JEST: N+1-version Differential Testing of Both JavaScript Engines and Specification

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PLRG @ KAIST

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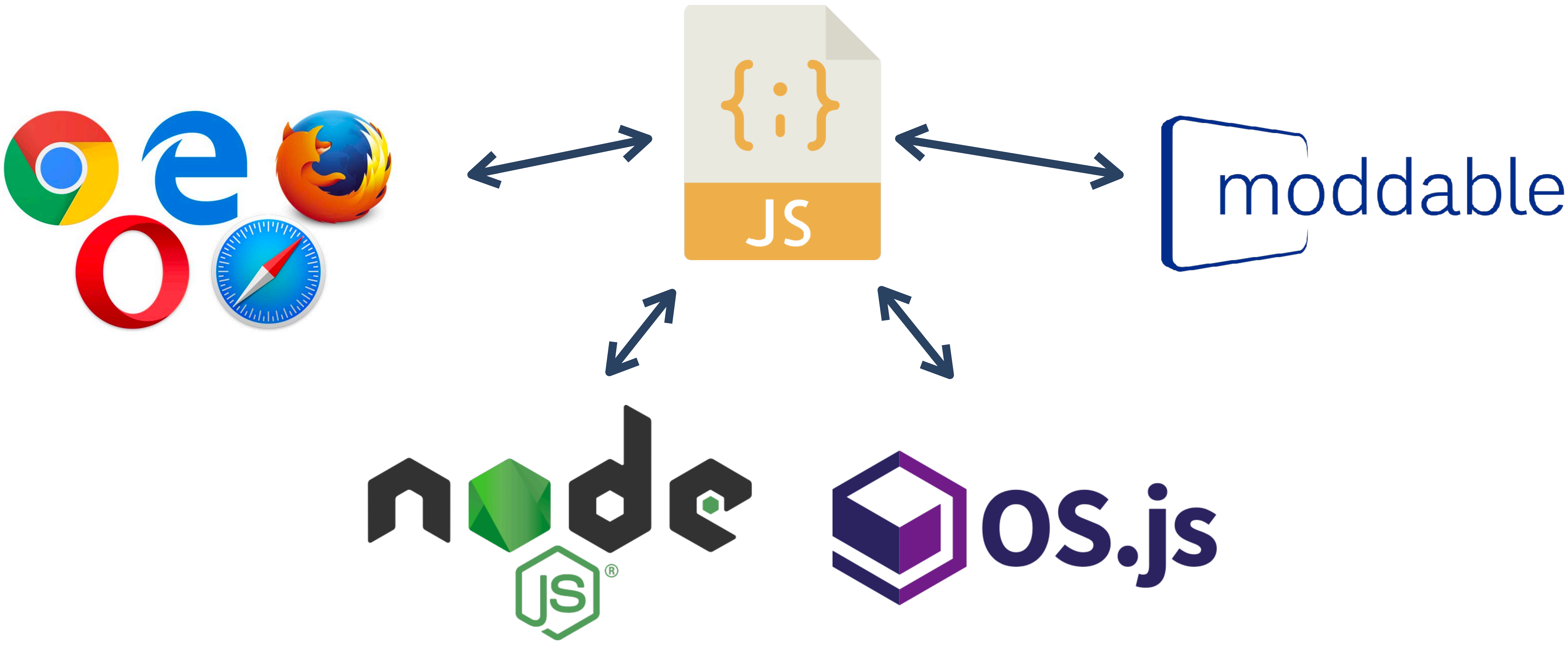
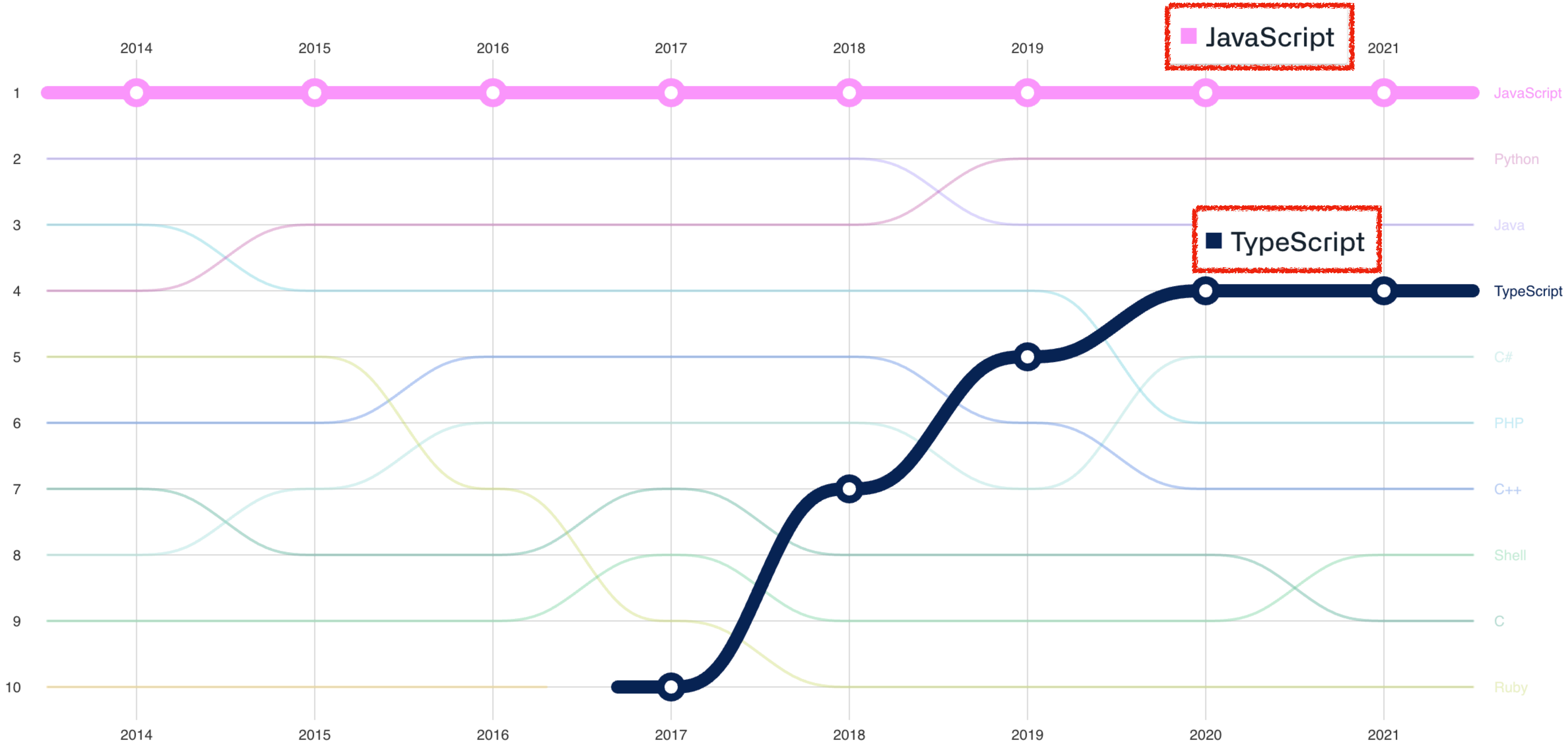
December 21, 2021

JavaScript is Everywhere





https://octoverse.github.com/

JavaScript Complex Semantics

```
function f(x) { return x == !x; }
```

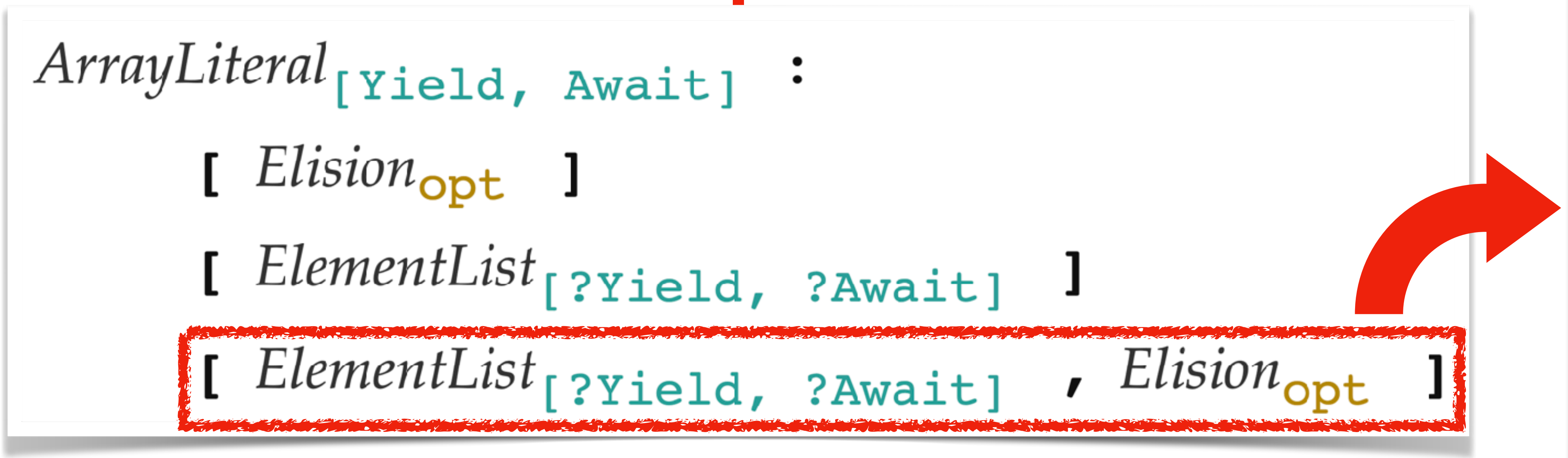
Always return `false`?

