Spatio-thematic data in a DL-based prototypical GIS

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Overview of Talk

- Vision of a “deductive GIS”

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- Vision of a "deductive GIS"
  - Conventional GIS
  - Scenario: digital city maps ("DISK")
  - Desirable reasoning services
  - Ontology-based querying of the DISK

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- A Pragmatic Prototype (DLMAPS)

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- Vision of a “deductive GIS”
- A Pragmatic Prototype (DLMAPS)
  - Bottom-up approach
  - Idea for architecture
  - Short Description Logic (DL) reminder
  - RacerPro: $\mathcal{ALCQHI}_{\mathcal{R}^+}(\mathcal{D}^-)$
  - Representing and querying the DISK

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- A Pragmatic Prototype (DLMAPS)
- DLMAPS functionality integrated into RacerPro
  - DLMAPS query language $\longrightarrow$ nRQL
  - Description of nRQL
  - Hybrid representations and queries
  - The (experimental) RCC substrate

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- Vision of a “deductive GIS”
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- Conclusion

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- "A GIS is a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information; that is, data identified according to location."
- . . . a few dozen more
- 4 main aspects: capturing, representation, analysis, presentation of spatial data

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- Representation (storage): spatial database (offering spatial datatypes)
  - vector or raster data (or both)
  - often organized by subject in “layers”
  - spatial index structures (e.g., R^{+}-Trees)

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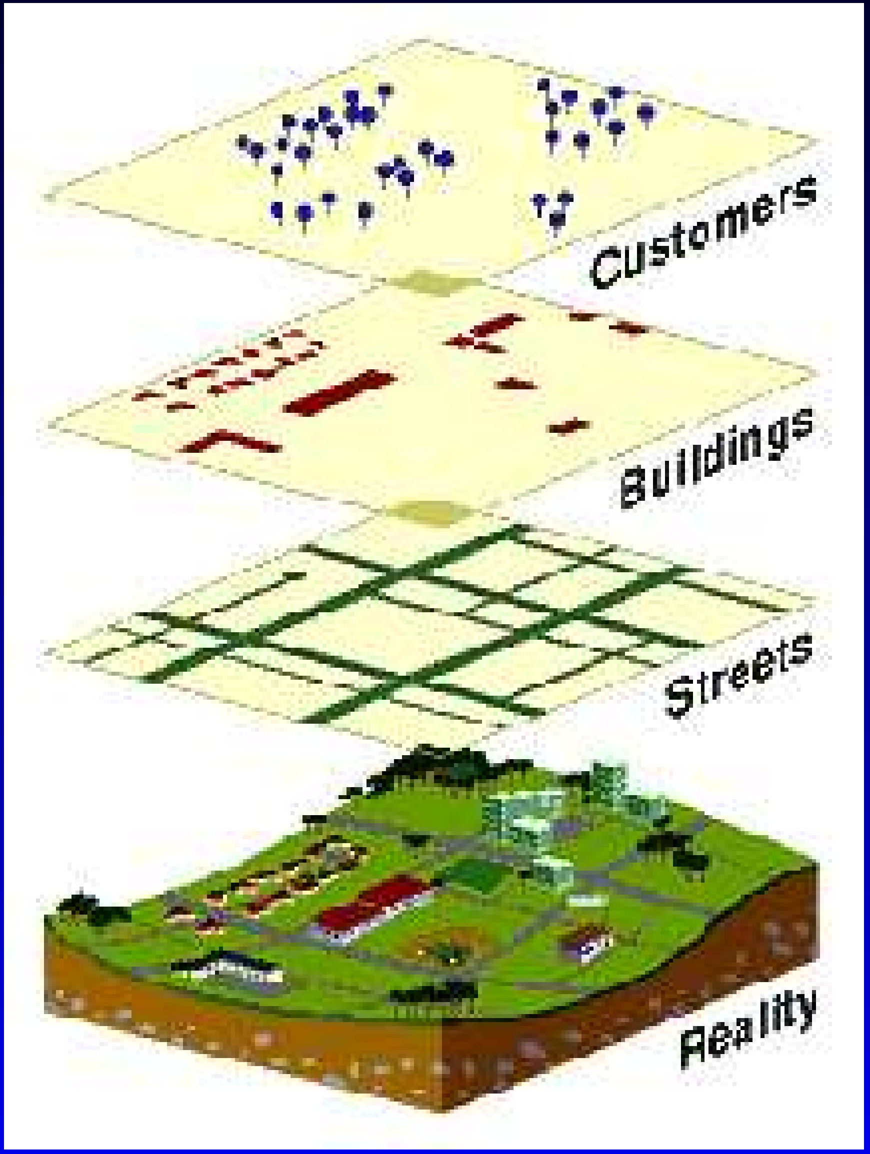

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    - Map 1: 2694 geo-objects, 361 primary

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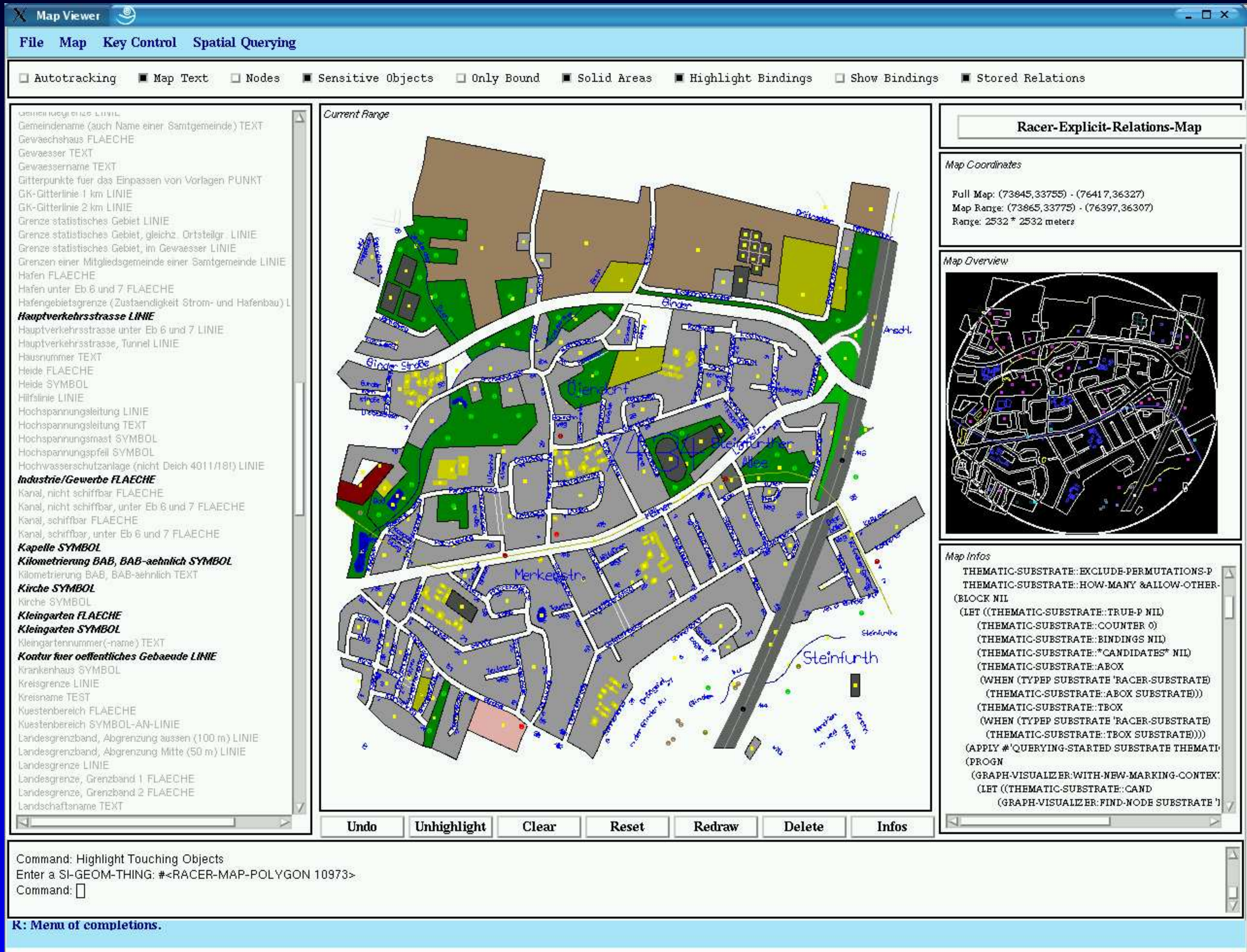

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  - Map 2: 18.039 geo-objects, 5.418 primary

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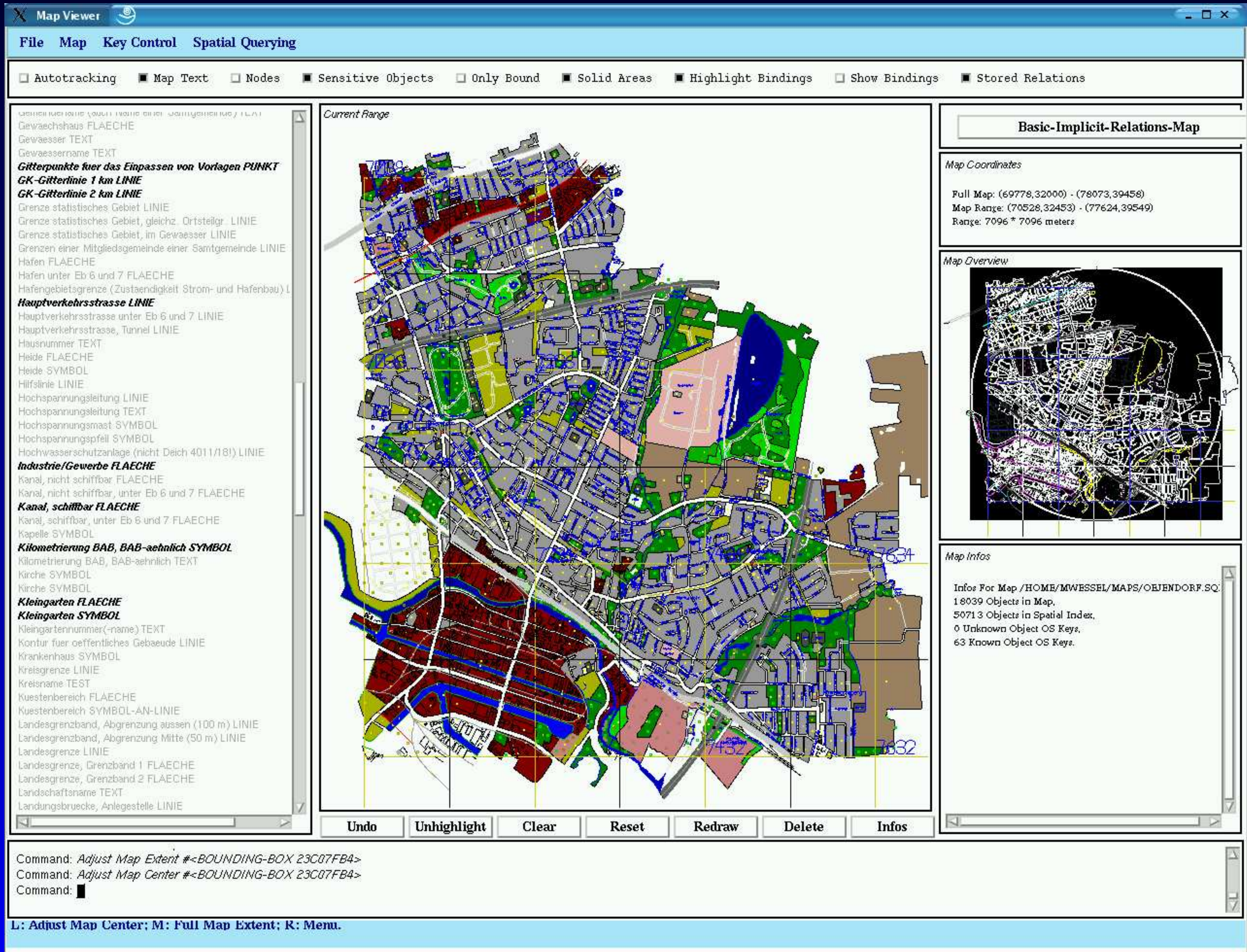

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- Reasoning with spatial concepts?

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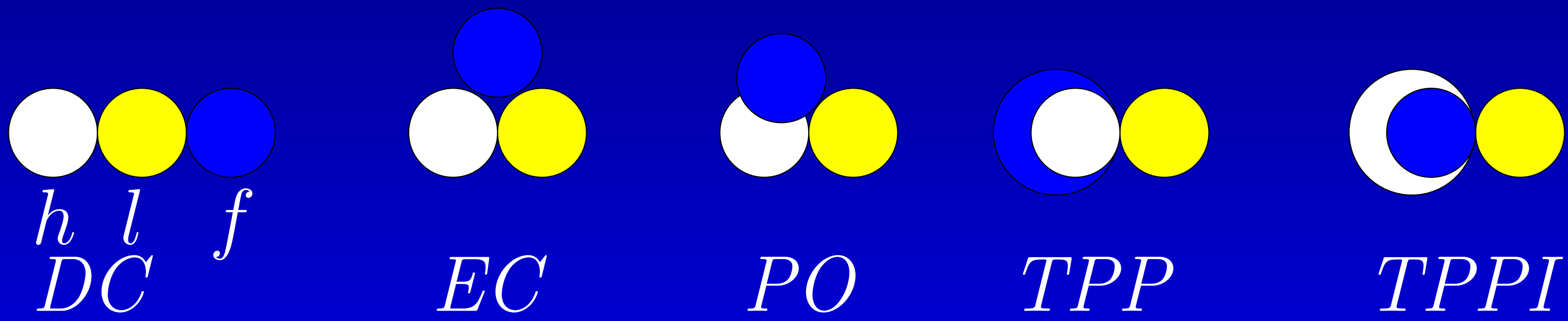

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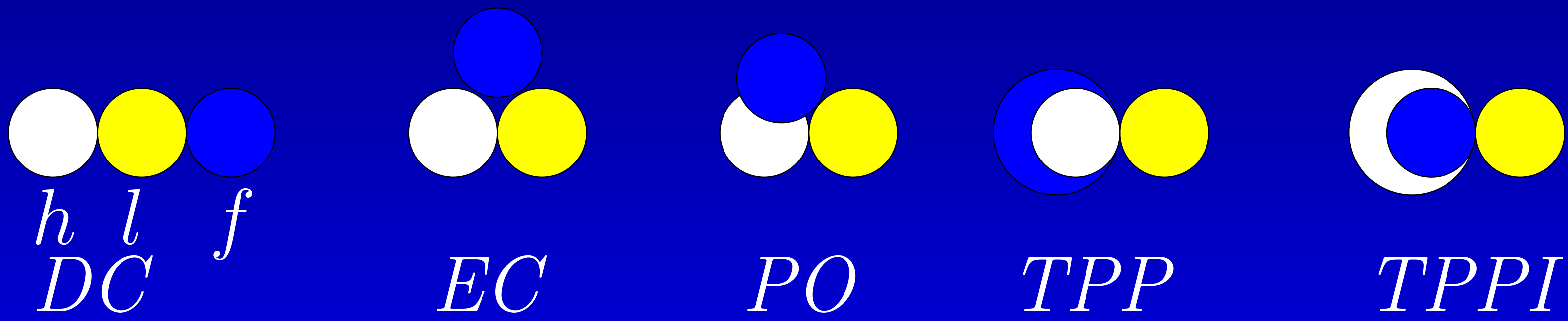

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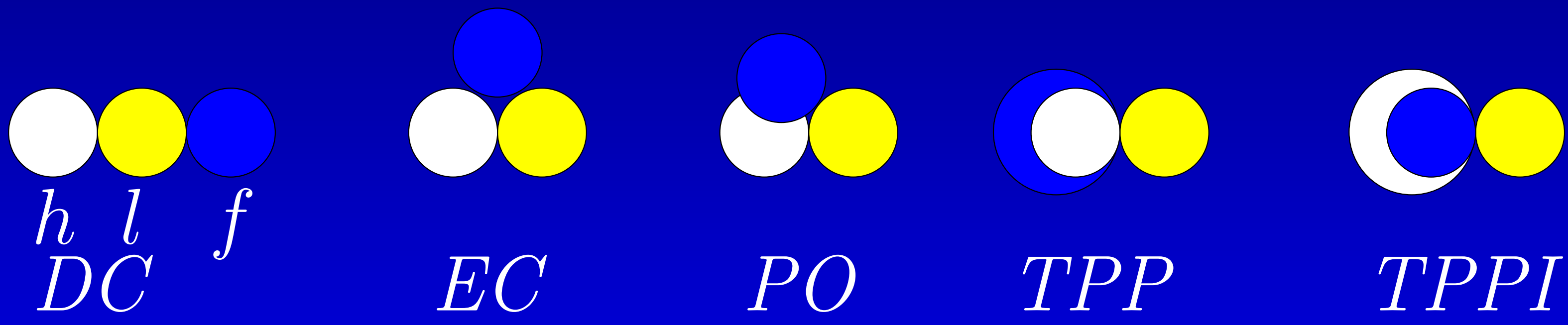

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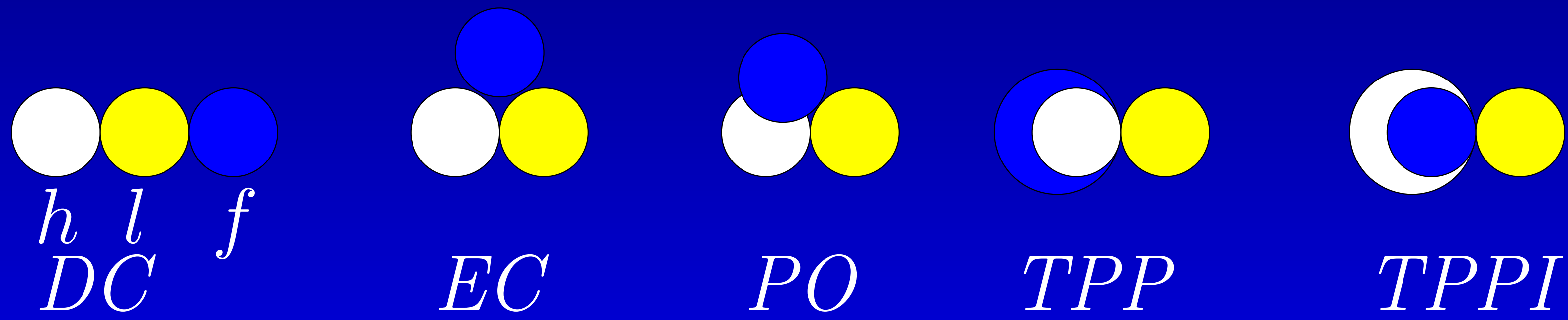

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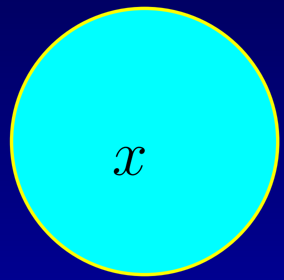
Spatial Incompleteness (Lemon)



$$circle_{r=10}(x) \wedge circle_{r=10}(y_1) \wedge \ldots \wedge circle_{r=10}(y_7) \wedge$$

$$EC(x, y_1) \wedge \ldots \wedge EC(x, y_7) \wedge$$

$$(EC(y_1, y_2) \wedge EC(y_2, y_3)) \wedge$$

$$(EC(y_2, y_3) \wedge EC(y_3, y_4)) \wedge \ldots \wedge$$

$$(EC(y_6, y_7) \wedge EC(y_7, y_1))$$

Satisfi able?

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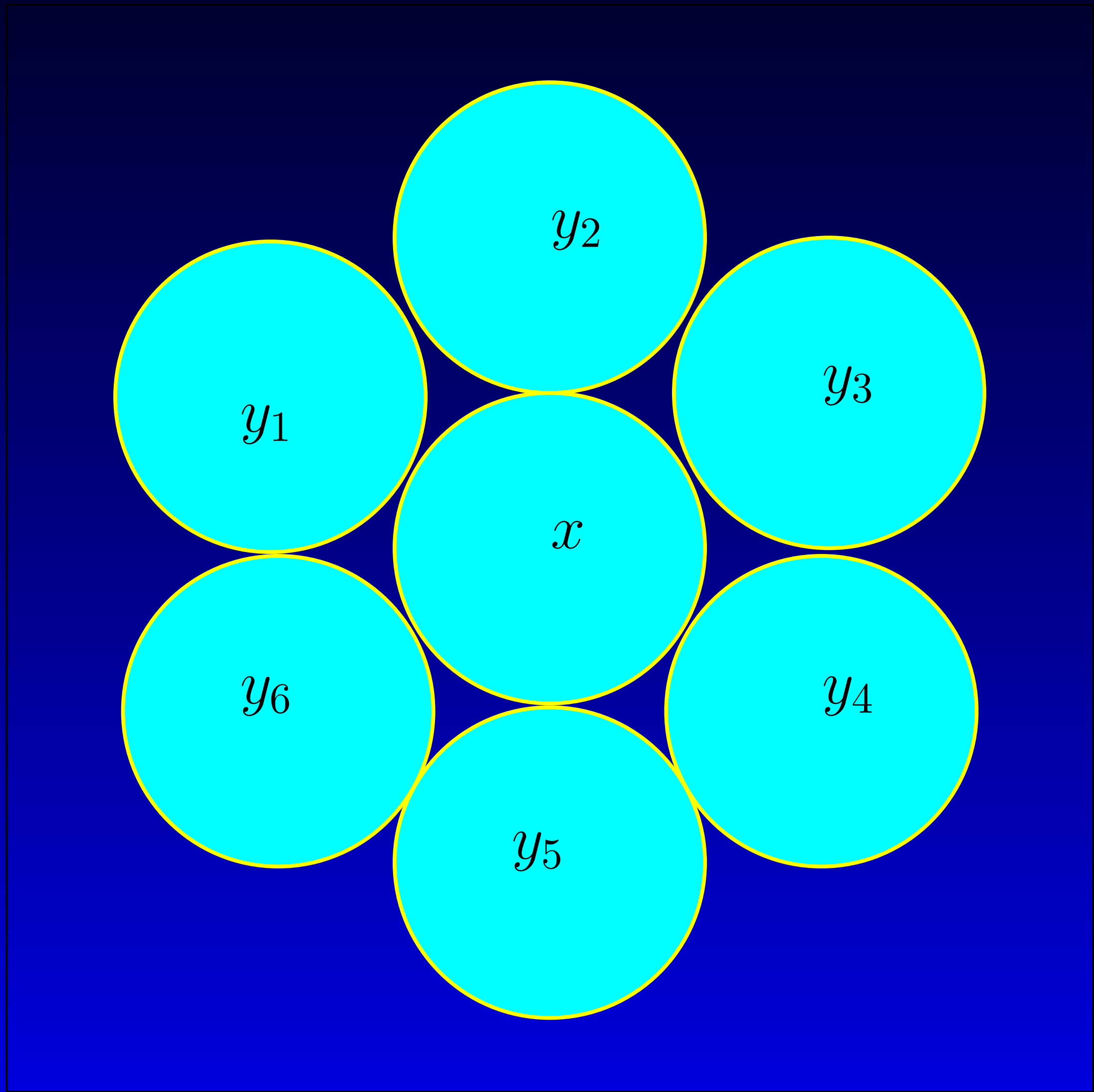

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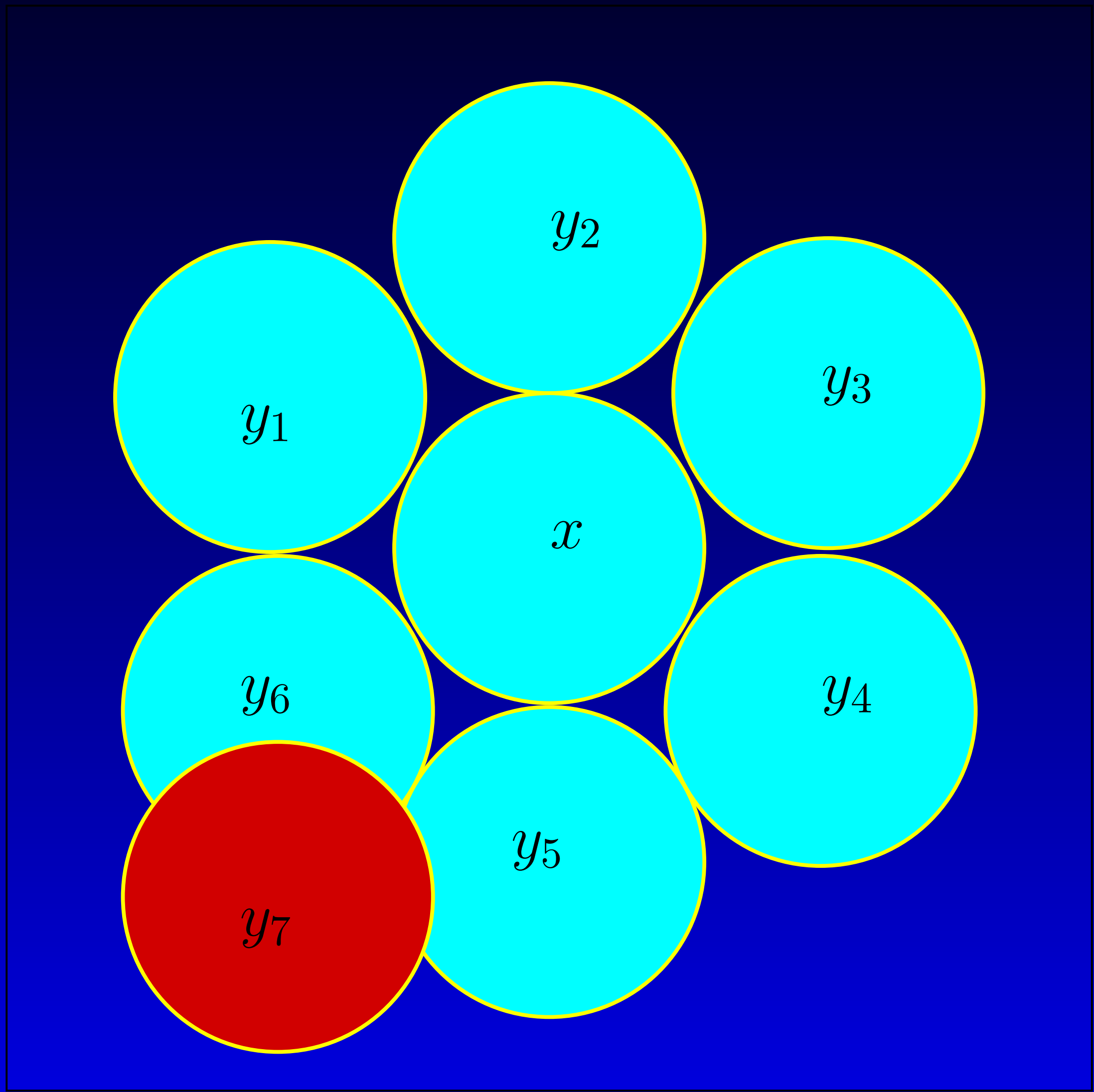
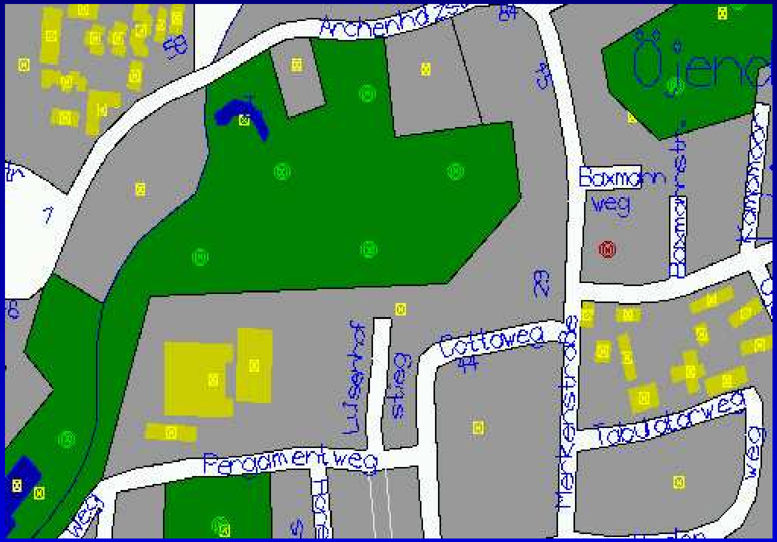


Unsatisfiable!

Spatial Incompleteness (Lemon)

The Vision of a Deductive GIS



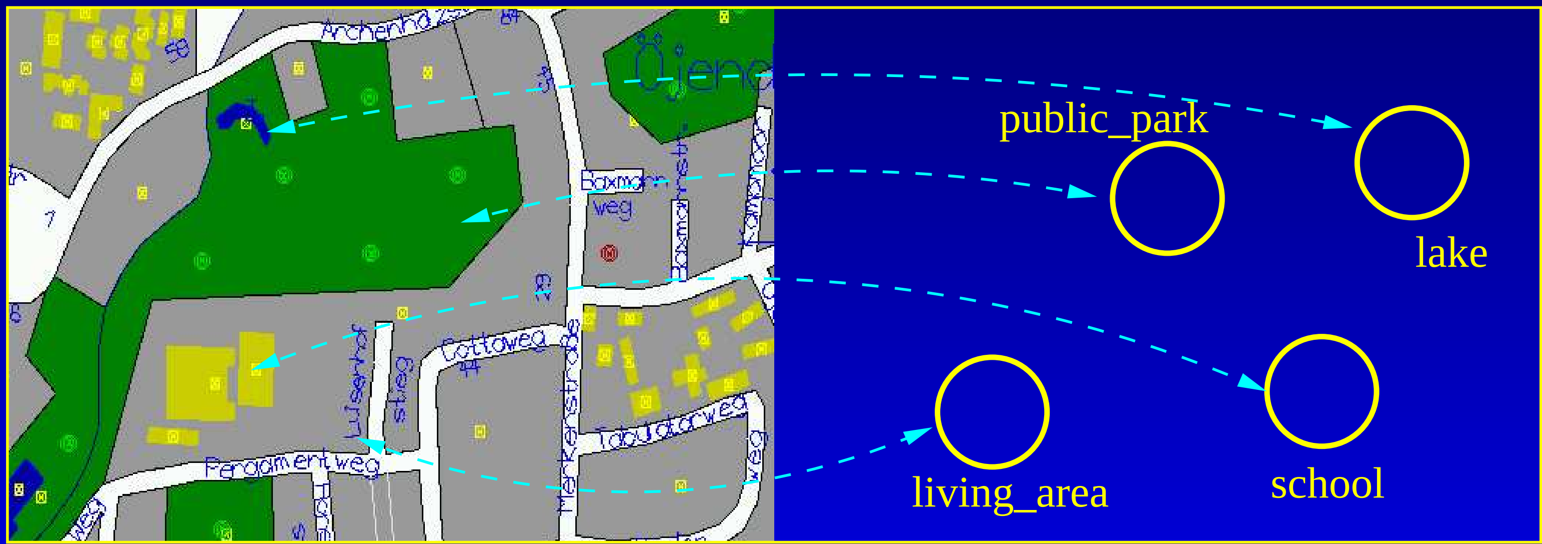
Concrete Geometry

Starting point: a digital vector map

TUHH Technische Universität Hamburg-Harburg

The Vision of a Deductive GIS

Extensional Component

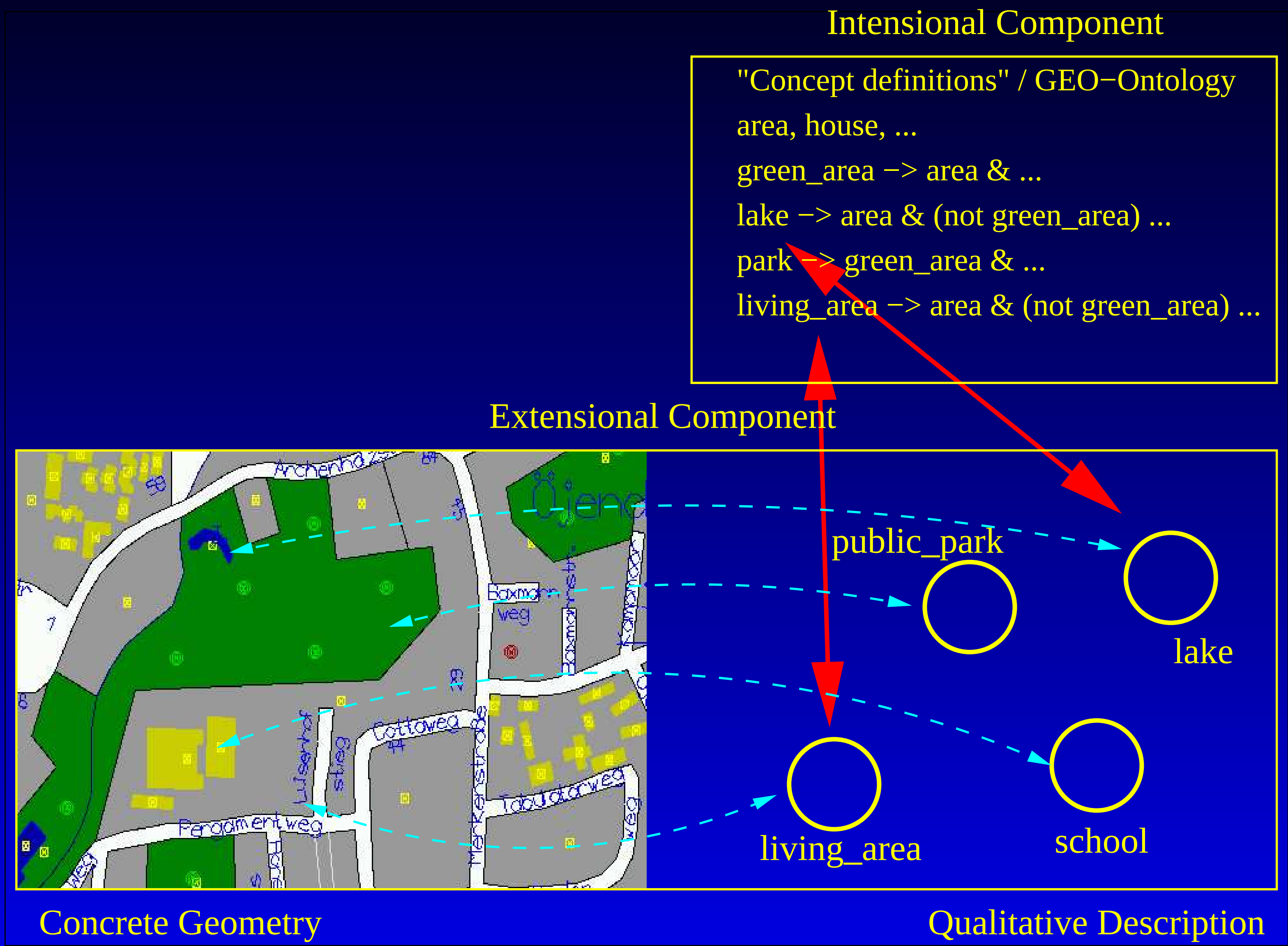


Concrete Geometry

Qualitative Description

Thematic information in a map

The Vision of a Deductive GIS



Modeling of thematic concepts

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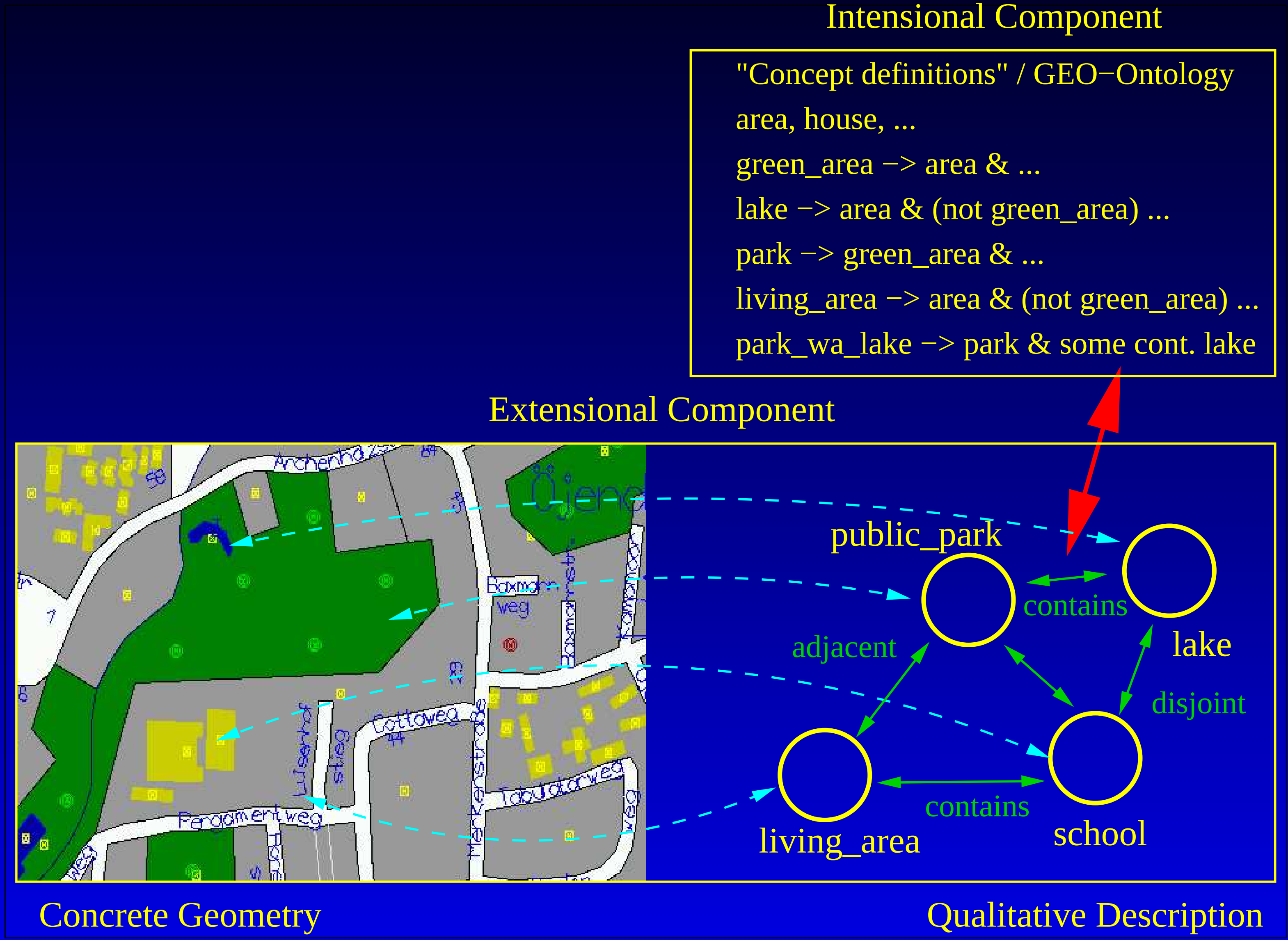


