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Context Modeling and Context-aware databases: can Datalog be of help?

Letizia Tanca

Contextual information

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- Content available at different sources and places
- User is an integral part of numerous applications interacting with:
  - service providers,
  - product sellers,
  - governmental organisations,
  - friends and colleagues,
  - sensing devices.

Information access personalization: *any set of actions that can appropriately tailor information to a particular user in each particular situation.*

A motivating scenario

Natural history museums visitors, endowed with a portable device which reacts to changes of context:

- adapting the user interface to the different *abilities* of the visitor – from low-sighted people to very young children –;
- providing different information contents based on the different *interests/profiles* of the visitor (geology, paleontology, . . . scholar, journalist, . . .), and on the room s/he is currently in;
- *learning*, from the current situation and the previous choices performed by the visitor, what information s/he is going to be interested in *next*;
- providing the visitor with *appropriate services* – to purchase the ticket for a temporary exhibition, or to reserve a seat for the next in-door show on the life of dinosaurs –;
- deriving *location information* from sensors which monitor the user environment;
- providing knowledge of the *sorrounding people* in terms of their roles and respective contexts, *as related to the user*
- providing *active features* within the various areas of the museum, which alert visitors with hints and stimuli on what is going on in each particular ambient.-

- It is generally accepted that knowledge has a *contextual component*
- <…> this is *rarely represented explicitly* in available knowledge representation systems and is *not used in subsequent processing of knowledge*
- Acquisition, representation and exploitation of *knowledge in context* would have a major contribution in:
  - **knowledge representation,**
  - **knowledge acquisition,**
  - **explanation,**
  - **maintenance,**
  - **documentation,**
  - **learning,**
  - **human-computer communication**
  - **validation or verification**
- A computational capability to understand, represent and reason about context will be very valuable for, and of immense benefit to, many (AI) problems.

Underlying, implicit principles

Principle 1 (Locality): reasoning uses only part of what is potentially available (e.g., what is known, the available inference procedures). The part being used while reasoning is what we call *context* (of reasoning);

Principle 2 (Compatibility): there is compatibility among the kinds of reasoning performed in different contexts.

(*Chiara Ghidini, Fausto Giunchiglia,* Local Models Semantics, or Contextual Reasoning = Locality + Compatibility, *Artificial Intelligence, 2001*)

Context

- derived from the Latin **CUM** (with or together) and **TEXERE** (to weave)

- a context is not just a profile, but *an active process dealing with the way humans weave their experience within their whole environment, to give it meaning*

- *Context is any information that can be used to characterize the situation of an entity [Dey],* where an entity is a person, a place, or an object that is considered as relevant for the interaction between a user and an application.

Accordingly…

- Context can contribute to the meaning that must be inferred from the adjacent world
- Such meaning ranges from the references intended for indefinite indications such as "take that" to the shared reference frame of ideas and objects that are suggested by a situation
- Context goes beyond immediate binding of variables to the establishment of *a framework for communication based on shared experience*
- Such a shared framework provides a collection of roles and relations to organize meaning for a piece of information

- The COGNITIVE SCIENCE view:

  context is used to model interactions and situations in a world of infinite breadth, and human behavior is key in extracting a model.
- The ENGINEERING view:

  context is useful in representing and reasoning about a restricted state space within which a problem can be solved.

The engineering view *is subsumed* by the cognitive science view.

The six "W" questions of context

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<u>What</u> is context?

<u>Who</u> might benefit from an awareness of their context; whose context is important to whom, or to what?

<u>Where</u> can an awareness of context be exploited?

<u>When</u> is context-awareness useful?

<u>Why</u> are context-aware applications useful?

Answers to these five questions underpin the meta-question:

<u>hoW</u> do we implement context-awareness so that we can develop context-aware applications?

(Proceedings of the CHI 2000 Workshop on "The What, Who, Where, When, Why and How of Context-Awareness", David R. Morse, Anind K. Dey, 2000, Georgia Institute of Technology)

What is context?

Different meanings in different realms of Computer Science

Is context a matter of….?....

Is context a matter of….?

COMMUNICATION:

- capability to *adapt content presentation* to different channels or to different devices (system *communication WITH the users*)
- *agreement and shared reasoning* among peers (*communication AMONG users or systems*)
- building *smart environments* (system *communication with the ENVIRONMENT*)

Is context a matter of….?

SITUATION AWARENESS:

- modeling *location and environment* aspects (physical situation)
- modeling what *the user is currently doing*
- supporting *autonomous behaviours* of the system
- making the *user interaction implicit*

Is context a matter of….?

MANAGING KNOWLEDGE CHUNKS:

- determining the set of *application/situation-relevant DATA*
- determining the set of *application/situation-relevant SERVICES*
- determining the set of *application/situation-relevant BEHAVIORS*

MODELING and REPRESENTATION:

- Orthogonal context modeling
- Multi-application model
- Context elements (dimensions): time, space, role, more…
- Space/Time coordinates (relative or absolute)
- User profile (e.g. role or features based)
- Variable context granularity
- Type of formalism: parameter-values pairs, rule-based, ontological, graph-based → NOT independent of the application
- Valid-context constraints

Summary of the "hoW's"

DINAMICITY MANAGEMENT

- On-line context changes
- On-line model changes
- Inter-context (dynamic) constraints
- Context history
- Automatic learning features

FURTHER FEATURES

- Context construction (distributed or centralized)
- Context quality monitoring
- Ambiguity/Incompleteness mgmt.

