Packrat Parsing: Simple, Powerful, Lazy, Linear Time

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Overview

- What Is Packrat Parsing?
- What is it Good (and not good) For?
- Practical Experience
- Related Work
- Conclusion

What is Packrat Parsing?

Answer:

Top-down parsing with backtracking –

except:

Uses memoization to achieve linear parse time

Example Grammar

Additive	→	Multitive '+' Additive
	|	Multitive
Multitive	→	Primary '*' Multitive
	|	Primary
Primary	→	'(' Additive ')'
	|	Decimal
Decimal	→	'0' | … | '9'

Recursive Descent Parser

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```
data Result v = Parsed v String
              | NoParse
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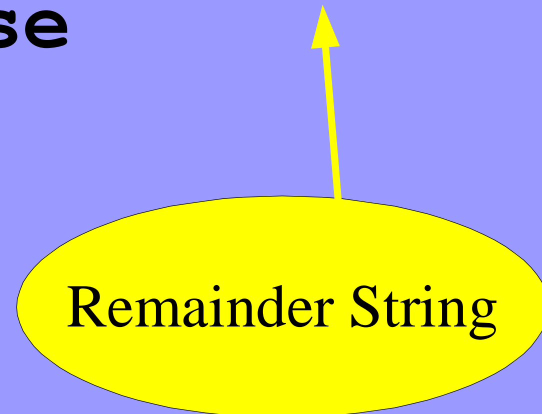

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Parsing Example

pAdditive “2*(3+4)”

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pAdditive "2*(3+4)"

$A \rightarrow M$ '+' A

Parsing Example

pAdditive “2*(3+4)”

pMultitive “2*(3+4)”

A → M '+' A

Parsing Example

pAdditive "2*(3+4)"   A → M '+' A

pMultitive "2*(3+4)"   M → P '*' M

Parsing Example

pAdditive “2*(3+4)”

pMultitive “2*(3+4)”

pPrimary “2*(3+4)”

$A \rightarrow M$ '+' A

$M \rightarrow P$ '*' M

Parsing Example

pAdditive "2*(3+4)" A → M '+' A

pMultitive "2*(3+4)" M → P '*' M

pPrimary "2*(3+4)" P → '(' A ')'

Parsing Example

pAdditive “2*(3+4)” A → M '+' A

pMultitive “2*(3+4)” M → P '*' M

pPrimary “2*(3+4)” ~~P → '(' A ')'~~

Parsing Example

pAdditive “2*(3+4)” A → M '+' A

pMultitive “2*(3+4)” M → P '*' M

pPrimary “2*(3+4)” P → D

Parsing Example

pAdditive "2*(3+4)" $A \rightarrow M$ '+' A

pMultitive "2*(3+4)" $M \rightarrow P$ '*' M

pPrimary "2*(3+4)" $P \rightarrow D$

pDecimal "2*(3+4)"

Parsing Example

pAdditive “2*(3+4)” A → M '+' A

pMultitive “2*(3+4)” M → P '*' M

pPrimary “2*(3+4)” P → D

pDecimal “2*(3+4)” ⇒ Parsed 2 “*(3+4)”

Parsing Example

pAdditive “2*(3+4)” $A \rightarrow M$ '+' A

pMultitive “2*(3+4)” $M \rightarrow P$ '*' M

pPrimary “2*(3+4)” $\Rightarrow$ Parsed 2 “*(3+4)”

Parsing Example

pAdditive "2*(3+4)" $A \to M$ '+' A

pMultitive "2*(3+4)" $M \to P$ '*' M

pPrimary "2*(3+4)" $\Rightarrow$ Parsed 2 "*(3+4)"

pChar '*' "*(3+4)"

Parsing Example

pAdditive “2*(3+4)” $A \to M$ '+' A

pMultitive “2*(3+4)” $M \to P$ '*' M

pPrimary “2*(3+4)” $\Rightarrow$ Parsed 2 “*(3+4)”

pChar '*' “*(3+4)” $\Rightarrow$ Parsed () “(3+4)”

Parsing Example

pAdditive “2*(3+4)” — A → M '+' A

pMultitive “2*(3+4)” — M → P '*' M

pPrimary “2*(3+4)” ⇒ Parsed 2 “*(3+4)”

pChar '*' “*(3+4)” ⇒ Parsed () “(3+4)”

pMultitive “(3+4)”

Parsing Example

pAdditive “2*(3+4)” $A \to M$ '+' A

pMultitive “2*(3+4)” $M \to P$ '*' M

pPrimary “2*(3+4)” $\Rightarrow$ Parsed 2 “*(3+4)”

pChar '*' “*(3+4)” $\Rightarrow$ Parsed () “(3+4)”

pMultitive “(3+4)”

…

Parsing Example

pAdditive “2*(3+4)” A → M '+' A

pMultitive “2*(3+4)” M → P '*' M

pPrimary “2*(3+4)” ⇒ Parsed 2 “*(3+4)”

pChar '*' “*(3+4)” ⇒ Parsed () “(3+4)”

pMultitive “(3+4)” ⇒ Parsed 7 “”

Parsing Example

pAdditive “2*(3+4)” $A \rightarrow M$ '+' A

pMultitive “2*(3+4)” $\Rightarrow$ Parsed 14 “”

Parsing Example

pAdditive “2*(3+4)” $A \rightarrow M$ '+' A

pMultitive “2*(3+4)” $\Rightarrow$ Parsed 14 “”

pChar '+' “”

Parsing Example

pAdditive “2*(3+4)” $A \rightarrow M$ '+' A

pMultitive “2*(3+4)” $\Rightarrow$ Parsed 14 “”

~~pChar '+'~~ “”

Parsing Example

pAdditive “2*(3+4)”

$A \rightarrow M$

Parsing Example

pAdditive “2*(3+4)”

pMultitive “2*(3+4)”

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Parsing Example

pAdditive "2*(3+4)"

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...

$A \rightarrow M$

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- Can yield exponential worst-case parse times
- **Typical solution:** avoid backtracking by
  - Prediction using one-token lookahead
  - Hacking the grammar
  - Designing the language for easy parsing
- **Alternate solution:** allow backtracking;
  - *memoize all intermediate results.*

Memoization of Results

Assumptions:

- Parsing functions depend *only* on input string.
- Parsing functions yield *at most one result*.

Implication:

- Requires results table of size $(m \times (n+1))$
  - m = number of nonterminals/parsing functions
  - n = length of input string

Building a Packrat Parser

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```
data Result v = Parsed v String
              | NoParse

pAdditive  :: String -> Result Int
pMultitive:: String -> Result Int
pPrimary   :: String -> Result Int
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pAdditive  :: String -> Result Int
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Building a Packrat Parser

```
data Result v = Parsed v Derivs
              | NoParse

pAdditive  :: Derivs -> Result Int
pMultitive :: Derivs -> Result Int
pPrimary   :: Derivs -> Result Int
pDecimal   :: Derivs -> Result Int
```

Building a Packrat Parser

```
data Result v = Parsed v Derivs
              | NoParse

data Derivs = Derivs {
        dvAdditive    :: Result Int,
        dvMultitive   :: Result Int,
        dvPrimary     :: Result Int,
        dvDecimal     :: Result Int,
        dvChar        :: Result Char}
```

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parse :: String -> Derivs
parse s = d where
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parse s = d where

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  chr = case s of
          (c:s') -> Parsed c (parse s')
          []     -> NoParse
```

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  add = pAdditive  d
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  prim= pPrimary   d
  dec = pDecimal   d
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  dec = pDecimal   d
```

Modifying the Parsing Functions

```
pAdditive :: Derivs -> Result Int
pAdditive =
       (do l <- pMultitive
           char '+'
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   <|> (do pMultitive)
```

Modifying the Parsing Functions

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```

Modifying the Parsing Functions

```
pAdditive :: Derivs -> Result Int
pAdditive =
        (do l <- dvMultitive
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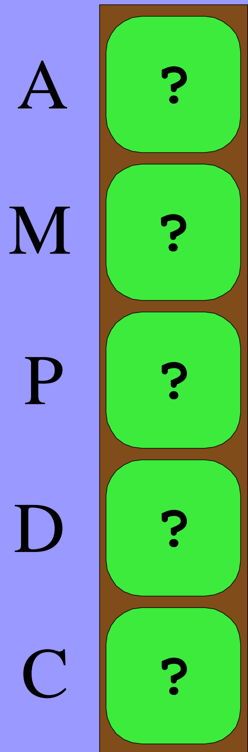
            r <- dvAdditive
            return (l + r))
    <|> (do dvMultitive)
```

Packrat Parsing Example

```
parse "2*(3+4)"
```

Packrat Parsing Example



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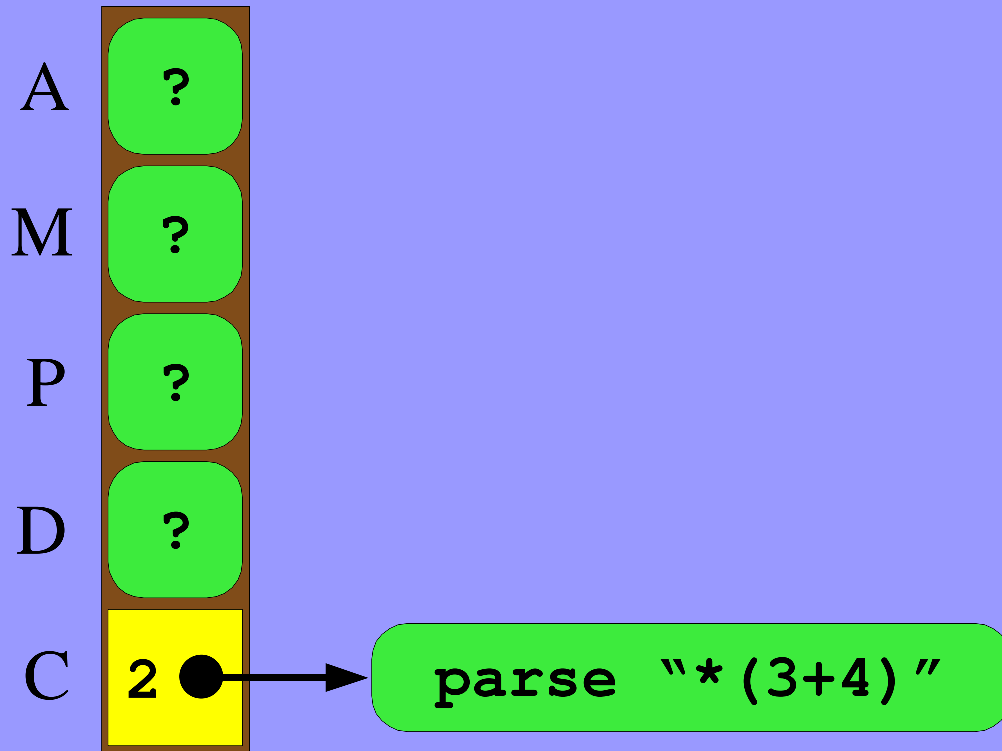

