Monitoring the Execution of Space Craft FIight Software

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thanks to members of the MSL flight software team

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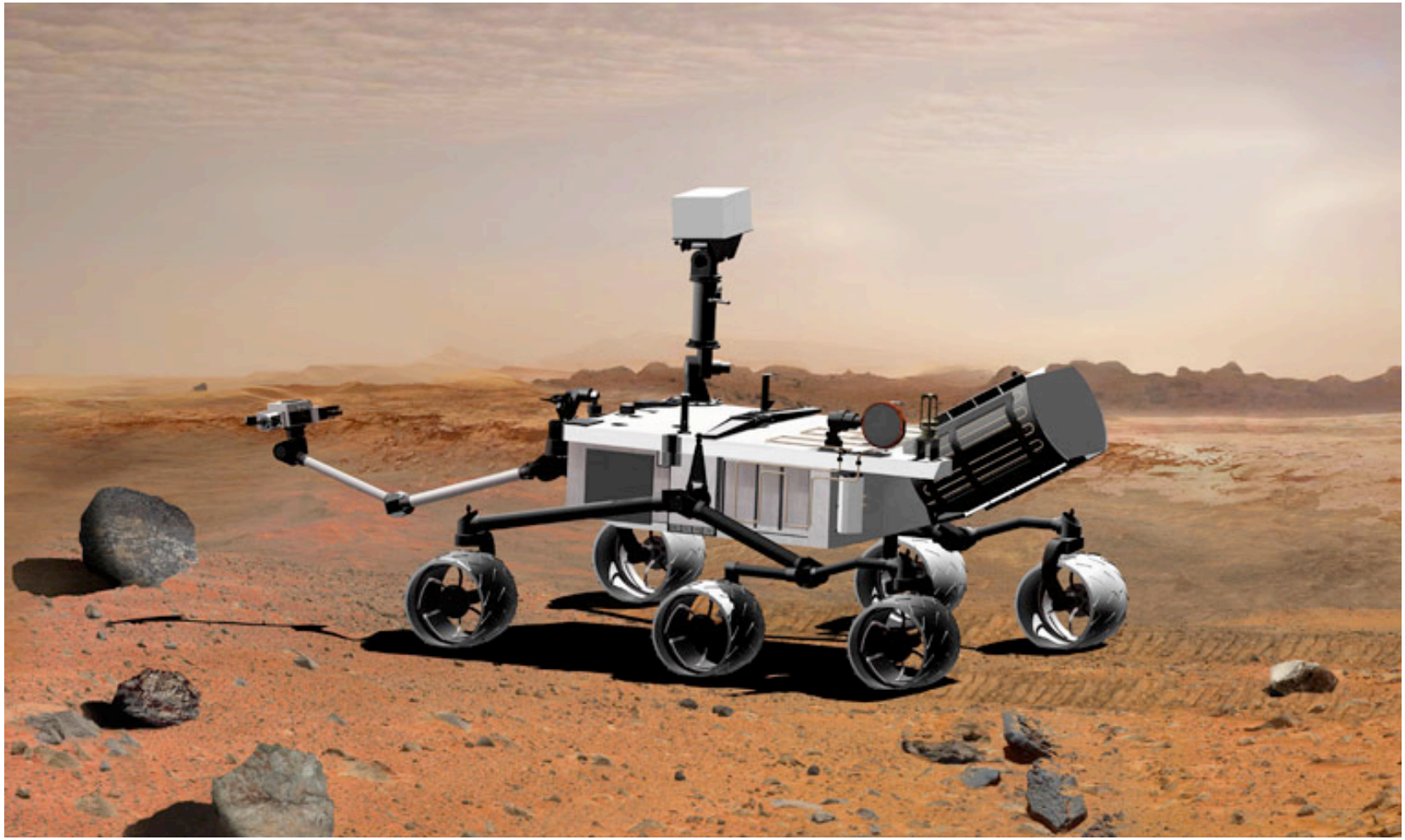
outline

- the Mars Science Laboratory
- suggested testing methodology
- the LogScope monitoring system
- relationship to other work

our contributions

- user-friendly temporal quantified logic
- translation into quantified automata
- both can be used for specification
- runtime verification of log files
- testing of real spacecraft software

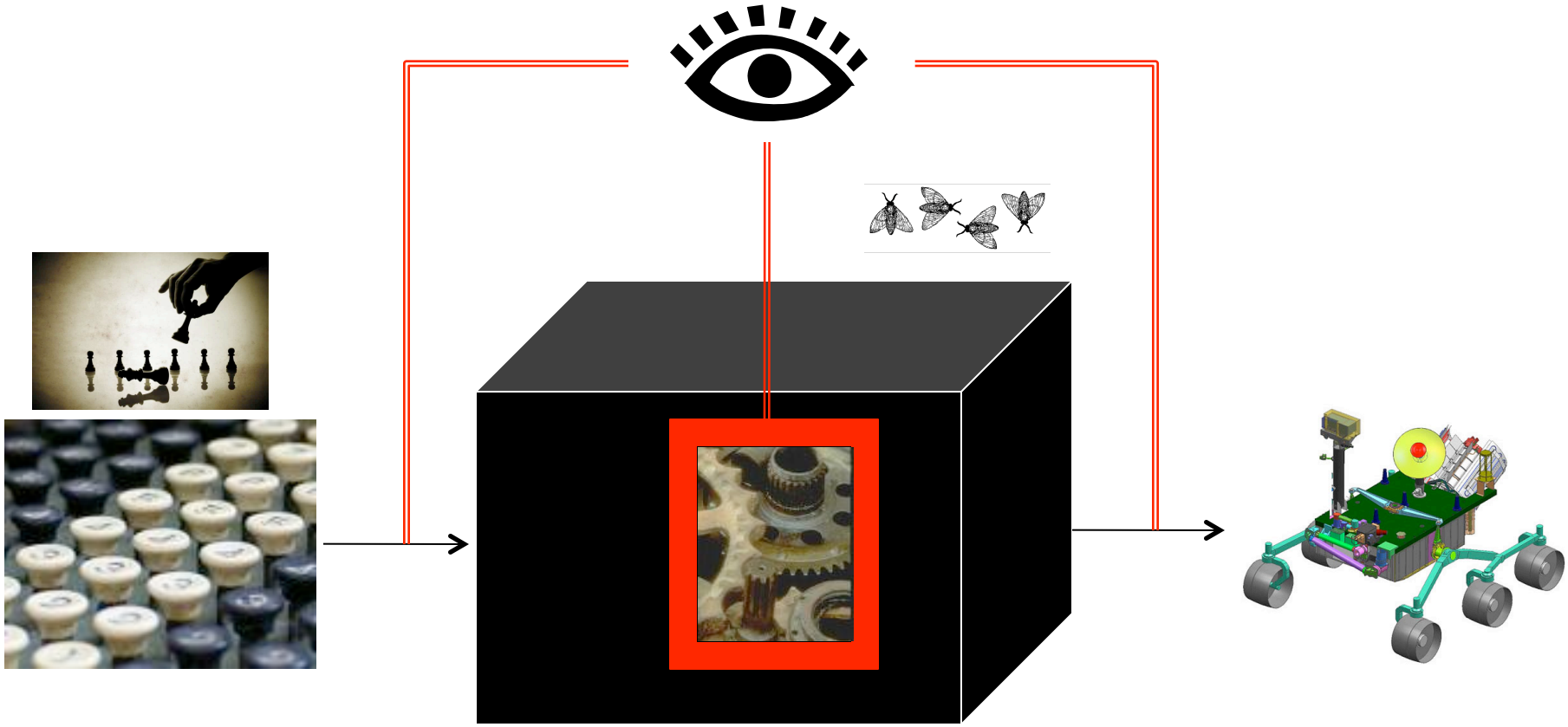
Mars Science Laboratory (MSL)



MSL information

- planned launch 2011
- biggest rover so far to be sent to Mars
- programmer team of 30
- testing team of 10+ people
- rover compute element (RCE): controls all stages of the integrated spacecraft
- programming language is C, 2.5 M LOC
- highly multi-threaded (over 130 threads)

