Testing

- Role in Unified Approach
- Coverage:
    - Structural/Coverage
    - Model Based
    - Test Generation from Model Checking (project)
- Interaction of Coverage/Model Based Testing
- Will Not Cover
    - Statistical Methods
    - Partition Methods
    - Functional Testing

Role of Testing

Most Accessible and Common Method of V&V

Thorough testing should precede application of formal methods.

Some properties may be rigorously verified by testing.

(particularly at the component level)

Interaction and Relationships with Other V&V Methods

•Functional testing may (should) based on property specifications

•Structural/overage testing based on static analysis

•Model checking can be used for test generation

•Model checking and testing are a continuum

•Runtime monitoring is continuous testing

•Open Issues:

Derivation of structural/coverage tests from property specifications.

Unification of model-based and coverage testing

Component/Unit Test

Requires precise specification at component level.

Functionality defined as properties or pre-conditions/post-conditions.

Pre-conditions (test cases) must be defined

Exceptions to preconditions must be defined

Coverage tests may be readily derivable.

Oracle Problems

Post-Condition verifiers (Oracles) must be constructed

- Complete oracle is correct implementation!
- Common oracles are not complete.
- Most oracles are human inspectors
- Oracles for specific properties??

Coverage Analyses

Control Flow

- Statement coverage
- Decision coverage
- Condition coverage
  single/multiple
- Condition/Decision coverage
  variants of C/D coverage
- Path coverage

Data Flow

Use/Def relations

coverage (other)

- Function coverage
- Call coverage
- Loop
- Race
- Mutation coverage
- Table coverage
- Relational operator coverage

Structural/Coverage Testing

Establishes that a given execution "covers" some set of program structures or functions.

Why useful?

- Errors are likely to arise from control flow.
- Errors are likely to arise from widely separated definition and use of variables

Challenges

- Generating test cases conforming to coverage cases
- Cost of creating test cases

Issues:

- Integration of property specification and coverage specification.
- Construction of property specific coverage, abstraction and state space specification.
- Combining abstraction with coverage testing

Role of Design in Testing

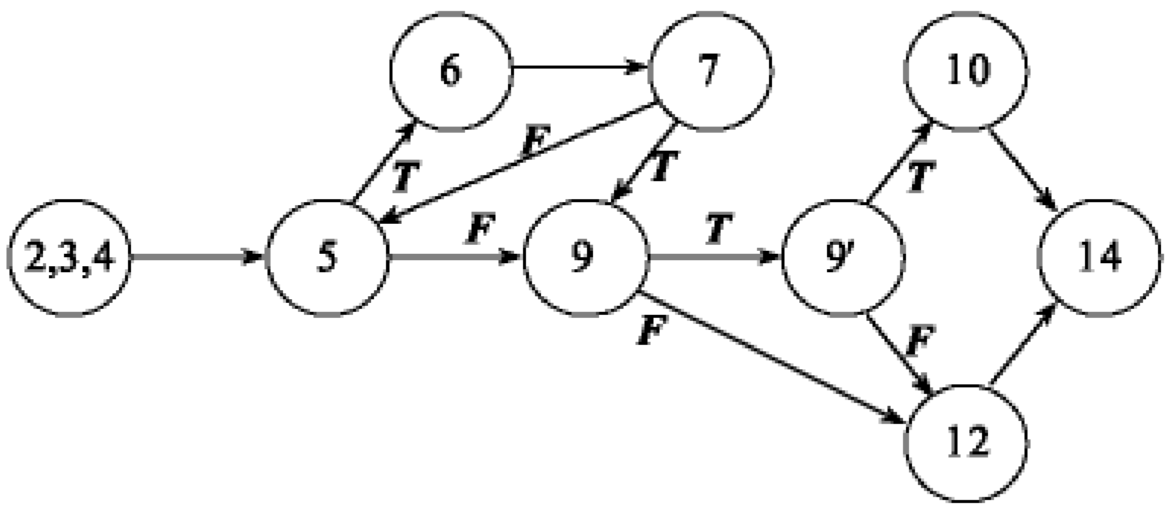
- Formal model for component
  - Components with precise definitions
  - Implementation should follow model
- Simple control structures
  - State machine structure
- Prescribed ranges for variables

Web Resources

- http://www.testing.com/
- http://www.bullseye.com/
- http://www.codecoveragetools.com/
- http://www.semdesigns.com/Products/TestCoverage/CTestCoverage.html

