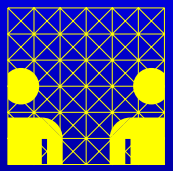
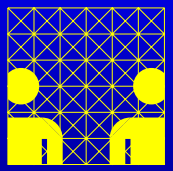


Extended Query Facilities for Racer and an Application to Software-Engineering Problems

Volker Haarslev, Ralf Möller,
Ragnhild Van Der Straeten and Michael Wessel

Cognitive Systems Group
University of Hamburg
Germany



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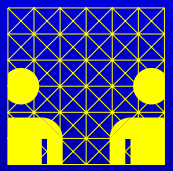

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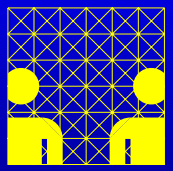

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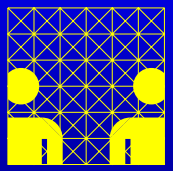

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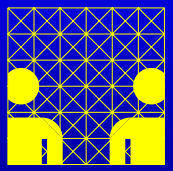

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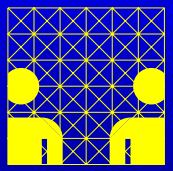
    - . . . a few dozens more (see Racer manual)



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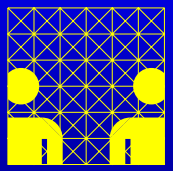

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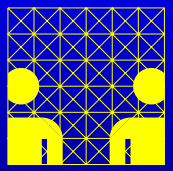

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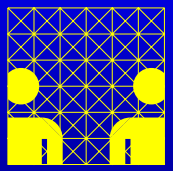

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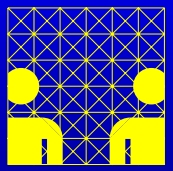

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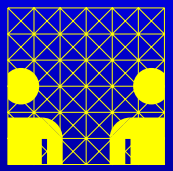

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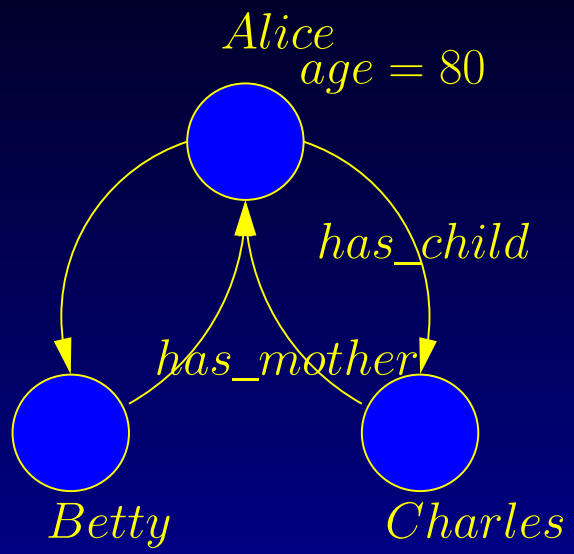
- pragmatic approach, straightforward combination of Racer's ABox API functions

Motivating Simple Example



$$mother(alice),\ age(alice) = 80,$$
$$has\_mother(betty, alice),$$
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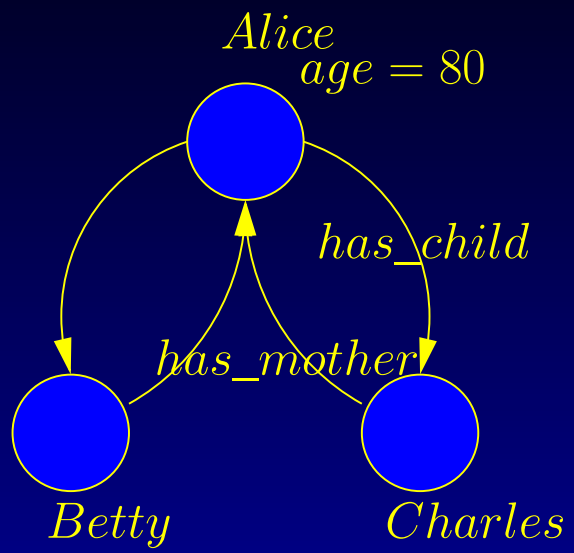

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- How do we retrieve pairs of siblings (e.g., $\{(betty, charles)\}$)?

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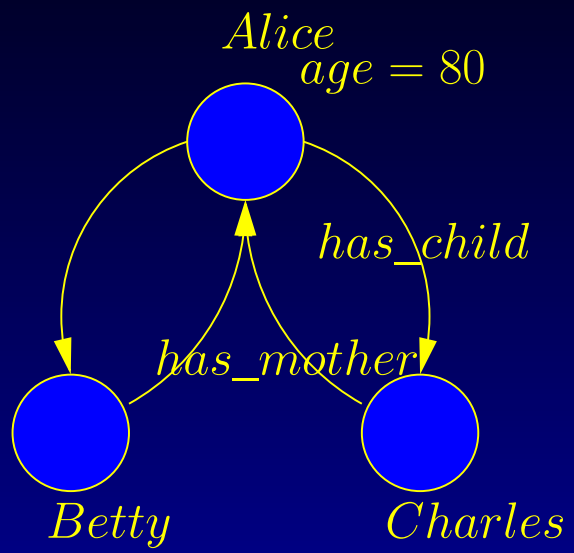

