Thinking Recursively

Part V

Outline for Today

- ***Recursive Backtracking***
  - Finding a needle in a haystack.
- ***On Tenacity***
  - Computational grit!
- ***Optional<T>***
  - Sending data out of functions.
- ***CHeMoWiZrDy***
  - Having some fun with the periodic table.

A Warm-Up Exercise

What's Wrong With This Code?

```
bool containsE(const string& str) {
    for (char ch: str) {
        return ch == 'e' || ch == 'E';
    }
    return false;
}
```

Answer at
https://pollev.com/cs106bwin23

What's Wrong With This Code?

```
bool containsE(const string& str) {
    for (char ch: str) {
        return ch == 'e' || ch == 'E';
    }
    return false;
}
```

It's exceedingly rare to have an unconditional return statement in a for loop. This almost certainly indicates the presence of a bug.

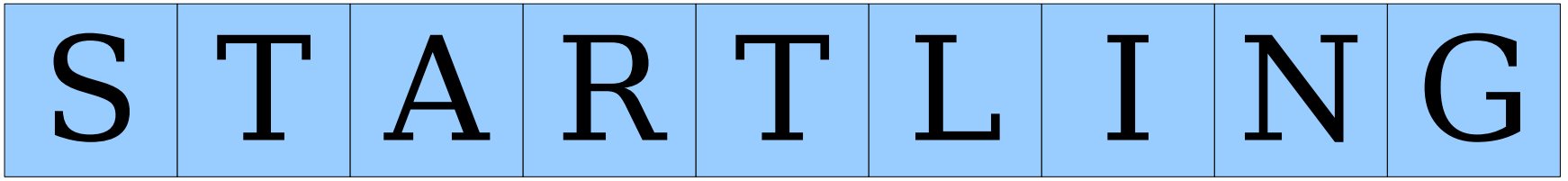
Specifically, this code makes its final decision based on the first character of the string.

Recap from Last Time

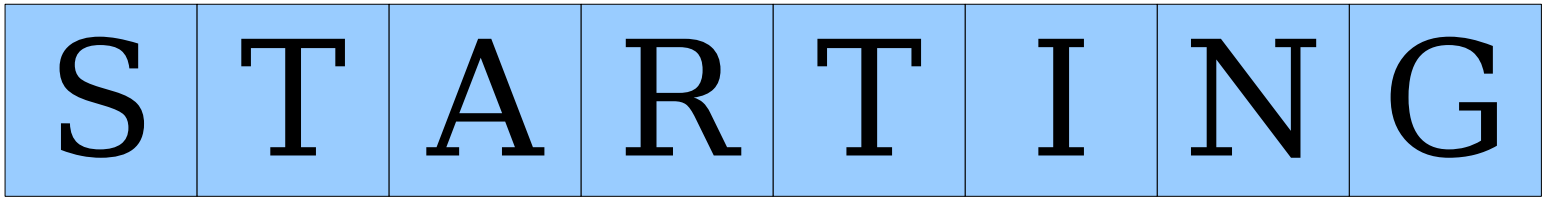
A Little Word Puzzle

“What nine-letter word can be reduced to a single-letter word one letter at a time by removing letters, leaving it a legal word at each step?”

One Solution



One Solution



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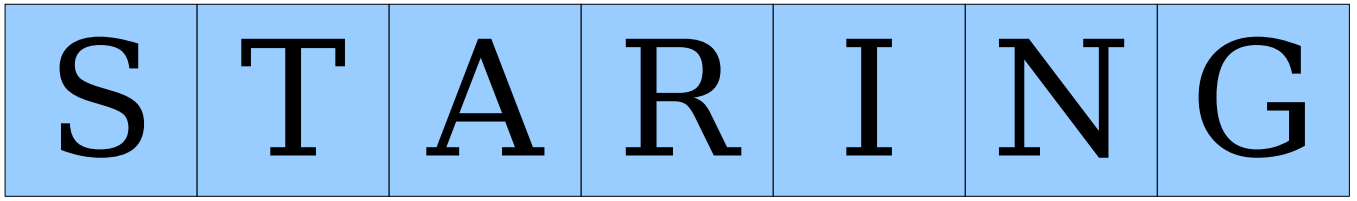
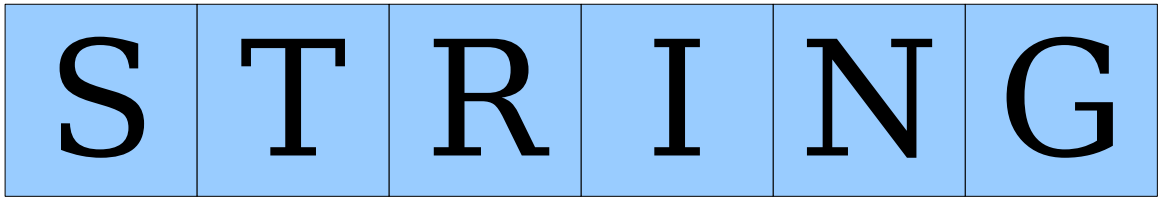
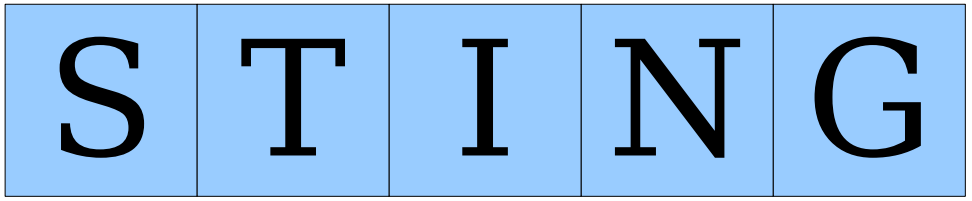


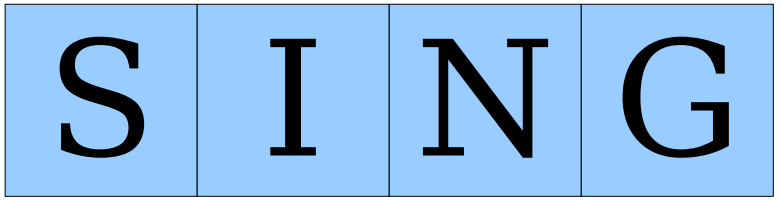
One Solution



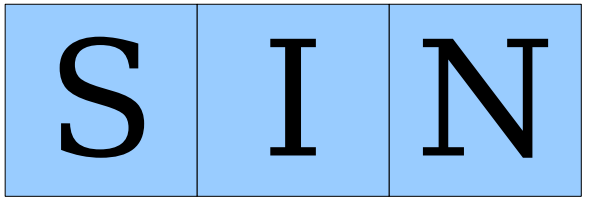
One Solution



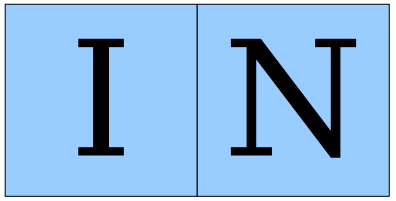
One Solution



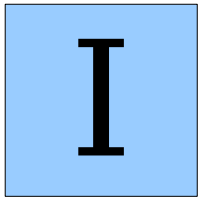
One Solution



One Solution



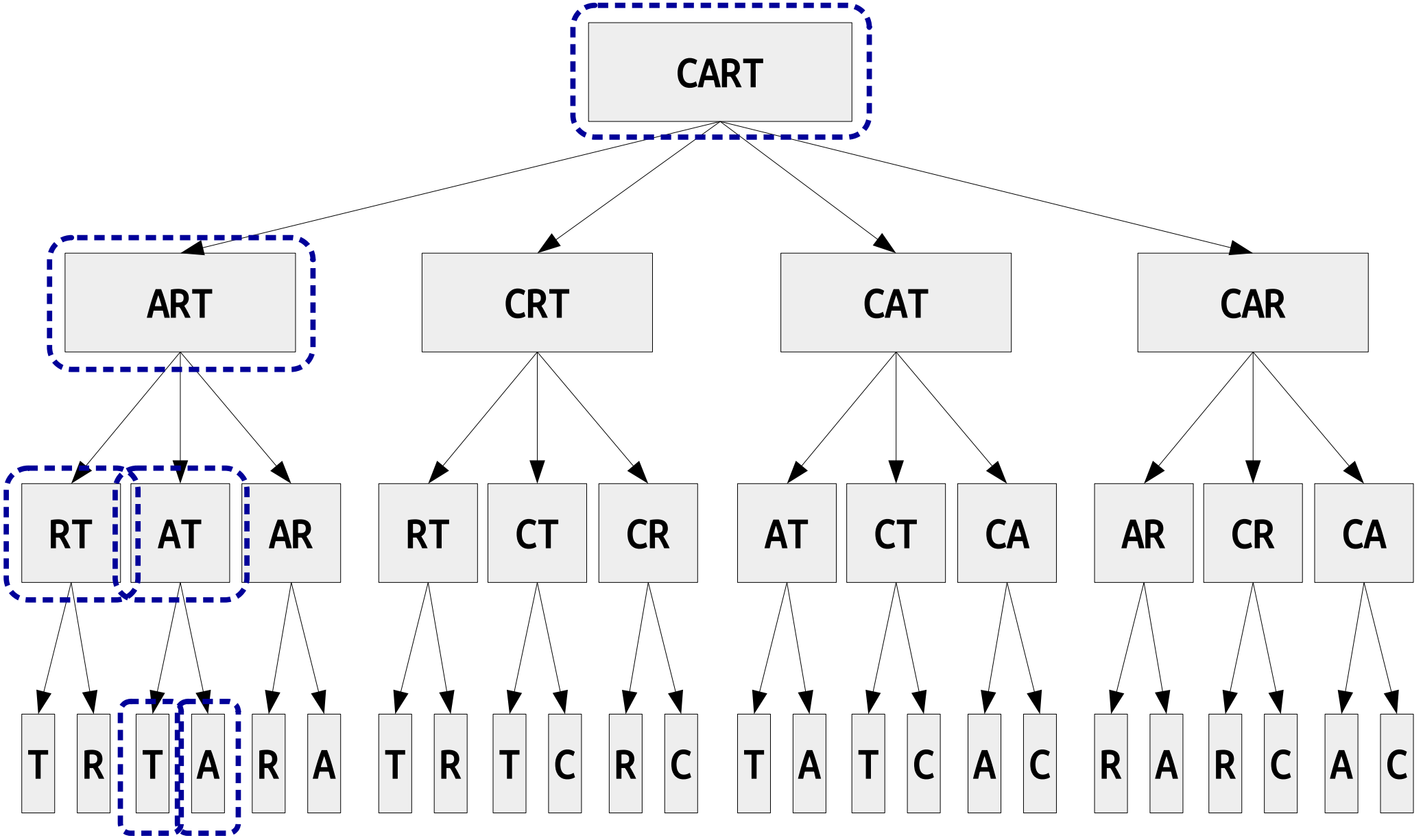
One Solution



New Stuff!

Our Solution, In Action

The Incredible Shrinking Word



```
bool isShrinkableWord(const string& word,
                      const Lexicon& english) {
    if (!english.contains(word)) {
        return false;
    }
    if (word.length() == 1) {
        return true;
    }

    for (int i = 0; i < word.length(); i++) {
        string shrunken = word.substr(0, i) + word.substr(i + 1);
        if (isShrinkableWord(shrunken, english)) {
            return true;
        }
    }
    return false;
}
```

```
bool isShrinkableWord(const string& word,
                      const Lexicon& english) {
    if (!english.contains(word)) {
        return false;
    }
    if (word.length() == 1) {
        return true;
    }

    for (int i = 0; i < word.length(); i++) {
        string shrunken = word.substr(0, i) + word.substr(i + 1);
        if (isShrinkableWord(shrunken, english)) {
            return true;
        }
    }
    return false;
}
```

```
bool isShrinkableWord(const string& word,
                      const Lexicon& english) {
    if (!english.contains(word)) {
        return false;
    }
    if (word.length() == 1) {
        return true;
    }

    for (int i = 0; i < word.length(); i++) {
        string shrunken = word.substr(0, i) + word.substr(i + 1);
        return isShrinkableWord(shrunken, english); // Bad idea!
    }
    return false;
}
```

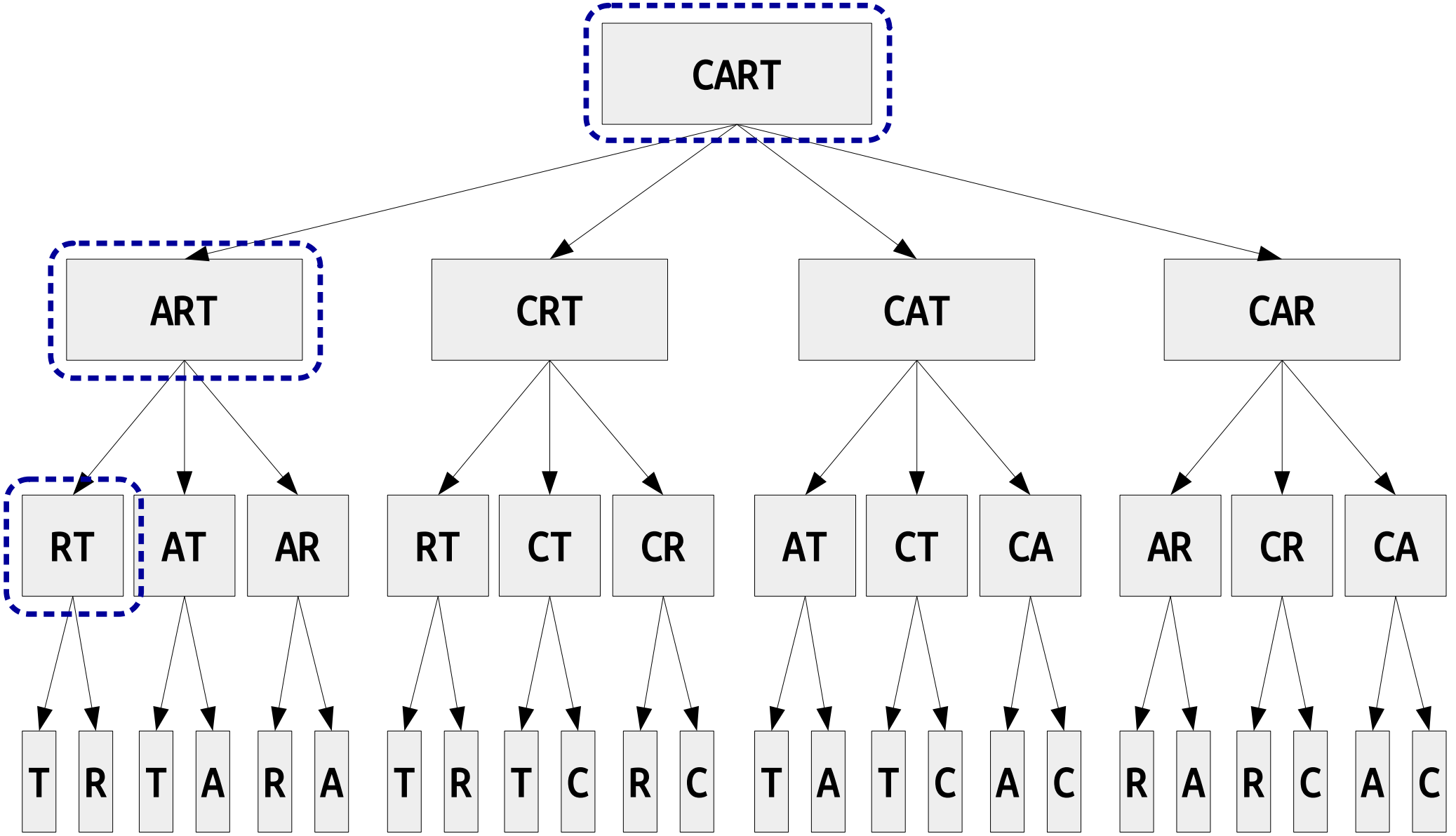
```
bool isShrinkableWord(const string& word,
                      const Lexicon& english) {
    if (!english.contains(word)) {
        return false;
    }
    if (word.length() == 1) {
        return true;
    }

    for (int i = 0; i < word.length(); i++) {
        string shrunken = word.substr(0, i) + word.substr(i + 1);
        return isShrinkableWord(shrunken, english); // Bad idea!
    }
    return false;
}
```

It's exceedingly rare to have an unconditional return statement in a for loop. This almost certainly indicates the presence of a bug.

