Model Counting with Applications to CodeHunt

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CodeHunt is built on

SAT or UNSAT?
And
Some solutions

Model Counting

SAT solutions?

Can we use this
for a Progress Bar?

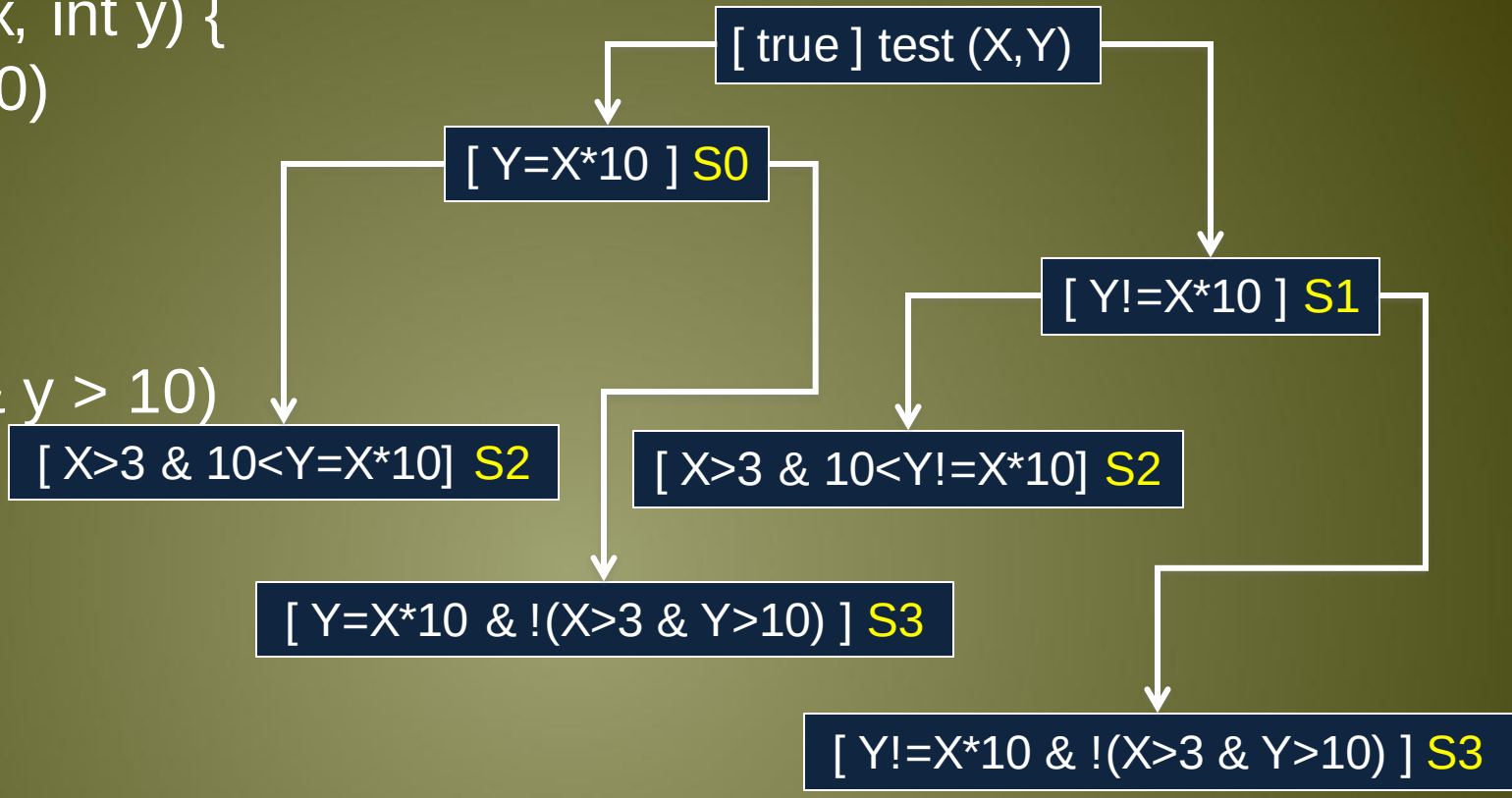
In a perfect world…

only linear integer constraints

and only uniform distributions

Symbolic Execution

```
void test(int x, int y) {
  if (y == x*10)
    S0;
  else
    S1;
  if (x > 3 && y > 10)
    S2;
  else
    S3;
}
```



