Abstract Syntax and Name Resolution

Tijs van der Storm

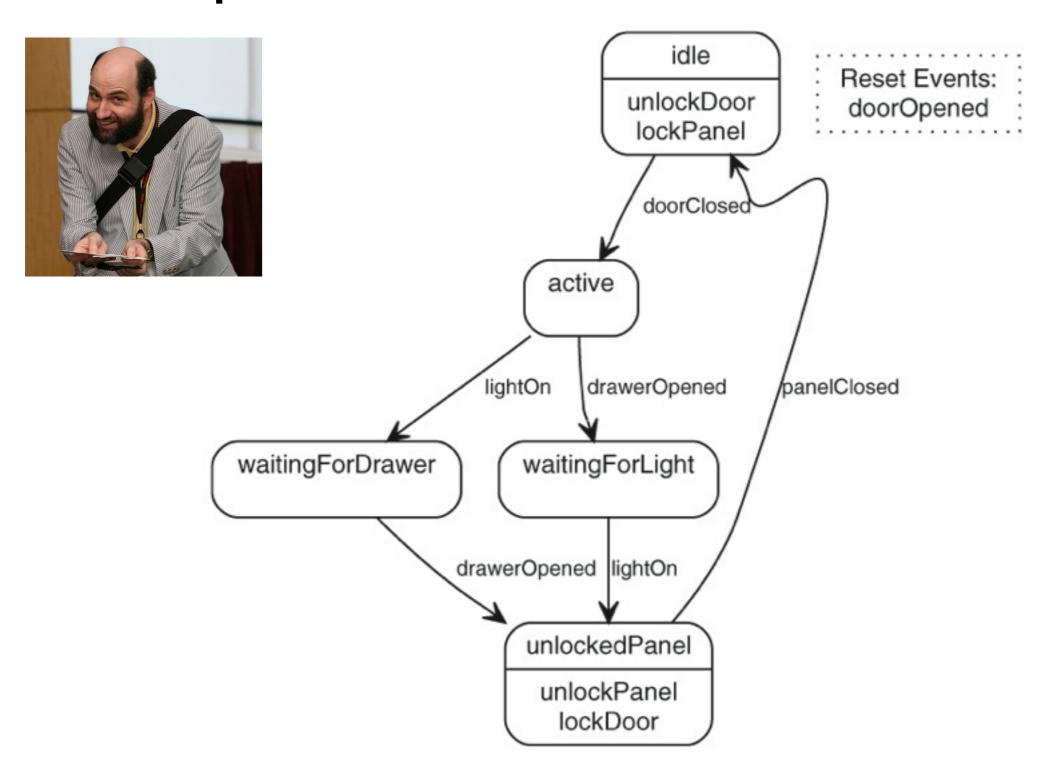




Recap

- Context-free grammars to define syntax
- Parser generator: Grammar -> Parser
- Parser: Text -> Concrete syntax tree
- Today:
 - abstract syntax representations
 - name resolution

Example: state machines



```
events
 doorClosed D1CL
 drawerOpened D2OP
 lightOn L10N
 doorOpened D10P
 panelClosed PNCL
end
resetEvents
 door0pened
end
commands
 unlockPanel PNUL
 lockPanel PNLK
 lockDoor D1LK
 unlockDoor D1UL
end
state idle
 actions {unlockDoor lockPanel}
 doorClosed => active
end
```

```
state active
drawerOpened => waitingForLight
lightOn => waitingForDrawer
end
state waitingForLight
lightOn => unlockedPanel
end
state waitingForDrawer
drawerOpened => unlockedPanel
end
state unlockedPanel
actions {unlockPanel lockDoor}
panelClosed => idle
end
```

```
module Syntax
extend lang::std::Layout;
start syntax Controller =
   controller:
      Events events
      ResetEvents? resets
      Commands? commands
      State+ states;
syntax Events
  = @Foldable "events" Event* "end";
syntax ResetEvents
  = @Foldable "resetEvents" Id* "end";
syntax Commands
  = @Foldable "commands" Command* "end";
```

```
standard
module Syntax
extend lang::std::Layout;
                                     Layout
start syntax Controller =
   controller:
      Events events
      ResetEvents? resets
      Commands? commands
      State+ states;
syntax Events
  = @Foldable "events" Event* "end";
syntax ResetEvents
  = @Foldable "resetEvents" Id* "end";
syntax Commands
  = @Foldable "commands" Command* "end";
```

```
standard
             module Syntax
             extend lang::std::Layout;
                                                   Layout
 start
             start syntax Controller =
symbol
                controller:
                   Events events
                   ResetEvents? resets
                   Commands? commands
                   State+ states;
             syntax Events
               = @Foldable "events" Event* "end";
             syntax ResetEvents
               = @Foldable "resetEvents" Id* "end";
             syntax Commands
               = @Foldable "commands" Command* "end";
```

```
standard
              module Syntax
              extend lang::std::Layout;
                                                   Layout
  start
              start syntax Controller =
symbol
                 controller:
                    Events events
                    ResetEvents? resets
production
                    Commands? commands
   label
                    State+ states;
              syntax Events
                = @Foldable "events" Event* "end";
              syntax ResetEvents
                = @Foldable "resetEvents" Id* "end";
              syntax Commands
                = @Foldable "commands" Command* "end";
```

```
standard
              module Syntax
              extend lang::std::Layout;
                                                   Layout
  start
              start syntax Controller =
symbol
                 controller:
                    Events events
                                            subelement
                    ResetEvents? resets
production
                                               labels
                    Commands? commands
   label
                    State+ states;
              syntax Events
                = @Foldable "events" Event* "end";
              syntax ResetEvents
                = @Foldable "resetEvents" Id* "end";
              syntax Commands
```

