PLRG
Programming Language
Research Group

JSTAR: JavaScript Specification Type Analyzer using Refinement

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PLRG @ KAIST

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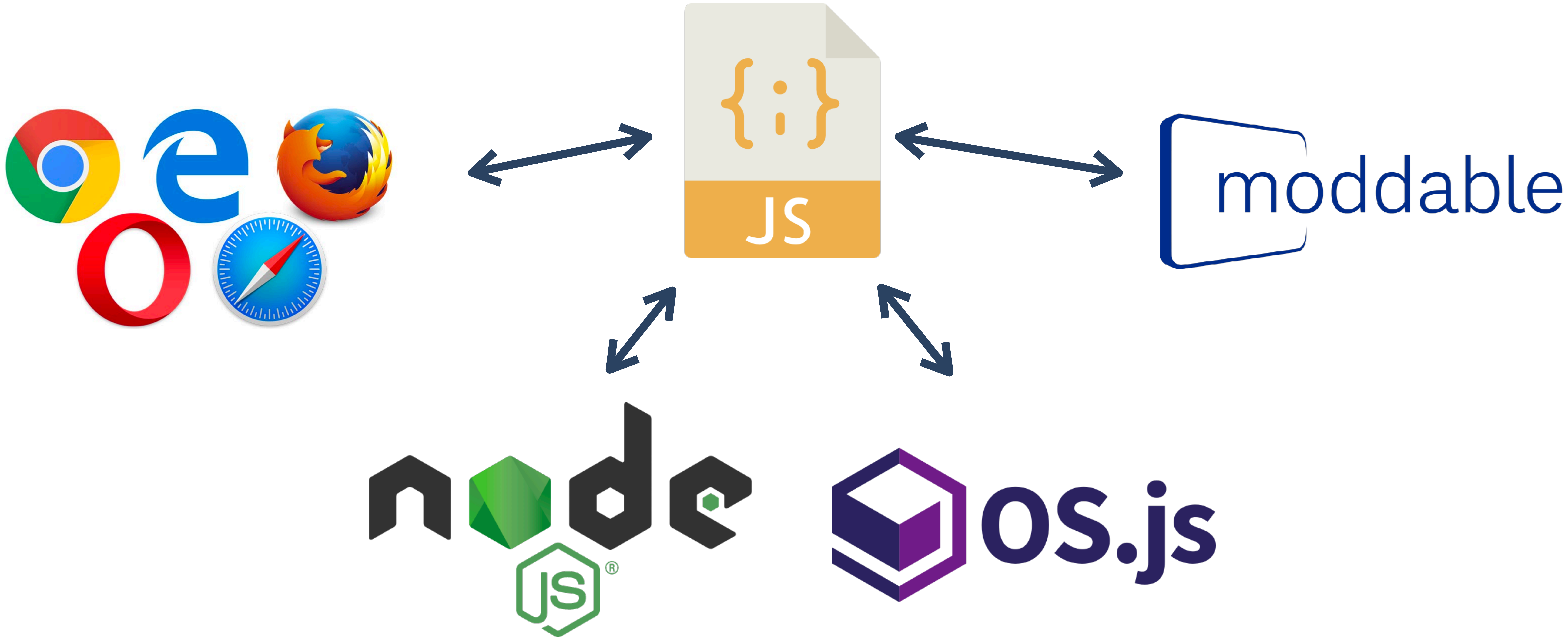
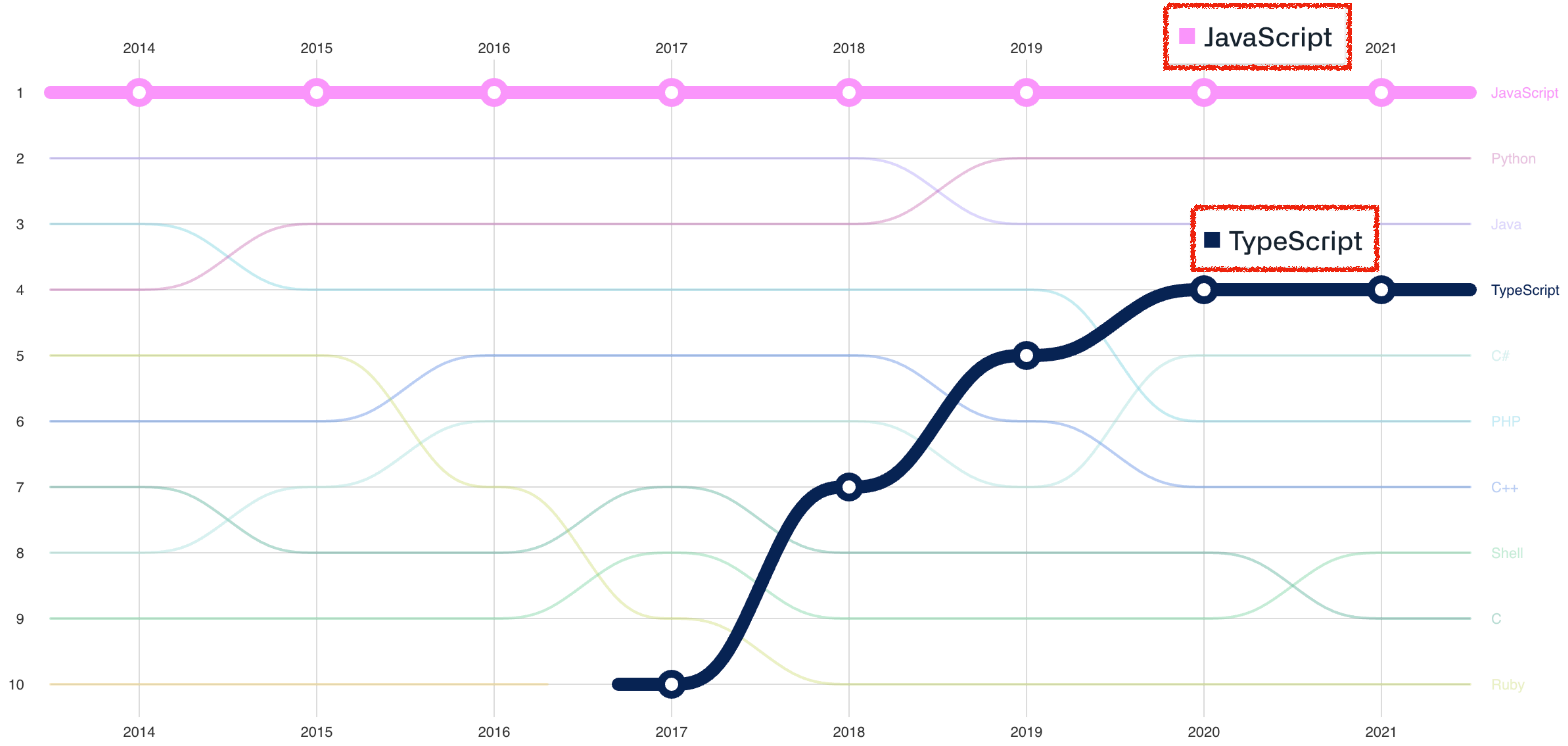
January 20, 2022

JavaScript is Everywhere





https://octoverse.github.com/

JavaScript Complex Semantics

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

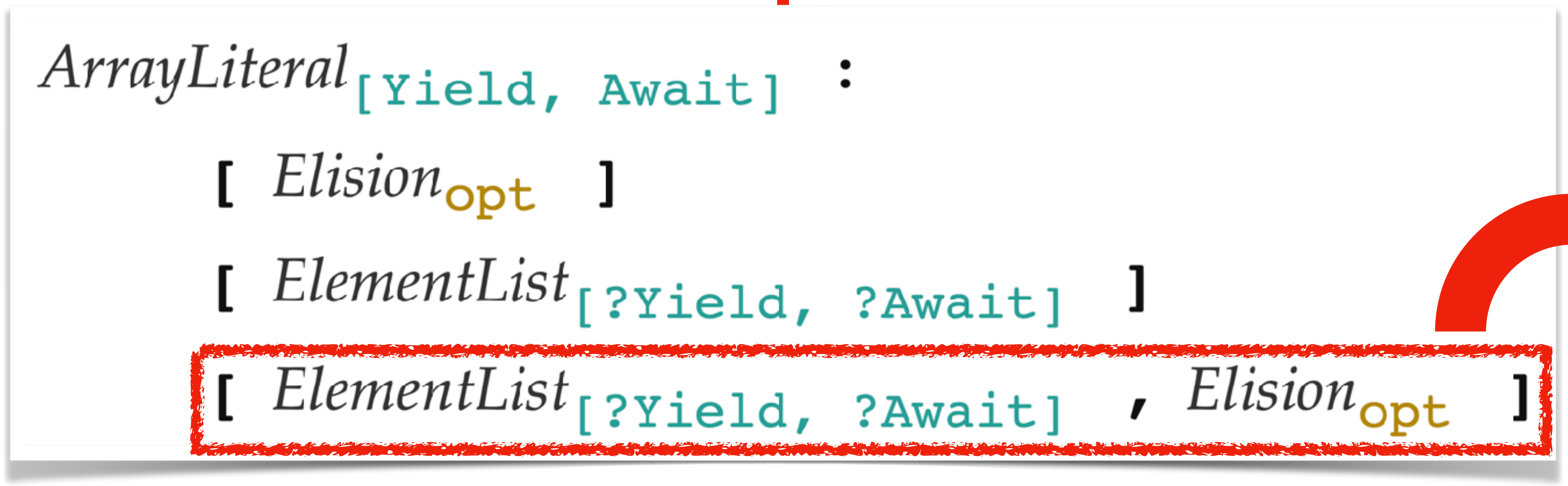
Always return `false`?