Specifically, this code makes its final decision based on the first character it tries removing.

Tenacity is a Virtue



When backtracking recursively,

don't give up if your first try fails!

Hold out hope that something else will work out. It very well might!

Recursive Backtracking

```
if (problem is sufficiently simple) {
    return whether the problem is solvable
} else {
    for (each choice) {
        try out that choice
        if (that choice leads to success) {
            return success;
        }
    }
    return failure;
}
```

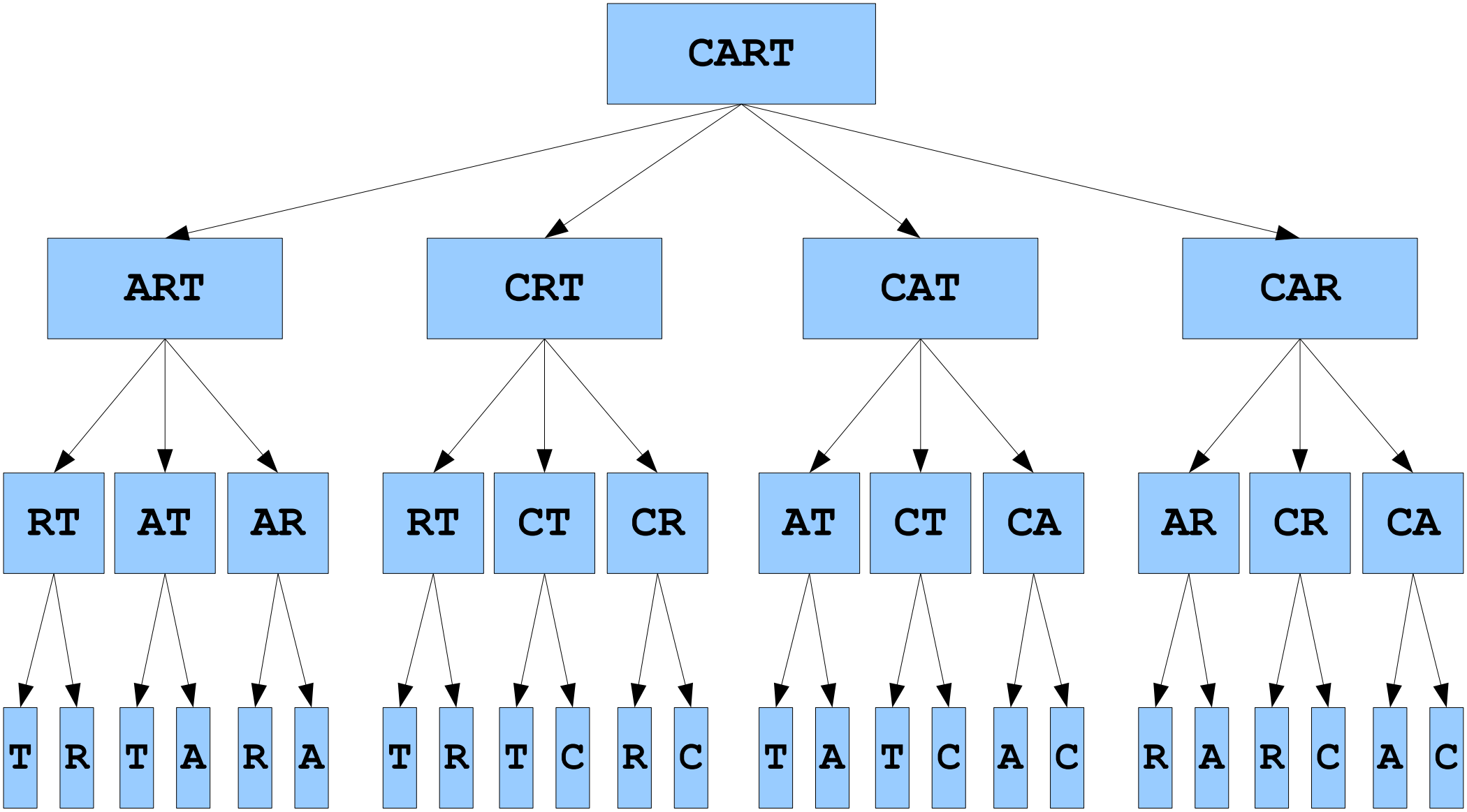
Note that *if* the recursive call succeeds, *then* we return success. If it doesn't succeed, that doesn't mean we've failed – it just means we need to try out the next option.

How do we know we’re correct?

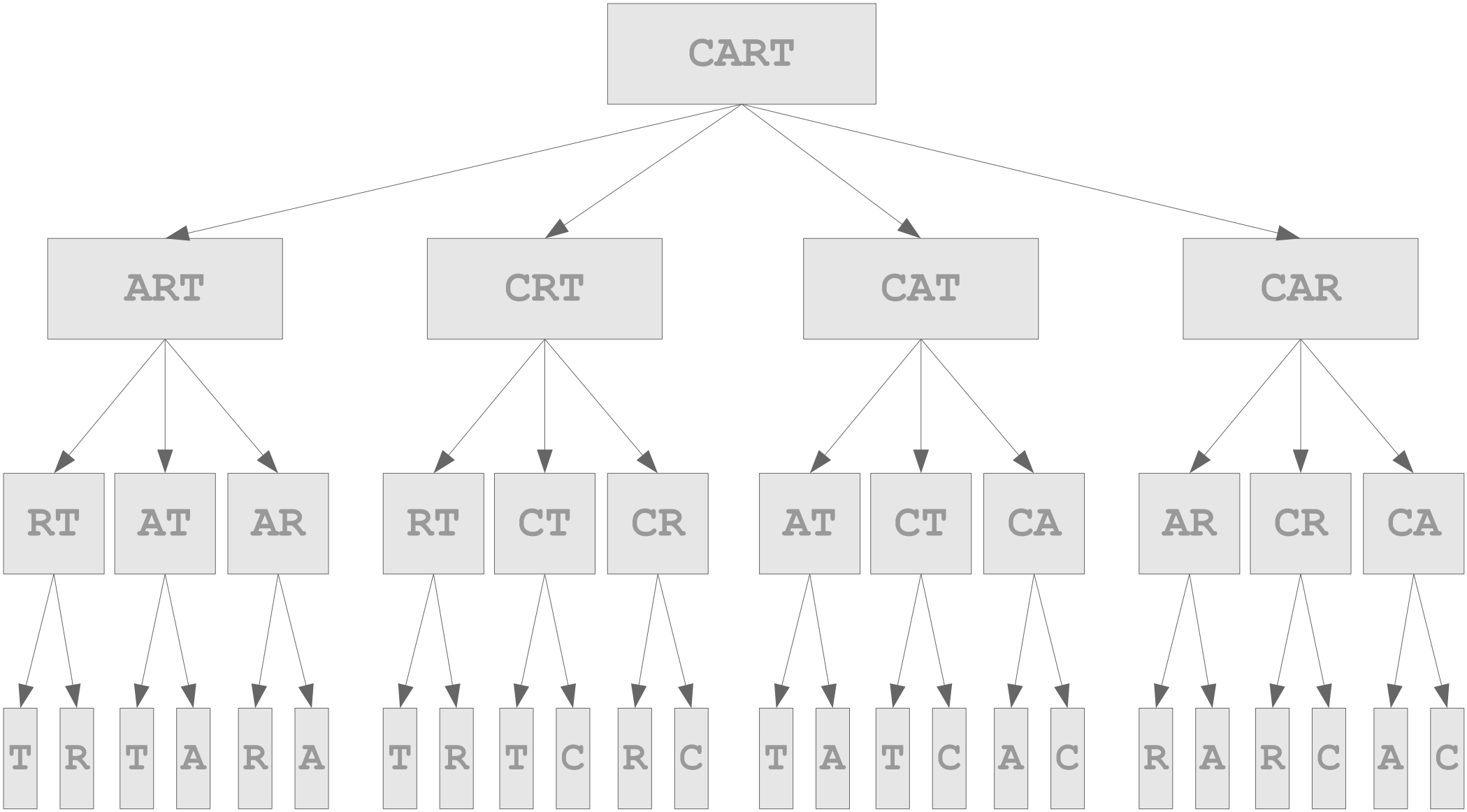
Optional<T>

- The `Optional<T>` type represents either an object of type `T` or is `Nothing` at all.
- It's useful when working with recursive functions that look for something that may or may not exist.
  - If a solution exists, return it as usual.
  - Otherwise, return `Nothing`.
- If the `Optional<T>` is a value of type `T`, you can call the `.value()` function to retrieve the underlying value.

Generating the Answer



Generating the Answer



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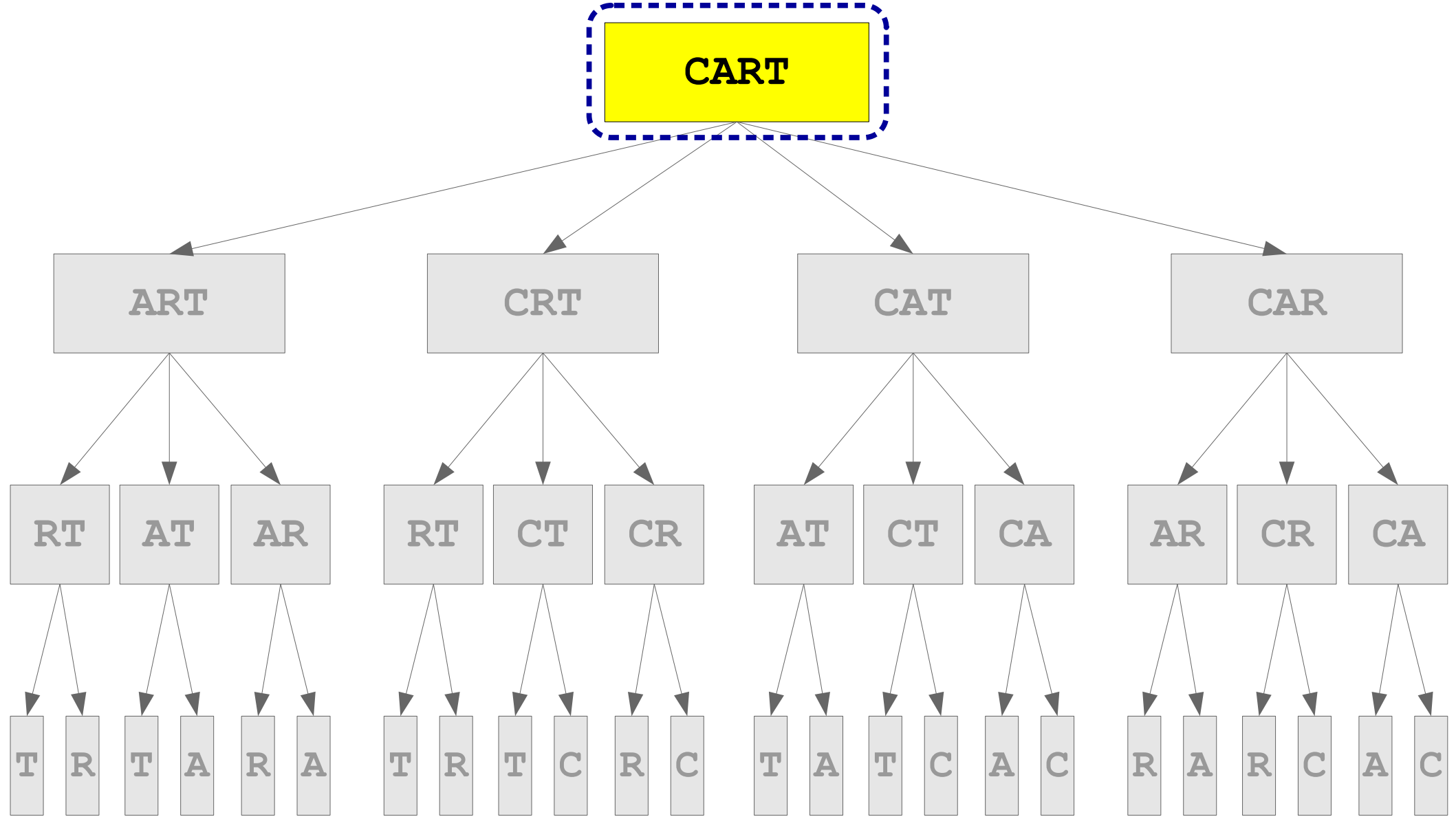

