Introduction to Software Testing

CSCI 5828: Foundations of Software Engineering
Lecture 05 — 01/31/2012

Goals

- Provide introduction to fundamental concepts of software testing
  - Terminology
  - Testing of Systems
    - unit tests, integration tests, system tests, acceptance tests
  - Testing of Code
    - Black Box
    - Gray Box
    - White Box
    - Code Coverage

Testing

- Testing is a **critical element** of software development life cycles
  - called **software quality control** or **software quality assurance**
  - basic goals: **validation** and **verification**
    - validation: **are we building the right product?**
    - verification: **does “X” meet its specification?**
      - where “X” can be code, a model, a design diagram, a requirement, …
    - At each stage, we need to verify that the thing we produce accurately represents its specification

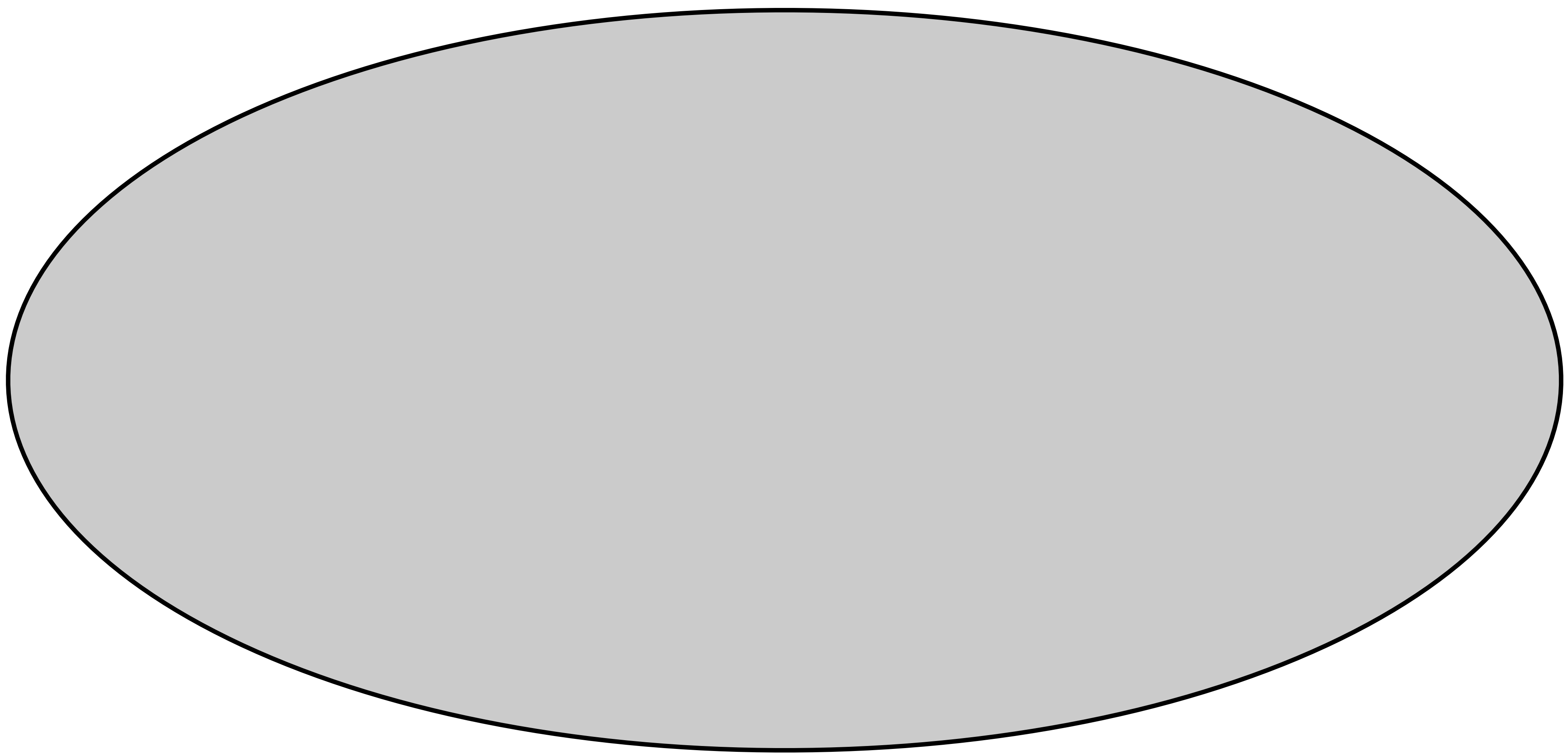
Terminology

- An **error** is a mistake made by an engineer
  - often a misunderstanding of a requirement or design specification
- A **fault** is a manifestation of that error in the code
  - what we often call “a bug”
- A **failure** is an incorrect output/behavior that is caused by executing a fault
  - The failure may occur immediately (crash!) or much, much later in the execution
- **Testing** attempts to **surface failures** in our software systems
  - **Debugging** attempts to **associate failures with faults** so they can be removed from the system
- If a system passes all of its tests, is it free of all faults?

No!

- Faults may be hiding in portions of the code that only rarely get executed
  - “Testing can only be used to prove the existence of faults not their absence” or “Not all faults have failures”
    - Sometimes faults mask each other resulting in no visible failures!
      - this is particularly insidious
- However, if we do a good job in creating a test set that
  - covers all functional capabilities of a system
  - and covers all code using a metric such as “branch coverage”
- Then, having all tests pass increases our confidence that our system has high quality and can be deployed

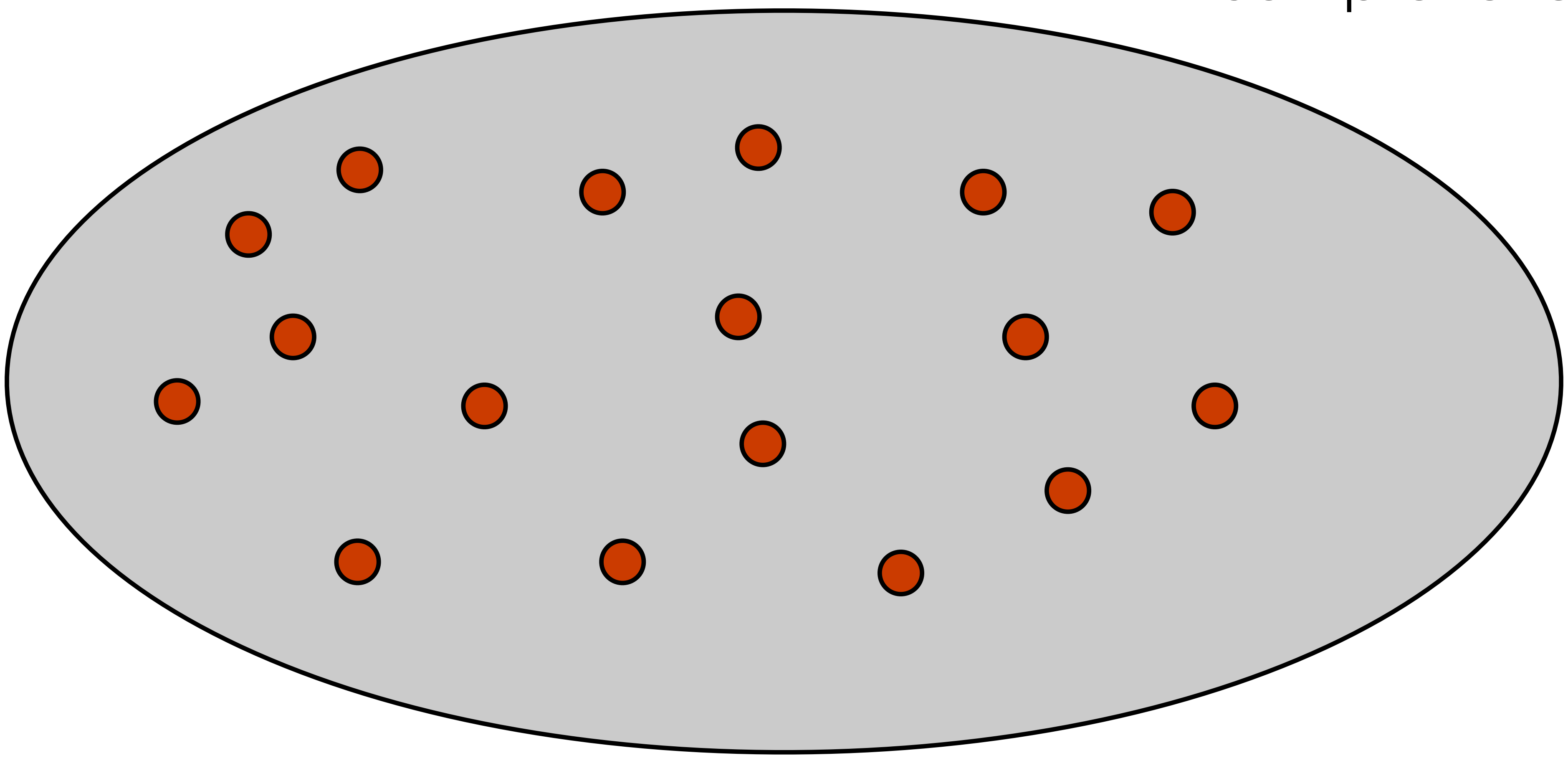
Looking for Faults



All possible states/behaviors of a system

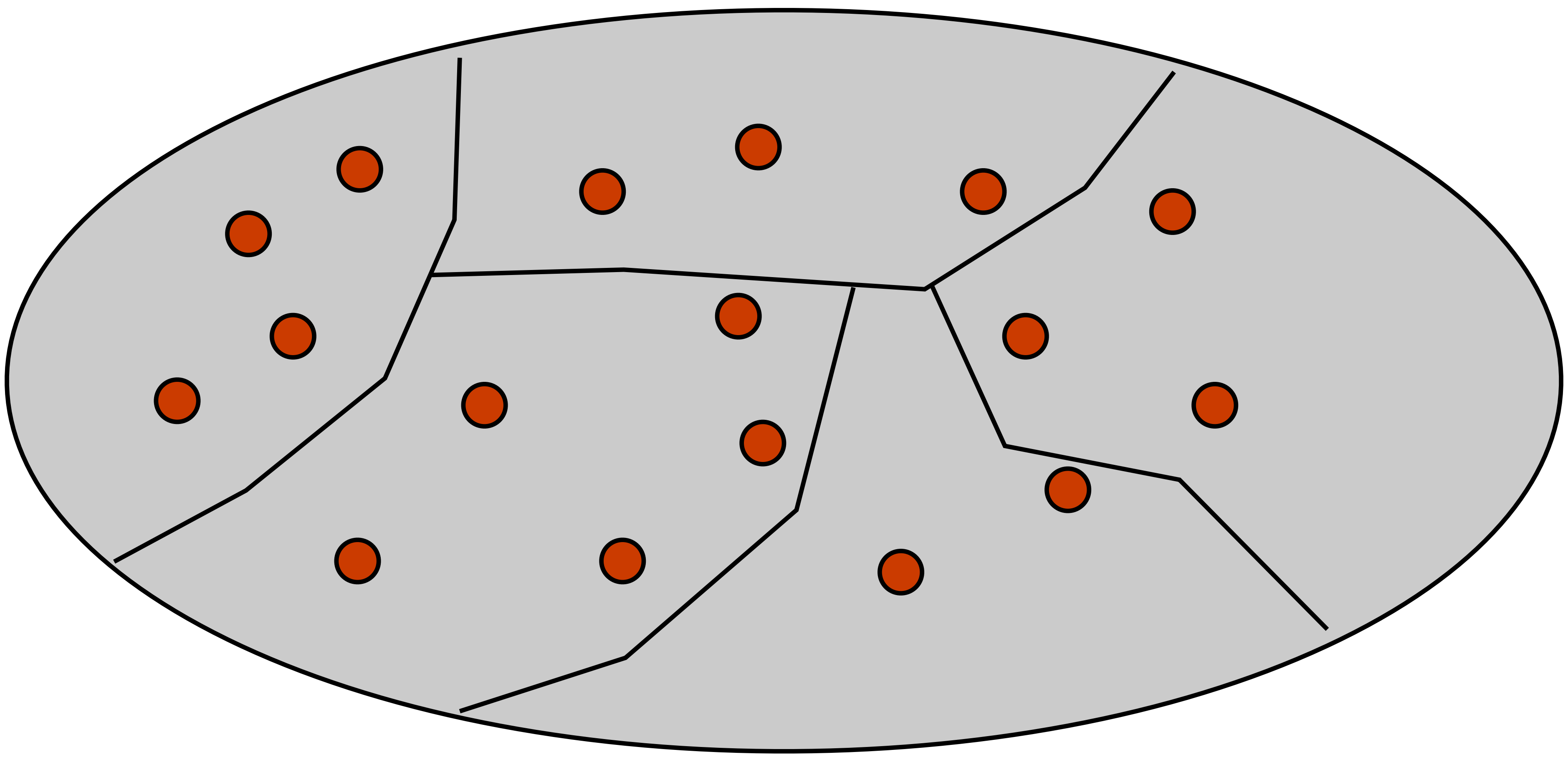
Looking for Faults

As you can see, its not very comprehensive



Tests are a way of sampling the behaviors of a software system, looking for failures

One way forward? Fold



The testing literature advocates folding the space into equivalent behaviors and then sampling each partition

What does that mean?

- Consider a simple example like the greatest common denominator function
  - int gcd(int x, int y)
    - At first glance, this function has an infinite number of test cases
  - But lets fold the space
    - x=6 y=9, returns 3, tests common case
    - x=2 y=4, returns 2, tests when x is the GCD
    - x=3 y=5, returns 1, tests two primes
    - x=9 y=0, returns ?, tests zero
    - x=-3 y=9, returns ?, tests negative

Completeness

- From this discussion, it should be clear that **“completely” testing a system is impossible**
  - So, **we settle for heuristics**
    - attempt to fold the input space into different functional categories
      - then create tests that sample the behavior/output for each functional partition
  - As we will see, we also look at our **coverage of the underlying code**; are we hitting all statements, all branches, all loops?

Continuous Testing

- Testing is a continuous process that should be performed at every stage of a software development process
  - During requirements gathering, for instance, we must continually query the user, "Did we get this right?"
  - Facilitated by an emphasis on iteration throughout a life cycle
    - at the end of each iteration
      - we check our results to see if what we built is meeting our requirements (specification)

Testing the System (I)

- **Unit Tests**
  - Tests that cover low-level aspects of a system
    - For each module, does each operation perform as expected
    - For method **foo()**, we'd like to see another method **testFoo()**
- **Integration Tests**
  - Tests that check that modules work together in combination
  - Most projects on schedule until they hit this point (MMM, Brooks)
    - All sorts of hidden assumptions are surfaced when code written by different developers are used in tandem
  - Lack of integration testing has led to spectacular failures (Mars Polar Lander)

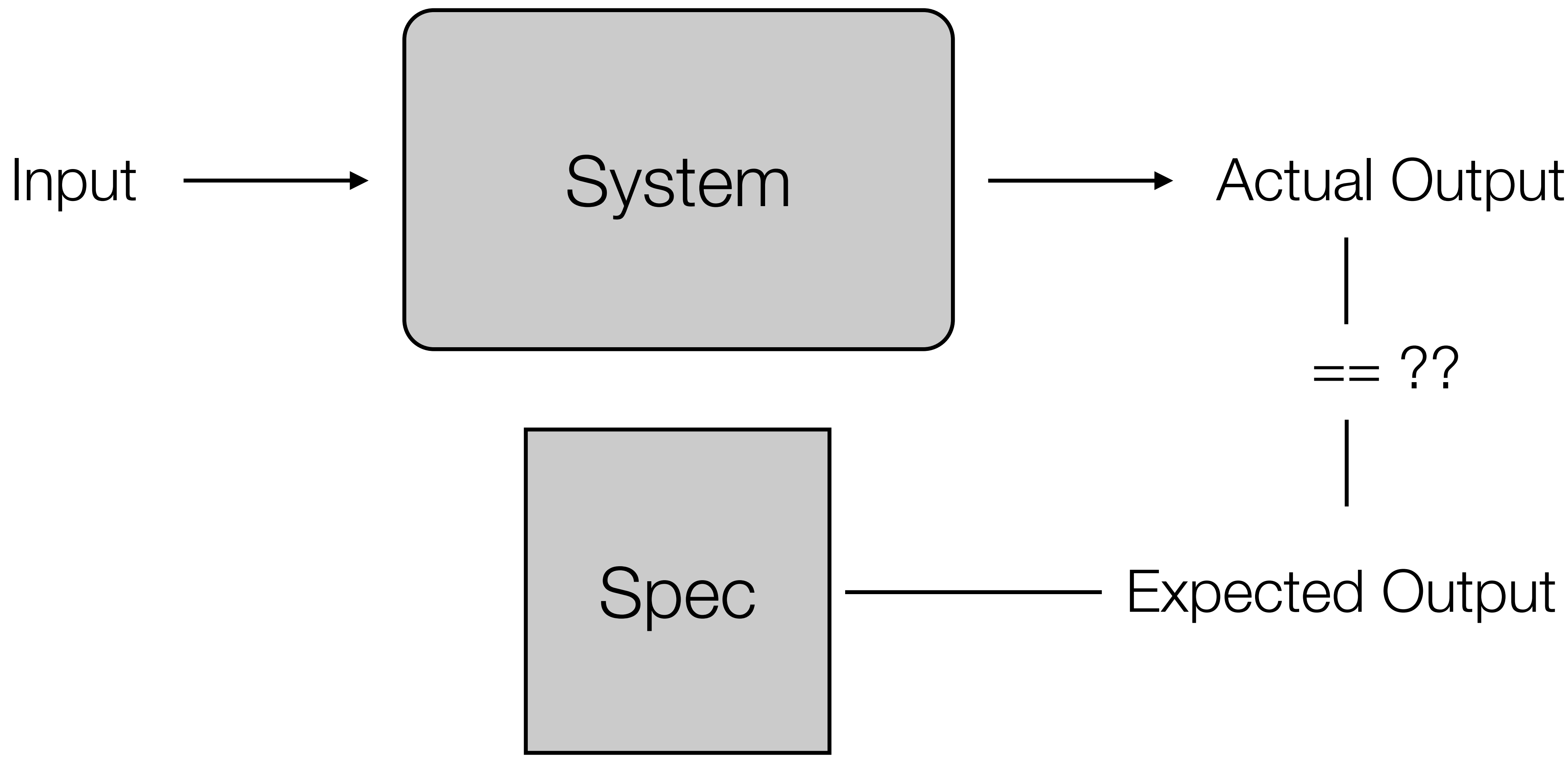
Testing the System (II)

- **System Tests**
  - Tests performed by the developer to ensure that all major functionality has been implemented
    - Have all user stories been implemented and function correctly?
- **Acceptance Tests**
  - Tests performed by the user to check that the delivered system meets their needs
    - In large, custom projects, developers will be on-site to install system and then respond to problems as they arise

Multi-Level Testing

- Once we have code, we can perform three types of tests
  - **Black Box Testing**
    - Does the system behave as predicted by its specification
  - **Grey Box Testing**
    - Having a bit of insight into the architecture of the system, does it behave as predicted by its specification
  - **White Box Testing**
    - Since, we have access to most of the code, lets make sure we are covering all aspects of the code: statements, branches, …

Black Box Testing



A **black box test** passes **input** to a system, records the **actual output** and compares it to the **expected output**

Note: if you do not have a spec, then any behavior by the system is correct!