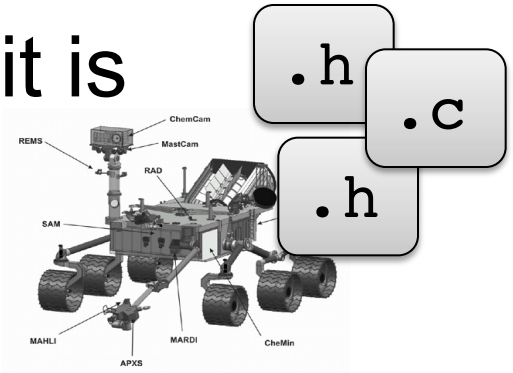
testing



problems with testing FSW

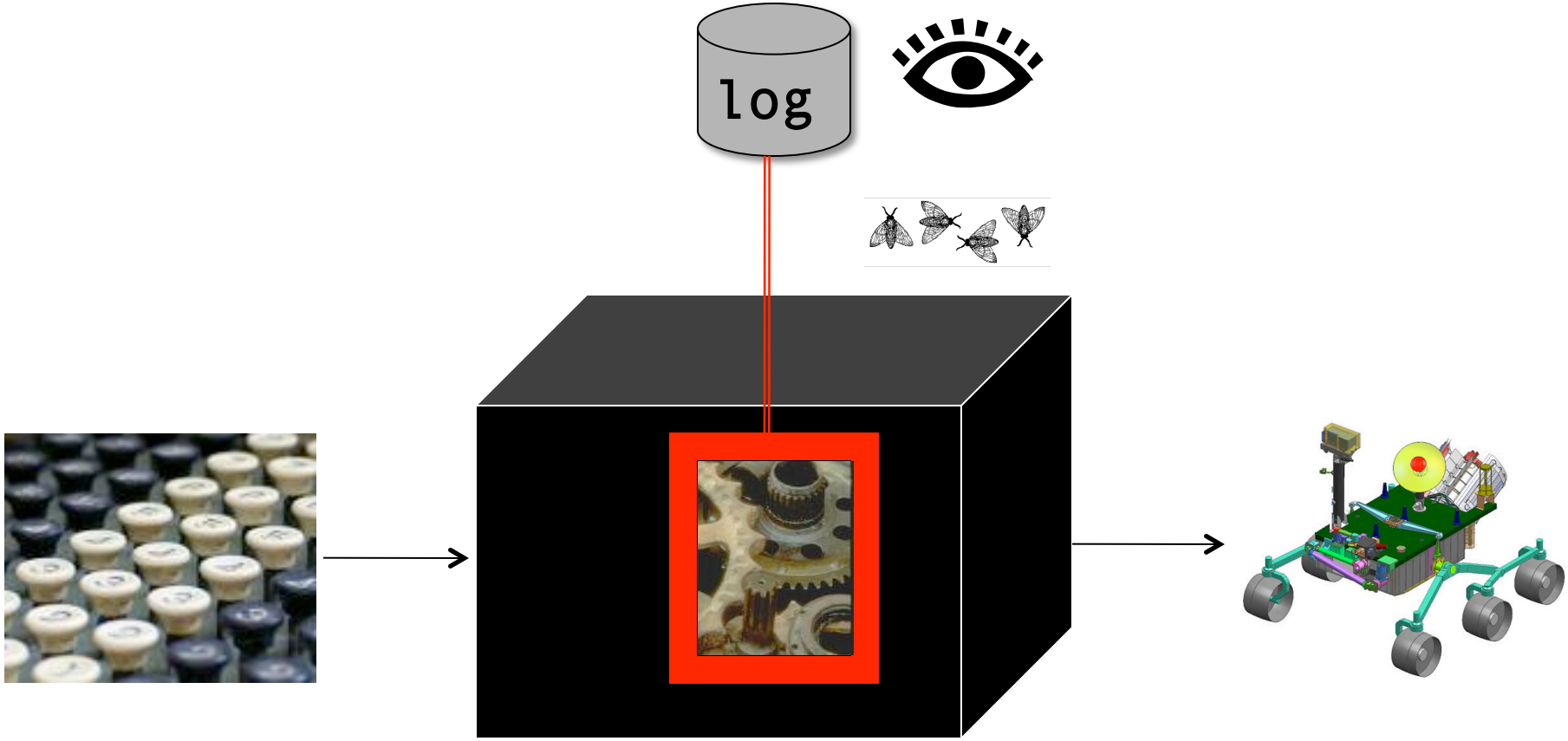
- flight software engineers work under tight schedules: hard to access.

- system = hardware + software: it is cumbersome to run.

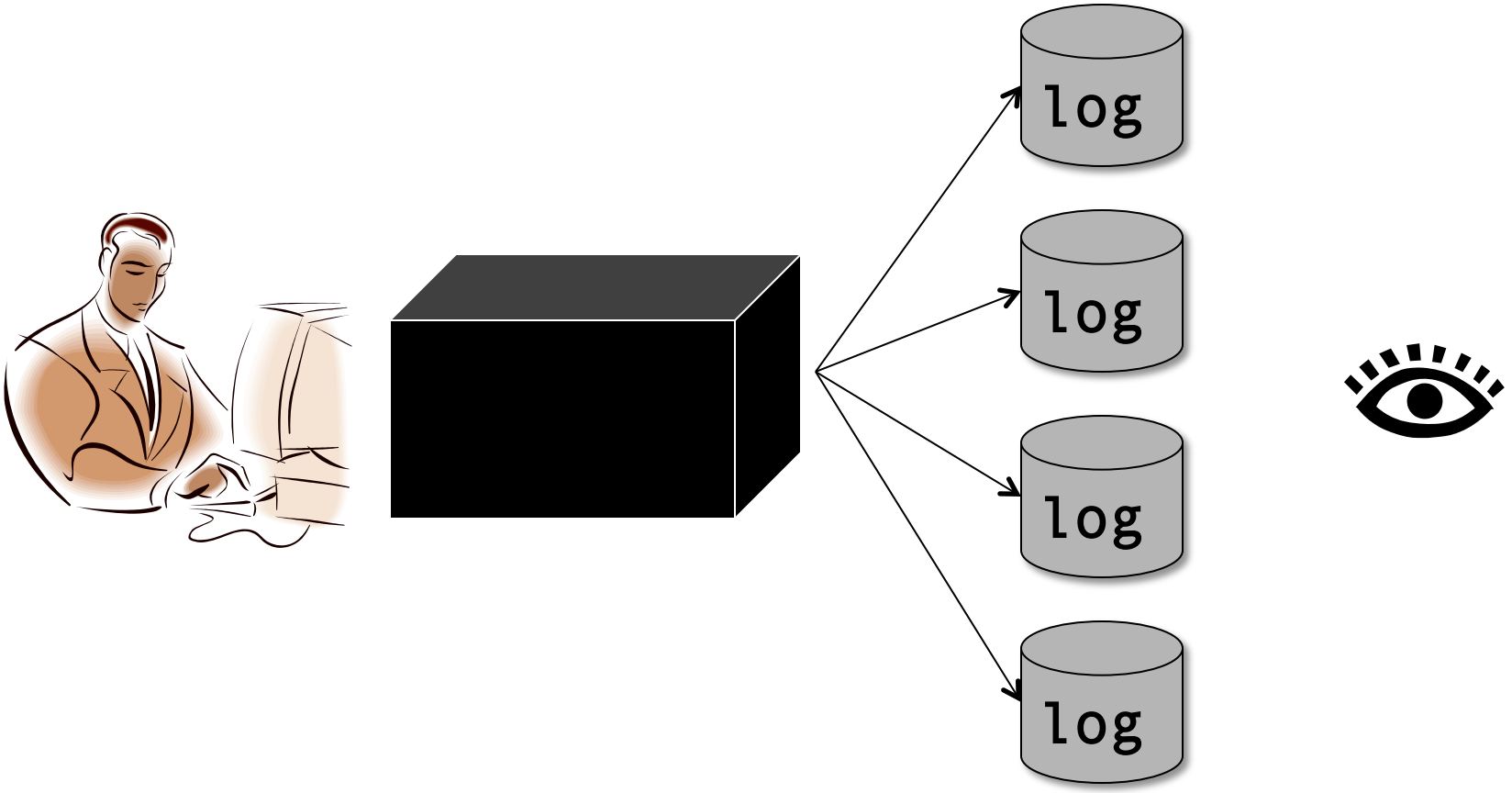


- difficult to determine what properties to define of what events.