Some concepts are really “spatio-thematic”

The Vision of a Deductive GIS

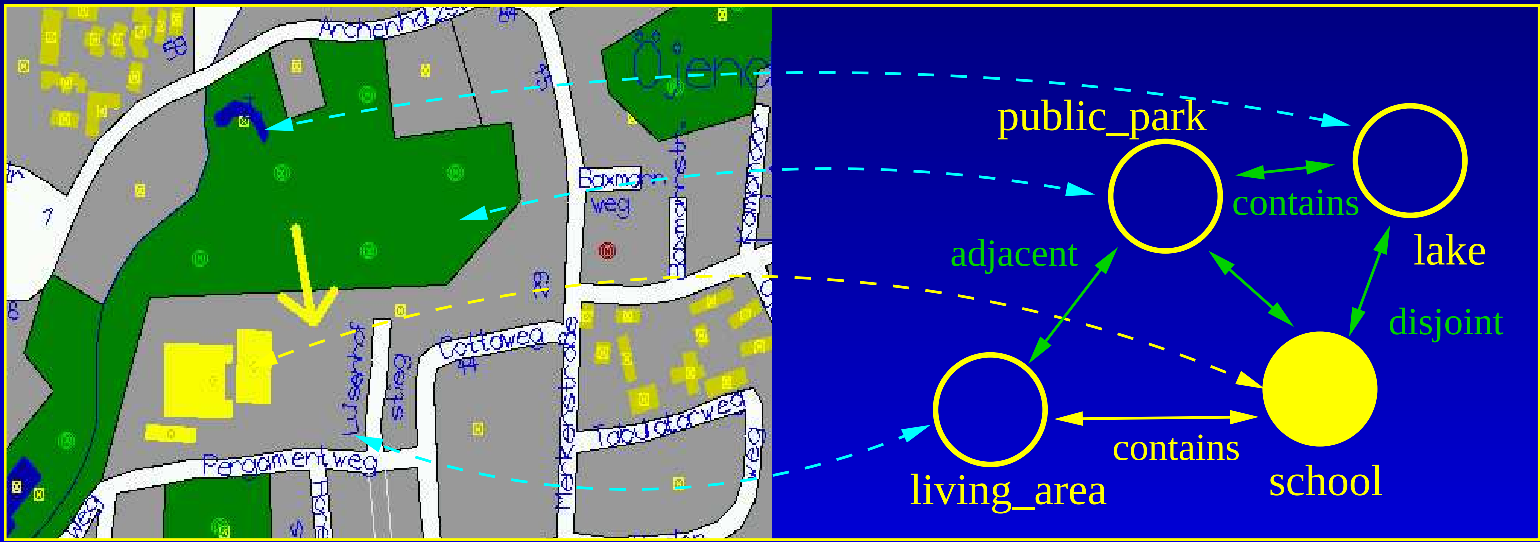
Query Component

Simple Spatial Queries:

Retrieve all areas contained within this area

Intensional Component

Extensional Component



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Qualitative Description

Purely spatial queries

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Thematic Queries:

retrieve_concept_instances(lake)

Intensional Component

"Concept definitions" / GEO−Ontology

area, house, ...

green_area −> area & ...

lake −> area & (not green_area) ...

park −> green_area & ...

living_area −> area & (not green_area) ...

park_wa_lake −> park & some cont. lake

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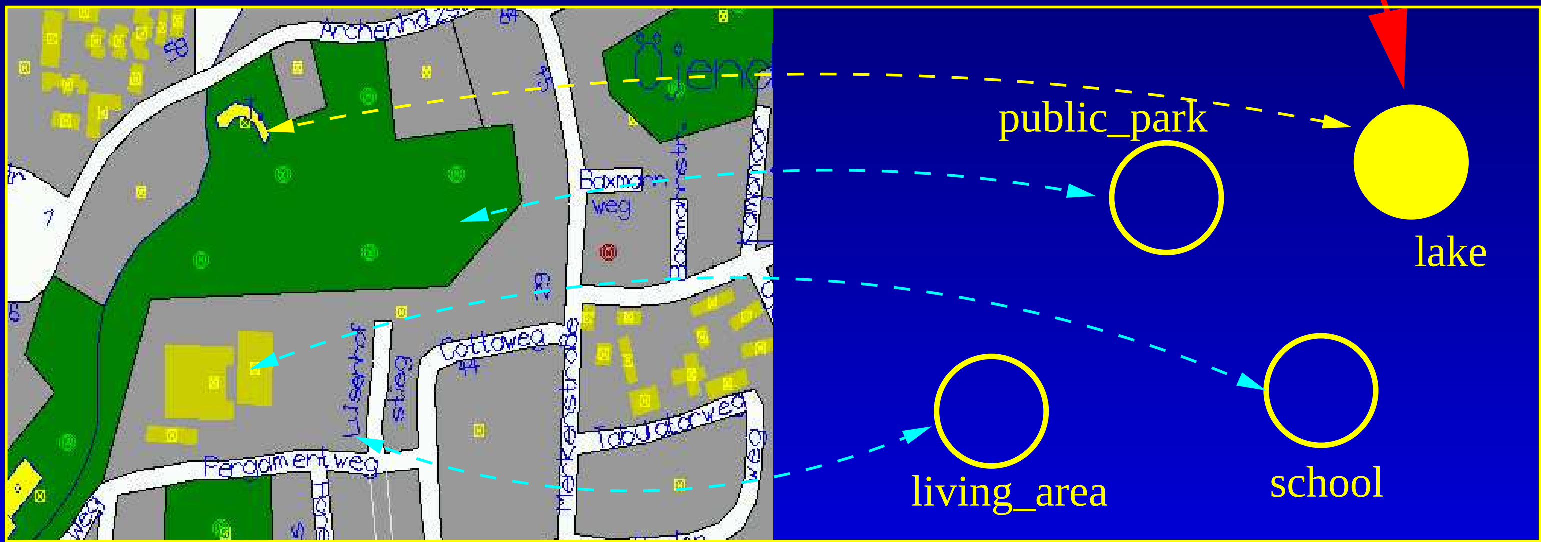

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Simple Spatial Queries:

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Thematic Queries:

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Spatio−thematic Queries:

- Retrieve all parks that contain a lake

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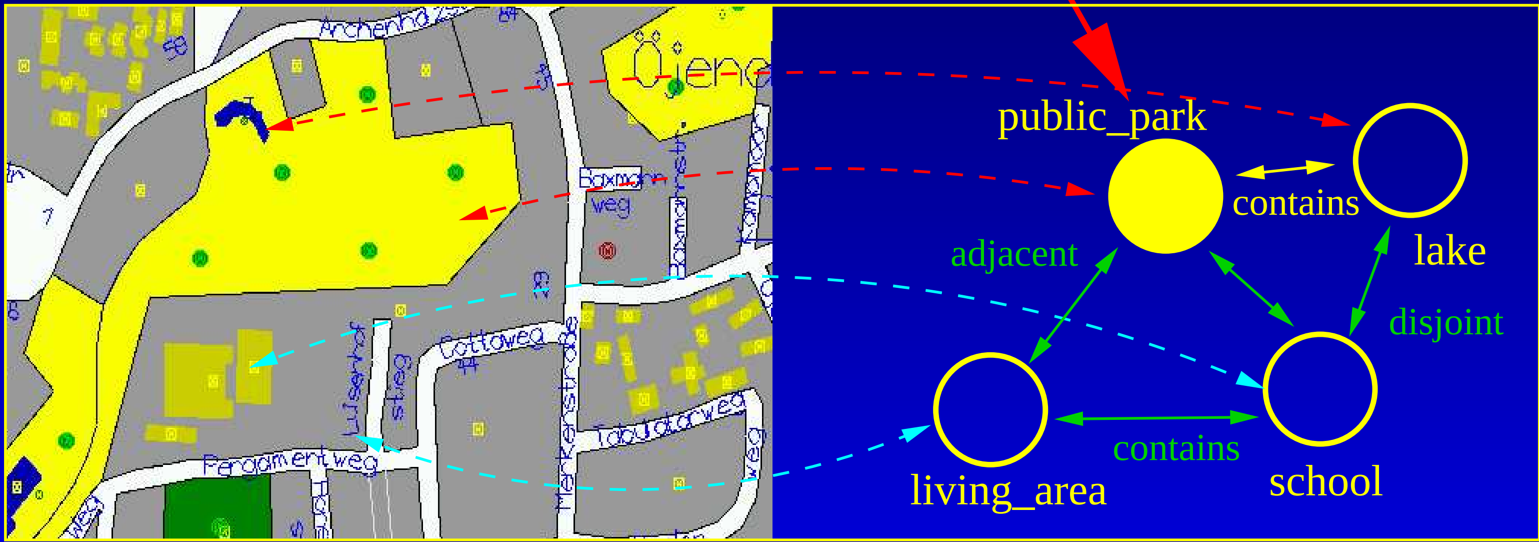

Concrete Geometry — Qualitative Description

“Spatio-thematic” queries

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- System metaphor: we want a GIS similar to a description logic (DL) system
- Extensional component $\mathcal{E}$
  - Representation of certain selected spatio-thematic aspects of a concrete map ("geographic world")
  - ? Which spatial and thematic aspects?
  - ? Underspecifi ed / indeterminate data?
  - ? Unifi ed or hybrid representation of spatial and/or thematic aspects (different "sources")?

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- Extensional component $\mathcal{E}$
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  - Modeling of geo ontologies with (spatial?) geo concepts in a description language (not necessary DL)
  - ? Which spatial and thematic aspects?
  - ? Thematic, spatial, spatio-thematic concepts?
  - ? Combined or separated description languages for different aspects?
  - ? Spatio-thematic interaction?

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- Query component $\mathcal{Q}$
  - Retrieval of interesting objects / constellations; "map analysis / reasoning"
  - ? Kind of queries
  - ? With spatial and thematic aspects are addressable?
  - ? Usage of concepts from the ontologies within queries
  - ? Evaluation of queries ("specialists" for sources)?

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- Reasoning tasks
  - $\mathcal{E}$: consistency checking of data
  - $\mathcal{I}$: consistency checking of ontology & concepts
  - $\mathcal{I}, \mathcal{Q}$: satisfi ability and entailment of queries / concepts
  - $\mathcal{I}, \mathcal{Q}$: computation of query / concept subsumption hierarchies ("taxonomies")
  - $\mathcal{E} \times \mathcal{I}$: instance "realization"

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  - Design suitable spatio-thematic logics
  - Very hard, problems with decidability
  - Long way to go until we get a working system

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  - Top Down
  - Design <u>suitable</u> spatio-thematic logics
  - Very hard, problems with decidability
  - Long way to go until we get a working system
- Practitioner's / Engineer's Approach:
  - Bottom Up, use and exploit existing components
  - Use an existing DL system: RacerPro
  - Add expressive query language suitable for <u>ontology-based spatio-thematic querying</u>
  - More limited but one gets a working system soon

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- “Global as View”: the ontology can be seen as defining views over the information sources

Ontology-based DISK Querying

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- Setting 2:
  - Source 1: Thematic annotations $\longrightarrow$ DL ABox
  - Source 2: Map geometry $\longrightarrow$ spatial box
  - Expressive <u>hybrid</u> query language needed
  - Query expansion

Ontology-based Querying (2)

- Benefits
  - Users can abstract from sources and schemas of the sources
  - Ontology is formal $\longrightarrow$ queries can be reasoned about (checking consistency, entailment, equivalence)
  - Ontologies can capture taxonomic ("is-a") relationships
  - The mapping expressed by the ontology is easily adjustable

$\Rightarrow$ declarative programming, the "ontology view" on the data can be changed easily

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- Not considered in the following (“Practitioner’s approach”)

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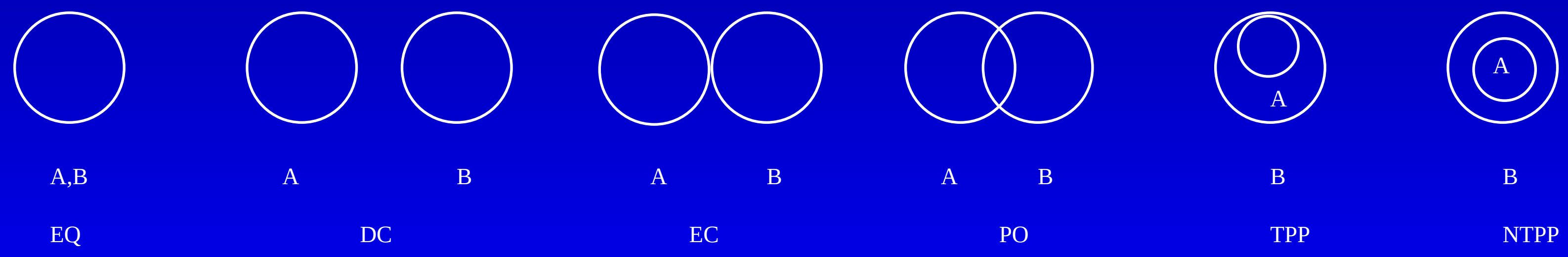

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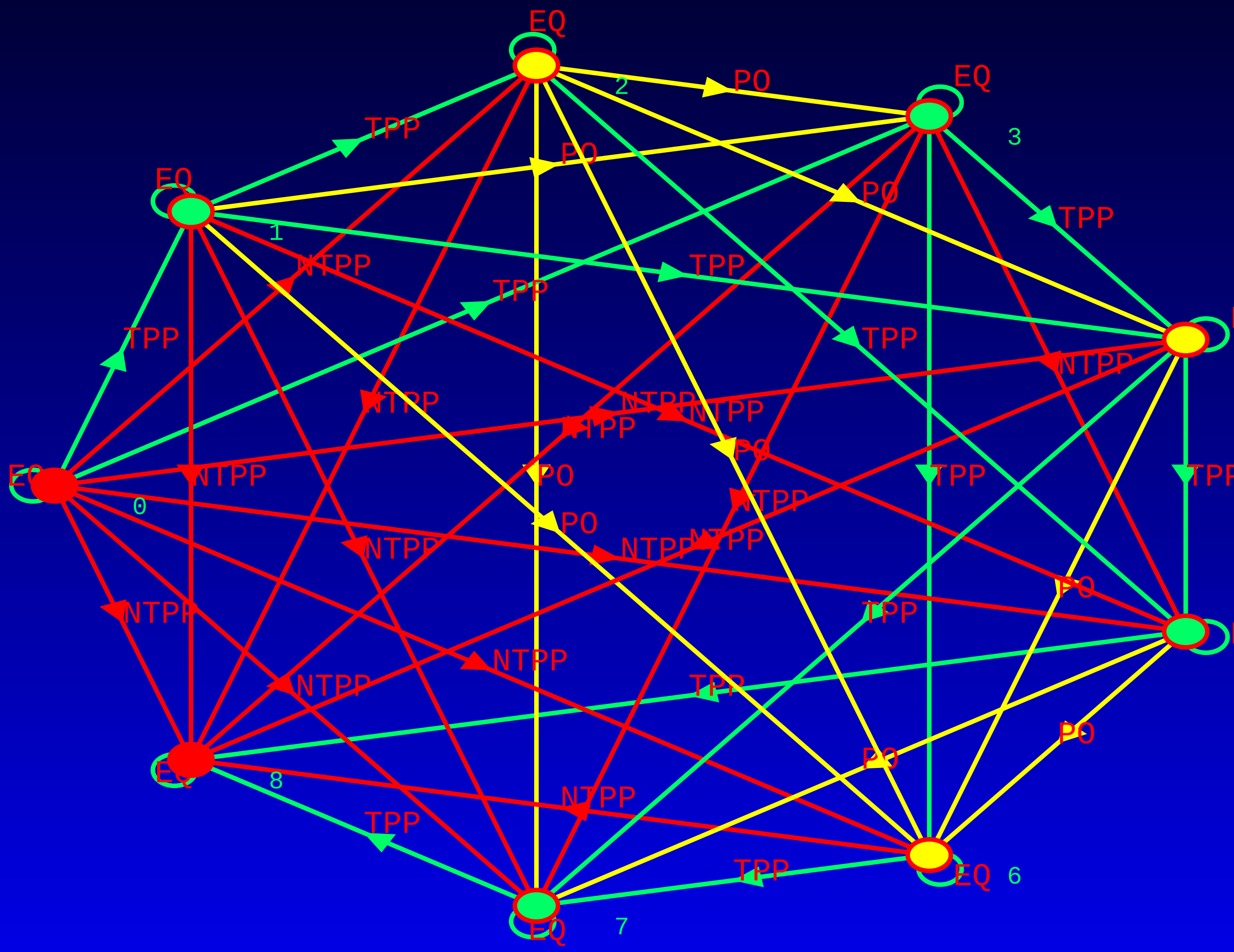
Illustration: DISK ABox



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  - RCC atoms
  - Geometric attributes: area, length, ...
  - Metric relationships: range queries, epsilon queries, ...

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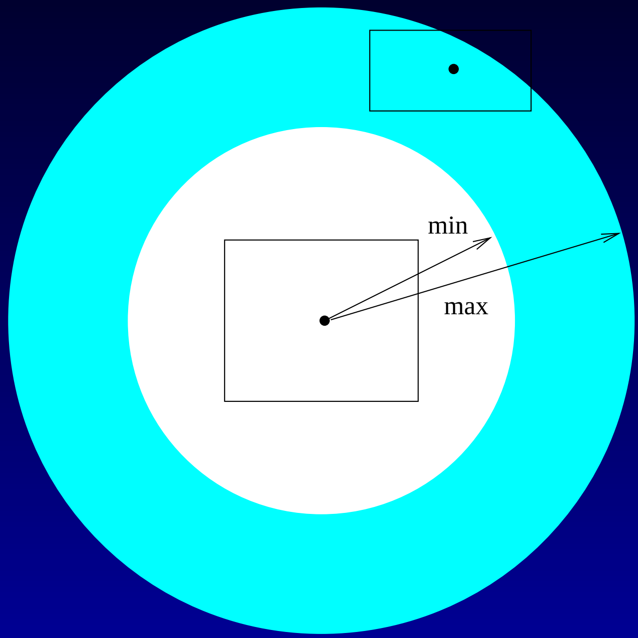
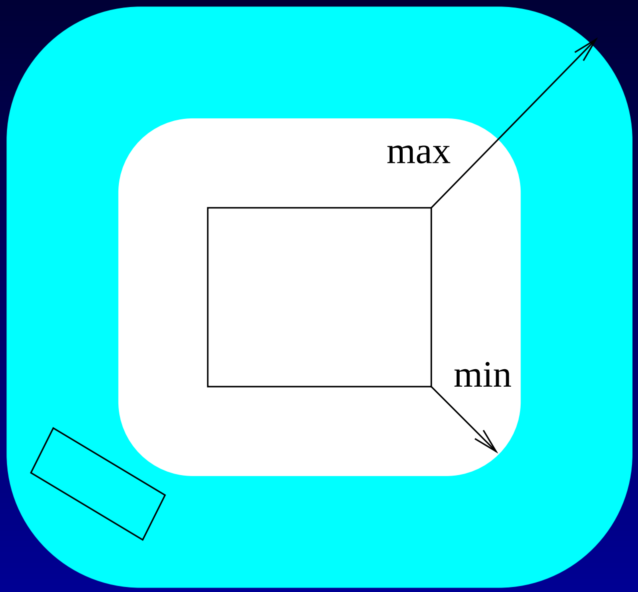


Range Query

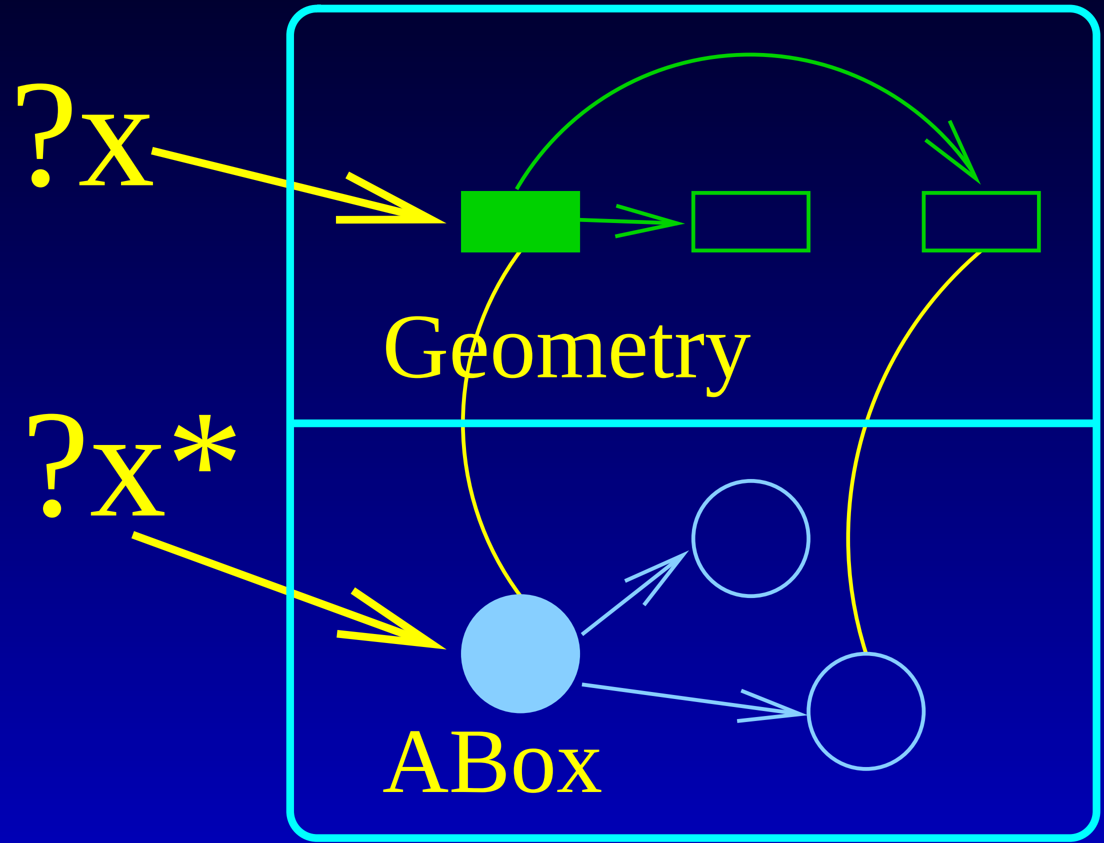


Epsilon Query

Hybrid Queries (Setting 2)

- Two sorts of atoms
- ABox atoms:
  - Variables range over ABox individuals
  - Atoms as in nRQL (see below)
- Spatial atoms:
  - Variables range over SBox individuals
  - RCC atoms
  - Geometric attributes: area, length, ...
  - Metric relationships: range queries, epsilon queries, ...
- Variables are bound in parallel, according to association

Hybrid Queries (Setting 2)



$?x^* / ?x$ are bound in parallel

Hybrid Queries (2)

- Hybridness can be made transparent

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- “Find a contaminated lake in a park in which a creek flows which borders an industrial area containing a chemical plant”
- $query(?x, ?y, ?z, ?f) \leftarrow$

$$industrial\_area(?x), creek(?y), lake\_or\_pond(?z),$$
$$contaminated(?z), chemical\_plant(?f), park(?u),$$
$$borders(?y, ?x), flows\_in(?y, ?z), contains(?u, ?z),$$
$$contains(?x, ?f)$$

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  - $lake\_or\_pond(?z) \longrightarrow$
    $?z^* : (lake \sqcup pond)$

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- Query rewriting / expansion
  - $contaminated(?z) \rightarrow$
    $?z^* : \exists water\_quality.poisoned$

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From DLMAPS to nRQL

- …DLMAPS query engine became core of nRQL engine
- …hybrid reprsentations added to RacerPro to faciliate "data representation"
- …the SBox of DLMAPS has not been incorporated, instead the RCC substrate has been added to support "RCC query atoms" (model checking no longer suffi cent!)

```
(retrieve (?x (told-value (age ?x)))
          (and (?x (and woman (an age)))
               (?x ?y has-child)
               (?y ?y (constraint
                           (has-father age)
                           (has-mother age)
                           (> age-1 (+ age-2 8))))))
```

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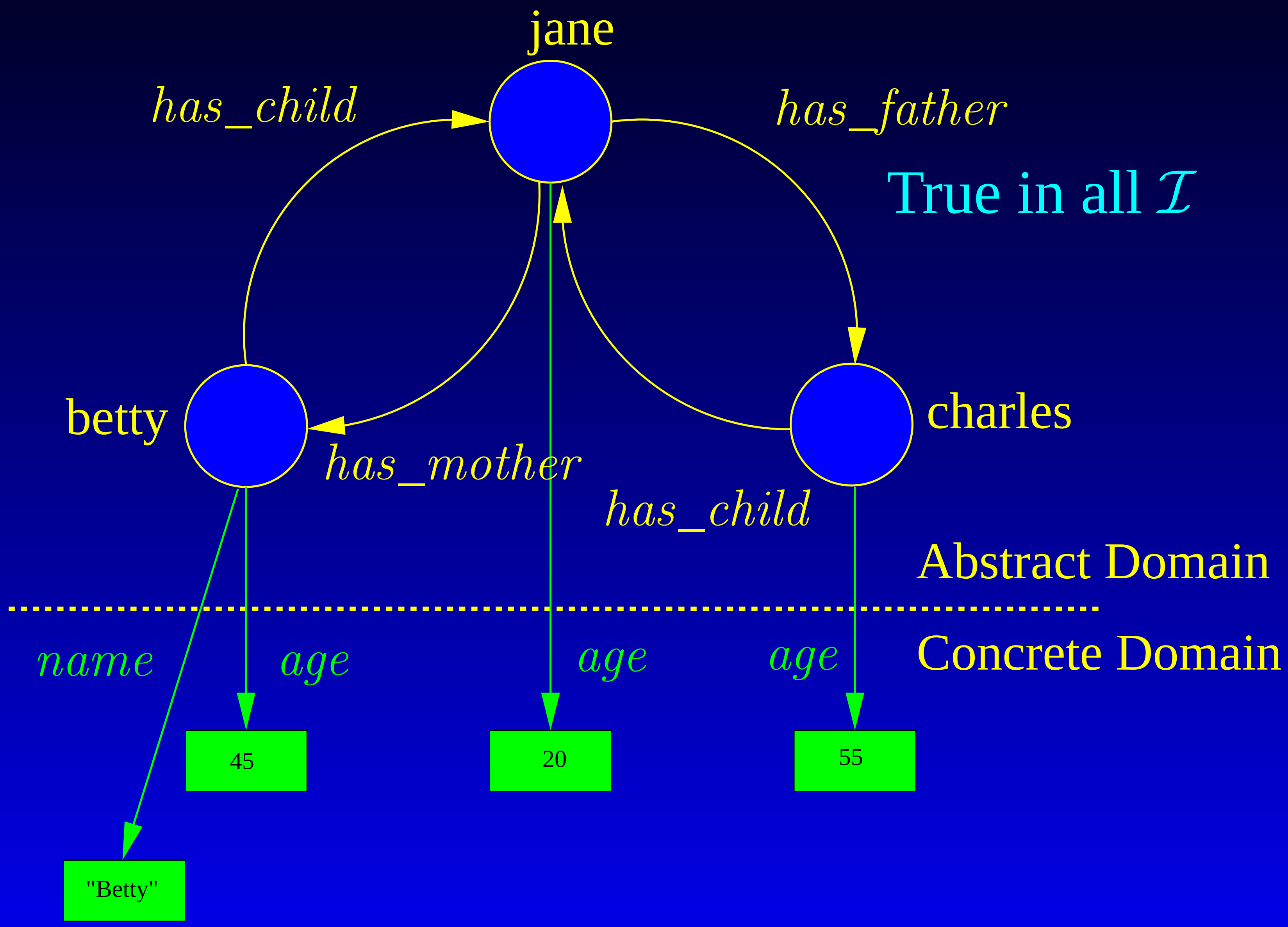
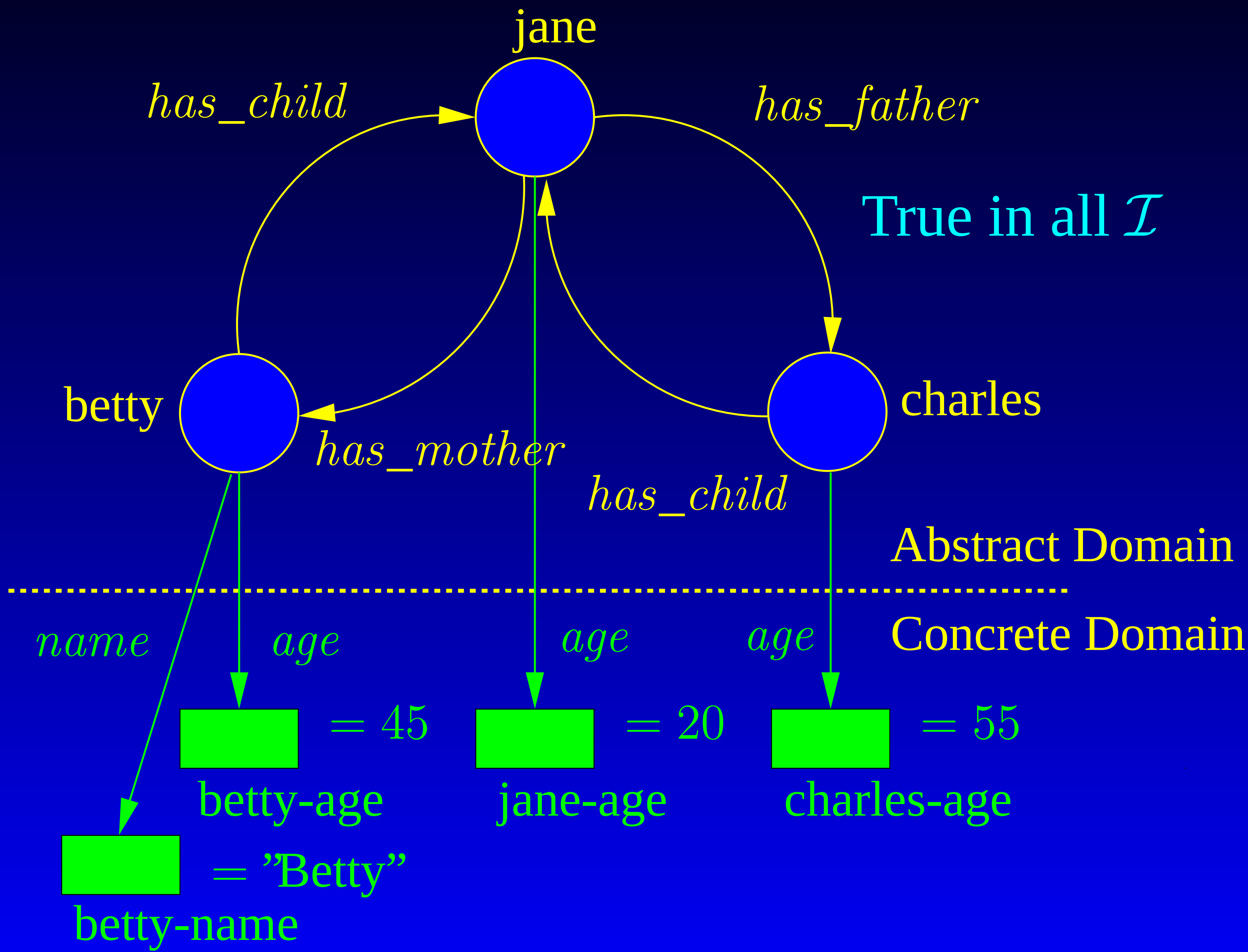
```
(((?x betty) ((told-value (age ?x)) 45))
 ((?x diana) ((told-value (age ?x)) 55))
          ⋮
           )
```

