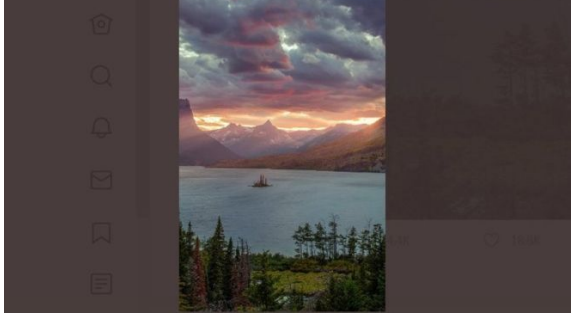
Lightweight Verification via Specialized Typecheckers

Martin Kellogg
University of Washington

Bugs in software



Hours	Seconds	Calculation Time (seconds)	Inaccuracy (seconds)	Approximate Shift in range gate (meters)
0	0	0	0	0
1	3600	3599.9966	.0034	7
8	28800	28799.9725	.0275	55
20^1	72000	71999.9313	.0687	137
48	172800	172799.8352	.1648	330
72	259200	259199.7528	.2472	494
100^2	360000	359999.6567	.3433	687

EQUIFAX

etc.

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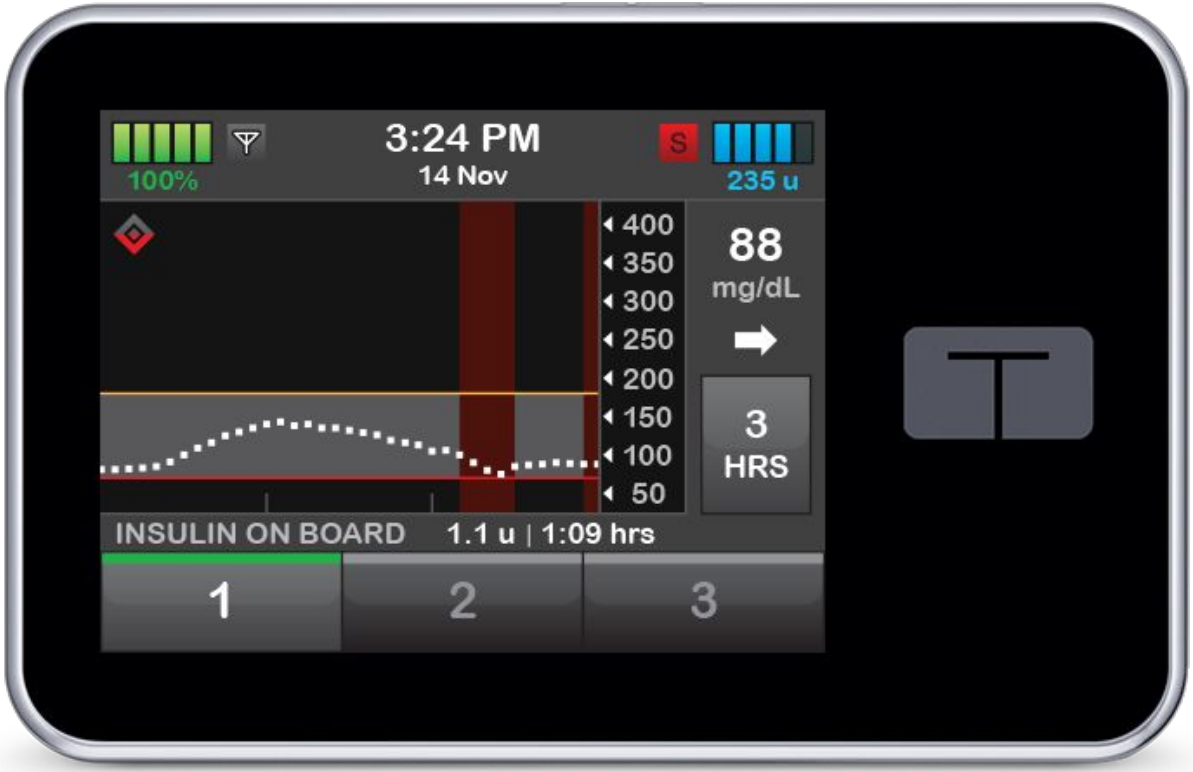
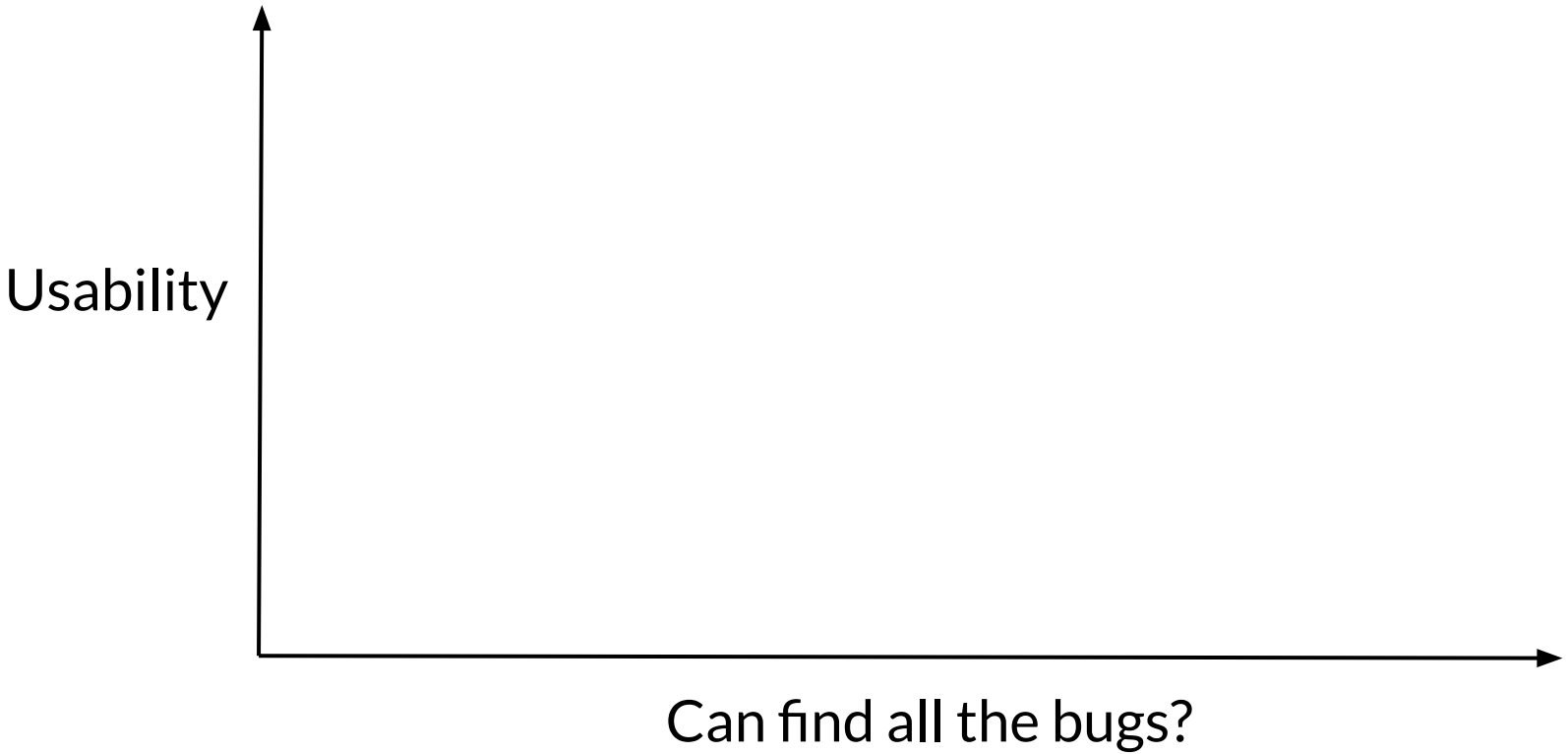


Goal: every developer uses verification

Preventing bugs: a gross oversimplification



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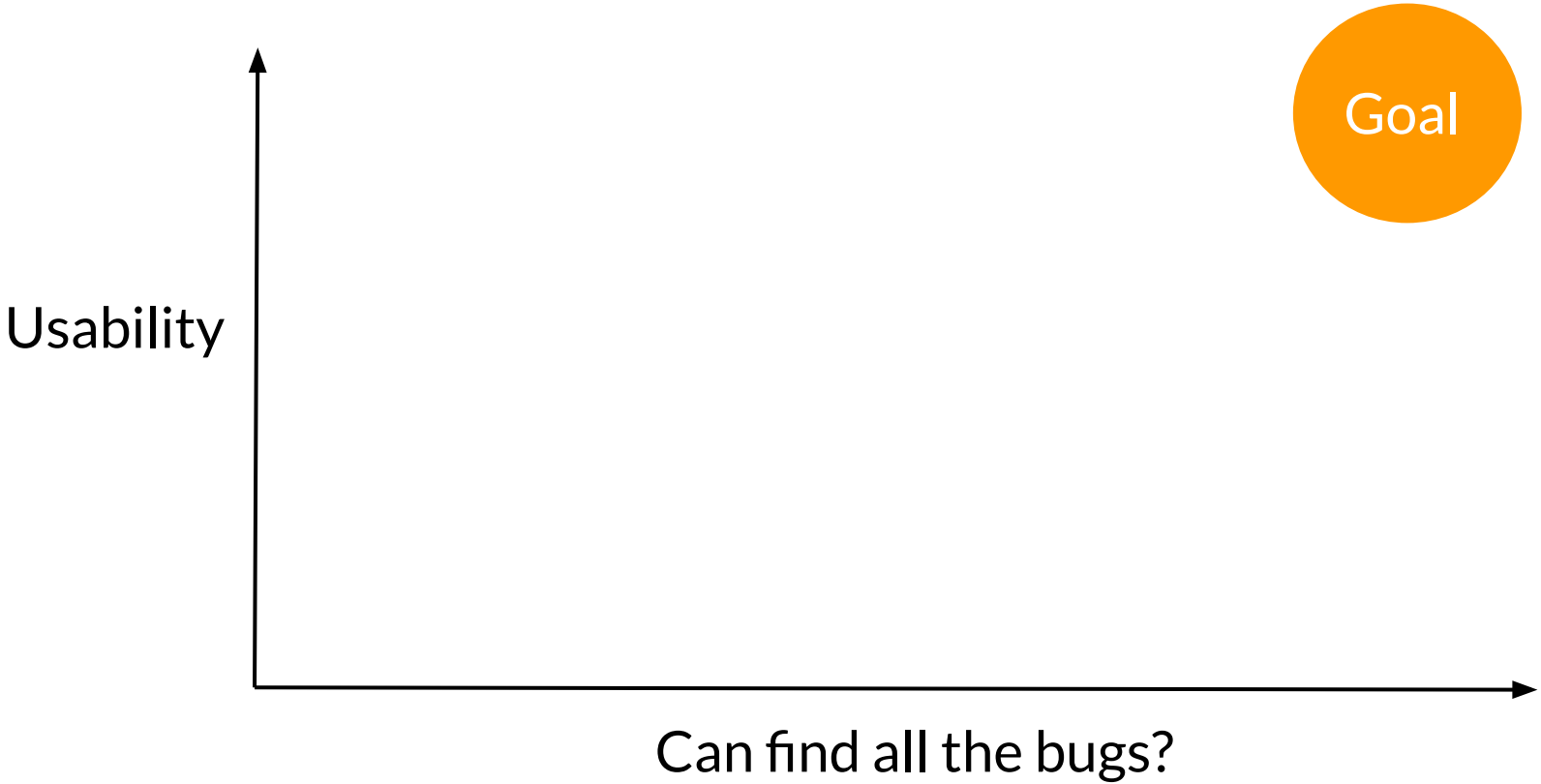

