Mastering Alloy

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Overloading

Overloading

- Fields in disjoint signatures can be *overloaded* (have the same name)
- *Ambiguity* errors may occur

Overloading example

```
abstract sig Object {}
sig Dir extends Object {
   contains : set Entry
}
sig File extends Object {}
one sig Root extends Dir {}
sig Entry {
   contains : one Object,
   has : one Name
}
sig Name {}
```

Constraints

```
fact {
   // All directories are referred to in at most one entry
   all d : Dir | lone contains.d

    // The root is not referred in any entry
   no contains.Root

   // All objects except the root are referred to in at least one entry
   Object - Root in Entry.contains

   // Different entries in a directory must have different names
   all d : Dir, n : Name | lone (d.contains & has.n)
}
```

Constraints

```
fact {
  // A directory cannot be contained in itself
  all d : Dir | d not in d.^(contains.contains)
}
```

Ambiguity errors

```
run { some contains }
```

```
A type error has occurred:
This name is ambiguous due to multiple matches:
field this/Dir <: contains
field this/Entry <: contains
```

Resolving ambiguities

```
run { some d : Dir | some d.contains }

run { some contains & Dir->Entry }

run { some Dir <: contains }
```

Predicates and functions

Predicates

- In Alloy *predicates* are parametrized reusable constraints
  - Can also be derived propositions (without arguments)
  - Parameters can be arbitrary relations
- Only hold when invoked in a fact, command, or other predicates
- Recursive definitions are not allowed
- Run commands can directly ask for an instance satisfying a predicate
  - Atoms instantiating the parameters are shown in the visualizer

Predicate example

```
pred isreachable [d : Dir, o : Object] {
  o in d.^(contains.refersTo)
}

fact {
  // A directory cannot be contained in itself
  all d : Dir | not isreachable[d,d]
}
```

Higher-order predicate example

```
pred acyclic [r : univ -> univ] {
  no ^r & iden
}

fact {
  // A directory cannot be contained in itself
  acyclic[contains.refersTo]
}
```

Functions

- *Functions* are parametrized reusable expressions
  - Parameters can be arbitrary relations
- Functions without parameters can be used to define derived relations
  - These show up in the visualizer
- Recursive definitions are not allowed

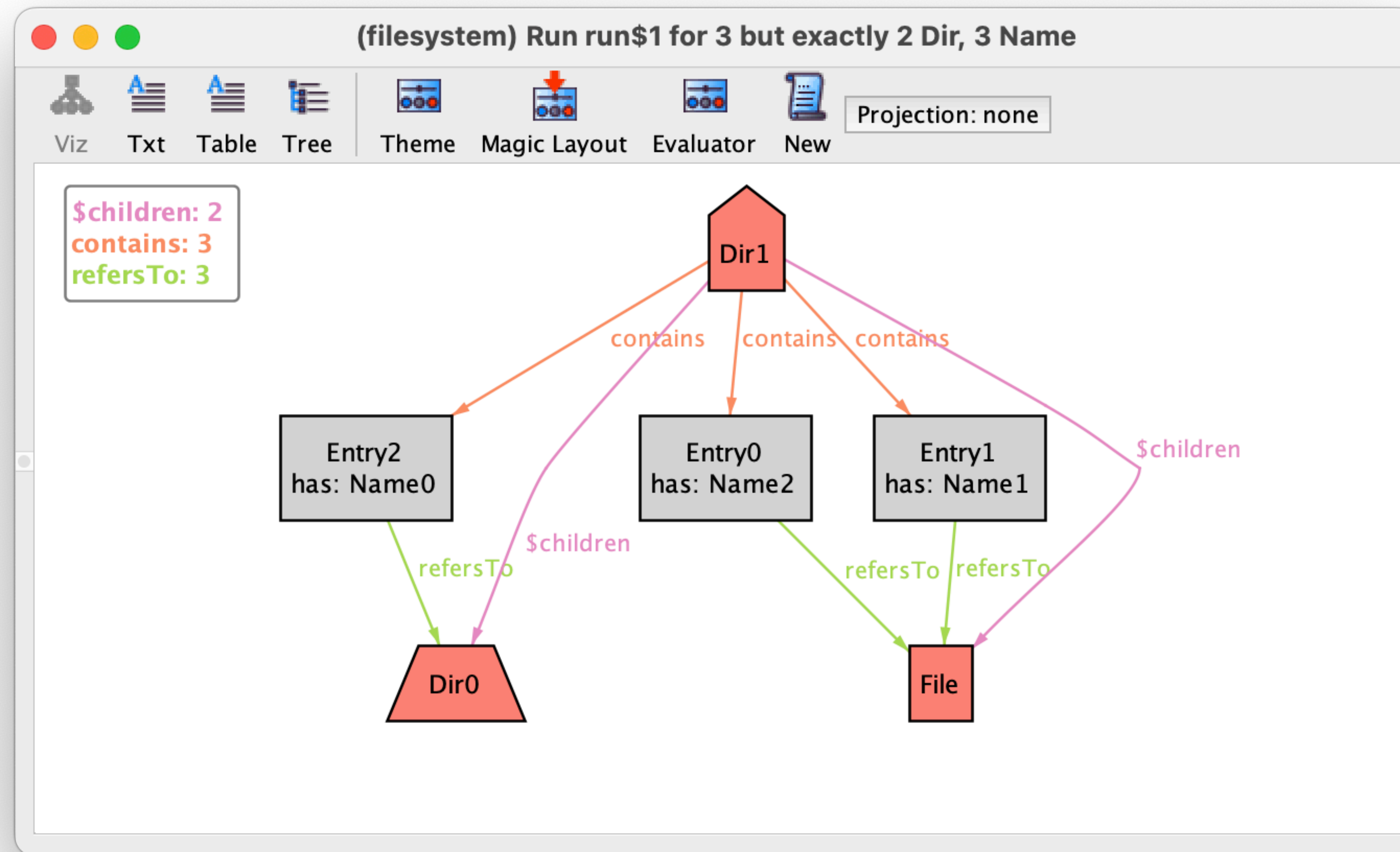
Function example

```
fun descendants [d : Dir] : set Object {
  d.^(contains.refersTo)
}

fact {
  // A directory cannot be contained in itself
  all d : Dir | d not in descendants[d]
}
```

