9th UCAAT User Conference on Advanced Automated Testing

Towards the Absence of Bugs

An Intelligent Combination of Static and Dynamic Analysis to Identify Vulnerabilities in the Development Process

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Agenda

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- Static and dynamic analysis
- Interactive analysis

Verification of static analysis findings

Residual Risk Estimation

- Good-Turing Estimator (GTE)

Conclusion

Acknowledgments
This work was developed within the IntelliSecTest project. The IntelliSecTest project is funded with 3.5 million euros over three years by the Fraunhofer PREPARE program.

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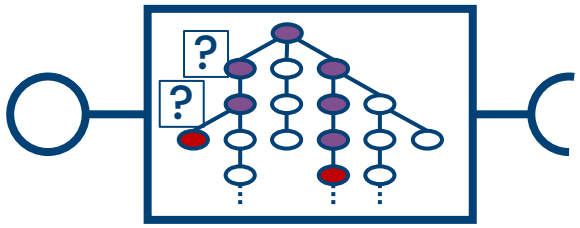
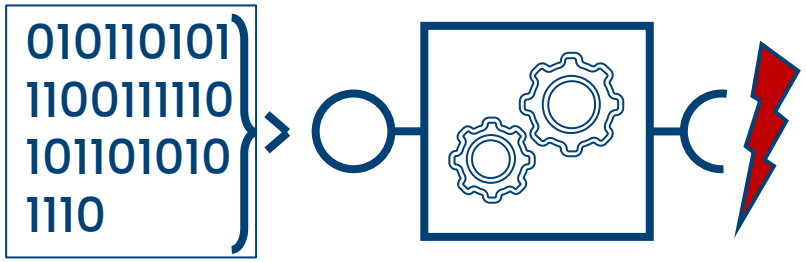
Two major approaches

Static Analysis



Dynamic Analysis



	Static Analysis	Dynamic Analysis
Advantages	▪ High path coverage ▪ Good presentation of results	▪ Very few false positives ▪ Provides input data triggering to vulnerability
Drawbacks	▪ High number of false positives	▪ Random path coverage ▪ Poor results presentation

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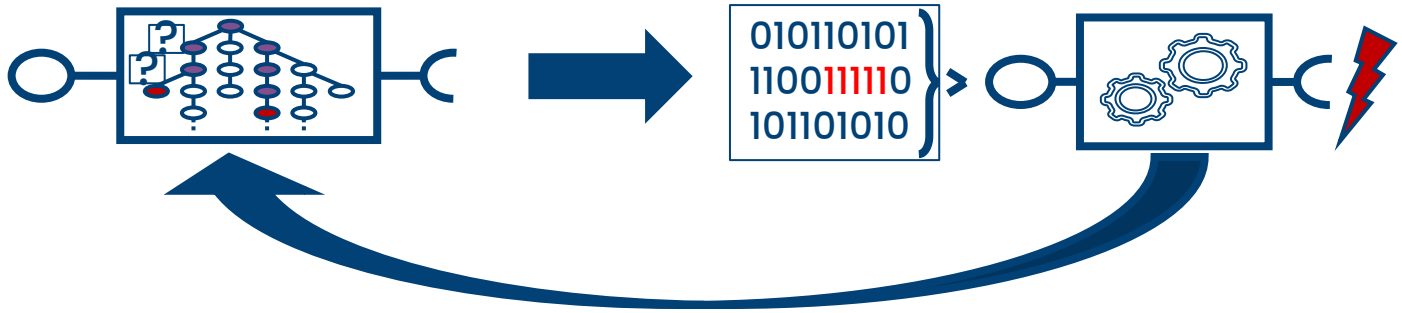
Interactive Analysis

