Masking and Data Flow

CSCE 747 - Lecture 8 - 02/13/2018

Previously...

- Test adequacy can be assessed through **adequacy metrics**.
- Many are based on elements from the **program structure**.
    - Statements, branches, conditions, procedure calls.
- Others are based on control paths.
    - Sequences of edges in the CFG.
    - Path coverage, boundary interior coverage, loop coverage.

Where Coverage Goes Wrong...

- Testing can only reveal a fault when execution of the faulty element causes a failure, but…
- Execution of a line containing a fault does not guarantee a failure.
  - (a <= b) accidentally written as (a >= b) - the fault will not manifest as a failure if a==b in the test case.
- Merely executing code does not guarantee that we will find all faults.
  - It depends on what inputs you choose.

Don’t Rely on Metrics

- Using coverage as a stopping criterion is good.
  - But, auto-generating tests with coverage as the goal produces poor tests.
- Two key problems - sensitivity to how code is written, and whether infected program state is detected by the test oracle.

Masking

- A single variable in an expression can determine the outcome, regardless of the value of other variables.
- `Y = ((A < 4) && Z);`
  - If Z is false, then the effect of (A < 4) is **masked**.
    - It doesn't matter what the value of (A < 4) is.
    - If there is a fault in (A < 4), we will miss the fault when Z is false.
  - MC/DC overcomes in-expression masking by requiring independent impact. Compound Condition overcomes it by requiring all condition combinations.

Masking

- One statement can mask the effect of another statement.
    - Z = (B && C)
    - Y = ((A < 4) && Z)
    - MC/DC can ensure that Z influences Y, but not that B influences Y.
    - This could **mask** a fault in B.
- Coverage metrics focus on one element at a time (one statement, one branch).
    - Many issues occur over paths.
    - This is why path coverage is theoretically powerful.

Sensitivity to Structure

```
expr_1 = in_1 || in_2;
out_1 = expr_1 && in_3;

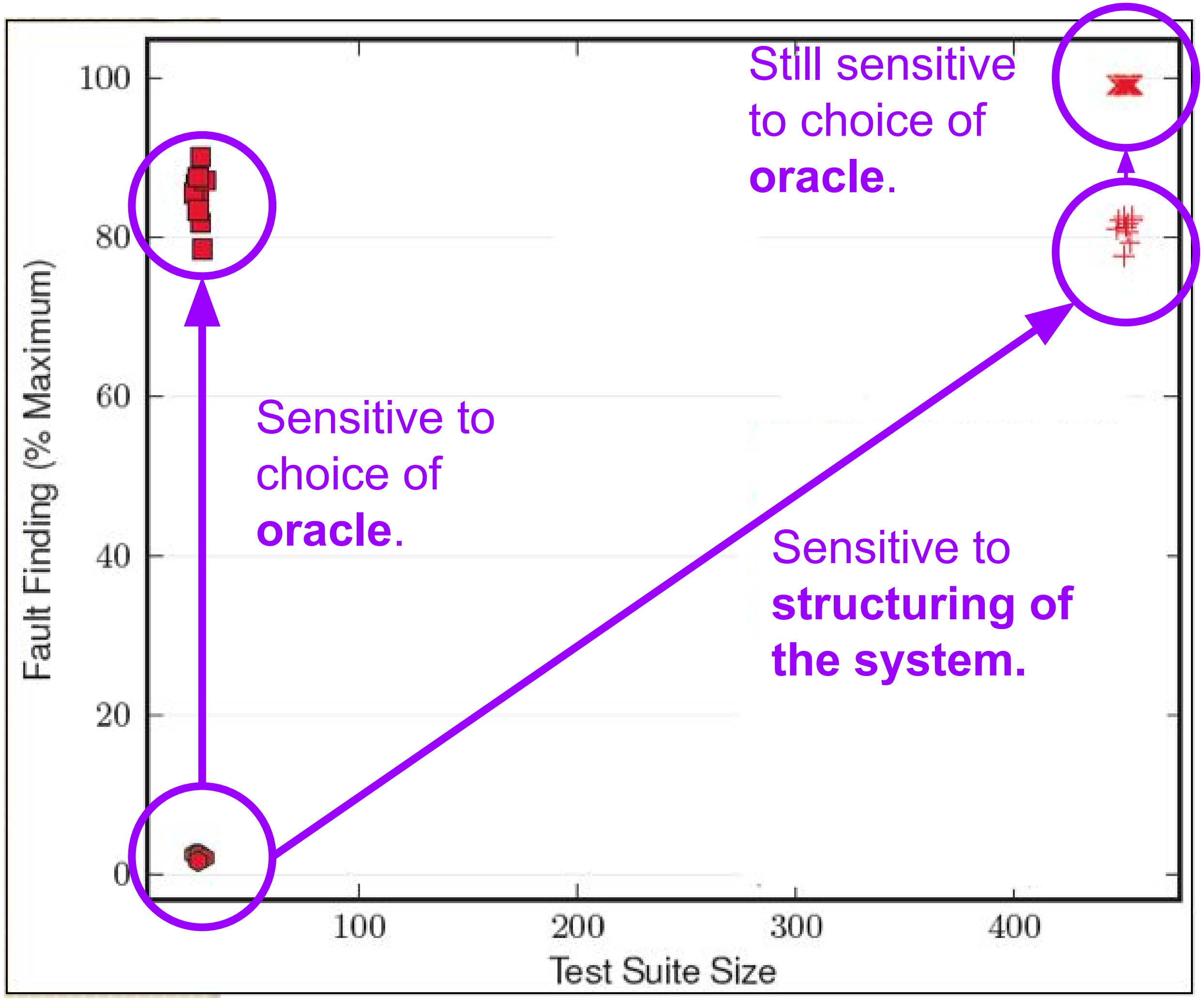
out_1 = (in_1 || in_2) && in_3;
```

