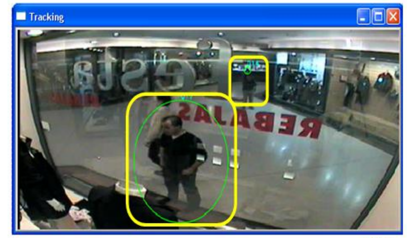
Track loss



322

323

Bad adaptation to tracked entities (people)



423

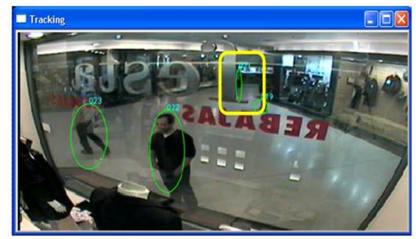
442

Reflections

220

225

Occlusions

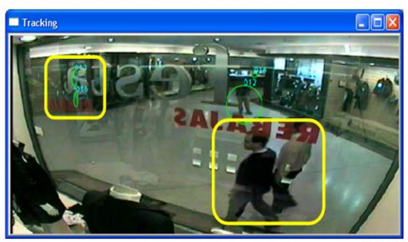


472

571

Undetected tracks & Reflections

350



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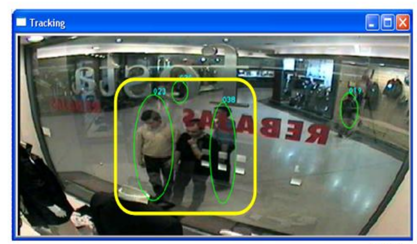
Groupings & Occlusions



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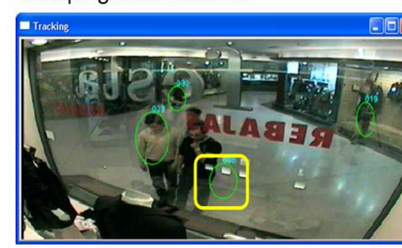


645

Tracking

```
Track 008
  pos ()
  vel ()

Track 010
  pos ()
  vel()
```

L1 → L2-L3

Person
Entry
> **Entering**
Mirror
> **Reflection**
Column

Interpretation

Person 1 *is*
(Entering *through* Entry 2)
and
(Reflected *by* Mirror 1)

User-Provided Context

Activity Modeling

Context-aware computing

Computational systems that use a massive amount of context knowledge

Context-aware systems

The interpretation of the available information depends on context knowledge

Ubiquitous Computing and **Ambient Intelligence**

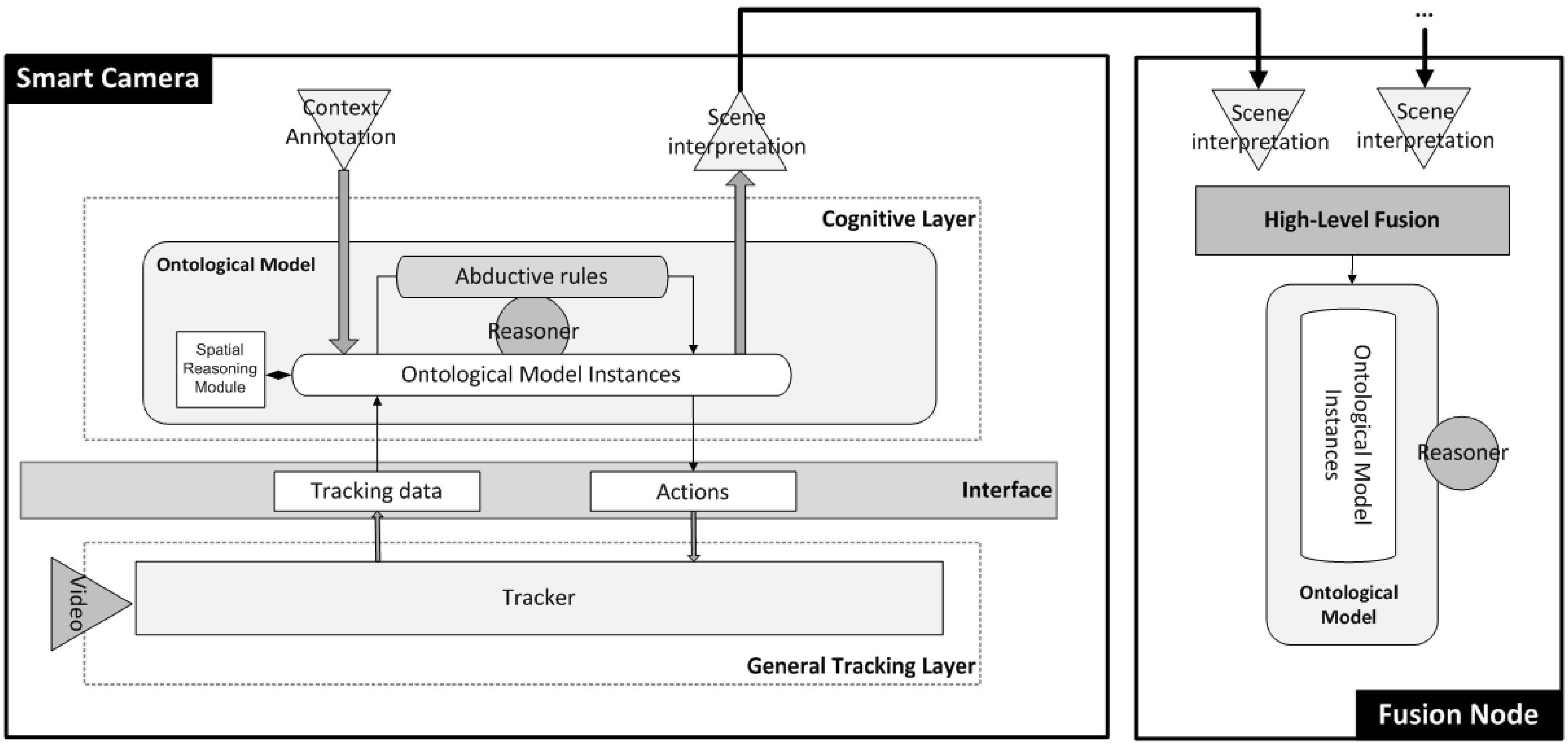
Context information is essential to determine interesting services

