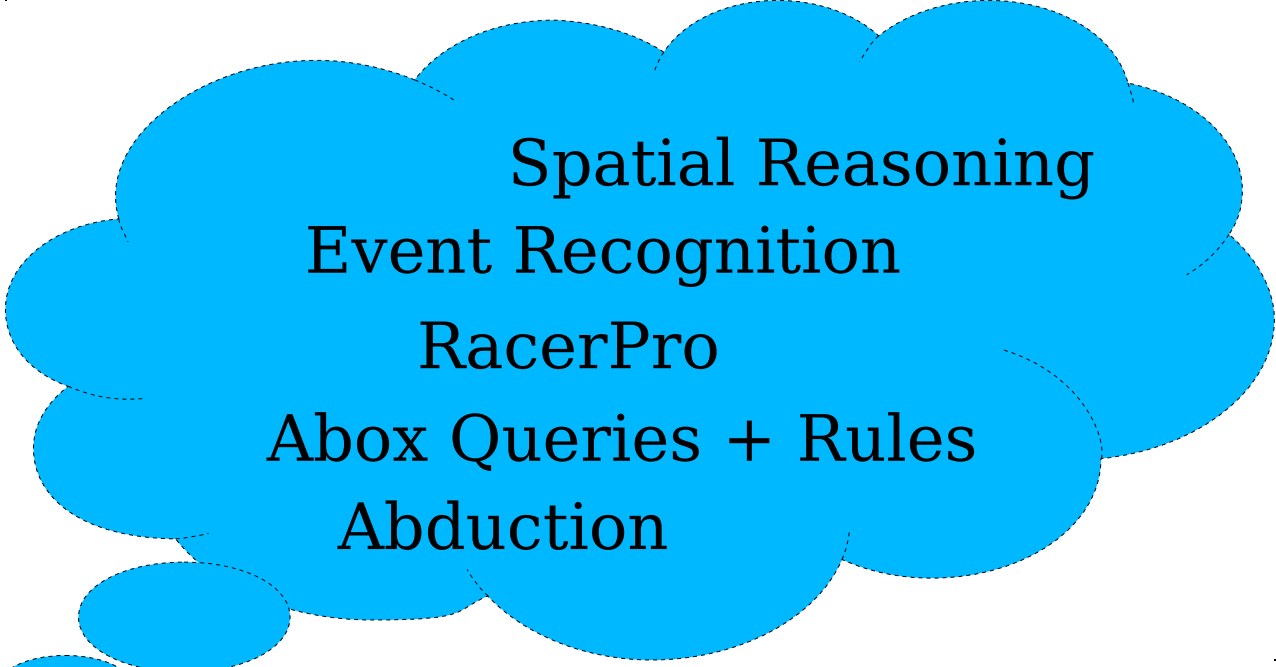
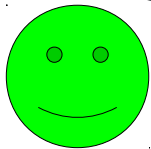


# Applications of Description Logics

---

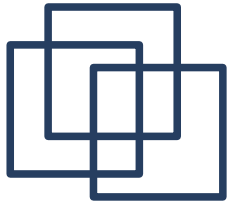


Spatial Reasoning  
Event Recognition  
RacerPro  
Abox Queries + Rules  
Abduction



joint work with many researchers:

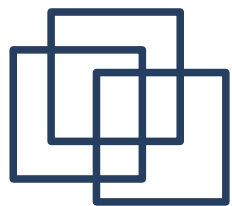
**V. Haarslev, R. Möller, B. Neumann,  
A. Kaya, S. Espinosa-Peraldi,  
A. Kaplunova, BOEMIE, CASAM, TONES**



# Why Description Logics?

---

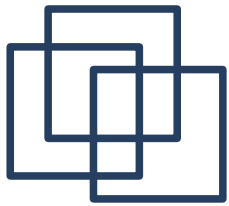
- Formal
  - suitable as **ontology** languages (Gruber definition)
- Well-understood
  - semantics, complexity, implementation techniques
- Family
  - complexity scalable (e.g., lightweight DLs)
- Decidable
  - unlike FOPL
- Basis for Semantic Web (OWL2, ...)
- Many tools available



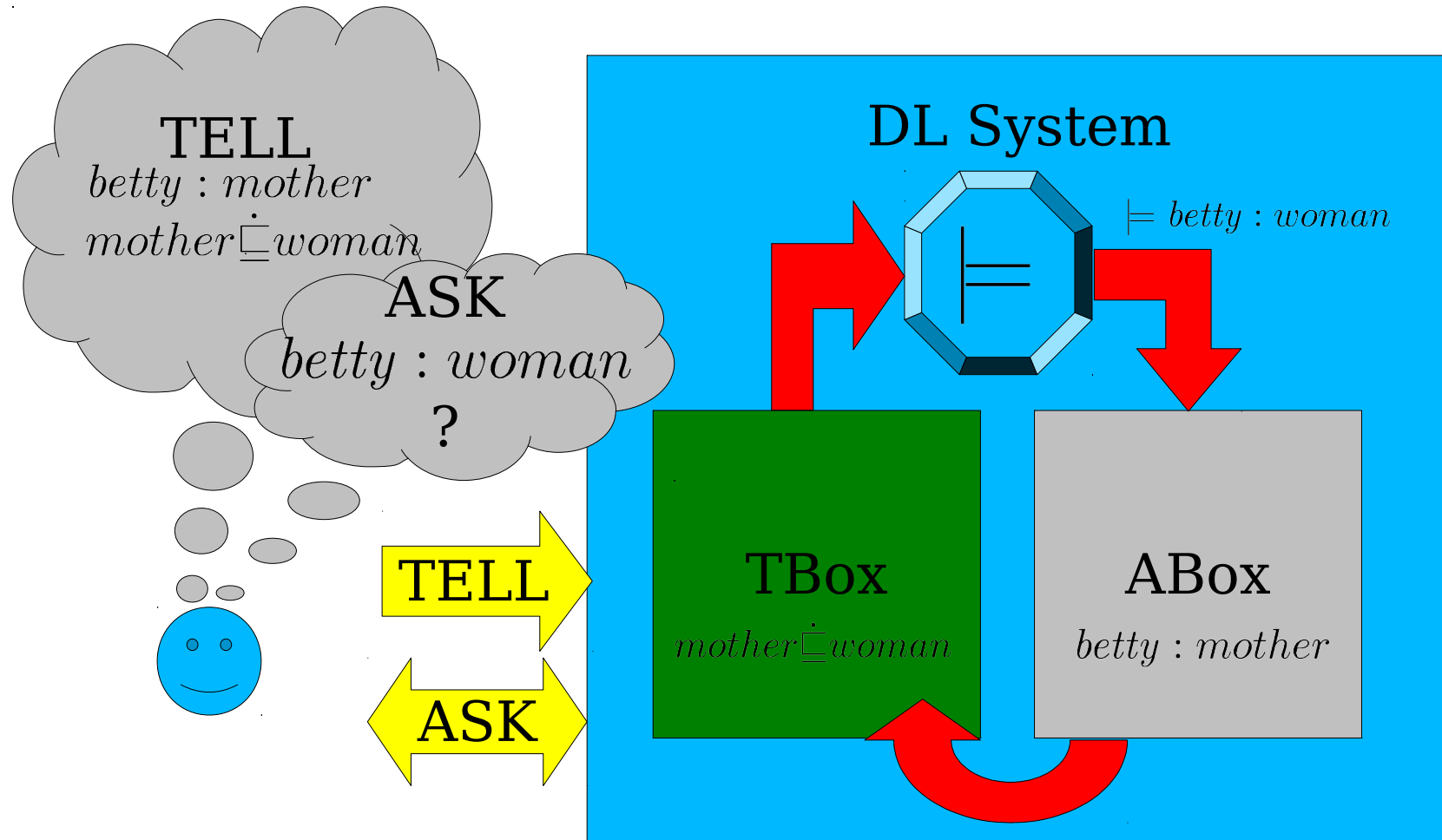
# Description Logics : Basic Notions

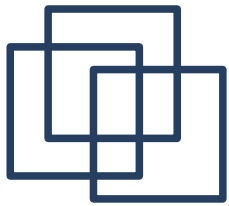
---

- Based on first order-logic
  - but variable-free and decidable
  - concept languages, class-based KR
- Central notions:
  - concept (OWL: class): unary predicate
  - role (OWL: property, RDF: predicate): binary predicate / relation
  - Abox individual: constant
  - Container data structures:
    - TBox: Set of terminological + role axioms:  
 $C(x) \rightarrow D(x)$ ,  $C(x) \leftrightarrow D(x)$
    - ABox: individuals and relations:  $C(i)$ ,  $R(i,j)$



# Architecture of a DL System

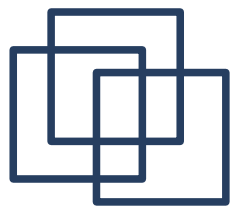




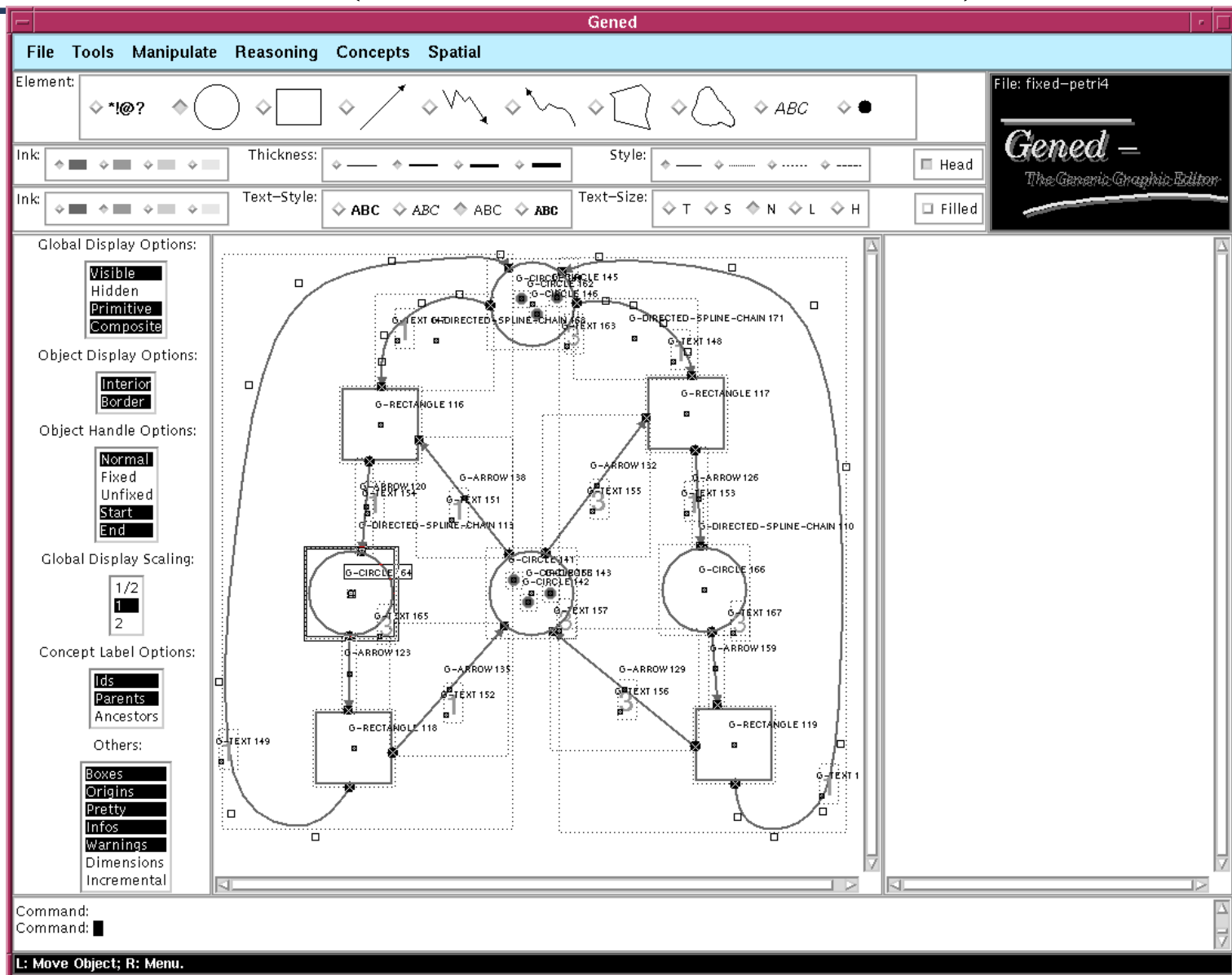
# ABox Inference Services

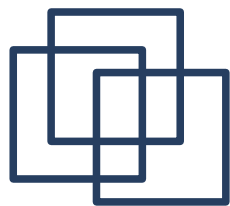
---

- Abox satisfiability (w.r.t. a possibly empty TBox)
  - does the Abox have a model?  
 $\{betty : \neg parent, betty : person, (betty, charles) : has\_child\}$
- Individual / ABox realization
  - compute the (most specific) concept names an individual is an instance of, e.g. in  
 $\{betty : person, (betty, charles) : has\_child\}$   
it is realized that *betty* is an instance of *parent*
- Instance checking: is *betty* an instance of *parent*?
- Role filler checking: is *charles* a filler (successor) of the *has\_child* role of *betty* ?

