

Exploring Scenario Exploration

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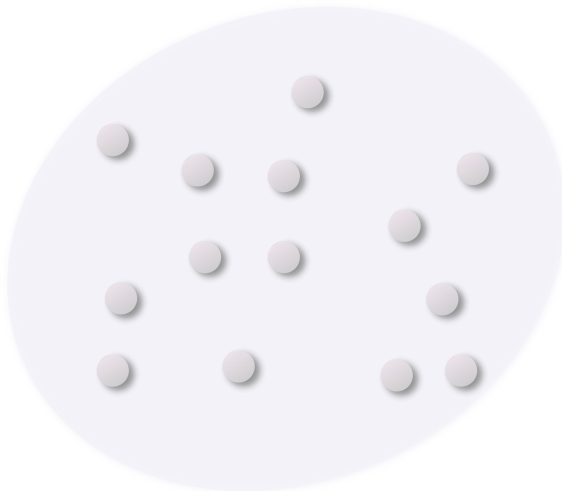
Universidade do Minho

InfoBlender
April 8, 2015
Braga, Portugal

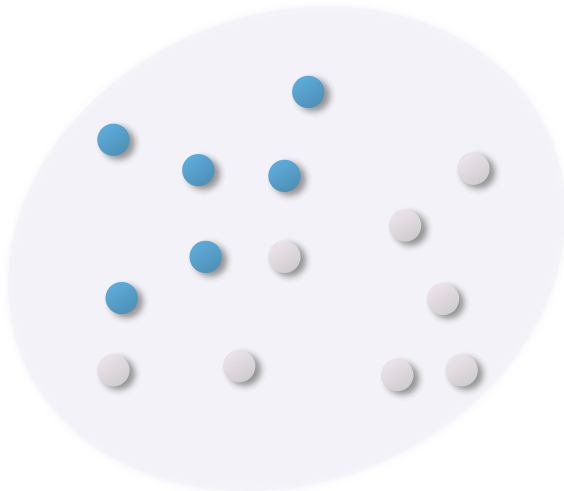
Introduction

- *Model finders* search for models that satisfy a given formula;
- Important at early MDE development stages to quickly generate *scenarios* and validate the specification;
- *Alloy*, and the underlying finder *Kodkod*, have proven suitable for this task;
- Limited usefulness: *no control* on how scenarios are generated:
 - Generate minimal / maximal scenarios;
 - Generate next closest / farthest scenarios;
 - Adapt to specification evolution;
 - ...