CONTEXTS project

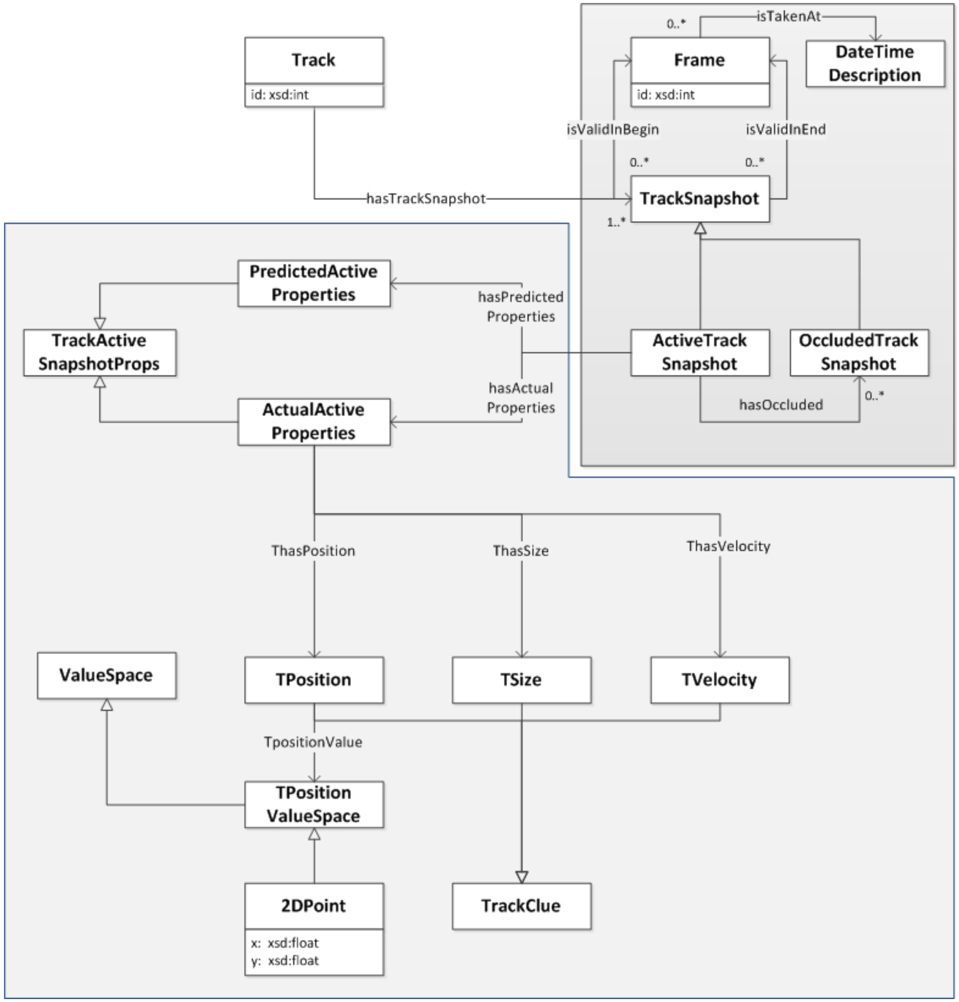
Contextual and customized services through advanced mobile devices by using non-invasive sensors and natural interfaces

