Linking Context Modelling and Contextual Reasoning

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Motivation

Representations of context

- Context modelling (CM):
  quantitative, procedural, object-oriented perspective
- Contextual reasoning (CR):
  qualitative, logic-based, fact-oriented perspective

Ontology-based context modelling to bridge the gap

- taxonomic knowledge about users, objects, classes, etc
  - tractable object-oriented ontology languages (e.g. DL)
- spatio-temporal knowledge, e.g. about locations, dates
- causal knowledge, e.g. about schedules, activities

Towards a tractable ontology language that supports taxonomic, spatio-temporal, and causal reasoning

Overview

Context Modelling

- Representation of context for context-aware computing applications
- Unified Context-Aware Application Model for developing context-aware applications
- Ontology-based user-centric context model

Context Logics

- Logics for specifying ontologies of context
- Special purpose logics: space, time, taxonomies
- Logical languages for specifying ontologies of context

Example

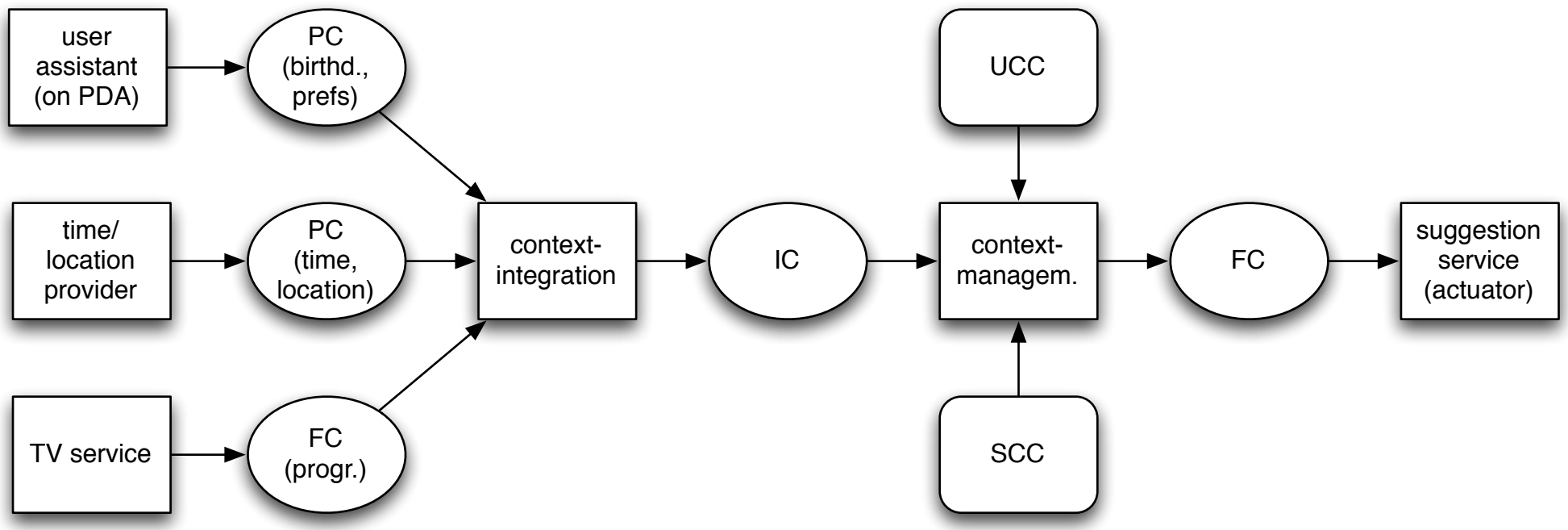
Context in Context-Aware Computing

Processing context: sensors → over a network → to applications → activating actuators in a meaningful manner

level of abstraction	representation	aspect	context models
communication	record-type, XML, key-value	hardware + network	Schilit et al. (1994)
sensors	key-value + time frame	sensors + uncertainty	Schmidt et al. (1999b)
developers	object-oriented	software-development	Dey (2000), Henricksen/ Indulska (2006), Bardram (2005)
common sense	logic-based	ontology	Strang et al. (2003), Ranganathan/Campbell (2003), Gu et al. (2005)

