# CSE 503

Software Engineering

Winter 2021

**Dynamic vs. static analysis**

January 08, 2021

## Recap

- Logistics
- Why program analysis?
- A few first examples

## Today

- Manual program analysis: Code review
- Terminology and important concepts
- Static vs. dynamic analysis
- Paper discussion
  - Static and dynamic analysis: synergy and duality
  - Lessons from Building Static Analysis Tools at Google

## Code review

Different types of reviews

- Code/design review
- Informal walkthrough
- Formal inspection

A requirement for many safety-critical systems.

## Code review

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- Code/design review
- Informal walkthrough
- Formal inspection

```
double foo(double[] d) {
  int n = d.length;
  double s = 0;
  int i = 0;
  while (i<n)
  s = s + d[i];
  i = i + 1;
  double a = s / n;
  return a;
}
```

Anything that could be improved in this (Java) code?

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double avg(double[] nums) {
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Anything that could be improved in this (Java) code?

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Anything that could be improved in this (Java) code?

```
static OSStatus
SSLVerifySignedServerKeyExchange(...) {
        OSStatus err;
        ...
        if ((err = SSLHashSHA1.update(&hashCtx, &clientRandom)) != 0)
                goto fail;
        if ((err = SSLHashSHA1.update(&hashCtx, &serverRandom)) != 0)
                goto fail;
        if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
                goto fail;
                goto fail;
        if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
                goto fail;
        err = sslRawVerify(ctx, ctx->peerPubKey, dataToSign, dataToSignLen, signature, signatureLen);
        if(err) {
                sslErrorLog("SSLDecodeSignedServerKeyExchange: sslRawVerify returned %d\n", (int)err);
                goto fail;
        }
        fail:
                SSLFreeBuffer(&signedHashes);
                SSLFreeBuffer(&hashCtx);
                return err;
}
```

Anything wrong with that code?

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static OSStatus
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```

Apple's "goto fail" bug:
A security vulnerability for 2 years!

Anything wrong with that code?

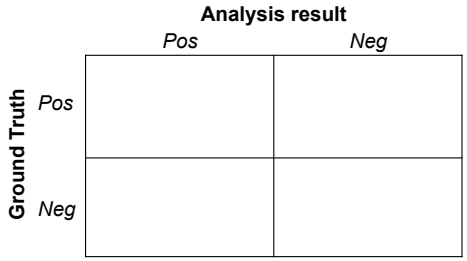
## Terminology and important concepts

**Form 4 groups, define the following terms, and give examples related to program analysis:**

1. Precision vs. Recall (and FP/FN/TP/TN)
2. Soundness vs. Completeness
3. Concrete domain vs. Abstract domain
4. Accuracy vs. Precision (and conservative analysis)

## Terminology and important concepts

1. Precision vs. Recall (and FP/FN/TP/TN)



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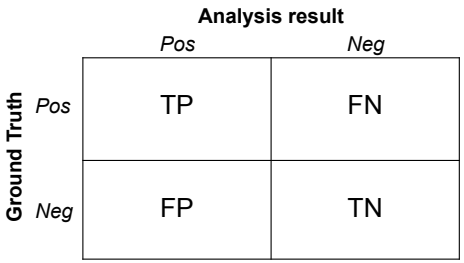


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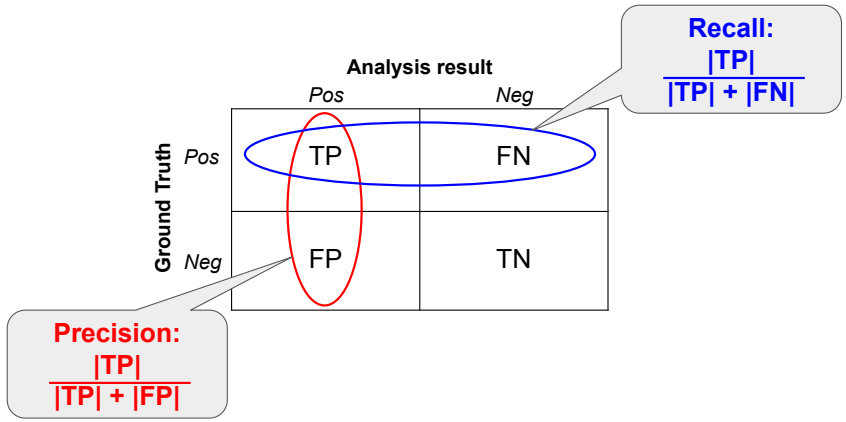


