Static DOM-Event Dependency Analysis for Testing Web Applications
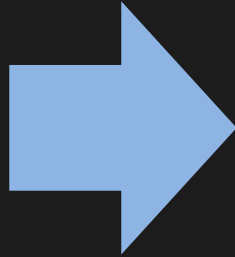
Chungha Sung | Markus Kusano | Nishant Sinha | Chao Wang

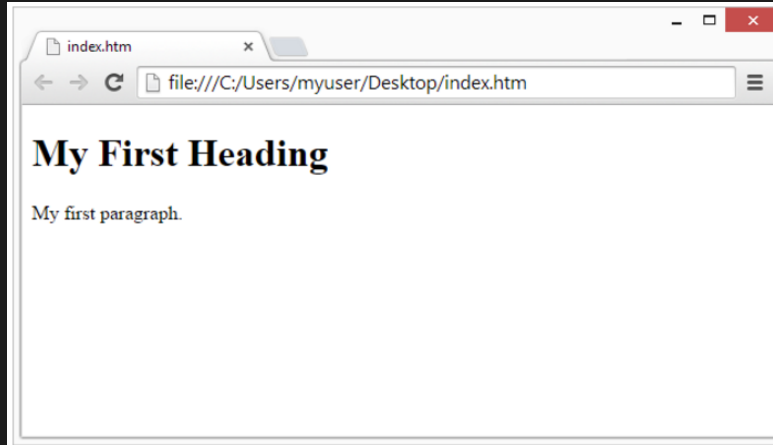**Virginia Tech | IBM Research (India) | University of Southern California**

What is a web application?

What is a web application?

Browser Page

HTML File
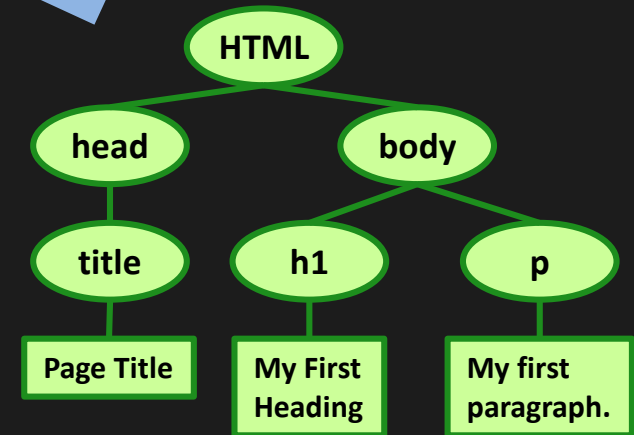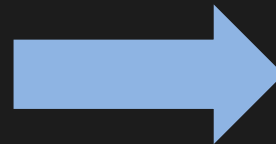
```
<!DOCTYPE html>
<html>
<head>
<title>Page Title</title>
</head>
<body>

<h1>My First Heading</h1>
<p>My first paragraph.</p>

</body>
</html>
```

DOM tree

3

What is a web application?

HTML

head   body

title   h1   p

Page Title   My First   My first
              Heading   paragraph.

DOM tree

HTML5 JS5 CSS3
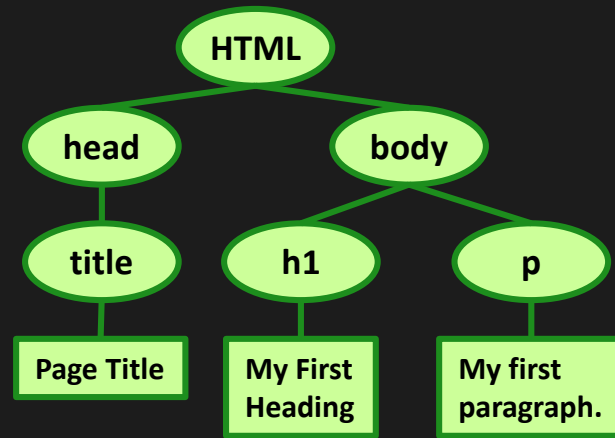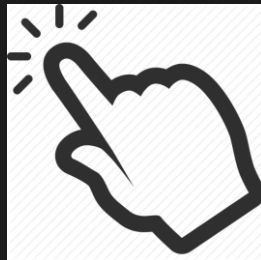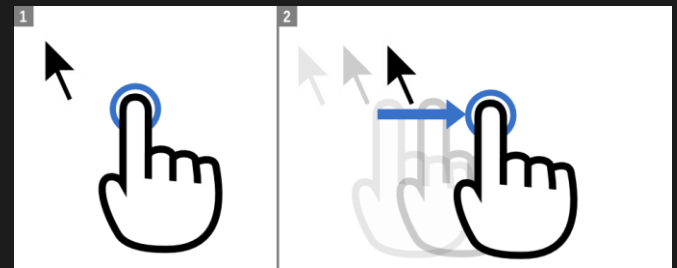
Click

Drag

Redundant event sequence

event1

event2

event2

event1

DOM-Event Dependency

event1

event2

Affect?

DOM-Event Dependency (1)

Data & Control Dependency

```
a.onclick = function ( ) {
    x = true;
};



b.onclick = function ( ) {
    if (x) {
        stmt1;
    } else {
        stmt2;
    }
};
```

event1

Affect?

event2

DOM-Event Dependency (2)

Data & Control Dependency

```
a.onclick = function ( ) {
    x = true;
};


b.onclick = function ( ) {
    if (x) {
        stmt1;
    } else {
        stmt2;
    }
};
```

DOM modification dependency

```
a.onclick = function ( ) {
        b.onclick = test1;
};

function test1 ( ) {
        …
}
```

event1

event2

Affect?

Outline

Motivation

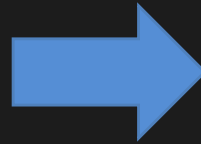**Contribution** **(static DOM-event dependency analysis)**

Experiments

Conclusion

Usefulness (to improve testing)

Code

```
 6 var a = document.getElementById('test1');
 7 var b = document.getElementById('test2');
 8 var c = document.getElementById('test3');
 9 var d = document.getElementById('test4');
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29 b.addEventListener("click", function() {
30     x = x + 1;
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33 d.addEventListener("click", function() {
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```

Testing tool (Artemis)

DOM-event Dependency Relationship
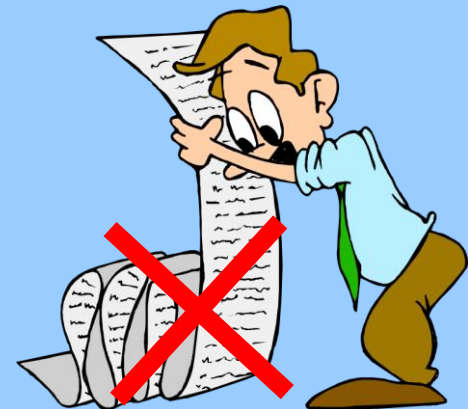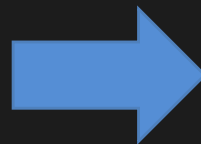
Motivating Example

```
 6 var a = document.getElementById('test1');
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```

DOM-Event Dependency Relationship

Motivating Example

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```

DOM-Event Dependency Relationship

test1 ➡ test3

Motivating Example

```
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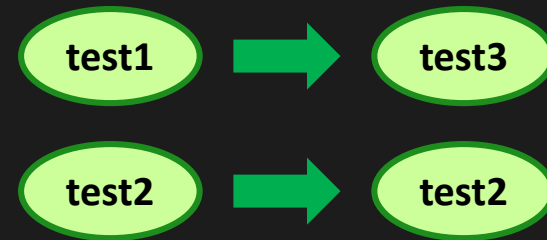
DOM-Event Dependency Relationship

test1 ➡ test3

test2 ➡ test2

Motivating Example

