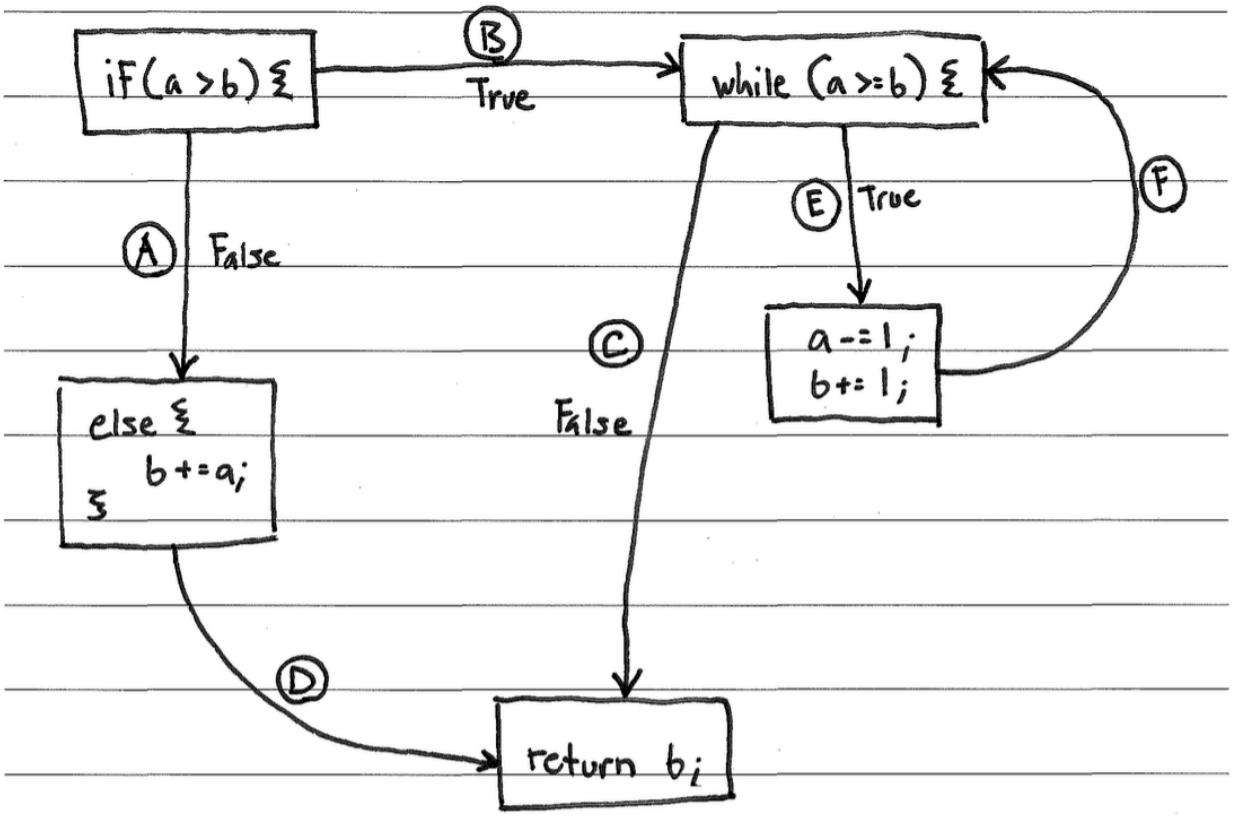
Problem: Draw a control flow diagram for this function. Label each edge with an uppercase letter.

```
int funWithNumbers(int a, int b) {
    if (a > b) {
        while (a >= b) {
            a -= 1;
            b += 1;
        }
    } else {
        b += a;
    }
    return b;
}
```

Solution:


iF(a >b) {
B
True
while (a >=b) {
A
False
E
True
F
a -= 1;
b += 1;
C
False
else {
b += a;
}
D
return b;

Problem: Fill in the table below with a test suite that provides *path coverage* of the code from the previous question. Cover no more than 2 iterations of the loop. In the covers column, list the relevant labeled items in your CFG that each test case covers. If there is some part of the coverage that is impossible to cover, then list it in the covers column, and put "N/A" in the associated x and y cells. Some cells in the table may be left blank.

Input		**Covers**
x	**y**	

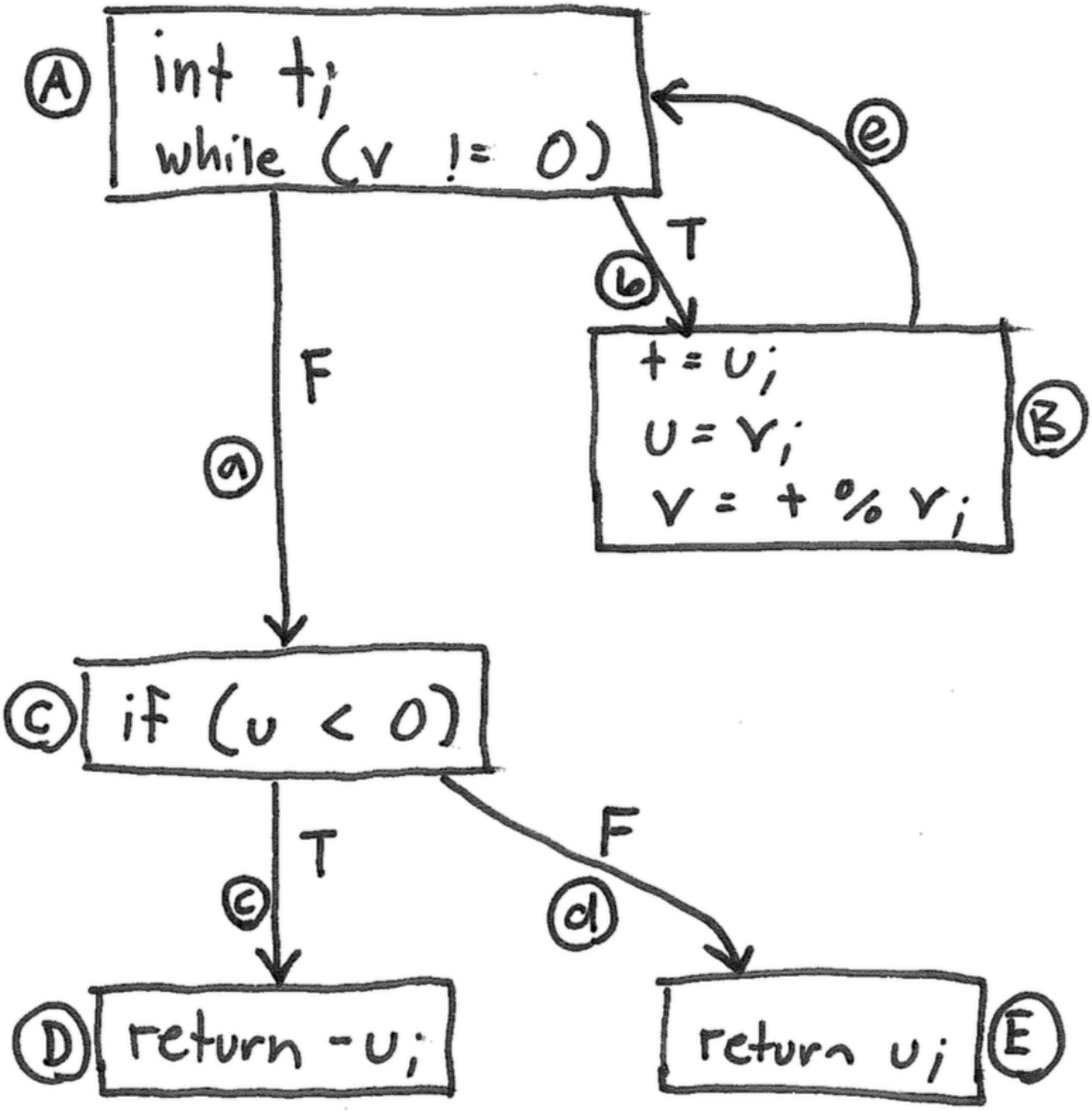
Solution:

Input		Covers
x	y	
1	2	AD
N/A	N/A	BC
1	0	BEFC
4	2	BEFEFC

Problem: Draw a control flow diagram for this function. Label each node in the graph with a capital letter, and label each edge with a lowercase letter.

```
int blammo(int u, int v) {
  int t;
  while (v != 0) {
    t = u;
    u = v;
    v = t % v; // Recall that % computes remainder of t/v
  }
  if (u < 0) { return -u; }
  return u;
}
```

Solution:


A
int t;
while (v != 0)
e
T
b
t = u;
u = v;
v = t % v;
B
F
a
c
if (u < 0)
T
F
c
d
D
return -u;
return u;
E

Problems:

1. Fill in the table below with a test suite that provides statement coverage of the "blammo" code. In the covers column, list the relevant labeled items in your CFG that each test case covers. Some cells in the table may be left blank.

