# CSE 503

Software Engineering

**Static and dynamic analysis**

# 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

Different types of reviews

- 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?

# Code review

Different types of reviews

- Code/design review
- Informal walkthrough
- Formal inspection

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

  int i = 0;
  while (i<n)
    sum = sum + nums[i];
    i = i + 1;

  double avg = sum / n;

  return avg;
}
```

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

# Code review

Different types of reviews

- Code/design review
- Informal walkthrough
- Formal inspection

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

  int i = 0;
  while (i<n)
    sum = sum + nums[i];
    i = i + 1;

  double avg = sum / n;

  return avg;
}
```

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?

```
static OSStatus
SSLVerifySignedServerKeyExchange(...) {
        OSStatus err;

        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;
}
```

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

Anything wrong with that code?

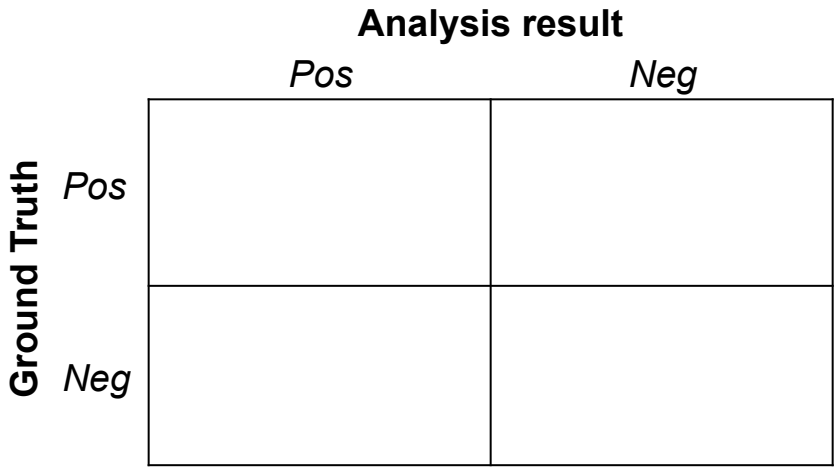
# Terminology and important concepts


**Form 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)

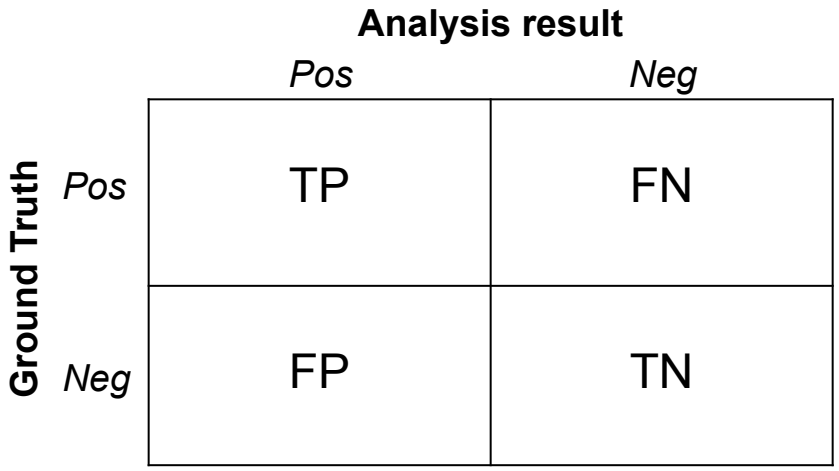
# Terminology and important concepts

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



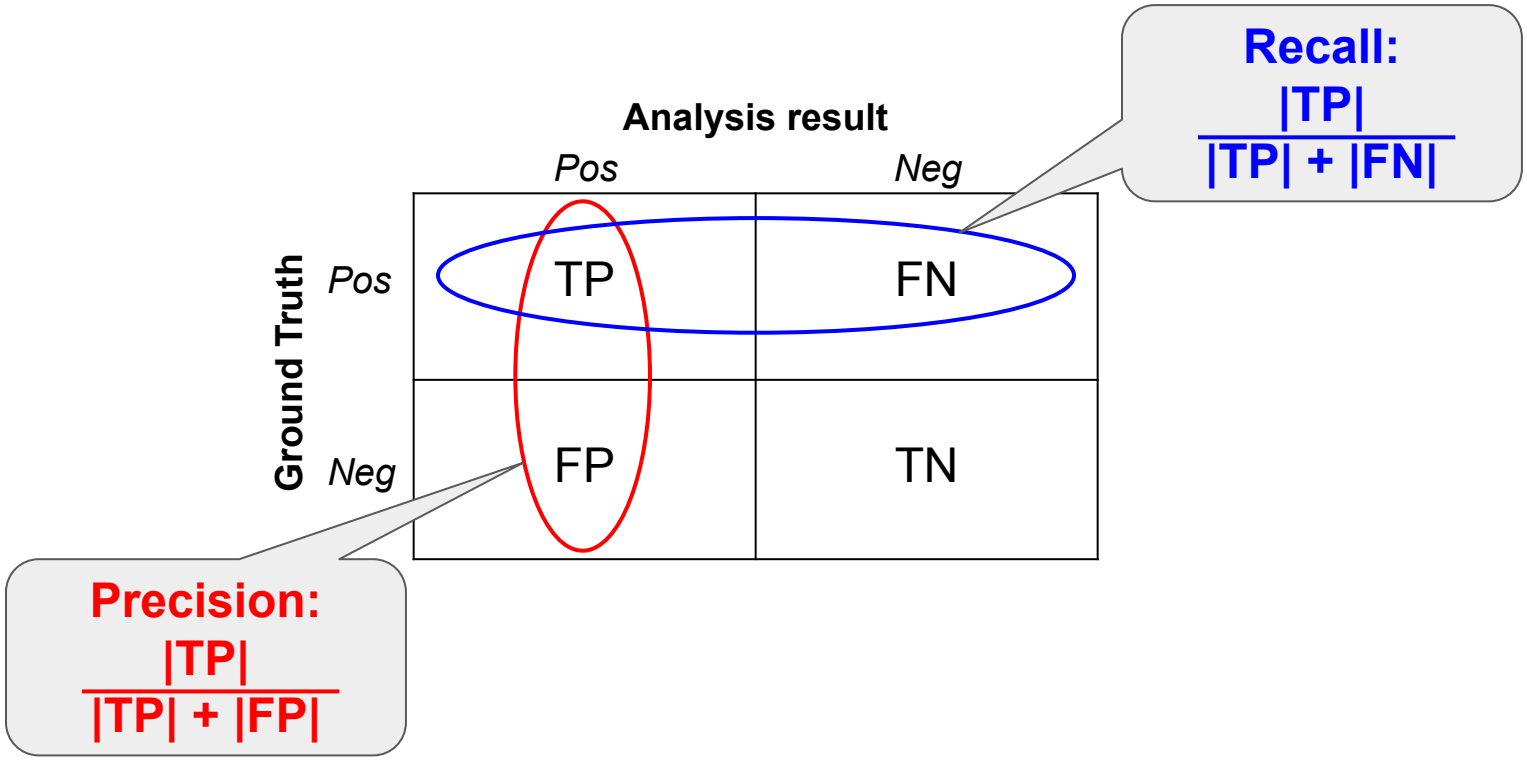
# Terminology and important concepts

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



# Terminology and important concepts

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



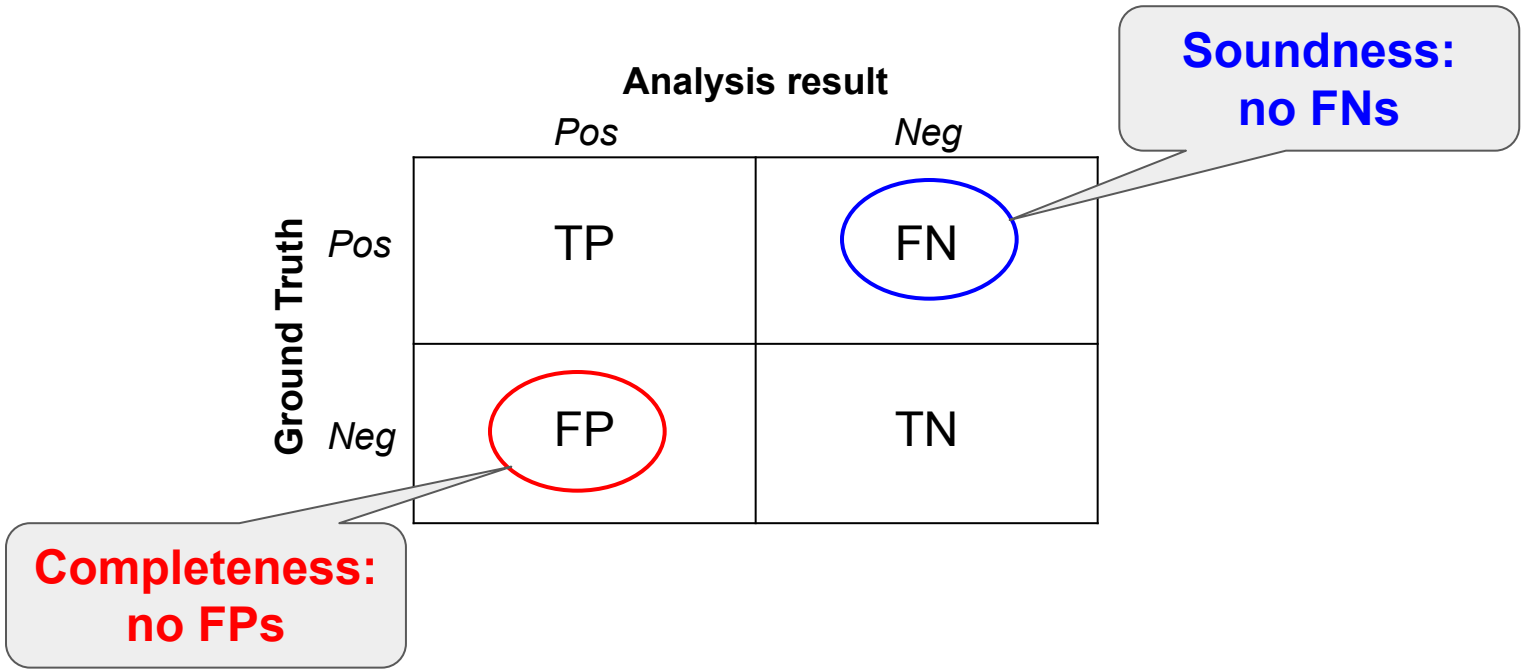
# Terminology and important concepts

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

| | | **Analysis result** | |
|---|---|---|---|
| | | *Pos* | *Neg* |
| **Ground Truth** | *Pos* | TP | FN |
| | *Neg* | FP | TN |