NO!!

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

ECMAScript: JavaScript Specification

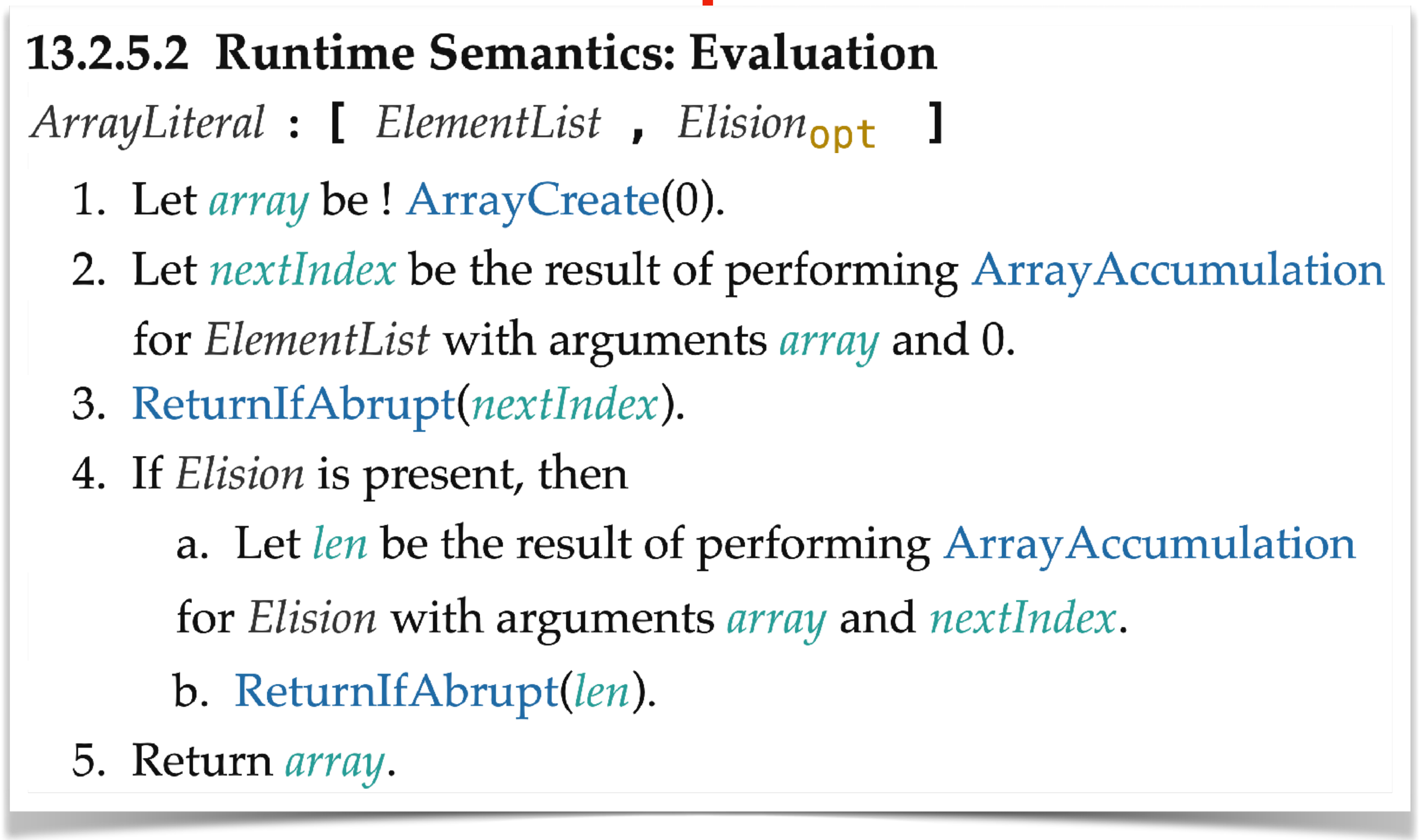
Syntax



```
ArrayLiteral[Yield, Await] :
    [ Elision_opt ]
    [ ElementList[?Yield, ?Await] ]
    [ ElementList[?Yield, ?Await] , Elision_opt ]
```