Context management lifecycle

Design-time loop:

- Context modeling
- Application domain modeling (data, functions)
- Design of the relationship between the context model and the application domain

Run-time loop:

- Context sensing (numeric observables)
- Context recognition (symbolic observables)
- Context feeding (binding)
- Context aware behavior

Design time

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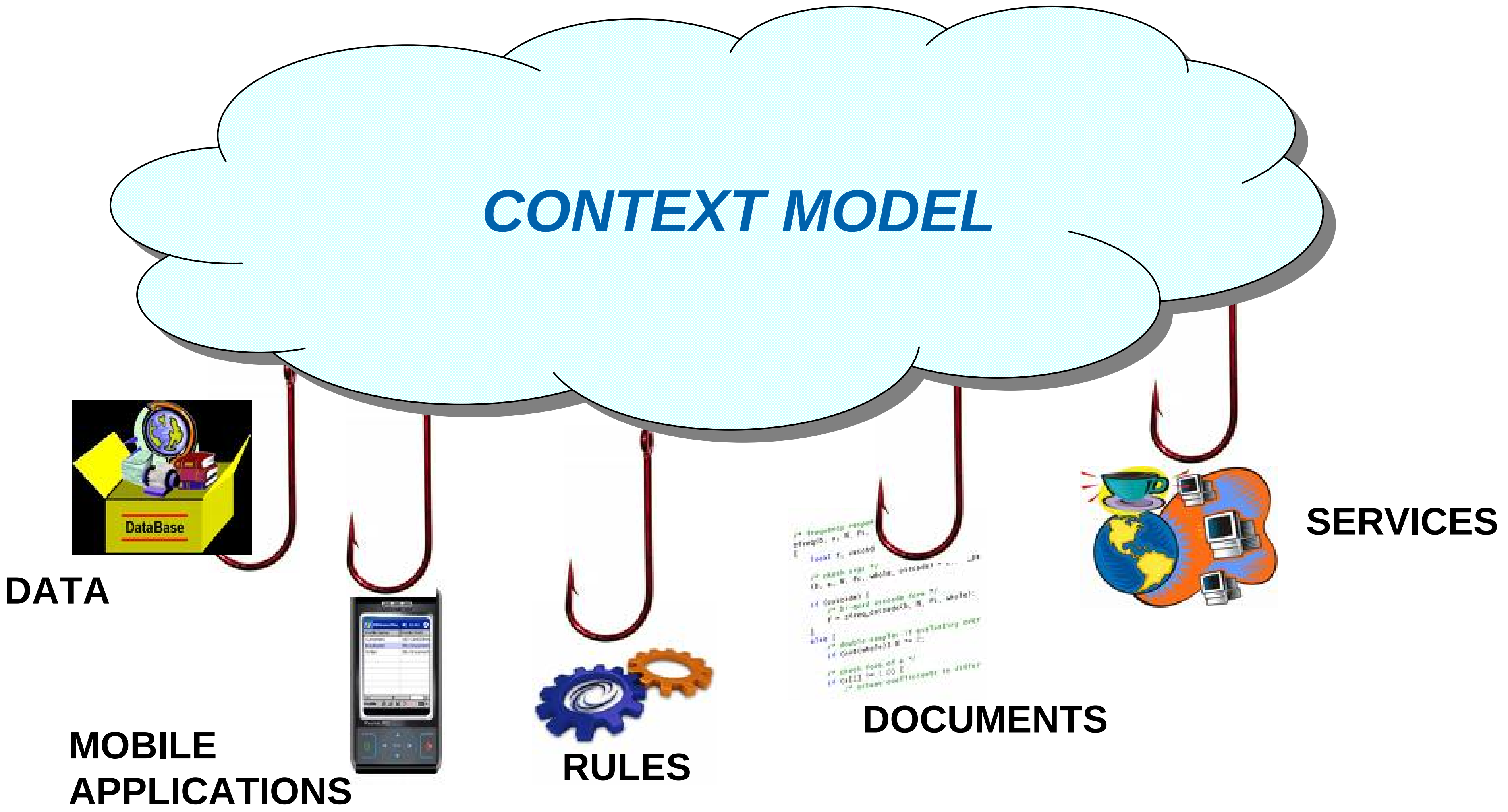

