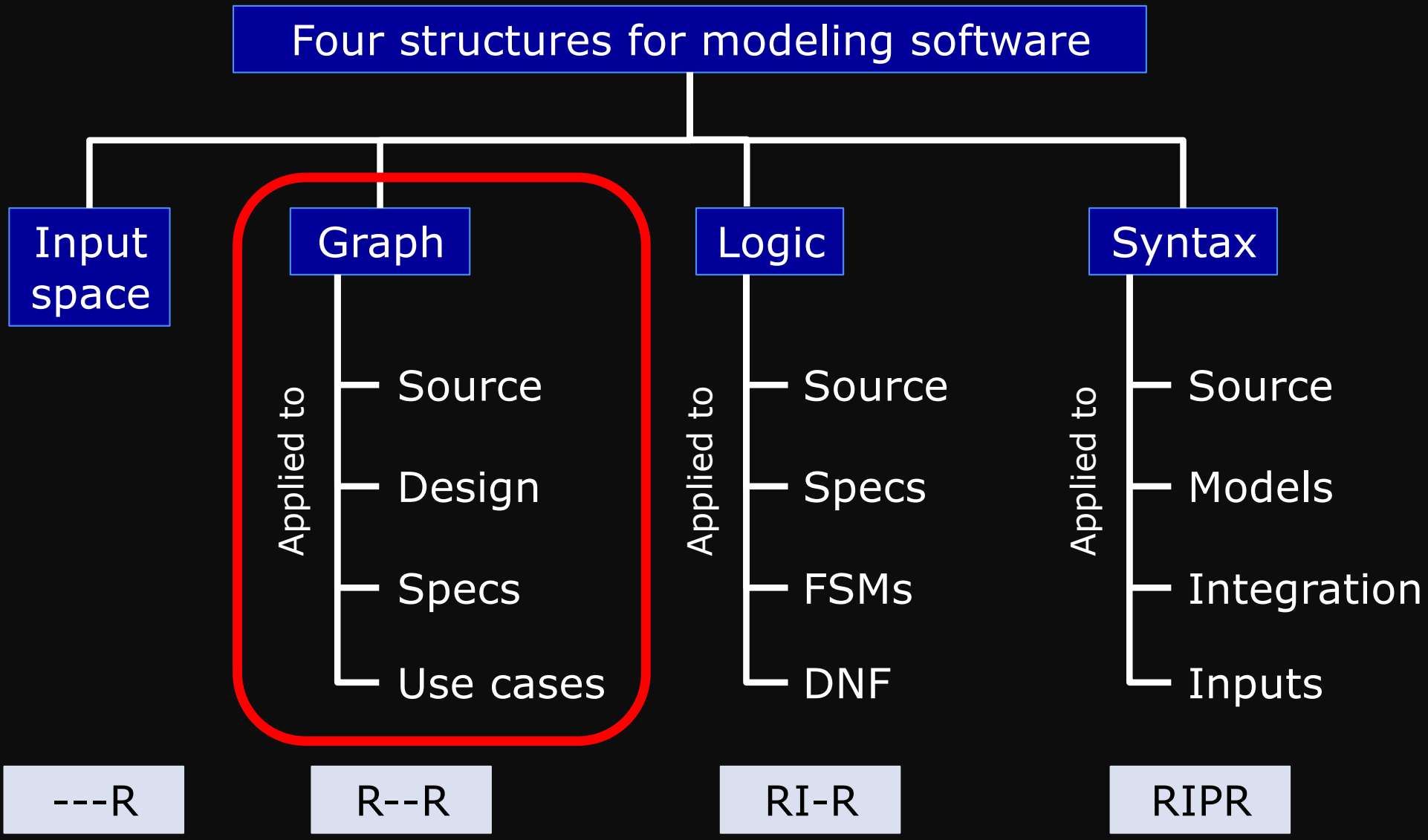
Graph Coverage for Source Code

CS 3250 Software Testing

[Ammann and Offutt, "Introduction to Software Testing," Ch. 7.3]

Structures for Criteria-Based Testing



Overview

- Graph coverage criteria are widely used on source code
- Define graph, then apply coverage criterion
- Control flow graph (CFG): the most common graph for source code
- Node coverage: execute every statement
- Edge coverage: execute every branch
- Data flow coverage: augment the CFG with
  - defs: statements that assign values to variables
  - uses: statements that use variables

Control Flow Graph (CFG)

