Thinking Recursively

Part V

What’s Wrong With This Code?

```
bool containsE(const string& str) {
    for (int i = 0; i < str.length(); i++) {
        return str[i] == 'e' || str[i] == 'E';
    }
    return false;
}
```

Take fifteen seconds to identify what's wrong with this code, but **please don't share your answer is chat just yet.**

What’s Wrong With This Code?

```
bool containsE(const string& str) {
    for (int i = 0; i < str.length(); i++) {
        return str[i] == 'e' || str[i] == 'E';
    }
    return false;
}
```

Now, share your answer in chat.

What’s Wrong With This Code?

```
bool containsE(const string& str) {
    for (int i = 0; i < str.length(); i++) {
        return str[i] == 'e' || str[i] == '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

S	T	A	R	T	L	I	N	G

One Solution

S	T	A	R	T	I	N	G

One Solution

S	T	A	R	I	N	G

One Solution

S	T	R	I	N	G

One Solution

S	T	I	N	G

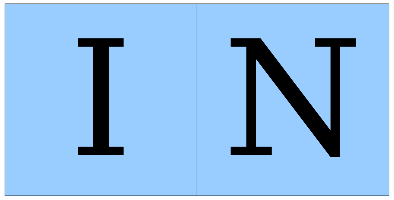
One Solution

S	I	N	G

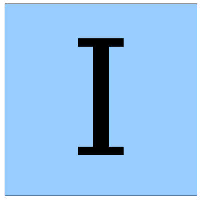
One Solution

S	I	N

One Solution



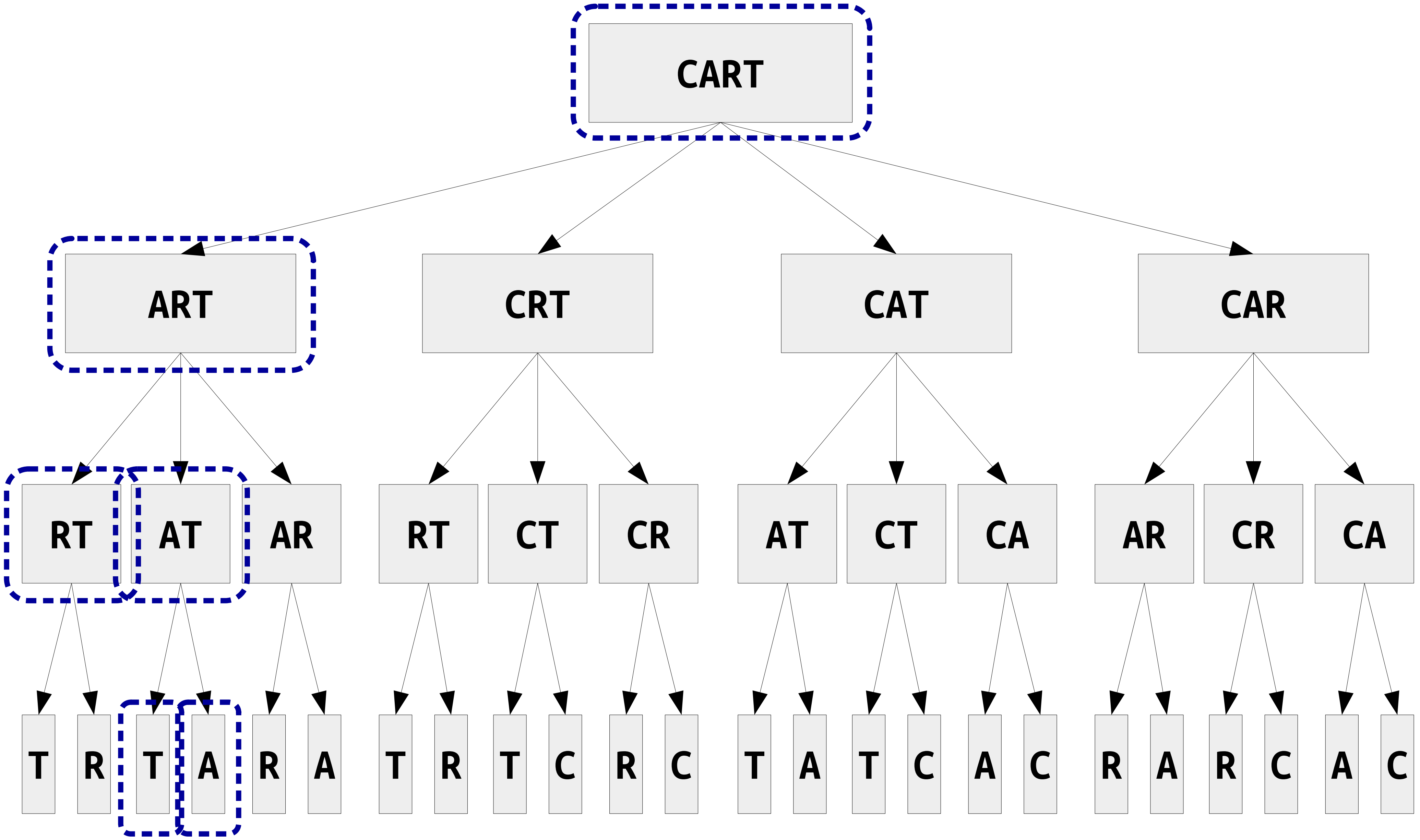
One Solution



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 (isShrinkable(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 (isShrinkable(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 isShrinkable(shrunken, english); // Bad idea!
    }
    return false;
}
```

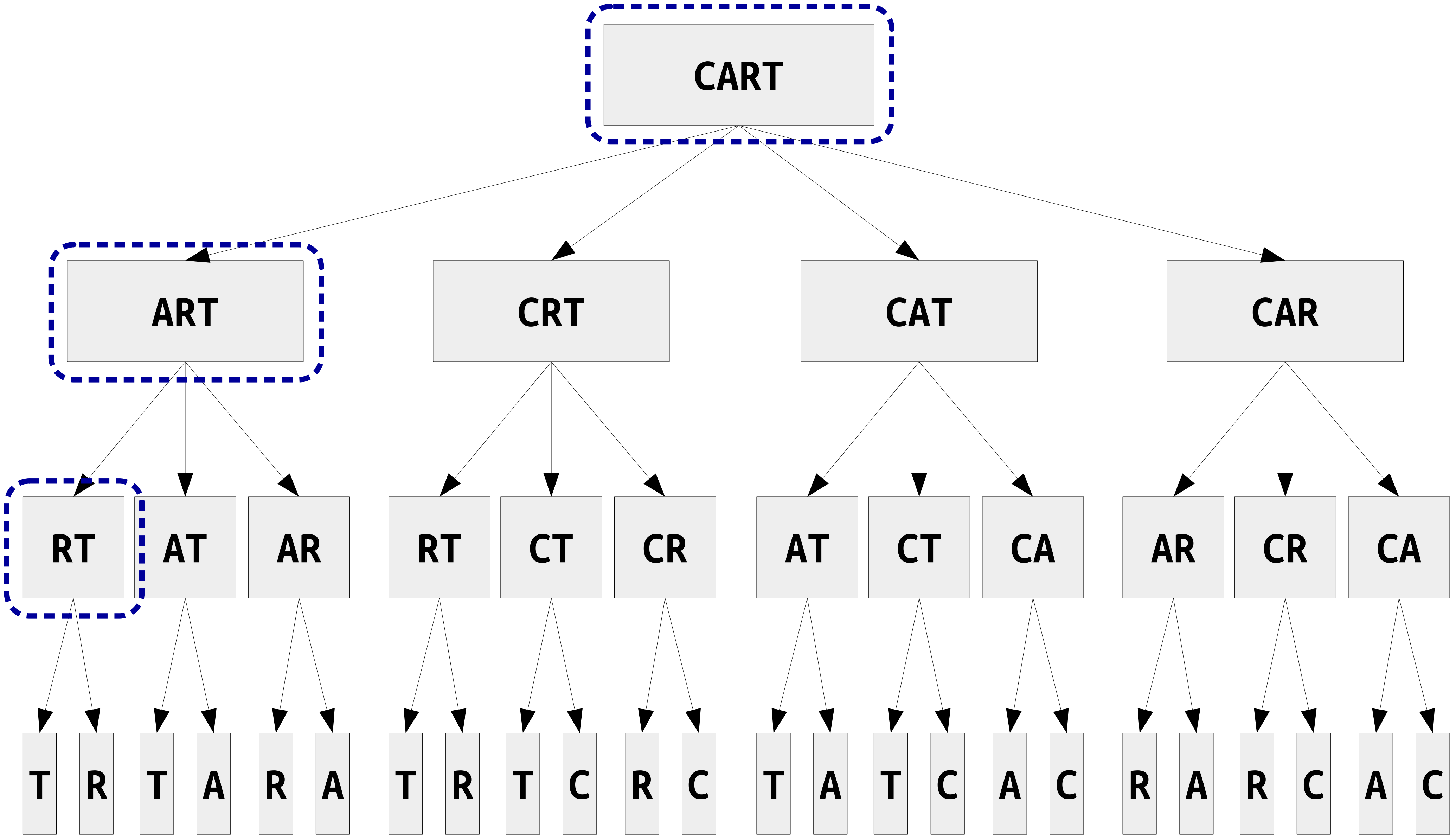
```
bool isShrinkableWord(const string& word,
                      const Lexicon& english) {
    if (!english.contains(word)) {
        return false;
    }
    if (word.length() == 1) {
        return true;
    }

    for (int i = 0; i < word.length(); i++) {
        string shrunken = word.substr(0, i) + word.substr(i + 1);
        return isShrinkable(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;
}
```

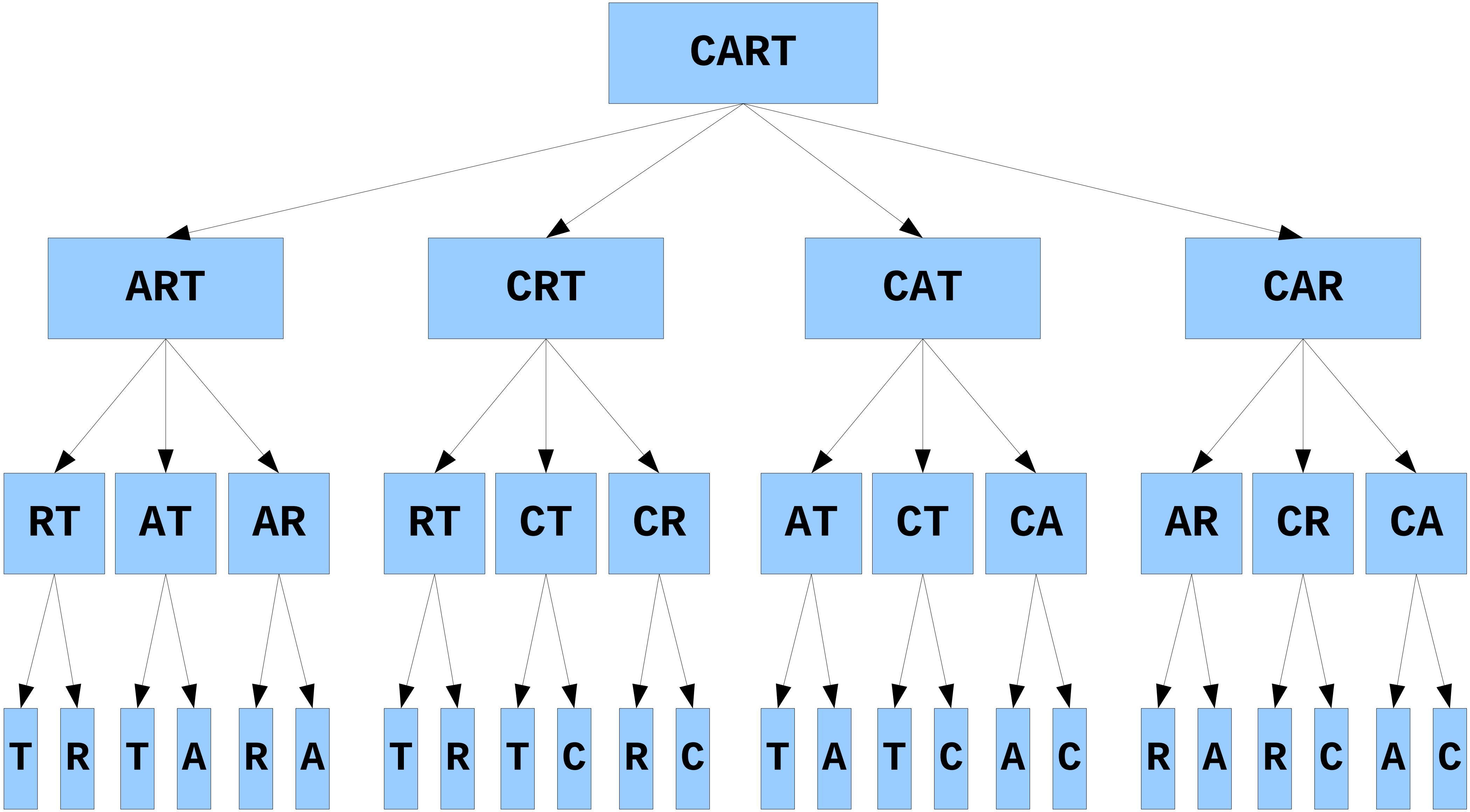
Note that *if* the recursive call succeeds, *then* we return success. If it doesn't succeed, that doesn't mean we've failed – it just means we need to try out the next option.

How do we know we’re correct?

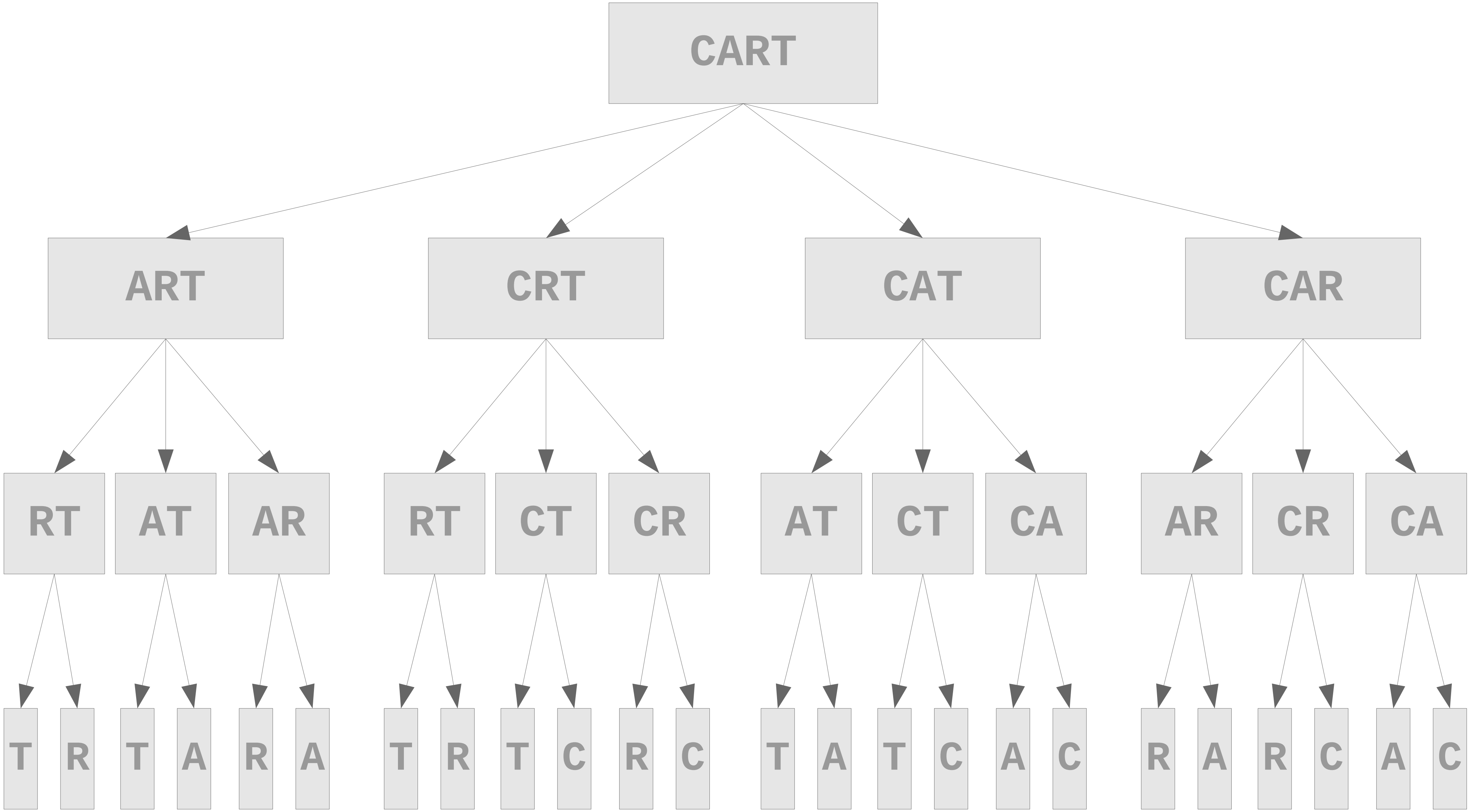
Output Parameters

- An ***output parameter*** (or ***outparam***) is a parameter to a function that stores the result of that function.
- Caller passes the parameter by reference, function overwrites the value.
- Often used with recursive backtracking:
  - The return value says whether a solution exists.
  - If one does, it’s loaded into the outparameter.

