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-i path coverage
    - 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

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

Test Oracles

- Discussion
  - Automation of oracle necessary
  - Expected behavior given
  - Necessary parts of an oracle

Test Oracle

- A test oracle determines whether a system behaves correctly for test execution
- Webster Dictionary - Oracle
  - a person giving wise or authoritative decisions or opinions
  - an authoritative or wise expression or answer

Purpose of Test Oracle

- Sequential Systems
  - Check functionality
- Reactive (event-driven) Systems
  - Check functionality
  - Timing
  - Safety

Reactive Systems

- Complete specification requires use of multiple computational paradigms
- Oracles must judge all behavioral aspects in comparison with all system specifications and requirements
- Hence oracles may be developed directly from formal specifications

Parts of an Oracle

- Oracle information
  - Specifies what constitutes correct behavior
    - Examples: input/output pairs, embedded assertions
- Oracle procedure
  - Verifies the test execution results with respect to the oracle information
    - Examples: equality
- Test monitor
  - Captures the execution information from the run-time environment
    - Examples
      - Simple systems: directly from output
      - Reactive systems: events, timing information, stimuli, and responses

Regression Testing

- Developed first version of software
- Adequately tested the first version
- Modified the software; version 2 now needs to be tested
- How to test version 2?
- Approaches
  - Retest entire software from scratch
  - Only test the changed parts, ignoring unchanged parts since they have already been tested
  - Could modifications have adversely affected unchanged parts of the software?

Regression Testing

- "Software maintenance task performed on a modified program to instill confidence that changes are correct and have not adversely affected unchanged portions of the program."

Regression Testing vs. Development Testing

- During regression testing, an established test set may be available for reuse
- Approaches
  - Retest all
  - Selective retest (selective regression testing) ← Main focus of research

Formal Definition

- Given a program P,
- its modified version P', and
- a test set T
  - used previously to test P
- find a way, making use of T to gain sufficient confidence in the correctness of P'

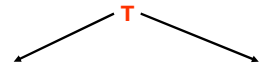
Regression Testing Steps

1. Identify the modifications that were made to P
   - Either assume availability of a list of modifications, or
   - Mapping of code segments of P to their corresponding segments in P'
2. Select T' ⊆ T, the set of tests to re-execute on P'
   - May need results of step 1 above
   - May need test history information, i.e., the input, output, and execution history for each test

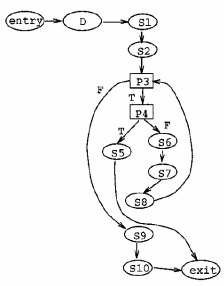
Regression Testing Steps

3. Retest P' with T'
   - Use expected output of P, if same
4. Create new tests for P', if needed
   - Examine whether coverage criterion is achieved
5. Create T"
   - The new test suite, consisting of tests from steps 2 and 4, and old tests that were not selected

Selective Retesting



- Tests to rerun
  - Select those tests that will produce different output when run on P'
    - Modification-revealing test cases
    - It is impossible to always find the set of modification-revealing test cases – (we cannot predict when P' will halt for a test)
  - Select modification-traversing test cases
    - If it executes a new or modified statement in P' or misses a statement in P' that it executed in P




```
Procedure avg
S1.  count = 0
S2.  fread(fileptr,n)
P3.  while (not EOF) do
P4.     if (n<0)
S5.        return(error)
        else
S6.        numarray[count] = n
S7.        count++
        endif
S8.     fread(fileptr,n)
     endwhile
S9.  avg = calcavg(numarray,count)
S10. return(avg)
```

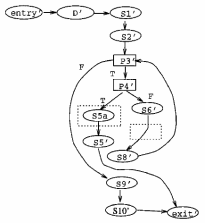
Fig. 1. Procedure avg and its CFG.

