

Automatically Deriving JavaScript Static Analyzers from Specifications using Meta-level Static Analysis

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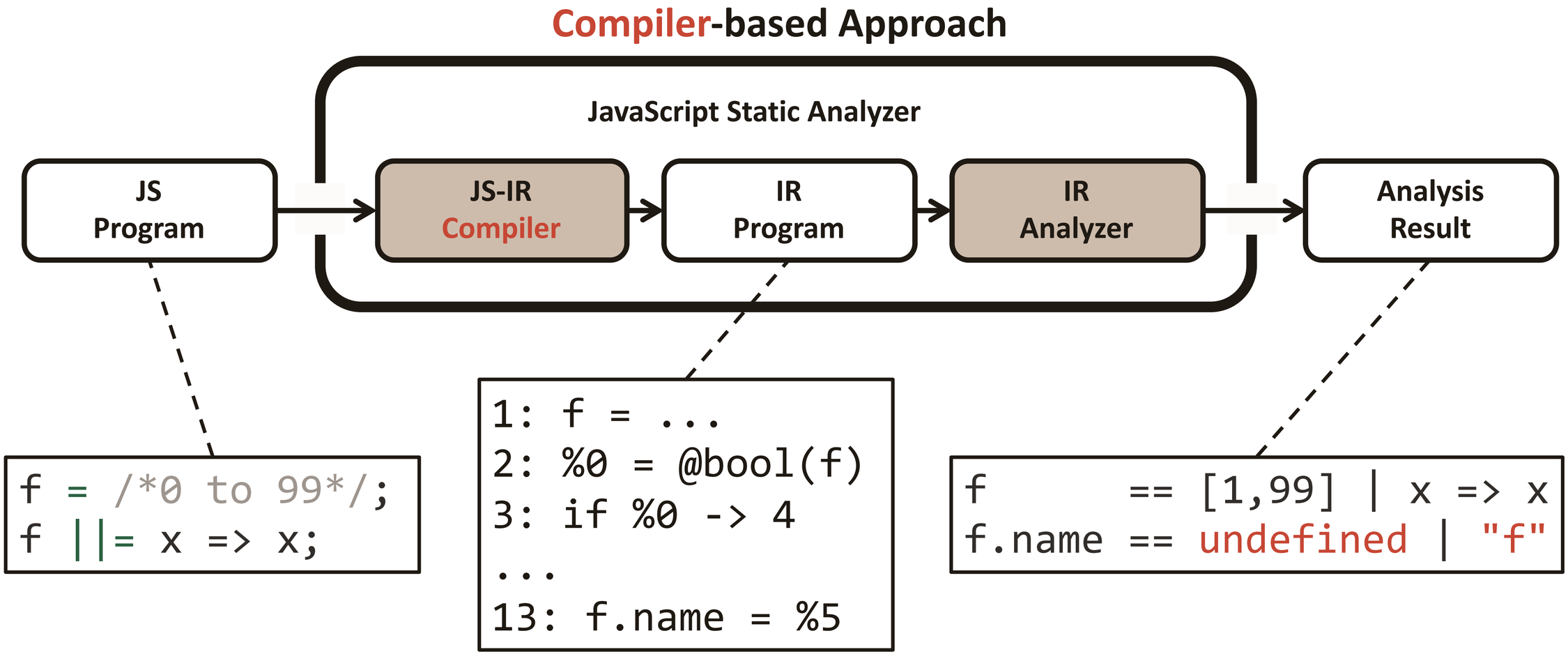
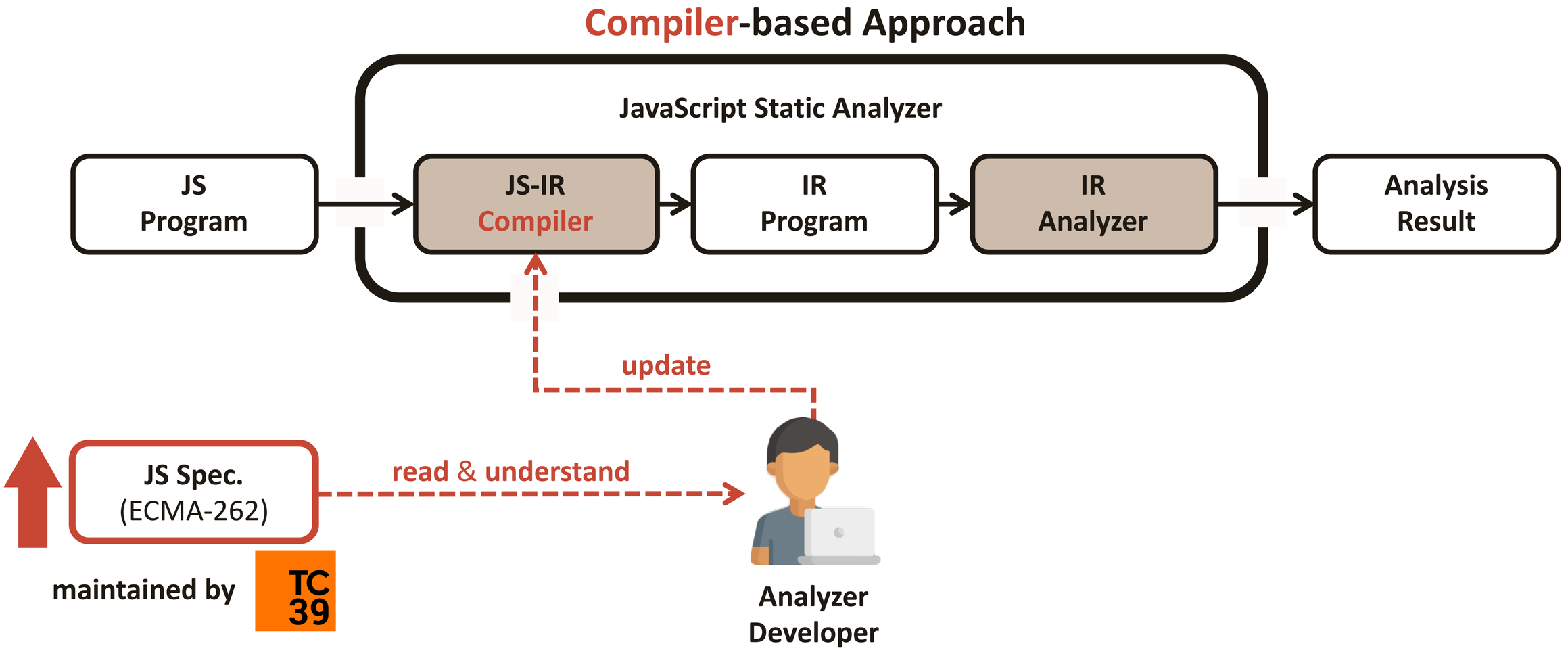
February 9, 2022