= @Foldable "commands" Command* "end";

```
standard
              module Syntax
              extend lang::std::Layout;
                                                   Layout
  start
              start syntax Controller =
symbol
                 controller:
                    Events events
                                            subelement
                    ResetEvents? resets
production
                                               labels
                    Commands? commands
   label
                    State+ states;
              syntax Events
                = @Foldable "events" Event* "end";
              syntax ResetEvents
enable
                = @Foldable "resetEvents" Id* "end";
folding
              syntax Commands
                = @Foldable "commands" Command* "end";
```

lexicals don't get layout

lexicals don't get layout

character class

I "state"

I "actions";

lexicals don't get layout

```
follow restriction
```

character class

I "state"

I "actions";

lexicals don't get layout

```
follow restriction
```

character class

```
lexical Id

= ([a-zA-Z][a-zA-Z0-9_]* !>> [a-zA-Z0-9_])

\ Reserved ;
```

keyword reservation

keyword Reserved

```
= "events"
| "end"
| "resetEvents"
| "state"
| "actions";
```

lexicals don't get layout

```
follow restriction
```

character class

```
lexical Id

= ([a-zA-Z][a-zA-Z0-9_]* !>> [a-zA-Z0-9_])

Reserved;
```

keyword reservation

keyword Reserved

```
= "events"
```

l "end"

l "resetEvents"

I "state"

l "actions";

keyword class

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[label("name",lex("Id")),layouts("Standard"),label("token",lex("Id"))],{}),[appl(prod(lex("Id"),[conditional(seq([\char-
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[appl(regular(\iter-star(sort("WhitespaceOrComment"))), [appl(prod(label("whitespace", sort("WhitespaceOrComment")), [lex("Whitespace")], {}),
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class([range(48,57), range(65,90), range(95,95), range(97,122)])), {\not-follow(\char-
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project://MissGrant/input/missgrant.ctll(56,2,<4,13>,<5,1>)],appl(prod(label("event",sort("Event")),
[label("name",lex("Id")),layouts("Standard"),label("token",lex("Id"))],{}),[appl(prod(lex("Id"),[conditional(seq([\char-
class([range(65,90), range(97,122)]), conditional(\iter-star(\char-class([range(48,57), range(65,90), range(95,95), range(97,122)])), {\not-
follow(\char-class([range(48,57),range(65,90),range(95,95),range(97,122)]))})]),{delete(keywords("Reserved"))})],{}),
[appl(regular(seq([\char-class([range(65,90),range(97,122)]),conditional(\iter-star(\char-
class([range(48,57), range(65,90), range(95,95), range(97,122)])), {\not-follow(\char-
```

Abstract syntax

```
data Controller
  = controller(list[Event] events,
               list[str] resets,
               list[Command] commands,
               list[State] states);
data State
 = state(str name,
          list[str] actions,
          list[Transition] transitions);
data Command = command(str name, str token);
data Event = event(str name, str token);
data Transition = transition(str event, str state);
```

non-terminals ostract syntax map to data type

```
data Controller
  = controller(list[Event] events,
               list[str] resets,
               list[Command] commands,
               list[State] states);
data State
 = state(str name,
          list[str] actions,
          list[Transition] transitions);
data Command = command(str name, str token);
data Event = event(str name, str token);
data Transition = transition(str event, str state);
```

non-terminals ostract syntax map to data type

```
data Controller
            = controller(list[Event] events,
                         list[str] resets,
productions to
                         list[Command] commands,
                         list[State] states);
 constructors
          data State
            = state(str name,
                    list[str] actions,
                    list[Transition] transitions);
          data Command
                          = command(str name, str token);
          data Event
                          = event(str name, str token);
          data Transition = transition(str event, str state);
```

non-terminals map to data type

bstract syntax

```
data Controller
                                                  regulars (+/*/?)
            = controller(list[Event] events,
                         list[str] resets,
                                                   map to lists
productions to
                         list[Command] commands,
                          list[State] states);
 constructors
          data State
            = state(str name,
                    list[str] actions,
                     list[Transition] transitions);
          data Command
                          = command(str name, str token);
          data Event
                          = event(str name, str token);
          data Transition = transition(str event, str state);
```

non-terminals map to data type

bstract syntax

list[str] actions,