NO!!

```
f([]) -> [] == ![]
      -> [] == false
      -> +[] == +false
      -> 0 == 0
      -> true
```

ECMAScript: JavaScript Specification

Syntax



ArrayLiteral$_{\texttt{[Yield, Await]}}$:

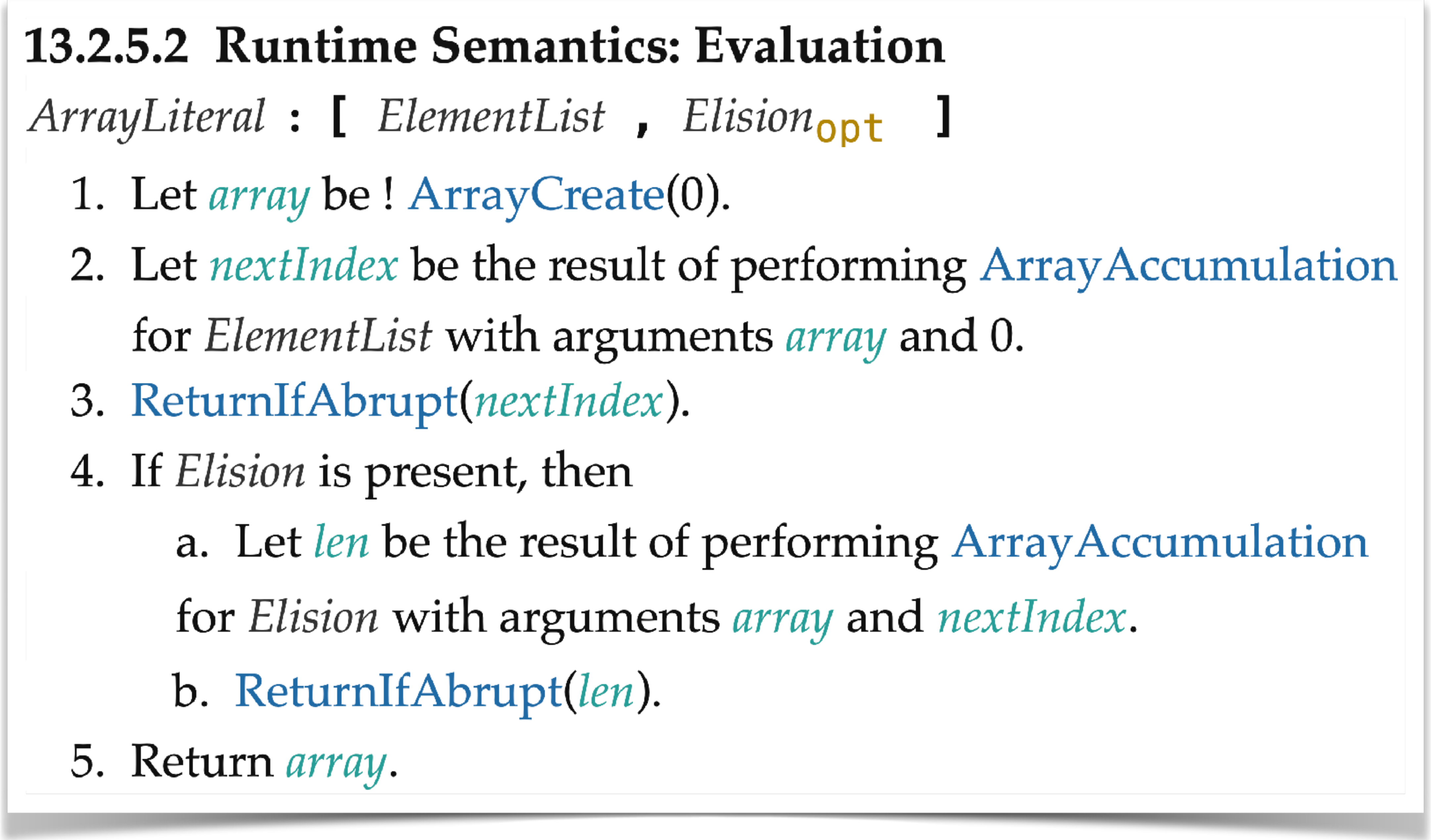
[*Elision*$_{\texttt{opt}}$]

[*ElementList*$_{\texttt{[?Yield, ?Await]}}$]

[*ElementList*$_{\texttt{[?Yield, ?Await]}}$, *Elision*$_{\texttt{opt}}$]

The production of *ArrayLiteral* in ES12

Semantics



13.2.5.2 Runtime Semantics: Evaluation

ArrayLiteral : [*ElementList* , *Elision*$_{\texttt{opt}}$]

```
1. Let array be ! ArrayCreate(0).
2. Let nextIndex be the result of performing ArrayAccumulation for ElementList with arguments array and 0.
3. ReturnIfAbrupt(nextIndex).
4. If Elision is present, then
    a. Let len be the result of performing ArrayAccumulation for Elision with arguments array and nextIndex.
    b. ReturnIfAbrupt(len).
5. Return array.
```

The Evaluation algorithm for
the third alternative of *ArrayLiteral* in ES12

JavaScript Specification and Engines

ecma INTERNATIONAL

Standard ECMA-262

11th Edition / June 2020

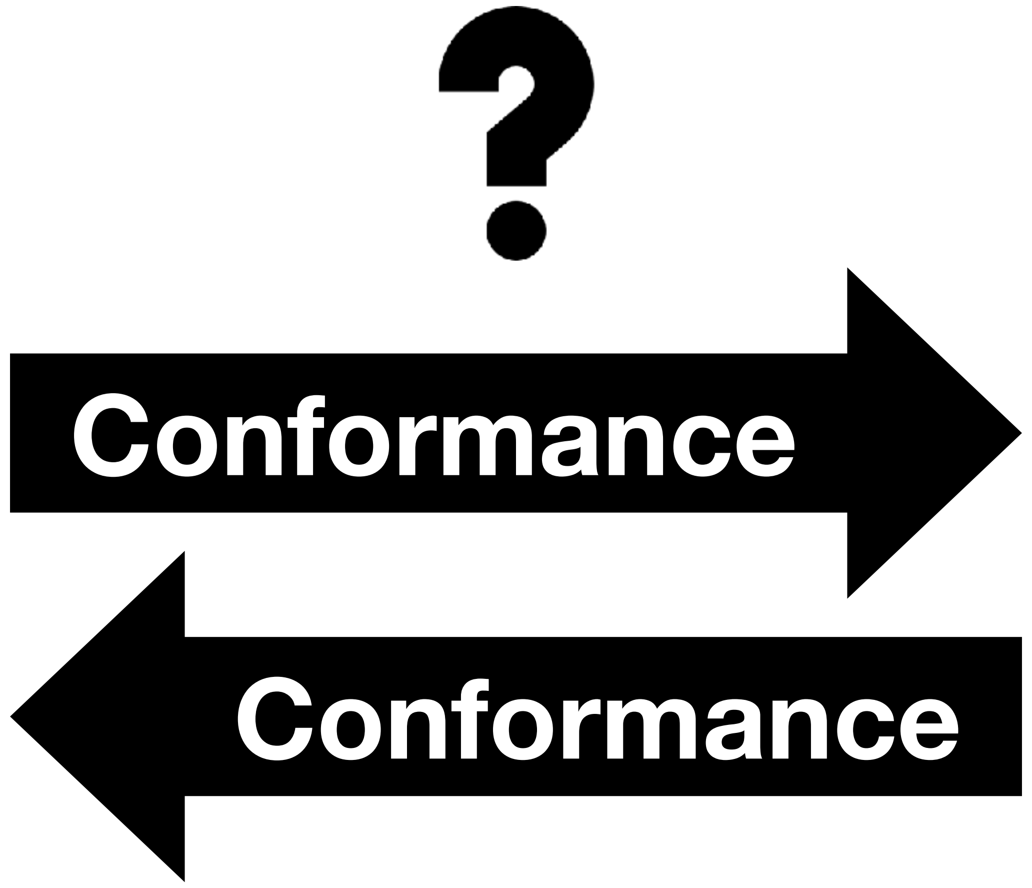
ECMAScript® 2020
Language Specification

Standard

Rue du Rhône 114 CH-1204 Geneva T: +41 22 849 6000 F: +41 22 849 6001

ECMAScript

TC 39



?