Background - JavaScript Static Analysis



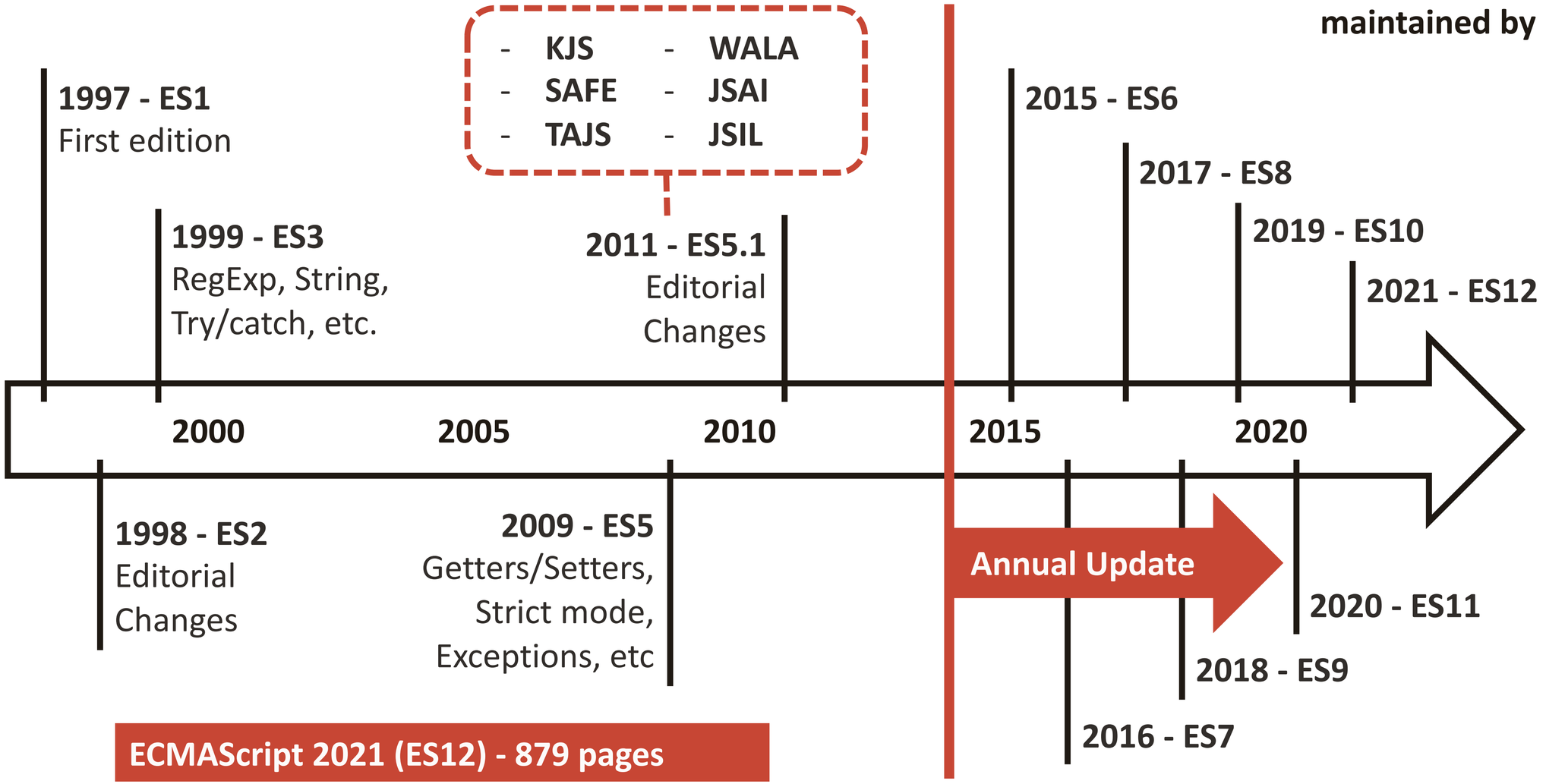
Problem - Manual Update of JS-IR Compiler



Problem - Fast Evolving JavaScript

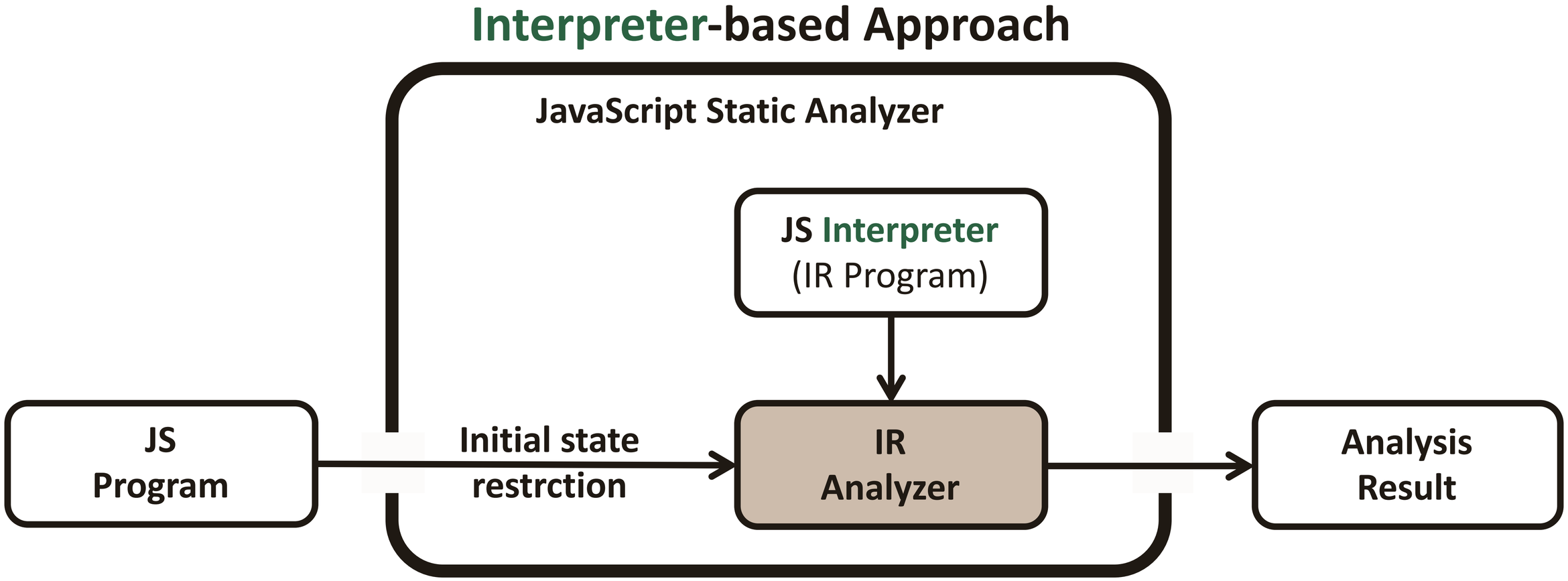
JS Spec.
(ECMA-262)