Derived relation example

```
fun children : Dir -> Object {
  contains.refersTo
}

fact {
  // A directory cannot be contained in itself
  all d : Dir | d not in d.^children
}
```

Visualizing derived relations



Modules

Modules

- A specification can be split into *modules*
- The module name is declared in the first line with keyword **`module`**
- A module can be imported with an **`open`** statement
  - The imported model name must match the path of the corresponding file
  - To disambiguate a call to an entity, the module name can be prepended
  - An alias can be given with the **`as`** keyword
- A module can be parametrised by one or more signatures

Module example

```
module relation

pred acyclic [r : univ -> univ] {
  no ^r & iden
}
```

Module example

```
open relation

fact {
  // A directory cannot be contained in itself
  acyclic[contains.refersTo]
}
```

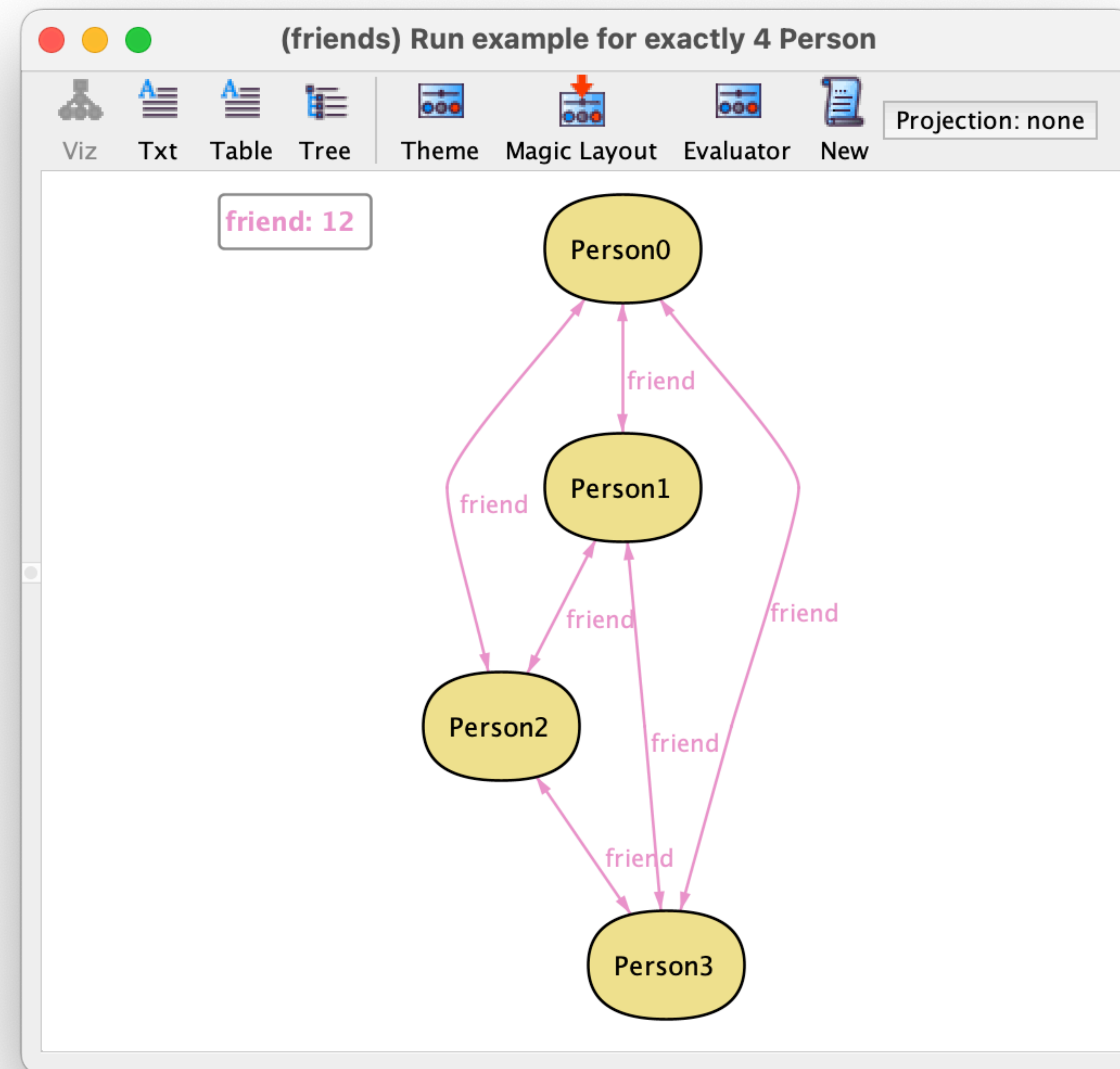
Parametrized module example

```
module graph[node]

pred complete[adj : node -> node] {
  all n : node | n.adj = node-n
}
```

Parametrized module example

```
open graph[Person]

sig Person {
  friend : set Person
}

fact { complete[friend] }
```

We are all friends



Predefined modules

`util/relation`	Useful functions and predicates for binary relations
`util/ternary`	Useful functions and predicates for ternary relations
`util/graph[A]`	Useful functions and predicates for graphs with nodes from signature `A`
`util/natural`	Natural numbers, including some arithmetic operations
`util/boolean`	Boolean type, including common logical connectives
`util/ordering[A]`	Imposes a total order on signature `A`