Conformance

Conformance

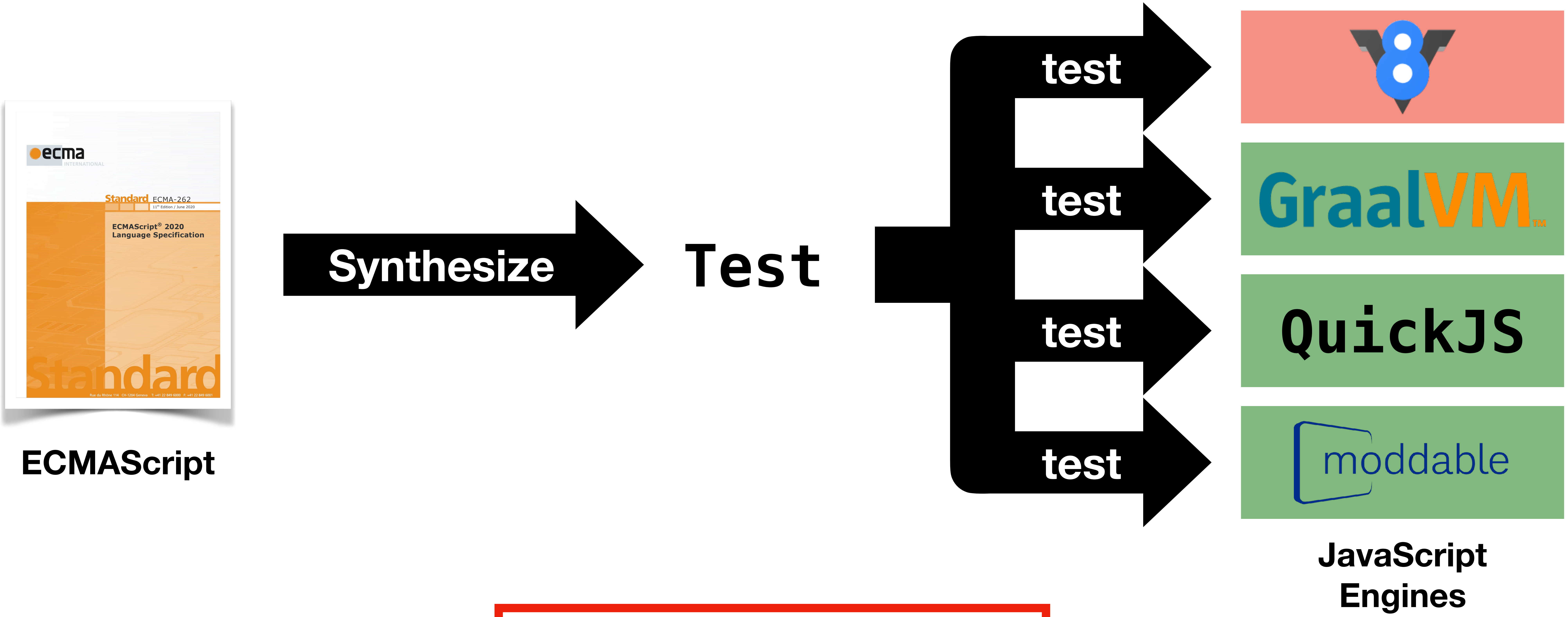
GraalVM™

QuickJS

moddable

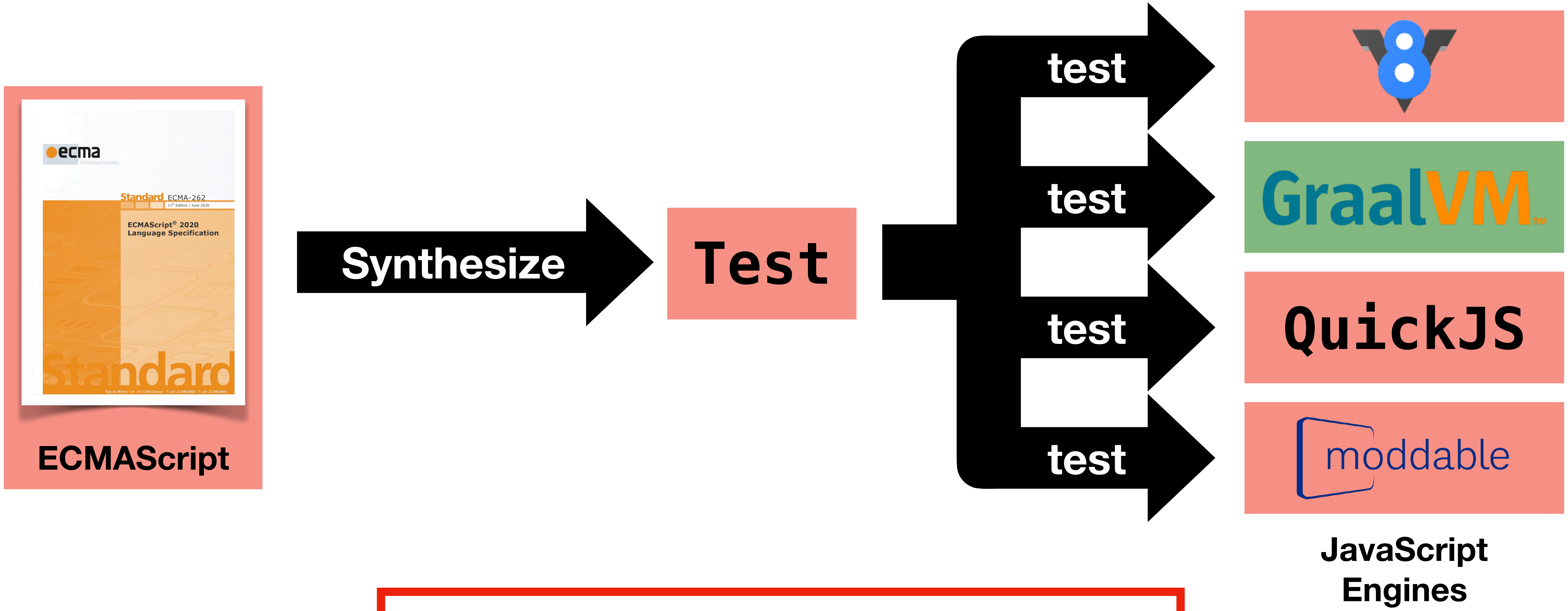
JavaScript Engines

Our Idea: N+1-version Differential Testing



An engine bug in V8

Our Idea: N+1-version Differential Testing

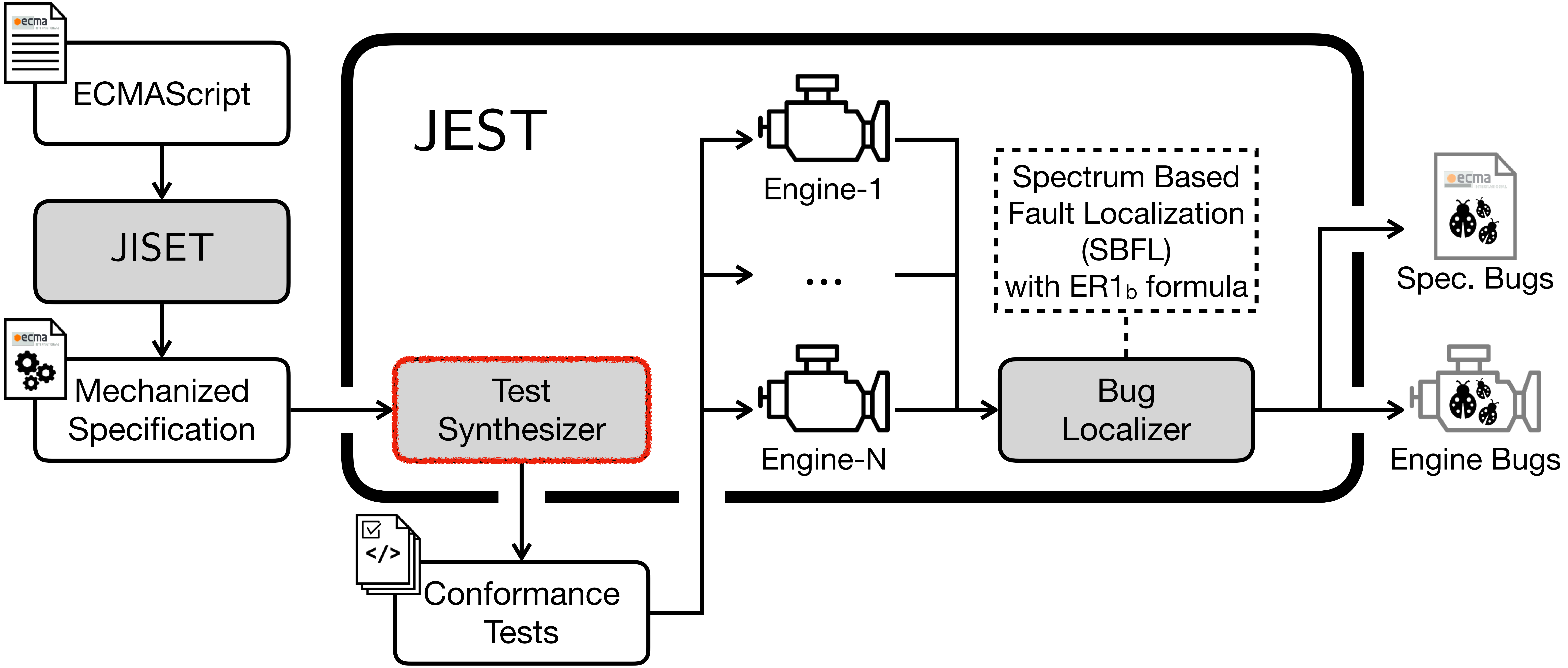


A specification bug in ECMAScript

An engine bug in GraalVM

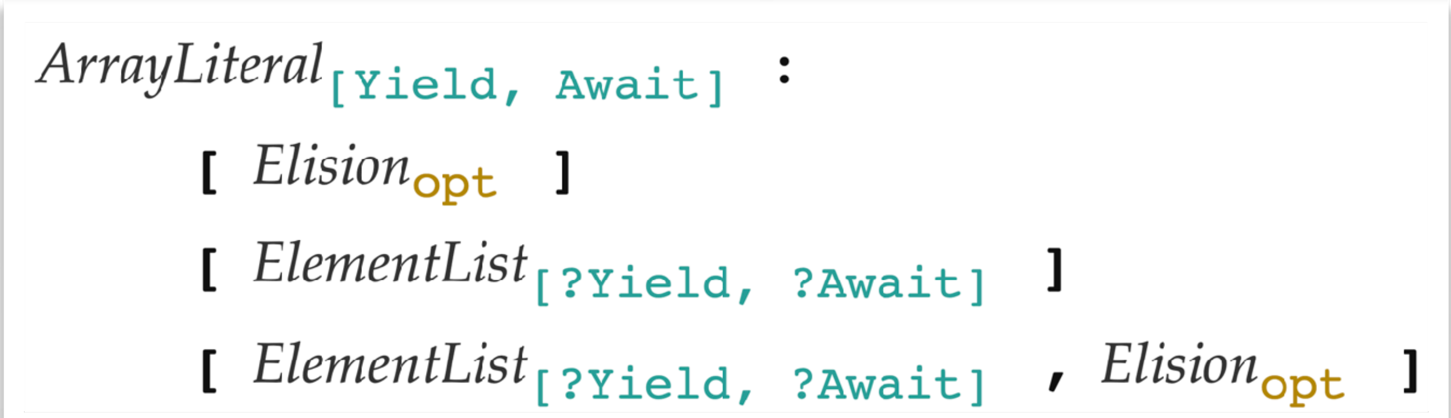
JEST

JavaScript Engines and Specification Tester



[ASE'20] Park et al, “JISET: Javascript IR-based Semantics Extraction Toolchain”

JEST - Test Synthesizer



