JISET: JavaScript IR-based Semantics Extraction Toolchain

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PLRG @ KAIST

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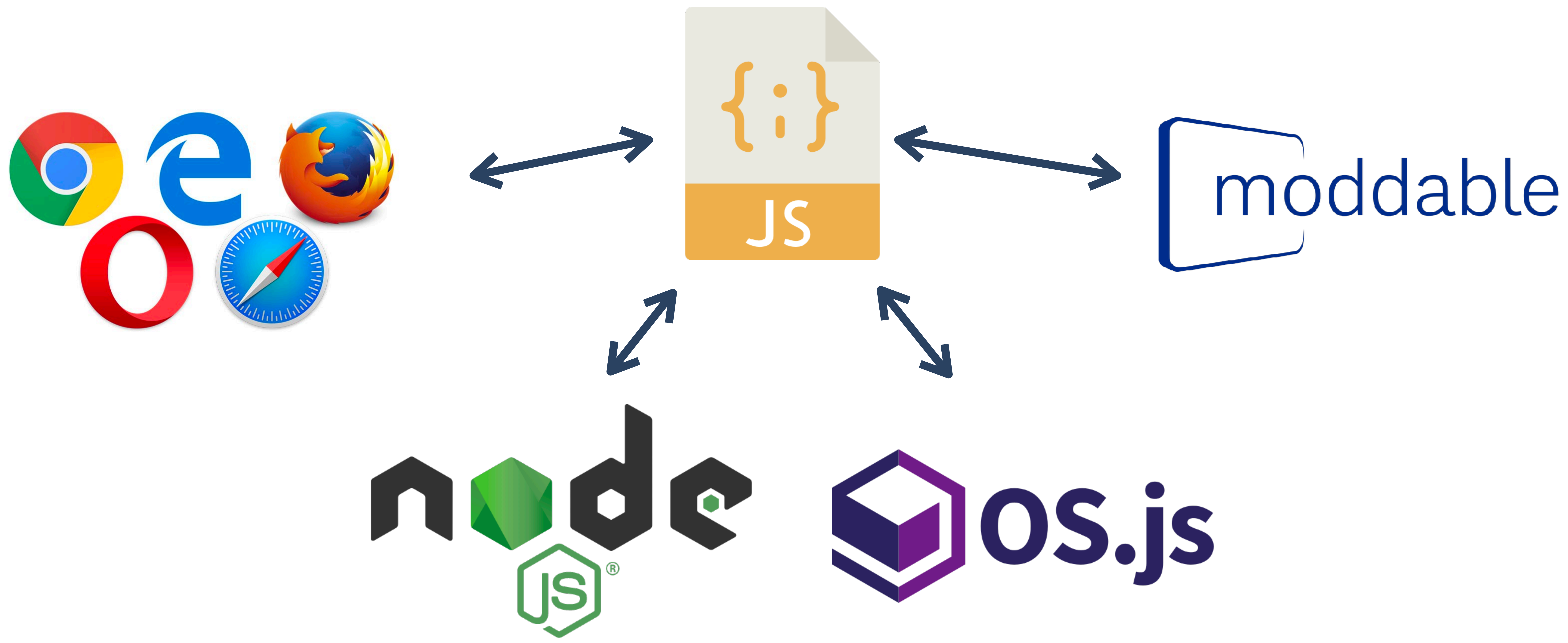
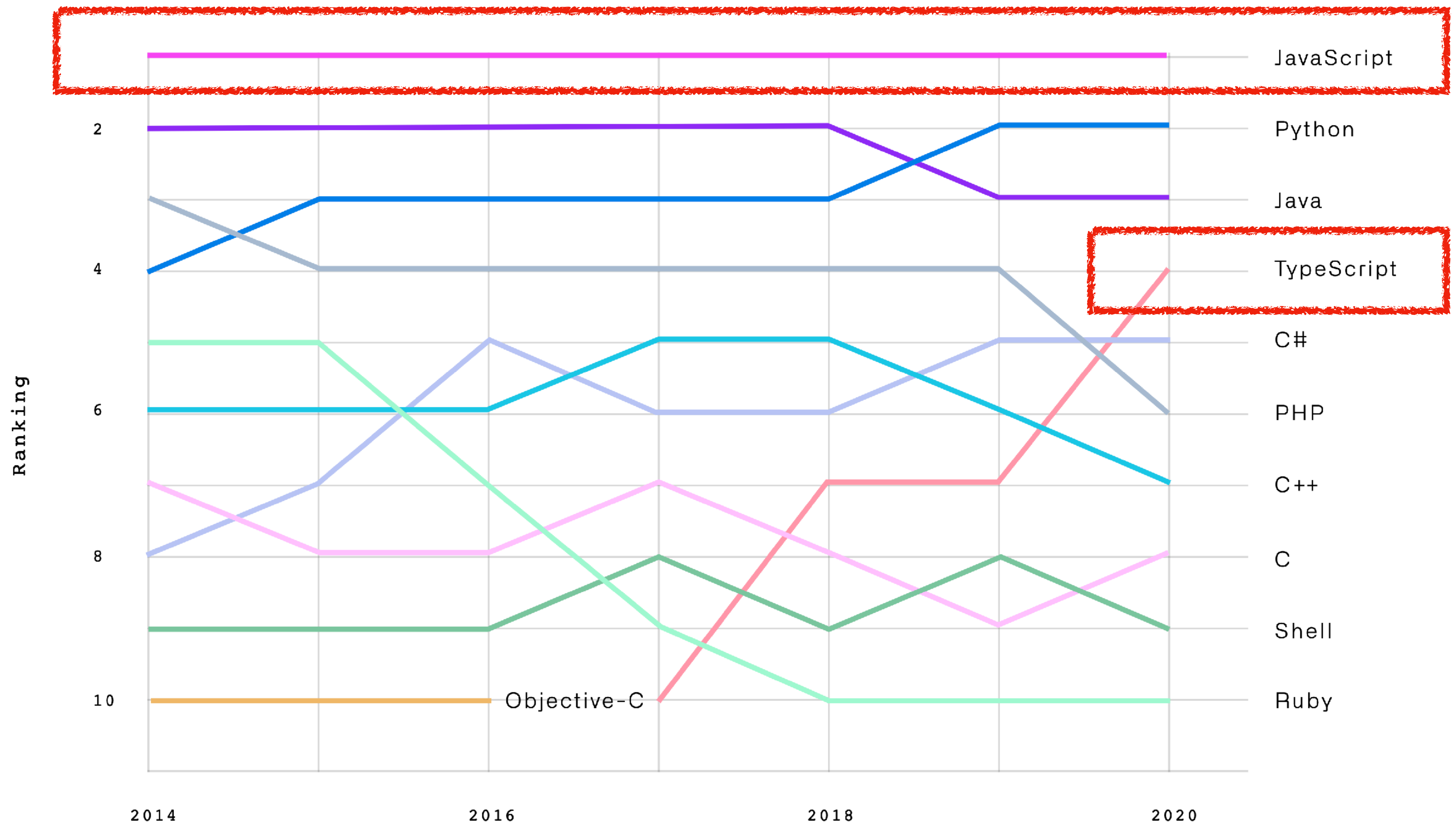
June 23, 2021

JavaScript is Everywhere



JavaScript is Dominating



https://octoverse.github.com/

JavaScript Complex Semantics

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

Always return `false`?

JavaScript Complex Semantics

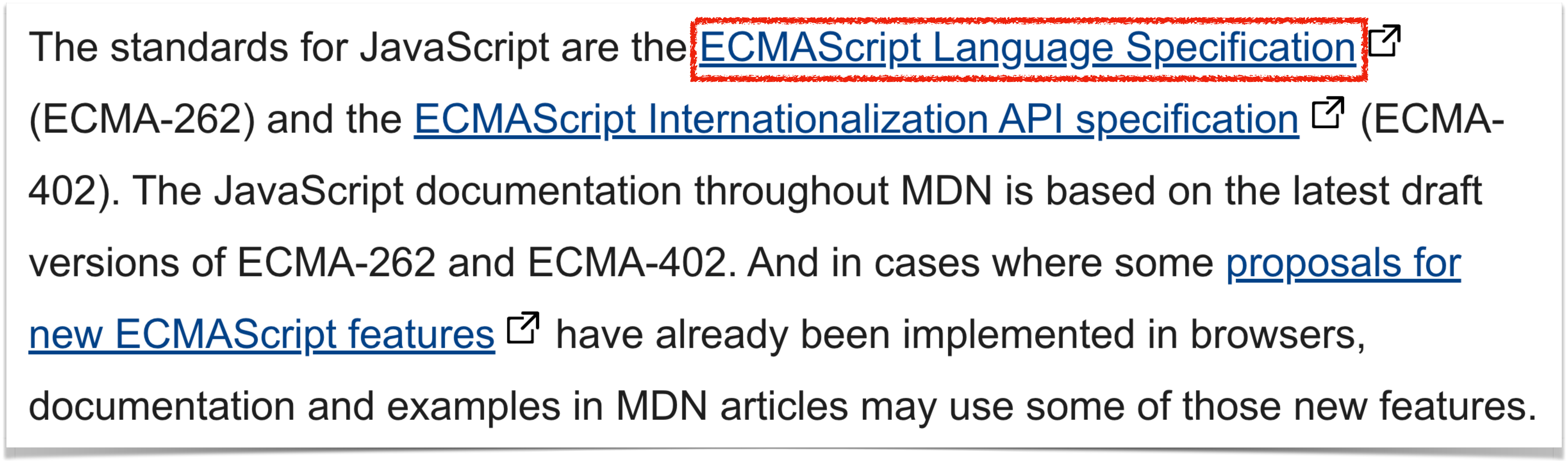
```
function f(x) { return x == !x; }
```

Always return `false`?

NO!!

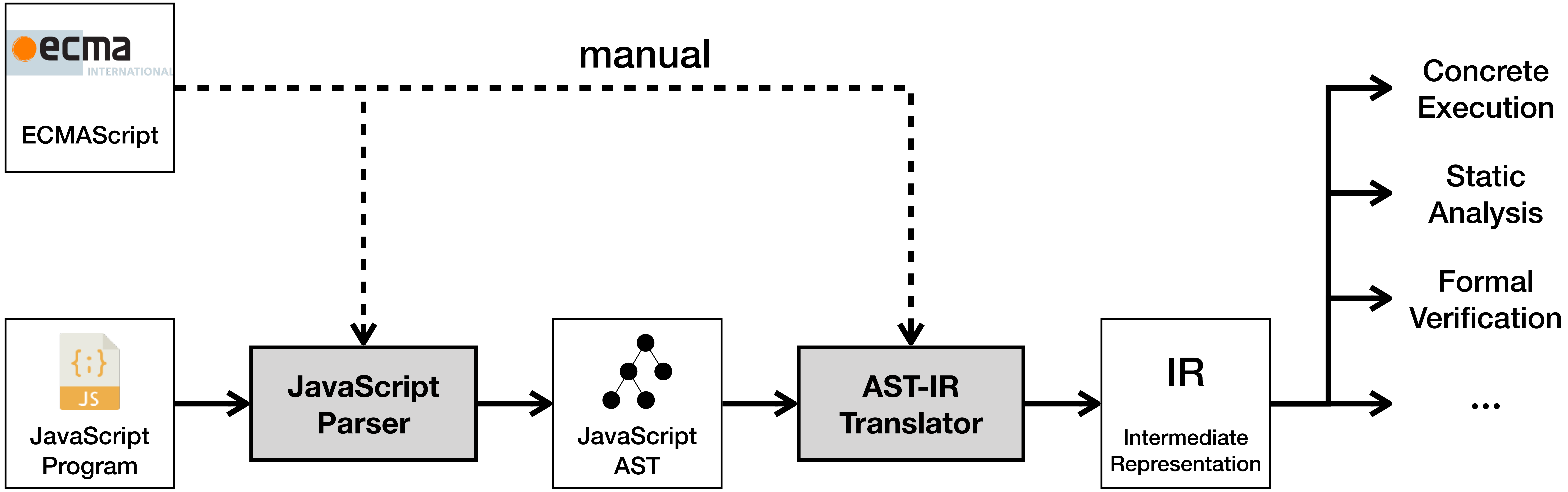
```
f([]) -> [] == ![]
      -> [] == false
      -> +[] == +false
      -> 0 == 0
      -> true
```

ECMAScript: JavaScript Specification

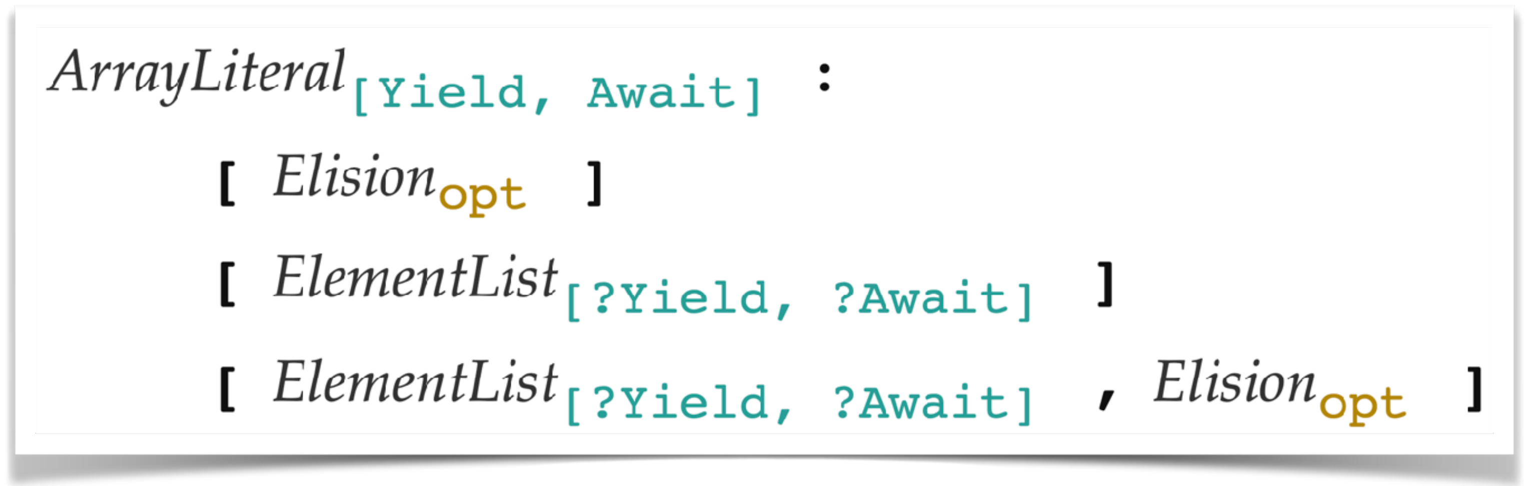

The standards for JavaScript are the ECMAScript Language Specification (ECMA-262) and the ECMAScript Internationalization API specification (ECMA-402). The JavaScript documentation throughout MDN is based on the latest draft versions of ECMA-262 and ECMA-402. And in cases where some proposals for new ECMAScript features have already been implemented in browsers, documentation and examples in MDN articles may use some of those new features.

