Lec 22: Fuzzing

CS492E: Introduction to Software Security

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Software Bugs

- Bugs are plentiful
- Some bugs are memory corruption, some bugs are not
- Bugs are bad: attackers exploit bugs

Build a System that Finds Bugs

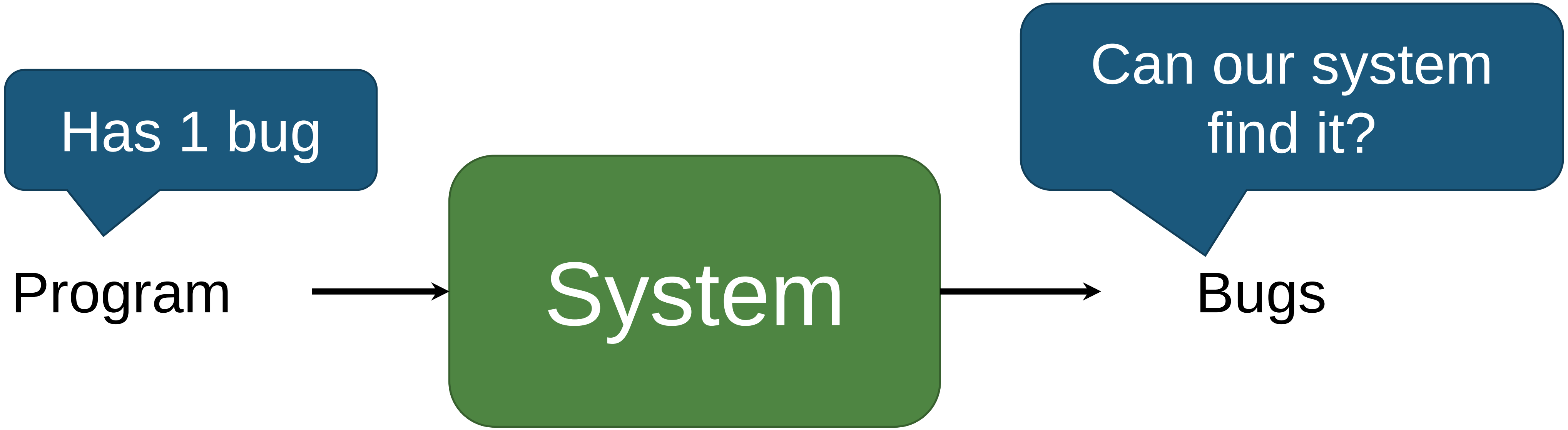
a.k.a. analyzer, fuzzer, etc.

Precision Matters

Program → System → Bugs

How ***precise*** can we make our system?

Precision Matters



Given an arbitrary program, can we build a system that decides whether the program is buggy or not?

Informal Proof

Define a function ***isBuggy*** that takes a program as input, and outputs true if the program has at least one bug, and false if otherwise. Let's assume that this function exists:

```
def isBuggy(prog):
    … # somehow test prog and returns true or false
```

Informal Proof

Define a function ***myProg***:

```
def myProg(): # consider myProg as a program
    if isBuggy(myProg):
        return # do nothing (normal)
    else:
        corruptMemory()
        showBuggyBehavior()
        return
```

Self contradictory

Building a Perfect Analyzer is Impossible

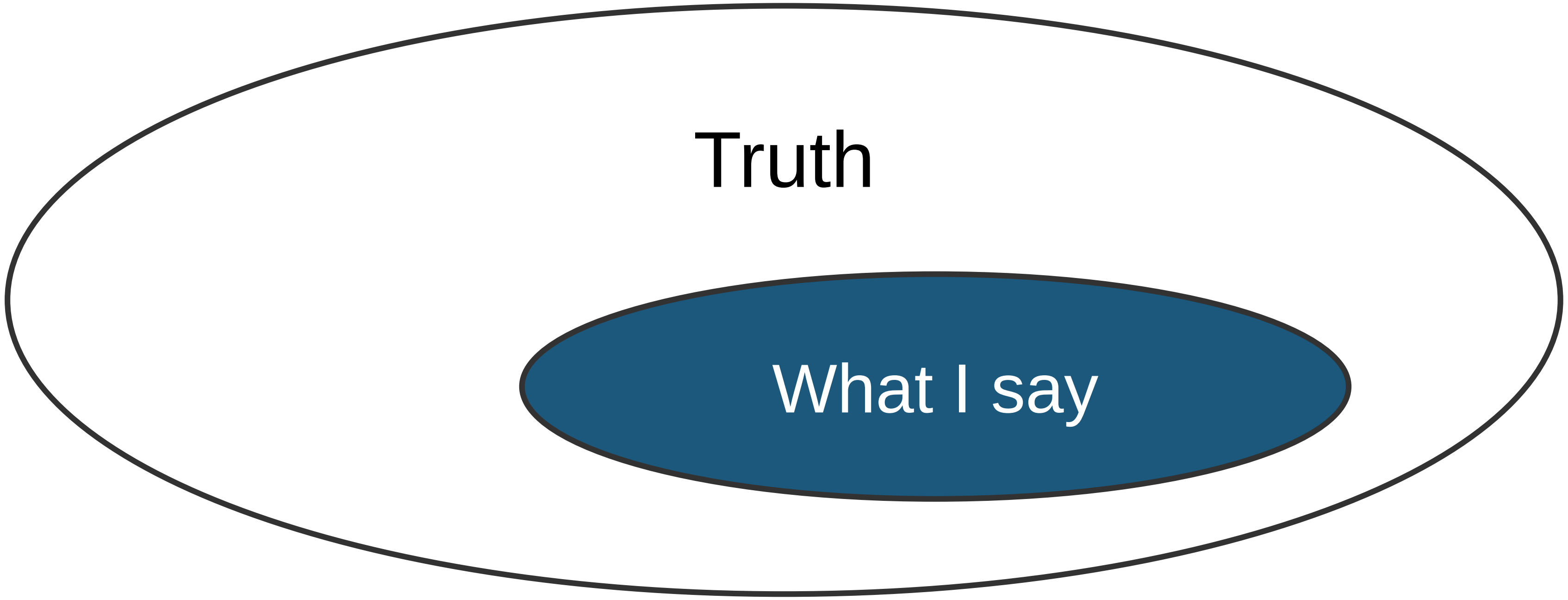
But, we can try to find as many bugs as possible.

