The RacerPro Environment for Lisp-based Semantic Web Applications

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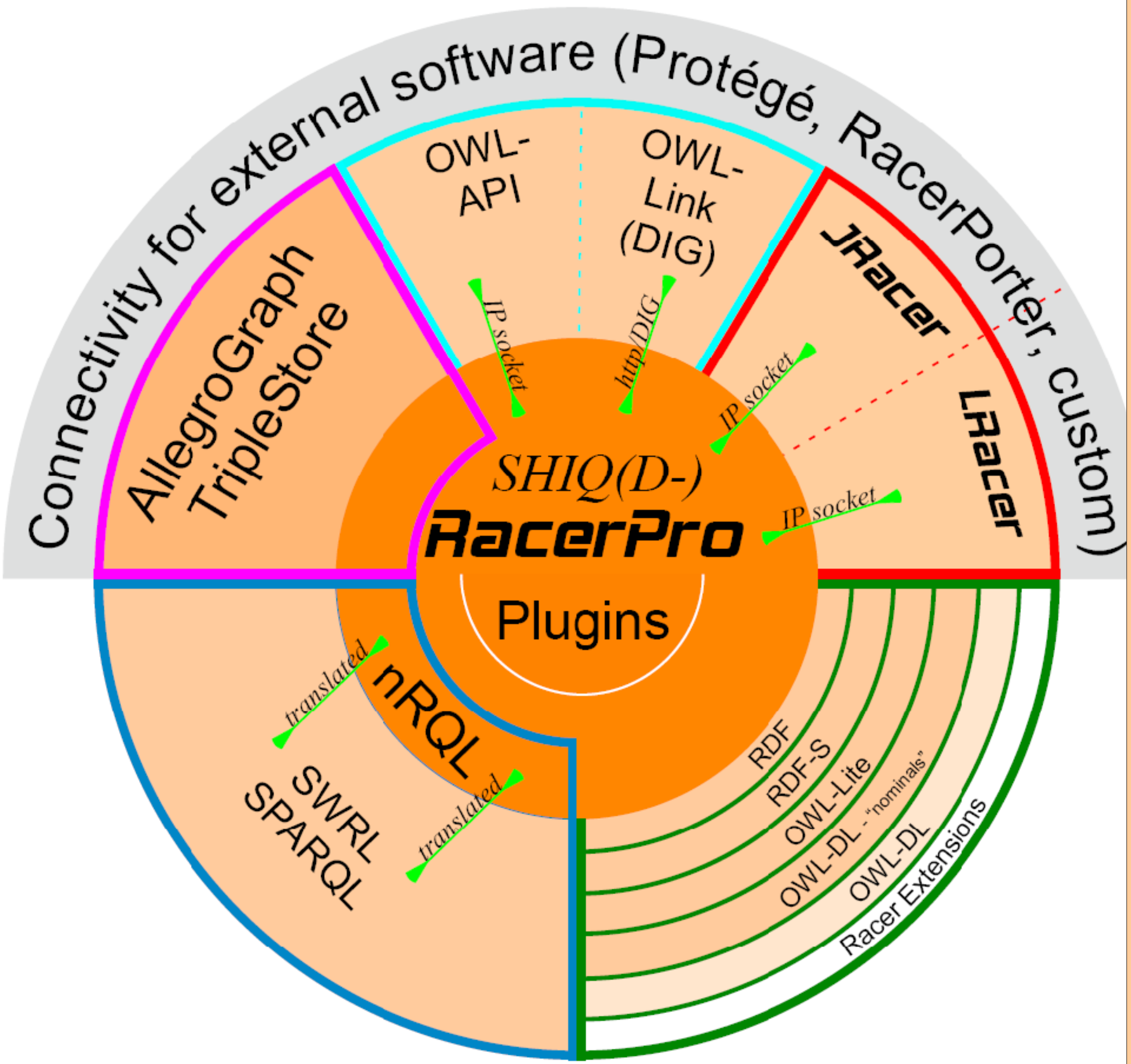
- Semantic Web programming in the „RacerPro environment“
  - JRacer, LRacer, MiniLisp, extensibility, OWLAPI, OWLlink, ...
- The role of Lisp

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 $\mathcal{SHIQ}(D)$
- 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**

Racer Systems – Partners & Friends

Prof.
Ralf Möller

Michael
Wessel

Prof.
Volker Haarsley

President
Kay Hidde

Research in
DLs, OWL,
Racer-projects

AllegroGraph
ACL
mutual
redistribution

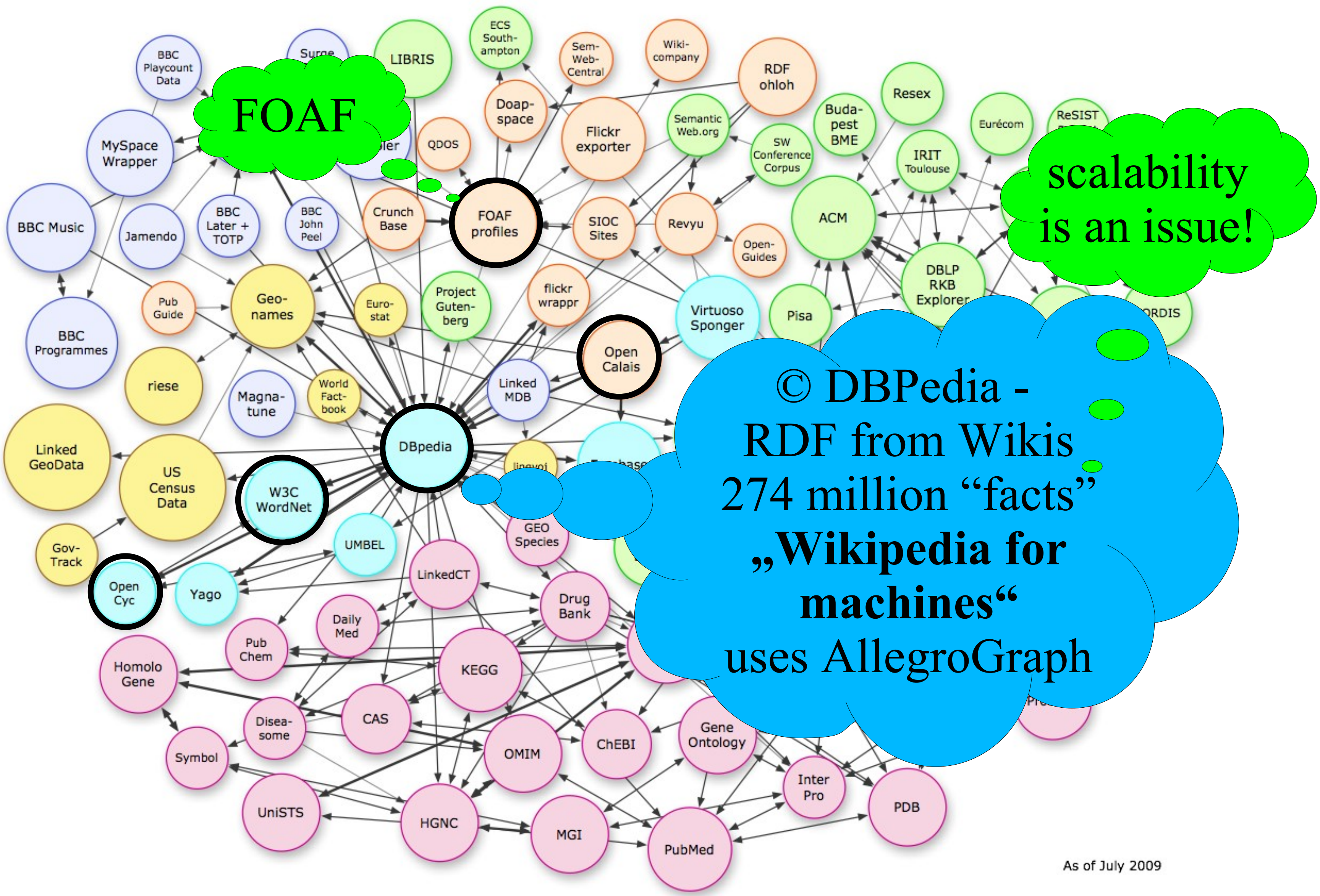
STS

FRANZ INC.
"WEB 3.0's DATABASE"

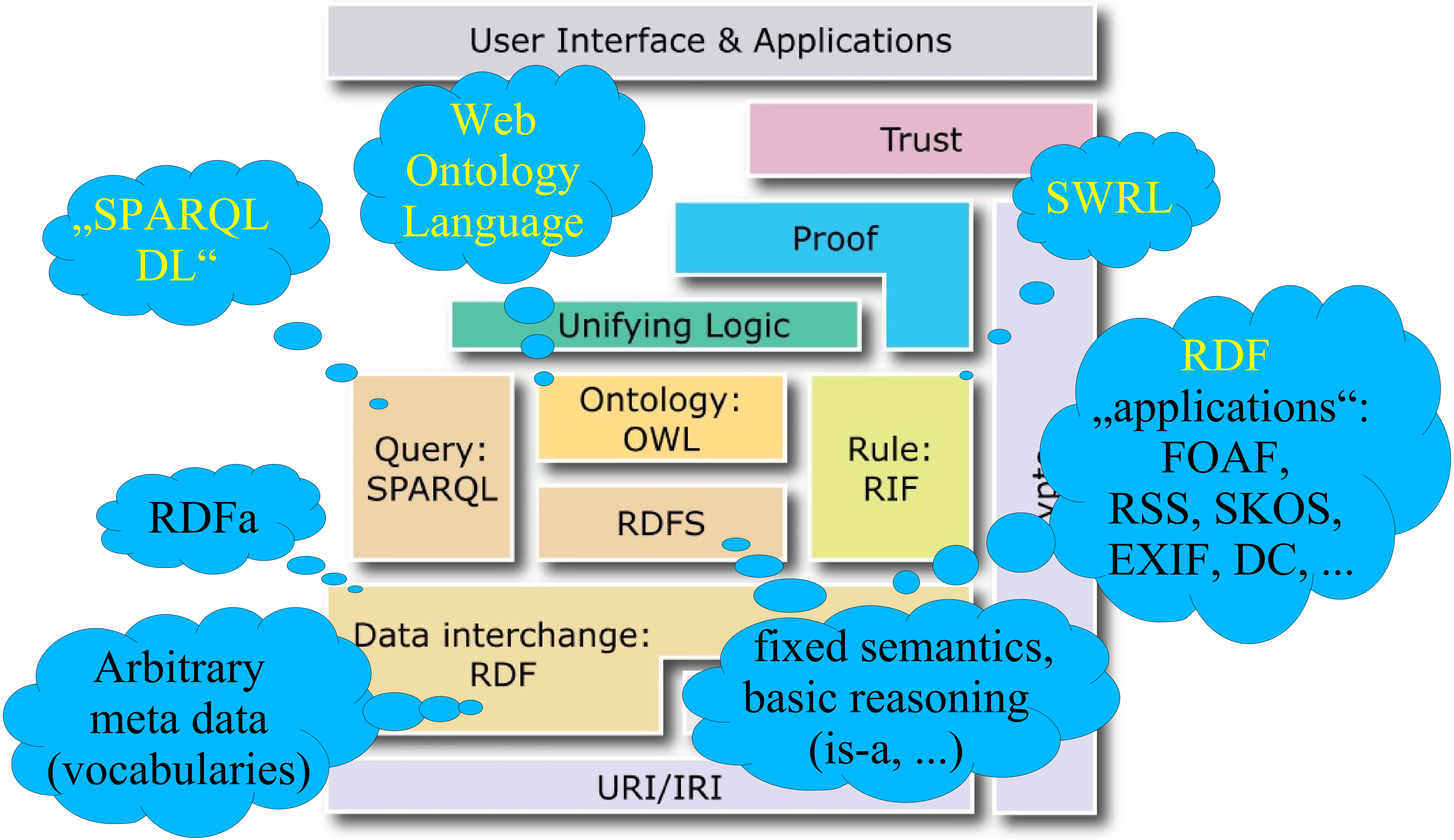
The Semantic Web - „A Web of Data“

- „The big database in the sky“
  - Web 1.0 – syntactic web, technical basis (HTTP, HTML, …)
  - Web 2.0 – social / community web **for people** (Wikis, Blogs, Boards, Flicker, Blogger, Twitter, ...)
    - folksonomies („(geo) tagging“)
  - Web 3.0 – Web 2.0 plus meta data **for machines**
    - meta data = page annotations, service descriptions, ... provided in terms of **ontologies** **(provide explicit formal semantics for terms → reasoning)**
    - annotations = logical propositions about resources identified by URIs
    - SPARQL endpoints & RDFa (RDF in HTML)
- Technically, the SemWeb is not really a „database“ (see below)

RDF Mashups / Linked Open Data (© LOD Cloud)