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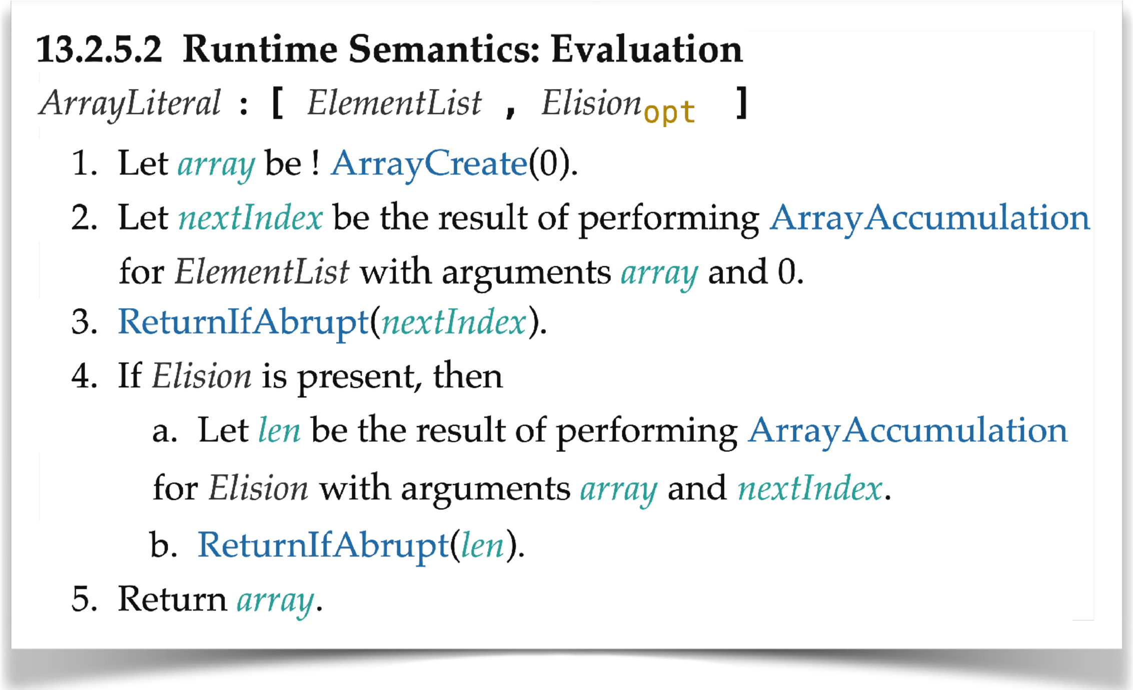
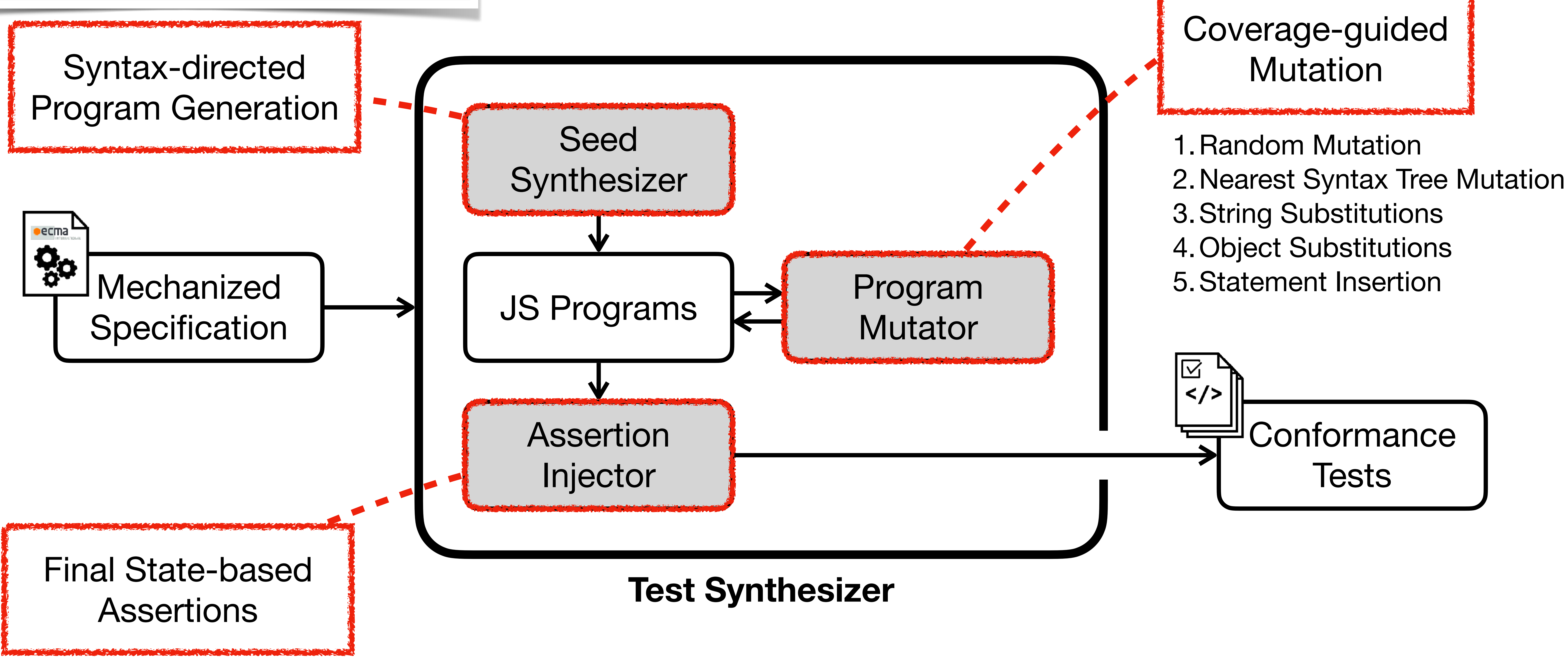


13.2.5.2 Runtime Semantics: Evaluation

ArrayLiteral : [*ElementList* , *Elision*$_{\texttt{opt}}$]

1. Let *array* be ! ArrayCreate(0).
2. Let *nextIndex* be the result of performing ArrayAccumulation for *ElementList* with arguments *array* and 0.
3. ReturnIfAbrupt(*nextIndex*).
4. If *Elision* is present, then
   a. Let *len* be the result of performing ArrayAccumulation for *Elision* with arguments *array* and *nextIndex*.
   b. ReturnIfAbrupt(*len*).
5. Return *array*.



