Lecture 14: 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

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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

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White-box Testing: Coverage

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

Details to follow...

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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

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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;
```


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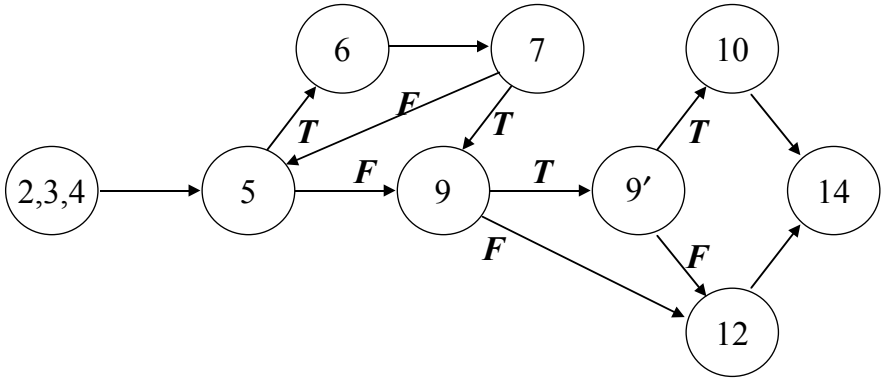
P's Control Flow Graph (CFG)



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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

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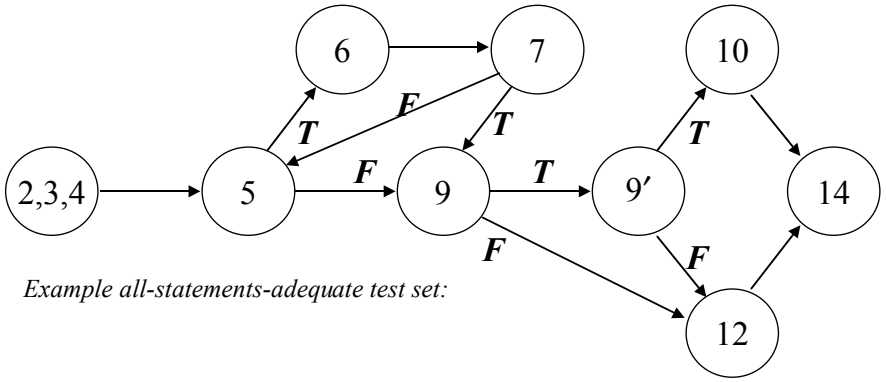
