FM 2006 Alloy Tutorial

Session 2: Language and Analysis

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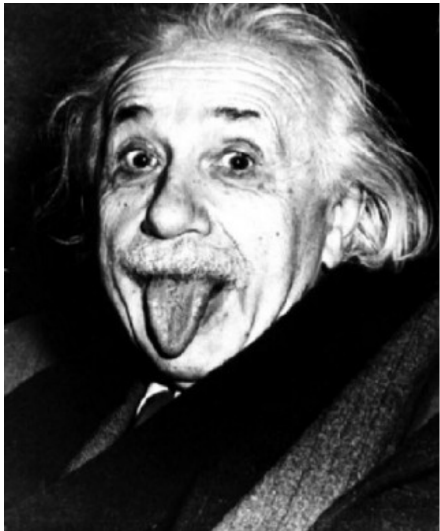


alloy language & analysis

- language = syntax for structuring specifications in logic
  - shorthands, puns, sugar

- analysis = tool for finding solutions to logical formulas
  - searches for and visualizes counterexamples

“I'm My Own Grandpa” Song

- popular radio skit originally written in the 1930's
- expanded into hit song by “Lonzo and Oscar” in 1948

“I'm My Own Grandpa” in Alloy

```
module examples/tutorial/grandpa

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)
  wife = ~husband
}
```

```
assert noSelfFather {
 no m: Man | m = m.father
}

check noSelfFather

fun grandpas(p: Person) : set Person {
 p.(mother + father).father
}

pred ownGrandpa(p: Person) {
 p in grandpas(p)
}

run ownGrandpa for 4 Person
```

language: module header

```
module examples/tutorial/grandpa
```

- first non-comment of an Alloy model
- saved as *examples/tutorial/grandpa.als*
  - relative to Alloy Analyzer's models directory

language: signatures

```
sig A {}
```

set of atoms A

```
sig A {}
sig B {}
```

disjoint sets A and B (no A & B)

```
sig A, B {}
```

same as above

```
sig B extends A {}
```

set B is a subset of A (B in A)

```
sig B extends A {}
sig C extends A {}
```

B and C are disjoint subsets of A
(B in A && C in A && no B & C)

```
sig B, C extends A {}
```

same as above

```
abstract sig A {}
sig B extends A {}
sig C extends A {}
```

A partitioned by disjoint subsets B and C
(no B & C && A = (B + C))

```
sig B in A {}
```

B is a subset of A – not necessarily
disjoint from any other set

```
sig C in A + B {}
```

C is a subset of the union of A and B

```
one sig A {}
lone sig B {}
some sig C {}
```

A is a singleton set
B is a singleton or empty
C is a non-empty set

grandpa: signatures

```
abstract sig Person {
   . . .
}

sig Man extends Person {
   . . .
}

sig Woman extends Person {
   . . .
}
```

- all men and women are persons
- no person is both a man and a woman
- all persons are either men or women

language: fields

```
sig A {f: e}
```

f is a binary relation with domain A and range given by expression e

f is constrained to be a function

(f: A -> one e) or (all a: A | a.f: e)

```
sig A {
  f1: one  e1,
  f2: lone e2,
  f3: some e3,
  f4: set  e4
}
```

(all a: A | a.fn : m e)

```
sig A {f, g: e}
```

two fields with same constraints

```
sig A {f: e1 m -> n e2}
```

(f: A -> (e1 m -> n e2)) or

(all a: A | a.f : e1 m -> n e2)

```
sig Book {
  names: set Name,
  addrs: names -> Addr
}
```

dependent fields

(all b: Book | b.addrs: b.names -> Addr)

grandpa: fields

```
abstract sig Person {
  father: lone Man,
  mother: lone Woman
}

sig Man extends Person {
  wife: lone Woman
}

sig Woman extends Person {
  husband: lone Man
}
```

- fathers are men and everyone has at most one
- mothers are women and everyone has at most one
- wives are women and every man has at most one
- husbands are men and every woman has at most one

language: facts

```
fact { F }
fact f { F }
sig S { ... }{ F }
```

facts introduce constraints that are assumed to always hold

```
sig Host {}
sig Link {from, to: Host}
```

```
fact {all x: Link | x.from != x.to}
```

no links from a host to itself

```
fact noSelfLinks {all x: Link | x.from != x.to}
```

same as above

```
sig Link {from, to: Host}{from != to}
```

same as above, with implicit 'this.'

grandpa: fact

```
fact {
  no p: Person |
    p in p.^(mother + father)
  wife = ~husband
}
```

- no person is his or her own ancestor
- a man's wife has that man as a husband
- a woman's husband has that woman as a wife

language: functions

```
fun f(x1: e1, ..., xn: en) : e { E }
```

functions are named expression with declaration parameters and a declaration expression as a result invoked by providing an expression for each parameter

```
sig Name, Addr {}
sig Book {
  addr: Name -> Addr
}

fun lookup(b: Book, n: Name) : set Addr {
  b.addr[n]
}

fact everyNameMapped {
  all b: Book, n: Name | some lookup(b, n)
}
```

language: predicates

```
pred p(x1: e1, ..., xn: en) { F }
```

named formula with declaration parameters

```
sig Name, Addr {}
sig Book {
  addr: Name -> Addr
}

pred contains(b: Book, n: Name, d: Addr) {
  n->d in b.addr
}

fact everyNameMapped {
  all b: Book, n: Name |
    some d: Addr | contains(b, n, a)
}
```

grandpa: function and predicate

```
fun grandpas(p: Person) : set Person {
  p.(mother + father).father
}

pred ownGrandpa(p: Person) {
  p in grandpas(p)
}
```

- a person's grandpas are the fathers of one's own mother and father

language: “receiver” syntax

```
fun f(x: X, y: Y, ...) : Z {...x...}
fun X::f(y:Y, ...) : Z {...this...}
```

```
f(x, y, ...)
x::f(y, ...)
```

```
pred p(x: X, y: Y, ...)  {...x...}
pred X::p(y:Y, ...) {...this...}
```