```
 6  var a = document.getElementById('test1');
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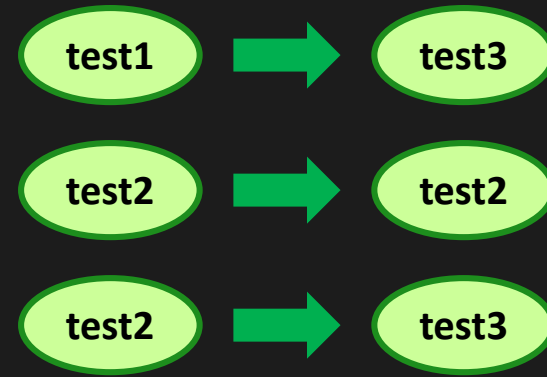
DOM-Event Dependency Relationship

test1 ➡ test3

test2 ➡ test2

test2 ➡ test3

10

Motivating Example

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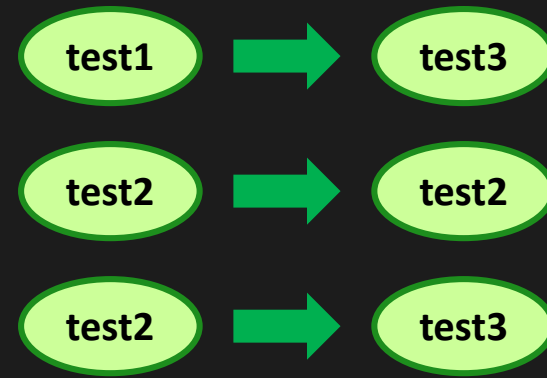
DOM-Event Dependency Relationship

