Program Analysis, University of Stuttgart, Winter 2020/21

Exercise 3: Information Flow and Slicing
—**Solution**—

Deadline for uploading solutions via Ilias:
January 29, 2021, 11:59pm Stuttgart time

Task 1 Information Flow Analysis [20 points]

This task is about dynamic information flow analysis. Consider the following JavaScript code to analyze:

```
var age = getAge();
var flag = getFlag();
var count = 0;
var mult = 2;
if (age === 20){
  count++;
} else {
  if (age === 25){
    flag = 2;
  } else {
    if (age === 30) {
      flag = 3;
    }
  }
}

if (flag === 2){
  flag = flag * mult;
  print_public(flag);
} else {
  print_public(mult);
}
```

There are three security classes: *secret*, *confidential*, and *public*, which are ordered into a lattice such that:

$$\mathit{secret} > \mathit{confidential} > \mathit{public}$$

By default, all values are labeled as *public*. Values returned by `getAge()` are labeled as *secret* and values returned by `getFlag()` are labeled as *confidential*. The function `print_public()` is an untrusted sink, which should only be reached by *public* information. Note that passing an argument to function should be handled like an assignment to the formal parameter of the function.

Subtask 1.1 Execution 1 [10 points]

Consider a dynamic information flow analysis that considers both explicit and implicit flows. Suppose an execution where `getAge()` returns 20 and `getFlag()` returns 3.

- What are the security labels of variables and expressions during the execution? Use the following template to provide your answer.

  Solution:

Line	Variable or expression	Security label of variable or expression (after executing the line)
1	`age`	*secret*
2	`flag`	*confidential*
3	`count`	*public*
4	`mult`	*public*
5	`age === 20`	*secret*
6	`count`	*secret*
17	`flag === 2`	*confidential*

- Does the execution violate the information flow policy? Explain your answer.

  Yes, because the execution reaches the line 21 due to a confidential *if* condition. For this reason, a confidential information, in this case that $flag \mathrel{!=} 2$, reaches an untrusted sink.

Subtask 1.2 Execution 2 [10 points]

Consider a dynamic information flow analysis that considers both explicit and implicit flows. Suppose an execution where `getAge()` returns 25 and `getFlag()` returns 1.

- What are the security labels of variables and expressions during the execution? Use the following template to provide your answer.

  Solution:

Line	Variable or expression	Security label of variable or expression (after executing the line)
1	`age`	*secret*
2	`flag`	*confidential*
3	`count`	*public*
4	`mult`	*public*
5	`age === 20`	*secret*
8	`age === 25`	*secret*
9	`flag`	*secret*
17	`flag === 2`	*secret*
18	`flag`	*secret*

- Does the execution violate the information flow policy? Explain your answer.

  Yes, because in line 19 a value with label *secret* flows in an untrusted sink.

Task 2 Universally Bounded Lattice [20 points]

In this task we will analyze the characteristics and properties of universally bounded lattices.

Subtask 2.1 Recognize a Universally Bounded Lattice [10 points]

Figure 1 shows structures that could represent universally bounded lattices.