- Represent the control flow of a piece of source code

Nodes	Basic blocks • Representing sequences of instructions / statements that always execute together in sequence
Edges	Control flow (branch) between basic blocks • Representing transfer of control
Initial nodes	Entry points (of a method)
Final nodes	Exit points (of a method) • E.g., `return` or `throw` in Java
Decision nodes	Choices in control flow • E.g., `if` or `switch-case` blocks or condition for loops in Java

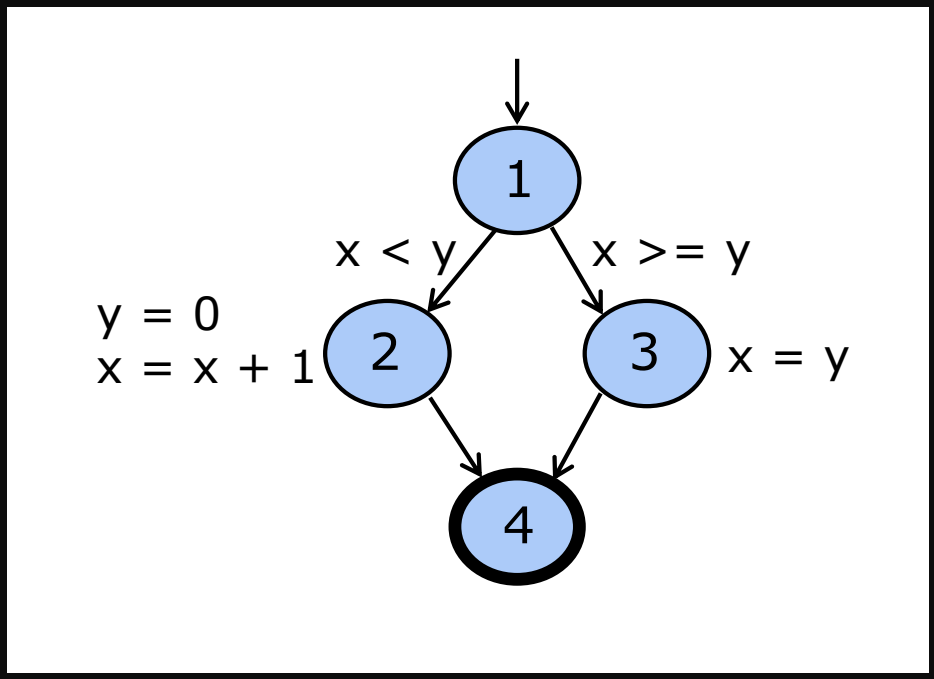
- Can be annotated with extra information such as branch predicates, defs, and uses

Example: CFG for *if-else*

```
if (x < y)
{
    y = 0;
    x = x+1;
}
else
{
    x = y;
}
```

- Basic blocks (nodes)
  - 1: if (x < y)
  - 2: y=0; x = x+1;
  - 3: x = y;
- Entry node
  - 1
- Decision nodes
  - 1
- Junction nodes
  - 4
- Exit nodes
  - 4

- Control flow (edges)
  - 1 → 2
  - 1 → 3
  - 2 → 4
  - 3 → 4



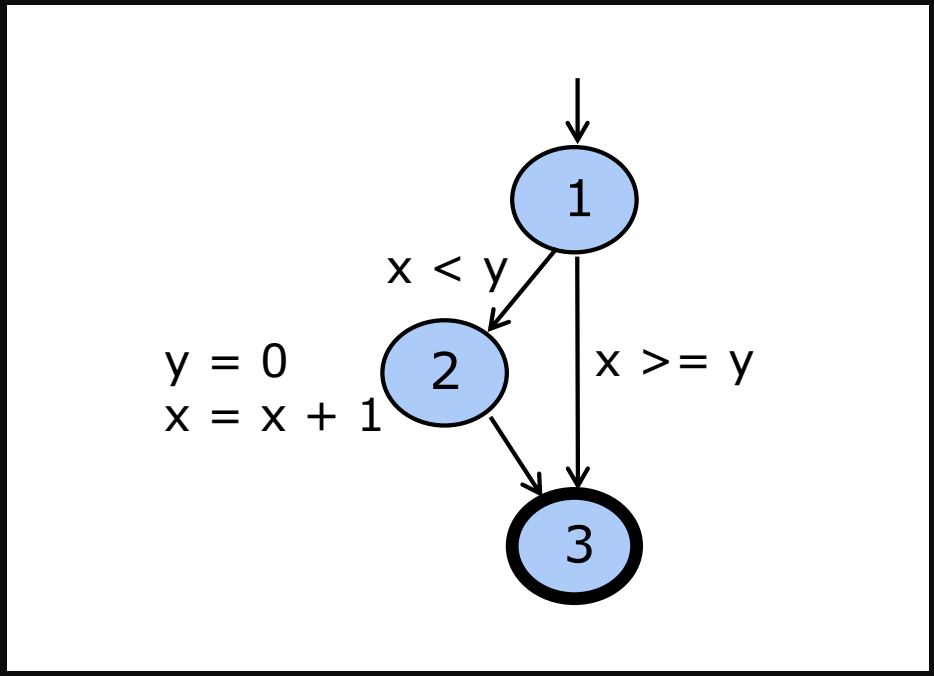
(Code snippet has been simplified)

