An Empirical Study of Information Flows in Real-World JavaScript

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Program Analyses of Different Complexity

```
// variable passwd is sensitive
var paddedPasswd = "xx" + passwd;
var gotIt = false;
var knownPasswd = null;
if (paddedPasswd === "xxacmccs2019") {
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}
// function sink is insensitive
sink(gotIt);
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information flow?

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lightweight $\rightarrow$ heavyweight		
taint tracking	observable tracking	information flow control

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- only track explicit flows
- `passwd = "acmccs2019"`

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- `passwd = "acmccs2019"`
- no security violation

Program Analyses of Different Complexity (3)

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- track some implicit flows
- `passwd = "acmccs2019"`

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- track some implicit flows
- `passwd = "foo"`
- **no security violation**

Program Analyses of Different Complexity (4)

lightweight → heavyweight		
taint tracking	observable tracking	**information flow control**

```
var paddedPasswd = "xx" + passwd;
var gotIt = false;
var knownPasswd = null;
if (paddedPasswd === "xxacmccs2019") {
  gotIt = true; // violation
  knownPasswd = passwd;
}
sink(gotIt);
```

- passwd = "acmccs2019"
- insert upgrade statement on monitor violation

Program Analyses of Different Complexity (4)

lightweight → heavyweight		
taint tracking	observable tracking	**information flow control**

```
var paddedPasswd = "xx" + passwd;
var gotIt = false;
var knownPasswd = null;
upgrade(paddedPasswd, gotIt);
if (paddedPasswd === "xxacmccs2019") {
  gotIt = true;
  knownPasswd = passwd;
}
sink(gotIt);
```

- `passwd = "foo"`
- insert upgrade statement on monitor violation

Program Analyses of Different Complexity (4)

lightweight → heavyweight		
taint tracking	observable tracking	**information flow control**

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upgrade(paddedPasswd, gotIt);
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```

- `passwd = "foo"`
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Cost-Benefit Analysis

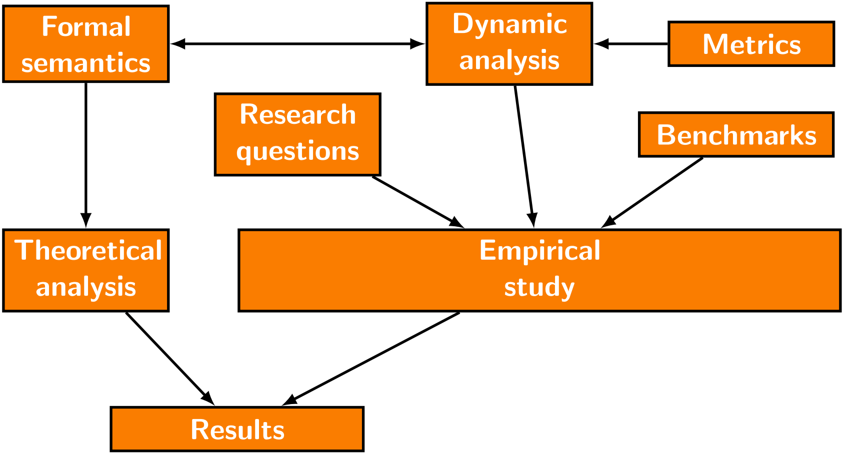
Benefits:

- more fine-grained flows
- more detected vulnerabilities

Costs:

- runtime cost
- label creep
- permissiveness

Overview


Formal semantics
Dynamic analysis
Metrics
Research questions
Benchmarks
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Empirical study
Results

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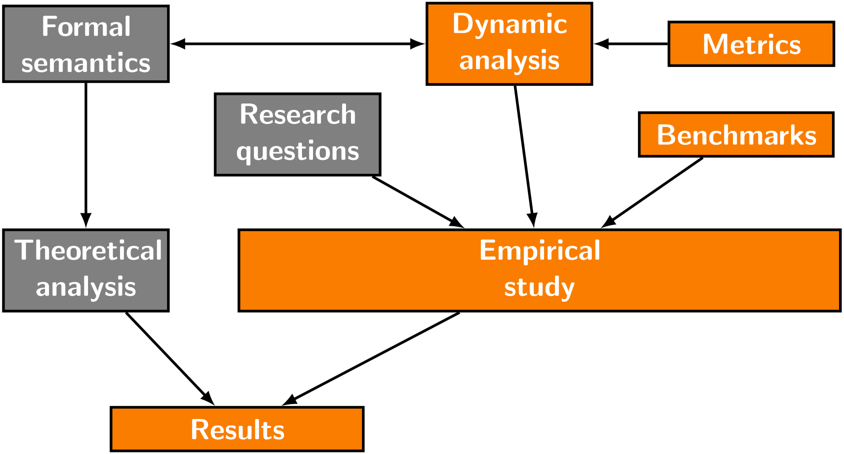
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Microflows

Definition

A microflow is an operation, e.g., write, that causes a variable to become sensitive.

Explicit flows