```
data Command = command(str name, str token);
data Event = event(str name, str token);
data Transition = transition(str event, str state);
```

list[Transition] transitions);

int/real/bool

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1.(232.1, 2-6, 32-, 27, 8).] and [arod(label('whitespace', sort('MittespaceDrGmenet')), [1ex('Mittespace')], {})], [pp][prod(lex('Tai'-[label('whitespace'), label('whitespace'), label('whitespace'),

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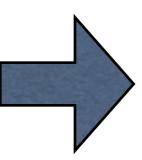
6>)]])[Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,5-.34,6-)])[Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,5-.34,6-)])[Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,5-.34,6-)])[Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,5-.34,6-.34)][Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,5-.34,6-.34)][Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,5-.34,6-.34)][Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,5-.34,6-.34)][Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,5-.34,6-.34)][Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,5-.34,6-.34)][Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,5-.34,6-.34)][Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,5-.34,6-.34)][Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,6-.34,6-.34,6-.34)][Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,6-.34,6-.34,6-.34,6-.34)][Bloc-|project:/Missfrant/input/missgrant.ctll(425,1,44,6-.34,6

]])[@loc-lproject:/Missfarnit/input/missgarant.ctli /Missfarnit/nput/missgarant.cli/473,2,435,9,636,0>],appl(prod(lt("end"),[)char-class([range(101,101)]),\cl tespoceDrCamment")),[lex("Mitespoce"),{}]),[appl(prod(lex("Mitespoce"),[\char-<66.6,476,0)])]]Miss[aminst-/Missfarent';mut/missarant

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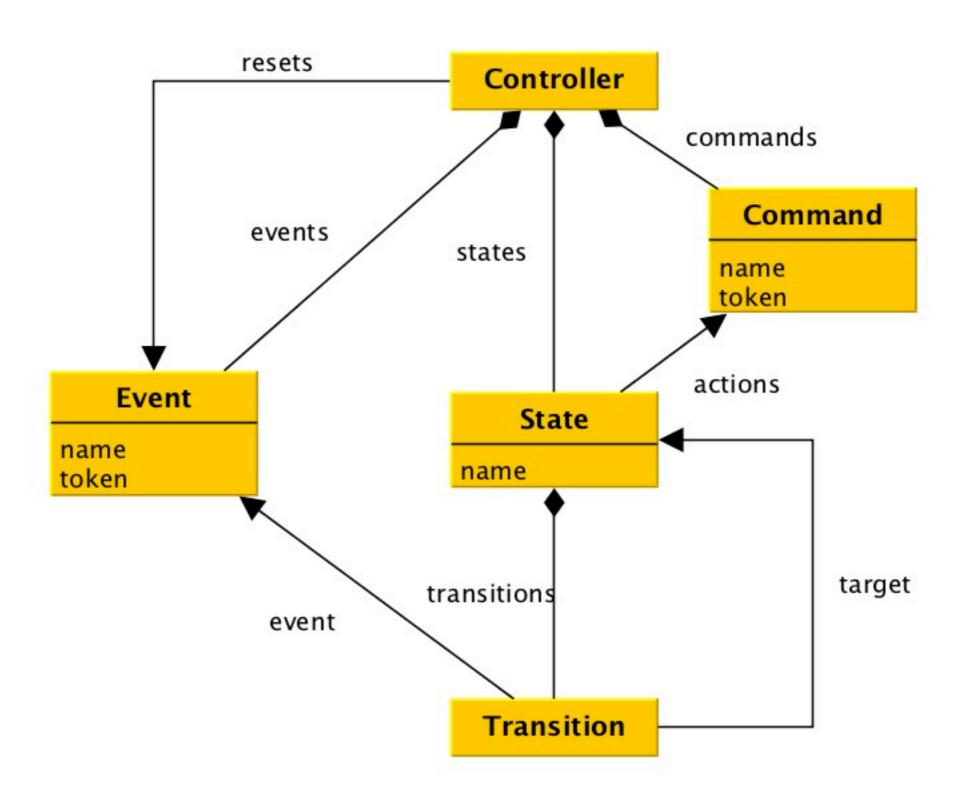


```
controller(
    event("doorClosed","D1CL"),
    event("drawer0pened","D20P"),
    event("lightOn", "L10N"),
    event("door0pened", "D10P"),
    event("panelClosed","PNCL")
  ["door0pened"],
    command("unlockPanel", "PNUL"),
    command("lockPanel", "PNLK"),
    command("lockDoor","D1LK"),
    command("unlockDoor", "D1UL")
    state(
      "idle",
      ["unlockDoor","lockPanel"],
      [transition("doorClosed", "active")]),
    state(
      "active",
      []
        transition("drawerOpened", "waitingForLight"),
        transition("lightOn", "waitingForDrawer")
      ]),
    state(
      "waitingForLight",
      [transition("lightOn", "unlockedPanel")]),
      "waitingForDrawer",
      [transition("drawerOpened", "unlockedPanel")]),
    state(
      "unlockedPanel",
      ["unlockPanel", "lockDoor"],
      [transition("panelClosed","idle")])
  ])
```

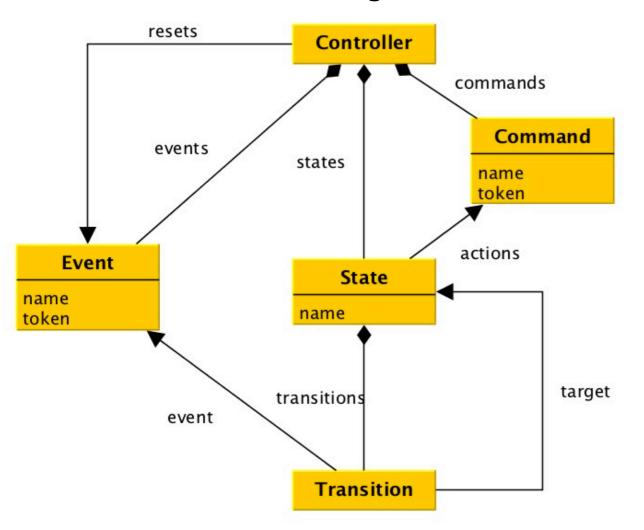
Meta Models

- Algebraic data types ("data Expr = ...")
 - Define type of abstract syntax trees
- Meta Models are UML-style class diagrams
 - Define type of of object *models*
- Both have benefits and disadvantages
- => Technological space (grammarware, modelware)

State machine meta model



References: explicit or using symbolic names