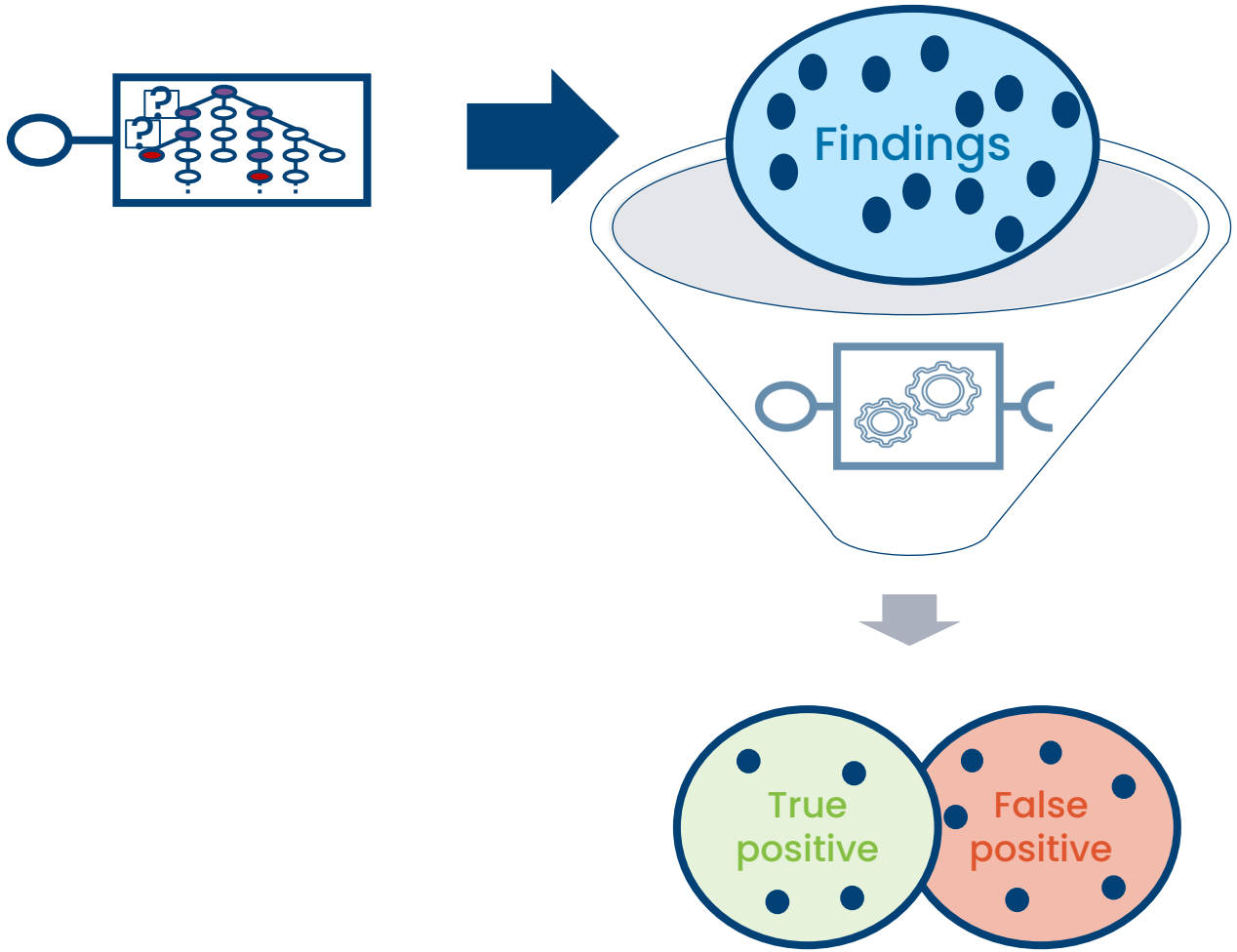
Combination of static and dynamic Analysis



Advantages

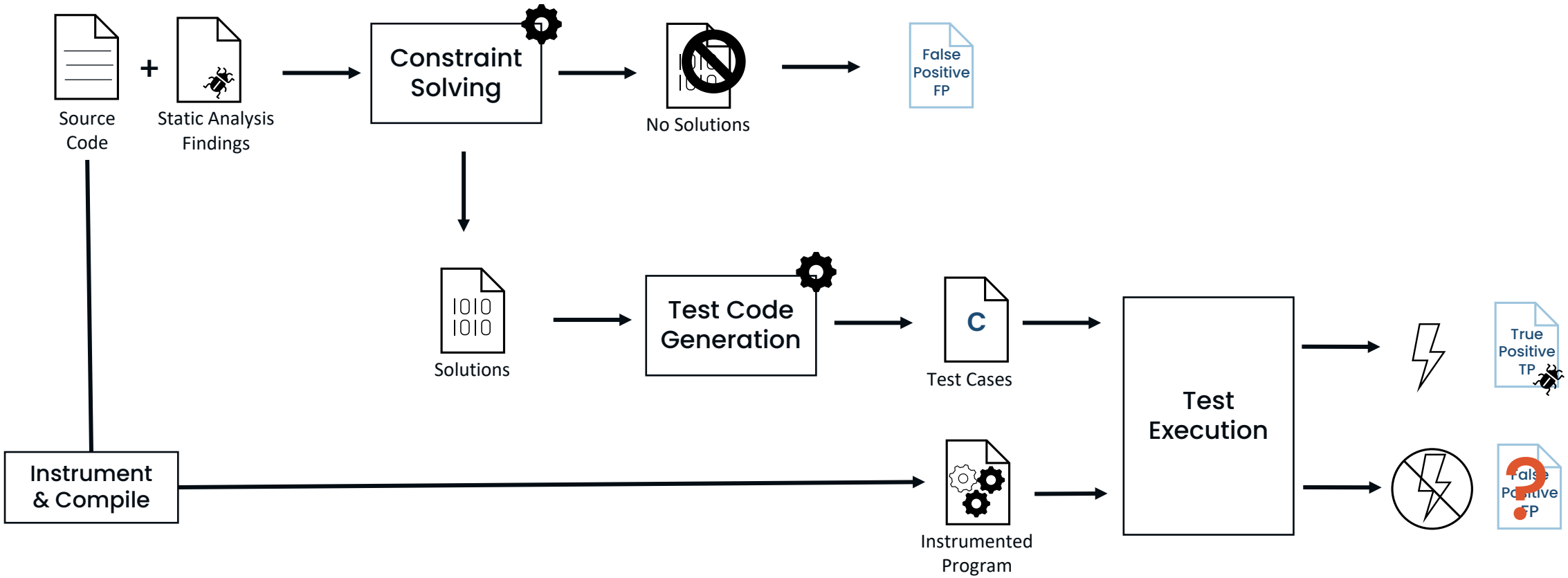
- High path coverage
- Good presentation of results
- Provides input data leading to vulnerability
- Reduce number of false positives

