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Maximising Axiomatization Coverage and Minimizing Regression Testing Time

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Who guards the guardians?

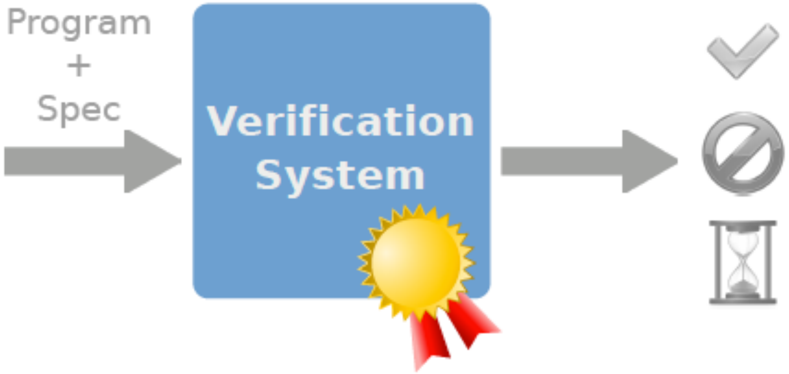
How to improve trust in **formal verification systems**?

$$a = b \vdash 2 = 1$$

Modern verification systems are large and complex systems

- Soundness bugs are not rare
- Such bugs are often hard to detect in a real proof

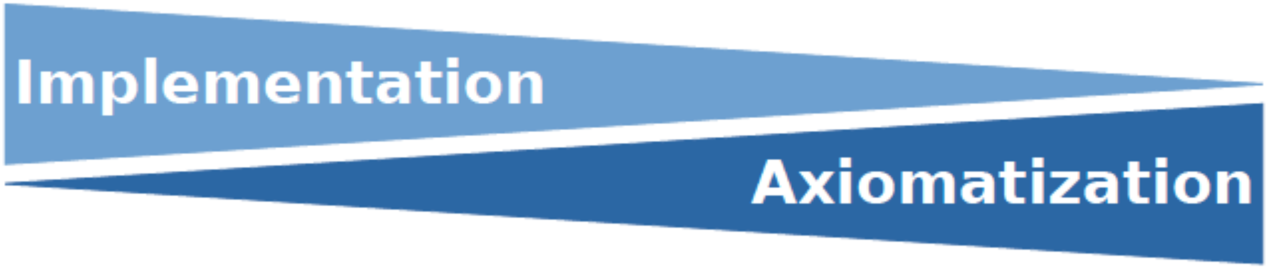
“Auto-active” Verification Systems



Validating verification systems by

- Formal methods
- Code inspection
- Testing
- …

Program Language Semantics



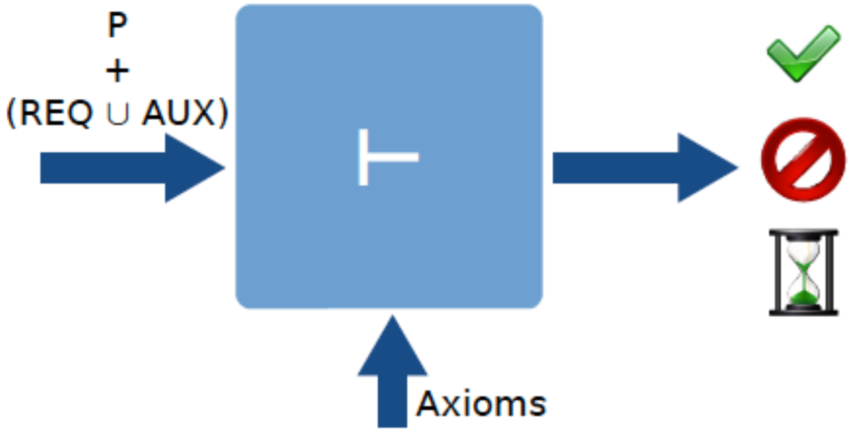
Static checkers Verifying compilers Logic frameworks

We have to test both!

