# CSE P 504

Advanced topics in Software Systems

Fall 2022

**Statistical fault localization**

November 14, 2022

## Today

- Recap: invariants and metamorphic testing
- Automated debugging
  - **Statistical fault localization**
  - Automated patch generation
- Defect prediction

**Recap: invariants and metamorphic testing**

## Kick-starting the discussion

**Six groups (2 groups per question)**

1. What is a program invariant? What guarantees does Daikon provide for its discovered invariants?
2. What is a partial test oracle, a follow-up test input, and a metamorphic relation?
3. How are invariants and metamorphic relations similar and how are they different? (Context: using them as partial test oracles in software testing.)

Post open questions/confusions to Slack (#lectures).

# Recap: Pre/post-conditions and invariants

```
double avgAbs(double[] nums) {
  int n = nums.length;
  double sum = 0;

  int i = 0;
  while (i != n) {
    if(nums[i]>0) {
     sum = sum + nums[i];
    else {
     sum = sum - nums[i];
    }
    i = i + 1;
  }

  return sum / n;
}
```

**Entry point**

**Exit point**

# Recap: data diversity and metamorphic testing

**Simple case: related inputs with identical outcomes**

- Expected output for a given input is unknown
- Two related inputs must result in the same output
- Example: `abs(x) == abs(-x)`

**Generalization: related inputs and related outputs**

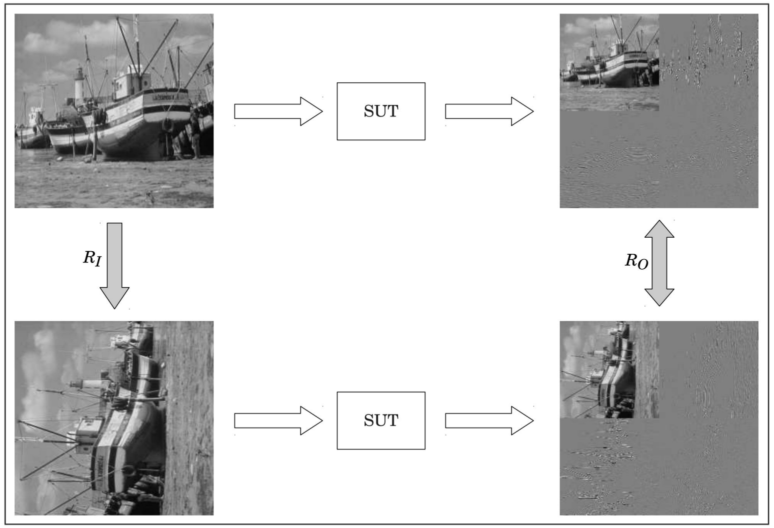
- Input $i_1$ yields (unknown) output $o_1$ (initial input)
- $R_i$: $i_1 \Rightarrow i_2$ (follow-up input)
- $R_o$: $o_1 \Rightarrow o_2$ (necessary condition)

# Recap: data diversity and metamorphic testing

**Generalization: related inputs and related outputs**

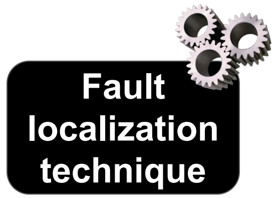
- A metamorphic relation defines a program property, such that for any given input $i_1$:
  - $o_1 = p(i_1)$ ***p*: *SUT*** *(System under test)*
  - $i_2 = f(i_1)$ ***f*: *$R_i$*** *(Input relation)*
  - $o_2 = g(o_1)$ ***g*: *$R_o$*** *(Output relation)*
- A test case in metamorphic testing asserts on the necessary condition $o_2 = g(o_1)$.