https://developer.mozilla.org/en-US/docs/Web/JavaScript

IR-based Semantics Extraction

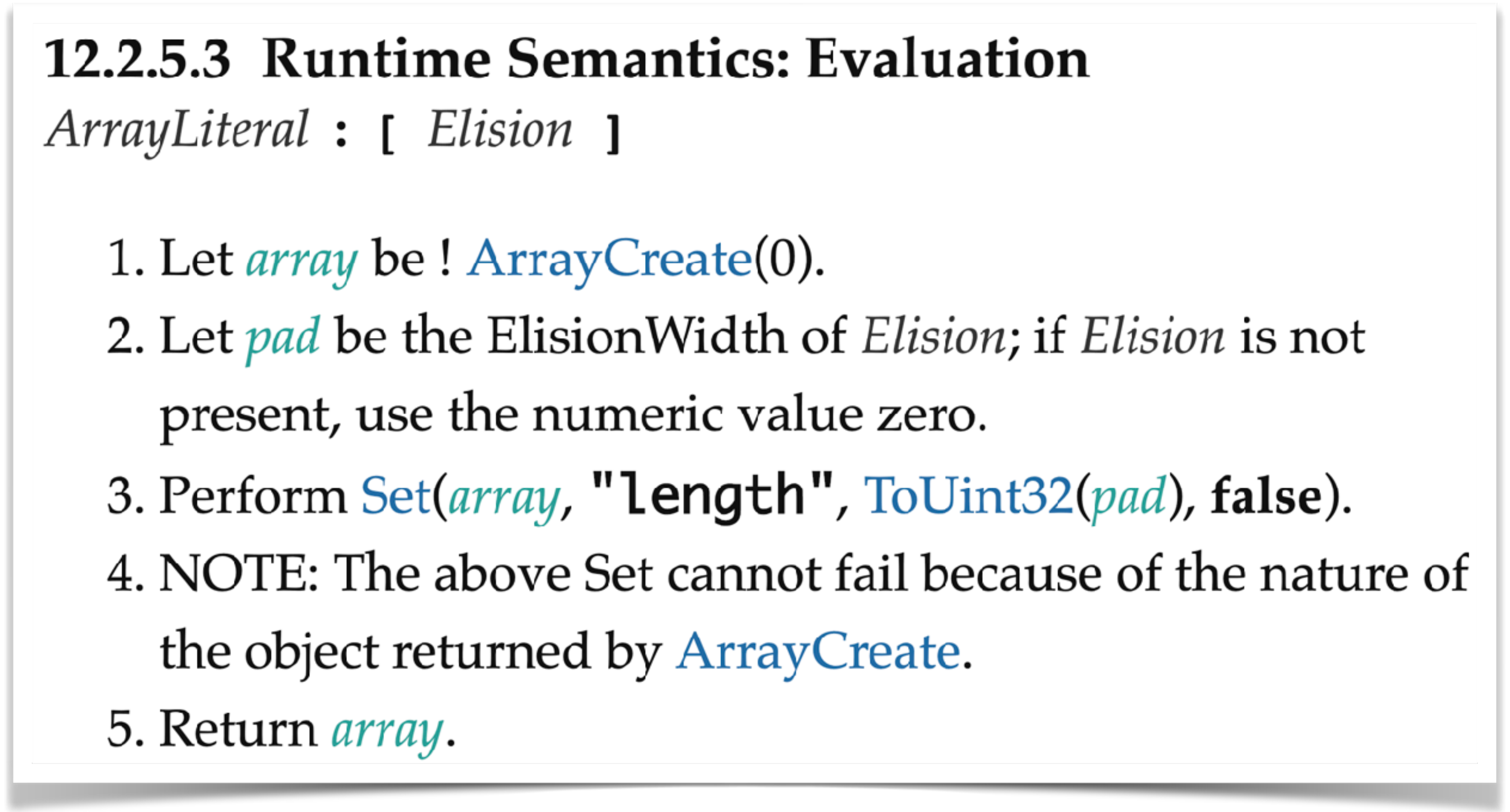


IR-based Semantics Extraction



ArrayLiteral`[Yield, Await]` :
  `[` *Elision*`opt` `]`
  `[` *ElementList*`[?Yield, ?Await]` `]`
  `[` *ElementList*`[?Yield, ?Await]` `,` *Elision*`opt` `]`

The production of *ArrayLiteral* in ES10

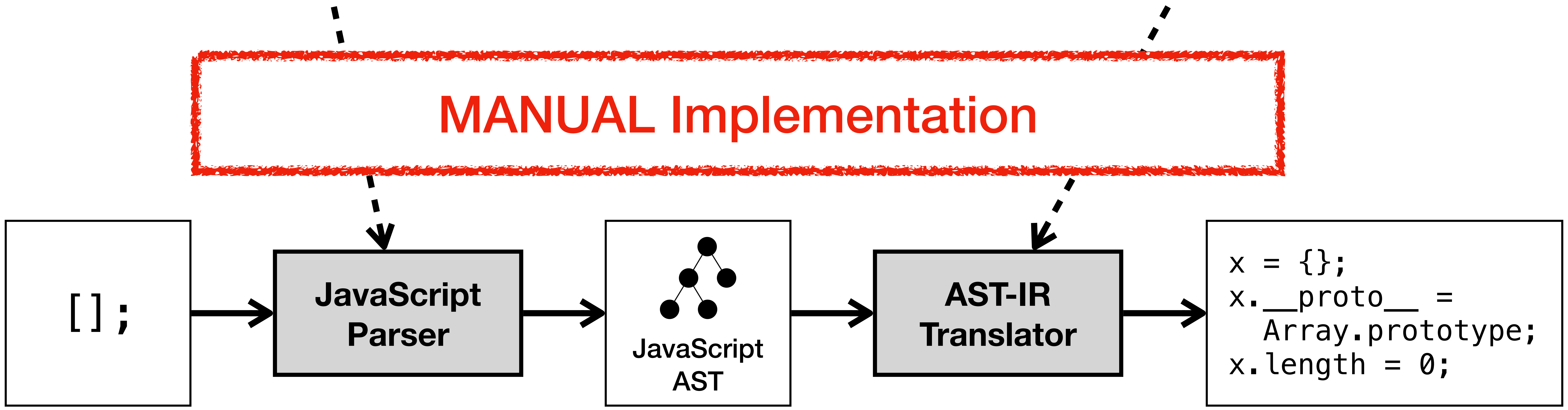


12.2.5.3 Runtime Semantics: Evaluation

ArrayLiteral : `[` *Elision* `]`

1. Let *array* be ! ArrayCreate(0).
2. Let *pad* be the ElisionWidth of *Elision*; if *Elision* is not present, use the numeric value zero.
3. Perform Set(*array*, `"length"`, ToUint32(*pad*), **false**).
4. NOTE: The above Set cannot fail because of the nature of the object returned by ArrayCreate.
5. Return *array*.

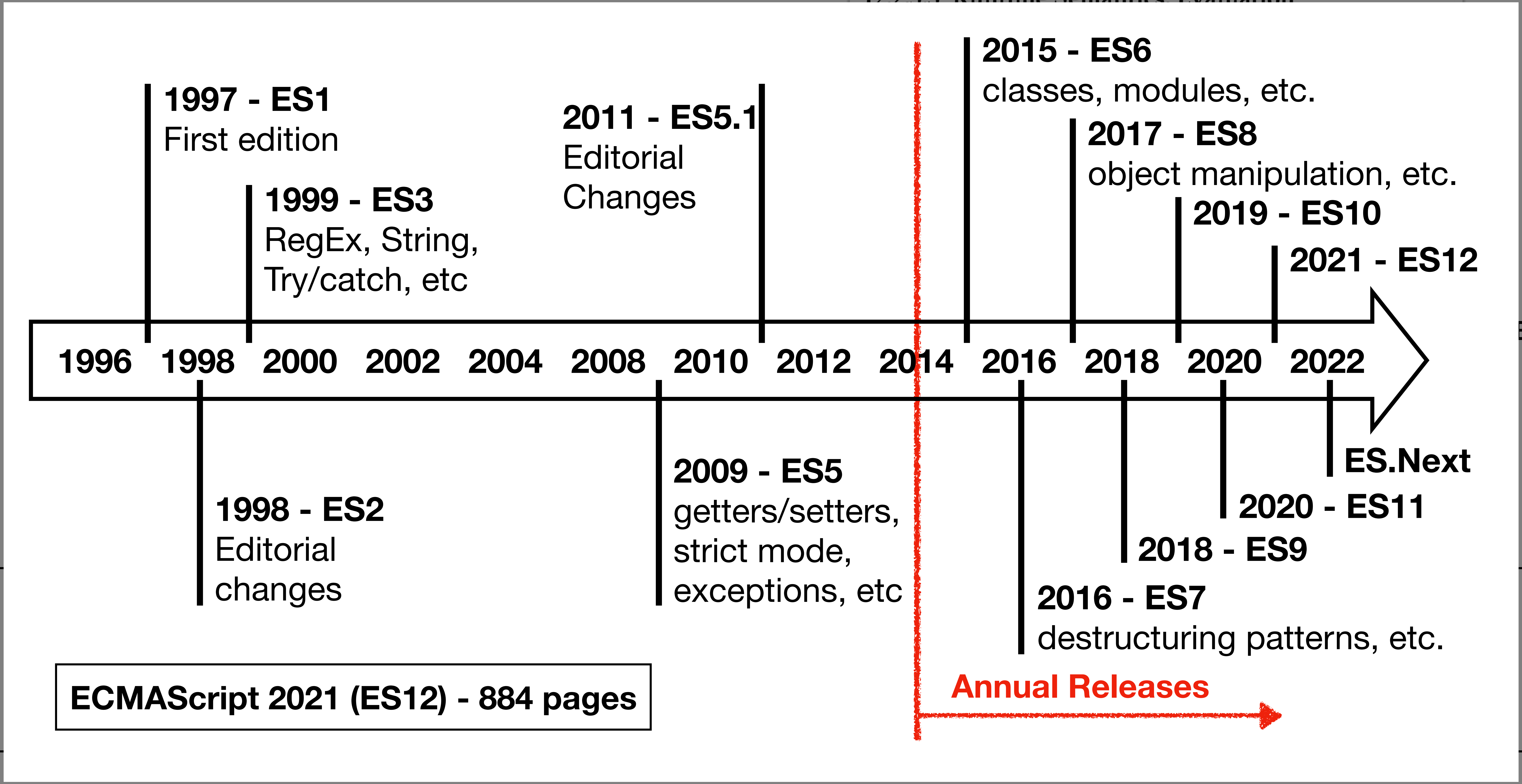
The Evaluation algorithm for the first alternative of *ArrayLiteral* in ES10



```
x = {};
x.__proto__ =
  Array.prototype;
x.length = 0;
```

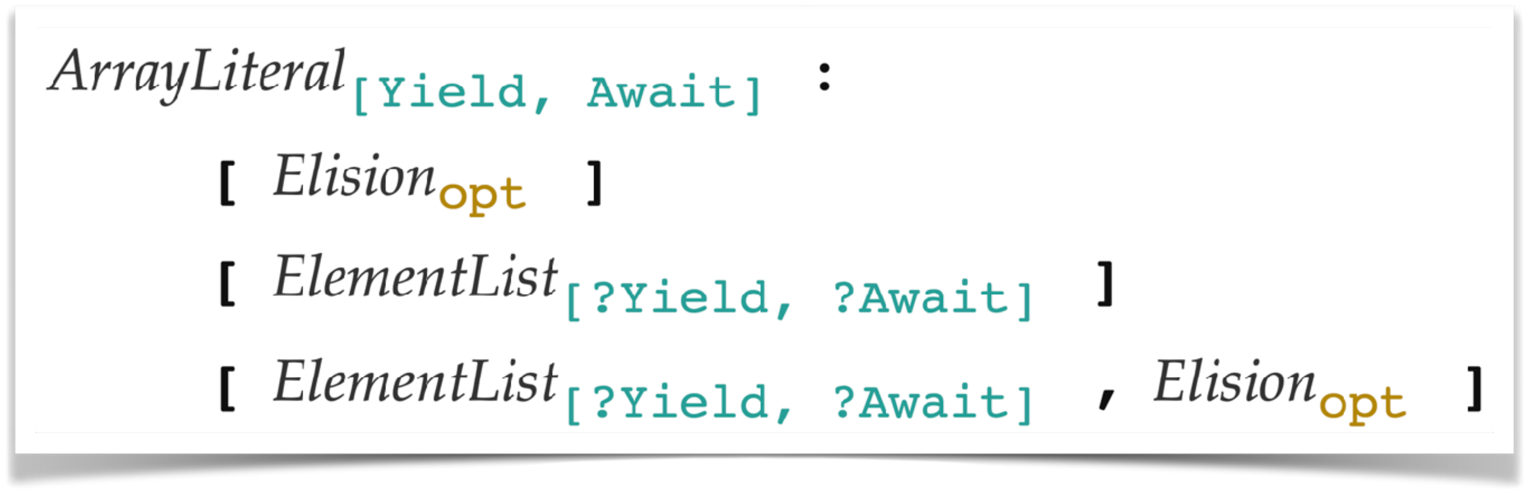
IR-based Semantics Extraction

12.2.5.3 Runtime Semantics: Evaluation



ES10

Our Approach



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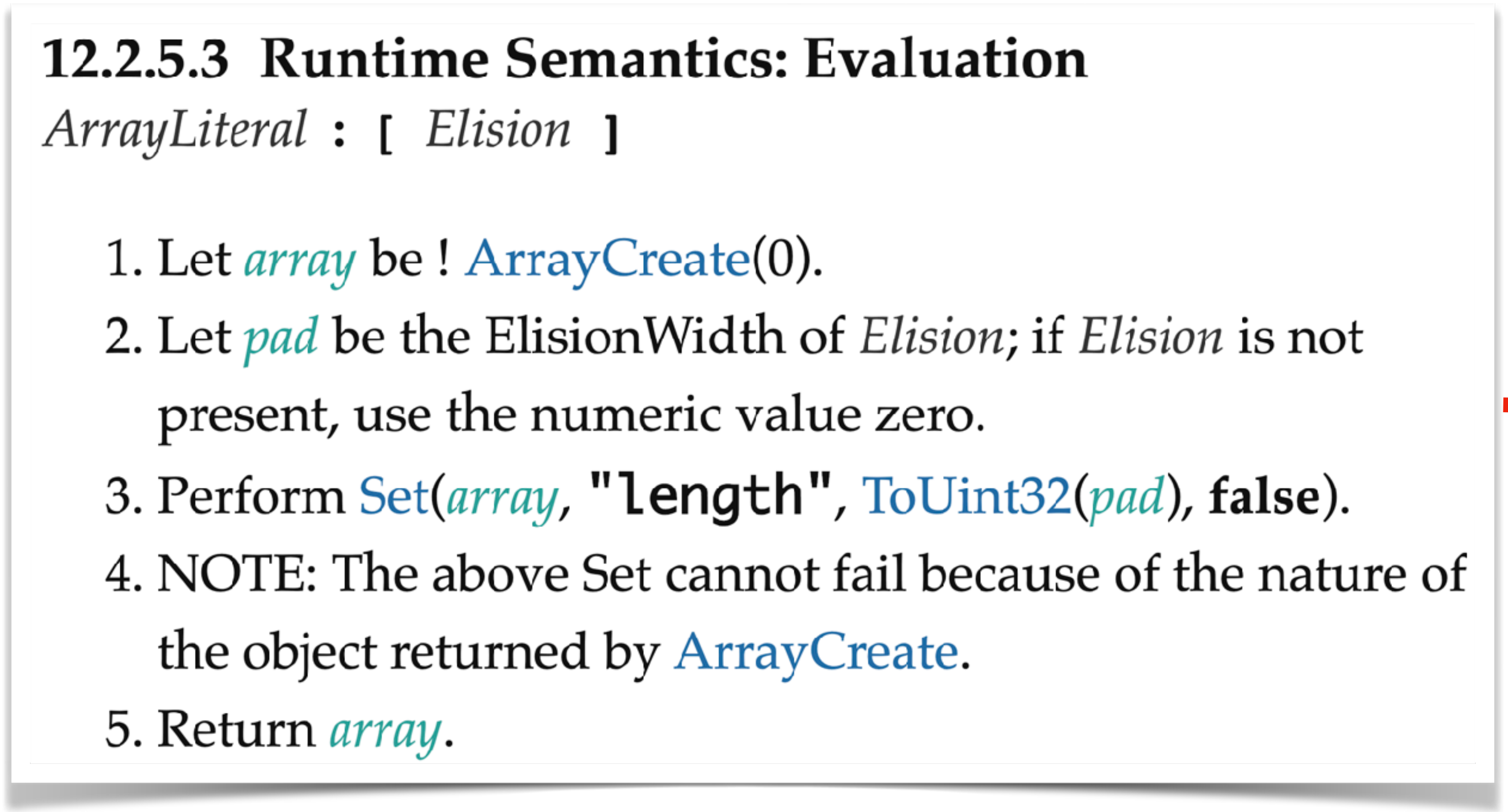
The production of *ArrayLiteral* in ES10