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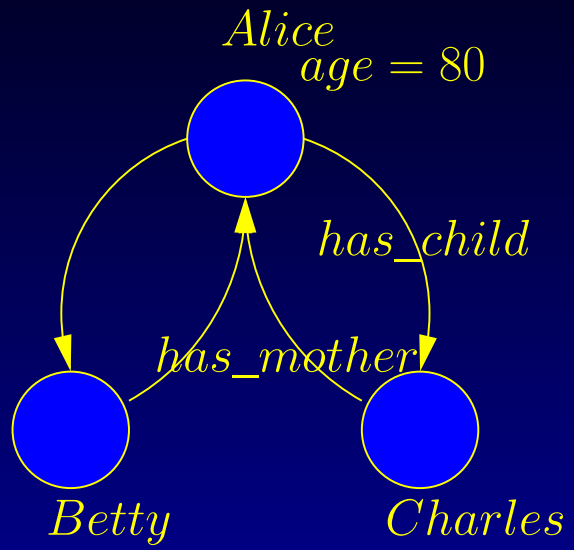

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- How do we retrieve pairs of siblings (e.g., $\{(betty, charles)\}$)?
- ⊖ write a “search program” (not declarative)
- ⊕ use nRQL:

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

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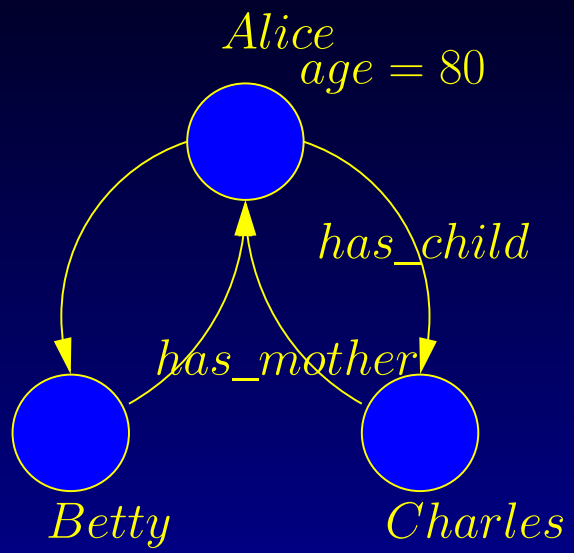

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    - ⇒
```
(((?X CHARLES) (?Y BETTY))
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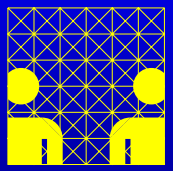
```



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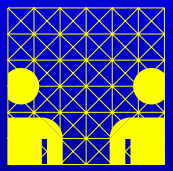

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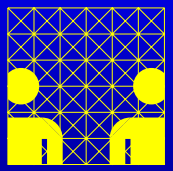

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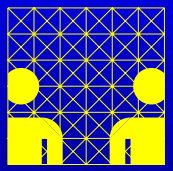

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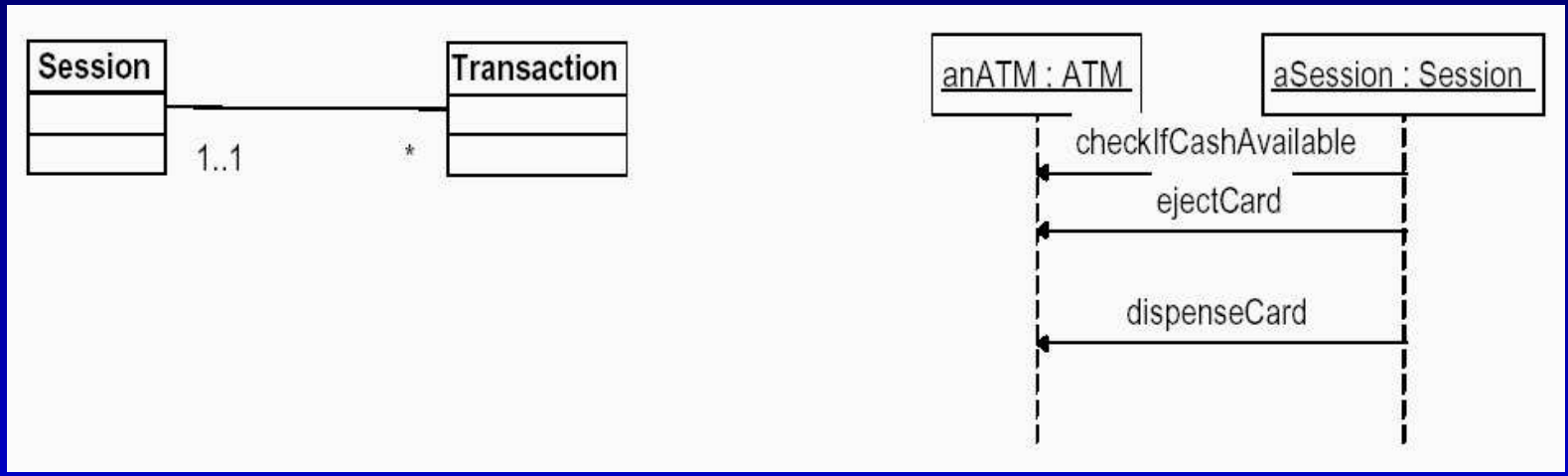