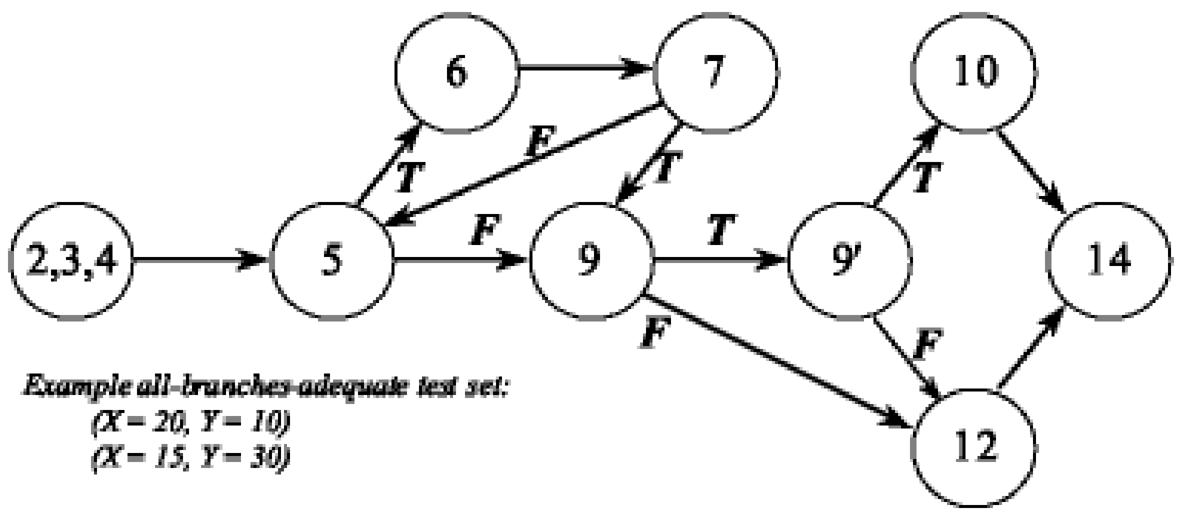
```
function P return INTEGER is
begin
    X, Y: INTEGER;
    READ(X); READ(Y); -- definition of X and Y
    while (X > 10) loop
        X := X – 10;
    exit when X = 10;
    end loop;
    if (Y < 20 and then X mod 2 = 0) then-- “short circuit” and operator
        Y := Y + 20;
    else
        Y := Y – 20;
    end if;
    return 2 * X + Y;
end P;
```

P's Control Flow Graph (CFG)



Branch Coverage of P

At least 2 test cases needed



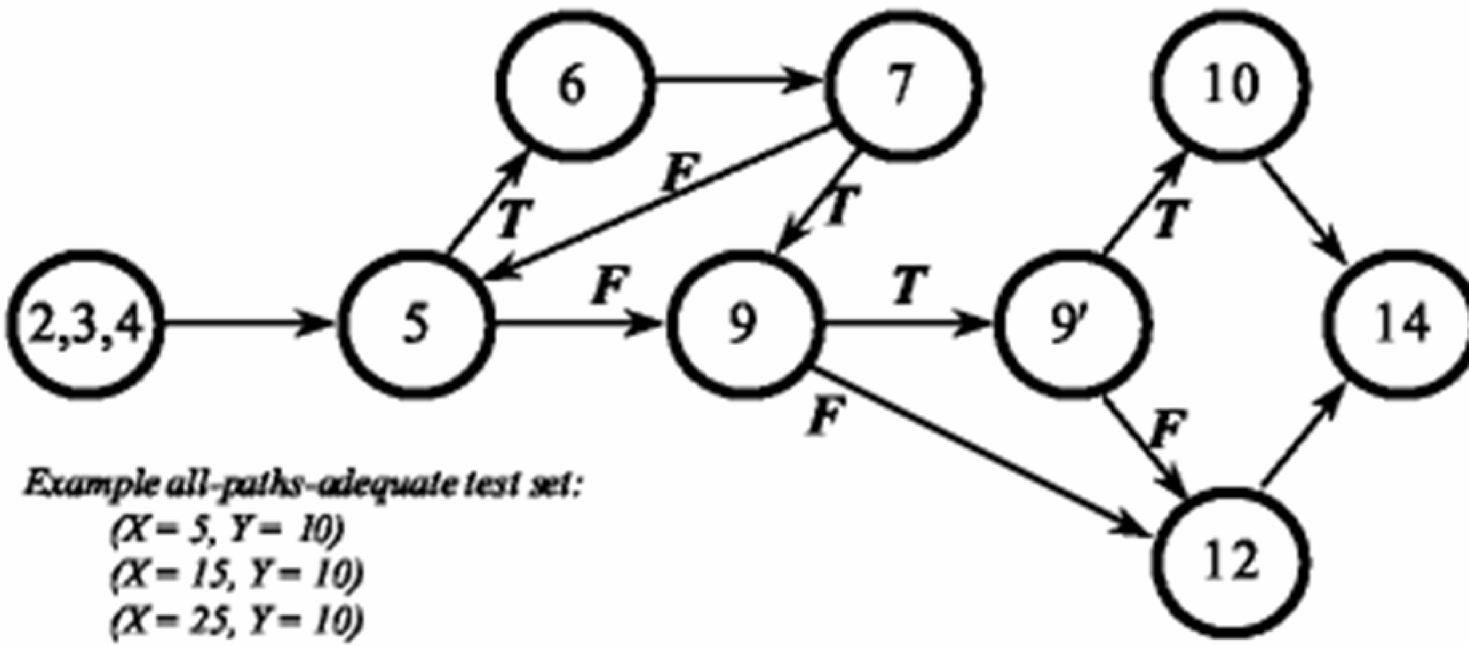
Example all-branches-adequate test set:

(X = 20, Y = 10)

(X = 15, Y = 30)

Path Coverage of P

Infinitely many test cases needed

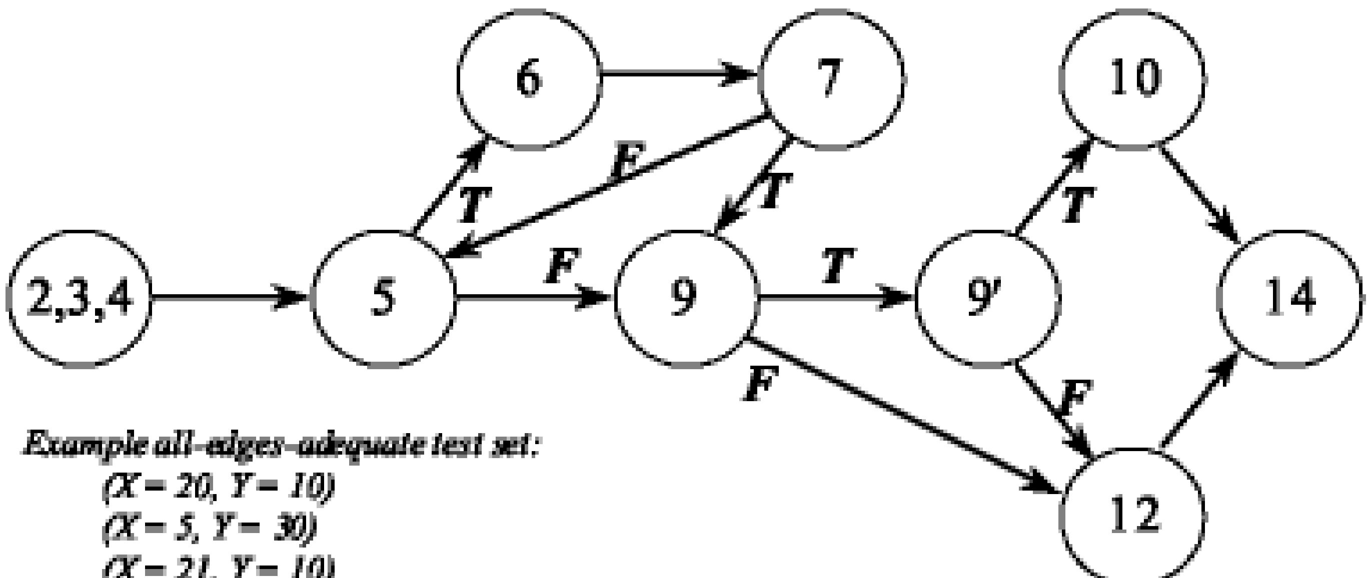


Example all-paths-adequate test set:

(X = 5, Y = 10)
(X = 15, Y = 10)
(X = 25, Y = 10)
(X = 35, Y = 10)
...