Example Context Acquisition

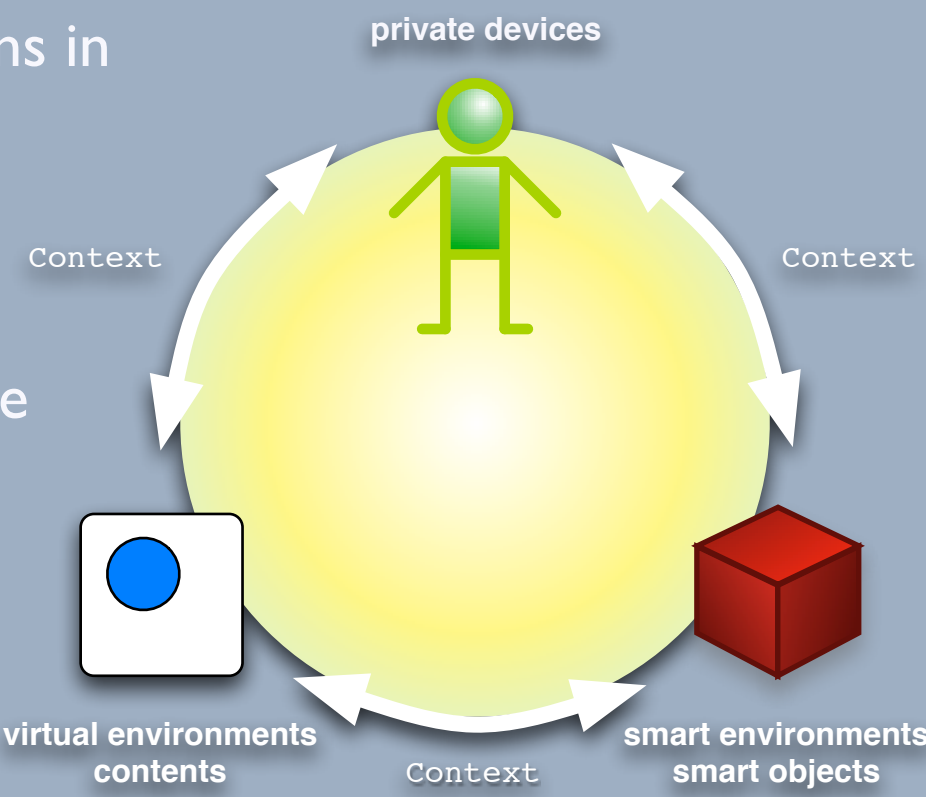
Processing context: sensors → over a network → to applications → activating actuators in a meaningful manner



Unified Context-aware Application Model

Context-aware applications in

- private devices:
  user is the same
- smart environments:
  fixed in a certain place
- smart objects:
  fixed service type



