micromodels of software
declarative modelling and analysis with Alloy

lecture 4: a case study

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why looseness?

risk-driven modelling
- give only crucial properties

implementation freedom
- allow concurrency
- representation independence

account for environment
- fewer assumptions better

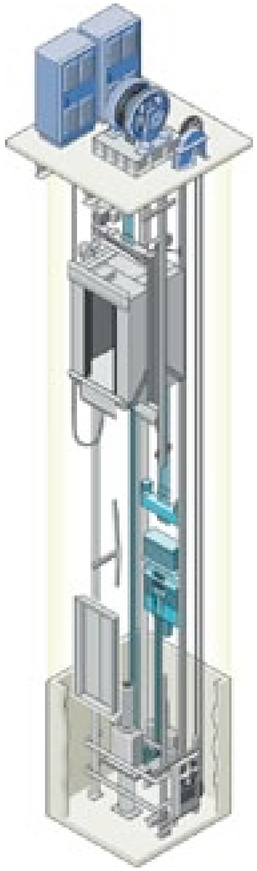
specify a family of systems
- every program is a family? [Parnas]

example: elevator policy

challenge
- specify a policy for scheduling lifts
- keep concerns separated

tight enough
- all requests eventually served
- don’t skip request from inside lift

loose enough
- no fixed configuration of floors, lifts, buttons
- not one algorithm but a family



complications

multiple lifts

- don’t send all to service one request

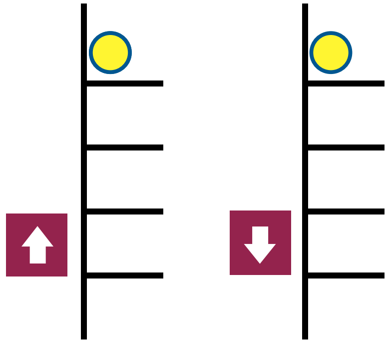
top and bottom

- lift going in wrong direction may be nearer

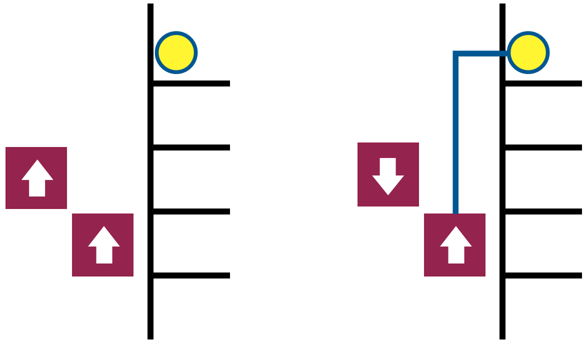
load balancing

- accommodate strategies based on occupancy, eg
- don’t force nearest lift to serve

approach: promises



ways to deny a request
- ‘skipping’: going past floor
- ‘bouncing’: doubling back before floor



policy
- a lift can’t deny a request from inside
- if a lift denies a floor request
  some lifts promise to serve it later
- a lift can’t deny the last promise

freedoms
- divide requests amongst lifts
- postpone allocation decision

basic abstractions

floor layout

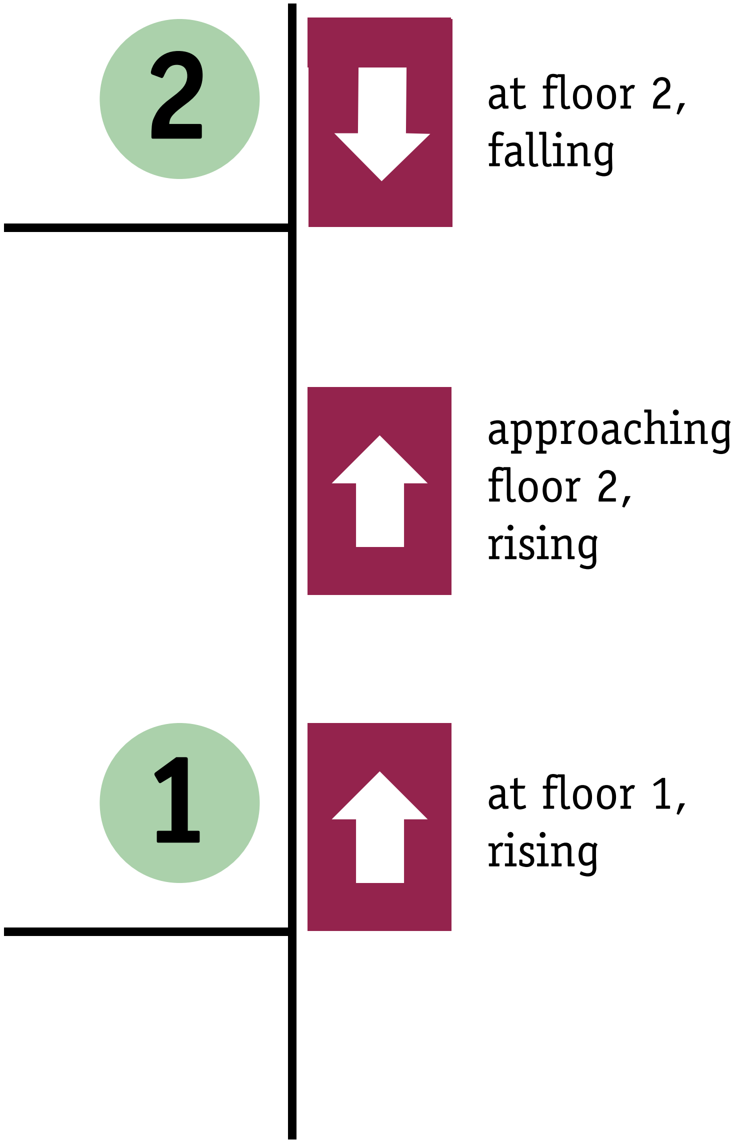
- orderings above and below
- top and bottom floors