For example,

- Bounded model checking
- Static analysis
- Software testing
- Etc.

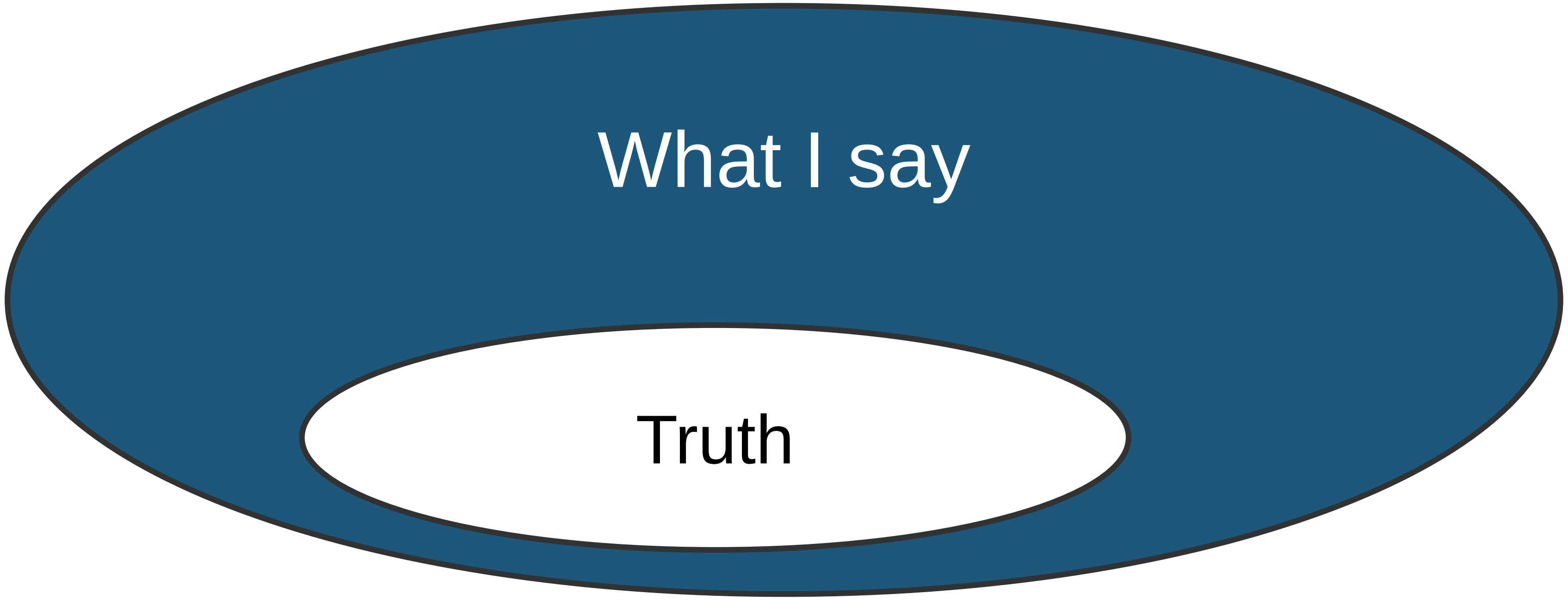
Defining Precision (Soundness vs. Completeness)

If an analyzer is ***sound***:



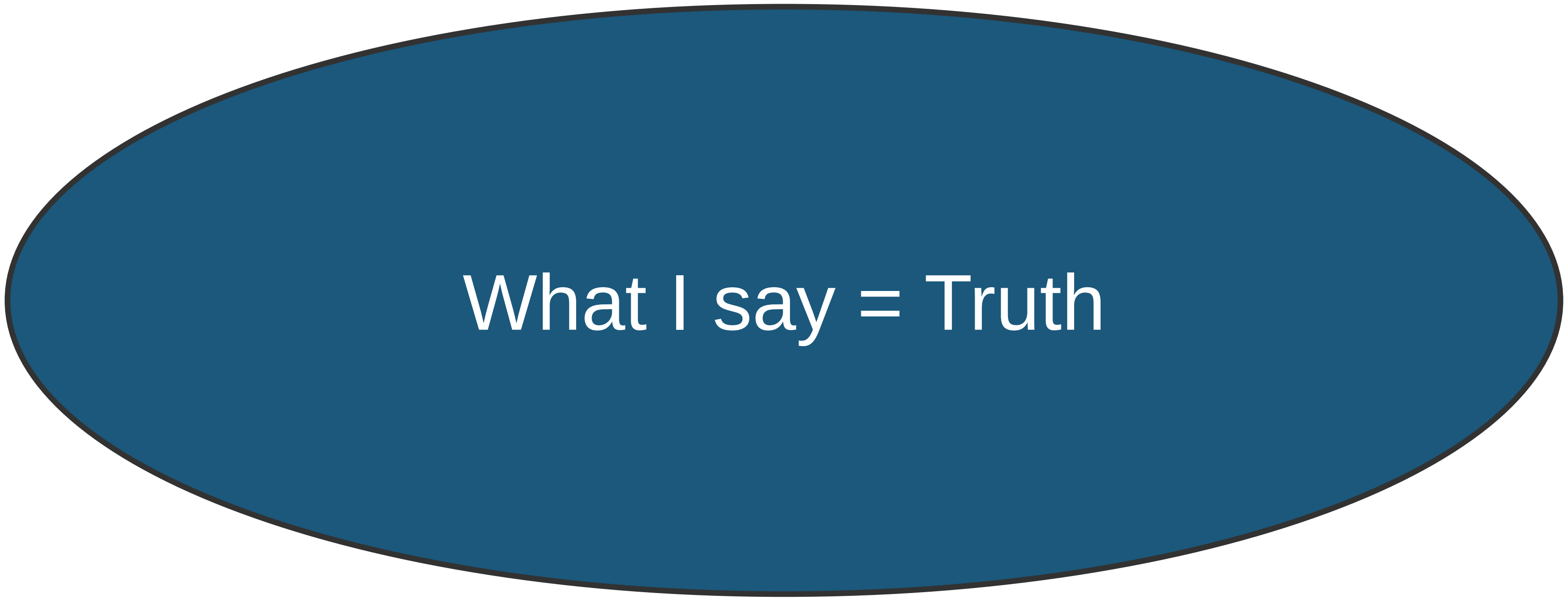
Defining Precision (Soundness vs. Completeness)

If an analyzer is ***complete***:

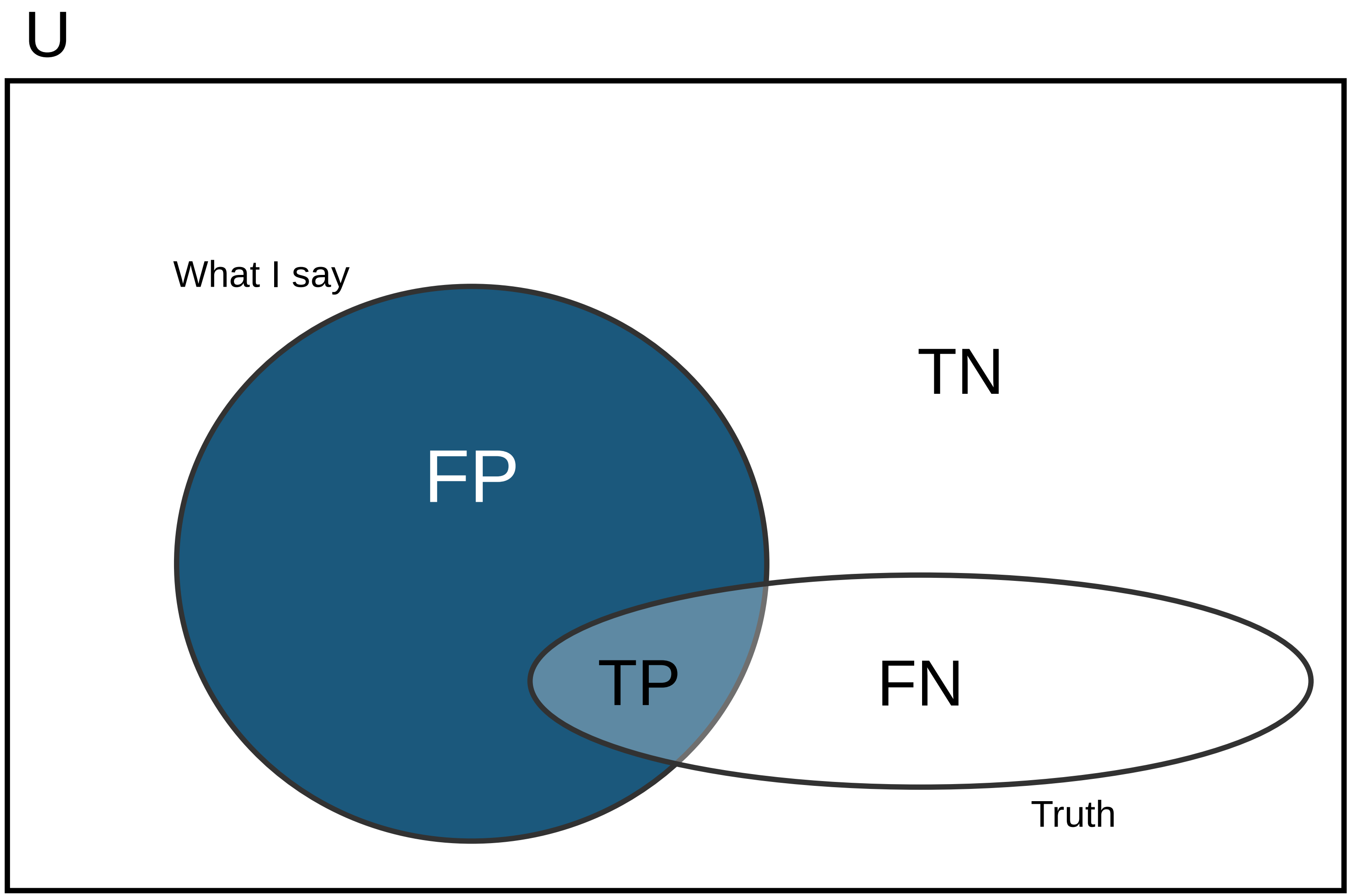


Defining Precision (Soundness vs. Completeness)