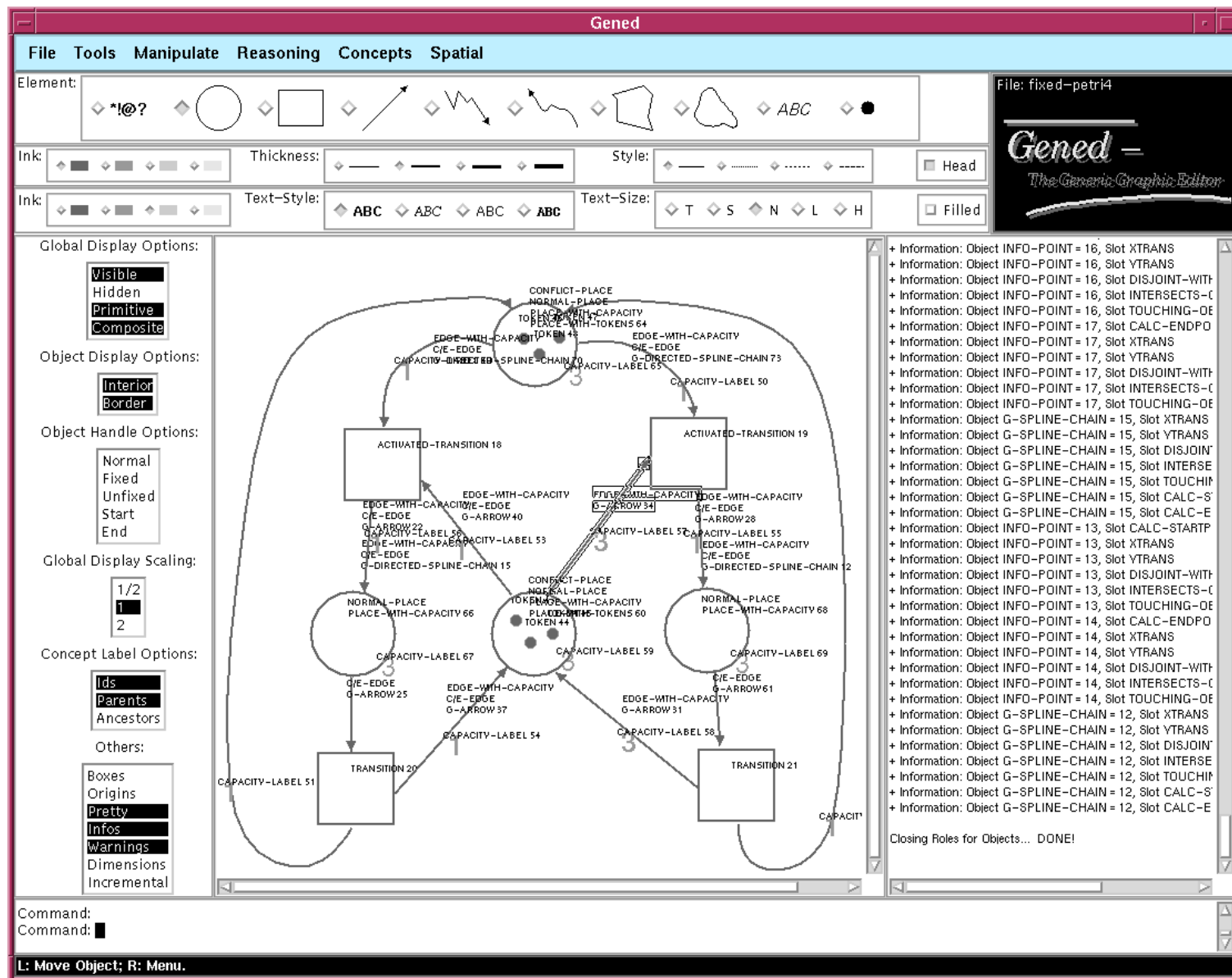


# Recognition of Spatial Concepts (1996, Classic DL)



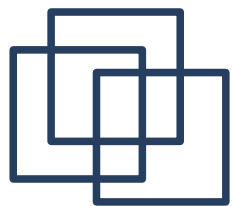


# Petri Nets

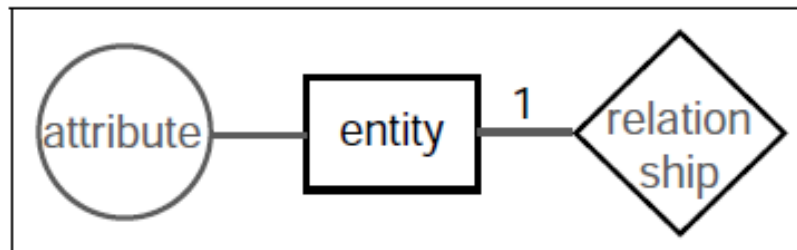








# Example TBox Definitions – ABox Realization for Recognition



Quantification  
over spatial  
relations

An *entity* is a rectangle  
touches at least one rela  
some attribute-entity co  
least one diamond.

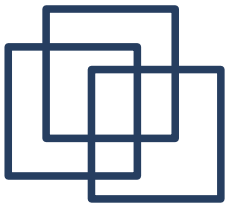
**named\_region**  $\equiv$   
(*region*  $\wedge$  ( $\exists_{=1}$  containin

**entity**  $\equiv$   
(*rectangle*  $\wedge$  *named\_region*  $\wedge$   
( $\exists_{\geq 1}$  touching *relationship\_entity*)  $\wedge$   
( $\forall$  touching (*attribute\_entity*  $\vee$  *relationship\_entity*)))  $\wedge$   
( $\exists_{\geq 1}$  linked\_with *diamond*)  $\wedge$   
( $\forall$  linked\_with (*circle*  $\vee$  *diamond*)))

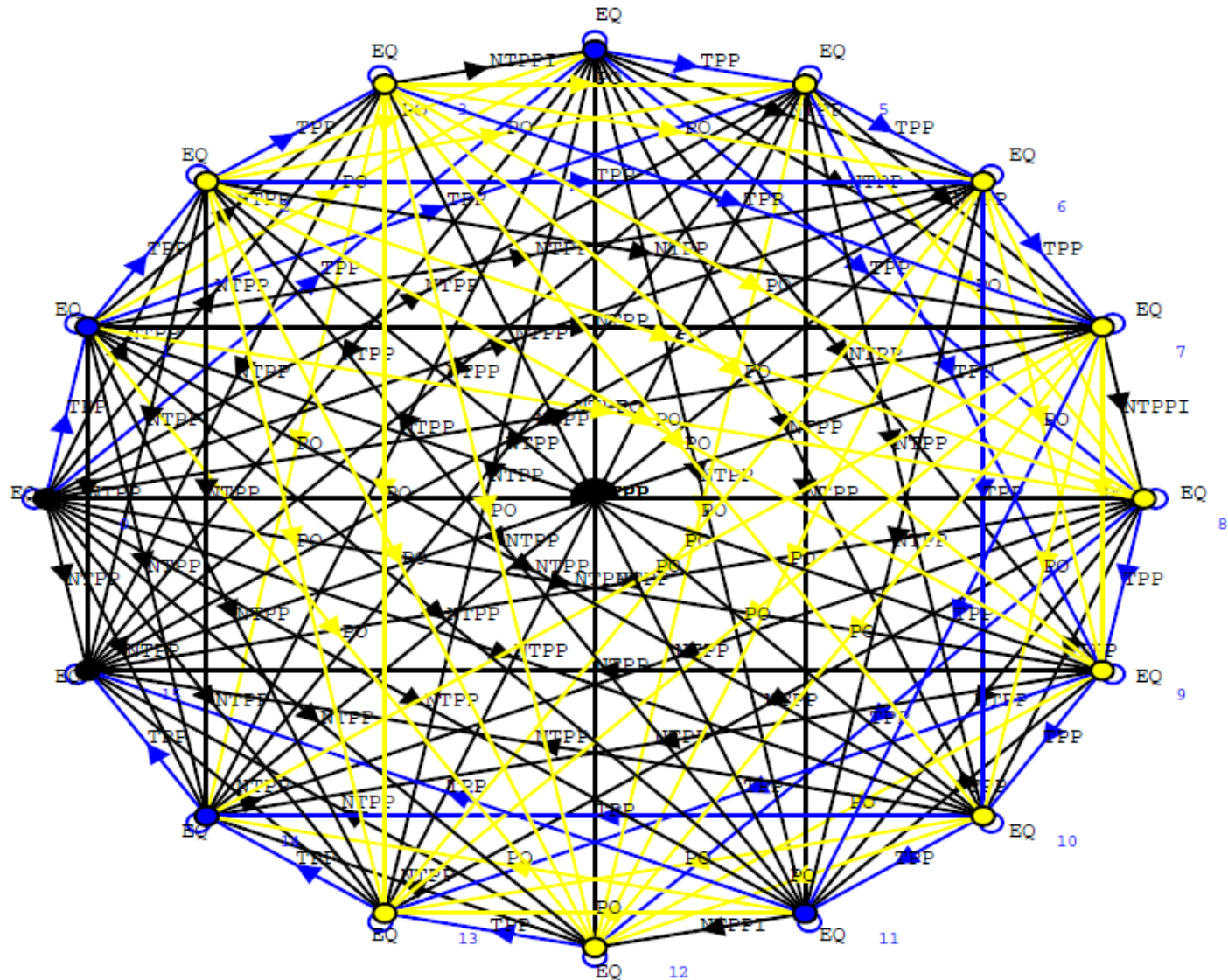
```

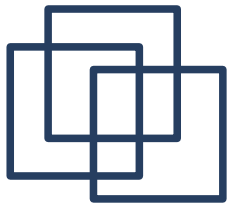
(defconcept entity
  (and rectangle
    named-region
    (some touching
      relationship-entity)
    (all touching
      attribute-or-relationship-entity)
    (some linked-with diamond)
    (all linked-with circle-or-diamond)))
  
```

+ ABox for  
concrete  
diagram



# ABoxes with Spatial Relations

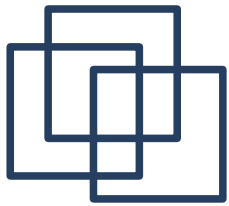




# Lessons Learned

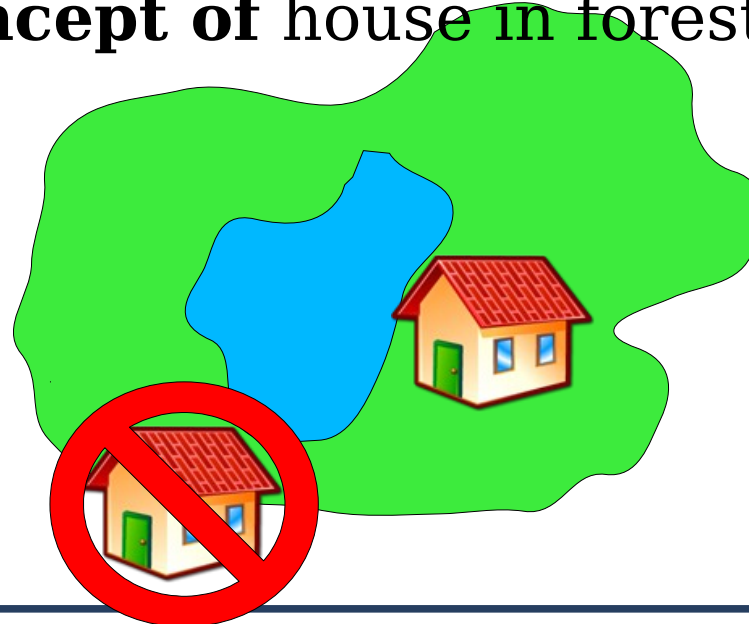
---

- Inexpressivity of CLASSIC: hacks required (disjunction, qualified subroles, rules for „qualified subroles“, ...) → motivation for Racer
- DL problem: we cannot recognize composite aggregates (e.g., whole ER diagrams or petri nets), only „placeholder individuals“
- CLASSIC performance: lots of spatial role relationships (disjoint!) → 40 minutes for realization... → motivation for Racer
- DL problem: open world assumption - forall usually not satisfied
- Criticism - why use DLs at all for that??
  - just used SQL queries or Datalog
  - we don't get the desired subsumption relationships between spatial concepts, as spatial relationships not properly axiomatized
    - work on spatial DLs

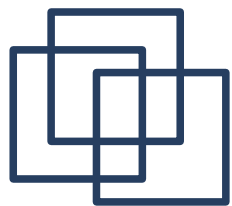


# DLs with Spatial Semantics

- Example of a desired subsumption relationship
    - Lake strictly contained in forest (NTPP)
    - House at (EC) lake strictly contained in forest not overlapping forest („PO“)
- 
- House at lake not overlapping forest **is subconcept of** house in forest



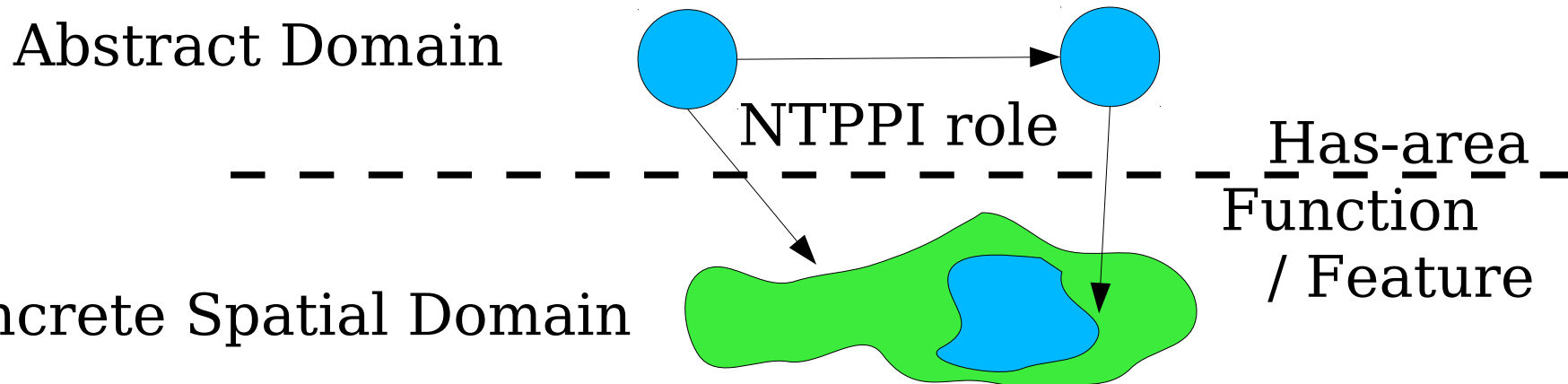
Quantification  
Over RCC  
relations

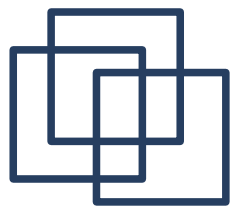


# 1998 - DLs with Spatial Semantics

---

- Lutz, Moeller, Haarslev:  $\mathcal{ALCRP}(\mathcal{S}_2)$ 
  - a DL with spatial concrete domains
    - concrete domain objects = spatial regions are connected to abstract domain objects of the DL via functions
    - properties between spatial objects induced roles / relations between corresponding abstract objects
    - the concrete geometry does not need to be known!