Verify static analysis findings

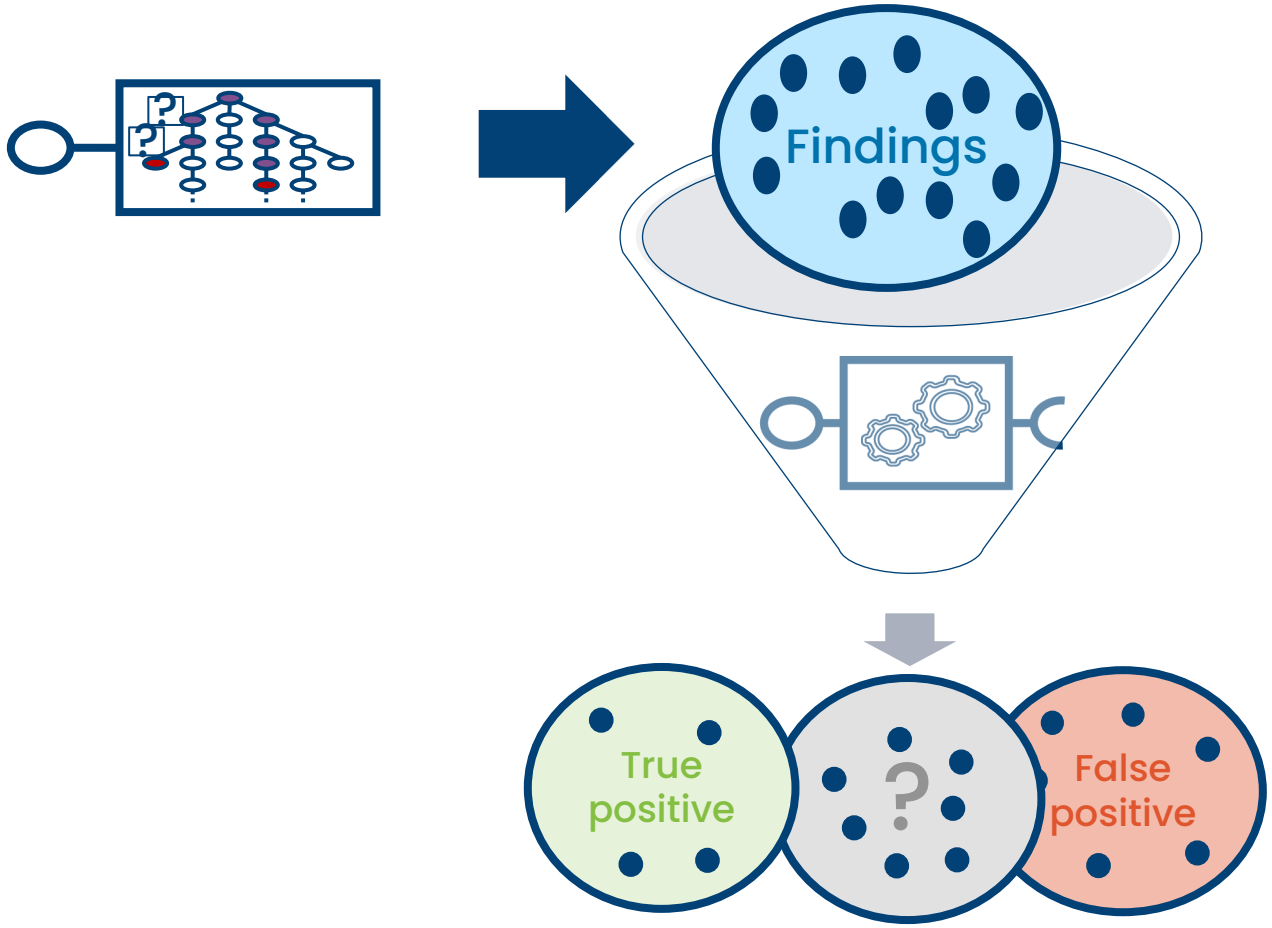


Verify static analysis findings

Create test cases using constraint solving



Verify static analysis findings



> *"Program* testing can *be used* to show the presence *of* bugs, *but never* to show their absence!"
>
> [E. Dijkstra]

→ Need a way to estimate the residual risk that there is an undiscovered vulnerability in the code

Residual Risk Estimation

Traditionally probability calculation:

- Assumption: the ratio of every element in the set in relation to the occurrence in the sample set is universally true
- Result: no prediction for unseen elements

Good-Turing Estimation (GTE):

- Assumption: the sample data just captures a part of the set
- Consequents: probability discounting to create room for unseen elements (pseudo count)

Residual Risk Estimation

Missing mass estimation

"the chance that the next […] sampled will belong to a new species is approximately"

$$P'_0 \approx \frac{n_1}{N}$$

P'_0 the probability for all unobserved species ("missing mass")
n_r number of species that were seen exactly r times
N is the total number of counts

Hence also the expected total chance of all species that are represented r times or more in the sample is approximately

$$N^{-1}\{(r+1)n_{r+1}+(r+2)n_{r+2}+\ldots\}. \quad (7)$$

In particular, the expected total chance of all species represented at all in the sample is approximately

$$N^{-1}(2n_2+3n_3+\ldots) = 1-n_1/N. \quad (8)$$

We may say that the proportion of the population represented by the sample is approximately $1-n_1/N$, and *the chance that the next animal sampled will belong to a new species is approximately*

