Better Testing with Less Work: QuickCheck Testing in Practice

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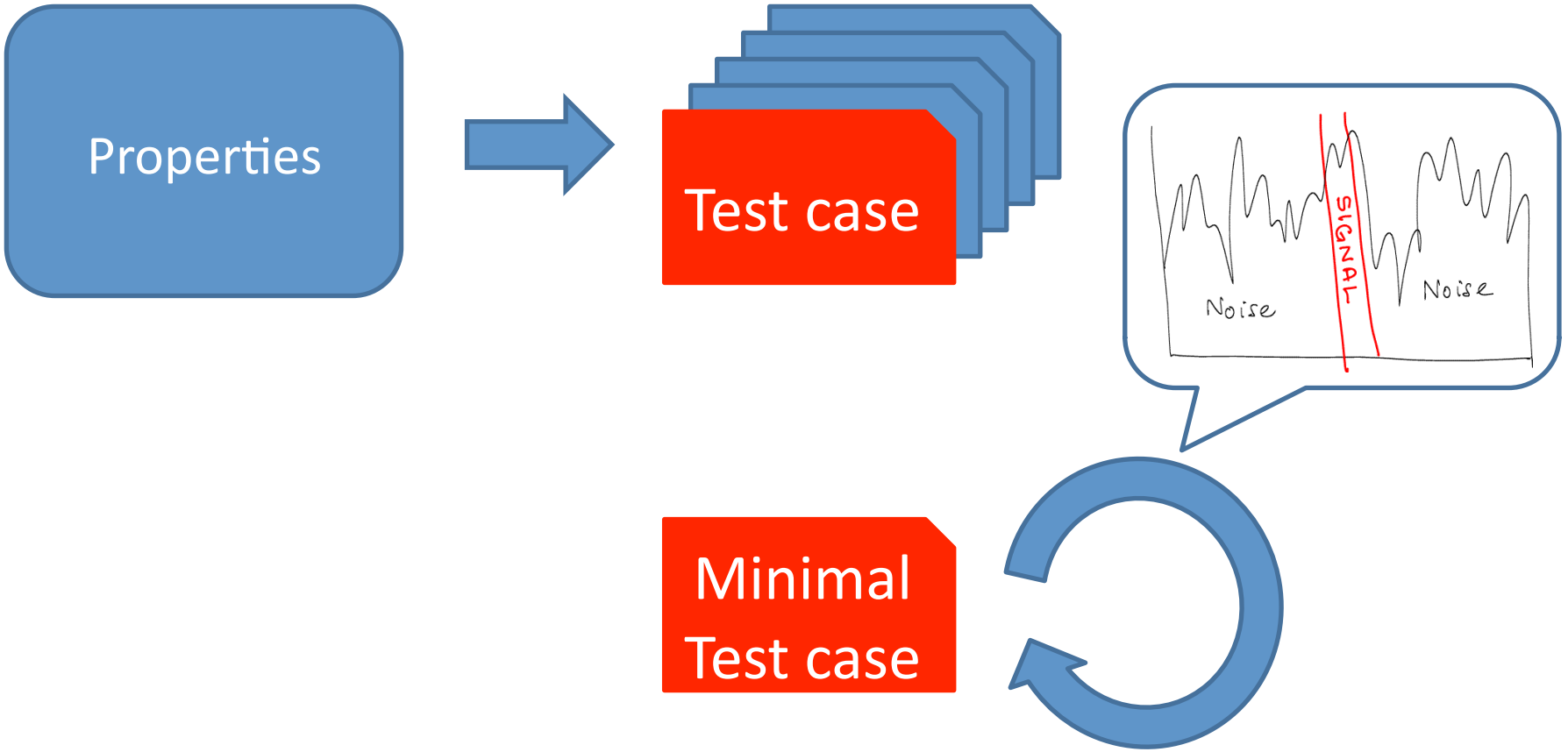
CHALMERS

QuviQ

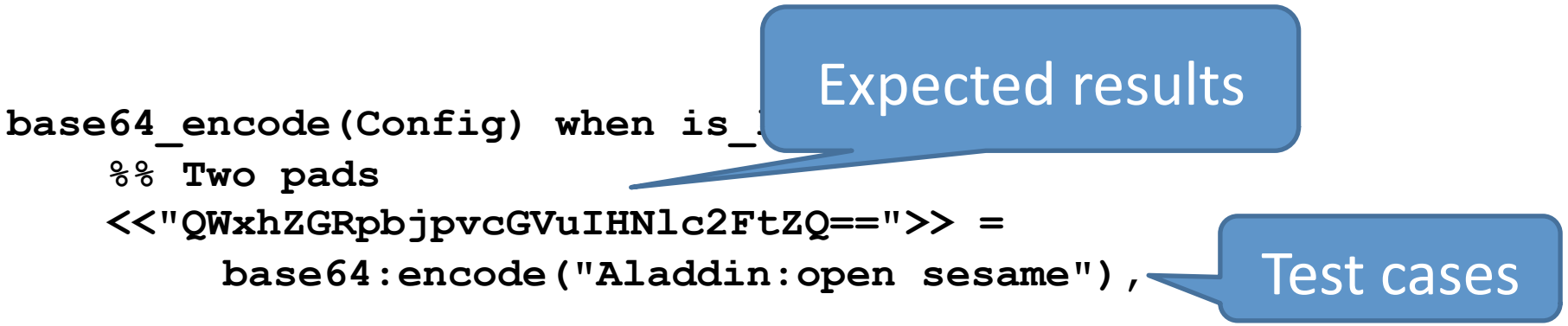
QuickCheck in a Nutshell



Benefits

- Less time spent writing test code
  - One property replaces many tests
- Better testing
  - Lots of combinations you'd never test by hand
- Less time spent on diagnosis
  - Failures minimized automagically

Tests for Base 64 encoding




```
base64_encode(Config) when is_
    %% Two pads
    <<"QWxhZGRpbjpvcGVuIHNlc2FtZQ==">> =
        base64:encode("Aladdin:open sesame"),

    %% One pad
    <<"SGVsbG8gV29ybGQ=">> = base64:encode(<<"Hello World">>),

    %% No pad
    "QWxhZGRpbjpvcGVuIHNlc2Ft" =
        base64:encode_to_string("Aladdin:open sesam"),

    "MDEyMzQ1Njc4OSFAIzBeJiooKTs6PD4sLiBbXXt9" =
        base64:encode_to_string(
            <<"0123456789!@#0^&*();:<>,. []{}">>),
    ok.
```

Writing a Property

```
prop_base64() ->
  ?FORALL(Data,list(choose(0,255)),
          base64:encode(Data)==???).
```

Back to the tests…

```
base64_encode(Config) when is_list(Config) ->
    %% Two pads
    <<"QWxhZGRpbjpvcGVuIHNlc2FtZQ==">> =
        base64:encode("Aladdin:open sesame"),

    %% One pad
    <<"SGVsbG8gV29ybGQ=">> = base64:encode(<<"Hello World">>),

    %% No pad
    "QWxhZGRpbjpvcGVuIHNlc2Ft" =
        base64:encode_to_string("Aladdin:open sesam"),

    "MDEyMzQ1Njc4OSFAIzBeJiooKTs6PD4sLiBbXXt9" =
        base64:encode_to_string(
            <<"0123456789!@#0^&*();:<>,. []{}">>),
    ok.
```

Where did these come from?

Possibilities

- Someone converted the data
- Another base64 encoder
- The same base64 encoder!
  - Only tests that changes don
    that the result is right

Use the other encoder as an oracle

Use an old version (or a simpler version) as an oracle

Round-trip Properties

```
prop_encode_decode() ->
  ?FORALL(L,list(choose(0,255)),
    base64:decode(base64:encode(L))
      == list_to_binary(L)).
```

What does this test?