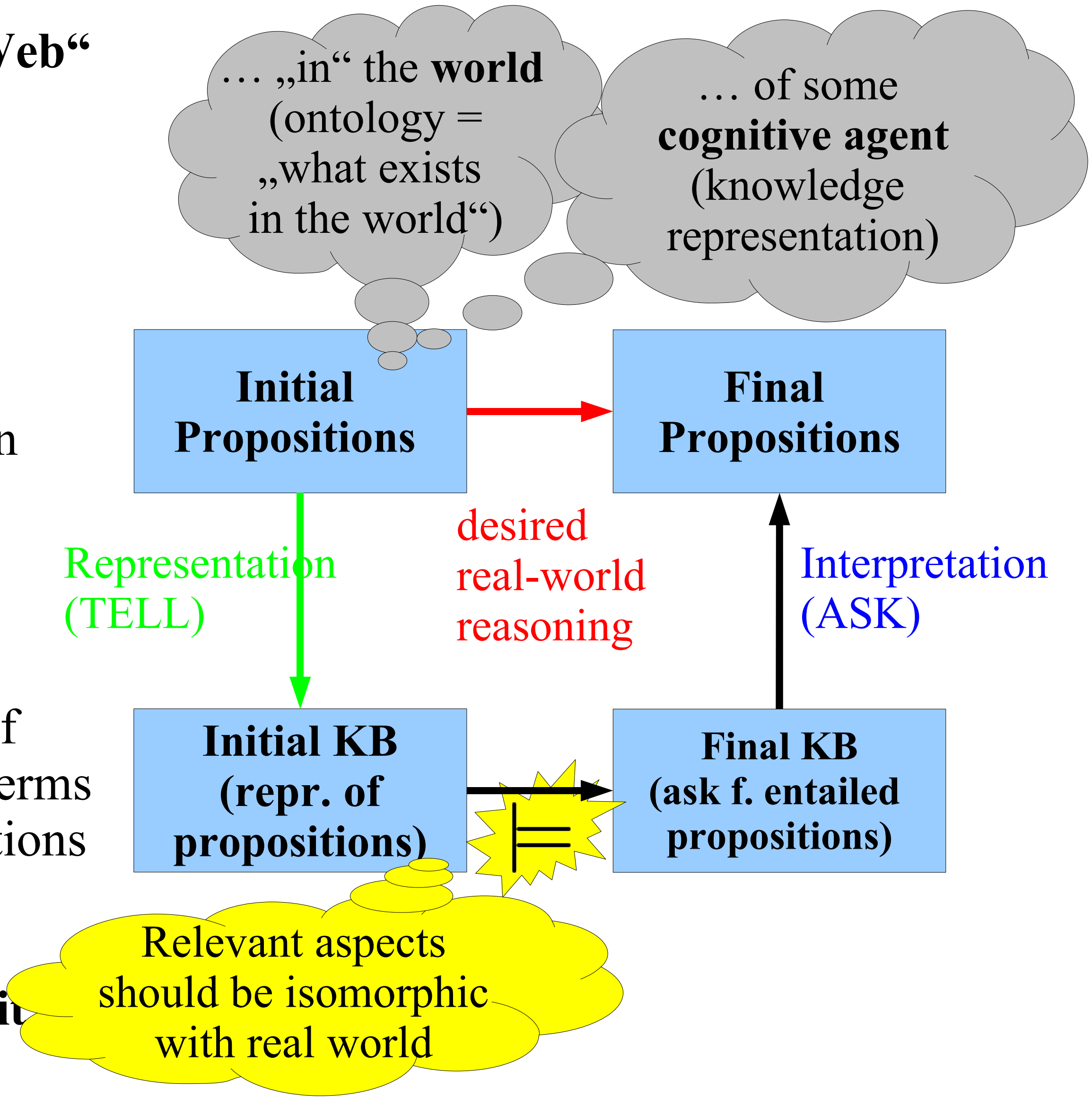


Semantic Web Stack (Layer Cake) © W3C

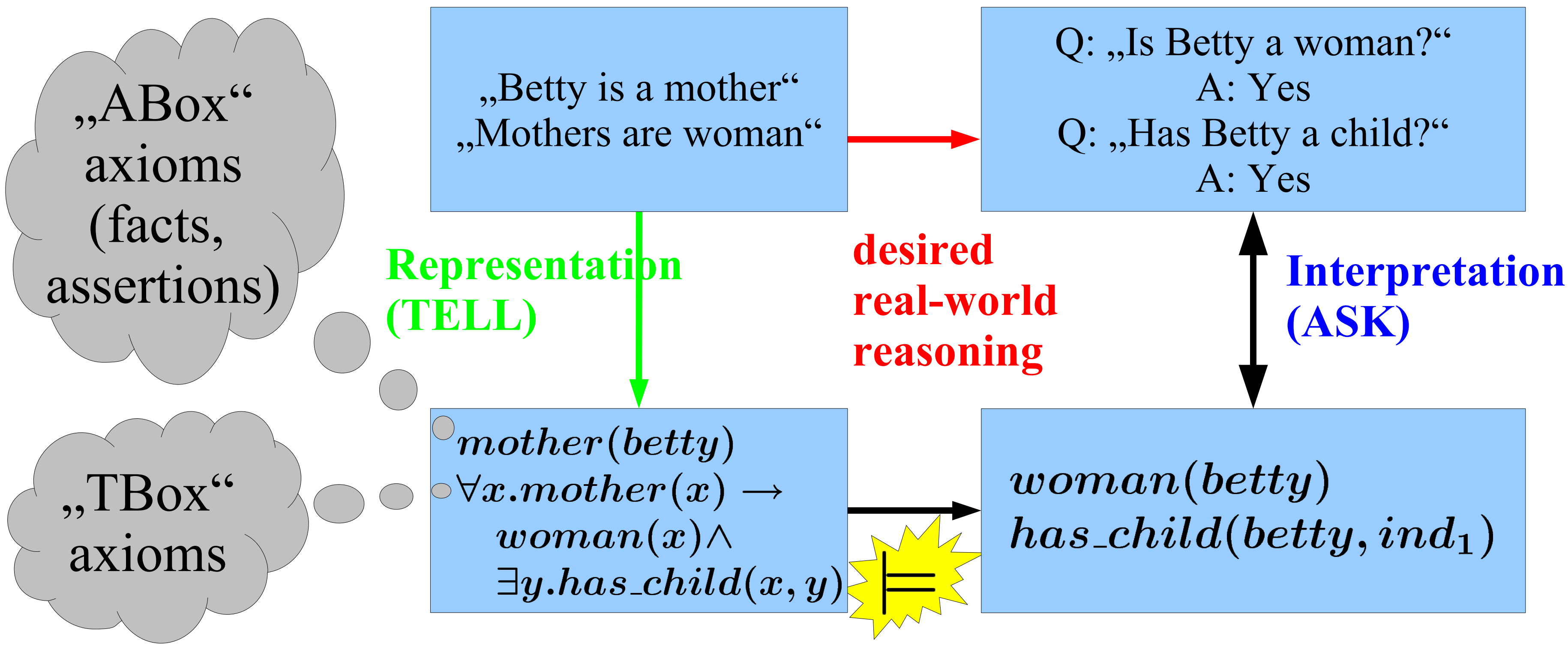


Logic-Based Knowledge Representation & Reasoning

- **SemWeb = „KR&R on the Web"**
- Replace real-world reasoning with computational operations performed in a model ($\models$)
- Model ~ representation ~ KB
- Ontology: explicit specification of a conceptualization
  - „formal account of what exists in the world"
  - logic-based definitions of concepts & relations in terms of other concepts & relations
  - automated reasoning
  - **inference makes implicit knowledge explicit**



Logic-Based KR&R (2)

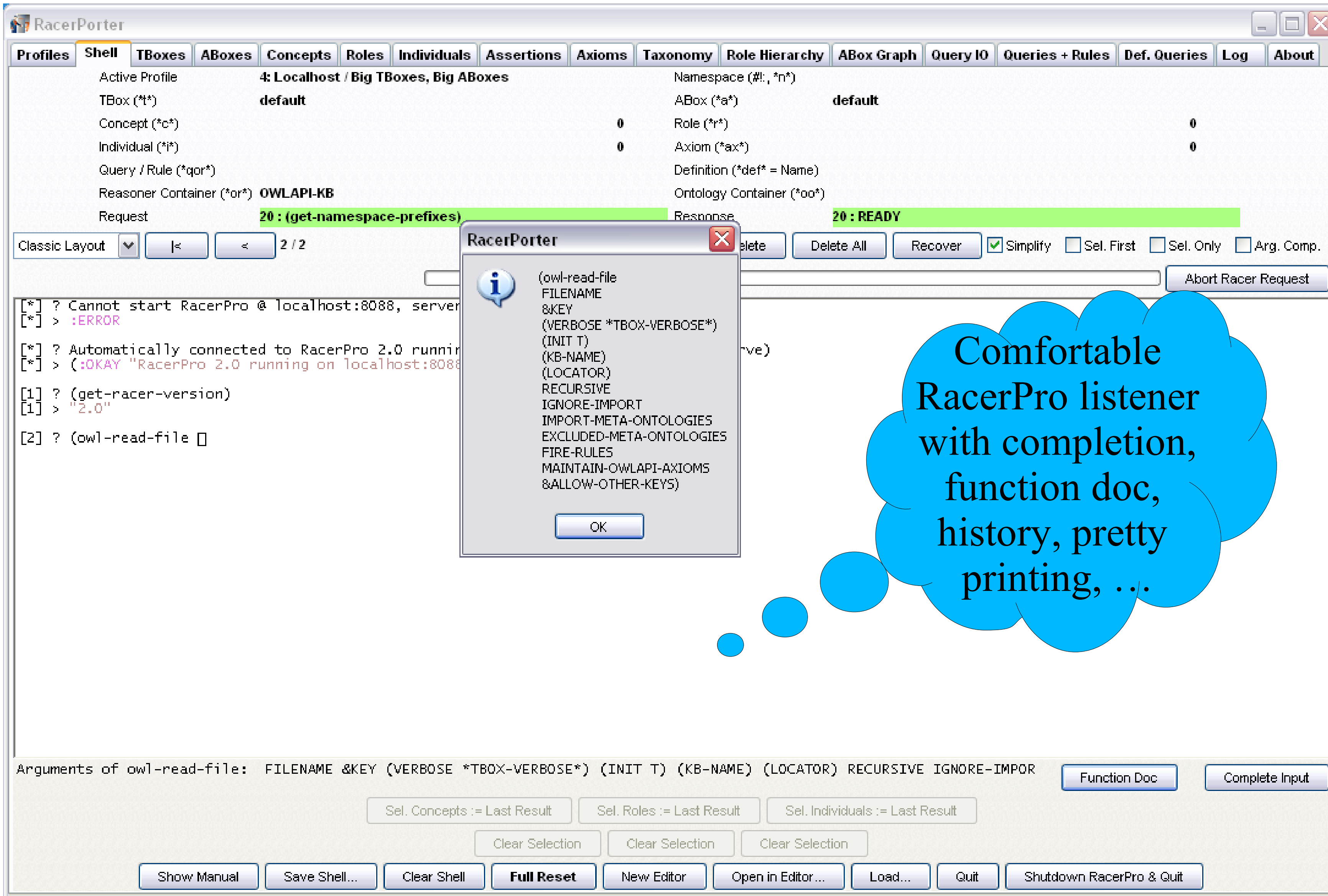


- First-Order Predicate Logic: $\models$ undeceidable
- Description Logics (OWL DL): deceidable, but NEXPTIME complete

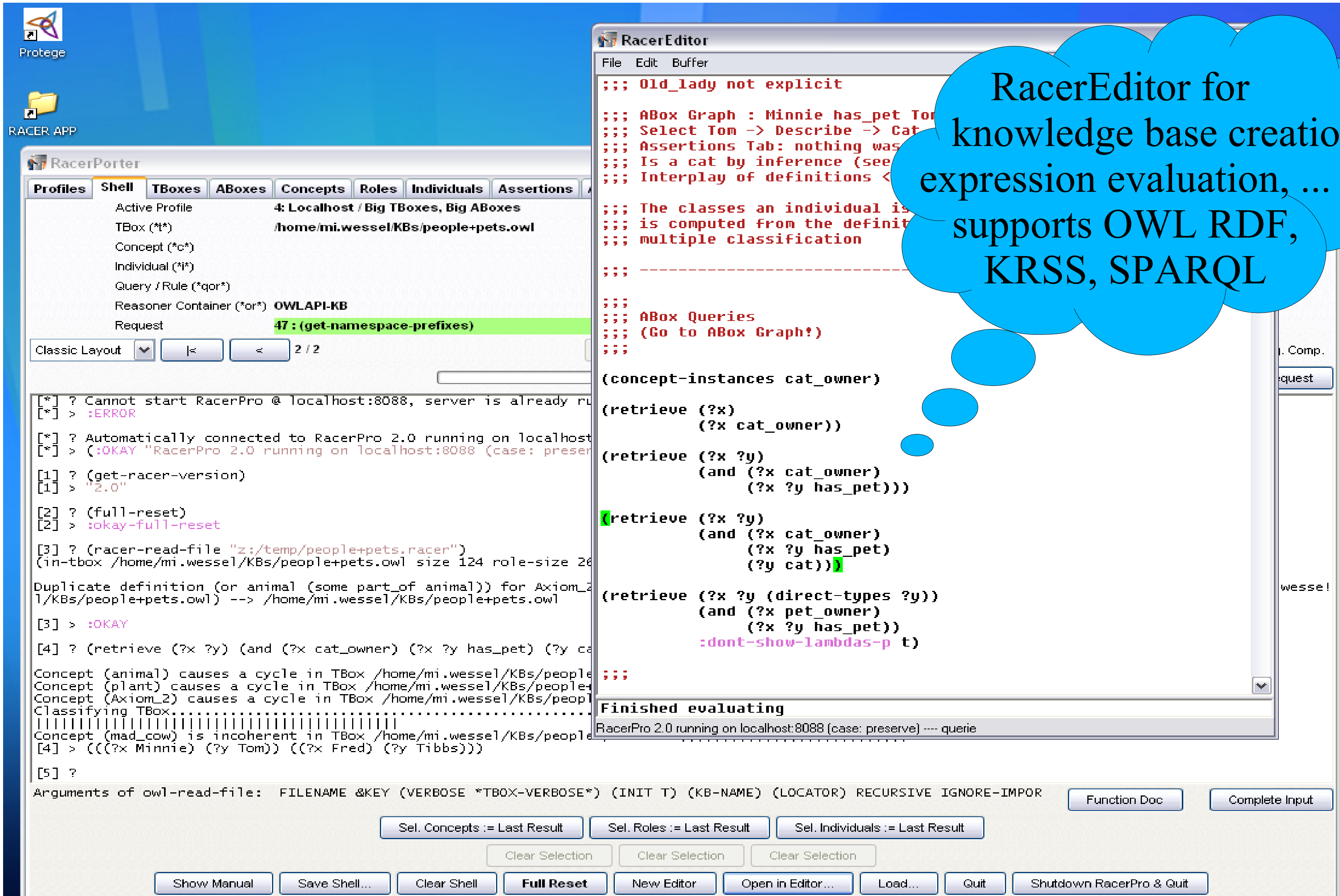
Reasoning with Formal Ontologies

- **Demo** of some standard inferences using RacerPro & RacerPorter
  - Basis: „People & Pets“ ontology
    by **Sean Bechhofer (Univ. of Manchester)**
  - but will use KRSS / Racer Lisp syntax in this demo
  - show some OWL syntaxes later

RacerPorter – The Listener („Racer Shell“)

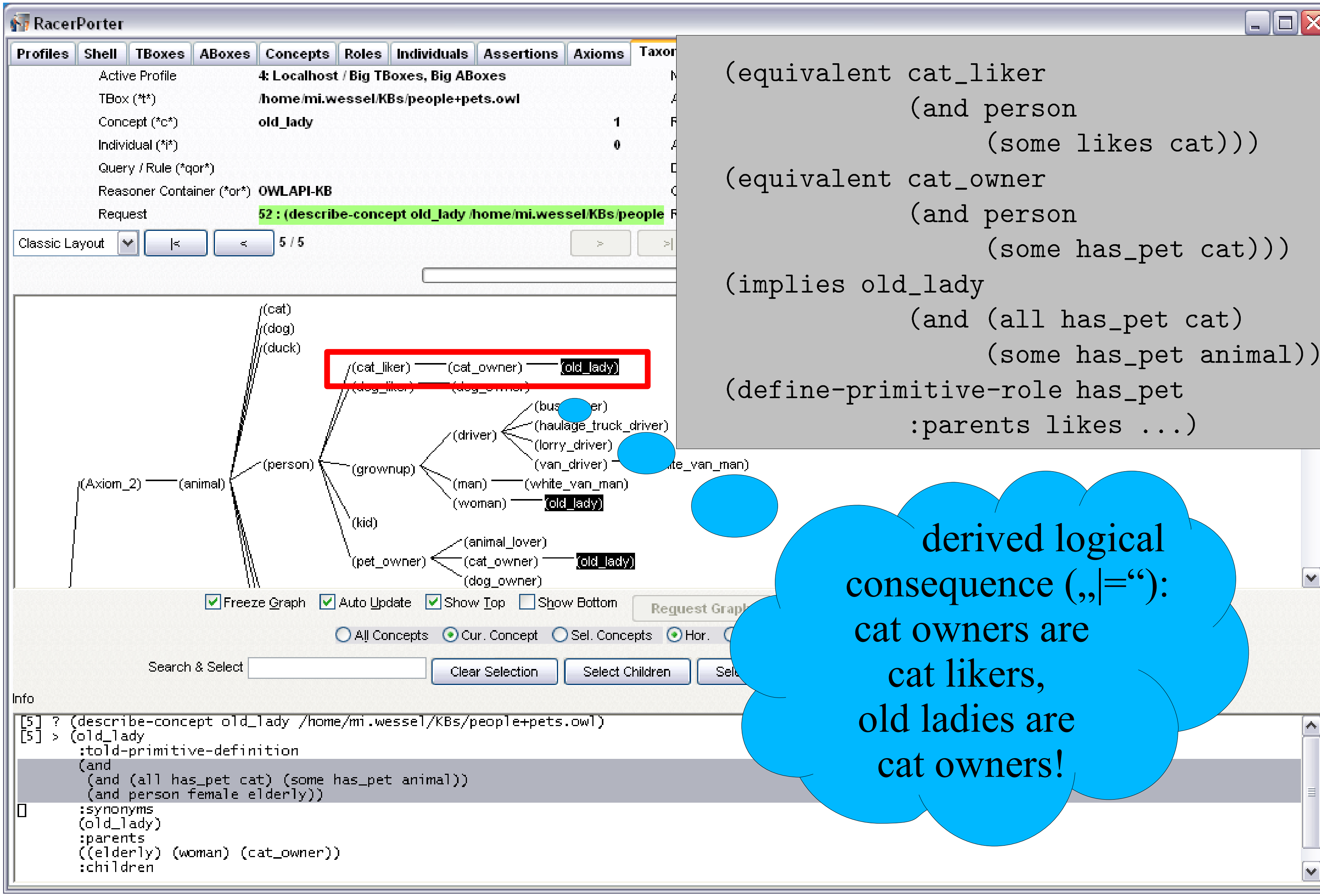


The Racer Editor with Some Example Queries



RacerEditor for knowledge base creation, expression evaluation, ... supports OWL RDF, KRSS, SPARQL

