Context Modeling
Overview

- A Data-oriented Survey of Context Models
- Modeling context in pervasive computing systems
A Data-oriented Survey of Context Models
Ideal System

- A simple, explicit, unified model of context able to gather in a single representation several individual contexts.
Sophisticated and General Context Models

- Adapt interfaces
- Tailor the set of application-relevant data
- Increase the precision of information retrieval
- Discover services
- Make the user interaction implicit
- Build smart environments
Natural History Museum Portable Device

- Adapting the UI to different abilities of the visit
  - Low sighted people, young children
- Different contents to the different interests/profiles of the visitor
  - Geologist, scholar, journalist
  - The room the visit is currently in
- Learning from previous choices performed by the visit, what information s/he is going to be interested next
- Providing the visitor with appropriate service
  - Buy ticket for something, reserve a seat for the next in-door show on dinosaurs.
- Deriving location information from sensors which monitor the user environment.
- Provide active features within the various areas of the museum
Context-based Data Tailoring

- What portion is relevant?
- The activity of defining data views
  - The identification of the various contexts the application user is going to experience in the envisaged scenario
  - The design of a set of data views for each of the identified contexts.
Data Tailoring – Target Application

- Provide the user with the appropriately tailored set of data
- Match devices’ physical constraints
- Operate on a manageable amount of data
- Provide the user with time and location relevant data.
Why Data Tailoring?

- Huge ontologies are starting to appear
  - Several millions of concepts and relations
- Common operations such as query answering, reasoning and consistency check may be exponential in the size of input ontology.
Model Aspects – Where, Who, What?

- **Spaces**
  - Does the considered context model deal with location related aspects?

- **Time**
  - Allow the representation of temporal aspects?

- **Absolute/relative space and time**
  - GMT time reference and GPS coordinate vs “near something”, “last week”, “after that”?

- **Context history**
  - Does the current context state depend on previous ones?

- **Subject**
  - Who/what is the subject of the described context?

- **User profile**
  - Is the user preferences/personal features represented in the context model?
  - Does the system describe the user’s characteristics one by one or does it provide a role-based model of user classes?
Representation Features

- **Type of formalism**
  - Key-value-, mark-up- scheme-, logic-, graph-, ontology-based

- **Level of formality**
  - The existence of a formal definition, whether the formalization well expresses the intuition

- **Flexibility**
  - Ability to easily adapt to different contexts

- **Variable Context Granularity**
  - Ability to represent the characteristics of the context at different levels in detail

- **Valid Context Constraints**
  - Possibility to reduce the number of admissible contexts by imposing semantic constraints that the contexts must satisfy for a given target application.
Context Management and Usage

- Context construction
  - A **central**, typically **design-time** description of the possible contexts is provided
  - A **distributed** set of partners reaches an agreement about the current context description at **run-time**

- Context reasoning
  - Context model enable reasoning to infer properties or more abstract context information
    - Deduce user activity combining sensor readings

- Context information quality monitoring
  - System explicitly considers and manages the quality of the retrieved context information.
    - When the context data are perceived by sensors
Context Management and Usage

- Ambiguity and incompleteness management
  - If system can “interpolate” and “mediate” somehow the context information and construct a reasonable “current context”

- Automatic learning features
  - Ability to derive knowledge about context by observing user behavior, individual past interactions with others, or the environment
    - Learn user preferences by studying the user’s browsing habits

- Multi-context modeling
  - Possibility to represent in a single instance of the model all the possible contexts of the target application, as opposite to a model where each instance represents a context
Classes of Use – Context as a matter of

- Channel-device-presentation
- Location and environment
- User activity
- Agreement and sharing
- Selecting relevant data, functionalities and services.
Context Model - CASS