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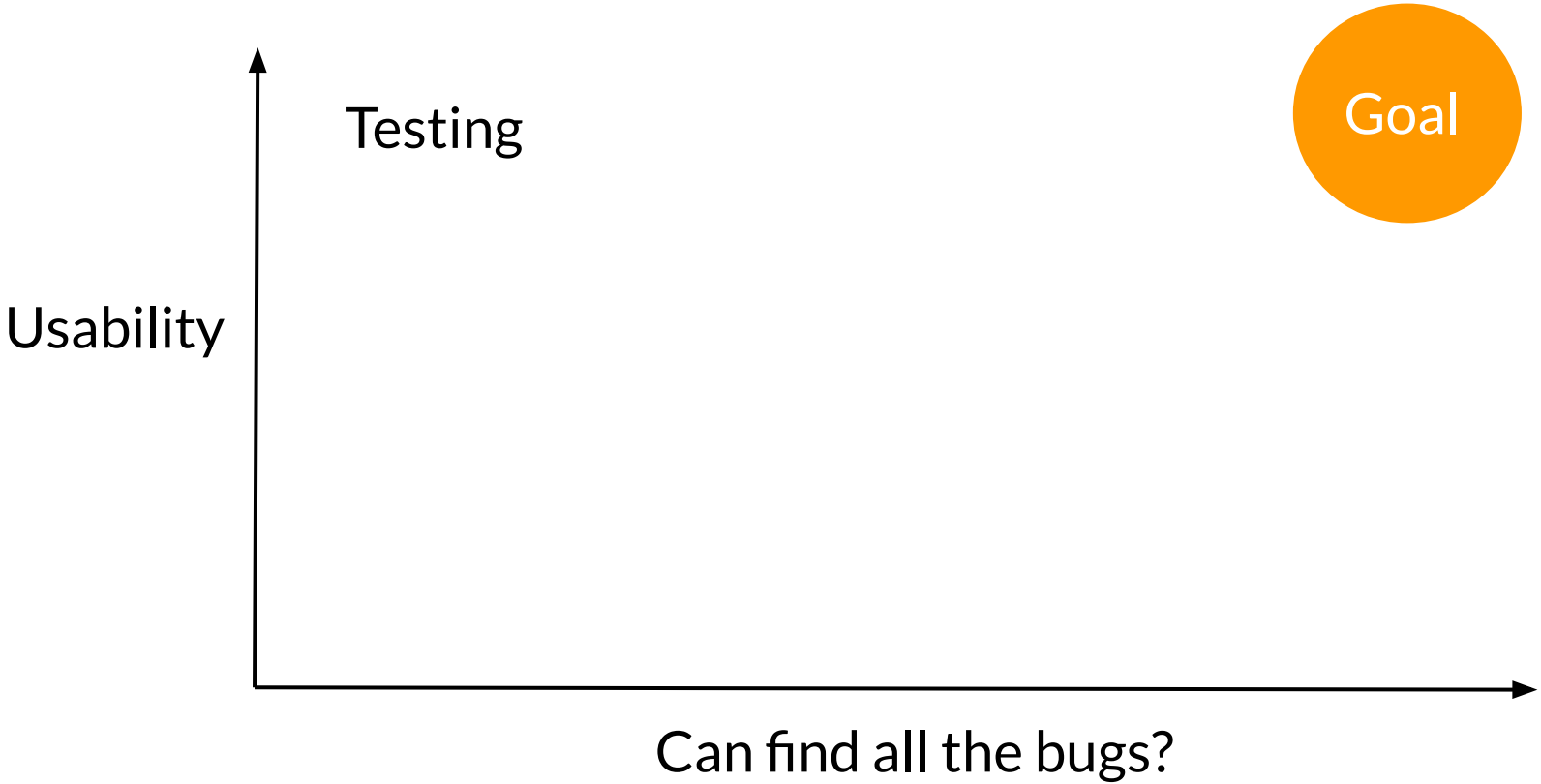

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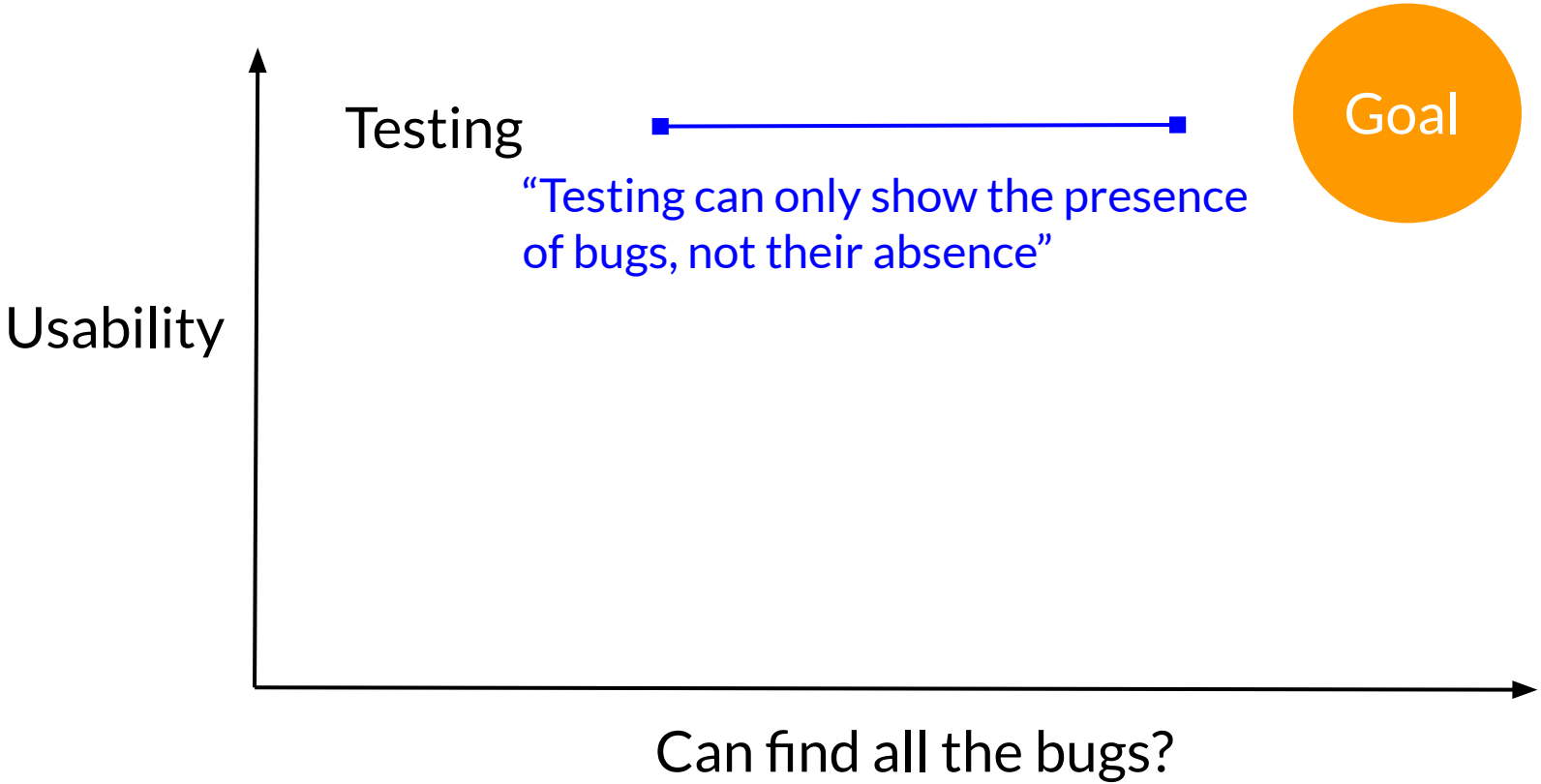

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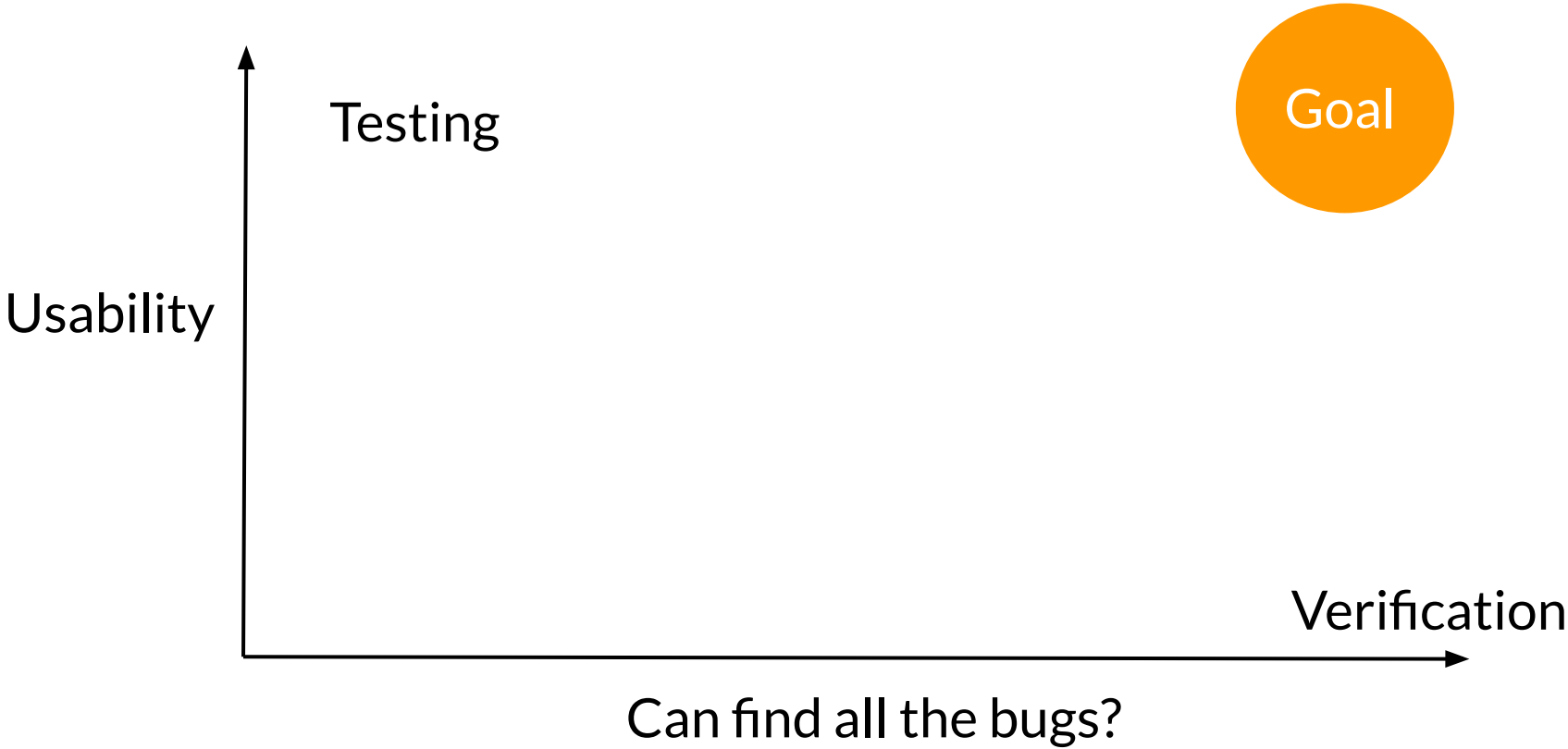

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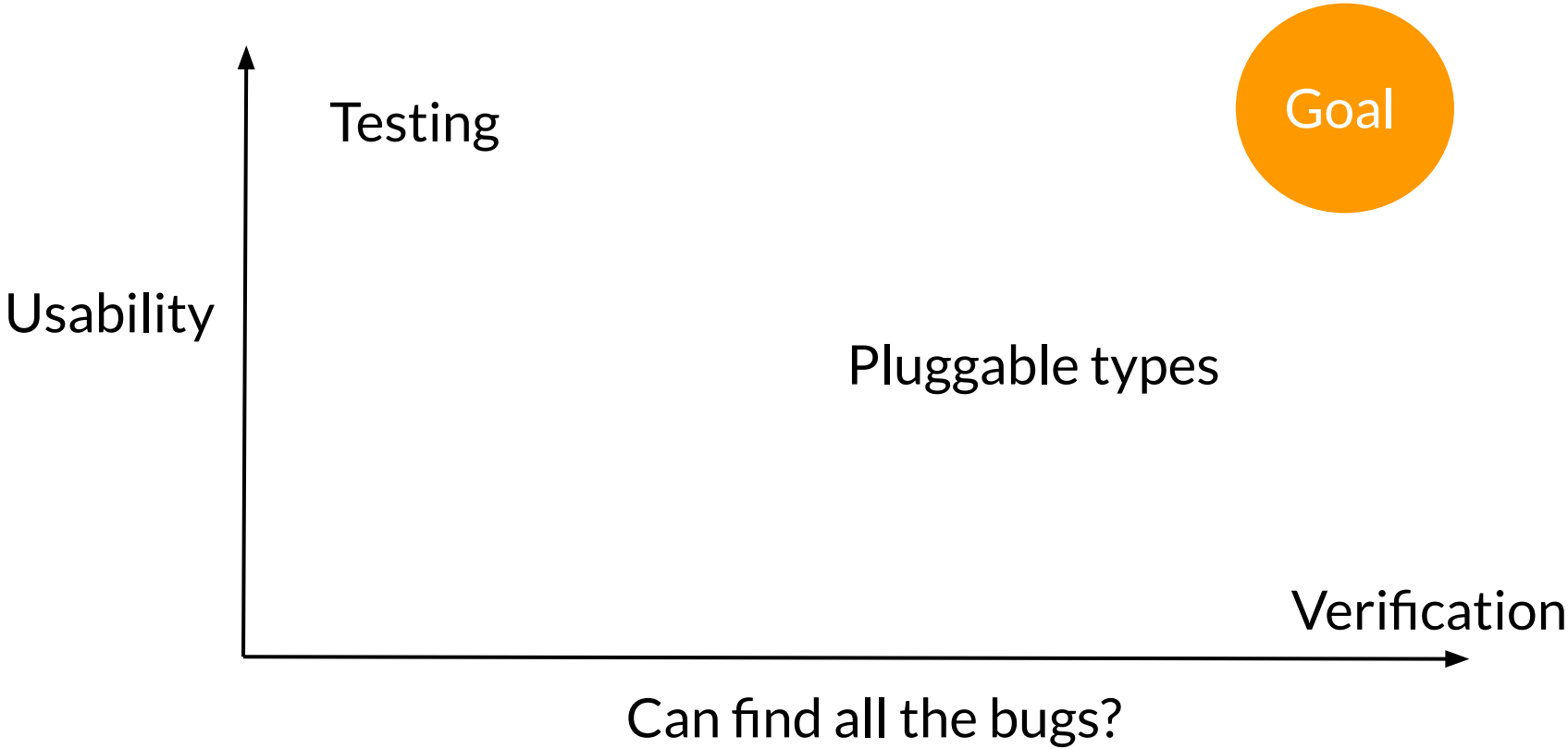