maintained by TC 39



ECMAScript 2021 (ES12) - 879 pages

Core Idea - Meta-level Static Analysis



Core Idea - Meta-level Static Analysis

- **Why Interpreter-based Approach?**
  - JavaScript specifications are written in an interpreter-based style

13.15.2 Runtime Semantics: Evaluation

AssignmentExpression : *LeftHandSideExpression* `||=` *AssignmentExpression*

1. Let *lref* be the result of evaluating *LeftHandSideExpression*.
2. Let *lval* be ? GetValue(*lref*).
3. Let *lbool* be ! ToBoolean(*lval*).
4. If *lbool* is **true**, return *lval*.
5. If IsAnonymousFunctionDefinition(*AssignmentExpression*) is **true** and IsIdentifierRef of *LeftHandSideExpression* is **true**, then
   a. Let *rval* be NamedEvaluation of *AssignmentExpression* with argument *lref*.[[ReferencedName]].
6. Else,
   a. Let *rref* be the result of evaluating *AssignmentExpression*.
   b. Let *rval* be ? GetValue(*rref*).
7. Perform ? PutValue(*lref*, *rval*).
8. Return *rval*.

Evaluation **algorithm** for *logical OR assignments* in **ES12 (ES2021)**

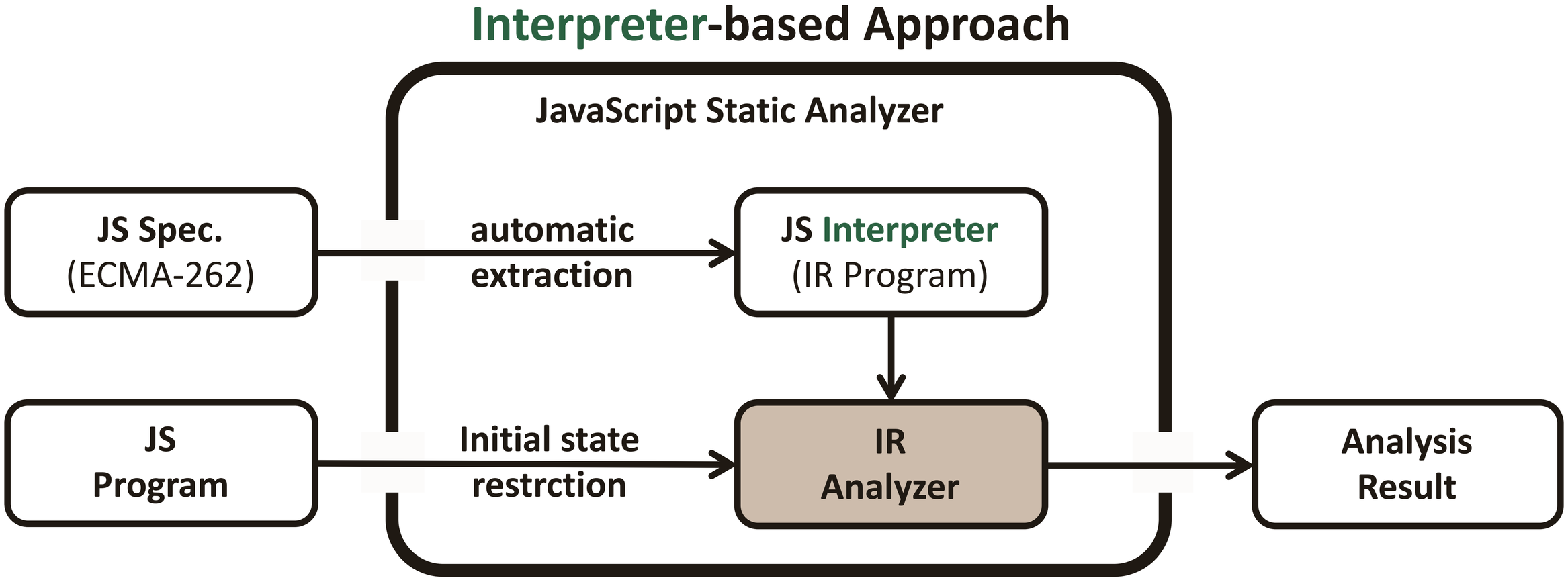
Core Idea - Meta-level Static Analysis

- **Why Interpreter-based Approach?**
  - JavaScript specifications are written in an interpreter-based style
  - **JISET**: JavaScript IR-based Semantics Extraction **(ASE 2020)**
    - Extracting JavaScript **definitional interpreters** as **IR_{ES} programs** from JS Lang. Spec. (ECMA-262).

```
1  syntax def AssignmentExpression[8].Evaluation(
2    this, LeftHandSideExpression, AssignmentExpression
3  ) { /* entry */
4    let lref = (LeftHandSideExpression.Evaluation)
5    let lval = [? (GetValue lref)]
6    let lbool = [! (ToBoolean lval)] /* #1 */
7    if (= lbool true) { /* #2 */ return lval } else {} /* #3 */
8    if (&& (IsAnonymousFunctionDefinition AssignmentExpression)
9       (LeftHandSideExpression.IsIdentifierRef)) { /* #4 */
10     let rval = (AssignmentExpression.NamedEvaluation
11                 lref.ReferencedName)
12   } else { /* #5 */
13     let rref = (AssignmentExpression.Evaluation)
14     let rval = [? (GetValue rref)]
15   } /* #6 */
16   [? (PutValue lref rval)]
17   return rval
18 } /* exit */
```

