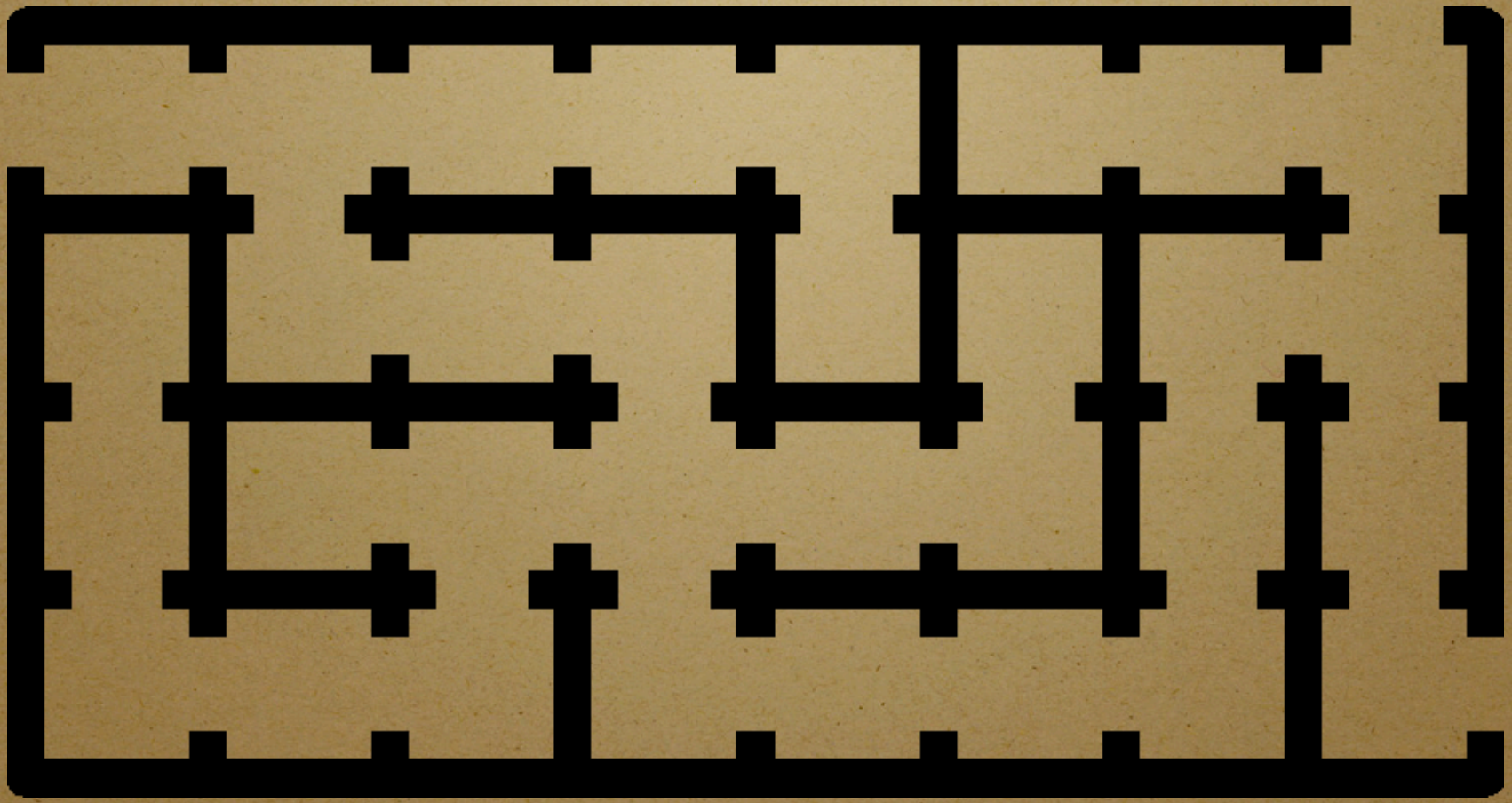
Scavenger Hunt



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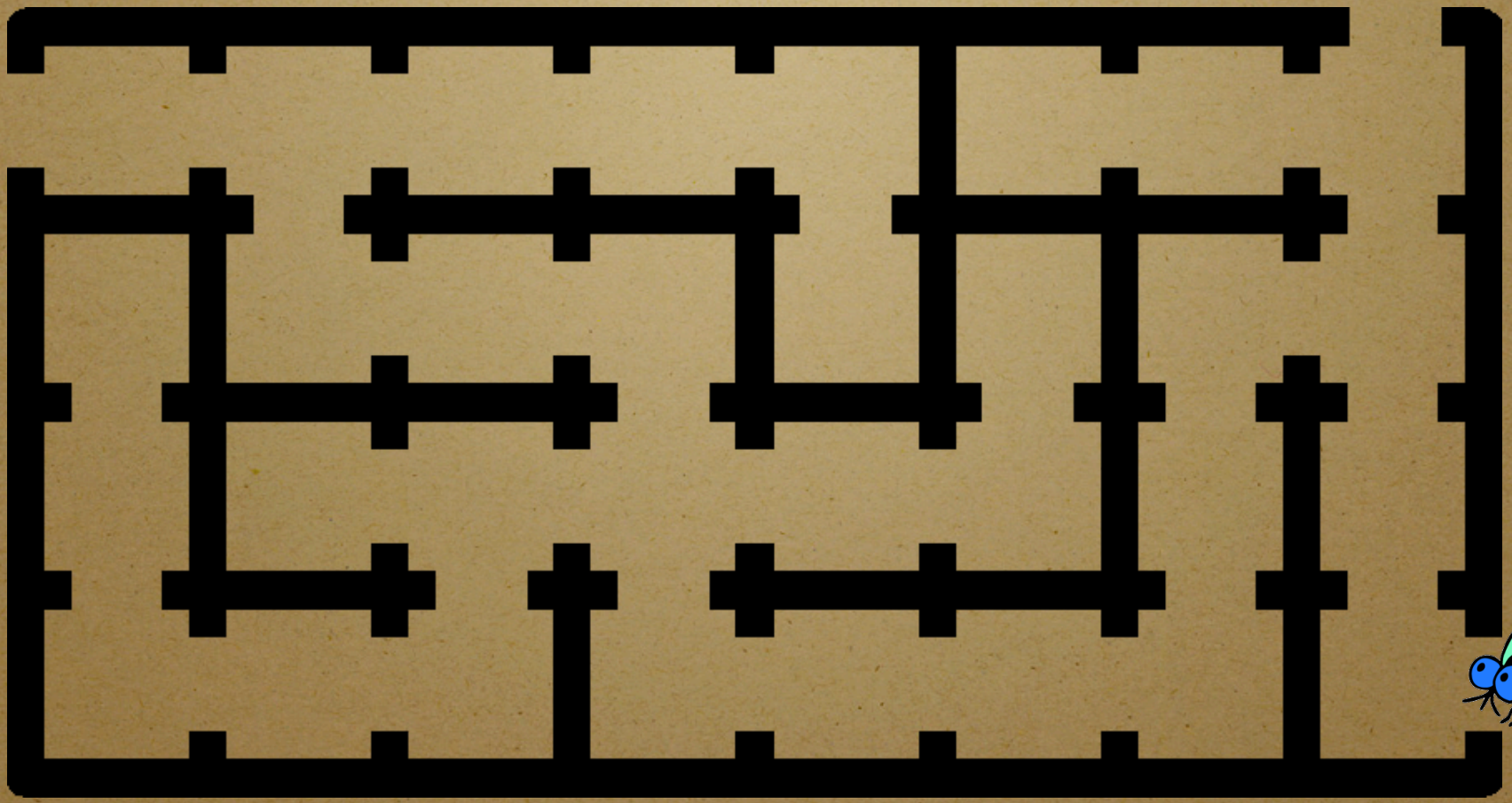

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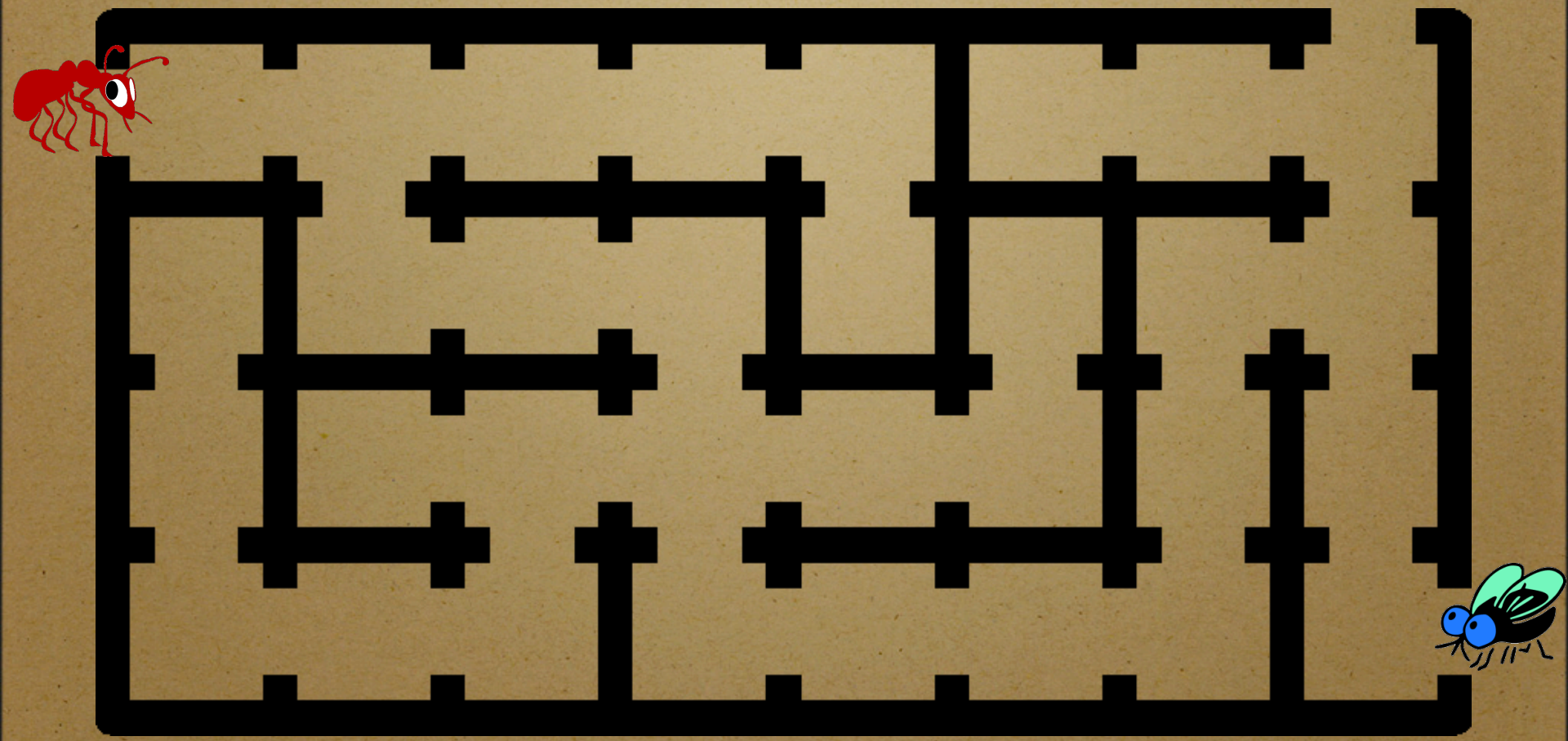

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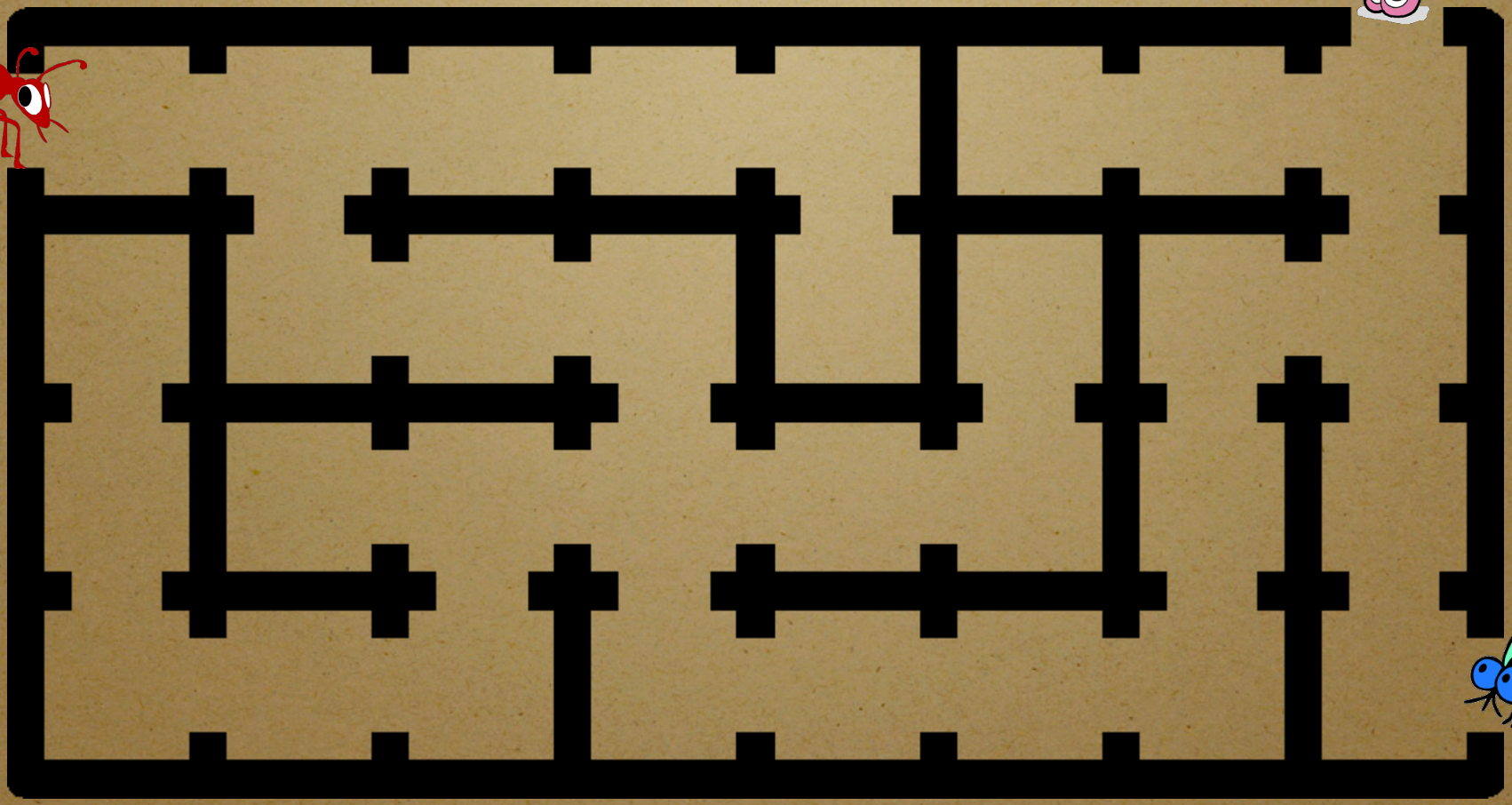

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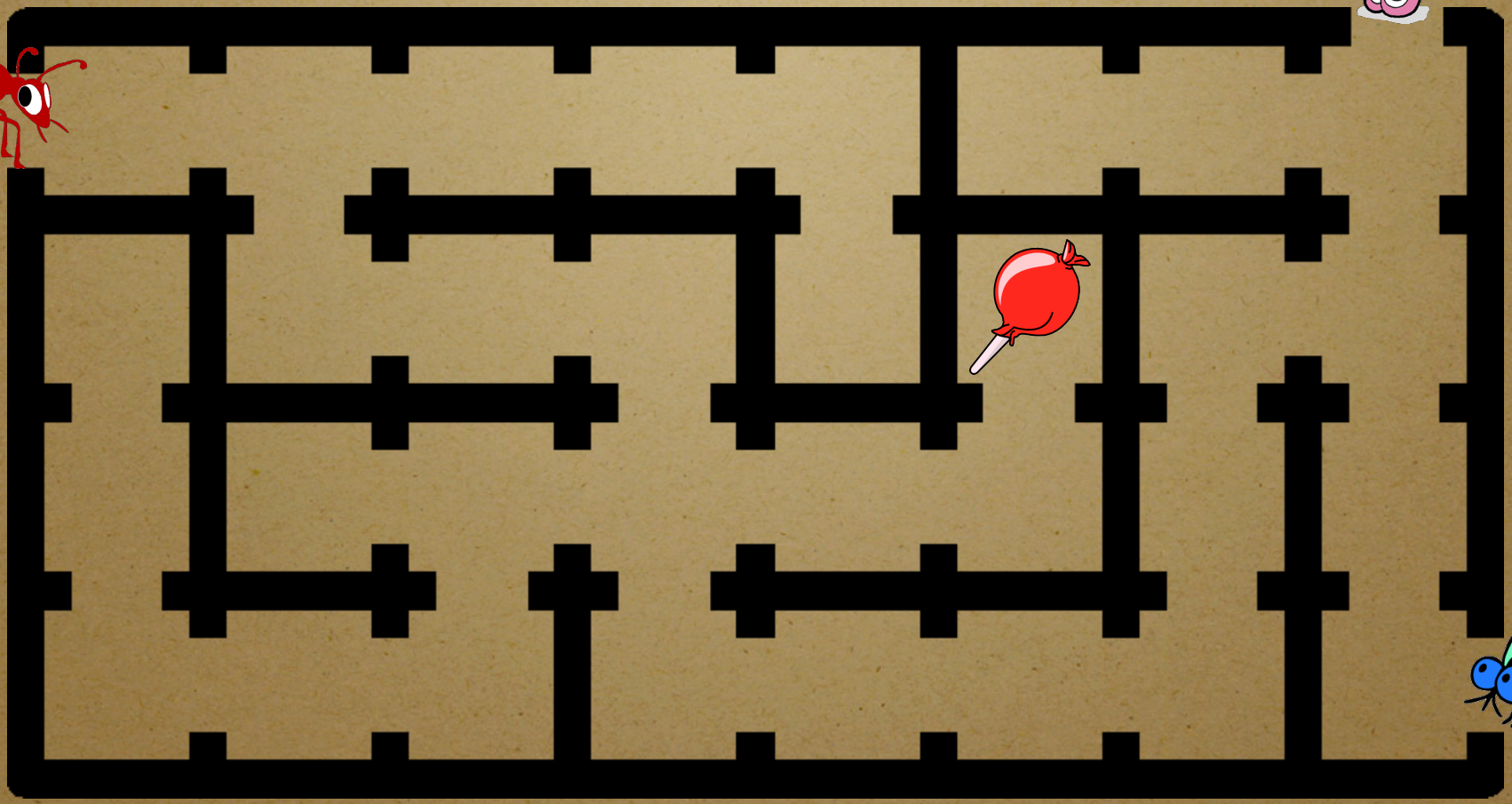
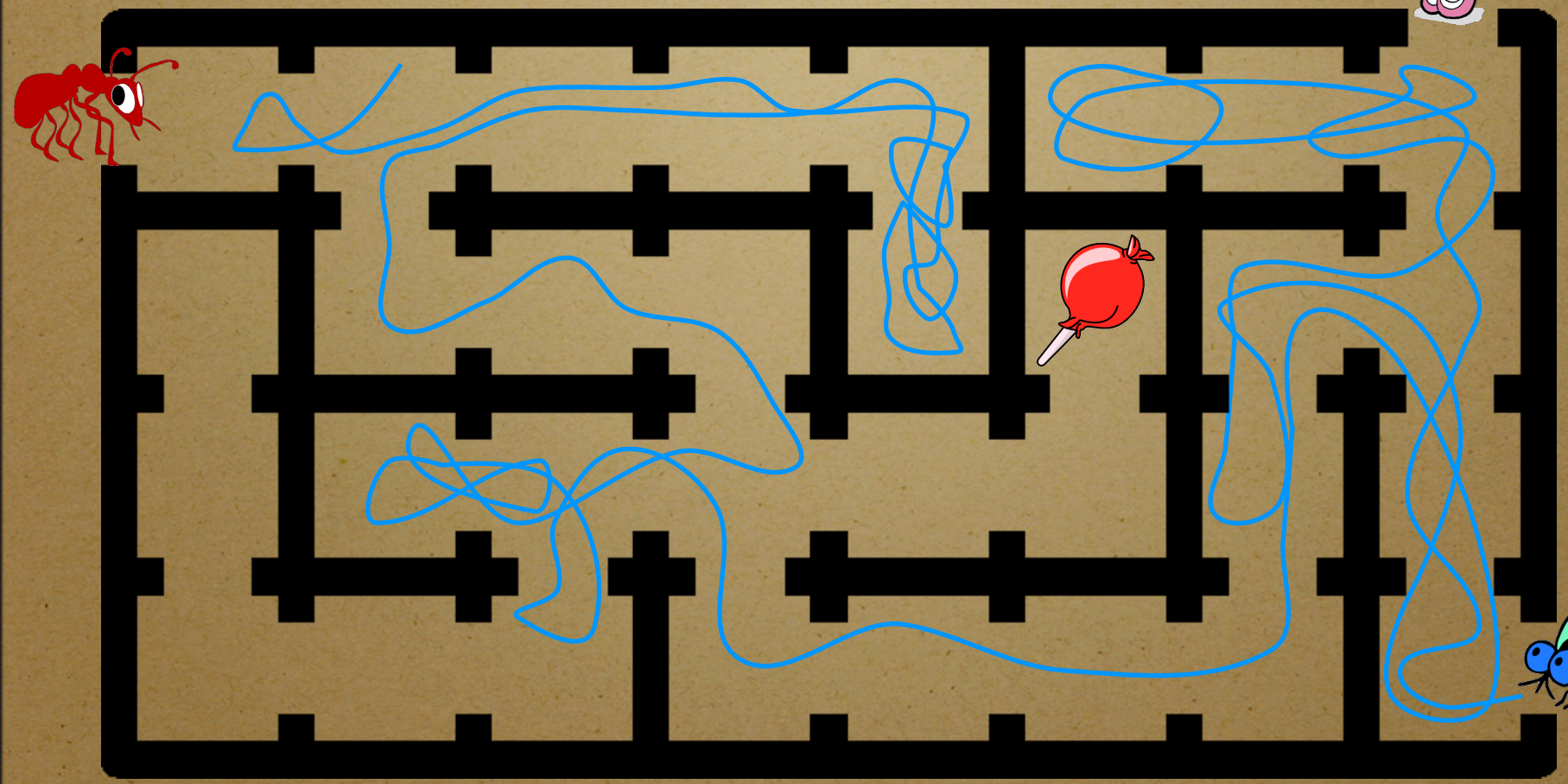
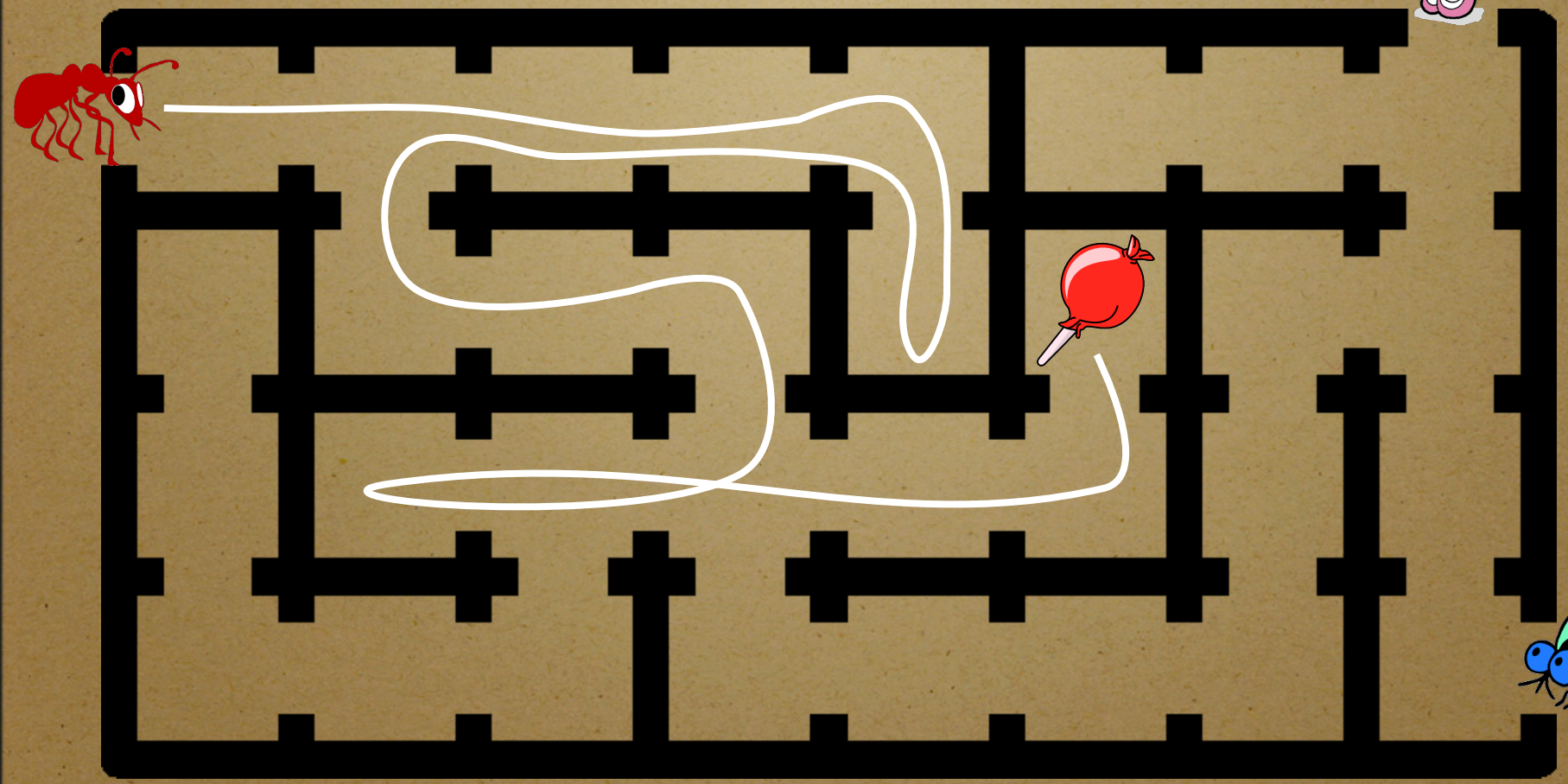


Scavenger Hunt



Scavenger Hunt



Scavenger Hunt

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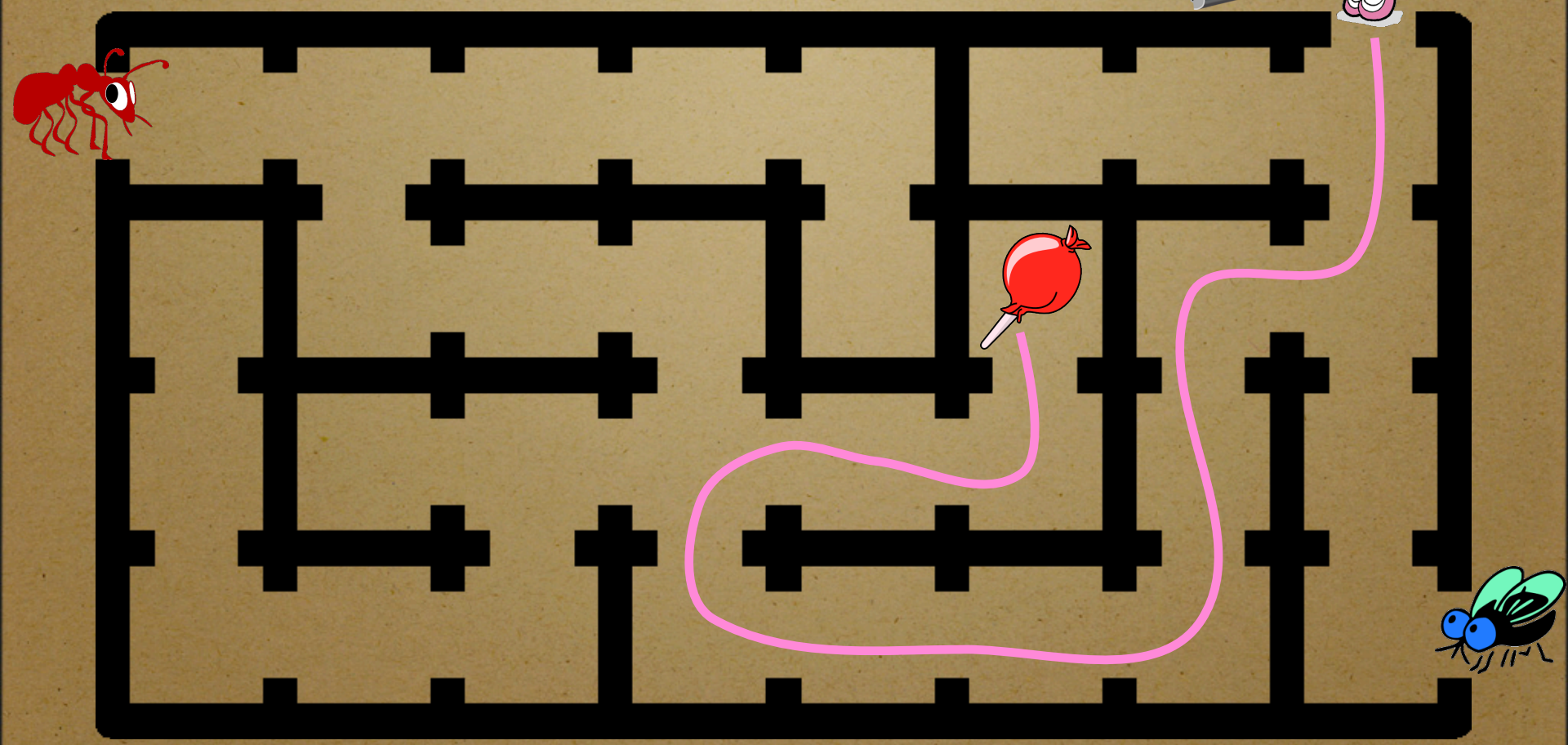
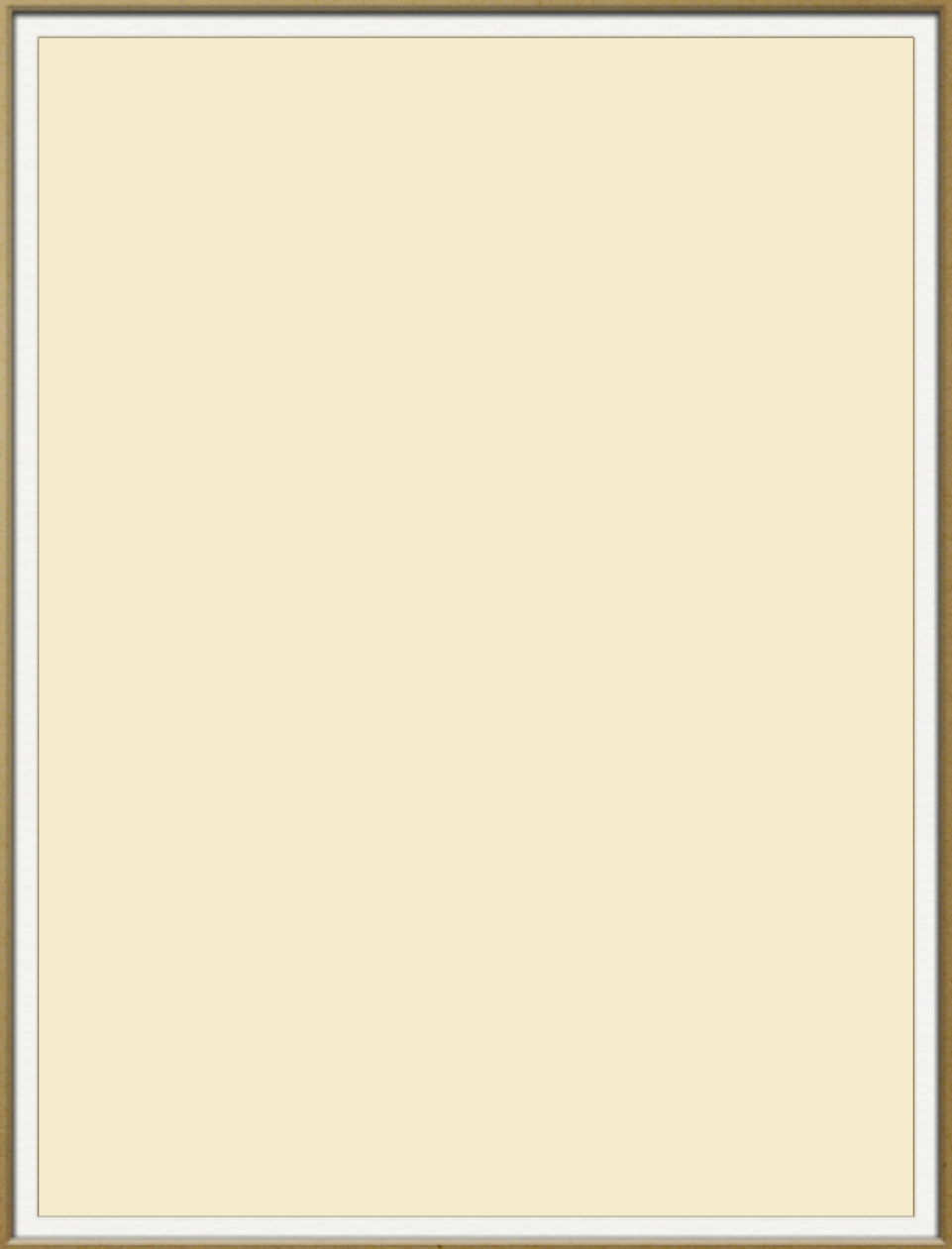


Software Testing



Software Testing

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Software Testing

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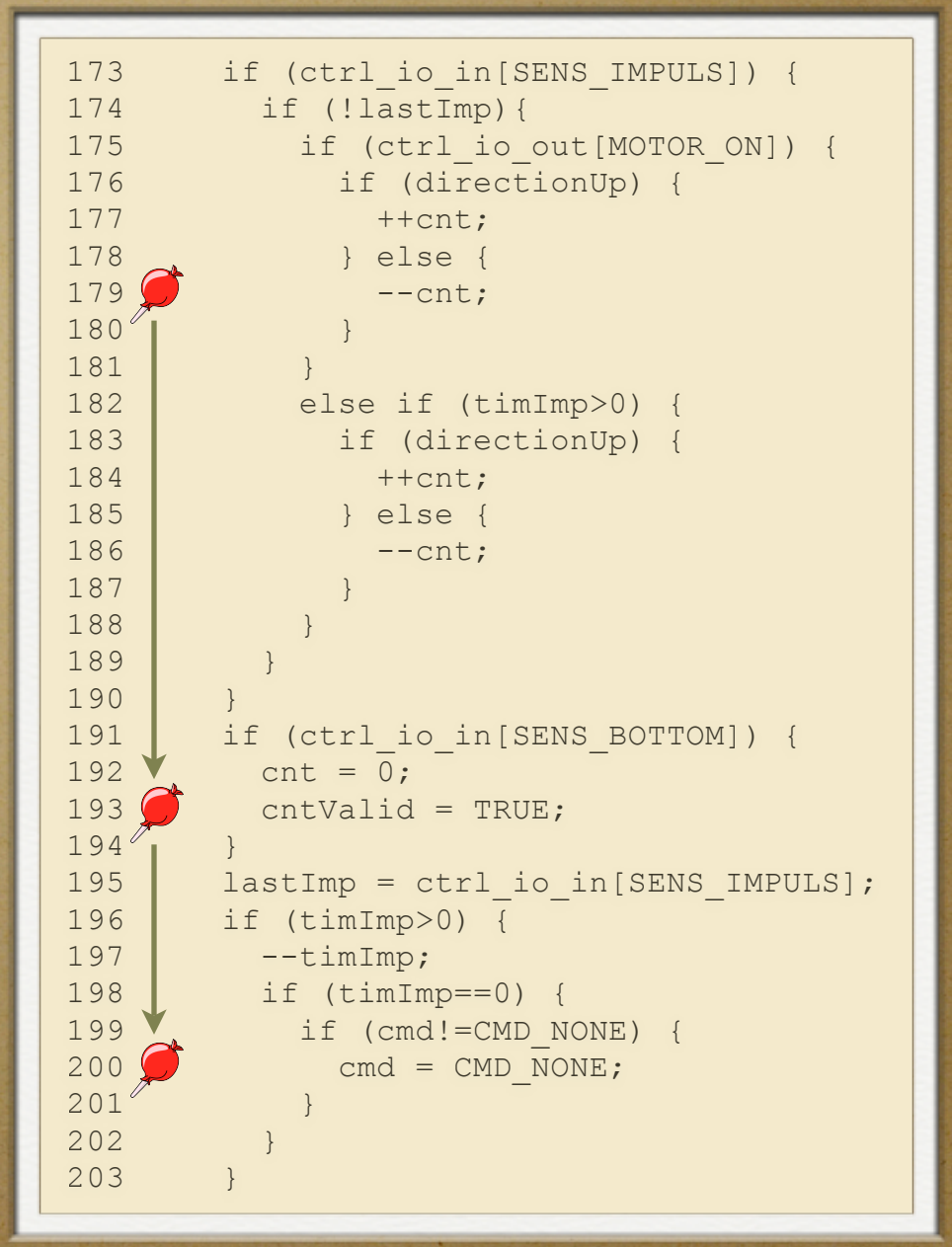
Software Testing



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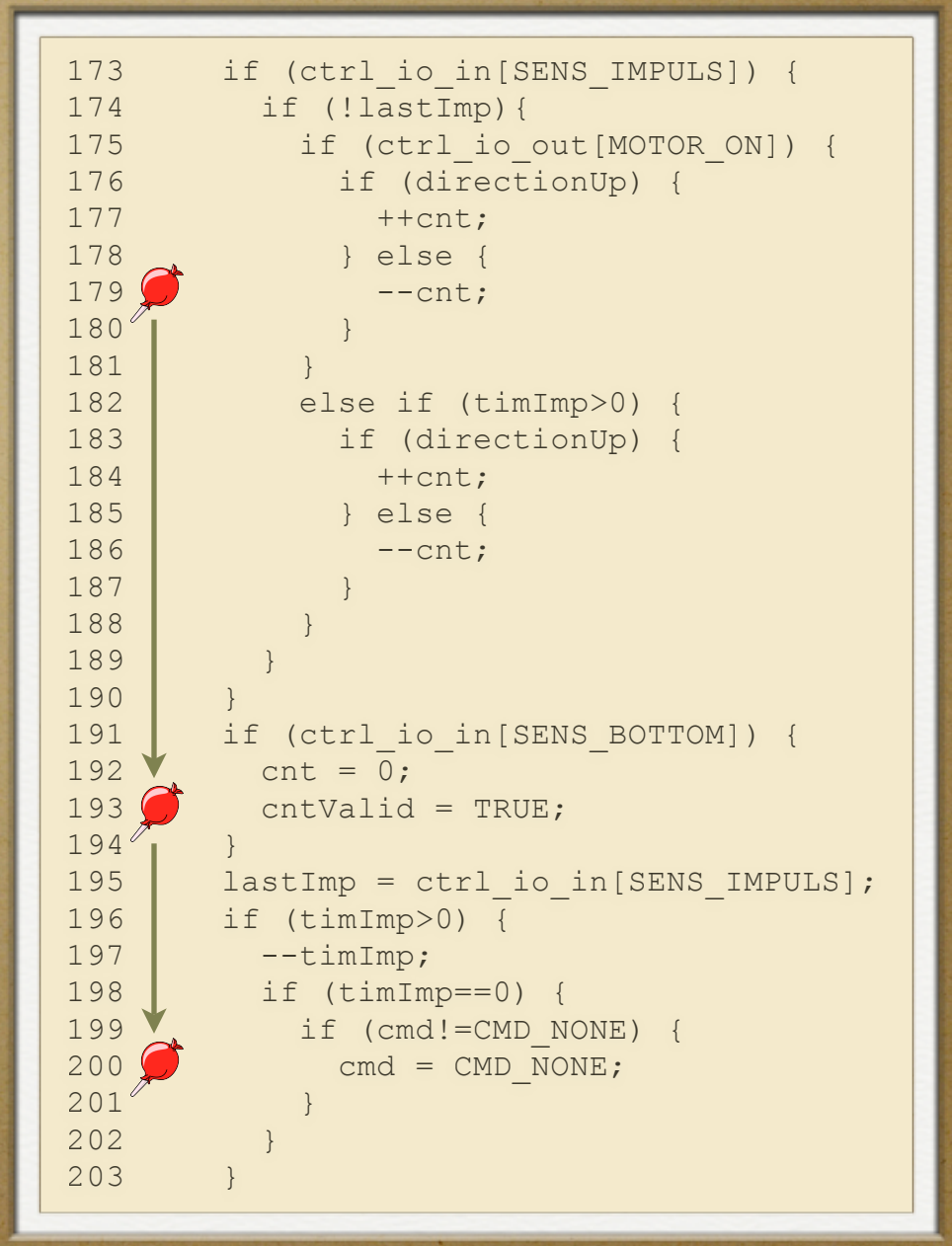
Software Testing

Random Testing?



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Software Testing

Random Testing?

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Software Testing

Random Testing?

Directed Testing?

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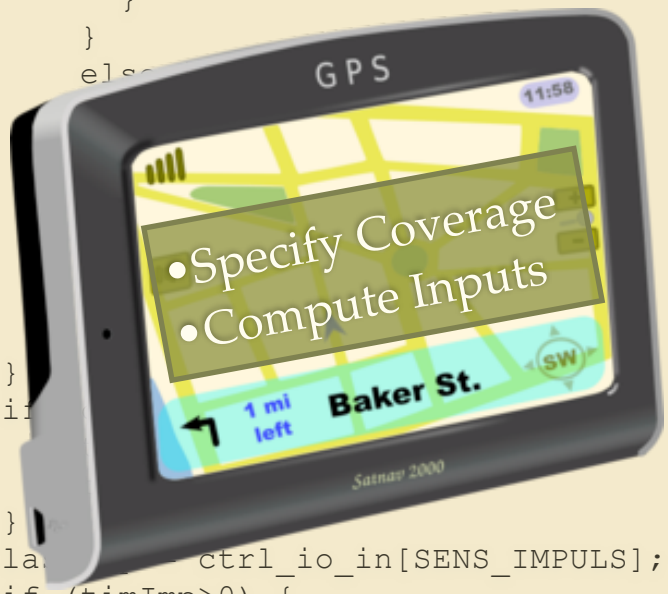

TECHNISCHE
UNIVERSITÄT
WIEN
Vienna University of Technology

How did you specify your test suite ?