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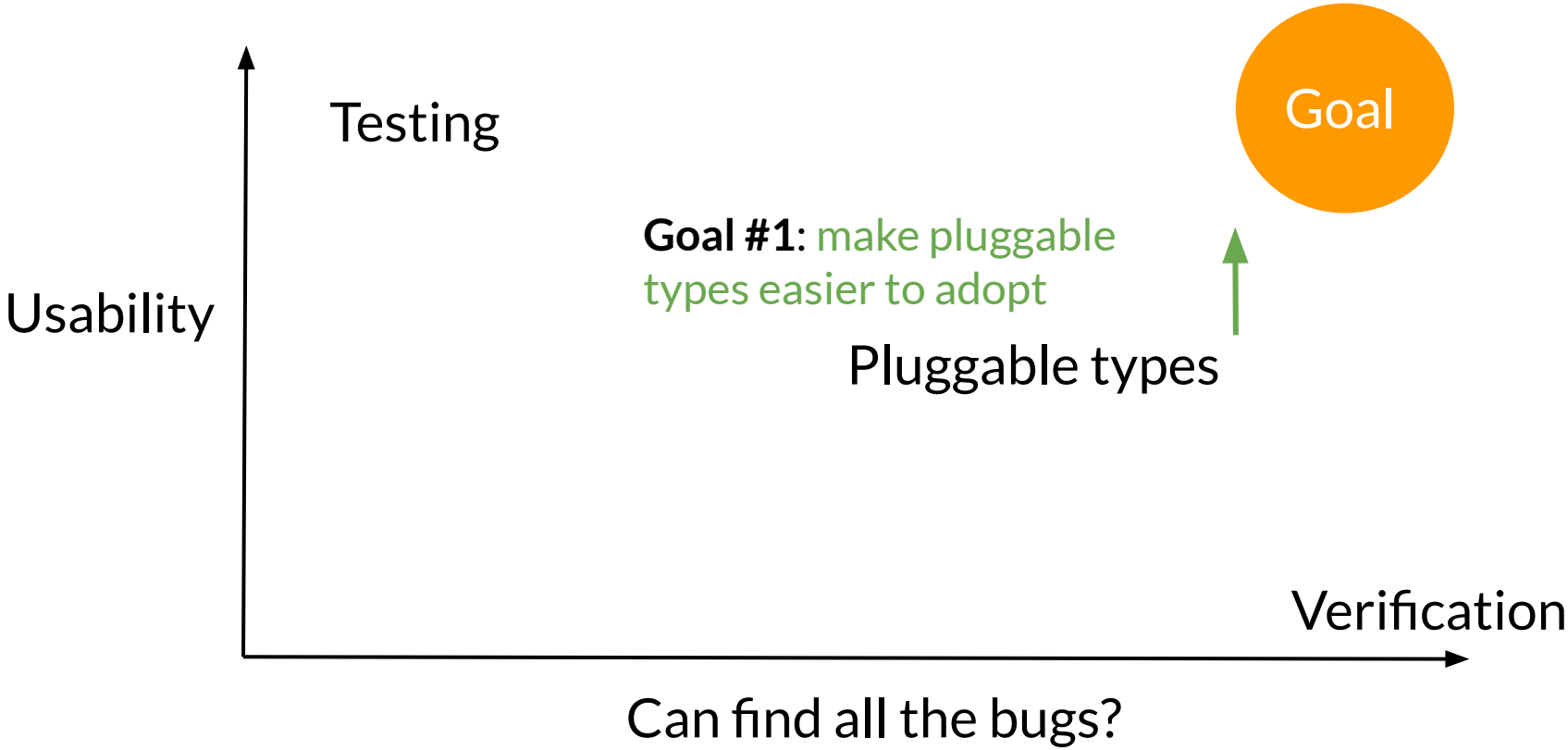

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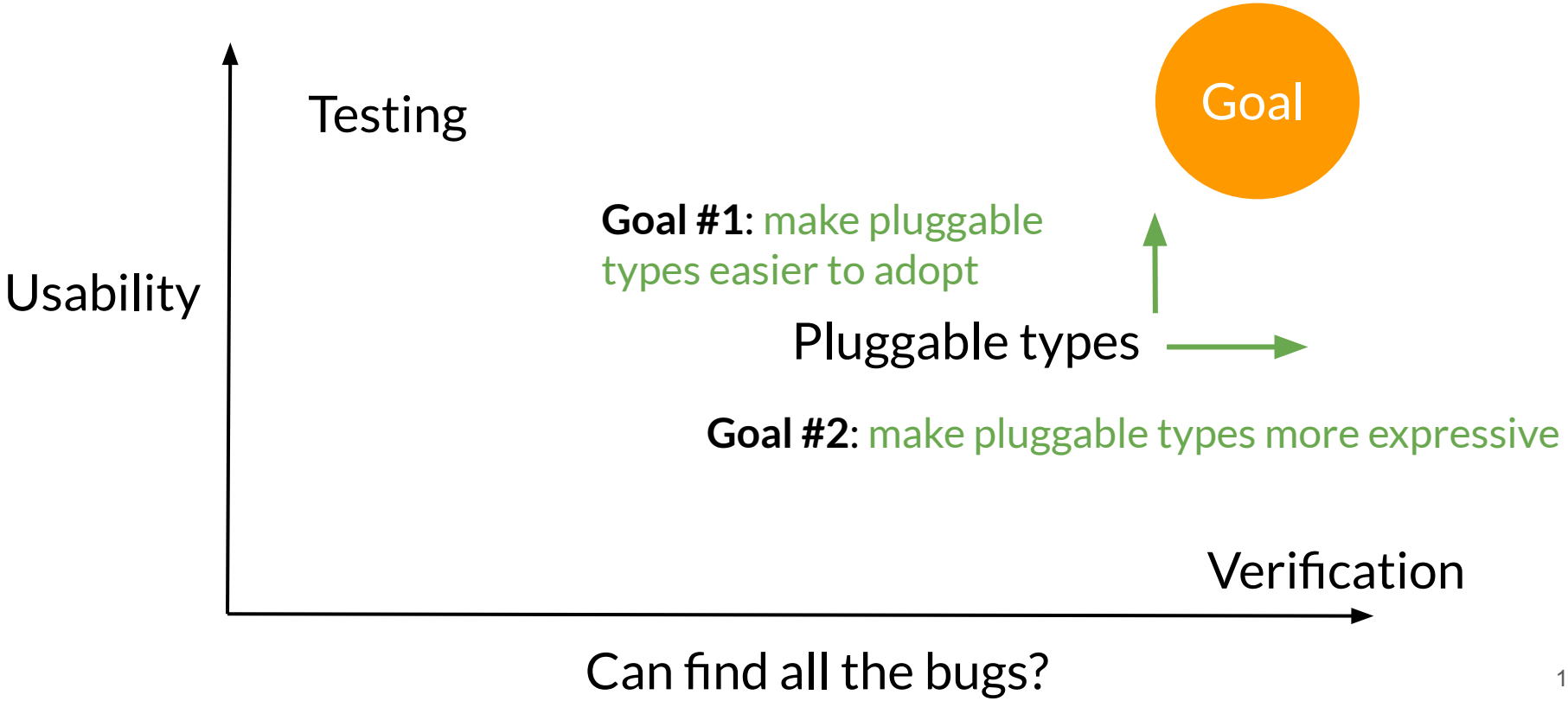

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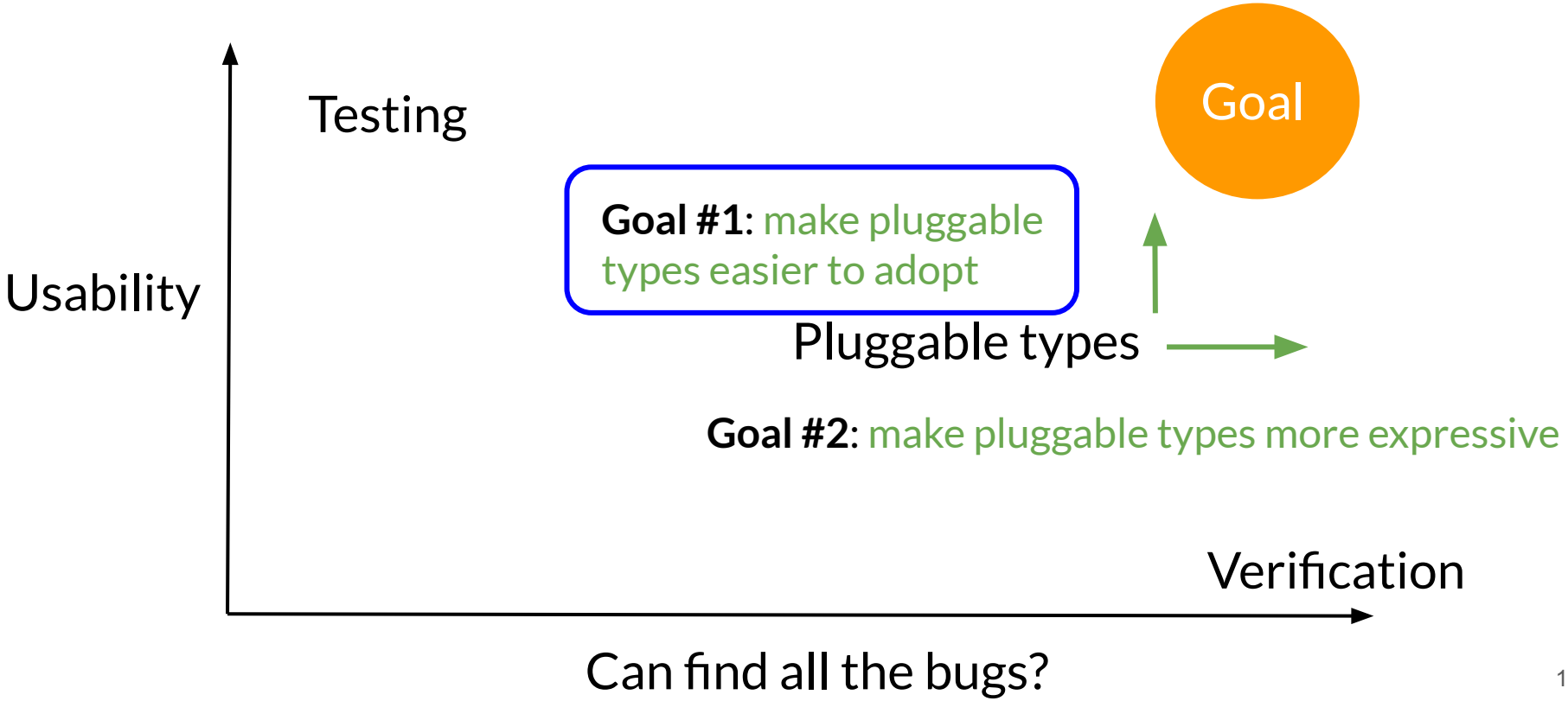

A new domain: compliance

- Certificates that a company follows a ruleset
  - PCI DSS for credit card transactions
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Kellogg, Schaef, Tasiran, Ernst. *Continuous Compliance*. ASE 2020.