# Recap: data diversity and metamorphic testing



# Statistical fault localization

## What is statistical fault localization?

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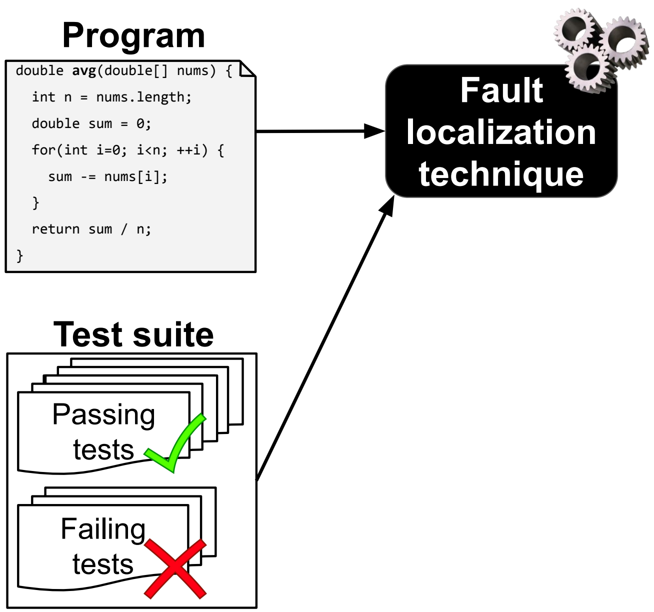
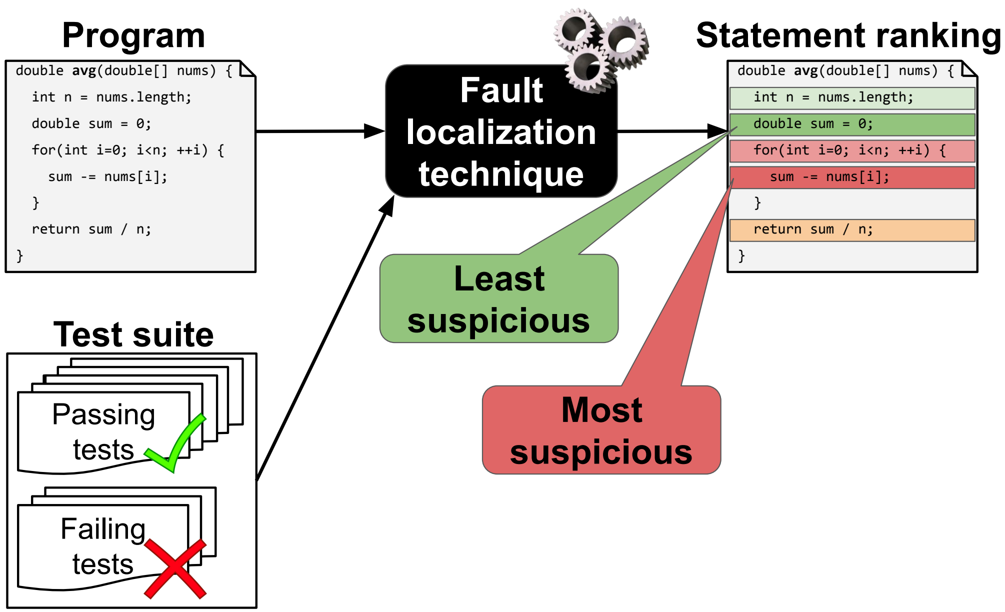



## What is statistical fault localization?



## Statistical fault localization: how it works

**Program**

```
double avg(double[] nums) {
  int n = nums.length;
  double sum = 0;
  for(int i=0; i<n; ++i) {
    sum -= nums[i];
  }
  return sum / n;
}
```

## Statistical fault localization: how it works

**Program**

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- Run all tests
  - t1 passes

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  - t4 fails

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- Run all tests
  - t1 passes
  - t2 passes
  - t3 passes
  - t4 fails
  - t5 fails

Which line(s) seem(s) most suspicious?