Condition Coverage of P

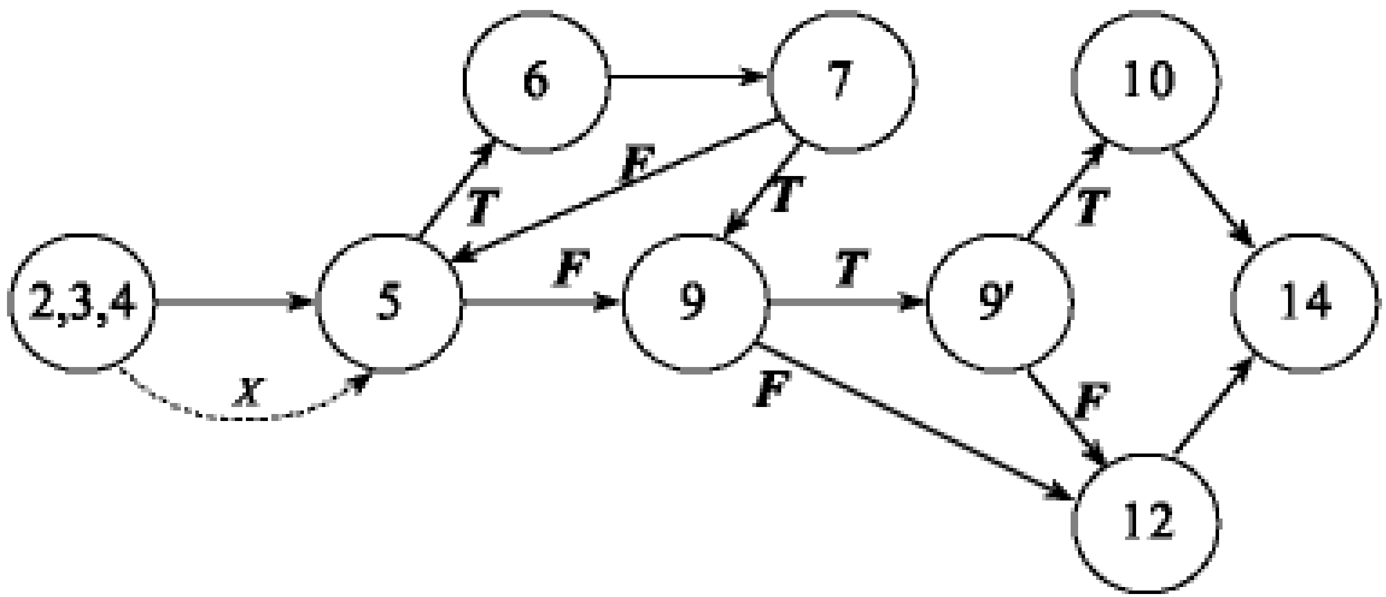
At least 3 test cases needed



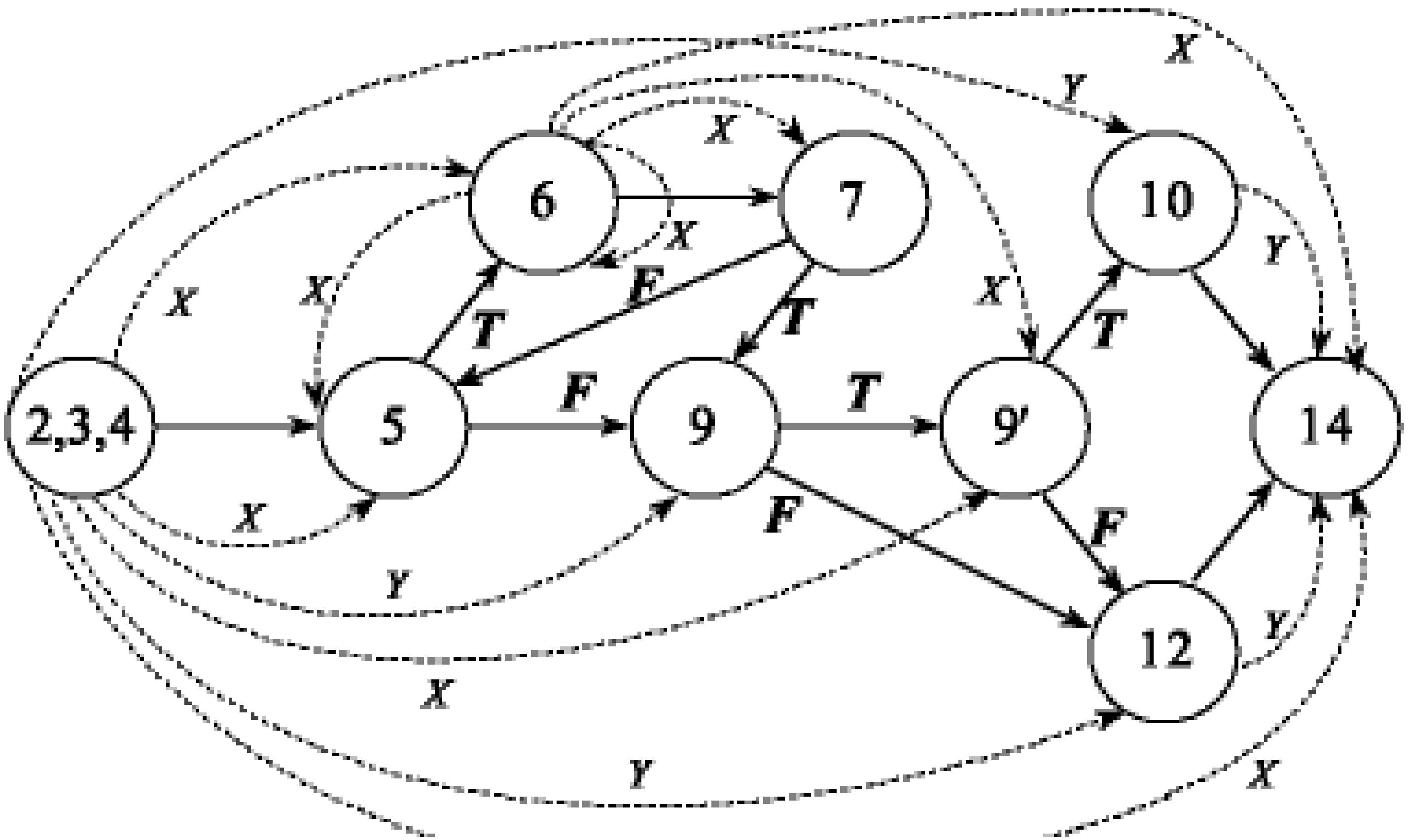
Example all-edges-adequate test set:

(X = 20, Y = 10)
(X = 5, Y = 30)
(X = 21, Y = 10)

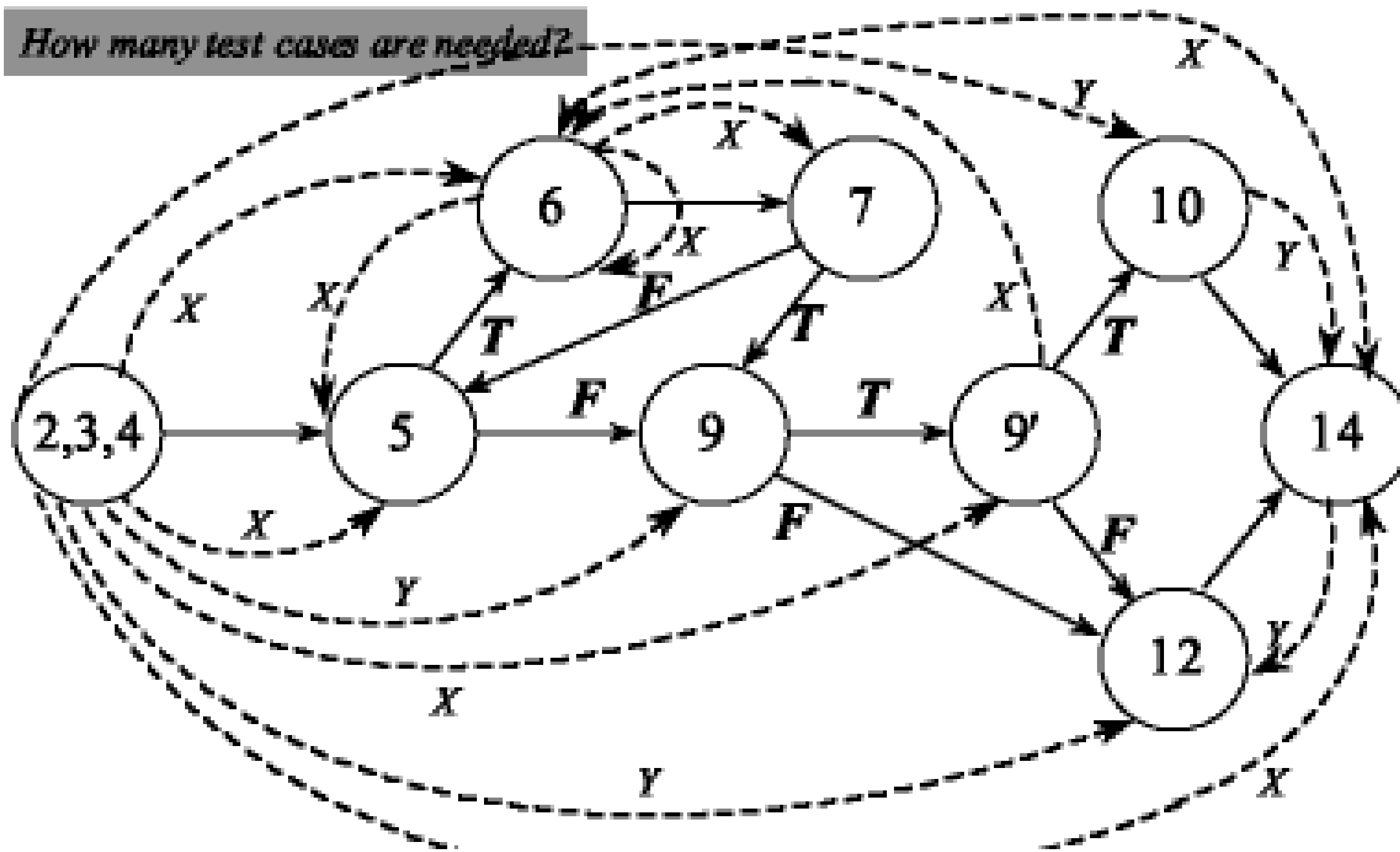
P's CFG with a Data Flow Edge



P's Control and Data Flow Graph



All-Uses Coverage of P

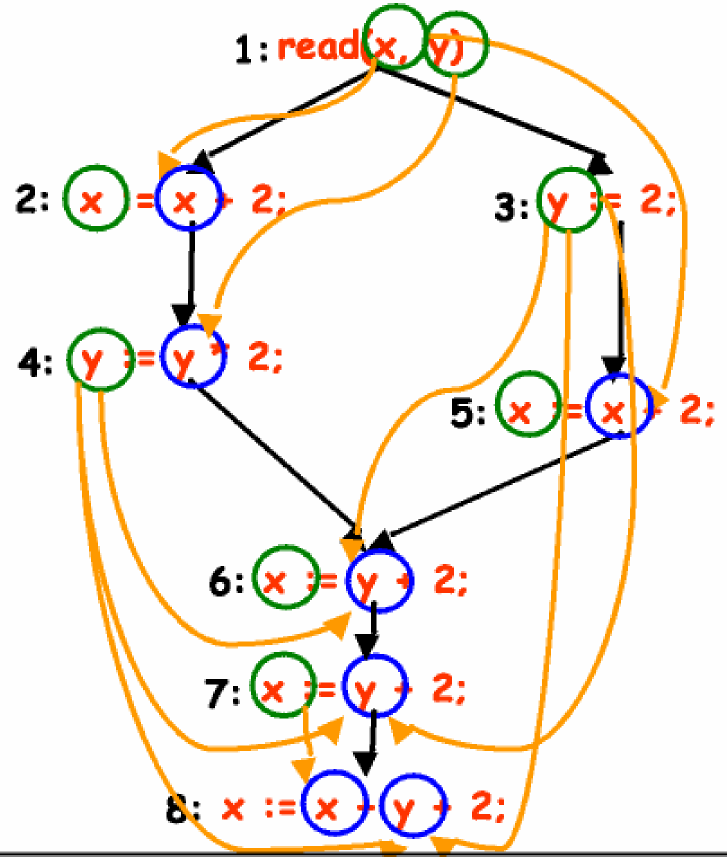


Structural Testing