The production of *ArrayLiteral* in ES12

Semantics

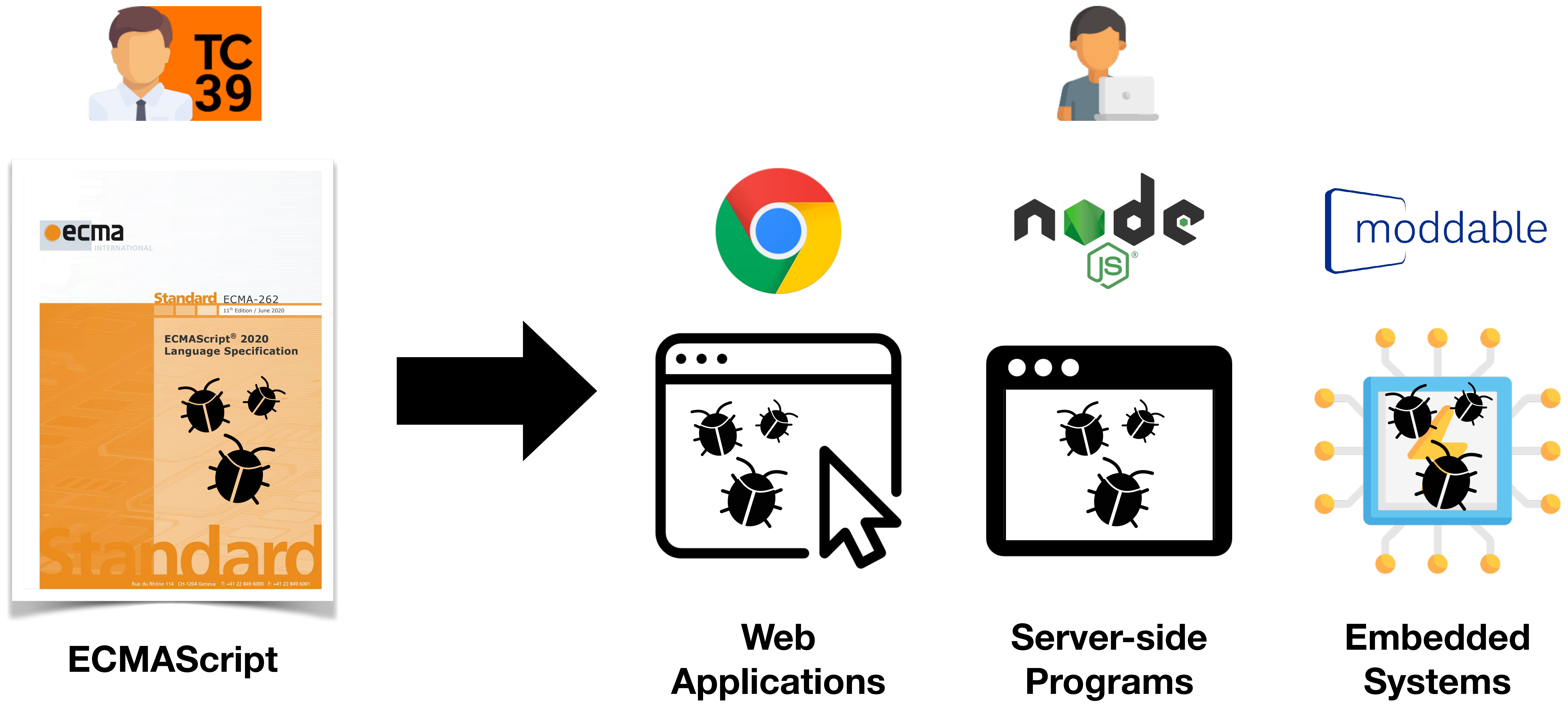


13.2.5.2 Runtime Semantics: Evaluation

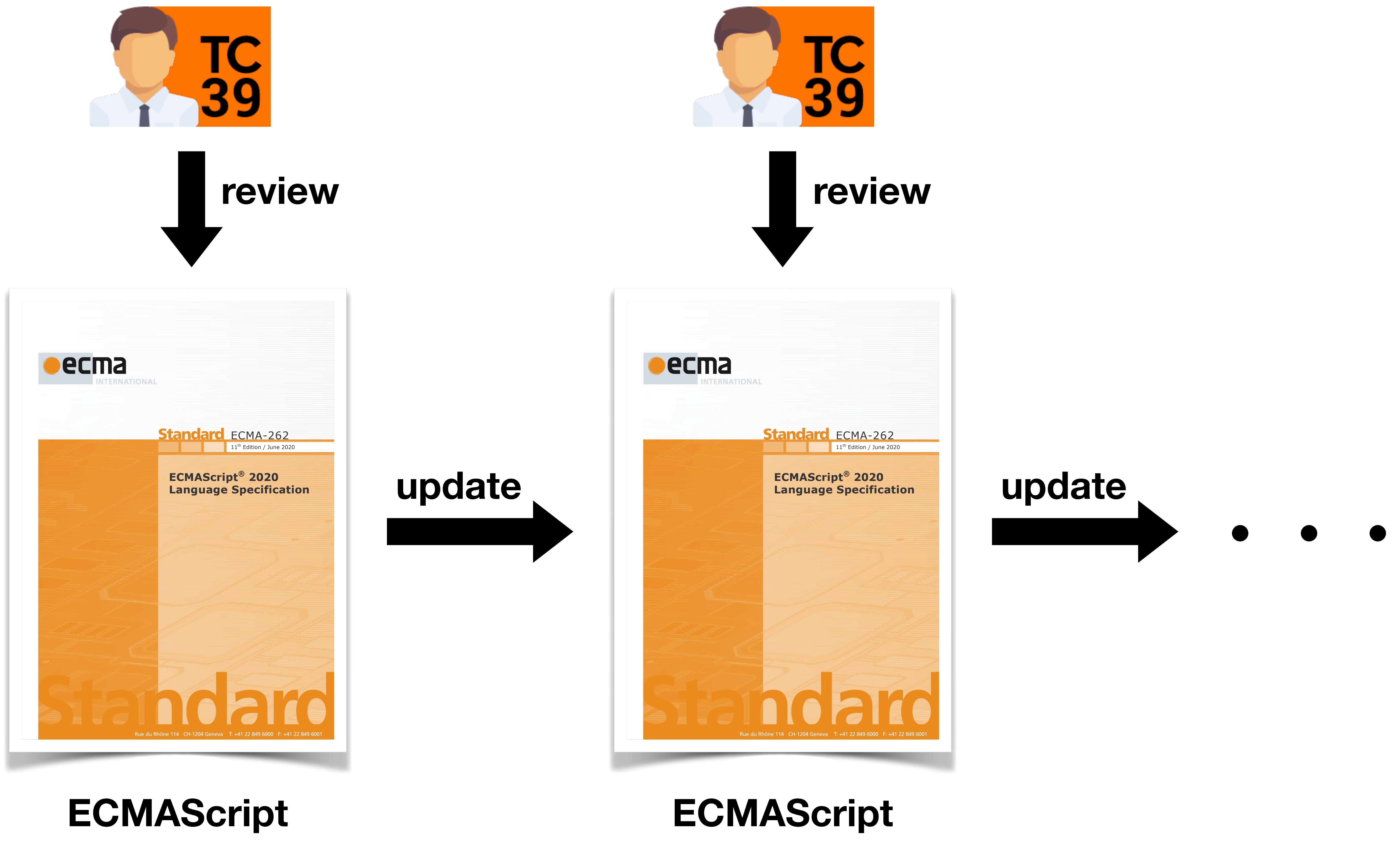
```
ArrayLiteral : [ ElementList , Elision_opt ]
1. Let array be ! ArrayCreate(0).
2. Let nextIndex be the result of performing ArrayAccumulation
   for ElementList with arguments array and 0.
3. ReturnIfAbrupt(nextIndex).
4. If Elision is present, then
    a. Let len be the result of performing ArrayAccumulation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

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

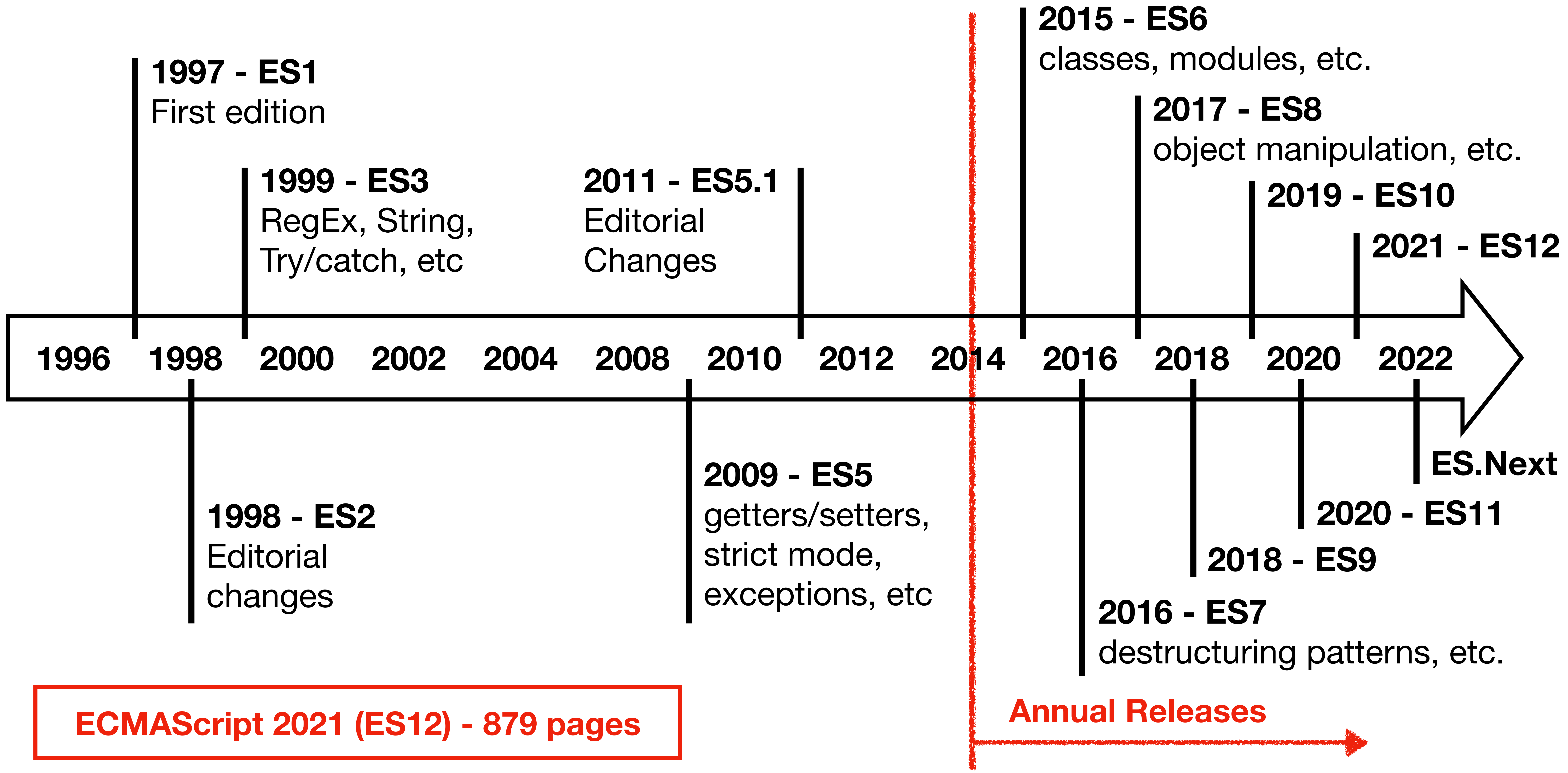
Correctness of ECMAScript is Important



Problem: Manual Review of ECMAScript

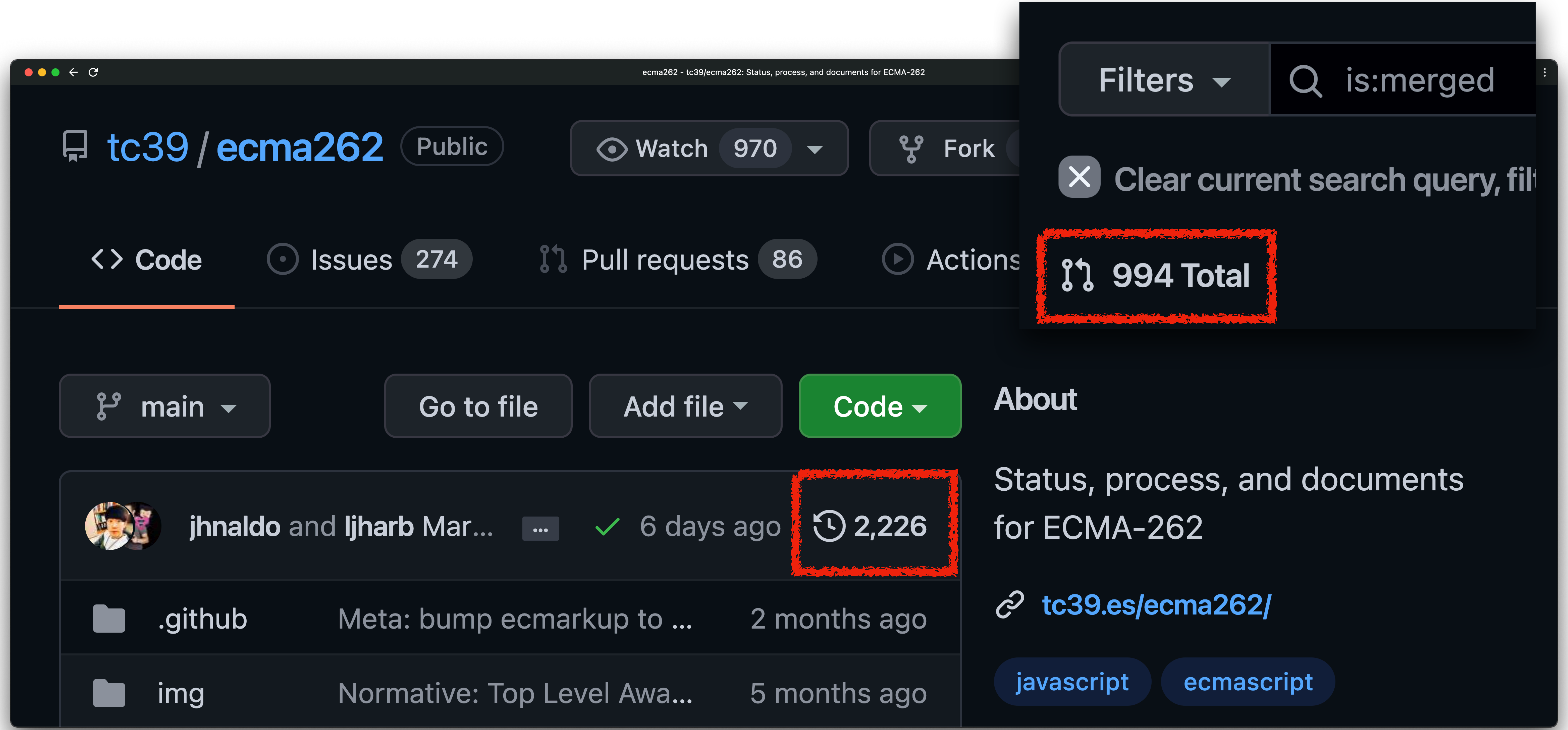


Problem: Fast Evolving JavaScript



ECMAScript 2021 (ES12) - 879 pages

Problem: Open Development Process


ecma262 - tc39/ecma262: Status, process, and documents for ECMA-262

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jhnaldo and ljharb Mar... ✓ 6 days ago 2,226

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About

Status, process, and documents for ECMA-262

tc39.es/ecma262/

javascript · ecmascript

Solution: Type Analysis for ECMAScript

20.3.2.28 Math.round ($\boxed{x}$) `x: (String ∨ Boolean ∨ Number ∨ Object ∨ ...)`

1. Let $\boxed{n}$ be ? ToNumber(x). `n: (Number) ∧ ToNumber(x): (Number ∨ Exception)`
2. If n is an integral Number, return n.
3. If $\boxed{x < 0.5}$ and $\boxed{x > 0}$, return **+0**.
4. If $\boxed{x < 0}$ and $\boxed{x \geq -0.5}$, return **-0**.

...

Type Mismatch for numeric operator `>`