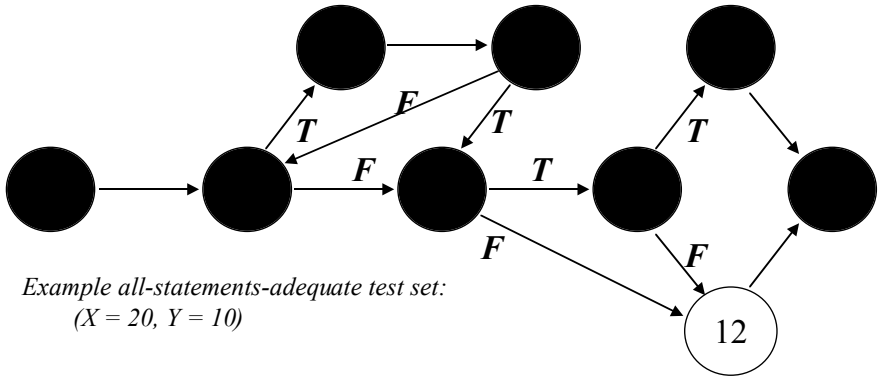
All-Statements Coverage of P



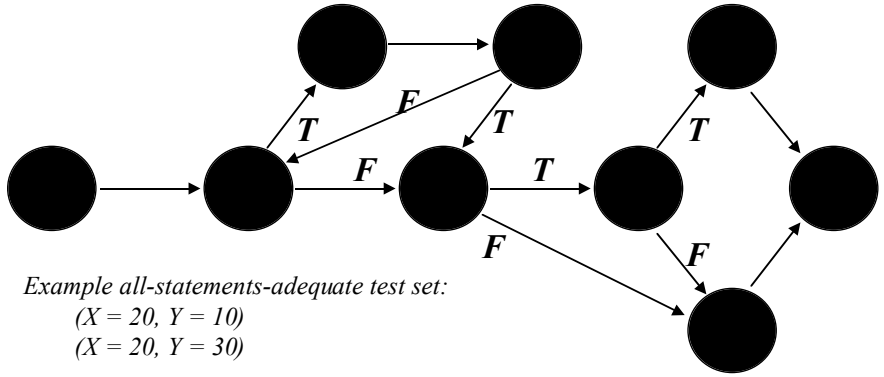
Example all-statements-adequate test set:

All-Statements Coverage of P



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

All-Statements Coverage of P



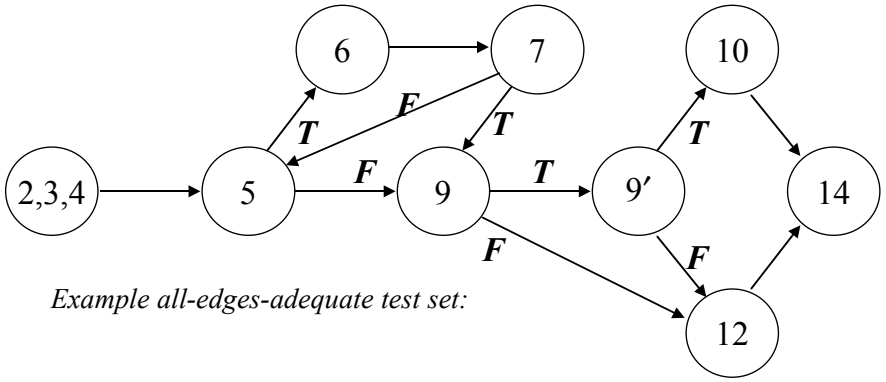
Example all-statements-adequate test set:
(X = 20, Y = 10)
(X = 20, Y = 30)

White-box Testing Criteria

- Edge Coverage

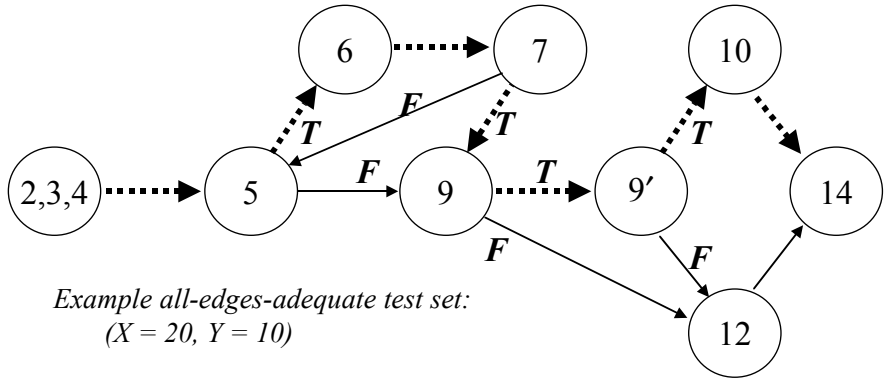
  Select a test set *T* such that, by executing *P* for each *d* in *T*, each edge of *P's* control flow graph is traversed at least once

All-Edges Coverage of P



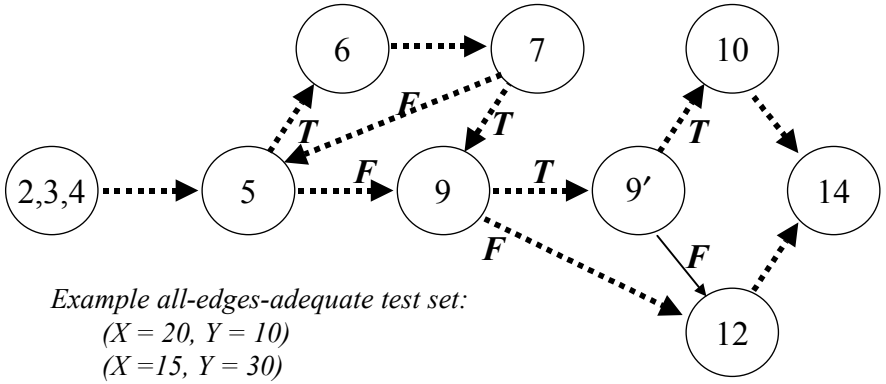
Example all-edges-adequate test set:

All-Edges Coverage of P



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

All-Edges Coverage of P



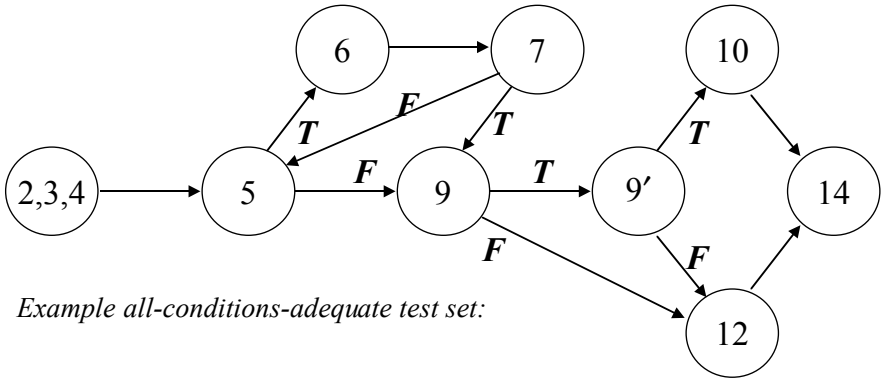
Example all-edges-adequate test set:
(X = 20, Y = 10)
(X =15, Y = 30)

White-box Testing Criteria

- Condition Coverage

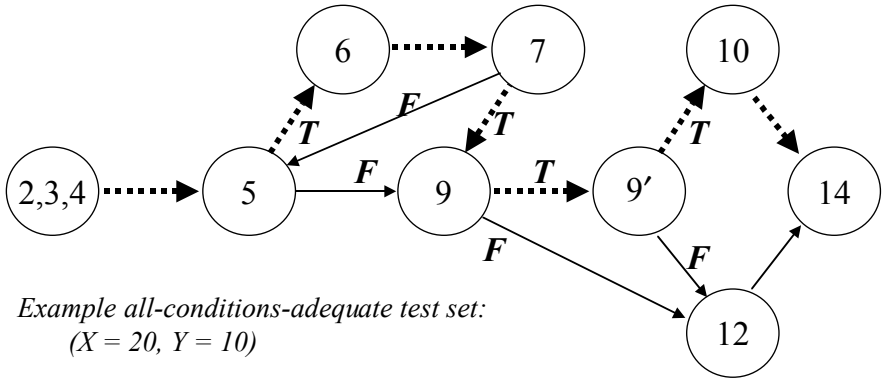
  Select a test set *T* such that, by executing *P* for each *d* in *T*, each edge of *P's* control flow graph is traversed at least once and all possible values of the constituents of compound conditions are exercised at least once

All-Conditions Coverage of P



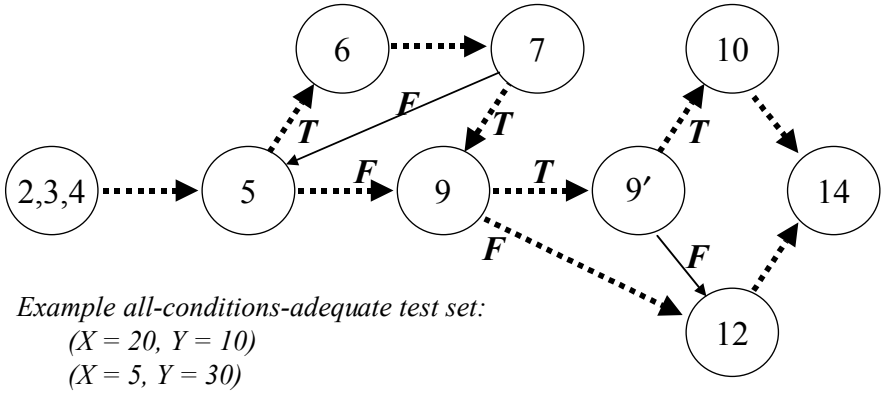
Example all-conditions-adequate test set:

All-Conditions Coverage of P



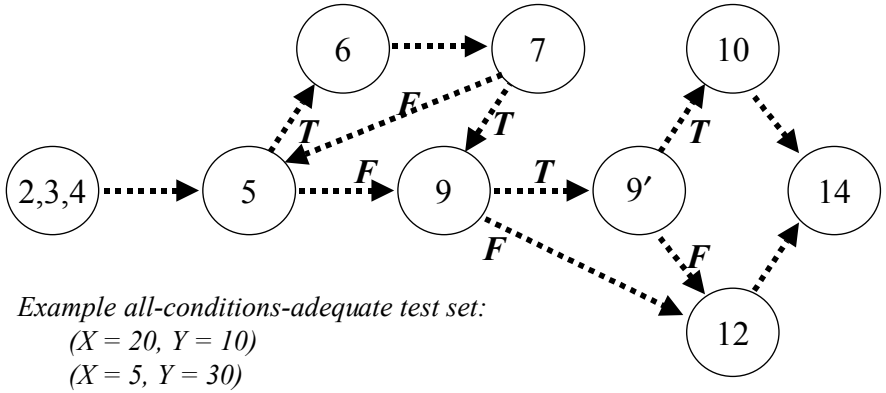
Example all-conditions-adequate test set:
(X = 20, Y = 10)

All-Conditions Coverage of P



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

All-Conditions Coverage of P



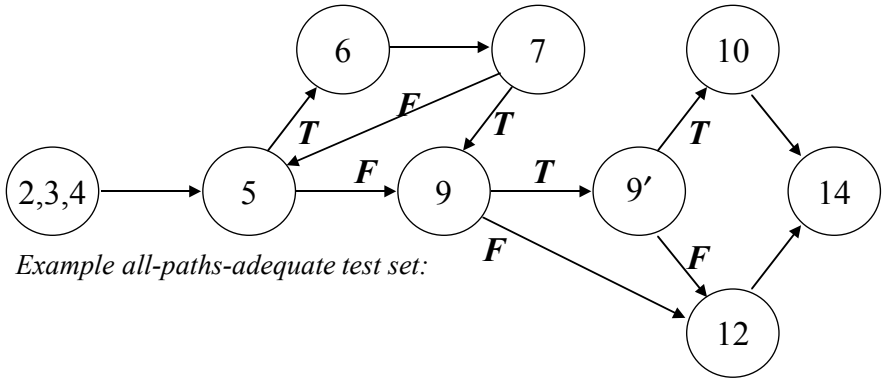
Example all-conditions-adequate test set:
(X = 20, Y = 10)
(X = 5, Y = 30)
(X = 21, Y = 10)

White-box Testing Criteria