Example: CFG for *If* without *else*

```
if (x < y)
{
    y = 0;
    x = x+1;
}
```

- Basic blocks (nodes)
  - 1: if (x < y)
  - 2: y=0; x = x+1;
- Entry node
  - 1
- Decision nodes
  - 1
- Junction nodes
  - 3
- Exit nodes
  - 3

- Control flow (edges)
  - 1 → 2
  - 1 → 3
  - 2 → 3



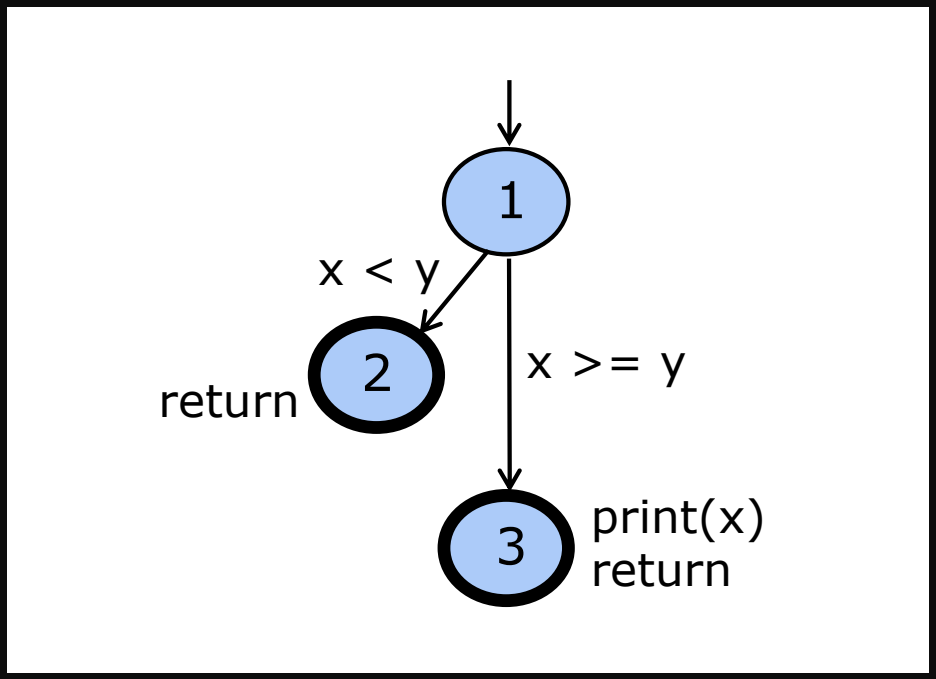
(Code snippet has been simplified)

Example: CFG for *If* with *return*

```
if (x < y)
{
    return;
}
print(x);
return;
```

- Basic blocks (nodes)
  - 1: if (x < y)
  - 2: return;
  - 3: print(x); return;
- Entry node
  - 1
- Decision nodes
  - 1
- Junction nodes
  - -
- Exit nodes
  - 2, 3

- Control flow (edges)
  - 1 → 2
  - 1 → 3



(Code snippet has been simplified)