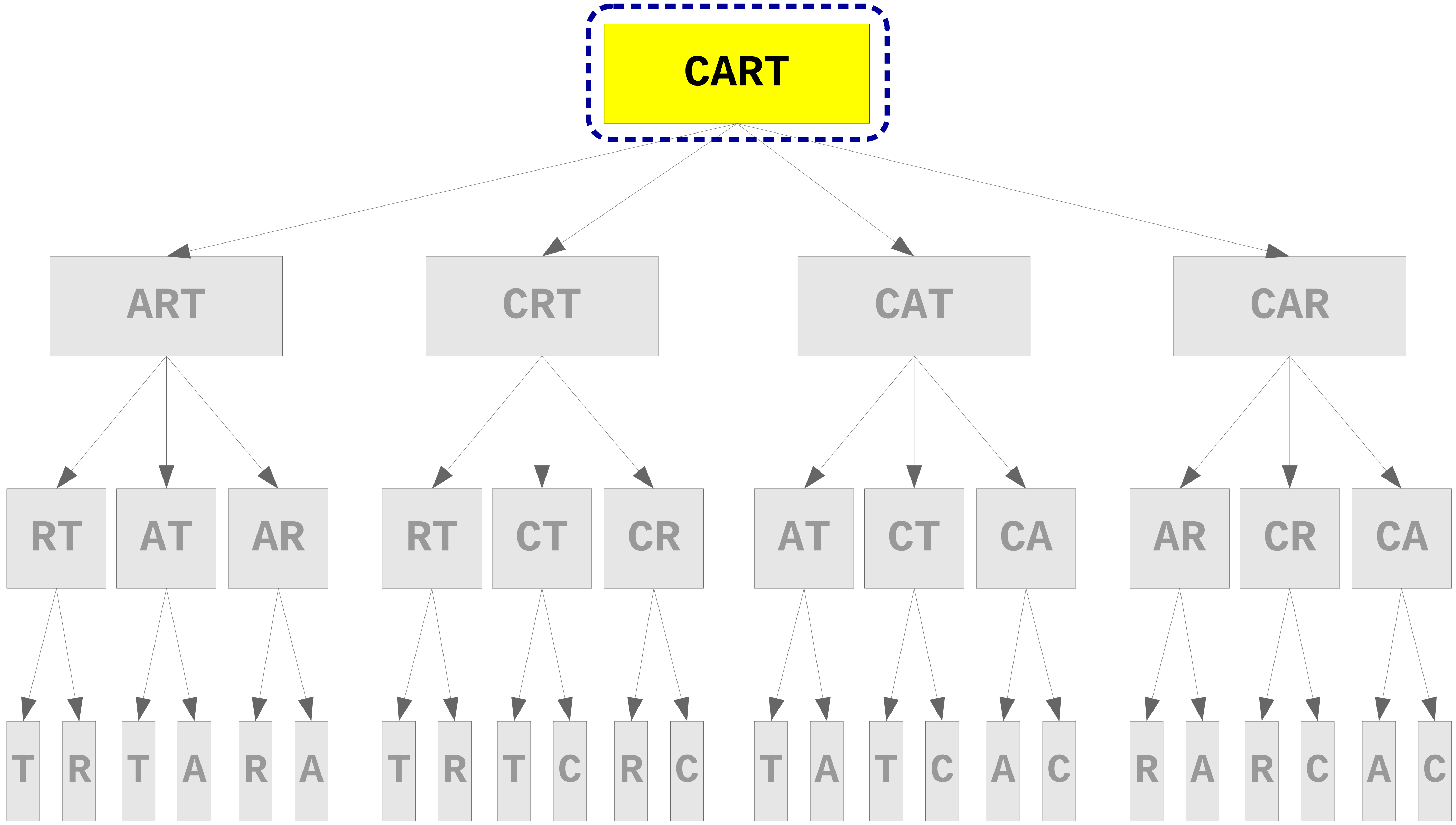
Generating the Answer



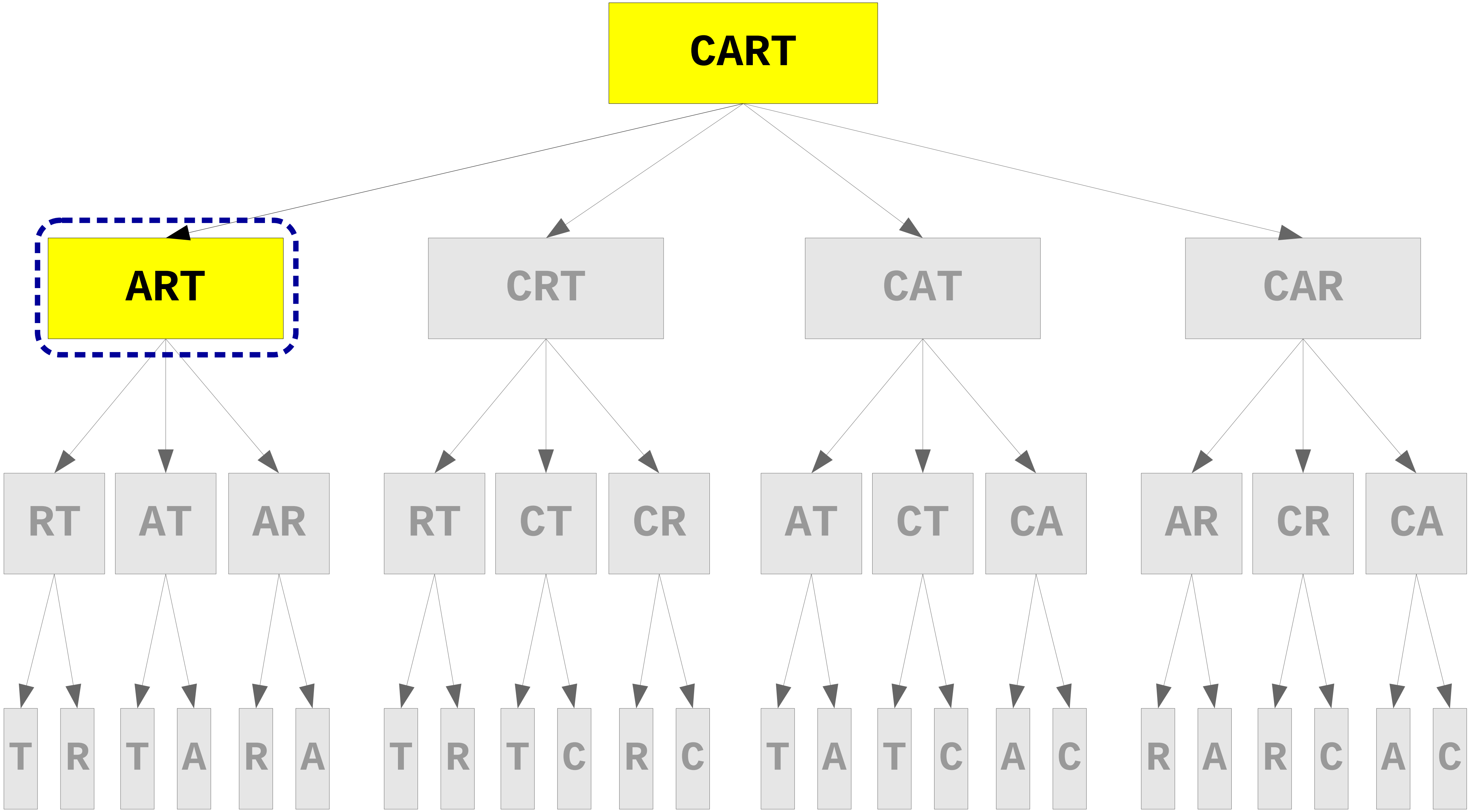
Generating the Answer



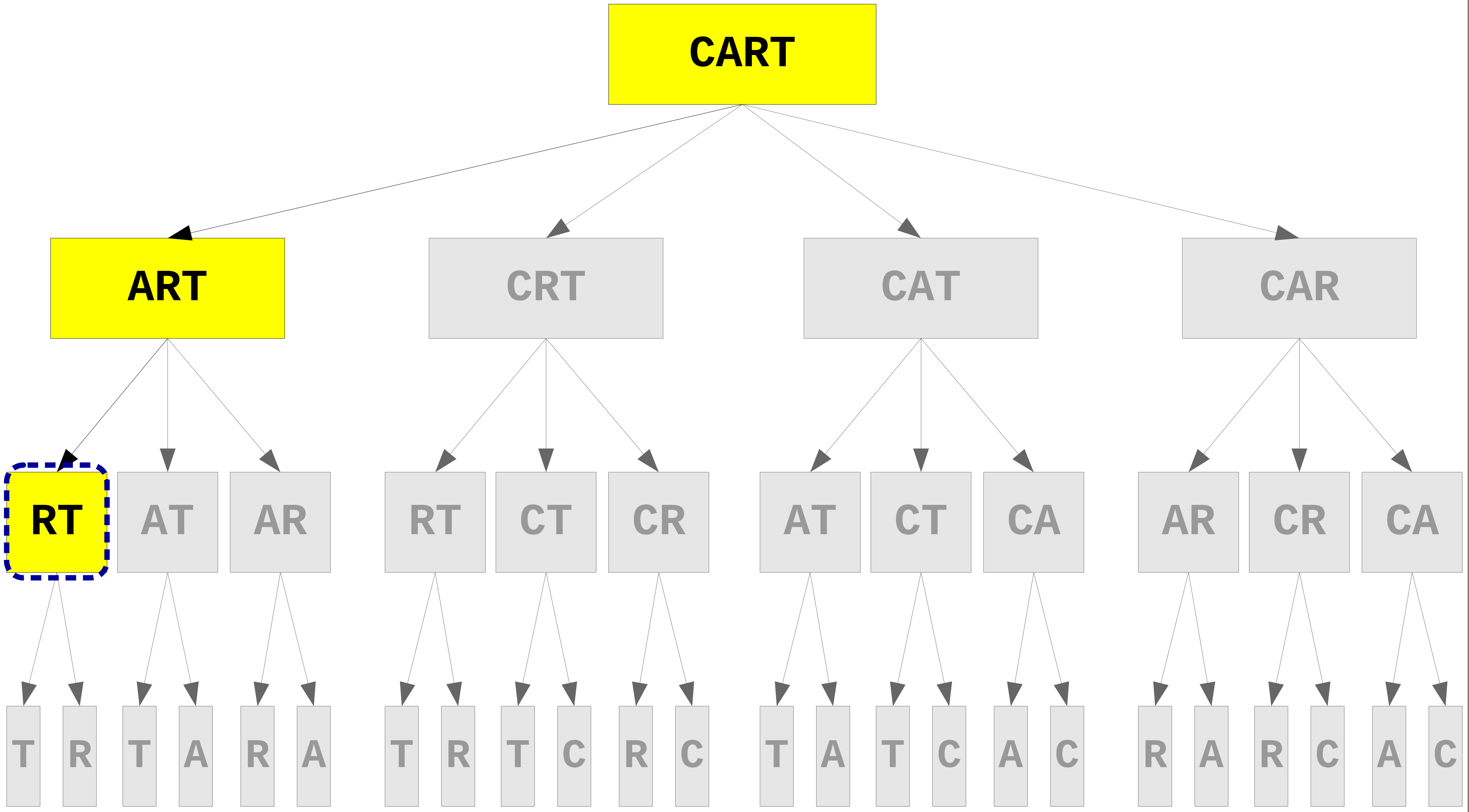
Generating the Answer



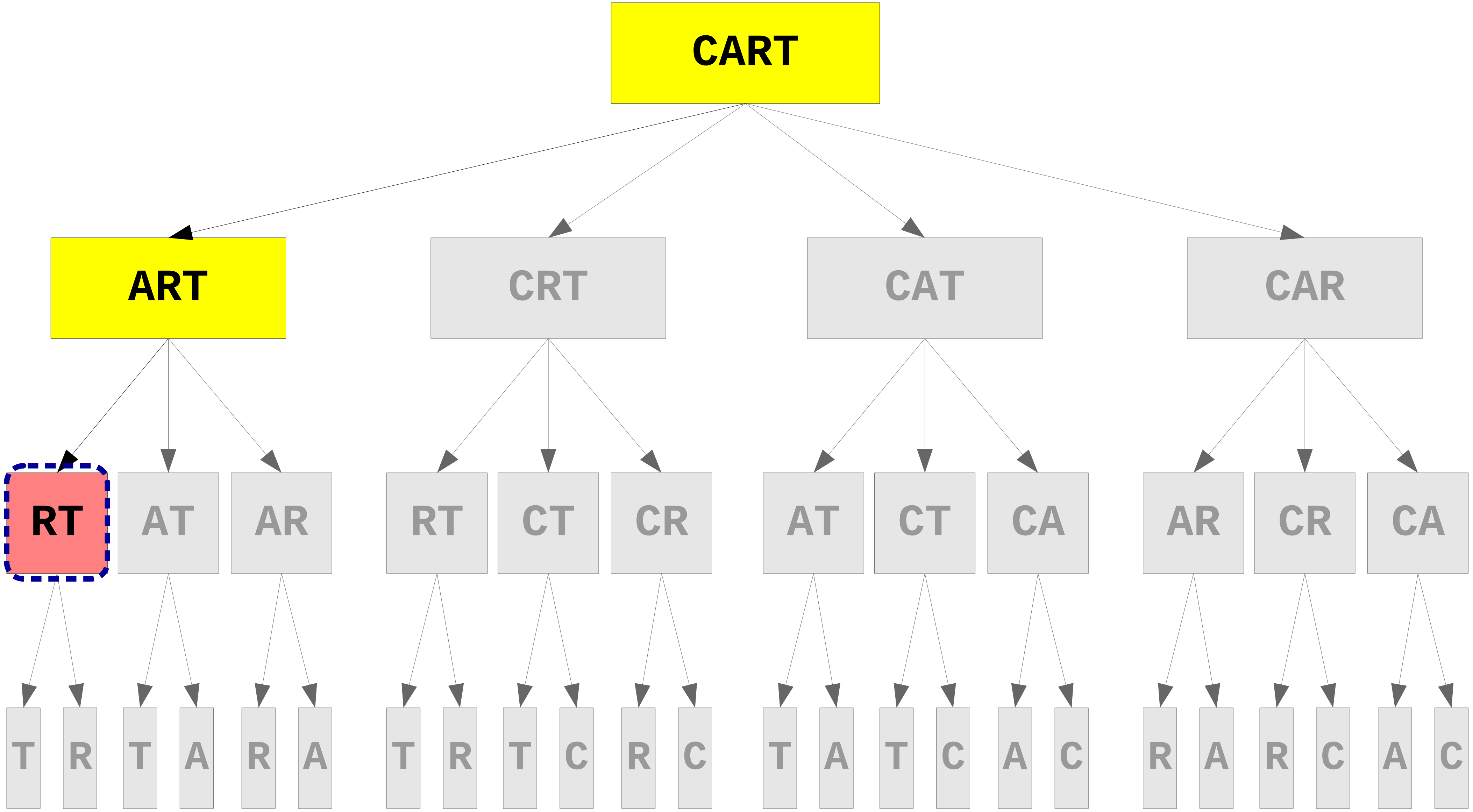
Generating the Answer



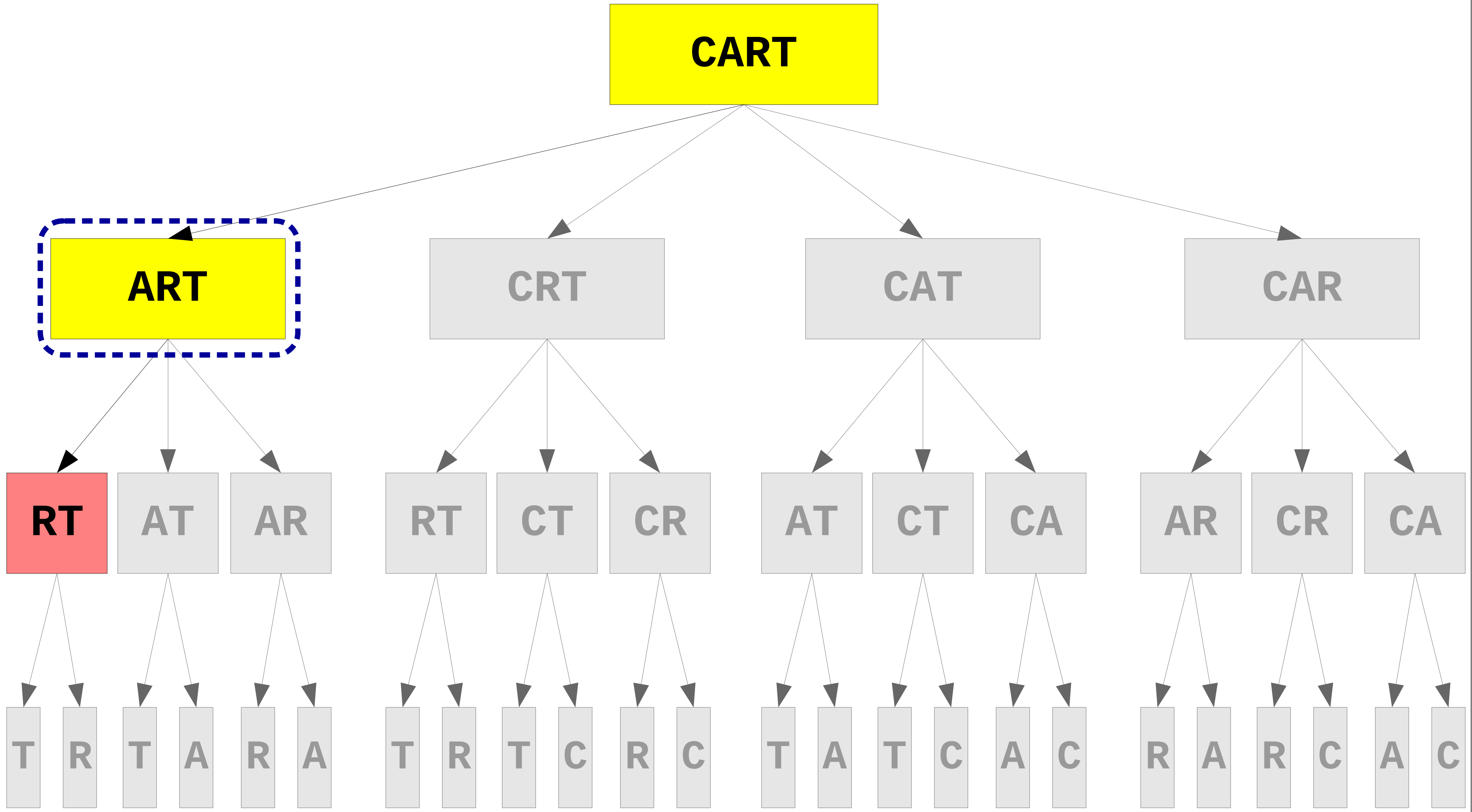
Generating the Answer



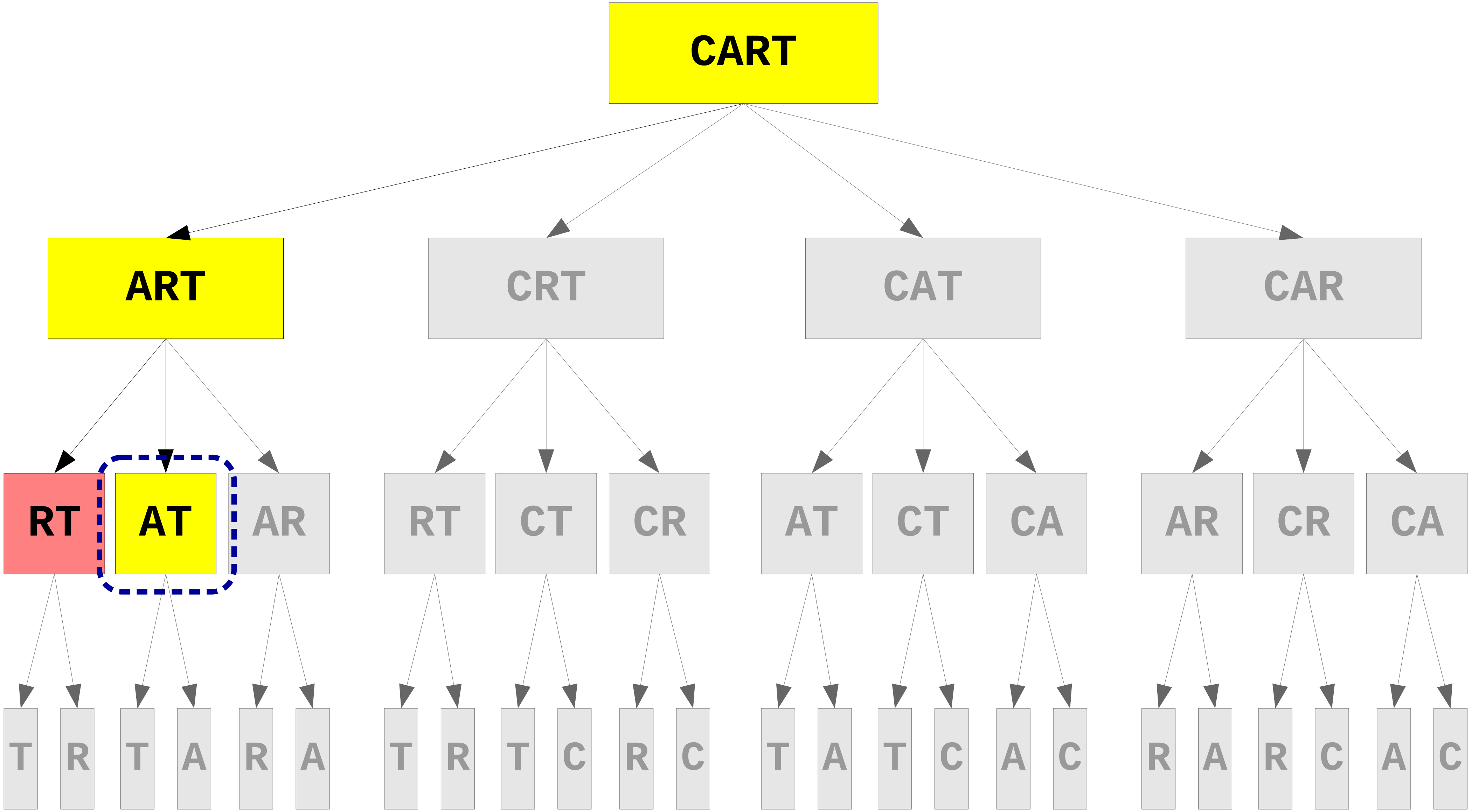
Generating the Answer



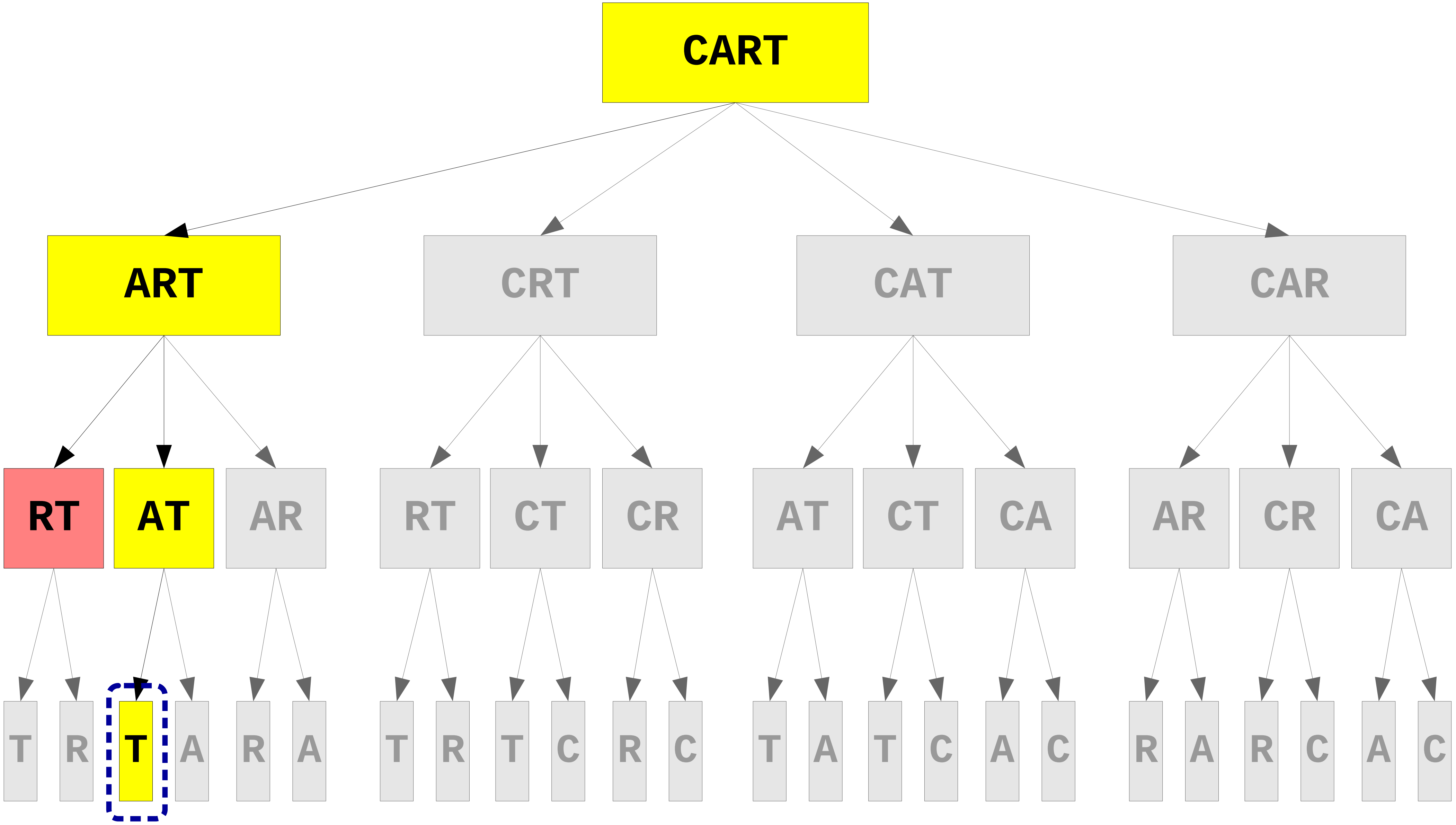
Generating the Answer



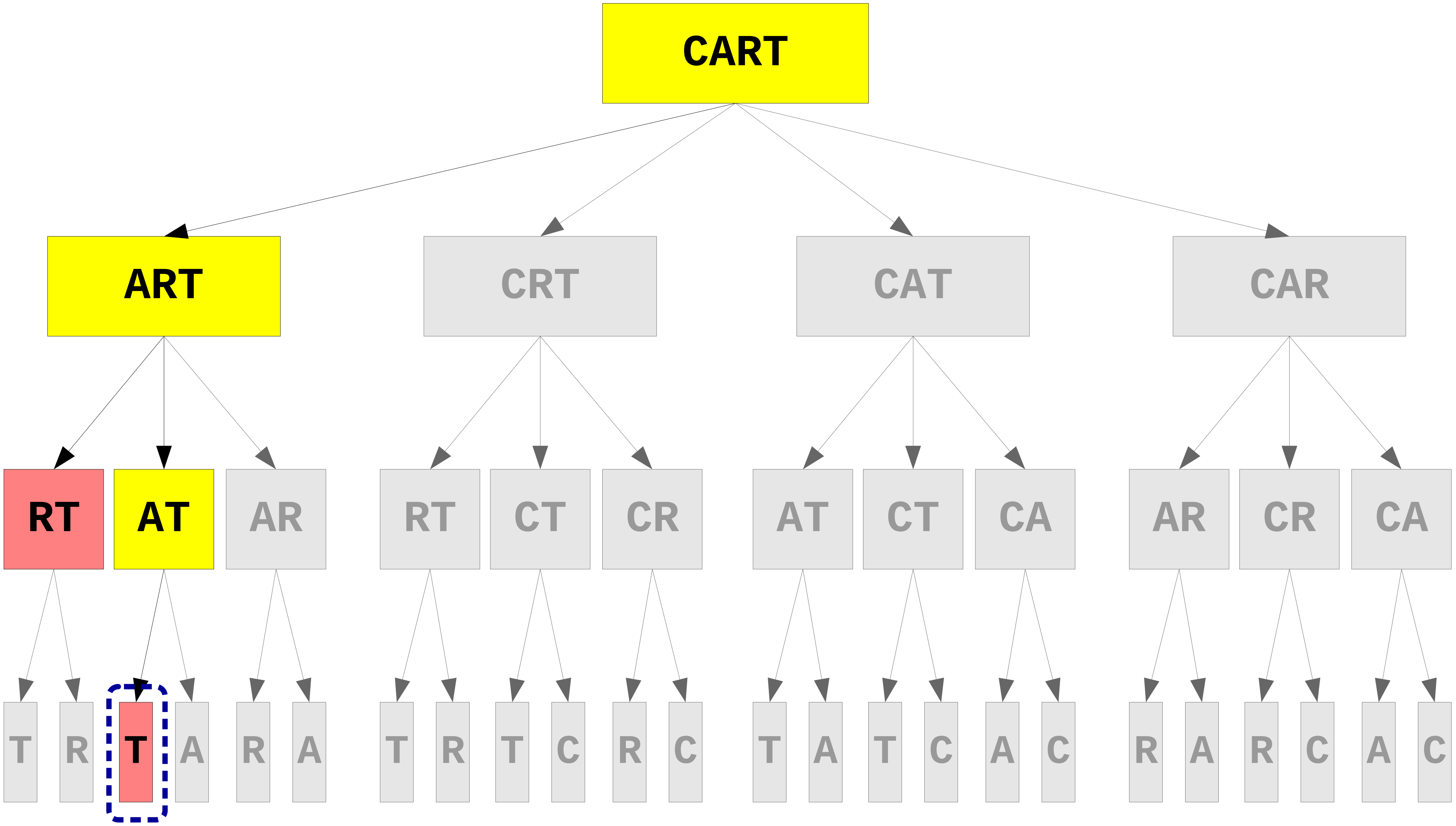