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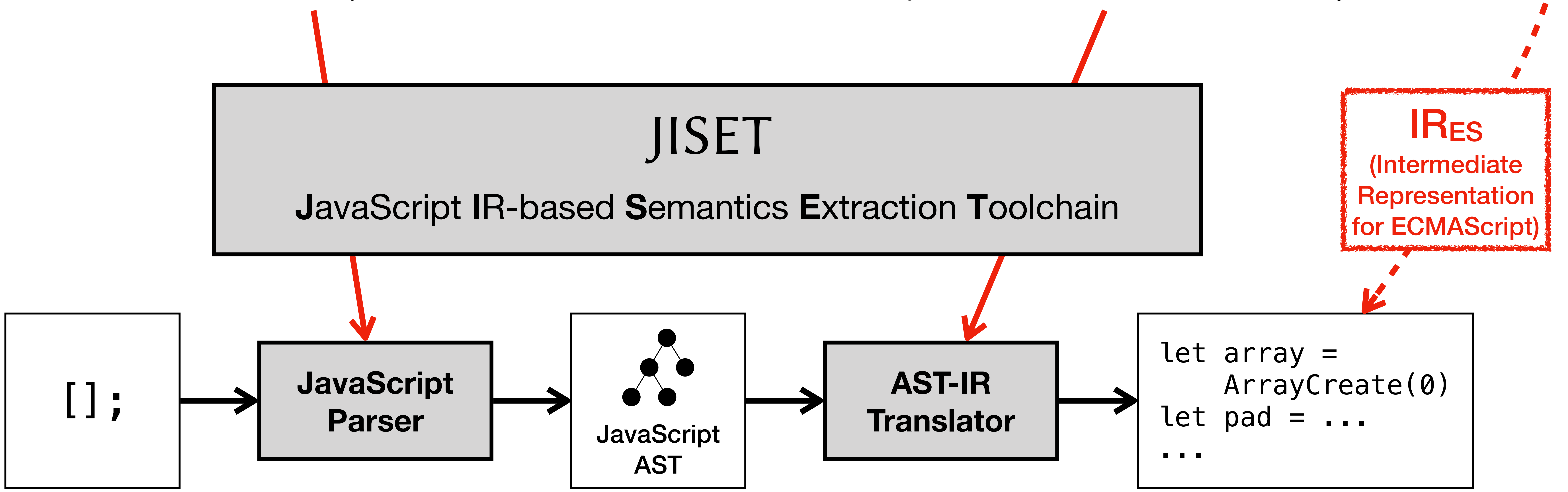
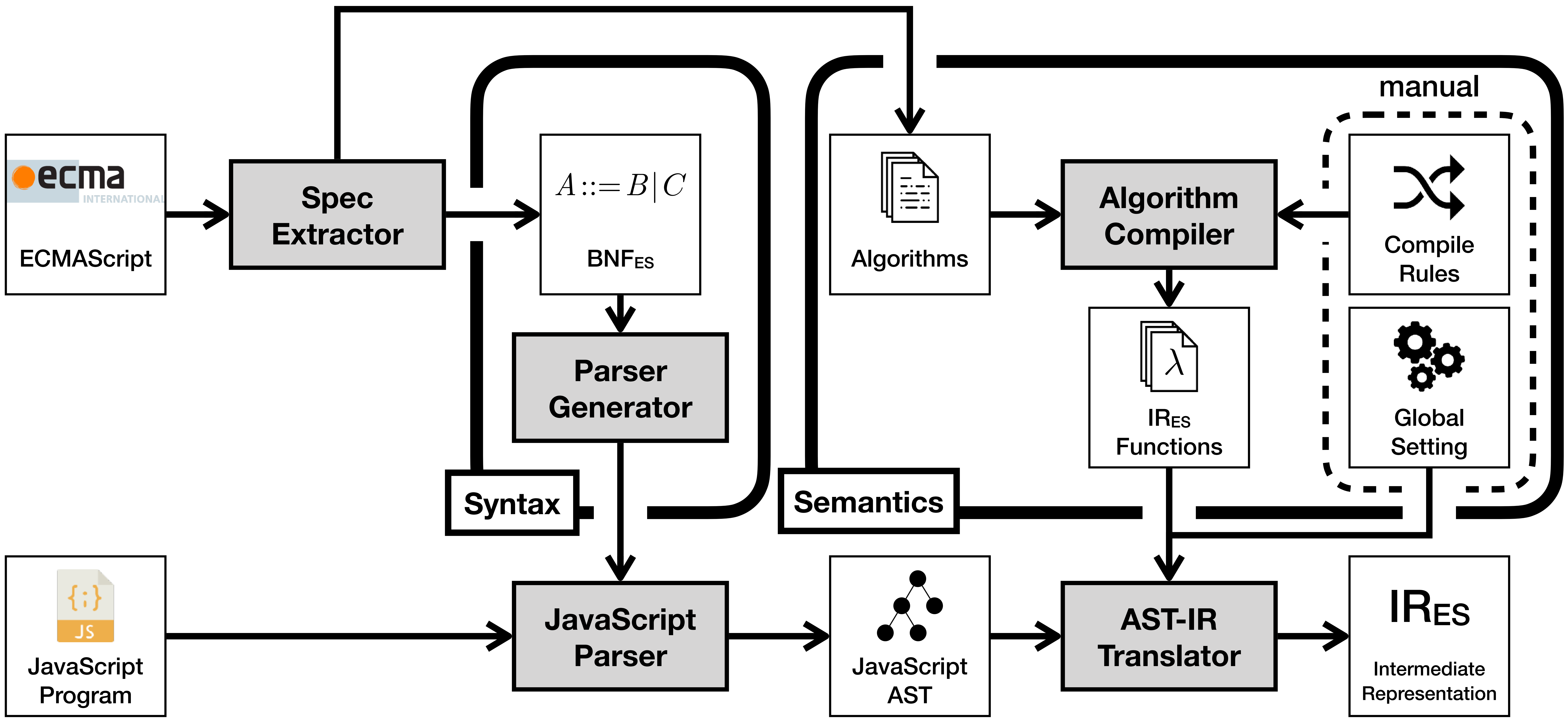

JISET
JavaScript IR-based Semantics Extraction Toolchain
IR_ES
(Intermediate Representation for ECMAScript)
[];
JavaScript Parser
JavaScript AST
AST-IR Translator

```
let array =
    ArrayCreate(0)
let pad = ...
...
```

Overall Structure of JISET



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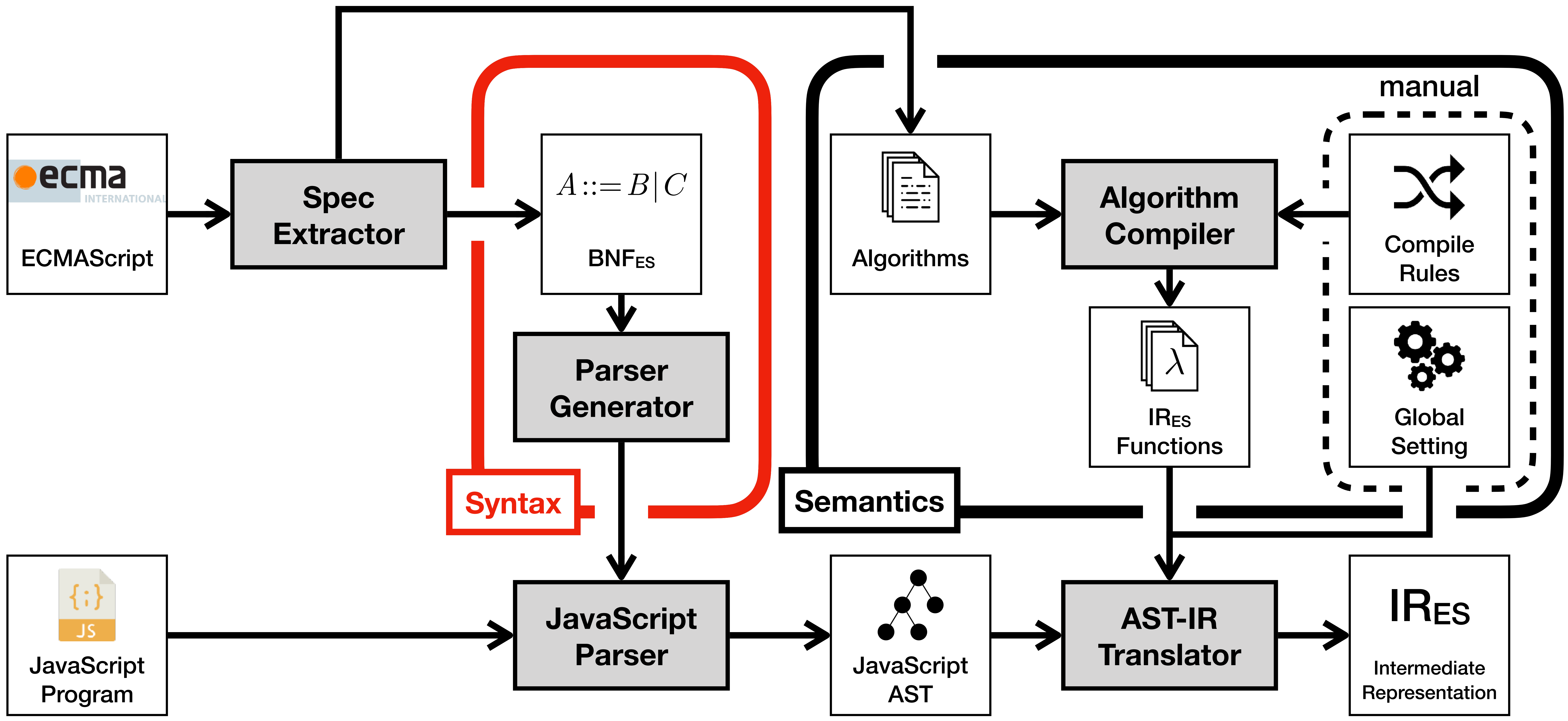
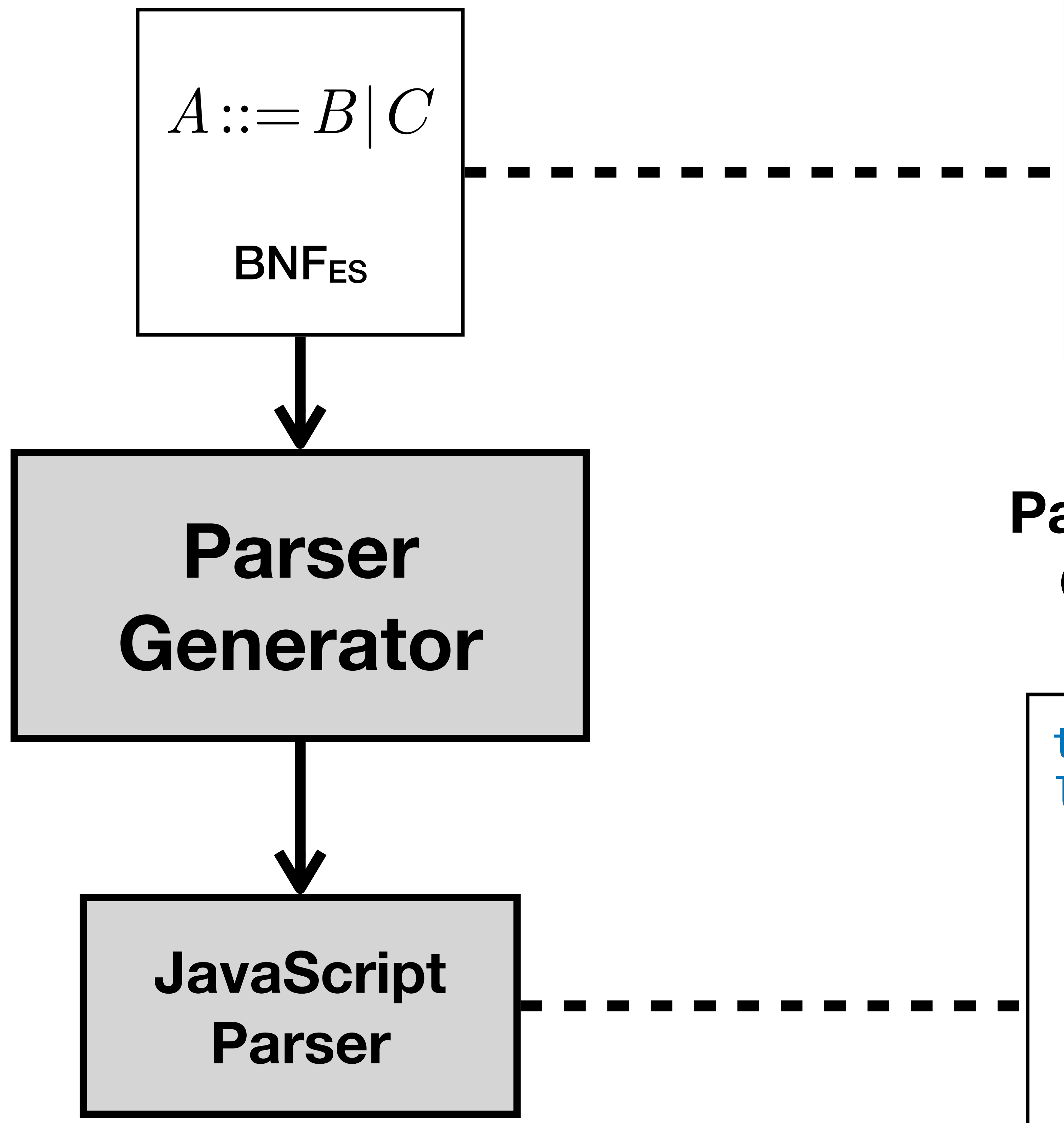
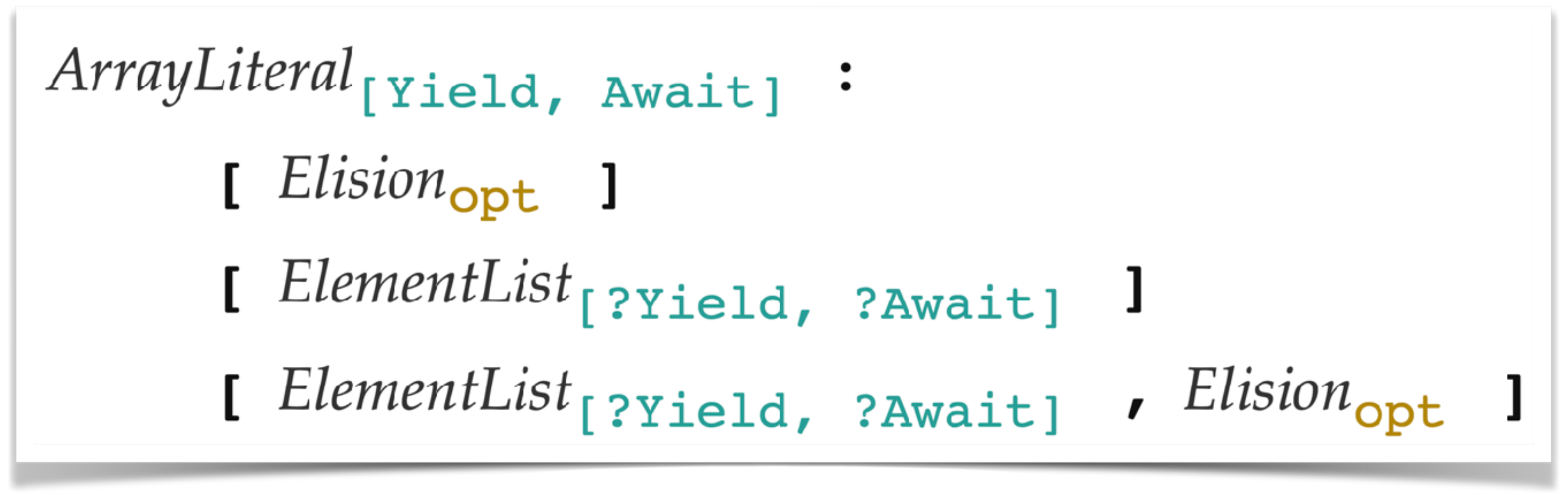


Syntax - Parser Synthesis





ArrayLiteral`[Yield, Await]` **:**

  [*Elision*`opt` **]**

  [*ElementList*`[?Yield, ?Await]` **]**

  [*ElementList*`[?Yield, ?Await]` **,** *Elision*`opt` **]**

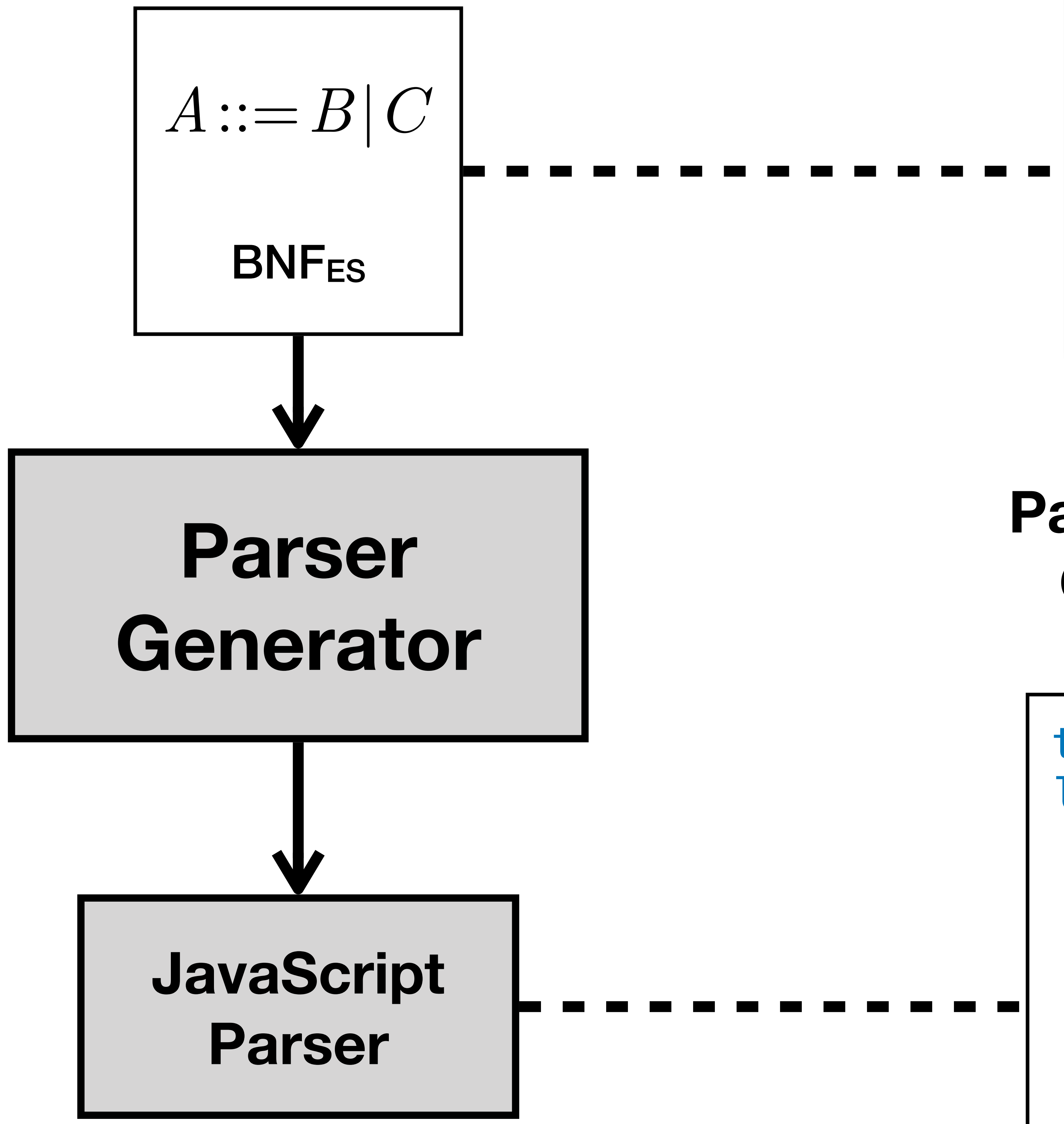
The production of *ArrayLiteral* in ES10