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Developers hate doing this work

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Developers love this, because it saves work

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Specialized compliance checkers, industry

Run on 76M NCNB LoC

Verified	37,315 pkgs
True pos.	173 pkgs
False pos.	1 pkg

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Specialized compliance checkers, industry

Only 23 annotations

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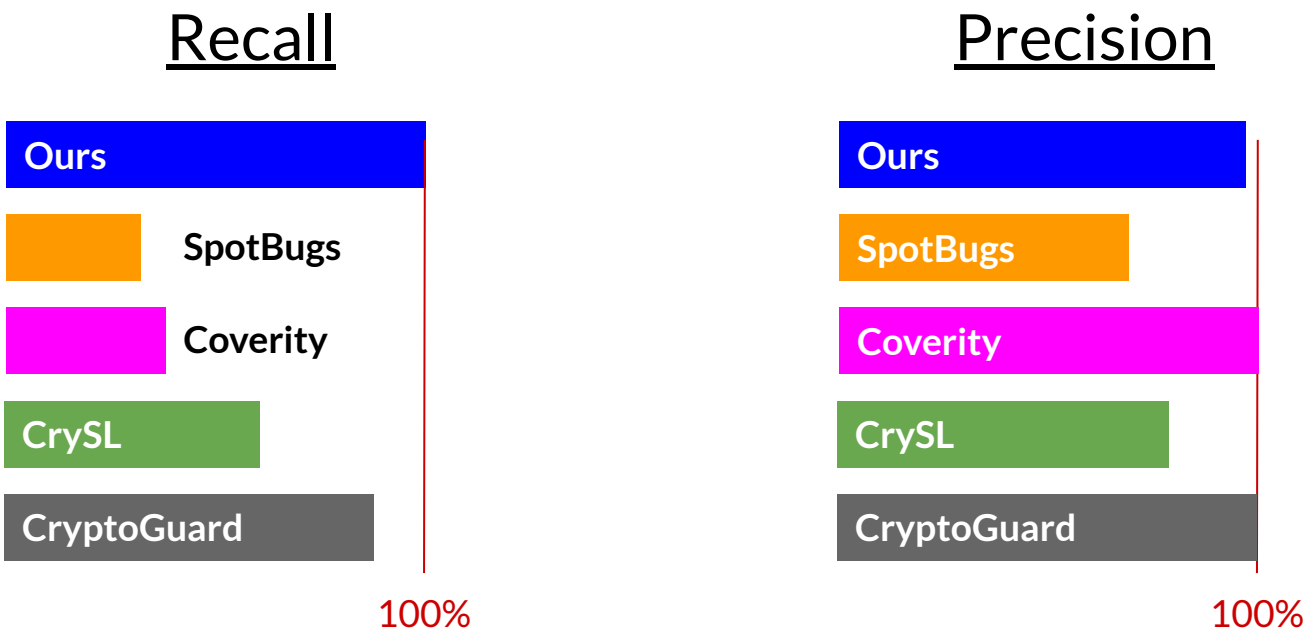
- Auditors accepted output of typecheckers as evidence during a **real audit**
- Checkers **integrated** into build process

Types vs. other approaches



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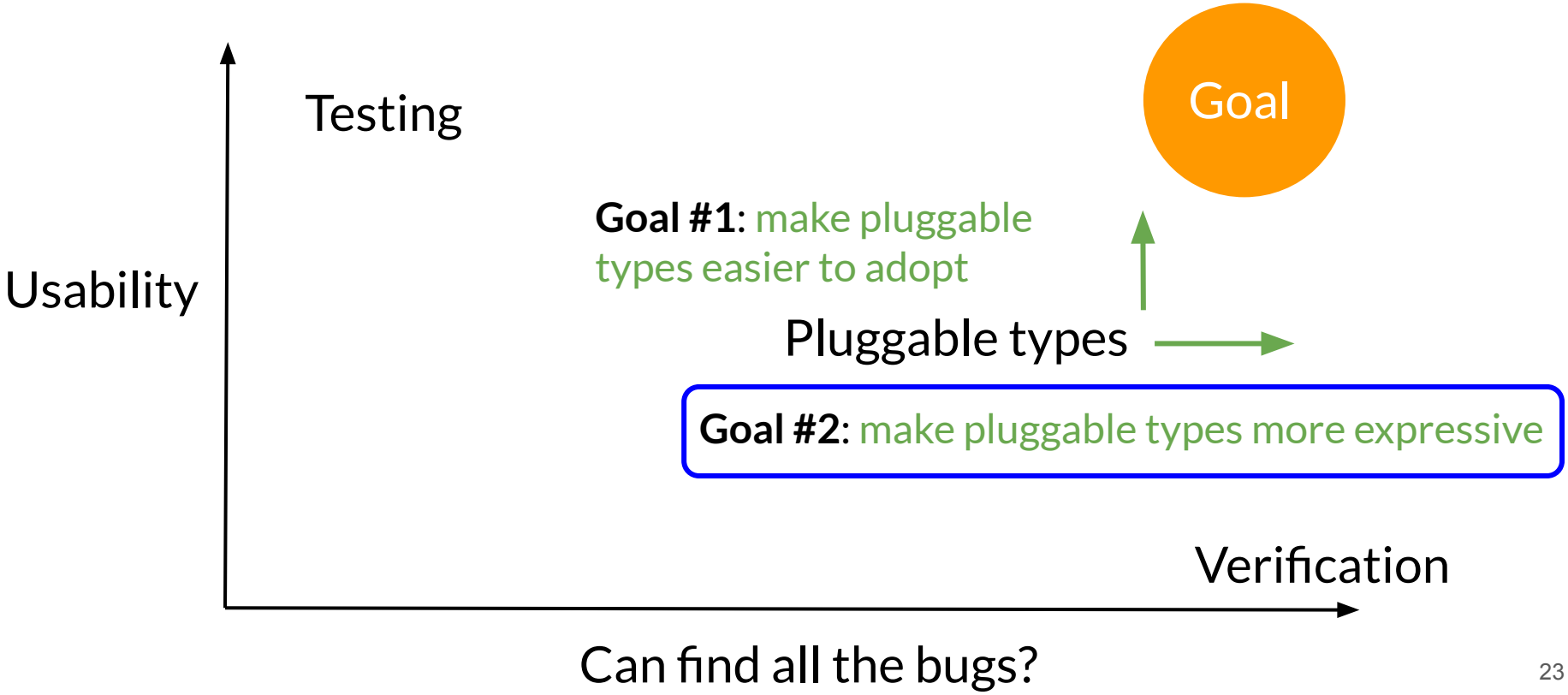

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```
T[] a = …;

int i = …;

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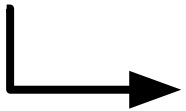
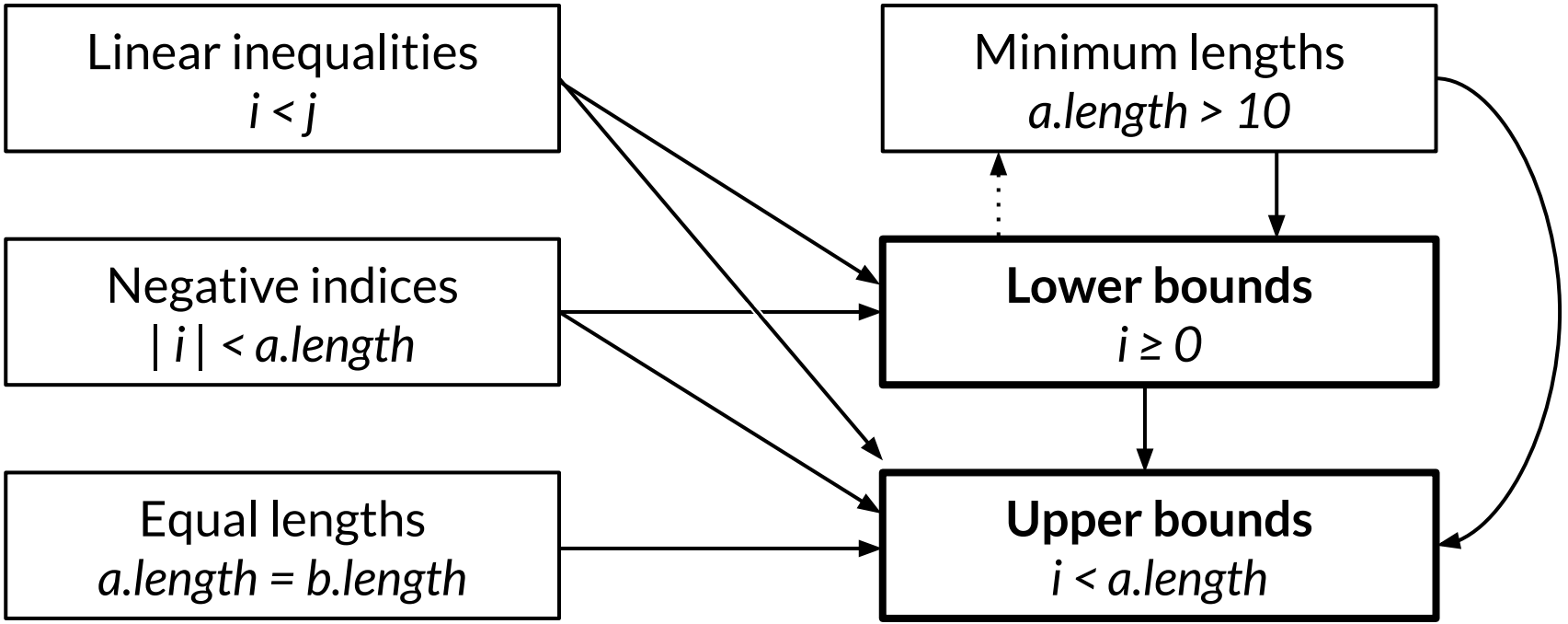


build many analyses instead of just one

Cooperating specialized checkers: array indexing



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Summary of results

- Found bugs in industrial codebases (Google Guava)

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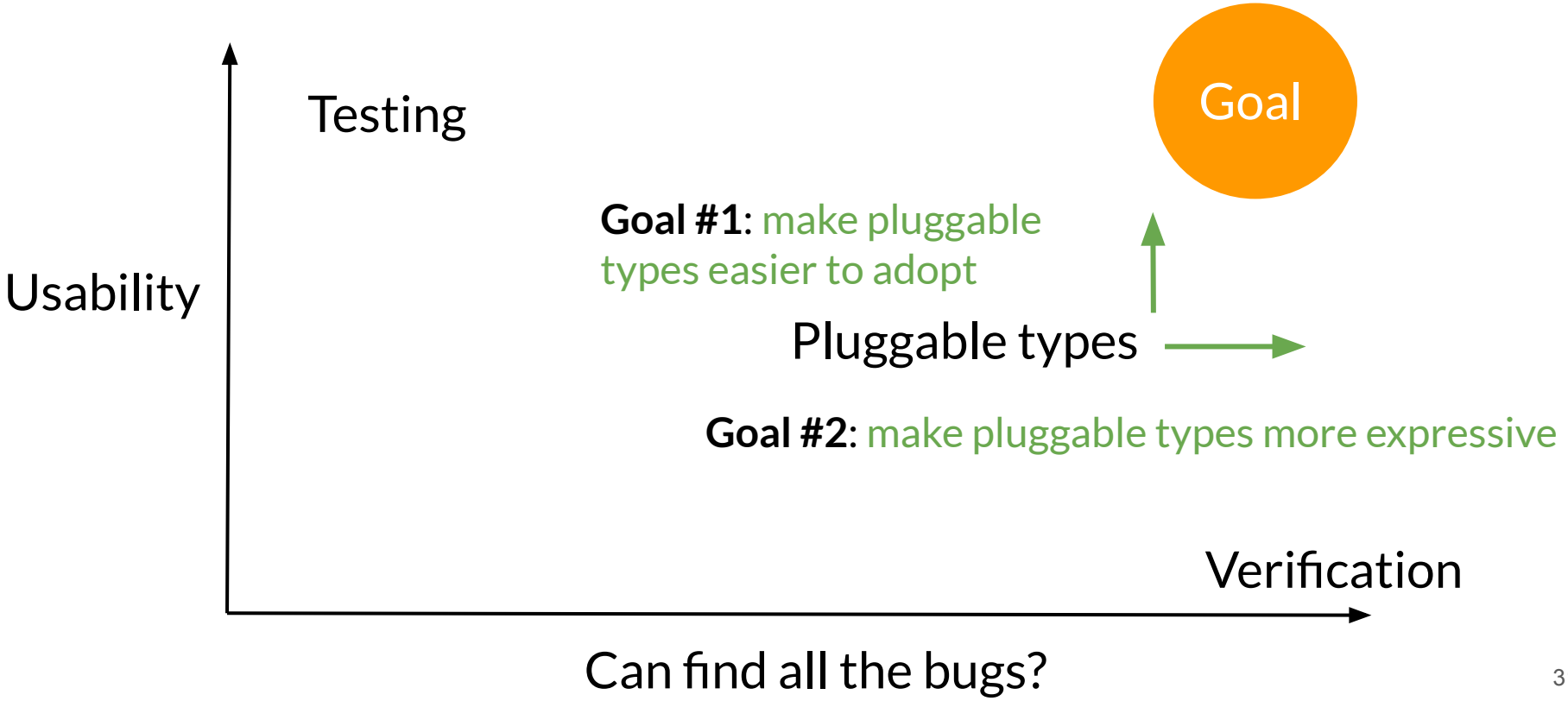
- vs prior verification approaches (KeY, Clousot):
  - **more sound** in microbenchmarks
  - **equally precise** on large codebases
  - **more scalable** - 10 min vs 3 hrs to check 100k LoC