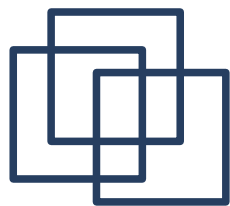


# 2001 - DLs with Spatial Semantics

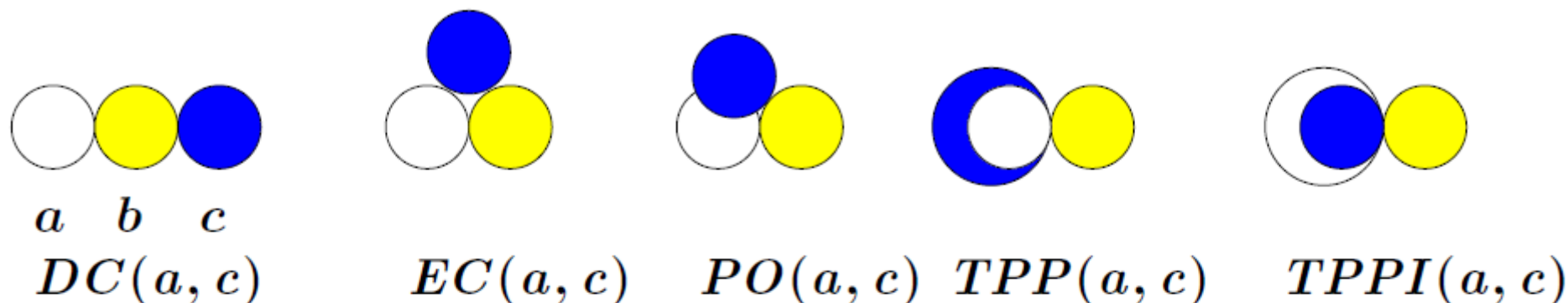
---

- Wessel
  - *ALCT<sub>RCC</sub>* family
    - DLs with complex role axioms of the form  
$$\text{forall } x,y,z : R(x,y) \wedge S(y,z) \rightarrow T1(x,z) \vee T2 \dots$$

(undecidable in general)
    - no concrete domains, but RCC relations axiomatized according to the RCC composition tables
    - some decidable fragments found (Rcc1 ... Rcc3)
    - RCC5 and RCC8 undecidable (Lutz + Wolter)



# Composition Axioms



Given  $EC(a, b)$ ,  $EC(b, c)$ , what do we know about the relationship between  $a$  and  $c$ ? Lookup  $EC \circ EC$  in the RCC8 composition-table:

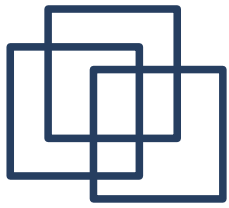
$$\forall x, y, z : EC(x, y) \wedge EC(y, z) \Rightarrow$$

$$(DC(x, z) \vee EC(x, z) \vee PO(x, z) \vee$$

$$TPP(x, z) \vee TPPI(x, z))$$

$$EC \circ EC \sqsubseteq DC \sqcup EC \sqcup PO \sqcup TPP \sqcup TPPI$$

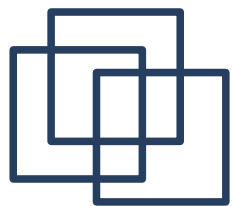




# RCC8 Composition Table

RCC8	DC(a,b)	EC(a,b)	PO(a,b)	TPP(a,b)	NTPP(a,b)	TPPI(a,b)	NTPPI(a,b)	EQ(a,b)
DC(b,c)	*	DC EC PO TPPI NT- PPI	DC EC PO TPPI NT- PPI	DC	DC	DC EC PO TPPI NT- PPI	DC EC TPPI NT- PPI	DC
EC(b,c)	DC EC PO TPP NTPP	DC EC PO TPP TPPI EQ	DC EC PO TPPI NT- PPI	DC EC	DC	EC PO TPPI NT- PPI	PO TPPI NT- PPI	EC
PO(b,c)	DC EC PO TPP NTPP	DC EC PO TPP NTPP	*	DC EC PO TPP NTPP	DC EC PO TPP NTPP	PO TPPI NT- PPI	PO TPPI NT- PPI	PO
TPP(b,c)	DC EC PO TPP NTPP	EC PO TPP NTPP	PO TPP NTPP	TPP NTPP	NTPP	PO EQ TPP TPPI	PO TPPI NT- PPI	TPP
NTPP(b,c)	DC EC PO TPP NTPP	PO TPP NTPP	PO TPP NTPP	NTPP	NTPP	PO TPP NTPP	PO TPPI TPP NTPP NT- PPI EQ	NTPP
TPPI(b,c)	DC	DC EC	DC EC PO TPPI NT- PPI	DC EC PO TPP TPPI EQ	DC EC PO TPP NTPP	TPPI NT- PPI	NTPPI	TPPI
NTPPI(b,c)	DC	DC	DC EC PO TPPI NT- PPI	DC EC PO TPPI NT- PPI	*	NTPPI	NTPPI	NTPPI
EQ(b,c)	DC	EC	PO	TPP	NTPP	TPPI	NTPPI	EQ





# $\mathcal{ALCI}_{RCC}$ Family

RCC1

SR

RCC2

DR

0

RCC3

DR

EQ

ONE

RCC5

DR

EQ

PP

PPI

PO

RCC8

DC

EC

EQ

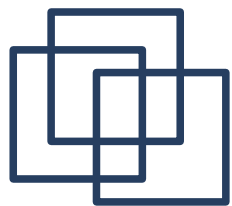
TPP

NTPP

TPPI

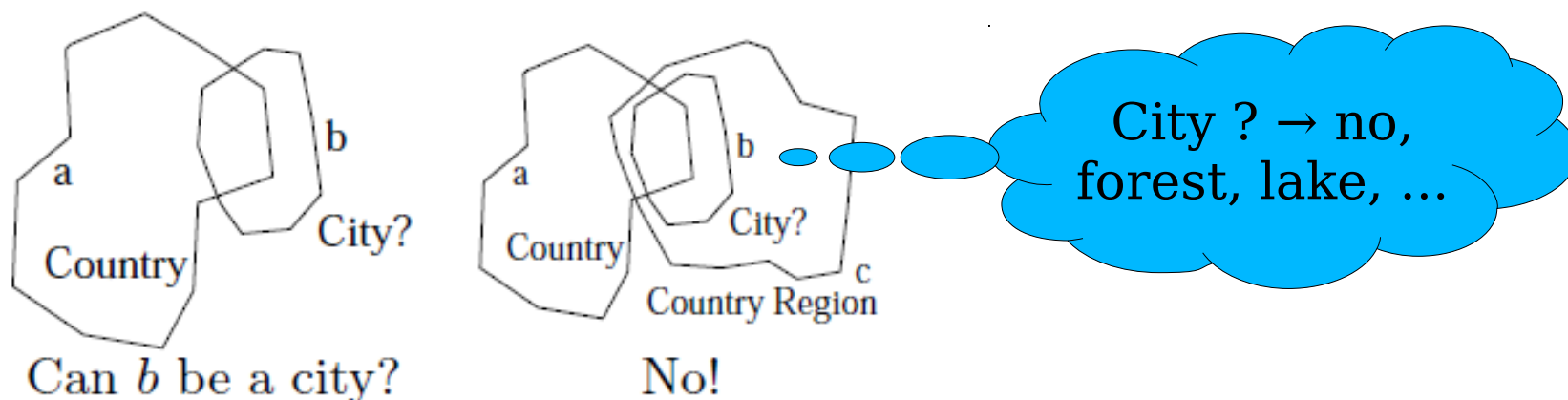
NTPPI

PO

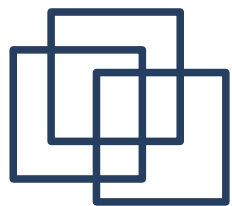


## 2000: Image Interpretation with Default Rules and $\mathcal{ALCRP}(\mathcal{S}_2)$

- In real life image interpretation applications, „recognition by entailment (e.g., Abox realization)“ does not work
- $b$  is an unknown region – what can it be?



- each city must be contained in exactly one country
  - countries don't overlap →  $b$  cannot be a city
- „Image Interpretation as Model Construction“ (completion)
- or unsound reasoning, e.g., default rules that hypothesize

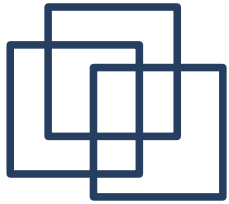


## $\mathcal{ALCRP}(\mathcal{S}_2)$ KB and Default Rules

---

$country \doteq country\_region \sqcap \forall contains. \neg country\_region \sqcap$   
 $\quad \forall overlaps. \neg country\_region \sqcap \forall inside. \neg country\_region$   
 $city \doteq city\_region \sqcap \exists inside. country\_region$   
 $lake \sqsubseteq lake\_region$   
 $river \doteq river\_region \sqcap \forall overlaps. \neg lake\_region \sqcap \forall inside. \neg lake\_region$

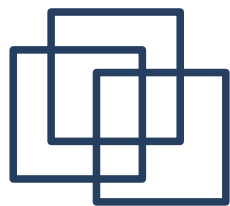
$$d_1 = \frac{area : city}{city}, \quad d_2 = \frac{area : lake}{lake}, \quad d_3 = \frac{area : country}{country}$$



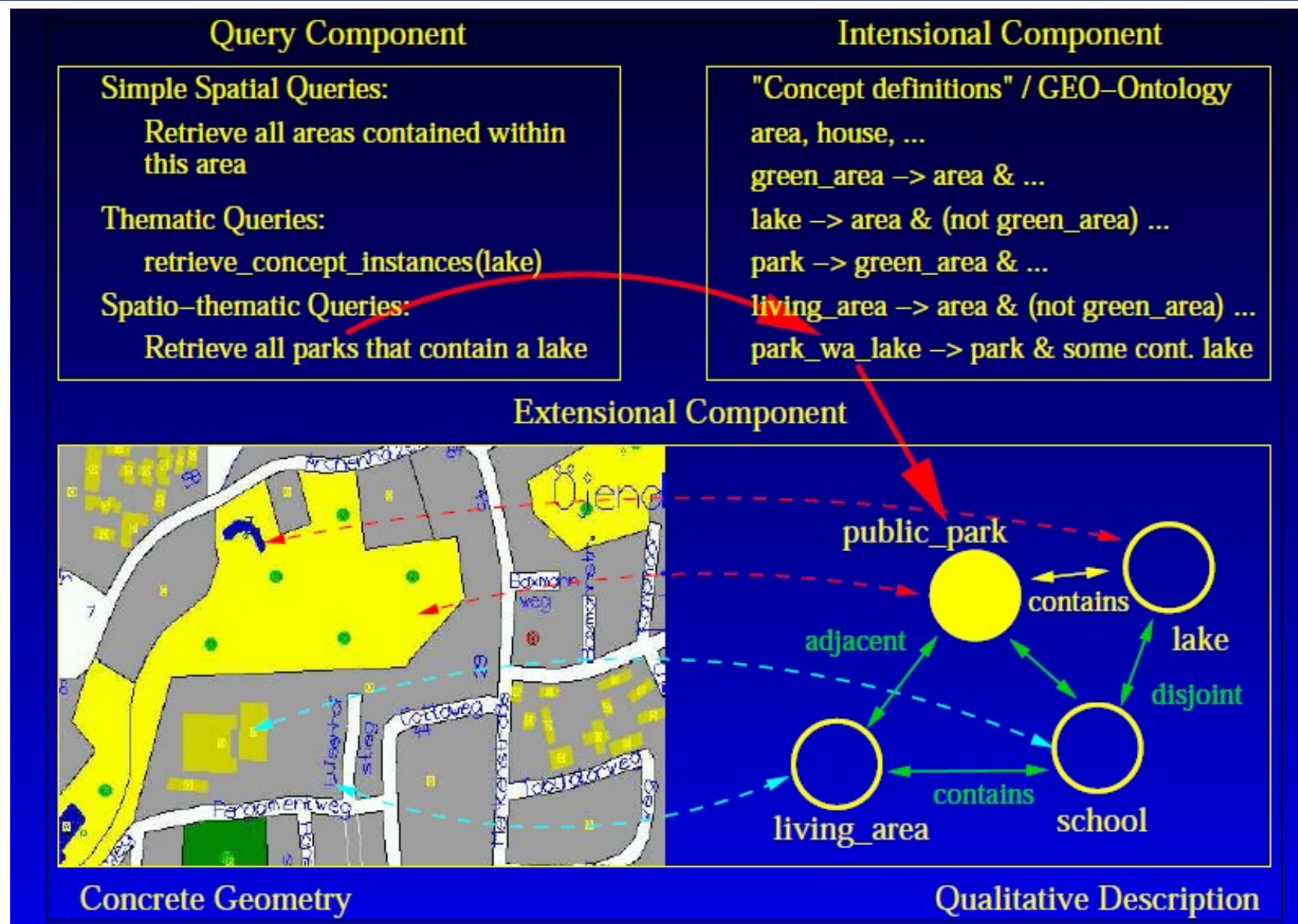
# 2003 - Deductive GIS with DLs

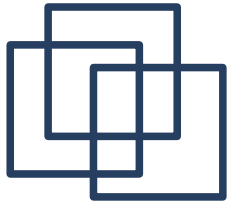
---

- Lessons learned:
  - spatial reasoning on the intensional (Tbox) level too difficult if quantification over spatial relations permitted ...
  - ... or to inexpressive
- work on the extensional level instead ;-)
  - many interesting problems on the extensional level too
  - large Aboxes – many regions, many relations → use Racer (by then, Racer had a reputation of dealing well with large ABoxes)
  - to recognize spatial constellations: expressive Abox query language (→ nRQL)
    - spatio-thematic complex queries
    - hybrid system with, „on thy fly evaluation“ of QSR from geometry, tightly integrated into a DL reasoner, ...



# DLMAPS - Hybrid Architecture





# Spatio-Thematic Hybrid Queries

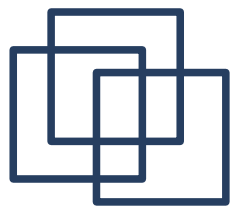
---

```
(retrieve (?*x ?*y)
  (and (?*x
    (and living-area
      (all living-quality
        first-class-area)))
    (?y ?x (:inside-distance 750))
    (?*y subway-station)
    (?x ?y :adjacent)
    (?*y golf-club)
    (?y (:area 10000000 nil)))))
```

- hybrid: ?\*x DL query atom, ?x spatial atom
- thematic, qualitative + quantitative spatial aspects
- composition-table based RCC reasoning
- cost-based optimizer  
(reused for „Abox-based“ conjunctive queries in AURA)







# DLMAPS - Query Answering

The screenshot shows the DLMAPS Inspector application window. The main area displays a grid of 24 map thumbnails, each showing a different spatial query result. The thumbnails are arranged in a 6x4 grid. The right-hand panel contains the following information:

**Info:**

Natürlichsprachlich:  
Zeige mir alle Wohngebiete,  
die an einem Park liegen.