Loops

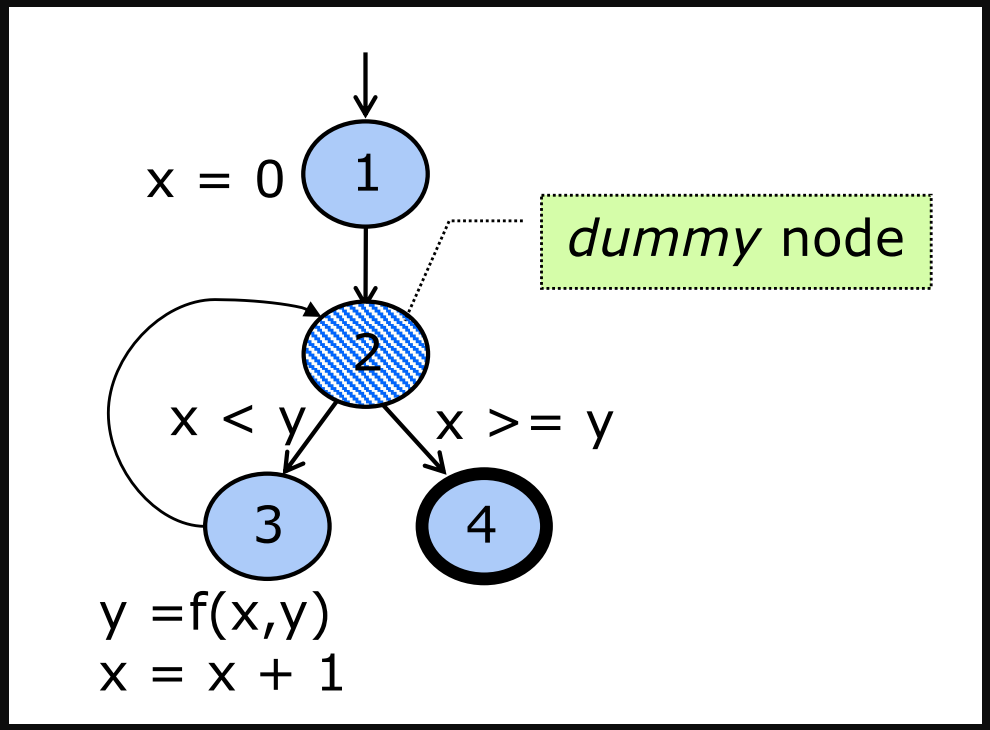
- Loops require extra nodes ("dummy" node)
  - Not directly derived from program statements
- Looping structures: *while* loop, *for* loop, *do-while* loop
- Common mistake
  - Try to have the edge go to the entry node

Example: CFG for a *while* loop

```
x = 0;
while (x < y)
{
    y = f(x,y);
    x = x + 1;
}
```

- Basic blocks (nodes)
  - 1: x = 0;
  - 2: while(x < y)
  - 3: y = f(x,y); x = x+1;
- Control flow (edges)
  - 1 → 2
  - 2 → 3
  - 2 → 4
  - 3 → 2

- Entry node
  - 1
- Decision nodes
  - 2
- Junction nodes
  - -
- Exit nodes
  - 4



