Lecture 24: Control Flow Graphs

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Foundations of Software Engineering

CSCI 5828 - Spring Semester, 1999

Today's Lecture

- White-Box Testing
  - Control Flow Graphs
    - Coverage Criteria

Testing Approaches

- Black Box Testing
  - Tests are selected based on specification of intended functionality
  - Tester can only see interface to test subject
  - Emphasis on proper use of test subject
- White Box Testing
  - Tests are selected based on internal structure
  - Tester can see inside test subject
  - Emphasis on proper structure of test subject

White-box Testing: Coverage

- Statement Coverage
- Edge Coverage *(Branch Coverage)*
- Condition Coverage *(Edge Coverage)*
- Path Coverage

Details to follow...

Flow Graphs

Graph representation of control flow and data flow relationships

- Control Flow

  The partial order of statement execution, as defined by the semantics of the language

- Data Flow

  The flow of values from definitions of a variable to its uses

A Sample Ada Program to Test

```
1     function P return INTEGER is
2     begin
3         X, Y: INTEGER;
4         READ(X); READ(Y);
5         while (X > 10) loop
6             X := X – 10;
7             exit  when  X = 10;
8         end  loop;
9         if (Y <  20  and  then  X  mod  2 = 0) then
10            Y := Y + 20;
11        else
12            Y := Y – 20;
13        end  if;
14        return  2 ∗ X + Y;
15    end  P;
```
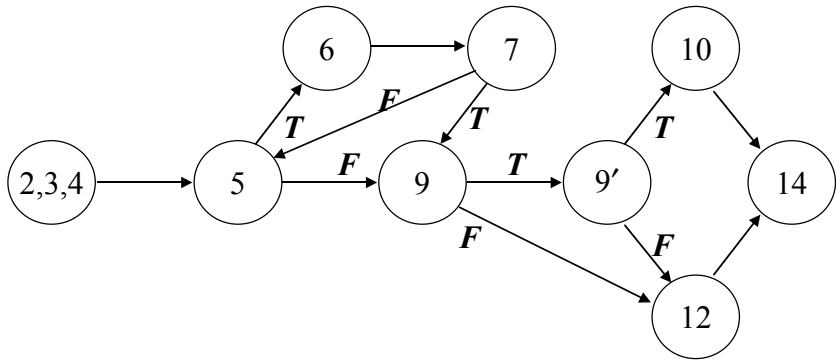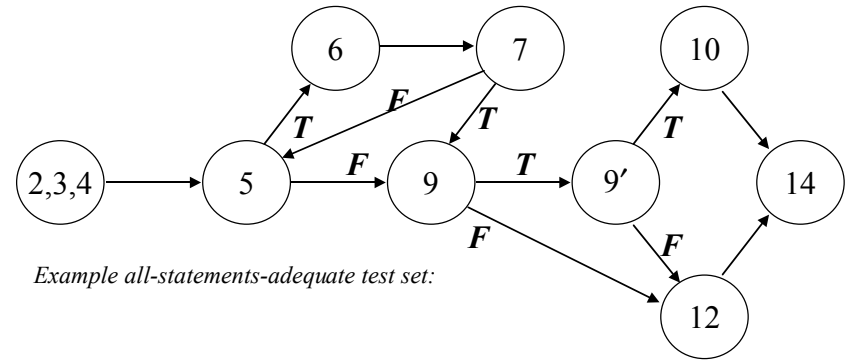
P's Control Flow Graph (CFG)
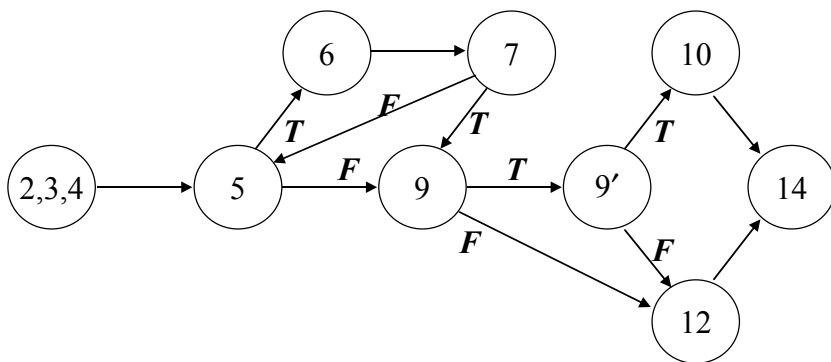
White-box Testing Criteria

- Statement Coverage

  Select a test set T such that, by executing P for each d in T, each elementary statement of P is executed at least once

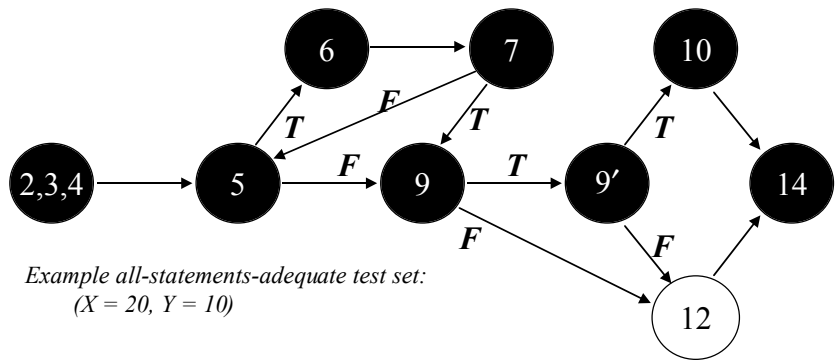# All-Statements Coverage of P
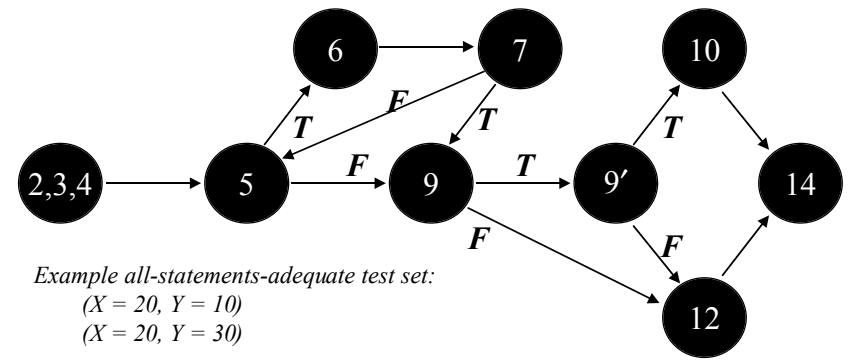
All-Statements Coverage of P

Example all-statements-adequate test set:

