ZipLex

Verified Linear-Time Invertible Lexer

Samuel Chassot, Viktor Kunčak

27.07.2026 - CAV26

Sorting Functions

Refactor Tool Example

```
def abs(x: Int): Int =
  if (x < 0) then
    -x
  else
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end abs
def mul(x: Int, y: Int): Int =
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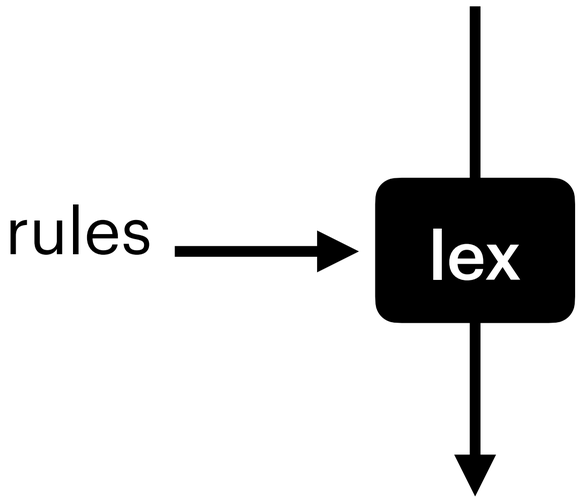

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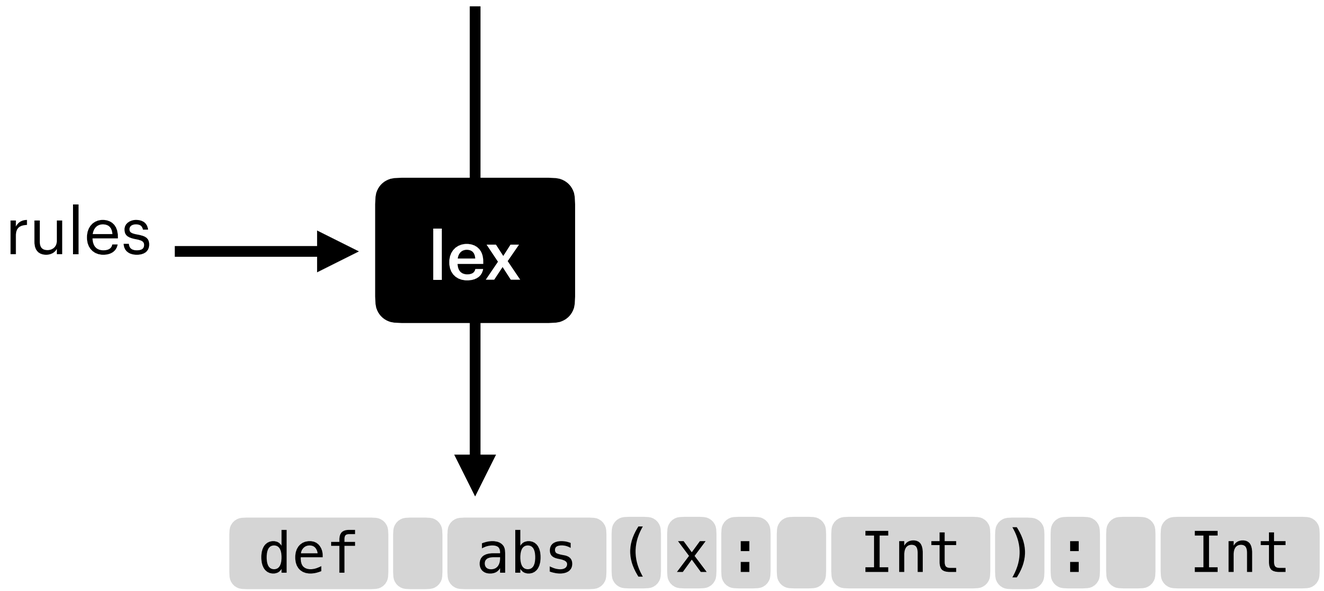

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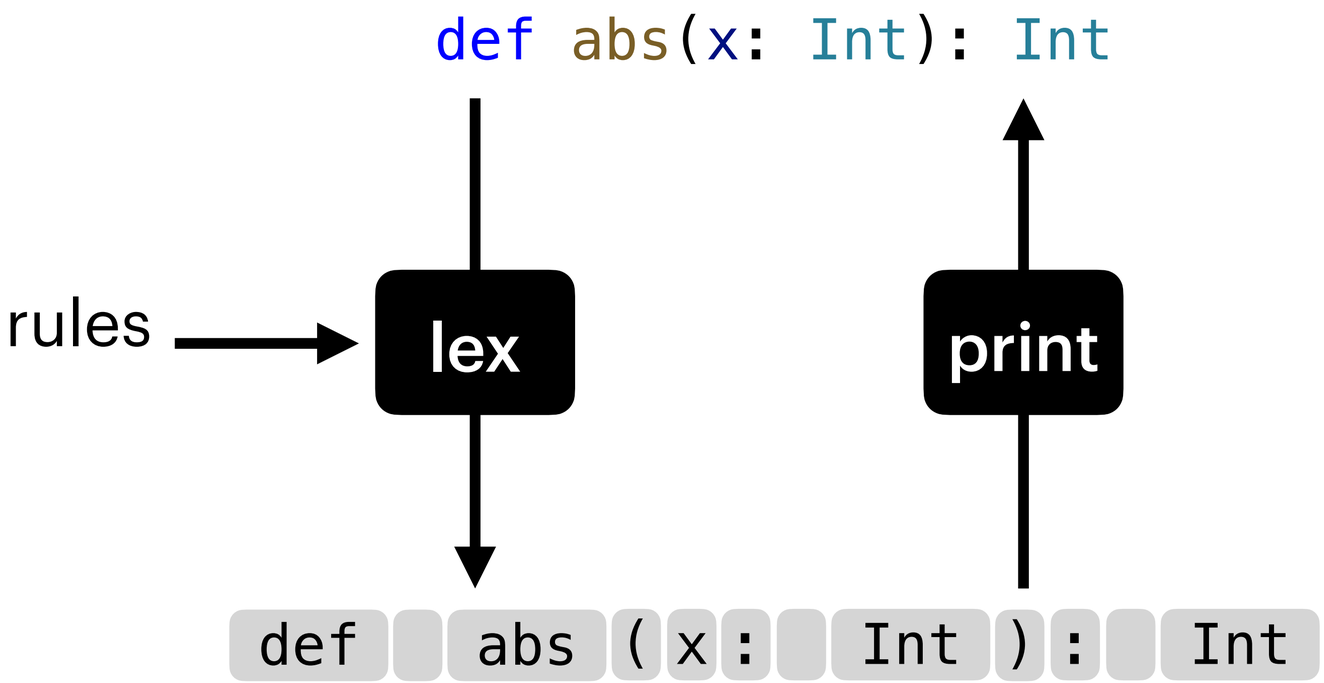

ZipLex Framework

Scala project, verified with Stainless

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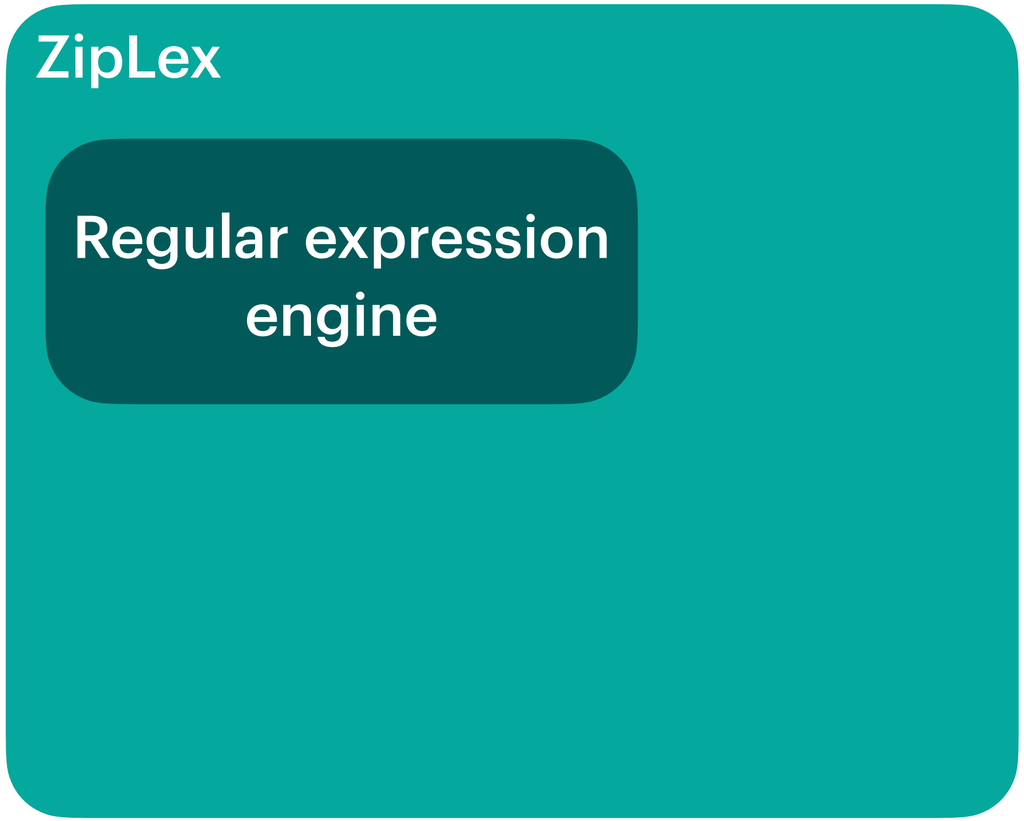

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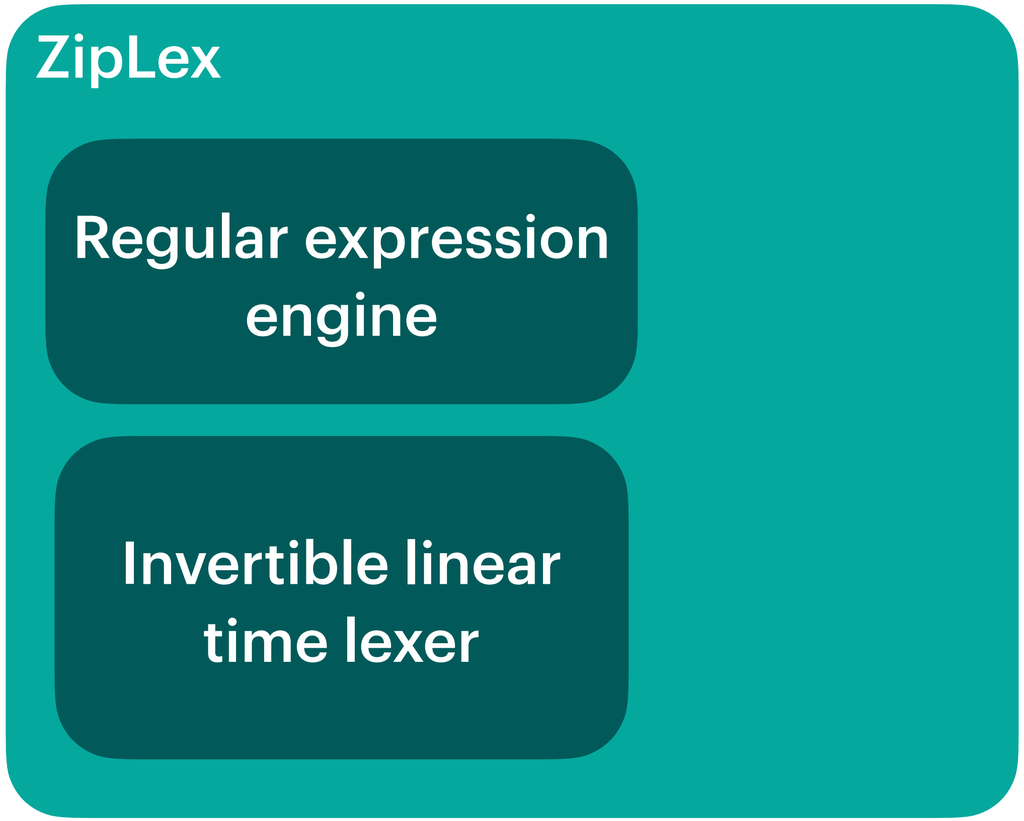

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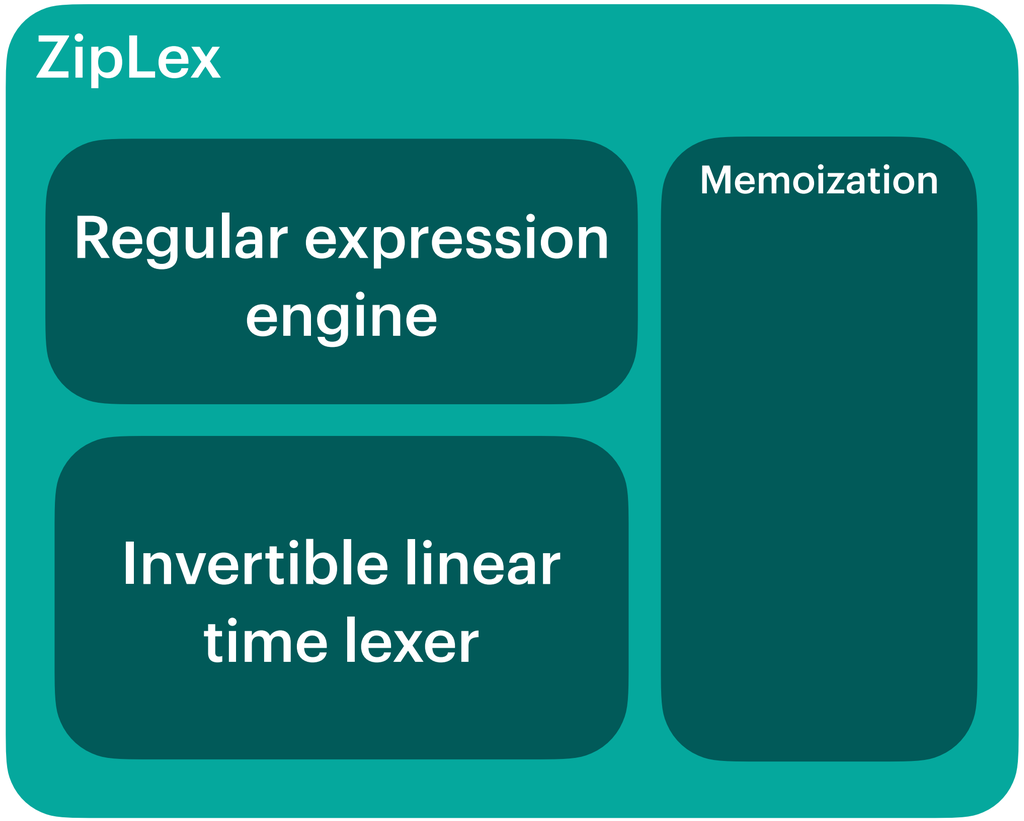

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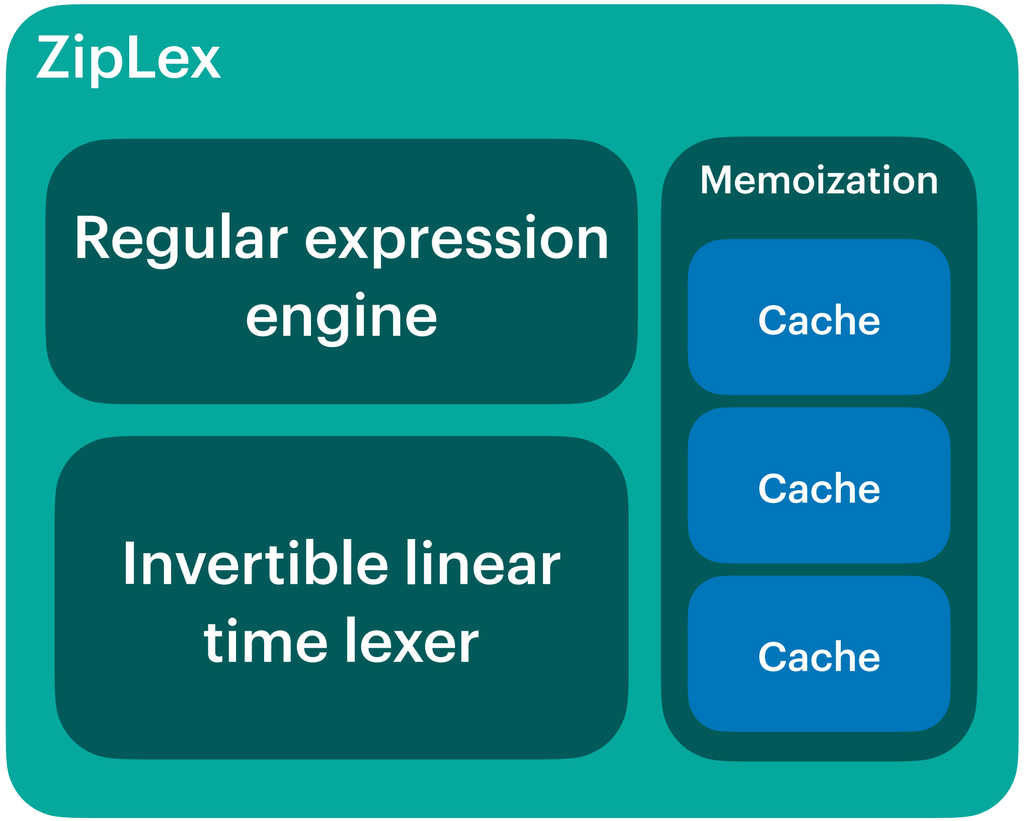

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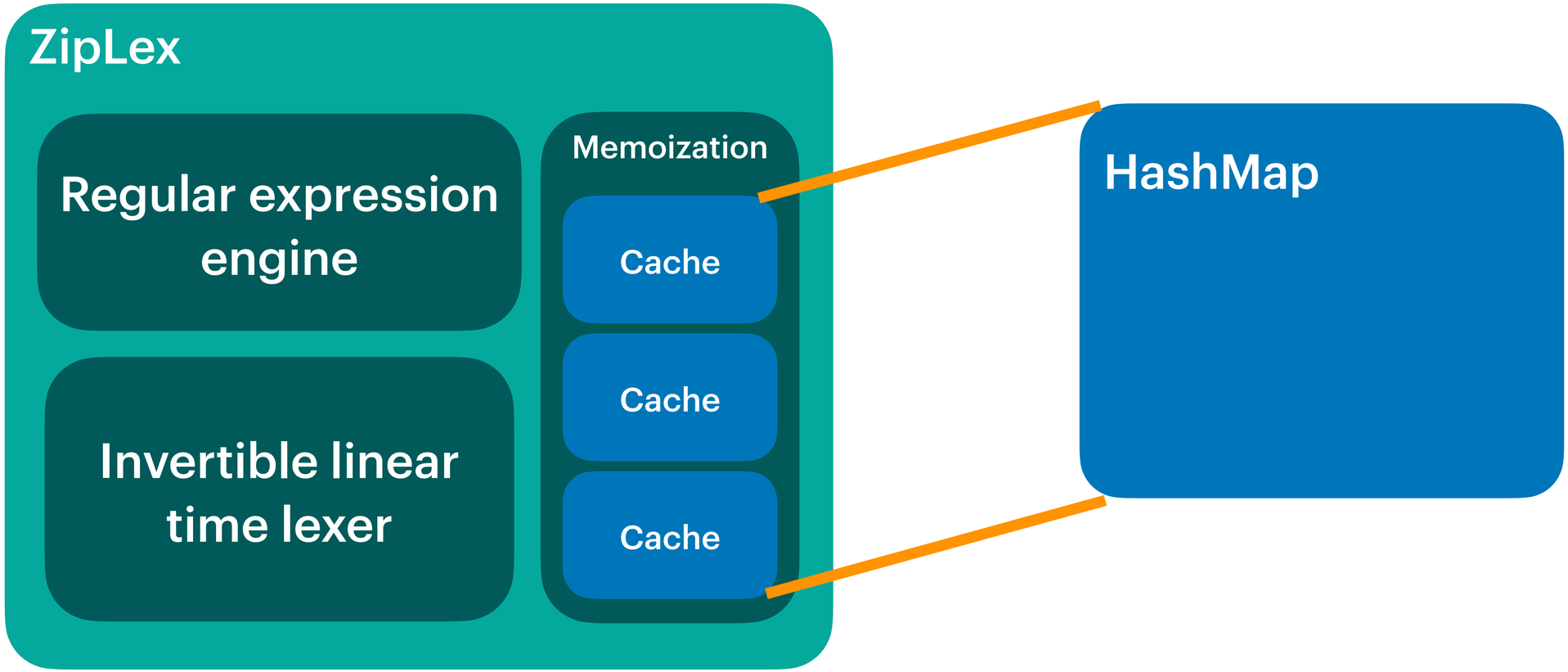

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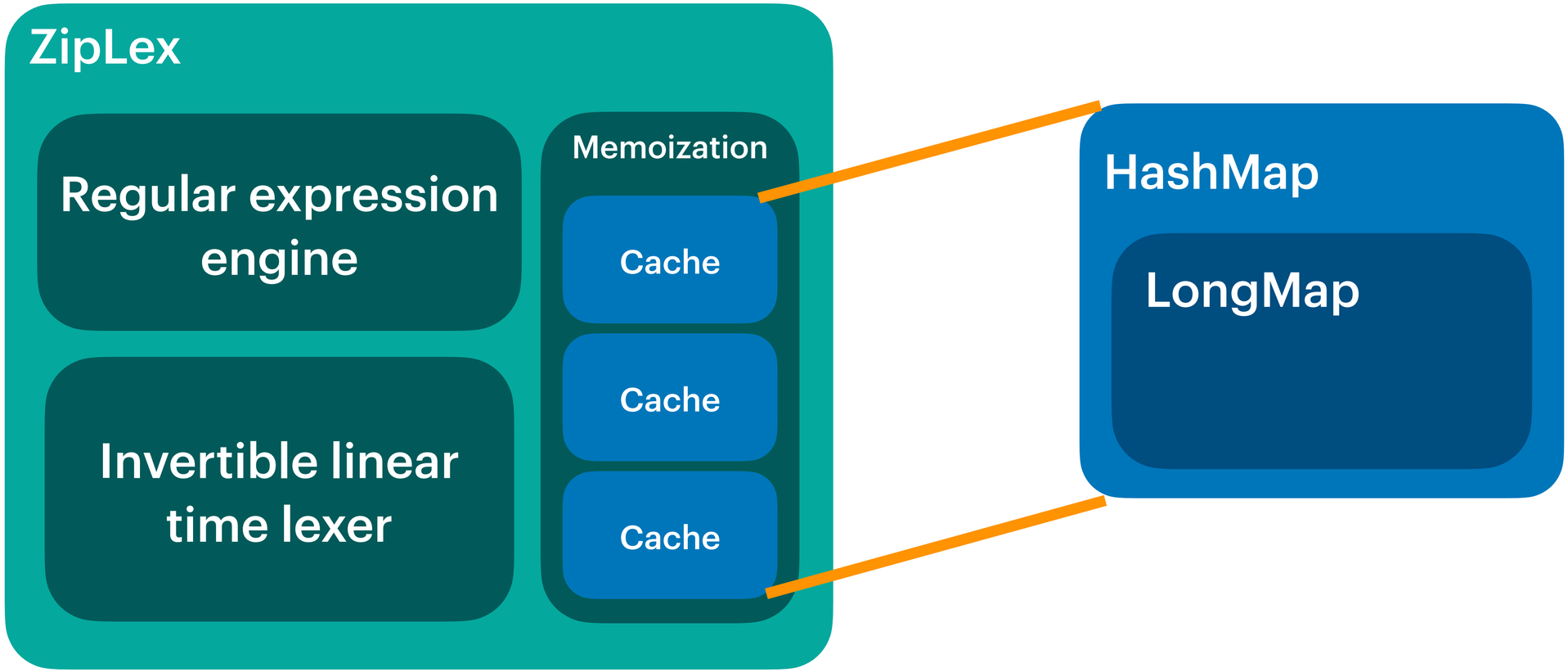

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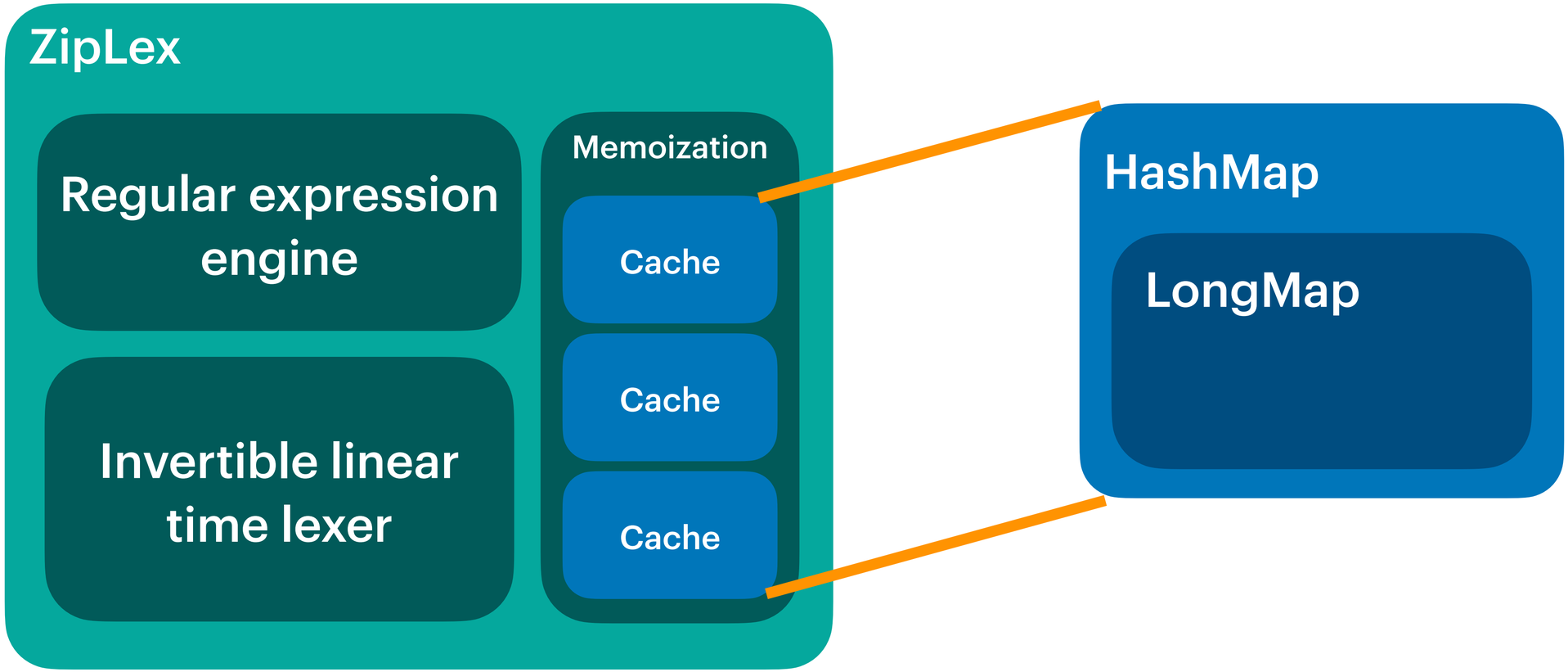