http://www.giaa.inf.uc3m.es/cms/?page_id=428

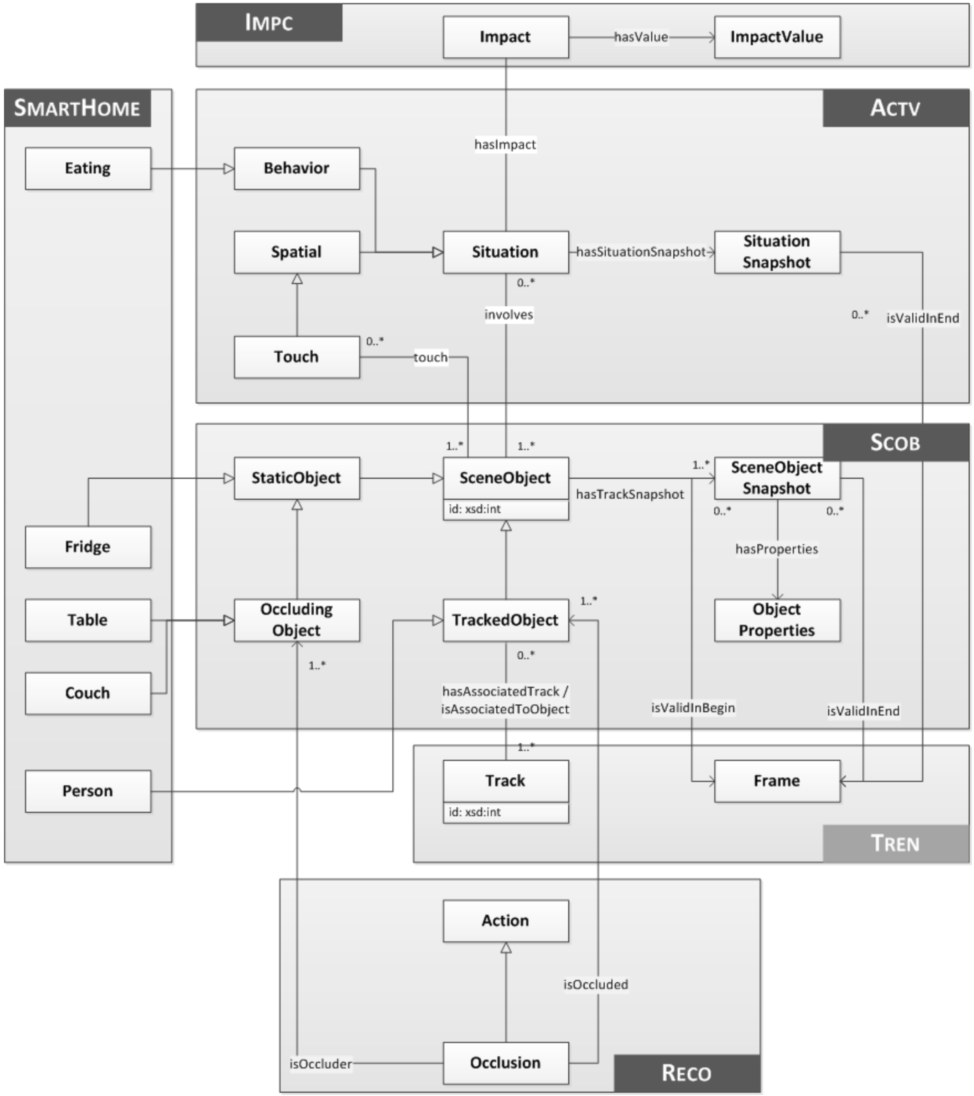
Architecture for context-based IF in VSNs



J. Gómez-Romero, M.A. Serrano, M.A. Patricio, J. García & J.M. Molina. *Context-based scene recognition from visual data in smart homes: an Information Fusion approach*. In: Personal and Ubiquitous Computing, To appear