```
var a = b; // explicit flow from a to b
```

Observable implicit flow

```
if (a === true) {
  b = 23; // observable implicit flow from a to b
} else {
  b = 42; // observable implicit flow from a to b
}
```

Hidden implicit flow

```
if (a === true) {
  b = 23; // observable implicit flow from a to b
} else {
  // hidden implicit flow from a to b
}
```

Source-to-Sink Flows

Definition

A sequence of cascaded microflows between a source and a sink is called a source-to-sink (S2S) flow.

```
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}
sink(gotIt);
```

One source-to-sink flow consisting of one explicit microflow and one observable implicit.

Label Creep

Definition

Label creep ratio (LCR) is the percentage of variables assigned a sensitive value in their lifetime out of the total number of variables ever assigned.

$$LCR = \frac{\#\text{ sensitive variables/fields ever assigned}}{\#\text{ variables/fields ever assigned}}$$

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var paddedPasswd = "xx" + passwd;
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$LCR = 0.33$

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if (paddedPasswd === "xxacmccs2019") {
  gotIt = true;
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```

$LCR = 0.66$

Inference of Upgrade Statements

Definition

Sensitive branch coverage (SBC) is the percentage of conditionals handling sensitive information that are covered on both branches.

$$SBC = \frac{|\{c \in C \text{ where both true and false branch covered}\}|}{|C|}$$

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```
var paddedPasswd = "xx" + passwd;
var gotIt = false;
if (gotIt === false) {
  console.log(23);
}
if (paddedPasswd === "xxacmccs2019") {
  gotIt = true;
}
```

Input: `foo`, `acmccs2019`

Branch coverage: 75%, **SBC:** 100%

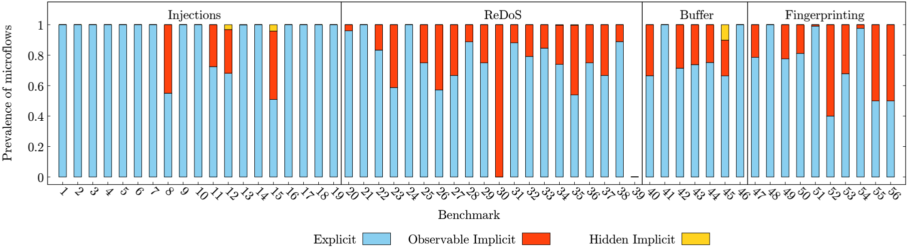
Implementation

- dynamic analysis based on **Jalangi**
- **expressive policy** language: function parameters, callback arguments
- **model** for native functions: arguments $\rightarrow$ return value
- **model** commonly used functions, e.g., Array.push, Object.call
- more than **100 unit tests** to test labels propagation

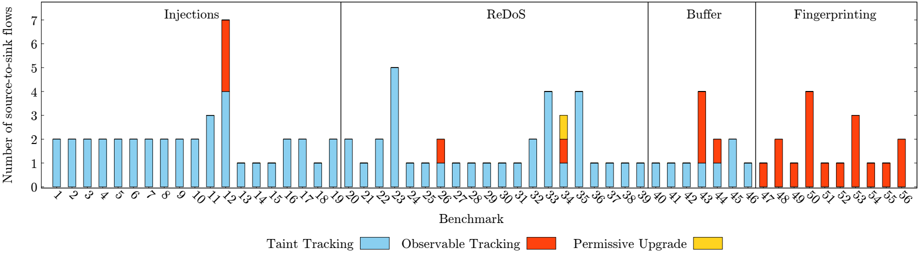
Benchmarks

- different security problems:
  - **integrity:** 19 injection vulnerabilities [Staicu et al., NDSS, 2018]
  - **availability:** 20 ReDoS vulnerabilities [Staicu et al., USENIX Security, 2018]
  - **confidentiality:** 7 buffer vulnerabilities
  - **confidentiality:** 10 client-side leaks
- inputs for triggering the attack and for increasing coverage
- realistic security policies that capture at least **one source-to-sink flow per benchmark**
- 50,547 LOC, 65 upgrades, 0.68 average SBC