## Spectrum-based fault localization

**Program**

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```

**Spectrum-based FL (SBFL)**

- **Compute** suspiciousness **per statement**
- Example:

$$S(s) = \frac{failed(s)/totalfailed}{failed(s)/totalfailed + passed(s)/totalpassed}$$

Statement **covered** by **failing test**
Statement **covered** by **passing test**

**More → statement is more suspicious!**

## Spectrum-based fault localization

**Program**

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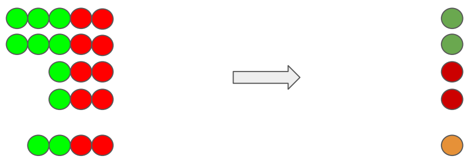
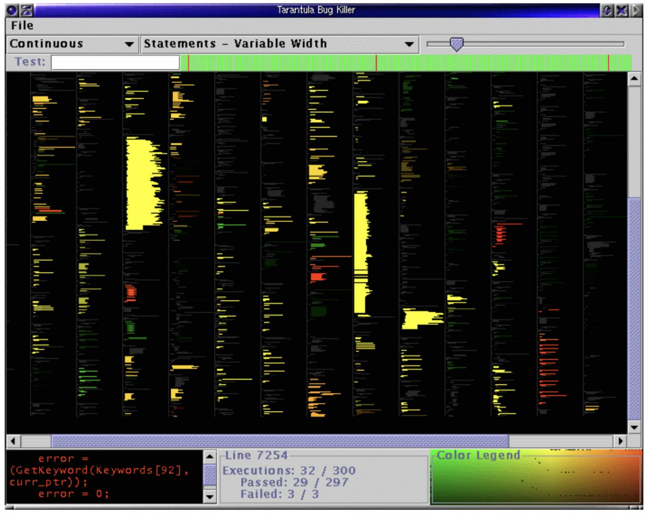
**Visualization:** the key idea behind Tarantula.



Jones et al., *Visualization of test information to assist fault localization*, ICSE'02

# Spectrum-based fault localization

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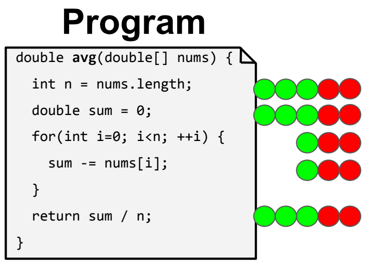


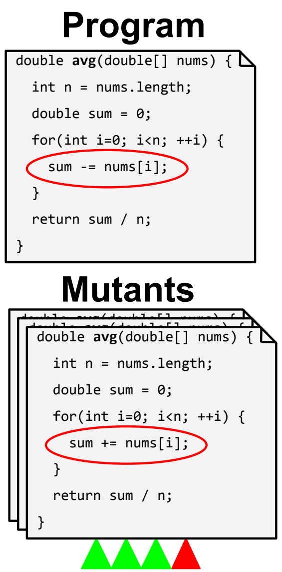

## Spectrum-based FL (SBFL)

- **Compute** suspiciousness **per statement**
- Example:

$$S(s) = \frac{failed(s)/totalfailed}{failed(s)/totalfailed + passed(s)/totalpassed}$$