nRQL Language – Example



nRQL Language – Example



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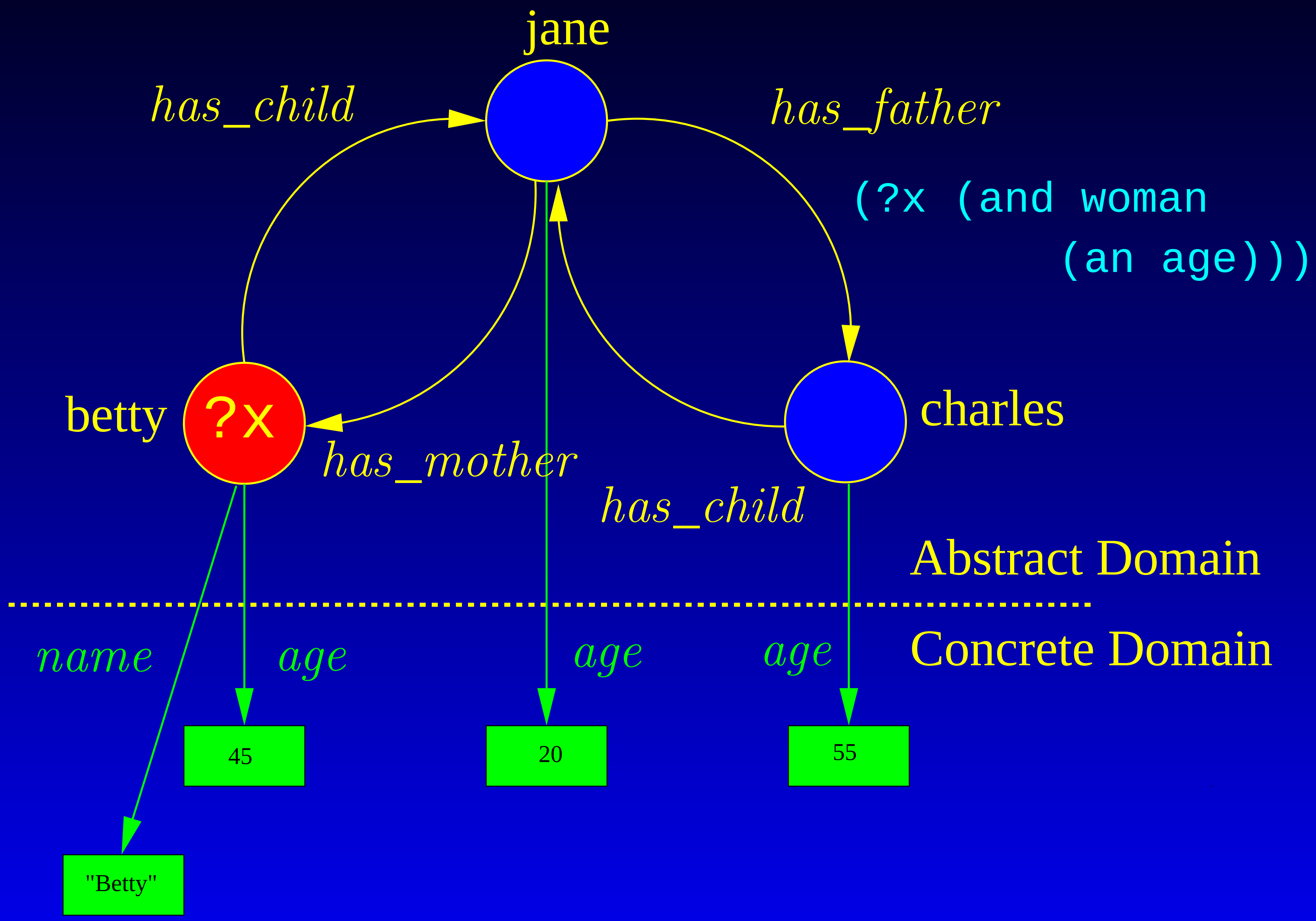
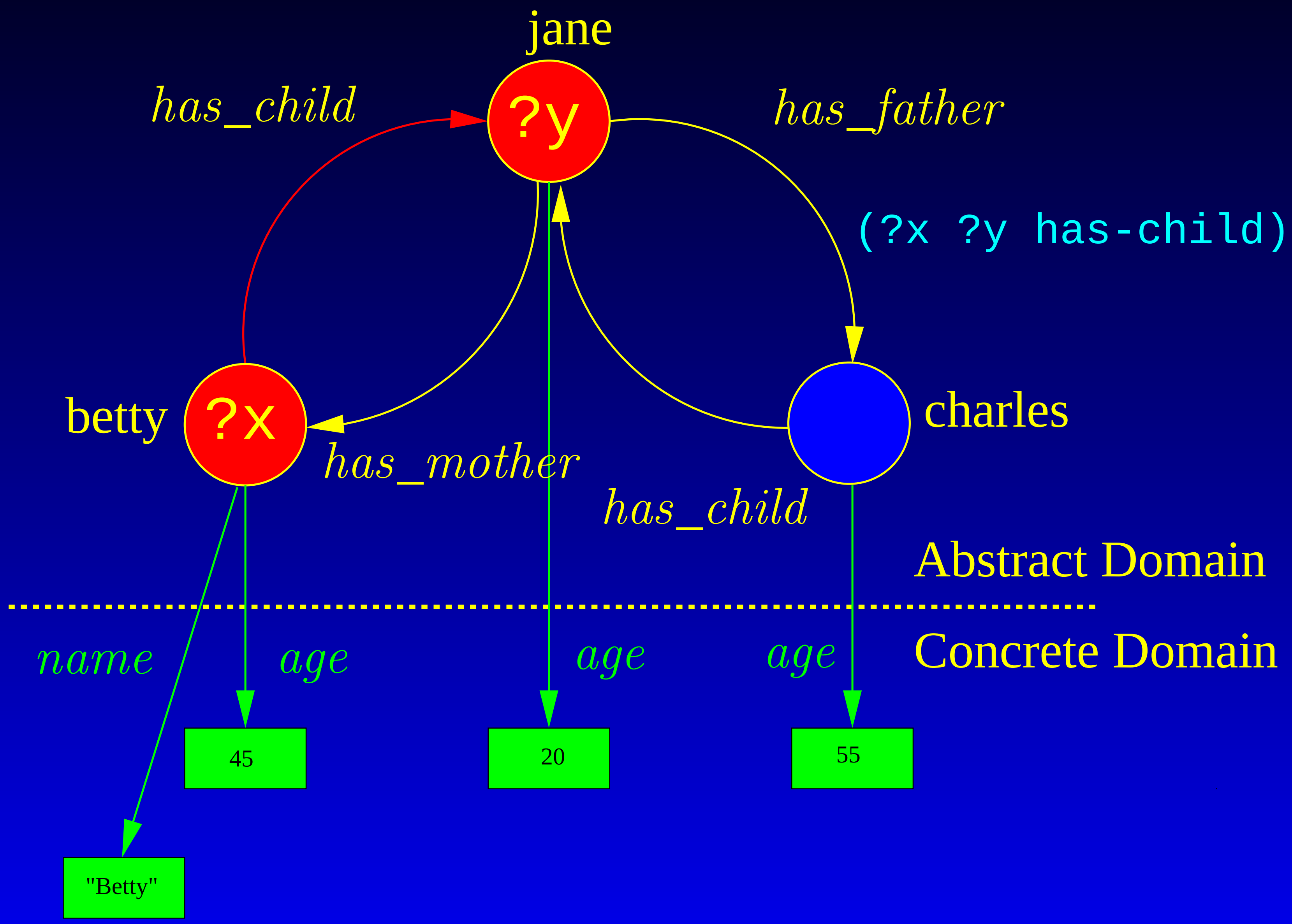
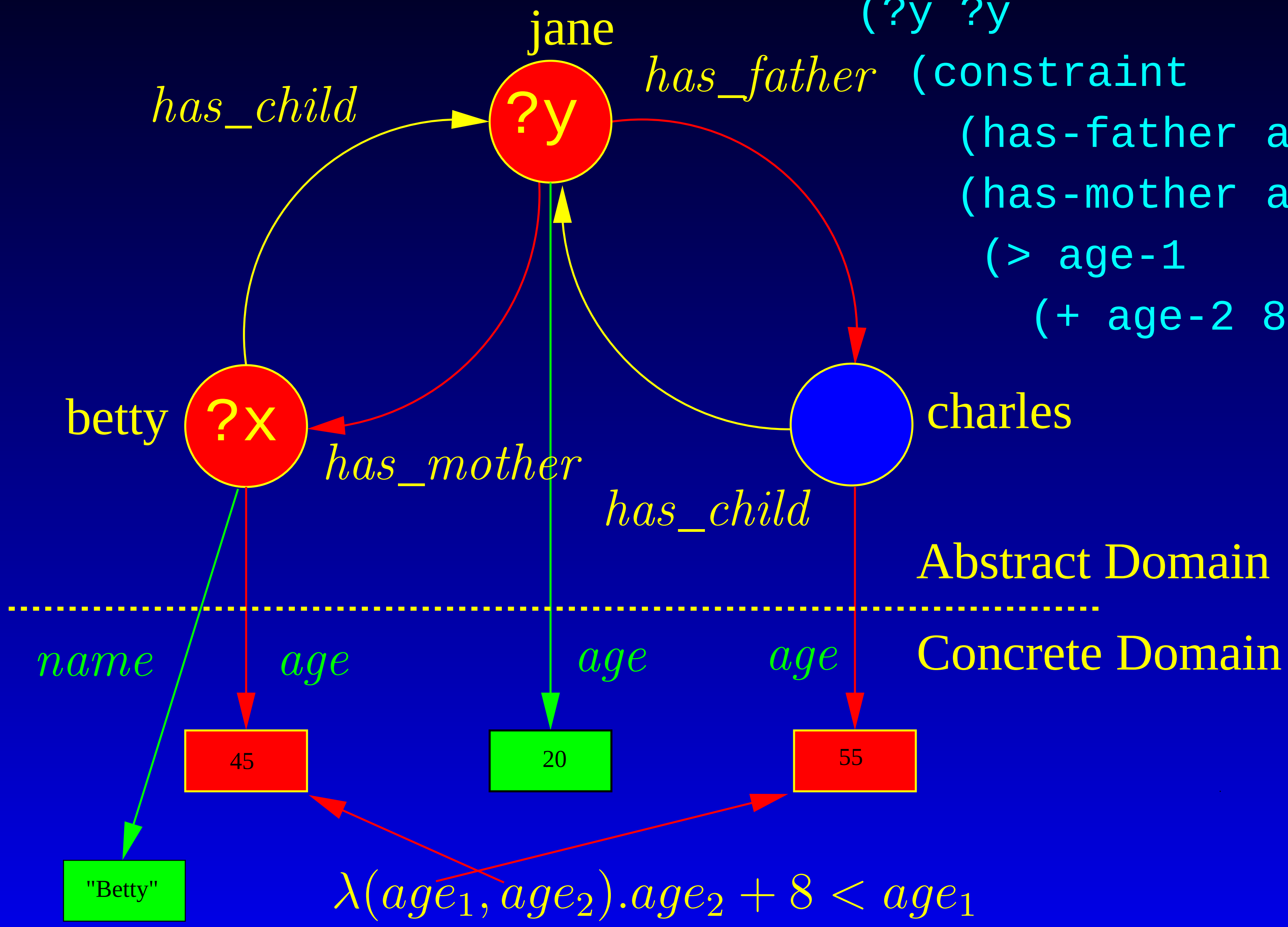


nRQL Language – Example



nRQL Language – Example

```
(?y ?y
 (constraint
   (has-father age)
   (has-mother age)
    (> age-1
      (+ age-2 8))))
```



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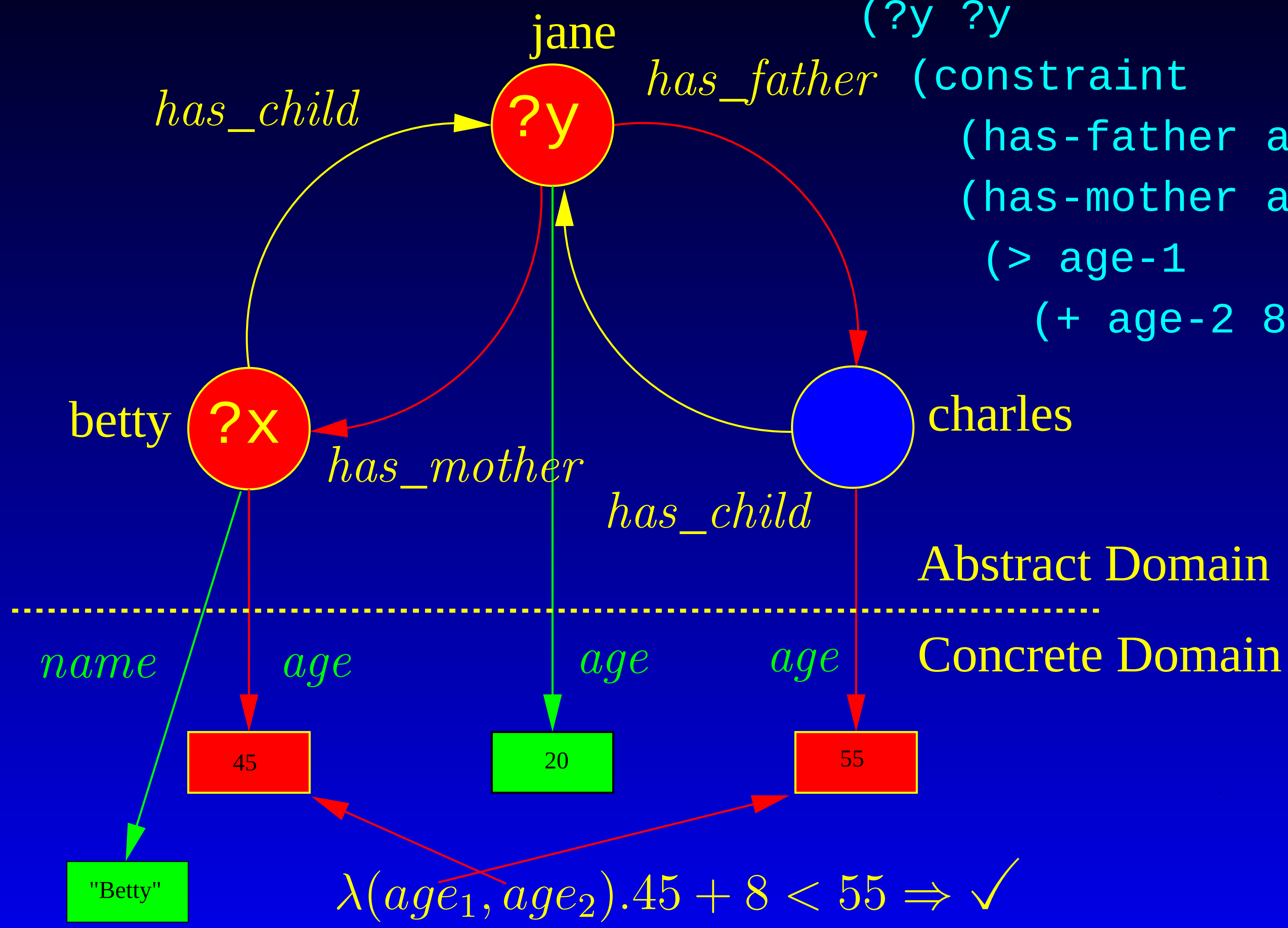
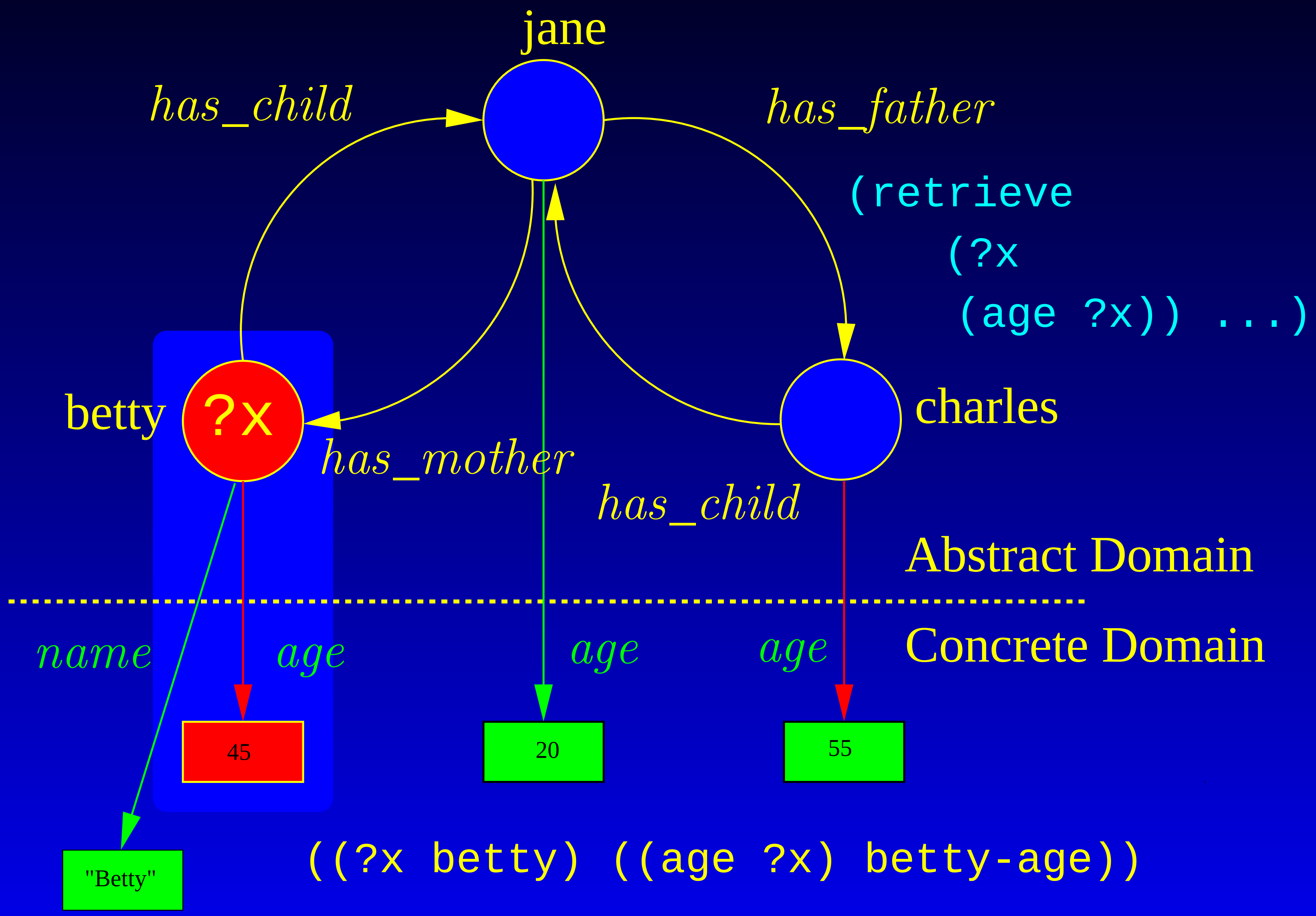


$\lambda(age_1, age_2).45 + 8 < 55 \Rightarrow \checkmark$

nRQL Language – Example



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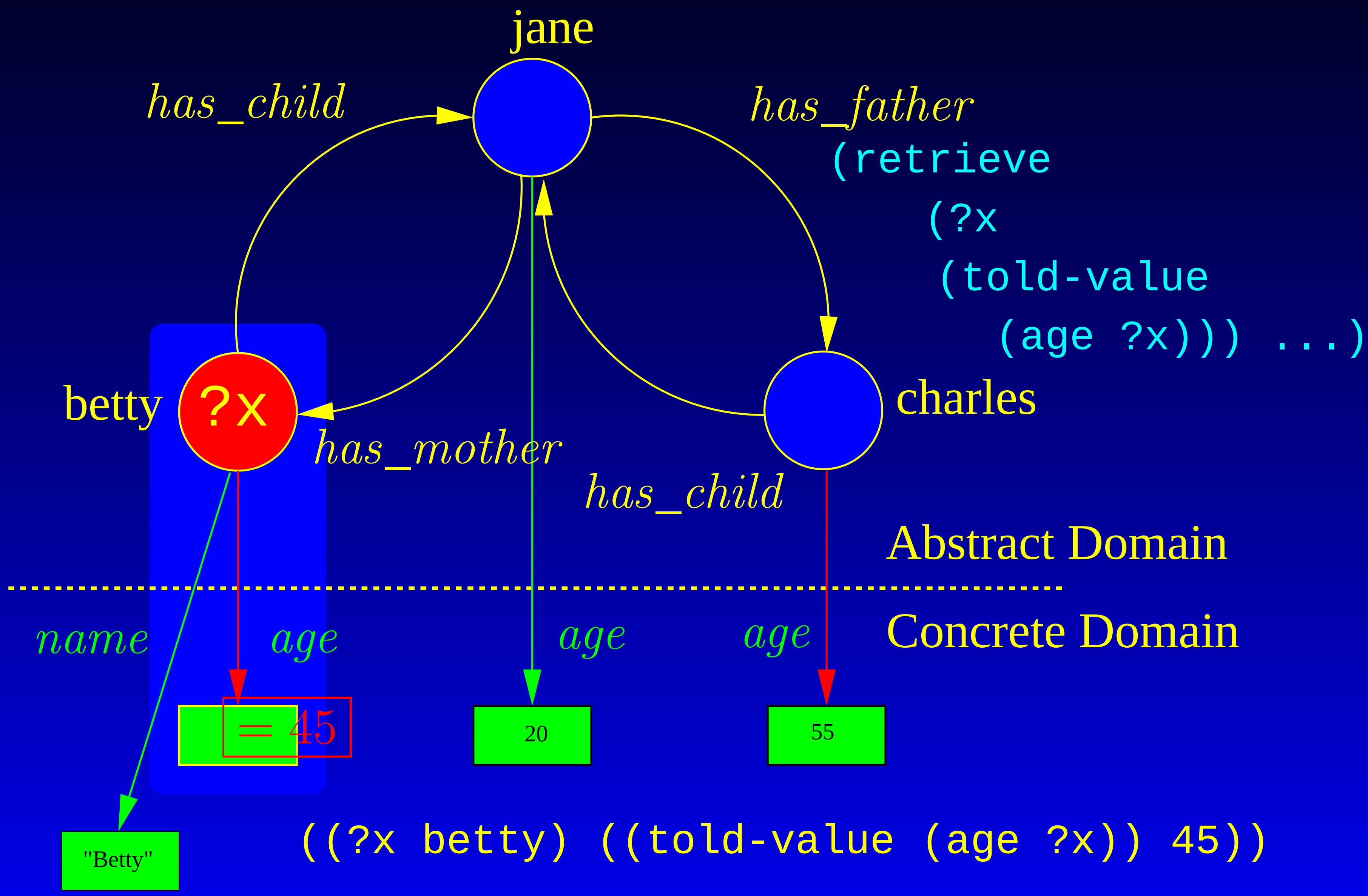

nRQL Language – Syntax

- Queries have a head and a body:
  `(retrieve <head> <body>)`
- Syntax for `<head>`

$$
\begin{array}{rcl}
head & := & (head\_entry^*) \\
head\_entry & := & object \mid head\_projection\_operator \\
object & := & variable \mid individual \\
variable & := & \text{a symbol beginning with “?”} \\
individual & := & \text{a symbol} \\
head\_projection\_operator & := &
\end{array}
$$

$$
\begin{array}{l}
(cd\_attribute\ object) \mid \\
(\texttt{told-value}\ (cd\_attribute\ object)) \mid \\
(\texttt{told-value}\ (datatype\_property\ object)) \mid \\
(\texttt{annotations}\ (annotation\_property\ object))
\end{array}
$$

nRQL Language – Syntax (2)

- Syntax for <body>

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$$\mathit{body} \quad := \quad \mathit{atom} \mid (\ \{\texttt{and} \mid \texttt{union}\}\ \mathit{body}^*) \mid (\ \{\ \texttt{neg} \mid \texttt{inv}\}\ \mathit{body}\ ) \mid$$
$$(\texttt{project-to}\ \ (\mathit{object}^*)\ \mathit{body})$$

nRQL Language – Syntax (2)

- Syntax for <body>

$$body \;:=\; atom \mid (\,\{\texttt{and} \mid \texttt{union}\}\; body^{*}) \mid (\,\{\,\texttt{neg} \mid \texttt{inv}\}\; body\,) \mid$$

$$(\texttt{project-to}\;\; (object^{*})\; body)$$

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$\quad (\texttt{project-to}\; (object^*)\; body)$

$atom \;:=\; (object\; concept\_expr) \mid (object\; object\; role\_expr) \mid$
$\quad (object\; object\; (\texttt{constraint}\; chain\; chain\; constraint\_expr)) \mid$
$\quad (\texttt{same-as}\; variable\; individual)$

$chain \;:=\; (role\_expr^*\; cd\_attribute)$

Example concept query atoms

- `(?x woman)`
- `(betty woman)`

nRQL Language – Syntax (2)

- Syntax for <body>

$$body \;:=\; atom \mid (\{\texttt{and} \mid \texttt{union}\}\ body^*) \mid (\{\texttt{neg} \mid \texttt{inv}\}\ body) \mid$$
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$$(\texttt{same-as}\ \ variable\ individual)$$
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Example role query atoms

- `(?x ?y has-child)`
- `(betty ?child-of-betty has-child)`
- `(?x ?y (inv has-child))`
- `(?x ?y (not has-father))`

nRQL Language – Syntax (2)

- Syntax for <body>

$$body \;:=\; atom \mid (\{\texttt{and} \mid \texttt{union}\}\ body^*) \mid (\{\texttt{neg} \mid \texttt{inv}\}\ body) \mid$$
$$(\texttt{project-to}\ (object^*)\ body)$$

$$atom \;:=\; (object\ concept\_expr) \mid (object\ object\ role\_expr) \mid$$
$$(object\ object\ (\texttt{constraint}\ \ chain\ chain\ constraint\_expr)) \mid$$
$$(\texttt{same-as}\ \ variable\ individual)$$
$$chain \;:=\; (role\_expr^*\ cd\_attribute)$$

Example constraint query atoms

- ```
  (?x ?y (constraint (has-mother age)
                     (has-father age) <))
  ```
- ```
  (?x ?y (constraint (has-brother age)
                     (age)
                     (= age-1 (+ 8 age-2))))
  ```

nRQL Language – Syntax (2)

- Syntax for `<body>`

$$body \quad := \quad atom \mid (\ \{\texttt{and} \mid \texttt{union}\}\ body^*) \mid (\ \{\ \texttt{neg} \mid \texttt{inv}\}\ body\ ) \mid$$
$$(\texttt{project-to}\ \ (object^*)\ body)$$

$$atom \quad := \quad (object\ concept\_expr) \mid (object\ object\ role\_expr) \mid$$
$$(object\ object\ (\texttt{constraint}\ \ chain\ chain\ constraint\_expr)) \mid$$
$$(\texttt{same-as}\ \ variable\ individual)$$
$$chain \quad := \quad (role\_expr^*\ cd\_attribute)$$

Example `same-as` query atoms

- `(same-as ?x betty)`

nRQL Language – Syntax (2)

- Syntax for `<body>`

$$
\begin{aligned}
\mathit{body} &:= \mathit{atom} \mid (\{\texttt{and} \mid \texttt{union}\}\ \mathit{body}^*) \mid (\{\texttt{neg} \mid \texttt{inv}\}\ \mathit{body}) \mid \\
&\quad (\texttt{project-to}\ (\mathit{object}^*)\ \mathit{body})
\end{aligned}
$$

$$
\begin{aligned}
\mathit{atom} &:= (\mathit{object}\ \mathit{concept\_expr}) \mid (\mathit{object}\ \mathit{object}\ \mathit{role\_expr}) \mid \\
&\quad (\mathit{object}\ \mathit{object}\ (\texttt{constraint}\ \mathit{chain}\ \mathit{chain}\ \mathit{constraint\_expr})) \mid \\
&\quad (\texttt{same-as}\ \mathit{variable}\ \mathit{individual}) \\
\mathit{chain} &:= (\mathit{role\_expr}^*\ \mathit{cd\_attribute})
\end{aligned}
$$

---

concept_expr	:=	a RacerPro concept, with some extensions for OWL
role_expr	:=	a RacerPro role | (`inv` *role_expr*) | (`not` *role_e*
constraint_expr	:=	a RacerPro concrete predicate
cd_attribute	:=	a RacerPro concrete domain attribute
datatype_property	:=	a RacerPro role used as OWL datatype property
annotation_property	:=	a RacerPro role used as OWL annotation property

nRQL Variables

- Variables can only be bound to ABox individuals, not to concrete domain objects or even concrete domain values
- nRQL offers two kinds of variables: `?x`, `$?x`
  - `?x` prohibits binding to individuals which are already bound by other variables, e.g. `?y` (mapping must be injective)
  - "UNA" for variables

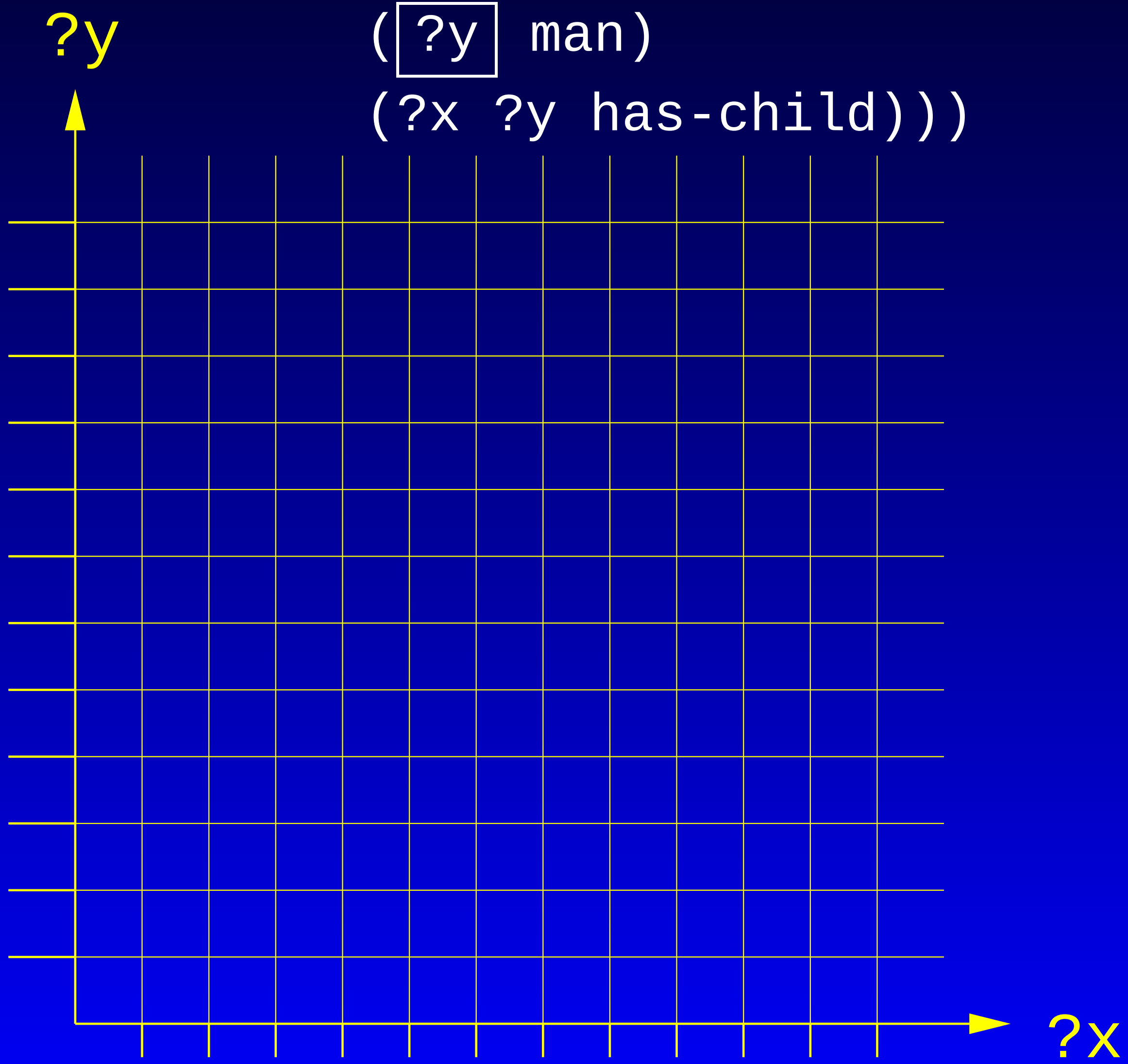
```
? (retrieve (?x ?y) (and (?x man) (?y man)))
> NIL
? (retrieve ($?x $?y) (and ($?x man)
                           ($?y man)))
> ((($?X CHARLES) ($?Y CHARLES)))
```

Complex nRQL Queries

- Compound nRQL queries are defined inductively
  - Every query atom `ai` is a body.
  - If `a1 ...an` are query bodies, then the following expressions are also bodies
    - `(neg ai)`
    - `(inv ai)`
    - `(and a1 ...an)`
    - `(union a1 ...an)`
    - `(project-to (objects-in-ai) ai)`
- Each variable creates a new axis in an n-dimensional tuple space
- A projection (specified by `<head>`) is made before that set is returned.