Query: (AND (?\*X WOHNGEBIET) (?\*Y PARK) (?\*X ?\*Y ADJACENT))

Variables: (?\*X ?\*Y)

#<MP:PROCESS Name "Process" Priority 850000 State "Running">

**Query Processor**

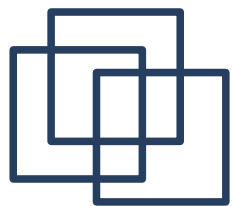
Command: Q3  
Command: Answer Query  
Enter Query: (AND (SPATIAL-SUBSTRATE::?\*X SPATIAL-SUBSTRATE::WOHNGEBIET) (SPATIAL-SUBSTRATE::?\*Y SPATIAL-SUBSTRATE::PARK) (SPATIAL-SUBSTRATE::?\*X SPATIAL-SUBSTRATE::?\*Y SPATIAL-SUBSTRATE::ADJACENT))  
Enter Variables: ?\*X, ?\*Y

Command: Inspector Inspect Query Result #<SPATIAL-SUBSTRATE::QUERY-RESULT 29ED5D84>  
Command: Show Query  
Command: Q3  
Command: Answer Query  
Enter Query: (AND (SPATIAL-SUBSTRATE::?\*X SPATIAL-SUBSTRATE::WOHNGEBIET) (SPATIAL-SUBSTRATE::?\*Y SPATIAL-SUBSTRATE::PARK) (SPATIAL-SUBSTRATE::?\*X SPATIAL-SUBSTRATE::?\*Y SPATIAL-SUBSTRATE::ADJACENT))  
Enter Variables: ?\*X, ?\*Y

Command:

At the bottom of the window, there is a status bar that reads: L: Inspector Inspect Query Result: R: Menu.





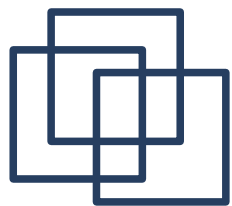
## ***Racer Systems*** – Partners & Friends

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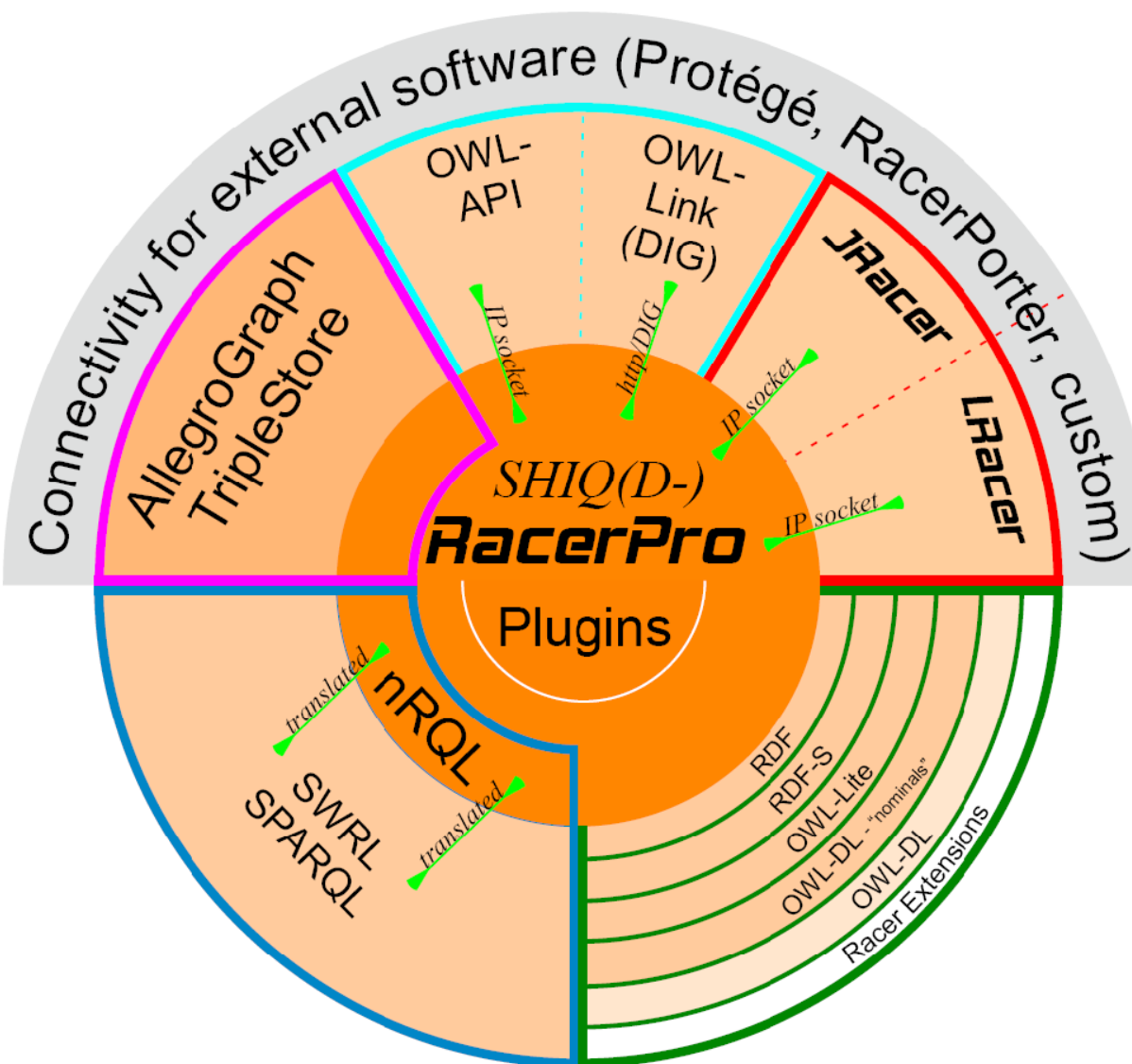


**October 2004 - today**

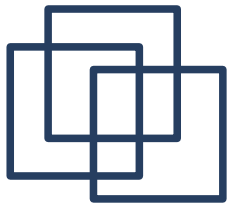




# **RacerPro** - Architecture & History

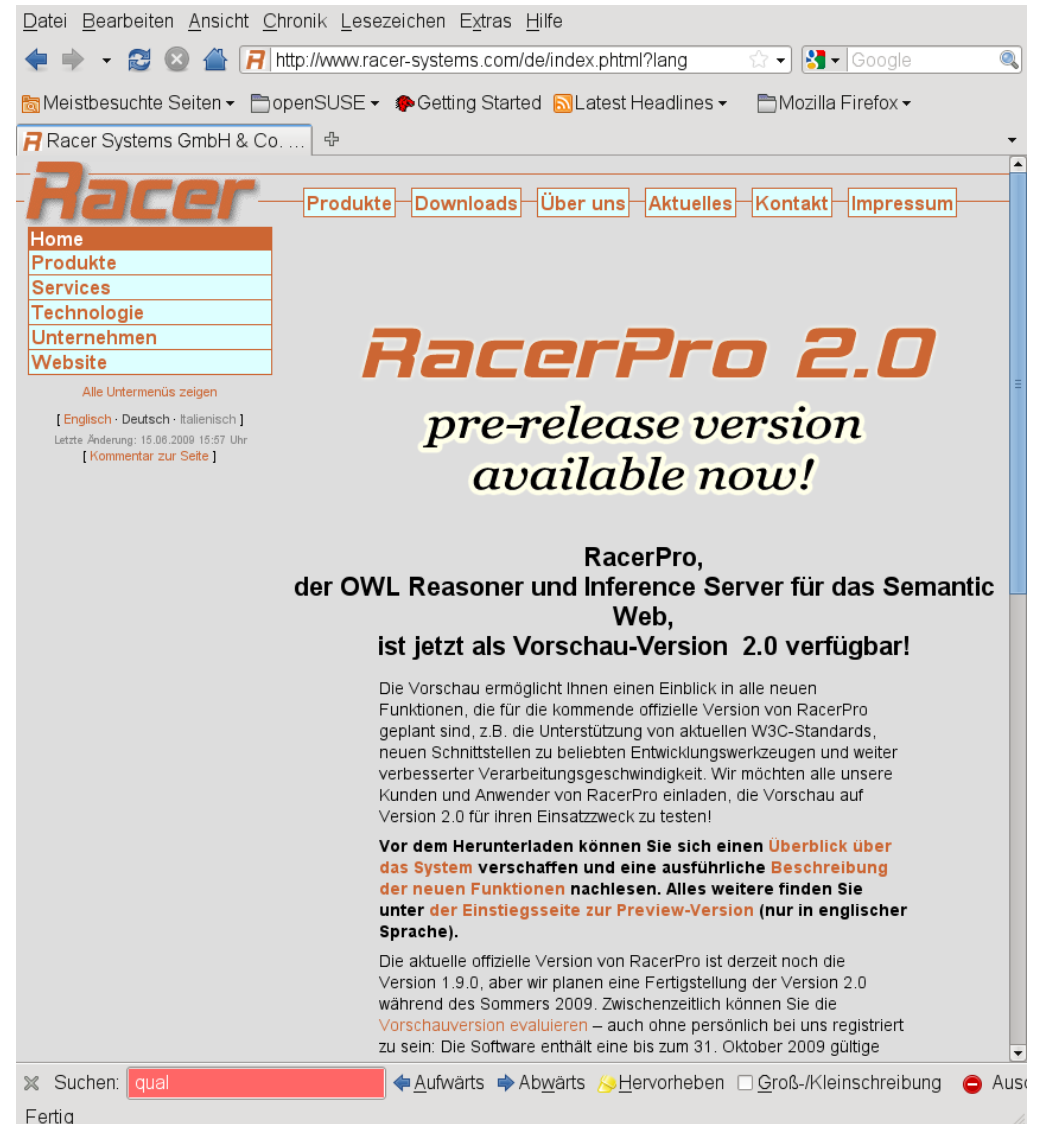


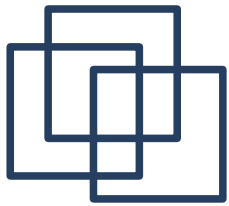
- Started as **Racer** at the University of Hamburg in **1998**, project of **Volker Haarslev & Ralf Möller**
- First description logic (DL) reasoner „of the new generation“ of highly optimized DL systems **with ABox (individuals, relations)**
- One of the **first OWL DL (-)** systems (**2002**), DL **SHIQ(D)**
- Commercial offspring **RacerPro** by **Racer Systems** (2004 - today)
- Expressive query language **nRQL**
- First DL system that could give **complete answers** to the **LUBM Benchmark** queries (2004)
- First DL system with **inference-aware SWRL & SPARQL**
- Main memory-based
- Recently: Integrated **AllegroGraph**
- Some **special-purpose representations and reasoning**
- **Free for education & research**



# How Do I Get RacerPro ?

- [www.racer-systems.com](http://www.racer-systems.com)  
there is the 2.0 preview version
  - no license required
  - to be finalized soon
- Latest activities
  - Protege 4.3 plugin  
(Ulm / Derivo GmbH)
  - EL consequence-based reasoning
  - OntoLisp framework





# Solving Sudokus by Reasoning

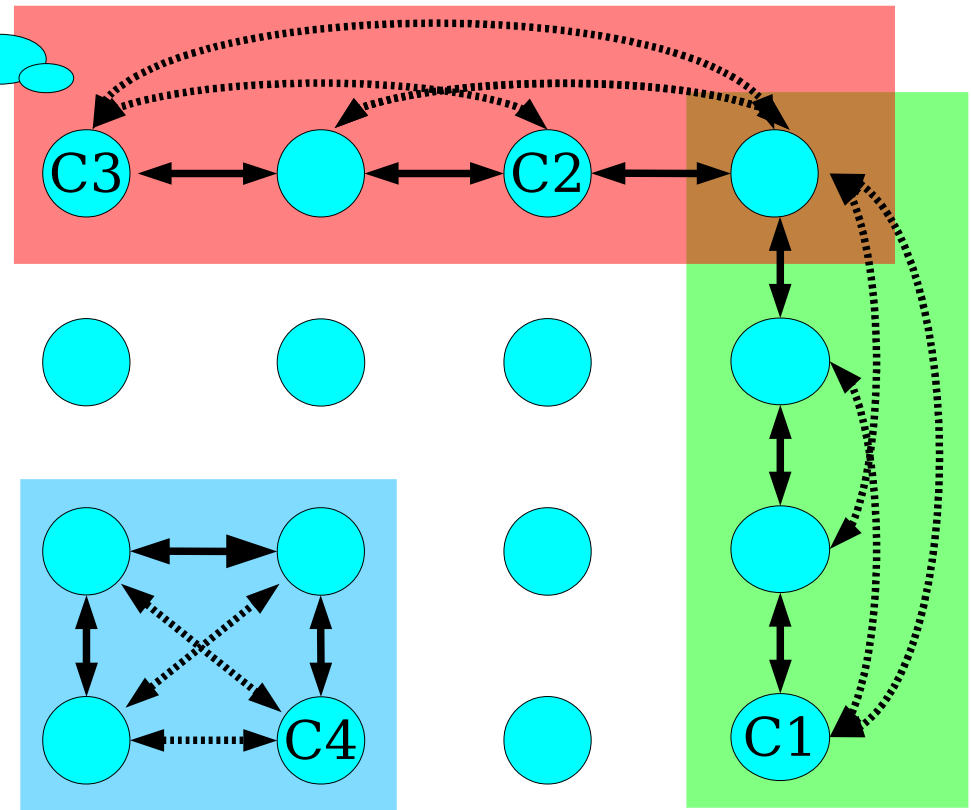
Create a KB whose logical models represent all possible Sudoku solutions. A good Sudoku has only ONE solution → entailed facts = solution!