Syntax-directed Program Generation

Coverage-guided Mutation

1. Random Mutation
2. Nearest Syntax Tree Mutation
3. String Substitutions
4. Object Substitutions
5. Statement Insertion

Seed Synthesizer

Mechanized Specification

JS Programs

Program Mutator

Assertion Injector

Conformance Tests

Final State-based Assertions

Test Synthesizer

JEST - Assertion Injector (7 Kinds)

1. **Exceptions (`Exc`)**

```
+ // Throw
  let x = 42;
  function x() {};
```

2. **Aborts (`Abort`)**

```
+ // Abort
  var x = 42; x++;
```

3. **Variable Values (`Var`)**

```
  var x = 1 + 2;
+ $assert.sameValue(x, 3);
```

4. **Object Values (`Obj`)**

```
  var x = {}, y = {}, z = { p: x, q: y };
+ $assert.sameValue(z.p, x);
+ $assert.sameValue(z.q, y);
```

JEST - Assertion Injector (7 Kinds)

1. **Object Properties (**`Desc`**)**

```
  var x = { p: 42 };
+ $verifyProperty(x, "p", {
+   value: 42.0, writable: true,
+   enumerable: true, configurable: true
+ });
```

2. **Property Keys (**`Key`**)**

```
  var x = {[Symbol.match]: 0, p: 0, 3: 0, q: 0, 1: 0}
+ $assert.compareArray(
+   Reflect.ownKeys(x),
+   ["1", "3", "p", "q", Symbol.match]
+ );
```

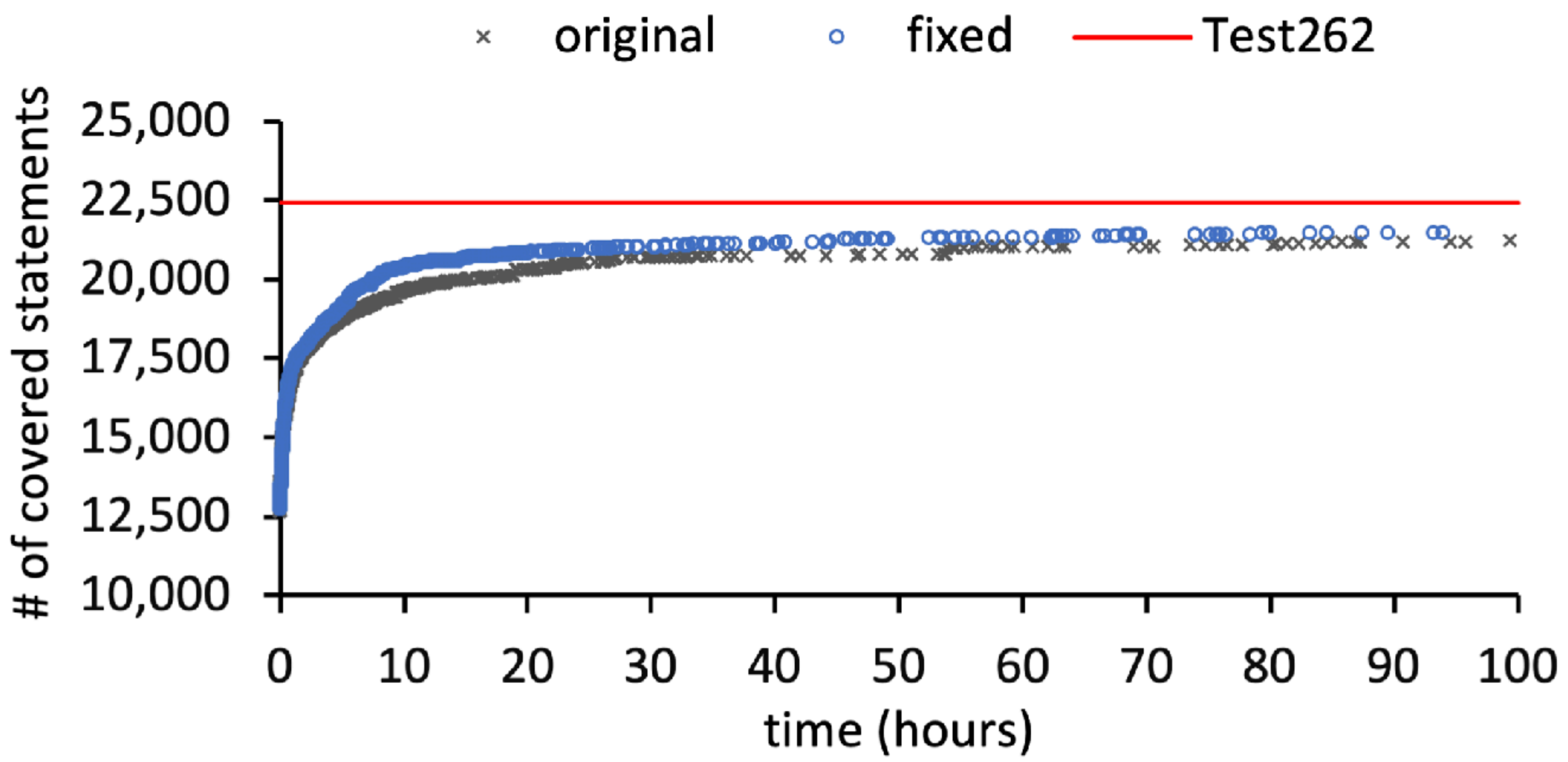
3. **Internal Methods and Slots (**`In`**)**

```
  function f() {}
+ $assert.sameValue(Object.getPrototypeOf(f),
+                   Function.prototype);
+ $assert.sameValue(Object.isExtensible(x), true);
+ $assert.callable(f);
+ $assert.constructable(f);
```

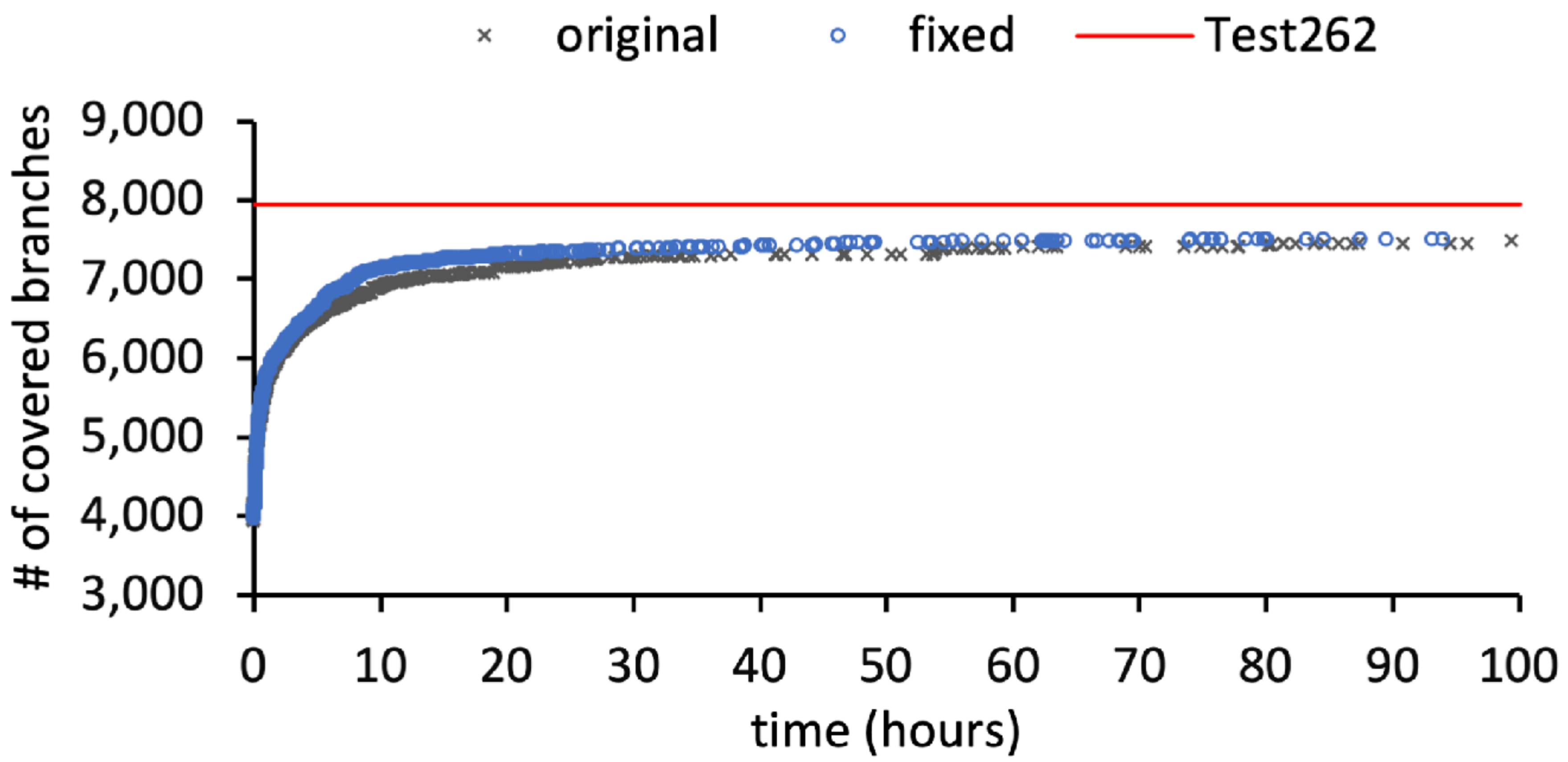
Evaluation

- **JavaScript Specification**
  - ECMAScript 2020 (ES11) - released in June 2020
- **JavaScript Engines**
  - **V8** - v8.3 by Google
  - **GraalJS** - v20.1.0 by Oracle
  - **QuickJS** - 2020-04-12 by Fabrice Bellard
  - **Moddable XS** - v10.3.0 by Moddable Tech Inc.

