DART:
Directed Automated Random Testing

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Motivation

- Software testing: “usually accounts for 50% of software development cost”
  - “Software failures cost $60 billion annually in the US alone”
- Unit testing: applies to individual software components
  - Goal: “white-box” testing for corner cases, 100% code coverage
  - Unit testing is usually done by developers (not testers)
- Problem: in practice, unit testing is rarely done properly
  - Testing in isolation with manually-written test harness/driver code is too expensive, testing infrastructure for system testing is inadequate
  - Developers are busy, (“black-box”) testing will be done later by testers…
  - Bottom-line: many bugs that should have been caught during unit testing remain undetected until field deployment (corner cases where severe reliability bugs hide)
- Idea: help automate unit testing by eliminating/reducing the need for writing manually test driver and harness code $\rightarrow$DART

DART: Directed Automated Random Testing

1. Automated extraction of program interface from source code
2. Generation of test driver for random testing through the interface
3. Dynamic test generation to direct executions along alternative program paths

- Together: (1)+(2)+(3) = DART
- Any program that compiles can be run and tested this way:

No need to write any test driver or harness code!

Example (C code)

```
int double(int x) {
    return 2 * x;
}

void test_me(int x, int y) {
  int z = double(x);
  if (z==y) {
    if (y == x+10)
        abort(); /* error */
  }
}
```

→ (1) Interface extraction:
- parameters of toplevel function
- external variables
- return values of external functions

→ (2) Generation of test driver for random testing:

```
main(){
    int tmp1 = randomInt();
    int tmp2 = randomInt();
    test_me(tmp1,tmp2);
}
```

→ Closed (self-executable) program that can be run

Problem: probability of reaching abort() is extremely low!

