Doctoral Consortium Extended Abstract:

Nonmonotonic Qualitative Spatial Reasoning

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ASPMT (QS)

Abstract

My work on PhD thesis consists in **nonmonotonic reasoning about spatial relations** and how they change in time. The work I have accomplished so far consists in a collaborated research with Mehul Bhatt and Carl Schultz which resulted in establishing the **ASPMT(QS) system [1] which is a novel approach for reasoning about spatial change within a KR paradigm**. ASPMT(QS) is based on a paradigm of Answer Set Programming Modulo Theories (ASPMT) [2] and polynomial encodings of spatial relations. The system is capable of sound and complete spatial reasoning, and combining qualitative and quantitative spatial information when reasoning nonmonotonically. Its first version is already implemented.

We have demonstrated (see [1]) that no other existing spatial reasoning system is capable of supporting the key nonmonotonic spatial reasoning features (e.g., spatial inertia, ramification) provided by ASPMT(QS) in the context of a mainstream knowledge representation and reasoning method, namely, answer set programming.

Qualitative Space

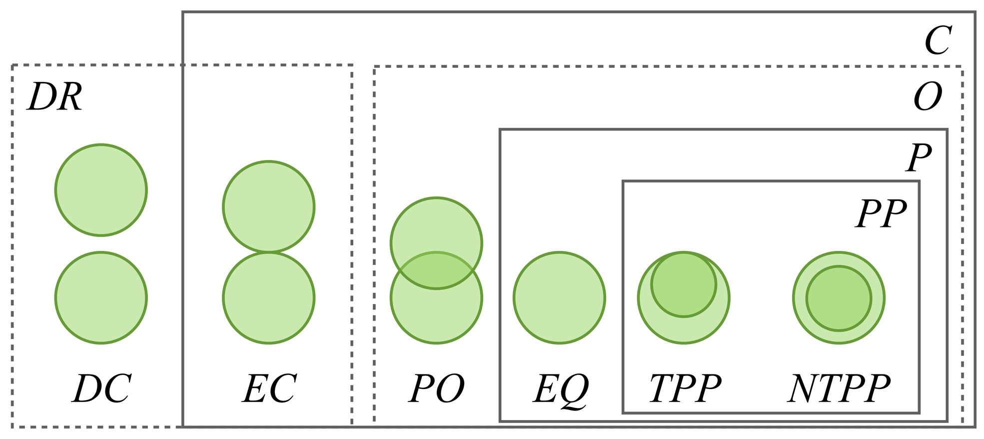
Basic **domain entities** in qualitative space with polynomial encodings include *circles, triangles, points* and *segments*:

- a *point* is a pair of reals x, y
- a *line segment* is a pair of end points p_1, p_2 $(p_1 \neq p_2)$
- a *circle* is a centre point p and a real radius r $(0 < r)$
- a *triangle* is a triple of vertices (points) p_1, p_2, p_3 such that p_3 is *left of* segment p_1, p_2.

We define a range of **spatial relations** with the corresponding polynomial encodings, e.g.,

- Relative orientation relations, e.g., *left, right, collinear*, orientation relations between *points* and *segments*, and *parallel, perpendicular* relations between *segments*,
- Mereotopology relations, e.g., *Part-whole* and *contact* relations between regions.

Our representation enables, e.g., to define all Region Connection Calculus topological relations:



The representation is expressive enough to cover a number of other relations known from the literature:

Proposition 1. *ASPMT(QS) is capable to define each relation of:*

- *Interval Algebra,*
- *Rectangle Algebra,*
- *Region Connection Calculus,*
- *Cardinal Direction Calculus.*

ASPMT(QS) system

ASPMT(QS) builds on ASPMT2SMT [2] – a compiler translating a tight fragment of ASPMT into SMT instances. Our system consists of an additional module for spatial reasoning and Z3 as the SMT solver.

The **input** program is divided into:

- `sorts` (data types),
- `objects` (particular elements of given types),
- `constants` (functions),
- `variables` (variables associated with declared types).

The second part of the program consists of clauses.

ASPMT(QS) supports:

- connectives: `&`, `|`, `not`, `->`, `<-`,
- arithmetic operators: `<`, `<=`, `>=`, `>`, `=`, `!=`, `+`, `=`, `*`,
- `sorts` for geometric objects types, e.g., `point`, `segment`, `circle`, `triangle`,
- functions describing objects parameters, e.g., x(`point`), r(`circle`),
- qualitative spatial relations, e.g., `rccEC(circle, circle)`, `coincident(point, circle)`.