But how to determine the quality of the test cases?*

*work started in 2008

Test Cases

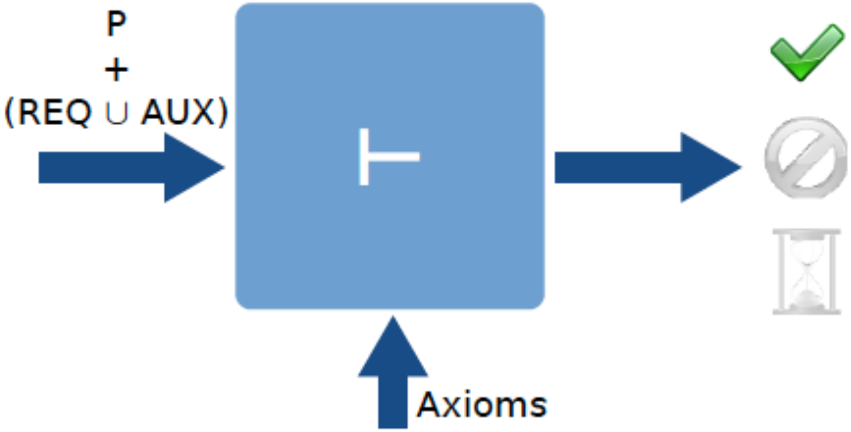


A test case is a program *P*, together with *REQuirements* and *AUXiliary specifications*.

Manually creating test cases is extremely time-consuming.

Computing coverage for the test cases takes from a few minutes to several hours.