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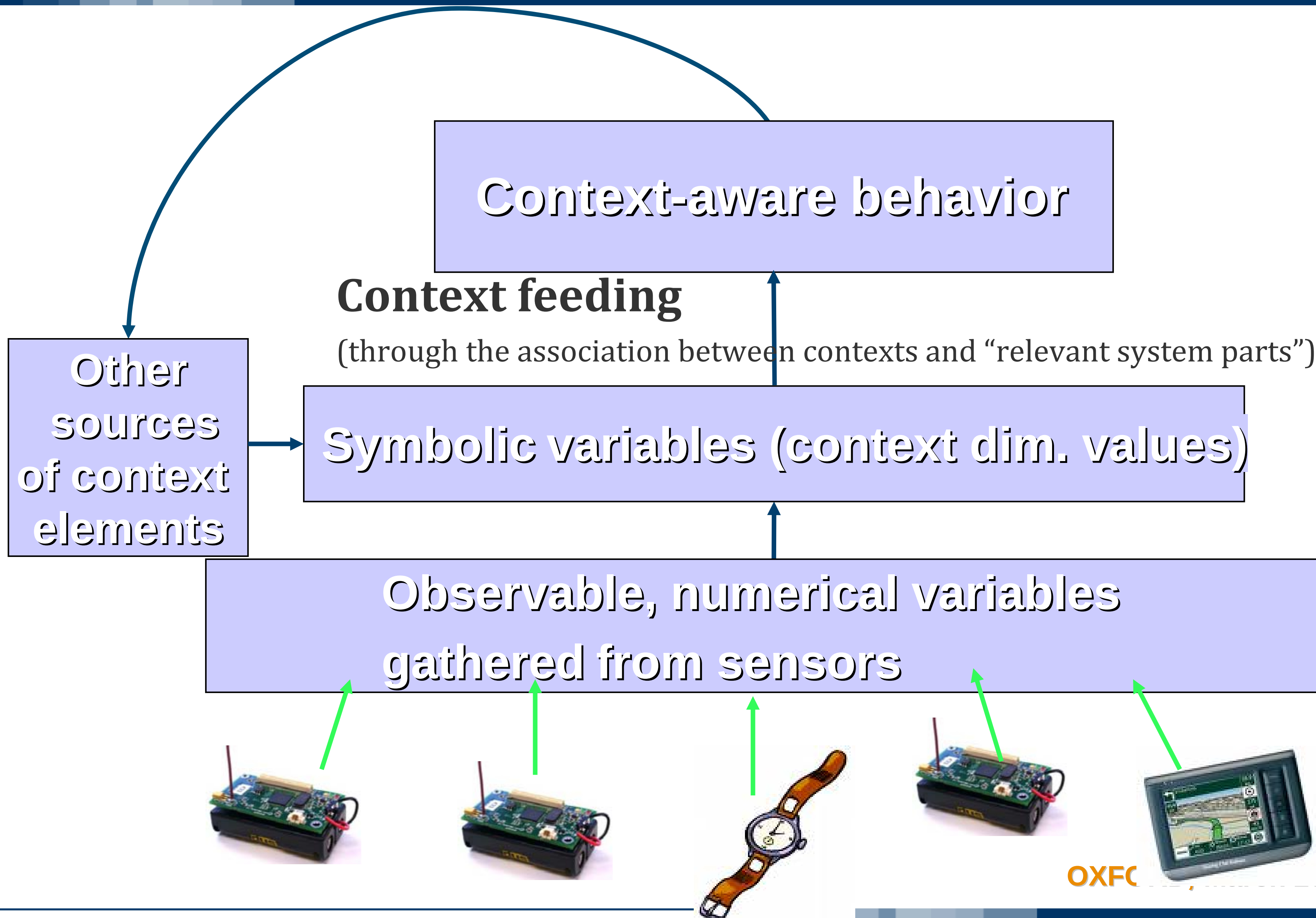
Run-time


Context-aware behavior
Context feeding
(through the association between contexts and "relevant system parts")
Other sources of context elements
Symbolic variables (context dim. values)
Observable, numerical variables gathered from sensors

Software and service "hooking"

Possible associations:

Context → *(associated to)*→ set of ECA rules

- Rules activate and deactivate behaviors

Context → *(associated to)*→ set of pairs <class, role>

- Each object takes a *context-aware role*

Context → *(associated to)*→ set of program "variations"

- An agent triggers context-aware variations which change process behavior

….

Based on the analysis of the *context dimensions*:

- different points of view the data are considered from
- they drive the portion of data to be handed over to the user (e.g. stored on the portable device)
- when possible, *views* over a global schema

Context Dimension Tree

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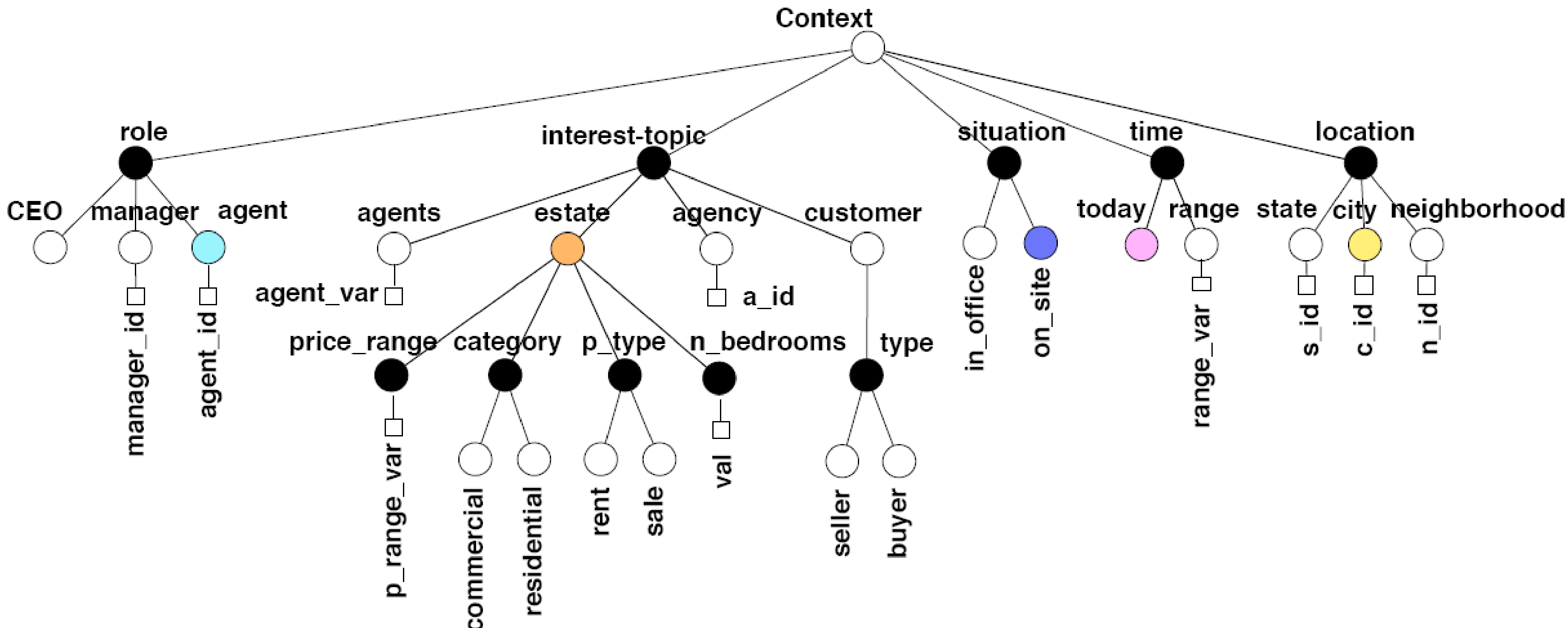