# Terminology and important concepts

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



# 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


Accuracy = correct estimate
Precision = small estimate

An analysis/measure can be precise and inaccurate at the same time!

# 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.

# Selecting an abstract domain

⟨ x = 2; y = 5 ⟩

```
y = x++;
```

⟨ x = 3; y = 2 ⟩

⟨ x = { 3, 5, 7 }; y = { 9, 11, 13 } ⟩

```
y = x++;
```

⟨ x = { 4, 6, 8 }; y = { 3, 5, 7 } ⟩

⟨ x is odd; y is odd ⟩

```
y = x++;
```

⟨ x is even; y is odd ⟩

⟨x=3, y=11⟩, ⟨x=5, y=9⟩, ⟨x=7, y=13⟩

```
y = x++;
```

⟨x=4, y=3⟩, ⟨x=6, y=5⟩, ⟨x=8, y=7⟩

⟨ x is prime; y is prime ⟩

```
y = x++;
```

⟨ x is anything; y is prime ⟩

⟨ $x_n = f(a_{n-1},\ldots,z_{n-1})$; $y_n = f(a_{n-1},\ldots,z_{n-1})$ ⟩

```
y = x++;
```

⟨ $x_{n+1} = x_n + 1$; $y_{n+1} = x_n$ ⟩

# 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.

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**".