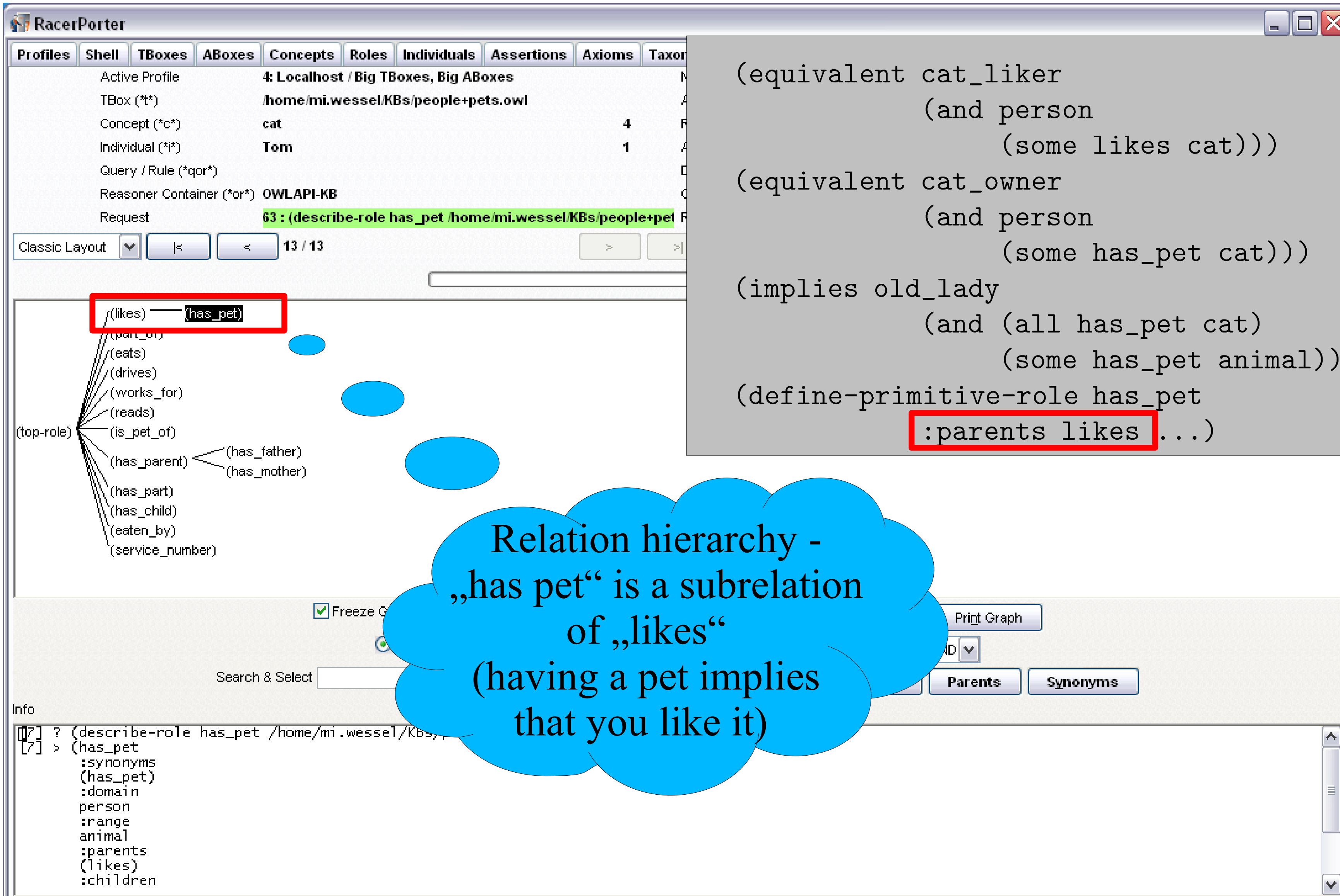
The Class (Concept) Hierarchy („Taxonomy“)




```
(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 ...)
```

derived logical
consequence („|=“):
cat owners are
cat likers,
old ladies are
cat owners!

The Relation (Role / Property) Hierarchy




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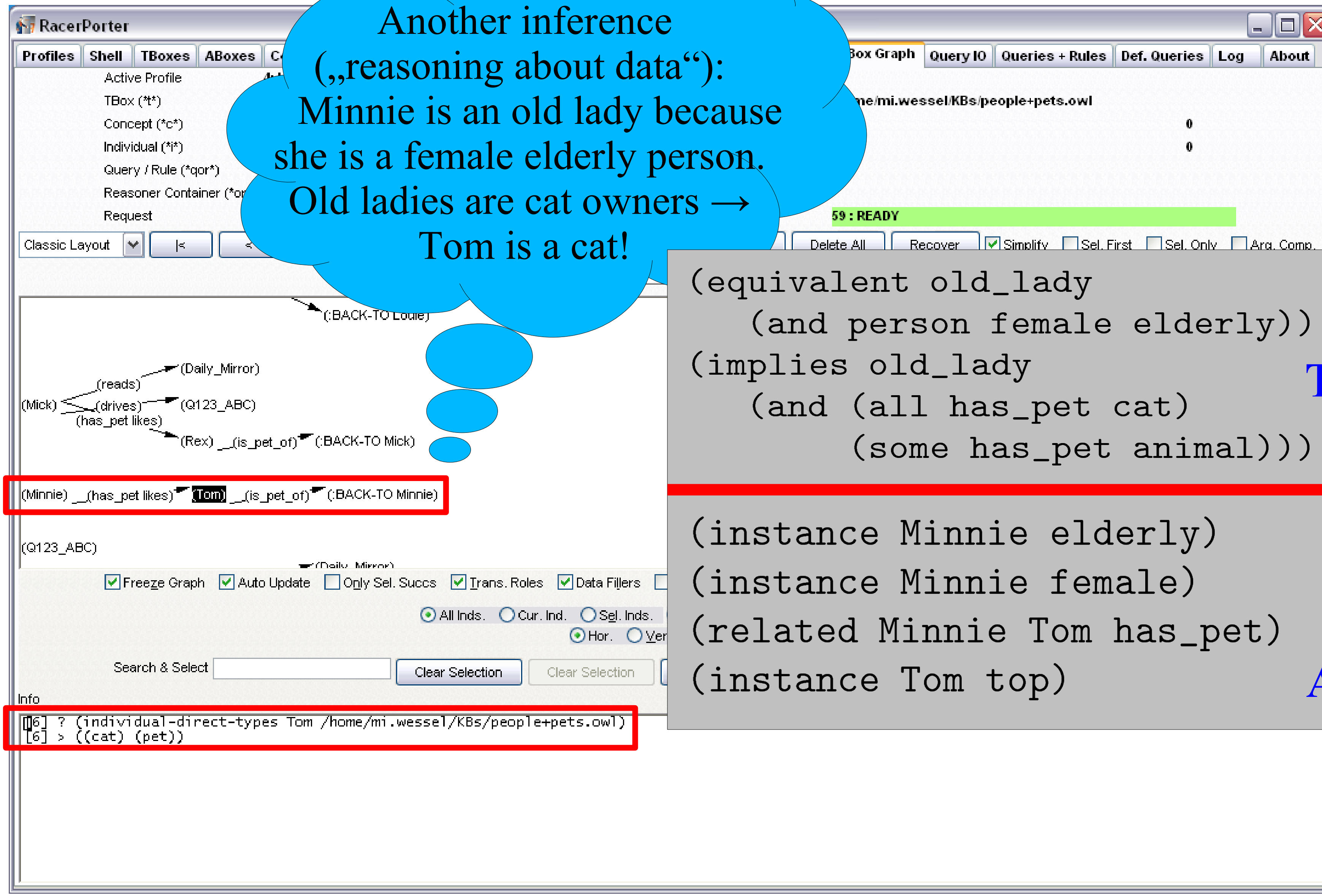

Relation hierarchy -
„has pet“ is a subrelation
of „likes“
(having a pet implies
that you like it)

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!

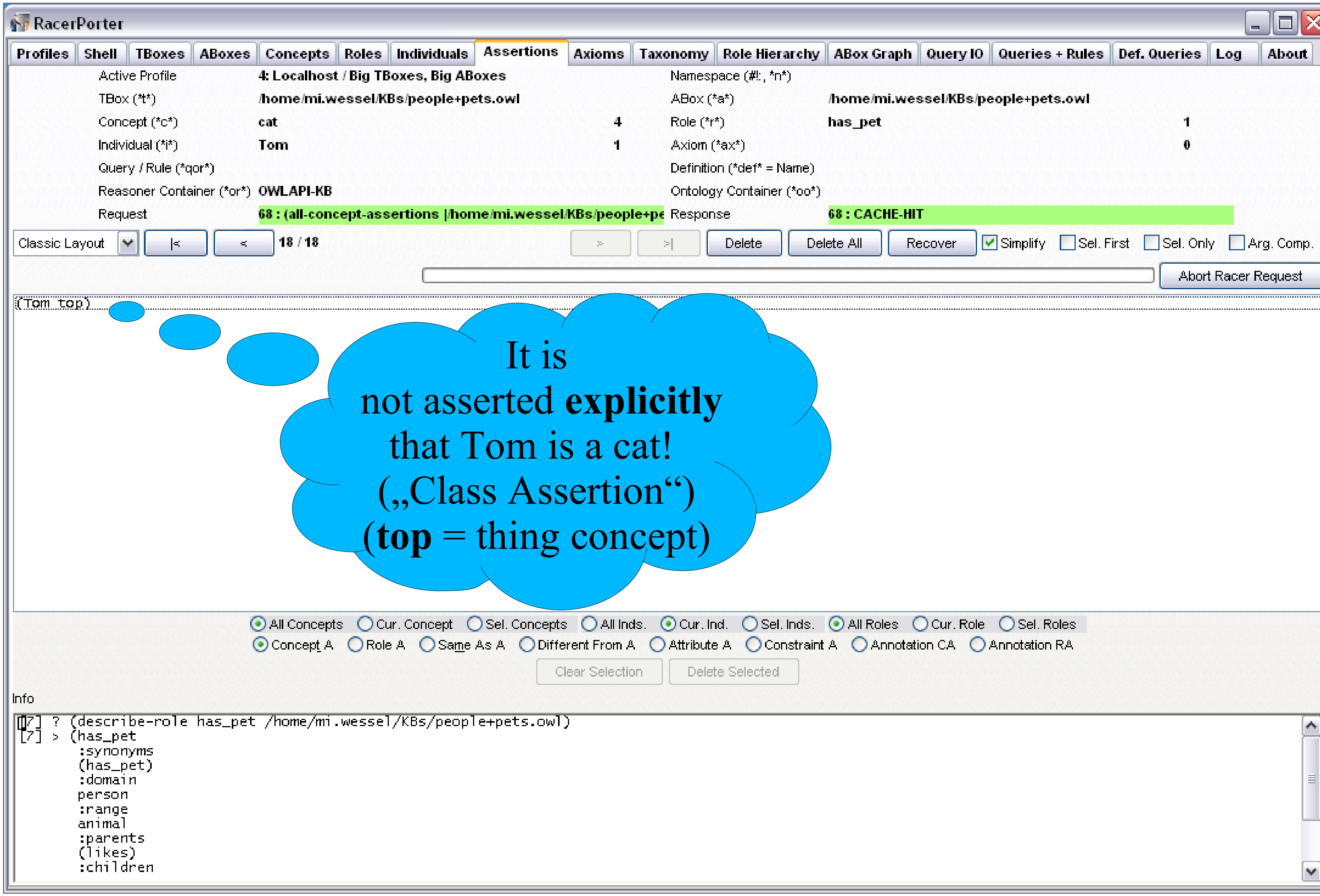
```
(equivalent old_lady
   (and person female elderly))
(implies old_lady
   (and (all has_pet cat)
        (some has_pet animal)))
```

TBox

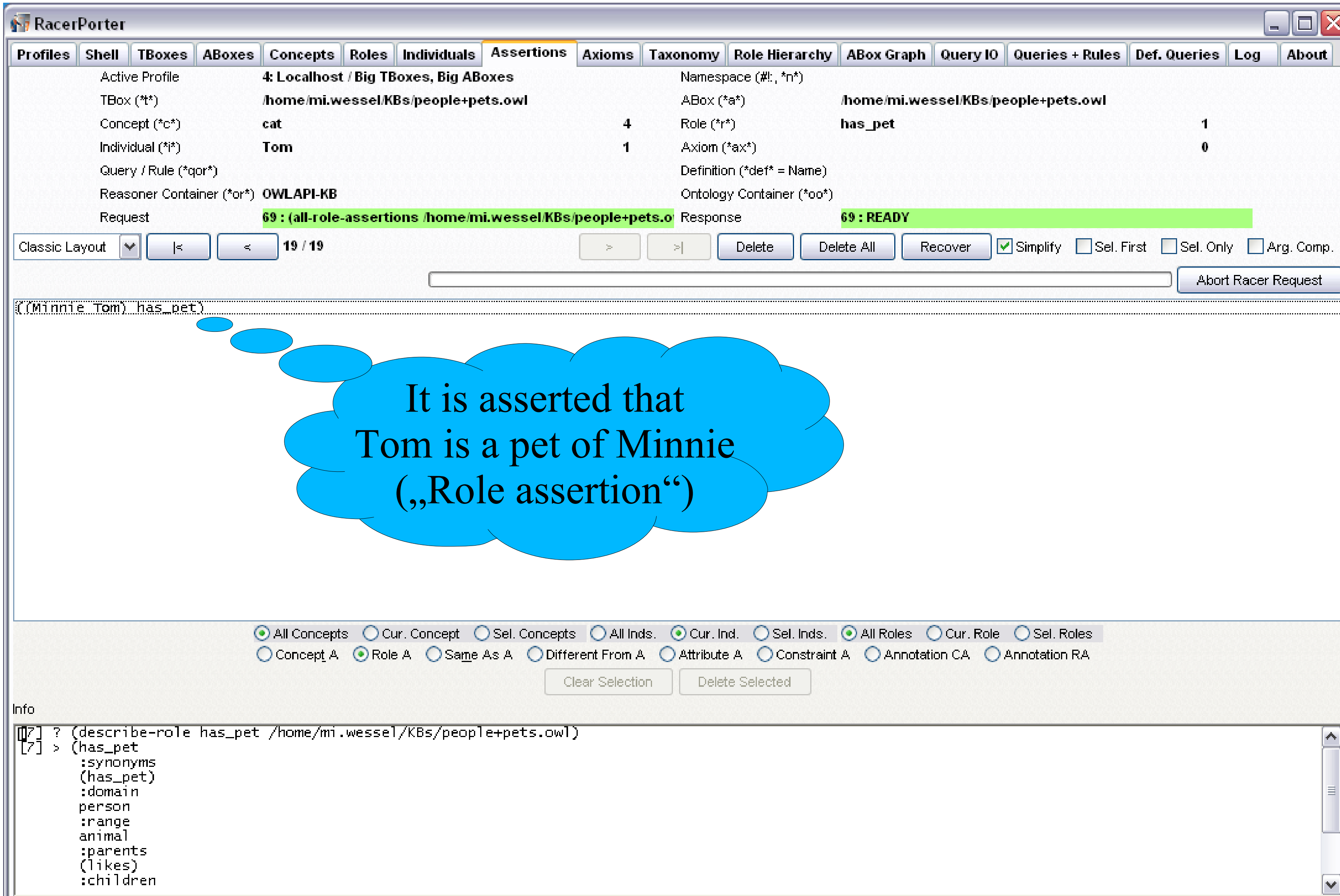
```
(instance Minnie elderly)
(instance Minnie female)
(related Minnie Tom has_pet)
(instance Tom top)
```

ABox

Inspecting Class Assertions for Tom



Relation („Role“) Assertions for Tom



Syntaxes

Racer can be used as a syntax converter

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

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

  - New: **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:**

(equivalent old_lady...

```
<owl:Class rdf:ID="old_lady">
    <owl:equivalentClass>
      <owl:Class>
        <owl:intersectionOf
      rdf:parseType="Collection">
          <owl:Class rdf:about="#person"/>
          <owl:Class rdf:about="#female"/>
          <owl:Class rdf:about="#elderly"/>
        </owl:intersectionOf>
      </owl:Class>
    </owl:equivalentClass>
  ...
```

… (and ...