buttons

- inside lift and at floors
- each has an associated floor
- in a given state, some lit

elevator state

- at or approaching a floor
- rising or falling
- promises to serve some buttons



floor layout

```
open std/orders

sig Floor {
  disj up, down: option FloorButton,
  above, below: option Floor
  }

sig Top extends Floor {} {no up}

sig Bottom extends Floor {} {no down}

fact Layout {
  Ord[Floor].next = above
  Ord[Floor].prev = below
  Ord[Floor].last = Top
  Ord[Floor].first = Bottom }
```

don’t require buttons on all floors
allow small scope
analysis will place buttons demonically

use ordering axioms from standard library

lifts

```
sig Lift {
 button: Floor ?->? LiftButton,
 buttons: set LiftButton
 }
```

button panel:
allows different lifts
to cover different sets
of floors

buttons

define classes of button;
redundant but convenient

```
sig Button {floor: Floor}
disj sig LiftButton extends Button {lift: Lift}
disj sig FloorButton extends Button {}
part sig UpButton, DownButton extends FloorButton {}
fact ButtonDefinitions {
  ~floor = Lift.button + up + down
  lift = {b: Button, p: Lift | some f: Floor | f->b in p.button}
  all p: Lift | p.buttons = p.button [Floor]
  UpButton = Floor.up
  }
```

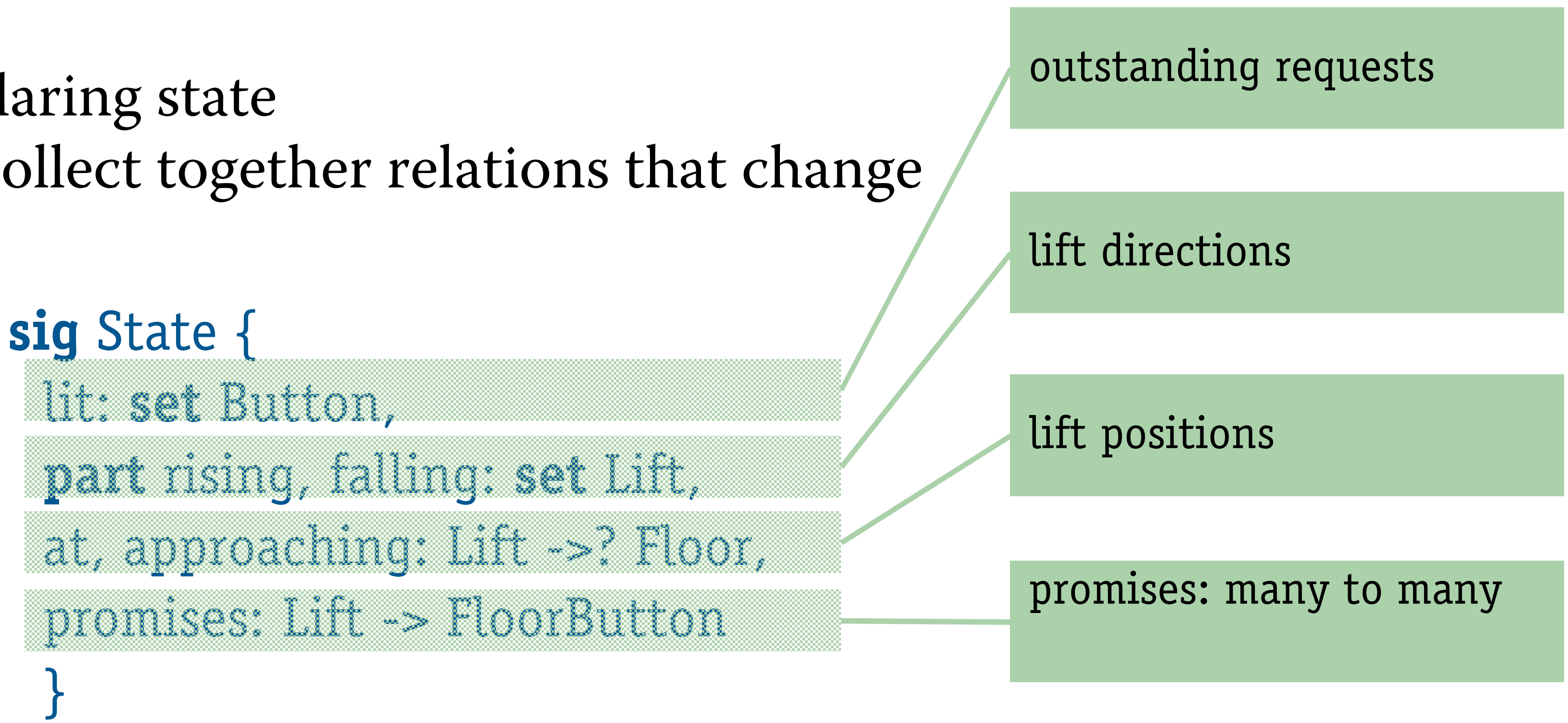
sample layout

```
fun showLayout () {some Lift.buttons}
run showLayout
```

