Exercises, Section 2.2.3

1. Below are four graphs, each of which is defined by the sets of nodes, initial nodes, final nodes, edges, and defs and uses. Each graph also contains a collection of test paths. Answer the following questions about each graph.

Graph I.
$N = \{0,\ 1,\ 2,\ 3,\ 4,\ 5,\ 6,\ 7\}$
$N_0 = \{0\}$
$N_f = \{7\}$
$E = \{(0,1),\ (1,2),\ (1,7),\ (2,3),\ (2,4),\ (3,2),$
$(4,5),\ (4,6),\ (5,6),\ (6,1)\}$
$def(0) = def(3) = use(5) = use(7) = \{x\}$

Test Paths:
$t1 = [0,\ 1,\ 7]$
$t2 = [0,\ 1,\ 2,\ 4,\ 6,\ 1,\ 7]$
$t3 = [0,\ 1,\ 2,\ 4,\ 5,\ 6,\ 1,\ 7]$
$t4 = [0,\ 1,\ 2,\ 3,\ 2,\ 4,\ 6,\ 1,\ 7]$
$t5 = [0,\ 1,\ 2,\ 3,\ 2,\ 3,\ 2,\ 4,\ 5,\ 6,\ 1,\ 7]$
$t6 = [0,\ 1,\ 2,\ 3,\ 2,\ 4,\ 6,\ 1,\ 2,\ 4,\ 5,\ 6,\ 1,\ 7]$

Graph II.
$N = \{1,\ 2,\ 3,\ 4,\ 5,\ 6\}$
$N_0 = \{1\}$
$N_f = \{6\}$
$E = \{(1,2),\ (2,3),\ (2,6),\ (3,4),\ (3,5),\ (4,5),\ (5,2)\}$
$def(x) = \{1,3\}$
$use(x) = \{3,6\}$ // Assume the use of x in 3 precedes the def
Test Paths:
$t1 = [1,\ 2,\ 6]$
$t2 = [1,\ 2,\ 3,\ 4,\ 5,\ 2,\ 3,\ 5,\ 2,\ 6]$
$t3 = [1,\ 2,\ 3,\ 5,\ 2,\ 3,\ 4,\ 5,\ 2,\ 6]$
$t4 = [1,\ 2,\ 3,\ 5,\ 2,\ 6]$

Graph III.
$N = \{1,\ 2,\ 3,\ 4,\ 5,\ 6\}$
$N_0 = \{1\}$
$N_f = \{6\}$
$E = \{(1,2),\ (2,3),\ (3,4),\ (3,5),\ (4,5),\ (5,2),\ (2,6)\}$
$def(x) = \{1,\ 4\}$
$use(x) = \{3,\ 5,\ 6\}$

Test Paths:
$t_1 = [1,\ 2,\ 3,\ 5,\ 2,\ 6]$
$t_2 = [1,\ 2,\ 3,\ 4,\ 5,\ 2,\ 6]$

Graph IV.
$N = \{1,\ 2,\ 3,\ 4,\ 5,\ 6\}$
$N_0 = \{1\}$
$N_f = \{6\}$
$E = \{(1,2),\ (2,3),\ (2,6),\ (3,4),\ (3,5),\ (4,5),\ (5,2)\}$
$def(x) = \{1,\ 5\}$
$use(x) = \{5,\ 6\}$ // Assume the use of x in 5 precedes the def
Test Paths:
$t1 = [1,\ 2,\ 6]$
$t2 = [1,\ 2,\ 3,\ 4,\ 5,\ 2,\ 3,\ 5,\ 2,\ 6]$
$t3 = [1,\ 2,\ 3,\ 5,\ 2,\ 3,\ 4,\ 5,\ 2,\ 6]$

   (a) Draw the graph.
   (b) List all of the du-paths with respect to x. (Note: Include all du-paths, even those that are subpaths of some other du-path).
   (c) For each test path, determine which du-paths that test path tours. For this part of the exercise, you should consider both direct touring and sidetrips. Hint: A table is a convenient format for describing this relationship.
   (d) List a minimal test set that satisfies *all defs* coverage with respect to x. (Direct tours only.) Use the given test paths.
   (e) List a minimal test set that satisfies *all uses* coverage with respect to x. (Direct tours only.) Use the given test paths.
   (f) List a minimal test set that satisfies *all du-paths* coverage with respect to x. (Direct tours only.) Use the given test paths.