… person female elderly ...

…))

Syntaxes (3)

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

(implies old_lady ...

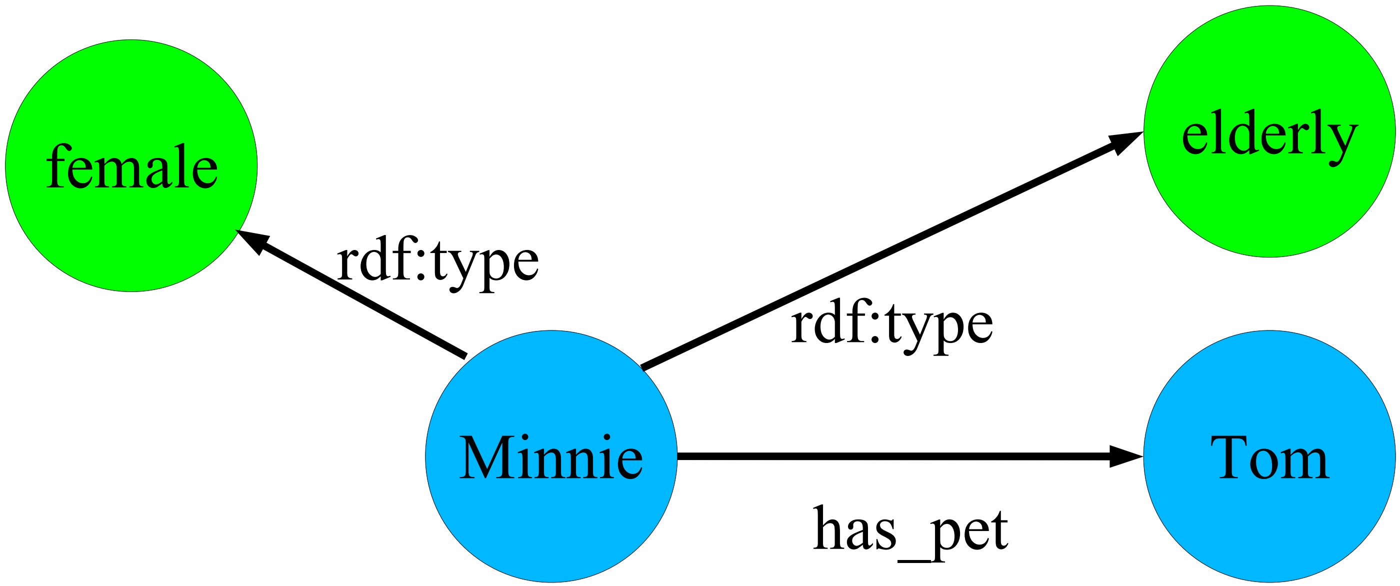
... (and ...

... (all has_pet cat) ...

... (some has_pet cat) ...

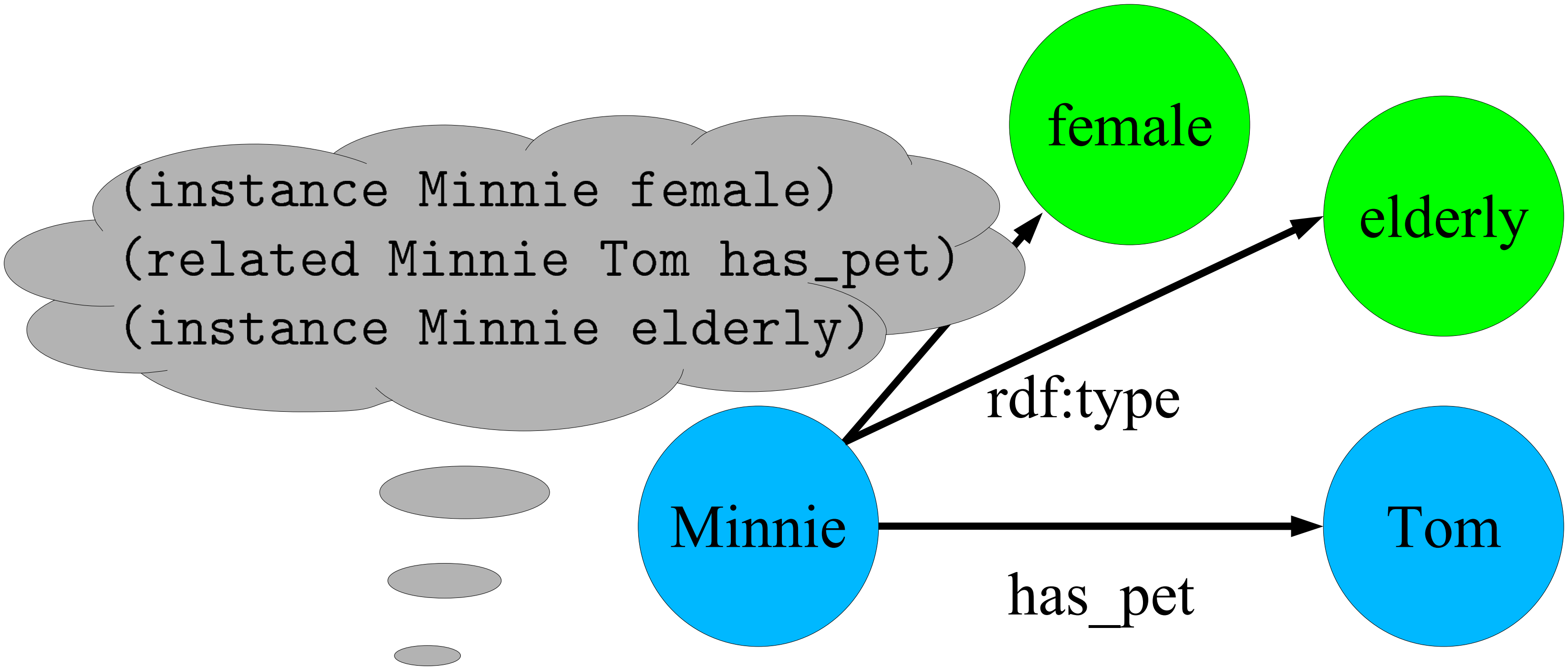
```
...
<rdfs:subClassOf>
  <owl:Class>
    <owl:intersectionOf rdf:parseType="Collection">
      <owl:Restriction>
        <owl:allValuesFrom rdf:resource="#cat"/>
        <owl:onProperty>
          <owl:ObjectProperty rdf:about="#has_pet"/>
        </owl:onProperty>
      </owl:Restriction>
      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

ABox Part of an OWL Ontology - RDF Graph




```
<rdf:Description rdf:ID="Minnie">
   <has_pet rdf:resource="#Tom"/>
   <rdf:type rdf:resource="#elderly"/>
   <rdf:type rdf:resource="#female"/>
</rdf:Description>
```

ABox Part of an OWL Ontology - RDF Graph




```
<female rdf:ID="Minnie">
    <has_pet rdf:resource="#Tom"/>
    <rdf:type rdf:resource="#elderly"/>
</female>
```

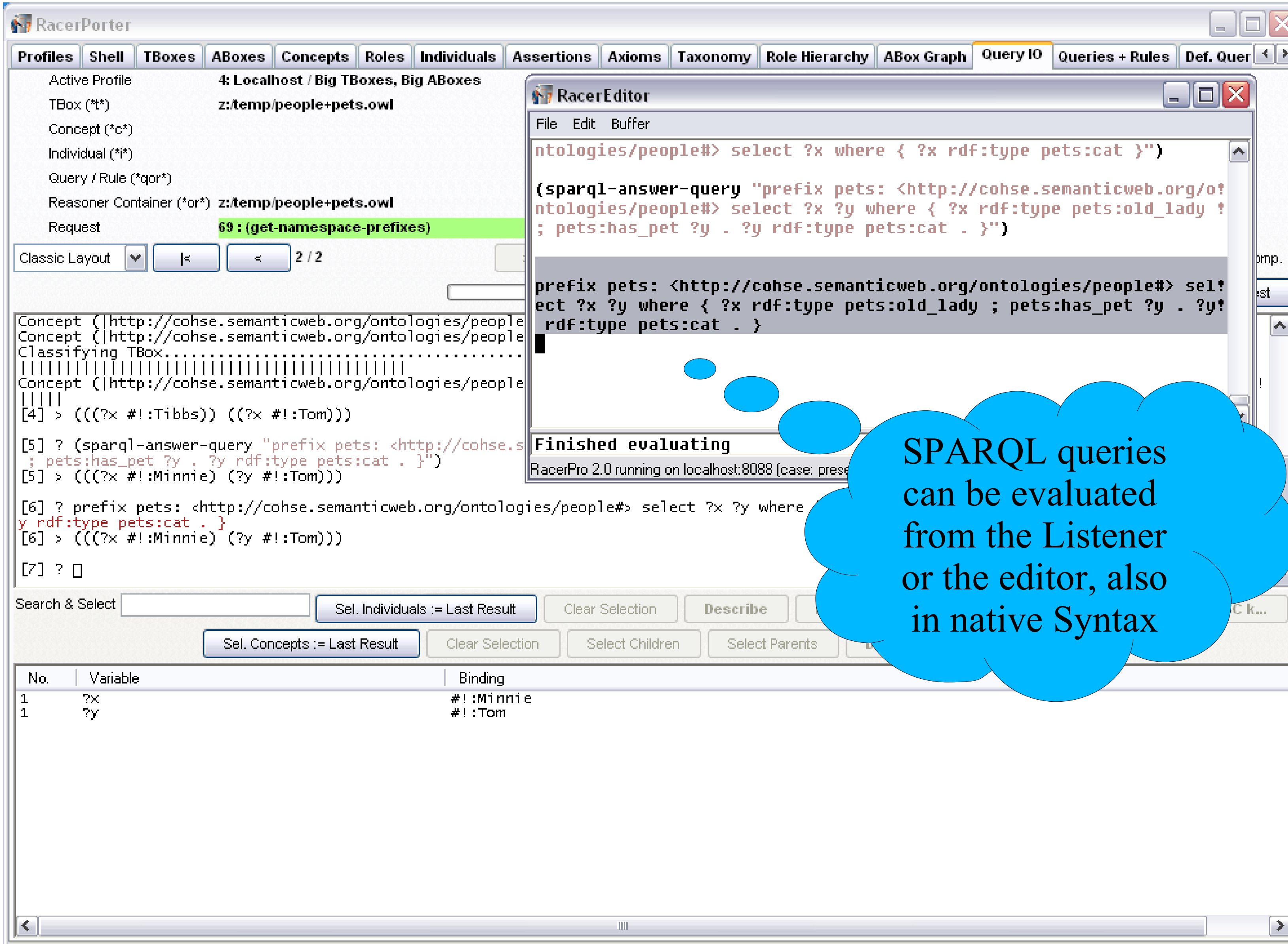
W3C RDF Query Language - SPARQL

```
prefix pets:
       <http://cohse.semanticweb.org/ontologies/people#>
select ?x ?y
where { ?x rdf:type pets:old_lady ;
            pets:has_pet ?y .
         ?y rdf:type pets:cat .
      }
```

SQL-like syntax

