CSE403 ● Software engineering ● sp12

Week 6				
Monday	Tuesday	Wednesday	Thursday	Friday
• Testing III • Reading due	• Group meetings	• Testing IV	• Section • ZFR due	• ZFR demos • Progress report due • Readings out

- Concolic testing – combine symb**olic** and **conc**rete testing
- Back to the basics of testing

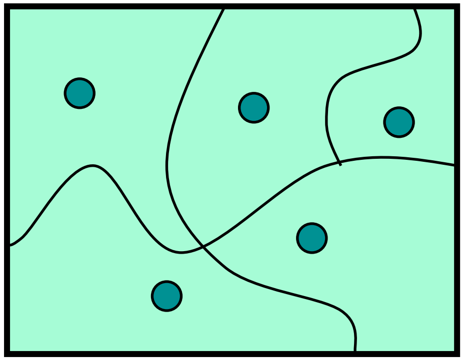
Concolic

- Symbolic execution (or evaluation or testing) counts on a constraint solver (a kind of automated theorem prover) to solver for path conditions that will exercise specific branches in the CFG – we saw this last lecture, and we'll see it again today
- The technology for constraint solvers is impressive, but there are still some constraints that cannot be automatically solved
- Concolic approaches combine concrete and symbolic execution to increase code coverage and, ideally, find bugs that would be otherwise hard to find
- KLEE, Cute, DART, etc. are examples of tools supporting concolic testing

To another's slide deck for examples

- From Pınar Sağlam – elided to examples
- Two examples, swapped in our slide deck
  - The (now) second example (starting at slide 12) is really only symbolic execution, but shows how it works on data structures with some complexity

Back to partitioning



- Ideal test suite
  - Identify sets with same behavior
  - Try one input from each set
- Two problems
  1. Notion of the same behavior is subtle
     Naive approach: execution equivalence
     Better approach: revealing subdomains
  2. Discovering the sets requires perfect knowledge
     - Use heuristics to approximate cheaply

Naive Approach: Execution Equivalence

```
// returns:  x < 0     => returns -x
//           otherwise => returns x
int abs(int x) {
   if (x < 0) return -x;
   else       return x;
}
```

- All **`x<0`** are execution equivalent – that is, the program takes same sequence of steps for any **`x<0`**
- All **`x`** ≥ **`0`** are also execution equivalent
- Suggests that **`{-3,3}`**, for example, is a good test suite

Execution Equivalence Doesn't Work

```
// returns:  x < 0      => returns -x
//           otherwise => returns x
int abs(int x) {
  if (x < -2) return -x;
  else        return x;
}
```

- So, what's the problem?
- There are two execution paths, but combined with the specification there are three separate behaviors
  - `x < -2`
  - `x = -2 v x = -1`
  - `x ≥ 0`
- {-3, 3} does not reveal the error behaviors!

Heuristic: Revealing Subdomains

- A subdomain is a subset of possible inputs
- A subdomain is *revealing* for error E if either
  - Every input in that subdomain triggers error E, or
  - No input in that subdomain triggers error E
- Need test only one input from a given subdomain
  - If subdomains cover the entire input space, then we are guaranteed to detect the error if it is present
- The trick is to guess these revealing subdomains

Ex: buggy `abs`, revealing subdomains?

```
int abs(int x) {
  if (x < -2) return -x;
  else        return x;
}
```

- Possible subdomains
  - `{-1}`
  - `{-2}`
  - `{-2,-1}`
  - `{-3,-2,-1}`
- Which of these is not a revealing subdomain for this bug?
- Which of these is the best revealing subdomain for this bug?

Heuristics for Designing Test Suites

- A good heuristic gives
  - few subdomains
  - $\forall$ errors E in some class of errors,
  - high probability that some subdomain is revealing for E
- Different heuristics target different classes of errors
  - In practice, combine multiple heuristics

Black Box Testing

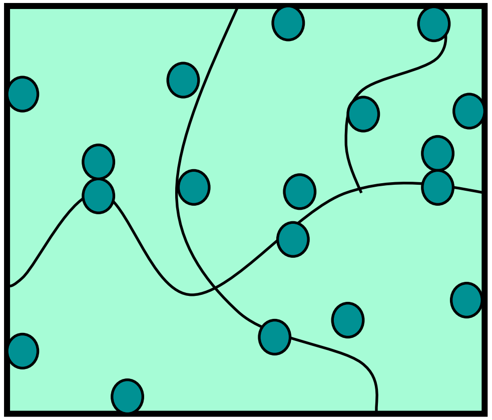
- Heuristic: Explore alternate specification paths
  - Procedure is a black box: interface visible, internals hidden
- Example
  -
```
int max(int a, int b)
// effects:  a > b => returns a
//           a < b => returns b
//           a = b => returns a
```
- Three paths, so three test cases
  - (4, 3) => 4 (i.e. any input in the subdomain a > b)
  - (3, 4) => 4 (i.e. any input in the subdomain a < b)
  - (3, 3) => 3 (i.e. any input in the subdomain a = b)

More Complex Example

```
int find(int[] a, int value) throws Missing
// returns: the smallest i such
//          that a[i] == value
// throws:  Missing if value is not in a
```

- Two obvious tests:
  ([4, 5, 6], 5) => 1
  ([4, 5, 6], 7) => throw Missing
- Must hunt for multiple cases in the specification
  ([4, 5, 5], 5) => 1

Heuristic: Boundary Testing



- Create tests at the edges of subdomains
  - off-by-one bugs
  - forgot to handle empty container
  - overflow errors in arithmetic
  - aliasing
- Small subdomains at the edges of the “main” subdomains have a high probability of revealing these common errors
- Also, you might have misdrawn the boundaries

Boundary Testing

- To define the boundary, need a distance metric
  - Define adjacent points
- One approach
  - Identify basic operations on input points
  - Two points are adjacent if one basic operation apart
- Point is on a boundary if either
  - There exists an adjacent point in a different subdomain
  - Some basic operation cannot be applied to the point
- Example: list of integers
  - Basic operations: create, append, remove
  - Adjacent points: <[2,3],[2,3,3]>, <[2,3],[2]>
  - Boundary point: [] (can't apply remove integer)

Boundary Cases: Aliases

```
<E> void appendList(List<E> src, List<E> dest) {
// modifies:       src, dest
// effects:        removes all elements of src and
//                 appends them in reverse order to
//                 the end of dest

  while (src.size()>0) {
    E elt = src.remove(src.size()-1);
    dest.add(elt)
  }
}
```

- What happens if **`src`** and **`dest`** refer to the same thing? This is aliasing, and it's easy to forget! Watch out for shared references in inputs

Regression Testing

- Whenever you find a bug
  - Store the input that elicited that bug, plus the correct output
  - Add these to the test suite
  - Verify that the test suite fails
  - Fix the bug
  - Verify the fix
- Ensures that your fix solves the problem
- Helps to populate test suite with good tests
- Protects against reversions that reintroduce bug
  - It happened at least once, and it might happen again

Rules of Testing

- First rule of testing: **Do it early and do it often**
  - Best to catch bugs soon, before they have a chance to hide.
  - Automate the process if you can
  - Regression testing will save time
- Second rule of testing: **Be systematic**
  - If you randomly thrash, bugs will hide in the corner until you're gone
  - Writing tests is a good way to understand the spec
    - Think about revealing domains and boundary cases
    - If the spec is confusing → write more tests
  - Spec can be buggy too
    - Incorrect, incomplete, ambiguous, and missing corner cases
  - When you find a bug → write a test for it first and then fix it

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