Input		Covers
u	v	

2. Fill in the table below with a test suite that provides path coverage of the "blammo" code. Cover no more than 1 iteration of the loop. In the covers column, list the relevant labeled items in your CFG that each test case covers. Some cells in the table may be left blank.

Input		Covers
u	v	

Solutions:

1.

Input		Covers
u	v	
2	2	A, B, C, E
-1	0	A, C, D

2.

Input		Covers
u	v	
-1	0	a, c
0	0	a, d
-2	-2	b, e, a, c
2	2	b, e, a, d

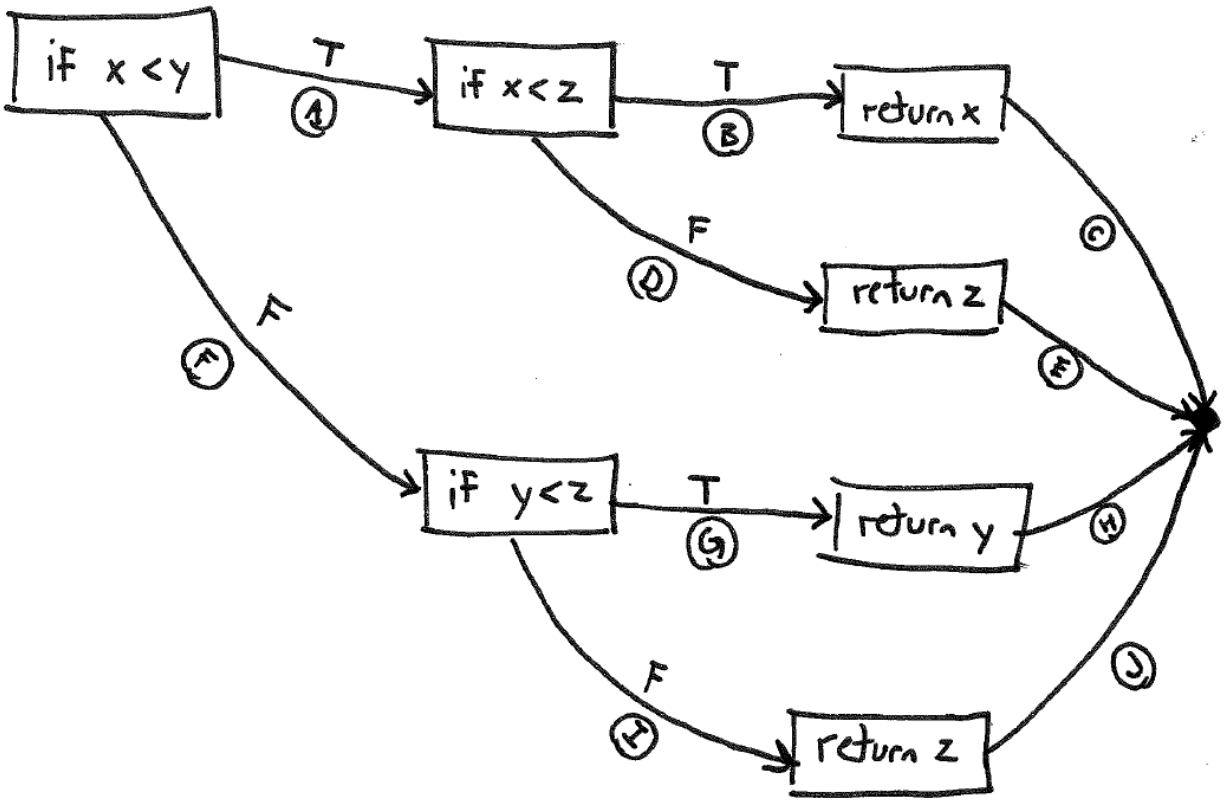
Paths:

a, c
a, d
b, e, a, c
b, e, a, d

Problem: Draw a control-flow graph for the following function. Label each edge in the graph with an uppercase letter.

```
def min_of_three(x, y, z)
  if x < y then
    if x < z then
      return x
    else
      return z
    end
  else
    if y < z then
      return y
    else
      return z
    end
  end
end
```

Solution:


if x<y
T
1
if x<z
T
B
return x
C
F
D
return z
E
F
if y<z
T
G
return y
H
F
I
return z
J

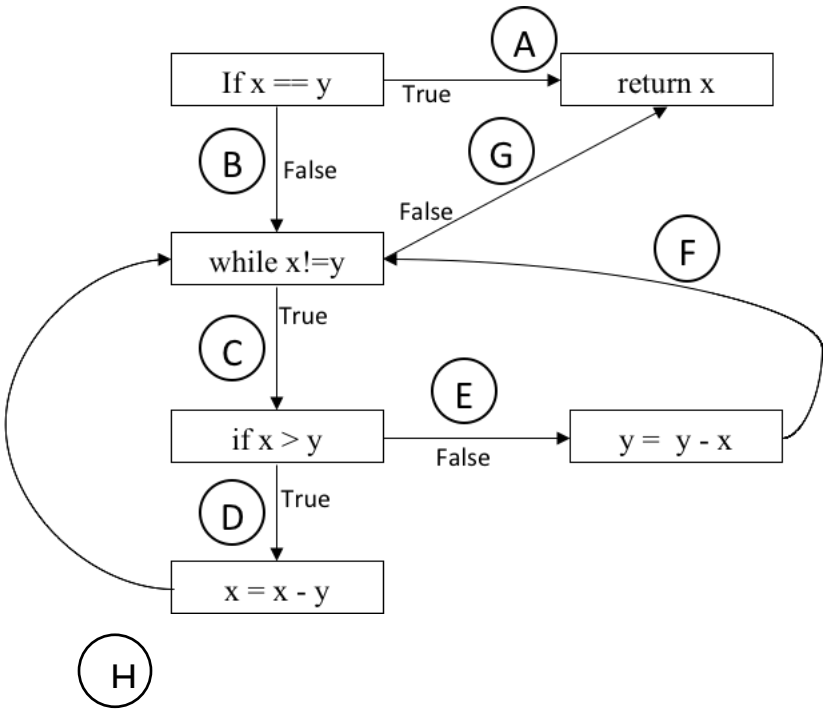
Problem: Fill in the table below with a test suite that provides path coverage of the `min_of_three` function from the previous question. In the covers column, list the relevant labeled edges in your CFG that each test case covers. Some cells in the table may be left blank.

Input			Expected Output	Covers
x	y	z		

Solution:

Input			Expected Output	Covers
x	y	z		
1	2	2	1	A, B, C
2	3	1	1	A, D, E
2	1	2	1	F, G, H
3	2	1	1	F, I, J

Consider the following control-flow graph for a `gcd` function in answering the questions below.



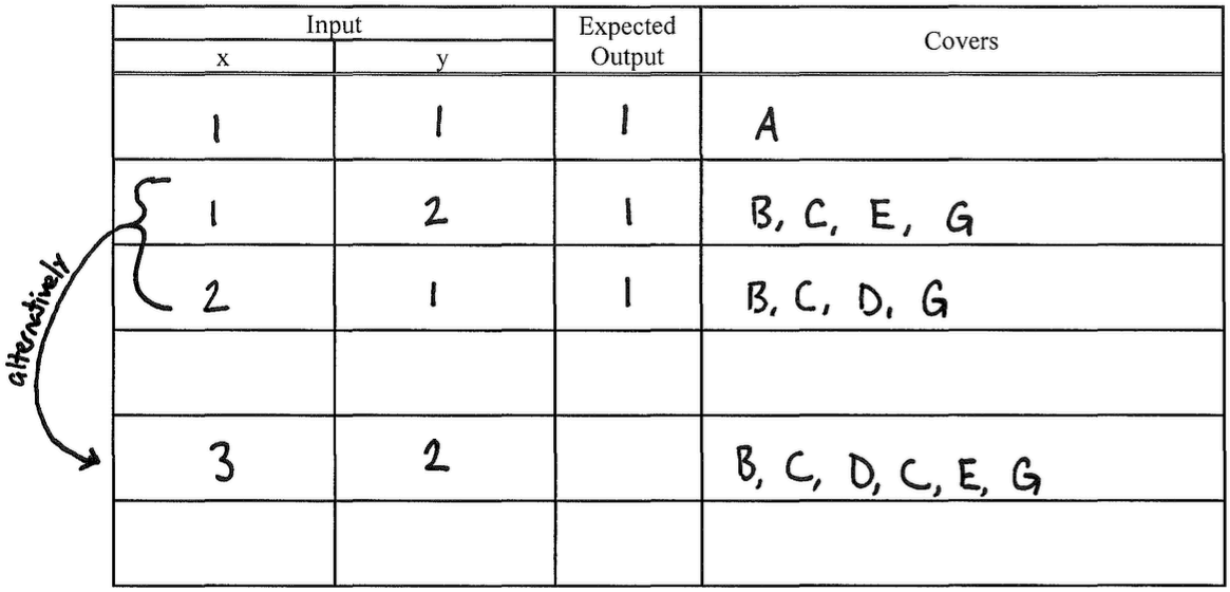
Problem: Fill in the table below with a test suite that provides condition coverage of the `gcd` function (see control-flow graph above). In the Covers column, list the relevant labeled edges in the CFG that each test case covers. Some cells in the table may be left blank.