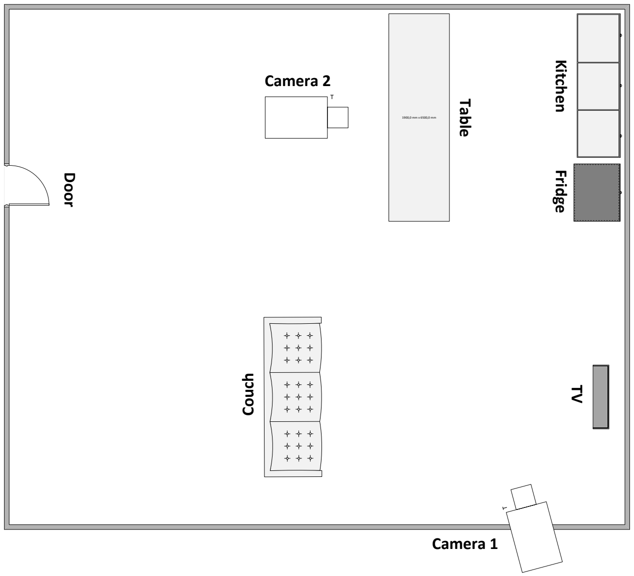


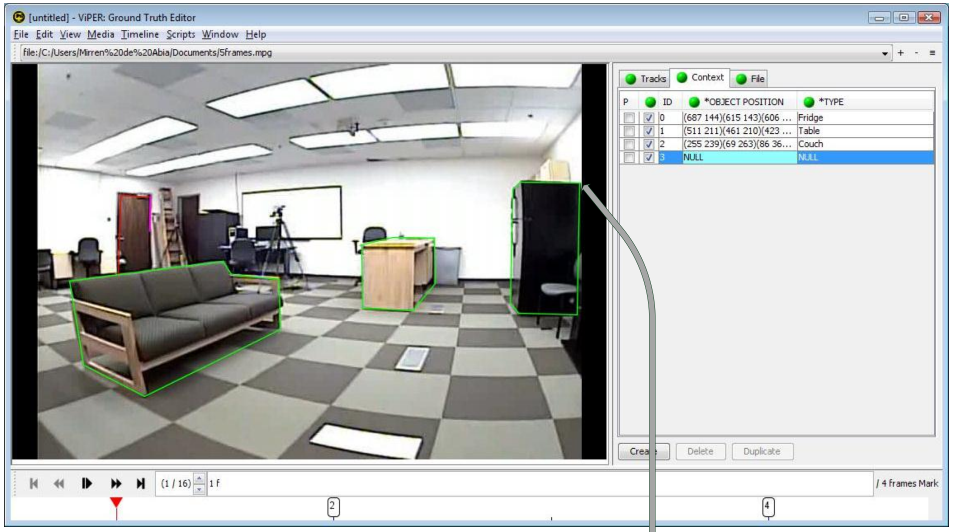
General ontology for representation of track information



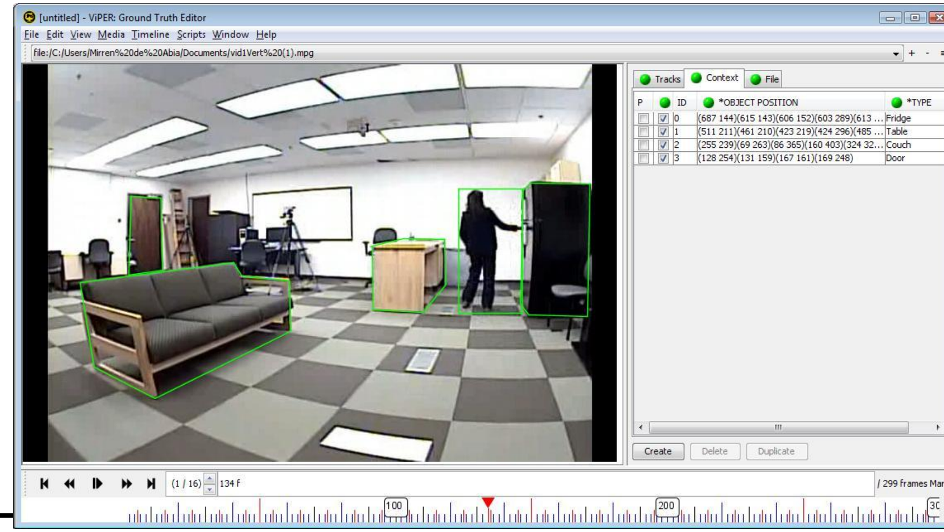
Set of layered ontologies to represent AmI information (specific/general)