- **NOT** a complete test—will not find a consistent misunderstanding of base64
- **WILL** find mistakes in encoder or decoder

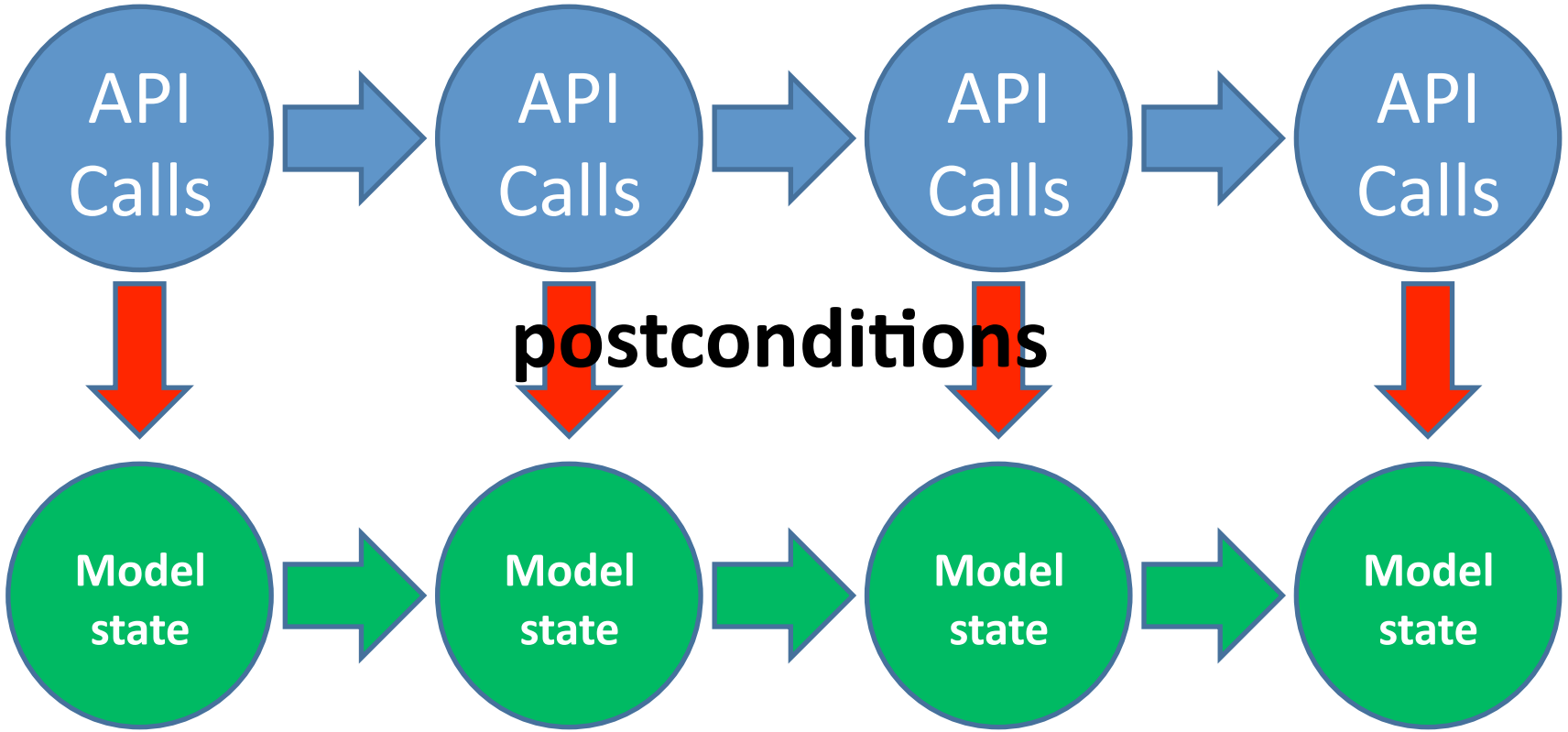
Simple properties find a lot of bugs!

Lessons

- Coming up with properties can require a little ingenuity…
- …but simple properties are surprisingly effective!
- Comparing two ways to compute the same thing is *often* powerful!

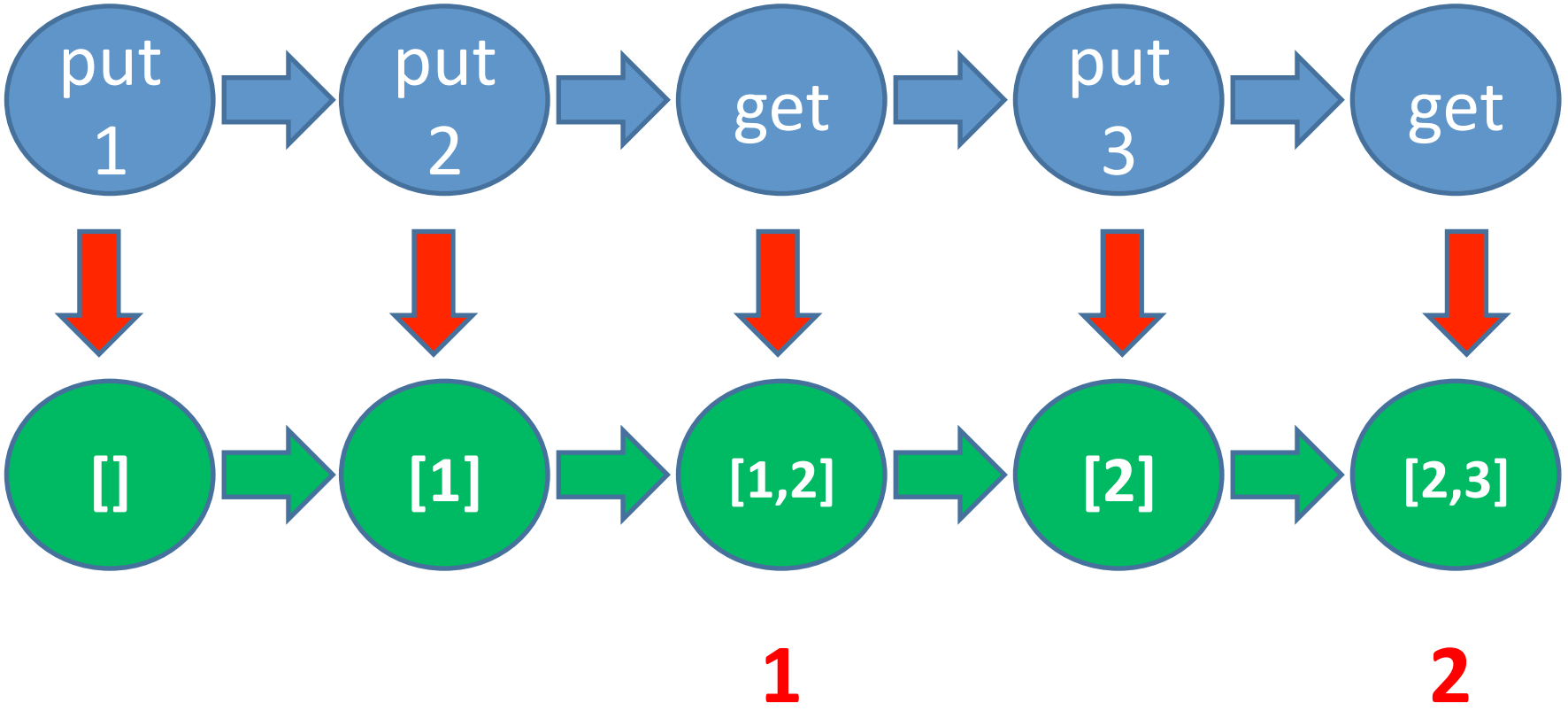
Time to test some C code…

Modelling in Erlang



Example

Use an Erlang list to model the contents of the queue!