```
data Controller
 = controller(list[Event] events,
               list[str] resets,
               list[Command] commands,
               list[State] states);
data State
  = state(str name,
      list[str] actions,
      list[Transition] transitions);
data Command
  = command(str name, str token);
data Event
  = event(str name, str token);
data Transition
  = transition(str event, str state);
```

```
events
 doorClosed D1CL
 drawerOpened D2OP
 lightOn L10N
 doorOpened D10P
 panelClosed PNCL
end
resetEvents
 door0pened
end
commands
 unlockPanel PNUL
 lockPanel PNLK
 lockDoor D1LK
 unlockDoor D1UL
end
state idle
 actions {unlockDoor lockPanel}
 doorClosed => active
end
```

```
state active
drawerOpened => waitingForLight
lightOn => waitingForDrawer
end
state waitingForLight
lightOn => unlockedPanel
end
state waitingForDrawer
drawerOpened => unlockedPanel
end
state unlockedPanel
actions {unlockPanel lockDoor}
panelClosed => idle
end
```

```
events
 doorClosed D1CL
 drawerOpened D2OP
 lidhtOn L10N
 dodr0pened D10P
 panelClosed PNCL
end
resetEvents
 door Opened
end
commands
 unldckPanel PNUL
 lockPanel PNLK
 lockDoor D1LK
 unlockDoor D1UL
end
state idle
 actions {unlockDoor lockPanel}
 doorClosed => active
end
```

```
state active
drawerOpened => waitingForLight
lightOn => waitingForDrawer
end
state waitingForLight
lightOn => unlockedPanel
end
state waitingForDrawer
drawerOpened => unlockedPanel
end
state unlockedPanel
actions {unlockPanel lockDoor}
panelClosed => idle
```

end

```
events
 doorClosed D1CL
 drawerOpened D2OP
 lidhtOn L10N
 dodr0pened D10P
 panelClosed PNCL
end
resetEvents
 door Opened
end
commands
 unldckPanel PNUL
 lockPanel PNLK
 lockDoor D1LK
 unlockDoor D1UL
end
state idle
 actions {unlockDoor lockPanel}
 doorClosed => active
end
```

```
state active
drawerOpened => waitingForLight
lightOn => waitingForDrawer
end
state waitingForLight
lightOn => unlockedPanel
end
state waitingForDrawer
drawerOpened => unlockedPanel
end
state unlockedPanel
actions {unlockPanel lockDoor}
panelClosed => idle
```

end

```
events
 doorClosed D1CL
 drawerOpened D2OP
 lidhtOn L10N
 dodr0pened D10P
 panelClosed PNCL
end
resetEvents
 door Opened
end
commands
 unldckPanel PNUL
 lockPanel PNLK
 lockDoor B1LK
 unlockDoor DIVL
end
state idle
 actions {unlockDoor lockPanel}
 doorClosed => active
end
```

```
state active
drawerOpened => waitingForLight
lightOn => waitingForDrawer
end
state waitingForLight
lightOn => unlockedPanel
end
state waitingForDrawer
drawerOpened => unlockedPanel
end
state unlockedPanel
actions {unlockPanel lockDoor}
panelClosed => idle
end
```

```
events
 doorClosed D1CL
 drawerOpened D2OP
 lidhtOn L10N
 dodr0pened D10P
 panelClosed PNCL
end
resetEvents
 door Opened
end
commands
 unldckPanel PNUL
 lockPanel PNLK
 lockDoor P1LK
 unlockDoor DNUL
end
state idle
 actions {unlockDogr lockPanel}
 doorClosed => active
end
```

```
state active
drawerOpened => waitingForLight
 lightOn => waitingForDrawer
end
state waitingForLight
lightOn => unlockedPanel
end
state waitingForDrawer
drawerOpened => unlockedPanel
end
state unlockedPanel
actions {unlockPanel lockDoor}
panelClosed => idle
end
```

```
events
 doorClosed D1CL
 drawerOpened $20P
 lidhtOn L10N
 dodr0pened D10P
 panelClosed PNCL
end
resetEvents
 door Opened
end
commands
 unldckPanel PNUL
 lockPanel PNLK
 lockDoor P1LK
 unlockDoor DNUL
end
state idle
 actions {unlockDogr lockPanel}
 doorClosed => active
end
```