Table I. Test Information and Test History for Procedure avg

Test Information			
Test	Type	Output	Edges Traversed
t1	Empty File	0	(entry, D), (D, S1), (S1, S2) (S2, P3) (P3, S9), (S9, S10), (S10, exit)
t2	−1	Error	(entry, D) (D, S1), (S1, S2), (S2, P3), (P3, P4), (P4, S5), (S5, exit)
t3	1 2 3	2	(entry, D) (D, S1), (S1, S2), (S2, P3), (P3, P4), (P4, S6), (S6, S7), (S7, S8), (S8, P3), (P3, S9), (S9, S10), (S10, exit)

Test History

Edge	TestsOnEdge(edge)
(entry, D)	111
(D, S1)	111
(S1, S2)	111
(S2, P3)	111
(P3, P4)	011
(P3, S9)	101
(P4, S5)	010
(P4, S6)	001
(S5, exit)	010
(S6, S7)	001
(S7, S8)	001
(S8, P3)	001
(S9, S10)	101
(S10, exit)	101




```
Procedure avg2
S1'. count = 0
S2'. fread(fileptr,n)
P3'. while (not EOF) do
P4'.    if (n<0)
S5a.        print("bad input")
S5'.        return(error)
          else
S6'.        numarray[count] = n
          endif
S8'.    fread(fileptr,n)
      endwhile
S9'. avg = calcavg(numarray,count)
S10'.return(avg)
```

Fig. 3. Procedure avg2 and its CFG.

```
     Procedure avg
S1.  count = 0
S2.  fread(fileptr,n)
P3.  while (not EOF) do
P4.     if (n<0)
S5.        return(error)
        else
S6.        numarray[count] = n
S7.        count++
        endif
S8.     fread(fileptr,n)
     endwhile
S9.  avg = calcavg(numarray,count)
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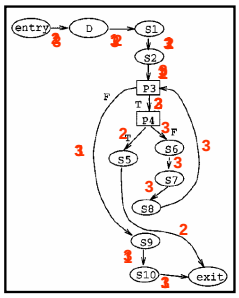
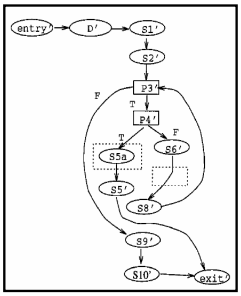
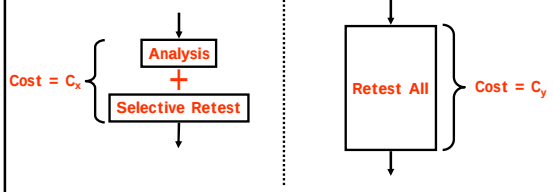




T' = {t2, t3}

Cost of Regression Testing



We want $C_x < C_y$

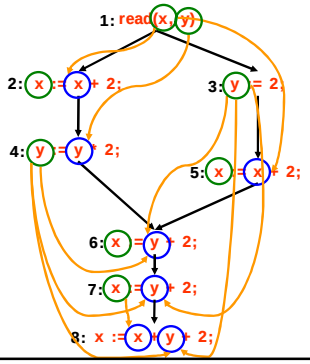
Key is the test selection algorithm/technique

We want to maintain the same "quality of testing"

Factors to consider

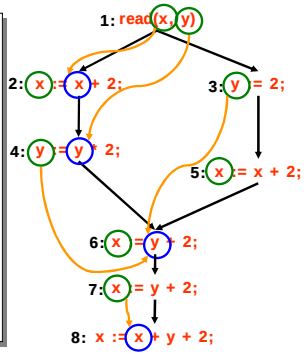
- Testing costs
- Fault-detection ability
- Test suite size vs. fault-detection ability
- Specific situations where one technique is superior to another

Data-flow Testing



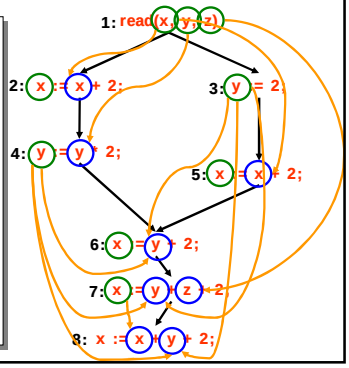
All Definitions Criterion

- 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

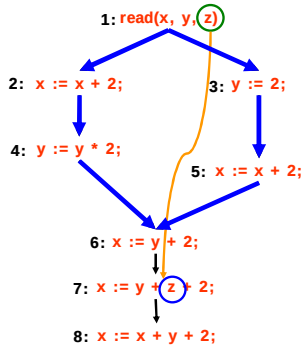


All Uses Criterion

- 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



All Uses Criterion



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