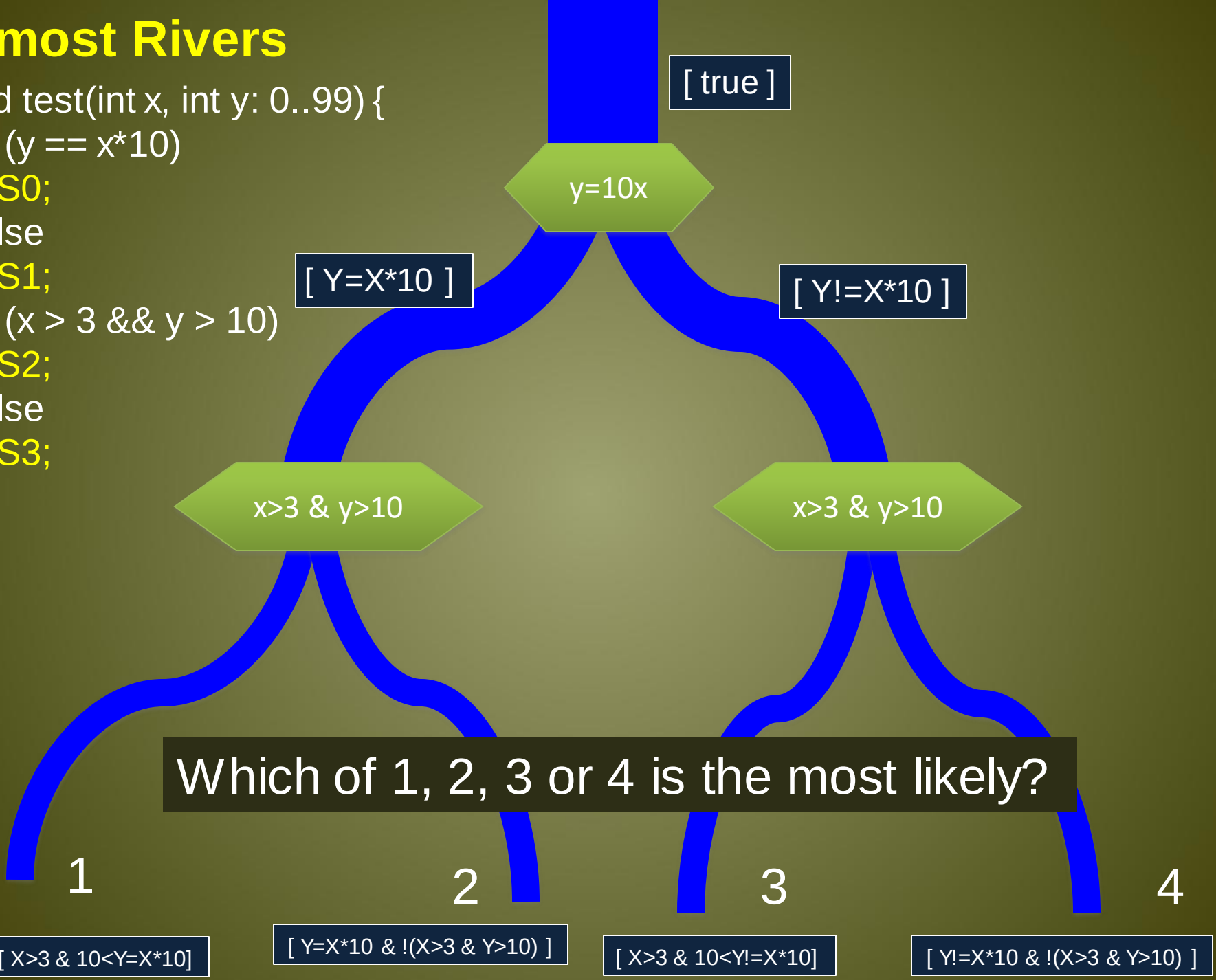
Test(1,10) reaches S0,S3
Test(0,1) reaches S1,S3
Test(4,11) reaches S1,S2