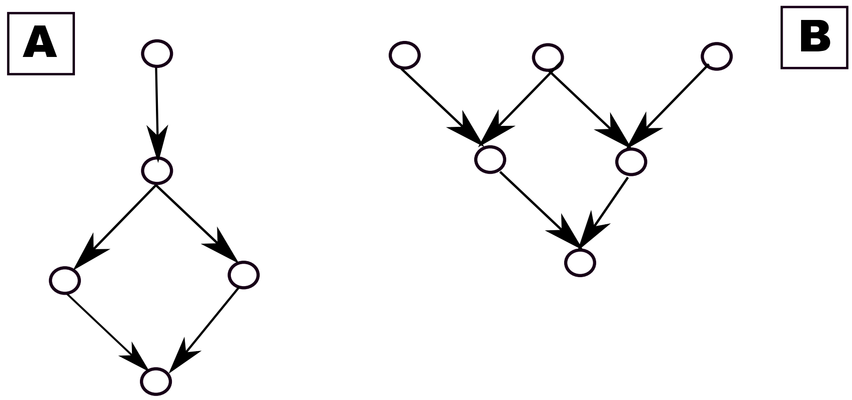


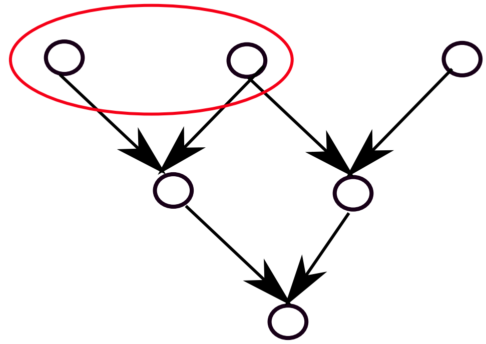
Figure 1: Two universally bounded lattice candidates.

- Are the two candidates universally bounded lattices? Explain why (not).

Solution:

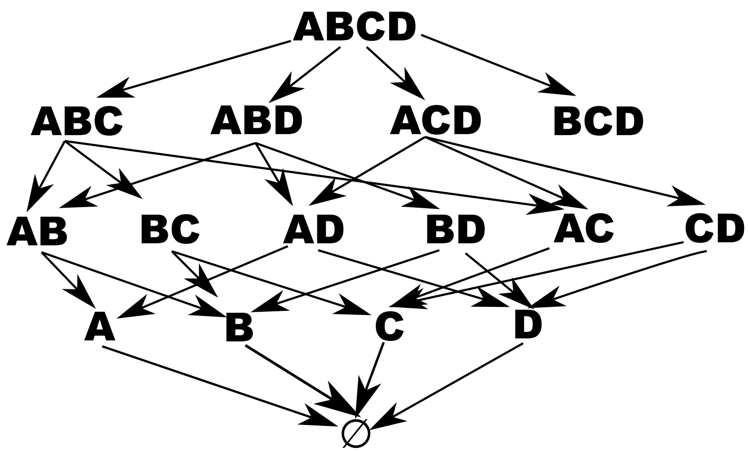
- A is a universally bounded lattice. It has all the necessary characteristics:
  - A limited set of security classes
  - A partial order
  - A lower bound
  - An upper bound
  - A least upper bound operator
  - A greatest lower bound operator

- B is not a universally bounded lattice. Reason: It is impossible to define a least upper bound operator.



Subtask 2.2 Characteristics [10 points]

Consider the following structure that represents a universally bounded lattice:



Answer the following questions:

- Give the set S of security classes.

  Solution:
  S = ABCD, ABC, ABD, ACD, BCD, AB, BC, AD, BD, AC, CD, A, B, C, D, $\emptyset$

- What is the lower bound $\perp$?

  Solution:
  $\perp = \emptyset$

- What is the upper bound $\top$?

  Solution:
  $\top$ = ABCD

- Let $\bigoplus$ be the least upper bound operator. What is the result of the following operations?

  Solution:
  $B \bigoplus BC$ = BC
  $ABCD \bigoplus CD$ = ABCD
  $ABC \bigoplus \emptyset$ = ABC

- Let $\bigotimes$ be the greatest lower bound operator. What is the result of the following operations?

  Solution:
  $D \bigotimes DC =$ D
  $ACD \bigotimes AD =$ AD
  $ABCD \bigotimes B =$ B

Task 3 Static Slicing as Proposed by Weiser [30 points]

Consider the following JavaScript program:

```
1  var year = getYear();
2  var flag = getFlag();
3  var count = 0;
4  var mult = 3;
5  if (year === 2020) {
6    count++;
7    mult = mult * count;
8  } else {
9    if (year === 2021) {
10     flag = 2 + flag;
11   }
12 }
13 var sliceHere = count;
```

Compute the static backward slice for variable `sliceHere` at line 13. Use the slicing approach of Weiser (IEEE TSE, 1984) and its formulation as a graph reachability problem, as it has been introduced in the lecture. To describe your solution, follow the steps outlined below.

Subtask 3.1 Data Flow Dependences [10 points]

Provide the data flow dependences between statements in the program. Use the following table to summarize the dependences. Each table cell represents a pair of statements. Mark all pairs of statements that have a definition-use relationship.