```
Math.round(true)  = ???
Math.round(false) = ???
```

3. If $n < 0.5$ and $n > 0$, return **+0**.
4. If $n < 0$ and $n \geq -0.5$, return **-0**.

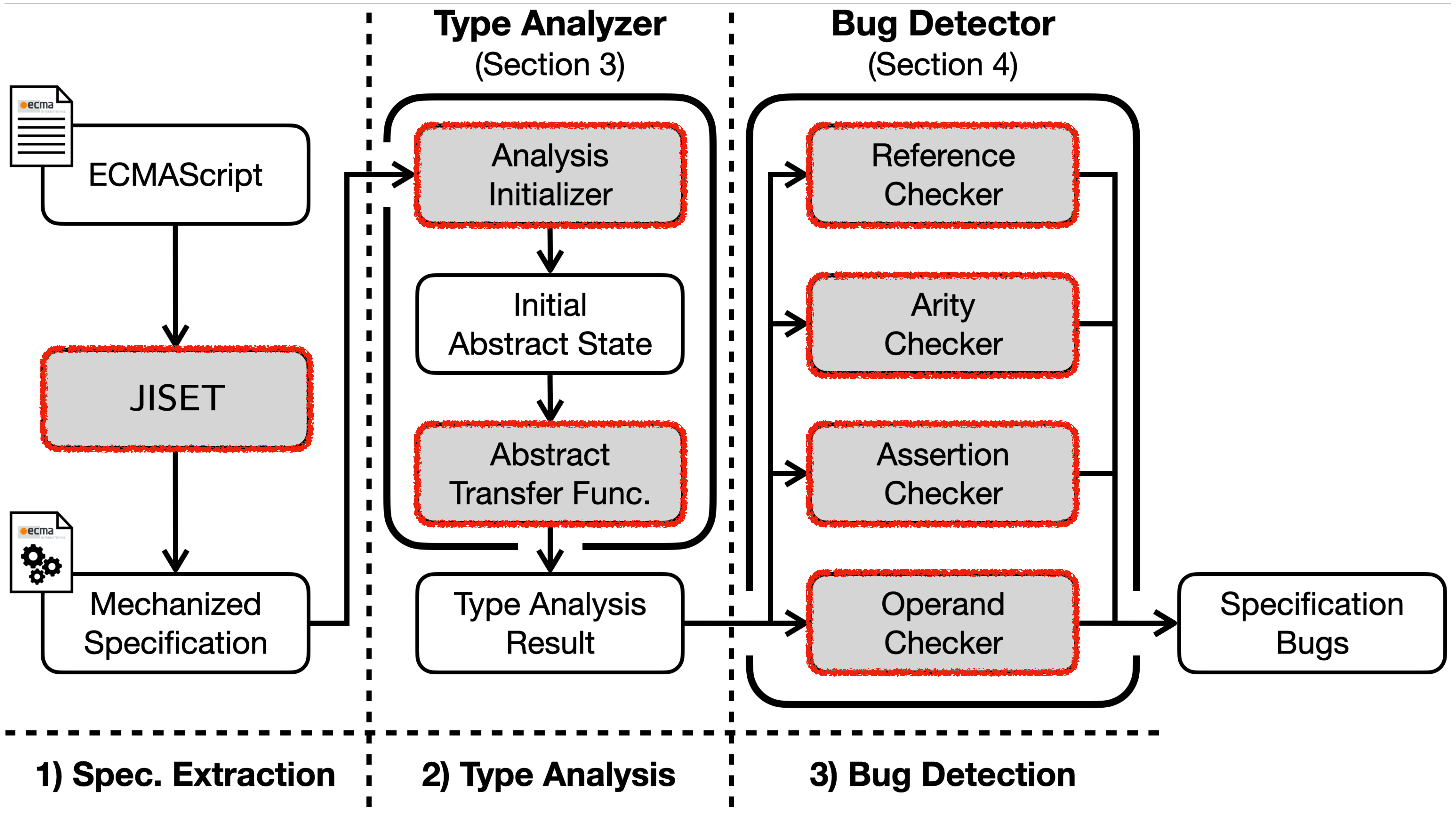
```
Math.round(true)  = 1
Math.round(false) = 0
```

https://github.com/tc39/ecma262/tree/575149cfd77aebcf3a129e165bd89e14caafc31c

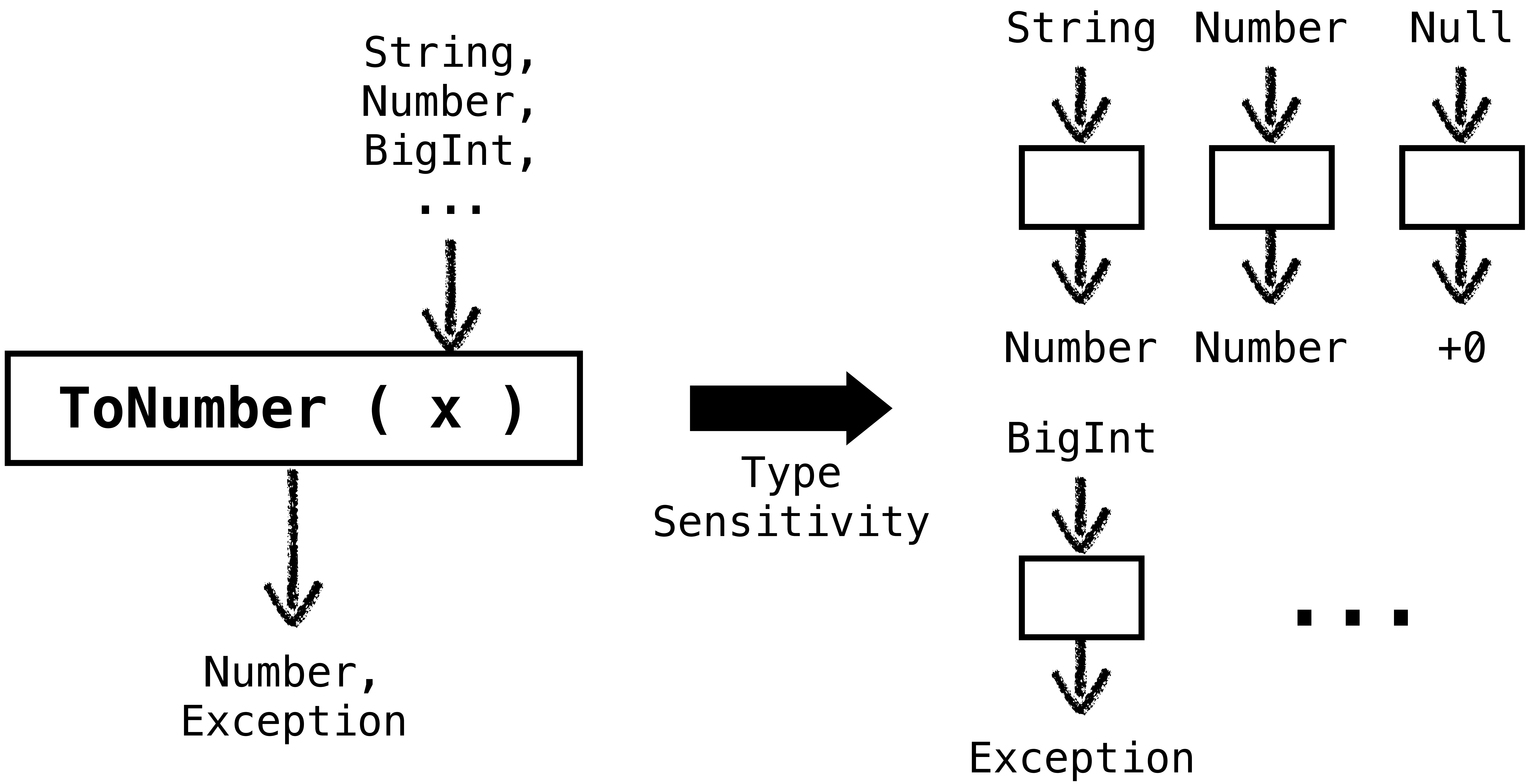
Overall Structure of JSTAR

JavaScript Specification Type Analyzer using Refinement

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



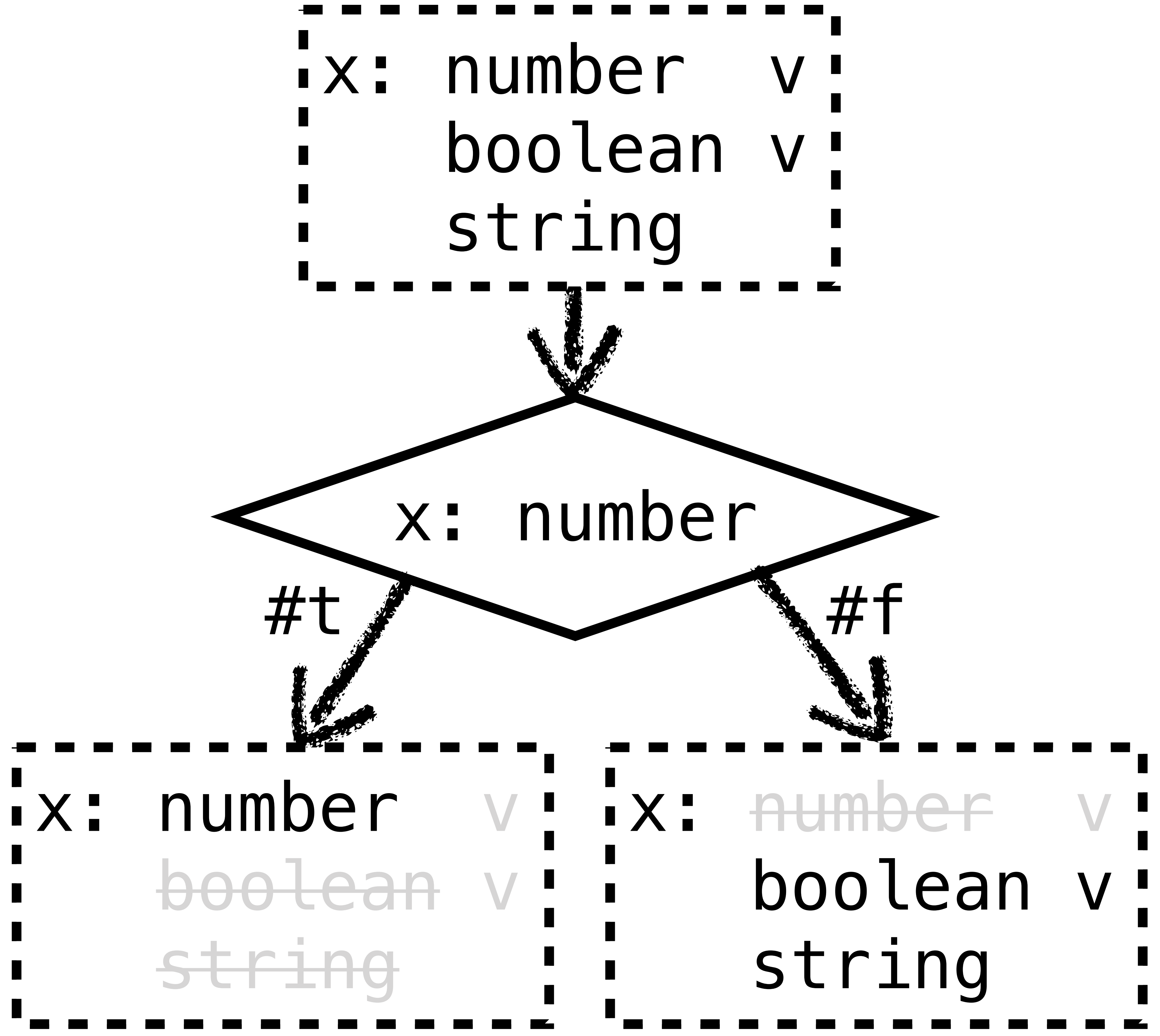
Precision ⇧ - 1) Type Sensitivity



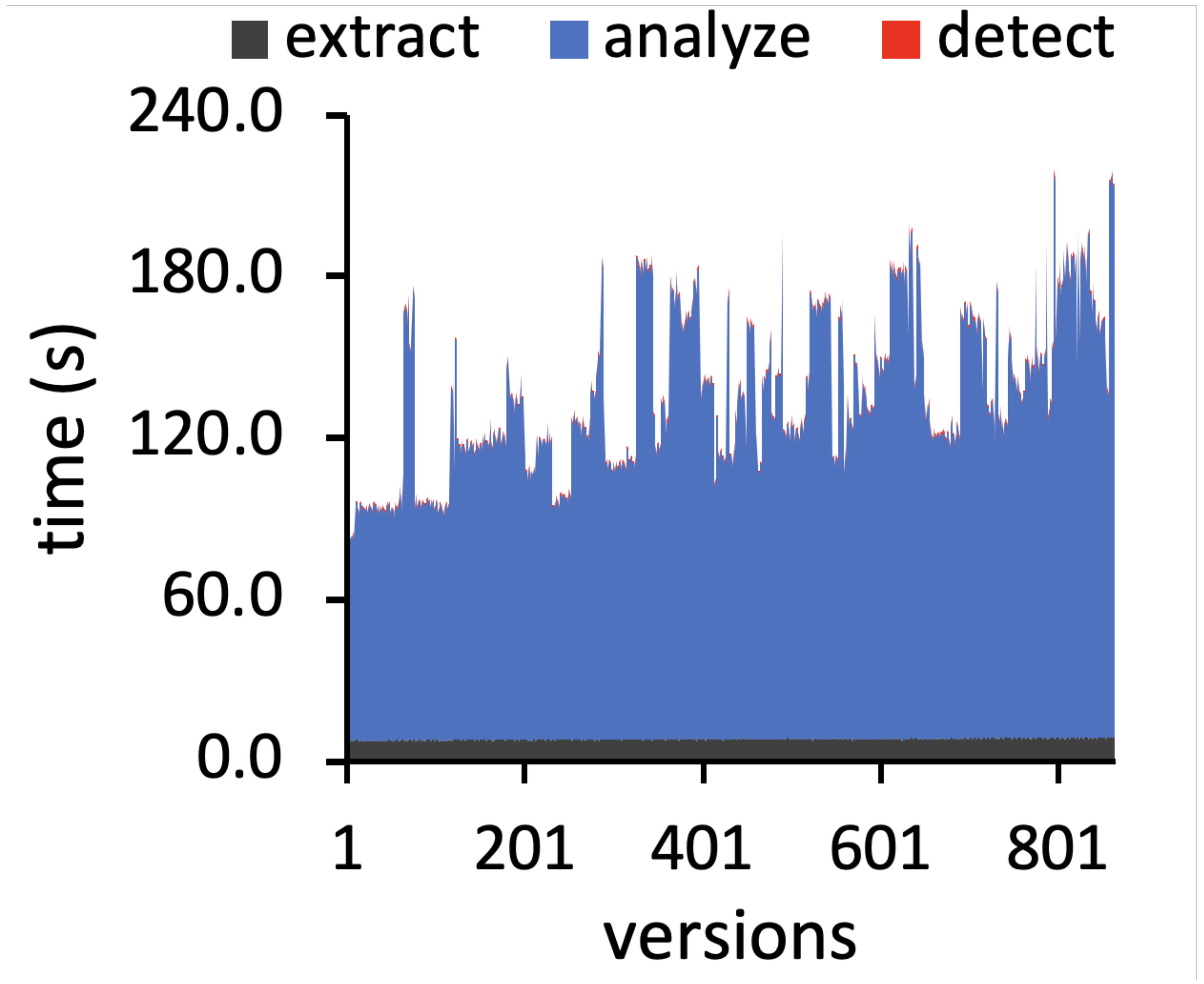
Precision ⇧ - 2) Condition-based Refinement

$$\begin{aligned}
\texttt{refine}(!e, b)(\sigma^\sharp) &= \texttt{refine}(e, \neg b)(\sigma^\sharp) \\
\texttt{refine}(e_0 \texttt{ || } e_1, b)(\sigma^\sharp) &= \begin{cases} \sigma_0^\sharp \sqcup \sigma_1^\sharp & \text{if } b \\ \sigma_0^\sharp \sqcap \sigma_1^\sharp & \text{if } \neg b \end{cases} \\