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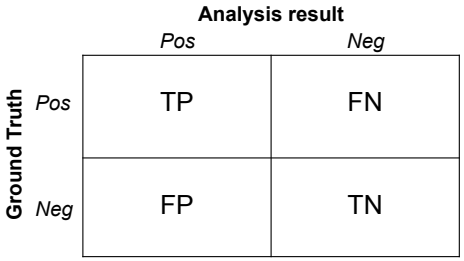


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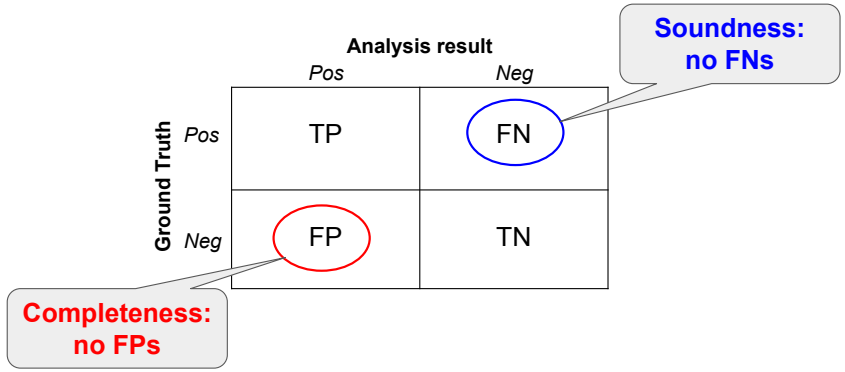


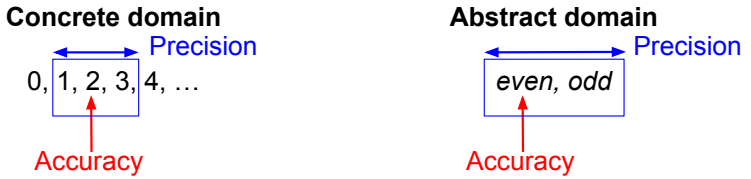
## Terminology and important concepts

1. Precision vs. Recall (and FP/FN/TP/TN)
2. Soundness vs. Completeness
3. Concrete domain vs. Abstract domain

| Concrete domain | Abstract domain |
| --- | --- |
| 0, 1, 2, 3, 4, … | *even, odd* |

## Terminology and important concepts

1. Precision vs. Recall (and FP/FN/TP/TN)
2. Soundness vs. Completeness
3. Concrete domain vs. Abstract domain
4. Accuracy vs. Precision




## Static vs. dynamic analysis

**What are the key differences?**

## Static vs. dynamic analysis: overview

**Static analysis**

- Reason about the program without executing it.
- Build an abstraction of run-time states.
- Reason over abstract domain.
- Prove a property of the program.
- Sound* but conservative.

* Some static analyses are unsound; dynamic analyses can be sound.

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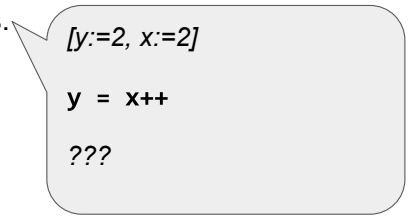


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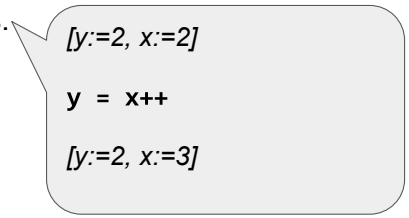


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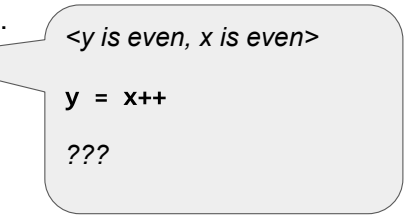


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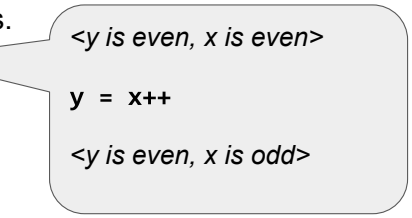


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*<y is prime, x is prime>*

`y = x++`

*???*

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*<y is prime, x is prime>*

`y = x++`

*<y is prime, x is anything>*

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# Static vs. dynamic analysis: overview

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*<y is prime, x is prime>*

`y = x++`

*<y is prime, x is even>*

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# Static vs. dynamic analysis: overview

**Static analysis**

- Reason about the program without executing it.
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The statement
"**f returns a non-negative value**"
is weaker (but easier to establish)
than the statement
"**f returns the absolute value of its argument**".