Solution:

Def	**Use**									
	1	2	3	4	5	6	7	9	10	13
1					x			x		
2									x	
3						x				x
4							x			
5										
6							x			x
7										
9										
10										
13										

Subtask 3.2 Control Flow Dependences [10 points]

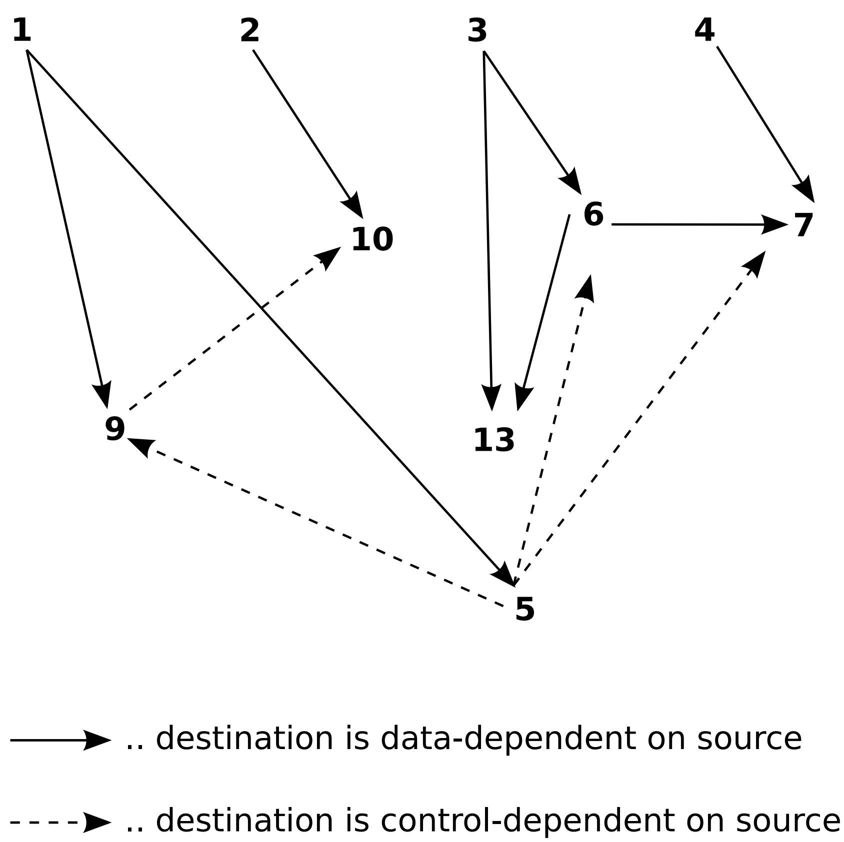
Provide the control flow dependences between statements in the program. Describe your solutions as a sequence of “Statement .. is control-flow dependent on statement ..” sentences.
Solution:

- Statement 6 is control flow-dependent on statement 5.
- Statement 7 is control flow-dependent on statement 5.
- Statement 9 is control flow-dependent on statement 5.
- Statement 10 is control flow-dependent on statement 9.

Subtask 3.3 Program Dependence Graph [5 points]

Summarize the data flow dependences and the control flow dependences into a program dependence graph. Use the following template to draw your solution.

Solution:



Subtask 3.4 Slice [5 points]

What is the slice for the slicing criterion (variable sliceHere at line 13)? Write down the source code of the sliced program as a syntactically correct program.