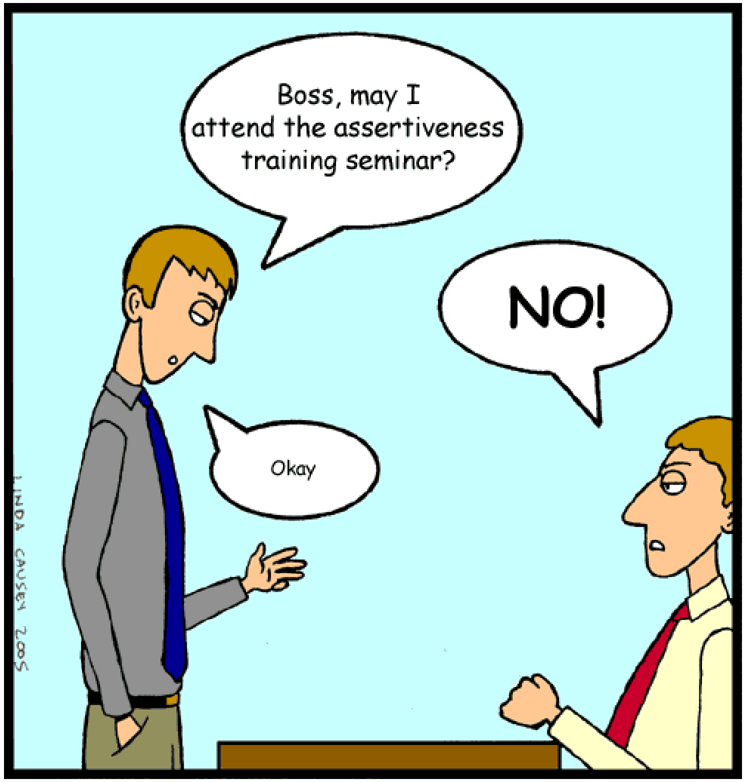
```
p(x, y, ...)
x::p(y, ...)
```

```
fun Person::grandpas() : set Person {
  this.(mother + father).father
}

pred Person::ownGrandpa() {
  this in p::grandpas()
}
```

language: assertions

```
assert a { F }
```

constraint intended to follow from facts of the model



```
sig Node {
  children: set Node
}

one sig Root extends Node {}

fact {
  Node in Root.*children
}

// invalid assertion:
assert someParent {
  all n: Node | some children.n
}

// valid assertion:
assert someParent {
  all n: Node - Root | some children.n
}
```

language: check command

```
assert a { F }
check a scope
```

instructs analyzer to search for counterexample to assertion within scope

if model has facts M finds solution to M && !F

```
check a
```

top-level sigs bound by 3

```
check a for default
```

top-level sigs bound by default

```
check a for default but list
```

default overridden by bounds in list

```
check a for list
```

sigs bound in list,
invalid if any unbound

```
abstract sig Person {}
sig Man extends Person {}
sig Woman extends Person {}
sig Grandpa extends Man {}

check a
check a for 4
check a for 4 but 3 Woman
check a for 4 but 3 Man, 5 Woman
check a for 4 Person
check a for 4 Person, 3 Woman
check a for 3 Man, 4 Woman
check a for 3 Man, 4 Woman, 2 Grandpa

// invalid:
check a for 3 Man
check a for 5 Woman, 2 Grandpa
```

grandpa: assertion check

```
fact {
  no p: Person | p in p.^(mother + father)
  wife = ~husband
}

assert noSelfFather {
  no m: Man | m = m.father
}

check noSelfFather
```

- sanity check
- command instructs analyzer to search for counterexample to *noSelfFather* within a scope of at most 3 *Persons*
- *noSelfFather* assertion follows from fact

language: run command

```
pred p(x: X, y: Y, ...) { F }
run p scope
```

instructs analyzer to search for instance of predicate within scope

if model has facts M, finds solution to M && (some x: X, y: Y, ... | F)

```
fun f(x: X, y: Y, ...) : R { E }
run f scope
```

instructs analyzer to search for instance of function within scope

if model has facts M, finds solution to M && (some x: X, y: Y, ..., result: R | result = E)

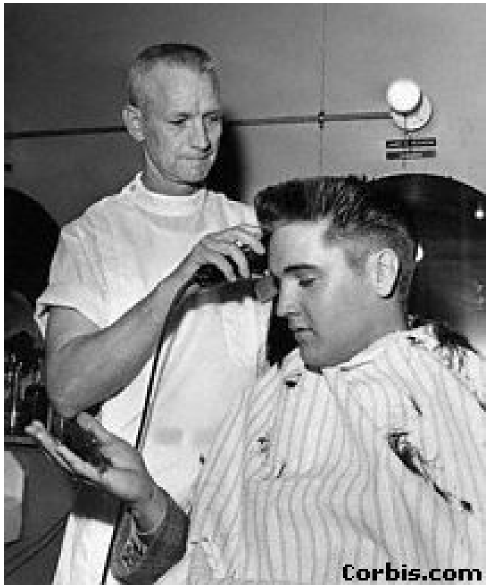
grandpa: predicate simulation

```
fun grandpas(p: Person) : set Person {
  p.(mother + father).father
}

pred ownGrandpa(p: Person) {
  p in grandpas(p)
}

run ownGrandpa for 4 Person
```

- command instructs analyzer to search for configuration with at most 4 people in which a man is his own grandfather

exercise: barber paradox

- open *examples/tutorial/barber.als*
- follow the instructions
- don't hesitate to ask questions



```
module examples/tutorial/barber
sig Man {shaves: set Man}
one sig Barber extends Man {}
fact {
   Barber.shaves = {m: Man | m not in m.shaves}
}
```