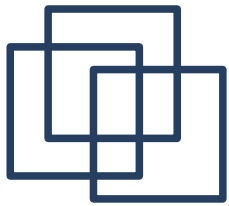
3		2	
	4		1

3		2	
	4		1

**pairwise\_disjoint**( $C_1, C_2, C_3, C_4$ )

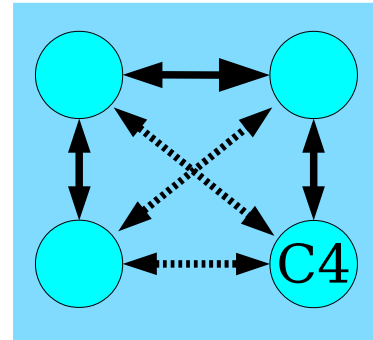
$\top \sqsubseteq (C_1 \sqcup C_2 \sqcup C_3 \sqcup C_4) \sqcap$   
 $(C_1 \rightarrow \forall R. \neg C_1) \sqcap (C_2 \rightarrow \forall R. \neg C_2) \sqcap$   
 $(C_3 \rightarrow \forall R. \neg C_3) \sqcap (C_4 \rightarrow \forall R. \neg C_4) \sqcap$   
 $\dots$





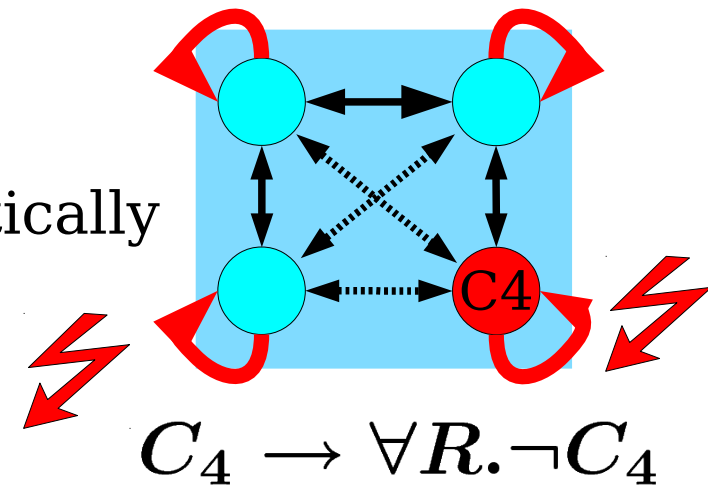
# Sudoku - ABox Construction

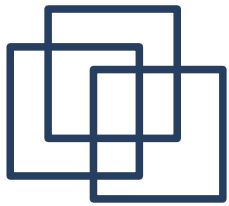
3		2	
			1



## ABox construction

- by hand? OK for 4x4, but for 9x9?  
→ create the structure programmatically (MiniLisp)
- transitive & symmetric property →
  - use different backward property instead of a symmetric property
  - quantification over common parent property
  - different props. for different rows, columns, diagonals





# Sudoku - Relational Structure

3		2	
			1

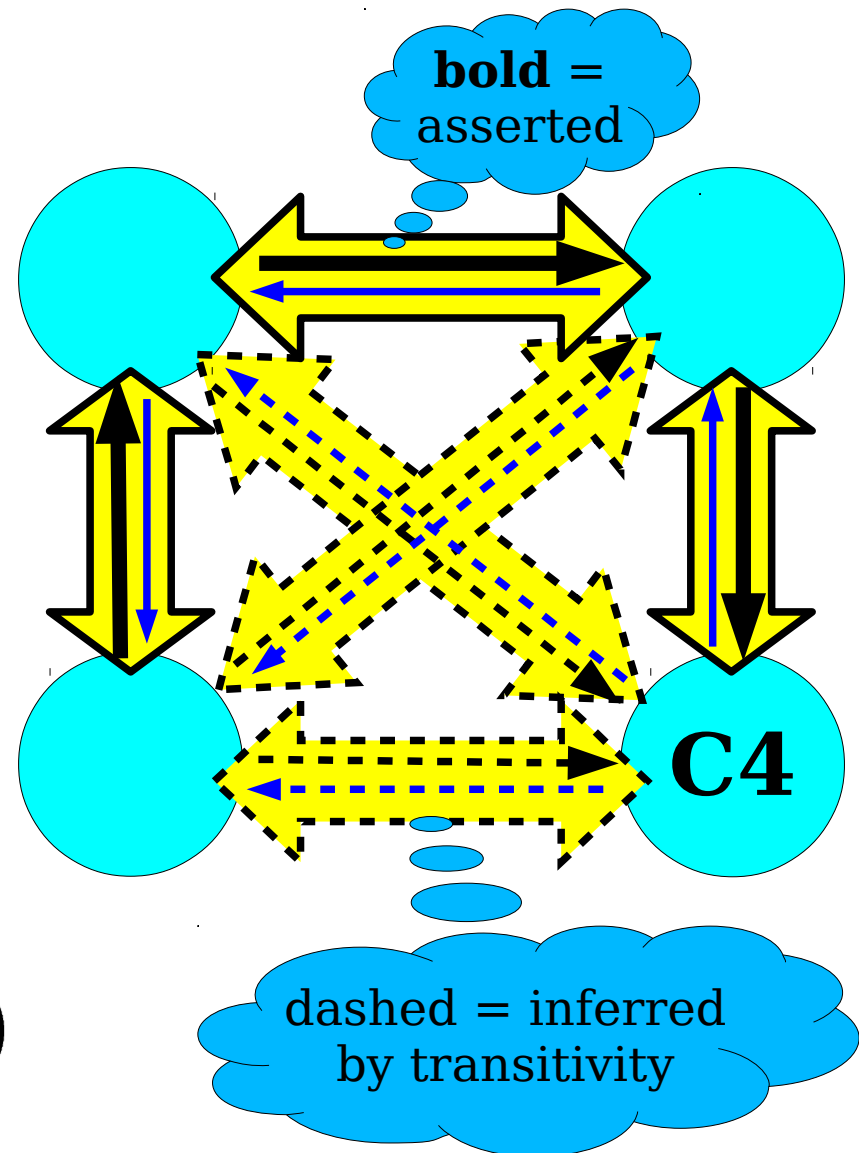
—  $Q_1 \dot{\subseteq} R$  —

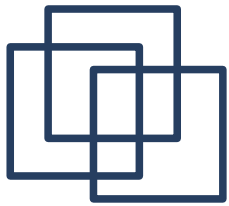
—  $Q_2 \dot{\subseteq} R$

$\text{transitive}(Q_1)$

$\text{transitive}(Q_2)$

$Q_1(x, y) \leftrightarrow Q_2(y, x)$



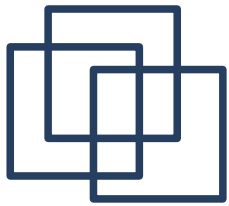


# Solving Sudokus by Reasoning

MiniLisp  
for programmatic KB  
(here: ABox) creation, and  
output generation.  
New „ad hoc“ server  
functions can be defined in  
MiniLisp.

The screenshot displays the RacerPro 2.0 application window. The main interface is divided into several panes. On the left, there's a 'Profiles' pane with tabs for 'Active Profiles', 'TBoxes', 'Concepts', 'Individuals', and 'Classes'. Below this is a 'Classic Layout' section showing a 9x9 Sudoku grid. The grid contains numbers and dashes representing unknown cells. Below the grid, there's a text area showing the evaluation of a MiniLisp query: `(SUDOKU ((0 6 0 5 0 3 2 0 8) (1 0 5 0 0 8 0 0 3) (8 0 0 0 0 6 4 0 0 0 0 6) (2 0 0 8 0 0 7 0 1) (7 0 6 1 0 5 0 3 0)))`. The result is `NIL`. On the right, there's a 'RacerEditor' window showing a MiniLisp script. The script defines a `sudoku-web` server function and a `sudoku` function. It also registers these functions and uses them to evaluate the `SUDOKU` query. The script ends with `Finished evaluating` and `RacerPro 2.0 running on localhost:8088 (case: preserve) --- s`. At the bottom of the RacerPro window, there are several buttons: 'Show Manual', 'Save Shell...', 'Clear Shell', 'Full Reset', 'New Editor', 'Open in Editor...', 'Load...', 'Quit', and 'Shutdown RacerPro & Quit'.





# MiniLisp HTML Generation

RacerPorter

Profiles Shell TBoxes ABoxes Concepts Roles Individuals Assertions Axioms Taxonomy Role Hierarchy Queries Log About

Active Profile  
TBox (\*\*)  
Concept (\*c\*)  
Individual (\*i\*)  
Query / Rule (\*qor\*)  
Reasoner Container (\*for\*)  
Request

Classic Layout

4: Localhost / Big TBoxes, Big ABoxes  
default

Sudoku - Mozilla Firefox

Sudoku Solution

2	4	9	8	5	3	1	6	7
8	7	6	4	1	9	5	3	2
5	3	1	6	2	7	4	9	8
9	6	4	5	7	2	3	8	1
7	1	2	3	6	8	9	4	5
3	8	5	9	4	1	7	2	6
6	5	3	7	8	4	2	1	9
4	2	8	1	9	5	6	7	3
1	9	7	2	3	6	8	5	4

Evaluating (SUDOKU ((0 6 0 0 0 0 6) (2 0 0 8 0 0 7) (13) > NIL  
[14] ? (time (SUDOKU-web (0 0 0 8 0 0 9) (0 2 0 0 9) (2 0 0 8 0 0 9) (0 2 0 0 9) (14) > "file-entity"  
[15] ?

Arguments of owl-read-file Fertig

HTML generation with MiniLisp - created page served with AllegroServe

```
(time (SUDOKU-web ((2 0 0 8 5 0 0 0 7) (0 7 0 4 1 0 0 3 0) (5 0 0 0 2 0 0 0 8) (0 0 0 0 0 0 0 8 1) (7 1 2 0 0 0 9 4 5) (3 8 0 0 0 0 0 0 0) (6 0 0 0 8 0 0 0 9) (0 2 0 0 9 5 0 7 0) (1 0 0 0 3 6 0 0 4))))
```

;;; open <http://localhost:8080/sudoku.html> in your WebBrowser!

Finished evaluating  
RacerPro 2.0 running on localhost:8088 (case: preserve) ---- s

T) (KB-NAME) (LOCATOR) RECURSIVE IGNORE-IMPOR

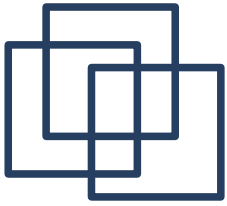
Function Doc Complete Input

Sel. Concepts := Last Result Sel. Roles := Last Result Sel. Individuals := Last Result

Clear Selection Clear Selection Clear Selection

Show Manual Save Shell... Clear Shell Full Reset New Editor Open in Editor... Load... Quit Shutdown RacerPro & Quit

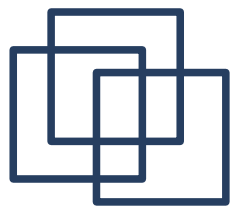




# Demos

---

- Sudoku
- People + Pets.owl Protege and RacerPorter
- JRacer + Eclipse
- LRacer...



# (2006 – today) RacerPorter – The Listener

RacerPorter

Profiles | **Shell** | TBoxes | ABoxes | Concepts | Roles | Individuals | Assertions | Axioms | Taxonomy | Role Hierarchy | ABox Graph | Query IO | Queries + Rules | Def. Queries | Log | About

Active Profile: 4: Localhost / Big TBoxes, Big ABoxes

Namespace (#l, \*n\*)

TBox (\*t\*) default

ABox (\*a\*) default

Concept (\*c\*) 0

Role (\*r\*) 0

Individual (\*i\*) 0

Axiom (\*ax\*) 0

Query / Rule (\*qor\*)

Definition (\*def\* = Name)

Reasoner Container (\*or\*) OWLAPI-KB

Ontology Container (\*oo\*)

Request: 20 : (get-namespace-prefixes)

Response: 20 : READY

Classic Layout | < | < 2 / 2

[\*] ? Cannot start RacerPro @ localhost:8088, server

[\*] > :ERROR

[\*] ? Automatically connected to RacerPro 2.0 running

[\*] > (:OKAY "RacerPro 2.0 running on localhost:8088")

[1] ? (get-racer-version)

[1] > "2.0"

[2] ? (owl-read-file []

RacerPorter

(owl-read-file  
FILENAME  
&KEY  
(VERBOSE \*TBOX-VERBOSE\*)  
(INIT T)  
(KB-NAME)  
(LOCATOR)  
RECURSIVE  
IGNORE-IMPORT  
IMPORT-META-ONTOLOGIES  
EXCLUDED-META-ONTOLOGIES  
FIRE-RULES  
MAINTAIN-OWLAPI-AXIOMS  
&ALLOW-OTHER-KEYS)

OK

Comfortable RacerPro listener with completion, function doc, history, pretty printing, ...

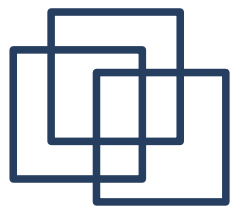
Arguments of owl-read-file: FILENAME &KEY (VERBOSE \*TBOX-VERBOSE\*) (INIT T) (KB-NAME) (LOCATOR) RECURSIVE IGNORE-IMPOR

Function Doc Complete Input

Sel. Concepts := Last Result Sel. Roles := Last Result Sel. Individuals := Last Result

Clear Selection Clear Selection Clear Selection

Show Manual Save Shell... Clear Shell Full Reset New Editor Open in Editor... Load... Quit Shutdown RacerPro & Quit



# The Racer Editor with Some Example Queries

The screenshot displays the RacerEditor application interface. On the left, the RacerPorter window shows a shell window with a series of commands and responses. The commands include connecting to RacerPro 2.0, checking the version, and performing a full reset. The responses indicate successful connections and version information. Below the shell window, there are buttons for 'Show Manual', 'Save Shell...', 'Clear Shell', 'Full Reset', 'New Editor', 'Open in Editor...', 'Load...', 'Quit', and 'Shutdown RacerPro & Quit'.

On the right, the RacerEditor window shows a query being evaluated. The query is a SPARQL query that retrieves instances of the class 'cat\_owner' and their associated 'cat' and 'pet' properties. The query is as follows:

```
;;; Old_lady not explicit
;;; ABox Graph : Minnie has_pet Tom
;;; Select Tom -> Describe -> Cat
;;; Assertions Tab: nothing was
;;; Is a cat by inference (see
;;; Interplay of definitions <

;;; The classes an individual is
;;; is computed from the definit
;;; multiple classification

;;; -----
;;; ABox Queries
;;; (Go to ABox Graph!)
;;;

(concept-instances cat_owner)

(retrieve (?x)
  (?x cat_owner))

(retrieve (?x ?y)
  (and (?x cat_owner)
        (?x ?y has_pet)))

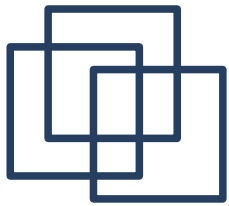
[retrieve (?x ?y)
  (and (?x cat_owner)
        (?x ?y has_pet)
        (?y cat))]

(retrieve (?x ?y (direct-types ?y))
  (and (?x pet_owner)
        (?x ?y has_pet)
        :dont-show-lambdas-p t))

Finished evaluating
RacerPro 2.0 running on localhost:8088 (case: preserve) ---- querye
```

A blue thought bubble with white text is overlaid on the RacerEditor window, stating: "RacerEditor for knowledge base creation, expression evaluation, ... supports OWL RDF, KRSS, SPARQL".