Completeness Coverage

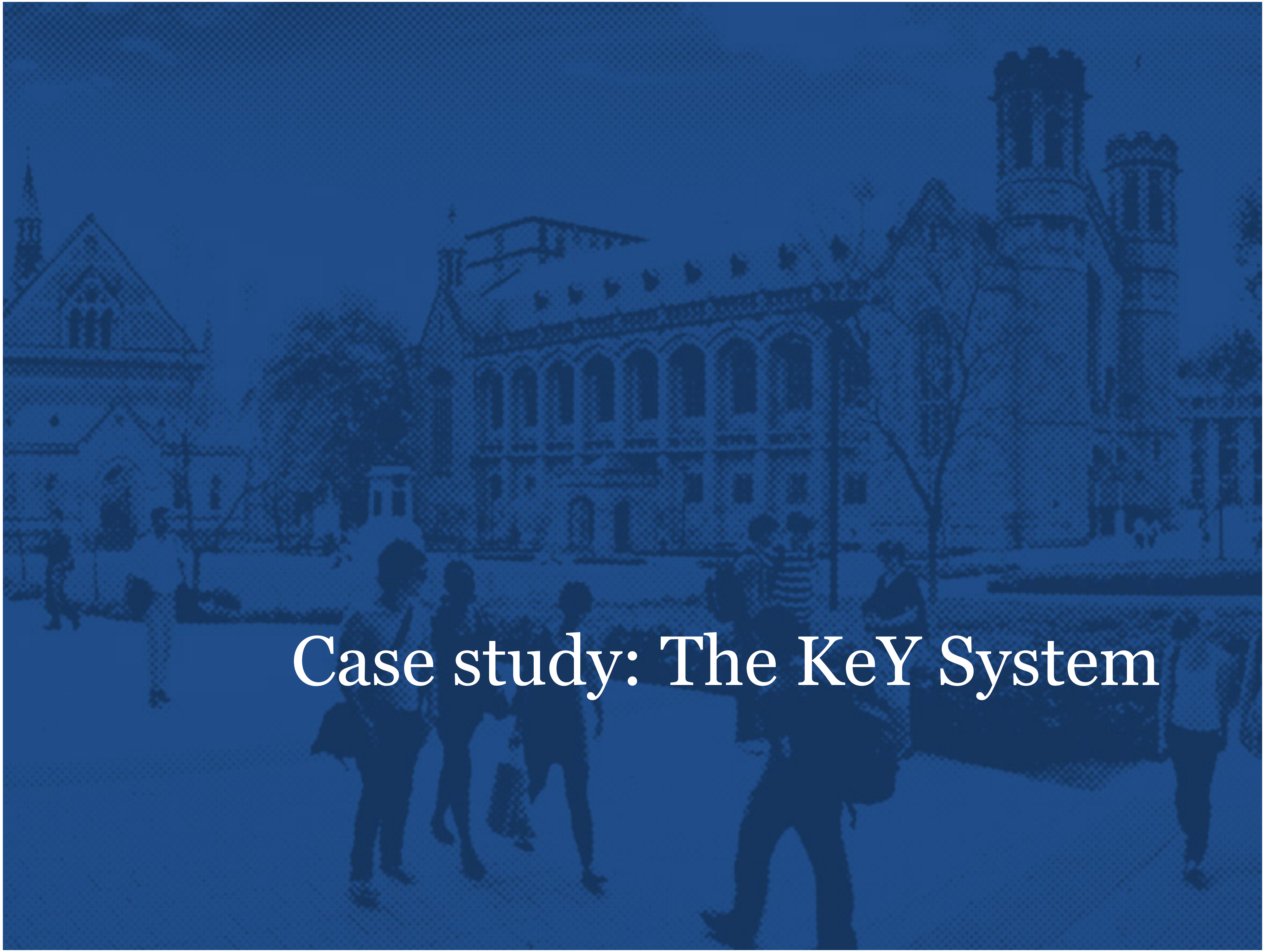


Definition (Completeness Coverage, TAP 2013)

A test case $P + (\, REQ \cup AUX\,)$ covers the set of *Axioms* if

- $Axioms \vdash P + (\, REQ \cup AUX\,)$
- and this does not hold for $Axioms' \subsetneq Axioms$

Note: covered set *Axioms* is not uniquely defined by the test case



Case study: The KeY System

The KeY System

Karlsruhe Institute of Technology
Technische Universität Darmstadt