- An orthogonal context model, which in principle can be adopted for any application (data tailoring, application and service adaptivity and fine-tuning, sensor query configuration…)
- Single contexts are defined as subtrees of a Context Tree, representing the contexts currently envisaged for that particular application
- The Context-Dimension Tree is *representation independent* and *extensible*
- Provides context-validity constraints support
- Induces a partial order on contexts (more or less abstract contexts)

Relevant areas, or projections

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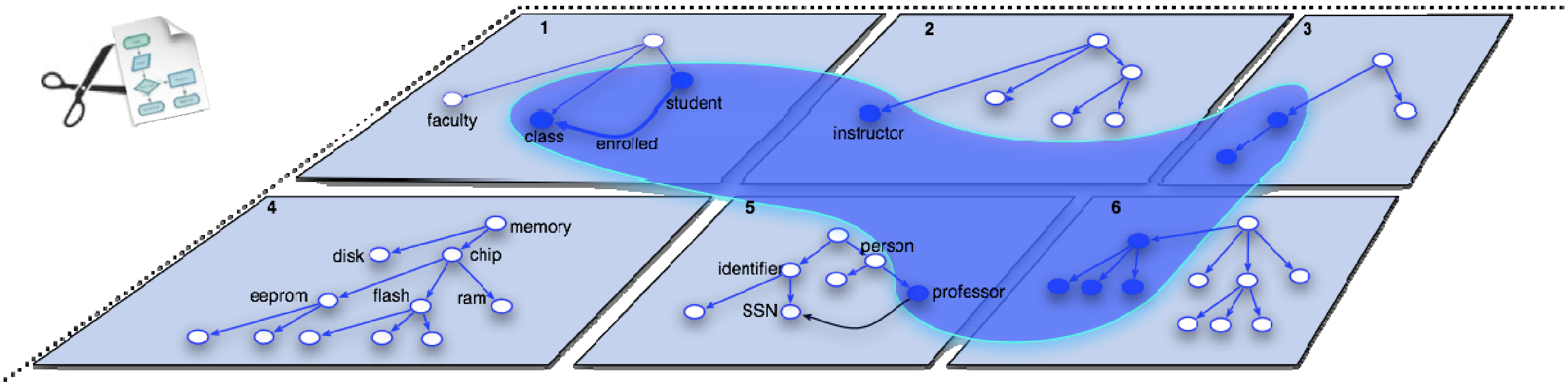

Projection:

- is the set of relevant data for a given user in a given context
- projected over the data source(s)
- is context-aware
- possible for any kind of data source (RFIDs, sensors,..)

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The real-estate example

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OWNER(<u>IdOwner</u>, Name, Surname, Type, Address,City, PhoneNumber)
ESTATE(<u>IdEstate</u>, IdOwner, Category, Area, City, Province, RoomsNumber,
Bedrooms, Garage, SquareMeters, Sheet, CadastralMap)
CUSTOMER(<u>IdCustomer</u>, Name, Surname, Type, Budget, Address, City, PhoneNum)
AGENT(<u>IdAgent</u>, Name, Surname, Office, Address,City,Phone)
AGENDA(<u>IdAgent, Data, Hour</u>, IdEstate, ClientName)
VISIT(<u>IdEstate, IdAgent, IdCustomer, Date</u>, ViewDuration)
SALE(<u>IdEstate, IdAgent, IdCustomer, Date</u>, AgreePrice, Status)
RENT(<u>IdEstate, IdAgent, IdCustomer, Date</u>, RatePrice, Status, Duration)
PICTURE(<u>IdPicture</u>, IdEstate, Date, Description, FileName)