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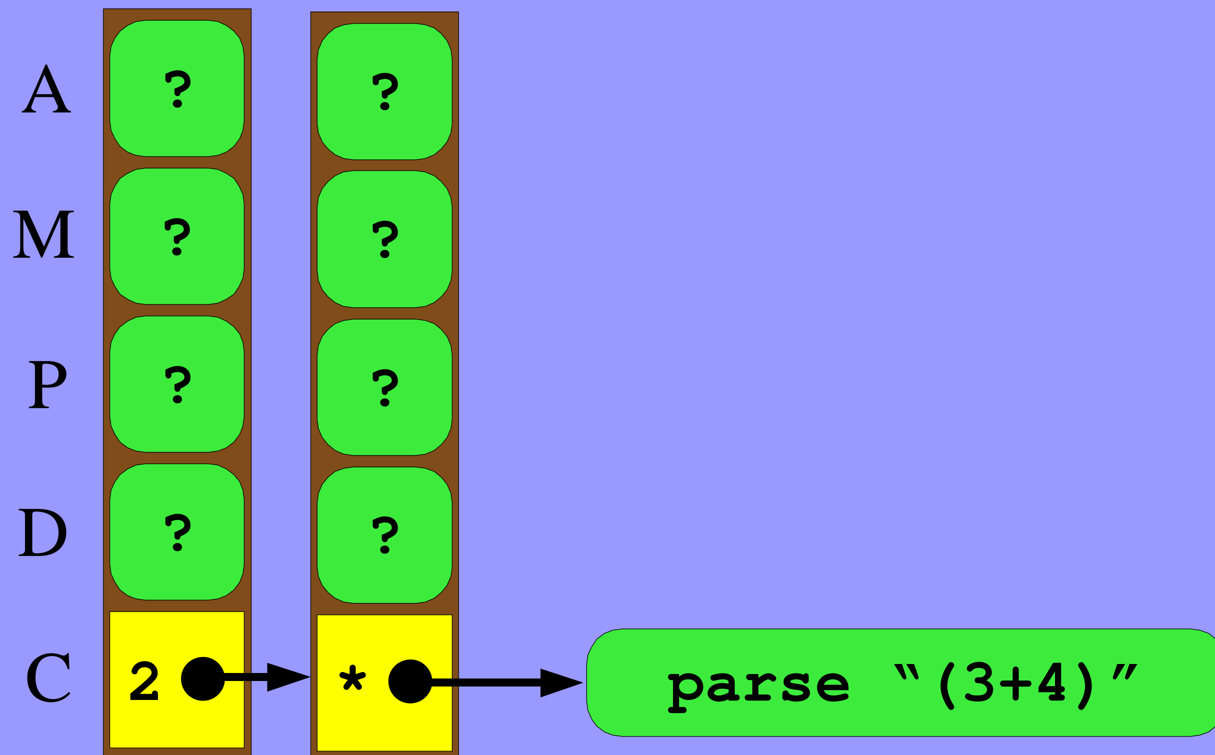

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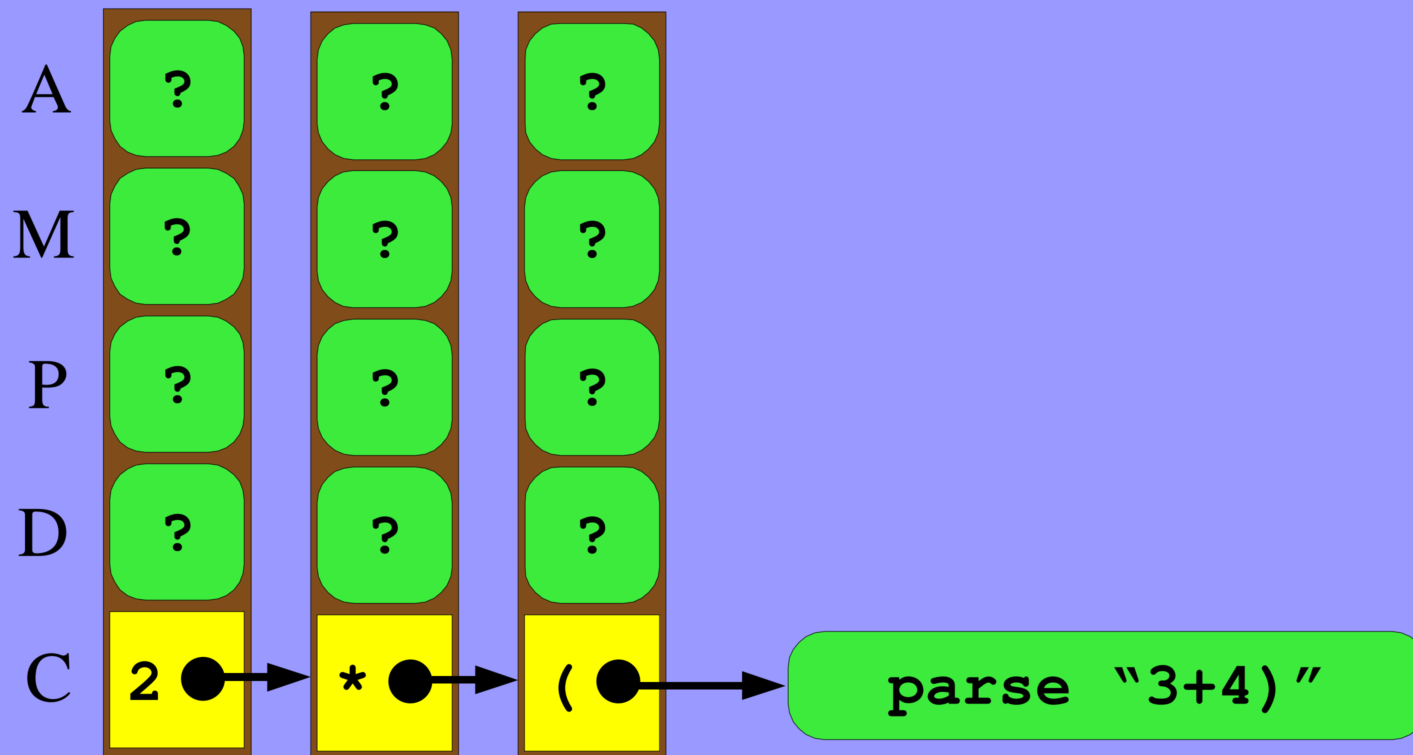

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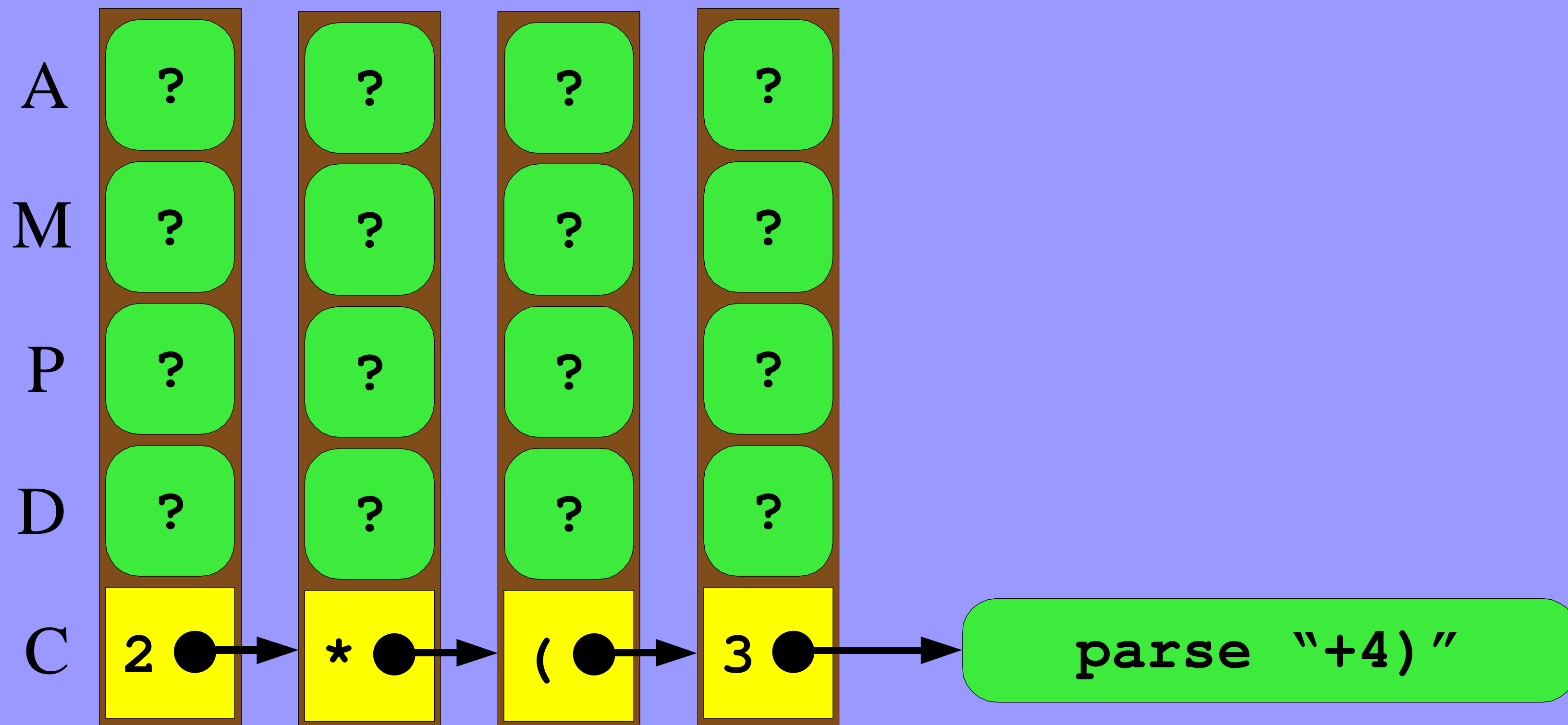