```
(define-prefix "pets"
    "http://cohse.semanticweb.org/ontologies/people#")
(retrieve (?x ?y)
   (and (?x #!pets;old_lady)
        (?x ?y #!pets:has_pet)
        (?y #!pets:cat)))
```

SPARQL with RacerPro Demo



Some Comments on SPARQL...

- SPARQL was not meant as an OWL query language
  - does it consider **inferred triples** (`rdf:type`? inferred properties?)
    - can't retrieve old ladies
  - **no negation as failure, no universal quantification, no aggregation**
    - most of our example queries cannot be formulated
  - as a rule language: has `construct`, but **cannot create new URIs**
- SPARQL in Racer, **2 modi:**

  1: use AllegroGraph SPARQL processor (filled by Racer with triples)
    - scalable, secondary memory, …, but only shallow inference

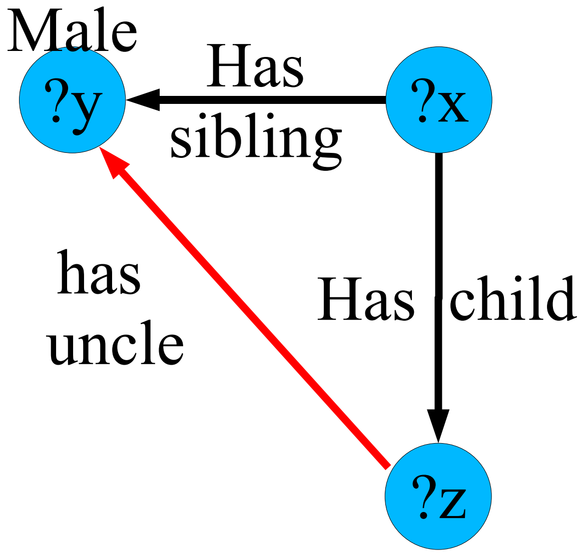
  2: translated into nRQL query (uses AllegroGraph SPARQL parser)
    - full OWL reasoning, but not so scalable, SPARQL subset only

  compromiss: let RacerPro **materialize** the inferred triples in AllegroGraph, then use mode 1 for SPARQL query answering

W3C Semantic Web Rule Language - SWRL

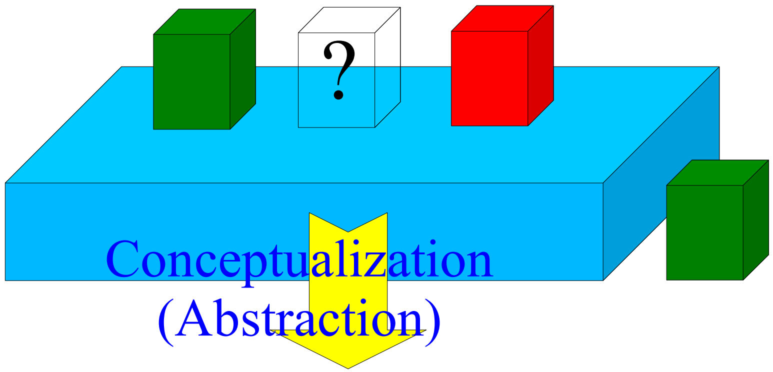
- Motiviation: enhanced **relational expressivity** (certain relational structures can't be encoded with concepts)

$$has\_sibling(?x, ?y) \wedge male(?y) \wedge has\_child(?x, ?z) \Rightarrow has\_uncle(?z, ?y)$$



- Horn rules in RDF/XML syntax
  - Jess-based implementations
- undeceidable, but deceidable fragments
- Racer supports restricted subset of SWRL
  - translated into nRQL rules
  - nRQL rules need not be horn
    - and can construct new individuals
    - but have a non-logical semantics (similar to Jess)

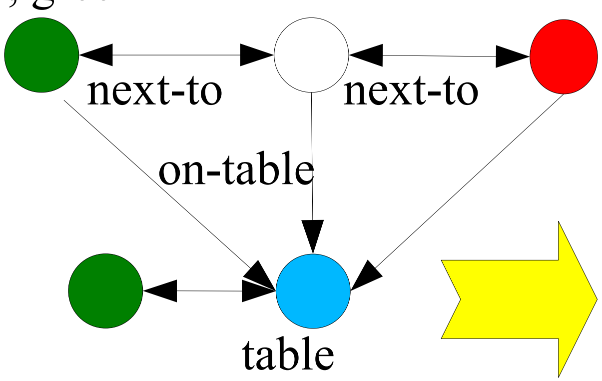
ABox Queries & Indefinite Information



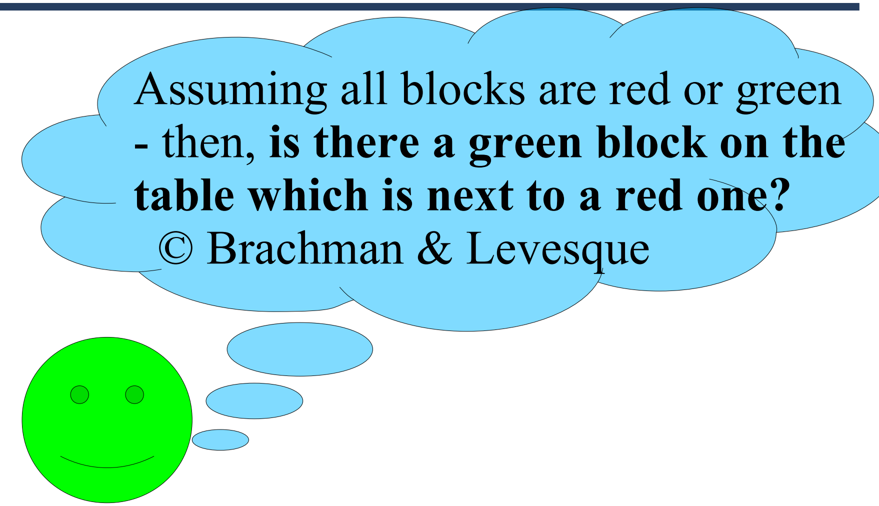
Conceptualization
(Abstraction)

on-table, next-to, block, green, red, ...

Formalization



Problem Solving



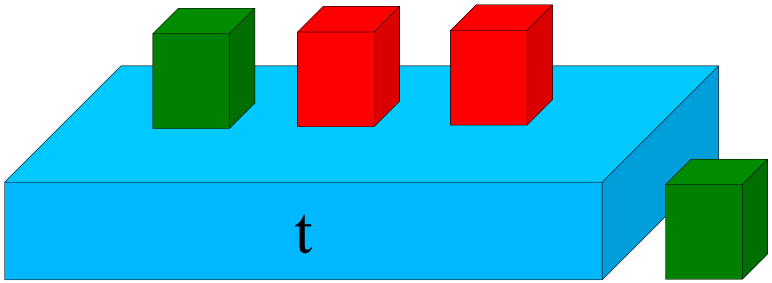
$$\{\ block \dot{\sqsubseteq} red \sqcup green, next\_to \doteq next\_to^{-1}\ \}$$

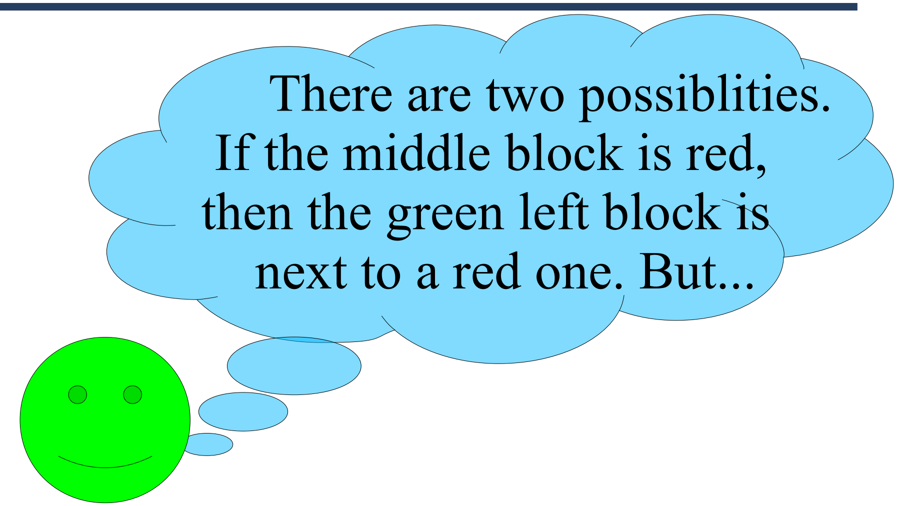
$$\begin{aligned}\{\ & t : table, lb : green \sqcap block, rb : red \sqcap block, \\ & mb : block, ob : green \sqcap block, \\ & (lb, t) : on\_table, (ml, t) : on\_table, (rb, t) : on\_table, \\ & (gb, ob) : next\_to, (ob, rb) : next\_to\ \}\end{aligned}$$

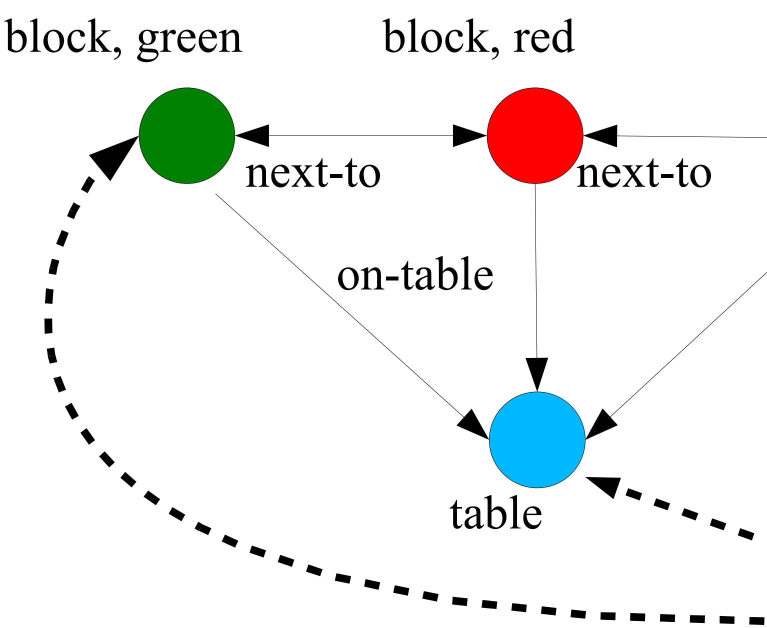
Ask for **instances of the concept**

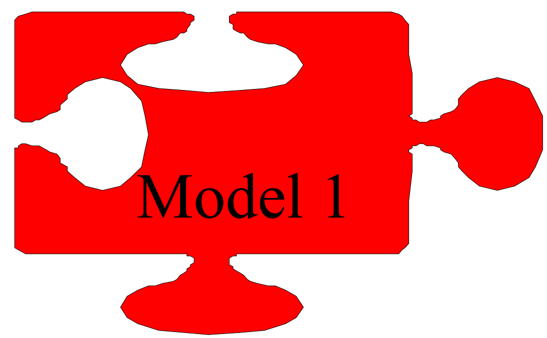
$$table \sqcap$$
$$\exists on\_table^{-1}.\ (block \sqcap green \sqcap$$
$$\exists next\_to.(red \sqcap block))$$

ABox Queries & Indefinite Information (2)



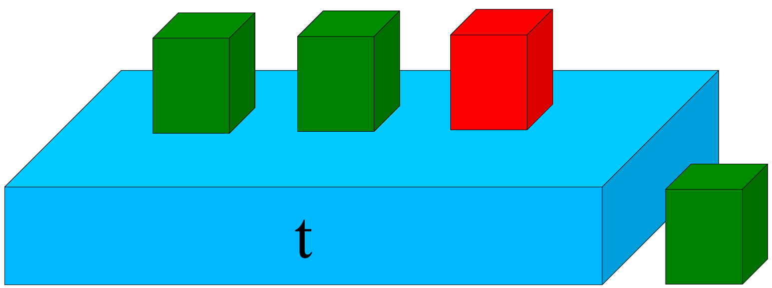


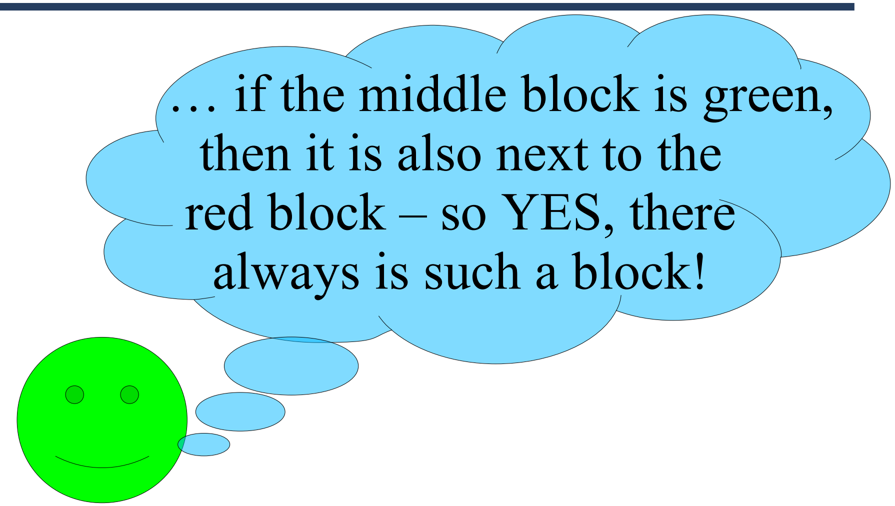


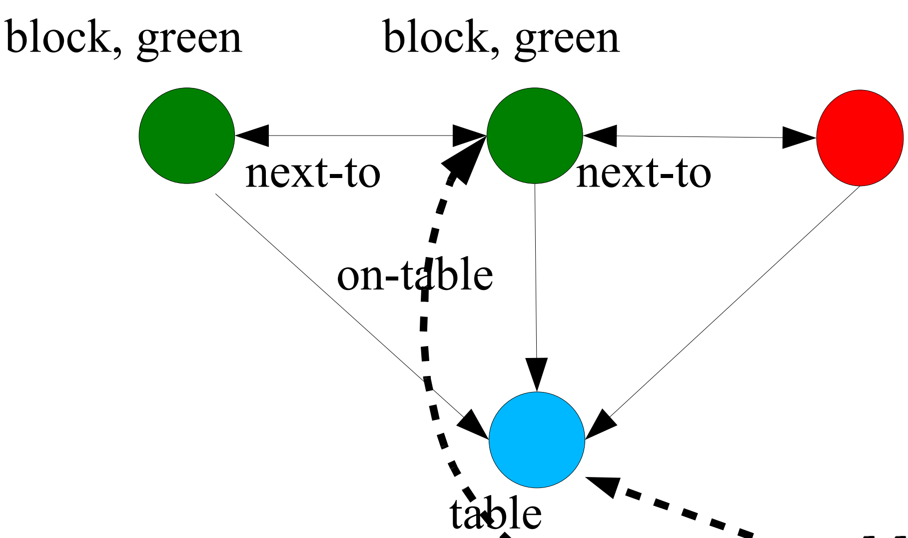


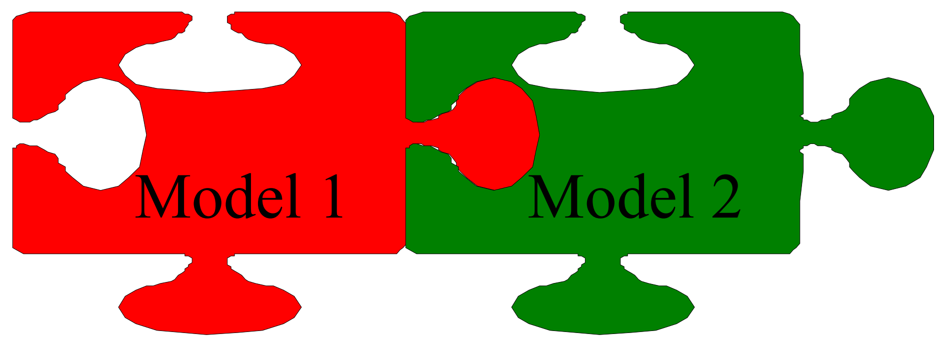
$$table \sqcap \exists on\_table^{-1}.\ (block \sqcap green \sqcap \exists next\_to.(red \sqcap block))$$

ABox Queries & Indefinite Information (3)