Photograph by Annie Griffiths Belt

NATIONAL GEOGRAPHIC

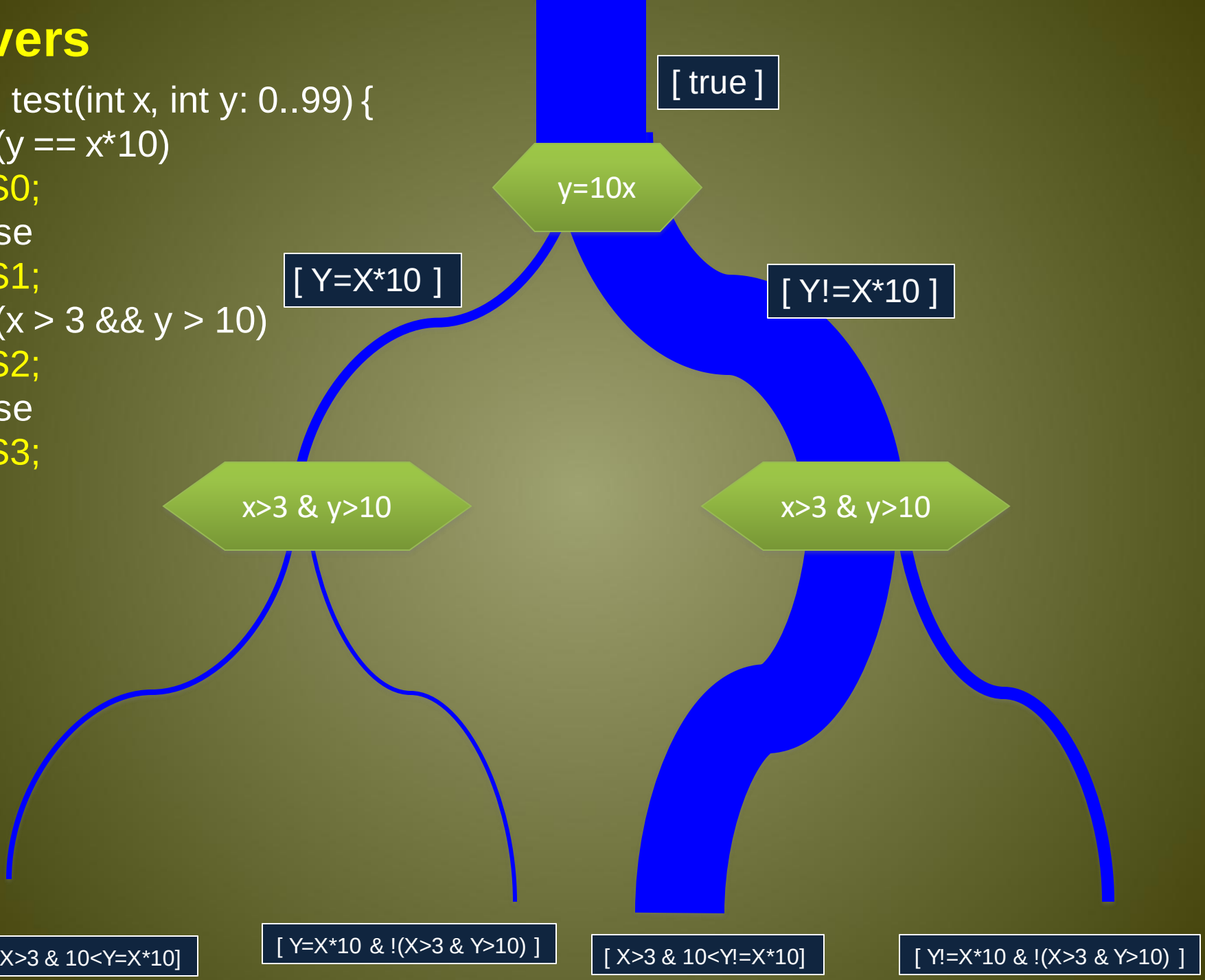
Almost Rivers

```
void test(int x, int y: 0..99) {
   if (y == x*10)
     S0;
   else
     S1;
   if (x > 3 && y > 10)
     S2;
   else
     S3;
}
```



Rivers

```
void test(int x, int y: 0..99) {
   if (y == x*10)
     S0;
   else
     S1;
   if (x > 3 && y > 10)
     S2;
   else
     S3;
}
```