If an analyzer is ***sound and complete (= perfect)***:

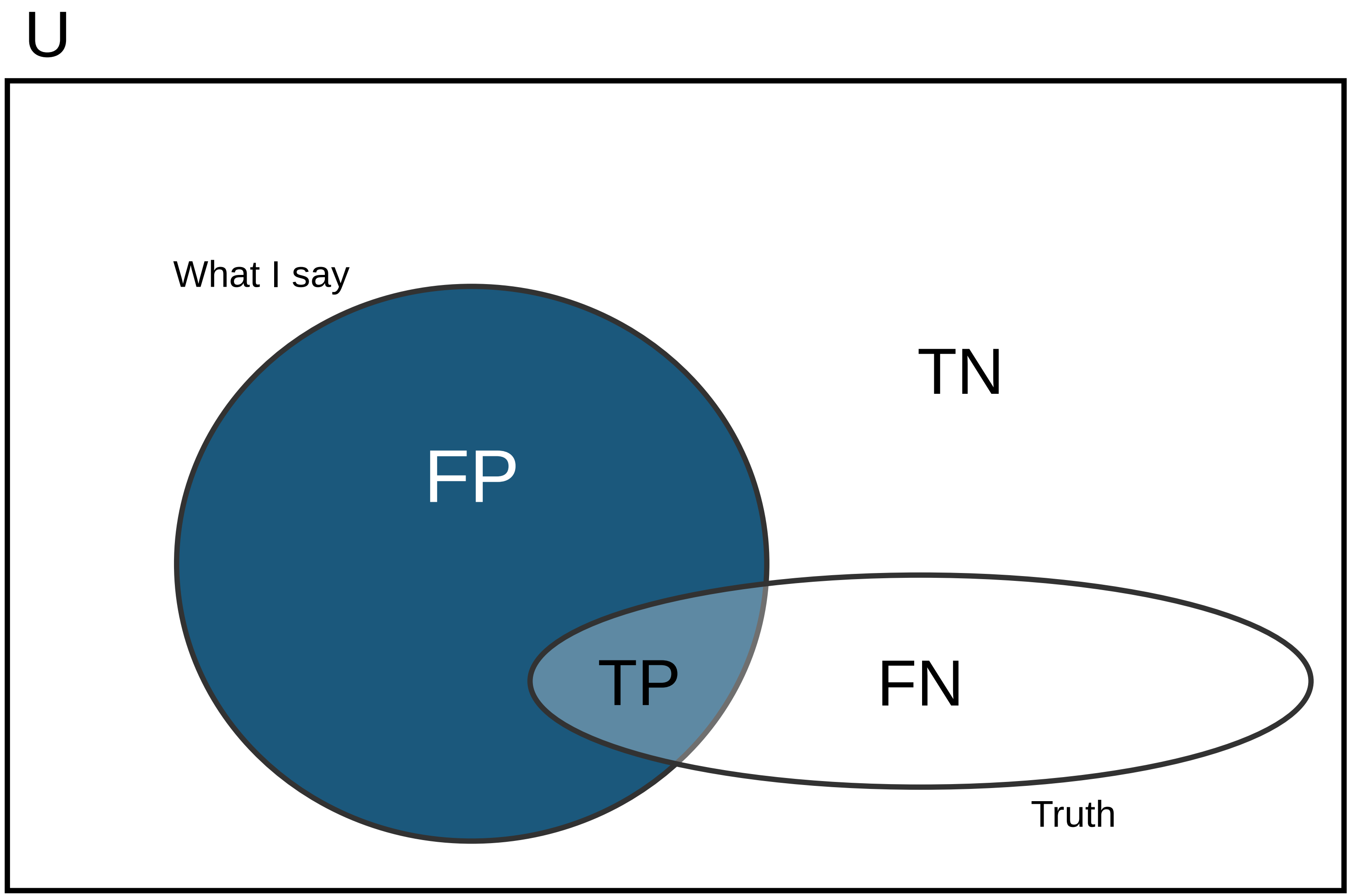


Precision, Recall, and Accuracy



- Precision
  = TP / (TP + FP)
- Recall
  = TP / (FN + TP)
- Accuracy
  = (TP+TN)/(U)

False-Positive Rate vs. False-Negative Rate



- FP Rate
  = FP / (TP + FP)
- FN Rate
  = FN / (FN + TN)

Fuzzing?

