Context-aware system design: a data-oriented perspective

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[2] PErvasive Database GRoup of EnginEers

Situational, ubiquitous, context-aware computing

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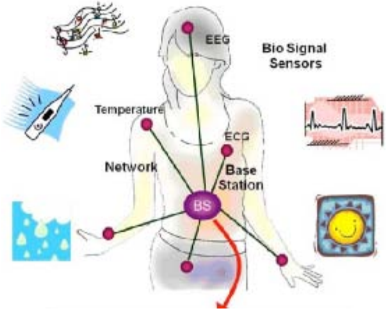
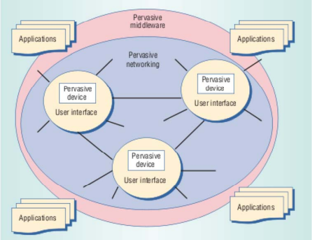
- From anytime, anyplace connectivity *for users* to connectivity and computing power available *for everything*
- RFID tags, wireless sensors and embedded devices allow the computer to *vanish in the background* becoming part of the infrastructure
- The middleware hides the heterogeneity of hundreds of devices making them *transparent to the application and to the user*



Pervasive systems

All models that describe *pervasive systems* share a high-level description [32]:



- a set of devices, adopting various technologies to perceive the environment and support the user in any interaction with it;
- a network, used to link devices together;
- a middleware, making dialogue possible between the pervasive network and the applications, possibly using a pervasive language;
- pervasive applications: the ultimate interfaces between final users and the system.

Pervasive computing

- Health, well-being, climate change, energy and transportations are all areas whose progress relies on strategic use of pervasive systems, for climate and traffic, managing emergencies, governing smart cities, on-line alert systems etc.
- The perception of the environment promotes
  - autonomicity
  - self-adaptivity
  - context-awareness
  - personalization
- In a pervasive system things "disappear", i.e. we are no more aware of their presence
- the system supports their management and we are free to use them without thinking
- $\Longrightarrow$ **we can focus on new goals**

Context-awareness and personalization in pervasive systems

- Using the knowledge of the *context* the system can relieve the user from the burden of specifying details, *focussing on core knowledge and activities*
- 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[3]
- User tastes and profile, external environmental factors, current trends and involved phenomena are today recognized as parts of the *notion of context* [2, 6, 33, 1, 4, 31]

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- 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.
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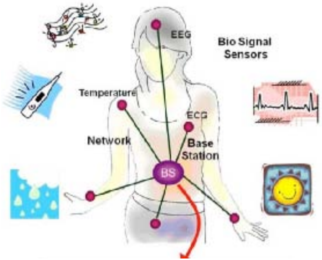
- The ENGINEERING view: context is useful in representing and reasoning about a restricted state space within which a problem can be solved.
- **The engineering view is subsumed by the cognitive science view.**

Examples: context in e-health and well-being:

- a person's vital parameters (blood pressure, heart beat, sweating,...)



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- weather conditions (very hot, moderate, very cold) , etc.

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- weather conditions (raining, snowing,...)
- system interface (smartphone, office PC, on-board tablet...), etc.

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A real case: the Green Move project

A concrete case: the Green Move project

- An ongoing project financed by the Lombardia Region
- Involves 8 departments and research centers of Politecnico di Milano
- Designing and implementing a Zero-Emission-Vehicles (ZEV)-sharing system in Milan
- Coordination of vehicles owned by different public administrations or companies
- Services and information spread over the territory and among vehicle fleet owners and users
- A trial will be carried out with a limited number of docking stations in a specific area of Milan

The Green Move project

A system for green mobility

- Availability: to have vehicle pick-up points close to the users' homes or offices – special "configurations" envisaged
- On-line traffic (and mobility in general) information – cars endowed with sensors and various devices that collect and forward mobility information
- Vehicle reservation and payment: a simple system for reserving a vehicle and reserving a parking place – sophisticated data mining and operations research algorithms on sensor streams will allow the system to know about vehicle availability for optimal reservations
- Ease of use: vehiche access and switch-on by means of the user's smartphones
- Flexibility w.r.t. parking and recharging availability - again by relying on sensor traffic data for previsions
- Costs: reasonable, and substantially less than car ownership

A data-centric vision of pervasivity

The variety and abundance of available data:

- when accessing information from portable, mobile devices, characterized by limited – although growing – resources and by high connection costs,
- when receiving information continuously from hundreds or thousands of devices scattered in the environment,
- and even when using powerful systems (see the *Big Data* challenge),

generates the need for

- removing *information noise*,
- effective and personalized information gathering, synthesizing and querying

....since the amount of "out-of-context" answers to a given user request may be overwhelming.