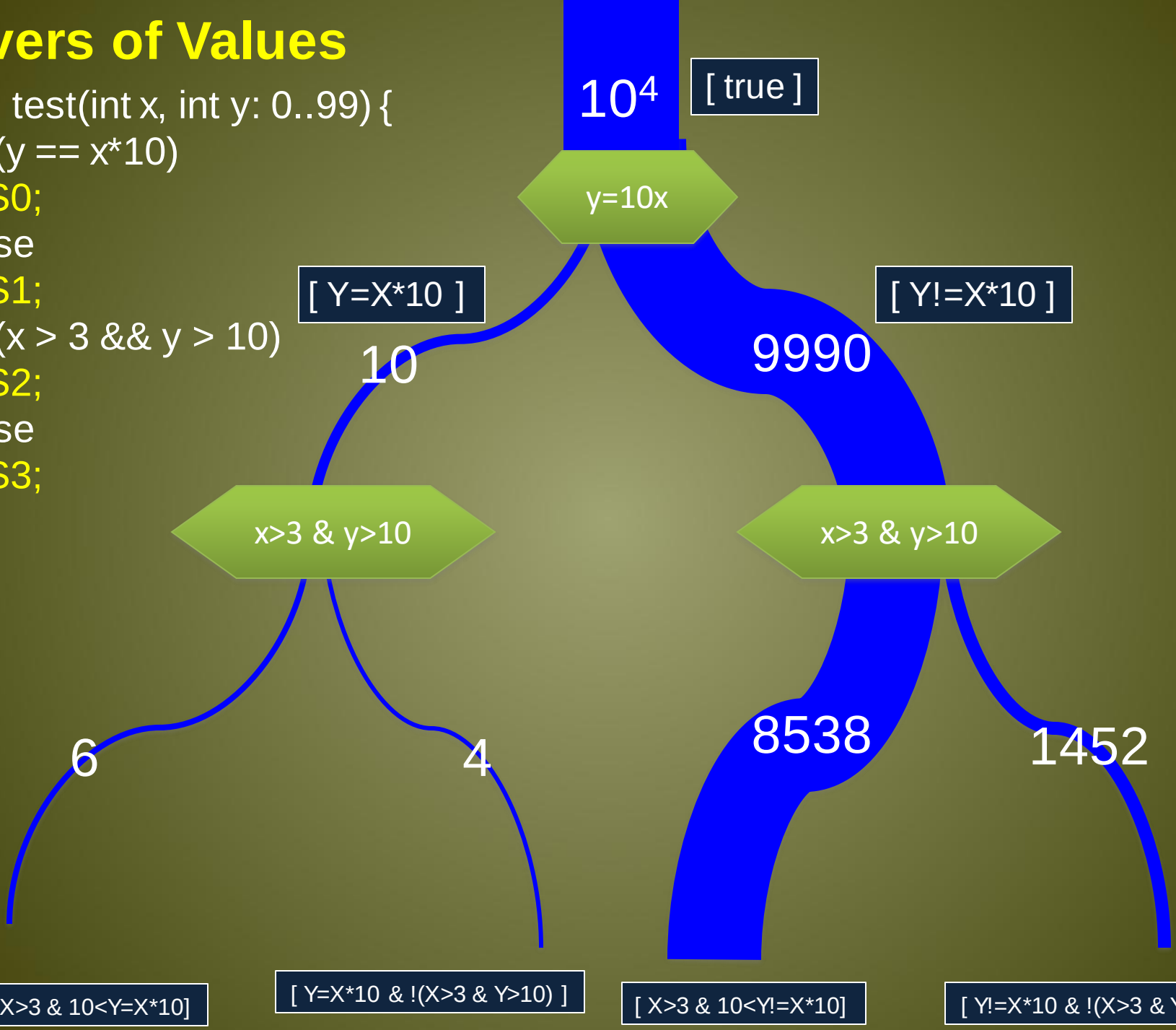
LattE Model Counter

http://www.math.ucdavis.edu/~latte/

Count solutions for
conjunction
of Linear Inequalities

Rivers of Values

```
void test(int x, int y: 0..99) {
   if (y == x*10)
     S0;
   else
     S1;
   if (x > 3 && y > 10)
     S2;
   else
     S3;
}
```