Michael Tautschnig
Formal Methods in Systems Engineering
Vienna University of Technology

Joint work with
Andreas Holzer, Christian Schallhart, and Helmut Veith

Standard Coverage Criteria

```
1  int example(int a, int d)
2  {
3    if (a)
4      d = 0;
5    else
6      unimplemented();
7    return d*2;
8  }
```

Basic Block Coverage

Requires a test suite such that each basic block is executed at least once

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Decision Coverage

Conditional statements evaluate to true/false

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Condition Coverage

Atomic conditions evaluate to true/false

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Condition/Decision Coverage

Union of condition and decision coverage

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Multiple Condition Coverage

All Boolean combinations of atomic conditions in complex conditions

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```

a	b	c
F	F	F
F	F	T
F	T	F
F	T	T
T	F	F
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Multiple Condition Coverage

All Boolean combinations of atomic conditions in complex conditions

Standard Coverage Criteria

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1  int example(int a, int d)
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3    if (a)
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5    else
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8  }
```

Def-Use Coverage

Cover all definition/use pairs of a variable *d*

Standard Coverage Criteria

```
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5    else
6      unimplemented();
7    return d*2;
8  }
```

Def-Use Coverage

Cover all definition/use pairs of a variable *d*

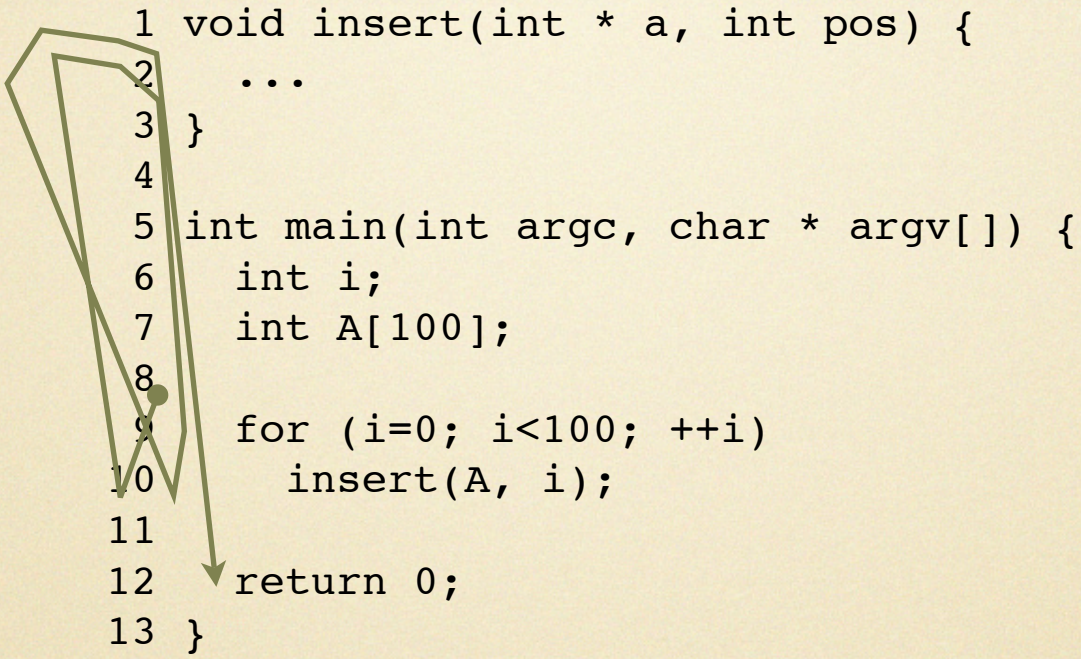
Beyond Standard Criteria

```
 1 void insert(int * a, int pos) {
 2   ...
 3 }
 4
 5 int main(int argc, char * argv[]) {
 6   int i;
 7   int A[100];
 8
 9   for (i=0; i<100; ++i)
10     insert(A, i);
11
12   return 0;
13 }
```

Loop-Bounded Path Coverage

- All paths through *main* and *insert*
- Pass each statement two times

Beyond Standard Criteria



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5  int main(int argc, char * argv[]) {
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13 }
```

Loop-Bounded Path Coverage

- All paths through *main* and *insert*
- Pass each statement two times

Beyond Standard Criteria

```
 1 int partition(int a[], int left, int right) {
 2   int v = a[right], i = left - 1, j = right, t;
 3   for (;;) {
 4     while (a[++i] < v) ;
 5     while (j > left && a[--j] > v) ;
 6     if (i >= j) break;
 7     t = a[i]; a[i] = a[j]; a[j] = t;
 8   }
 9   t = a[i]; a[i] = a[right]; a[right] = t;
10   return i;
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```

Cartesian Block Coverage

All pairs and triples of basic blocks in function *partition*

Beyond Standard Criteria

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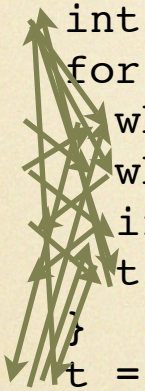

Cartesian Block Coverage

All pairs and triples of basic blocks in function *partition*

Specs for Working Programmers

```
1  int example(int a, int b, int c, int d)
2  {
3    if ((a || b) && c)
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7    return d*2;
8  }
```

Cover Specific Lines of Code

Lines 4 and 6

Specs for Working Programmers

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1  int example(int a, int b, int c, int d)
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7    return d*2;
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```

Cover Specific Lines of Code

Lines 4 and 6

Specs for Working Programmers

```
 1 void eval(int * a, int first, int last) {
 2   if (first > last) return;
 3   printf("a[%d]=%d\n", first, a[first]);
 4   eval(a+1, first+1, last);
 5   return;
 6 }
 7
 8 int main(int argc, char * argv[]) {
 9   int i;
10   int A[100];
11
12   for (i=0; i<100; ++i)
13     insert(A, i);
14
15   eval(A, 0, 100);
16   return 0;
17 }
```

Restricted Scope of Analysis

Basic block coverage in function *eval* only

Specs for Working Programmers

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 8 int main(int argc, char * argv[]) {
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12   for (i=0; i<100; ++i)
13     insert(A, i);
14
15   eval(A, 0, 100);
16   return 0;
17 }
```

Restricted Scope of Analysis

Basic block coverage in function *eval* only

Specs for Working Programmers

```
 1 void sort(int * a, int len) {
 2   int i, t;
 3   for (i=1; i<len; ++i) {
 4     if (compare(a[i-1], a[i])) continue;
 5     t=a[i]; a[i]=a[i-1]; a[i-1]=t;
 6   }
 7 }
 8
 9 void eval(int * a, int len) {
10   int i;
11   for (i=0; i < 3; ++i)
12     printf("a[%d]=%d\n", i, a[i]);
13 }
14
15 int main(int argc, char * argv[]) {
16   int i; int A[100];
17   for (i=0; i < 100; ++i) sort(A, 100);
18   eval(A, 100);
19   return 0;
20 }
```

Interaction Coverage

Cover all pairs of conditions in *sort* and basic blocks in *eval*

Specs for Working Programmers

```
 1 void sort(int * a, int len) {
 2   int i, t;
 3   for (i=1; i<len; ++i) {
 4     if (compare(a[i-1], a[i])) continue;
 5     t=a[i]; a[i]=a[i-1]; a[i-1]=t;
 6   }
 7 }
 8
 9 void eval(int * a, int len) {
10   int i;
11   for (i=0; i < 3; ++i)
12     printf("a[%d]=%d\n", i, a[i]);
13 }
14
15 int main(int argc, char * argv[]) {
16   int i; int A[100];
17   for (i=0; i < 100; ++i) sort(A, 100);
18   eval(A, 100);
19   return 0;
20 }
```

Interaction Coverage

Cover all pairs of conditions in *sort* and basic blocks in *eval*

Specs for Working Programmers

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 1 void sort(int * a, int len) {
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 6     a[i]=a[i-1];
 7     a[i-1]=t;
 8   }
 9   return;
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```

Constrained Inputs

- Basic block coverage in *sort*
- Each test case shall use list of 2 to 15 elements

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Constrained Inputs

- Basic block coverage in *sort*
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Specs for Working Programmers

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1  int example(int a, int d)
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3    if (a)
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```

Avoid Unfinished Code

- Basic block coverage in *example*
- Never call *unimplemented*

Specs for Working Programmers

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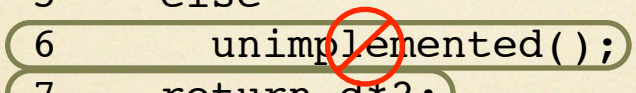

Avoid Unfinished Code

- Basic block coverage in *example*
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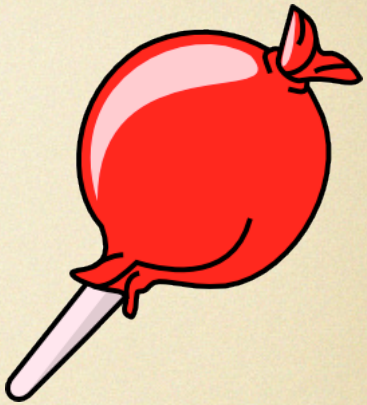
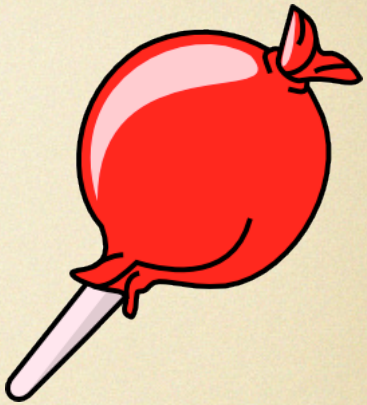
Test Specification Language



Test Specification Language



Precise and simple formalism to describe test suites

Precise semantics

High expressive power

Simple specifications easily expressible

Suitable for working programmer

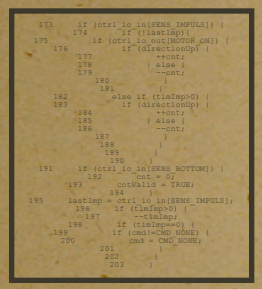
Algorithmic Solution

Algorithmic Solution

Tool for the working programmer

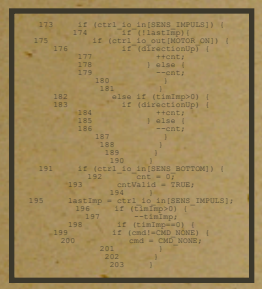
Applicability to real world C code (embedded systems)

Efficient test input generation engines



```
173     if (ctrl_io_in[SENS_IMPULS]) {
174         if (!lastImp) {
175             if (ctrl_io_out[MOTOR_ON]) {
176                 if (directionUp) {
177                     ++cnt;
178                 } else {
179                     --cnt;
180                 }
181             }
182         } else if (timImp>0) {
183             if (directionUp) {
184                 ++cnt;
185             } else {
186                 --cnt;
187             }
188         }
189         lastImp = 0;
190     }
191     if (ctrl_io_in[SENS_BOTTOM]) {
192         cnt = 0;
193         cntValid = TRUE;
194     }
195     lastImp = ctrl_io_in[SENS_IMPULS];
196     if (timImp>0) {
197         --timImp;
198         if (timImp==0) {
199             if (cmd!=CMD_NONE) {
200                 cmd = CMD_NONE;
201             }
202         }
203     }
```

Lines 179, 193, 200



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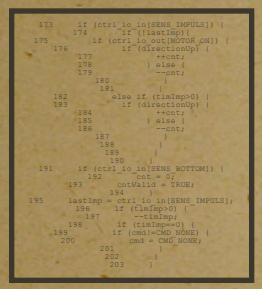
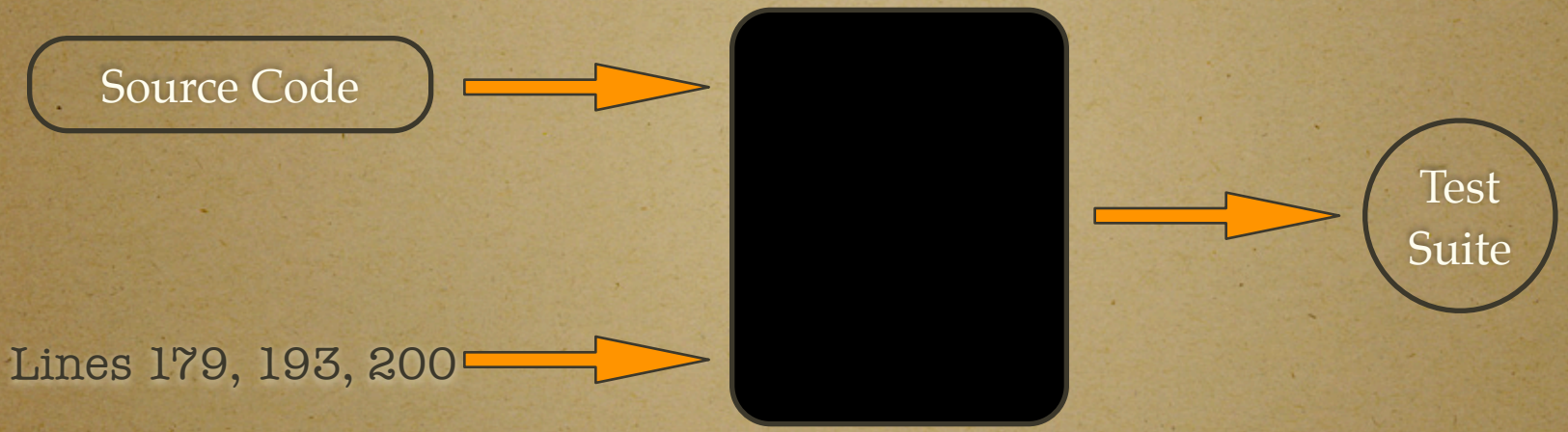
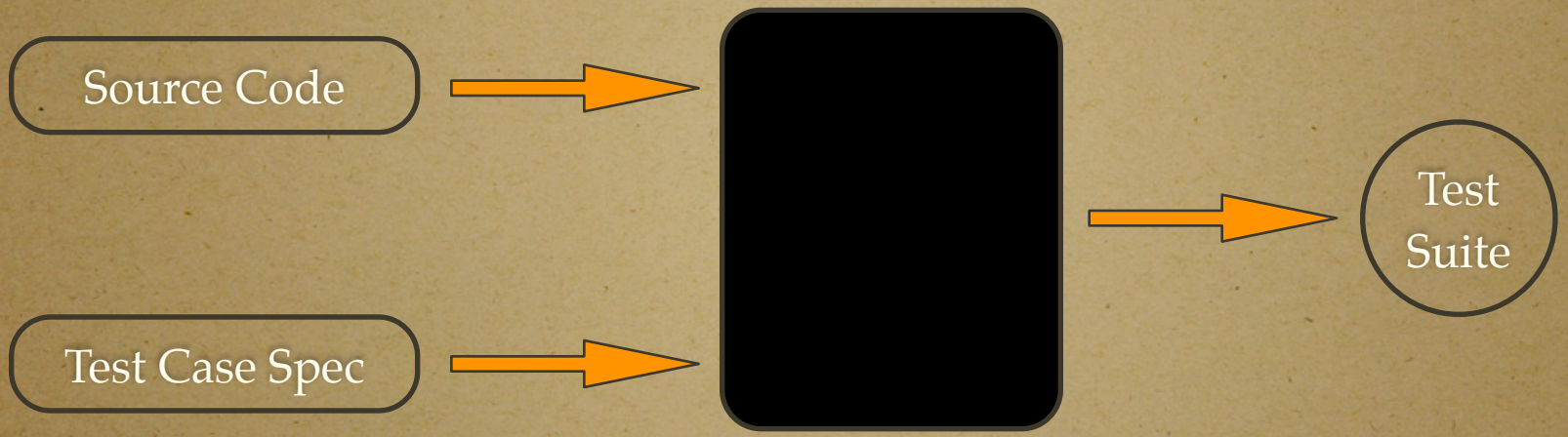
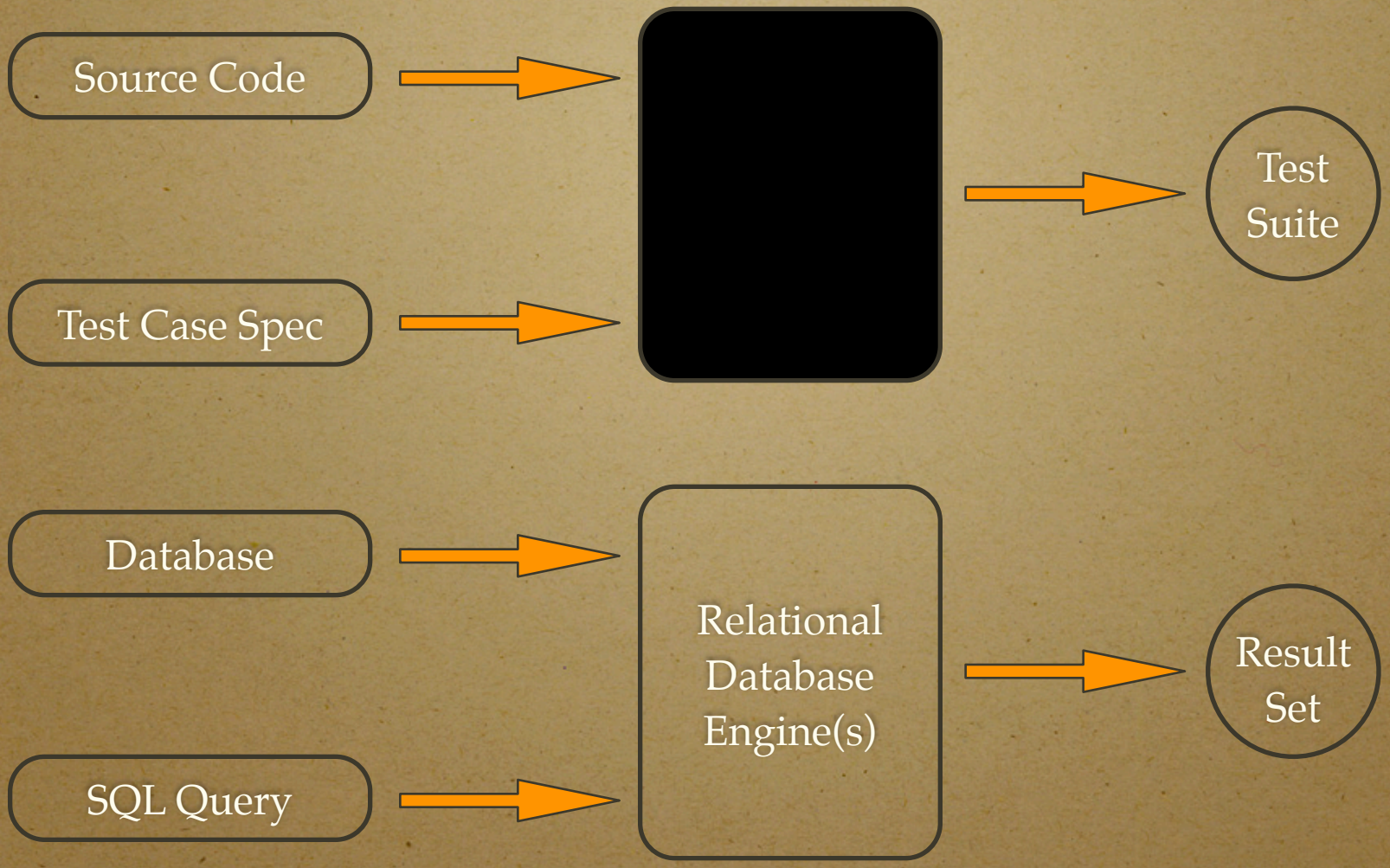


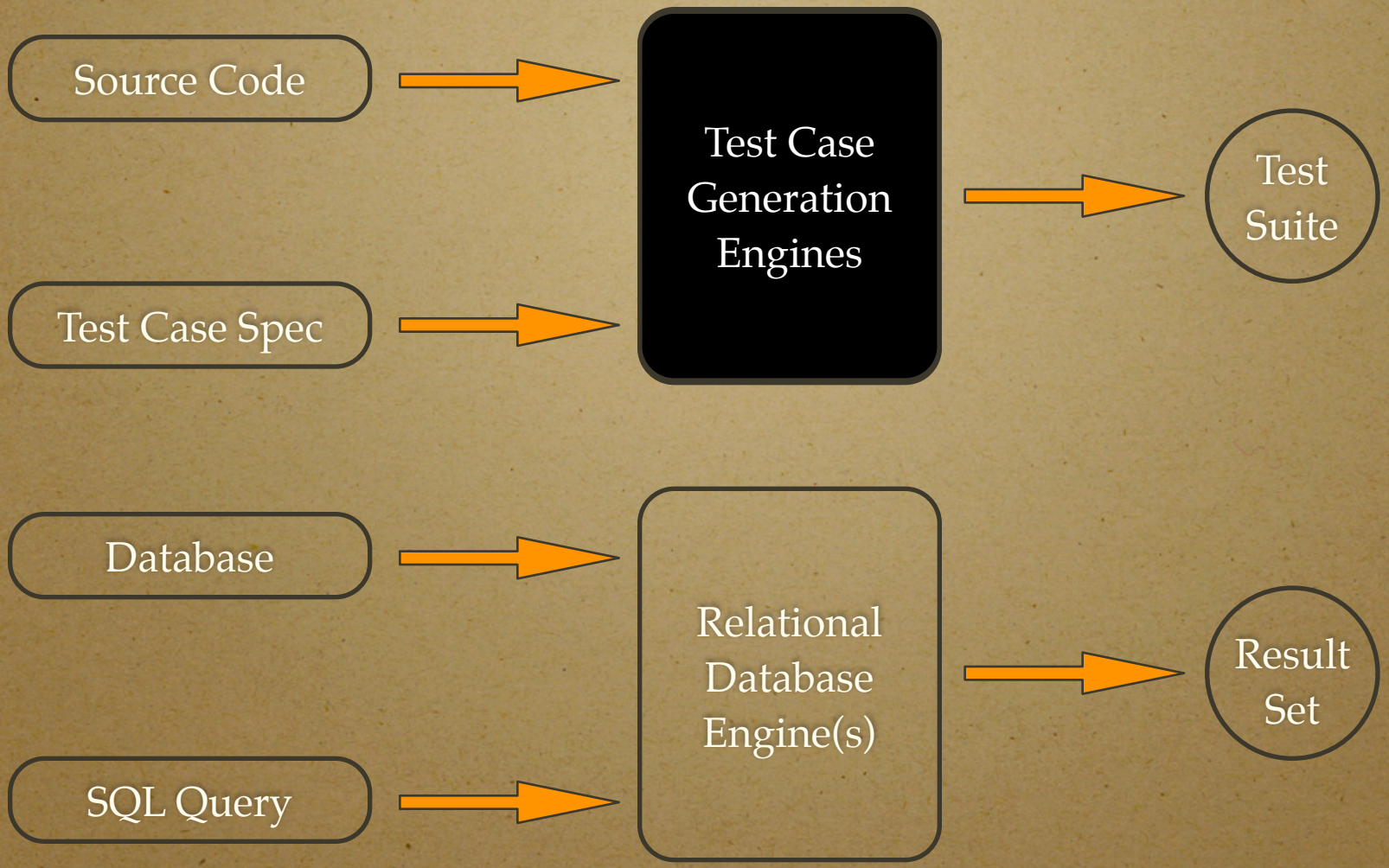
Lines 179, 193, 200

Test Suite

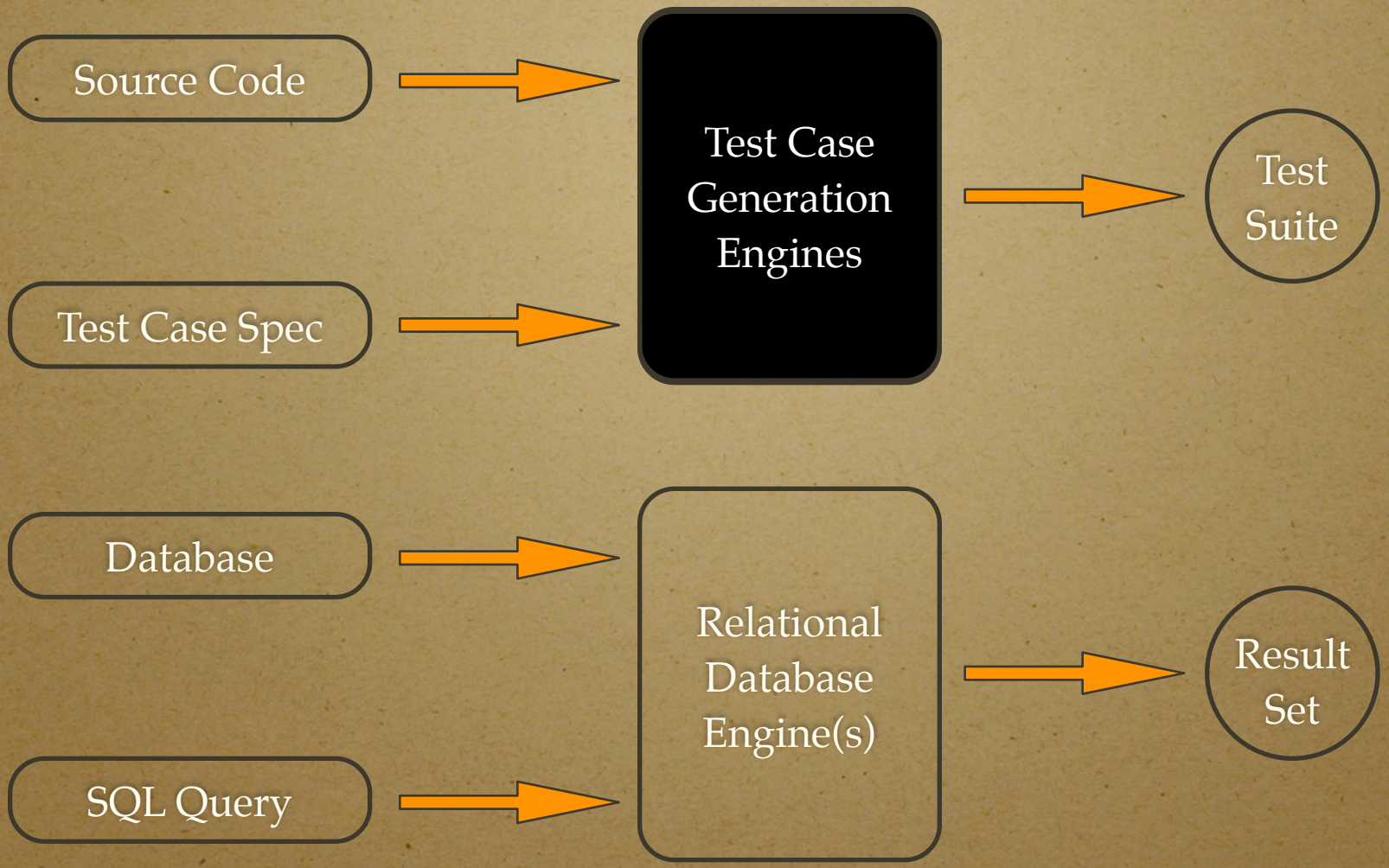

Source Code
Lines 179, 193, 200
Test
Suite


Source Code
Test Case Spec
Test
Suite

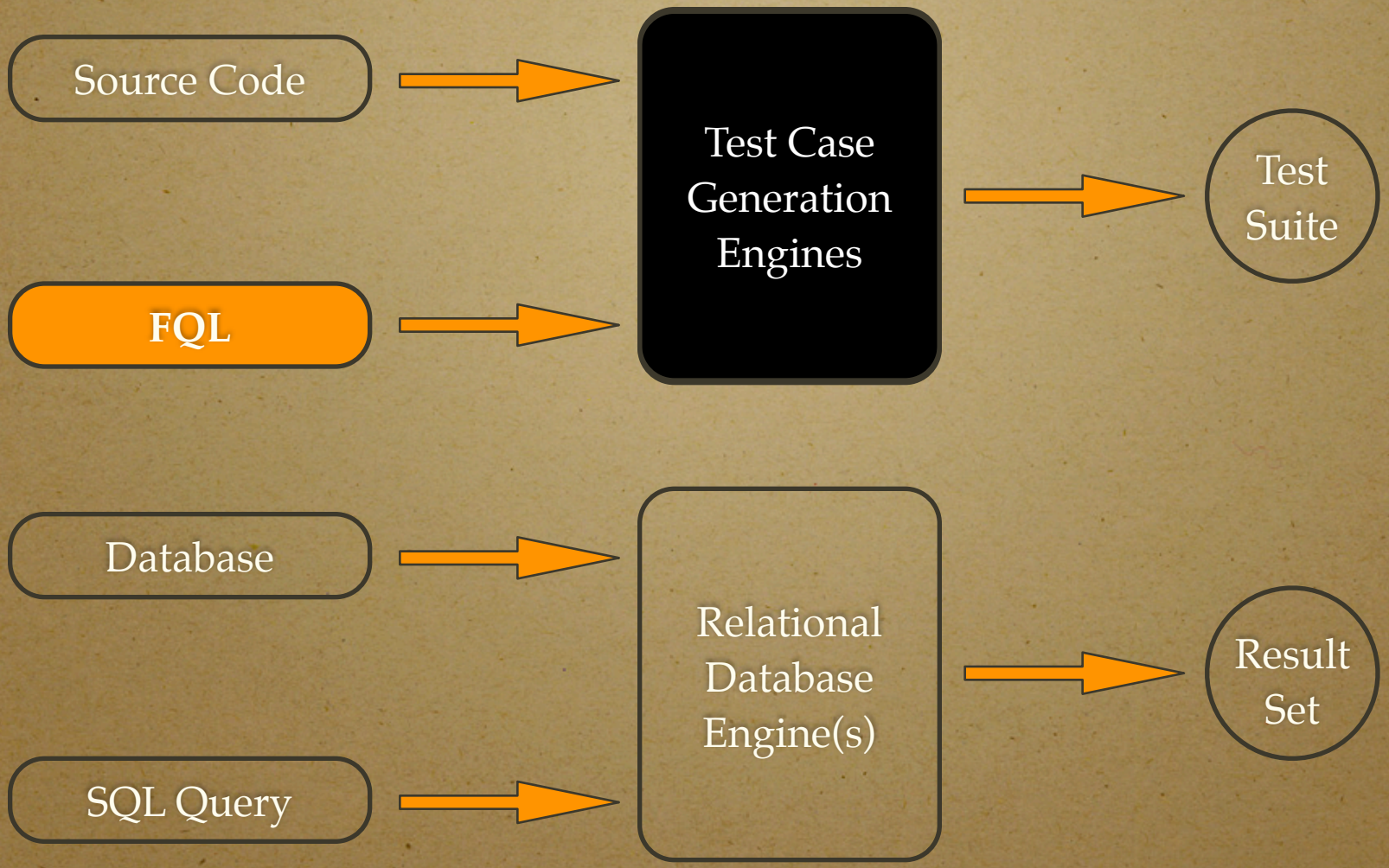

Source Code
Test Case Spec
Database
SQL Query
Relational Database Engine(s)
Test Suite
Result Set


Source Code
Test Case Spec
Test Case Generation Engines
Test Suite
Database
SQL Query
Relational Database Engine(s)
Result Set

Query-Driven Program Testing



Query-Driven Program Testing



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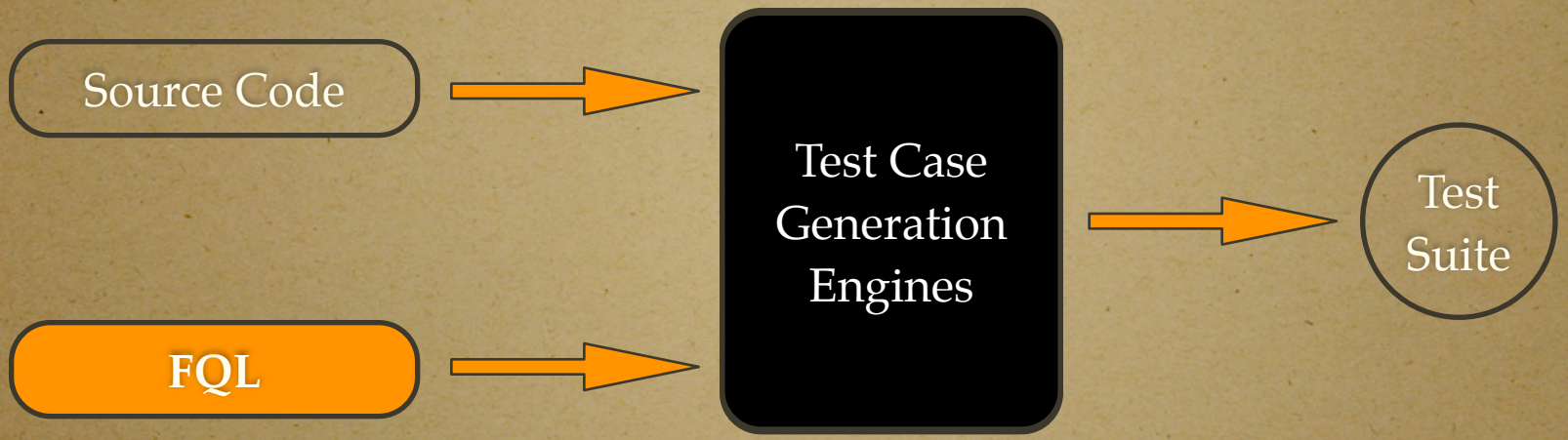
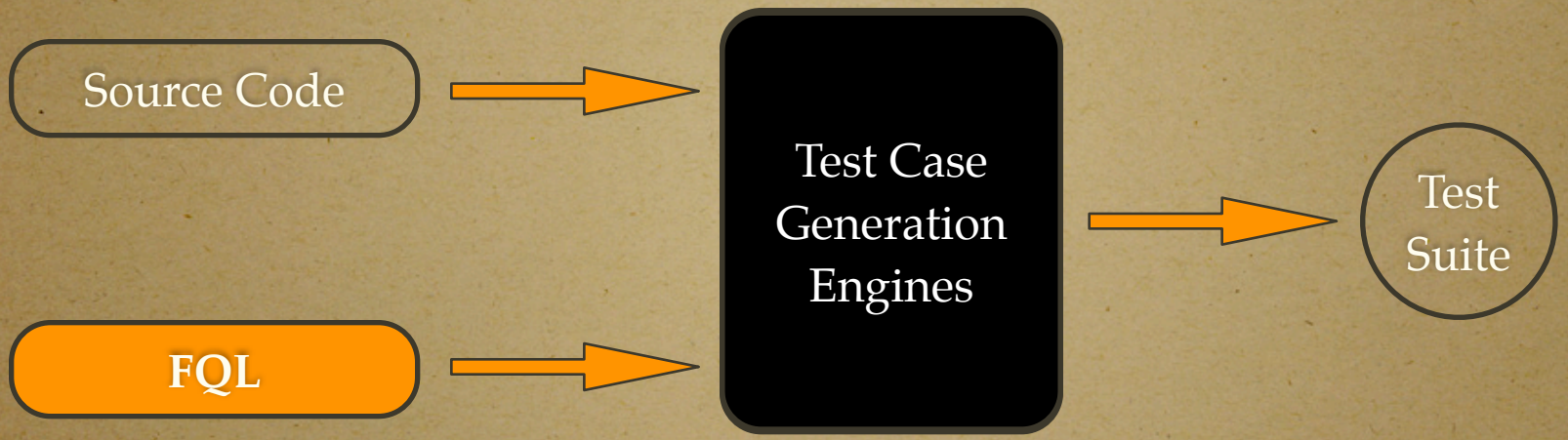


- Algorithmic approach presented at CAV'08, VMCAI'09
- Two engines already exist
  - FShell: Based on CBMC (C Bounded Model Checker)
  - FlleSh: Uses CPAchecker (Configurable Program Analysis)

Query-Driven Program Testing



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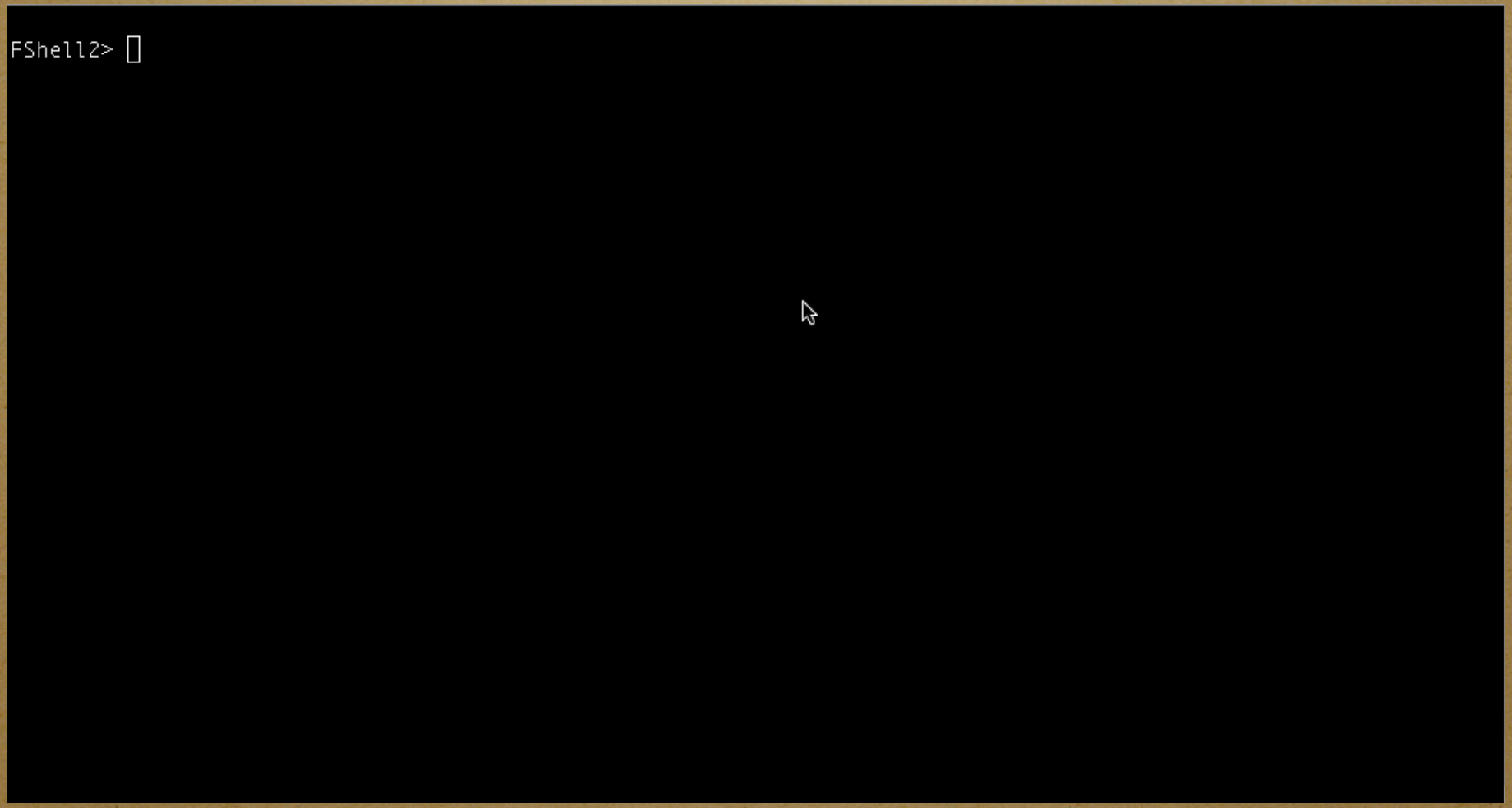
http://code.forsyte.de/fshell

Using FShell to Compute a Test Suite



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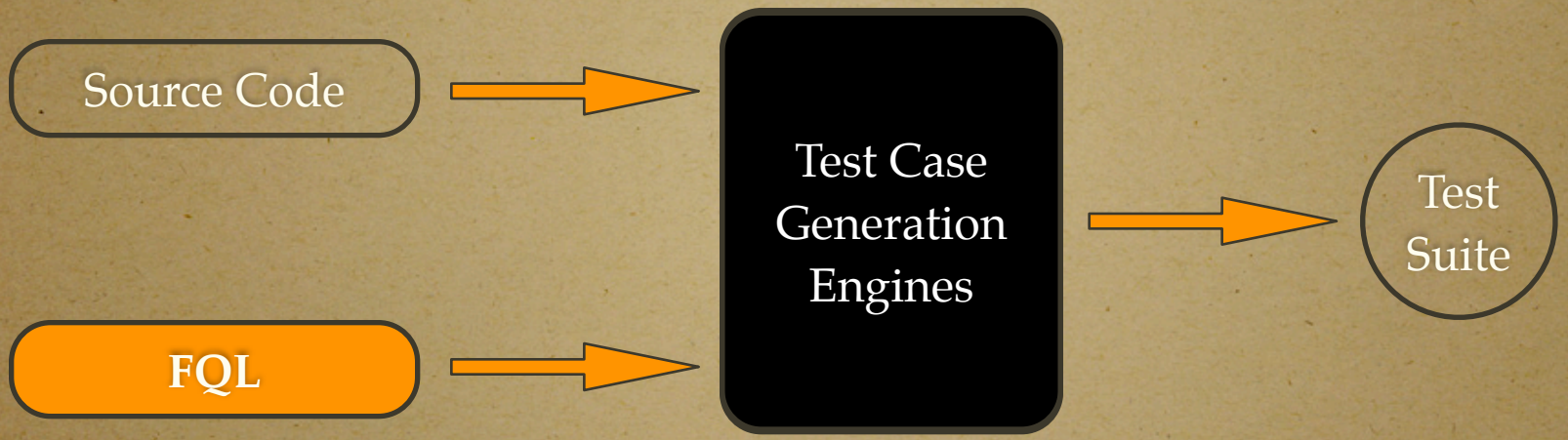
Applications of FQL/FShell



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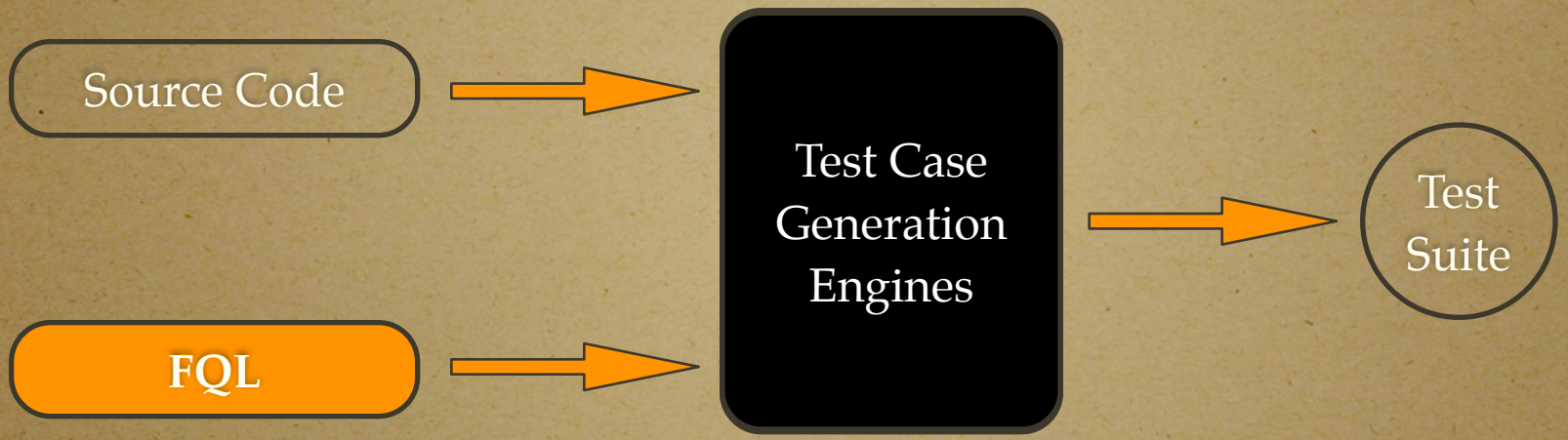


- Test case generation
- Certification
- Requirement-driven testing
- Coverage Evaluation
- Reasoning about test specifications

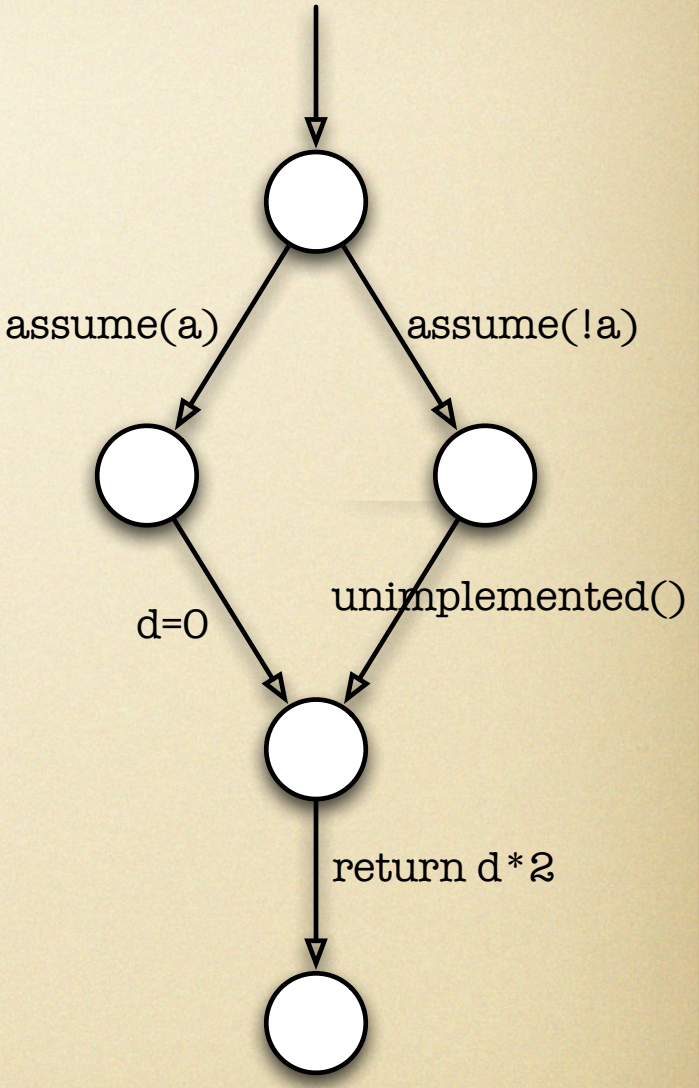
Software Testing using FQL

- Program Representation: Control Flow Automata
- Describing Single Test Cases
- Describing Test Suites

Control Flow Automaton (CFA)

```
1  int example(int a, int d)
2  {
3    if (a)
4      d = 0;
5    else
6      unimplemented();
7    return d*2;
8  }
```

- Henzinger et al. (POPL'02)
- Edges:
  - assume (conditional branches)
  - assignment
  - function call
  - function return
  - skip
- Nodes: locations



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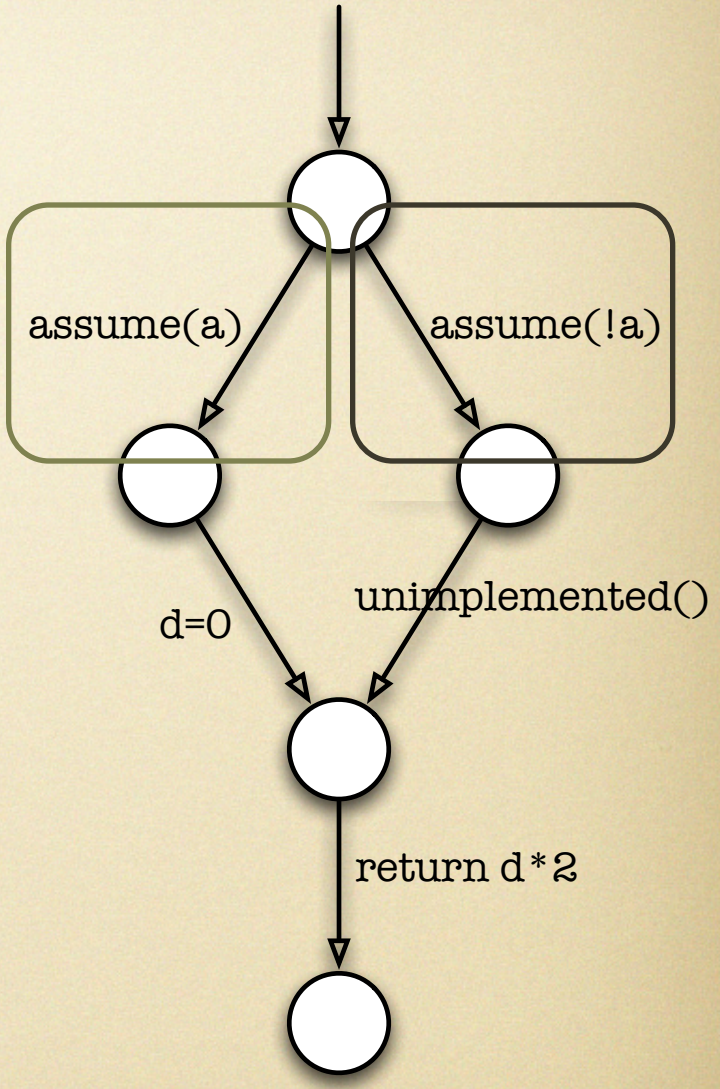

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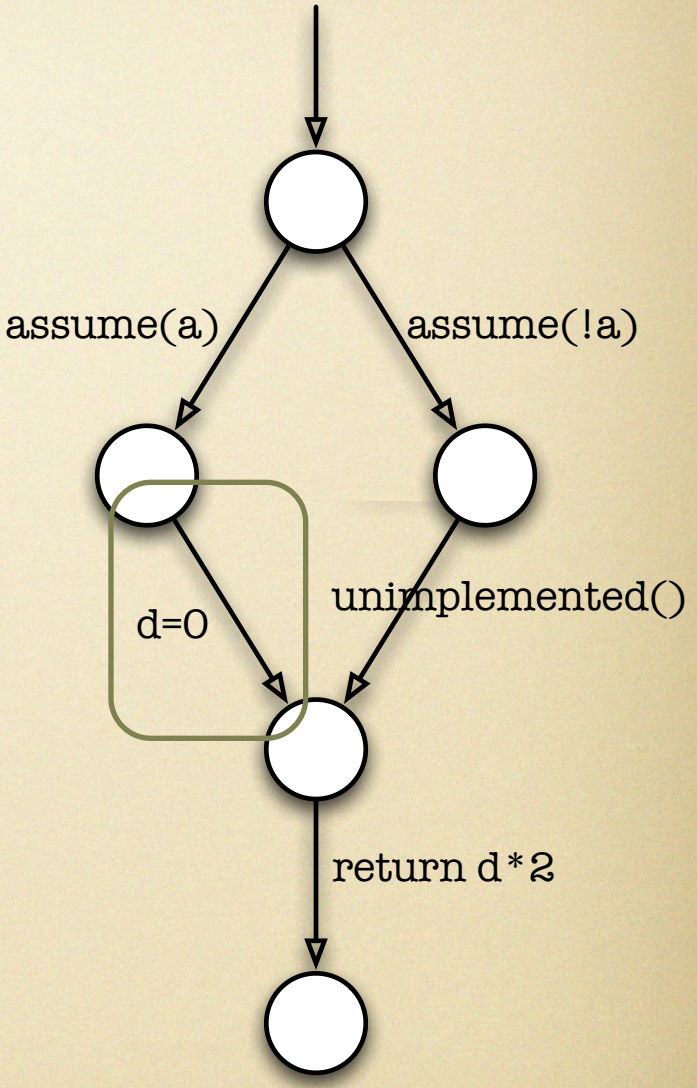

