Software Reliability and Testing

Data Flow Coverage

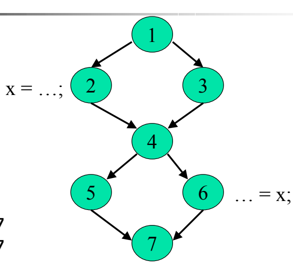
Based on material by Professor Lori A. Clarke, University of Massachusetts.

Control Flow Coverage Criteria

- Statement coverage
- Branch coverage
- Path coverage

- Can we also make use of data flow information to guide us in selecting test cases?

Path Selection Problem



- All branches:
  1, 2, 4, 5, 7
  1, 3, 4, 6, 7
- We haven't exercised the relationship between the definition in statement 2 and the reference in statement 6?

Definitions

- $d_n(x)$: variable x is assigned a value at node/statement n.
- $u_m(y)$: variable y is used at node/statement m.
- A *definition clear* path p wrt x is a subpath where x is not defined at any of the nodes/statements in p.
- A definition $d_m(x)$ reaches a use $u_n(x)$ iff there is a subpath (m) • p • (n) such that p is a definition clear path wrt x.

Data Flow Path Selection

- Rapps and Weyuker
  - Definition-clear subpaths from definitions to uses
- Laski and Korel
  - Combinations of definitions that reach uses at a node via a subpath

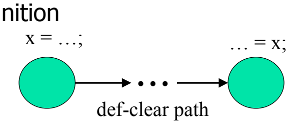
Rapps and Weyuker's Criteria

Rapps and Weyuker's Data Flow Criteria

- All-Defs
- All-Uses
- All-C-Uses, Some-P-Uses
- All-P-Uses, Some-C-Uses
- All-P-Uses
- All-Du-Paths

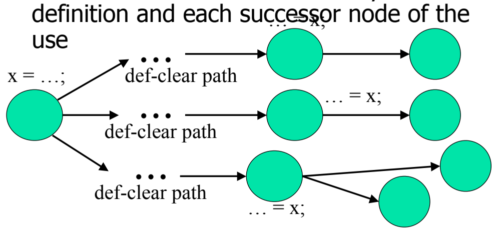
Rapps and Weyuker's Data Flow Criteria

- All-Defs
  - Some definition-clear subpath from each definition to some use reached by that definition



Rapps and Weyuker's Data Flow Criteria

- All-Uses
  - Some definition-clear subpath from each definition to each use reached by that definition and each successor node of the use



Rapps and Weyuker's Data Flow Criteria

- C-use is a "computation use" E.g. y = x * 2;
- P-use is a "predicate use" E.g. if (x < 2) …
- All-C-Uses, Some-P-Uses
  - Some definition-clear subpath from each definition to each C-Use reached by that definition.
  - If no C-Uses is reached by a definition, then some definition-clear subpath from that definition to at least one P-Use reached by that definition.

Rapps and Weyuker's Data Flow Criteria

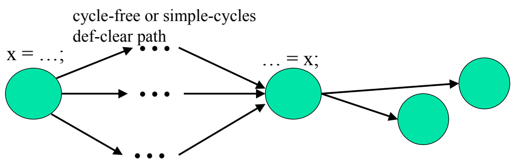
- All-P-Uses, Some-C-Uses
  - Some definition-clear subpath from each definition to each P-Use reached by that definition and each successor node of the use.
  - If no P-Uses is reached by a definition, then some definition-clear subpath from that definition to at least one C-Use reached by that definition.

Rapps and Weyuker's Data Flow Criteria

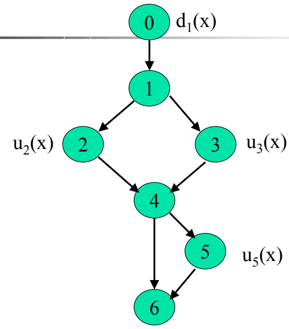
- All-P-Uses
  - Some definition-clear subpath from each definition to each P-Use reached by that definition and each successor node of the use

Rapps and Weyuker's Data Flow Criteria

- All-DU-Paths (DU stands for definition use).
  - All definition-clear subpaths that are cycle-free or simple-cycles from each definition to each use reached by that definition and each successor node of the use.