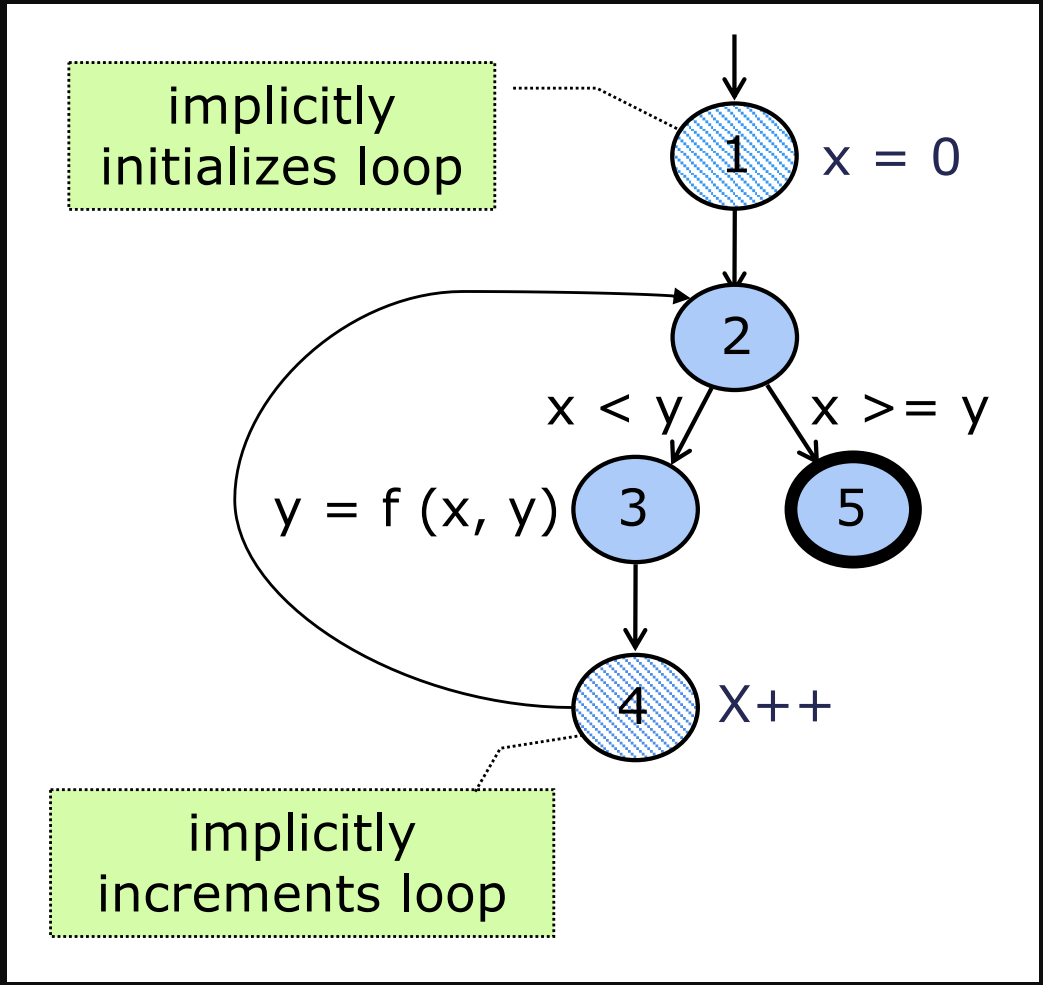
(Code snippet has been simplified)

Example: CFG for a *for* loop

```
for (x=0; x<y; x++)
{
    y = f(x,y);
}
```

- Basic blocks (nodes)
  - 1: x = 0;
  - 2: x < y
  - 3: y = f(x,y);
  - 4: x++;
- Entry node
  - 1
- Decision nodes
  - 2
- Junction nodes
  - -
- Exit nodes
  - 5

- Control flow (edges)
  - 1 → 2, 2 → 3, 2 → 5, 3 → 4, 4 → 2



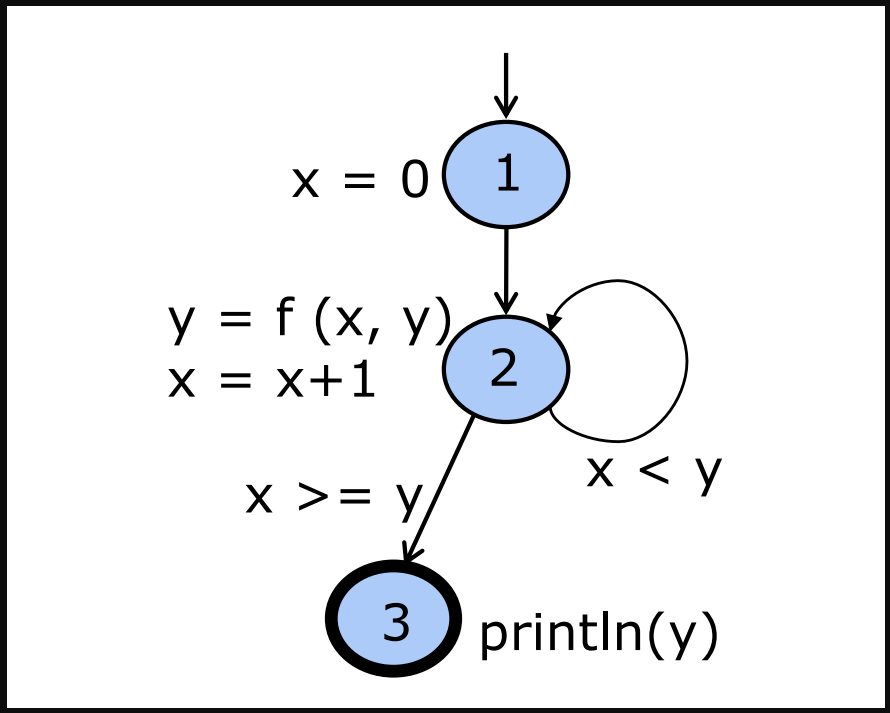
(Code snippet has been simplified)