Composition pattern for efficient programs verification

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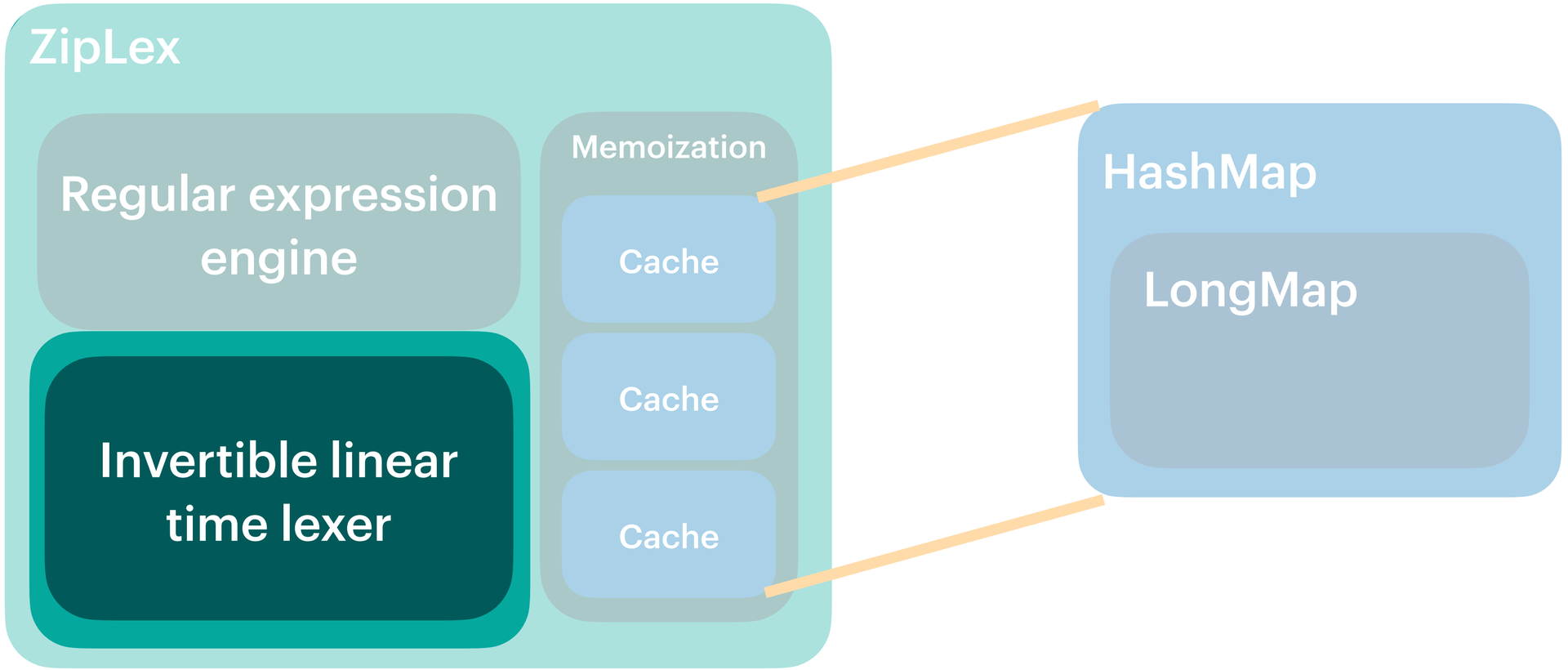

Composition pattern for efficient programs verification

Implementation and verification methodology

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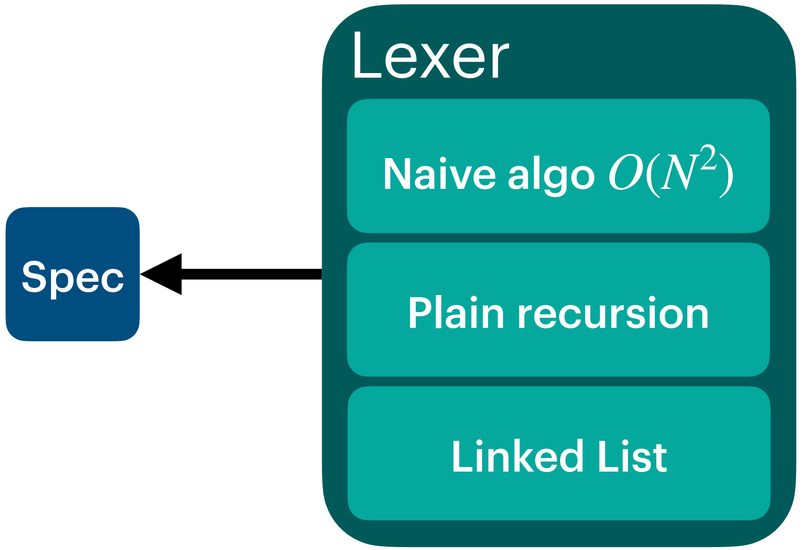

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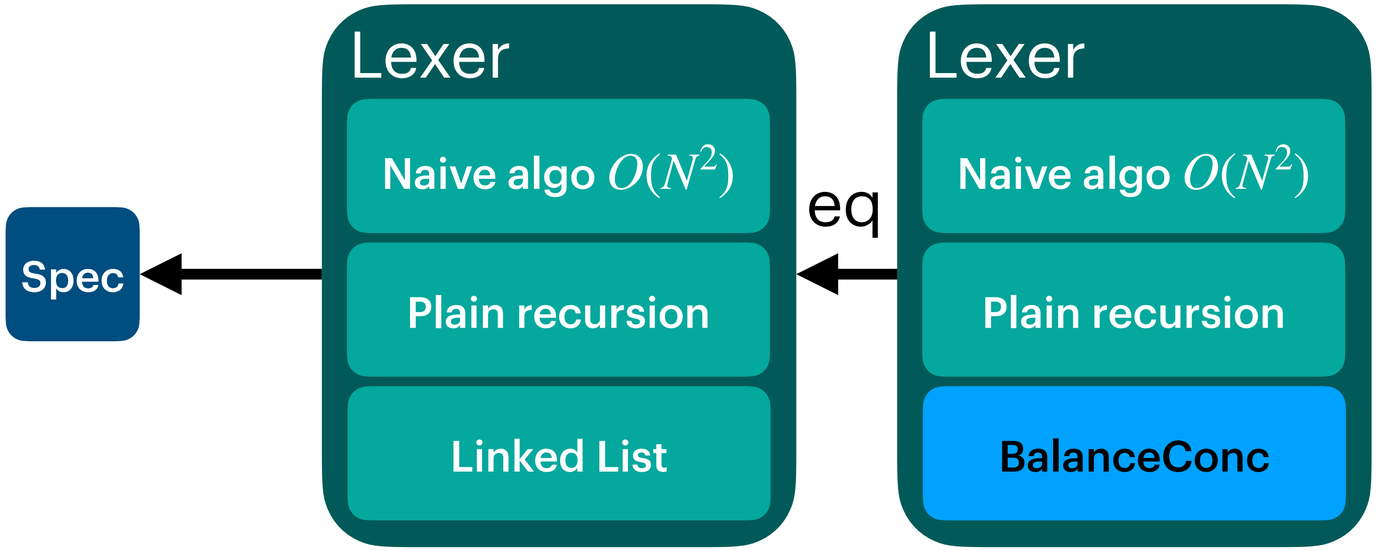

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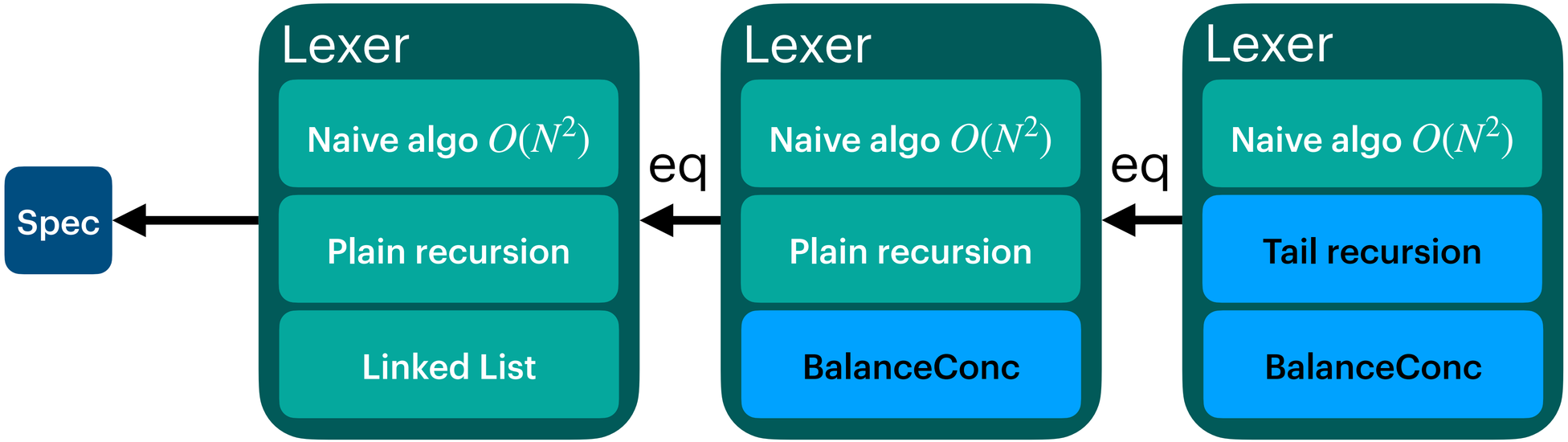

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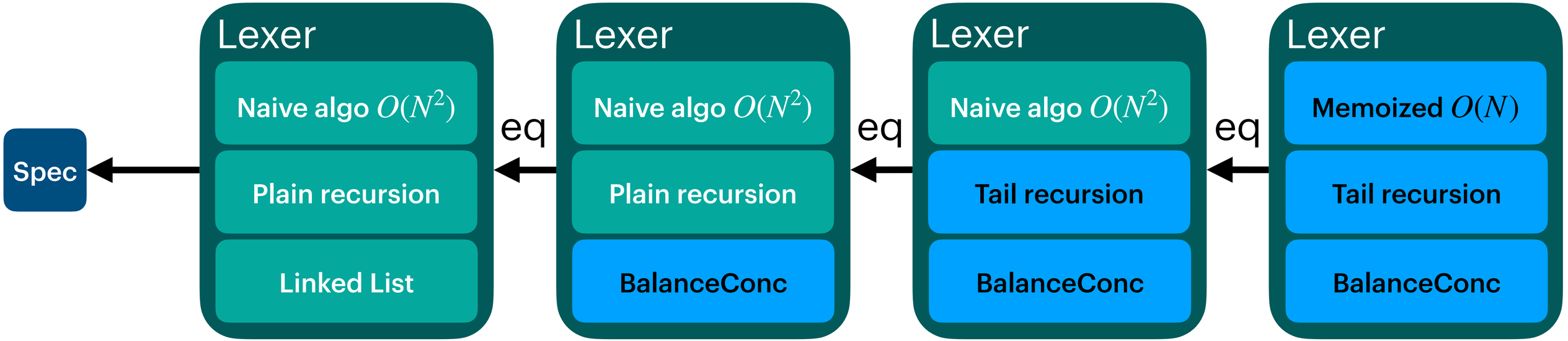

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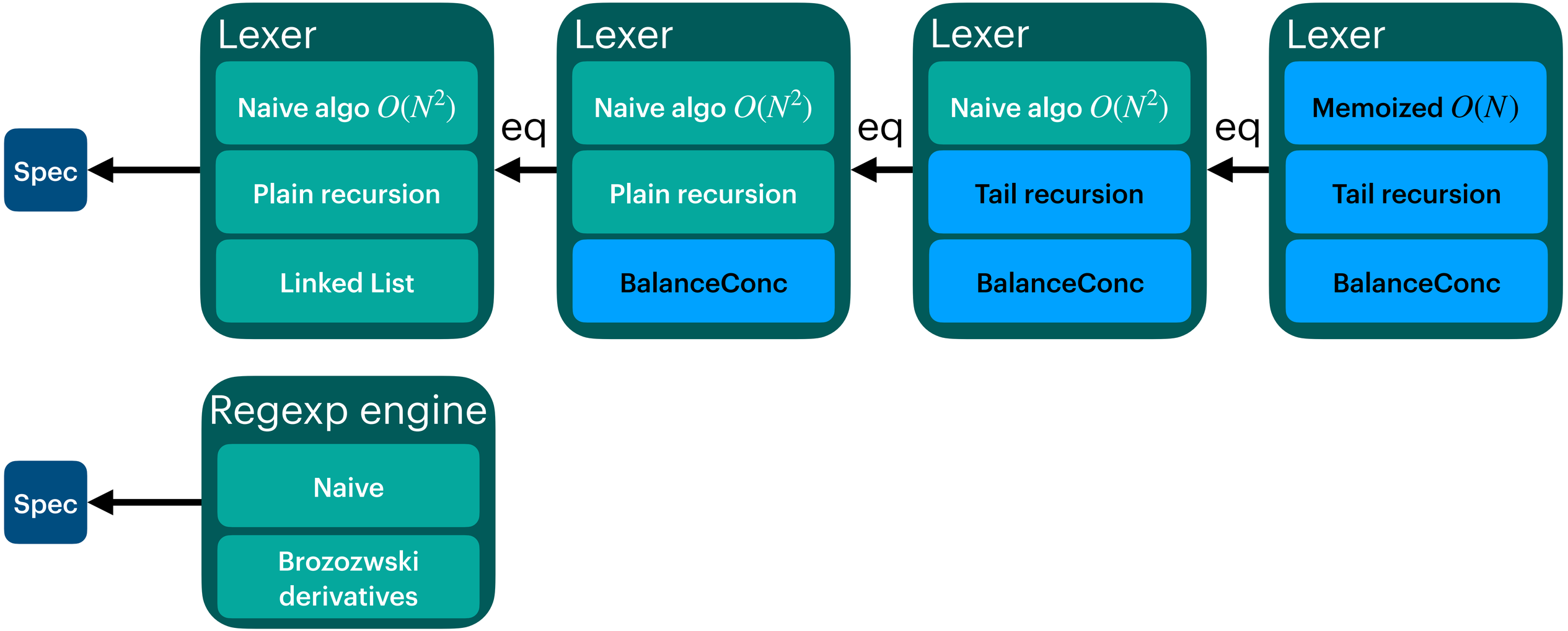

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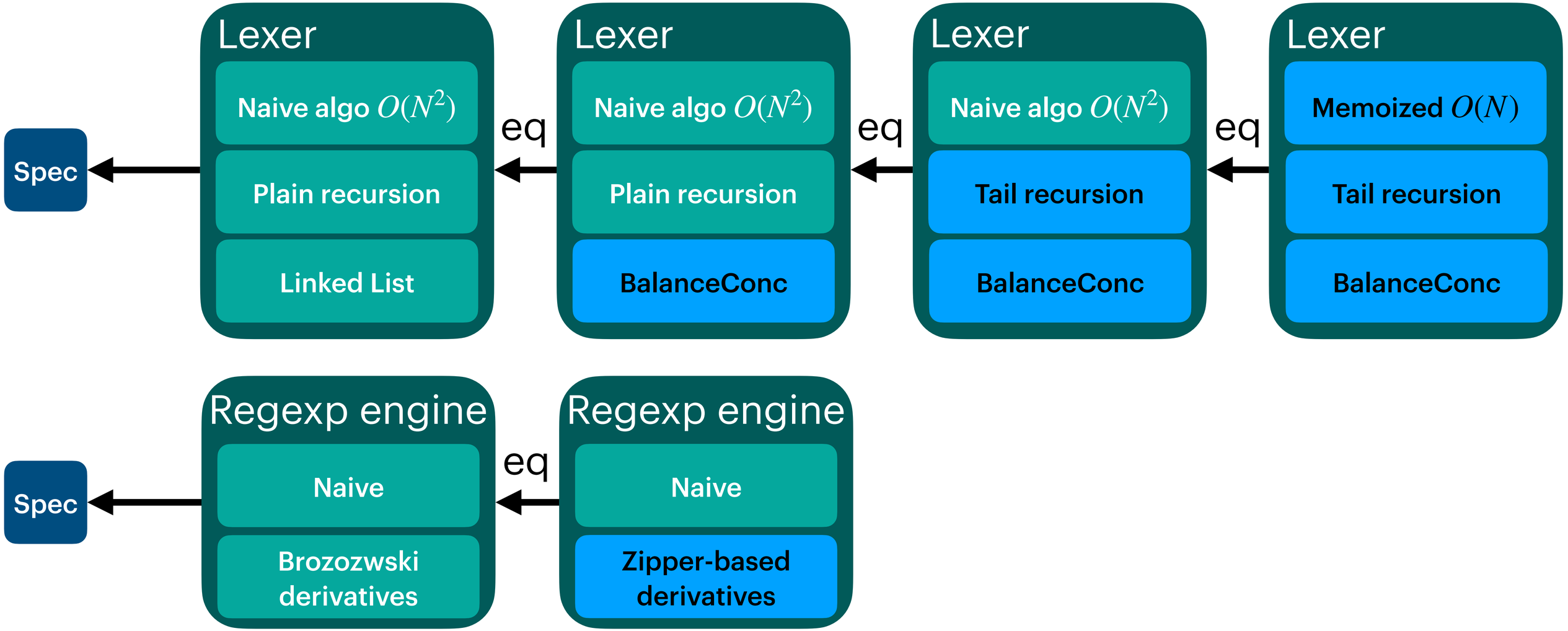

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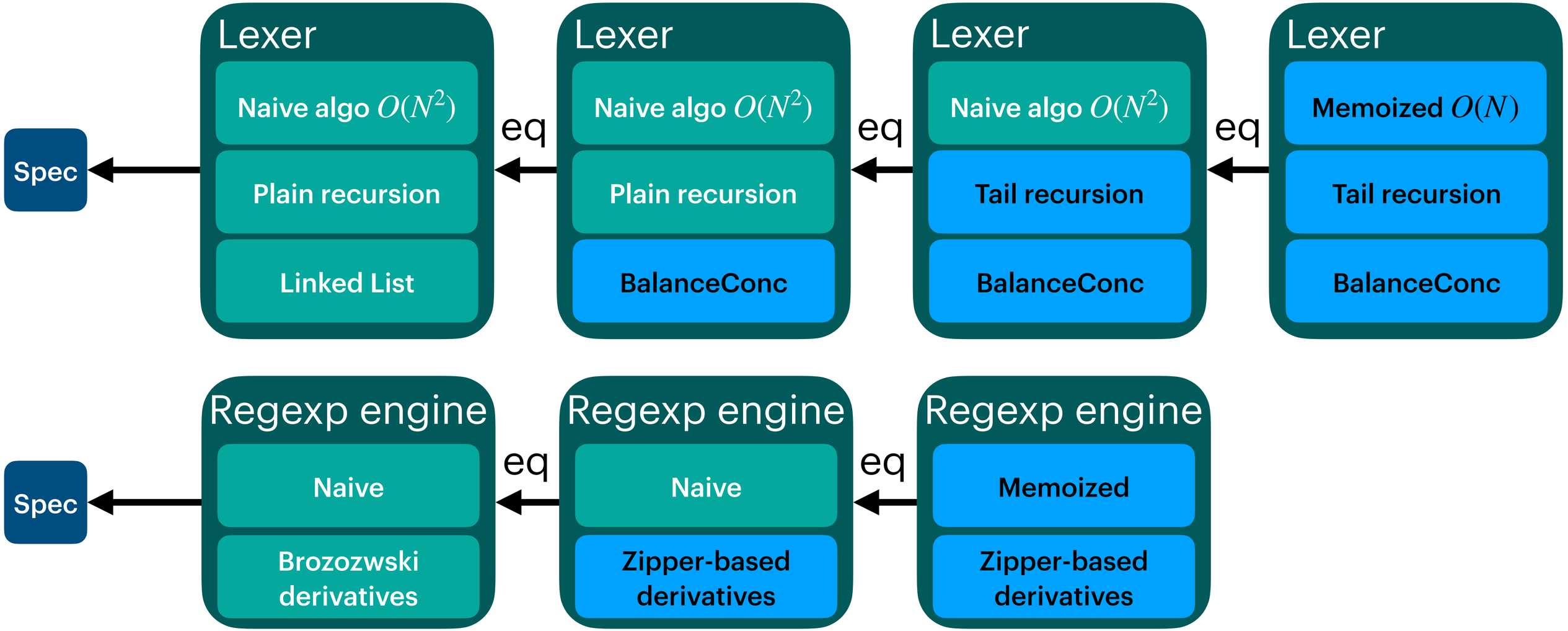

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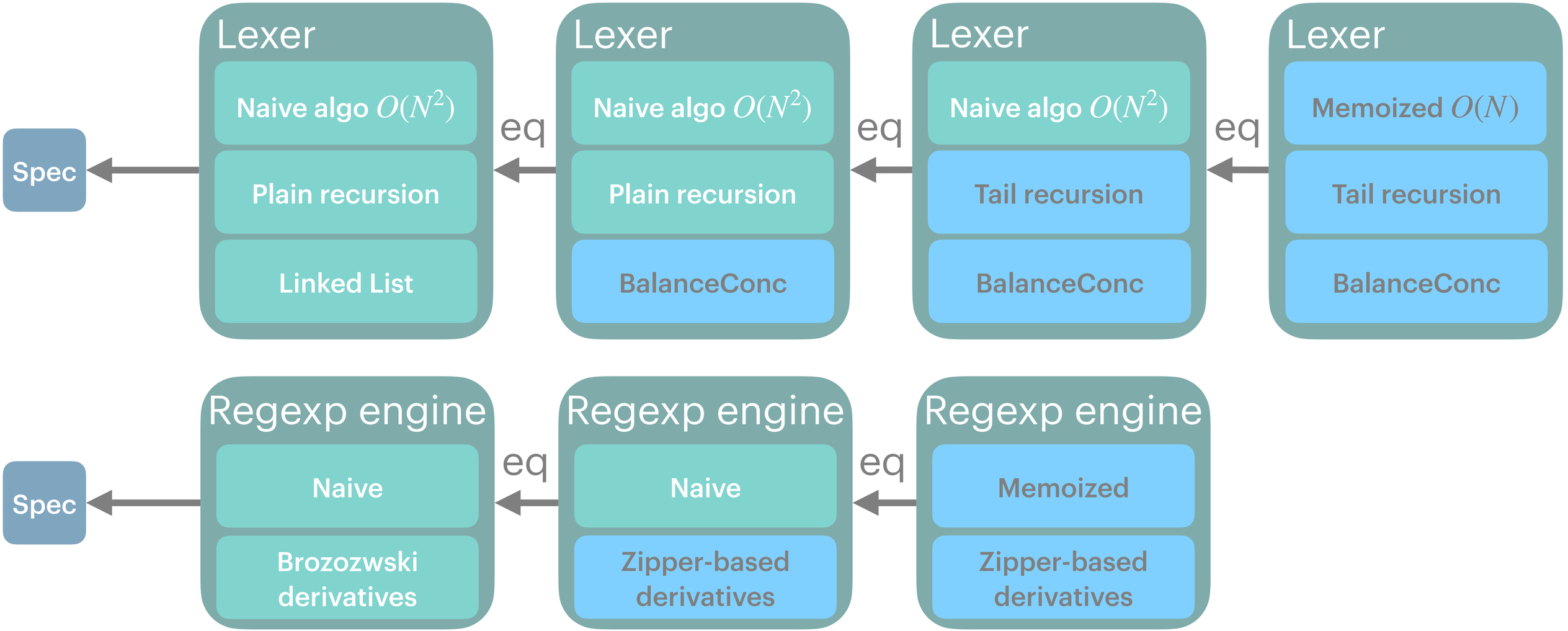

Iterative approach to efficiently verify efficient programs

Specification

Introduction

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Longest match

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Longest possible prefix for each token

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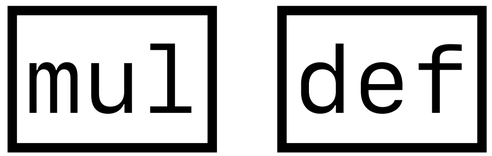