- Path Coverage

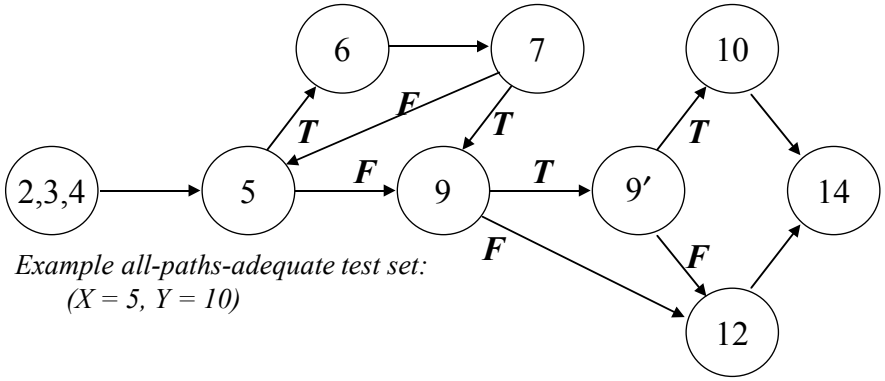
  Select a test set *T* such that, by executing *P* for each *d* in *T*, all paths leading from the initial to the final node of *P*'s control flow graph are traversed at least once

All-Paths Coverage of P



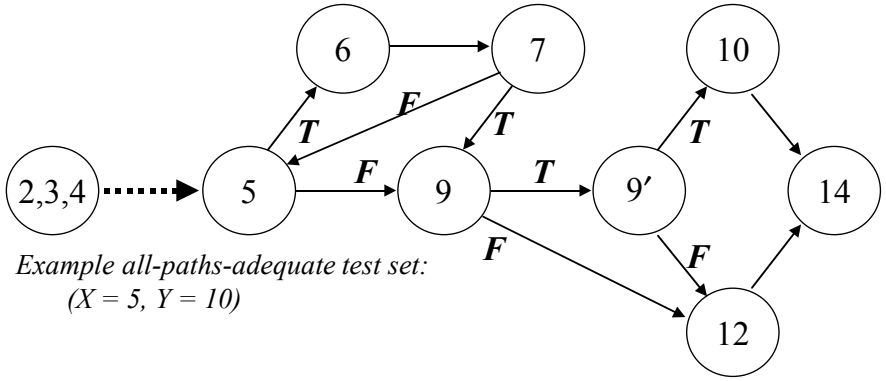
Example all-paths-adequate test set:

All-Paths Coverage of P



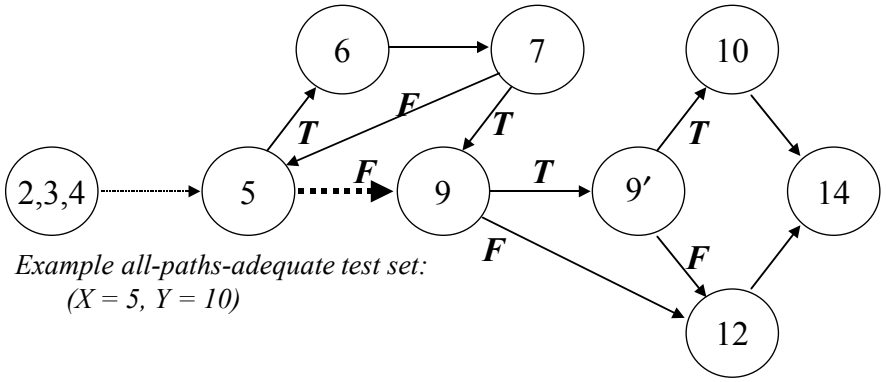
Example all-paths-adequate test set:
(X = 5, Y = 10)

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)

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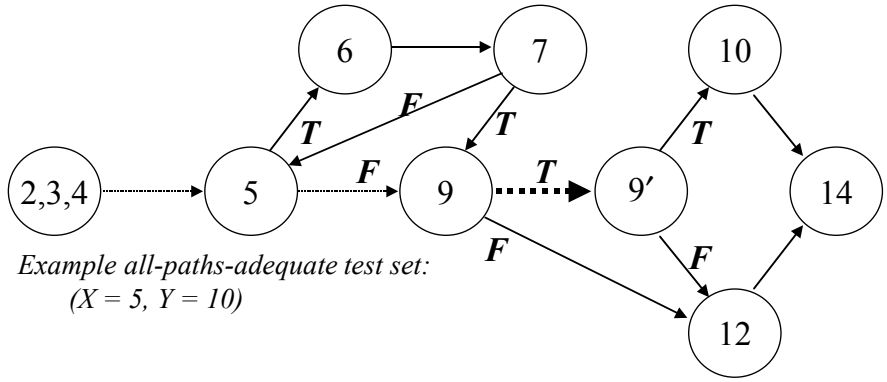
All-Paths Coverage of P



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

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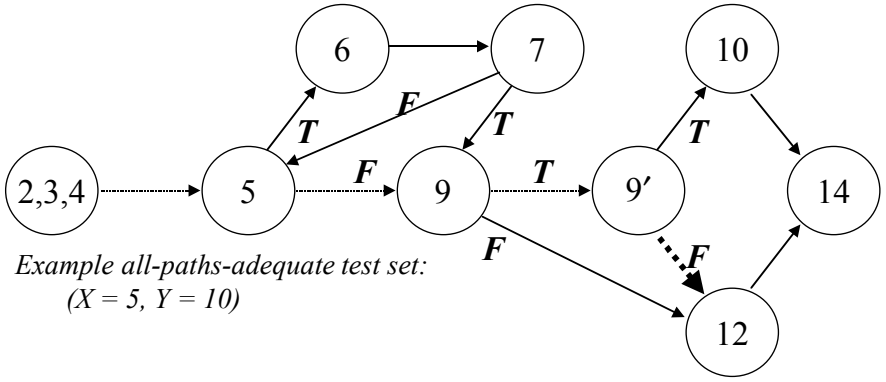
All-Paths Coverage of P



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(X = 5, Y = 10)

