Teaching Computers to Validate Themselves

Andrew DeOrio

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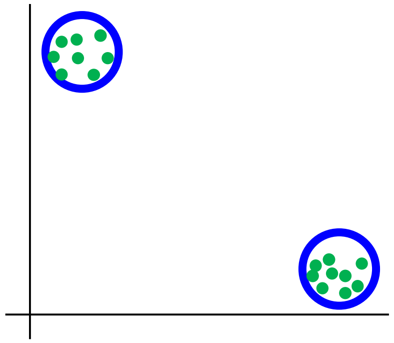
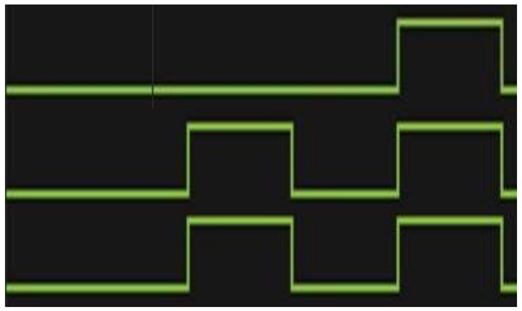
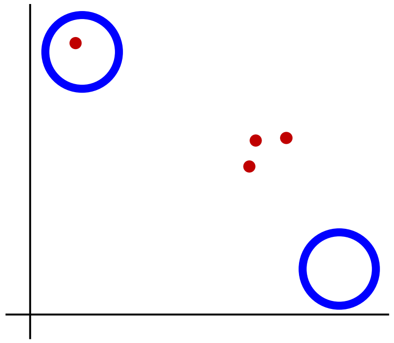
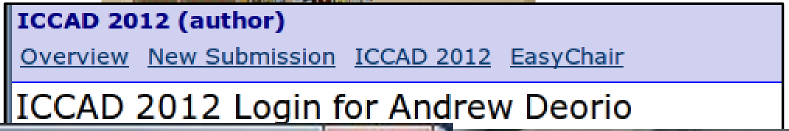
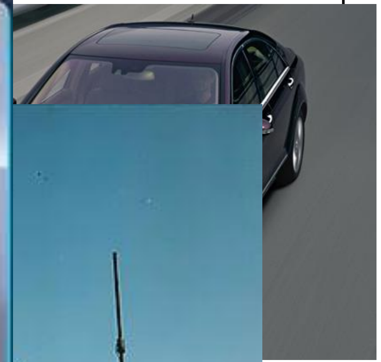
andrewdeorio.com

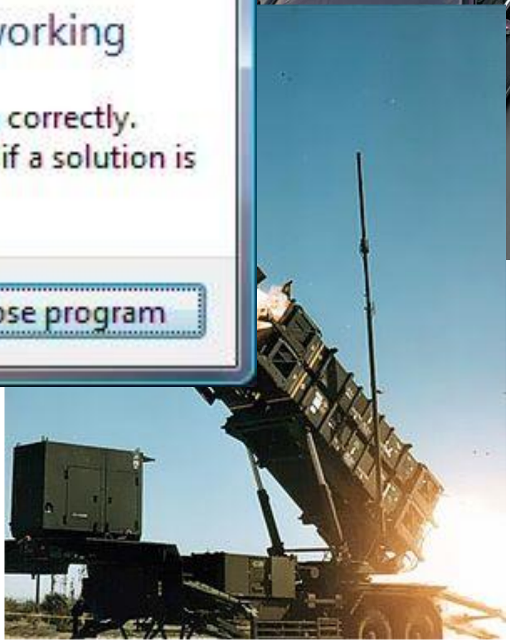




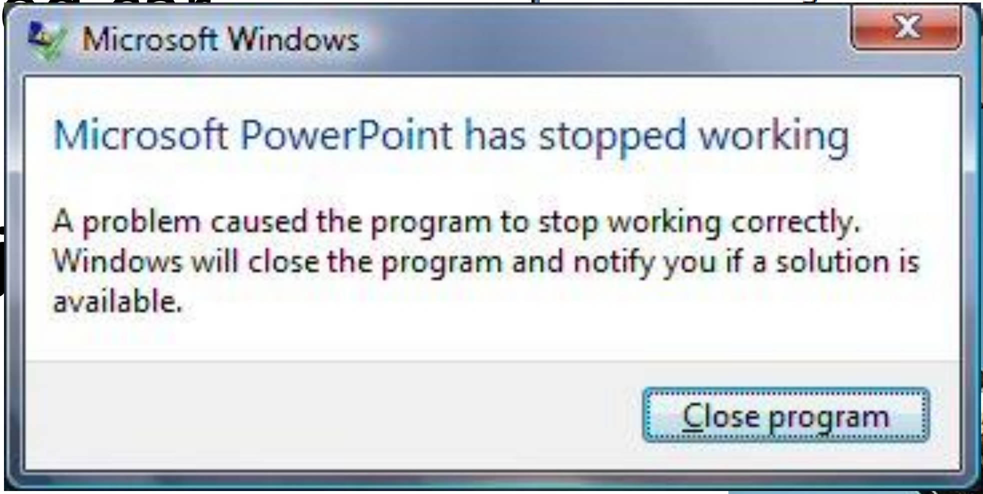
Five worst times for computers to fail

5. Using your credit card
4. Submitting a paper
3. Automated car
2. Missile d
1. Giving a j


ICCAD 2012 (author)
Overview New Submission ICCAD 2012 EasyChair
ICCAD 2012 Login for Andrew Deorio



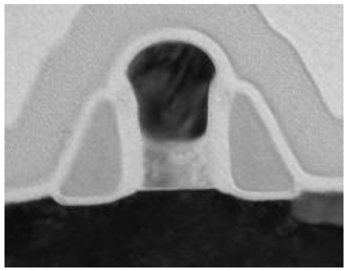



Microsoft Windows

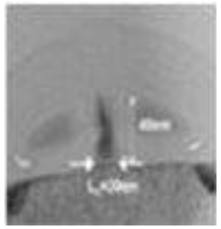
Microsoft PowerPoint has stopped working

A problem caused the program to stop working correctly. Windows will close the program and notify you if a solution is available.