# The Relation (Role / Property) Hierarchy

RacerPorter

Profiles Shell TBoxes ABoxes Concepts Roles Individuals Assertions Axioms Taxonomy

Active Profile 4: Localhost / Big TBoxes, Big ABoxes

TBox (\*t\*) /home/mi.wessel/KBs/people+pets.owl

Concept (\*c\*) cat 4

Individual (\*i\*) Tom 1

Query / Rule (\*qor\*)

Reasoner Container (\*or\*) OWLAPI-KB

Request 63: (describe-role has\_pet /home/mi.wessel/KBs/people+pets.owl)

Classic Layout |< < 13 / 13 > >|

(likes) — (has\_pet)

(top-role)

- (part\_of)
- (eats)
- (drives)
- (works\_for)
- (reads)
- (is\_pet\_of)
- (has\_parent)
  - (has\_father)
  - (has\_mother)
- (has\_part)
- (has\_child)
- (eaten\_by)
- (service\_number)

Freeze Graph

Search & Select

Print Graph

Parents Synonyms

Info

```
[02] ? (describe-role has_pet /home/mi.wessel/KBs/people+pets.owl)
[07] > (has_pet
      :synonyms
      (has_pet)
      :domain
      person
      :range
      animal
      :parents
      (likes)
      :children
```

```
(equivalent cat_liker
  (and person
    (some likes cat)))
(equivalent cat_owner
  (and person
    (some has_pet cat)))
(implies old_lady
  (and (all has_pet cat)
    (some has_pet animal)))
(define-primitive-role has_pet
  :parents likes ...)
```

Relation hierarchy -  
„has pet“ is a subrelation  
of „likes“  
(having a pet implies  
that you like it)



# Individuals & Relationships - ABox Graph

Another inference („reasoning about data“):  
Minnie is an old lady because she is a female elderly person.  
Old ladies are cat owners → Tom is a cat!

(equivalent old\_lady  
(and person female elderly))  
(implies old\_lady  
(and (all has\_pet cat)  
(some has\_pet animal)))

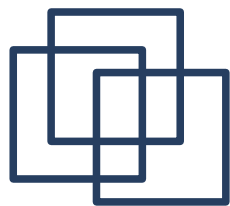
(instance Minnie elderly)  
(instance Minnie female)  
(related Minnie Tom has\_pet)  
(instance Tom top)

**TBox**

**ABox**

Info

```
[6] ? {individual-direct-types Tom /home/mi.wessel/KBs/people+pets.owl}
[6] > {(cat) (pet)}
```



# Inspecting Class Assertions for Tom

RacerPorter

Profiles Shell TBoxes ABoxes Concepts Roles Individuals **Assertions** Axioms Taxonomy Role Hierarchy ABox Graph Query IO Queries + Rules Def. Queries Log About

Active Profile: 4: Localhost / Big TBoxes, Big ABoxes  
TBox (\*t): /home/mi.wessel/KBs/people+pets.owl  
Concept (\*c\*): cat  
Individual (\*i\*): Tom  
Query / Rule (\*qor\*):  
Reasoner Container (\*or\*): OWLAPI-KB  
Request: 68 : (all-concept-assertions /home/mi.wessel/KBs/people+pe  
Response: 68 : CACHE-HIT

Namespace (#l, \*n\*):  
ABox (\*a\*): /home/mi.wessel/KBs/people+pets.owl  
Role (\*r\*): has\_pet  
Axiom (\*ax\*):  
Definition (\*def\* = Name):  
Ontology Container (\*oo\*):

Classic Layout |< < 18 / 18 > >| Delete Delete All Recover ☒ Simplify ☐ Sel. First ☐ Sel. Only ☐ Arg. Comp. Abort Racer Request

(Tom top)

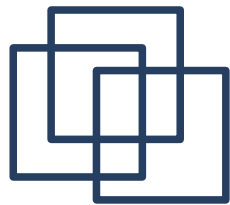
It is not asserted **explicitly** that Tom is a cat! („Class Assertion“) (**top** = thing concept)

☒ All Concepts ☐ Cur. Concept ☐ Sel. Concepts ☐ All Inds. ☒ Cur. Ind. ☐ Sel. Inds. ☒ All Roles ☐ Cur. Role ☐ Sel. Roles  
☒ Concept A ☐ Role A ☐ Same As A ☐ Different From A ☐ Attribute A ☐ Constraint A ☐ Annotation CA ☐ Annotation RA

Clear Selection Delete Selected

Info

```
[0] ? (describe-role has_pet /home/mi.wessel/KBs/people+pets.owl)
[7] > (has_pet
      :synonyms
      (has_pet)
      :domain
      person
      :range
      animal
      :parents
      (likes)
      :children
```



# Relation („Role“) Assertions for Tom

RacerPorter

Profiles | Shell | TBoxes | ABoxes | Concepts | Roles | Individuals | **Assertions** | Axioms | Taxonomy | Role Hierarchy | ABox Graph | Query IO | Queries + Rules | Def. Queries | Log | About

Active Profile	4: Localhost / Big TBoxes, Big ABoxes		Namespace (#!, *n*)	
TBox (*t*)	/home/mi.wessel/KBs/people+pets.owl		ABox (*a*)	/home/mi.wessel/KBs/people+pets.owl
Concept (*c*)	cat		Role (*r*)	has_pet
Individual (*i*)	Tom		Axiom (*ax*)	1
Query / Rule (*qor*)			Definition (*def* = Name)	0
Reasoner Container (*or*)	OWLAPI-KB		Ontology Container (*oo*)	

Request: 69 : (all-role-assertions /home/mi.wessel/KBs/people+pets.o) Response: 69 : READY

Classic Layout | < | < 19 / 19 | > | > | Delete | Delete All | Recover | ☒ Simplify | ☐ Sel. First | ☐ Sel. Only | ☐ Arg. Comp. | Abort Racer Request

{(Minnie Tom) ... has\_pet}

It is asserted that Tom is a pet of Minnie („Role assertion“)

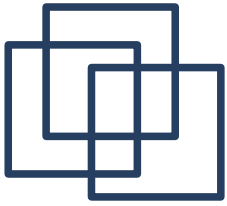
☒ All Concepts | ☐ Cur. Concept | ☐ Sel. Concepts | ☐ All Inds. | ☒ Cur. Ind. | ☐ Sel. Inds. | ☒ All Roles | ☐ Cur. Role | ☐ Sel. Roles  
☐ Concept A | ☒ Role A | ☐ Same As A | ☐ Different From A | ☐ Attribute A | ☐ Constraint A | ☐ Annotation CA | ☐ Annotation RA

Clear Selection | Delete Selected

Info

```
[0] ? (describe-role has_pet /home/mi.wessel/KBs/people+pets.owl)
[7] > (has_pet
      :synonyms
      (has_pet)
      :domain
      person
      :range
      animal
      :parents
      (likes)
      :children
```





# Syntaxes

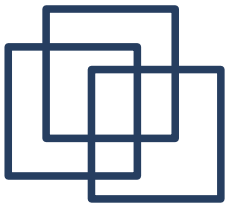
- Old lady concept in...
  - **KRSS / Racer native:**

Racer has its own parsers

```
(equivalent old_lady (and person female elderly))  
(implies old_lady (and (all has_pet cat)  
                        (some has_pet animal)))
```

- **OWL 2 Functional Syntax** (almost S-Expressions...)

```
EquivalentClasses(  
  old+lady  
  ObjectIntersectionOf(female person elderly))  
SubClassOf(old+lady  
  ObjectIntersectionOf(  
    ObjectAllValuesFrom(has_pet cat)  
    ObjectSomeValuesFrom(has_pet animal)))
```



## Syntaxes (2)

- **Old lady** concept in **OWL RDF/XML**:

```
<owl:Class rdf:ID="old_lady">
```

```
  <owl:equivalentClass>
```

```
    <owl:Class>
```

(equivalent old\_lady...

... (and ...

```
      <owl:intersectionOf
```

```
        rdf:parseType="Collection">
```

```
          <owl:Class rdf:about="#person"/>
```

```
          <owl:Class rdf:about="#female"/>
```

```
          <owl:Class rdf:about="#elderly"/>
```

```
        </owl:intersectionOf>
```

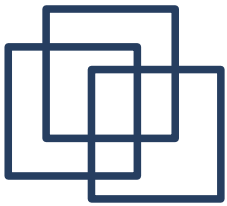
```
      </owl:Class>
```

... person female elderly ...

```
    </owl:equivalentClass>
```

...

... ))



# Syntaxes (3)

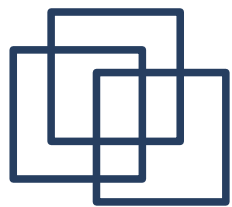
- **Old lady** concept in **OWL RDF/XML** cont.

```
<rdfs:subClassOf> (implies old_lady ...  
  <owl:Class>  
    <owl:intersectionOf rdf:parseType="Collection">  
      <owl:Restriction>  
        <owl:allValuesFrom rdf:resource="#cat"/>  
        <owl:onProperty>  
          <owl:ObjectProperty rdf:about="#has_pet"/>  
        </owl:onProperty>  
      </owl:Restriction>  
      <owl:Restriction>  
        <owl:onProperty>  
          <owl:ObjectProperty rdf:about="#has_pet"/>  
        </owl:onProperty>  
        <owl:someValuesFrom rdf:resource="#animal"/>  
      </owl:Restriction>  
    </owl:intersectionOf>  
  </owl:Class>  
</rdfs:subClassOf>  
</owl:Class>
```

... (and ...

... (all has\_pet cat) ...

... (some has\_pet cat) ...



# DOCOMO ContextWatcher / IYouIt

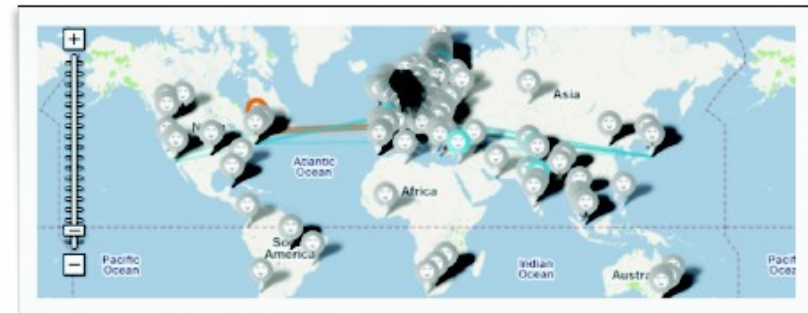


## A mobile community service

- 1300+ users in 60+ countries
- Connected to emerging Web 2.0 services

## Your digital life recorder

- Facilitating context awareness on standard phones
- Integration of key Semantic Web technologies



flickr®



You Tube



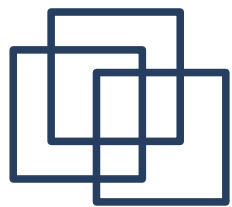
twitter

DOPPLR



The timeline visualization shows a 'Special Working Day' for Basti. The day is divided into Night (03:00-07:00), Day (07:00-18:00), and Night (18:00-23:00). The weather is 'Partly Sunny' during the day and 'Rain' at night. The temperature is 'Very warm'. Basti's activities include driving from Fürstenfeldbruck to Munich at 07:00, walking during office hours (08:00-18:00) at Docomo, and driving back to Fürstenfeldbruck at 18:00. He has a 'Special Working Day' from 07:00 to 18:00. Other people involved include Fra (Wife), Kim (CTO), and Basti (Colleague). A 'Demo' is scheduled for 13:00, and an 'Imp. Meeting' is at 14:00. A small inset photo shows two men in suits looking at a laptop.





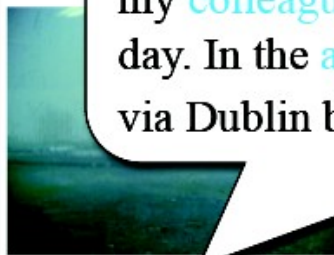
# Regonized Events for „Life Logging“ Blogging

## ContextWatcher Blogs in 2005

FRIDAY, NOVEMBER 11, 2005

### A busy ISWC day

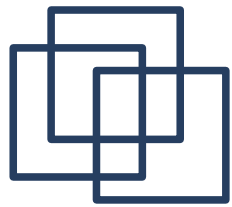
Today was a busy ISWC day (84.1% covered). I took 9 pictures in Dublin and Galway.



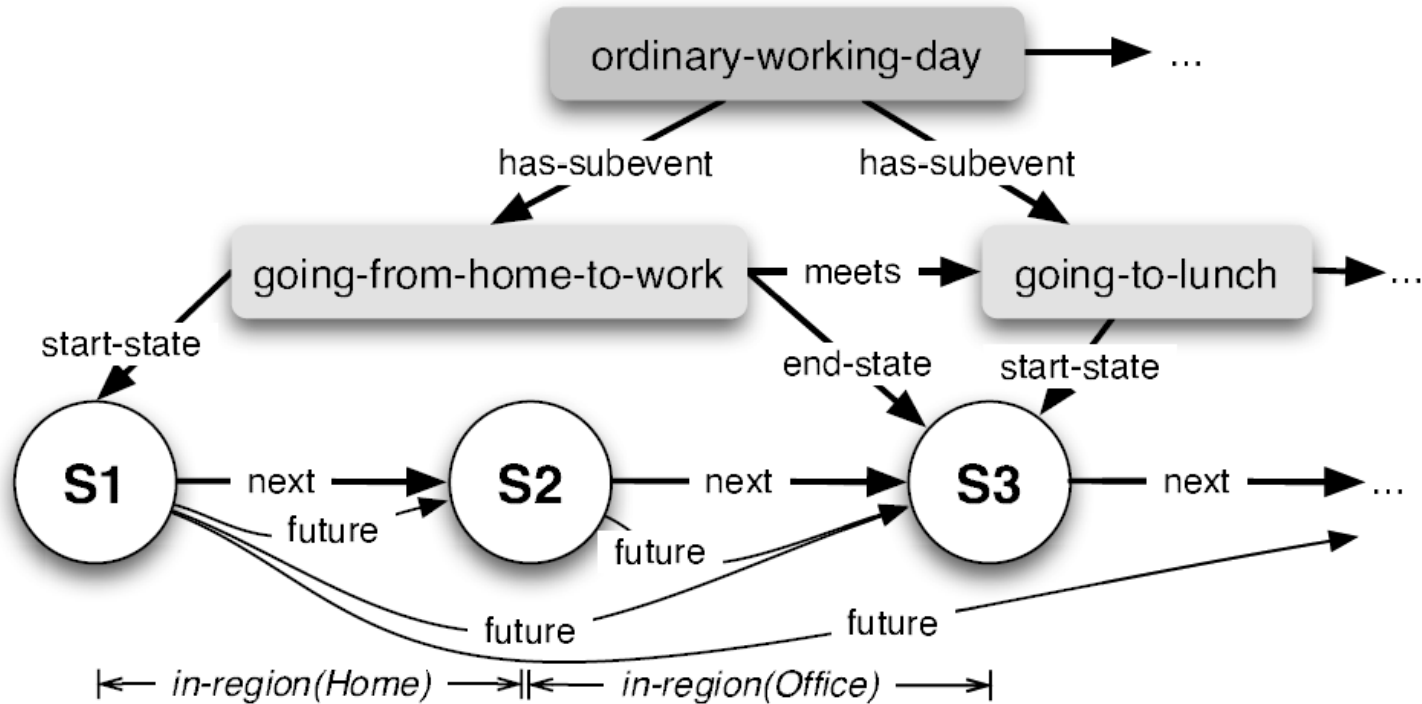
Today was the **last day** of my **business trip** to the ISWC'05 **conference** in Galway together with my **colleague** M. Luther. It was a cold and rainy day. In the **afternoon** I **traveled back** to Munich via Dublin by plane.