\texttt{refine}(e_0 \texttt{ \&\& } e_1, b)(\sigma^\sharp) &= \begin{cases} \sigma_0^\sharp \sqcap \sigma_1^\sharp & \text{if } b \\ \sigma_0^\sharp \sqcup \sigma_1^\sharp & \text{if } \neg b \end{cases} \\
\texttt{refine}(\texttt{x.Type == } c_{\texttt{normal}}, \texttt{\#t})(\sigma^\sharp) &= \sigma^\sharp[\texttt{x} \mapsto \tau_{\texttt{x}}^\sharp \sqcap \texttt{normal}(\mathbb{T})] \\
\texttt{refine}(\texttt{x.Type == } c_{\texttt{normal}}, \texttt{\#f})(\sigma^\sharp) &= \sigma^\sharp[\texttt{x} \mapsto \tau_{\texttt{x}}^\sharp \sqcap \{\texttt{abrupt}\}] \\
\texttt{refine}(\texttt{x == } e, \texttt{\#t})(\sigma^\sharp) &= \sigma^\sharp[\texttt{x} \mapsto \tau_{\texttt{x}}^\sharp \sqcap \tau_e^\sharp] \\
\texttt{refine}(\texttt{x == } e, \texttt{\#f})(\sigma^\sharp) &= \sigma^\sharp[\texttt{x} \mapsto \tau_{\texttt{x}}^\sharp \setminus \lfloor \tau_e^\sharp \rfloor] \\
\texttt{refine}(\texttt{x} : \tau, \texttt{\#t})(\sigma^\sharp) &= \sigma^\sharp[\texttt{x} \mapsto \tau_{\texttt{x}}^\sharp \sqcap \{\tau\}] \\
\texttt{refine}(\texttt{x} : \tau, \texttt{\#f})(\sigma^\sharp) &= \sigma^\sharp[\texttt{x} \mapsto \tau_{\texttt{x}}^\sharp \setminus \{\tau' \mid \tau' <: \tau\}] \\