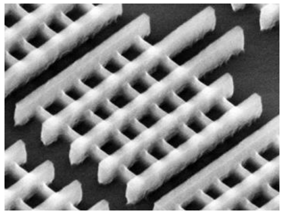
Trends in today's processors



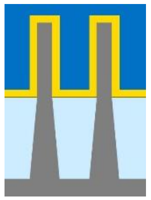
45nm



32nm



22nm



14nm

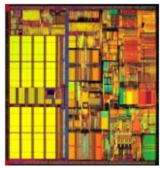
Shrinking transistor size

waning reliability

Increasing cores and complexity

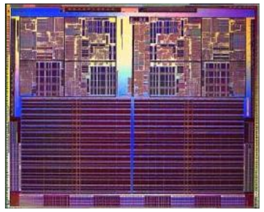
verification challenges

Intel Pentium4



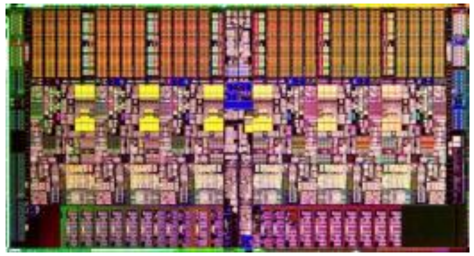
1 core, 2000

AMD Opteron



2 cores, 2005

Intel Core i7



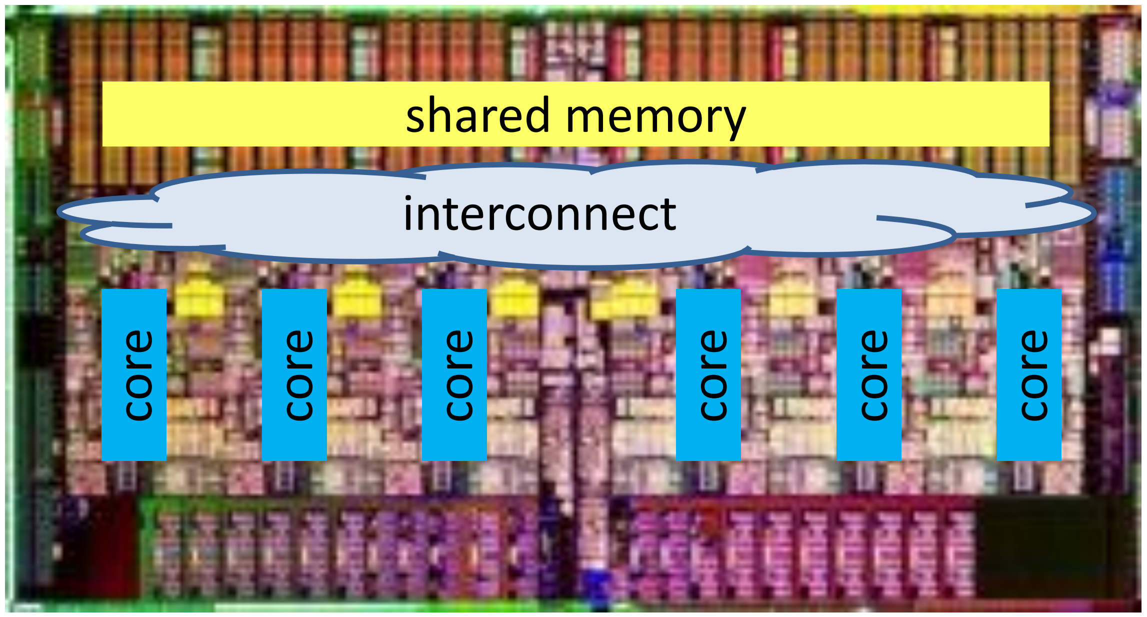
6 cores, 2010

Tilera TILE-Gx72

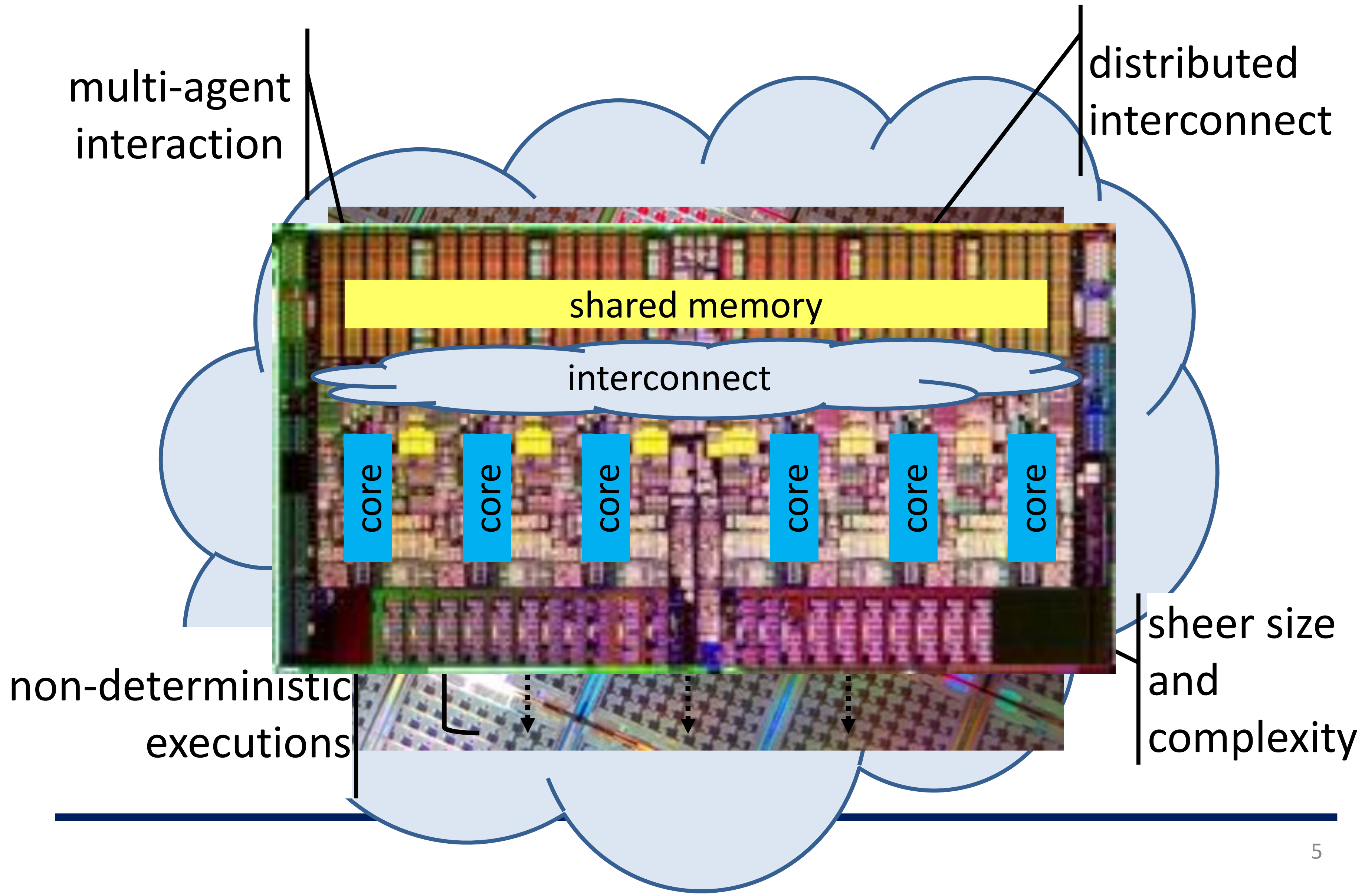
72 cores, 2013

Today’s multi-core / SoC

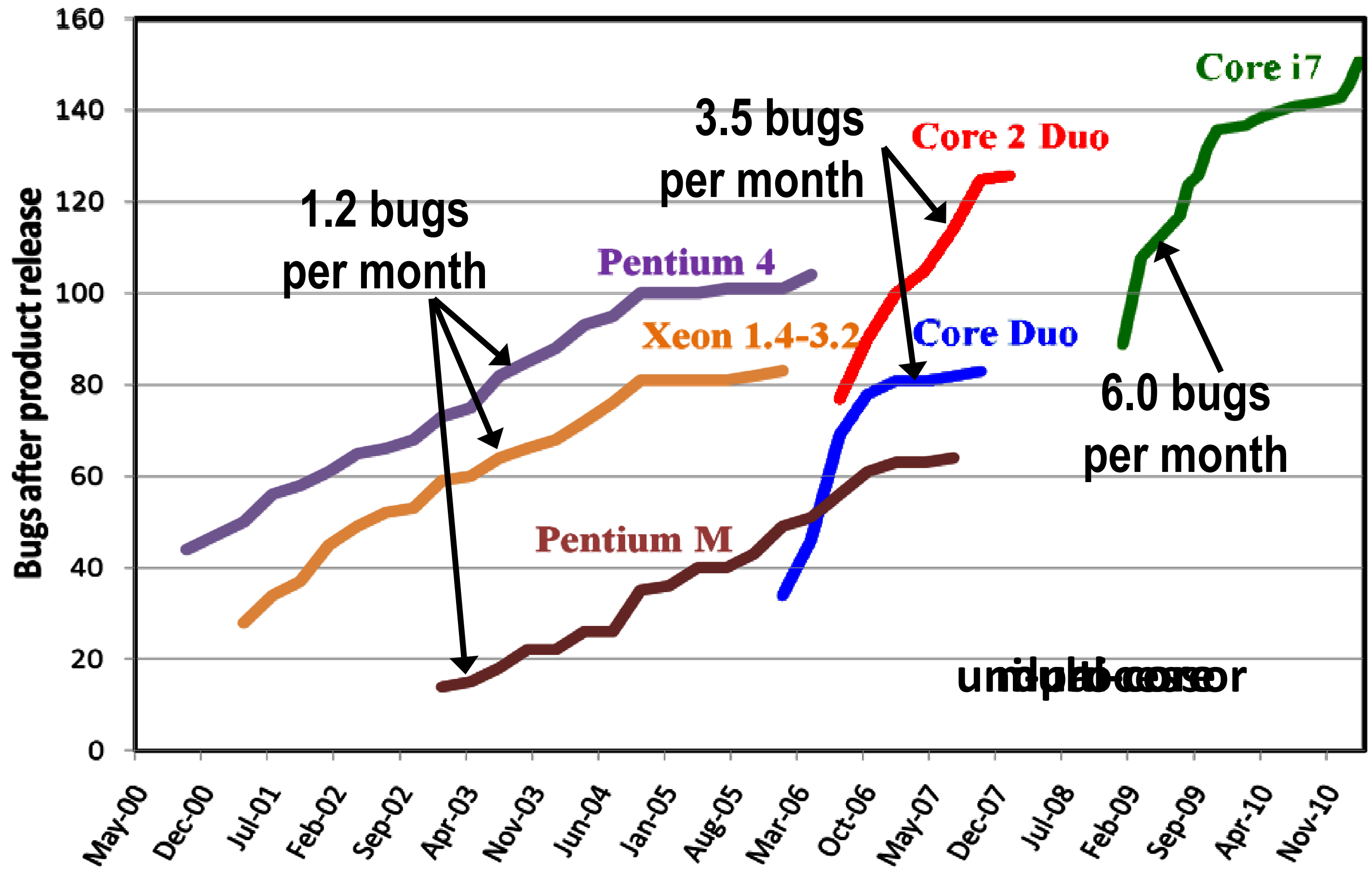
- Many IPs communicate through interconnect
- Recent system $\longrightarrow$ new verification challenges



Tomorrow's multi-core / SoC



Escaped errors in final products



10-13% of bugs are communication related

*Data compiled from Intel product errata documents

1 in 190 windows crashes are due to HW errors

[Nightingale, *et al.* 2011]

```
A problem has been detected and windows has been shut down to prevent damage
to your computer.

The problem seems to be caused by the following file: SPCMDCON.SYS

PAGE_FAULT_IN_NONPAGED_AREA

If this is the first time you've seen this Stop error screen,
restart your computer. If this screen appears again, follow
these steps:

Check to make sure any new hardware or software is properly installed.
If this is a new installation, ask your hardware or software manufacturer
for any windows updates you might need.

If problems continue, disable or remove any newly installed hardware
or software. Disable BIOS memory options such as caching or shadowing.
If you need to use Safe Mode to remove or disable components, restart
your computer, press F8 to select Advanced Startup Options, and then
select Safe Mode.

Technical information:

*** STOP: 0x00000050 (0xFD3094C2,0x00000001,0xFBFE7617,0x00000000)


***  SPCMDCON.SYS - Address FBFE7617 base at FBFE5000, DateStamp 3d6dd67c
```

Impact of errors

- Functional bugs

Intel's Haswell processors hit by TSX bug

2014

- Electrical failures

Another day, another microprocessor delay

2007

- Transistor faults

Intel's Sandy Bridge Glitch: 7 Things You Need to Know

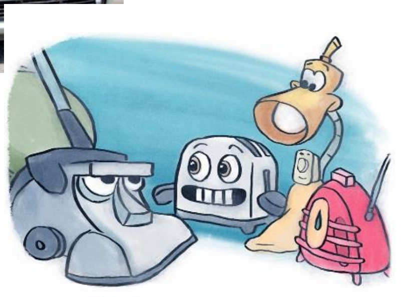
2011

Future impact of errors

- The impact of errors will get worse as we rely more on computers

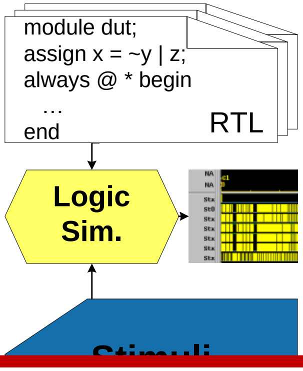
- Wearables
- Self-driving cars
- Internet of things

- Security depends on hardware correctness!



Verification today

Pre-Silicon



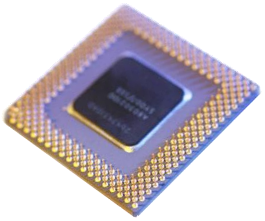
```
module dut;
assign x = ~y | z;
always @ * begin
  …
end
```

low speed

- Slow simulation
-
-

high observability

Post-Silicon



low observability

- Fast HW prototypes
- d,

high speed

Runtime

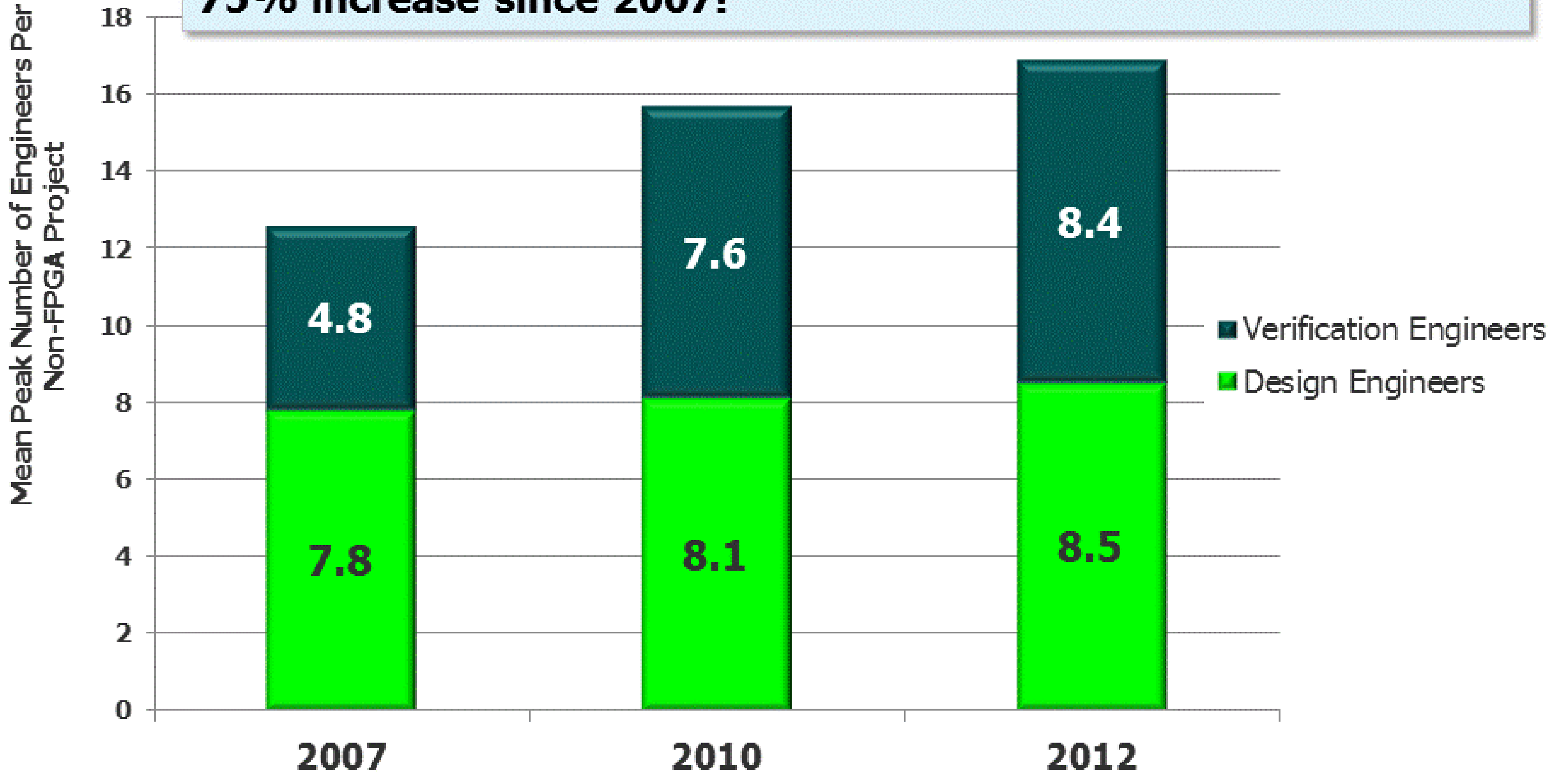
low flexibility

- Hardware overhead
-
-

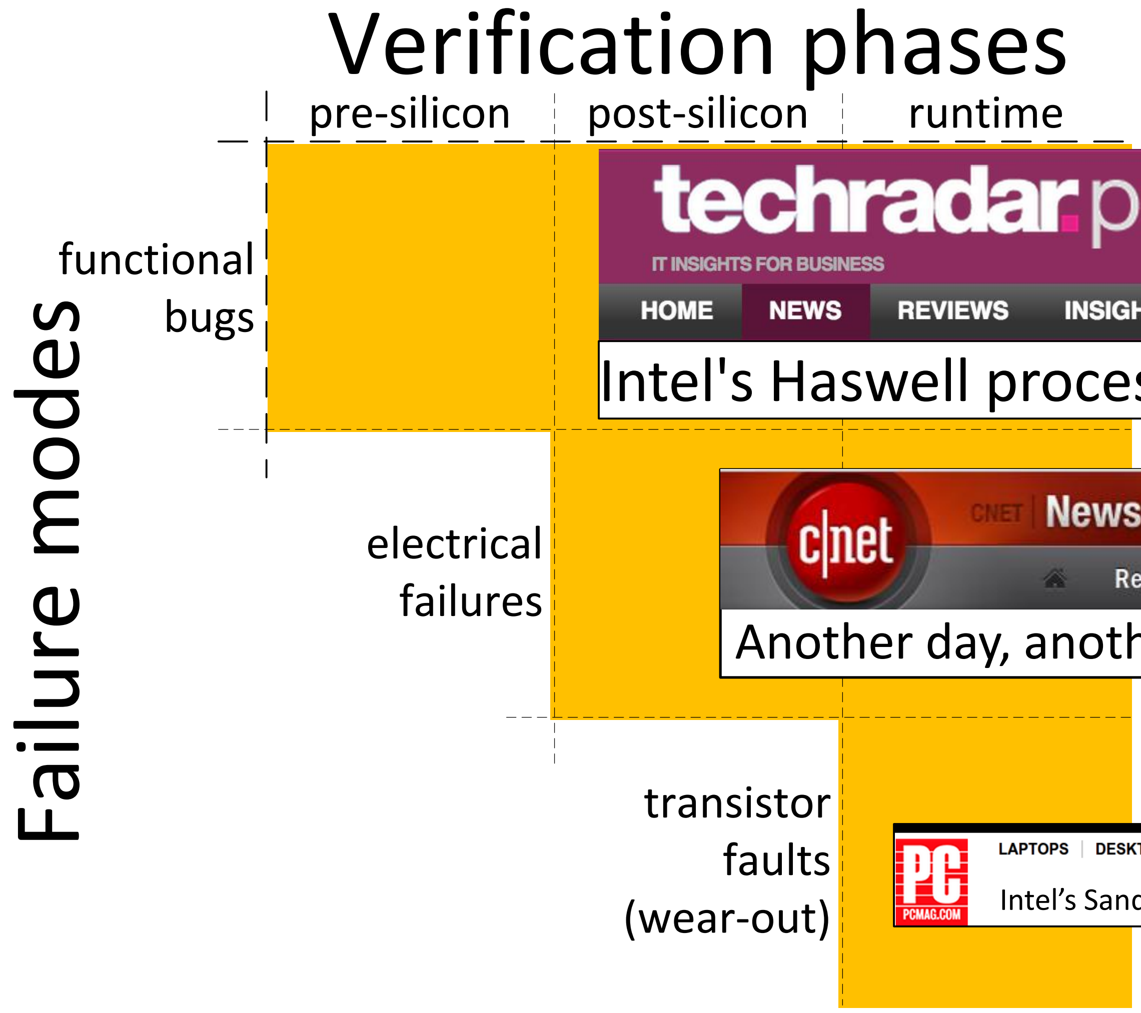
last chance

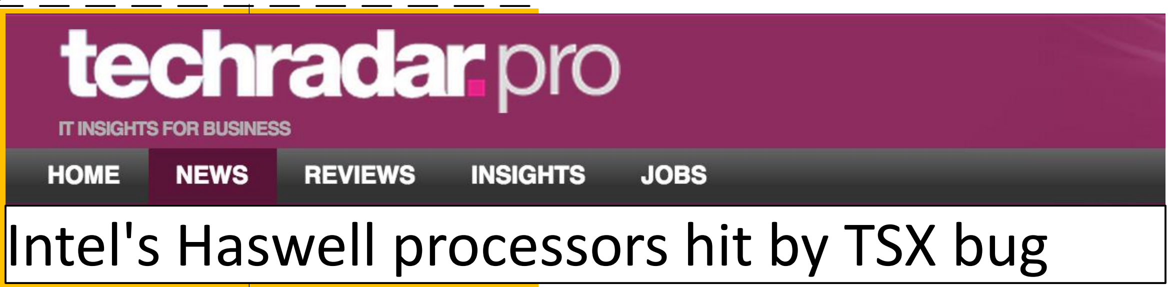
Verification today

2012 ~ 1-to-1 ration of peak design and verification engineers!
75% increase since 2007!