test1 ➡ test3

test2 ➡ test2

test2 ➡ test3

test4 does not affect any other event

10

Motivating Example

```
 6 var a = document.getElementById('test1');
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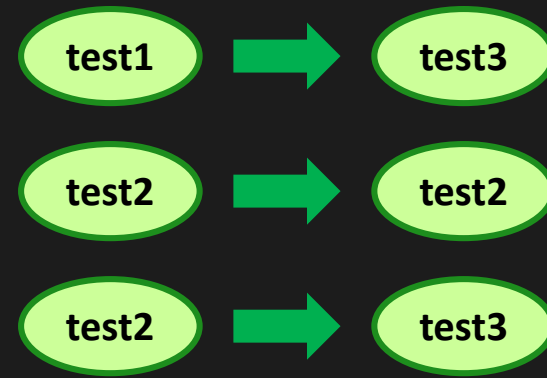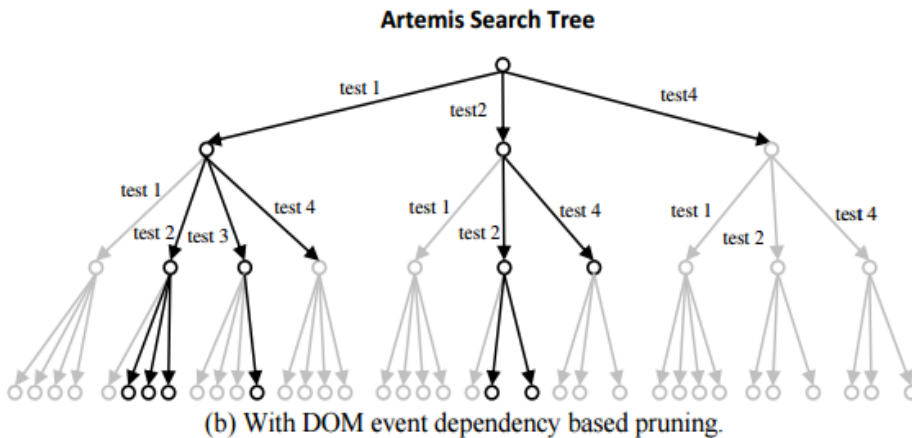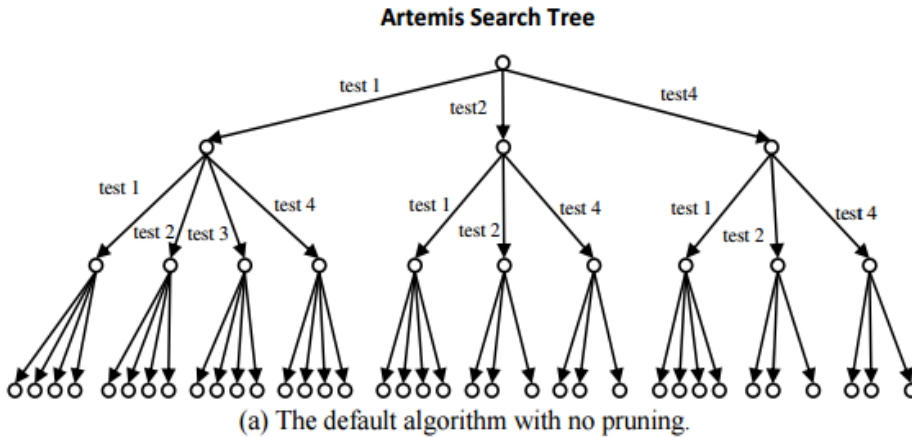
DOM-Event Dependency Relationship

test1 ➡ test3

test2 ➡ test2

test2 ➡ test3

To cover all lines,
Test1 has to be clicked 1 time
Test2 has to be clicked 8 times
Test3 has to be clicked 5 times
Test4 has to be clicked 1 time

10

Motivating Example

(a) The default algorithm with no pruning.

(b) With DOM event dependency based pruning.

16 dependencies
vs
3 dependencies
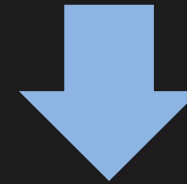
21,523,359 iterations
vs
60 iterations

Implementation

JS files

Web application

Dom-event Dependency Analysis

Normalized → CFG → Datalog Facts

JS_WALA

Datalog Rules → Z3 fixed-point engine

DOM-event Dependency

Artemis (modified)

More efficient !!!

Implementation

JS files

Normalized → CFG → Datalog Facts → Z3 fixed-point engine

JS_WALA

Datalog Rules →

Dom-event Dependency Analysis

DOM-event Dependency

Web application → Artemis (modified) More efficient !!!
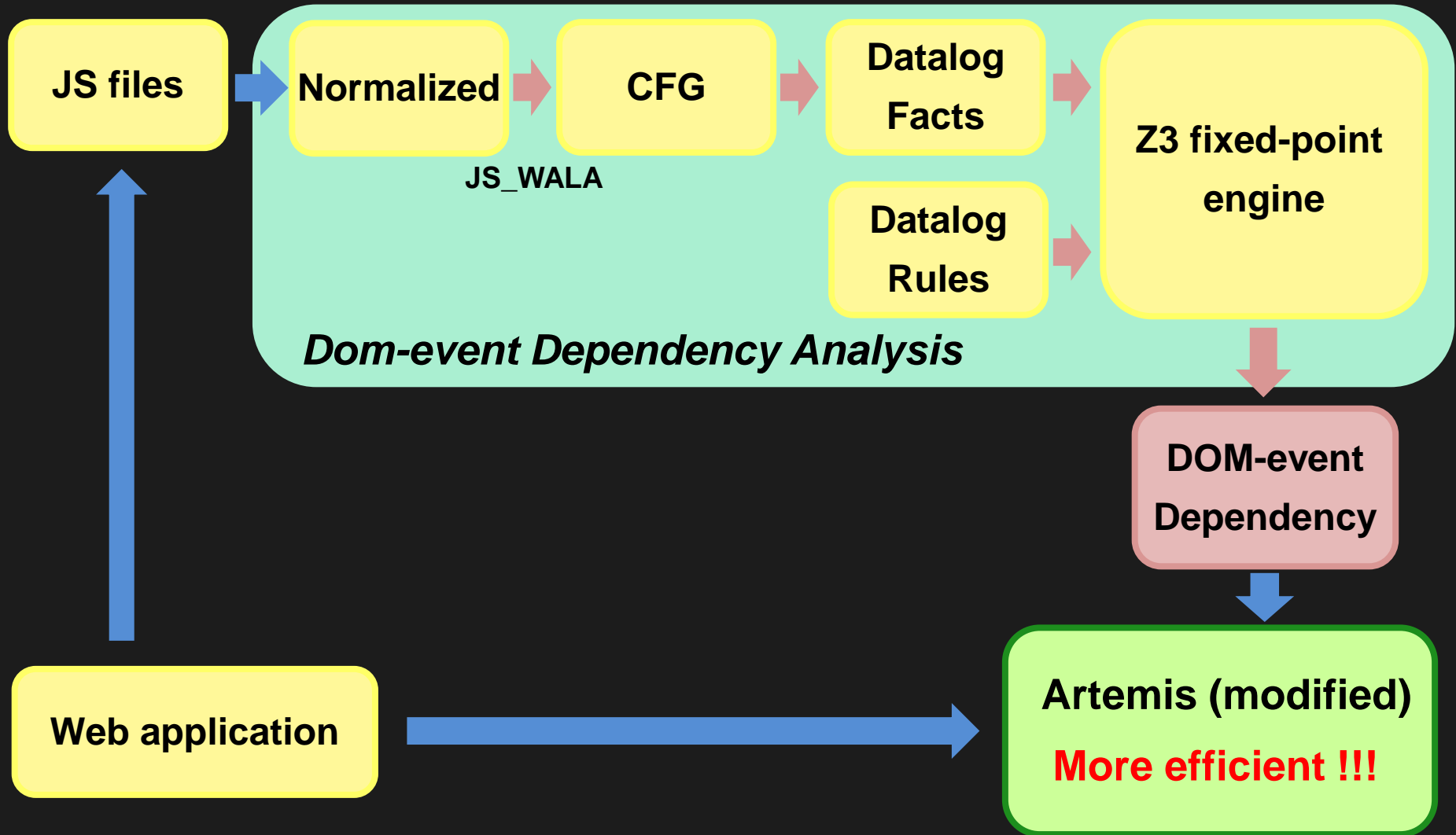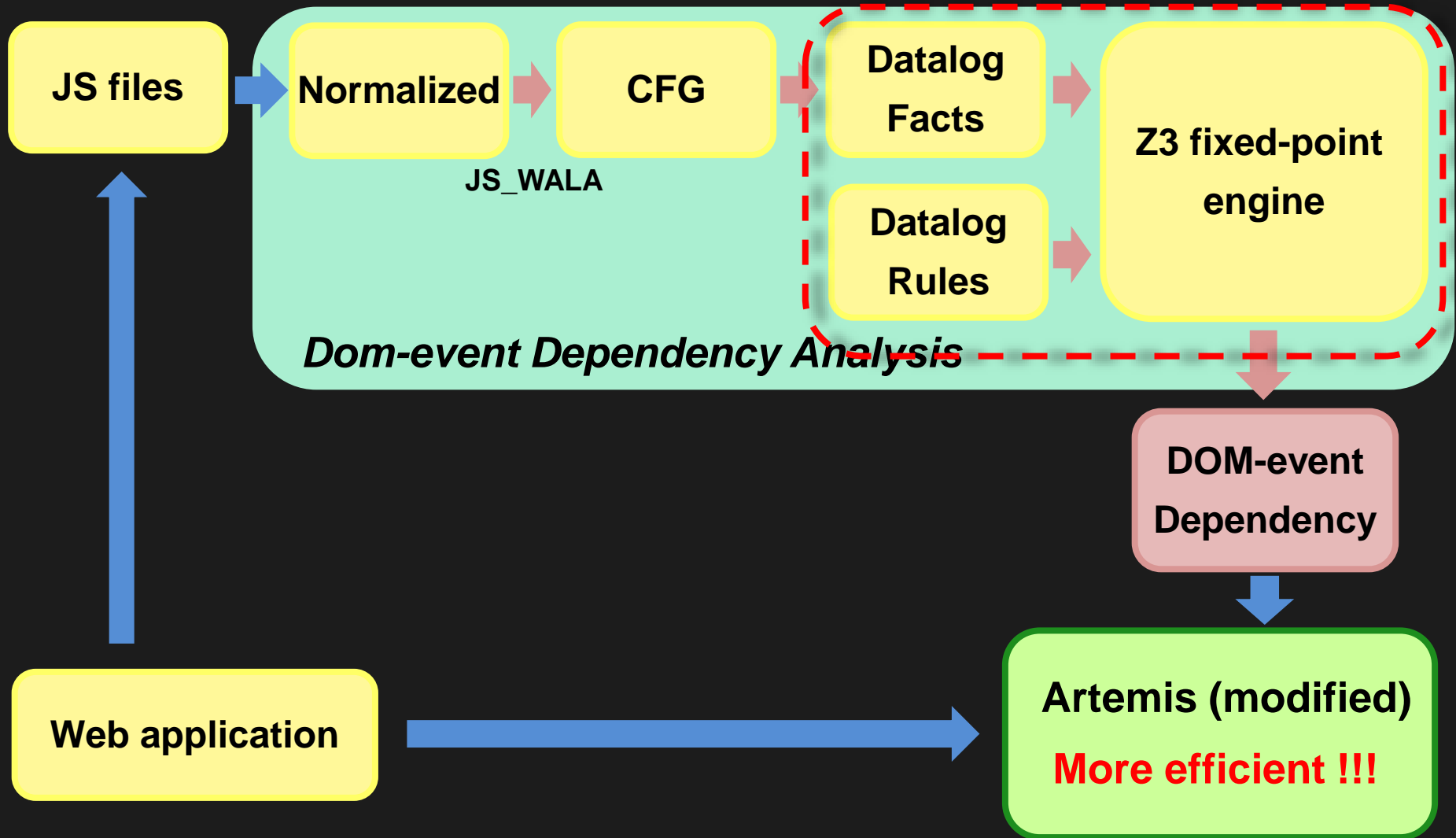
Program Analysis in Datalog

[Whaley & Lam, 2004]
[Livshits & Lam, 2005]

HTML/JavaScript code → **Datalog facts**

Datalog rules

Datalog Engine

**DOM-event
Dependency relation**

13
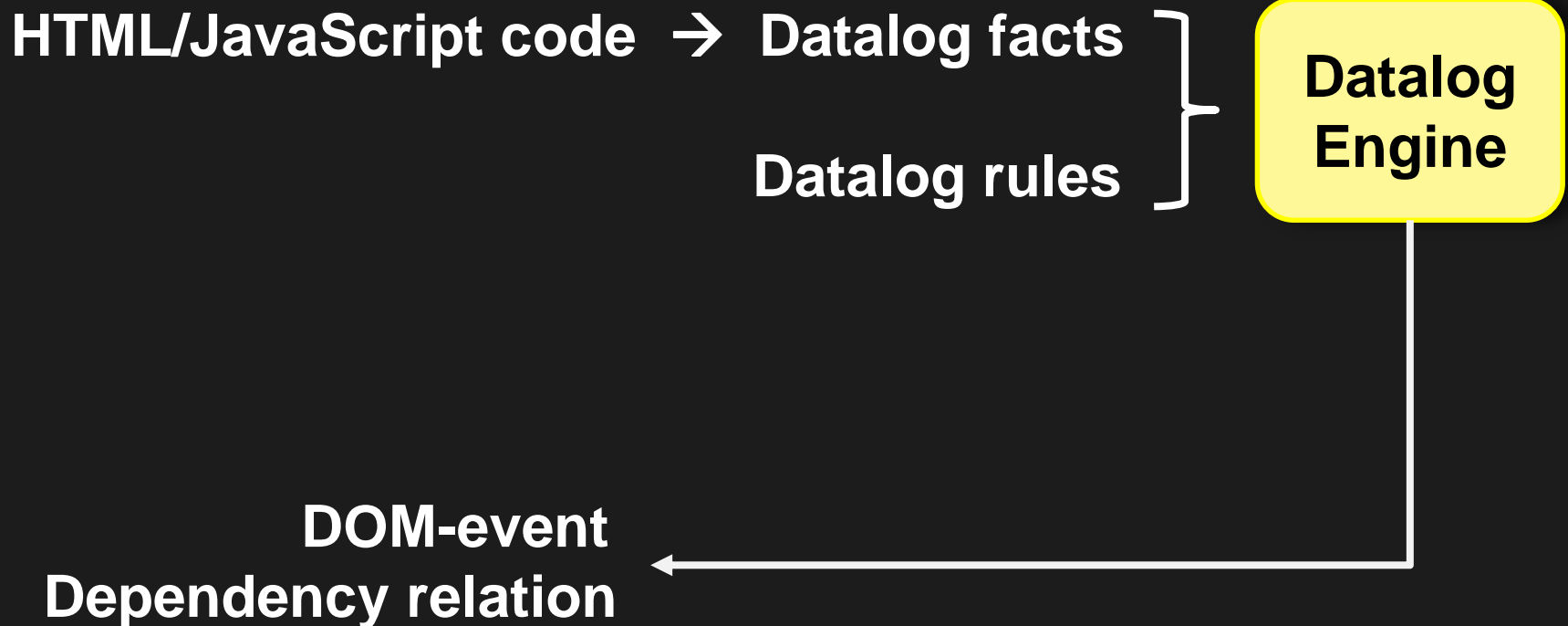
What is Datalog?

Declarative language for deductive databases [Ullman 1989]

Facts
parent (bill, mary)
parent (mary, john)

Rules
ancestor (X, Y) ← parent (X, Y)
ancestor (X, Y) ← parent (X, Z), ancestor (Z, Y)

New relationship: ancestor (bill, john)

Datalog Translation