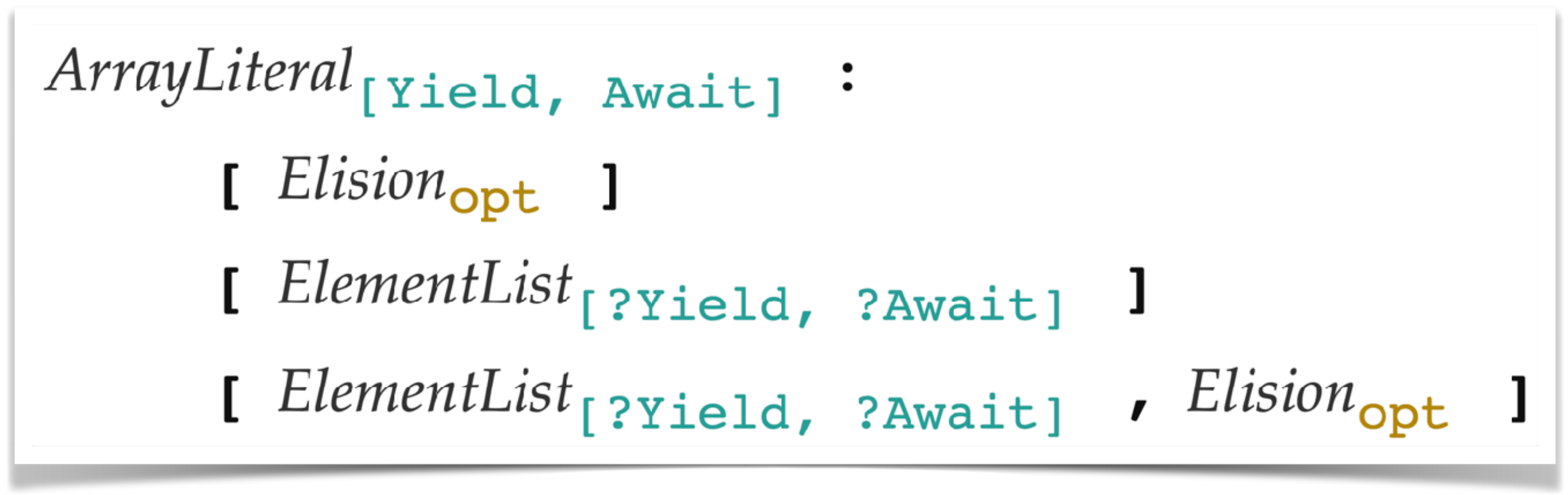
Parsing Expression Grammar (PEG)

```
type P[T] = List[Boolean] => LAParser[T]
lazy val ArrayLiteral: P[ArrayLiteral] = memo {
  case List(Yield, Await) =>
  "[" ~ opt(Elision) ~ "]"
      ^^ ArrayLiteral0 |
  "[" ~ ElementList(Yield, Await) ~ "]"
      ^^ ArrayLiteral1 |
  "[" ~ ElementList(Yield, Await)
      ~ "," ~ opt(Elision) ~ "]"
      ^^ ArrayLiteral2
}
```

The generated parser for *ArrayLiteral* in ES10

Syntax - Parser Synthesis

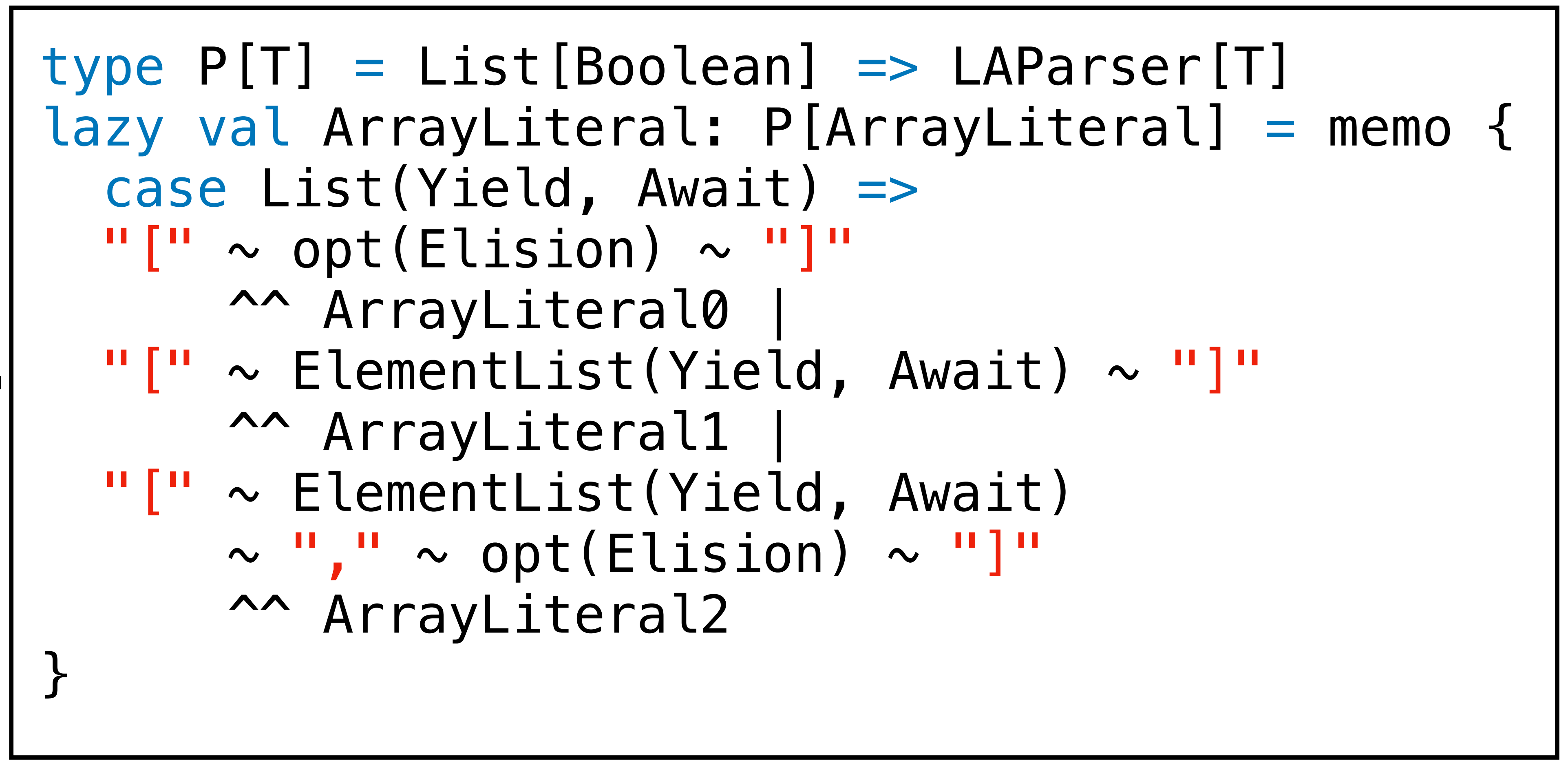




ArrayLiteral`[Yield, Await]` :
  `[` *Elision*`opt` `]`
  `[` *ElementList*`[?Yield, ?Await]` `]`
  `[` *ElementList*`[?Yield, ?Await]` `,` *Elision*`opt` `]`