Example: CFG for a *do-while* loop

```
x = 0;
do
{
    y = f(x,y);
    x = x + 1;
} while (x < y)
println(y);
```

- Basic blocks (nodes)
  - 1: x = 0; do
  - 2: y = f(x,y); x = x+1; while(x < y)
  - 3: print(y);
- Control flow (edges)
  - 1 → 2
  - 2 → 2
  - 2 → 3

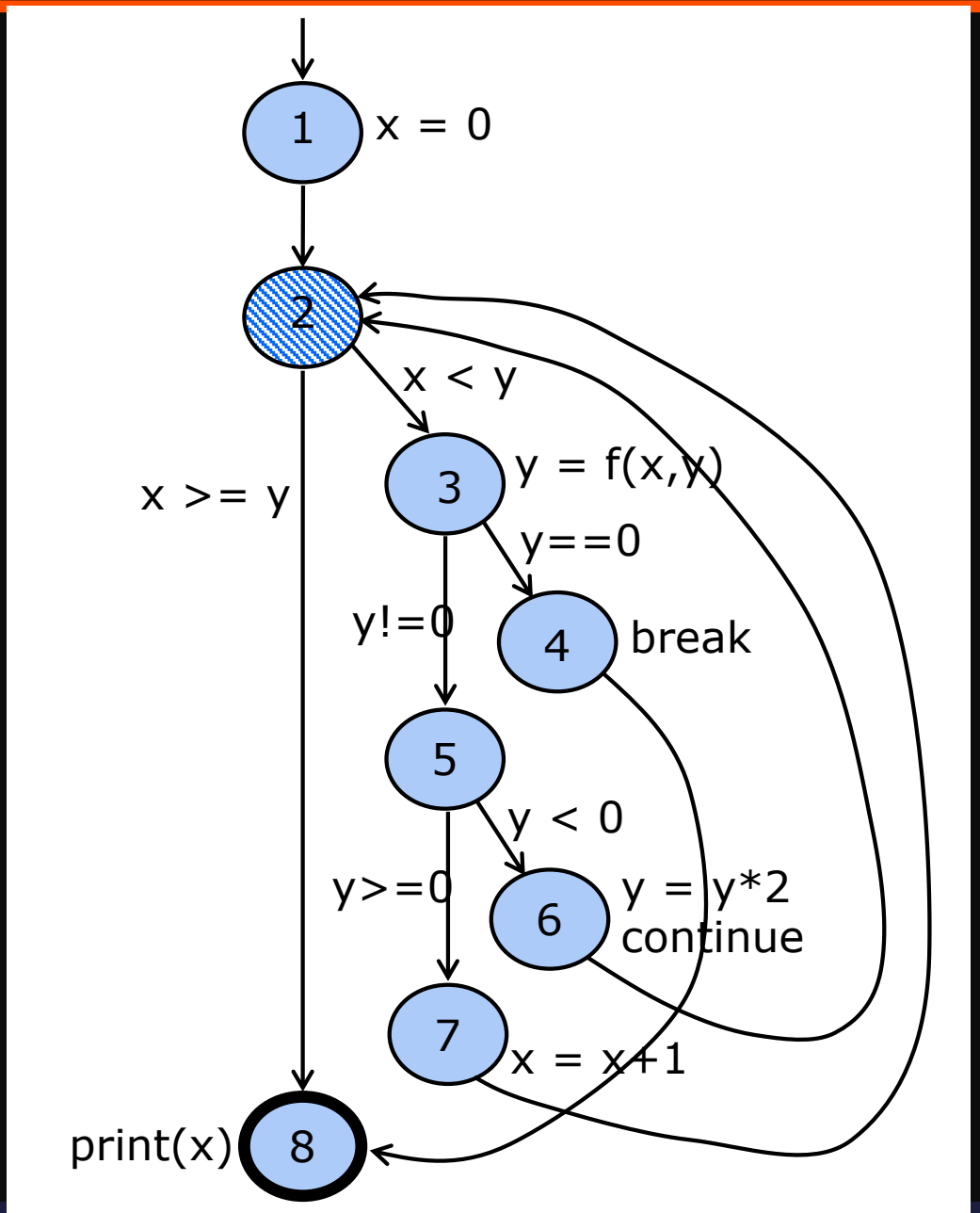
- Entry node
  - 1
- Decision nodes
  - 2
- Junction nodes
  - -
- Exit nodes
  - 3