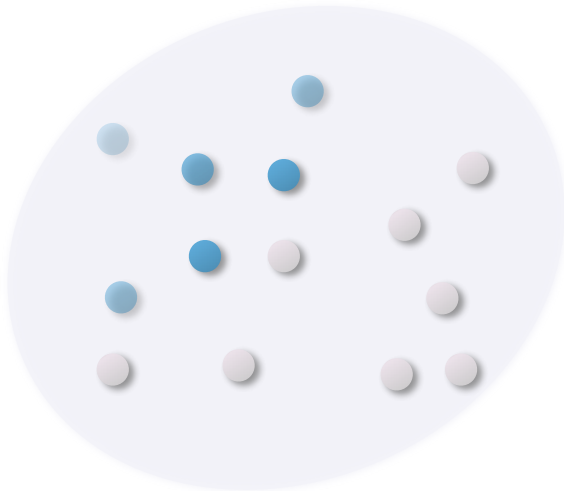
Motivation



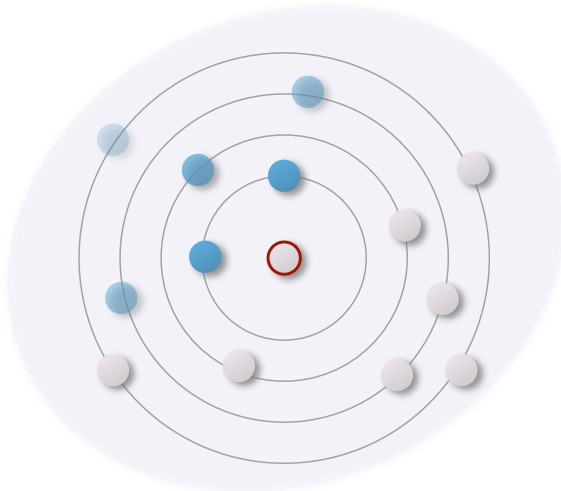
Motivation



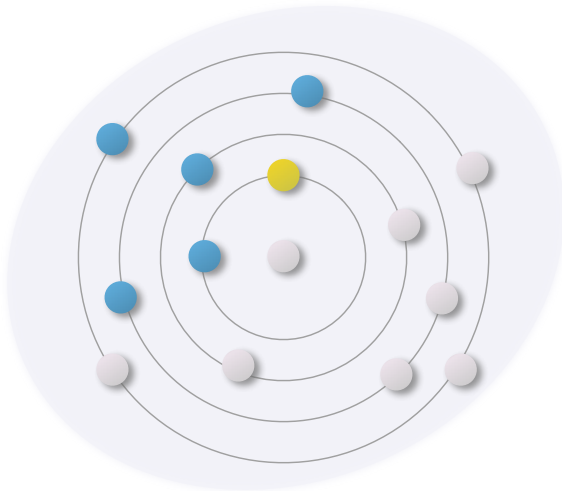
Motivation



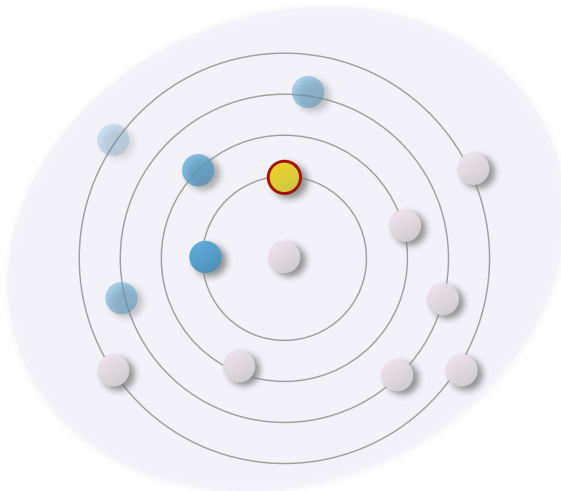
Motivation



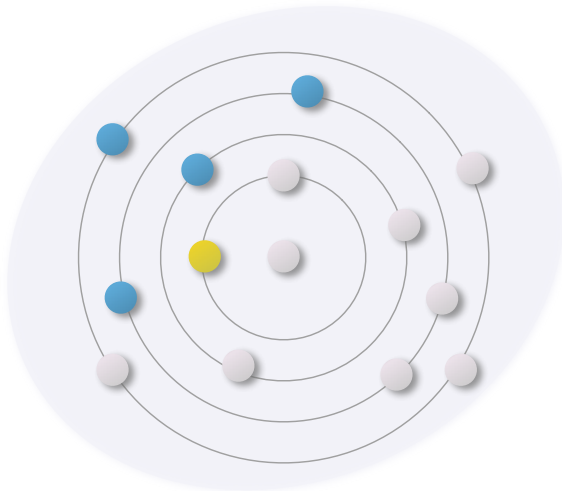
Motivation



Motivation



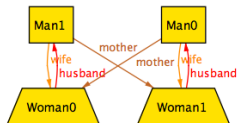
Motivation



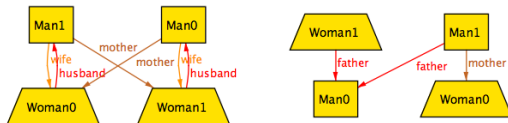
“I’m My Own Grandpa” in Alloy

```
abstract sig Person {  
    father  : lone Man,  
    mother  : lone Woman  
}  
sig Man extends Person {  
    wife    : lone Woman  
}  
sig Woman extends Person {  
    husband : lone Man  
}  
fact {  
    no p:Person | p in p.^(mother+father)      // Biology  
    wife = ~husband                             // Terminology  
    no (wife+husband) & ^^(mother+father)      // SocialConvention  
    Person in                                   // NoSolitary  
        Person.(mother+father+~mother+~father+wife+husband)  
}  
run {} for exactly 2 Man, exactly 2 Woman
```