```
state active
_drawgrOpened => waitingForLight
 lightOn => waitingForDrawer
end
state waitingForLight
lightOn => unlockedPanel
end
state waitingForDrawer
drawerOpened => unlockedPanel
end
state unlockedPanel
actions {unlockPanel lockDoor}
panelClosed => idle
end
```

```
events
 doorClosed D1CL
 drawerOpened $20P
 lidhtOn L1ON ←
 dodr0pened D10P
 panelClosed PNCL
end
resetEvents
door Opened
end
commands
 unldckPanel PNUL
 lockPanel PNLK
 lockDoor P1LK
 unlockDoor DNUL
end
state idle
 actions {unlockDogr lockPanel}
doorClosed => active
end
```

```
state active
_drawerOpened => waitingForLight
 lightOn => waitingForDrawer
end
state waitingForLight
 lightOn => unlockedPanel
end
state waitingForDrawer
 drawerOpened => unlockedPanel
end
```

state unlockedPanel
 actions {unlockPanel lockDoor}
 panelClosed => idle
end

```
events
 doorClosed D1CL
 drawerOpened $20P
 lidhtOn L10N ←
 dodr0pened D10P
 panelClosed PNCL
end
resetEvents
door Opened
end
commonds
 unldckPanel PNUL
 lockPanel PNLK
 lockDoor DILK
 unlockDoor DNL
end
state idle
 actions {unlockDogr lockPanel}
doorClosed => active
end
```

```
state active
  drawerOpened => waitingForLight
  lightOn => waitingForDrawer
  end

state waitingForLight
  lightOn => unlockedPanel
  end

state waitingForDrawer
  drawerOpened => unlockedPanel
  end
```

state unlockedPanel
 actions {unlockPanel lockDoor}
 panelClosed => idle
end

```
events
 doorClosed D1CL
 drawerOpened $20P
 lightOn L10N ←
 dodr0pened D10P
 panelClosed PNCL
end
resetEvents
door Opened
end
commonds
 unldckPanel PNUL
 lockPanel PNLK
 lockDoor DILK
 unlockDoor DNL
end
state idle
 actions {unlockDogr lockPanel}
doorClosed => active
end
```

```
state active
  drawerOpened => waitingForLight
  lightOn => waitingForDrawer
  end

state waitingForLight
  lightOn => unlockedPanel
  end

state waitingForDrawer
  drawerOpened => unlockedPanel
  end
```

state unlockedPanel
 actions {unlockPanel lockDoor}
 panelClosed => idle
end

```
events
 doorClosed D1CL
 drawerOpened $20P
 lightOn L10N←
 doorOpened D10P
 panelClosed PNCL
end
resetEvents
door Opened
end
commands
 unldckPanel PNUL
 lockPanel PNLK
 lockDoor DILK
 unlockDoor DNL
end
state idle
 actions {unlockDogr lockPanel}
doorClosed => active
end
```

```
state active
  drawerOpened => waitingForLight
  lightOn => waitingForDrawer
end

state waitingForLight
  lightOn => unlockedPanel
end

state waitingForDrawer
  drawerOpened => unlockedPanel
```

state unlockedPanel
 actions {unlockPanel lockDoor}
 panelClosed => idle
end

end

```
events
 doorClosed D1CL
 drawerOpened $20P
 lightOn L10N←
 doorOpened D10P
 panelClosed PNCL
end
resetEvents
door Opened
end
commonds
 unldckPanel PNUL
 lockPanel PNLK
 lockDoor DILK
 unlockDoor DNL
end
state idle
 actions {unlockDogr lockPanel}
doorClosed => active
end
```

```
state active
  drawerOpened => waitingForLight
  lightOn => waitingForDrawer
end

state waitingForLight
  lightOn => unlockedPanel
end

state waitingForDrawer
  drawerOpened => unlockedPanel
end
```

state unlockedPanel
 actions {unlockPanel lockDoor}
 panelClosed => idle
end

```
events
 doorClosed D1CL
 drawerOpened $20P
 lightOn 110N ◀
 doorOpened D10P
 panelClosed PNC
end
resetEvents
 door Opened
end
commands
 unldckPanel PNUL
 lockPanel PNLK
 lockDoor DILK
 unlockDoor DNL
end
state idle
 actions {unlockDogr lockPanel}
 doorClosed => active
end
```

```
state active
   drawerOpened => waitingForLight
   lightOn => waitingForDrawer
end

state waitingForLight
   lightOn => unlockedPanel
end

state waitingForDrawer
drawerOpened => unlockedPanel
end
```

state unlockedPanel
 actions {unlockPanel lockDoor}
 panelClosed => idle
end