```
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31 });
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33 d.addEventListener("click", function() {
34     console.log("d is clikced!");
35 });
```

Datalog Translation ex)

test2 ➡ test3

```
 6 var a = document.getElementById('test1');
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```

DOM (b, test2)

DOM (c, test3)

14

Datalog Translation   ex)   test2 → test3

```
 6 var a = document.getElementById('test1');
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```

DOM (b, test2)

DOM (c, test3)

READ (x, 13)
STMT (13, makeSomeNoise)

14

Datalog Translation

ex) test2 ➡ test3

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```

DOM (b, test2)

DOM (c, test3)

READ (x, 13)
STMT (13, makeSomeNoise)

DOM-MODIFY (c, click, makeSomeNoise)

14

Datalog Translation

ex) test2 ➡ test3

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```

DOM (b, test2)

DOM (c, test3)

READ (x, 13)
STMT (13, makeSomeNoise)

DOM-MODIFY (c, click, makeSomeNoise)

WRITE (x, 30)
STMT (30, functionB)

14

Datalog Translation ex)

test2 ➡ test3

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```

DOM (b, test2)

DOM (c, test3)

READ (x, 13)
STMT (13, makeSomeNoise)

DOM-MODIFY (c, click, makeSomeNoise)

WRITE (x, 30)
STMT (30, functionB)

DOM-MODIFY (b, click, functionB)

14

Datalog Translation ex)

test2 ➡ test3

```
 6  var a = document.getElementById('test1');
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33  d.addEventListener("click", function() {
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```

DOM (b, test2)

DOM (c, test3)

New Relationship

READ (x, 13)
STMT (13, makeSomeNoise)

DOM-MODIFY (c, click, makeSomeNoise)

WRITE (x, 30)
STMT (30, functionB)

DOM-MODIFY (b, click, functionB)

14

Datalog Translation ex)

test2 ➡ test3

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DOM (b, test2)

DOM (c, test3)

New Relationship

DATA-DEP (30, 13)

READ (x, 13)
STMT (13, makeSomeNoise)

DOM-MODIFY (c, click, makeSomeNoise)

WRITE (x, 30)
STMT (30, functionB)

DOM-MODIFY (b, click, functionB)

Rule:
READ (var1, stmt1) & WRITE (var1, stmt2) =>
DATA-DEP (stmt2, stmt1)

Datalog Translation   ex)

test2 ➡ test3

```
 6 var a = document.getElementById('test1');
 7 var b = document.getElementById('test2');
 8 var c = document.getElementById('test3');
 9 var d = document.getElementById('test4');
10 var t1 = 0;
11 var x = 0;
12 function makeSomeNoise() {
13     if (x < 2) {
14         console.log("x is lower than 2");
15     } else if (x < 4) {
16         console.log("x is lower than 4");
17     } else if (x < 6) {
18         console.log("x is lower than 6");
19     } else if (x < 8) {
20         console.log("x is lower than 8");
21     } else {
22         console.log("x is higher than 8");
23     }
24 }
25 a.addEventListener("click", function() {
26     c.onclick = makeSomeNoise;
27 });
28
29 b.addEventListener("click", function() {
30     x = x + 1;
31 });
32
33 d.addEventListener("click", function() {
34     console.log("d is clikced!");
35 });
```

DOM (b, test2)

DOM (c, test3)

New Relationship

DATA-DEP (30, 13)

FUNC-DEP (functionB, makeSomeNoise)

READ (x, 13)

STMT (13, makeSomeNoise)

DOM-MODIFY (c, click, makeSomeNoise)

WRITE (x, 30)

STMT (30, functionB)

DOM-MODIFY (b, click, functionB)

Rule:
STMT (stmt1, func1) & STMT (stmt2, func2) &
DATA-DEP (stmt1, stmt2)
=> FUNC-DEP (func1, func2)

14

Datalog Translation ex) test2 ➡ test3

```
 6 var a = document.getElementById('test1');
 7 var b = document.getElementById('test2');
 8 var c = document.getElementById('test3');
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21     } else {
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34     console.log("d is clikced!");
35 });
```

DOM (b, test2)

DOM (c, test3)

New Relationship

DATA-DEP (30, 13)

FUNC-DEP (functionB, makeSomeNoise)

DOM-TEMP-DEP (b, click, c, click)

READ (x, 13)
STMT (13, makeSomeNoise)

DOM-MODIFY (c, click, makeSomeNoise)