Input		Expected Output	Covers
x	y		

Problem: Fill in the table below with a test suite that provides path coverage of the `gcd` function (see control-flow graph above). In the Covers column, list the relevant labeled edges in the CFG that each test case covers. Some cells in the table may be left blank. You need only cover executions that involve 1 iteration of the loop.

Input		Expected Output	Covers
x	y		

Solution: Condition Coverage



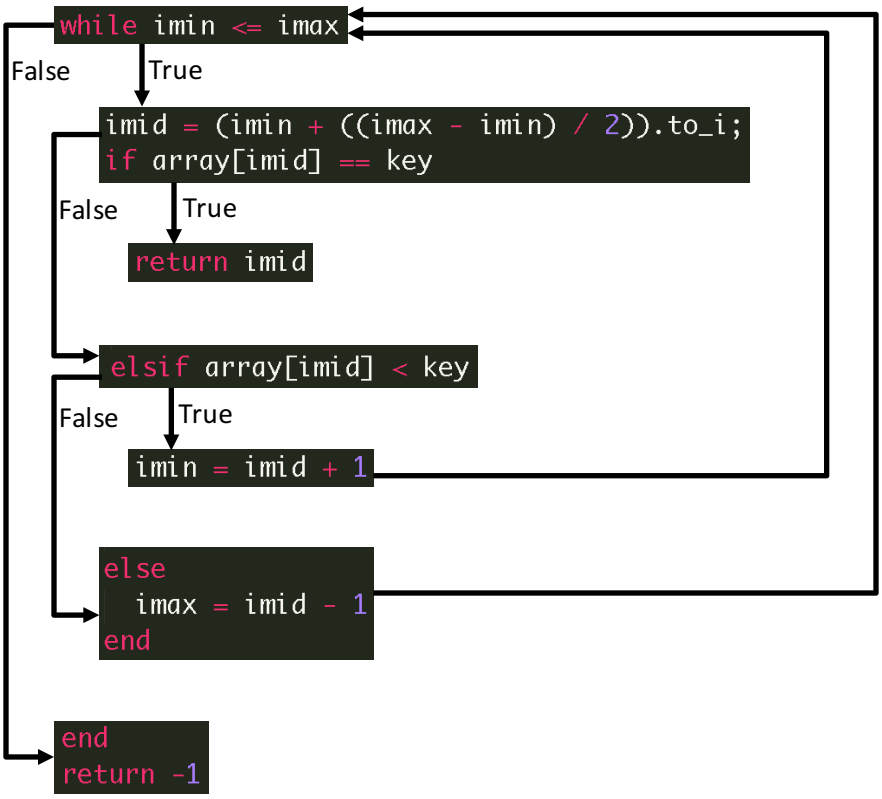
Input		Expected Output	Covers
x	y		
1	1	1	A
1	2	1	B, C, E, G
2	1	1	B, C, D, G
3	2		B, C, D, C, E, G

Solution: Path Coverage

Input		Expected Output	Covers
x	y		
1	1	1	A
2	1	1	B, C, D, H, G
1	2	1	B, C, E, F, G
			B, G ← not possible

Consider this binary-search function and its associated control-flow graph.

```
def binary_search(array, key, imin, imax)
  while imin <= imax
      imid = (imin + ((imax - imin) / 2)).to_i;
      if array[imid] == key
        return imid
      elsif array[imid] < key
        imin = imid + 1
      else
        imax = imid - 1
      end
  end
  return -1
end
```



Problems:

Consider the following test cases for the `binary_search` function.

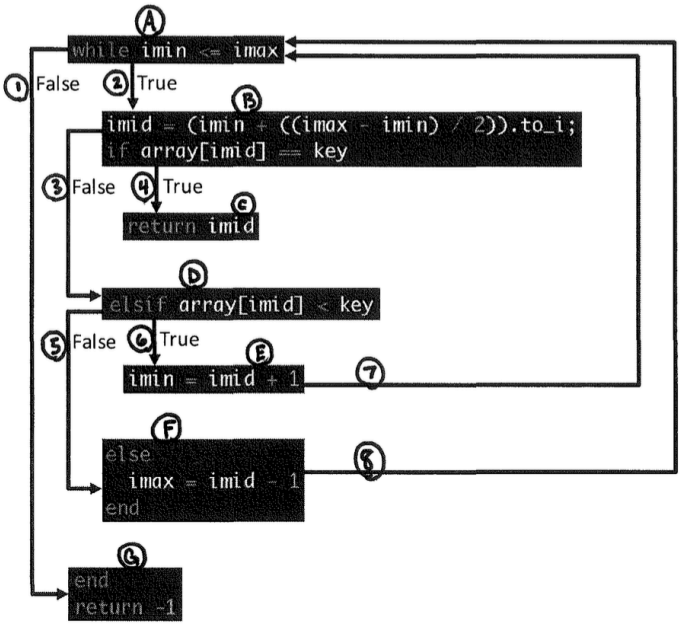
	array	key	imin	imax
a.	`[1]`	0	0	0
b.	`[1]`	1	0	0
c.	`[1]`	1	1	0
d.	`[1, 2, 3]`	1	0	2
e.	`[1, 2, 3]`	2	0	2
f.	`[1, 2, 3]`	3	0	2
g.	`[1, 2, 3]`	1	2	0
h.	`[1, 2, 3]`	2	2	0
i.	`[1, 2, 3]`	3	2	0

1. Select tests from the above to create a test suite that provides statement coverage of the `binary_search` function. Your suite should contain the minimum number of tests to provide the coverage.

2. Select tests from the above to create a test suite that provides condition coverage of the `binary_search` function. Your suite should contain the minimum number of tests to provide the coverage.

3. Select tests from the above to create a test suite that provides path coverage of the `binary_search` function. Cover only paths that contain one loop iteration or fewer (i.e., no path should enter the loop more than once). Your suite should contain the minimum number of tests to provide the coverage.

Solutions:



	array	key	imin	imax	Statements Covered	Edges Covered
a.	[1]	0	0	0	ABDFAG	23581
b.	[1]	1	0	0	ABC	24
c.	[1]	2	0	0	ABDEAG	23671
d.	[1, 2, 3]	1	0	2	ABDFABC	235824
e.	[1, 2, 3]	2	0	2	ABC	24
f.	[1, 2, 3]	3	0	2	ABDEABC	236724
g.	[1, 2, 3]	1	2	0	AG	1
h.	[1, 2, 3]	2	2	0	AG	1
i.	[1, 2, 3]	3	2	0	AG	1

1. a, F or c, d
(Need to cover statements A, B, C, D, E, F, G)

2. a, F or c, d
(Need to cover edges 1, 2, 3, 4, 5, 6)

3. (g|h|i), (b|e), c, a

Any 1 of these — Any 1 of these

Possible paths	Tests that cover
1	g, h, i
24	b, e
23671	c
23581	a

Problems:

Consider the following test cases for the `binary_search` function.

