CSE 503

Software Engineering

Winter 2021

Partial test oracles

February 12, 2021

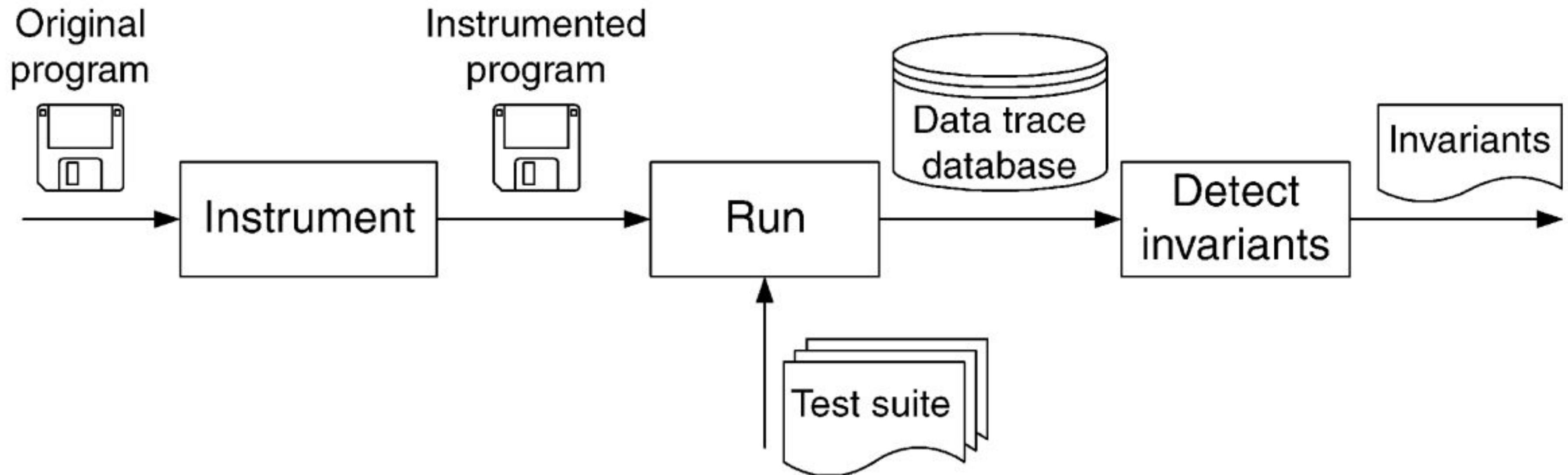
Recap: Preconditions, postconditions, invariants

```
1  double avgAbs(double[] nums) {
2   int n = nums.length;
3   double sum = 0;
4
5   int i = 0;
6   while (i != n) {
7     if(nums[i]>0) {
8      sum = sum + nums[i];
9     else {
10     sum = sum - nums[i];
11    }
12    i = i + 1;
13  }
14
15  return sum / n;
16 }
```