Chalmers University of Technology

- Deductive verification system for JavaCard
- Sequent calculus for Java Dynamic Logic, uses symbolic execution for Java programs
- Interactive verification with automatic proof mode

Important

- The semantics of JavaCard is encoded in 1520 axioms (“small, well-understood set of sentences”)

Coverage Example: PostConditionTaclets2

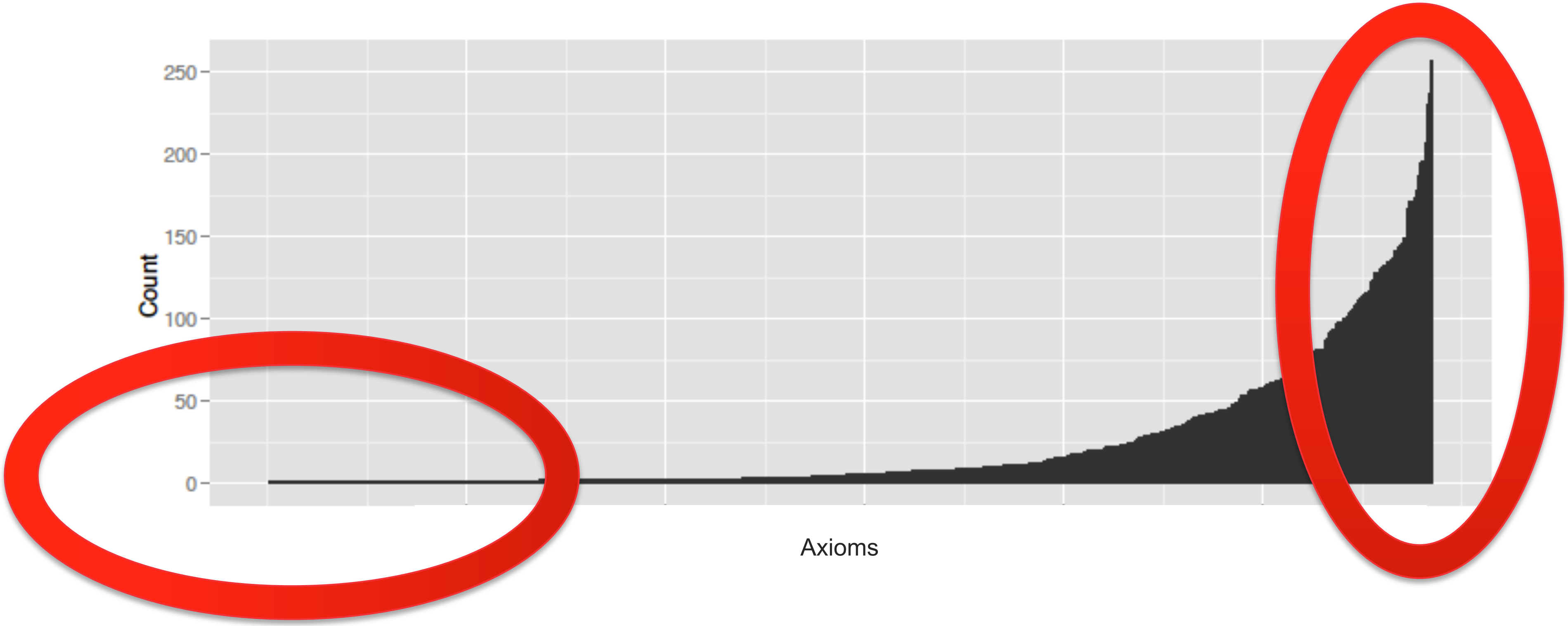
- Code Coverage (EMMA Tool)