Results

- if actual output == expected output
  - TEST PASSED
- else
  - TEST FAILED

- Process
  - Write at least one test case per functional capability
  - Iterate on code until all tests pass
- Need to automate this process as much as possible

Black Box Categories

- Functionality
  - User input validation (based off specification)
  - Output results
  - State transitions
    - are there clear states in the system in which the system is supposed to behave differently based on the state?
  - Boundary cases and off-by-one errors

Grey Box Testing

- Use knowledge of system's architecture to create a more complete set of black box tests
  - Verifying auditing and logging information
    - for each function is the system really updating all internal state correctly
  - Data destined for other systems
  - System-added information (timestamps, checksums, etc.)
  - "Looking for Scraps"
    - Is the system correctly cleaning up after itself
      - temporary files, memory leaks, data duplication/deletion

White Box Testing

- Writing test cases with complete knowledge of code
  - Format is the same: input, expected output, actual output
- But, now we are looking at
  - code coverage (more on this in a minute)
  - proper error handling
  - working as documented (is method “foo” thread safe?)
  - proper handling of resources
    - how does the software behave when resources become constrained?

Code Coverage (I)

- A criteria for knowing white box testing is "complete"
  - statement coverage
    - write tests until all statements have been executed
  - branch coverage (a.k.a. edge coverage)
    - write tests until each edge in a program's control flow graph has been executed at least once (covers true/false conditions)
  - condition coverage
    - like branch coverage but with more attention paid to the conditionals (if compound conditional, ensure that all combinations have been covered)

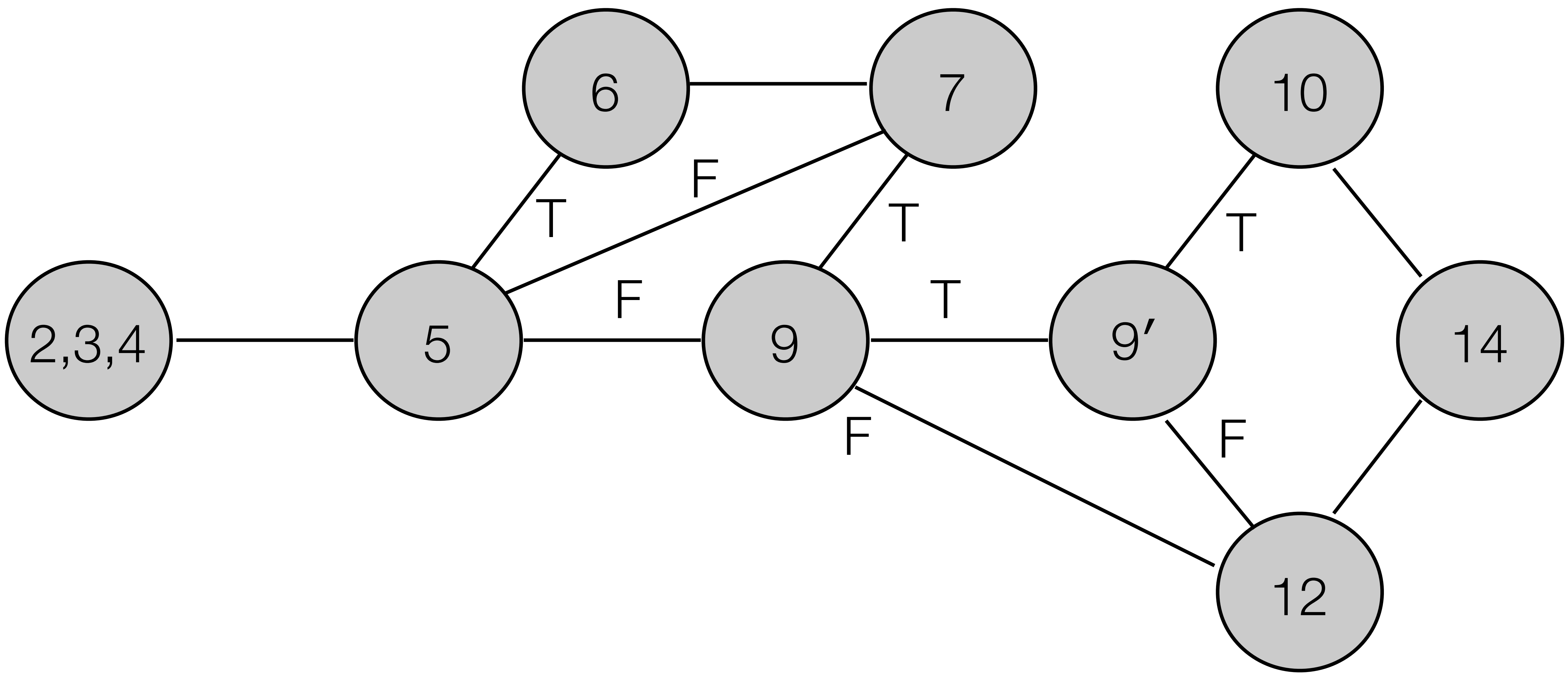
Code Coverage (II)

- A criteria for knowing white box testing is “complete”
  - path coverage
    - write tests until all paths in a program’s control flow graph have been executed multiple times as dictated by heuristics, e.g.,
    - for each loop, write a test case that executes the loop
      - zero times (skips the loop)
      - exactly one time
      - more than once (exact number depends on context)

A Sample Ada Program to Test

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

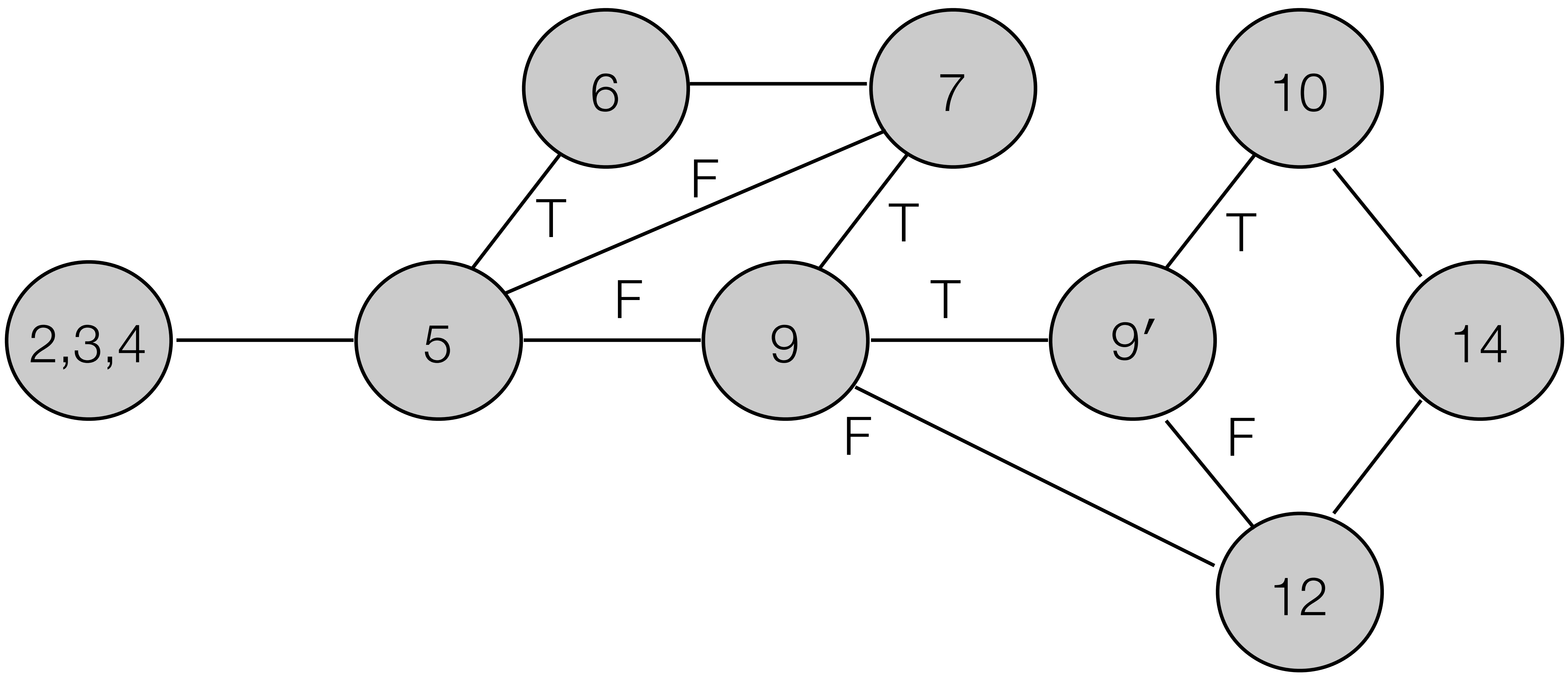
P’s Control Flow Graph (CFG)



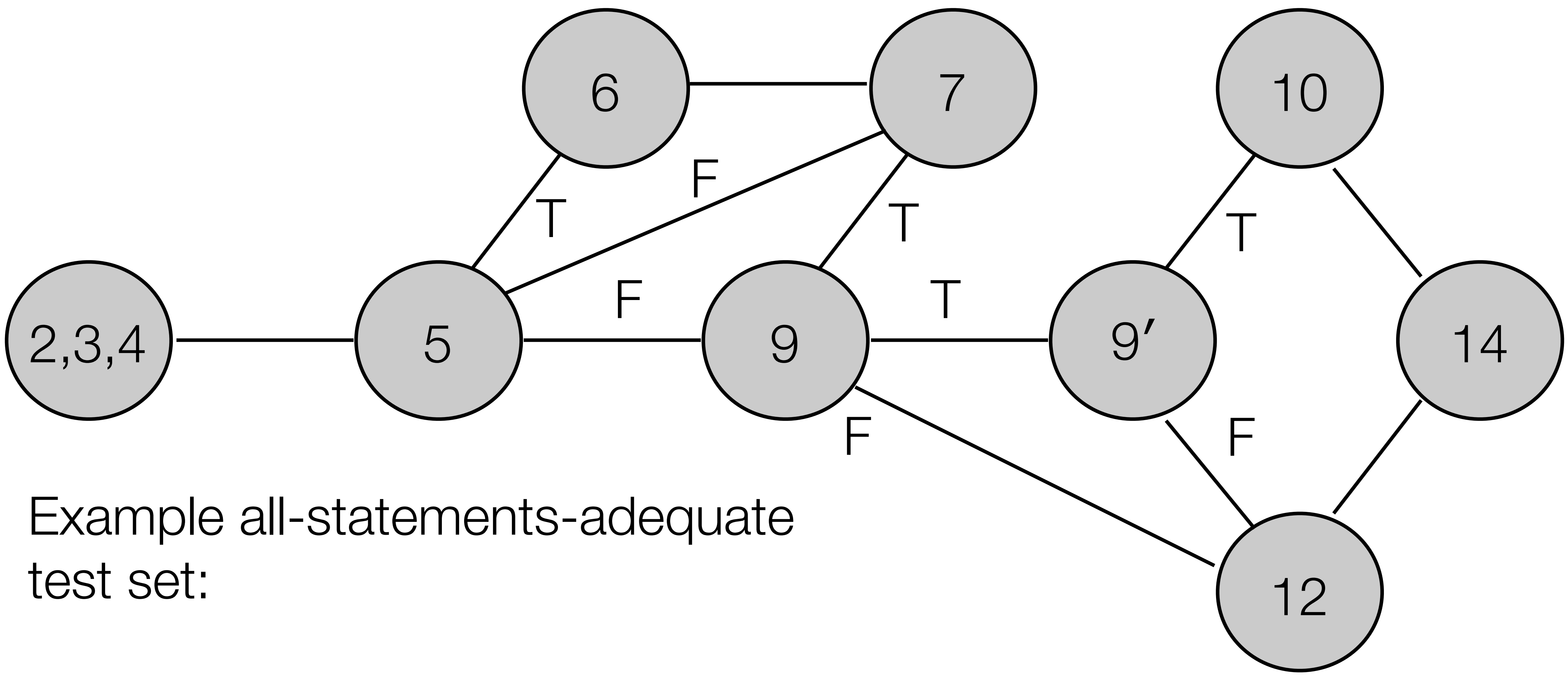
White-box Testing Criteria

- Statement Coverage
  - Create a test set T such that
    - by executing P for each t in T
      - each elementary statement of P is executed at least once