Entry point

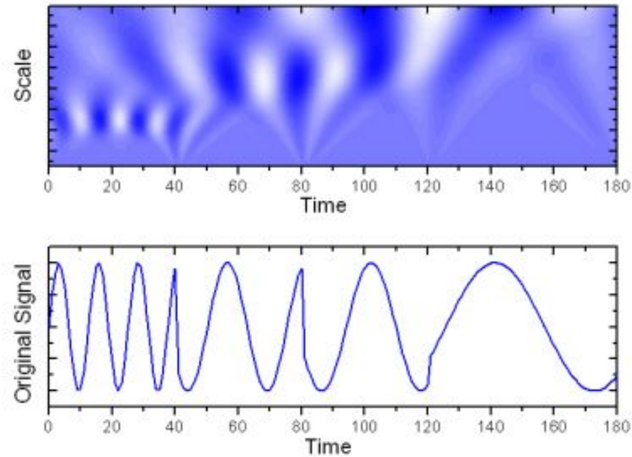
Exit point

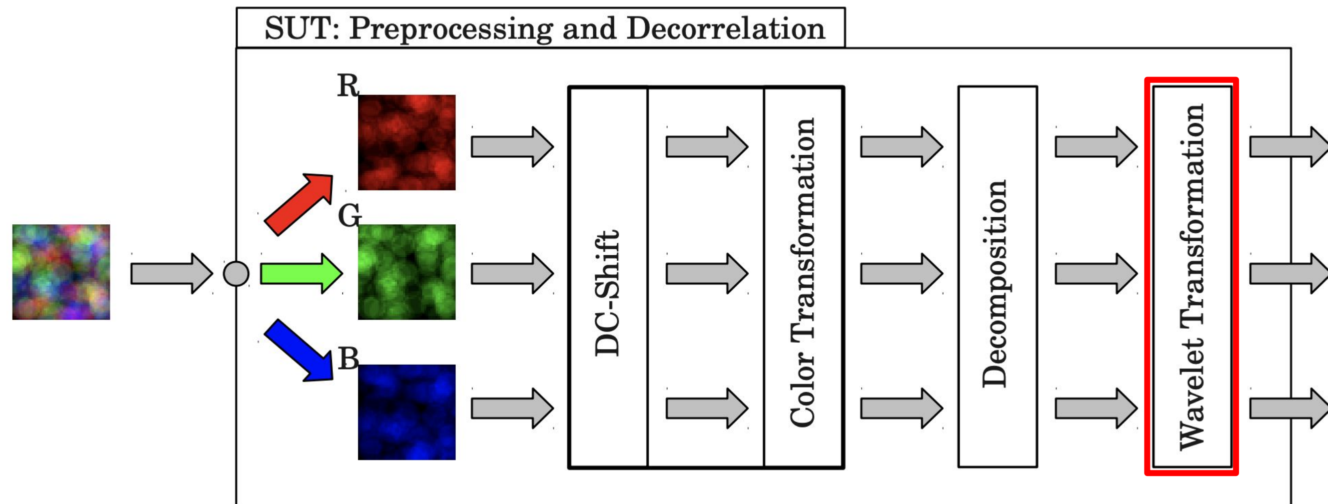
Recap: Detection of likely invariants (Daikon)



