Program Analysis – Lecture 9

Information Flow Analysis (Part 2)

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Warm-up Quiz

What does the following code print?

```
var x = 5;
var y = Number(5);
var z = new Number(5);
x.foo = "bar"; y.foo = "bar"; z.foo = "bar";
console.log(x.foo);
console.log(y.foo);
console.log(z.foo);
```

bar	undefined	bar	Some-
bar	undefined	undefined	thing
bar	undefined	bar	else

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console.log(x.foo);
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console.log(z.foo);
```

"undefined" (x and y are primitive values, which cannot have properties)

"bar" (z is an object)

bar	undefined	bar	Some-thing else
bar	undefined	undefined	
bar	undefined	bar	

Outline

1. **Introduction**
2. **Information Flow Policy**
3. **Analyzing Information Flows** ←
4. **Implementation**

Mostly based on these papers:

- *A Lattice Model of Secure Information Flow*, Denning, Comm ACM, 1976
- *Dytan: A Generic Dynamic Taint Analysis Framework*, Clause et al., ISSTA 2007

Analyzing Information Flows

Given an information flow policy, analysis checks for policy violations

Applications:

- Detect vulnerable code (e.g, potential SQL injections)
- Detect malicious code (e.g., privacy violations)
- Check if program behaves as expected (e.g., secret data should never be written to console)

Explicit vs. Implicit Flows

- **Explicit flows**: Caused by data flow dependence
- **Implicit flows**: Caused by control flow dependence

Explicit vs. Implicit Flows

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```
var creditCardNb = 1234;
var x = creditCardNb;
var visible = false;
if (x > 1000) {
  visible = true;
}
```

Explicit vs. Implicit Flows

- **Explicit flows: Caused by data flow dependence**
- **Implicit flows: Caused by control flow dependence**

```
var creditCardNb = 1234;
var x = creditCardNb;
var visible = false;
if (x > 1000) {
  visible = true;
}
```

Explicit flow from `creditCardNb` to `x`

Implicit flow from `x> 1000` to `visible`

Explicit vs. Implicit Flows

- **Explicit flows: Caused by data flow dependence**
- **Implicit flows: Caused by control flow dependence**

Some analyses consider only these

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var creditCardNb = 1234;
var x = creditCardNb;
var visible = false;
if (x > 1000) {
  visible = true;
}
```

Explicit flow from `creditCardNb` to `x`

Implicit flow from `x> 1000` to `visible`

Static and Dynamic Analysis

- **Static information flow analysis**
  - Overapproximate all possible data and control flow dependences
  - Result: Whether information ”may flow” from secret source to untrusted sink
- **Dynamic information flow analysis**
  - Associate security labels (”taint markings”) with memory locations
  - Propagate labels at runtime

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- **Dynamic information flow analysis**
  - Associate security labels (”taint markings”) with memory locations
  - Propagate labels at runtime

Focus of rest of this lecture

Taint Sources and Sinks

- **Possible sources**:
  - Variables
  - Return values of a particular function
  - Data from a type of I/O stream
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Taint Sources and Sinks

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  - Parameters given to a particular function
  - Instructions of a particular type (e.g., jump instructions)

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  - Parameters given to a particular function
  - Instructions of a particular type (e.g., jump instructions)

Report illegal flow if taint marking flows to a sink where it should not flow

Taint Propagation

1) Explicit flows

For every operation that produces a new value, propagate labels of inputs to label of output:

$$label(result) \leftarrow label(inp_1) \oplus ... \oplus label(inp_2)$$

Taint Propagation (2)

2) Implicit flows

- Maintain security stack S: Labels of all values that influence the current flow of control
- When x influences a branch decision at location loc, push $label(x)$ on S
- When control flow reaches immediate post-dominator of loc, pop $label(x)$ from S
- When an operation is executed while S is non-empty, consider all labels on S as input to the operation

Example 1

Policy:
- security classes: public, secret
- source: variable "creditCardNb"
- sink: variable "visible"

```
var creditCardNb = 1234;
var x = creditCardNb;
var visible = false;
if (x > 1000) {
  visible = true;
}
```

label(creditCardNb) = secret

explicit flow: label(x) = secret

label(visible) = public

produce intermediate value b,

$label(b) = label(x) \oplus label(1000)$

$= secret \oplus public = secret$

push 'secret' onto S

labels on S are part of input

$label(visible) = secret \oplus label(true)$

$= secret$

→ violation of policy

Example 2: Quiz

```
var x = getX();
var y = x + 5;
var z = true;
if (y === 10)
  z = false;
foo(z);
```

Policy:

- Security classes: public, secret
- Source: `getX`
- Sink: `foo()`

Suppose that `getX` returns 5. Write down the labels after each operation.

Is there a policy violation?

https://ilias3.uni-stuttgart.de/vote/KN2I

Example 2

```
var x = getX();
var y = x + 5;
var z = true;
if (y === 10)
  z = false;
foo(z);
```

label (x) = secret

label(y) = label (x) ⊕ label(5)
= secret

label (z) = public

yields "b", label(b) = secret,
push secret

label (z) = secret ⊕ public = secret

pop secret

violation because z is secret

Hidden Implicit Flows

- **Implicit flows may happen even though a branch is not executed**
- **Approach explained so far will miss such ”hidden” flows**

```
// label(x) = public, label(secret) = private
var x = false;
if (secret)
  x = true;
```

Hidden Implicit Flows

- Implicit flows may happen even though a branch is not executed
- Approach explained so far will miss such ”hidden” flows

```
// label(x) = public, label(secret) = private
var x = false;
if (secret)
  x = true;
```

Copies `secret` into `x`

But: Execution where `secret` is `false` does not propagate anything

Hidden Implicit Flows (2)

Approach to reveal hidden flows:

For every conditional with branches b_1 and b_2:

- Conservatively overapproximate which values may be defined in b_1
- Add spurious definitions into b_2

Hidden Implicit Flows (2)

Approach to reveal hidden flows:

For every conditional with branches b_1 and b_2:

- Conservatively overapproximate which values may be defined in b_1
- Add spurious definitions into b_2

```
var x = false;
if (secret)
  x = true;
else
  x = x;    // spurious definition
```

All executions propagate "secret" label to `x`

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Implementation in Dytan

Dynamic information flow analysis for x86 binaries

- Taint markings stored as bit vectors
- One bit vector per byte of memory
- Propagation implemented via instrumentation (i.e., add instructions to existing program)
- Computes immediate post-dominators via static control flow graph

Summary

- Information flow analysis:
  Track secrecy of information handled by program
- Goal: Check information flow policy
  - Security classes, sources, sinks
- Various applications
  - E.g., malware detection, check for vulnerabilities
- There exist channels missed by information flow analysis
  - E.g., power consumption, timing