Name	Class %	Method %	Line %
Coverage	86% (1.175 out of 1.361)	43% (7.369 out of 17.260)	35% (31.873 out of 92.139)

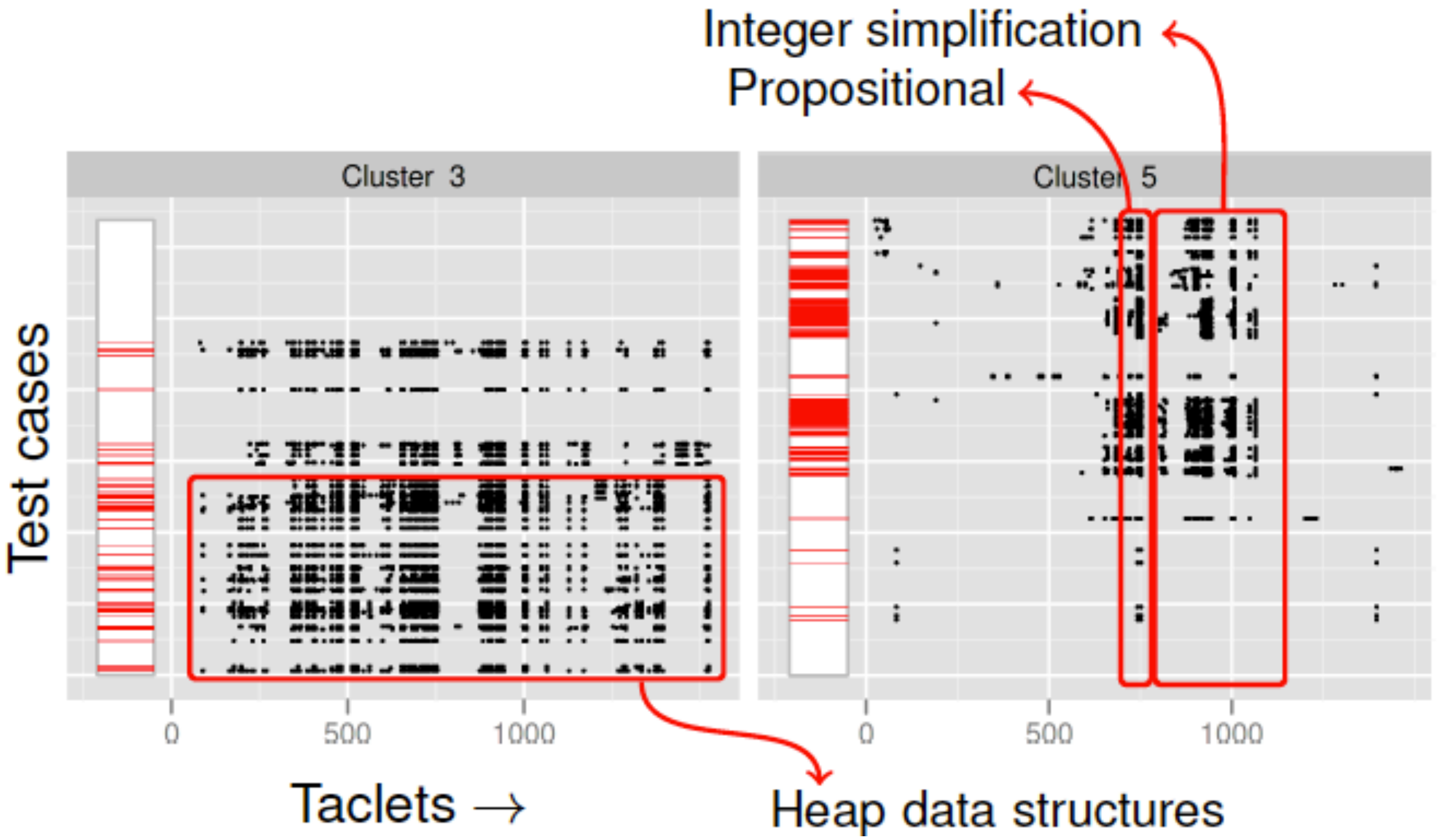
- Axiom Coverage: 0.32% (5 out of 1520)