Generating the Answer



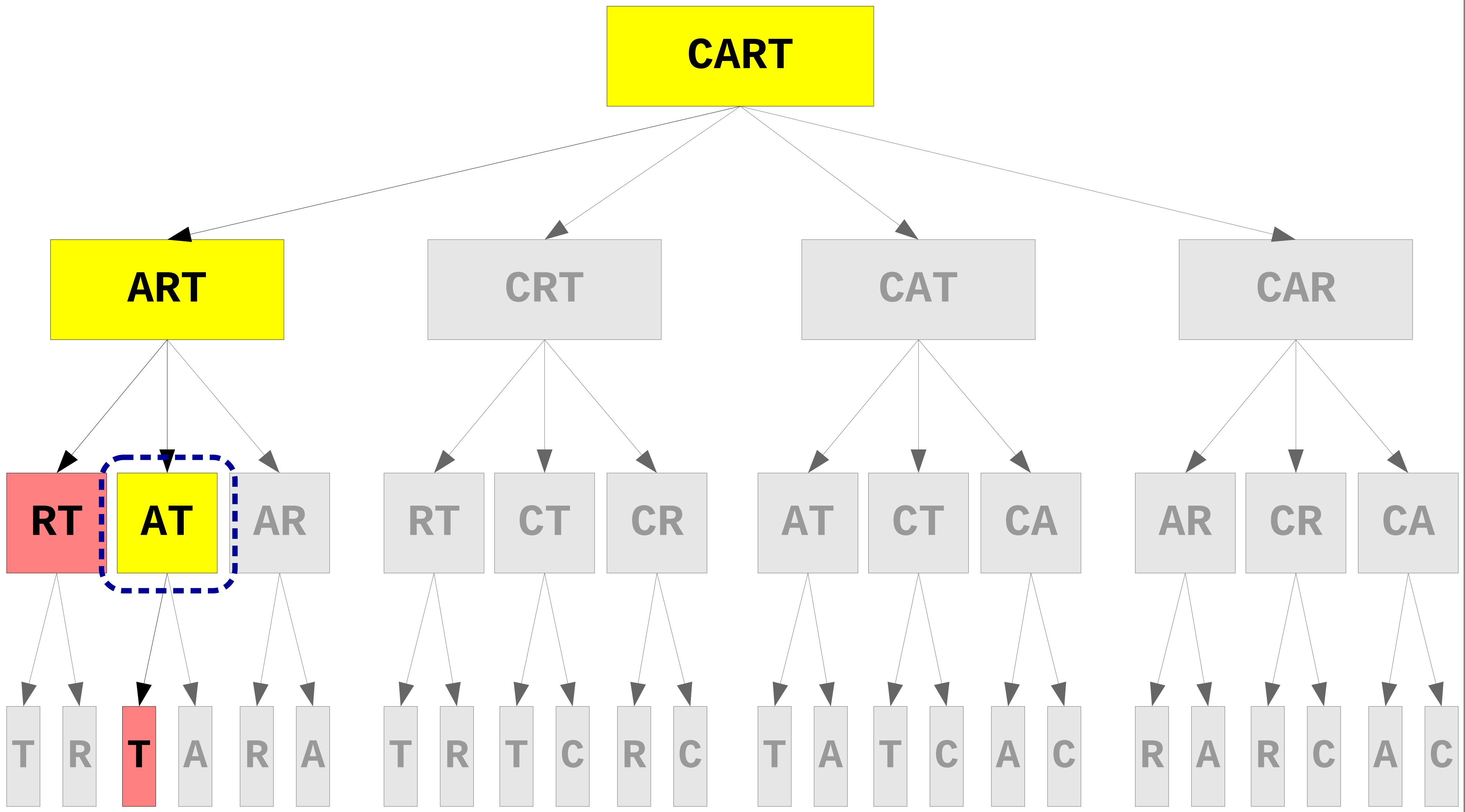
Generating the Answer



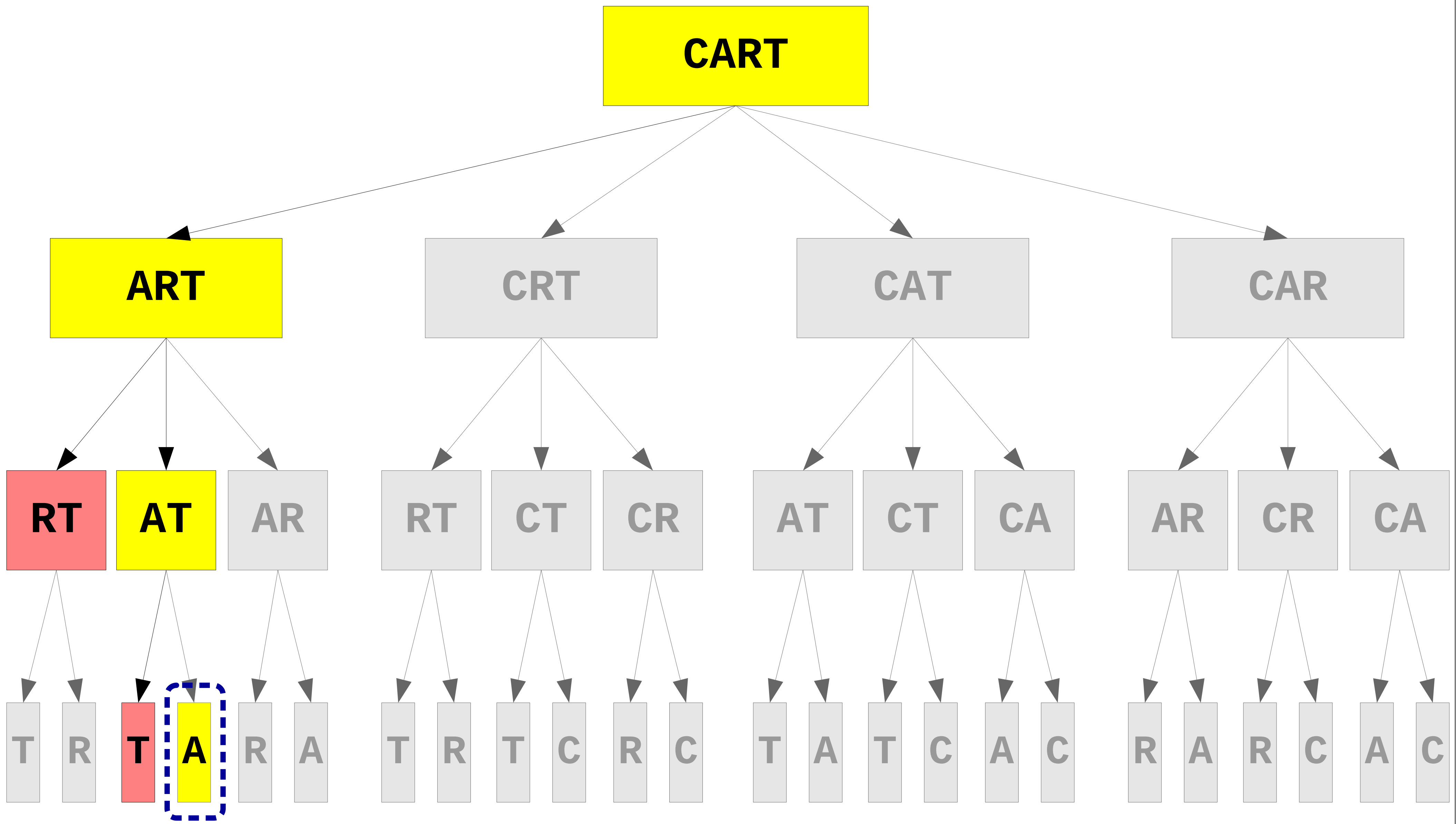
Generating the Answer



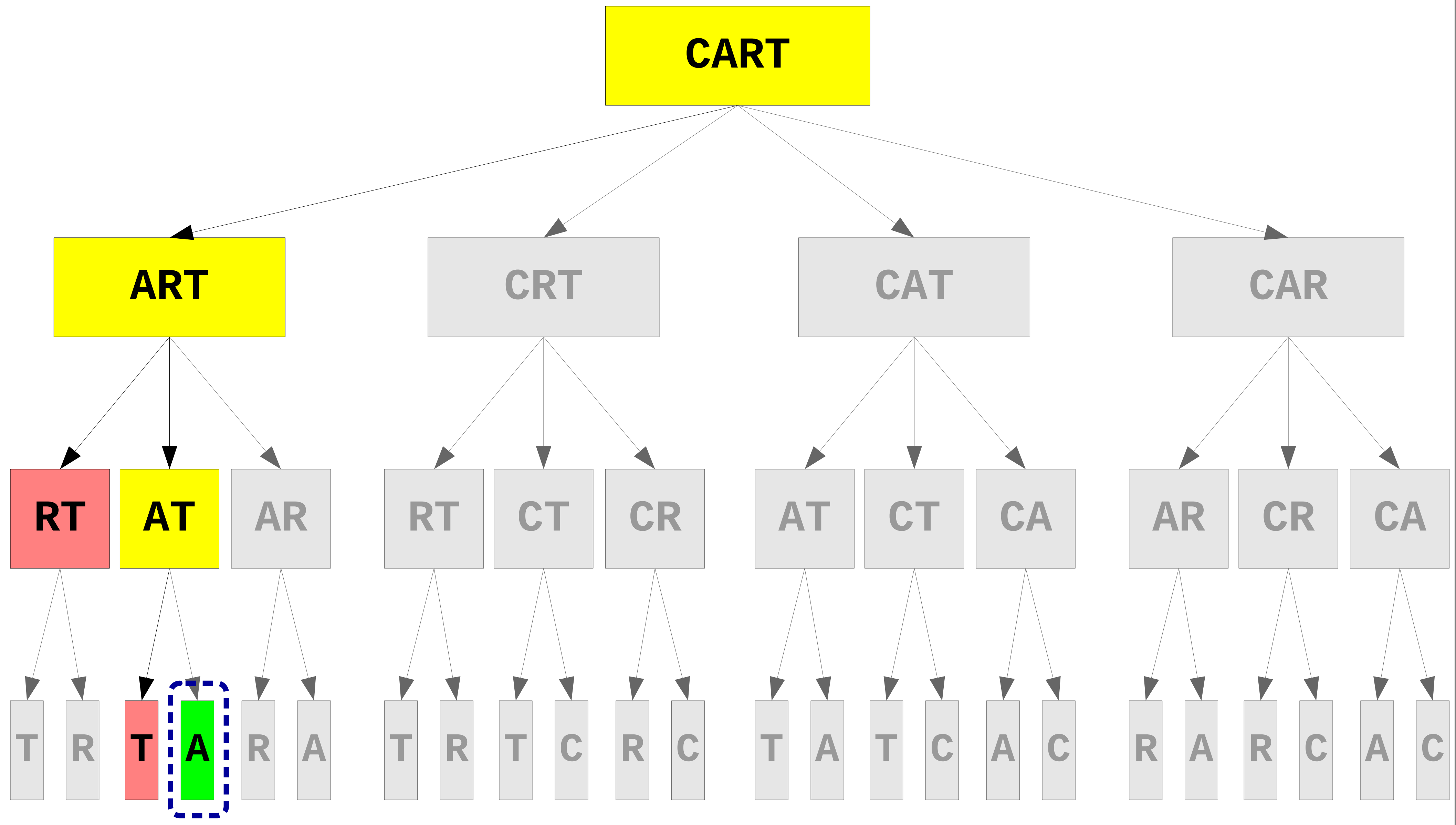
Generating the Answer



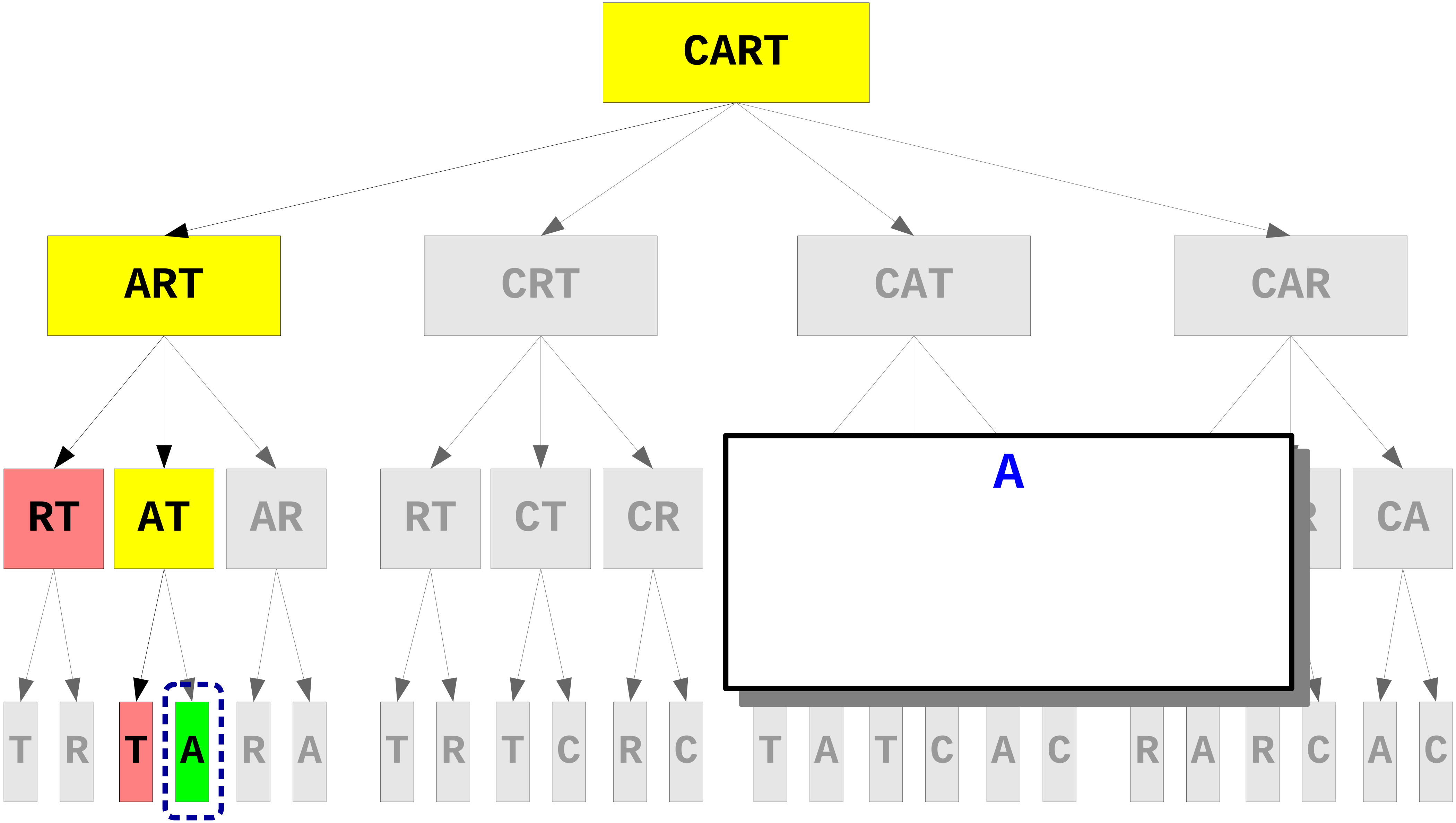
Generating the Answer



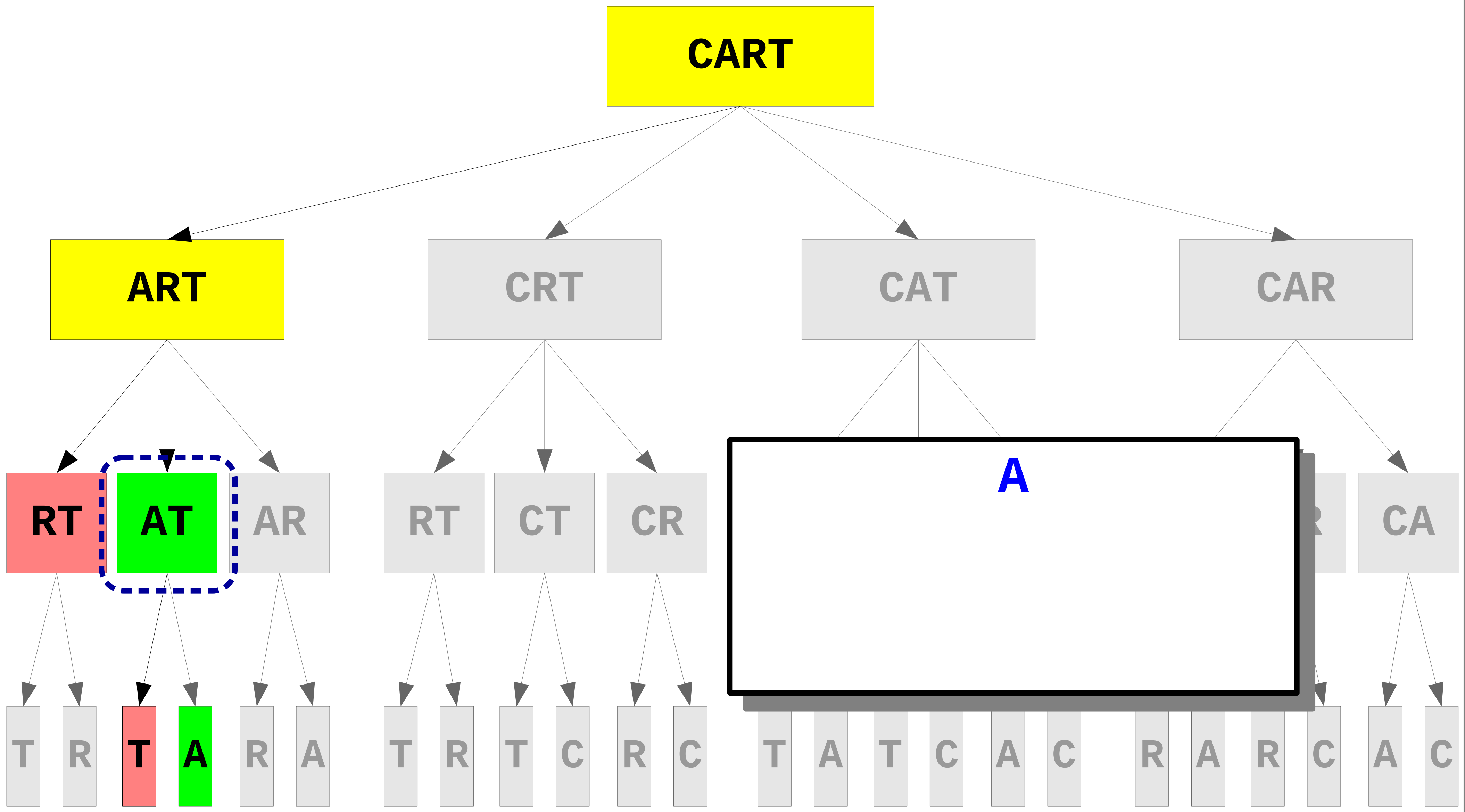
Generating the Answer



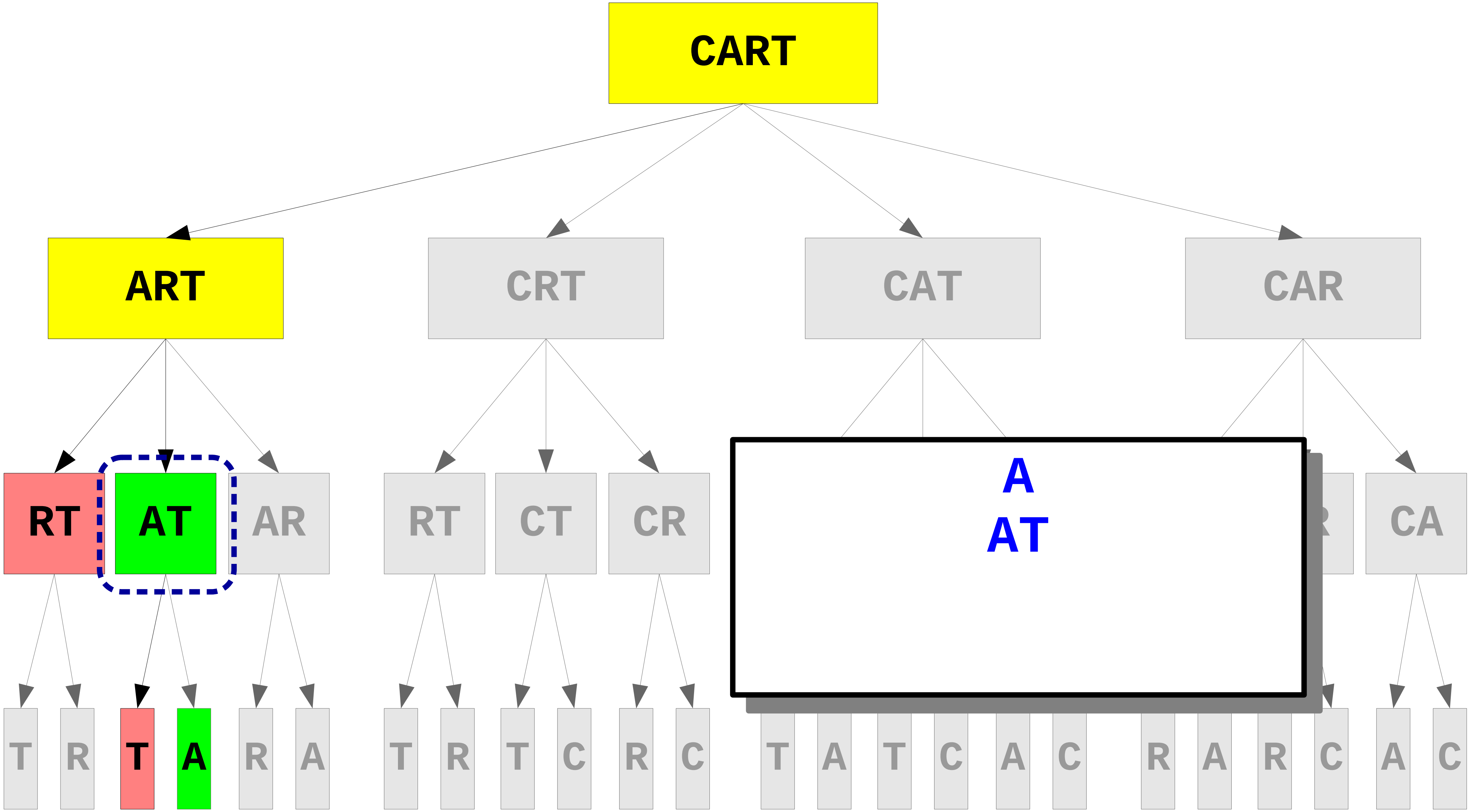
Generating the Answer



Generating the Answer

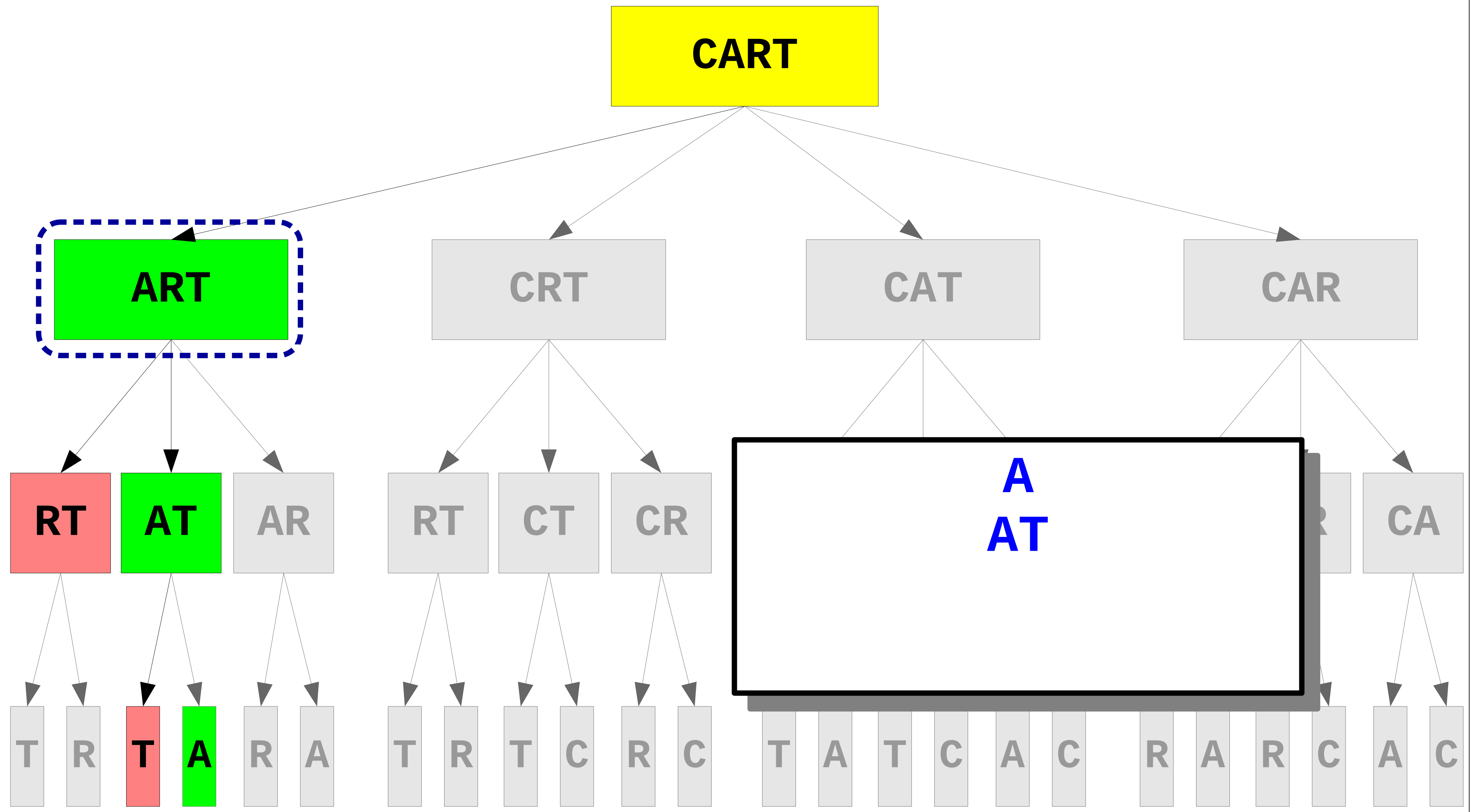


