Automated Testing&Verification

Dynamic Symbolic Execution

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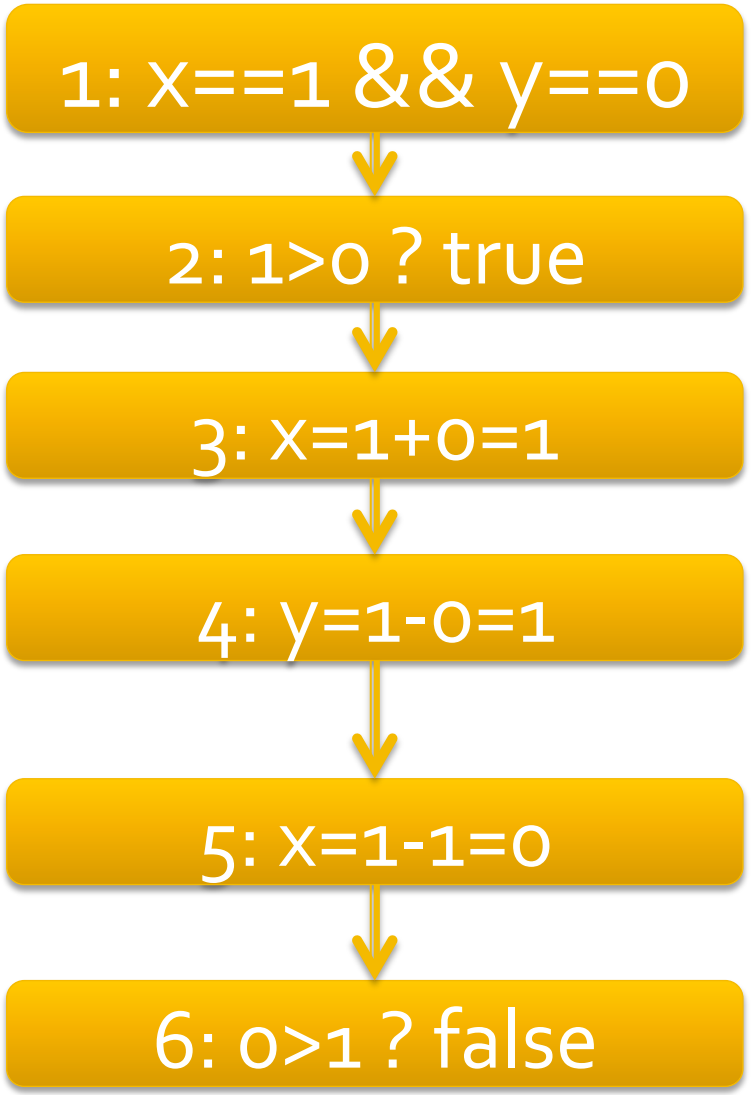
Symbolic Execution

- King [Comm. ACM 1976]
- Analysis of programs with unspecified inputs
  - "Execute" a program on symbolic inputs
- Symbolic states represents sets of concrete states
- For each path, build a path condition
  - Condition on inputs –for the execution to follow that path
  - Check path condition satisfiability – explore only feasible paths