➡ Communication via context-objects

Context Model

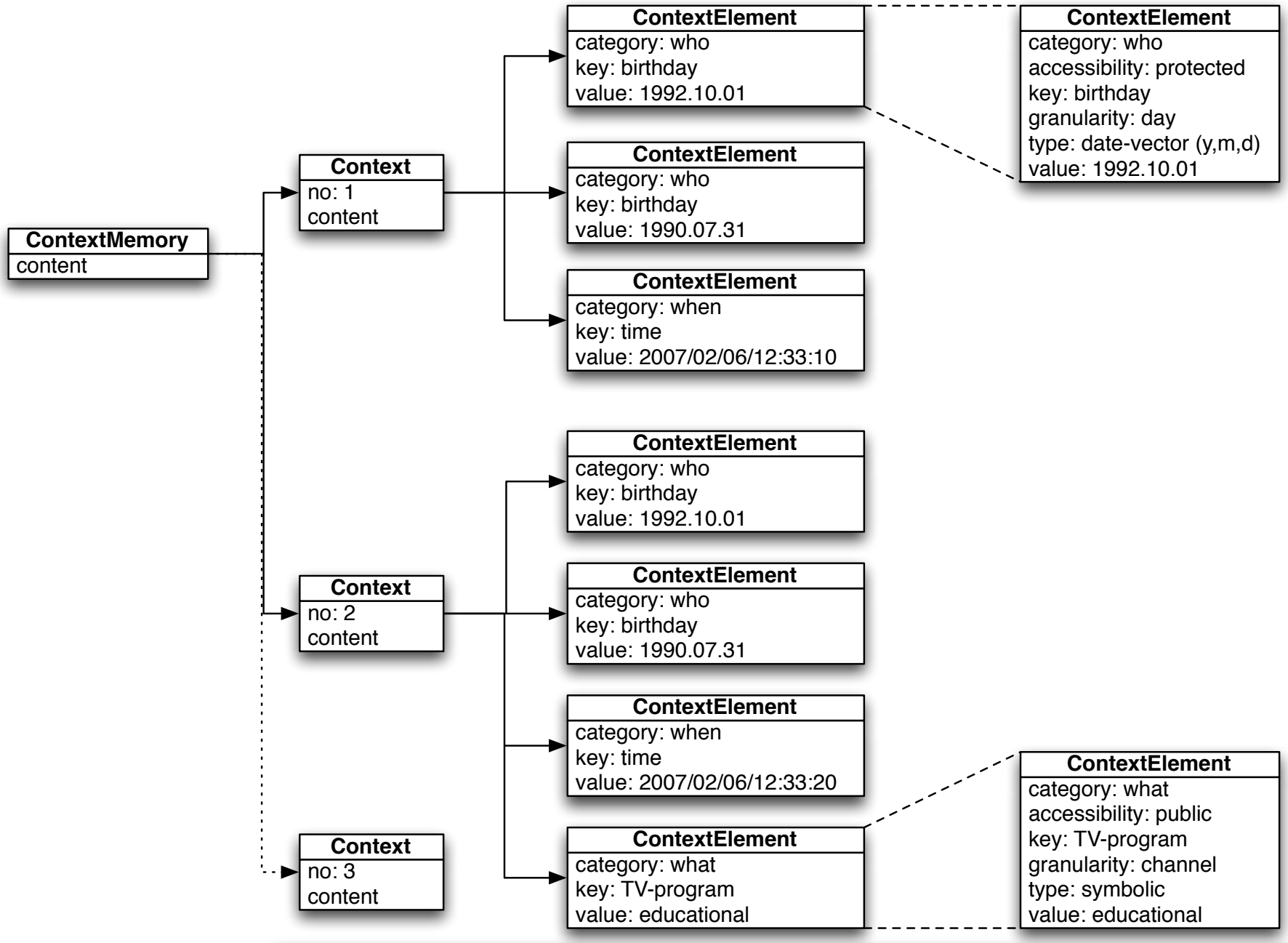
Context objects

- contain a complete description of the context of the user at a certain time
- consist of one or more context element objects
- are collected into a temporally ordered history: context memory

Context element objects

- regard a specific category: who, when, where, what, how, or why
- allow the user to control publication of data (accessibility): public, private, protected
- store concrete contextual data (e.g. from a certain sensor) in the form of key, granularity (unit), type, value