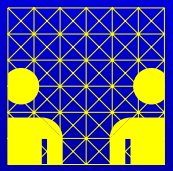

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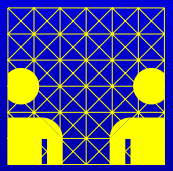

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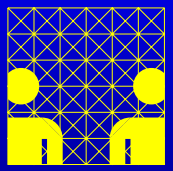

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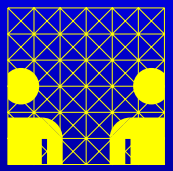
- LOOM:

```
(do-retrieve (?object ?class)
   (:and (Object ?object)
         (Instance-of-class ?object ?class)
         (has-classmodel ?class NIL)))
```



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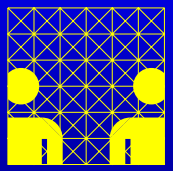
- Racer without nRQL:

```
(loop for ?o in (concept-instances object) do
  (loop for ?c in
        (ret.-ind.-fillers ?o 'instance-of-class)
    when (null (retr.-ind.-fillers
                ?c 'has-classmodel)) do
      (format t ''Classless instance'')))
```



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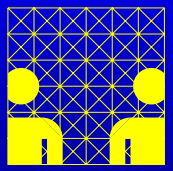
```
(retrieve (?o ?c)
    (and (?c class) (?o object)
         (?o ?c instance-of)
         (not (?c (:has-known-successor
                   has-classmodel)))))
```



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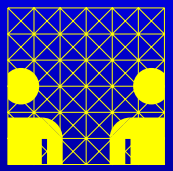

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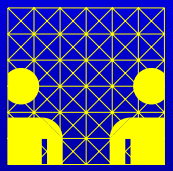
- Variables range over ABox individuals only



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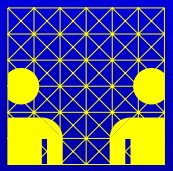

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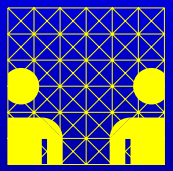
    `(?x ?y R)` $\Rightarrow$ `(?x (some R top))`



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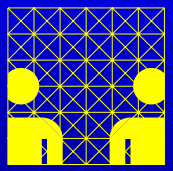

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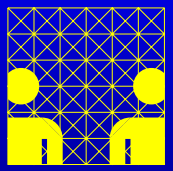

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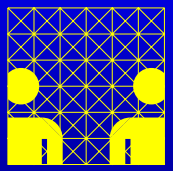
- Support for concrete domain predicates



nRQL Syntax - Query Atoms

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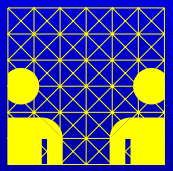
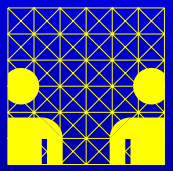


nRQL Syntax - Query Atoms

- Unary Atoms
  - Concept query atoms: $woman(alice)$



nRQL Syntax - Query Atoms

- Unary Atoms
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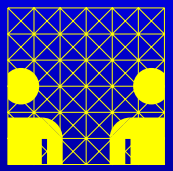
```
(retrieve () (alice woman))
⇒ T
```



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```
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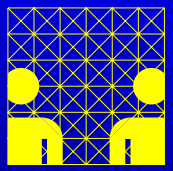
⇒ T

(individual-instance? alice woman)
⇒ T
```



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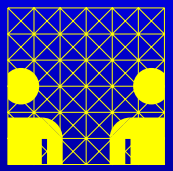

nRQL Syntax - Query Atoms

- Unary Atoms
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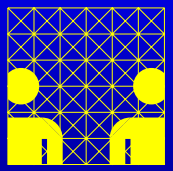
```
(retrieve (?x) (?x woman))
⇒ (((?x alice)) ((?x betty)))
```



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```
(retrieve (?x) (?x woman))
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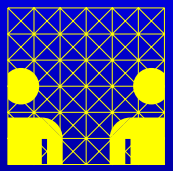
(concept-instances woman)
⇒ (betty alice)
```



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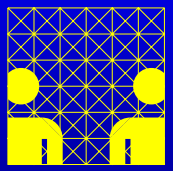

nRQL Syntax - Query Atoms

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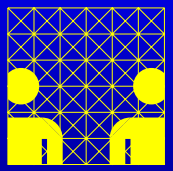

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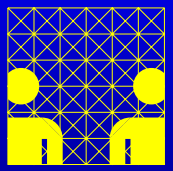
- Unary Atoms
  - Concept query atoms: $C(a)$
  - "Has known successor" atoms: $has\_known\_successor(alice, has\_child)$

```
(retrieve ()
    (alice (:has-known-successor
                has-child)))
```