WRITE (x, 30)
STMT (30, functionB)

DOM-MODIFY (b, click, functionB)

Rule
DOM-MODIFY (v1, e1, func1) & DOM-MODIFY (v2, e2, func2) & FUNC-DEP (func1, func2)
=> DOM-TEMP-DEP (v1, e1, v2, e2)

14

Datalog Translation ex)

test2 ➡ test3

```
 6 var a = document.getElementById('test1');
 7 var b = document.getElementById('test2');
 8 var c = document.getElementById('test3');
 9 var d = document.getElementById('test4');
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18         console.log("x is lower than 6");
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20         console.log("x is lower than 8");
21     } else {
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25 a.addEventListener("click", function() {
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29 b.addEventListener("click", function() {
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33 d.addEventListener("click", function() {
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35 });
```

DOM (b, test2)

DOM (c, test3)

New Relationship

DATA-DEP (30, 13)

FUNC-DEP (functionB, makeSomeNoise)

DOM-TEMP-DEP (b, click, c, click)

DOM-DEP (test2, click, test3, click)

READ (x, 13)
STMT (13, makeSomeNoise)

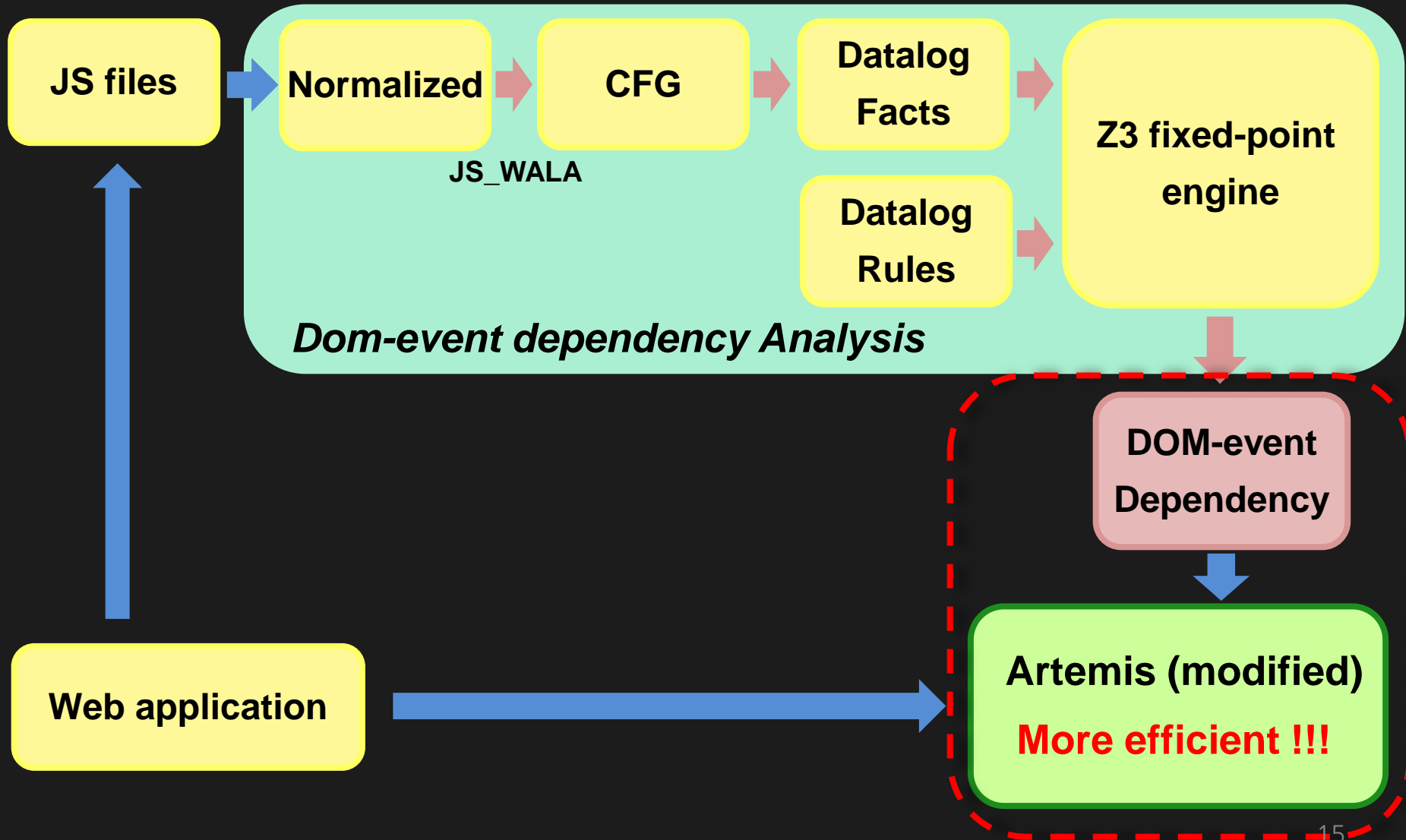DOM-MODIFY (c, click, makeSomeNoise)

WRITE (x, 30)
STMT (30, functionB)

DOM-MODIFY (b, click, functionB)

Rule:
DOM-TEMP-DEP (v1, e1, v2, e2)
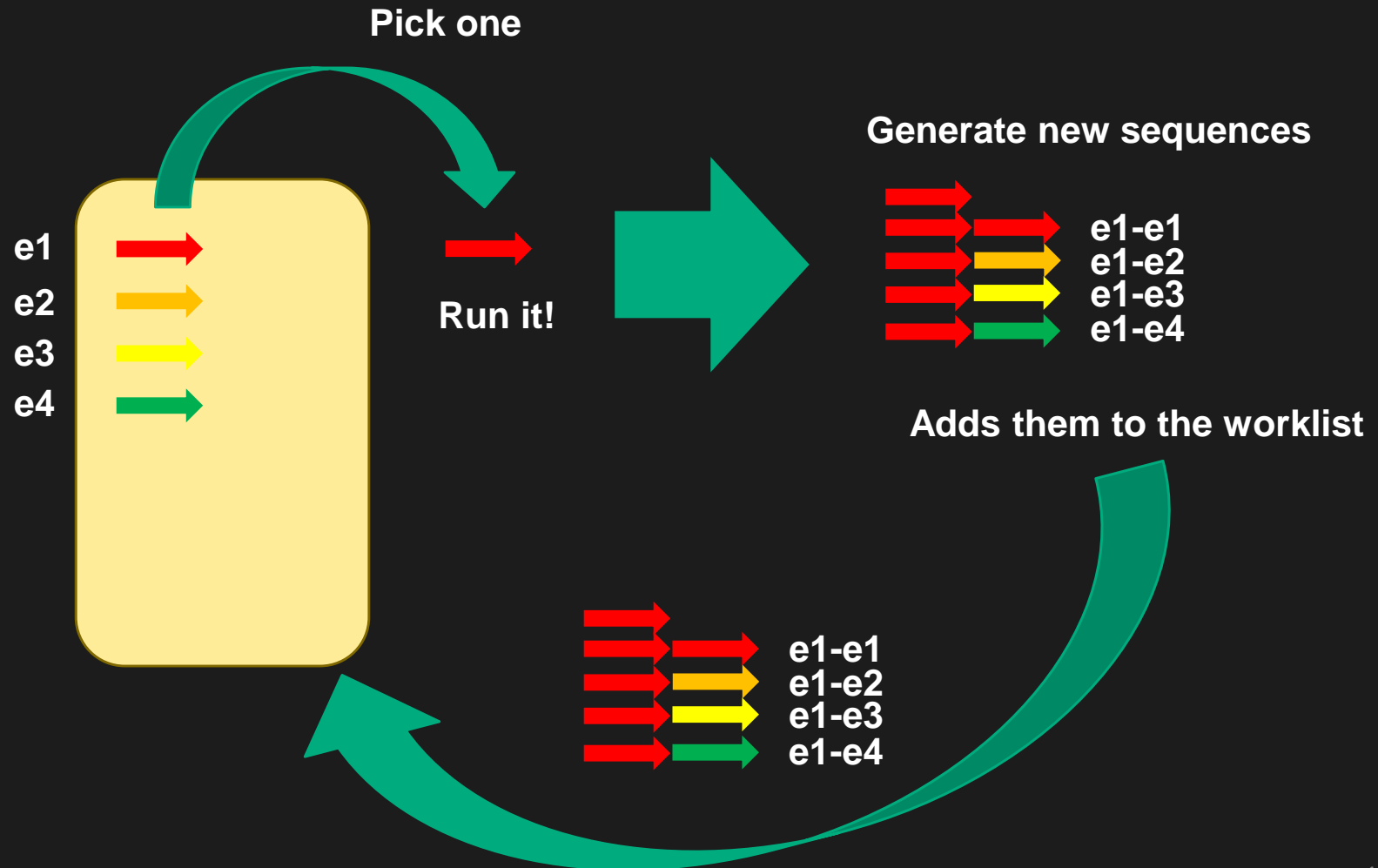*& DOM (v1, d1) & DOM (v2, d2)*
=> DOM-DEP (d1, e1, d2, e2)