DART Step (3): Directed Search

```
main(){
      int t1 = randomInt();
      int t2 = randomInt();
      test_me(t1,t2);
}
int double(int x) {return 2 * x; }


void test_me(int x, int y) {
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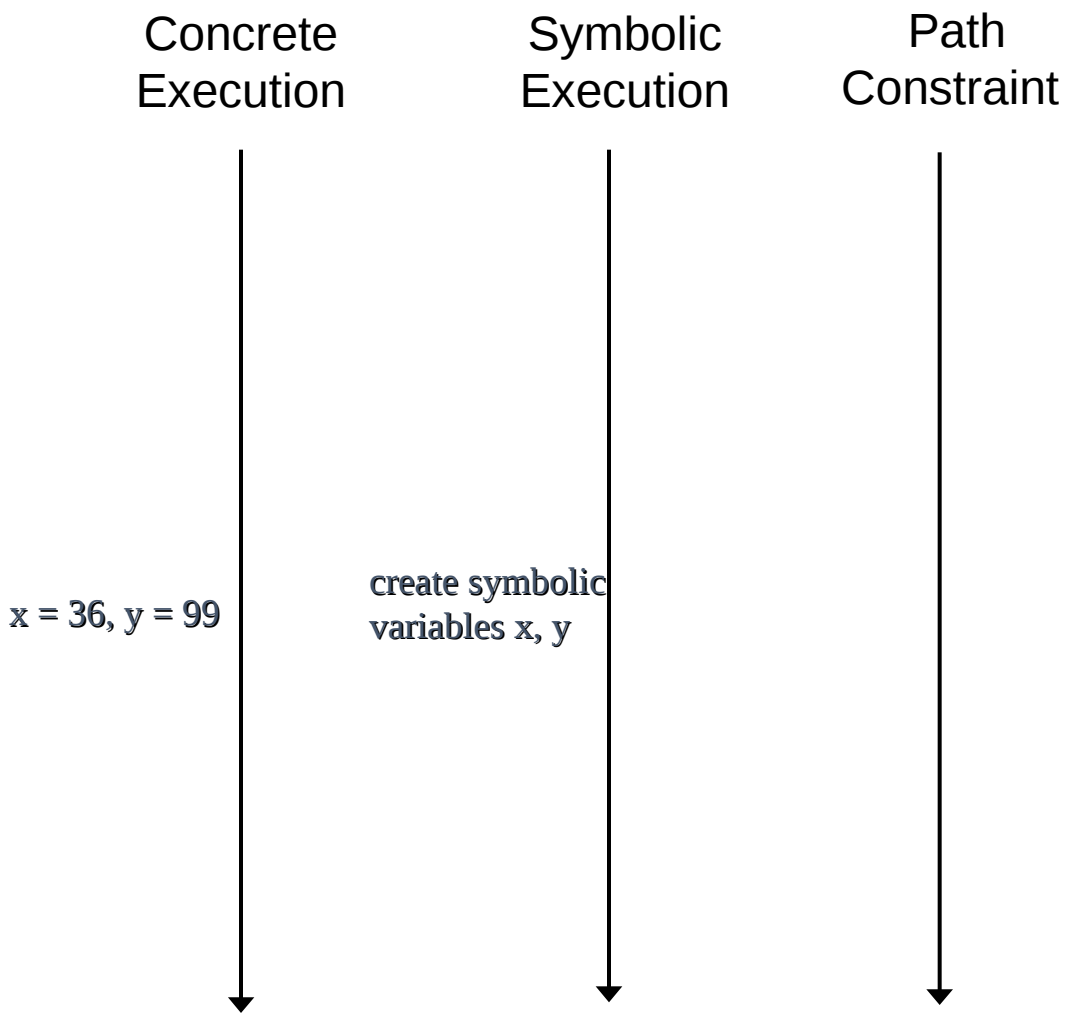

