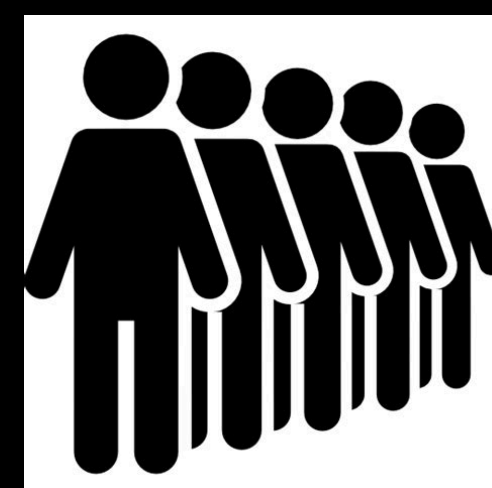
Stack & Queue ADTs



Tiziana Ligorio
Hunter College of The City University of New York

Today's Plan

ADT Recap

Stack ADT

Stack Applications

Queue ADT

Queue Applications

ADT Recap

Abstract Data Types:

- Bag (unordered)
- List (ordered)

ADT operations

- add/insert, remove, find

Stack

An ADT representing a stack of items

Objects can be pushed onto the stack or popped from the stack

Stack

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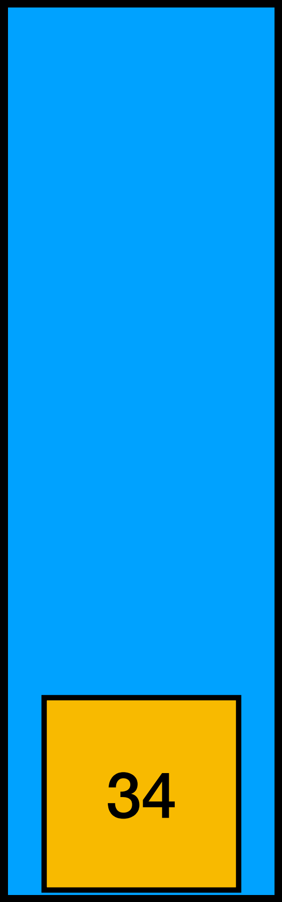
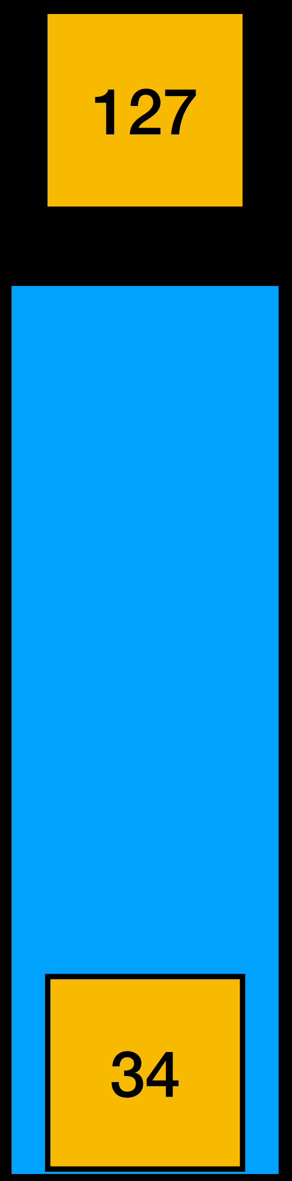


Stack



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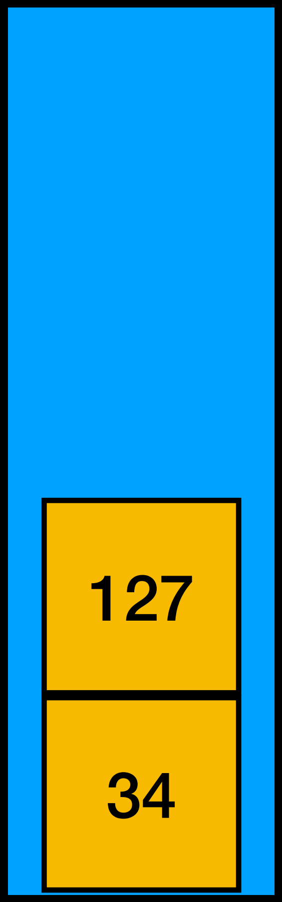

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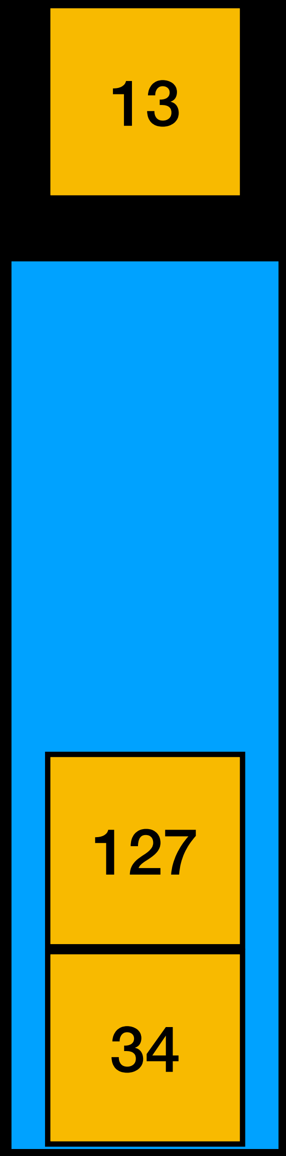

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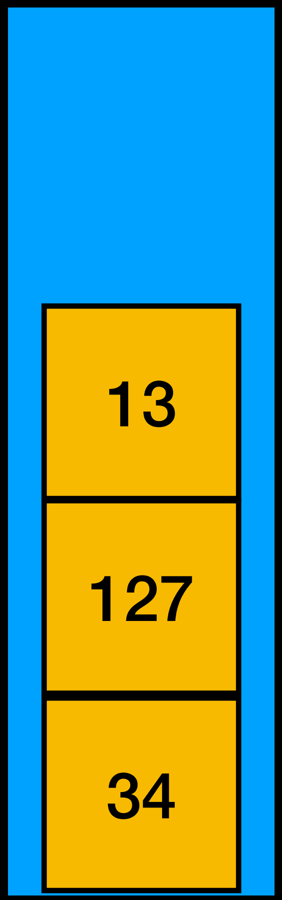
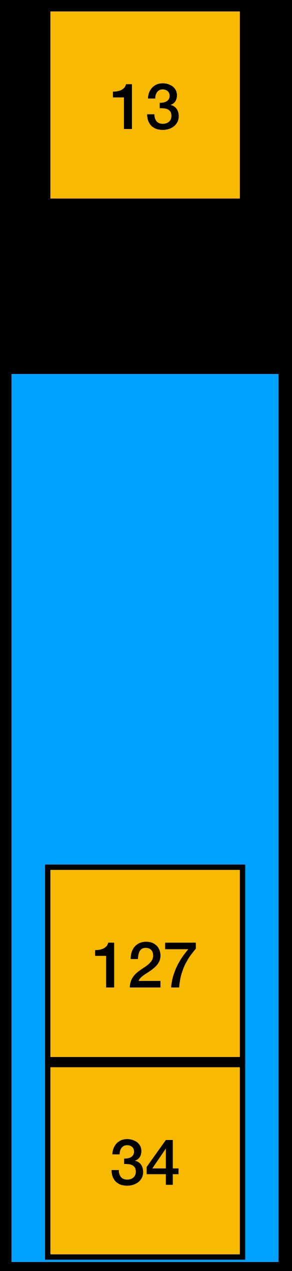


Stack



An ADT representing a stack of items

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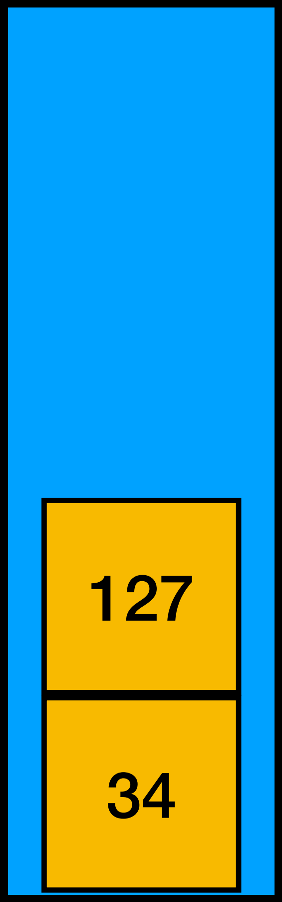
Stack

An ADT representing a stack of items

Objects can be pushed onto the stack or popped from the stack

LIFO: Last In First Out

Only top of stack is accessible (top), no other objects on the stack are visible



Applications

Very simple structure

Many applications:
- program stack
- balancing parenthesis
- evaluating postfix expressions
- backtracking
- . . . and more

Program Stack

Program Stack

```
void f(int x, int y)
{
  int a;
  // stuff here
  if(a<13)
     a = g(a);
  // stuff here
}

int g(int z)
{
  int p ,q;
  // stuff here
  return q;
}
```

Program Stack

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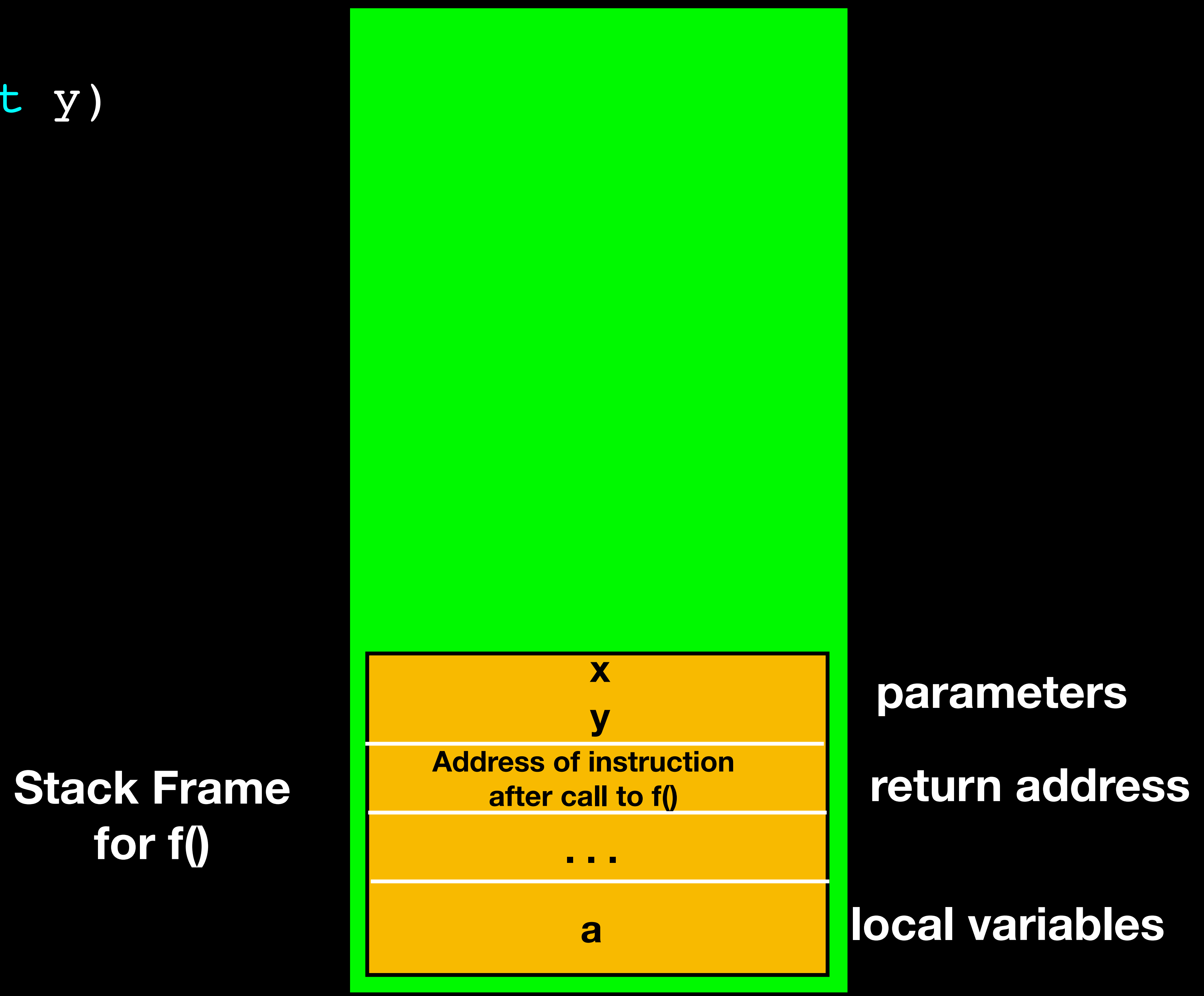
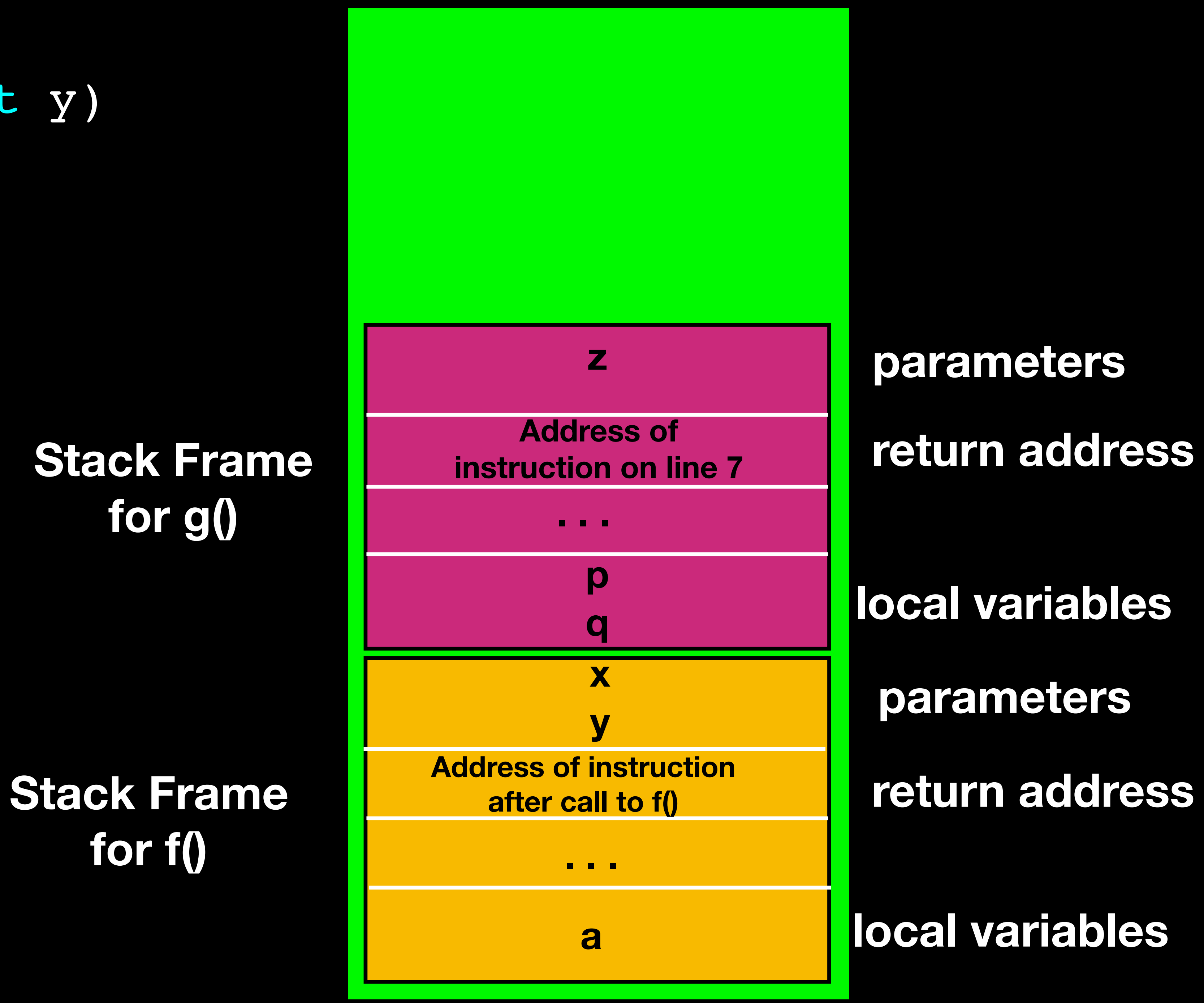


Program Stack

```
1  void f(int x, int y)
2  {
3    int a;
4    // stuff here
5    if(a<13)
6       a = g(a);
7    // stuff here
8  }

9  int g(int z)
10 {
11   int p ,q;
12   // stuff here
13   return q;
14 }
```



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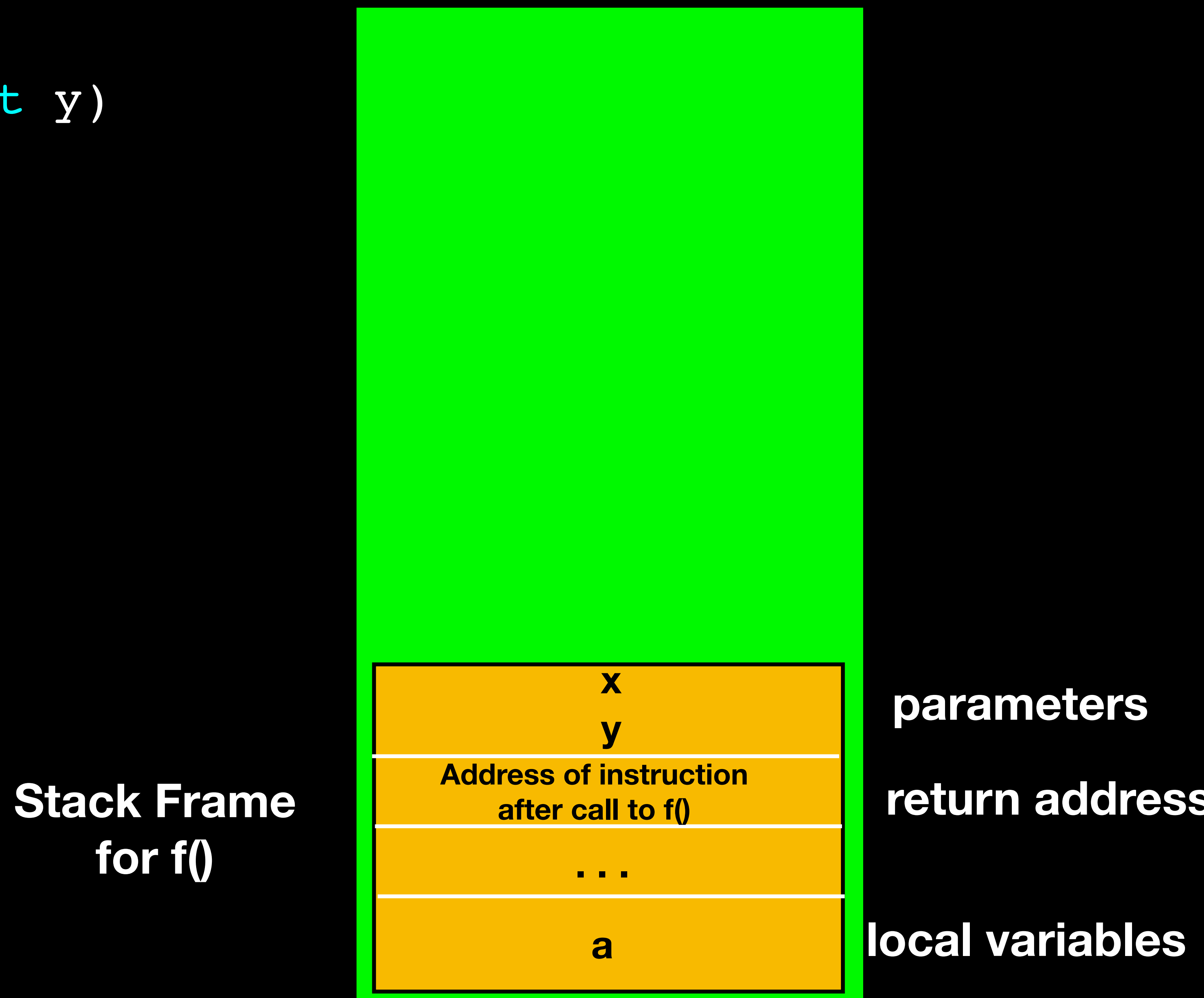


How would you solve it?