A software testing technique for finding software bugs

History of Fuzzing

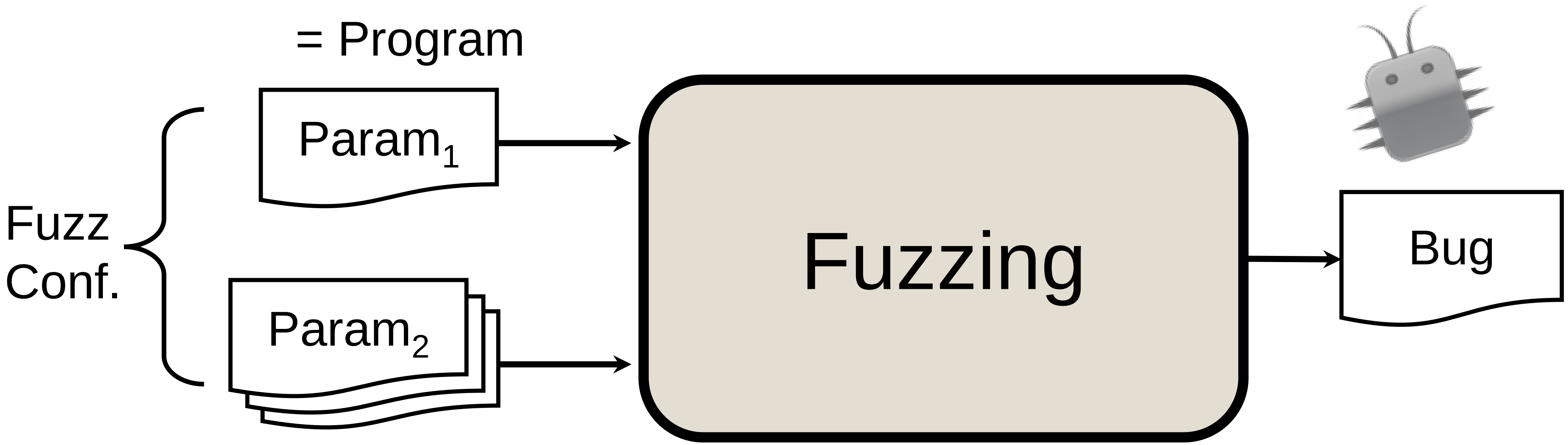
The original work was inspired by being logged on to a modem during a storm with lots of line noise. And the line noise was generating junk characters that seemingly were causing programs to crash. The noise suggested the term ***fuzz***.

The term was coined by ***Barton Miller*** in ***1990***.

Image from http://ls.wisc.edu/wp-content/uploads/2016/01/Barton-Miller-200.jpg

Fuzzing in 1990s

An Empirical Study of the Reliability of UNIX Utilities,
CACM 1990



Fuzzing in 1990s

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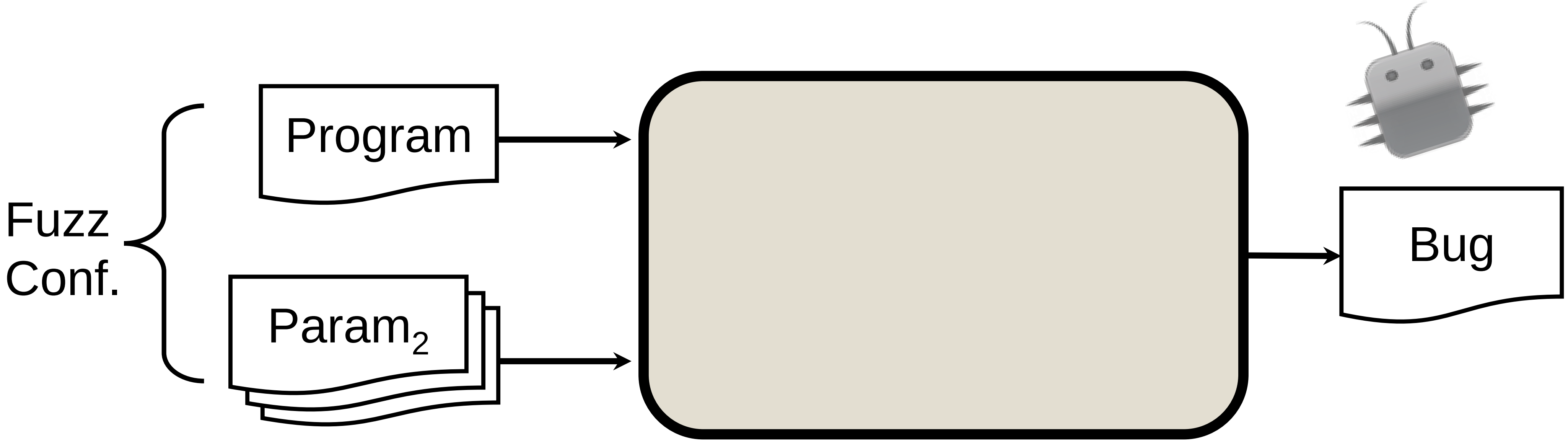
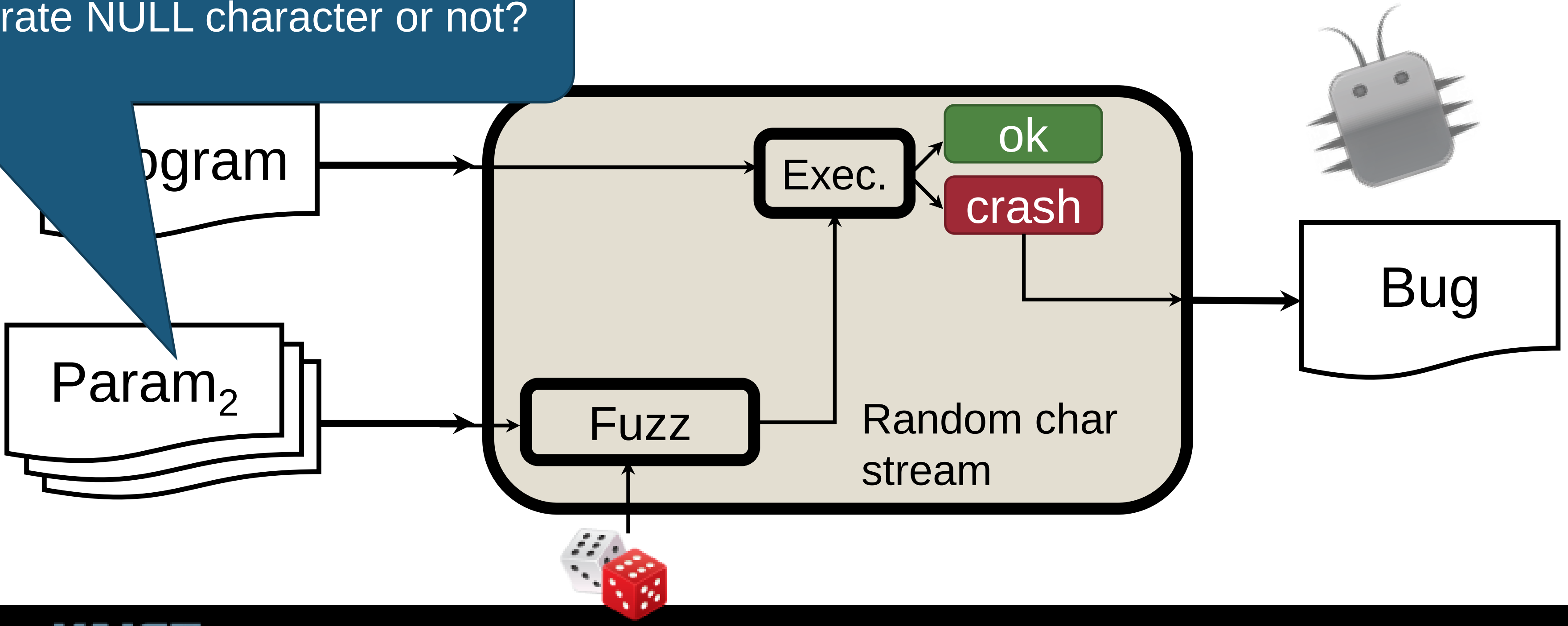