RQ1: Coverage of Synthesized Tests



(a) Statement coverage

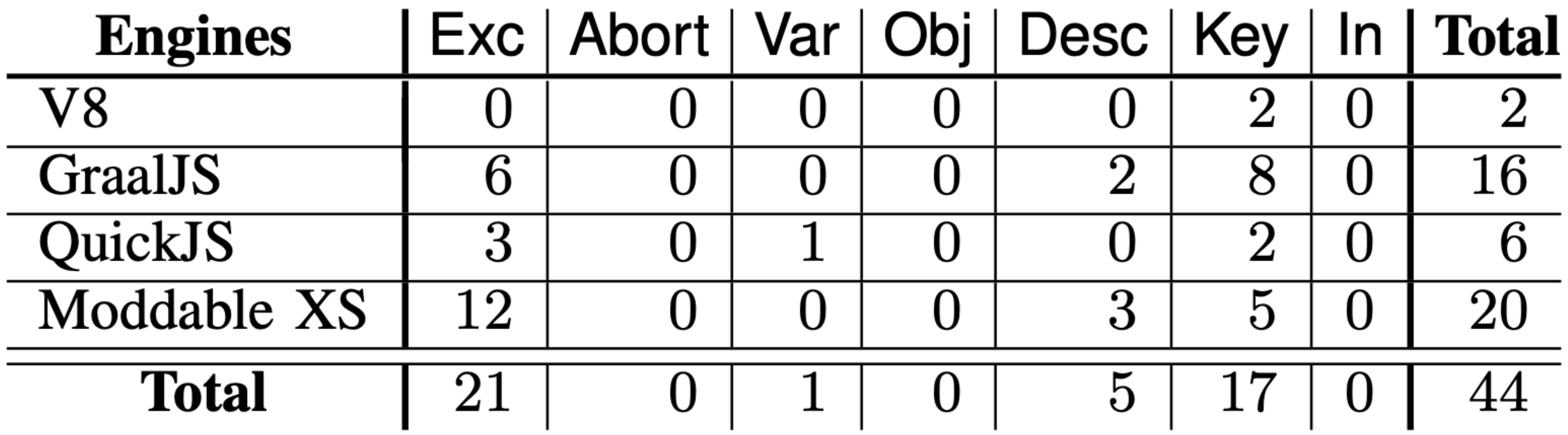


(b) Branch coverage

- 1,700 **Synthesized Tests in** 100 hours
- **Syntax Coverage:** 97.79% (397 / 406)
- **Semantics Coverage**
  - Statement: 86.67% (21,230 / 24,495)
  - Branch: 77.95% (7,480 / 9,596)

RQ2: Bug Detection in JavaScript Engines

TABLE II: The number of engine bugs detected by JEST



Engines	Exc	Abort	Var	Obj	Desc	Key	In	Total
V8	0	0	0	0	0	2	0	2
GraalJS	6	0	0	0	2	8	0	16
QuickJS	3	0	1	0	0	2	0	6
Moddable XS	12	0	0	0	3	5	0	20
Total	21	0	1	0	5	17	0	44

44 Bugs
in Engines

```
function f (... { x = x }) { return x; } var y = f();
```

QuickJS initializes 'x' with 'undefined' instead of throwing a 'ReferenceError'

```
try { ++undefined; } catch(e) { }
```

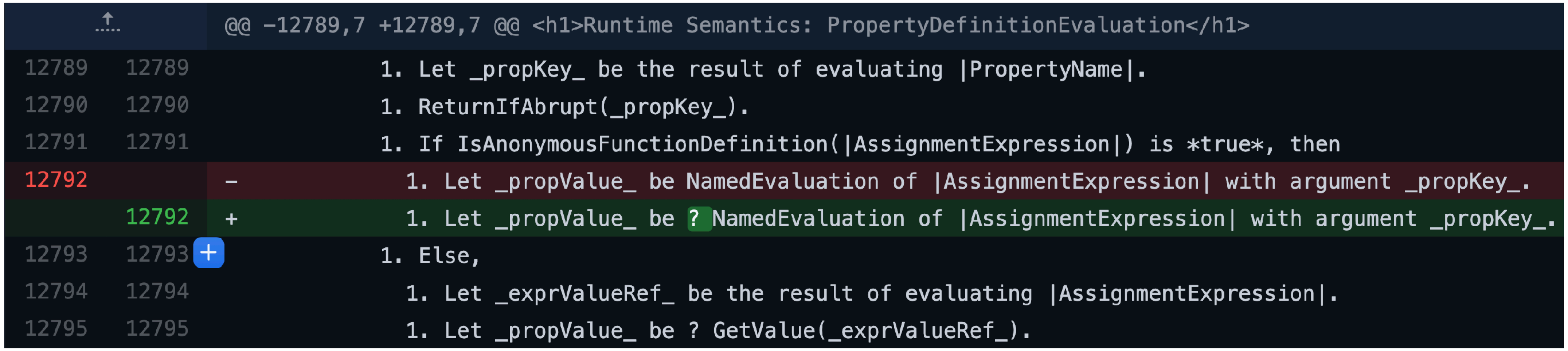
GraalJS crashes with an exception 'java.lang.IllegalStateException'