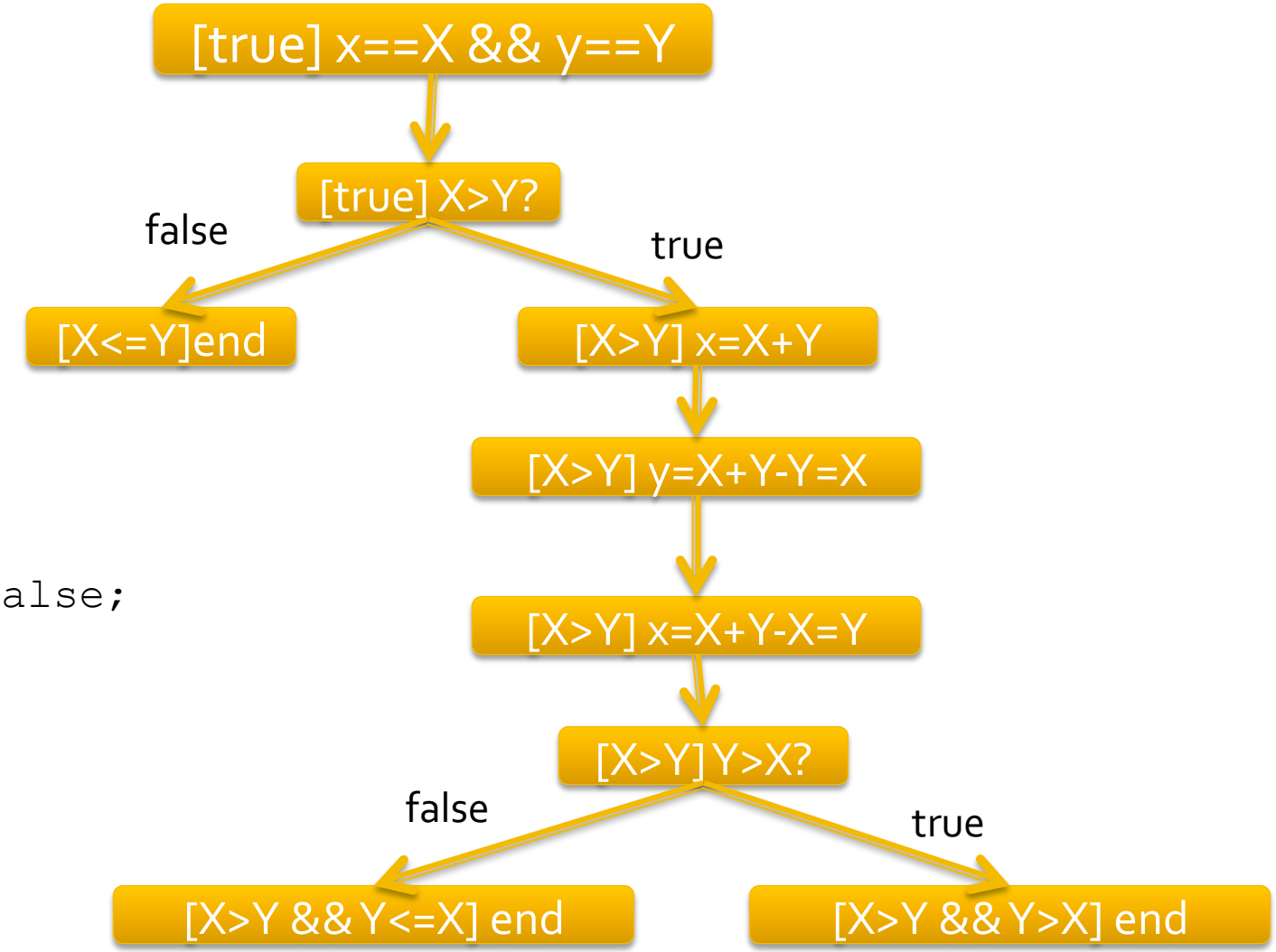
Standard execution

```
1: int x,y;
2: if (x>y) {
3:    x = x+y;
4:    y = x-y;
5:    x=x-y;
6:    if (x>y) {
7:       assert false;
   }
}
```



Symbolic Execution

```
1: int x,y;
2: if (x>y) {
3:    x = x+y;
4:    y = x-y;
5:    x=x-y;
6:    if (x>y) {
7:      assert false;
  }
8: return;
}
```



Symbolic Execution

- Use a off-the-shelf constraint solver to solve path conditions
  - SMT-Solver / SAT-Solver
- Solutions are inputs to force that trasversal
- Path constraints:
  - Solve(X<=Y) → x==-1 && y==54
  - Solve(X>Y && Y<=X) → x==10 && y==5
  - Solve(X>Y && Y>X) → UNSAT

Symbolic Execution Limitations

- Too many path conditions
  - Exploring a very small set of executions

```
test_me(int x,int y) {
  if ((x%y)*4!=17)) {
      ERROR
  } else {
      ERROR
  }
}
```