Context-aware systems

The capability to model, perceive and enforce context-awareness can be used to manage:

1. **communication**
2. **situation-awareness / behavioral variations**
3. **managing knowledge access**

Most approaches to context-aware personalization

- model the user context and personalization by means of static models, with fixed dimensions
- rely on unclear relationship between context management and information management:
  - mix-up context- and domain-modeling
  - mix-up context-aware and domain-aware behaviour
- are bound to specific data models and formalisms

Communication

- aiming to adapt content presentation to different channels or to different devices:
  - CSCP [7], following the CC/PP (Composite Capabilities/Preference Profiles) W3C recommendation where a profile is a description of device capabilities and user preferences
  - MAIS (Multi Channel Adaptive Information System [4]), used to configure the software on board of a mobile device based on presentation, device characteristics and available channels
- manage the agreement and shared reasoning among peers (among *users* or *systems*), or with the aim of building smart environments:
  - CoBra [8], where an agent-based architecture supports context-aware computing in physical spaces (e.g., living rooms, vehicles, corporate offices and meeting rooms), where a user can communicate *with* the environment.

[4] http://www.mais-project.it

situation-awareness and behavioral variations

- modeling what the user is currently doing [13] or his/her physical situation [21];
- making user interaction implicit by adapting information to user's needs, like in QUALEG [30], or in [11, 34], which propose context-aware service discovery in pervasive environments;
- extending programming languages to support behavioral adaptation [1] and providing dynamic changes in the offered functionalities through the combination of different layers in which the behavioral adaptation is specified and composed at run time (Context Oriented Programming [12]).

Managing knowledge access

- determining the set of relevant services, particularly in pervasive environments [25];
- determining the set of relevant behaviors: in [15, 34] the framework supports context-specific naming and representation of conceptual entities, relativised transaction execution, operations for context construction and manipulation, authorization mechanisms and change propagation;
- using *perspectives* in data management: [27] have extended the relational model to deal with context introducing *facets* of the data under different contexts.

Context-based information personalization

Objective: "shaping" user- or device-consumable information (e.g. answers to queries) according to the user or device situation and "preferences"

Basic activities:

- analyze, model and recognize characteristics of the users, or devices, or groups thereof
- implement context-aware behavior

Noticeably:

- user characteristics are mostly implicit – collected by behavioral analysis, sensing, . . .)
- non-functional aspects are also context-dependent (e.g., data quality[3], security)

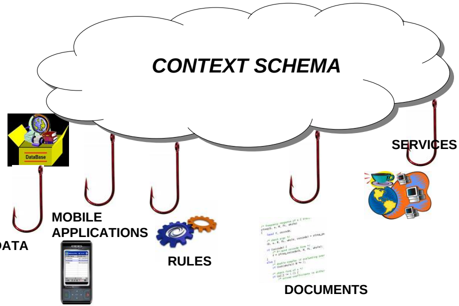
Development of a context-management framework

Because the applications are so different, we feel that context modelling should be addressed independently of the specific objective

- on the side of the operational system we design the *context management system*,
- where all the variables contributing to context have the special role of *context variables* and are modelled orthogonally with respect to the other instantaneous system inputs
- rather that being considered just as all the other system parameters (*holistic* view)

Background: Context management lifecycle

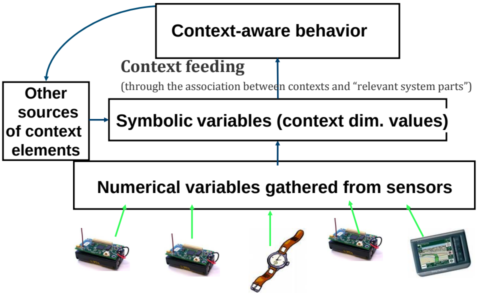
- **context-aware system design:**
  in which, using a *context model*, the *context schema* for the application problem and the "hooks" to the context-aware behaviours are designed