Generating the Answer

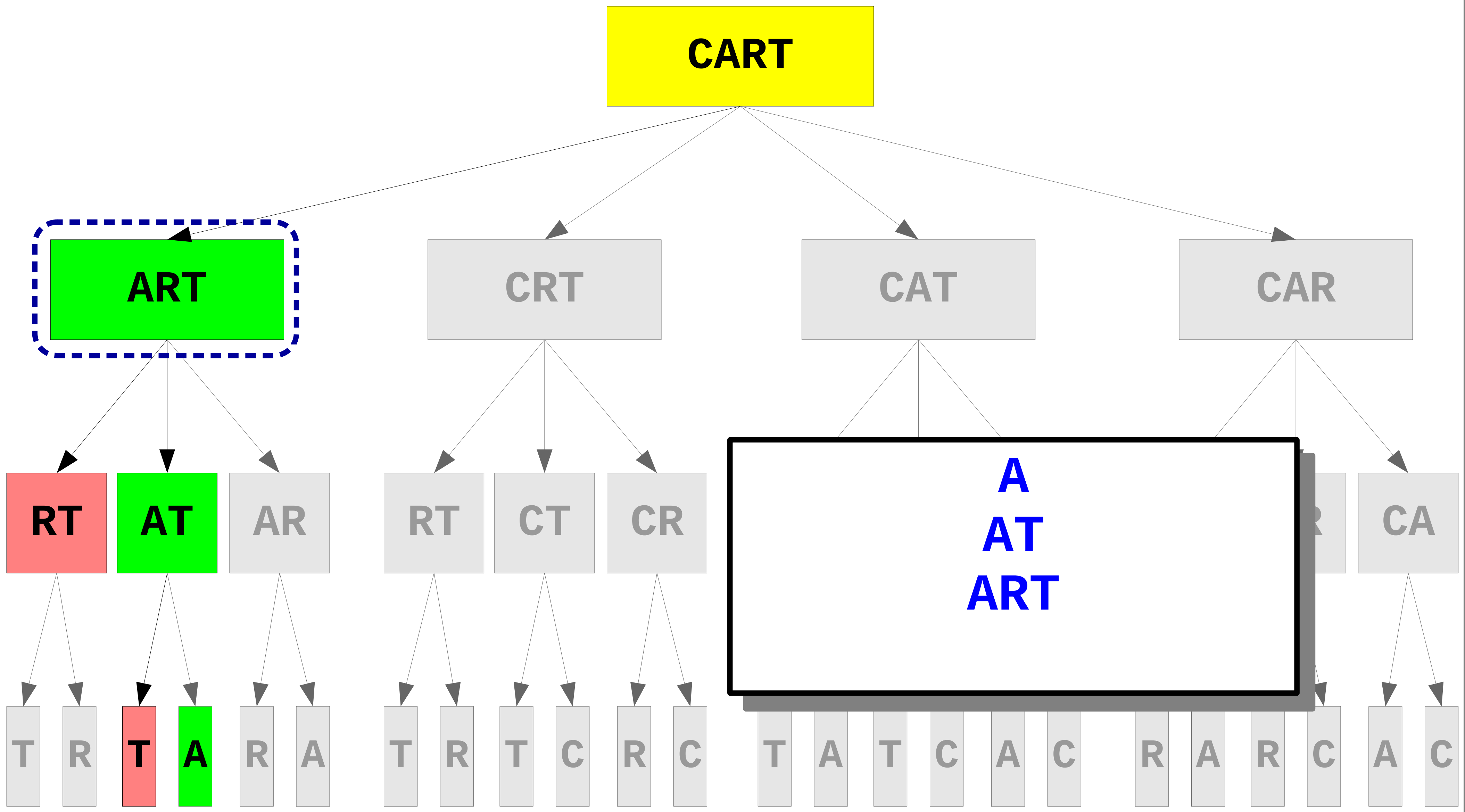


A
AT

Generating the Answer

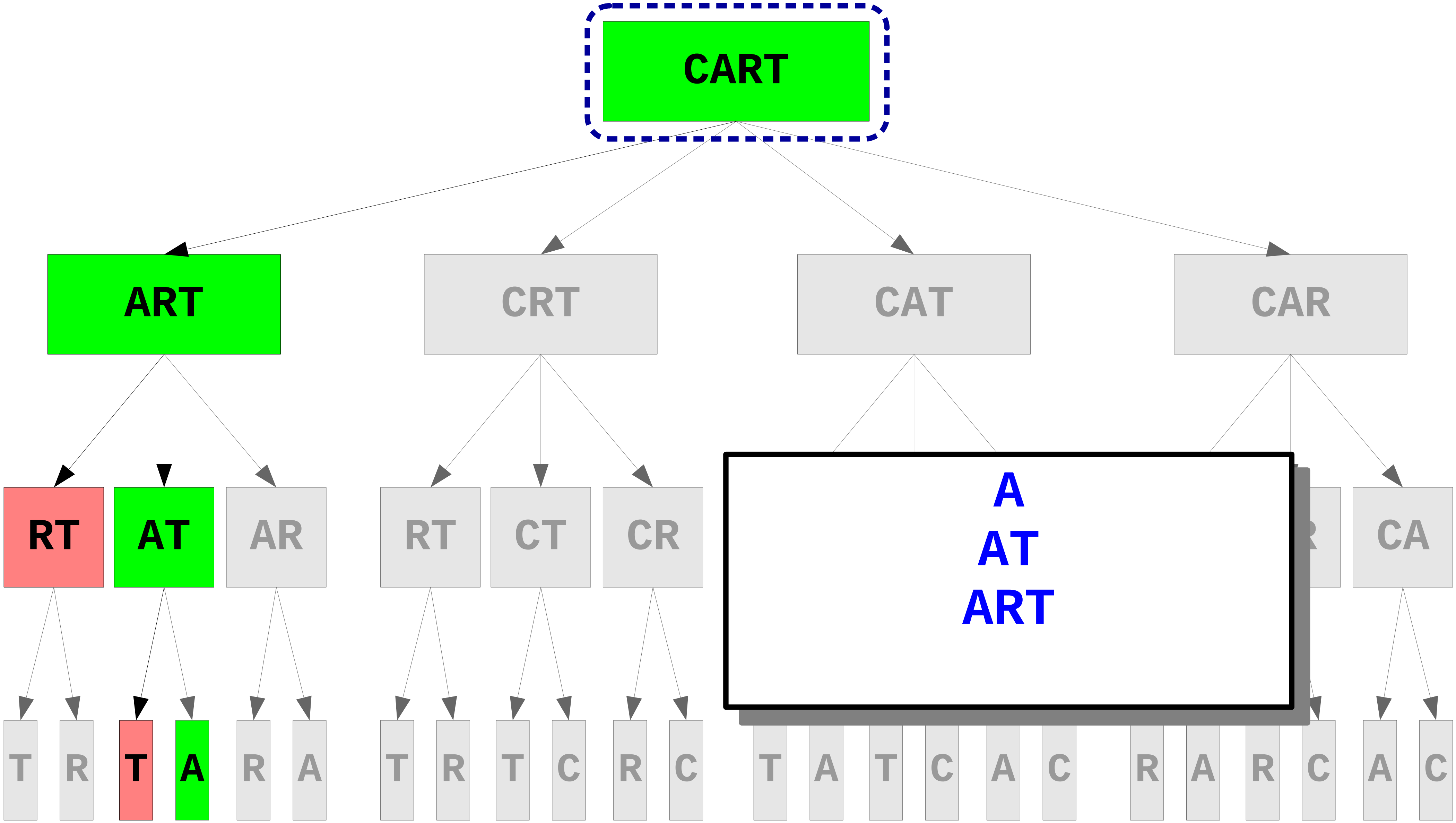


Generating the Answer

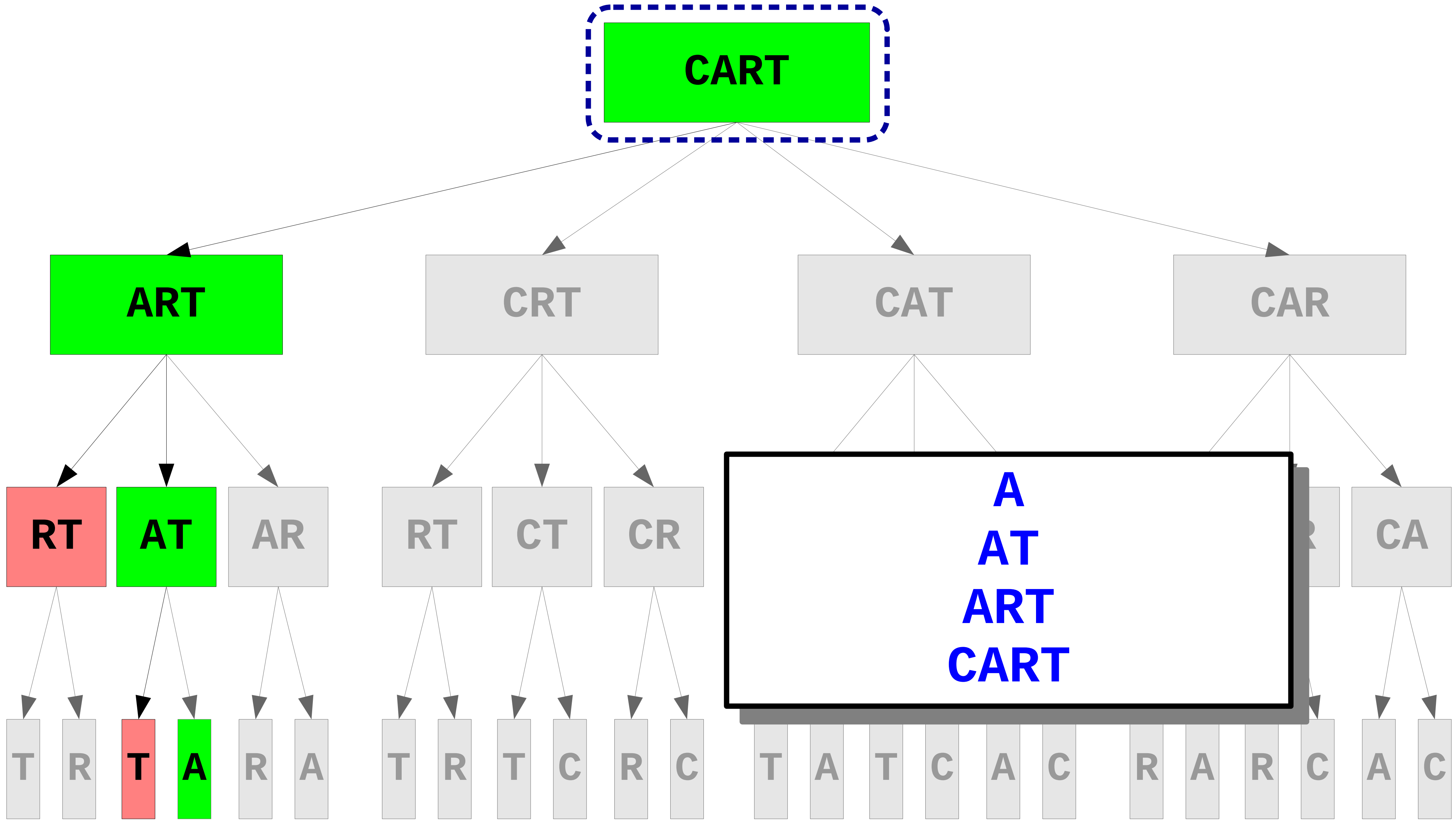


A
AT
ART

Generating the Answer

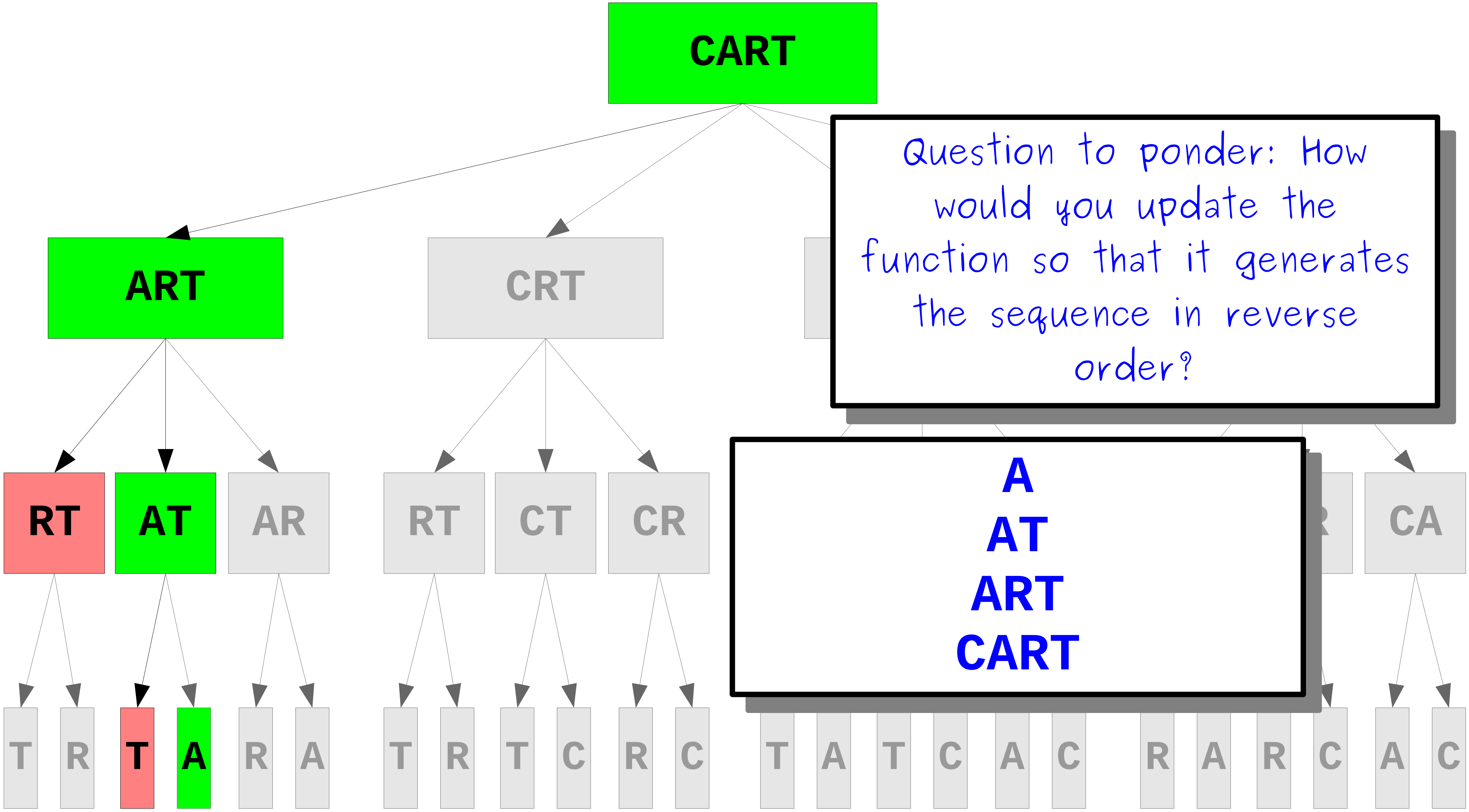


Generating the Answer



A
AT
ART
CART

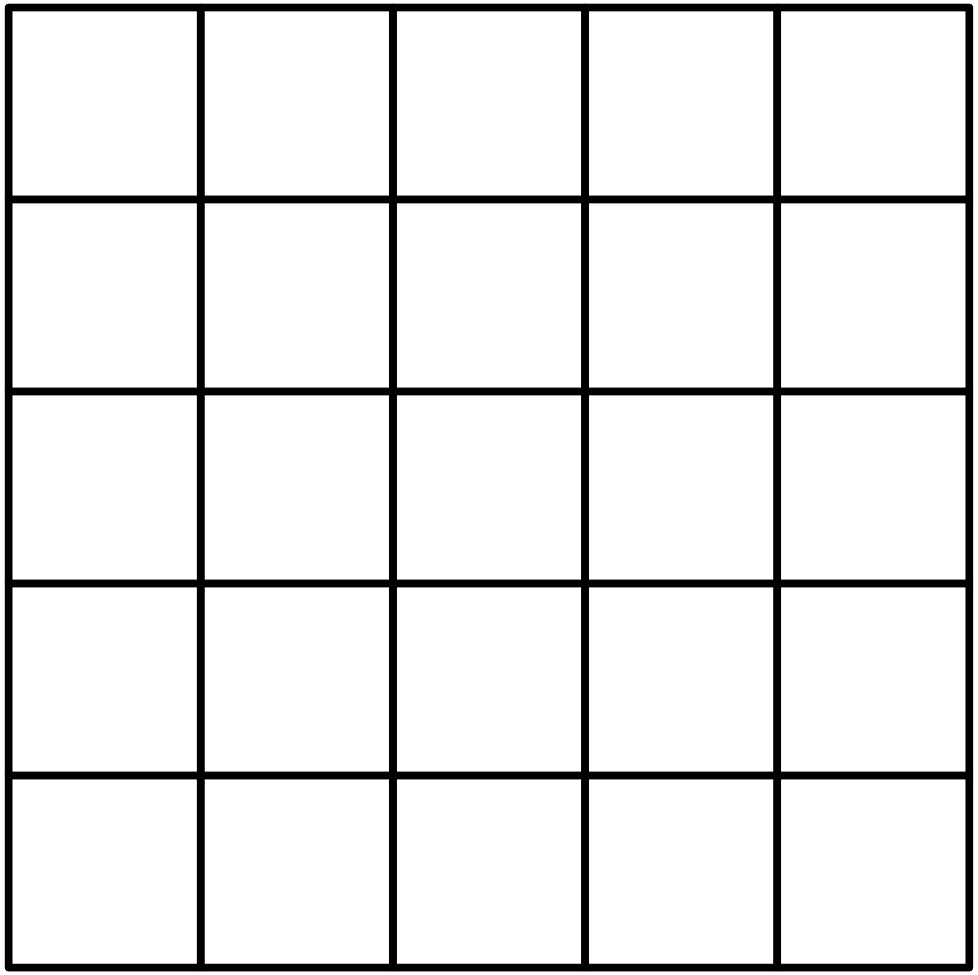
Generating the Answer



Question to ponder: How would you update the function so that it generates the sequence in reverse order?