All-Statements Coverage of P

Example all-statements-adequate test set:
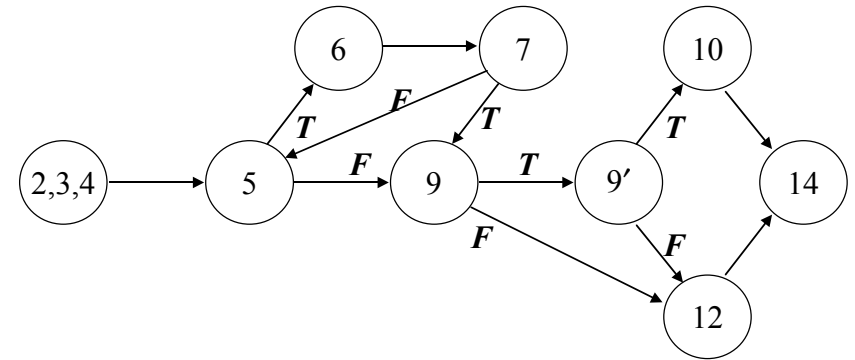 *(X = 20, Y = 10)*

All-Statements Coverage of P

Example all-statements-adequate test set:
  (X = 20, Y = 10)
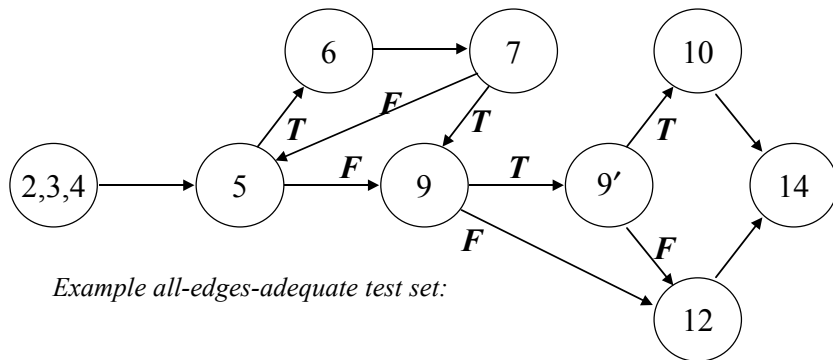 *(X = 20, Y = 30)*

White-box Testing Criteria

- Edge Coverage

  Select a test set *T* such that, by executing *P* for each *d* in *T*, each edge of *P's* control flow graph is traversed at least once
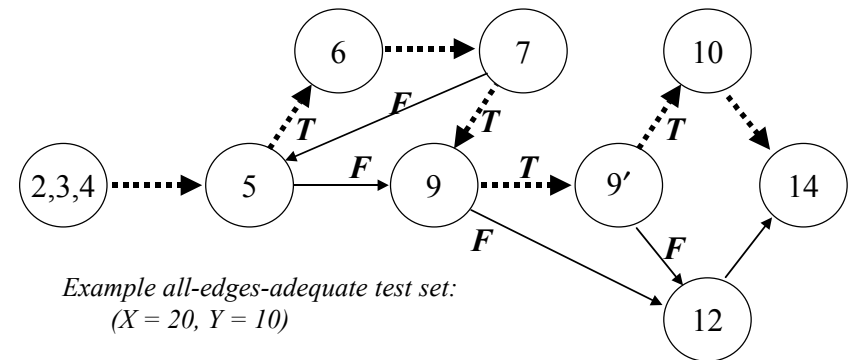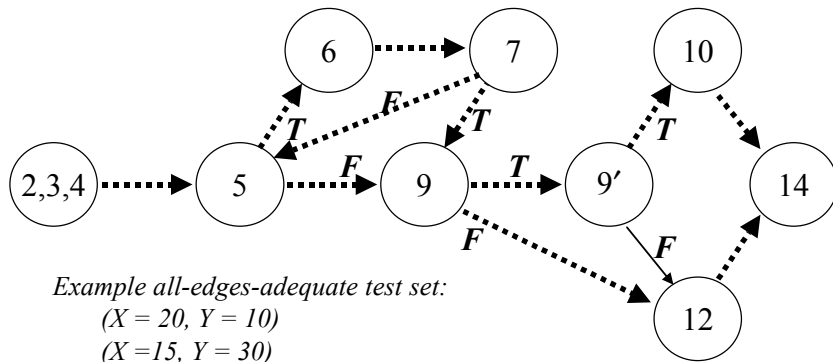
All-Edges Coverage of P

All-Edges Coverage of P

Example all-edges-adequate test set:

All-Edges Coverage of P

Example all-edges-adequate test set:
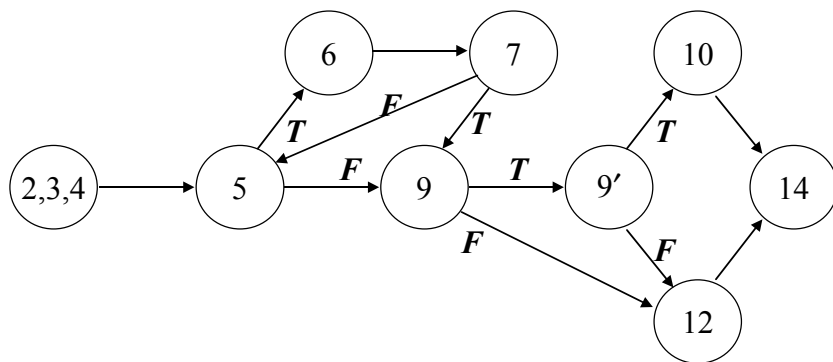*(X = 20, Y = 10)*

All-Edges Coverage of P

Example all-edges-adequate test set:
(X = 20, Y = 10)
(X =15, Y = 30)
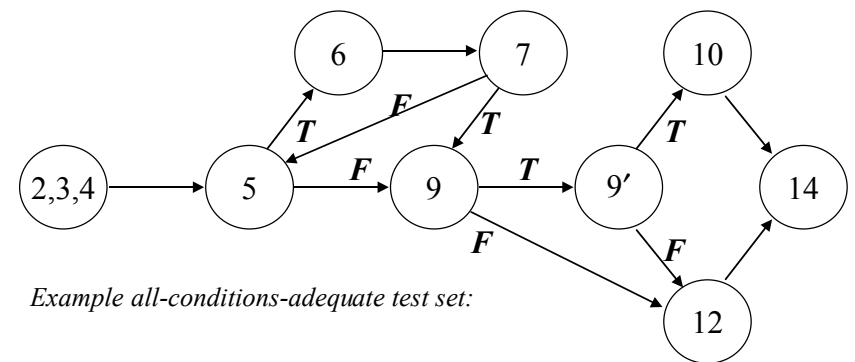
White-box Testing Criteria