Solution:

```
var year = getYear();
var count = 0;
if (year === 2020) {
  count++;
}
var sliceHere = count;
```

Task 4 Dynamic Slicing (Revised Approach) [30 points]

Consider the following JavaScript program:

```
1  var year = getInput();
2  var actual_year = 2021;
3  var count = 0;
4  var flag = false
5  var diff = actual_year - year
6  var i = 0;
7  while (i < diff) {
8    i++;
9    year++;
10   if (year > 2000) {
11     count++;
12   }
13 }
14 if (count > 10) {
15   flag = true
16 }
17 console.log(i)
```

Subtask 4.1 Execution History [5 points]

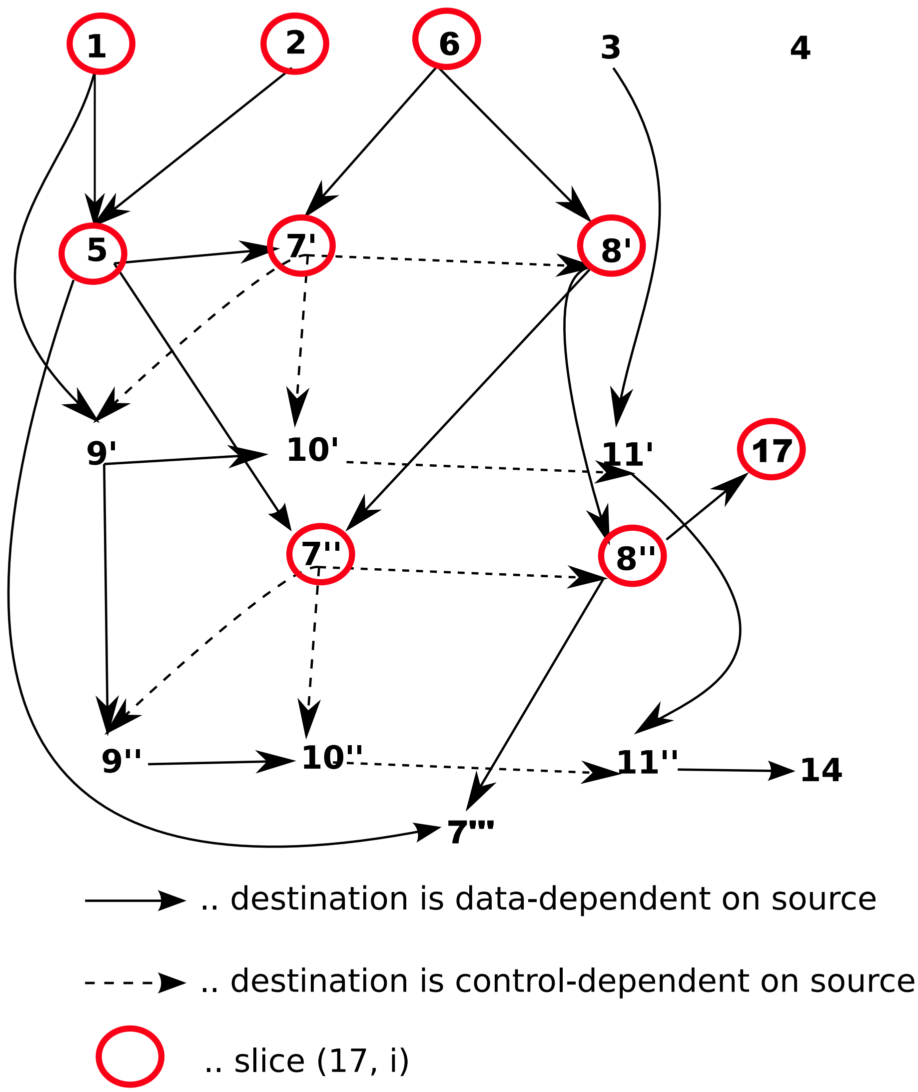
Give the execution history with $getInput() = 2018$. You can use the line numbers to refer to statements. Do not include the lines with the closing curly brackets (}) into the history.

Solution: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 7, 8, 9, 10, 11, 7, 8, 9, 10, 11, 7, 14, 17

Subtask 4.2 Dynamic Dependence Graph [20 points]

Suppose we want to compute the dynamic backward slice with the last statement (*console.log(i)*) as the slicing criterion. Use $getInput() = 2019$ (note that this input is different from above). Provide the dynamic dependence graph, using the "revised approach" presented in the lecture.

Solution:



Subtask 4.3 Slice [5 points]

Write the sliced program.
Solution:

```
var year = getInput();
var actual_year = 2021;
var diff = actual_year - year
var i = 0;
while (i < diff) {
  i++;
}
console.log(i)
```