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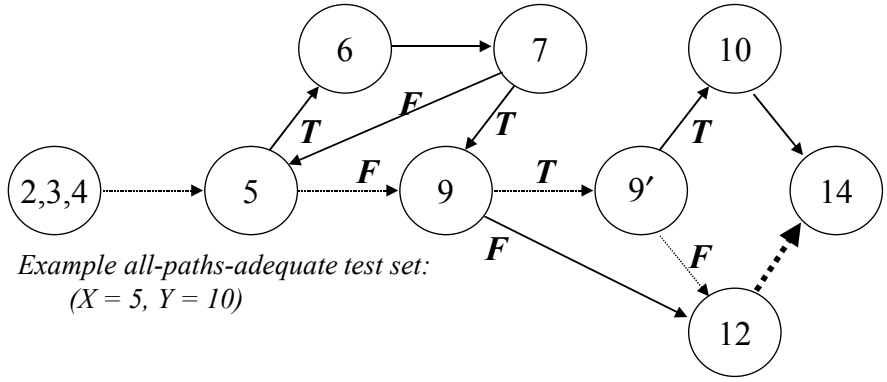
All-Paths Coverage of P



Example all-paths-adequate test set:
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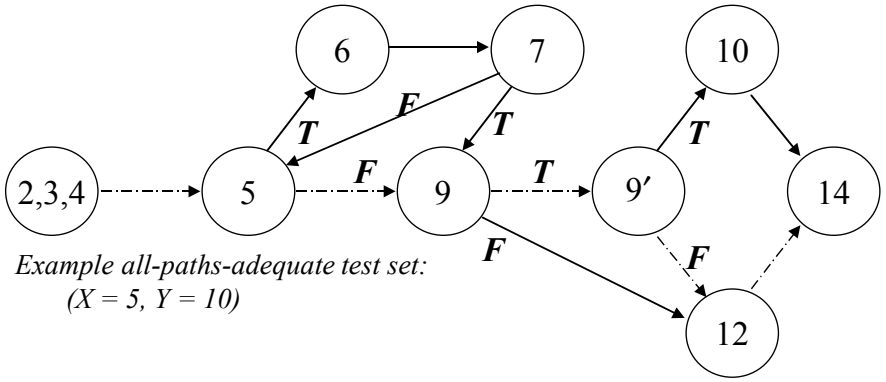
All-Paths Coverage of P



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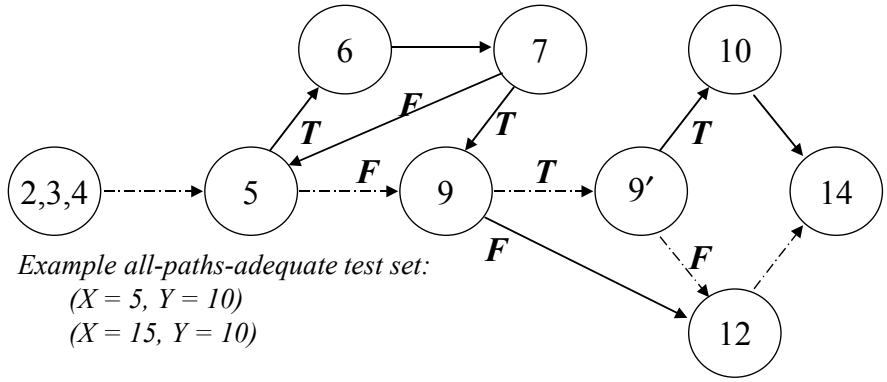

Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)

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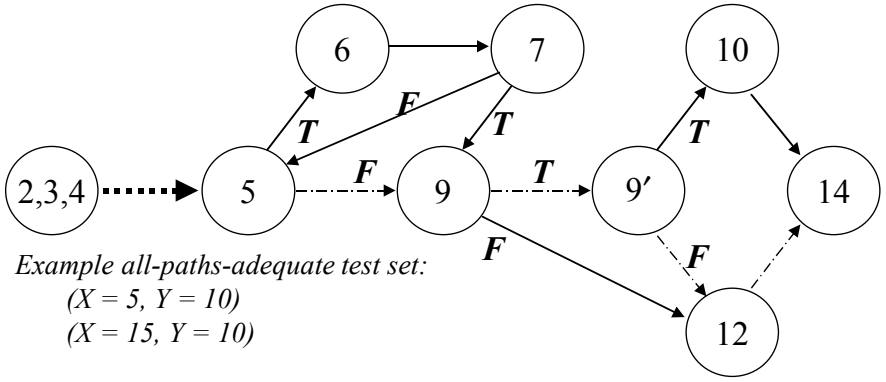
All-Paths Coverage of P



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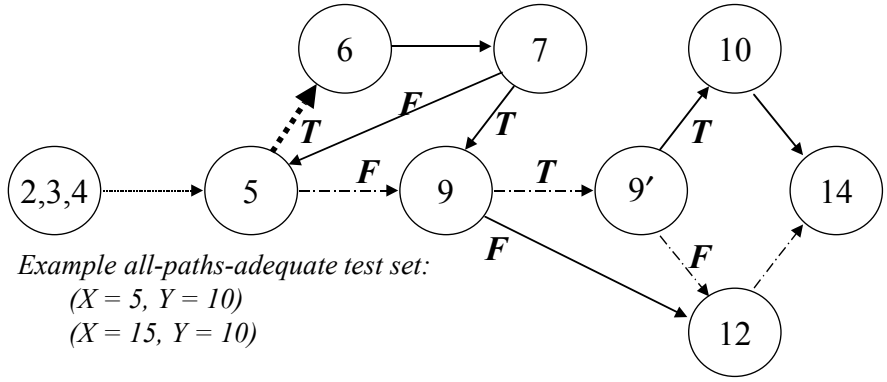
All-Paths Coverage of P



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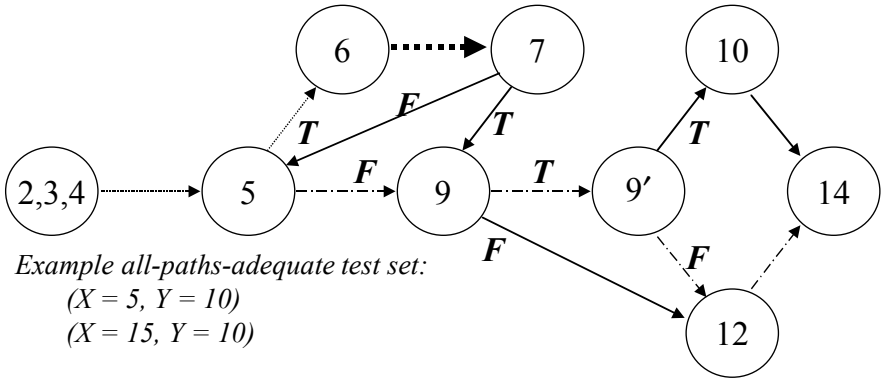

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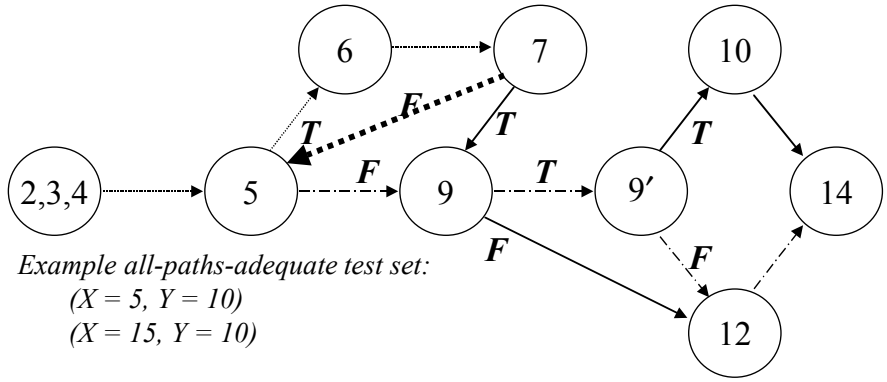
All-Paths Coverage of P