Background: Context management lifecycle

- **context-aware system design:** in which, using a *context model*, the *context schema* for the application problem and the "hooks" to the context-aware behaviours are designed

- **context-aware system at run-time:** in which the system interprets context parameters and, at each change of context, enacts *the specific context-aware behaviours*

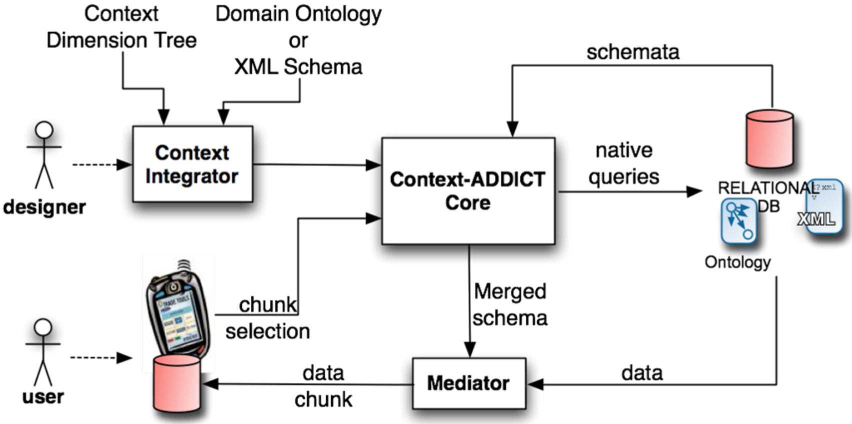


An architecture for Context-Management[9]

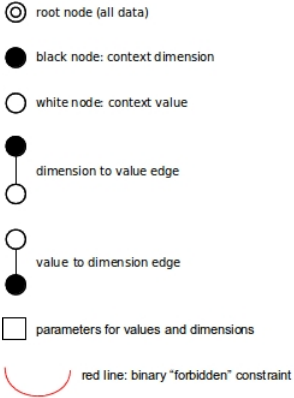
1. **Design-Time Context Integrator**: in charge of supporting
   - the design of the context schema of the specific application scenario by means of a suitable *context model*,
   - for each context admitted by the context schema, its association with the appropriate *context-aware view* over the available data sources.
2. **System Core or Context-Aware Personalization Manager**: determines, at each instant, the currently *active context*, applies contextualization to the queries issued towards the different data sources and delivers the context-aware data to the users and applications.
3. **Data Access Mediator**: offers access to data that can reside internally, for instance in a database, or in other, external data sources, providing an early-tailored, context-aware unified answer.

Processing, queries and data retrieval actions – needed to contextualize the information – transparent to the user

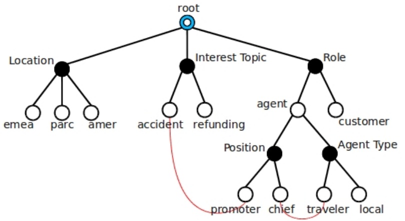
The Context-Management Architecture



Context Dimension Tree (CDT)

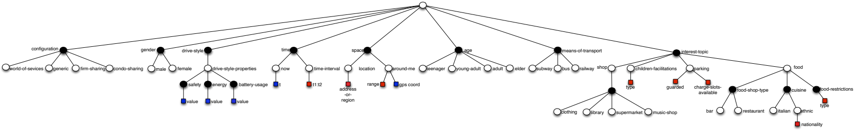


Elements of the *CDT context model*



- Context is hierarchically modelled in terms of *observable* parameters that have a symbolic internal representation within the *CDT context schema*
- The CDT model is completely independent of the specific formalism adopted.