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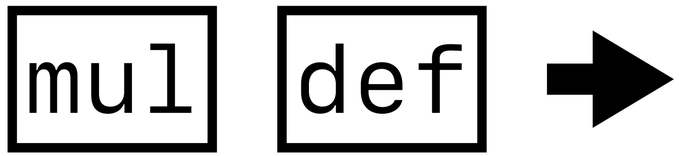

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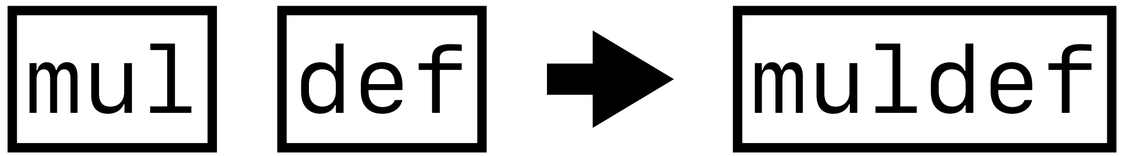

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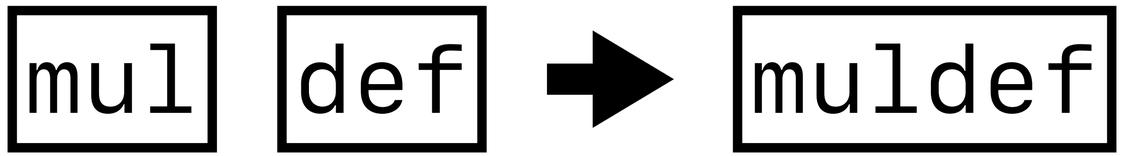

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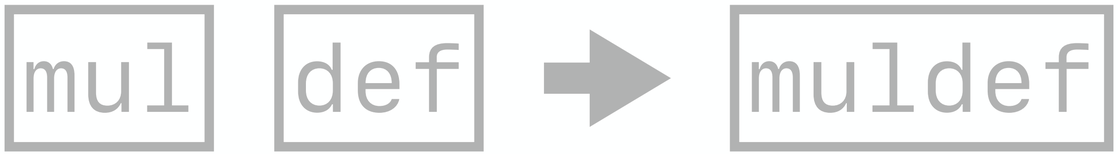

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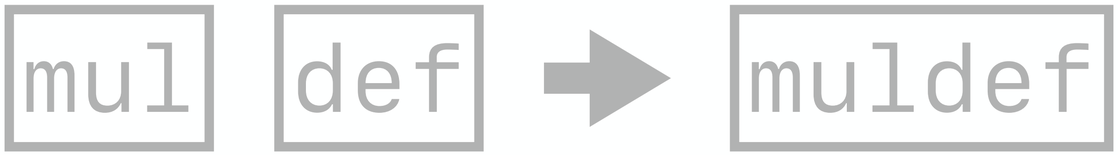

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$$sep(ts) \implies lex(print(ts)) = ts$$

Token Separability

Predicate definition

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   Look only at adjacent tokens

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Given a binary relation R, a sequence $s = s_1, s_2, \ldots, s_n$ is an *R-Path* if the relation holds for each consecutive pair

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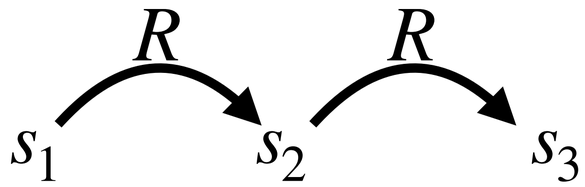

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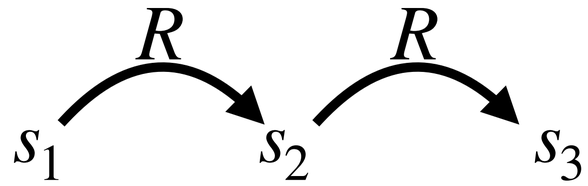

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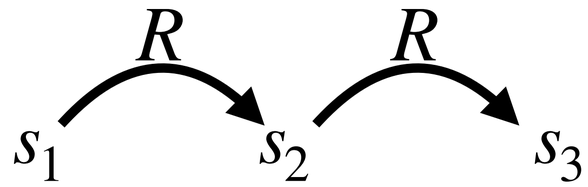

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Predicates over sequences requiring only local computations

