Program Analysis – Lecture 10

Program Slicing (Part 2)

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Warm-up Quiz

What does the following code print?

```
function d(a, b) {
  var sum = 0;
  for (var i = 0; i < arguments.length; i++) {
    sum += arguments[i];
  }
  console.log(sum == (a + b + 67));
}

d(23, 45, 67);
```

true **false** **Something else**

Warm-up Quiz

What does the following code print?

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function d(a, b) {
  var sum = 0;
  for (var i = 0; i < arguments.length; i++) {
    sum += arguments[i];
  }
  console.log(sum == (a + b + 67));
}

d(23, 45, 67);
```

Includes all passed arguments, independent of declared parameters

true | **false** | **Something else**

Quiz

```
var x = 1;      // 1
var y = 2;      // 2
if (x < y) {    // 3
  y = x;        // 4
}
var z = x;      // 5
```

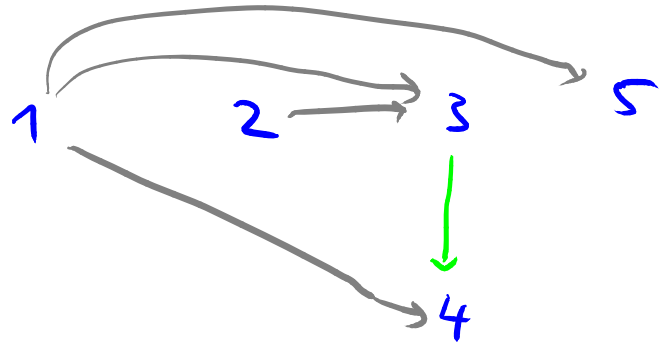
Draw the PDG and compute $slice(5, \{z\})$.

What is the sum of

- **the number of nodes,**
- **the number of edges, and**
- **the number of statements in the slice?**

Example 2 (Quiz)

```
1  var x = 1
2  var y = 2
3  if (x < y) {
4      y = x
   }
5  var z = x
```



⟶ .. data dep.

⟶ .. control dep.

slice (5, {z}) = {1, 5}

Solution: 5 nodes + 5 edges + 2 stmts. = 12

Outline

1. **Introduction**
2. **Static Slicing**
3. **Thin Slicing** ←
4. **Dynamic Slicing**

Mostly based on these papers:

- *Program Slicing*, Weiser., IEEE TSE, 1984
- *Thin Slicing*, Sridharan et al., PLDI 2007
- *Dynamic Program Slicing*, Agrawal and Horgan, PLDI 1990
- *A Survey of Program Slicing Techniques*, Tip, J Prog Lang 1995

Thin Slicing: Overview

- Challenge: Static slices are often very large
  - Worst case: Entire program
  - Too large for common debugging and program understanding tasks
- Main reason: Aims at an executable program
  - But: Not needed for many tasks
- Idea: Heuristically focus on statements needed for common debugging tasks
  $\rightarrow$ Thin slice
- Let user expand the thin slice on demand

Thin Slicing: Definition

- Statement directly uses a memory location if it uses it for some computation other than pointer dereference
  - Example: `x.f+y` uses `x` for pointer dereference and directly uses `y`
- Dependence graph G for thin slicing:
  Data dependences computed based on direct uses only
- Thin slice: Statements reachable from criterion's statement via G

Expanding Thin Slices

- Thin slices include ”producer statements” but exclude ”explainer statements”
  - Why do heap accesses read/write the same object?
  - Why can this producer execute?
- Most explainers are not useful for common tasks
- Expose explainers on demand via incremental expansion

Example: Thin Slicing

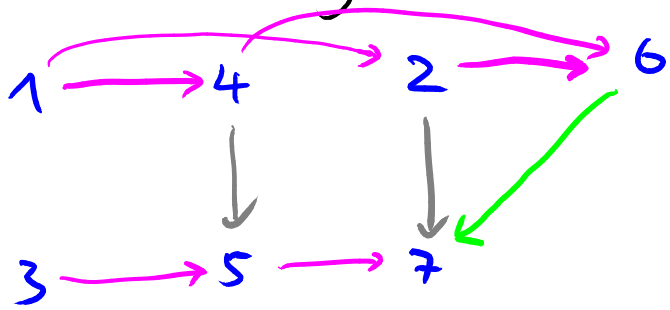
```
1 var x = {};
2 var z = x;
3 var y = {};
4 var w = x;
5 w.f = y;
6 if (w === z) {
7   var v = z.f;   // criterion
  }
```

→ .. direct data dep.

→ .. data dep. only for pointer deref. (ignored)

→ .. control flow dep. (ignored)

Dependence graph:



- Traditional slice: All statements
- Thin slicing
- On demand expansion, e.g., "Why are w and z aliased?"

Evaluation and Results

- Simulate developer effort for bug finding
  - Set of known bugs that crash the program (and their root causes)
  - Assume that developer inspects statements with breadth-first search on PDG, starting from crash point
  - Count inspected statements with traditional and thin slice
- Results:
  - Mean of 12 inspected statements per thin slice
  - Overall, 3.3x fewer inspected statements

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Dynamic Slicing

- Various definitions

  Here: Agrawal & Horgan, PLDI 1990

- Dynamic slice: Statements of an execution that must be executed to give a variable a particular value
  - For an execution, i.e., a particular input
  - Slice for one input may be different from slice for another input

- Useful, e.g., for debugging: Get a reduced program that leads to the unexpected value

Dynamic Slice (Simple Approach)

- **Given: Execution history**
  - Sequence of PDG nodes that are executed
- **Slice for statement n and variable v:**
  - Keep PDG nodes only if there are in history
  - Use static slicing approach (= graph reachability) on reduced PDG

Example 1