The CDT of the Green Move project



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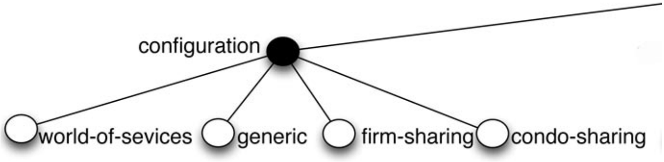

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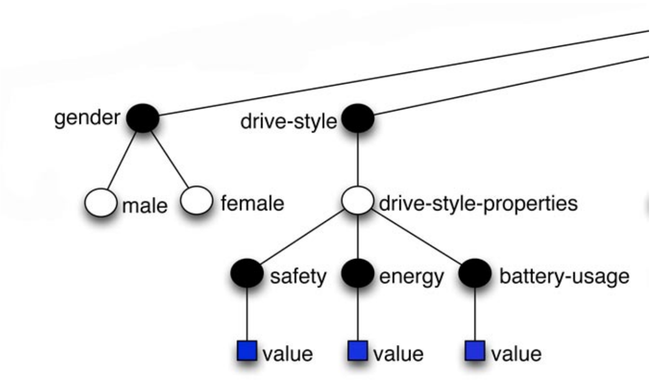

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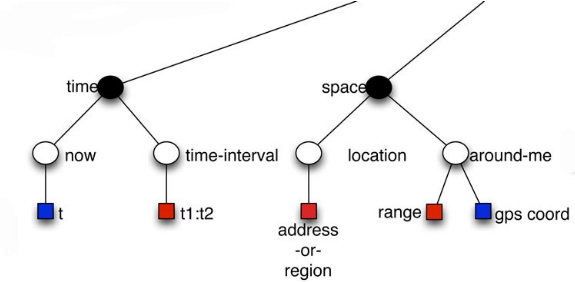

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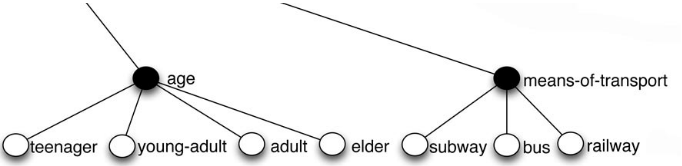

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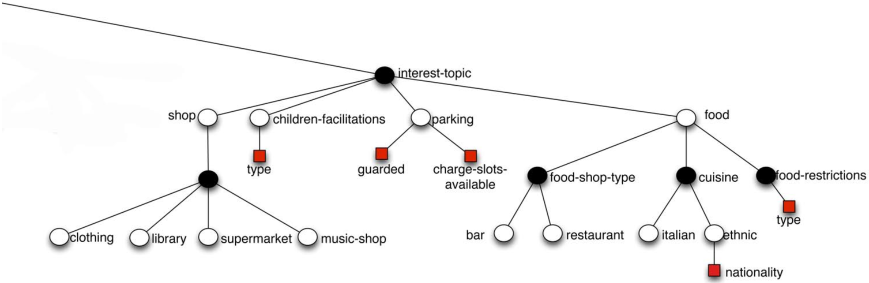
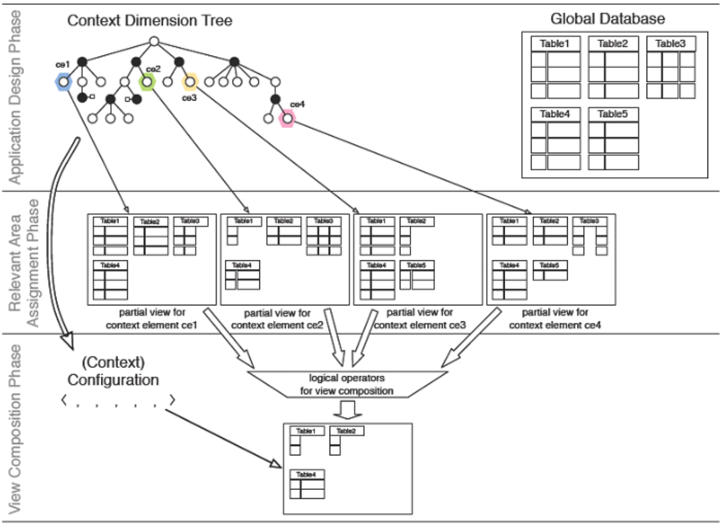