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Efficient operations with statically checked invariant

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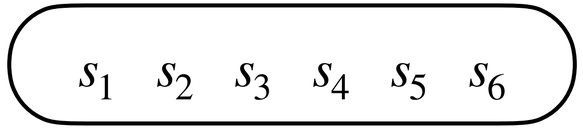
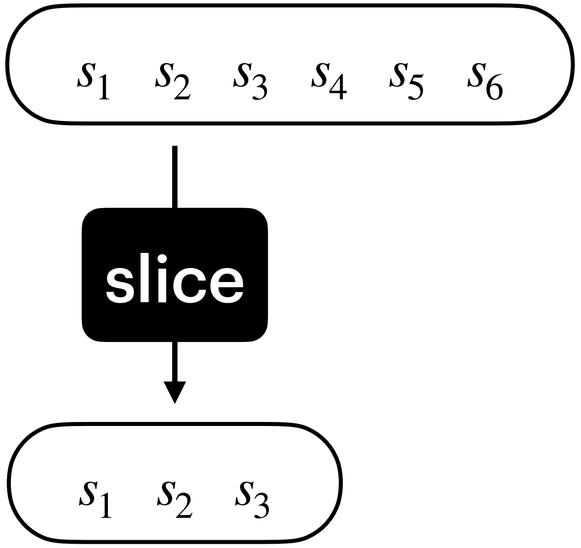


R-Path

Efficient operations with statically checked invariant



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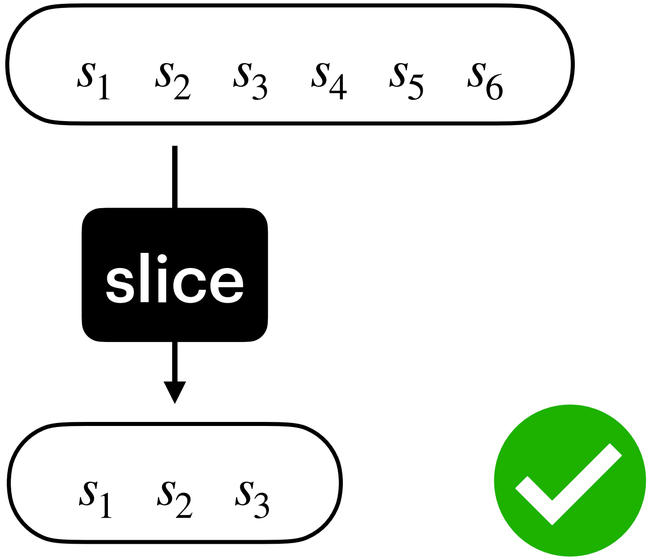

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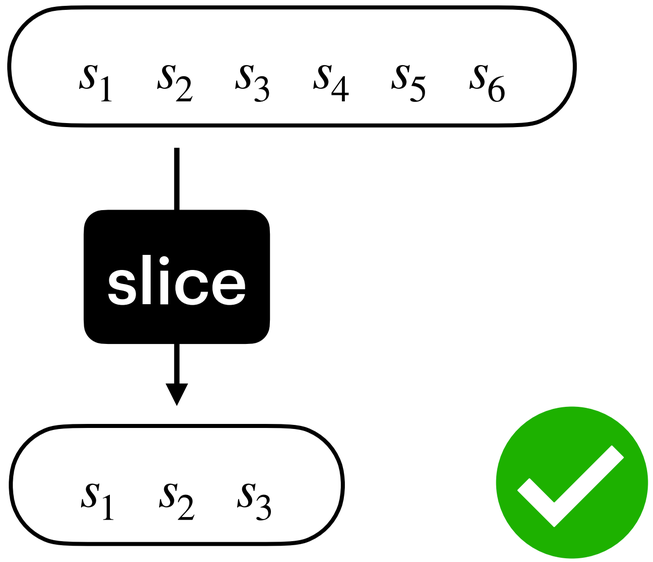

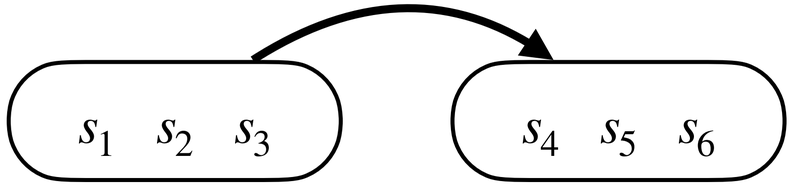

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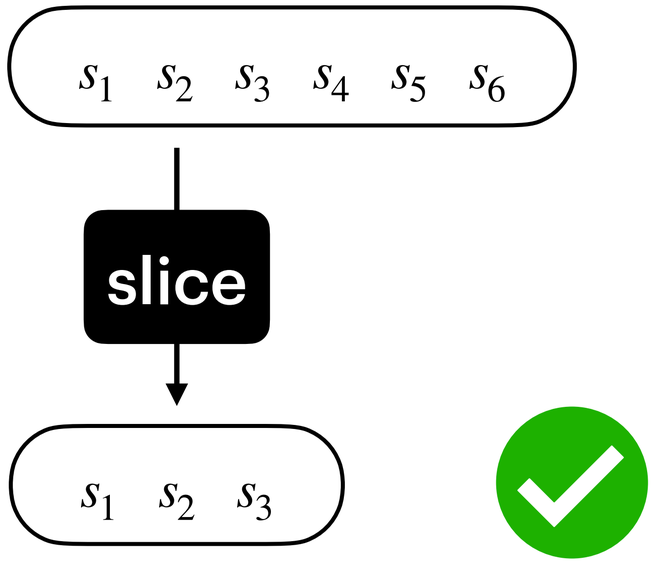

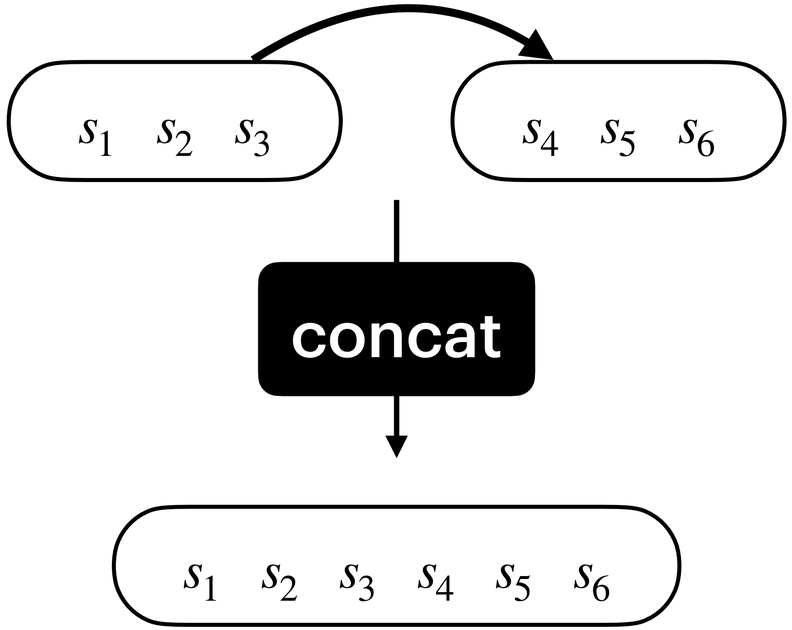

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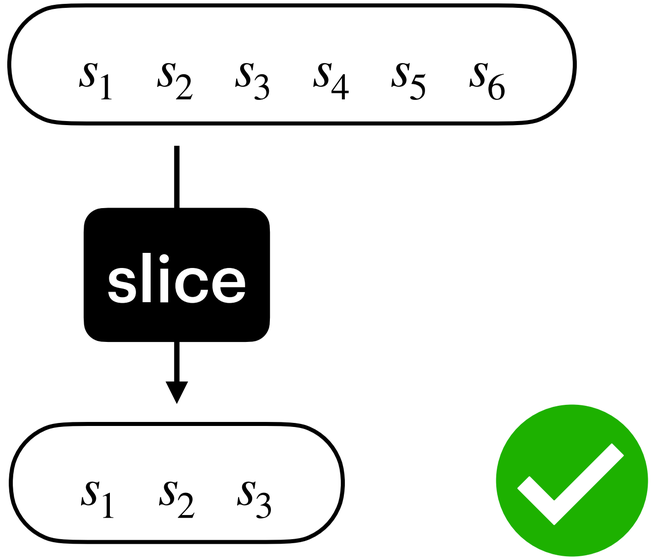

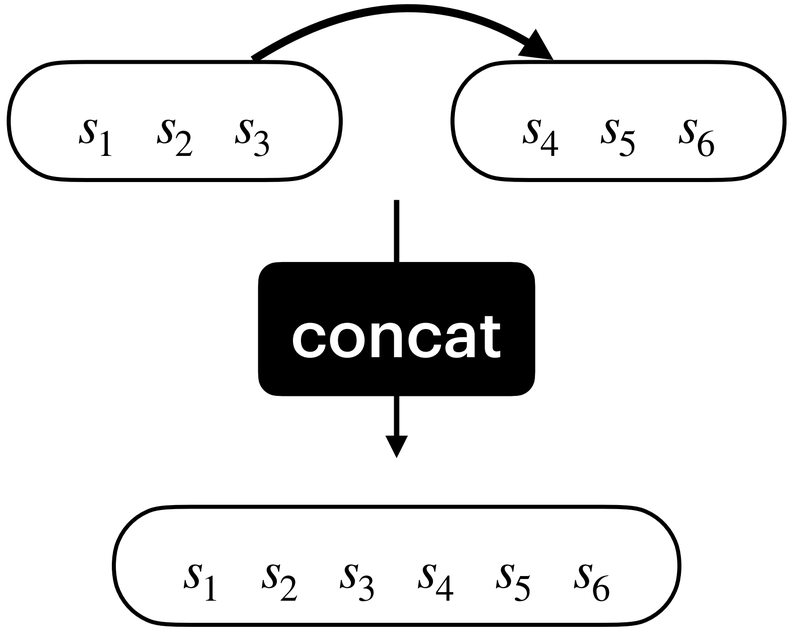

if $R(s_3, s_4)$ holds

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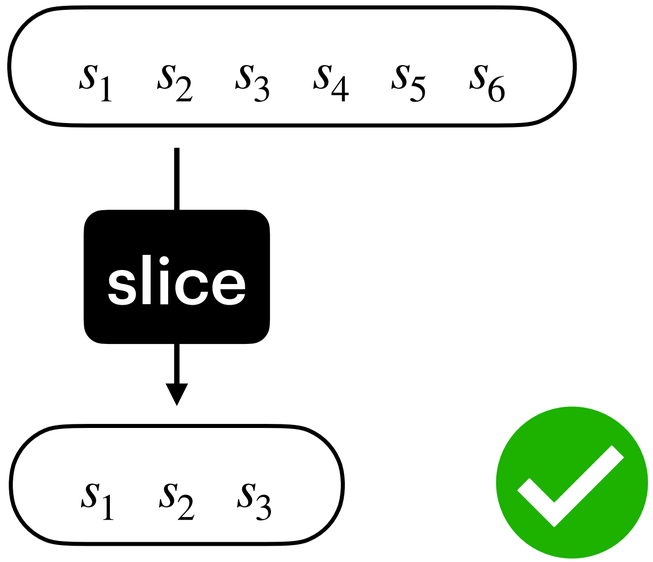

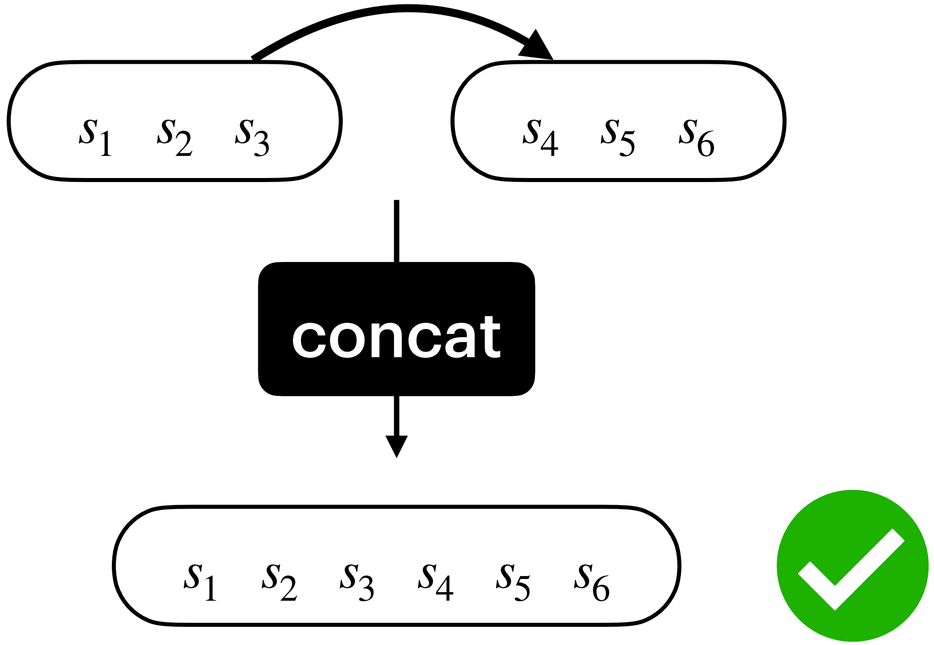

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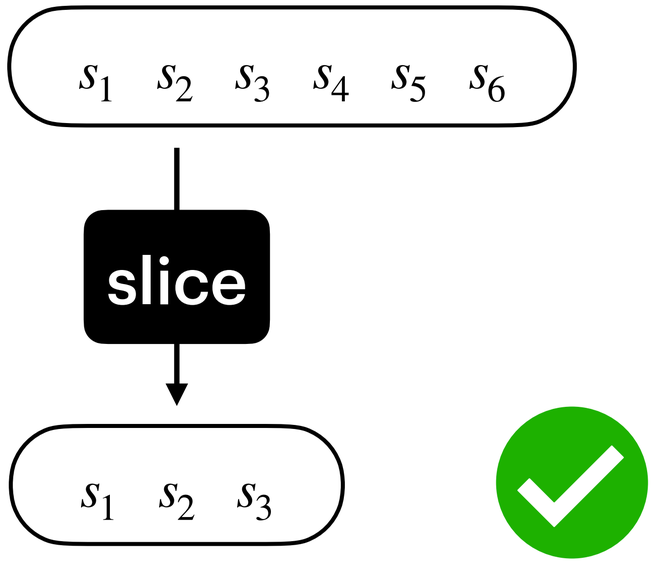

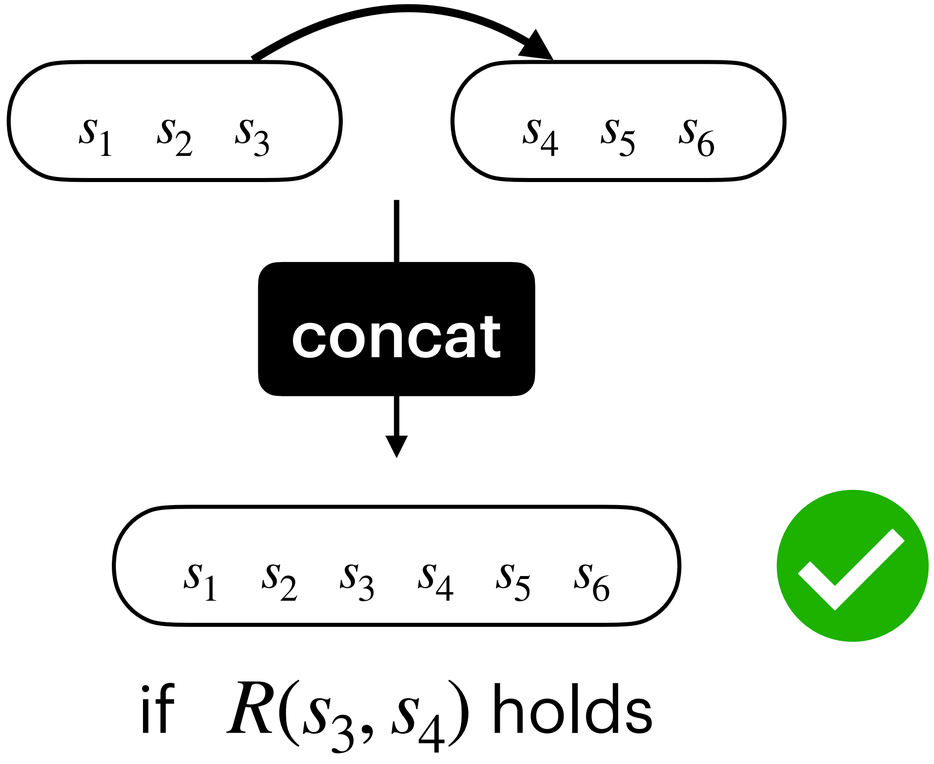

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Efficient to manipulate with a mix of static and runtime checks

Separability

As R-Paths

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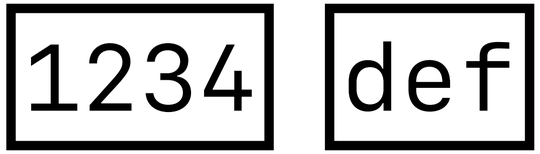