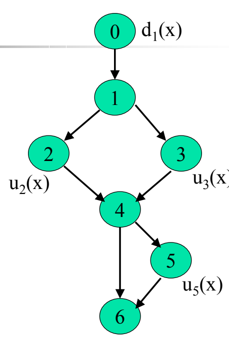


Example



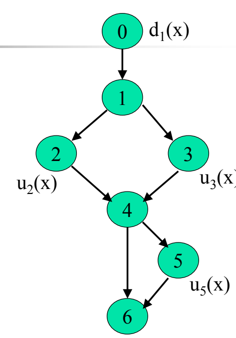
Example - All-Defs

- Requires:
  $d_1(x)$ to a use
- Satisfactory path:
  - 0, 1, 2, 4, 6



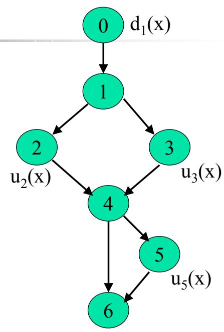
Example - All-Uses

- Requires:
  - $d_1(x)$ to a $u_2(x)$
  - $d_1(x)$ to a $u_3(x)$
  - $d_1(x)$ to a $u_5(x)$
- Satisfactory path:
  - 0, 1, 2, 4, 5, 6
  - 0, 1, 3, 4, 6



Example - All-DU-Paths

- Requires:
  - $d_1(x)$ to a $u_2(x)$
  - $d_1(x)$ to a $u_3(x)$
  - Both paths for $d_1(x)$ to a $u_5(x)$
- Satisfactory path:
  - 0, 1, 2, 4, 5, 6
  - 0, 1, 3, 4, 5, 6



Laski and Korel's Criteria

More Definitions

- Definition $d_n(v)$ of variable v is said to be live at statement m, if the definition at n reaches m.
- DE(i) denotes the data environment for statement i.
  - It is the set of all live definitions of all variables used (referenced) in statement i.

More Definitions

- Data environment example:

```
1  read(x);          d1(x)
2  y = 1;            d2(y)
3  z = y;            d3(z)
4  while (x > 0)
   {
5    if (x - y > 0)
6      y = y + 1;    d6(y)
     else
7      x = 1;        d7(x)
8    z = y / x;      d8(z)
   }
9  write(z);
```

$DE(3) = \{ d_2(y) \}$,
$DE(4) = \{ d_1(x), d_7(x) \}$,
$DE(5) = \{ d_1(x), d_2(y), d_7(x), d_6(y) \}$,
$DE(6) = \{ d_2(y), d_6(y) \}$,
$DE(8) = \{ d_1(x), d_2(y), d_7(x), d_6(y) \}$,
$DE(9) = \{ d_3(z), d_8(z) \}$

More Definitions

- An elementary context of statement i consists of the definitions that are live at statement i for a particular path to statement i.

```
1  read(x);      d1(x)
2  y = 1;        d2(y)
3  z = y;        d3(z)
4  while (x > 0)
   {
5    if (x - y > 0)
6      y = y + 1;  d6(y)
     else
7      x = 1;     d7(x)
8    z = y / x;   d8(z)
   }
9  write(z);
```

For example:

$ec(8) = (d_1(x), d_6(y))$

More Definitions

- The data context of statement i, DC(i), is defined as the set of all its elementary contexts.

```
1  read(x);      d1(x)
2  y = 1;        d2(y)
3  z = y;        d3(z)
4  while (x > 0)
   {
5    if (x-y > 0)
6      y = y + 1; d6(y)
     else
7      x = 1;     d7(x)
8    z = y/x;     d8(z)
   }
9  write(z);
```

$DC(3) = \{ (d_2(y)) \}$

$DC(4) = \{ (d_1(x)), (d_7(x)) \}$

$DC(5) = \{ (d_1(x), d_2(y)), (d_1(x), d_6(y)), (d_7(x), d_2(y)), (d_7(x), d_6(y)) \}$