$\Rightarrow$ `T`



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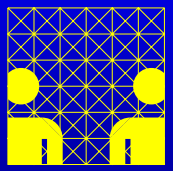

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```
(retrieve ()
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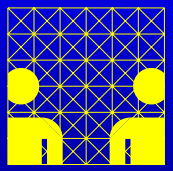
```

$\Rightarrow$ `(((?x alice)))`



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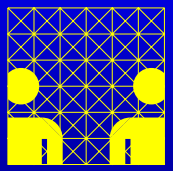
  - What about Betty? ABox: $mother(betty)$



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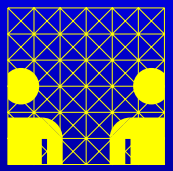
```

$\Rightarrow$ `(((?x alice)))`

  - What about Betty? ABox: $mother(betty)$
  - `(retrieve (?x)`

```
    (?x (some has-child top)))
```

$\Rightarrow$ `(((?x alice)) ((?x betty)))`



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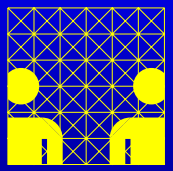

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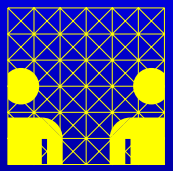

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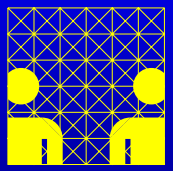

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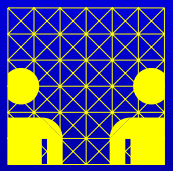
```
(retrieve ()
    (alice charles has-child))
⇒ T
```



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```
(retrieve ()
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⇒ T
(individuals-related? alice charles
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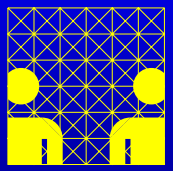
⇒ T
```



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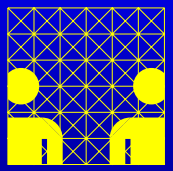

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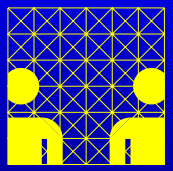
```
(retrieve (?y) (alice ?y has-child))
```

$\Rightarrow$ `(((?y betty)) ((?y charles)))`



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```
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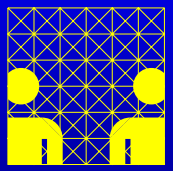
⇒ (((?y betty)) ((?y charles)))

(individual-fillers alice has-child)
⇒ (betty charles)
```



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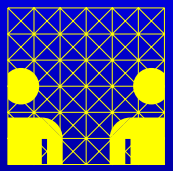

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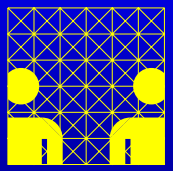
```
(retrieve (?x ?y) (?x ?y has-child))
```

$\Rightarrow$

```
(((?x alice) (?y betty))
 ((?x alice) (?y charles)))
```



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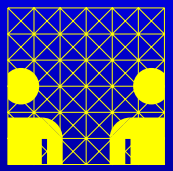
```
(retrieve (?x ?y) (?x ?y has-child))
⇒ (((?x alice) (?y betty))
   ((?x alice) (?y charles)))

(related-individuals has-child)
⇒ ((alice betty) (alice charles))
```



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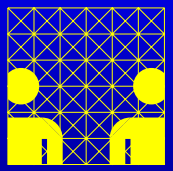

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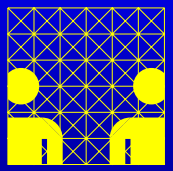
    $= (has\_mother \circ age(x), has\_mother \circ age(y))$



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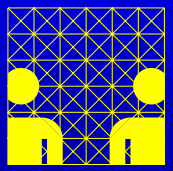
```
(retrieve (?x ?y)
    (?x ?y (:constraint (h-mother age)
                        (h-mother age) =)))
```



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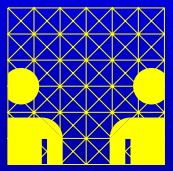
```

$\Rightarrow$ `( ((?x alice) (?y betty)) ...)`



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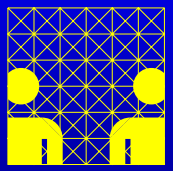

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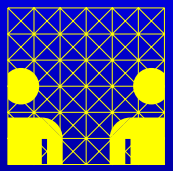

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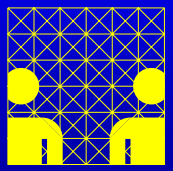

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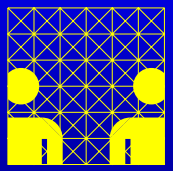
```
(retrieve () (charles woman))
⇒ NIL
```



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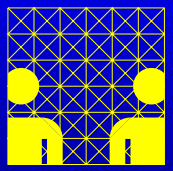
```
(retrieve () (not (charles woman)))
⇒ T
```



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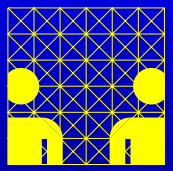

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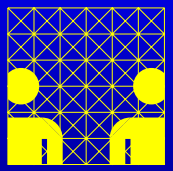
```
(retrieve (?x) (?x woman))
⇒ (((?x betty)) ((?x alice)))
```



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  - Concept query atoms: $C(a)$
  - "Has known successor" atoms: $has\_known\_successor(a, R)$
- Binary Atoms
  - Role query atoms: $R(a, b)$
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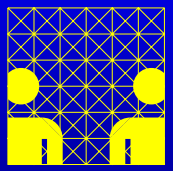
- "Negated" Atoms
  - $\backslash(C(a))$