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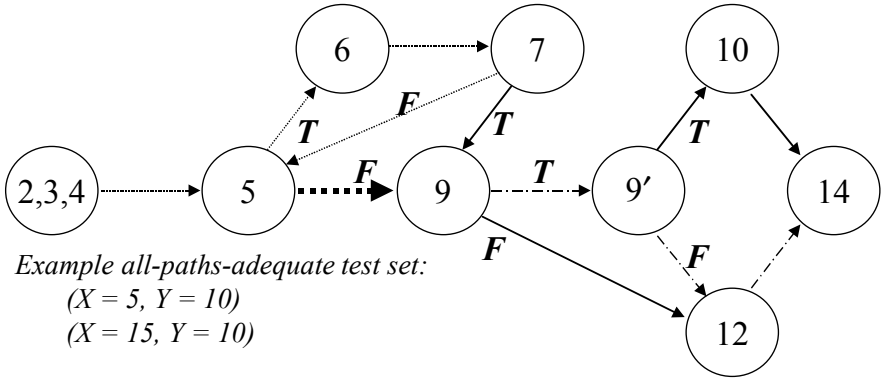

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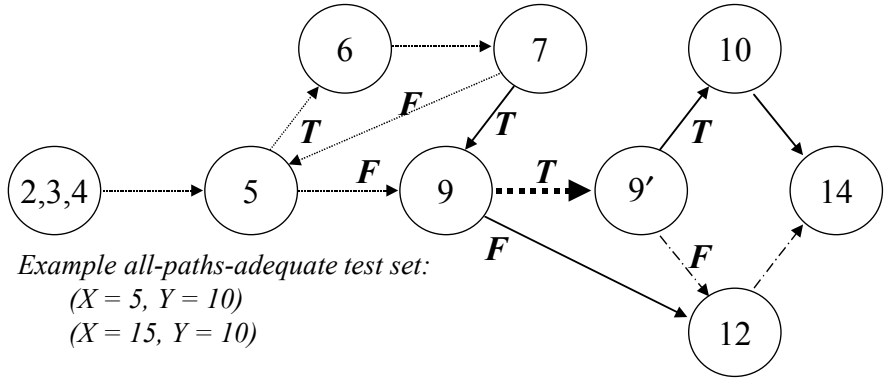

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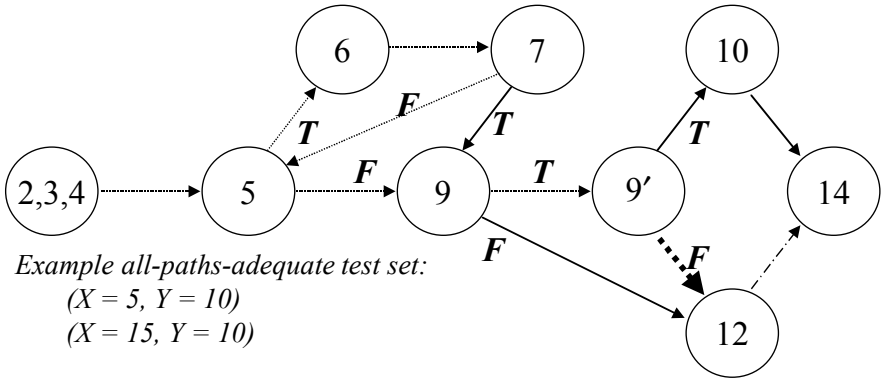

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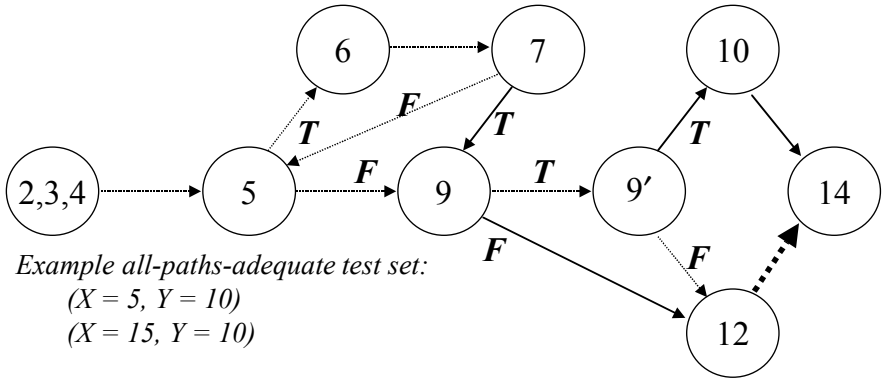
All-Paths Coverage of P



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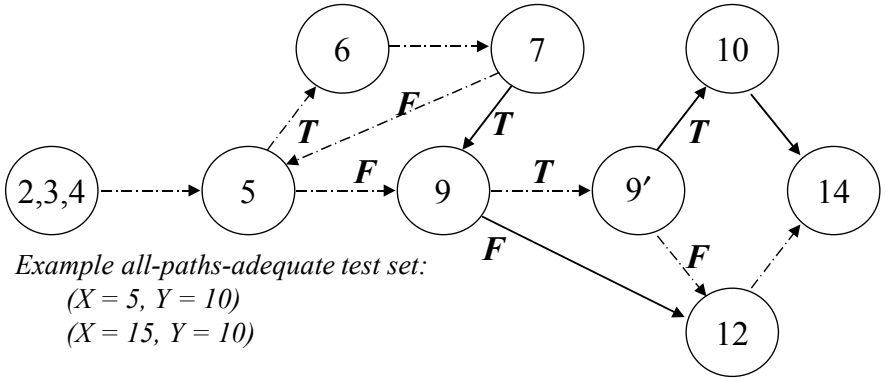
(X = 5, Y = 10)
(X = 15, Y = 10)

All-Paths Coverage of P



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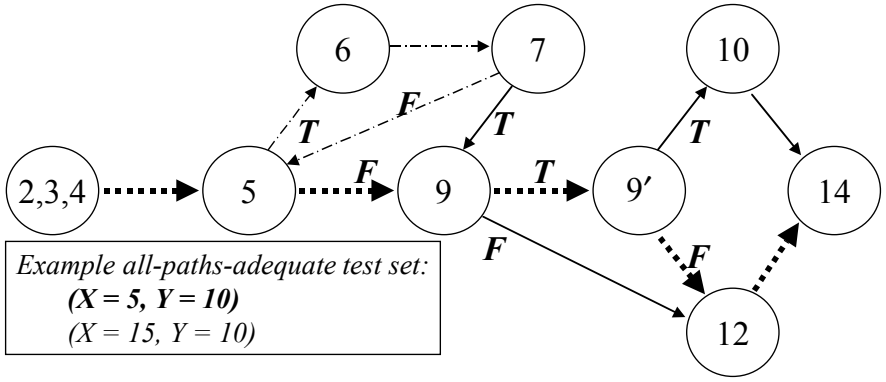
(X = 15, Y = 10)

All-Paths Coverage of P



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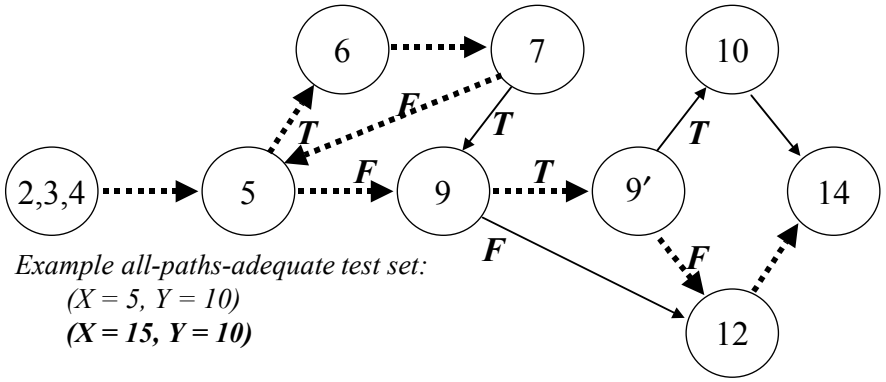
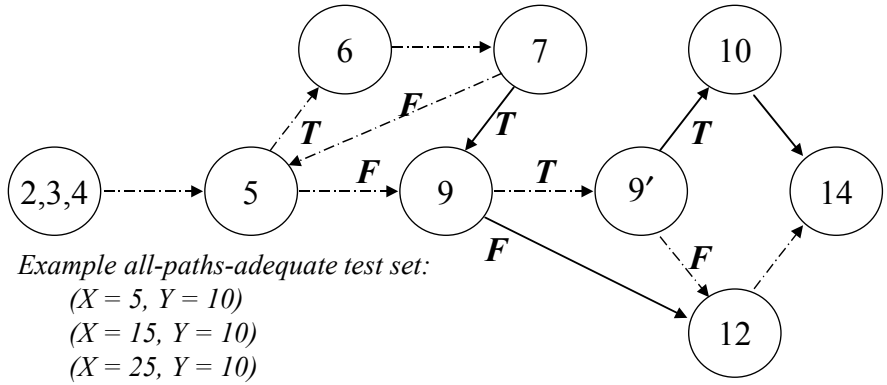


Example all-paths-adequate test set:

(X = 5, Y = 10)