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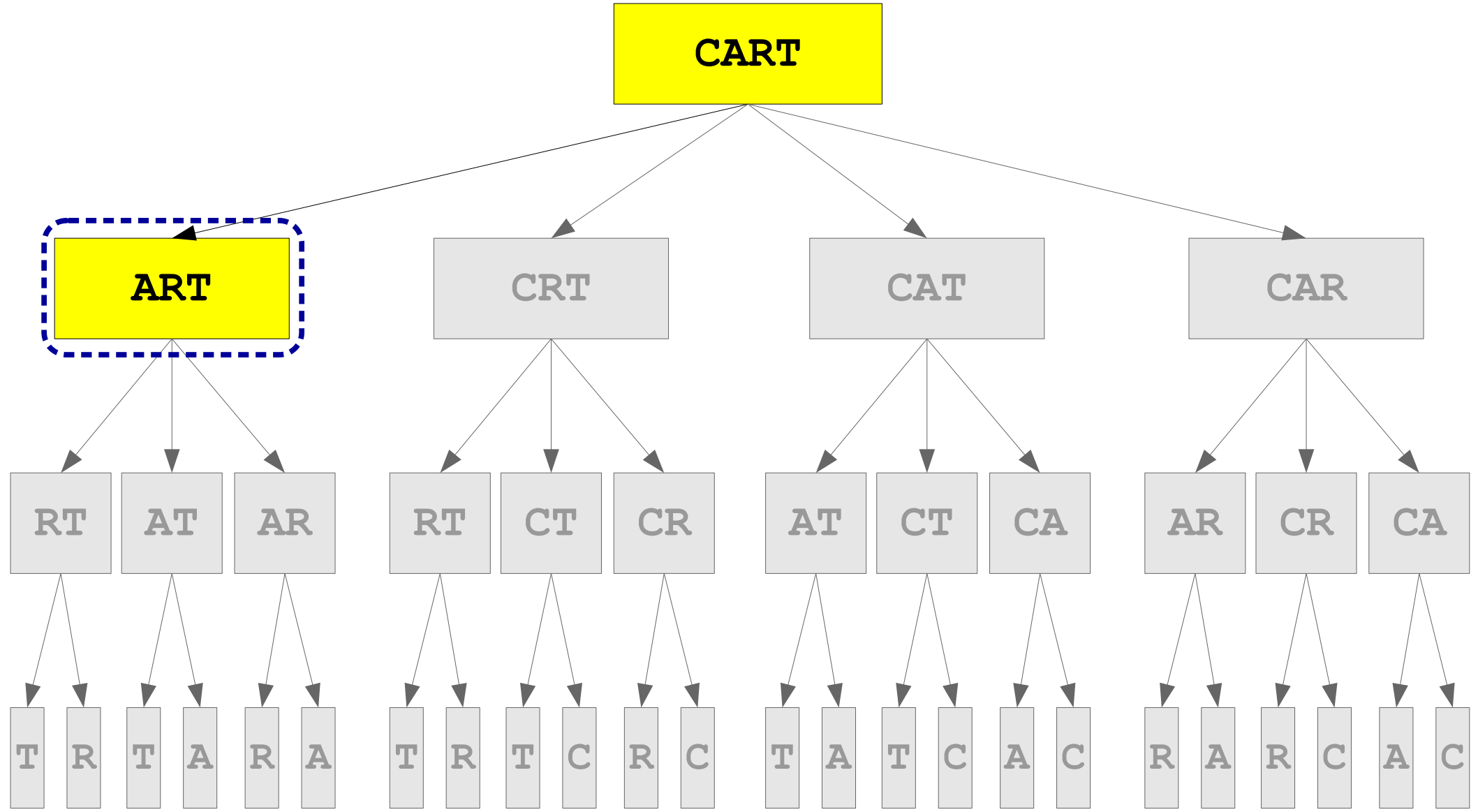

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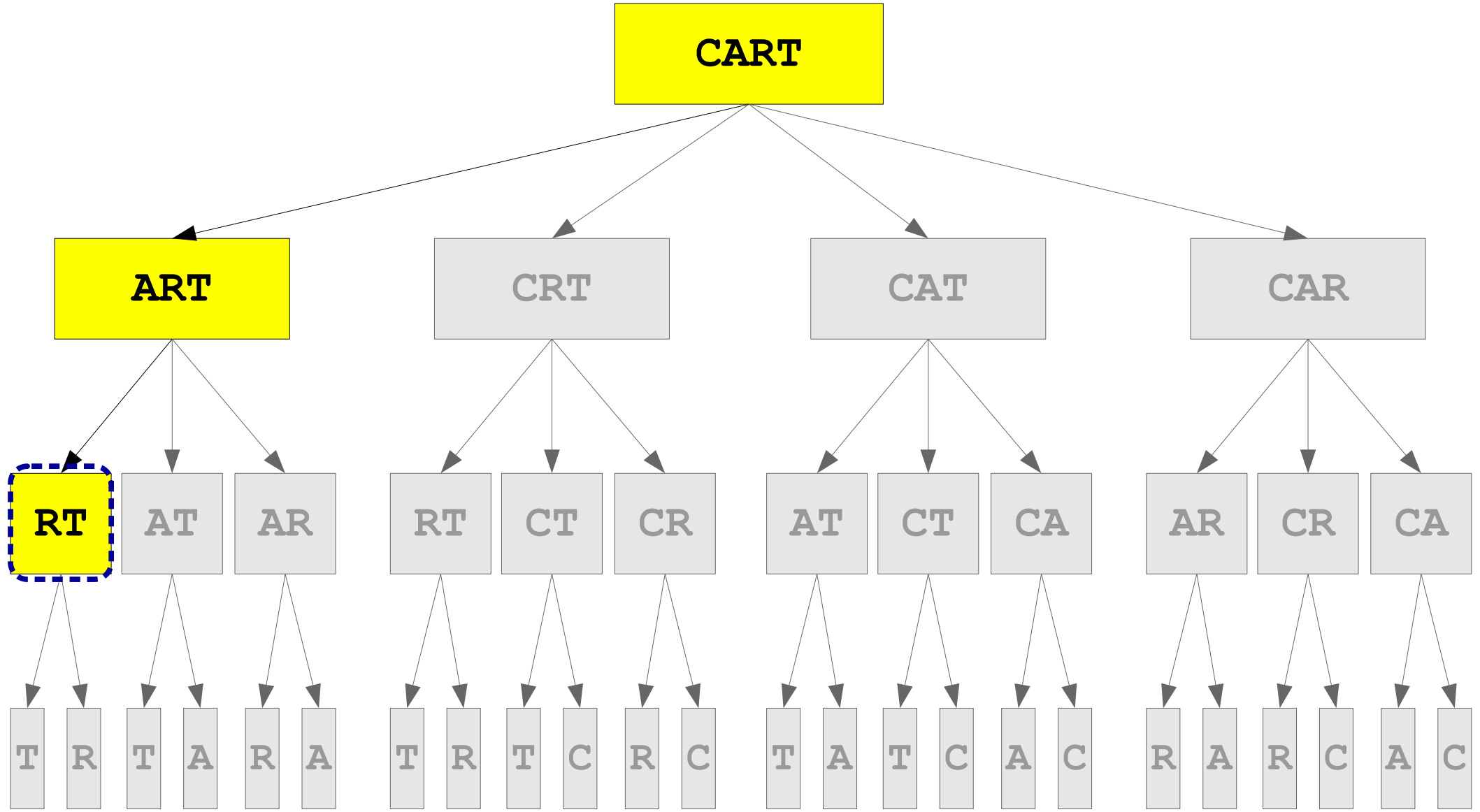

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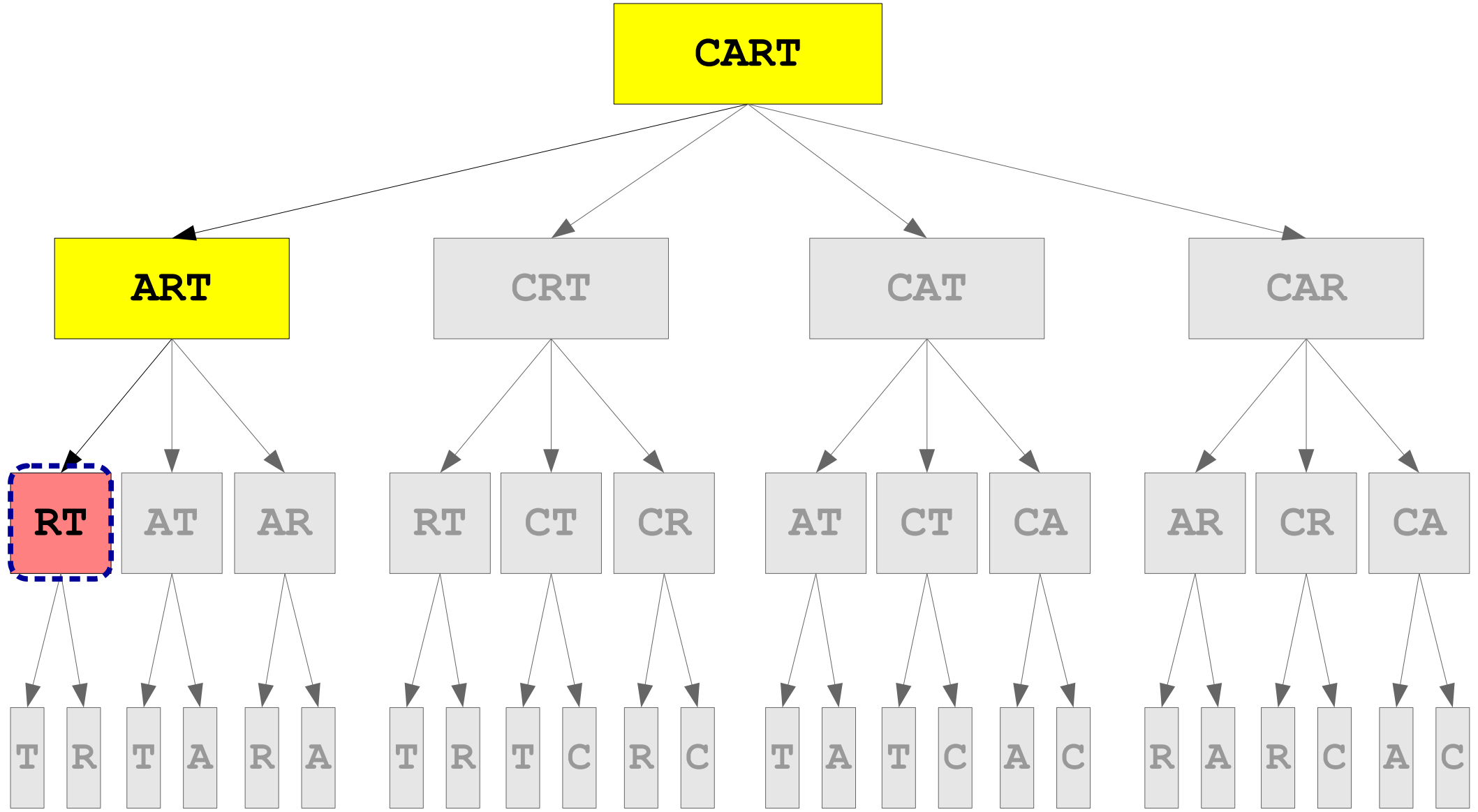

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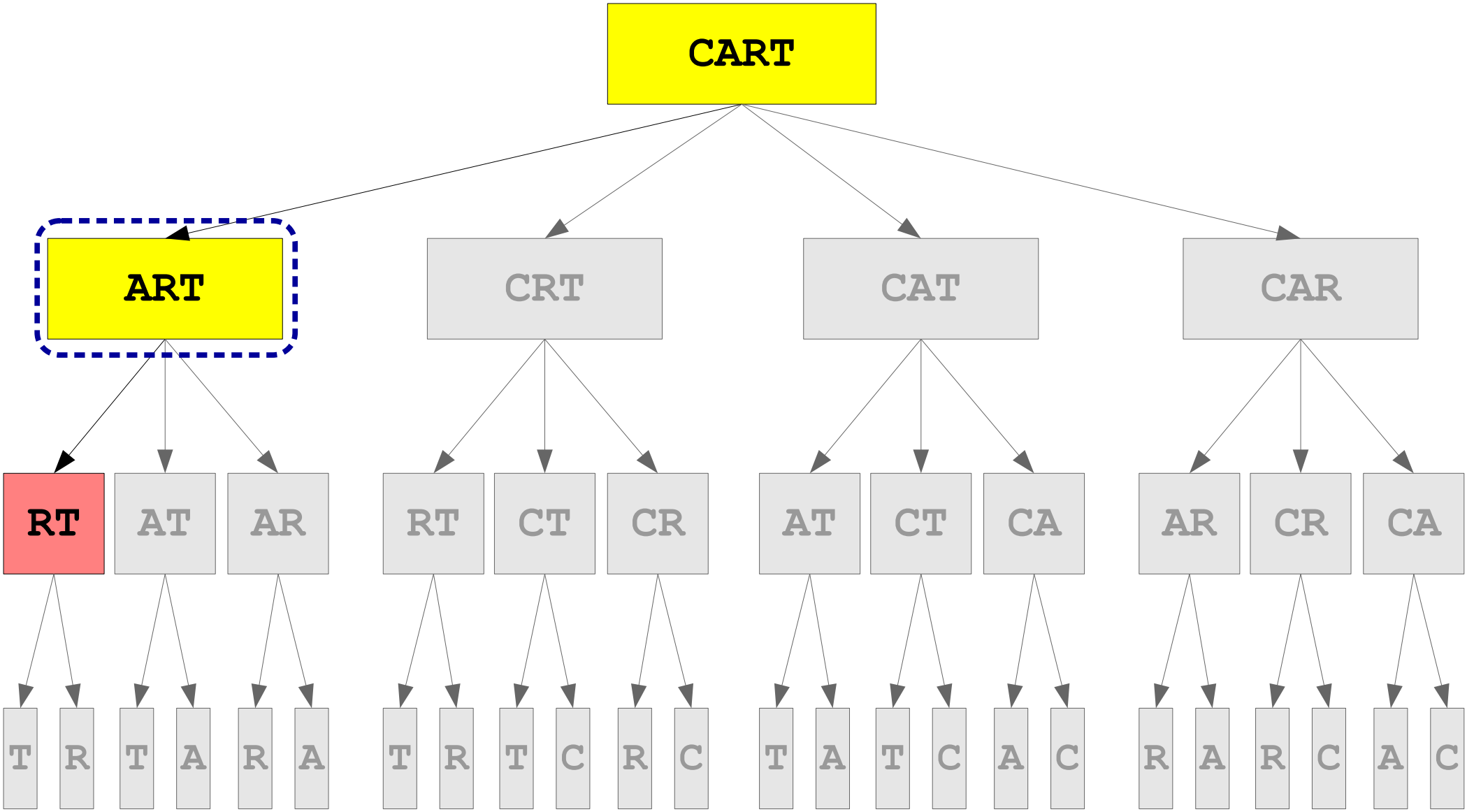

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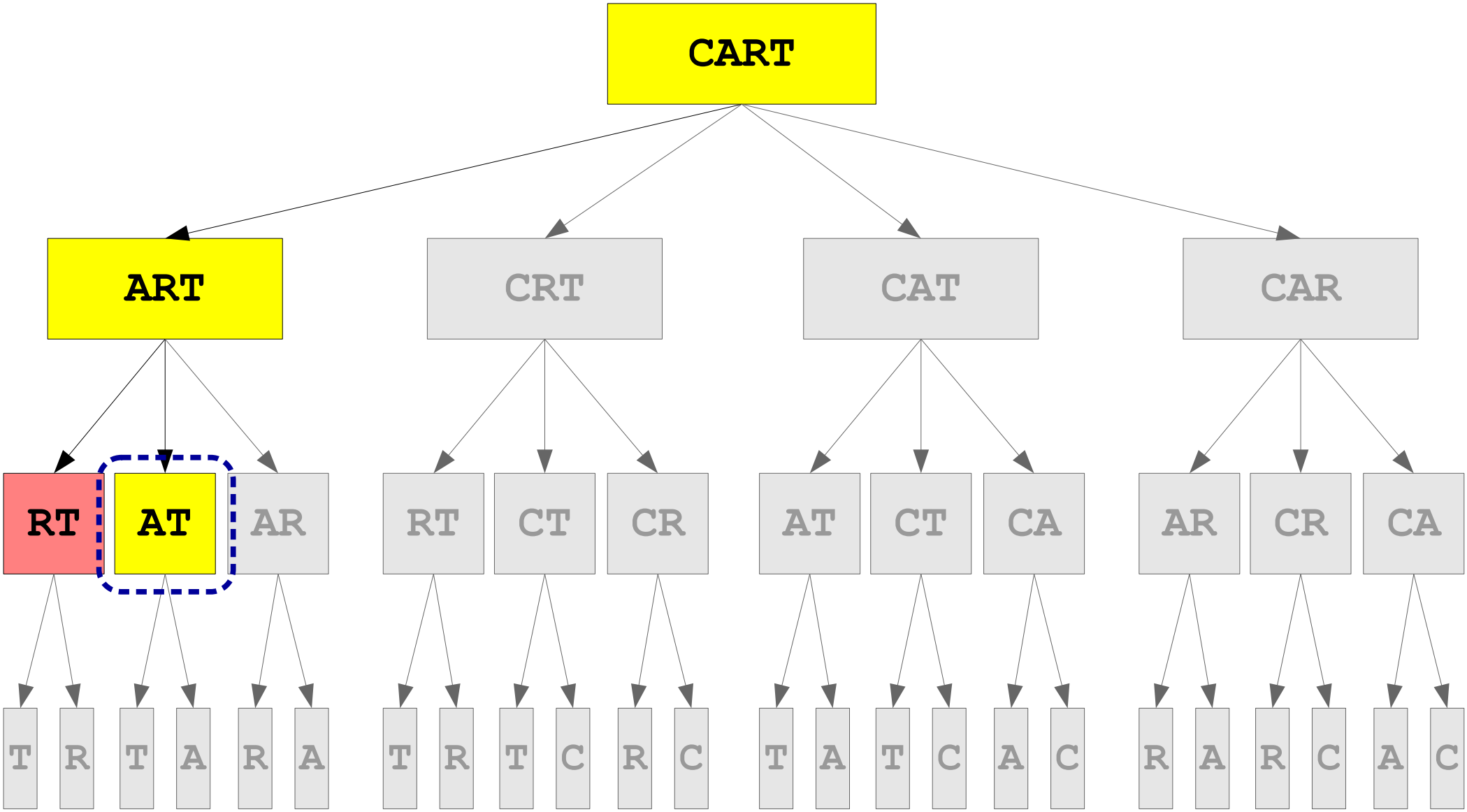