The production of *ArrayLiteral* in ES10

Parsing Expression Grammar (PEG) + **Lookahead Parsing**



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lazy val ArrayLiteral: P[ArrayLiteral] = memo {
  case List(Yield, Await) =>
  "[" ~ opt(Elision) ~ "]"
      ^^ ArrayLiteral0 |
  "[" ~ ElementList(Yield, Await) ~ "]"
      ^^ ArrayLiteral1 |
  "[" ~ ElementList(Yield, Await)
      ~ "," ~ opt(Elision) ~ "]"
      ^^ ArrayLiteral2
}
```

The generated parser for *ArrayLiteral* in ES10

Syntax - Lookahead Parsing

$$
\begin{aligned}
\mathbf{first}_\alpha(s_1 \cdots s_n) &= \mathbf{first}_s(s_1) :+ \mathbf{first}_s(s_2 \cdots s_n) \\
&\quad \text{where } x :+ y = \begin{cases} x \cup y & \text{if } \circ \in x \\ x & \text{otherwise} \end{cases} \\
\mathbf{first}_s(\epsilon) &= \{\circ\} \\
\mathbf{first}_s(\mathsf{a}) &= \{\mathsf{a}\} \\
\mathbf{first}_s(A(a_1, \cdots, a_k)) &= \mathbf{first}_\alpha(\alpha_1) \cup \cdots \cup \mathbf{first}_\alpha(\alpha_n) \\
&\quad \text{where } A(a_1, \cdots, a_k) = \alpha_1 \mid \cdots \mid \alpha_n \\
\mathbf{first}_s(s?) &= \mathbf{first}_s(s) \cup \{\circ\} \\
\mathbf{first}_s(+s) &= \mathbf{first}_s(s) \\
\mathbf{first}_s(-s) &= \{\circ\} \\
\mathbf{first}_s(s \setminus s') &= \mathbf{first}_s(s) \\
\mathbf{first}_s(\langle \neg \mathsf{LT} \rangle) &= \{\circ\}
\end{aligned}
$$

Algorithm for first tokens of BNF$_{\mathbf{ES}}$

Algorithm for lookahead parsing

$$
\begin{aligned}
(s_1 \cdots s_n)[L] &= s_1[\mathbf{first}_s(s_2 \cdots s_n) :+ L]\ (s_1 \cdots s_n)[L] \\
\epsilon[L] &= +\mathbf{get}_s(L) \\
\mathsf{a}[L] &= \mathsf{a}\ + \mathbf{get}_s(L) \\
A(a_1, \cdots, a_k)[L] &= \alpha_1[L] \mid \cdots \mid \alpha_n[L] \\
&\quad \text{where } A(a_1, \cdots, a_k) = \alpha_1 \mid \cdots \mid \alpha_n \\
s?[L] &= s[L] \mid \epsilon[L] \\
(\pm s)[L] &= \pm(s[L]) \\
(s \setminus s')[L] &= s[L] \setminus s' \\
\langle \neg \mathsf{LT} \rangle &= \langle \neg \mathsf{LT} \rangle\ + \mathbf{get}_s(L)
\end{aligned}
$$

Syntax - Evaluation

Version	ES7	ES8	ES9	ES10	Average
# Lexical productions	78	78	78	81	78.75
# Syntactic productions	157	167	167	174	166.25

Old version	ES7	ES8	ES9	Average
New version	ES8	ES9	ES10	
Δ # Lexical productions	3	5	6	4.67
Δ # Syntactic productions	140	15	8	54.33

Syntax - Evaluation

All Success!!

Version	ES7	ES8	ES9	ES10	Average
# Lexical productions	78	78	78	81	78.75
# Syntactic productions	157	167	167	174	166.25

Pass all parsing tests
in Test262

Old version	ES7	ES8	ES9	Average
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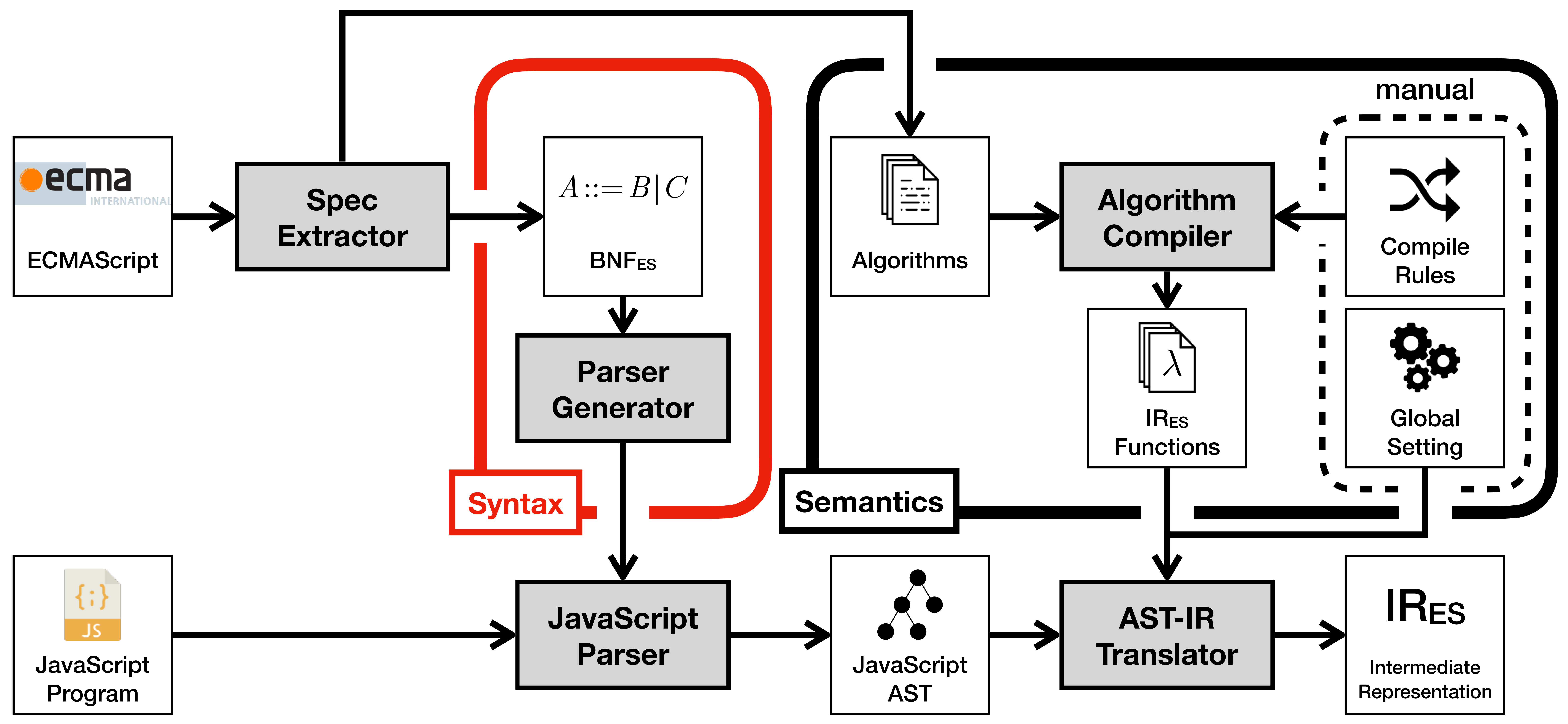
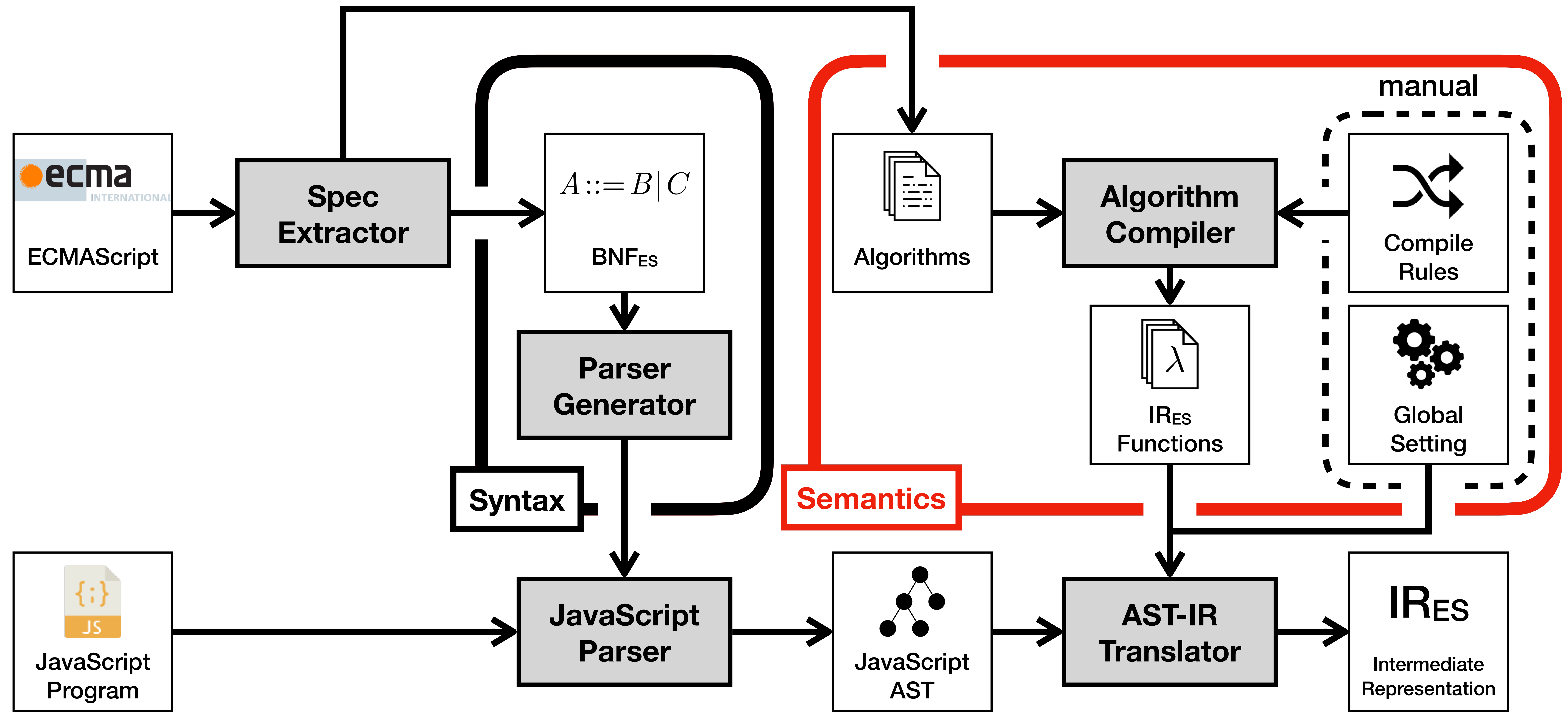
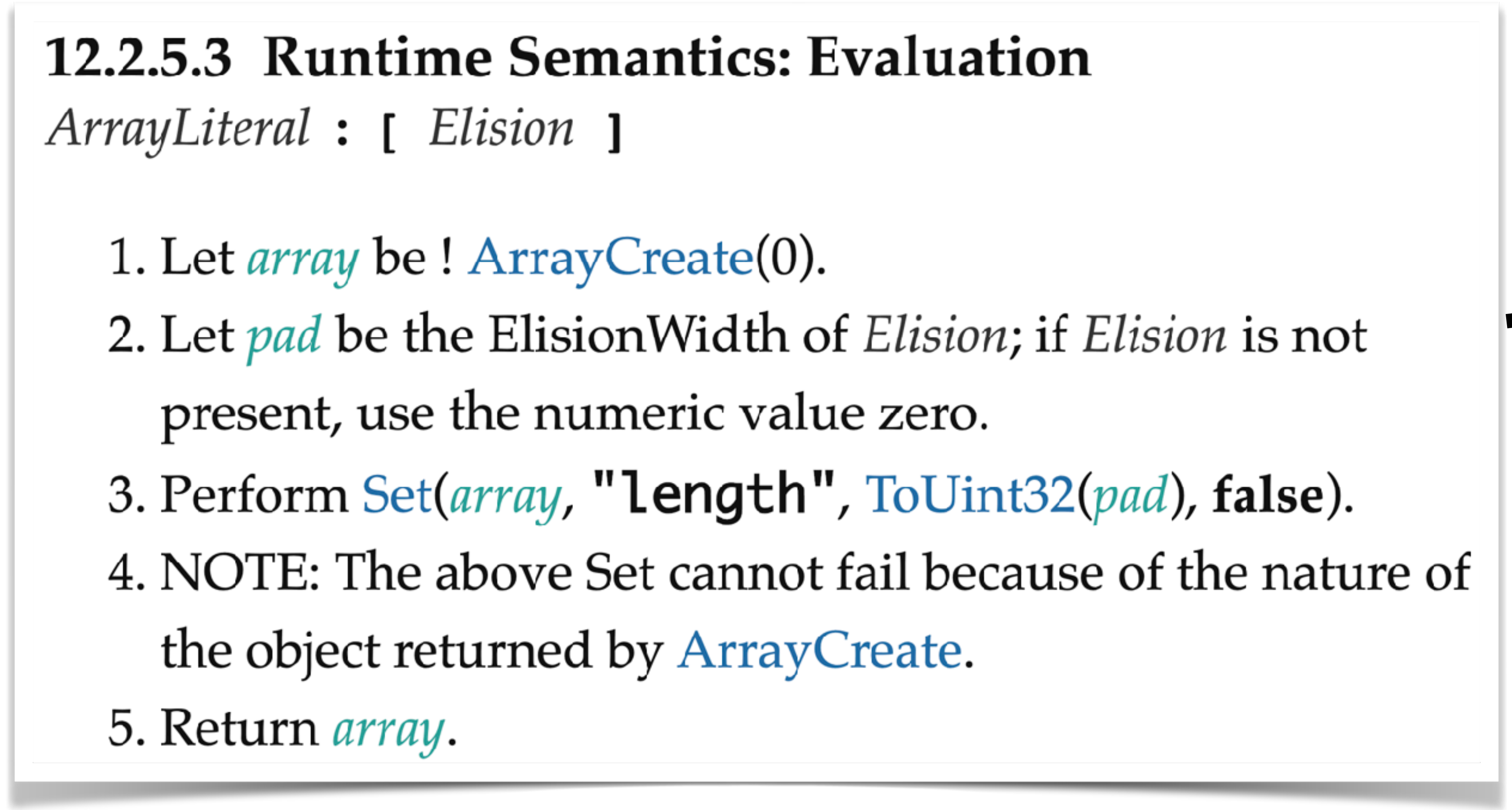


Overall Structure of JISET



Semantics - Algorithm Compilation



12.2.5.3 Runtime Semantics: Evaluation

ArrayLiteral : `[` *Elision* `]`

1. Let *array* be ! ArrayCreate(0).
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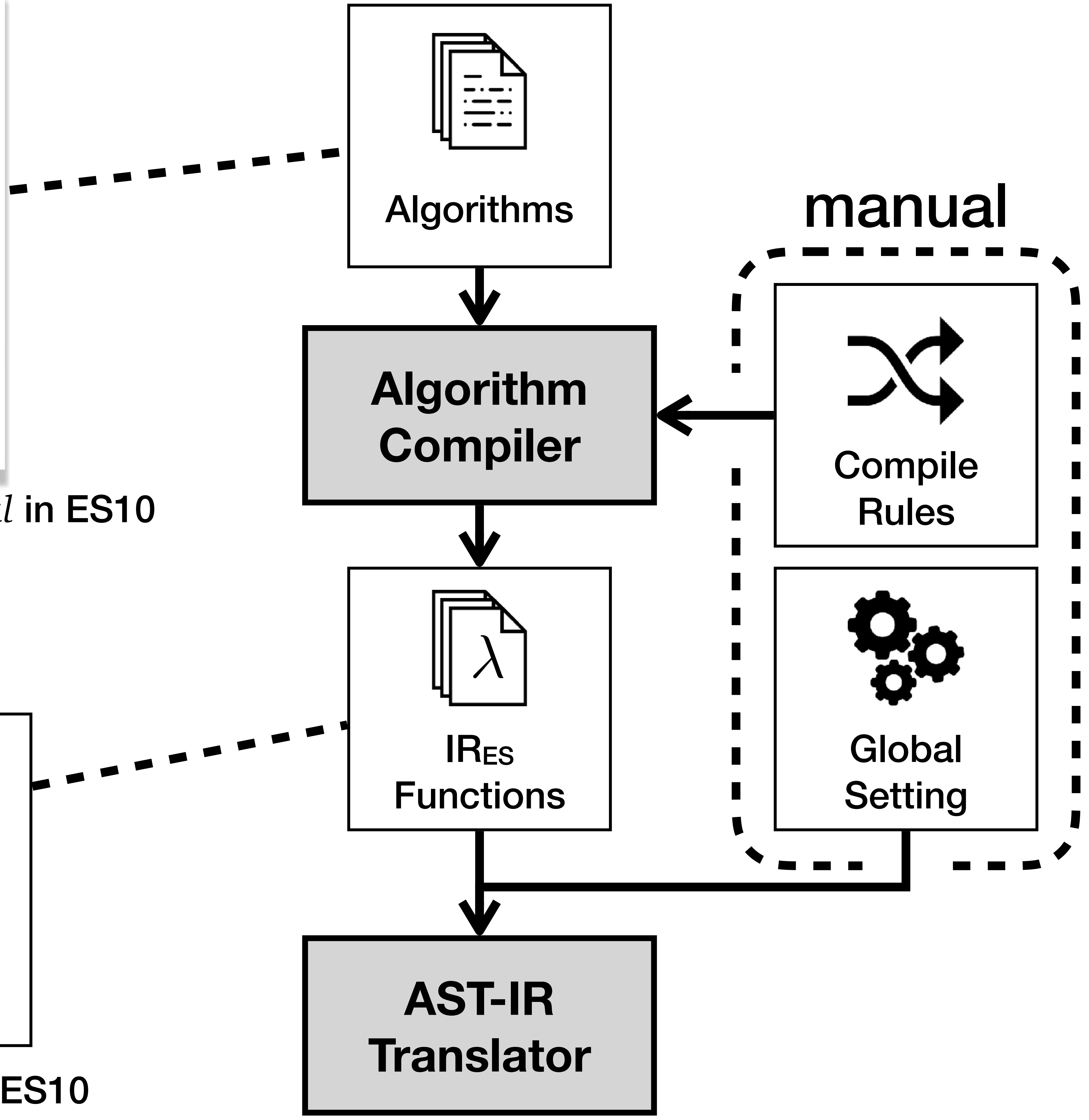
4. NOTE: The above Set cannot fail because of the nature of the object returned by ArrayCreate.
5. Return *array*.

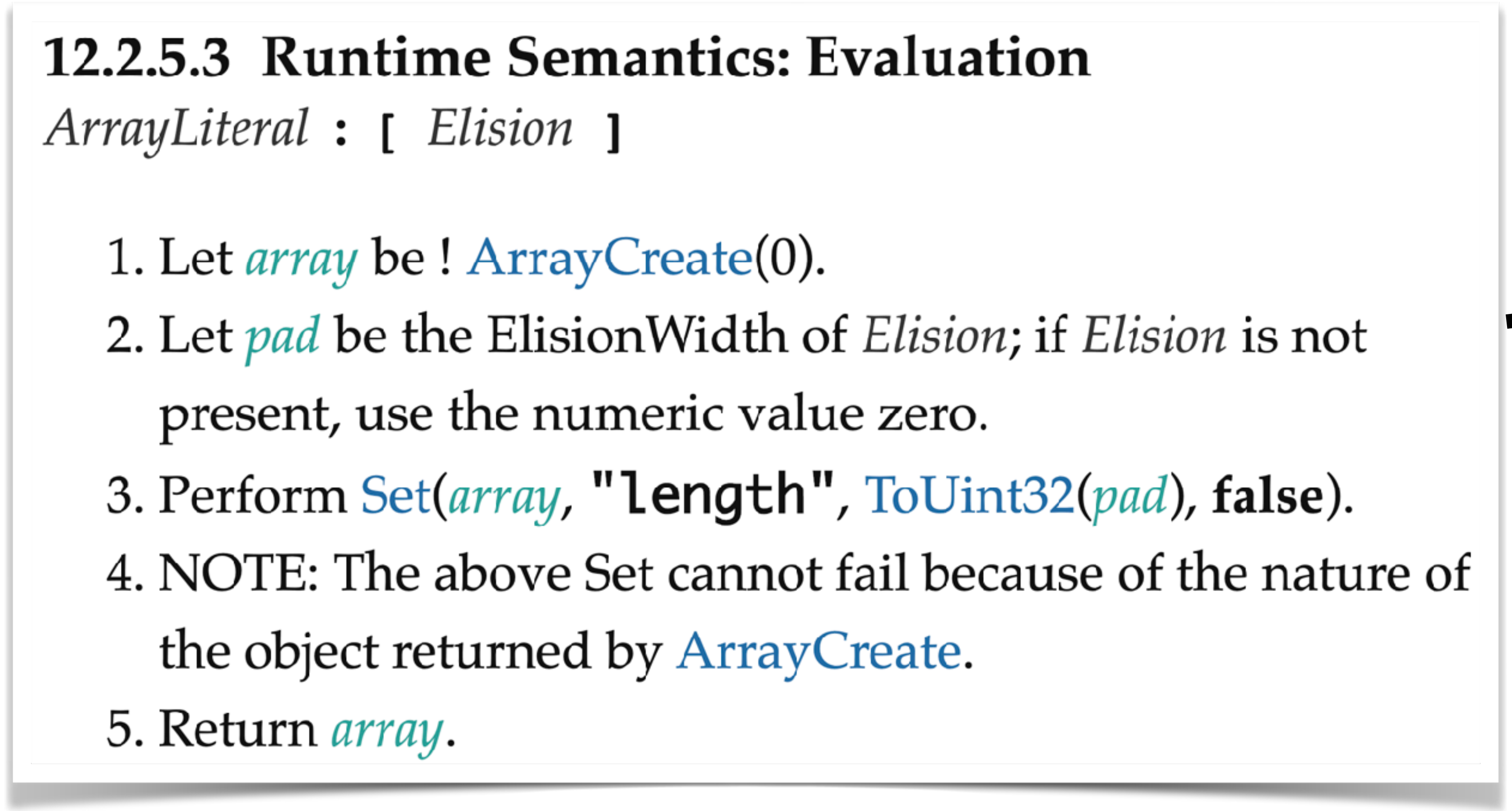
The Evaluation **algorithm for the first alternative of** *ArrayLiteral* **in ES10**

