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?

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

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- Code/design review
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```java
double avg(double[] nums) {
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  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;
```

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

```
        if ((err = SSLHashSHA1.update(&hashCtx, &signedParams)) != 0)
                goto fail;
                goto fail;
        if ((err = SSLHashSHA1.final(&hashCtx, &hashOut)) != 0)
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        }
        fail:
                SSLFreeBuffer(&signedHashes);
                SSLFreeBuffer(&hashCtx);
                return err;
}
```

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)

		Analysis result	
		Pos	*Neg*
Ground Truth	*Pos*		
	Neg		

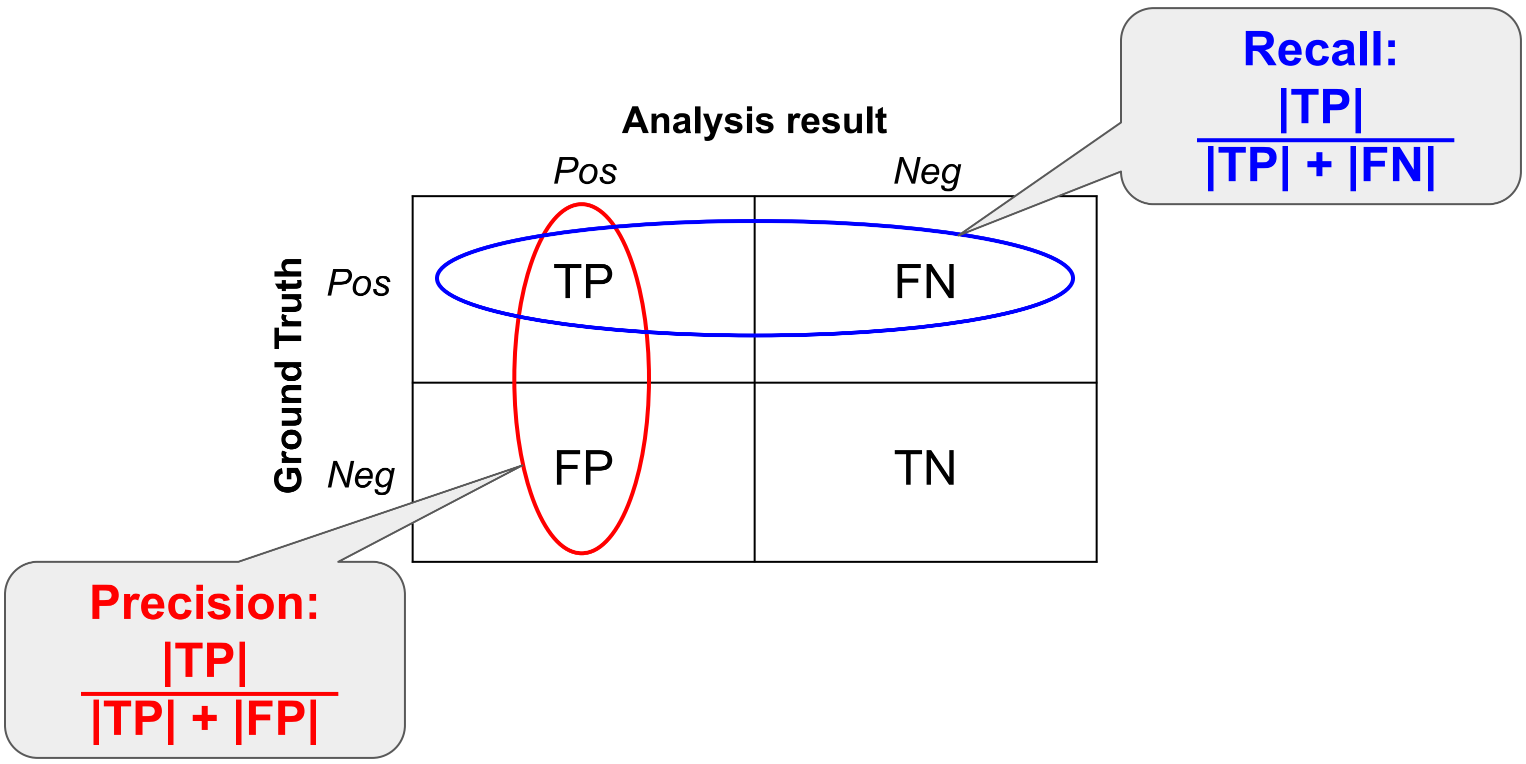
Terminology and important concepts

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

		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)



Terminology and important concepts

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		Analysis result	
		Pos	*Neg*
Ground Truth	*Pos*	TP	FN
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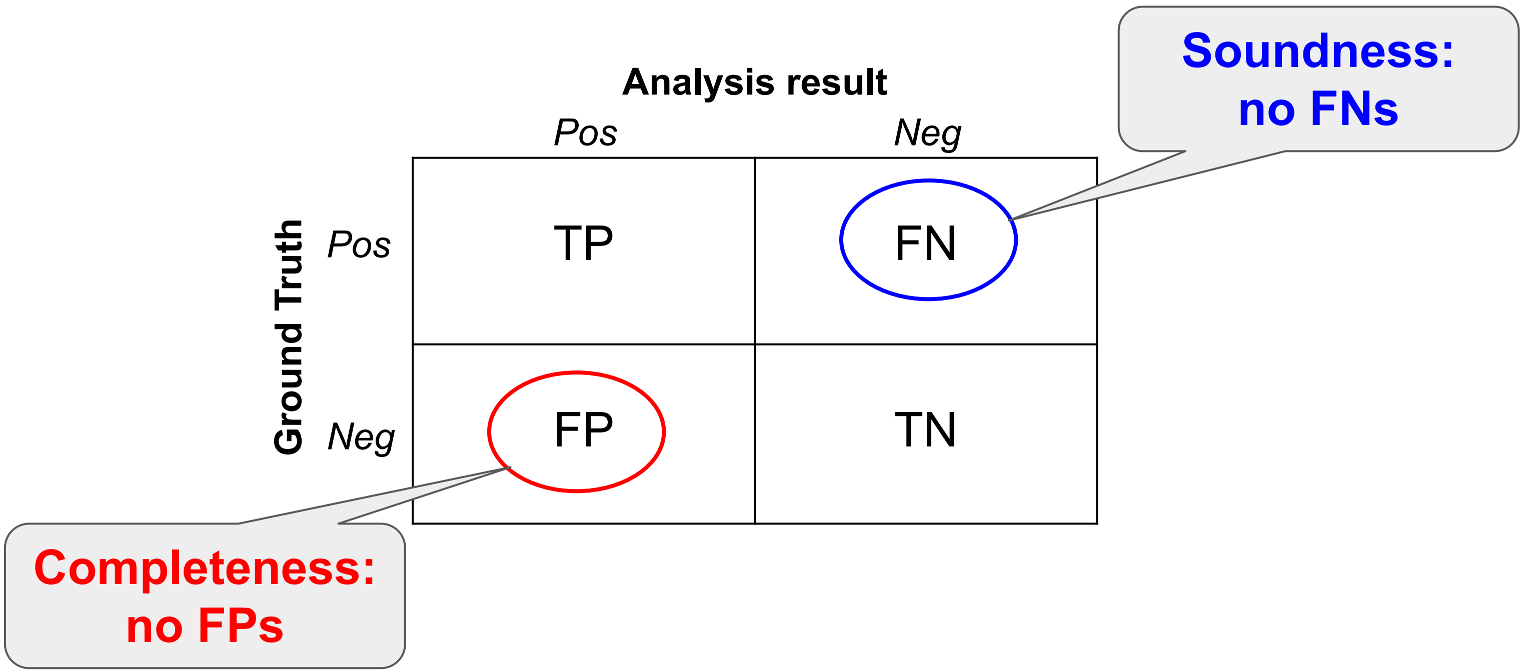

Terminology and important concepts

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.

Static vs. dynamic analysis: overview

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[y:=2, x:=2]

```
y = x++
```

???

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

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[y:=2, x:=2]

y = x++

[y:=2, x:=3]

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- Prove a property of the program.
- Sound* but conservative.

<y is even, x is even>

```
y = x++
```

???

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- Sound* but conservative.

<y is even, x is even>

y = x++

<y is even, x is odd>

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Static analysis

- Reason about the program without executing it.
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<y is prime, x is prime>

```
y = x++
```

???

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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.

<y is prime, x is prime>

```
y = x++
```

<y is anything, x is anything>

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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.
- Reason over abstract domain.
- Prove a property of the program.
- Sound* but conservative.

<y is prime, x is prime>

```
y = x++
```

<y is prime, x is even>

* 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.

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;
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  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

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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)

```
int RunMe(int a, int b) {                                7
  if (a == b || b == 1) {                                8
```

▾ **Mutants**
14:25, 28 Mar

```
Changing this 1 line to

  if (a != b || b == 1) {

does not cause any test exercising them to fail.

Consider adding test cases that fail when the code is mutated to
ensure those bugs would be caught.

Mutants ran because goranpetrovic is whitelisted
```

Please fix   Not useful

Petrovic et al., ICSTW'18

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Do you agree with this characterization?

Is effective false positive rate an adequate measure?