Example Context



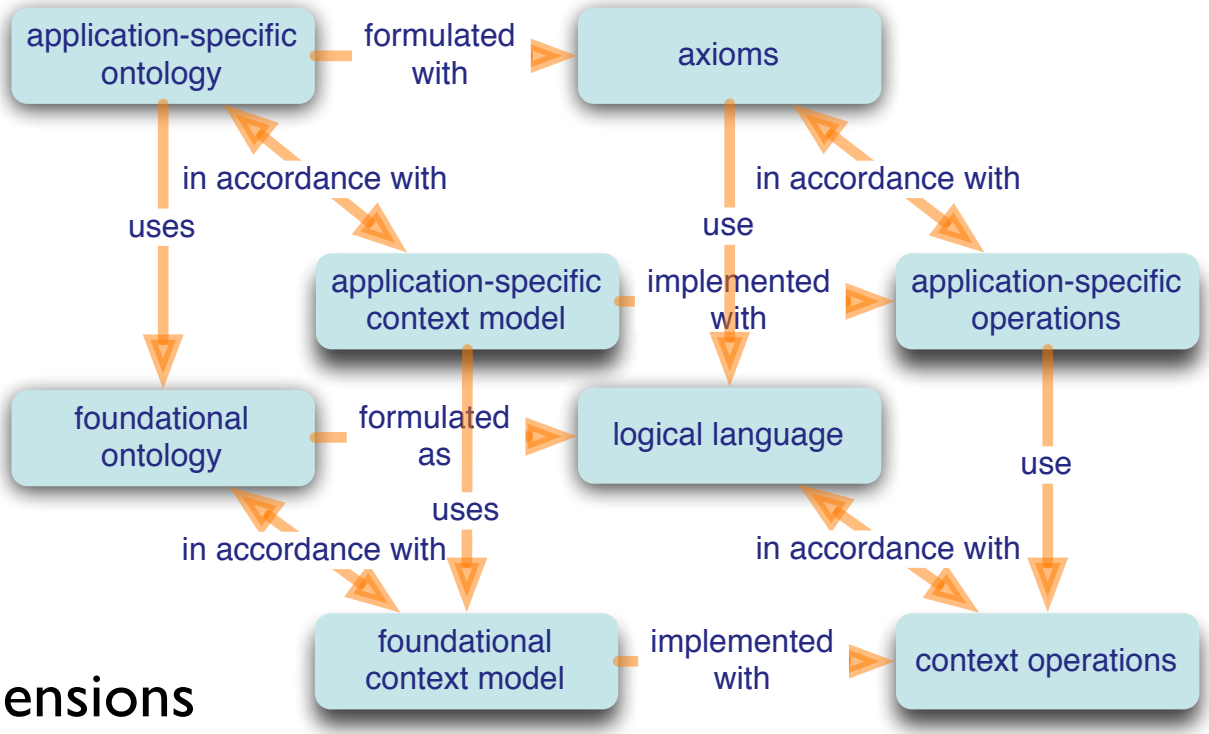
Categories

Context as describing circumstances of a certain *interaction*:

User(s) (*who*) interact in a certain manner (*how*) and for a certain reason (*why*) with objects and services (*what*) at a certain time (*when*) and place (*where*).

	context model	example	semantics
who	basic user information	name, birthday	sets of users
what	relevant objects	applications, services, commands	sets of objects
when	time	time stamp, time of day, season	time intervals
where	location	coordinate with uncertainty radius (x,y, r), place, region	spatial regions
how	ongoing processes	signals from sensors, e.g. current activity	sets of time series
why	intentions, explanations	stress, emotion, future events from a schedule	sets of time-lines

Approach to Ontology-based Context Modelling



Dimensions

- foundation (bottom) – application-specific (top)
- procedural (front) – logic-based (back)
- concept (left) – realisation (right)

➡ Why should context ontologies need a new logical formalism?

Ontologies of Context

	Description Logics (OWL, DAML +OIL)	F-Logic (Ontobroker)	First Order Logic
ASC/CoOL	optional	o	
GAIA	o		o
SOUPA/ COBRA-ONT	o		o
SOCAM/ CONON	o		o

Do context ontologies require expressive power beyond the taxonomic constructs provided in DL?

Space, time, processes (time series), causality

Semantic Web Logics

Ontology specification logics with tractable reasoning

- Description Logics
  - concepts and concept hierarchies (taxonomies)
  - roles connect individuals (objects)
- F-Logic
  - classes, class hierarchies, types
  - attributes and methods (relations and procedures)

Object-oriented knowledge representation

- taxonomic knowledge (sub-class)
  semantics: sets of individuals, subset
- connections between individuals (attributes/roles)
  semantics: relations

Special Purpose Logics

Reducing generality makes reasoning formalisms decidable, e.g.