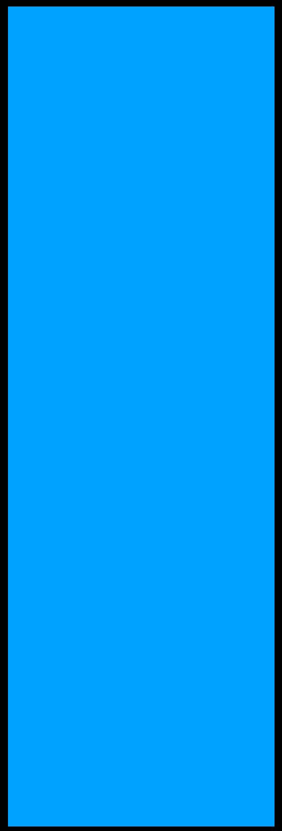
Balancing Parentheses

Given a string, determine if parenthesis are balanced.
Parentheses can be { }, [ ] or ( ), and must be nested properly.
E.g. “ [({ })] “ is balanced, while “ [({ }] “ or “ [({) }] “ are not.

Typical applications: parsers and compilers.

Balancing Parentheses

```
int f(){if(x*(y+z[i])<47){x += y}}
↑
```



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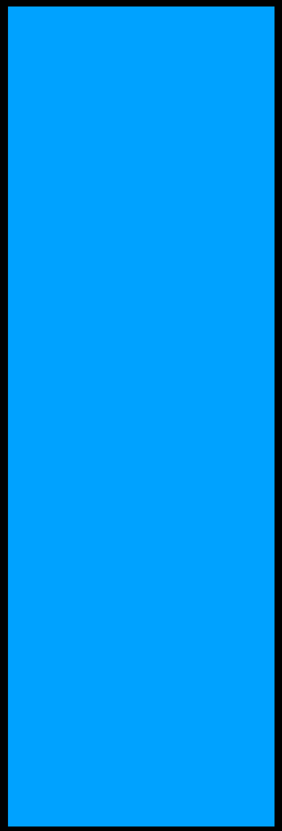

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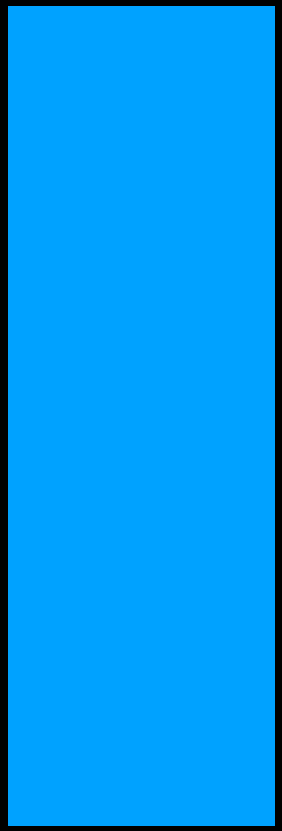

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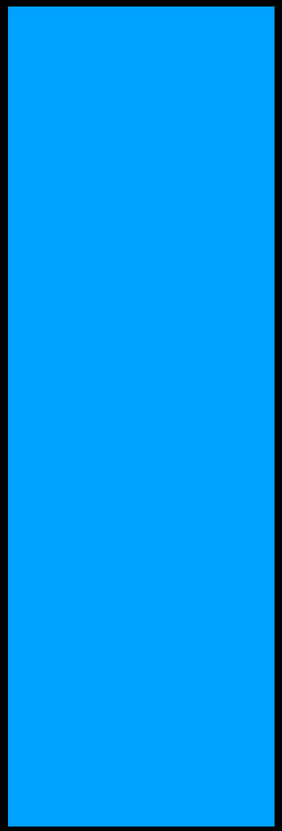

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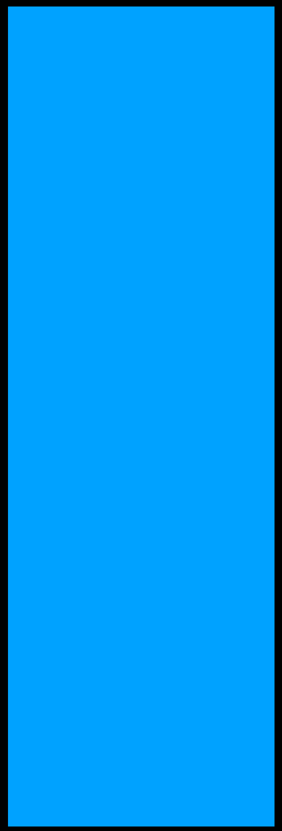

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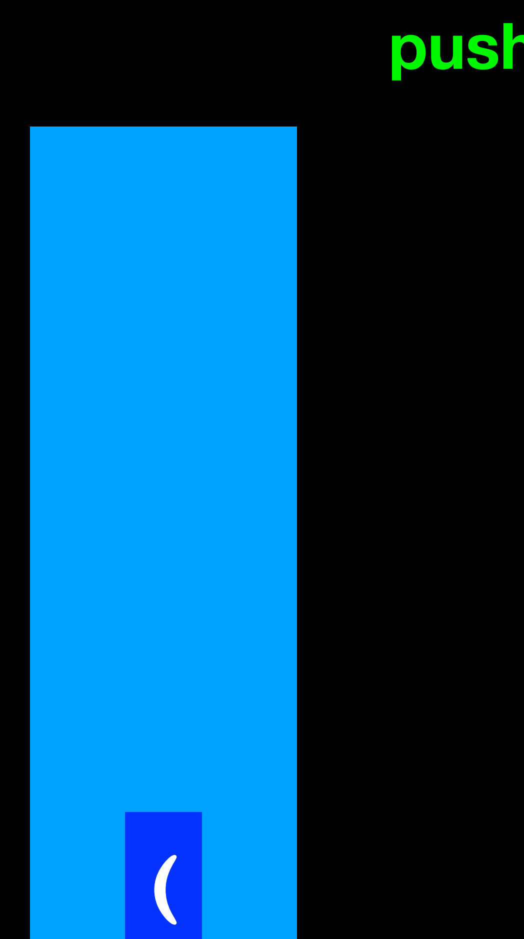