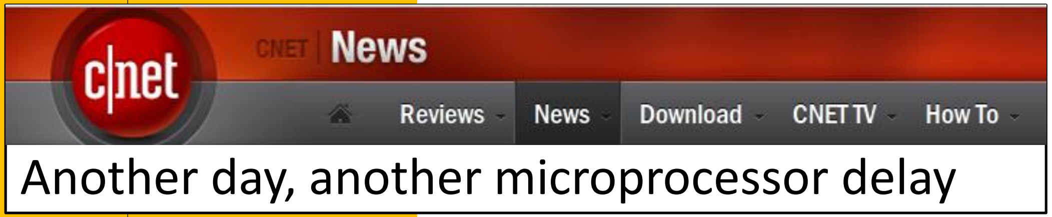


How errors are addressed

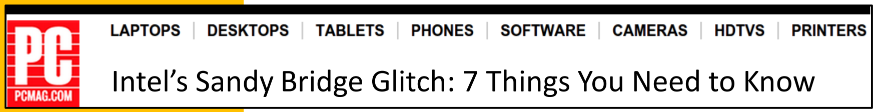




Intel's Haswell processors hit by TSX bug



Another day, another microprocessor delay



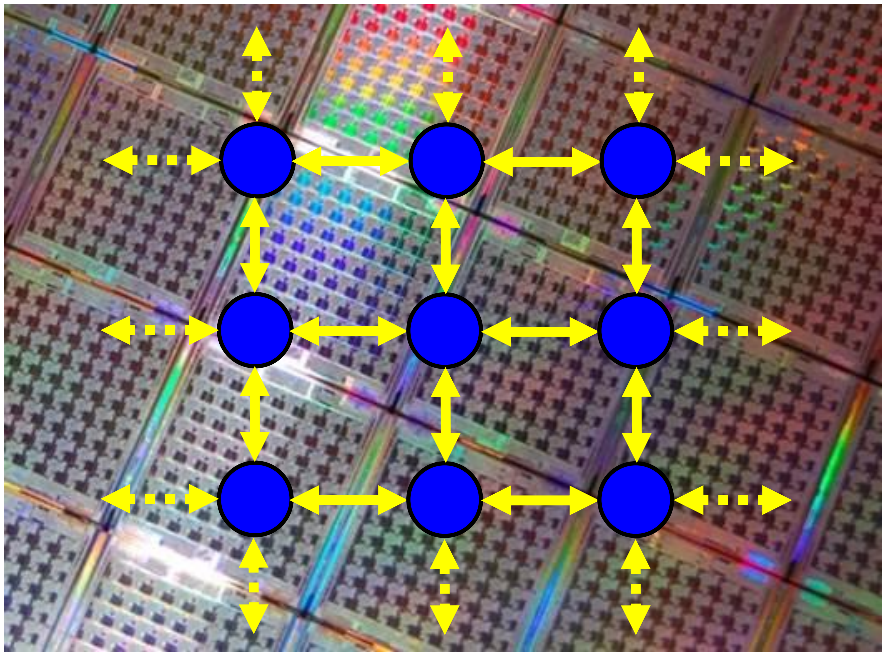
Intel's Sandy Bridge Glitch: 7 Things You Need to Know

My research

Ensure **correct** operation

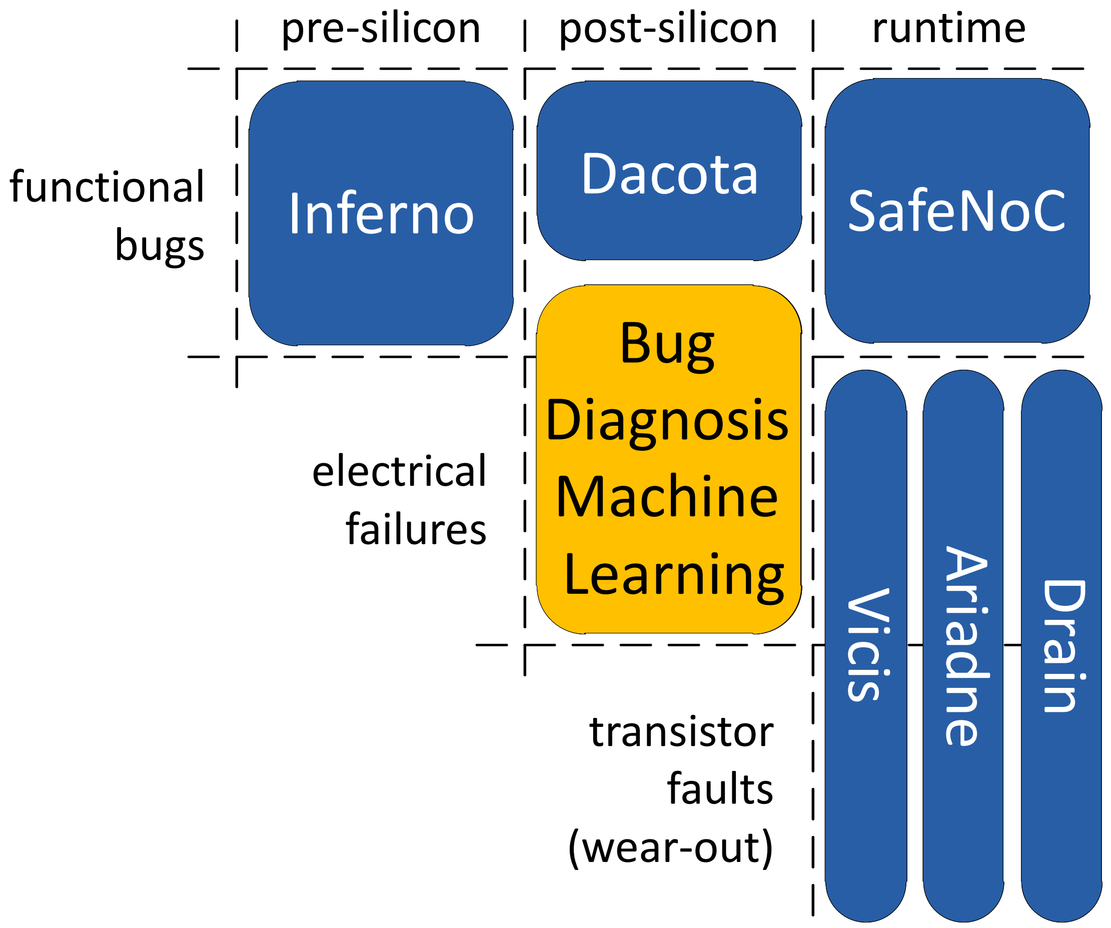
of **digital designs**

throughout the **lifetime** of the chip

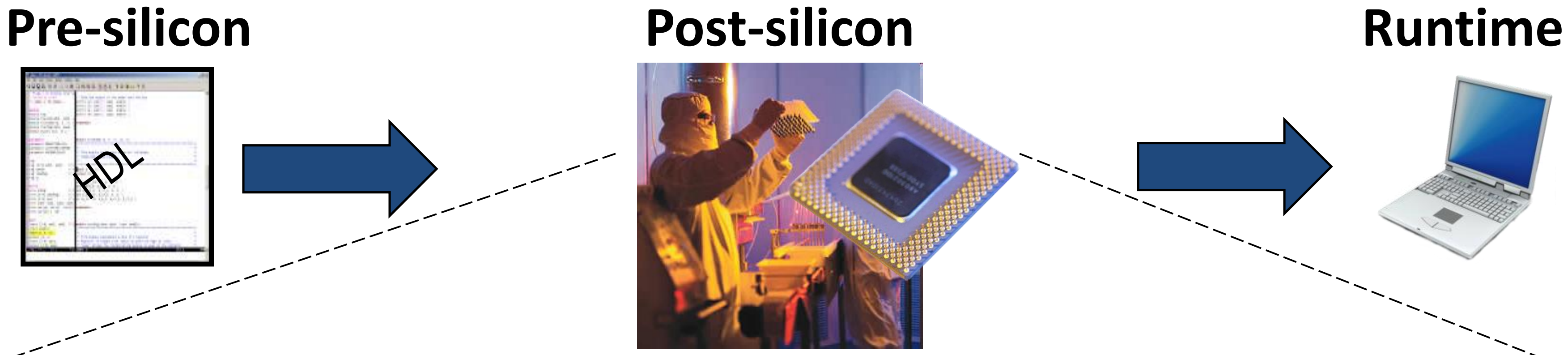


My research

- Breadth of work across the verification spectrum
- Depth of work in several areas, such as post-si validation



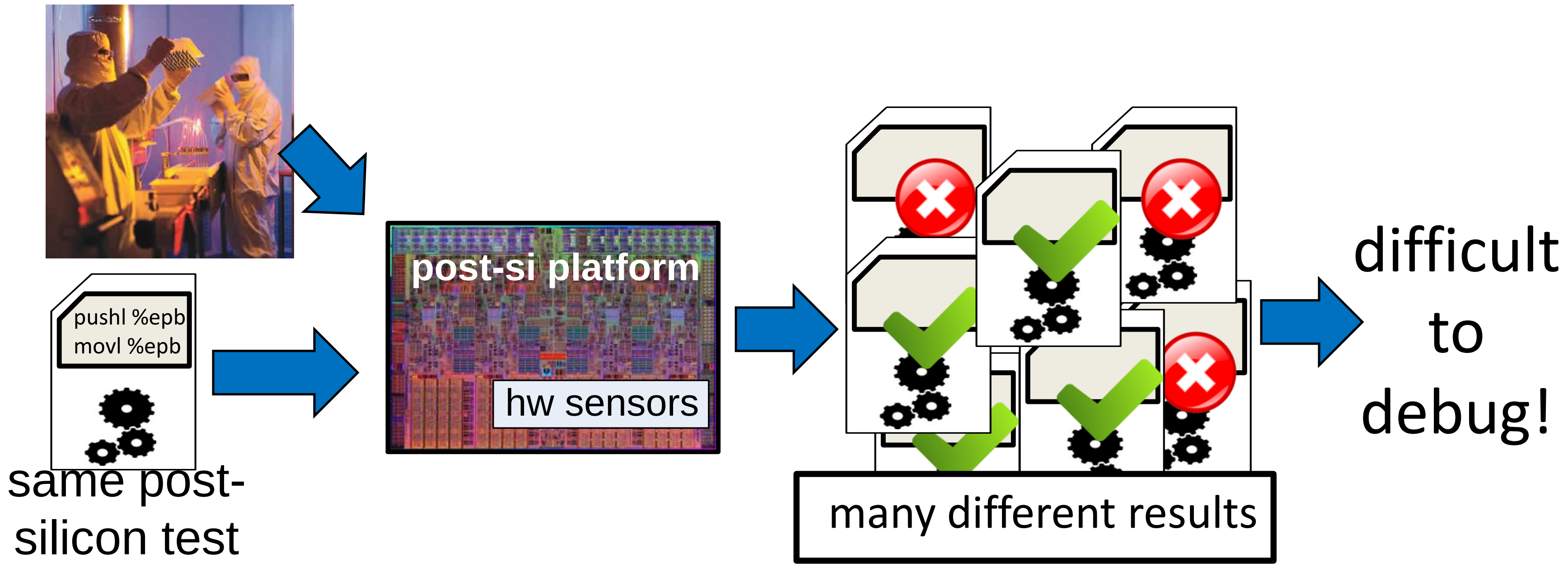
Post-silicon validation



Goal: locate bug	
+ Fast prototypes	- Poor observability
+ High coverage	- Slow off-chip transfer
+ Test full system	- Noisy
+ Find deep bugs	- Intermittent bugs

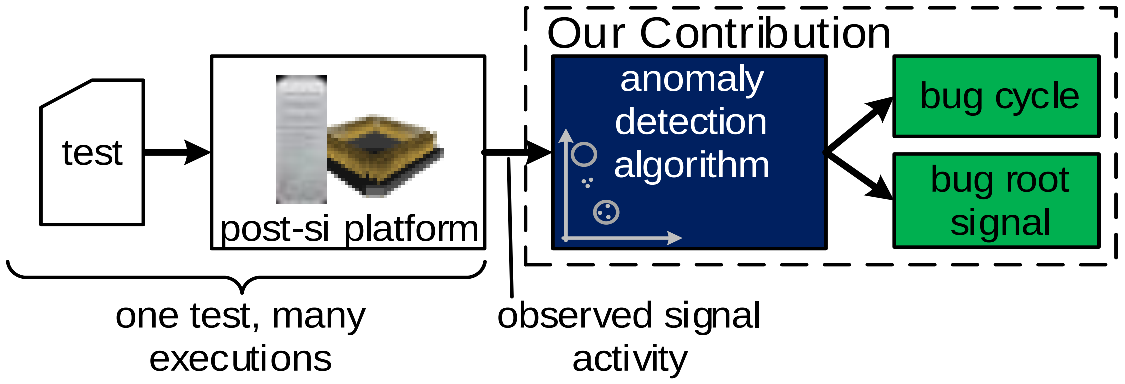
The most challenging post-silicon bugs

- A same test does not expose the bug in every run
- Each run exhibits different behaviors

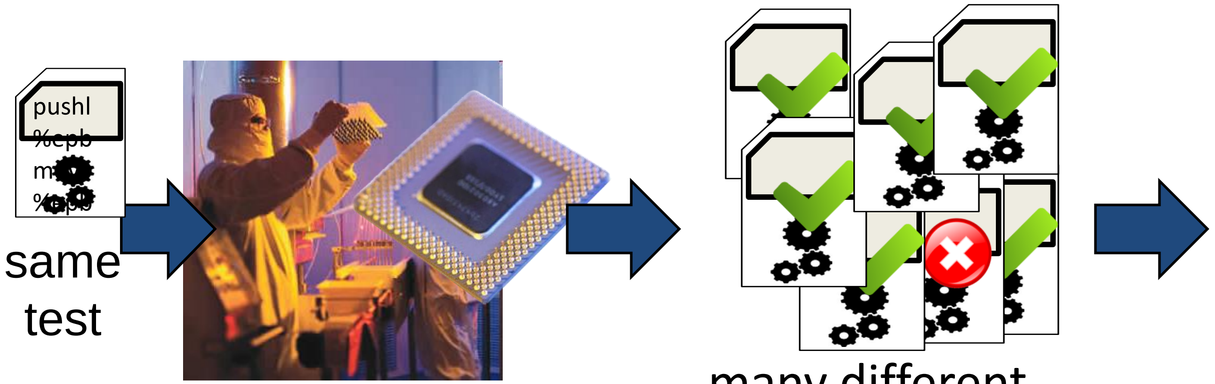


Debugging intermittent failures

- Localize failures
  - Time (cycle) and space (signals)
- Tolerate non-repeatable executions
  - Statistical machine learning approach
- Scalable, adaptable to many HW subsystems