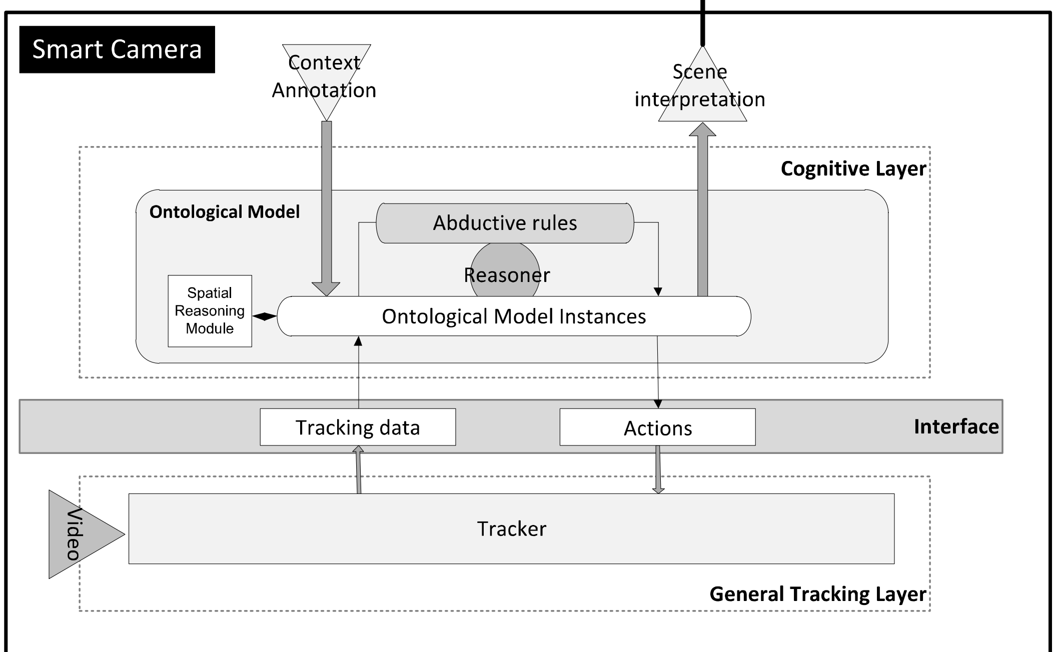
Context-based IF in VSNs – AmI application