system state

declaring state

- collect together relations that change



```
sig State {
  lit: set Button,
  part rising, falling: set Lift,
  at, approaching: Lift ->? Floor,
  promises: Lift -> FloorButton
  }
```

outstanding requests

lift directions

lift positions

promises: many to many

physical constraints on lift state

```
fun LiftPosition (s: State) {
  all p: Lift | with s {
    one (at + approaching)[p]
    no (at & approaching)[p]
    p in rising =>
      no approaching[p] & Bottom,
      no approaching[p] & Top
    p in rising =>
      no at[p] & Top,
      no at[p] & Bottom
    }
  }
```

lift is at or approaching one floor

lift is not at *and* approaching

no rising on approach to bottom

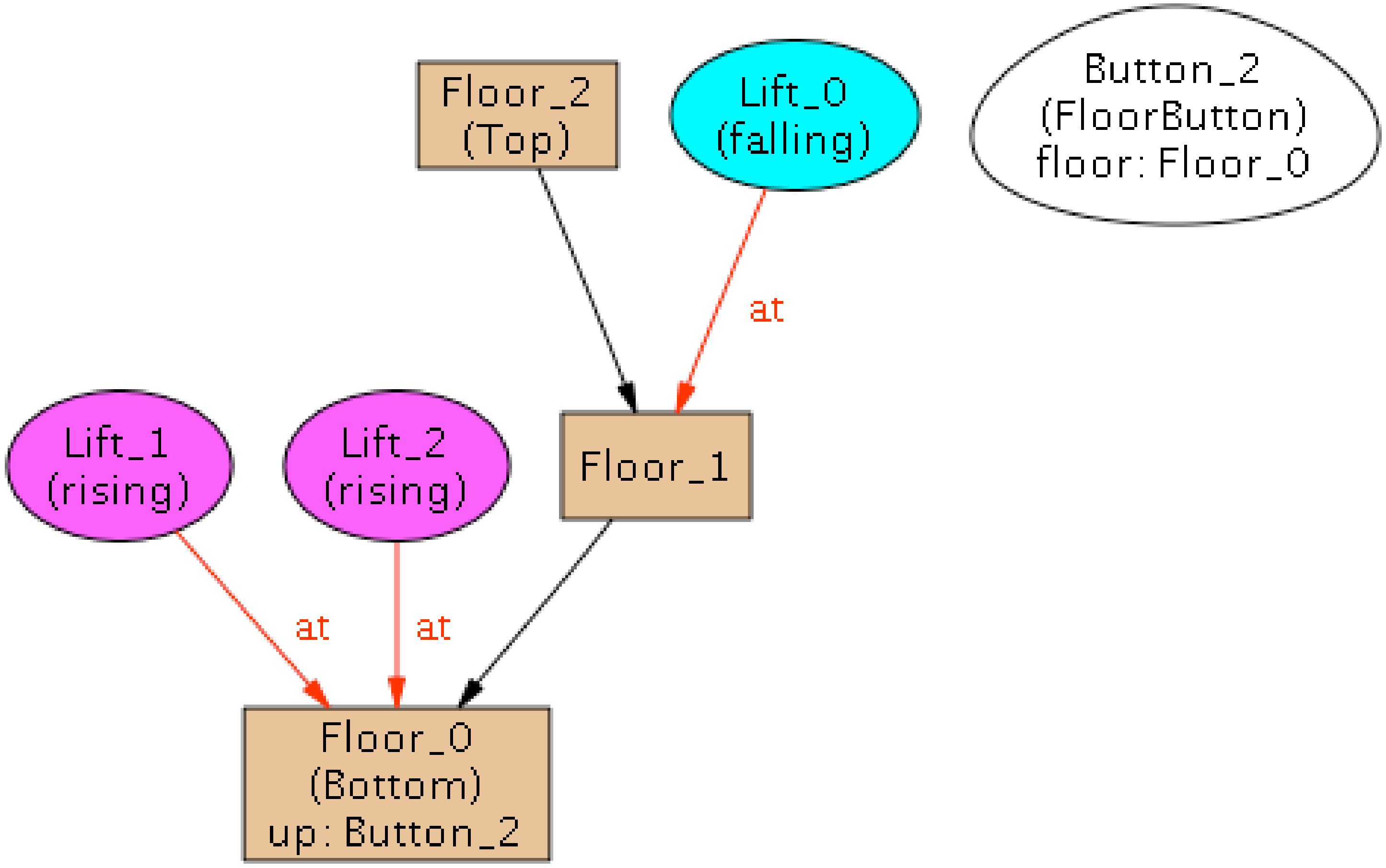
no rising at top floor

```
sig State {
  at, approaching: Lift ->? Floor,
  part rising, falling: set Lift ...}
```