I visited Galway (51.8%), München (7.3%), Dublin (18.9%) and Offaly (9.9%), mainly Commute (5.2%) and ISWC (35.1%). I met luther (38.7%). My maximum speed was 131.2 km/h.

POSTED BY MATTHIAS AT 1:01 PM 0 COMMENTS



# Situations, Simple & Complex Events

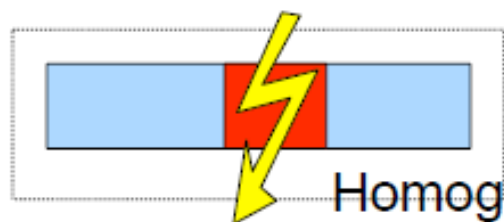


- States = situations → simple events → complex events
  - Linear time model (**next** role, transitive superrole **future**)
  - Allen temporal relation via concrete domain reasoning
  - Event constructions (aggregates!) via forward chaining rules

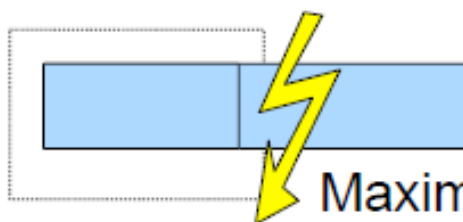


# Realization of Event *Recognizers*

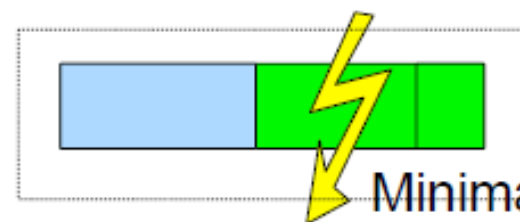
- Assuming events are already present as aggregates in the ABox, how to recognize them?
  - Defined concepts
    - Problems with relational expressivity for complex events
      - only tree-shaped temporal constraints expressible
      - Important event properties cannot be expressed (required for definitions of complex events!)



Homogeneity



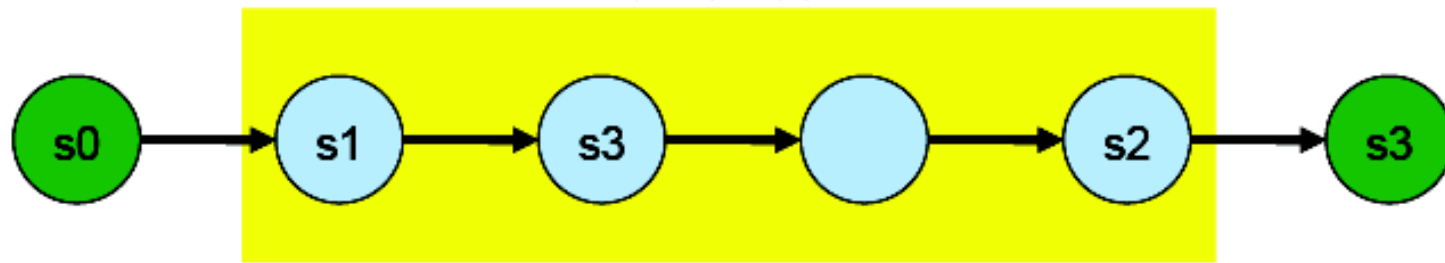
Maximality



Minimality

- Queries and rules
  - High relational expressivity over the ABox
  - Universal closed-domain quantifier (SPARQL, SQL, nRQL)

# Recognizing Homogeneous Events (1)

$$\begin{aligned}
 ans(s_1, s_2) \leftarrow & \text{state}(s_1), \text{state}(s_2), \text{future}(s_1, s_2), \\
 & P(s_1), P(s_2), \\
 & \backslash \pi(s_1) (\text{state}(s_0), \text{next}(s_0, s_1), P(s_0)), \\
 & \backslash \pi(s_2) (\text{state}(s_3), \text{next}(s_2, s_3), P(s_3)), \\
 & \backslash \pi(s_1, s_2) ( \text{state}(s_3), \text{future}(s_1, s_3), \text{future}(s_3, s_2), \\
 & \quad \backslash P(s_3))
 \end{aligned}$$


```

(retrieve (?s1 ?s2)
  (and (?s1 state) (?s2 state) (?s1 ?s2 future)
    (?s1 P) (?s2 P)
    (neg (project-to (?s1) (and (?s0 state) (?s0 ?s1 next) (?s0 P))))
    (neg (project-to (?s2) (and (?s3 state) (?s2 ?s3 next) (?s3 P))))
    (neg (project-to (?s1 ?s2) (and (?s3 state) (?s1 ?s3 future) (?s3 ?s2 future)
      (neg (?s3 P)))))))
  
```

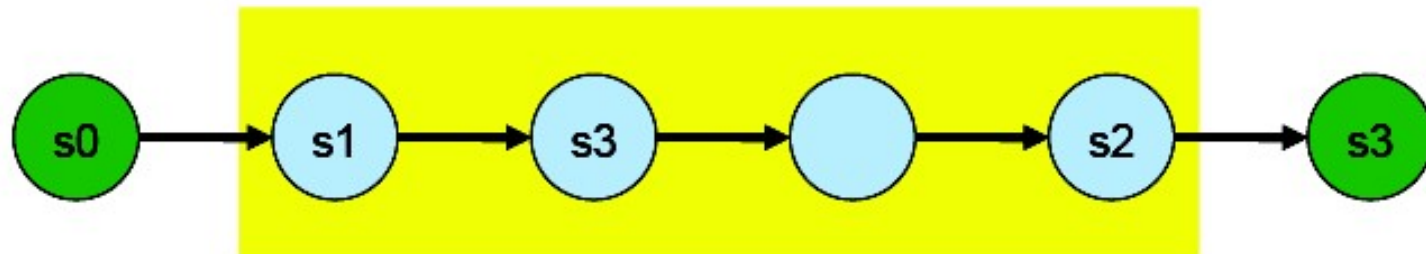
# Recognizing Homogeneous Events (2)

$\mathcal{S}_{\mathcal{A}} = (\Delta^{\mathcal{I}}, C^{\mathcal{I}}, \dots, R^{\mathcal{I}}, \dots)$ , with

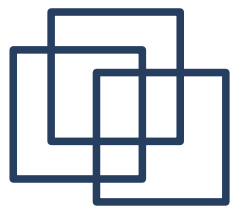
$$\Delta^{\mathcal{I}} = \text{inds}(\mathcal{A}),$$

$$C^{\mathcal{I}} = \{ i \mid i \in \text{inds}(\mathcal{A}), \mathcal{A} \models C(i) \} ,$$

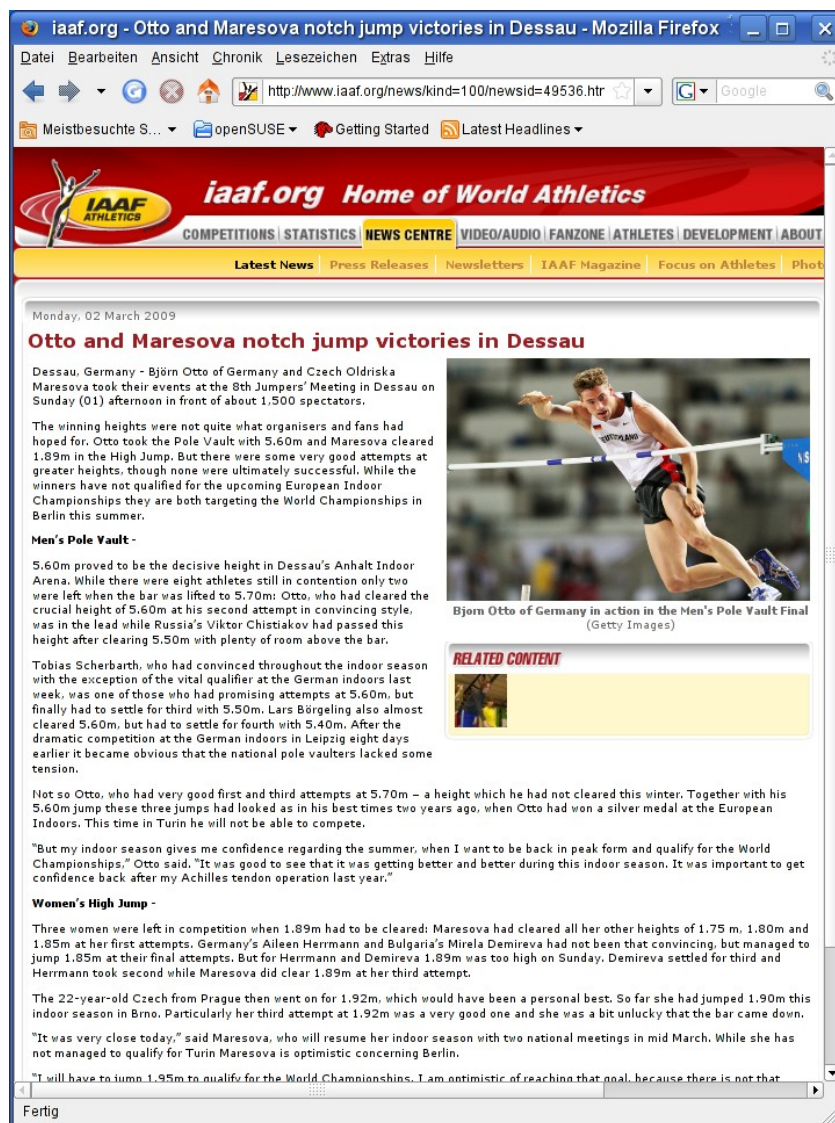
$$R^{\mathcal{I}} = \{ (i, j) \mid \text{inds}(\mathcal{A}), \mathcal{A} \models R(i, j) \} ,$$



$$\begin{aligned} \{ (s_1, s_2) \mid & \exists s_1, s_2 : \text{state}(s_1) \wedge \text{state}(s_1) \wedge \text{future}(s_1, s_2) \wedge \\ & P(s_1) \wedge P(s_2) \wedge \\ & \neg \exists s_0 : \text{state}(s_0) \wedge \text{next}(s_0, s_1) \wedge P(s_0) \wedge \\ & \neg \exists s_3 : \text{state}(s_3) \wedge \text{next}(s_2, s_3) \wedge P(s_3) \wedge \\ & \neg \exists s_3 : \text{state}(s_3) \wedge \text{future}(s_1, s_3), \text{future}(s_3, s_2) \wedge \\ & \neg P(s_3) \} \end{aligned}$$



# BOEMIE Project – Interprete / Understand Athletics News Pages

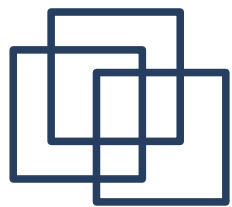


Goal:

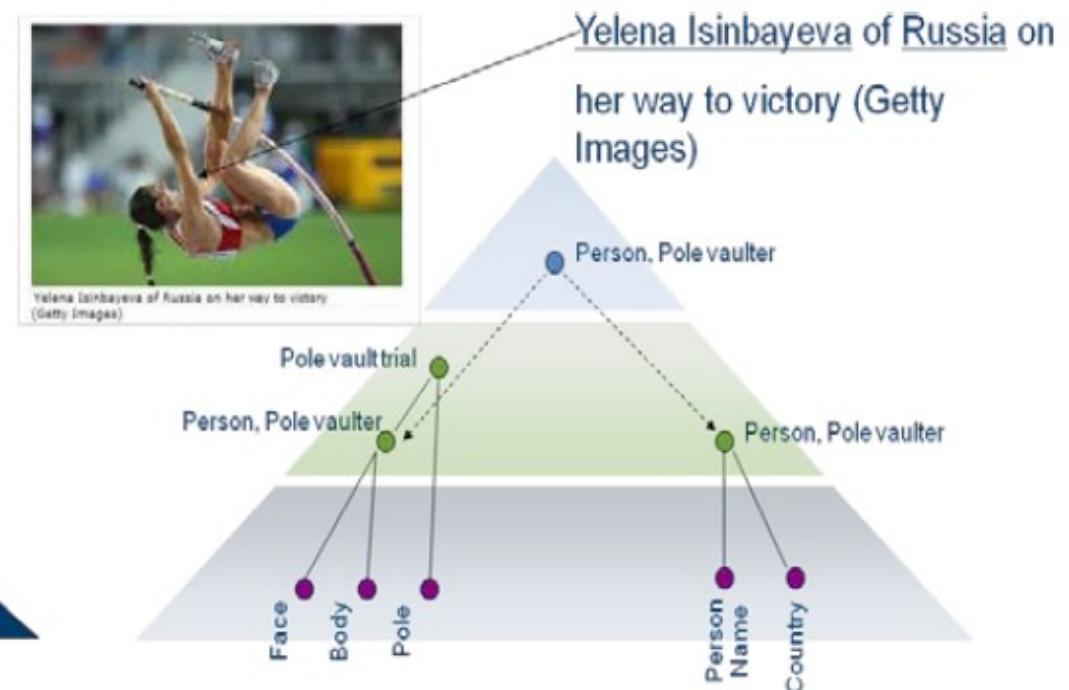
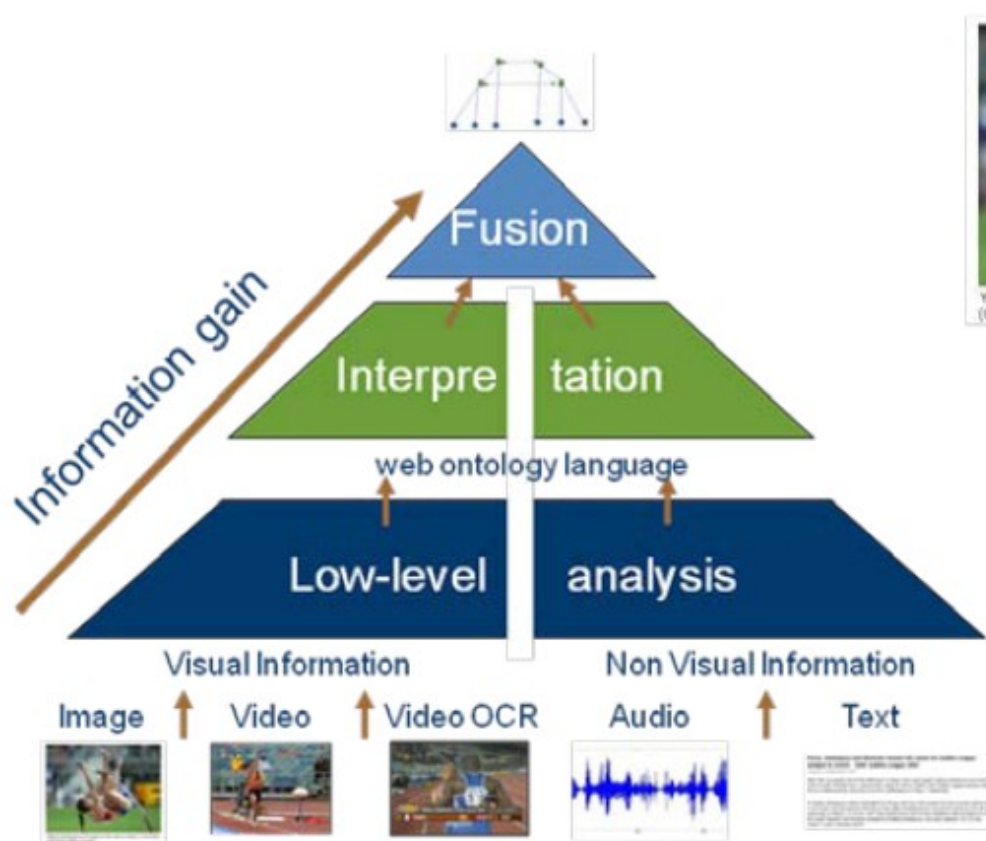
use clues from different modalities (text, image, video, sound) and named entity recognition + background KB with athletics knowledge to interpret. Hypothesize and integrate (fusion). Label the paragraphs appropriately („text understanding“).