RQ3: Bug Detection in ECMAScript

27 Bugs in Spec.

TABLE III: Specification bugs in ECMAScript 2020 (ES11) detected by JEST

Name	Feature	#	Assertion	Known	Created	Resolved	Existed
ES11-1	Function	12	Key	O	2019-02-07	2020-04-11	429 days
ES11-2	Function	8	Key	O	2015-06-01	2020-04-11	1,776 days
ES11-3	Loop	1	Exc	O	2017-10-17	2020-04-30	926 days
ES11-4	Expression	4	Abort	O	2019-09-27	2020-04-23	209 days
ES11-5	Expression	1	Exc	O	2015-06-01	2020-04-28	1,793 days
ES11-6	Object	1	Exc	X	2019-02-07	2020-11-05	637 days



```
@@ -12789,7 +12789,7 @@ <h1>Runtime Semantics: PropertyDefinitionEvaluation</h1>
        1. Let _propKey_ be the result of evaluating |PropertyName|.
        1. ReturnIfAbrupt(_propKey_).
        1. If IsAnonymousFunctionDefinition(|AssignmentExpression|) is *true*, then
-         1. Let _propValue_ be NamedEvaluation of |AssignmentExpression| with argument _propKey_.
+         1. Let _propValue_ be ? NamedEvaluation of |AssignmentExpression| with argument _propKey_.
        1. Else,
          1. Let _exprValueRef_ be the result of evaluating |AssignmentExpression|.
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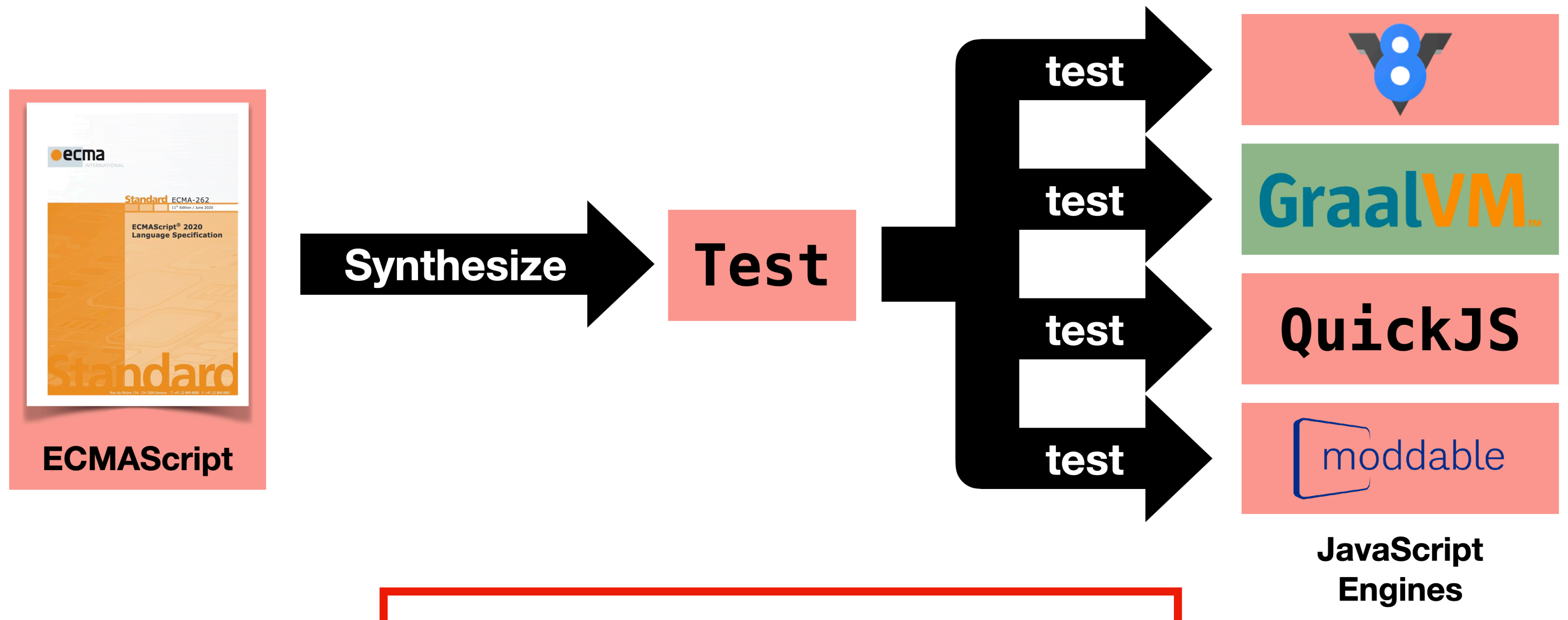
https://github.com/tc39/ecma262/pull/2130/files

Our Idea: N+1-version Differential Testing

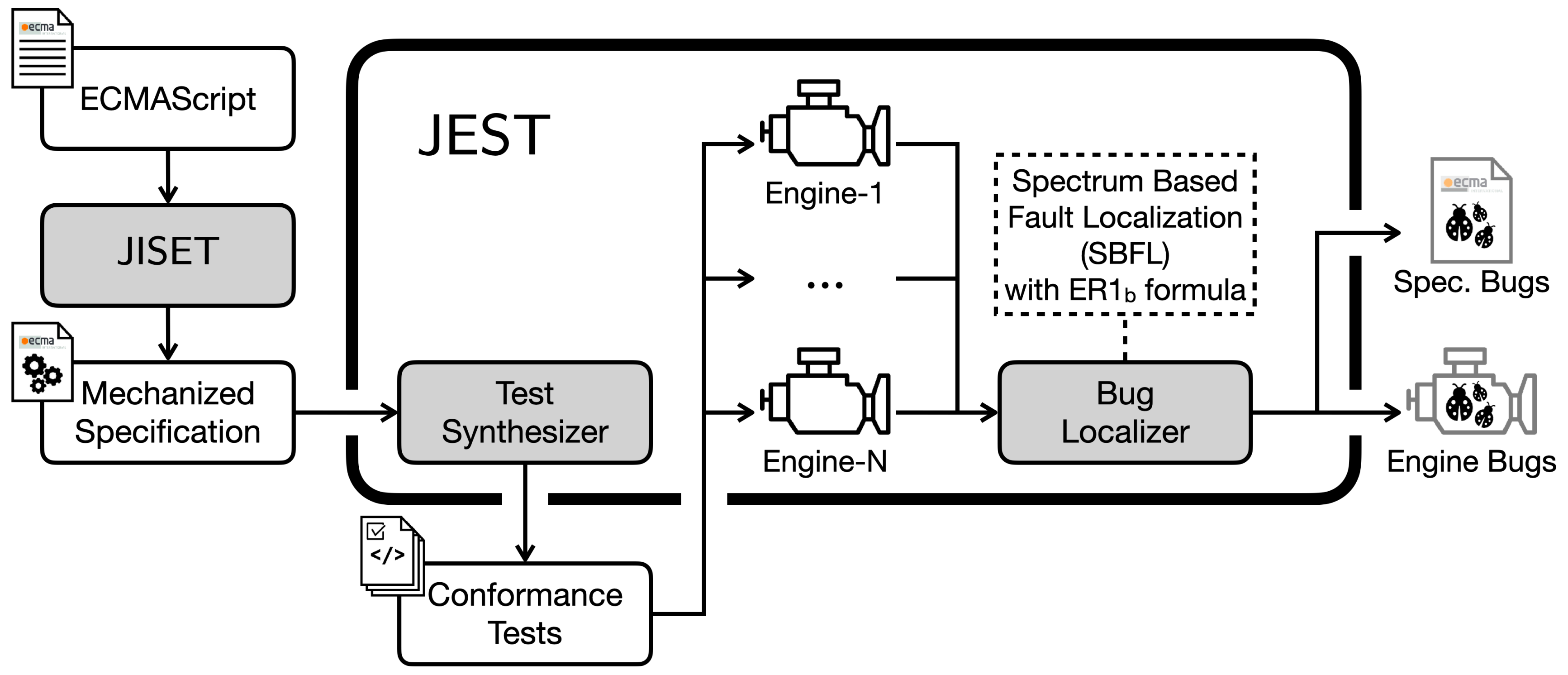