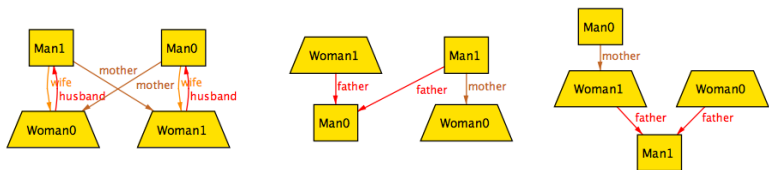
"I'm My Own Grandpa" in Alloy



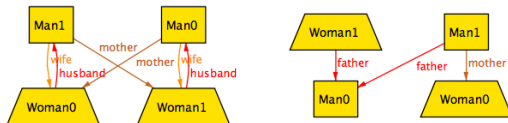
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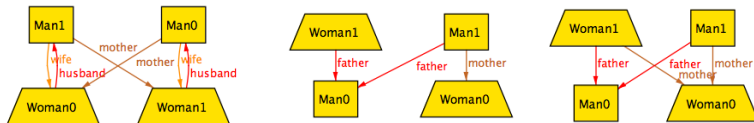
“I’m My Own Grandpa” in Alloy



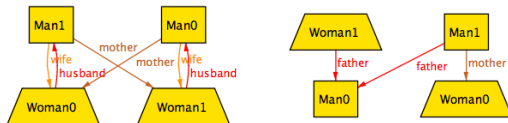
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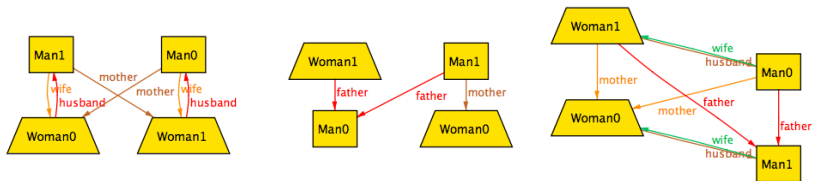
"I'm My Own Grandpa" in Alloy



“I’m My Own Grandpa” in Alloy



“I’m My Own Grandpa” in Alloy



Overview

- We formalize the notion of *weighted target-oriented model finding*;
- Kodkod is extended to support such model finding problems;
- We explore a set of *scenario exploration operations* over them;
- The Alloy Analyzer is extended to support these scenario exploration operations.

Kodkod

- Kodkod = relational logic + partial instances;
- Relational logic:
 - High-level specification language;
 - Favors a navigational style similar to OO;
 - Includes closures to express reachability properties;
- Partial instances:
 - Capture a priori knowledge about the desired outcome;
 - Bound the set of admissible instances (by specifying which elements may or must be present).

Model Finding

- A *model finding problem* $\langle \mathcal{A}, L, U, \phi \rangle \in \mathcal{P}$ consists of:
 - a universe of atoms \mathcal{A} , from which tuple sets \mathcal{T} are drawn;
 - lower- and upper-bounds $L, U : \mathcal{R} \rightarrow \mathcal{T}$ that define and bound the free relational variables \mathcal{R} ;
 - a relational formula ϕ over \mathcal{R} variables.
- Model finding returns (arbitrary) bindings $B : \mathcal{R} \rightarrow \mathcal{T}$ within L and U that satisfy ϕ .