Illustration of Semantics

```
(retrieve (?x)
          (and (?x woman)
               (?y man)
               (?x ?y has-child)))
```



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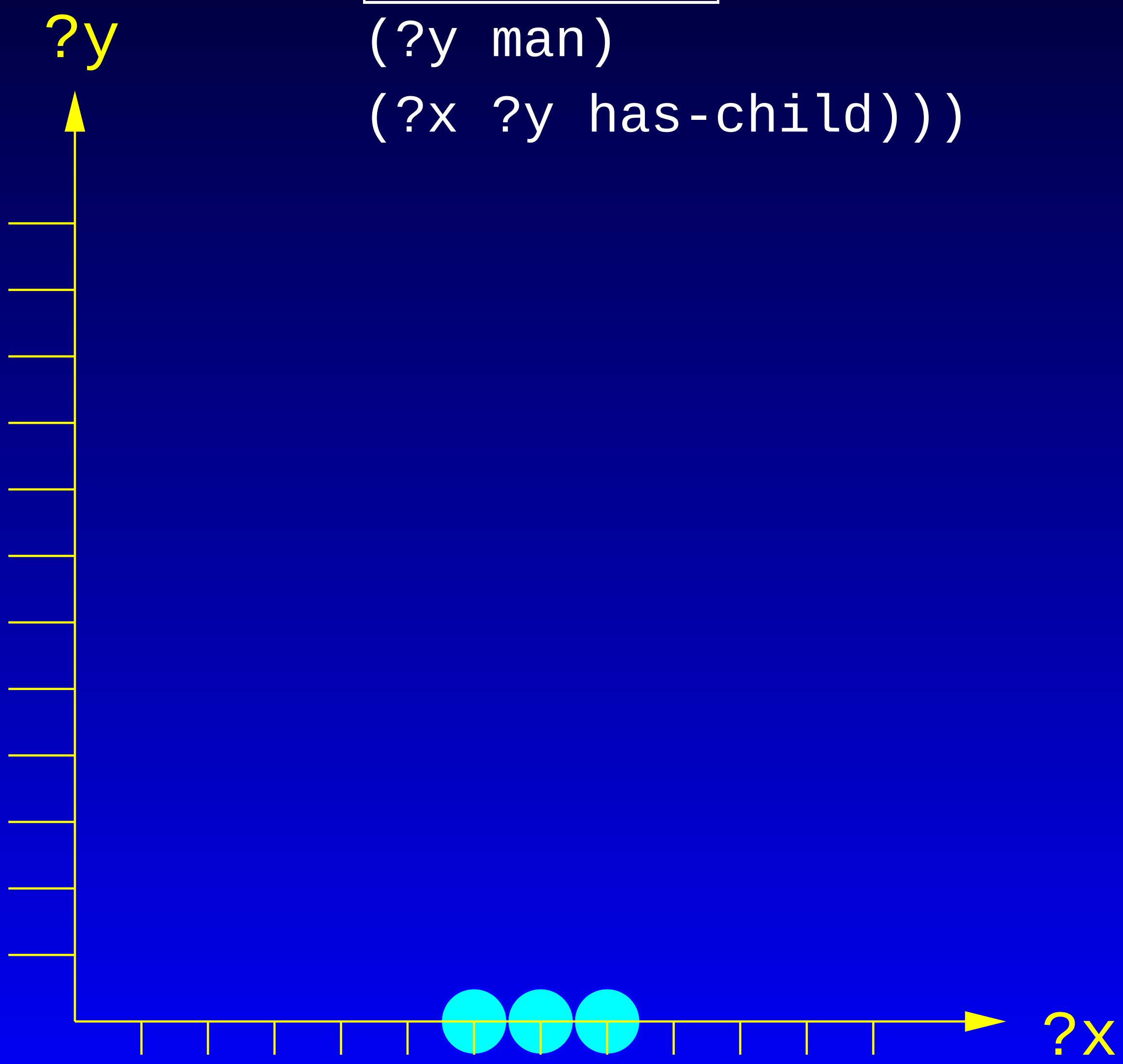

Illustration of Semantics

```
(retrieve (?x)
          (and (and (?x woman) (?y top))
               (?y man)
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```

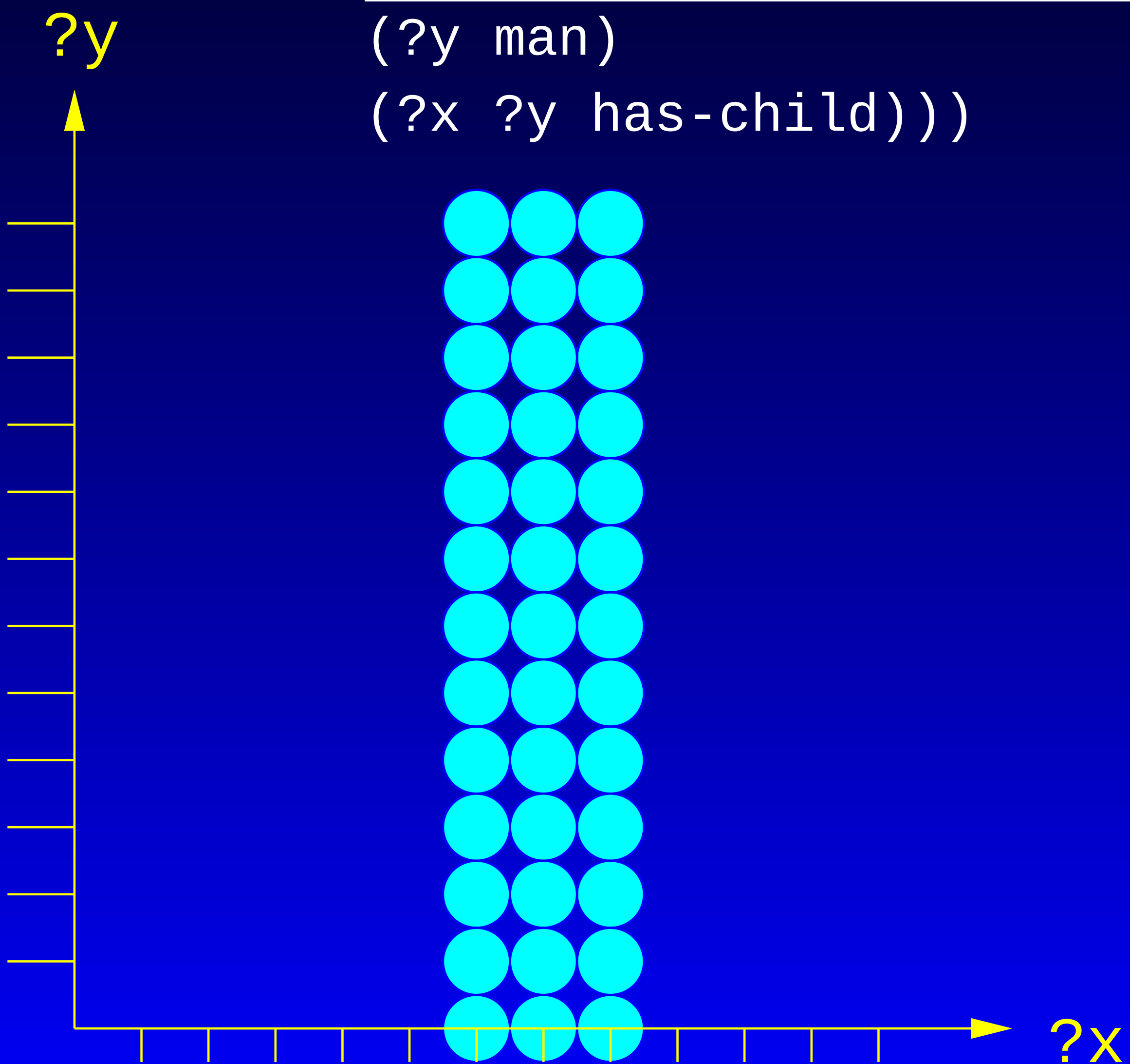

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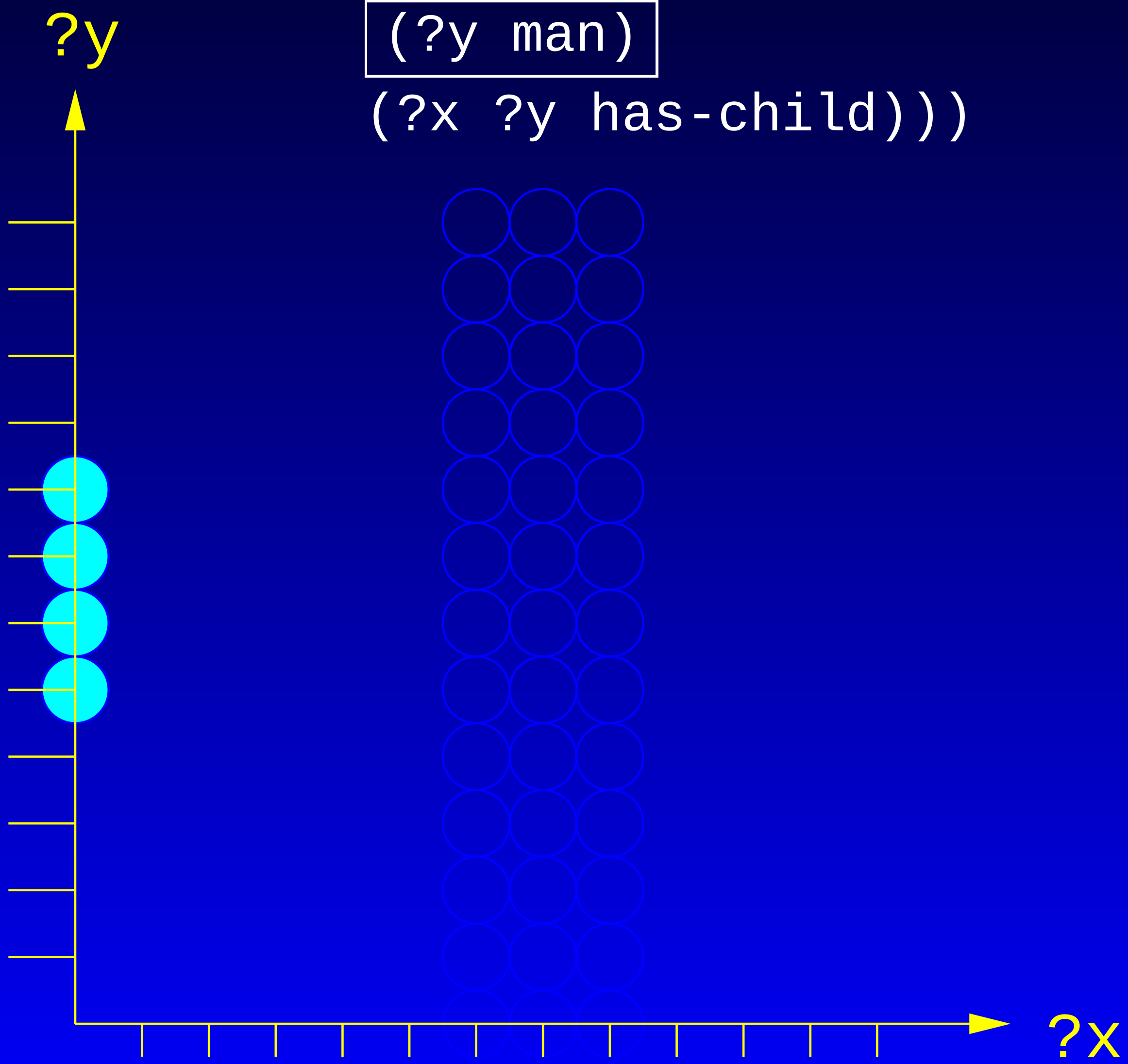

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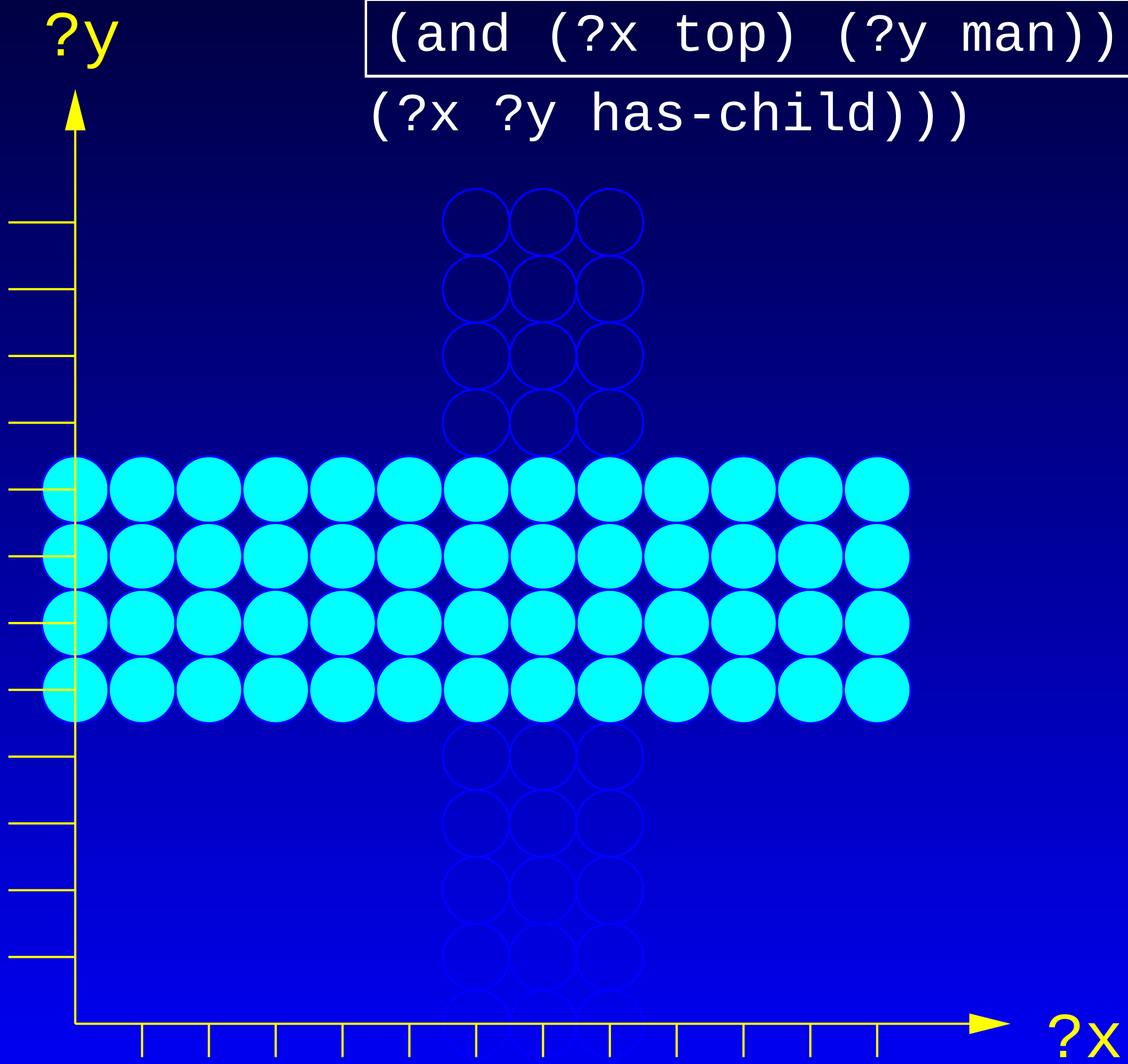

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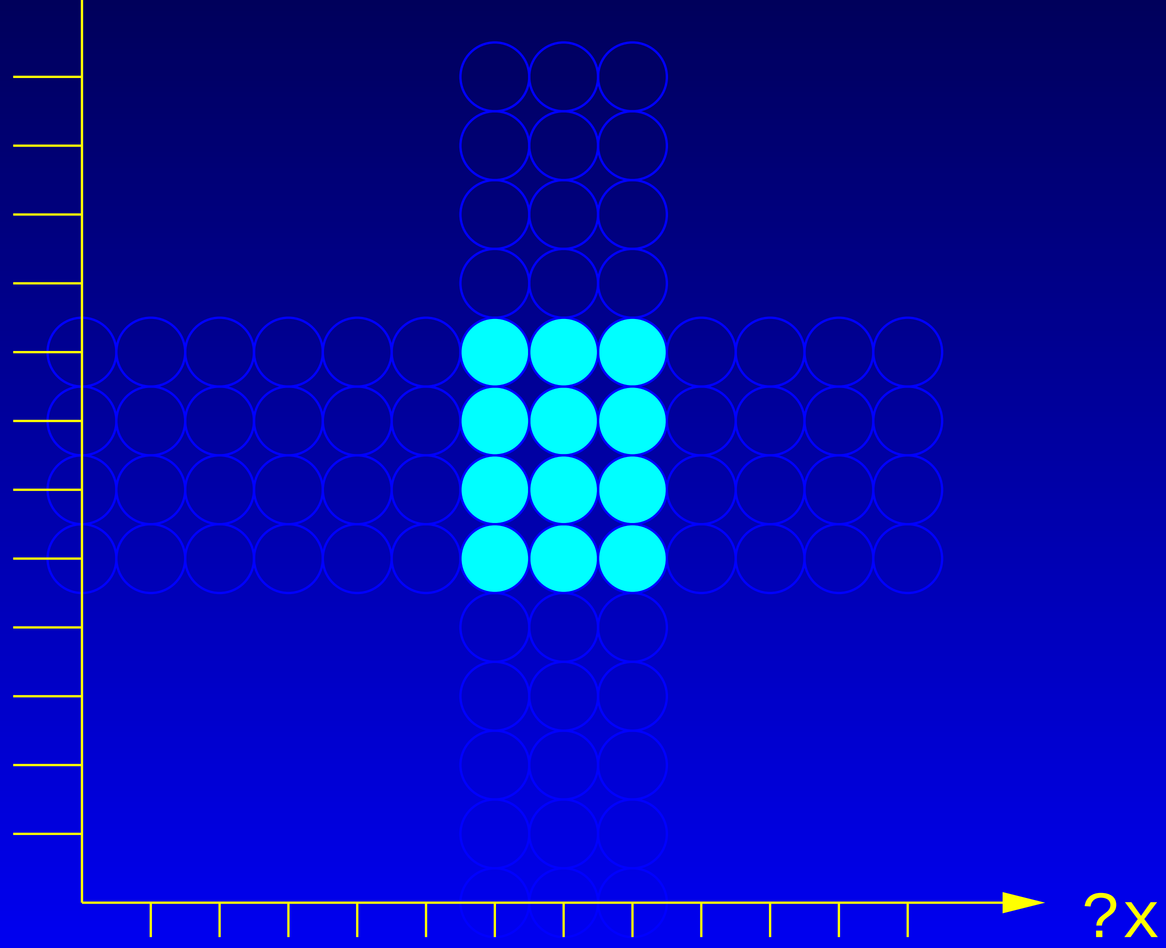

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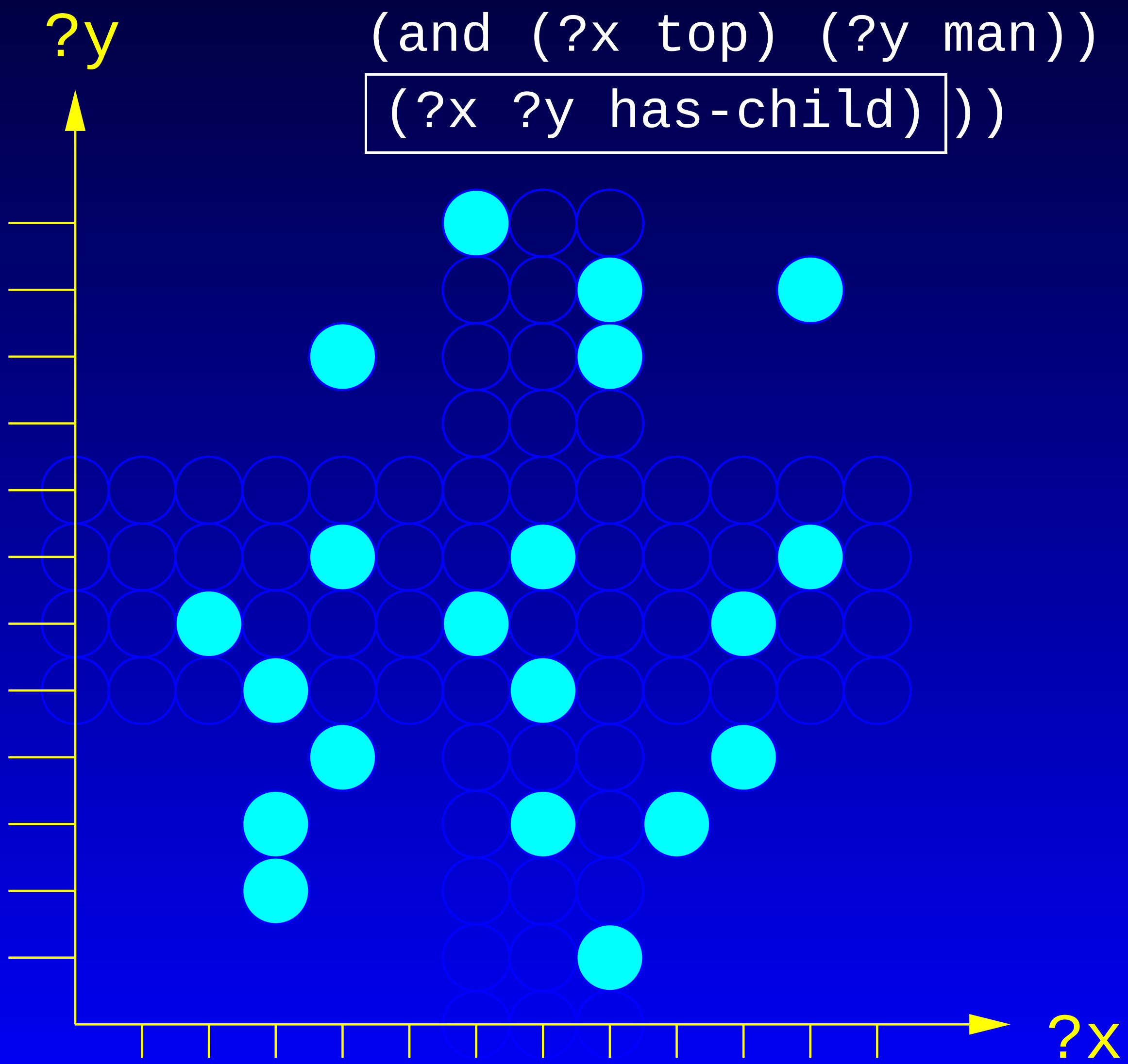

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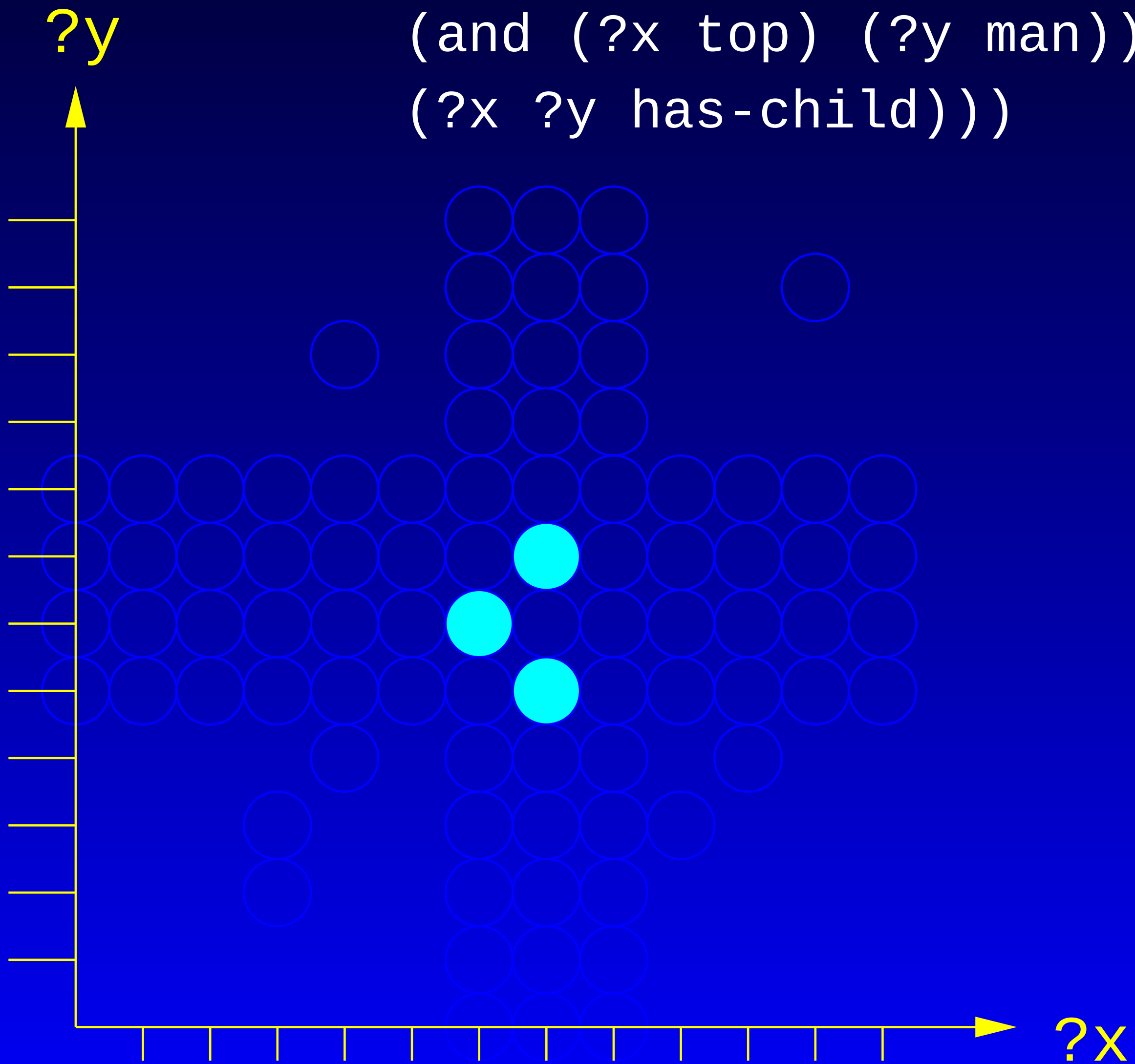

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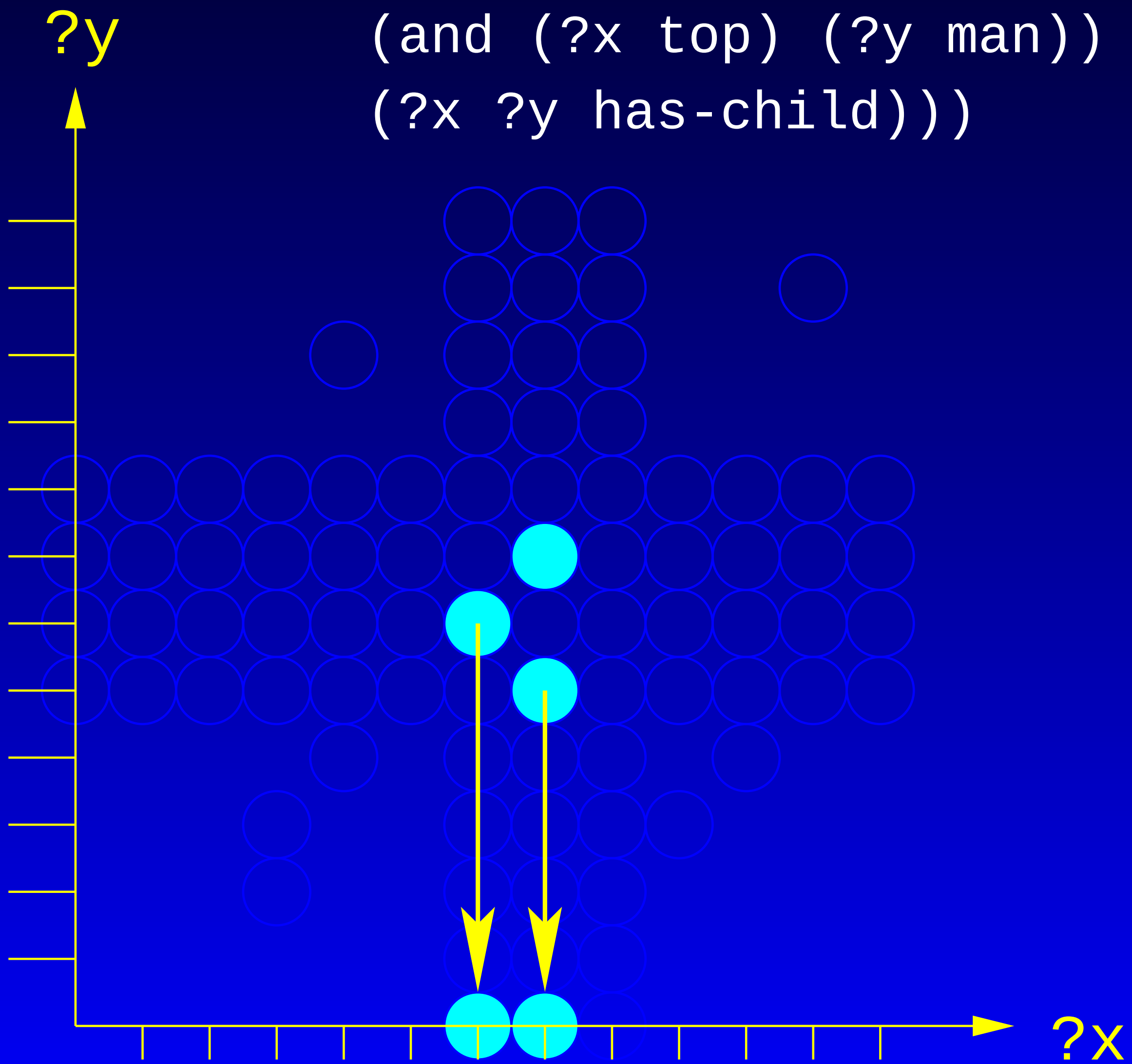

Negation in nRQL

- nRQL offers NAF with `neg`
- Semantics: simple set complement
  - well-defined for concept and role query atoms
  - well-defined for compound queries (DeMorgan etc.)
  - some “tricks” are needed for `same-as` and `constraint` query atoms
- Classical DL-like negation
  - obviously, in concept query atoms
  - but also in role query atoms `(?x ?y (not has-father))`

Illustration of neg

```
(retrieve (?x)
          (and (?x woman)
               (?y man)
               (?x ?y has-child)))
```

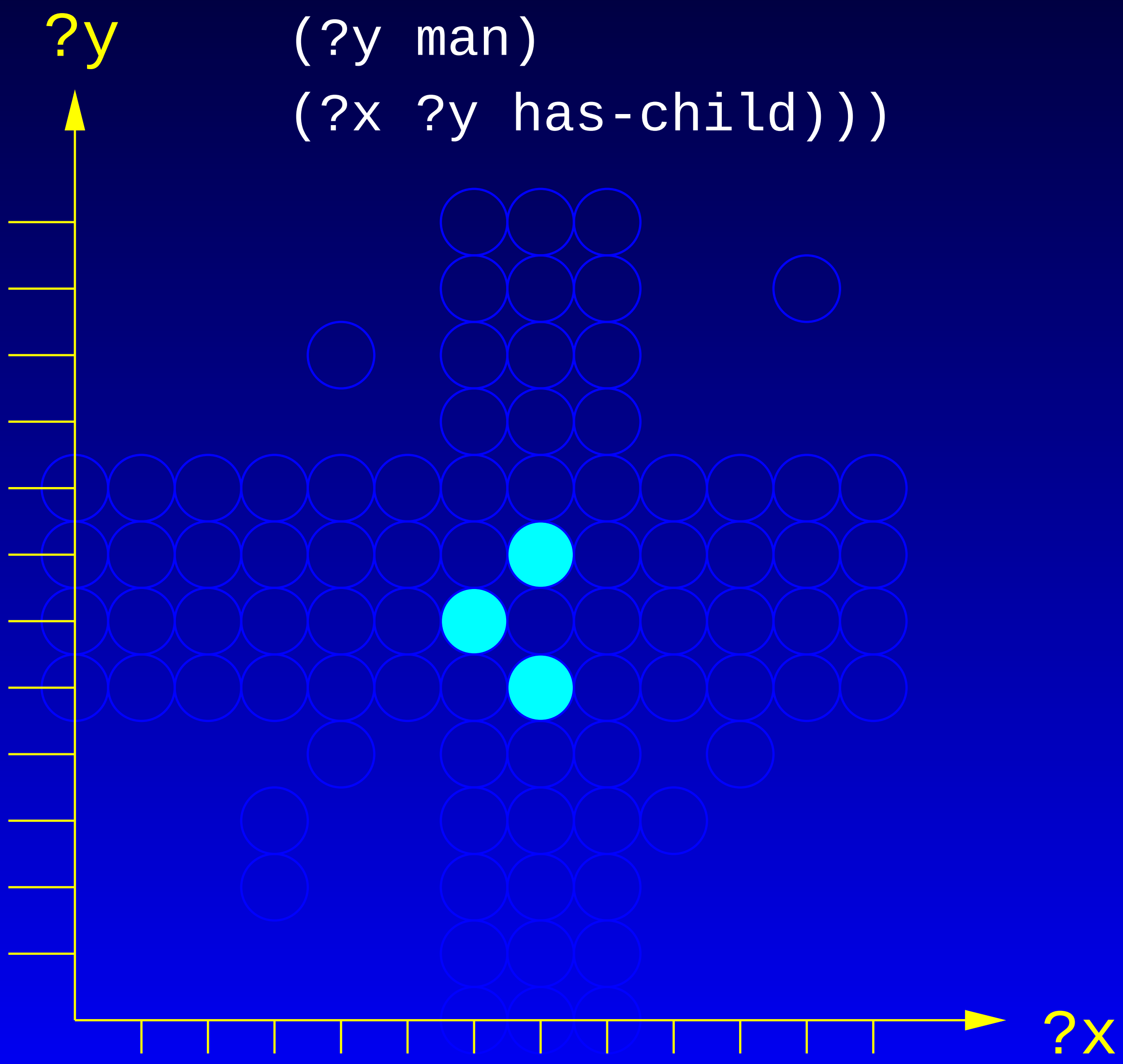

Illustration of neg

```
(retrieve (?x)
          (neg (and (?x woman)
                    (?y man)
                    (?x ?y has-child))))
```

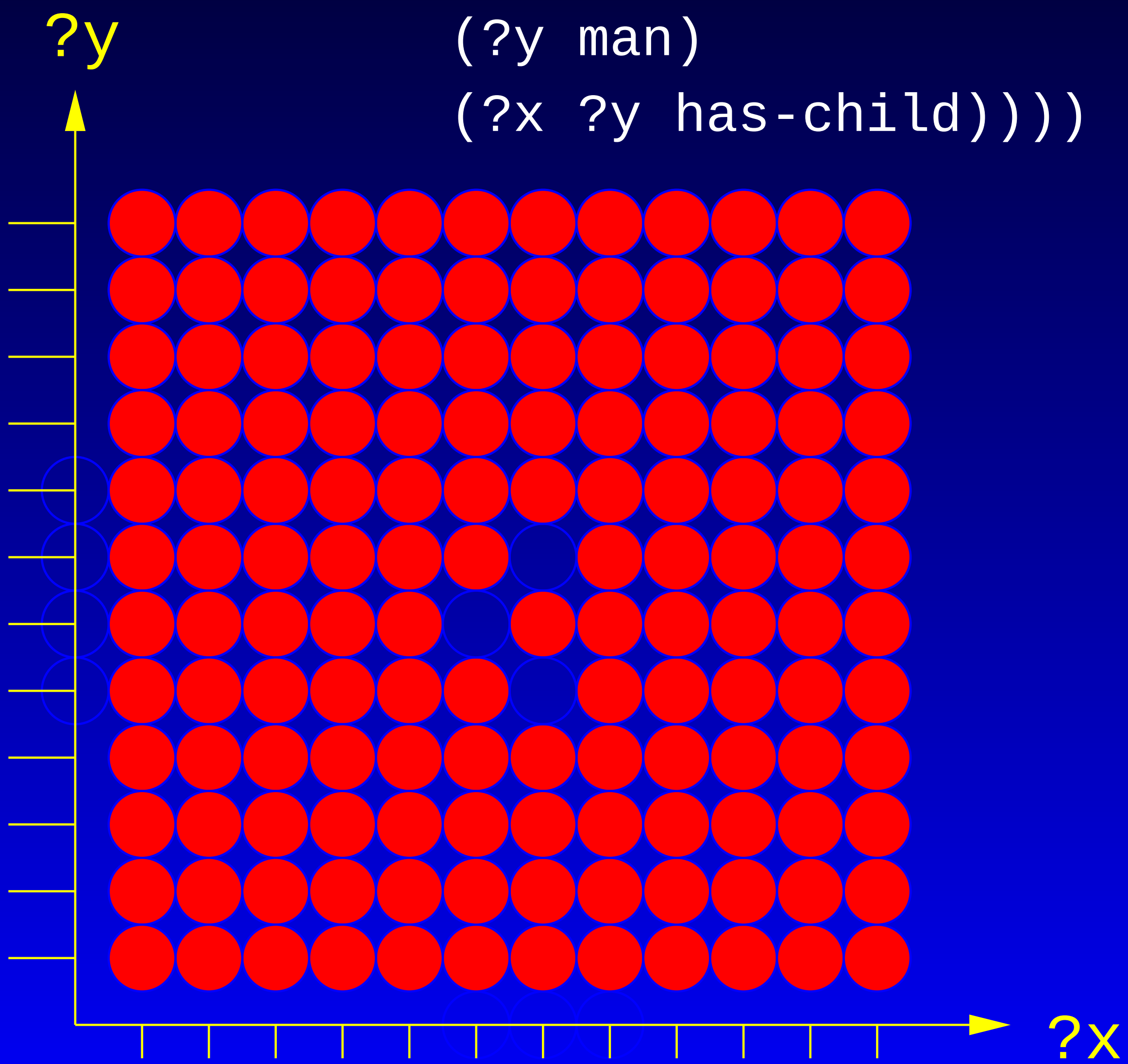

Illustration of `neg`