(X = 15, Y = 10)

All-Paths Coverage of P



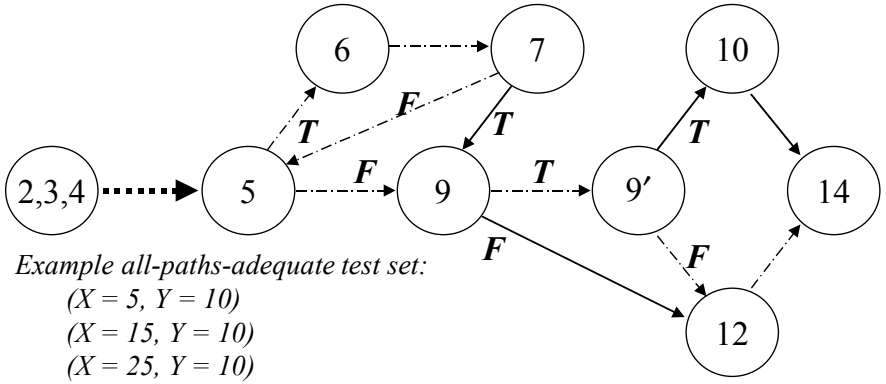
Example all-paths-adequate test set:

(X = 5, Y = 10)

(X = 15, Y = 10)

(X = 25, Y = 10)

All-Paths Coverage of P



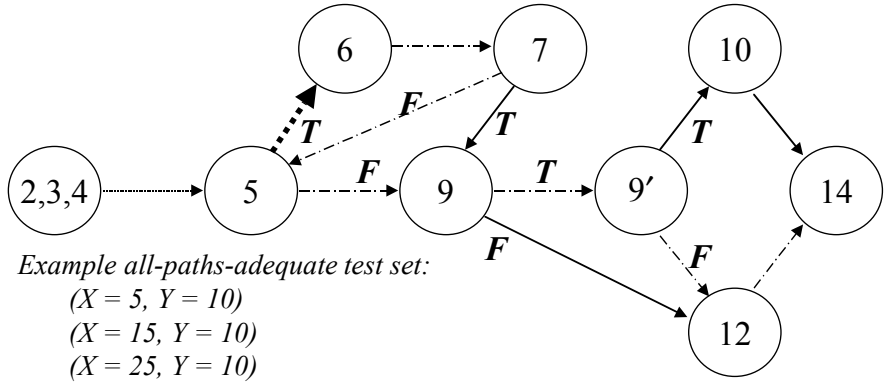
Example all-paths-adequate test set:

(X = 5, Y = 10)

(X = 15, Y = 10)

(X = 25, Y = 10)

All-Paths Coverage of P



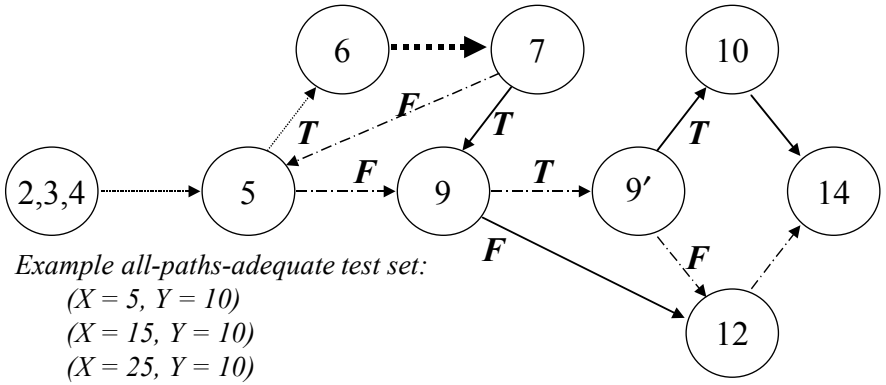
Example all-paths-adequate test set:

(X = 5, Y = 10)

(X = 15, Y = 10)

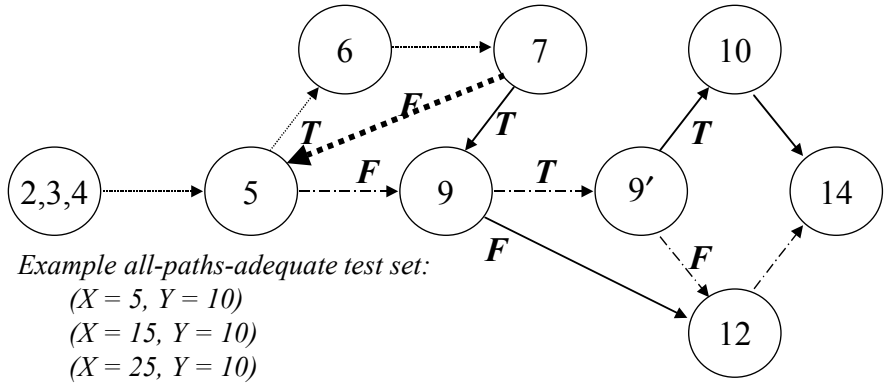
(X = 25, Y = 10)

All-Paths Coverage of P



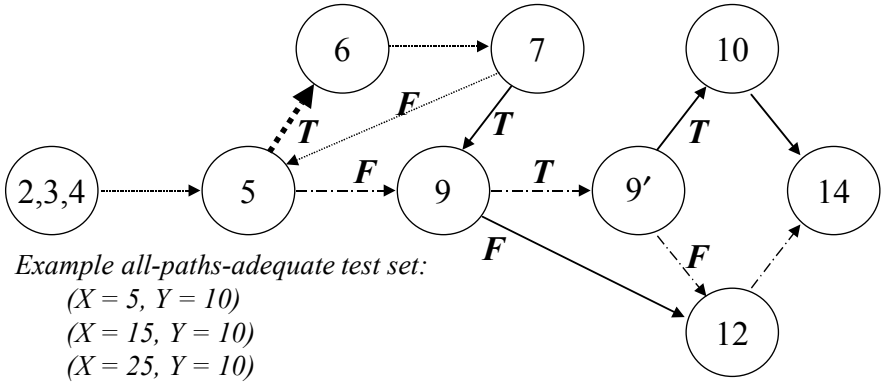
Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)
(X = 25, Y = 10)

All-Paths Coverage of P



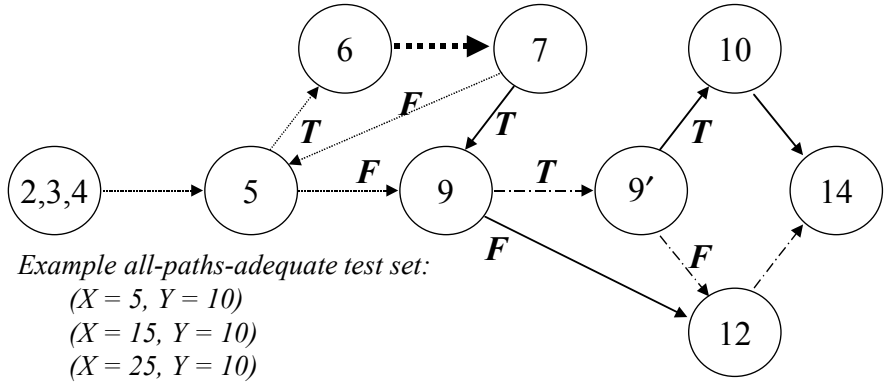
Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)
(X = 25, Y = 10)

All-Paths Coverage of P



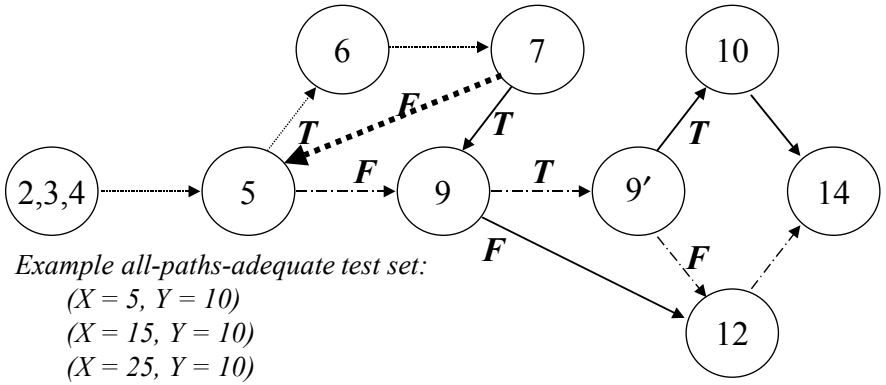