```
"ArrayLiteral0.Evaluation" (Elision) => {
  let array = ! (ArrayCreate 0)
  if (= Elision absent) let pad = 0
  else let pad = Elision.ElisionWidth
  (Set array "length" (ToUint32 pad) false)
  return array
}
```

The IR$_{\text{ES}}$ **function of the first alternative of** *ArrayLiteral* **in ES10**



Semantics - Algorithm Compilation



12.2.5.3 Runtime Semantics: Evaluation

ArrayLiteral : [*Elision*]

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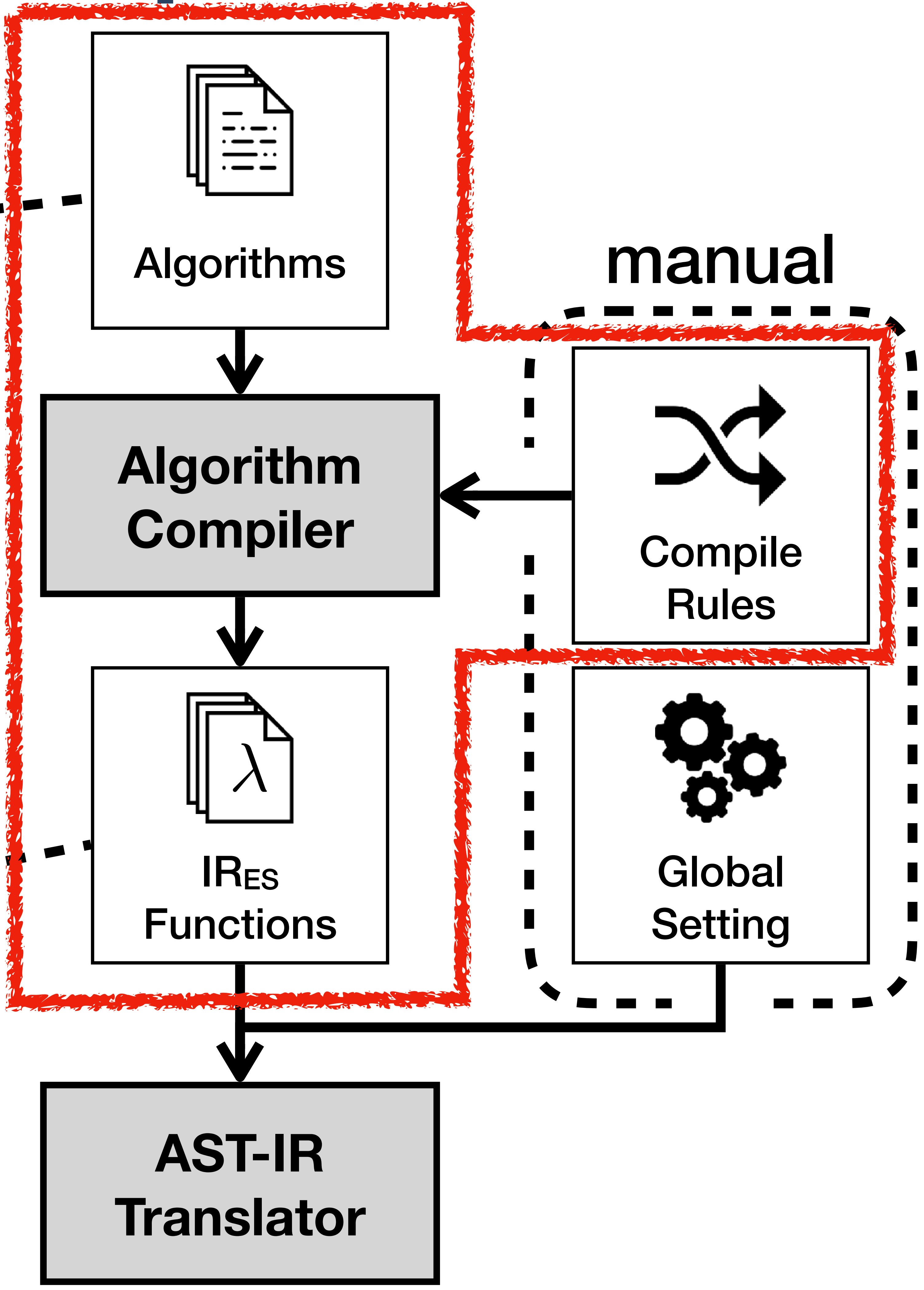

Parsing rules   Conversion Rules

```
S = // statements
  Let ~ V ~ be ~ E ~ . ^^ ILet

E = // expressions
  ! E                  ^^ EAbruptCheck |
  str ~ ( ~ E ~ )      ^^ ECall        |
  num                  ^^ _.toDouble
```

Simplified compile rules

Let *array* be ! ArrayCreate (0) .

Parsing rules Conversion Rules

```
S = // statements
  Let ~ V ~ be ~ E ~ . ^^ ILet

E = // expressions
  ! E                 ^^ EAbruptCheck |
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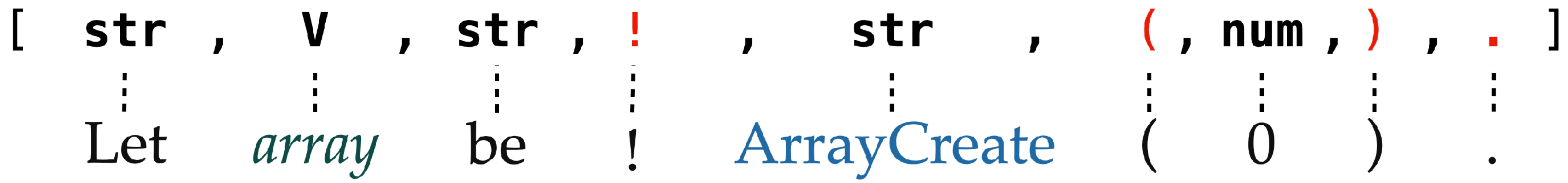
Simplified compile rules



Parsing rules   Conversion Rules

```
S = // statements
  Let ~ V ~ be ~ E ~ .  ^^ ILet

E = // expressions
  ! E                   ^^ EAbruptCheck |
  str ~ ( ~ E ~ )       ^^ ECall        |
  num                   ^^ _.toDouble
```

Simplified compile rules

```
[ str ,   V   , str , ! ,     str     , ( , num , ) , . ]
  Let   array   be    !   ArrayCreate   (    0    )   .
```

Parsing rules

Conversion Rules

```
S = // statements
  Let ~ V ~ be ~ E ~ .  ^^ ILet

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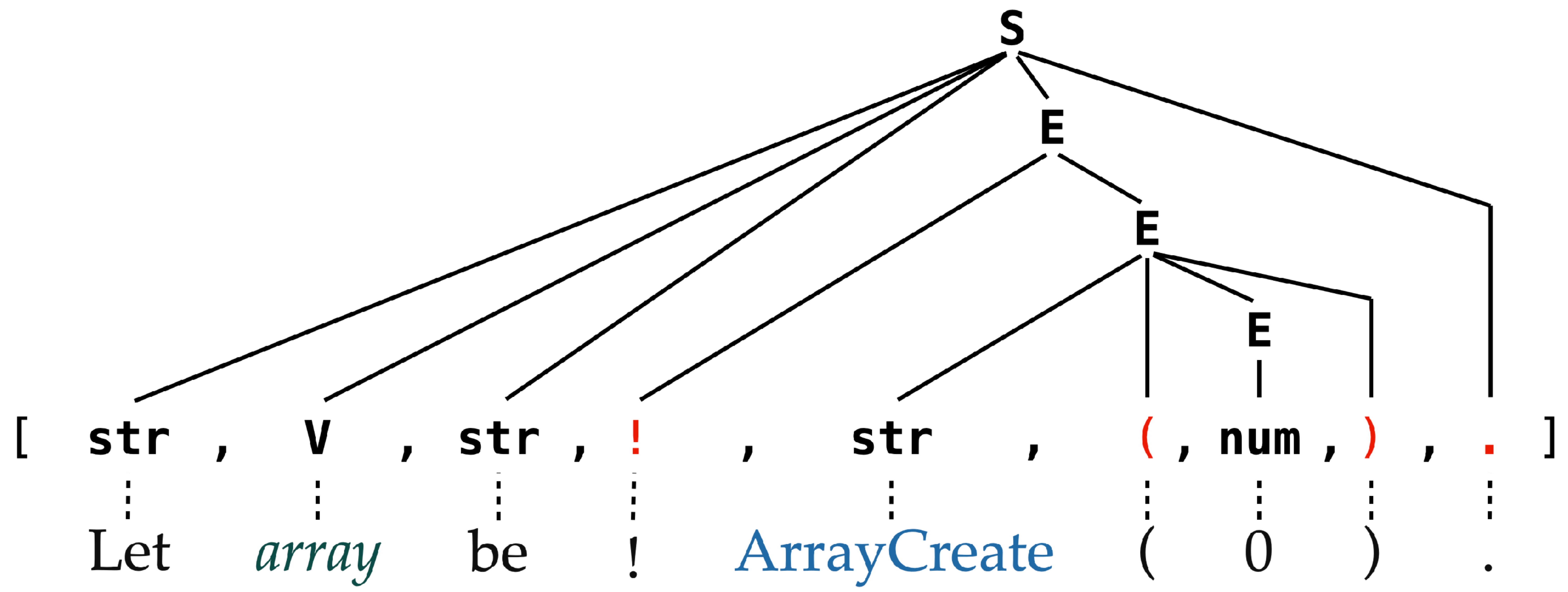

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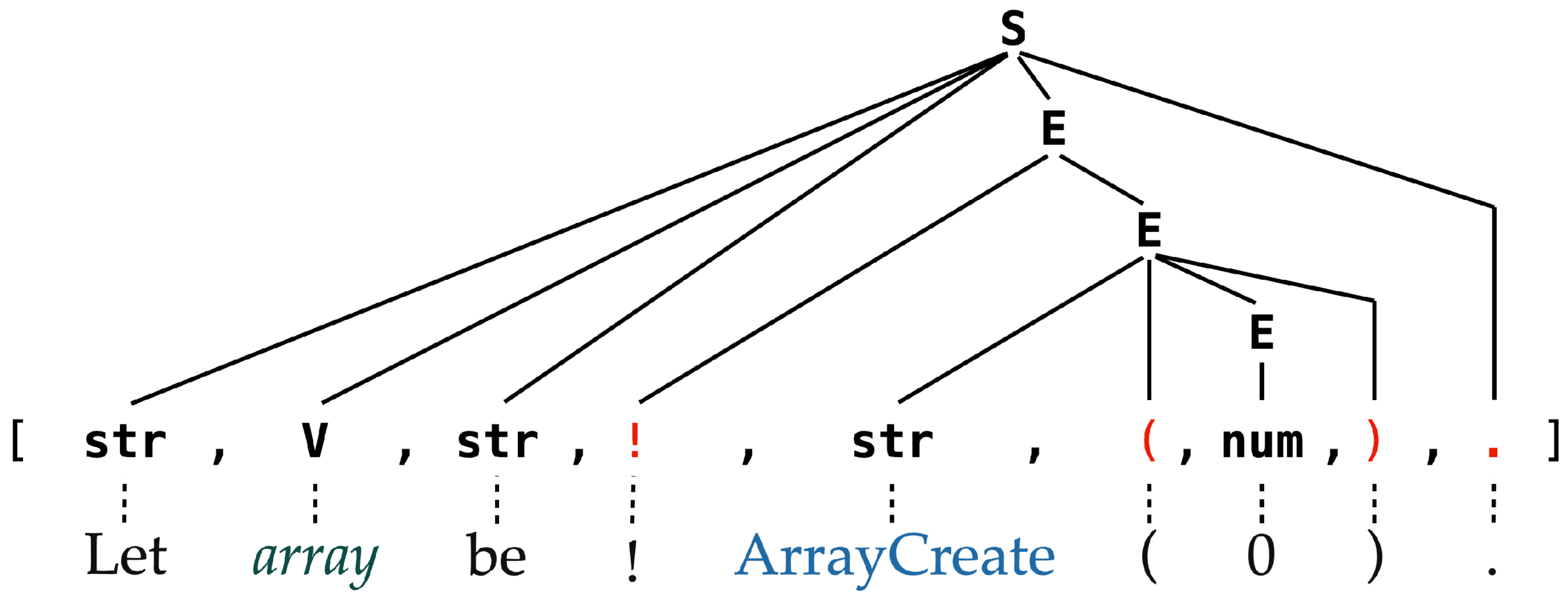

Parsing rules　　　Conversion Rules

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E = // expressions
  ! E                   ^^ EAbruptCheck |
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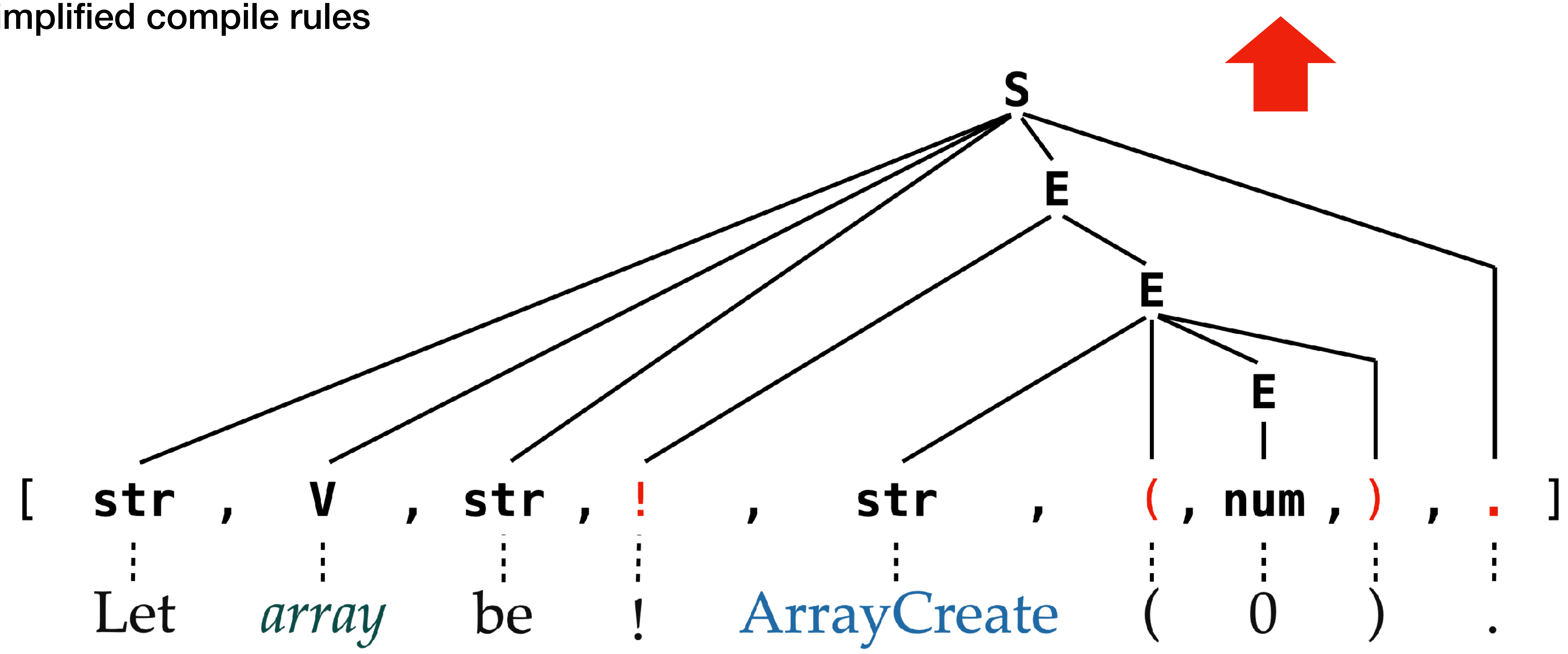
  num                   ^^ _.toDouble
```

Simplified compile rules

```
ILet(array, EAbruptCheck(
  ECall("ArrayCreate", 0)))
```



Parsing rules Conversion Rules

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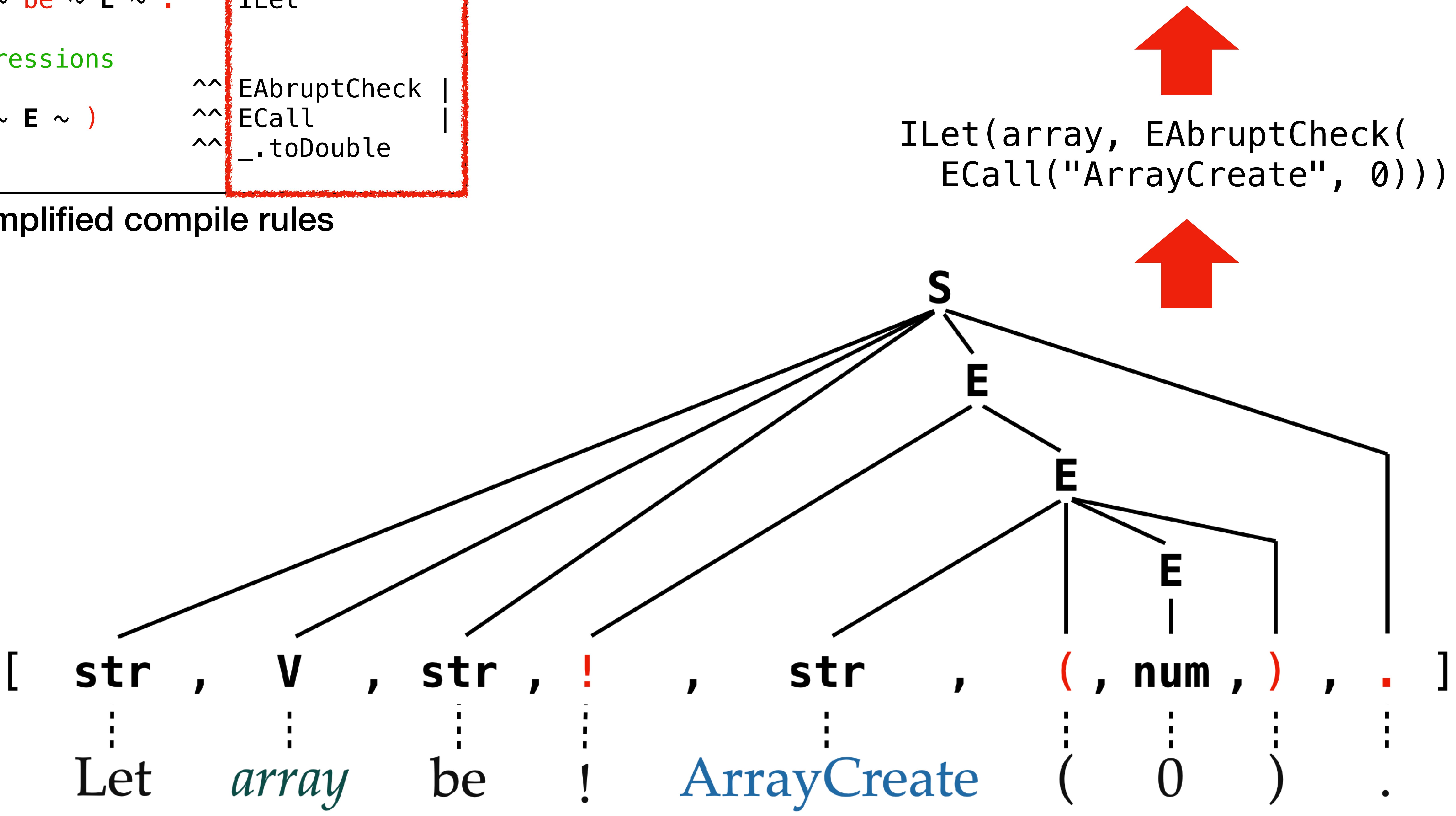
```

Simplified compile rules