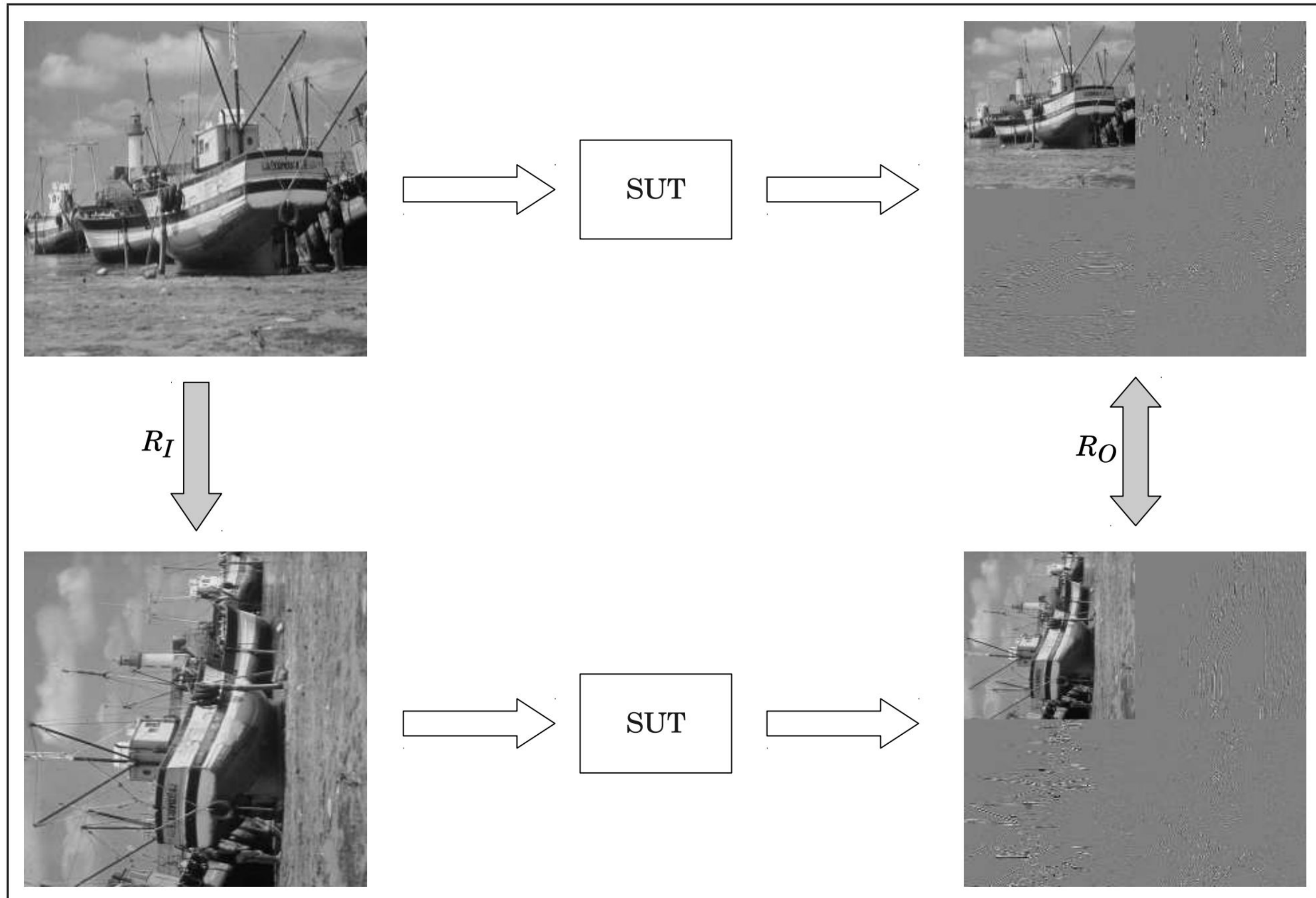
Metamorphic testing

Metamorphic testing: an example system

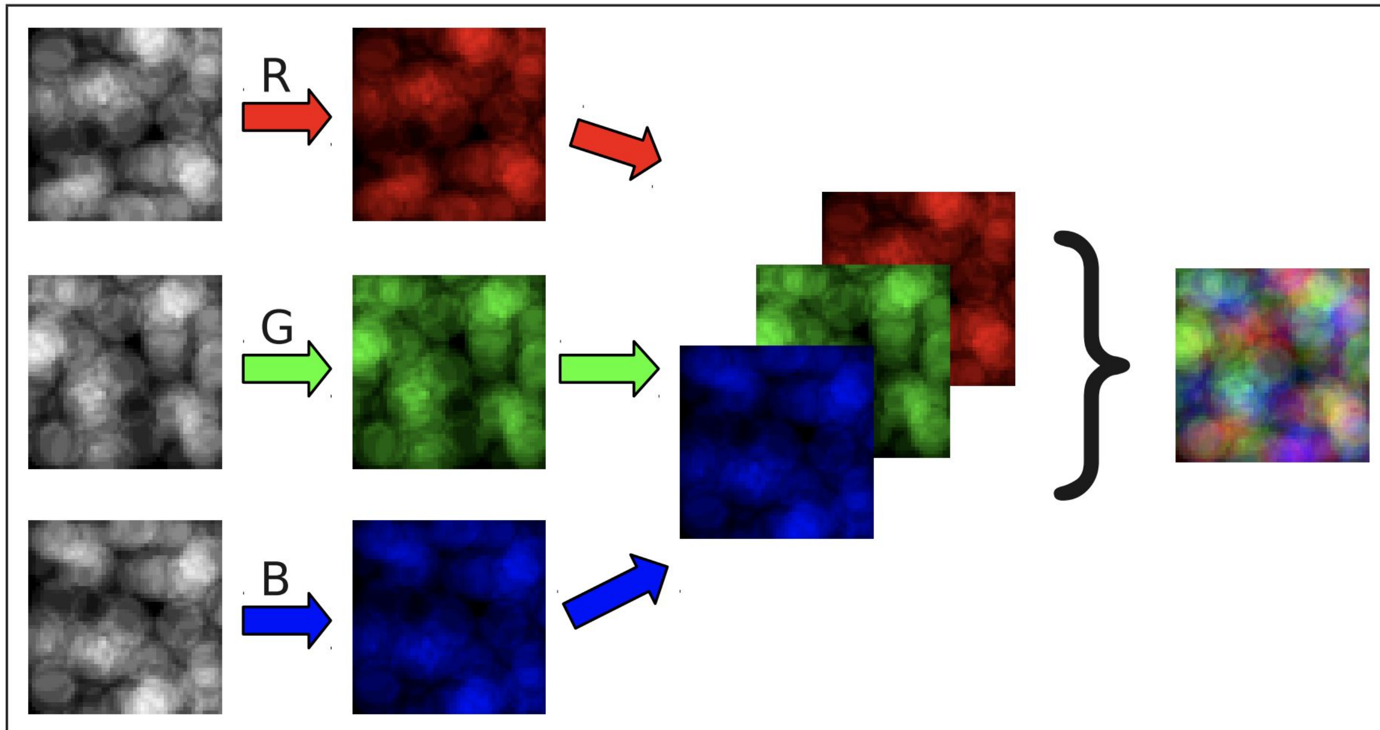




Metamorphic testing: SUT (Wavelet transformation)

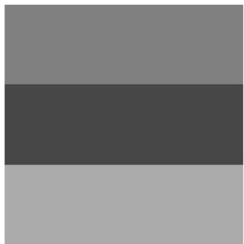


Metamorphic testing: Input generation



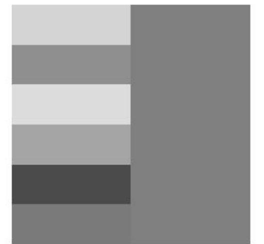
Metamorphic testing: Relations

R1 R_I: Add an offset to the color values.
R_O: Only the DC component must be affected.



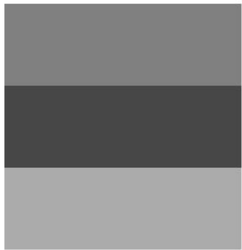
$\overset{R_I}{\Longrightarrow}$

$\overset{R_O}{\Longleftrightarrow}$

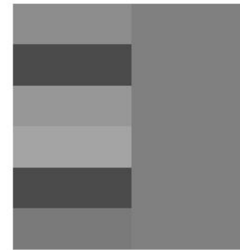


Metamorphic testing: Relations

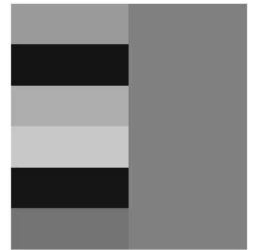
R1 R_I: Add an offset to the color values.
R_O: Only the DC component must be affected.
R2 R_I: Multiply the color values by a coefficient.
R_O: Every pixel has to be affected.