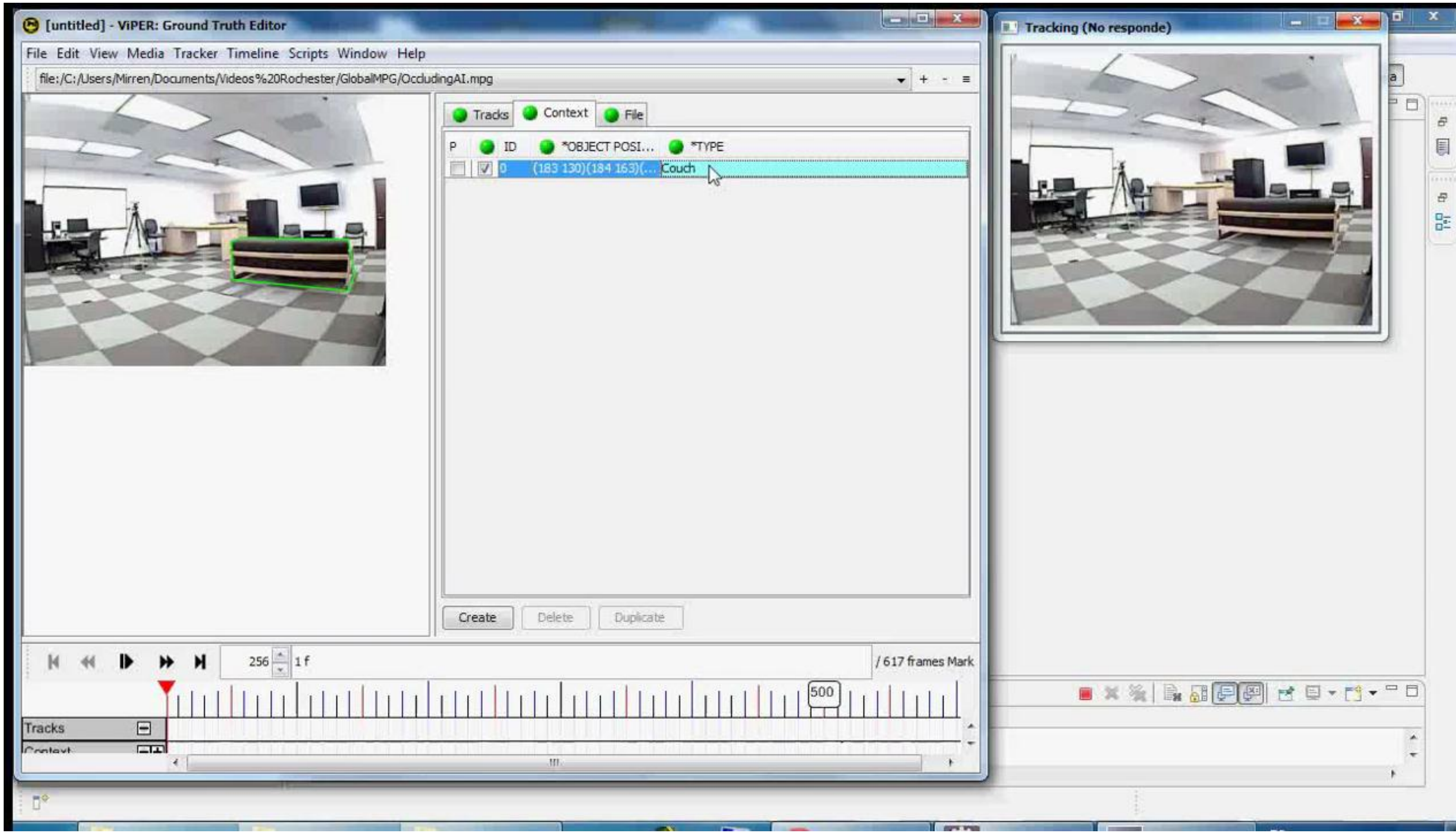



```
<!-- fridge1 instance -->
<owl:Thing rdf:about="#fridge1">
  <rdf:type rdf:resource="#Fridge"/>
  <scob:hasObjectSnapshot rdf:resource="#osn_fridge1"/>
</owl:Thing>

<!-- object snapshot of fridge1 -->
<owl:Thing rdf:about="#osn_fridge1">
  <rdf:type rdf:resource="&scob;SceneObjectSnapshot"/>
  <scob:hasObjectProperties rdf:resource="#fridge1_props"/>
  <tren:isValidInEnd rdf:resource="&tren;unknown_frame"/>
</owl:Thing>

<!-- properties of fridge1 snapshot (position) -->
<owl:Thing rdf:about="#fridge1_props">
  <rdf:type rdf:resource="&scob;ObjectSnapshotProperties"/>
  <scob:OhasPosition rdf:resource="#fridge1_position"/>
</owl:Thing>

<!-- fridge1 position -->
<owl:Thing rdf:about="#fridge1-position">
  <rdf:type rdf:resource="&scob;OPosition"/>
  <scob:OpositionValue rdf:resource="#p1"/>
  <scob:OpositionValue rdf:resource="#p2"/>
  <scob:OpositionValue rdf:resource="#p3"/>
  <scob:OpositionValue rdf:resource="#p4"/>
  <scob:OpositionValue rdf:resource="#p5"/>
  <scob:OpositionValue rdf:resource="#p6"/>
</owl:Thing>

<!-- fridge1 point1 coordinates -->
<owl:Thing rdf:about="#p1">
  <rdf:type rdf:resource="&tren;2DPoint"/>
  <tren:y rdf:datatype="&xsd;float">687.0</tren:y>
  <tren:x rdf:datatype="&xsd;float">144.0</tren:x>
</owl:Thing>
```