- Condition Coverage

  Select a test set T such that, by executing P for each d in T, each edge of $P's$ control flow graph is traversed at least once and all possible values of the constituents of compound conditions are exercised at least once
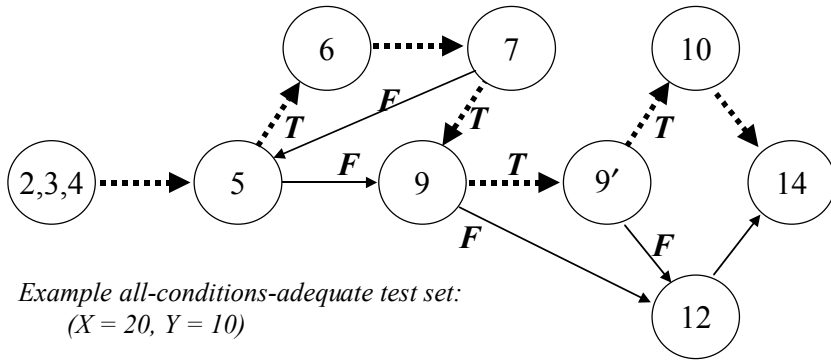
All-Conditions Coverage of P
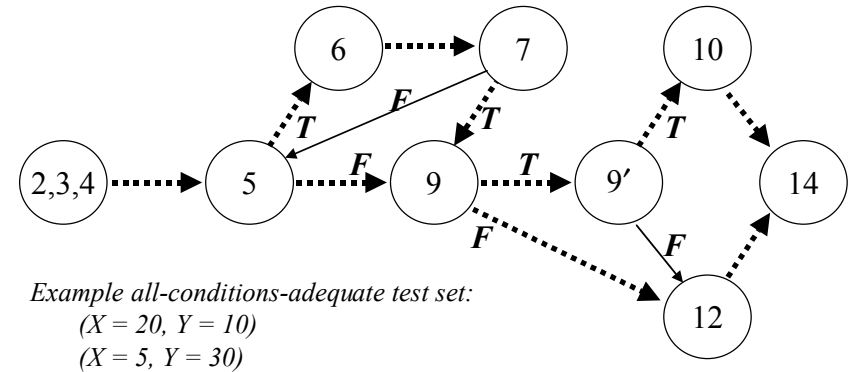
All-Conditions Coverage of P
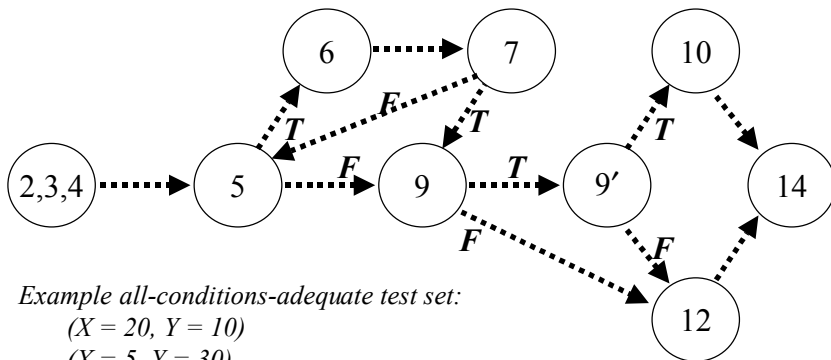

Example all-conditions-adequate test set:

All-Conditions Coverage of P

Example all-conditions-adequate test set:
   (X = 20, Y = 10)

All-Conditions Coverage of P

Example all-conditions-adequate test set:
   (X = 20, Y = 10)
   (X = 5, Y = 30)

All-Conditions Coverage of P

Example all-conditions-adequate test set:
   (X = 20, Y = 10)
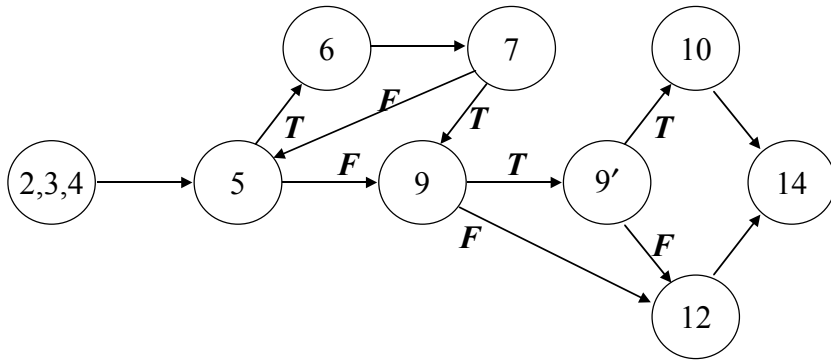   *(X = 5, Y = 30)*
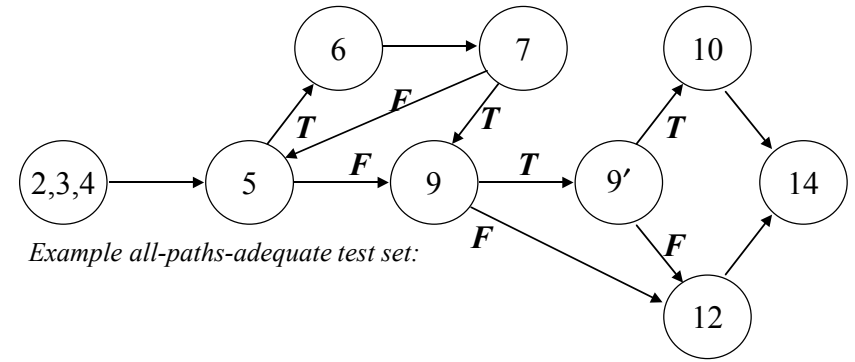   *(X = 21, Y = 10)*

White-box Testing Criteria

- Path Coverage

  Select a test set *T* such that, by executing *P* for each *d* in *T*, all paths leading from the initial to the final node of *P*'s control flow graph are traversed at least once
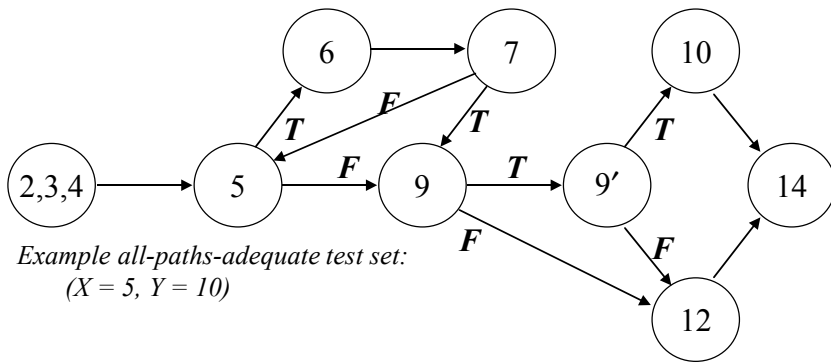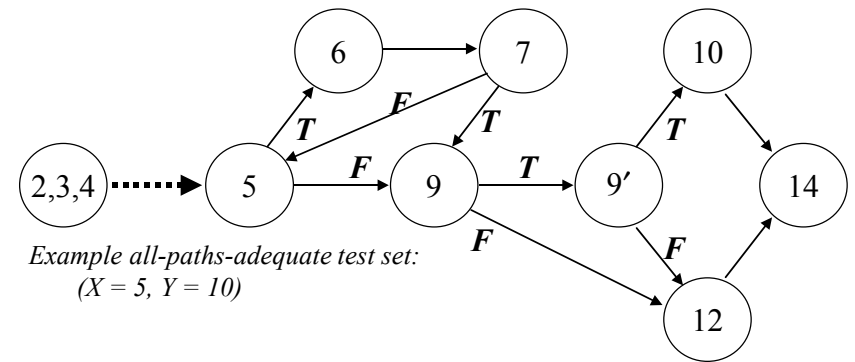
All-Paths Coverage of P