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Implementation

JS files

Dom-event dependency Analysis

Normalized → CFG → Datalog Facts → Z3 fixed-point engine

JS_WALA

Datalog Rules →

DOM-event Dependency

Web application → Artemis (modified) **More efficient !!!**
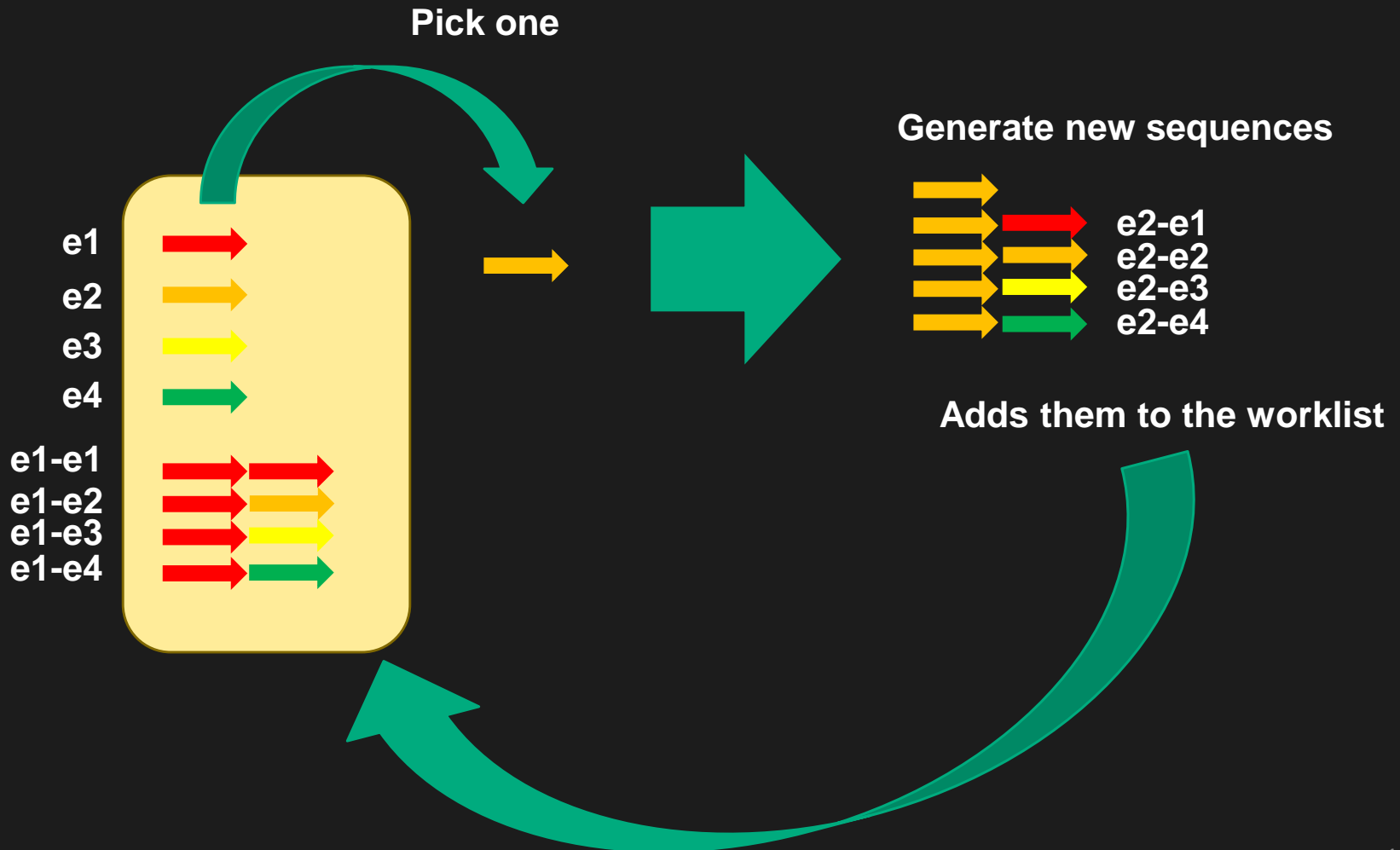
15

Artemis (testing tool) [Artzi et al., ICSE 2011]

Artemis (testing tool) [Artzi et al., ICSE 2011]

__Each iteration__

Improving Artemis?

