Qualitative Spatial and Terminological Representation & Reasoning for Ambient Environments

Recent Trends and Future Directions — A Survey Discussion

Joana Hois, Frank Dylla, and Mehul Bhatt

SFB/TR 8 Spatial Cognition – Universität Bremen

Spatial and Temporal Reasoning for Ambient Intelligence Systems
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Universität Bremen

Outline

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Introduction

Spatial Aspects of Ambient Environments (AmE)

- Assisted Living
- Smart Spaces

Contributions from two different fields

- What are qualitative spatial requirements of AmE?
- And how can qualitative spatial representation support AmE?

- What are terminological requirements of AmE?
- And how can ontological engineering support AmE?

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- And how can ontological engineering support AmE?

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Motivating Example: BAALL

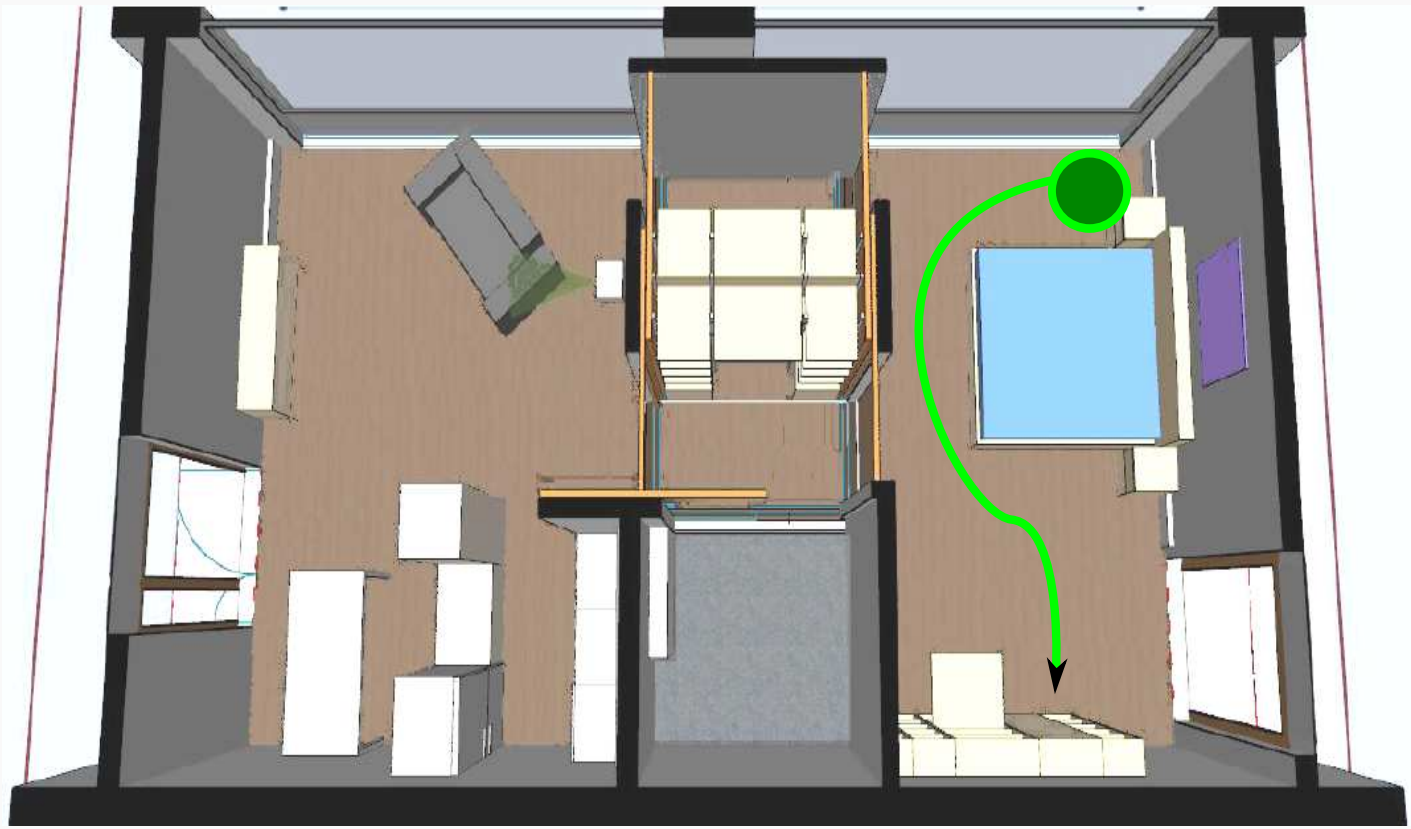
Bremen Ambient Assisted Living Lab

- suitable for the elderly and people with physical or cognitive impairments
- provides monitoring and ambient control, health-critical components and user-based profiles
- developed by German Research Center for Artificial Intelligence (DFKI), Bremen