Post-silicon and credit cards



same test

many different results

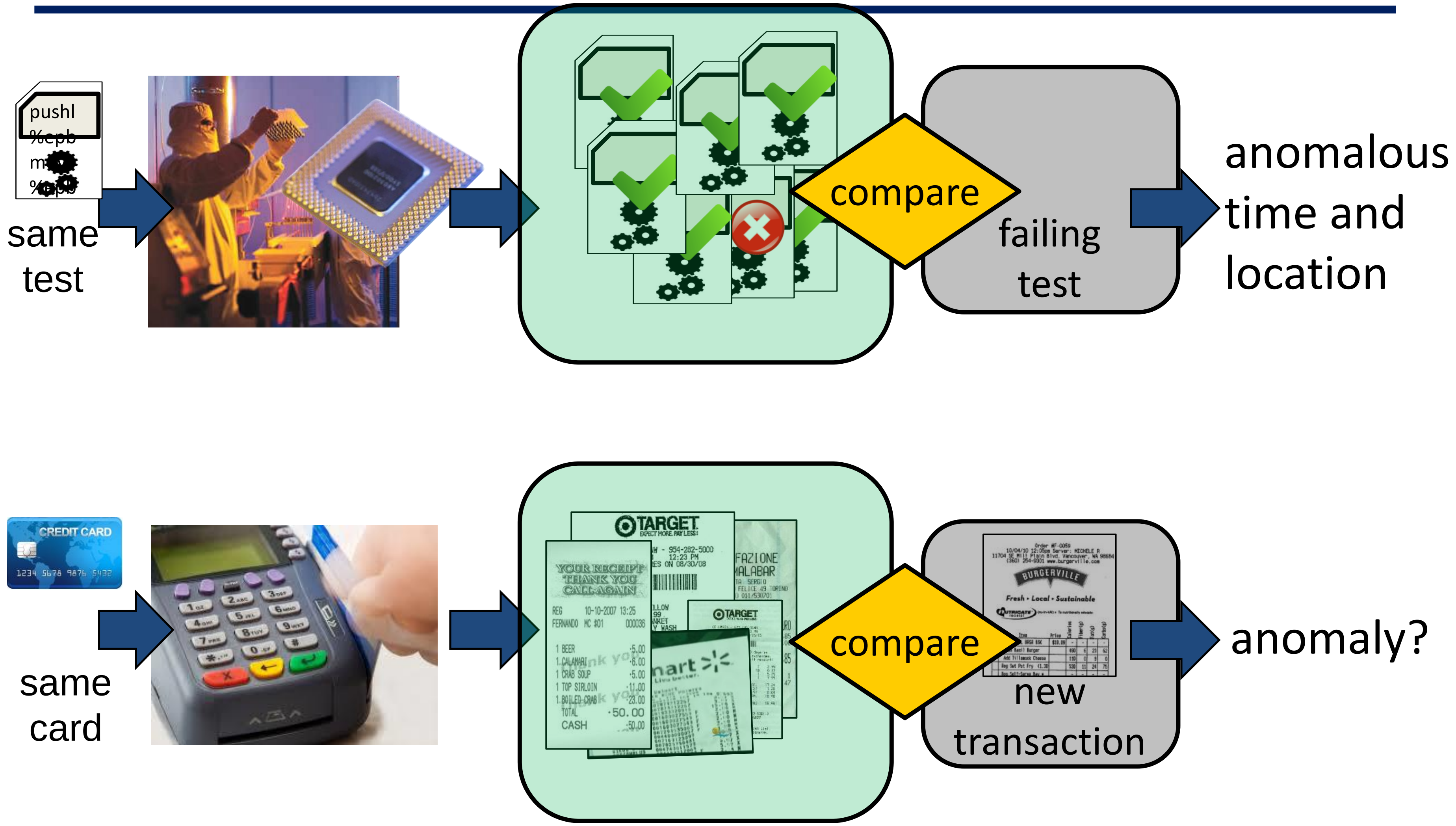
difficult to locate bug!

same card

many different transactions

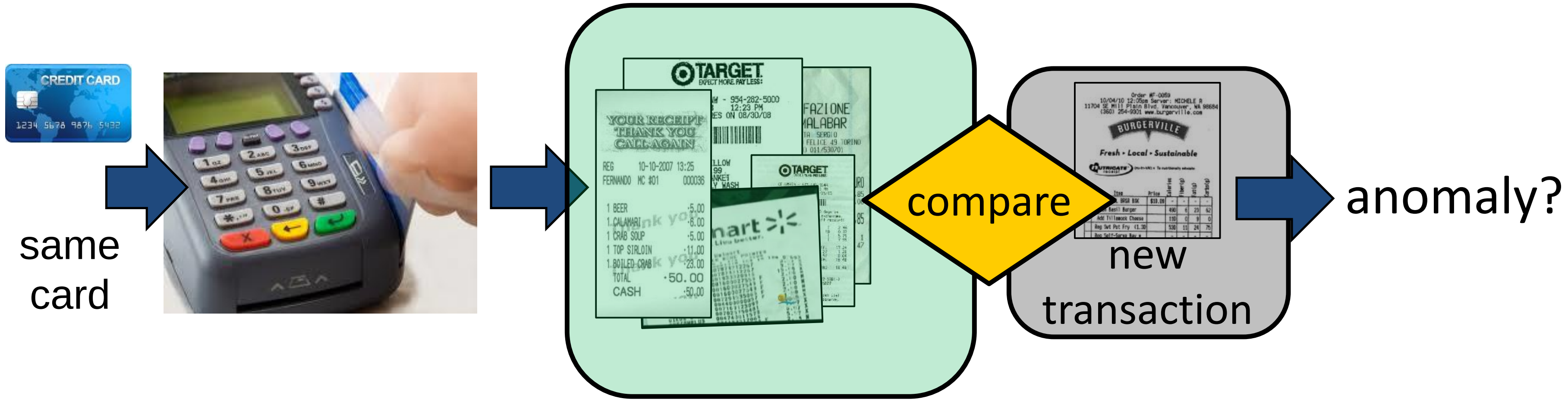
difficult to locate fraud!

Post-silicon and credit cards



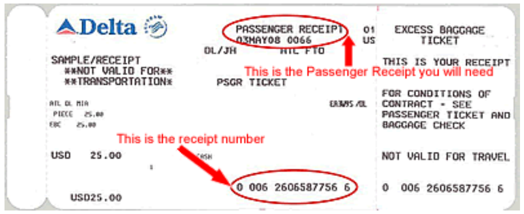
Machine learning background

- Goal: build a statistical model from examples
- Use model to make predictions for new examples



Machine learning background

- Each example described by *features*
  - Merchant, $ amount, location, etc.



Delta

PASSENGER RECEIPT 01
03MAY08 0066 US

DL/JH ATL FTO

SAMPLE/RECEIPT
NOT VALID FOR
**TRANSPORTATION*

PSGR TICKET

This is the Passenger Receipt you will need

ATL DL MIA
PIECE 25.00
EBC 25.00

This is the receipt number

USD 25.00

CASH

0 006 2606587756 6

USD25.00

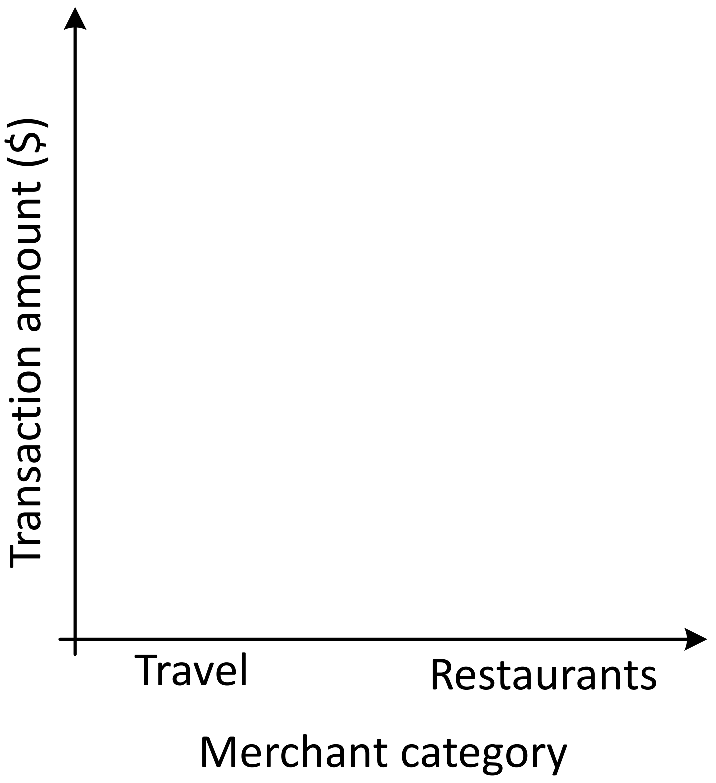
EXCESS BAGGAGE
TICKET

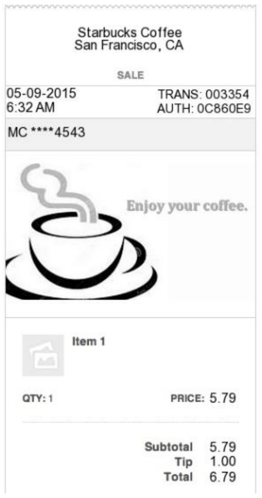
THIS IS YOUR RECEIPT

FOR CONDITIONS OF
CONTRACT - SEE
PASSENGER TICKET AND
BAGGAGE CHECK

NOT VALID FOR TRAVEL

0 006 2606587756 6





Starbucks Coffee
San Francisco, CA

SALE

05-09-2015 TRANS: 003354
6:32 AM AUTH: 0C860E9

MC ****4543

Enjoy your coffee.

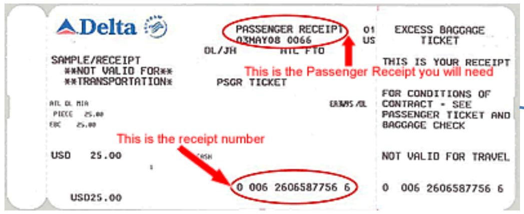
Item 1

QTY: 1 PRICE: 5.79

Subtotal 5.79
Tip 1.00
Total 6.79

Machine learning background

- Learn correct behavior using *training data*
  - *Positive* labeled examples in this application



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0 006 2606587756 6

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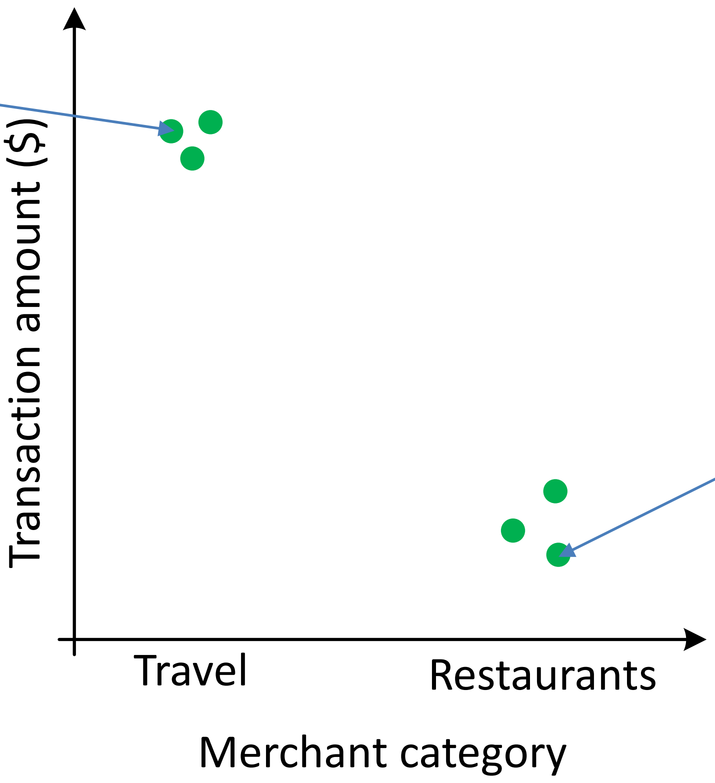
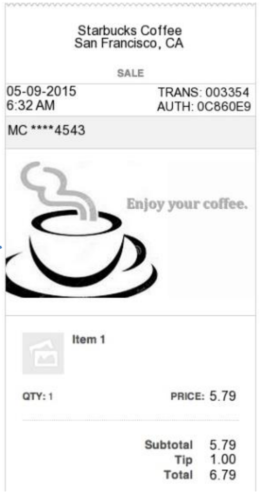
USD25.00





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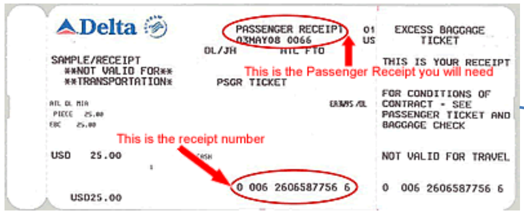
Tip	1.00
Total	6.79

Machine learning background

- Clustering: a machine learning algorithm that groups examples with similar characteristics



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01
US

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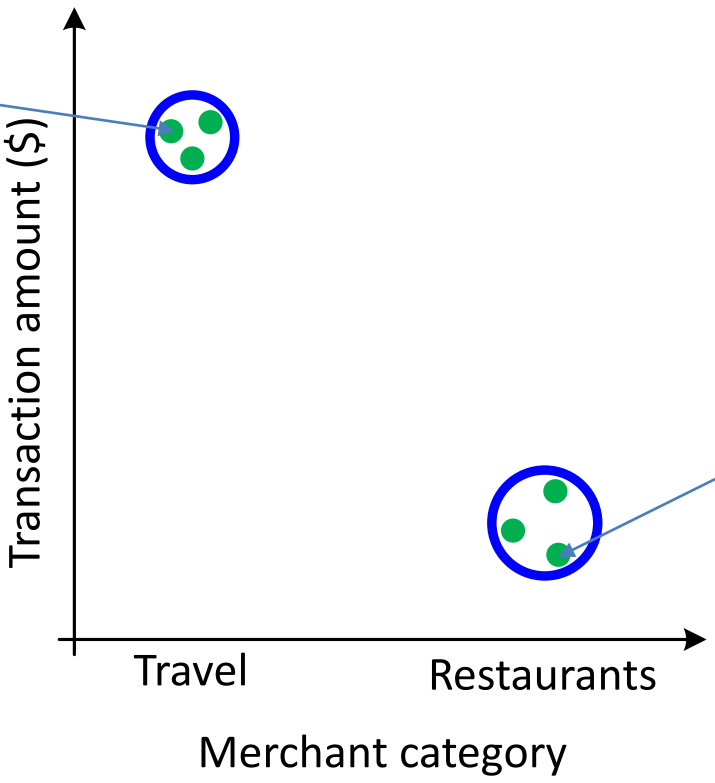