Extracted **IR_{ES} function** for *logical OR assignments* via **JISET**

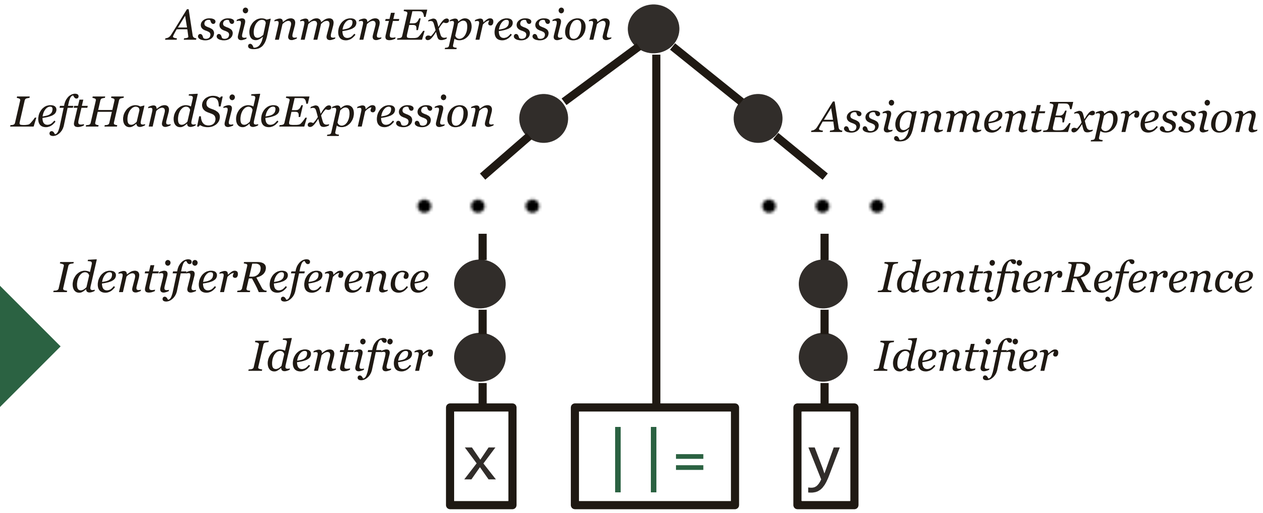
Core Idea - Meta-level Static Analysis



Example

```
x ||= y
```

PARSE



JavaScript

IR_{ES}

```
syntax def AssignmentExpression[8].Evaluation(
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) {
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  if (= lbool true) return lval
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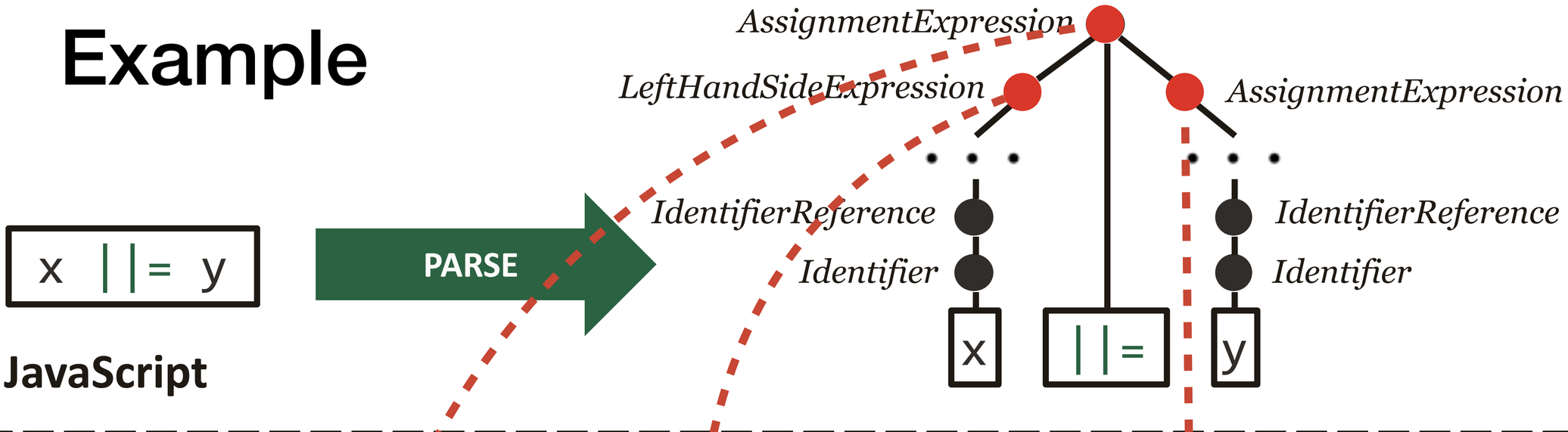
```