“I’m My Own Grandpa” in Kodkod

```
{M0,M1,W0,W1}
```

```
Man      : ({M0,M1},{M0,M1})
```

```
Woman    : ({W0,W1},{W0,W1})
```

```
father    : ({},{(M0,M0),(M0,M1),(M1,M0),(M1,M1),
                (W0,M0),(W0,M1),(W1,M0),(W1,M1)})
```

```
mother    : ({},{(M0,W0),(M0,W1),(M1,W0),(M1,W1),
                (W0,W0),(W0,W1),(W1,W0),(W1,W1)})
```

```
wife      : ({},{(M0,W0),(M1,W0),(M0,W1),(M1,W1)})
```

```
husband   : ({},{(W0,M0),(W1,M0),(W0,M1),(W1,M1)})
```

```
all p:Man | lone p.wife && all p:Woman | lone p.husband
```

```
all p:Man+Woman | lone p.father && lone p.mother
```

```
all p:Man+Woman | !(p in p.^(mother+father))
```

```
wife = ~husband
```

```
no ((wife+husband) & ^(mother+father))
```

```
Man+Woman in (Man+Woman).(father+mother+~father+~mother+wife+husband)
```

Target-oriented Model Finding

- A *weighted target-oriented model finding problem* $\langle \mathcal{A}, L, U, T, w, \phi \rangle \in \mathcal{P}$ consists of:
 - a regular model finding problem $\langle \mathcal{A}, L, U, \phi \rangle$;
 - targets $T : \mathcal{R} \rightarrow \mathcal{T}$ for some of the \mathcal{R} variables within the bounds;
 - weights $w : \mathcal{R} \rightarrow \mathbb{N}_0$ for some of the \mathcal{R} variables.
- Model finding returns bindings $B : \mathcal{R} \rightarrow \mathcal{T}$ that are solutions of $\langle \mathcal{A}, L, U, \phi \rangle$ and minimize the following distance:

$$\sum_{r \in \text{dom } W} w(r) |B(r) \ominus T(r)| + \sum_{r \in \text{dom } T \setminus \text{dom } W} |B(r) \ominus T(r)|$$

“I’m My Own Grandpa” in Target-oriented Kodkod

```
{M0,M1,W0,W1}
```

```
Man      : ({M0,M1},{M0,M1},{M0,M1},3)
```

```
Woman    : ({W0,W1},{W0,W1},{W0,W1},3)
```

```
father    : ({},{(M1,M0),(W1,M0)},{(M0,M0),(M0,M1),(M1,M0),(M1,M1),
                                     (W0,M0),(W0,M1),(W1,M0),(W1,M1)},3)
```

```
mother    : ({},{(M1,W0)},{(M0,W0),(M0,W1),(M1,W0),(M1,W1),
                                     (W0,W0),(W0,W1),(W1,W0),(W1,W1)},3)
```

```
wife      : ({},{},{(M0,W0),(M1,W0),(M0,W1),(M1,W1)},1)
```

```
husband   : ({},{},{(W0,M0),(W1,M0),(W0,M1),(W1,M1)},1)
```

```
all p:Man | lone p.wife && all p:Woman | lone p.husband
```

```
all p:Man+Woman | lone p.father && lone p.mother
```

```
all p:Man+Woman | !(p in p.^(mother+father))
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wife = ~husband
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Man+Woman in (Man+Woman).(father+mother+~father+~mother+wife+husband)
```

Embedding Specifications

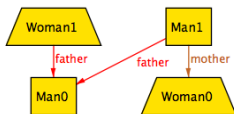
- A specification S is embedded in Kodkod as:

$$\llbracket S \rrbracket = \langle \mathcal{A}_S, L_S, U_S, \{\}, \underline{1}, \phi_S \rangle$$

- Atoms are reified as relations:

$$\forall A \in \mathcal{A} | A \in \mathcal{R} \wedge L(A) = U(A) = \{A\}$$

- $[B]_{=}$ tests whether the value of the relations is that of B :



$M0 + M1$	= Man	and
$W0 + W1$	= Woman	and
$M1 \rightarrow M0 + W1 \rightarrow M0$	= father	and
$M1 \rightarrow W0$	= mother	and
none \rightarrow none	= wife	and
none \rightarrow none	= husband	