```
(retrieve (?x) (not (?x woman)))
⇒ (((?x charles)))
```



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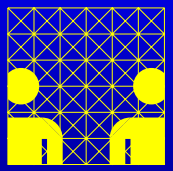
```
(retrieve (?x) (?x (not woman)))
⇒ ()
```



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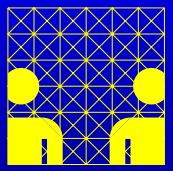

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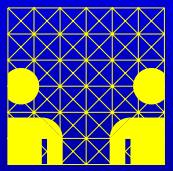
    LOOM: `(retrieve (?x) (?x NIL R))`



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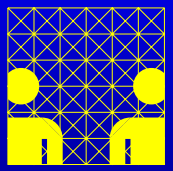

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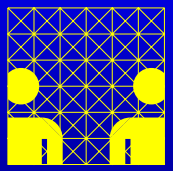

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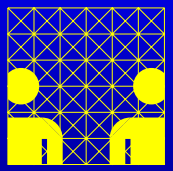

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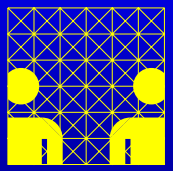

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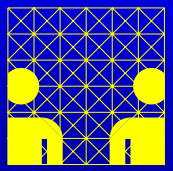

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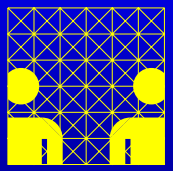

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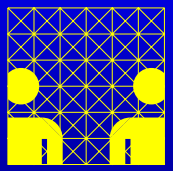

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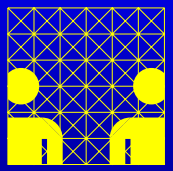

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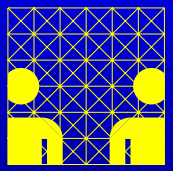

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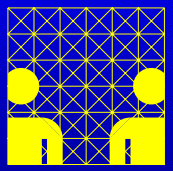

Neg. Atoms with Individuals?

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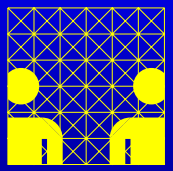

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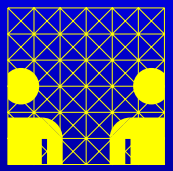
- $atom$ and $\backslash(atom)$ are always complementary
- `(retrieve () (betty woman))`
  $\Rightarrow$ `T`



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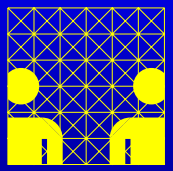

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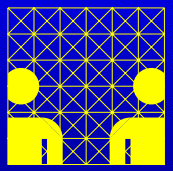

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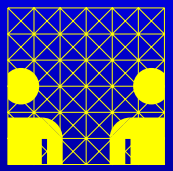

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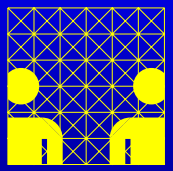

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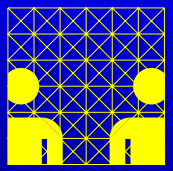

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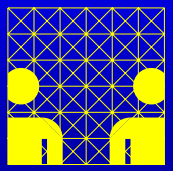

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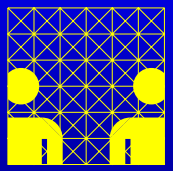

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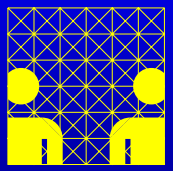
```
(retrieve (betty)
    (and (not (betty man))
         (bind-individual betty)))
```

$\Rightarrow$ `(((betty betty)))`



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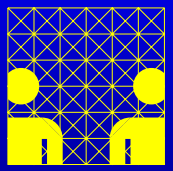

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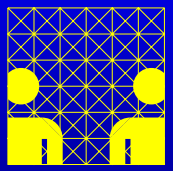

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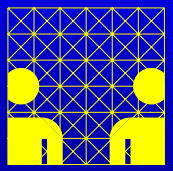

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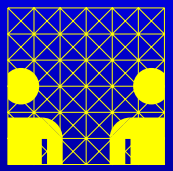

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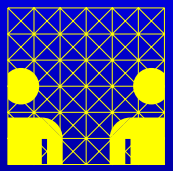

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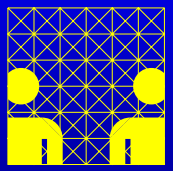

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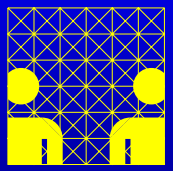

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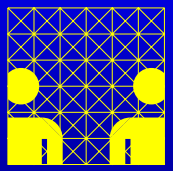
  - `(concept-instances woman)` $\cup$
    `(concept-instances man)`
    $\subset$ `(concept-instances (or woman man))`



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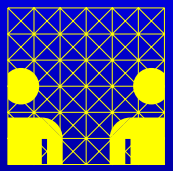

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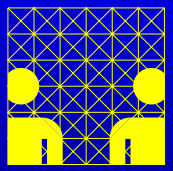

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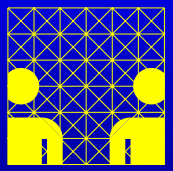

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- We want the NNF:
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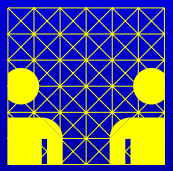
`(not (?y D))))`



Arity of Query Bodies

- Arity of `(and (?x C) (?y D))`: 2
- Arity of `(or (?x C) (?y D))`: ?
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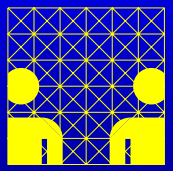

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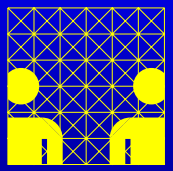

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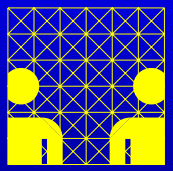
  $\Rightarrow$ Arity of `(or (?x C) (?y D))`: 2
- Internally rewritten into