A
AT
ART
CART

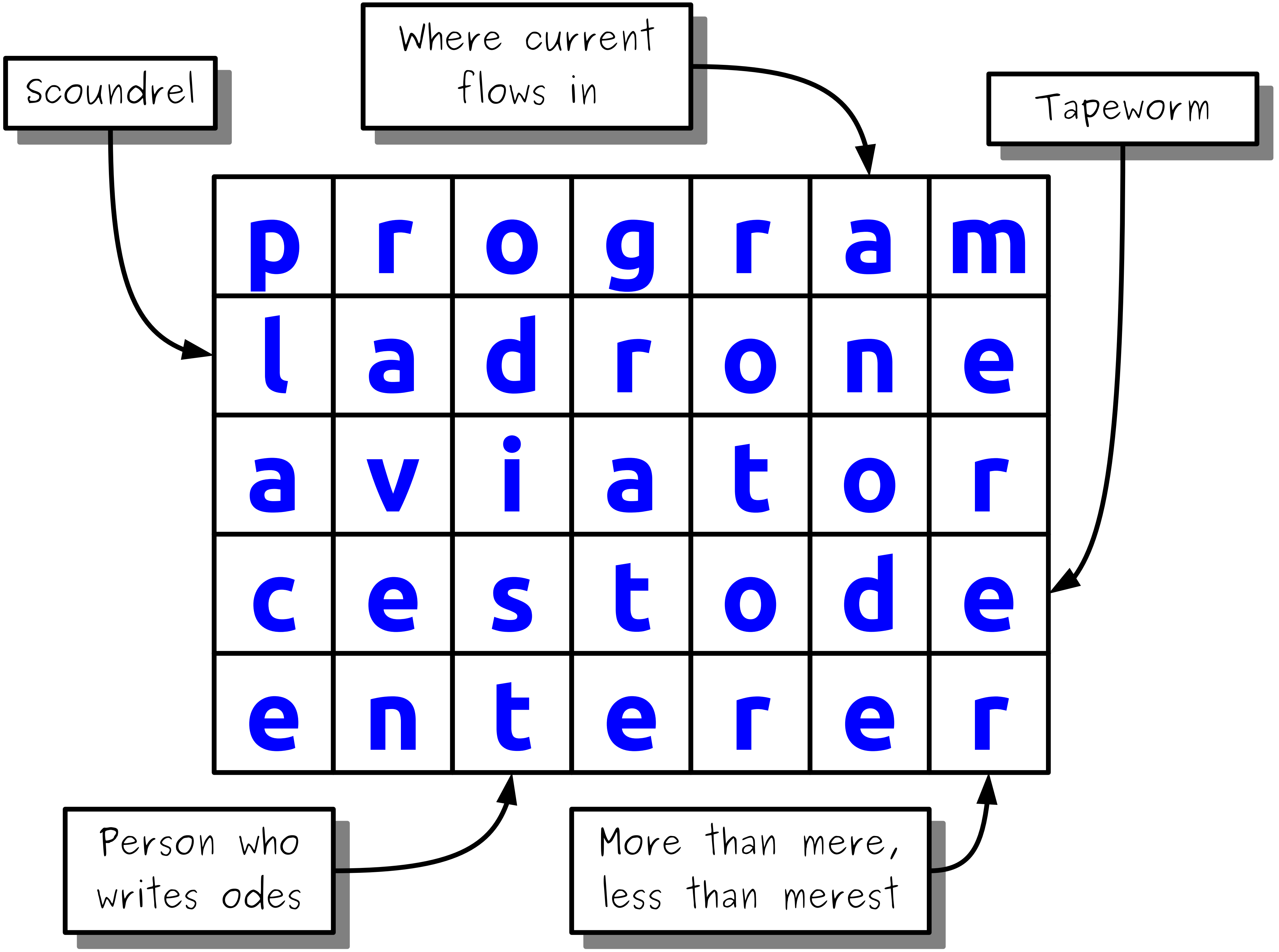
Dense Crosswords

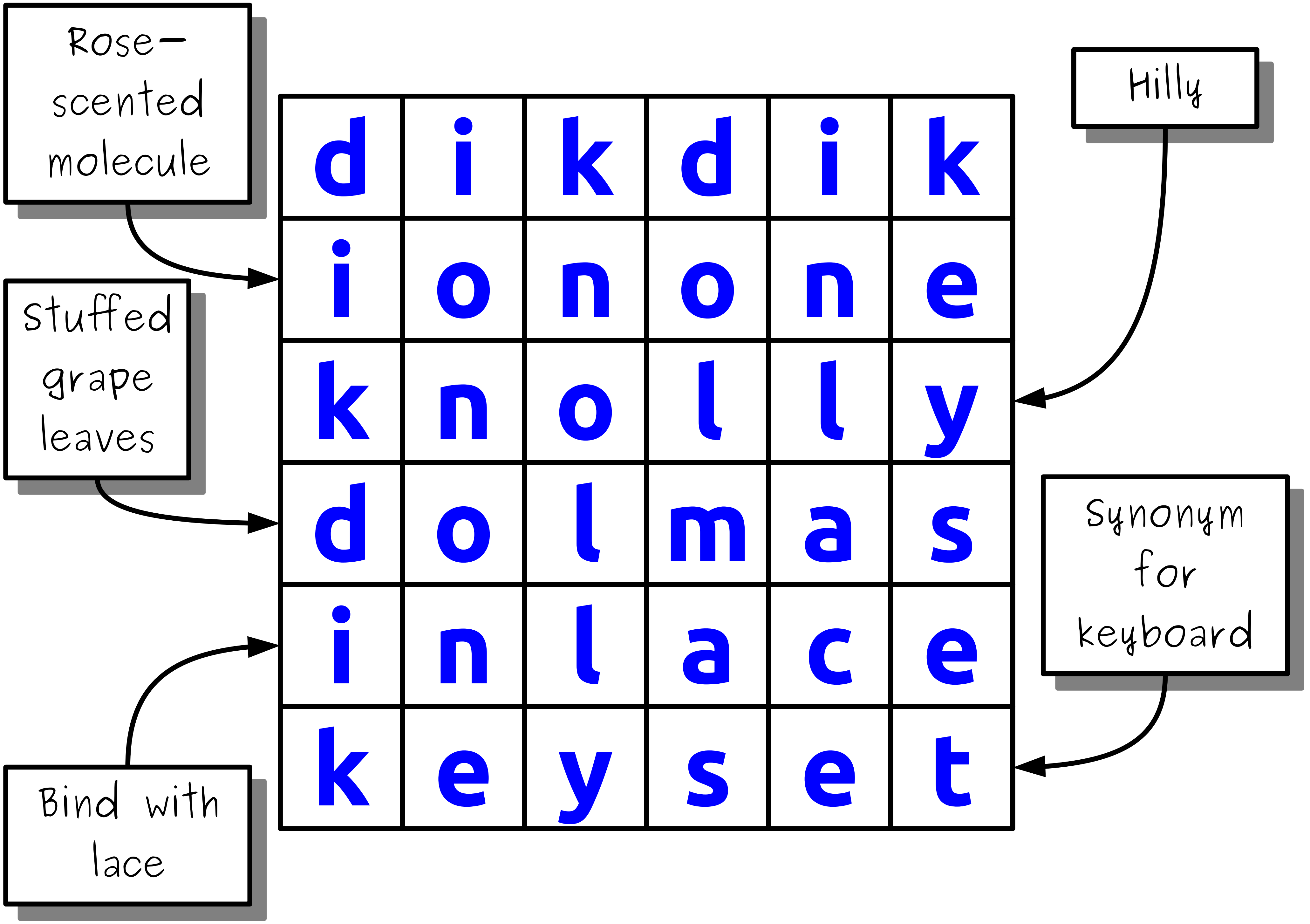


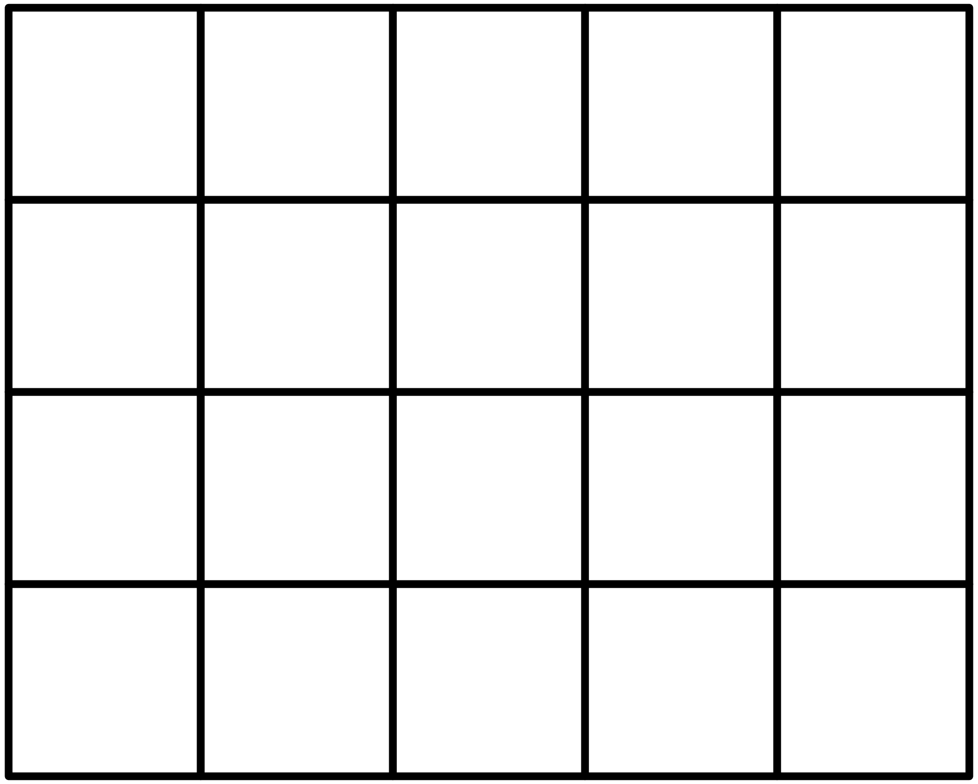
New York Times Mini Crossword, January 24, 2020

s	t	r	a	w
i	r	i	s	h
m	a	s	s	e
o	c	e	a	n
n	e	r	d	s

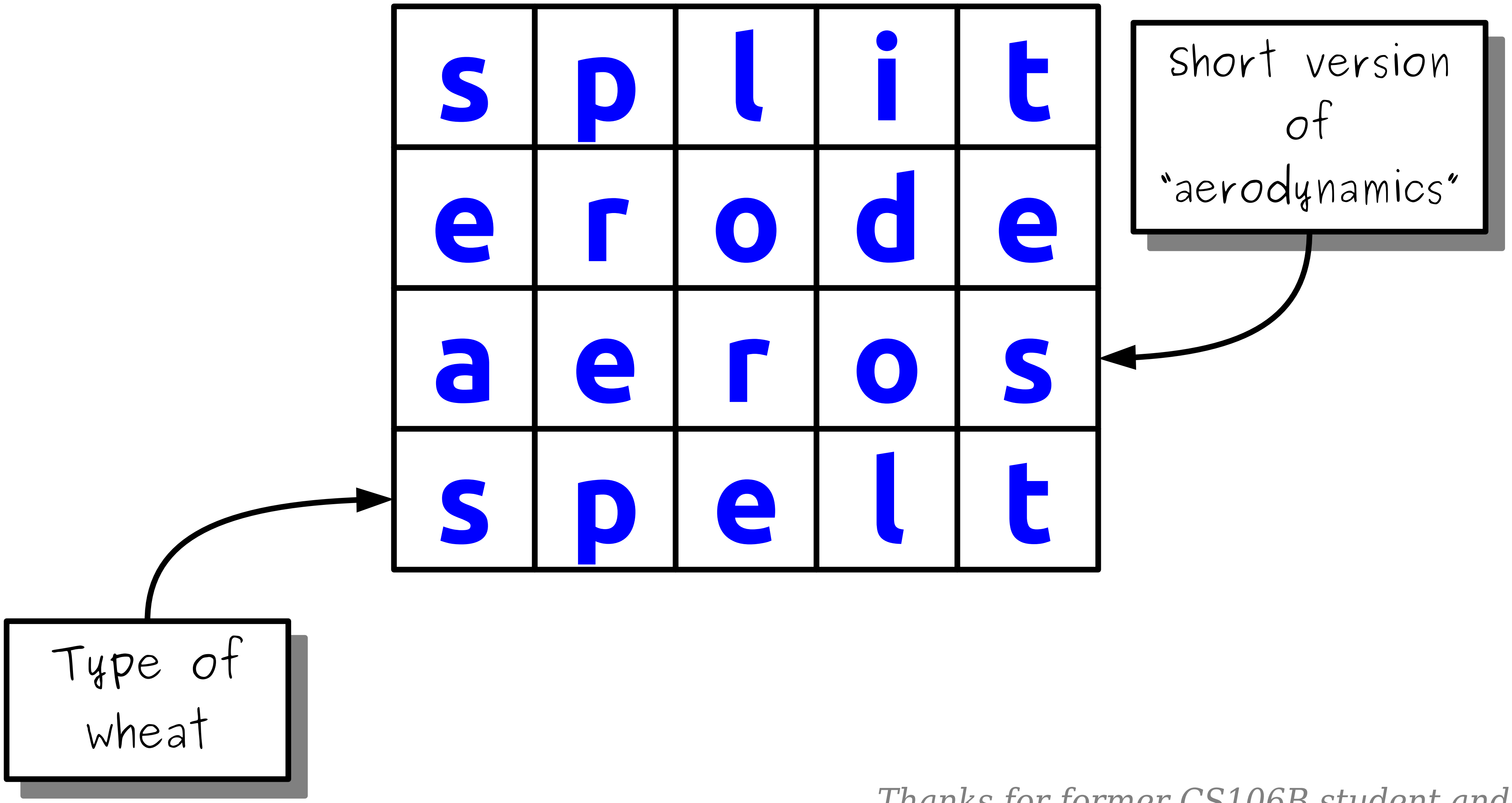
New York Times Mini Crossword, January 24, 2020


Scoundrel
Where current flows in
Tapeworm
p r o g r a m
l a d r o n e
a v i a t o r
c e s t o d e
e n t e r e r
Person who writes odes
More than mere, less than merest

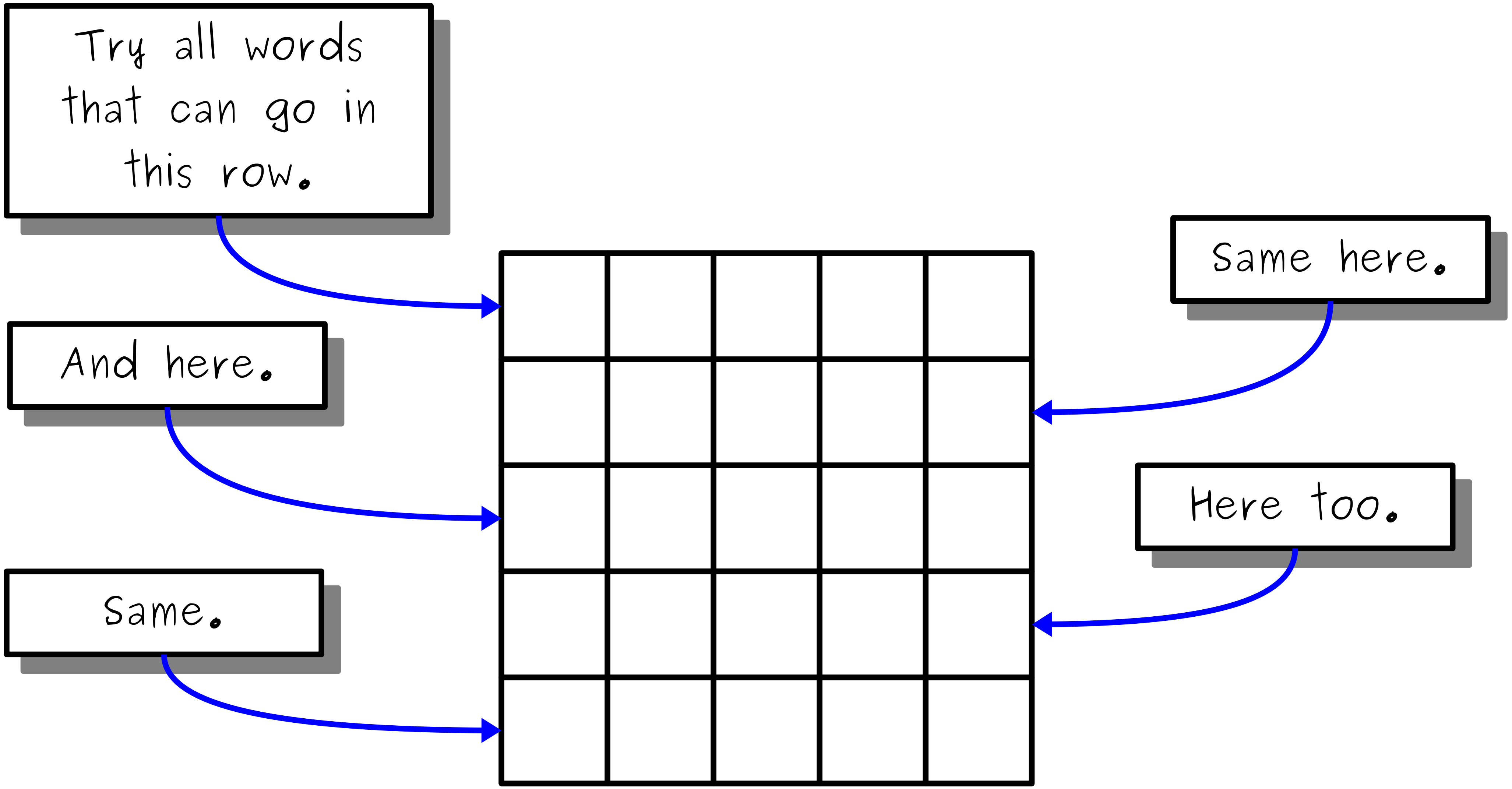

Rose-scented molecule
Stuffed grape leaves
Bind with lace
Hilly
Synonym for keyboard
d i k d i k
i o n o n e
k n o l l y
d o l m a s
i n l a c e
k e y s e t



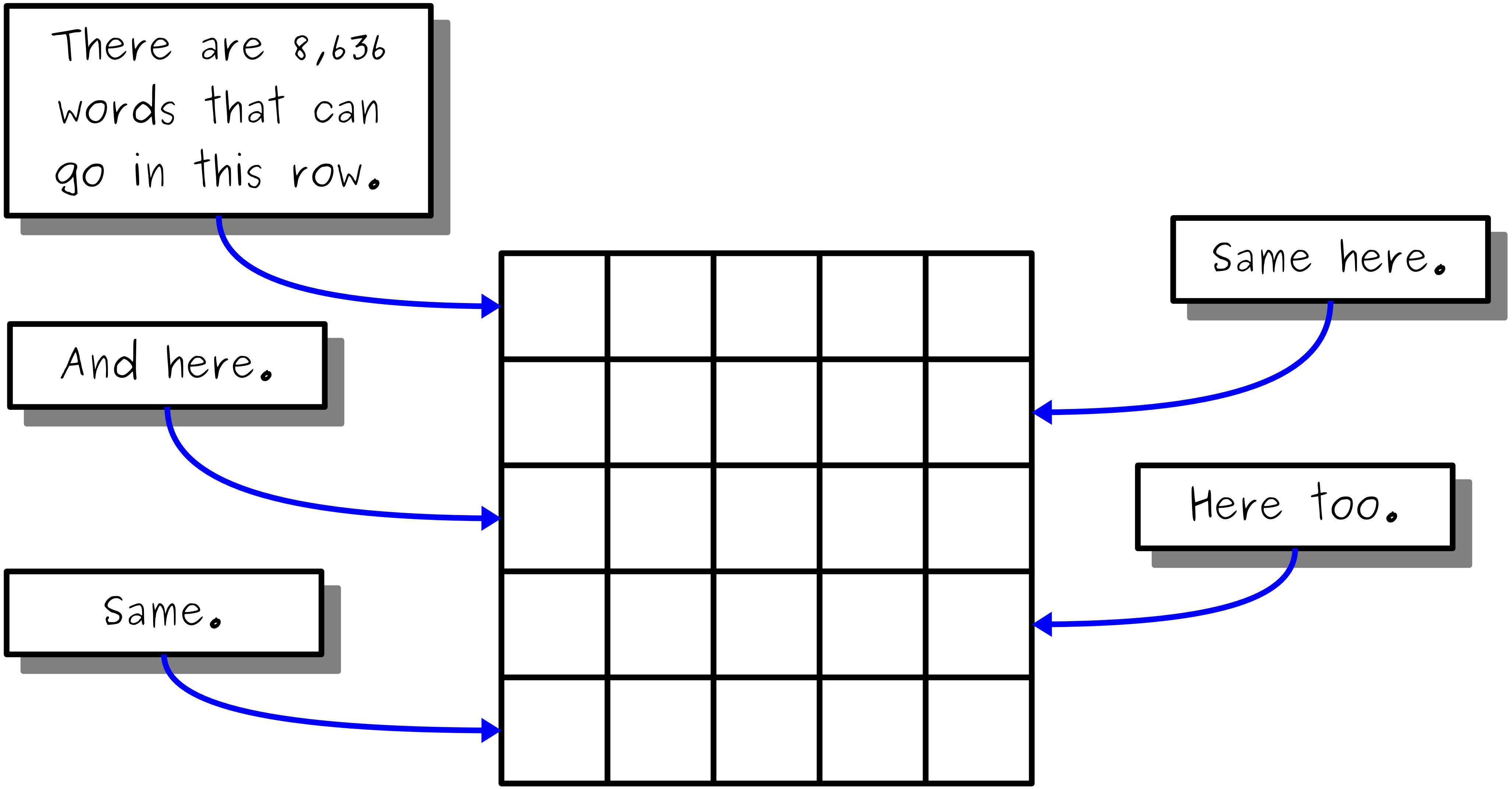
*Thanks for former CS106B student and current CS106B SL **Jose Francisco**!*



Thanks for former CS106B student and current CS106B SL ***Jose Francisco****!*



Idea: Fill this in using recursive backtracking.