- Description Logics – Modal Logics (Schild, 1991)
- Spatial Logics: topological relations between regions – propositional logic (Bennett, 1994)
- Combinations of decidable logics (Kutz et al.): two types
  - *fusions* of decidable logics are decidable
  - *multi-dimensional* logics are often undecidable

Tailored multi-purpose logics can be tractable
where general-purpose logics would become intractable

➡ If context ontologies are to be used to represent context, they need more than the taxonomic constructs of DL

➡ If context ontologies are to be used to reason about context they need a language whose expressiveness is below that of full First Order Logic

Context Logics: Motivation

Aims

1. Expressiveness to encode
    1. application ontologies for context-aware applications (not only taxonomic but also spatial, temporal, causal knowledge)
    2. knowledge about a given series of contexts (input from the context modelling side)
2. Decidable, fast reasoning as with DL (OWL-DL)

Approach

- basic assumption: a context is fully described by the categories of 5W1H:
  who does *what where when how* and *why*?
- usually knowledge about a context is uncertain

Context Logics – Context Model

User(s) (*who*) interact in a certain manner (*how*) and for a certain reason (*why*) with objects and services (*what*) at a certain time (*when*) and place (*where*).

Idea: a *context object* (CM) corresponds to a *context term* (CL)

	context model	example	semantics
who	basic user information	name, birthday	sets of users
what	relevant objects	applications, services, commands	sets of objects
when	time	time stamp, time of day, season	time intervals
where	location	coordinate with uncertainty radius (x,y, r), place, region	spatial regions
how	ongoing processes	signals from sensors, e.g. current activity	sets of time series
why	intentions, explanations	stress, emotion, future events from a schedule	sets of time-lines

Not yet covered in current version

Terms and Formulae

Example

context8 $=_{who}$ john $\sqcup$ jane,

context8 $\sqsubseteq_{what}$ tv-program $\sqcap$ -comedy

Syntax

- terms: context8, john, john $\sqcup$ jane, comedy, -comedy, etc
- atomic formulae: context8 $=_{who}$ john $\sqcup$ jane,
  context8 $\sqsubseteq_{what}$ tv-program $\sqcap$ -comedy

Semantics:

- each term is to be interpreted by a four-tuple consisting of a group of users, a set of objects, a time (sets of time points), a location (sets of points)
- an atomic formula compares two contexts with respect to one category

Example

Each context term corresponds to a tuple
(who, what, when, where)
A context can have none, one, several, or all of these dimensions

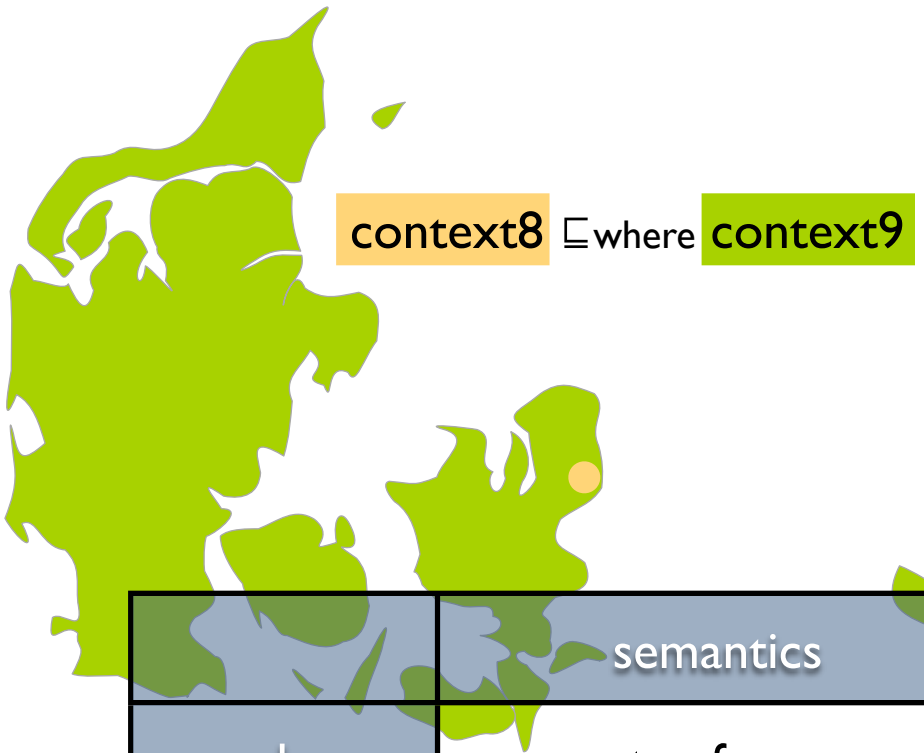
I(john) is the context that has only John as a user and is undetermined with respect to all other dimensions