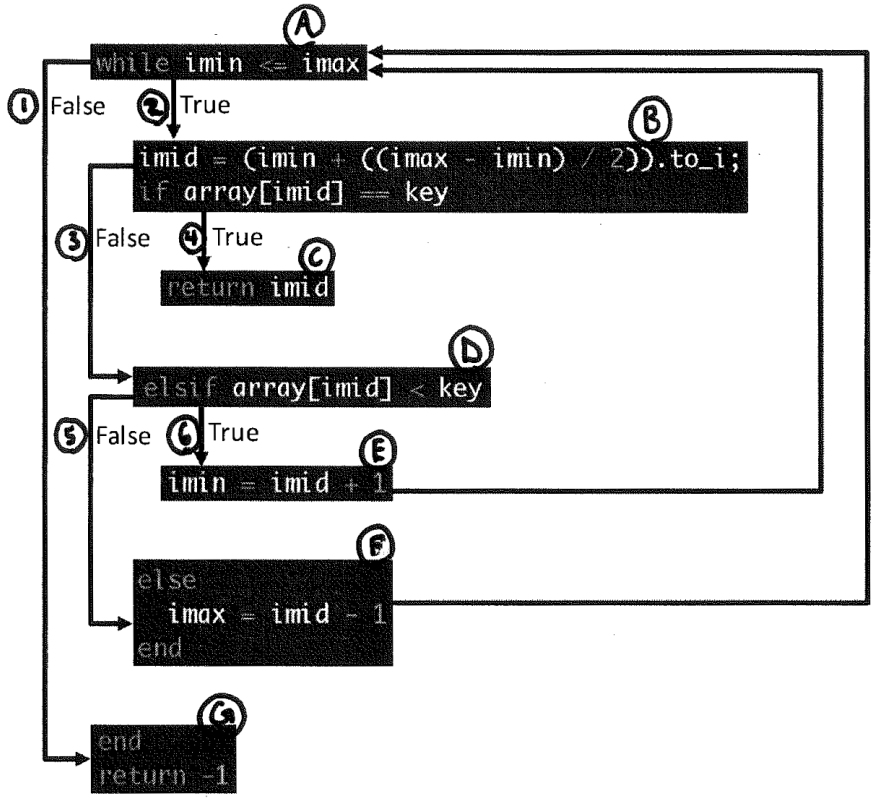
	array	key	imin	imax
a.	[0]	0	0	0
b.	[0]	1	0	0
c.	[0]	1	1	0
d.	[0]	-1	0	0

1. Select tests from the above to create a test suite that provides statement coverage of the `binary_search` function. Your suite should contain the minimum number of tests to provide the coverage.

2. Select tests from the above to create a test suite that provides condition coverage of the `binary_search` function. Your suite should contain the minimum number of tests to provide the coverage.

3. Select tests from the above to create a test suite that provides path coverage of the `binary_search` function. Cover only paths that contain one loop iteration or fewer (i.e., no path should enter the loop more than once). Your suite should contain the minimum number of tests to provide the coverage.

Solutions:



	array	key	imin	imax	Statements Covered	Conditions Covered
a.	[0]	0	0	0	A B C	2 4
b.	[0]	1	0	0	A B D E G	2 3 6 1
c.	[0]	1	1	0	A G	1
d.	[0]	-1	0	0	A B D F G	2 3 5 1

Path	Covered by
A G	c
A B C	a
A B D E A G	b
A B D F A G	d

1. a, b, d
2. a, b, d
3. a, b, c, d

Consider this figure in answer the following questions.

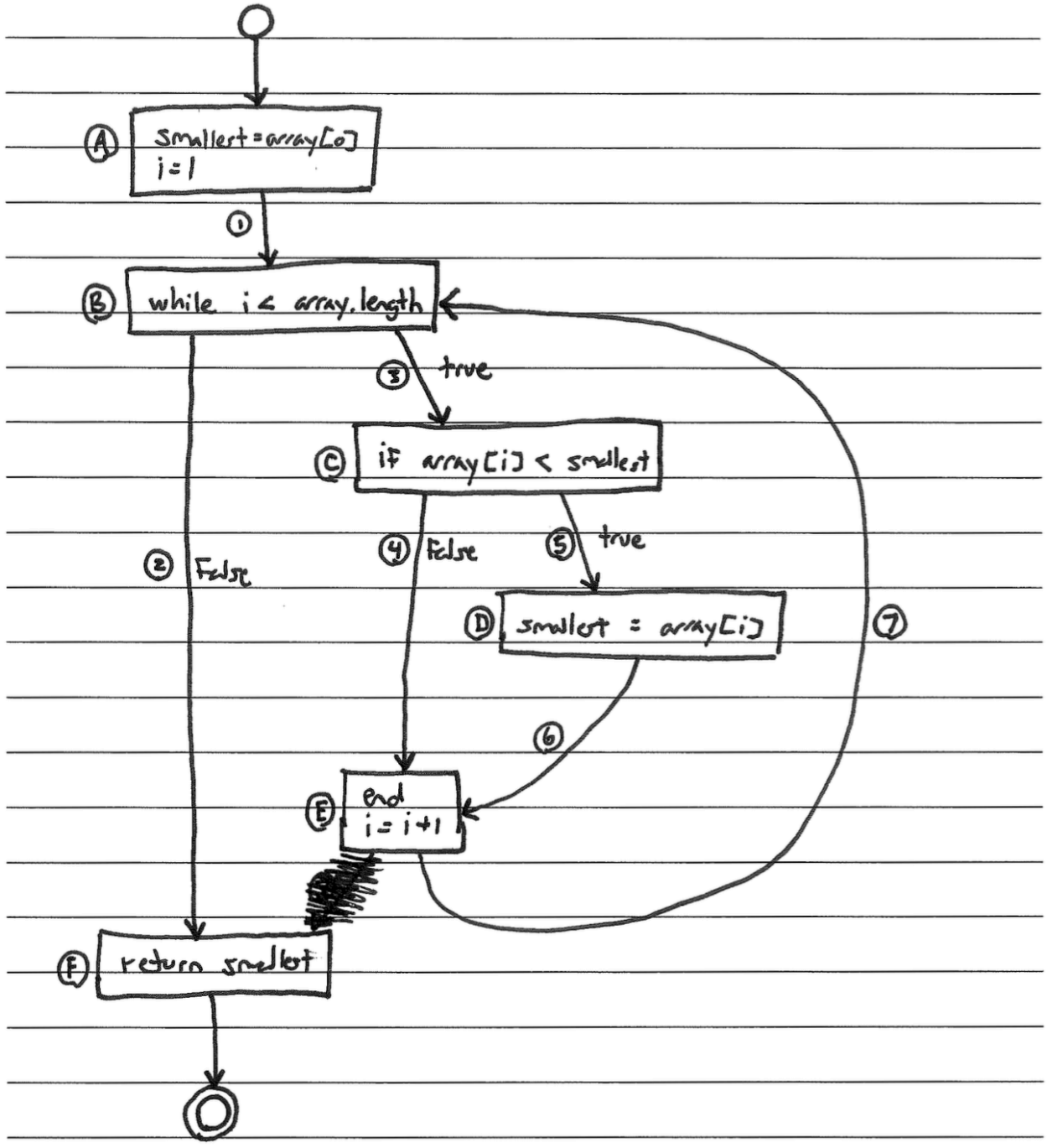
```
def find_smallest(array)
  smallest = array[0]
  i = 1
  while i < array.length
    if array[i] < smallest
        smallest = array[i]
    end
    i = i + 1
  end
  return smallest
end
```

Figure 1. Function that finds the smallest value in an array.

Problem:

Draw a control-flow graph (CFG) for the function in Figure 1. In addition to the usual CFG features, label the nodes with capital letters (A, B, C, etc.), and label the edges with numbers (1, 2, 3, etc.). Don't forget to include entry and exit points.

Solution:


A
smallest = array[0]
i = 1
1
B
while i < array.length
3
true
C
if array[i] < smallest
2
False
4
False
5
true
D
smallest = array[i]
7
6
E
end
i = i+1
F
return smallest

Problems:

Use the CFG you created for the function in Figure 1 to answer the following questions.

1. Fill in the table below with a test suite that provides statement coverage. In the Covers column, list the letter labels (A, B, C, etc.) of the nodes covered by each test case.

Input array	Expected Output	Covers

2. Fill in the table below with a test suite that provides branch coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case (only true/false edges needed).

Input array	Expected Output	Covers

3. Fill in the table below with a test suite that provides path coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case. You need only cover executions that involve at most 1 iteration of each loop (if there are any). Before you fill in the table, list all the paths to be covered.

Paths:

Input array	Expected Output	Covers

Solutions:

Multiple solutions are possible. These are just examples of correct solutions.

1.

Input array	Expected Output	Covers
[1,0]	0	A, B, C, D, E, B, F

2.

Input array	Expected Output	Covers
[1,0,2]	0	3, 5, 3, 4, 2

3.

- 1, 2
- 1, 3, 5, 6, 7, 2
- 1, 3, 4, 7, 2

Input array	Expected Output	Covers
[0]	0	1,2
[1,0]	0	1,3,5,6,7,2
[0,1]	0	1, 3, 4, 7, 2

Consider this figure in answer the following questions.