- Centralized server-based context agreement framework
- Meant for small portable devices, offering a high level abstraction on context sensed by appropriate sensors.
- Manages time and space, taking into account the context history and provides context reasoning
- No user profiling capabilities
- Context is a matter of location and environment.
| System               | Space | Time | Space/Time coordinates (Relative or Absolute) | Context history | Subject (User or Application) | User profile (Role or Features based) | User profile (Role or Features based) | Valid context constraints | Type of formalism: Key-value based | Type of formalism: Mark-up based | Type of formalism: Logic-based | Type of formalism: Graph-based | Type of formalism: Ontology-based | Formality level (High or Low) | Flexibility | Context construction (Distributed or Centralized) | Context reasoning | Context quality monitoring | Ambiguity/Incompleteness mgmt. | Automatic learning features | Multi-context model |
|----------------------|-------|------|-----------------------------------------------|-----------------|-------------------------------|----------------------------------------|---------------------------------------|-------------------------------|----------------------------------|-------------------------------|-----------------------------------|-------------------------------|----------------------------------|--------------------------|-----------------------------|---------------------------------|-------------------------------|-----------------------------|-----------------------------|
| ACTIVITY             | +     | +    | A                                             | +               | U                             | F                                       | +                                     | +                             | +                               | +                             | +                                 | +                              | +                                | Low (L)                           | +                         | +                           | +                              | +                            | +                          | +                          |
| CASS                 |       |      |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| CoBrA                |       |      |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| CoDaMoS              |       |      |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| COMANTO              | +     | +    | +                                             |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| Context-ADDICT       |       |      |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| Conceptual-CM        | +     | +    |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| CSCP                 |       |      |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| EXPDOC               | +     | +    |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| FAWIS                | +     | +    |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| Graphical-CM         | +     | +    |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| HIPS/HyperAudio      | +     | +    |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| MAIS                 | +     | +    |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| SCOPES               |       |      |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| SOCAM                | +     | +    |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
| U-Learn              | +     | +    |                                               |                 |                               |                                         |                                       |                               |                                 |                               |                                   | +                              | +                                |                          | +                         |                               | +                            | +                          | +                          |
Conclusions

- Context management and representation can hardly be considered assessed.
- Advocate model that are fully general and have a well-defined focus, and try to support only a specific context sub-problem.
- Systems whose aim is to be completely general and to support the context modeling problem as a whole for any application often fail to be effective.
  - The more expressive and powerful, the less practical and usable.
- Context model should be chosen depending on the target application.
- Analysis proposed can be used by an application designer to choose among the available model or define the requirements for a new context model.
Model Context Information in Pervasive Computing Systems

- Nature of applications must change accordingly as computing becomes more pervasive.
  - More flexible to respond to highly dynamic computing environments
  - Application must become more context aware and demand fewer demands on user attention.
- Need appropriate context modeling concepts for pervasive computing
  - General, formal, high information quality
  - Tackles complex relationships amongst context information and temporal aspects of context
Example Context-Aware Communication

- Bob - finished reviewing a paper for Alice, and wishes to share his comments with her.
- Bob - instructs his communication agent to initiate a discussion with Alice.
- Alice’s agent – Alice is busy and should not be interrupted
- Alice’s agent – Bob should either email Alice or meet with her in one hour
- Bob’s agent – consults Bob’s schedule and decides that Bob will be busy with something else after one hour
- Bob’s agent – prompts Bob to email on the workstation he is currently using and dispatches it according to the instructions of Alice’s agent.
- Alice’s supervisor Charlie – has Alice finished the paper?
- Alice’s agent – determines the query needs to be answered asap
- Alice’s agent – suggests Charles telephones her on her office number
- Charlie’s agent – establishes the call using the mobile phone Charlie’s currently carrying.
Agents

- Rely upon information about the participants and their communication devices and channels.
- Require knowledge about the participants activities (current and planned), the devices the participant owns and the devices currently being used.
- Require knowledge about relationships between people
  - Who supervises whom
  - Who works with whom
- Require information about the communication channels that a participant can use and the devices that are required by each channel.
Knowledge Acquisition

- Users supply relationships between people and the device ownerships and communication channels.
- Other information may be obtained by hardware or software sensors
  - Proximity of users to their computing devices
- Other information may be derived from multiple sources
  - User activity may be partly determined by the information stored in the user’s diary and partly derived from the user’s location
Context Information Characteristics

- Context information exhibits a range of temporal characteristics
- Context information is imperfect
- Context has many alternative representations
- Context information is highly interrelated
Context information exhibits a range of temporal characteristics

- **Static**
  - Ex. Birth date
  - Obtain directly from users

- **Dynamic**
  - Ex. Relationships between people
  - Obtain through indirect means (sensors)
  - May rely on past, present and feature
Context information is Imperfect

- Pervasive systems are highly dynamic, thus information can quickly become out of date.
  - Information may be distributed and information supplied by producers require processing, which cause delays
- Context producers (e.g. sensors, derivation algorithms and users) may provide faulty information.
  - Bad if information is inferred from this data
- Disconnections or failures can mean part or all of the context is unknown.
Context has many alternative representations