$$n_1/N. \quad (9)$$

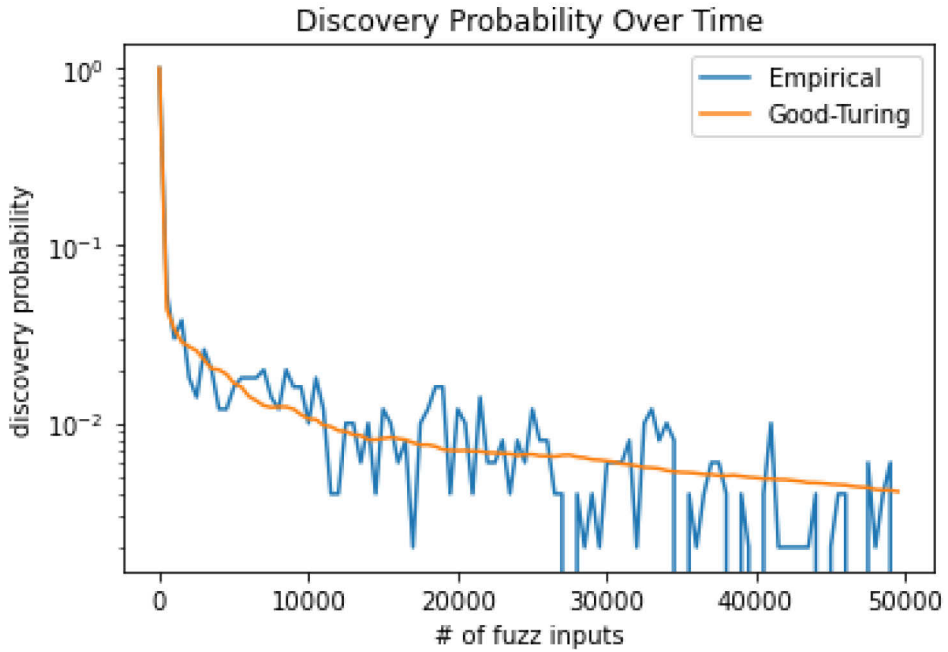
I.J.Good: THE POPULATION FREQUENCIES OF SPECIES AND THE ESTIMATION OF POPULATION PARAMETERS (1953)

Residual Risk Estimation

GTE Applying to Fuzzing

*"If no error has been exposed throughout the [fuzzing] campaign, the **Good-Turing estimator gives an upper bound** on the probability to generate a test input that exposes an error."*

[M. Böhme]



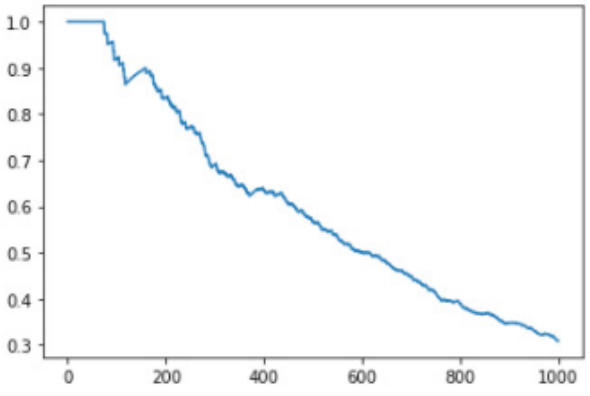
Empirical estimator

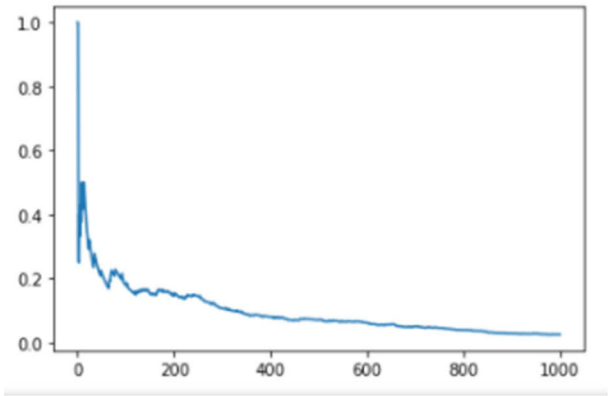
To measure the empirical probability, we execute the same population of inputs (n=50000) and measure in regular intervals (measurements=100 intervals). During each measurement, we repeat the following experiment repeats=500 times, reporting the average: If the next input yields a new trace, return 1, otherwise return 0. Note that during these repetitions, we do not record the newly discovered traces as observed. [1]

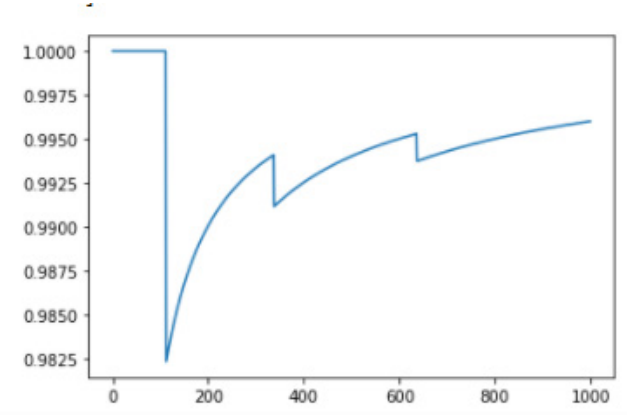
[1] https://www.fuzzingbook.org/html/WhenToStopFuzzing.html