BAALL Floor Plan

BAALL: Example

BAALL: Demo-Video



BAALL: Example

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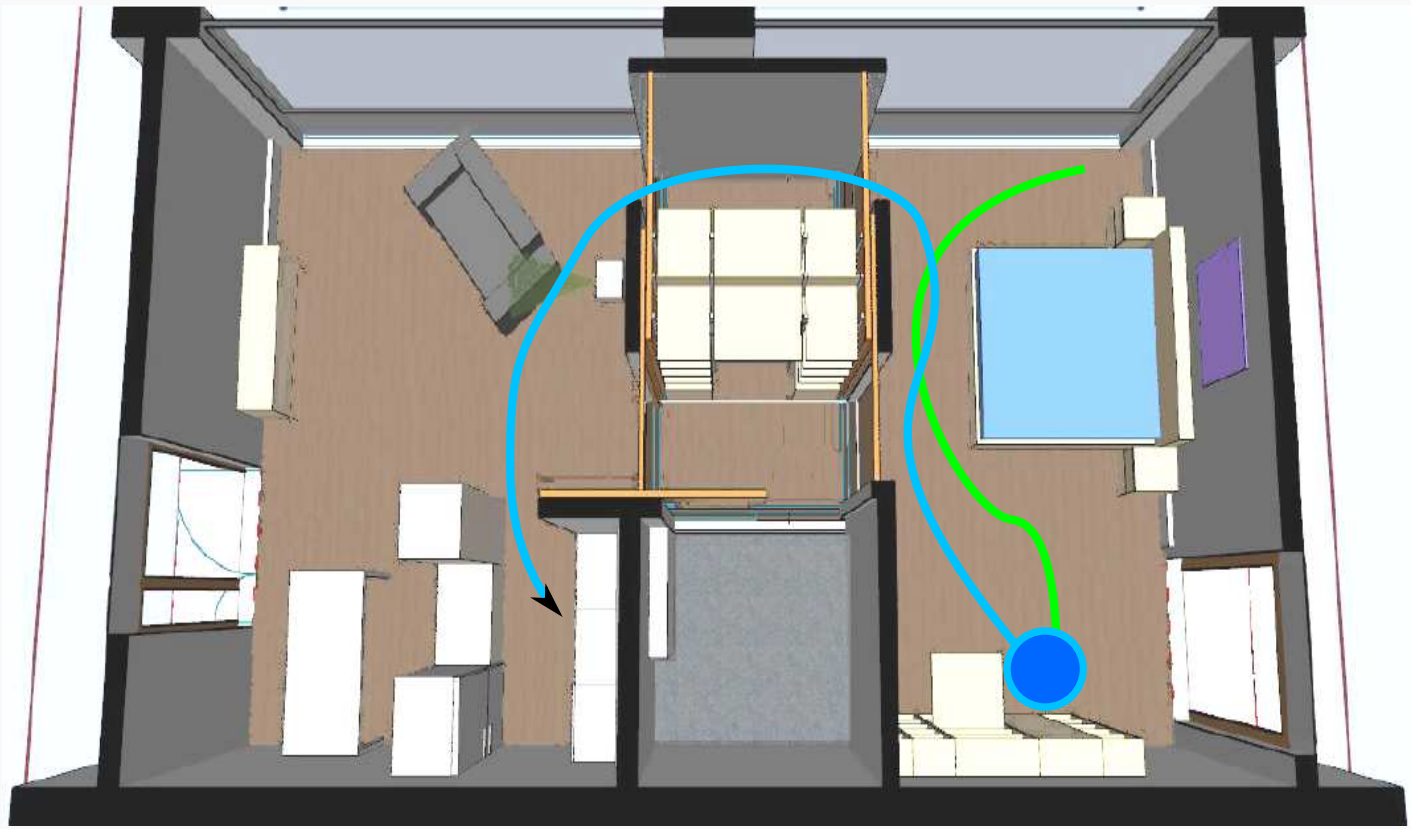

Qualitative Spatial Characteristics in BAALL

Regions

"in the kitchen", "adjacent to the cupboard", "on the sofa"

Orientations and Directions

"to the cupboard", "passing the closet", "in front of the bed"

Distances

"near the bed", "close to the refrigerator"

...and more

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Terminological Characteristics in BAALL

Entities

"kitchen", "sliding door", "books"

Properties of Entities

"open/closed", "locked", "on/off"

Relations between Entities

"user access to apartment", "functional aspects of kitchen", "user-specific movements of shelfs"

Different Types of Information

"door", "sliding door", "wooden door", "front door"