Example



IR_{ES}

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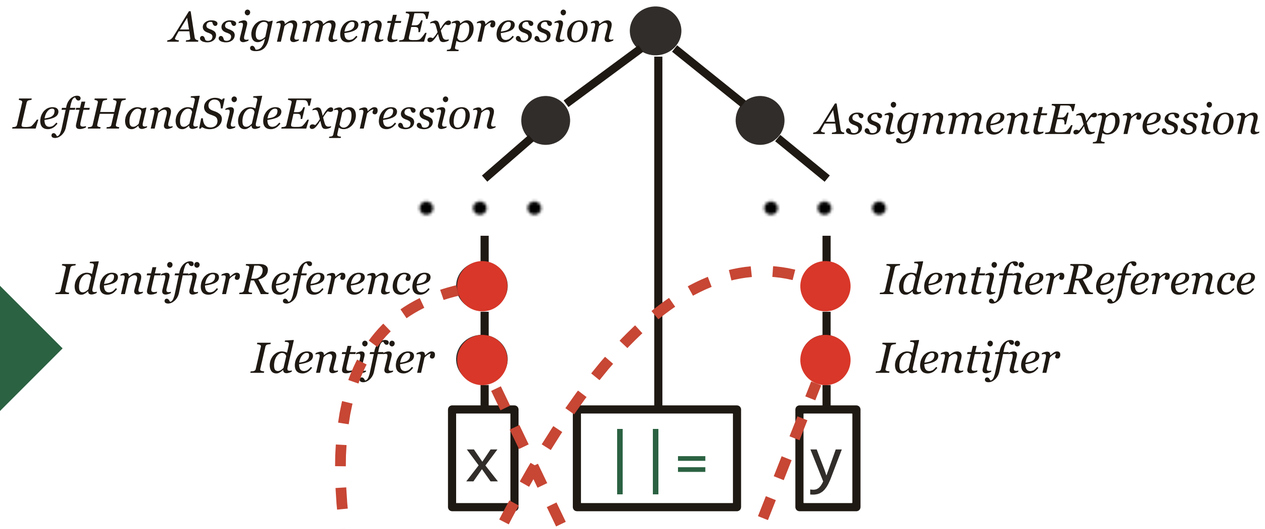
}
```

AST Sensitivity

```
x ||= y
```

PARSE

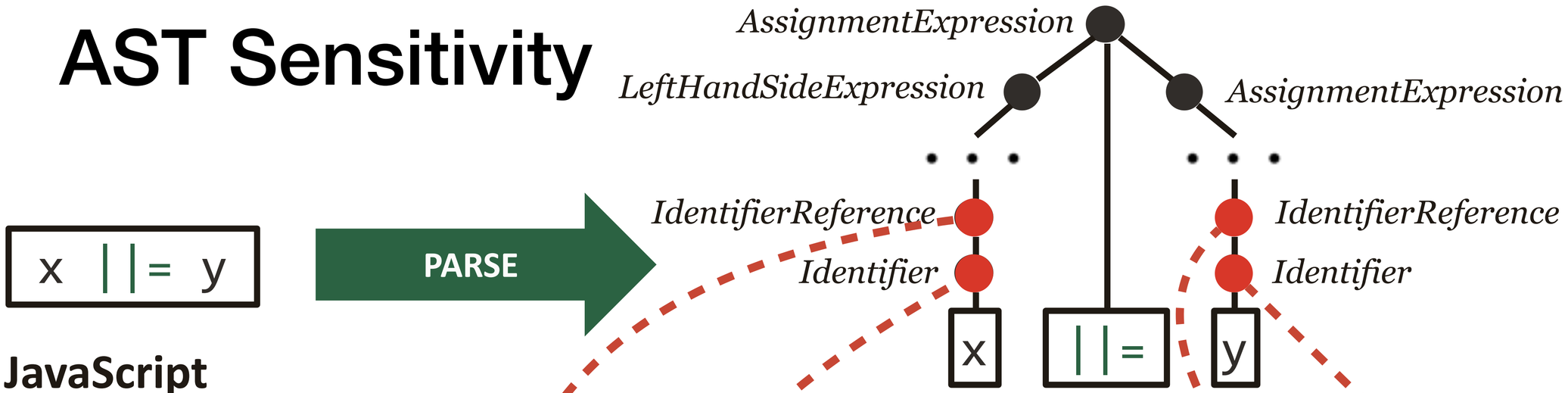


JavaScript

IR_{ES}