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

# 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.

## 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) {
  int n = nums.length;
  double sum = 0;

  int i = 0;
  while (i<n) {
    sum = sum + nums[i];
    i = i + 1;
  }
  double avg = sum / n;

  return avg;
}
```

# Static analysis: examples

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

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

  int i = 0;
  while (i<n)
    sum = sum + nums[i];
    i = i + 1;

  double avg = sum / n;

  return avg;
}
```

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

  int i = 0;
  while (i<n) {
    sum = sum + nums[i];
    i = i + 1;
  }
  double avg = sum / n;

  return avg;
}
```

# Dynamic analysis: examples

Software testing (also monitoring and profiling)

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

  int i = 0;
  while (i<n)
    sum = sum + nums[i];
    i = i + 1;

  double avg = sum / n;

  return avg;
}
```

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**

- Abstract domain
- Conservative due to abstraction
- Sound due to conservatism
- Slow if precise

**Dynamic analysis**

- Concrete execution
- Precise no approximation
- Unsound, does not generalize
- 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?

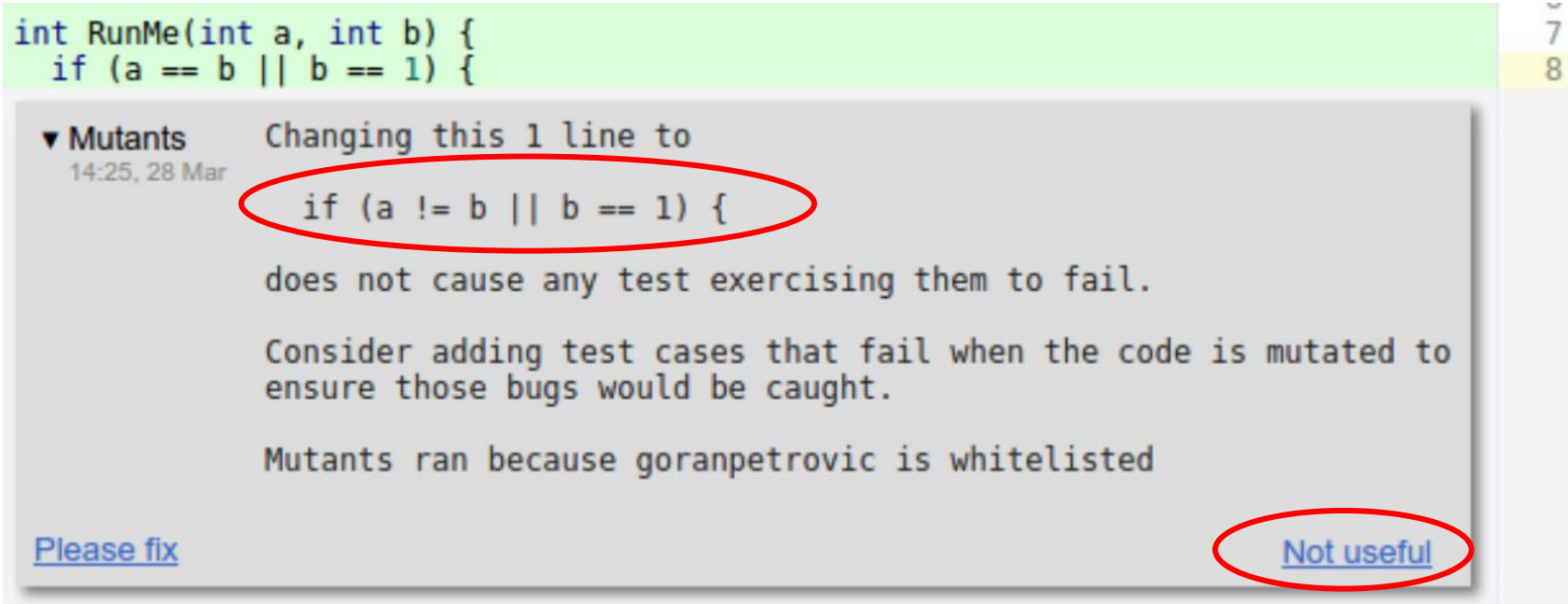
- **Not integrated** into the developer's workflow.
- Reported **issues** are **not actionable**.
- Developers **do not trust the results** (FPs).
- Fixing an issue **is too expensive** or risky.
- Developers **do not understand** the reported **issues**.
- **Issues** theoretically possible but **don't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

# 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.*

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