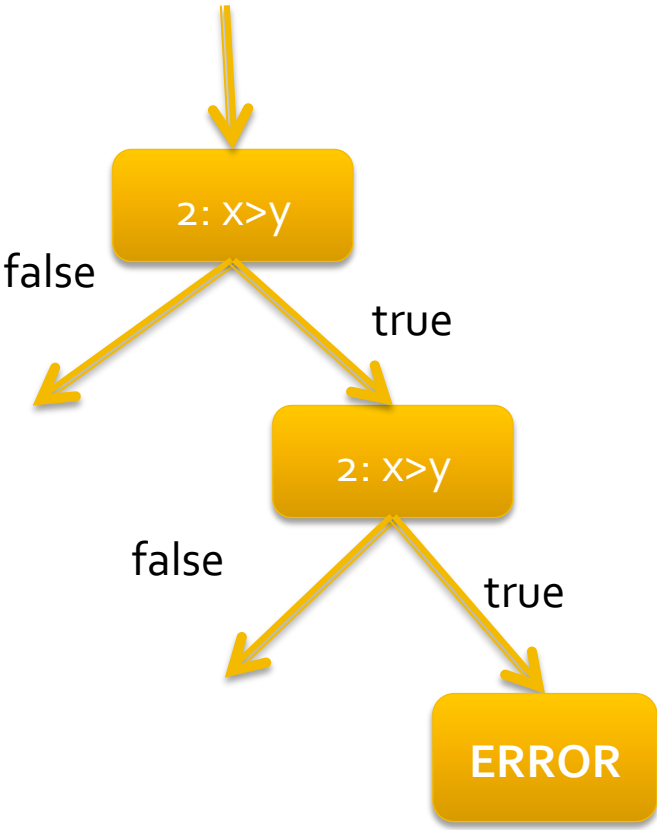
Constraint solver capabilities

```
test_me(int x, int y) {
  if (bbox(x,y)=17)) {
      ERROR
  } else {
      ERROR
  }
}
```

Native code (no access to source code/ environment)

Executions Paths of a Program

- Can be seen as a binary tree with possibly infinity depth
  - Computation tree
- Each **node** represents the execution of a "if then else"
- Each **edge** represents the execution of a sequence of non-conditional statements
- Each **path** in the tree represents an equivalence class of inputs



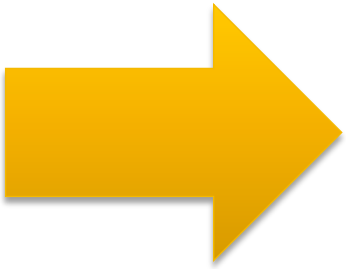
Computation tree

- How many feasible execution paths do you have in this program?

```
void testme1(int x) {
1:   for (int j=0; j<2; j++) {
2:     if (x==j) {
3:       printf("Good\n");
       }
     }
   }
```

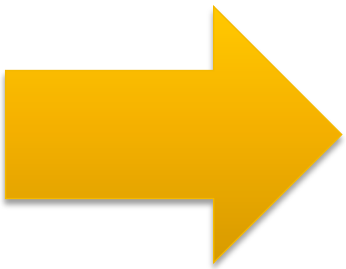
Add assertions as new branches

- Divide by zero
  - x = 3 /i;



```
if (i!=0) {
  x=3/i;
} else {
  ERROR
}
```

- Buffer overflow
  - a[i]=4;



```
if (i>=0 && i<a.length)
{
  a[i]=4;
} else {
  ERROR
}
```

Random testing

- Generate random inputs
- Execute the program on generated inputs
- Probability of reaching an error can be astronomically lesser.

```
1: testme(int x) {
2:   if (x==94389) {
3:     assert false;
     }
   }
```