– Data-flow based adequacy criteria

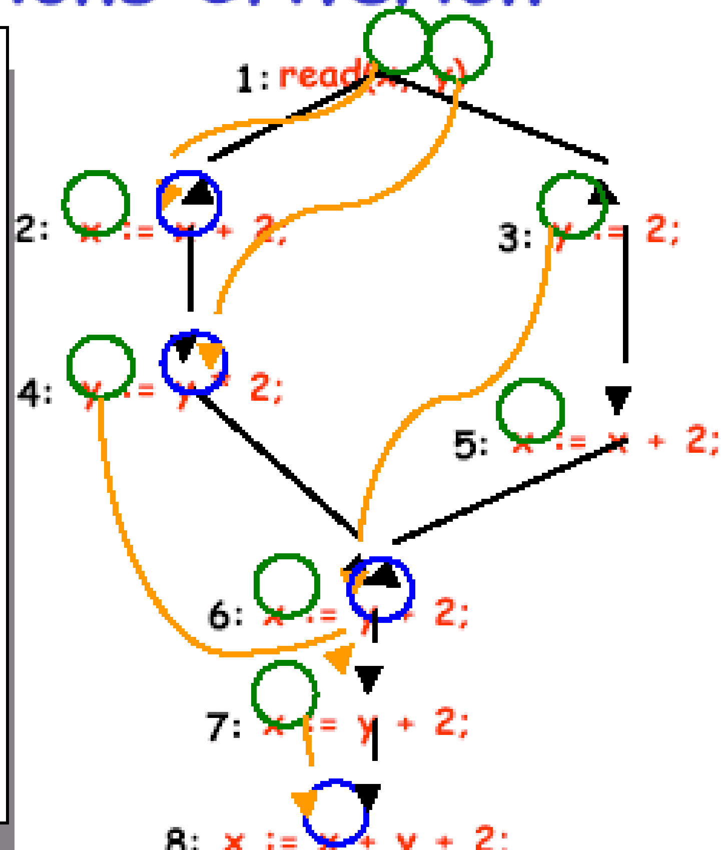
- All definitions criterion
  - Each definition to some reachable use
- All uses criterion
  - Definition to each reachable use
- All def-use criterion
  - Each definition to each reachable use