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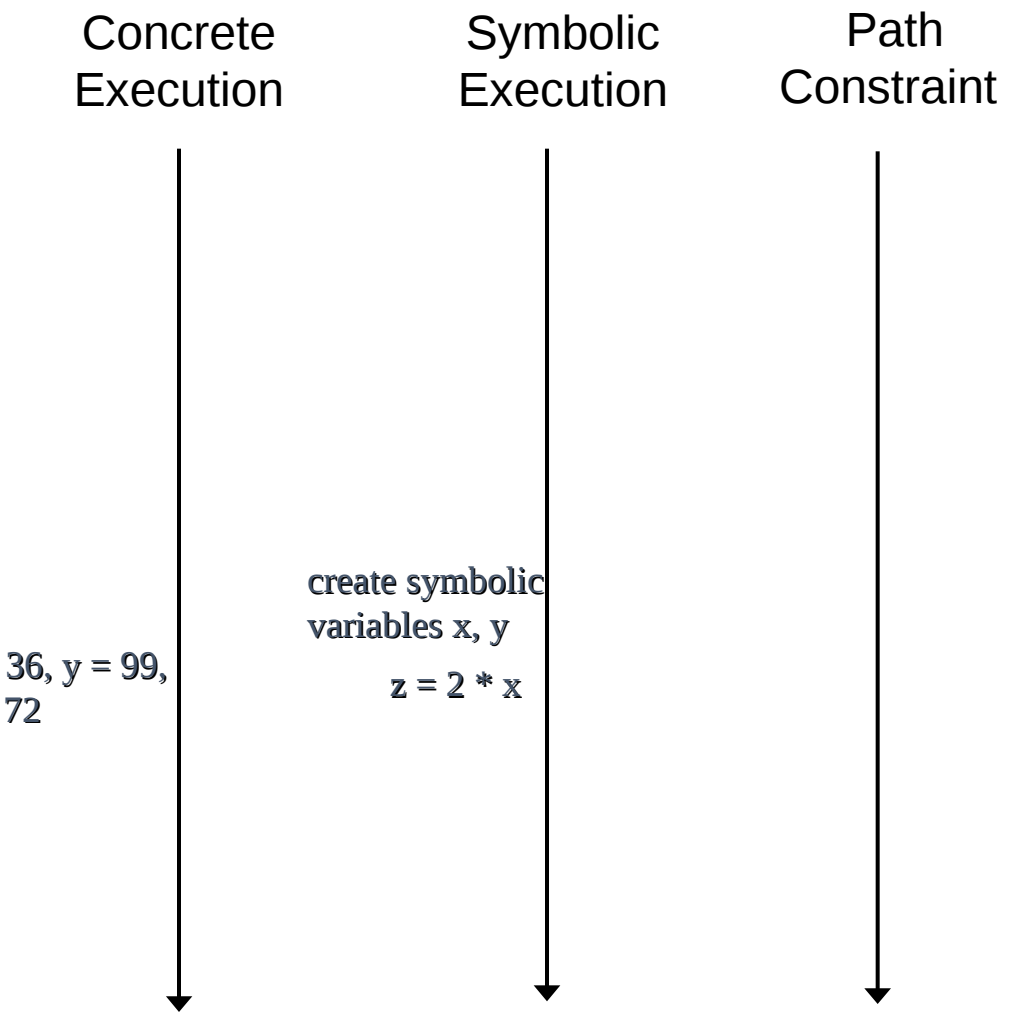

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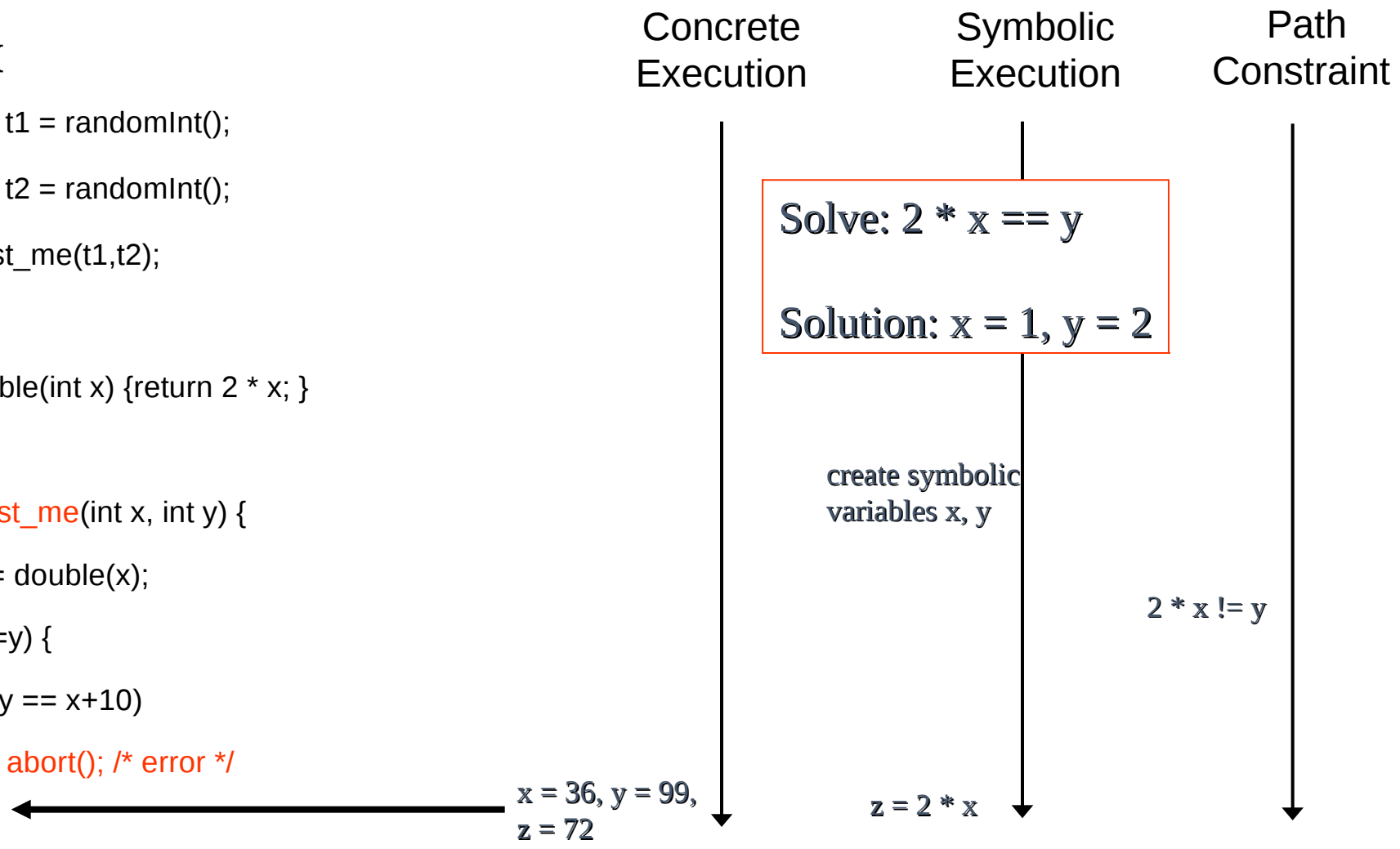

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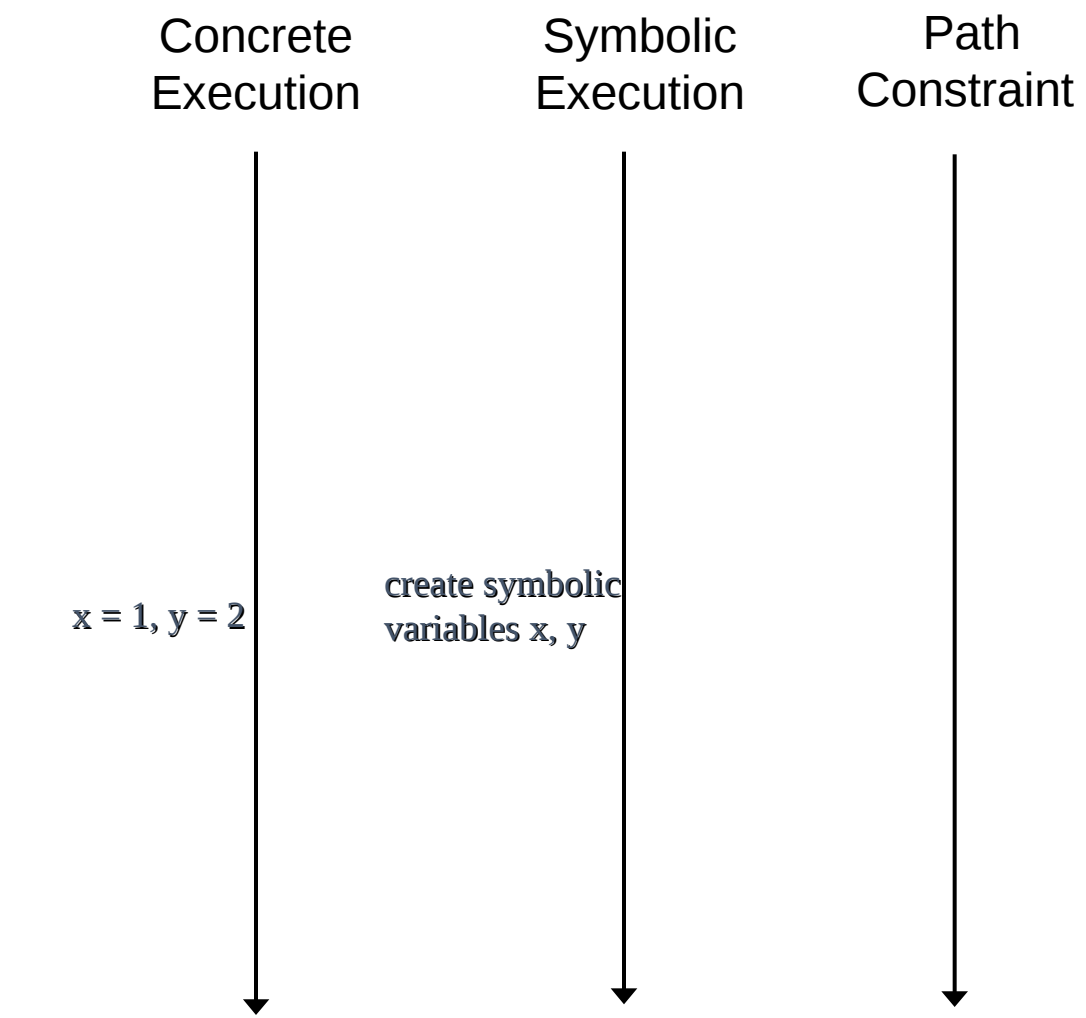

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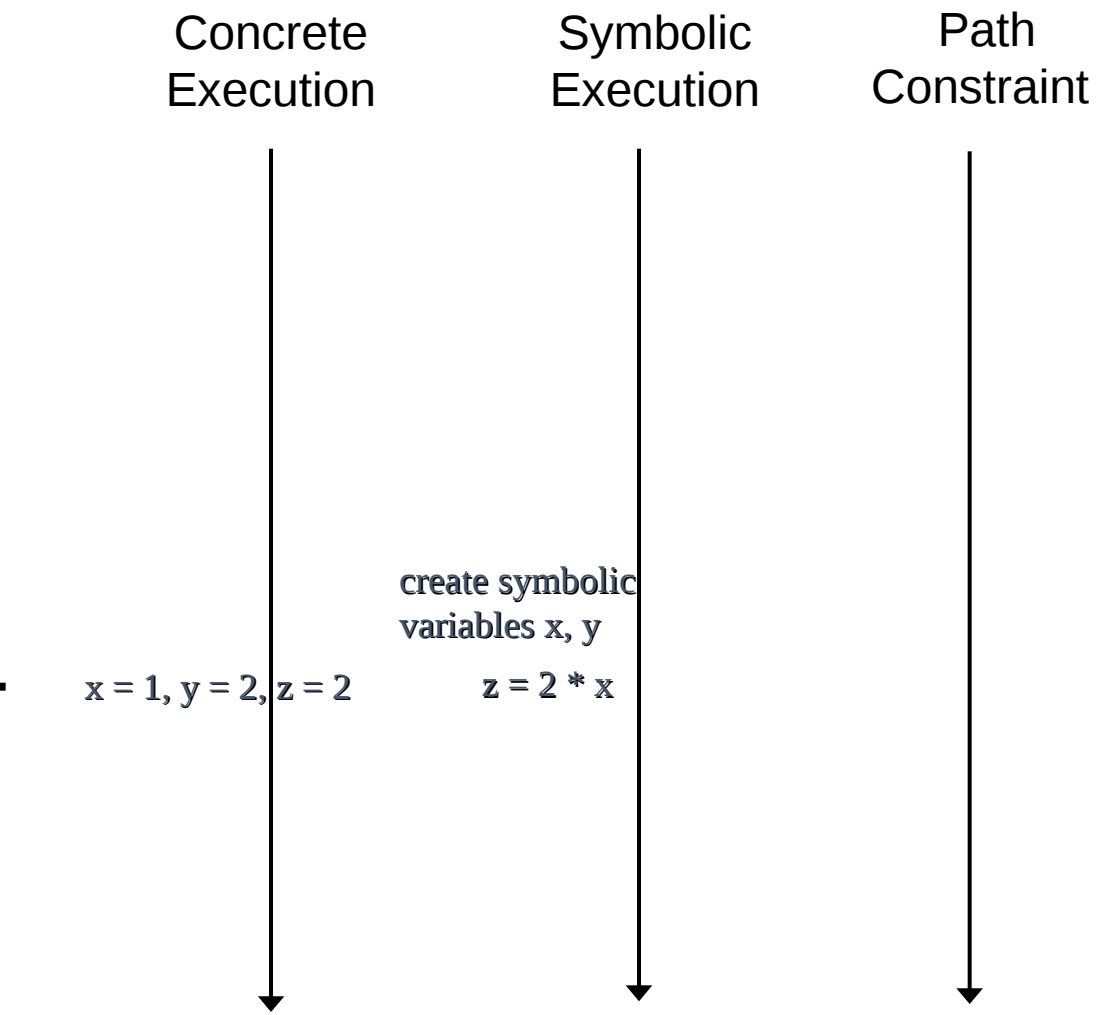