Balancing Parentheses

pop

```
int f(){if(x*(y+z[i])<47){x += y}}
```

Balancing Parentheses

push

```
int f(){if(x*(y+z[i])<47){x += y}}
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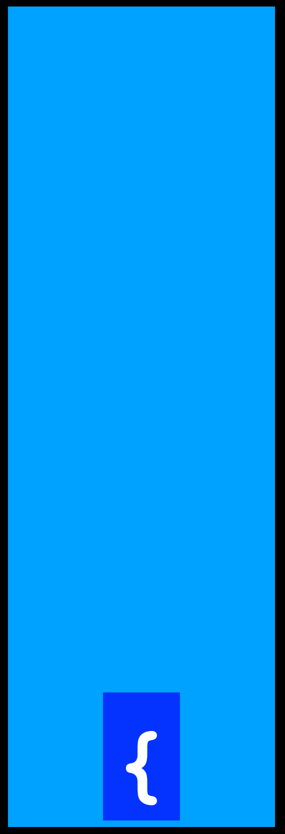

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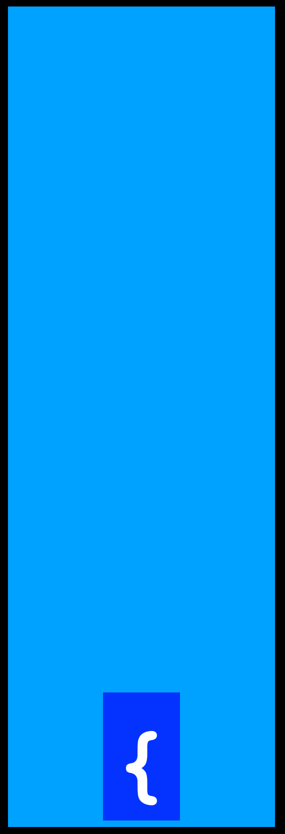

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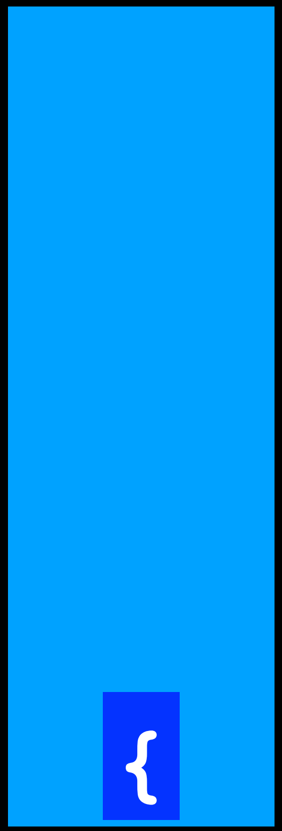

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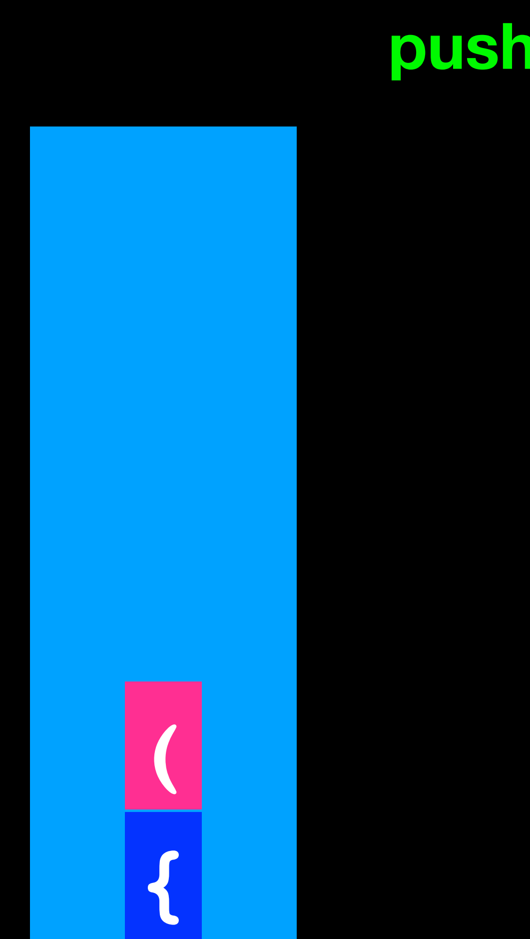

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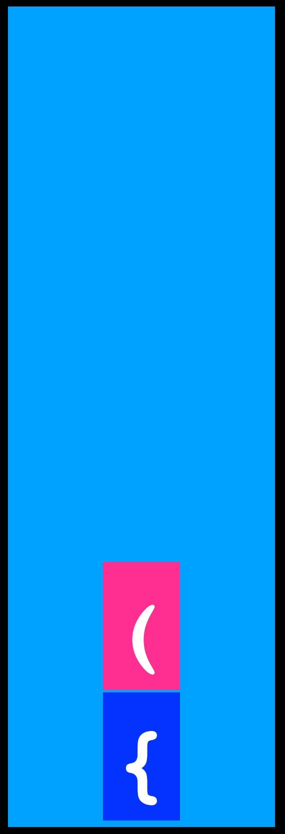

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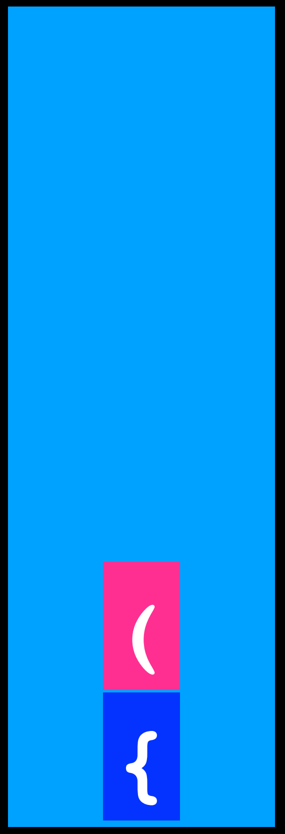

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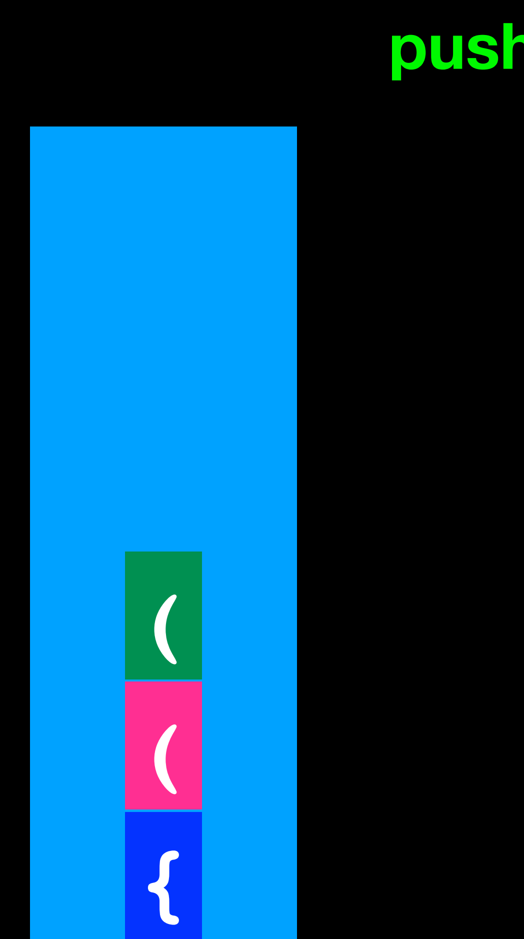

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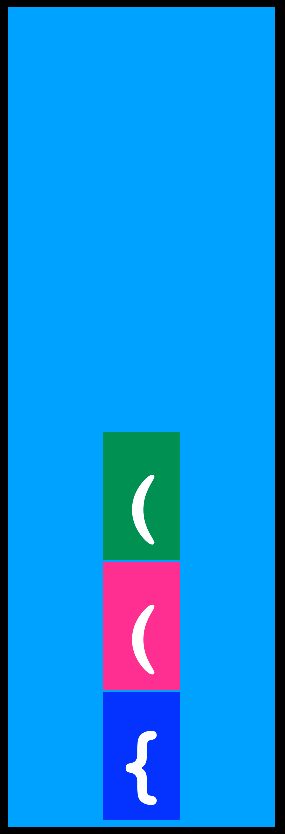

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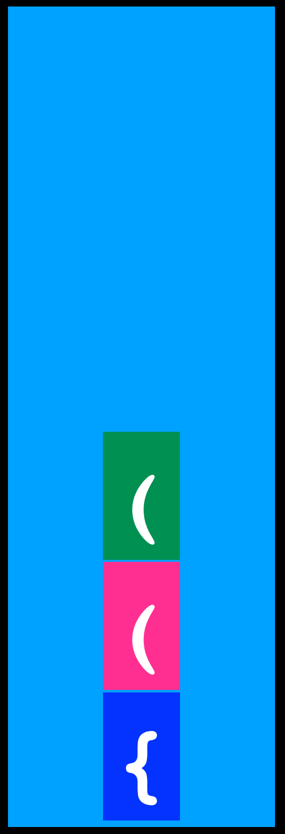

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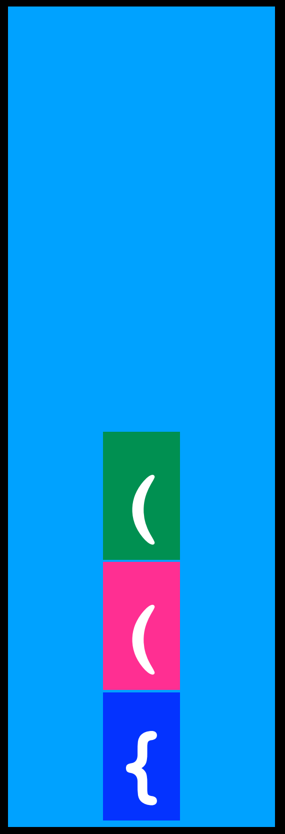

Balancing Parentheses

push

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int f(){if(x*(y+z[i])<47){x += y}}
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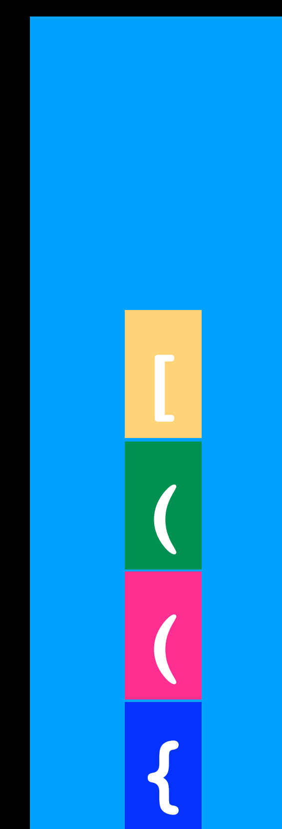

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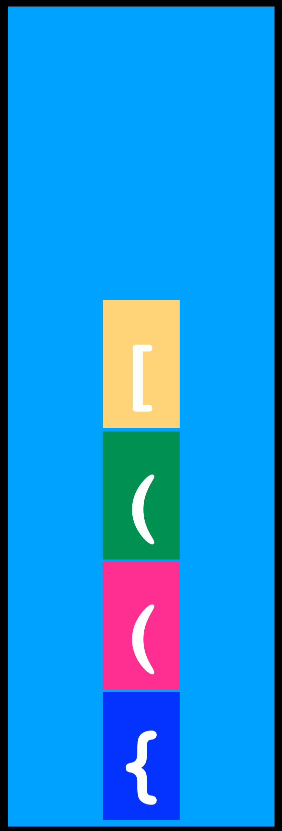

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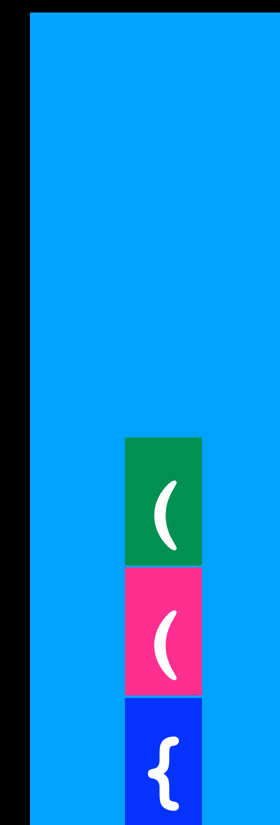

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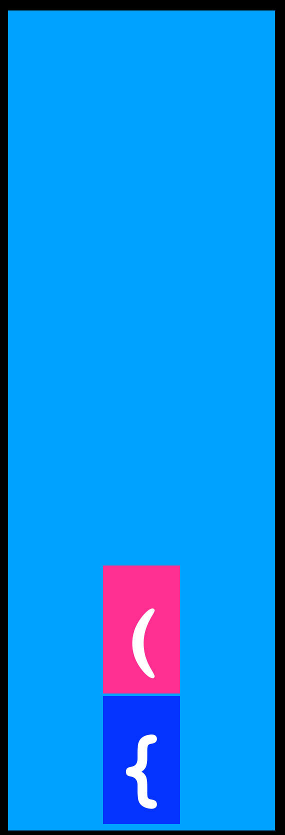

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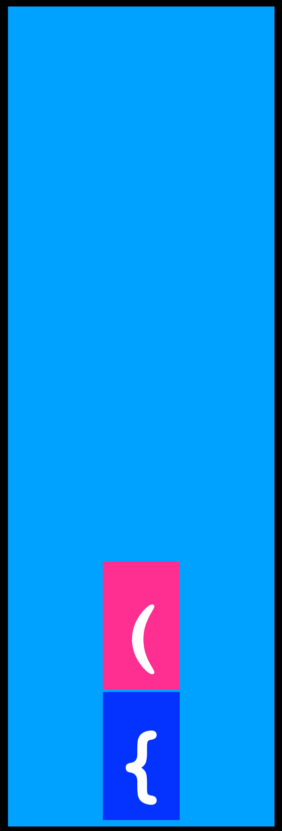

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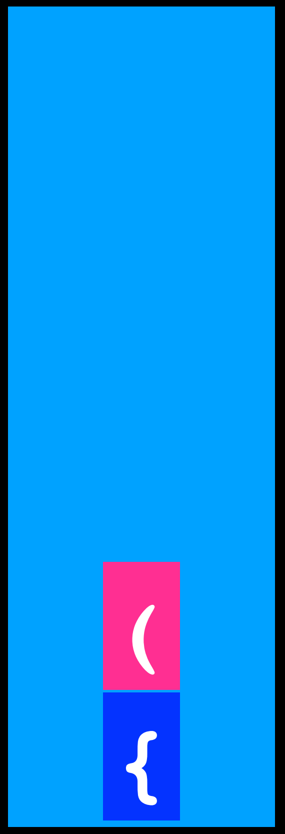

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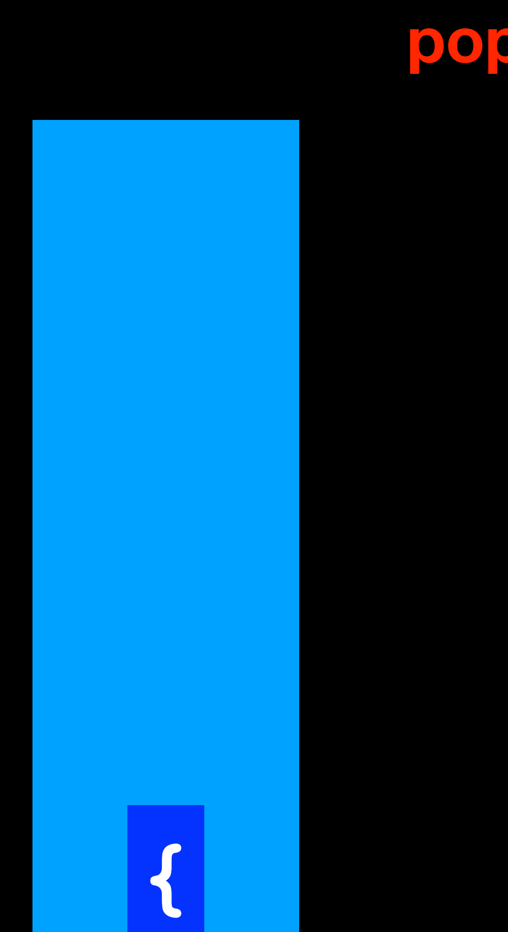

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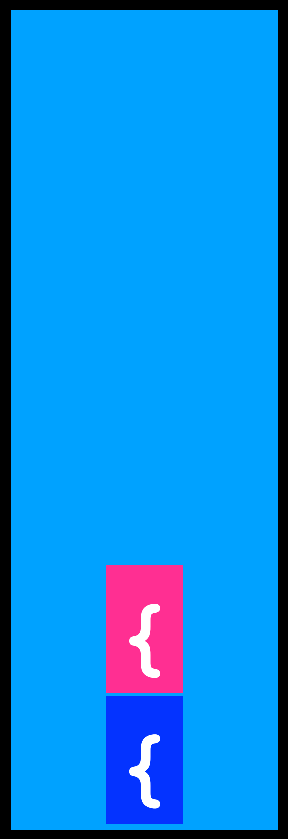

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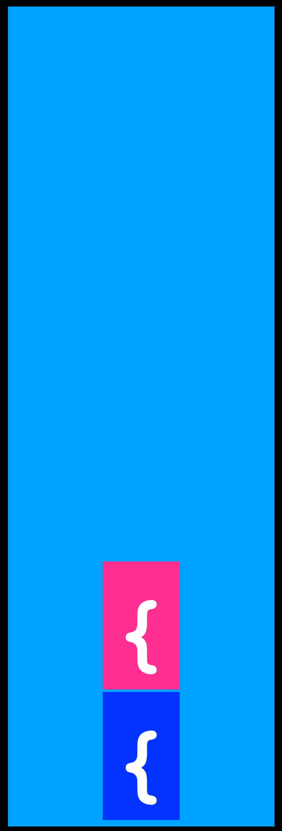

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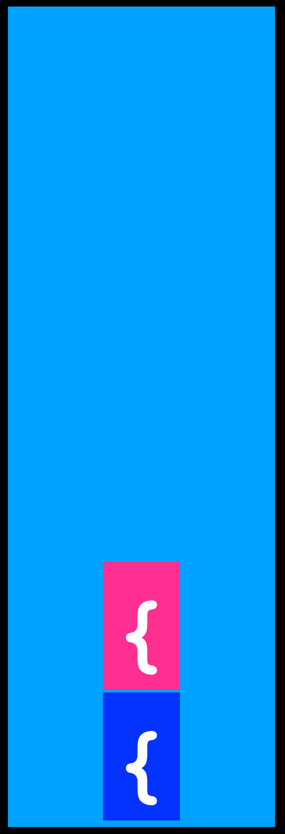

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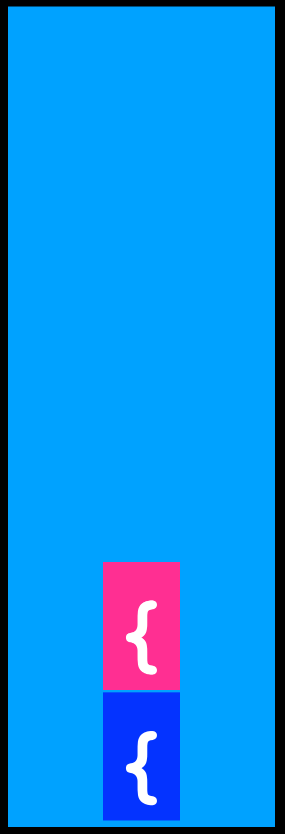

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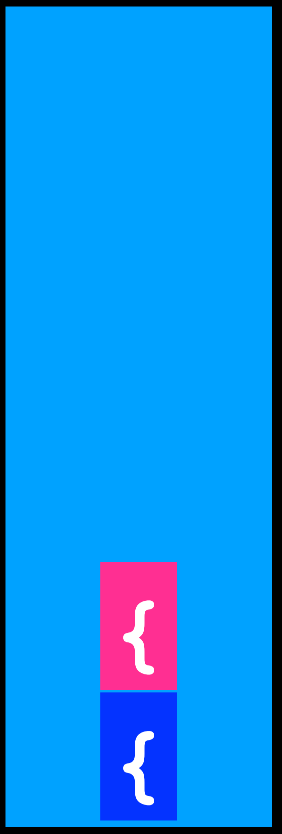

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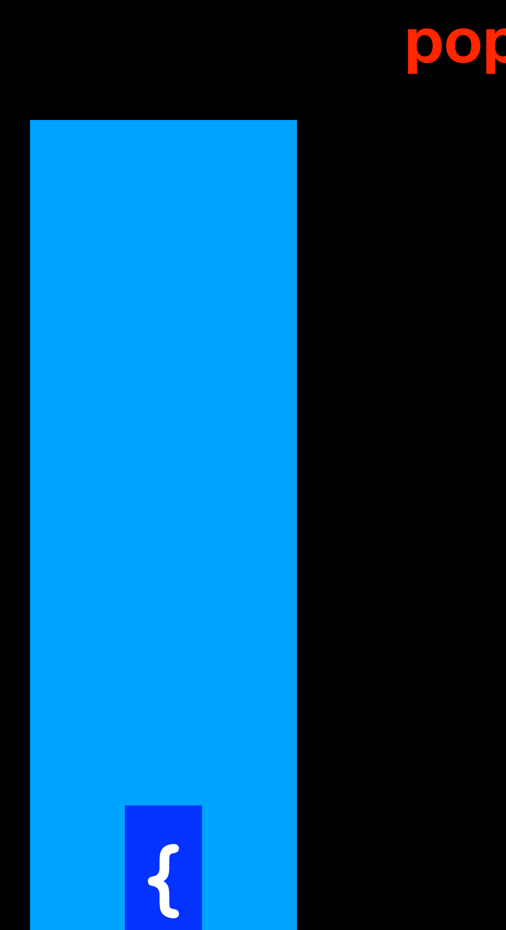
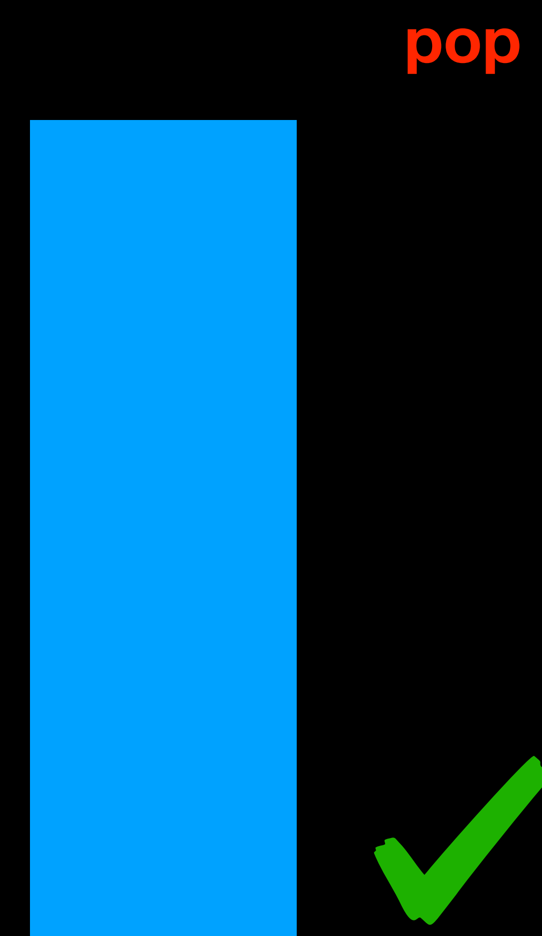


Balancing Parentheses

```
int f(){if(x*(y+z[i])<47){x += y}}
```

Finished reading
Stack is empty
Parentheses are balanced



Balancing Parentheses

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int f(){if(x*(y+z[i])<47){x += y}
```
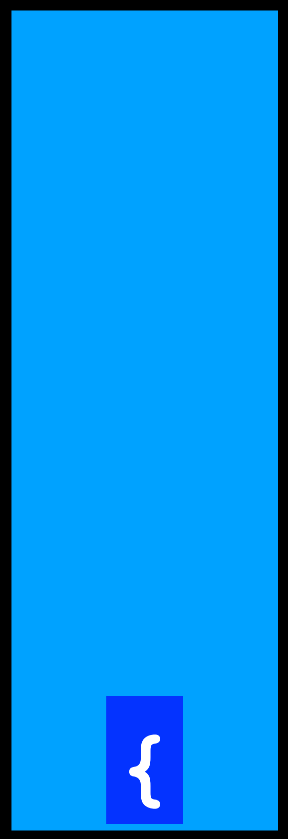

Finished reading
Stack not empty
Parentheses NOT balanced



Balancing Parentheses

```
for(char ch : st)
{
   if ch is an open parenthesis character
       push it on the stack
   else if ch is a close parenthesis character
       if it matches the top of the stack
       pop the stack
       else
          return unbalanced
   // else it is not a parenthesis
}

if stack is empty
   return balanced
else
   return unbalanced
```

O(n)

Evaluating Postfix Expressions

Postfix Expressions

Operator applies to the two operands immediately preceding it

Infix:	**Postfix:**
2 * (3 + 4)	**2 3 4 + ***
2 * 3 + 4	**2 3 * 4 +**

Evaluating Postfix Expressions

Operator applies to the two operands immediately preceding it

Postfix:

2 3 4 + *

Assumptions / simplifications:

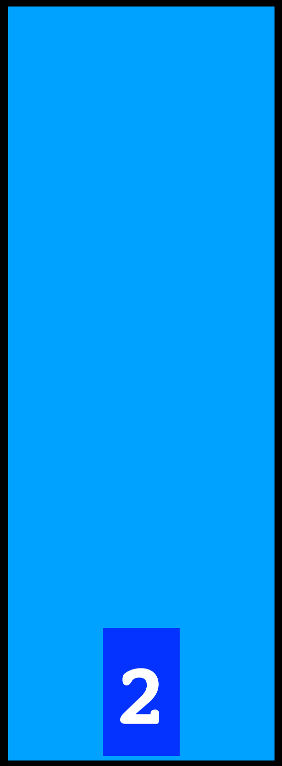
- String is syntactically correct postfix expression
- No unary operators
- No exponentiation operation
- Operands in string are single integer values

Evaluating Postfix Expressions

Postfix:

2 3 4 + *

↑



Evaluating Postfix Expressions

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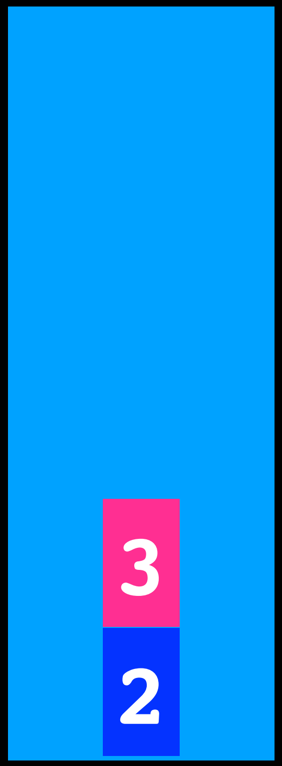

Evaluating Postfix Expressions

Postfix:

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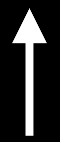
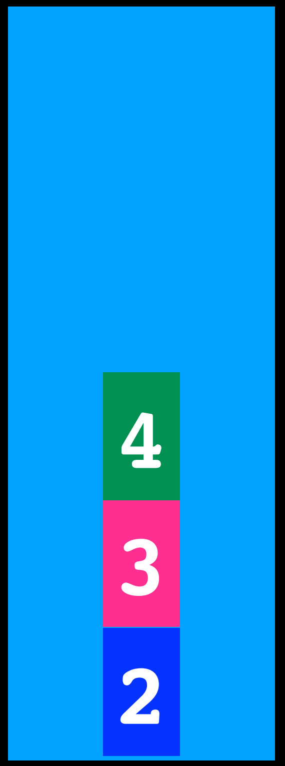
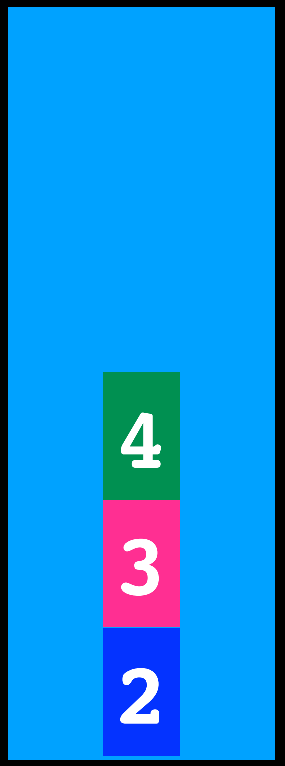




Evaluating Postfix Expressions

Postfix:

2 3 4 + *



Evaluating Postfix Expressions

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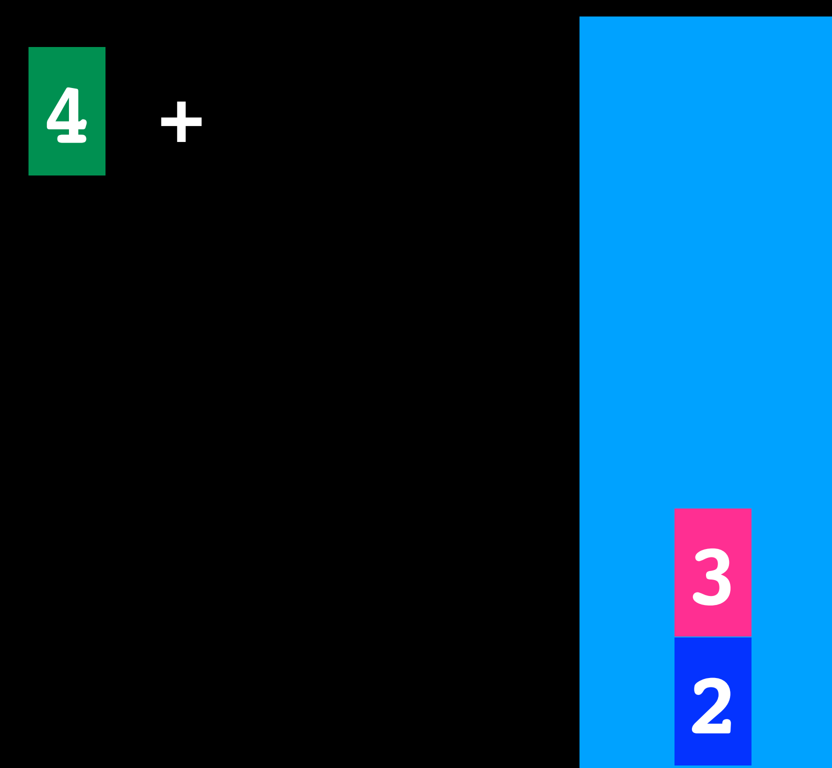
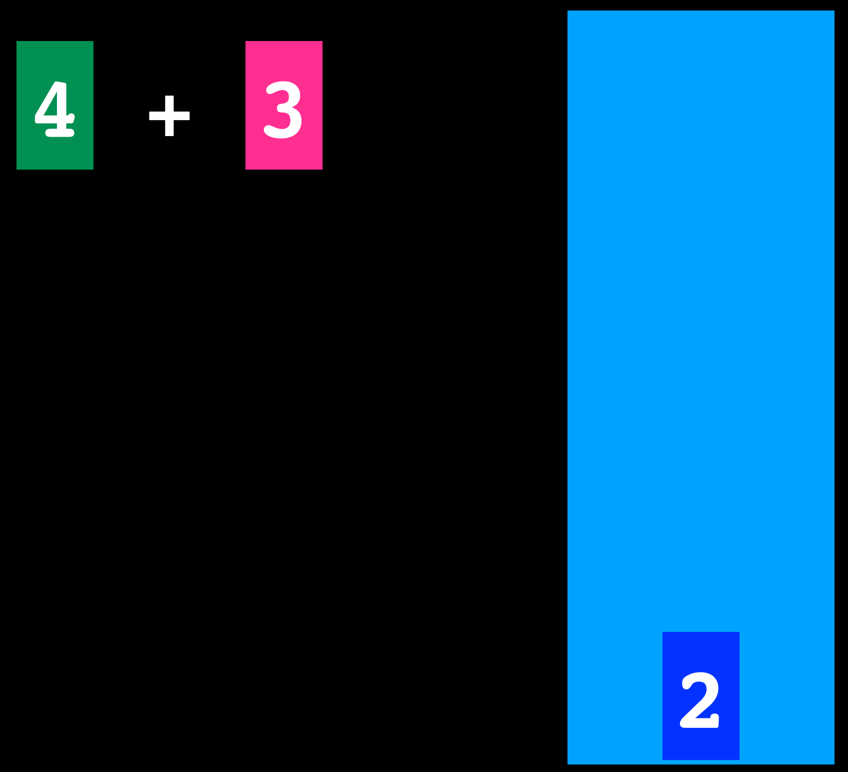


Evaluating Postfix Expressions

Postfix:

2 3 4 + *



Evaluating Postfix Expressions

Postfix:

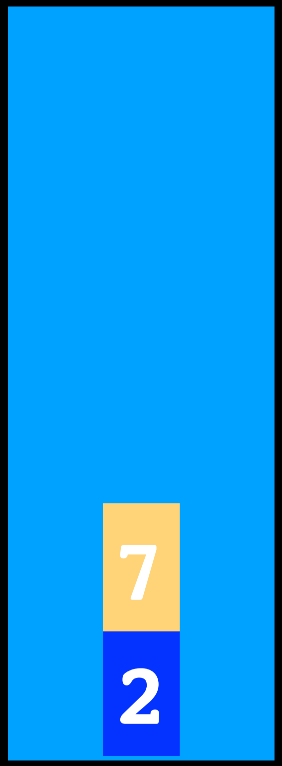
2 3 4 + *

4 + 3 = 7

Evaluating Postfix Expressions

Postfix:

2 3 4 + *



Evaluating Postfix Expressions

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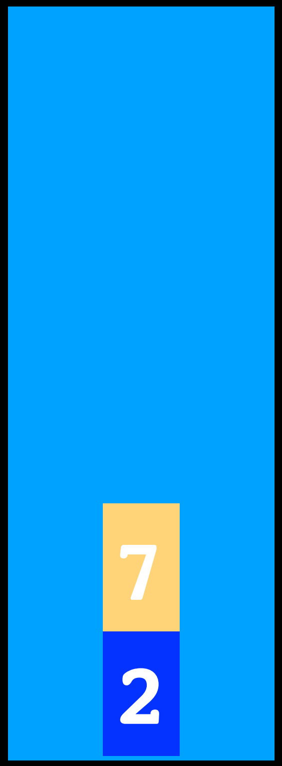

Evaluating Postfix Expressions

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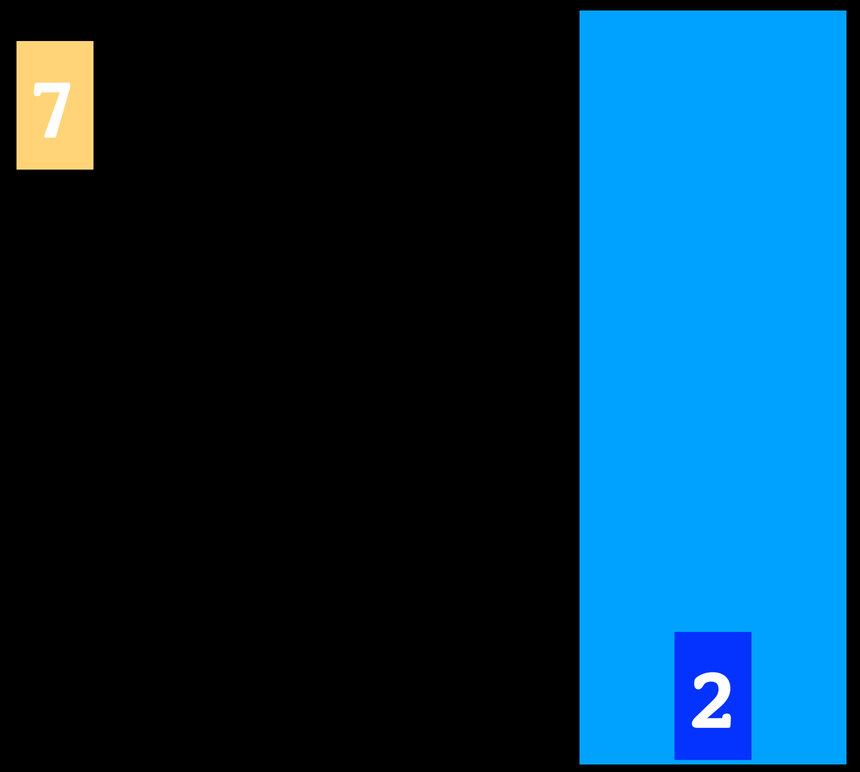


Evaluating Postfix Expressions

Postfix:

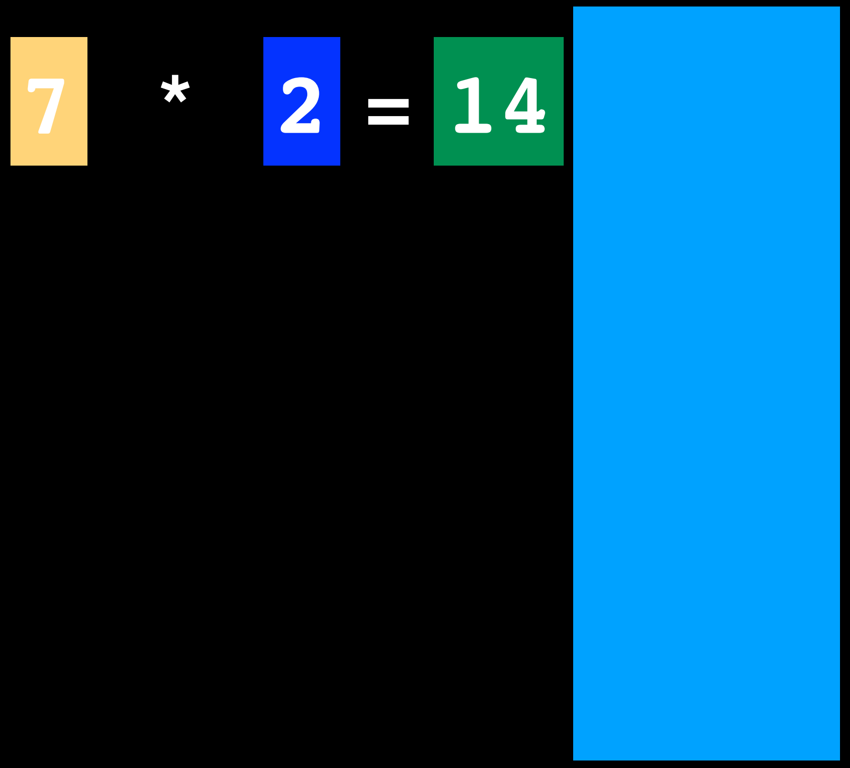
2 3 4 + *

7 * 2

Evaluating Postfix Expressions

Postfix:

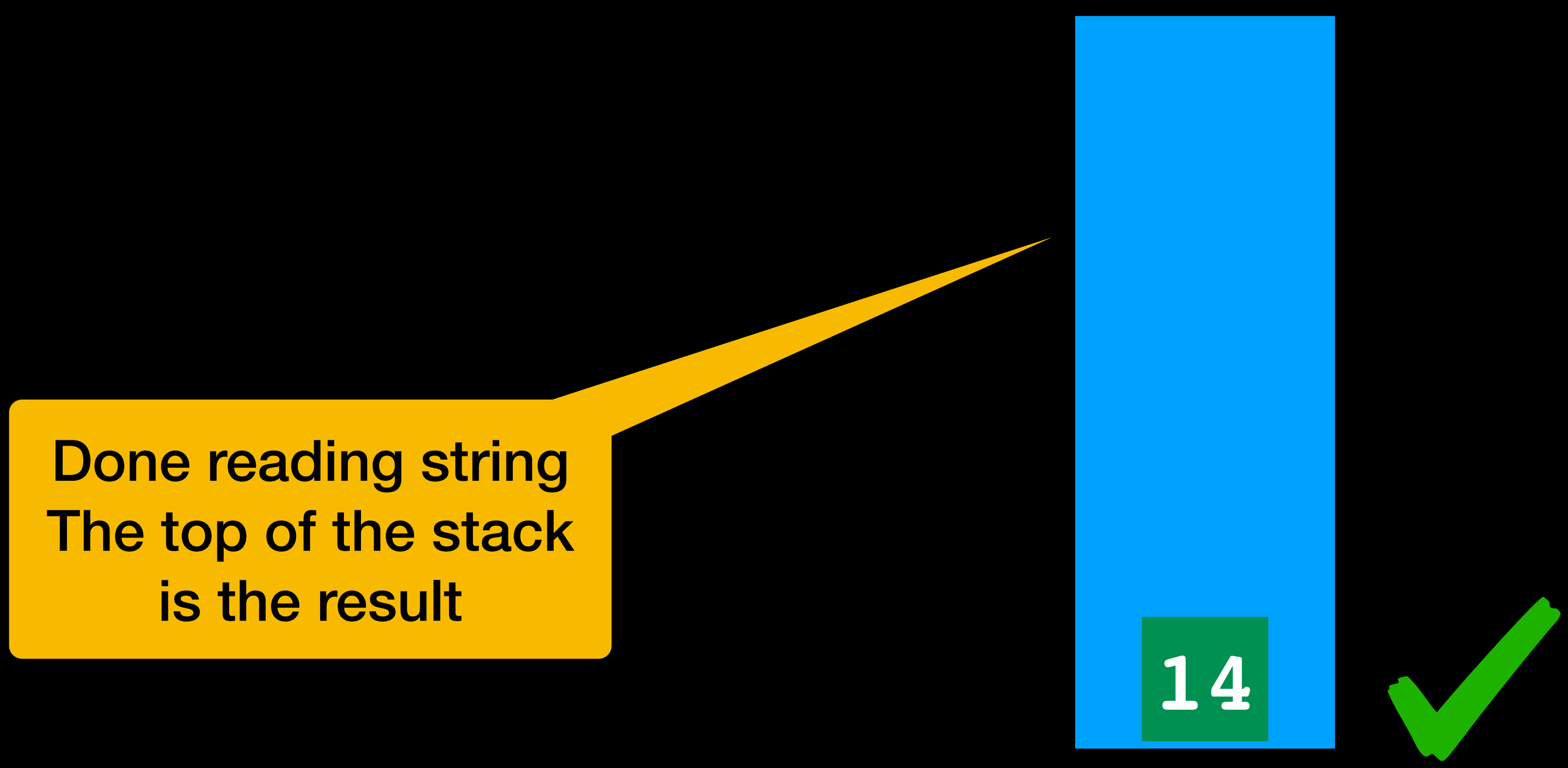
2 3 4 + *



Evaluating Postfix Expressions

Postfix:

2 3 4 + *



Evaluating Postfix Expressions

Operator applies to the two operands immediately preceding it

Postfix:
2 3 * 4 +

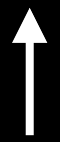
Assumptions / simplifications:

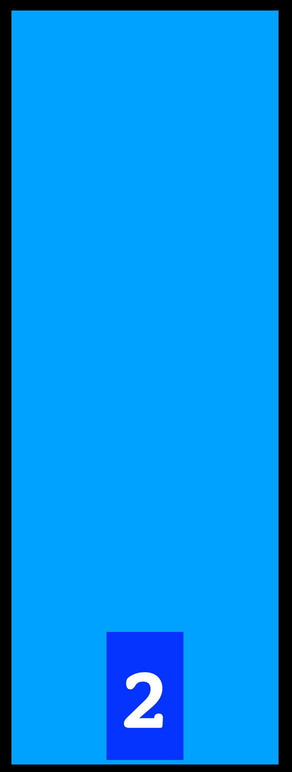
- string is syntactically correct postfix expression
- No unary operators
- No exponentiation operation
- Operands in string are single integer values

Evaluating Postfix Expressions

Postfix:

2 3 * 4 +

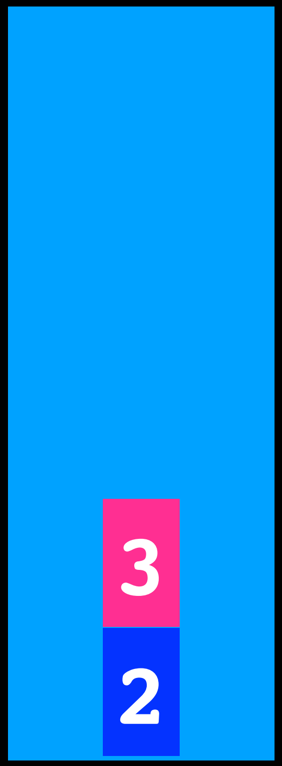




Evaluating Postfix Expressions

Postfix:

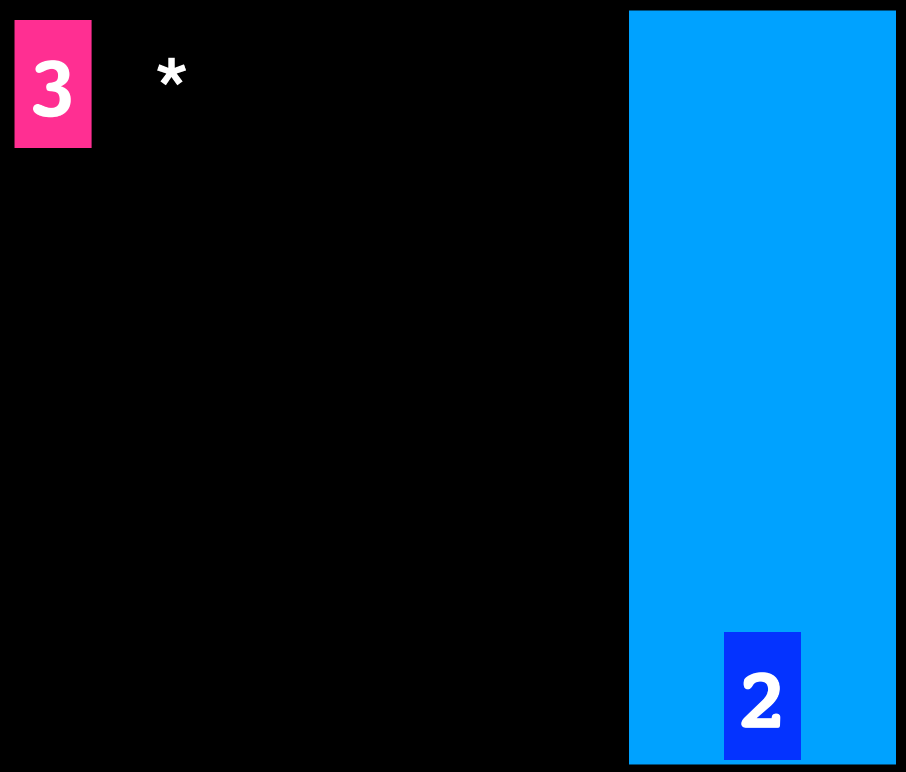
2 3 * 4 +



Evaluating Postfix Expressions

Postfix:

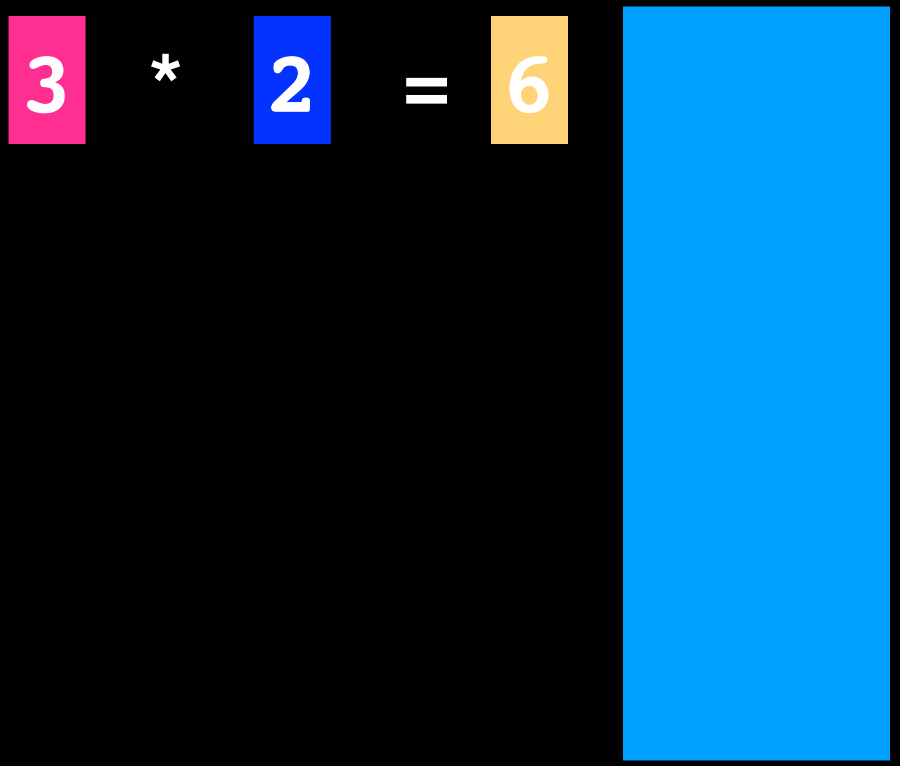
2 3 * 4 +



Evaluating Postfix Expressions

Postfix:

2 3 * 4 +



Evaluating Postfix Expressions

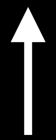
Postfix:

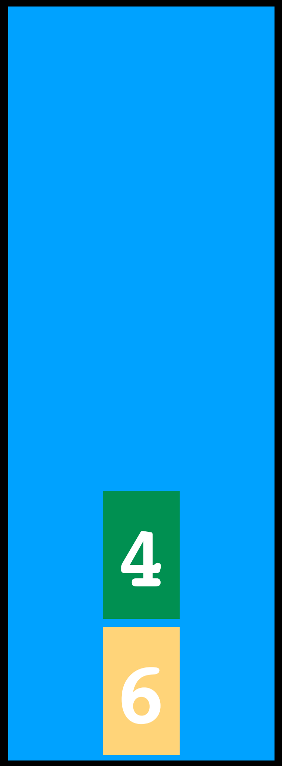
2 3 * 4 +

Evaluating Postfix Expressions

Postfix:

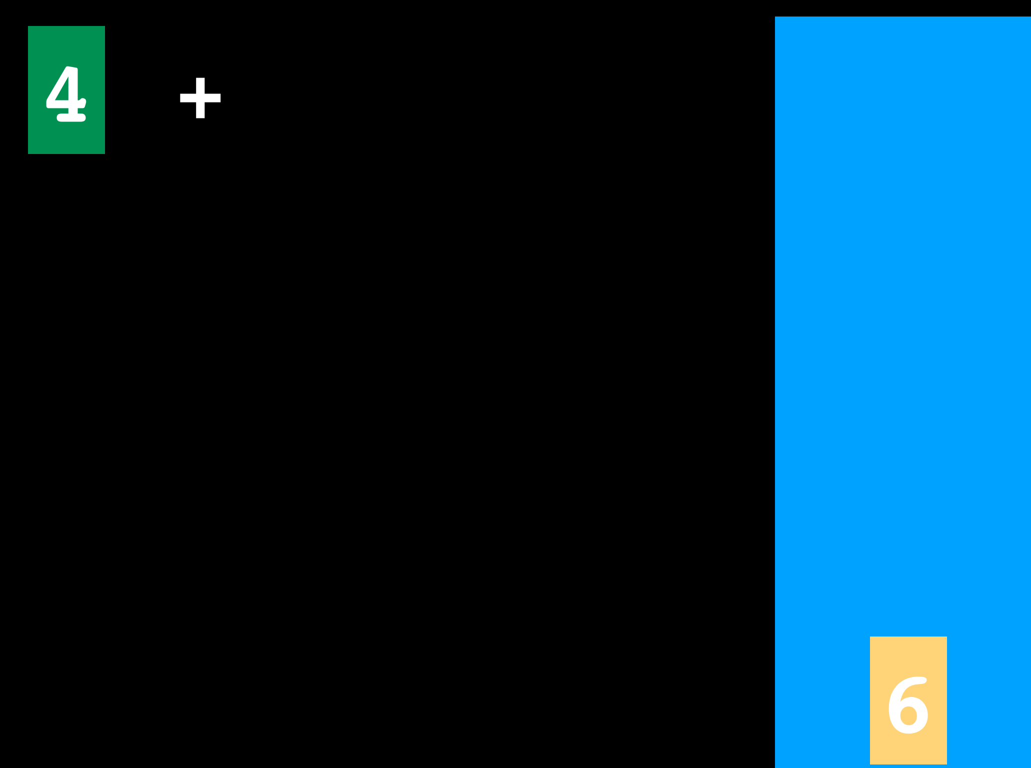
2 3 * 4 +





Evaluating Postfix Expressions

Postfix:
2 3 * 4 +



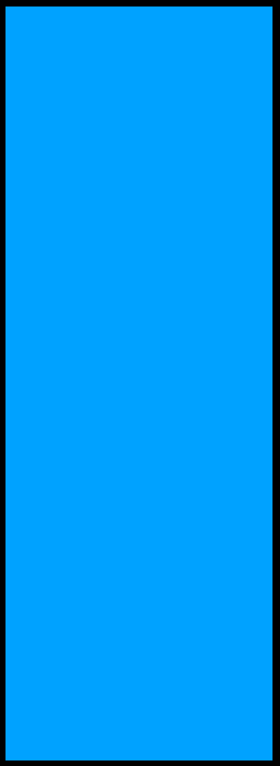
Evaluating Postfix Expressions

Postfix:

2 3 * 4 +

↑

4 + 6 = 10

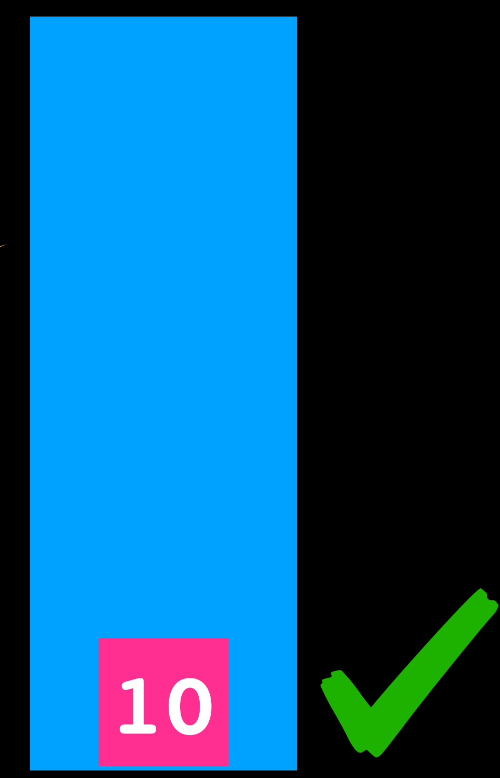


Evaluating Postfix Expressions

Postfix:

2 3 * 4 +

Done reading string
The top of the stack
is the result



Evaluating Postfix Expressions

```
for(char ch : st)
{
  if ch is an operand
      push it on the stack
  else // ch is an operator op
  {
      //evaluate and push the result
     operand2 = pop stack
     operand1 = pop stack
     result = operand1 op operand2
     push result on stack
   }
}
```

O(n)

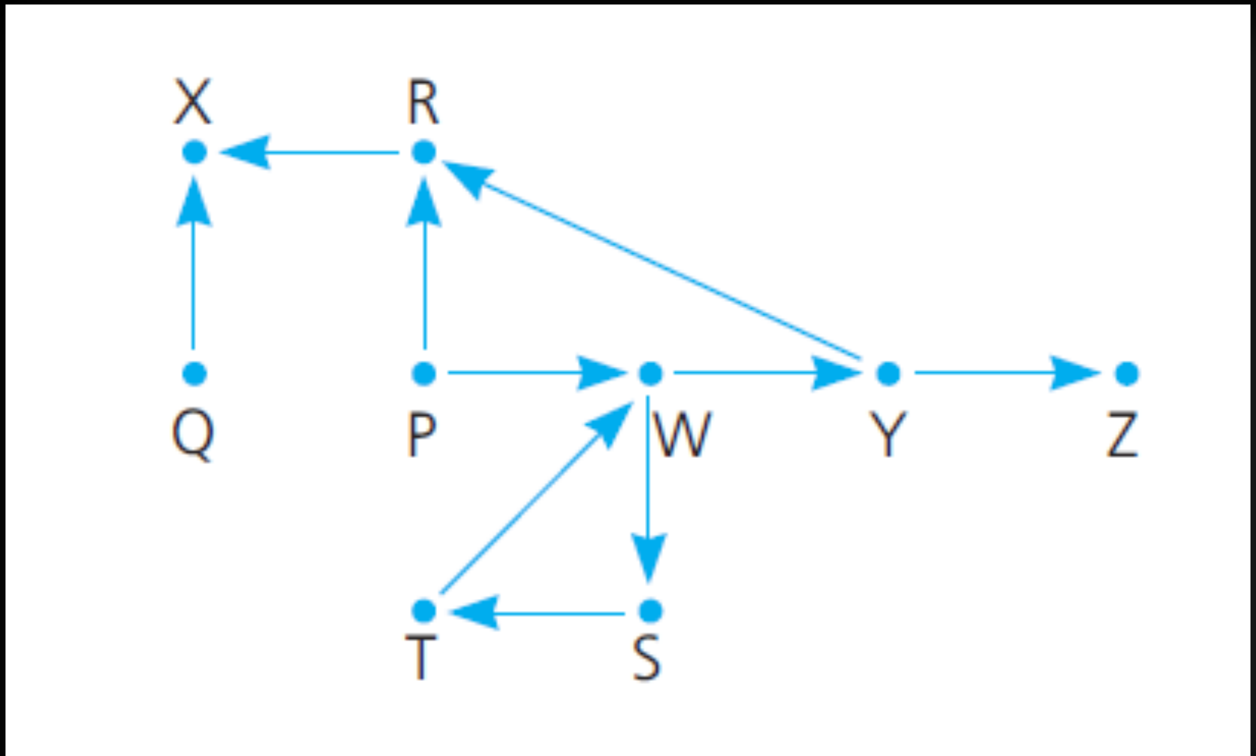
Search a Flight Map

Fly from Origin to Destination following map

1. Reach destination

2. Reach city with no departing flights (dead end)

3. Go in circles forever



Backtracking

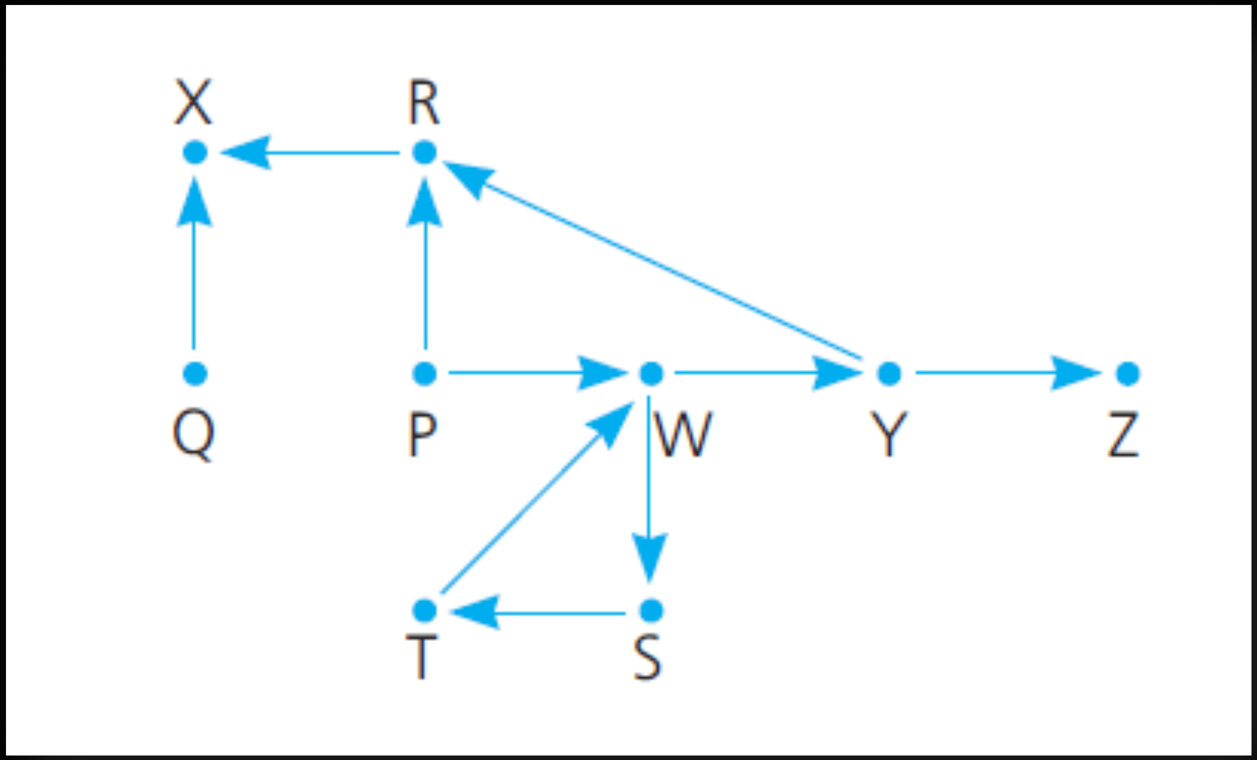
C = visited

C = backtracked

Avoid dead end by backtracking

Avoid traveling in circles by marking visited cities

Origin = P , Destination = Z



P

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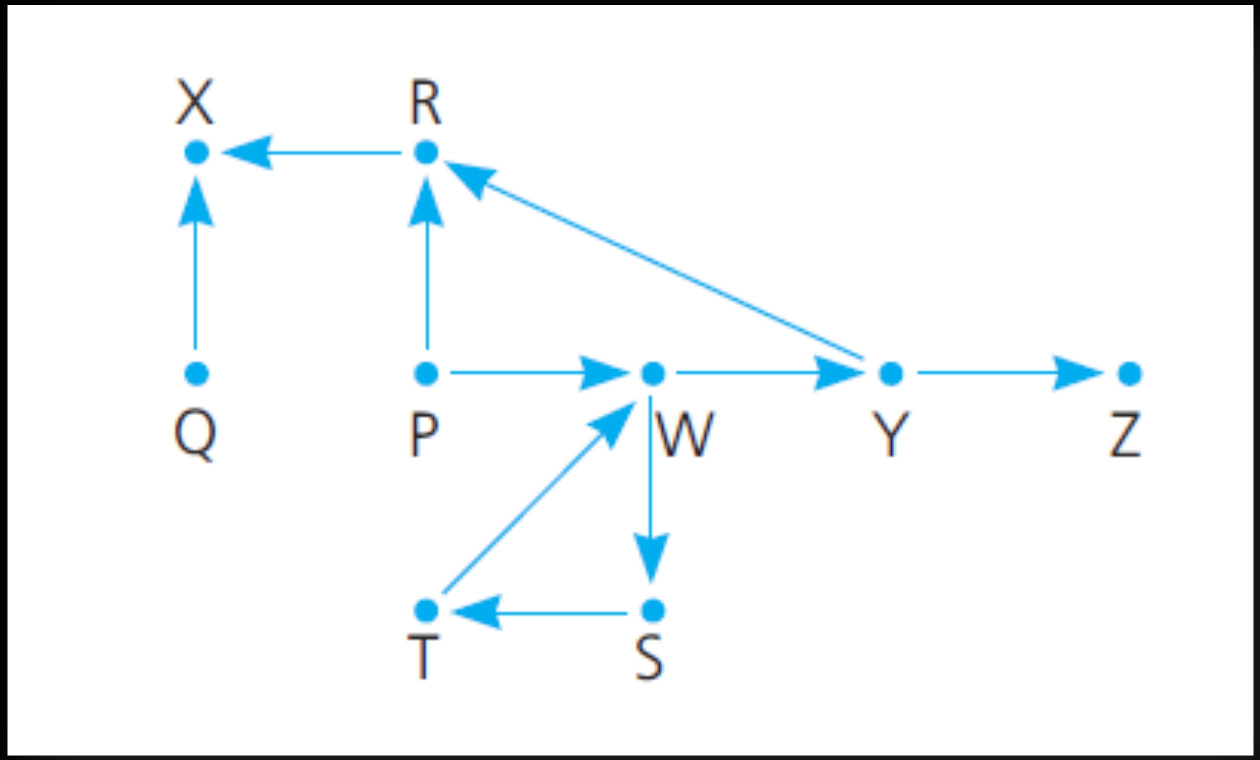

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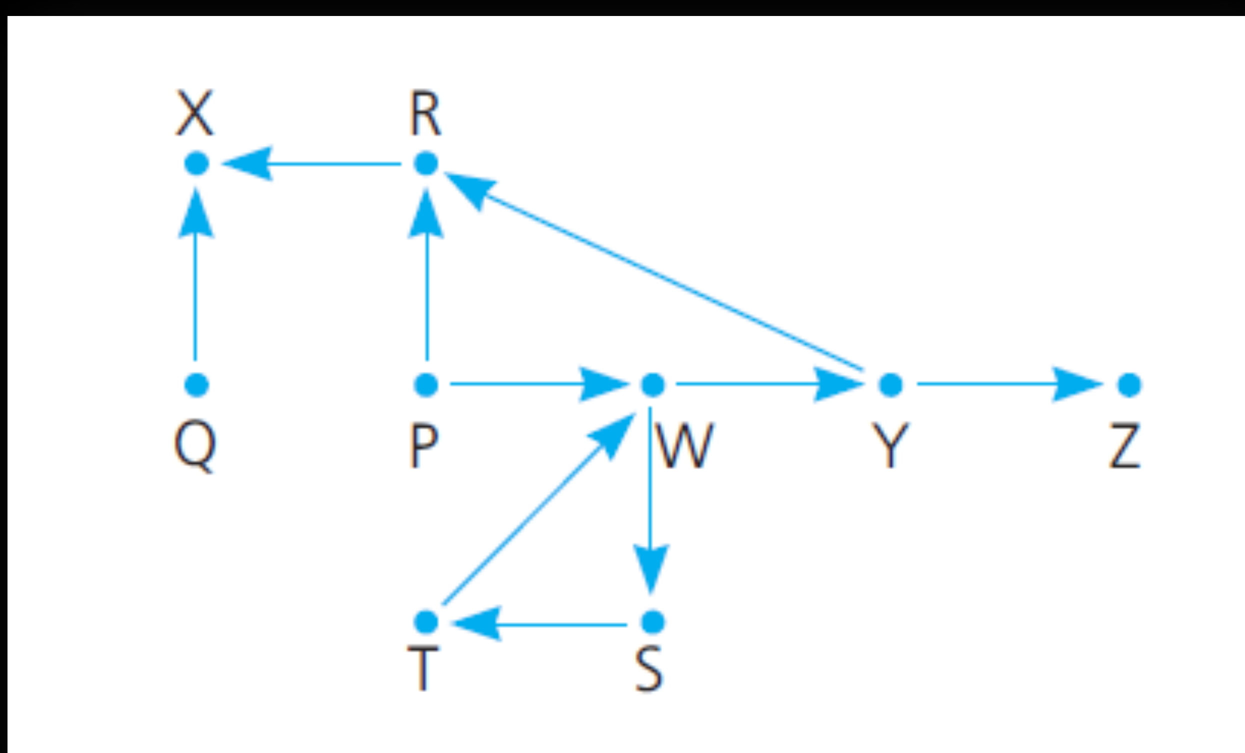