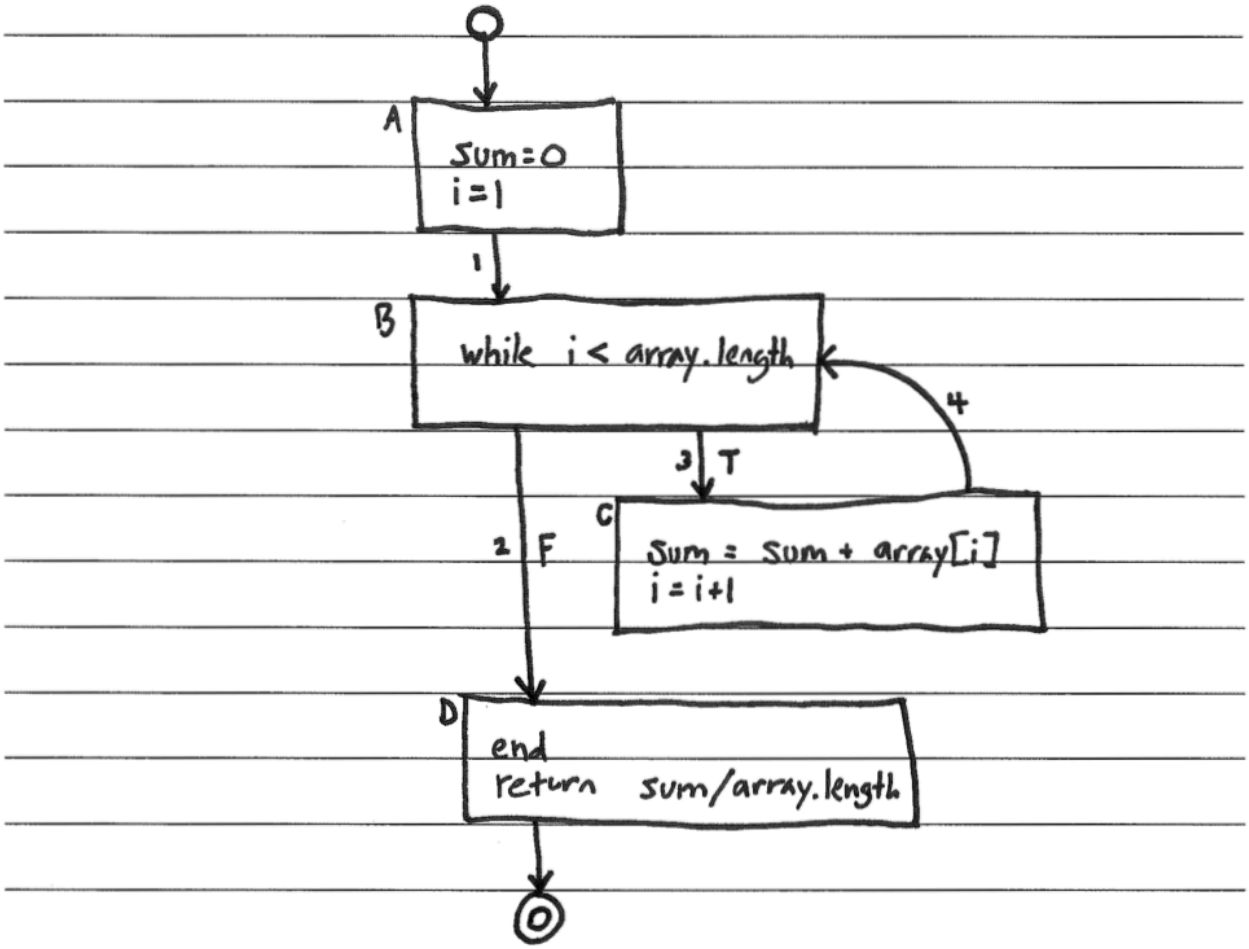
```
def average(array)
  sum = 0
  i = 1
  while i < array.length
    sum = sum + array[i]
    i = i + 1
  end
  return sum/array.length
end
```

Figure 2. Buggy function that computes the average value of an array of numbers.

Problem:

Draw a control-flow graph (CFG) for the function in Figure 2. In addition to the usual CFG features, label the nodes with capital letters (A, B, C, etc.), and label the edges with numbers (1, 2, 3, etc.). Don't forget to include entry and exit points.

Solution:


A
Sum=0
i=1
1
B
while i < array.length
4
3 T
C
2 F
Sum = Sum + array[i]
i = i+1
D
end
return sum/array.length

Problems:

Use the CFG you created for the function in Figure 2 to answer the following questions.

1. Fill in the table below with a test suite that provides statement coverage. In the Covers column, list the letter labels (A, B, C, etc.) of the nodes covered by each test case.

Input array	Expected Output	Covers

2. Fill in the table below with a test suite that provides branch coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case (only true/false edges needed).

Input array	Expected Output	Covers

Solutions:

1.

Input array	Expected Output	Covers
[1,1]	1	A, B, C, D

2.

Input array	Expected Output	Covers
[1,1]	1	3, 2

Problem:

Fill in the table below with a test suite that provides path coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case. You need only cover executions that involve at most 1 iteration of each loop (if there are any). Before you fill in the table, list all the paths to be covered.

Paths:

Input array	Expected Output	Covers

Solution:

Paths:

- 1,2
- 1,3,4,2

Input array	Expected Output	Covers
[1]	1	1,2
[1,1]	1	1,3,4,2

Question:

Which, if any, of your above three test suites would have caught the bug in the function?

Solution:

All of the above test suites would have caught the bug.

Problems:

Consider this function.

```
def is_it_xmas?(month, day)
    if month == 12 && day == 25
        return true
    else
        return false
    end
end
```

1. Draw a control-flow graph for the function. In addition to the usual CFG features, label the nodes with capital letters (A, B, C, etc.), and label the edges with numbers (1, 2, 3, etc.).

2. Fill in the table below with a test suite that provides statement coverage. In the Covers column, list the letter labels (A, B, C, etc.) of the nodes covered by each test case.

Input		Expected Output	Covers
month	day		

The function is correct to the best of my knowledge.

3. What change to a line in the function would introduce a bug that your above test suite catches?

4. What change to a line in the function would introduce a bug that your above test suite does not catch?

5. Fill in the table below with a test suite that provides branch coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case (only true/false edges needed).

Input		Expected Output	Covers
month	day		

The function is correct to the best of my knowledge.

6. What change to a line in the function would introduce a bug that your above test suite catches?

7. What change to a line in the function would introduce a bug that your above test suite does not catch?

8. Fill in the table below with a test suite that provides path coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case. You need only cover executions that involve at most 1 iteration of each loop (if there are any).

Input		Expected Output	Covers
month	day		

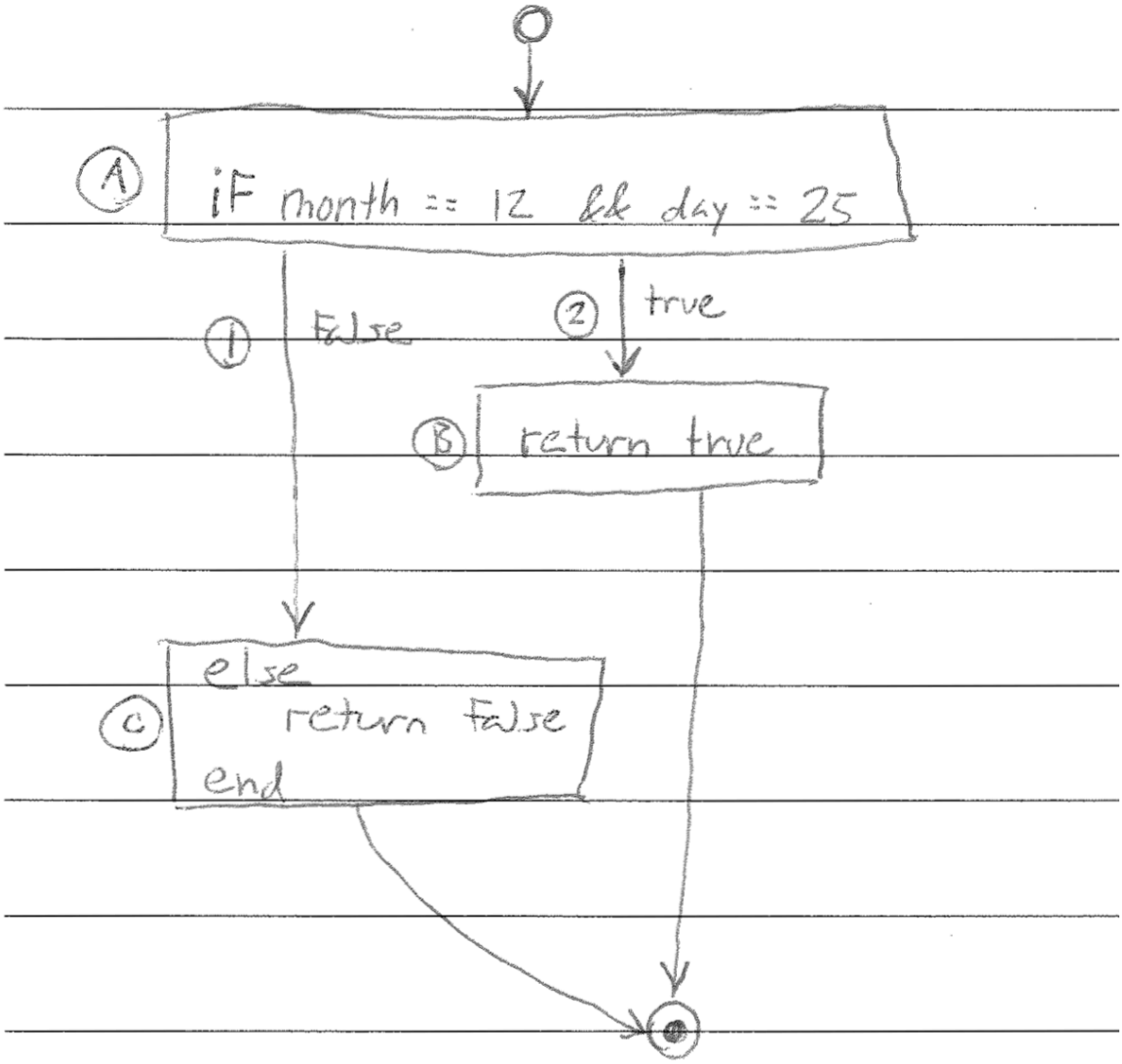
The function is correct to the best of my knowledge.