rising *short for* s.rising

sample state

run LiftPosition



physical constraints on lift motion

```
fun nextFloor (s: State, p: Lift): Floor -> Floor {
  result = if p in s.rising then above else below
  }

fun LiftMotion (s, s': State) {
  all p: Lift {
    p & s.rising != p & s'.rising => some s'.at[p]
    s'.at[p] in s.(at + approaching)[p]
    s'.approaching[p] in
      s.approaching[p] + s.(at + approaching)[p].nextFloor(s,p)
    }
  }
```

no dir change except at floor

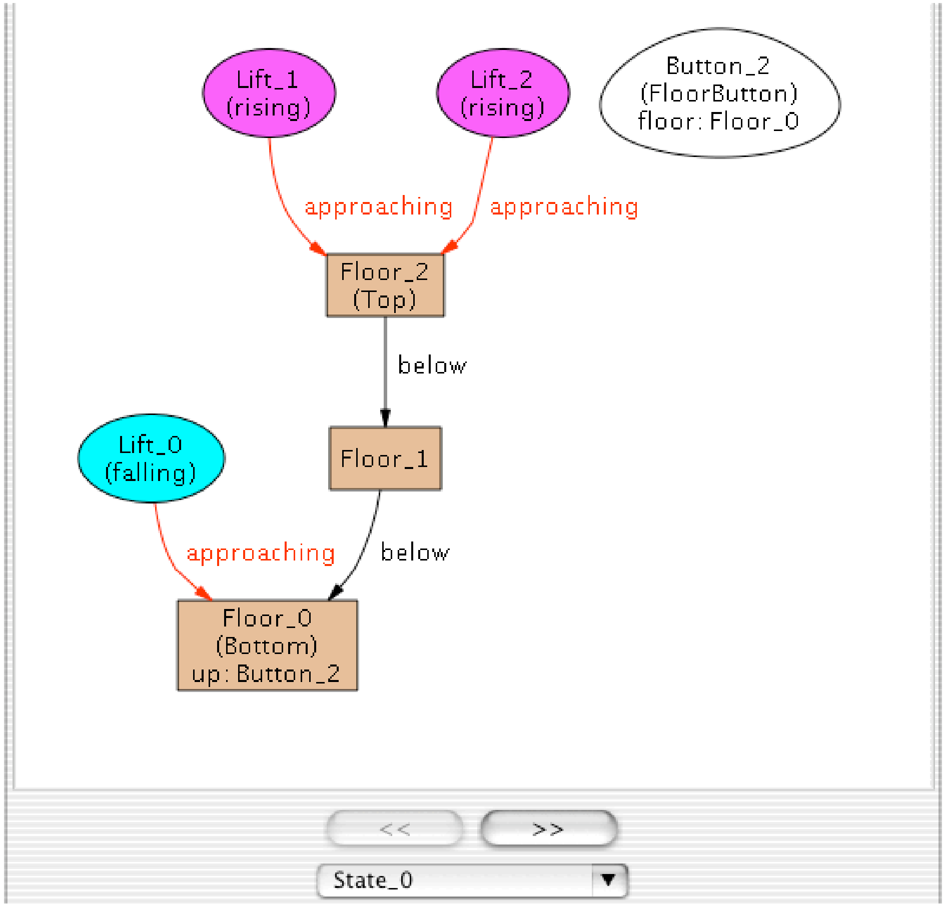
floor at after is floor at or approaching before