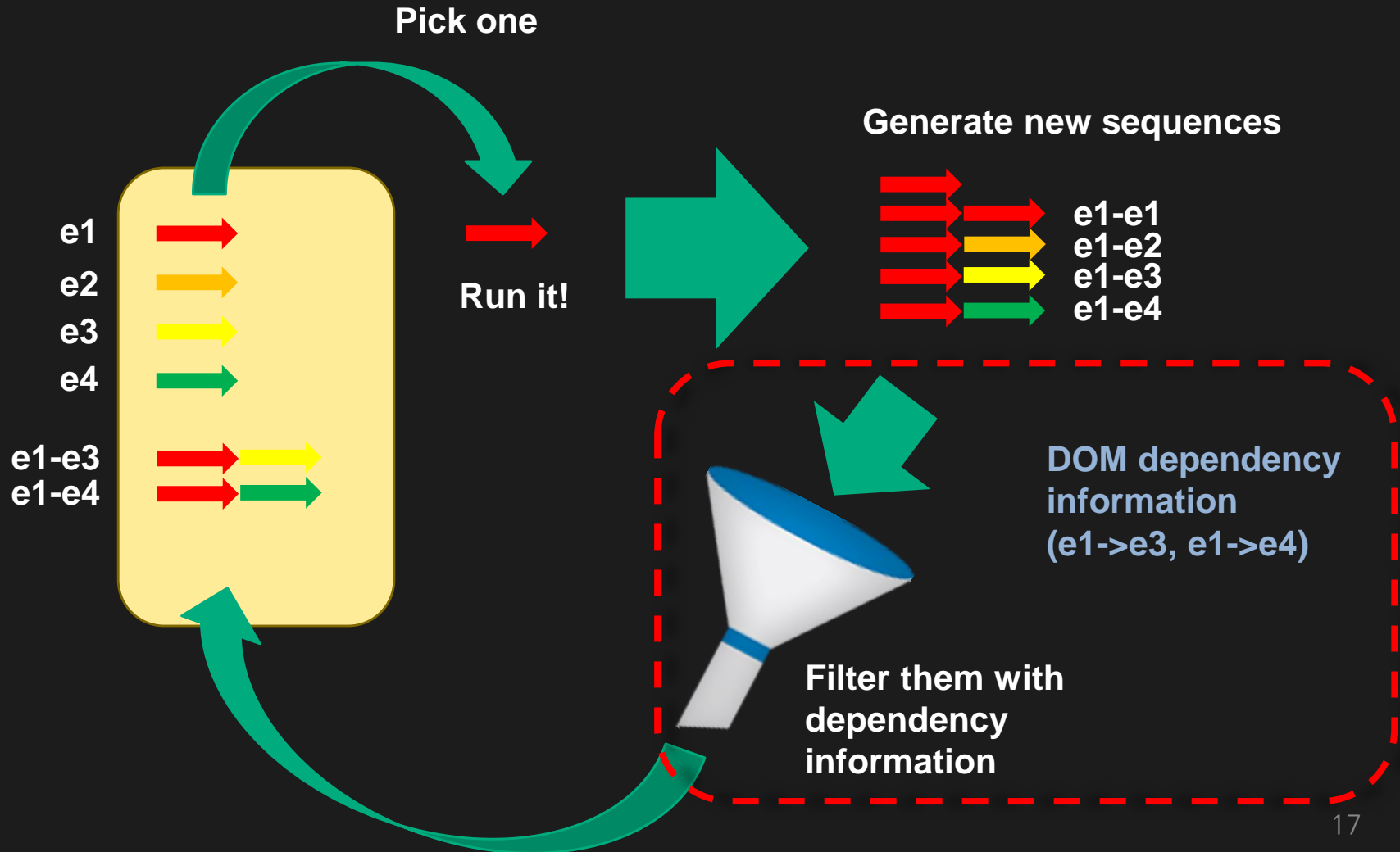*Each iteration*

Pick one

e1 →
e2 →
e3 →
e4 →

Run it!

Generate new sequences

e1-e1
e1-e2
e1-e3
e1-e4

DOM dependency information
(e1->e3, e1->e4)

Filter them with dependency information

e1-e3
e1-e4

Improving Artemis?

Each iteration

Pick one

Generate new sequences

e1
e2
e3
e4

e1-e3
e1-e4

Run it!

e1-e1
e1-e2
e1-e3
e1-e4

DOM dependency information (e1->e3, e1->e4)

Filter them with dependency information

17
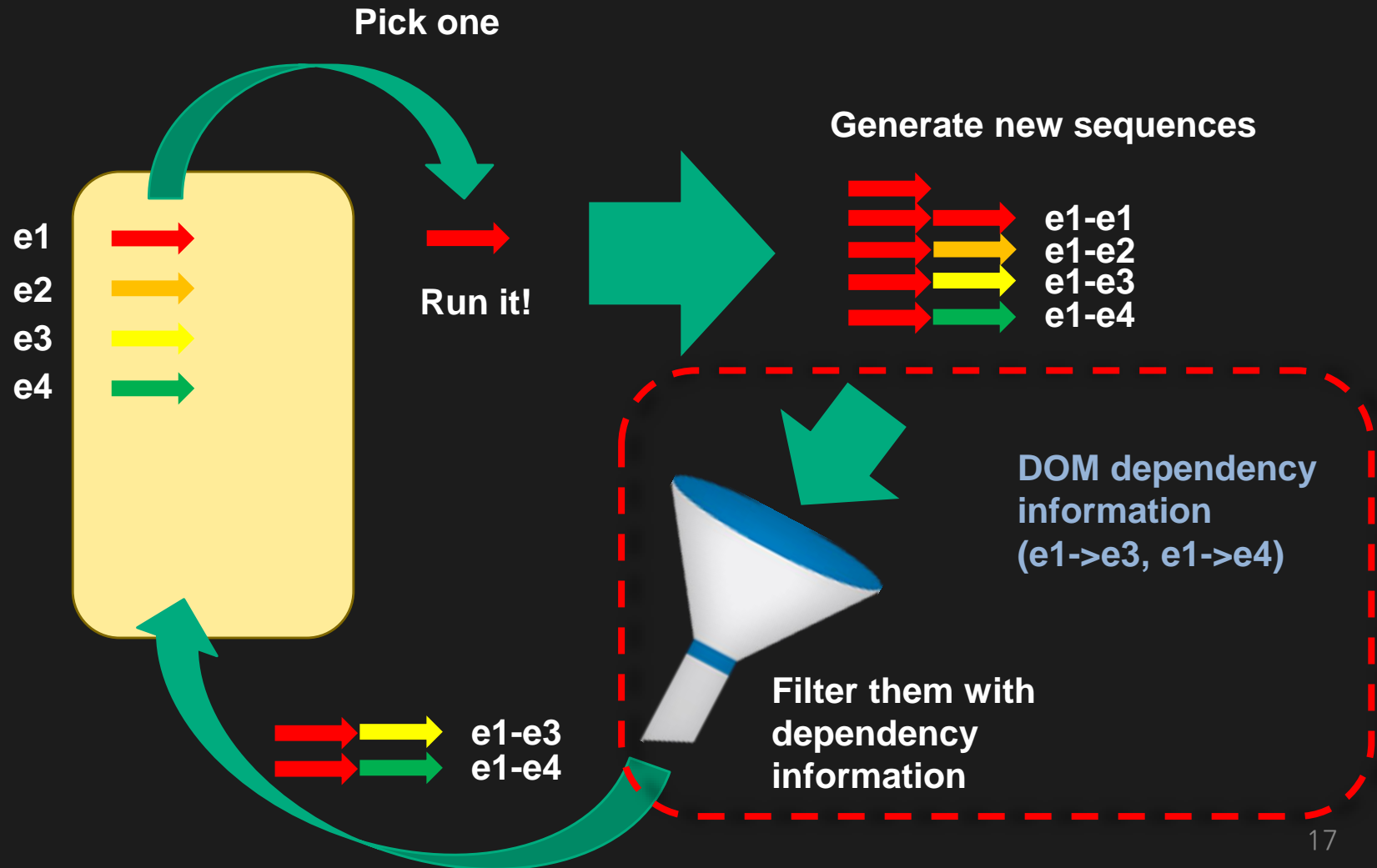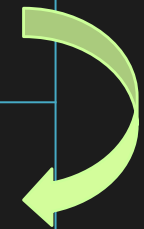
Experimental Results 1