Context Dimension Tree:
the Real Estate Case Study

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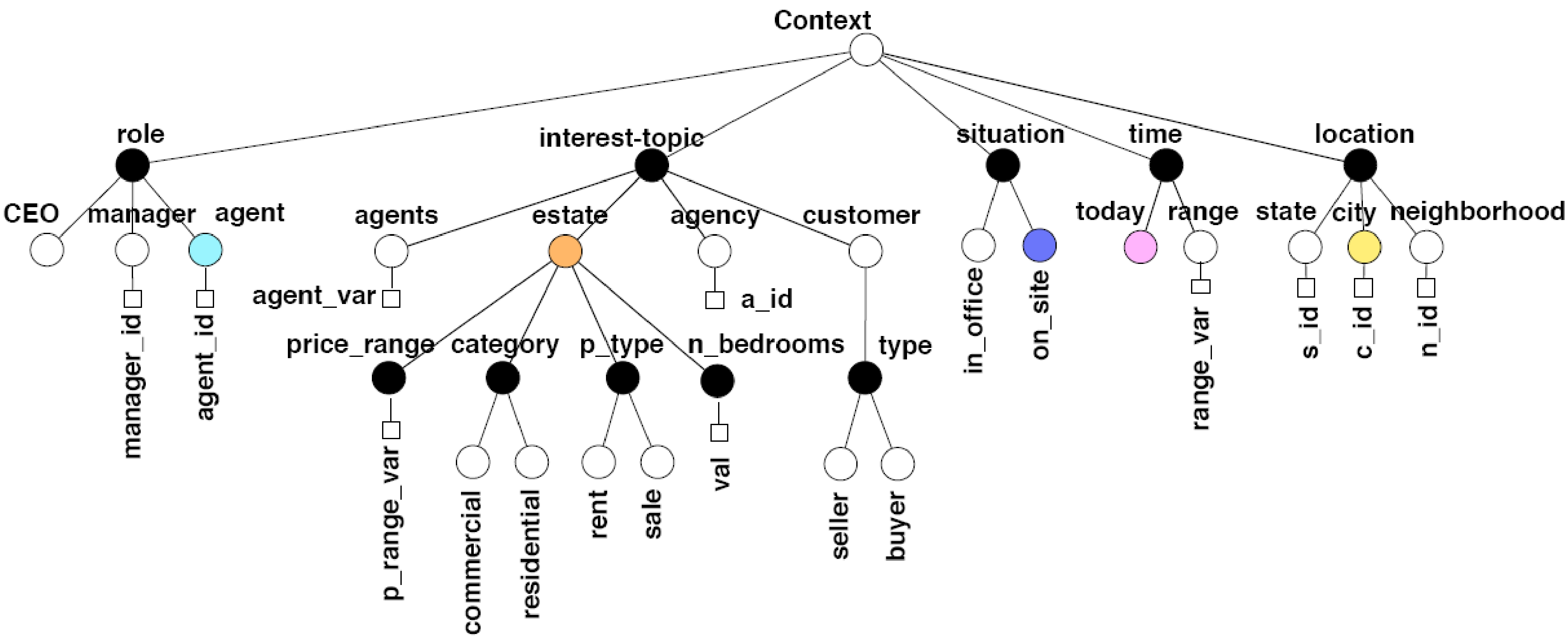

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Real-estate context dimensions

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Dimension	Meaning	Examples
Role	The actors using the system.	`CEO`, `agency manager`, `agent`.
Interest Topic	The areas of interest for the possible users of the application.	"`agencies`", i.e., information about agencies (and one in particular) that can be controlled by the CEO, "`agents`", i.e., information about agents that can be viewed by the CEO or by the agency's manager, "`customers`", i.e., information about sellers and buyers that can be viewed by the agent and manager, and "`properties`", i.e., all the knowledge about estates to be sold or rented. This last interest topic can be further decomposed w.r.t. two different criteria: commercial/residential estates or rented/sold properties.
Situation	Phases of the application life.	The user is consulting his/her data when at the office, i.e., `in_office` as opposed to the `on_site` situation, when, for instance, an agent is showing an apartment to a prospective customer.
Time	Temporal indication based on the current time. Time can be relative or absolute and its granularity may vary.	In our example we have chosen a relative view of time, and allowed two choices: the current day, or a variable time interval centered on the current instant, suitable for data analysis.
Space	A location indication, normally referring to the place where the user is currently located. Space can be relative or absolute, and its granularity may vary.	In our example, "`here`" or "`this city`" are relative space data, while "`Marina del Rey district in L.A.`" is absolute.
Interface	Indication of channel or presentation for delivering information.	In some application cases, some data have to be used by humans, directly perusing text and multimedia information, but in others data could be managed by electronic devices solely, requiring only compact codes.

Data Tailoring:
the View Specification Problem

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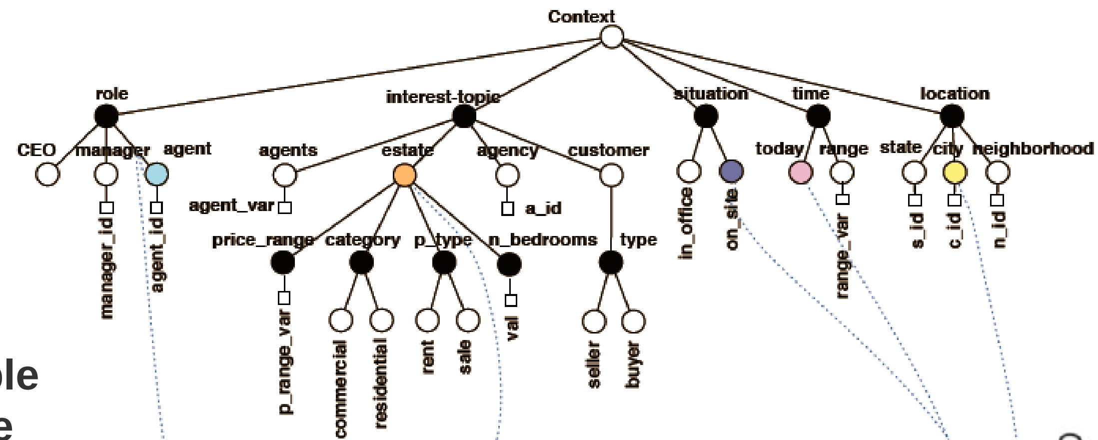
Context-aware database design based on the *viewpoint abstraction* (Motschnig-Pitrik, Mylopoulos)