2,3,4 → 5 → 6 → 7
T   F   T   F

5 → 9 → 9′ → 10 → 14

9 → 12 → 14

All-Paths Coverage of P

Example all-paths-adequate test set:

All-Paths Coverage of P

Example all-paths-adequate test set:
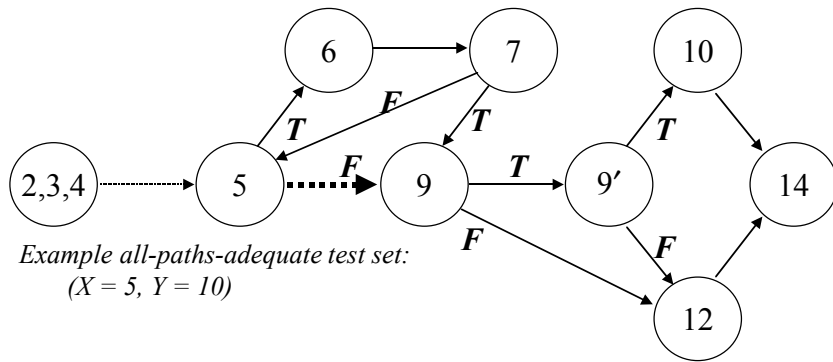   *(X = 5, Y = 10)*

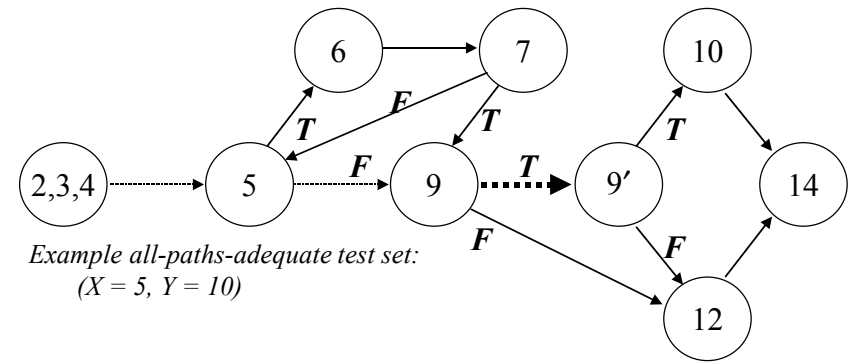---

All-Paths Coverage of P

Example all-paths-adequate test set:
   (X = 5, Y = 10)

All-Paths Coverage of P

Example all-paths-adequate test set:
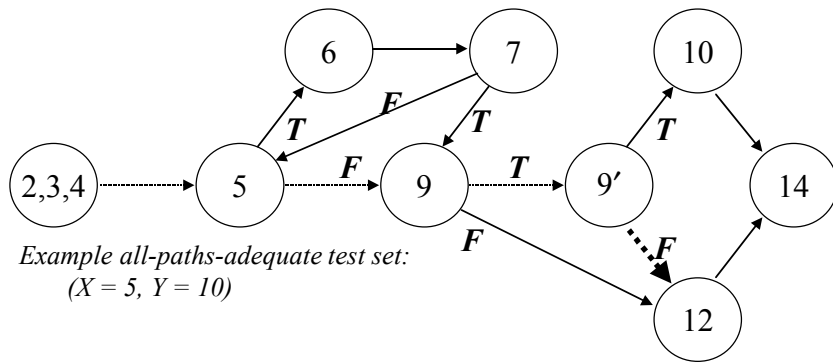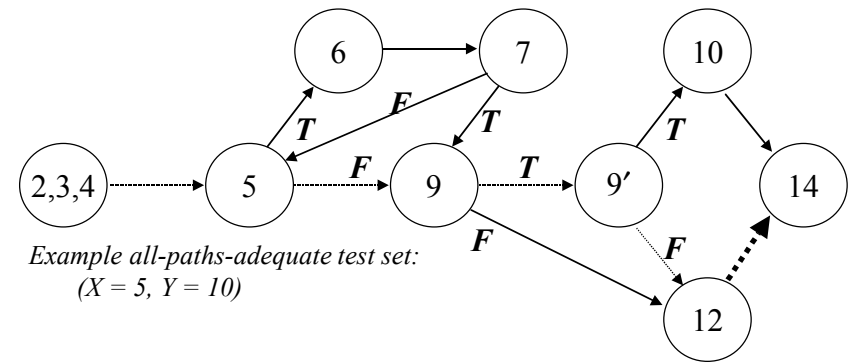 *(X = 5, Y = 10)*

All-Paths Coverage of P

Example all-paths-adequate test set:
  (X = 5, Y = 10)

All-Paths Coverage of P

Example all-paths-adequate test set:
  (X = 5, Y = 10)
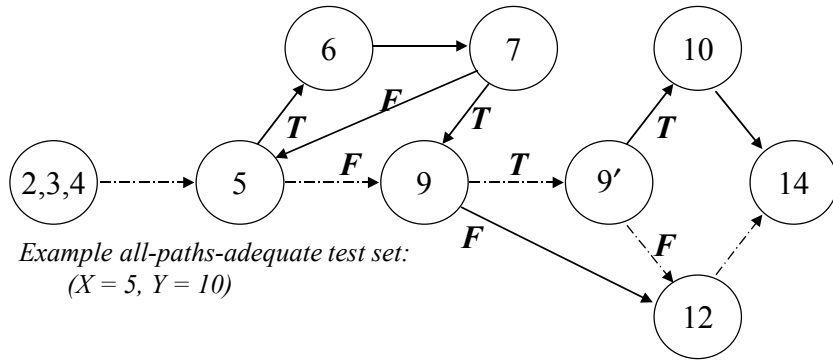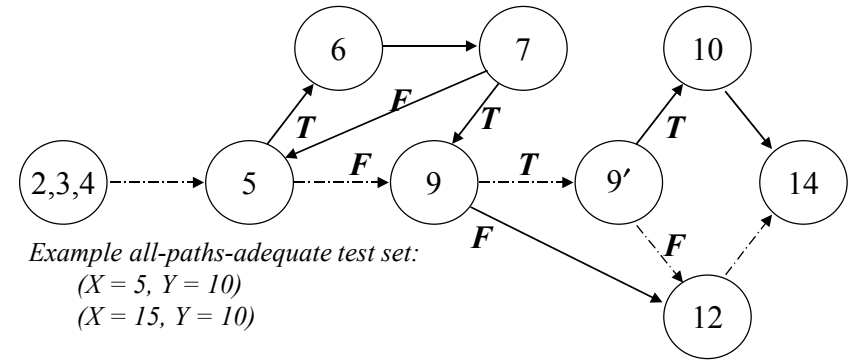
All-Paths Coverage of P