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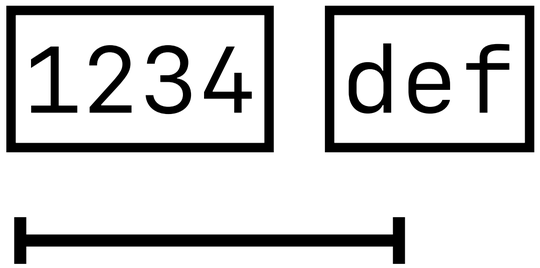

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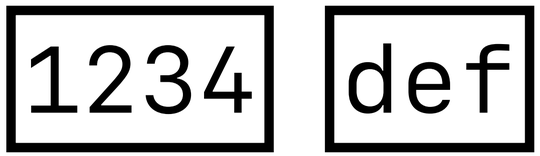

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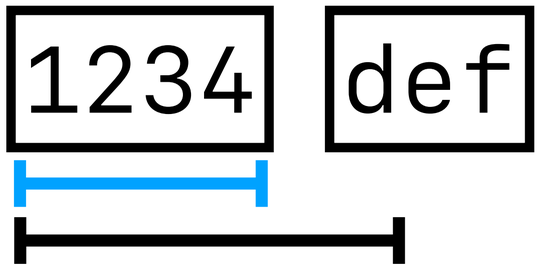

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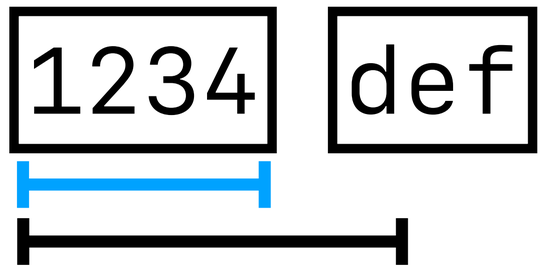

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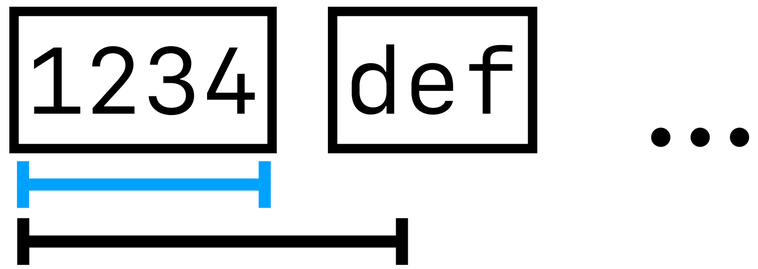

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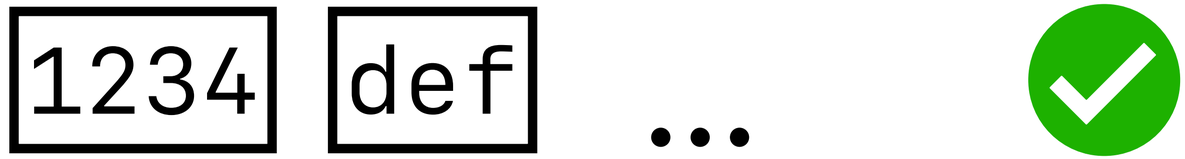

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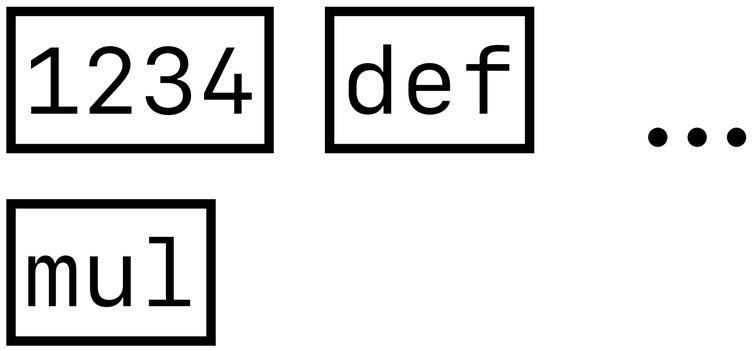

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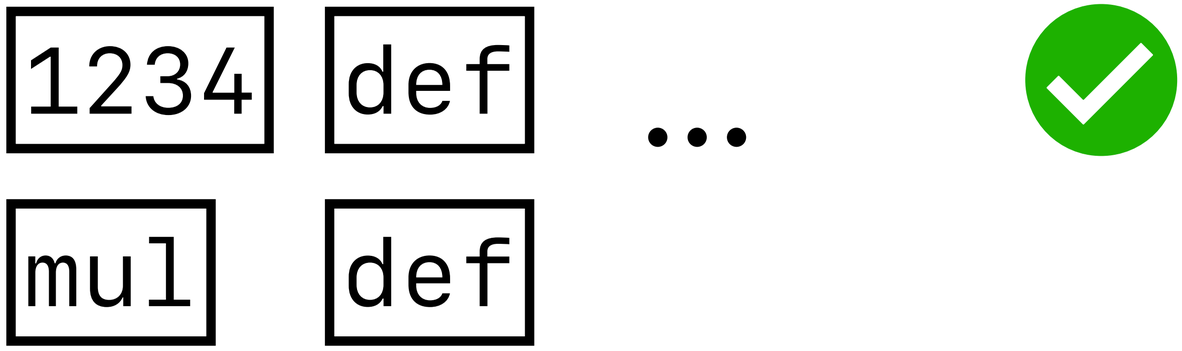

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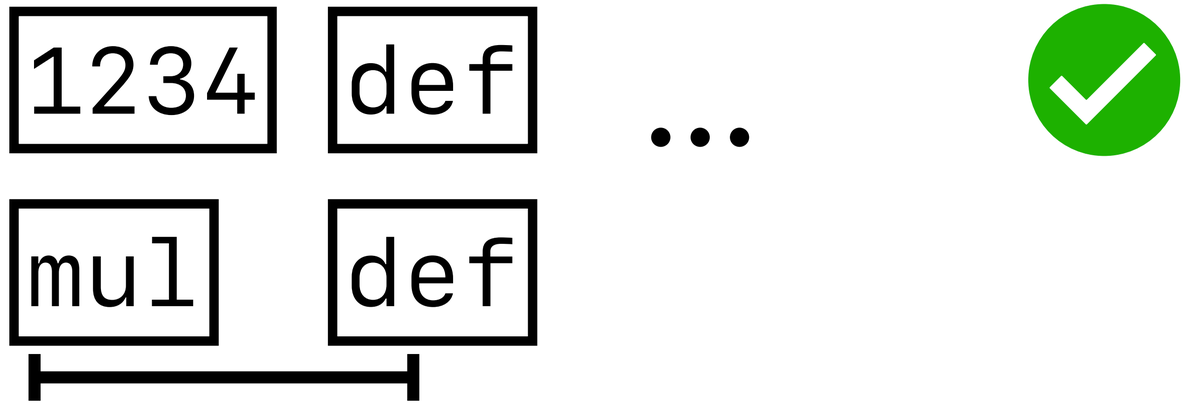

Identifier rule matches strings starting with `muld`

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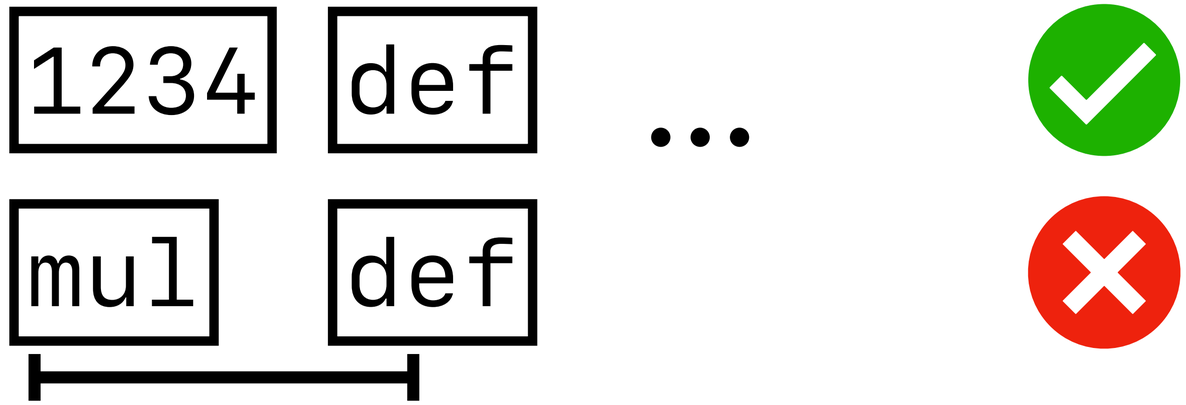

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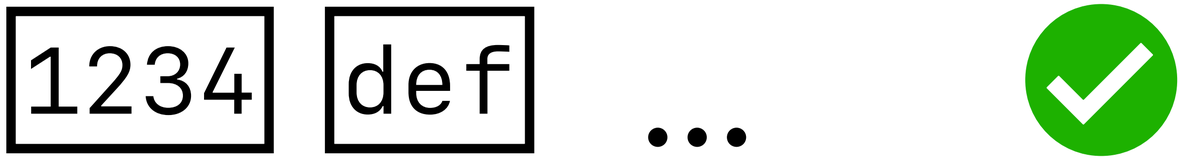

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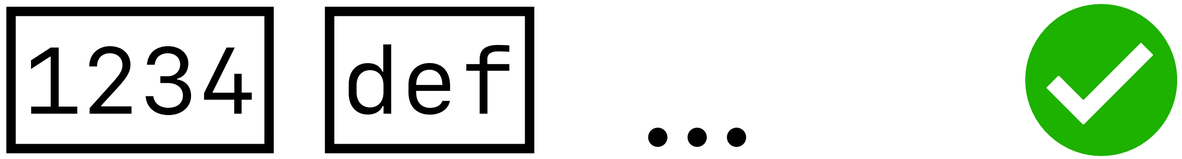
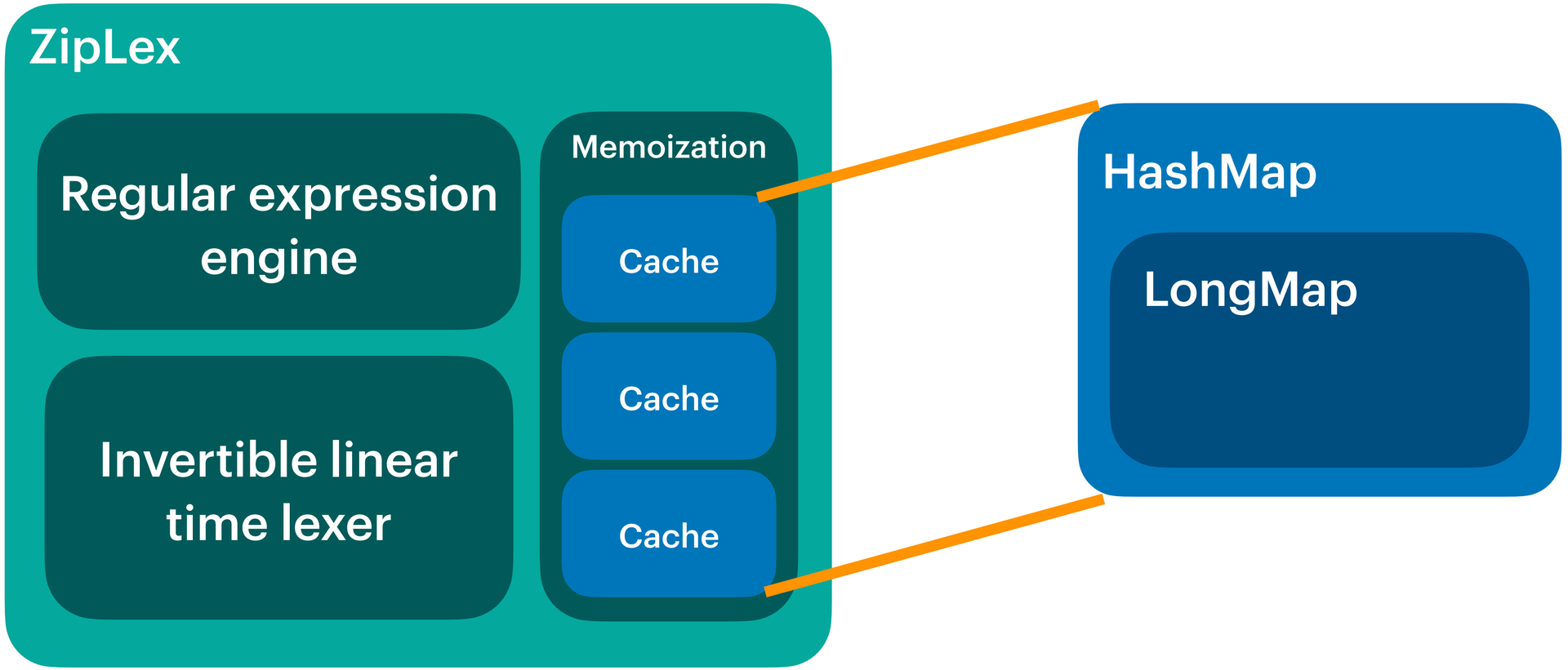