Program Understanding

10^4 [true]

y=10x

10 [Y=X*10]

9990 [Y!=X*10]

x>3 & y>10

x>3 & y>10

6

4

8538

1452

[X>3 & 10<Y=X*10]

[Y=X*10 & !(X>3 & Y>10)]

[X>3 & 10<Y!=X*10]

[Y!=X*10 & !(X>3 & Y>10)]

Probabilities

1

y=10x

0.001

0.999

x>3 & y>10

x>3 & y>10

0.6

0.4

0.855

0.145

0.0006

0.0004

0.8538

0.1452

[X>3 & 10<Y=X*10]

[Y=X*10 & !(X>3 & Y>10)]

[X>3 & 10<Y!=X*10]

[Y!=X*10 & !(X>3 & Y>10)]

Reliability

1

y=10x

0.001

0.999

x>3 & y>10

x>3 & y>10

0.9996 Reliable

0.6

0.4

0.855

0.145

0.0006

0.0004

0.8538

0.1452

[X>3 & 10<Y=X*10]

[Y=X*10 & !(X>3 & Y>10)]

[X>3 & 10<Y!=X*10]

[Y!=X*10 & !(X>3 & Y>10)]

Can you add a progress bar?

How wrong is the program?

Which correct program is *better*?

Triangle Classification

- 2 Correct versions
- 2 Buggy versions
  - One created ourselves accidentally
    - Small typo >= instead of <=
  - One from a student coding exercise
    - Missed one condition

```
public static int classify(int i, int j, int k) {
   if ((i <= 0) || (j <= 0) || (k <= 0))
       return 4;
   int type = 0;
   if (i == j) type = type + 1;
   if (i == k) type = type + 2;
   if (j == k) type = type + 3;
   if (type == 0) {
// Confirm it is a legal triangle before declaring it to be scalene.
      if ((i + j <= k) || (j + k <= i) || (i + k <= j))  type = 4;
      else type = 1;
      return type;
   }
// Confirm it is a legal triangle before declaring it to be isosceles or
// equilateral.
   if (type > 3) type = 3;
   else if ((type == 1) && (i + j > k))  type = 2;
   else if ((type == 2) && (i + k > j))  type = 2;
   else if ((type == 3) && (j + k > i))  type = 2;
   else type = 4;
   return type;
}
```

Correct1

```
public static int classify(int i, int j, int k) {
   if ((i <= 0) || (j <= 0) || (k <= 0))
      return 4;
   int type = 0;
   if (i == j) type = type + 1;
   if (i == k) type = type + 2;
   if (j == k) type = type + 3;
   if (type == 0) {
// Confirm it is a legal triangle before declaring it to be scalene.
      if ((i + j <= k) || (j + k <= i) || (i + k >= j))  type = 4;
      else type = 1;
      return type;
   }
// Confirm it is a legal triangle before declaring it to be isosceles or
// equilateral.
   if (type > 3) type = 3;
   else if ((type == 1) && (i + j > k))  type = 2;
   else if ((type == 2) && (i + k > j))  type = 2;
   else if ((type == 3) && (j + k > i))  type = 2;
   else type = 4;
   return type;
}
```

Buggy1

Correct2

```
public static int classify(int a, int b, int c) {
        if (a <= 0 || b <= 0 || c <= 0)
            return 4;
        if (! (a > c - b && a > b - c && b > a - c))
            return 4;
        if (a == b && b == c)
            return 3;
        if (a == b || b == c || a == c)
            return 2;
        return 1;
}
```

Buggy2

```
public static int classify(int a, int b, int c) {
        if ((a <= 0) || (b <= 0) || (c <= 0))
            return 4;
        if ((a <= c - b) || (a<= b - c) || (b<= a - c))
            return 4;
        if (a == b && b == c)
            return 3;
        if (((a == b) && (b != c)) ||
            ((a == c) && (a != b) && ((b == c) && (b != a))))
            return 2;
        return 1;
    }
```