Code Fragments

```
next_state_data(_,_,S,_,{call,_,put,[_,X]}) ->
   S#state{elements=S#state.elements++[X]};

next_state_data(_,_,S,_,{call,_,get,_}) ->
   S#state{elements=tl(S#state.elements)};


postcondition(_,_,S,{call,_,get,_},Res) ->
   Res == hd(S#state.elements);

postcondition(_,_,S,{call,_,size,_},Res) ->
   Res == length(S#state.elements);
```

A QuickCheck Property

```
prop_q() ->
    ?FORALL(Cmds,commands(?MODULE),
            begin
              {H,S,Res} = run_commands(?MODULE,Cmds),
              Res == ok)
            end).
```

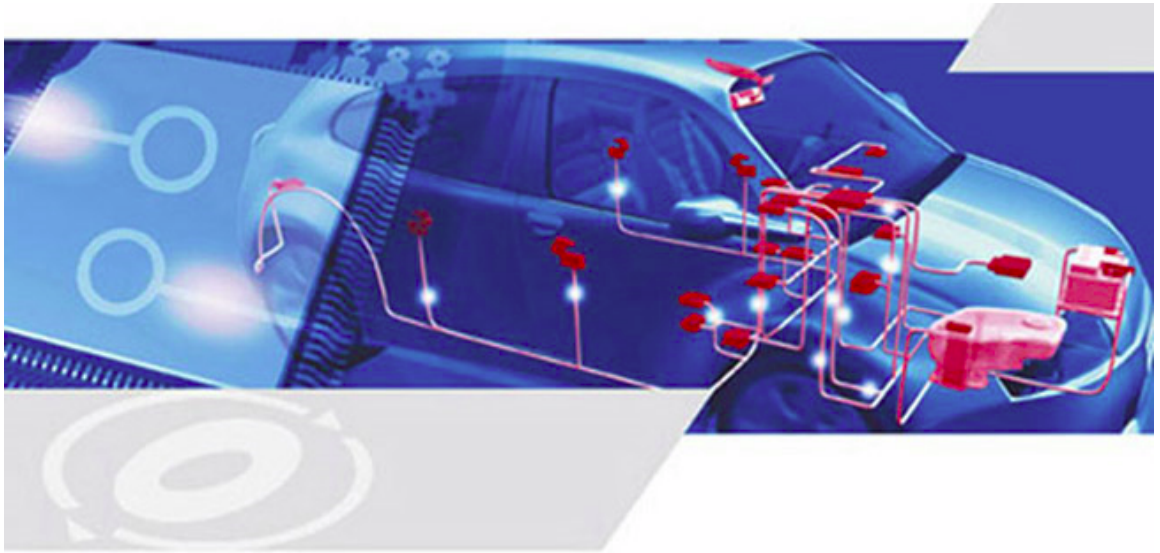
Let’s run some tests…

Lessons

- One property can find *many* bugs

- Shrinking makes diagnosis *very* simple

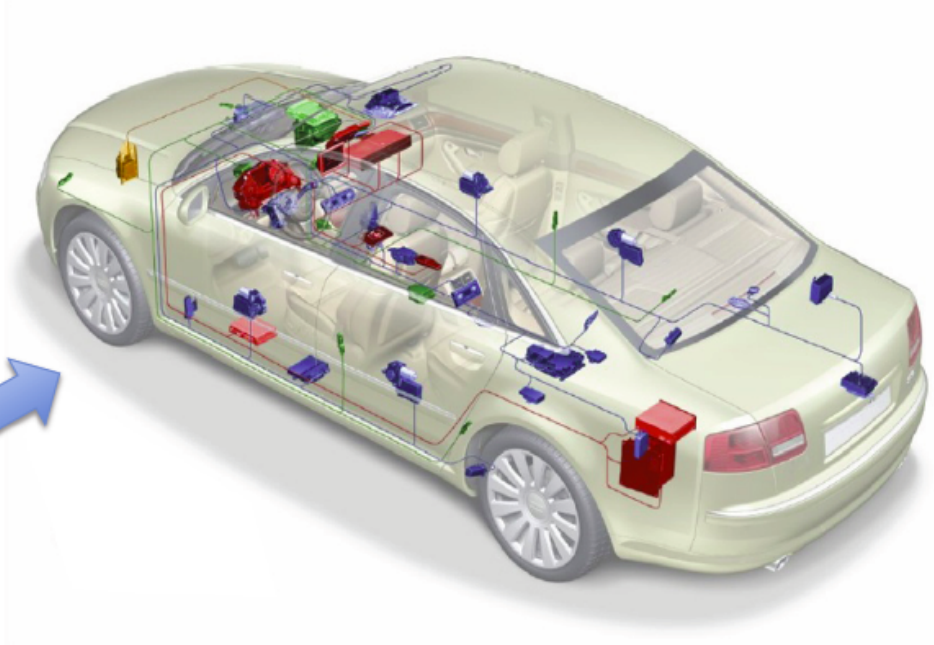
AutoSAR



- Joint project with Quviq, SP, Volvo Cars and Mentor Graphics

Is the software in different ECUs compatible?

Car Maker (OEM)



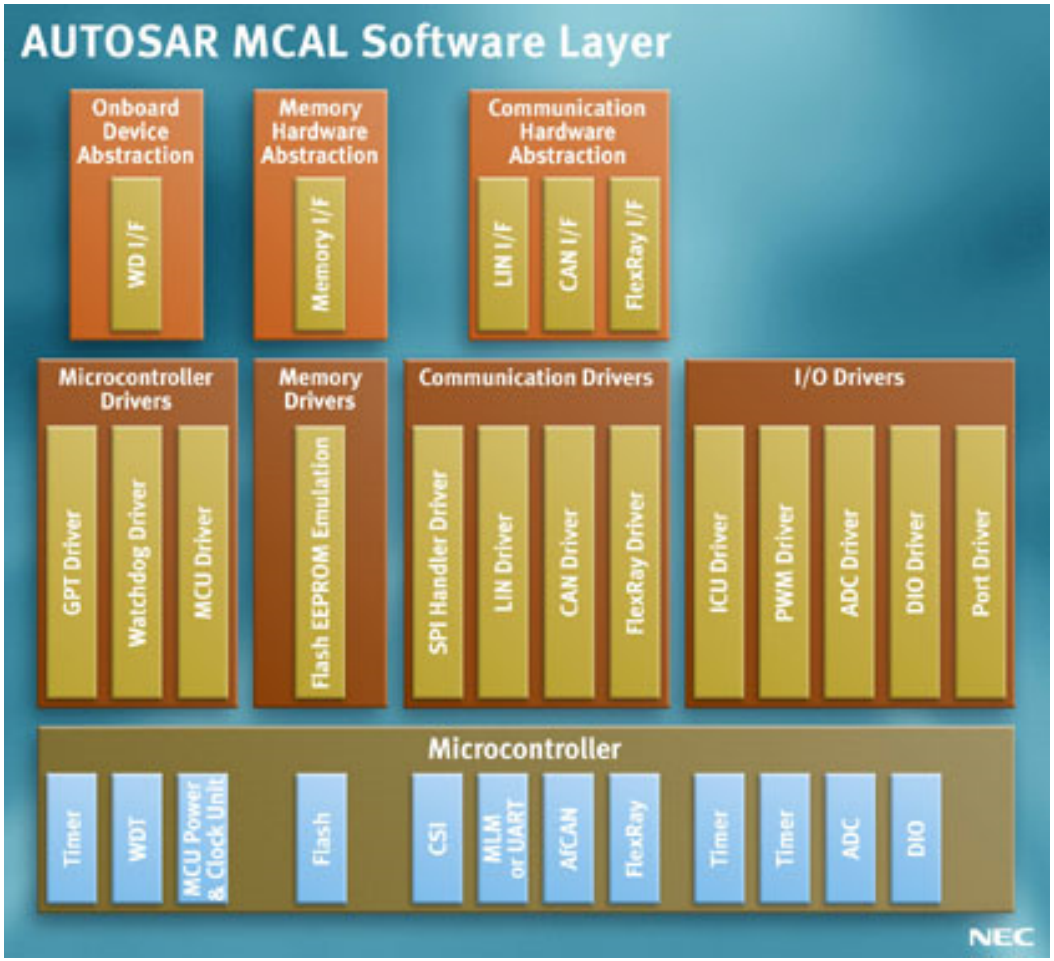
First Order Supplier (Tier 1)