Example all-paths-adequate test set:
(X = 5, Y = 10)
(X = 15, Y = 10)
(X = 25, Y = 10)

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:
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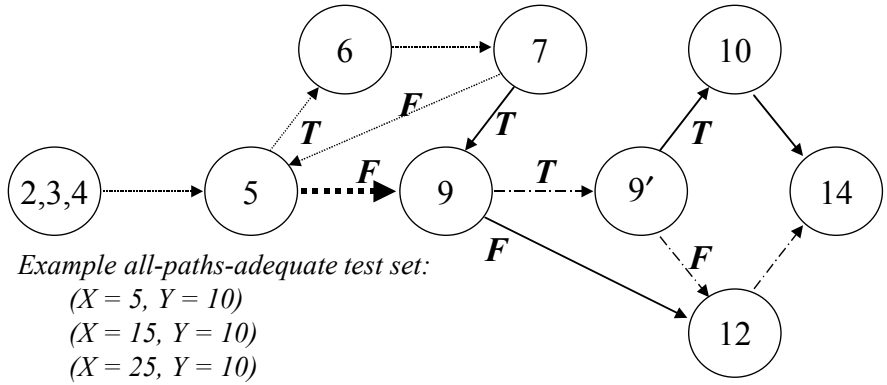
(X = 15, Y = 10)
(X = 25, Y = 10)

All-Paths Coverage of P



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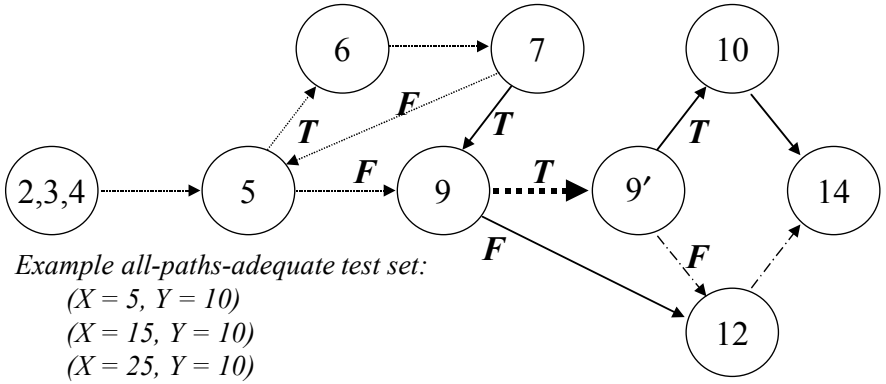
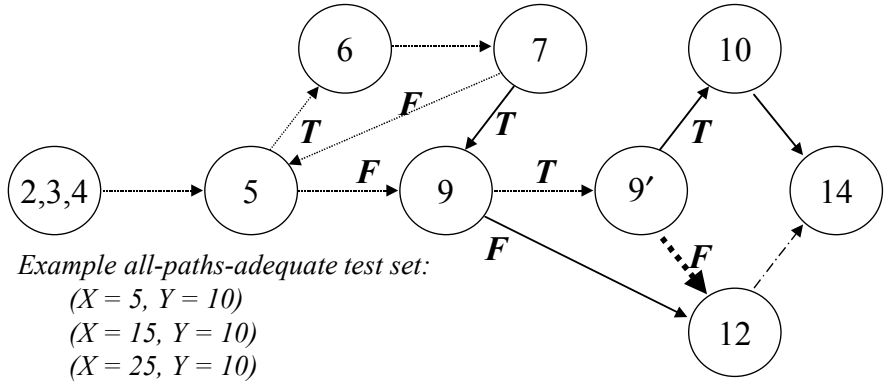
(X = 25, Y = 10)

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



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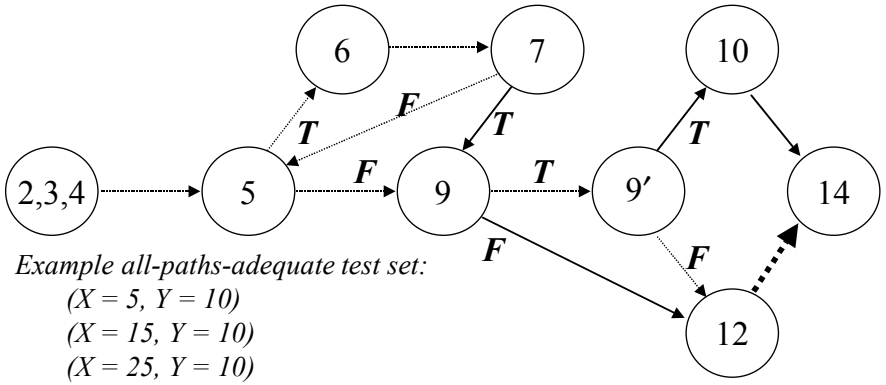

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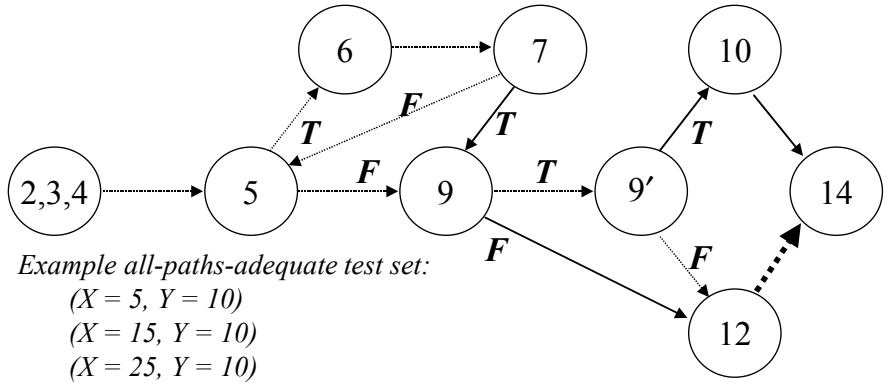

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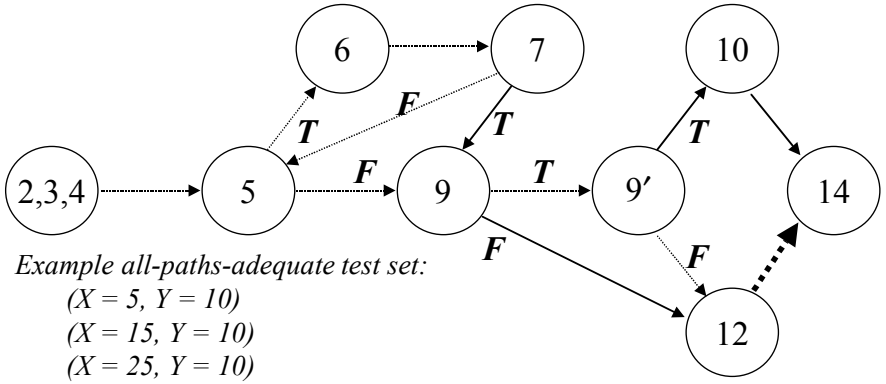
All-Paths Coverage of P



Example all-paths-adequate test set:

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