All-Statements Coverage of P

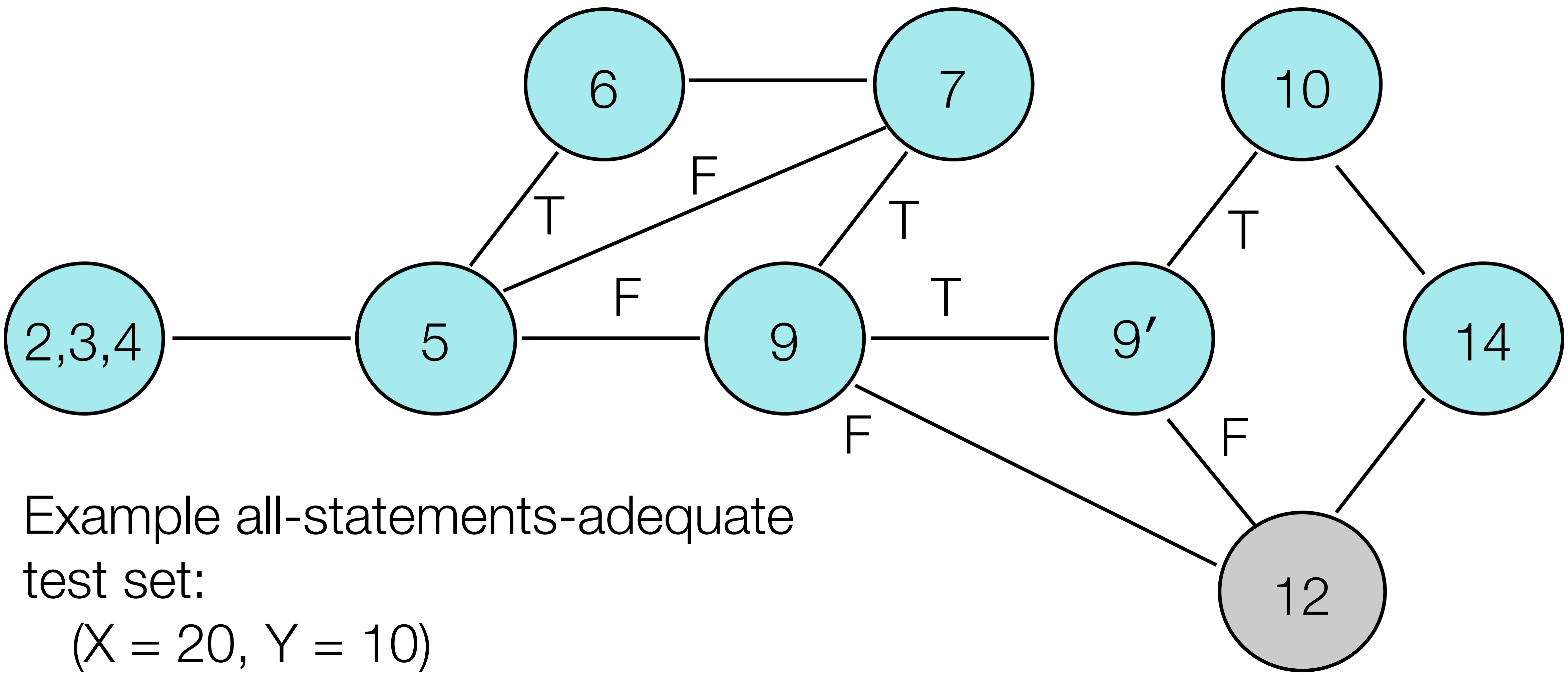


All-Statements Coverage of P



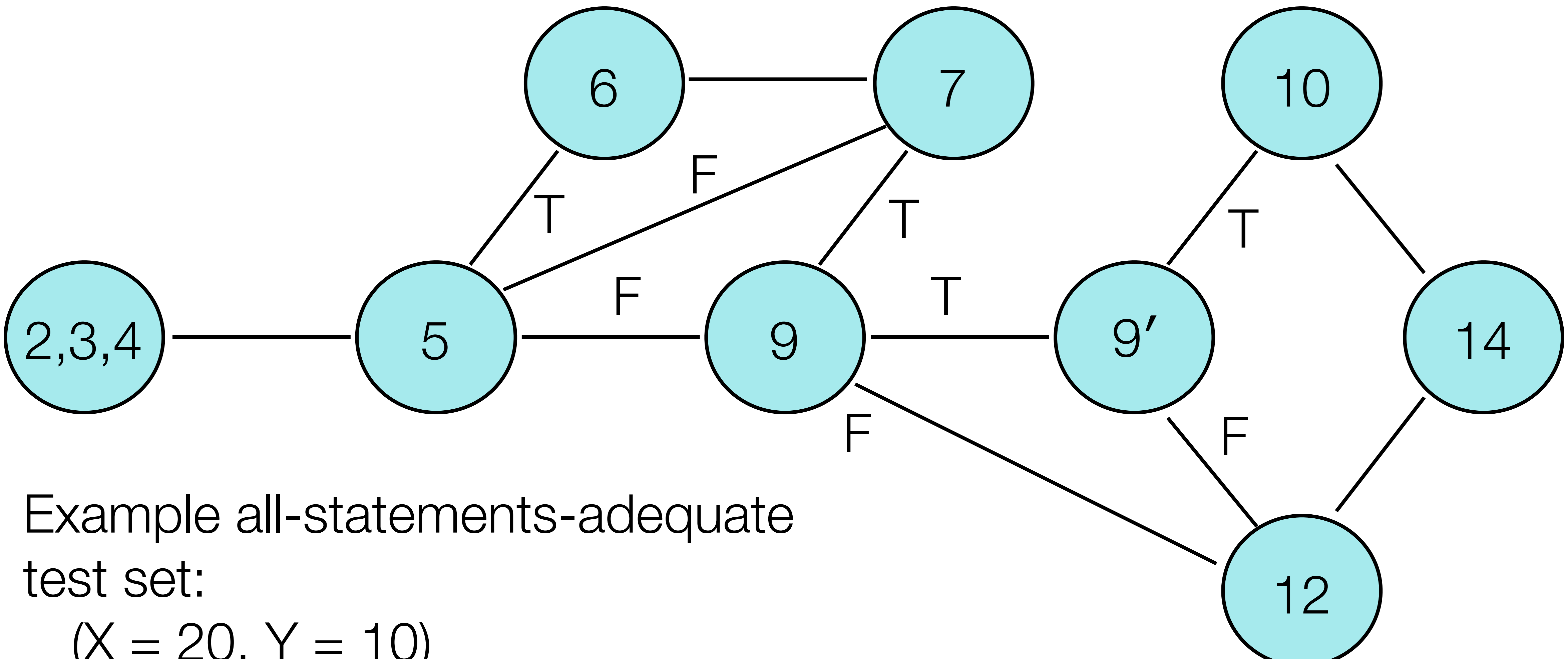
Example all-statements-adequate test set:

All-Statements Coverage of P



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

All-Statements Coverage of P



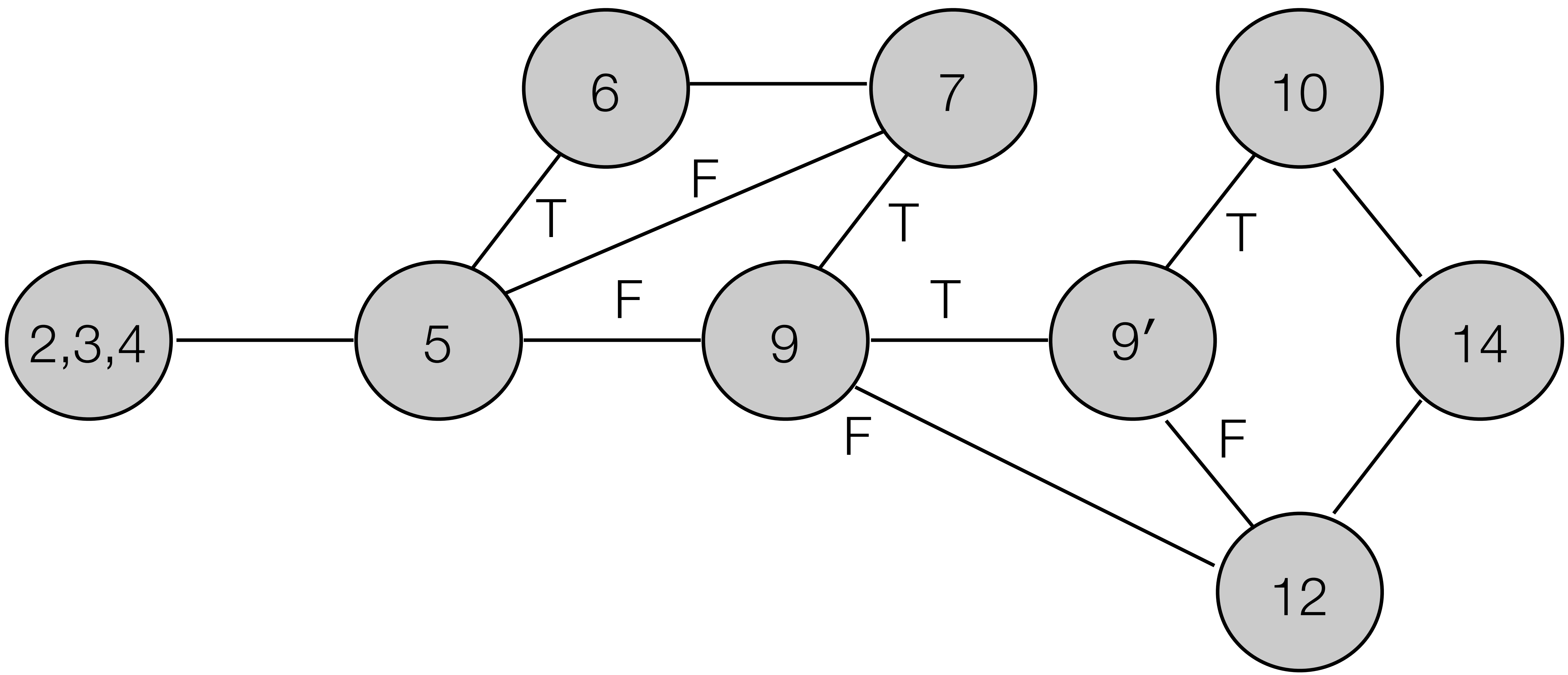
Example all-statements-adequate test set:

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

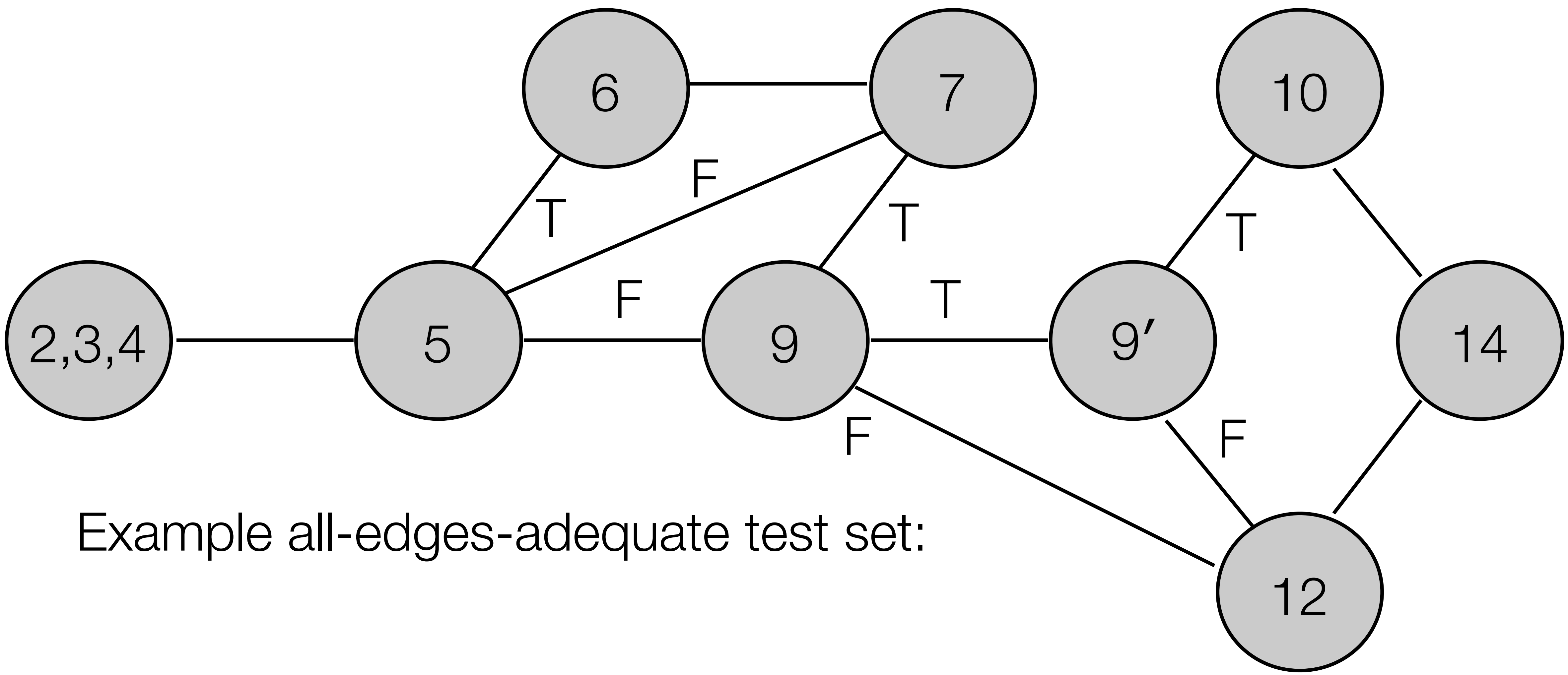
White-box Testing Criteria

- Edge Coverage
  - Select a test set T such that
    - by executing P for each t in T
      - each edge of P’s control flow graph is traversed at least once

All-Edges Coverage of P

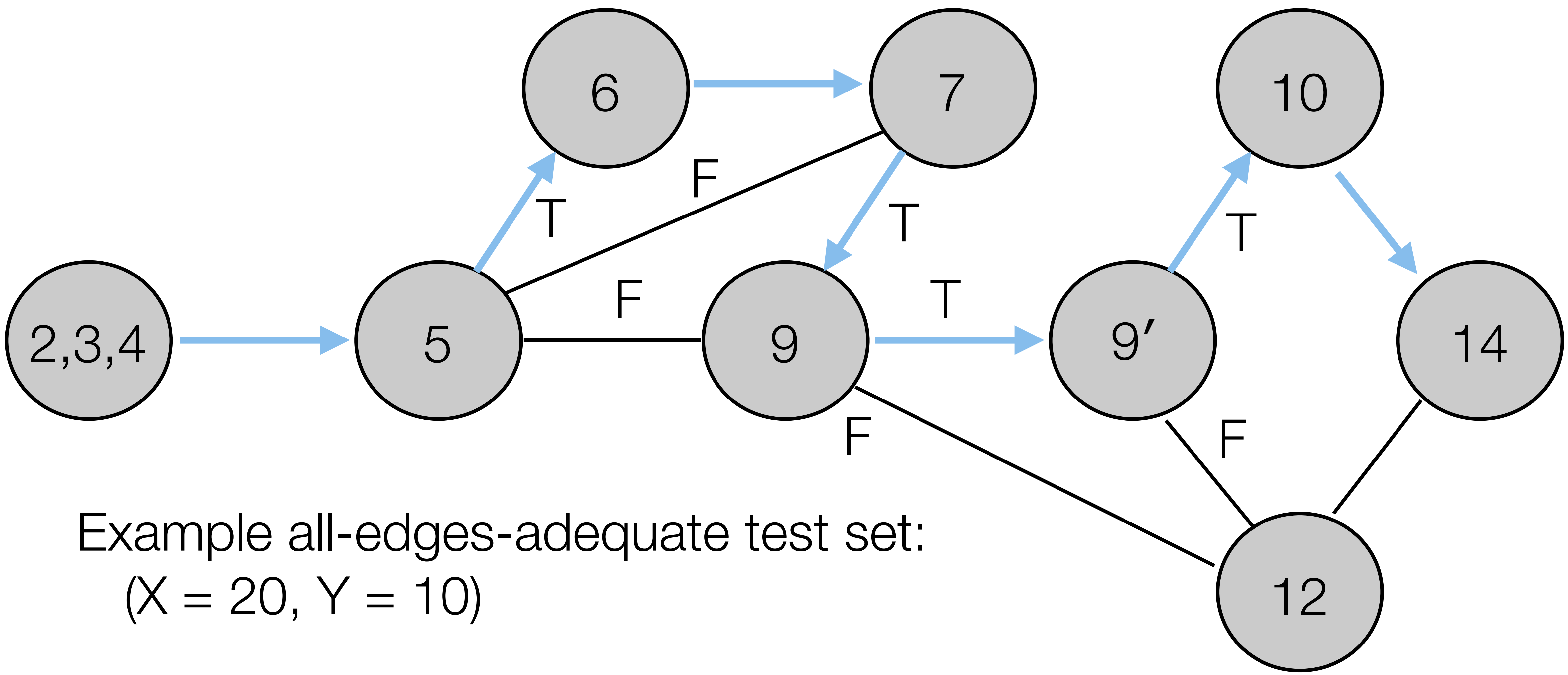


All-Edges Coverage of P



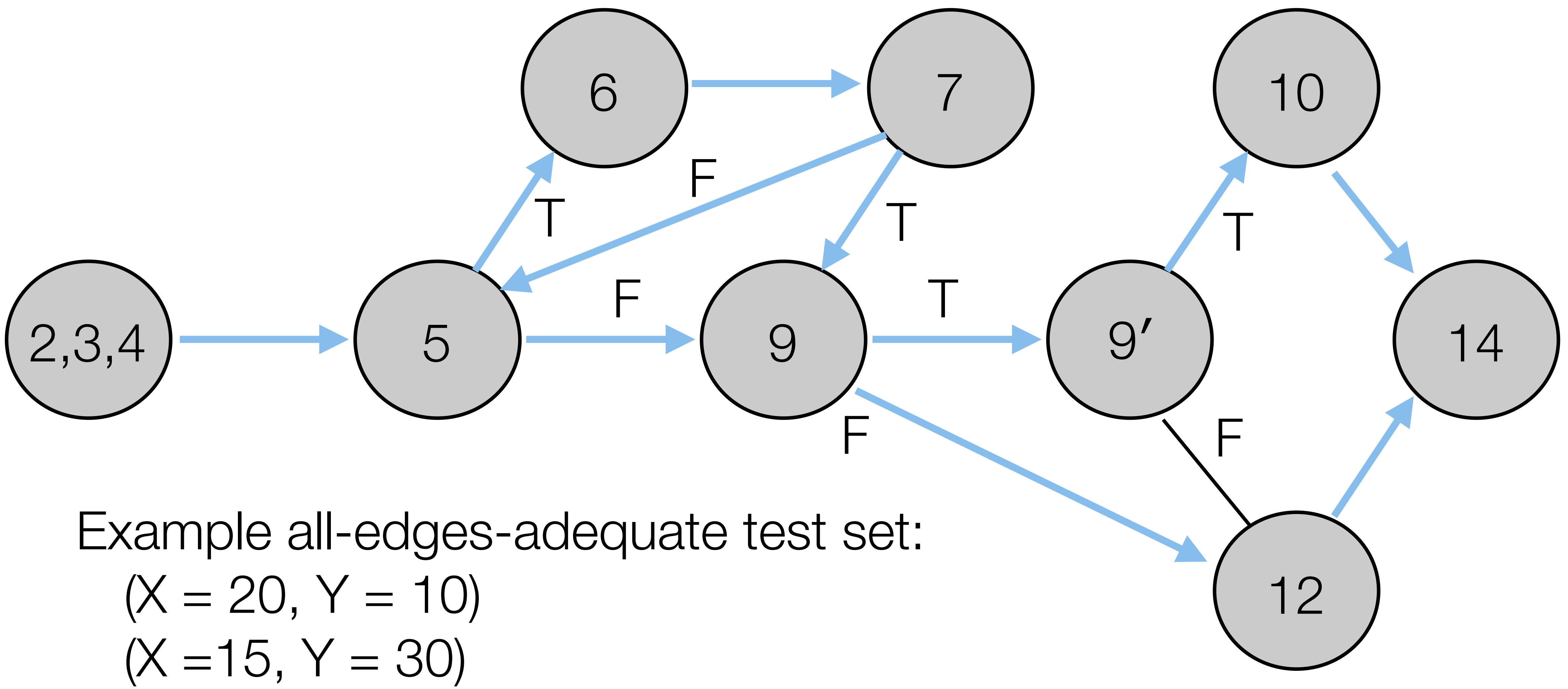
Example all-edges-adequate test set:

All-Edges Coverage of P



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

All-Edges Coverage of P

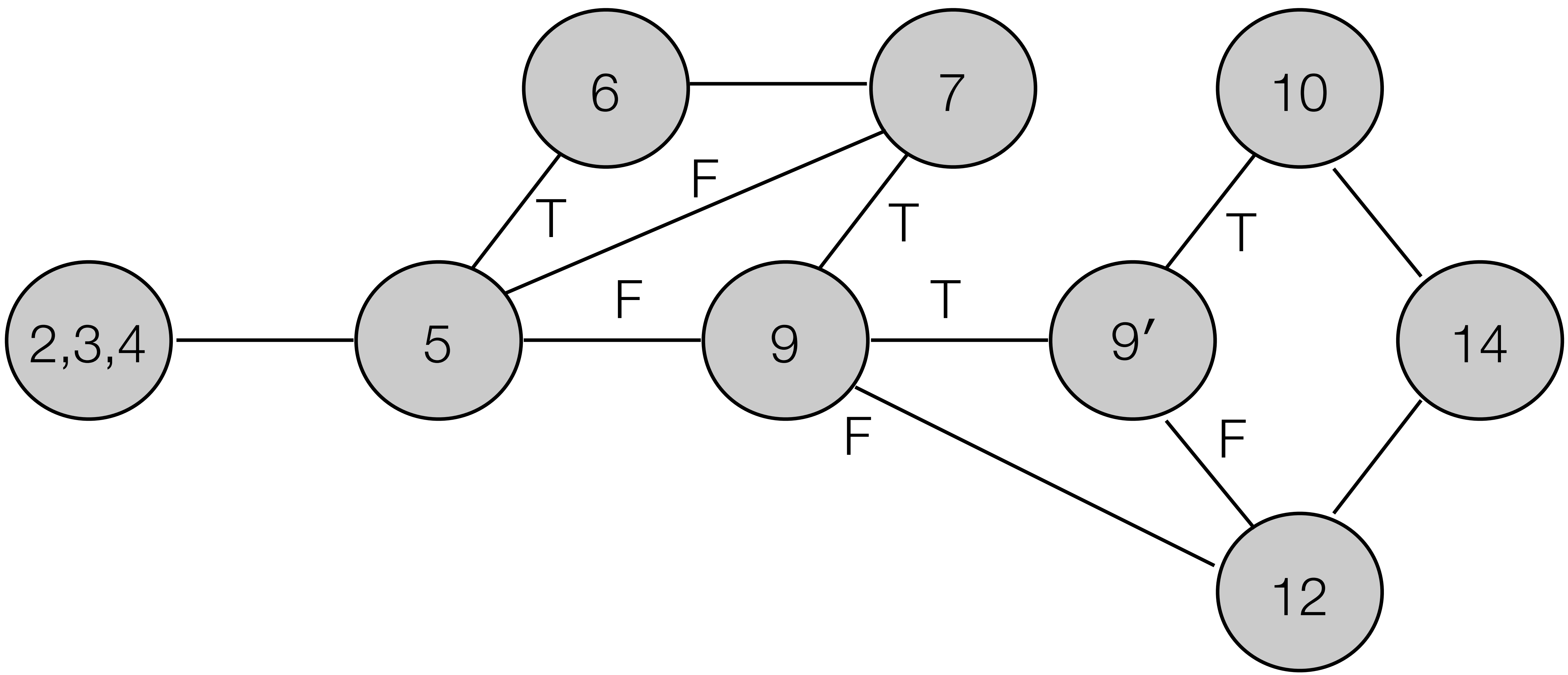


Example all-edges-adequate test set:
(X = 20, Y = 10)
(X =15, Y = 30)

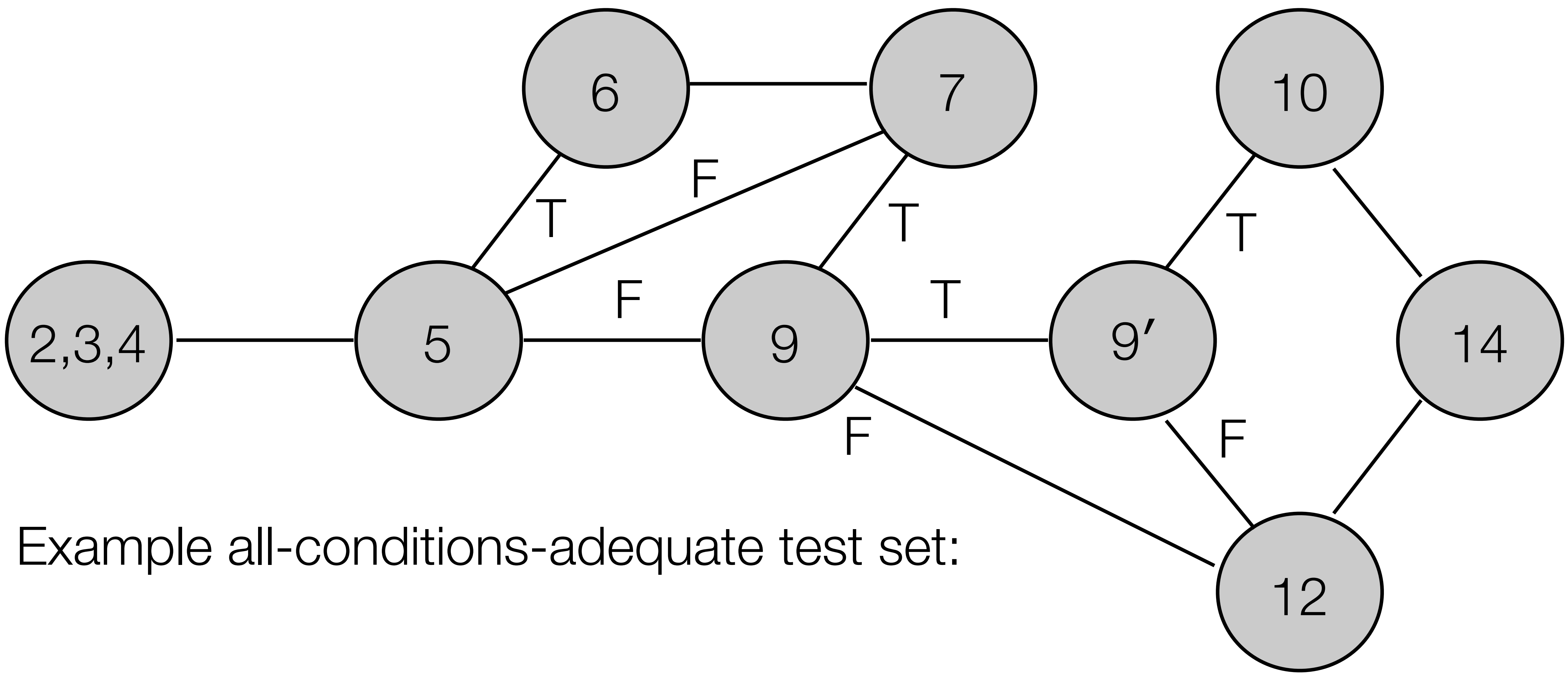
White-box Testing Criteria

- Condition Coverage
  - Select a test set T such that
    - by executing P for each t 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

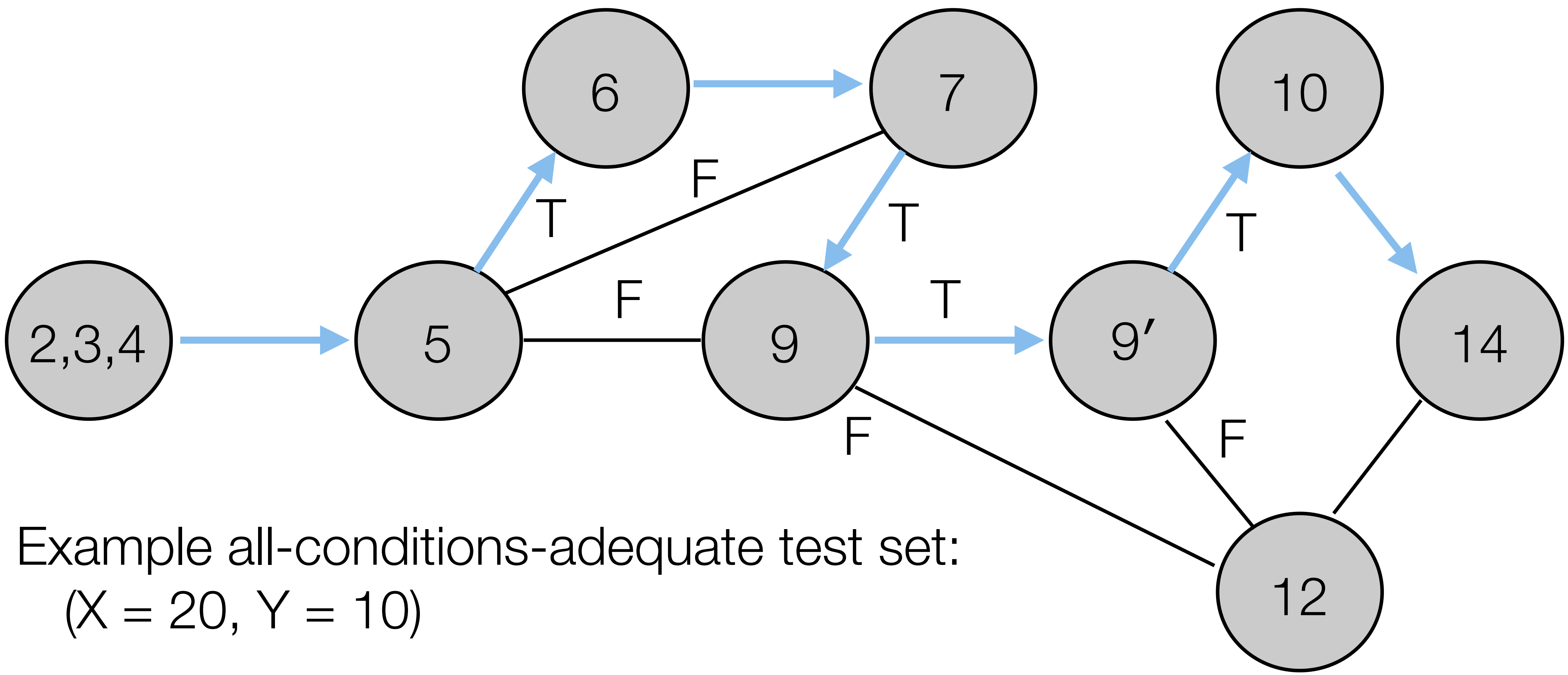


All-Conditions Coverage of P



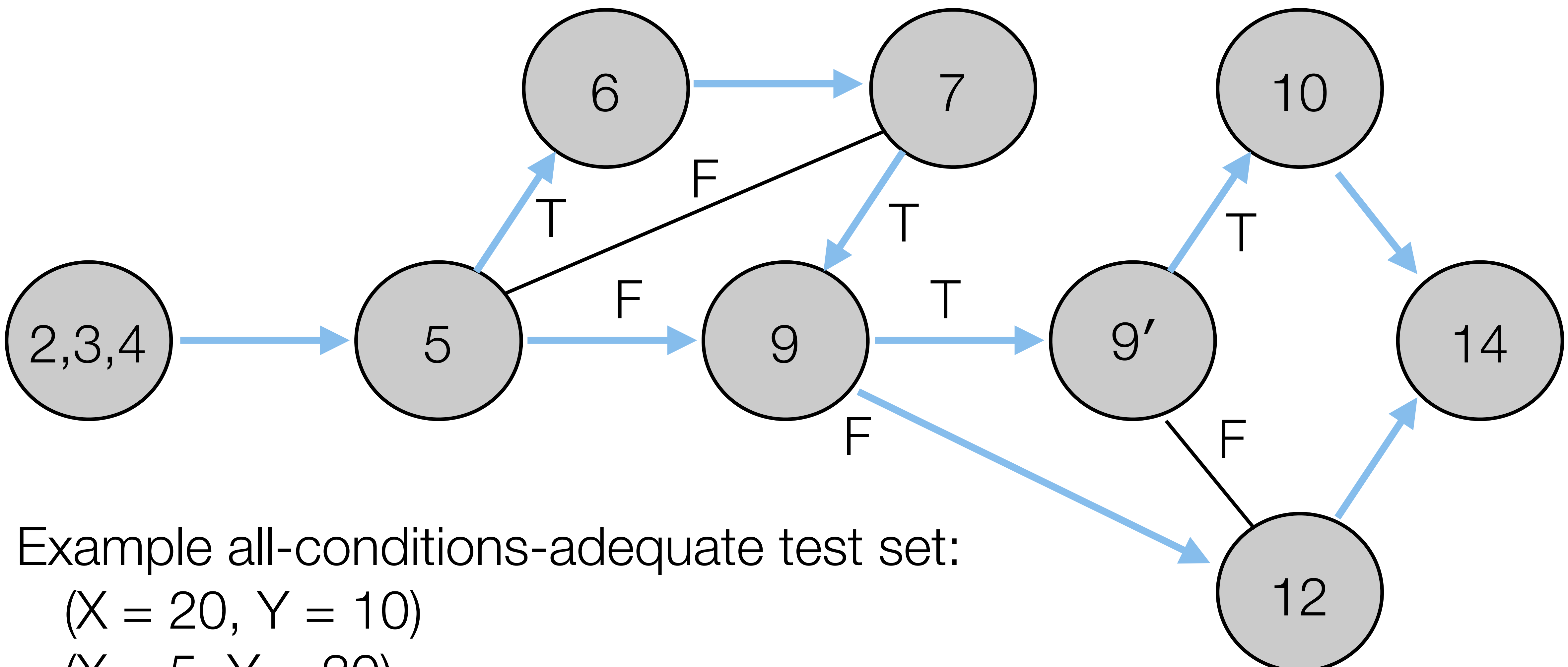
Example all-conditions-adequate test set:

All-Conditions Coverage of P



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

All-Conditions Coverage of P

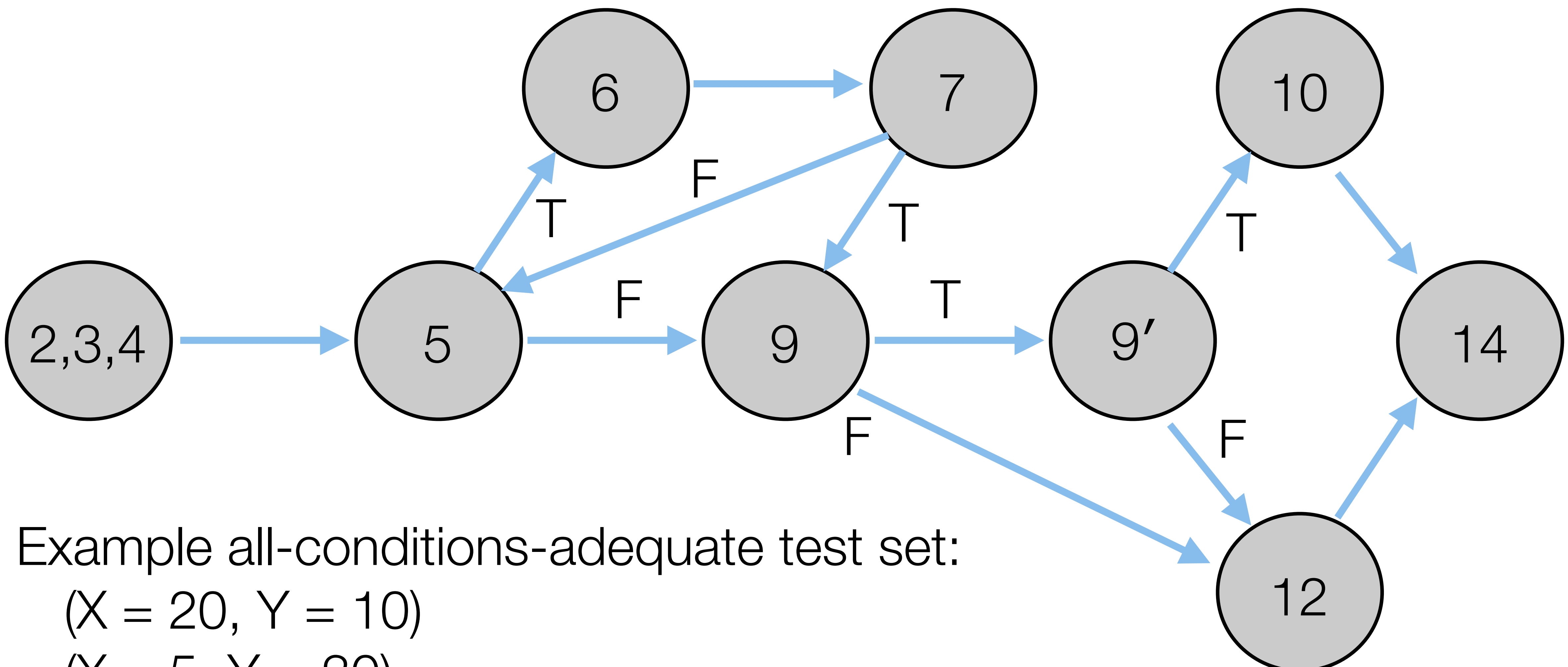


Example all-conditions-adequate test set:

(X = 20, Y = 10)

(X = 5, Y = 30)