Which of Correct1 or Correct2 is “better”?

```
public static int classify(int i, int j, int k) {
   if ((i <= 0) || (j <= 0) || (k <= 0))
       return 4;
   int type = 0;
   if (i == j) type = type + 1;
   if (i == k) type = type + 2;
   if (j == k) type = type + 3;
   if (type == 0) {
      if ((i + j <= k) || (j + k <= i) || (i + k <= j))
         type = 4;
      else type = 1;
      return type;
   }
   if (type > 3) type = 3;
   else if ((type == 1) && (i + j > k))  type = 2;
   else if ((type == 2) && (i + k > j))  type = 2;
   else if ((type == 3) && (j + k > i))  type = 2;
   else type = 4;
   return type;
}
```

```
public static int classify(int a, int b, int c) {
    if (a <= 0 || b <= 0 || c <= 0)
       return 4;
    if (! (a > c - b && a > b - c && b > a - c))
       return 4;
    if (a == b && b == c)
       return 3;
    if (a == b || b == c || a == c)
       return 2;
    return 1;
}
```

Correct1 All Partitions with sizes

463344	(k+i>j)&&((k+j)>i)&&(j+i)>k)&&(j!=k)&&(i!=k)&&(i!=j)&&(k>0)&&(j>0)&&(i>0)
159250	(k+i<=j)&&(k+j>i)&&(j+i>k)&&(j!=k)&&(i!=k)&&(i!=j)&&(k>0)&&(j>0)&&(i>0)
159250	(k+j<=i)&&(j+i>k)&&(j!=k)&&(i!=k)&&(i!=j)&&(k>0)&&(j>0)&&(i>0)
159250	(j+i<=k)&&(j!=k)&&(i!=k)&&(i!=j)&&(k>0)&&(j>0)&&(i>0)
10000	(i<=0)
9900	(j<=0)&&(i>0)
9801	(k<=0)&&(j>0)&&(i>0)
7252	(k+j>i)&&(j==k))&&(i!=k)&&(i!=j)&&(k>0)&&(j>0)&&(i>0)
7252	(j+i>k)&&(i!=k)&&(i==j)&&(k>0)&&(j>0)&&(i>0)
7252	(k+i>j)&&(i==k)&&(i!=j)&&(k>0)&&(j>0)&&(i>0)
2450	(k+j<=i)&&(j==k)&&(i!=k)&&(i!=j)&&(k>0)&&(j>0))&&(i>0)
2450	(j+i<=k)&&(i!=k))&&(i==j)&&(k>0)&&(j>0)&&(i>0)
2450	(k+i<=j)&&(i==k)&&(i!=j)&&(k>0)&&(j>0)&&(i>0)
99	(i==k)&&(i==j)&&(k>0)&&(j>0)&&(i>0)

Correct2 All Partitions with sizes

463344	(a!=c)&&(b!=c)&&a!=b&&b>a-c&&(a>(b-c)&&(a>(c-b)&&(c>0)&&(b>0)&&(a>0)
161700	b<=(a-c))&&(a>(b-c)))&&(a>(c-b)))&&(c>0))&&(b>0))&&(a>0)
161700	(a<=(b-c))&&(a>(c-b)))&&(c>0))&&(b>0))&&(a>0)
161700	(((a<=(c-b))&&(c>0))&&(b>0))&&(a>0)
10000	(a<=0)
9900	(b<=0)&&(a>0)
9801	(c<=0)&&(b>0)&&(a>0)
7252	a==c&&(b!=c)&&(a!=b))&&b>a-c&&a>b-c&&a>c-b&&c>0&&b>0&&(a>0)
7252	b!=c&&a==b&&(b>(a-c)))&&(a>(b-c)))&&(a>(c-b)))&&(c>0))&&(b>0))&&(a>0)
7252	b==c&&a!=b&&(b>(a-c)))&&(a>(b-c)))&&(a>(c-b)))&&(c>0))&&(b>0))&&(a>0)
99	(i==k)&&(i==j)&&(k>0)&&(j>0)&&(i>0)

Correct2 is “better”

it has less paths dealing with the Illegal Triangle case

Test harness

```
public static void check(int a, int b, int c) {
        int test = classifyBuggy1(a, b, c);
        int oracle = classifyCorrect1(a, b, c);
        assert (test == oracle);
}
```

Record path conditions
when assertion fails and
count their sizes

Counting size of failing partitions

Correct vs Buggy1

2 failing paths: 463344 and 154448

Correct vs Buggy2

2 failing paths: 7252 and 7252

Buggy2 is closer than Buggy1

Observation

- Buggy1 is closer in edit distance to a correct version
  - One might intuitively think it is thus “closer” to correct
  - Clearly this is not the case, and, which syntactically correct version should one consider?
  - However, might it be an issue for a progress bar?