For each possible context instance we specify the relevant data <u>as views</u>

This is all <u>intensional information</u>



<<agent($agent_id)>, <estate>, <on_site>, <today>, <city($c_id)>>

```
CREATE VIEW ContextualEstate AS{
  SELECT E.*
  FROM Estate as E, EstateAgent as EA, City AS C
  WHERE EA.Agent_PersonnelID = $agent_ID AND
        E.estateID = EA.Estate_estateID AND
        E.CityZip = $c_id
}

CREATE VIEW ContextualAgenda AS{
  SELECT A.*
  FROM Agenda A
  WHERE A.Agent_Personell_personelID = $agent_ID AND
        A.date >= date() AND A.date <= date()+5
}

CREATE VIEW ContextualMultimedia AS{
  SELECT M.*
  FROM MultimediaContent AS MC, EstateAgent AS EA
  WHERE MC.Estate_ID = EA.Estate_estateID AND
        EA.Agent_Personnel_personelID = $agent_ID AND
        MC.type="gif" AND
        MC.ImageHeight < '320' AND
        MC.ImageWidth < '240' AND
        E.estateID = EA.Estate_estateID AND
        E.CityZip = $c_id
}
....
```

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Composing relevant areas

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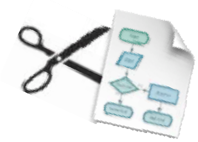
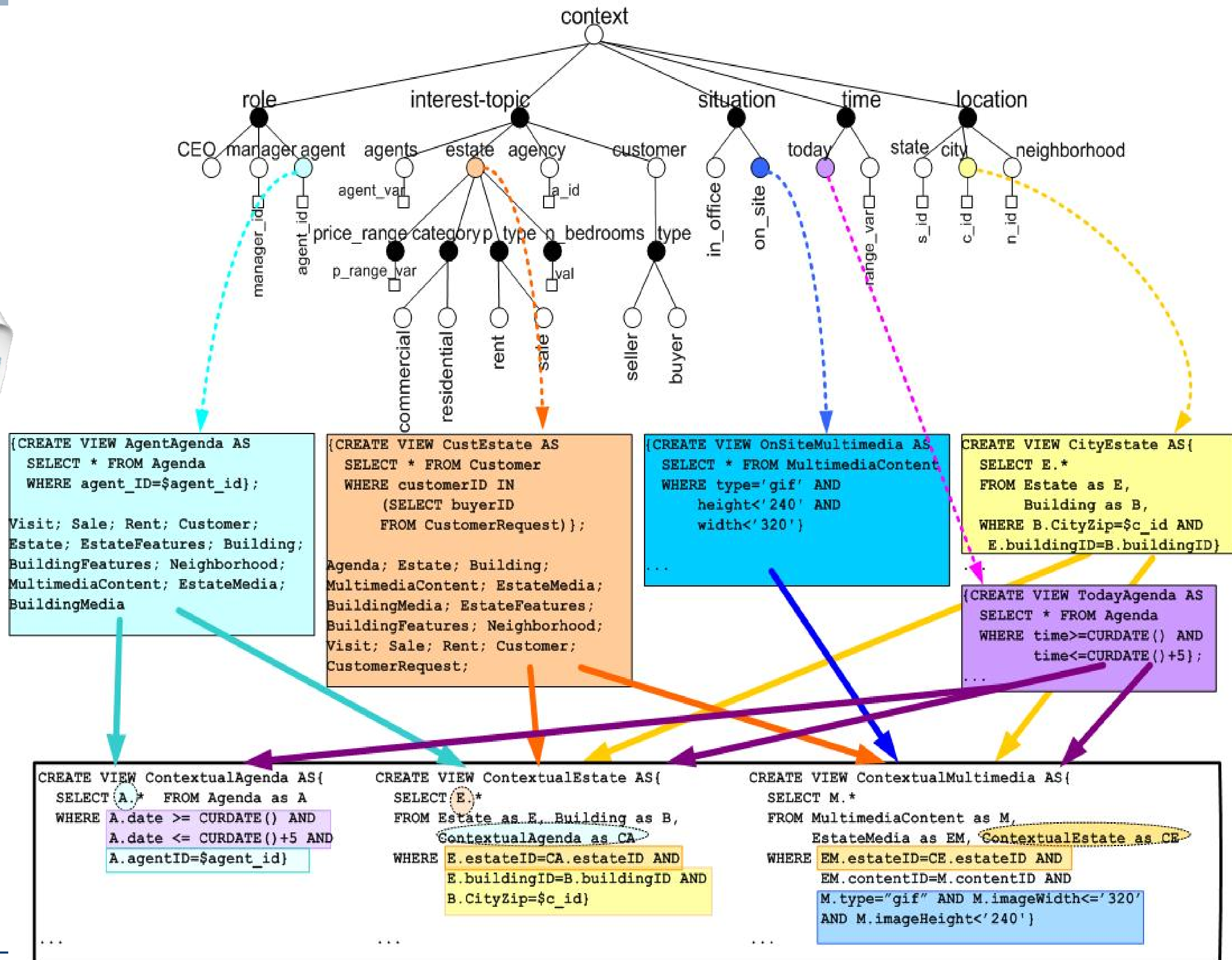
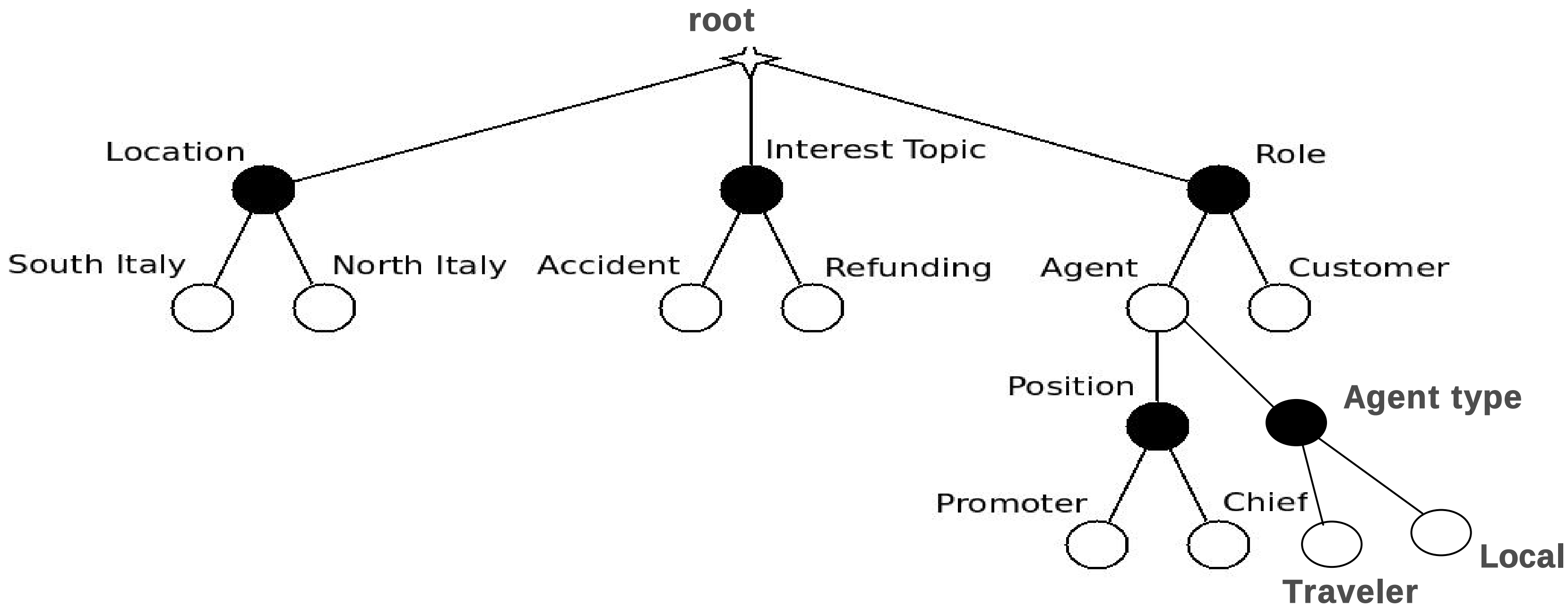




The CDT of the insurance case

The Context-Dimension Tree is

- ***representation independent***
- ***extensible***