`util/ordering`

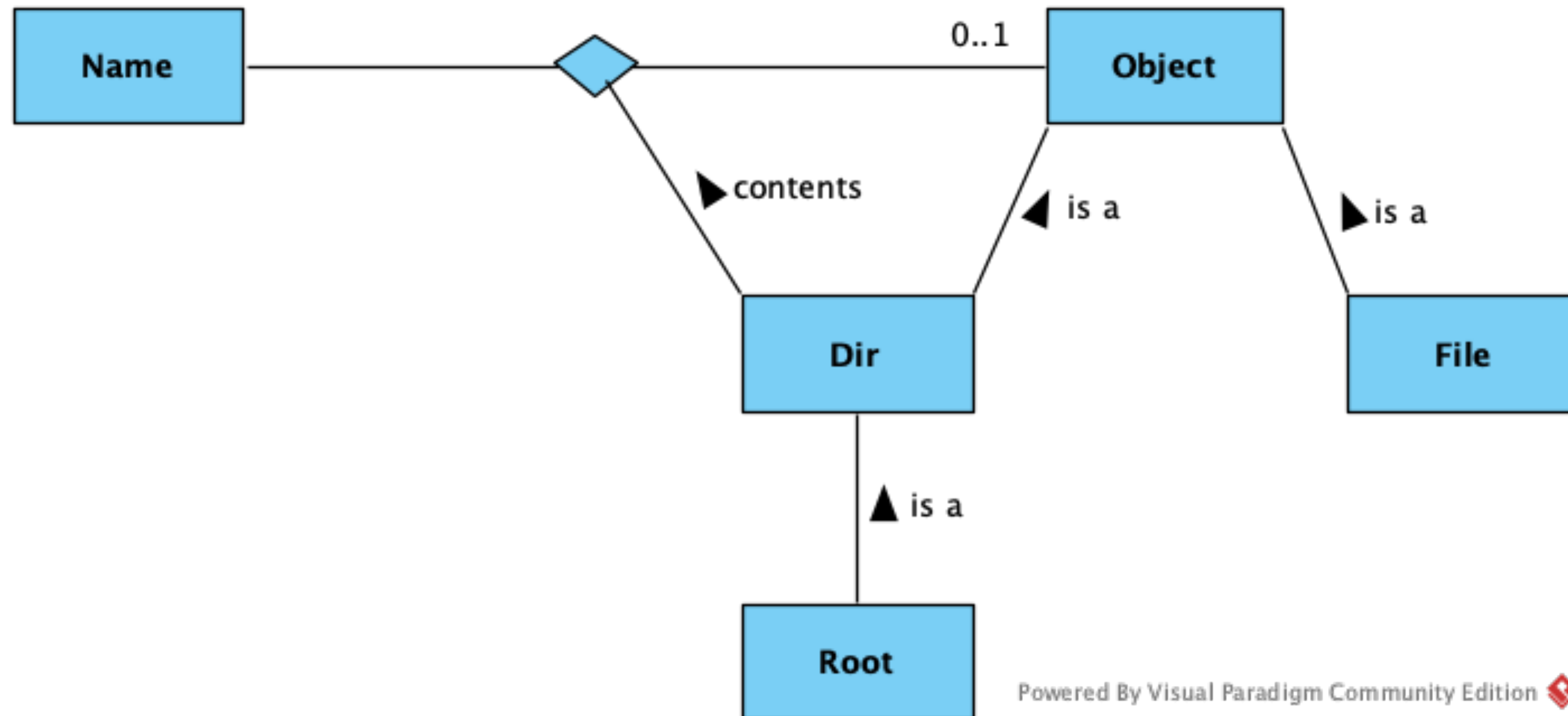
- Imposes a total order on the parameter signature
- For efficiency reasons the scope on that signature becomes exact
- Visualiser attempts to name atoms according to the order
- Many useful functions and relations, including
  - `next` and `prev` binary relations
  - `first` and `last` singleton sets
  - `lt`, `lte`, `gt`, and `gte` comparison predicates

util/ordering example

```
open util/ordering[Date]

sig Date {}
sig Entry {
   refersTo : one Object,
   has   : one Name,
   date : one Date
}

fact {
   // A directory cannot be contained in itself
   all e : Entry, c : e.refersTo.contains | lt[e.date, c.date]
}
```