- Location sensor may supply raw coordinates, but an application may be interested in the identity of the building or room a user is in.
- Requirements can vary between applications.
- A context model must support multiple representations of the same context in different forms and different levels of abstractions.
- Must be able to capture relationships that exist between the alternative representations.
Context information is highly interrelated

- A person’s current activity may be partially derived from other context information
- The person’s location and history of past activities

Dependency

- The characteristics of the derived information (its persistence, quality and so on) and intimately linked to the properties of the information it is derived from
Shortcomings of Context Models

- Lack the formal basis to capture context in an unambiguous way and support reasoning about its various properties
- Do not address all of the context characteristics
- Ignore temporal aspects
- Do not address context quality
Core Modeling Concepts

- Founded on an object oriented approach
  - Context info is structured around a set of entities, each describing a physical or conceptual object such as a person or a communication channel
  - Attributes are properties of entities
    - i.e. name of a person or id of communication channel
  - Entity is linked to its attributes and other entities by uni-directional relationships known as associations.
- Directed graph
Classifying Associations

- Static Associations
- Dynamic Associations
- Derived Association
Static Associations

- Fixed relationships over the lifetime of the entity that owns them
- High confidence
Dynamic Associations

- Sensed associations obtained from sensors.
  - Typically not inserted directly into the model straight from the sensor, but transformed in some way to bring it closer to the level of the application’s abstraction requirement.
  - Sensed context may change frequently
  - Sensor errors due to the limitations in the sensing technology.
Derived Associations

- Obtained from one or more other associations using a derivation function
  - Simple calculation or complex AI algorithm
- Assumes some of the properties of the classes of information it is derived from.
- Derivation functions are often liable to draw incorrect or imprecise conclusions.
Derived Association Example

- Located near relationship
  - For each person, describe the set of devices located nearby
  - Relationships can be derived for a given person by examining the Location Coordinates attribute of every device and comparing it with the Location Coordinates attribute of the user
Dynamic association captures profiled information

- Information supplied by users
  - More reliable and longer-lived
  - May be stale – user may neglect to update
- Ex. User names, and the *works with* and *supervised by* associations that exist between people
Structural Constraints on Associations

- Simple, atomic facts
  - Each entity participating as owner of the association participates no more than once in this role.

- Complex histories
  - Collection association
  - Alternative association
  - Temporal association
Composition Associations

- **Collection**
  - Owning entity can be associated with several attribute values and/or other entities
  - People may work with many other people, and may have several communication channels

- **Alternative**
  - Alternative possibilities that can be considered to be logically linked by the “or” rather than “and”
  - A channel requires one of the devices it is associated with, rather than “all”.

- **Temporal**
  - Associated with a set of alternative values, but each is attached to a given time interval.
Modeling Dependencies

- Not between entities and attributes, but between associations themselves.
- \( a_1 \) depends on \( a_2 \) iff a change to \( a_2 \) has potential to change \( a_1 \).
- Dependencies may exist independently of derived associations
  - Battery life depends on bandwidth
∀p: Person, d: Device  \( \Rightarrow p \) is located near 

\( \text{dependsOn} \) p. located at

∀p: Person \( \Rightarrow p \). engaged in 

\( \text{dependsOn} \) p. located at

\[ \text{Legend} \]

Participation constraint 

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Dependency

Activity

\( \text{engaged in [ ]} \)

\( \text{located at} \)

works with supervised by

\( \text{named} \)

Name

Person

②

\( \text{has channel} \)

Device

④

\( \text{is authorised to use} \)

Device Identifier

\( \text{identified by} \)

Device Type

Location Coordinates

①

\( \text{located at} \)

Channel

③

\( \text{is located near} \)

\( \text{is authorised to use} \)

\( \text{requires} \)

Channel Identifier

Channel

③

\( \text{has type} \)

Channel Type

③

\( \text{identified by} \)
Modeling Context Quality

- Errors come from sensing and classification errors, changes in the environment leading to staleness, etc.
- Existing model did not formally define what to do with ambiguities.
- Should allow associations to be annotated with a number of quality parameters, and each parameter is described by one more appropriate quality metrics.
Concluding Remarks

- Detecting conflicts
- Context information integration
- Management of sensors and derived context
- Privacy
- Partition and distribution of context information
References

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