Fuzzing in 1990s

An Empirical Study of the Reliability of UNIX Utilities,
CACM 1990

- Only printable characters?
- Generate NULL character or not?
- Etc.

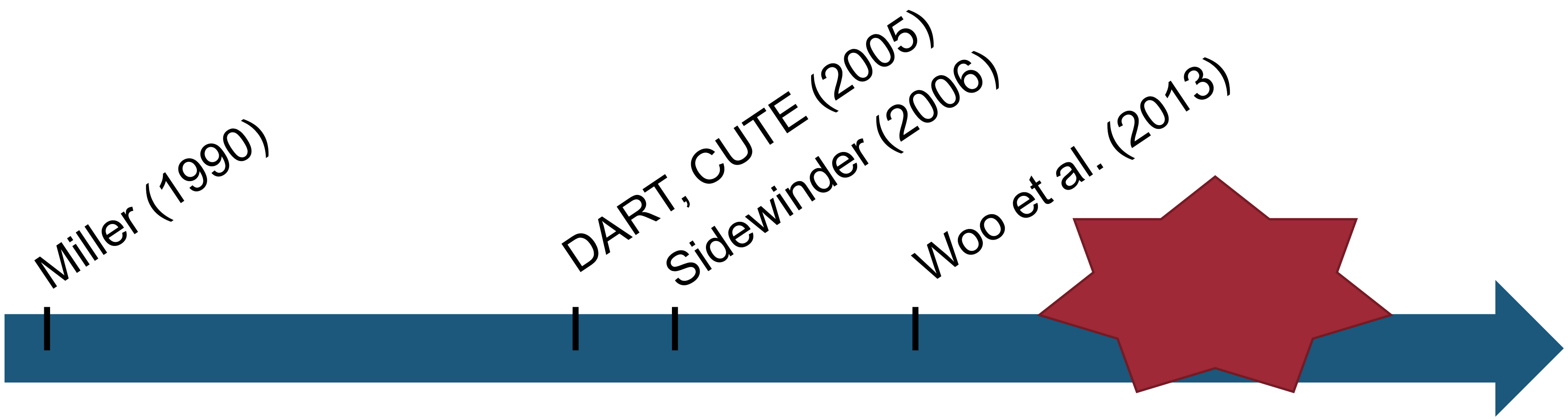


Fuzzing is …

- ***Simple***, and popular way to find security bugs
- Used by security practitioners
- But, ***not studied systematically until recently (~2013)***
  - Why fuzzing works so well in practice?
  - Are we maximizing the ability of fuzzing?

Can we answer these questions?