When 2 tokens are separable, the longest prefix by any rule is always the first token

ZipLex Framework

Overview



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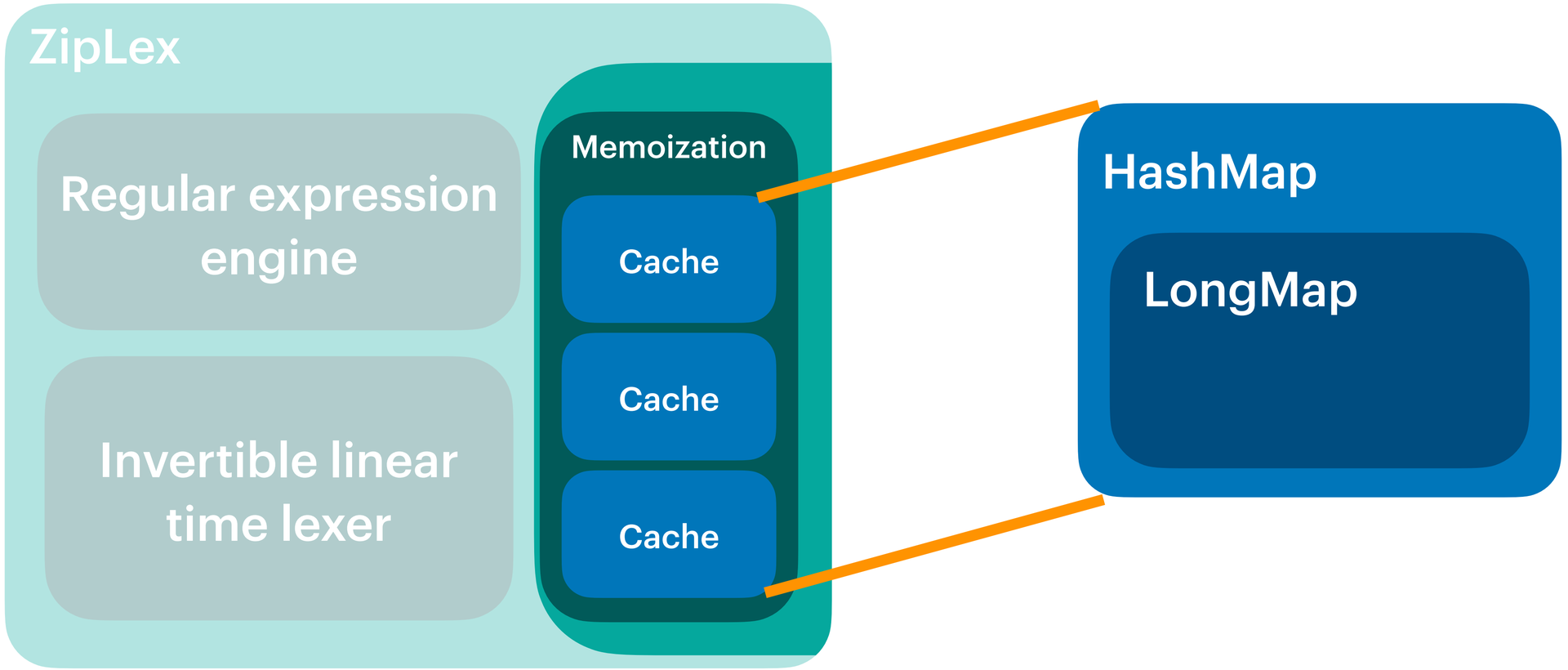

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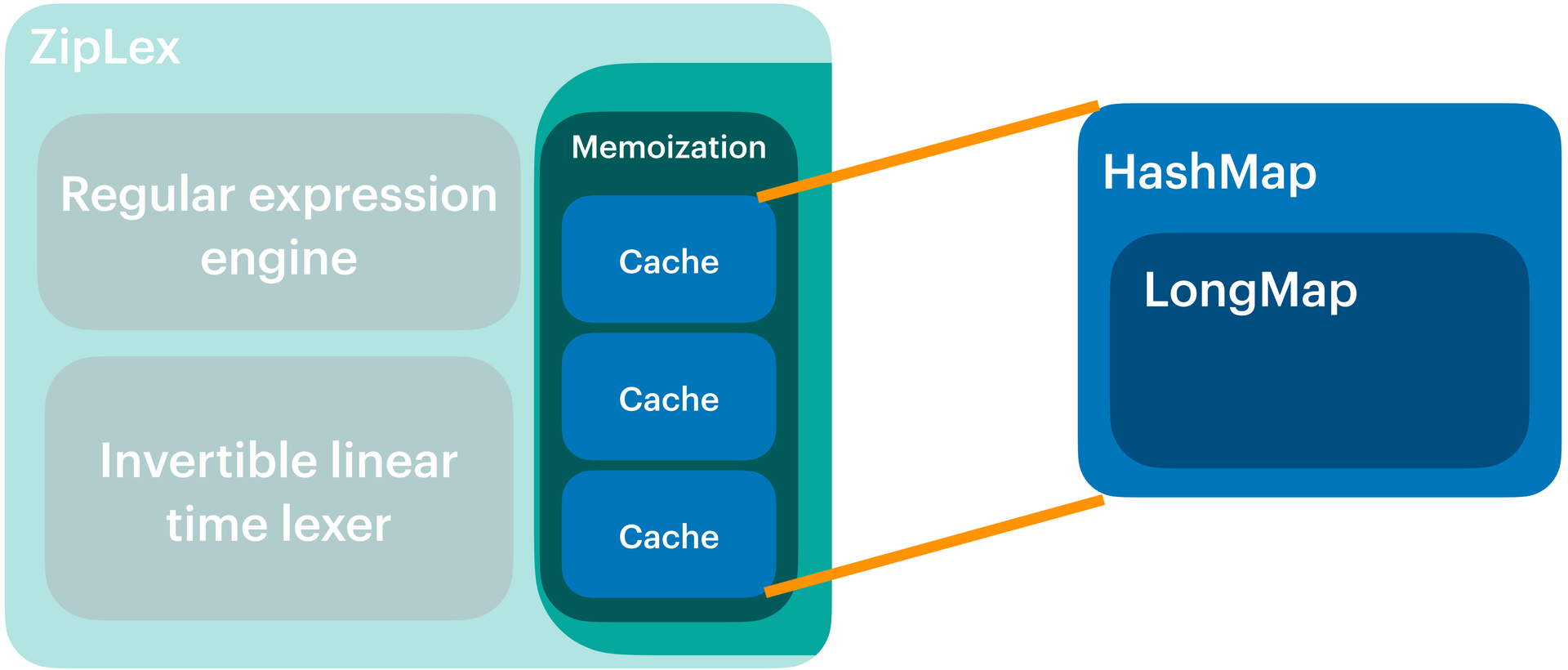

Reusable Verified Memoization Framework

Implementation

Reuse LongMap[1]

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LongMap[List[(K, V)]]

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Composition allowed for reuse and saved resources

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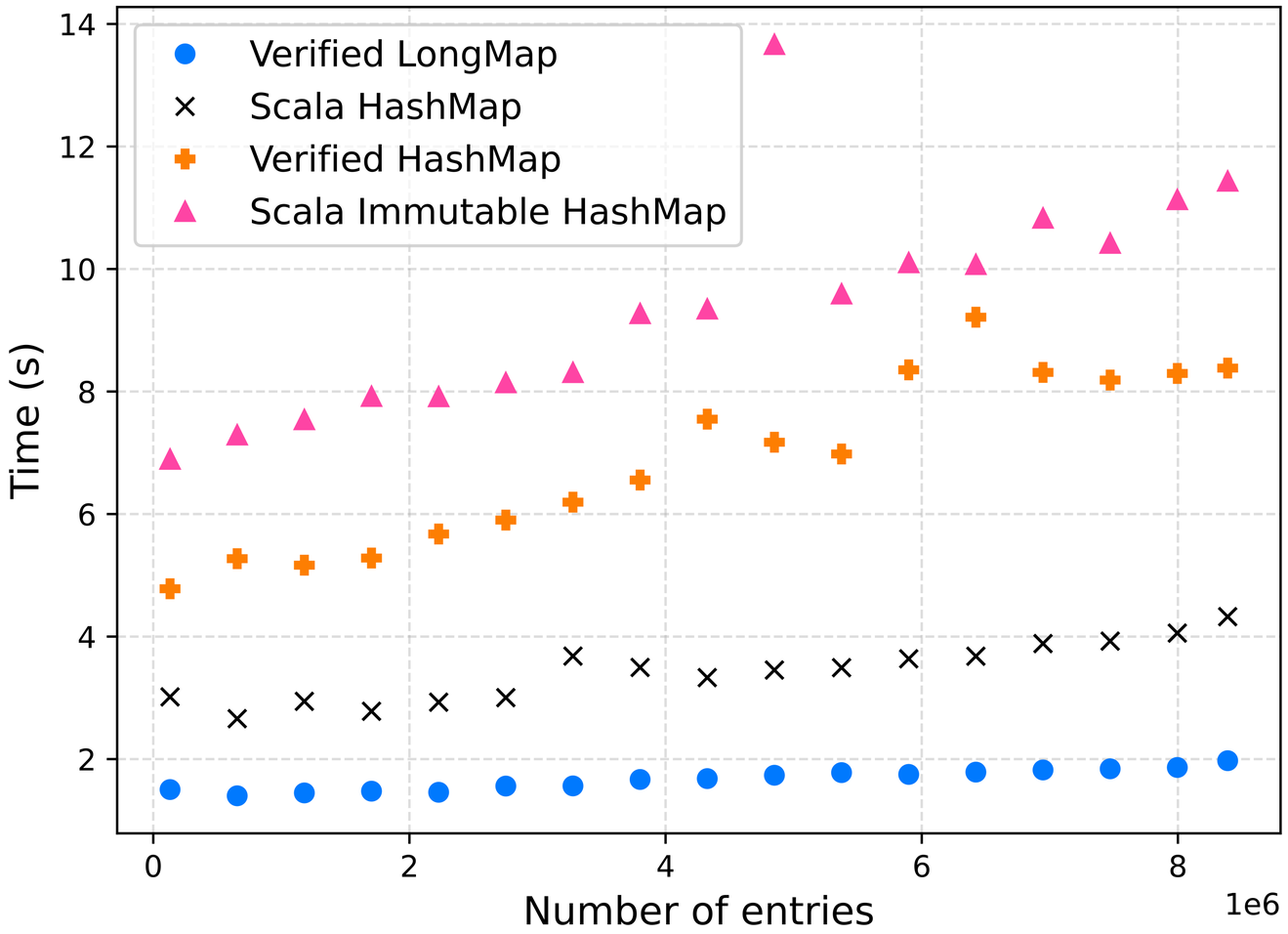
Hash Tables Performance



⇒ Our **verified mutable** hash table outperforms the Scala library **unverified immutable** map

Insert N pairs, remove N/2, insert N

Memoization

Regular expression matching and lexing

Memoization

Regular expression matching and lexing

Regular expression engine

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Memoized zipper-**derivatives computation** yielding **DFAs**

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Memoization enables **linear complexity** lexing (Reps 1998)[1]

[1]**Reps**, Thomas. 1998. **"'Maximal-Munch' Tokenization in Linear Time."** *ACM Trans. Program. Lang. Syst.* 20 (2): 259–73. https://doi.org/10.1145/276393.276394.