DIMENSIONS AND THEIR VALUES

- `dim(location). dim(interest-topic). dim(role).`
  `dim(position).   dim(agent-type).`
- `val(root). val(southern-italy). val(northern-italy).`
  `val(accident).   val(refunding). val(agent).`
  `val(customer).   val(promoter).   val(chief).`
  `val(traveler). val(local).  val(all).`

The polymorphic value ***all*** is admitted

Building the insurance CDT

TREE CONSTRUCTION

- `dimValue(location, southern-italy). dimValue(location, northern-italy). dimValue(interest-topic,accident). dimValue(interest-topic,refunding). dimValue(role,agent). dimValue(role,customer). dimValue(position,promoter). dimValue(position,chief). dimValue(agent-type,traveler). dimValue(agent-type,local).`
- `dimvalue(D, all)` is true for any dimension `D`
- `sub(root,location).sub(root,interest-topic).sub(root,position). sub(agent,position). sub(agent,agent-type).`

General transitive rules

Dimension values' inheritance:

```
dimValue(D1,V2) ← dimValue(D1,V1), sub(V1,D2),
                  dimValue(D2,V2)
```

Subdimension inheritance:

```
sub(V1,D3) ← sub(V1,D2),dimValue(D2,V2),sub(V2,D3).
```

Context dominance (rule schema):

```
dominates(CID1, CID2) ← dimValue(D1,V11),
  dimValue(D1,V21),  sub(V11,D2),not dimValue(D2,V11),
  CorrectContext (CID1, V11, V12, V13, …, V1n),
  CorrectContext (CID2, V21, V22, V23, …, V2n).
```