Example all-paths-adequate test set:
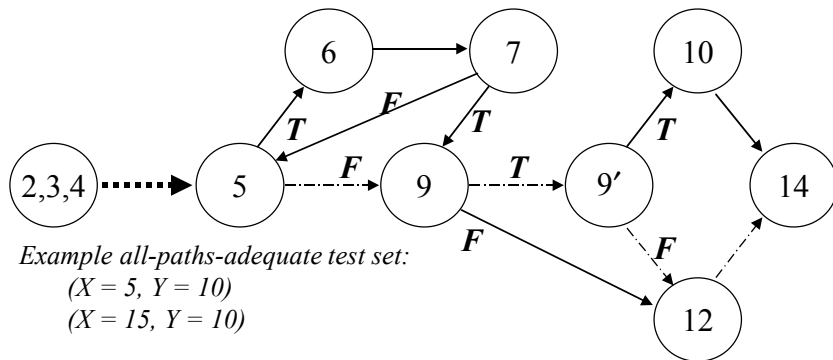 *(X = 5, Y = 10)*

All-Paths Coverage of P

Example all-paths-adequate test set:
(X = 5, Y = 10)

All-Paths Coverage of P

Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)

All-Paths Coverage of P

Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)

All-Paths Coverage of P

Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)

All-Paths Coverage of P

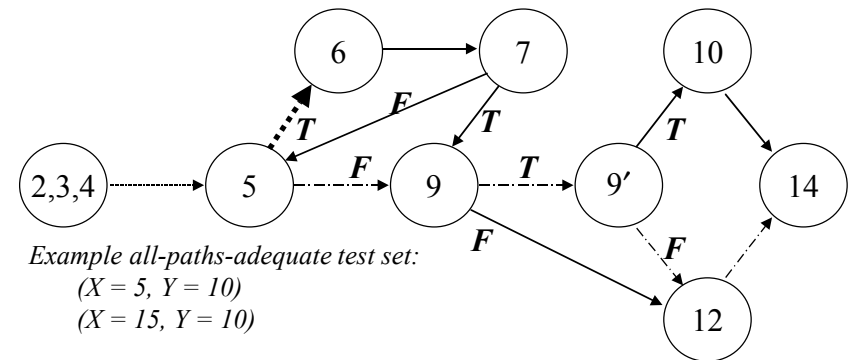
Example all-paths-adequate test set:
  (X = 5, Y = 10)
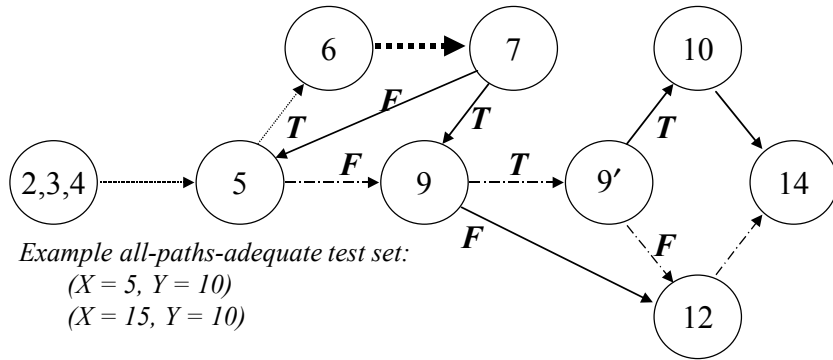 (X = 15, Y = 10)

All-Paths Coverage of P

Example all-paths-adequate test set:
  (X = 5, Y = 10)
  (X = 15, Y = 10)

All-Paths Coverage of P

Example all-paths-adequate test set:
  (X = 5, Y = 10)
  (X = 15, Y = 10)

All-Paths Coverage of P

Example all-paths-adequate test set:
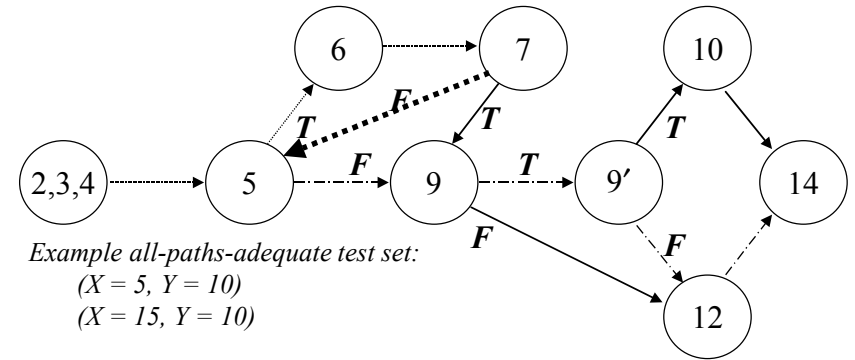 (X = 5, Y = 10)
  (X = 15, Y = 10)
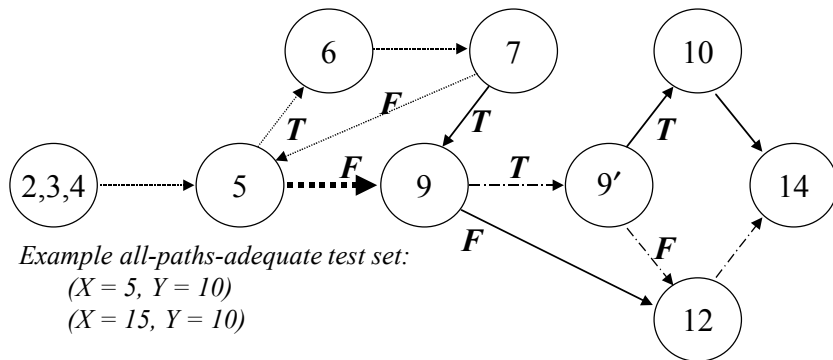
All-Paths Coverage of P
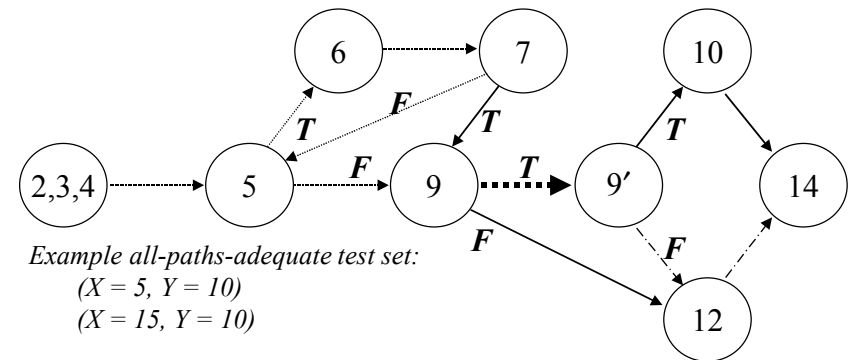