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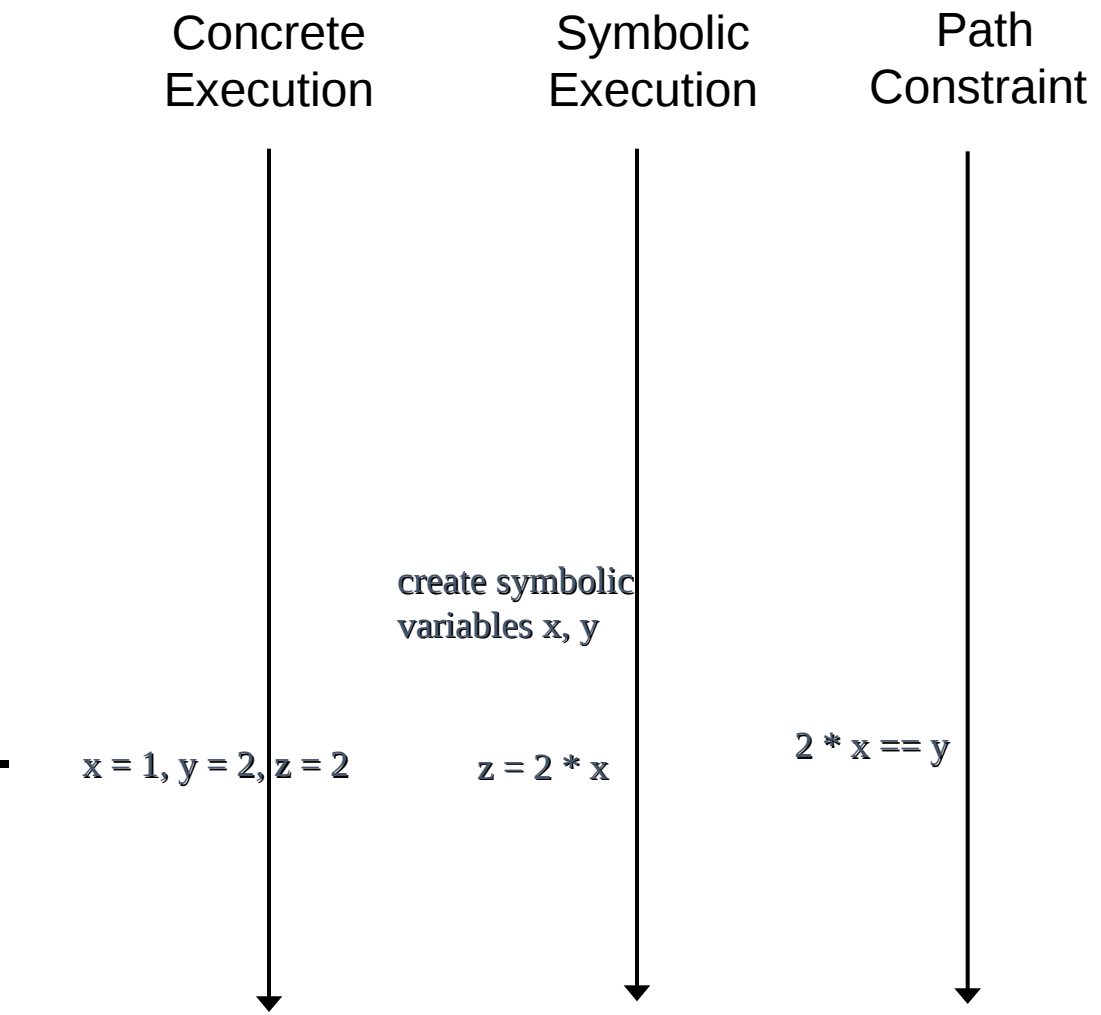

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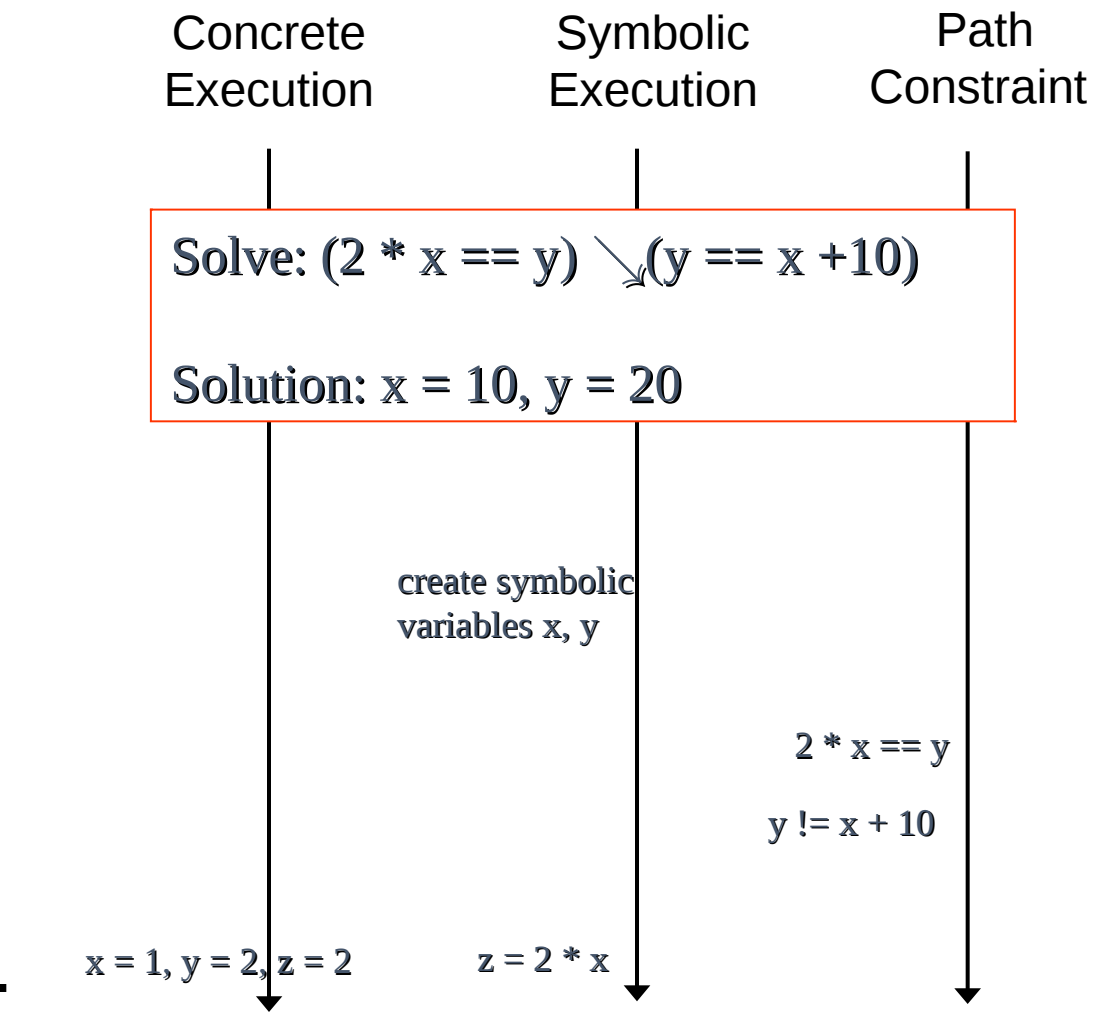

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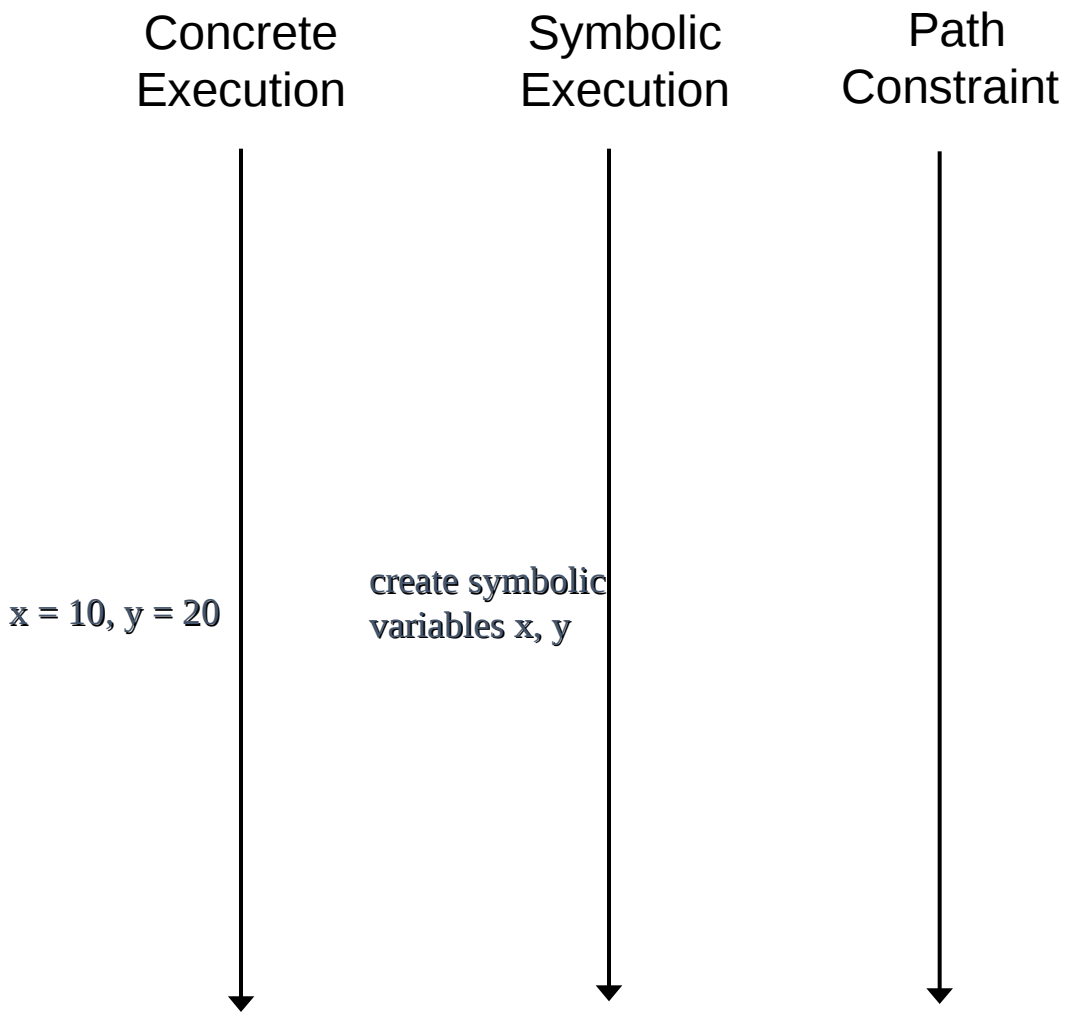