introduction to visualization

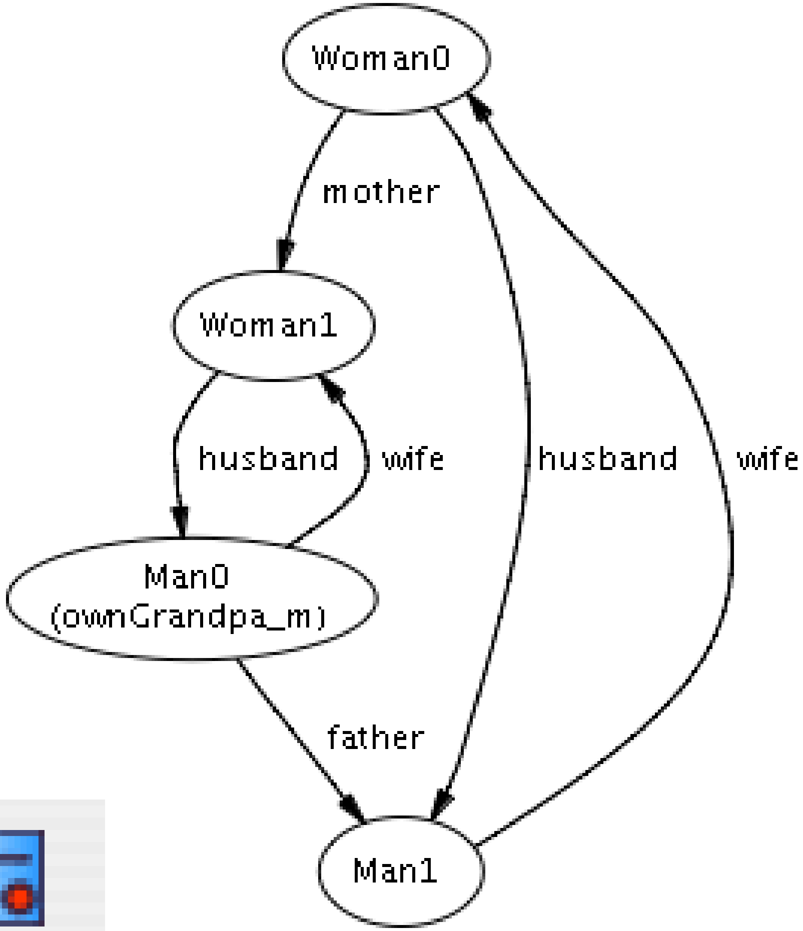
- open *examples/tutorial/grandpa.als*
- build-execute
- select “layout”

Save

Build

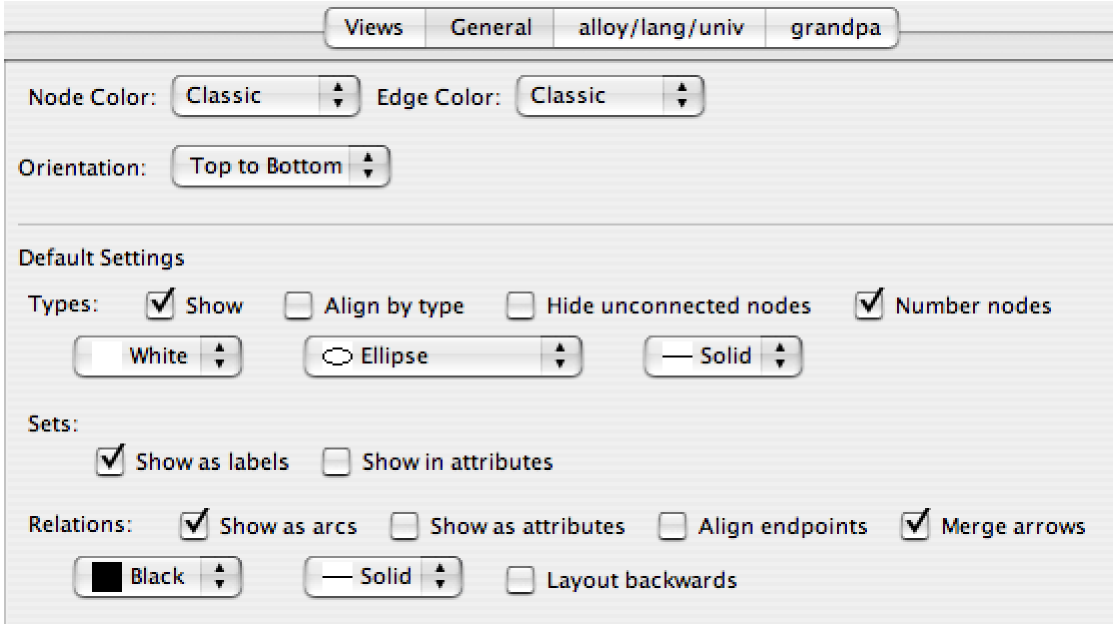
Execute

Layout



visualization layout pane

- the tabs
  - palette = set of views (lightweight)
  - general (default for inheritance)
  - univ (ignore)
  - modules (for us, just “grandpa”)



Node Color: Classic Edge Color: Classic

Orientation: Top to Bottom

Default Settings

Types: ☑ Show □ Align by type □ Hide unconnected nodes ☑ Number nodes

White ⬭ Ellipse — Solid

Sets:

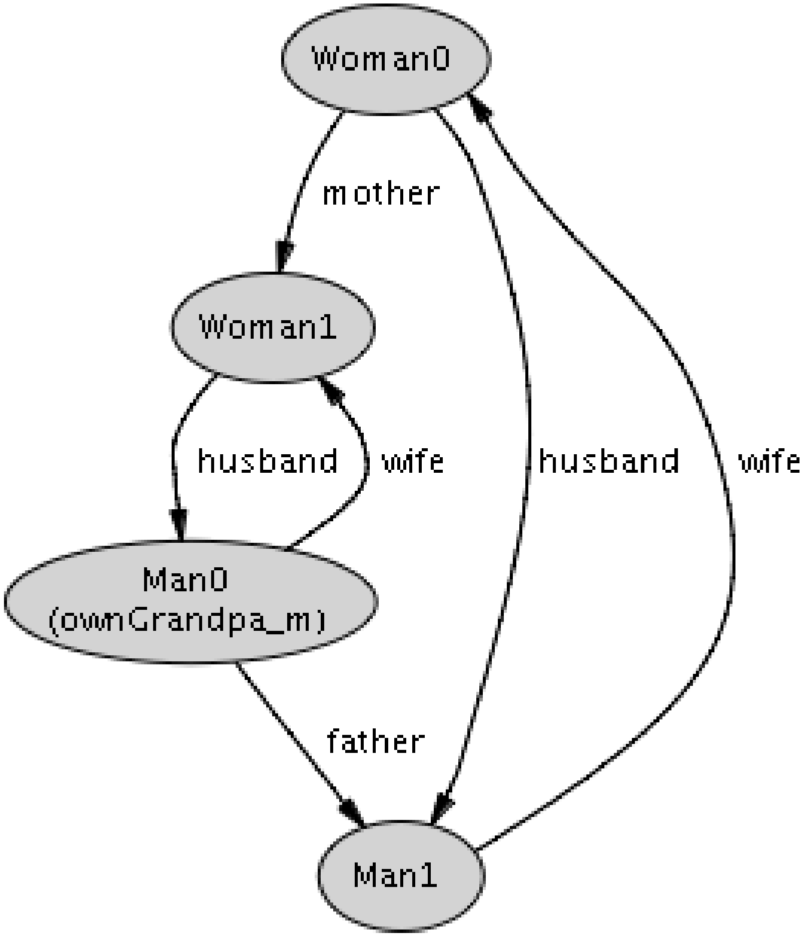
☑ Show as labels □ Show in attributes

Relations: ☑ Show as arcs □ Show as attributes □ Align endpoints ☑ Merge arrows

■ Black — Solid □ Layout backwards

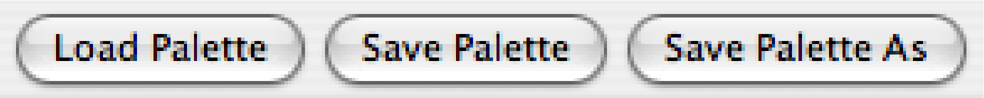
superficial

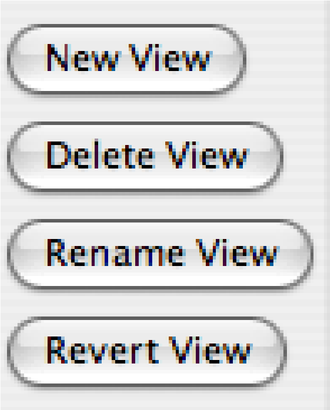
- general tab
  - default type color → gray
  - Update *update*
- also notice:
  - hide unconnected nodes
  - orientation
  - layout backwards

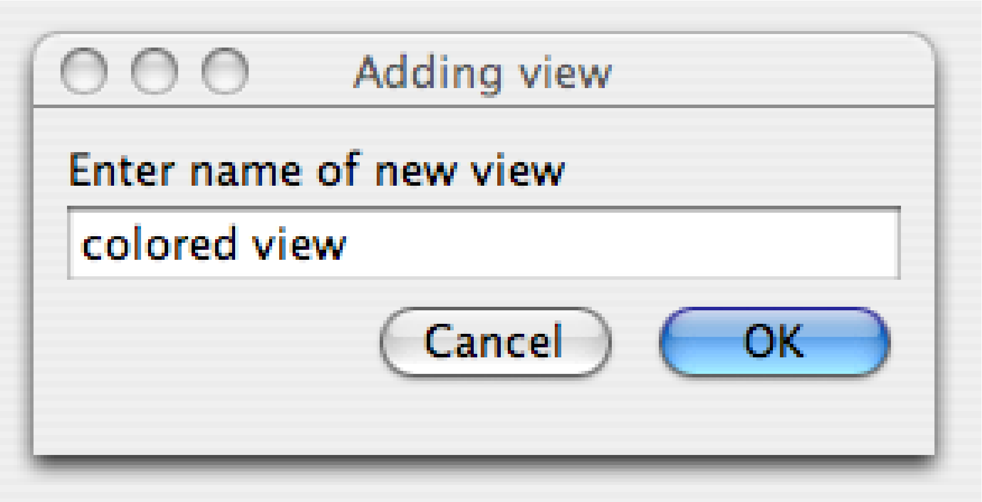


another view . . .

- views tab
  - save palette
  - new view “colored view”
  - automatically selected (but not applied)
- general tab
  - node color → martha
- grandpa tab
  - man color → blue
  - woman color → red
  - *update*



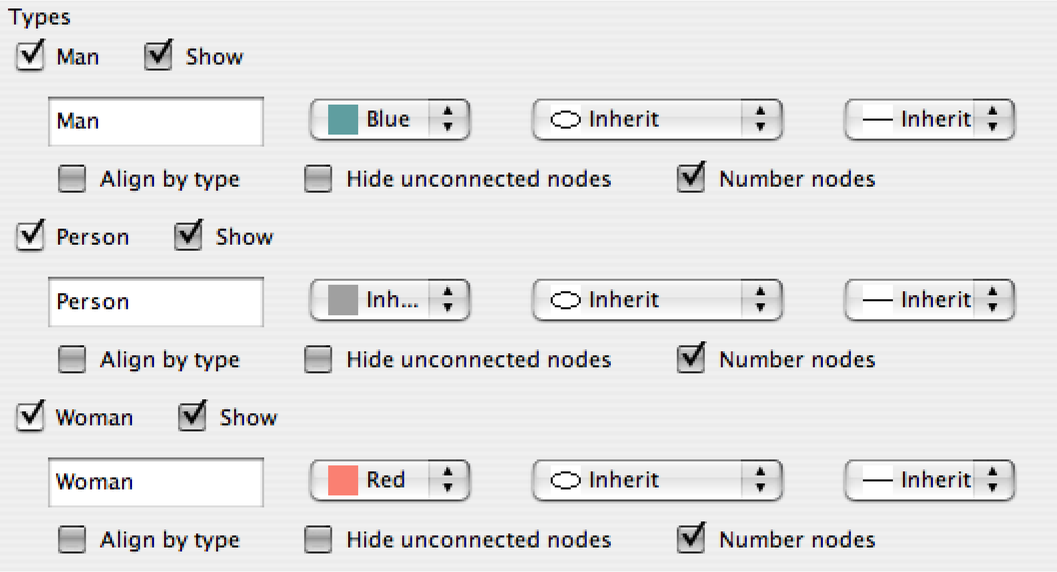



Adding view

Enter name of new view

colored view

another view . . .