```
(retrieve (?x)
          (union (neg (?x woman))
                 (neg (?y man))
                 (neg (?x ?y has-child))))
```

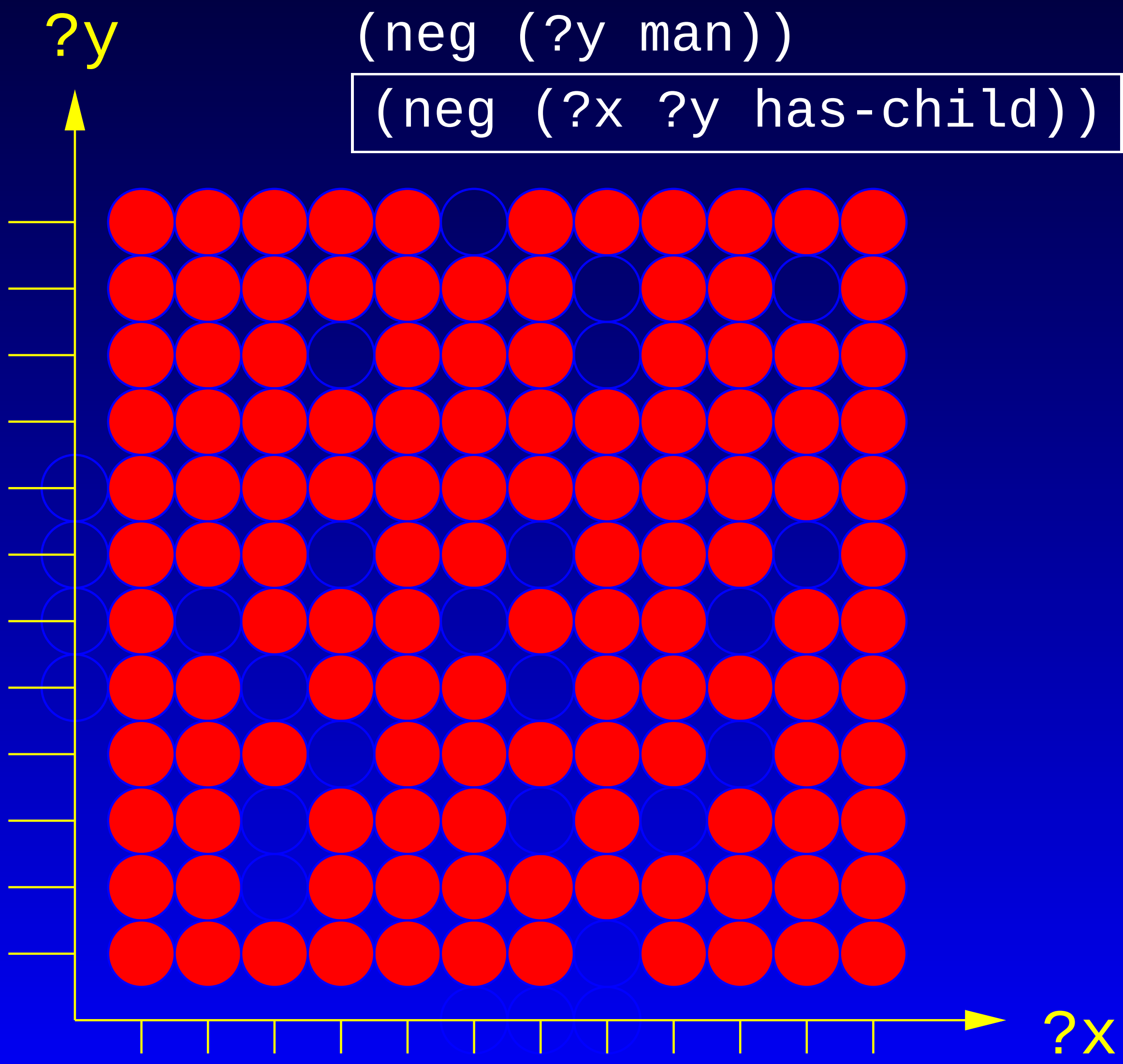

Illustration of neg

```
(retrieve (?x)
          (union (neg (?x woman))
                 (neg (?y man))
                 (neg (?x ?y has-child))))
```

?y

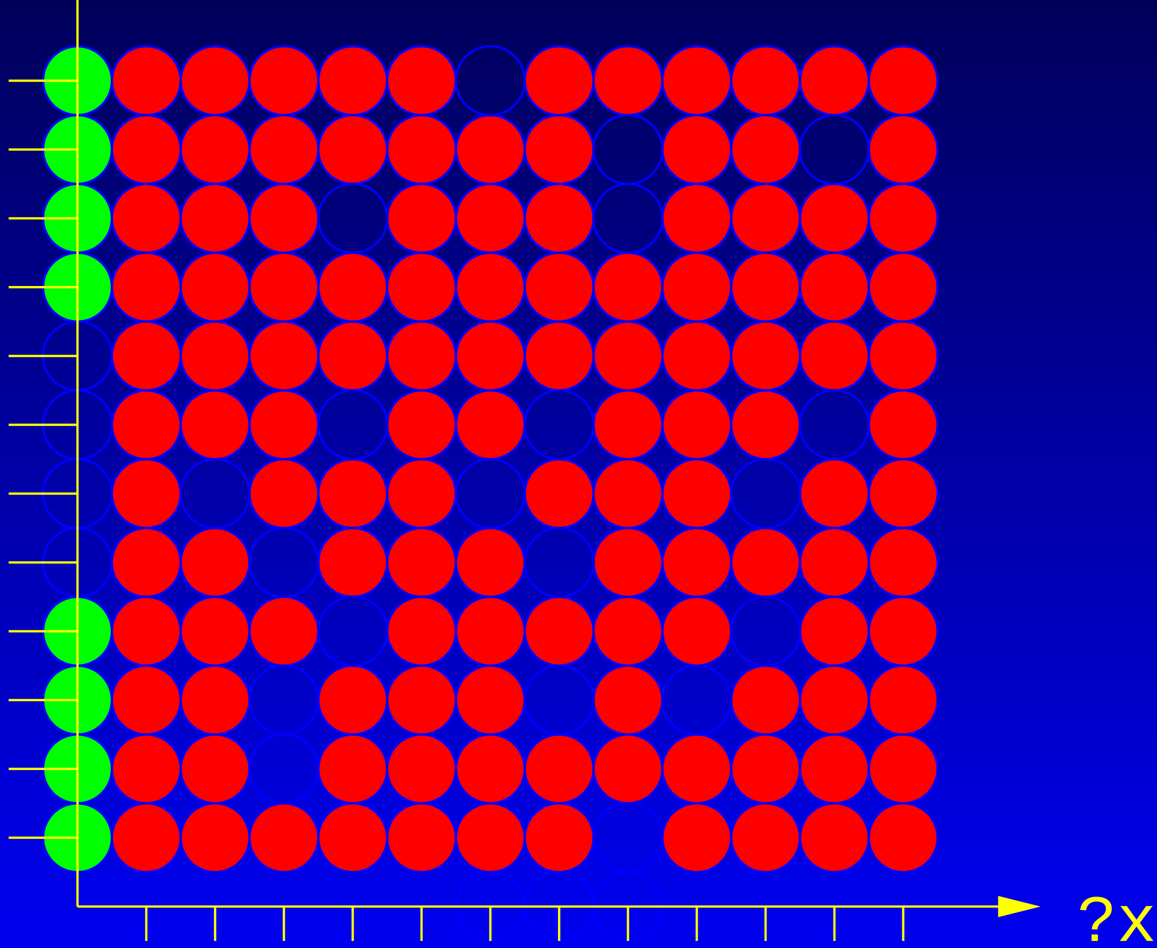

Illustration of `neg`

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(retrieve (?x)
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                 (and (?x top) (neg (?y man)))
                 (neg (?x ?y has-child))))
```

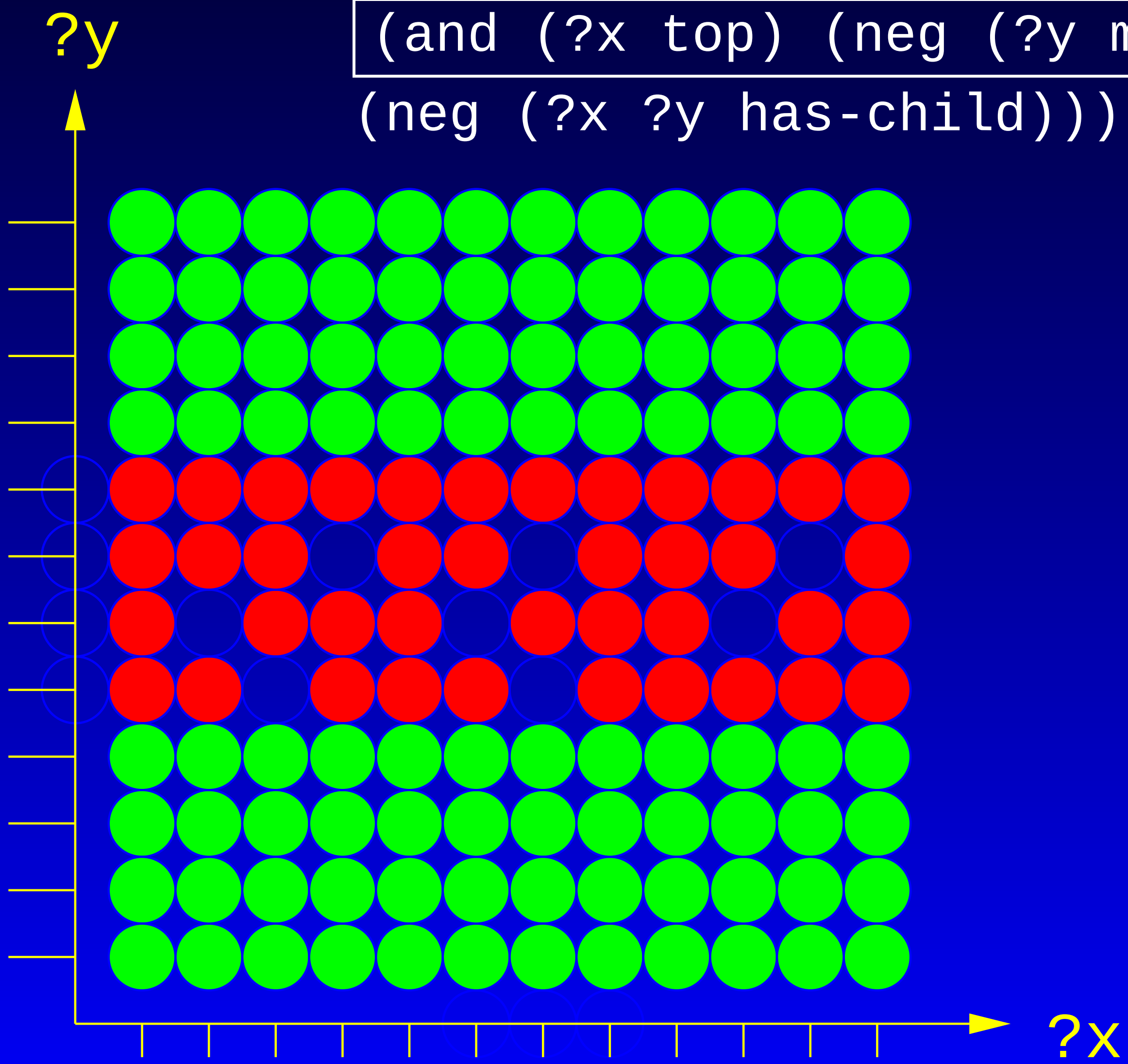

Illustration of neg

```
(retrieve (?x)
          (union (?x woman)
                 (and (?x top) (neg (?y man)))
                 (neg (?x ?y has-child))))
```

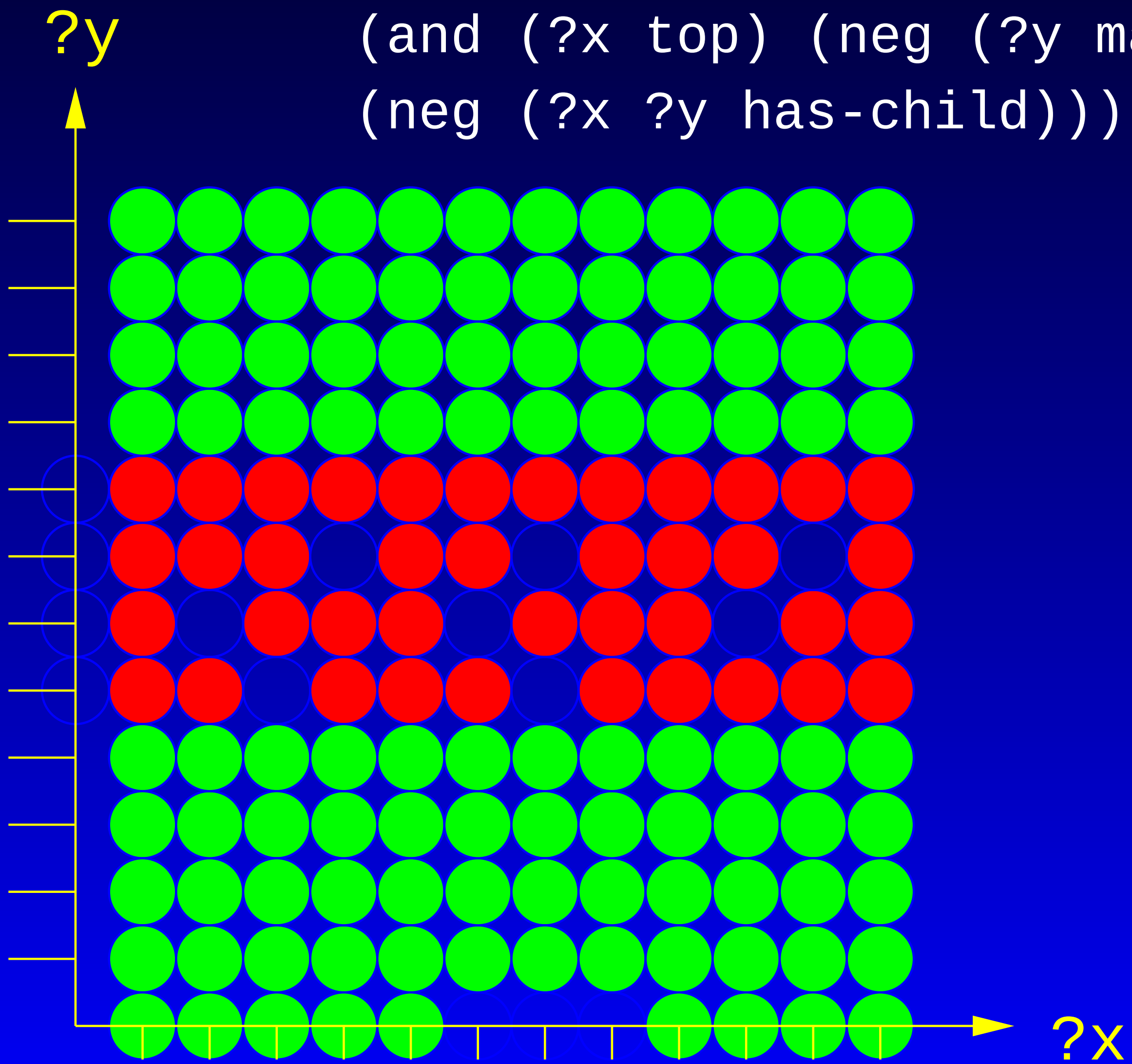

Illustration of `neg`

```
(retrieve (?x)
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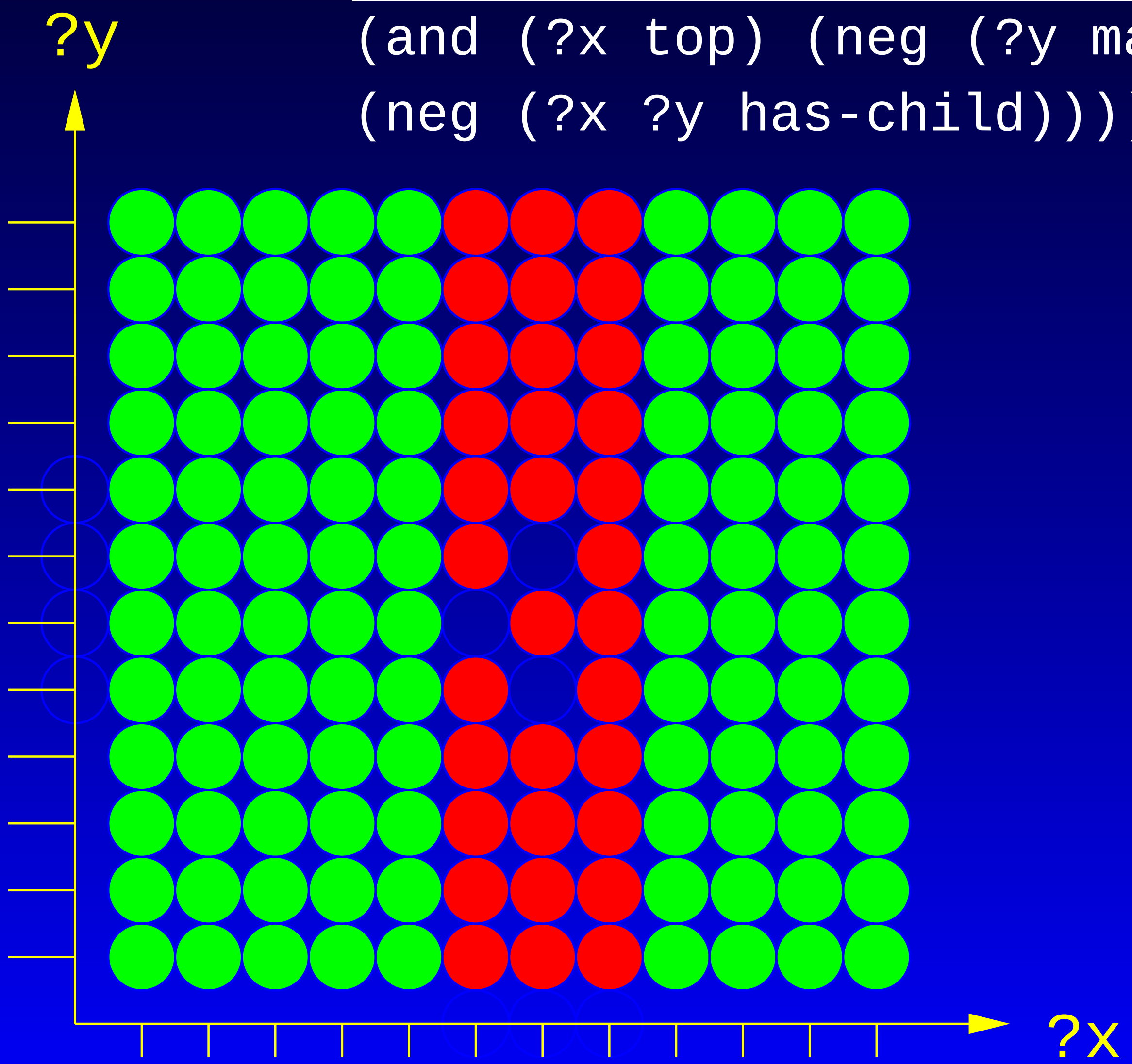
```



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```

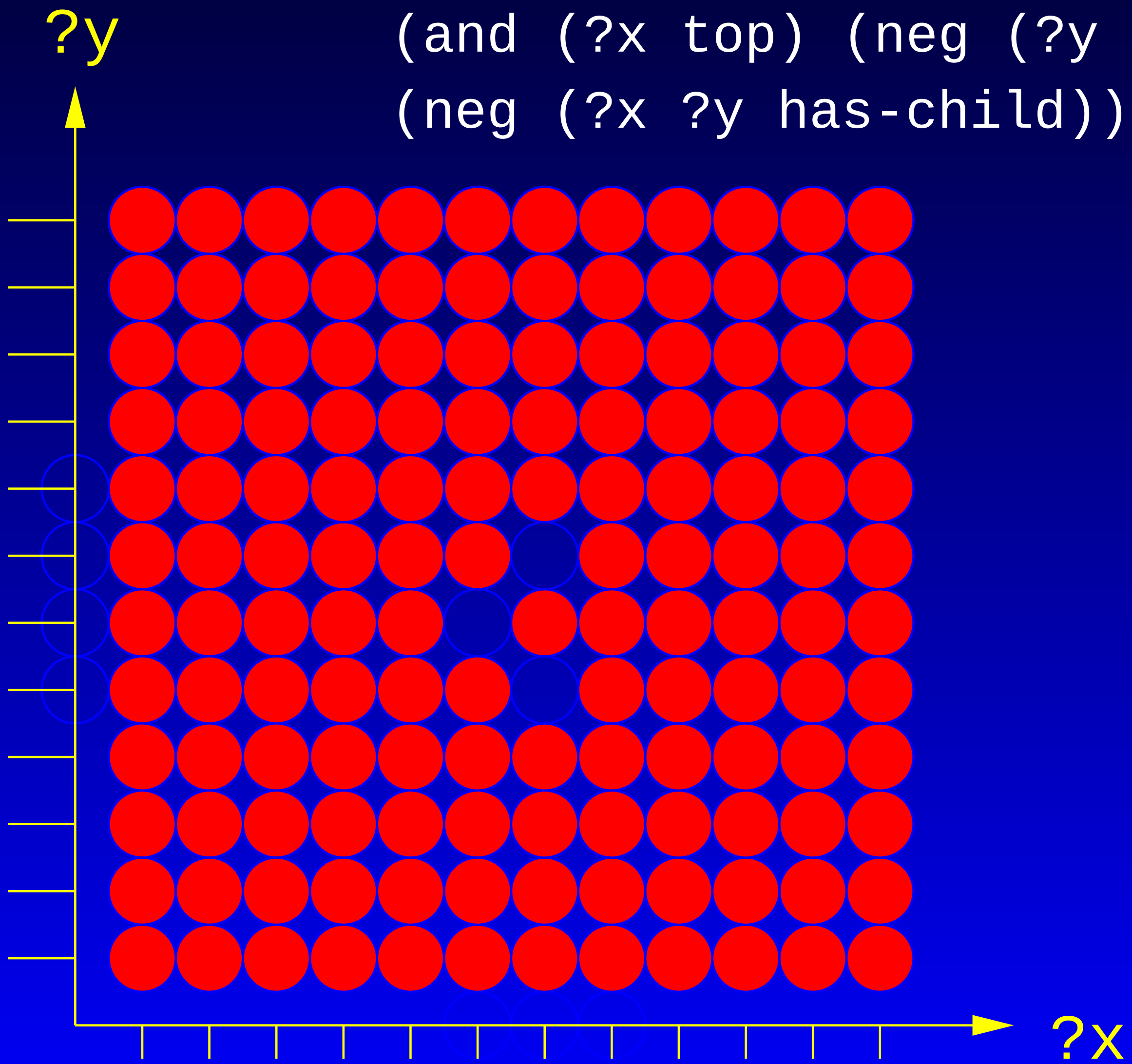

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          (and (?x woman)
               (?y man)
               (?x ?y has-child)))
```

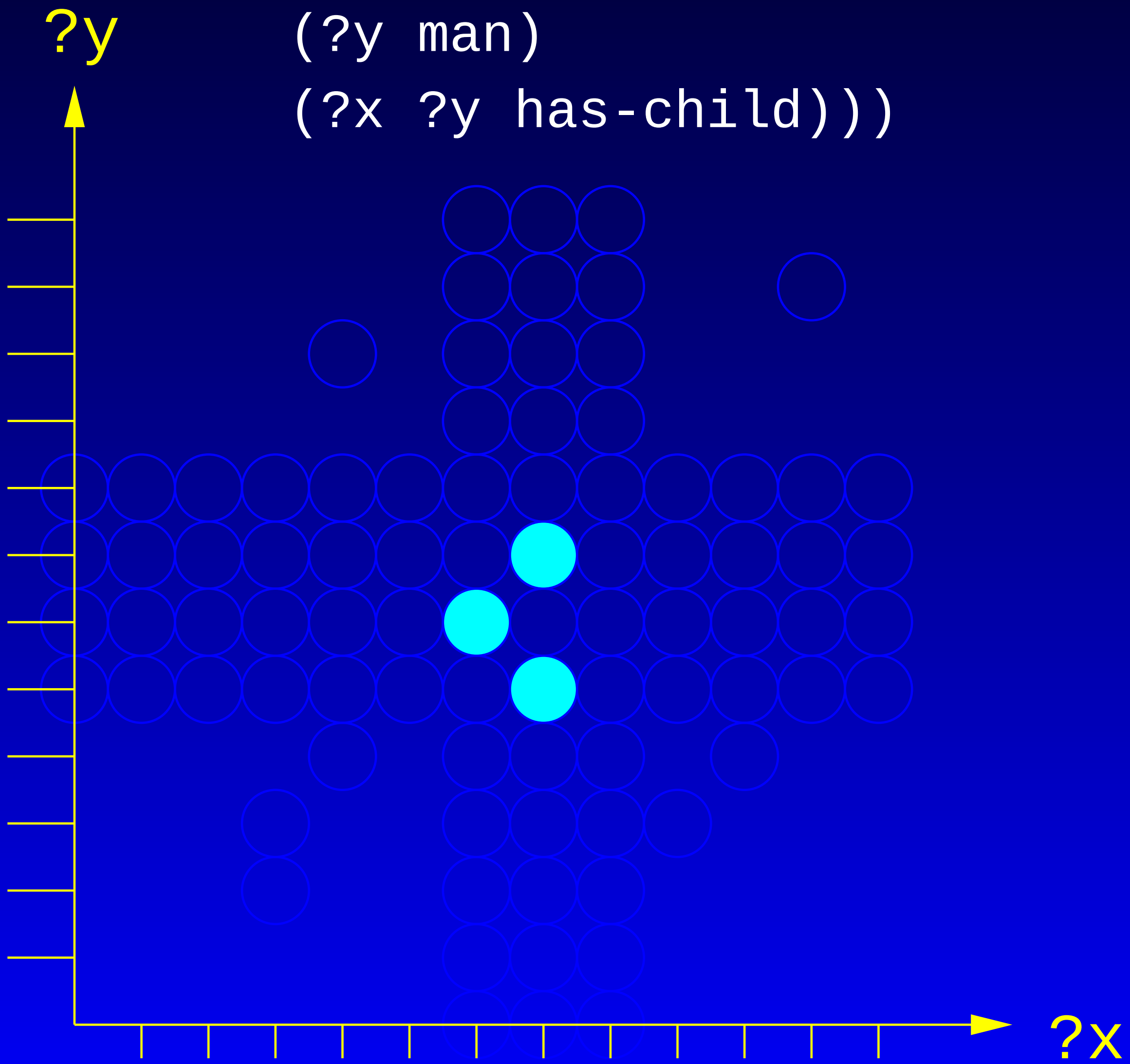
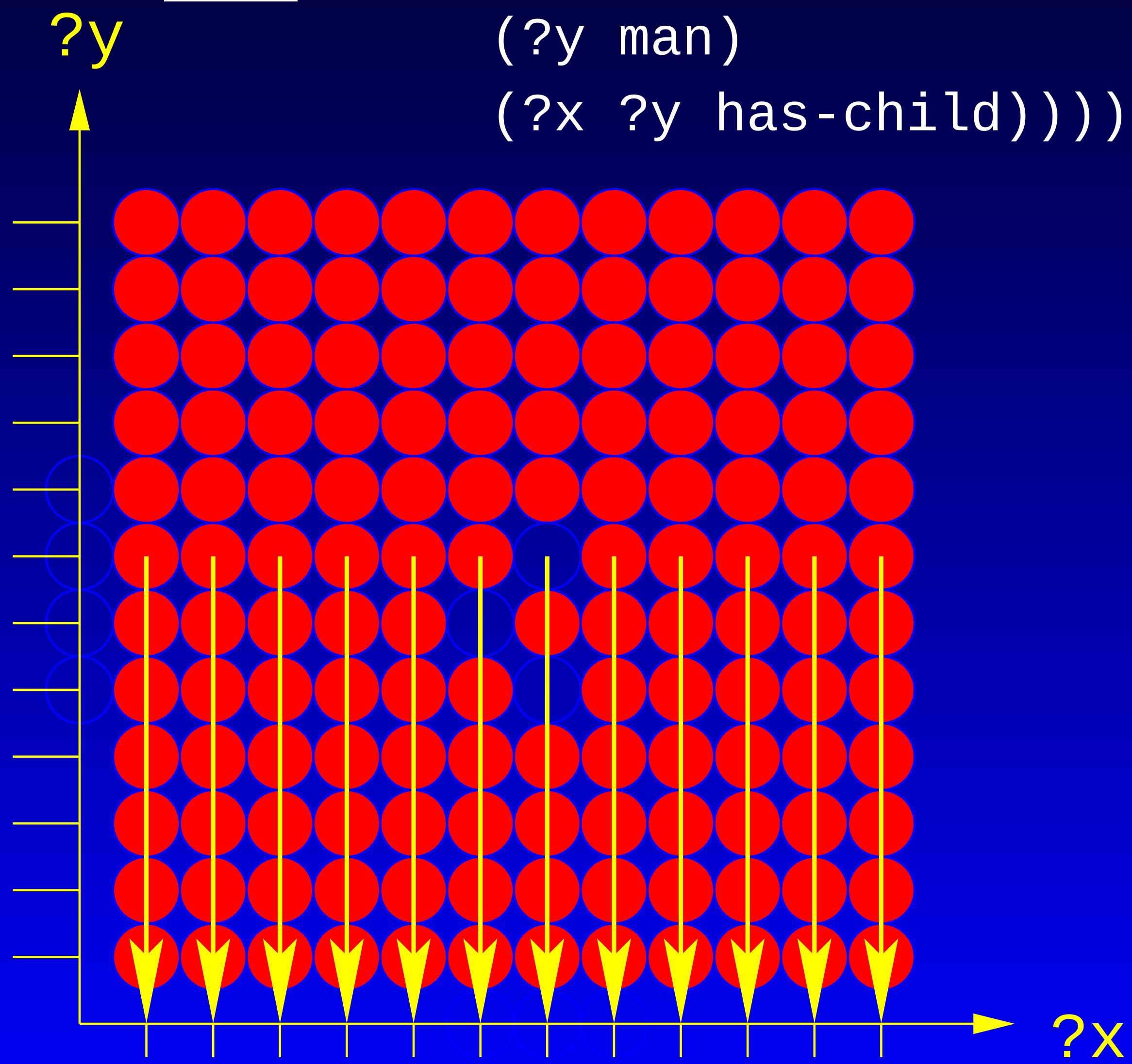


Illustration of neg

```
(retrieve (?x)
          ( neg  (and (?x woman)
                      (?y man)
                      (?x ?y has-child))))
```



TUHH Technische Universität Hamburg-Harburg

Illustration of `neg`

