Test Coverage & Adequacy

- How much testing is enough?
- When to stop testing
- Test data selection criteria
- Test data adequacy criteria
  - Stopping rule
  - Degree of adequacy
- Test coverage criteria
- Objective measurement of test quality

Preliminaries

- Test data selection
  - What test cases
- Test data adequacy criteria
  - When to stop testing
- Examples
  - Statement Coverage
  - Branch coverage
  - Def-use coverage
  - Path coverage

Goodenough & Gerhart ['75]

- What is a software test adequacy criterion
  - Predicate that defines “what properties of a program must be exercised to constitute a thorough test”, i.e., one whose successful execution implies no errors in a tested program
Goodenough & Gerhart ['75]

- Reliability requirement
  - “Test criterion always produces consistent test results”
  - If a program tested successfully on one test set that satisfies the criterion, then the program also tested successfully on all test sets that satisfy the criterion
- Validity requirement
  - “Test always produces a meaningful result”
  - For every error in a program, there exists a test set that satisfies the criterion and is capable of revealing the error
- There is no computable criterion that satisfies the above requirements

Uses of test adequacy

- Objectives of testing
- In terms that can be measured
  - For example branch coverage
- Two levels of testing
  - First as a stopping rule
  - Then as a guideline for additional test cases

Categories of Criteria

- Specification based
  - All-combination criterion
  - Each-choice-used criterion
- Program based
  - Statement
  - Branch
- Note that in both the above types, the correctness of the output must be checked against the specifications
Classification according to underlying testing approach

- Structural testing
  - Coverage of a particular set of elements in the structure of the program
- Fault-based testing
  - Some measurement of the fault detecting ability of test sets
- Error-based testing
  - Check on some error-prone points

Structural Testing

- Program-based structural testing
  - Control-flow based adequacy criteria
    - Statement coverage
    - Branch coverage
    - Path coverage
      - Length-based coverage
    - Cyclomatic number criterion
      - Set of \( v \) independent paths, where \( v = e - n + 1 \)
    - Multiple condition coverage
      - All possible combinations of truth values of predicates
  - Data-flow based adequacy criteria
Structural Testing

- Data-flow based adequacy criteria
  - All definitions criterion
    - Each definition to some reachable use
  - All uses criterion
    - Definition to each reachable use
  - All def-use criterion
    - Each definition to each reachable use

Data-flow Testing

```
read(x, y)
x := x + 2; y := 2;
x := x + 2;
x := y + 2;
```

```
1: read(x, y)
2: 3:
4: 5: 6:
7: 8:
```

All Definitions Criterion

- A set P of execution paths satisfies the all-definitions criterion iff
  - for all definition occurrences of a variable x such that
    - there is a use of x, which is feasibly reachable from that definition,
  - there is at least one path p in P such that
    - p includes a subpath through which the definition of x reaches some use occurrence of x
A set $P$ of execution paths satisfies the all-uses criterion iff

- for all definition occurrences of a variable $x$ and all use occurrences of $x$,
  - that the definition feasibly reaches,
  - there is at least one path $p$ in $P$ such that
    - $p$ includes a subpath through which that definition reaches the use.

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All DU-paths criterion

- A set $P$ of execution paths satisfies the all-DU paths criterion iff
  - for all definitions of a variable $x$ and all paths $q$ through which that definition reaches a use of $x$,
  - there is at least one path $p$ in $P$ such that
    - $q$ is a subpath of $p$ and $q$ is cycle-free.
Fault-based Adequacy

- Error seeding
  - Introducing artificial faults to estimate the actual number of faults

- Program mutation testing
  - Distinguishing between original and mutants
    - Competent programmer assumption
      - Mutants are close to the program
    - Coupling effect assumption
      - Simple and complex errors are coupled

Subsumption

- Criteria $C_1$ subsumes criteria $C_2$, iff
  - For all programs $p$ being tested with specifications $s$
  - All test sets $t$
  - $t$ is adequate according to $C_1$ for testing $p$ with respect to $s$
    that $t$ is adequate according to $C_2$ for testing $p$ with respect to $s$

- Path subsumes branch
- Path subsumes statement