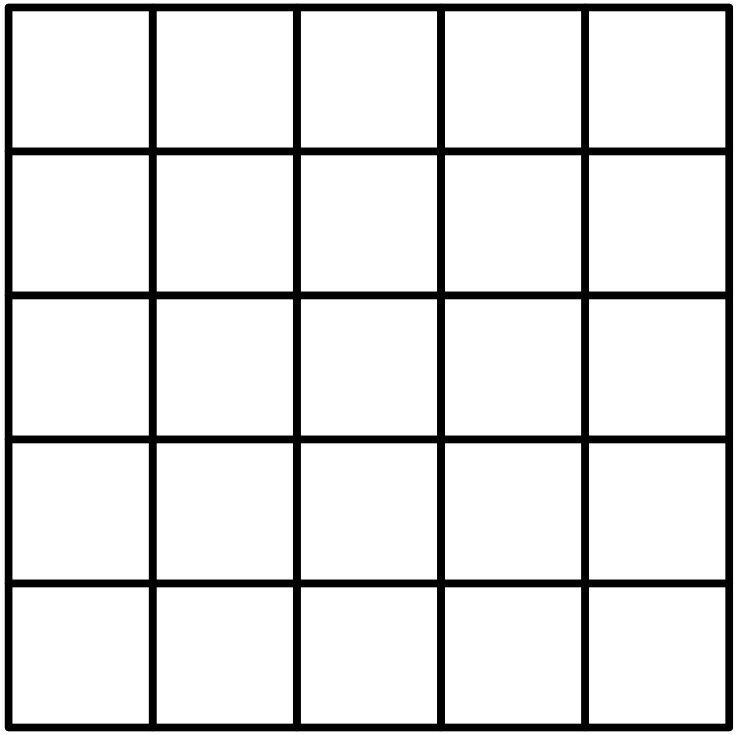


$$8{,}636^5 = 48{,}035{,}594{,}312{,}821{,}554{,}176$$

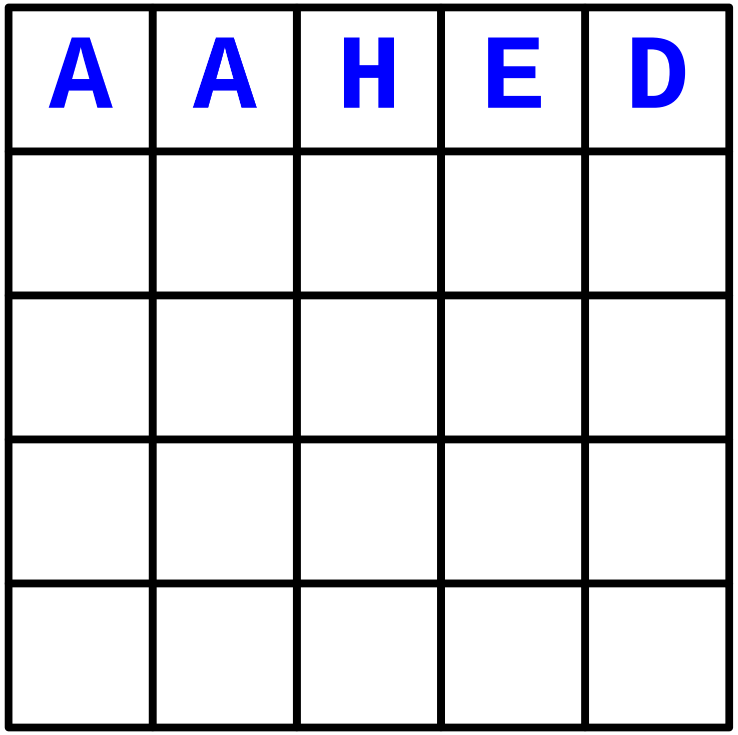
At one billion grids per second, this will take about ***three hundred years*** to complete.

Speeding Things Up

Generating Dense Crosswords



Generating Dense Crosswords



Generating Dense Crosswords

A	A	H	E	D
A	A	H	E	D

Generating Dense Crosswords

A	A	H	E	D
A	A	H	E	D
A	A	H	E	D

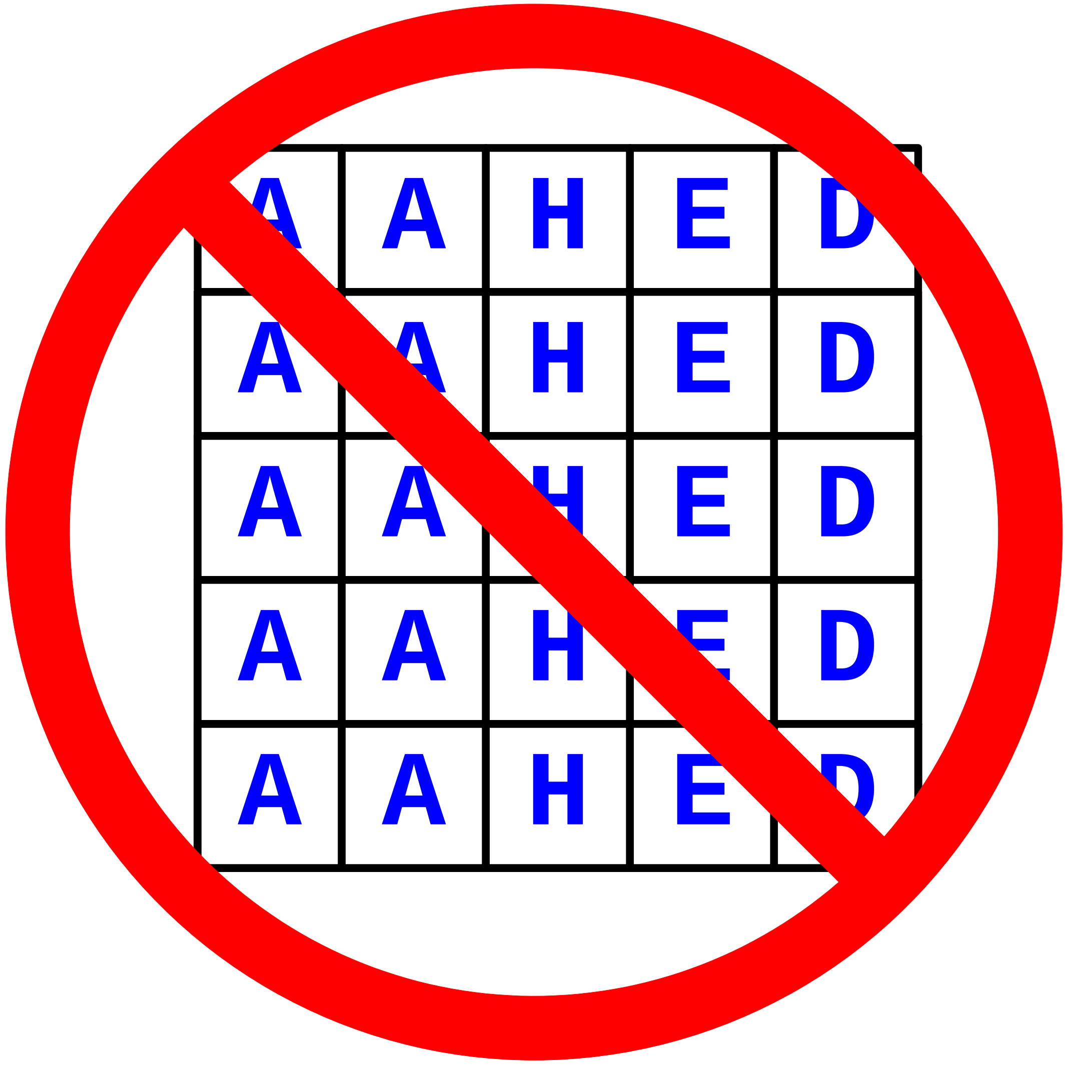
Generating Dense Crosswords

A	A	H	E	D
A	A	H	E	D
A	A	H	E	D
A	A	H	E	D

Generating Dense Crosswords

A	A	H	E	D
A	A	H	E	D
A	A	H	E	D
A	A	H	E	D
A	A	H	E	D

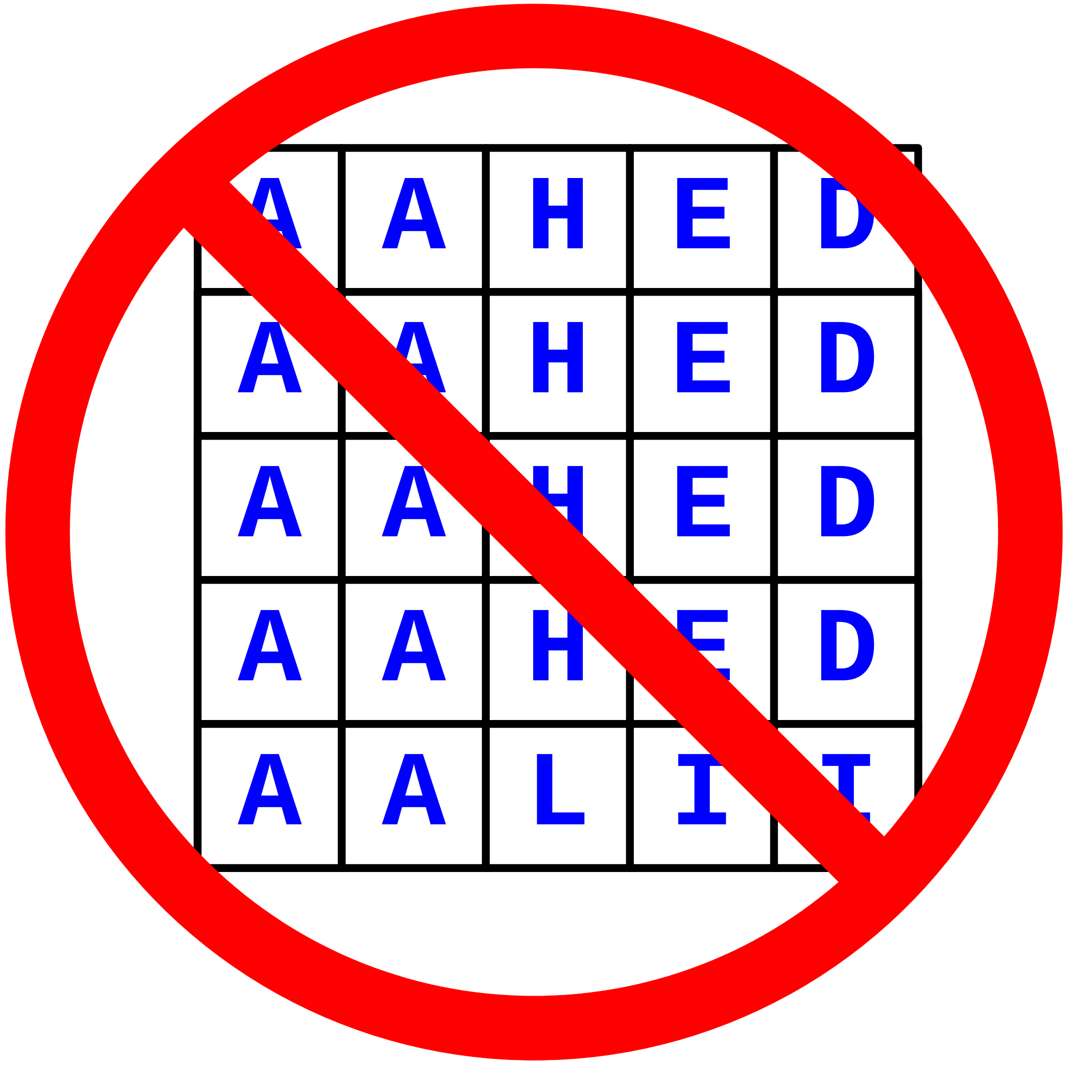
Generating Dense Crosswords



Generating Dense Crosswords

A	A	H	E	D
A	A	H	E	D
A	A	H	E	D
A	A	H	E	D
A	A	L	I	I

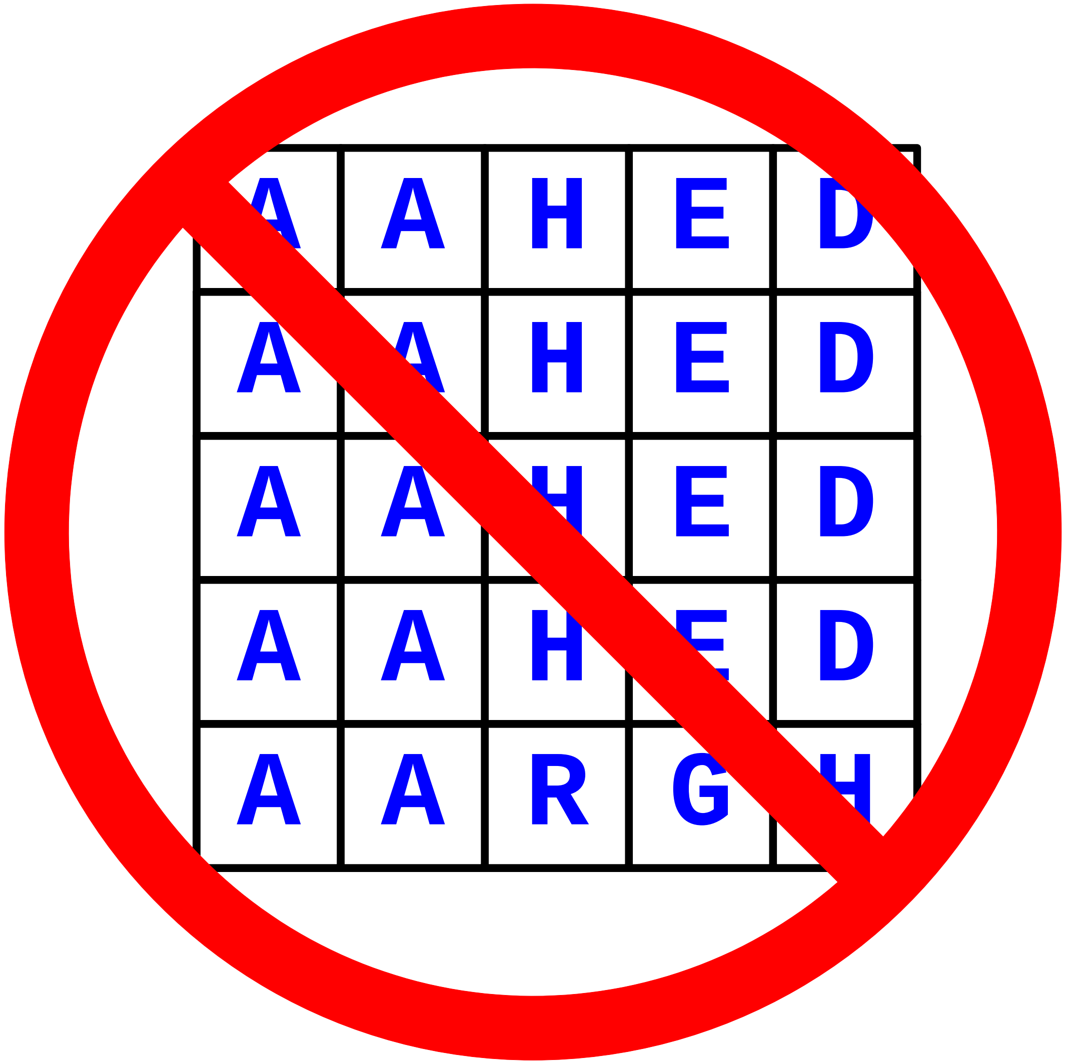
Generating Dense Crosswords



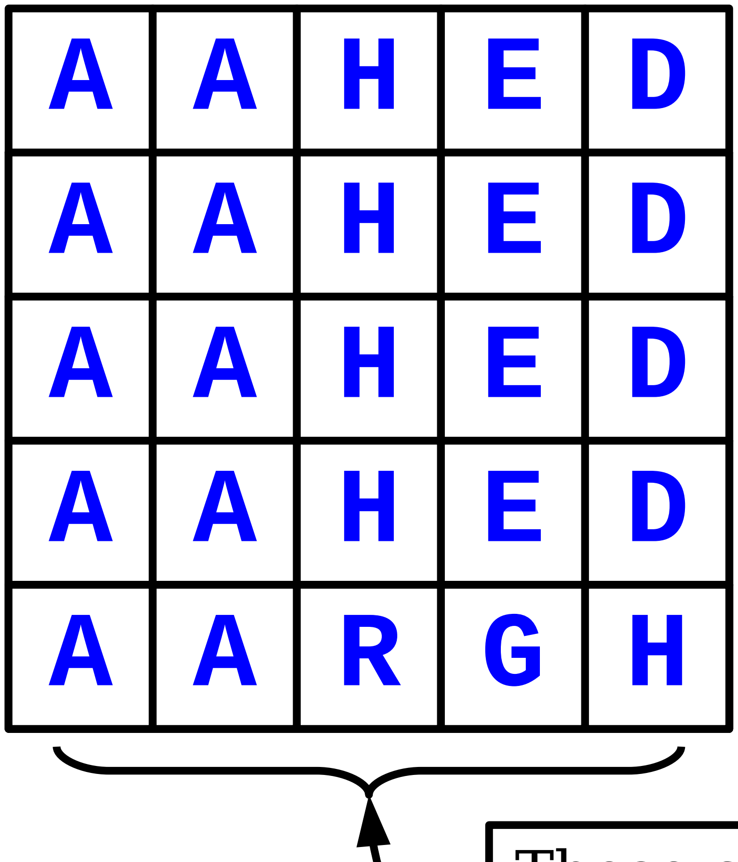
Generating Dense Crosswords

A	A	H	E	D
A	A	H	E	D
A	A	H	E	D
A	A	H	E	D
A	A	R	G	H

Generating Dense Crosswords



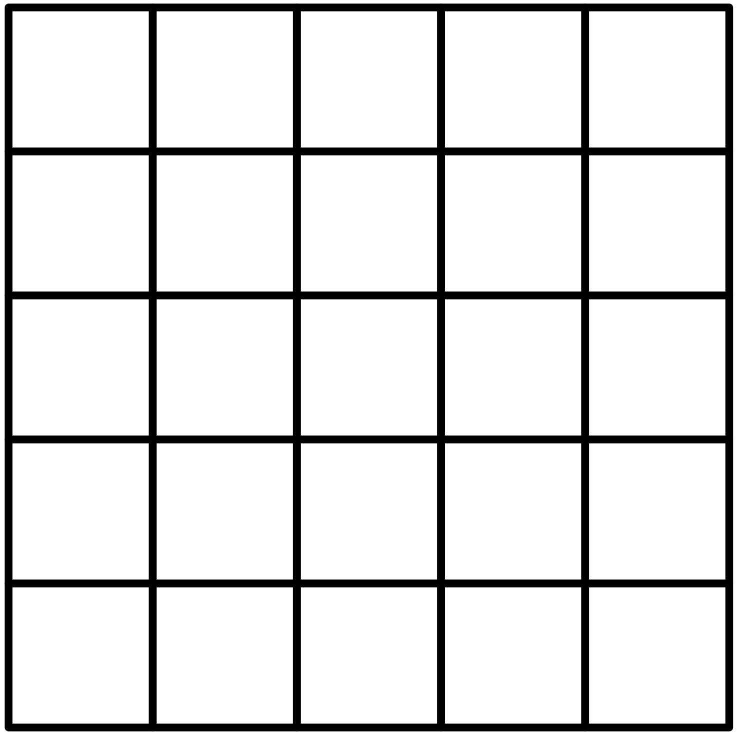
Generating Dense Crosswords



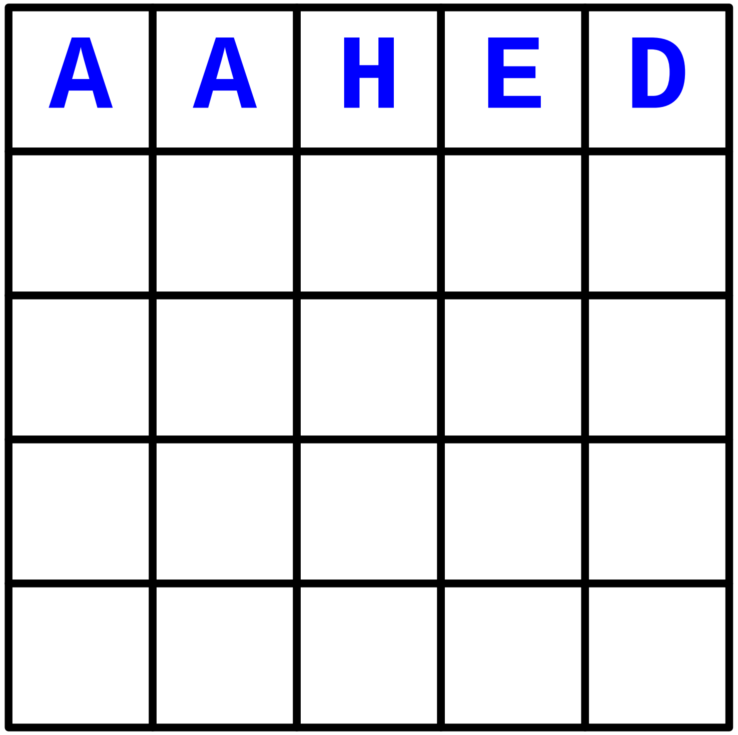
A	A	H	E	D
A	A	H	E	D
A	A	H	E	D
A	A	H	E	D
A	A	R	G	H

These columns are silly. No words start with three A’s, or three H’s, etc.