```
(or (and (?x C) (?y TOP))
    (?y D) (?x TOP))
```



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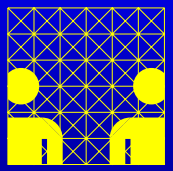
$\Rightarrow$ If C as well as D instances are present, then



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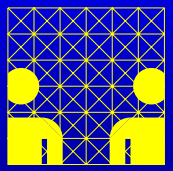
- Internally rewritten into

```
(or (and (?x C) (?y TOP))
         (?y D) (?x TOP))
```

$\Rightarrow$ If C as well as D instances are present, then

```
(retrieve (?x) (or (?x C) (?y D)))
```



Arity of Query Bodies

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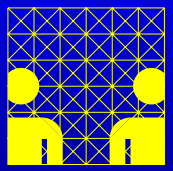
  - `(not (and (not (?x C))`
    `(not (?y D))))`
  - `NOT` preserves arity

  $\Rightarrow$ Arity of `(or (?x C) (?y D))`: 2
- Internally rewritten into

```
(or (and (?x C) (?y TOP))
    (?y D) (?x TOP))
```

$\Rightarrow$ If C as well as D instances are present, then is equivalent to



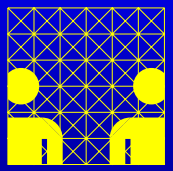
Arity of Query Bodies

- Arity of `(and (?x C) (?y D))`: 2
- Arity of `(or (?x C) (?y D))`: ?
- We want the NNF:
  - `(not (and (not (?x C)) (not (?y D))))`
  - `NOT` preserves arity

  $\Rightarrow$ Arity of `(or (?x C) (?y D))`: 2
- Internally rewritten into

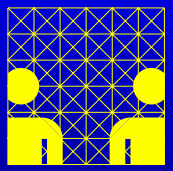
```
(or (and (?x C) (?y TOP))
         (?y D) (?x TOP))
```

$\Rightarrow$ If C as well as D instances are present, then `(retrieve (?x) (?x TOP))`



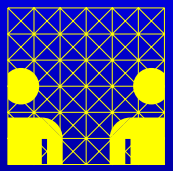
nRQL Query Processing Chain

- Replace syntactic sugar



nRQL Query Processing Chain

- Replace syntactic sugar
  - `(?x NIL R)`
    $\Rightarrow$ `(not (?x (:has-known-successor R)))`



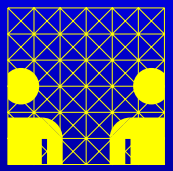
nRQL Query Processing Chain

- Replace syntactic sugar
  - `(?x NIL R)`
    $\Rightarrow$ `(not (?x (:has-known-successor R)))`
  - Break up feature chains

```
(?x ?y (:constraint (has-father age)
                    (has-mother age) =))
```

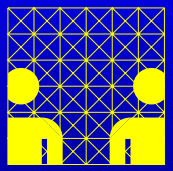
$\Rightarrow$