Data-flow Testing

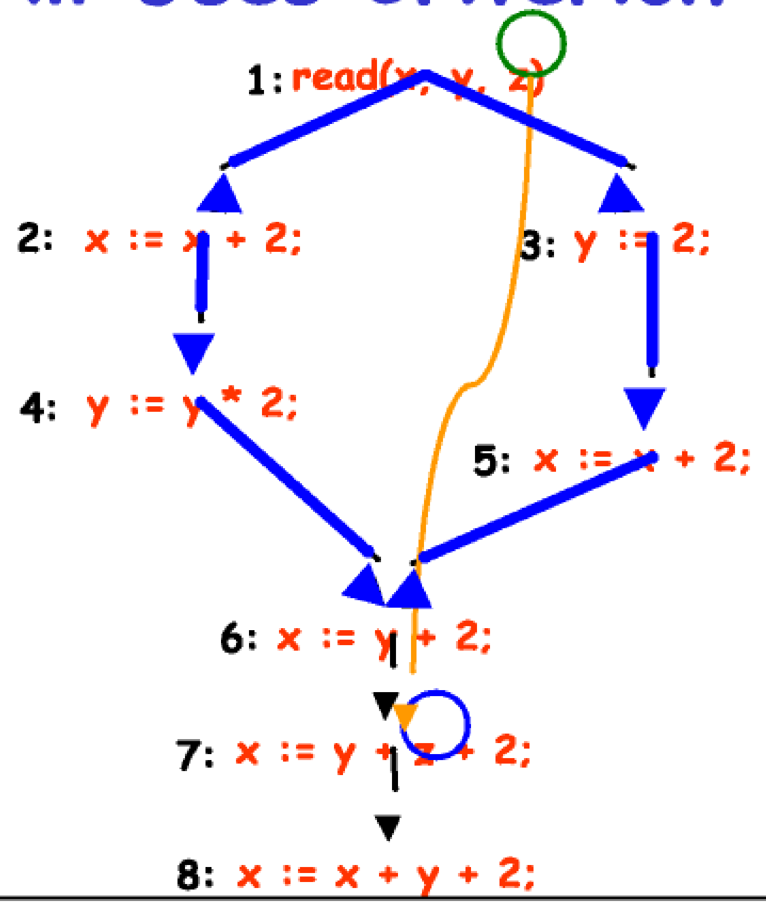


All Definitions Criterion

- 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



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

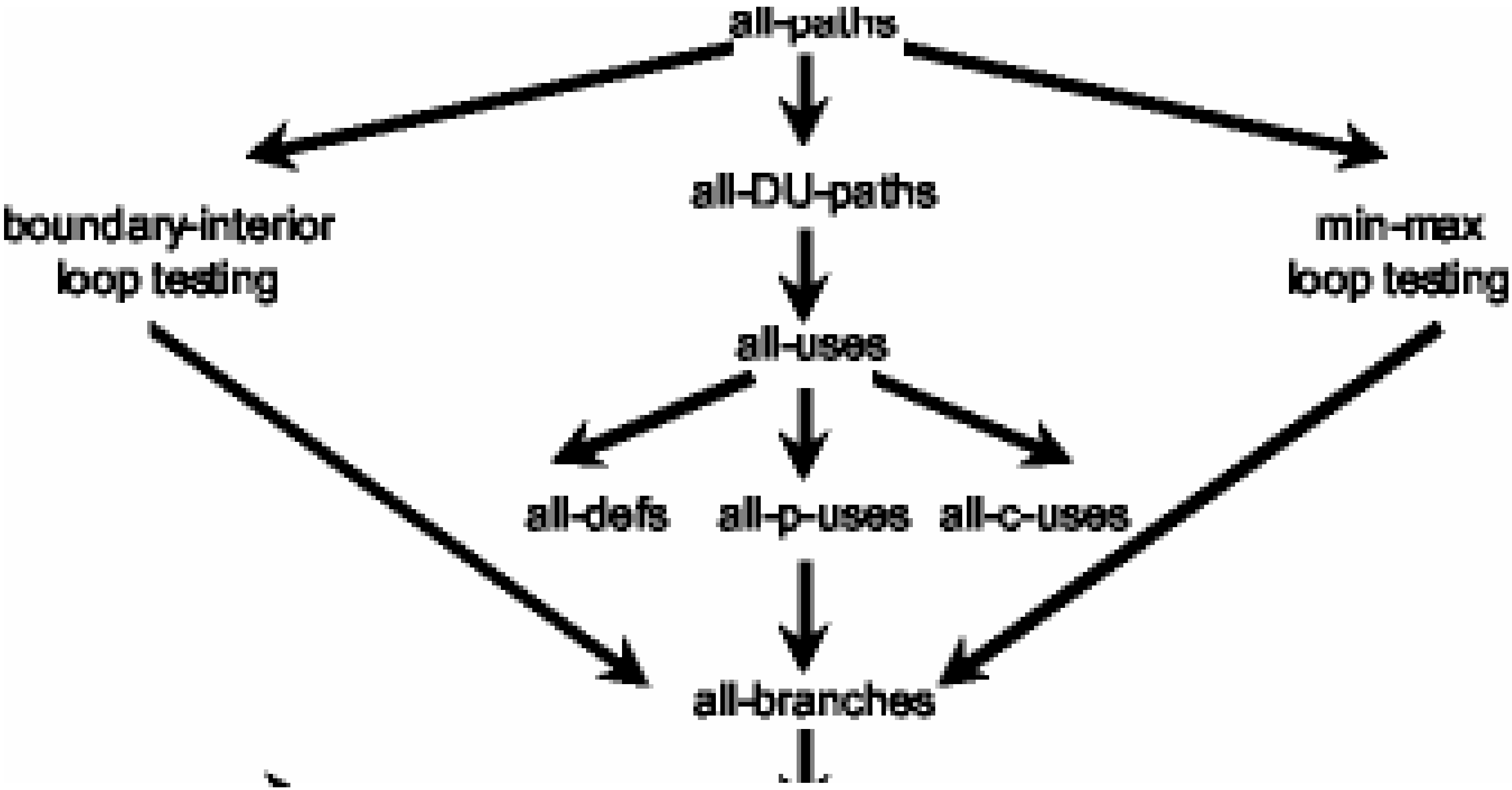
Subsumption

- Criteria C1 subsumes criteria C2, iff
  - For all programs p being tested with specifications s
  - All test sets t
  - t is adequate according to C1 fortesting p with respect to s impliesthat t is adequate according to C2 fortesting p with respect to s
- Path subsumes branch
- Path subsumes statement

Subsumption and Covers

- C1 *subsumes* C2 if any C1-adequate T is also C2-adequate – But some T1 satisfying C1 may detect fewer faults than some T2 satisfying C2
- C1 *properly covers* C2 if each subdomain induced by C2 is a union of subdomains induced by C1

Clarke, Podgurski, Richardson & Zeil, "A Formal Evaluation of Data Flow Path Selection Criteria", IEEE Transactions on Software Engineering, November 1989.


all-paths
all-DU-paths
boundary-interior
loop testing
min-max
loop testing
all-uses
all-defs
all-p-uses
all-c-uses
all-branches

Challenges in Structural Coverage

Interprocedural and gross-level coverage

– e.g., interprocedural data flow, call-graph coverage

Regression testing

Late binding (OO programming languages)

– coverage of actual and apparent polymorphism

Fundamental challenge: Infeasible behaviors

– underlies problems in inter-procedural and polymorphic coverage, as well as obstacles to adoption of more sophisticated coverage criteria and dependence analysis

The Infeasibility Problem

- Syntactically indicated behaviors (paths, data flows, etc.) are often impossible
  - Infeasible control flow, data flow, and data states
- Adequacy criteria are typically impossible to satisfy
- Unsatisfactory approaches:
  - Manual justification for omitting each impossible test case (esp.. for more demanding criteria)
  - Adequacy “scores” based on coverage

    example: 95% statement coverage, 80% def-use coverage

Coverage and Components

State and Encapsulation

- **Procedural programming**
  - **– Basic component: Subroutine**
  - **– Testing method: Subroutine input/output based**
- **Object-oriented and component programming**
  - **– Basic component: Class = Data structure + Set of operations**
  - **– Objects are instances of classes**
  - **– The data structure defines the *state* of the object. Correctness is not based only on output, but also on the state.**
  - **– The data structure is not directly accessible, but can only be accessed using the class *public* operations *(Encapsulation)*.**
- **Problems:**
  - **– What are the basic elements to test?**
  - **– Is it enough to observe input/output relations?**
  - **– How is it possible to observe the state without violating encapsulation?**
  - **– What if the source code is not available (for a third-party component)?**