Types

☑ Man ☑ Show

Man | 🟦 Blue | ⬭ Inherit | — Inherit

□ Align by type □ Hide unconnected nodes ☑ Number nodes

☑ Person ☑ Show

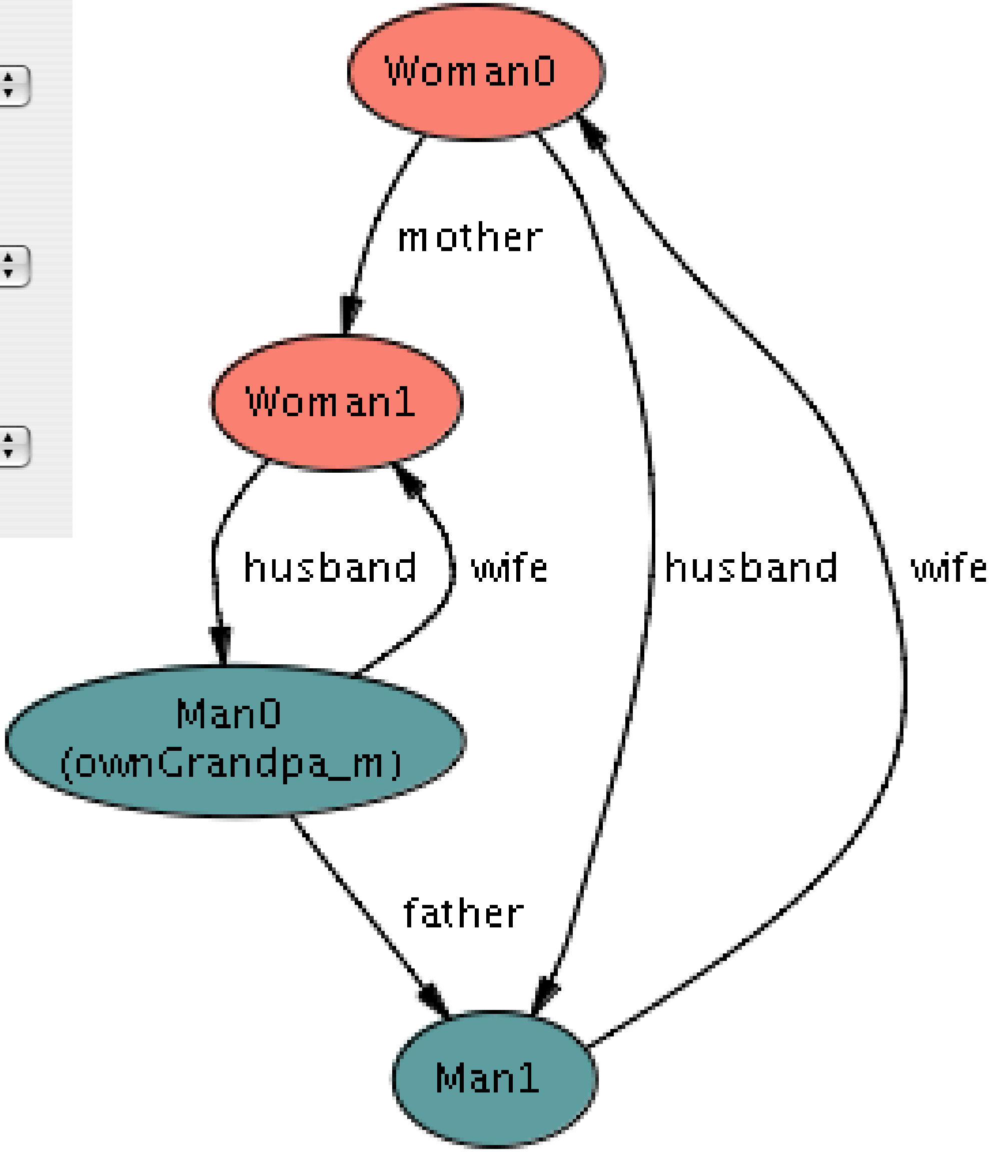
Person | Inh... | ⬭ Inherit | — Inherit

□ Align by type □ Hide unconnected nodes ☑ Number nodes

☑ Woman ☑ Show

Woman | 🟥 Red | ⬭ Inherit | — Inherit

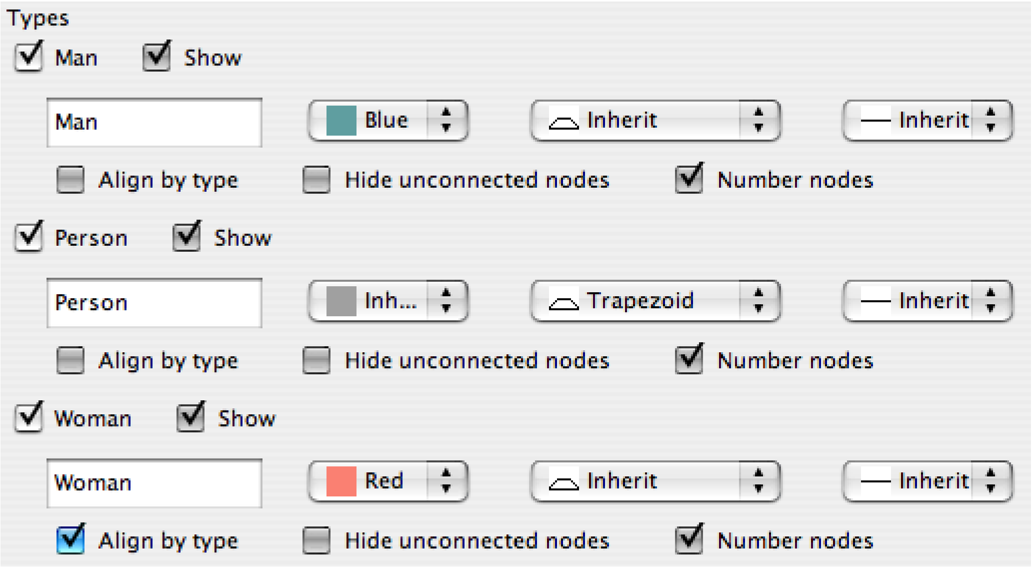
□ Align by type □ Hide unconnected nodes ☑ Number nodes



types & sets

- types: from signatures
  - person shape → trapezoid
  - notice it carries down to man, woman
  - woman: align by type
  - *update*