```
events
 doorClosed D1CL
 drawerOpened $20P
 lightOn 110N ◀
 doorOpened D10P
 panelClosed PNC
end
resetEvents
 door Opened
end
commands
 unldckPanel PNUL
 lockPanel PNLK
 lockDoor DILK
 unlockDoor DNL
end
state idle
 actions {unlockDogr lockPanel}
 doorClosed => active
end
```

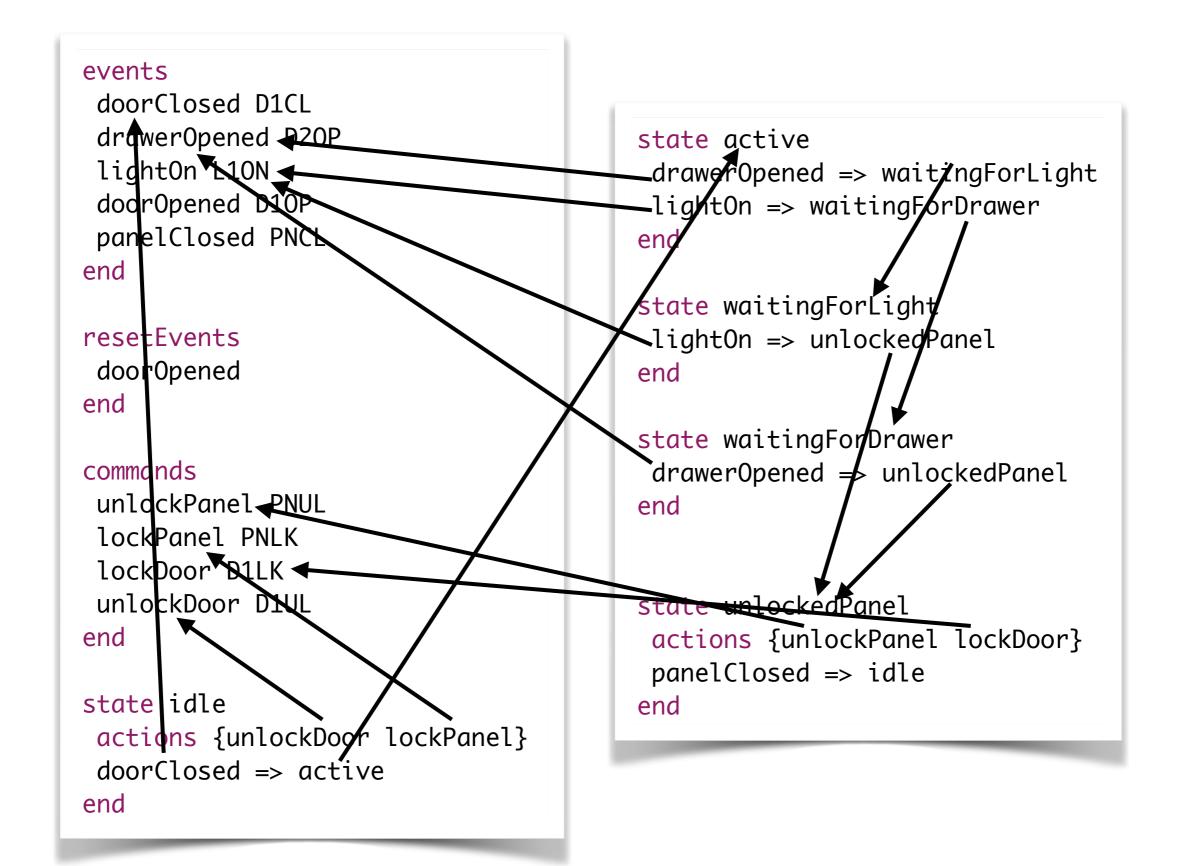
state active