```
syntax def IdentifierReference[0]
  .Evaluation(this, Identifier) {
  return [?
    (ResolveBinding
      (Identifier.StringValue)
    )
  ]
}
```

AST Sensitivity



IR_{ES}

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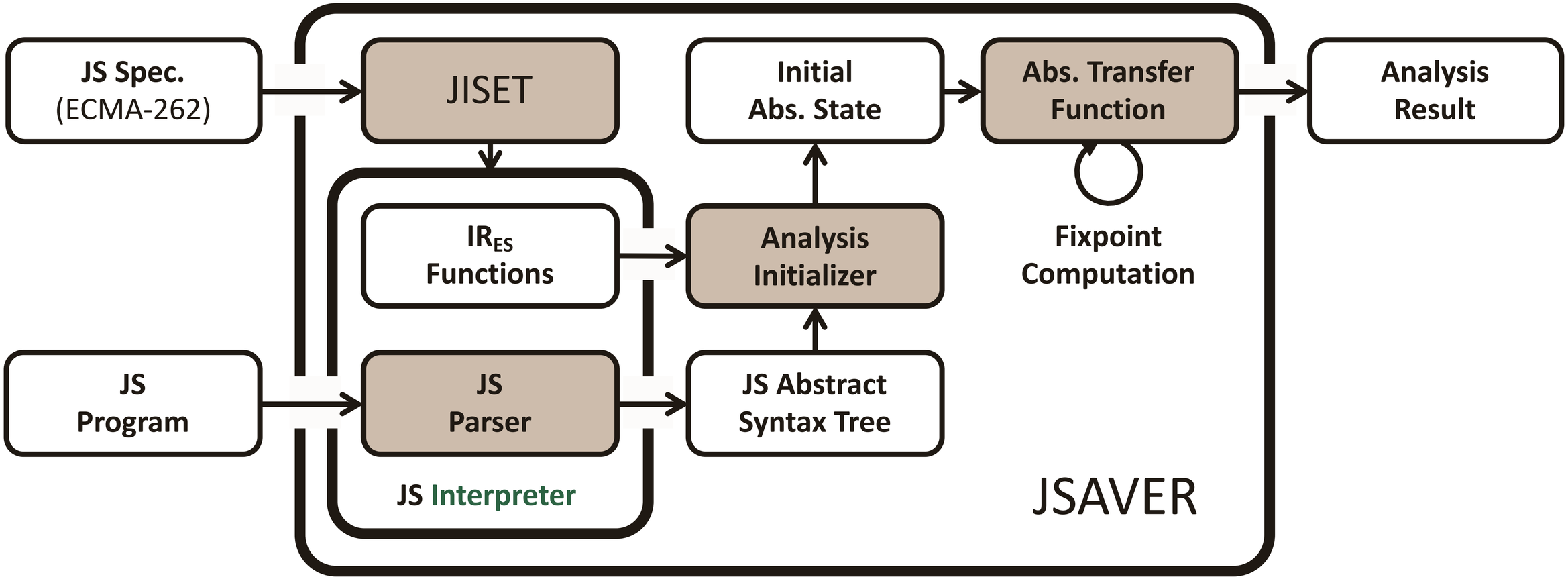
AST Sensitivity

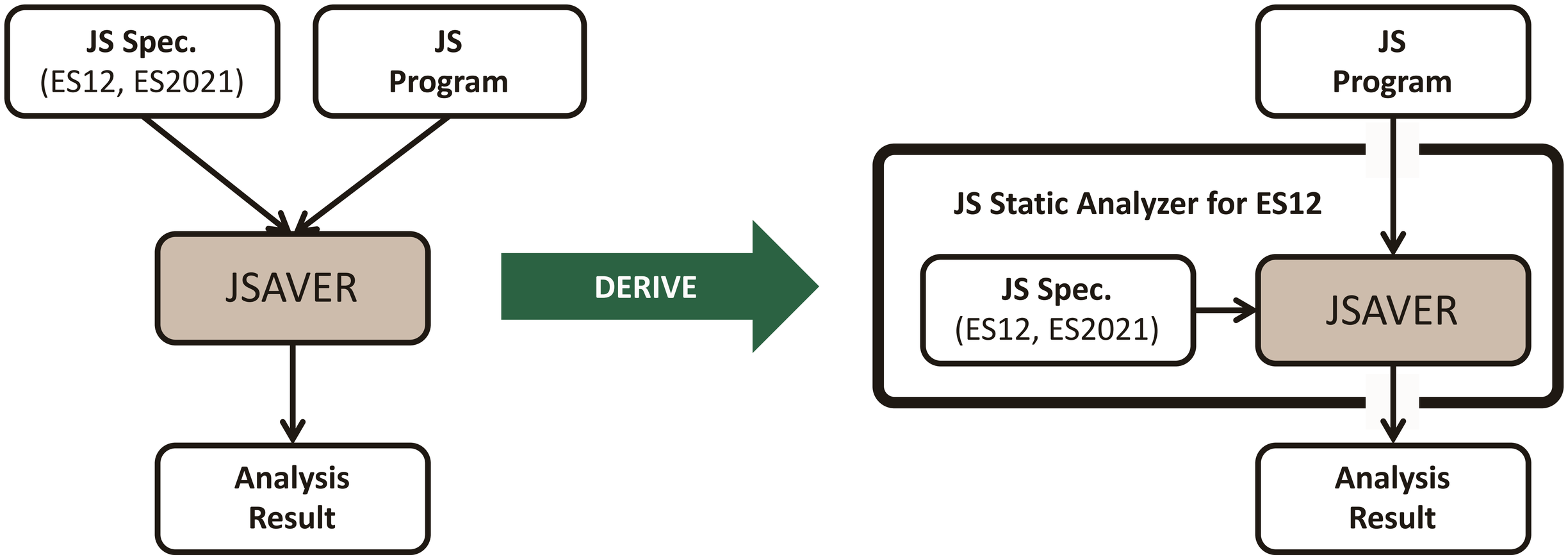
JavaScript	AST Sensitivity in IR_{ES}
Flow-Sensitivity	$\delta^{\text{js-flow}}(t_\perp) = \{\sigma = (\_, \_, \overline{c}, \_) \in \mathbb{S} \mid \text{ast}(\overline{c}) = t_\perp\}$
k-Callsite-Sensitivity	$\delta^{\text{js-}k\text{-cfa}}([t_1, \cdots, t_n]) = \{\sigma = (\_, \_, \overline{c}, \_) \in \mathbb{S} \mid n \leq k \wedge (n = k \vee \text{js-ctxt}^{n+1}(\overline{c}) = \perp) \wedge \forall 1 \leq i \leq n.\ \text{ast} \circ \text{js-ctxt}^{i}(\overline{c}) = t_i\}$

Our Tool - JSAVER

- **J**avaScript **S**tatic **A**nalyzer **v**ia **E**CMAScript **R**epresentation