Electronic Control Unit (ECU)

Software

Second Order Supplier (Tier 2)

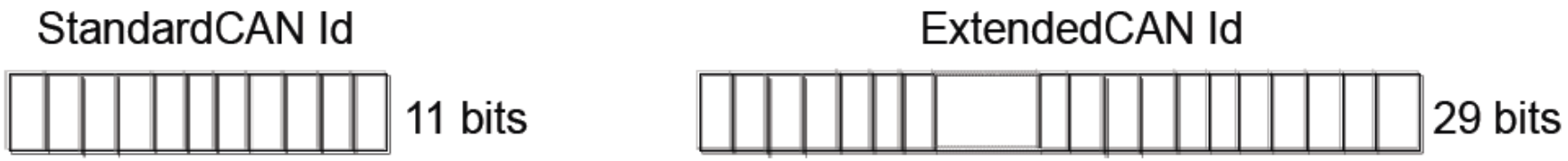
AutoSAR Architecture



The Story So Far…

- QuickCheck state-machine models for AutoSAR clusters
  - Com, PDUR, CAN, FlexRay, Lin, DEM…
- Used to test software from 3 suppliers
  - test code 10x smaller than implementation
  - 20x smaller than the standard!
- Bugs and inconsistencies revealed in all!
  - And in the standard…

Example: Mixed features

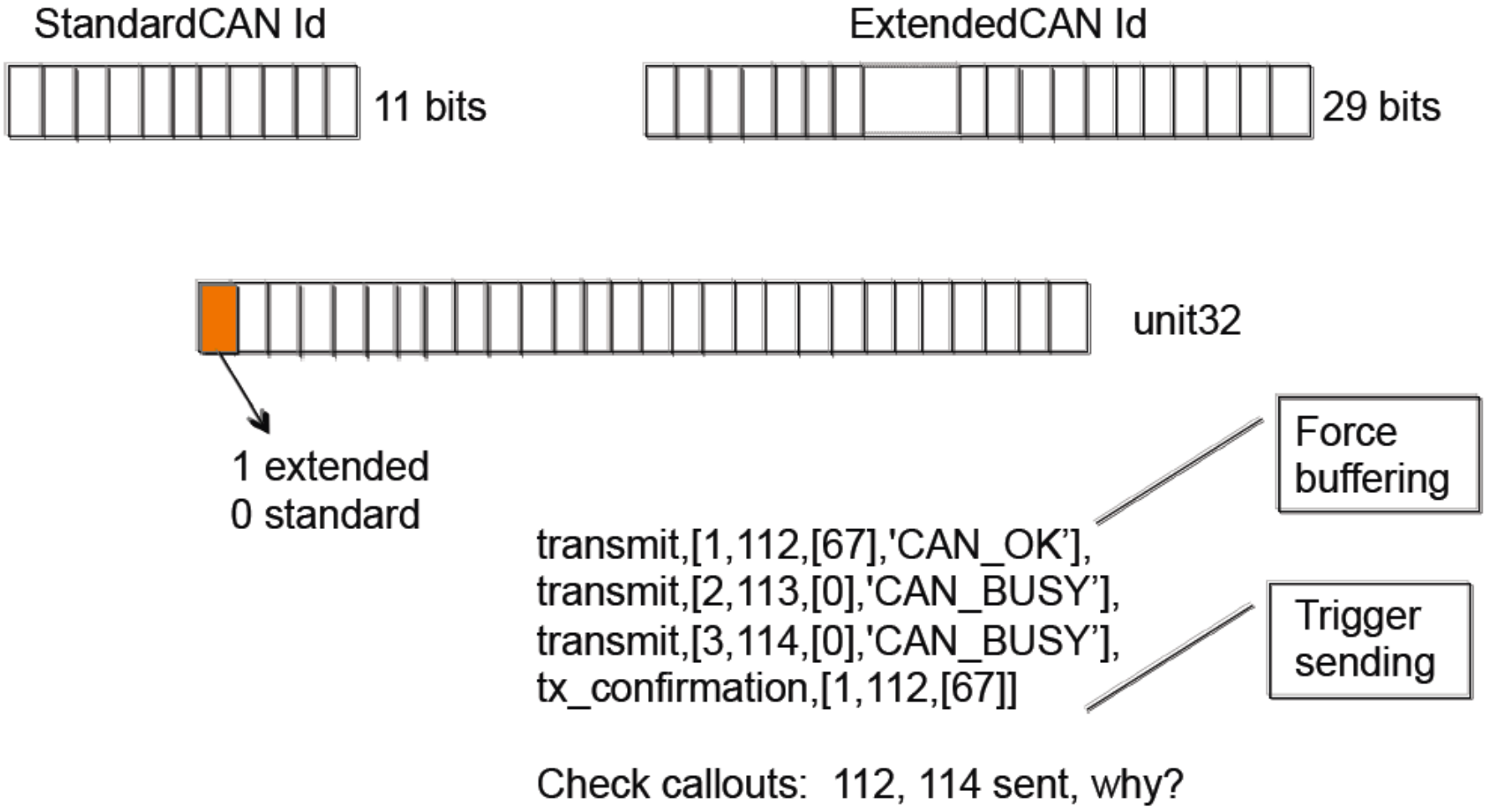


Priority: lowest number has highest priority

Example:
Extended Id 113 has higher
priority than standard Id 114

Buffered higher priority
messages should be sent first

Example: Mixed features

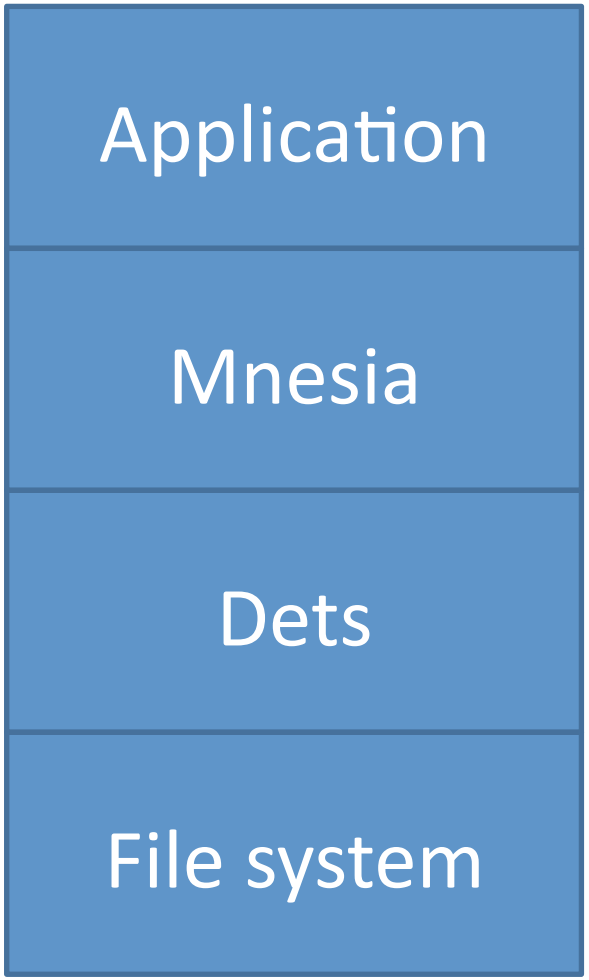


"We know there is a lurking bug somewhere in the dets code. We have got 'bad object' and 'premature eof' every other month the last year. We have not been able to track the bug down since the dets files is repaired automatically next time it is opened.“

Tobbe Törnqvist, Klarna, 2007

What is it?

