Program Testing and Analysis: Program Slicing (Part 1)

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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

Program Slicing

Extract an executable subset of a program that (potentially) affects the values at a particular program location

- Slicing criterion = program location + variable
- An observer focusing on the slicing criterion cannot distinguish a run of the program from a run of the slice

Example

```
var n = readInput();
var i = 1;
var sum = 0;
var prod = 1;
while (i <= n) {
  sum = sum + i;
  prod = prod * i;
  i = i + 1;
}
console.log(sum);
console.log(prod);
```

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Slice for value of `sum` at this statement?

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```

Slice for value of `prod` at this statement

Example

```
var n = readInput();
var i = 1;
var sum = 0;
var prod = 1;
while (i <= n) {
  sum = sum + i;
  prod = prod * i;
  i = i + 1;
}
console.log(sum);
console.log(prod);
```

Slice for value of `n` at this statement

Why Do We Need Slicing?

Various applications, e.g.

- Debugging: Focus on parts of program relevant for a bug
- Program understanding: Which statements influence this statement?
- Change impact analysis: Which parts of a program are affected by a change? What should be retested?
- Parallelization: Determine parts of program that can be computed independently of each other

Slicing: Overview

Forward vs. backward

- Backward slice (our focus): Statements that influence the slicing criterion
- Forward slice: Statements that are influenced by the slicing criterion

Static vs. dynamic

- Statically computing a minimum slice is undecidable
- Dynamically computed slice focuses on particular execution/input

Static Program Slicing

- **Introduced by Weiser**

  (IEEE TSE, 1984)

- **Various algorithms to compute slices**
- **Here: Graph reachability problem based on program dependence graph**

Program Dependence Graph

Directed graph representing the data and control dependences between statements

- Nodes:
  - Statements
  - Predicate expressions
- Edges:
  - Data flow dependences: One edge for each definition-use pair
  - Control flow dependences

Example: Data Flow Dependences

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

Def \ Use	1	2	3	4	5	6	7	8	9	10
1					X					
2					X	X	X	X		
3						X			X	
4							X			X
5										
6						X			X	
7							X			X
8					X	X	X	X		
9										
10										

Control Flow Dependences

- Post-dominator:
  Node n_2 (strictly) post-dominates node $n_1 (\neq n_2)$ if every path $n_1, ..., exit$ in the control flow graph contains n_2

Control Flow Dependences

- Post-dominator:
  Node n_2 (strictly) post-dominates node $n_1 (\neq n_2)$ if every path $n_1, ..., exit$ in the control flow graph contains n_2
- Control dependence:
  Node n_2 is control-dependent on node $n_1 \neq n_2$ if
  - there exists a control flow path $P = n_1, ..., n_2$ where n_2 post-dominates any node in P (excluding n_1), and
  - n_2 does not post-dominate n_1

Example: Post-dominators

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

n_1 \ n_2	1	2	3	4	5	6	7	8	9	10
1		x	x	x	x				x	x
2			x	x	x				x	x
3				x	x				x	x
4					x				x	x
5									x	x
6					x		x	x	x	x
7					x			x	x	x
8					x				x	x
9										x
10										

Control-dependences:

6 is control-dep. on 5
7 — " — 5
8 — " — 5

Computing Slices

Given:

- Program dependence graph G_{PD}
- Slicing criterion (n, V), where n is a statement and V is the set of variables defined or used at n

Slice for (n, V):

All statements from which n is reachable

(i.e., all statements on which n depends)

Example: Program Dep. Graph

```
1  var n = readInput();
2  var i = 1;
3  var sum = 0;
4  var prod = 1;
5  while (i <= n) {
6    sum = sum + i;
7    prod = prod * i;
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   }
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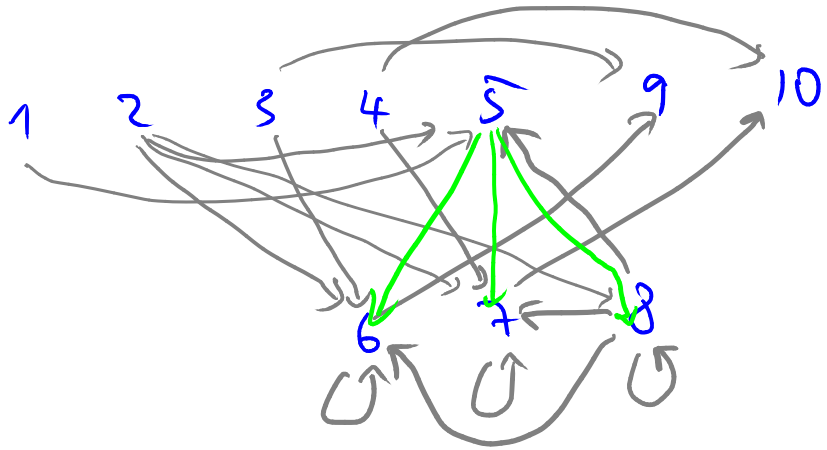
```



→ data dep.

→ control dep.

$$\text{slice}(9, \{\text{sum}\})$$
$$= \{ n \mid \text{reachable}(n, 9) \}$$
$$= \{1, 2, 3, 5, 6, 8, 9\}$$

Quiz

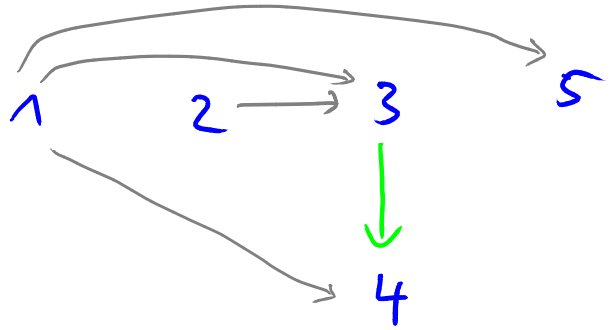
```
var x = 1;      // 1
var y = 2;      // 2
if (x < y) {    // 3
  y = x;        // 4
}
var z = x;      // 5
```

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?**

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



→ data

→ control

slice (5) = {1, 5}

Solution: 5 nodes + 5 edges + 2 statements = 12

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