```
(retrieve (?x)
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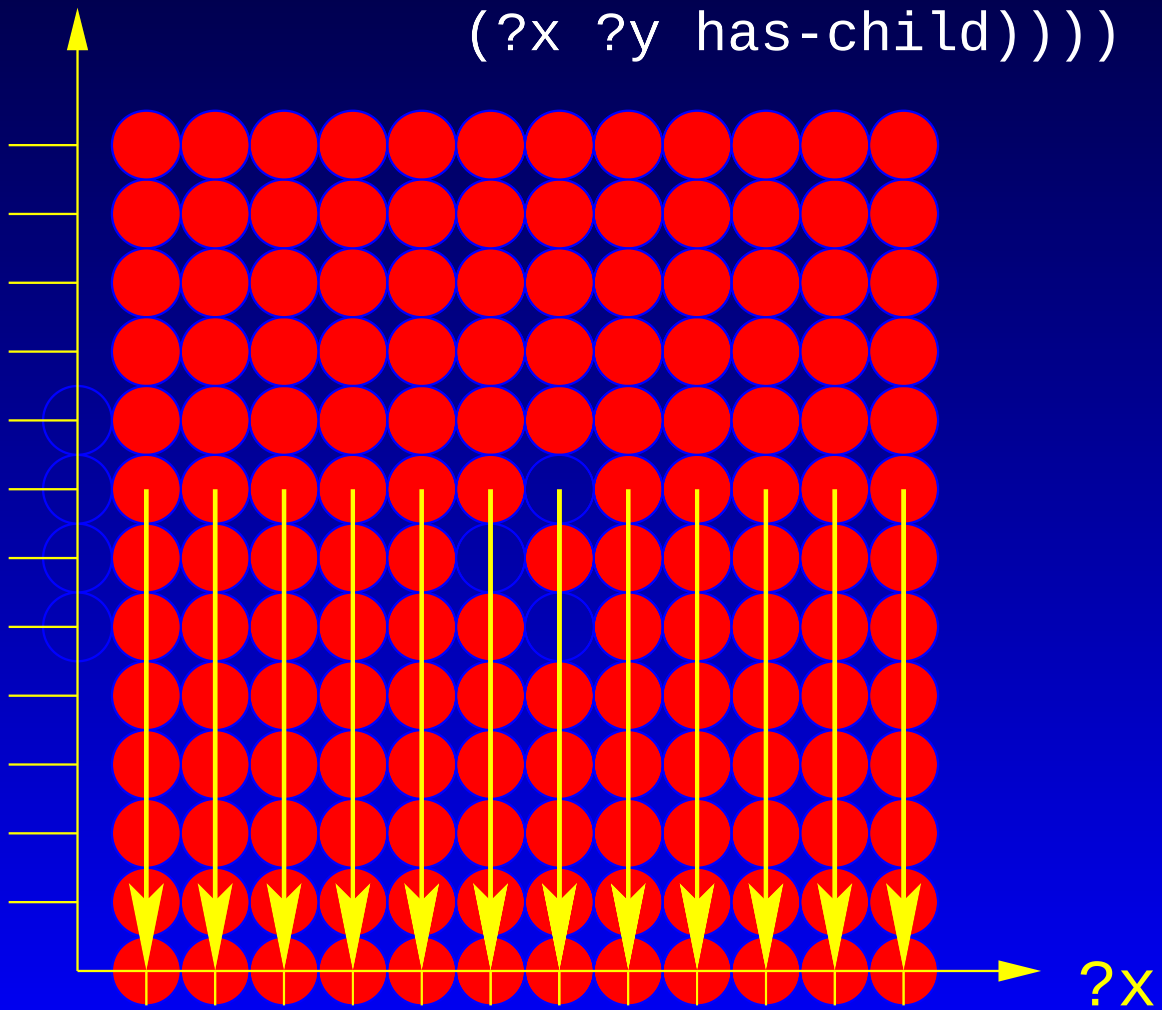
```



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```
(retrieve (?x)
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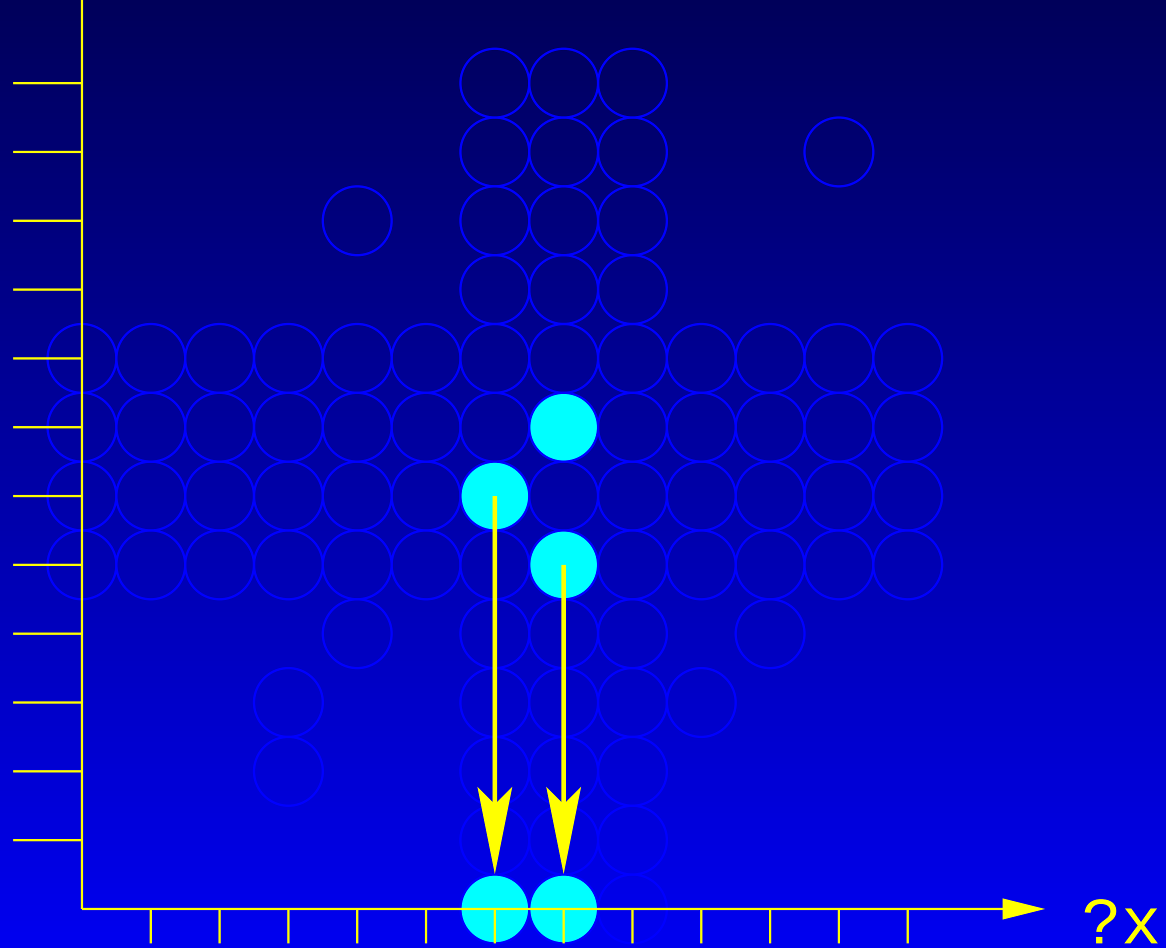


Illustration of neg

```
(NEG (retrieve (?x)
               (and (?x woman)
                    (?y man)
                    (?x ?y has-child))))
```

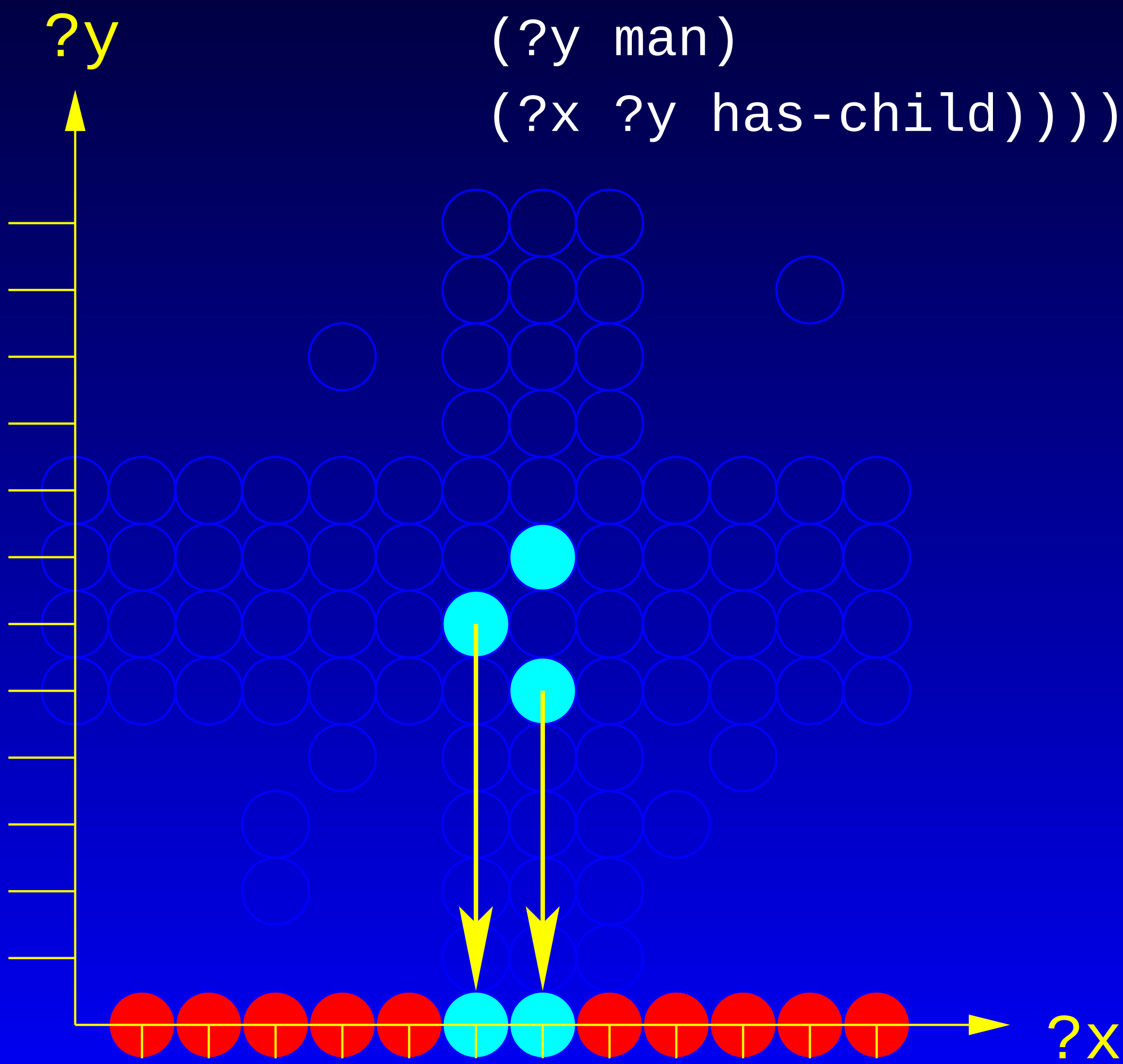
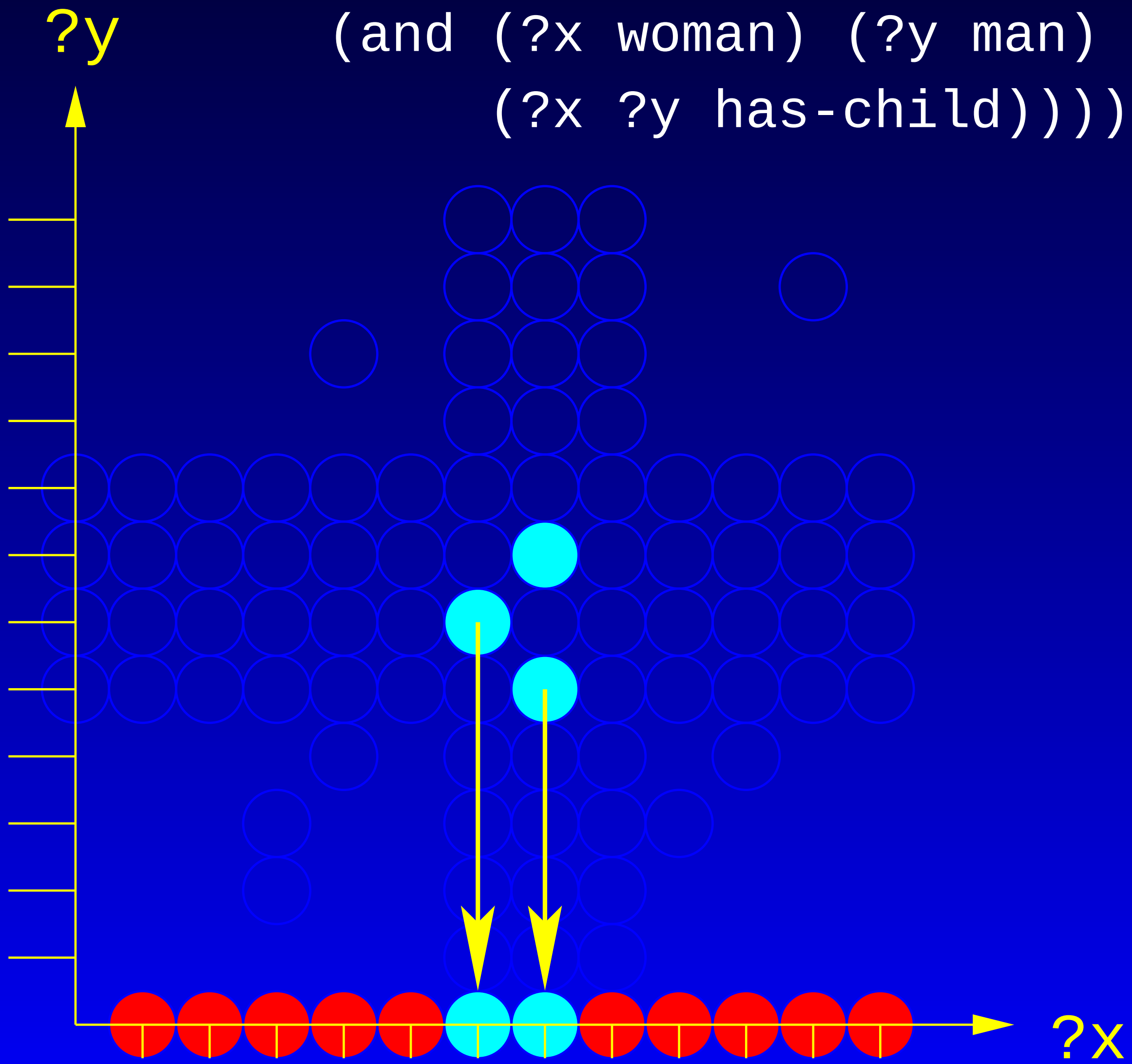


Illustration of neg

```
(retrieve (?x)
          (neg (project-to (?x)
                   (and (?x woman) (?y man)
                        (?x ?y has-child))))
```



Queries with Individuals

```
? (retrieve (betty)
            (betty woman))
```

```
> ((($?BETTY BETTY)))
```

- Explanation: query is rewritten into

```
(AND (SAME-AS $?BETTY BETTY)
     ($?BETTY WOMAN))
```

- `$?BETTY` is a variable that does not obey the unique name assumption for variables
- `(SAME-AS $?BETTY BETTY)` enforces binding of `$?BETTY` to `BETTY`

Semantic Consequences

- “NAF” for atoms with individuals can be tricky

```
(retrieve (betty)
          (neg (betty woman)))
=
(retrieve ($?betty)
    (neg (and ($?betty woman)
              (same-as $?betty betty))))
=
(retrieve ($?betty)
    (UNION (neg ($?betty woman))
           (neg (same-as $?betty betty))))
```

- one must define the semantics in such a way if the orthogonality of the language shall be preserved!

The Projection Operator

- We can retrieve all woman having children with

```
(retrieve (?x)
  (and (?x woman) (?x ?y has-child)))
```

- How can we retrieve woman which have <u>no</u> (known) children?

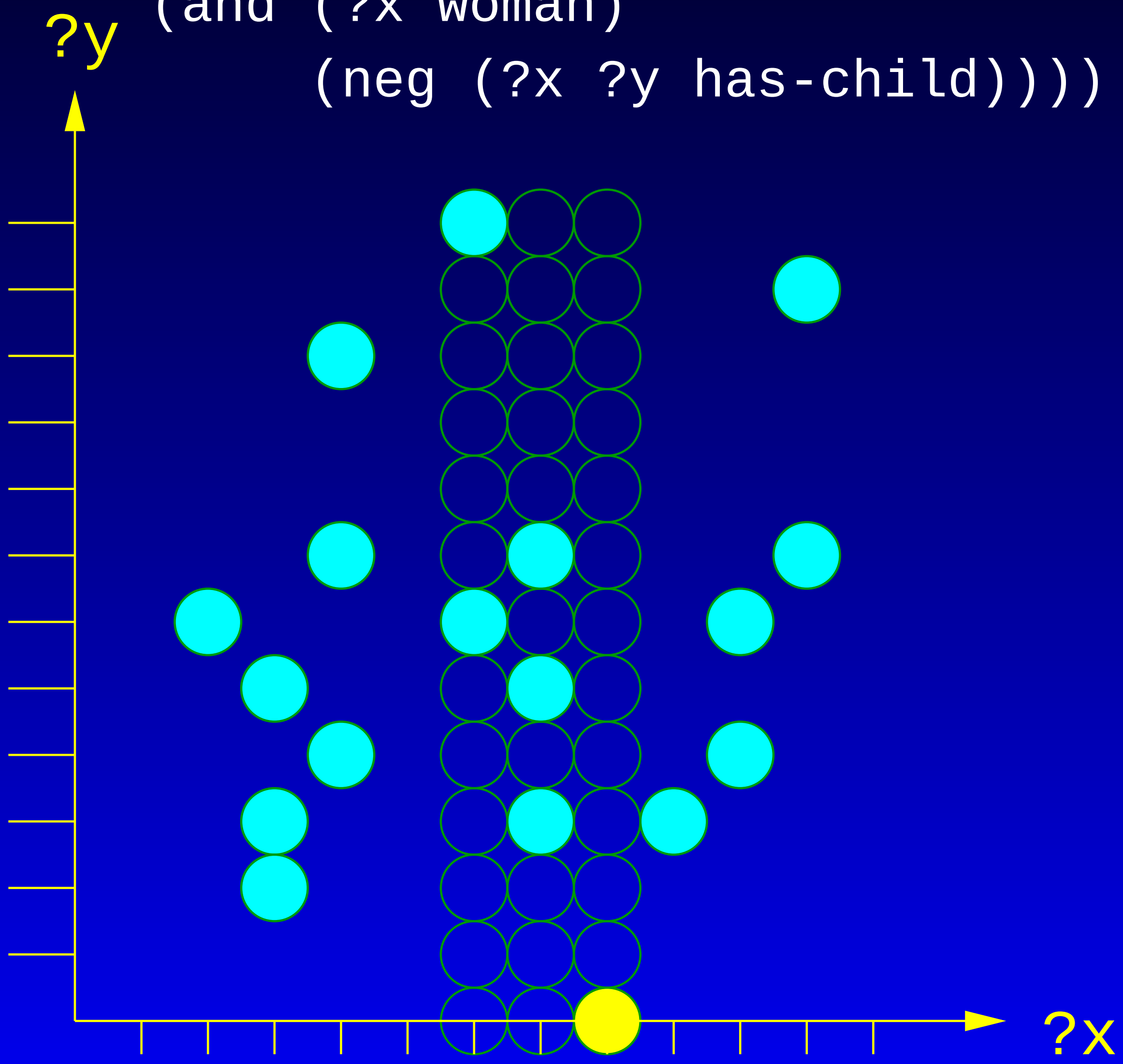
```
? (retrieve (?x)
     (?x (and woman (all has-child bottom))))

? (retrieve (?x)
     (and (?x woman)
          (neg (?x ?y has-child))))

? (retrieve (?x)
     (neg (and (?x woman) (?x ?y has-child))))
```

The Projection Operator (2)

```
Q1: (retrieve (?x)
              (and (?x woman)
                   (neg (?x ?y has-child))))
```



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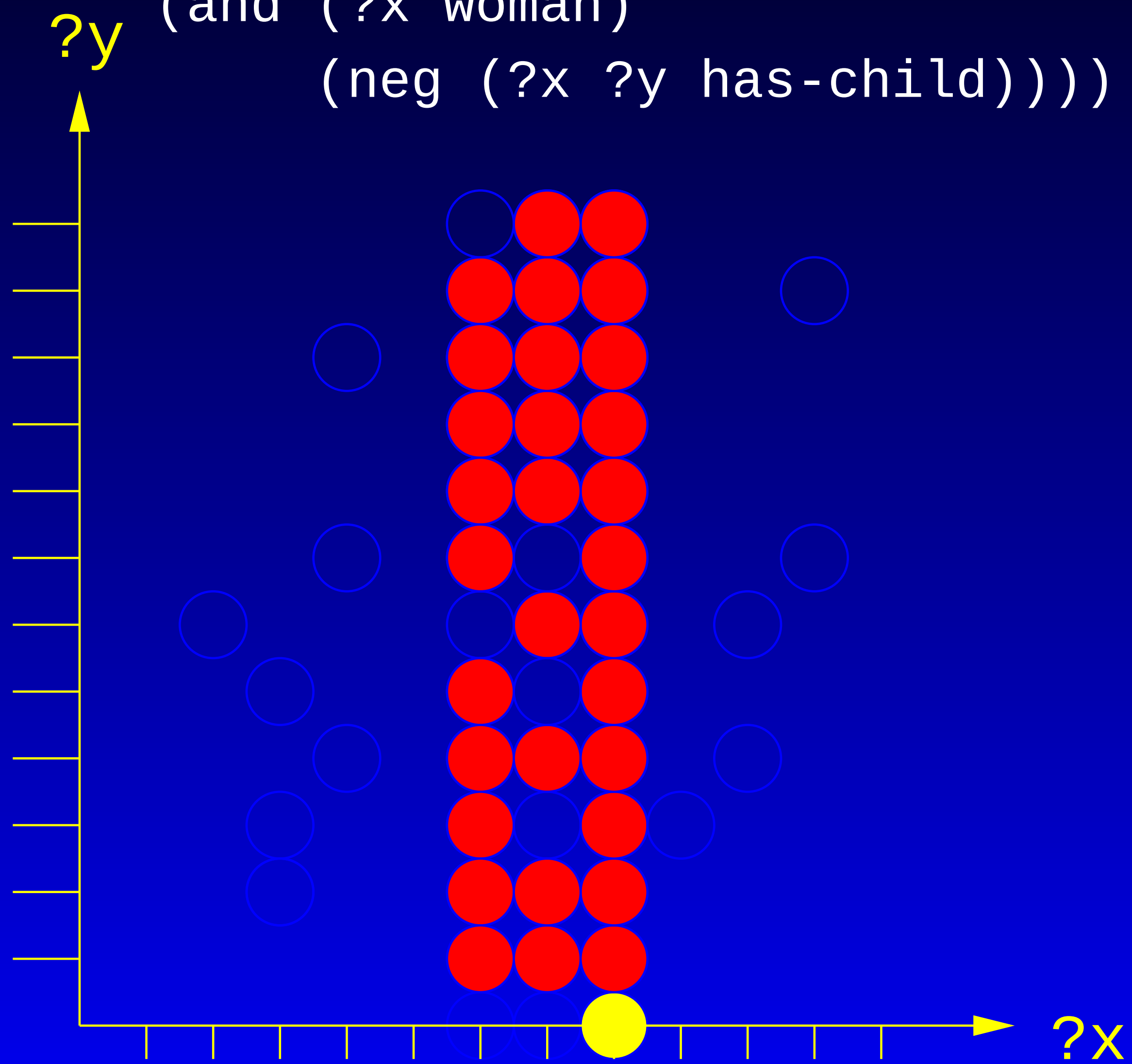

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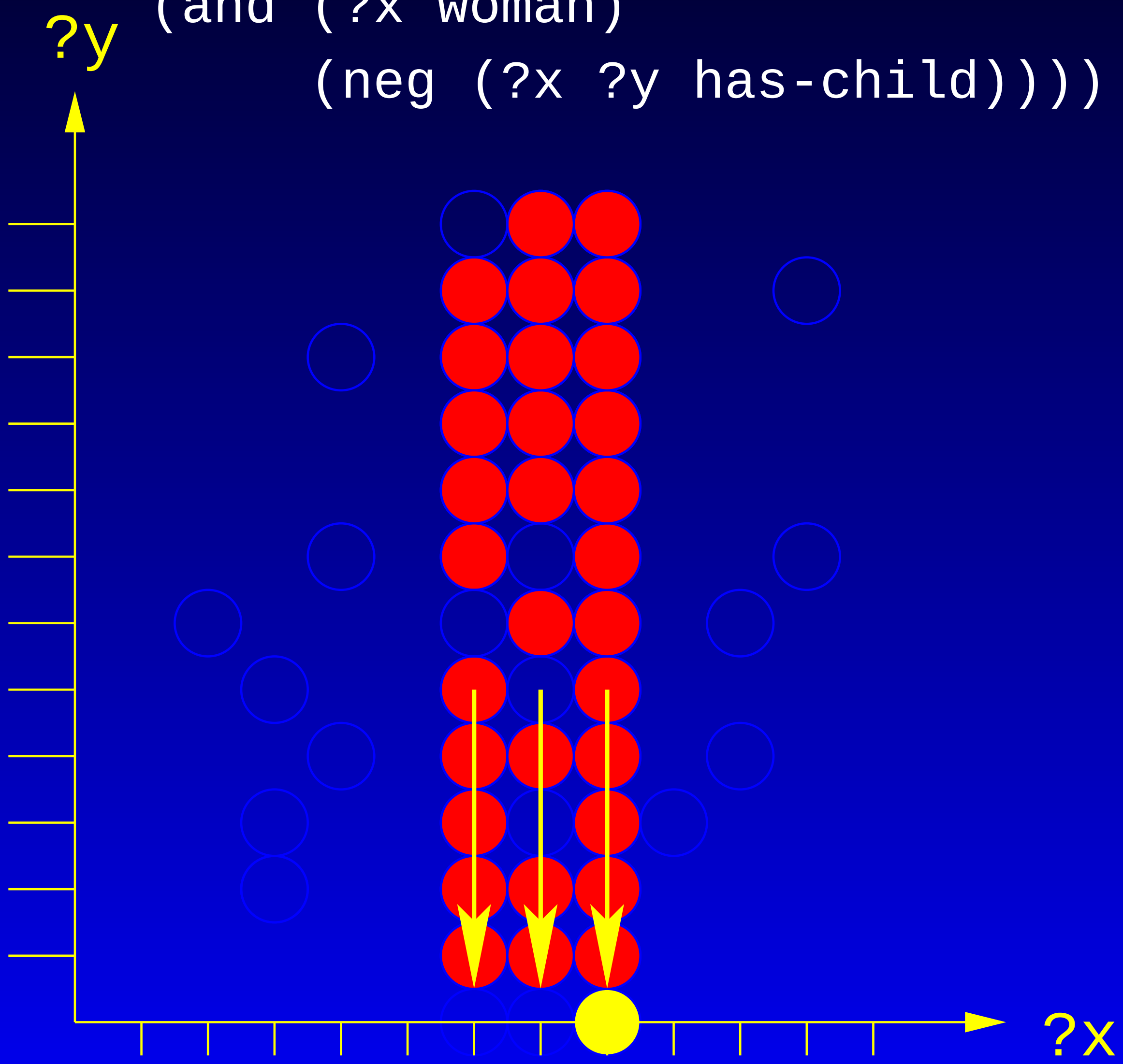
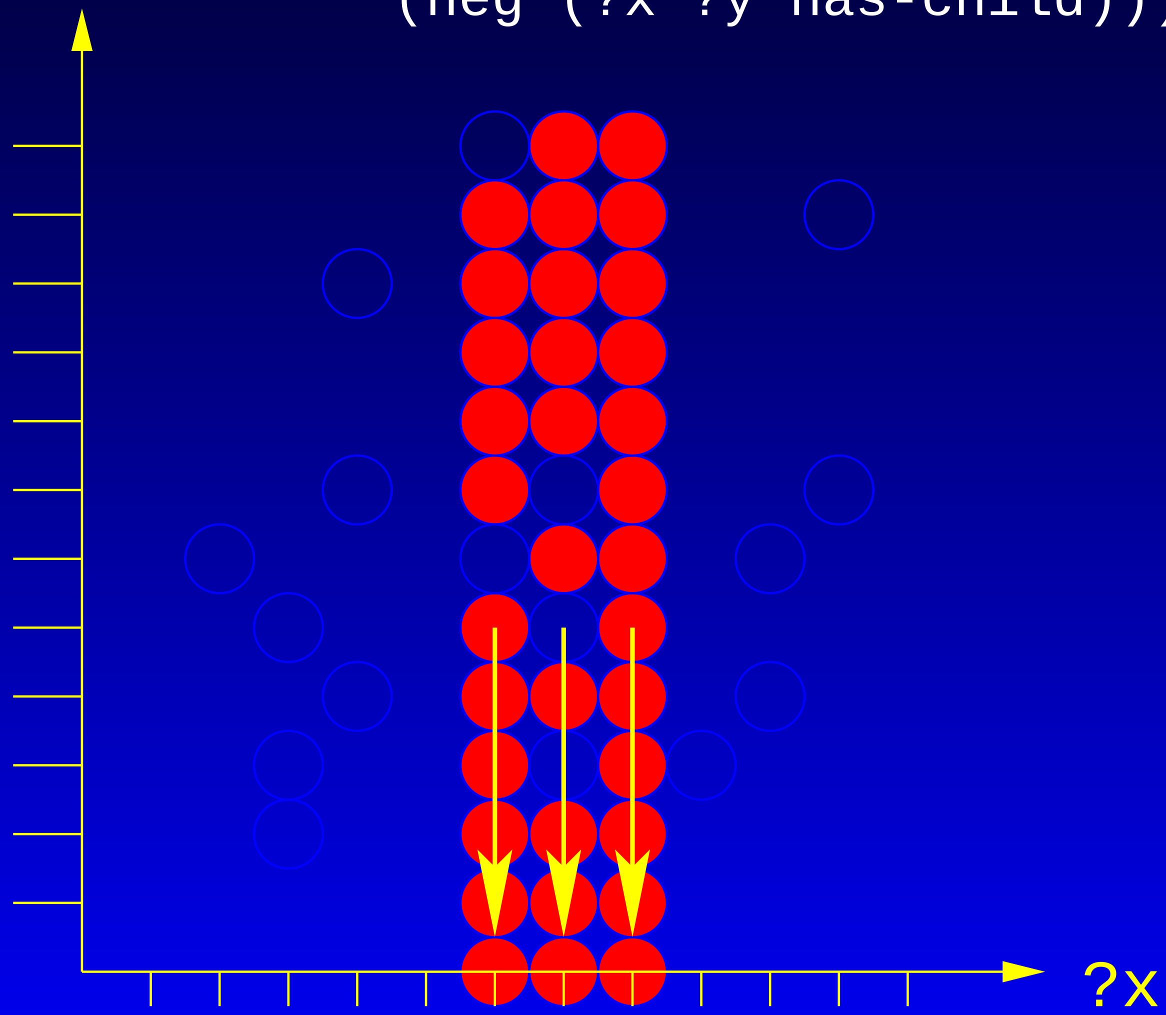


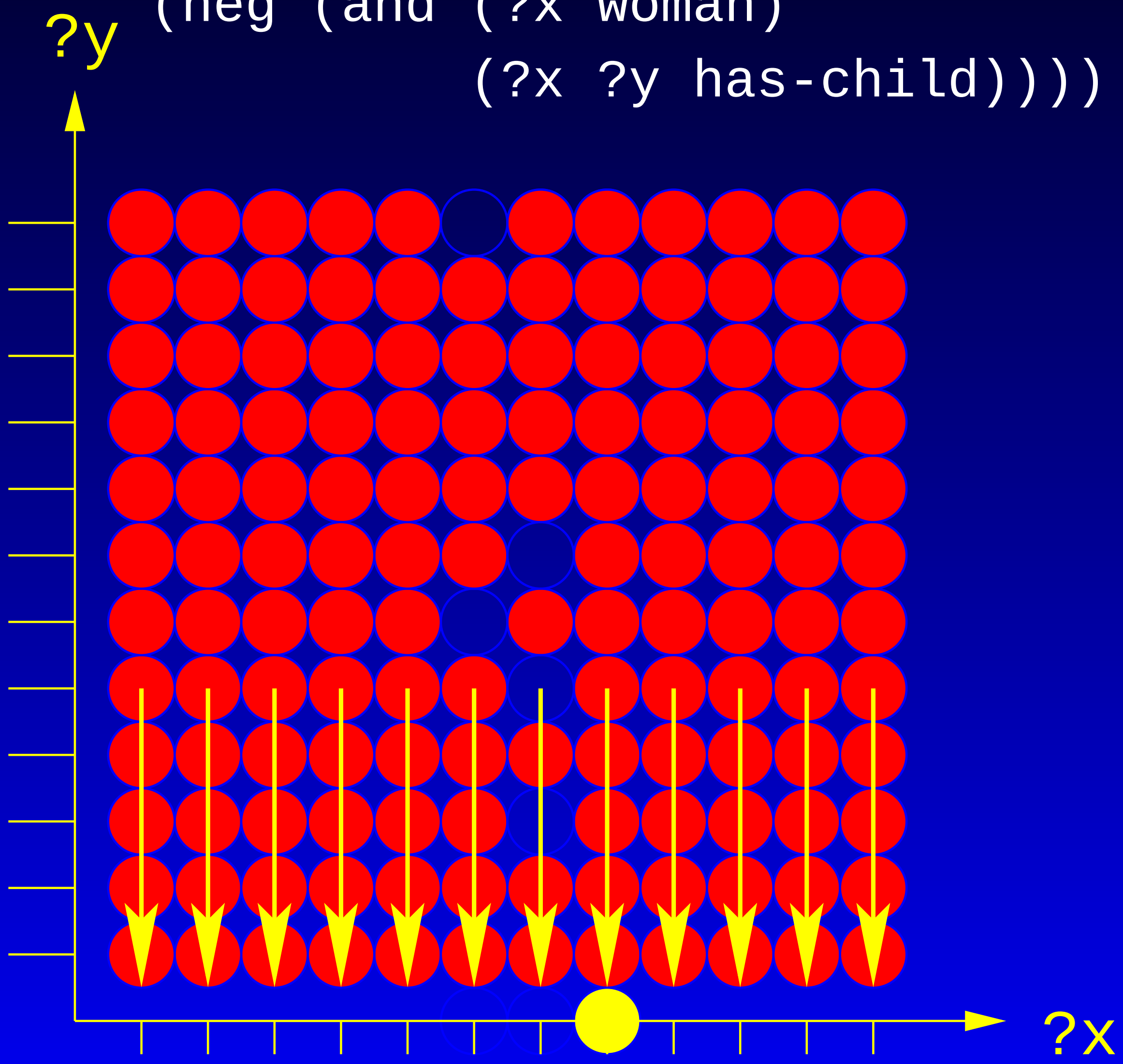
The Projection Operator (2)

Q1: (retrieve $\boxed{\texttt{(?x)}}$
(and (?x woman)
(neg (?x ?y has-child)))



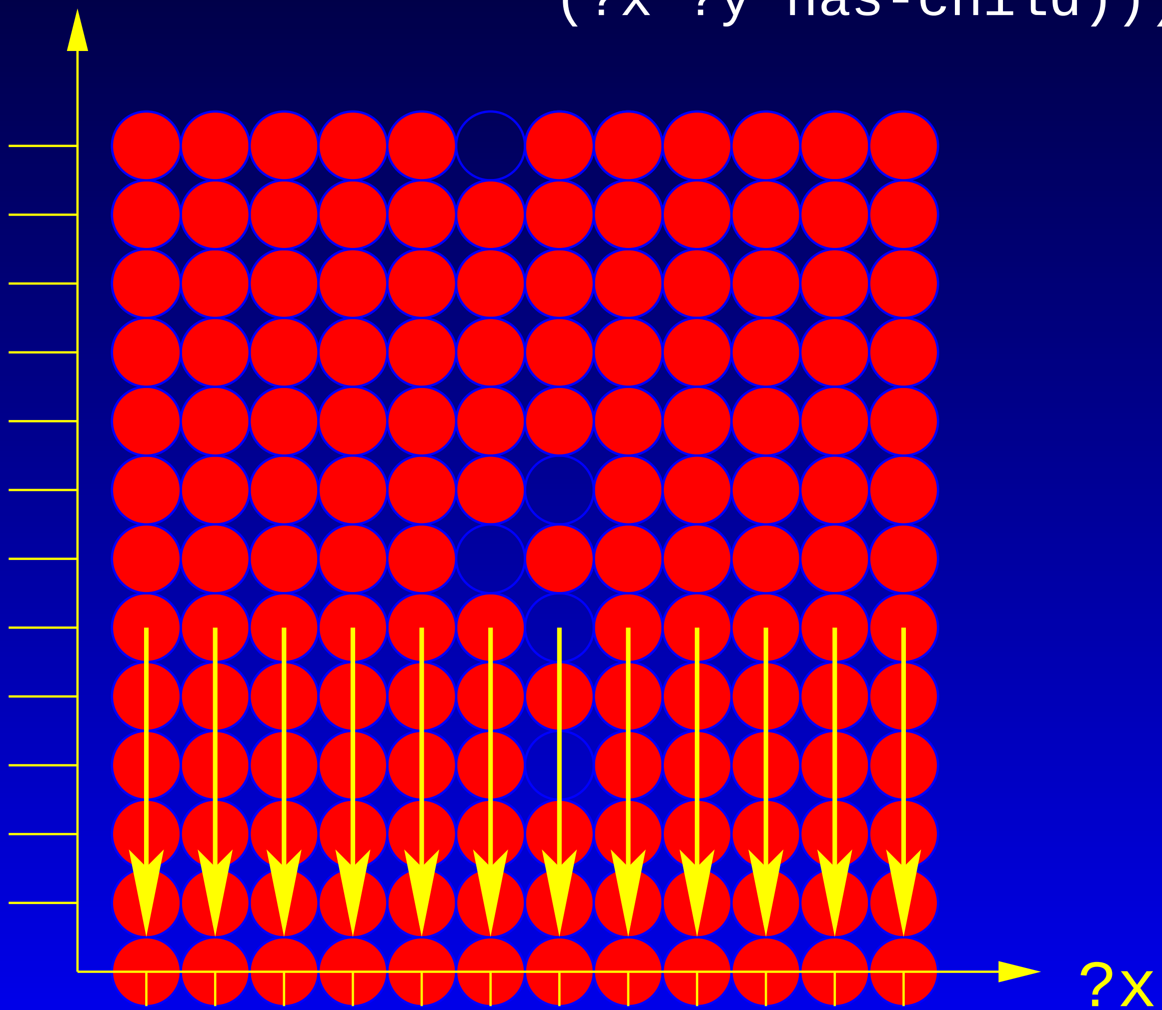
The Projection Operator (2)