500+ people in 5 years



klarna

Invoicing services for web shops

Distributed database: transactions, distribution, replication

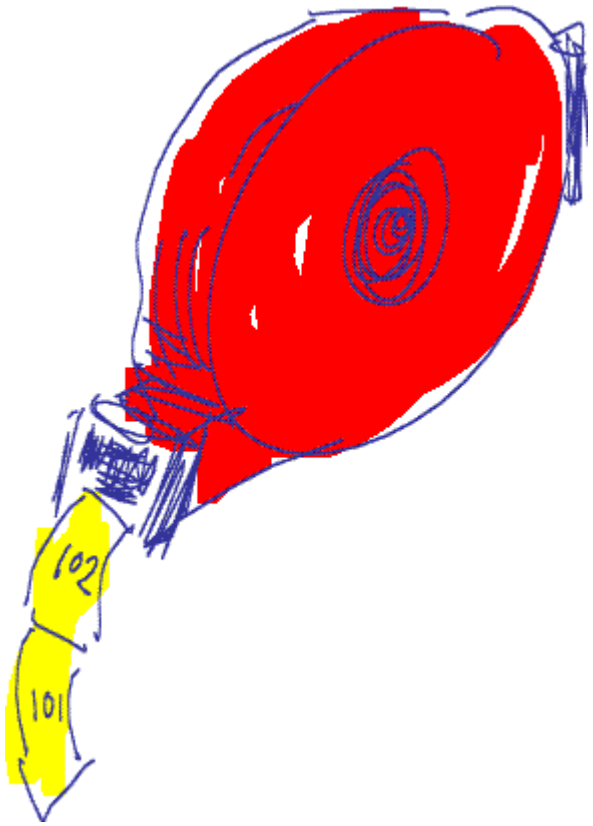
Tuple storage

Race conditions?

Imagine Testing This…

dispenser:take_ticket()

dispenser:reset()



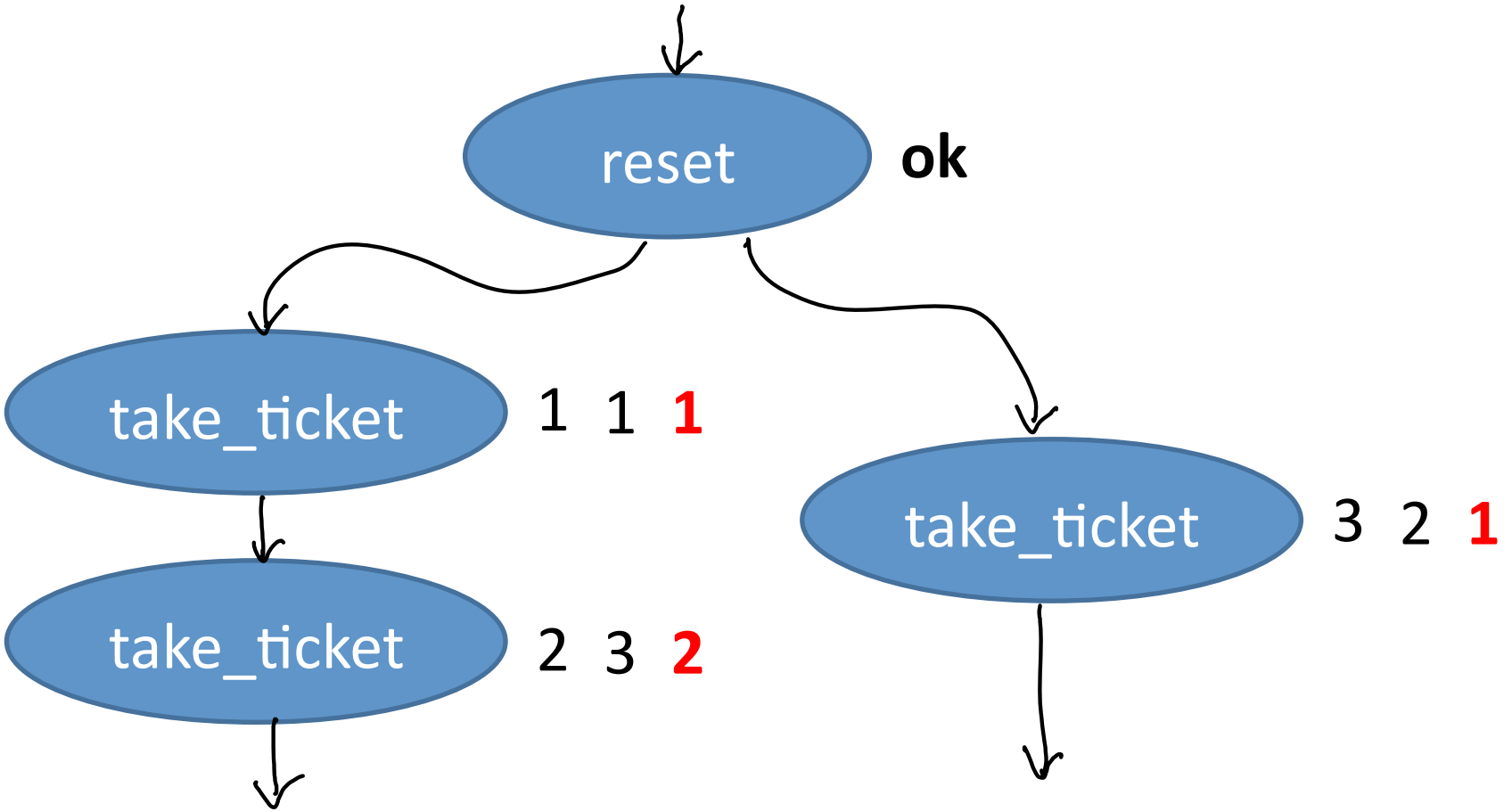
A Unit Test in Erlang

```
test_dispenser() ->
      ok =  reset(),
      1  =  take_ticket(),
      2  =  take_ticket(),
      3  =  take_ticket(),
      ok =  reset(),
      1  =  take_ticket().
```