(Code snippet has been simplified)

Example: CFG for a loop with *break* and *continue*

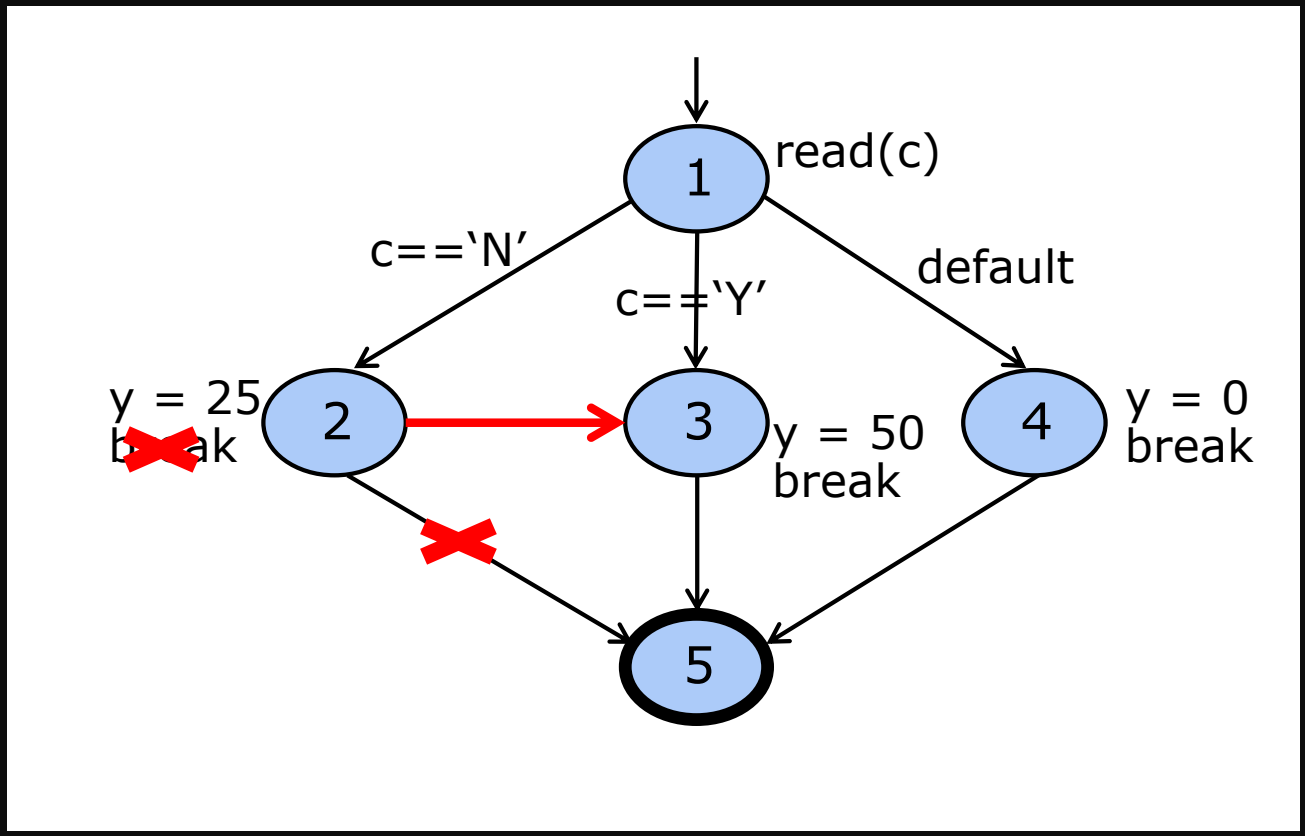
```
x = 0;
while (x < y)
{
    y = f(x,y);
    if (y==0)
        break;
    else if (y < 0)
    {
        y = y*2;
        continue;
    }
    x = x + 1;
}
print(x);
```



(Code snippet has been simplified)

Example: CFG for (*switch*) *case*

```
read(c);
switch(c)
{
case 'N':
    y = 25;
    break;
case 'Y':
    y = 50;
    break;
default:
    y = 0;
    break;
}
```