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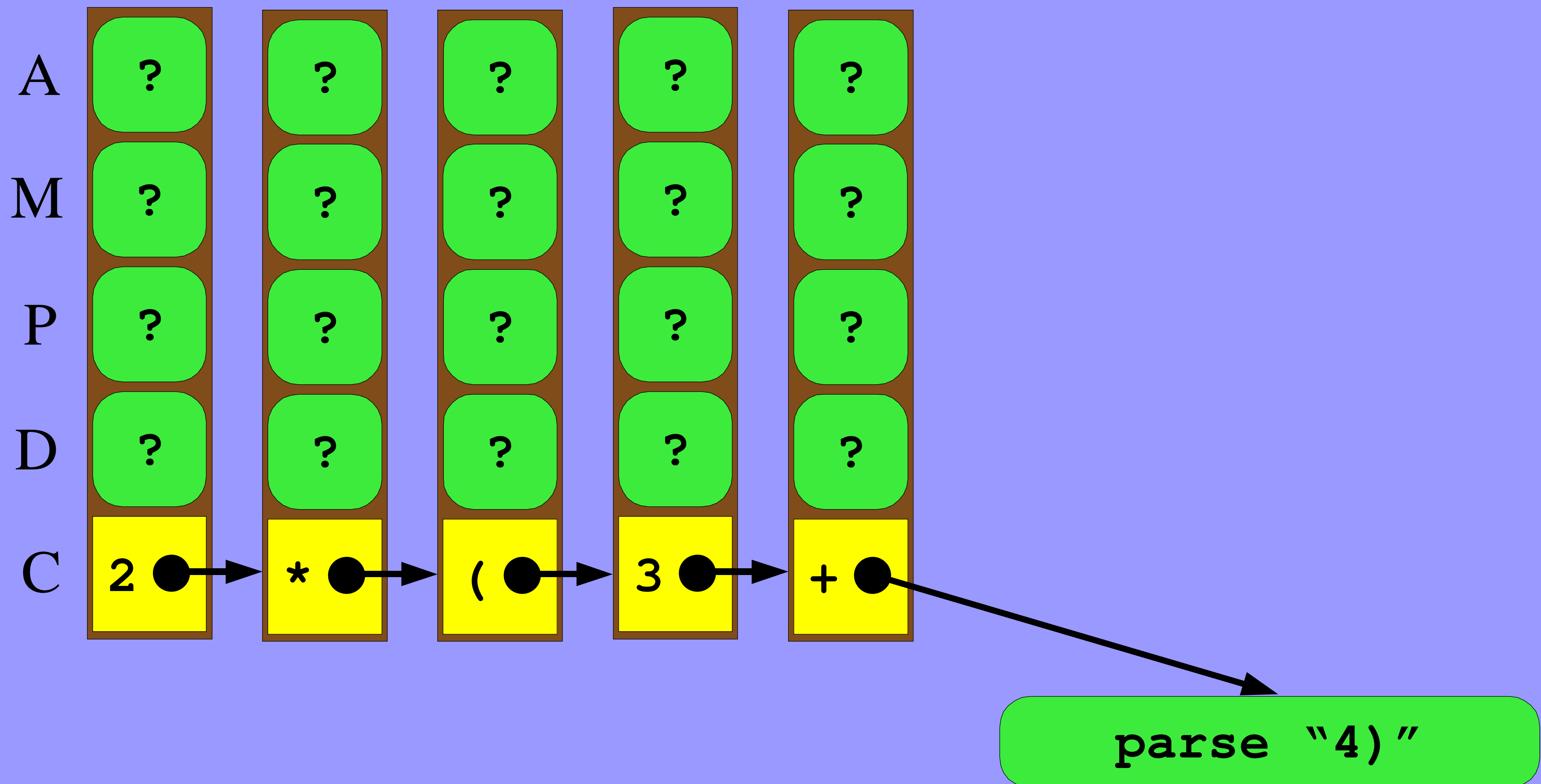

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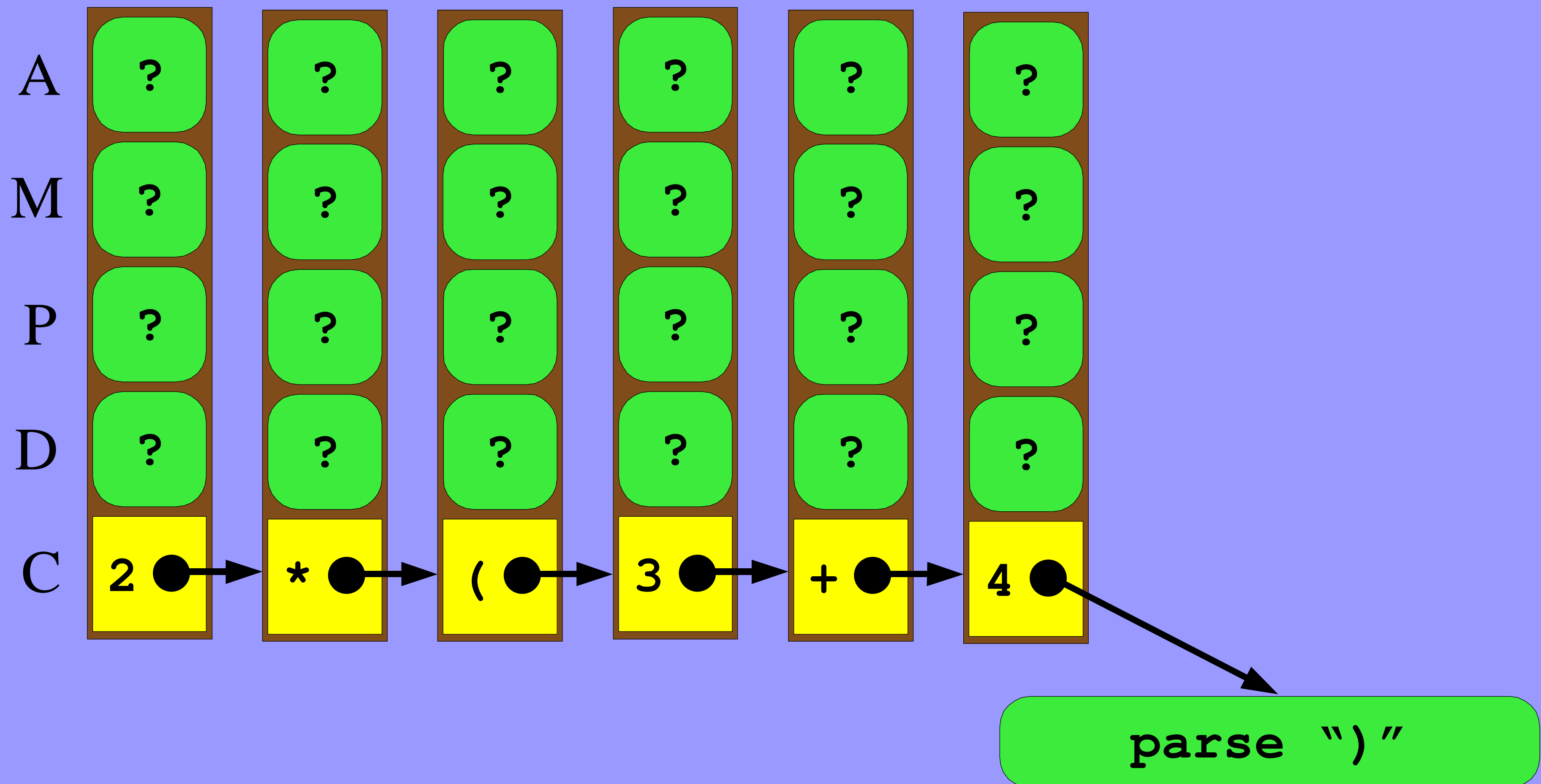

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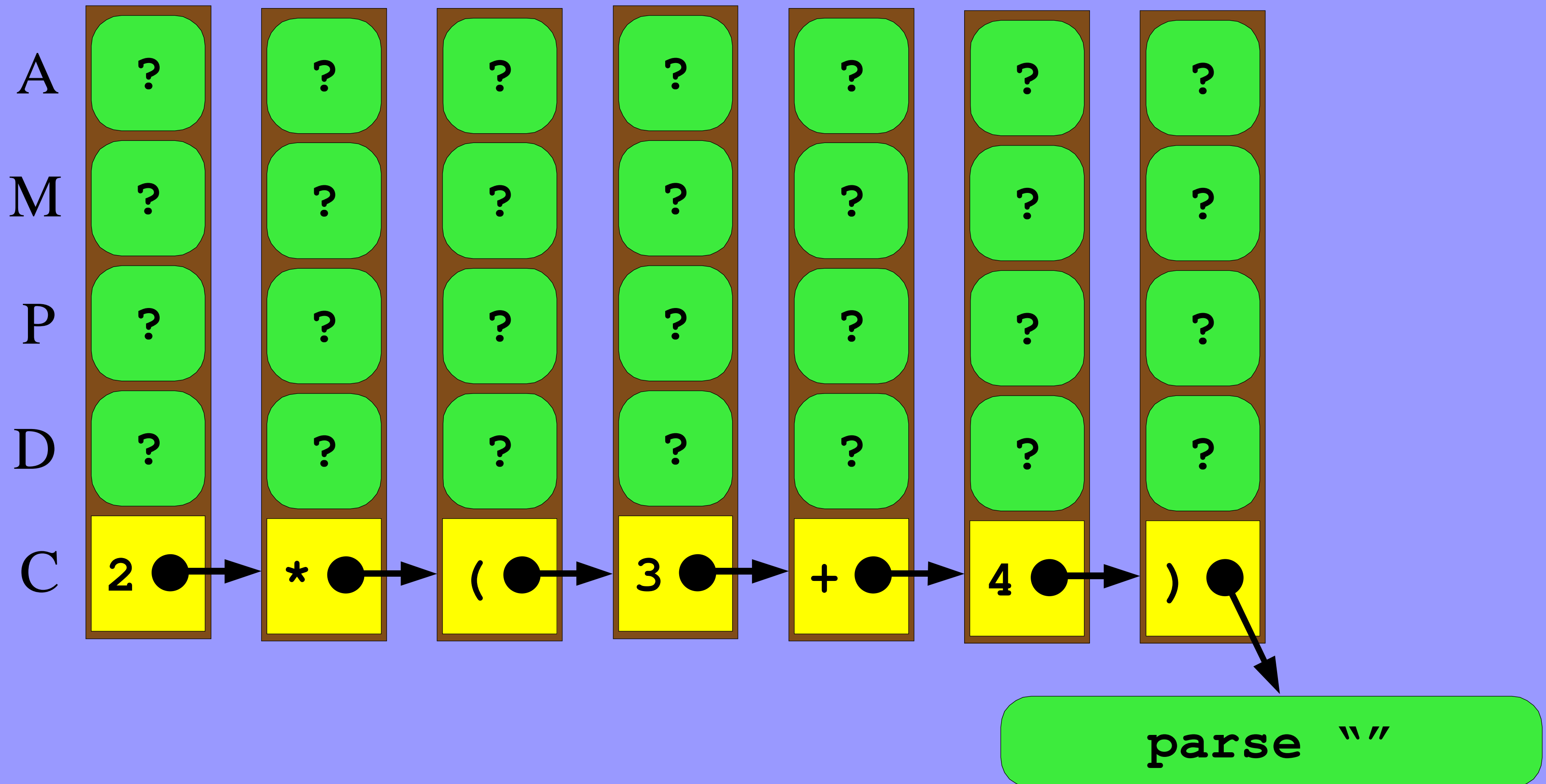