Expected results

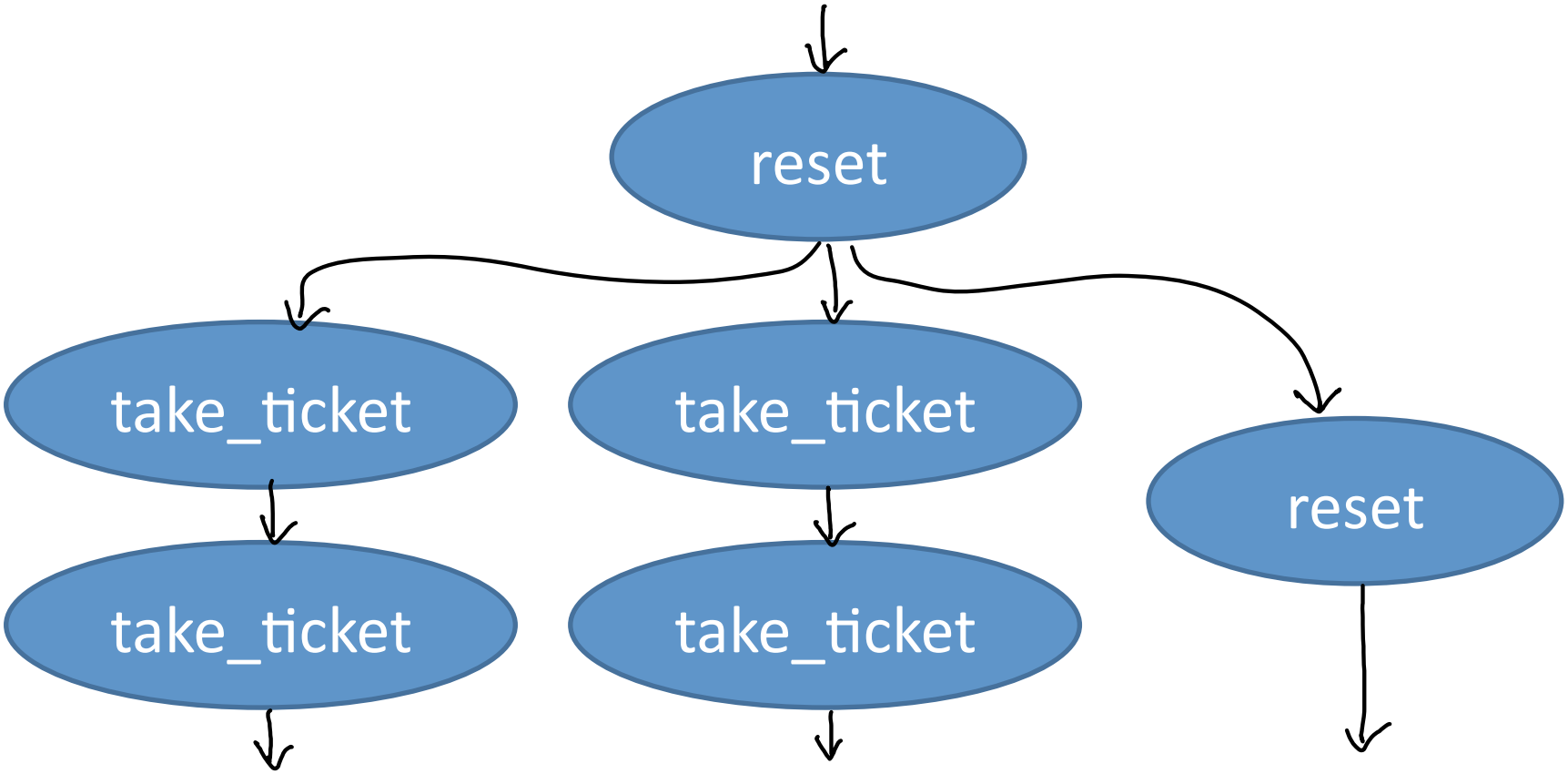
BUT…

A Parallel Unit Test



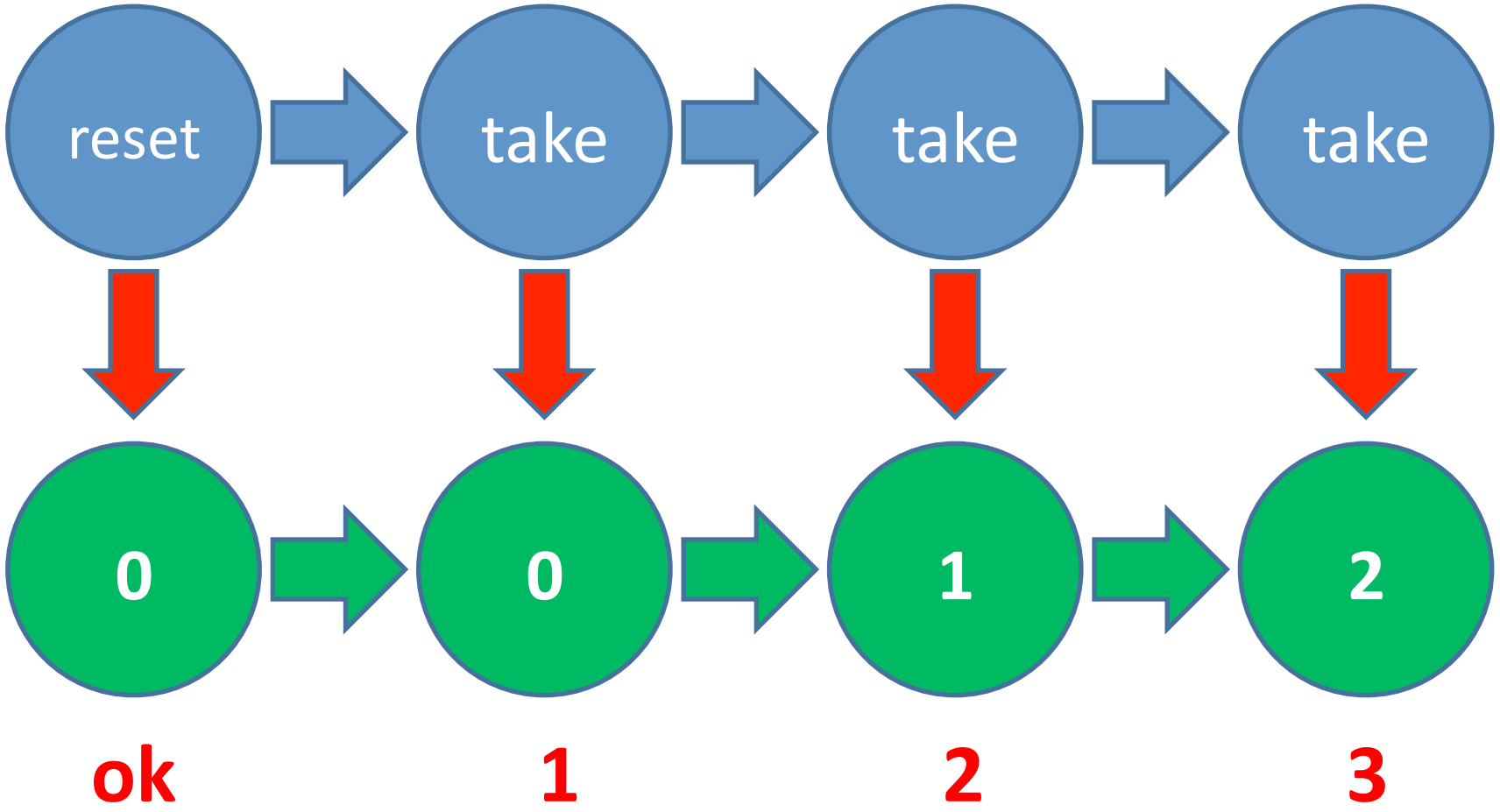
- Three possible correct outcomes!