9. What change to a line in the function would introduce a bug that your above test suite catches?

10. What change to a line in the function would introduce a bug that your above test suite does not catch?

Solutions:

1.


A
if month == 12 && day == 25
1
false
2
true
B
return true
else
C
return false
end

2.

Input		Expected Output	Covers
month	day		
12	24	false	A, C
12	25	true	A, B

3.

day == 25 → day == 24

4.

day == 25 → day >= 25

5.

Input		Expected Output	Covers
month	day		
12	24	false	1
12	25	true	2

6.

day == 25 ⟶ day == 24

7.

day == 25 ⟶ day >= 25

8.

Input		Expected Output	Covers
month	day		
11	24	false	1
11	25	true	2
			Paths: - 1
			- 2

9.

day == 25 ⟶ day == 24

10.

day == 25 → day >= 25

Consider this function.

```
def min_of_three(x, y, z)
    if x < y then
        if x < z then
            return x
        else
            return z
        end
    else
        if y < z then
            return y
        else
            return z
        end
    end
end
```

1. Draw a control-flow graph for the function. In addition to the usual CFG features, label the nodes with capital letters (A, B, C, etc.), and label the edges with numbers (1, 2, 3, etc.).

2. Fill in the table below with a test suite that provides statement coverage. In the Covers column, list the letter labels (A, B, C, etc.) of the nodes covered by each test case.

Input			Expected Output	Covers
x	y	z		

The function is correct to the best of my knowledge.

3. What change to a line in the function would introduce a bug that your above test suite catches?

4. What change to a line in the function would introduce a bug that your above test suite does not catch?

5. Fill in the table below with a test suite that provides branch coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case (only true/false edges needed).

Input			Expected Output	Covers
x	y	z		

The function is correct to the best of my knowledge.

6. What change to a line in the function would introduce a bug that your above test suite catches?

7. What change to a line in the function would introduce a bug that your above test suite does not catch?

8. Fill in the table below with a test suite that provides path coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case. You need only cover executions that involve at most 1 iteration of each loop (if there are any).

Input			Expected Output	Covers
x	y	z		

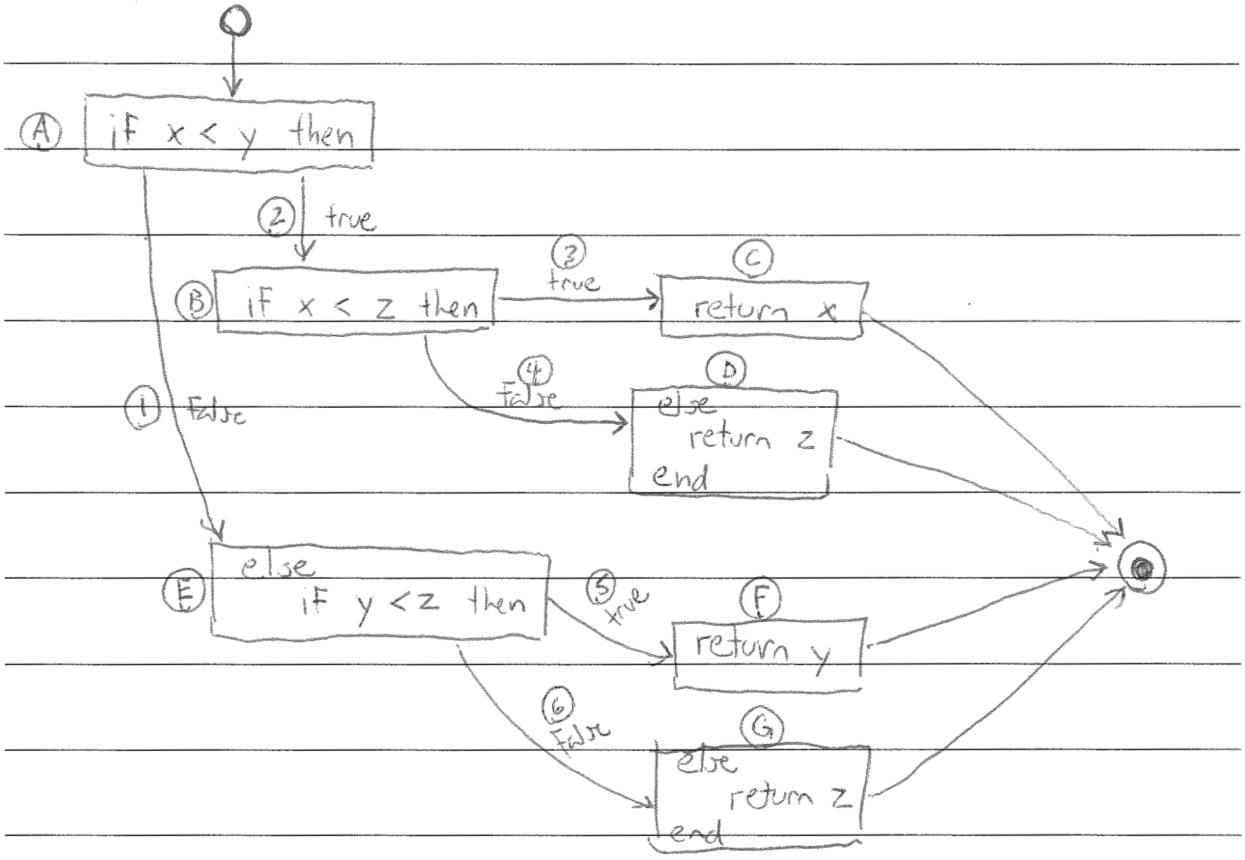
The function is correct to the best of my knowledge.

9. What change to a line in the function would introduce a bug that your above test suite catches?

10. What change to a line in the function would introduce a bug that your above test suite does not catch?

Solutions:

1.


A
if x < y then
2
true
B
if x < z then
3
true
C
return x
1
false
4
false
D
else
return z
end
E
else
if y < z then
5
true
F
return y
6
false
G
else
return z
end

2.

Input			Expected Output	Covers
x	y	z		
1	2	3	1	A, B, C
1	2	0	0	A, B, D
2	1	3	1	A, E, F
2	1	0	0	A, E, G

3.

x < y → x > y

4.

return x → return y - x

5.

Input			Expected Output	Covers
x	y	z		
1	2	3	1	2, 3
1	2	0	0	2, 4
2	1	3	1	1, 5
2	1	0	0	1, 6

6.

x < y → x > y

7.

return x → return y - x

8.

Input			Expected Output	Covers
x	y	z		
1	2	3	1	2,3
1	2	0	0	2,4
2	1	3	1	1,5
2	1	0	0	1,6
				Paths - 2,3 - 2,4
				- 1,5 - 1,6

9.

x < y → x > y

10.

return x → return y - x

Problems:

Consider this function.

```
def gcd(x, y)
    if x == 0
        return y
    end
    if y == 0
        return x
    end
    while x != y
        if x > y
            x = x - y
        else
            y = y - x
        end
    end
    return x
end
```

1. Draw a control-flow graph for the function. In addition to the usual CFG features, label the nodes with capital letters (A, B, C, etc.), and label the edges with numbers (1, 2, 3, etc.).

2. Fill in the table below with a test suite that provides statement coverage. In the Covers column, list the letter labels (A, B, C, etc.) of the nodes covered by each test case.

Input		Expected Output	Covers
x	y		

The function is correct to the best of my knowledge.