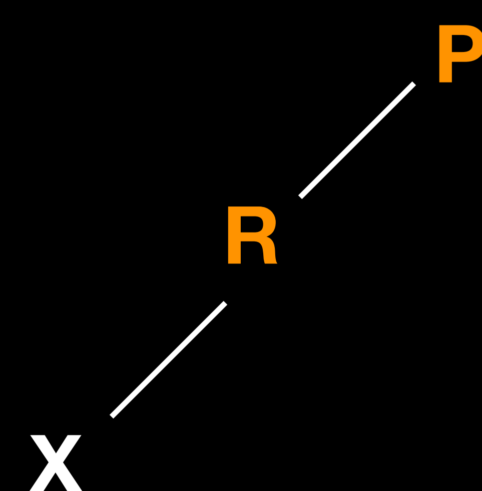

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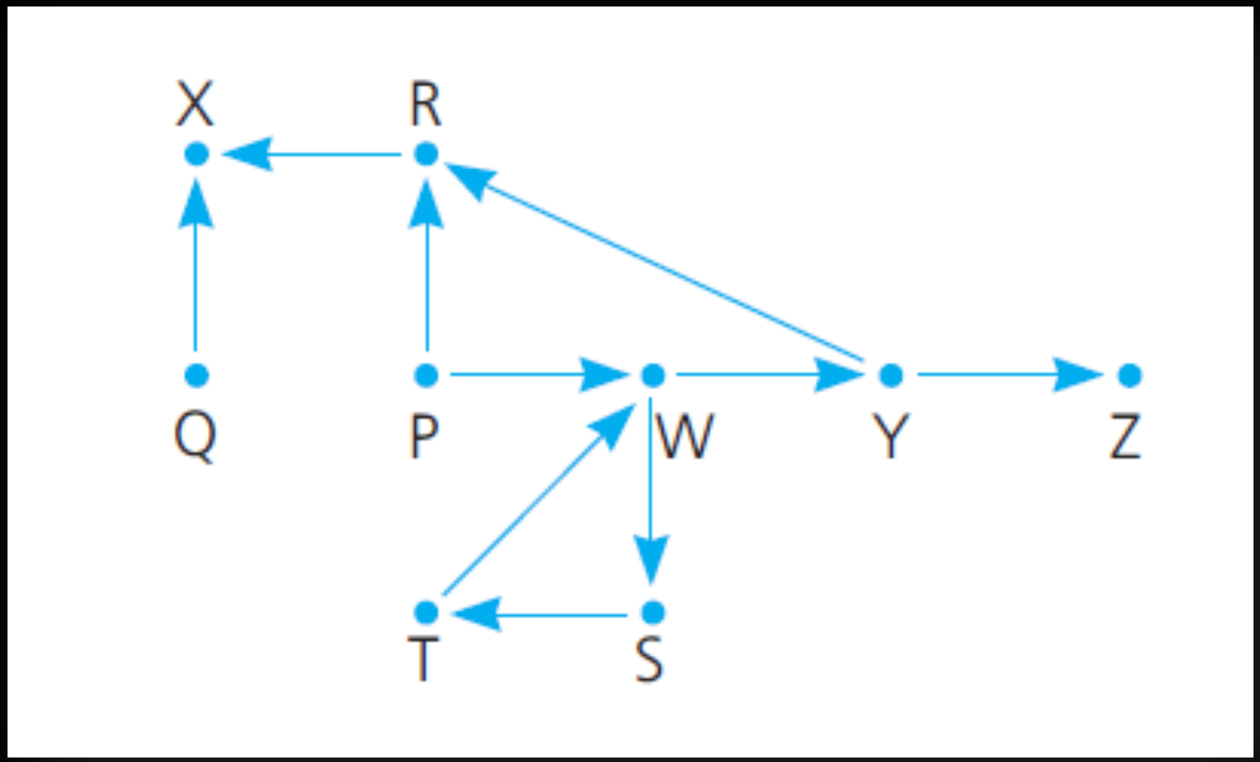

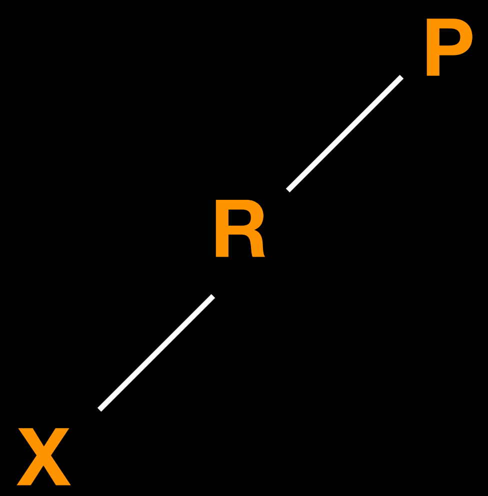

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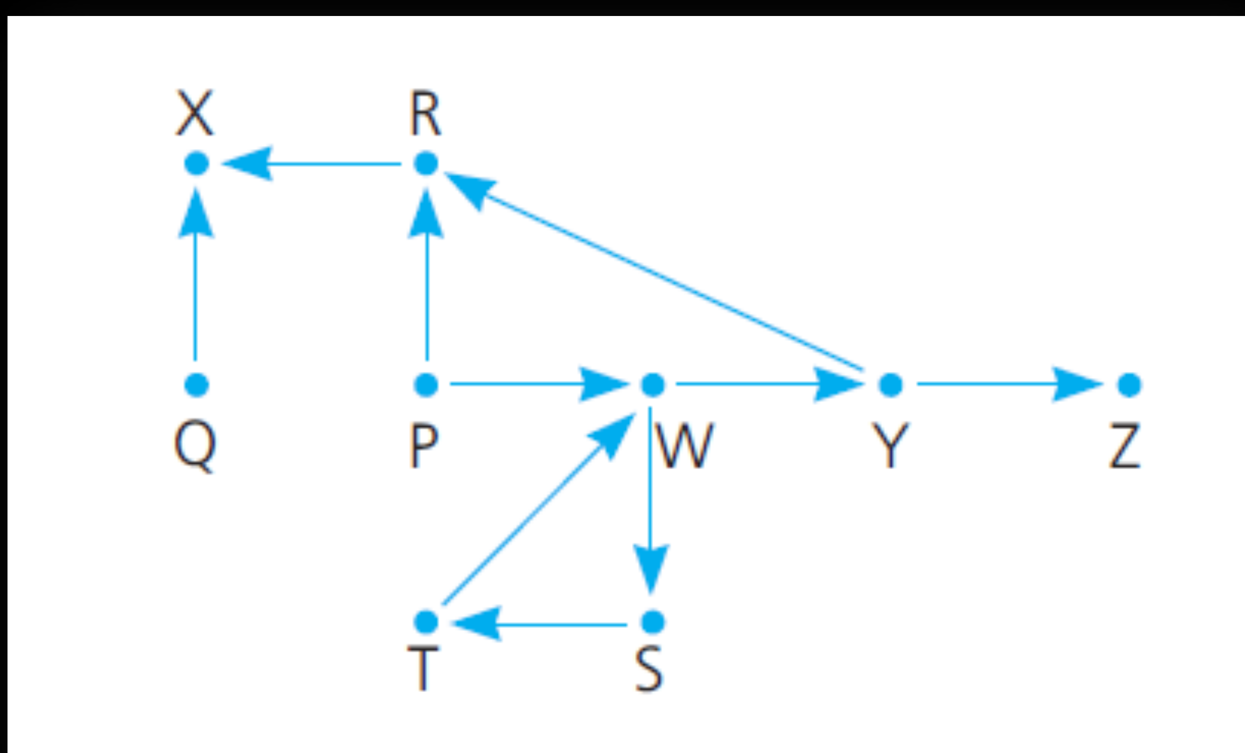

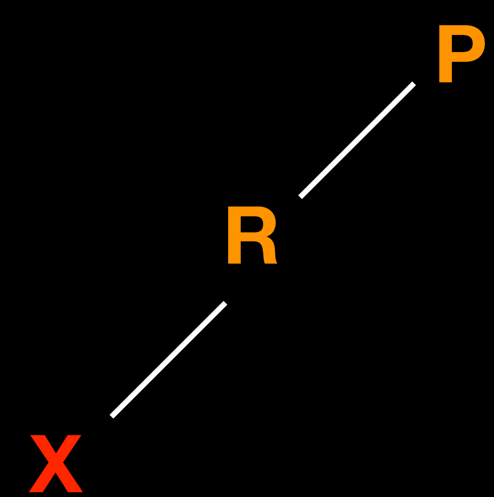

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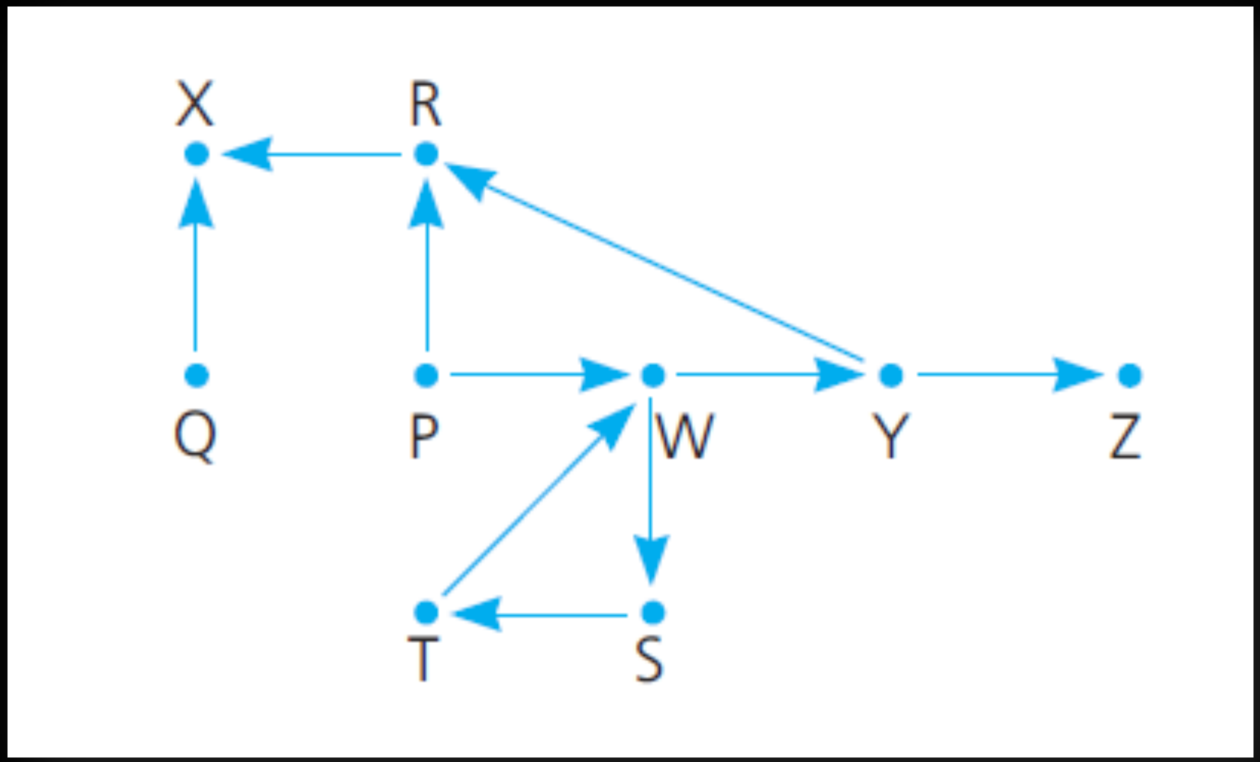

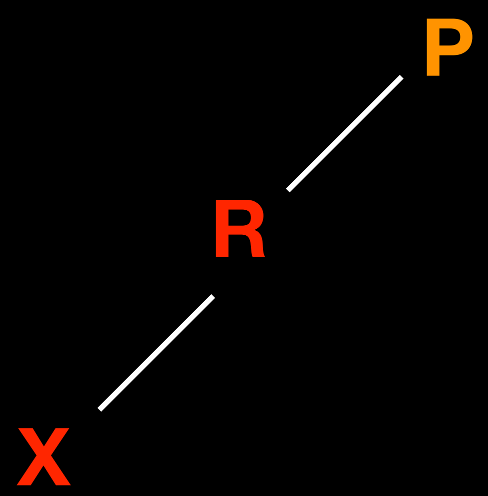

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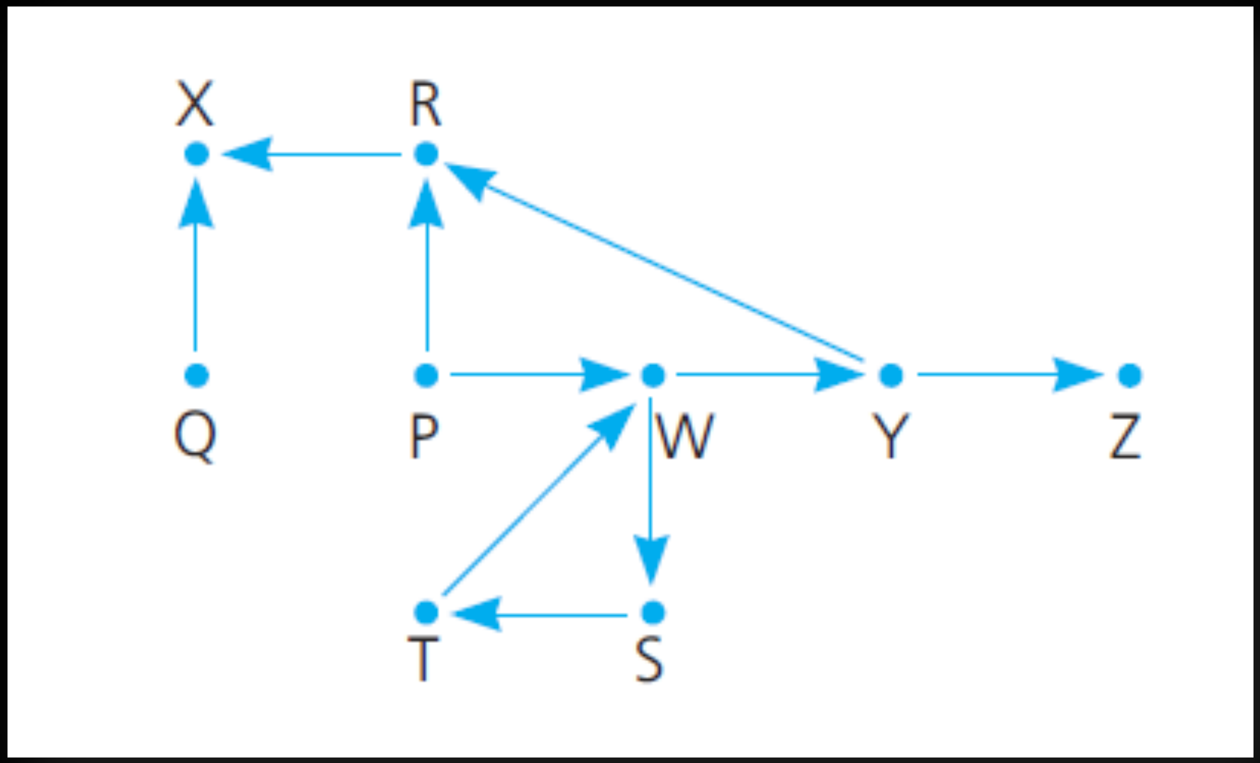