N-ary relations

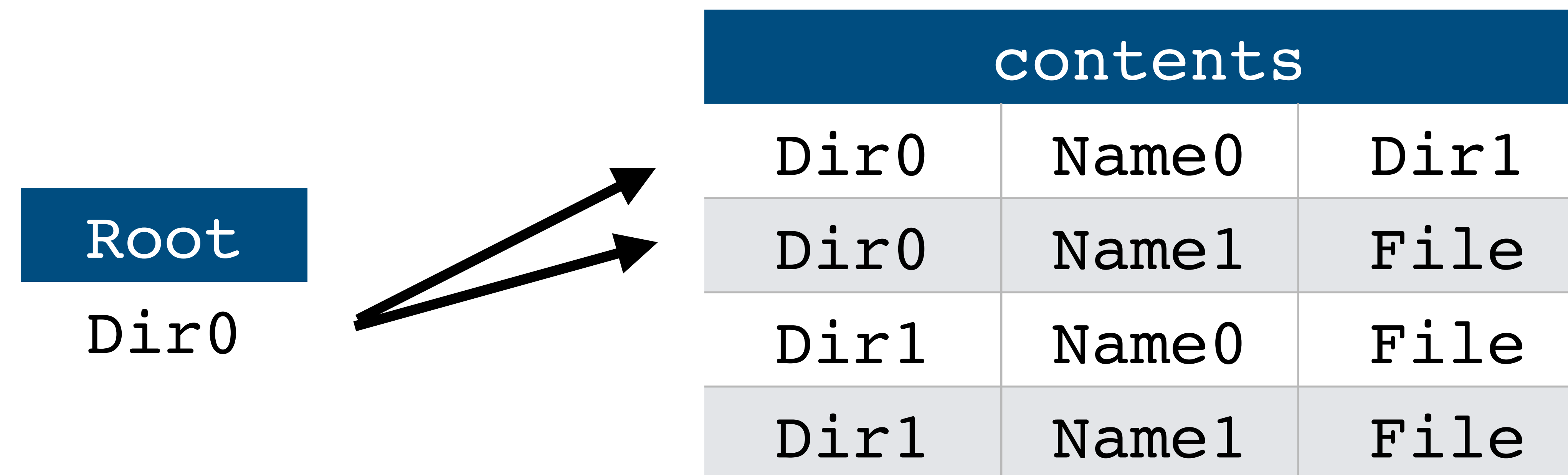
N-ary relationships *a la* UML



Ternary relation example

```
abstract sig Object {}
sig Dir extends Object {
   contents : Name -> lone Object
}
sig File extends Object {}
one sig Root extends Dir {}
sig Name {}
```

Composition



Root
Dir0

contents		
Dir0	Name0	Dir1
Dir0	Name1	File
Dir1	Name0	File
Dir1	Name1	File

Root . contents	
Name0	Dir1
Name1	File

Constraints

```
fact {
   // All directories are referred to in at most one entry
   all d : Dir | lone contents.d

   // The root is not referred in any entry
   no contents.Root

   // All objects except the root are referred to in at least one entry
   Object - Root in Name.(Dir.contents)
}
```

Constraints

```
fun children : Dir -> Object {
  ???
}

fact {
  // A directory cannot be contained in itself
  all d : Dir | d not in d.^children
}
```