```
let array = ! (ArrayCreate 0)
```

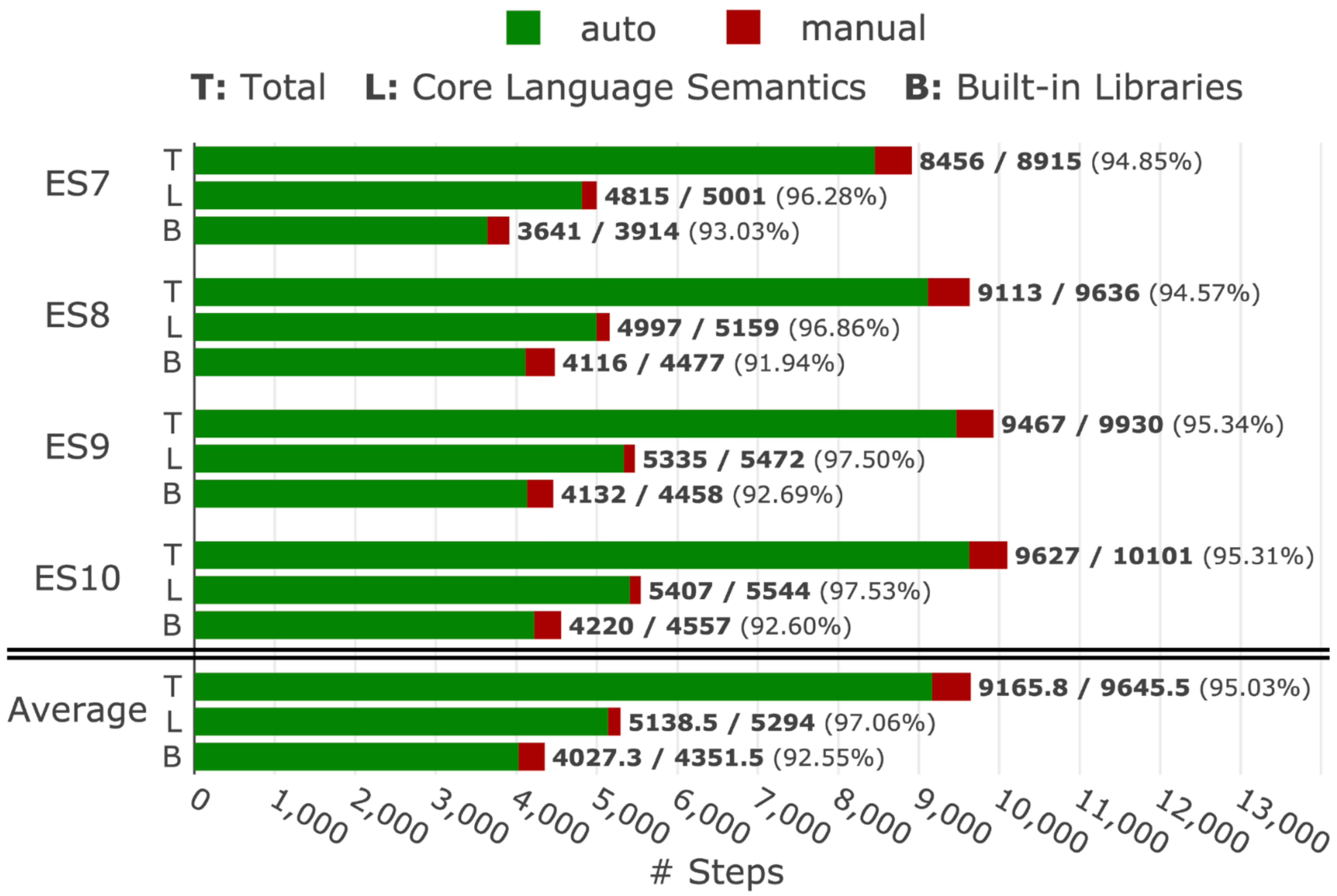
```
ILet(array, EAbruptCheck(
  ECall("ArrayCreate", 0)))
```


S
E
E
E
[str , V , str , ! , str , (, num ,) , .]
Let array be ! ArrayCreate (0) .

Semantics - Evaluation

The number of compile rules

Name	# Rules
Statment	21
Expression	27
Condition	16
Value	11
Type	34
Reference	9
Total	118



Semantics - Evaluation

≈ 95% Compiled

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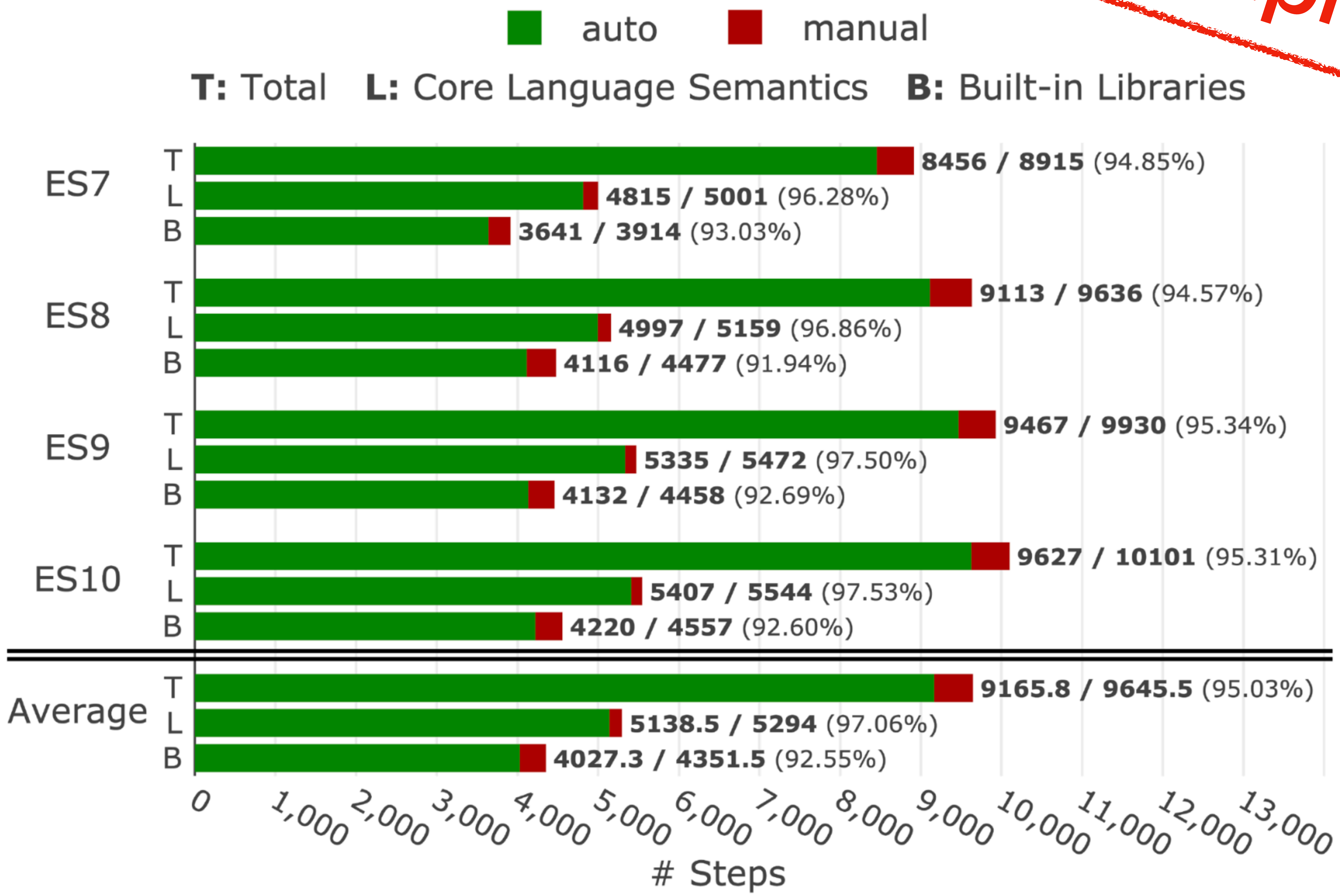

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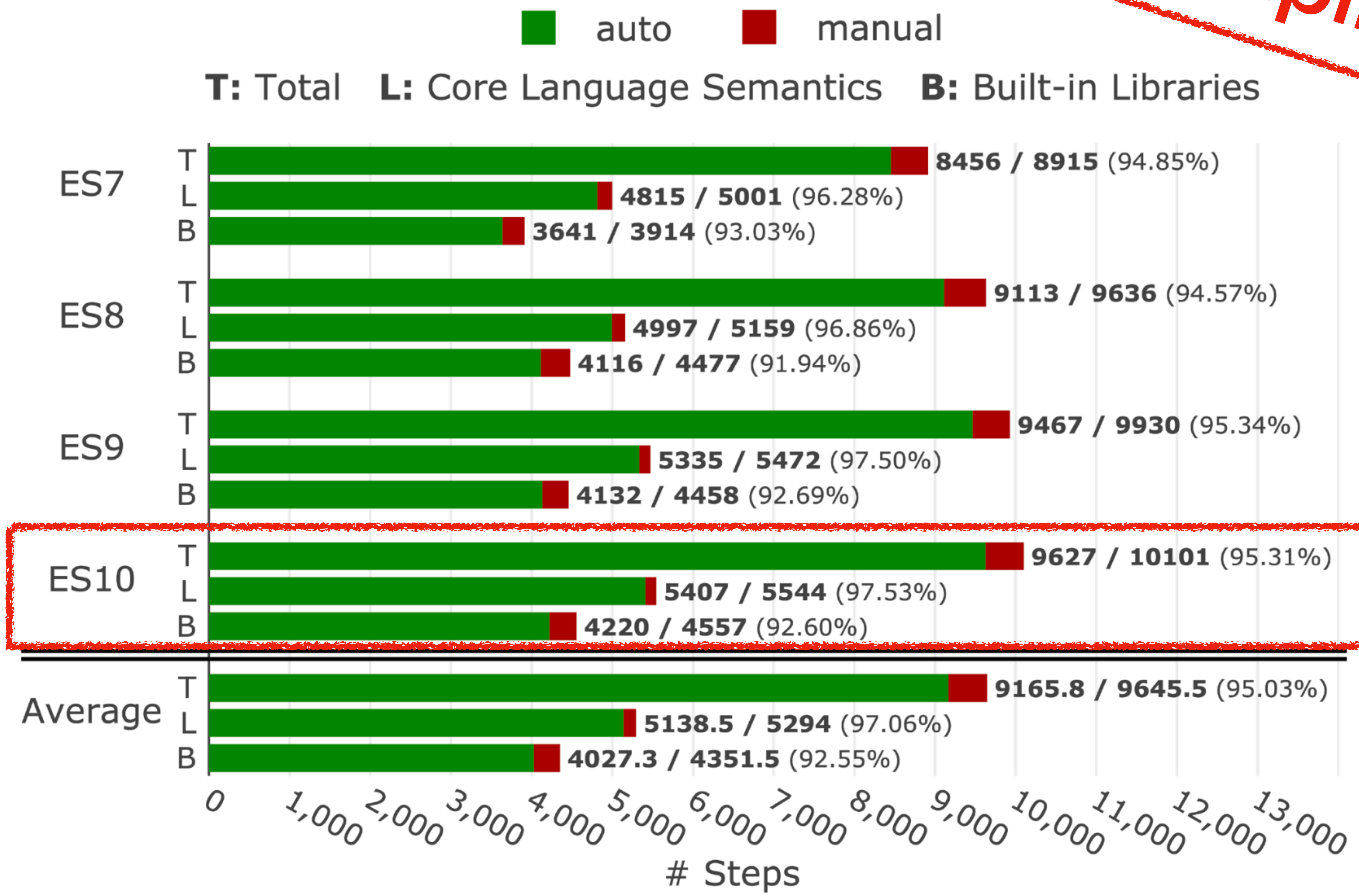

Semantics - Evaluation

- **Test262** - Official ECMAScript test suite

16,355 / 18,064 (90.54%)

Name	Feature	Description	Known	Created	Resolved	Existed	# Fails
ES10-1	Iteration	Missing the `async-iterate` case in the assertion of **ForIn/OfHeadEvaluation**	X	2018-02-16	2020-03-25	768 days	1,116
ES10-2	Condition	Ambiguous grammar production for the dangling `else` problem in *IfStatement*	X	2015-06-01	TBD	TBD	1
ES10-3	String	Wrong use of the = operator in **StringGetOwnProperty**	X	2015-06-01	2020-05-07	1,802 days	7
ES10-4	Completion	Unhandling abrupt completion in **Abstract Equality Comparison**	X	2015-06-01	2020-04-28	1,793 days	9
ES10-5	Completion	Unhandling abrupt completion in **Evaluation** of *EqualityExpression*	O	2015-06-01	2019-05-02	1,431 days	2
ES10-6	Await	Passing a value of wrong type to the second parameter of **PromiseResolve**	O	2019-02-27	2019-04-13	45 days	1,294
ES10-7	Function	No semantics of **IsFunctionDefinition** for `function(...){...}`	O	2015-10-30	2020-01-18	1,541 days	306
ES10-8	Function	No semantics of **ExpectedArgumentCount** for the base case of *FormalParameters*	O	2016-11-02	2020-02-20	1,205 days	81
ES10-9	Iteration	Two semantics of **VarScopedDeclarations** for `for await(var x of e){...}`	O	2018-02-16	2019-10-11	602 days	0

292 / 303 (96.37%)

Name	Feature	Description	Known	Created	Resolved	Existed	# Fails
BigInt-1	Expression	Using the wrong variable `oldvalue` instead of `oldValue` in **Evaluation** of *UpdateExpression*	X	2019-09-27	2020-04-23	209 days	533
BigInt-2	Number	Using **ToInt32** instead of **ToUint32** in **Number::unsignedRightShift**	X	2019-09-27	2020-04-23	209 days	2
BigInt-3	Number	Unhandling BigInt values in the **Number** constructor	O	2019-09-27	2019-11-19	53 days	1

Semantics - Evaluation

- **Test262** - Official ECMAScript test suite

16,355 / 18,064
(90.54%)

9 bugs in ES10

18,064 / 18,064
(100.00%)

Name	Feature	Description	Known	Created	Resolved	Existed	# Fails
ES10-1	Iteration	Missing the `async-iterate` case in the assertion of **ForIn/OfHeadEvaluation**	X	2018-02-16	2020-03-25	768 days	1,116