Generating Dense Crosswords



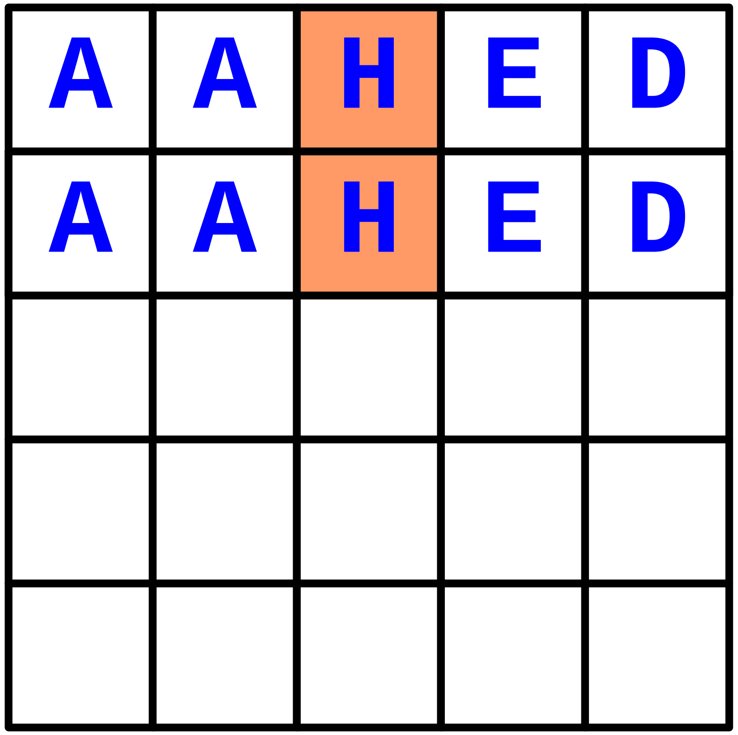
Generating Dense Crosswords



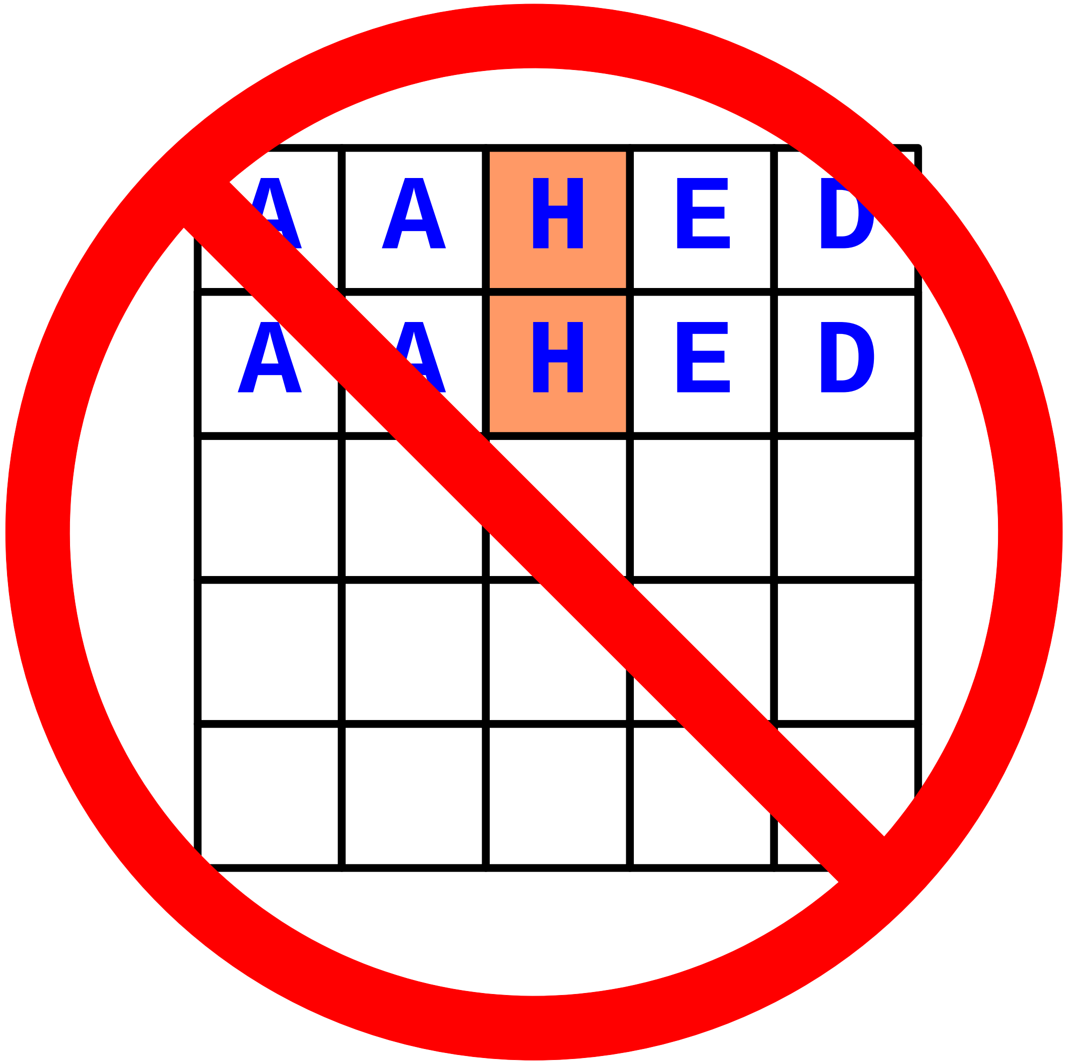
Generating Dense Crosswords

A	A	H	E	D
A	A	H	E	D

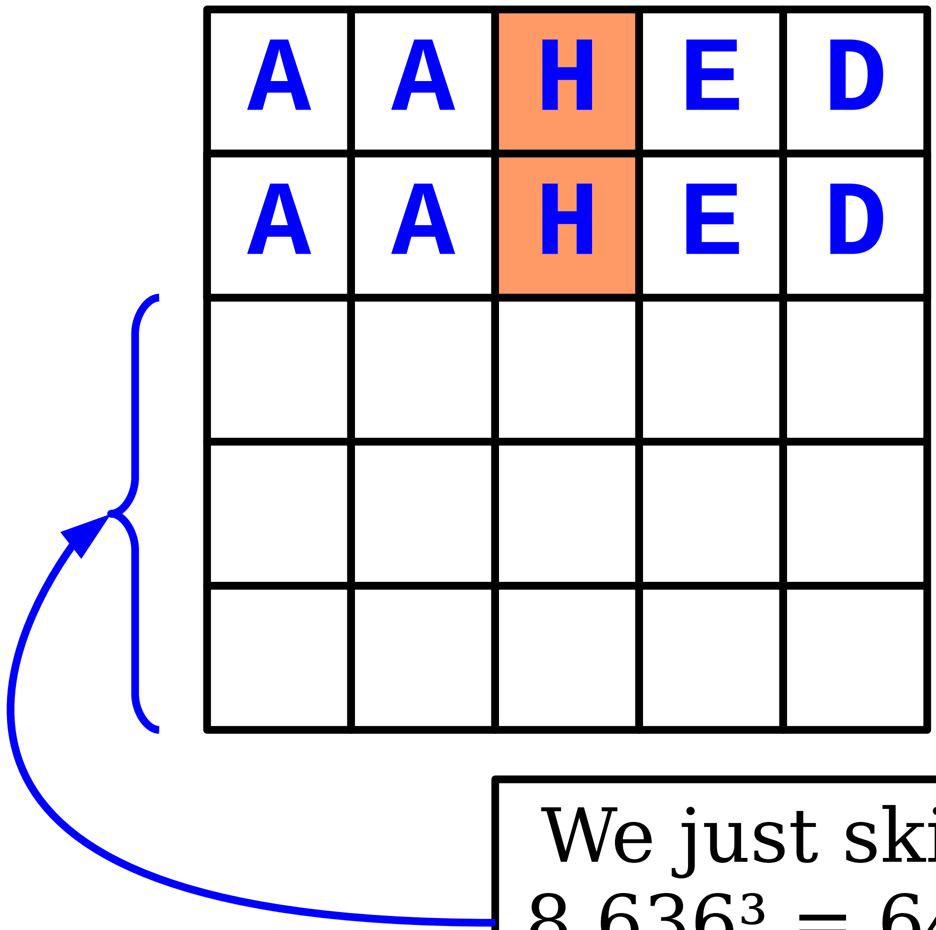
Generating Dense Crosswords



Generating Dense Crosswords

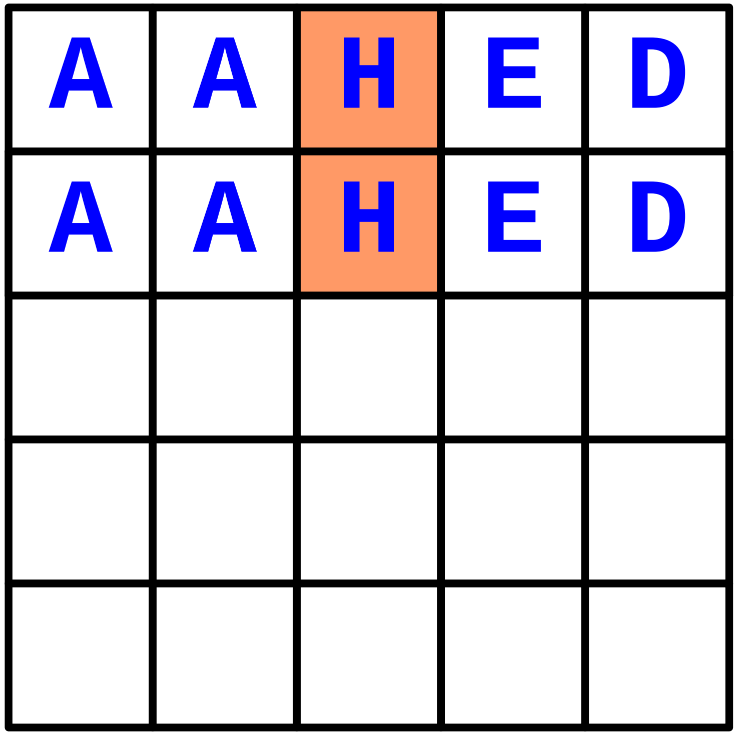


Generating Dense Crosswords



We just skipped checking $8{,}636^3 = 644{,}077{,}163{,}456$ combinations of words.

Generating Dense Crosswords



The `Lexicon` has a fast function `containsPrefix` that's perfect for this.