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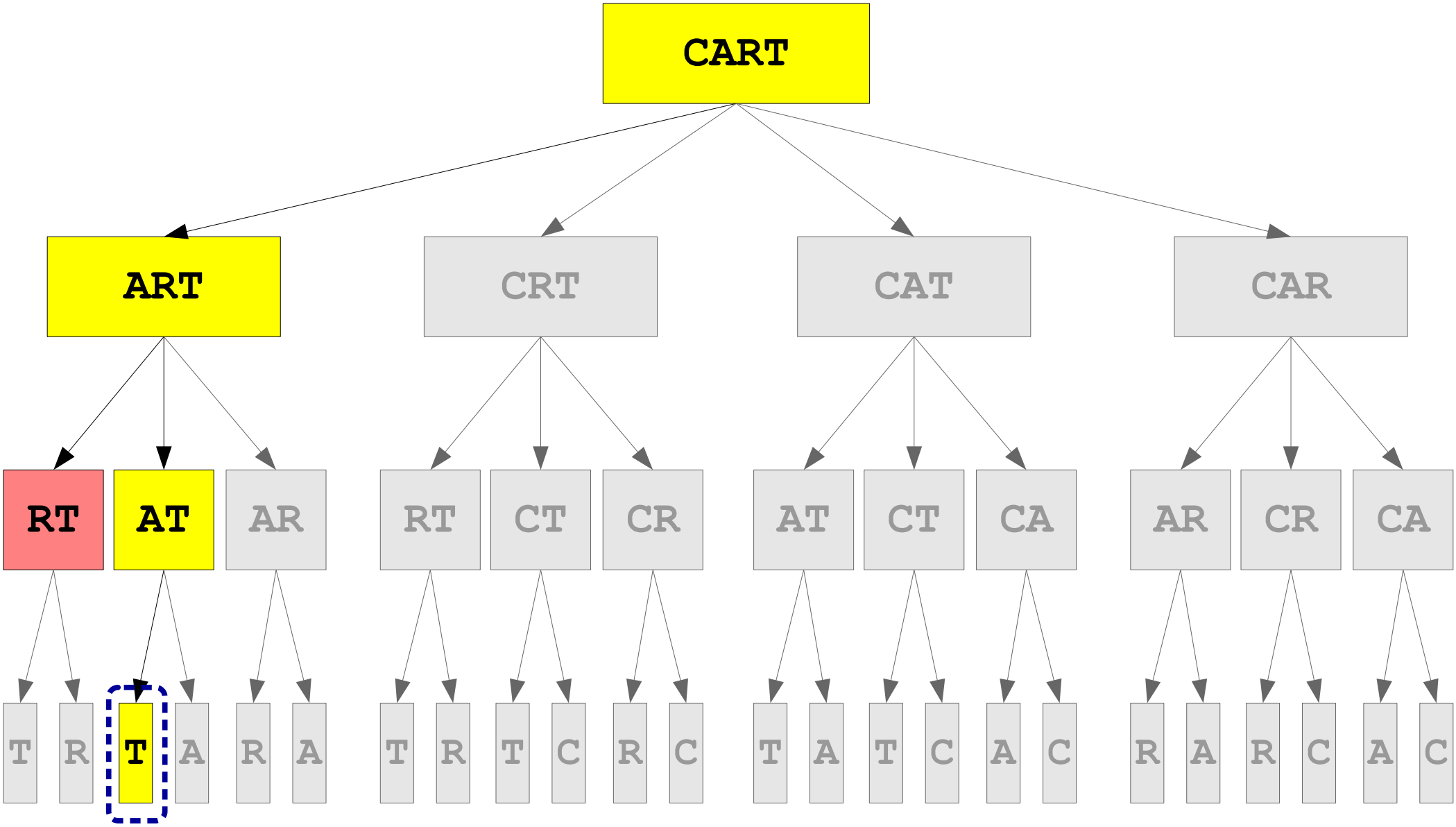

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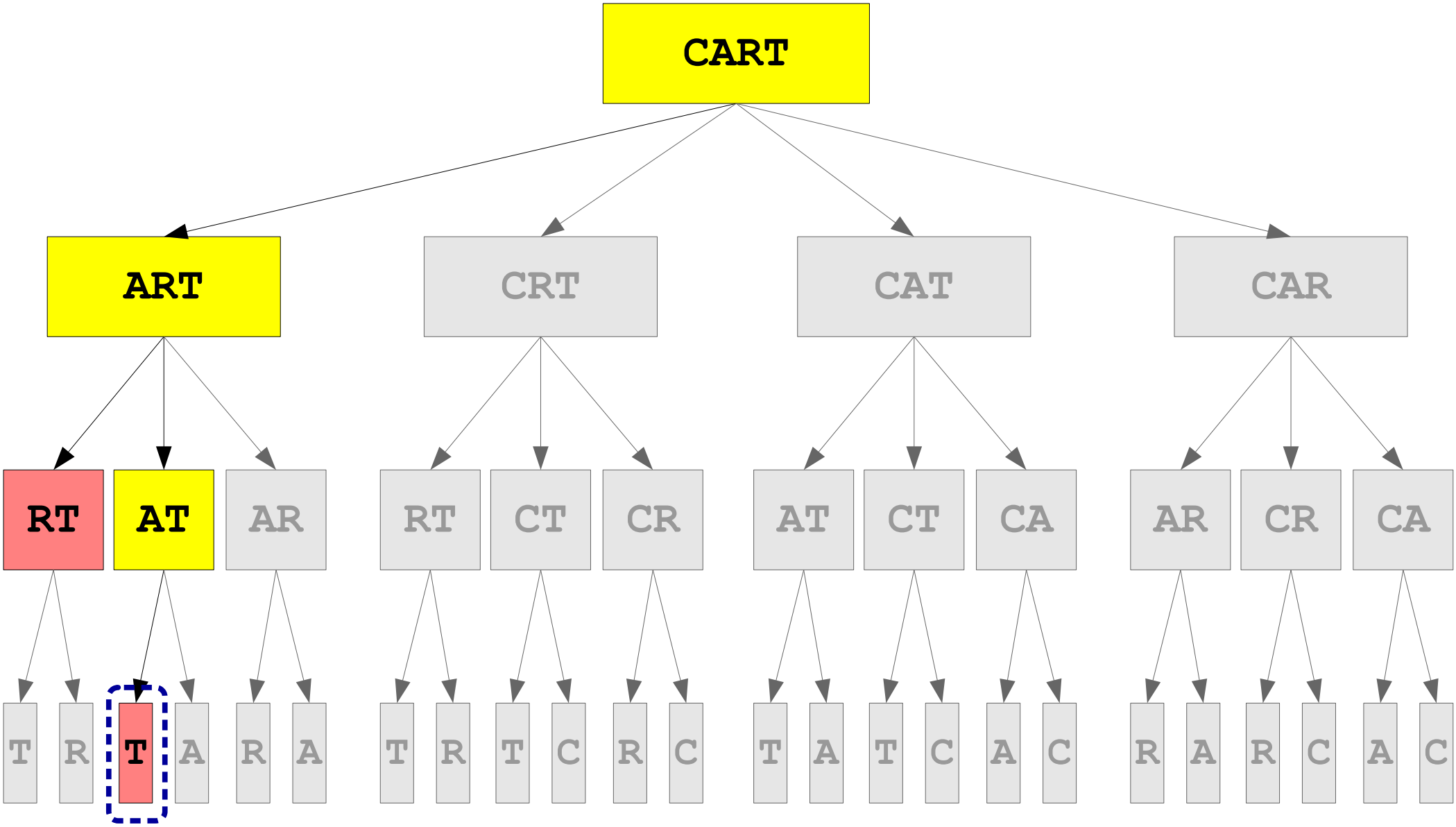

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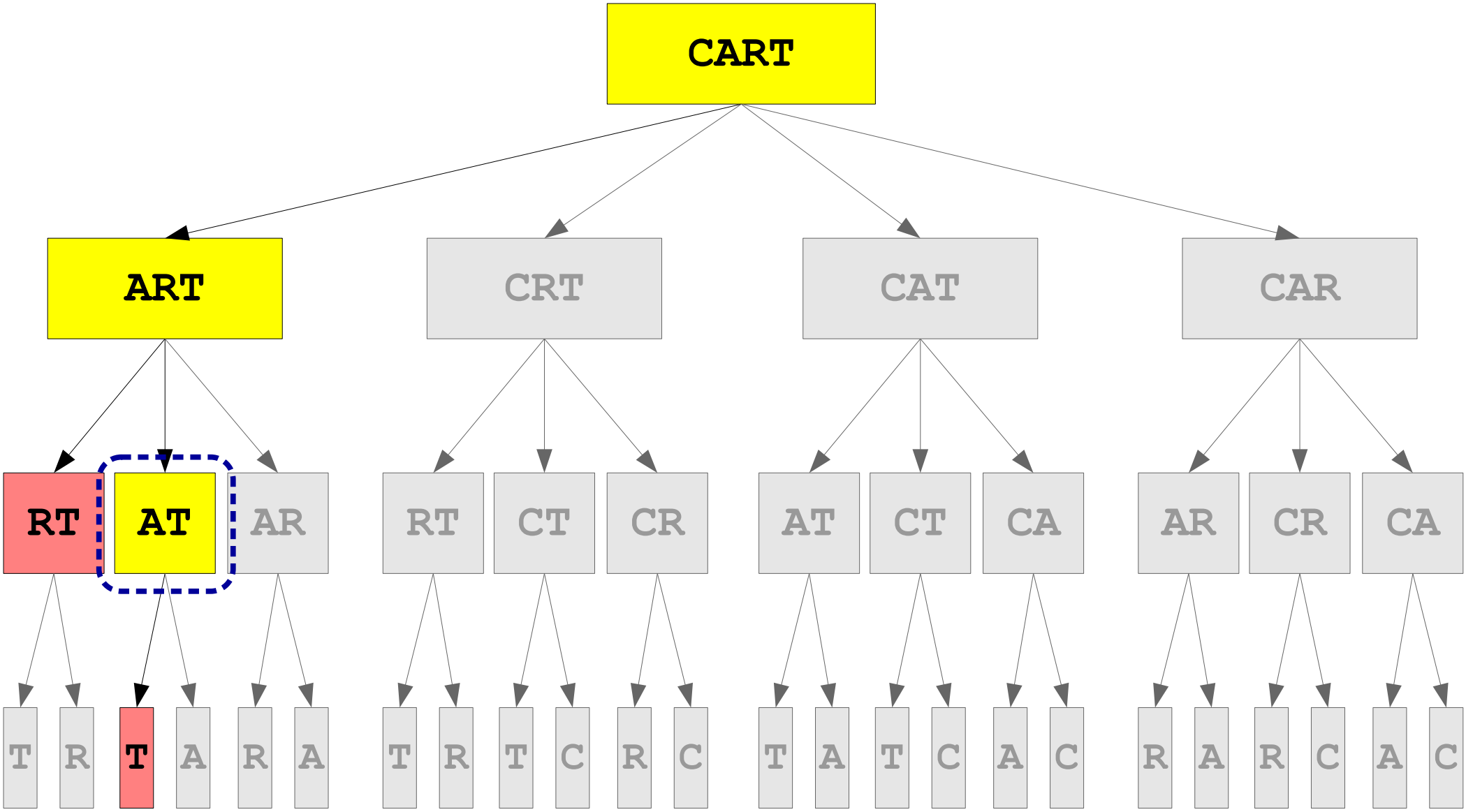

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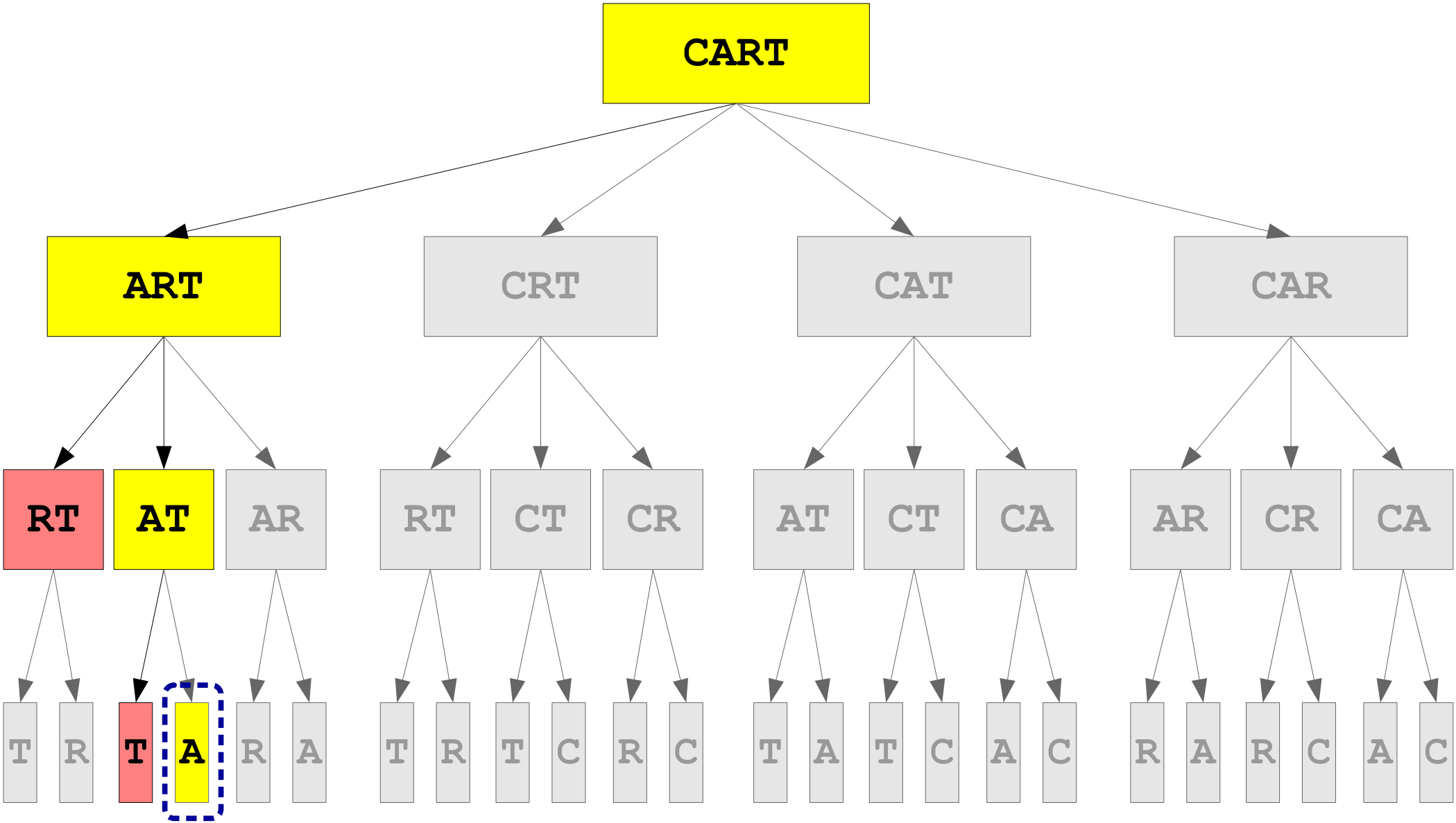