All-Conditions Coverage of P



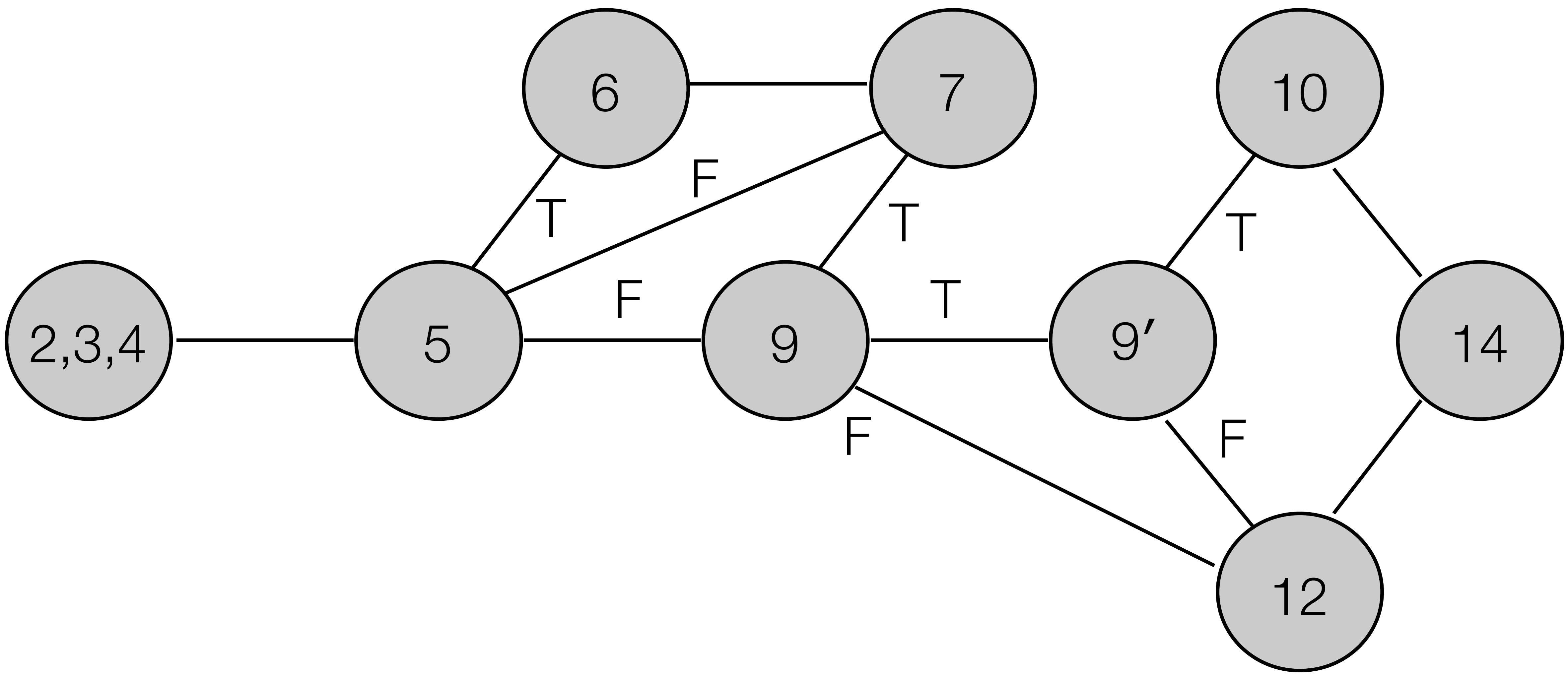
Example all-conditions-adequate test set:

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

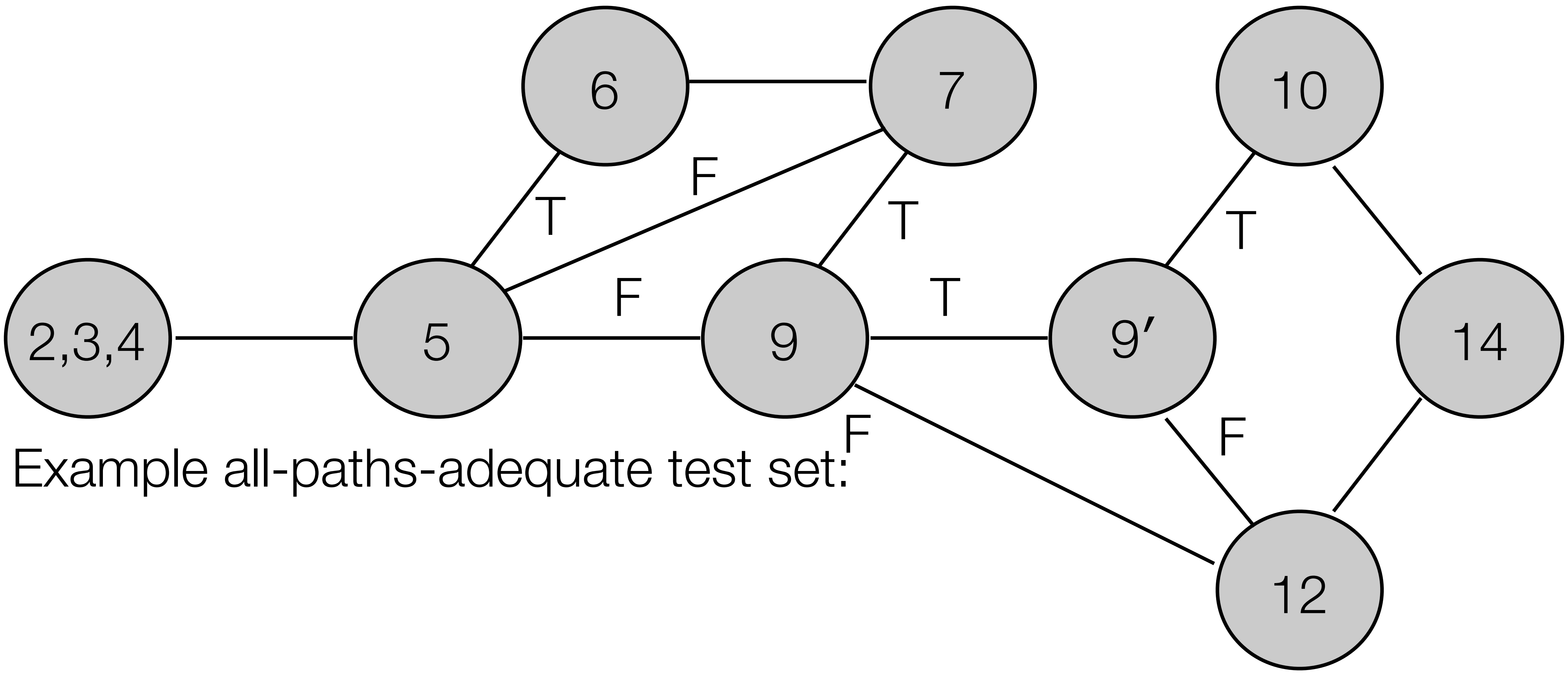
White-box Testing Criteria

- Path Coverage
  - Select a test set T such that
    - by executing P for each t 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

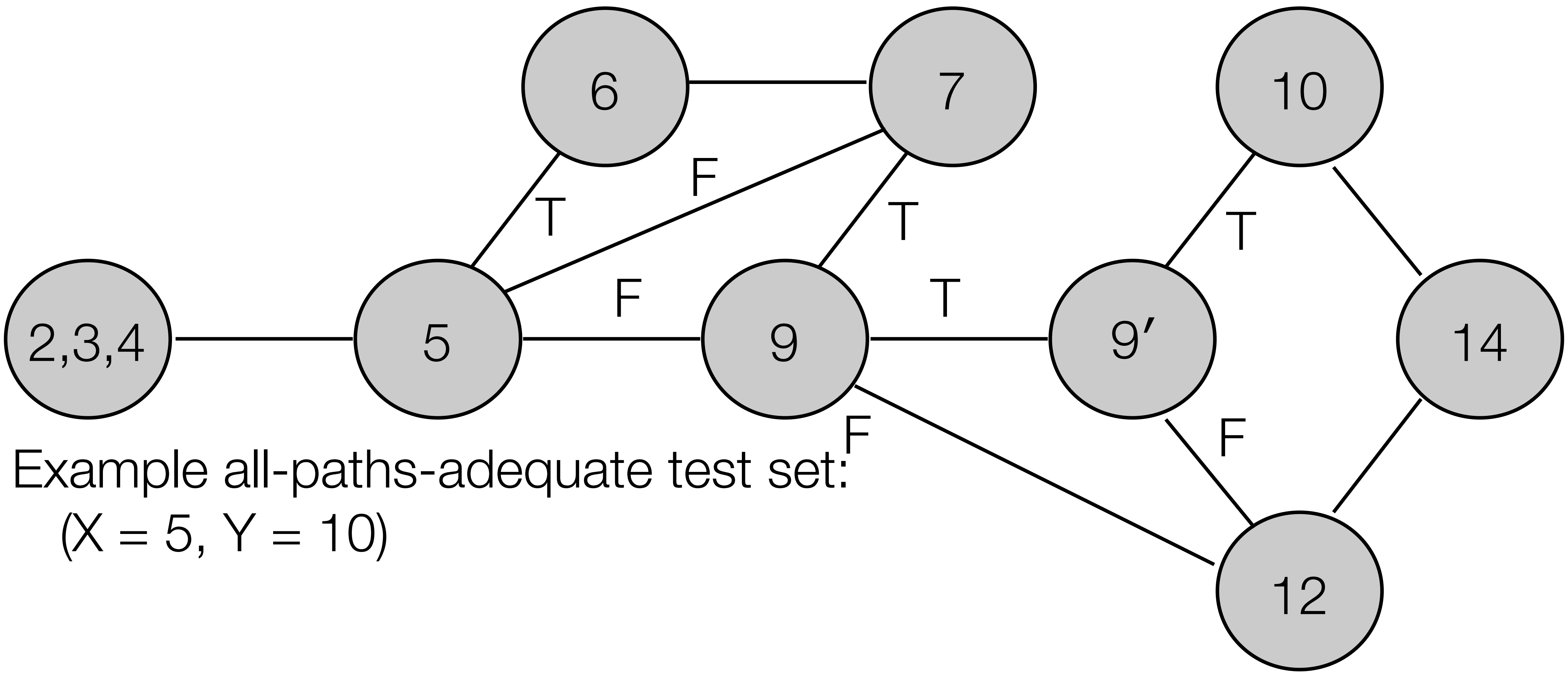


All-Paths Coverage of P



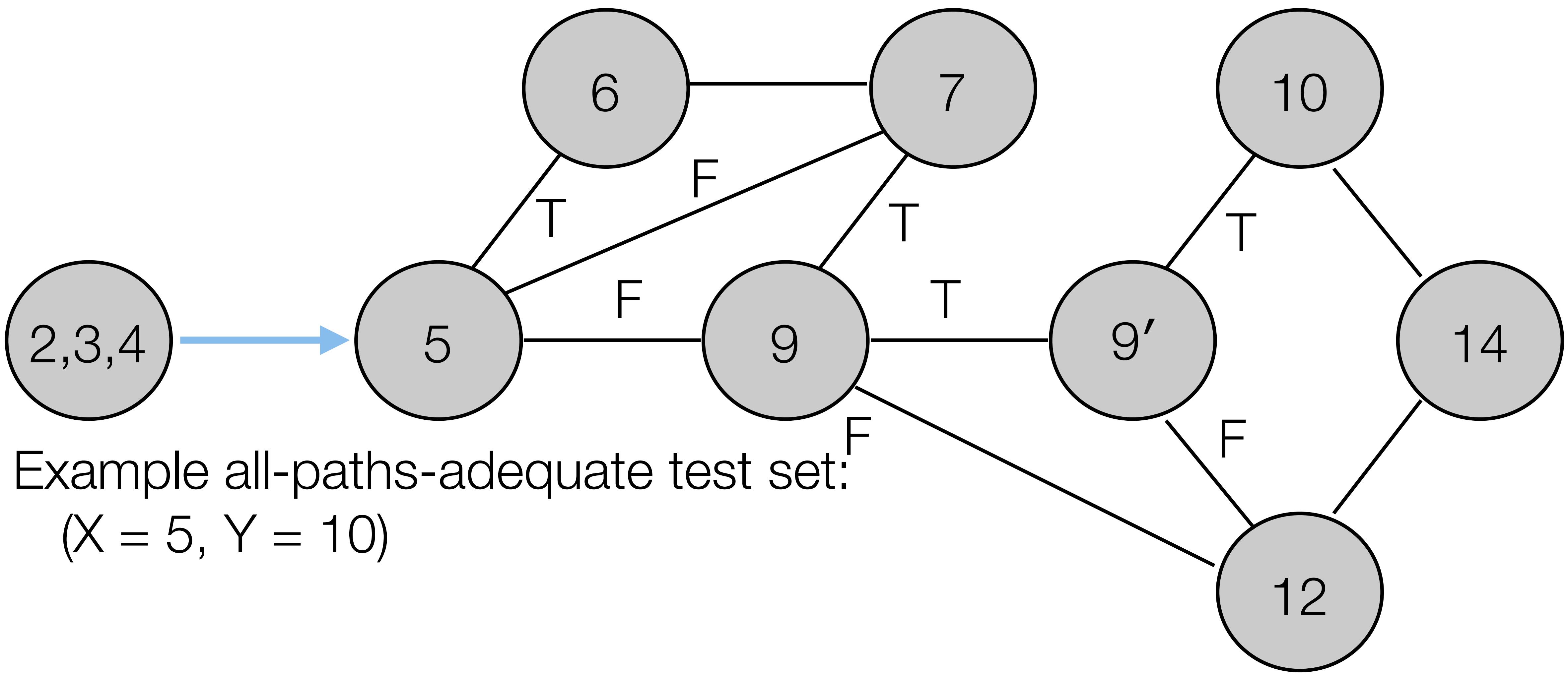
Example all-paths-adequate test set:

All-Paths Coverage of P



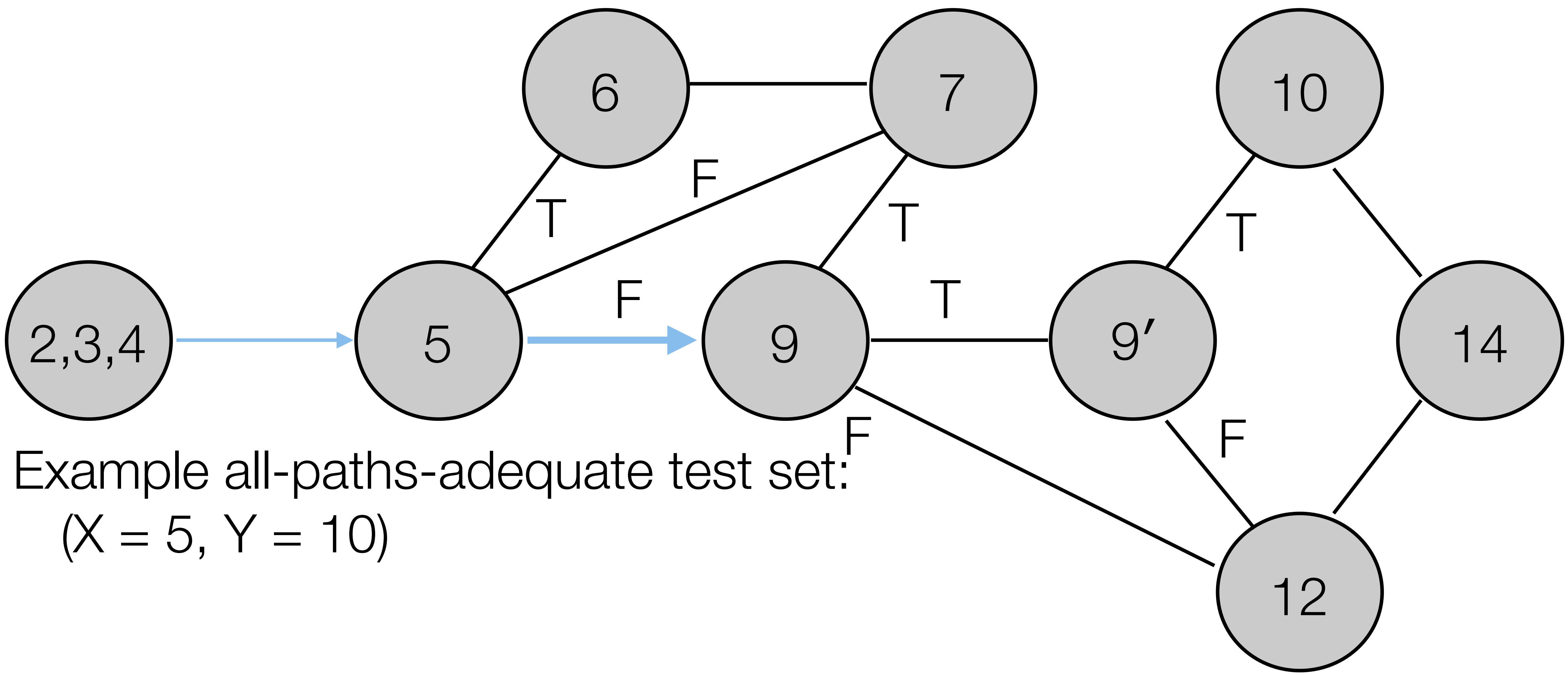
Example all-paths-adequate test set:
(X = 5, Y = 10)