Context-aware data tailoring

- Recall: once the context schema has been designed...
- we have to associate the possible contexts with the relevant parts of information
- thus we tailor the data by associating a set of “relevant” data to each context
- such set is defined by means of a *view* over the entire data set

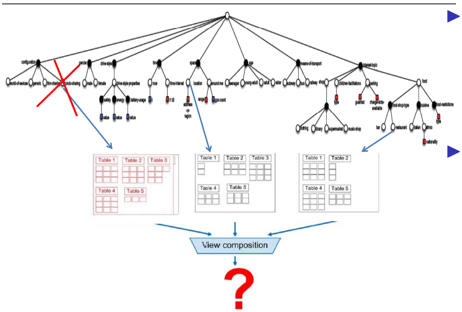
Data tailoring via view composition



Context schema evolution[22]

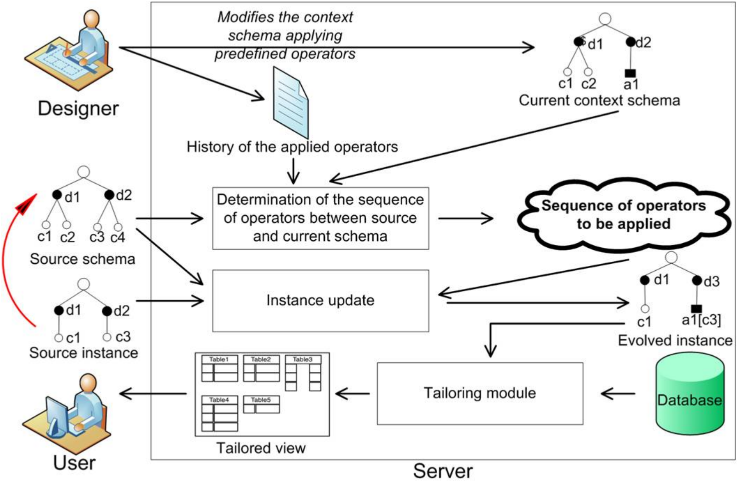
1. the designer's role is to envisage the possible contexts the user will incur during the system's life
2. the application requirements of a context-aware system are intrinsically dynamic and thus can evolve
3. what if during system life the possible situations change?
   - e.g. the configuration *world-of-services* is not available any more
4. the context schema used as the basis of the tailoring process should be allowed to change over time
5. along with the design and assignment of the related context-aware views

Context schema evolution



- Delete the *world-of-services* configuration
- All contexts (aka *context instances*) containing the world of services configuration will not make sense any more
- The designer might need to redefine the views for the sibling configurations

Context schema evolution



Properties of context schema evolution

- **Completeness of the schema evolution** Given two arbitrary context schemas S_1 and S_2, it is possible to find a finite sequence of the defined operators that transforms S_1 into S_2. The instances are transformed accordingly.
- **Soundness of the schema and instance evolution** Let S_S be a context schema, I_S an instance of S_S; the application of a schema and instance evolution operator to S_S and I_S gives as result another context schema S_T and an instance I_T of it.

Contextual Preferences[14]

- Preferences express interests on data as *numerical scores* or as explicit *order relations*
- data scoring is commonly used to rank information in several data management applications and search engines
- the system personalizes the query results by presenting them sorted in order of preference

Preference-based Personalization[5]

Green Move Interface:

What kind of vehicle do you prefer? $\Longleftarrow$ Tuple Preferences

Customer:

A car is better, if it is the same make. And it should include a baby seat.

Green Move Interface:

Which is more important for you: the vehicle or the presence of the seat? $\Longleftarrow$ Attribute Preferences

Customer:

The presence of the seat, definitely.

Green Move Interface:

These are the best available vehicles, according to your preferences $\Longleftarrow$ Preference combination

Customer: ...

[5] adapted from Jan Chomicki in [31]

Contextual preferences

- *Contextual preferences* are used to refine the views associated with contexts, by imposing a ranking on the data of a context-aware view and adding the opportunity to dispose of the less interesting portion if needed
- We cannot actually expect a user to manually specify the long list of preferences that might be applied to all available data when a context becomes active
- With the *PREMINE* component of the Context-Aware Personalization Manager, data mining is used to learn contextual preferences from the previous user activity

Contextual preferences

Context $C \equiv <config = condosharing, interest\ topic = children\text{-}facilities>$

Green Move Interface:

What kind of vehicle do you prefer?