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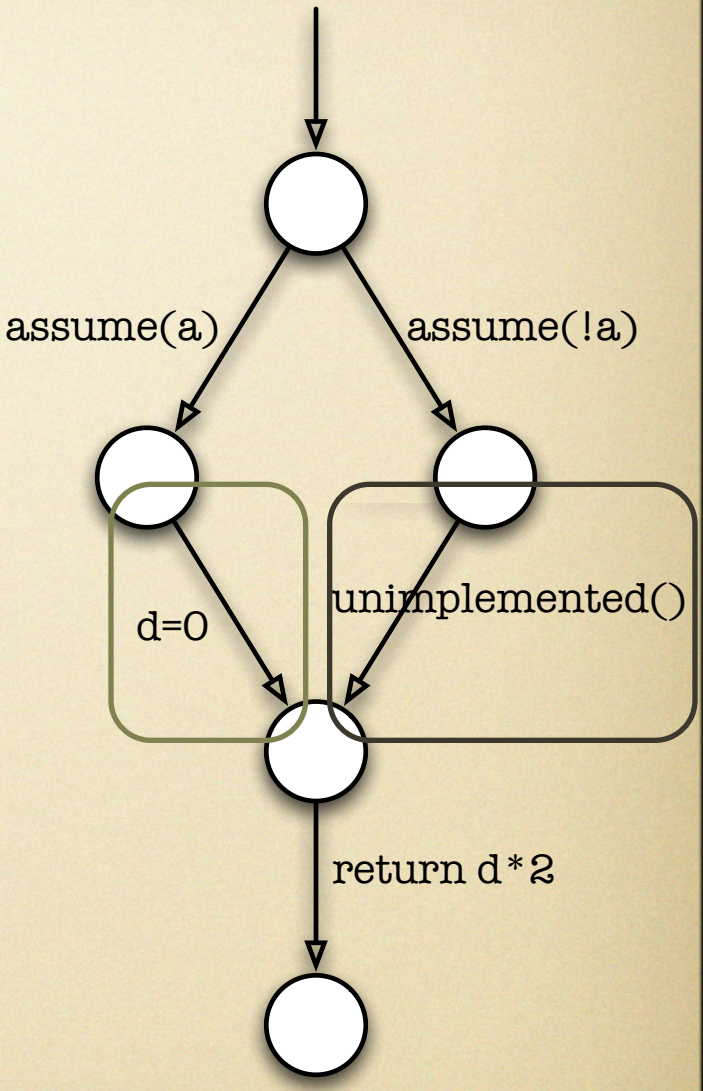

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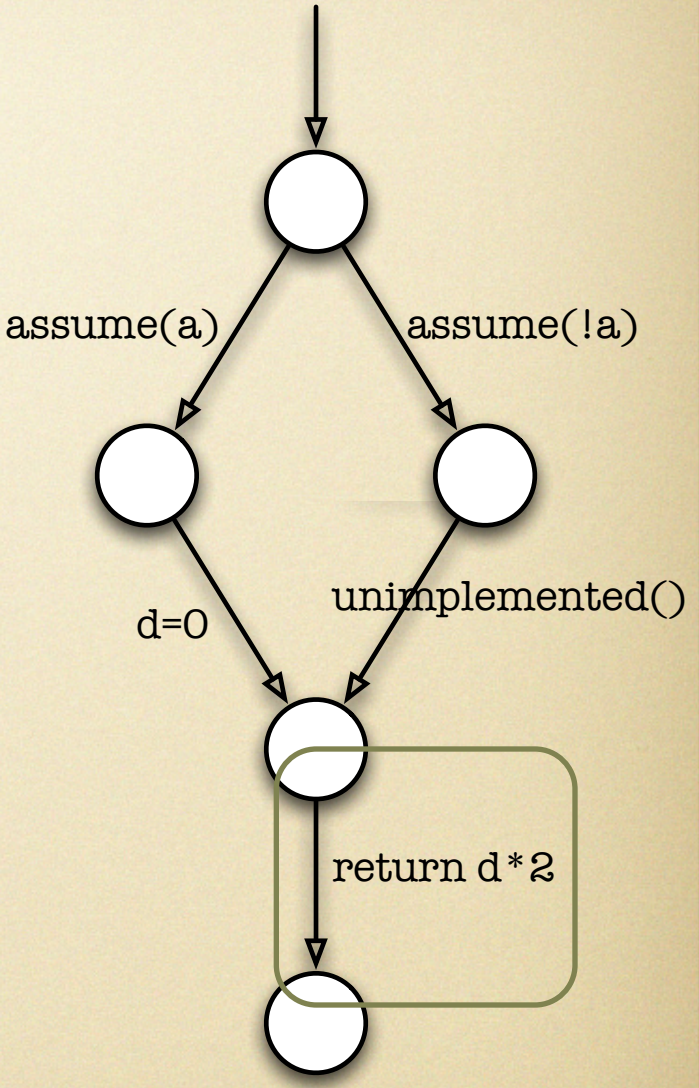

Software Testing using FQL

- ☑ Program Representation: Control Flow Automata
- **Describing Single Test Cases**
- Describing Test Suites

Filter Functions

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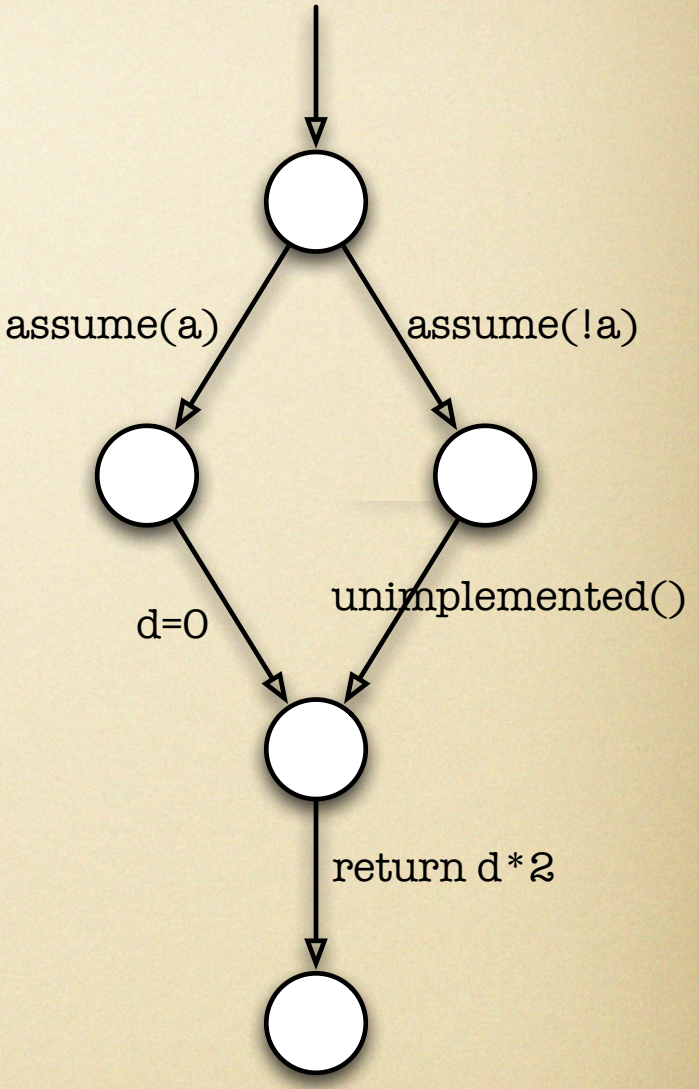

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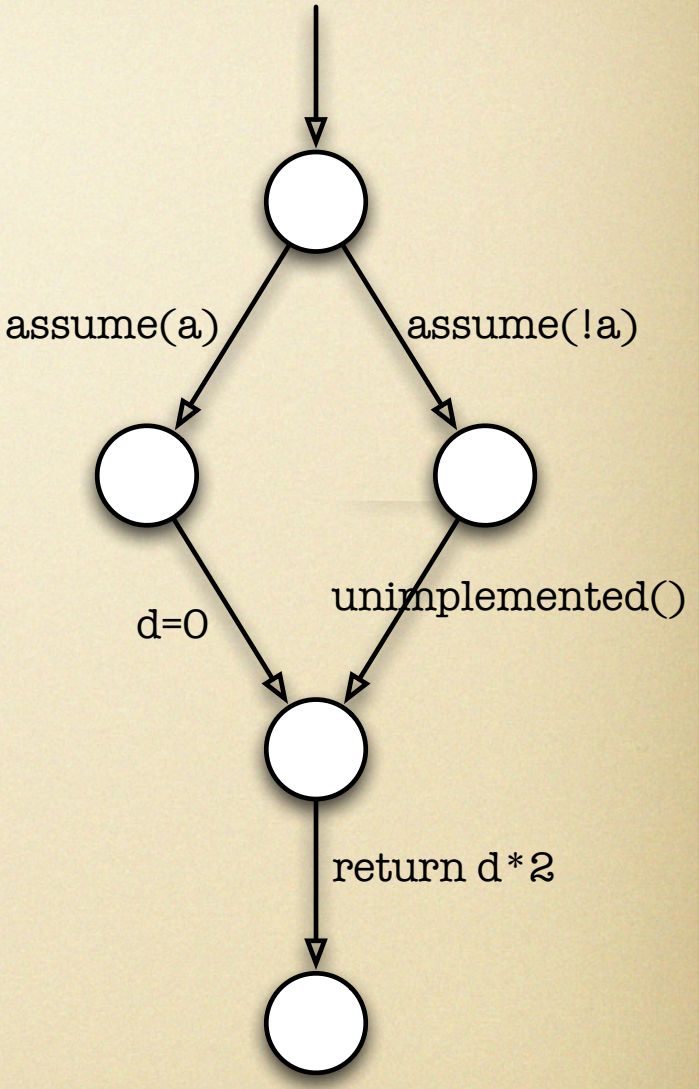
- Cover *line 4*



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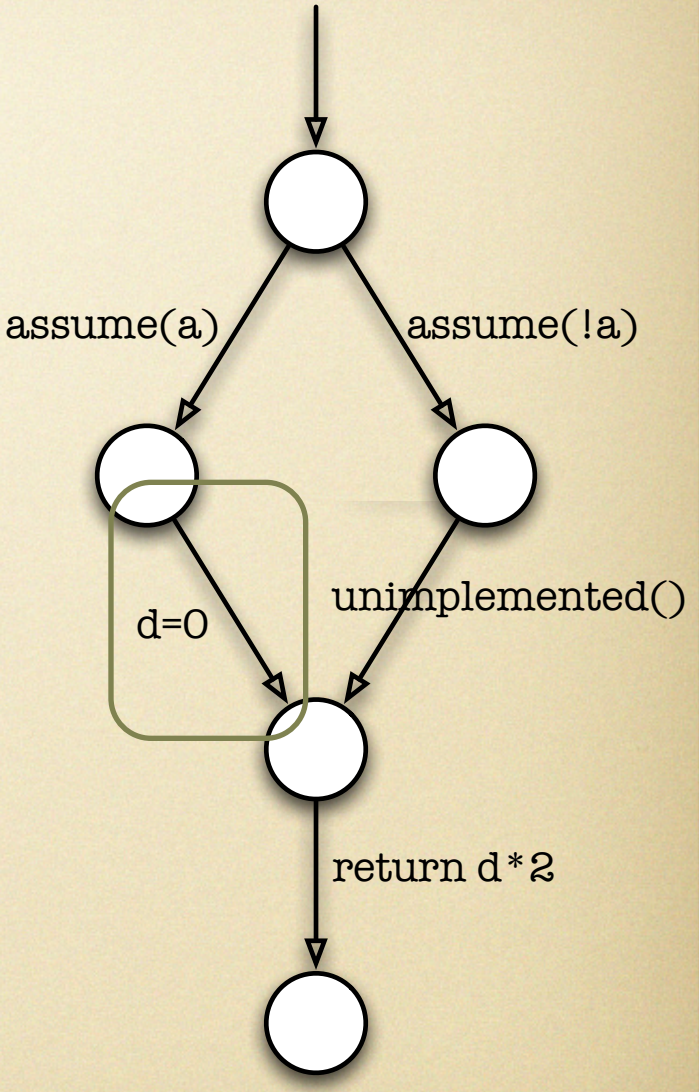

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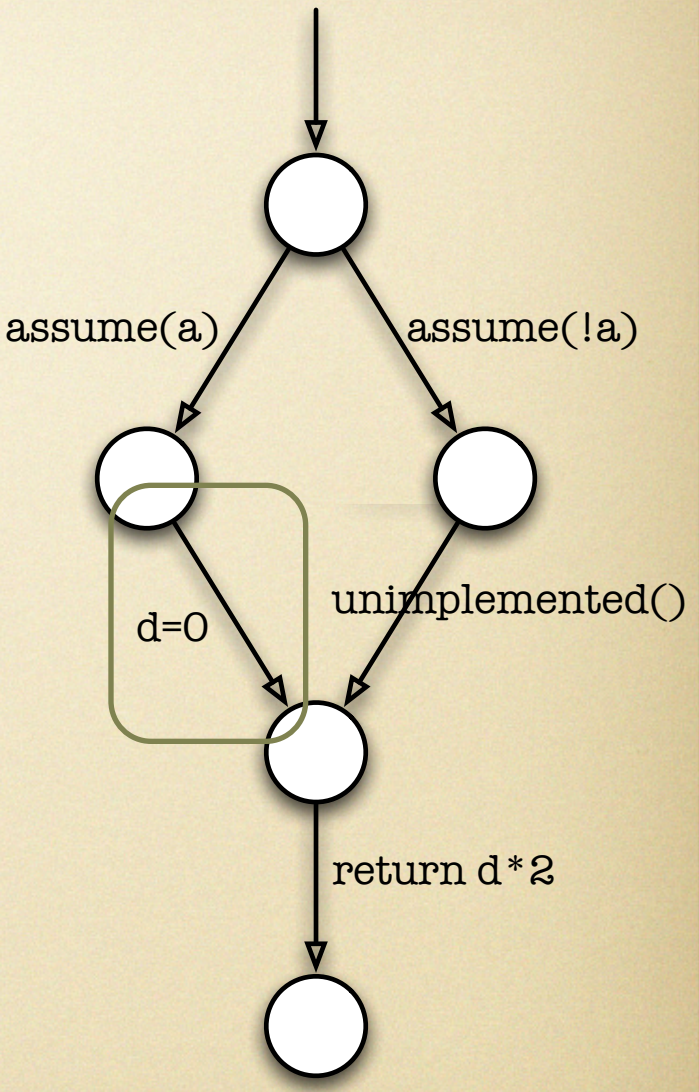
- Cover *line 4*
  - **`cover "@4"`**



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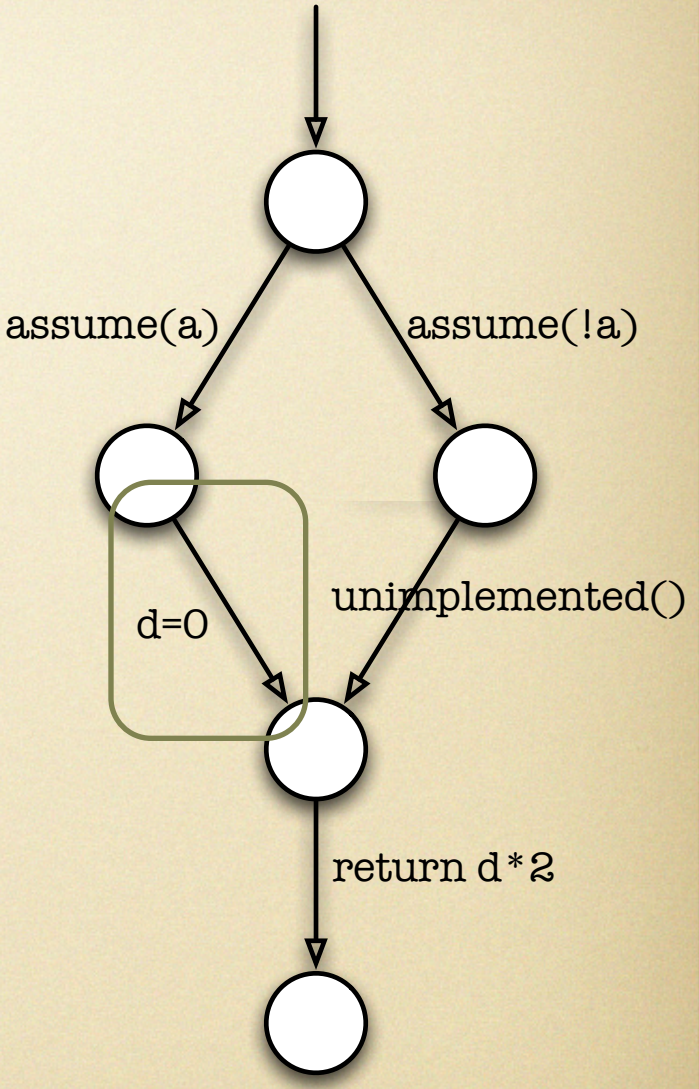
- Cover *line 4*
  - **`cover "@4"`**

    IN:
    a=2
    d=0



Filter Functions

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1  int example(int a, int d)
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```
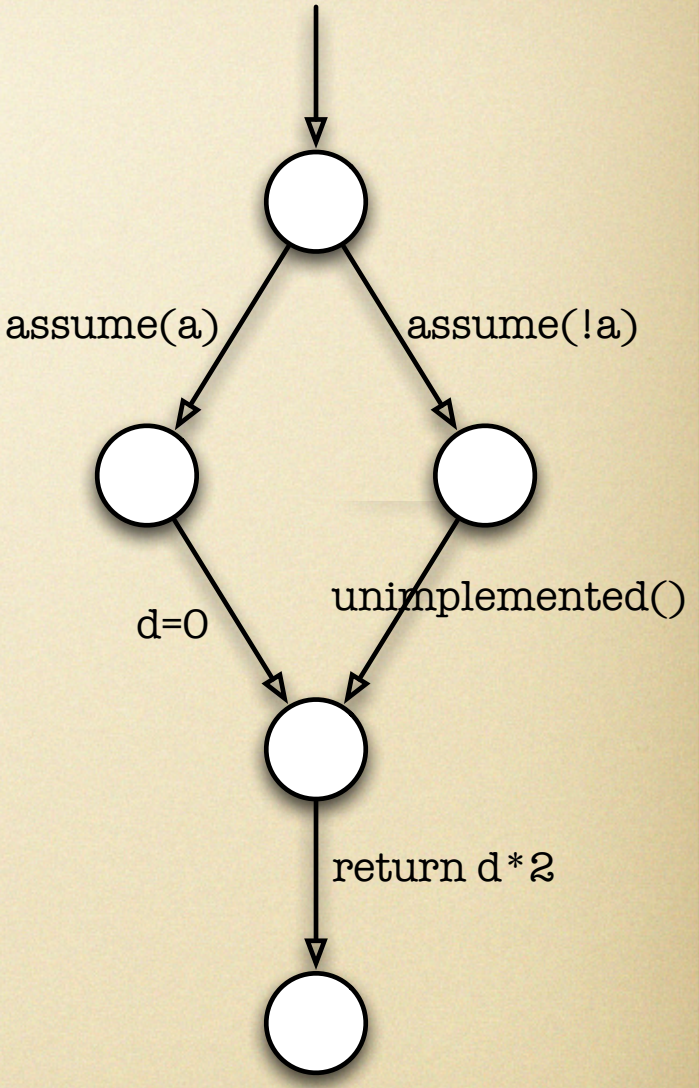

- Cover *line 4*
  - **`cover "@4"`**

    IN:
    a=2
    d=0
- Cover *some statement*



Filter Functions

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- Cover *line 4*
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    a=2
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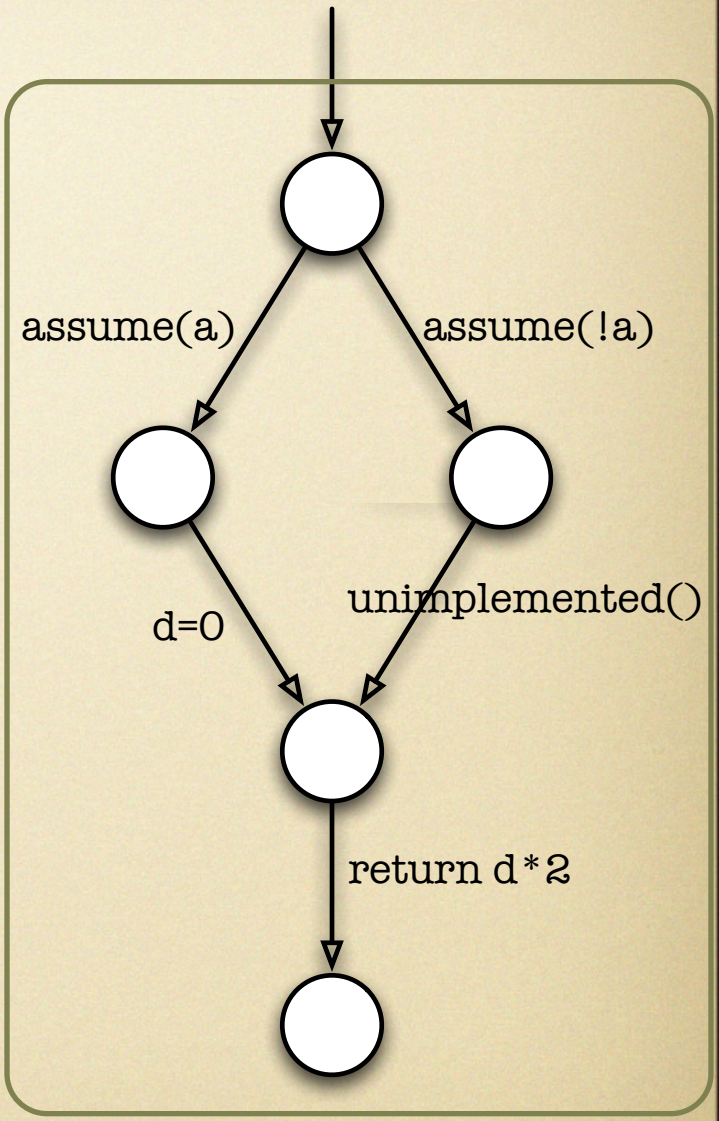

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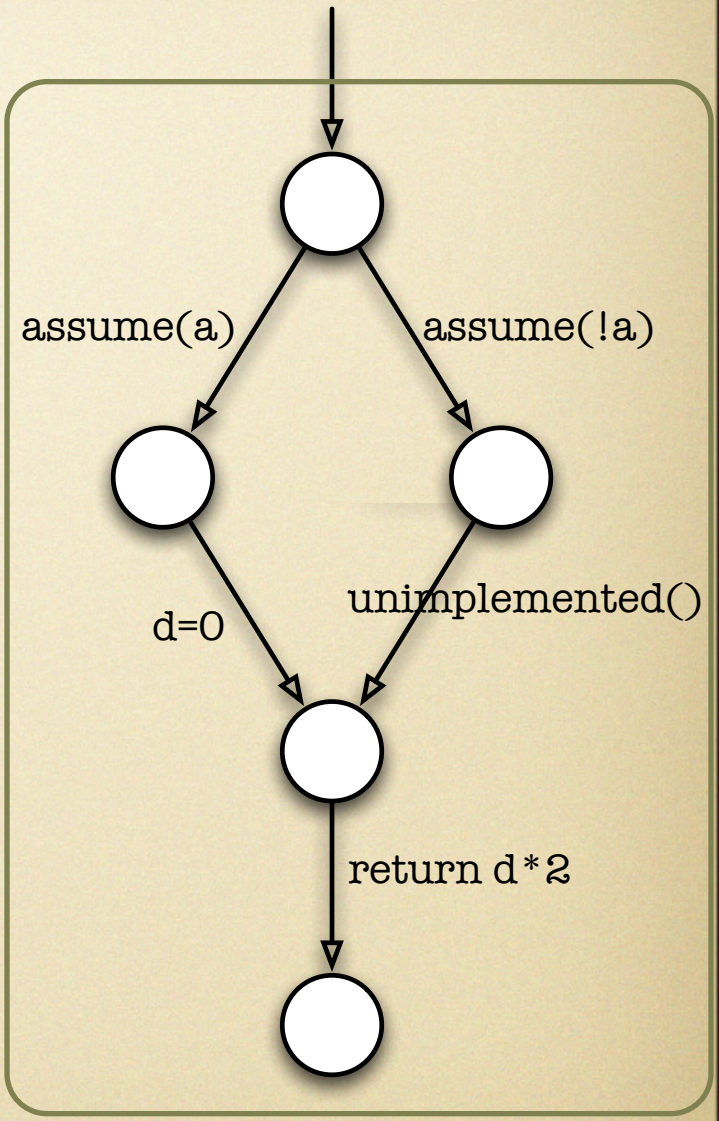
```

- Cover *line 4*
  - **`cover "@4"`**

    IN:
    a=2
    d=0
- Cover *some statement*
  - **`cover "ID"`**



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```
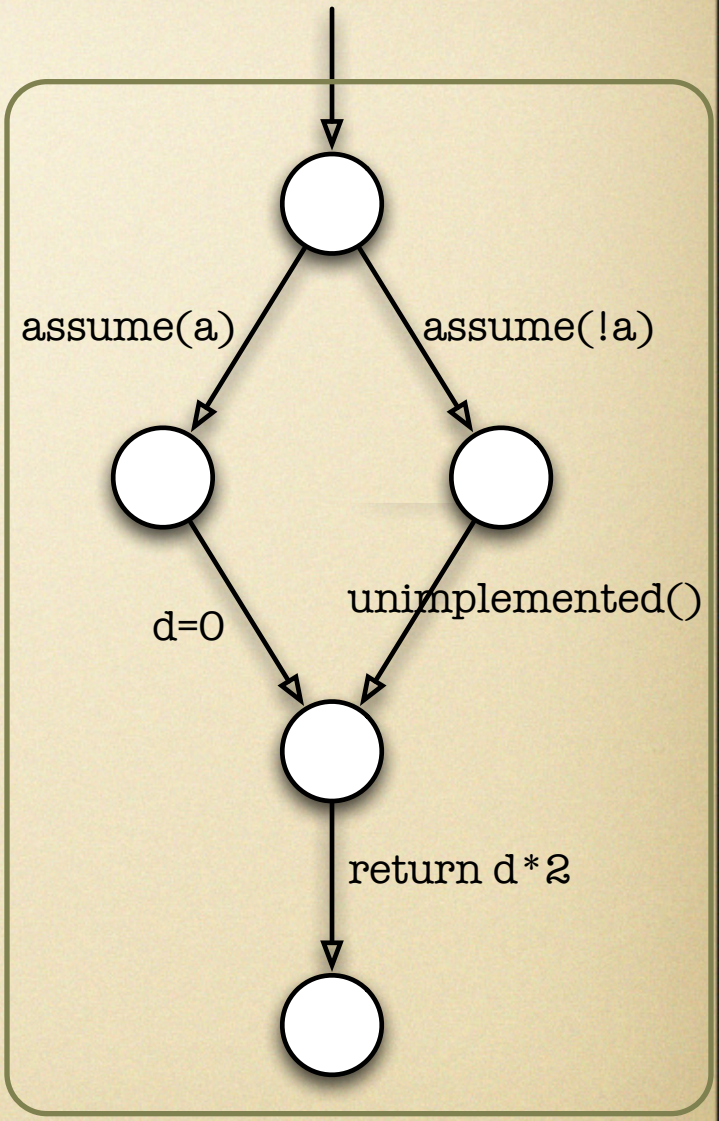

- Cover *line 4*
  - **`cover "@4"`**

    IN:
    a=2
    d=0
- Cover *some statement*
  - **`cover "ID"`**

    IN:
    a=8192
    d=0



Describing Single Test Cases

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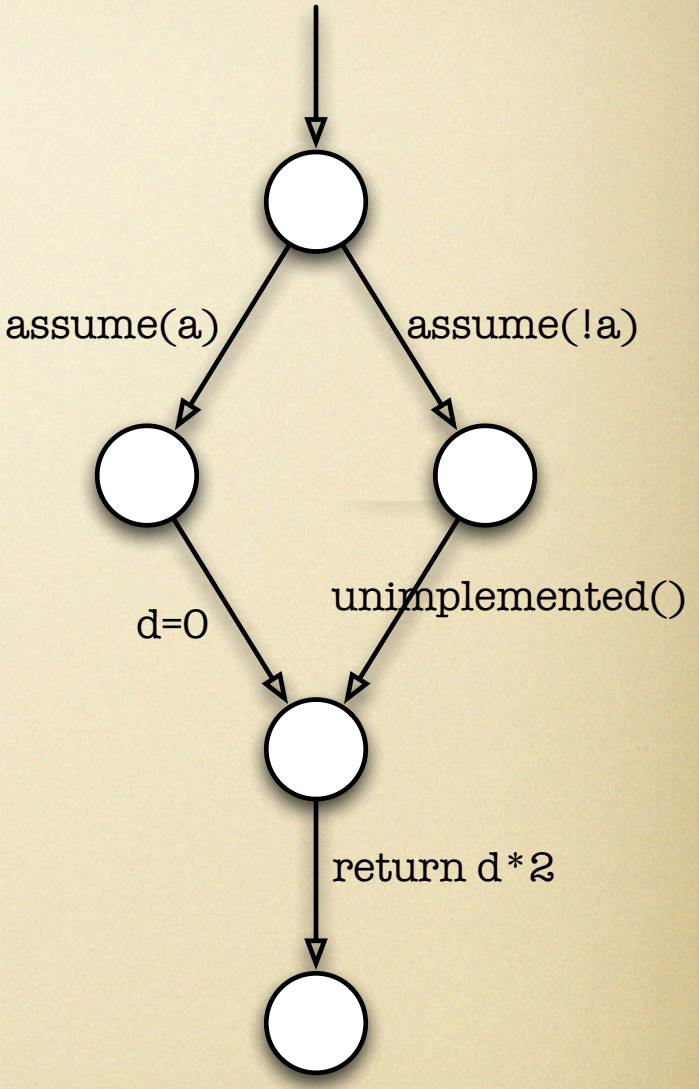

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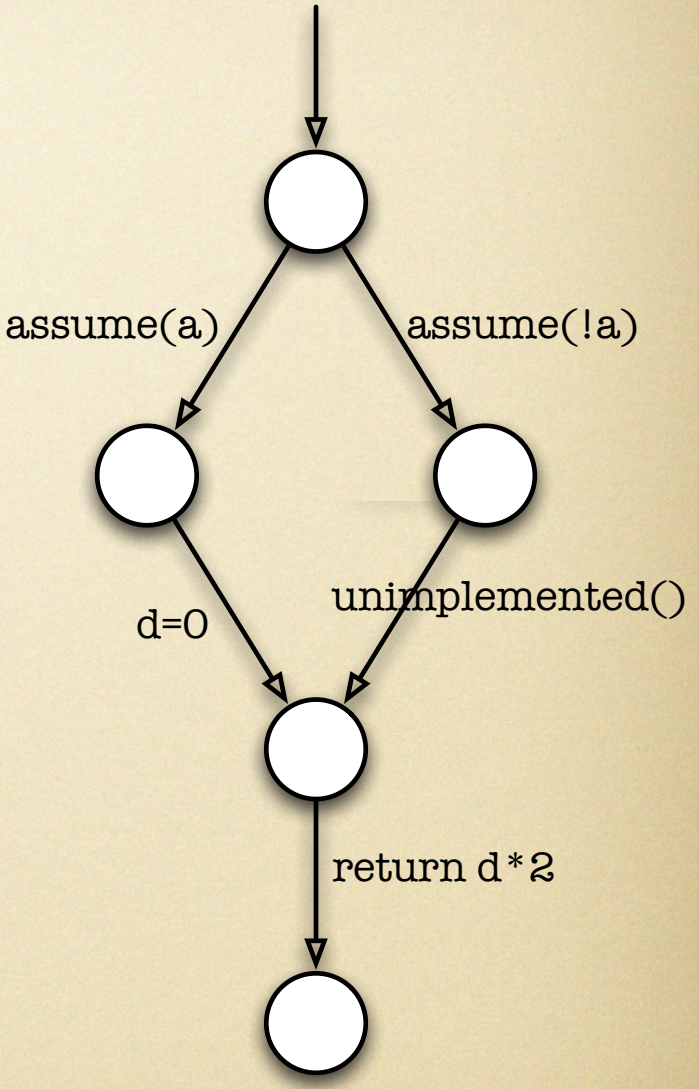
```

- Cover *line 4 or line 6*



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```
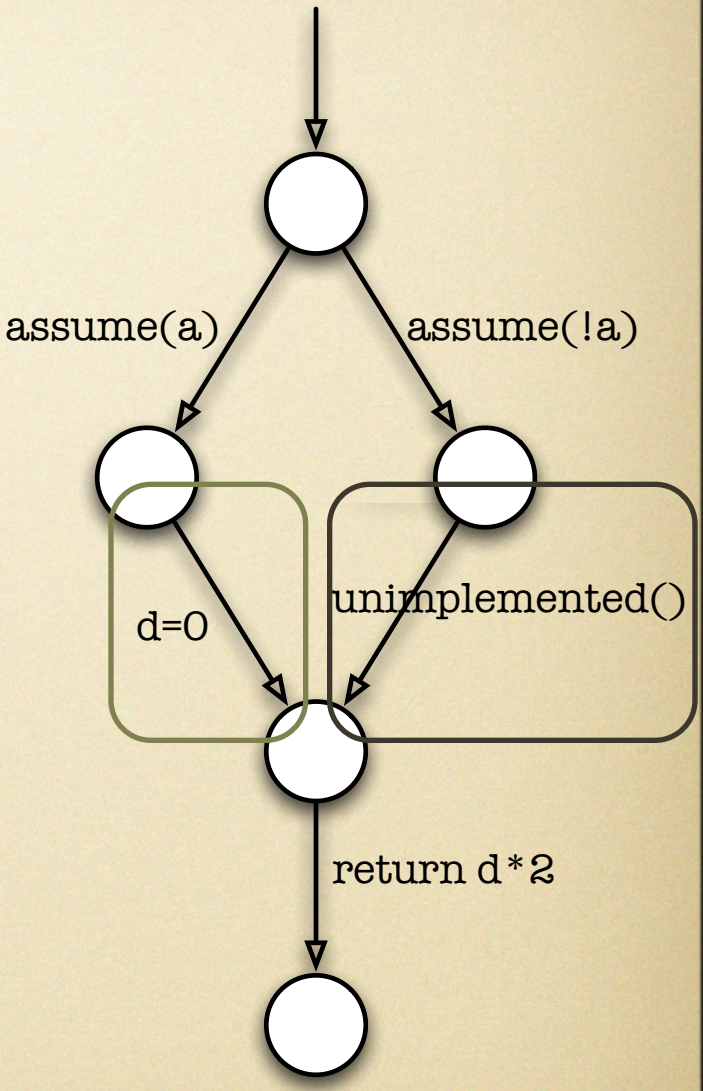

- Cover *line 4 or line 6*



Describing Single Test Cases

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1  int example(int a, int d)
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3    if (a)
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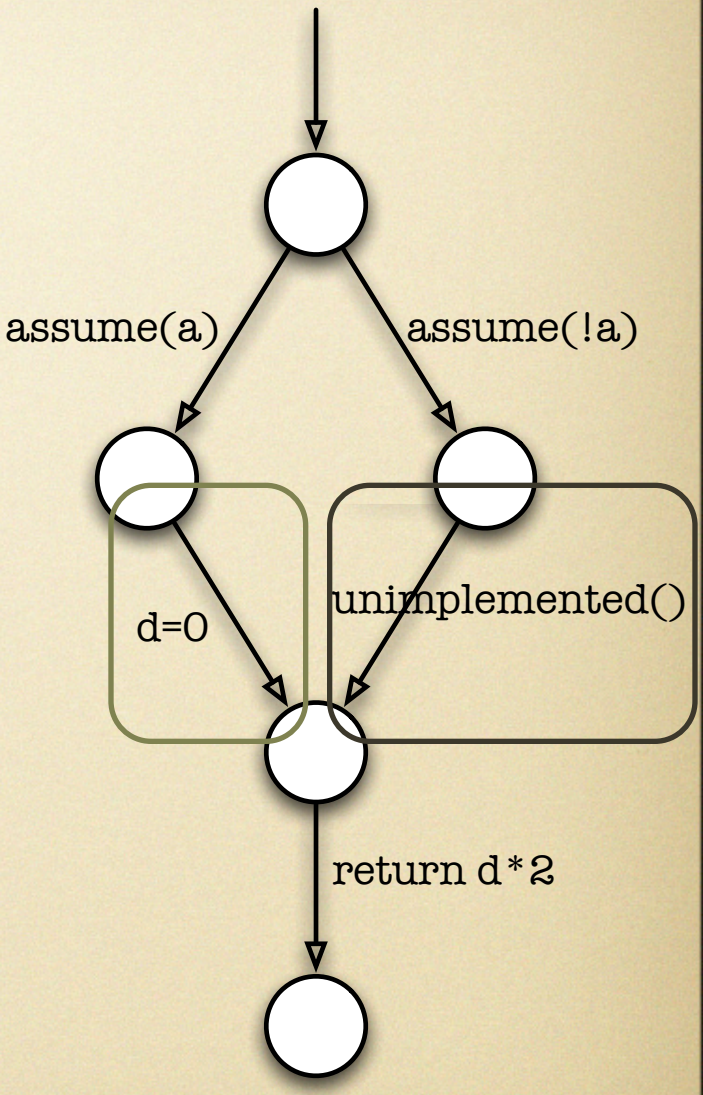
```

- Cover *line 4 or line 6*
  - **`cover "@4+@6"`**



Describing Single Test Cases