All-Paths Coverage of P



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

All-Paths Coverage of P



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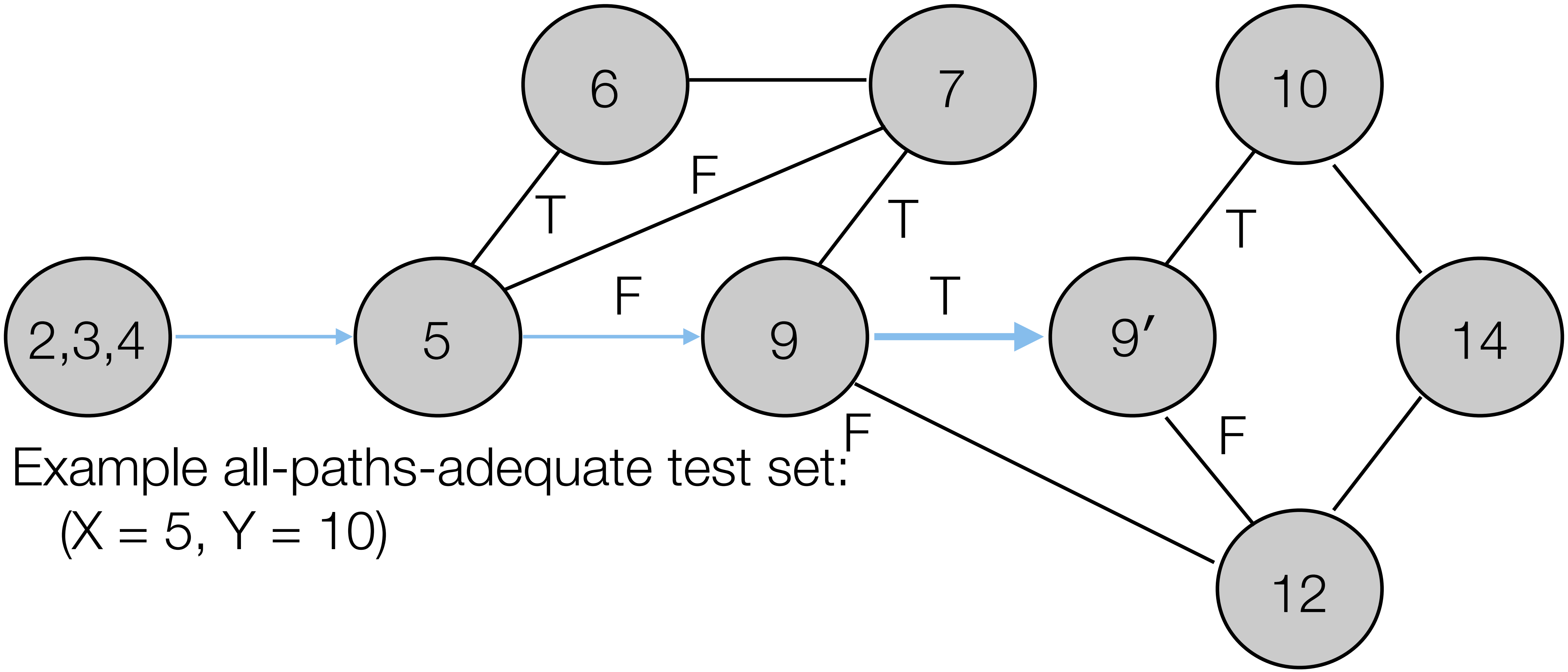
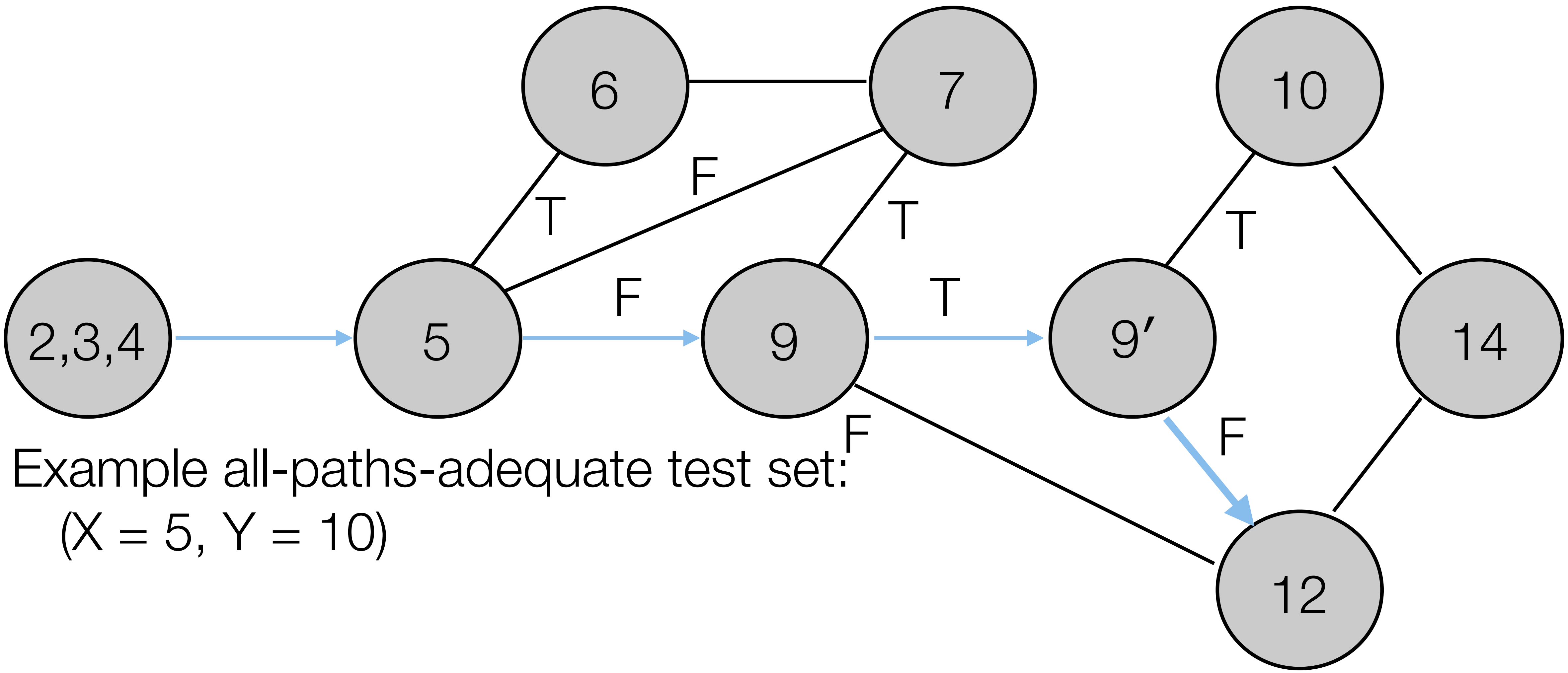
(X = 5, Y = 10)

All-Paths Coverage of P



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

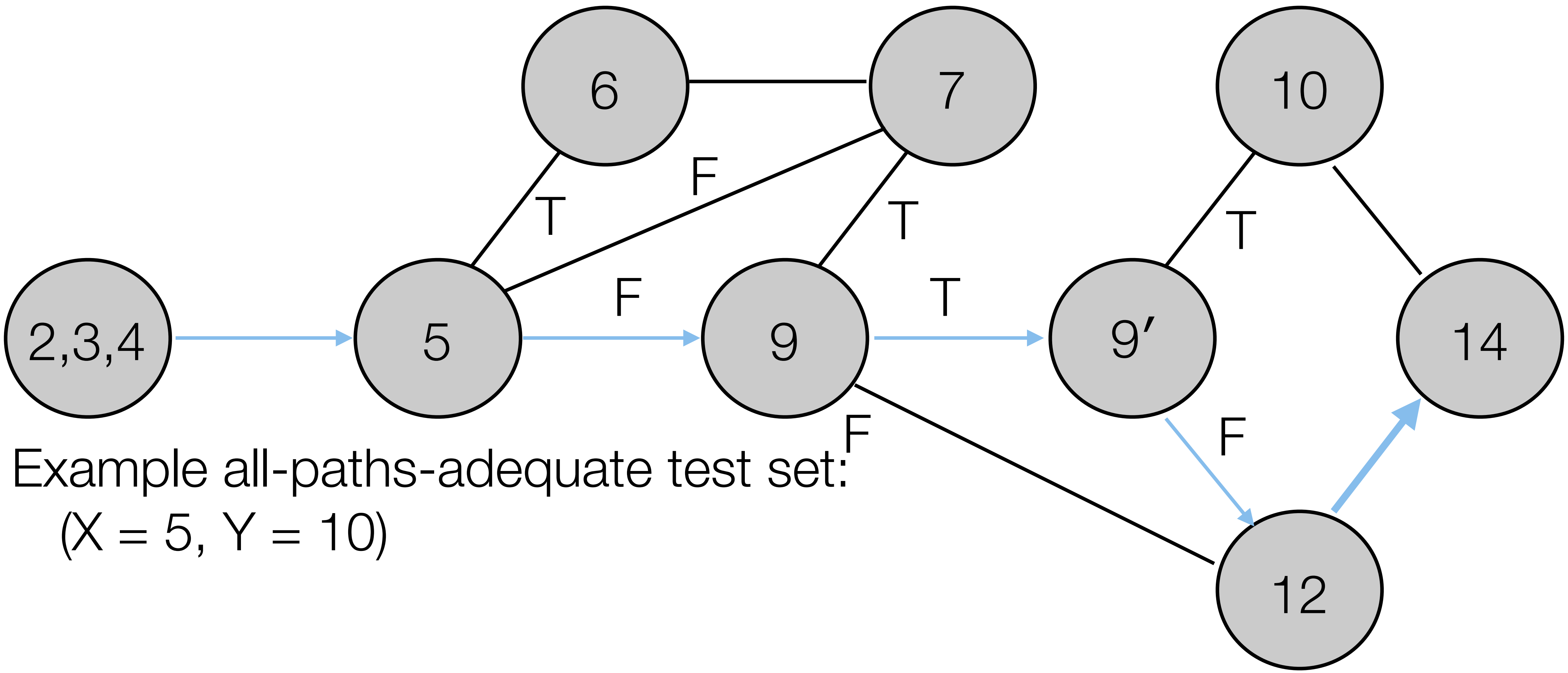
All-Paths Coverage of P



Example all-paths-adequate test set:

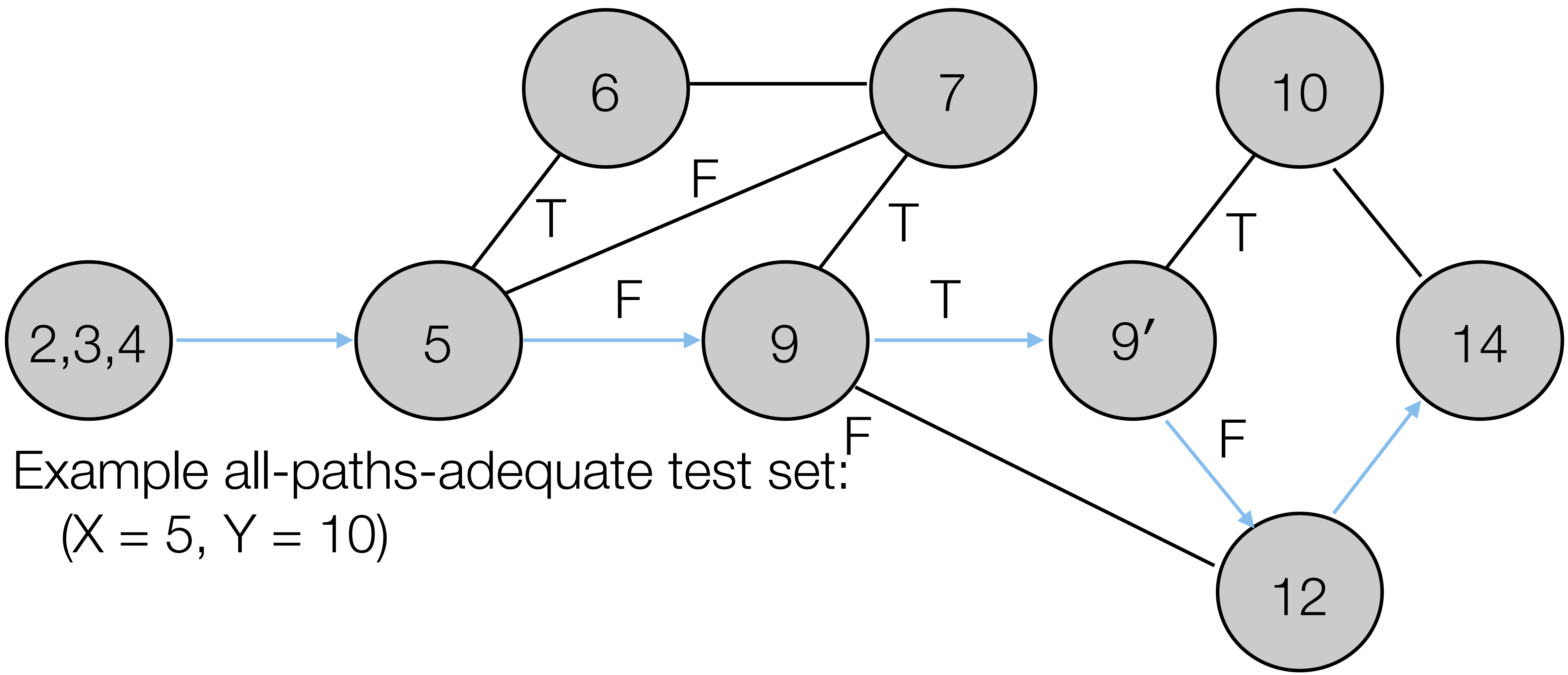
(X = 5, Y = 10)

All-Paths Coverage of P



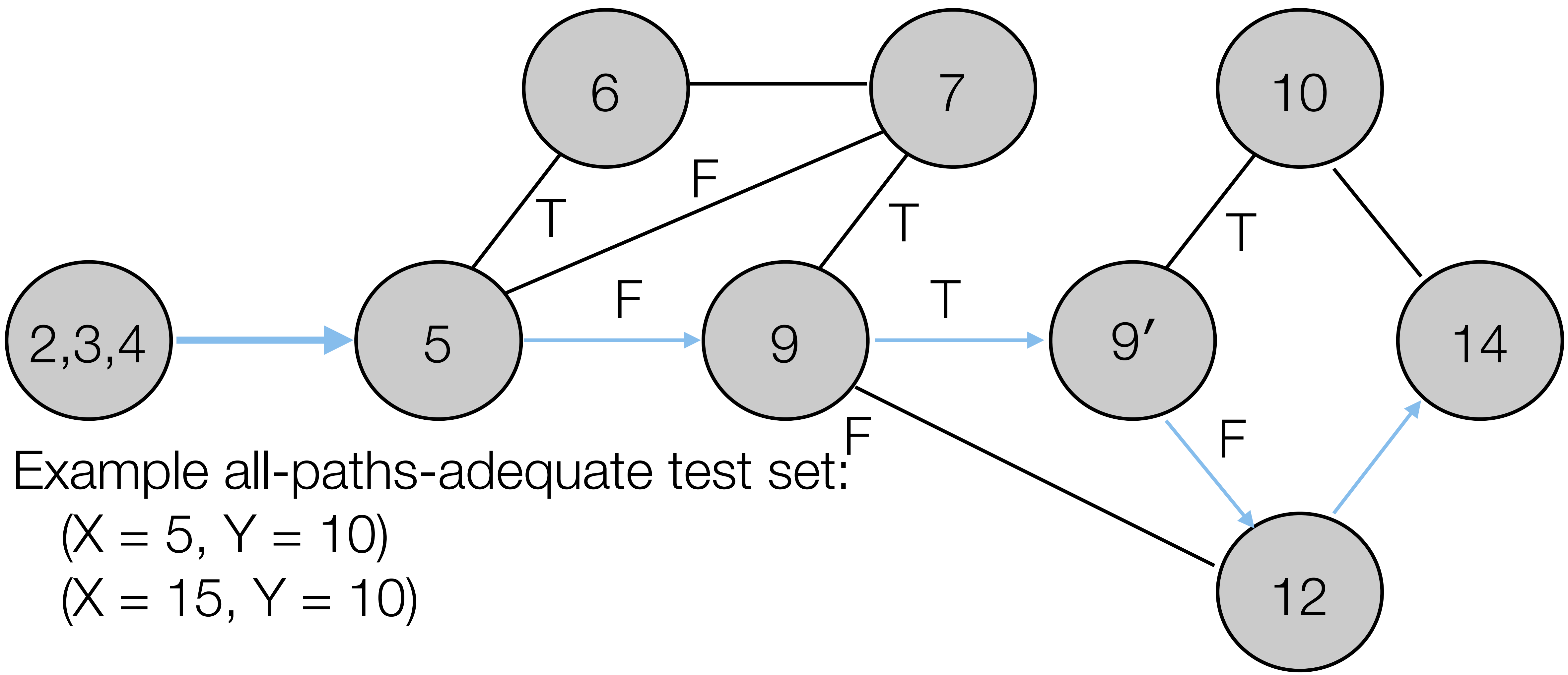
Example all-paths-adequate test set:
(X = 5, Y = 10)