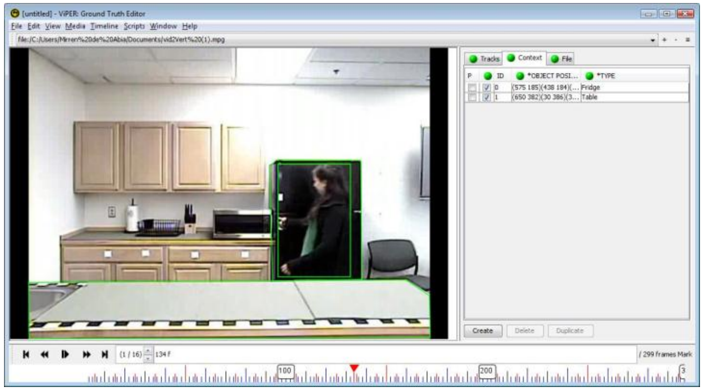


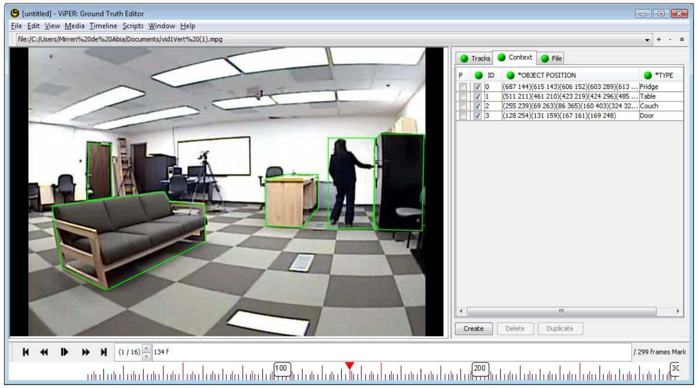
person ***touches*** fridge

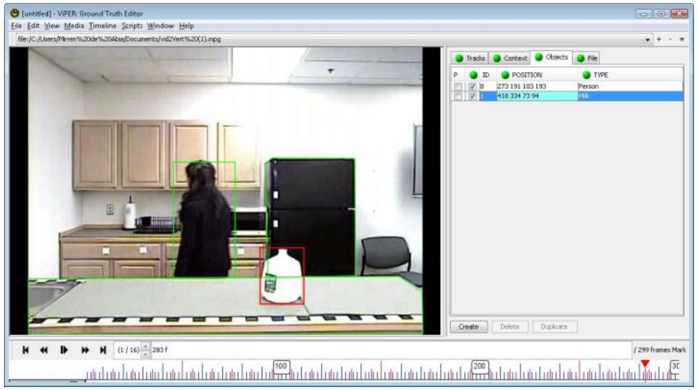


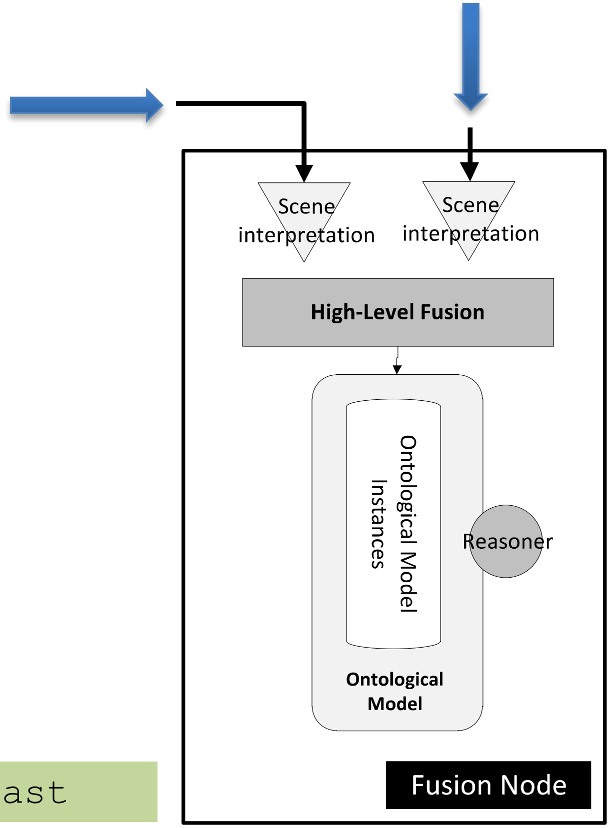
Occlusion detection and tracking enhancement

Context-based IF in VSNs – AmI applications









person ***action*** breakfast

Spatial reasoning

OWL ontologies allow us to model **any kind of relationship**

part-of, *temporal*, *spatial*, etc.

Axioms to endow them with suitable semantics

relation *part-of* is transitive

relation *close-to* is transitive (**?**)

Applications

geo-location

natural resources, artificial objects

modeling physical installations

buildings, roads, harbors, etc.

absolute positioning and tracking

security, Ambient Intelligence

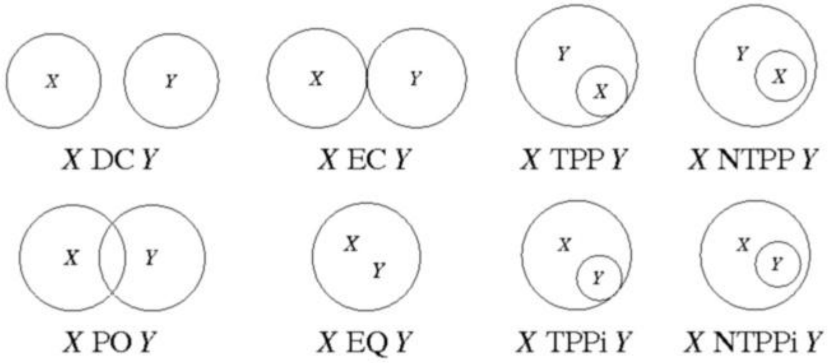
data linking and visualization

mash-ups with map applications

RCC (*Region Connection Calculus*)

Logic theory for qualitative spatial knowledge representation and reasoning

DC (disconnected from)
TPP (is a tangential proper part of)
PO (partially overlaps)
TPPi (inverse of TPP)
EC (externally connected with)
NTPP (is a non-tangential proper part of)
EQUAL
NTPPi (inverse of NTPP)