...and more

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Qualitative Spatial and Terminological Abstraction

Abstraction of Environment

- Abstract formalization of environment
- Interface to other tools or users
- Global representation of AmE in general

Support for Different Tasks

- Human-Computer Interaction
  (including Natural Language Processing)
- Monitoring and Predicting Behavior in Environments
- (Proactive) Decision Support
- Analysis of Actions in Environments

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Qualitative Spatial Representation & Reasoning

General Motivation

- taking into account multi-modality of space in a cognitively acceptable way [Freksa,91]
- capturing distinctions that are 'relevant'
- abstracting from geometric primitives (points, lines, regions, ...)
- specifying representation with discrete set of symbols

Qualitative Spatial Calculi

- complete model for a certain domain
- set of relations between objects
- operations: composition, converse, intersection, ...

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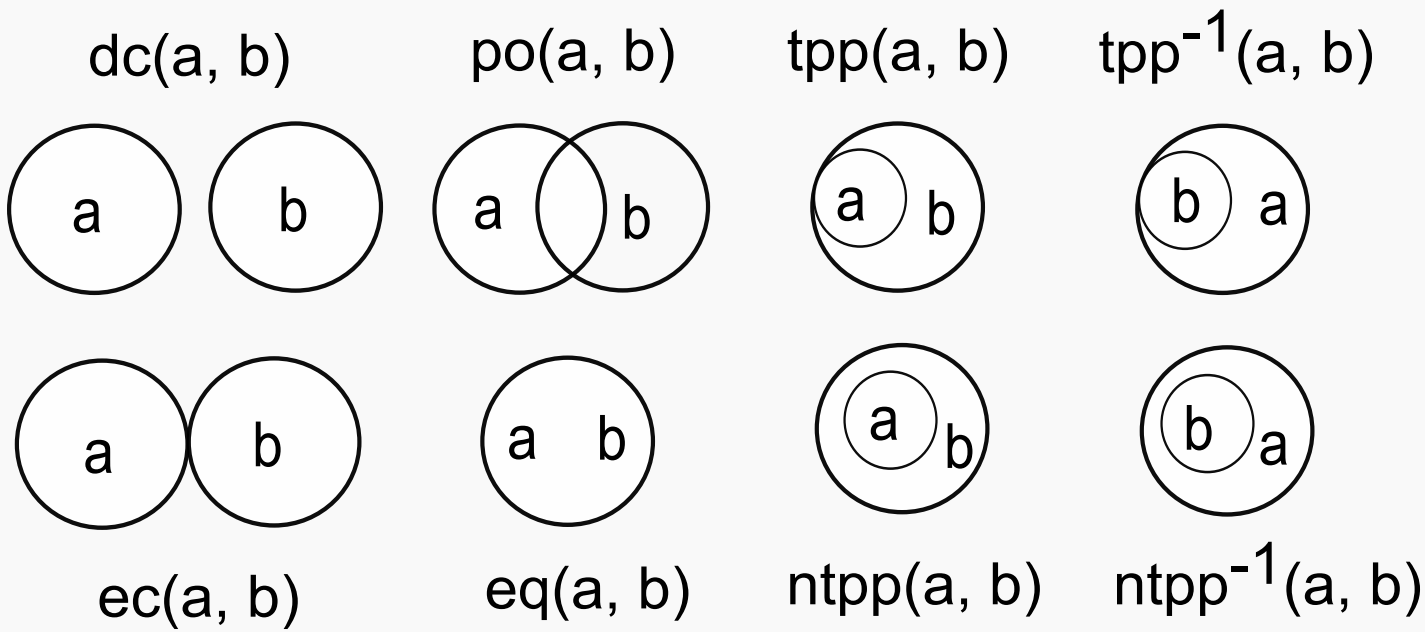
QSR: Region/Topology

Region Connection Calculus RCC-8 [Randell, Cui, Cohn 1992]