- Both pieces of code do the same thing.
- How code is written impacts the number and type of tests needed.
- Simpler statements result in simpler tests.
    - Introduces risk of **masking** between expressions.

Sensitivity to Oracle

- The oracle judges test correctness.
  - We need to choose what results we check when writing an oracle.
- Typically, we check certain output variables.
  - However, **masking** can prevent us from noticing a fault if we do not check the right variables.
  - We can’t monitor and check all variables.
  - But, we can carefully choose a small number of bottleneck points and check those.
    - Some techniques for choosing these, but still more research to be done.

Coverage Effectiveness



Masking

Why do we care about faults in masked expressions?

- Effect of fault is only masked out for *this* test.
- It is still a fault. In another execution scenario, it might not be masked.
  - We just haven't noticed it yet.
  - The fault isn't gone, we just have bad tests.
- One solution - ensure that there is a path from assignment to output where we will **notice the fault**.

Path Conditions

- Most coverage criteria impose constraints on a single element.
- However, test obligations can also impose constraints on the path taken.
  - I.e., path coverage, boundary interior coverage
- Path Coverage is too expensive.
  - But, we could try to capture what is important about path coverage - the important interactions between elements.

Observability

- MC/DC eliminates masking in individual statements by requiring independent impact.
- However, that statement’s effect can be masked by another statement.
- Observability measures ability to infer internal system activity from information we monitor.
  - Can increase by using a larger oracle.
  - Or... build it into the coverage criterion.

Observable Coverage Metrics

- Assessing “independent impact” requires showing that a change in a condition’s value affects the value of an expression.
- Same idea can be applied to the path.
- Observability requires showing that a change to a targeted element affects a monitored variable.
- Adds constraints to a “host criterion”.

Observable Coverage Metrics

- Adds constraints to a “host criterion”.
  - Same number of obligations, but each is tougher to satisfy.
    - `Y = ((A < 4) && Z);`
    - Tests must show independent impact of Z, **and** that Z can influence the outcome of a monitored variable.
  - Still feasible - does not require exponential number of test cases like path coverage.
    - **Instead, we focus on the information passed along the path.**

Tracking Observability

Assign each condition a **tag set**:

`(ID, Boolean Outcome)`

Evaluation determines tag propagation:

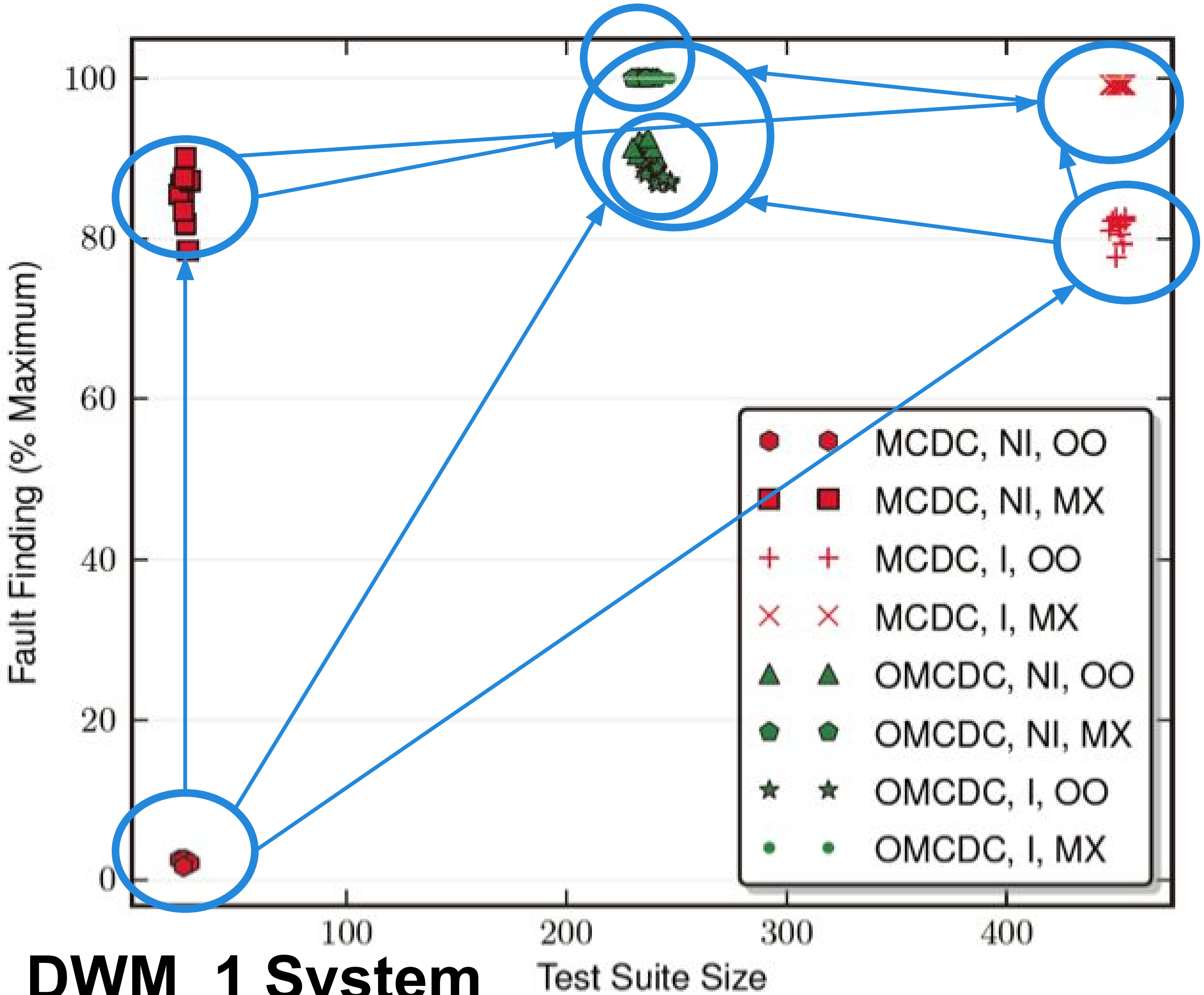
`exp1=c1 && c2;`	[~~(c1,true)~~, (c2,false)]
`exp2=c3 || c4;`	[(c3,true), ~~(c4,false)~~]
`out=if (c5) then`	[(c5,true),(c2, false),
`exp1 else exp2;`	~~<exp2>~~,]<exp2>]

Benefits of Observability

Observability should improve test effectiveness by accounting for **program structure** and **oracle composition**:

- We select what points the oracle monitors, observability requires propagation path to those points.
- No sensitivity to structure because impact must be propagated to monitoring points.
  - We place conditions on the path taken.