```
var x = readInput();
if (x < 0) {
  y = x + 1;
  z = x + 2;
} else {
  if (x === 0) {
    y = x + 3;
    z = x + 4;
  } else {
    y = x + 5;
    z = x + 6;
  }
}
console.log(y);
console.log(z);
```

Example: Dynamic Slicing (Simple Approach)

```
1  var x = readInput();
2  if (x < 0) {
3    y = x + 1;
4    z = x + 2;
   } else {
5    if (x === 0) {
6      y = x + 3;
7      z = x + 4;
     } else {
8      y = x + 5;
9      z = x + 6;
     }
   }
10 console.log(y);
11 console.log(z);
```

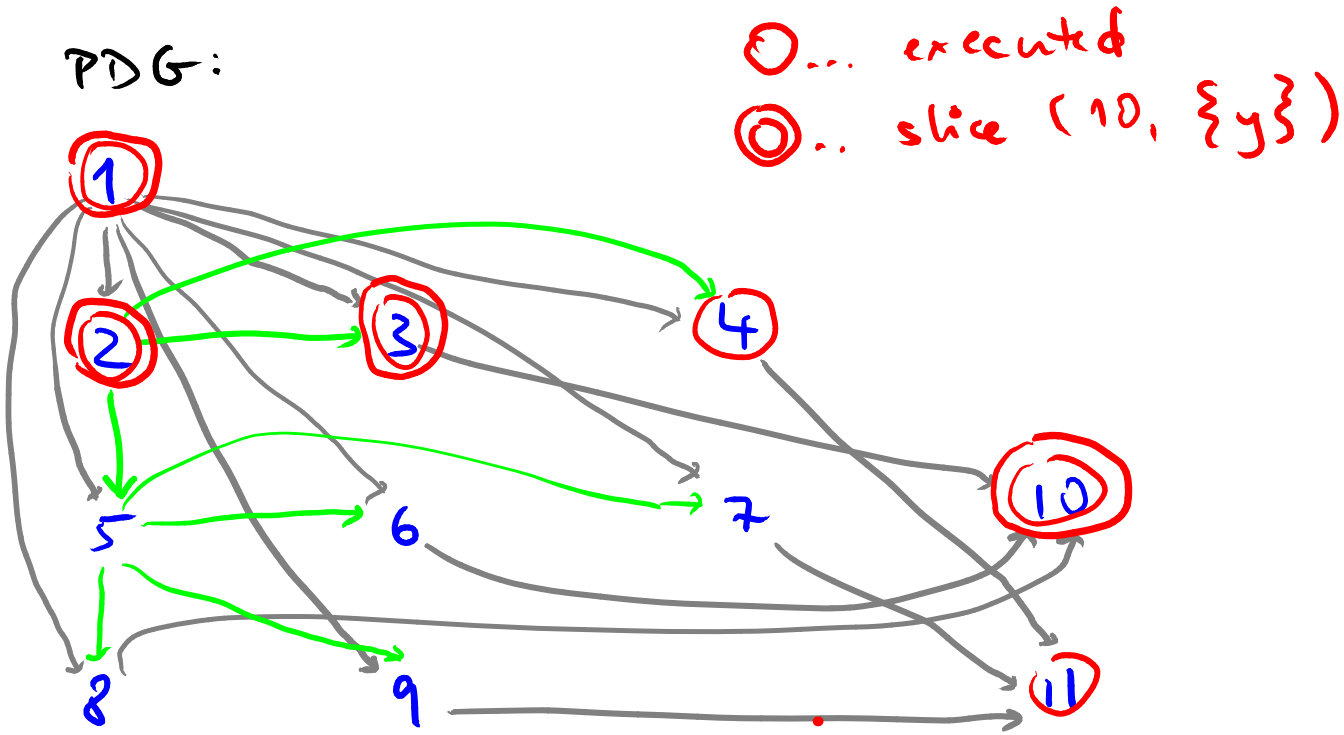
→ data dep.

→ control flow dep.

Input: −1

History: 1, 2, 3, 4, 10, 11

PDG:



○ ... executed

◎ .. slice (10, {y})

Example 2: Quiz

```
var n = readInput(); // 1
var z = 0;           // 2