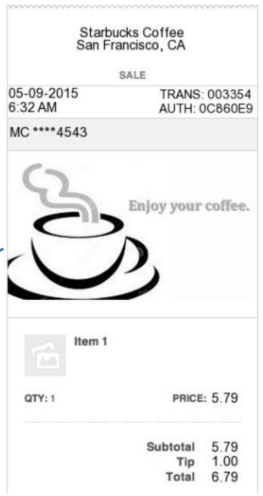

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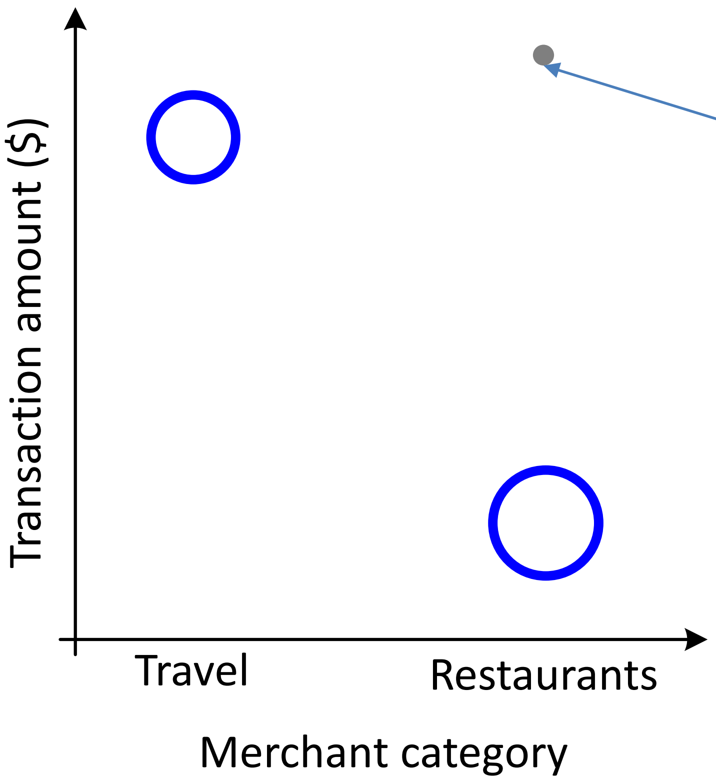
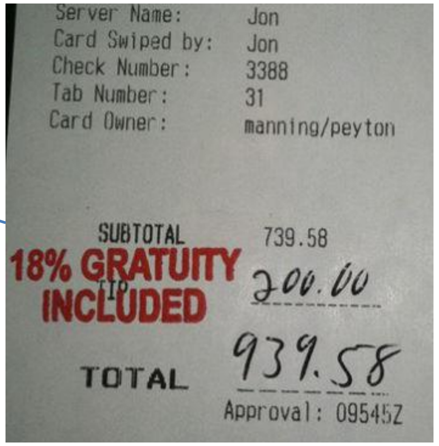
Machine learning background

- *One-class learning* requires only a single label
- Good for anomaly detection





Server Name: Jon
Card Swiped by: Jon
Check Number: 3388
Tab Number: 31
Card Owner: manning/peyton

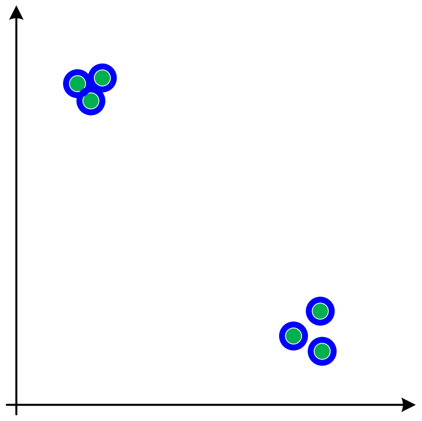
SUBTOTAL 739.58
18% GRATUITY INCLUDED
TIP 200.00
TOTAL 939.58
Approval: 09545Z

unknown example

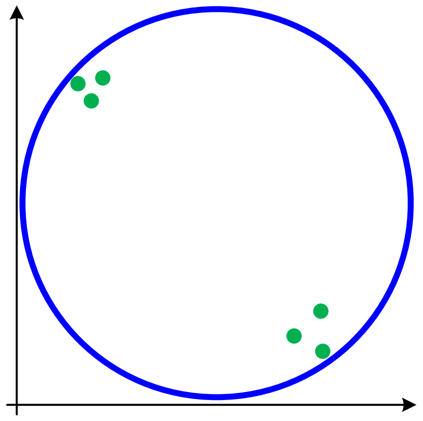
Machine learning background

- Overfitting: model is too specific
  - Everything looks like an anomaly
- Underfitting: model is too general
  - Nothing looks like an anomaly

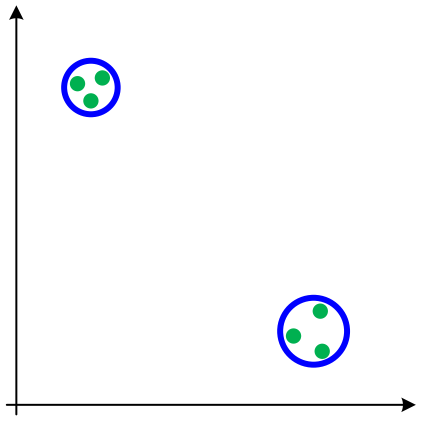
Overfitting



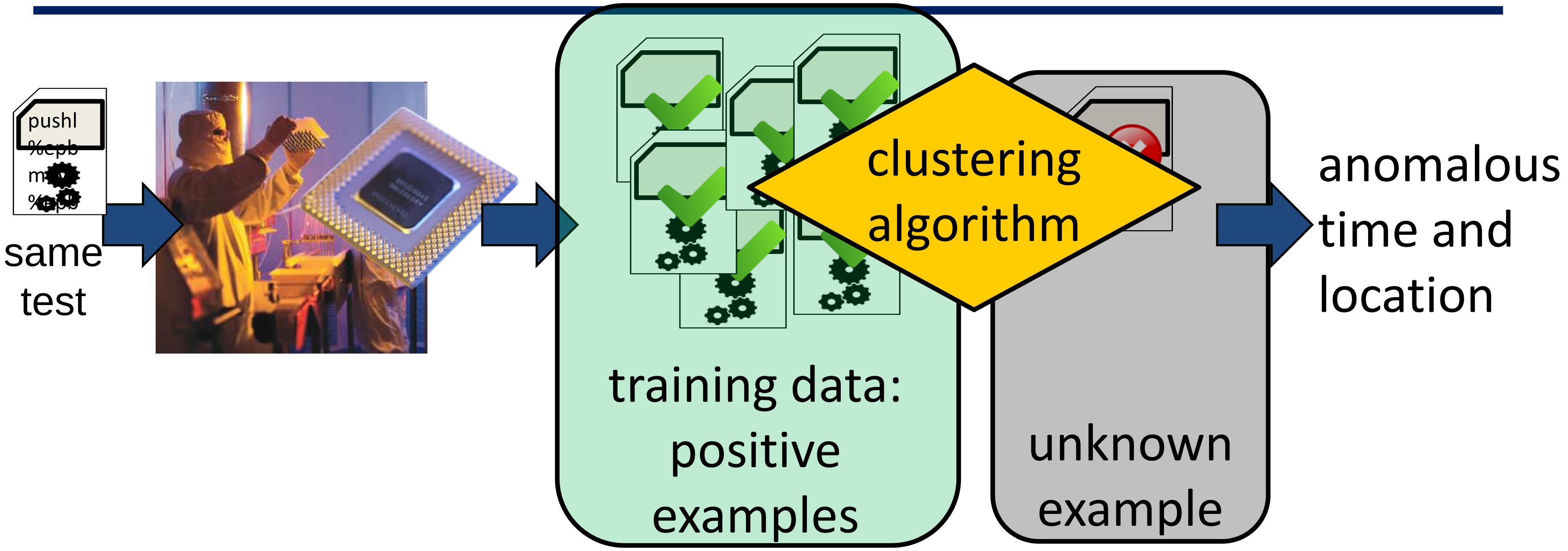
Underfitting



Good fit



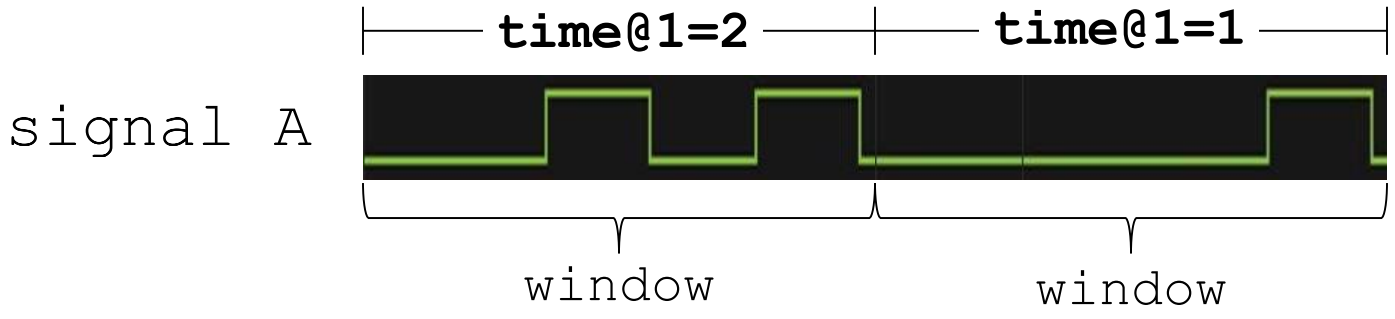
Features for post-silicon tests



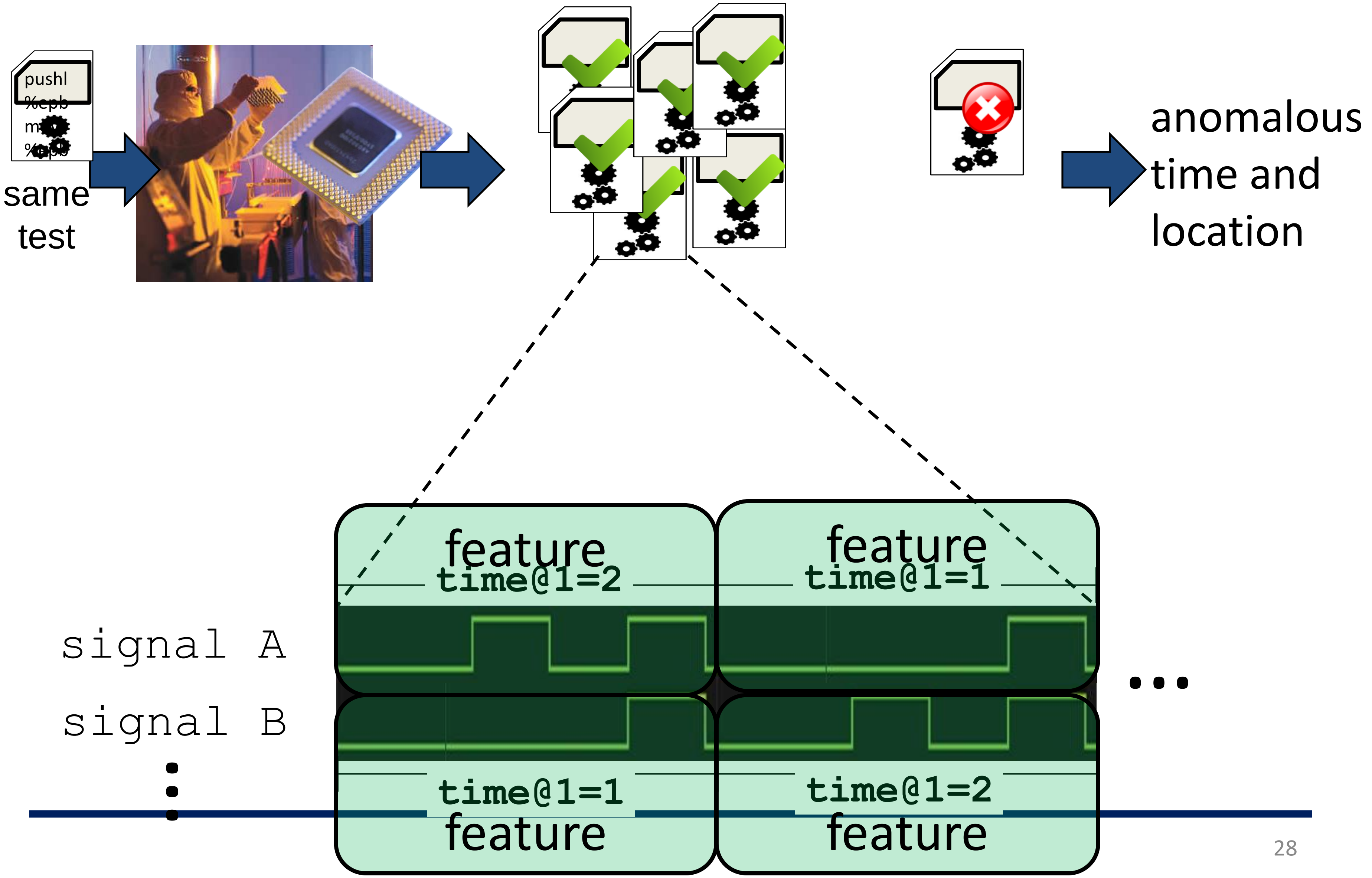
- What are some possible features that could be used to describe a post-silicon test execution?