Update



Types

☑ Man ☑ Show

Man | 🟦 Blue | ⏢ Inherit | — Inherit

□ Align by type □ Hide unconnected nodes ☑ Number nodes

☑ Person ☑ Show

Person | ⬜ Inh... | ⏢ Trapezoid | — Inherit

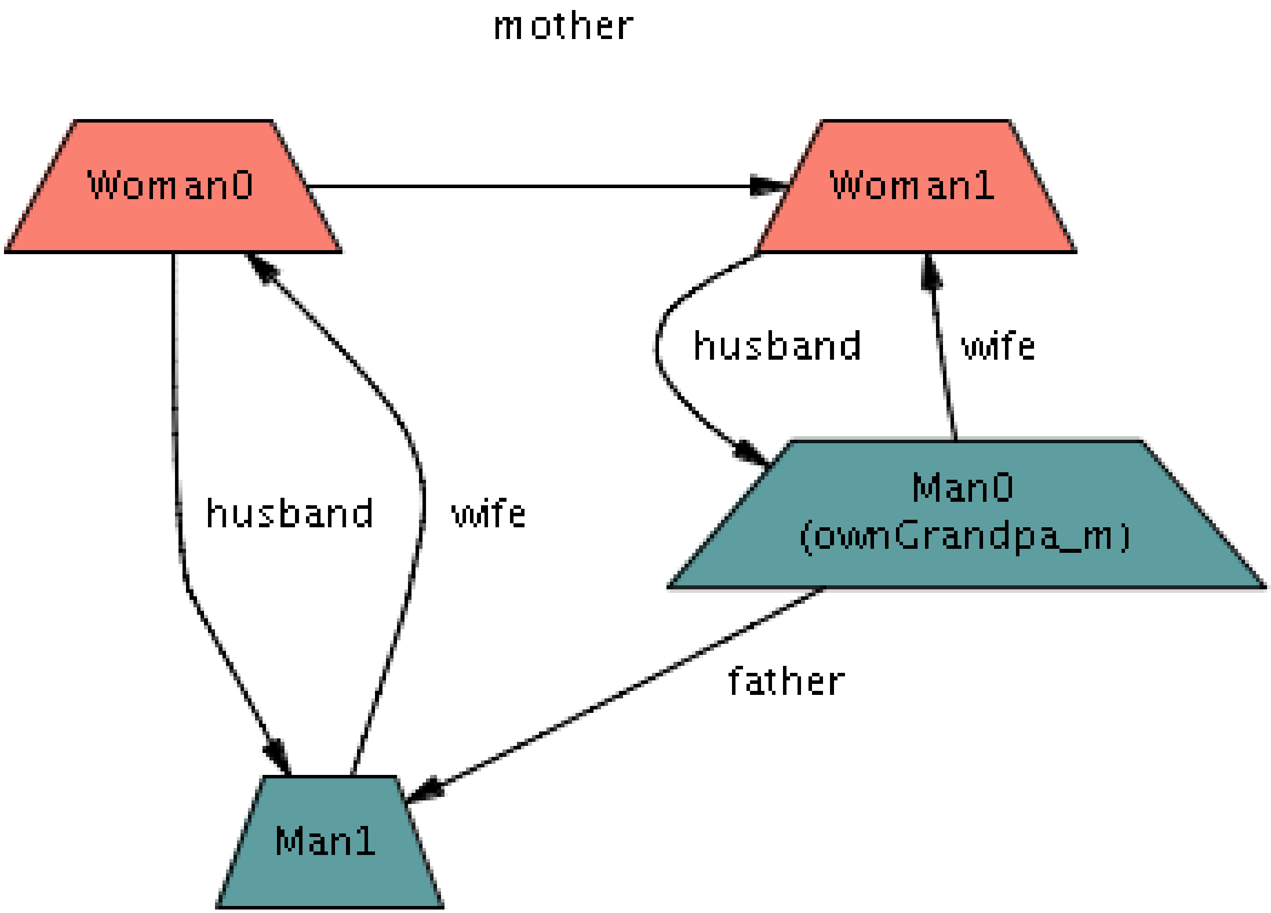
□ Align by type □ Hide unconnected nodes ☑ Number nodes

☑ Woman ☑ Show

Woman | 🟥 Red | ⏢ Inherit | — Inherit

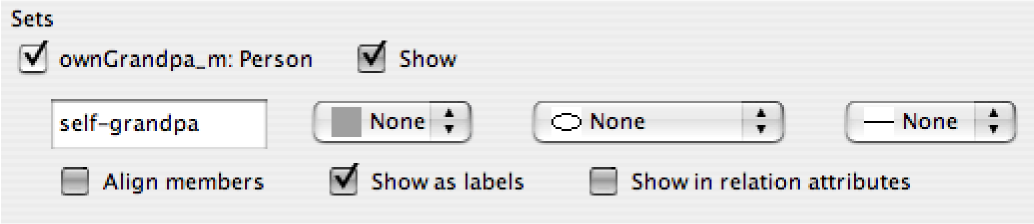
☑ Align by type □ Hide unconnected nodes ☑ Number nodes

types & sets


mother
Woman0
Woman1
husband
wife
husband
wife
Man0
(ownGrandpa_m)
father
Man1

types & sets

- sets: from existentials, runs, checks
  - somewhat intelligently named
  - ownGrandpa_m label → self-grandpa
  - Update *update*

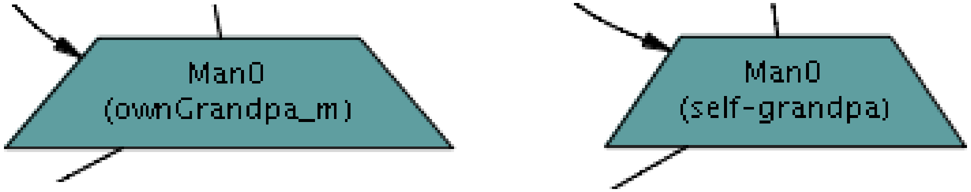


Sets

☑ ownGrandpa_m: Person ☑ Show

self-grandpa | None | None | None

□ Align members ☑ Show as labels □ Show in relation attributes

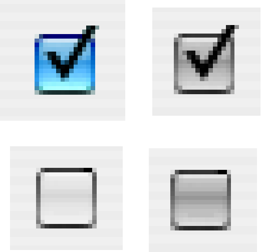


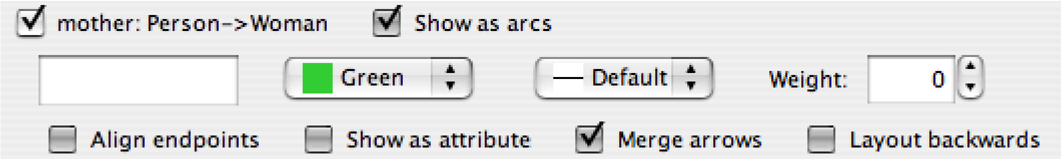
  - pitfall: don't show vs. don't show as label
    (vs. don't show in customizer...)