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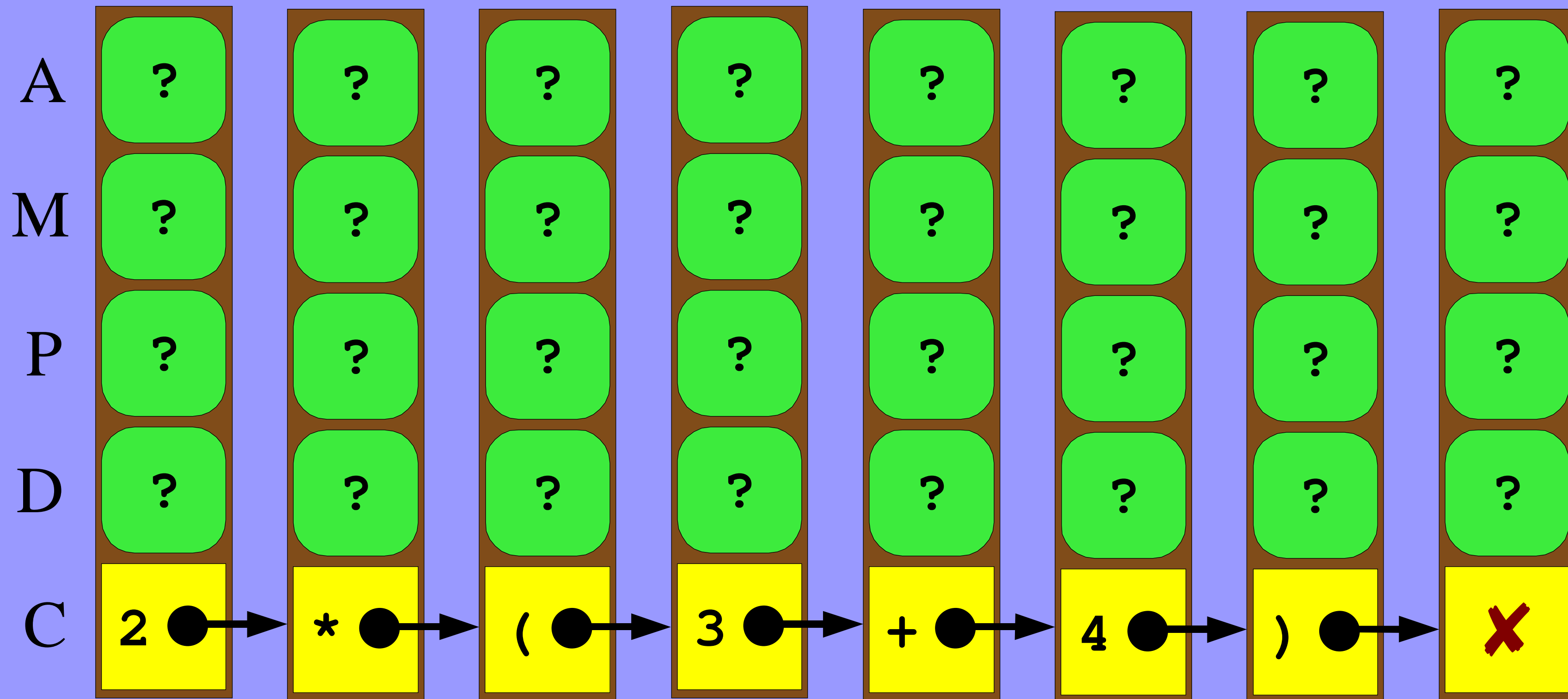

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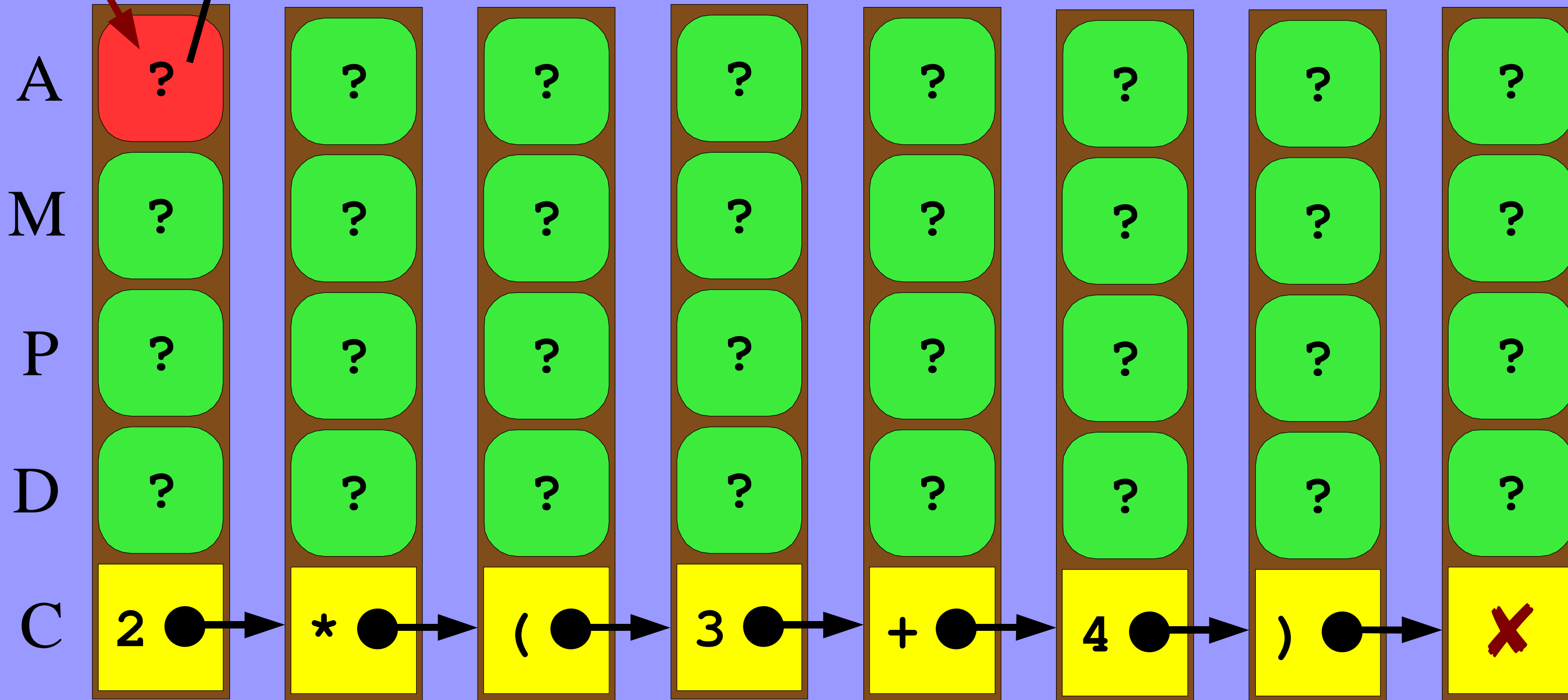

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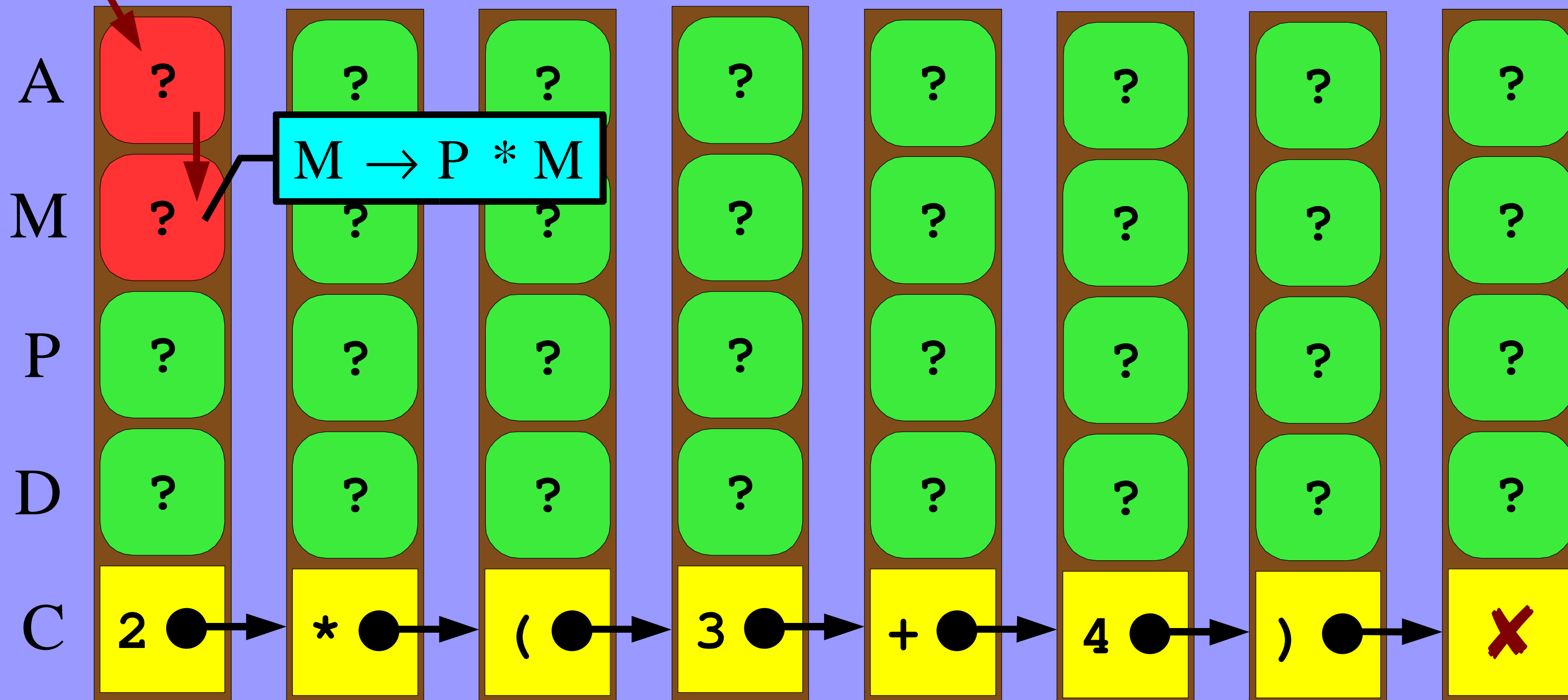