Customer:

A car is better, if it is the same make.

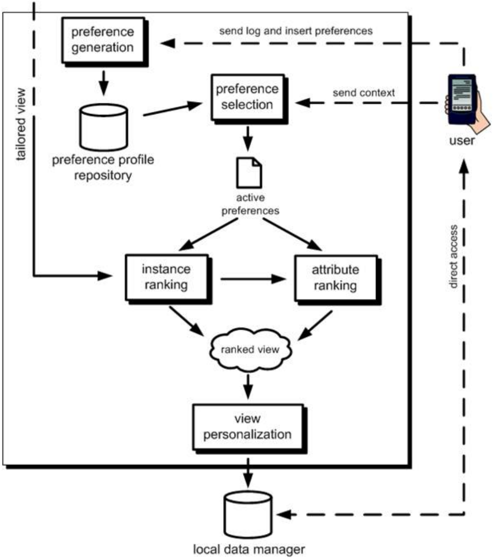
(The system knows that, in a context where the interest topic is "children facilities", the presence of the seat is a priority)

Green Move Interface:

These are the best available vehicles, according to your preferences

Customer: ...

PREMINE

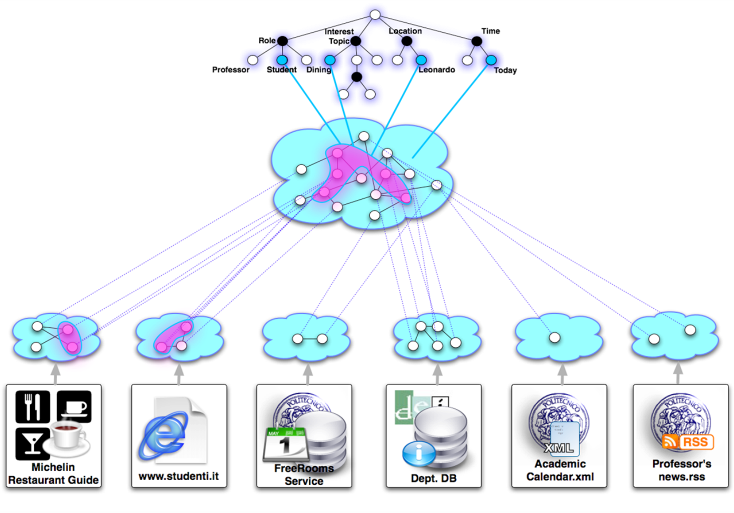

preference generation
send log and insert preferences
tailored view
preference selection
send context
user
preference profile repository
active preferences
direct access
instance ranking
attribute ranking
ranked view
view personalization
local data manager

Context-aware Querying of Heterogeneous and Dynamic Datasources

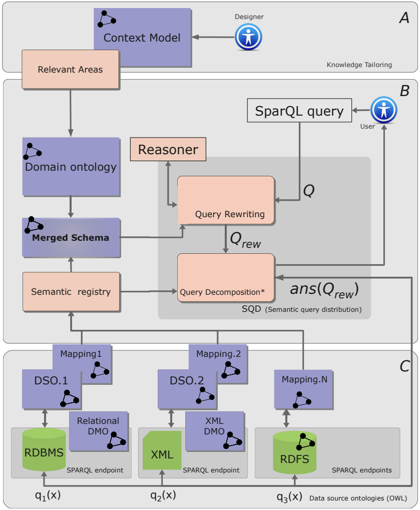
- Retrieve from the sources only the data that are consistent with the current context
- Sensors as data providers: spatially distributed and possibly mobile devices that monitor different kinds of physical phenomena *are datasources*

Moreover: context-aware detection of contextual data $\longrightarrow$ sensors to collect *numeric observables*