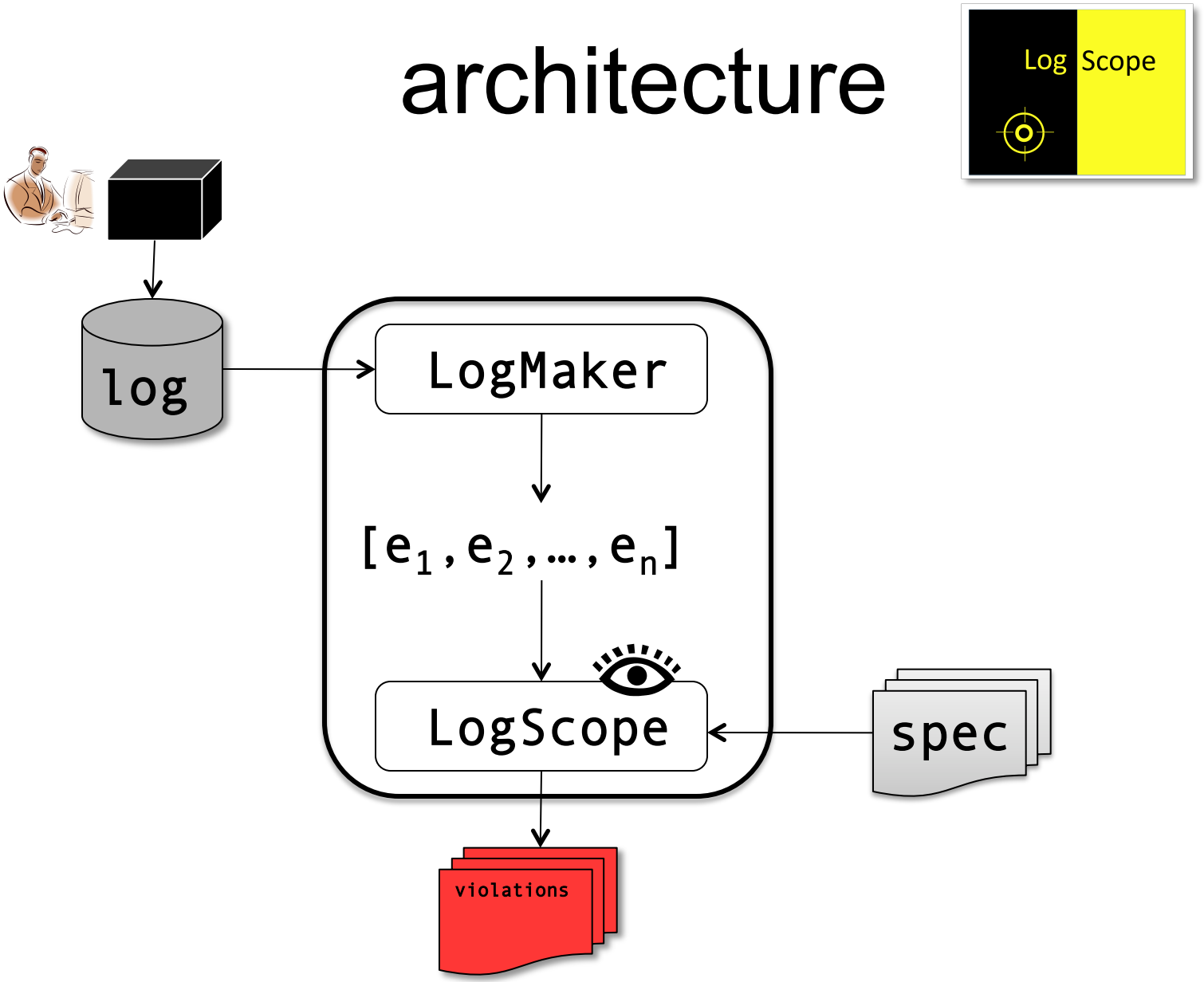
emphasis on offline log analysis



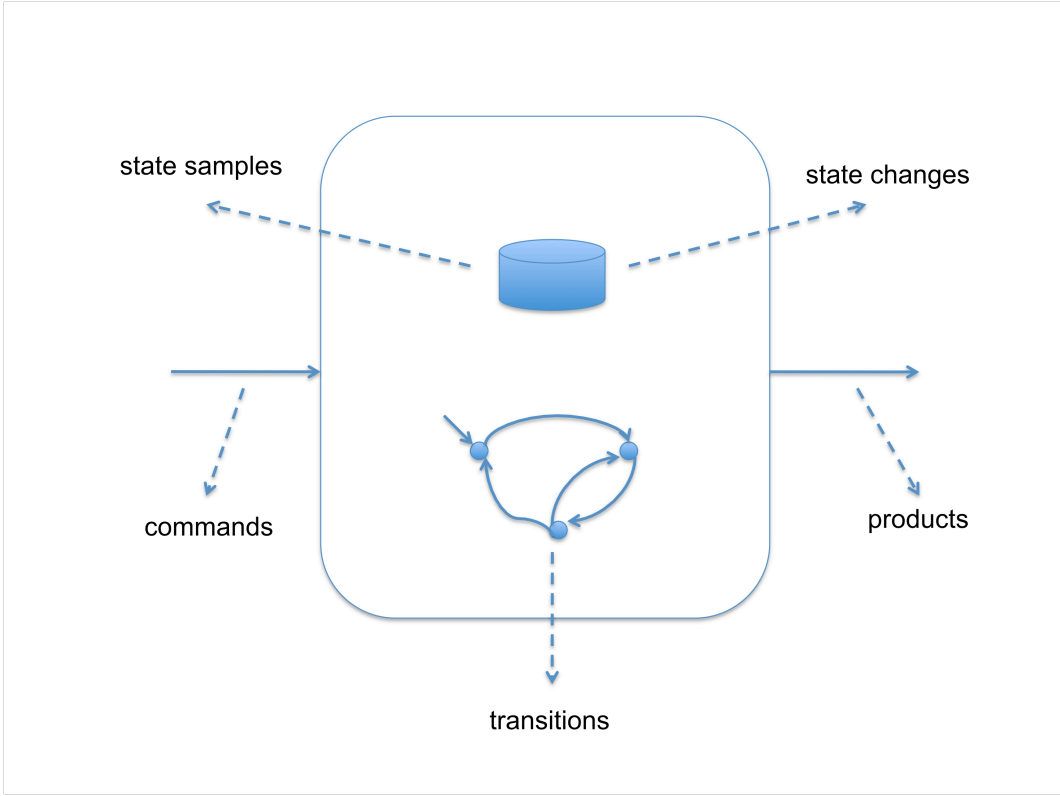
separation of concerns



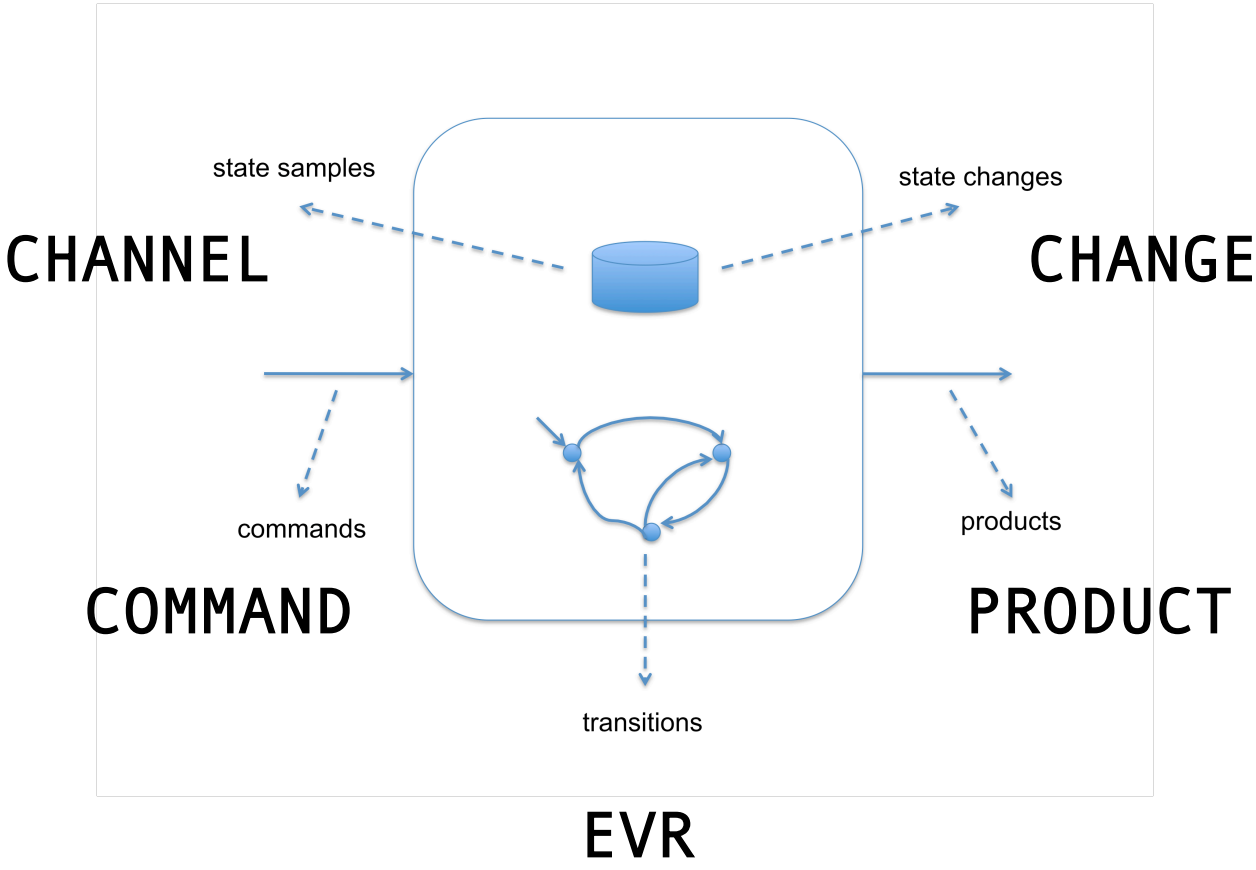
architecture



log events


state samples
state changes
commands
products
transitions

log events


state samples
state changes
CHANNEL
CHANGE
commands
products
COMMAND
PRODUCT
transitions
EVR

example log

```
...
COMMAND 7308 {
  Args := ['CLEAR_RELAY_PYRO_STATUS']
  Time := 51708322925696
  Stem := "POWER_HOUSEKEEPING"
  Number := "4"
  type := "FSW"
}

EVR 7309 {
  message := "Dispatched immediate command
    POWER_HOUSEKEEPING: number=4,
    seconds=789006392, subseconds=1073741824."
  Dispatch := "POWER_HOUSEKEEPING"
  Time := 51708322925696
  name := "CMD_DISPATCH"
  level := "COMMAND"
  Number := "4"
}
...
EVR 7311 {
  name := "POWER_SEND_REQUEST"
  Time := 51708322925696
  message := "power_queue_card_request-
    sending request to PAM 0."
  level := "DIAGNOSTIC"
}


EVR 7312 {
  message := "Successfully completed command
    POWER_HOUSEKEEPING: number=4."
  Success := "POWER_HOUSEKEEPING"
  Time := 51708322944128
  name := "CMD_COMPLETED_SUCCESS"
  level := "COMMAND"
  Number := "4"
}
```


```
EVR 7313 {
  name := "PWR_REQUEST_CALLBACK"
  Time := 51708322944128
  message := "power_card_request -
    FPGA request successfully sent to
    RPAM A."
  level := "DIAGNOSTIC"
}

CHANNEL 7314 {
  channelId := "PWR-3049"
  DNChange := 67
  dnUnsignedValue := 1600
  type := "UNSIGNED_INT"
  Time := 51708323217408
  ChannelName := "PWR-BCB1-AMP"
}
...
COMMAND 9626 {
  Args := ['set_device(1)', 'TRUE']
  Time := 51708372934400
  Stem := "RUN_COMMAND"
  Number := "18"
  type := "FSW"
}

EVR 9627 {
  message := "Validation failed for command
    RUN_COMMAND: number=18."
  DispatchFailure := "RUN_COMMAND"
  Time := 51708372934499
  name := "CMD_DISPATCH_VALIDATION_FAILURE"
  level := "COMMAND"
  Number := "18"
}
...
```