3. What change to a line in the function would introduce a bug that your above test suite catches?

4. What change to a line in the function would introduce a bug that your above test suite does not catch?

5. Fill in the table below with a test suite that provides branch coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case (only true/false edges needed).

Input		Expected Output	Covers
x	y		

The function is correct to the best of my knowledge.

6. What change to a line in the function would introduce a bug that your above test suite catches?

7. What change to a line in the function would introduce a bug that your above test suite does not catch?

8. Fill in the table below with a test suite that provides path coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case. You need only cover executions that involve at most 1 iteration of each loop (if there are any).

Input		Expected Output	Covers
x	y		

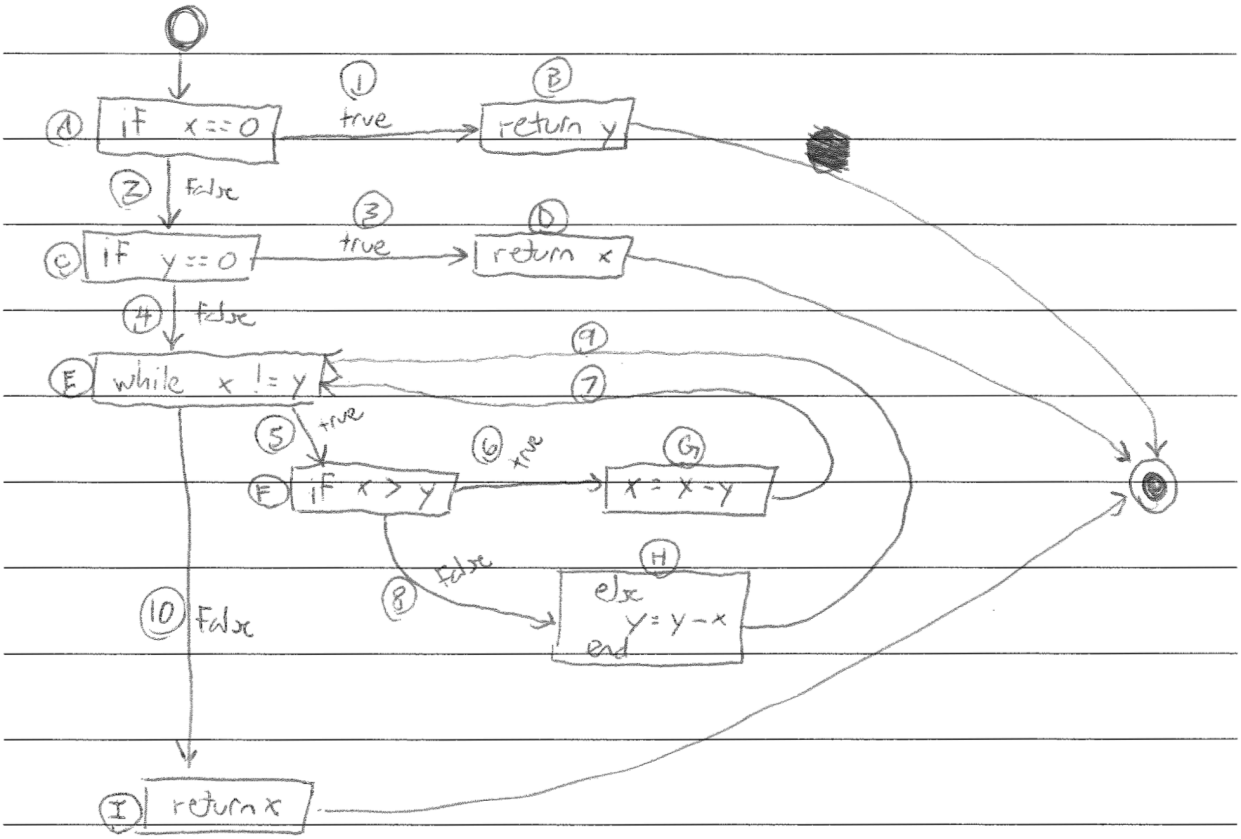
The function is correct to the best of my knowledge.

9. What change to a line in the function would introduce a bug that your above test suite catches?

10. What change to a line in the function would introduce a bug that your above test suite does not catch?

Solutions:

1.


A
if x == 0
1
true
B
return y
2
false
C
if y == 0
3
true
D
return x
4
false
E
while x != y
9
7
5
true
6
true
F
if x > y
G
x = x - y
8
false
H
else
y = y - x
end
10
false
I
return x

2.

Input		Expected Output	Covers
x	y		
0	1	1	A, B
1	0	1	A, C, D
3	2	1	A, C, E, F, G, E, F, H, I

3.

x == 0 ⟶ x >= 0

4.

y = y - x ⟶ y = x = 1

5.

Input		Expected Output	Covers
x	y		
0	1	1	1
1	0	1	2, 3
3	2	1	2, 4, 5, 6, [redacted] 5, 8, [redacted] 10

6.

x == 0 → x >= 0

7.

y = y - x → y = x = 1

8.

Input		Expected Output	Covers
x	y		
0	1	1	1
1	0	1	2, 3
1	1	1	2, 4, 10
2	1	1	2, 4, 5, 6, 7, 10
1	2	1	2, 4, 5, 8, 9, 10

Paths
- 1
- 2, 3
- 2, 4, 10
- 2, 4, 5, 6, 7, 10
- 2, 4, 5, 8, 9, 10

9.

x == 0 → x >= 0

10.

return y → return 1

Problems:

Consider this function.

```
def binary_search(array, key)
    imin = 0
    imax = array.length - 1
    while imin <= imax
        imid = (imin + ((imax - imin) / 2)).to_i
        if array[imid] == key
                        return imid
        elsif array[imid] < key
                        imin = imid + 1
        else
                        imax = imid - 1
        end
    end
    return -1
end
```

1. Draw a control-flow graph for the function. In addition to the usual CFG features, label the nodes with capital letters (A, B, C, etc.), and label the edges with numbers (1, 2, 3, etc.).

2. Fill in the table below with a test suite that provides statement coverage. In the Covers column, list the letter labels (A, B, C, etc.) of the nodes covered by each test case.

Input		Expected Output	Covers
array	key		

The function is correct to the best of my knowledge.

3. What change to a line in the function would introduce a bug that your above test suite catches?

4. What change to a line in the function would introduce a bug that your above test suite does not catch?

5. Fill in the table below with a test suite that provides branch coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case (only true/false edges needed).

Input		Expected Output	Covers
array	key		

The function is correct to the best of my knowledge.

6. What change to a line in the function would introduce a bug that your above test suite catches?

7. What change to a line in the function would introduce a bug that your above test suite does not catch?

8. Fill in the table below with a test suite that provides path coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case. You need only cover executions that involve at most 1 iteration of each loop (if there are any).

Input		Expected Output	Covers
array	key		

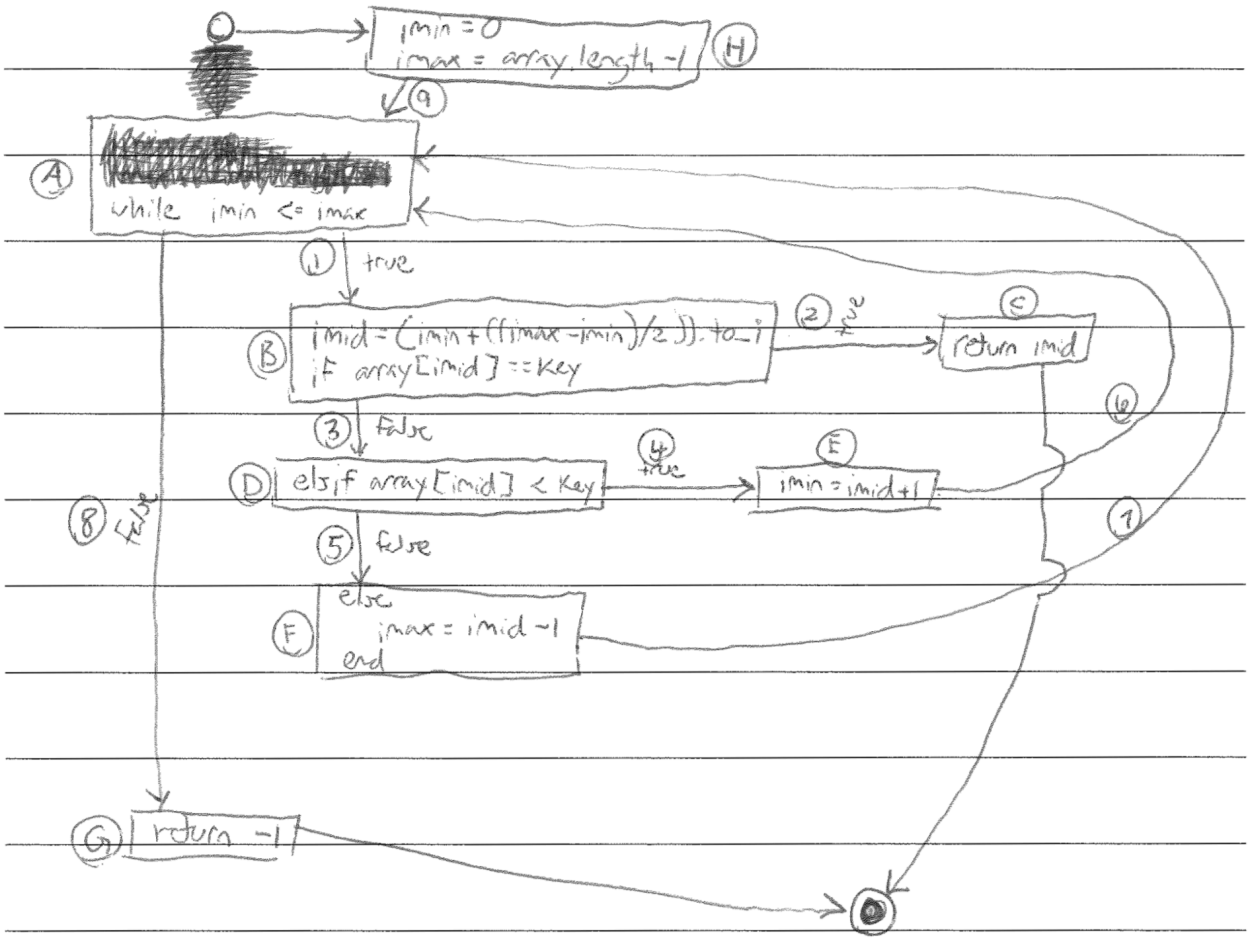
The function is correct to the best of my knowledge.