Example all-paths-adequate test set:
   (X = 5, Y = 10)
   (X = 15, Y = 10)

All-Paths Coverage of P

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   (X = 5, Y = 10)
   (X = 15, Y = 10)

All-Paths Coverage of P

Example all-paths-adequate test set:
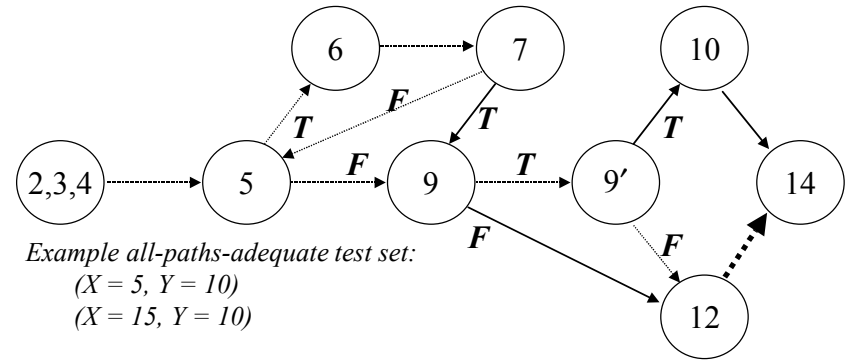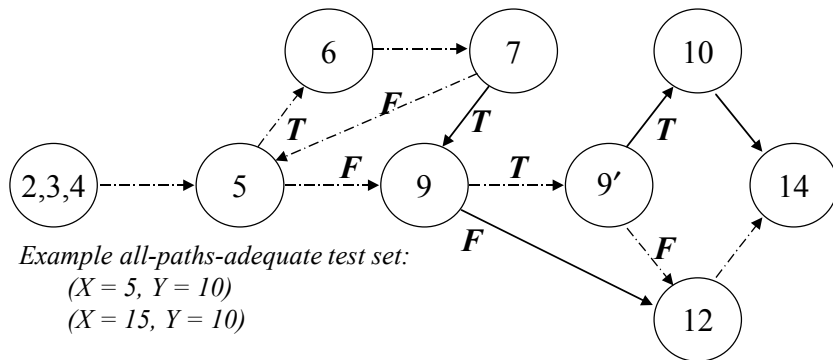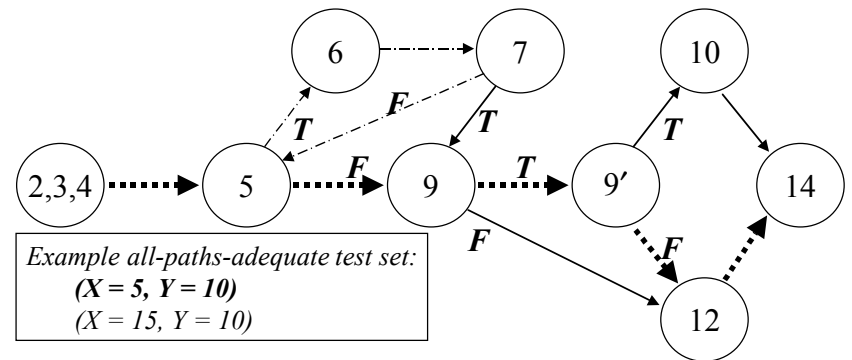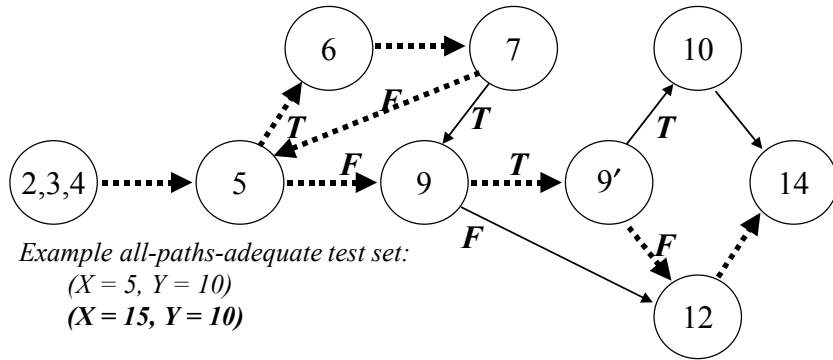   *(X = 5, Y = 10)*
   (X = 15, Y = 10)

All-Paths Coverage of P

Example all-paths-adequate test set:
   (X = 5, Y = 10)
   (X = 15, Y = 10)
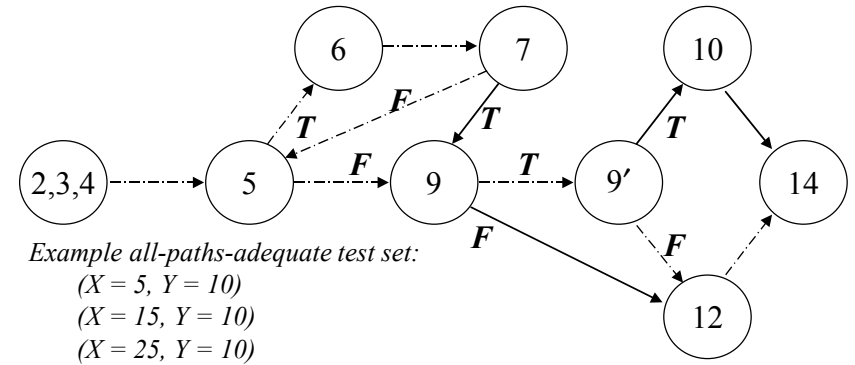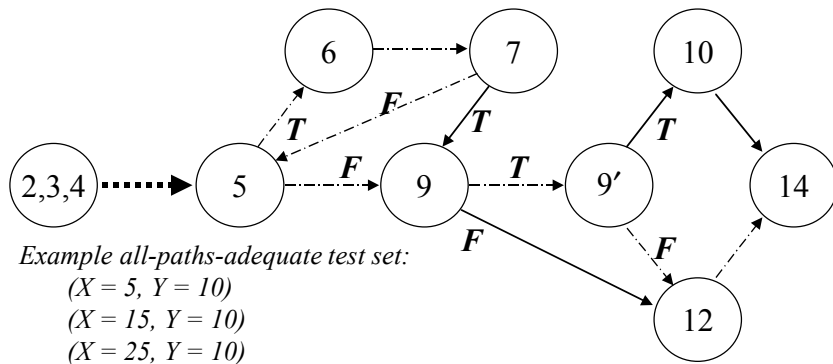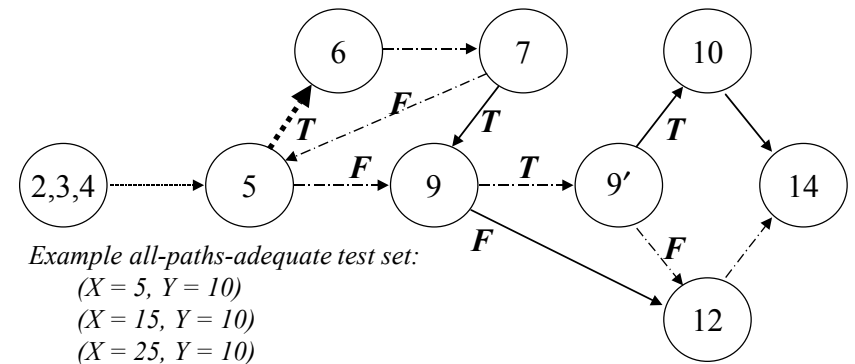
All-Paths Coverage of P