$\overset{R_I}{\Longrightarrow}$



$\overset{R_O}{\Longleftrightarrow}$



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R3 R_I: Transpose the pixel array of the input image.
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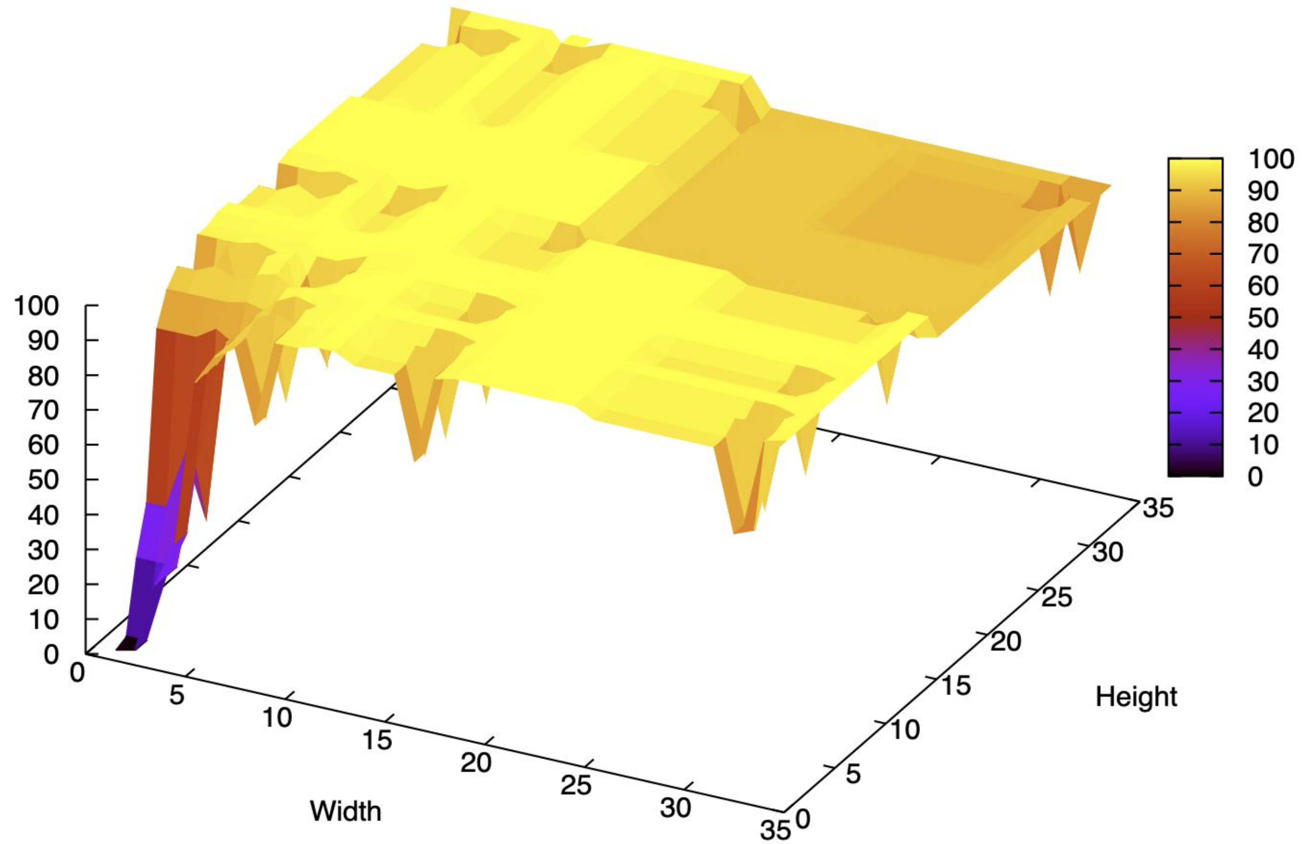
Commutative

Time-invariant

It turns out that composition makes strong oracles.

Metamorphic testing: Effectiveness



Your turn

1. Hash out two metamorphic relations (ideally for your course project).
2. Discuss effectiveness and composability.
3. Present your results to the class.

A primer on solver-aided reasoning

(507 covers this topic in detail)

What is Z3?

- An SMT (Satisfiability Modulo Theories) solver.
- Uses a standard language (SMT-LIB).
  - Print to the screen.

```
(echo "Running Z3...")
```

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(declare-const a Int)
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(echo "Running Z3...")
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(assert (> a 0))
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(get-model)
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(echo "Running Z3...")
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Which question does this code answer?

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  - Define constraints.
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  - ...

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(echo "Running Z3...")
(declare-const a Int)
(assert (> a 0))
(check-sat)
(get-model)
```

This code is asking the question:
Does an integer greater than 0 exist?

A first example

```
1 int simpleMath(int a, int b) {
2   assert(b>0);
3   if(a + b < a) {
4     return 1;
5   }
6   return 0;
7 }
```

Does this method ever return 1?

A first example

```
1 int simpleMath(int a, int b) {
2   assert(b>0);
3   if(a + b < a) {
4     return 1;
5   }
6   return 0;
7 }
```

```
(declare-const a Int)
(declare-const b Int)

(assert (> b 0))
(assert (< (+ a b) a))

(check-sat)
```

Does this method ever return 1? Let’s ask Z3...

A more complex example

```
1 int getNumber(int a, int b, int c) {
2   if (c==0) return 0;
3   if (c==4) return 0;
4   if (a + b <  c) return 1;
5   if (a + b >  c) return 2;
6   if (a * b == c) return 3;
7   return 4;
8 }
```

Does this method ever return 3?

A more complex example