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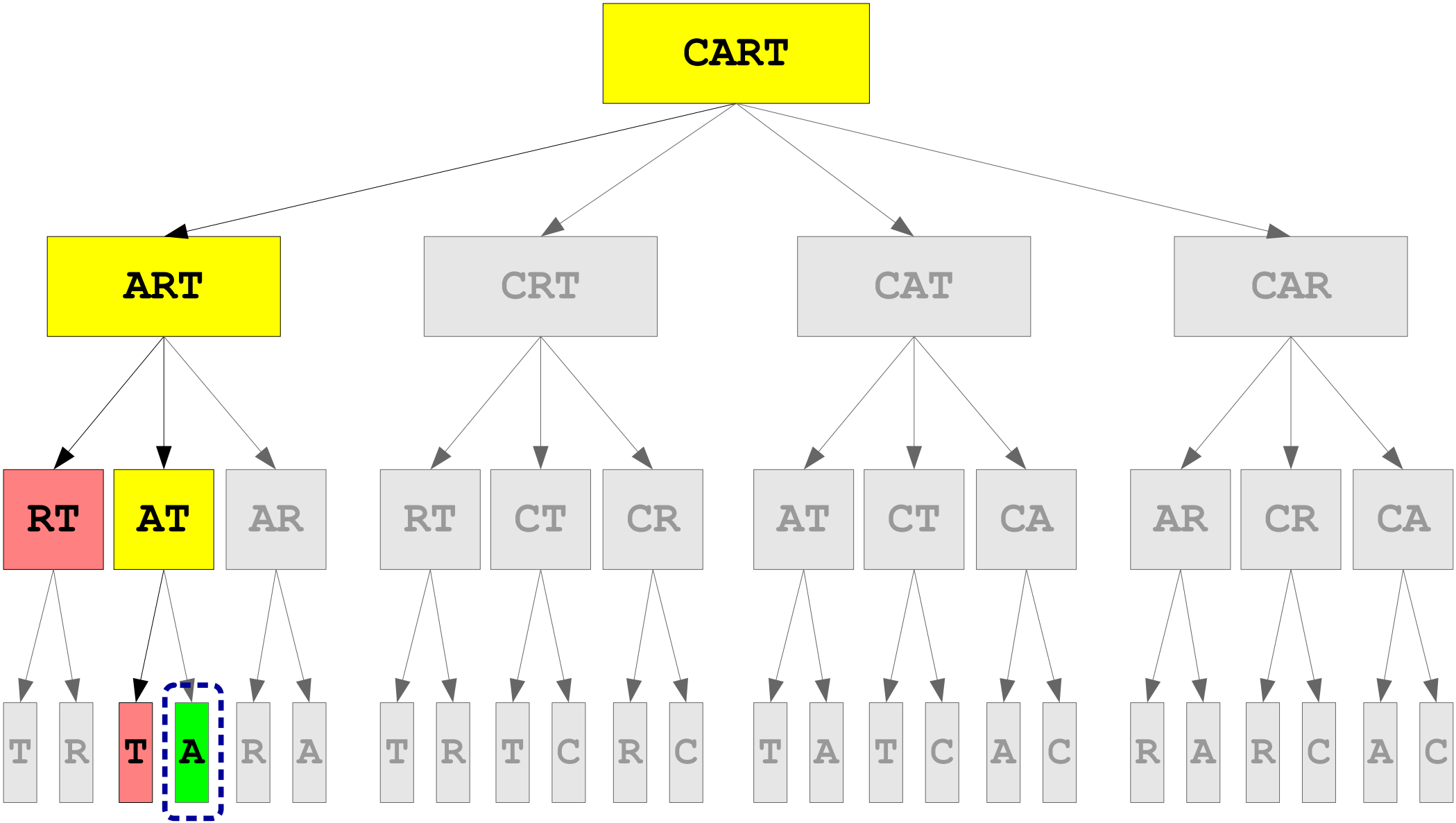

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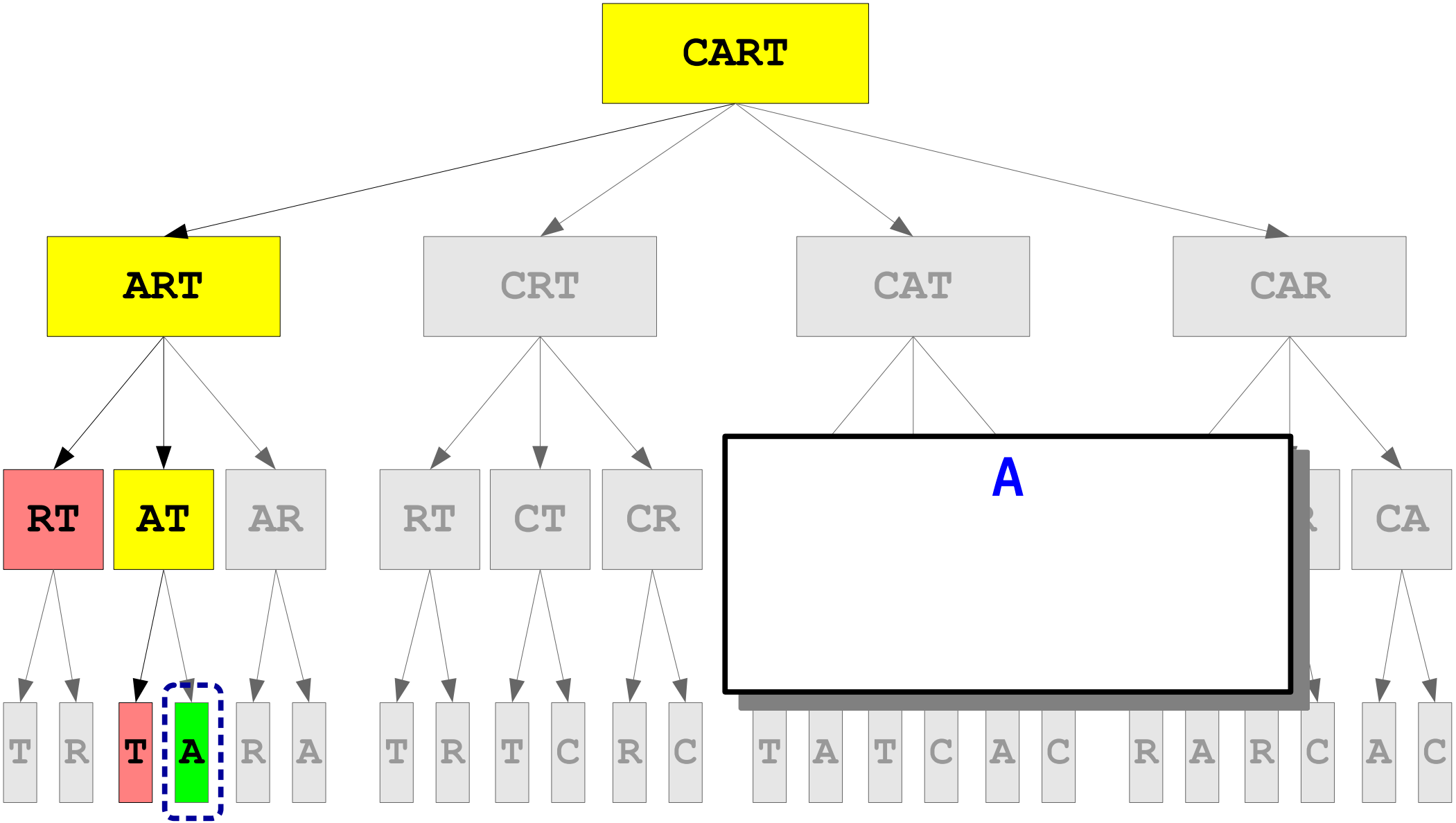

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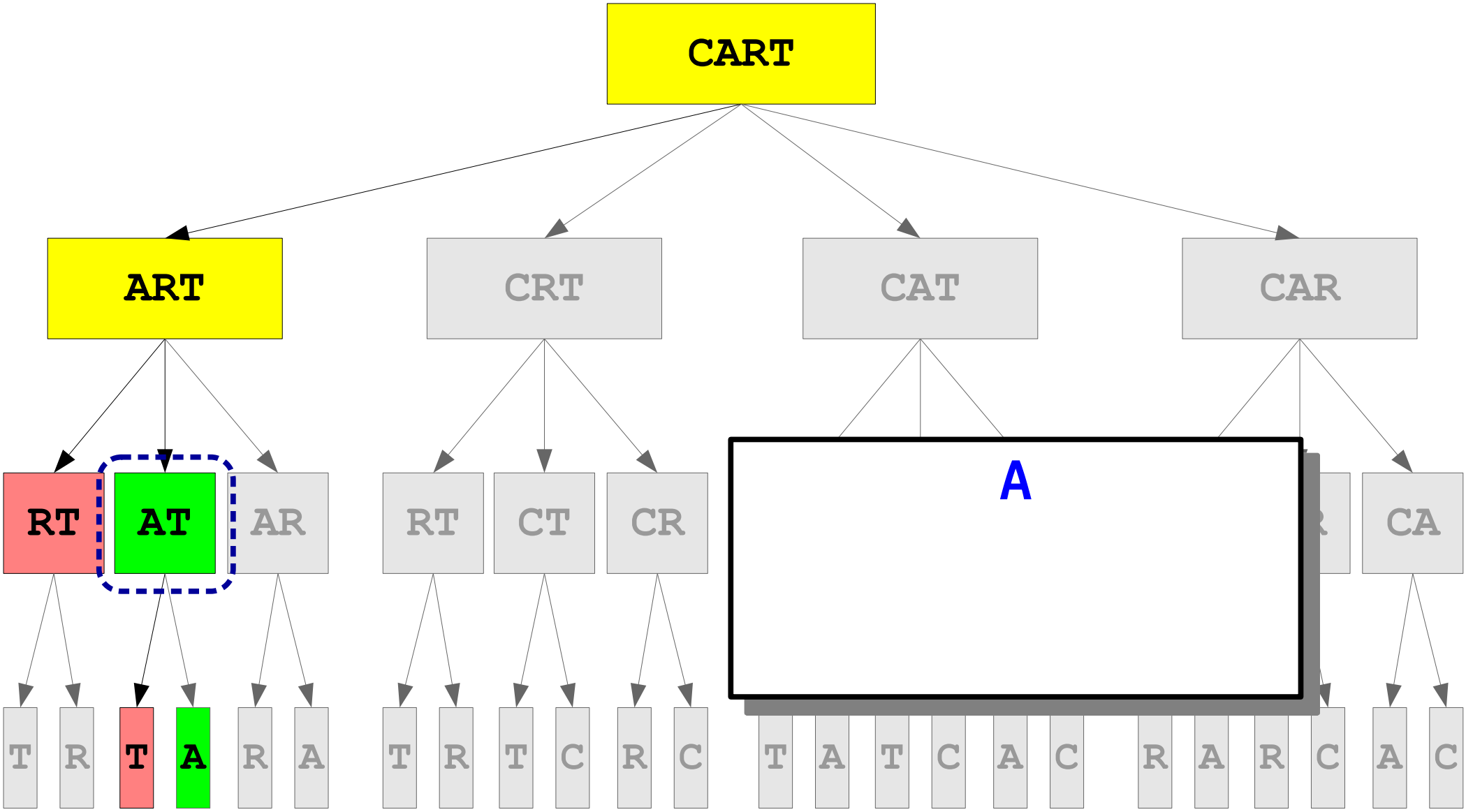

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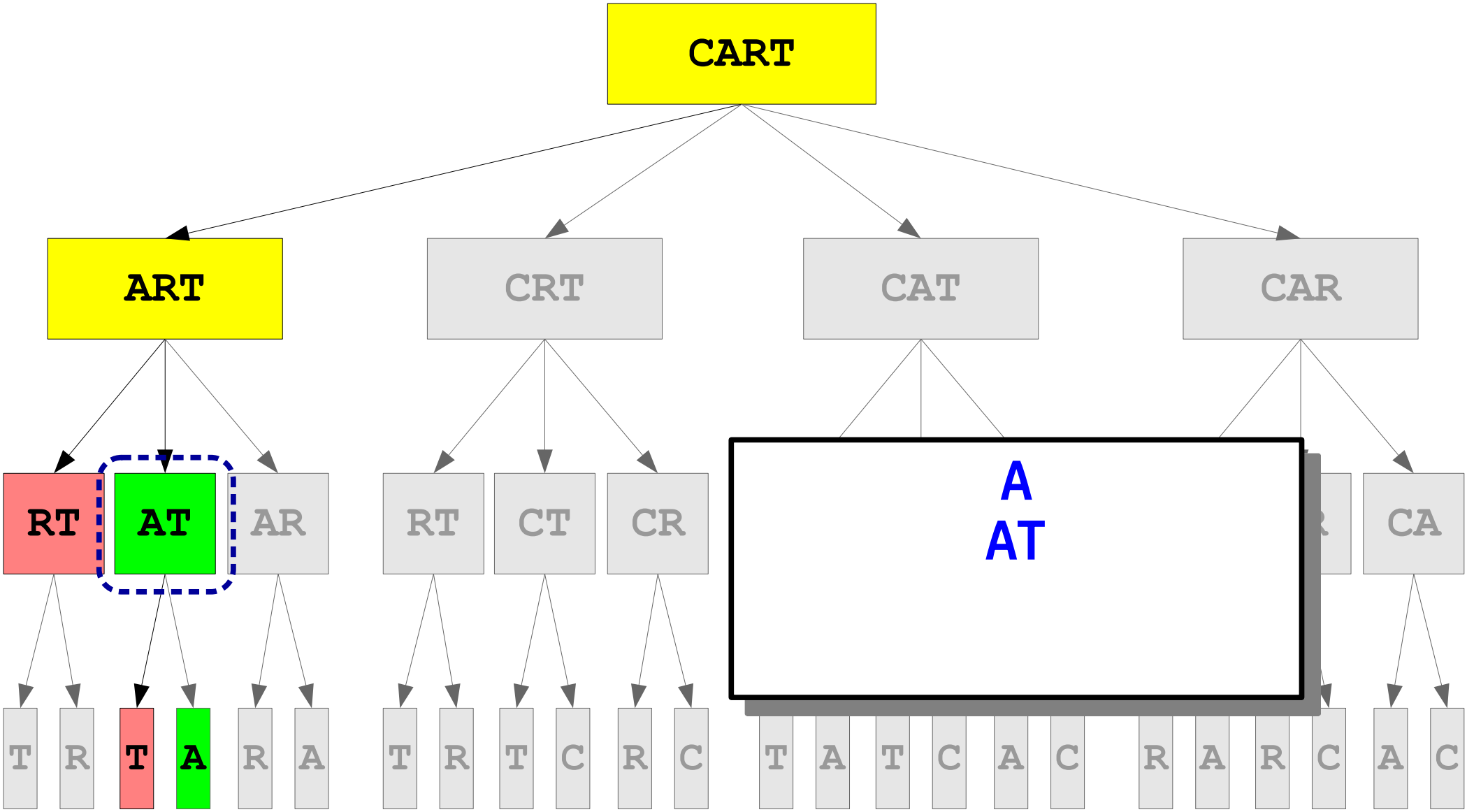