example log

```
...
COMMAND 7308 {
  Args := ['CLEAR_RELAY_PYRO_STATUS']
  Time := 51708322925696
  Stem := "POWER_HOUSEKEEPING"
  Number := "4"
  type := "FSW"
}

EVR 7309 {
  message := "Dispatched immediate command
    POWER_HOUSEKEEPING: number=4,
    seconds=789006392, subseconds=1073741824."
  Dispatch := "POWER_HOUSEKEEPING"
  Time := 51708322925696
  name := "CMD_DISPATCH"
  level := "COMMAND"
  Number := "4"
}
...
EVR 7311 {
  name := "POWER_SEND_REQUEST"
  Time := 51708322925696
  message := "power_queue_card_request-
    sending request to PAM 0."
  level := "DIAGNOSTIC"
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  level := "COMMAND"
  Number := "4"
}

EVR 7313 {
  name := "PWR_REQUEST_CALLBACK"
  Time := 51708322944128
  message := "power_card_request -
    FPGA request successfully sent to
    RPAM A."
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CHANNEL 7314 {
  channelId := "PWR-3049"
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  Stem := "RUN_COMMAND"
  Number := "18"
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EVR 9627 {
  message := "Validation failed for command
    RUN_COMMAND: number=18."
  DispatchFailure := "RUN_COMMAND"
  Time := 51708372934499
  name := "CMD_DISPATCH_VALIDATION_FAILURE"
  level := "COMMAND"
  Number := "18"
}
...
```

standard practice

- logs analyzed by writing Python scripts
  - properties coded up in Python
- this results in “specifications” that are:
  - time consuming to write
  - difficult to read, hindering:
    - maintenance
    - communication
    - specification-sharing
    - reuse
  - difficult to auto-generate

representation of logs in Python

```
log =
[
  {"OBJ_TYPE”:"COMMAND",
     "Type”:"FSW”,"Stem”:"PICT”,"Number”:231},

  {"OBJ_TYPE”:"EVR”,
     "Dispatch”:"PICT”,"Number”:231},

  {"OBJ_TYPE”:"CHANNEL",
     "DataNumber" : 5},

  {"OBJ_TYPE”:"EVR",
     "Success”:"PICT”, "Number”:231},

  {"OBJ_TYPE”:"PRODUCT",
     "ImageSize" : 1200}
]
```

the first scripture

trigger

consequences

```
look:DRILL_DMP\
  evr(CMD_DISPATCH,positive)\
  evr(CMD_COMPLETED_SUCCCESS,positive)\
  evr(CMD_COMPLETED_FAILURE,negative)\
  chan(id:CMD-0004,positive,contains opcode
                    of last immediate command)\
  chan(id:CMD-0007,positive)\
  chan(id:CMD-0001,negative)\
  chan(id:CMD-0009,negative)\
  prod(name:DrillAll,1,*)
```

Property P_1

P_1: Whenever a flight software command is issued, then eventually an EVR should indicate success of that command

Property P_1 refined

P_1: Whenever a COMMAND is issued with the Type field having the value "FSW", the Stem field (command name) having some unknown value x, and the Number field having some unknown value y, then eventually an EVR should occur, with the field Success mapped to x and the Number field mapped to y.

formalization

pattern P1:
COMMAND{Type:"FSW", Stem:x, Number:y} =>
EVR{Success:x, Number:y}

$$\forall x, y \bullet \\ \quad \Box(\texttt{COMMAND\{Type:"FSW", Stem:x, Number:y\}} \Rightarrow \\ \quad\quad \Diamond(\texttt{EVR\{Success:x, Number:y\}}))$$

pattern syntax

pattern ::=
'pattern' NAME ':' event '=>' consequence

consequence ::=
event ⟸
| '!' event ⟸
| '[' consequence$_1$,...,consequence$_n$ ']'
| '{' consequence$_1$,...,consequence$_n$ '}'

Property P_2

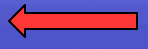
P_2: Whenever a COMMAND is issued with the Type field having the value "FSW", the Stem field (command name) having some unknown value x, and the Number field having some unknown value y, Then an EVR should thereafter not occur, with the field Failure mapped to x and the Number field mapped to y.

formalization

```
pattern P2:
  COMMAND{Type:"FSW", Stem:x, Number:y} =>
    ! EVR{Failure:x, Number:y}
```

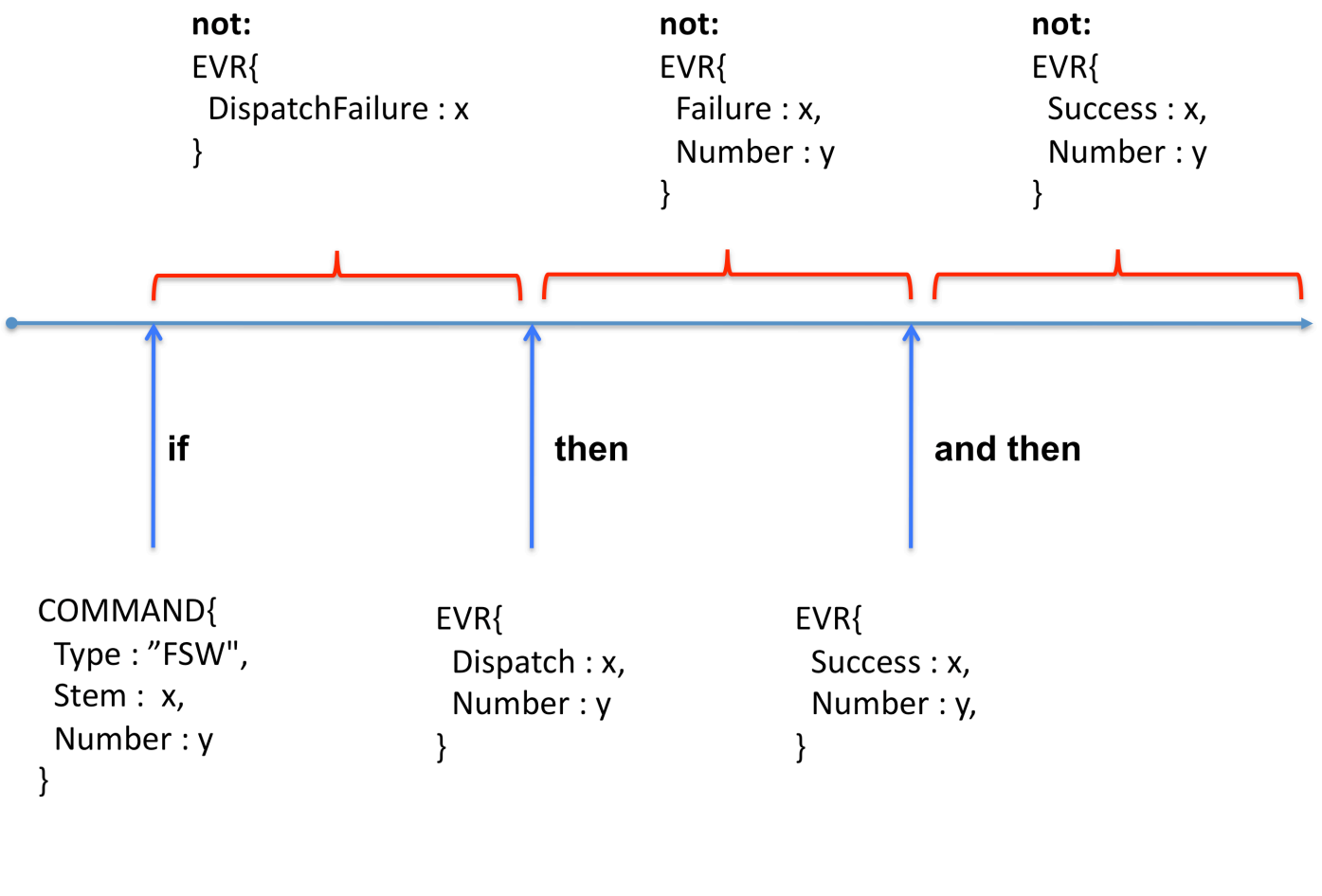
pattern syntax

pattern ::=
'pattern' NAME ':' event '=>' consequence

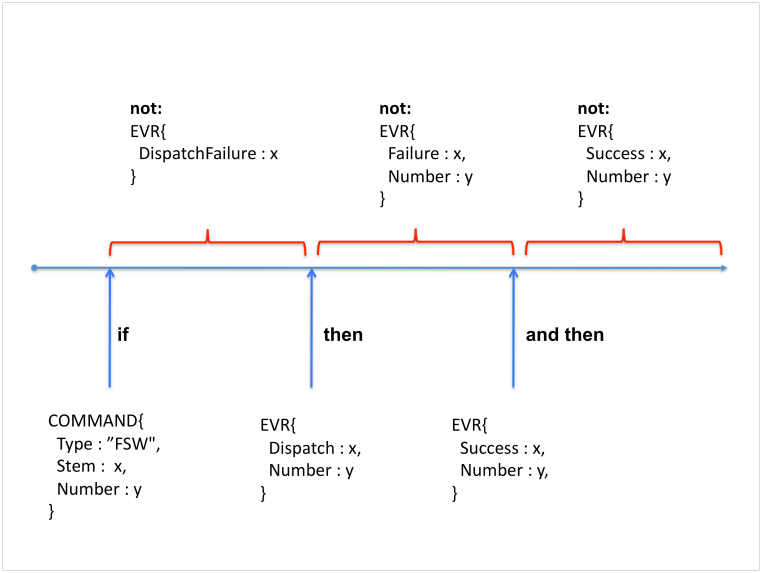
consequence ::=
event
| '!' event
| '[' consequence$_1$,...,consequence$_n$ ']' 
| '{' consequence$_1$,...,consequence$_n$ '}'

Property P_3

P_3: Whenever a flight software command is issued, there should follow a dispatch of that command, and no dispatch failure before that, followed by a success of that command, and no failure before that, and no more successes of that command (exactly one success).