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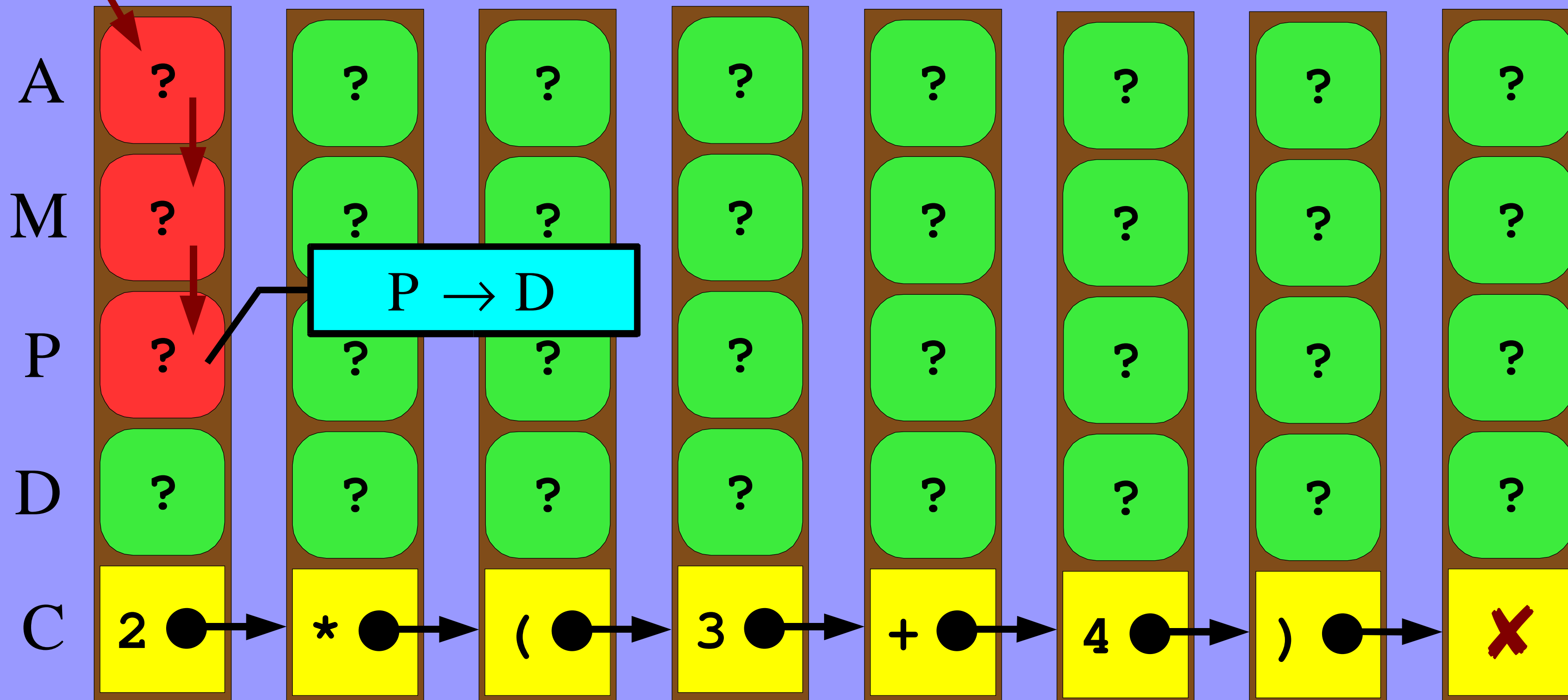

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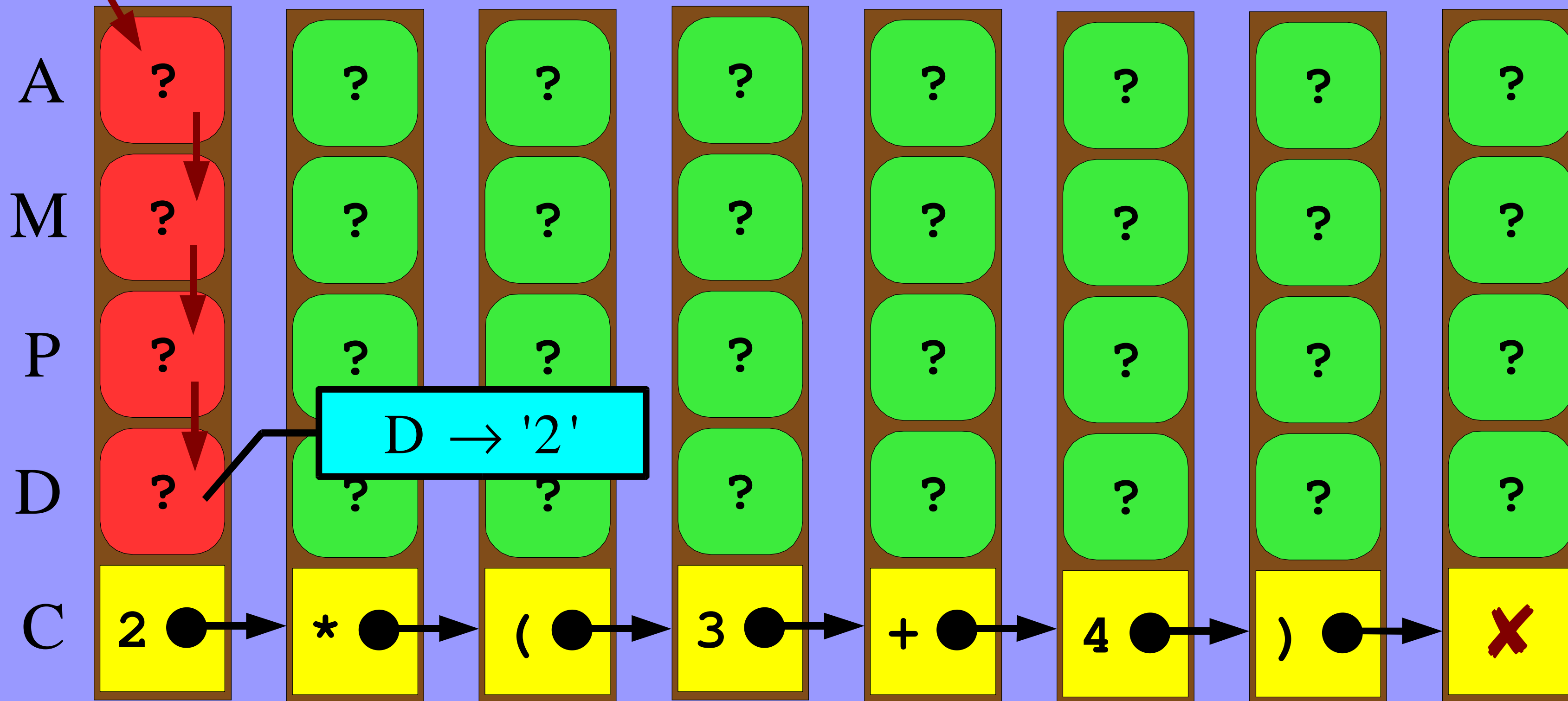

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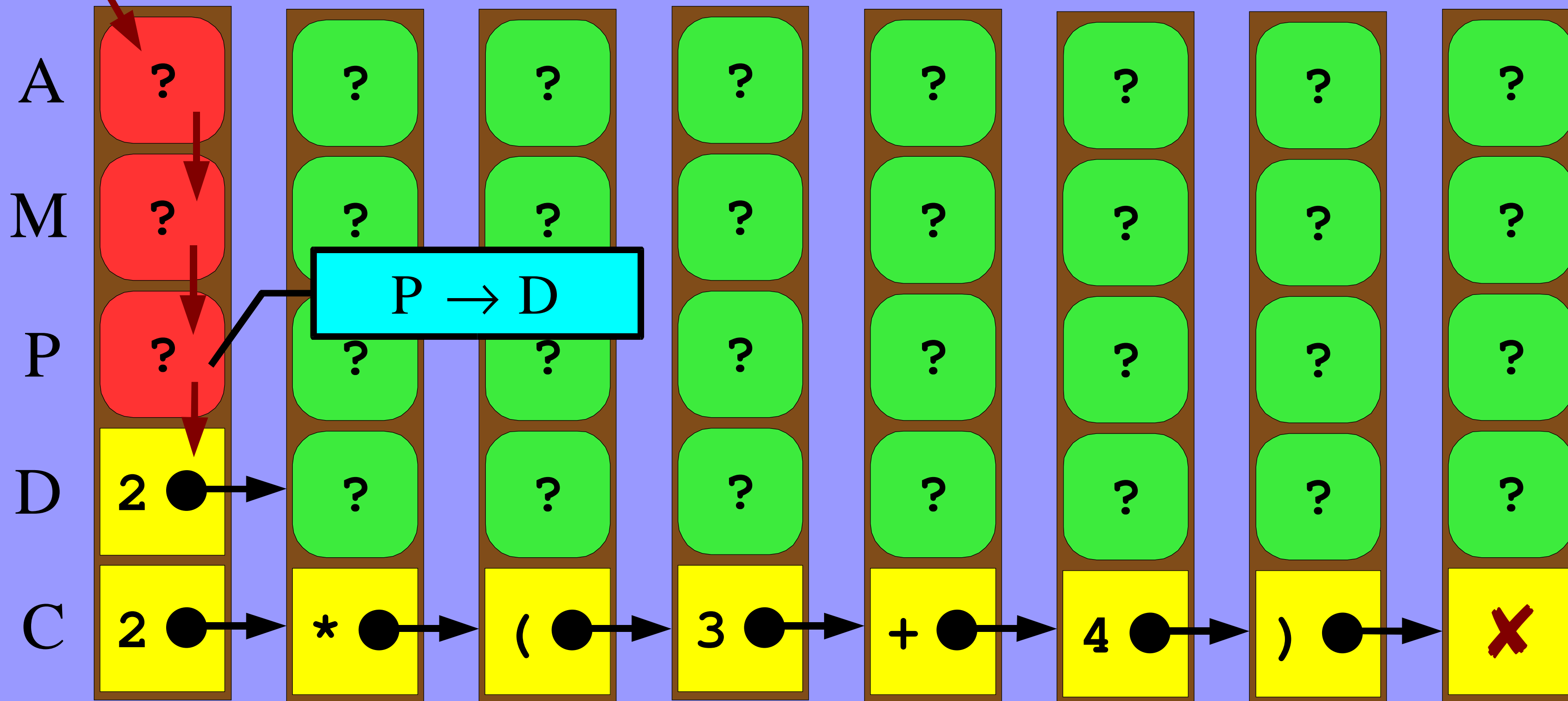