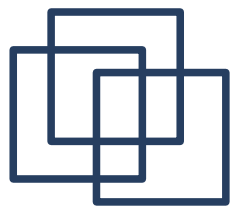
Jerry  
Hobbs





# BOEMIE Project – „DIKW“ Pyramid





# BOEMIE Project – Text Modality

The screenshot displays the BOEMIE Project interface. At the top, there are navigation tabs: Map, Media Gallery, Image, Webpage, and Video. Below these, a status bar shows 'Context: London', 'Status: retrieving picture', 'POIs: 2', 'Images: 15/15', 'Webpages: 13/13', and 'Videos: 8/8'. The main content area shows a news article titled 'Hestrie Cloete on her lap of honour' from ISTAF Berlin. A yellow callout box labeled 'PersonName' points to the name 'Hestrie Cloete' in the article text. A 'Boemieinfo' popup window is open, displaying information about Hestrie Cloete, including a link to 'Read all about the person of Hestrie Cloete' and a link to 'Add this person to your address book'. The article text mentions the 9th IAAF World Championships in Athletics (23-31 August 2003) and Hestrie Cloete's performance in the 2.05m African record in Berlin.

Context: London Status: retrieving picture POIs: 2 Images: 15/15 Webpages: 13/13 Videos: 8/8

http://143.233.226.31/BoemieVi.../news/Kind=2/newsId=22287.html

Denis was undoubtedly ...

Hestrie Cloete on her lap of honour ISTAF Berlin (Getty Images)

Zurich offers high profile dress rehearsal for Paris Worlds Fri 15 Aug 2003

Zurich, Switzerland again convened to celebrate another edition of the 'Weltklasse' at the adjacent Letzigrund stadium today

As the penultimate stage of the IAAF Golden League takes on particular significance as the high pressure gauge of form, just a week before the 9th IAAF World Championships in Athletics (23-31 August 2003).

Cloete and Ayhan to headline again

Hestrie Cloete and S?reya Ayhan were the undoubted stars of last Sunday's ISTAF Golden League meeting in Berlin, and the South African World High Jump champion and the Turkish European 1500m gold medalist are sure to be headlining again in Zurich.

Cloete with a practically unblemished score card up to and including her 2.05m African record in Berlin, will have a World record 2.10 clearance in her sights once more today. Wearing the 210 bib number on her vest last Sunday was perhaps too weighty a burden to carry as her three heavily failed attempts proved but that height is surely within

Boemieinfo

Read all about the person of Hestrie Cloete

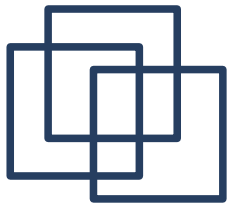
Read more about other athletes

Add this person to your address book

S?reya Ayhan wins in ISTAF Berlin (Getty Images)

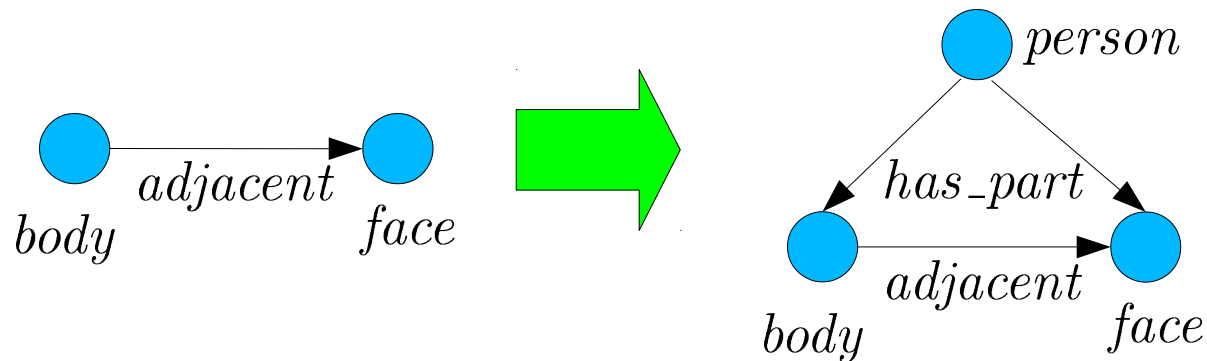
- Live from Zurich - IAAF Golden League quotes  
Fri 15 Aug 2003  
15 August 2003 - "Zurich is just magical. I have been winning every year since 1993 here and today ...

- Zurich offers high profile dress rehearsal for Paris Worlds  
Fri 15 Aug 2003  
15 August 2003 ? Zurich, Switzerland ? The 'who's who' of world athletics has once again convened ...



# Interpretation with OWL / SWRL?

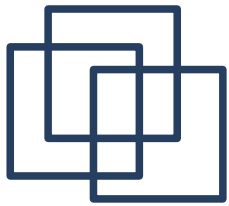
- The low-level annotations are incomplete
  - no person instance, but face & body region adjacency
  - often, aggregates must be instantiated, which is challenging



$body \sqcap \exists adjacent.face \sqsubseteq \exists part\_of.person$  ⚡

$body(x), face(y), adjacent(x, y) \rightarrow$   
 $person(z), has\_part(z, x), has\_part(z, y)$  ⚡



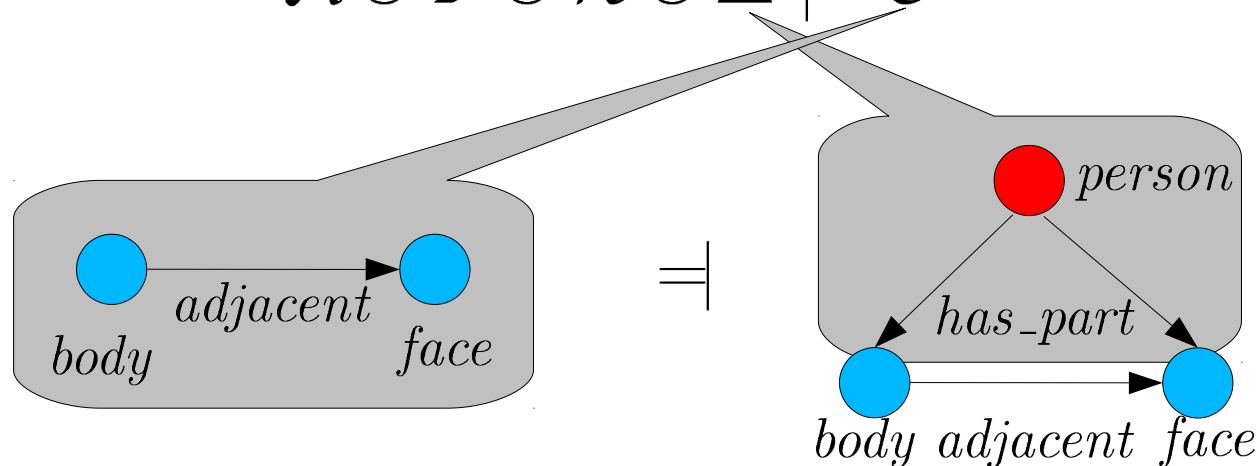


# BOEMIE Abduction Framework

- abductive horn rules which „explain observations“ (Shanahan) – implemented in nRQL

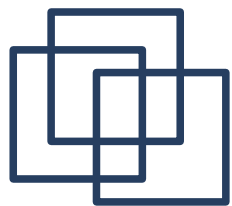
$$\text{adjacent}(x, y) \leftarrow \text{person}(z), \text{body}(y), \text{face}(x), \\ \text{has\_part}(z, x), \text{has\_part}(z, y)$$

$$\mathcal{A} \cup \mathcal{T} \cup \mathcal{R} \cup \Delta \models \mathcal{O}$$



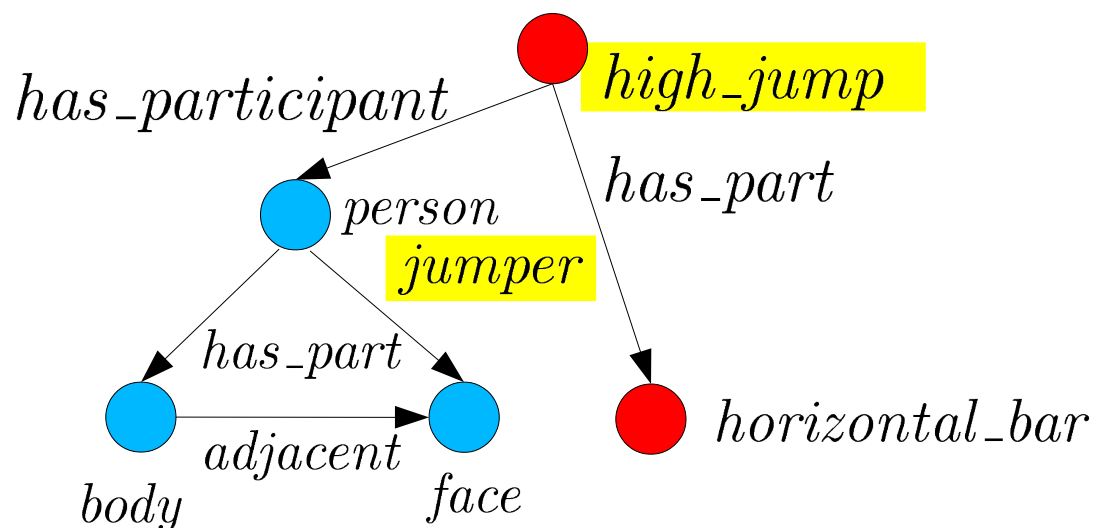
In general, more than one explanation possible

- minimality, consistency, preference, specificity
- probabilistic ranking (→ CASAM project)



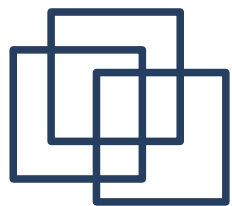
## BOEMIE Abduction Framework (2)

- Apply rules until fixpoint is reached



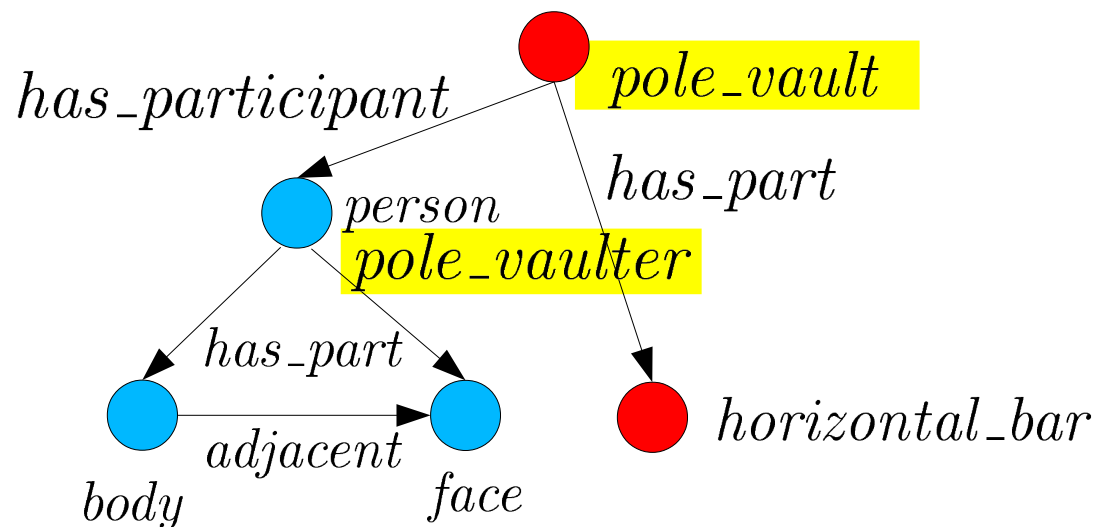
$adjacent(y, z) \leftarrow$   
 $high\_jump(x), jumper(y), horizontal\_bar(z),$   
 $has\_participant(x, y), has\_part(x, z)$

$adjacent(y, z) \leftarrow$   
 $pole\_vault(x), pole\_vaulter(y), horizontal\_bar(z),$   
 $has\_participant(x, y), has\_part(x, z)$



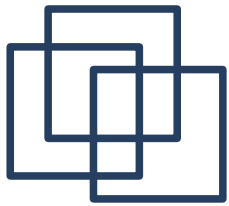
## BOEMIE Abduction Framework (3)

- Apply rules until fixpoint is reached



$adjacent(y, z) \leftarrow$   
 $high\_jump(x), jumper(y), horizontal\_bar(z),$   
 $has\_participant(x, y), has\_part(x, z)$

$adjacent(y, z) \leftarrow$   
 $pole\_vault(x), pole\_vaulter(y), horizontal\_bar(z),$   
 $has\_participant(x, y), has\_part(x, z)$



# Discussion and Opportunities

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- Geo-spatial semantic web:
  - **GeoSPARQL** + Open Street Map + Map Server + Big Data + SemWeb → spatially aware semantic web → smarter SIRI, smarter QA, ...
- I would like to participate in any project on logic-based image or scene understanding
  - some experience
  - probabilistic ranking of hypotheses (CASAM)
    - MARKO Description Logic + Rules
- Racer is still the best environment for Lisp-based ontology and SemWeb development
  - integration with Franz Allegro Graph technology