relations

- relations
  - mother: show as attribute → check (still shown as arc)
  - gray = inherited (vs. overridden)
  - *update*

Update

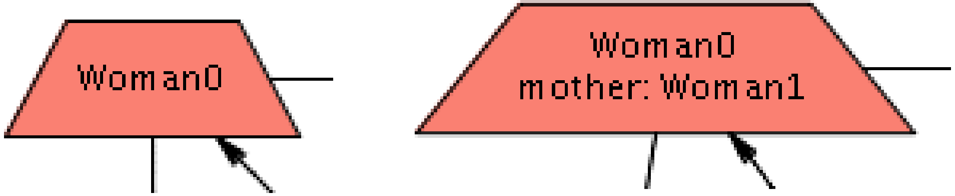




☑ mother: Person->Woman ☑ Show as arcs

🟩 Green — Default Weight: 0

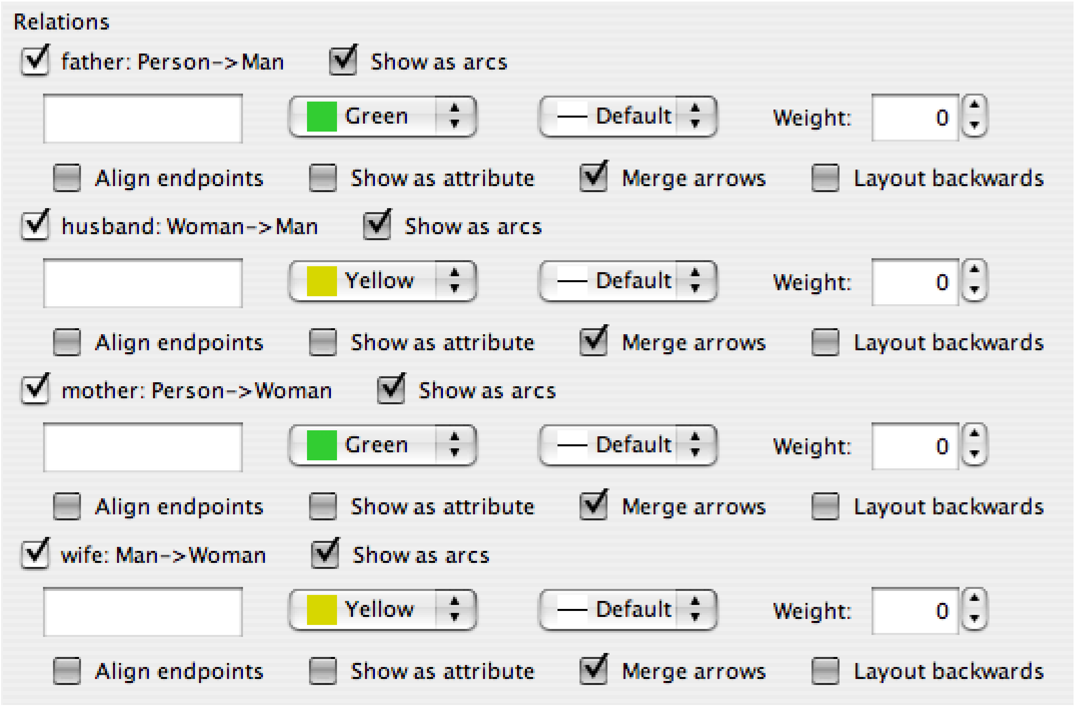
☐ Align endpoints ☐ Show as attribute ☑ Merge arrows ☐ Layout backwards



relations

- relations
  - mother: show as attribute → uncheck
  - father, mother, husband, wife: label → “”
  - father, mother: color → green
  - husband, wife: color → yellow
  - *update*