I(context8) = ({johnS, janeS}, {tv-news-prog3}, [070820/20:15–070820/20:17], Copenhagen)

Representation "the users in context8 are john and jane":
context8 $=_{who}$ john $\sqcup$ jane

	semantics	I(john)	I(context8)	I(john $\sqcup$ jane)
who	sets of users	{johnS}	{johnS, janeS}	{johnS, janeS}
what	sets of objects	$\varnothing$	{tv-news-prog3}	$\varnothing$
when	time intervals	$\varnothing$	[070820/20:15–070820/20:17]	$\varnothing$
where	spatial regions	$\varnothing$	Copenhagen	$\varnothing$

Time and Space: Containment

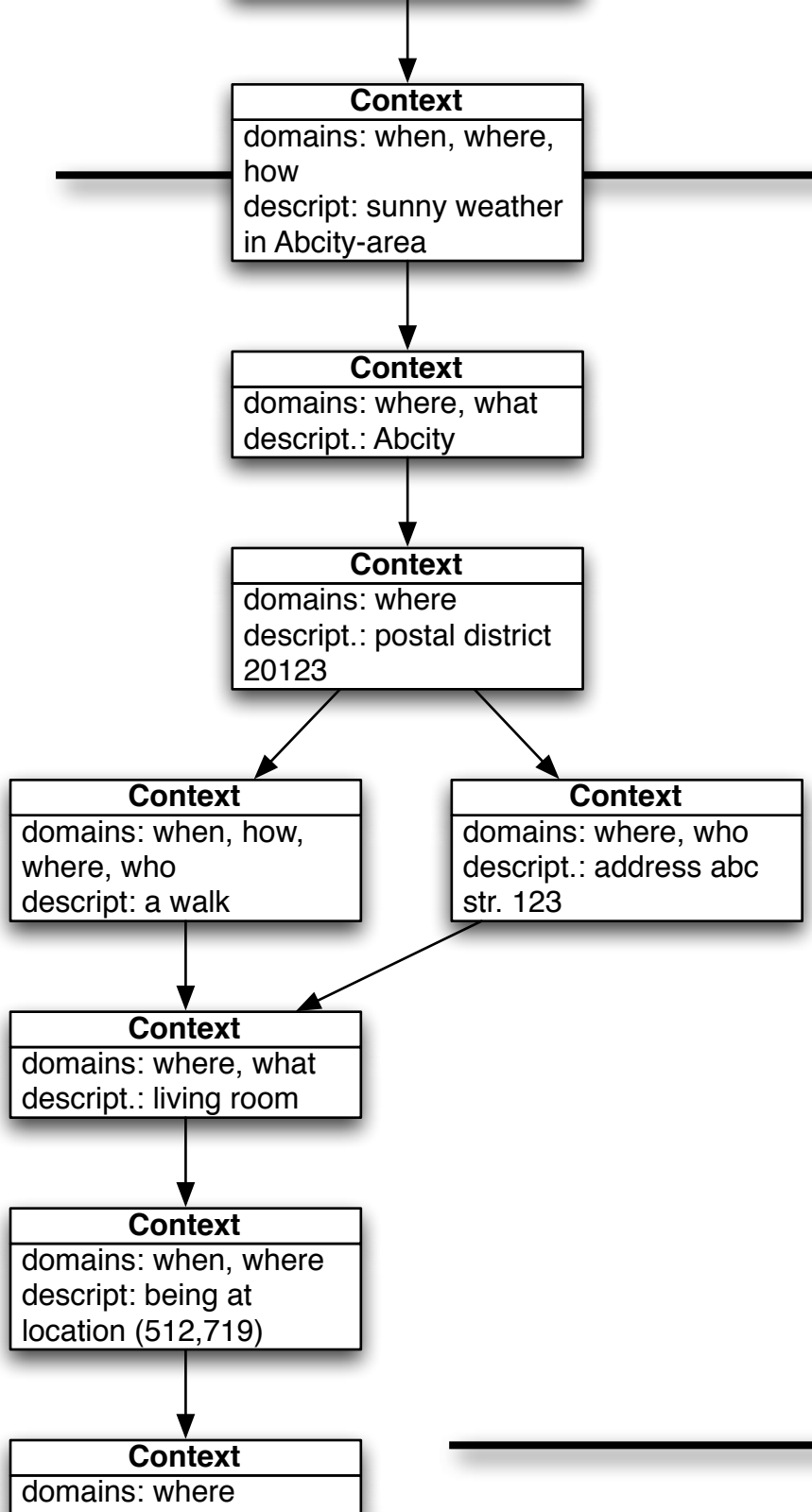


context8 ⊑where context9

context8 ⊑when context9

	semantics	I(context9)	I(context8)
who	sets of users	∅	{johnS, janeS}
what	sets of objects	∅	{tv-news-prog13}
when	time intervals	[070820/0:00–070820/23:59]	[070820/20:15–070820/21:17]
where	spatial regions	Denmark	Copenhagen

Example: where



The $\sqsubseteq_{\text{where}}$ hierarchy generates a directed acyclic graph (DAG) that can serve as a location model (cf Leonhardt, 1998)

each *where*-node corresponds to a specific region (not classes of regions):

- the key-value pair gives a (possibly underspecified) description
- the edges correspond to the spatial part-of-relation interpreting $\sqsubseteq_{\text{where}}$

Example: the user has taken a walk to a park nearby their home

- the region of the walk overlaps the region of the adress where the house of the user lies
- the living room as the starting point is part of the route

Context Logics Example: Who

John's birthday is August, 20th.

	context model	example	semantics
who	basic user information	name, birthday	sets of users

	Context Model		Context Logics		
	key	value	expression	type	who-semantics
John	name	"john"	name-john	context term	{johnS}
Birthday on August, 20th	birthday	"0820"	birthday-0820	context term	{johnS, janeS, ...}
John's birthday is August, 20th.			name-john $\sqsubseteq_{who}$ birthday-0820	formula	{johnS} $\subseteq$ {johnS, janeS, ...}

Context Logics Example: When