Examples

in the kitchen, on the sofa, adjacent to the closet

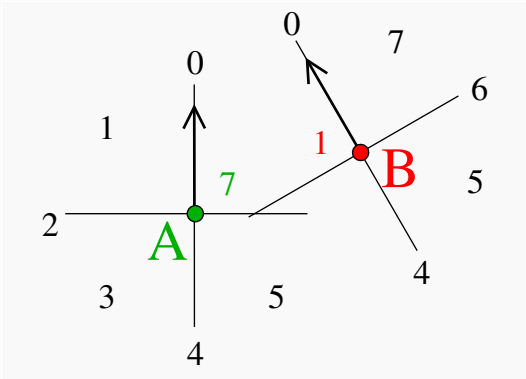
Example Scenario for Region/Topology

Region-Based Model of Floor Plan

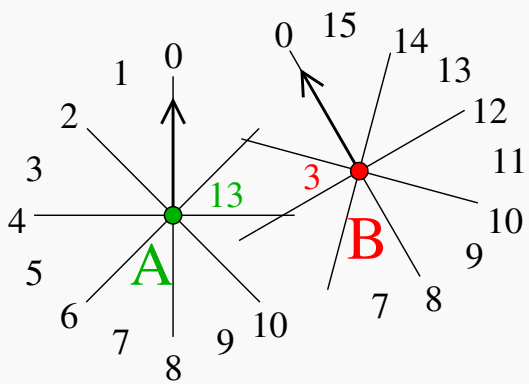
	bedroom	$hall_1$	$hall_2$	closet	bath	liv. room	kitchen	$door_1$	$door_2$	$door_3$	$door_4$	$door_5$
bedroom	EQ	EC	EC	DC	DC	DC	DC	EC	DC	EC	DC	DC
$hall_1$		EQ	DC	EC	EC	EC	DC	EC	EC	DC	DC	EC
$hall_2$			EQ	EC	DC	EC	DC	DC	DC	EC	EC	DC
closet				EQ	DC	DC	DC	DC	DC	DC	DC	DC
bath					EQ	DC	DC	DC	DC	DC	DC	EC
liv. room						EQ	EC	DC	EC	DC	EC	DC
kitchen							EQ	DC	DC	DC	DC	DC
$door_1$								EQ	DC	DC	DC	DC
$door_2$									EQ	DC	DC	DC
$door_3$										EQ	DC	DC
$door_4$											EQ	DC
$door_5$												EQ

QSR: Orientation

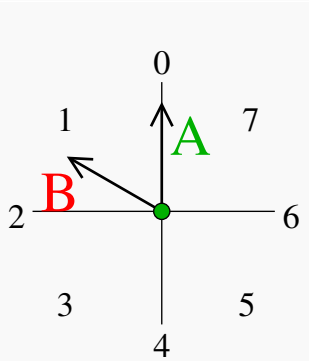
$\mathcal{OPRA}_m$[Moratz 2006]