9. What change to a line in the function would introduce a bug that your above test suite catches?

10. What change to a line in the function would introduce a bug that your above test suite does not catch?

Solutions:

1.


imin = 0
imax = array.length -1
H
9
A
while imin <= imax
1
true
B
imid = (imin + ((imax - imin)/2)).to_i
if array[imid] == key
2
true
C
return imid
3
false
D
elsif array[imid] < key
4
true
E
imin = imid+1
6
7
8
false
5
false
else
imax = imid -1
end
F
G
return -1

2.

Input		Expected Output	Covers
array	key		
[ ]	a	-1	H, A, G
[a,b,c,d,e,f,g]	e	4	H, A, B, D, E, A, B, D, F, A, B, C

3.

return -1 → return 0

4.

return imid → return 4

5.

Input		Expected Output	Covers
array	key		
[ ]	a	-1	8
[a,b,c,d,e,f,g]	e	4	1, 3, 4, 1, 3, 5, 1, 2

6.

return -1 → return 0

7.

return imid → return 4

8.

Input		Expected Output	Covers
array	key		
[ ]	a	-1	a, 8
[a, b, c]	b	1	a, 1, 2
[a]	b	-1	a, 1, 3, 4, 6, 8
[b]	a	-1	a, 1, 3, 5, 7, 8
			Paths – a, 8 – a, 1, 2 – a, 1, 3, 4, 6, 8 – a, 1, 3, 5, 7, 8

9.

return -1 → return 0

10.

return imid → return 1

Problems:

```
def sum_the_first_n(array, n)
  sum = 0
  i = 0
  while i <= n && i < array.length
    sum = sum + array[i]
    i = i + 1
  end
  return sum
end
```

Figure 3. Buggy function that sums the first *n* numbers in an array.

1. Draw a control-flow graph (CFG) for the function in Figure 3. In addition to the usual CFG features, label the nodes with capital letters (A, B, C, etc.), and label the edges with numbers (1, 2, 3, etc.). Don't forget to include entry and exit points.

Use the CFG you created for the function in Figure 3 to answer the following questions.

2. Fill in the table below with a test suite that provides statement coverage. In the Covers column, list the letter labels (A, B, C, etc.) of the nodes covered by each test case.

Input		Expected Output	Covers
array	n		

3. Fill in the table below with a test suite that provides branch coverage. In the Covers column, list the number labels (1, 2, 3, etc.) of the edges covered by each test case (only true/false edges needed).

Input		Expected Output	Covers
array	n		

4. Fill in the table below with a test suite that provides path coverage. Before you fill in the table, first list all the paths to be covered, and label each path ("P1", "P2", "P3", etc.). You need only cover executions that involve at most 1 iteration of each loop (if there are any). In the Covers column, list the path labels covered by each test case.

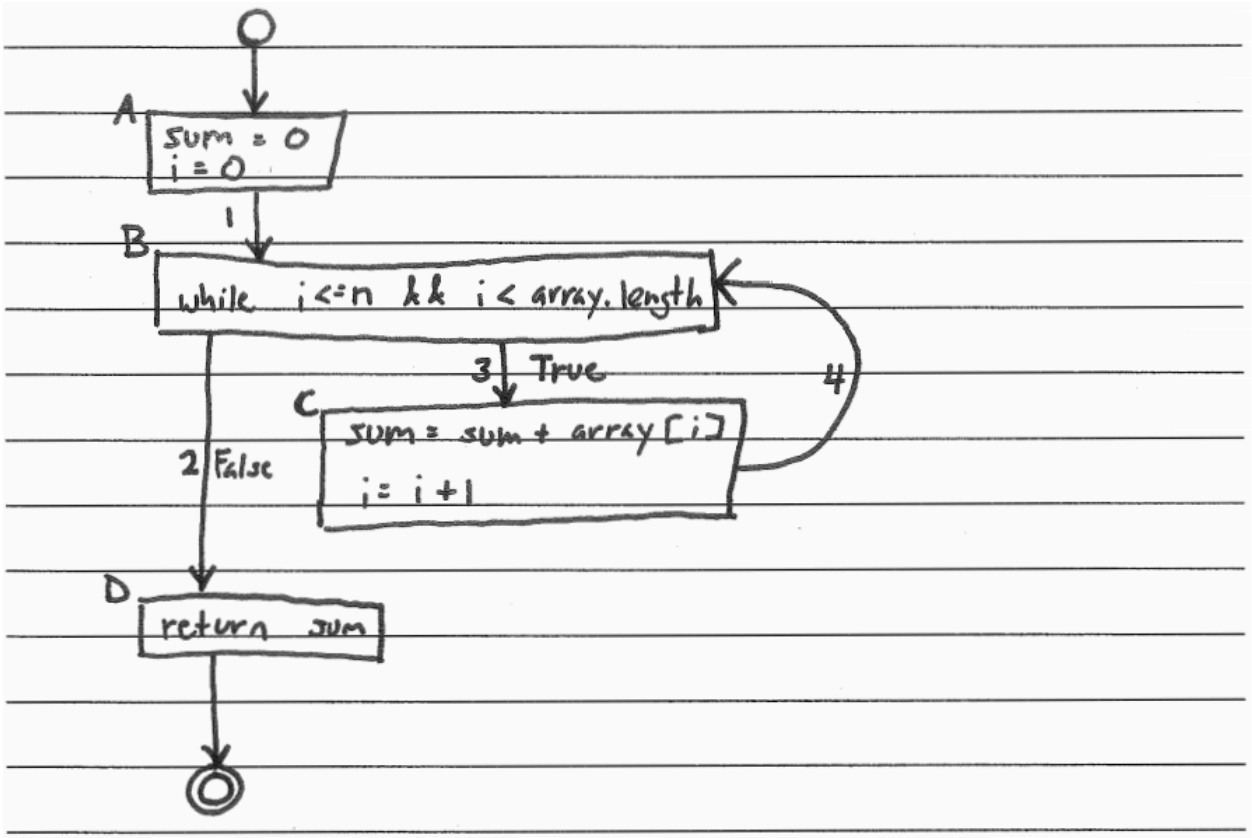
Paths:

Input		Expected Output	Covers
array	n		

5. Which, if any, of your above three test suites would have caught the bug in the function?

Solutions:

1.


A
sum = 0
i = 0
1
B
while i<=n && i < array.length
3 True
4
C
sum = sum + array[i]
i = i + 1
2 False
D
return sum

2.

Input		Expected Output	Covers
array	n		
[1,1]	1	1	A, B, C, D

3.

Input		Expected Output	Covers
array	n		
[1,1]	1	1	2, 3

4.

Paths:

P1: 1, 2

P2: 1, 3, 4, 2

Input array	n	Expected Output	Covers
[ ]	0	0	P1
[1]	1	1	P2

5.

The statement- and branch-coverage suites would have caught the bug (but not the path-coverage one).