```
1  int example(int a, int d)
2  {
3    if (a)
4      d = 0;
5    else
6      unimplemented();
7    return d*2;
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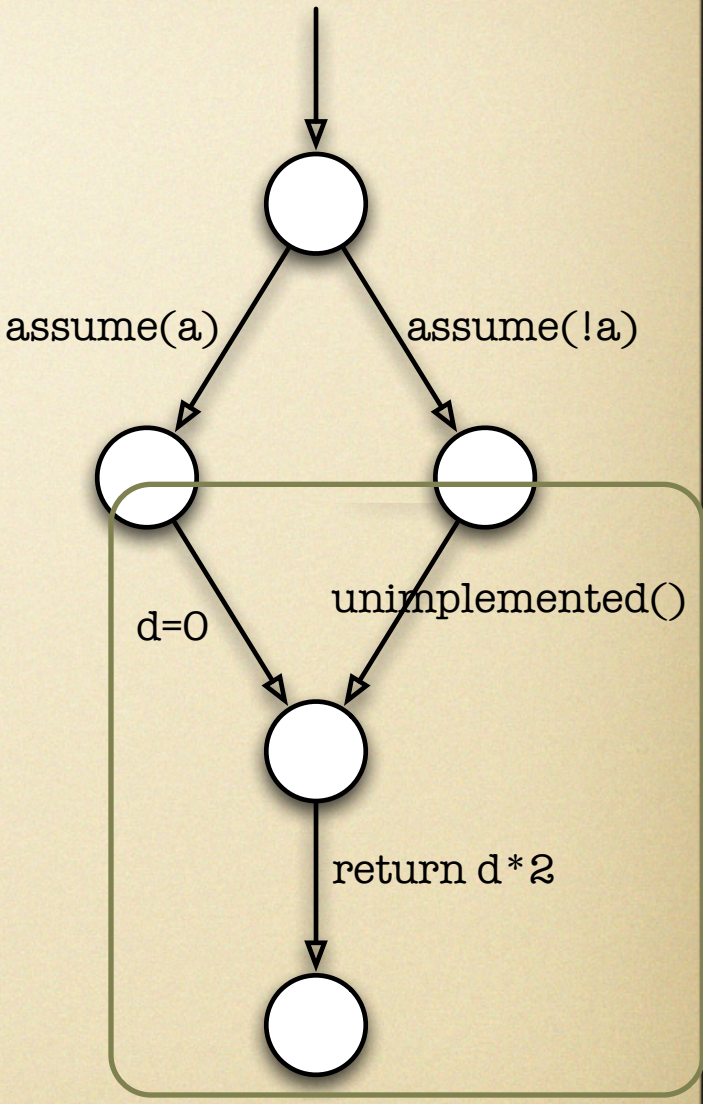
```

- Cover *line 4 or line 6*
  - **`cover "@4+@6"`**
- Cover a *basic block*



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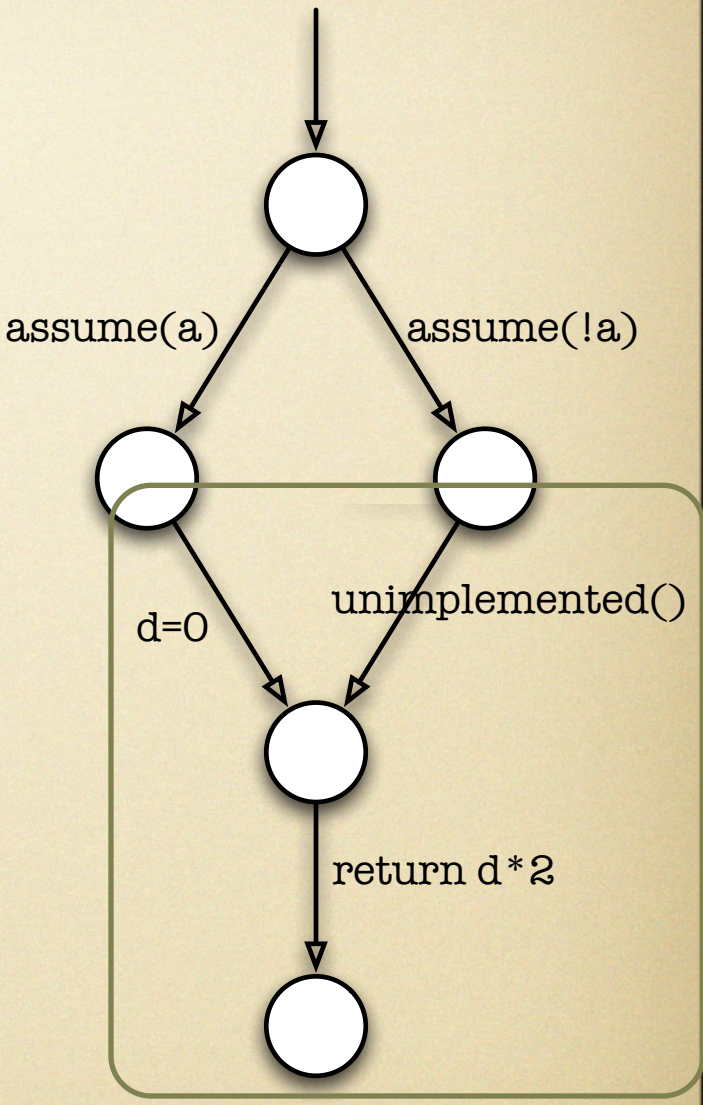

- Cover *line 4 or line 6*
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  - **`cover "@basicblockentry"`**

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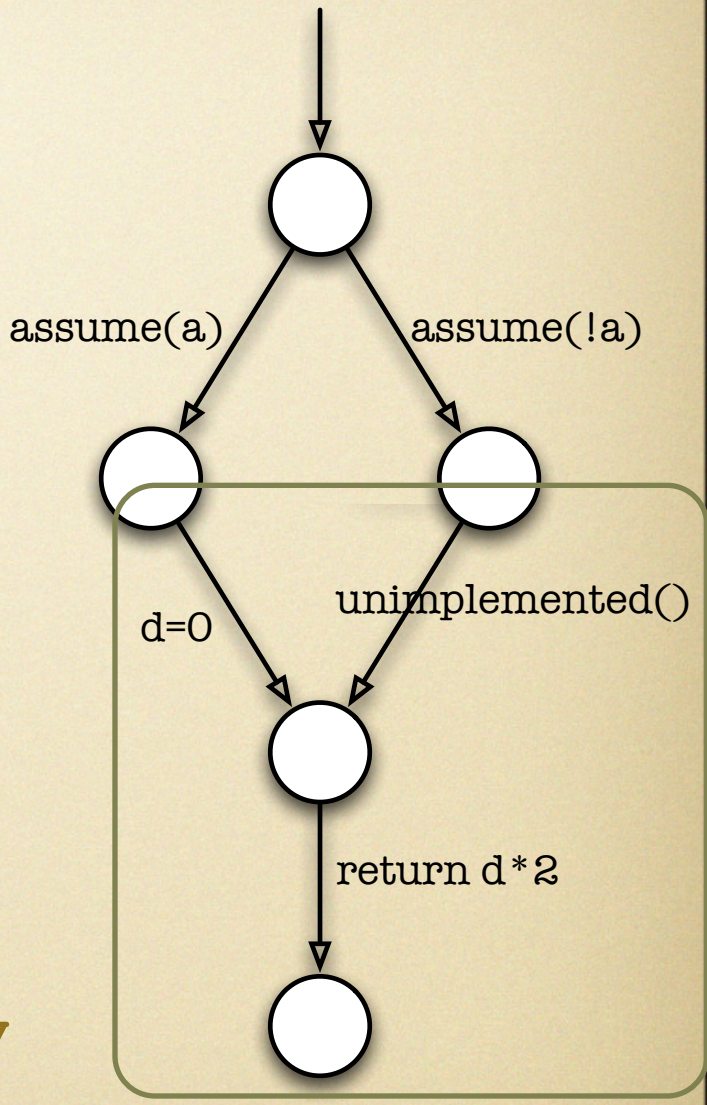

- Cover *line 4 or line 6*
  - **`cover "@4+@6"`**
- Cover a *basic block*
  - **`cover "@basicblockentry"`**
- For this example **`@basicblockentry`** is tantamount to **`@4+@6+@7`**

Describing Single Test Cases

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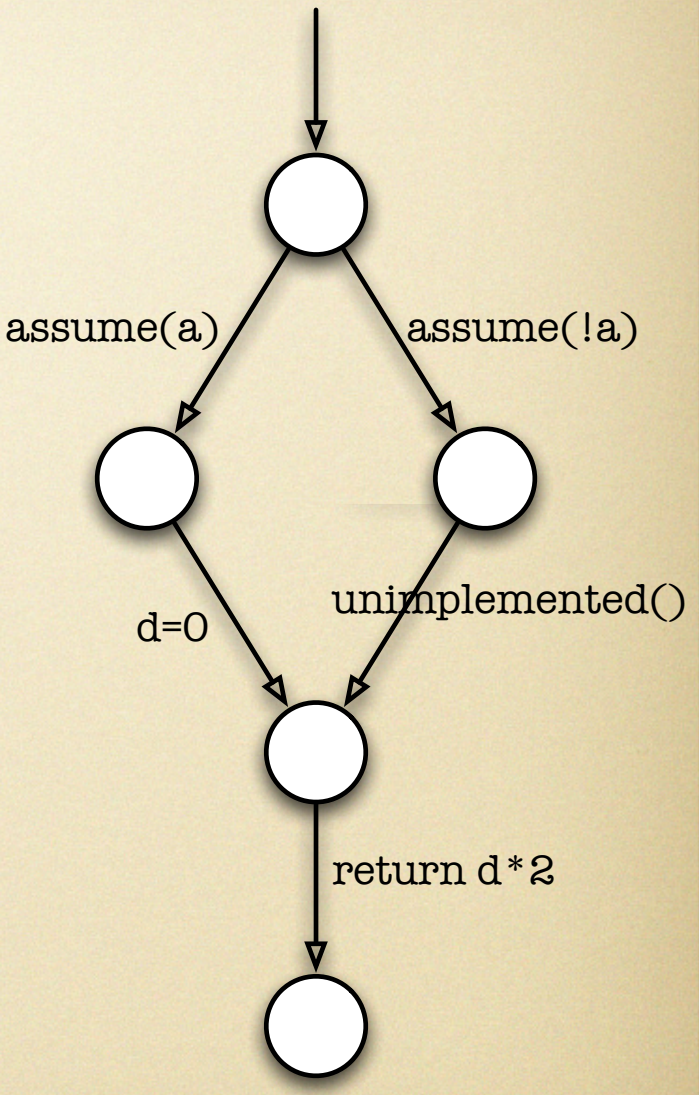

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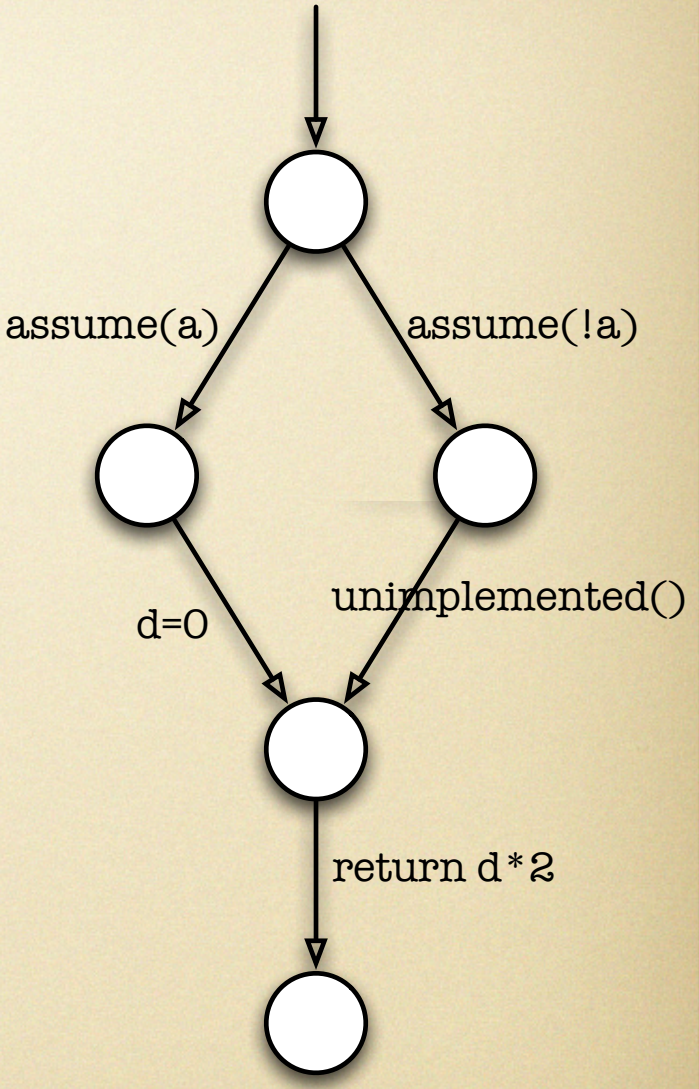

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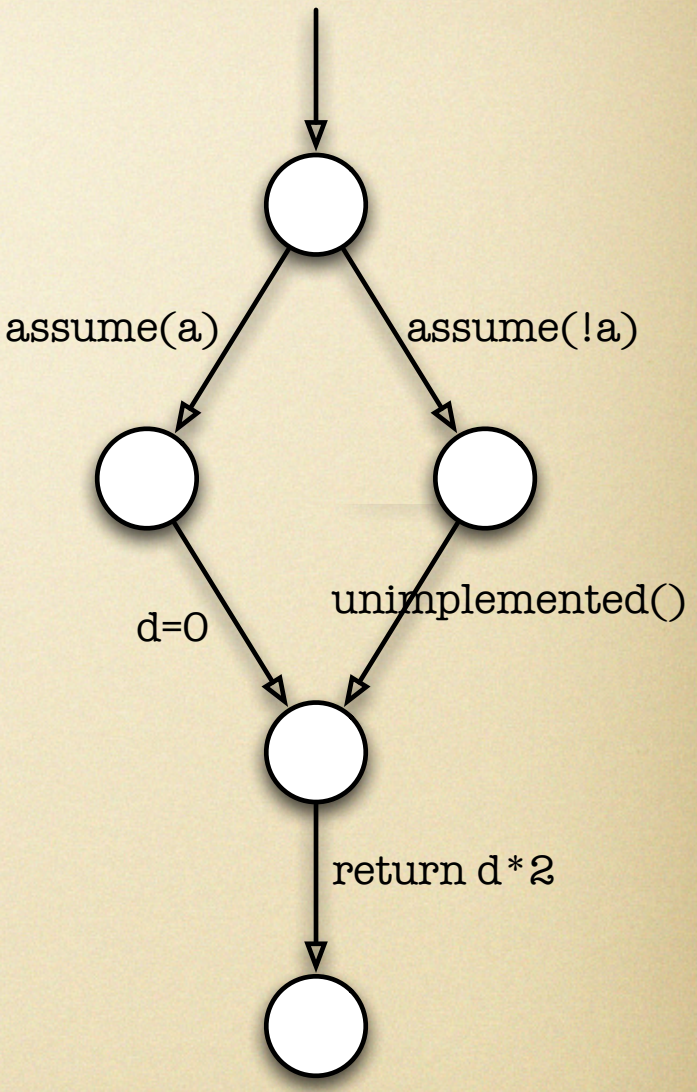
- Intuitively: “cover line 4” =



Describing Single Test Cases

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- Test case is execution (program path)
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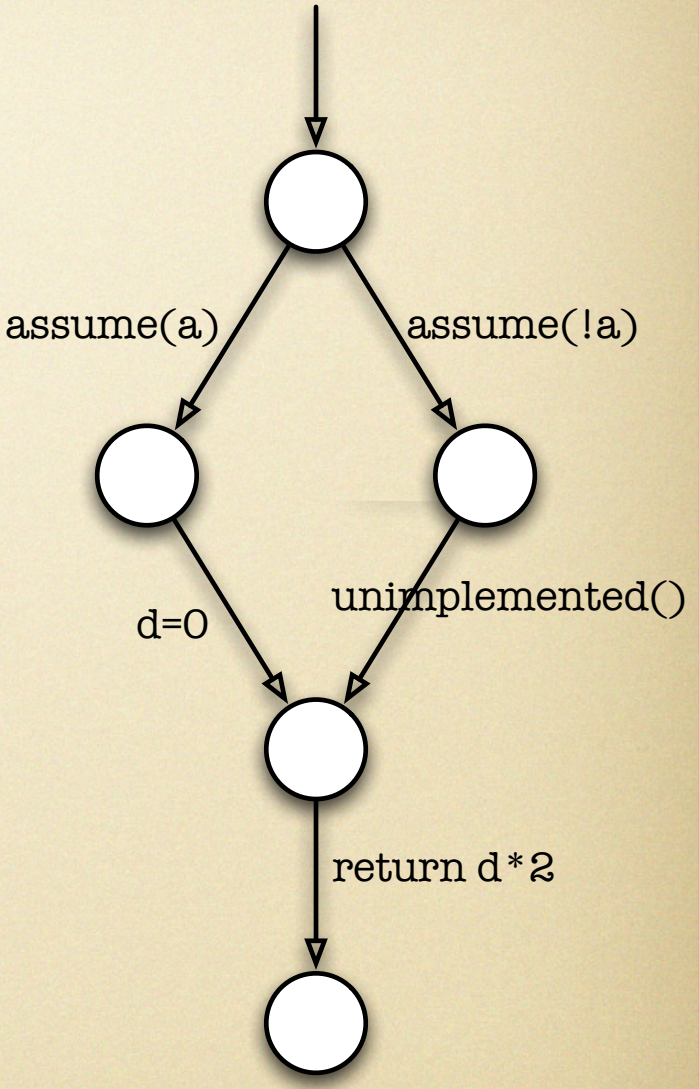
  - Execute some statement(s)



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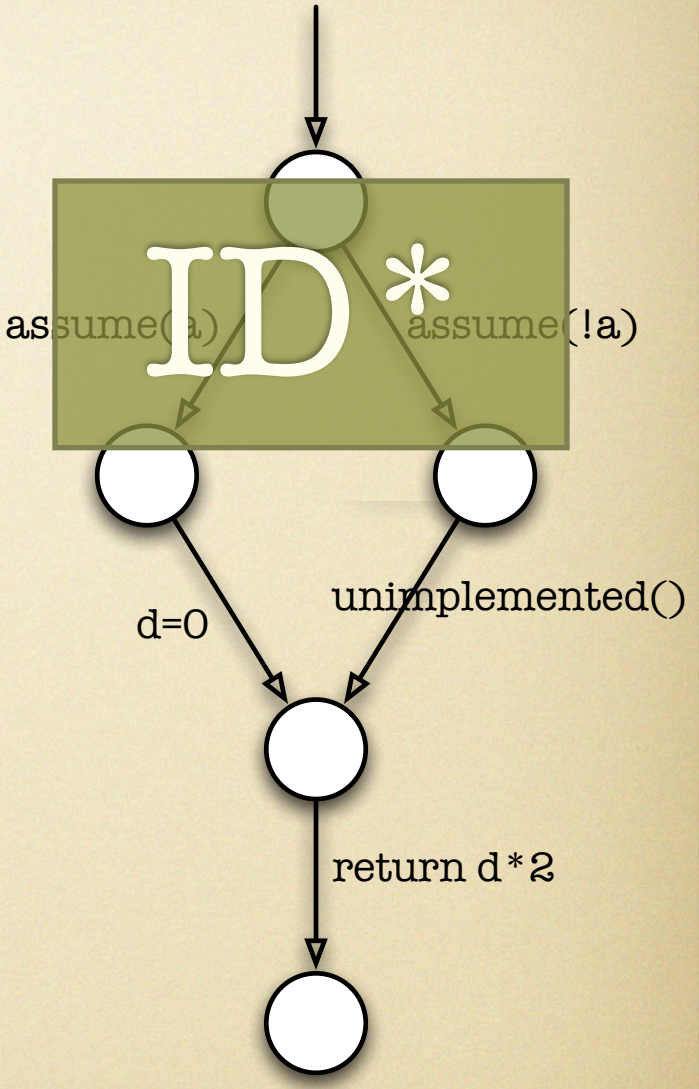

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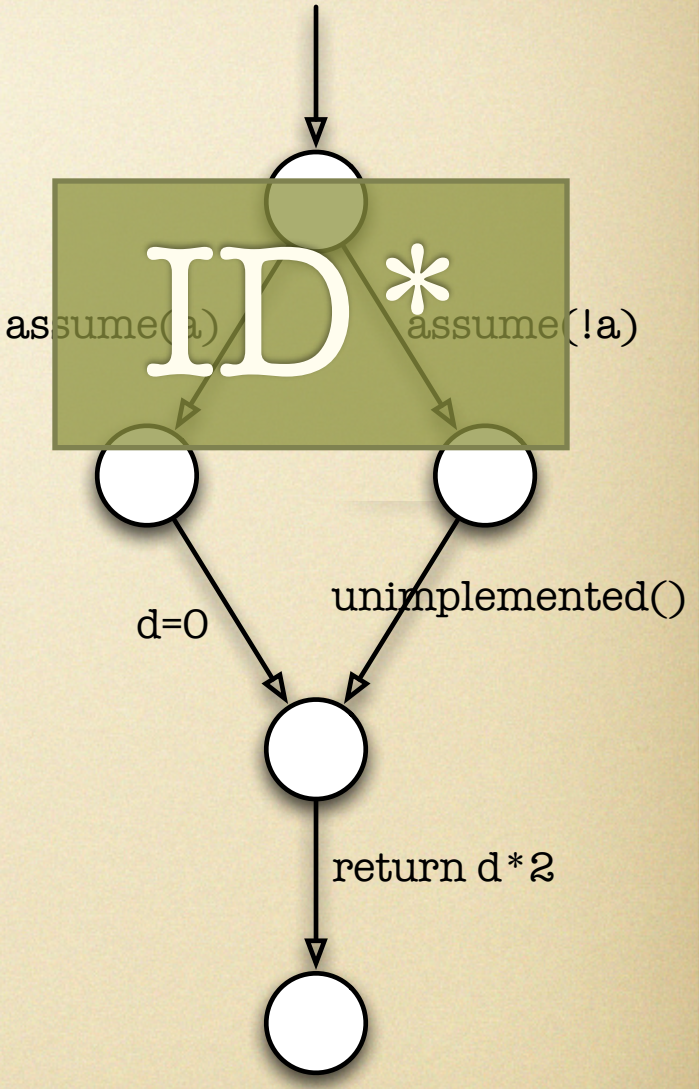
- Test case is execution (program path)
- Intuitively: “cover line 4” =
  - Execute some statement(s)
  - Reach line 4



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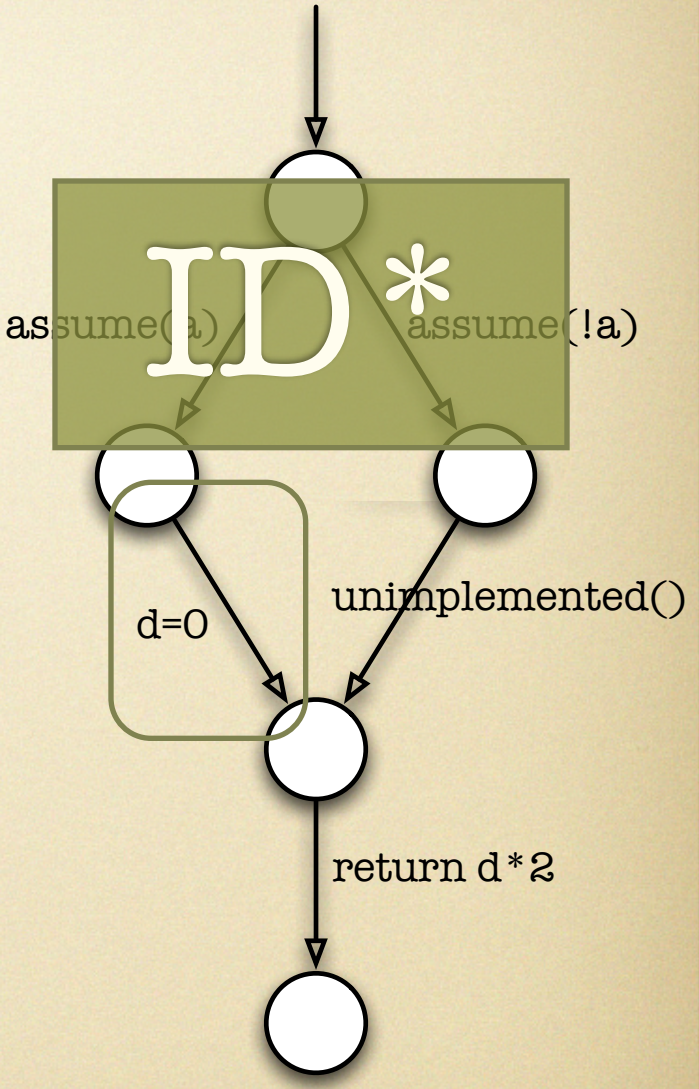

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  - Reach line 4
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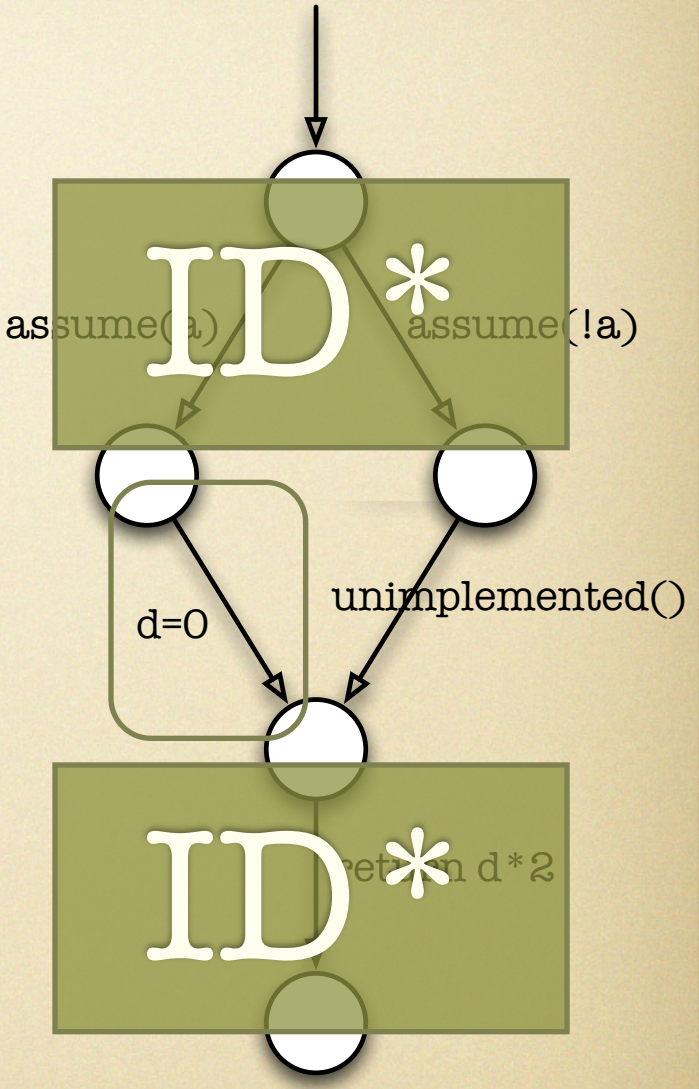

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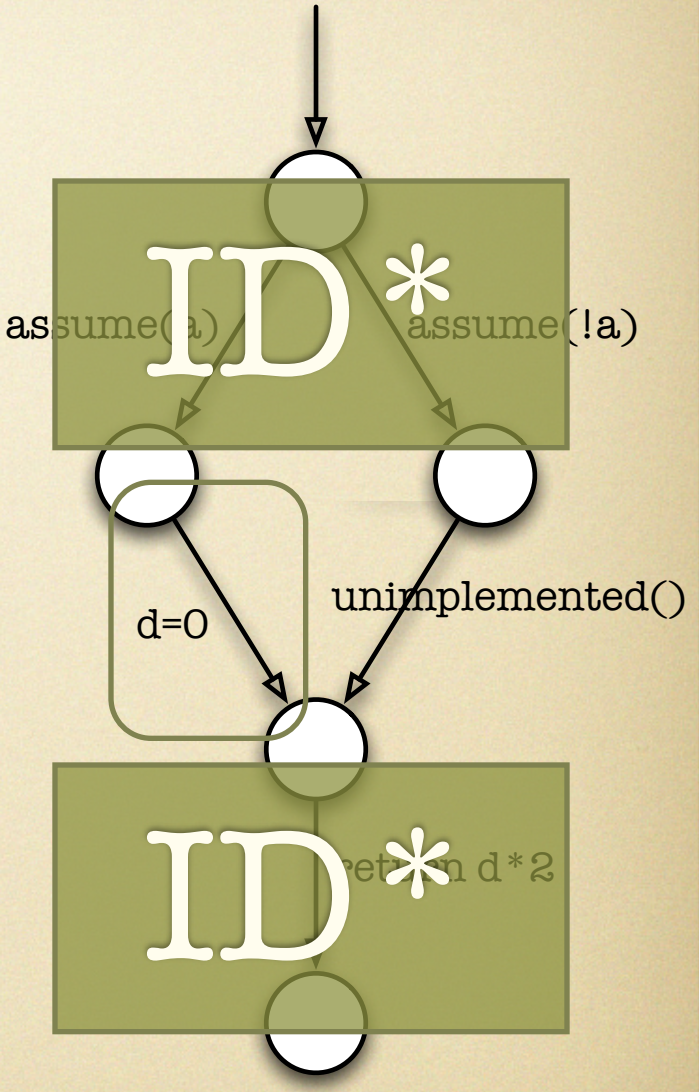
  - **`cover "ID*.@4.ID*"`**



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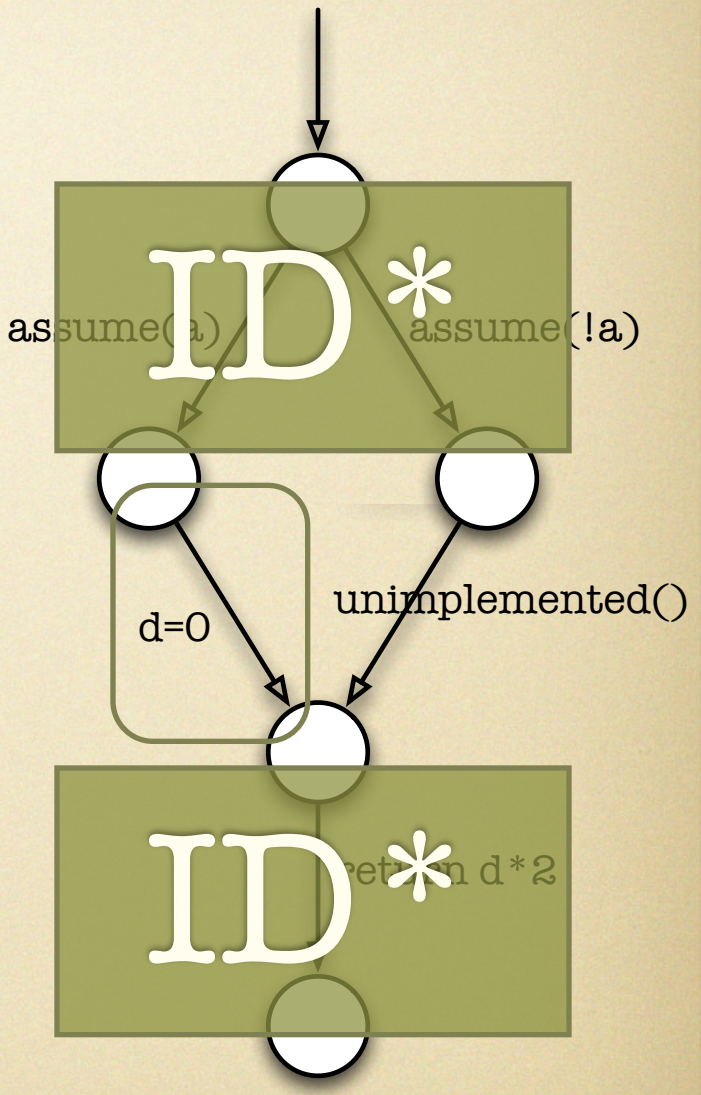
  - **`cover "ID*.@4.ID*"`**

    IN:

    a=2
    d=0



Path Patterns

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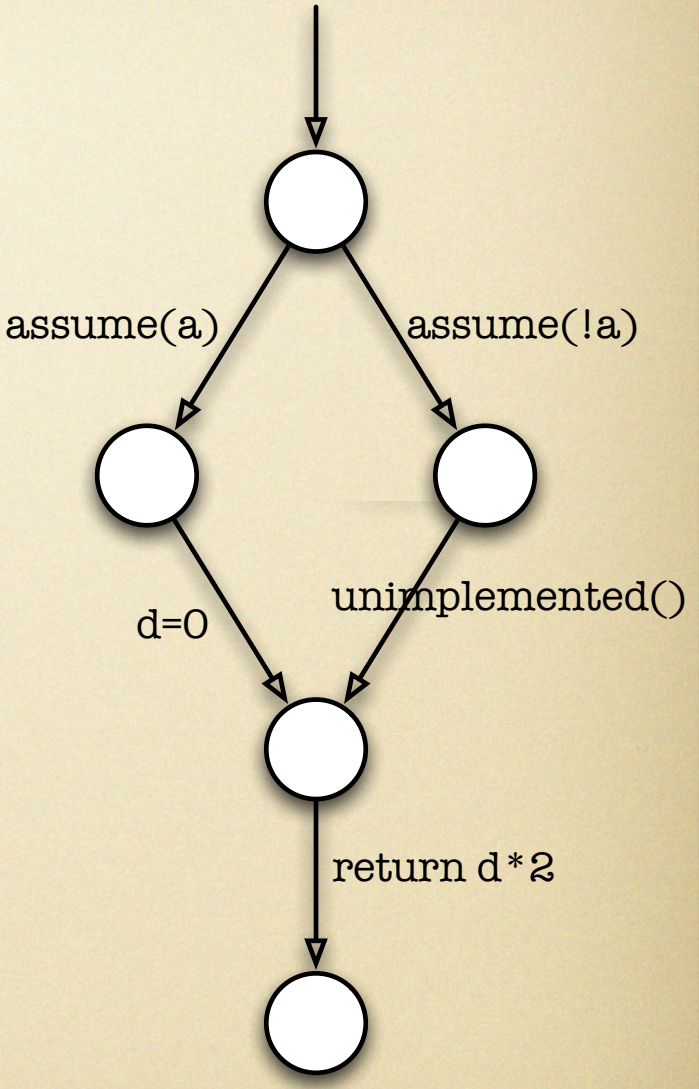

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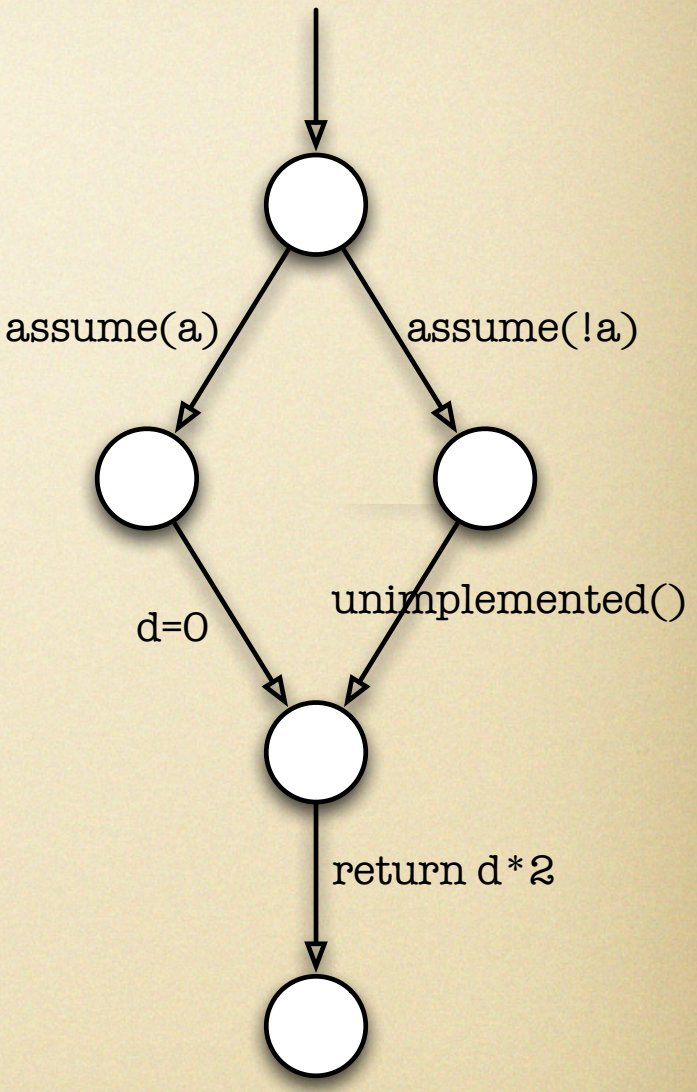
- `cover "ID* . @4 . ID* + ID* . @6 . ID*"`



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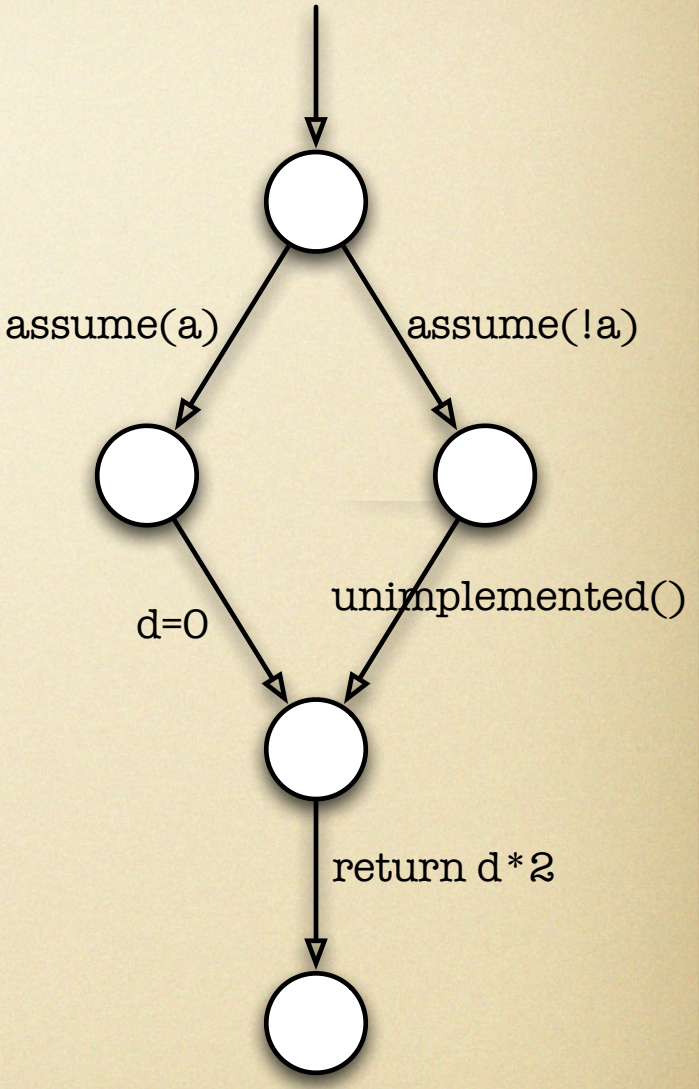
- Path patterns are regular expressions:



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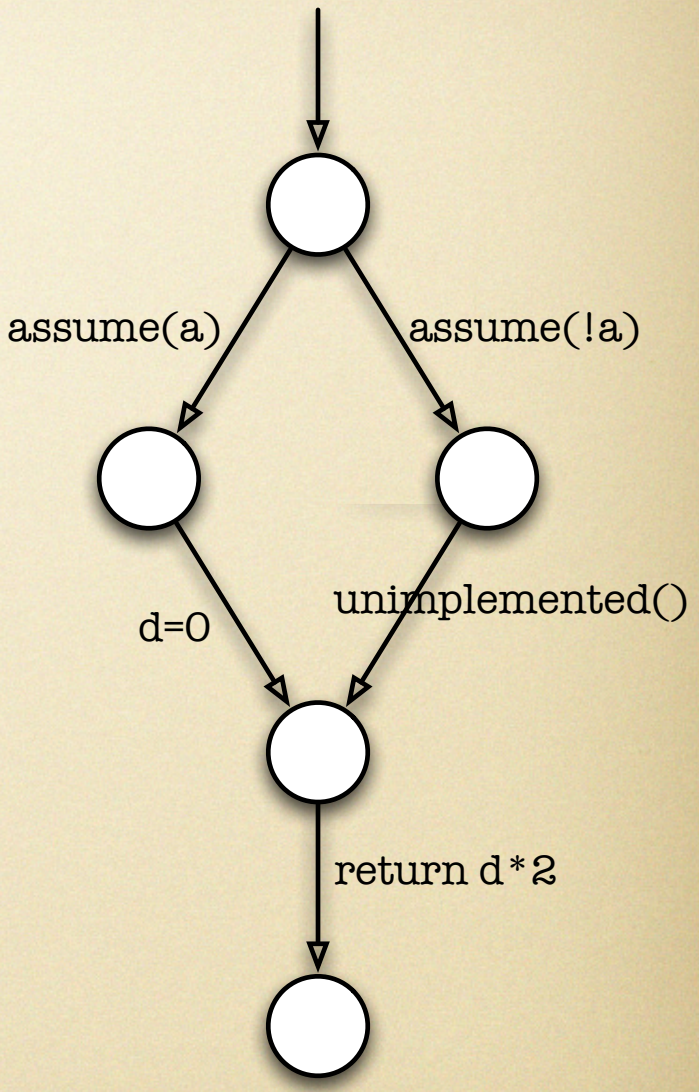

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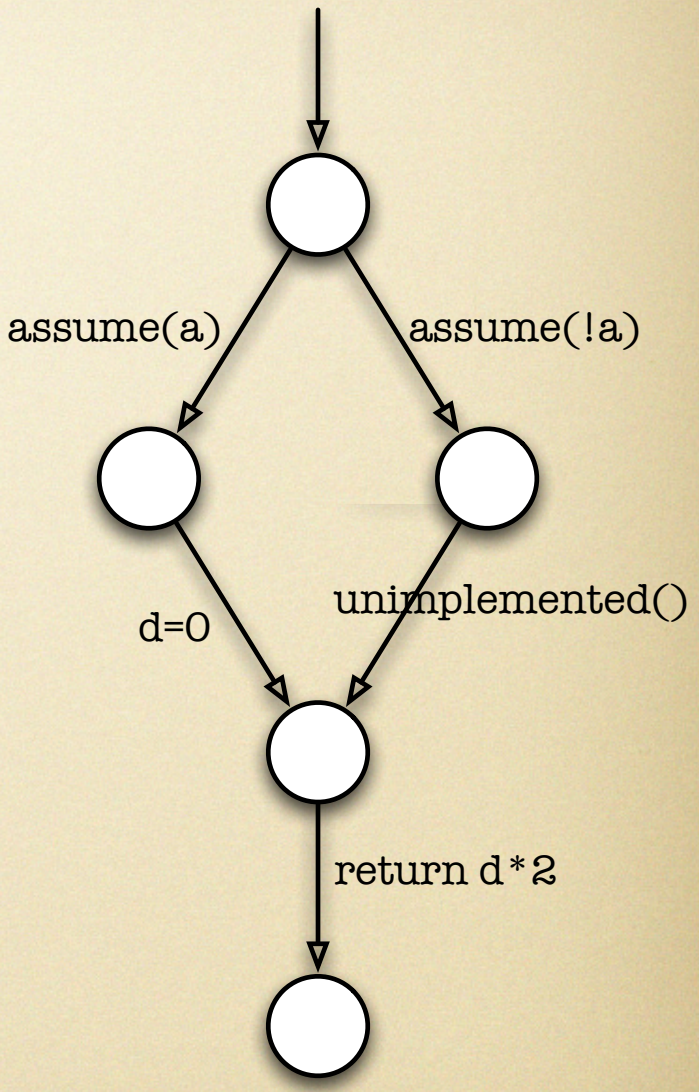

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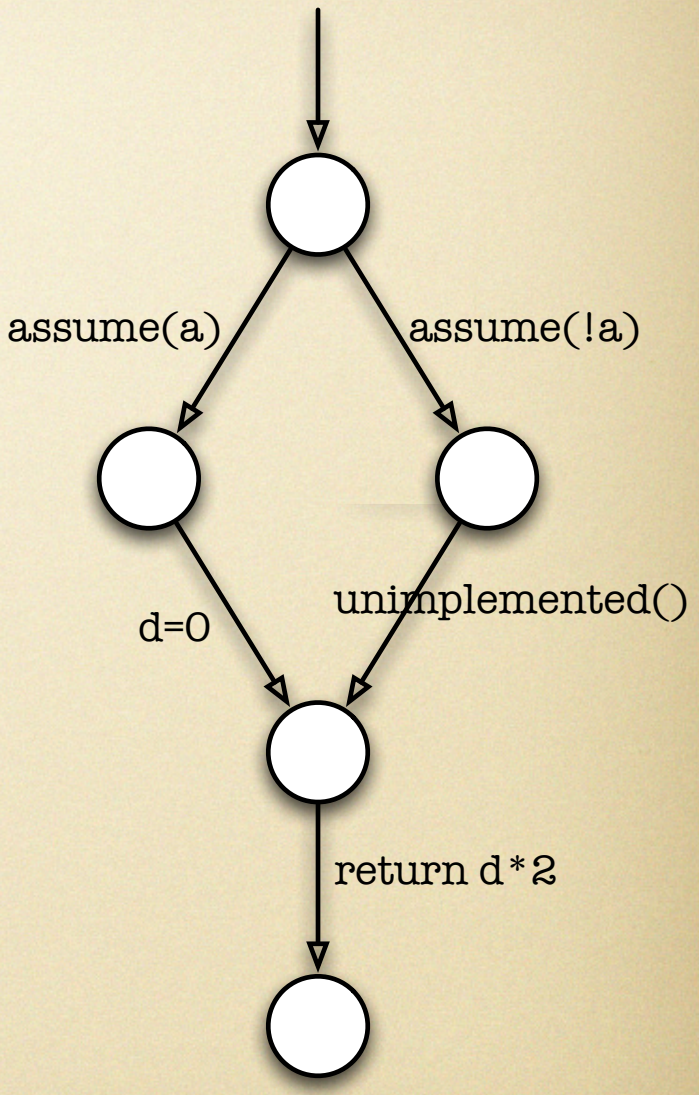

- **`cover "ID* . @4 . ID* + ID* . @6 . ID*"`**
- Path patterns are regular expressions:
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  - Concatenation (.)
  - Alternative/Union (+)

Alphabet of Path Patterns

Alphabet of Path Patterns

- Further filter functions

Alphabet of Path Patterns

- Further filter functions
- CFA transformers

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- Predicates over program variables

Alphabet of Path Patterns

- Further filter functions
- CFA transformers
- Predicates over program variables
- Beyond CFA edges (statements)

Further Filter Functions