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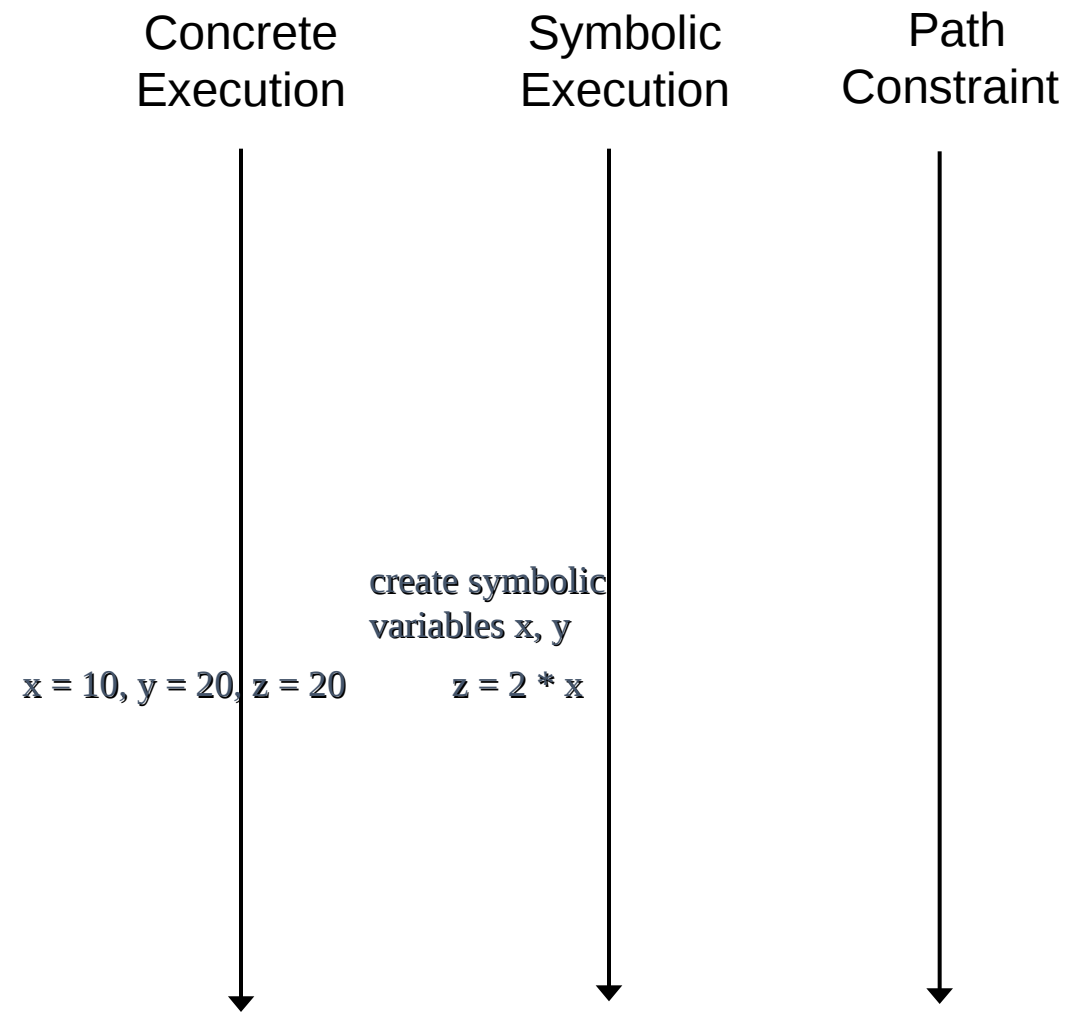

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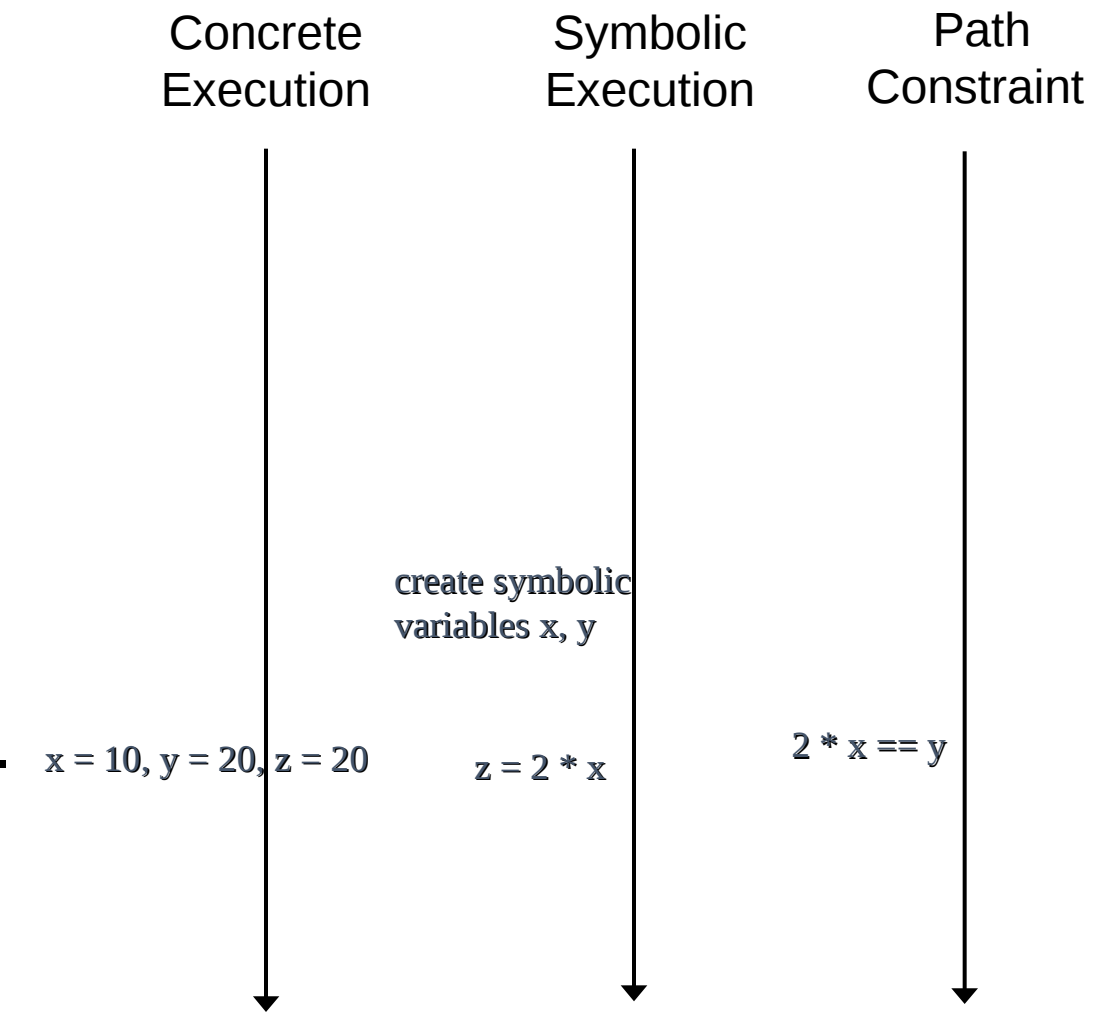

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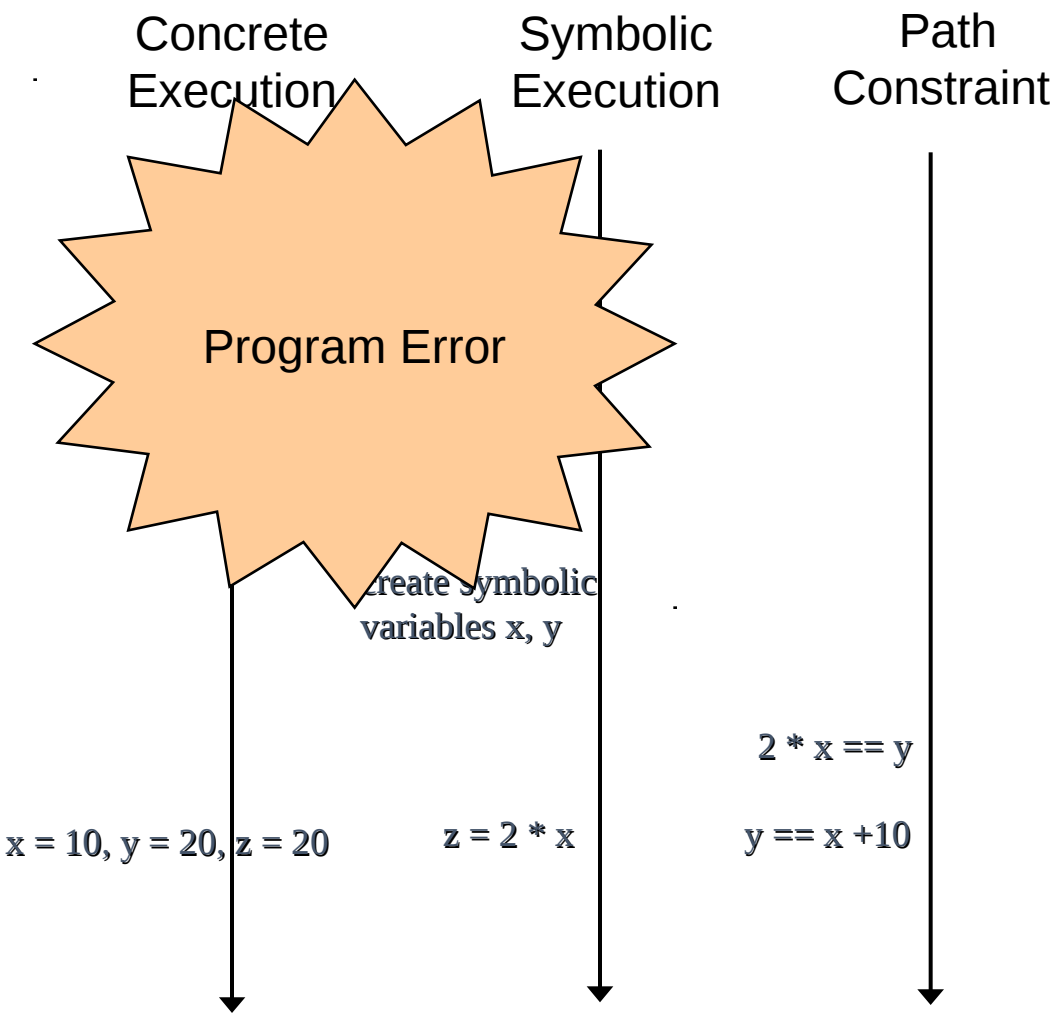

Directed Search: Summary

- Dynamic test generation to direct executions along alternative program paths
  - collect symbolic constraints at branch points (whenever possible)
  - negate one constraint at a branch point to take other branch (say b)
  - call constraint solver with new path constraint to generate new test inputs
  - next execution driven by these new test inputs to take alternative branch b
  - check with dynamic instrumentation that branch b is indeed taken
- Repeat this process until all execution paths are covered
- Significantly improves code coverage vs. pure random testing

Other Advantages of Dynamic Analysis