ES10-2	Condition	Ambiguous grammar production for the dangling `else` problem in *IfStatement*	X	2015-06-01	TBD	TBD	1
ES10-3	String	Wrong use of the = operator in **StringGetOwnProperty**	X	2015-06-01	2020-05-07	1,802 days	7
ES10-4	Completion	Unhandling abrupt completion in **Abstract Equality Comparison**	X	2015-06-01	2020-04-28	1,793 days	9
ES10-5	Completion	Unhandling abrupt completion in **Evaluation** of *EqualityExpression*	O	2015-06-01	2019-05-02	1,431 days	2
ES10-6	Await	Passing a value of wrong type to the second parameter of **PromiseResolve**	O	2019-02-27	2019-04-13	45 days	1,294
ES10-7	Function	No semantics of **IsFunctionDefinition** for `function(...){...}`	O	2015-10-30	2020-01-18	1,541 days	306
ES10-8	Function	No semantics of **ExpectedArgumentCount** for the base case of *FormalParameters*	O	2016-11-02	2020-02-20	1,205 days	81
ES10-9	Iteration	Two semantics of **VarScopedDeclarations** for `for await(var x of e){...}`	O	2018-02-16	2019-10-11	602 days	0

292 / 303 (96.37%)

Name	Feature	Description	Known	Created	Resolved	Existed	# Fails
BigInt-1	Expression	Using the wrong variable `oldvalue` instead of `oldValue` in **Evaluation** of *UpdateExpression*	X	2019-09-27	2020-04-23	209 days	533
BigInt-2	Number	Using **ToInt32** instead of **ToUint32** in **Number::unsignedRightShift**	X	2019-09-27	2020-04-23	209 days	2
BigInt-3	Number	Unhandling BigInt values in the **Number** constructor	O	2019-09-27	2019-11-19	53 days	1

Semantics - Evaluation

- **Test262** - Official ECMAScript test suite

16,355 / 18,064 (90.54%)

9 bugs in ES10

18,064 / 18,064 (100.00%)

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292 / 303 (96.37%)

3 bugs in ES.Next

303 / 303 (100.00%)

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Semantics - Evaluation

All Tests Passed

- **Test262** - Official ECMAScript test suite

16,355 / 18,064 (90.54%)

9 bugs in ES10

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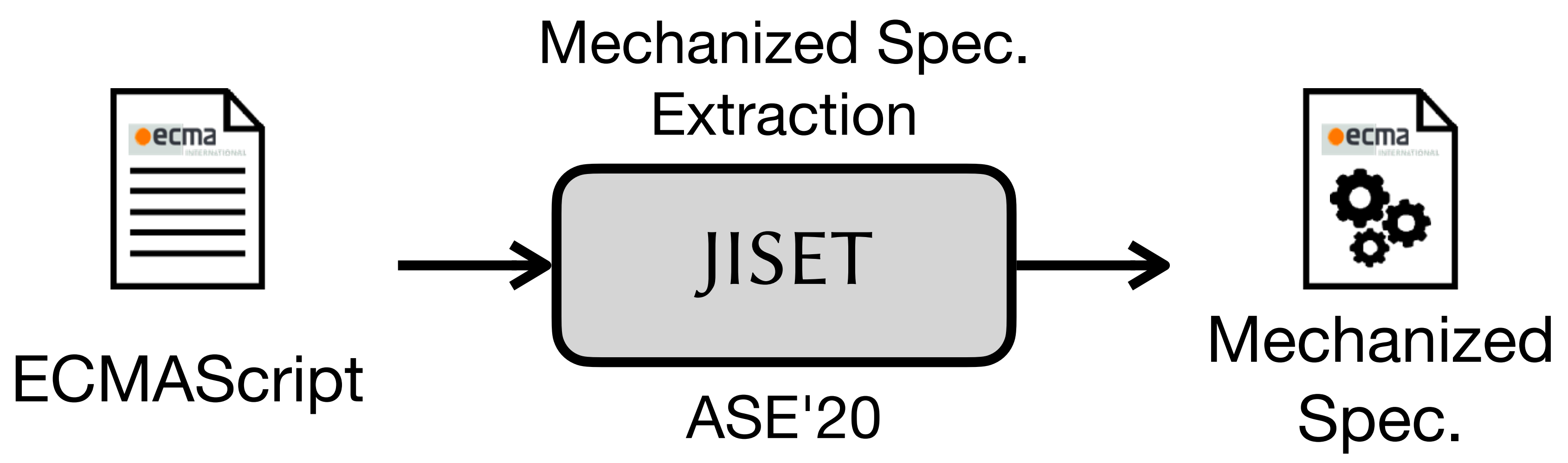
Future Work



ECMAScript
Mechanized Spec.
Extraction
JISET
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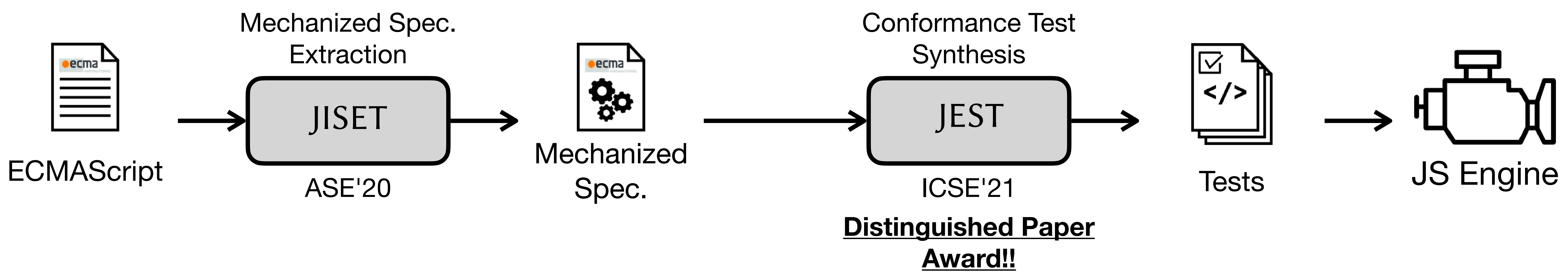
Future Work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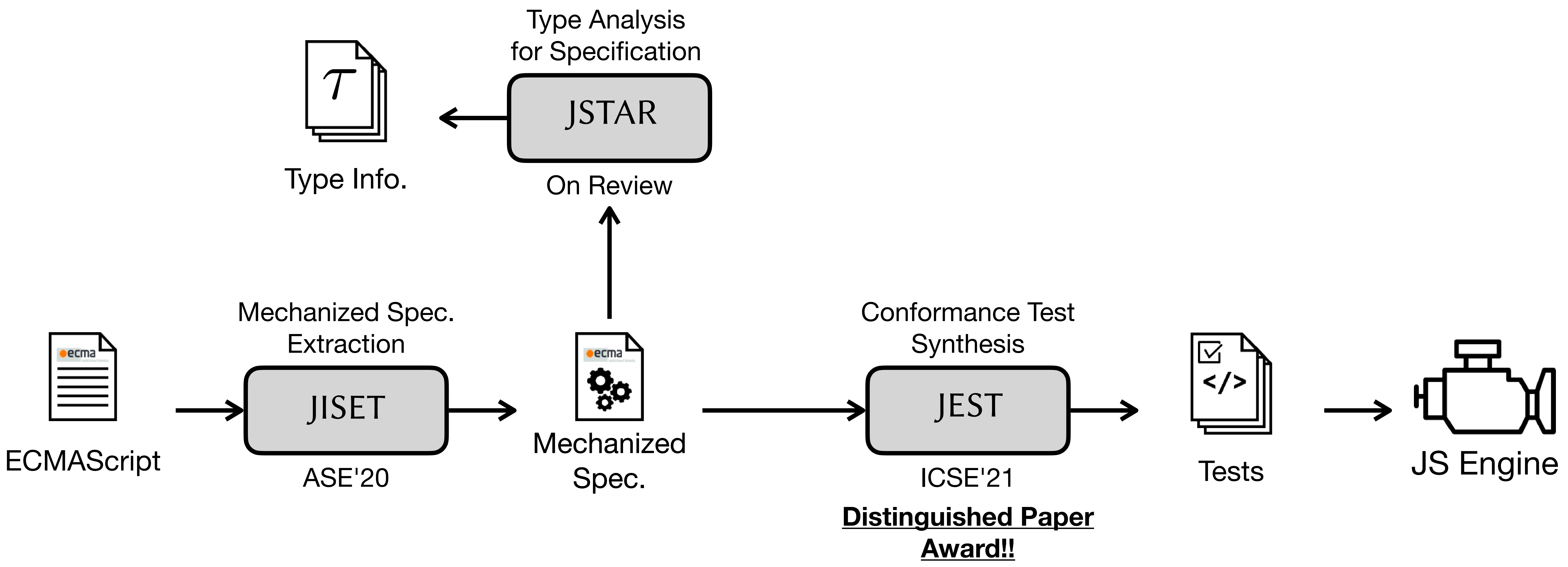
Distinguished Paper
Award!!
Tests
JS Engine

Future Work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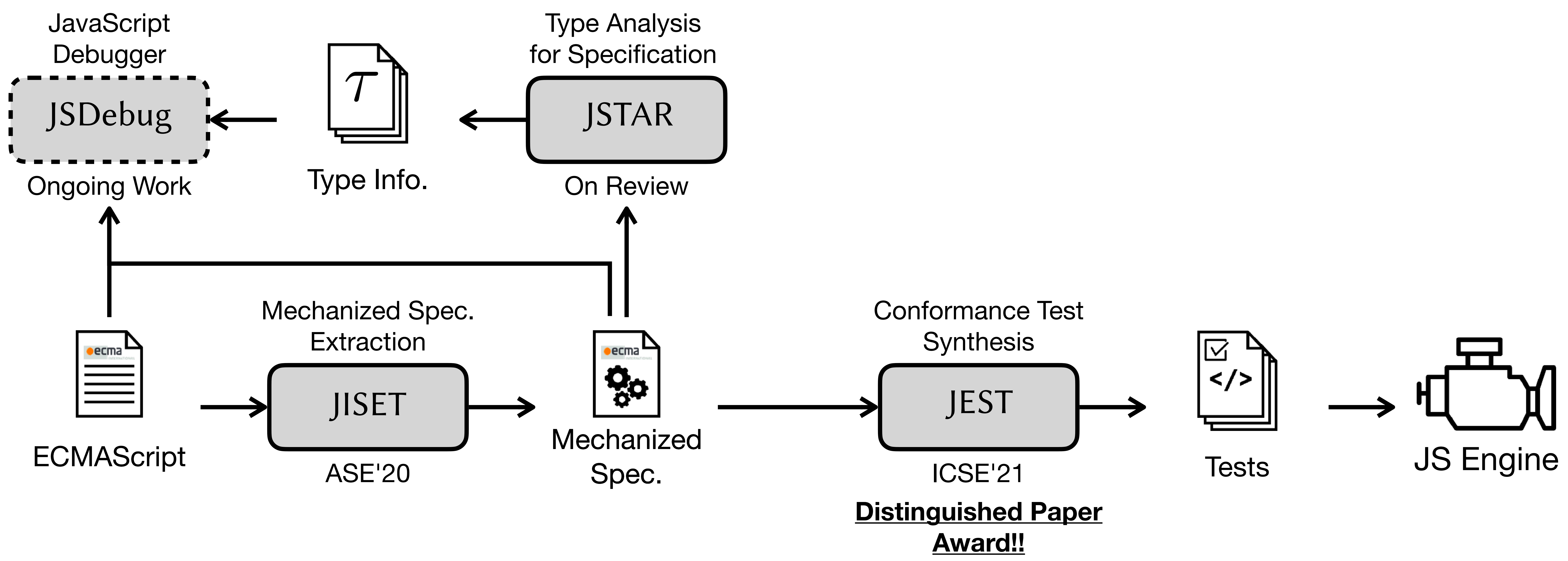

JavaScript Debugger
JSDebug
Ongoing Work
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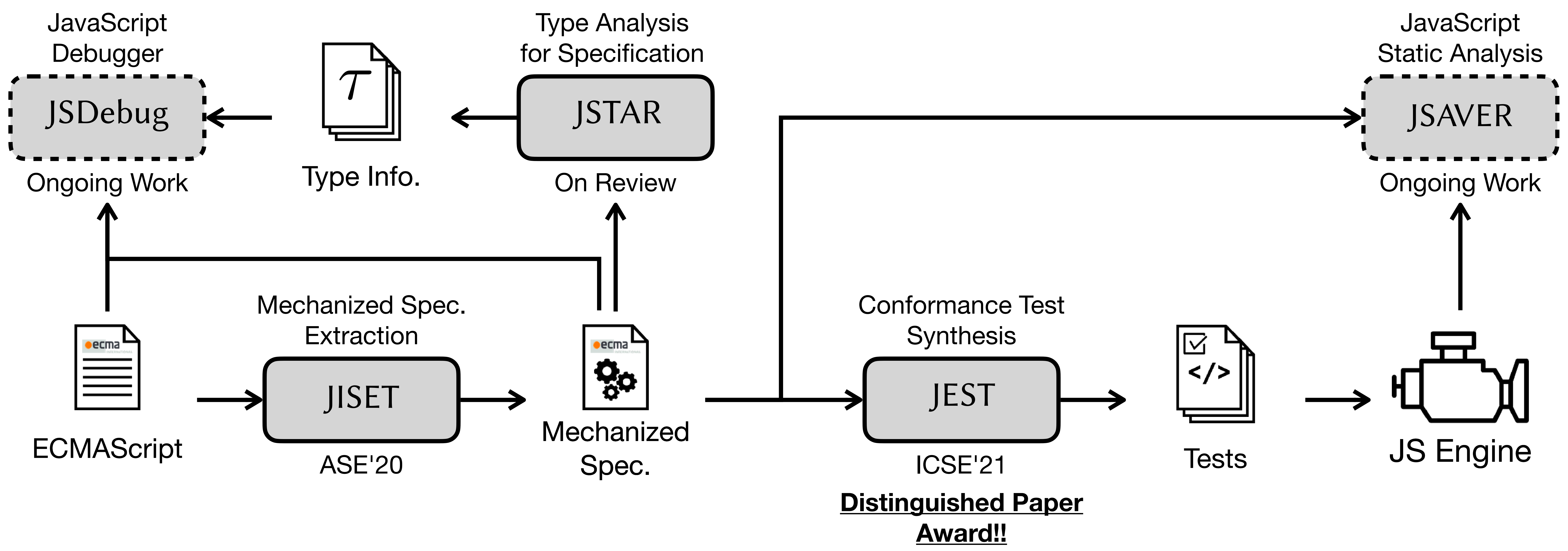
JavaScript Debugger
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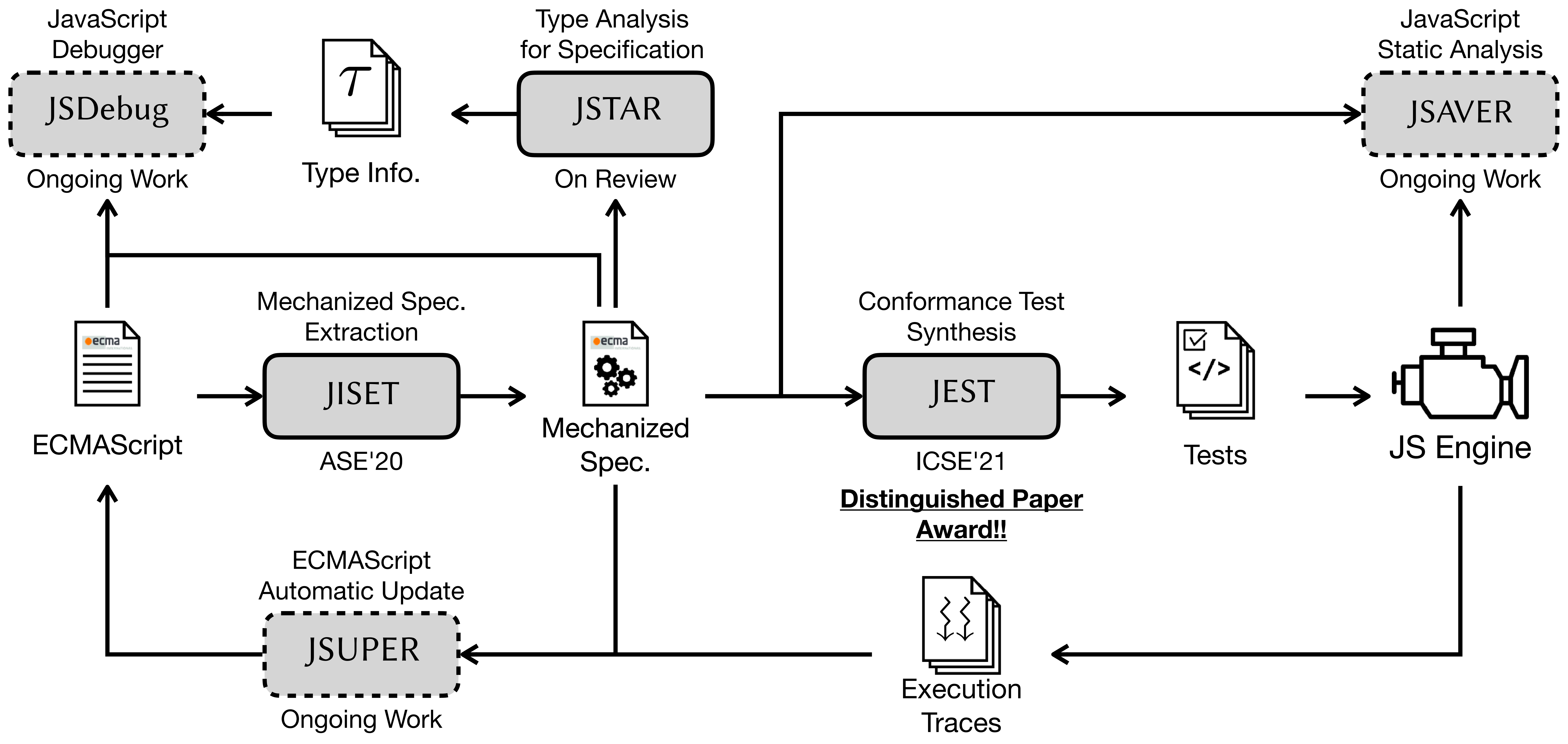

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JSUPER
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Execution Traces