**Suspiciousness formula:** how to compute it (intuitively)?

# Mutation-based fault localization




## Mutation-based FL (MBFL)

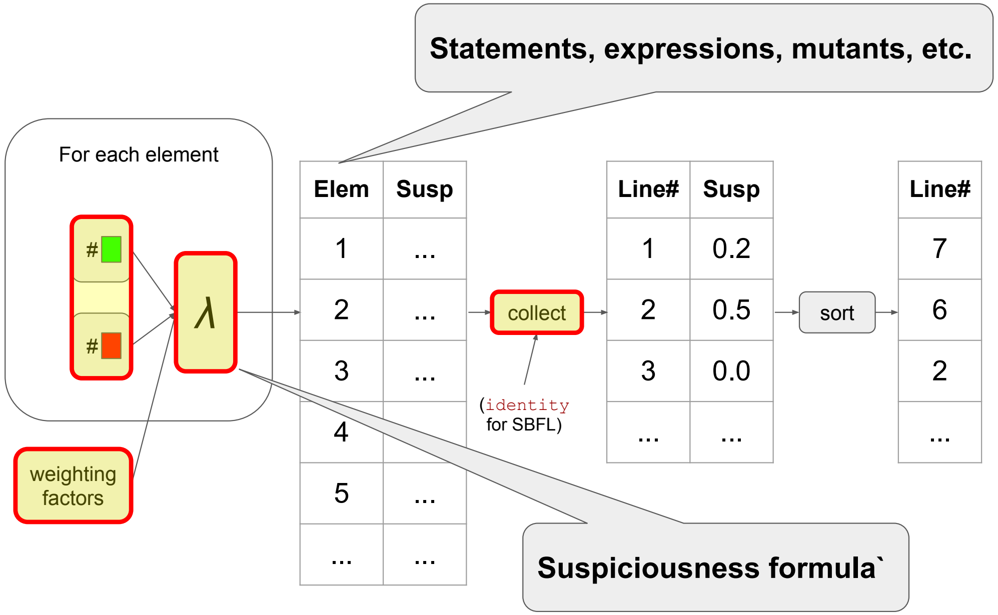
- **Compute** suspiciousness **per mutant**
- **Aggregate** results **per statement**
- Example:

$$S(s) = \max_{m \in mut(s)} \frac{failed(m)}{\sqrt{totalfailed \cdot (failed(m) + passed(m))}}$$

▲Mutant **affects failing test** outcome
▲Mutant **breaks passing test**

**More ▲ ➡ mutant is more suspicious!**

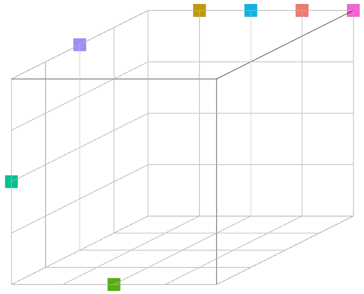
# Common structure of SBFL and MBFL



## What design decisions matter?

**Defined and explored a design space for SBFL and MBFL**

- 4 design factors (e.g., formula)



Pearson et al., *Evaluating and Improving Fault Localization*, ICSE'17

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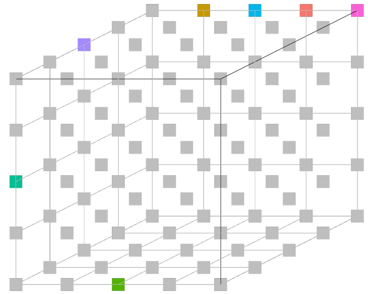

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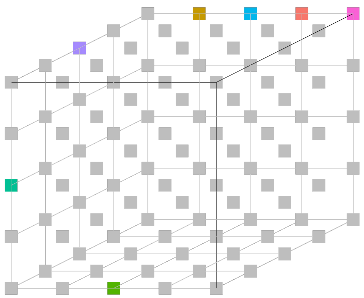

**Results**

- Most design decisions don't matter (in particular for SBFL)
- Definition of test-mutant interaction matters for MBFL
- Barinel, D*, Ochiai, and Tarantula are indistinguishable

Pearson et al., *Evaluating and Improving Fault Localization*, ICSE'17

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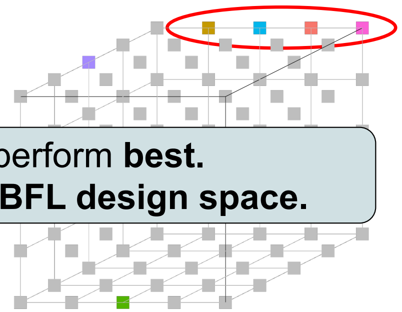

Existing **SBFL techniques** perform **best.**
**No breakthroughs** in the **MBFL/SBFL design space.**

- Most design decisions don't matter (in particular for SBFL)
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# Effectiveness of SBFL and MBFL

- Top-10 useful for practitioners[1].
- Top-200 useful for automated patch generation[2].

| Technique | Top-5 | Top-10 | Top-200 |
|---|---|---|---|
| Hybrid | 36% | 45% | 85% |
| DStar (*best SBFL*) | 30% | 39% | 82% |
| Metallaxis (*best MBFL*) | 29% | 39% | 77% |

What assumptions underpin these results? Are they realistic?