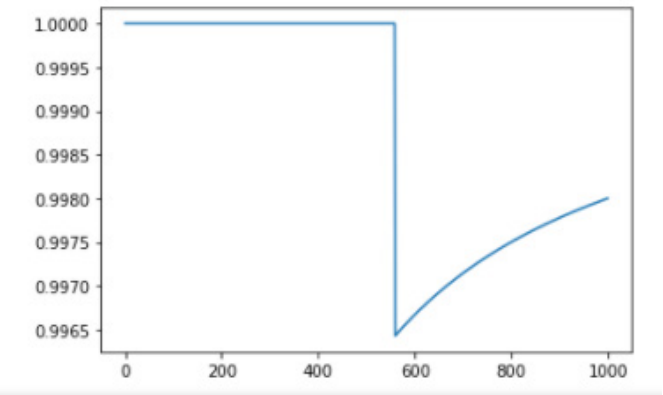
Residual Risk Estimation

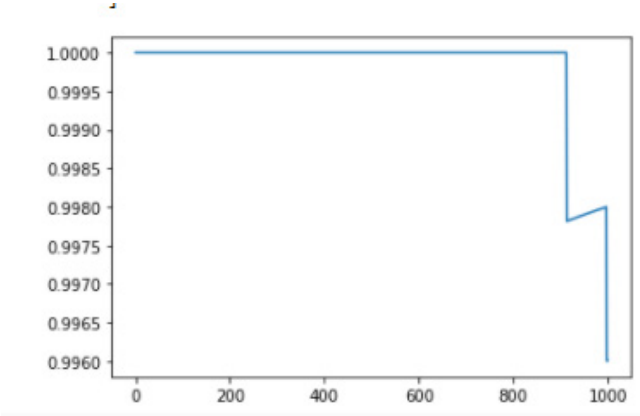
GTE Applying to different examples

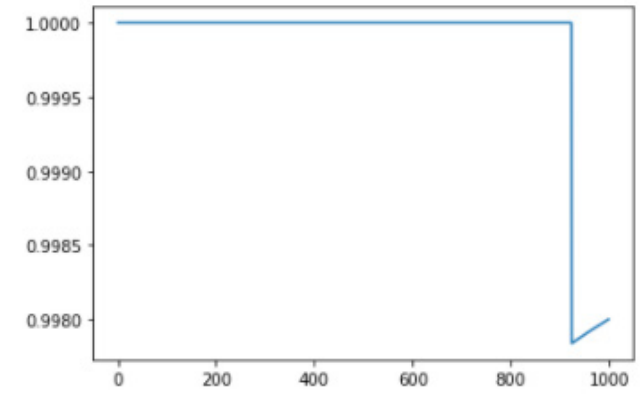






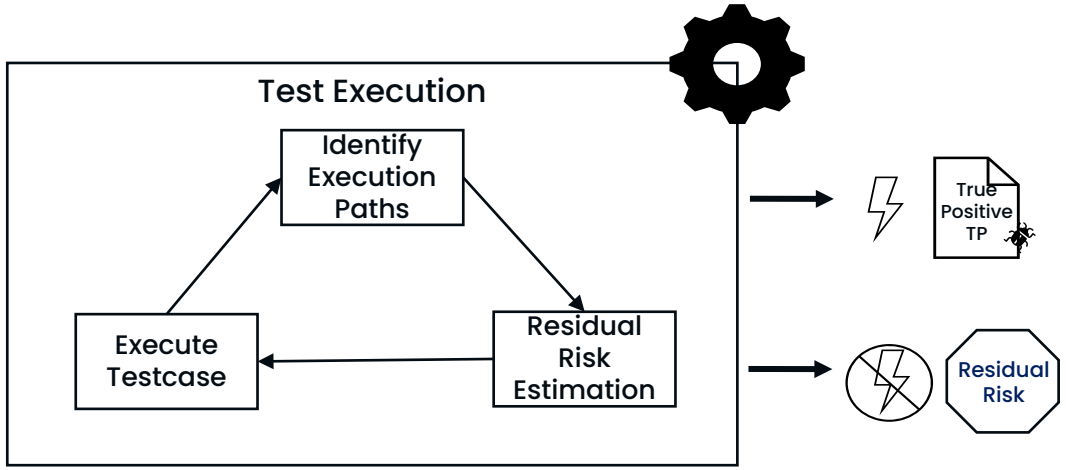






Residual Risk Estimation

Verification of Static Analysis Findings

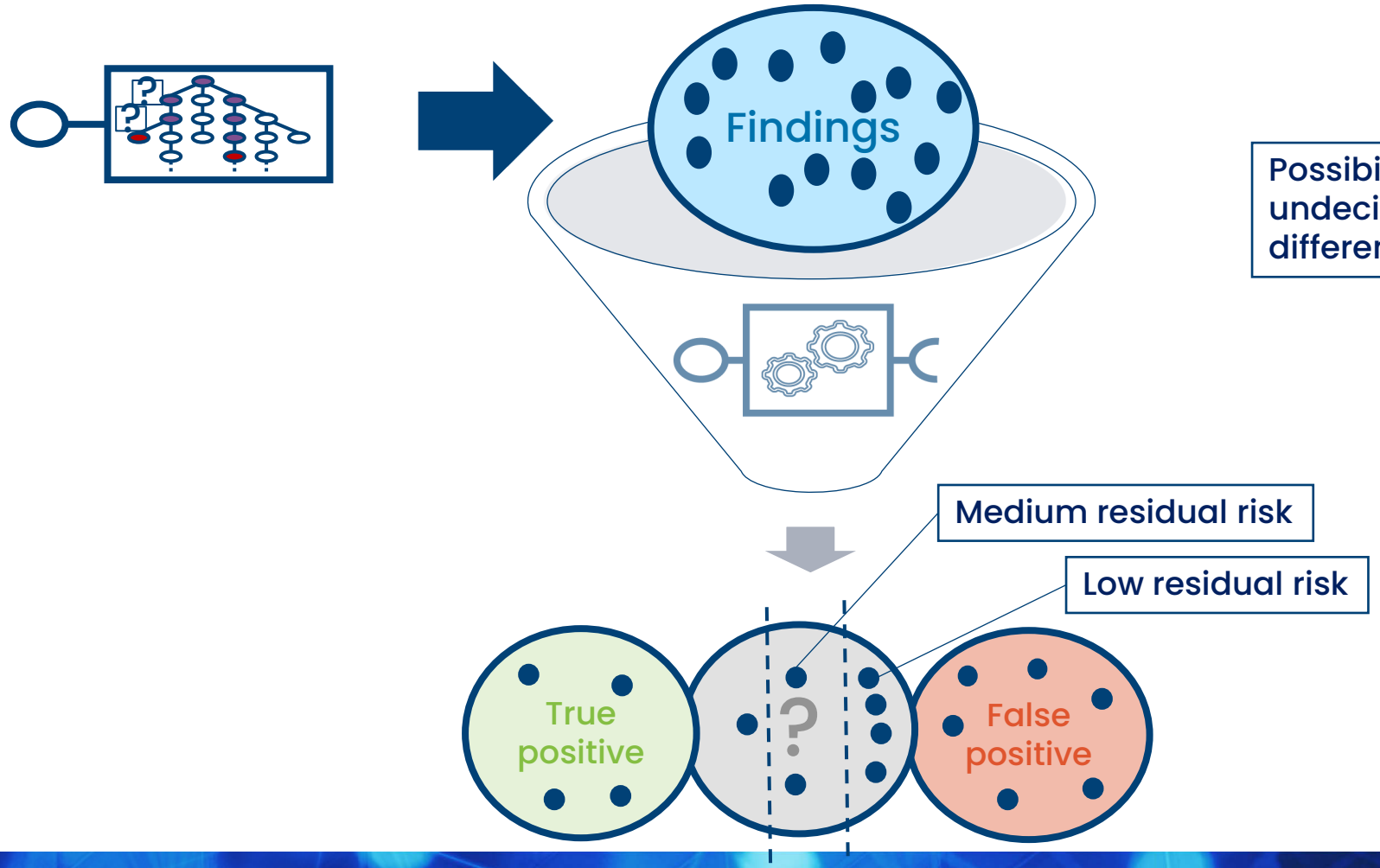


When to stop the test execution?

- Use relative GTE Values (no absolute value)
- Consider a calibration period
- Monitoring the trend in GTE values across multiple test cases
- End test execution when no more significant changes are monitored

Residual Risk Estimation

Verification of Static Analysis Findings



Possibility of grouping undecidable findings into different residual risk classes

Summary

- Static and dynamic analysis can benefit from each other
- Dynamic analysis can be used to verify static analysis findings
- Good-Turing estimation can estimate the residual risk of a test campaign

Even if tests does not provide absolute evidence,