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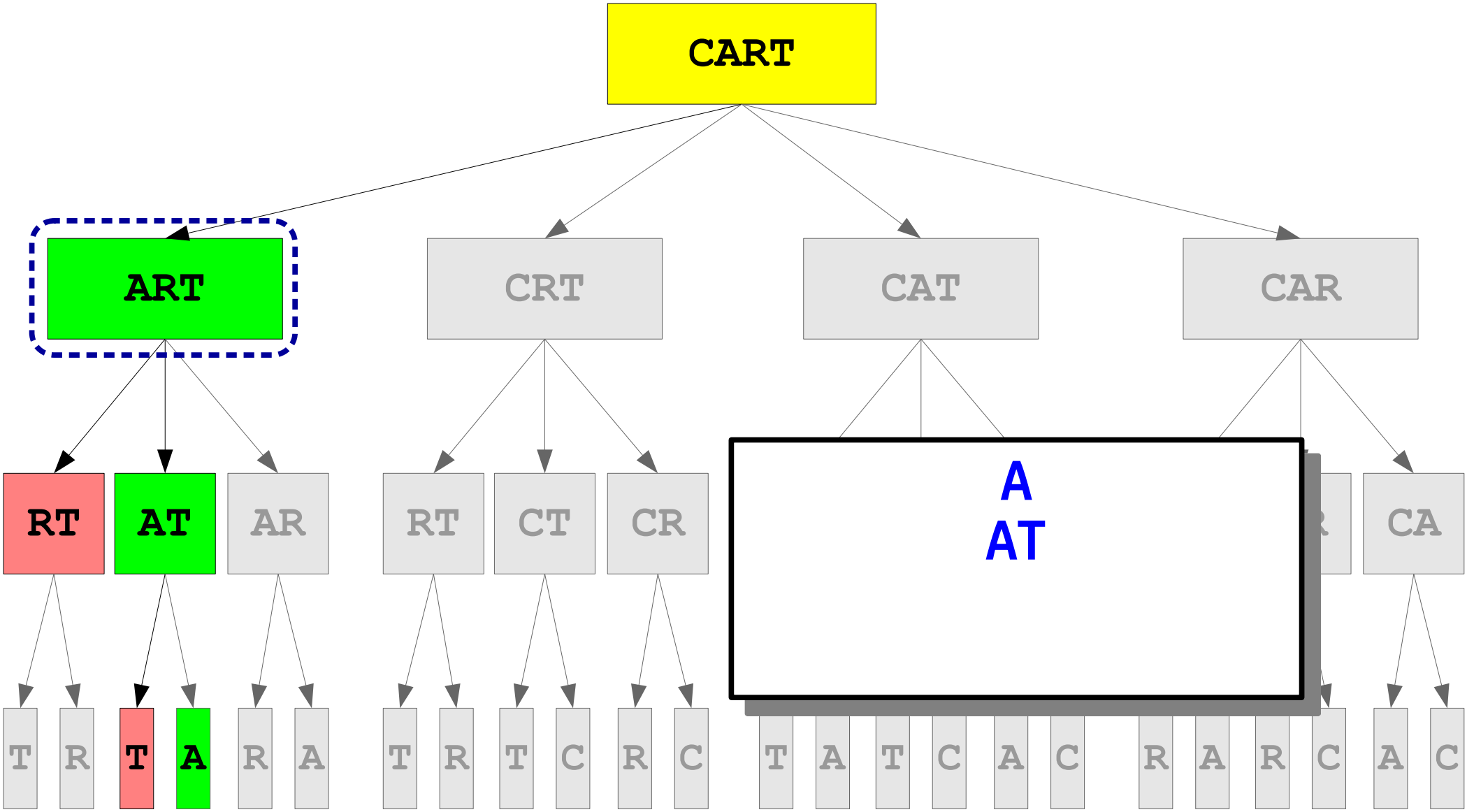

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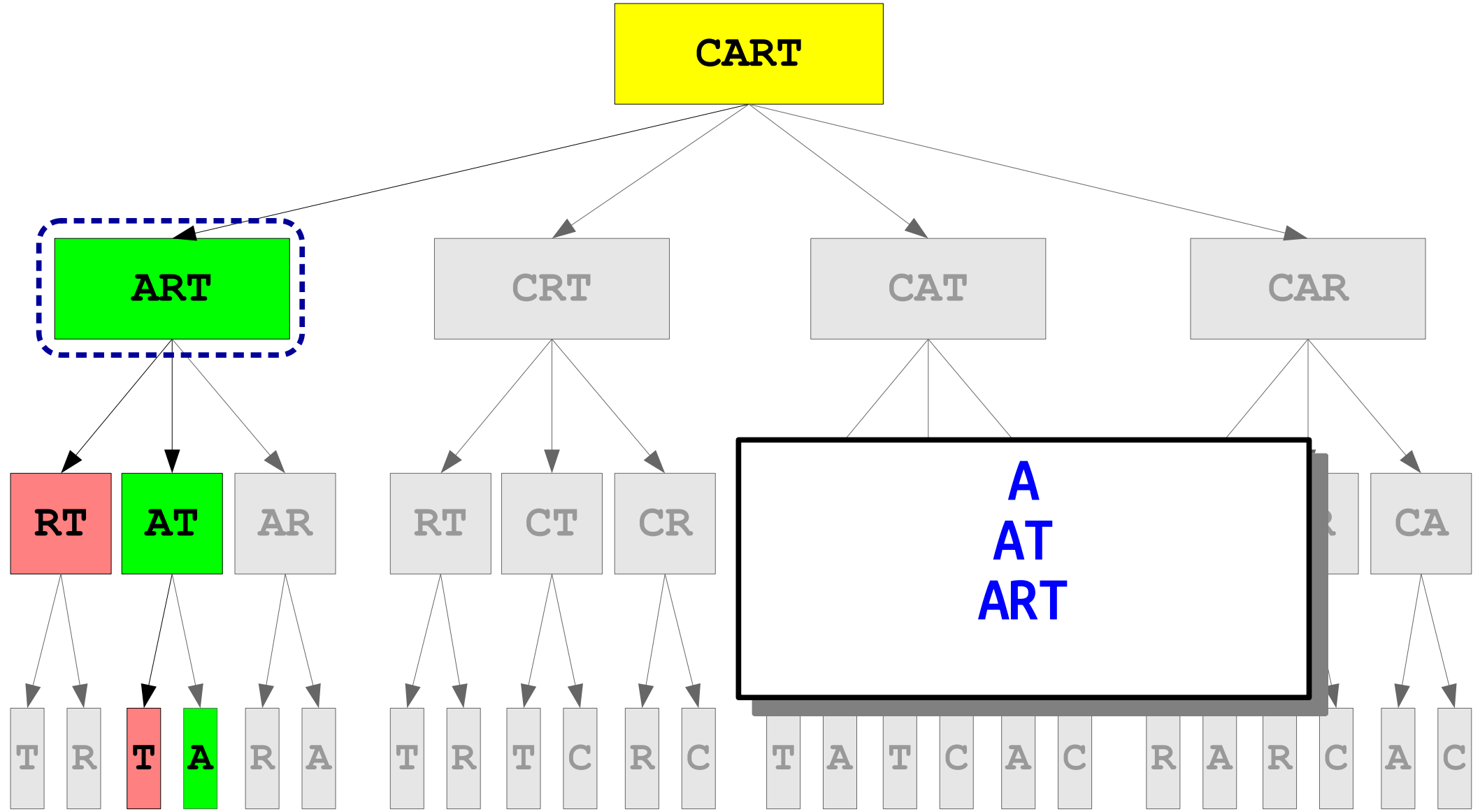

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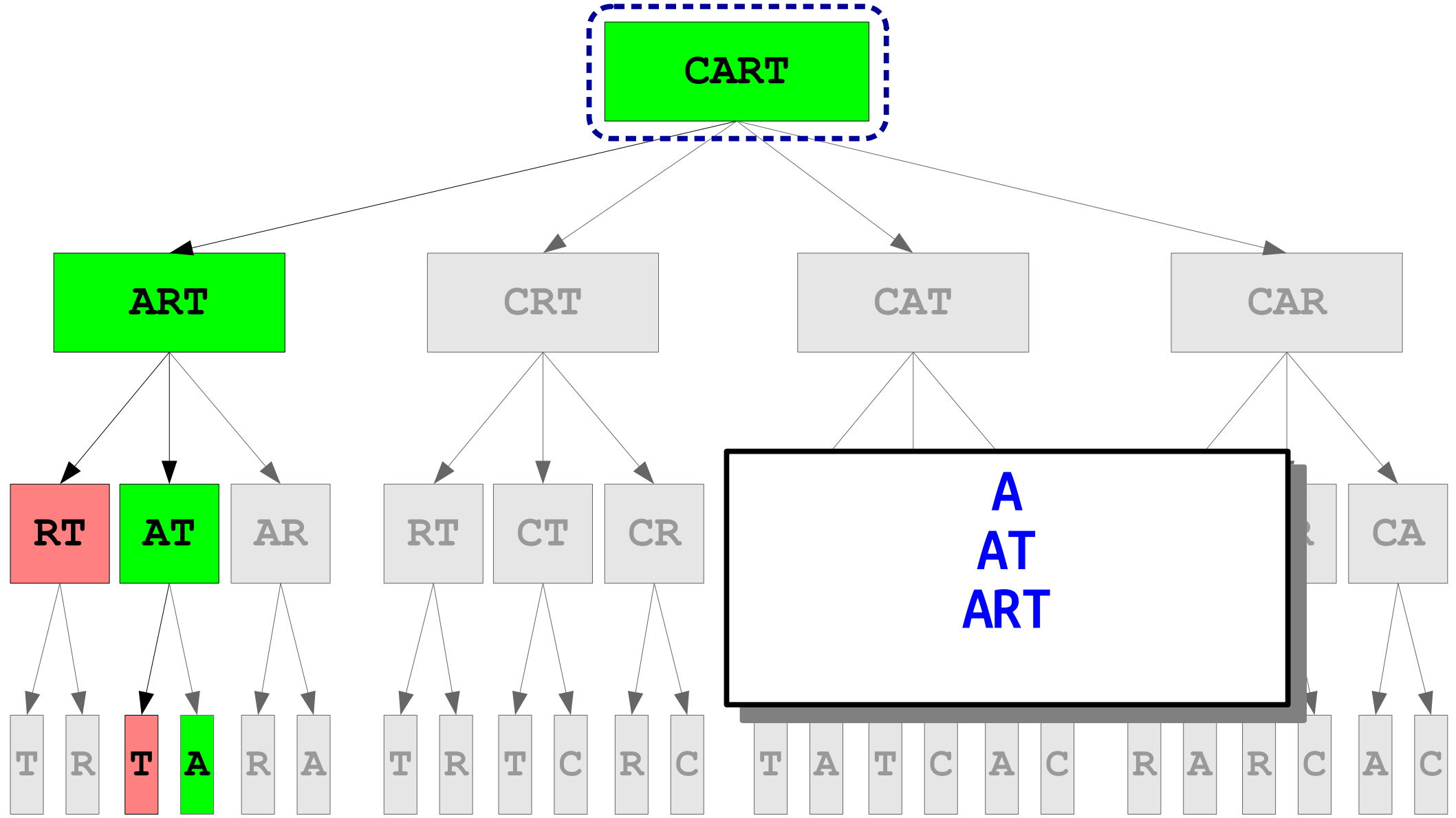