$DC(6) = \{ (d_2(y)), (d_6(y)) \}$

$DC(8) = \{ (d_1(x), d_6(y)), (d_7(x), d_2(y)), (d_7(x), d_6(y)) \}$

$DC(9) = \{ (d_3(z)), (d_8(z)) \}$

More Definitions

- An ordered data context also takes into account the order in which the definitions occur.

```
1  read(x);      d1(x)
2  y = 1;        d2(y)
3  z = y;        d3(z)
4  while (x > 0)
   {
5    if (x-y > 0)
6      y = y + 1; d6(y)
     else
7      x = 1;     d7(x)
8    z = y/x;     d8(z)
   }
9  write(z);
```

For example:

$DC(8) = \{ (d_1(x), d_6(y)), (d_7(x), d_2(y)), (d_7(x), d_6(y)) \}$

$ODC(8) = \{ [d_1(x), d_6(y)], [d_2(y), d_7(x)], [d_7(x), d_6(y)], [d_6(y), d_7(x)] \}$

Laski and Korel's Criteria

- Context Coverage
  - Every data context DC(n) is exercised at least once.
- Ordered Context Coverage
  - Every ordered data context ODC(n) is exercised at least once.

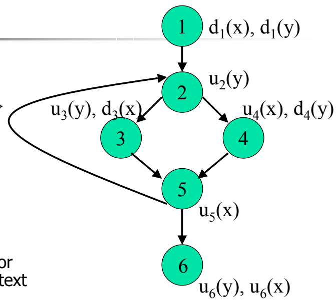
Example - Context Coverage

DC(6) = { ($d_1(x)$, $d_4(y)$),
($d_3(x)$, $d_1(y)$),
($d_3(x)$, $d_4(y)$) }

Paths:

1, 2, 4, 5, 6
1, 2, 3, 5, 6
1, 2, 3, 5, 2, 4, 5, 6

Need to determine paths for all DC(i) to achieve context coverage.



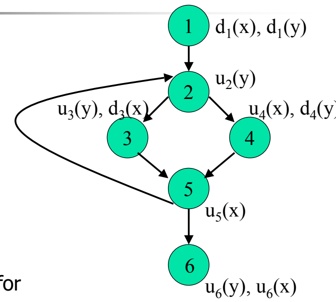
Example - Ordered Context Coverage

DC(6) = { [$d_1(x)$, $d_4(y)$],
[$d_1(y)$, $d_3(x)$],
[$d_3(x)$, $d_4(y)$],
[$d_4(y)$, $d_3(x)$] }

Paths:

1, 2, 4, 5, 6
1, 2, 3, 5, 6
1, 2, 3, 5, 2, 4, 5, 6
1, 2, 4, 5, 2, 3, 5, 6

Need to determine paths for all ODC(i) to achieve ordered context coverage.



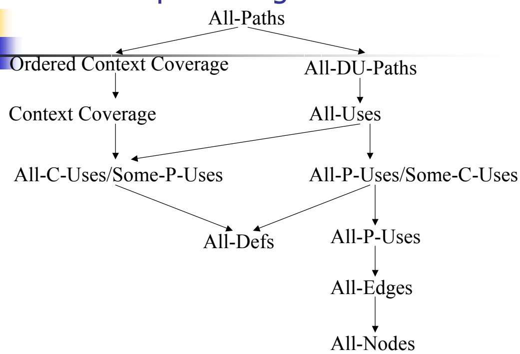
How can we compare these criteria?

- All select a set of paths, so compare the paths that they select
  - Set of paths that satisfy a criterion are not necessarily unique
  - E.g. s1 or s2 satisfies criterion A
    s1, s2, or s3 satisfies criterion B

How can we compare these criteria?

- Define a subsumption relationship
- Criterion A subsumes criterion B iff for any flow graph:
  P satisfies A ==> P satisfies B
  (P is a set of paths)
- Criteria A is equivalent to criteria B iff A subsumes B, and B subsumes A.

Relationships among these criteria



Conclusions

- An improvement over control flow techniques
- Provides a rationale for which combinations of subpaths to consider
- Most commonly used criteria is all-uses
- One problem with data flow coverage is infeasible paths
  - Don't usually get 100% coverage