not:
EVR{
DispatchFailure : x
}
not:
EVR{
Failure : x,
Number : y
}
not:
EVR{
Success : x,
Number : y
}
if
then
and then
COMMAND{
Type : ”FSW",
Stem : x,
Number : y
}
EVR{
Dispatch : x,
Number : y
}
EVR{
Success : x,
Number : y,
}

formalization




```
pattern P3:
  COMMAND{Type:"FSW", Stem:x, Number:y} =>
    [
      ! EVR{DispatchFailure:x},
        EVR{Dispatch:x, Number:y},
      ! EVR{Failure:x, Number:y},
        EVR{Success:x, Number:y},
      ! EVR{Success:x, Number:y}
    ]
```

expressed in “quantified” LTL

$$
\begin{array}{l}
\forall x, y \bullet \\
\quad \Box(\texttt{COMMAND\{Type:"FSW",Stem:x,Number:y\}} \Rightarrow \\
\quad\quad \neg\texttt{EVR\{DispatchFailure:x\}}\ \mathcal{U} \\
\quad\quad\quad (\texttt{EVR\{Dispatch:x,Number:y\}} \\
\quad\quad\quad \wedge (\neg\texttt{EVR\{Failure:x,Number:y\}}\ \mathcal{U} \\
\quad\quad\quad\quad (\texttt{EVR\{Success:x,Number:y\}} \\
\quad\quad\quad\quad\quad \wedge \bigcirc\Box\neg\texttt{EVR\{Success:x,Number:y\}})))
\end{array}
$$

not as easy to read

pattern syntax

```
pattern ::=
    'pattern' NAME ':' event '=>' consequence

consequence ::=
    event
  | '!' event
  | '[' consequence1,...,consequencen ']'
  | '{' consequence1,...,consequencen '}'
```

property P4

P_4: Whenever a flight software command is issued, there should follow a dispatch of that command, and also a success, but the two events can occur in any order. In addition, there should never at any time (to the end of the log) after the command occur a dispatch failure or a failure of that command. Finally, after a success there should not follow another success for that same command and number.

formalized

```
pattern P4:
  COMMAND{Type:"FSW", Stem:x, Number:y} =>
    {  EVR{Dispatch:x, Number:y},
       [
          EVR{Success:x, Number:y},
        ! EVR{Success:x, Number:y}
       ],
     ! EVR{DispatchFailure:x},
     ! EVR{Failure:x, Number:y}
    }
```

predicates

P_5: The success of a command with a number y should never be followed by the success of a command with an equal or lower number $z \leq y$.

```
pattern P5:
  EVR{Success:_, Number:y} =>
    ! EVR{Success:_,Number:z} where {: z <= y :}
```

Python predicate definitions

```
{:
def within(t1,t2,max):
  return (t2-t1) <= max
:}

pattern P6:
  COMMAND{Type:"FSW",Stem:x,Number:y,Time:t1}
    where {: x.startswith("PWR_") :}
  =>
  EVR{Success:x, Number:y, Time:t2}
    where within(t1,t2,10000)
```

specialized range predicates

```
pattern P7:
  COMMAND {Type: "FSW", Stem: "PICT"} =>
    [
      CHANNEL {DataNumber : {0 : 1, 4 :0}},
      PRODUCT ImageSize : [1000,2000]
    ]
```

DataNumber bit nr 0 should be 1, and bit nr 4 should be 0

ImageSize should be in the interval 1000 … 2000

event actions

```
{:
counter = 0

def count():
  global counter;counter = counter + 1

def within():
  return counter < 3
:}

pattern P8 :
  COMMAND {Name : x} where {: within() :} do {: count() :} =>
    EVR {Success : x} do {: print x + " succeeded" :}
```

scopes

- sometimes need for limiting the scope of a property
- without such scope a pattern is checked from it is triggered until the end of the log
- for example: check that some command leads to some behavior, but only up to the next command

scoped version of P4

```
pattern P4_:
  COMMAND{Type:"FSW", Stem:x, Number:y} =>
    {  EVR{Dispatch:x, Number:y},
       [   EVR{Success:x, Number:y},
         ! EVR{Success:x, Number:y} ],
      ! EVR{DispatchFailure:x},
      ! EVR{Failure:x, Number:y}
    }
    upto COMMAND{Type: "FSW”}
```

syntax for patterns

pattern ::=
'pattern' NAME ':' event '=>' consequence
['upto' event]

consequence ::=
event
| '!' event
| '[' consequence$_1$,...,consequence$_n$ ']'
| '{' consequence$_1$,...,consequence$_n$ '}'

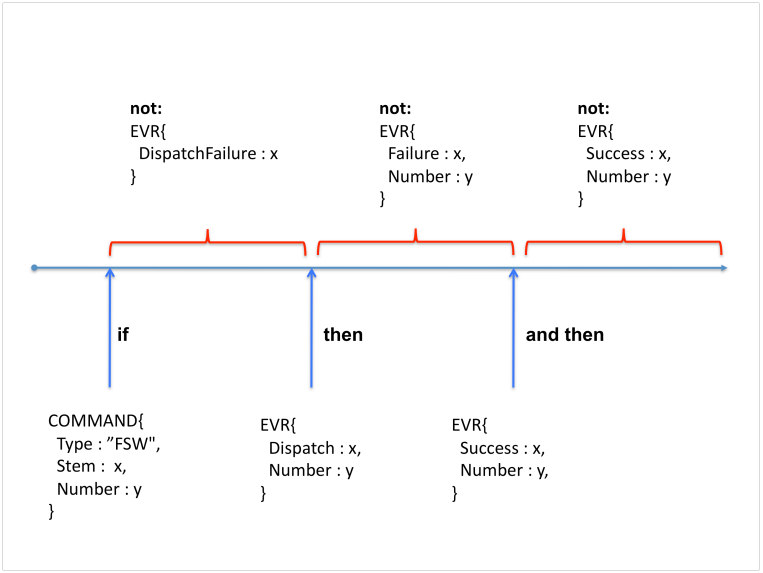
from patterns to automata

- temporal patterns are translated into parameterized universal automata
- automata language more expressive
- user can use both, in practice only temporal patterns have been used for testing MSL
- automaton language forms a subset of the RuleR language (to be discussed)

automata characteristics

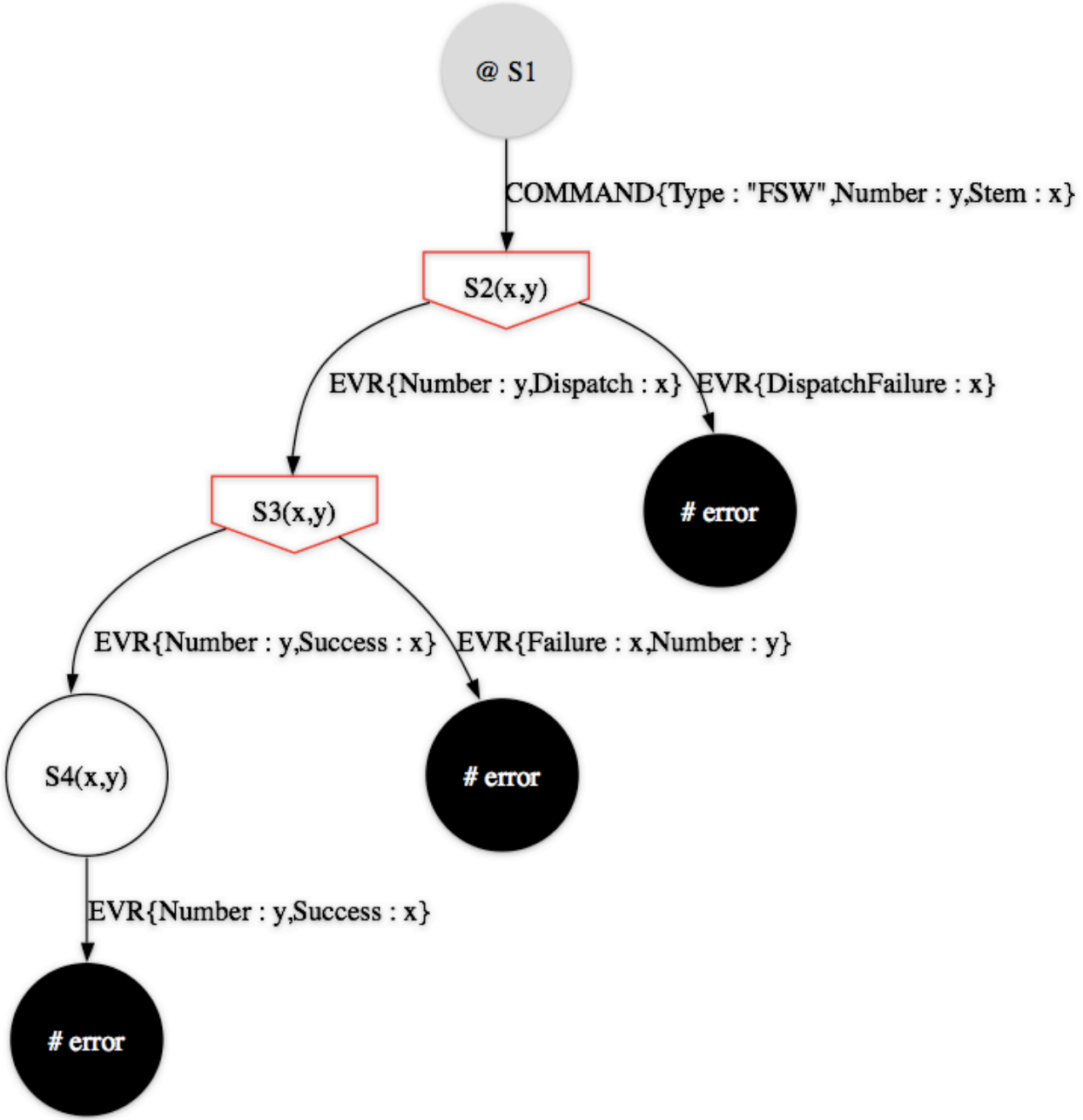
- states, transitions and events
- events are as in patterns:
  - can carry/bind data
  - can have executable Python predicates
  - can have executable Python actions
- states can be parameterized with data
- a transition can target multiple states
  - all must lead to success ($\wedge$-semantics)

recall P3




```
pattern P3:
  COMMAND{Type:"FSW", Stem:x, Number:y} =>
    [
      ! EVR{DispatchFailure:x},
        EVR{Dispatch:x, Number:y},
      ! EVR{Failure:x, Number:y},
        EVR{Success:x, Number:y},
      ! EVR{Success:x, Number:y}
    ]
```