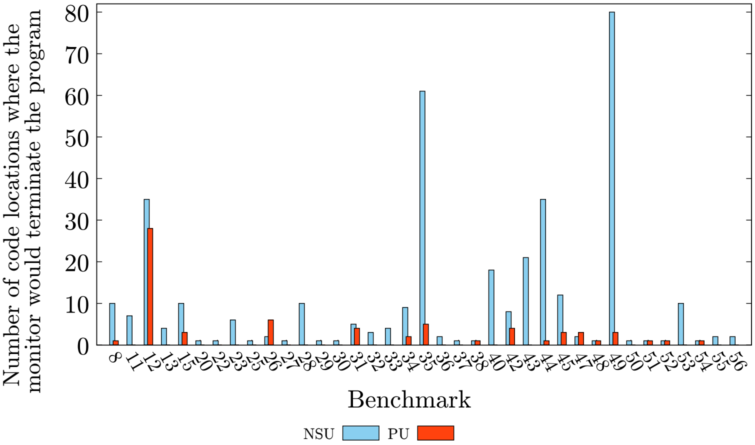
Benefit: Microflows



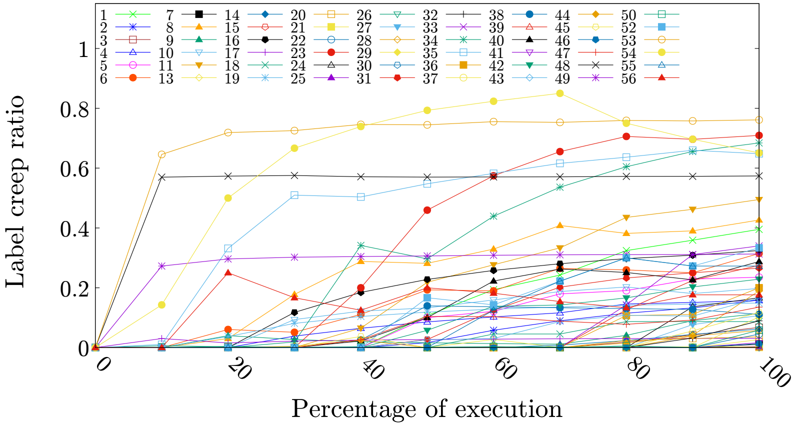
Benefit: Source-to-Sink Flows



Cost: Permissiveness



Cost: LCR - Label Creep Ratio



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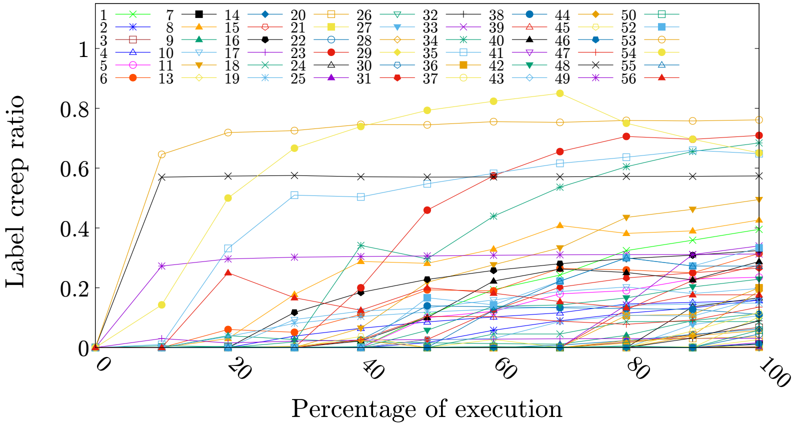
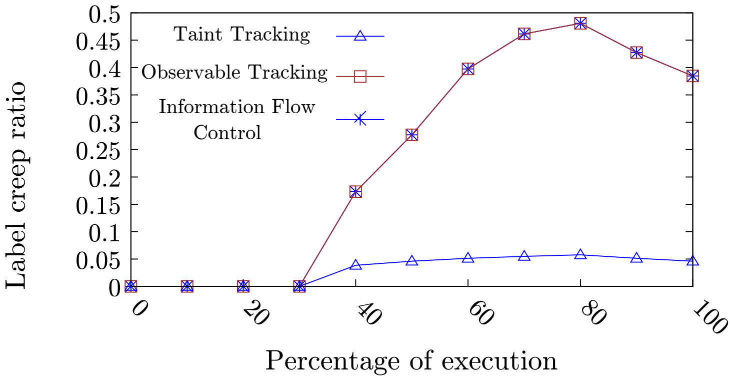


Average $max(LCR) = $ **20%**

Cost: LCR - Label Creep Ratio (2)



Cost: Runtime Overhead

Measure taint relevant operations, e.g., binary operators, method calls, conditionals.

	Taint Tracking	Observable Tracking	Information Flow Control
Command injection	59,339	59,383	59,540
ReDoS vulnerabilities	210	540	633
Buffer vulnerabilities	5,740	6,007	6,084
Client-side programs	5,919	19,555	20,890

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2.5-fold increase in runtime operations when considering implicit flows

Conclusions

56 benchmarks

integrity, availability, confidentiality; mostly non-malicious

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