6   7   10

5   9   9'   14

2,3,4

12

T *F* *T* *T* *F* *T* *F* *F*

Example all-paths-adequate test set:
  (X = 5, Y = 10)
  (X = 15, Y = 10)

Lecture 24   45

All-Paths Coverage of P

6   7   10

5   9   9'   14

2,3,4

12

T *F* *T* *T* *F* *T* *F* *F*

Example all-paths-adequate test set:
  (X = 5, Y = 10)
  (X = 15, Y = 10)
  (X = 25, Y = 10)

Lecture 24   46

All-Paths Coverage of P

6   7   10

5   9   9'   14

2,3,4

12

T *F* *T* *T* *F* *T* *F* *F*

Example all-paths-adequate test set:
  (X = 5, Y = 10)
  (X = 15, Y = 10)
  (X = 25, Y = 10)

Lecture 24   47

All-Paths Coverage of P

6   7   10

5   9   9'   14

2,3,4

12

T *F* *T* *T* *F* *T* *F* *F*

Example all-paths-adequate test set:
  (X = 5, Y = 10)
  (X = 15, Y = 10)
  (X = 25, Y = 10)

Lecture 24   48
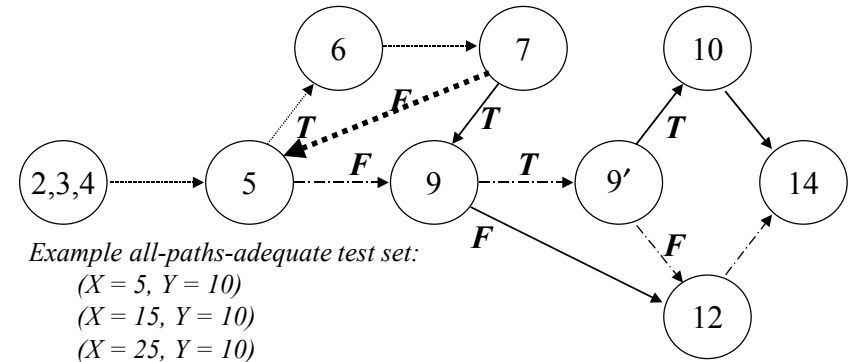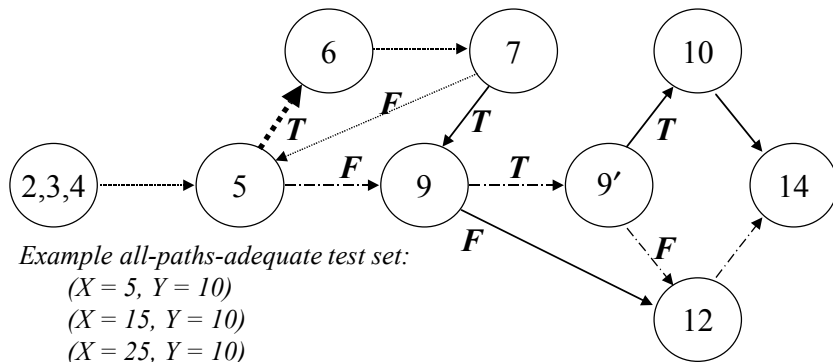
All-Paths Coverage of P

Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)
(X = 25, Y = 10)

Lecture 24

49

All-Paths Coverage of P

Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)
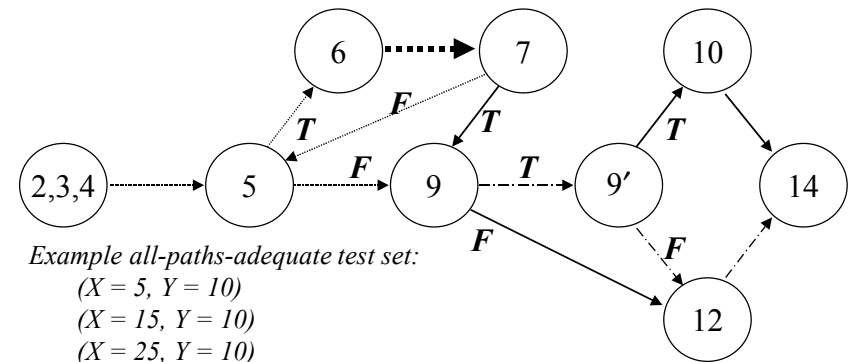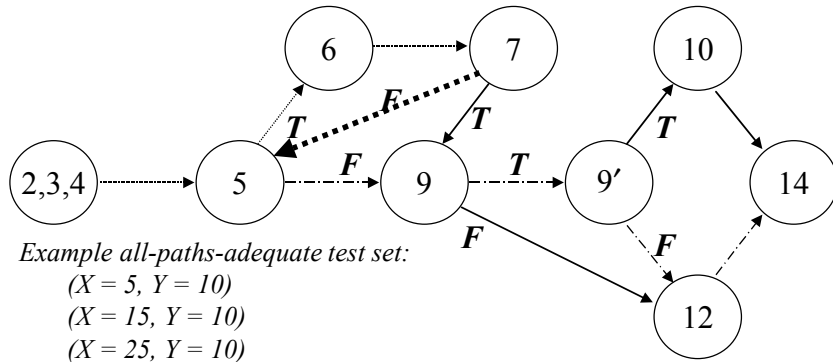(X = 25, Y = 10)

Lecture 24

50

All-Paths Coverage of P

Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)
(X = 25, Y = 10)

Lecture 24

51

All-Paths Coverage of P

Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)
(X = 25, Y = 10)