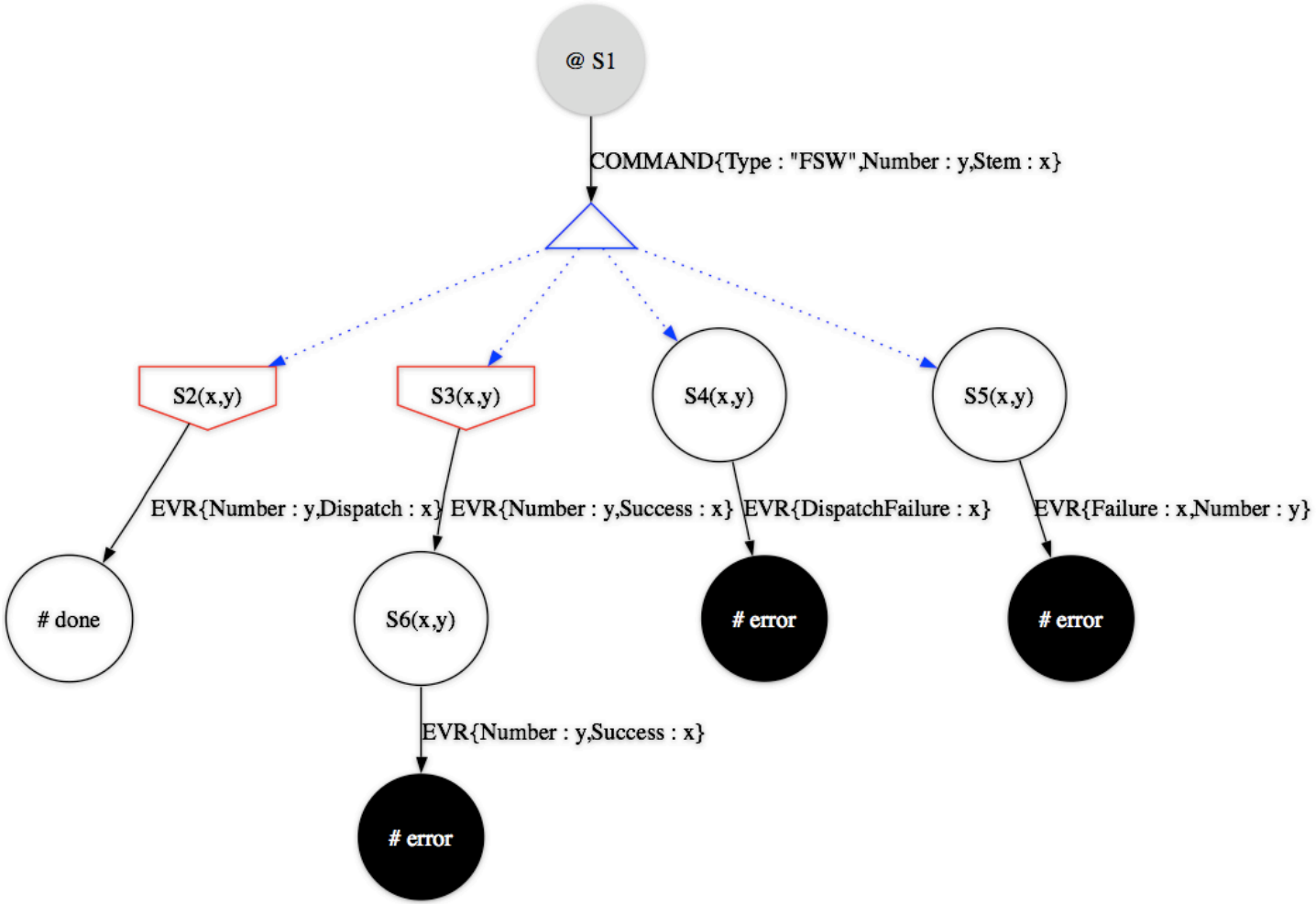
```
automaton A3 {
  always S1 {
    COMMAND{Type:"FSW",Stem:x,Number:y} =>
        S2(x,y)
  }

  hot state S2(x,y) {
    EVR{DispatchFailure:x} => error
    EVR{Dispatch:x, Number:y} => S3(x,y)
  }

  hot state S3(x,y) {
    EVR{Failure:x, Number:y} => error
    EVR{Success:x, Number:y} => S4(x,y)
  }

  state S4(x,y) {
    EVR{Success:x, Number:y} => error
  }
}
```


@ S1
COMMAND{Type : "FSW",Number : y,Stem : x}
S2(x,y)
EVR{Number : y,Dispatch : x}
EVR{DispatchFailure : x}
S3(x,y)
# error
EVR{Number : y,Success : x}
EVR{Failure : x,Number : y}
S4(x,y)
# error
EVR{Number : y,Success : x}
error

recall P4

```
pattern P4:
  COMMAND{Type:"FSW", Stem:x, Number:y} =>
    {  EVR{Dispatch:x, Number:y},
       [   EVR{Success:x, Number:y},
         ! EVR{Success:x, Number:y} ],
      ! EVR{DispatchFailure:x},
      ! EVR{Failure:x, Number:y}
    }
```

```
automaton A4 {
  always S1 {
    COMMAND{Type:"FSW",Stem:x,Number:y} =>
        S2(x,y), S3(x,y), S4(x,y), S5(x,y)
  }

  hot state S2(x,y) {
    EVR{Dispatch:x,Number:y} => done
  }

  hot state S3(x,y) {
    EVR{Success:x,Number:y} => S6(x,y)
  }

  state S4(x,y) {
    EVR{DispatchFailure:x} => error
  }

  state S5(x,y) {
    EVR{Failure:x,Number:y} => error
  }

  state S6(x,y) {
    EVR{Success:x,Number:y} => error
  }
}
```


@ S1
COMMAND{Type : "FSW",Number : y,Stem : x}
S2(x,y)
S3(x,y)
S4(x,y)
S5(x,y)
EVR{Number : y,Dispatch : x}
EVR{Number : y,Success : x}
EVR{DispatchFailure : x}
EVR{Failure : x,Number : y}
# done
S6(x,y)
# error
# error
EVR{Number : y,Success : x}
error

expressiveness

trigger = one event

recall syntax for patterns:

```
pattern ::=
    'pattern' NAME ':' event '=>' consequence
          ['upto' event]

consequence ::=
    event
  | '!' event
  | '[' consequence1,...,consequencen ']'
  | '{' consequence1,...,consequencen '}'
```

so we cannot write

```
pattern P_with_composite_trigger:
   [
      COMMAND{Type:"FSW", Stem:x, Number:y},
    ! EVR{DispatchFailure:x},
      EVR{Dispatch:x, Number:y}
  ]
  =>
  [
    ! EVR{Failure:x, Number:y},
      EVR{Success:x, Number:y},
    ! EVR{Success:x, Number:y}
   ]
```

we can of course write an automaton that expresses the intended semantics.

other automata features

- success states (dual to hot states)
- step states: have to be left in next transition

running LogScope

```
import logscope

log = createLog(fromsomewhere)

observer = logscope.Observer("$ISSTA/spec")
observer.monitor(log)
```

summary of errors

```
==========================
   Summary of Errors:
==========================

P1   :   1 error
P2   :   0
P3   :   1 error
P4   :   3 errors
P5   :   0
P6   :   0
P7   :   3 errors
A3   :   1 error
A4   :   3 errors
```

```
automaton A4 {
  always S1 {
    COMMAND{Type:"FSW",Stem:x,Number:y} =>
        S2(x,y), S3(x,y), S4(x,y), S5(x,y)
  }

  hot state S2(x,y) {
    EVR{Dispatch:x,Number:y} => done
  }

  hot state S3(x,y) {
    EVR{Success:x,Number:y} => S6(x,y)
  }

  state S4(x,y) {
    EVR{DispatchFailure:x} => error
  }

  state S5(x,y) {
    EVR{Failure:x,Number:y} => error
  }

  state S6(x,y) {
    EVR{Success:x,Number:y} => error
  }
}
```