Coverage Results (naïve, TAP 2013)

The 319 completeness tests of KeY covered 40% of all axioms (611 out of 1520).

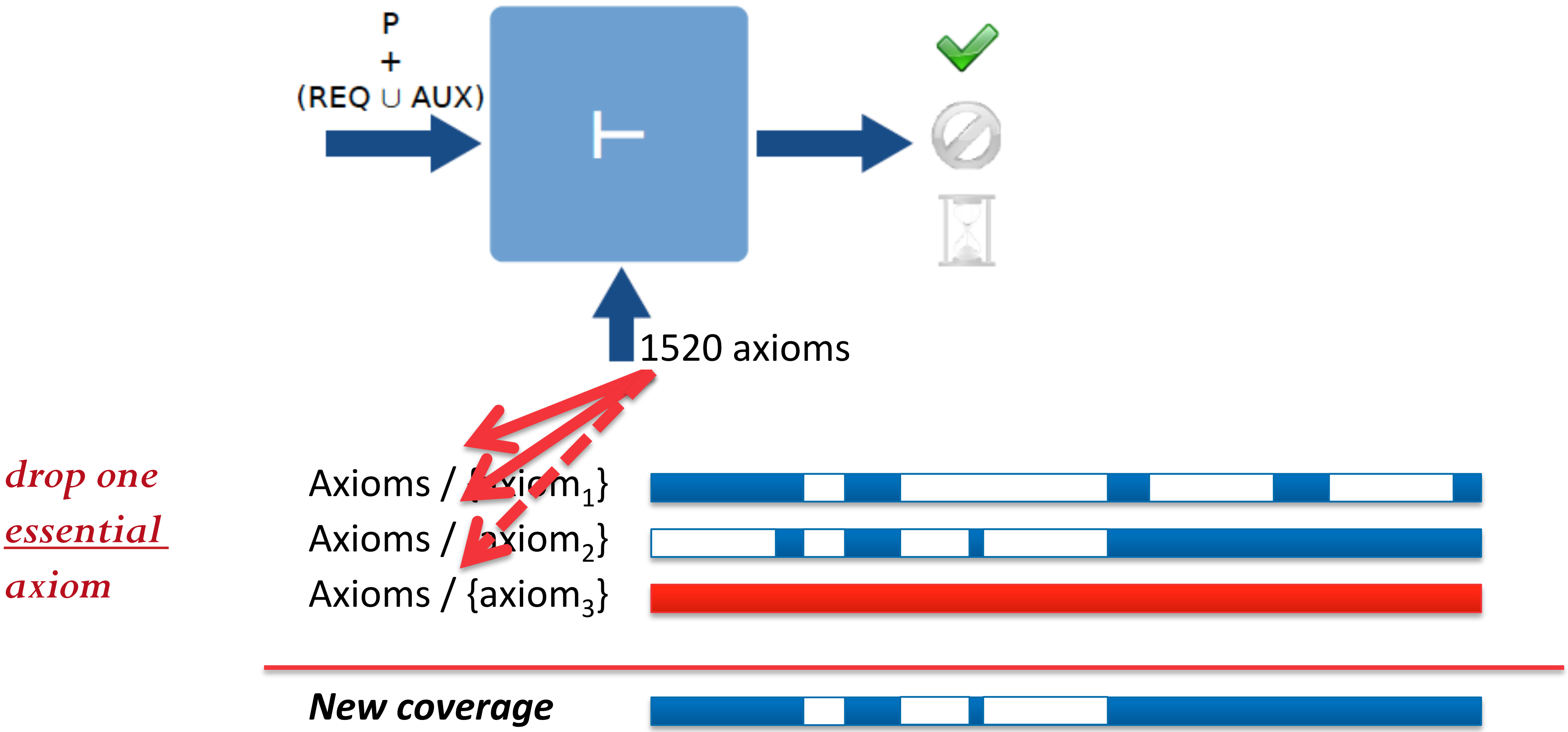


What is tested?



Heuristic Approaches

Reusing Test Cases



P + (REQ ∪ AUX)

$\vdash$

1520 axioms

drop one essential axiom

Axioms / {axiom$_1$}

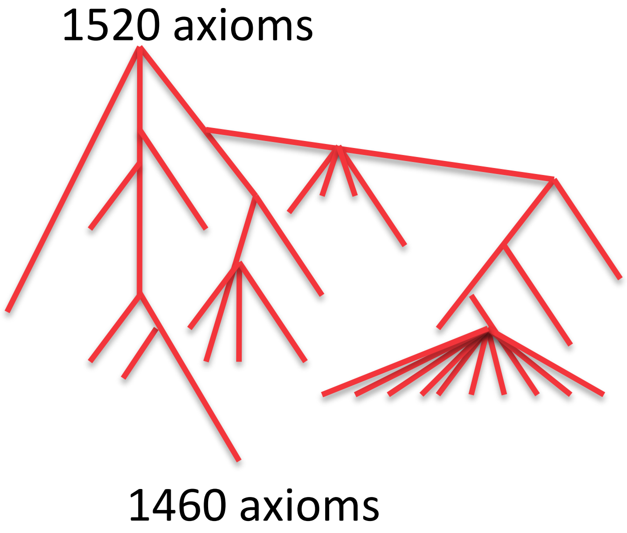
Axioms / {axiom$_2$}

Axioms / {axiom$_3$}

New coverage

Idea: given a test case *T*, run the tool with just a subset of the 1520 axioms.

Reusing Test Cases



Note:

- 24h per heuristic per test case

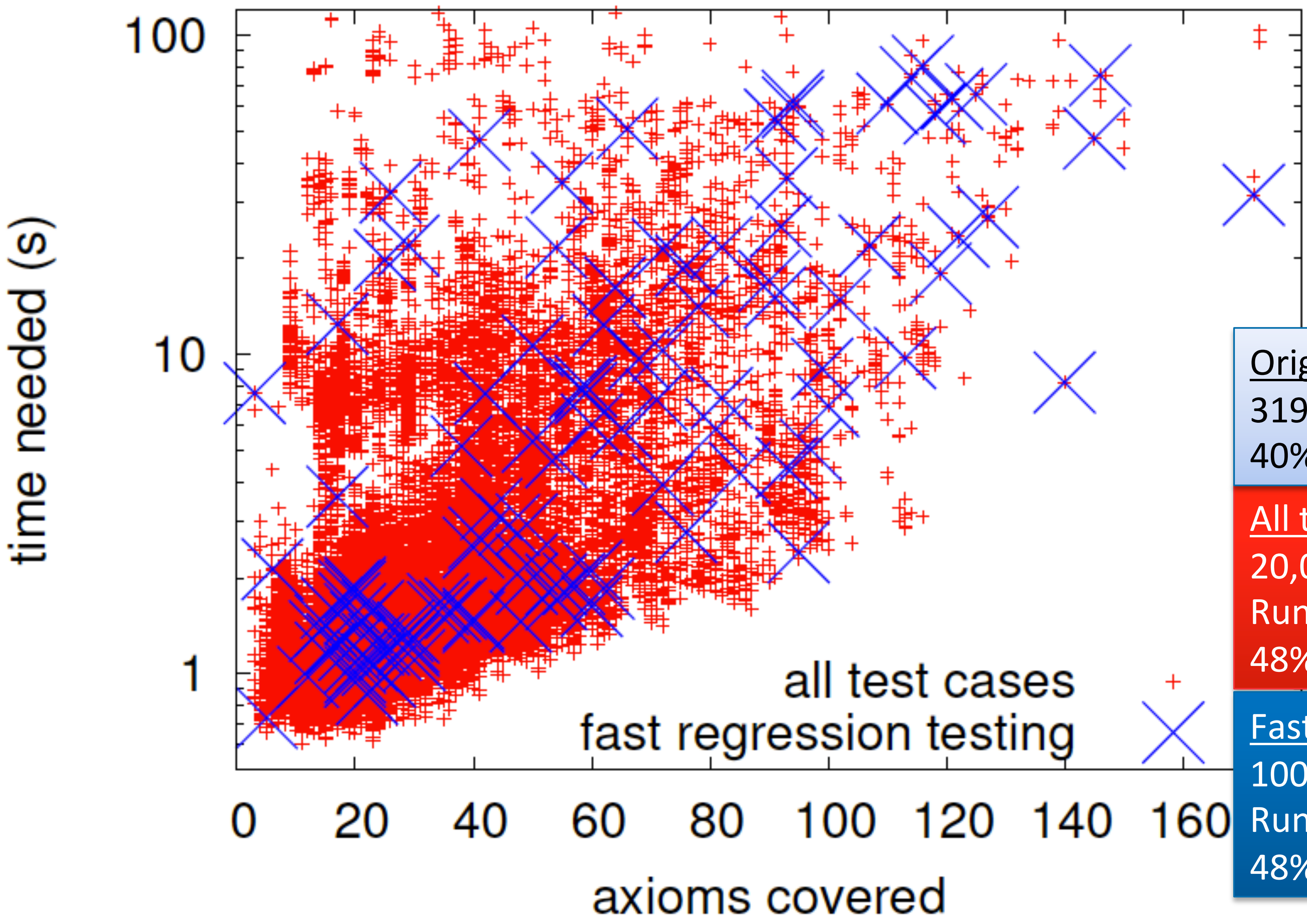
- Extremely fragile

Three simple heuristics to pick the "next axiom to drop":

[0.	Base case]	611 (40%)	
1.	Depth-first	701 (46%)	Naïve and good results
2.	Depth-first, ra	699 (46%)	More diverse sets
3.	Greedy (try to	688 (45%)	Often unsuccessful
4.	Breadth-first	687 (45%)	
5.	Breadth-first, random selection	684 (45%)	

→ Complimentary by design, verified by experiments.