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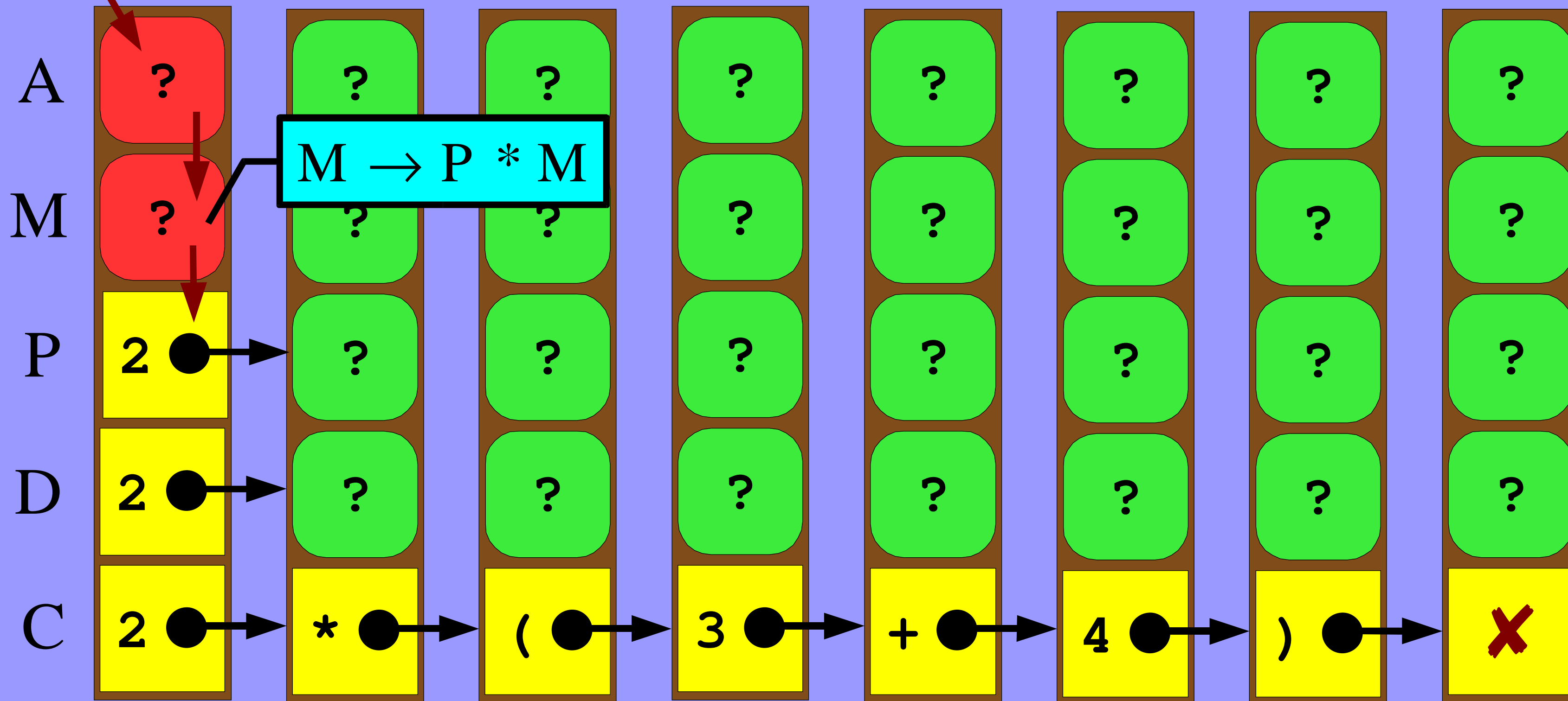

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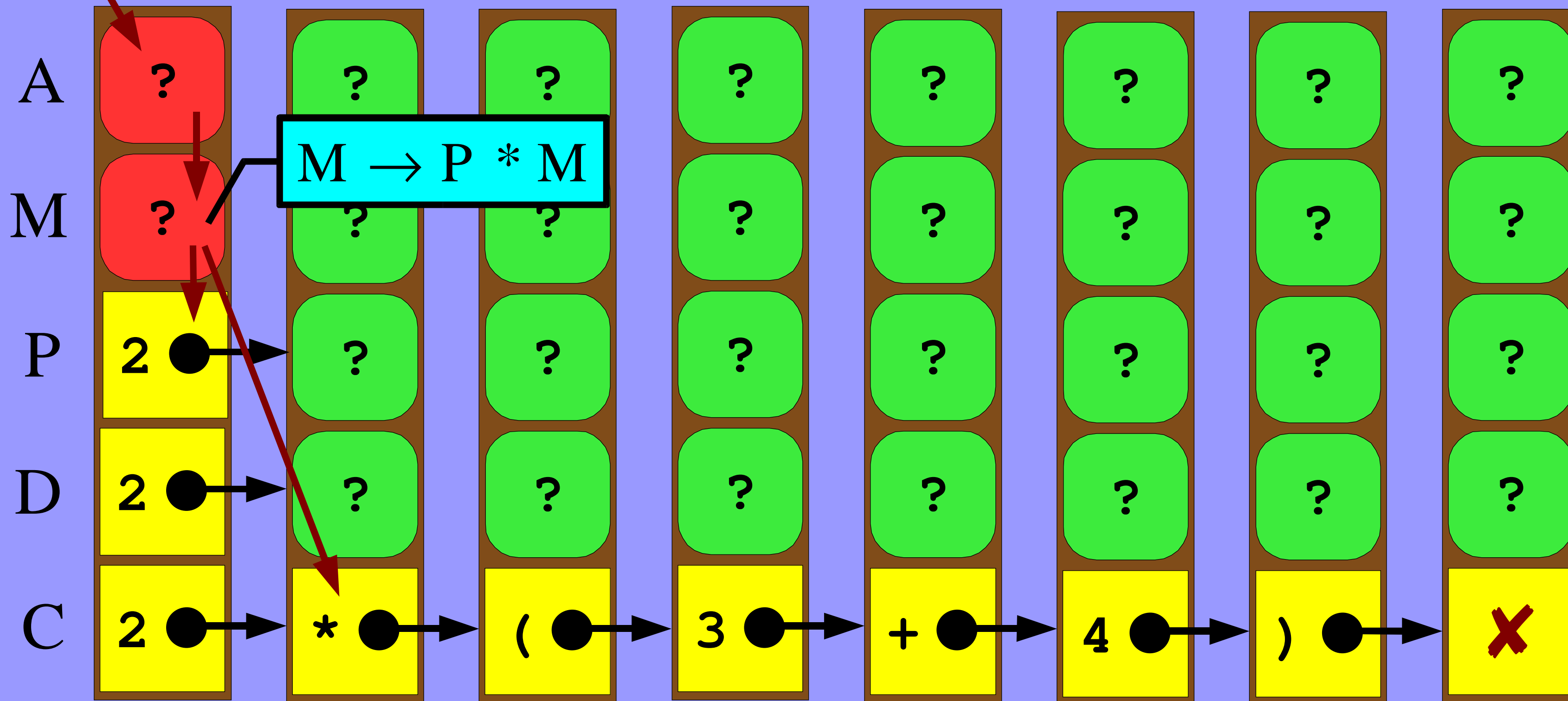

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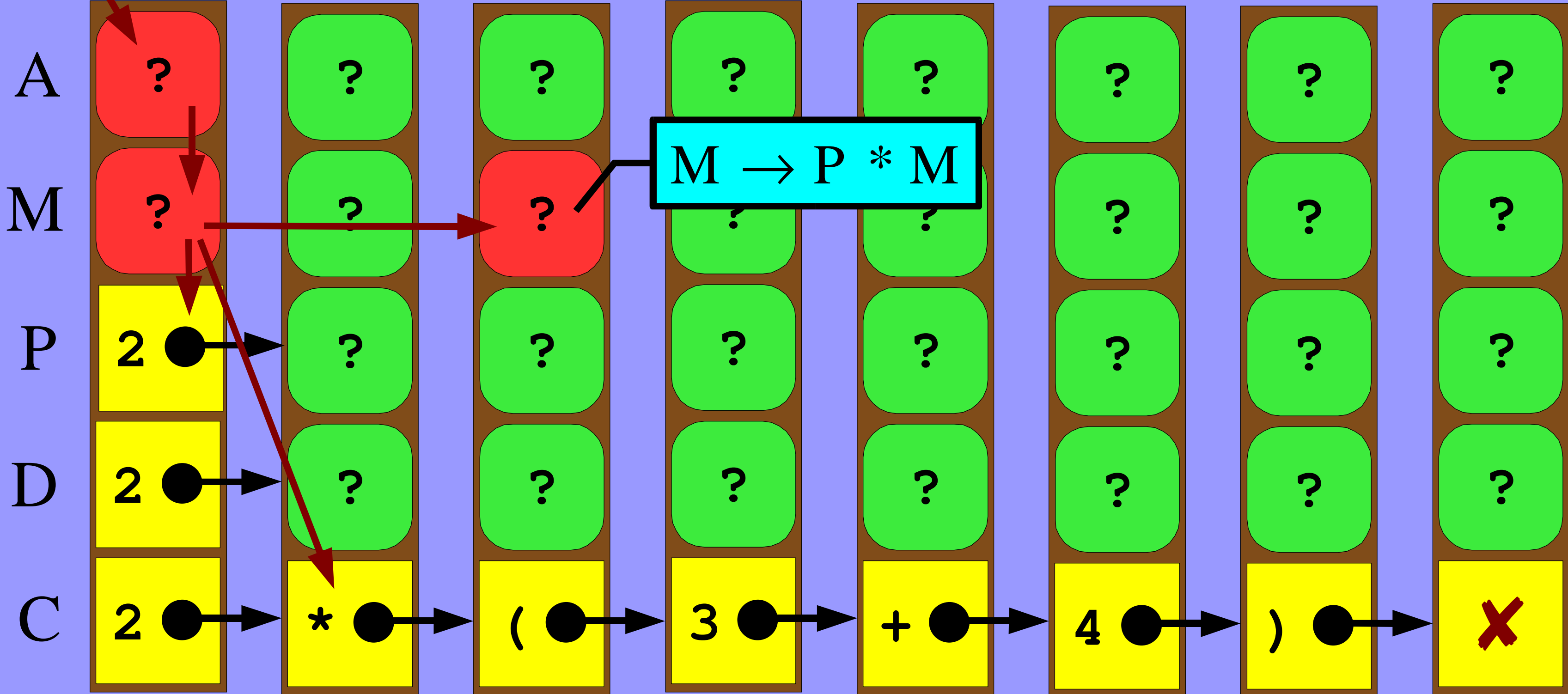
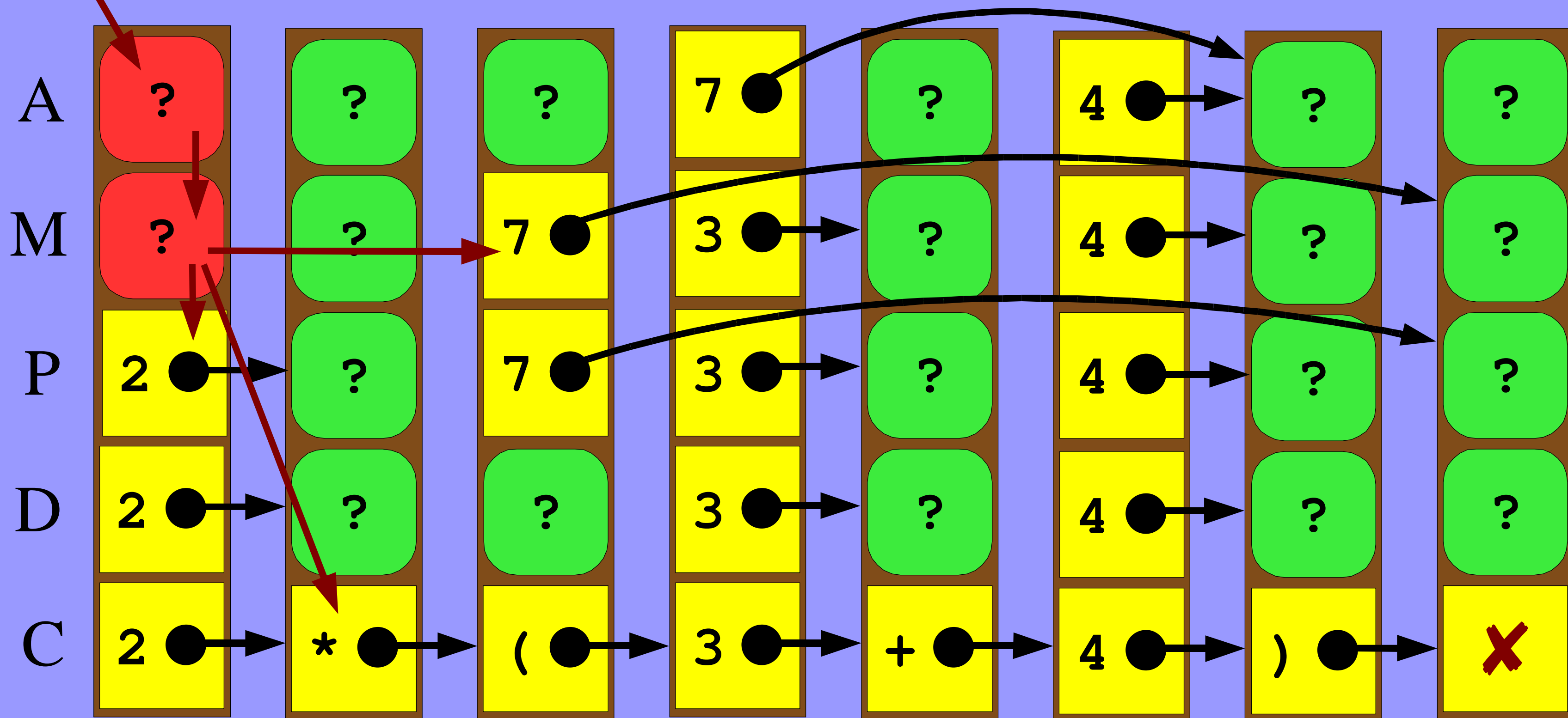