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Project Scale

Scala project formally verified using Stainless

Module	**Program**	**Spec + Proof**	**Total**
Longest Match Lexing	580	2030	2610
Lexer Printing + Invertibility	130	1430	1560
Regex Derivative Based Matching	470	2440	2910
Zipper Based Matching	390	2670	3060
BalanceConc	255	320	575
List & Set lemmas	-	1610	1610
Mutable HashMap (excluding LongMap)	90	2700	2790
Total	**1'915**	**13'200**	**15'115**

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Mutable LongMap	410	8200	8610

Performance analysis

Performance

a and a^*b Benchmark

Input: “$aaa\ldots a$”

Performance

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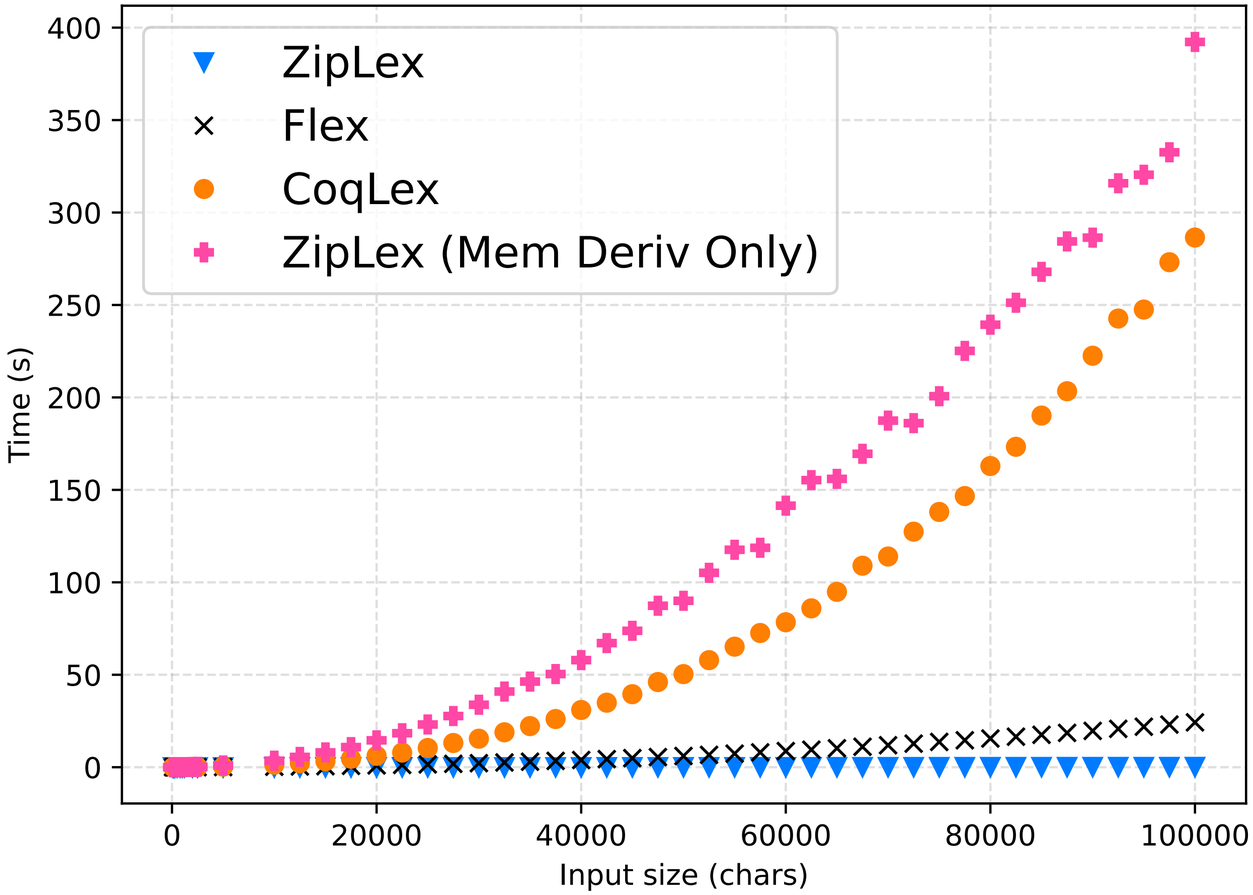

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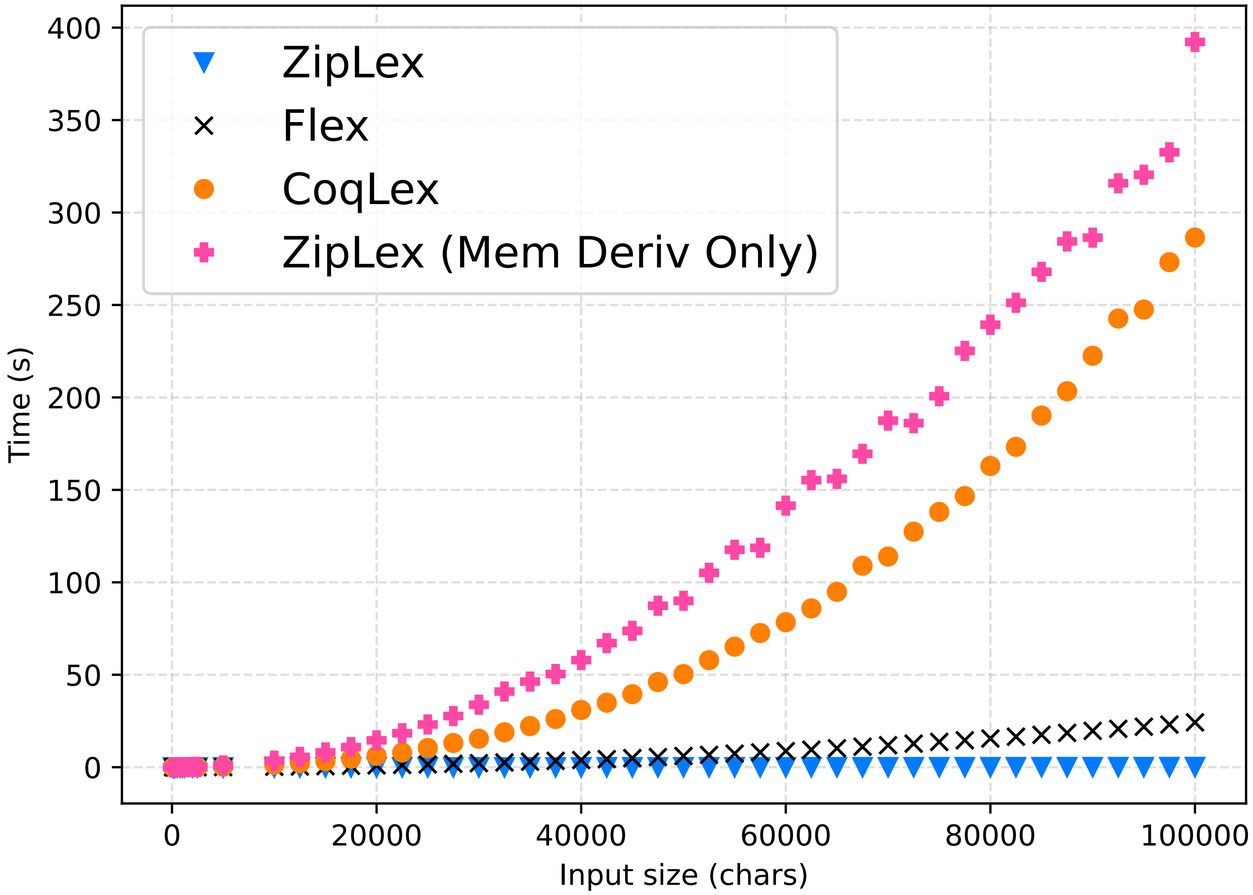

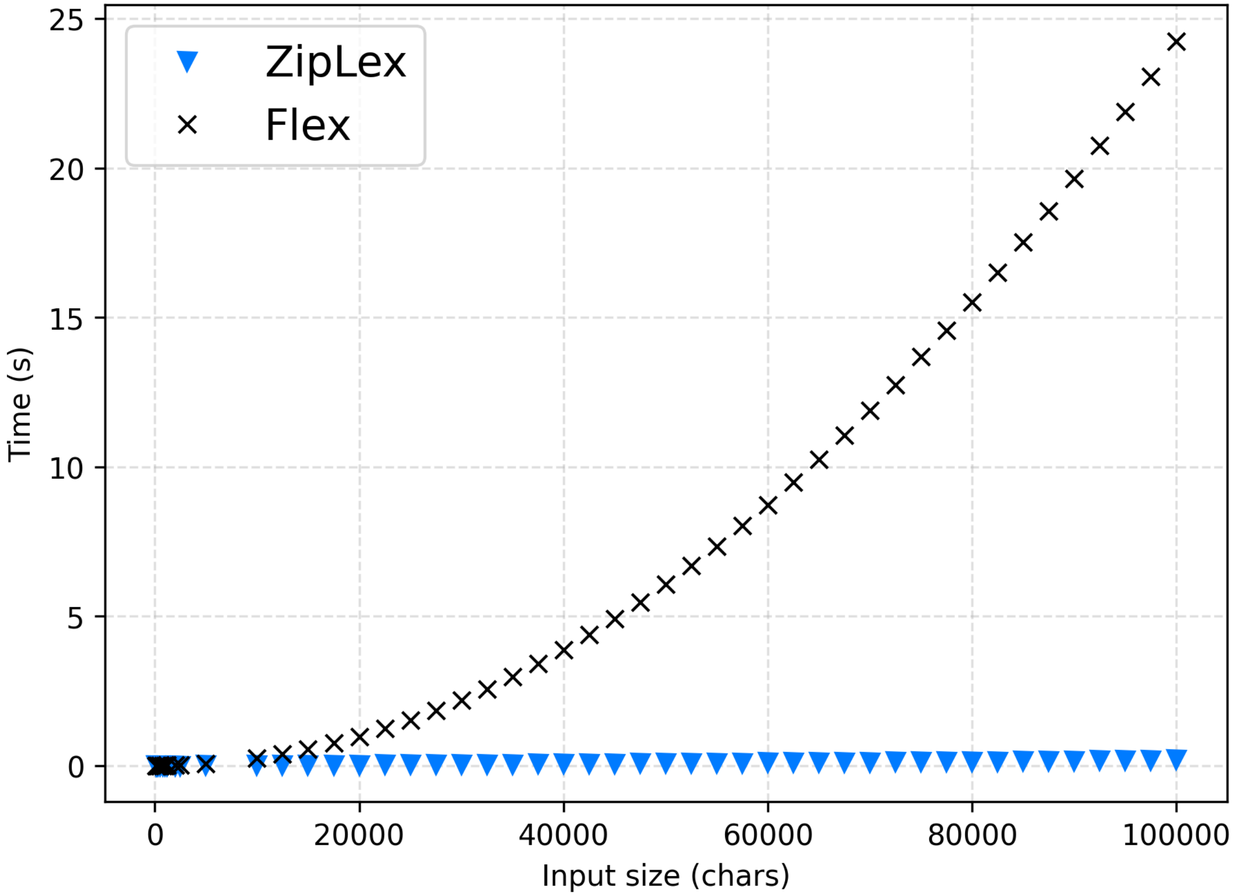

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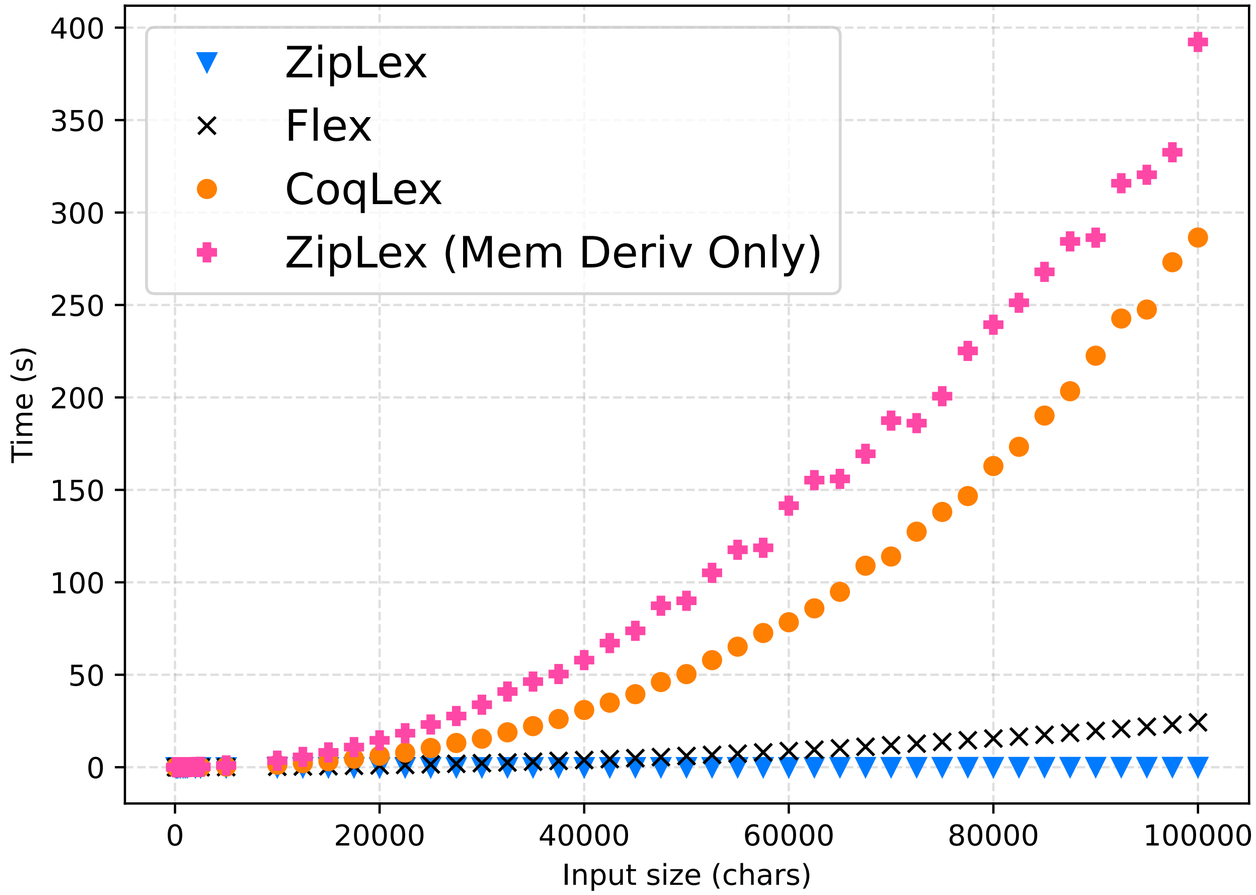
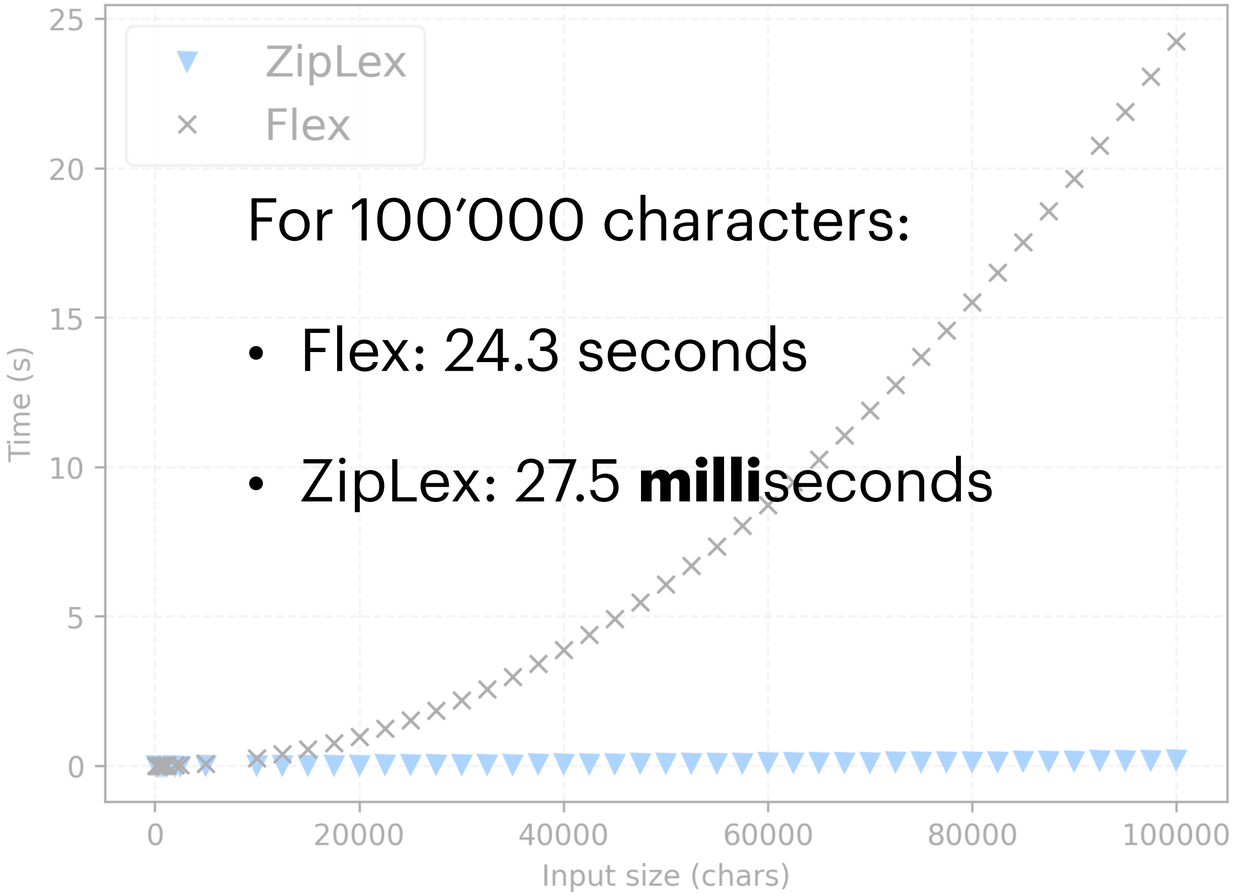
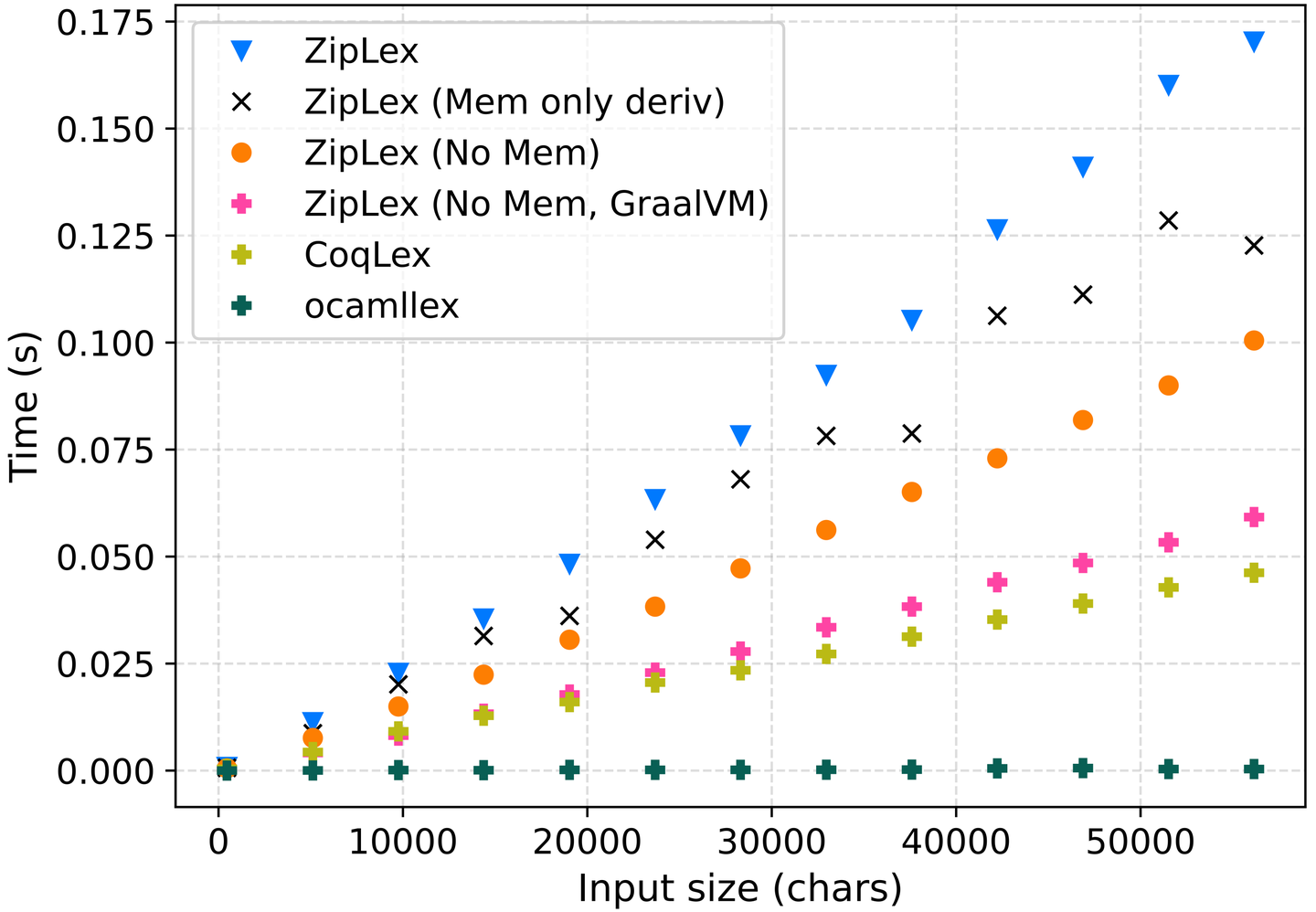




Performance

JSON Benchmark



Input: JSON objects and arrays[1]

Coqlex works on ASCII alphabet and does not verify invertibility

[1]Ouedraogo, Wendlasida, Gabriel Scherer, and Lutz Strassburger. 2023. **"Coqlex: Generating Formally Verified Lexers."** *The Art, Science, and Engineering of Programming* 8 (1): 3.

Conclusion

ZipLex

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Fully verified and **linear-time** lexer

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Longest match and **invertible** along with **R-Path** predicates

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Personal page

samuel.chassot@epfl.ch

Stainless

ZipLex

Backup

Token Separability

Examples

Token Separability

Examples

$$r_1 = a^+ \quad r_2 = b^+$$

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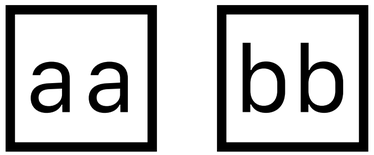