Preventing bugs: a gross oversimplification



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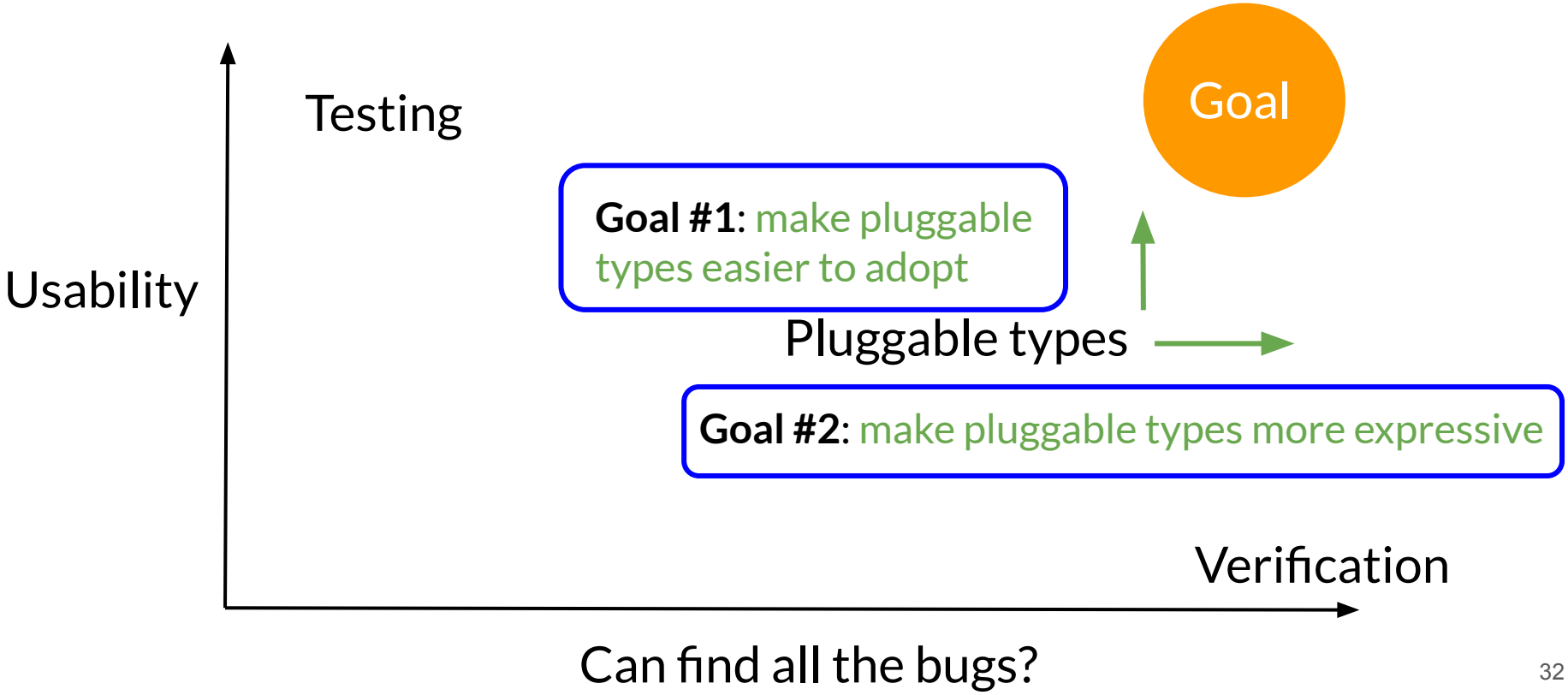
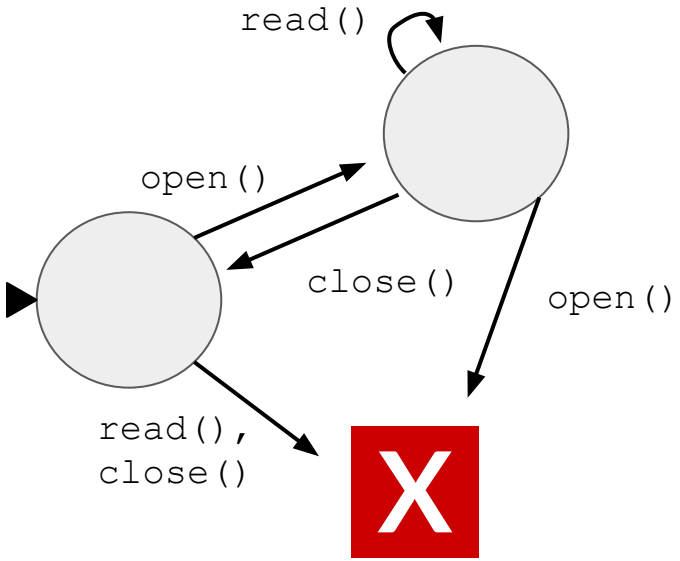


Typestate analysis




```
File f = …;
f.open();
File f2 = f;
f.close();
f2.read();
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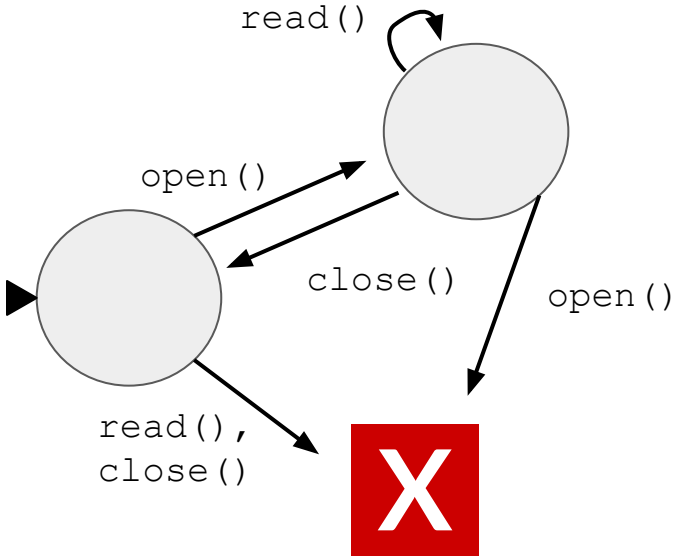
Typestate analysis

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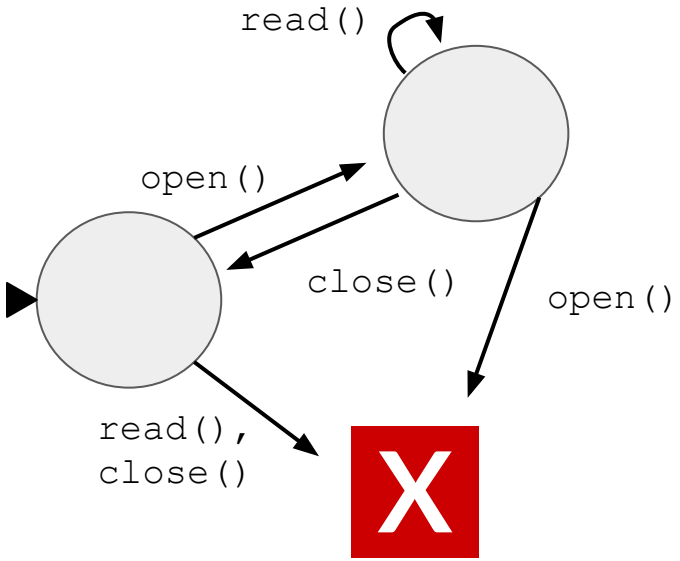


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Aliasing!

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The builder pattern

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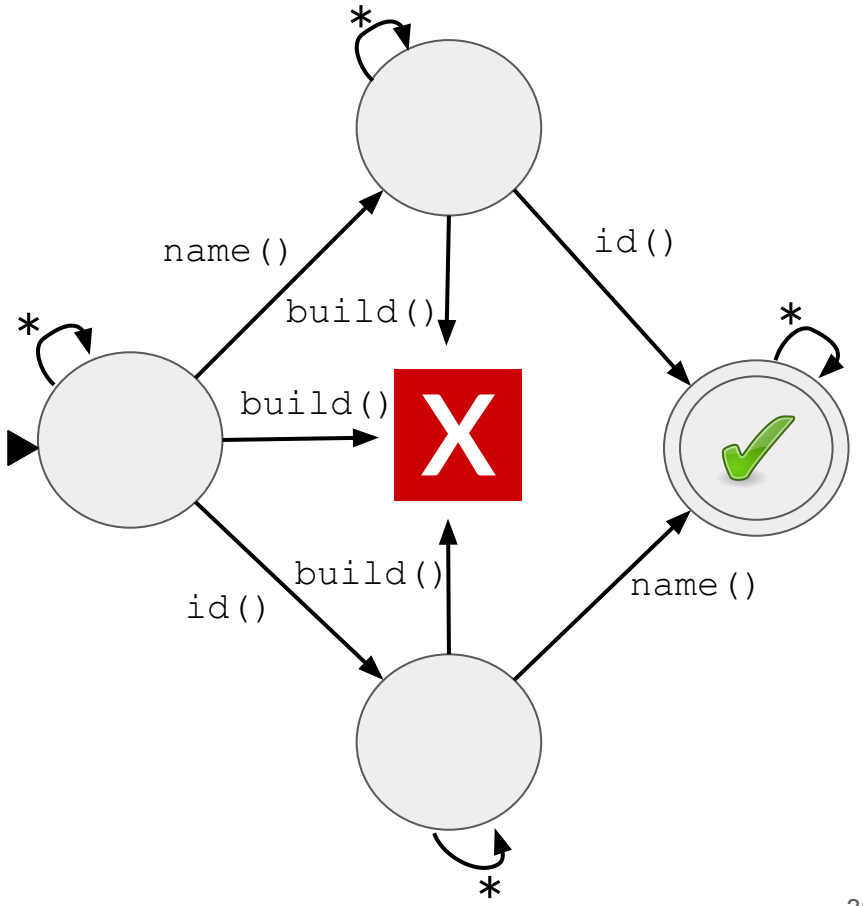

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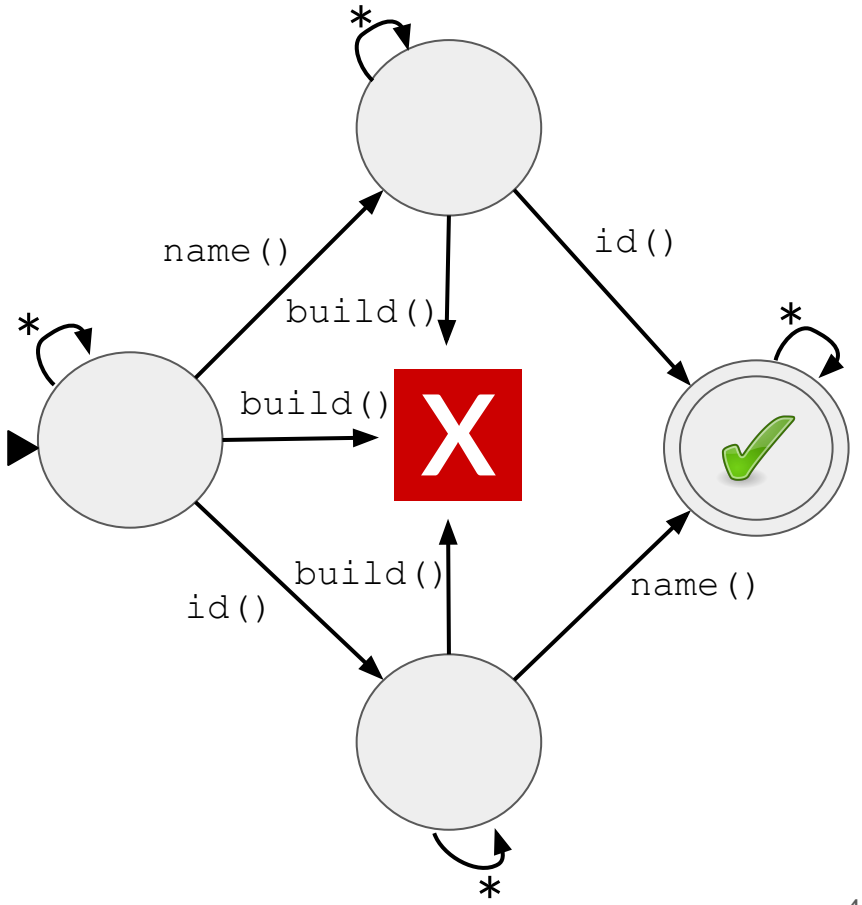
The builder pattern

Key insight:
No loops in this FSM!
(except self loops)



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The builder pattern

“accumulation analysis”

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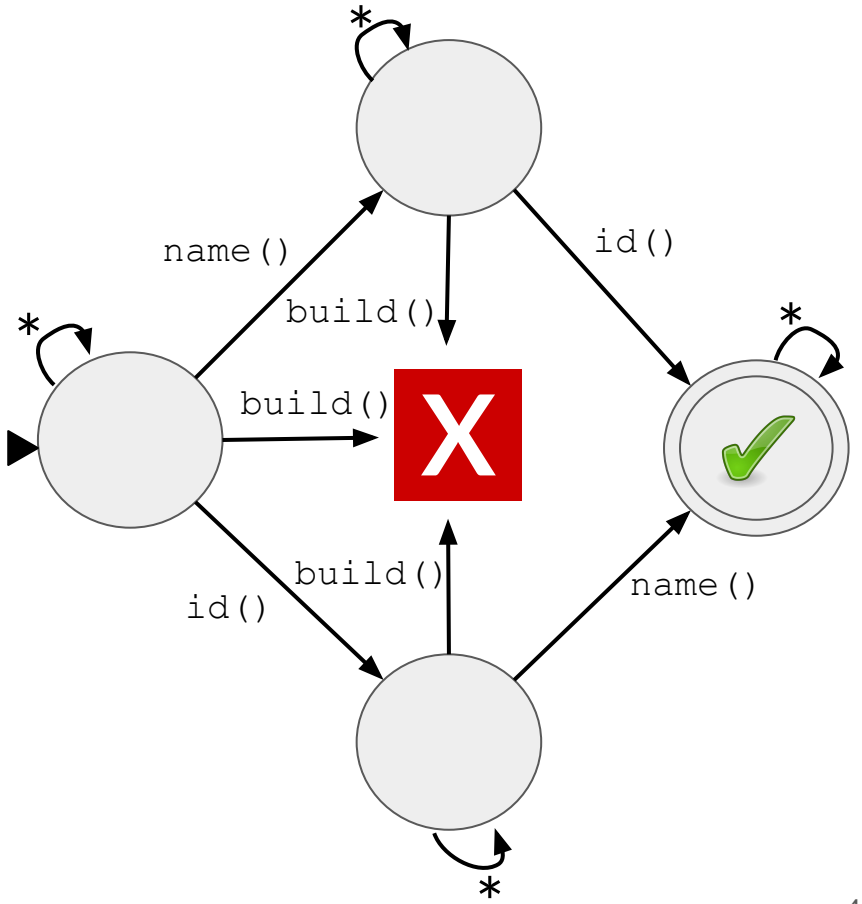

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Accumulation analysis

*A typestate analysis whose state representation is a **monotonically-increasing set**.*

Kellogg, Ran, Sridharan, Schaef, Ernst. *Verifying Object Construction*. ICSE 2020.

Accumulation analysis

*A typestate analysis whose state representation is a **monotonically-increasing set**.*

Advantages:

- Does **not** require alias analysis for soundness
- **Modular**

User study

Task: add a new required field to a builder

Results:

- +50% **success rate**
- ~50% **faster**

Accumulation for resource leaks