Lecture 24

52

All-Paths Coverage of P

6 → 7 → 10
5 (T) 6, 7 (F), 7 (T) 9
2,3,4 → 5 (F) 9 (T) 9′ (T) 10 → 14
9′ (F) 12

Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)
(X = 25, Y = 10)
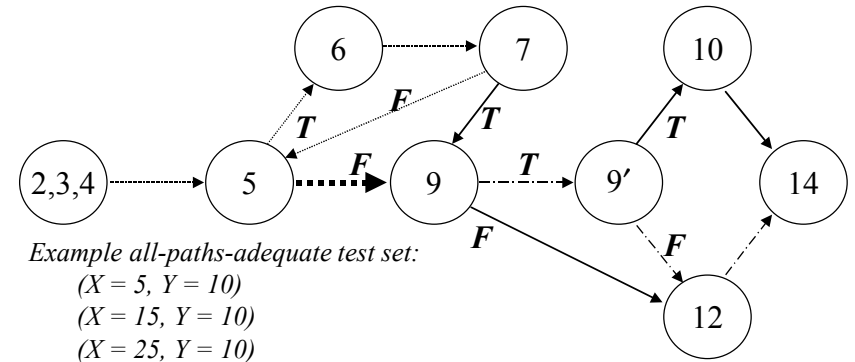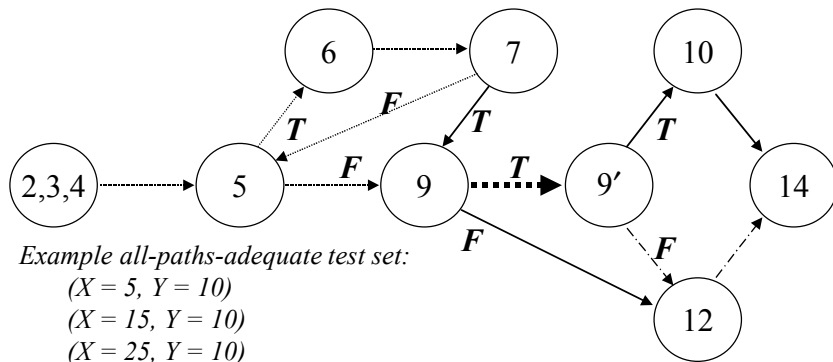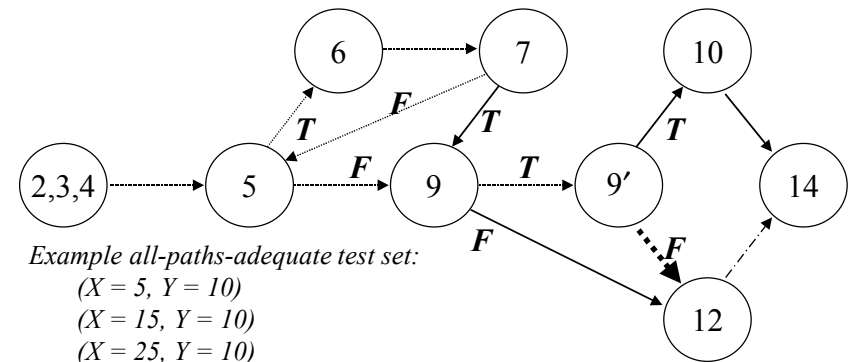
Lecture 24

53

All-Paths Coverage of P

Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)
(X = 25, Y = 10)

Lecture 24

54

All-Paths Coverage of P

Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)
(X = 25, Y = 10)

Lecture 24

55

All-Paths Coverage of P

Example all-paths-adequate test set:
(X = 5, Y = 10)
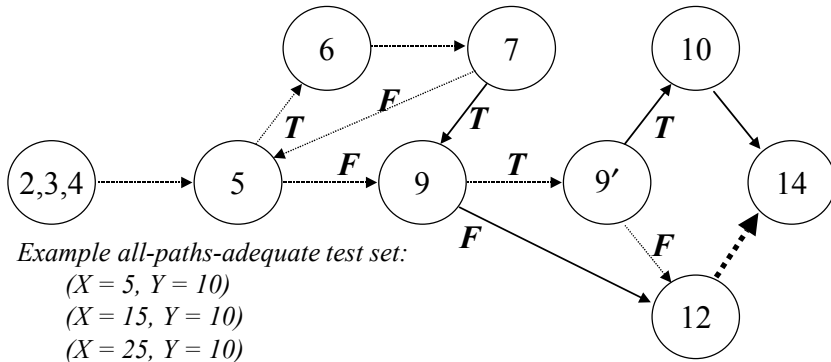(X = 15, Y = 10)
(X = 25, Y = 10)

Lecture 24

56

All-Paths Coverage of P

Example all-paths-adequate test set:
  (X = 5, Y = 10)
  (X = 15, Y = 10)
  (X = 25, Y = 10)

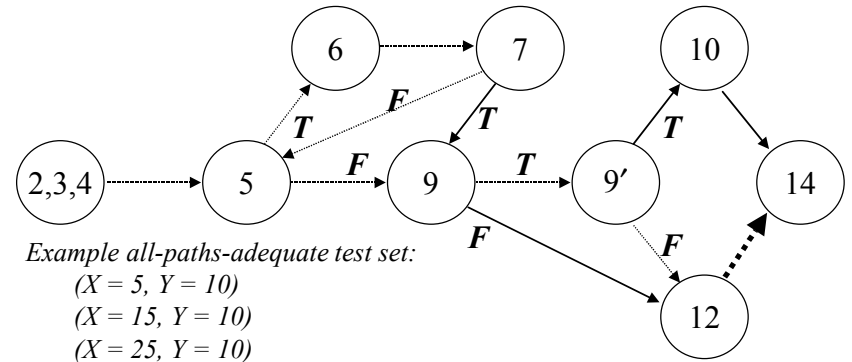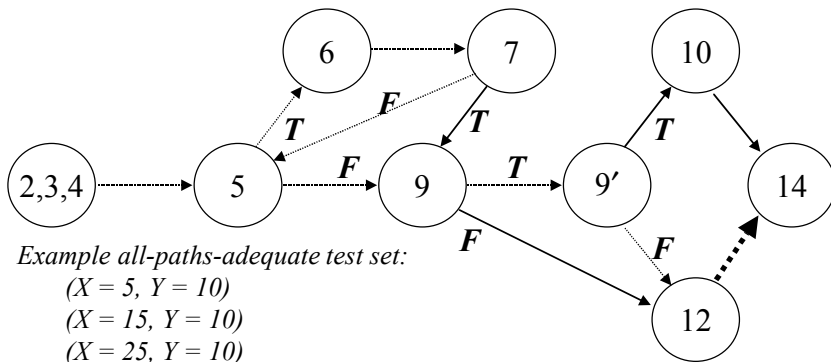# All-Paths Coverage of P

Example all-paths-adequate test set:
  (X = 5, Y = 10)
  (X = 15, Y = 10)
  (X = 25, Y = 10)

All-Paths Coverage of P

Example all-paths-adequate test set:
  (X = 5, Y = 10)
  (X = 15, Y = 10)
  (X = 25, Y = 10)
  (X = 35, Y = 10)

  ...