Scenario Exploration

- State transition system with model finding problems as states;
- Generates the first problem:

$$\text{init} : \mathcal{S} \rightarrow \mathcal{P}$$

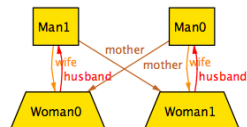
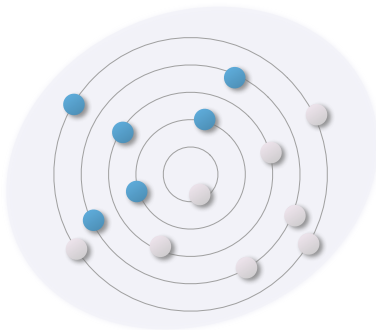
- Given the previous solution, generates the succeeding problem:

$$\text{next} : \mathcal{P} \times (\mathcal{R} \rightarrow \mathcal{T}) \rightarrow \mathcal{P}$$

Regular Generation

- Arbitrary scenarios.

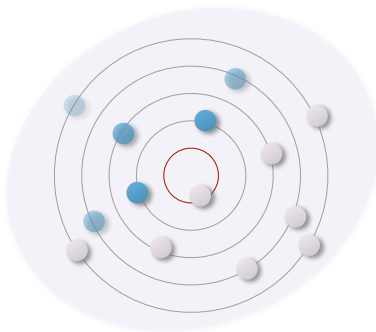
$$\text{init}(S) = \langle \mathcal{A}_S, L_S, U_S, \{\}, \underline{1}, \phi_S \rangle$$



Minimal Generation

- Minimal scenarios.

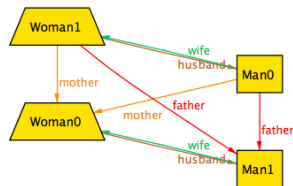
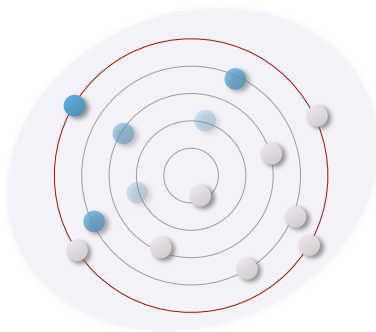
$$\text{init}_\perp(S) = \langle \mathcal{A}_S, L_S, U_S, L_S, \underline{1}, \phi_S \rangle$$



Maximal Scenarios

- Maximal scenarios (high complexity).

$$\text{init}_T(S) = \langle \mathcal{A}_S, L_S, U_S, U_S, \underline{1}, \phi_S \rangle$$

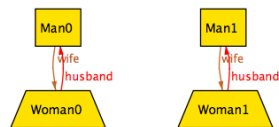
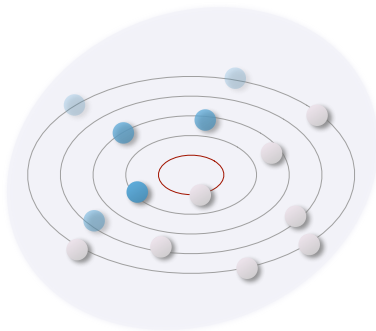


Weighted Generation

- Control the notion of 'minimal' and 'maximal' with w .

$$\text{init}_{\perp}^w(S) = \langle \mathcal{A}_S, L_S, U_S, L_S, w, \phi_S \rangle$$

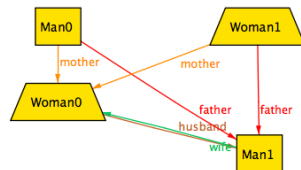
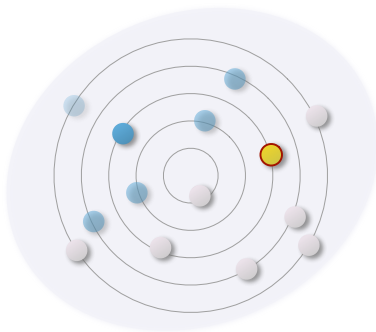
$$\text{init}_{\top}^w(S) = \langle \mathcal{A}_S, L_S, U_S, U_S, w, \phi_S \rangle$$



Generation from Instance

- Restart from a previously known instance B .