\texttt{refine}(e, b)(\sigma^\sharp) &= \sigma^\sharp
\end{aligned}$$

where $\sigma_j^\sharp = \texttt{refine}(e_j, b)(\sigma^\sharp)$ for $j = 0, 1$, $\tau_e^\sharp = [\![e]\!]_e^\sharp(\sigma^\sharp)$, and $\lfloor \tau^\sharp \rfloor$ returns $\{\tau\}$ if $\tau^\sharp$ denotes a singleton type τ, or returns $\varnothing$, otherwise.



RQ1) Performance

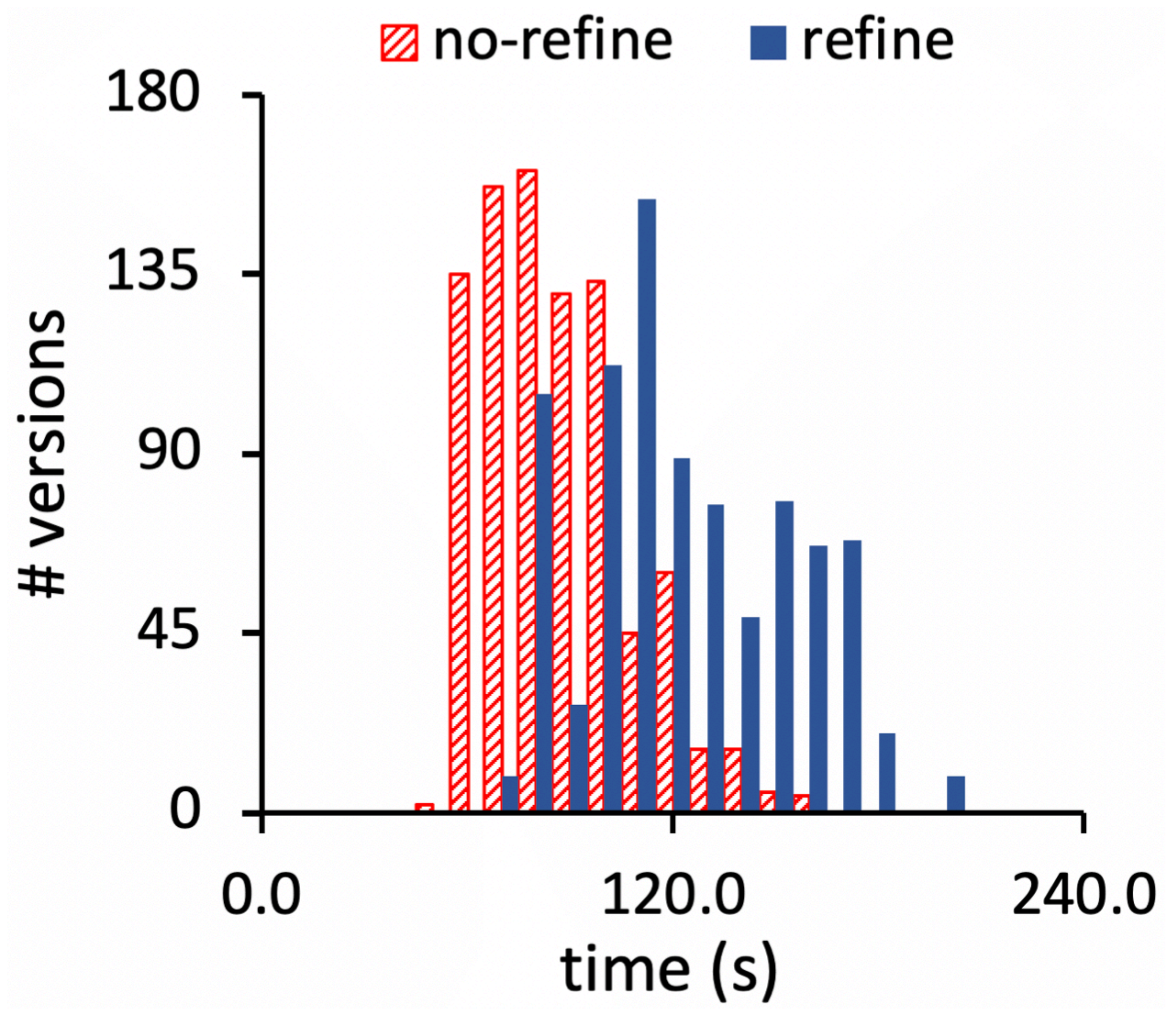


- **864 versions** of ECMAScript (Jan. 1, 2018 to Mar. 9, 2021)
- 4.2GHz Quad-Core Intel Core i7
- 32GB of RAM
- **Average Time : 137.3 s**
  - extract : 8.0 s
  - **analyze: 128.5 s**
  - detect: 0.8 s

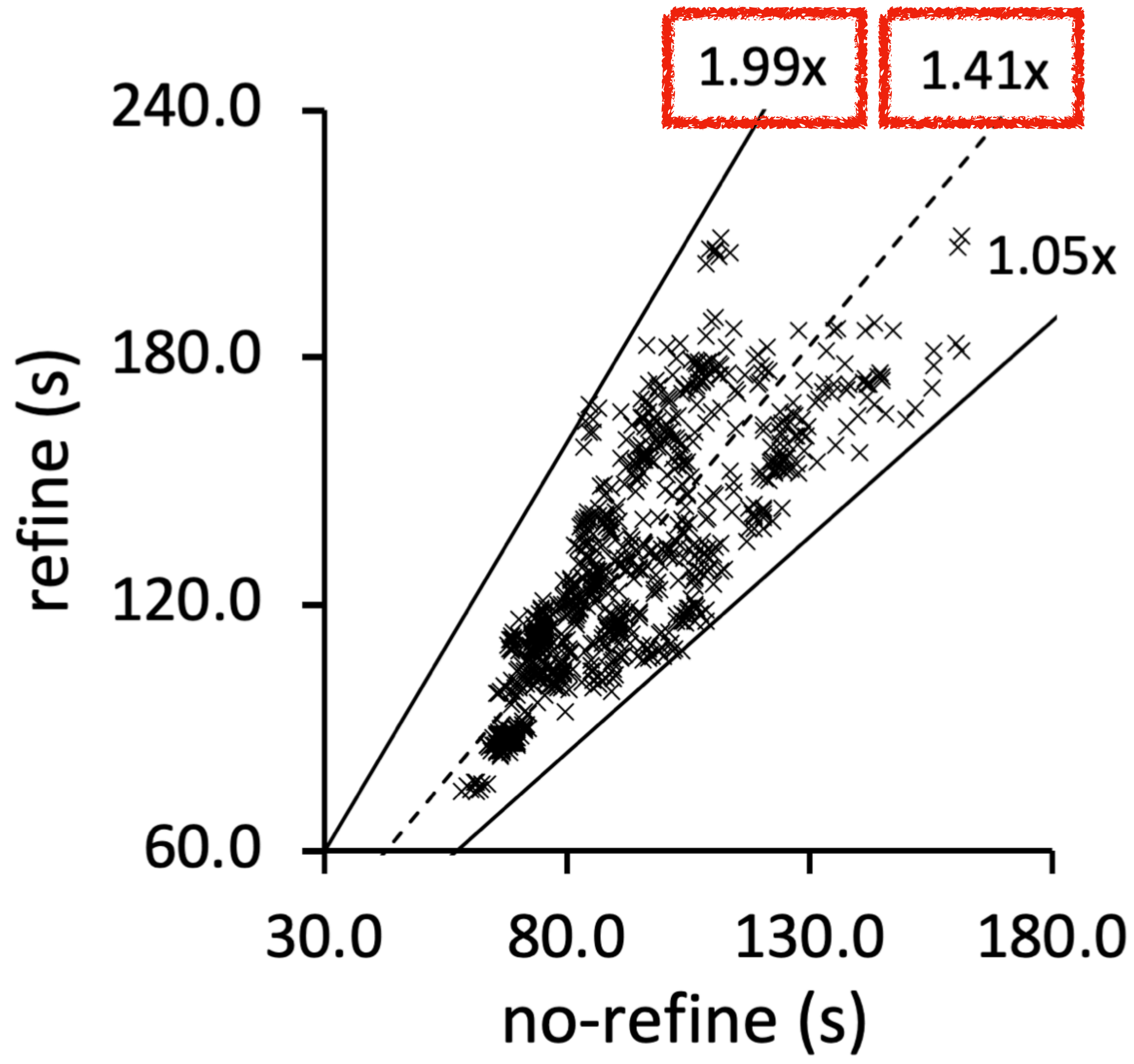
RQ2) Precision

Checker	**Bug Kind**	**Precision = (# True Bugs) / (# Detected Bugs)**					
		no-refine		refine		$\triangle$	
Reference	UnknownVar	62 / 106	17 / 60	63 / 78	17 / 31	+1 / -28	/ -29
	DuplicatedVar		45 / 46		46 / 47		+1 / +1
Arity	MissingParam	4 / 4	4 / 4	4 / 4	4 / 4	/	/
Assertion	Assertion	4 / 56	4 / 56	4 / 31	4 / 31	/ -25	/ -25
Operand	NoNumber	22 / 113	2 / 65	22 / 44	2 / 6	/ -69	/ -59