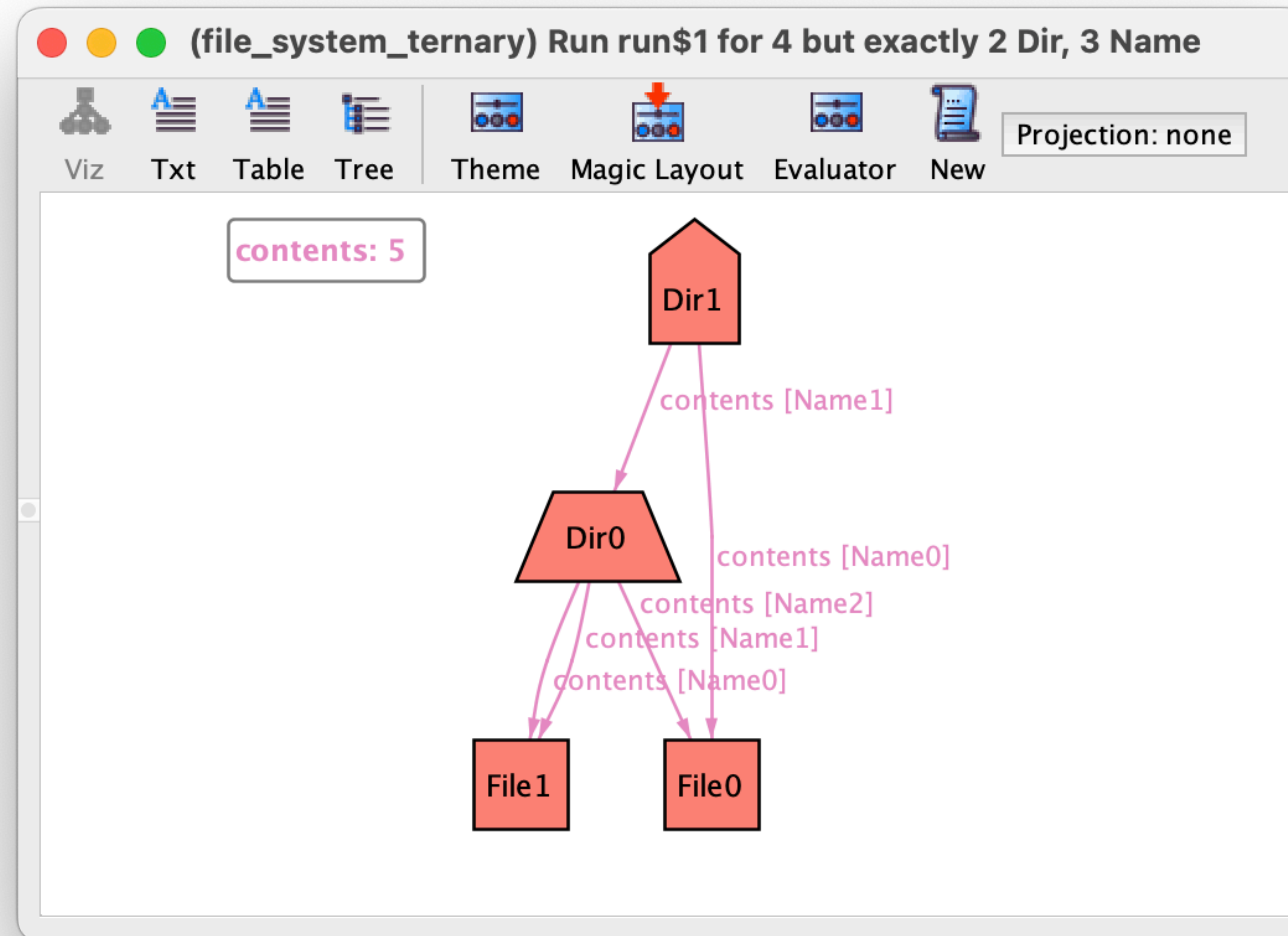
Comprehension

$$\{\ x_1 : A_1, \ldots, x_n : A_n \ \mid\ \phi\ \}$$

Constraints

```
fun children : Dir -> Object {
  { x : Dir, y : Object | some x.contents.y }
}

fact {
  // A directory cannot be contained in itself
  all d : Dir | d not in d.^children
}
```

Visualizing N-ary relations



Type system

Arity error

```
run { some has & File }
```

```
A type error has occurred:
& can be used only between 2 expressions of the same arity.
Left type = {this/Entry->this/Name}
Right type = {this/File}
```

Ambiguity error

```
run { some contains }
```

```
A type error has occurred:
This name is ambiguous due to multiple matches:
field this/Dir <: contains
field this/Entry <: contains
```

Irrelevance warning

```
run { some Dir.has }
```

```
Warning #1
The join operation here always yields an empty set.
Left type = {this/Dir}
Right type = {this/Entry->this/Name}
```

Test automation

NetworkX

networkx.org

NetworkX
Network Analysis in Python

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Drawing
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Exceptions

`is_arborescence(G)` [source]

Returns True if `G` is an arborescence.

An arborescence is a directed tree with maximum in-degree equal to 1.

Parameters:

G : *graph*

The graph to test.

Returns:

b : *bool*

A boolean that is True if `G` is an arborescence.

See also

`is_tree`

Notes

In another convention, an arborescence is known as a *tree*.

Examples

```
>>> G = nx.DiGraph([(0, 1), (0, 2), (2, 3), (3, 4)])
>>> nx.is_arborescence(G)
True
>>> G.remove_edge(0, 1)
>>> G.add_edge(1, 2)  # maximum in-degree is 2
>>> nx.is_arborescence(G)
False
```


On this page
`is_arborescence()`

NetworkX

networkx.org

NetworkX
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Efficiency
Eulerian
Flows
Graph Hashing
Graphical degree sequence
Hierarchy
Hybrid
Isolates
Isomorphism
Link Analysis
Link Prediction

`strongly_connected_components(G)` [source]

Generate nodes in strongly connected components of graph.

Parameters:

G : ***NetworkX Graph***

A directed graph.

Returns:

comp : ***generator of sets***

A generator of sets of nodes, one for each strongly connected component of G.

Raises:

NetworkXNotImplemented

If G is undirected.