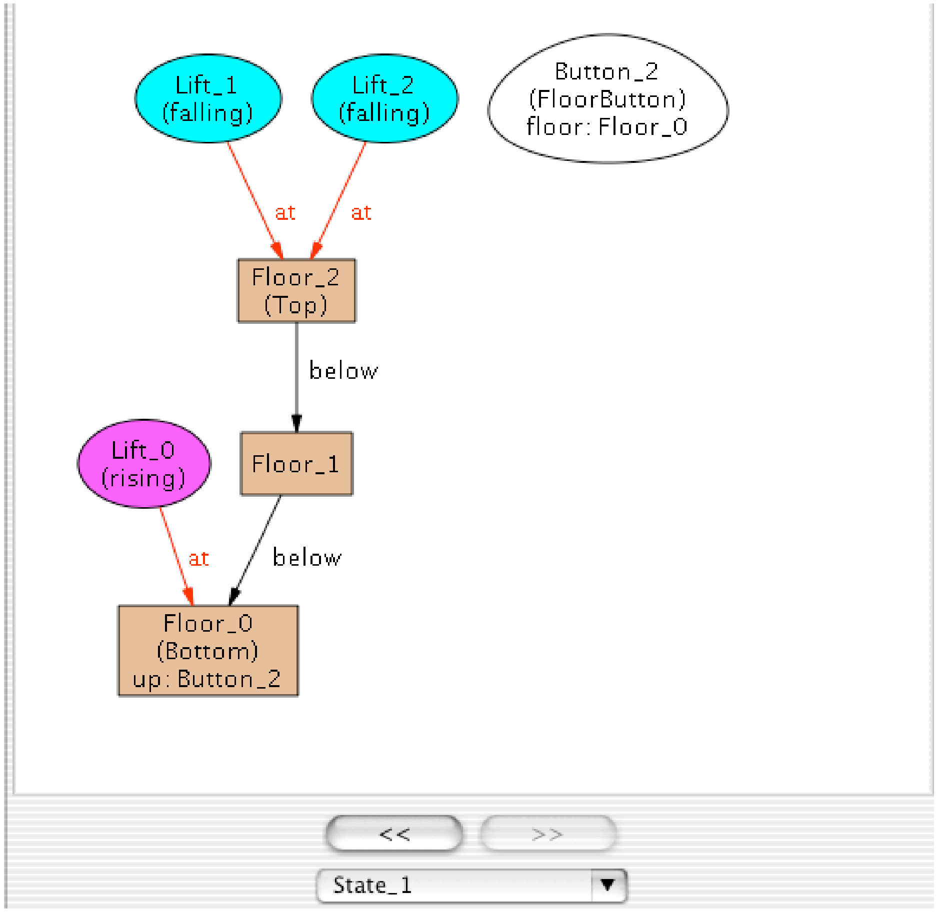
floor approaching after is floor approached before, or next floor

sample transition

```
fun NiceMotion (s, s': State) {
  LiftMotion (s,s') && LiftPosition (s) && LiftPosition (s')
  s.at != s'.at}

run NiceMotion for 3 but 2 State
```





button update

```
fun ButtonUpdate (s, s': State, press: set Button) {
  s'.lit = s.lit -
     {b: Button | some p: Lift | Serves (s,s',p,b)}
     + press
  no b: press & LiftButton | b.floor in (s+s').at[b.lift]
  no press & s.lit
  s.promises[Lift] - s'.promises[Lift] in s.lit - s'.lit
  }
```

denying service

```
fun Towards (s: State, p: Lift, f: Floor) {
  let next = nextFloor(s,p) |
    f in s.at[p].^next + s.approaching[p].*next
  }
fun Denies (s, s': State, p: Lift, b: Button) {
  let f = b.floor {
    Towards (s,p,f)
    not Towards (s',p,f)
    not Serves (s,s',p,b)
    }
  }
```

a policy

```
fun Policy (s, s': State) {
 no p: Lift, b: p.buttons & s.lit | Denies (s,s',p,b)
 all b: s.lit & FloorButton, p: Lift |  Denies (s,s',p,b) =>
   (some q: Lift | Serves(s,s',q,b))
   or (b in s'.promises[Lift]
     and some b': s.lit | Towards (s',p,b'.floor))
 NoStuckLift (s,s')
 AvoidStops (s,s')
 }
```