 drawerOpened => waitingForLight
 lightOn => waitingForDrawer
 end

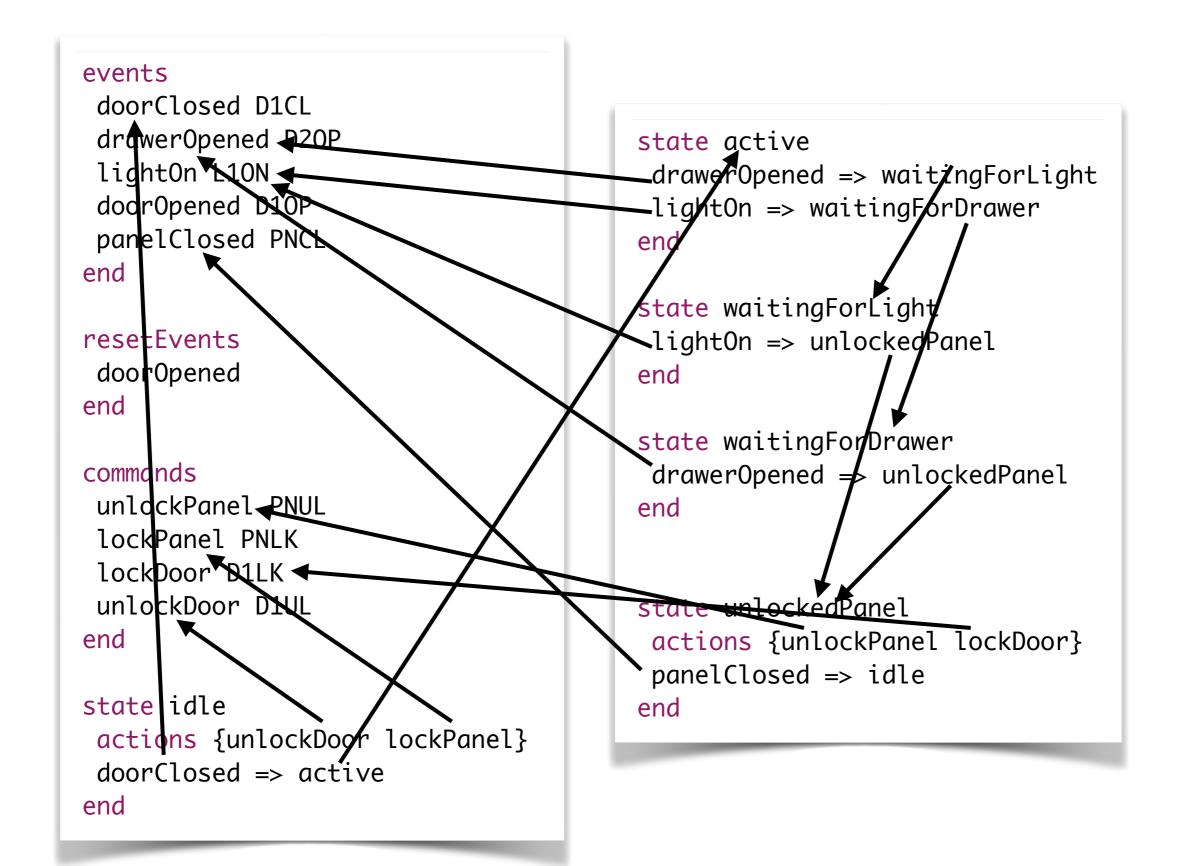
state waitingForLight
 lightOn => unlockedPanel
 end

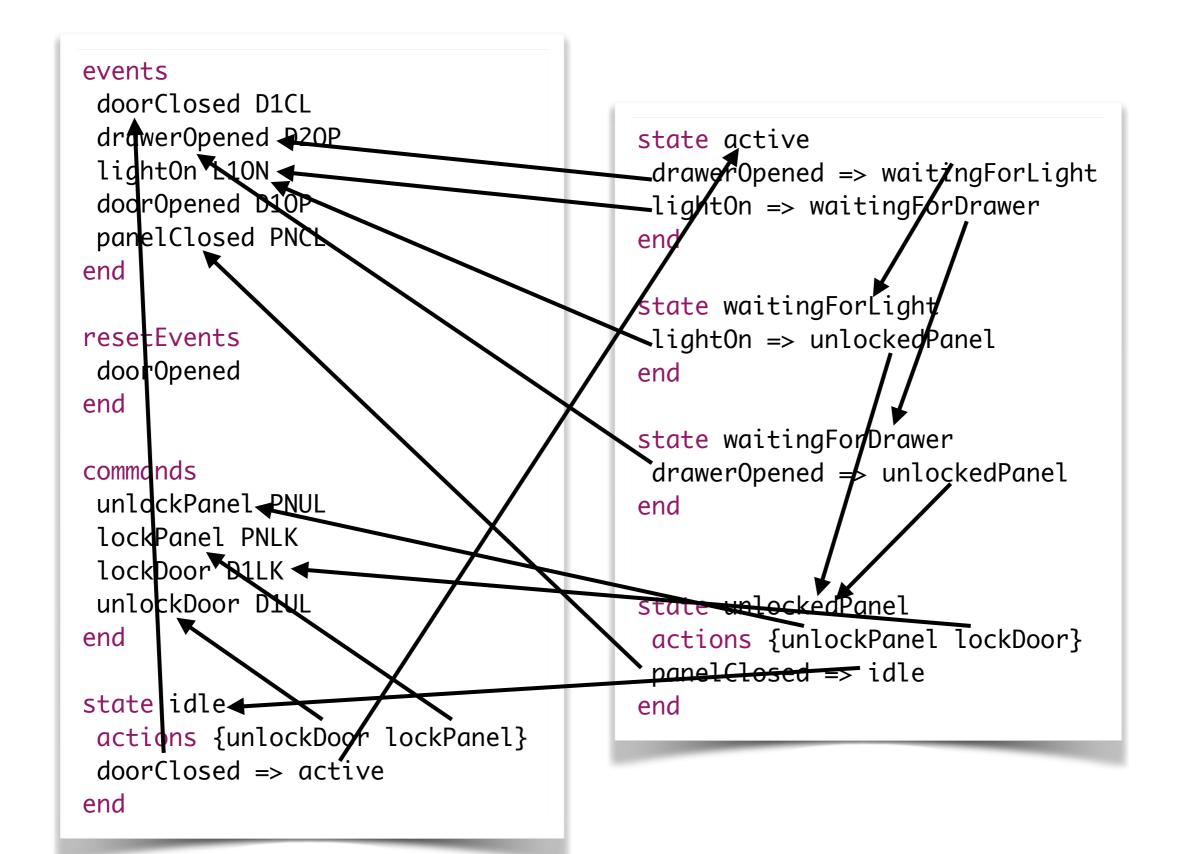
state waitingForDrawer
drawerOpened = unlockedPanel
end

state unlockedPanel
 actions {unlockPanel lockDoor}
 panelClosed => idle
end