$2\angle^{1}_{7}$



$4\angle^{3}_{13}$

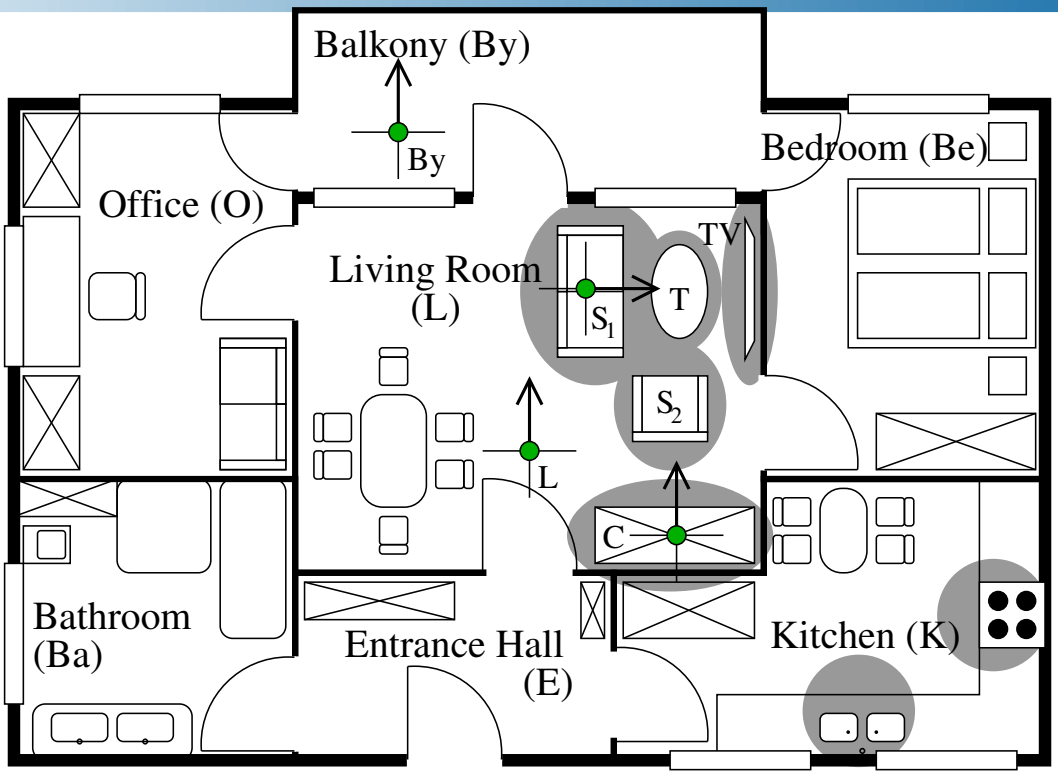


$2\angle 1$

Examples

to the front-left of the TV, to the right of the shelf, behind the sofa

Example Scenario for Orientation

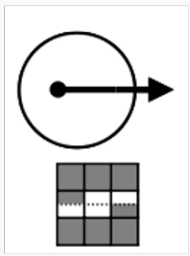


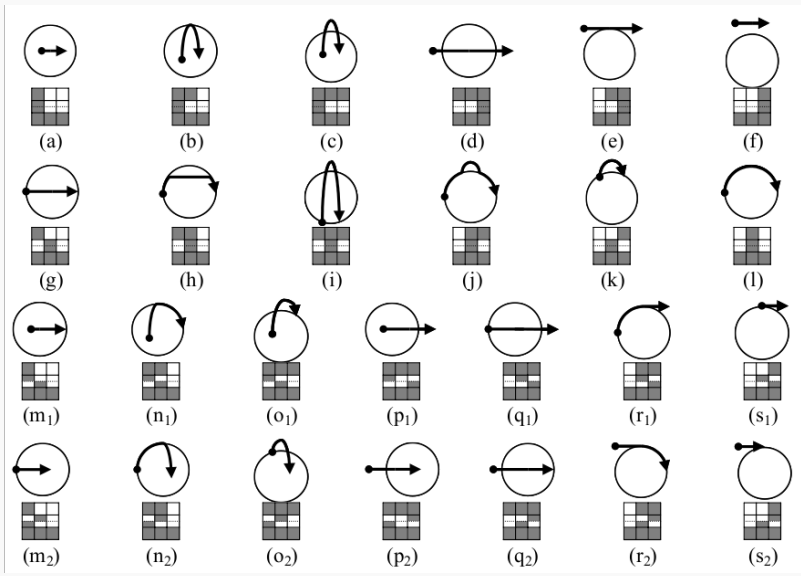
Orientation-Based Model of Floor Plan

ϕ_{top}/ϕ_{ort}	S_1	S_2	T	TV	C
S_1	x x	DC $2\angle^{1}_{7}$	DC $2\angle^{0}_{0}$	DC $2\angle^{0}_{0}$	DC $2\angle^{1}_{7}$
S_2	DC $2\angle^{7}_{1}$	x x	DC $2\angle^{2}_{0}$	DC $2\angle^{1}_{7}$	DC $2\angle^{0}_{4}$
T	DC $2\angle^{0}_{0}$	DC $2\angle^{0}_{2}$	x x	DC $2\angle^{0}_{4}$	DC $2\angle^{0}_{2}$
TV	DC $2\angle^{0}_{0}$	DC $2\angle^{7}_{1}$	DC $2\angle^{4}_{0}$	x x	DC $2\angle^{7}_{1}$
C	DC $2\angle^{7}_{1}$	DC $2\angle^{4}_{0}$	DC $2\angle^{2}_{0}$	DC $2\angle^{1}_{7}$	x x

QSR: Region & Direction Mix

9^+-intersection calculus for topological relations between a directed line segment (DLine) and a region [Kurata 2008]