a measure of evaluation can be provided
to reduce the degree of uncertainty

Thank You!

Any further questions?

Contact me:
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References

- Good, Irving J. "The population frequencies of species and the estimation of population parameters." *Biometrika* 40.3-4 (1953): 237-264.
- Böhme, Marcel. "STADS: Software testing as species discovery." *ACM Transactions on Software Engineering and Methodology (TOSEM)* 27.2 (2018): 1-52.
- https://www.fuzzingbook.org/html/WhenToStopFuzzing.html
- Gale, William A., and Geoffrey Sampson. "Good-turing frequency estimation without tears." *Journal of quantitative linguistics* 2.3 (1995): 217-237.
- Can Good-Turing Frequency Estimation Tell Us When to Stop Fuzzing? (Blog) https://bshastry.github.io/2018/10/08/good-turing-fuzzing.html

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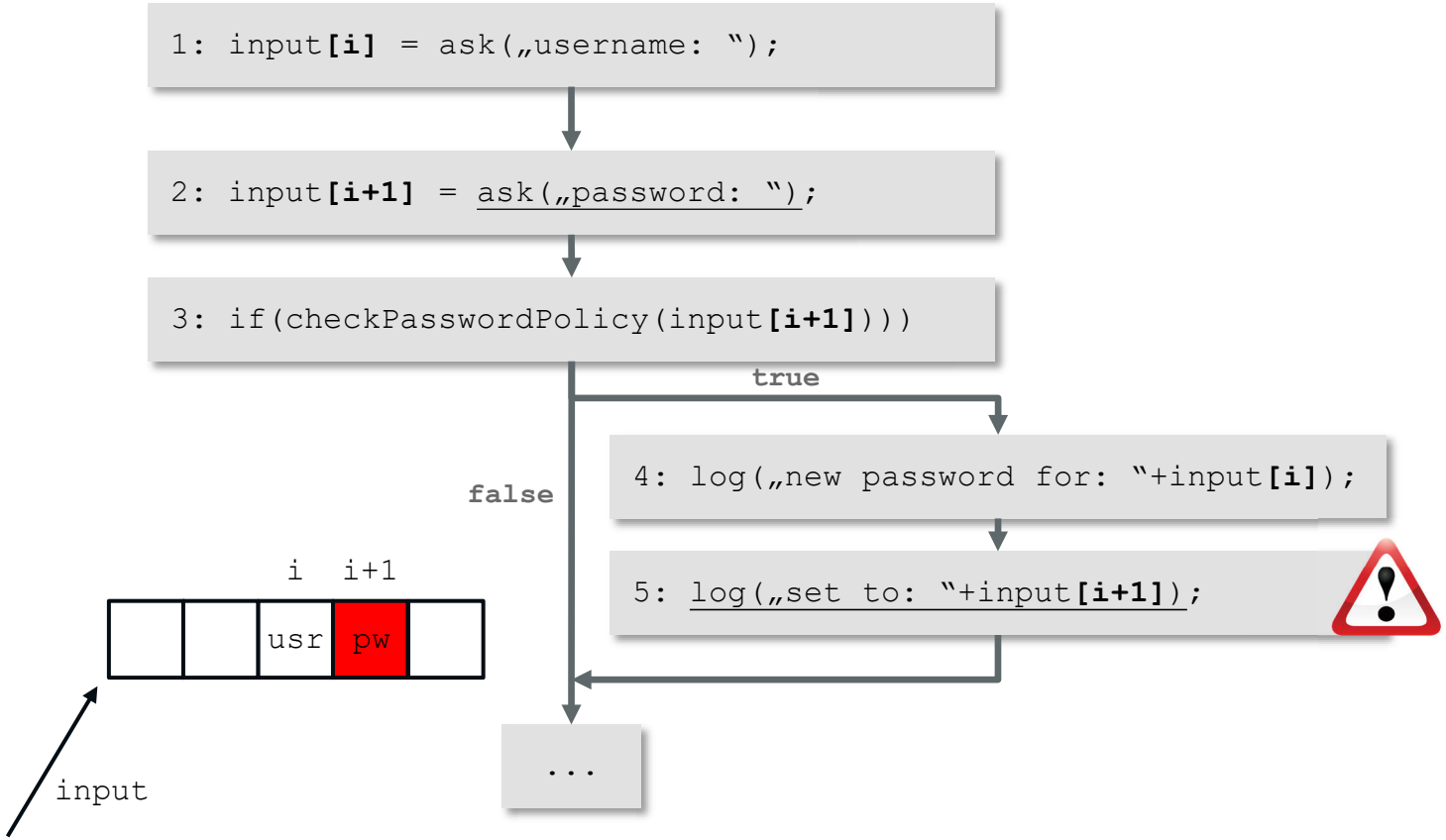
Example: Implementation of a password change