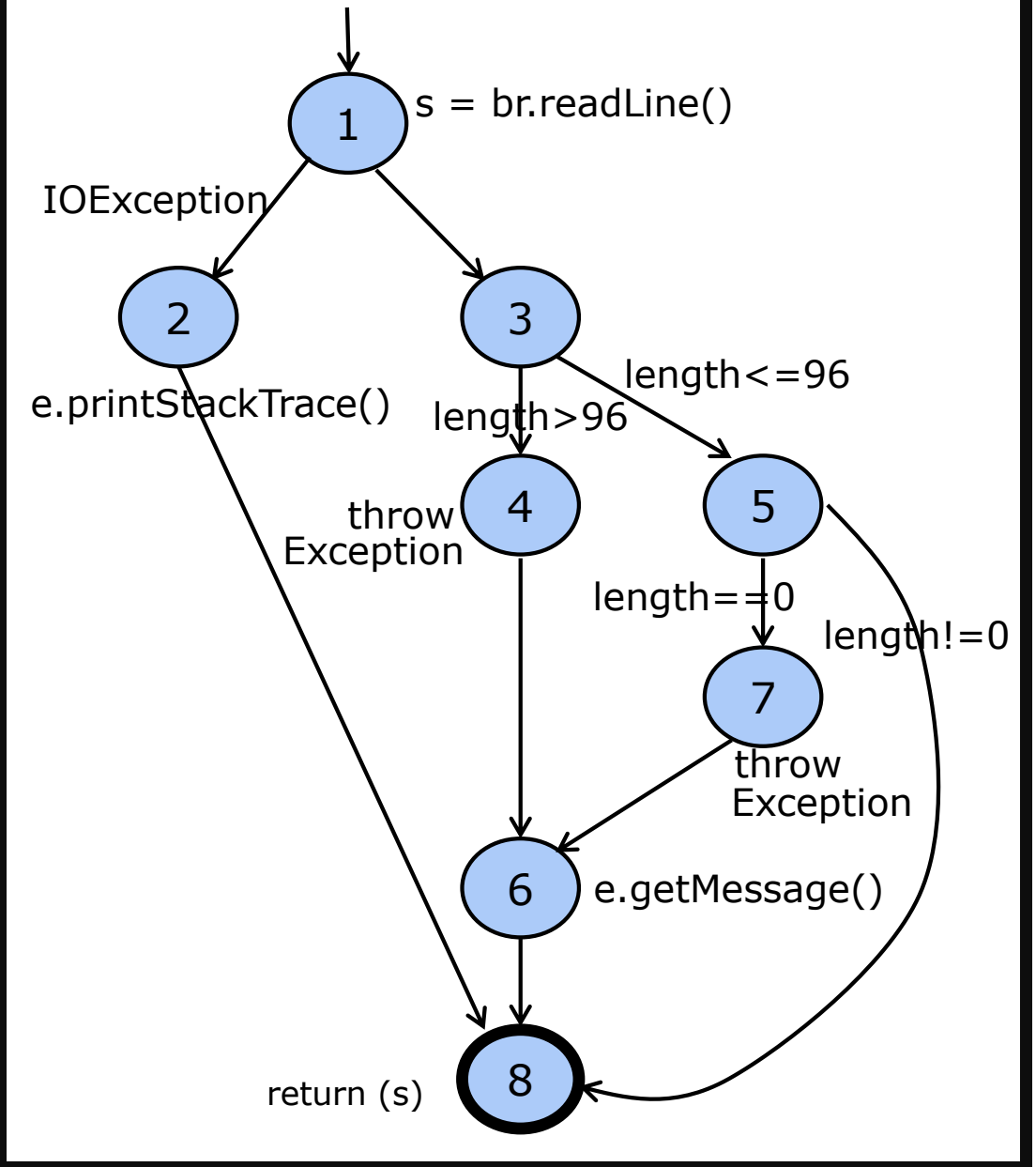
Cases without break?

- Fall through to the next case

(Code snippet has been simplified)

Example: CFG for Exceptions (*try-catch*)

```
try
{
    s = br.readLine();
    if (s.length() > 96)
        throw new Exception("too long");
    if (s.length() ==0)
        throw new Exception("too short");
} catch (IOException e) {
    e.printStackTrace();
} catch (Exception e) {
    e.getMessage();
}
return(s);
```



(Code snippet has been simplified)

Summary

- A common application of graph coverage criteria is to program source – control flow graph (CFG)
- Applying graph coverage criteria to control flow graphs is relatively straightforward
- A few decisions must be made to translate control structures into the graph
- We use basic blocks when assigning program statements to nodes while some tools assign each statement to a unique node.
  - Coverage is the same, although the bookkeeping will differ