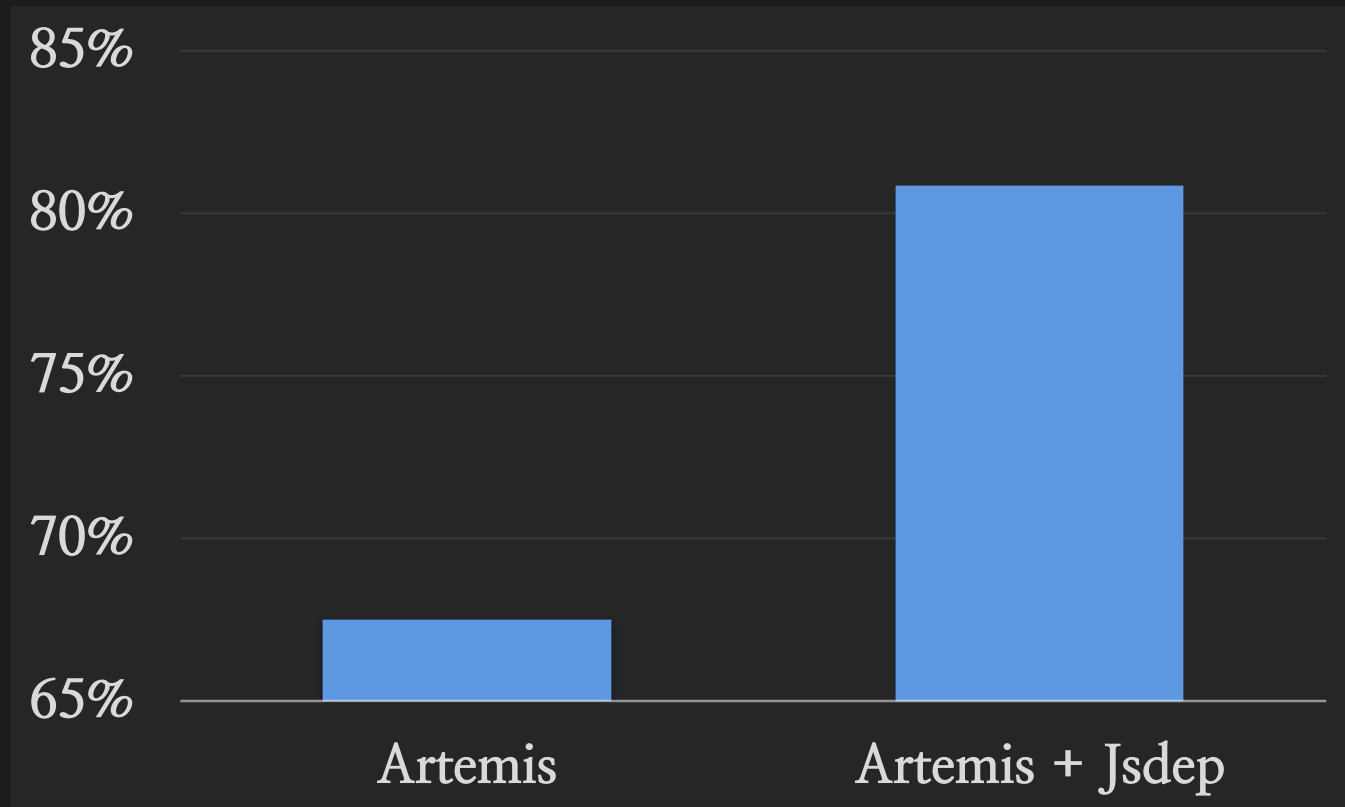| Summary	
Num. of Benchmarks	21
Total LOC	18,599 lines
Maximum Deps.	3,898
Calculated Deps.	2,120
Constraints	50,246
Analysis time	*50.11 s*

↓*46%*

Experimental Results 2
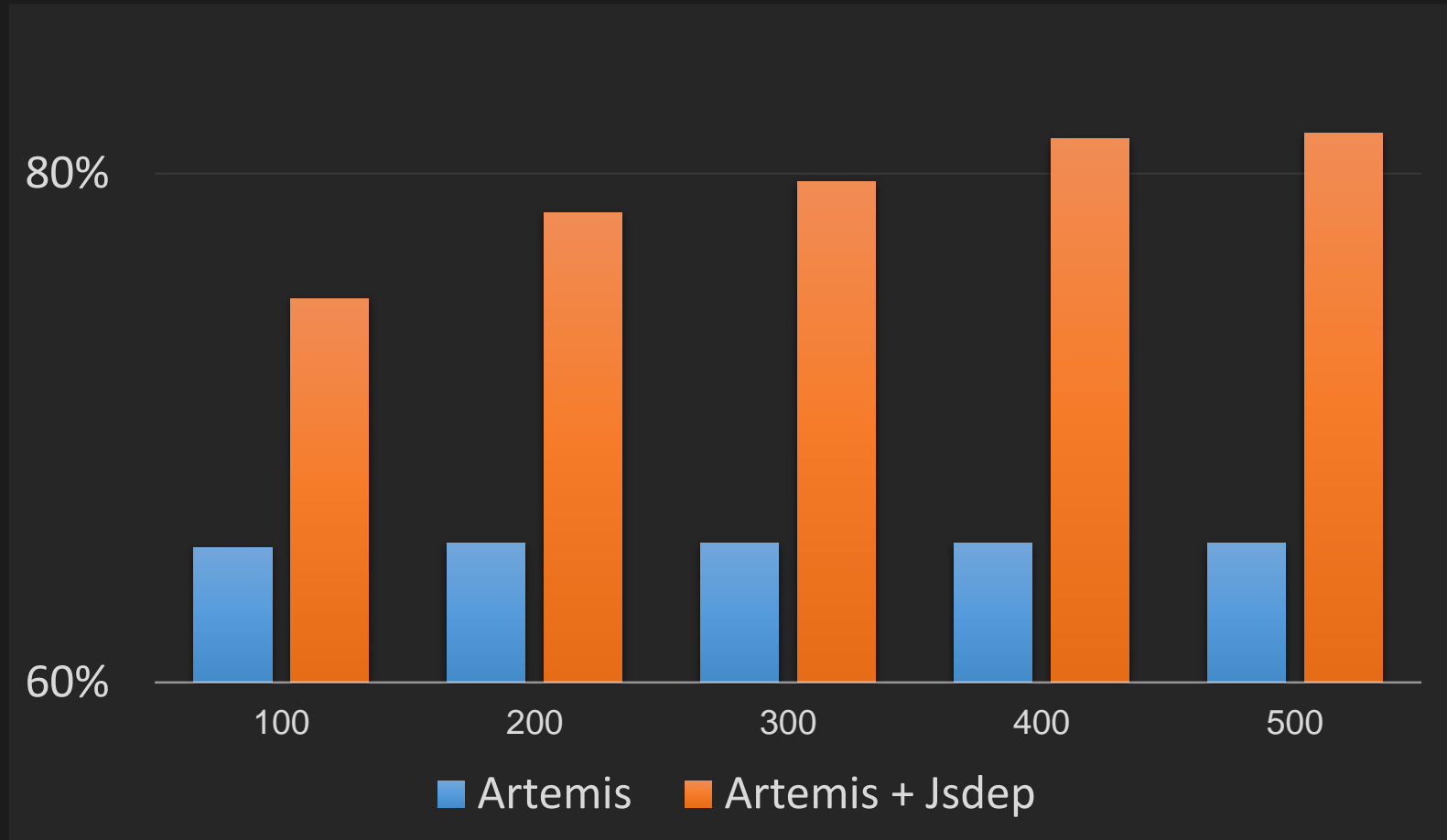
branch coverage w.r.t. the number of iterations

Experimental Results 3

branch coverage after testing for 10 mins

Conclusion

Proposed a static analysis method for computing "DOM-event dependency"

Leveraged results of the static analysis to improve Artemis (web testing tool)

Demonstrated the significant performance improvements

Thank you!

✓ Artifact evaluated by FSE

https://github.com/sch8906