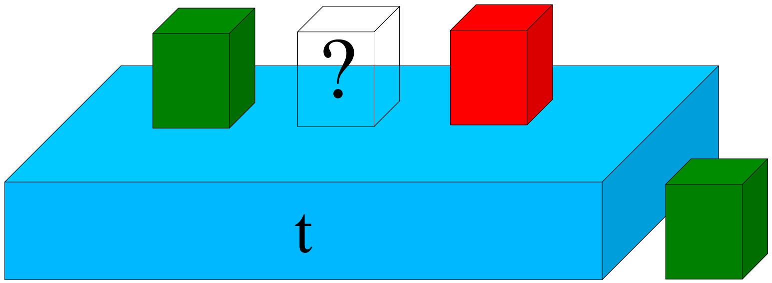






$$table \sqcap \exists on\_table^{-1}.\ (block \sqcap green \sqcap \exists next\_to.(red \sqcap block))$$

ABox Queries vs. Database Queries



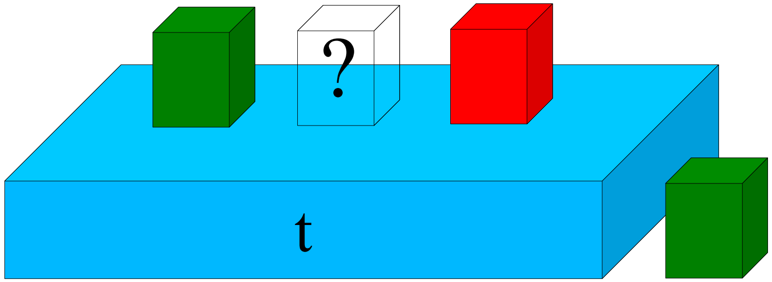
concept_instances($table \sqcap \exists on\_table^{-1}.\ (block \sqcap green \sqcap \exists next\_to.(red \sqcap block))) = \{t\}$

However:

concept_instances($block \sqcap green \sqcap \exists next\_to.(red \sqcap block))) = \{\}$

- Unlike DB queries, instance retrieval queries can cope with
  - incomplete information (have to perform **case analysis**)
  - have to **consider ALL models,** not only one („model = DB“)
  - only the **existence** of such a block is entailed

More Expressive Queries: Conjunctive ABox Queries



$$
\begin{aligned}
ans(?x) \leftarrow \quad & table(?x), on\_table(?y, ?x), \\
& block(?y), green(?y), \\
& next\_to(?y, ?z), red(?z), block(?z).
\end{aligned}
$$

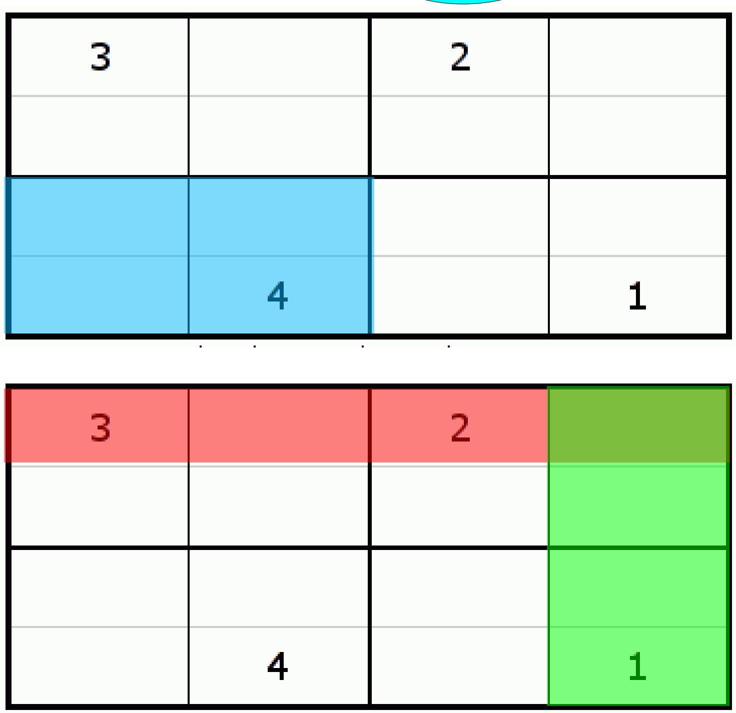
- Answer should be: $?x = t$
  - most DL systems nowadays **return no answer**
  - deceidability open until recently
- You can't retrieve $?y$ because its binding can't be fixed
  - answer (head) variables & other variables

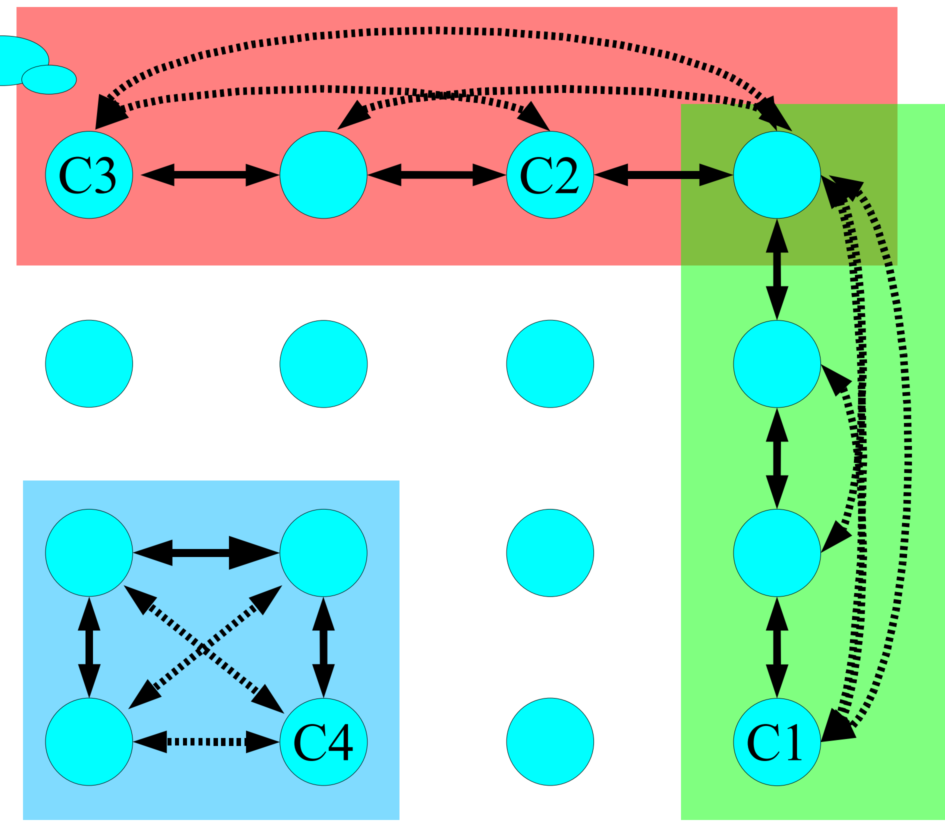
Solving Problems with Reasoning - Sudoku

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

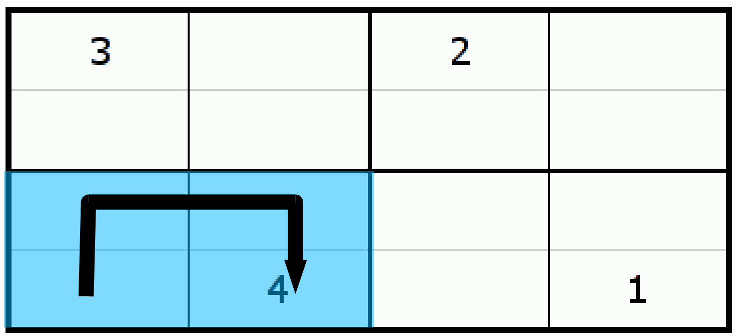
$$\textsf{pairwise\_disjoint}(C_1, C_2, C_3, C_4)$$

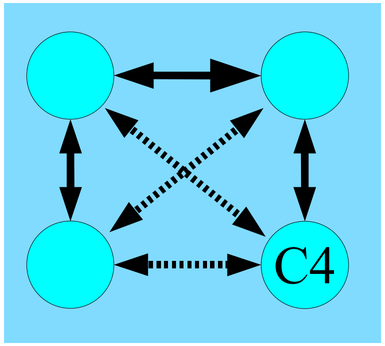
$$\begin{aligned}\top \dot{\sqsubseteq}\ & (C_1 \sqcup C_2 \sqcup C_3 \sqcup C_4) \sqcap \\ & (C_1 \rightarrow \forall R.\neg C_1) \sqcap (C_2 \rightarrow \forall R.\neg C_2) \sqcap \\ & (C_3 \rightarrow \forall R.\neg C_3) \sqcap (C_4 \rightarrow \forall R.\neg C_4) \sqcap \\ & \ldots\end{aligned}$$





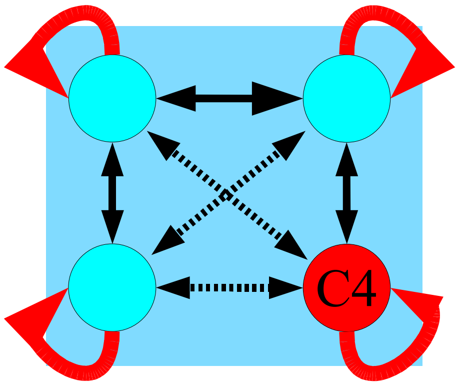
Sudoku – ABox Construction





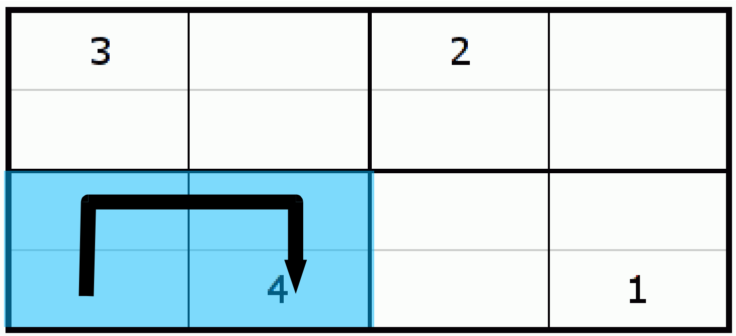
ABox construction

- 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



$$C_4 \longrightarrow \forall R.\neg C_4$$

Sudoku – Relational Structure



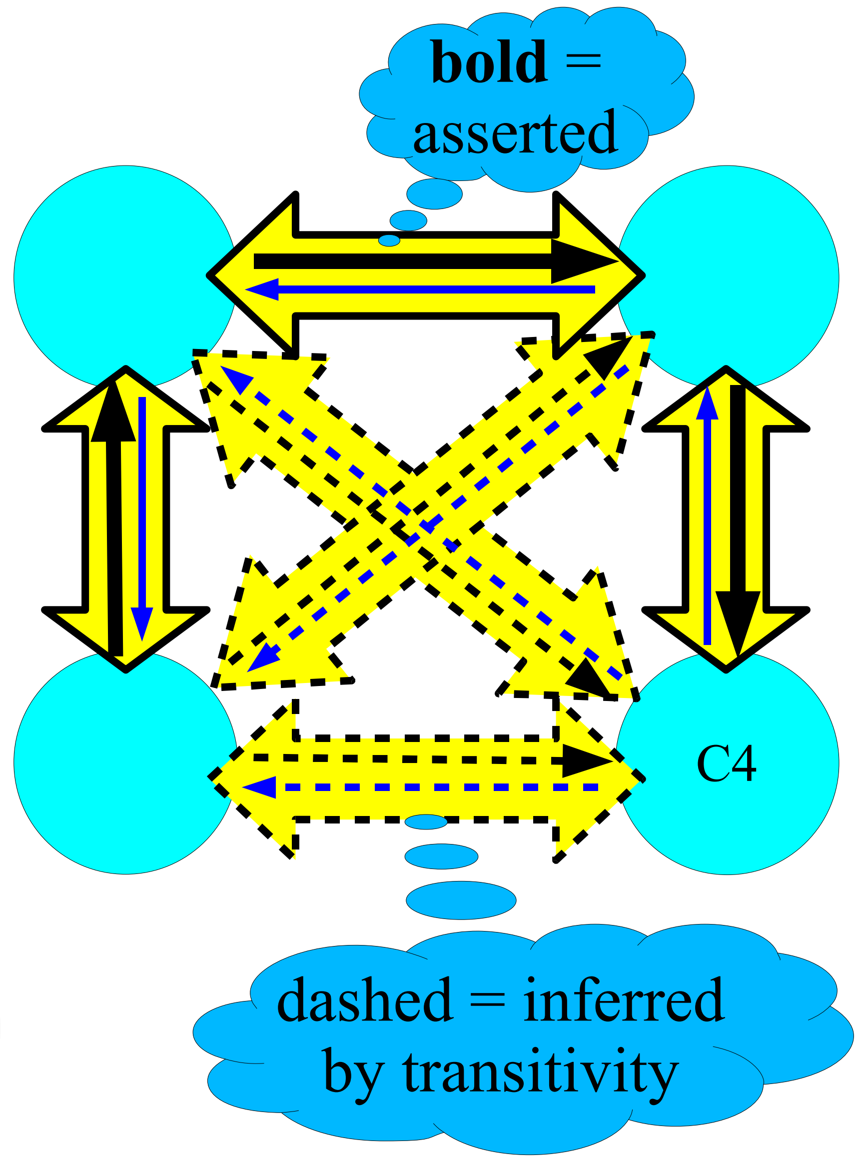
$Q_1 \dot{\sqsubseteq} R$

$Q_2 \dot{\sqsubseteq} R$

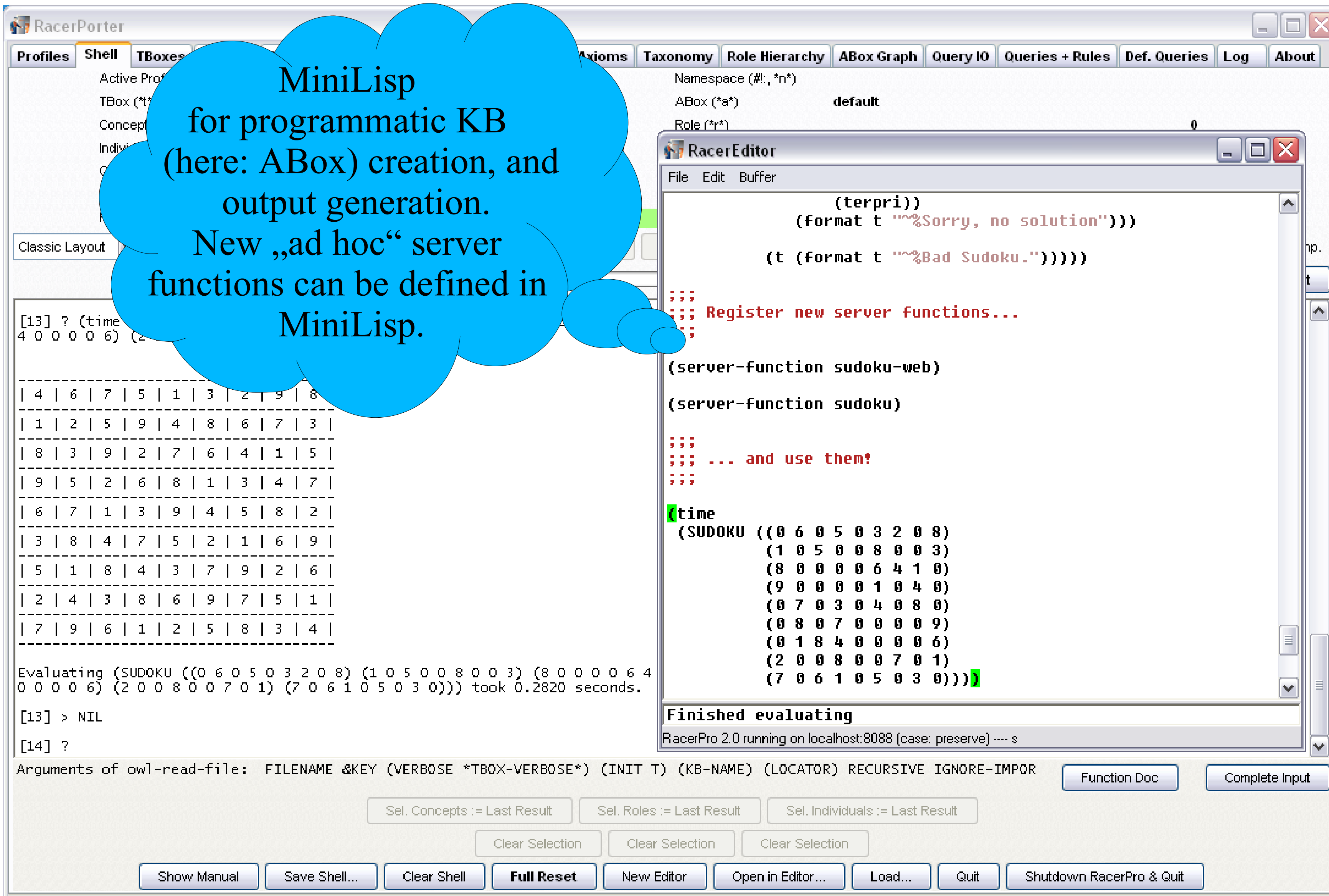
$\mathsf{transitive}(Q_1)$

$\mathsf{transitive}(Q_2)$

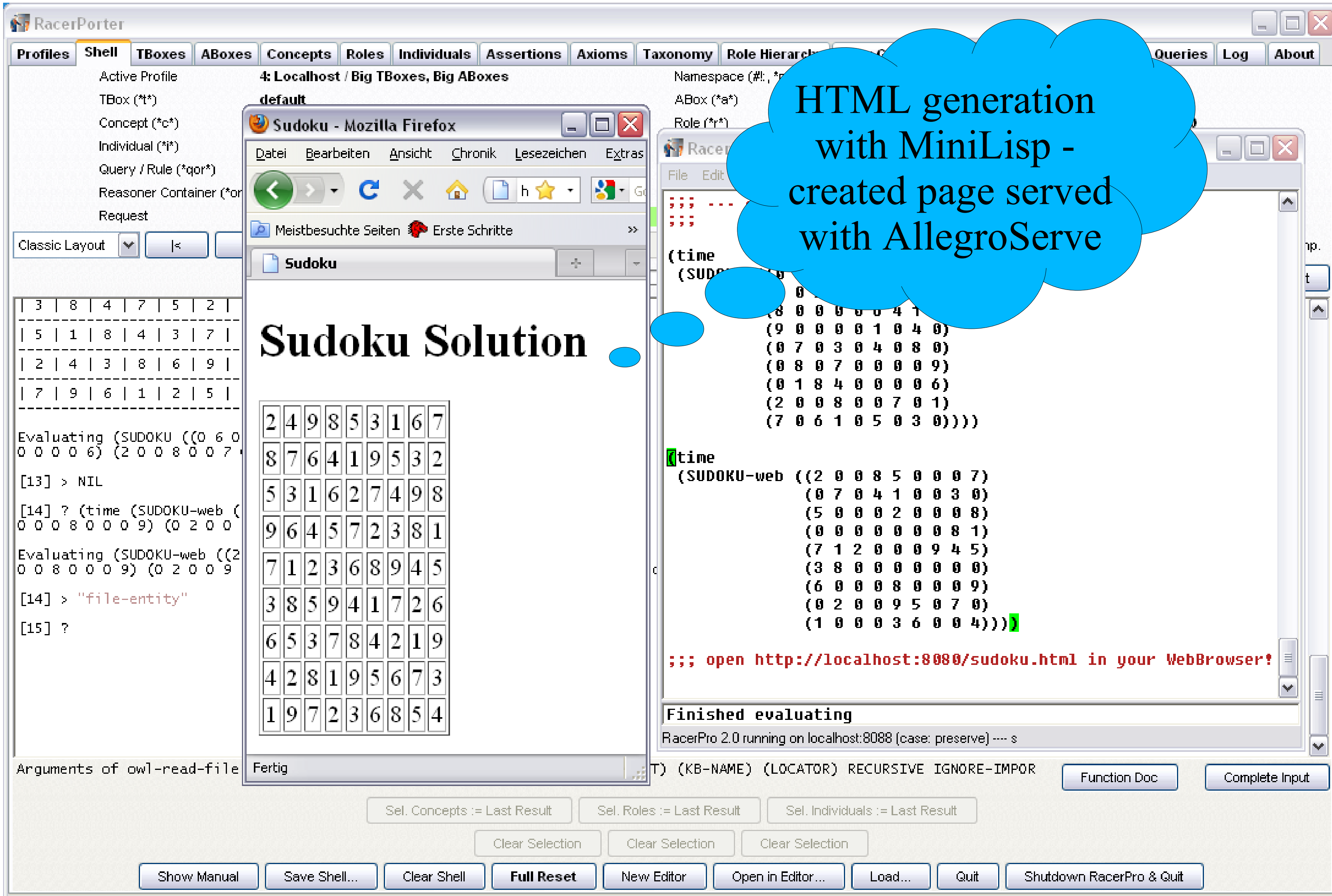
$Q_1(x, y) \leftrightarrow Q_2(y, x)$



Solving Sudokus with Racer Reasoning!



RacerPorter – MiniLisp HTML Generation

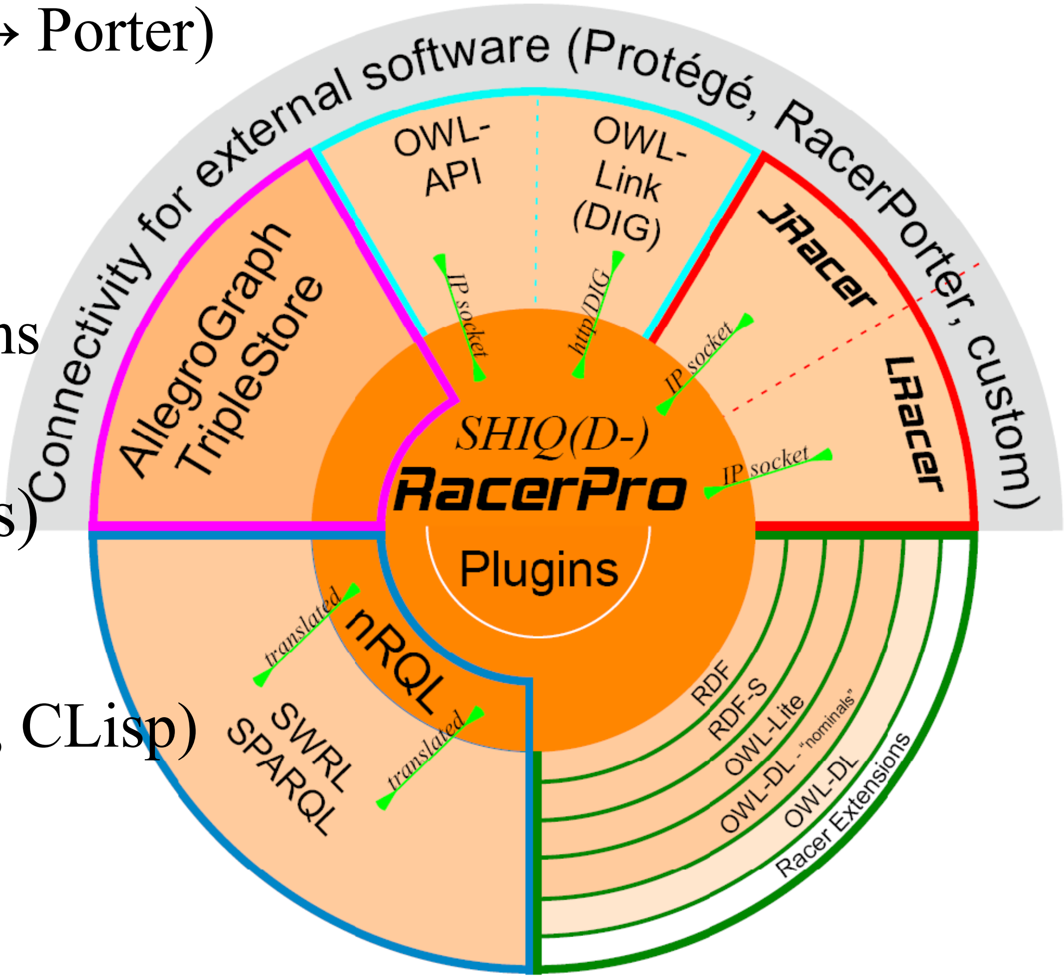


End of Presented Material...

… due to a lack of time I couldn't
present the remaining material but
I am including the slides here anyway.

„SemWeb“ Development with Racer

- RacerPro is a server: 2 sockets / ports
  - 8088 TCP Lisp syntax (→ Porter)
  - 8080 HTTP XML (DIG)
  - file IO
  - approx 1000 API functions
- RacerPro remote access libraries (sets of stubs)
  - **LRacer** for Lispers (ACL, Lispworks, SBCL, CLisp)
  - **JRacer** for Java
  - unicode (UTF8)
- DIG, OWLlink, OWLAPI



LRacer for Lispers