```
1  int example(int a, int b, int c, int d)
2  {
3    if ((a || b) && c)
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5    else
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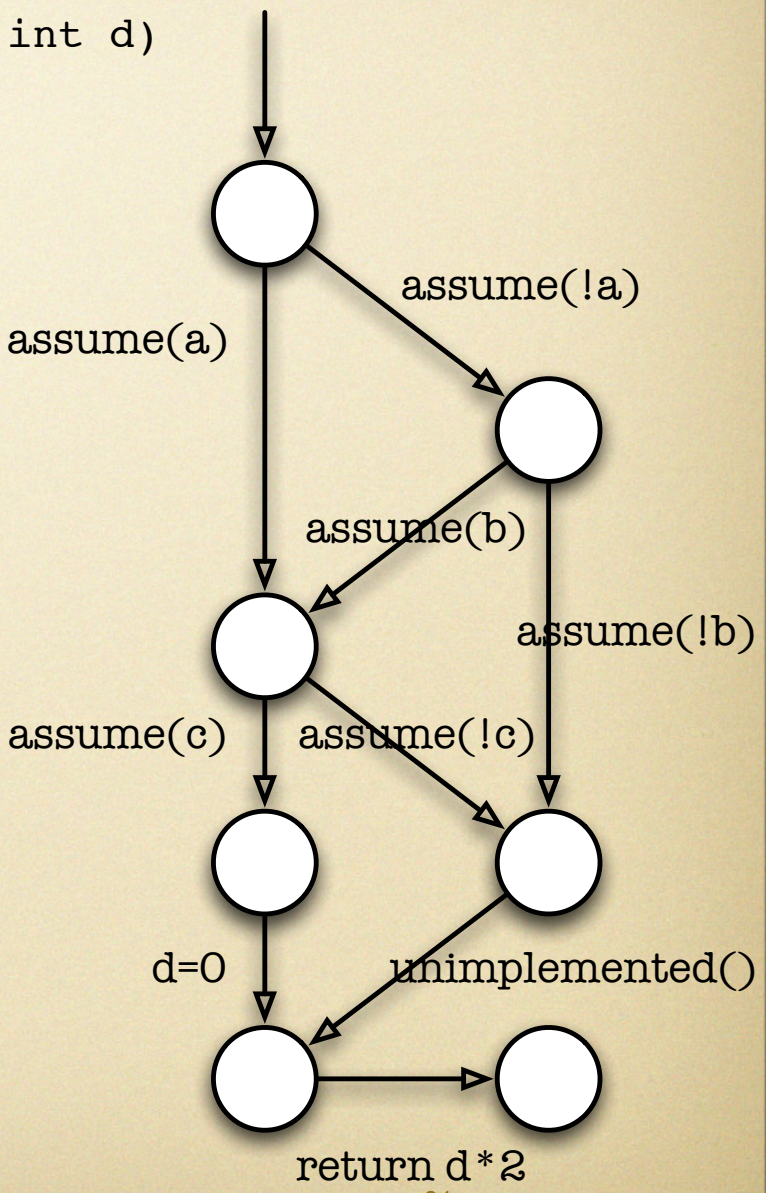
```



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```
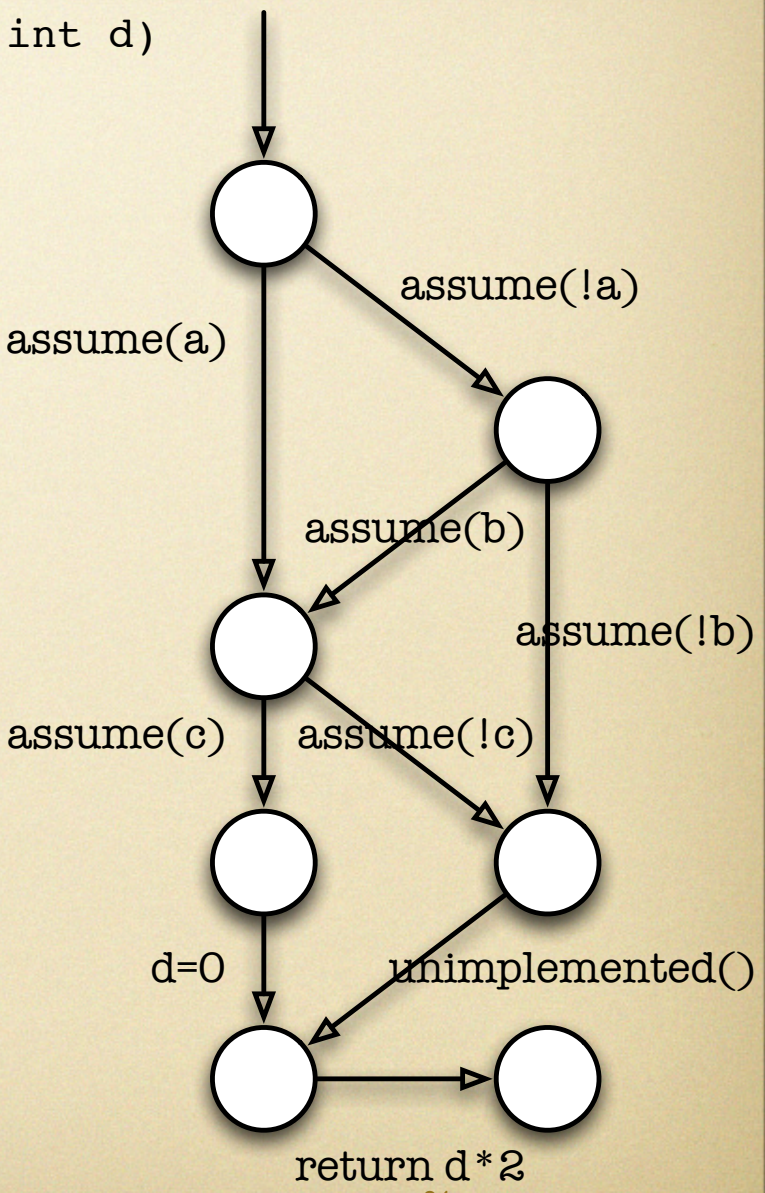

- `cover "@conditionedge"`



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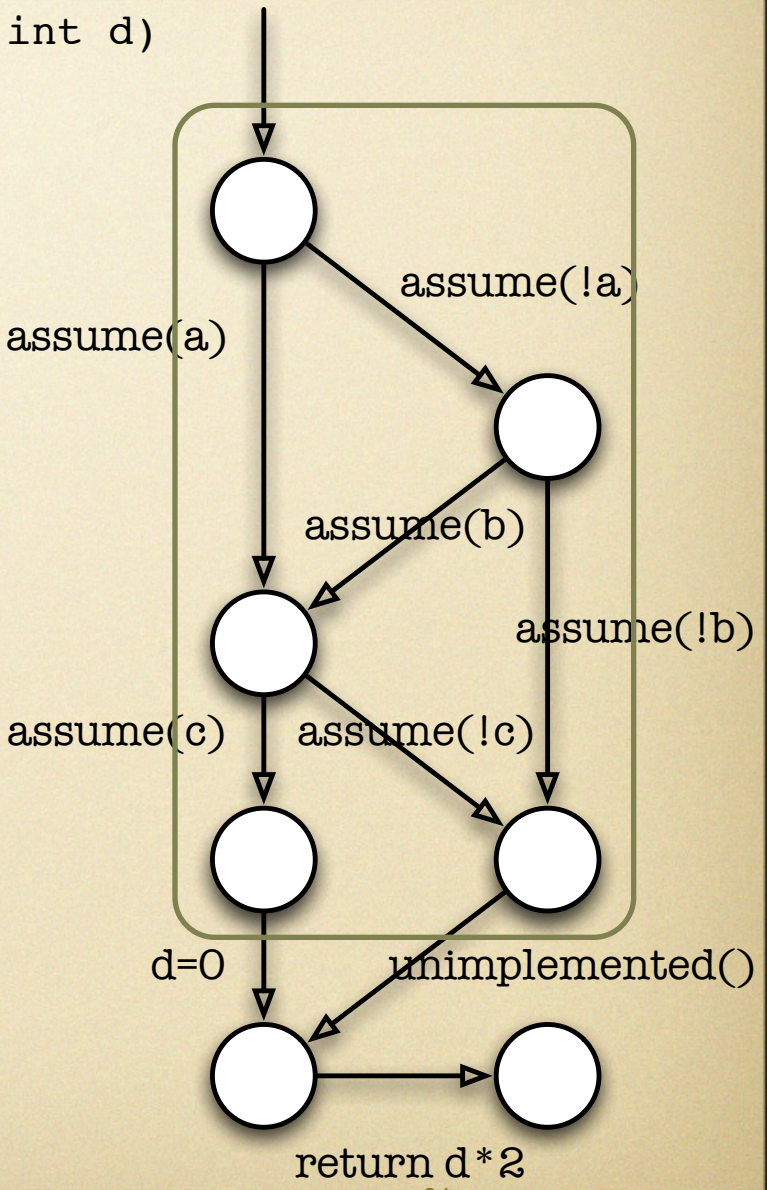
- cover "@conditionedge"



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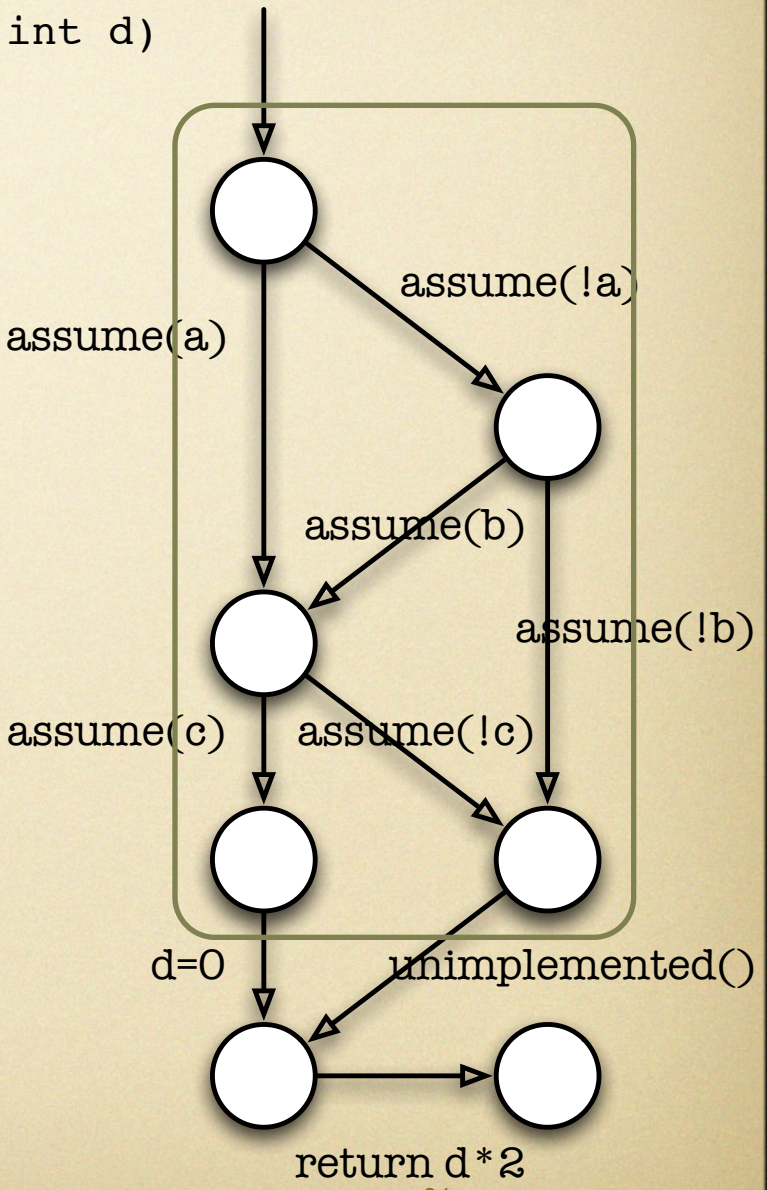
- cover "@conditionedge"
- cover "@conditiongraph"



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- cover "@conditionedge"
- cover "@conditiongraph"
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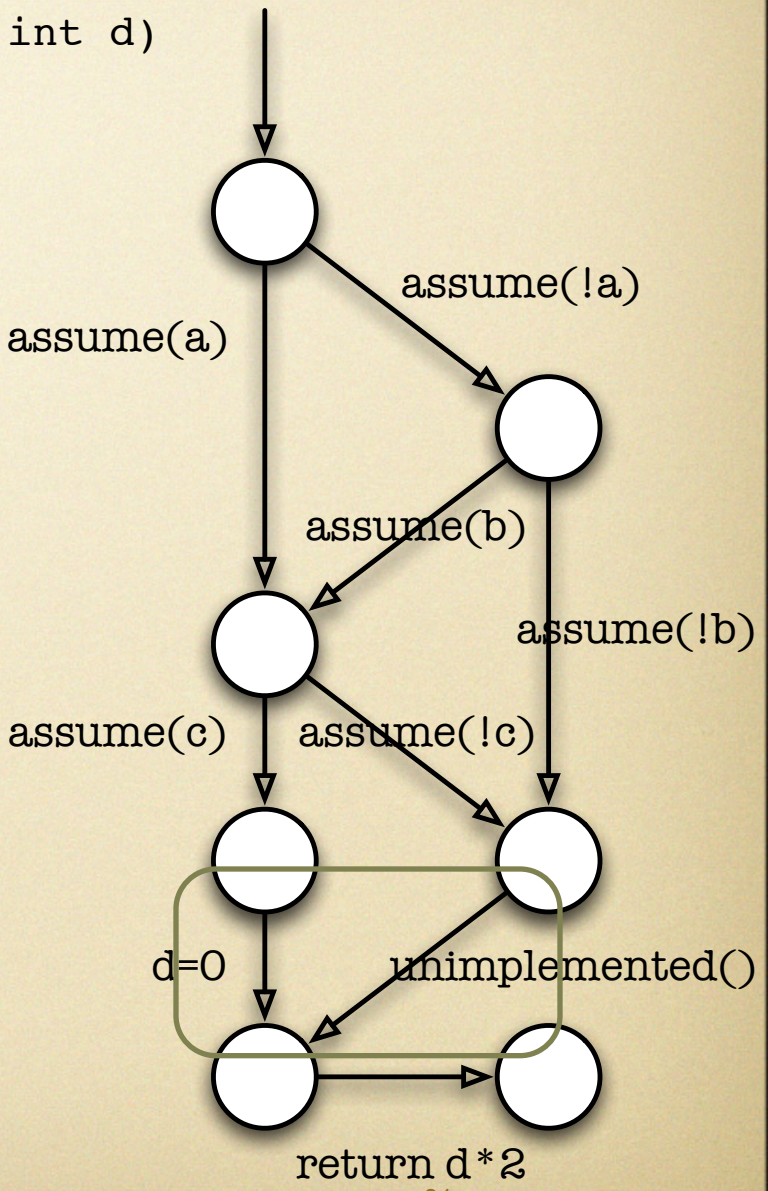

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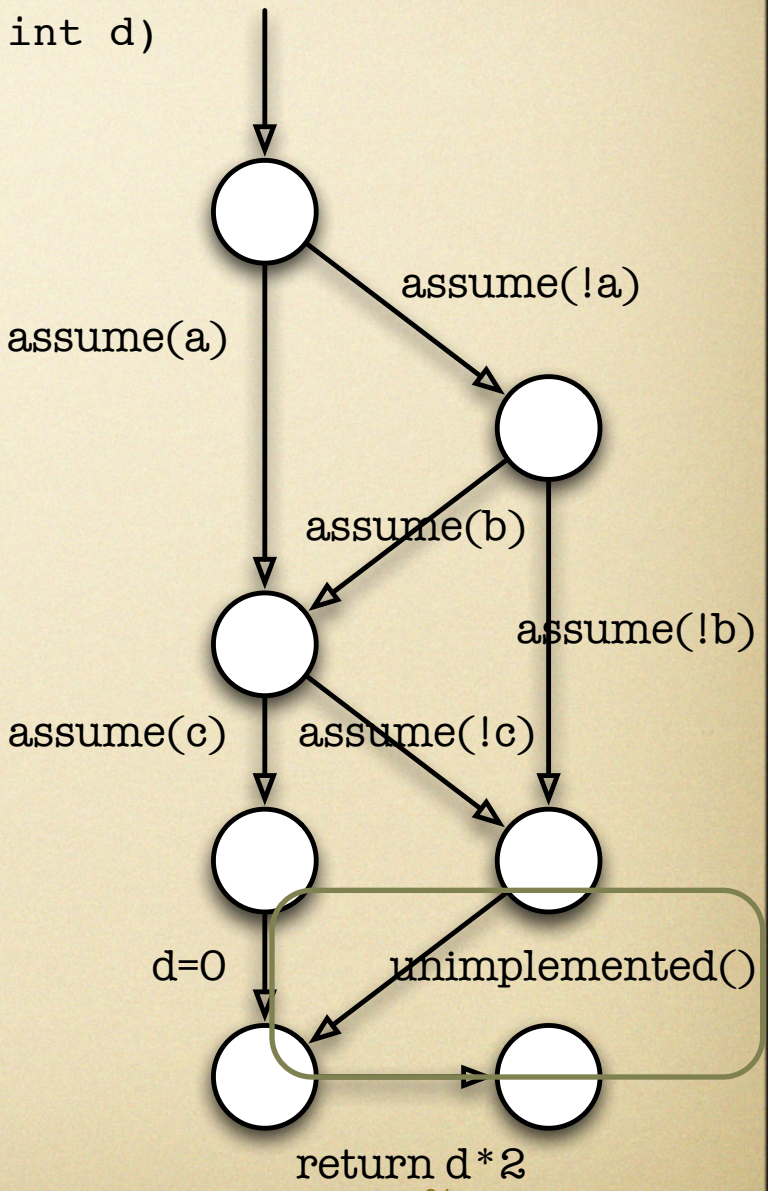
- cover "@conditionedge"
- cover "@conditiongraph"
- cover "@decisionedge"
- cover "@calls"



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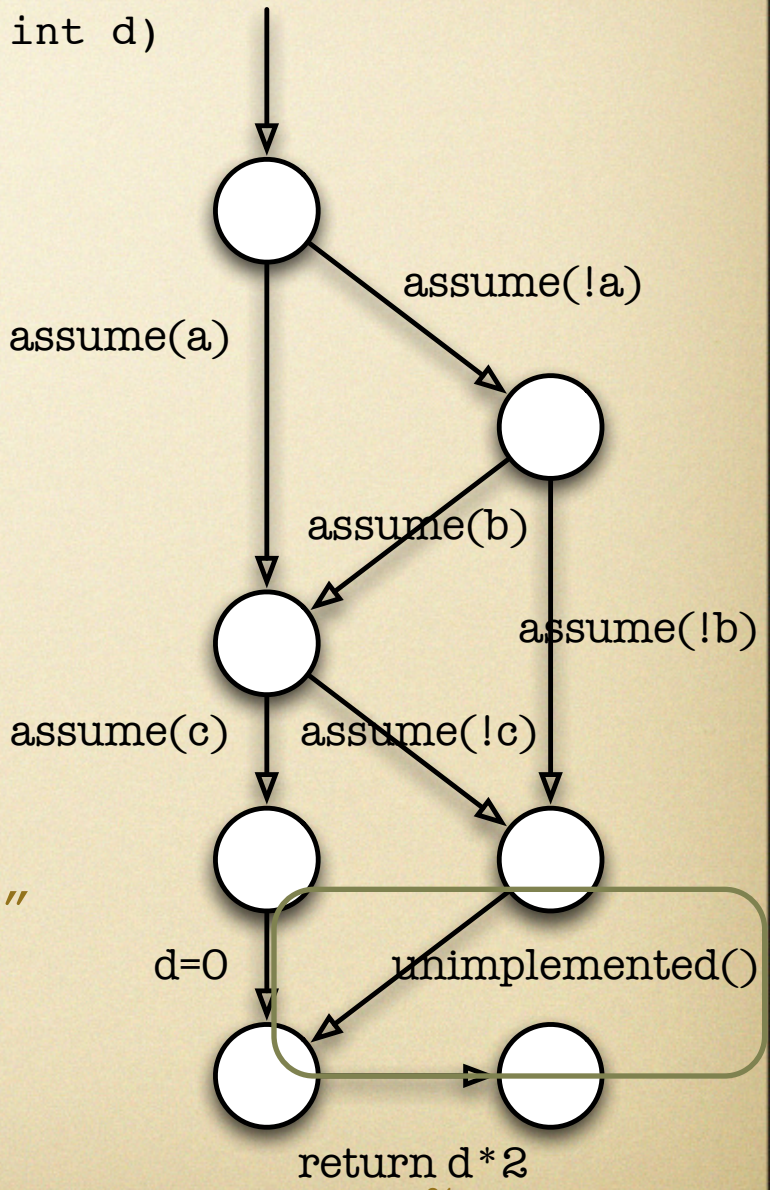
- cover "@conditionedge"
- cover "@conditiongraph"
- cover "@decisionedge"
- cover "@calls"
- cover "@call(unimplemented)"



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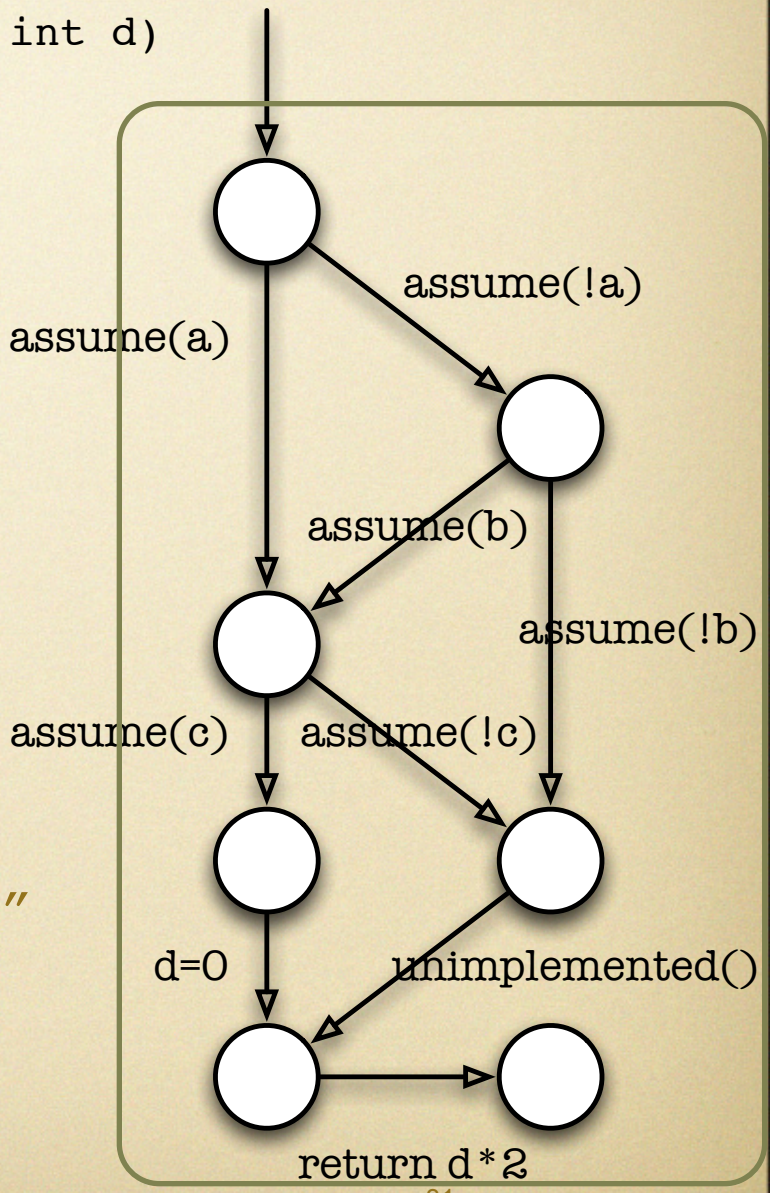
- cover "@conditionedge"
- cover "@conditiongraph"
- cover "@decisionedge"
- cover "@calls"
- cover "@call(unimplemented)"
- cover "@func(example)"



CFA Transformers

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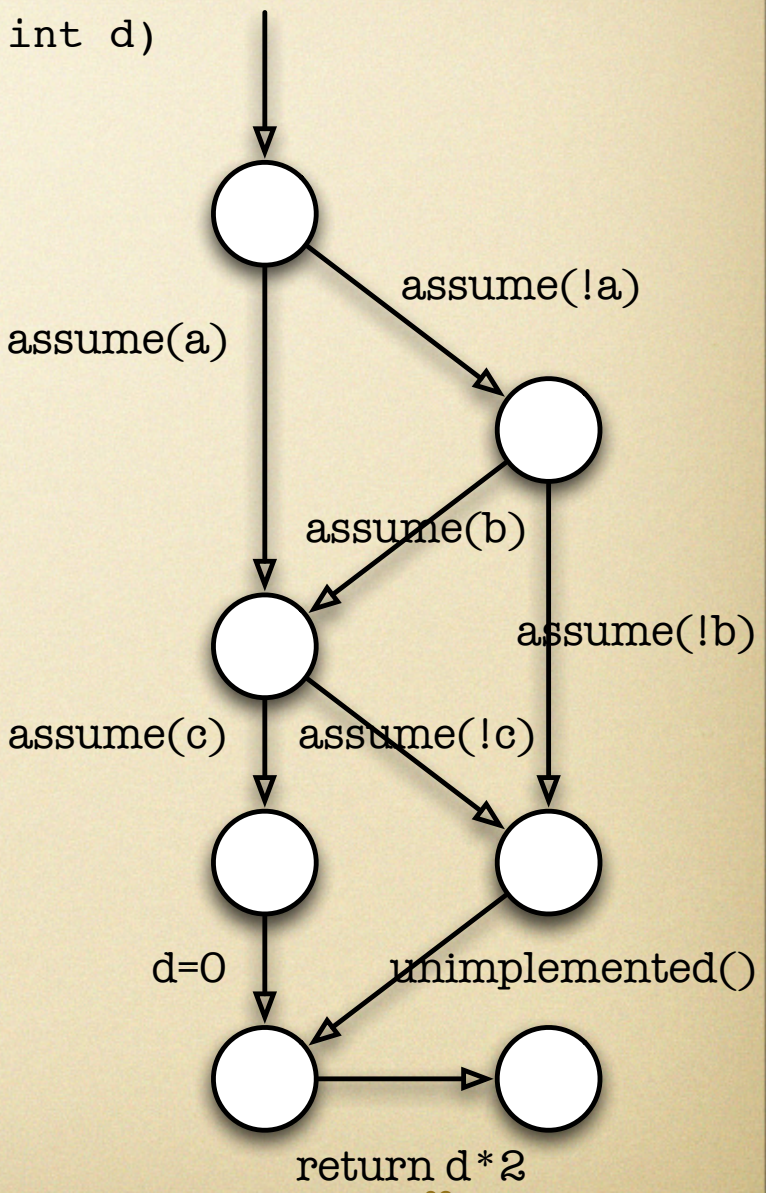

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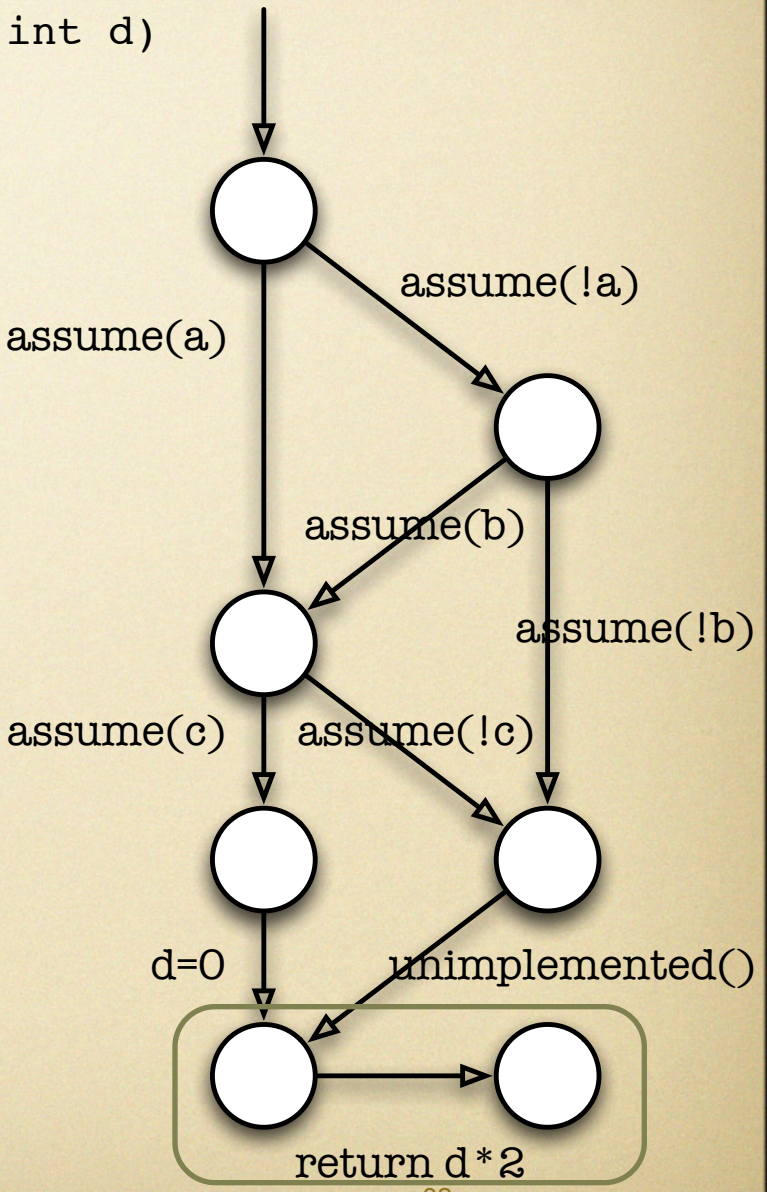

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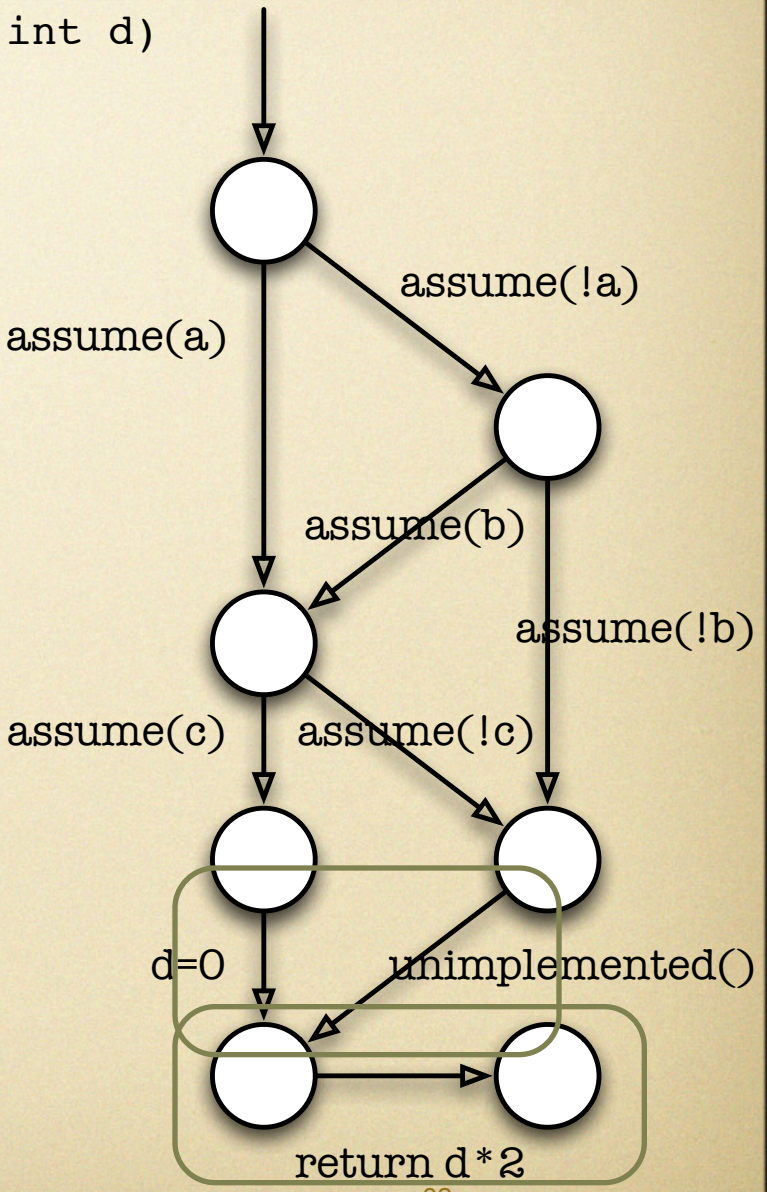

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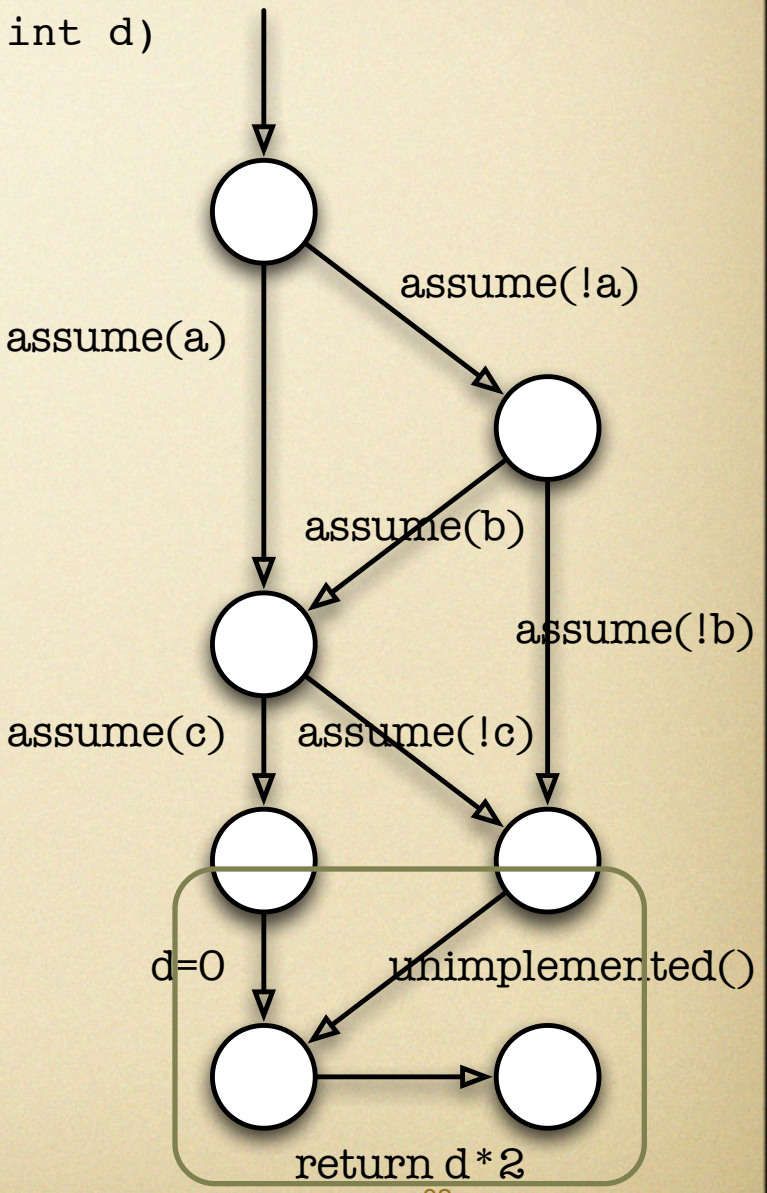
- `cover "@7 | @decisionedge"`



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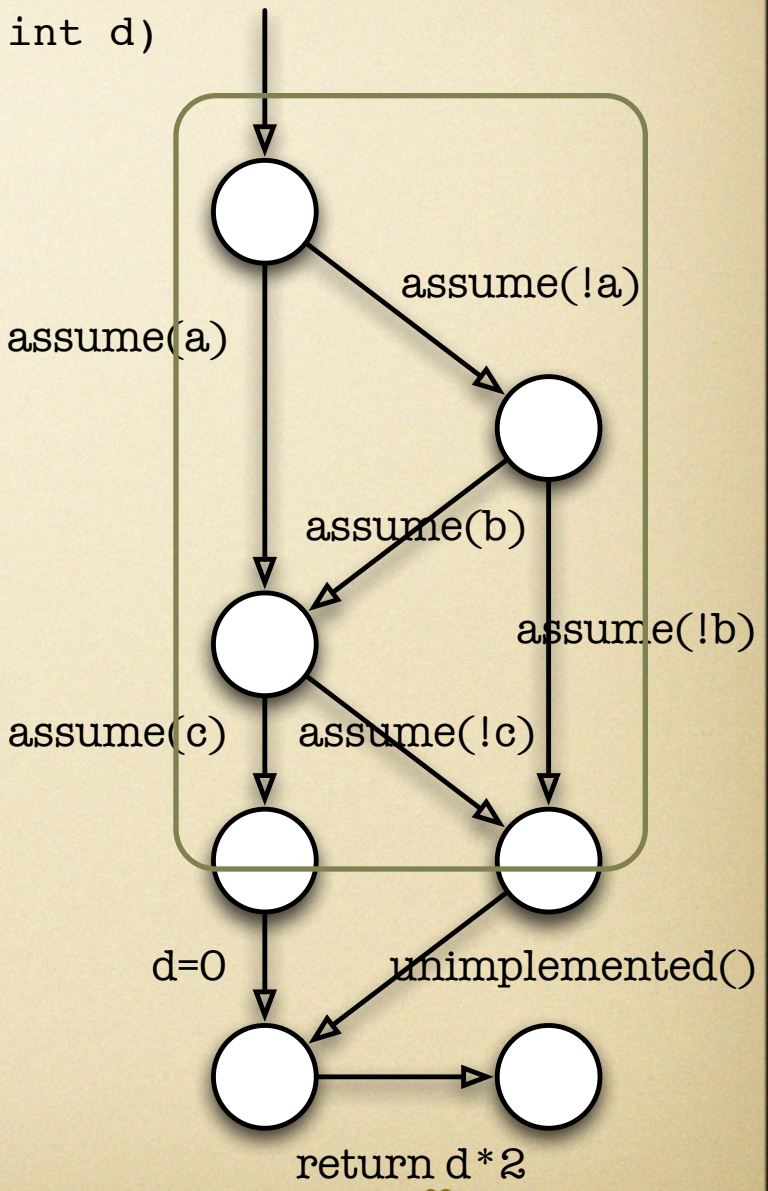

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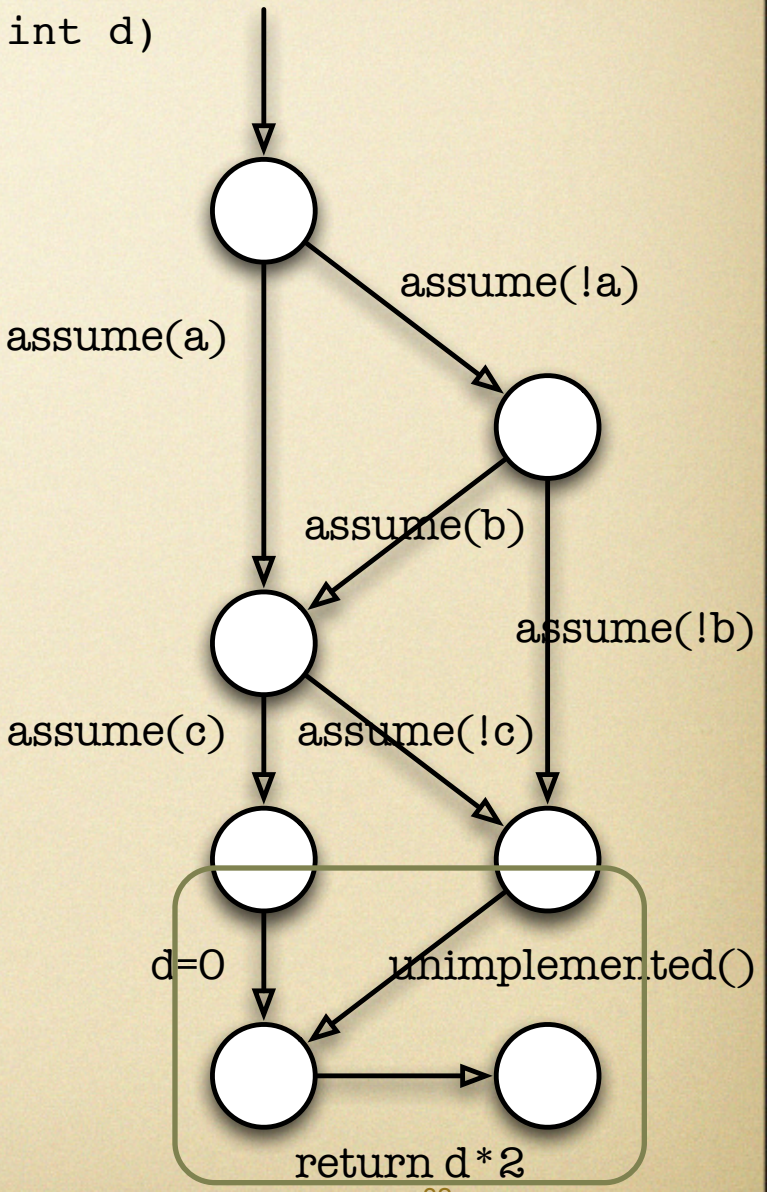
- `cover "@7 | @decisionedge"`
- `cover "not(@3)"`



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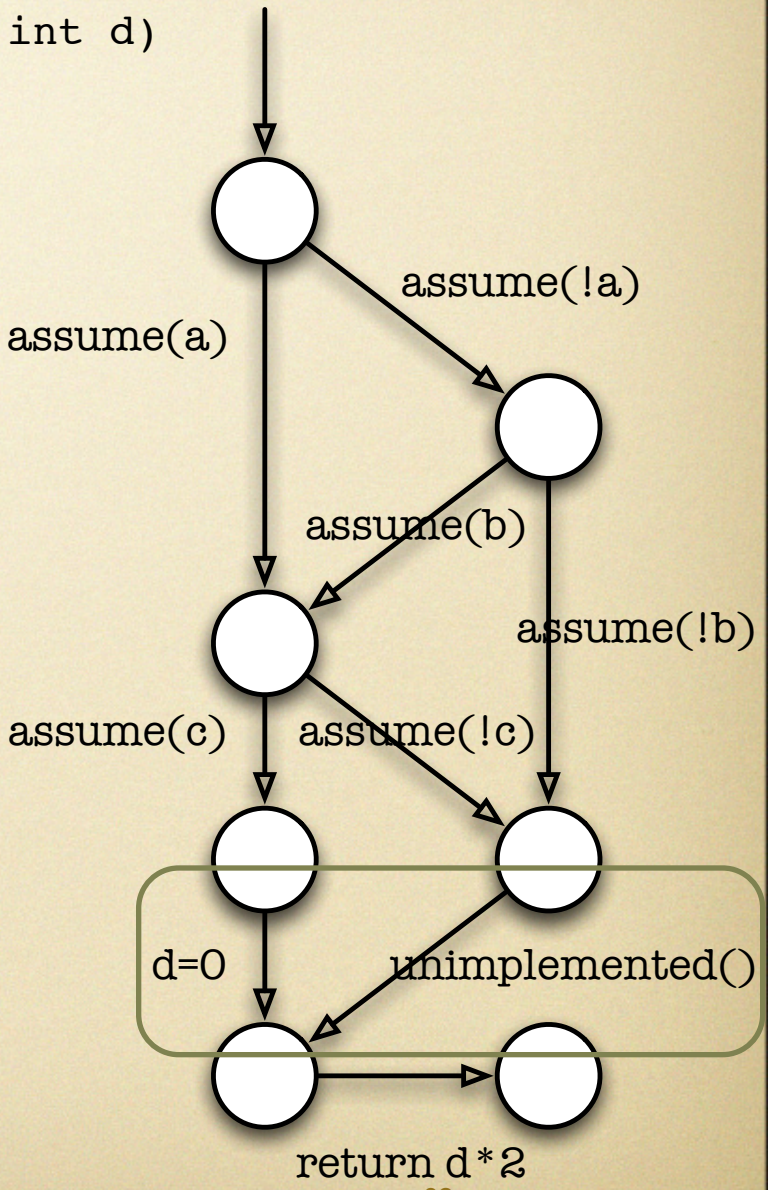
- `cover "@7 | @decisionedge"`
- `cover "not(@3)"`



CFA Transformers

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1  int example(int a, int b, int c, int d)
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3    if ((a || b) && c)
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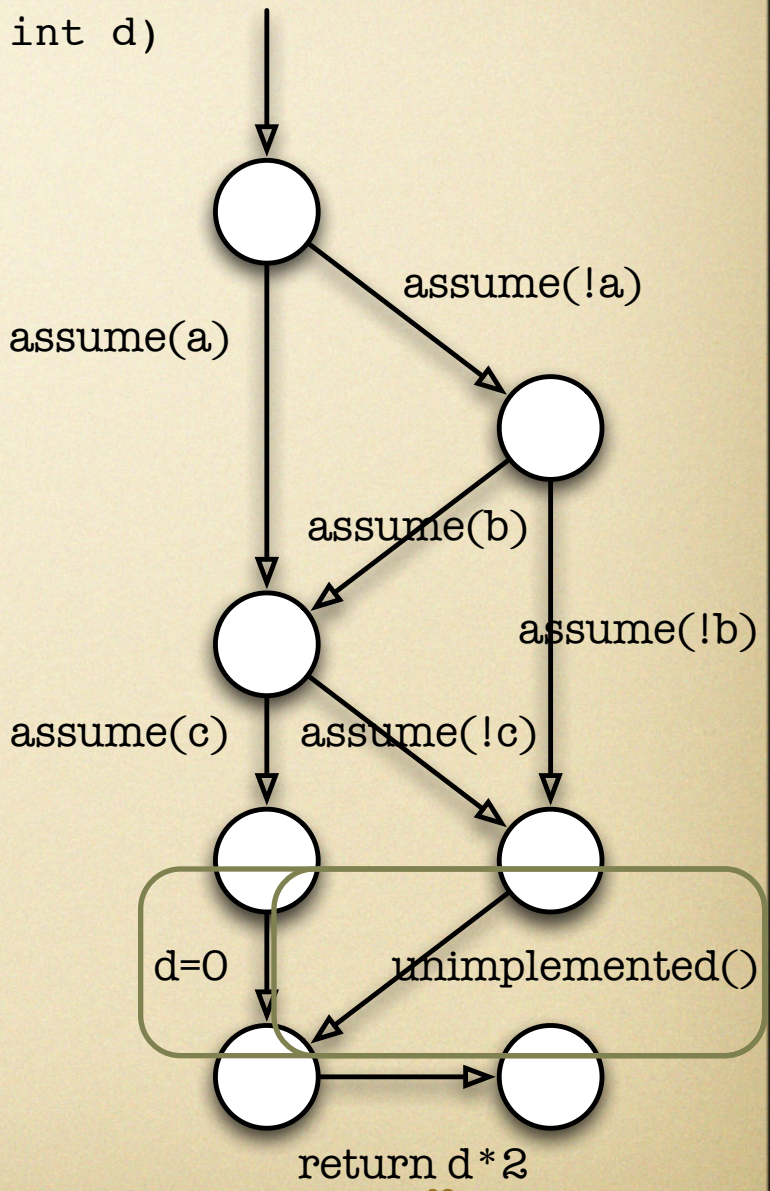

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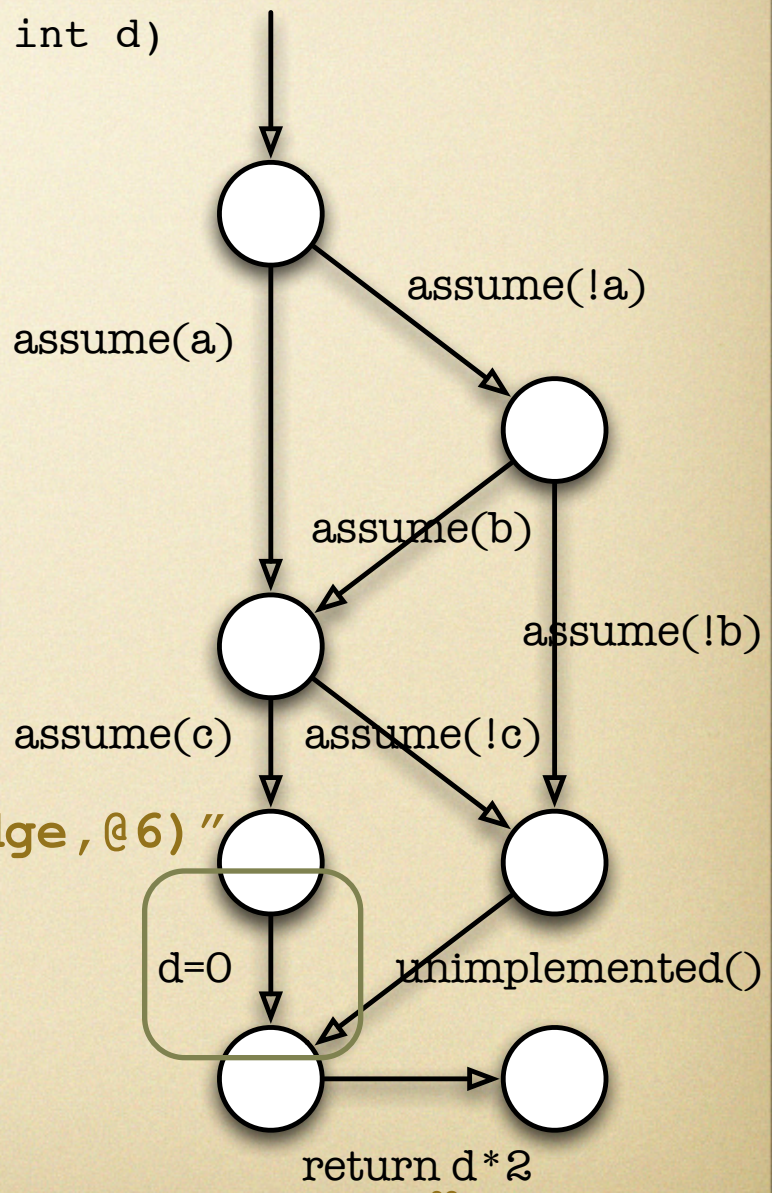

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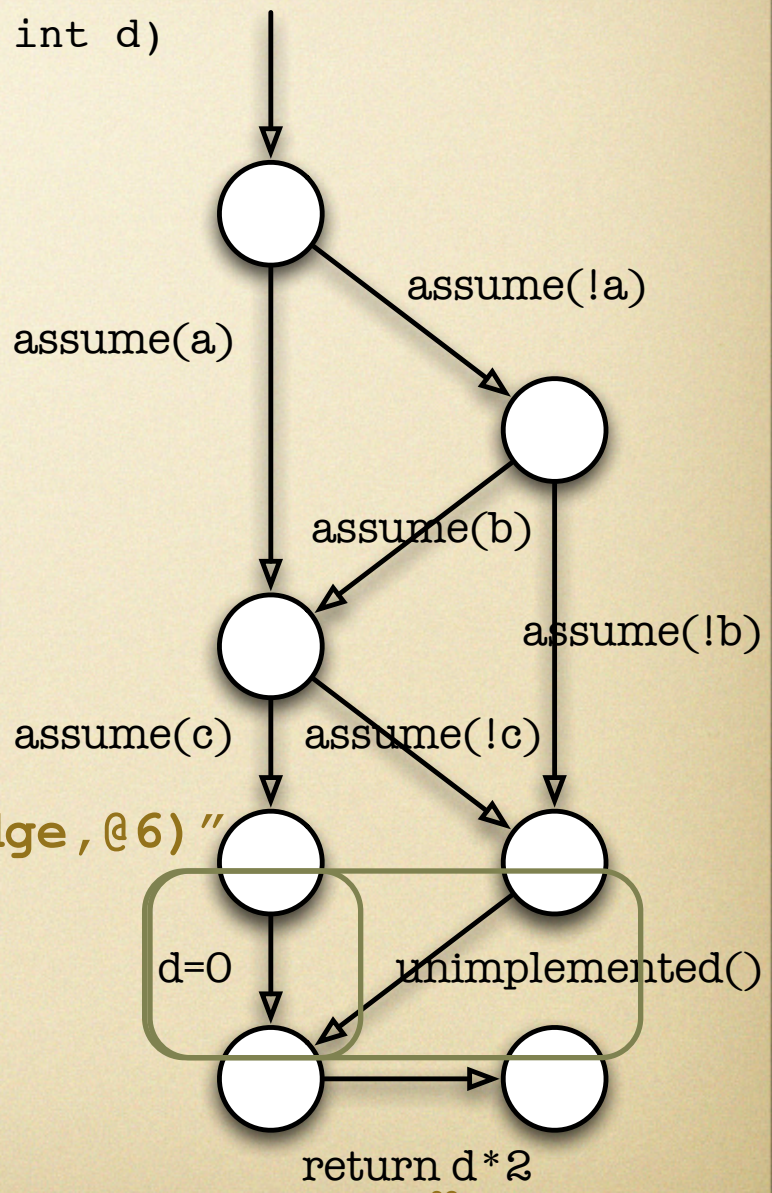

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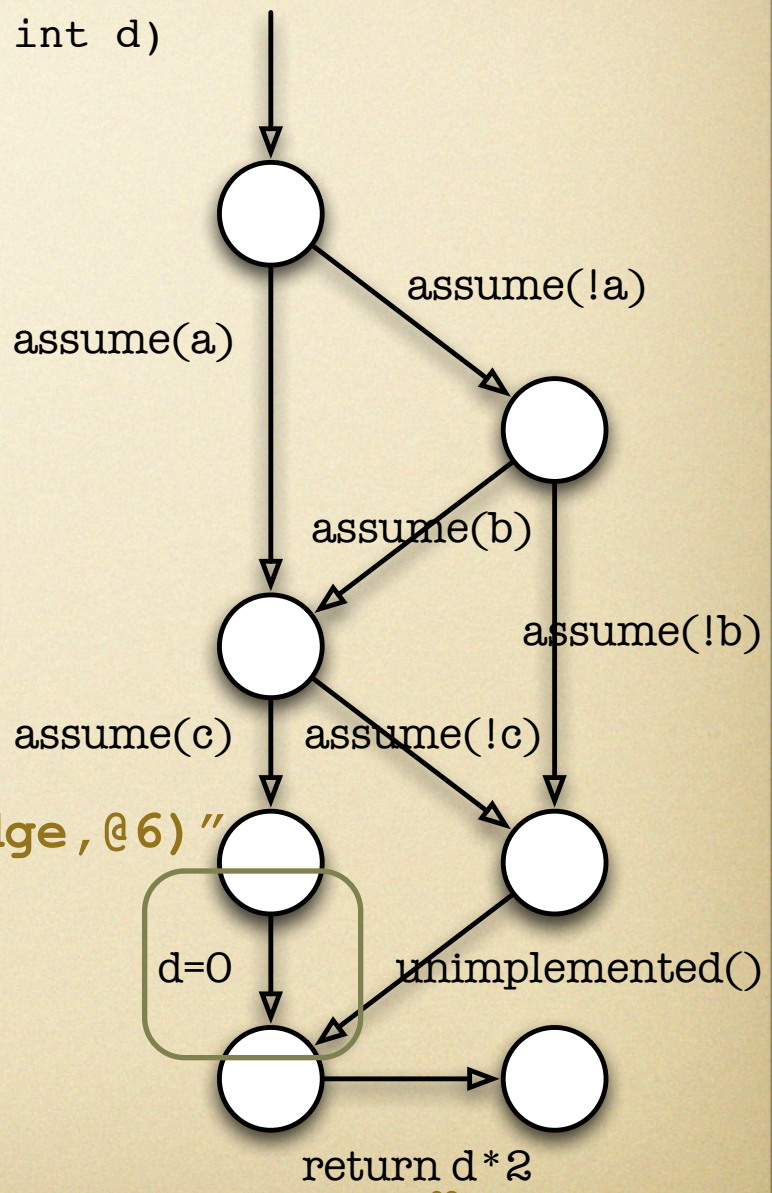

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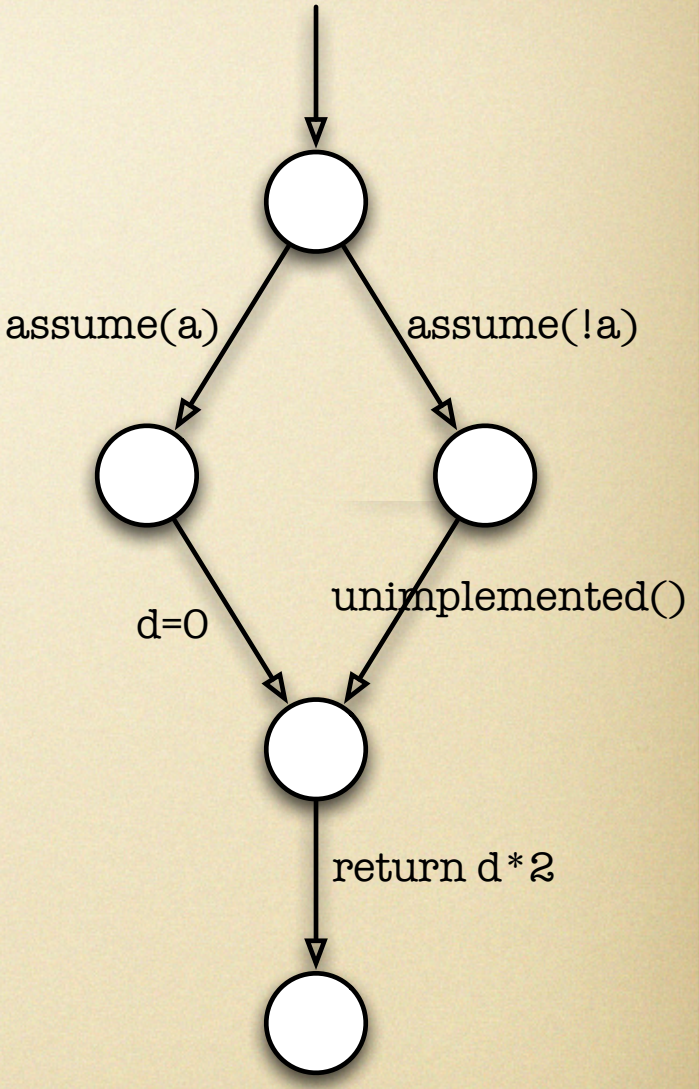

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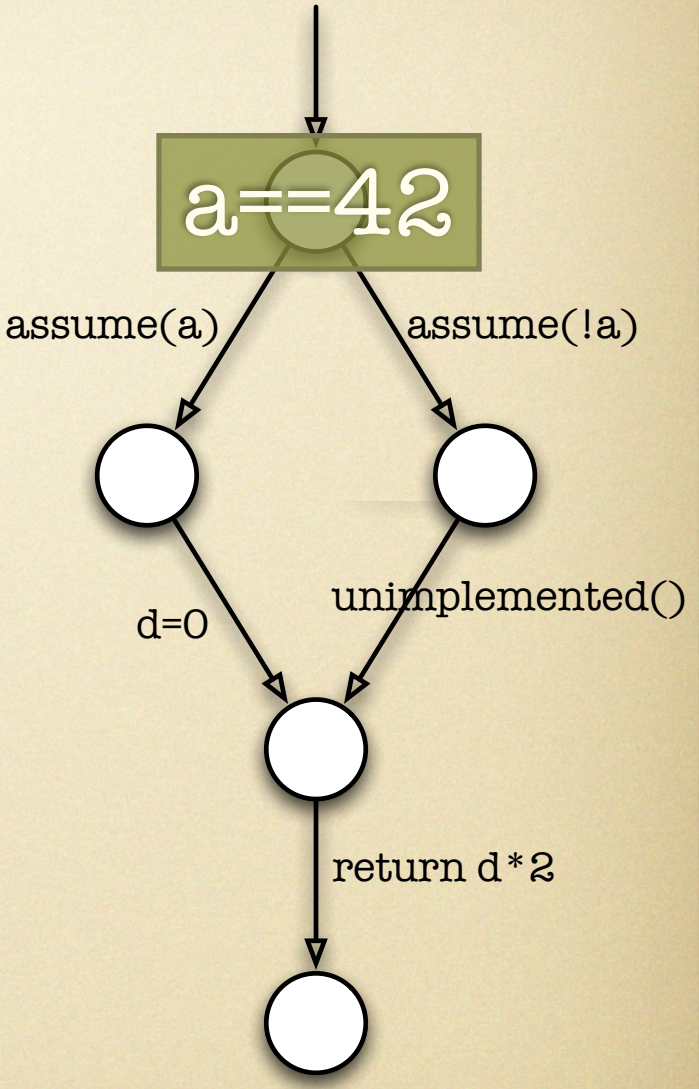

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- **cover "{a==42}.@3"**

  IN:

  a=42
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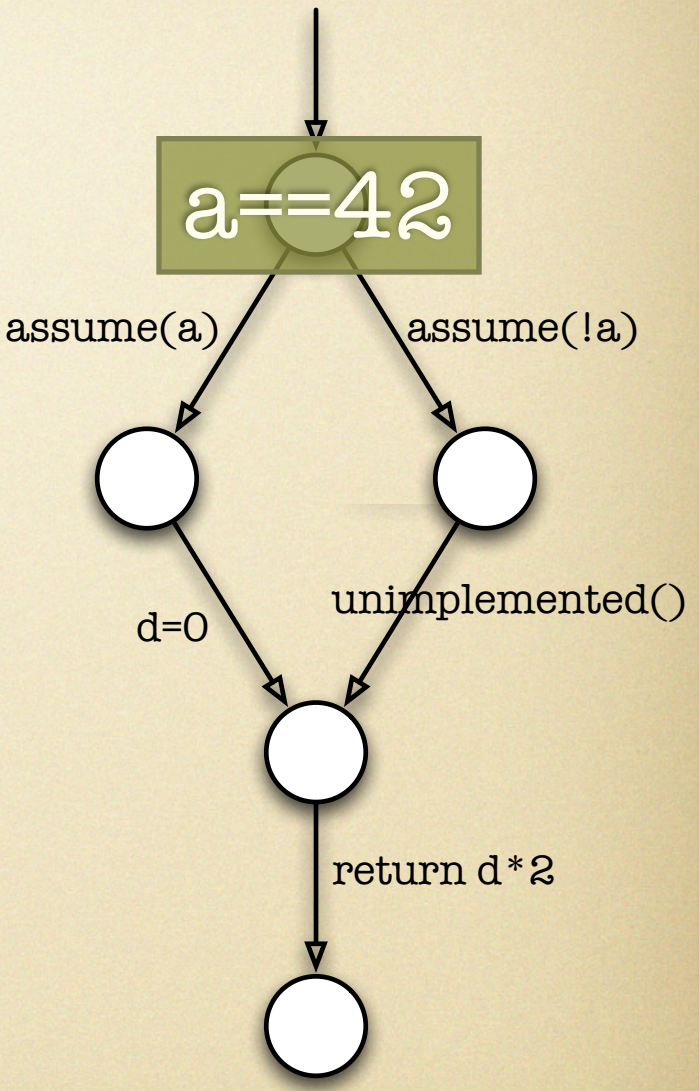