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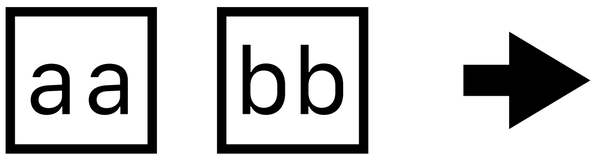
Examples

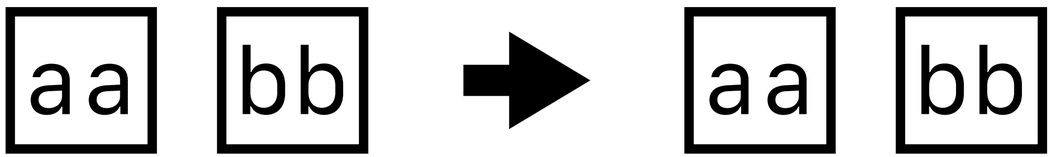
$$r_1 = a^+ \quad r_2 = b^+$$



Token Separability

Examples

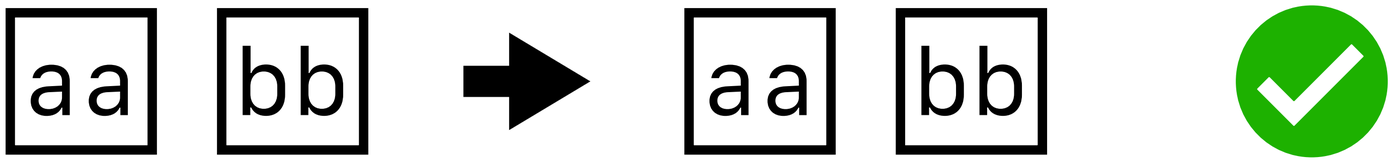
$$r_1 = a^+ \quad r_2 = b^+$$



Token Separability

Examples

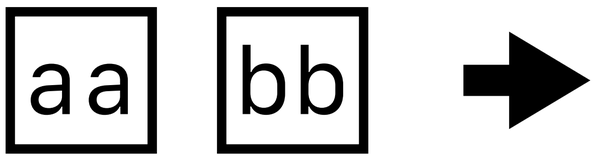
$r_1 = a^+ \quad r_2 = b^+$



Token Separability

Examples

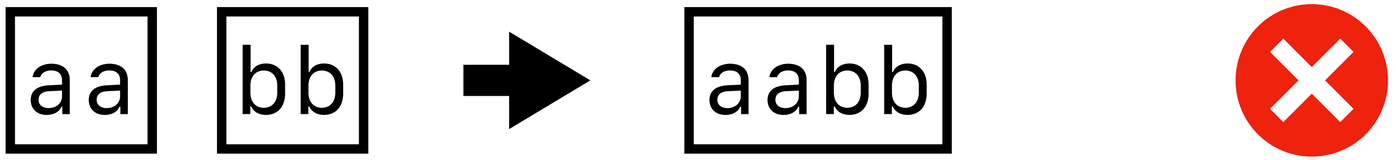
$$r_1 = a^+ \quad r_2 = b^+ \quad r_3 = (a \mid b)^+$$



Token Separability

Examples

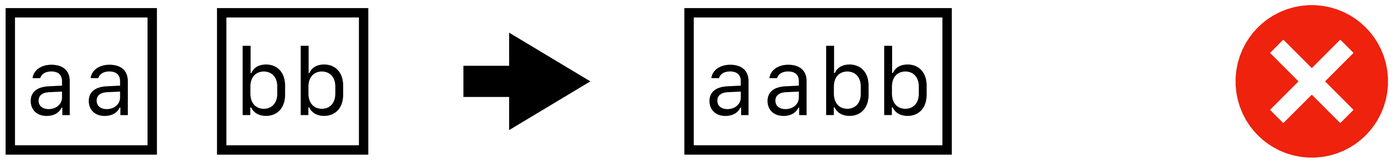
$$r_1 = a^+ \quad r_2 = b^+ \quad r_3 = (a \mid b)^+$$



Token Separability

Examples

$$r_1 = a^+ \quad r_2 = b^+ \quad r_3 = (a \mid b)^+$$

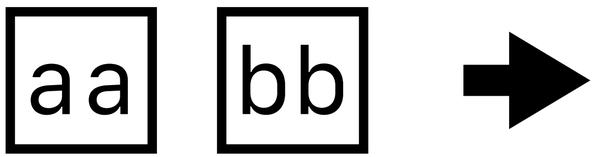


Separability is affected by ALL the rules

Token Separability

Examples

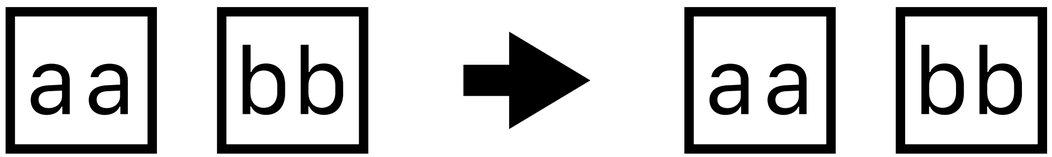
$$r_1 = a^+ \quad r_2 = b^+ \quad r_3 = (a \mid b)^+ \cdot c$$



Token Separability

Examples

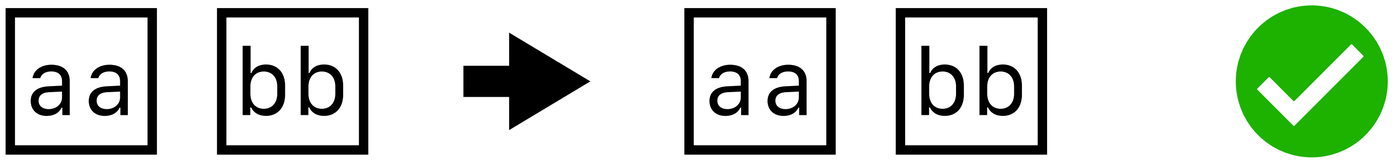
$$r_1 = a^+ \quad r_2 = b^+ \quad r_3 = (a \mid b)^+ \cdot c$$



Token Separability

Examples

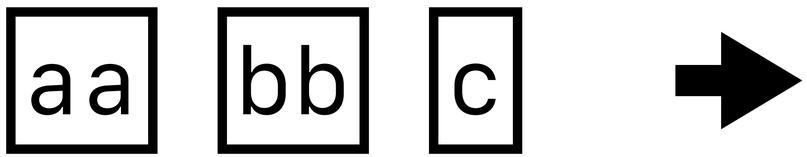
$$r_1 = a^+ \quad r_2 = b^+ \quad r_3 = (a \mid b)^+ \cdot c$$



Token Separability

Examples

$$r_1 = a^+ \quad r_2 = b^+ \quad r_3 = (a \mid b)^+ \cdot c$$



Token Separability

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$$r_1 = a^+ \quad r_2 = b^+ \quad r_3 = (a \mid b)^+ \cdot c$$

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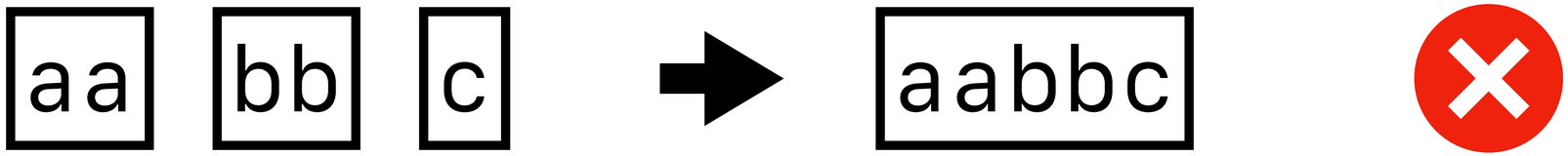
Examples

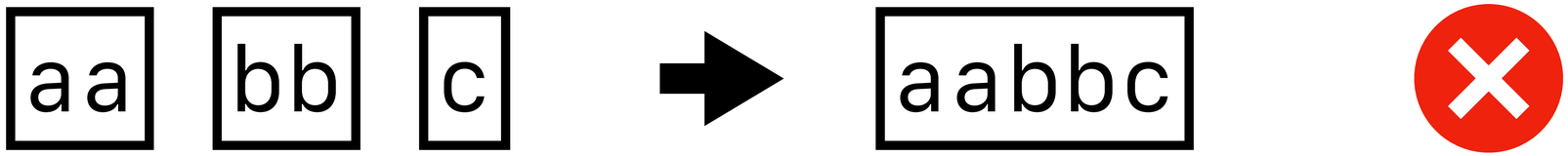
$$r_1 = a^+ \quad r_2 = b^+ \quad r_3 = (a \mid b)^+ \cdot c$$



Token Separability

Examples

$$r_1 = a^+ \quad r_2 = b^+ \quad r_3 = (a \mid b)^+ \cdot c$$



Separability is affected by following tokens

Performance

a and a^*b Benchmark

Input: “$aaa\ldots a$”

Performance

a and a^*b Benchmark

Input: "$aaa\ldots a$"