```
1 int getNumber(int a, int b, int c) {
2   if (c==0) return 0;
3   if (c==4) return 0;
4   if (a + b <  c) return 1;
5   if (a + b >  c) return 2;
6   if (a * b == c) return 3;
7   return 4;
8 }
```

All of the following must be true (why?):

- `!(c == 0)`
- `!(c == 4)`
- `!(a + b < c)`
- `!(a + b > c)`
- `a * b == c`

Does this method ever return 3?

A more complex example

```
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```

All of the following must be true (why?):

- `!(c == 0)`
- `!(c == 4)`
- `!(a + b < c)`
- `!(a + b > c)`
- `a * b == c`

```
(declare-const a Int)
(declare-const b Int)
(declare-const c Int)

(assert (not (= c 0)))
(assert (not (= c 4)))
(assert (not (< (+ a b) c)))
(assert (not (> (+ a b) c)))
(assert (= (* a b) c))

(check-sat)
```

A first example: limited precision

```
1 int simpleMath(int a, int b) {
2   assert(b>0);
3   if(a + b < a) {
4     return 1;
5   }
6   return 0;
7 }
```

Z3 supports Bitvectors of arbitrary size.
Let’s model Java ints (32 bits) and ask the same question...

A first example: limited precision

```
1 int simpleMath(int a, int b) {
2   assert(b>0);
3   if(a + b < a) {
4     return 1;
5   }
6   return 0;
7 }
```

```
(declare-const a (_ BitVec 32))
(declare-const b (_ BitVec 32))

(assert (bvsgt b #x00000000))
(assert (bvslt (bvadd a b) a))

(check-sat)
(get-model)
```

Z3 supports Bitvectors of arbitrary size.

Let's model Java ints (32 bits) and ask the same question...

A more complex example: limited precision

```
1 int getNumber(int a, int b, int c) {
2   if (c==0) return 0;
3   if (c==4) return 0;
4   if (a + b <  c) return 1;
5   if (a + b >  c) return 2;
6   if (a * b == c) return 3;
7   return 4;
8 }
```

```
(define-sort JInt () (_ BitVec 32))

(declare-const a JInt)
(declare-const b JInt)
(declare-const c JInt)

(assert (not (= c #x00000000)))
(assert (not (= c #x00000004)))
(assert (not (bvslt (bvadd a b) c)))
(assert (not (bvsgt (bvadd a b) c)))
(assert (= (bvmul a b) c))

(check-sat)
(get-model)
```

Reasoning about program equivalence

```
1 int add1(int a, int b) {
2   return a + b;
3 }
4
5 int add2(int a, int b) {
6   return a * b;
7 }
```

Are these two methods semantically equivalent?

Reasoning about program equivalence

```
1 int add1(int a, int b) {
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```

```
(declare-const a Int)
(declare-const b Int)

(declare-const add1 Int)
(declare-const add2 Int)

(assert (= add1 (+ a b)))
(assert (= add2  (* a b)))
(assert (= add1 add2))

(check-sat)
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Reasoning about program equivalence

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(declare-const a Int)
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(declare-const add1 Int)
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(assert (= add1 (+ a b)))
(assert (= add2  (* a b)))
(assert (= add1 add2))

(check-sat)
(get-model)
```

Yes, for a=0 and b=0.

What have we actually proven here?

Reasoning about program equivalence

```
1 int add1(int a, int b) {
2   return a + b;
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5 int add2(int a, int b) {
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7 }
```

```
(declare-const a Int)
(declare-const b Int)

(declare-const add1 Int)
(declare-const add2 Int)

(assert (= add1 (+ a b)))
(assert (= add2  (* a b)))
(assert (not (= add1 add2)))

(check-sat)
(get-model)
```

Our goal is to prove the absence of counter examples (i.e., the defined constraints are unsatisfiable)!

What's next?

- **Week 1:** Introduction **HW 1**
- **Week 2:** Abstract Interpretation
- **Week 3:** Abstract Interpretation **HW 2**
- **Week 4:** Testing
- **Week 5:** Delta Debugging **In-class exercise**
- **Week 6:** Invariants
- **Week 7:** Program Repair
- **Week 8:** Empirical Software Engineering
- **Week 9:** ML for Software Engineering
- **Week 10:** Wrap up **Project presentation**