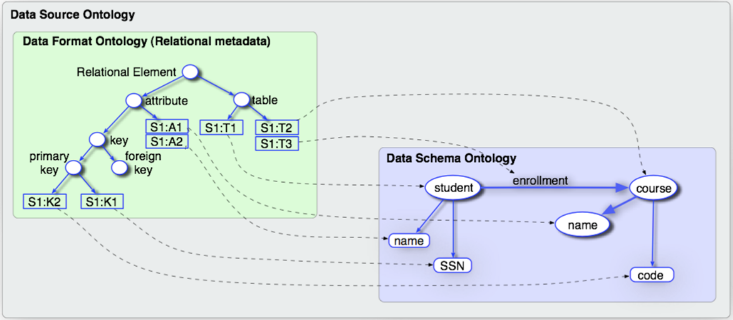
Extracting Context-aware Data from Heterogeneous Data Sources



The Data Access Mediator



Semantic Extraction from Relational Data Sources



Sensor Data Extraction: the PerLa language[28]

PerLa
PERvasive LAnguage

http://perlawsn.sourceforge.net/index.php

- A middleware and a language to manage pervasive systems hiding the complexity of handling the different device technologies
- A database-like abstraction of the whole sensor network
- Users can retrieve both functional and non-functional data from the system
- Users can send configuration/activation commands to the sensors in a fast and easy way
- Plug-and-play
- A context-management extension permits to provide the actual values for the context parameters

Context-aware sensor network

- Suppose we want to monitor the temperature of some containers inside a container ship
- we are only interested in those containers exposed to direct sunlight
- every container has a light sensor on the outside, and several temperature sensors inside
- we only have to query the sensors in containers subject to direct light
- trigger the temperature query when that container's light is over threshold

Context management in PerLa[17]

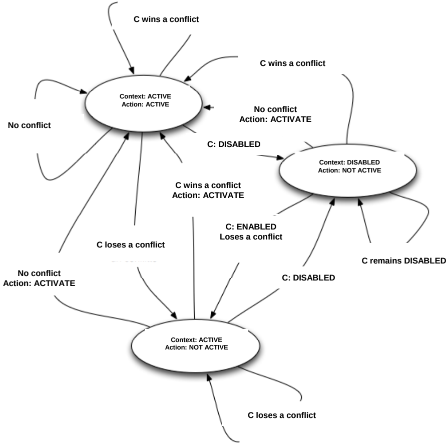
- *define the CDT structure*, also with the capability of acquiring that part of context information that cannot be deduced from sensor readings;
- *create a context* on a defined CDT;
- *activate/deactivate a context* at run-time as by the actual values of the context variables;
- *perform the contextual actions* required on the system, e.g.: activating actuators, changing measurement modalities
- *tailoring and composing partial queries* for run-time creation of a contextual query.

```
CREATE OUTPUT STREAM Monitoring
  (temperature FLOAT, humidity FLOAT,
  location_X FLOAT, location_y FLOAT)
AS LOW:
/*Low level query*/
EVERY ONE
SELECT temperature , humidity ,
  location_x , location_y
SAMPLING EVERY 1 m
  EXECUTE IF EXISTS (temperature) AND
    isInVineyard(location_x , location_y)
  REFRESH EVERY 10m
```

```
CREATE CONTEXT Growth_Monitoring
ACTIVE IF phase = 'growth' AND role='farmer'
        AND Disease.Type=3
        AND Disease.Affected_Hectares = 200
ON ENABLE:
SELECT humidity,temperature
WHERE humidity > 0 AND temperature > 0
SAMPLING EVERY 6 h
EXECUTE IF EXISTS humidity,temperature
    AND location='vineyard'
ON DISABLE:
    DROP Growth_Monitoring;
REFRESH EVERY 1 d;
```

Problems may arise

- do we allow concurrent activation of different contexts?
- conflicts might arise when two concurrent contexts perform incompatible actions



A data-centric vision of the cyber-physical systems

- A comprehensive research that tries to deal with all information-related problems of pervasive systems
- A data-centric vision of pervasivity is fundamental for advancing towards an empowered and inclusive society, where secure, easy-to-use, effective methods for data production and management are needed
- ICT progresses in all critical challenges of our society will mostly stem from making good use of the vast amount of information which is already available and often underused

This is the end: questions?

The context-ADDICT people

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