all errors caused by reaction to command 9626

```
...
COMMAND 7308 {
  Args := ['CLEAR_RELAY_PYRO_STATUS']
  Time := 51708322925696
  Stem := "POWER_HOUSEKEEPING"
  Number := "4"
  type := "FSW"
}

EVR 7309 {
  message := "Dispatched immediate command
    POWER_HOUSEKEEPING: number=4,
    seconds=789006392, subseconds=1073741824."
  Dispatch := "POWER_HOUSEKEEPING"
  Time := 51708322925696
  name := "CMD_DISPATCH"
  level := "COMMAND"
  Number := "4"
}
...
EVR 7311 {
  name := "POWER_SEND_REQUEST"
  Time := 51708322925696
  message := "power_queue_card_request-
    sending request to PAM 0."
  level := "DIAGNOSTIC"
}


EVR 7312 {
  message := "Successfully completed command
    POWER_HOUSEKEEPING: number=4."
  Success := "POWER_HOUSEKEEPING"
  Time := 51708322944128
  name := "CMD_COMPLETED_SUCCESS"
  level := "COMMAND"
  Number := "4"
}
```

```
EVR 7313 {
  name := "PWR_REQUEST_CALLBACK"
  Time := 51708322944128
  message := "power_card_request -
    FPGA request successfully sent to
    RPAM A."
  level := "DIAGNOSTIC"
}

CHANNEL 7314 {
  channelId := "PWR-3049"
  DNChange := 67
  dnUnsignedValue := 1600
  type := "UNSIGNED_INT"
  Time := 51708323217408
  ChannelName := "PWR-BCB1-AMP"
}
...
COMMAND 9626 {
  Args := ['set_device(1)', 'TRUE']
  Time := 51708372934400
  Stem := "RUN_COMMAND"
  Number := "18"
  type := "FSW"
}

EVR 9627 {
  message := "Validation failed for command
    RUN_COMMAND: number=18."
  DispatchFailure := "RUN_COMMAND"
  Time := 51708372934499
  name := "CMD_DISPATCH_VALIDATION_FAILURE"
  level := "COMMAND"
  Number := "18"
}
...
```

```
*** violated: by event 9627 in state:

  state S4(x,y) {
    EVR{DispatchFailure:x} => error
  }
  with bindings:
    {'y':'18', 'x':'RUN_COMMAND'}

by transition 1 :
EVR{'DispatchFailure':'RUN_COMMAND'} => error


--- error trace: ---

COMMAND 9626 {
  Args := ['set_dev(1)', 'TRUE']
  Number := "18"
  Stem := "RUN_COMMAND"
  Time := 51708372934400
  Type := "FSW"
}

EVR 9627 {
  name := "CMD_DISPATCH_VALIDATION_FAILURE"
  level := "COMMAND"
  Number := "18"
  DispatchFailure := "RUN_COMMAND"
  Time := 51708372934499
  message := "Validation failed for command
    RUN_COMMAND: number=18."
}
```

```
automaton A4 {
  always S1 {
    COMMAND{Type:"FSW",Stem:x,Number:y} =>
        S2(x,y), S3(x,y), S4(x,y), S5(x,y)
  }

  hot state S2(x,y) {
    EVR{Dispatch:x,Number:y} => done
  }

  hot state S3(x,y) {
    EVR{Success:x,Number:y} => S6(x,y)
  }

  state S4(x,y) {
    EVR{DispatchFailure:x} => error
  }

  state S5(x,y) {
    EVR{Failure:x,Number:y} => error
  }

  state S6(x,y) {
    EVR{Success:x,Number:y} => error
  }
}
```

```
*** violated: in hot end state:

  state S2(x,y) {
    EVR{Number:y,Dispatch:x} =>
      done
  }
  with bindings:
    {'y':'18', 'x':'RUN_COMMAND'}


--- error trace: ---

COMMAND 9626 {
  Args := ['set_device(1)','TRUE']
  Number := "18"
  Stem := "RUN_COMMAND"
  Time := 51708372934400
  Type := "FSW"
}
```

```
*** violated: in hot end state:

  state S3(x,y) {
    EVR{Number:y,Success:x} =>
      S6(x,y)
  }
  with bindings:
    {'y':'18', 'x':'RUN_COMMAND'}


--- error trace: ---

COMMAND 9626 {
  Args := ['set_device(1)','TRUE']
  Number := "18"
  Stem := "RUN_COMMAND"
  Time := 51708372934400
  Type := "FSW"
}
```

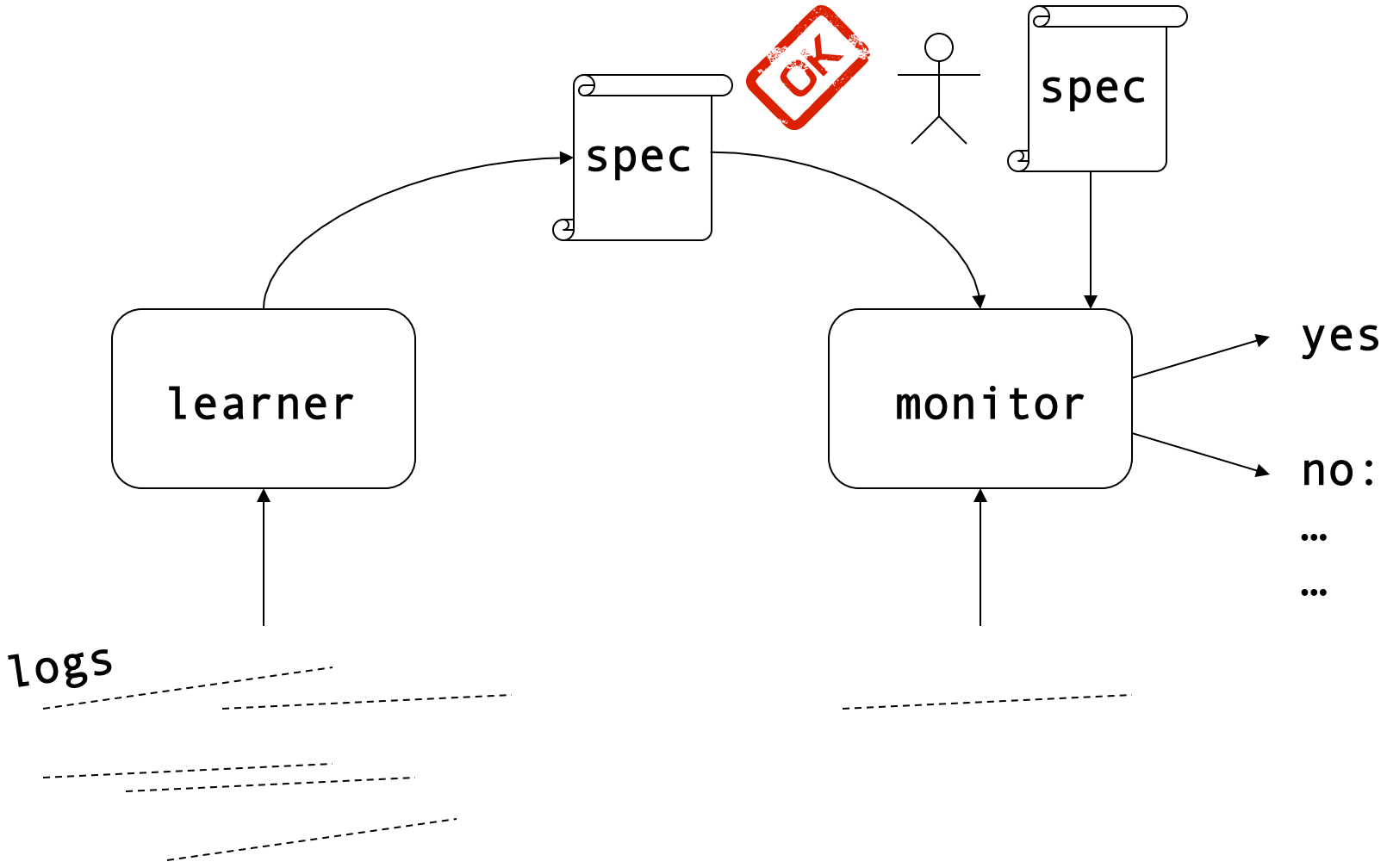
dynamic typing

- checking that specification format is “consistent” with log format
  - fields in events misspelled in spec
  - types of fields in spec inconsistent with log
- can of course be handled by static declaration of log event format – however, there may be hundreds of different events making it unpractical
- tool does its best to detect problems

specification learning

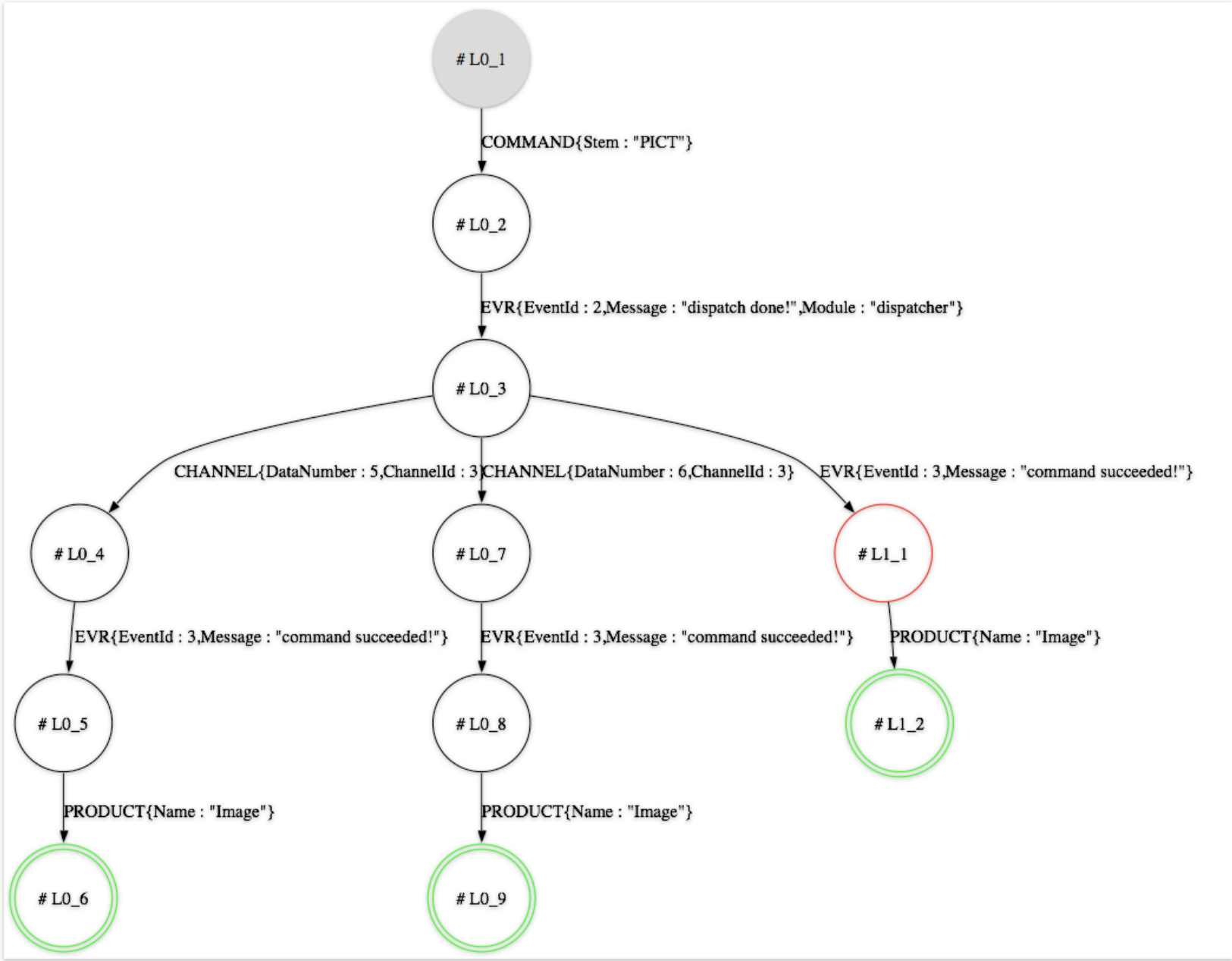
- writing specs is time consuming
- often hard come up with properties
- one approach is to use already generated log files to “get ideas”
- in the extreme case, specifications can be automatically generated from log files