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# Static vs. dynamic analysis: overview

**Static analysis**

- Reason about the program without executing it.
- Build an abstraction of run-time states.
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- Prove a property of the program.
- Sound* but conservative.

**Dynamic analysis**

- Reason about the program based on some program executions.
- Observe concrete behavior at run time.
- Improve confidence in correctness.
- Unsound* but precise.

* Some static analyses are unsound; dynamic analyses can be sound.

# Static analysis: examples

Type checking (also compiler optimizations)

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

  int i = 0.0;
  while (i<n) {
    sum = sum + nums[i];
    i = i + 1;
  }
  double avg = sum / n;

  return avg;
}
```

```
double avg(double[] nums) {
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# Static analysis: examples

Rule/pattern-based analysis (PMD, Findbugs, etc.).

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# Dynamic analysis: examples

Software testing (also monitoring and profiling)

```
double avg(double[] nums) {
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    sum = sum + nums[i];
    i = i + 1;

  double avg = sum / n;

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}
```

A test for the avg function:

```
@Test
public void testAvg() {
  double nums =
      new double[]{1.0, 2.0, 3.0});
  double actual = Math.avg(nums);
  double expected = 2.0;
  assertEquals(expected,actual,EPS);
}
```

## Static vs. dynamic analysis

**What are the key challenges?**

## Static vs. dynamic analysis: challenges

**Static analysis: choose good abstractions**

- Chosen abstraction **determines cost** (time and space)
- Chosen abstraction **determines precision** (what information is lost)

**Dynamic analysis: choose good representatives (tests)**

- Chosen tests **determine cost** (time and space)
- Chosen tests **determine accuracy** (what executions are never seen)

## Static vs. dynamic analysis: summary

| Static analysis | Dynamic analysis |
|---|---|
| Abstract domain | Concrete execution |
| Conservative due to abstraction | Precise no approximation |
| Sound due to conservatism | Unsound, does not generalize |
| Slow if precise | Slow if exhaustive |

## Today

- Manual program analysis: Code review
- Terminology and important concepts
- Static vs. dynamic analysis
- Paper discussion
  - Static and dynamic analysis: synergy and duality
  - Lessons from Building Static Analysis Tools at Google

## Google: Why developers don't use static analysis?

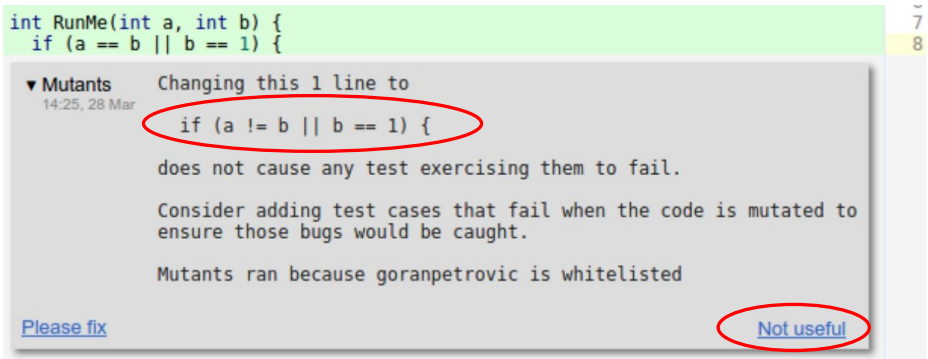
- **Not integrated** into the developer's workflow.
- Reported **issues** are **not actionable**.
- Developers **do not trust the results** (FPs).
- Fixing an issue **is too expensive** or risky.
- Developers **do not understand** the reported **issues**.
- **Issues** theoretically possible but **don't manifest in practice.**

*"Produce **less than 10% effective false positives**. Developers should feel the check is pointing out an actual issue at least 90% of the time."*

## Google: effective false positive

- *We consider an issue to be an "**effective false positive**" if developers did not take positive action after seeing the issue.*
- *If an analysis incorrectly reports an issue, but developers make the fix anyway to improve code readability or maintainability, that is not an effective false positive.*
- *If an analysis reports an actual fault, but the developer did not understand the fault and therefore took no action, that is an effective false positive.*

## Google: example (mutation-based testing)




*Petrovic et al., ICSTW'18*

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Do you agree with this characterization?
Is effective false positive rate an adequate measure?