Solution:
Solution for Graph I:

(a) *See the graph tool at* `www.introsoftwaretesting.com`
(b) *x has 5 du-paths, as enumerated below:*

i	*[0, 1, 7]*
ii	*[0, 1, 2, 4, 5]*
iii	*[3, 2, 4, 5]*
iv	*[3, 2, 4, 6, 1, 7]*
v	*[3, 2, 4, 5, 6, 1, 7]*

(c) *The numbers in the table below correspond to the du-paths in the previous table. The table indicates whether each test path tours each du-path with or without a sidetrip.*

	direct	*w/ sidetrip*
t_1	*i*	
t_2		*i*
t_3	*ii*	*i*
t_4	*iv*	*i*
t_5	*iii, v*	*i, ii*
t_6		*i, ii, iii, iv, v*

(d) *This question has multiple possible answers. Either* t_1 *or* t_3 *can be used to directly tour a path that satisfies all-defs for the def at node 0, and either* t_4 *or* t_5 *can be used to directly tour a path that satisfies all-defs for the def at node 3.*
Possible answers: $\{t_1,\ t_4\}$ *or* $\{t_1,\ t_5\}$ *or* $\{t_3,\ t_4\}$ *or* $\{t_3,\ t_5\}$
(e) *This question only has one possible answer:* $\{t_1,\ t_3,\ t_5\}$
(f) *This question only has one possible answer:* $\{t_1,\ t_3,\ t_4,\ t_5\}$

Solution (Instructor only):
Solution for Graph II:

(a) See the graph tool at `www.introsoftwaretesting.com`

(b) x has 6 du-paths, as enumerated below:

i	*[1, 2, 3]*
ii	*[1, 2, 6]*
iii	*[3, 4, 5, 2, 3]*
iv	*[3, 4, 5, 2, 6]*
v	*[3, 5, 2, 3]*
vi	*[3, 5, 2, 6]*

(c) The numbers in the table below correspond to the du-paths in the previous table. The table indicates whether each test path tours each du-path with or without a sidetrip.

	direct	*w/ sidetrip*
t_1	*ii*	
t_2	*i, iii, vi*	
t_3	*i, iv, v*	
t_4	*i, vi*	

Note that, for example, although t_2 does not tour path (v) with a sidetrip, it does tour path (v) with a detour.

(d) This question has multiple possible answers. All test paths use the def in 1*, and test paths $\{t_2\}$, $\{t_3\}$, $\{t_4\}$ each use the def in* 3*. Possible answers: $\{t_2\}$, $\{t_3\}$, or $\{t_4\}$.*

(e) This question only has two possible answers. $\{t_1\}$ is required for the def in 1 *to reach the use in* 6*. Either t_2 or t_3 is required for the def in* 3 *to reach the use in* 3*. Possible answers: $\{t_1, t_2\}$ or $\{t_1, t_3\}$.*

(f) This question has one possible answer: $\{t_1, t_2, t_3\}$. t_1 is required for path (ii). t_2 is required for path (iii). t_3 is required for path (iv). Since t_1, t_2, and t_3 together tour all six du-paths, t_4 is not needed.

Solution:
Solution for Graph III: Note that this exercise is the same as Graph II, except that the def/use sets are slightly different.

(a) See the graph tool at `www.introsoftwaretesting.com`

(b) x has 6 du-paths, as enumerated below:

i	*[1, 2, 3]*
ii	*[1, 2, 3, 5]*
iii	*[1, 2, 6]*
iv	*[4, 5]*
v	*[4, 5, 2, 3]*
vi	*[4, 5, 2, 6]*

(c) The numbers in the table below correspond to the du-paths in the previous table. The table indicates whether each test path tours each du-path with or without a sidetrip.

	direct	*w/ sidetrip*
t_1	*i, ii*	*iii*
t_2	*i, iv, vi*	

Note that neither t_1 nor t_2 tours du-path (v), either directly or with a sidetrip. Also note that neither t_1 nor t_2 tours du-path (iii), except with a sidetrip.

(d) This question has one possible answer: $\{t_2\}$.

(e) Since the given test set does not have a test path that directly tours from the def in node 1 to the use in node 6, this aspect of the question is unsatisfiable for direct touring. However, if we consider best-effort touring, then test set $\{t_1, t_2\}$ achieves all-uses.

(f) Since the given test set does not have a test path that tours du-path (v), this question is unsatisfiable. To directly tour the given $du - paths$, we would two additional test paths. An example ADUP adequate test set (direct touring) is: $\{t_1, t_2, [1, 2, 6], [1, 2, 3, 4, 5, 2, 3, 5, 2, 6]\}$.

Solution (Instructor only):

Solution for Graph IV: Note that this exercise is the same as Graph II, except that the def/use sets are slightly different.

(a) See the graph tool at `www.introsoftwaretesting.com`

(b) x has 6 du-paths, as enumerated below:

i	*[1, 2, 3, 4, 5]*
ii	*[1, 2, 3, 5]*
iii	*[1, 2, 6]*
iv	*[5, 2, 3, 4, 5]*
v	*[5, 2, 3, 5]*
vi	*[5, 2, 6]*

(c) The numbers in the table below correspond to the du-paths in the previous table. The table indicates whether each test path tours each du-path with or without a sidetrip.

	direct	*w/ sidetrip*
t_1	*iii*	
t_2	*i, v, vi*	
t_3	*ii, iv, vi*	

Note that, for example, although t_2 does not tour path (ii) with a sidetrip, it does tour path (ii) with a detour.

(d) This question has two possible answers: $\{t_2\}$ or $\{t_3\}$.

(e) This question two possible answers: $\{t_1, t_2\}$ or $\{t_1, t_3\}$.

(f) This question has one possible answer: $\{t_1, t_2, t_3\}$.