architecture



learner API

```
import logscope

log1 = … ; log2 = … ; log3 = … ; log4 = …

learner = logscope.ConcreteLearner(“P”)
learner.learnlog(log1)
learner.learnlog(log2)
learner.dumpSpec(sfile)

learner = logscope.ConcreteLearner(“P”,sfile)
learner.learnlog(log3)
learner.dumpSpec(sfile)

obs = logscope.Observer(sfile)
obs.monitor(log4)
```


L0_1
COMMAND{Stem : "PICT"}
L0_2
EVR{EventId : 2,Message : "dispatch done!",Module : "dispatcher"}
L0_3
CHANNEL{DataNumber : 5,ChannelId : 3}
CHANNEL{DataNumber : 6,ChannelId : 3}
EVR{EventId : 3,Message : "command succeeded!"}
L0_4
L0_7
L1_1
EVR{EventId : 3,Message : "command succeeded!"}
EVR{EventId : 3,Message : "command succeeded!"}
PRODUCT{Name : "Image"}
L0_5
L0_8
L1_2
PRODUCT{Name : "Image"}
PRODUCT{Name : "Image"}
L0_6
L0_9

```
automaton LogPattern {
  step L0_1 {
    COMMAND{Stem : "PICT"} => L0_2
  }

  step L0_2 {
    EVR{EventId : 2,Message : "dispatch done!",
          Module : "dispatcher"} => L0_3
  }

  step L0_3 {
    CHANNEL{DataNumber : 5,ChannelId : 3} => L0_4
    CHANNEL{DataNumber : 6,ChannelId : 3} => L0_7
    EVR{EventId : 3,Message : "command succeeded!"} => L1_1
  }

  step L0_4 {
    EVR{EventId : 3,Message : "command succeeded!"} => L0_5
  }

  step L0_5 {
    PRODUCT{Name : "Image"} => L0_6
  }

  step L0_6 {}

  step L0_7 {
    EVR{EventId : 3,Message : "command succeeded!"} => L0_8
  }

  step L0_8 {
    PRODUCT{Name : "Image"} => L0_9
  }

  step L0_9 {}

  step L1_1 {
    PRODUCT{Name : "Image"} => L1_2
  }

  step L1_2 {}

  initial L0_1
  success L0_6,L0_9,L1_2
}
```

the learned spec

using step and success states

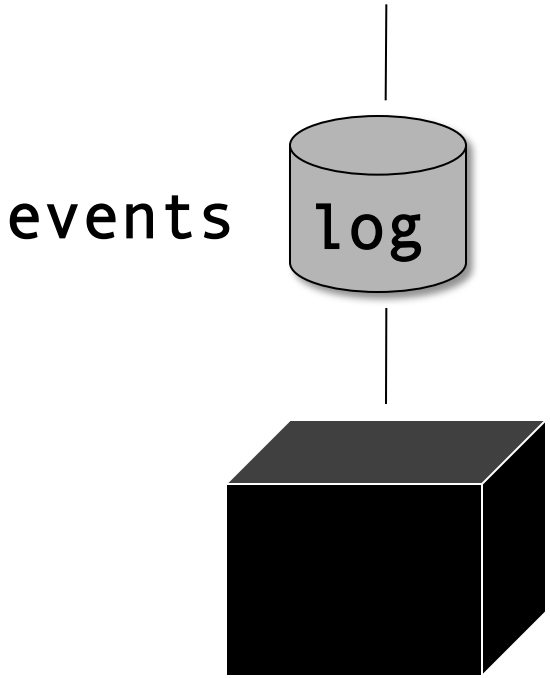
case study

- tool design focused on test engineers
- dispatch/success pattern checked on 400 command scenarios part of pre-defined regression test suite: leading to discovery of double successes.
- one engineer auto-generated specs, leading to further error discoveries.
- one engineer used learning capability.

methodology observation

requirements:

```
pattern P1:
  COMMAND{Type:"FSW", Stem:x, Number:y} =>
    EVR{Success:x, Number:y}
```



integration of event-based requirements and logging

LogScope's Inspirations

- RuleR : for the automata language, including how to handle parameters
- RCAT : for the emphasis on state machines and for hot states
- RMOR : for the lexical representation of state machines (and automated code instrumentation experience)

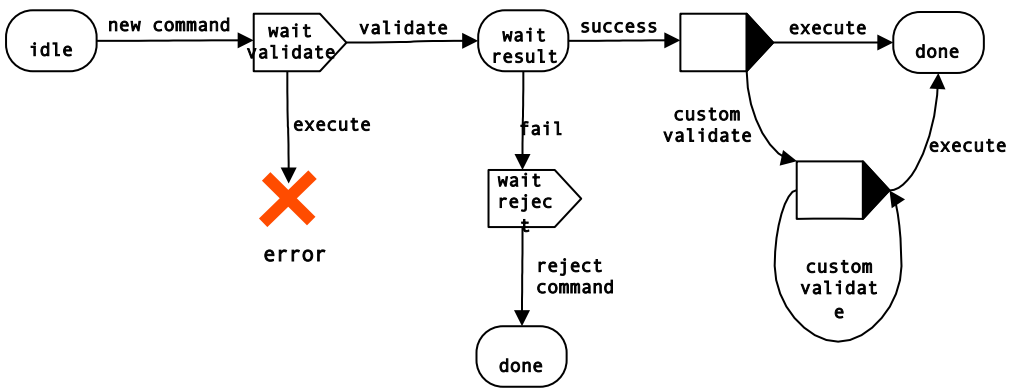
RuleR

- $R_1(x) : R_2,R_3(y),a(x) \rightarrow R_4(x+1),R_5 \mid R_6(10)$

- includes state machines
- states as well as events parameterized
  - with data : what we need
  - with rules : one can define temporal operators
- Petri-net semantics: lhs = conjunct
- AND + OR nodes : rhs = disjunct of conjuncts

requirements capture and analysis

RCAT formal Requirements Capture & Analysis Tool



a sample behavioral design requirement

integration with
SPIN verification
and
RMOR monitoring

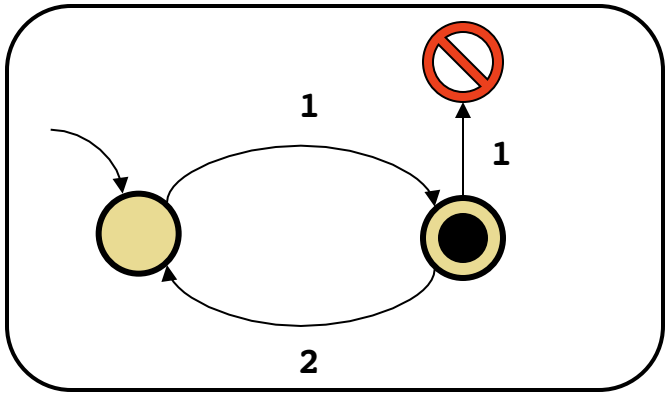
Reliable Software
Systems Development

RMOR

specification

```
monitor OpenClose{
  symbol open  = before call(main.c:openfile);
  symbol close = after call(main.c:closefile);

  state FileClosed{
    when open -> FileOpen;
  }

  live state FileOpen{
    when open => error;
    when close -> FileClosed;
  }
}
```

monitor



event stream

program

```
file = openfile("file42");
if (file != NULL) {
  process_file(file);
  closefile(file);
}
else
   error_handling();
```

RMoR

instrumented program

```
M_submit(2);
file = openfile("file42");
if (file != NULL) {
  process_file(file);
  closefile(file);
  M_submit(1);
}
else
   error_handling();
```

conclusions

- introduced temporal quantified patterns
- translated to quantified universal automata
- applied to log analysis : easy access
- suggestion: combine requirements engineering and event logging
- future work includes: GUI and better output, learning, merge with RuleR system: unifying patterns and automata

end