Evaluation - Results



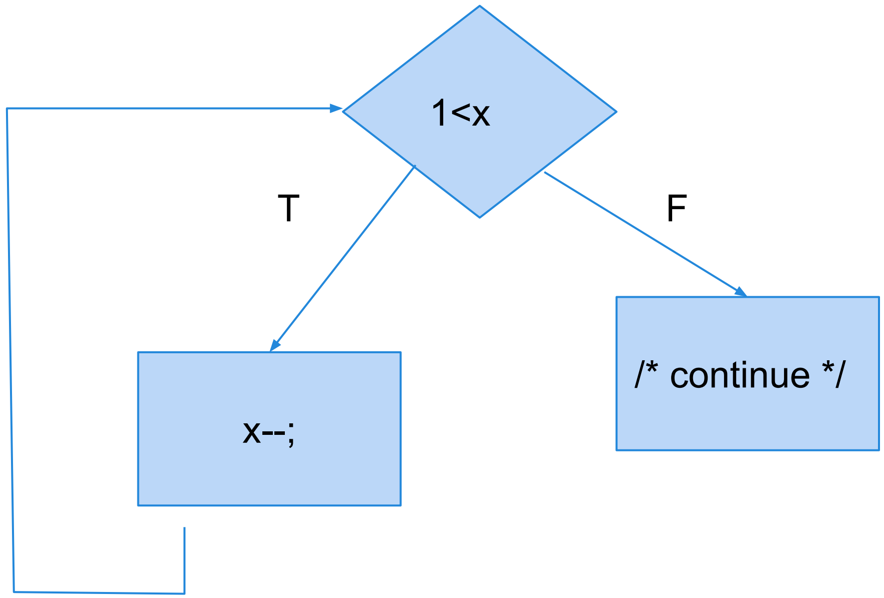
DWM_1 System

Still Not a Solved Problem

- Observability often prescribes a large number of infeasible obligations.
- Tests can be difficult to derive.
  - Generally requires automated generation.
- Often results in better fault-finding, but not 100% fault-finding (especially in complex systems).
- Points to our next topic - **the importance of how code executes**.

Control Flow

- Capture dependencies in terms of how control passes between parts of a program.
- We care about the effect of a statement when it affects the path taken.
  - but deemphasize the information being transmitted.



Data Flow

- Another view - program statements compute and transform data…
    - So, look at how that data is passed through the program.
- Reason about **data** dependence
    - A variable is used here.
        - Where does its value come from?
    - Is this value ever used?
    - Is this variable properly initialized?
    - If the expression assigned to a variable is changed what else would be affected?

Data Flow

- Basis of the optimization performed by compilers.
- Used to derive test cases.
  - Have we covered the dependencies?
- Used to detect faults and other anomalies.
  - Is this string tainted by a fault in the expression that calculates its value?