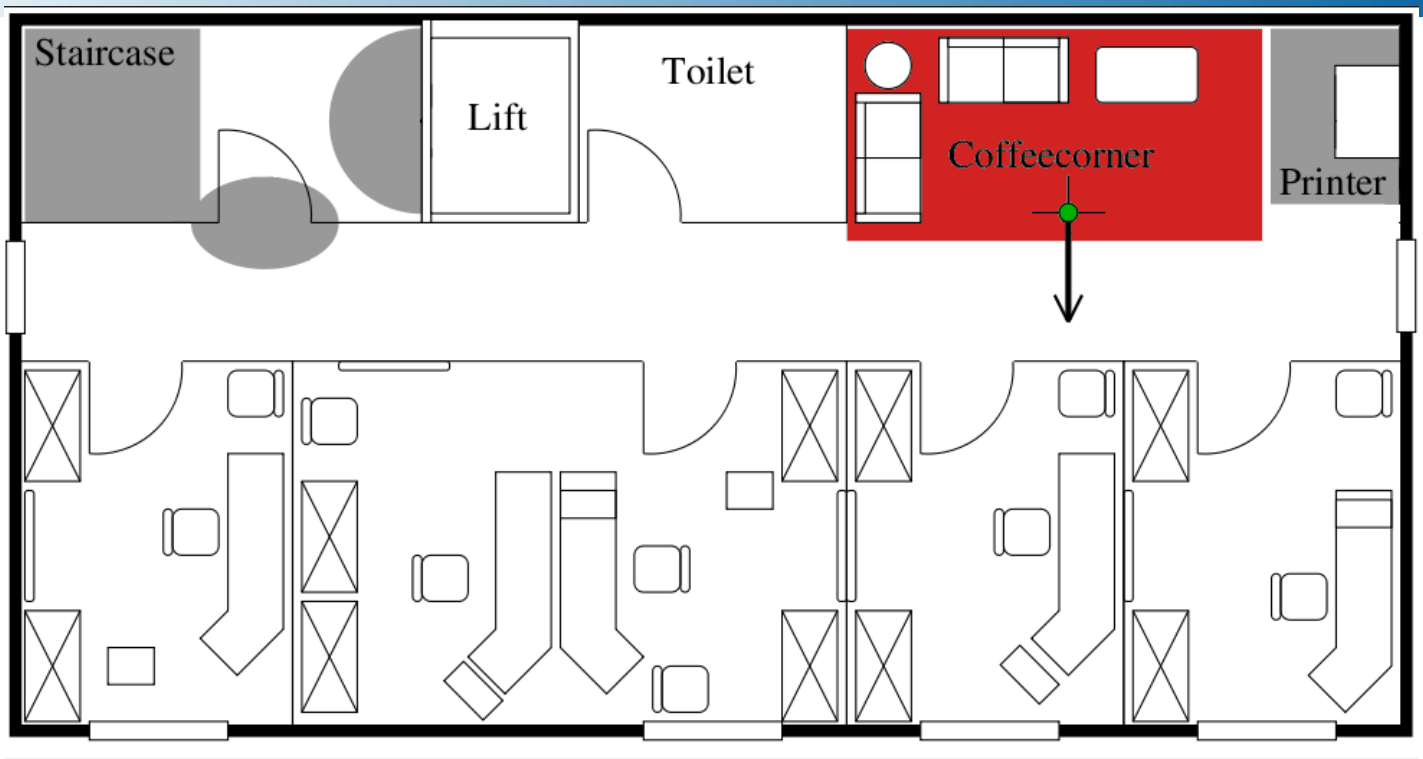




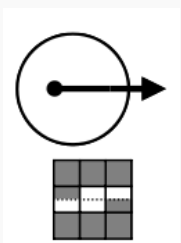
Examples

into the living room, out of the kitchen, towards the shelf

Example Scenario for Region & Direction Mix

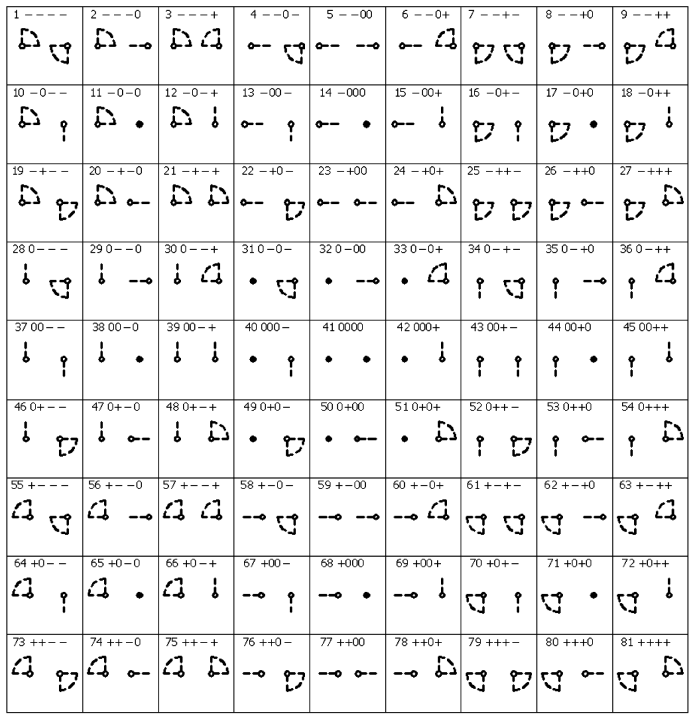


9^+-Intersection-Based Model of 'out of the coffee corner'



QSR: Dynamic Orientations

QTC - Qualitative Trajectory Calculus [Van de Weghe 2004]