```
events
 doorClosed D1CL
 drawerOpened $20P
                                       state active
 lightOn 110N ◀
                                        _drawerOpened => waitingForLight
 doorOpened D10P
                                        lightOn => waitingForDrawer
 panelClosed PNC
                                       end
end
                                       state waitingForLight
resetEvents
                                       lightOn => unlockedPanel
 door Opened
                                       end
end
                                       state waitingForDrawer
commonds
                                        drawerOpened ≠ unlockedPanel
 unlackPanel PNUL
                                       end
 lockPanel PNLK
 lockDoor B1LK
 unlockDoor DNL
                                       state unlockedPanel
end
                                        actions {unlockPanel lockDoor}
                                        panelClosed => idle
state idle
                                       end
 actions {unlockDogr lockPanel}
 doorClosed => active
end
```





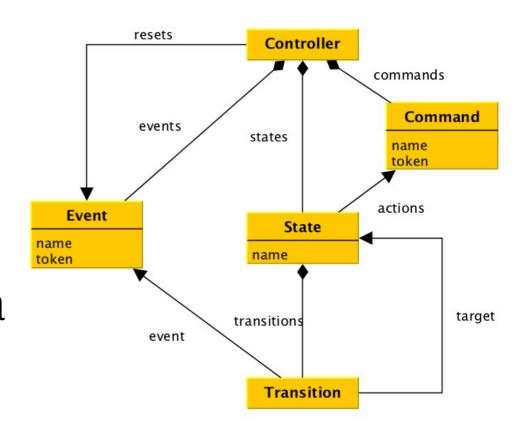


Names

- defining occurrence: declaration, or entity, introduction of a name
 - Example: states, events, commands
- use occurence: reference, variable use, etc.
 - Example: reference to event/target state in transition, reference to commands in states

Name resolution

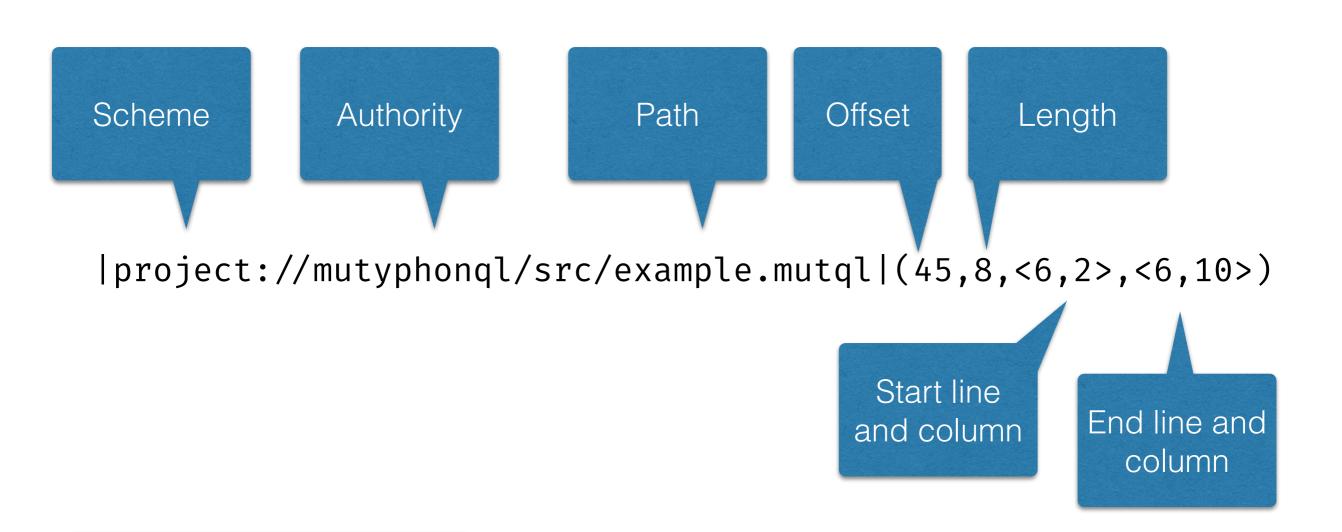
- Finding which use occurrences refer to which defining occurrences
- Recovering the referential structure represented in meta models (roughly)
- IOW: defining the scoping rules of a language



Name resolution in Rascal

- Name occurrences (both defining and using) can be identified by source locations
- Source locations are unique: no two name occurrences can overlap.
- So we can use source locations as identities to represent the referential structure of a program.

Source locations



NB: clicking on a source location jumps to exact location in an editor

Reference graphs

- Using source locations as identities of concepts in a language, the referential structure is typically represented as reference graph
- In Rascal: "rel[loc, loc]"
- This can be used to:
 - find naming errors and warnings
 - provide jump-to-definition IDE support
 - use in a compiler to find the declaration of an identifier
 - visualization, etc.

Next up

- Live coding a simpler state machine example
 - abstract syntax, implode, name analysis
- Providing an introduction to the lab assignment skeleton code for this week.