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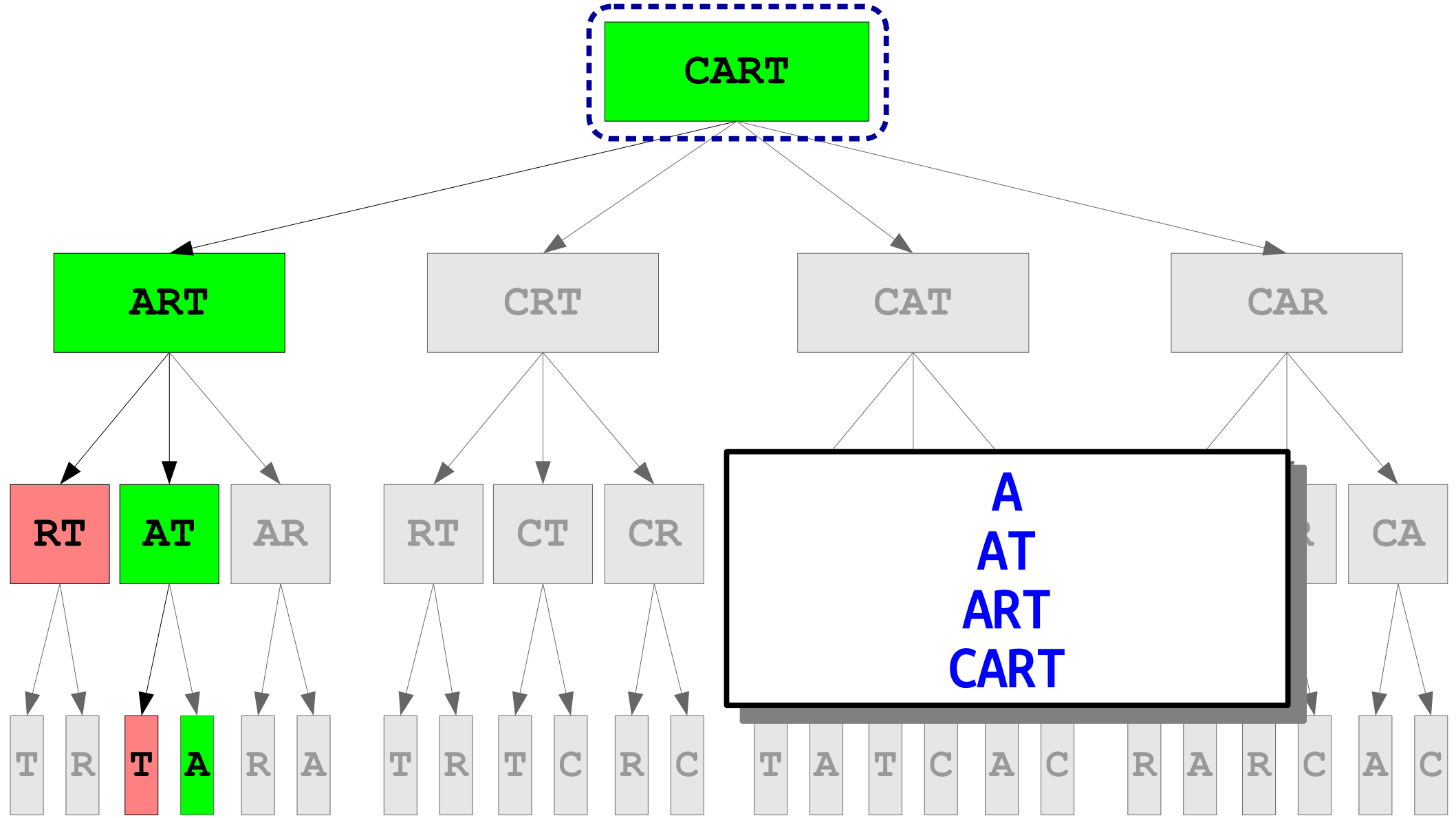
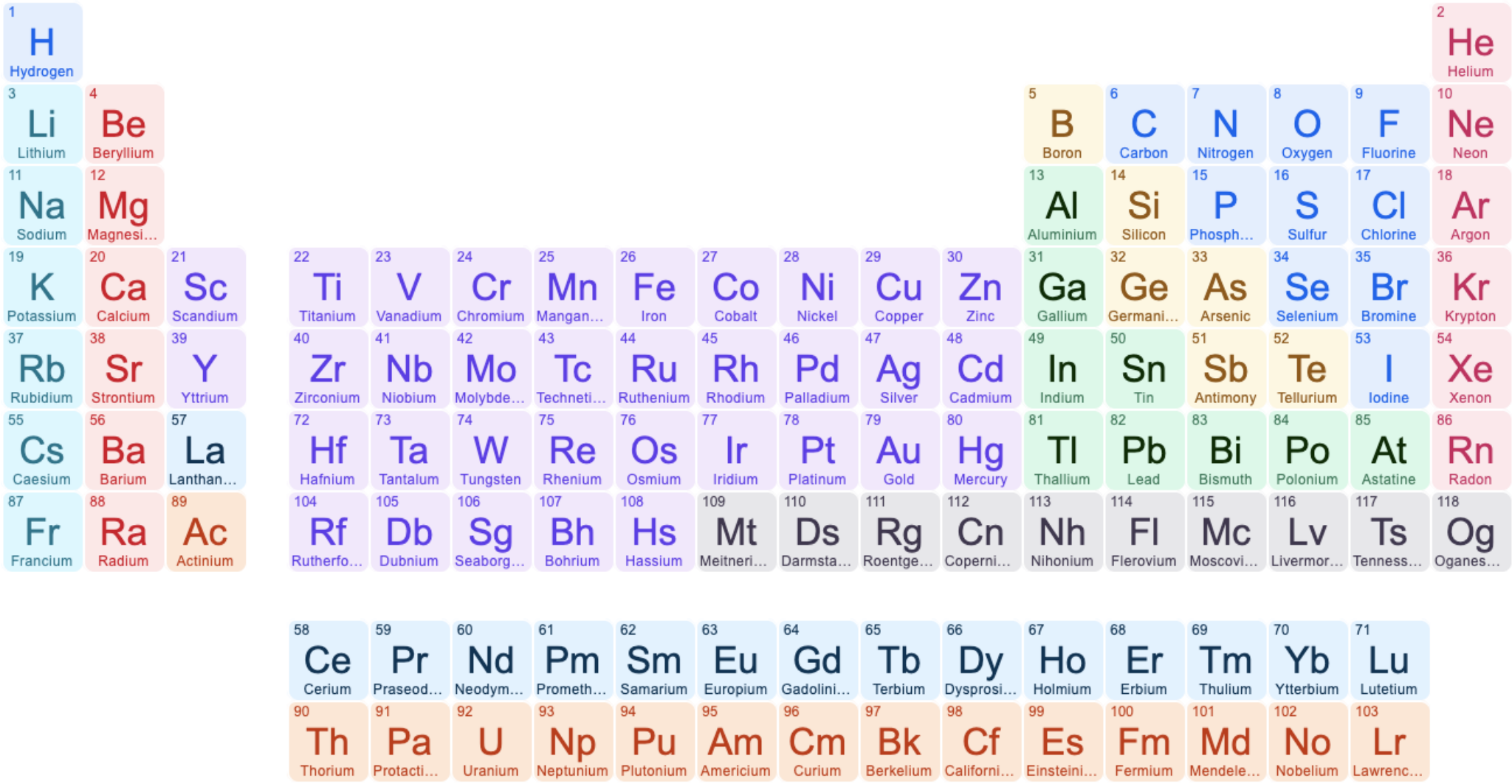
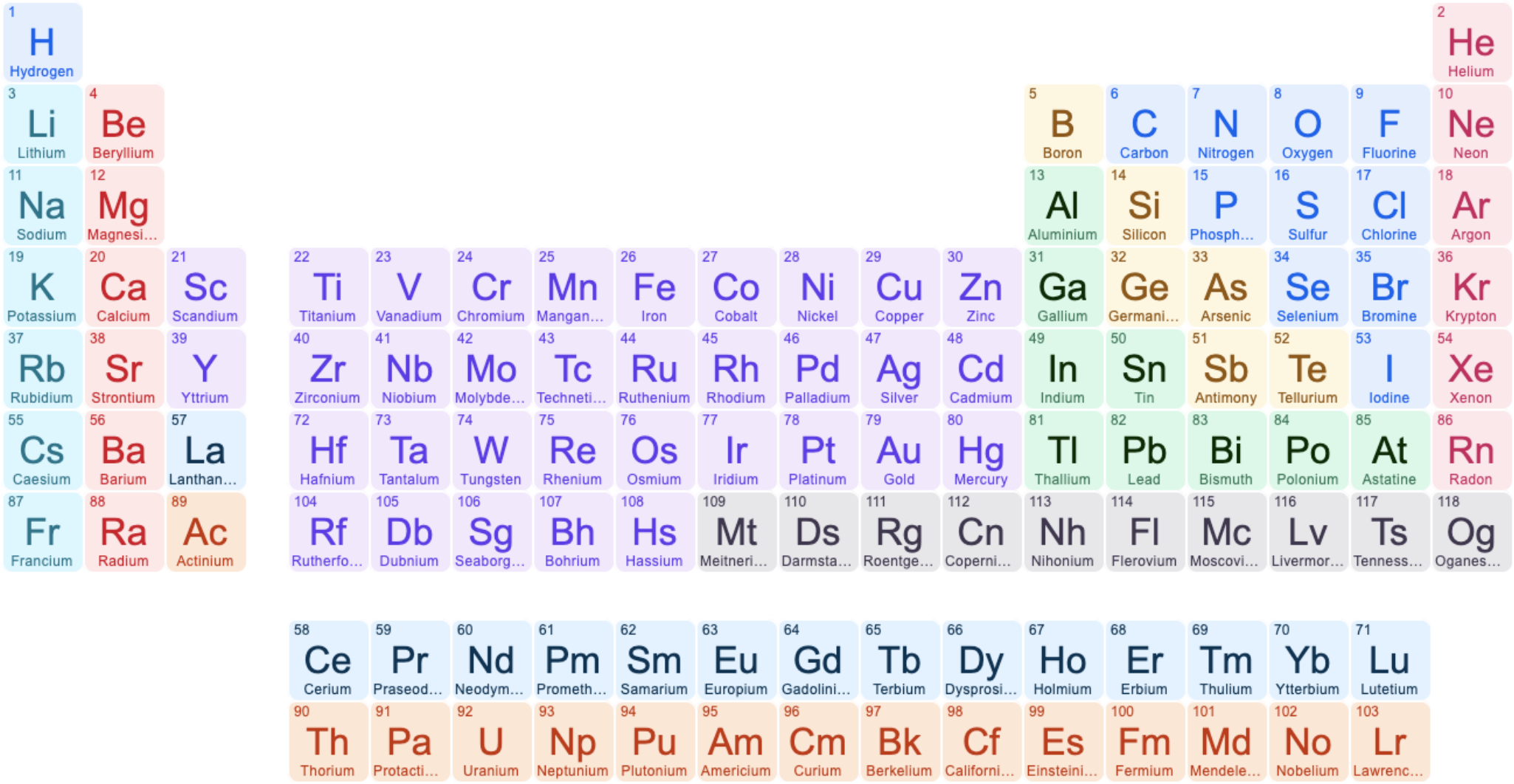


Another Backtracking Example

A Great Tool of Science



Oooh! Letters!



Oooh! Letters!

Can We Do Better?

CHeMoWIZrDy

- Some words can be spelled using just element symbols from the periodic table.
- For example:

CaNiNe FeLiNe PHYSiCs

UNIVErSITiEs HAlLuCINoGeNiCs

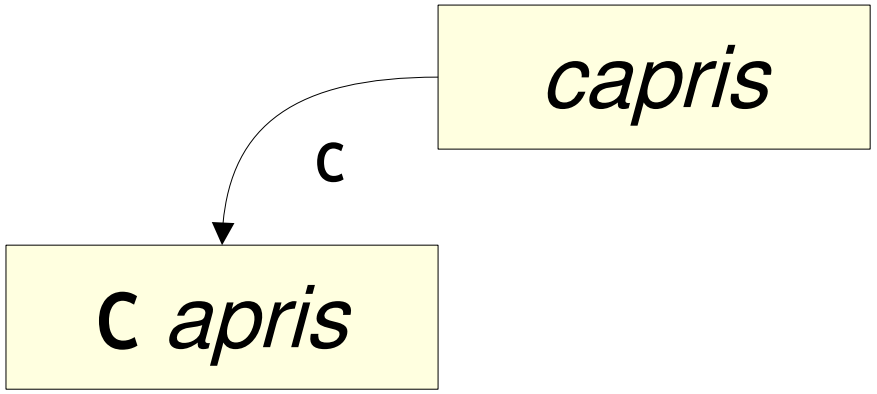
- Given a word, can we spell it using only symbols from the periodic table?
- And, if so, how?

NoTiCe ThAt

NoTiCe ThAt

capris

NoTiCe ThAt



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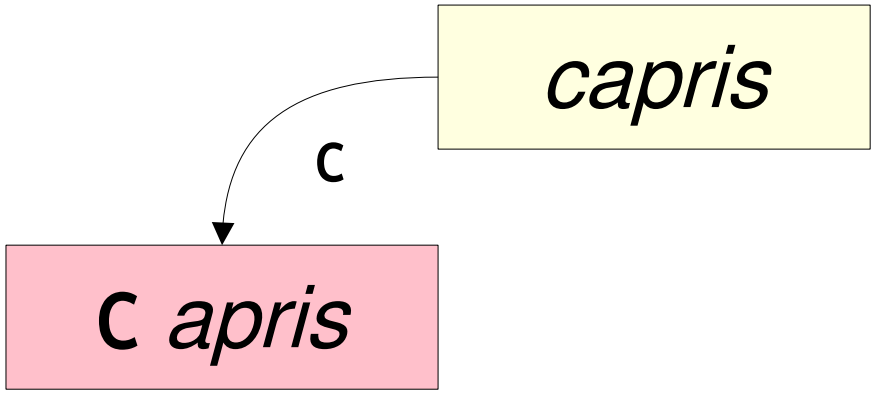

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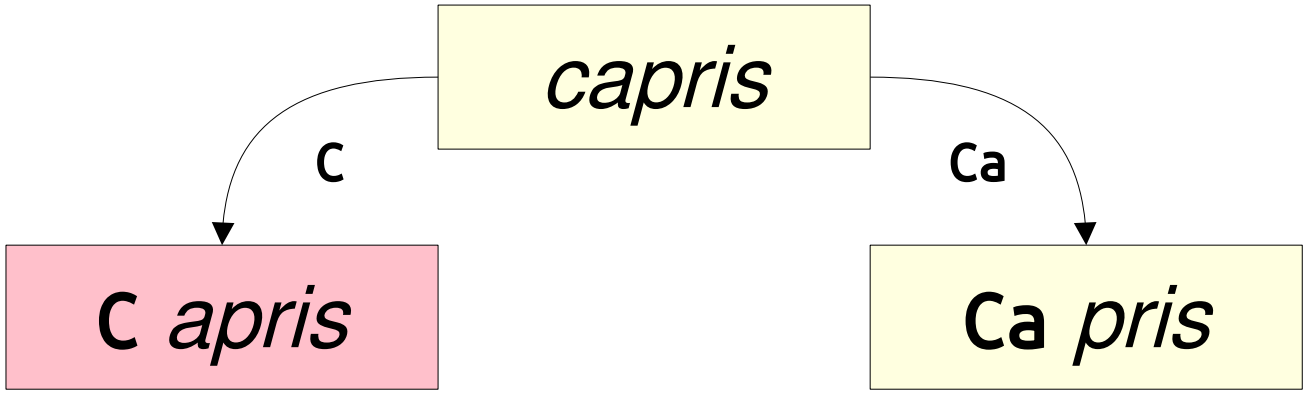

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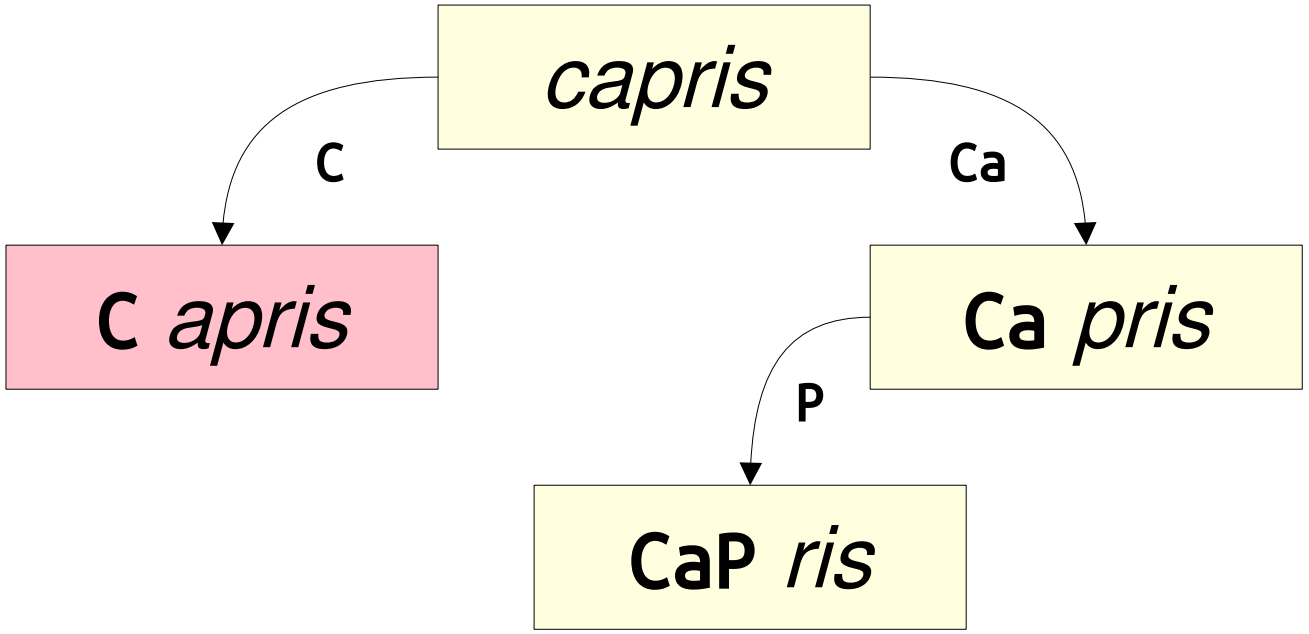