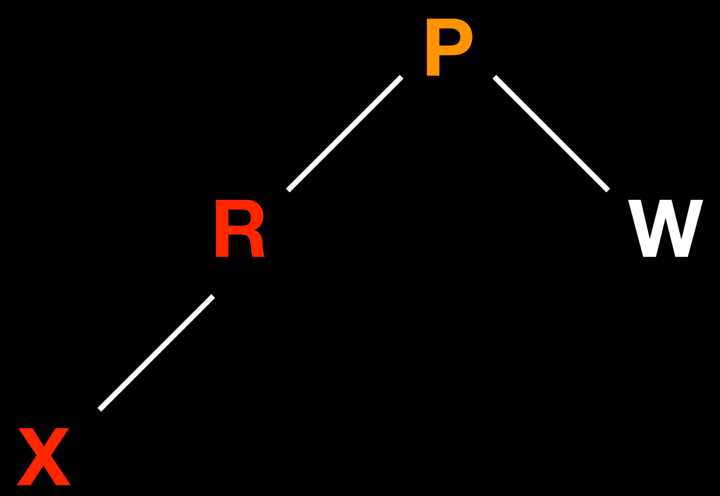

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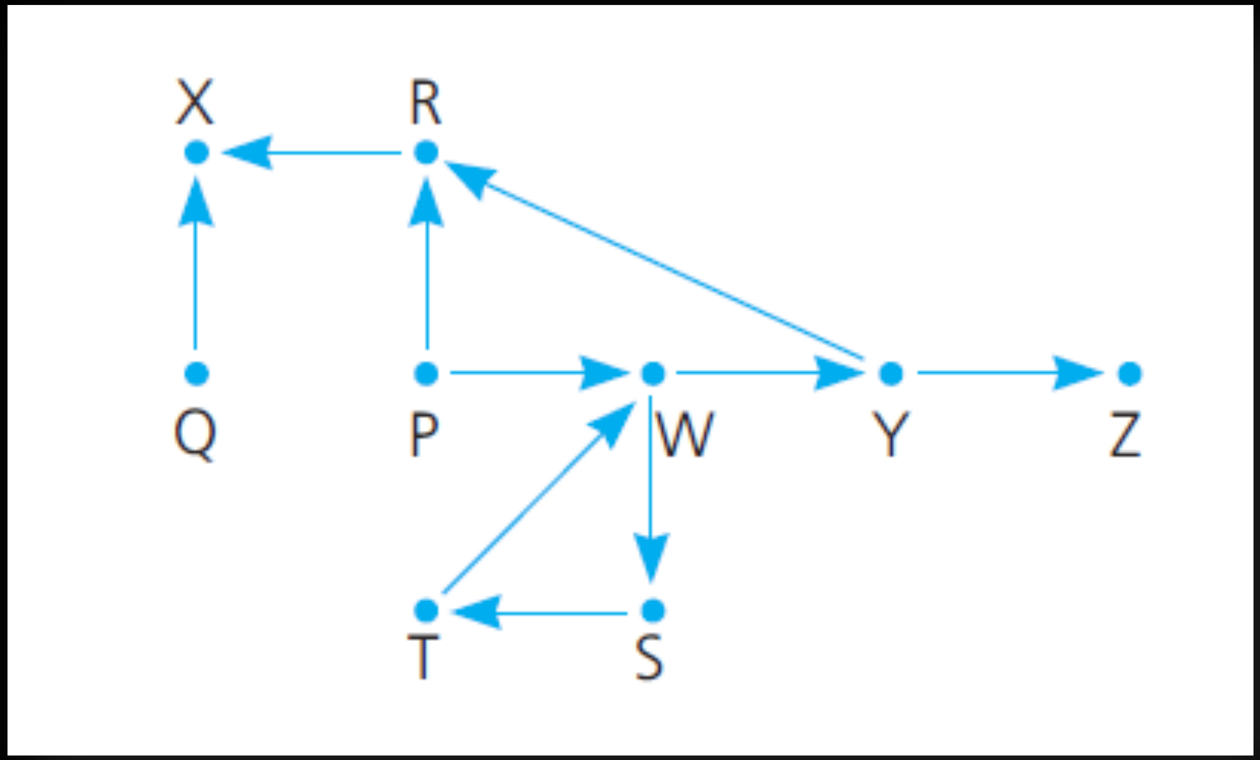

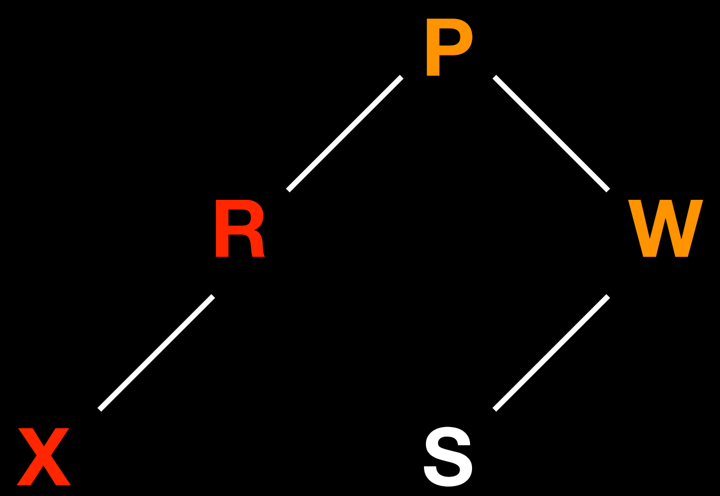

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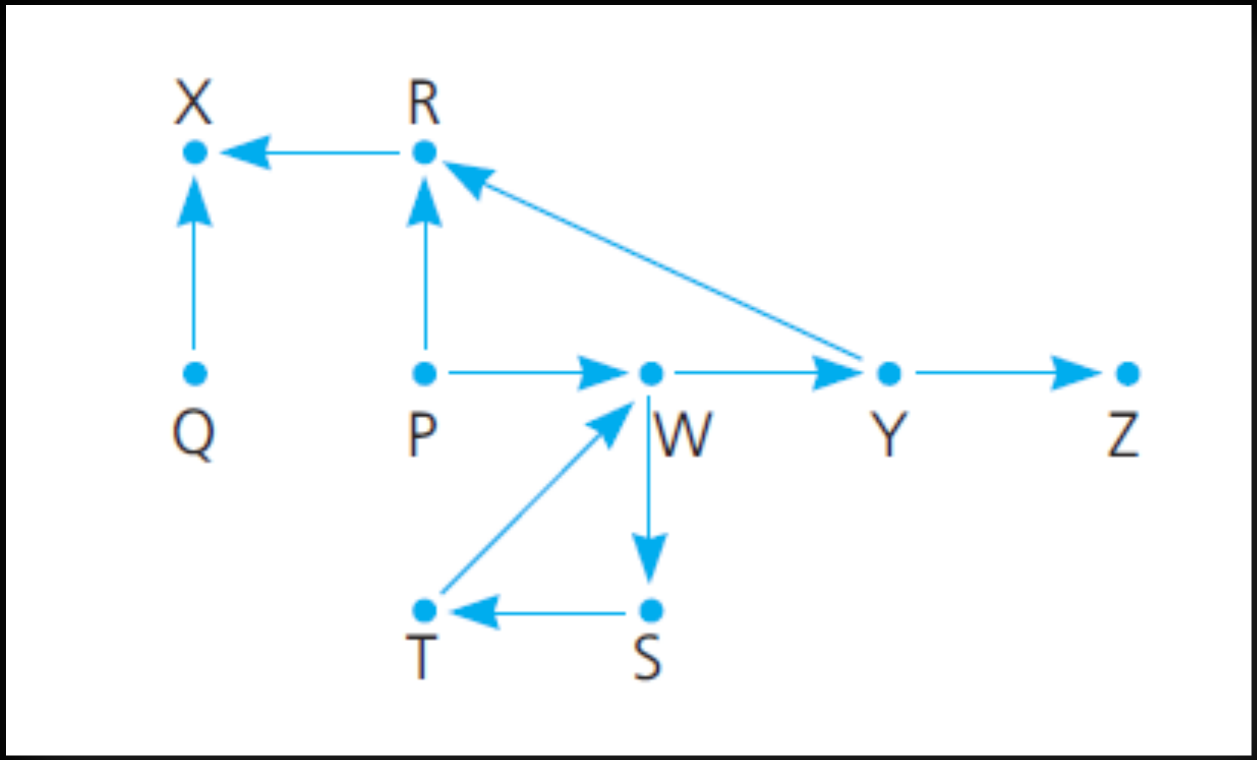

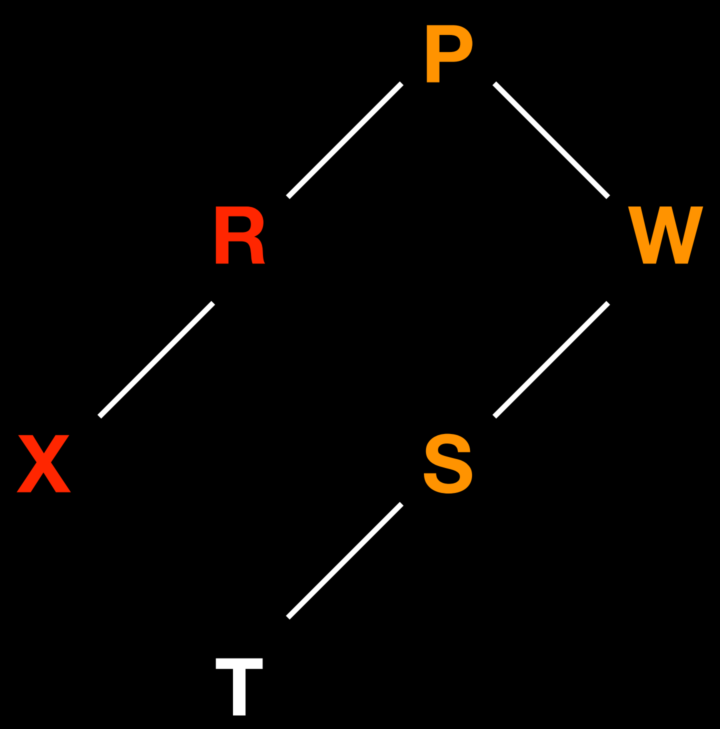

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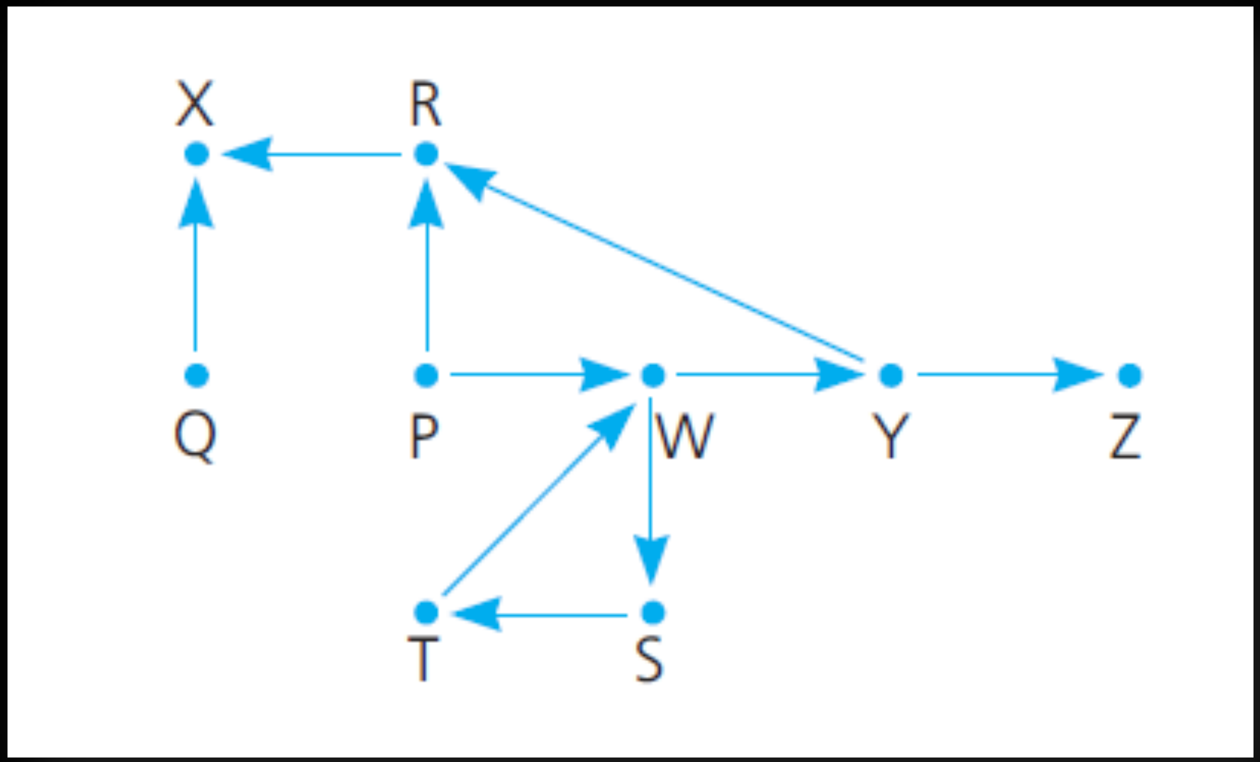

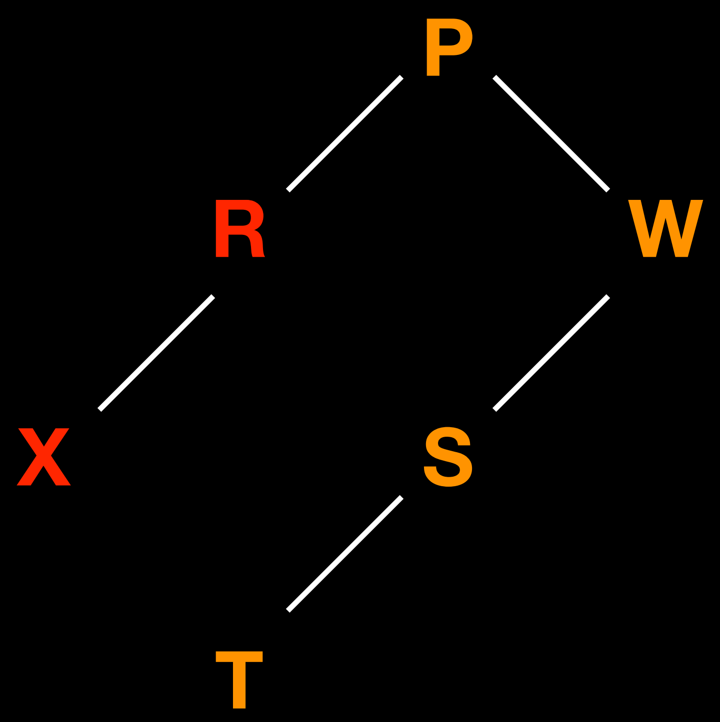

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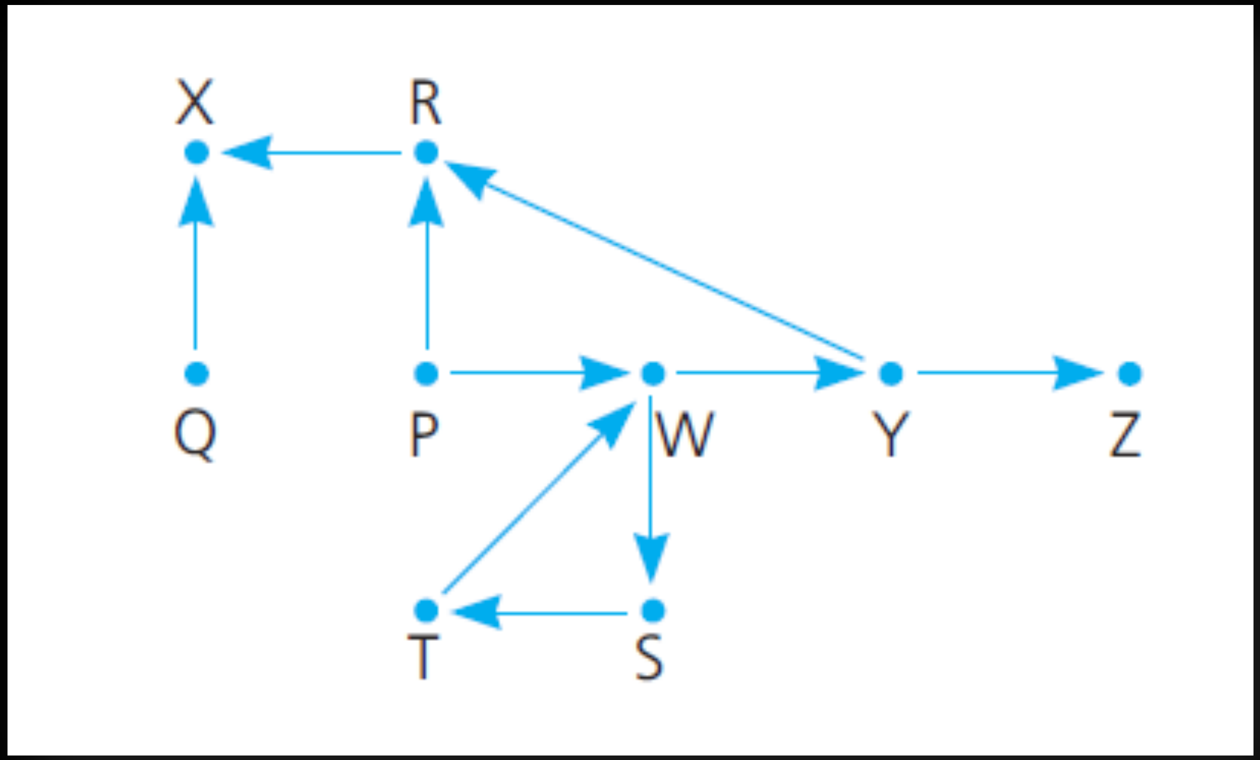

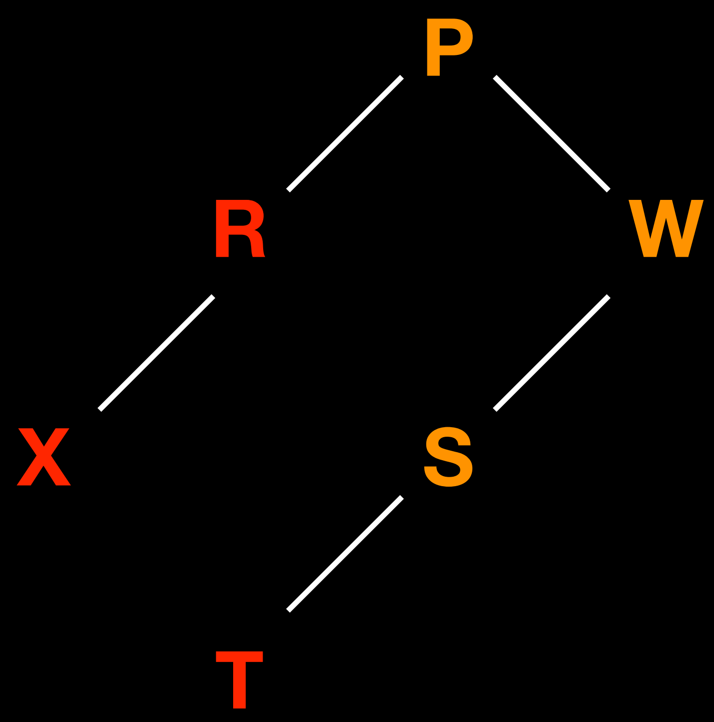

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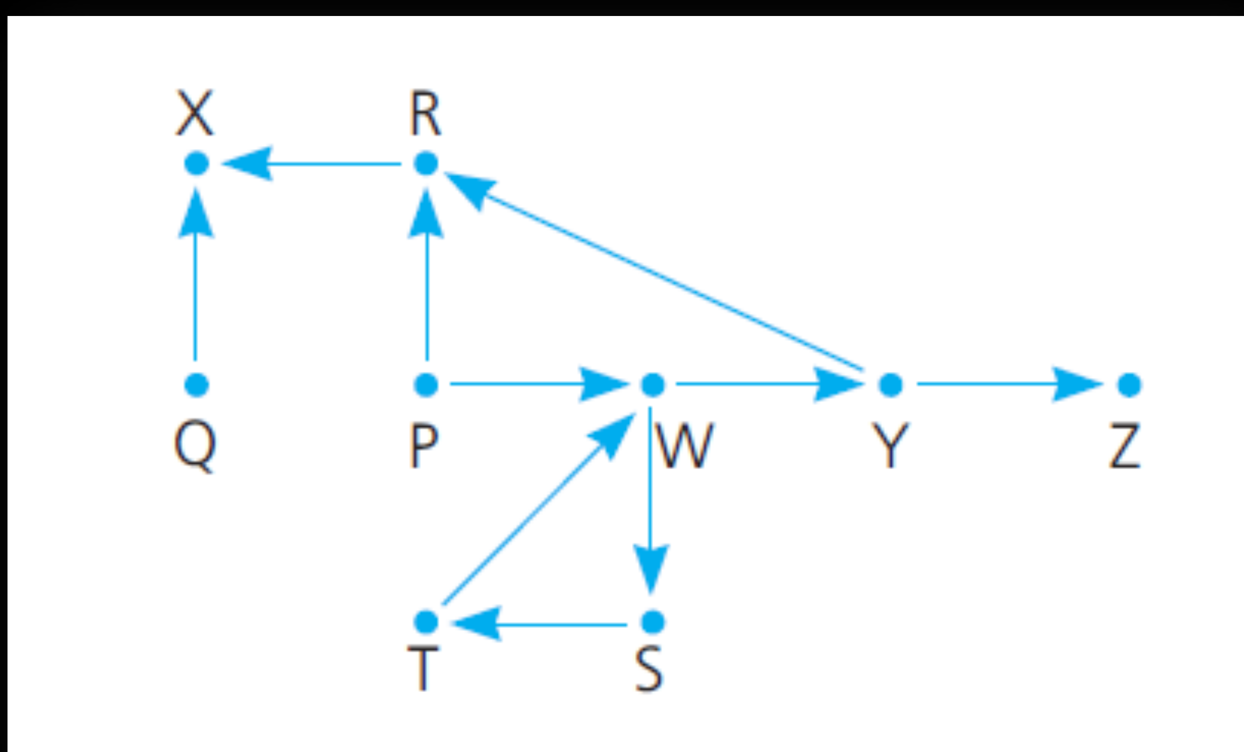