Rough History of Fuzzing

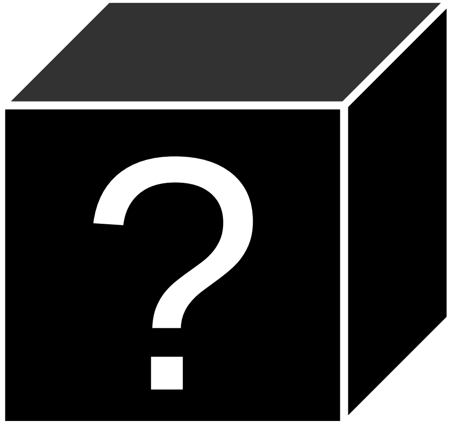


* Visit https://fuzzing-survey.org/ to learn more

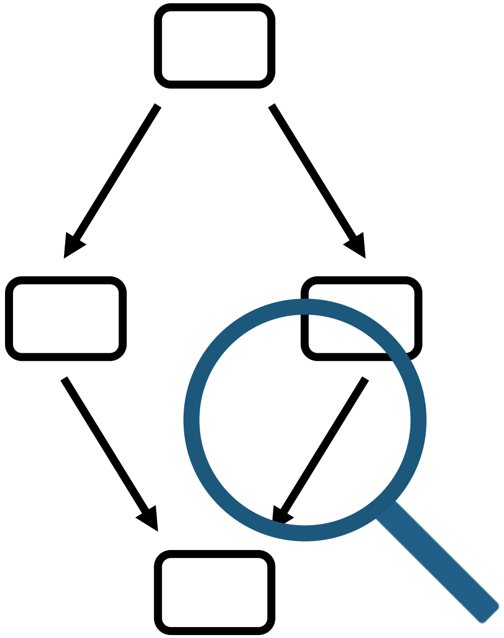
Fuzzing is an Overloaded Term

- White-box, black-box, grey-box fuzzing
- Directed fuzzing, Feedback-driven fuzzing
- Generational fuzzing
- Mutational fuzzing
- Grammar-based fuzzing
- Seed-based fuzzing
- Model-based, model-less fuzzing
- Etc.

Black-box vs. White-box Fuzzing



vs.



Grey-Box Fuzzing

- White-box fuzzing (strictly speaking)
- Obtain some partial information about the program execution

Mutation- vs. Generation-based Fuzzing

- ***Seed***: an input to a program
- Mutation: mutate a given seed to generate test cases
- Generation: generate test cases from a model

Why Mutation?

Random inputs are likely to be rejected

Many Questions Remain

- Given a seed, how do we mutate the seed?
- How much portion do we mutate from the seed?
- How do we obtain seeds?

Why Generation?

Empty model = Random fuzzing

Random inputs are likely to be rejected!

Grammar-based Fuzzing

- Fuzzing compiler/interpreter
- Fuzzing VMs (Virtual Machines)

Fuzzing Algorithm

Key Properties of Fuzzing

- Generate test cases

- Run the program under test with the test cases

- Check if the program crashes

Definitions

- ***Fuzzing*** is the execution of the program using input(s) sampled from an input space that protrudes the expected input space of the PUT.

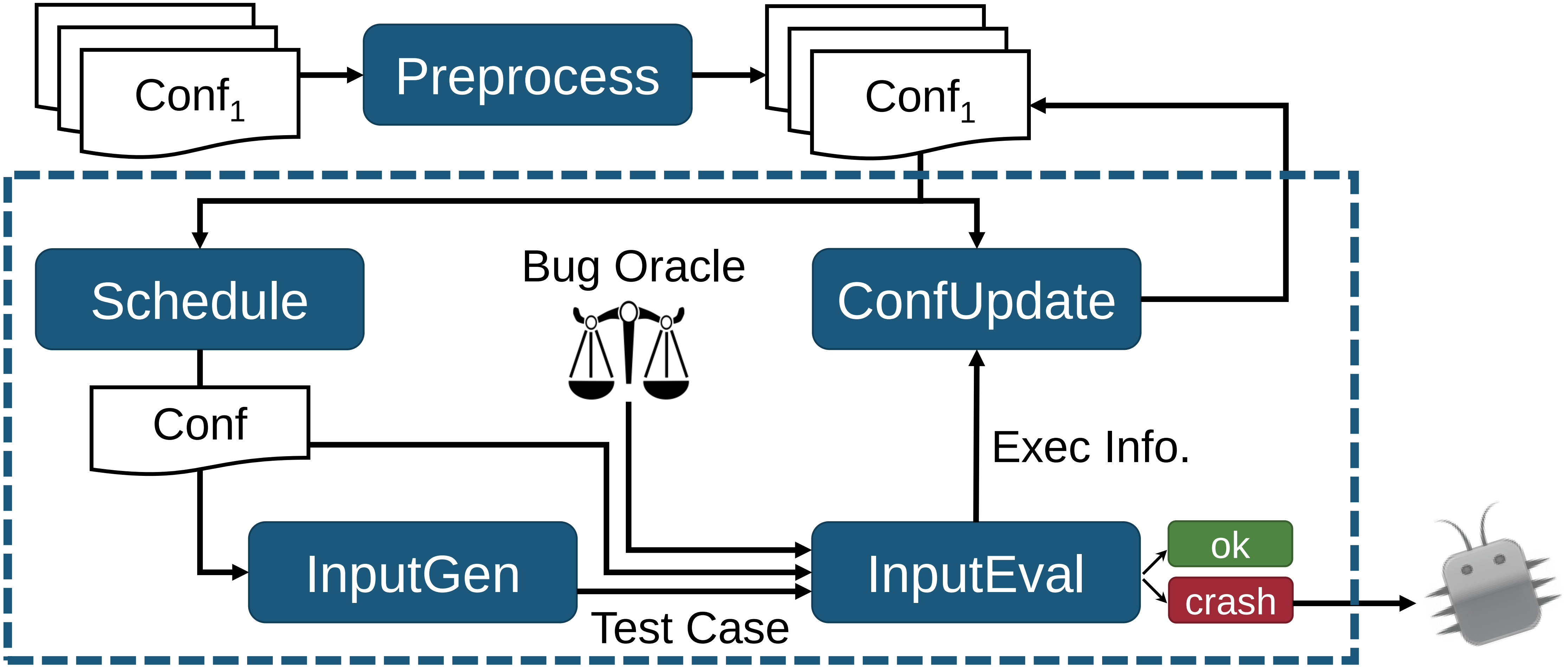
- ***Fuzz testing*** is the use of fuzzing to test if a program violates a correctness policy (e.g., security policy).