```
try {
    Socket s = new Socket(address, port);
    ...
    s.close();
} catch (IOException e) {

}
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Accumulation for resource leaks

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try {
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Missing call to close()

Accumulation for resource leaks

3 stage checker:

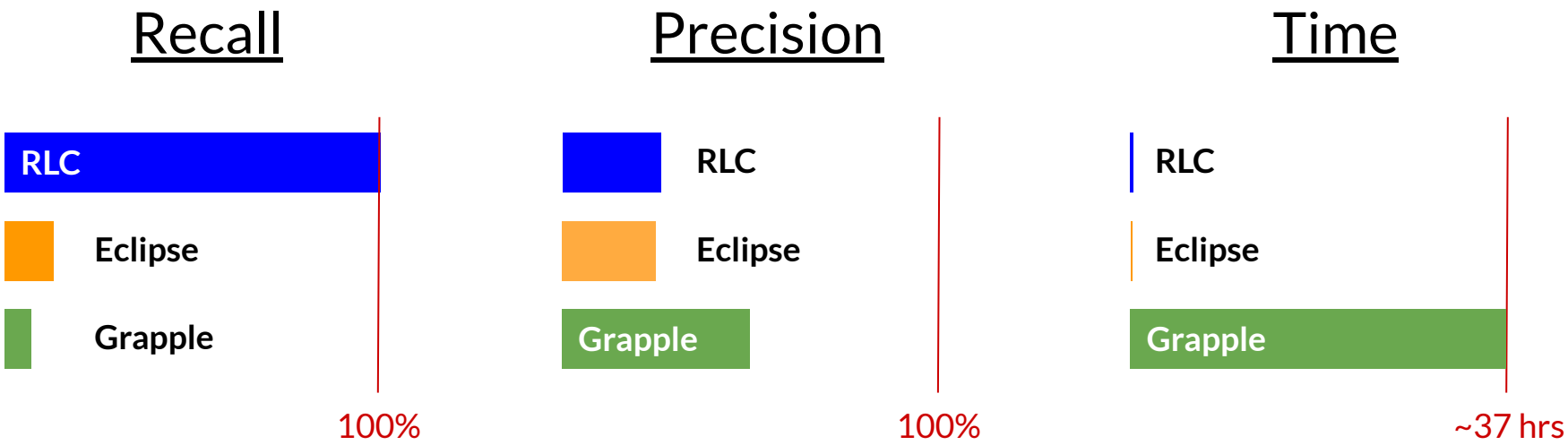
1. taint-tracker over-approximates methods that **need to be called**
2. accumulation under-approximates methods that **have been called**
3. dataflow analysis **compares** the two at “going out-of-scope” points

Accumulation for resource leaks: results

For full results, come to our talk on 26 August, 4pm Athens time ;)

Kellogg, Shadab, Sridharan, Ernst. *Lightweight and Modular Resource Leak Verification*. ESEC/FSE 2021.

Accumulation for resource leaks: results



Accumulation: future plans

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Big question: How much of typestate is accumulation?

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What we know for sure is accumulation:

- **builders**
- **resource leaks**

How much of typestate is accumulation?

Plan #1: survey the literature

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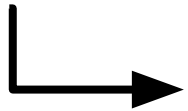

5/8 can be expressed as accumulation

60% of specifications they found in the wild!

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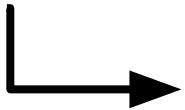
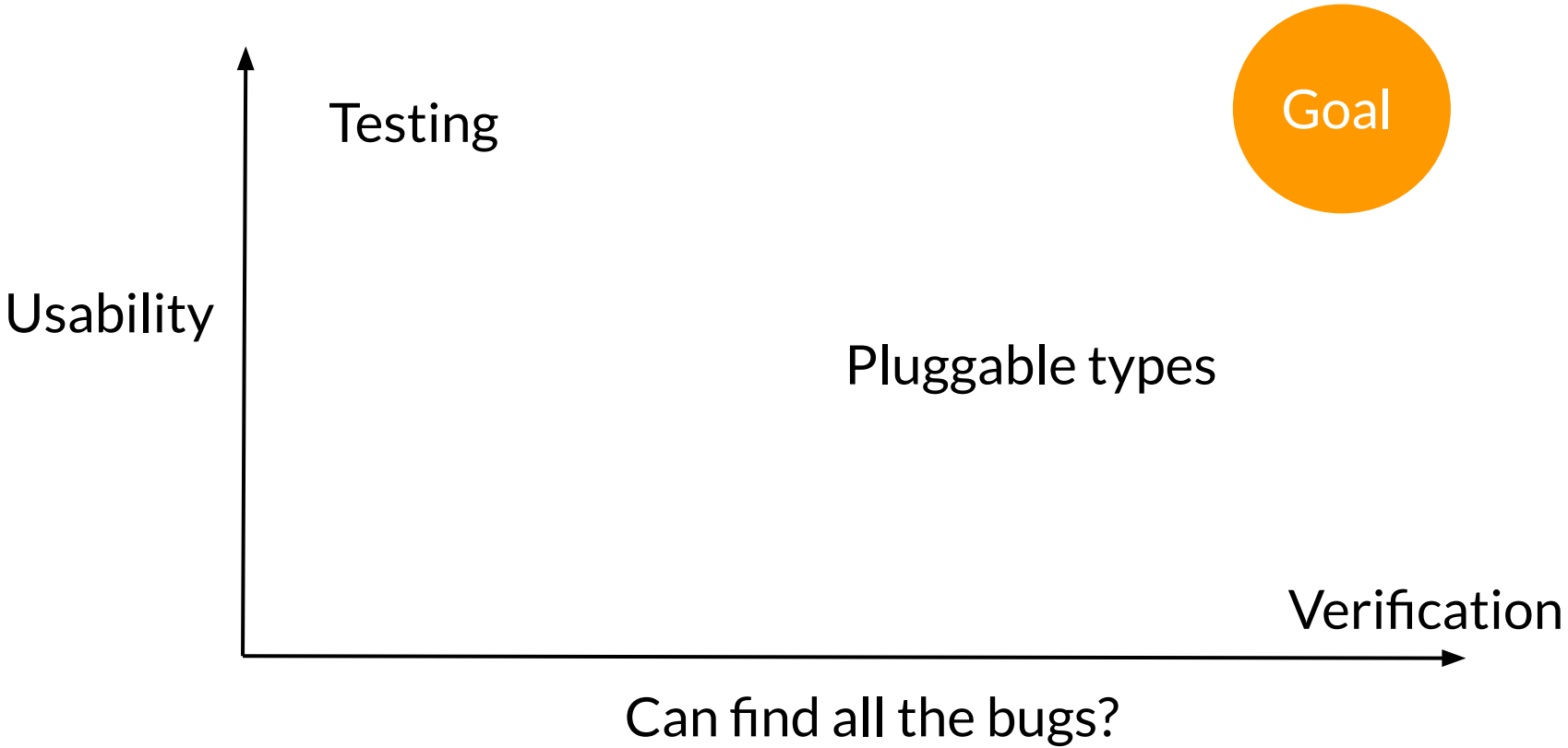


Masked types are an accumulation analysis that accumulates **fields** rather than method calls