```
(enable-lracer-read-macros)
(full-reset)
(define-prefix "people"
     "http://cohse.semanticweb.org/o
(owl-read-file  "people+pets.owl")
(abox-consistent?)
(taxonomy)
(concept-synonyms #!people:bottom)
(retrieve (?x ?y)
  (and (?x #!people:person)
        (?x ?y #!people:has_pet)))
(instance #!people:betsy #!people:ma
(abox-consistent?)
```

- Size: > 1000 API functions / macros
  - HAS to be generated automatically
- Some roblems with UTF8 socket streams on different Lisps
- ACL „modern Lisp“
  - Racer is case sensitive „mlisp“
  - LRacer: maybe „alisp“
  - `NIL` ↔ `nil`
  - conversion required! … but for which symbols? depends on packages!
- `with`-macros...

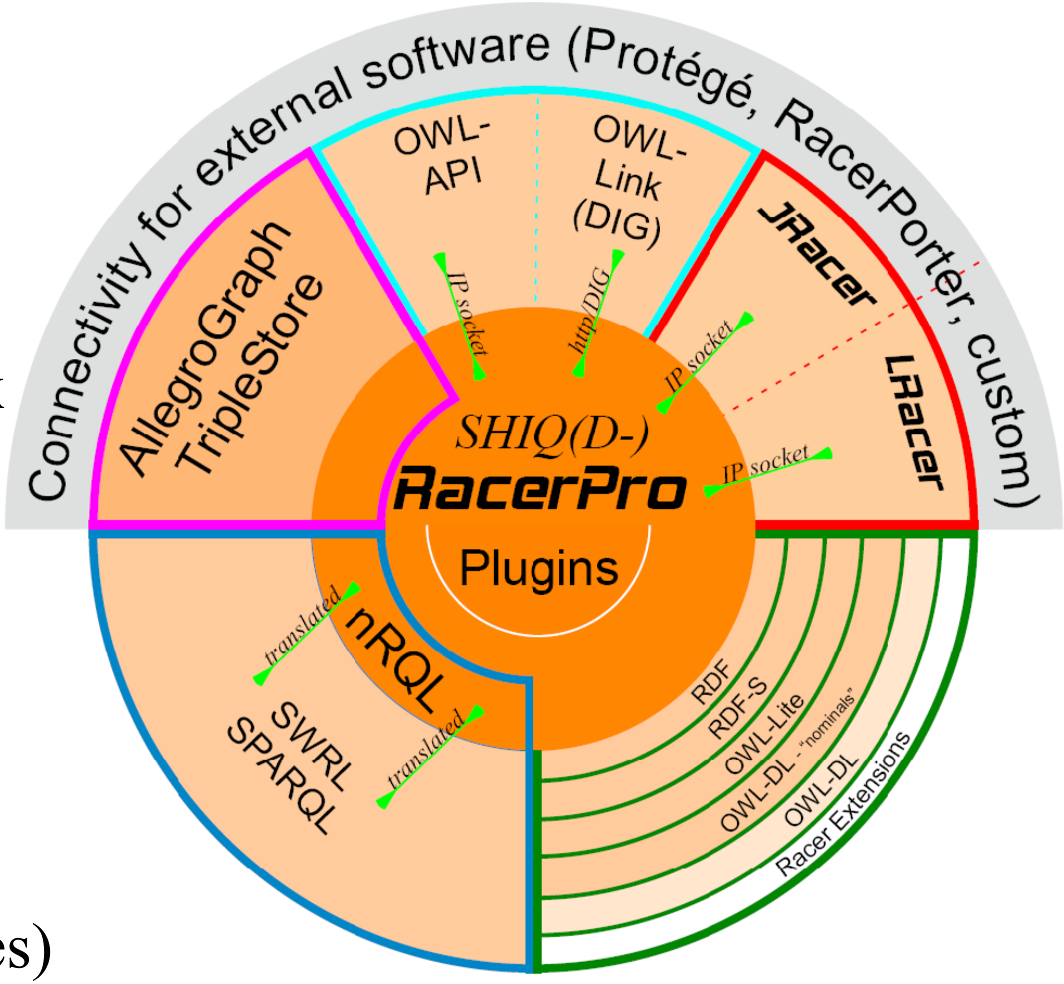
JRacer for Java Developers