	Abrupt		20 / 48		20 / 38		/ -10
Total		92 / 279 (33.0%)		93 / 157 (59.2%)		+1 / -122 (+26.3%)	

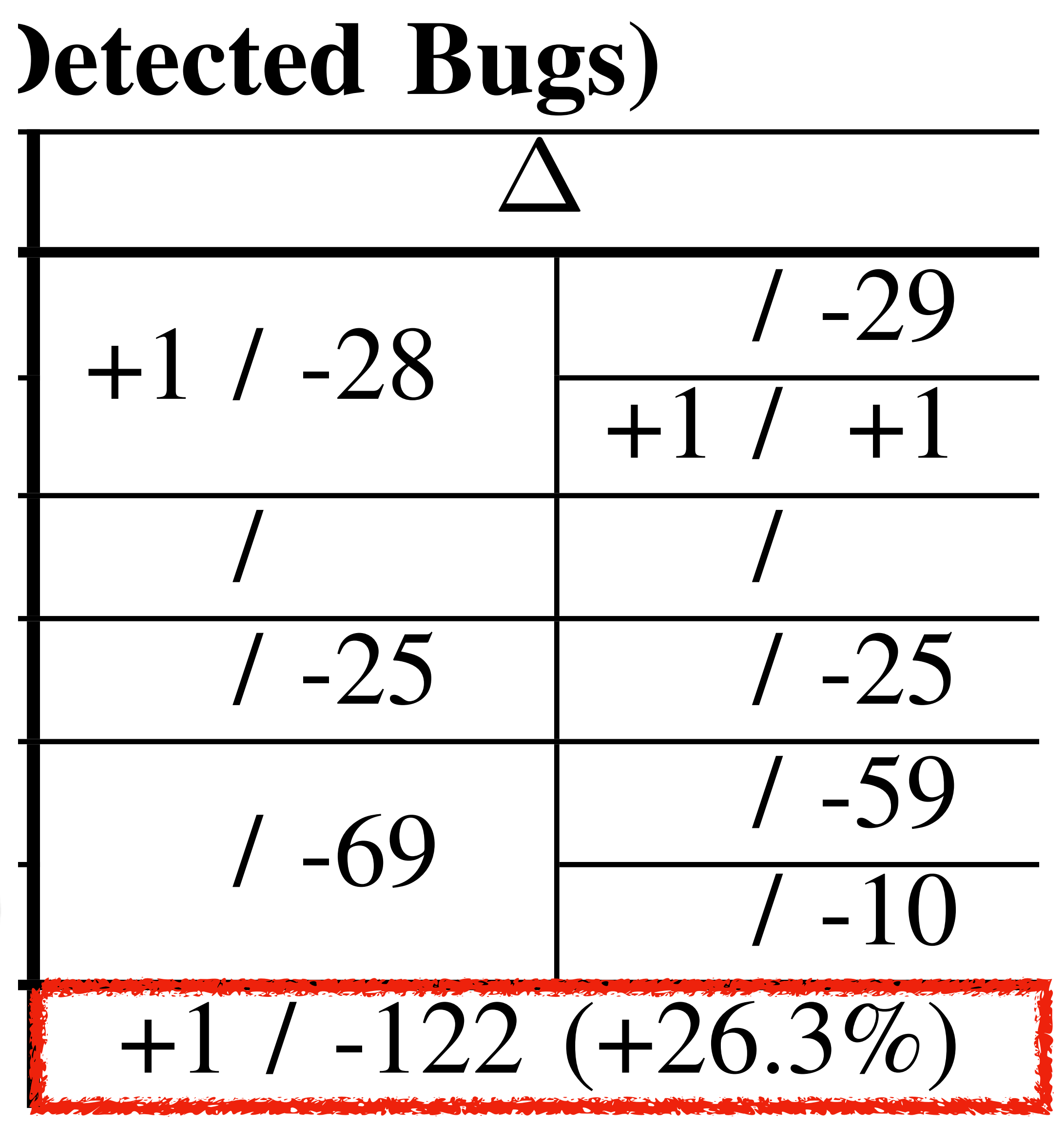
RQ3) Effectiveness of Refinement



(c) The histogram of time



(d) The ratio of time



etected Bugs)

Δ	
+1 / -28	/ -29
	+1 / +1
/	/
/ -25	/ -25
/ -69	/ -59
	/ -10
+1 / -122 (+26.3%)	

RQ4) Detection of New Bugs

- The Latest Version: **ECMAScript 2021 (ES12)**

14 Bugs in Spec.

Name	Feature	#	Checker	Created	Life Span
ES12-1	Switch	3	Reference	2015-09-22	1,996 days
ES12-2	Try	3	Reference	2015-09-22	1,996 days
ES12-3	Arguments	1	Reference	2015-09-22	1,996 days
ES12-4	Array	2	Reference	2015-09-22	1,996 days
ES12-5	Async	1	Reference	2015-09-22	1,996 days
ES12-6	Class	1	Reference	2015-09-22	1,996 days
ES12-7	Branch	1	Reference	2015-09-22	1,996 days
ES12-8	Arguments	2	Operand	2015-12-16	1,910 days

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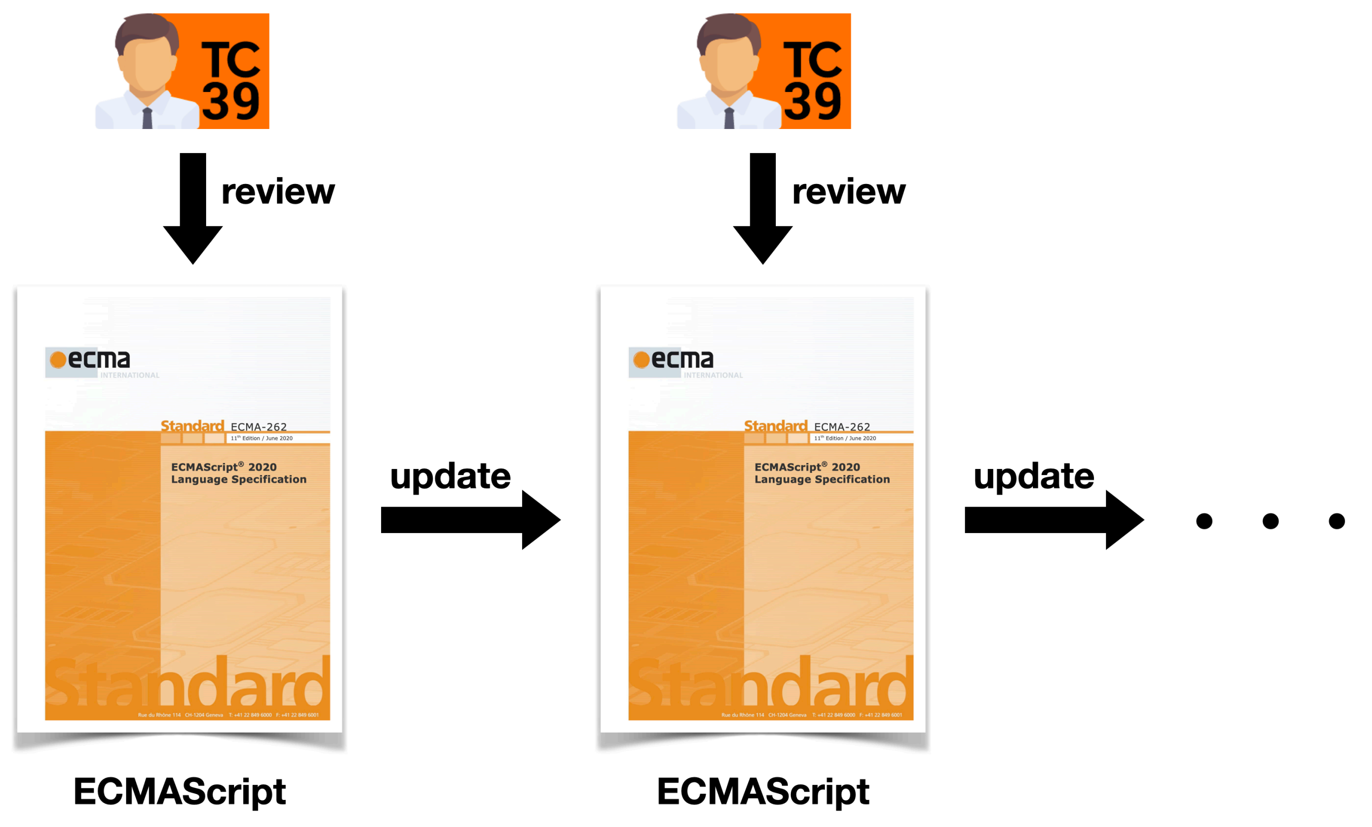

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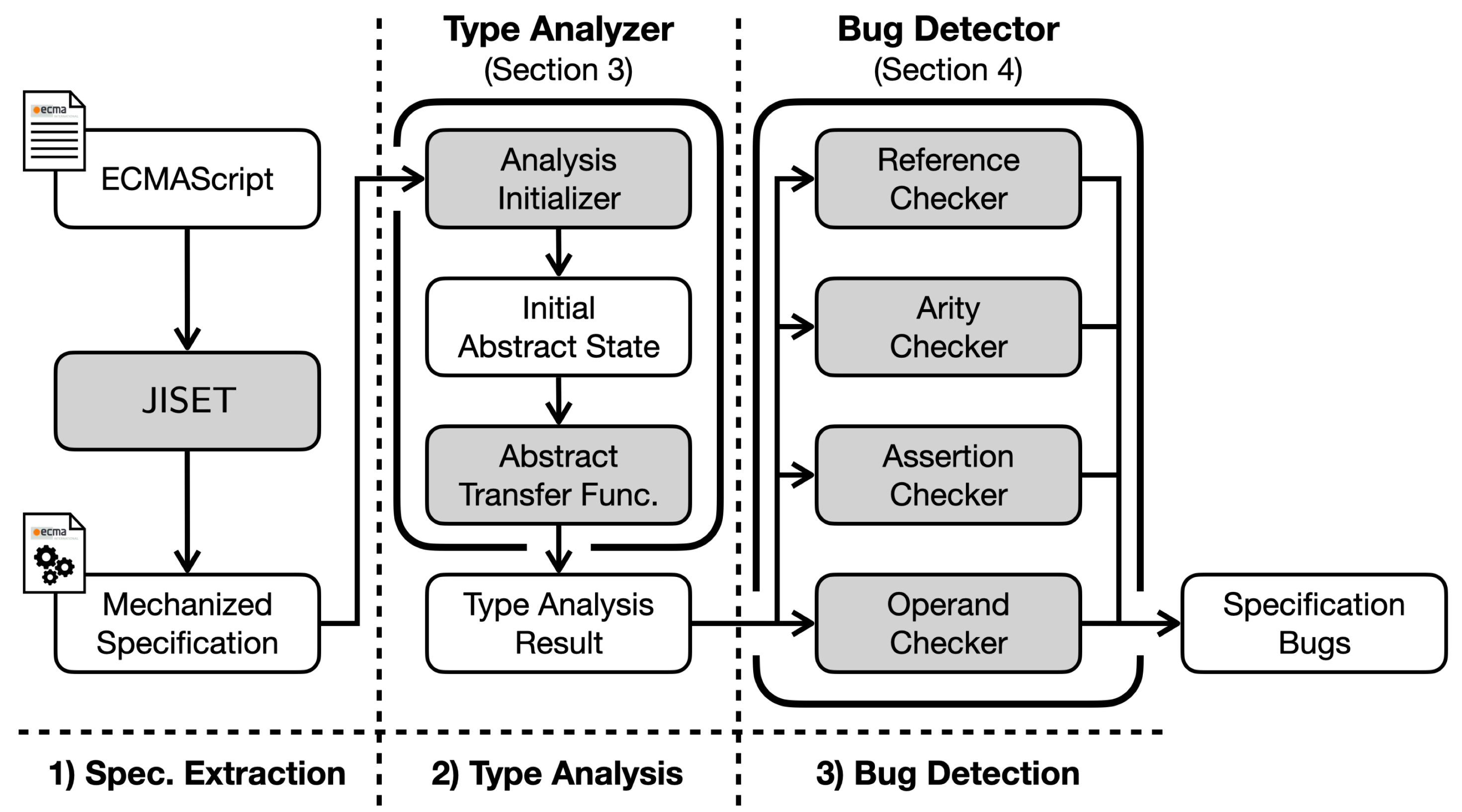

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