Related work



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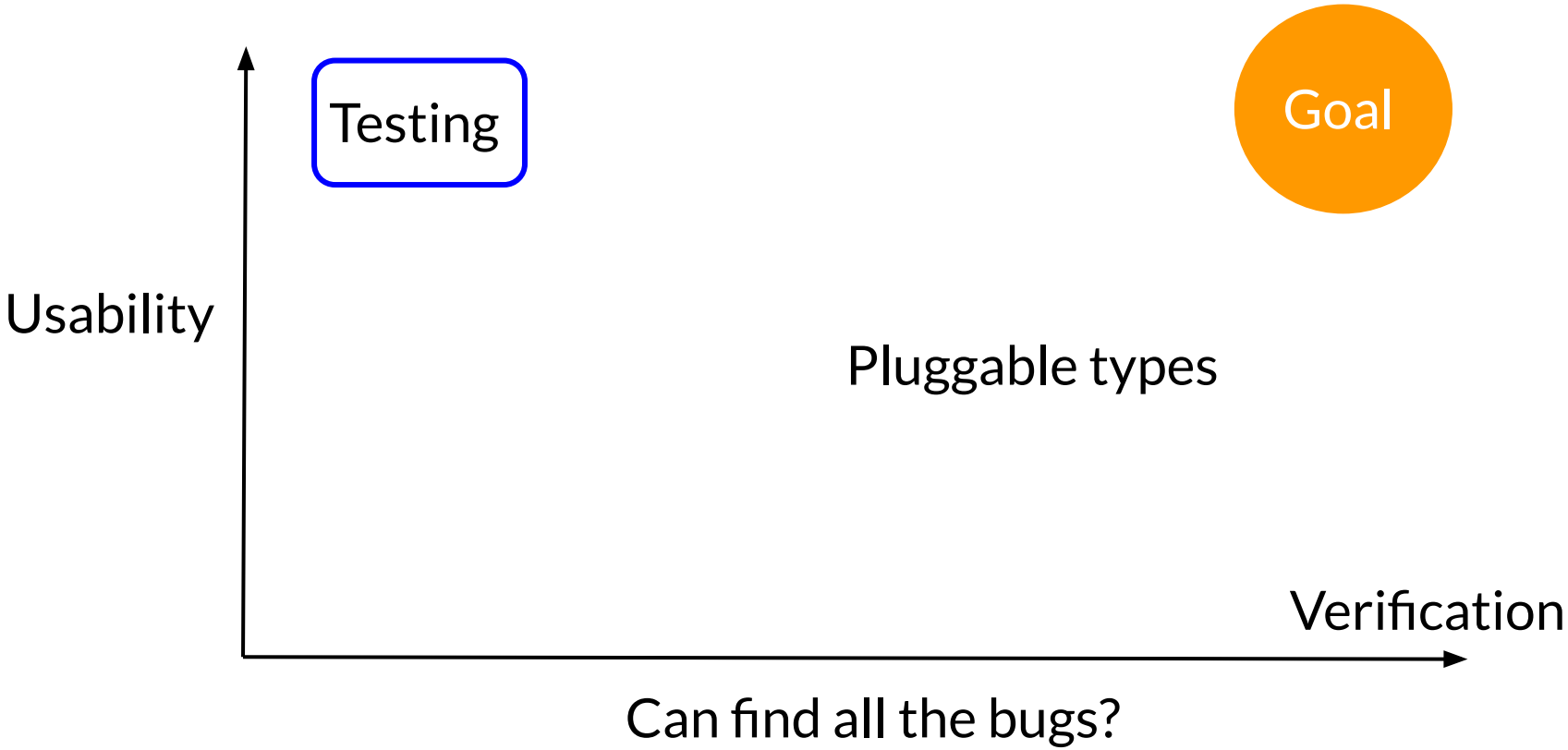
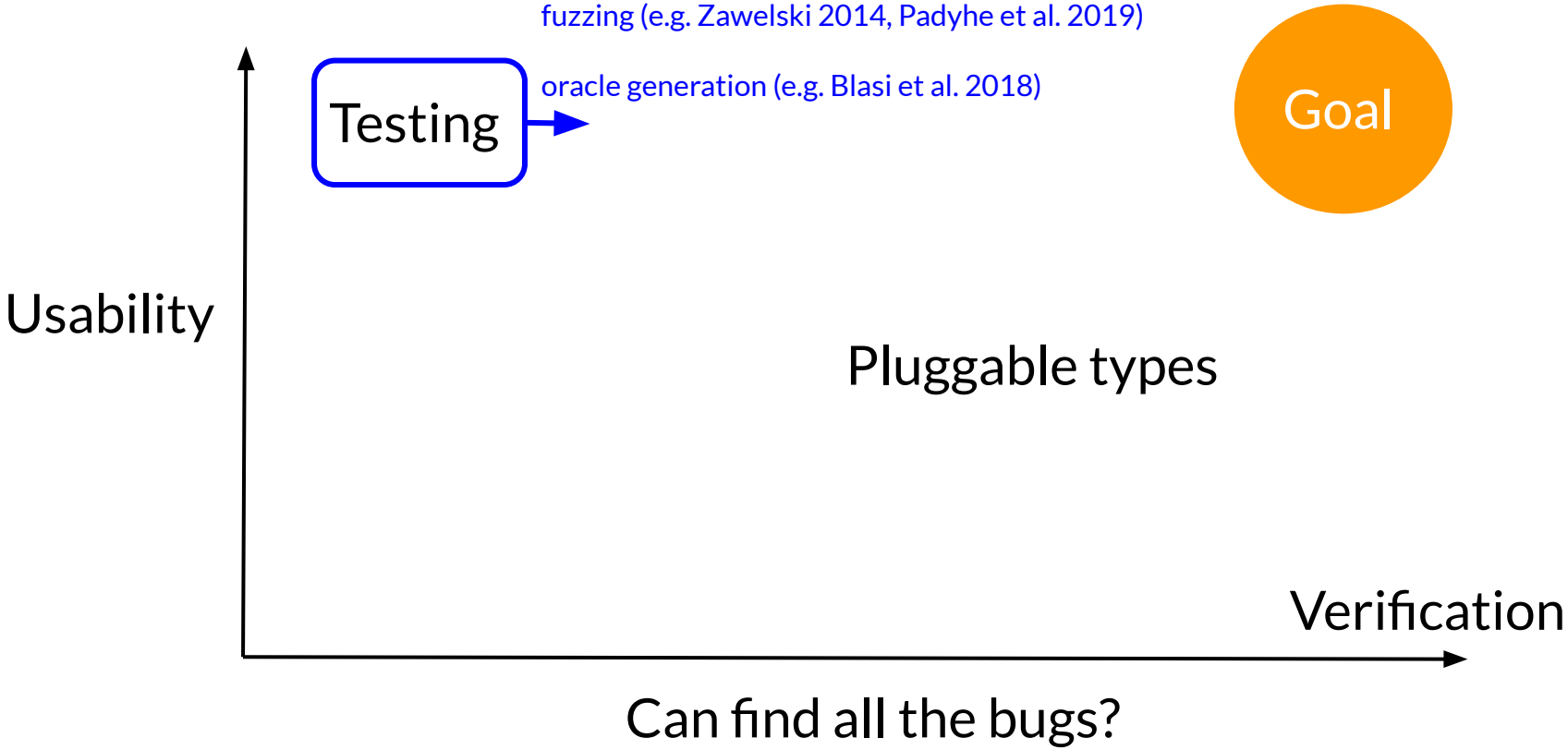


Related work

continuous integration (Fowler & Foemmel 2006)

fuzzing (e.g. Zawelski 2014, Padyhe et al. 2019)

oracle generation (e.g. Blasi et al. 2018)



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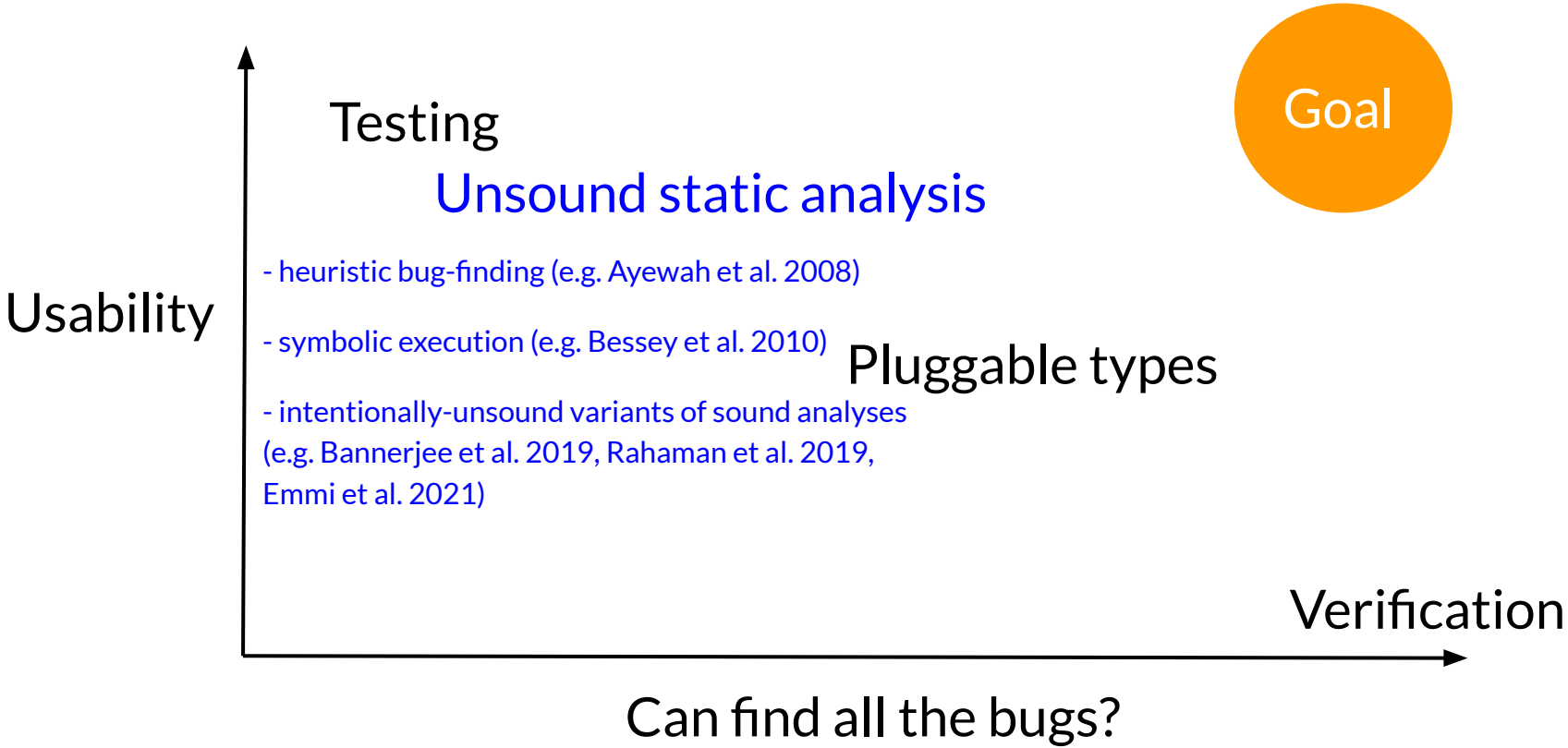

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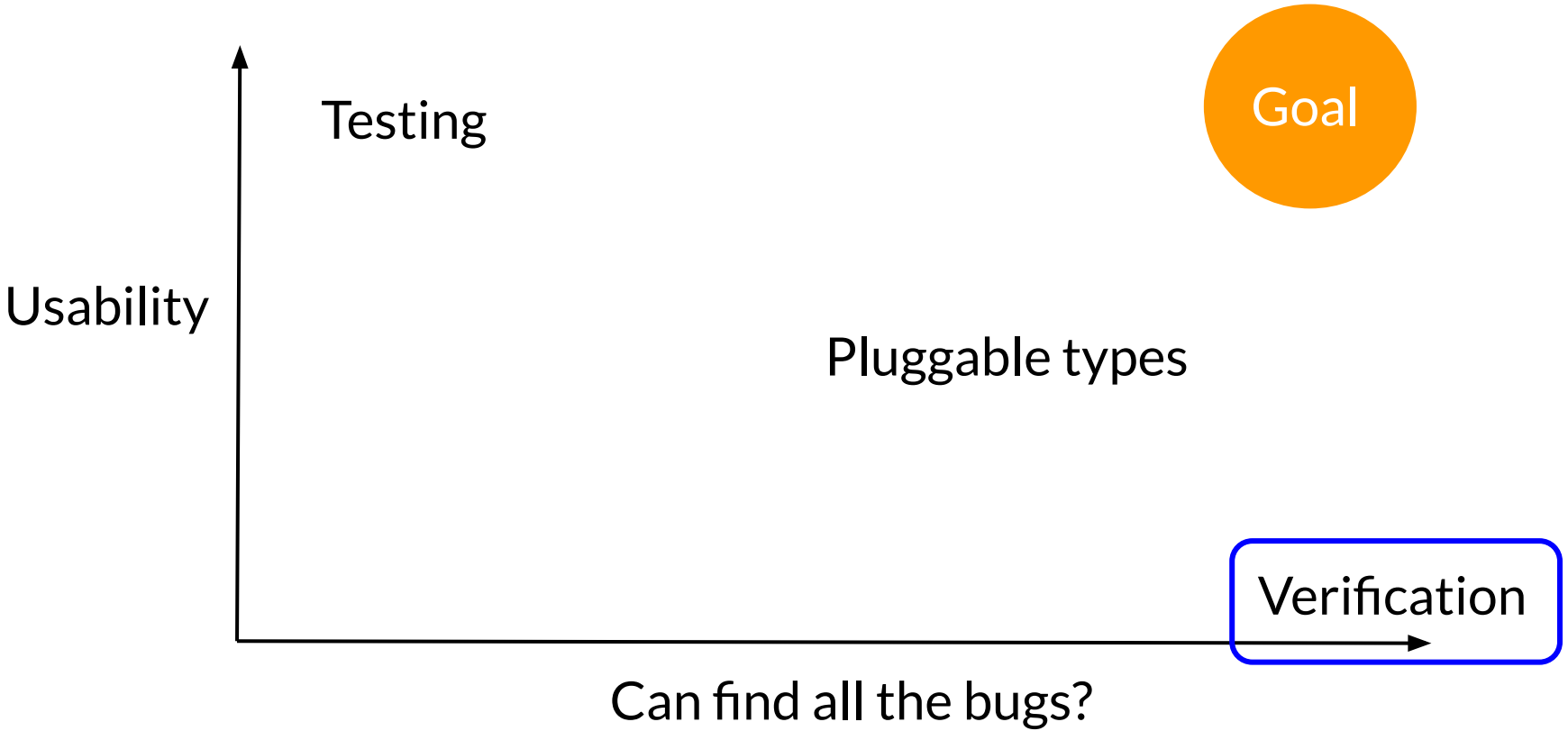