Password leak in line 5!

(Password from line 2)



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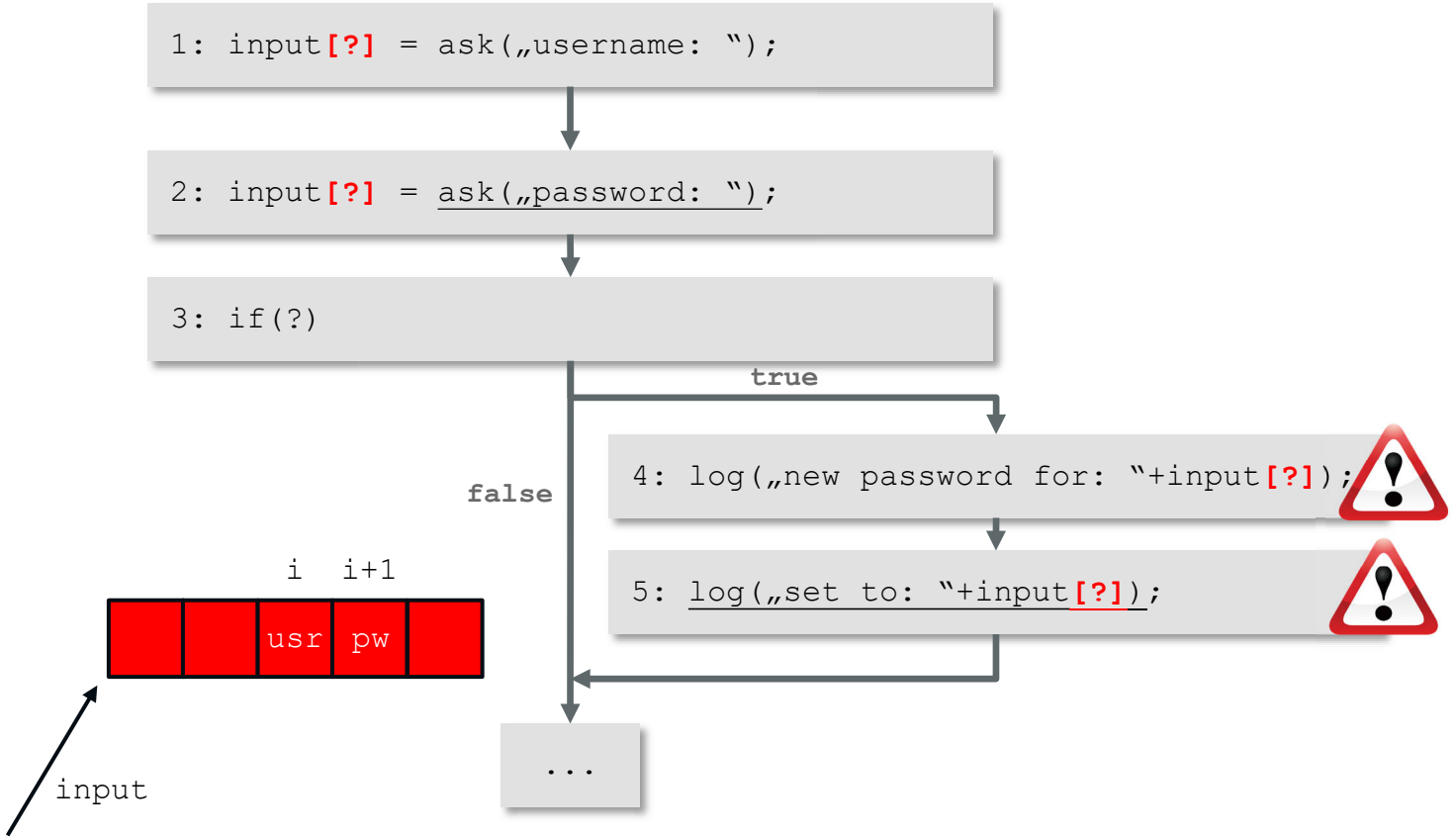
Static Analysis

Common approximation:

- Abstracting path constraints
- Abstraction of array indices

➡ Wrong warning in line 4



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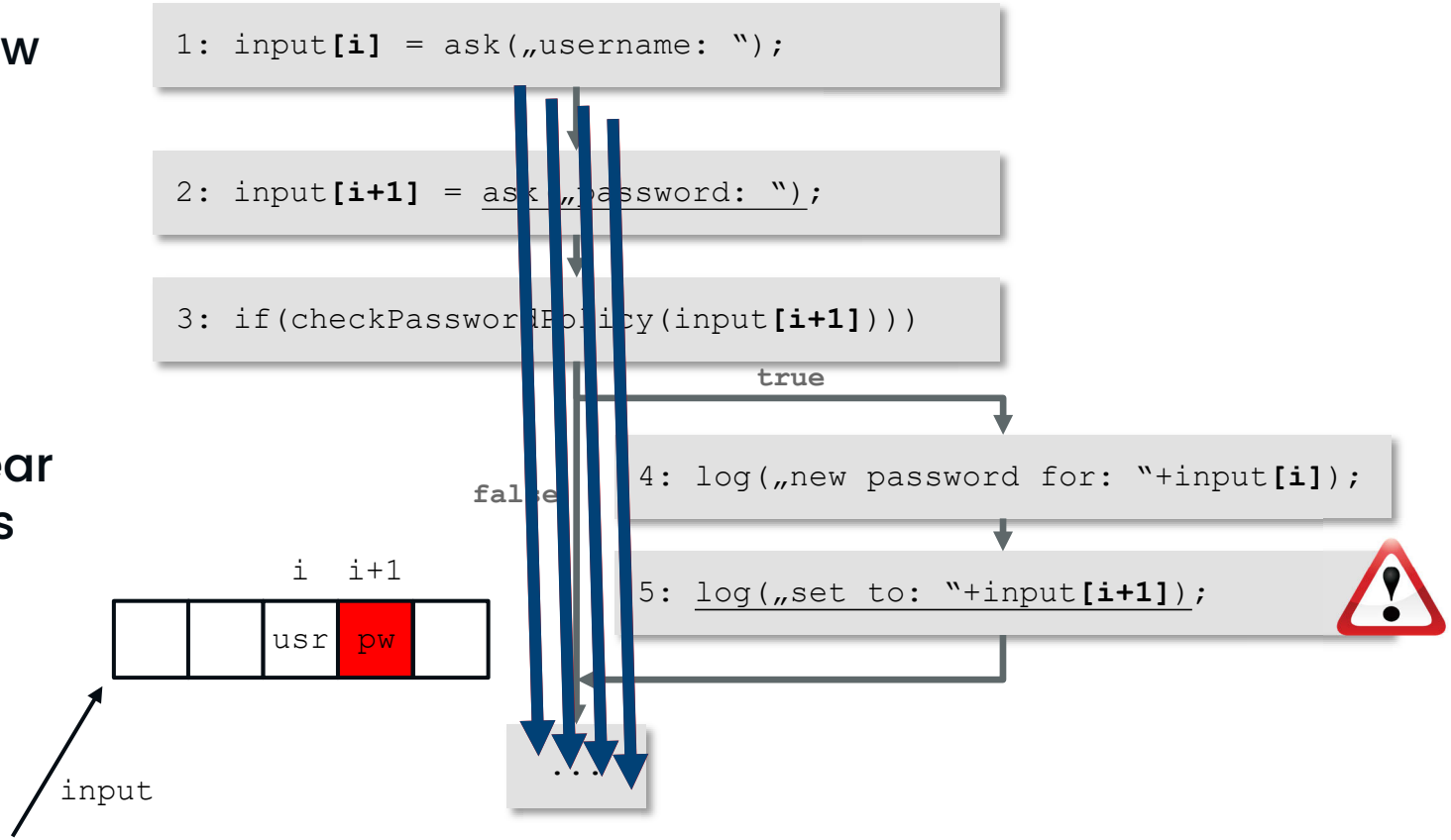
Dynamic Analysis

- Probability to execute line 5 very low
- Vulnerability remains undetected

AND

- If password leak is observed, unclear where the vulnerable line of code is



Good-Turing Estimator

How does it work

GT Estimation:

$$\mathrm{P'_r} = \frac{1}{N}(r+1)\frac{n_{r+1}}{n_r}$$

- P'_0 the probability for all unobserved species ("missing mass")
- P'_r the probability to observe r individuals for species X
- r number of individuals that have been observed for species X
- n_r number of species that were seen exactly r times
- N is the total number of counts

Good-Turing Estimator

How does it work

Set: {a, b, c, d, e, f, g}

Sample data: "aabdeeefff" *(N = 10)*

GT Estimation: $P'_r = \frac{1}{N}(r+1)\frac{n_{r+1}}{n_r}$

- a = 2 times → r = 2
- b = 1 time → r = 1
- c = 0 times → r = 0
- d = 1 time → r = 1
- e = 3 times → r = 3
- f = 3 times → r = 3
- g = 0 times → r = 0

$n_0 = 2$

$n_1 = 2$

$n_2 = 1$

$n_3 = 2$

$P'(c,g) = P'_0 = \frac{1}{10} * \frac{2}{2} = \frac{1}{10}$

$P'(b,d) = P'_1 = \frac{2}{10} * \frac{1}{2} = \frac{1}{10}$

$P'(a) = P'_2 = \frac{3}{10} * \frac{2}{1} = \frac{6}{10}$

$P'(e,f) = P'_3 = \frac{4}{10} * \frac{?}{3} = \frac{?}{10}$

Use interpolation for higher counts or lacks