Examples

the wheelchair is moving towards the kitchen

QSR: Overview

Qualitative Spatial and Temporal Calculi and their Properties

Name	Domain	No. of Base Relations	NP-Hard	a-closure decide consistency for atomic networks	Extensional	Tractable Subsets
Allens Interval	1D Line Segments	13	yes	yes	yes	ORDHorn
rectangle calculus	rectangles	169				
Closed Disk Algebra	2D Closed Disks	8	yes	no	yes	
LR Calculus	Points	9	yes	no		
Dipole Calculus DRAc	Directions from Line Segments	24				
Dipole Calculus DRAf	Directions from Line Segments	72				
Dipole Calculus DRAfp	Directions from Line Segments	80				
OPRA1	Oriented Points	20				
OPRAm	Oriented Points	4m*(4m+1)				
Single Cross Calculus	Points	8				
Double Cross Calculus	Points	15				
Nine-Intersection Model	Simple 2D Regions	8		no	yes	
Point Algebra	Points along a line	3	yes	yes	yes	all
RCC5	General 2D Regions	5	yes	yes	no	n.a.
RCC8	General 2D Regions	8	yes [1]	yes [2]	No	H^8, C8, Q8
RCC23	General 2D Concave Regions	23				
Star Algebra	Directions from a point					
INDU	1D-Line Segments + Size	25				
Cardinal direction calculus	Directions					
Qualitative trajectory calculus QTC-B11	Moving Point Objects in 1D	9				
Qualitative trajectory calculus QTC-B21	Moving Point Objects in 2D	9				
Qualitative trajectory calculus QTC-B12	Moving Point Objects in 1D	17				
Qualitative trajectory calculus QTC-B22	Moving Point Objects in 2D	27				
Qualitative trajectory calculus QTC-C21	Moving Point Objects in 2D	81				
Qualitative trajectory calculus QTC-C22	Moving Point Objects in 2D	305				
Qualitative trajectory calculus QTC-N	Moving Point Objects in a network	17				
TPCC	Points	25				
CYC-t	oriented lines	24			yes	

[http://quail.rsise.anu.edu.au]

Qualitative Spatial Reasoning

Reasoning

- constraint-based reasoning
- neighborhood-based reasoning

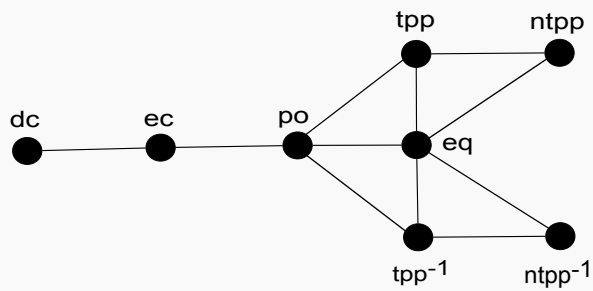
Constraint-based Reasoning

- reasoning about static configurations
- constraint satisfaction problem (CSP)
- consistency check by using composition & intersection

Qualitative Spatial Reasoning

Reasoning About Changing Configurations

- Conceptual Neighborhood: two relations are conceptually neighbored, if they can be *continuously* transformed into each other
- Example: RCC-8



- Complexity high, if many objects potentially move simultaneously
- Extension: action-augmented conceptual neighborhood

QSR: Tools

Tools

- SparQ: Spatial Reasoning done Qualitatively (in Lisp,C++) [Dylla, Frommberger, Wallgrün, Wolter 2006]
  - collection of tools for qualitative spatial calculi and reasoning
  - `www.sfbtr8.uni-bremen.de/project/r3/sparq`
- GQR: Generic Qualitative Reasoner in C++ [Westphal, Wölfl, Gantner 2008]
  - solver for binary qualitative constraint networks
  - `sfbtr8.informatik.uni-freiburg.de/R4LogoSpace/Resources/GQR`
- QAT: Qualitative Algebra Toolkit in Java [Condotta, Ligozat, Saade 2006]
  - constraint reasoning for n-ary calculi
  - generic tools for defining and manipulating qualitative algebras
  - `www.cril.univ-artois.fr/~saade/QAT`

Ontological Scene Description

Domain Ontologies for AmE

- Definitions of ambient-specific and general entities, their properties and relations
- Ontology-inherent reasoning techniques
- Re-usability and Interface to other tools
- Distinction between different *thematic* and *logical* layers

Scene Description

- Description of AmE instance can based on ontological representation
- Requirements consistency can be analyzed
- Specific queries can be formulated and proven
- (Ex: BAALL apartment environment as a concrete instance of an AmE ontology)