Another Parallel Test

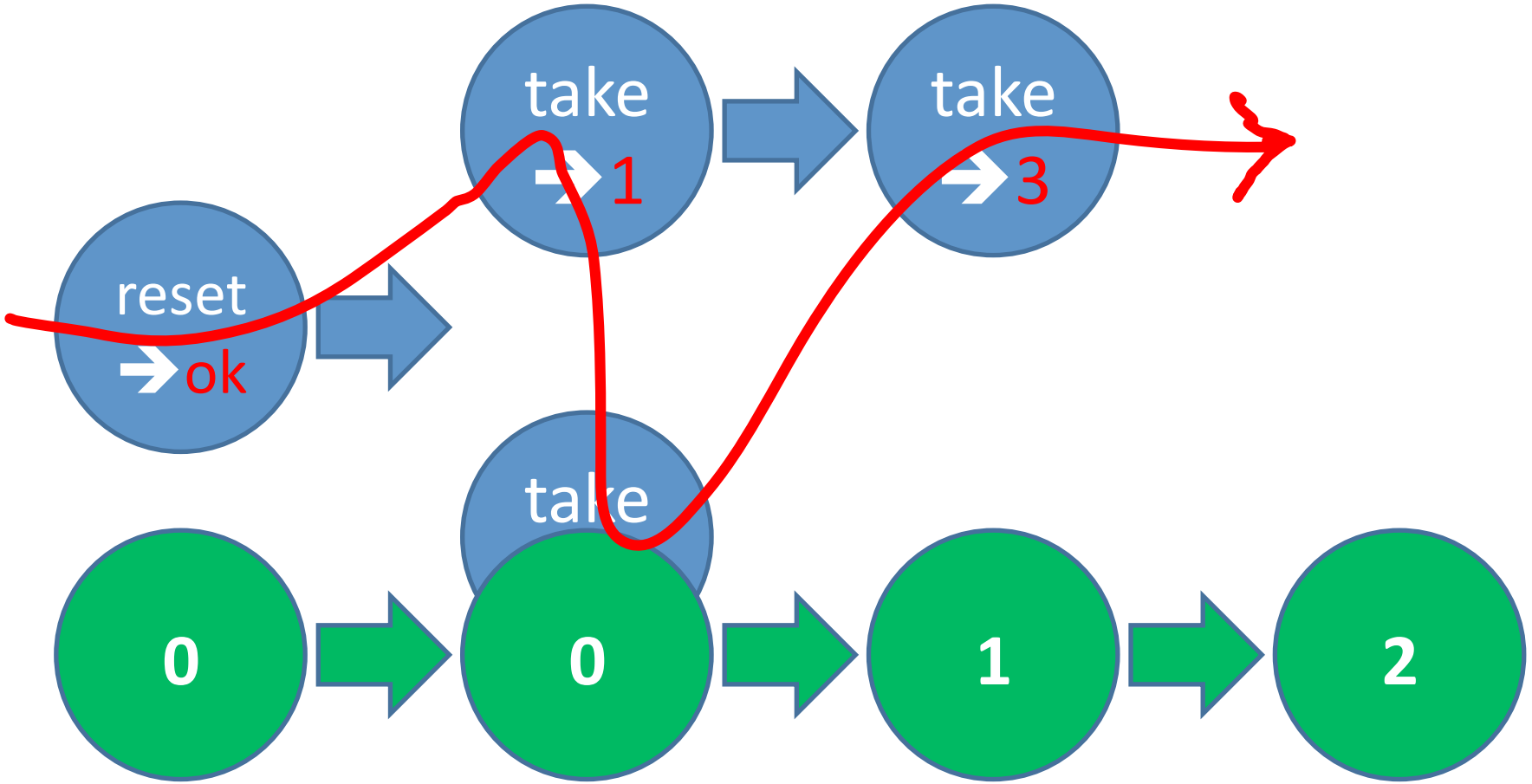


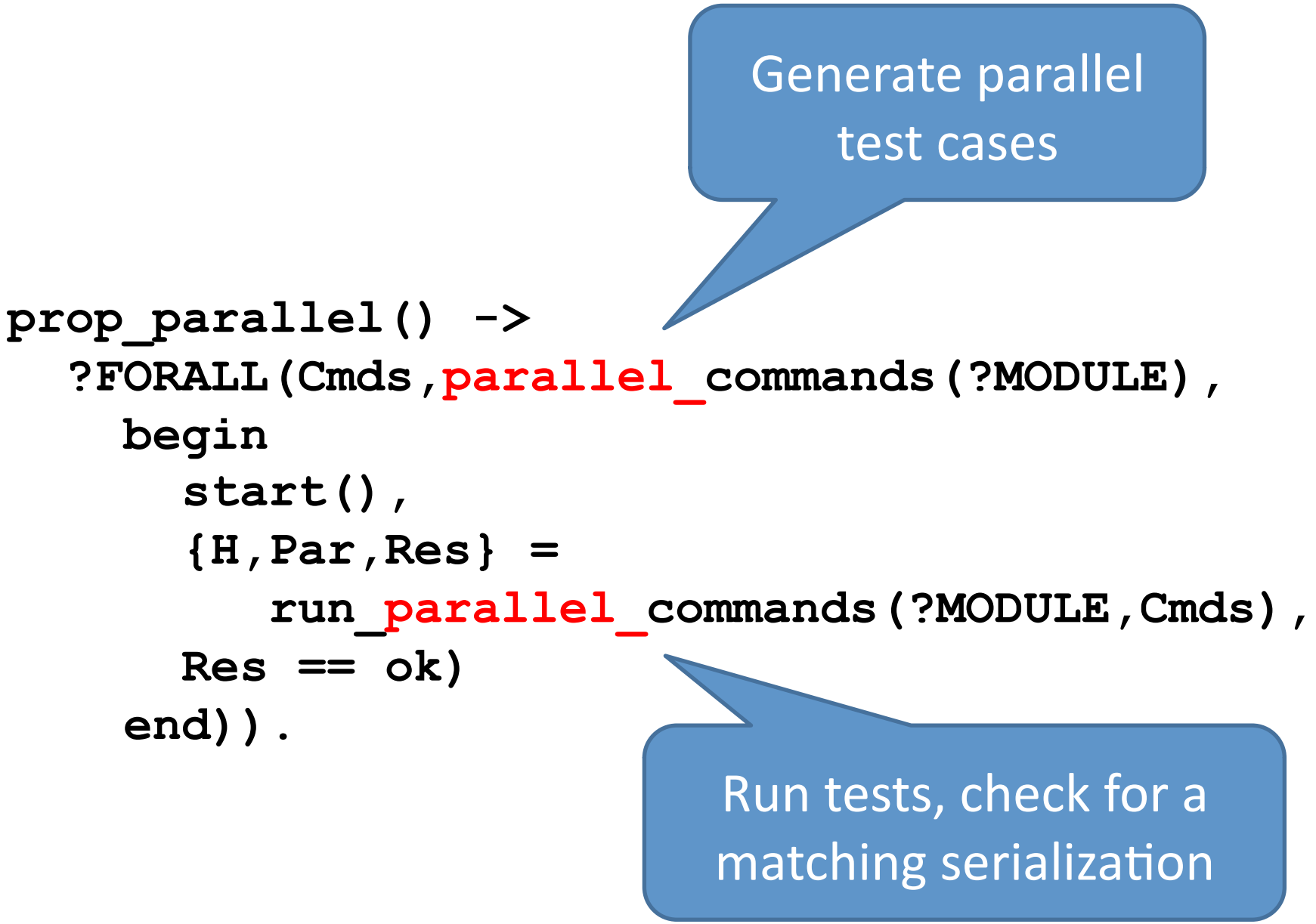
- 42 possible correct outcomes!

Modelling the dispenser



Parallel Test Cases




Generate parallel test cases
prop_parallel() ->
?FORALL(Cmds,parallel_commands(?MODULE),
begin
start(),
{H,Par,Res} =
run_parallel_commands(?MODULE,Cmds),
Res == ok)
end)).
Run tests, check for a matching serialization

Let’s run some tests

```
take_ticket() ->
    N = read(),
    write(N+1),
    N+1.
```

Prefix:

Parallel:

1. take_ticket() --> 1

2. take_ticket() --> 1

Result: no_possible_interleaving

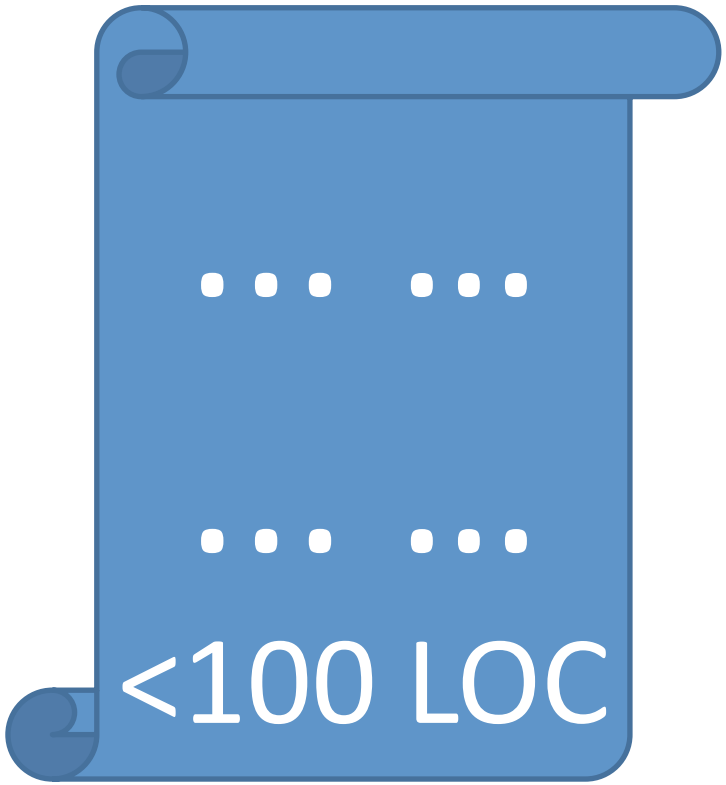
dets

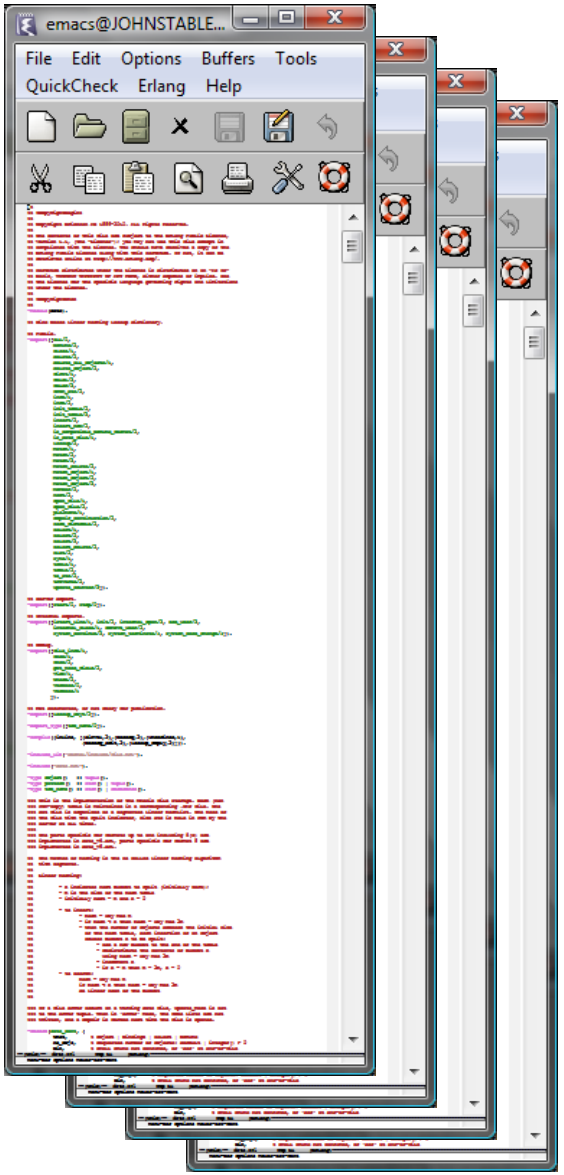
- Tuple store:

  {Key, Value1, Value2…}

- Operations:
  - insert(Table,ListOfTuples)
  - delete(Table,Key)
  - insert_new(Table,ListOfTuples)
  - …
- Model:
  - List of tuples (almost)

QuickCheck Specification





> 6,000 LOC

DEMO

Bug #1

insert_new(Name, Objects) -> Bool

Types:
Name = name()
Objects = object() | [object()]
Bool = bool()

```
Prefix:
   open_file(dets

      dets_table

Parallel:
1. insert(dets_table,[]) --> ok

2. insert_new(dets_table,[]) --> ok

Result: no_possible_interleaving
```

Bug #2

```
Prefix:
   open_file(dets_table,[{type,set}]) --> dets_table

Parallel:
1. insert(dets_table,{0,0}) --> ok

2. insert_new(dets_table,{0,0}) --> …time out…
```

=ERROR REPORT==== 4-Oct-2010::17:08:21 ===
** dets: Bug was found when accessing table dets_table

Bug #3

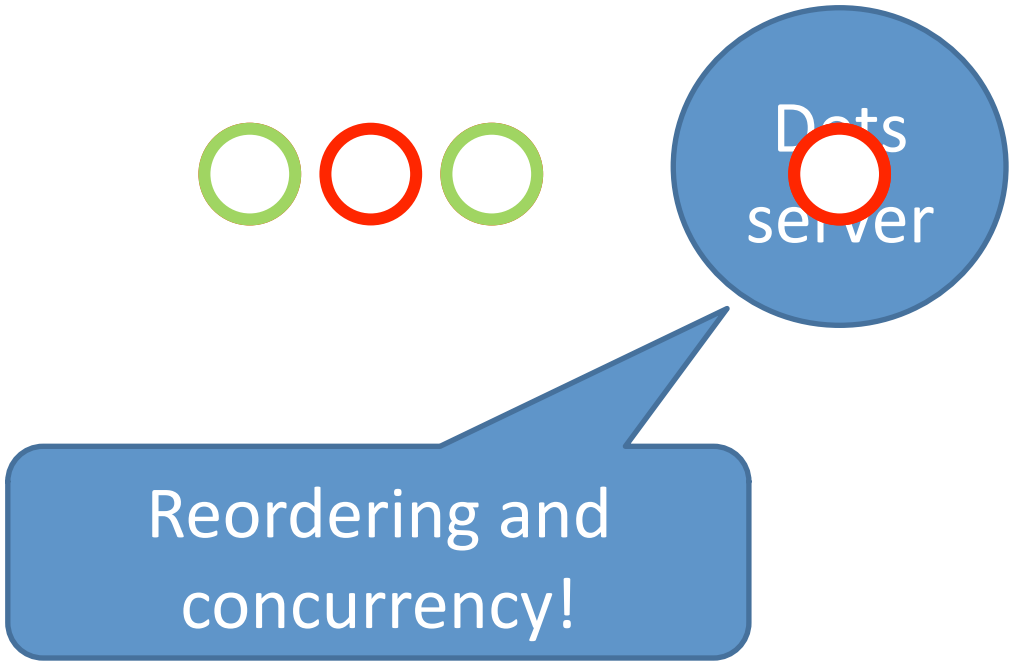
```
Prefix:
   open_file(dets_table,[{type,set}]) --> dets_table

Parallel:
1. open_file(dets_table,[{type,set}]) --> dets_table

2. insert(dets_table,{0,0}) --> ok
   get_contents(dets_table) --> []

Result: no_possible_interleaving
```

What’s going on?



Is the file corrupt?

Bug #4

```
Prefix:
   open_file(dets_table,[{type,bag}]) --> dets_table
   close(dets_table) --> ok
   open_file(dets_table,[{type,bag}]) --> dets_table

Parallel:
1. lookup(dets_table,0) --> []

2. insert(dets_table,{0,0}) --> ok

3. insert(dets_table,{0,0}) --> ok

Result: ok
```

Bug #5

```
Prefix:
   open_file(dets_table,[{type,set}]) --> dets_table
   insert(dets_table,[{1,0}]) --> ok

Parallel:
1. lookup(dets_table,0) --> []
   delete(dets_table,1) --> ok

2. open_file(dets_table,[{type,set}]) --> dets_table

Result: ok
false
```

"We know there is a lurking bug somewhere in the dets code. We have got 'bad object' and 'premature eof' every other month the last year."

Tobbe Törnqvist, Klarna, 2007

Each bug fixed the day after reporting the failing case

How come?

- The bugs weren't found earlier?
  - Mature production code
  - >6 weeks of work
  - …files of over 4GB?
  - …rehashing could be the problem?
  - Diagnosing races in production is hopeless
- The bugs weren't found in testing?
  - Unit tests for races are hard to write…
  - …so people don't!
  - Races=feature interaction → impractically many tests

The Initial Phases

- Lots of work to develop specification
  - Understanding and generating test inputs
- Many errors to fix in the *specification*, due to…
  - New code is buggy
  - Misunderstandings of the informal spec
  - Undocumented features of the system
  - Undocumented *limitations* of the system
    - ”happy case” programming

Making Progress

- QuickCheck tends to find the *same* problem in every run
  - There is a ”most likely bug”
  - Other bugs usually *shrink* to the most likely one
- To make progress, the most likely bug must be excluded
  - *Bug preconditions* document the limitations of the system

The Payoff

- Once the spec is corrected, and limitations accounted for, *real* bugs start to appear
- Each extension to the spec yields a *non-linear* improvement in the variety of tests
- The *same* spec can find many, many bugs

Summary: Property-Based Testing

Better testing for less work!