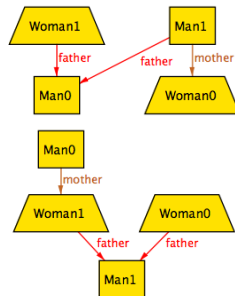
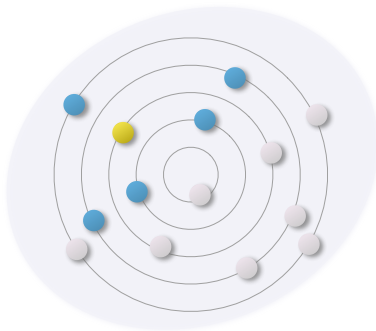
$$\text{init}_B(S) = \langle \mathcal{A}_S, L_S, U_S, B, \underline{1}, \phi_S \rangle$$



Regular Iteration

- Arbitrary solution.

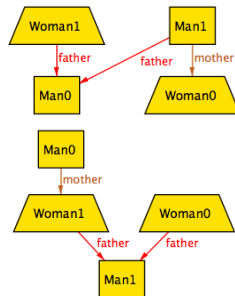
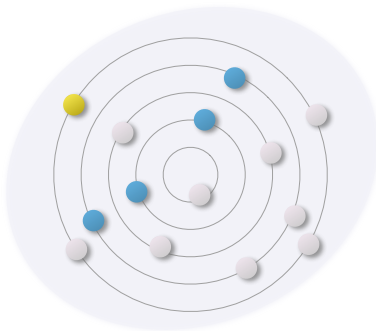
$$\text{next}(\langle \mathcal{A}, L, U, _, _, \phi \rangle, B_0) = \langle \mathcal{A}, L, U, \{\}, \underline{1}, \phi \wedge \neg[B_0] = \rangle$$



Regular Iteration

- Arbitrary solution.

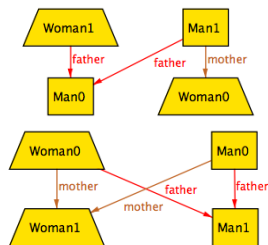
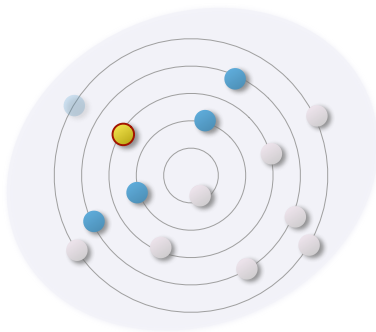
$$\text{next}(\langle \mathcal{A}, L, U, _, _, \phi \rangle, B_0) = \langle \mathcal{A}, L, U, \{ \}, \underline{1}, \phi \wedge \neg[B_0] = \rangle$$



Least-change Iteration

- Generate solutions closest to the current one.

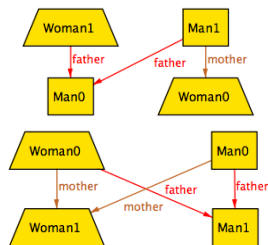
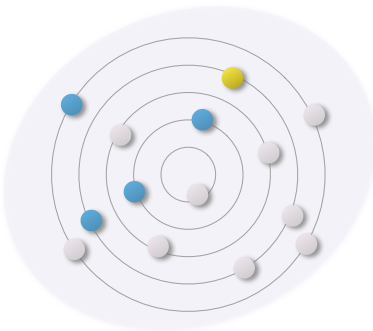
$$\text{next}_{\perp}(\langle \mathcal{A}, L, U, _, _, \phi \rangle, B_0) = \langle \mathcal{A}, L, U, B_0, \underline{1}, \phi \wedge \neg[B_0] = \rangle$$



Least-change Iteration

- Generate solutions closest to the current one.