Packrat Parsing Example

(eval)



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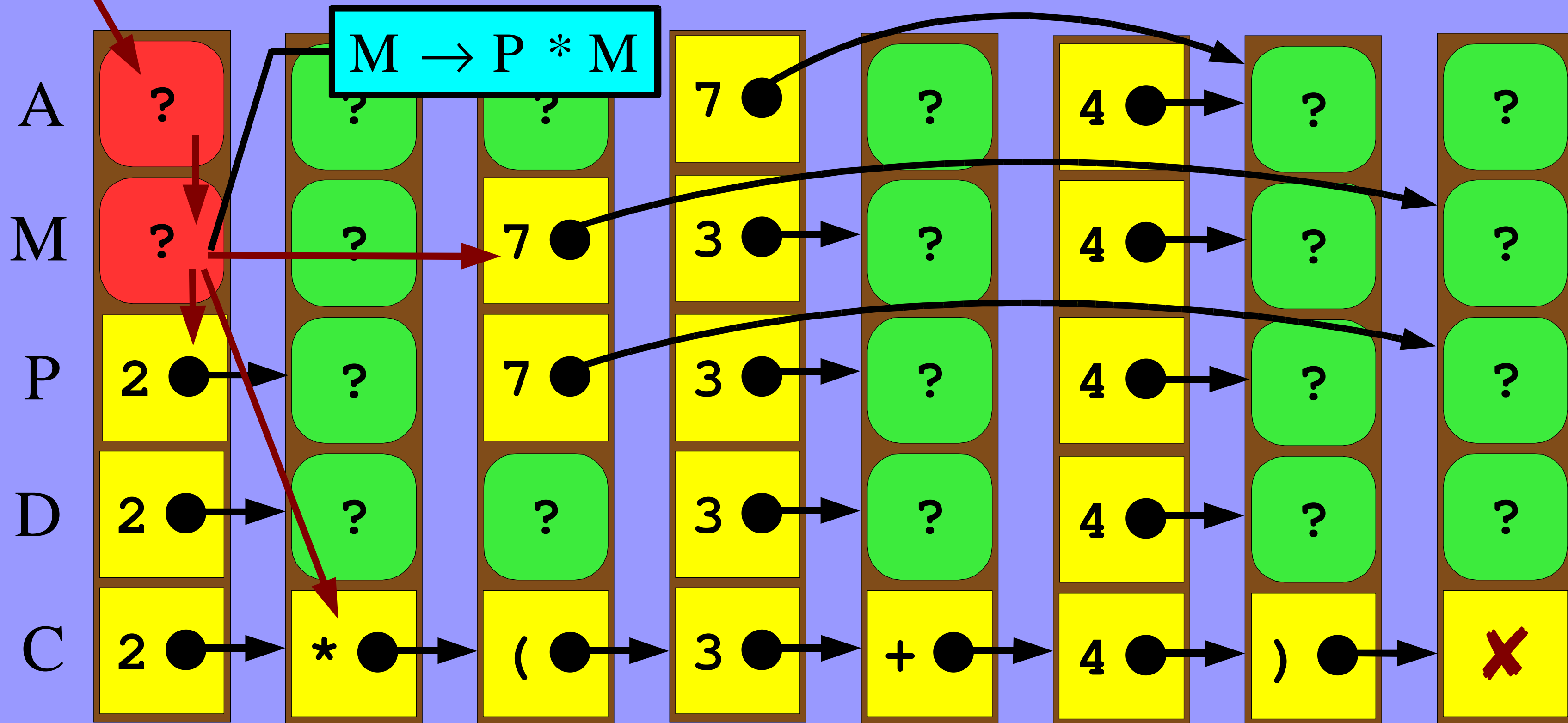

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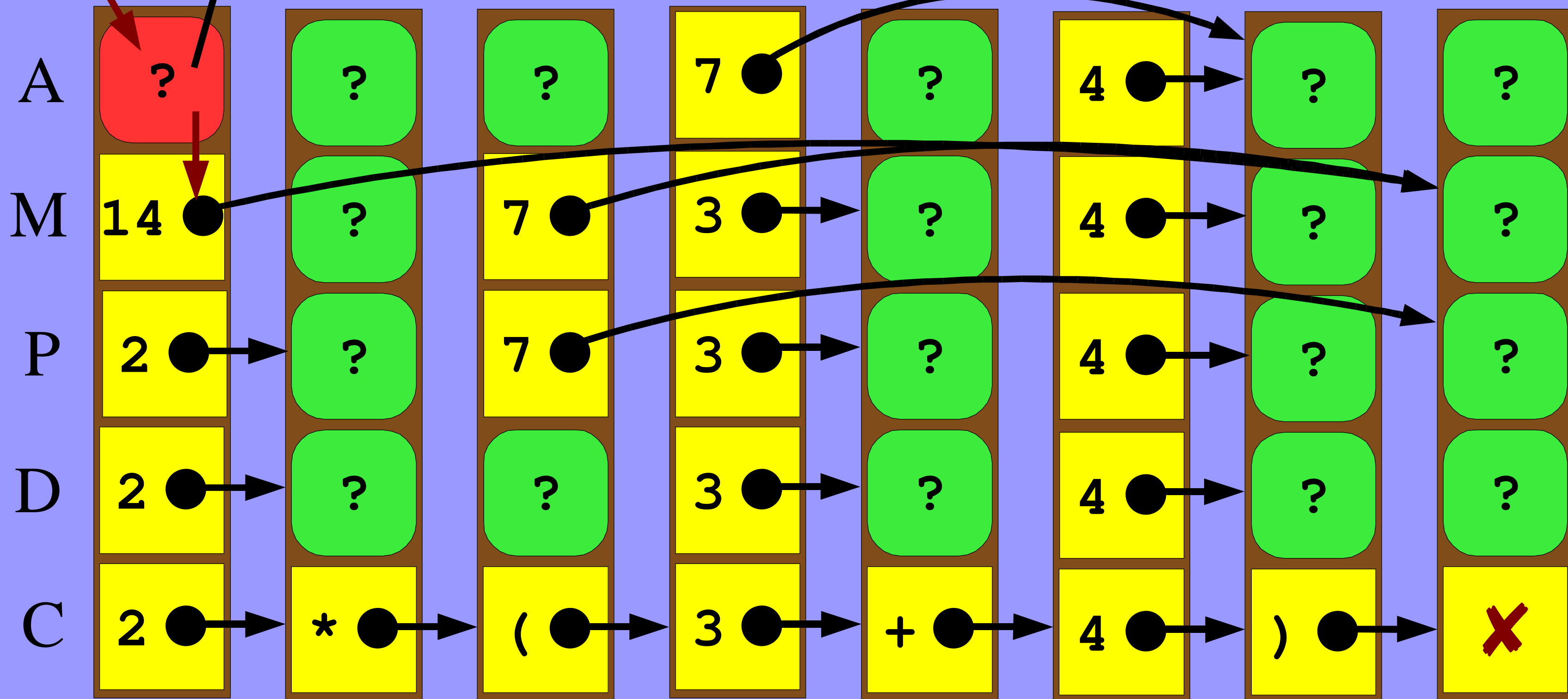

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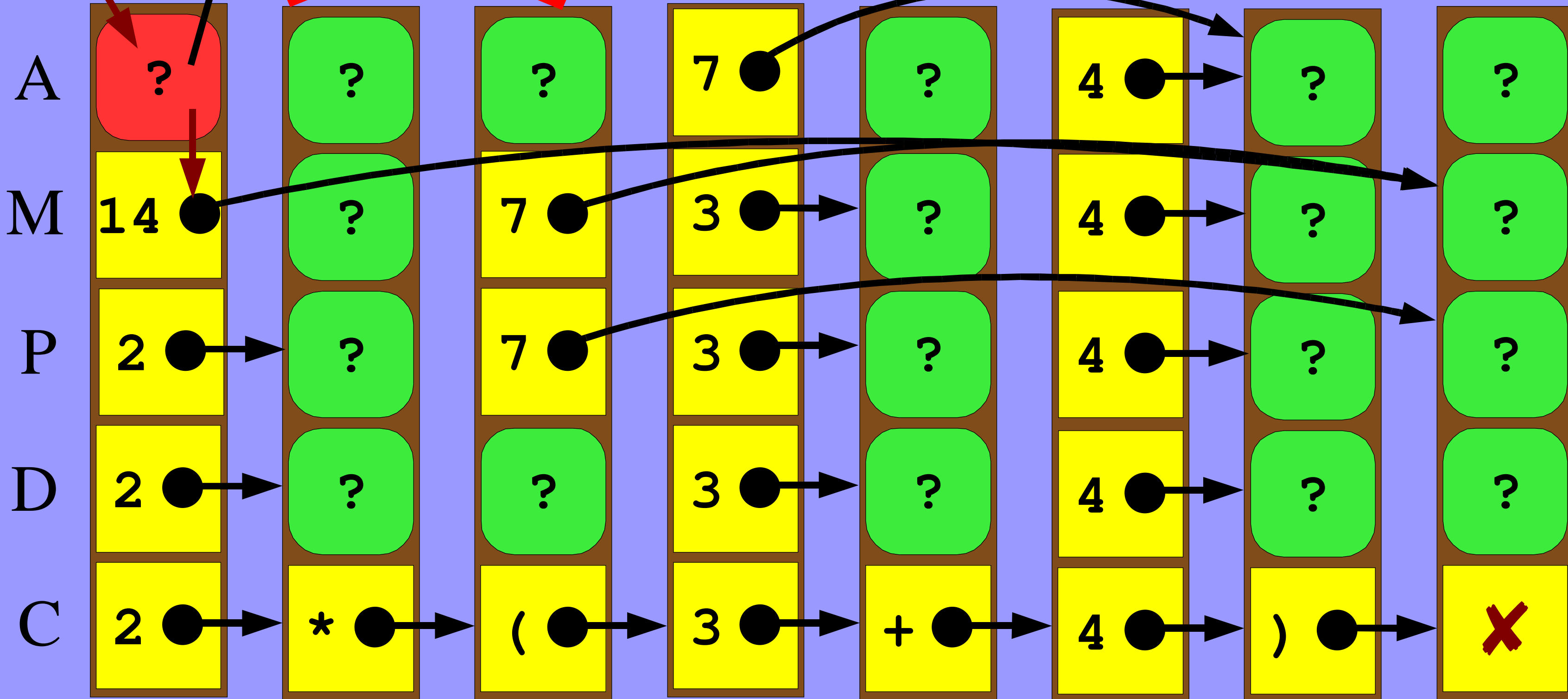