(ugly: one rule for each pair of values V1i, V2i, and for each n-ary combination of dimension values)

Constraints

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a. Structural constraints over the tree, like incompatible dimension values, e.g. between the value **`customer`** of dimension **`role`** and the value **`refunding`** of dimension **`interest-topic`**:

   `ForbidCombination (refunding, customer).`

b. Constraint that forbids that the context contains two incompatible values for the same dimension (e.g. if **`role=customer`** the context cannot contain the subrole **`promoter`**)

   `ForbidCombination(V1,V2) ← dimValue(D1,Vi), dimValue(D1,V1), sub(Vi,D2), dimValue(D2,V2)(EGD)`

- Constraint that forbids that the same dimension take two different values in the same context

`V1i=V1j, V2i=V2j, ..., VNi=VNj ← CorrectContext (ID1, V1i, V2i, V1i, …,VNi), CorrectContext (ID1, V1j, V2j, V3j, …, VNj). (EGD)`

More, interesting Constraints

- Dynamic constraints among contexts (context **`c1`** cannot come after context **`c2`**)
- Other kinds of constraints, e.g. causal (context **`c1`** is always caused by context **`c2`**)

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Context generation

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```
Ex.ID CorrectContext (ID, Location, Interest-topic,
  Role, Position, Agent-type)
←
  dimValue(location, LocationValue),
  dimValue(interest-topic,Interest-topicValue),
  dimValue(role,RoleValue),
  dimValue(position,PositionValue), dimValue(agent-
  type,Agent-typeValue), ¬ ForbidCombination
  (LocationValue,Interest-topicValue),
 ¬ ForbidCombination (Interest-topicValue,
  RoleValue), [OTHER CONSTRAINTS)]…
```

- This definition is application-dependent and takes into account the constraints that have been written
- With second-order constructs we could obviously write general rules

Relevant area association

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Partial relevant areas:

For each (intensional or extensional) predicate **`p(Att1,…Attm),`** and for each possible dimension value, definition of the new predicate:

```
val_p (DVal, Att1,…Attm) ← p(Att1,…Attm), <other
  involved predicates>, [valappl(Dval, Att1,…Attm)],…
```

Relevant areas (contextual predicates):

```
ctxt_p(C_ID, Att1,…Attm)← val_p(Dval1, Att1,…Attm),….
  val_p(Dvaln,Att1,…Attm), CorrectContext (C_ID,
  DVal1,…DValn).
```

Example

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Insurance Company DB schema

```
CUSTOMER (C_ID, NAME, LOCATION, RISKID, GENDER)
MOTORBIKE (PLATENO, C_ID, MANUFACTURER, MODEL)
RISKCLASS (R_ID, DESCRIPTION)
AGENT (A_ID, NAME, AREA)
```

Insurance Company Relevant Areas

```
val_CUST(southern-italy,ID,NAME,LOCATION,RISKCLASS,GENDER)
  ← CUSTOMER(ID,NAME,LOCATION,RISKCLASS,GENDER),
   LOCATION=southern-italy.

val_CUST(northern-italy ,ID,NAME,LOCATION,RISKCLASS,GENDER)
  ← CUSTOMER(ID,NAME,LOCATION,RISKCLASS,GENDER),
   LOCATION=northern-italy.

val_CUST (promoter,C-ID,null,null,RISKCLASS,GENDER) ←
CUSTOMER(C-ID,C-NAME,LOCATION,RISKCLASS,GENDER), AGENT (A-
  ID, A-NAME,AREA), AREA=LOCATION.
```

Contextual Queries

Given **Q(X_1,…X_k) ← p_1,…p_n.**

Where **p_i** are intensional or extensional predicates, it is replaced by the contextual query

```
ctxtQ(X_1,…X_k, C_ID) ← ctxtp_1 (C_ID, Att1,…Attk),…,
 ctxtp_n(C_ID, Att1,…Atth).
```

where each predicate has been replaced by the contextual predicate, defined as in the rule schemata above.

Interesting, multifacet research

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- Context modeling and representation
- Context application
- Context acquisition
- Context learning
- …

Still from IJCAI ’93 Workshop:

- Can the notion of context be separated from the representation formalism?
- Is a single representation adequate?

(our) future work on context

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Design time:

- Context modeling
  - **Modeling dynamics and special context-to-context relationships**
- Study and design of the context model / application domain relationships for the different resources we want to "contextualize"
  - **context-to-resource links are surely resource- and application-dependent**
  - **Is context modeling resource-dependent?**

Run time:

- Context sensing (numeric observables) → the PerLa sensor language?
- Context recognition (symbolic observables)
  - **Resource-dependent**
- Context feeding and context-aware behavior
  - **Resource-dependent**
  - **Dynamic context generation and recognition**

Research @ the PErvasive Database GRoup PeDiGREE

- Databases for small devices [TOIS 2003]
- Sensor Network query languages [PERSens 2008, PERCom2009]
- Context modeling and context awareness [MDM 2006, Inf. Systems 2007, CACM 2009…]
- Contextual preferences and ranking [EDBT 2009]
- On-the-fly data integration [subm.]
- Ontology matching and consistency support [OTM, ESWC Wksh.]

The other group members: C. Bolchini, C.A. Curino, G. Orsi, E. Quintarelli, F.A. Schreiber