All-Paths Coverage of P



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

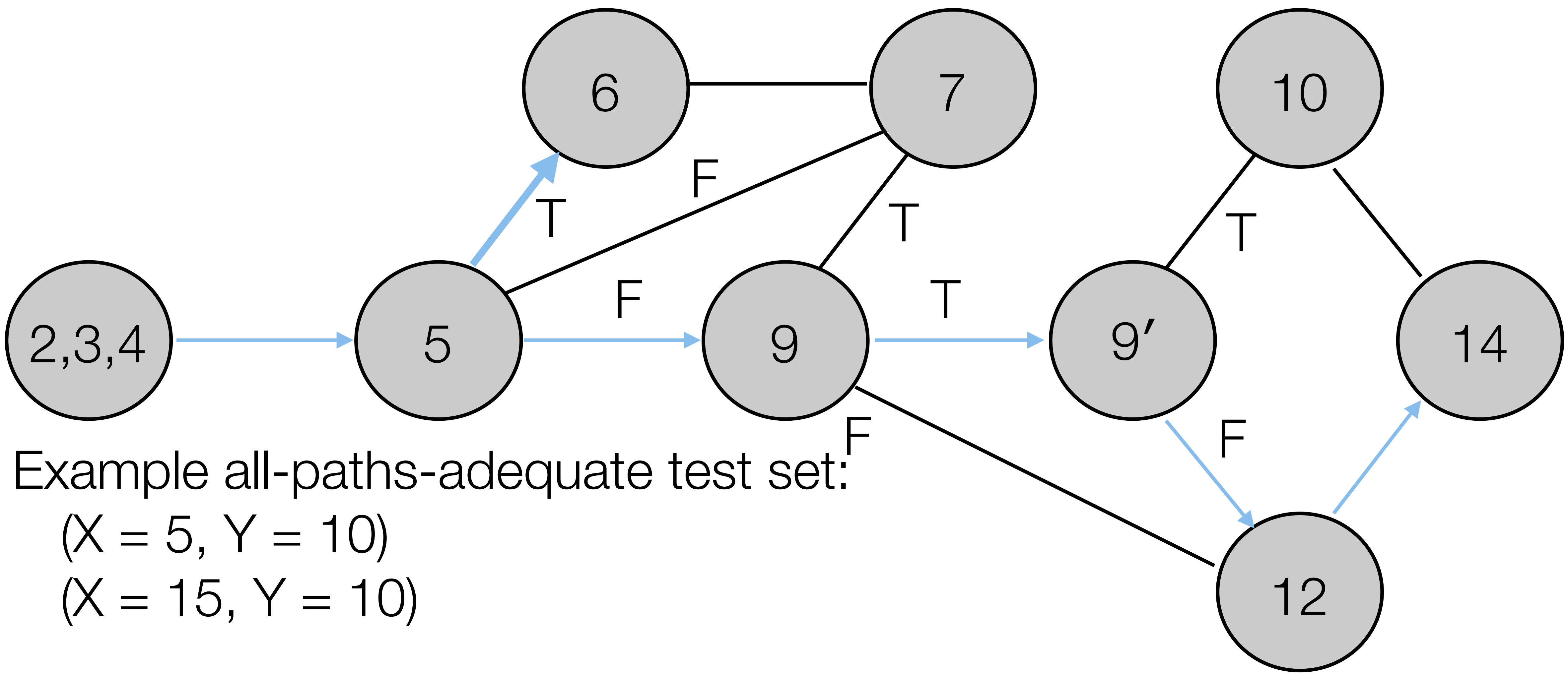
All-Paths Coverage of P



Example all-paths-adequate test set:

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

All-Paths Coverage of P

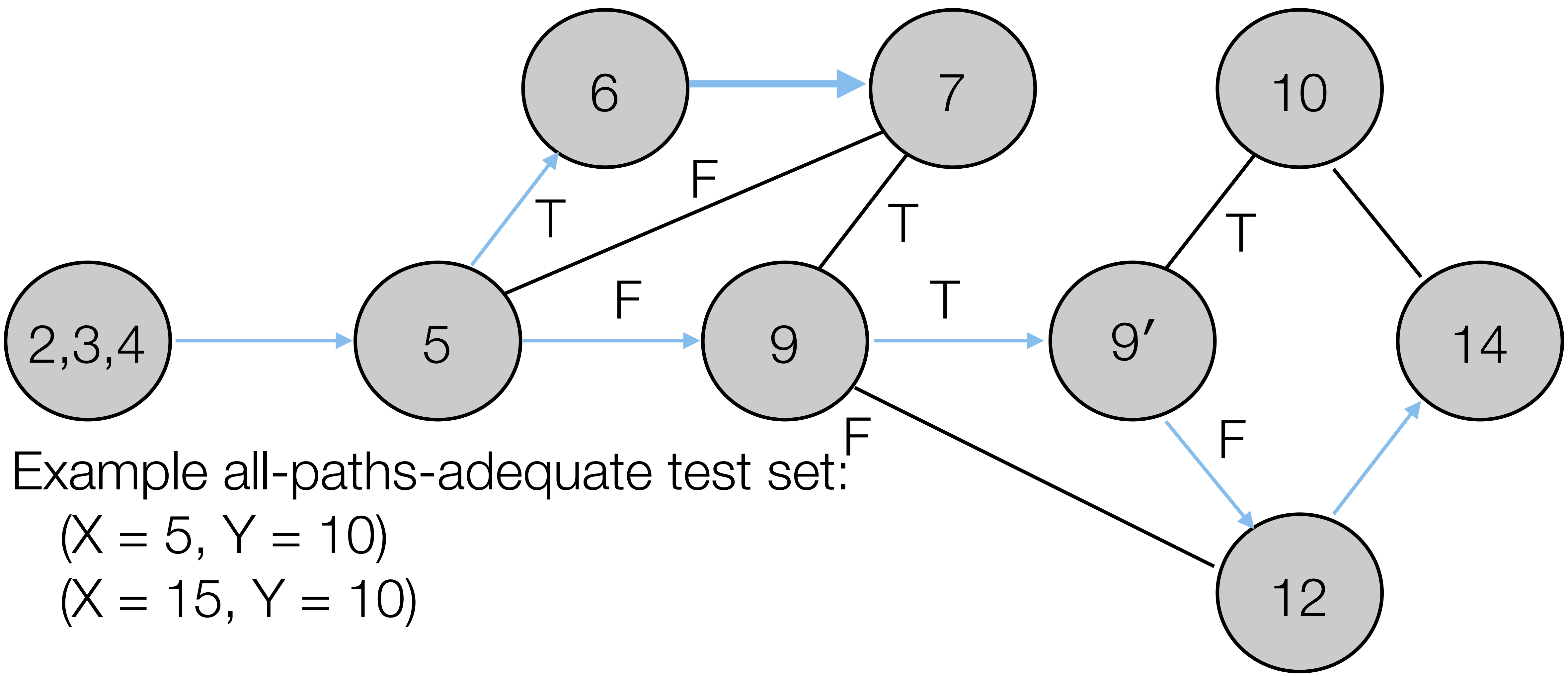


Example all-paths-adequate test set:

(X = 5, Y = 10)

(X = 15, Y = 10)

All-Paths Coverage of P

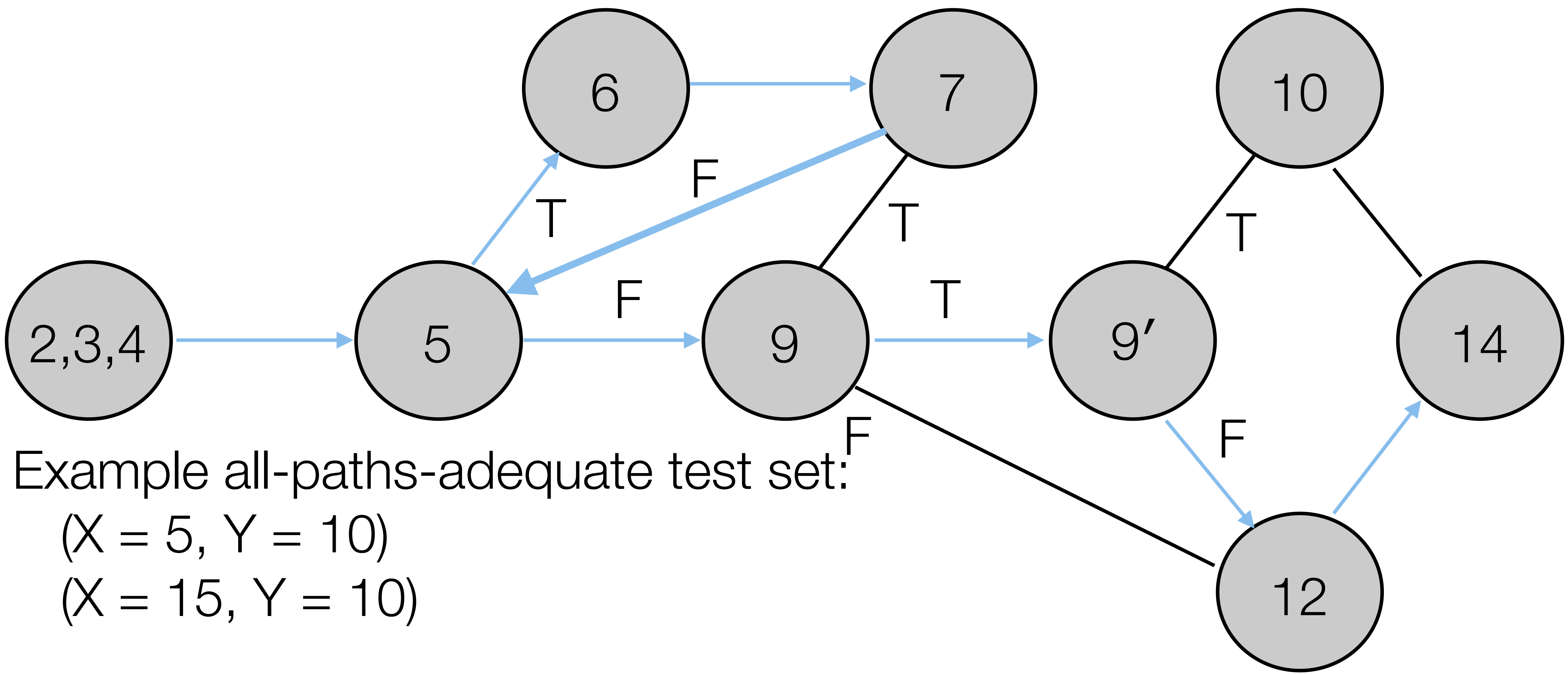


Example all-paths-adequate test set:

(X = 5, Y = 10)

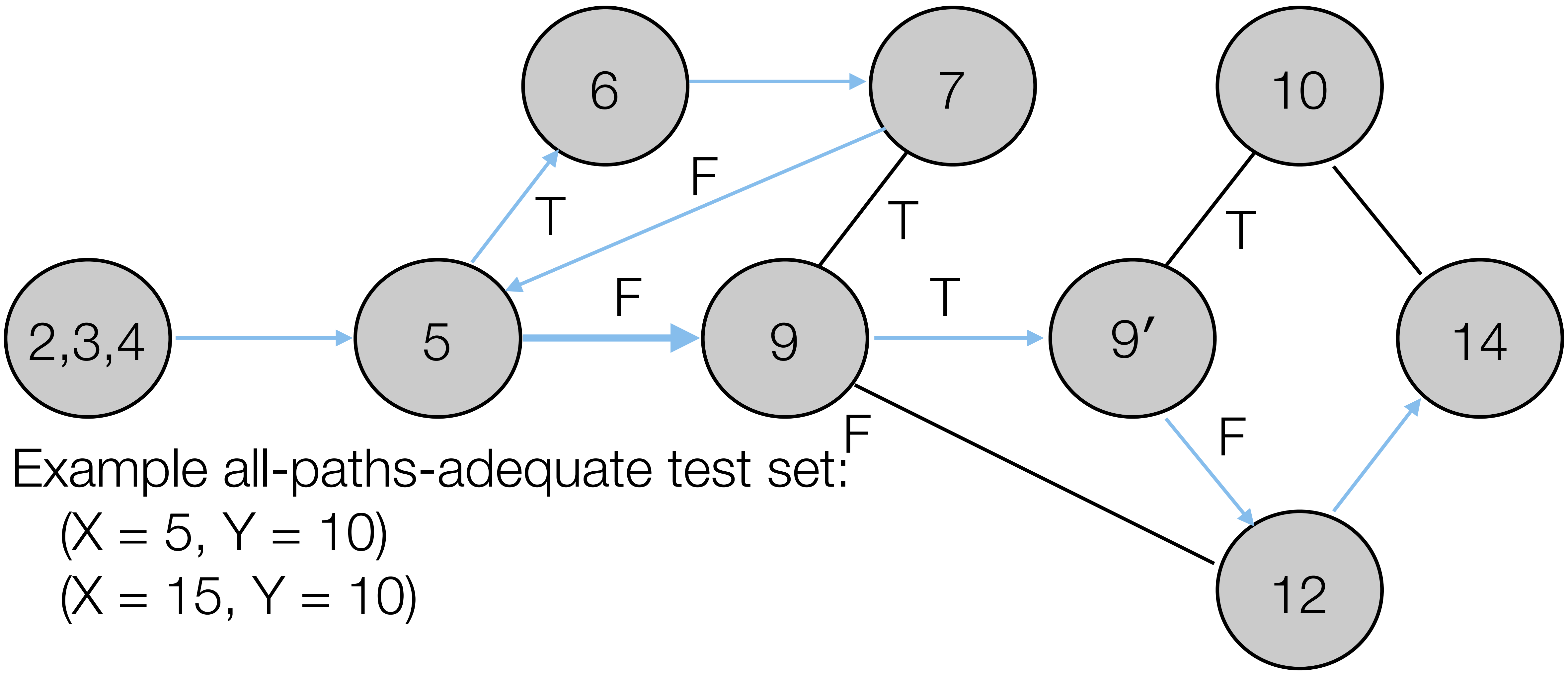
(X = 15, Y = 10)

All-Paths Coverage of P



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

All-Paths Coverage of P

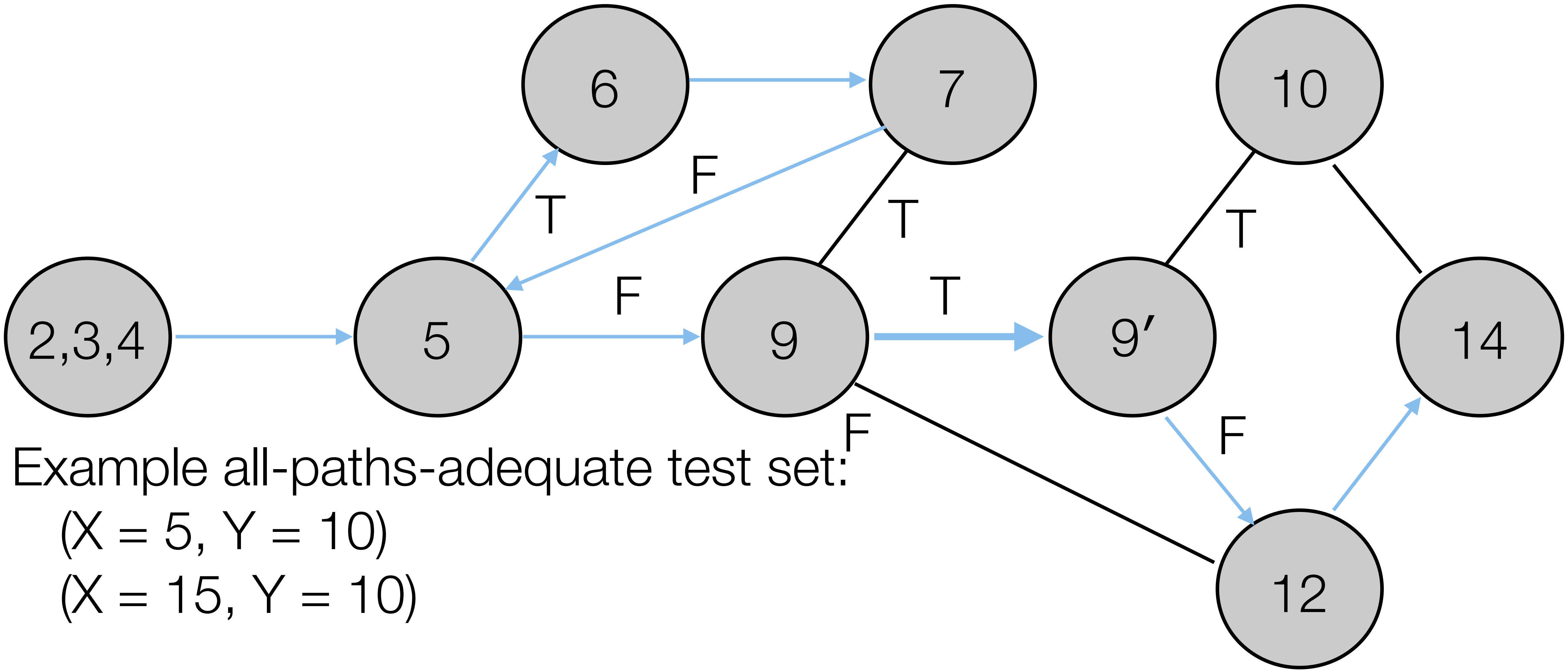


Example all-paths-adequate test set:

(X = 5, Y = 10)

(X = 15, Y = 10)