```
RacerClient racer = new RacerClient(ip,port);
try {
  racer.openConnection();
  racer.fullReset$();
  racer.owlReadFile$(peopleAndPets);
  boolean consistent = racer.aboxConsistentP();
  RacerResult res2 = (RacerResult)
    racer.racerAnswerQuery$("(?x ?y)",
      "(and (?x #!:person) (?x ?y #!:has_pet))");

  if (res2 instanceof RacerSymbol) {
    System.out.println("No instances!");
  } else {
    for (RacerList<RacerList<RacerSymbol>> bindings :
           (RacerList<RacerList<RacerList<RacerSymbol>>>)res2) {
      for (RacerList<RacerSymbol> binding : bindings) {
        for (RacerSymbol varval : binding) {
          System.out.println(varval);
  }}} ...
```

- Automatically generated
- `Strings` or `ArrayLists` for S-Expressions → generics, structure iteration
- Typecasts and runtime checks not avoidable...
- UTF8
- Java ellipsis for `&rest, &key`
- overloaded methods for `&optional a b` ...
- `with-`... macros
- > 3000 Java methods

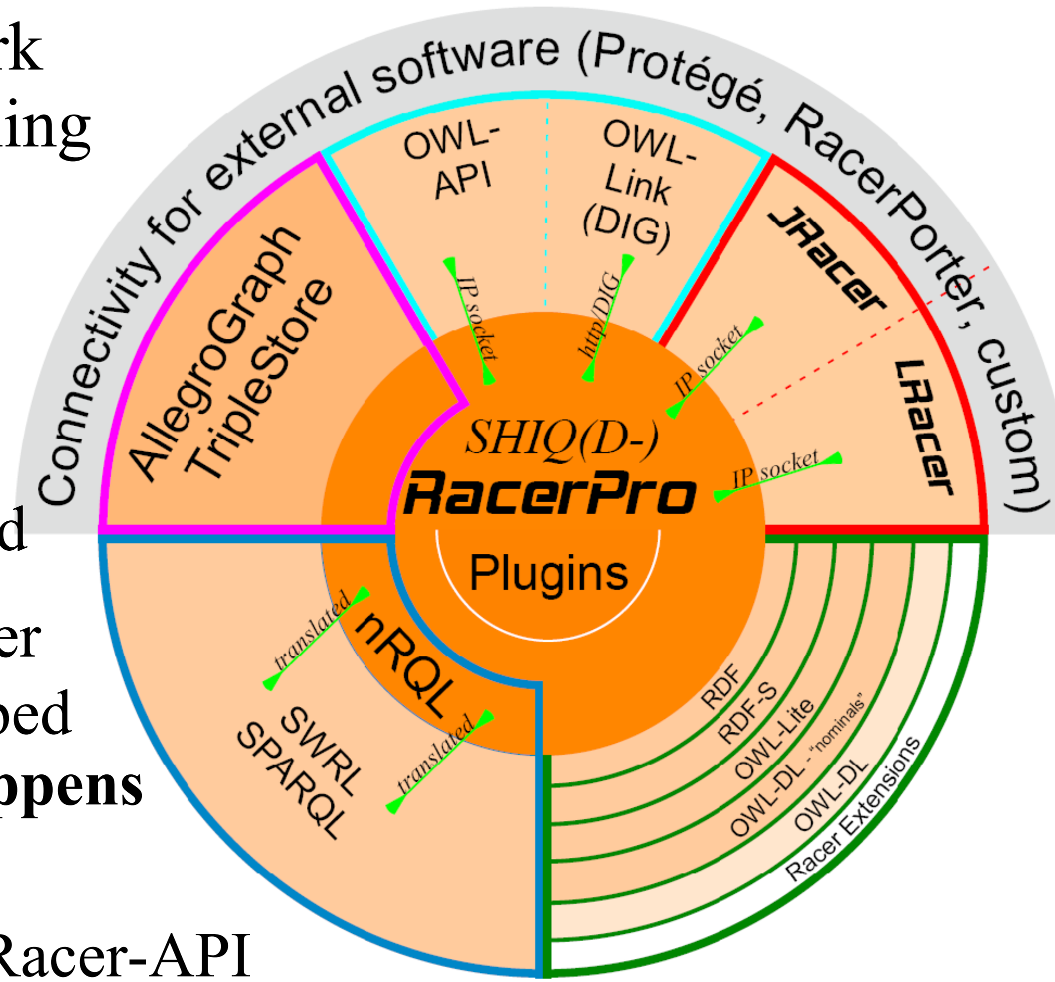
DIG & OWLlink – XML-over-HTTP APIs

- XML over HTTP-based
  - 8080 port of RacerPro
  - AllegroServe / CL-HTTP
  - DIG used by **Protégé 3.x** ontology editor
- OWLlink
  - successor of DIG
  - we are developing an S-Expression over HTTP (instead of XML messages) binding for the protocol (idea: turn OWL functional syntax into S-Expressions)

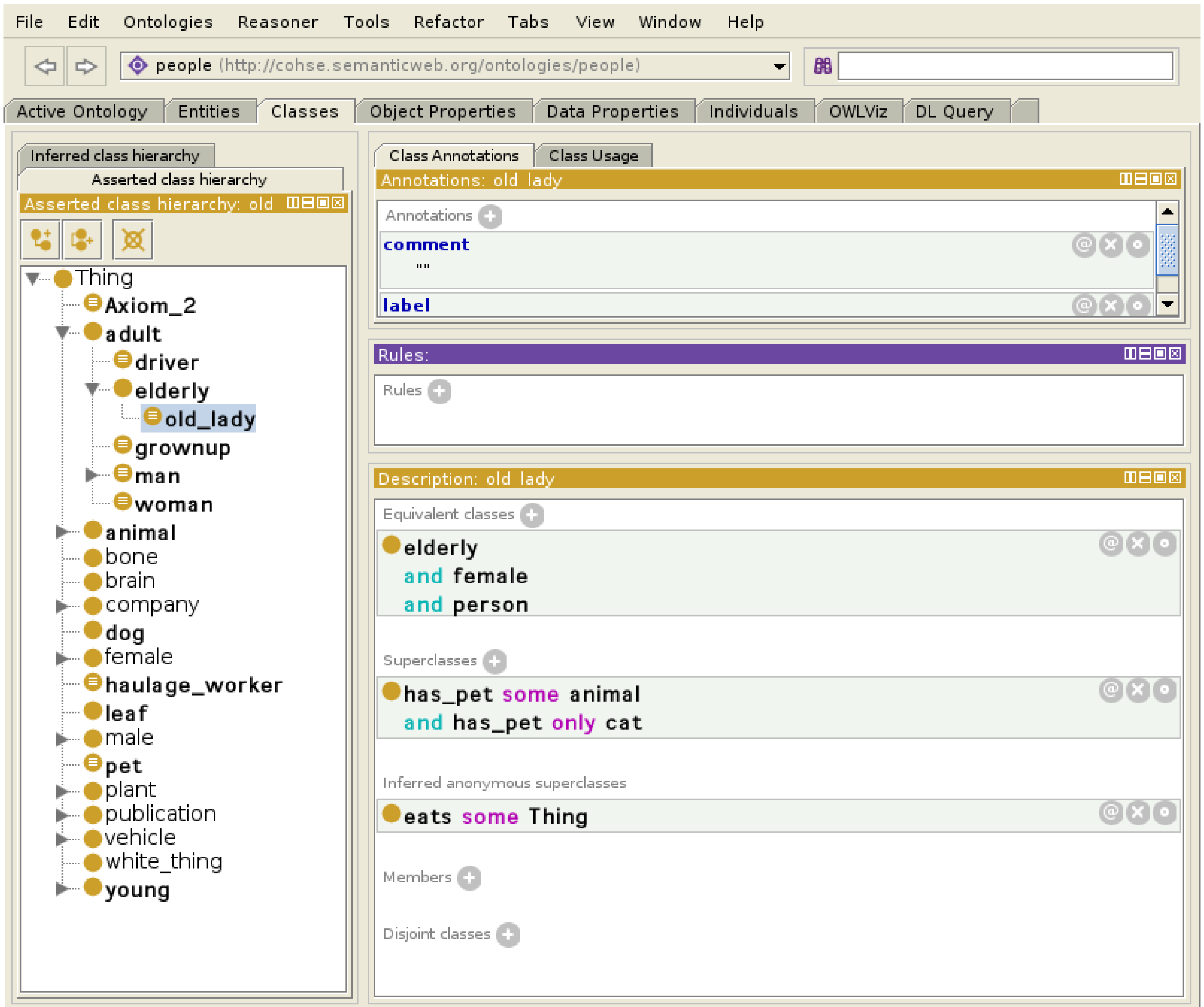


The OWLAPI Java „SemWeb“ Framework

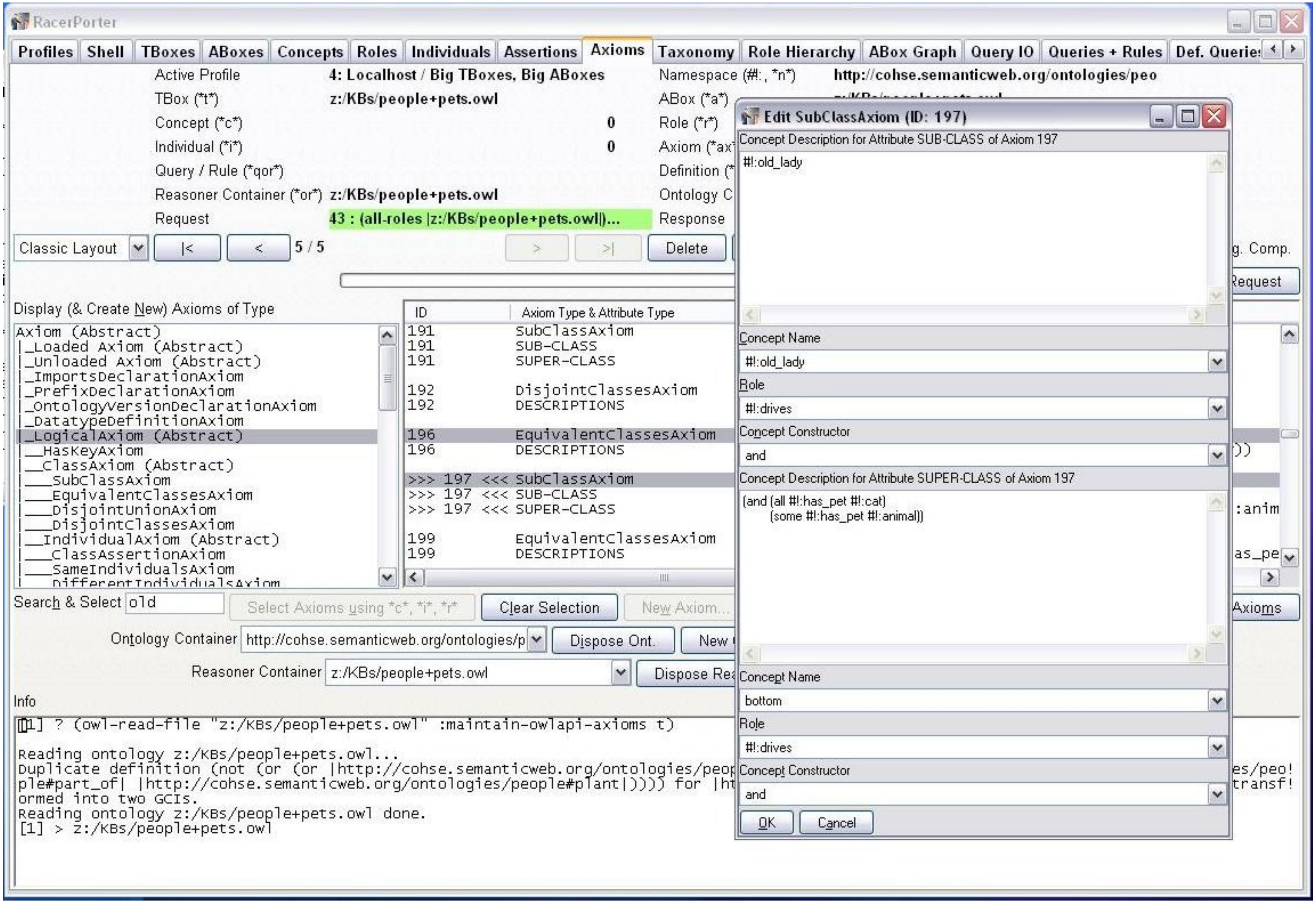
- An important Java framework for SemanticWeb programming (similar to Jena for RDF, ...)
- Basis of **Protégé 4.x**
  - handles reasoner access
  - `RacerAdapter` required
  - `RacerReasoner` adapter & Protégé plugin developed and provided by **Olaf Noppens from Ulm University**
  - required an entirely new Racer-API (Racer-OWLAPI) in order to make the adapter work (have to support the core OWLAPI abstractions)



Graphical OWL2 Modeling with Protégé 4



Graphical OWL2 Modeling with RacerPorter



RacerPro Extensibility

- MiniLisp
  - ad-hoc server extensions (API function missing?)
  - executed on the server (no communication latency → fast)
  - user-defined query predicates
  - report generation, programmatic knowledge base creation („Sudoku Grid“), „Racer scripting“
- Plugin mechanism
  - create a FASL file with AllegroExpress, convert it into a plugin
  - server extensions possible (hook mechanism)
  - „at our own risk“, full access to Racer internals, ...
  - faster & more general than MiniLisp, but not „ad hoc“

MiniLisp in a Nutshell

- A simple **„Lisp 1 Lisp in Lisp“** (own evaluator)
- Motivation: termination safe & simple (important if used in queries!)
  - **total recursive functions**
- Basic datatypes and operations (both borrowed from CL) for
  - lists, numbers, symbols, characters, booleans, basic IO streams
  - no cyclic lists
- Control structures (mostly borrowed from CL)
  - **bounded loops**, structure mapping (no cyclic lists)
    `dotimes, dolist, maplist, maptree,` …
  - `if, when, unless, cond,` …
- `defun` and `defpar`, `defcon`
  - recursion always aborted at runtime (stack inspection)

MiniLisp in a Nutshell (2)

- No macros
- All RacerPro API functions / macros callable (macros treated as functions)
- `setq (incf, decf)`, but no generalized variables (prevent cyclic lists)
- No closures
  - impossible

    `((lambda (x x) (x x)) (lambda (x x) (x x)))`
  - (built-in) higher order functions have to be special forms
    `(maplist (lambda (x) (1+ x)) '(1 2 3))`
- `evaluate`
  - but no `(evaluate … (evaluate …) …)`
- Quote, backquote, …
- **Claim: covers 99,99% of the typical „Racer programming“ cases!**

Benefits of Lisp

- Racer could have been implemented in another language...
  - … but some Lisp-features are especially valuable here
  - „standard arguments“ (GC, closures, …) apply to may languages nowadays (Haskell, Phython, Ruby, JavaScript, F#, …)
- Merits of functional programming
  - Racer tableaux prover (= system core / kernel) was implemented in a functional style (seems natural)
  - good for debugging
  - but problems with stack size someday
    - switched to closures for representation of backtracking context („continuation-passing style“)
    - implementation didn't break although this was a drastic change in the system architecture → flexibility of Lisp

Benefits of Lisp (2)

- Ability to concisely represent and conveniently manipulate complex expression
  - **structured literals**
  - you don't want
    `expr.add(new this(„a“).add(new that(„b“)));`
  - `ArrayLists`: [„a“, „b“]
  - S-Expressions were invented for symbolic computation
    → perfect
  - S-Expressions for the **front-end syntax**
    (things get encoded later)

    … LOTS of operations deal with front-end syntax only

Benefits of Lisp (3)

- **Abstraction**
  - W3C standards such as OWL2 are still a moving target
    - a very flexible basis is needed / prototyping
    - decouple implementation from standardization ;-)
    - transform OWL (SPARQL, SWRL, ...) into that representation (but keep the original representation)
  - Lisp allows you to **defer decisions**
    - no static typing (no extensive „type“ or class hierarchy refactorings)
    - no tight data structure (class hierarchy) / operations coupling

      → operations can be combined in a more flexible way
    - macros can save you a LOT of refactoring time (change the macro, keep the code!)
    - „open“ method / function signatures / delegation chains:

```
(defun f1 (… &rest args &allow-other-keys)
   … (apply #'f2 args))))
```

Benefits of Lisp (4)

- **Reflexive / introspective qualities** of Lisp
  - meta-information is always there

    within the SAME environment (→ synergy effect), e.g.
    - `racer-defun` does many things in one place:
      - registers the function for the server listener
      - creates LRacer & JRacer stubs based on lambda list
      - creates code for RacerPorter to support completion, …
    - `defowlaxiomclass`
      - creates the axiom editor CAPI dialogs for Porter by „inspecting“ its slots, conjoining appropriate CAPI code for the different attributes
    - „data driven“ meta programming

→ **Lisp allows a very small company (us!) to survive W3C Semantic Web standards ;-)**

Drawbacks of Lisp

- Lack of „(quasi) standardized“ frameworks / solutions
  - and quality of the existing frameworks probably not as good as in the Java world (MUCH less developers are using them on a daily basis)
    - Java ↔ Lisp „in memory“ integration still very hard
  - e.g., very nice graph layouters in Java
  - Java developers get much more for free

    → Lispers have to work harder: more hand-crafted solutions
- Language too old (?)
  - unicode sockets, custom streams (e.g., gzipped streams), …
- GC is a big plus, but very hard to control sometimes (for large KBs)

Exploited Lisp Frameworks

- CL-HTTP (John Mallery) / AllegroServe
  - `owl-read-document` (HTTP client)
    - `owl:Import` (downloads an ontology from the web)
  - DIG / OWLlink server
- Wilbur (Ora Lassila)
  - basic RDF processing
- AllegroGraph
  - SPARQL parser & triple store for RacerPro
- Lispworks CAPI and Lispworks editor
  - for RacerPorter / RacerEditor
  - thanks to Martin Simmons for great CAPI support

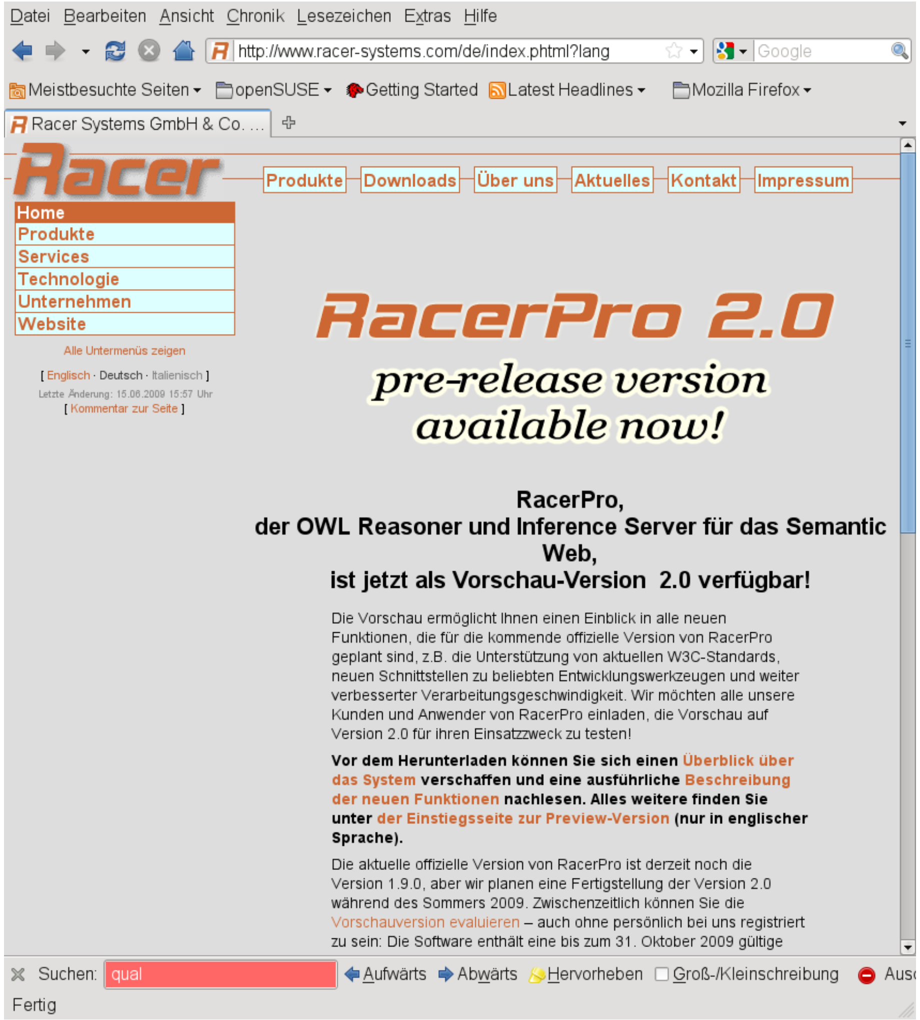
How do I get RacerPro ?

- www.racer-systems.com

  there is the 2.0 preview version

  - no license required
  - to be finalized soon

- A recent research project which uses RacerPro: www.boemie.org



Thanks!