A **specification** bug in ECMAScript

An **engine** bug in GraalVM

JEST

JavaScript **E**ngines and **S**pecification **T**ester



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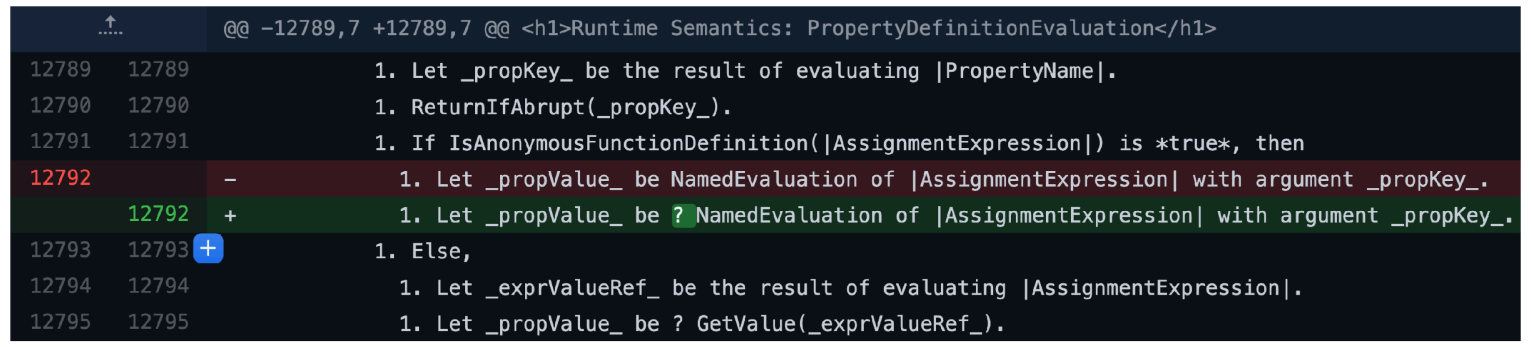

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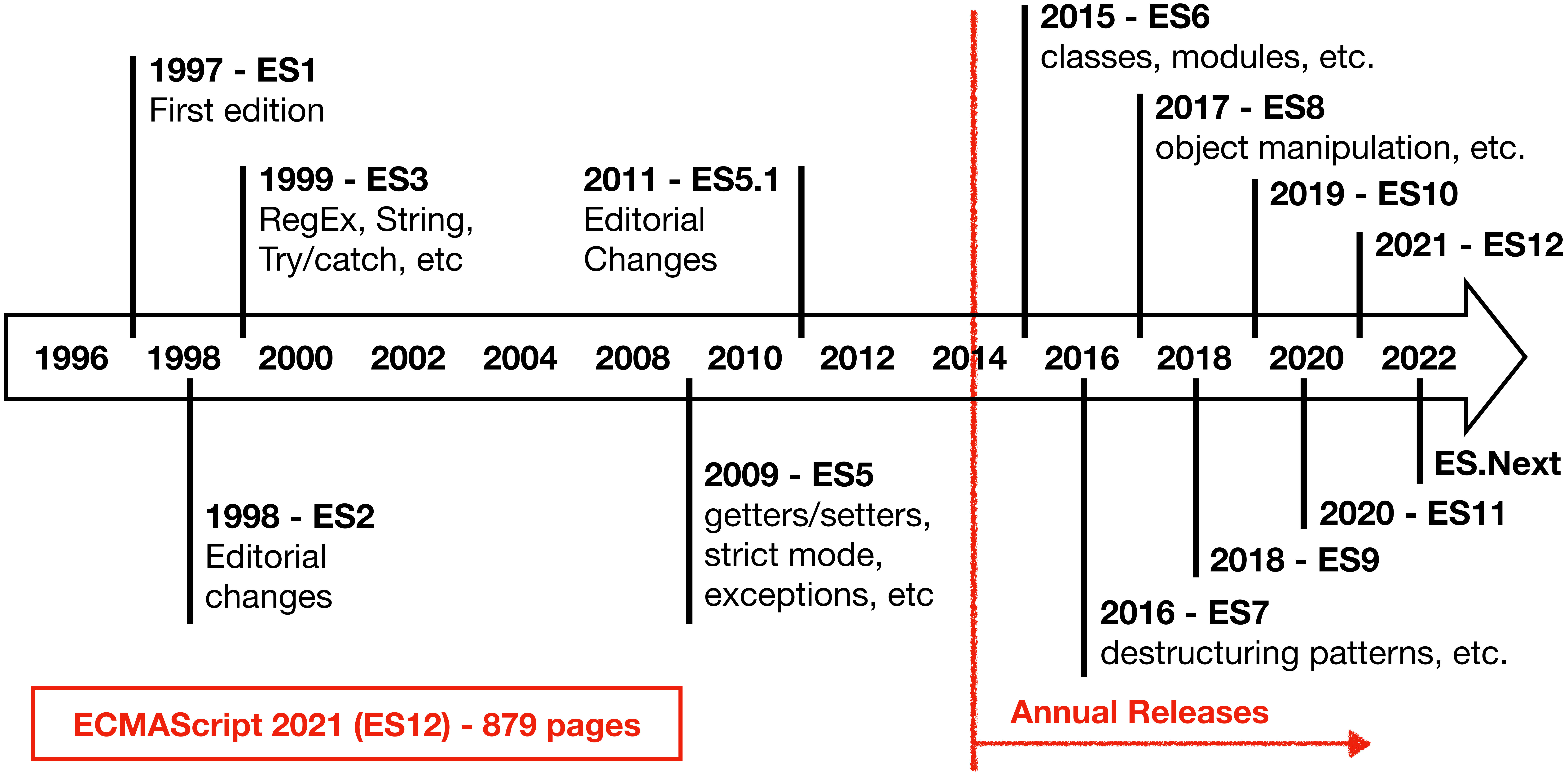
https://github.com/tc39/ecma262/pull/2130/files

Backup Slides

Problem: Fast Evolving JavaScript



1997 - ES1
First edition

1998 - ES2
Editorial
changes

1999 - ES3
RegEx, String,
Try/catch, etc

2009 - ES5
getters/setters,
strict mode,
exceptions, etc

2011 - ES5.1
Editorial
Changes

2015 - ES6
classes, modules, etc.

2016 - ES7
destructuring patterns, etc.

2017 - ES8
object manipulation, etc.

2018 - ES9

2019 - ES10

2020 - ES11

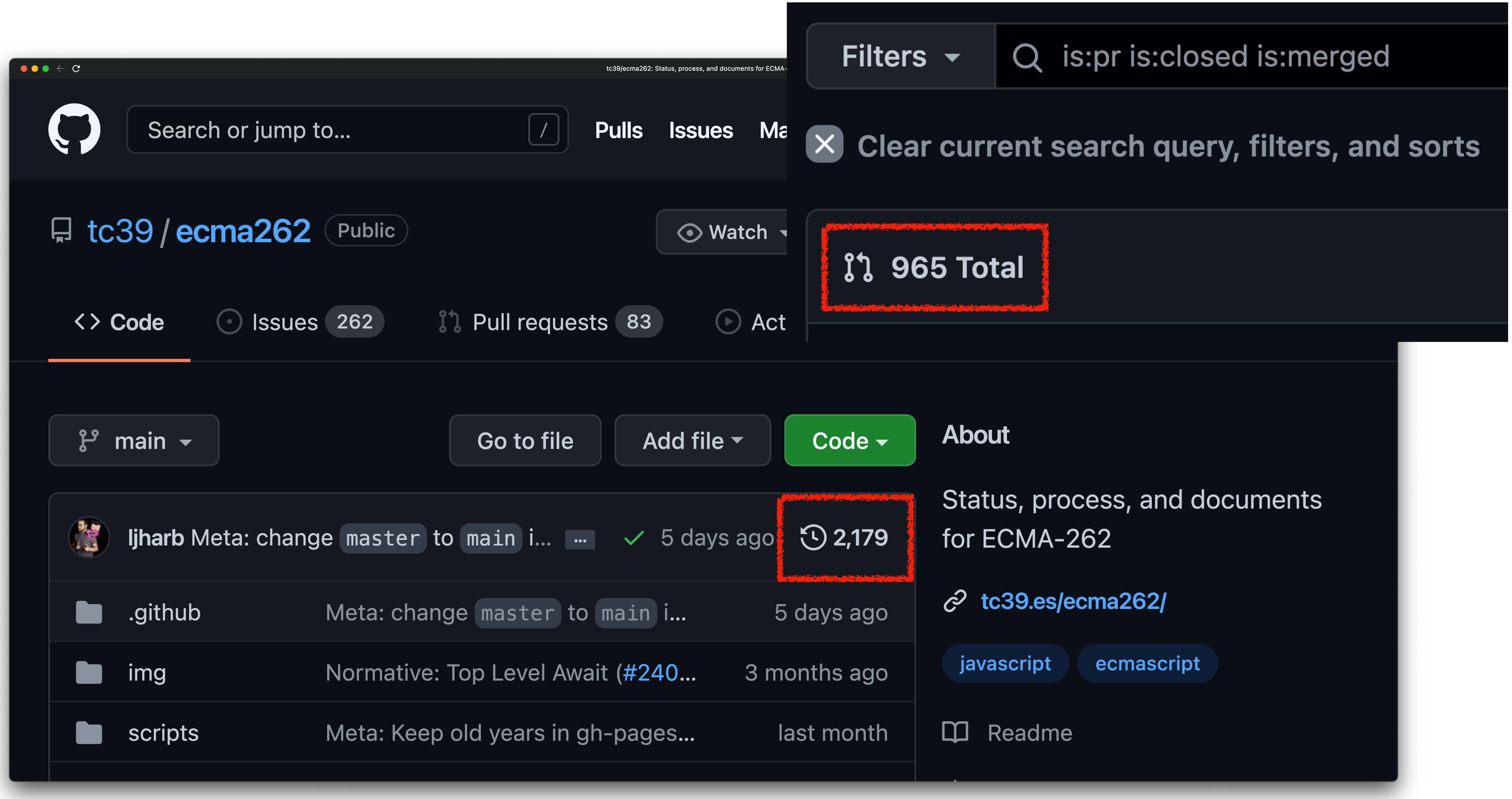
2021 - ES12

ES.Next

Annual Releases

ECMAScript 2021 (ES12) - 879 pages

Problem: Open Development Process



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scripts	Meta: Keep old years in gh-pages...	last month

About

Status, process, and documents for ECMA-262

tc39.es/ecma262/

javascript ecmascript

Readme

RQ4: Accuracy of Bug Localization

- **64 out of 71 bugs are semantics bugs**

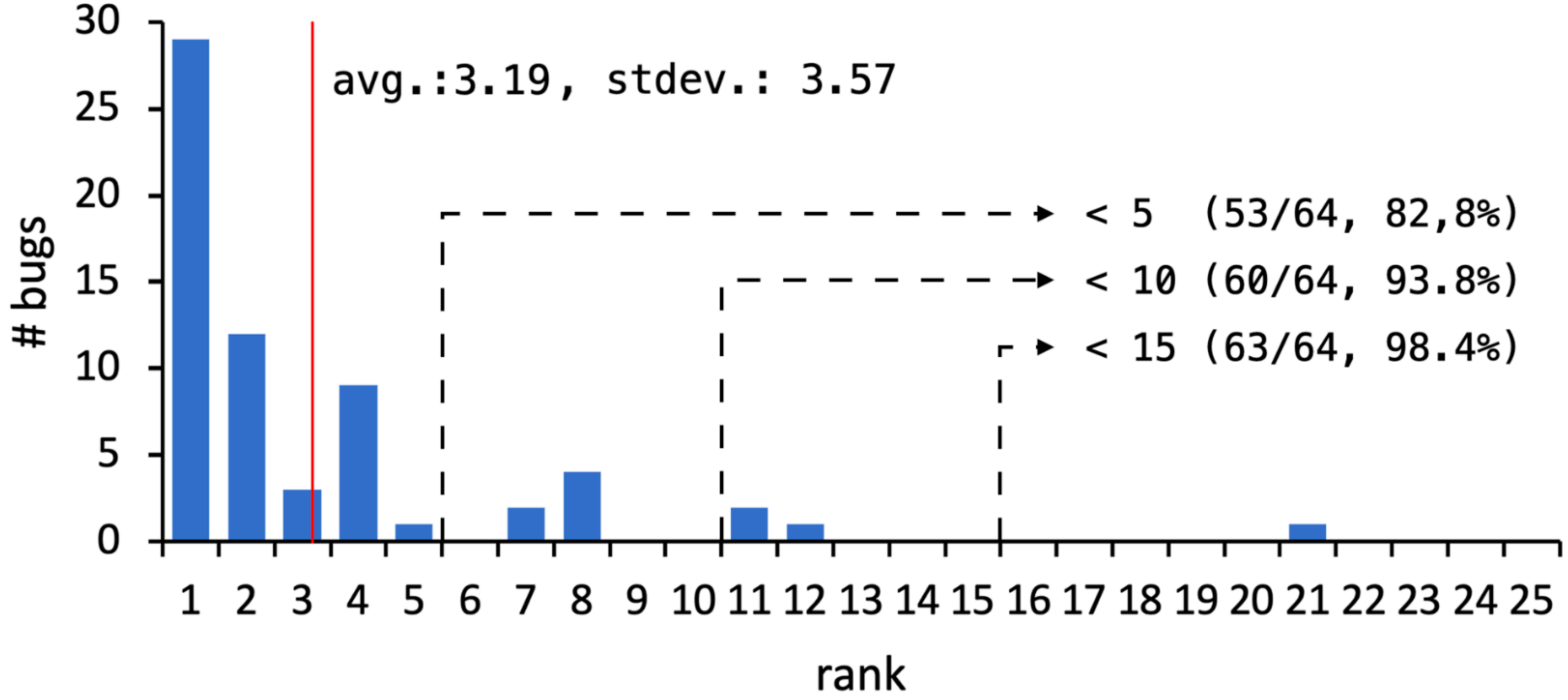

Fig. 5: Ranks of algorithms that caused the bugs detected by JEST