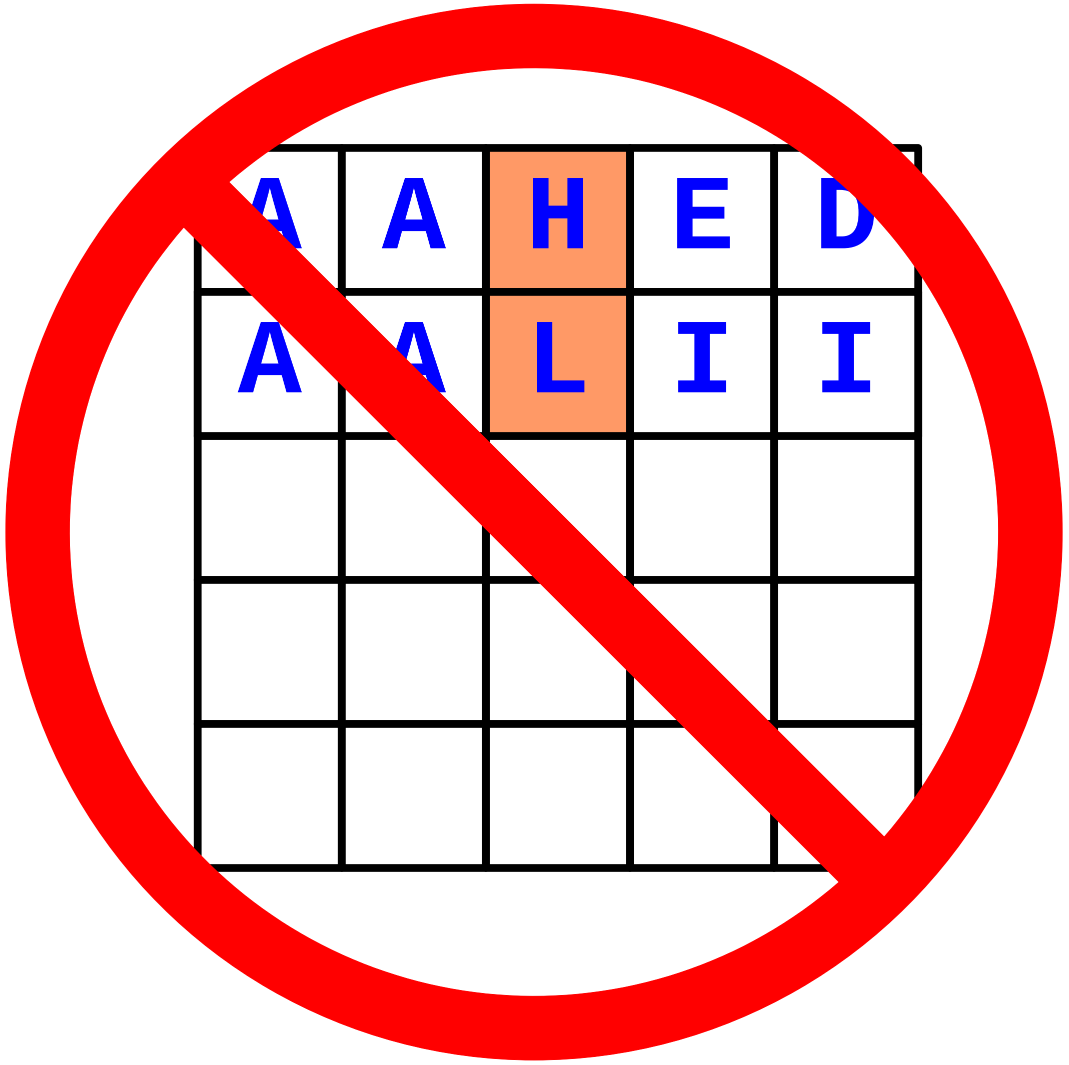
Generating Dense Crosswords

A	A	H	E	D
A	A	L	I	I

Generating Dense Crosswords

A	A	H	E	D
A	A	L	I	I

Generating Dense Crosswords



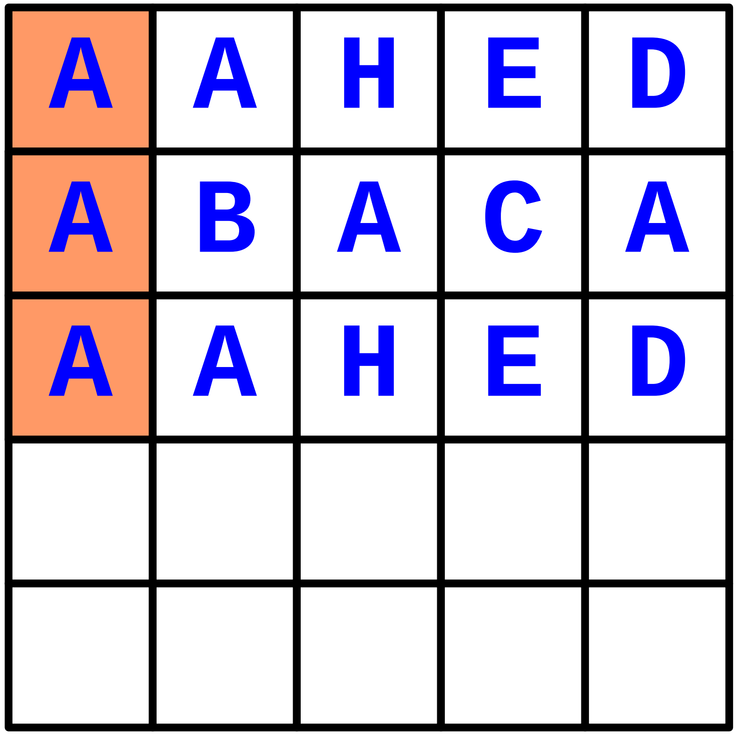
Generating Dense Crosswords

A	A	H	E	D
A	B	A	C	A

Generating Dense Crosswords

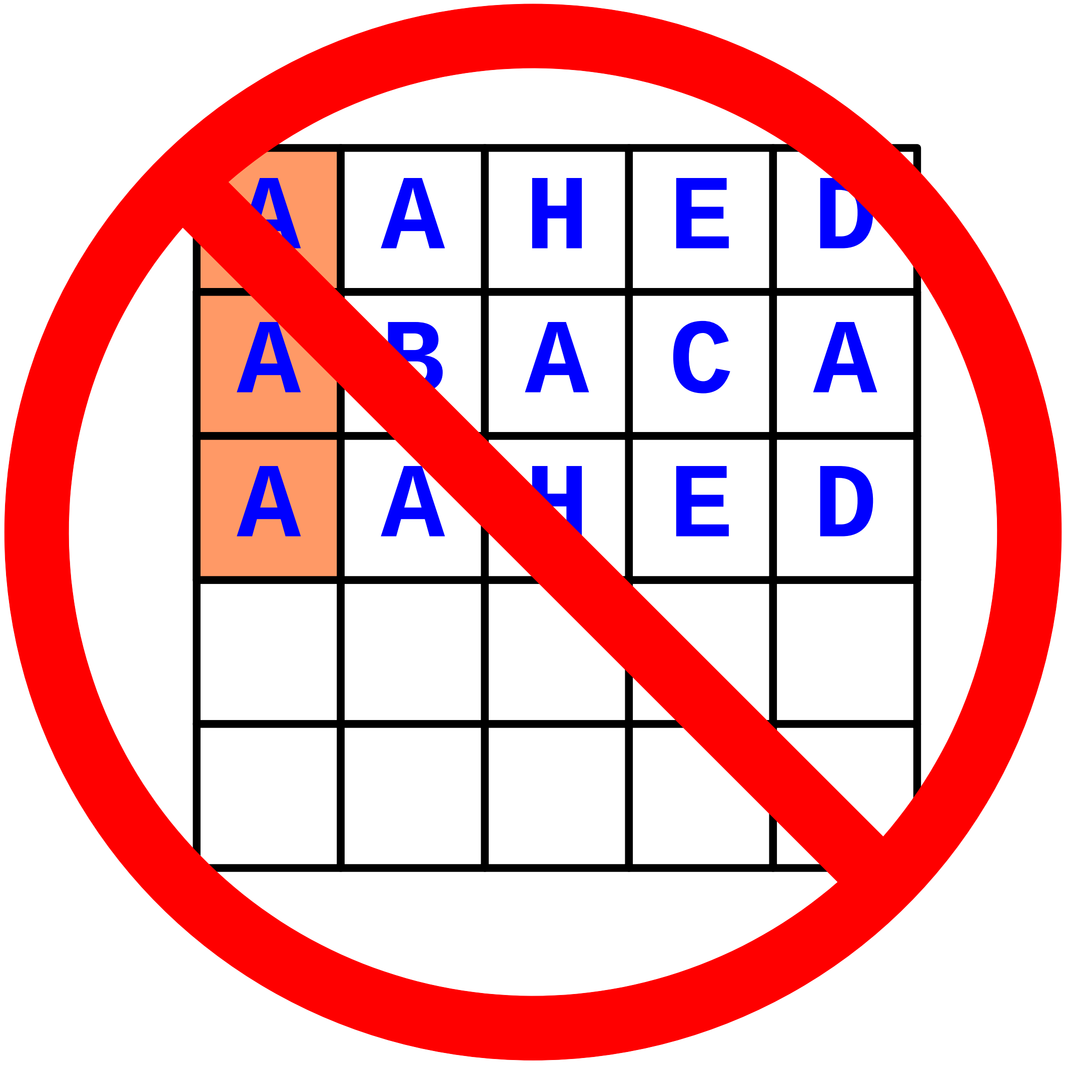
A	A	H	E	D
A	B	A	C	A
A	A	H	E	D

Generating Dense Crosswords



A	A	H	E	D
A	B	A	C	A
A	A	H	E	D

Generating Dense Crosswords



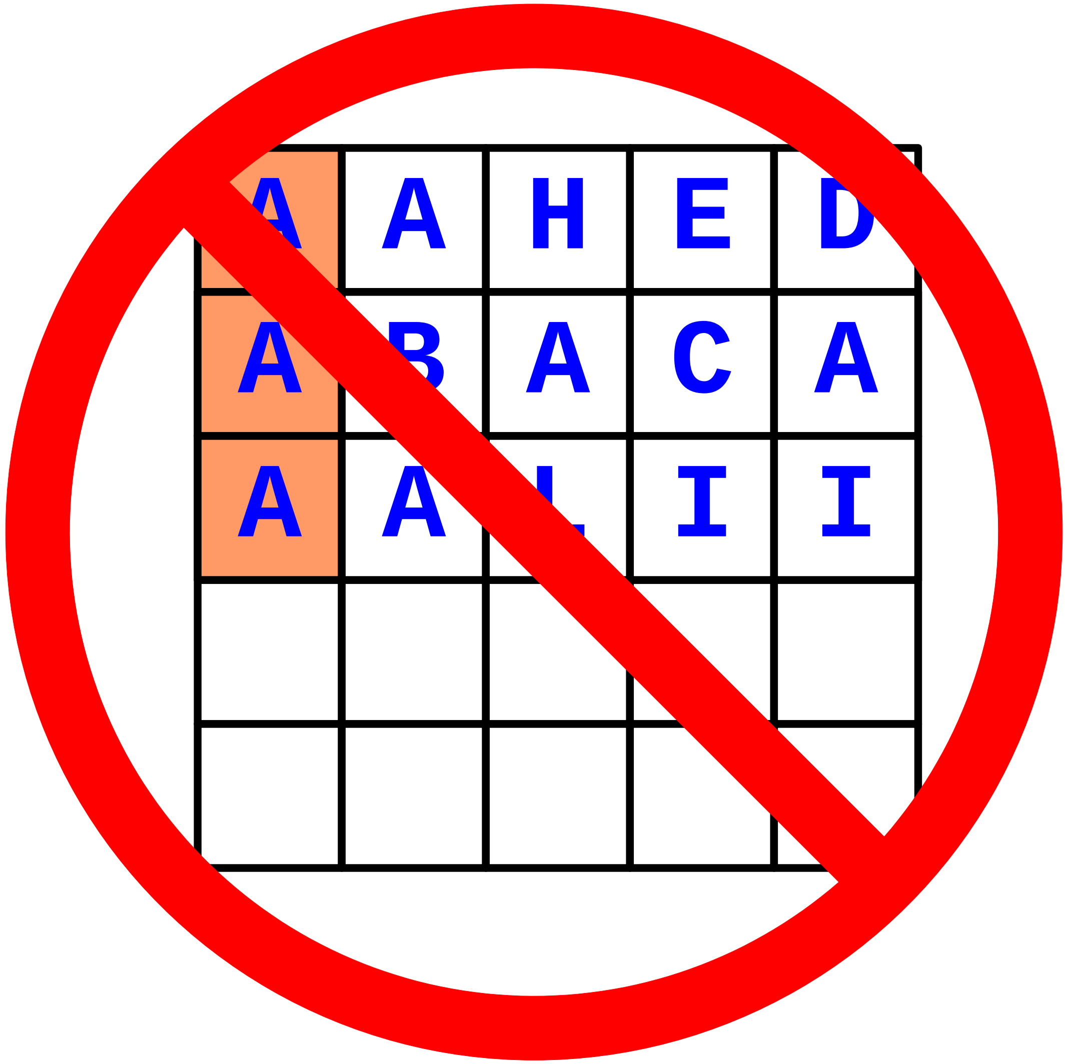
Generating Dense Crosswords

A	A	H	E	D
A	B	A	C	A
A	A	L	I	I

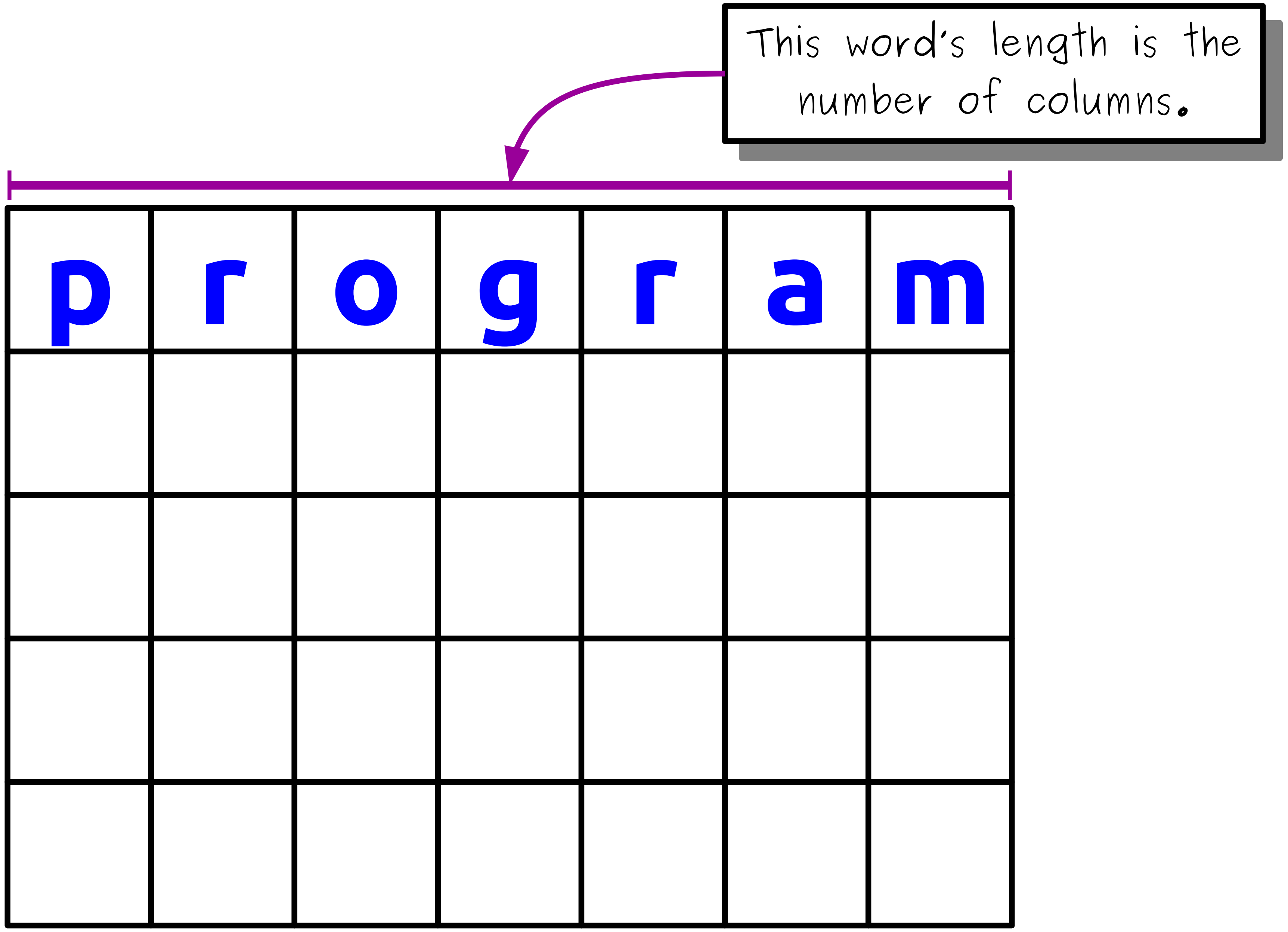
Generating Dense Crosswords

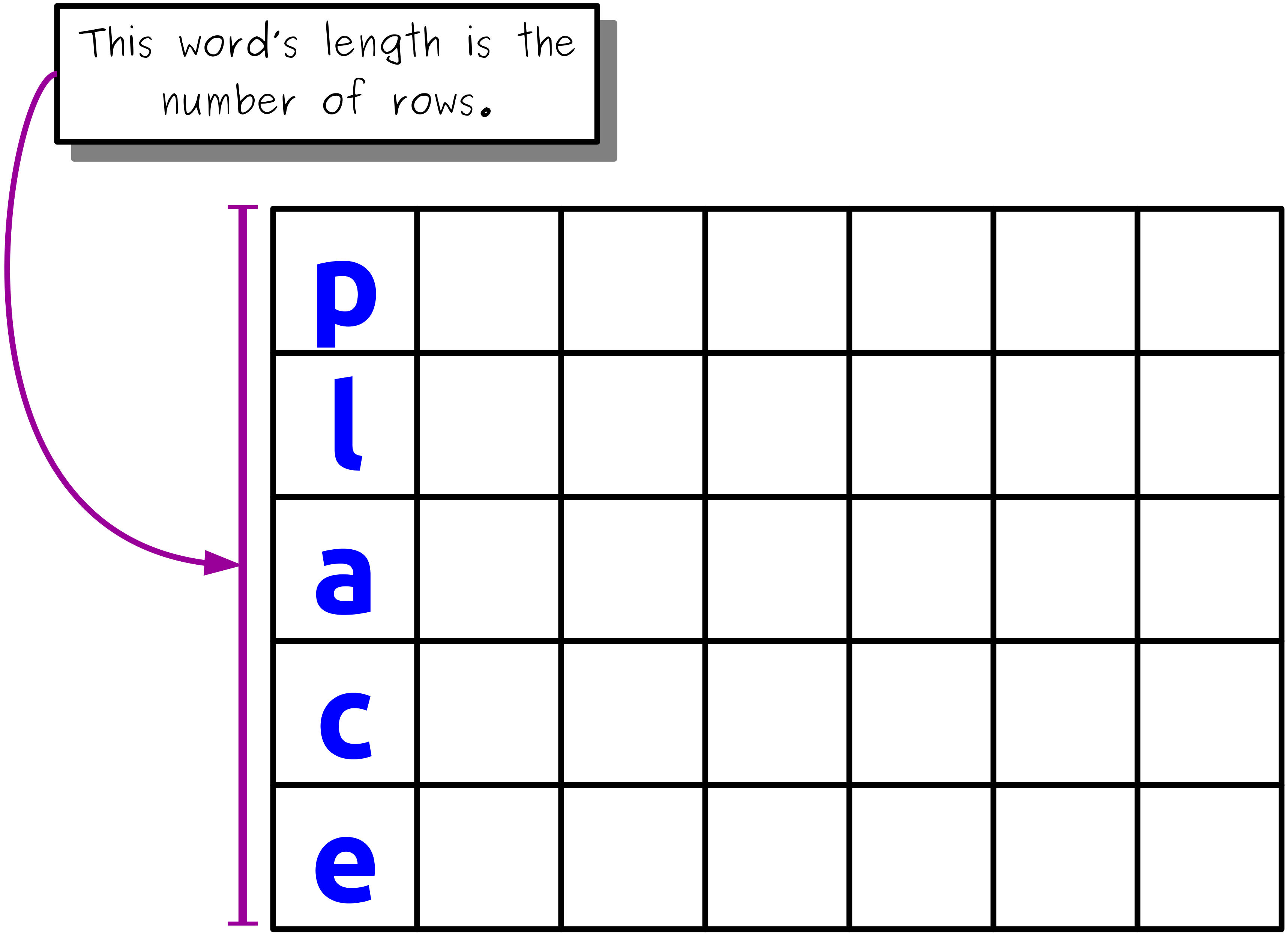
A	A	H	E	D
A	B	A	C	A
A	A	L	I	I

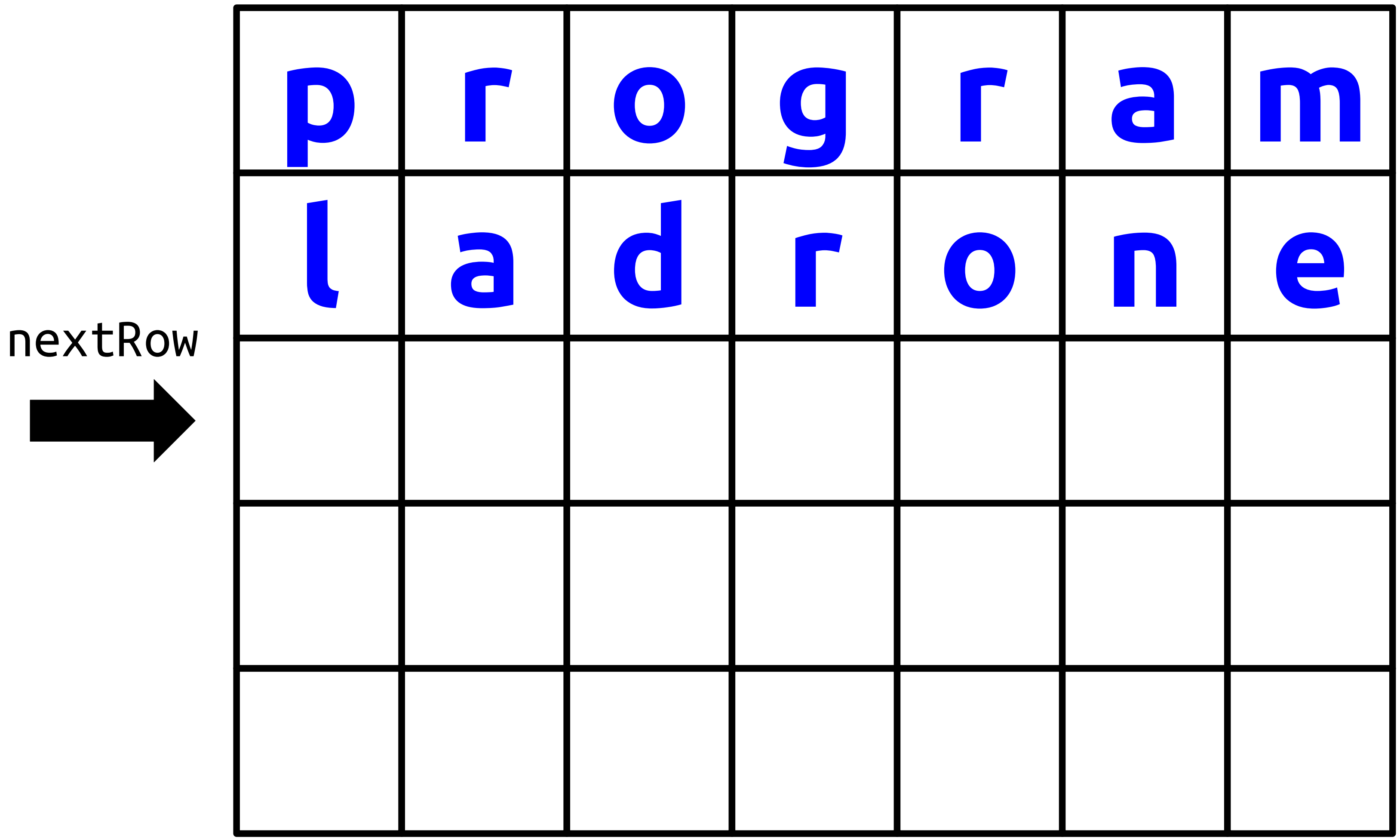
Generating Dense Crosswords



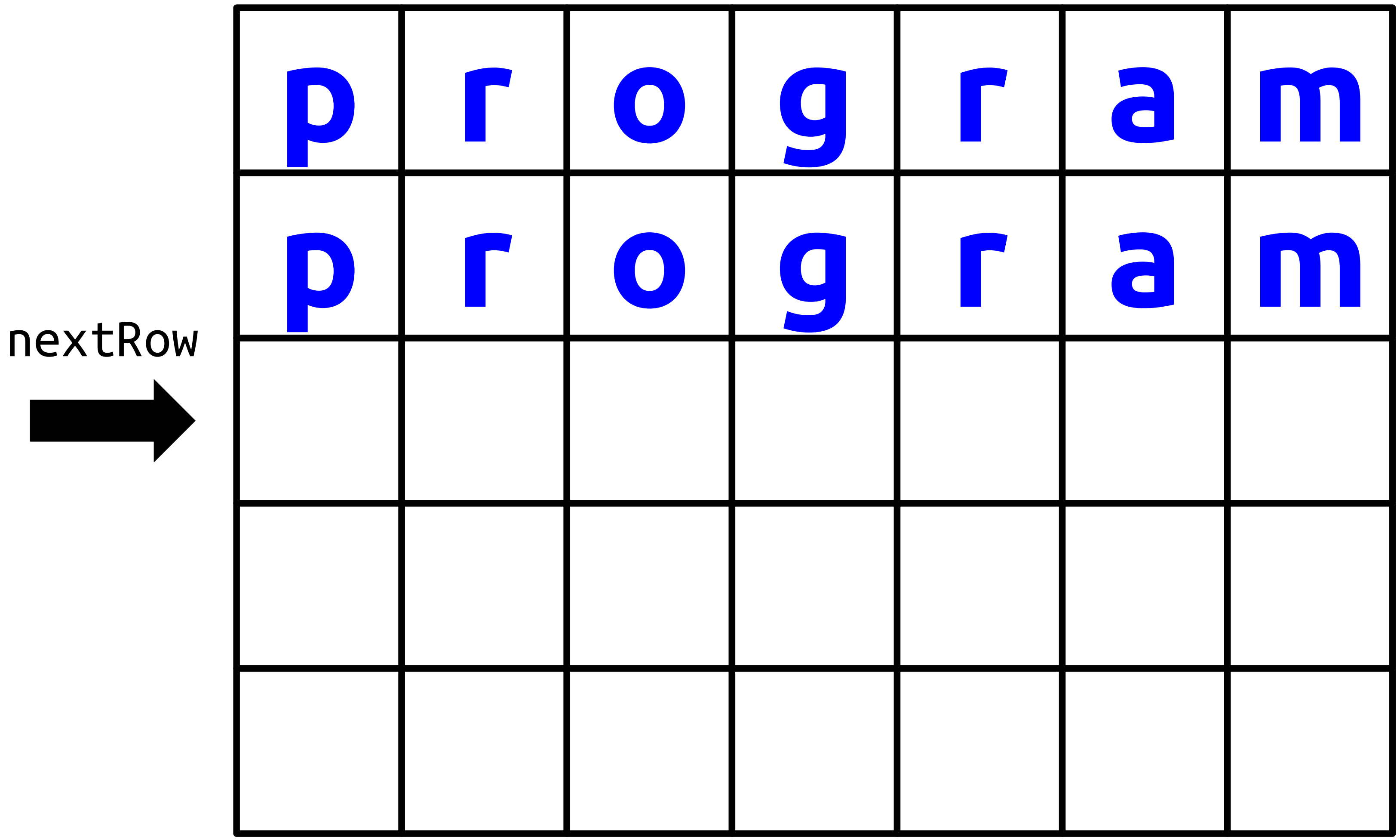
Let’s Code it Up!


This word's length is the number of columns.
p r o g r a m


This word's length is the number of rows.
p
l
a
c
e

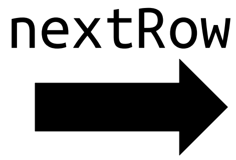


```
bool canMakeCrosswordRec(Grid<char>& crossword,
                         int nextRow,
                         const Lexicon& rowWords,
                         const Lexicon& colWords);
```

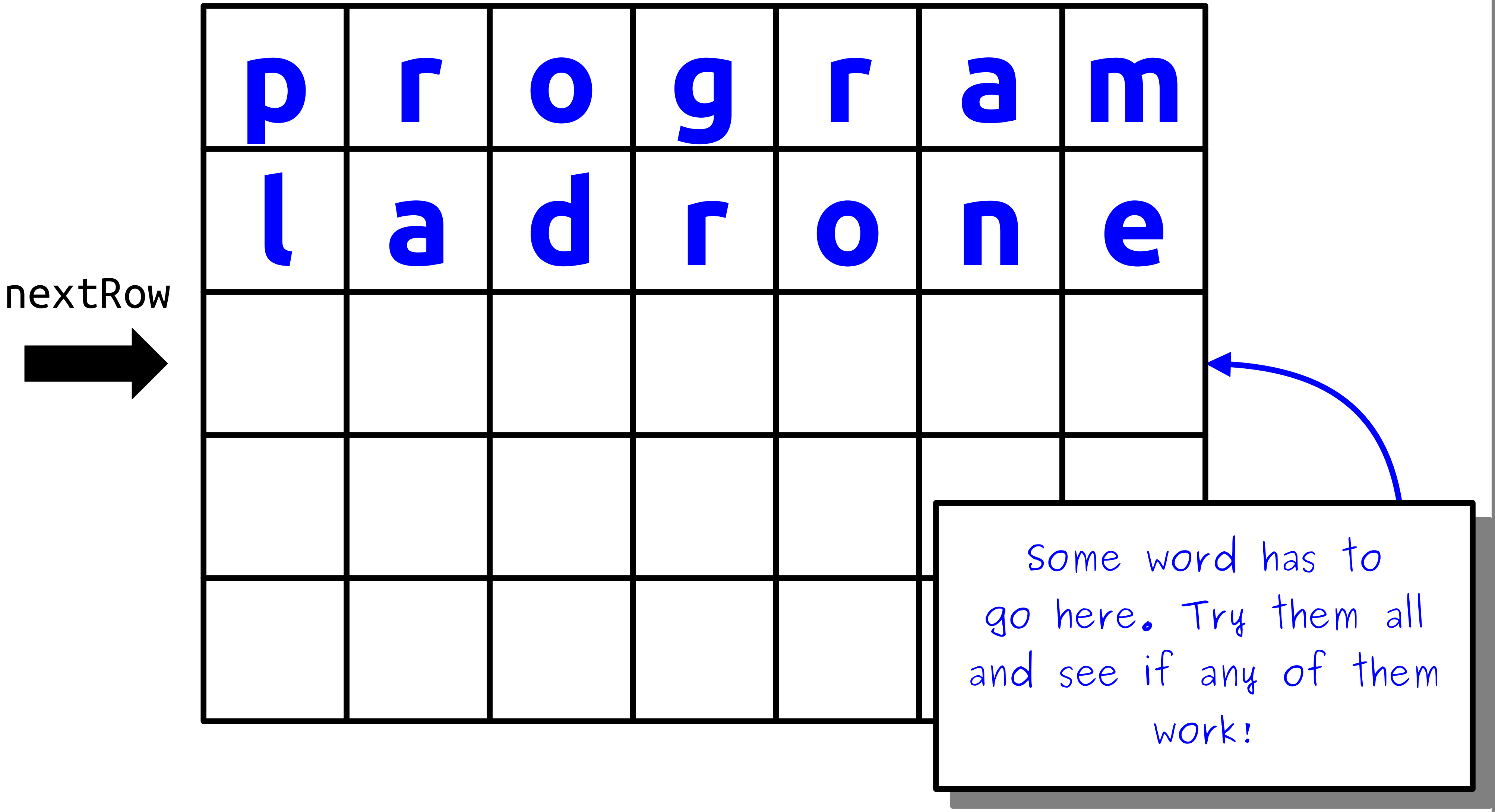


```
bool canMakeCrosswordRec(Grid<char>& crossword,
                         int nextRow,
                         const Lexicon& rowWords,
                         const Lexicon& colWords);
```

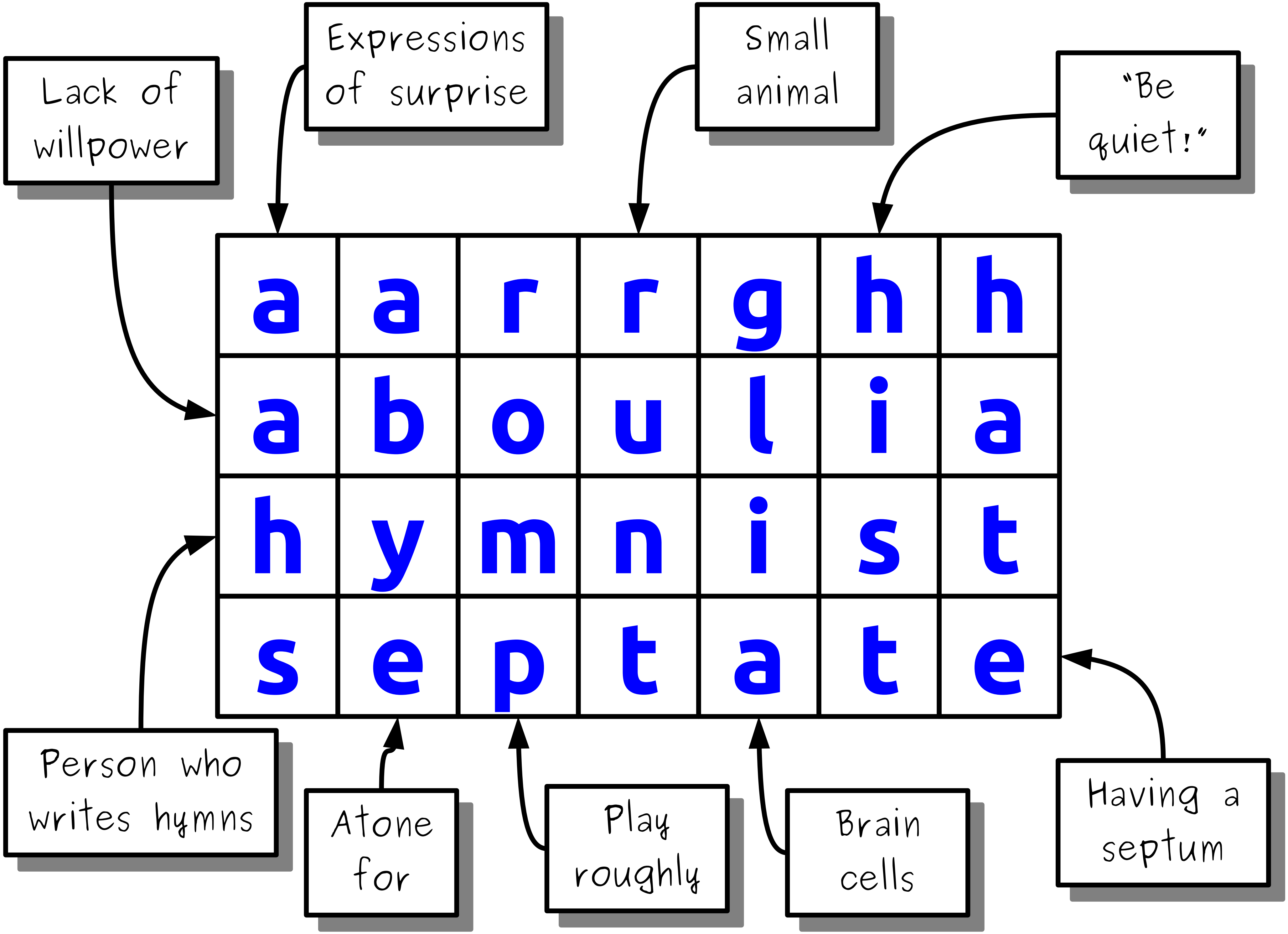
p	r	o	g	r	a	m
l	a	d	r	o	n	e
a	v	i	a	t	o	r
c	e	s	t	o	d	e
e	n	t	e	r	e	r



```
bool canMakeCrosswordRec(Grid<char>& crossword,
                         int nextRow,
                         const Lexicon& rowWords,
                         const Lexicon& colWords);
```


p r o g r a m
l a d r o n e
nextRow
Some word has to go here. Try them all and see if any of them work!

```
bool canMakeCrosswordRec(Grid<char>& crossword,
                         int nextRow,
                         const Lexicon& rowWords,
                         const Lexicon& colWords);
```


Lack of willpower
Expressions of surprise
Small animal
"Be quiet!"
a a r r g h h
a b o u l i a
h y m n i s t
s e p t a t e
Person who writes hymns
Atone for
Play roughly
Brain cells
Having a septum

Going Deeper

- You can speed this up even more if you're more clever. Here are some thoughts to get you started:
  - Once you've placed a few rows down, the columns will be very constrained. Consider switching to going one *column* at a time versus one *row* at a time at that point.
  - Figure out which row or column is most constrained at each point, and only focus on that row/column.
- ***Completely optional challenge:*** Make this program run faster, and find a cool dense crossword. If you find something interesting (and PG-13), we'll share it with the rest of the class!

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.***
    - Have questions? Call into our office hours, ask on EdStem, or sign up for LaIR help!

Next Time

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