relations



Relations

☑ father: Person->Man ☑ Show as arcs

🟩 Green — Default Weight: 0

□ Align endpoints □ Show as attribute ☑ Merge arrows □ Layout backwards

☑ husband: Woman->Man ☑ Show as arcs

🟨 Yellow — Default Weight: 0

□ Align endpoints □ Show as attribute ☑ Merge arrows □ Layout backwards

☑ mother: Person->Woman ☑ Show as arcs

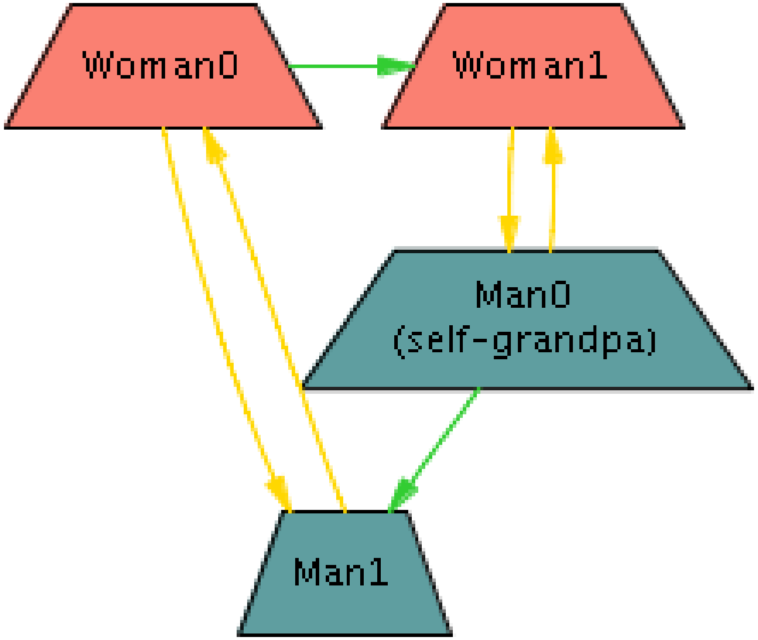
🟩 Green — Default Weight: 0

□ Align endpoints □ Show as attribute ☑ Merge arrows □ Layout backwards

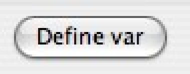
☑ wife: Man->Woman ☑ Show as arcs

🟨 Yellow — Default Weight: 0

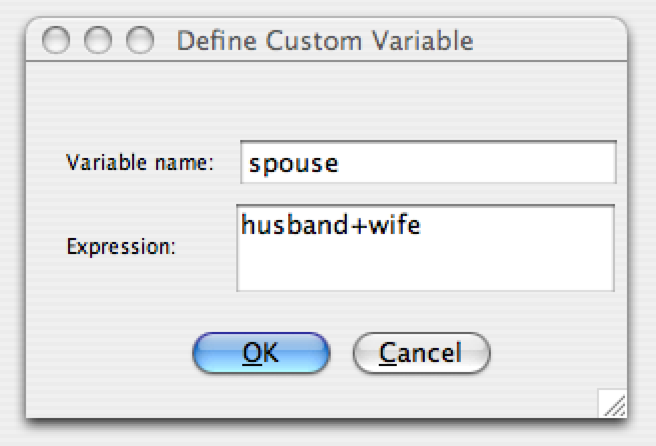
□ Align endpoints □ Show as attribute ☑ Merge arrows □ Layout backwards



defined variables

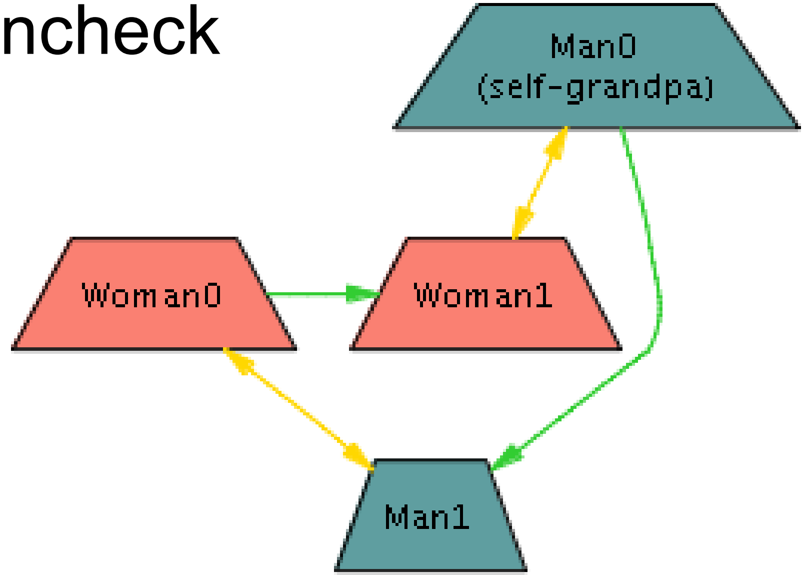
- Define var 

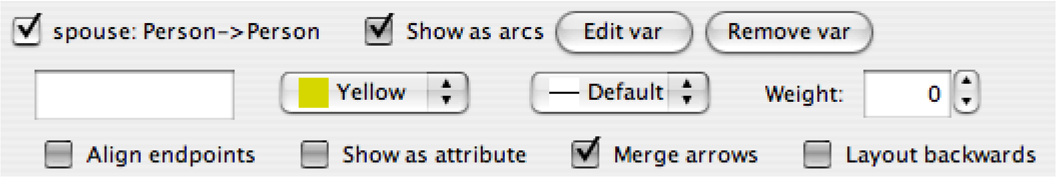
  - spouse = husband + wife
  - spouse: label = “”, color = yellow
  - husband, wife: show as arcs: uncheck



Variable name: spouse

Expression: husband+wife



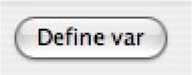

☑ spouse: Person->Person ☑ Show as arcs

Yellow — Default Weight: 0

□ Align endpoints □ Show as attribute ☑ Merge arrows □ Layout backwards

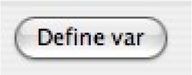
defined variables

- Define var



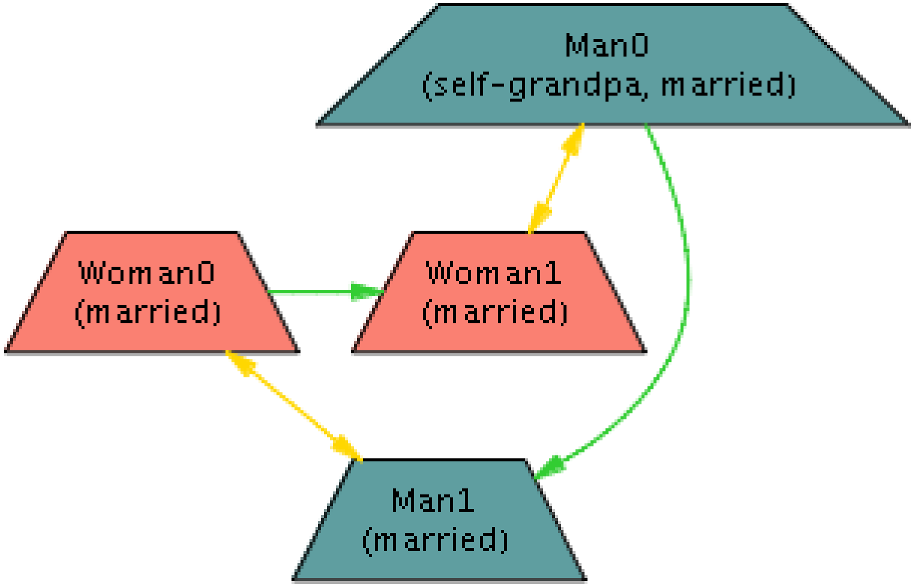
  - married = ?

defined variables

- Define var 

  - married = *Person.(husband + wife)*

  - *update*



  - *handy trick: define in order to hide*

finishing up

- views
  - save palette
- close layout

➢ create your own visualization for the barber exercise!