Definition-Use Pairs

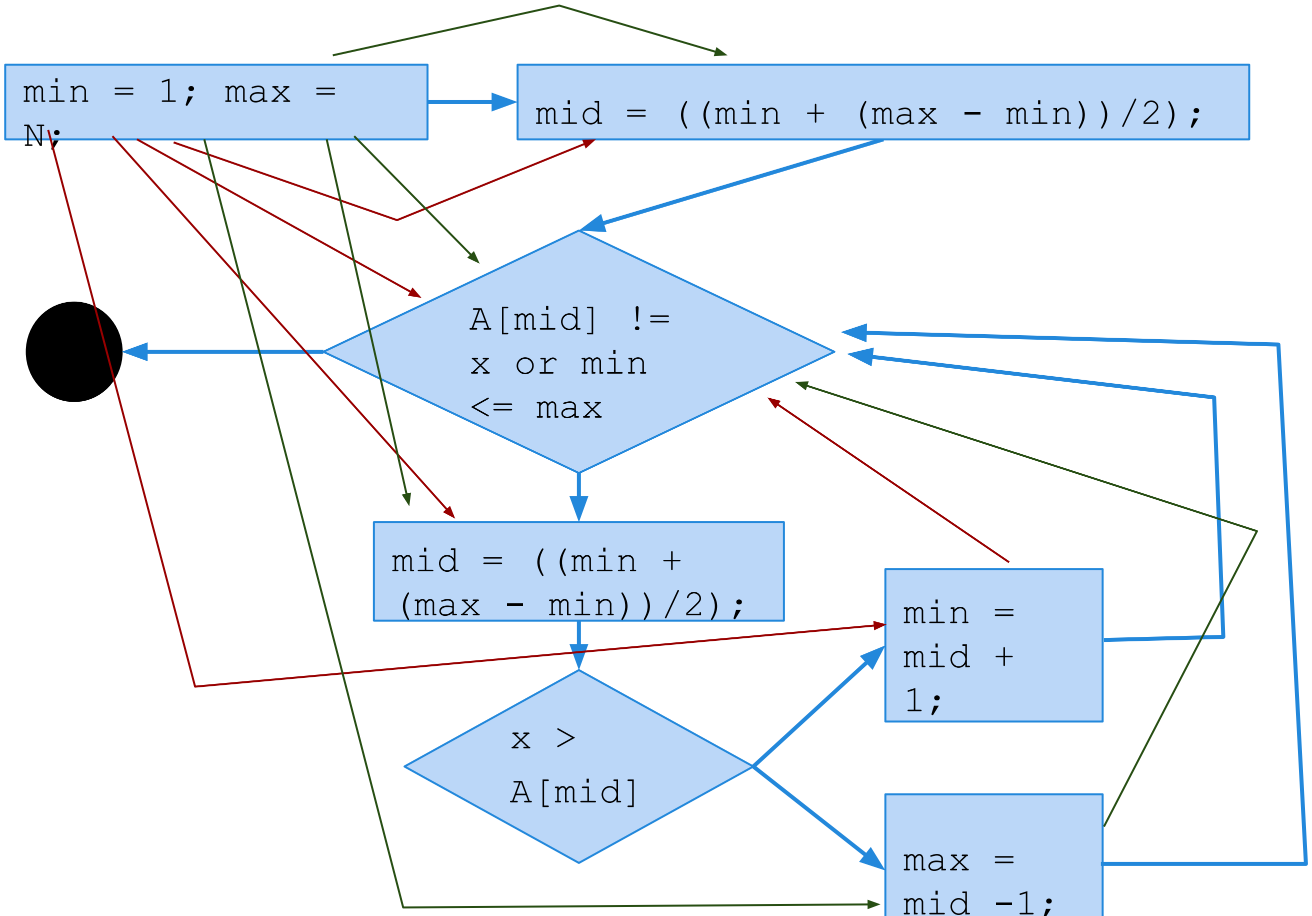
- Data is defined.
  - Variables are declared and assigned values.
- … and data is used.
  - Those variables are used to perform computations.
- Associations of definitions and uses capture the flow of information through the program.
  - Definitions occur when variables are declared, initialized, assigned values, or received as parameters.
  - Uses occur in expressions, conditional statements, parameter passing, return statements.

Example - Definition-Use Pairs

```
1.  min = 1;
2.  max = N;
3.  mid = ((min + (max - min))/2);
4.  while (A[mid] != x or min <= max){
5.      mid = ((min + (max - min))/2);
6.      if (x > A[mid]){
7.          min = mid + 1
8.      } else {
9.          max = mid - 1;
10.     }
11. }
```

1. **def** - min
2. **def** - max, **use** - N
3. **def** - mid, **use** - min, max
4. **use** - A[mid], mid, x, min, max
5. **def** - mid, **use** - min, max
6. **use -** x, A[mid], mid
7. **def -** min, **use** - mid
8. -
9. **def -** max, **use -** mid

Example - Definition-Use Pairs



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6. **use** - x, A[mid], mid
7. **def** - min, **use** - mid
8. -
9. **def** - max, **use** - mid

Def-Use Pairs

- We can say there is a def-use pair when:
  - There is a *def* (definition) of variable *x* at location A.
  - Variable *x* is *use*d at location B.
  - A control-flow path exists from A to B.
  - and the path is *definition-clear* for x.
    - If a variable is redefined, the original def is *killed* and the pairing is between the new definition and its associated use.

Example - Definition-Use Pairs

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10.     }
11. }
```

DU Pairs
min: (1, 3), (1, 4), (1, 5), (7, 4), (7, 5)
max: (2, 3), (2, 4), (1, 5), (9, 4), (9, 5)
N: (0, 2)
mid: (3, 4), (5, 6), (5, 7), (5, 9), (5, 4)
x: (0, 4), (0, 6)
A: (0, 4), (0, 6)

Example - GCD