Definitions

- A ***fuzz configuration*** of a fuzz algorithm comprises the parameter value(s) that control(s) the fuzz algorithm.

- A ***bug oracle*** (O_{bug}) is a program, perhaps as part of a fuzzer, that determines whether a given execution of the program violates a specific security policy.

Fuzzing Algorithm



Fuzzing Algorithm

Algorithm 1: Fuzz Testing

Input: $\mathbb{C}$, t_{limit}
Output: $\mathbb{B}$ // a finite set of bugs

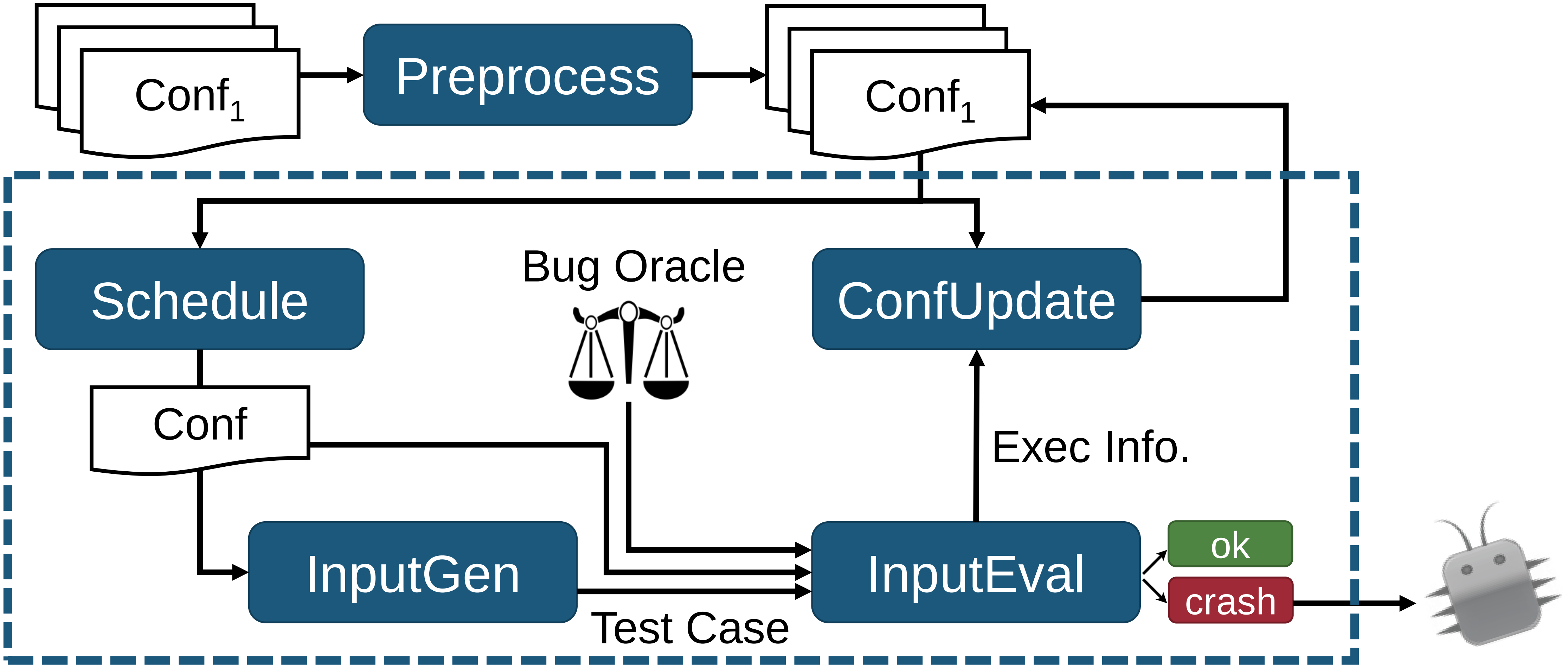
$\mathbb{B} \leftarrow \varnothing$
$\mathbb{C} \leftarrow$ PREPROCESS($\mathbb{C}$)
while $t_{\text{elapsed}} < t_{\text{limit}} \wedge$ CONTINUE($\mathbb{C}$) **do**
    conf $\leftarrow$ SCHEDULE($\mathbb{C}$, $t_{elapsed}$, t_{limit})
    tc $\leftarrow$ INPUTGEN(*conf*)
    // O_{bug} is embedded in a fuzzer
    $\mathbb{B}'$, execinfo $\leftarrow$ INPUTEVAL(*conf*, *tc*, O_{bug})
    $\mathbb{C} \leftarrow$ CONFUPDATE($\mathbb{C}$, *conf*, *execinfo*)
    $\mathbb{B} \leftarrow \mathbb{B} \cup \mathbb{B}'$
return $\mathbb{B}$

Fuzzing is AI!

Finding paths in a maze

1. Move the agent based on the knowledge
2. Observe the environment (walls, passages, etc.)
3. Update the learnt knowledge
4. Goto 1

Research Challenges?



Questions?