[1]Kochhar et al., *Practitioners' Expectations on Automated Fault Localization*, ISSTA'16
[2]Long and Rinard, *An analysis of the search spaces for generate and validate patch generation systems*, ICSE'16

**Automated patch generation**

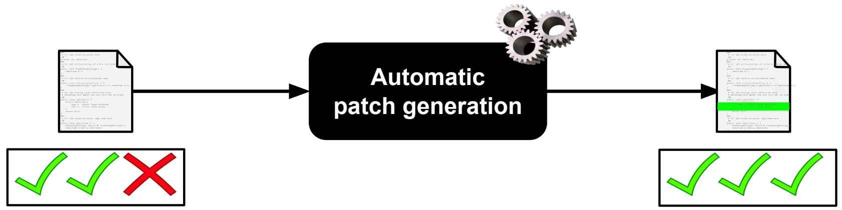
# Automatic patch generation (program repair)

**Generate-and-validate Approaches**


What are the **main components** of a (generate-and-validate) patch generation approach?

# Automatic patch generation (program repair)

**Generate-and-validate Approaches**




**Main components:**

- **Fault localization**
- Mutation + fitness evaluation
- Patch validation

## Defect prediction

## Defect prediction: the addressed problem

**Problem**

- QA is limited...

## Defect prediction: the addressed problem

**Problem**

- QA is limited...by time and money.

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- QA is limited...by time and money.
- How should we allocate limited QA resources?

# Defect prediction: the addressed problem

**Problem**

- QA is limited...by time and money.
- How should we allocate limited QA resources?
  - Focus on components that are most error-prone.
  - Focus on components that are most likely to fail in the field.

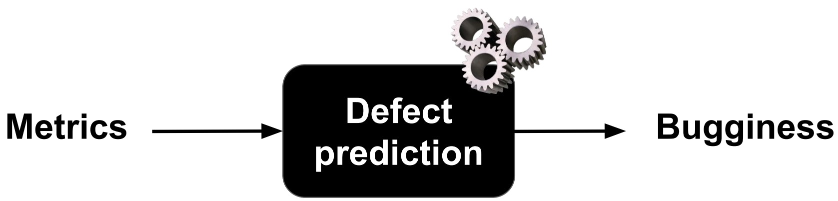
How do we know what components are critical or error-prone?

# Defect prediction: a bird's-eye view


**Model**

- Learn a model from historic data (same project vs. different project)

# Defect prediction: a bird's-eye view




**Model**

- Learn a model from historic data (same project vs. different project)

**Predictions**

- Classification: is a file/method buggy
- Ranking: how many bugs does a file/method contain

**Granularity**

- Most research has focused on file-level granularity

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Which type of prediction and what granularity are most useful?

## Defect prediction: a bird's-eye view


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What types of metrics matter?

## Defect prediction: metrics

**Change metrics**
- Source-code changes
- Code churn
- Previous bugs

**Code metrics**
- Complexity metrics (e.g., size, McCabe, dependencies)
- Design metrics (e.g., inheritance hierarchy)

**Organizational metrics**
- Team structure
- Contribution structure
- Communication

What metrics are most important?

## Defect prediction: some results

| Predictor | Precision | Recall |
| --- | --- | --- |
| Pre-Release Bugs | 73.80% | 62.90% |
| Test Coverage | 83.80% | 54.40% |
| Dependencies | 74.40% | 69.90% |
| Code Complexity | 79.30% | 66.00% |
| Code Churn | 78.60% | 79.90% |
| Org. Structure | 86.20% | 84.00% |

*From: N. Nagappan, B. Murphy, and V. Basili. The influence of organizational structure on software quality. ICSE 2008.*

## In-class exercise: fault localization