```
1 struct foo { int i; char c; }
2
3 bar (struct foo *a) {
4     if (a->c == 0) {
5         *((char *)a + sizeof(int)) = 1;
6         if (a->c != 0) {
7             abort();
8         }
9     }
10 }
```

- Dealing with dynamic data is easier with concrete executions
- Due to limitations of alias analysis, static analysis tools cannot determine whether “a->c” has been rewritten
  - “the abort may be reachable”
- In contrast, DART finds the error easily (by solving the linear constraint a->c == 0)

Experiments: NS Authentication Protocol

- Tested a C implementation of a security protocol (Needham-Schroeder) with a known attack
  - About 400 lines of C code; experiments on a Linux 800Mz P-III machine
  - DART takes less than 2 seconds (664 runs) to discover a (partial) attack, with an unconstrained (possibilistic) intruder model
  - DART takes 18 minutes (328,459 runs) to discover a (full) attack, with a realistic (Dolev-Yao) intruder model
  - DART found a new bug in this C implementation of Lowe's fix to the NS protocol (after 22 minutes of search; bug confirmed by the code's author)
- In contrast, a systematic state-space search of this program composed with a concurrent nondeterministic intruder model using VeriSoft (a sw model checker) does not find the attack

A Larger Application: oSIP

- Open Source SIP library (Session Initiation Protocol)
  - 30,000 lines of C code (version 2.0.9), 600 externally visible func
- Results:
  - DART crashed 65% of the externally visible functions within 1000 runs
  - Most of these due to missing(?) NULL-checks for pointers…
  - Analysis of results for oSIP parser revealed a simple attack to cra

Attack: send a packet of size 2.5 MB (cygwin) with no 0 or "|" character

oSIP version 2.0.9 (August 2004)

```
Int osip_message_parse (osip_message_t * sip,
                        const char *buf)
{ [ … ]
  char *tmp;
  tmp = alloca (strlen (buf) + 2);
  osip_strncpy (tmp, buf, strlen (buf));
  osip_util_replace_all_lws (tmp);
```

alloca fails and returns NULL

crash!

oSIP version 2.2.0 (December 2004)

```
Int osip_message_parse (osip_message_t * sip,
                        const char *buf, size_t length)
{ [ … ]
  char *tmp;
  tmp = osip_malloc (length + 2);
  if (tmp==NULL) { [… print error msg and return –1; ]
}
  osip_strncpy (tmp, buf, length);
  osip_util_replace_all_lws (tmp);
```