JS Static Analyzer Derivation via JSAVER

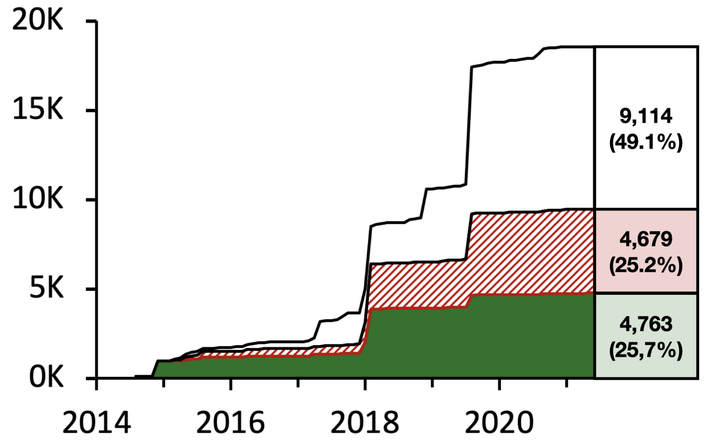


Evaluation Setting

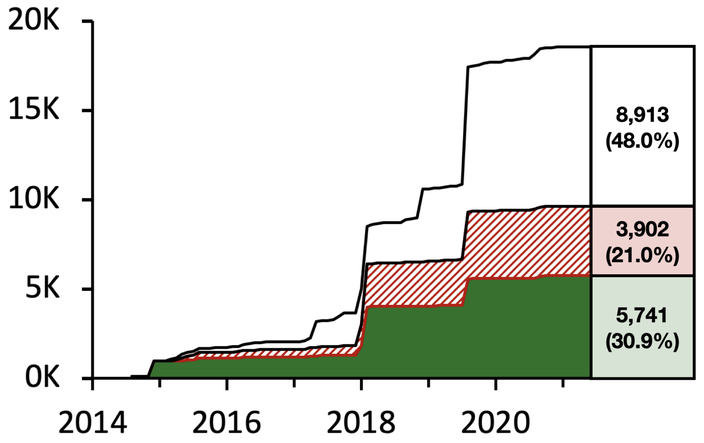
- **Derived Analyzer - JSA_{ES12}**
  - JavaScript Static Analyzer derived from **ES12** (ES2021) via **JSAVER**
- **Comparison Targets**
  - State-of-the-art JavaScript Static Analyzers + JavaScript Transpiler
    - TAJS / SAFE + Babel
- **Analysis Targets**
  - **Test262** (Official Conformance Test Suite) maintained by TC39
    - Used 18,556 applicable conformance tests
- **Experiment Environment**
  - An Ubuntu machine
    - 4.2GHz Quad-Core Intel Core i7 and 32GB of RAM.

RQ1) Soundness

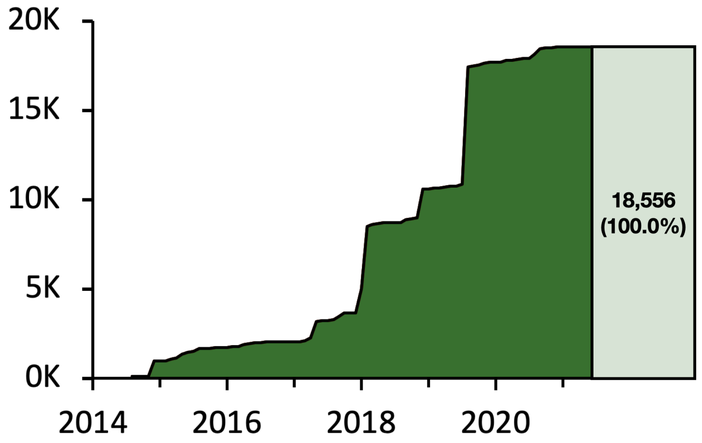
- Can JSA_{ES12} analyze JavaScript programs using new language features in a sound way?



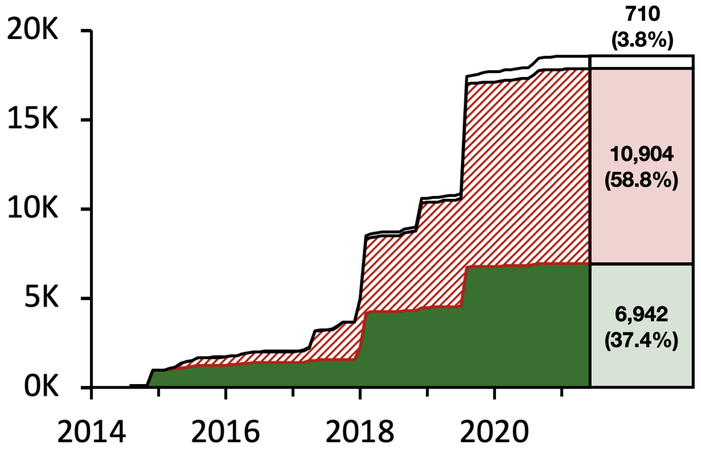
(a) Analysis results of TAJS



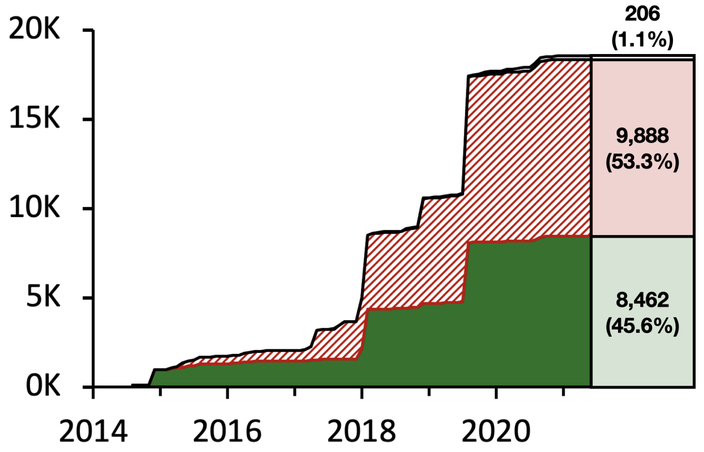
(b) Analysis results of SAFE