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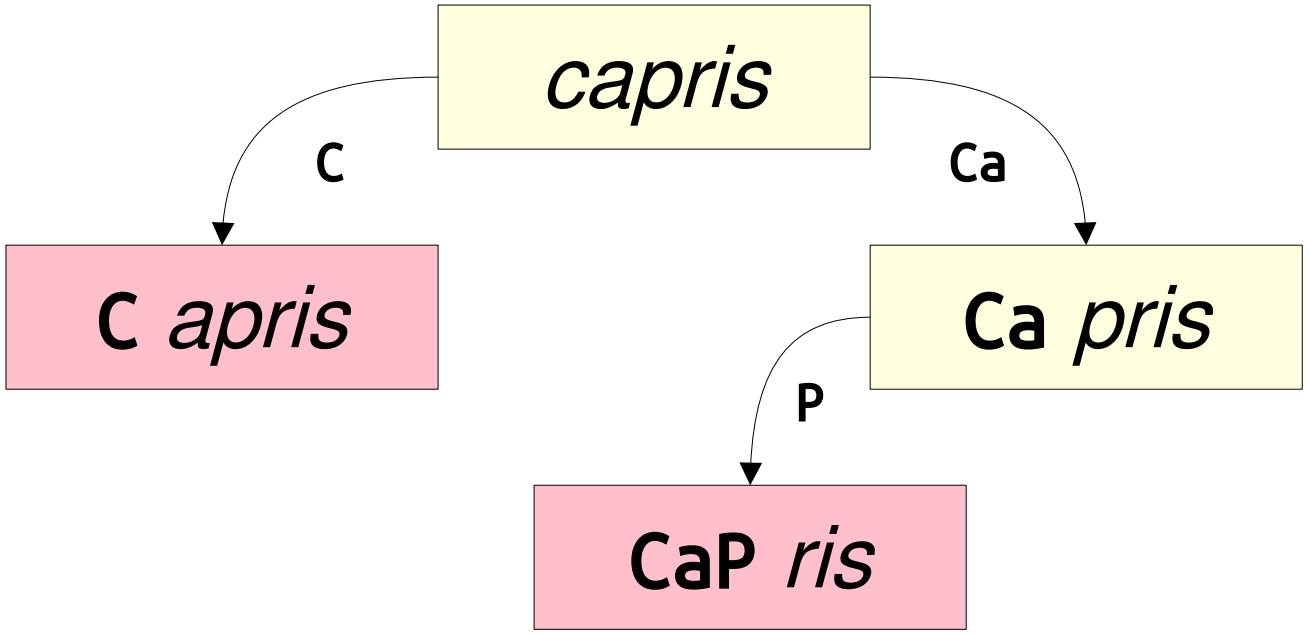

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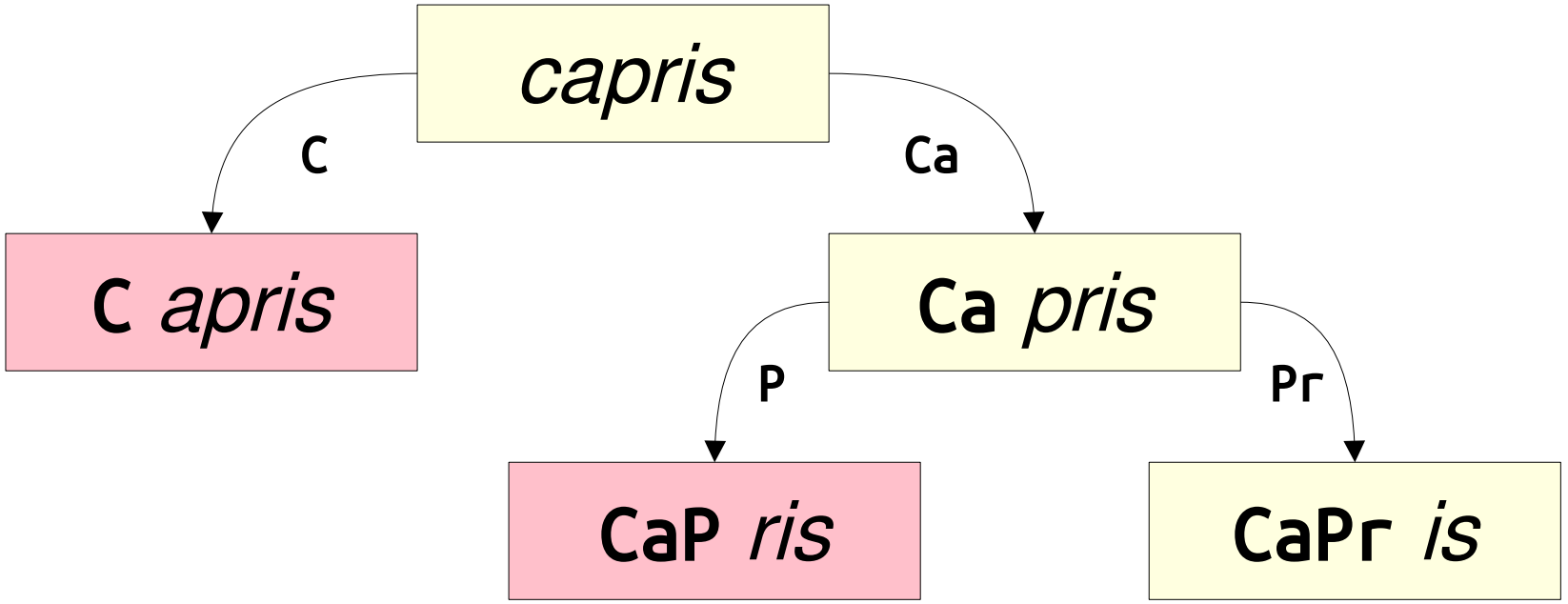

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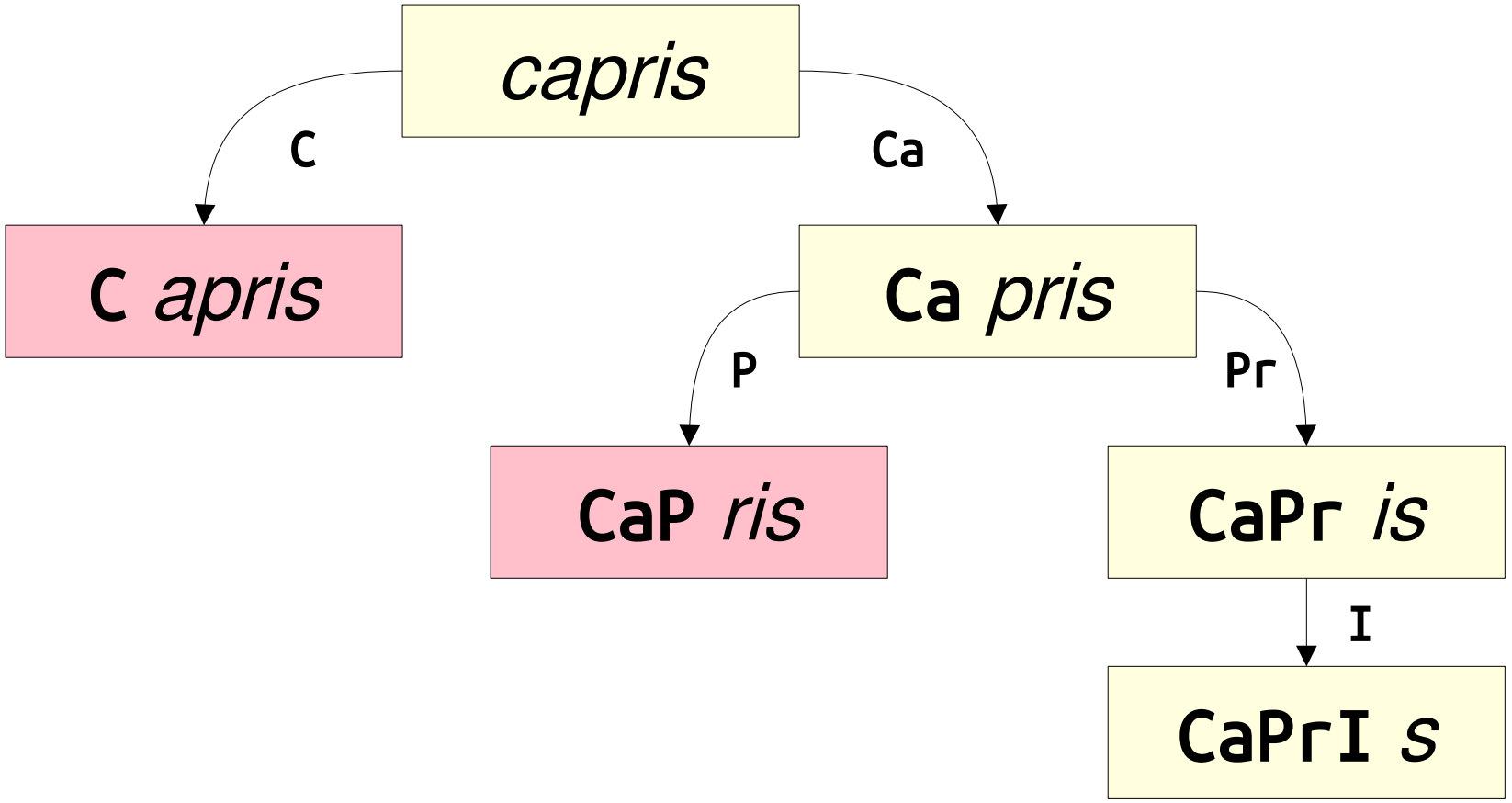

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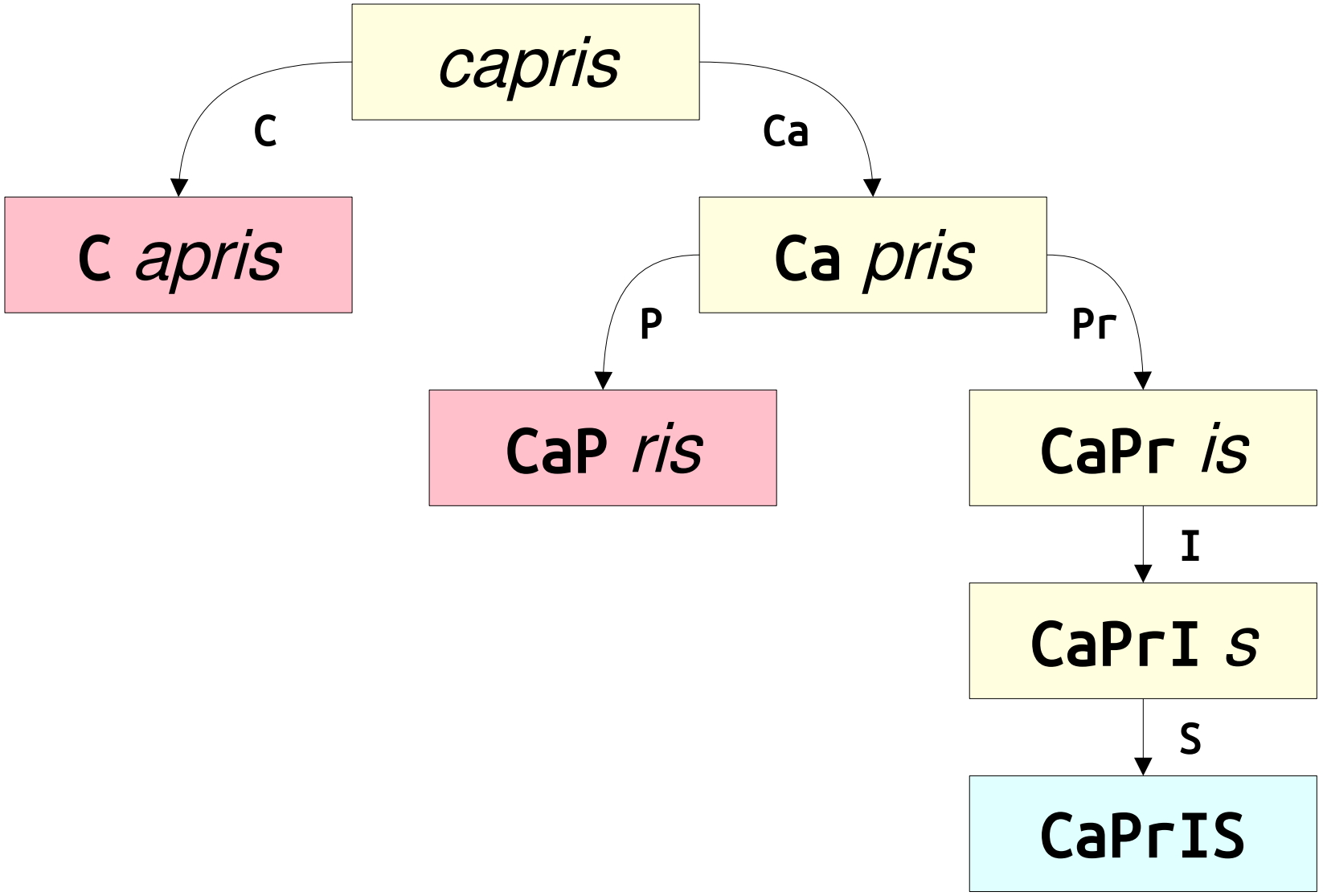
capris
C
Ca
C apris
Ca pris
P
Pr
CaP ris
CaPr is
I
CaPrI s
s
CaPrIS

RhHeCuRhSiON

- **BaSe CaSe:**
  - The empty string can be spelled using just element symbols.
- **RhHeCuRhSiV STeP:**
  - For each element symbol:
    - If the string starts with that symbol, check if the rest of the word is spellable.
    - If so, then the original word is spellable too.
  - Otherwise, no option works, so the word isn't spellable.

Closing Thoughts on Recursion

You now know how to use recursion to ***view problems from a different perspective*** that can lead to ***short and elegant solutions***.

You've seen how to use recursion to ***enumerate all objects of some type***, which you can use to find the ***optimal solution to a problem***.

You've seen how to use recursive backtracking to ***determine whether something is possible*** and, if so to ***find some way to do it***.

Congratulations on making it this far!

Your Action Items

- ***Finish Chapter 9.***
  - It’s all about backtracking, and there are some great examples in there!
- ***Finish Assignment 3.***
  - As always, get in touch with us if we can help out!

Next Time

- ***Algorithmic Analysis***
  - How do we formally analyze the complexity of a piece of code?
- ***Big-O Notation***
  - Quantifying efficiency!