Features

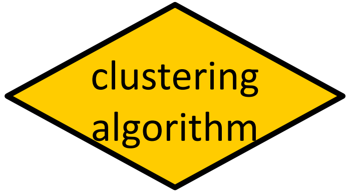
- Goal: summarize signal value
- Encodings (hamming, CRC, etc.)
  - Large hardware
  - Small change in input -> large change in output
- Counting schemes (time@1, toggle count)

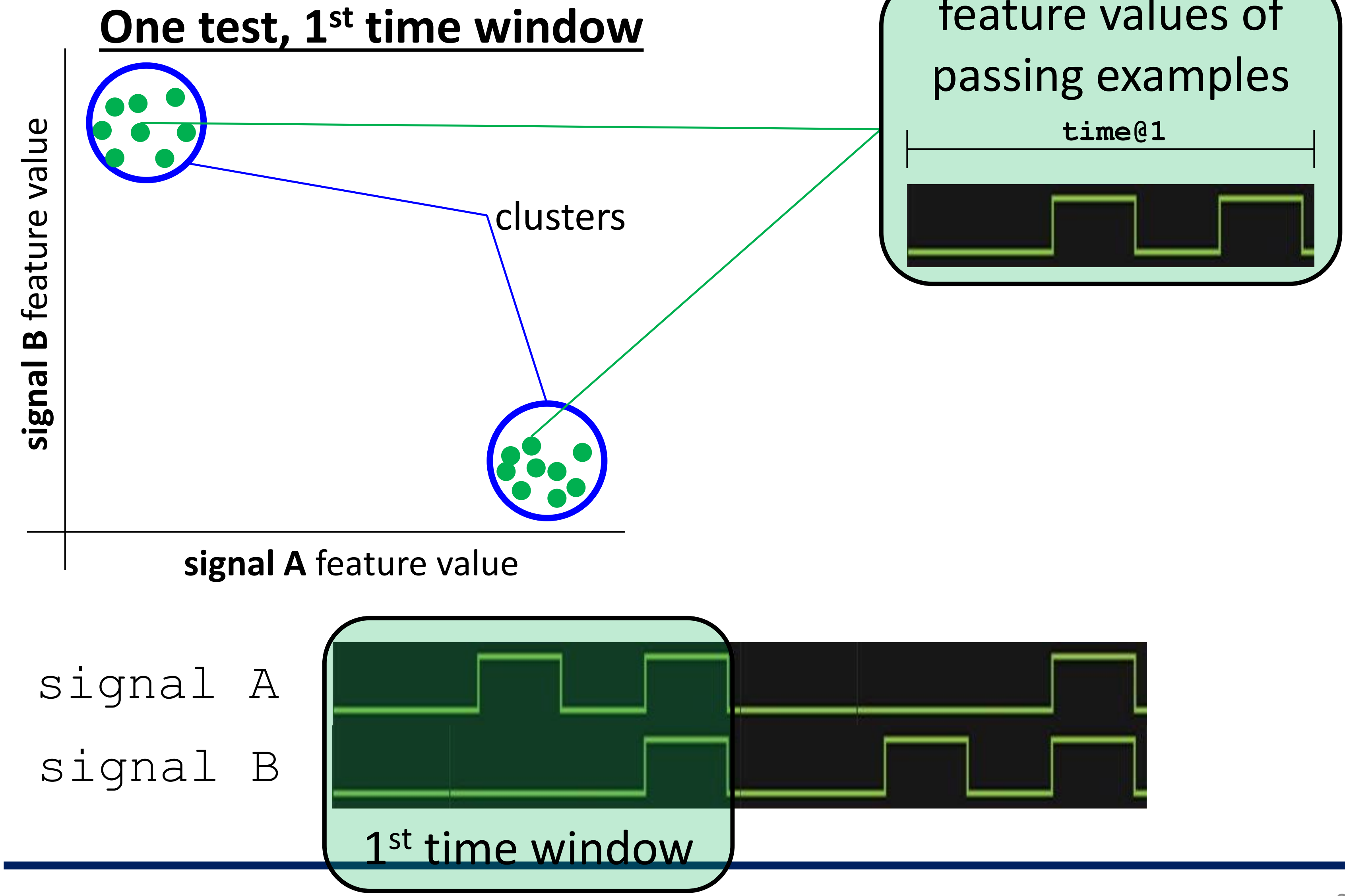


Features


pushl
%ebp
mov
%esp
same test
anomalous time and location
feature
time@1=2
feature
time@1=1
signal A
signal B
time@1=1
feature
time@1=2
feature
...

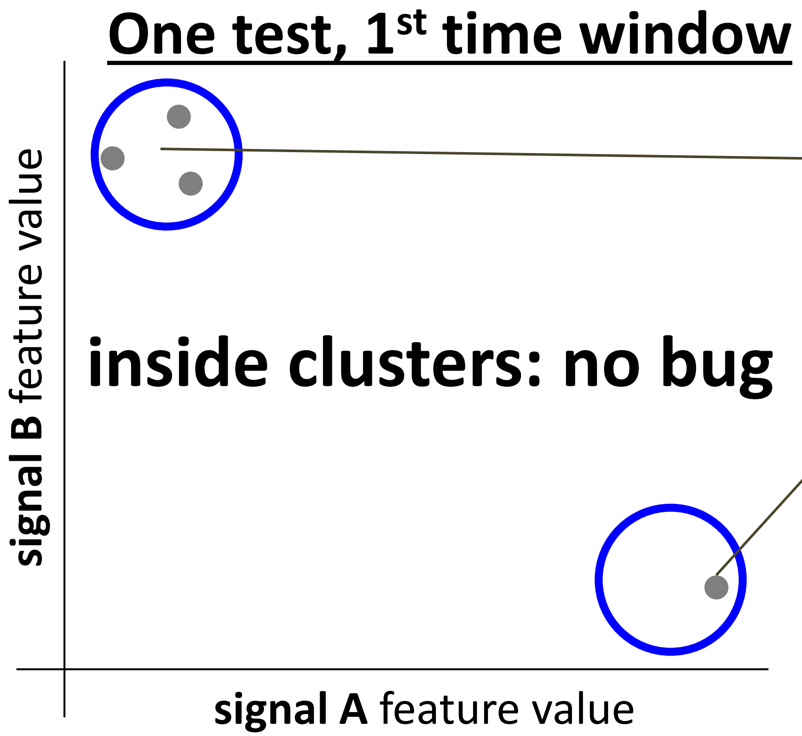
Learning clusters



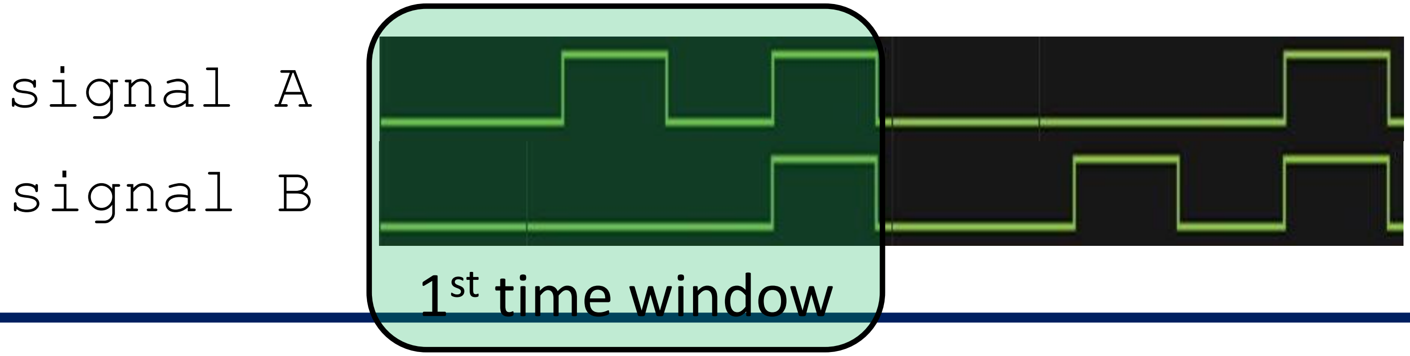


Searching for anomalies

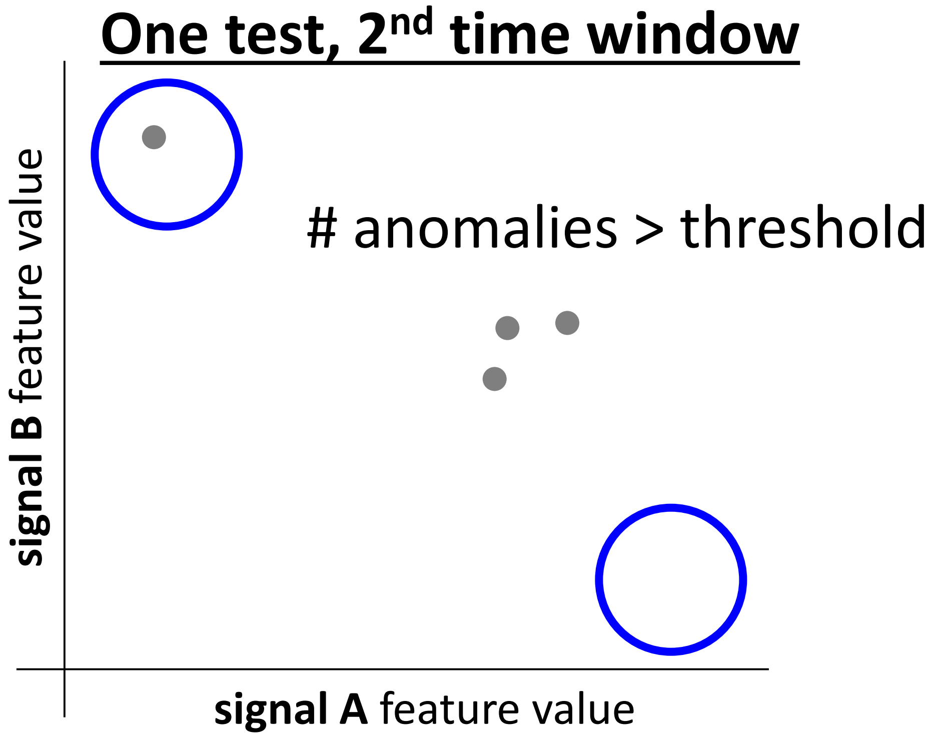
clustering algorithm



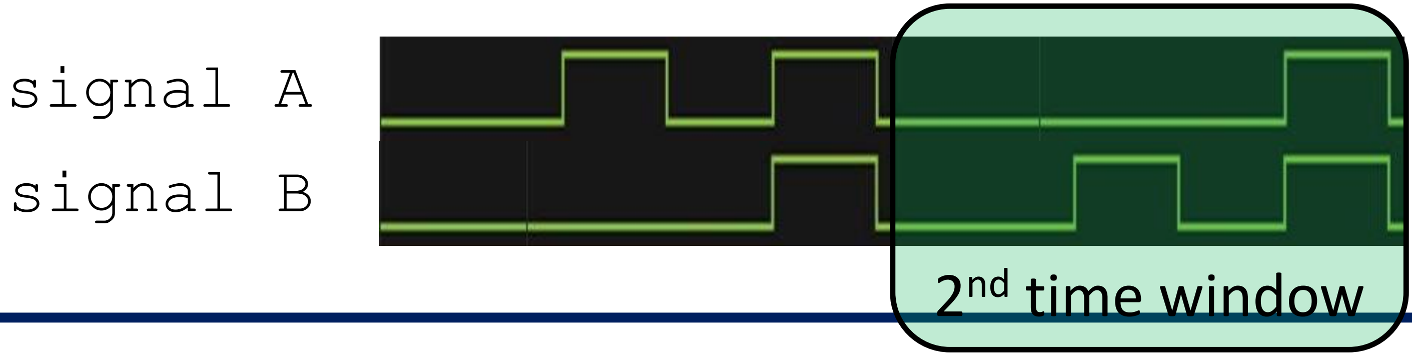
Added *after* clustering



Searching for anomalies

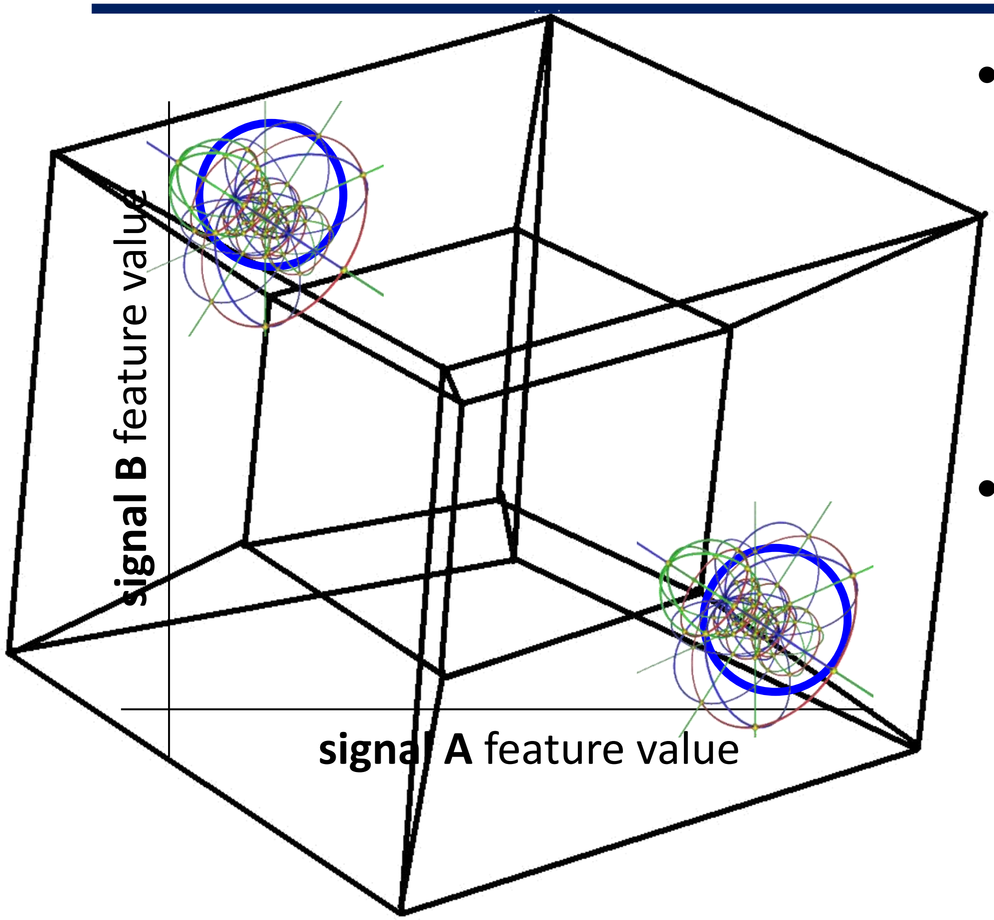


Outside clusters: bug found



clustering algorithm

Clustering in X,000 dimensions



- Each signal is a dimension
  - Circular clusters become hyper-spheres
  - High dimensionality is a challenge
- In practice:
  - Cap #signals in one clustering set (500)
  - Group signals by module(s) (100-500 signals)
  - Apply clustering to each group