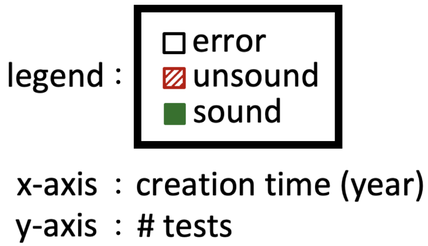
(c) Analysis results of JSA_{ES12}



(d) Analysis results of TAJS with Babel

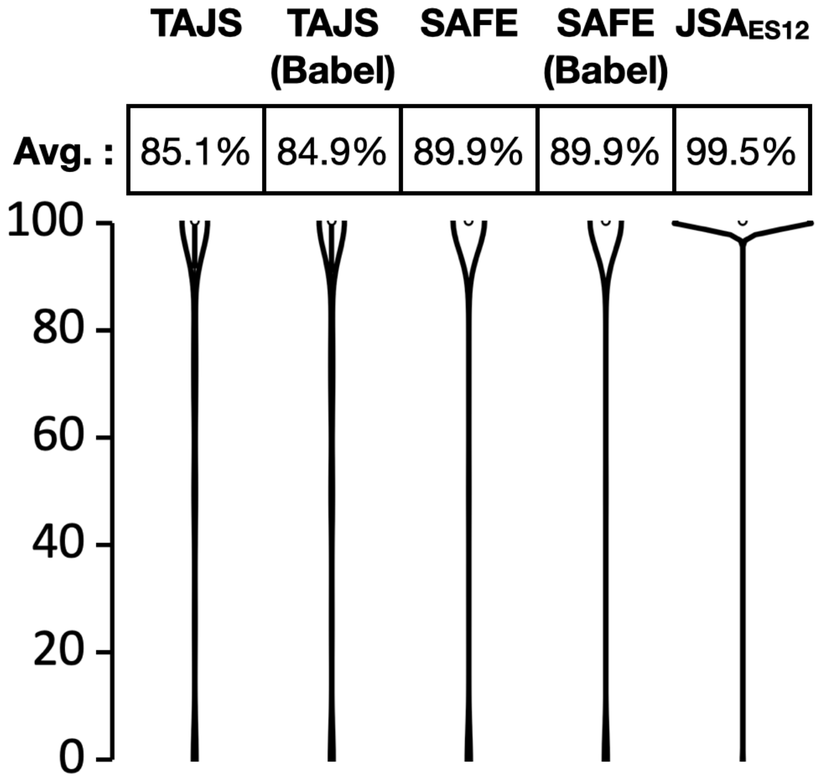


(e) Analysis results of SAFE with Babel

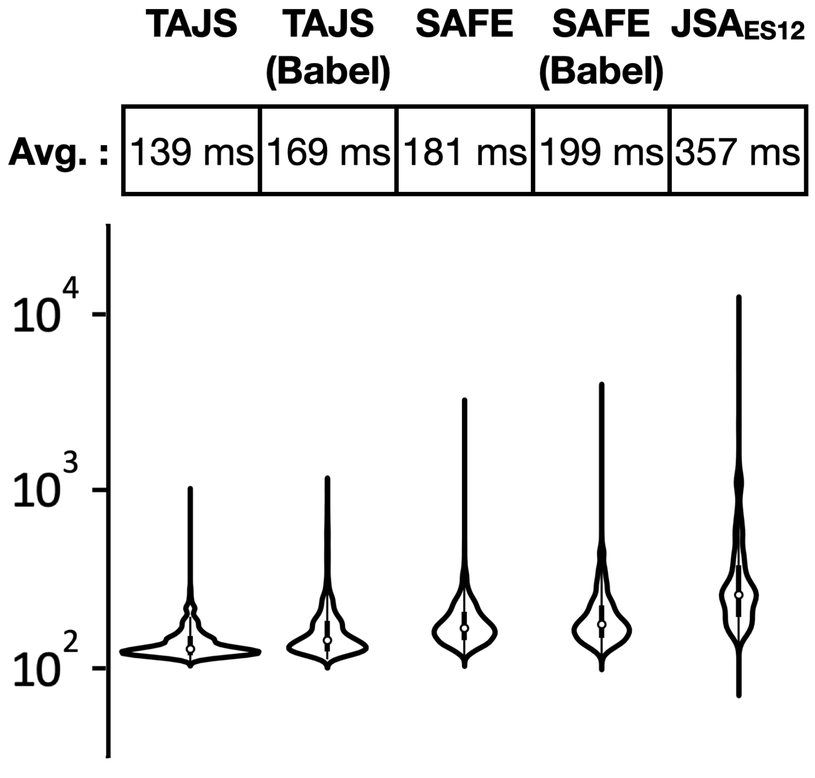


RQ2) Precision & Performance

- Can JSA_{ES12} precisely analyze JavaScript programs compared to the existing static analyzers?
  - **Targets**: 3,878 programs soundly analyzable by all of five analyzers



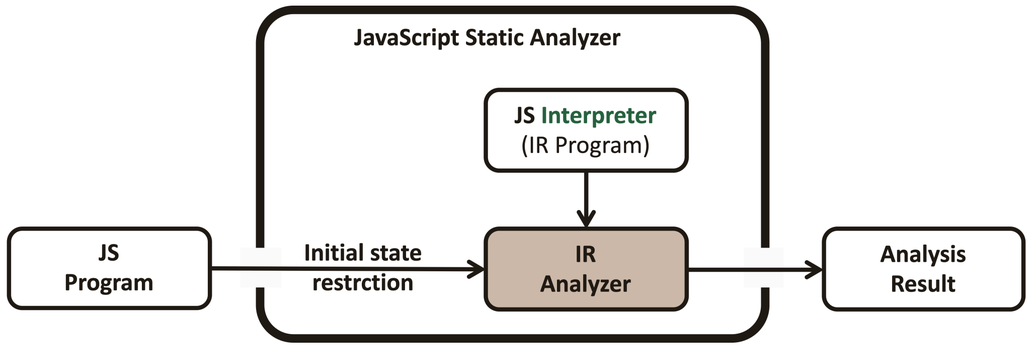
(a) The analysis precision



(b) The analysis performance

Core Idea - Meta-level Static Analysis

Interpreter-based Approach



AST Sensitivity

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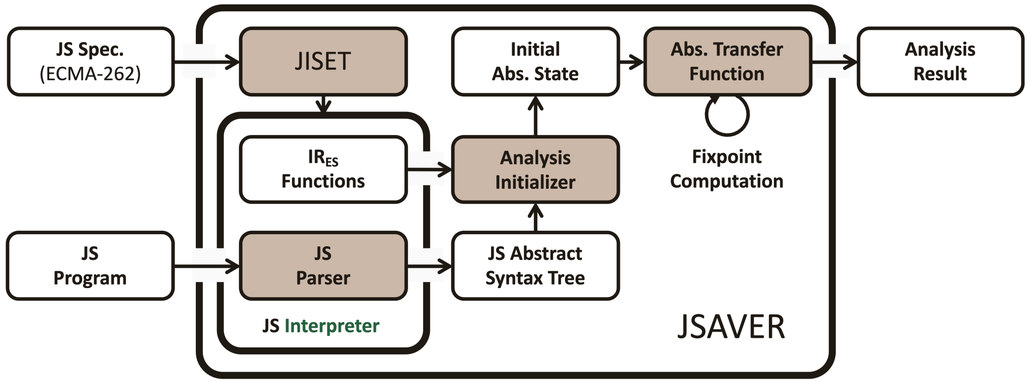
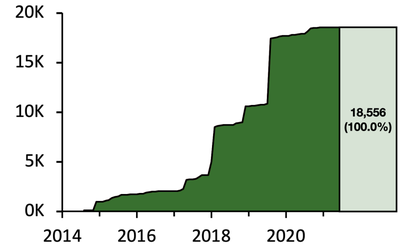
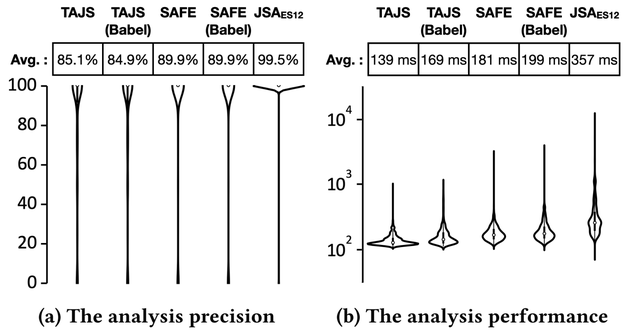


RQ1) Soundness



RQ2) Precision & Performance



(a) The analysis precision (b) The analysis performance