```
(and (?x $?x-father has-father)
     (?y $?y-mother has-mother)
     ($?x-father $?y-mother
                 (:constraint age age =)))
```



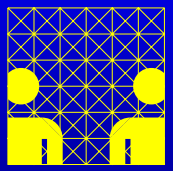
nRQL Query Processing Chain

- Replace syntactic sugar
- Bring query into DNF



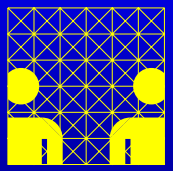
nRQL Query Processing Chain

- Replace syntactic sugar
- Bring query into DNF
- Reasoning (incomplete in general, but useful!)



nRQL Query Processing Chain

- Replace syntactic sugar
- Bring query into DNF
- Reasoning (incomplete in general, but useful!)
  - `(and (?x woman)`
    `(?x ?y has-child)`
    `(?x (not mother)))`



nRQL Query Processing Chain

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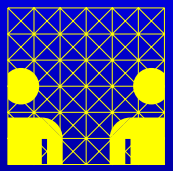
- Bring query into DNF
- Reasoning (incomplete in general, but useful!)
  - `(and (?x woman)`
    `(?x ?y has-child)`
    `(?x (not mother)))`

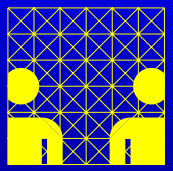
  $\Rightarrow$ inconsistent
  - `(and (?x woman) (?y mother)`
    `(?x ?y has-child))`

  $\Rightarrow$ `(and (?x grandmother) (?y mother)`
    `(?x ?y has-daughter))`



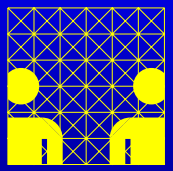
nRQL Query Processing Chain

- Replace syntactic sugar
- Bring query into DNF
- Reasoning (incomplete in general, but useful!)
- Heuristic Optimization



nRQL Query Processing Chain

- Replace syntactic sugar
- Bring query into DNF
- Reasoning (incomplete in general, but useful!)
- Heuristic Optimization
  - `(and (?x woman) (?y man)`
    `(?x ?y has-child))`



nRQL Query Processing Chain

- Replace syntactic sugar
- Bring query into DNF
- Reasoning (incomplete in general, but useful!)
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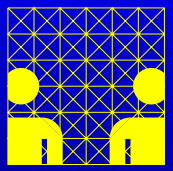
  - `(and (?x woman) (?y man)`
`(?x ?y has-child))`
  - $3! = 6$ orderings of conjuncts



nRQL Query Processing Chain

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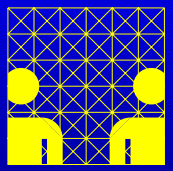
  - $3! = 6$ orderings of conjuncts

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

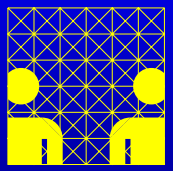
⊕ `(?x woman) (?x ?y has-child) (?y man)`

⊕⊕ `(?y man) (?y ?x child-of) (?x woman)`



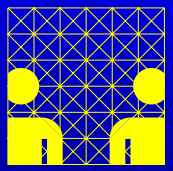
nRQL Query Processing Chain

- Replace syntactic sugar
- Bring query into DNF
- Reasoning (incomplete in general, but useful!)
- Heuristic Optimization
- Execution: find solutions of a finite domain CSP



nRQL Query Processing Chain

- Replace syntactic sugar
- Bring query into DNF
- Reasoning (incomplete in general, but useful!)
- Heuristic Optimization
- Execution: find solutions of a finite domain CSP
  - Compilation of a LISP program from query
  - Backtracking Search



nRQL Query Processing Chain

- Replace syntactic sugar
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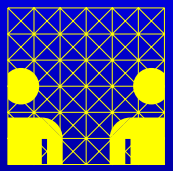
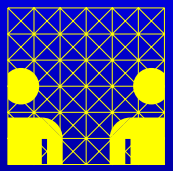
- Reasoning (incomplete in general, but useful!)
- Heuristic Optimization
- Execution: find solutions of a finite domain CSP
- Construction of result tuples from body bindings



nRQL Query Processing Chain

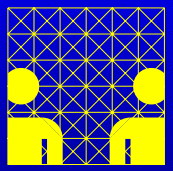
- Replace syntactic sugar
- Bring query into DNF
- Reasoning (incomplete in general, but useful!)
- Heuristic Optimization
- Execution: find solutions of a finite domain CSP
- Construction of result tuples from body bindings
  - Duplications and reorderings possible, e.g.

```
(retrieve (?x ?y ?x)
      (and (?y ...) (?x ...) ...))
```



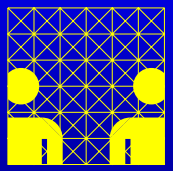
Future Work

- Reasoning with queries



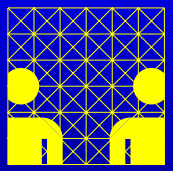
Future Work

- Reasoning with queries
  - $\Rightarrow$ Functions for Racer's API



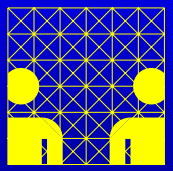
Future Work

- Reasoning with queries
  - $\Rightarrow$ Functions for Racer's API
- Server Continuations



Future Work

- Reasoning with queries
  - ⇒ Functions for Racer's API
- Server Continuations
  - "Tuple at a time"
  - "Set at a time"
  - ⇒ Functions / Switches for Racer's API



Future Work

- Reasoning with queries

  $\Rightarrow$ Functions for Racer's API

- Server Continuations
  - "Tuple at a time"
  - "Set at a time"

  $\Rightarrow$ Functions / Switches for Racer's API

- Complex constraint expressions:

```
(?x ?y (:constraint
                (>= (- (father age) 10)
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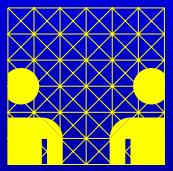
```



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- Reasoning with queries

  $\Rightarrow$ Functions for Racer's API

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  - "Tuple at a time"
  - "Set at a time"

  $\Rightarrow$ Functions / Switches for Racer's API

- Complex constraint expressions:

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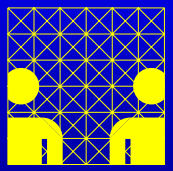
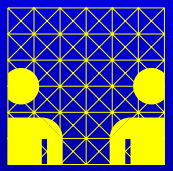
- Enhance efficency



Limitations of nRQL

- Consider the ABox $\mathcal{A} =_{def} \{(\exists R.C)(i)\}$



Limitations of nRQL

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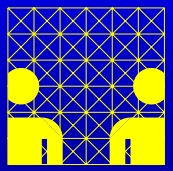
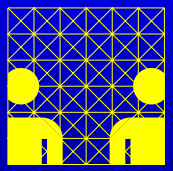
- Logic tells us $\mathcal{A} \models \exists x.C(x)$



Limitations of nRQL

- Consider the ABox $\mathcal{A} =_{def} \{(\exists R.C)(i)\}$
- Logic tells us $\mathcal{A} \models \exists x.C(x)$
- But there is no $j \in \mathsf{individuals}(\mathcal{A})$ with $j^{\mathcal{I}} \in C^{\mathcal{I}}$ in all $(\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$ with $(\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}}) \models \mathcal{A}$



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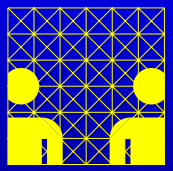
- `(retrieve (?x) (?x C))` $\Rightarrow$ `NIL`



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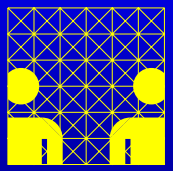
- `(retrieve (?x) (?x C))` $\Rightarrow$ `NIL`
- Reason: `(concept-instances C)` $\Rightarrow$ `NIL`



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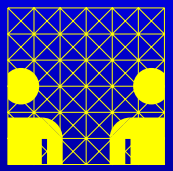
- `(retrieve (?x) (?x C))` $\Rightarrow$ `NIL`
- Reason: `(concept-instances C)` $\Rightarrow$ `NIL`
- `(retrieve (?x) (?x C))`

  $\Rightarrow$ `(((?x temp123))) better?`



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- Consider the ABox $\mathcal{A} =_{def} \{(\exists R.C)(i)\}$
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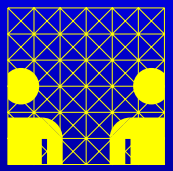
- `(retrieve (?x) (?x C))` $\Rightarrow$ `NIL`
- Reason: `(concept-instances C)` $\Rightarrow$ `NIL`
- `(retrieve (?x) (?x C))`

  $\Rightarrow$ `(((?x (and C (some (inv R)`
  `(one-of i))))))`

  better?



Limitations of nRQL

- Consider the ABox $\mathcal{A} =_{def} \{(\exists R.C)(i)\}$
- Logic tells us $\mathcal{A} \models \exists x.C(x)$
- But there is no $j \in \mathsf{individuals}(\mathcal{A})$ with $j^{\mathcal{I}} \in C^{\mathcal{I}}$ in all $(\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}})$ with $(\Delta^{\mathcal{I}}, \cdot^{\mathcal{I}}) \models \mathcal{A}$
- `(retrieve (?x) (?x C))` $\Rightarrow$ `NIL`
- Reason: `(concept-instances C)` $\Rightarrow$ `NIL`
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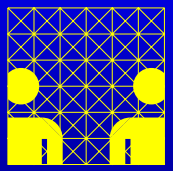

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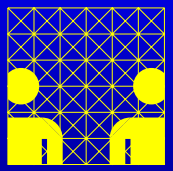

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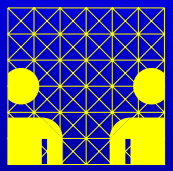

Summing up, nRQL . . .

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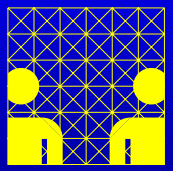

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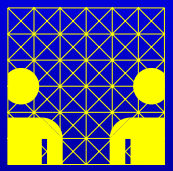

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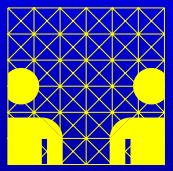

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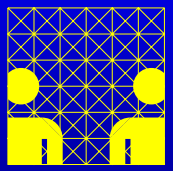

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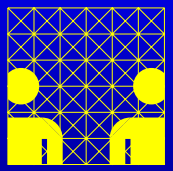

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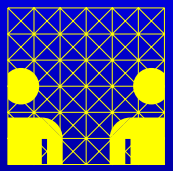

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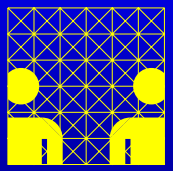

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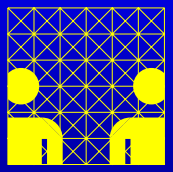

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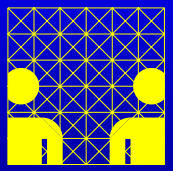

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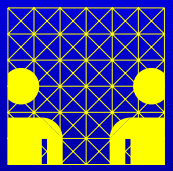

Thank you!