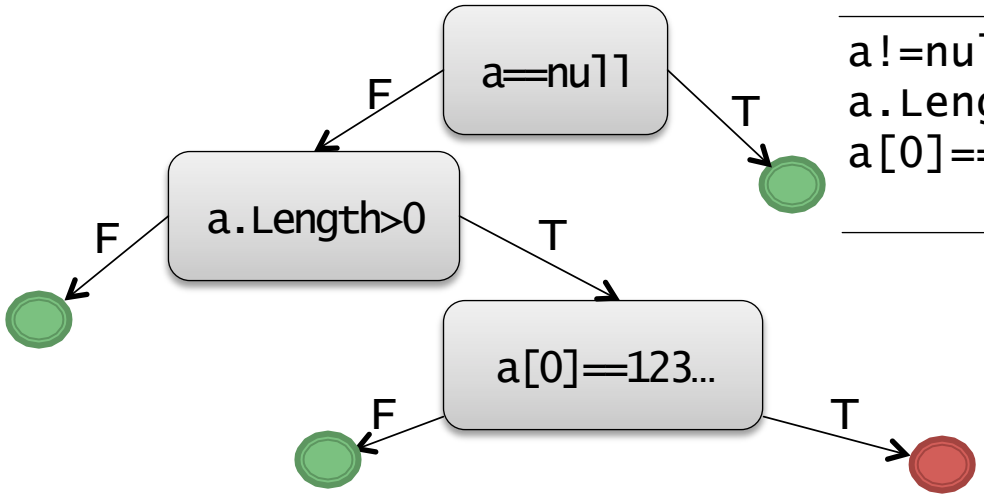
1/ (2^32)

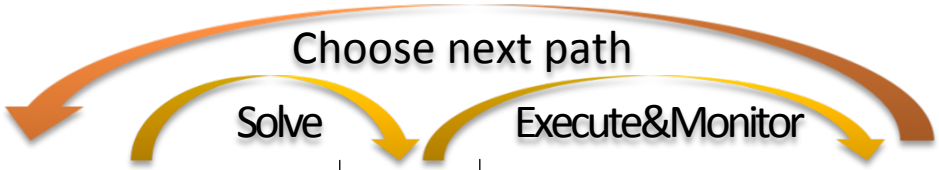
(very low)

Dynamic Symbolic Execution

Code to generate inputs for:

```
void CoverMe(int[] a)
{
  if (a == null) return;
  if (a.Length > 0)
    if (a[0] == 1234567890)
      throw new Exception("bug");
}
```





Constraints to solve	Data	Observed constraints
	null	a==null
a!=null	{}	a!=null && !(a.Length>0)
a!=null & a.Length>		& 90
a!=null && a.Length>0 && a[0]==1234567890	{123..}	a!=null && a.Length>0 && a[0]==1234567890

Negated condition

Done: There is no path left.

Dynamic Symbolic Execution

- Efficiently traverse all execution paths one by one to detect errors
  - Assertion violations
  - Program crash
  - Uncaught exceptions
- In the path build a test suite
  - Branch coverage

Dynamic Symbolic Execution

```
1: void testme(x,y){
2:   z=foo(y);
3:   if (z==x) {
4:     if (x>y+10) {
5:       ERROR
6:     }
7:   }
8:   return;
9: }
```

Initial data:
x==15 && y==-541

Path constraint:
foo(Y)!=X

Don't know how to solve foo(Y)==X! Stuck?

Dynamic Symbolic Execution

```
1: void testme(x,y){
2:    z=foo(y);
3:    if (z==x) {
4:      if (x>y+10) {
5:        ERROR
6:      }
7:    }
8:    return;
9: }
```

Initial data:

x==15 && y==-541 && foo(-541)==85

Path constraint:

85!=X

Solve(85==X) → X==85 && Y==-541

DSE

- We can use concrete values in the constraint system instead of symbolic representation
  - Sound
  - Incomplete (we stop trying to reason about some part of the code)

Tools! Tools!

- CUTE (C), jCUTE (Java), CREST (C)
- PEX
  - Visual Studio 2010 Power Tool
  - http://pexforfun.com
- SAGE
  - X86 assembly
  - Targets security problems
  - 24x7 use (million-dollar bugs)
- EXE and KLEE

Challenges

- Scalability
  - Key challenge!
  - Path Space of a Large program is Huge
- Complex Non-Linear constraint
  - Floating point numbers
- Testing web apps and security problems
  - String constraints
  - Mixed numeric and string constraints

Dynamic Symbolic Execution

- Dynamic Technique
  - In contrast symbolic execution is static
- More coverage: Guide exploration using collected path conditions
- Whenever you can't reason about something, use a collected concrete value