don't deny lift buttons

if deny floor button
  some lift serves it
  or some lift promises to

putting it all together

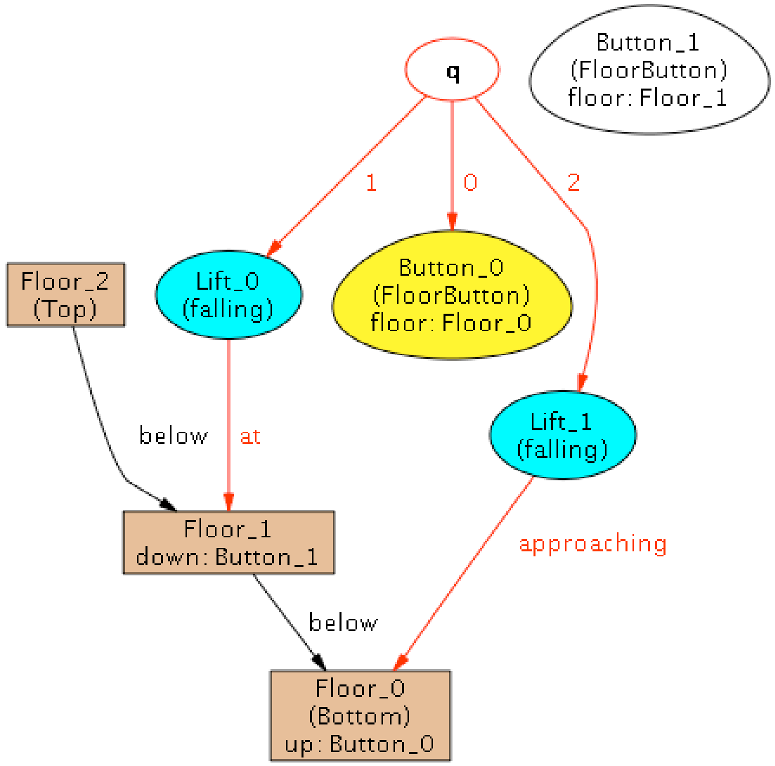
```
fun Trans (s, s': State) {
  LiftPosition (s)
  LiftPosition (s')
  LiftMotion (s,s')
  Policy (s,s')
  some press: set Button | ButtonUpdate (s, s', press)
  }
```

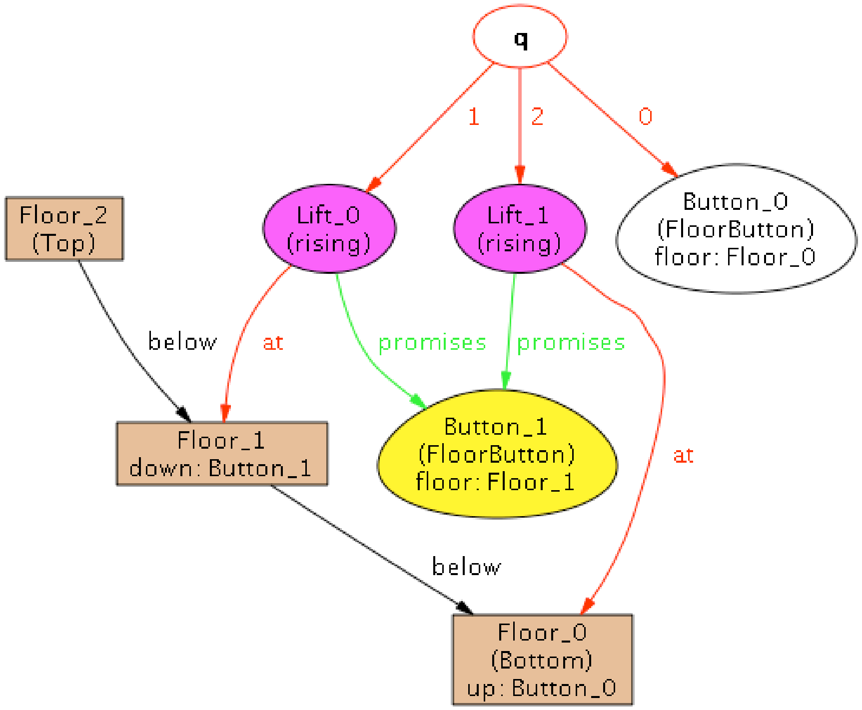
in a transition, some set of buttons is pressed and buttons are updated

sample denial

```
fun ShowPolicy (s, s': State) {
  Trans (s, s')
  some b: s.lit & FloorButton, p: Lift | Denies (s,s',p,b)
  no s.promises && some s'.promises}

run ShowPolicy for 3 but 2 State, 2 Lift, 2 Button
```





traces

```
fun Init (s: State) {
  no s.lit.floor &  s.at[Lift]
  no s.promises
  }
fun Trace () {
  Init (Ord[State].first)
  all s: State - Ord[State].last |
    let s' = Ord[State].next[s] | Trans (s,s')
  }
```