var y = 0;           // 3
var i = 1;           // 4
while (i <= n) {     // 5
  z = z + y;         // 6
  y = y + 1;         // 7
  i = i + 1;         // 8
}
console.log(z);      // 9
```

Example 2: Quiz

```
var n = readInput();  // 1
var z = 0;            // 2
var y = 0;            // 3
var i = 1;            // 4
while (i <= n) {      // 5
  z = z + y;          // 6
  y = y + 1;          // 7
  i = i + 1;          // 8
}
console.log(z);       // 9
```

Draw the PDG and compute the dynamic slice for statement 9 and variable `z`, with input `n=1`.

How many statements are in the slice?

Example 2 (Quiz)

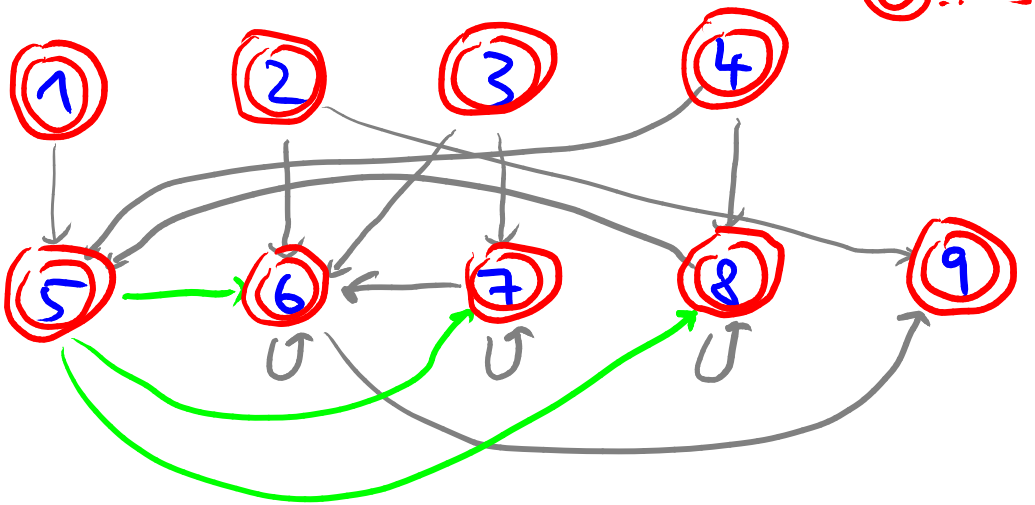
Input: 1

History: 1, 2, 3, 4, 5, 6, 7, 8, 5, 9

O... in history

◎.. slice (9, {z})