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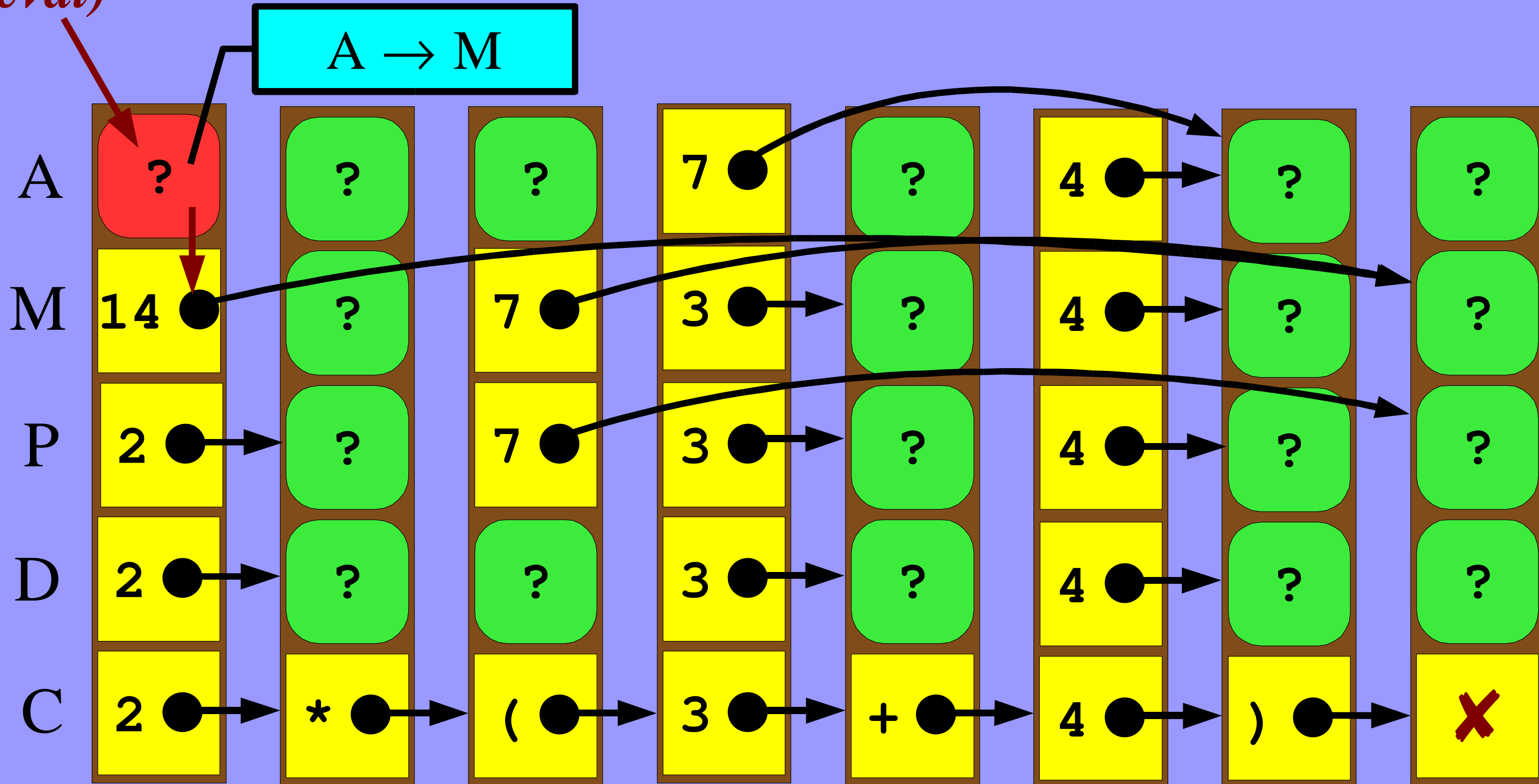

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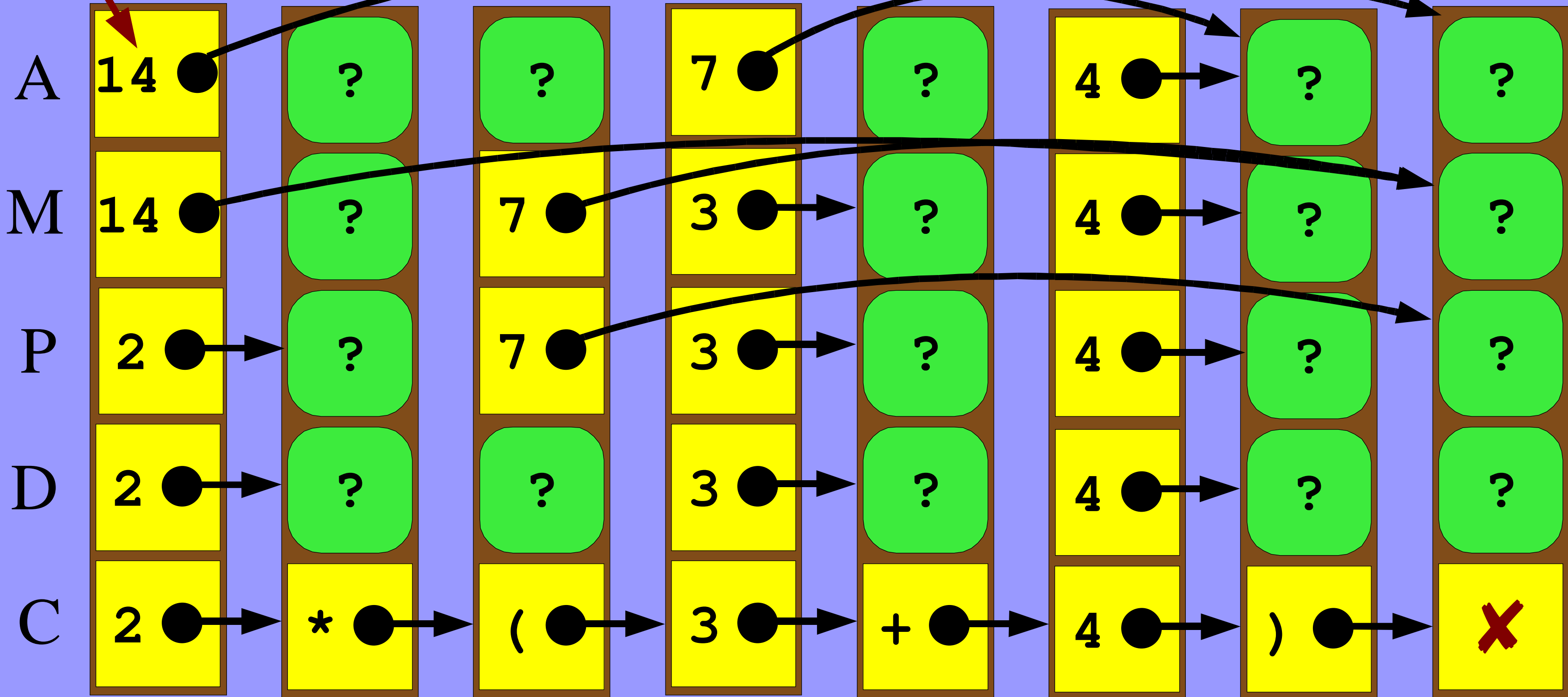

What is Packrat Parsing Good (and not good) For?

Theoretical Properties

- Formally developed by Birman in 1970s
  - Proved existence of linear-time parsing algorithm
  - *...but apparently never implemented*
- Recognizable languages:
  - Strictly larger than deterministic parsing algorithms: e.g., LL(k), LR(k)
  - Incomparable to class of context-free languages

Scannerless Parsing

- Traditional linear-time parsers limited by fixed (e.g., one-token) lookahead
  - If we only have one lookahead token, then it's easier if tokens are *big*.
- Packrat parsers provide unlimited lookahead
  - No longer need to separate lexical analysis
- Why scannerless parsing?
  - Simplicity: unified grammar for entire language
  - Power: lexical elements with complex syntax

Syntactic Flexibility

- Syntactic predicates
  - Parse X only if Y also matches
  - Parse X only if followed by Y
- Subtractive syntax
  - Parse X only if Y doesn't match
  - Parse X only if *not* followed by Y
- Semantic predicates
  - Parse X if its semantic value satisfies condition

Limitations

What is a packrat parser *not* good for?

- General CFG parsing: e.g., ambiguous grammars

  (because of “at-most-one result” limitation)

- Parsing highly “stateful” syntax: e.g., C, C++

  (memoization depends on statelessness)

- Parsing in minimal space

  (LL/LR parser grows with stack depth, not input size)

Practical Parsers

Example packrat parser for the Java language:

- Unified (scannerless) parser
- Implemented in Haskell
- Three versions:
  1. Hand-coded with monadic combinators
  2. Hand-coded with primitive pattern-matching
  3. Automatically built by prototype parser generator

Performance Results (Summary)

Parse Time:

- Reliably linear growth with input size
- 26-52KB/s (600-1200 lines/sec)
  (GHC 5.04, 1.2GHz Athlon)
- Comparable to Happy-generated LR parser
  (faster for average-size Java sources)

- Heap usage:
  - Reliably linear growth with input size
  - 300-600× expansion ratio

Related Work

Functional/ monadic Parsing:

- Wadler, Fokker, Hutton, Meijer, etc.

Scannerless Parsing:

- Tai, Salomon, Cormack – NSLR(1)
  - (linear time, but restrictive of grammar)
- Visser et al. – Generalized-LR
  - (not linear time)

Syntactic & Semantic Predicates:

- Parr, Quong – pred-LL(k)

Conclusion

Packrat parsing:

- Uses memoization to provide backtracking and unlimited lookahead in a linear-time parser
- Is easily expressed as a lazy data structure
- Provides more flexibility than LL or LR parsing
- Enables practical scannerless parsing
- Has substantial storage cost, but often reasonable

For More Information

Papers, Master's Thesis
Prototype Packrat Parser Generator
Source Code for Example Parsers
Test Suite for Example Java Parsers

available at:

`http://pdos.lcs.mit.edu/~baford/packrat/`