```
Q2: (retrieve (?x)
              (neg (and (?x woman)
                        (?x ?y has-child))))
```



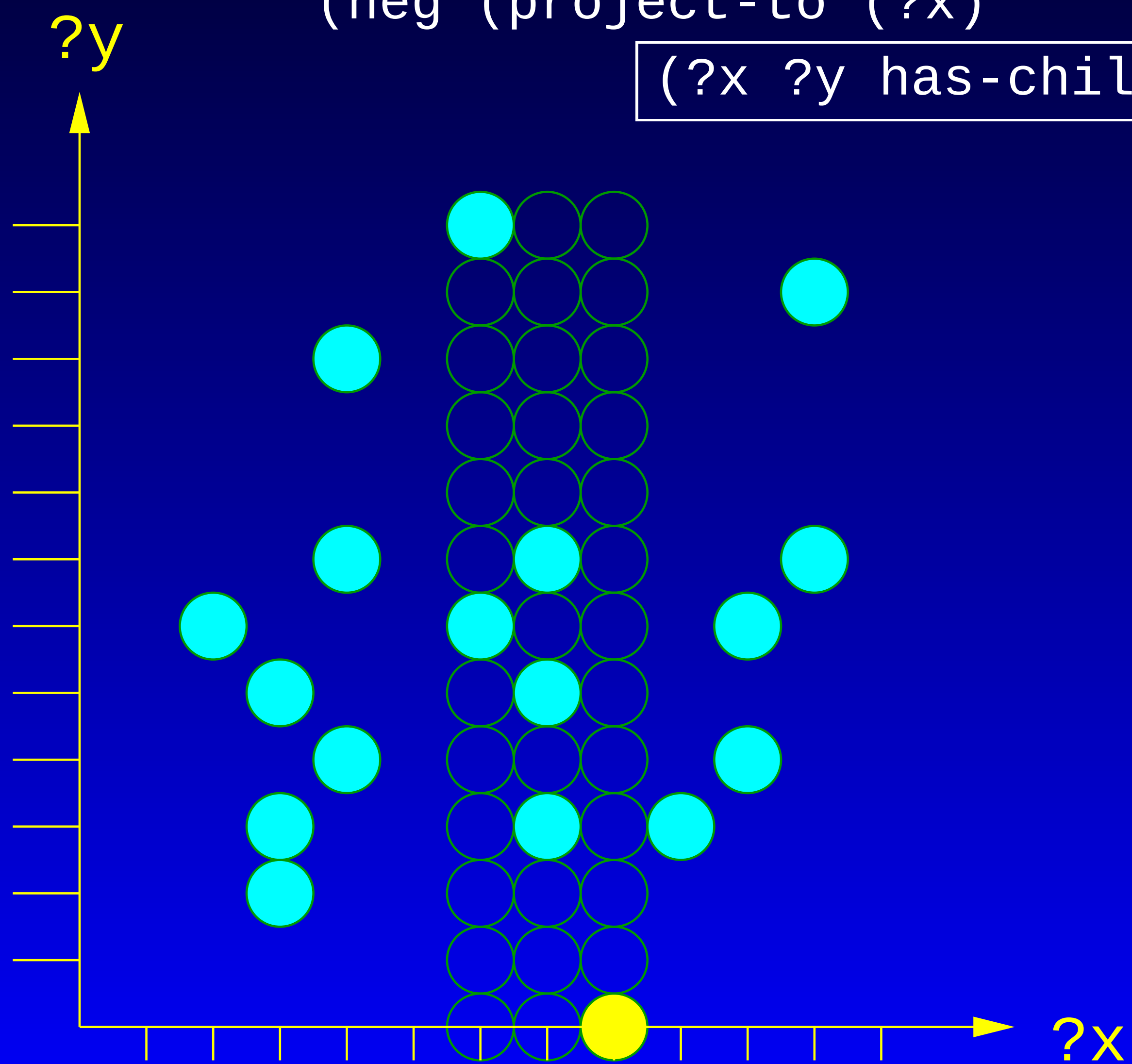
The Projection Operator (2)

- Q2: (retrieve $\boxed{\texttt{(?x)}}$
  (neg (and (?x woman)
  (?x ?y has-child)))



The Projection Operator (2)

```
Q3: (retrieve (?x)
              (and (?x woman)
                   (neg (project-to (?x)
                                    (?x ?y has-child)))))
```



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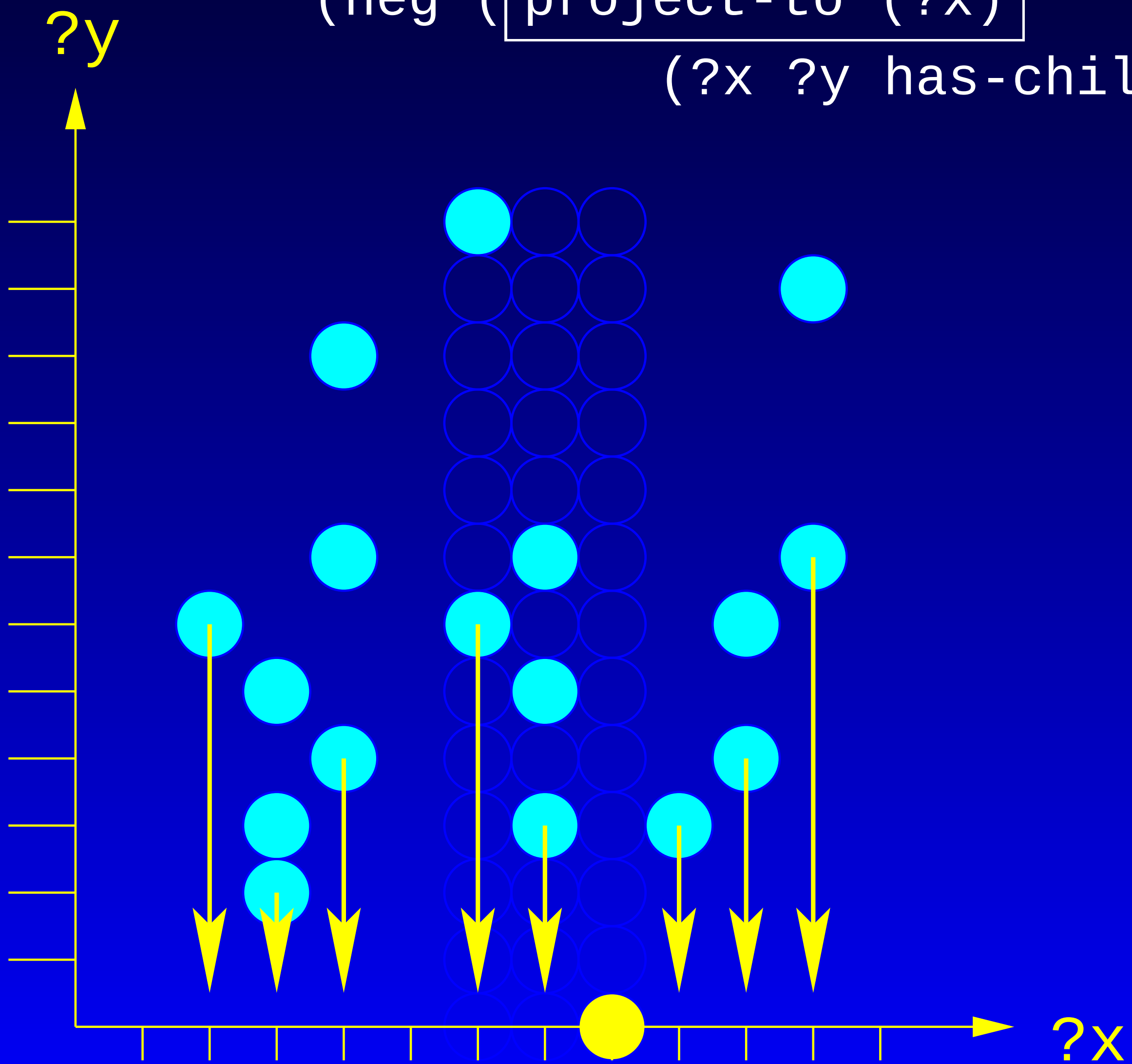
```



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```

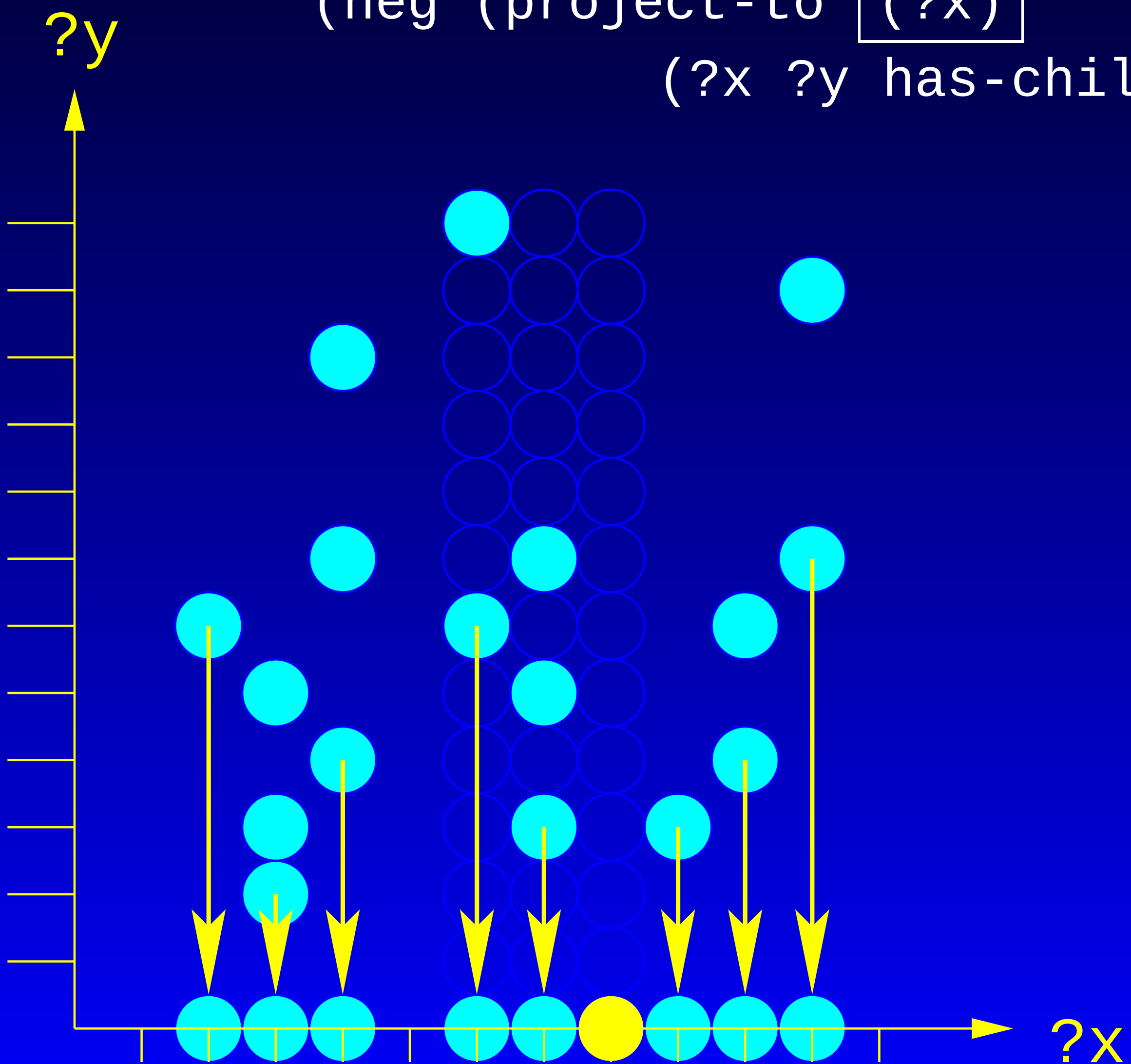

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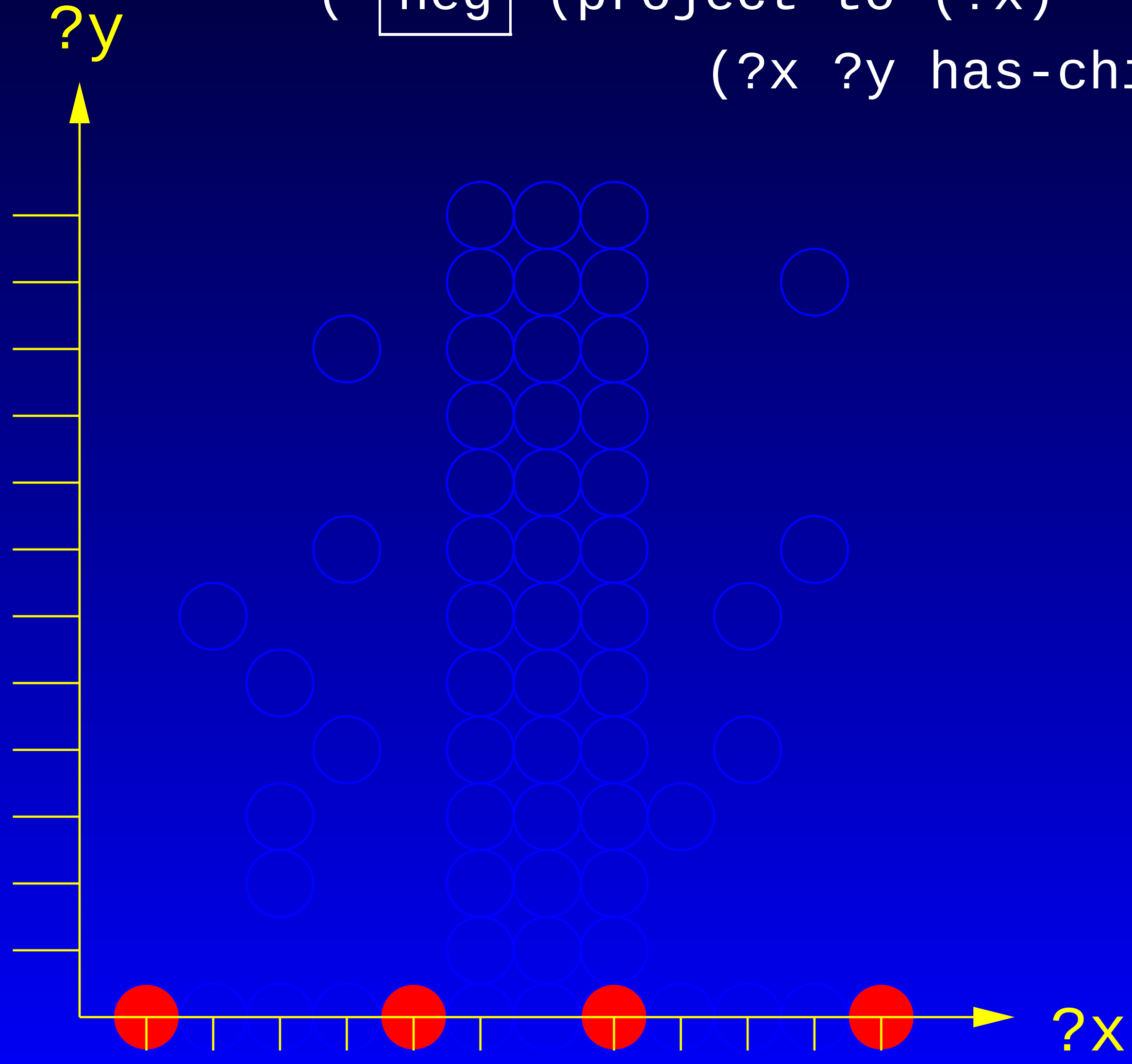
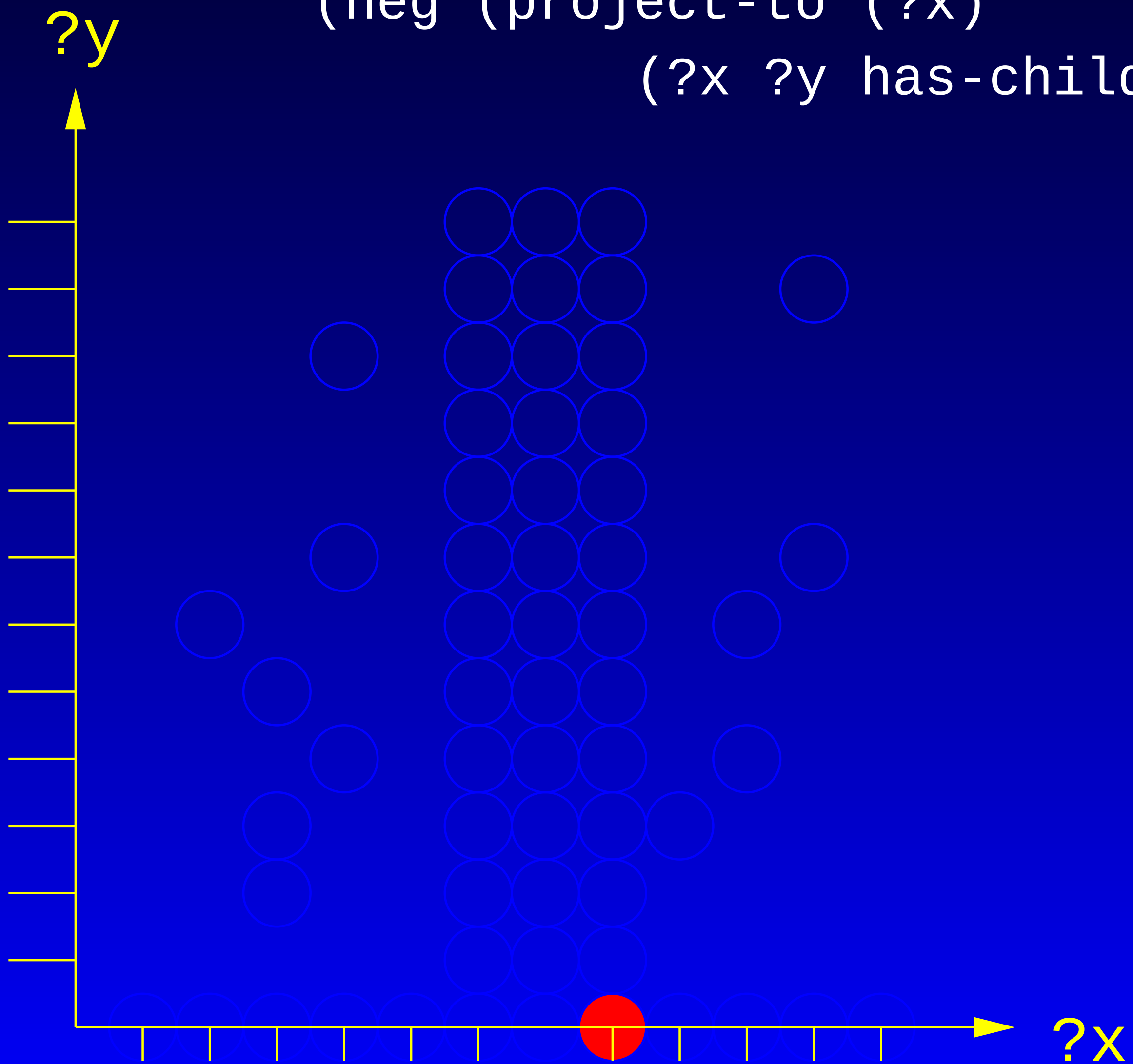
```



The Projection Operator (2)

```
Q3: (retrieve (?x)
              (and (?x woman)
                   (neg (project-to (?x)
                             (?x ?y has-child))))) ✓
```



. . . Some Syntactic Sugar

- Due to the new projection operator, some "special syntax" from the older nRQL (DL '04) can now be expressed
- `(?x (has-known-successor has-child))`
  = `(project-to (?x) (?x ?y has-child))`
- `(?x NIL has-child)` (borrowed from LOOM)
  = `(neg`
  `(?x (has-known-successor has-child)))`
  = `(neg`
  `(project-to (?x) (?x ?y has-child)))`
- now expressible in terms of `project-to`

Querying OWL KBs

- OWL datatype properties:

```
<owl:Class rdf:ID="Person">
  <rdfs:label>person</rdfs:label>
</owl:Class>

<owl:DatatypeProperty rdf:ID="age">
  <rdfs:domain rdf:resource="#Person" />
  <rdfs:range rdf:resource=
    "http://www.w3.org/2001/XMLSchema#integer" />
</owl:DatatypeProperty>

<Person rdf:about="http://www.test.com/michael">
   <age>34</age>
</Person>
```

nRQL & Datatype Properties

- Idea: handle OWL DTP like concrete domain attributes

```
? (retrieve
    (?x
      (datatype-fillers
         (|http://www.test.com/test.owl#age| ?x)))
    (?x (some |http://www.test.com/test.owl#age|
              (and (min 30) (max 35)))))

> (((?X |http://www.test.com/michael|)
    ((:TOLD-VALUE
     (|http://www.test.com/test.owl#age| ?X)) (34))))
```

- Extended RacerPro concept syntax (expressions like `(and (min 30) (max 35))` only recognized by nRQL)

nRQL & Annotation Properties

```
<owl:AnnotationProperty rdf:ID="my-comment">
  <rdf:type rdf:resource=
    "http://www.w3.org/2002/07/owl#DatatypeProperty"/>
  <rdfs:domain rdf:resource="#person"/>
</owl:AnnotationProperty>

<person rdf:ID="i">
  <my-comment rdf:datatype=
       "http://www.w3.org/2001/XMLSchema#string"
  >My comment</my-comment>
</person>
```

- A special head projection operator `annotations (told-value)` is provided by nRQL
- Similar to querying for datatype properties

Expressivity Problems

- Access to "data values" in OWL docs (fillers of datatype/annotation properties) is restricted
- from the DL perspective, only the (extended) RacerPro concept expression language can be used
- How to retrieve all individuals which have (CD attribute or DTP) fillers containing substring x?
- Solution: maintain a data substrate in parallel to an ABox
- the data substrate is used to automatically "mirror" the ABox
- offer query access to this substrate by means of a hybrid query language - nRQL

Hybrid Queries - Data Substrate

```
(retrieve (?x ?*name ?*age)
   (and (?x (and |http://...#person|
                 (an |http://...#age|)))
        (?*x ?*name |http://...#name|)
        (?*name ( (:predicate (search "wessel"))
                  ((:predicate (search "michael"))
                   (:predicate (search "achim")))))
        (?*x ?*age |http://...#age|)
        (?*age ((:predicate (< 40))))))
```

- New sort of variables: `*?x (*$?x)`, ranging over data nodes
- Data nodes can also be data values in OWL documents
- Data nodes/edges have descriptive labels: kind, role, property, . . .
- Notion of entailment for labels of nodes/edges
- Data query atoms are in pos. CNF & contain literals and predicates.

The RCC Substrate

- Associates an RCC8 (RCC5) network with an ABox

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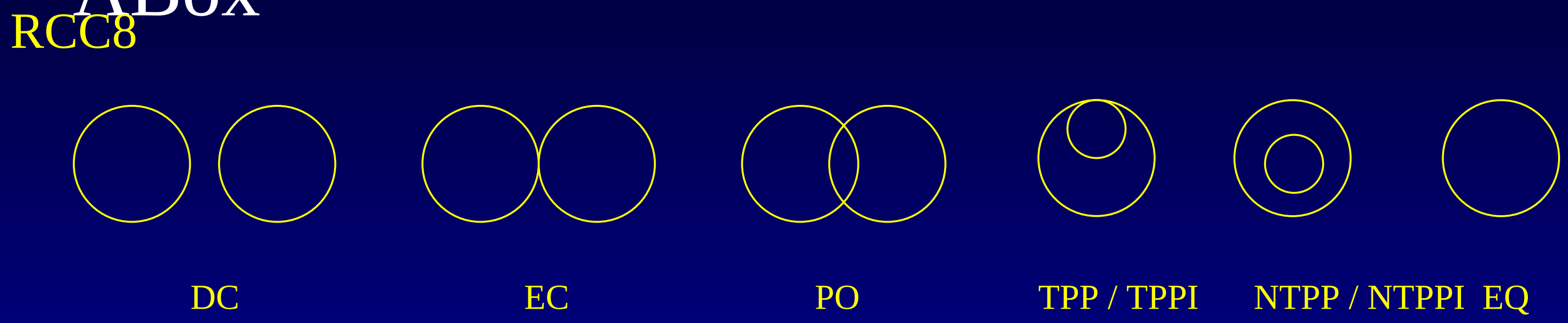

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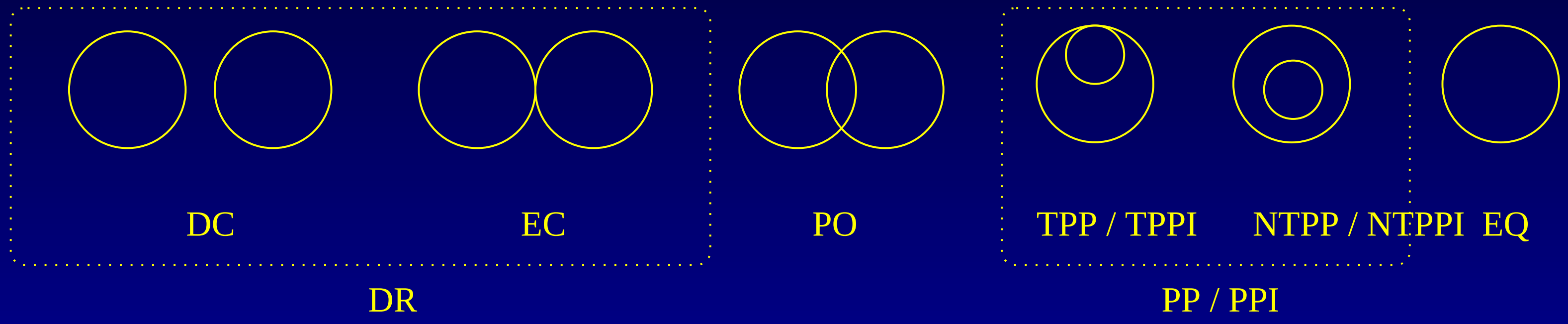
RCC8



RCC5

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- JEPD property for base relations = jointly exhaustive, pairwise disjoint
- No knowledge about relationship: use disjunction of all 8 base relations

The RCC Substrate (2)

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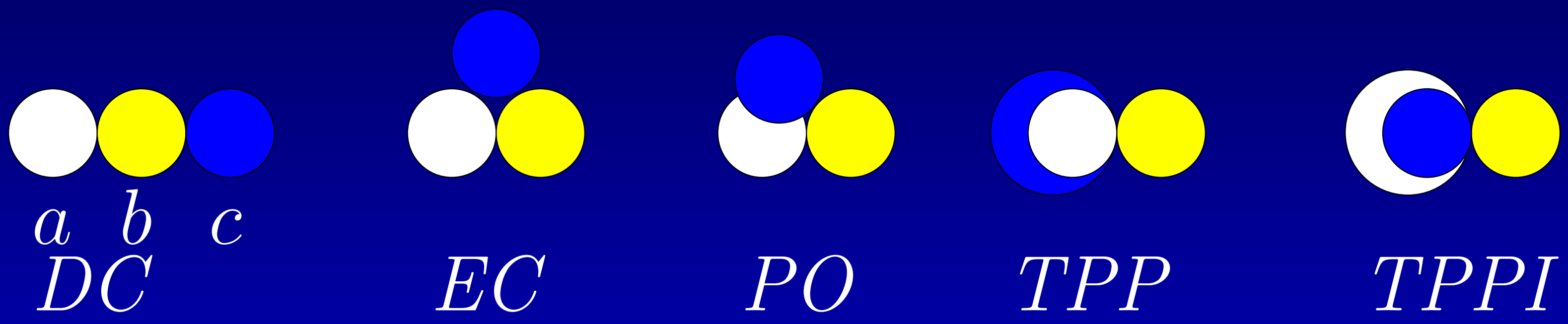

The RCC Substrate (2)

RCC5 Composition Table

∘	DR(a,b)	PO(a,b)	EQ(a,b)	PPI(a,b)	PP(a,b)
DR(b,c)	*	DR PO PPI	DR	DR PO PPI	DR
PO(b,c)	DR PO PP	*	PO	PO PPI	DR PO PP
EQ(b,c)	DR	PO	EQ	PPI	PP
PP(b,c)	DR PO PP	PO PP	PP	PO EQ PP PPI	PP
PPI(b,c)	DR	DR PO PPI	PPI	PPI	*

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- Notions of consistency:
  - Constraint satisfaction: find an instantiation of the network with base relations such that the composition table axioms are satisfied (requires search, exponential)

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  $R(x, y) \circ S(y, z) \rightarrow T_1(x, z) \vee \cdots \vee T_n(x, z)$
- Notions of consistency:
  - Polynominal methods (incomplete): Constraint propagation, "path or 3-consistency algorithm": for all x, y, z, compute
    $T(x, z) =_{def} T(x, z) \cap R(x, y) \circ S(y, z)$
    until fixpoint is reached

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- Notions of consistency:
  - Spatial realizabilty: find a spatial model (not considered here)

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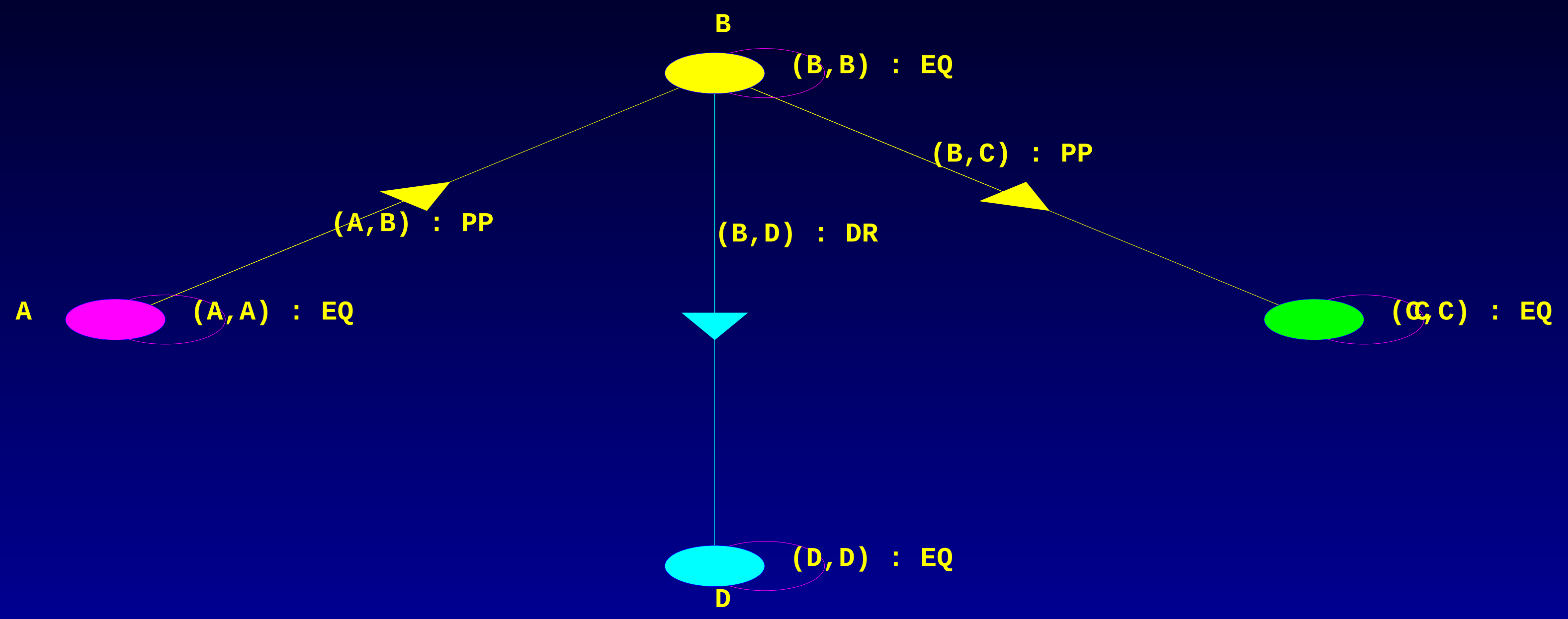

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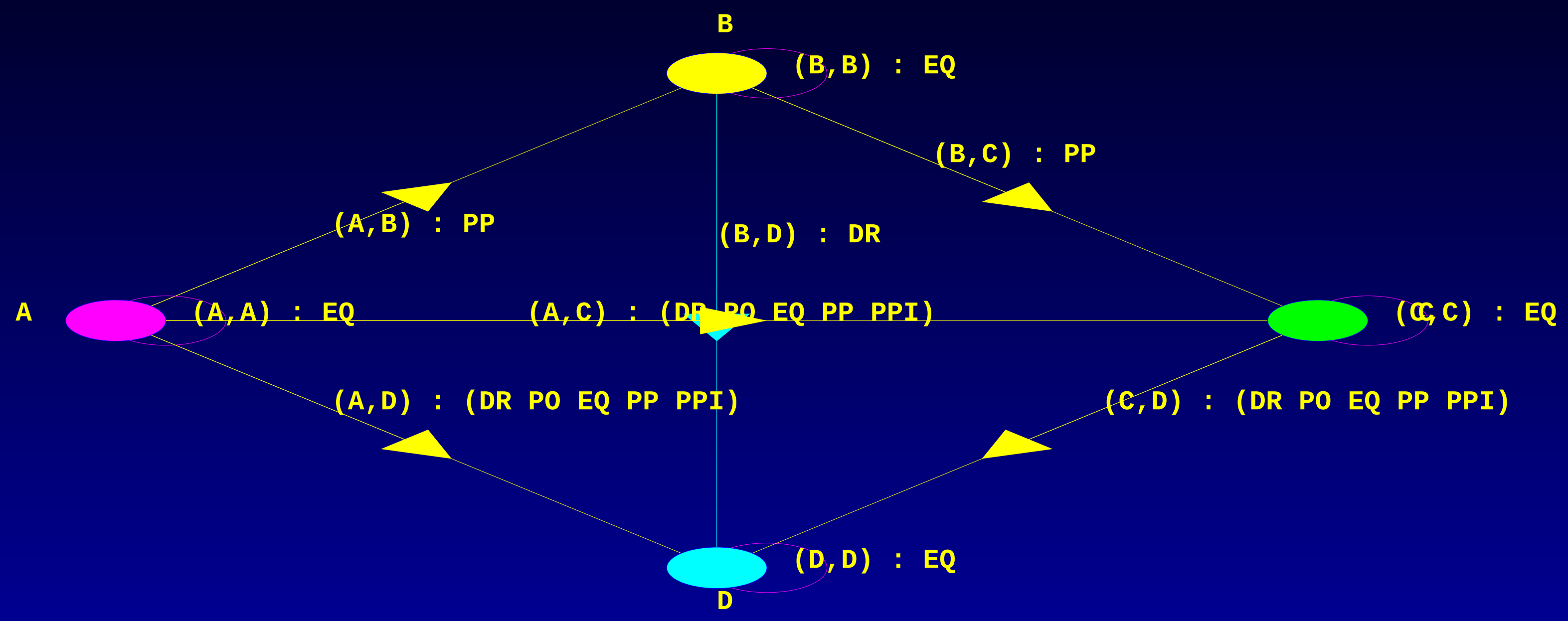

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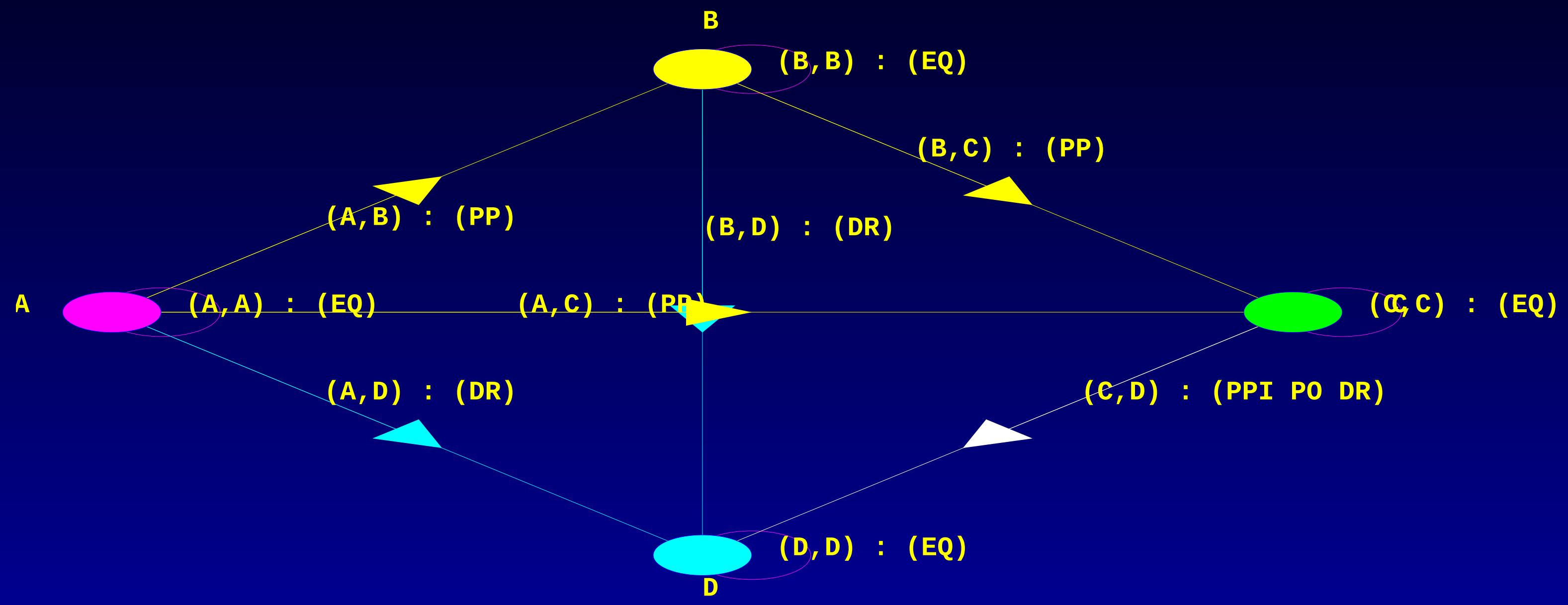

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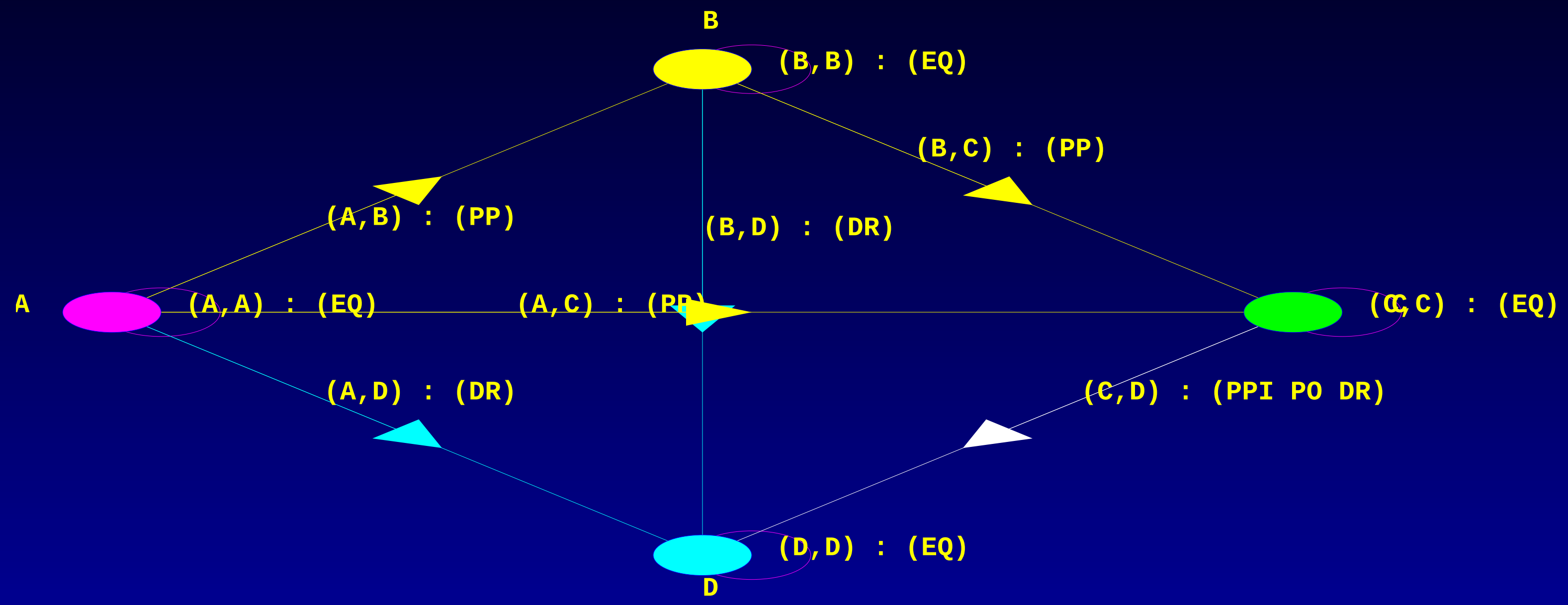

$$\models DR(A, D)$$
$$\models PP(A, C)$$
$$\models \{PPI, PO, DR\}(C, D)$$
$$\models \ldots$$

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The RCC Substrate (4)

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```
(in-rcc-box geo-example :rcc5)
(implies city bavarian-city)
(implies software-department
computer-science-department)
(implies computer-science-department
university-department)
(implies computer-science-department it-specialists)
(implies it-company it-specialists)
(implies it-company company)
```