```
1 var n = readInput();
2 var z = 0;
3 var y = 0;
4 var i = 1;
5 while (i <= n) {
6   z = z + y;
7   y = y + 1;
8   i = i + 1;
  }
9 console.log(z);
```



→ 9 stmts. in the slice

Limitations of Simple Approach

- Multiple occurrences of a single statement are represented as a single PDG node
- Difference occurrences of a statement may have different dependences
  - All occurrences get conflated
- Slices may be larger than necessary

Dynamic Slice (Revised Approach)

Dynamic dependence graph

- Nodes: Occurrences of nodes of static PDG
- Edges: Dynamic data and control flow dependences

Slice for statement n and variables V that are defined or used at n:

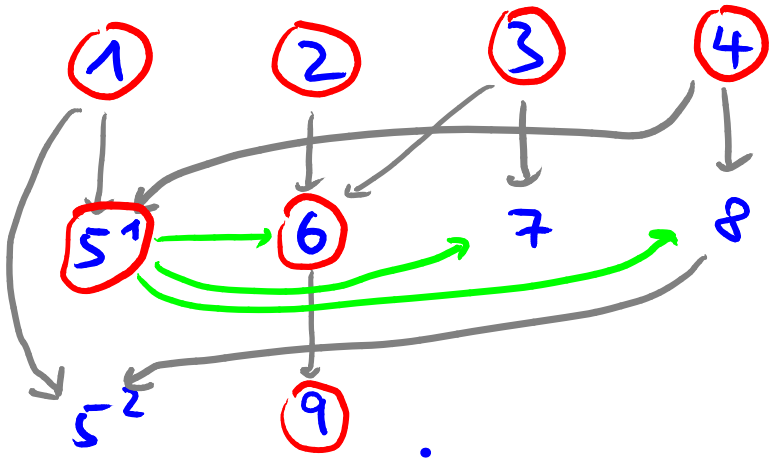
- Compute nodes S_{dyn} that can reach any of the nodes that represent occurrences of n
- Slice = statements with at least one node in S_{dyn}

Example 2 (revised approach)

Input: 1

History: 1, 2, 3, 4, 5, 6, 7, 8, 5, 9

```
1 var n = readInput();
2 var z = 0;
3 var y = 0;
4 var i = 1;
5 while (i <= n) {
6   z = z + y;
7   y = y + 1;
8   i = i + 1;
  }
9 console.log(z);
```



O.. slice(9, {z})

→ .. data dep.

→ .. control flow dep.

Discussion: Dynamic Slicing

- May yield a program that, if executed with another input, does not give the same value for the slicing criterion than the original program
- Instead: Focuses on isolating statements that affect a particular value
  - Useful, e.g., for debugging and program understanding
- Other approaches exist, see F. Tip's survey (1995) for an overview

Summary

- Program slicing: Extract subset of statements for a particular purpose
  - Debugging, program understanding, change impact analysis, parallelization
- Various techniques
  - Traditional static slicing: Executable but potentially very large slice
  - Thin slicing: Focus on producer statements, reveal explainer statements on demand
  - Dynamic slicing: Useful for understanding behavior of particular execution