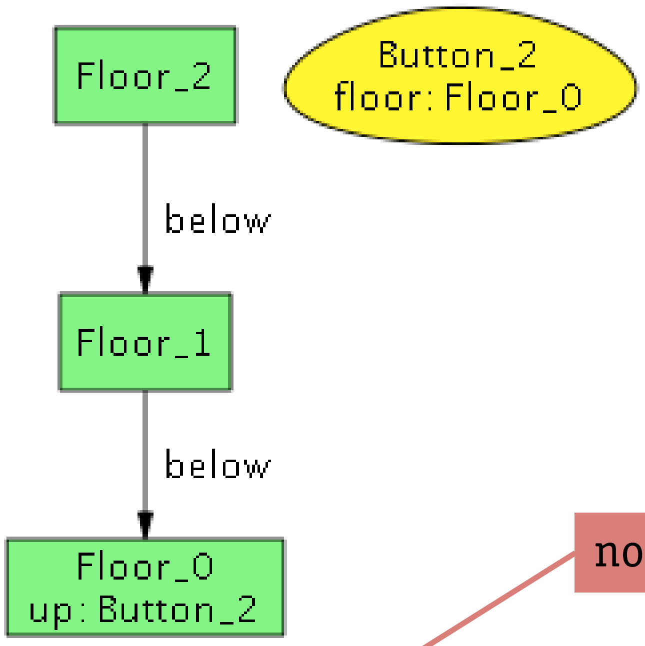
initial condition holds in first state

transition relation relates each state except the last to the next state

asserting eventual service

```
assert EventuallyServed {
  Trace () =>
    let start = Ord[State].first {
      all b: start.lit | some s': OrdNexts (start) | b !in s'.lit
      }
  }
```

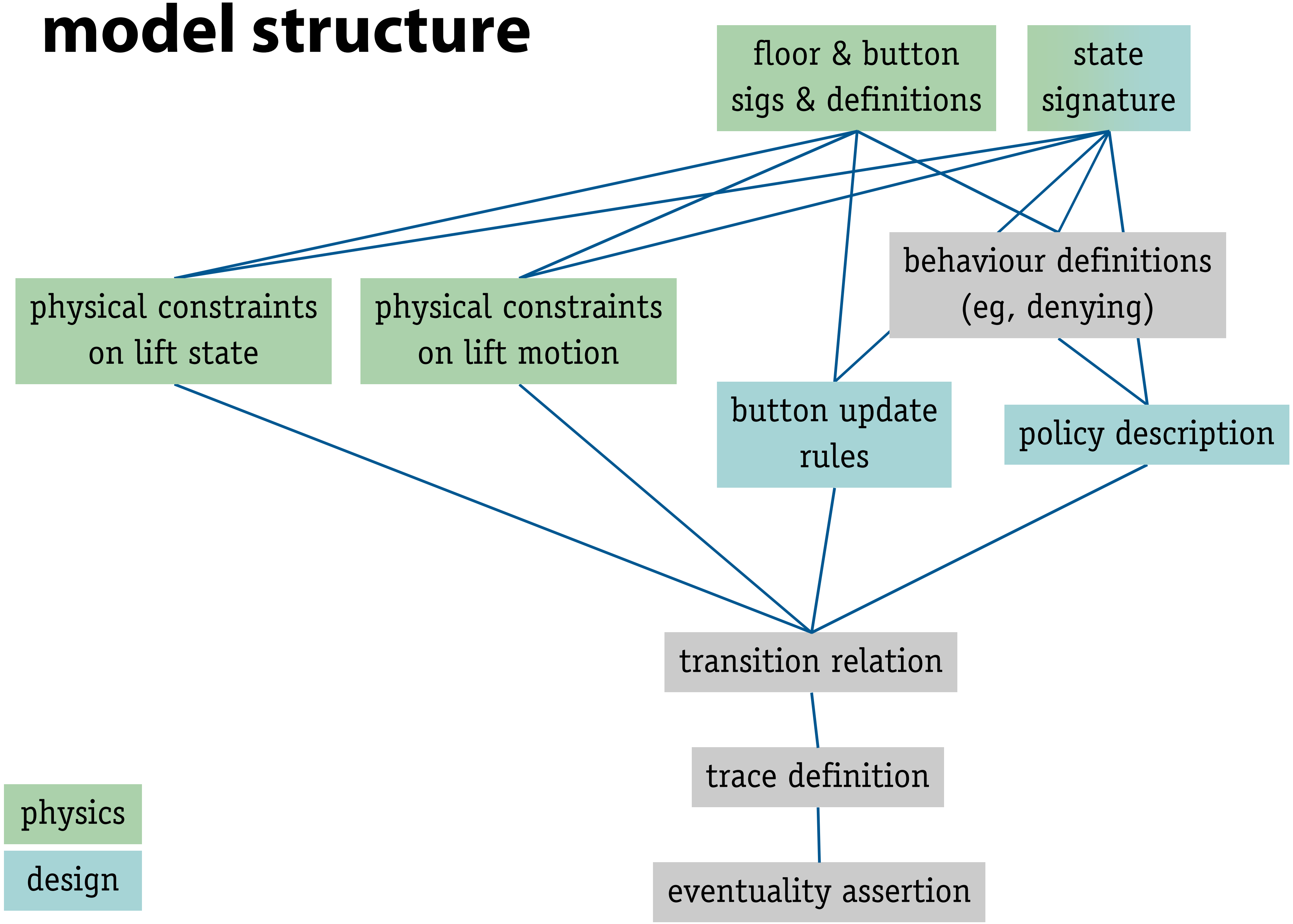
counterexample!