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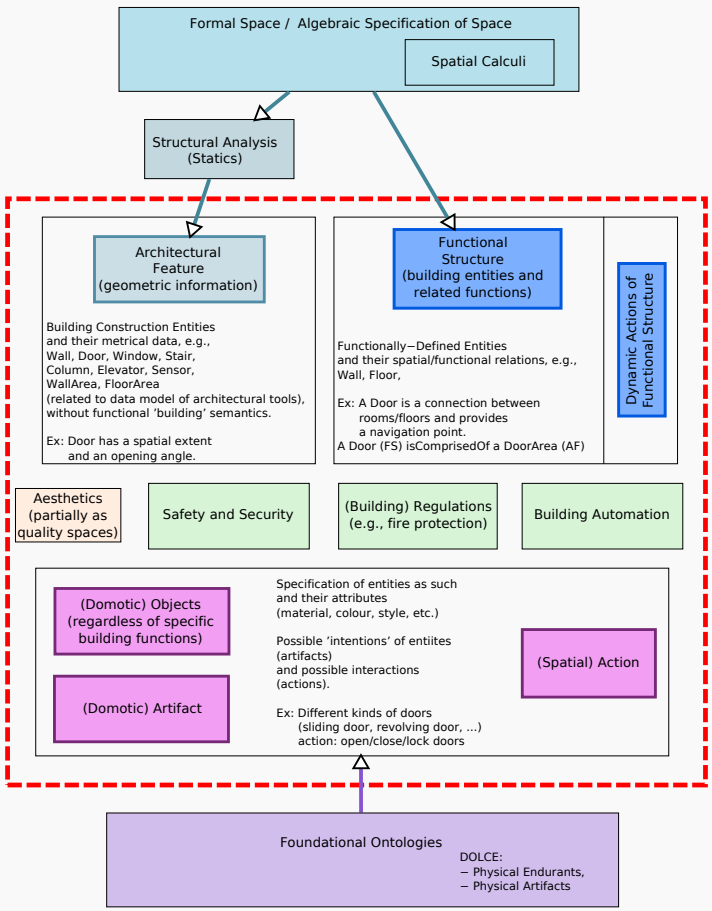
Example of Ontological Scene Description

Domotic Ontologies



Different Ontological Modules

- Basic Modules:

  Quantitative, Qualitative, Conceptual Spaces
- Thematically-Specific Modules:

  Access Control, Heating, Entertainment
- Integration of different perspectives:

  dependencies and constraints across domains
- Extension:

  specific ambient environment requirements

Ontologies: Tools

$\mathcal{OWL}$ 2.0

- DL ($\mathcal{SROIQ}$)
- OWL API
- XML format (connection to AmE-related tools)
- editors & reasoners

RacerPro

- Consistency Proof
- Queries
- Terminological and Spatial Reasoning (TBox, ABox, RBox, SBox)

Application Example

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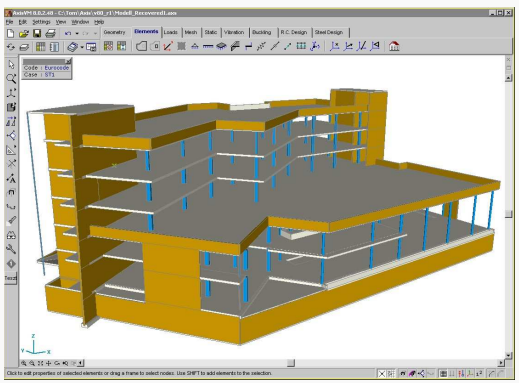
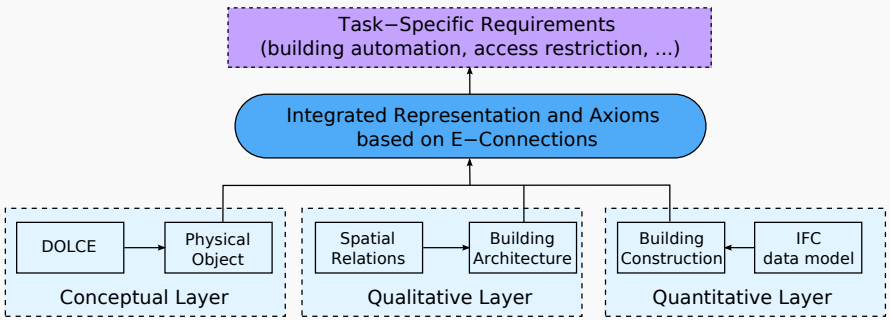
- taking into account some of the previous methods
- applying them to architectural design for AmE
- connecting results with different tools

- see: Mehul Bhatt, Frank Dylla, and Joana Hois "*Spatio-Terminological Inference for the Design of Ambient Environments*", COSIT'09 (Thursday, 12:00)





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Summary & Future Directions

Summary

- Overview of different approaches:
  - qualitative spatial reasoning
  - ontological engineering
  - their applicability to requirements in AmE
- Qualitative spatial descriptions can assist in formalizing essential spatial relations and their compositions
- Ontological descriptions can assist in formalizing essential AmE entities

Future Directions

- Combinations and Interaction of different (technical) components
- Simulation of interaction between user and ambient environment (evaluation aspects)
- Motion pattern abstraction for activity analysis and interpretation

Thanks for your attention!