All-Paths Coverage of P

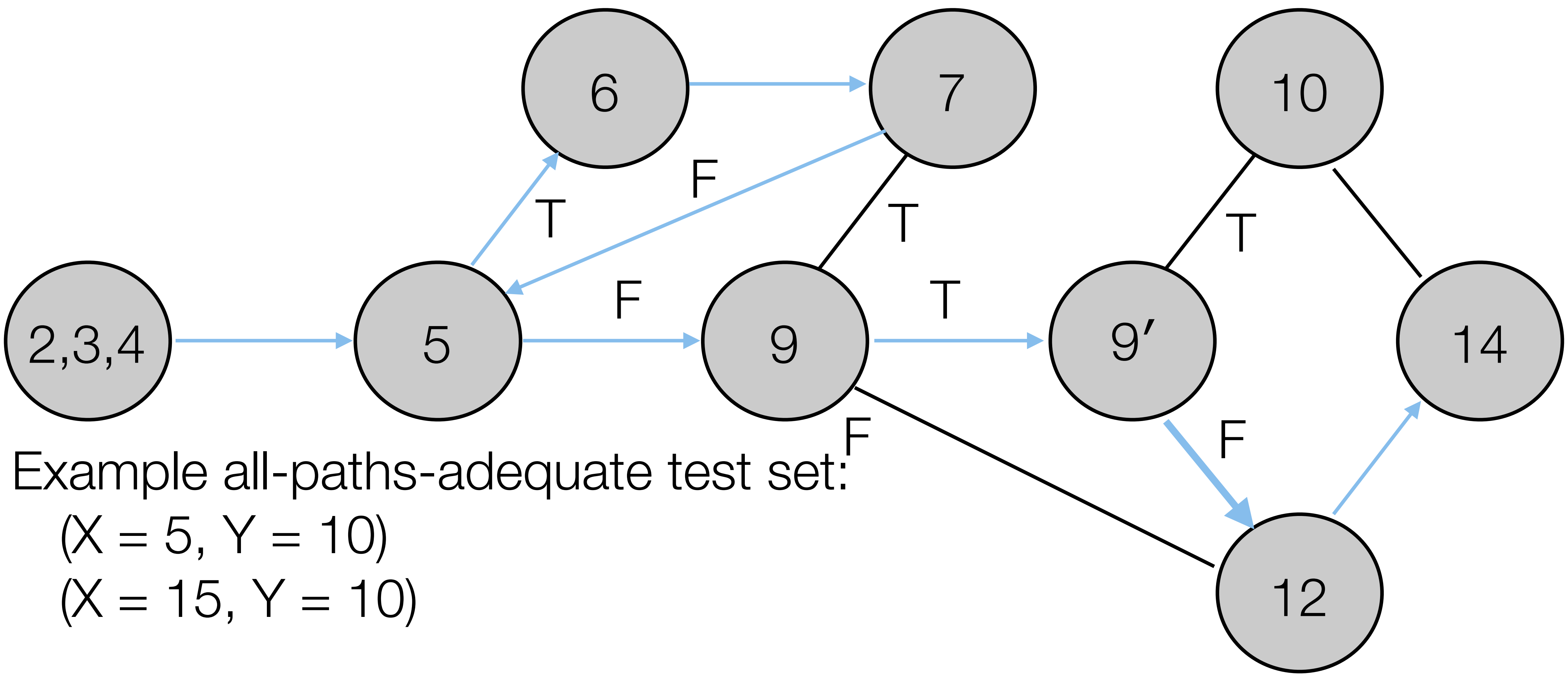


Example all-paths-adequate test set:

(X = 5, Y = 10)

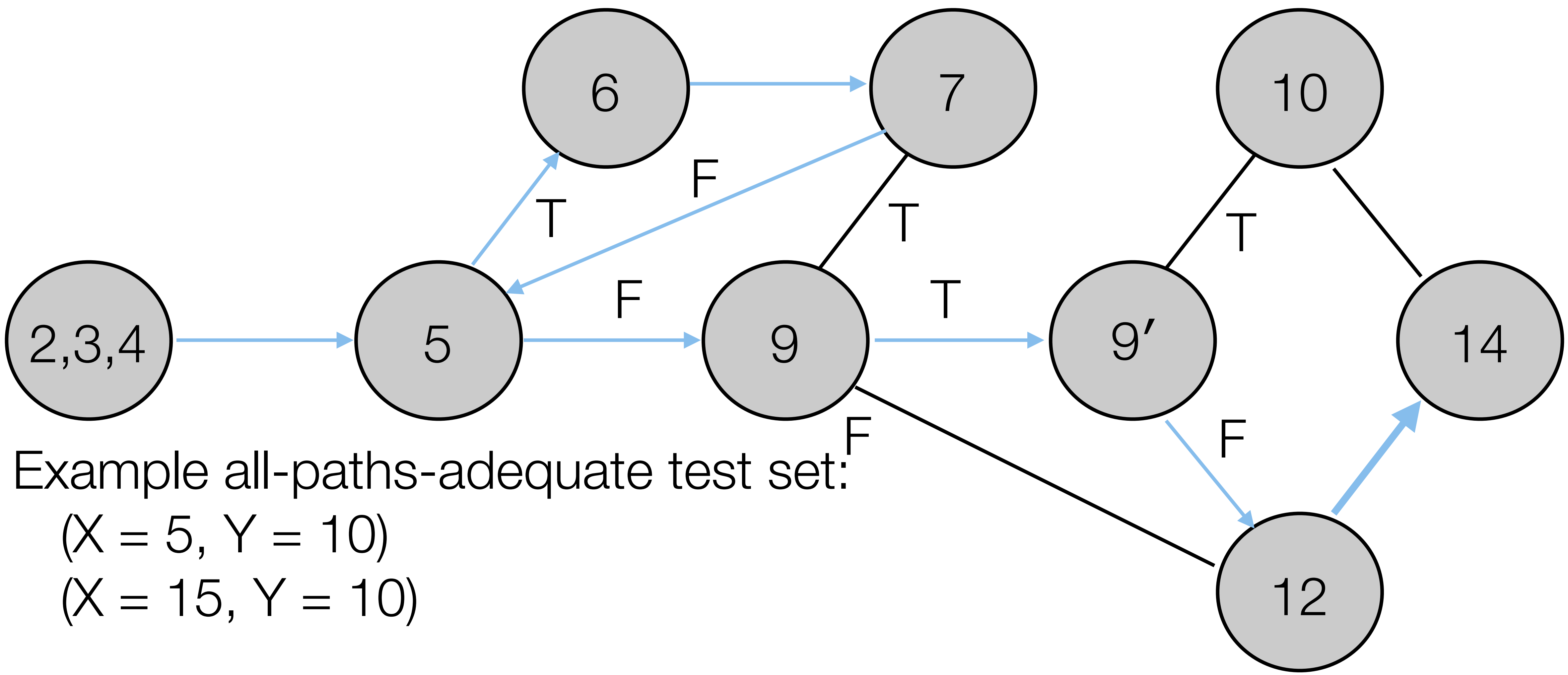
(X = 15, Y = 10)

All-Paths Coverage of P



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

All-Paths Coverage of P

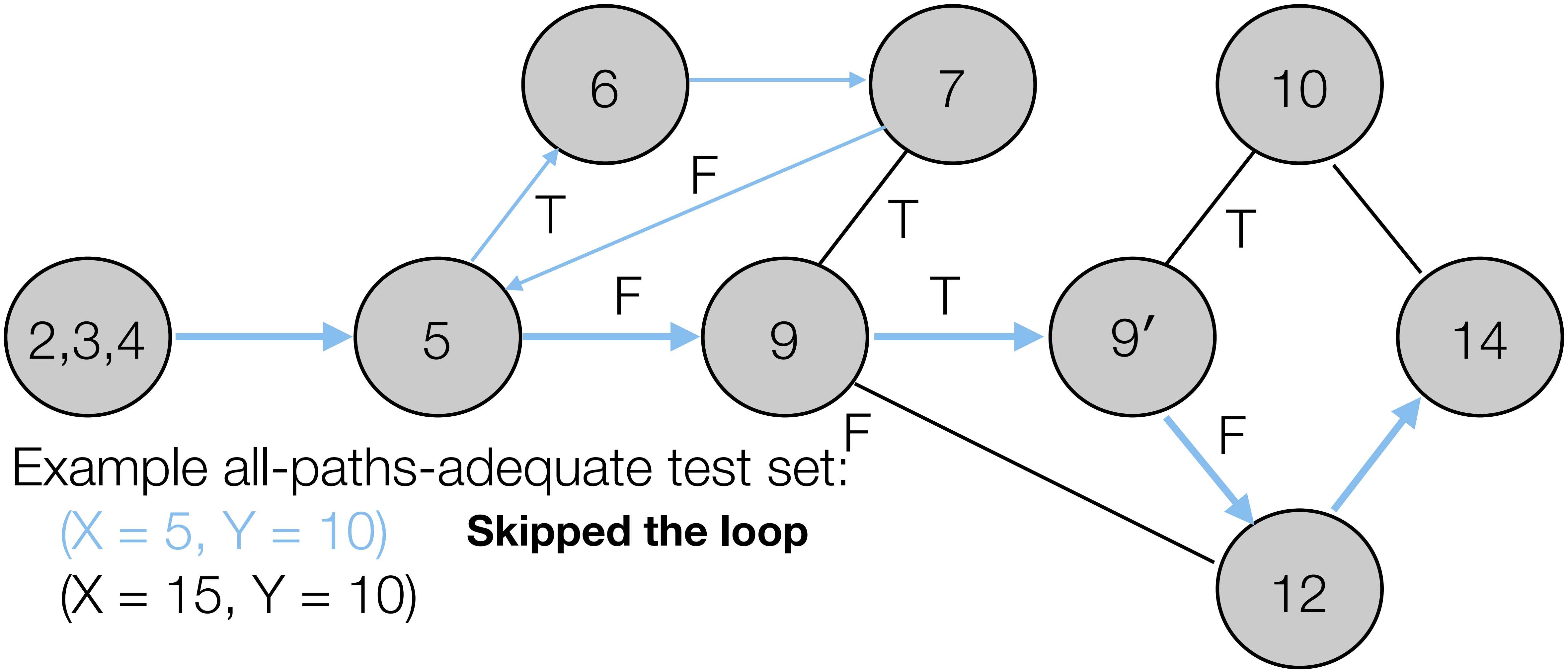


Example all-paths-adequate test set:

(X = 5, Y = 10)

(X = 15, Y = 10)

All-Paths Coverage of P

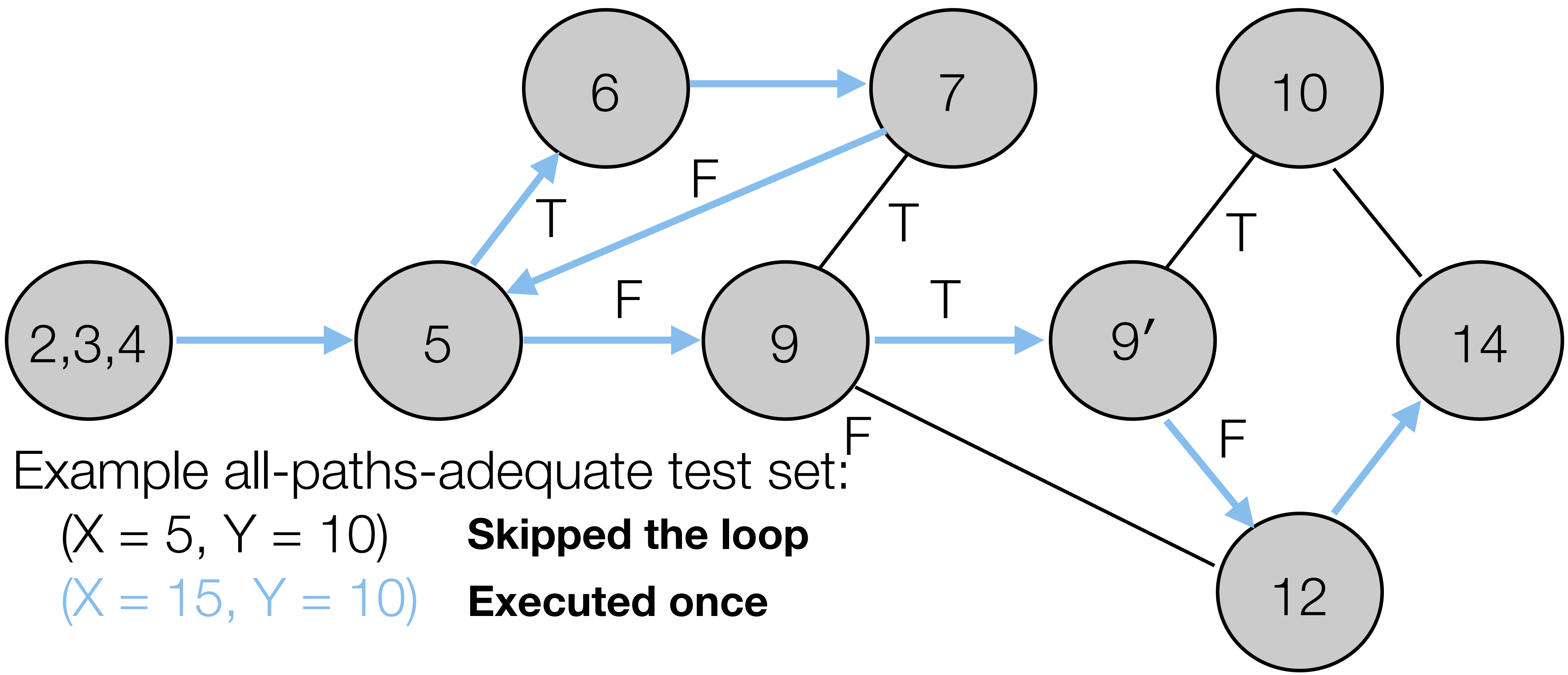


Example all-paths-adequate test set:

(X = 5, Y = 10) **Skipped the loop**

(X = 15, Y = 10)

All-Paths Coverage of P

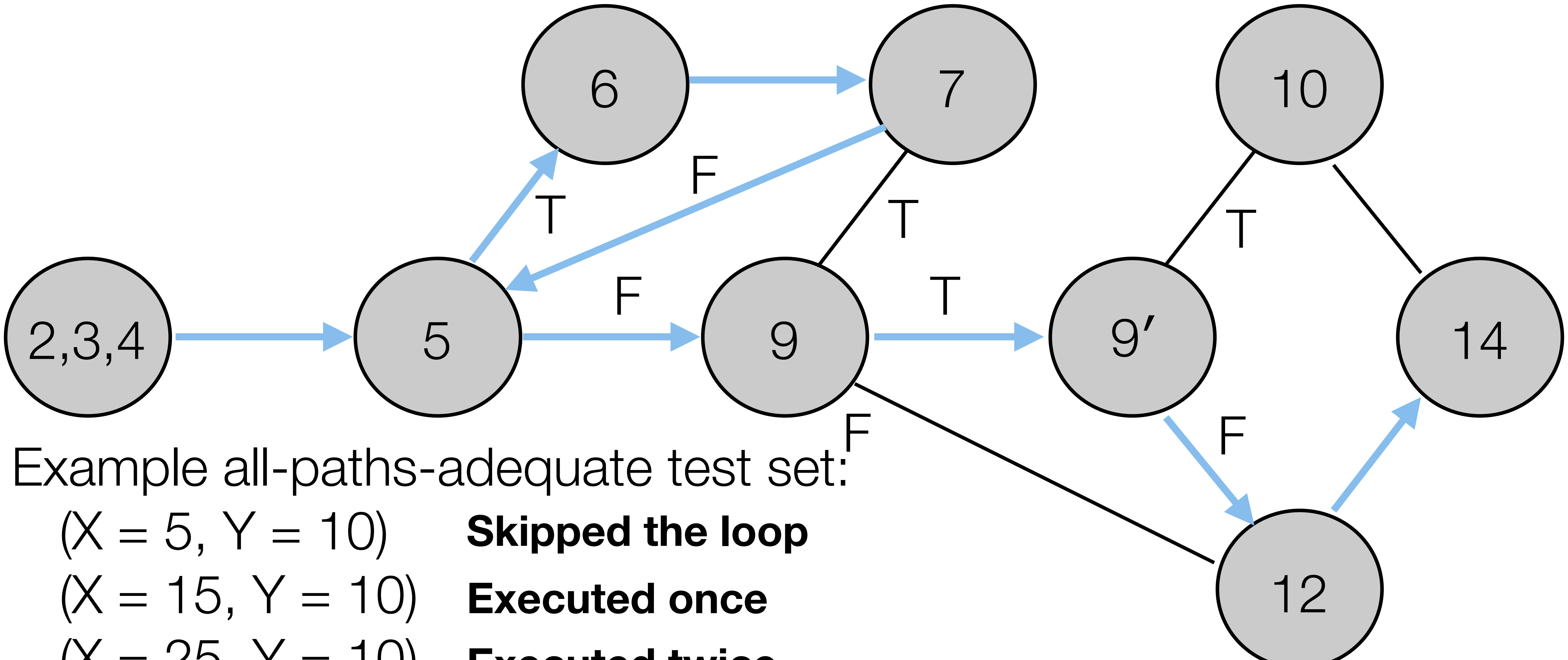


Example all-paths-adequate test set:

(X = 5, Y = 10) **Skipped the loop**

(X = 15, Y = 10) **Executed once**

All-Paths Coverage of P



Example all-paths-adequate test set:

(X = 5, Y = 10) **Skipped the loop**

(X = 15, Y = 10) **Executed once**

(X = 25, Y = 10) **Executed twice**

And so on… you would also want permutations that exit the loop early

Code Coverage Tools

- Doing this by hand would be hard!
  - Fortunately, there are tools that can track code coverage metrics for you
    - typically just statement and branch coverage
  - These systems generate reports that show the percentage of the metric being achieved
    - they will also typically provide a view of the source code annotated to show which statements and conditions were “hit” by your test suite

Testing Automation (I)

- It is important that your tests be automated
  - More likely to be run
  - More likely to catch problems as changes are made
- As the number of tests grow, it can take a long time to run the tests, so it is important that the running time of each individual test is as small as possible
  - If that's not possible to achieve then
    - segregate long running tests from short running tests
      - execute the latter multiple times per day
      - execute the former at least once per day (they still need to be run!!)

Testing Automation (II)

- It is important that running tests be easy
  - testing frameworks allow tests to be run with a single command
    - often as part of the build management process
- We'll see examples of this later in the semester

Continuous Integration

- Since test automation is so critical, systems known as continuous integration frameworks have emerged
- Continuous Integration (CI) systems wrap version control, compilation, and testing into a single repeatable process
  - You create/debug code as usual;
    - You then check your code and the CI system builds your code, tests it, and reports back to you

Summary

- Testing is one element of software quality assurance
  - Verification and Validation can occur in any phase
- Testing of Code involves
  - Black Box, Grey Box, and White Box tests
  - All require: input, expected output (via spec), actual output
  - White box additionally looks for code coverage
- Testing of systems involves
  - unit tests, integration tests, system tests and acceptance tests
- Testing should be automated and various tools exists to integrate testing into the version control and build management processes of a development organization

Coming Up Next:

- Lecture 6: Agile Methods and Agile Teams
- Lecture 7: Division of Labor and Design Approaches in Concurrency