OWL does not support RCC

Inference engines provide support to RCC by means of a *RCC substrate*

RCC properties must be instantiated according to data provided by the low-level tracking procedure

A person is inside region 1

a) Embed spatial reasoning rules into the knowledge base

Not recommended, the performance is highly reduced

b) Develop a module to perform spatial properties processing

1. Low-level tracking information is inserted into an optimized geometric model with object position information
2. A specific procedure makes a topological analysis to detect spatial relations: inclusion, overlapping, adjacency, etc.
3. Detected spatial relations are instantiated into the ontological scene model as RCC relations

1. Information Fusion
2. Ontologies
3. Ontology-based IF applications
4. **Present and future research**

Ontologies for HLIF in the maritime domain

Situation and threat assessment in the harbor surveillance scenario

- Detected and estimated vessel information from Vessel Traffic System
  - Position, AIS identification
- Context knowledge
  - Restrictions to the fusion process
    - *Is the situation plausible?*
  - Enrich available information
    - *Link to external information sources*
- Normalcy models
  - Harbor navigation restrictions
  - Expert knowledge about threats

Prevent potential threats · Detect rule-breaking ships · Avoid piracy

J. García, J. Gómez-Romero, M.A. Patricio, J.M. Molina & G. Rogova. *On the representation and exploitation of context knowledge in a harbor surveillance scenario*. In Proceedings of the 14th International Conference on Information Fusion (2011). Pp. 1787-1794

OWL ontologies cannot manage imprecise or uncertain knowledge

A person is quite close to the T.V.

A sensor detects a ship with speed 30 kn with a precision of 0.85

Extending DLs

Fuzzy DLs

Probabilistic DLs

T. Lukasiewicz & U. Straccia. *Managing uncertainty and vagueness in Description Logics for the Semantic Web.* In: Journal of Web Semantics 6 (4) (2008). Pp. 291-308

Fuzzy Ontologies

Concepts denote a **fuzzy set** of individuals

An individual belongs to a concept with a degree in [0, 1]

Relations denote **fuzzy binary relations**

A pair of individuals are related with a degree in [0, 1]

Axioms hold to a **degree**

C is included into *D* with a degree in [0, 1]

The semantics of the ontology constructors are conveniently extended to the fuzzy case

Different fuzzy DLs, depending on the expressivity of the original DL, the fuzzy operators used to define the semantics of the constructors

> **f-OWL** - fuzzy $\mathcal{SHOIN}$(D)

G. Stoilos, N. Simou, G. Stamou & Stefanos Kollias. *Uncertainty and the Semantic Web*. In: IEEE Intelligent Systems 21 (2006). Pp. 84–87

> **Fuzzy DLs con semántica Zadeh y Gödel**

F. Bobillo, M. Delgado, J. Gómez-Romero & U. Straccia. *Fuzzy Description Logics under Gödel semantics*. In: International Journal of Approximate Reasoning 50.3 (2009). Pp. 494-514

New reasoning algorithms are required

Specific procedures for fuzzy DLs

FiRE

G. Stoilos, G. Stamou, J.Z. Pan, N. Simou & V. Tzouvaras. *Reasoning with the Fuzzy Description Logic f-$\mathcal{SOIN}$: Theory, Practice and Applications*. In: Uncertainty Reasoning for the Semantic Web I. Springer, 2008

FuzzyDL

F. Bobillo & U. Straccia. *fuzzyDL: An expressive Fuzzy Description Logic reasoner*. In: Proceedings of the 2008 International Conference on Fuzzy Systems (FUZZ-IEEE 2008) (2008). Pp. 923- 930

Procedure to reduce the fuzzy ontology to an equivalent non-fuzzy ontology and re-use existing tools

DeLorean

F. Bobillo, M. Delgado & J. Gómez-Romero. *DeLorean: A Reasoner for Fuzzy OWL 2*. In: Expert Systems with Applications, 39(1) (2012). Pp. 258-272

To sum up…

1. *Information Fusion*

Combining sensor information to obtain a better understanding of the scene

Context knowledge is essential

2. *Ontologies*

Formal knowledge representation formalism

Concepts, relations, individuals, and axioms in HLIF domain

3. *Ontology-based IF applications (@ GIAA)*

Context-based video surveillance (mono/multi-camera)

Applications in AmI

4. *Present and future research*

Extensions to harbor domain

Fuzzy and probabilistic ontologies

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icon set

Natsu icon set

http://raindropmemory.deviantart.com/art/Natsu-Icon-Set-81597962

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- Kandefer, M., & Shapiro, S.C. (2008). A categorization of contextual constraints. In *Biologically inspired cognitive architectures: Papers from the AAAI Fall Symposium 2008*, 88-93.
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