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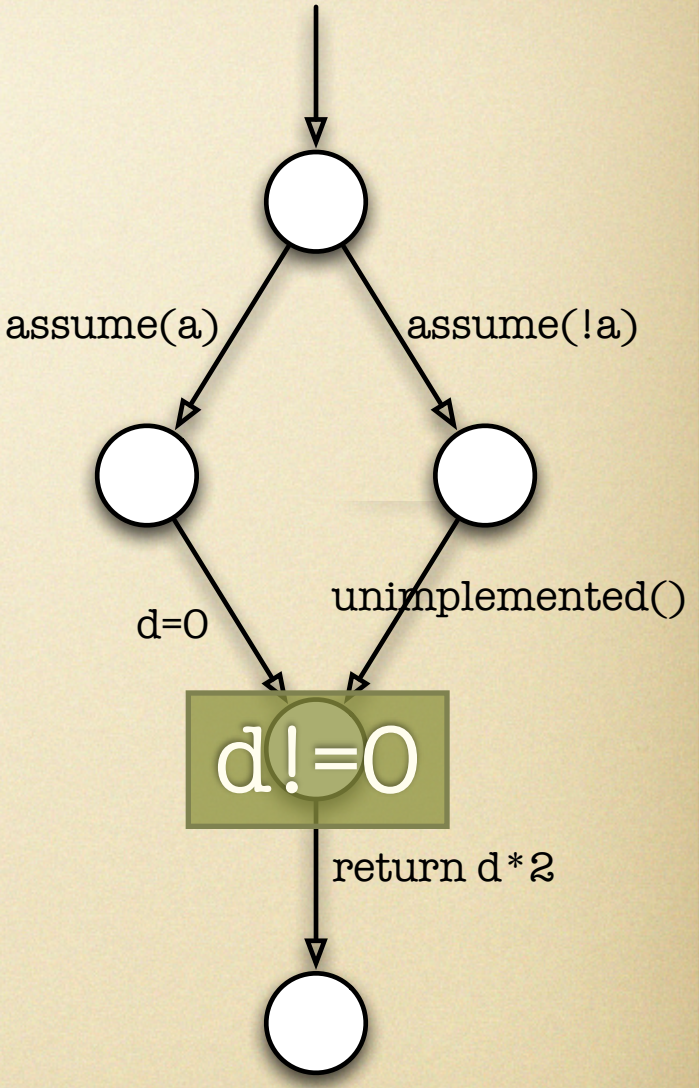

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- **cover "(@4+@6).{d!=0}"**

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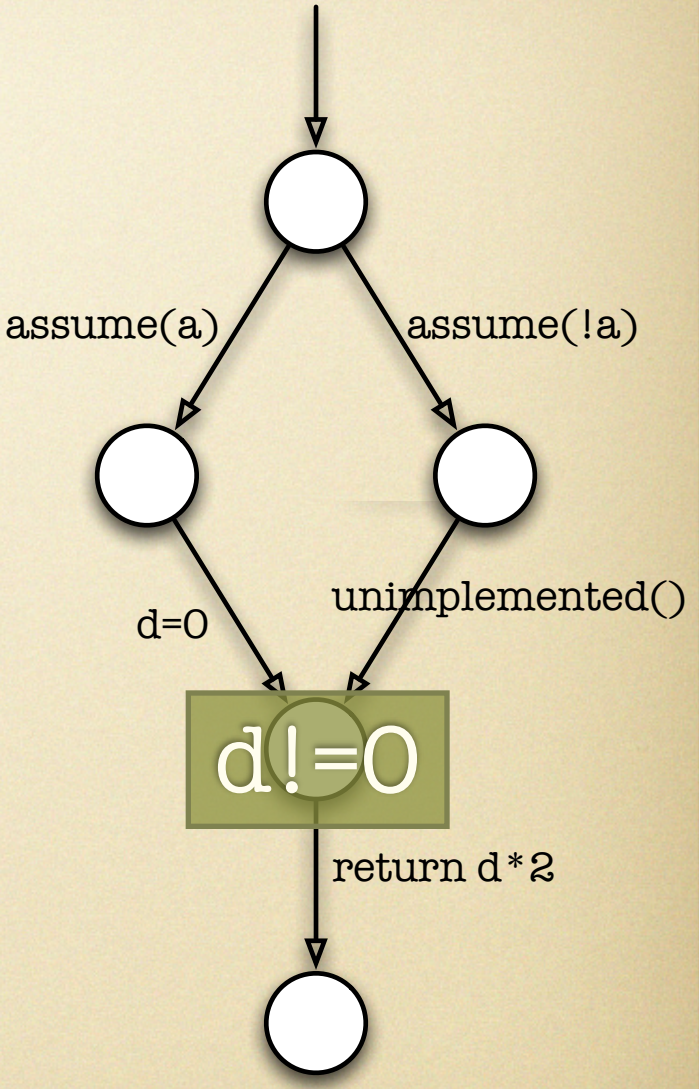

Software Testing using FQL

- ☑ Program Representation: Control Flow Automata
- ☑ Describing Single Test Cases
- **Describing Test Suites**

Coverage Patterns

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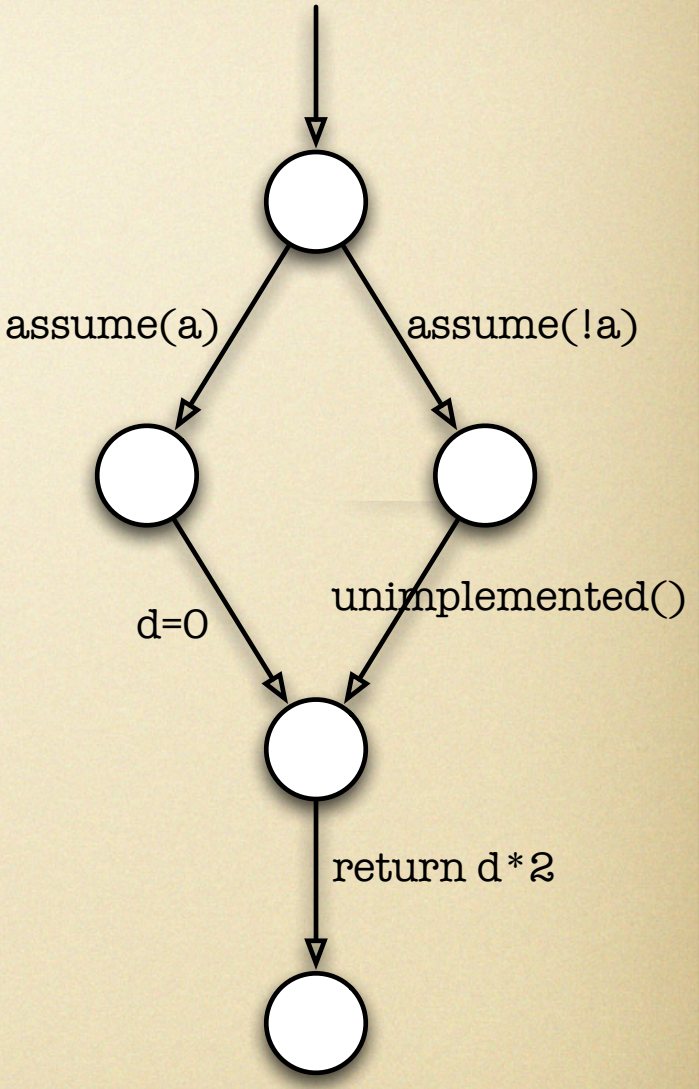

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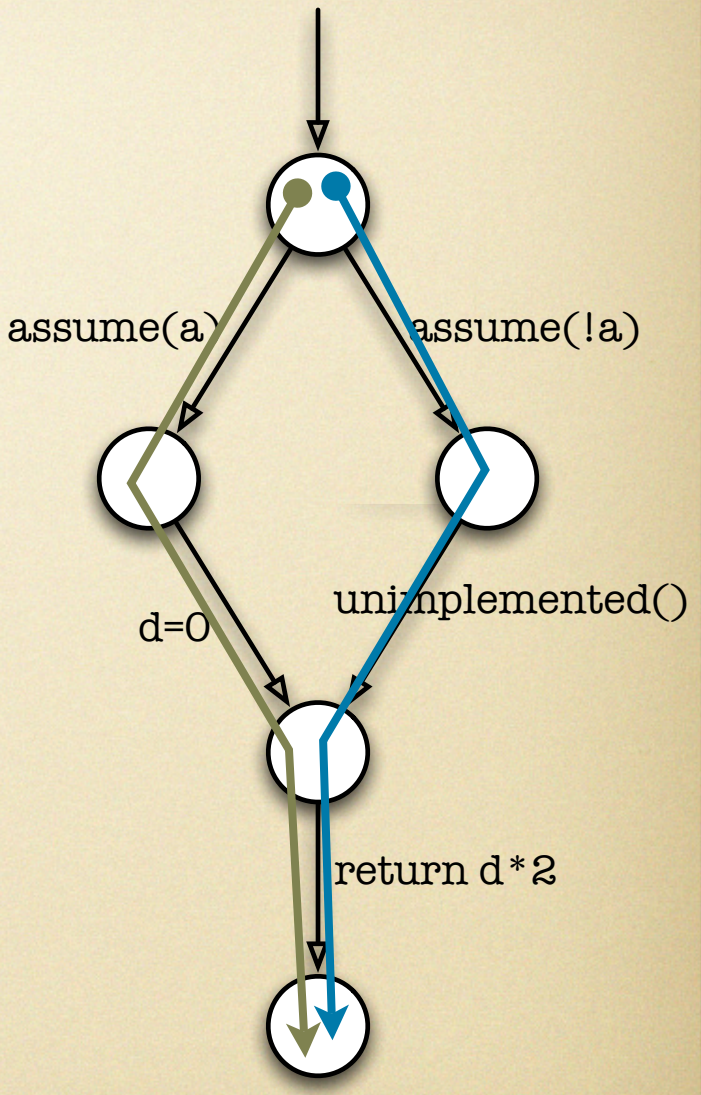

- Cover if **and** else branch ?

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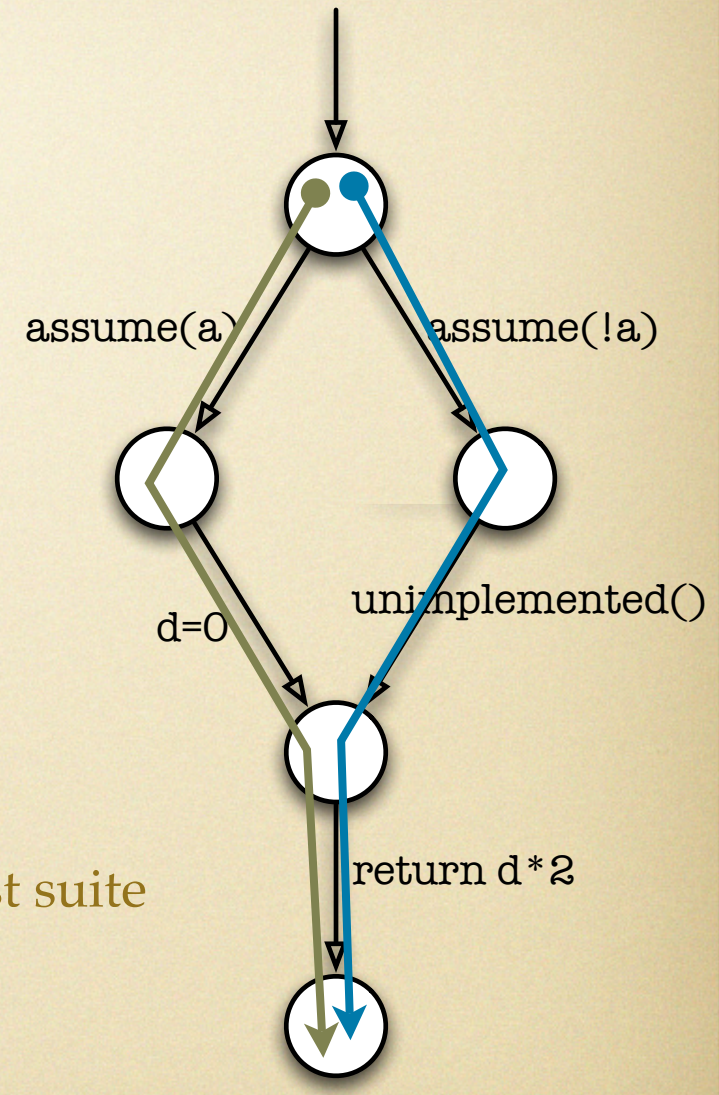

- Cover if **and** else branch ?
- We need more than one test case - a test suite

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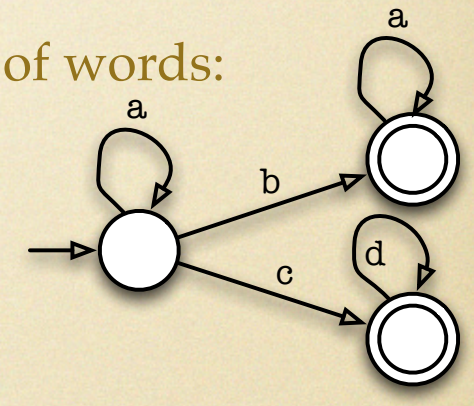

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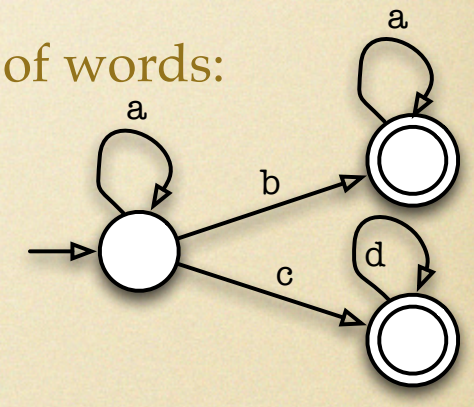

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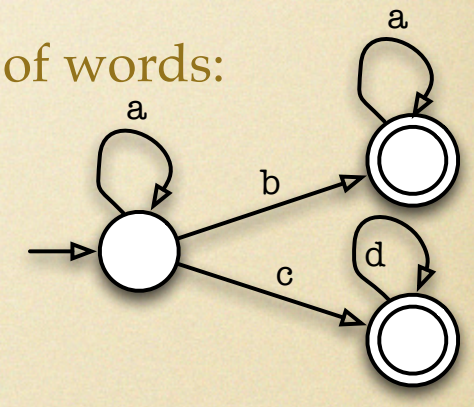

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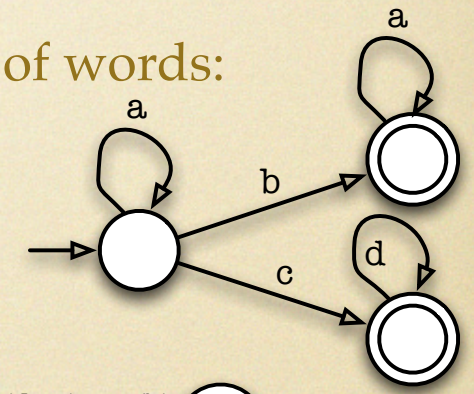

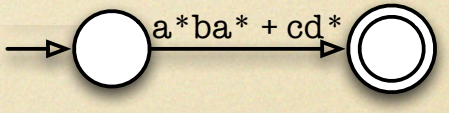

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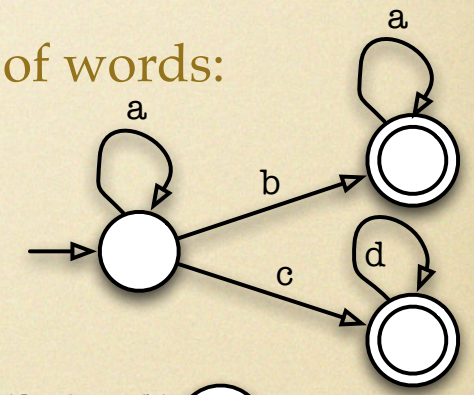

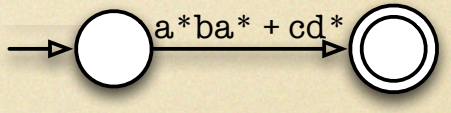

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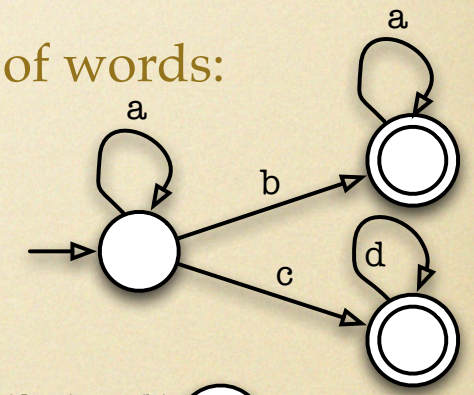

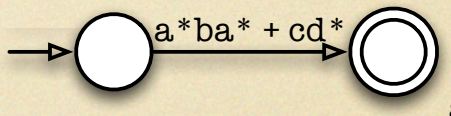

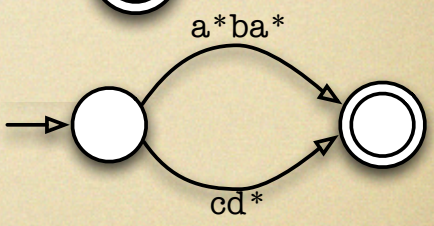

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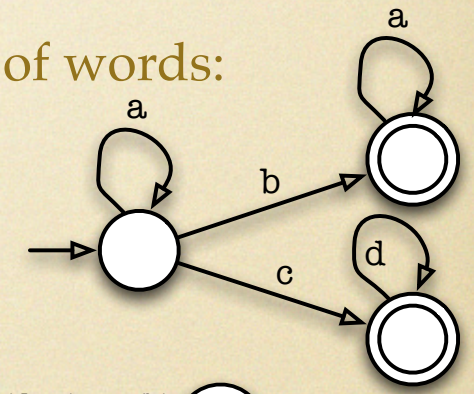

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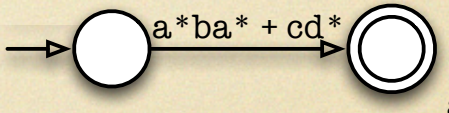

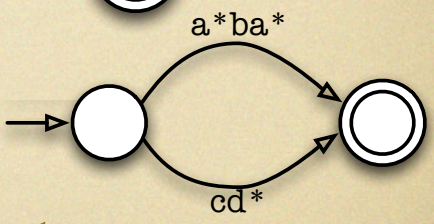

- In coverage patterns: Kleene star only within quotes

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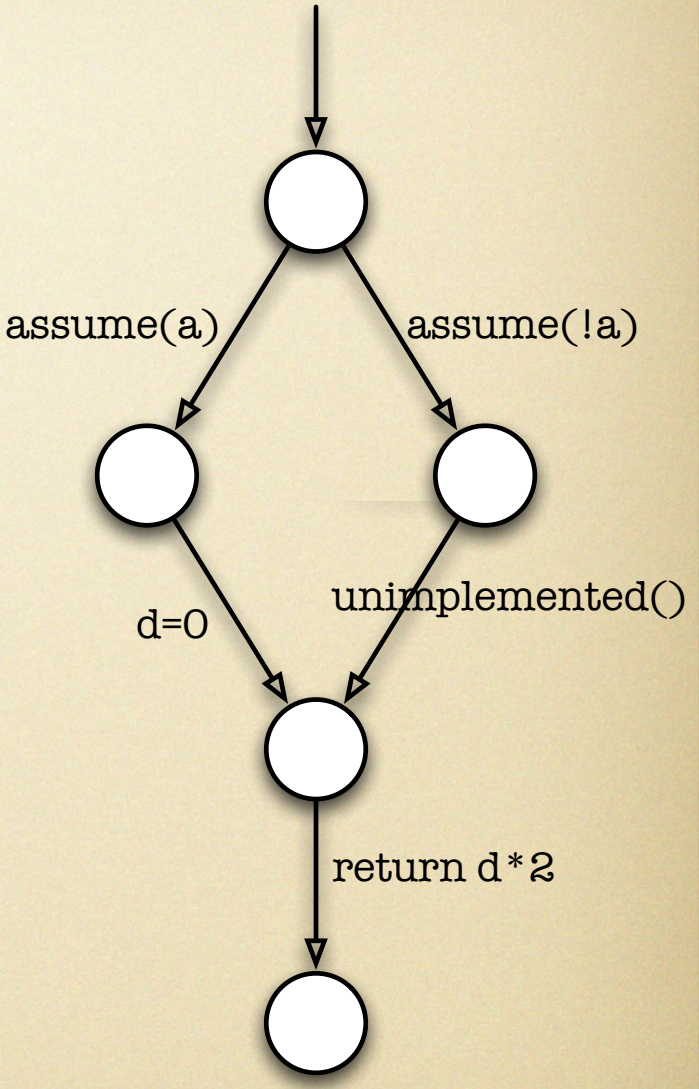

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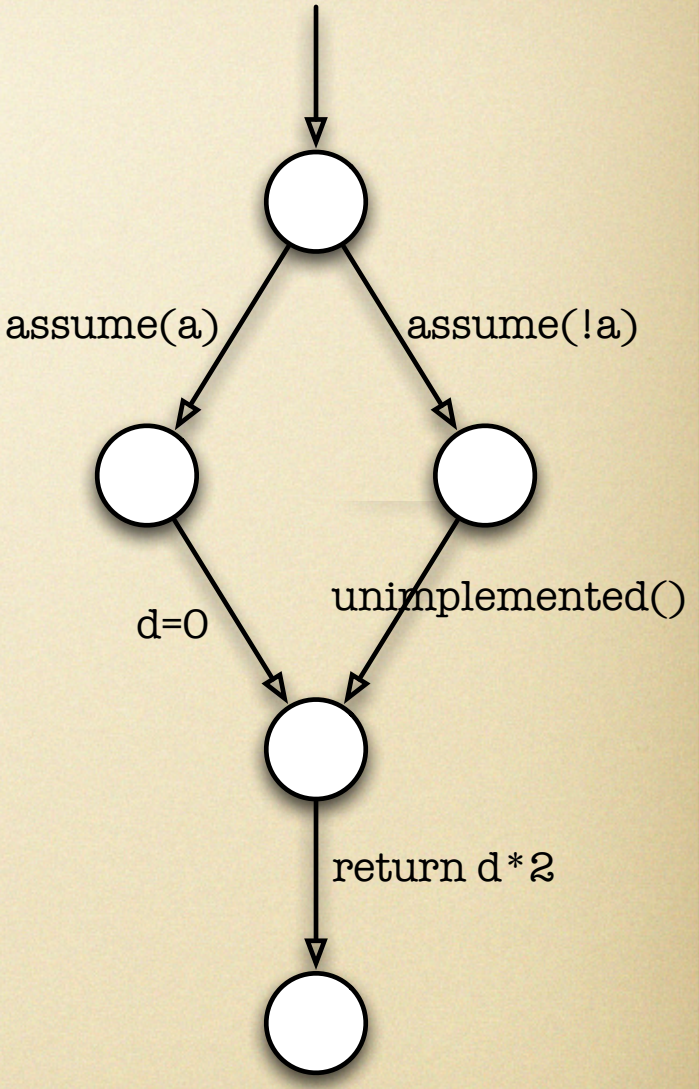

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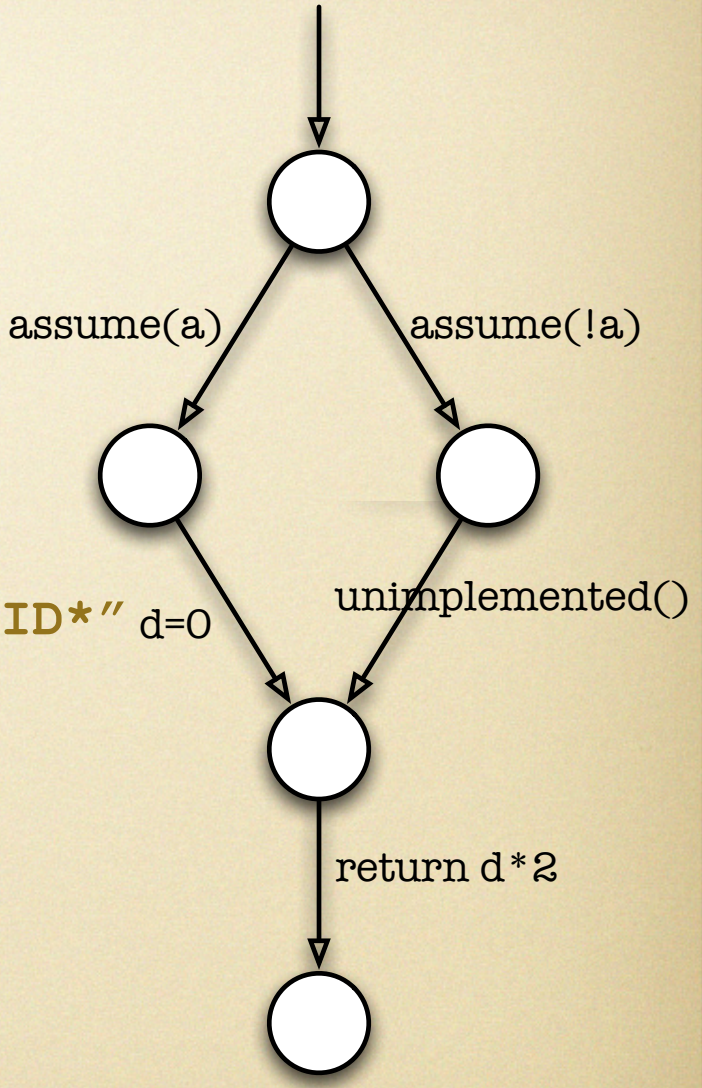
- `cover "ID*.@4.ID*" + "ID*.@6.ID*"`



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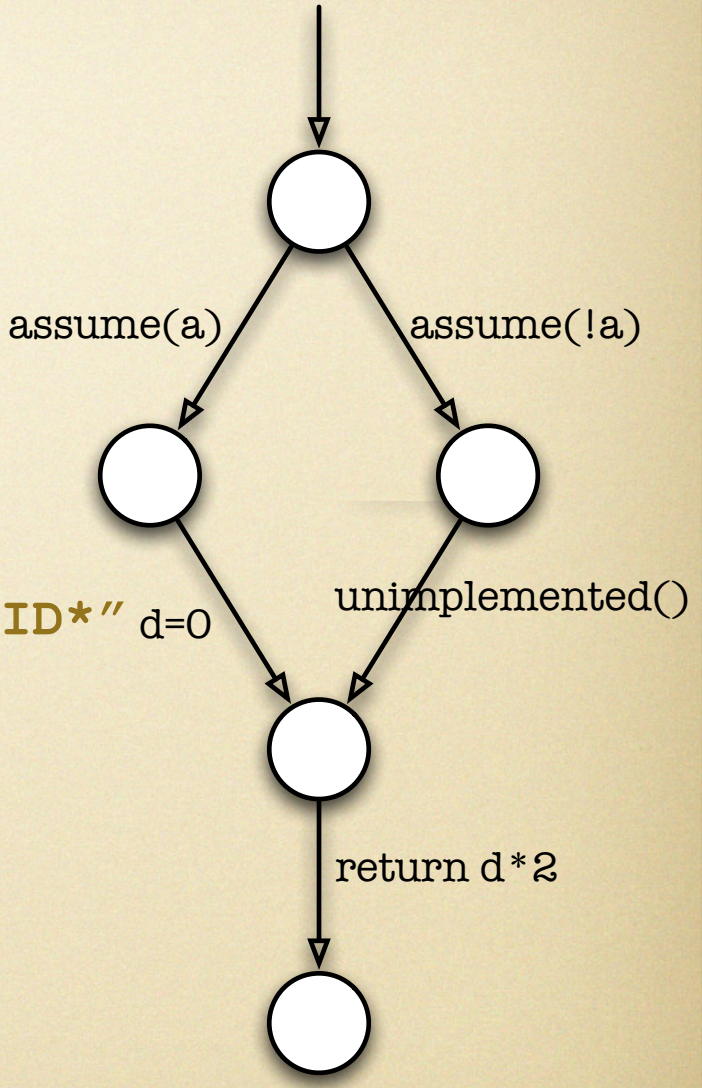

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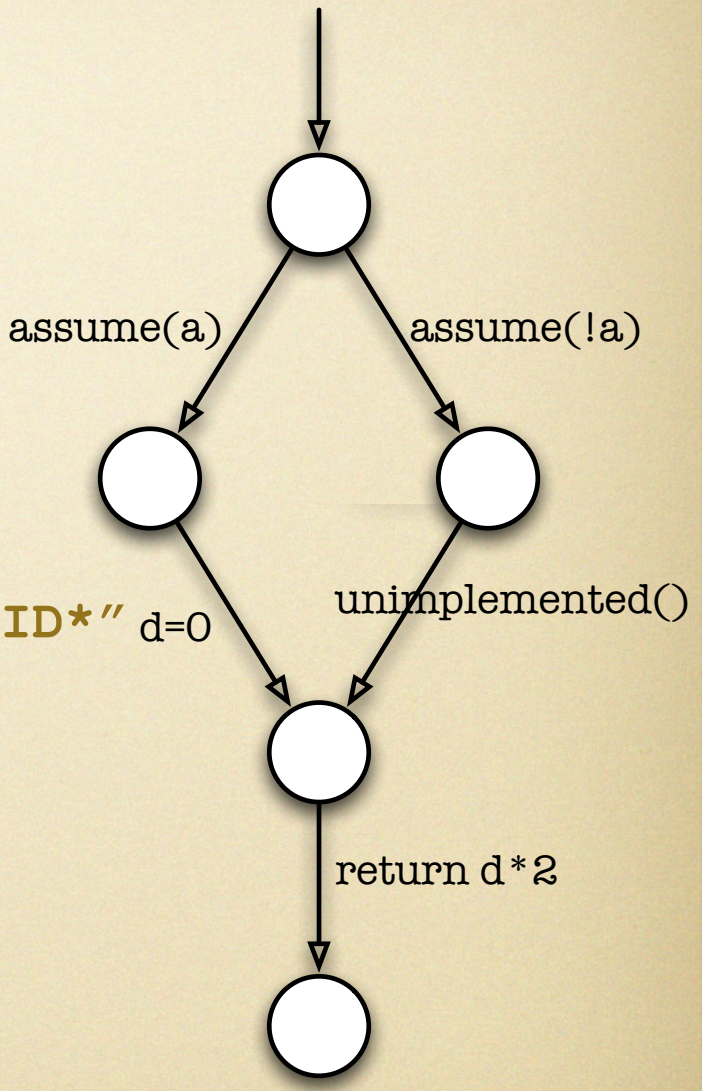

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IN:

a=2
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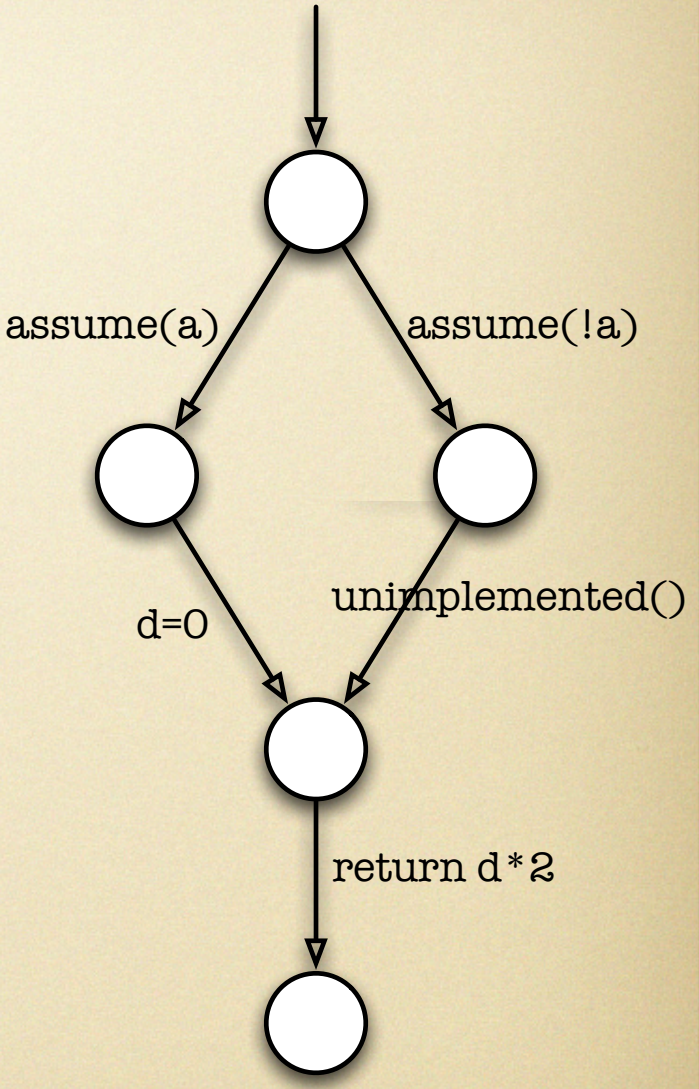

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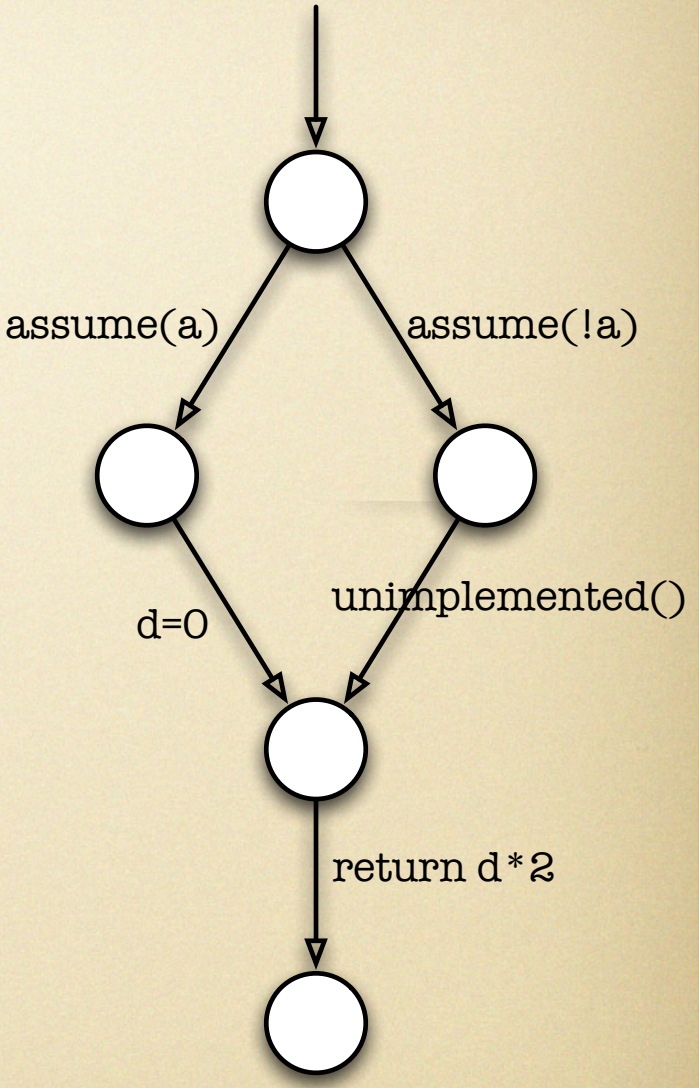
- Can we cover pairs of lines?



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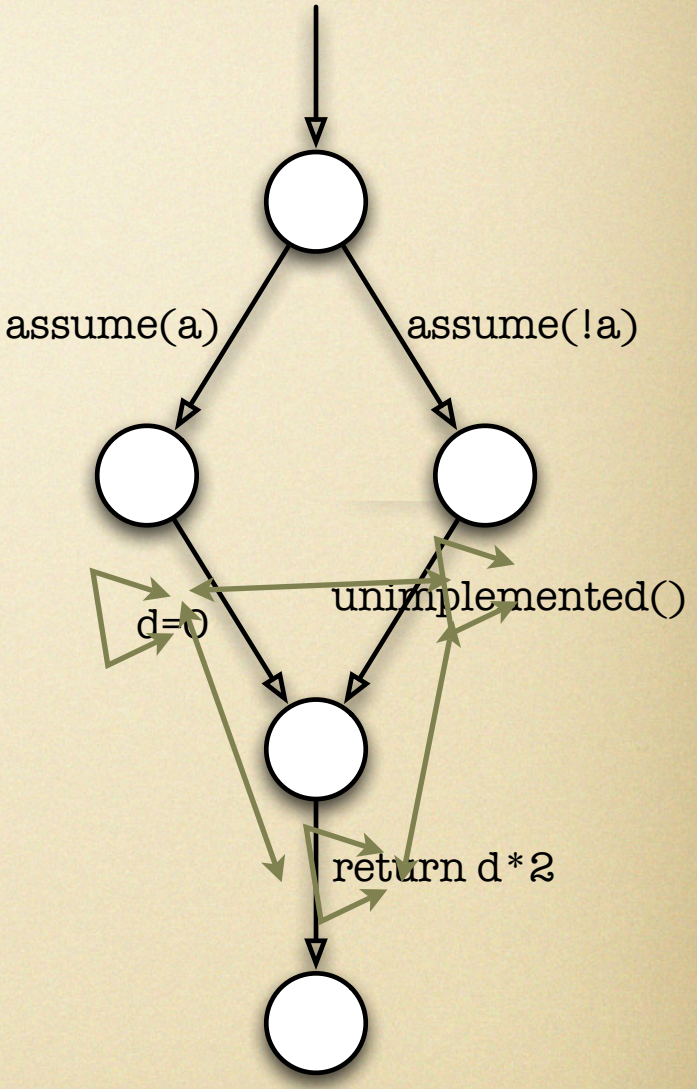

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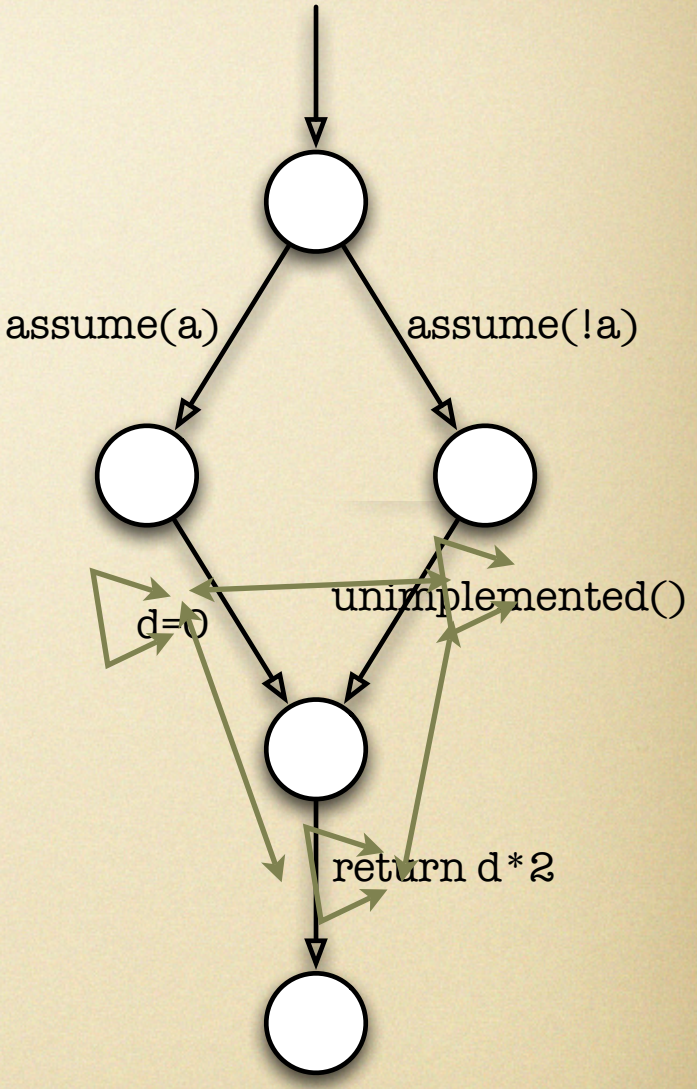

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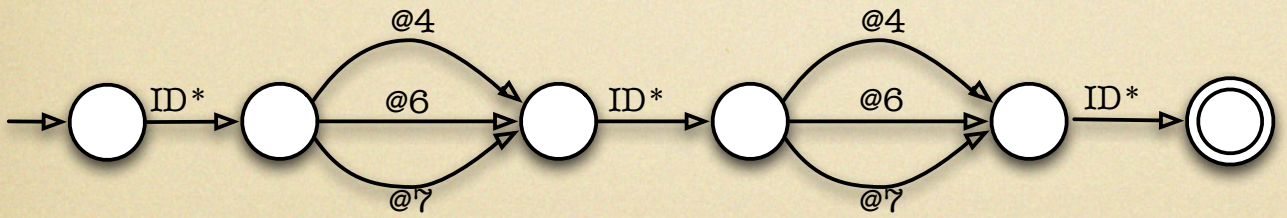

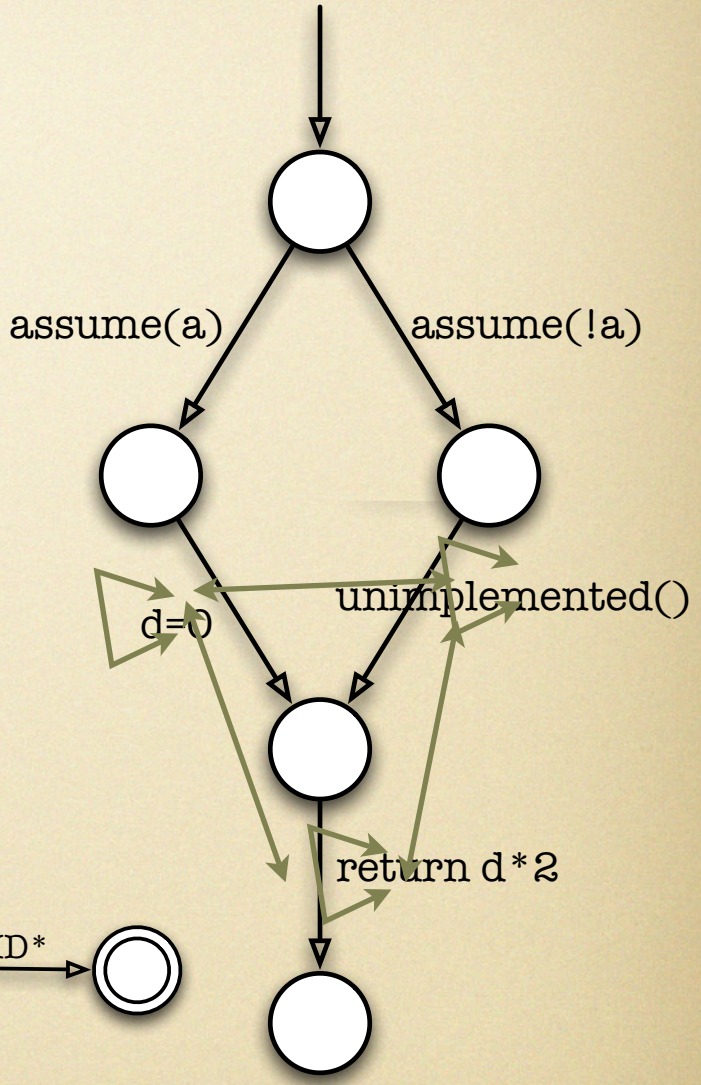

Coverage Patterns

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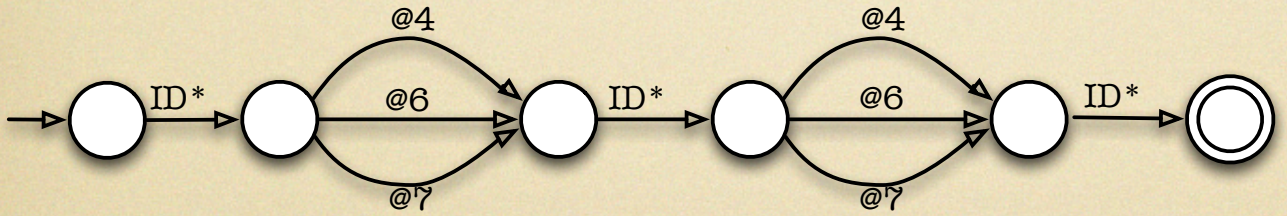

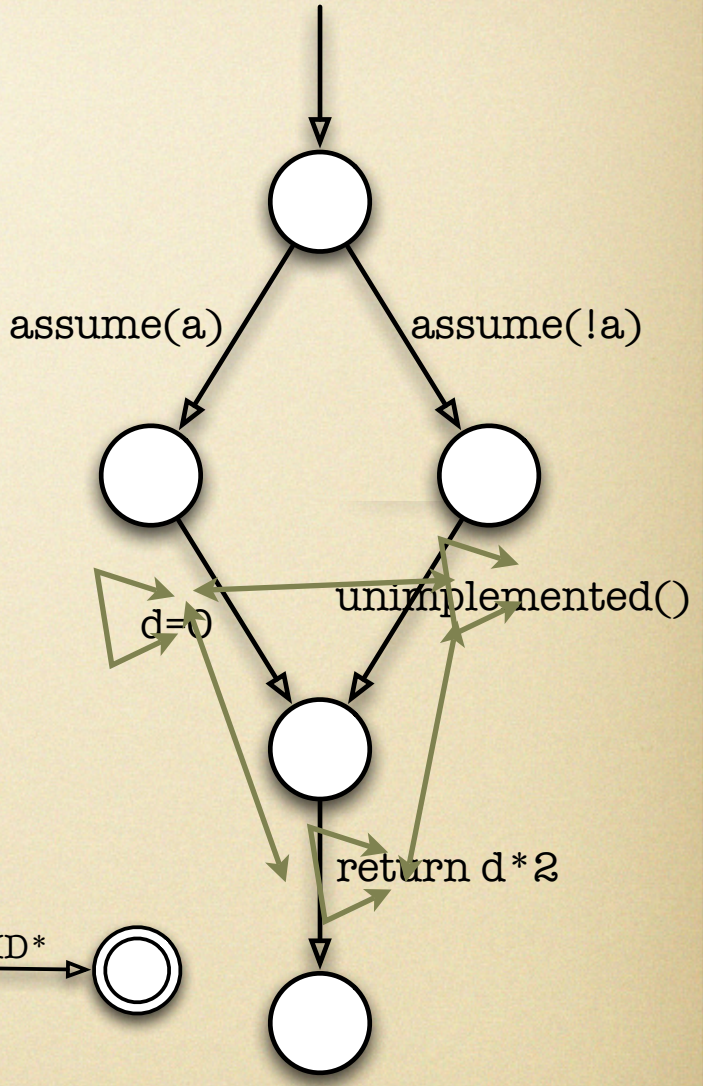

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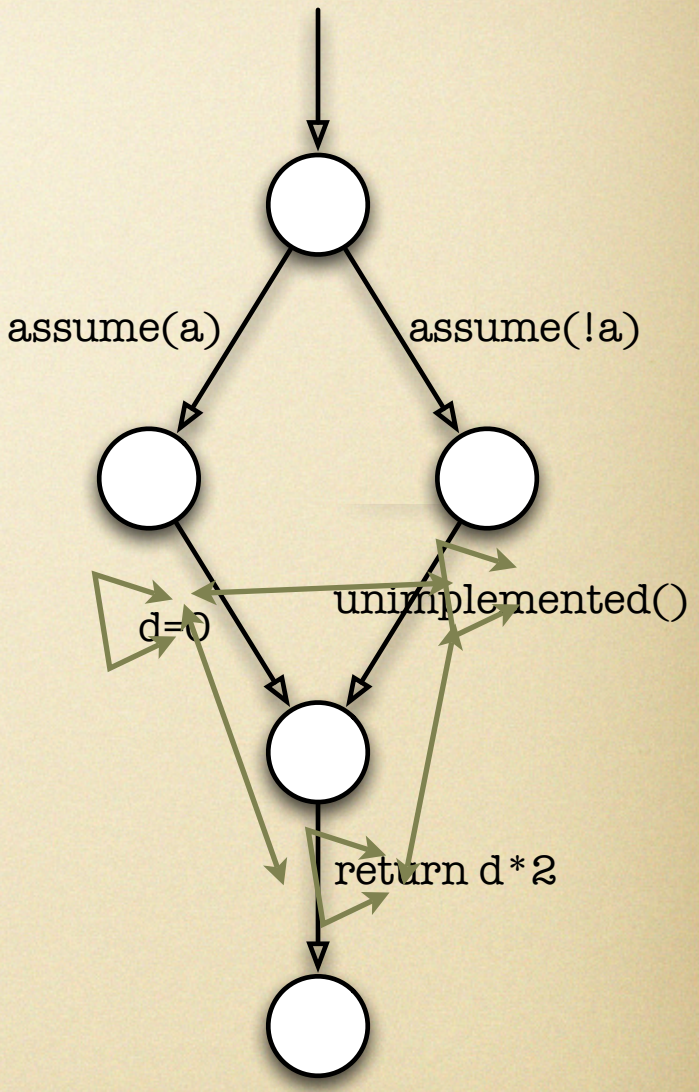

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```
IN:
  a=67108864
  d=0
IN:
  a=0
  d=0
```