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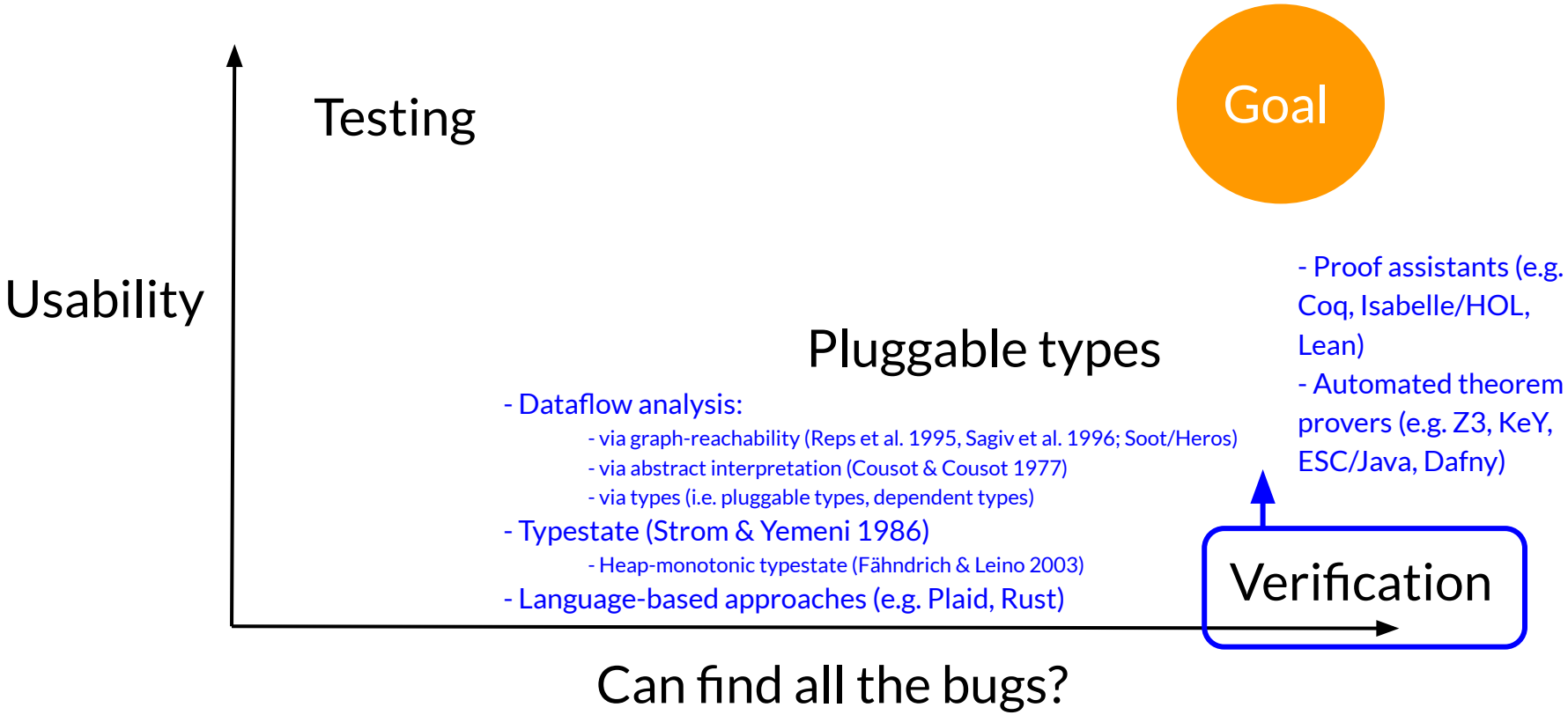

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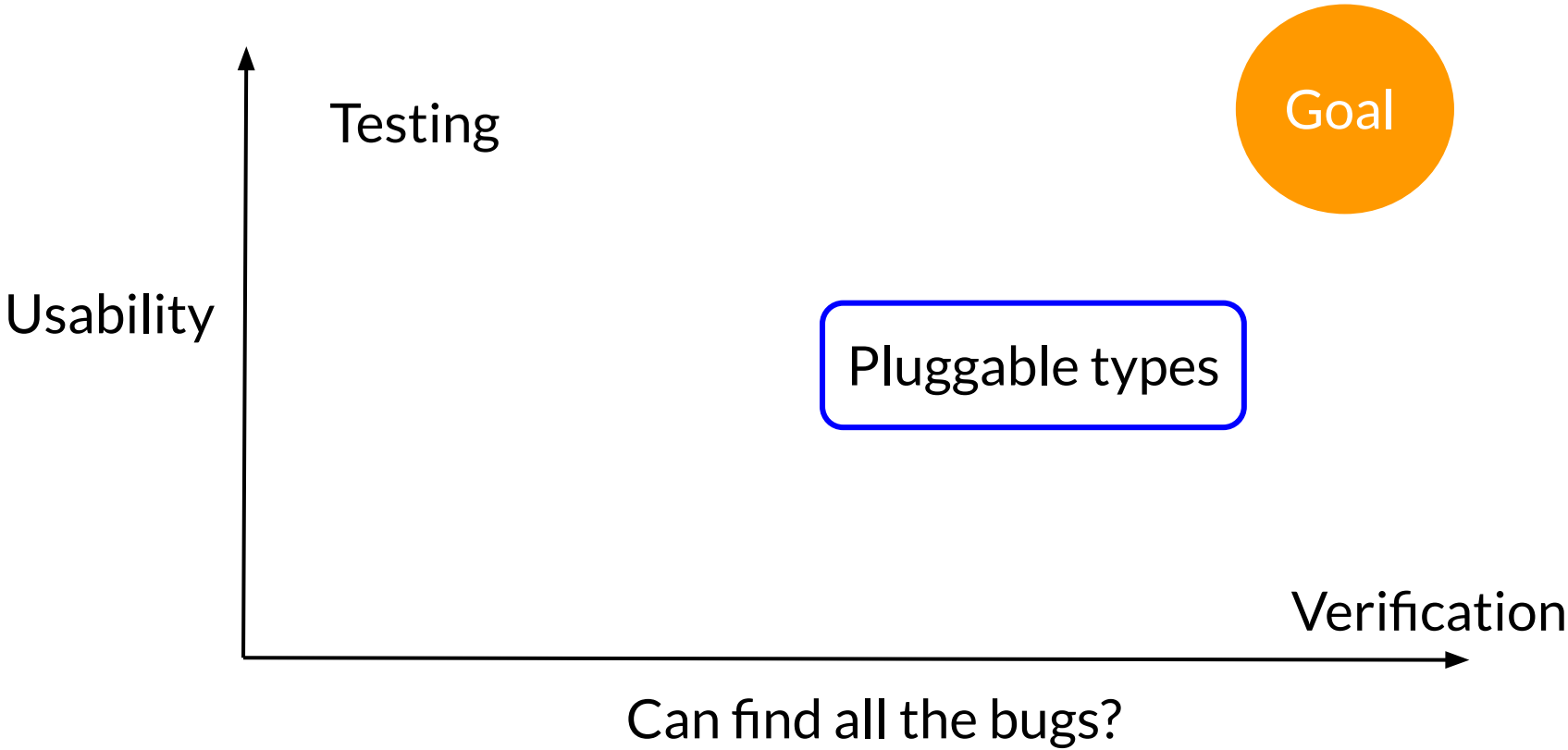

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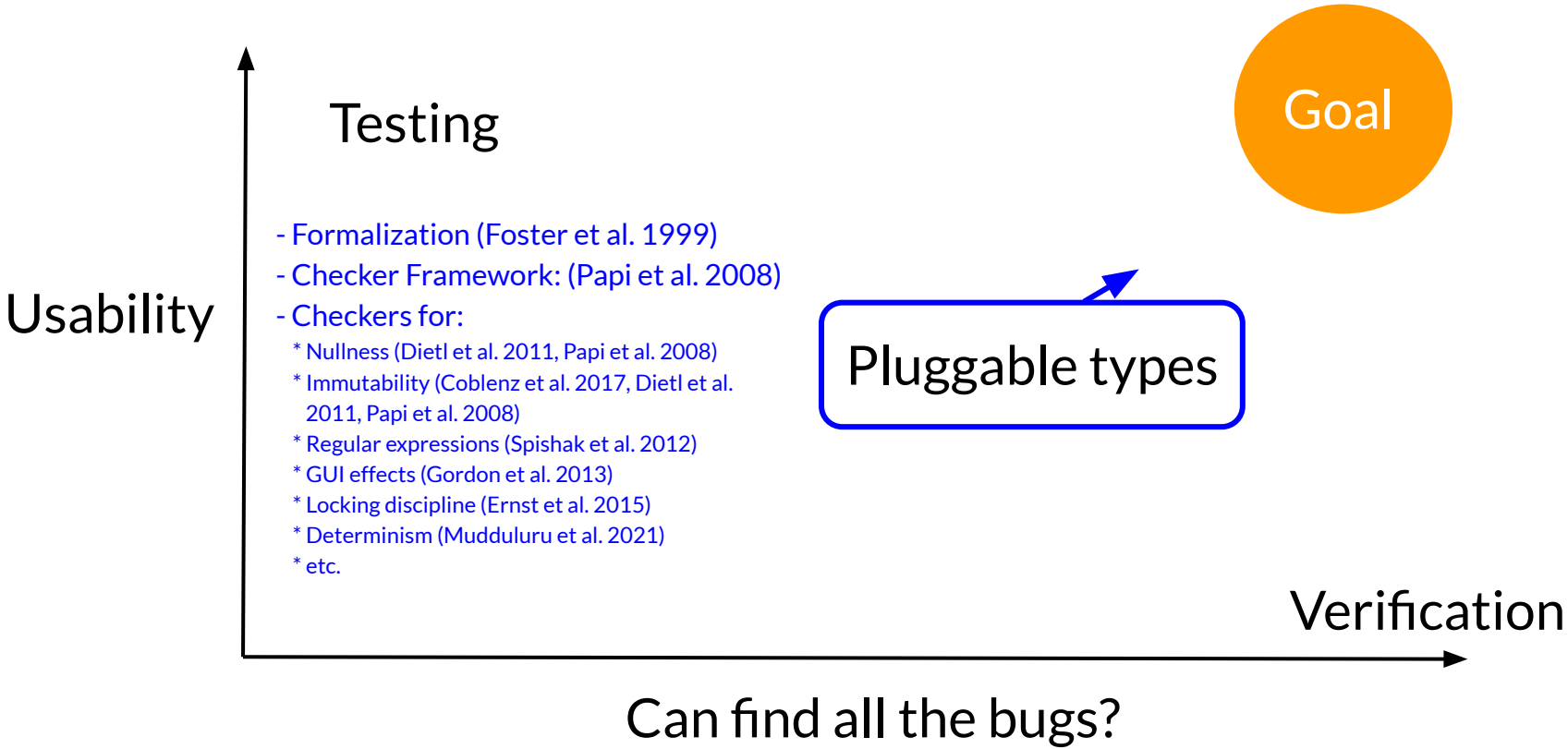

Conclusion

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Our contributions:

- Pluggable types are a **powerful and useable** kind of verification
- Using types in **new domains** makes devs want to do verification
- **Cooperating type systems** can solve hard problems
- **Accumulation** can often replace typestate