The RCC Substrate (4)

```
(rcc-node germany country country)
(rcc-node hamburg city city)
(rcc-node munich bavarian-city bavarian-city)
(rcc-node harburg district district)
(rcc-node sts software-department
software-department)
(rcc-node docomo-euro-labs company it-company)
```

The RCC Substrate (4)

```
(rcc-related germany hamburg :ppi)
(rcc-related germany munich :ppi)
(rcc-related hamburg harburg :ppi)
(rcc-related hamburg munich :dr)
(rcc-related munich docomo-euro-labs :ppi)
(rcc-related hamburg sts :ppi)
```

The RCC Substrate (4)

```
> (retrieve (?x ?y) (and (?x country) (?*x ?*y :ppi)
                         (?y it-specialists)))
(((?X GERMANY) (?Y DOCOMO-EURO-LABS))
 ((?X GERMANY) (?Y STS)))
```

The RCC Substrate (4)

```
> (retrieve (?x ?y) (and (?x country) (?*x ?*y :ppi)
                         (?y it-specialists)))
(((?X GERMANY) (?Y DOCOMO-EURO-LABS))
 ((?X GERMANY) (?Y STS)))
```

```
> (retrieve (?x ?y) (and (?*x ?*y :dr) (?x it-specialists)
                         (?y it-specialists)))
(((?X DOCOMO-EURO-LABS) (?Y STS))
 ((?X STS) (?Y DOCOMO-EURO-LABS)))
```

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(((?X GERMANY) (?Y DOCOMO-EURO-LABS))
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```

```
> (retrieve (?x ?y) (and (?*x ?*y :dr) (?x it-specialists)
                         (?y it-specialists)))
(((?X DOCOMO-EURO-LABS) (?Y STS))
 ((?X STS) (?Y DOCOMO-EURO-LABS)))
```

```
> (retrieve (?x ?y)
            (and (?*x ?*y :dr) (?x it-specialists)
                 (?y it-specialists)
                 (?*y ?*z :pp) (?z bavarian-city)))
(((?X STS) (?Y DOCOMO-EURO-LABS))
((?X DOCOMO-EURO-LABS) (?Y STS)))
```

RCC Substrate & OWL?

- OWL DL = $\mathcal{SHOIN}(Dn)$
- RacerPro supports $\mathcal{SHIN}(Dn)$ (Nominals, $\mathcal{O}$, approximated)
- An OWL KB can be mirrored into the data substrate (additional retrieval predicates possible)
- Idea: declare a set of object properties as spatial relationships, then automatically create an RCC substrate from an OWL KB

$\Rightarrow$ "RCC substrate" addition for OWL

- Already requested by a user of RacerPro, but not implemented yet

Reasoning about Queries

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  - RCC conjuncts: construct an RCC substrate and check its consistency
  - Conjecture: somehow “weak” since no interaction, but quite useful in this scenario

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$$query(?germany, ?city, ?sea) \leftarrow$$

$$germany(?germany^*), federal\_division(?division^*),$$

$$german\_city(?city^*), (baltic\_see \sqcup north\_sea)(?sea^*),$$

$$\boxed{\text{PPI(?germany,?division), PPI(?division,?city),}}$$

$$\boxed{\text{DR(?division,?sea)}}$$

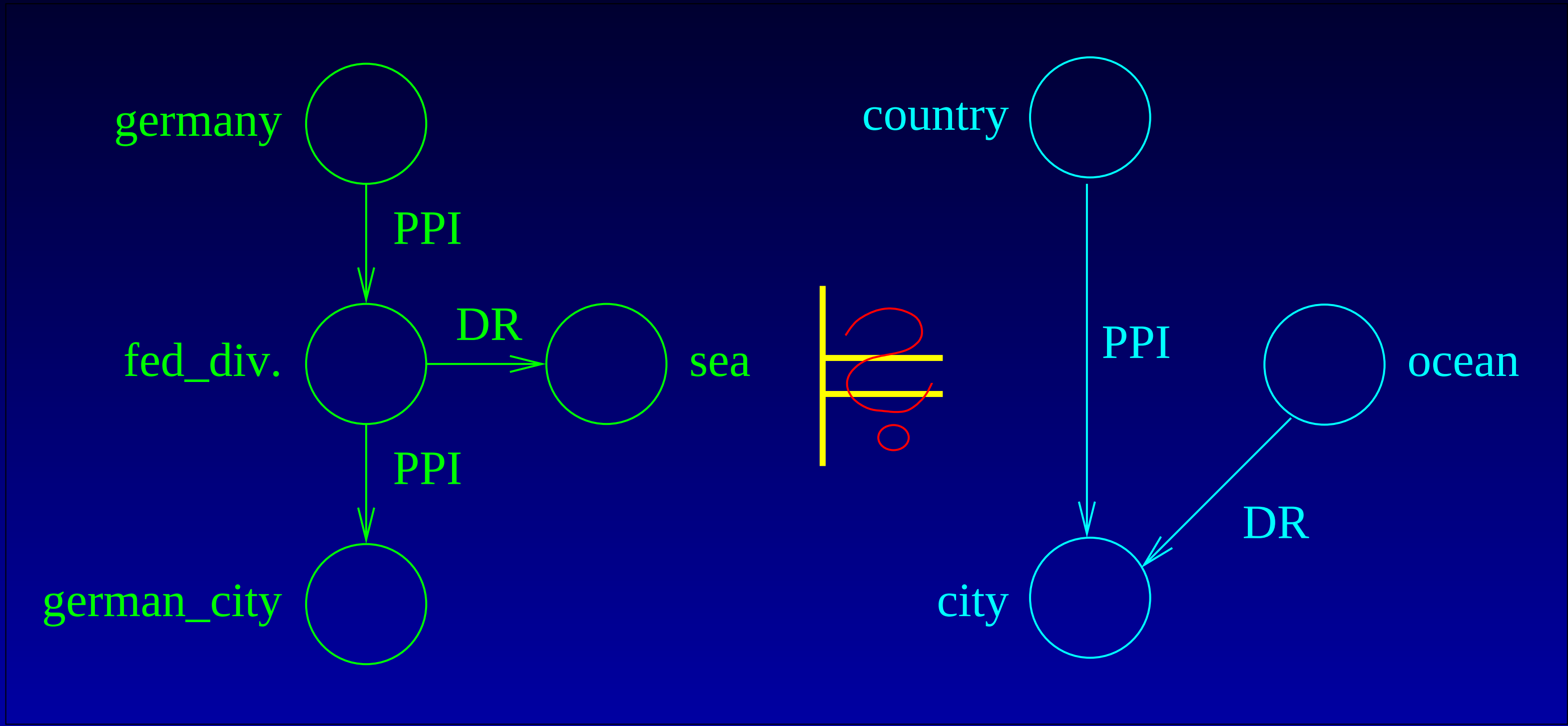
$$\models$$

$$query(?country, ?city, ?ocean) \leftarrow$$

$$country(?country^*), city(?city^*), ocean(?ocean^*),$$

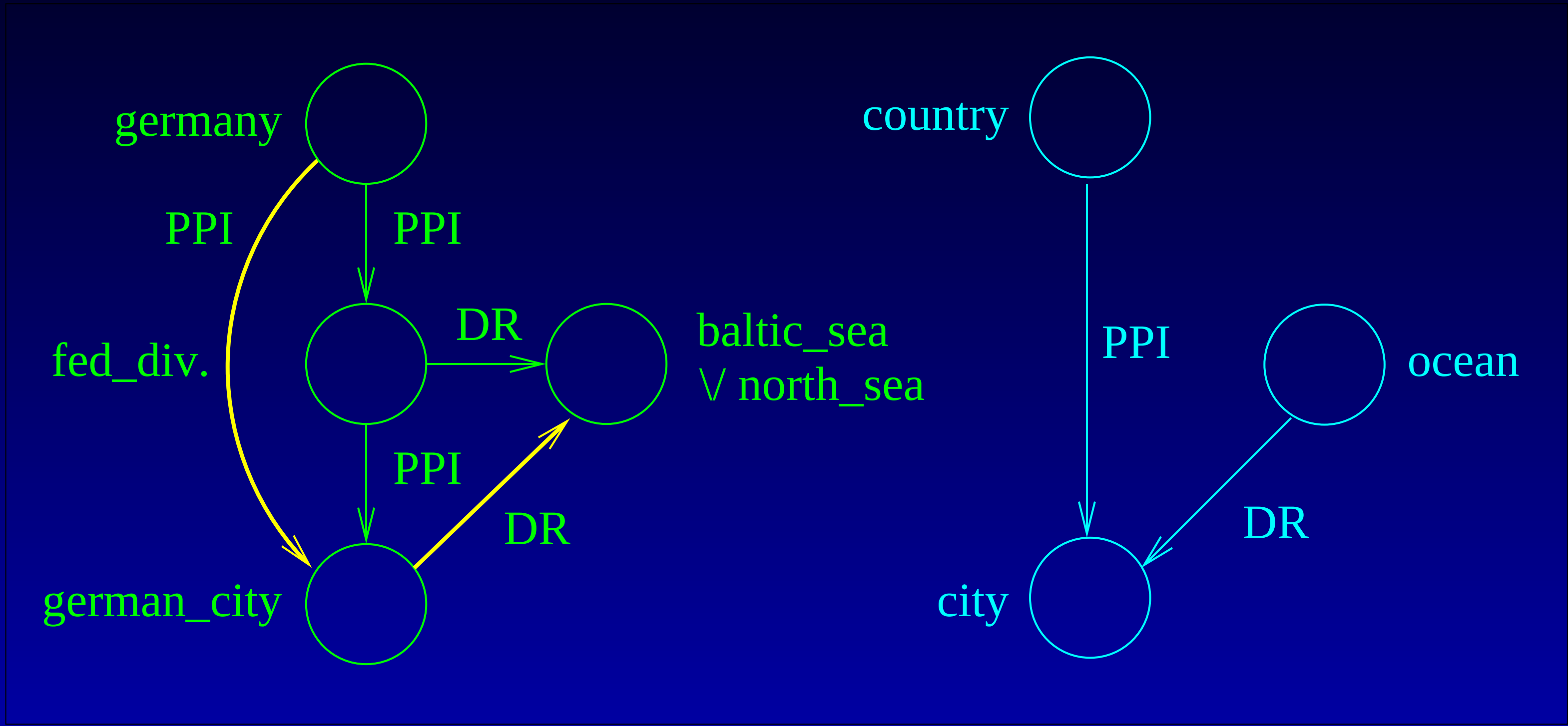
$$\boxed{\text{DR(?ocean,?city), PPI(?country,?city)}}$$

Reasoning about Queries



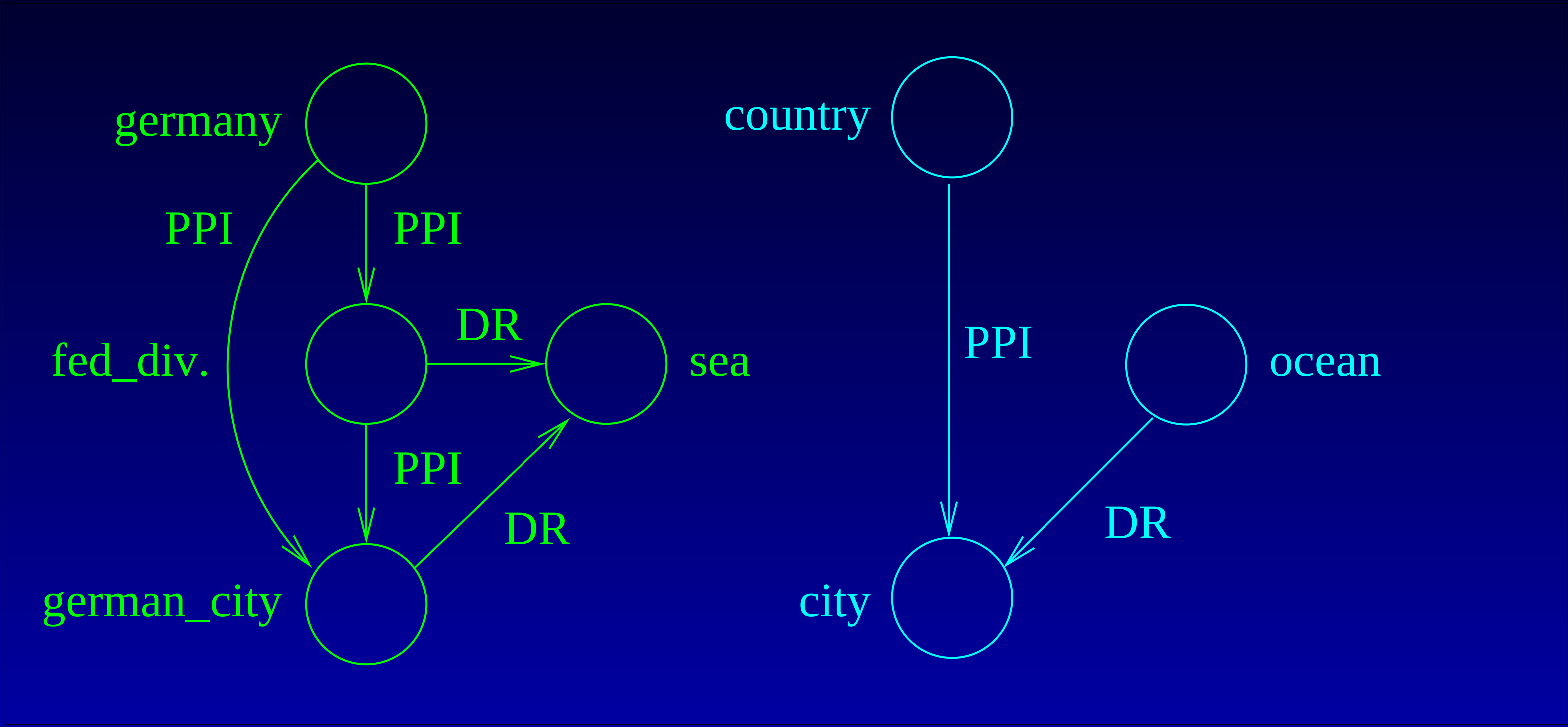
Two queries - does Green entail Blue?

Reasoning about Queries

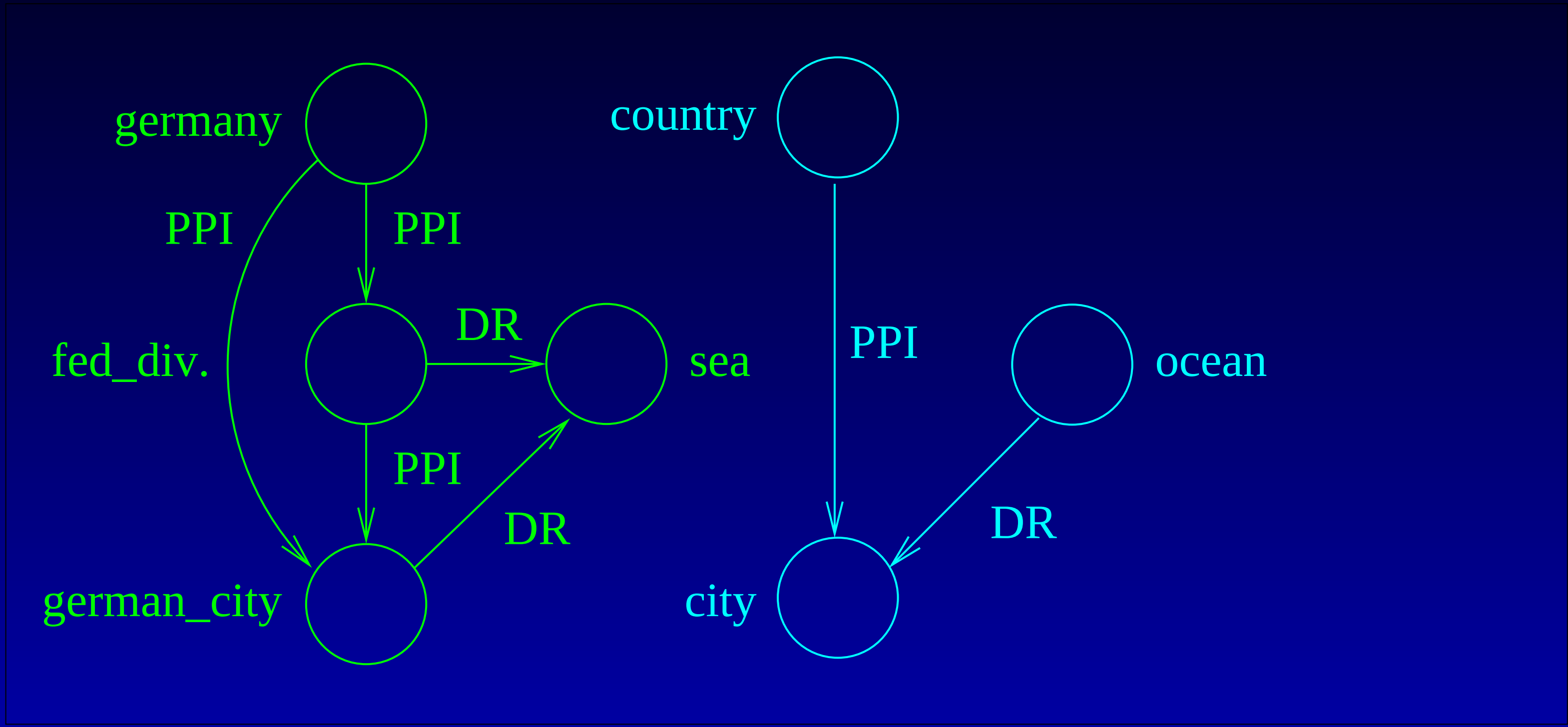


Adding entailed constraints for Green

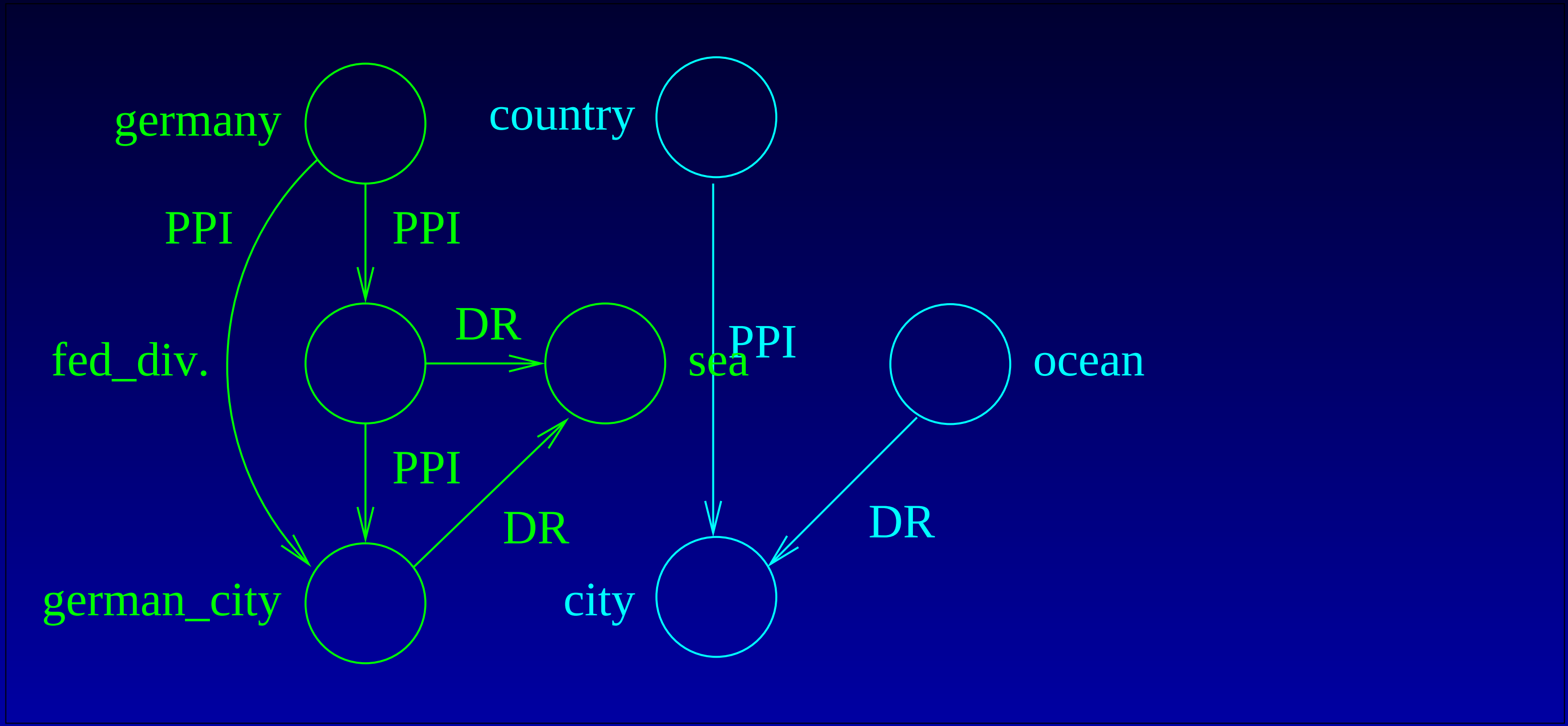
Reasoning about Queries



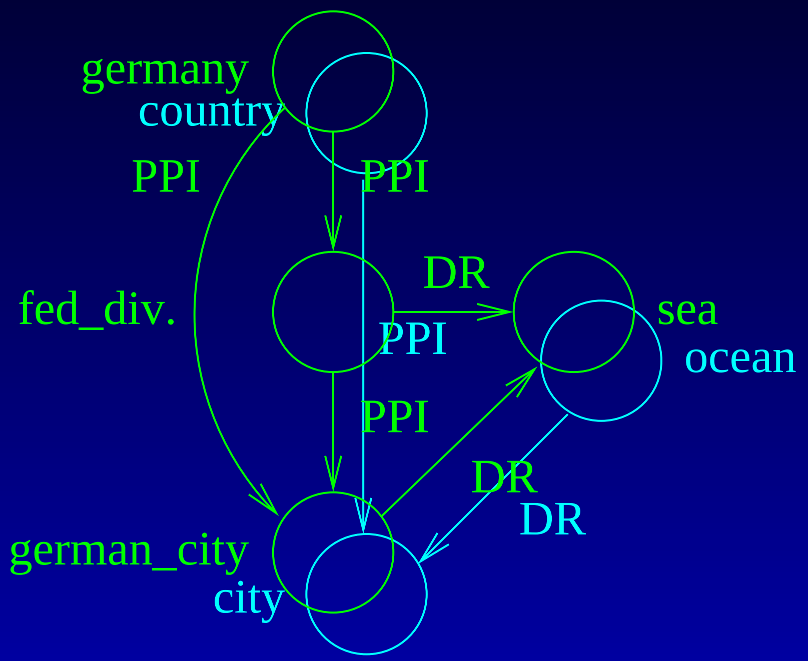
Reasoning about Queries



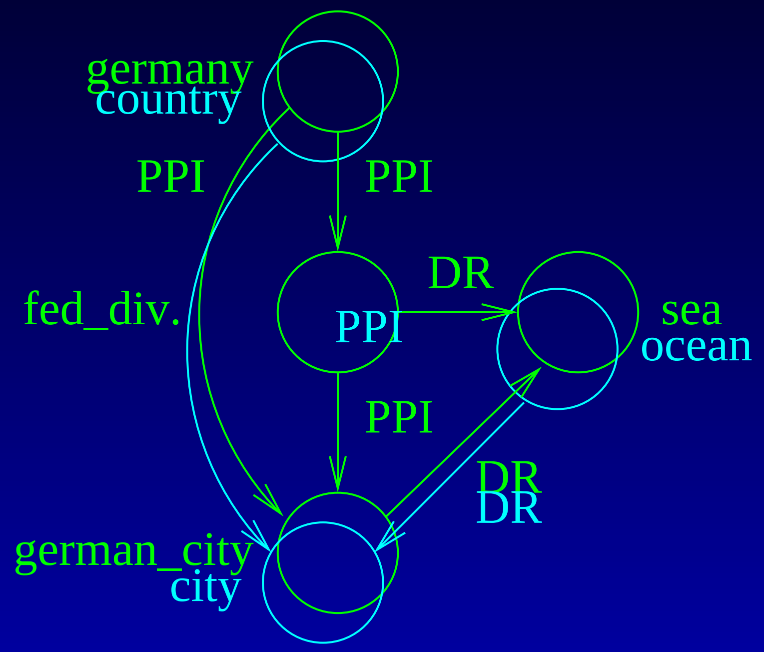
Reasoning about Queries



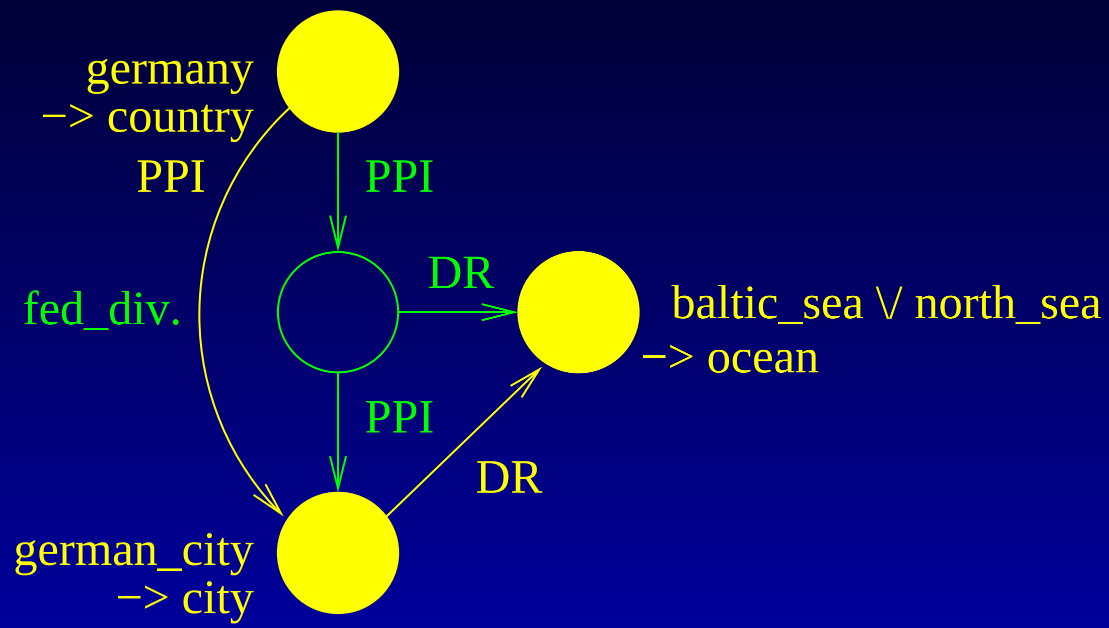
Reasoning about Queries



Reasoning about Queries



Reasoning about Queries



Match - Green is more specific than Blue

Reasoning about Queries

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  $\Rightarrow$ By reduction to query consistency

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Conclusion

- Handling of space by logical means is difficult
- Standard-DLs or languages such as OWL are not tailored for this purpose
- Good for thematic aspects
- Tailored spatial languages should be decidable (conflict: expressiveness vs. decidability)
- The OWL "standard ontologies" for GIS (found on the web) can be understood as data schema specifications for GIS data, reasoning concerning the spatial aspects is not addressed
- RacerPro supports "spatial reasoning" only in the query answering engine

Thanks

for your

attention!