The **output**:

produces a stable model of the input program, or states that no such model exists.

Example:
topology and relative orientation

Topological information about circles a, b, c:

- a is a proper part of b,
- b is discrete from c,
- a is in contact with c.

Input program:

```
:- sorts
   circle.
:- objects
   a, b, c      ::  circle.
:- constants
   .
:- variables
   C, C1, C2    ::  circle.

{x(C)=X}. {y(C)=X}. {r(C)=X}.
rccPP(a,b)=true. rccDR(b,c)=true. rccC(a,c)=true.
```

Output:

```
r(a) = 1.0            r(b) = 2.0            r(c) = 1.0
x(a) = 1.0            x(b) = 0.0            x(c) = 3.0
y(a) = 0.0            y(b) = 0.0            y(c) = 0.0
rccTPP(a,b) = true    rccEC(a,c) = true     rccEC(b,c) = true
```

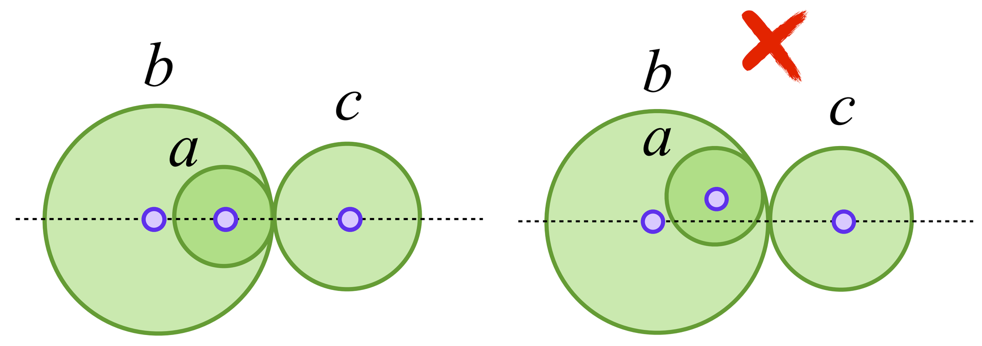
We then add an additional constraint that the centre of a is *left of* the segment between the centres b to c.

Additional input:

```
...
left_of(center(a),center(b),center(c)).
```

Output:

```
UNSATISFIABLE;
```

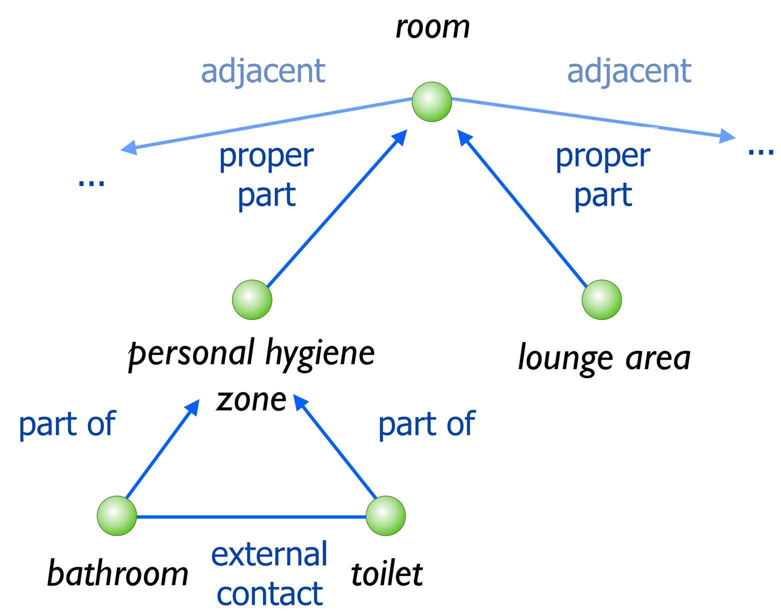


ASPMT(QS) refines the topological relations to infer that:

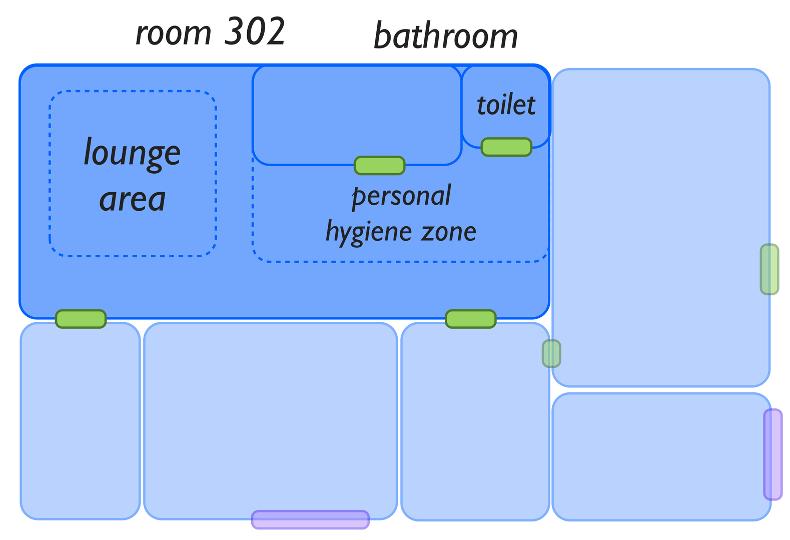
- a must be a *tangential proper part* of b,
- both a and b must be *externally connected* to c.

Application:
parametric (architecture) design

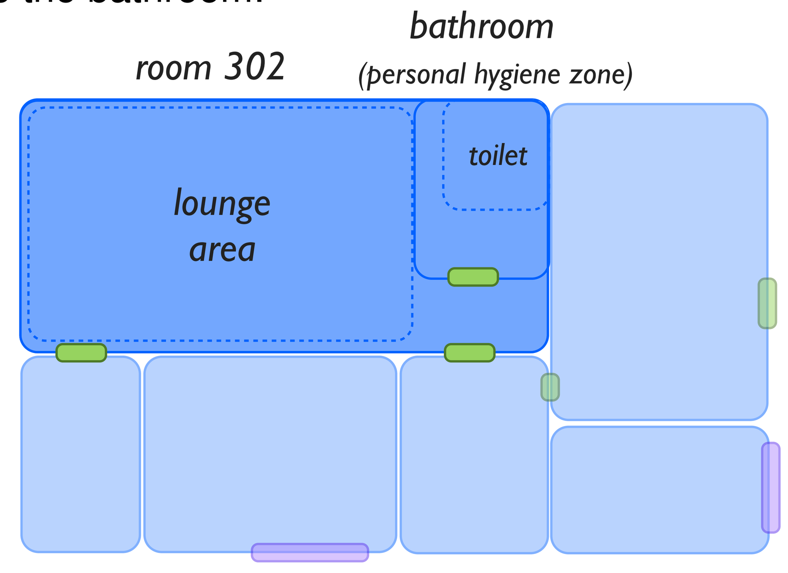
Qualitative spatial graph of the architectural building:



Initial floor plan consistent with qualitative specification:



When additional requirements for dimensions of: room $302 - 20m^2$, the lounge area – $15m^2$, bathroom – $4m^2$ and toilet – $3m^2$, ASPMT(QS) infers that the design has to be changed at a qualitative level. Toilet needs to be located inside the bathroom:



Example (Attach):
geometric reasoning and frame problem

In S_0 the car is attached to the $trailer$ and they are outside the $garage$. In S_1, the car is inside the $garage$. What actions have been performed?

Allowed domain-specific actions:

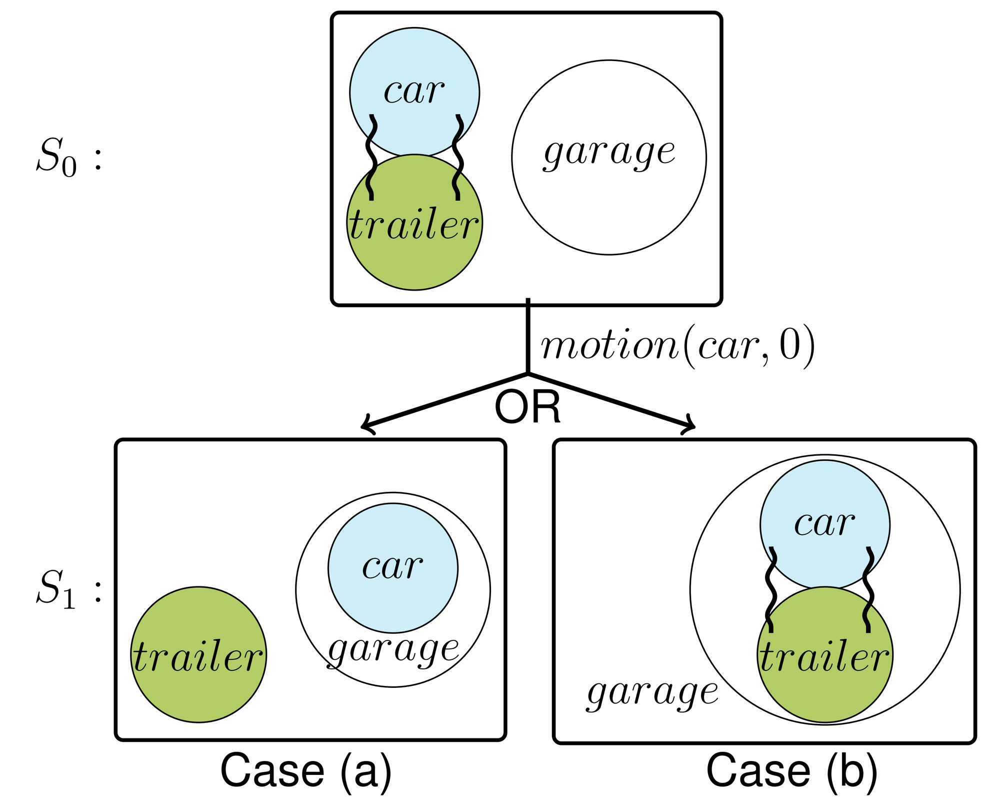
- the car can move, move(car, X),
- the $trailer$ can be detached, detach$(car, trailer, X)$ in time step X.

Attachment I. Given the topological information in S_0, ASPMT(QS) infers that there are two possible solutions:

(a) the car is detached from the $trailer$,

(b) the car, together with the $trailer$ move into the $garage$.

Attachment II. Given additional geometric information: $r(car) = 2$, $r(trailer) = 2$ and $r(garage) = 3$, ASPMT(QS) infers that (b) is now inconsistent, and the only possible solution is (a).



Evaluation

In [1] we have performed an empirical evaluation of ASPMT(QS) in comparison with other existing spatial reasoning systems:

- Clingo – an ASP grounder and solver [3],
- GQR – a binary constraint calculi reasoner [4],
- CLP($\mathcal{QS}$) – a declarative spatial reasoning system [5].

The range of tested problems demonstrate the unique, nonmonotonic spatial reasoning features that ASPMT(QS) provides beyond what is possible using other currently available systems.

Cumulative results of performed tests are presented in the below table, where "—" indicates that the problem can not be formalised, "^{I}" indicates that indirect effects can not be formalised, "^{D}" indicates that default rules can not be formalised.

Problem	Clingo	GQR	CLP($\mathcal{QS}$)	ASPMT(QS)
Growth	0.004s^I	0.014s^{I,D}	1.623s^D	0.396s
Motion	0.004s^I	0.013s^{I,D}	0.449s^D	15.386s
Attach I	0.008s^I	—	3.139s^D	0.395s
Attach II	—	—	2.789s^D	0.642s

Tests were performed on an Intel Core 2 Duo 2.00 GHZ CPU with 4 GB RAM running Ubuntu 14.04.

Future work

Extensions of the ASPMT(QS) system:

- performing complex spatio-temporal reasoning
- applying to practical problems: computer-aided architecture design, mobile robots control, etc.

Additionally, introduce another approach for nonmonotonic spatial reasoning based on Equilibrium Logic, that has been used for temporal reasoning but not for spatial reasoning.

References

[1] P. A. Wałęga, M. Bhatt, and C. Schultz, "ASPMT(QS): Non-Monotonic Spatial Reasoning with Answer Set Programming Modulo Theories," *ArXiv e-prints*, Jun. 2015.

[2] M. Bartholomew and J. Lee, "System aspmt2smt: Computing ASPMT Theories by SMT Solvers," in *Logics in Artificial Intelligence*. Springer, 2014, pp. 529–542.

[3] M. Gebser, R. Kaminski, B. Kaufmann, and T. Schaub, "Clingo= ASP+ control: Preliminary report," *arXiv preprint arXiv:1405.3694*, 2014.

[4] Z. Gantner, M. Westphal, and S. Wölfl, "GQR-A fast reasoner for binary qualitative constraint calculi," in *Proc. of AAAI*, vol. 8, 2008.

[5] M. Bhatt, J. H. Lee, and C. Schultz, "CLP (QS): a declarative spatial reasoning framework," in *Spatial Information Theory*. Springer, 2011, pp. 210–230.