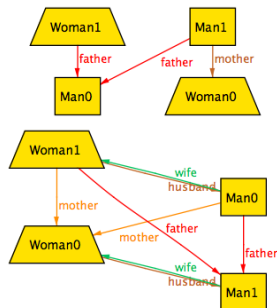
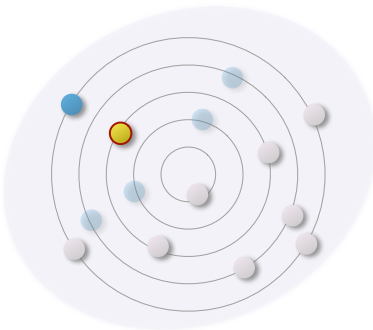
$$\text{next}_{\perp}(\langle \mathcal{A}, L, U, _, _, \phi \rangle, B_0) = \langle \mathcal{A}, L, U, B_0, \underline{1}, \phi \wedge \neg[B_0] = \rangle$$



Most-change Iteration

- Generate solutions farthest from the current one.

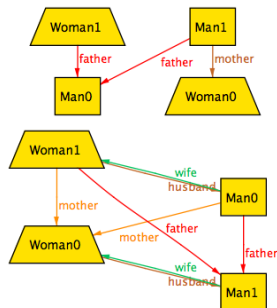
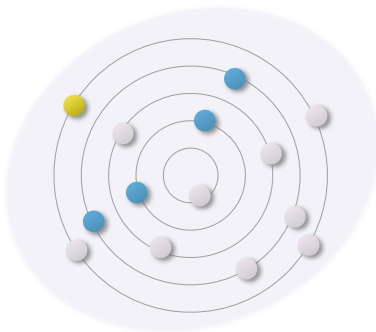
$$\text{next}_T(\langle \mathcal{A}, L, U, _, _, \phi \rangle, B_0) = \langle \mathcal{A}, L, U, \overline{B_0}, \underline{1}, \phi \wedge \neg[B_0] = \rangle$$



Most-change Iteration

- Generate solutions farthest from the current one.

$$\text{next}_T(\langle \mathcal{A}, L, U, _, _, \phi \rangle, B_0) = \langle \mathcal{A}, L, U, \overline{B_0}, \underline{1}, \phi \wedge \neg[B_0] = \rangle$$



Other Iteration Operations

- *Weighted iteration*: control the notion of least- and most-change with w .

$$\text{next}_{\perp}^w(\langle \mathcal{A}, L, U, _, _, \phi \rangle, B_0) = \langle \mathcal{A}, L, U, B_0, w, \phi \wedge \neg[B_0]_{=} \rangle$$

$$\text{next}_{\top}^w(\langle \mathcal{A}, L, U, _, _, \phi \rangle, B_0) = \langle \mathcal{A}, L, U, \overline{B_0}, w, \phi \wedge \neg[B_0]_{=} \rangle$$

- *Circular iteration*: circulate a fixed preferred solution T .

$$\text{next}_T(\langle \mathcal{A}, L, U, _, _, \phi \rangle, B_0) = \langle \mathcal{A}, L, U, T, \underline{1}, \phi \wedge \neg[B_0]_{=} \rangle$$

- *Extended iteration*: introduce a new constraint ψ .

$$\text{next}_{\psi}(\langle \mathcal{A}, L, U, _, _, \phi \rangle, B_0) = \langle \mathcal{A}, L, U, B_0, \underline{1}, \phi \wedge \psi \rangle$$

Alloy Analyzer Extension

- The Alloy Analyzer was extended to support Kodkod with weighted target-oriented model finding;
- Implemented support for init_{\perp} , init_{\top} , next_{\perp}^w and next_{\top}^w as proof of concept;
- Seamless integration to the regular Alloy user;
 - Weights are stored in the theme.

Conclusions

- Scenario exploration operations formalized over weighted target-oriented problems;
- New functionalities improve the usefulness of the Alloy Analyzer in scenario exploration;
- *Extension*: Implement the additional operations in the Analyzer;
- *Usability*: Infer weights from user feedback;
- *Evaluation*: Empirical study on the effectiveness of new scenario exploration operations.