Maximising Coverage & Minimising Time

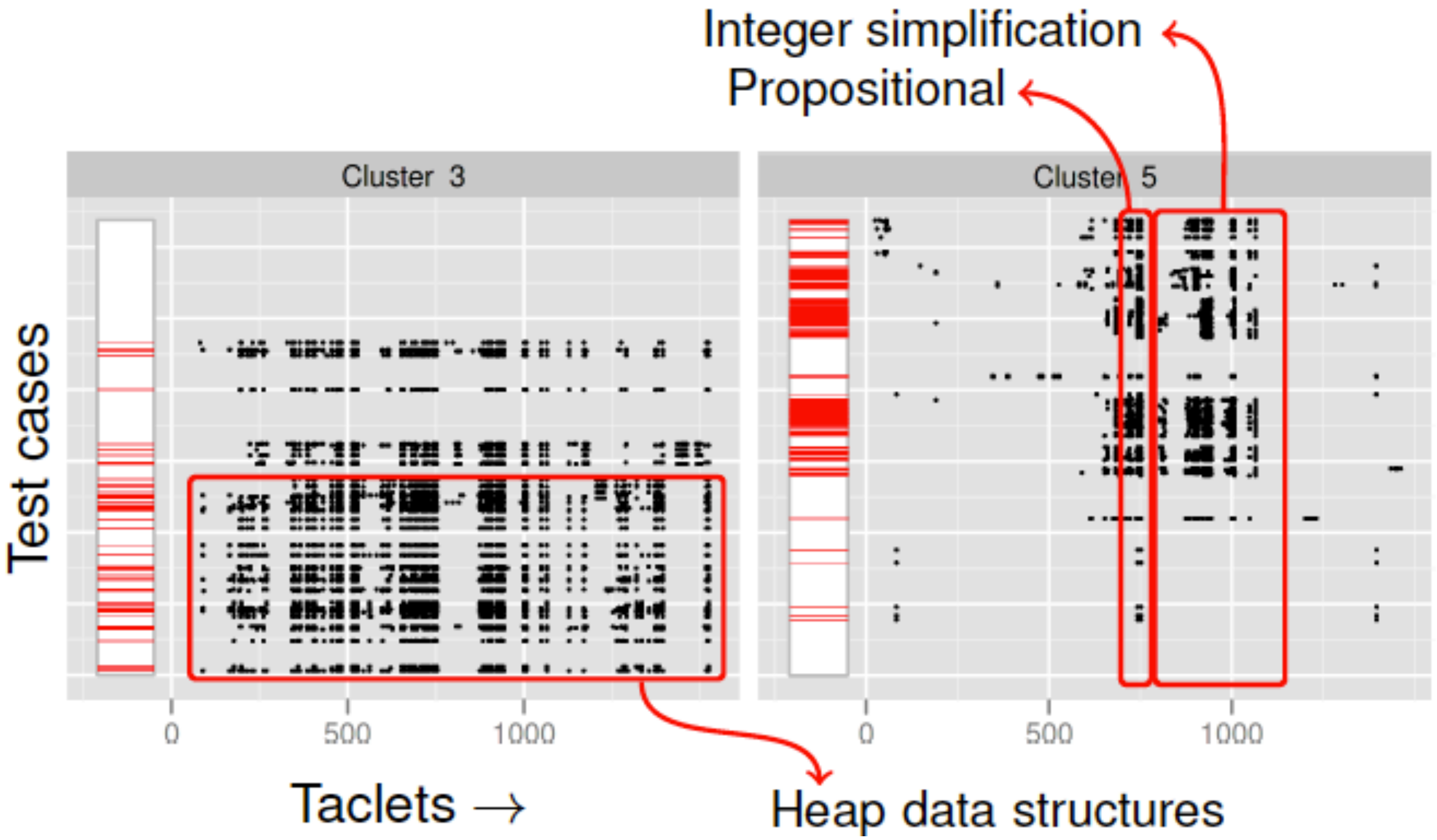


<u>Originally</u>
319 test cases
40% coverage

<u>All test cases</u>
20,000 test cases
Runtime: days
48% coverage

<u>Fast Regr. Testing</u>
100 test cases
Runtime: 1 h
48% coverage

What have we learned?



→ Problem understanding!

Take away

- We discovered that
  - Some KeY features are tested several times
  - Many KeY features are not tested (or are they unnecessary?)

- We hope
  - to discover bugs in the axiomatisation
  - to achieve 100% coverage (specialised test cases needed)

→ Comprehensive testing is necessary to achieve certain certifications.