Coverage Patterns

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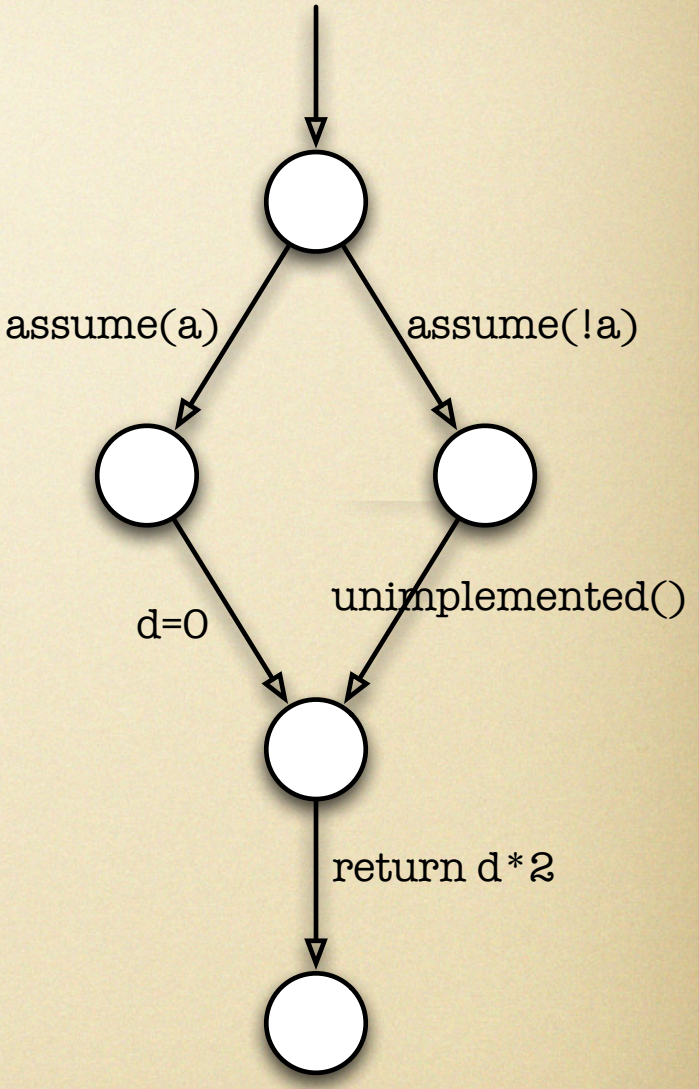

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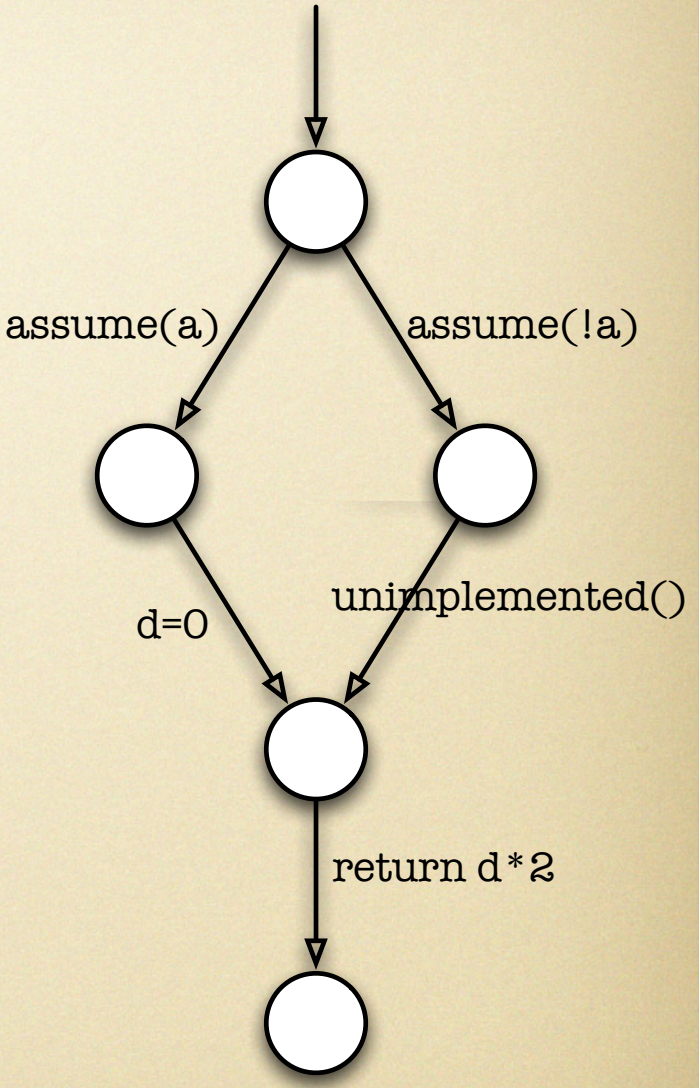

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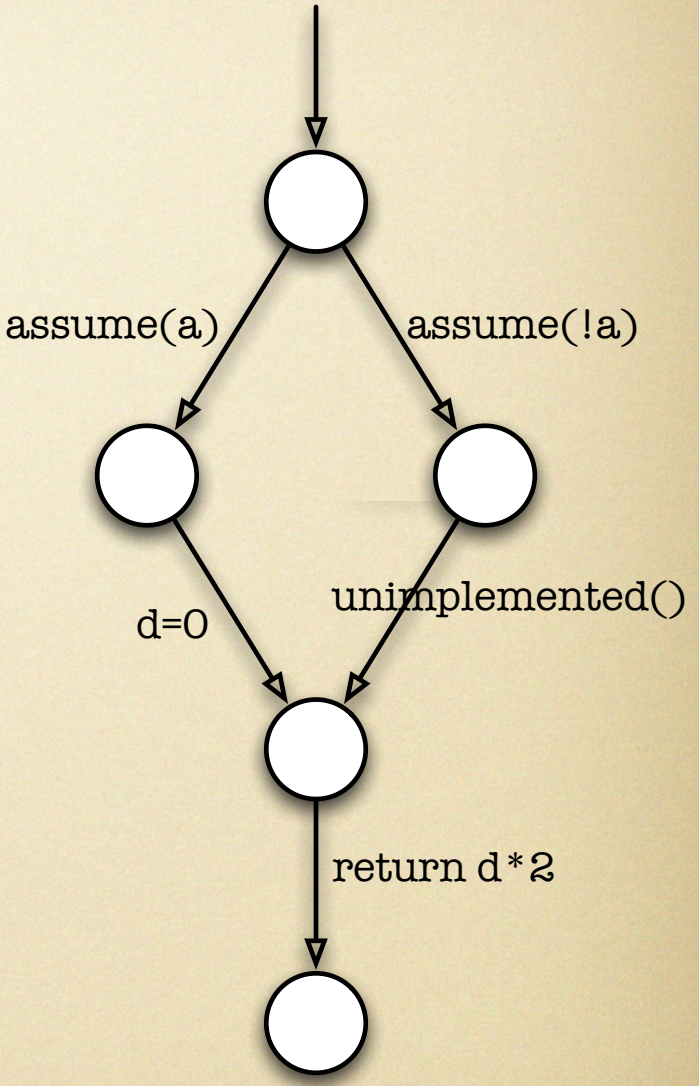

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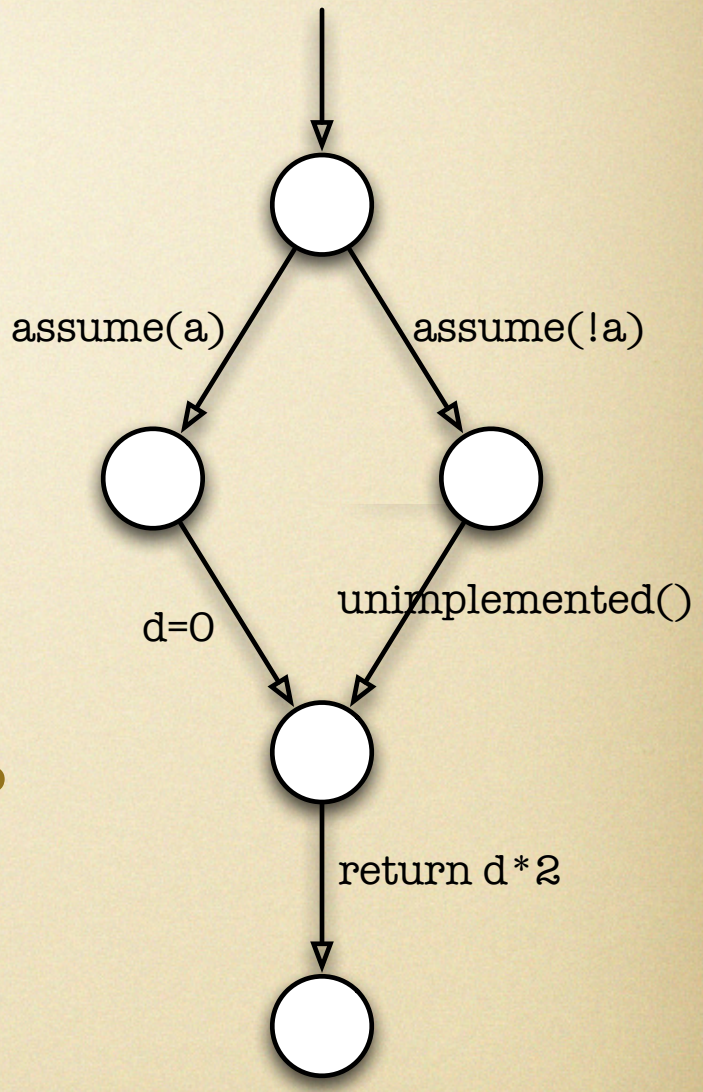

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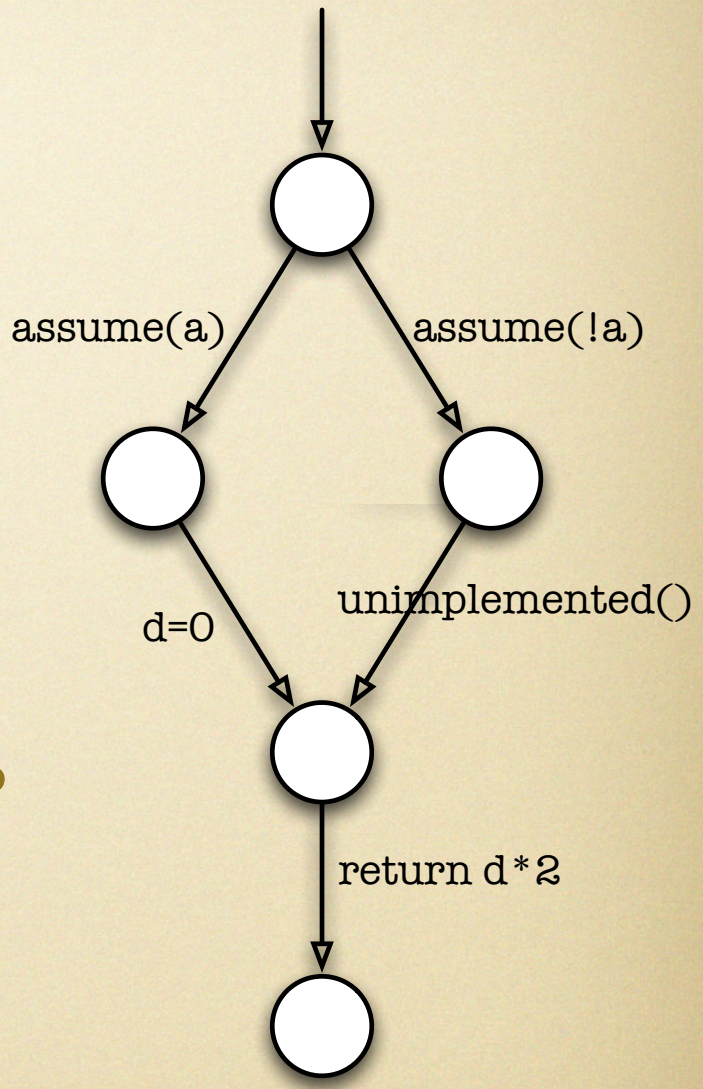

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- **`@basicblockentry`** and **`@4+@6+@7`** describe *the same language of CFA edges*