no service without lifts

```
assert EventuallyServed {
 Trace () and some Lift =>
   let start = Ord[State].first {
     all b: start.lit | some s': OrdNexts (start) | b !in s'.lit
     }
 }
```

model structure



floor & button sigs & definitions

state signature

physical constraints on lift state

physical constraints on lift motion

behaviour definitions (eg, denying)

button update rules

policy description

transition relation

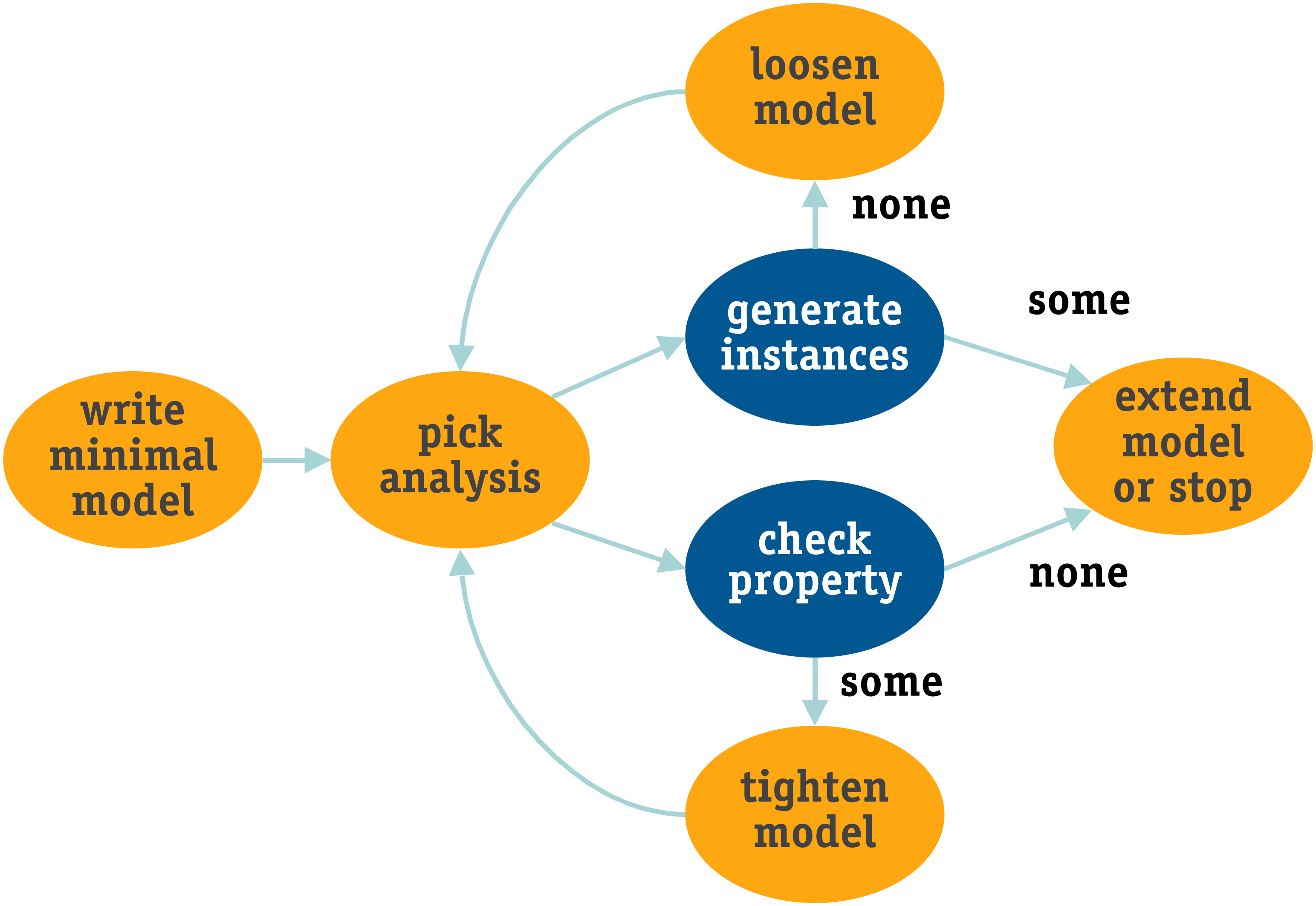
trace definition

eventuality assertion

physics

design

incremental development



write minimal model

pick analysis

loosen model

none

generate instances

some

extend model or stop

check property

none

some

tighten model

challenges for you

key properties of all lift systems
- what are they?
- are they just cultural?

replacing promises
- a better way to allow load balancing?