See also

`connected_components`
`weakly_connected_components`
`kosaraju_strongly_connected_components`

Notes

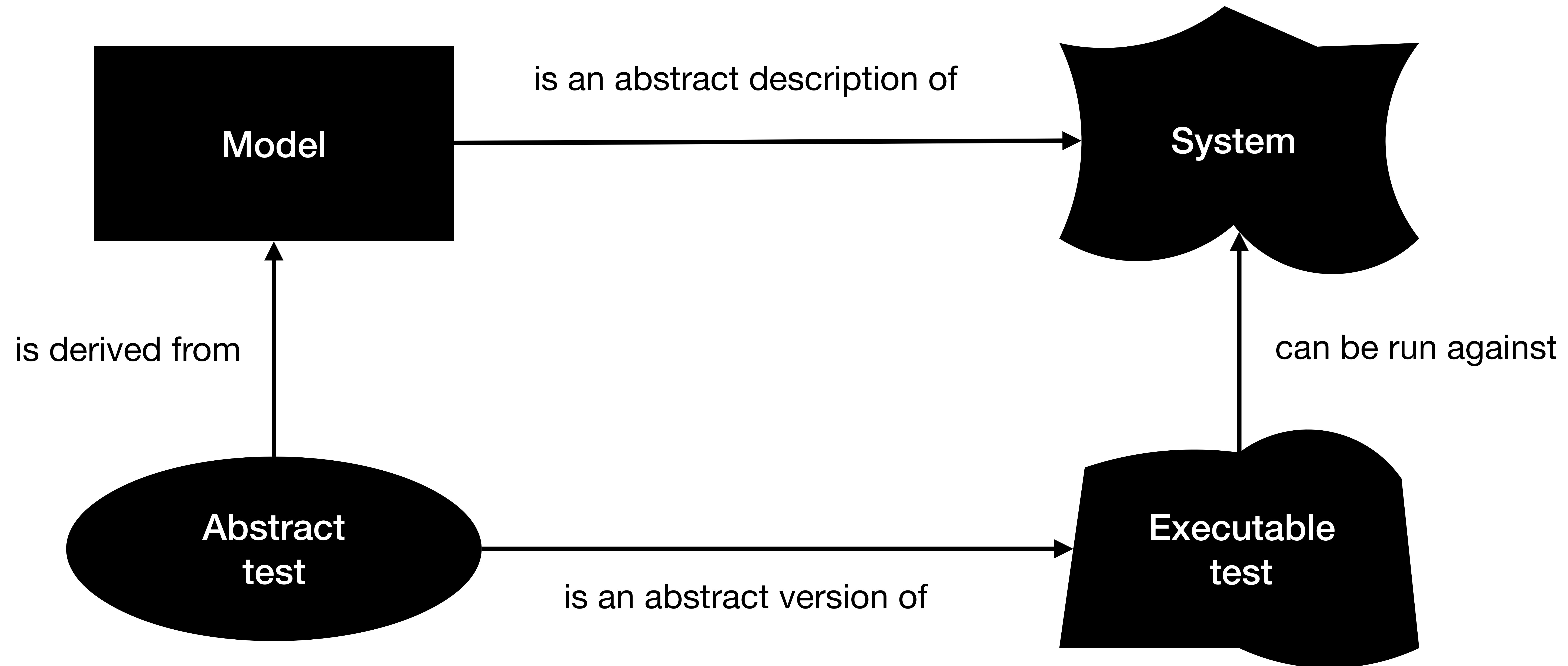
Uses Tarjan's algorithm[R827335e01166-1]_ with Nuutila's modifications[R827335e01166-2]_. Nonrecursive version of algorithm.

References

[1] Depth-first search and linear graph algorithms, R. Tarjan SIAM Journal of Computing

On this page
`strongly_connected_components()`

Model-based testing



Arborescence

```
some sig Node {
    adj : set Node
}

pred isArborescence {
    // In-degree at most one
    all n : Node | lone adj.n
    // No cycles
    all n : Node | n not in n.^adj
    // All nodes can be reached from a root
    some n : Node | Node-n in n.^adj
}

run {isArborescence} for 7
run {not isArborescence} for 7
```

Components

```
sig Node {
   adj : set Node,
   component : one Component
}
sig Component {}

fact {
  // Nodes belong to same component iff they are reachable from each other
  all x,y : Node | x.component = y.component iff x in y.*adj and y in x.*adj
  // Only return necessary components
  Component = Node.component
}

run {} for 6
```

Let’s do it with Alloy API!