Edges and Beyond

```
1  int example(int a, int b, int c, int d)
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3    if ((a || b) && c)
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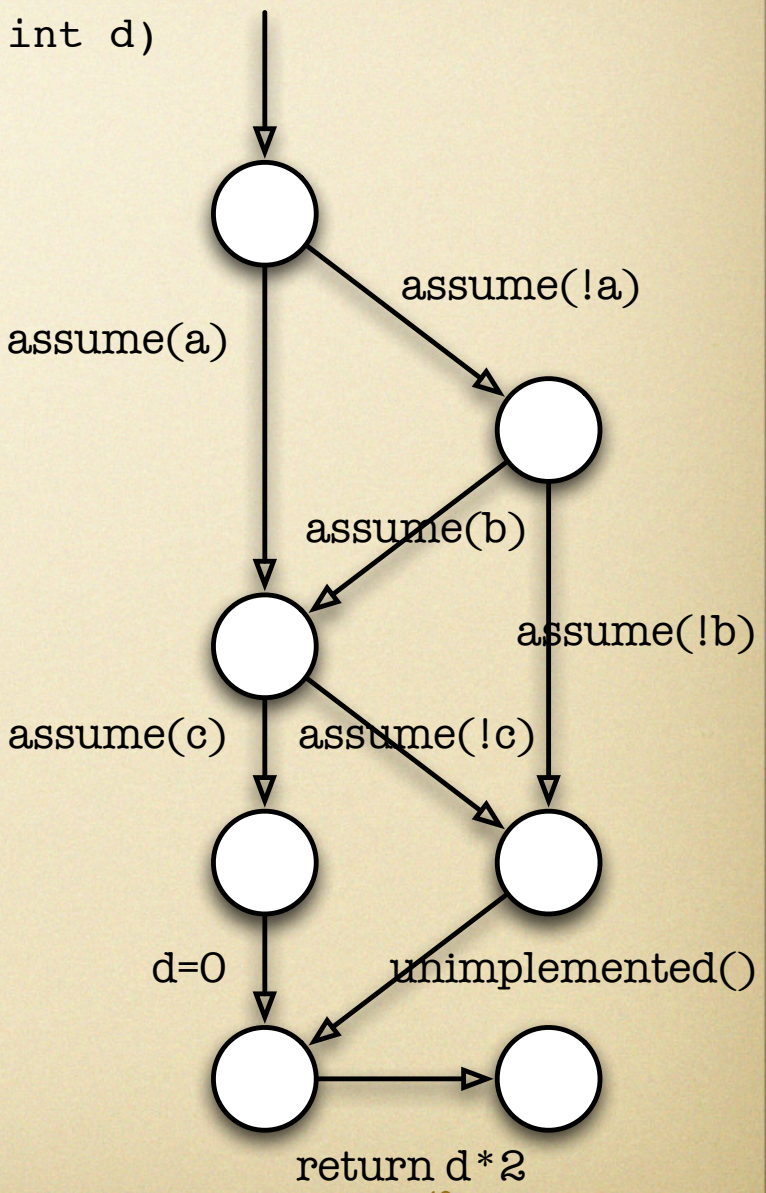

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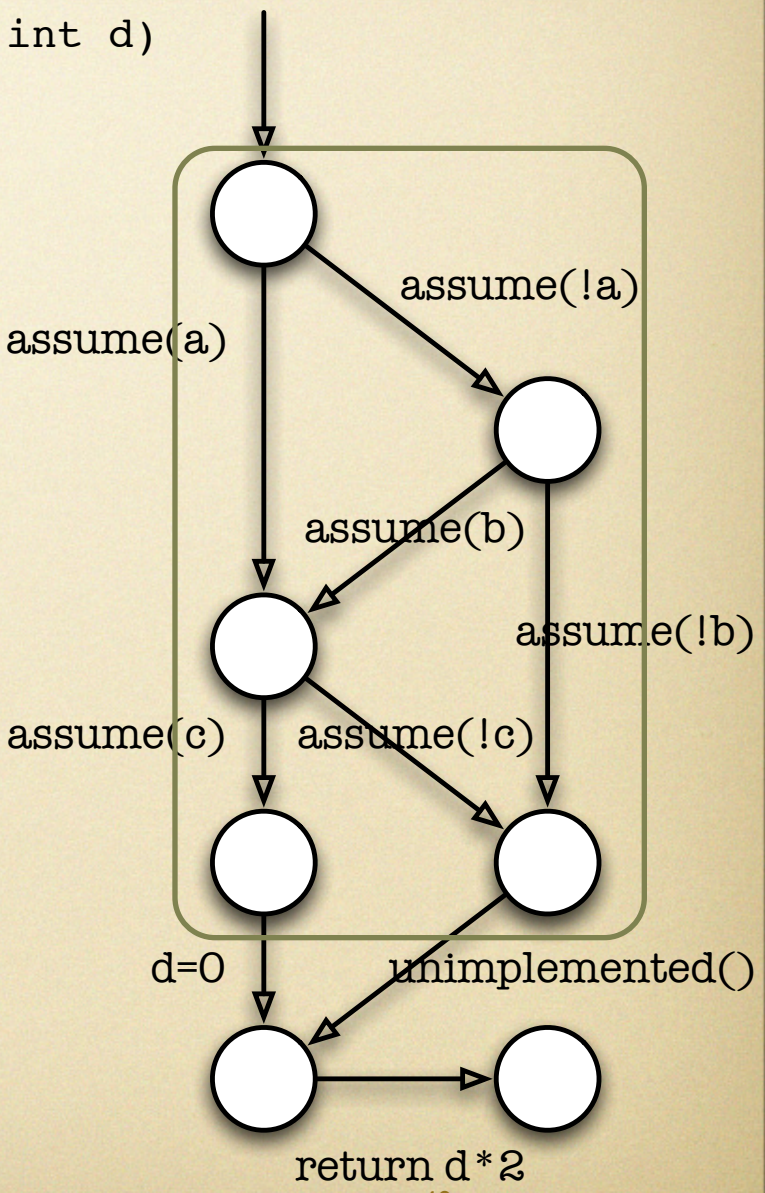

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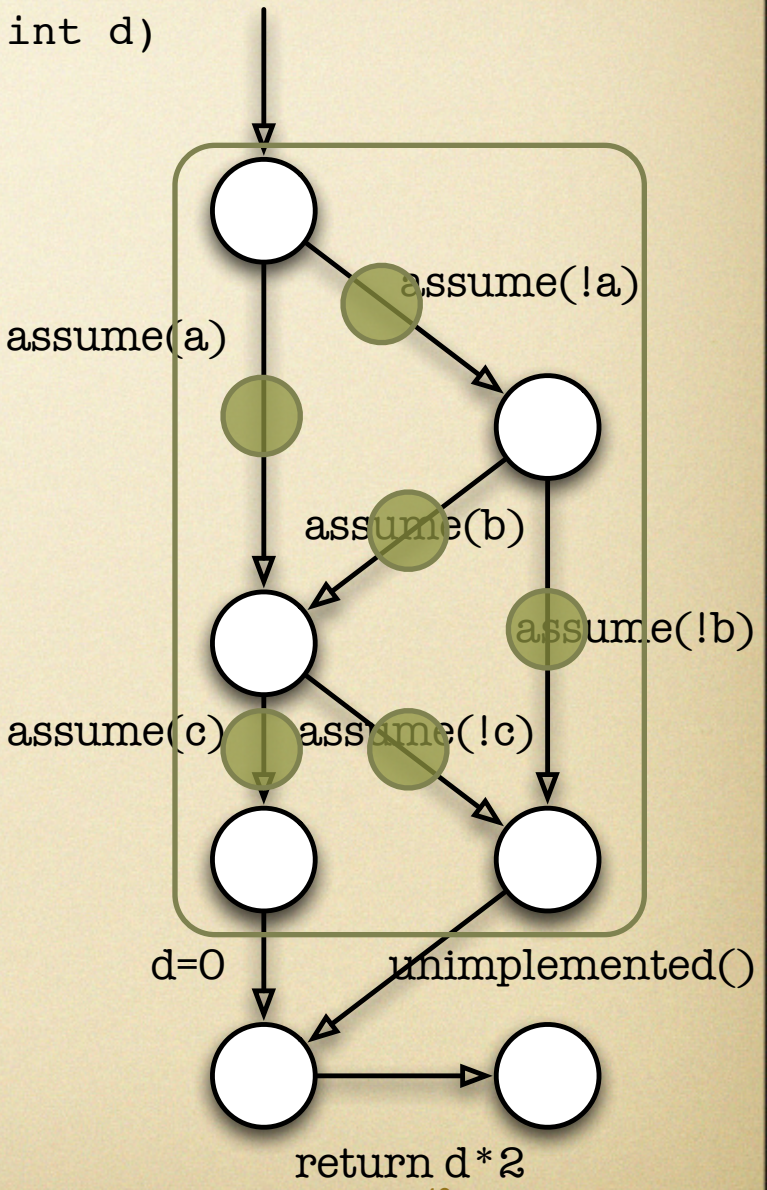

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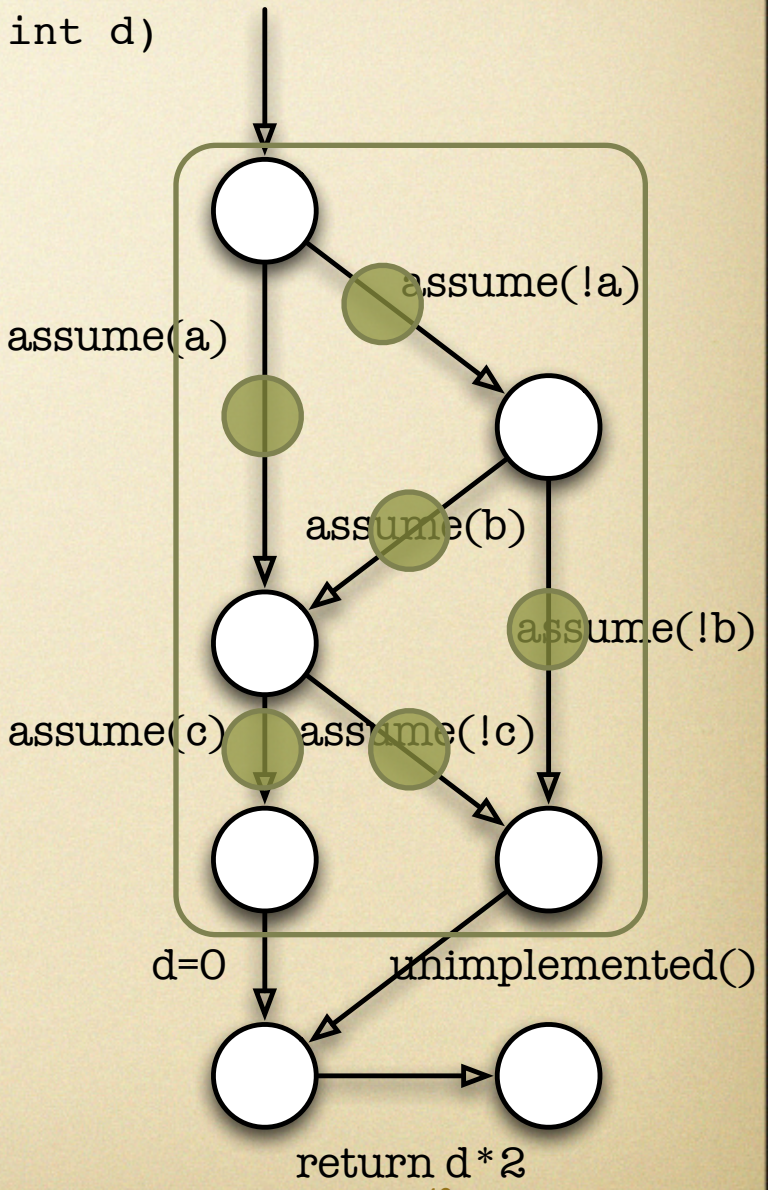

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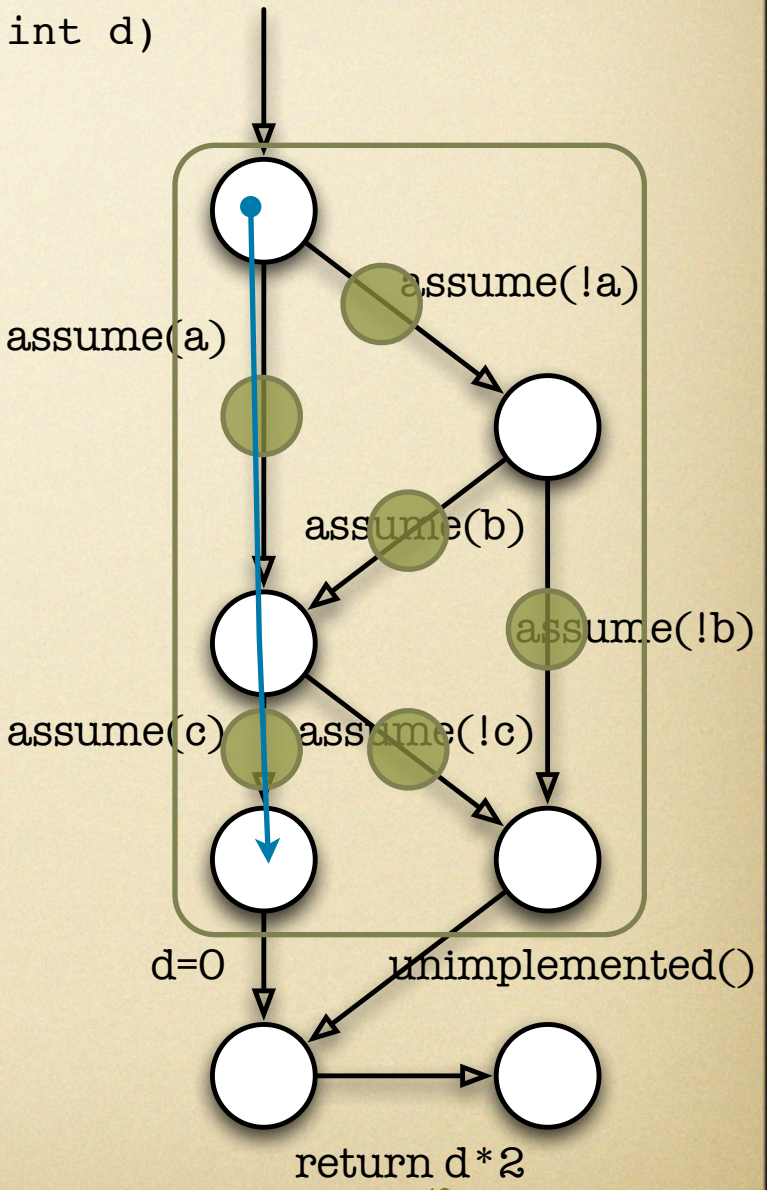

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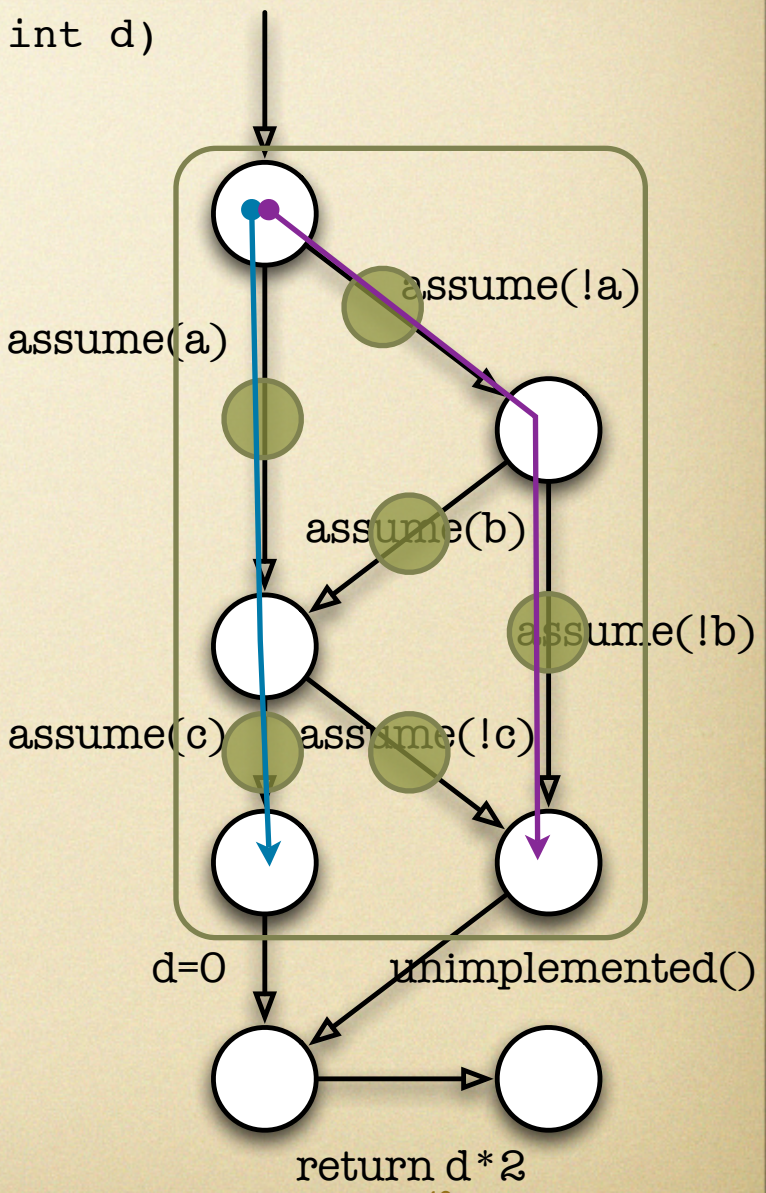

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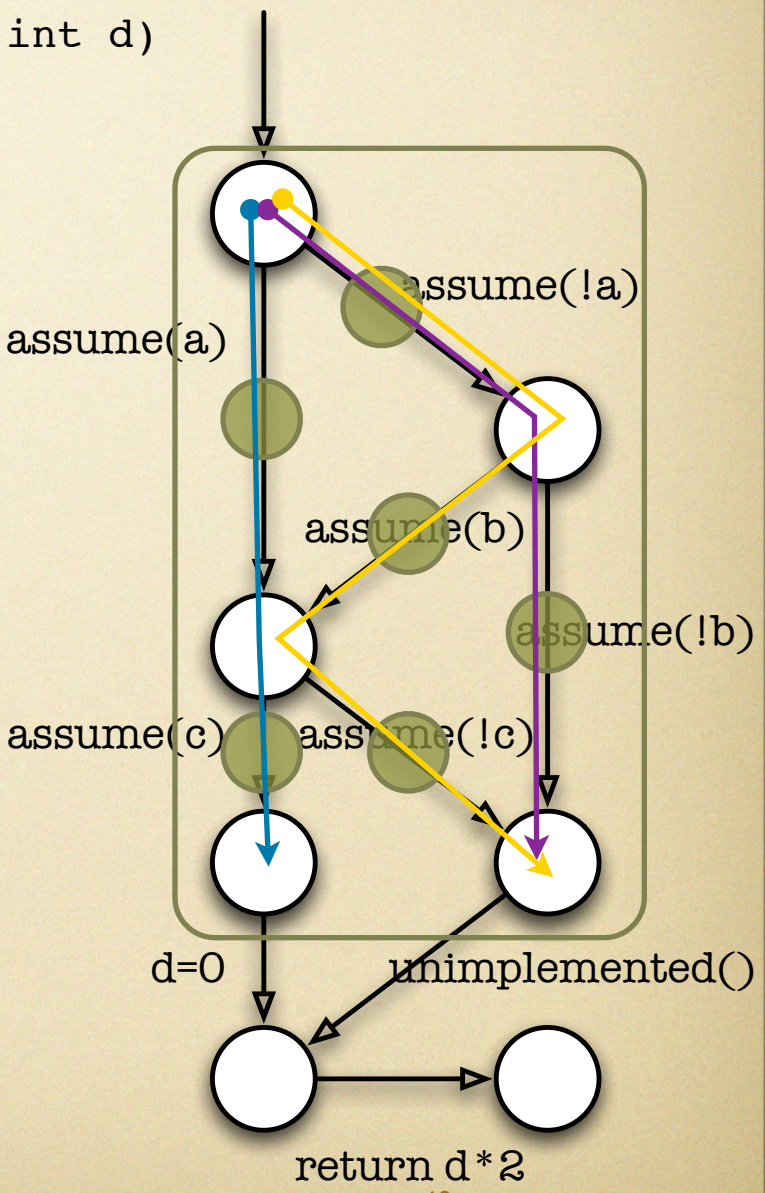

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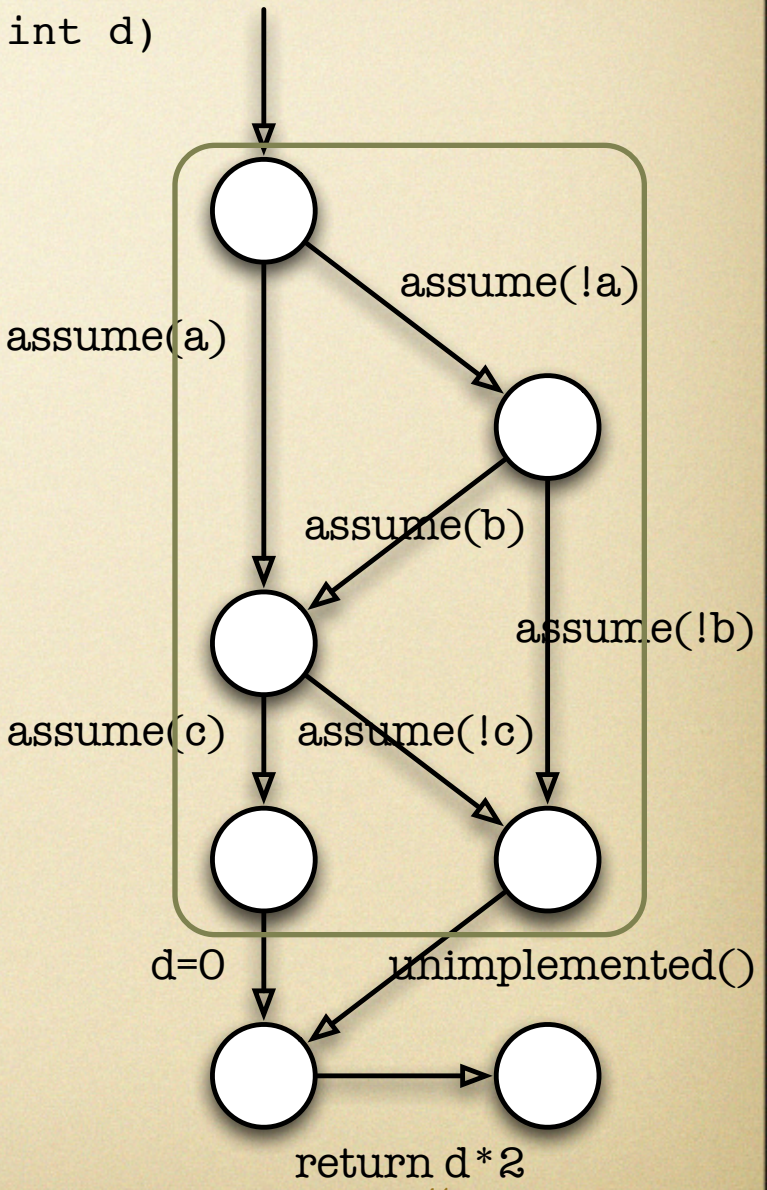

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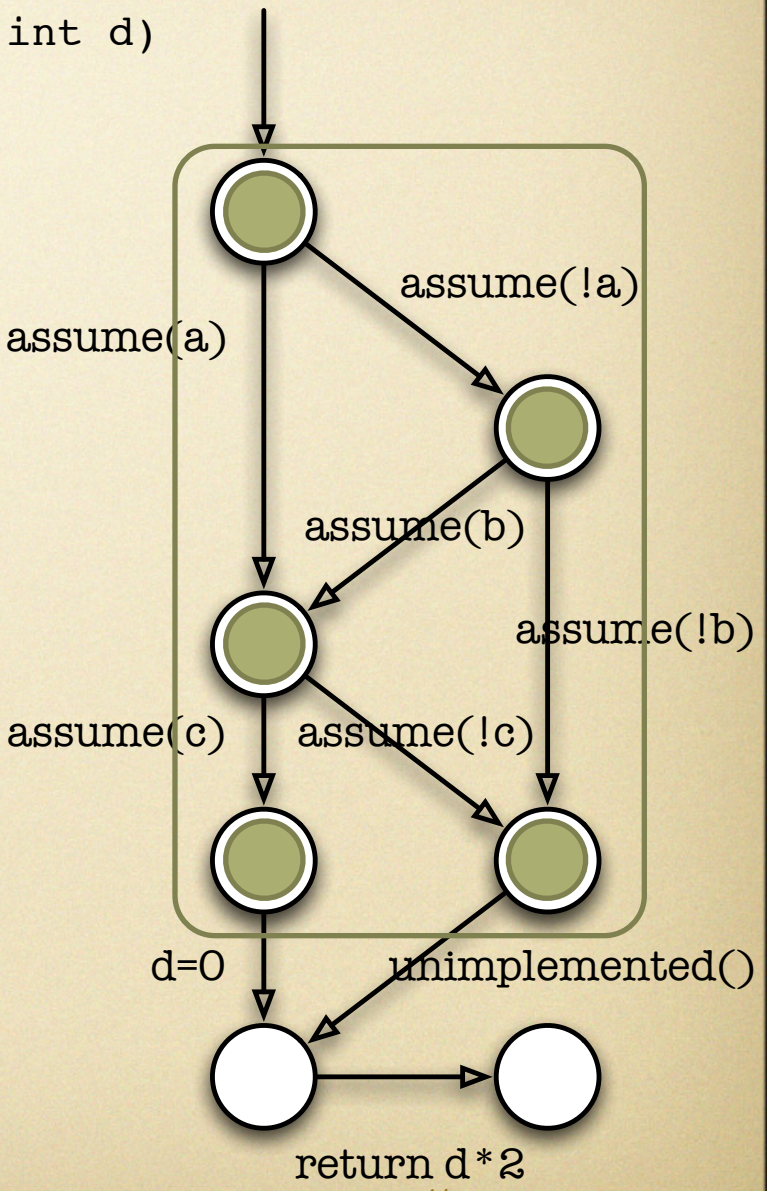

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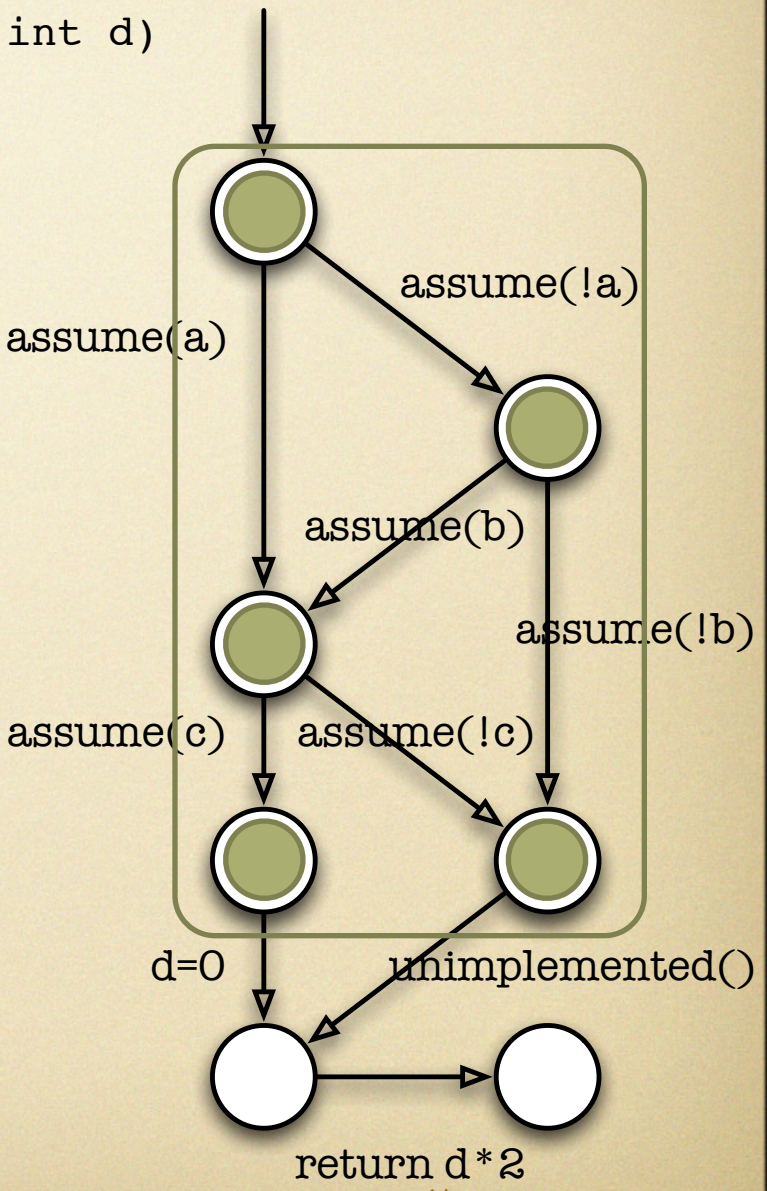

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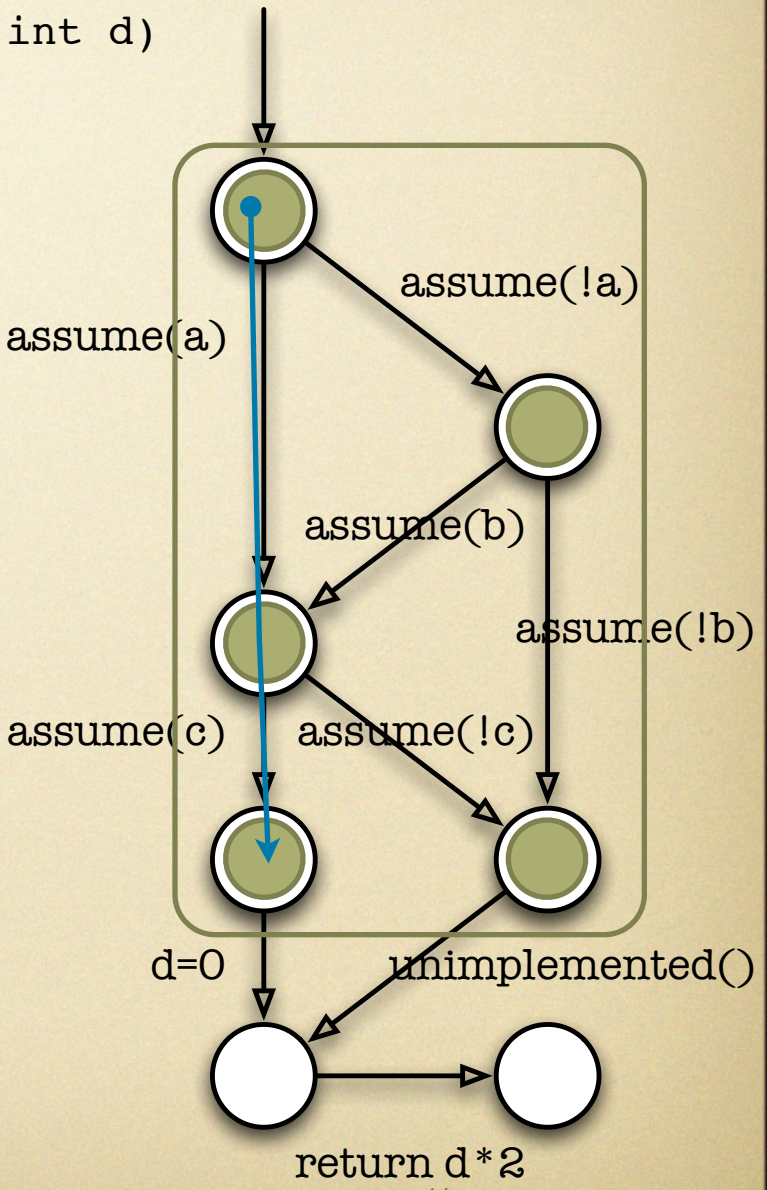

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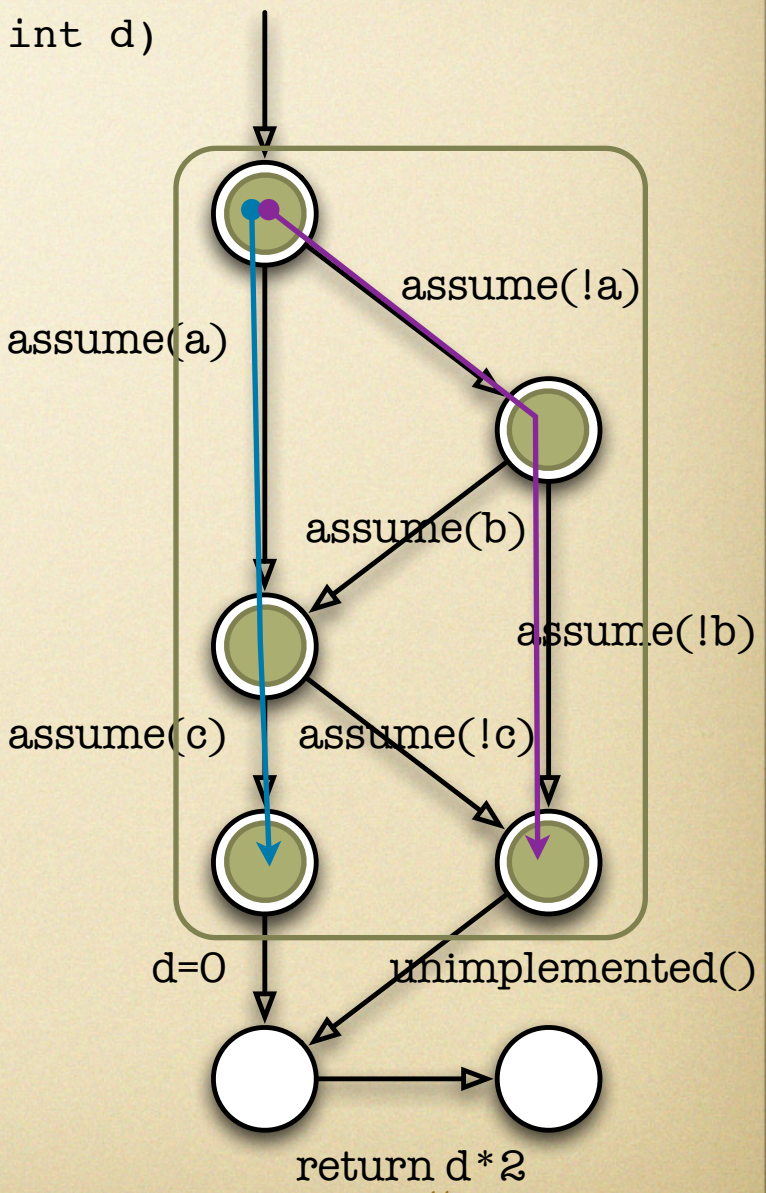

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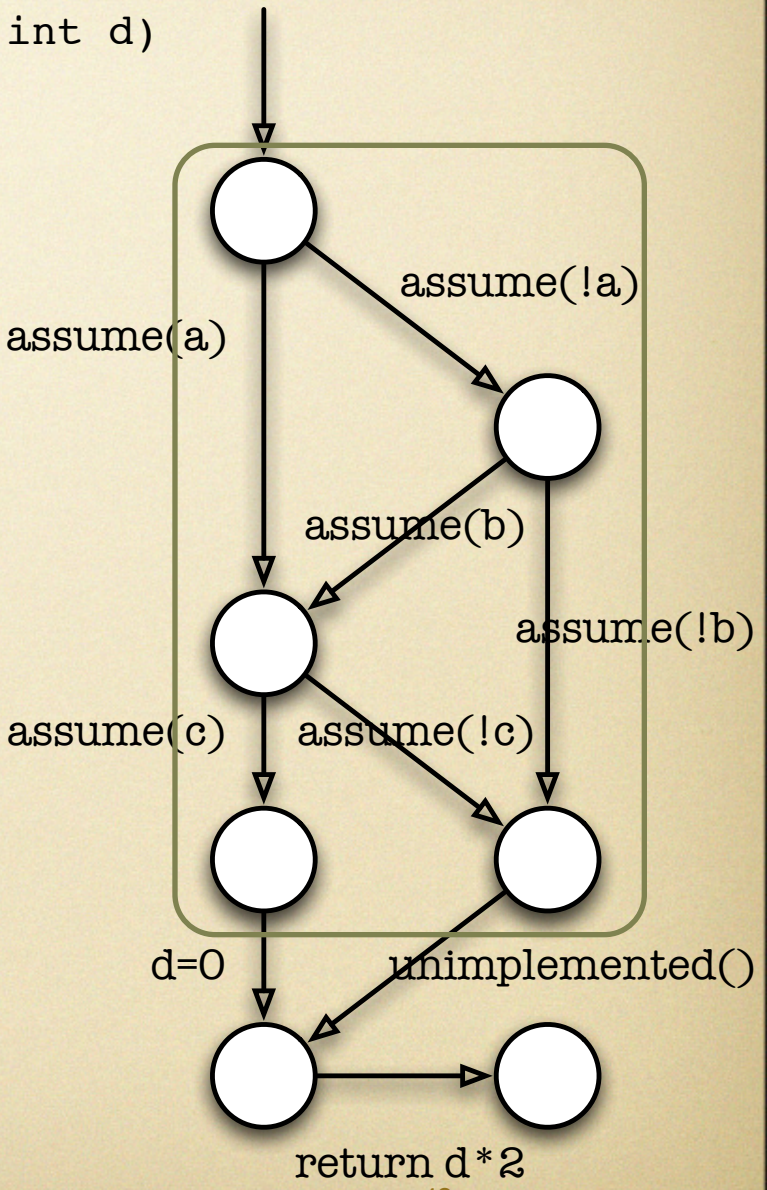

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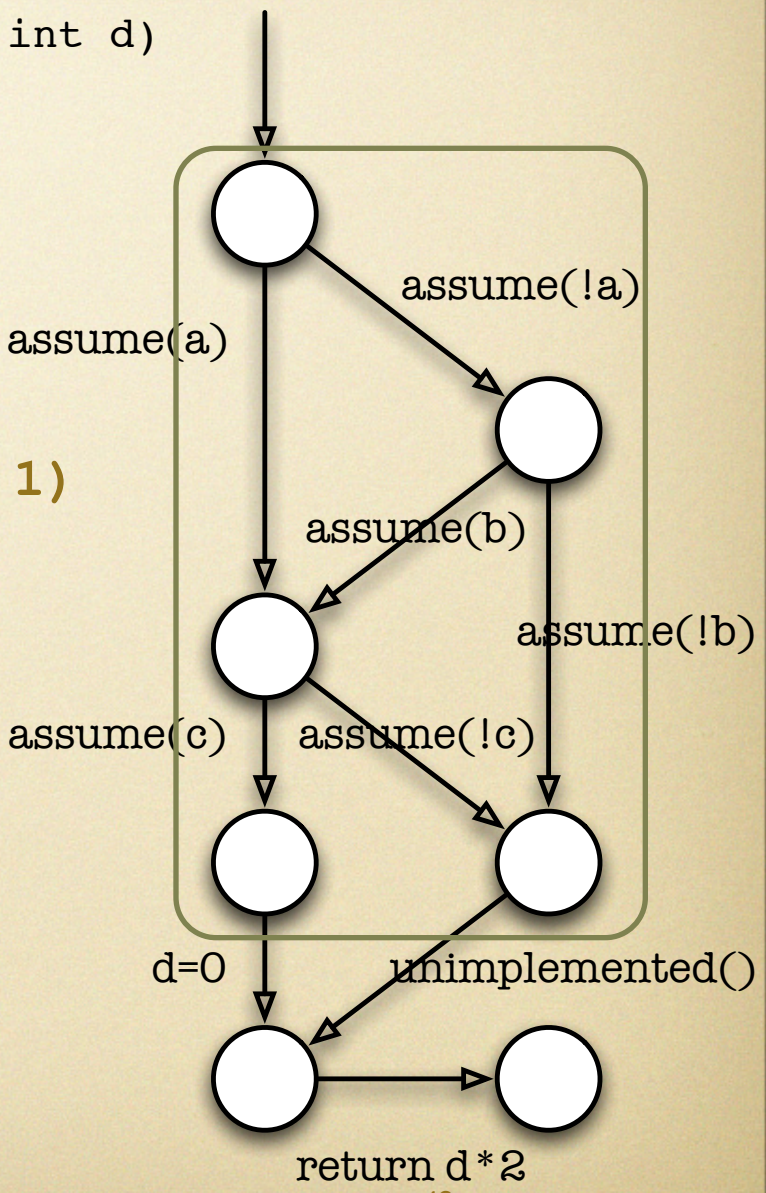

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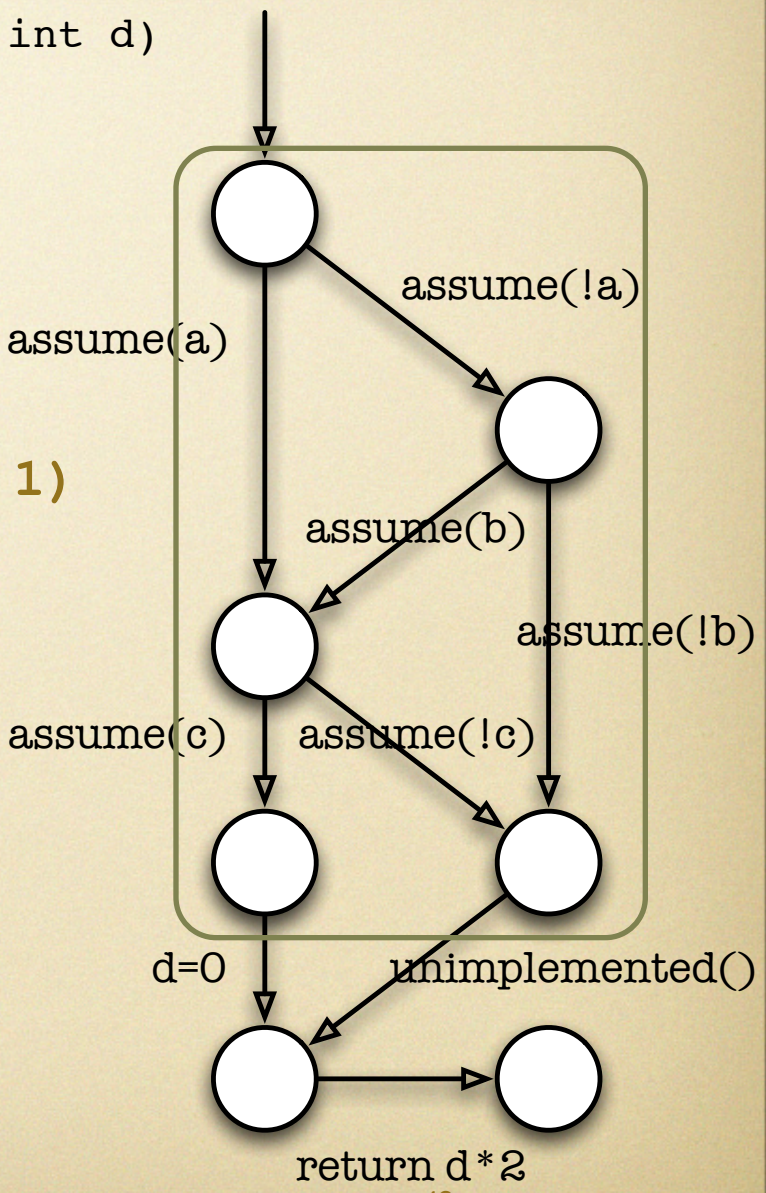

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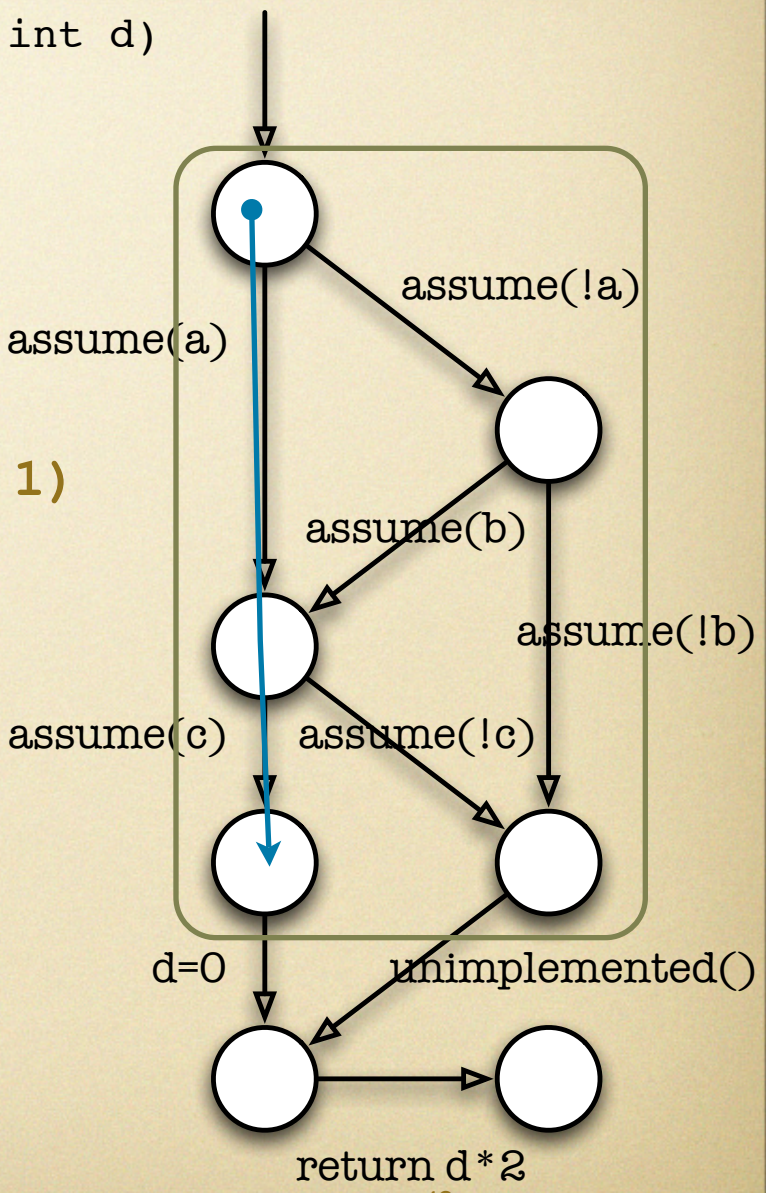

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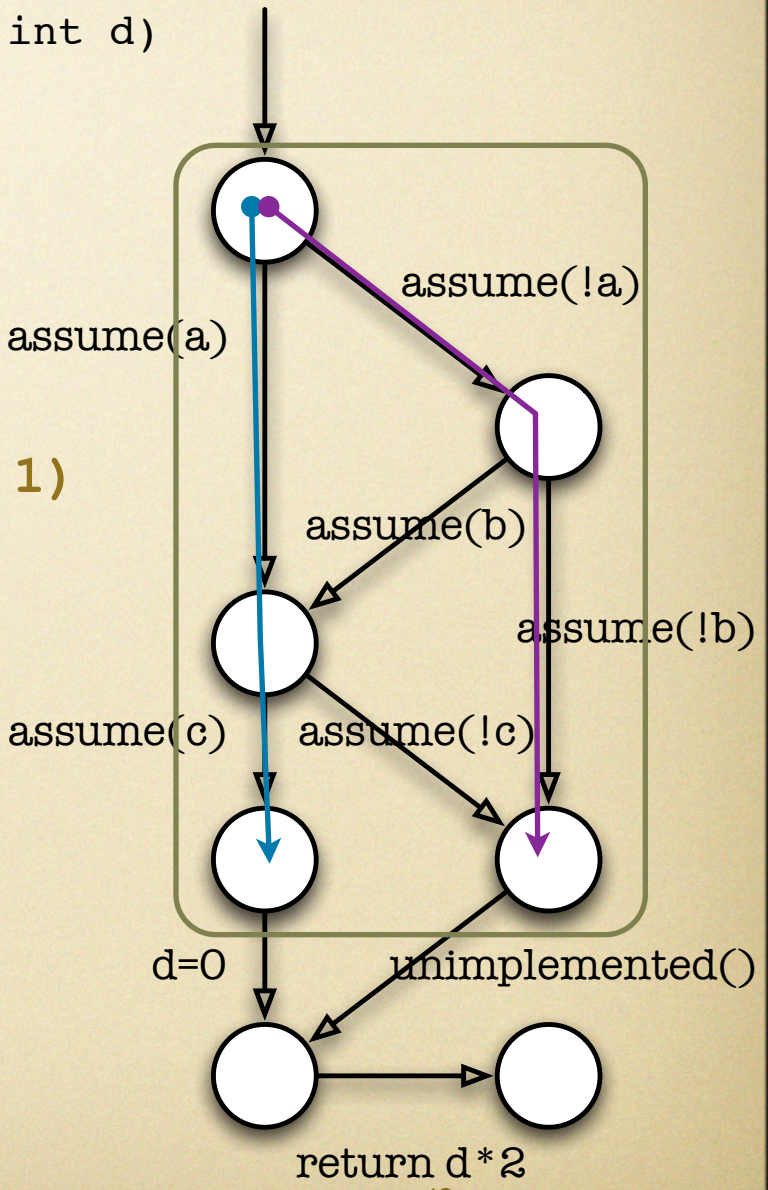

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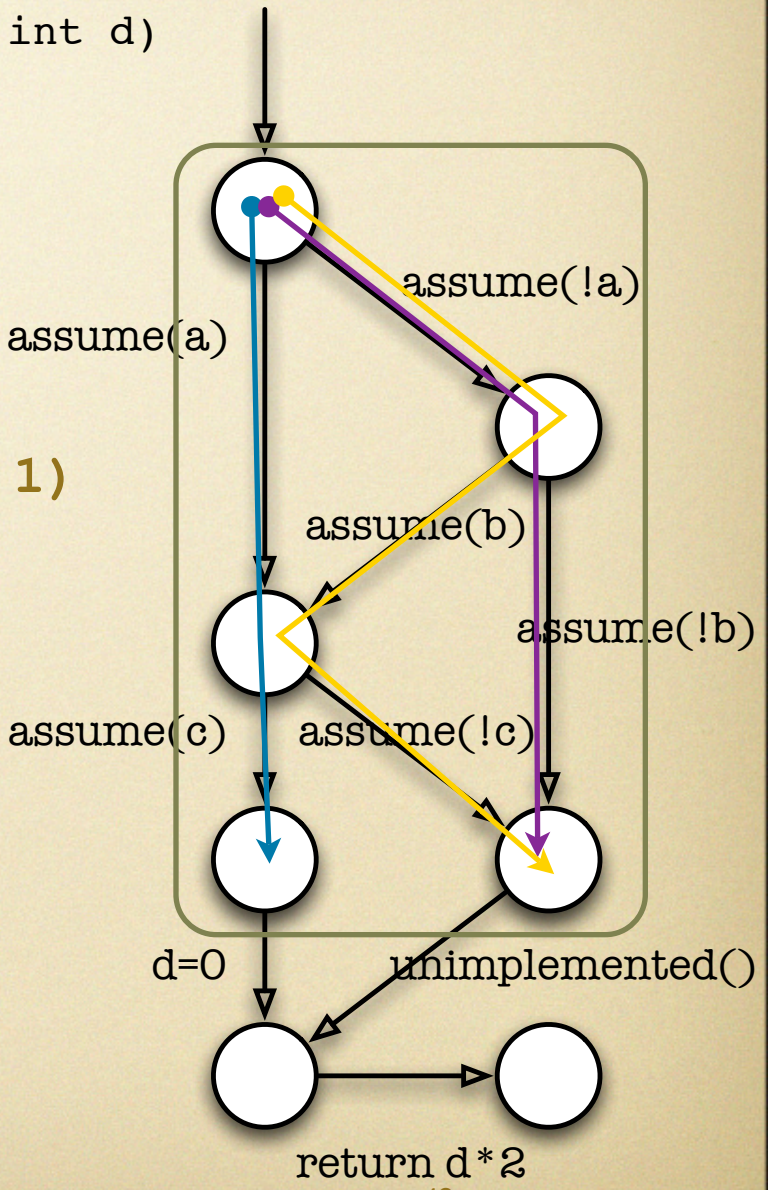

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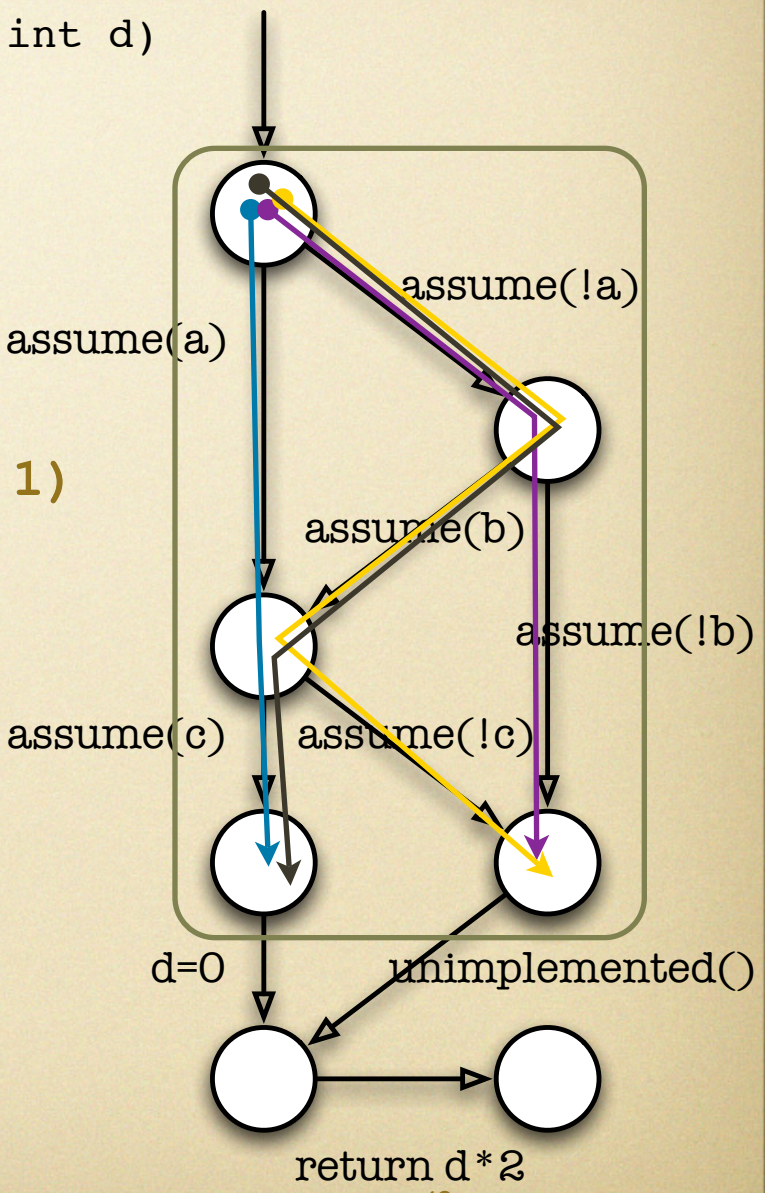

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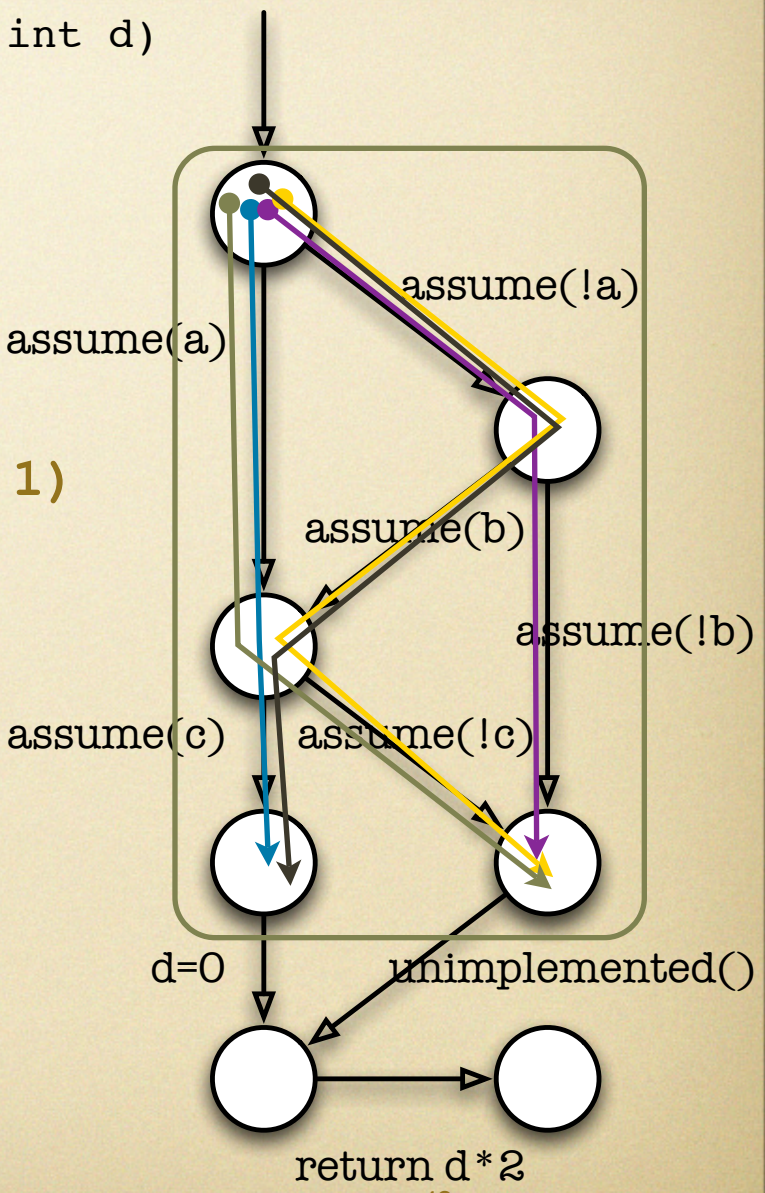

FQL Queries

FQL Queries

in *scope* **cover** *goals* **passing** *constraints*

FQL Queries

```
in scope cover goals passing constraints
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- *scope:* CFA transformer/filter function

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"For each test goal inside scope, provide a test case which satisfies the passing constraints."

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Condition coverage in function *partition* with test cases that reach *line 7* at least once.

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"For each test goal inside scope, provide a test case which satisfies the passing constraints."

```
in @func(partition) cover @conditionedge passing @7
```

Condition coverage in function *partition* with test cases that reach *line 7* at least once.

Standard Coverage Criteria

```
1  int example(int a, int d)
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3    if (a)
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```

```
cover @basicblockentry
```

Basic Block Coverage

Requires a test suite such that each basic block is executed at least once

Standard Coverage Criteria

```
 1 int partition(int a[], int left, int right) {
 2   int v = a[right], i = left - 1, j = right, t;
 3   for (;;) {
 4     while (a[++i] < v) ;
 5     while (j > left && a[--j] > v) ;
 6     if (i >= j) break;
 7     t = a[i]; a[i] = a[j]; a[j] = t;
 8   }
 9   t = a[i]; a[i] = a[right]; a[right] = t;
10   return i;
11 }
```

```
cover @basicblockentry
```

Basic Block Coverage

Requires a test suite such that each basic block is executed at least once

Standard Coverage Criteria

```
1  int example(int a, int b, int c, int d)
2  {
3    if ((a || b) && c)
4      d = 0;
5    else
6      unimplemented();
7    return d*2;
8  }
```

```
cover @decisionedge
```

Decision Coverage

Conditional statements evaluate to true/false

Standard Coverage Criteria

```
1  int example(int a, int b, int c, int d)
2  {
3    if ((a || b) && c)
4      d = 0;
5    else
6      unimplemented();
7    return d*2;
8  }
```

```
cover @conditionedge
```

Condition Coverage

Atomic conditions evaluate to true/false

Standard Coverage Criteria

```
1  int example(int a, int b, int c, int d)
2  {
3    if ((a || b) && c)
4      d = 0;
5    else
6      unimplemented();
7    return d*2;
8  }
```

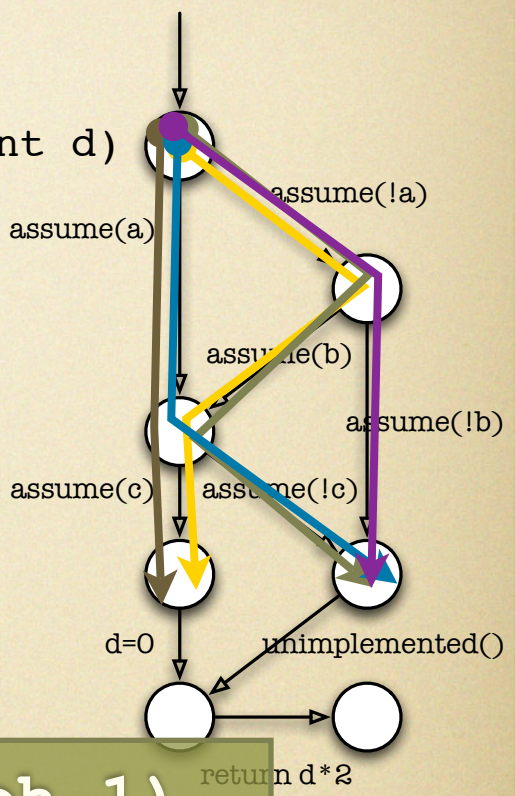
```
cover @conditionedge+@decisionedge
```

Condition/Decision Coverage

Union of condition and decision coverage

Standard Coverage Criteria

```
1  int example(int a, int b, int c, int d)
2  {
3    if ((a || b) && c)
4      d = 0;
5    else
6      unimplemented();
7    return d*2;
8  }
```




```
cover paths(@conditiongraph,1)
```

Multiple Condition Coverage

All Boolean combinations of atomic conditions in complex conditions

Standard Coverage Criteria

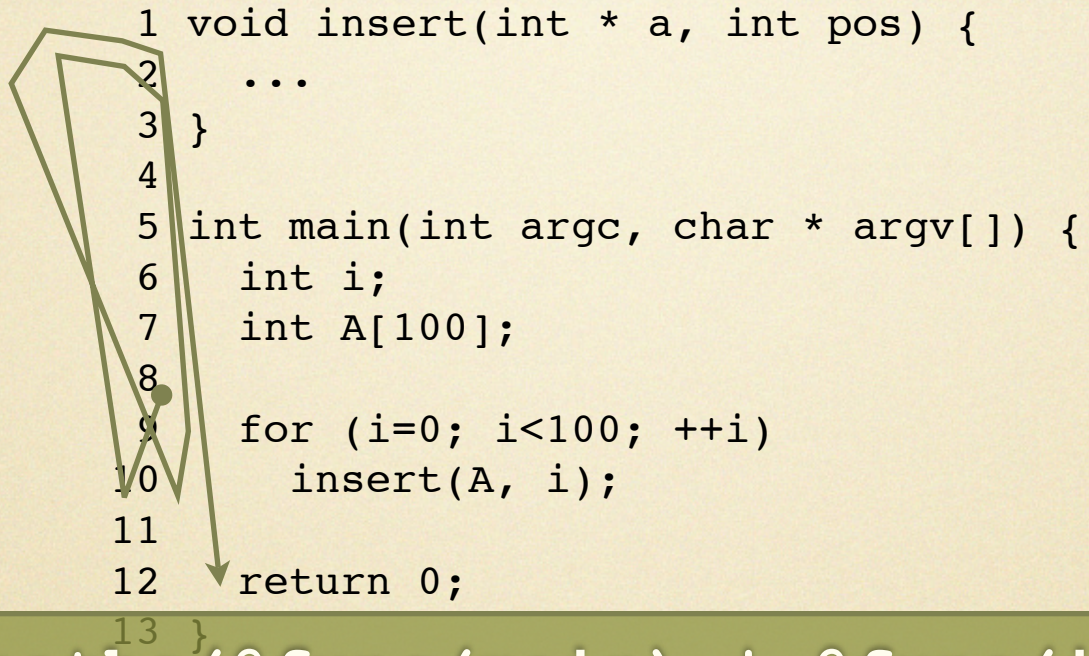
```
1  int example(int a, int d)
2  {
3    if (a)
4      d = 0;
5    else
6      unimplemented();
7    return d*2;
8  }
```

```
cover @def(d).”not(@def(d))*”.@use(d)
```

Def-Use Coverage

Cover all definition/use pairs of a variable *d*

Beyond Standard Criteria



```
1  void insert(int * a, int pos) {
2    ...
3  }
4
5  int main(int argc, char * argv[]) {
6    int i;
7    int A[100];
8
9    for (i=0; i<100; ++i)
10     insert(A, i);
11
12   return 0;
13 }
```

```
cover paths(@func(main) | @func(insert),2)
```

Loop-Bounded Path Coverage

- All paths through *main* and *insert*
- Pass each statement two times

Beyond Standard Criteria

```
 1 int partition(int a[], int left, int right) {
 2   int v = a[right], i = left - 1, j = right, t;
 3   for (;;) {
 4     while (a[++i] < v) ;
 5     while (j > left && a[--j] > v) ;
 6     if (i >= j) break;
 7     t = a[i]; a[i] = a[j]; a[j] = t;
 8   }
 9   t = a[i]; a[i] = a[right]; a[right] = t;
10   return i;
11 }
```

```
cover @basicblockentry->@basicblockentry+
@basicblockentry->@basicblockentry->
@basicblockentry
```

Cartesian Block Coverage

All pairs and triples of basic blocks in function *partition*

Specs for Working Programmers

```
1  int example(int a, int b, int c, int d)
2  {
3    if ((a || b) && c)
4      d = 0;
5    else
6      unimplemented();
7    return d*2;
8  }
```

```
cover @4+@6
```

Cover Specific Lines of Code

Lines 4 and 6

Specs for Working Programmers

```
 1 void eval(int * a, int first, int last) {
 2   if (first > last) return;
 3   printf("a[%d]=%d\n", first, a[first]);
 4   eval(a+1, first+1, last);
 5   return;
 6 }
 7
 8 int main(int argc, char * argv[]) {
 9   int i;
10   int A[100];
11
12   for (i=0; i<100; ++i)
13     insert(A, i);
14
15   eval(A, 0, 100);
16   return 0;
17 }
```

```
cover @basicblockentry & @func(eval)
```

Restricted Scope of Analysis

Basic block coverage in function *eval* only

Specs for Working Programmers

```
 1 void sort(int * a, int len) {
 2   int i, t;
 3   for (i=1; i<len; ++i) {
 4     if (compare(a[i-1], a[i])) continue;
 5     t=a[i]; a[i]=a[i-1]; a[i-1]=t;
 6   }
 7 }
 8
 9 void eval(int * a, int len) {
10   int i;
11   for (i=0; i < 3; ++i)
12     printf("a[%d]=%d\n", i, a[i]);
13 }
14
15 int main(int argc, char * argv[]) {
16   int i; int A[100];
17   for (i=0; i < 100; ++i) sort(A, 100);
18   eval(A, 100);
19   return 0;
20 }
```

```
cover (@conditionedge & @func(sort)) ->
  (@basicblockentry & @func(eval))
```

Interaction Coverage

Cover all pairs of conditions in *sort* and basic blocks in *eval*

Specs for Working Programmers

```
 1 void sort(int * a, int len) {
 2   int i, t;
 3   for (i=1; i<len; ++i) {
 4     if (compare(a[i-1], a[i])) continue;
 5     t=a[i];
 6     a[i]=a[i-1];
 7     a[i-1]=t;
 8   }
 9   return;
10 }
```

```
cover {len>=2} . {len<=15} .
@basicblockentry & @func(sort)
```

Constrained Inputs

- Basic block coverage in *sort*
- Each test case shall use list of 2 to 15 elements

Specs for Working Programmers

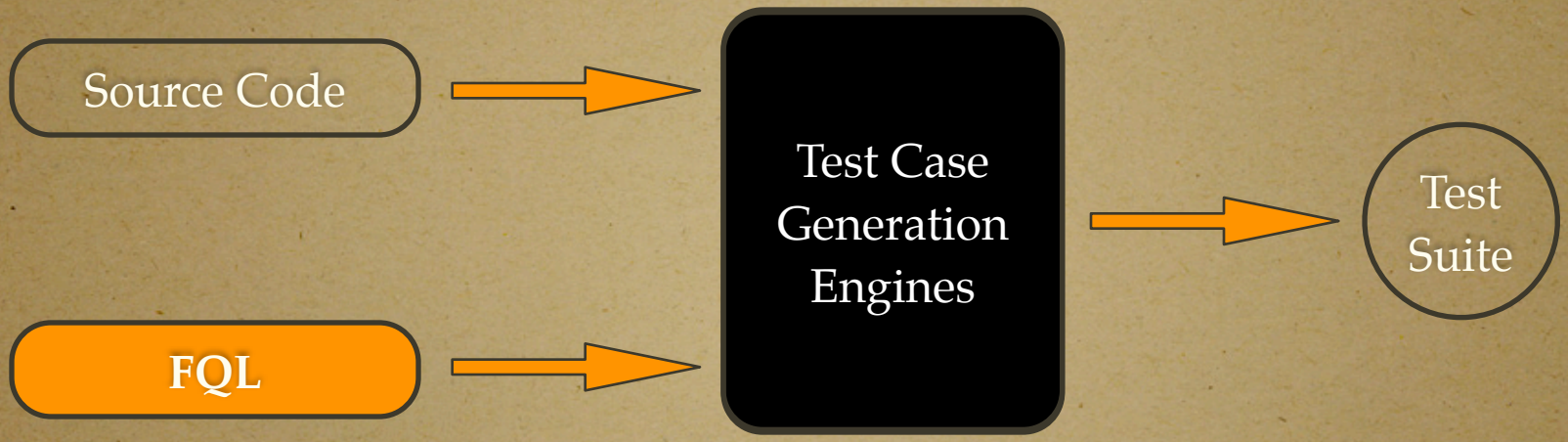
```
1  int example(int a, int d)
2  {
3    if (a)
4      d = 0;
5    else
6      unimplemented();
7    return d*2;
8  }
```

```
cover @basicblockentry & @func(example)
  passing ^not(@call(unimplemented))*$
```

Avoid Unfinished Code

- Basic block coverage in *example*
- Never call *unimplemented*

Conclusions and Current Work



- Specification language based on quoted regular expressions to precisely specify where to go
- Two test input generation engines
- Currently evaluating with partners from automotive and avionics industry
- Extending our work to model-based testing

http://code.forsyte.de/fshell

http://code.forsyte.de/fshell

Experimental Results

Source	SLOC	BB (**Q1**) #goals	#tc	CC (**Q2**) #goals	#tc	BB^2 (**Q18**) #goals	#tc	#inf
coreutils/cat.c	27	16	4	10	4	224	6	39
coreutils/echo.c	161	27	8	20	11	675	93	198
coreutils/nohup.c	33	17	6	12	5	255	13	133
coreutils/seq.c	37	28	7	20	7	728	23	394
coreutils/tee.c	73	21	9	16	8	399	30	127
kbfiltr.c	3507	250	2	196	2	62000	2	61911
pseudo-vfs.c	553	10	3	6	3	80	3	44
matlab.c	3444	30	6	22	6	840	10	441
memman.c	245	53	8	40	8	2756	29	1749
PicoSAT	6592	191	43	153	39	36099	417	26352