```
1.  public int gcd(int x, int y){
2.      int tmp;
3.      while(y!=0){
4.          tmp = x % y;
5.          x = y;
6.          y = tmp;
7.      }
8.      return x;
9.  }
```

1. def: x, y
2. def: tmp
3. use: y
4. use: x, y
   def: tmp
5. use: y
   def: x
6. use: tmp
   def: y
7. -
8. use: x

Example - GCD

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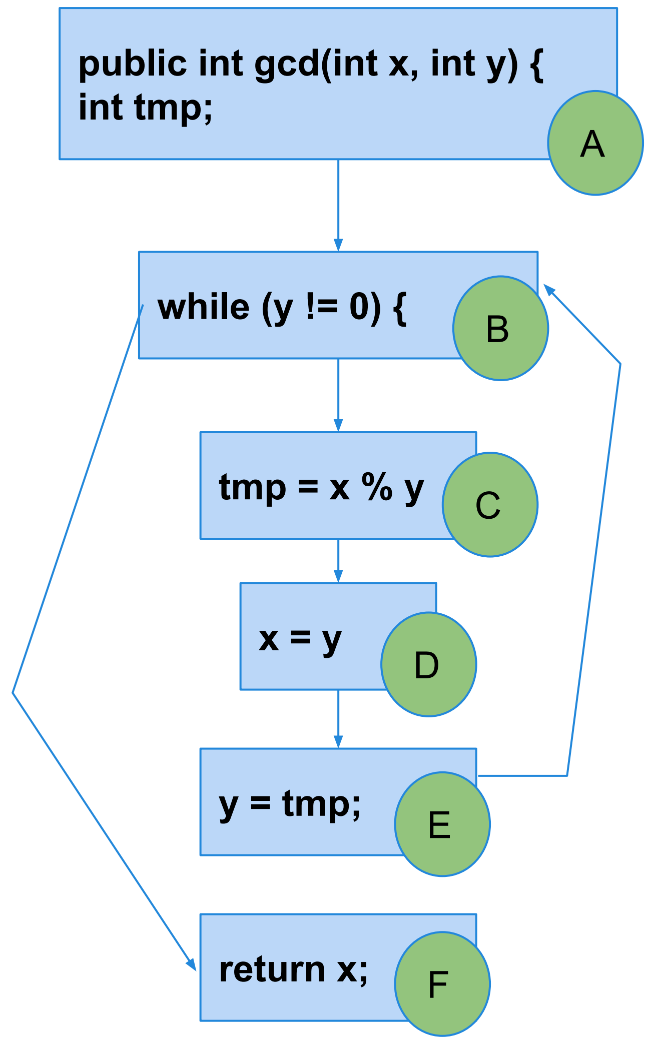

Def-Use Pairs

x: (1, 4), (5, 4), (5, 8), (1, 8)

y: (1, 3), (1, 4), (1, 5), (6, 3), (6, 4), (6, 5)

tmp: (4, 6)

Activity - DU Pairs

- For the provided code, identify all DU pairs.
  - Hint - first, find all definitions and uses, then link them.
  - DU Pair = there exists a *definition-clear path* between the definition of x and a use of x.
    - If x is redefined on the path, the original definition is *killed* and replaced.
  - Remember that there is a loop.

Activity Solution - Defs and Uses

```
7. public static String collapseNewlines(String argStr)
8. {
9.   char last = argStr.charAt(0);
10.  StringBuffer argBuf = new StringBuffer();
11.
12.  for(int cldx = 0; cldx < argStr.length(); cldx++)
13.  {
14.       char ch = argStr.charAt(cldx);
15.       if(ch != ‘\n’ || last != ‘\n’)
16.       {
17.            argBuf.append(ch);
18.            last = ch;
19.       }
20.  }
21.
22.  return argBuf.toString();
23. }
```

Variable	Definitions	Uses
argStr	7	9, 12, 14
last	9, 18	15
argBuf	10, 17	22
cldx	12	12, 14
ch	14	15, 17, 18

Activity Solution - Def-Use Pairs

```
7. public static String collapseNewlines(String argStr)
8. {
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16.      {
17.          argBuf.append(ch);
18.          last = ch;
19.      }
20.  }
21.
22.  return argBuf.toString();
23. }
```

Variable	D-U Pairs
argStr	(7, 9), (7,12), (7, 14)
last	(9, 15), (18, 15)
argBuf	(17, 22)
cldx	(12, 12), (12, 14)
ch	(14, 15), (14, 17), (14

We Have Learned

- Control-flow and data-flow both capture important paths in program execution.
- Analysis of how variables are defined and then used and the dependencies between definitions and usages can help us reveal important faults.
- Many forms of analysis can be performed using data flow information.

Next Class

- Data flow analysis.
  - Using Def-Use pairs to understand how programs work.

- Reading: Chapter 6
- Homework 1 due tonight.
- Reading assignment 2 out.
  - Due February 20th.