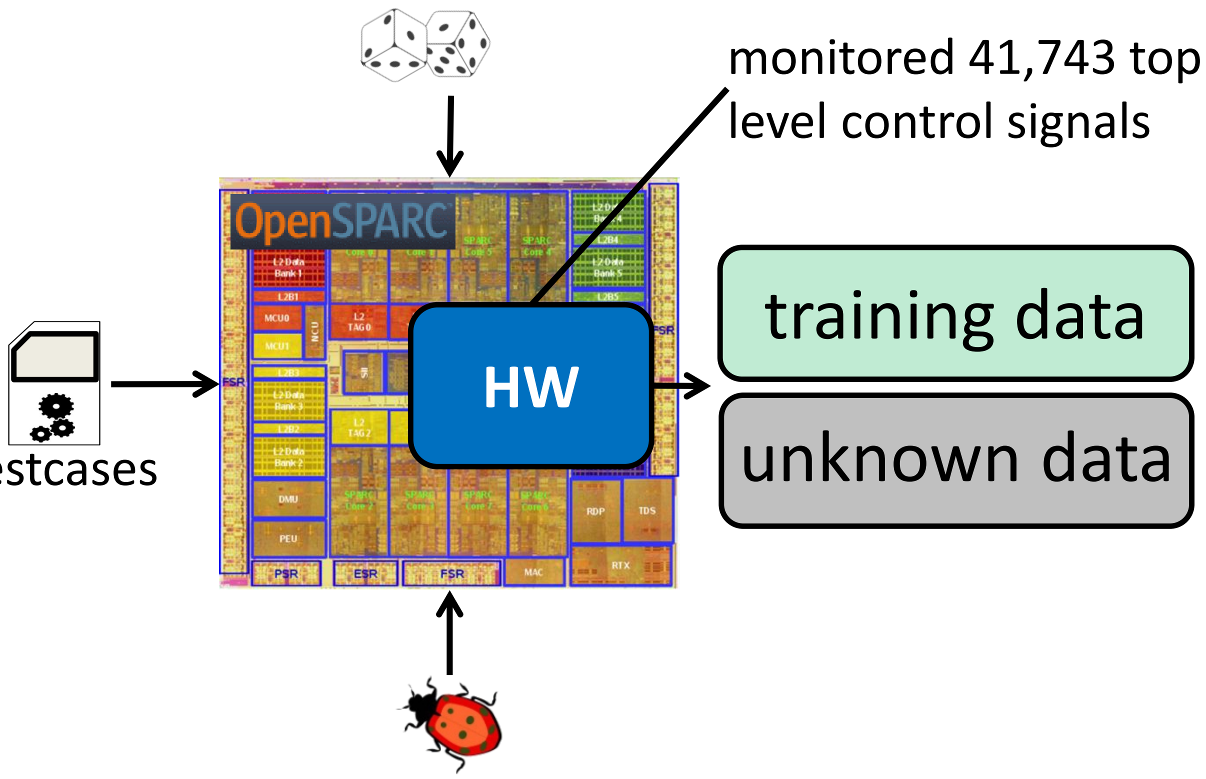
Experimental setup

10 seeds 100 random seeds: variable memory delay, crossbar random traffic

1000 passing runs

10 testcases

1000 buggy runs

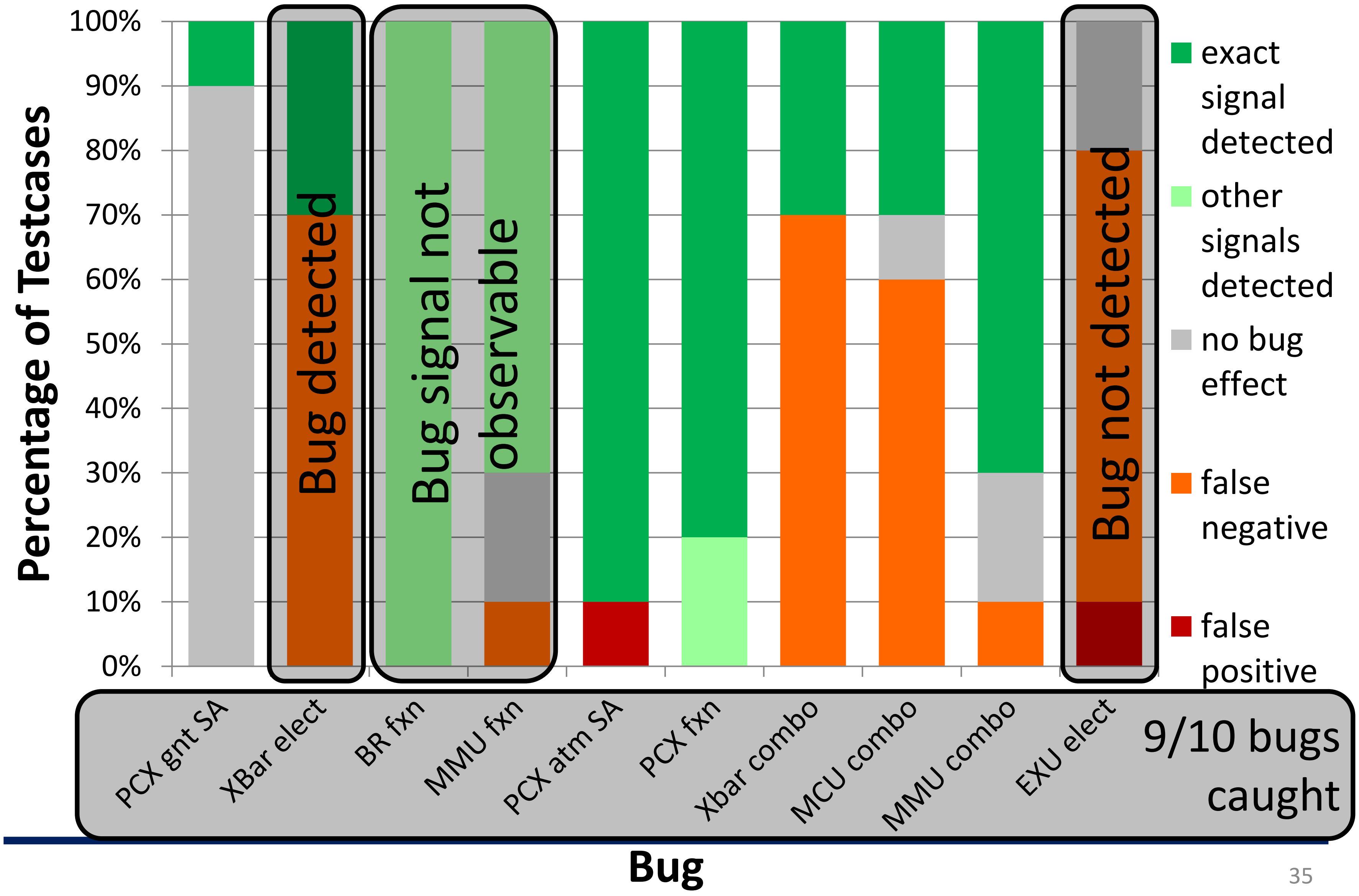


10 bugs: *e.g.*, functional bug in PCX, electrical error in Xbar

Bug injection

Bug	Description
PCX_gnt SA	Stuck-at in PCX grant
Xbar elect	Electrical error in crossbar
BR fxn	Functional bug in branch logic
MMU fxn	Functional bug in memory controller
PCX_atm SA	Stuck-at in PCX atomic grant
PCX fxn	Functional bug in PCX
XBar combo	Combined electrical errors in Xbar/PCX
MCU combo	Combined electrical errors in mem/PCX
MMU combo	Combined functional bugs in MMU/PCX
EXU elect	Electrical error in execute unit

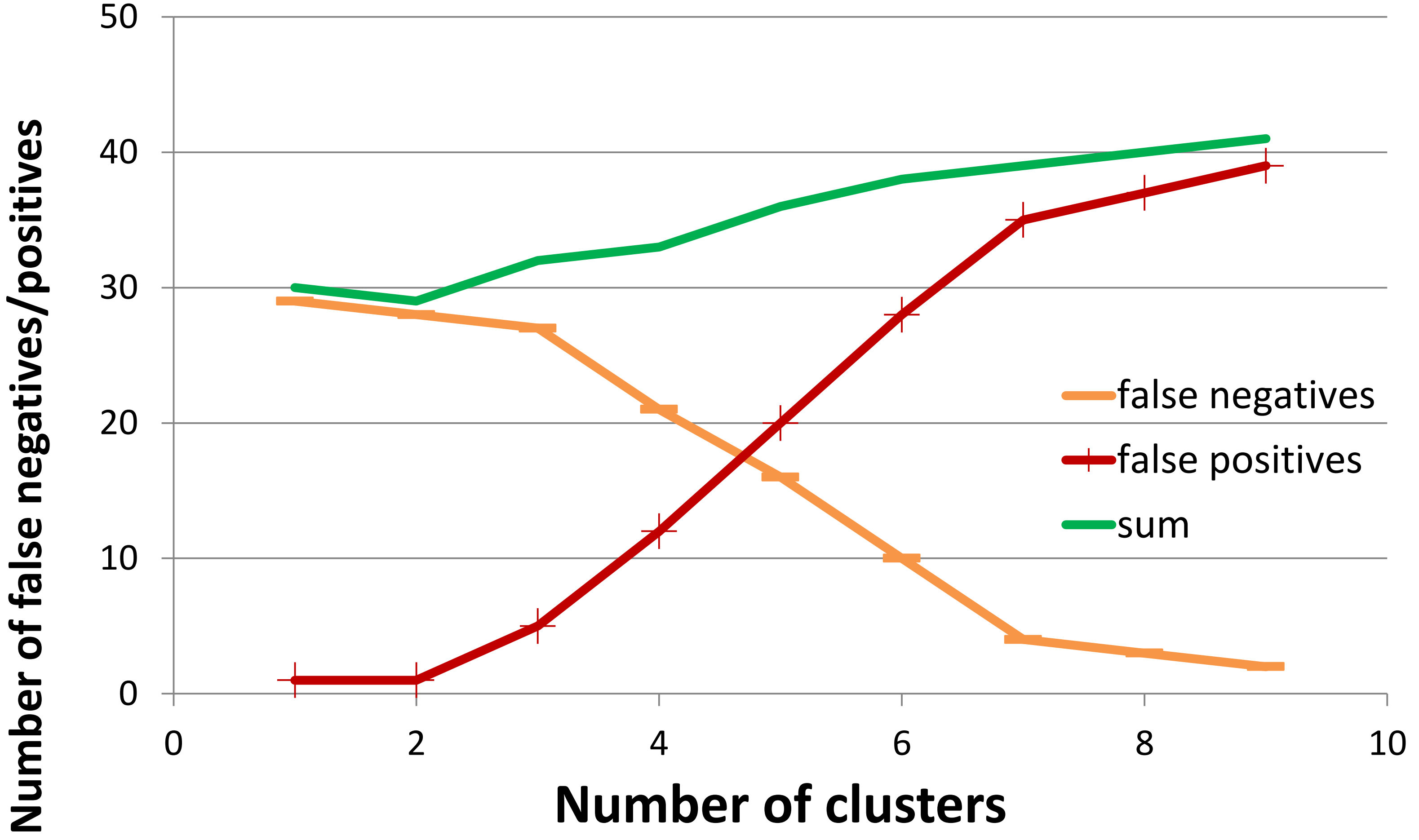
Bug detection on OpenSPARC T2



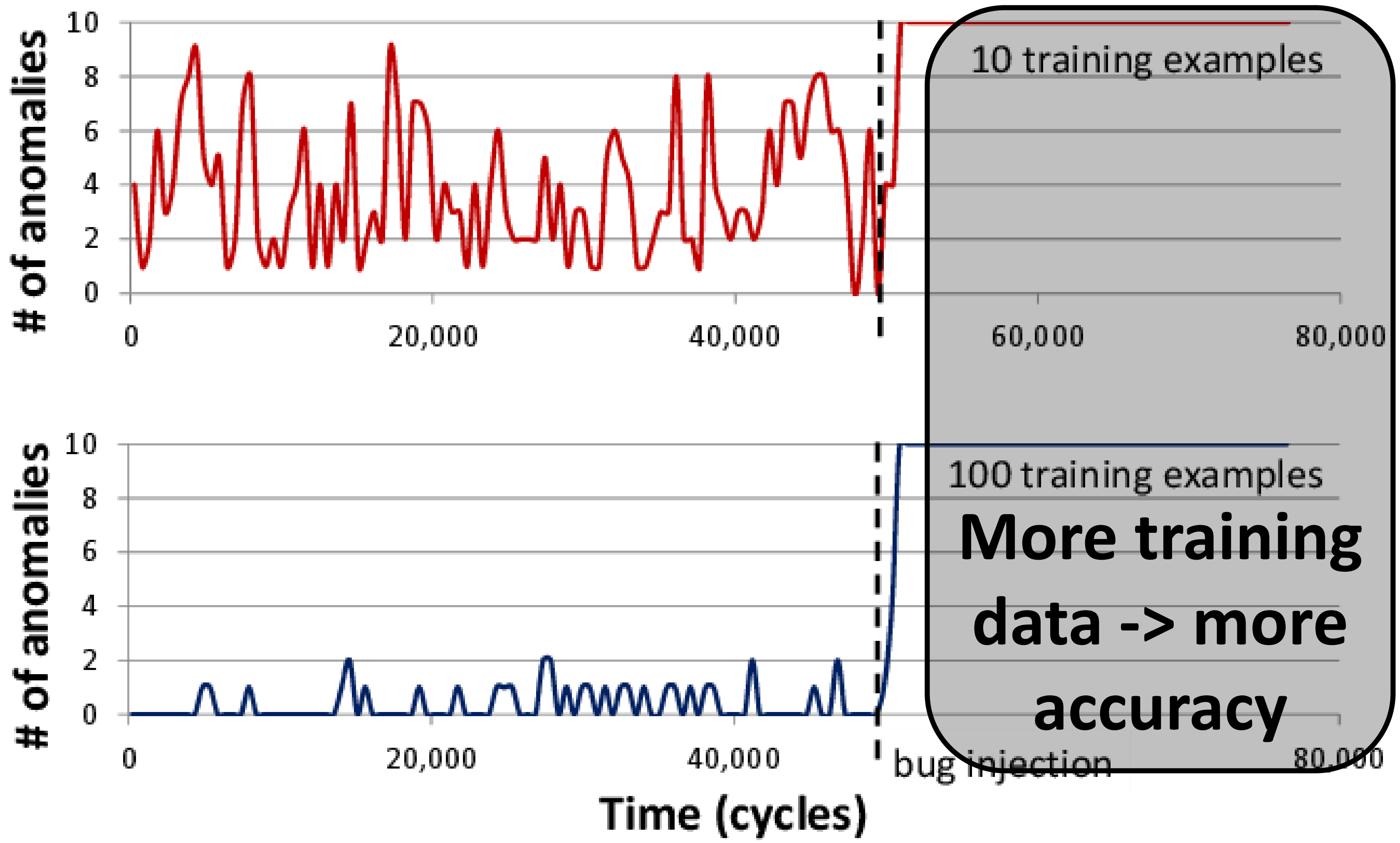
9/10 bugs caught

Number of clusters

Exercise: where does overfitting occur? Underfitting?