Side track

- Mutations in programs can have bigger effect than one might think
- Notice how a small <= to >= change made the program incorrect on more inputs than a logical mistake
- Can we rank mutation operators according to how much of the behavior of a program they mutate?

Mutation Example

```
boolean classify1(int i, int j : 0..99) {
   return i <= j;
}
```

1 99% wrong

```
boolean classify1(int i, int j) {
   return i >= j;
}
```

2 1% wrong

```
boolean classify1(int i, int j) {
   return i < j;
}
```

3 49.5% wrong

```
boolean classify1(int i, int j) {
   return i == j;
}
```

4 49.5% wrong

```
boolean classify1(int i, int j) {
   return true;
}
```

Lets try it…

10

```
int Correct(int x : 0..9)
   return x*2;
```

Cut and paste

```
int A(int x)
   if (x == 2) return 4;
   if (x == 6) return 12;
   return 0;
```

7

saw the comment…

```
int A(int x)
   if (x == 1) return 2;
   if (x == 2) return 4;
   if (x == 6) return 12;
   return x+3;
```

6

and one more…

```
int A(int x)
   if (x == 1) return 2;
   if (x == 2) return 4;
   if (x == 6) return 12;
   return 0;
```

6

And Again…

```
Int B(int x, int y)
   if (x == 0 && y == 0) return 0;
   if (x == 0 && y == 1) return 1;
   if (x == 1 && y == 0) return 1;
   return 0;
```

9997

```
Int B(int x, int y)
   if (x == 0 && y == 0) return 0;
   if (x == 0 && y == 1) return 1;
   if (x == 1 && y == 0) return 1;
   if (x == 0 && y == 33) return 33;
   if (x == 33 && y == 0) return 33;
   return 0;
```

9995

And Again...

10000

```
int Correct(int x,y : 0..99)
    return x+y;
```

```
Int B(int x, int y)
   if (x == 0 && y == 0) return 0;
   if (x == 0 && y == 1) return 1;
   if (x == 1 && y == 0) return 1;
   if (x == 0 && y == 33) return 33;
   if (x == 33 && y == 0) return 33;
   return x-y;
```

9898

```
Int B(int x, int y)
   return x-y;
```

9900

Oh no, backwards!

```
Int B(int x, int y)
   if (x >= y)
      return x – y;
   return y - x;
```

9801

Time passed and he played CodeHunt…

To get to the interesting examples!

Last one...

```
Bool Correct(int x : 0..199)
    return (x>=50) ? false : true;
```

49

```
Bool C(int x) {
   if (x == 0) return true;
   return false;
```

46

```
Bool C(int x) {
   if (x == 0) return true;
   if (x == 4) return true;
   if (x == 32) return true;
   if (x == 36) return true;
   return false;
```

46

```
Bool C(int x) {
   if (x == 0) return true;
   if (x == 4) return true;
   if (x == 32) return true;
   if (x == 36) return true;
   if (x >= 64) return false;
   return false;
```

14

```
Bool C(int x) {
   if (x >= 64) return false;
   else return true;
```

Conclusions

- The bounds are important
  - Even in CodeHunt now you can expose the bounds PEX is using
  - For model counting the bounds must be exposed
- Should we give raw scores or descriptions
  - Way Off, A little better, Now you are getting there,…
- Can we actually do Model Counting for all the required domains?
  - Strings are new to the model counting game

The Green Framework

http://green-solver.googlecode.com

Already integrated into
Symbolic PathFinder

Resources

- ISSTA 2012
  - Probabilistic Symbolic Execution
- FSE 2012
  - Green: Reduce, Reuse and Recycle Constraints…
- ICSE 2013
  - Software Reliability with Symbolic PathFinder
- PLDI 2014
  - Compositional Solution Space Quantification for Probabilistic Software Analysis
- FSE 2014
  - Statistical Symbolic Execution with Informed Sampling
- ASE 2014
  - Exact and Approximate Probabilistic Symbolic Execution for Nondeterministic Programs
- Implemented in Symbolic PathFinder
  - Using LattE