Today is a user's birthday.

	context model	example	semantics
who	time	time-stamp, date, time of day	time intervals

	Context Model		Context Logics		
	key	value	expression	type	when-semantics
Today	date	"070820"	today	context term	[2007.8.20] = [2007.8.20:00:00–2007.08.23:59:59]
Birthday on August, 20th	birthday	"0820"	birthday-0802	context term	... ∪ [2006.8.20] ∪ [2007.8.20] ∪ [2008.8.20] ∪ ...
Today is a user's birthday			today $\sqsubseteq_{when}$ birthday-0802	formula	[2007.8.20] $\subseteq$ ... ∪ [2006.8.20] ∪ [2007.8.20] ∪ [2008.8.20] ∪ ...

Expressiveness of Context Logics

The most simple context logic: hierarchies

- terms (recursive, all combinations with complement, union, intersection): john, jane, teenagers, john $\sqcup$ jane, context8, teenagers $\sqcap$ context8, birthday-0802, watchingTV, $\top$, $\bot$
- formulae (only atoms): today $\sqsubseteq_{\text{when}}$ birthday-0802, teenagers $\sqcap$ context8 $\sqsubseteq_{\text{who}}$ $\bot$ (there are no teenagers in context 8)

A more expressive context logic

- terms as before
- formulae (recursive, all combinations with negation, disjunction, conjunction, implication interpreted as usual): $\neg$[teenagers $\sqcap$ context8 $\sqsubseteq_{\text{who}}$ $\bot$]
- Example tautology: ([admin $\sqsubseteq_{\text{who}}$ staff] $\wedge$ [staff $\sqsubseteq_{\text{who}}$ notification]) $\rightarrow$ [admin $\sqsubseteq_{\text{who}}$ notification]

Outlook and Conclusions

Conclusions

- Context is more than time and location, but also: context is more than taxonomy
- Interesting rudimentary taxonomic, spatial, and temporal reasoning capabilities already with very simple logics

Future and Ongoing Works

- Investigation of extensions of Context Logics
  - Granularity is represented in the Context Model but not yet in the Context Logics
  - Representation and reasoning about how (processes and time series) and why (causality)
- Extension of UCAM into an application model for fine-tuned reasoning and representation