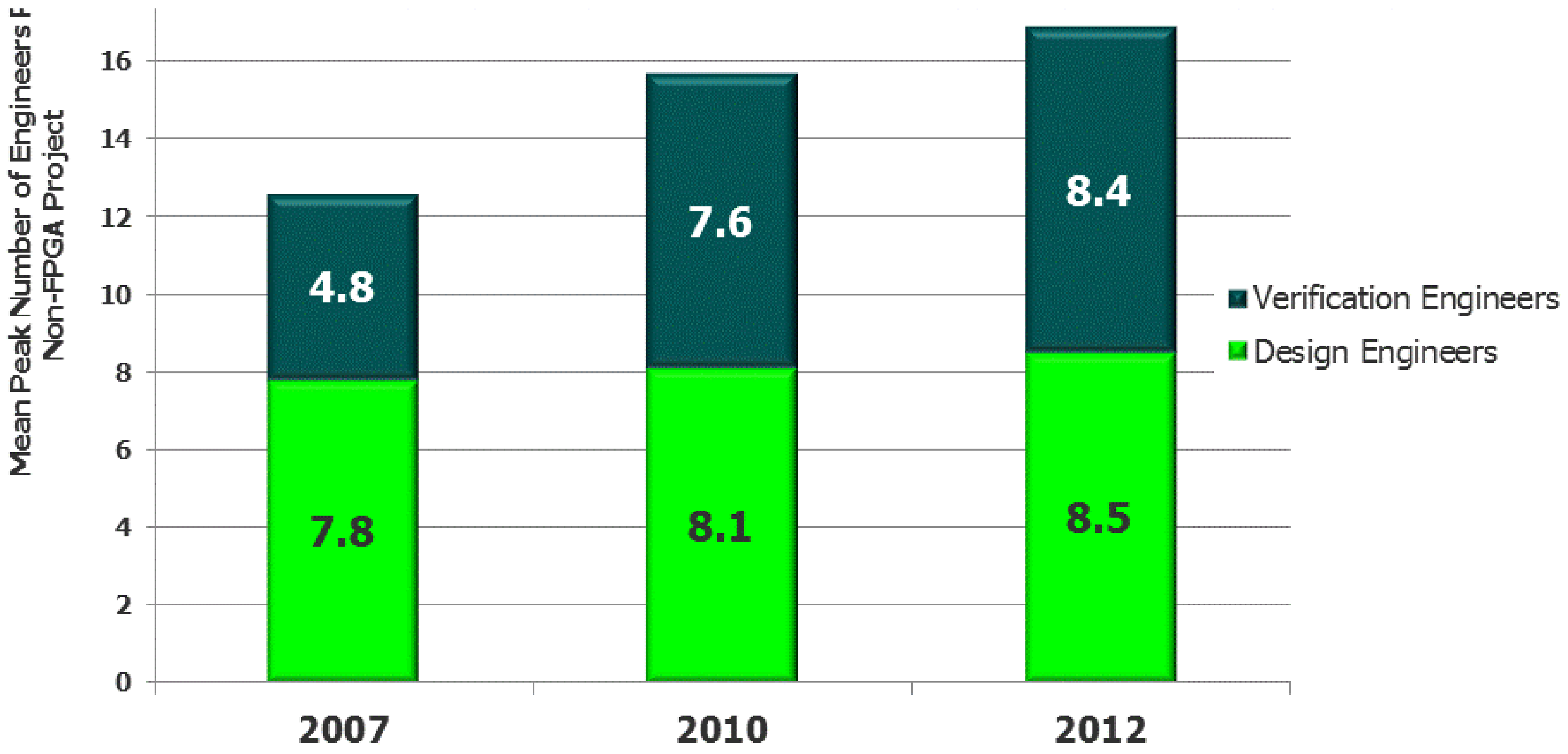
Bug signal vs. noise



More training data -> more accuracy

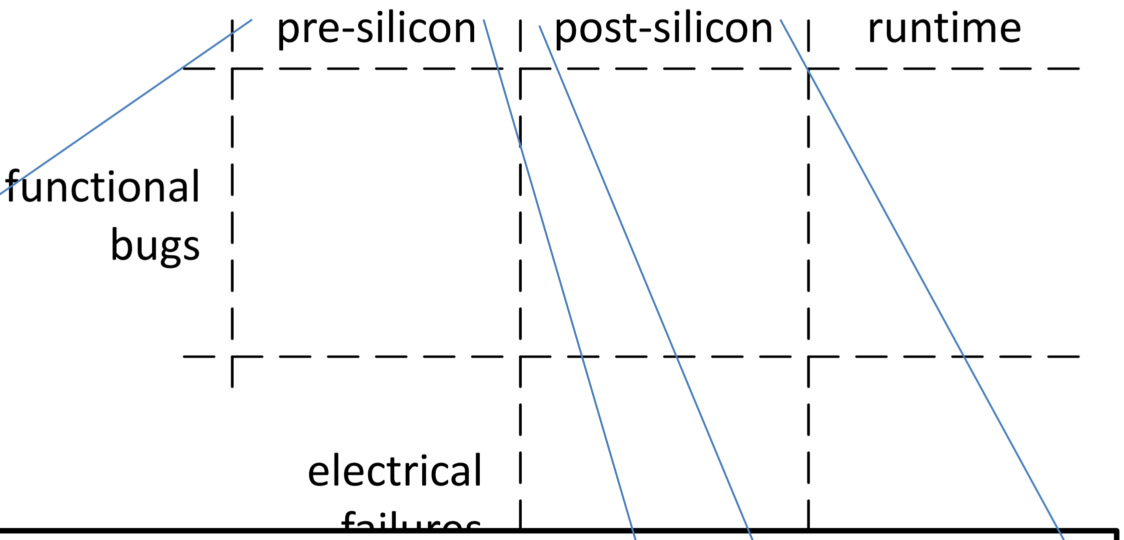
Impact

- Improved diagnosis of difficult bugs
- Improved verification efficiency

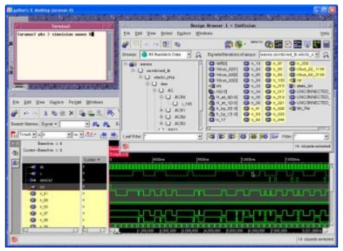


Future trends in verification

- Increasing high-speed verification
- Increasing data generated during verification



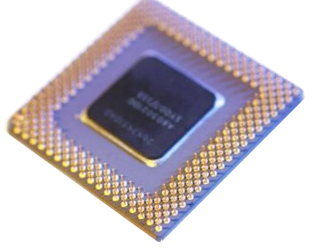
SW Simulation
1-10 cycles/s



Acceleration
10-100k cycles/s

Emulation
10-100M cycles/s

Silicon
1G cycles/s



Future trends in verification

- Increasing high-speed verification
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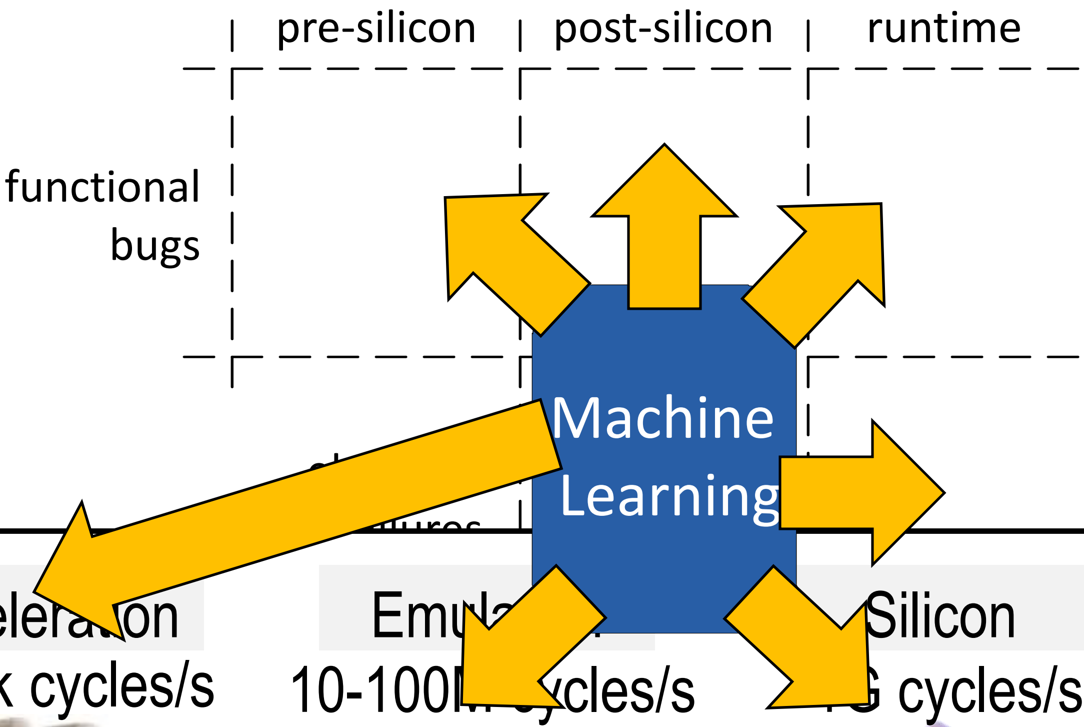
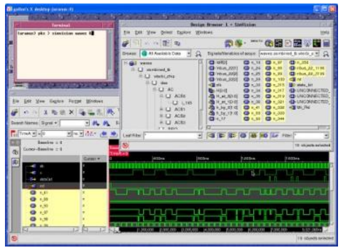


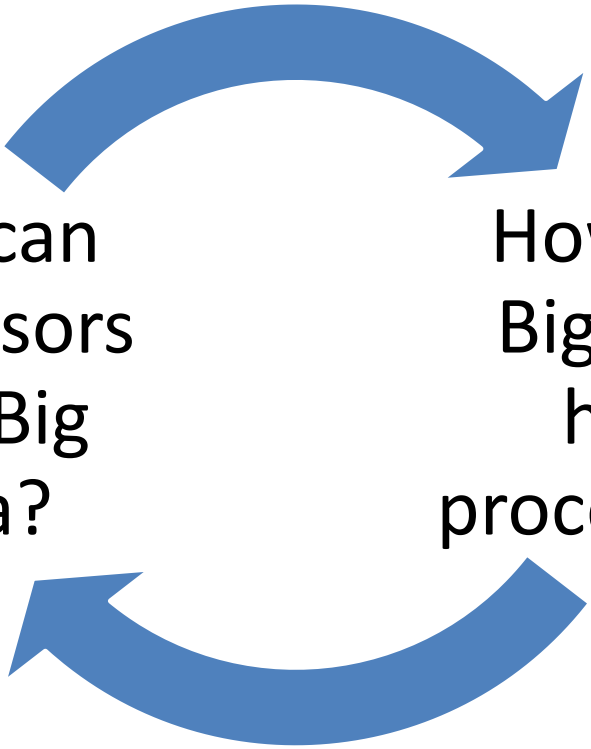
SW Simulation	Acceleration	Emulation	Silicon
1-10 cycles/s	10-100k cycles/s	10-100M cycles/s	1G cycles/s



Research vision

Traditional machine learning research

My research



How can processors help Big Data?

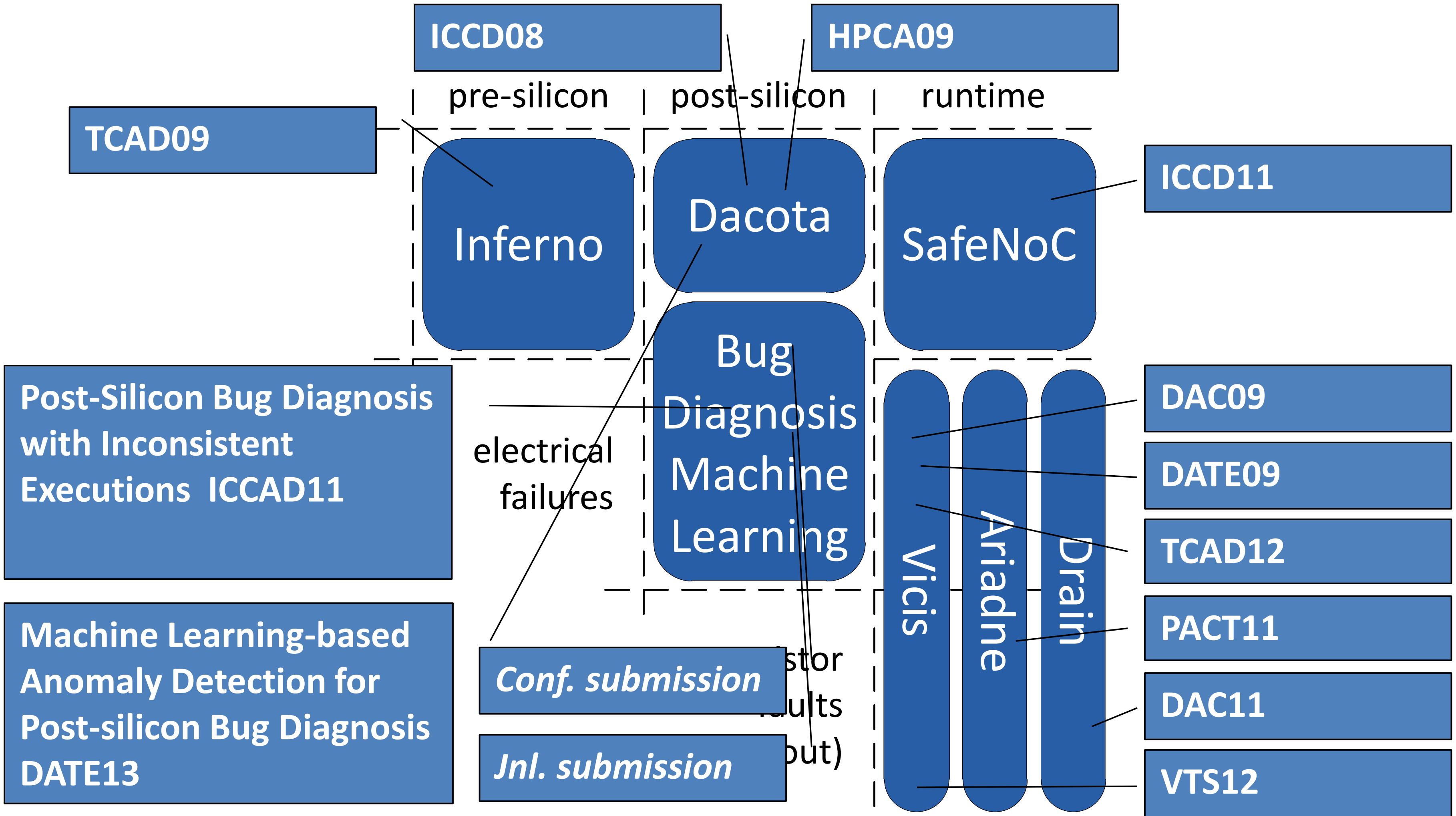
How can Big Data help processors?

Data science for digital design

Research vision

- **Correctness** is the driving force behind my research
- My research brings a **data science approach** to electronic design automation
- Use machine learning techniques to enable verification to **keep up with growing design complexity**

Selected publications



Post-Silicon Bug Diagnosis with Inconsistent Executions ICCAD11

Machine Learning-based Anomaly Detection for Post-silicon Bug Diagnosis DATE13

Conf. submission

Jnl. submission

More at andrewdeorio.com/research

Conclusion

- With a data science approach to electronic design automation, we can teach computers to verify themselves