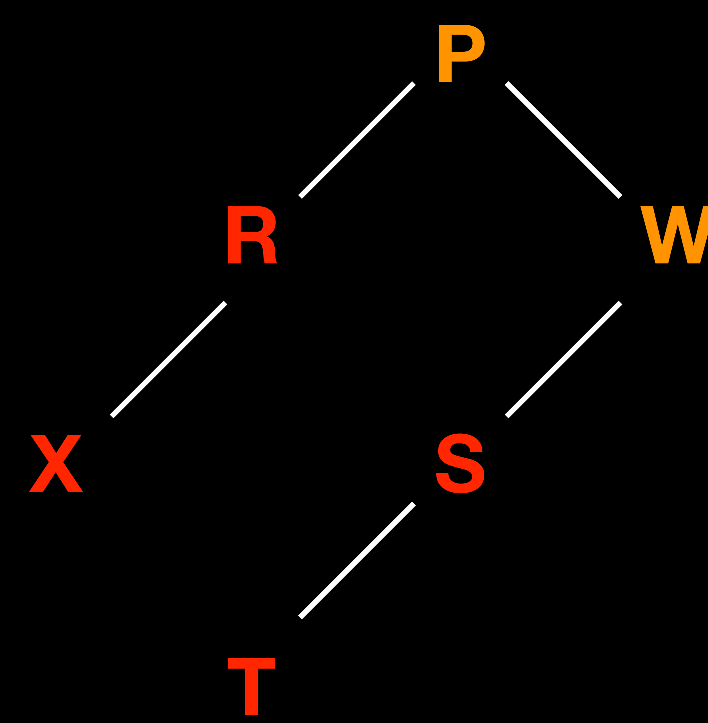

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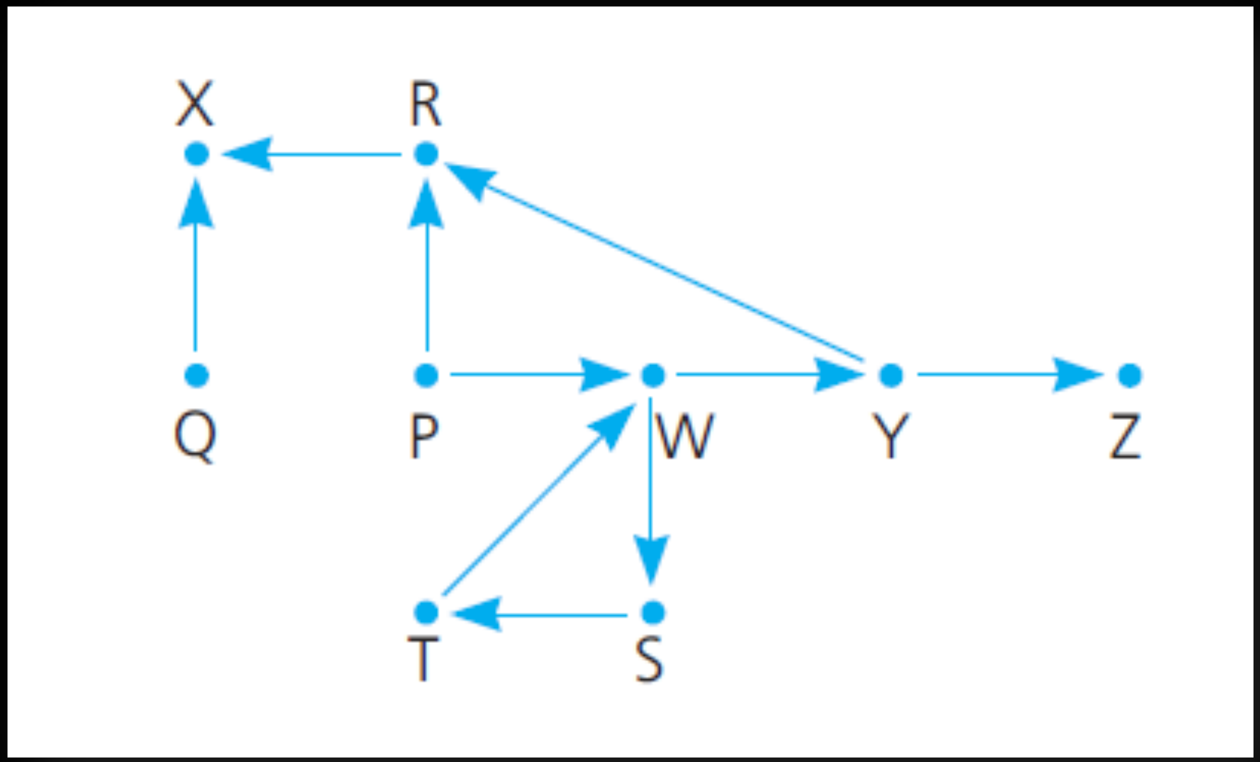

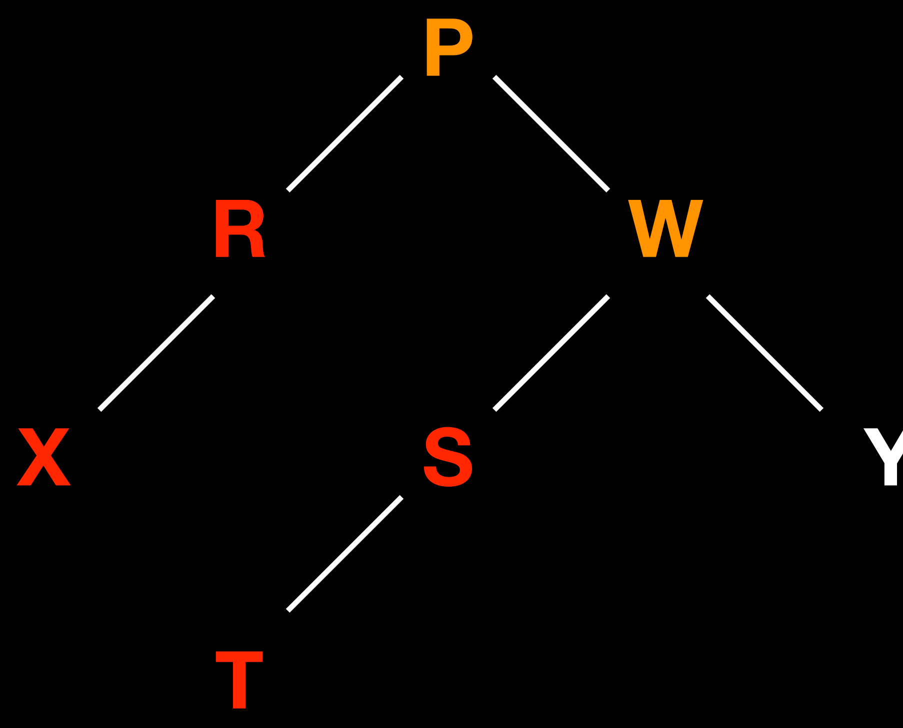

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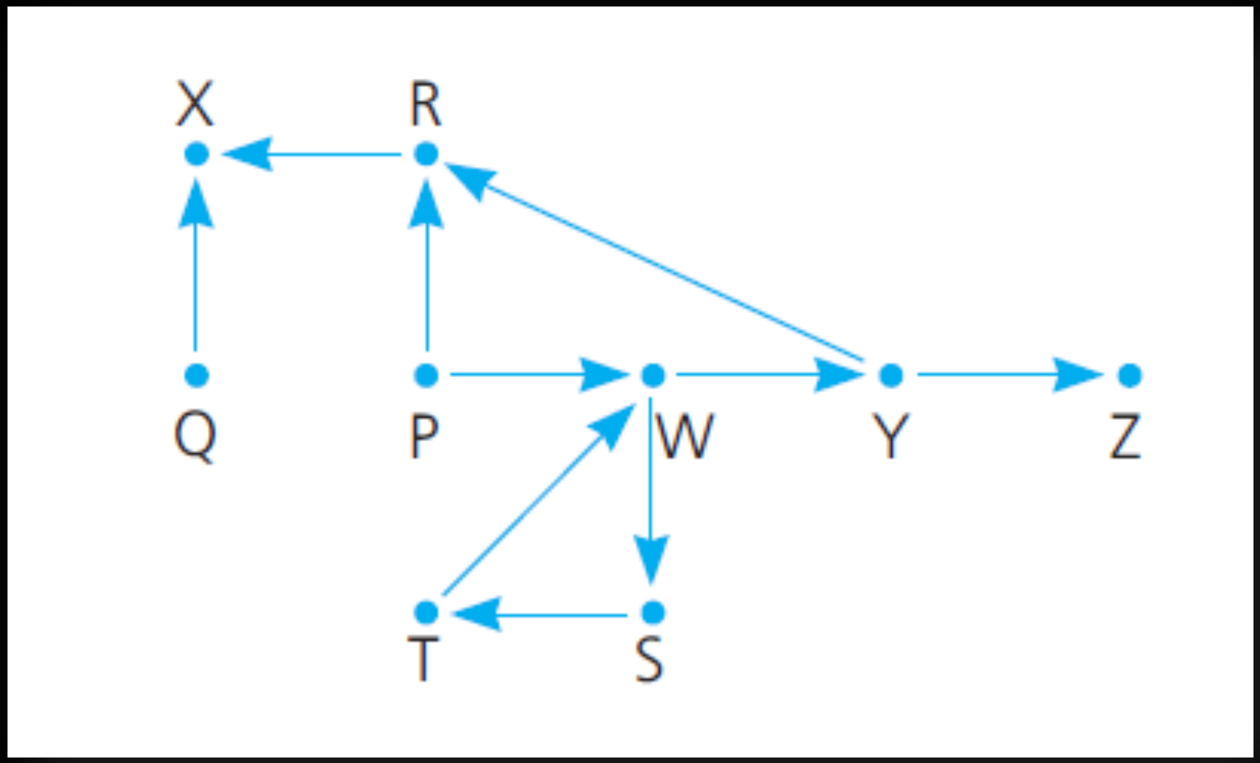

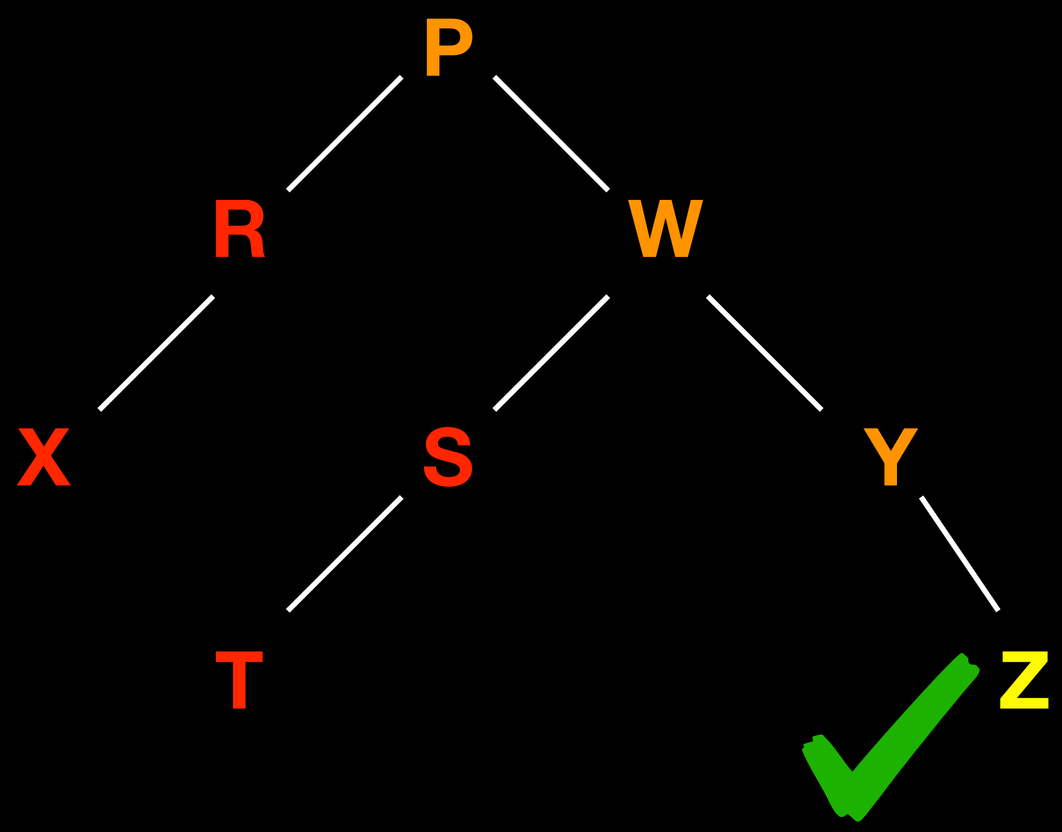

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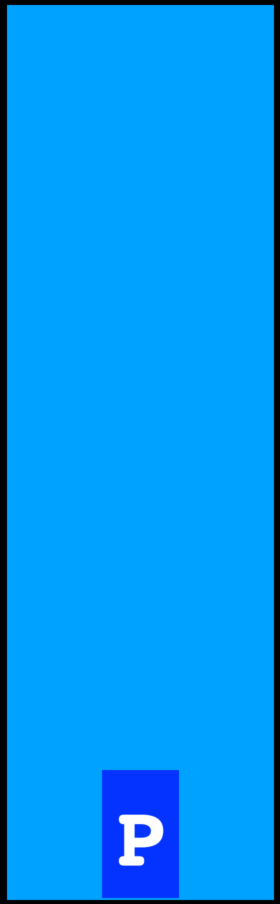

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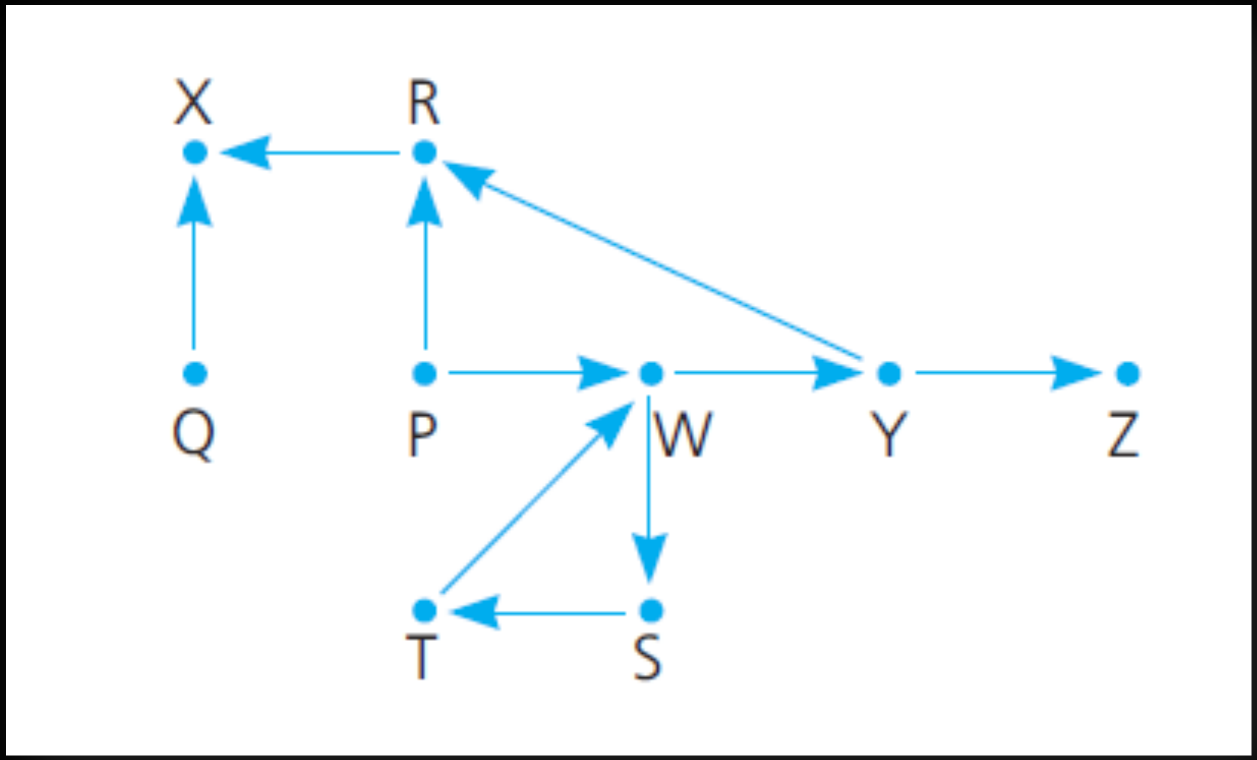

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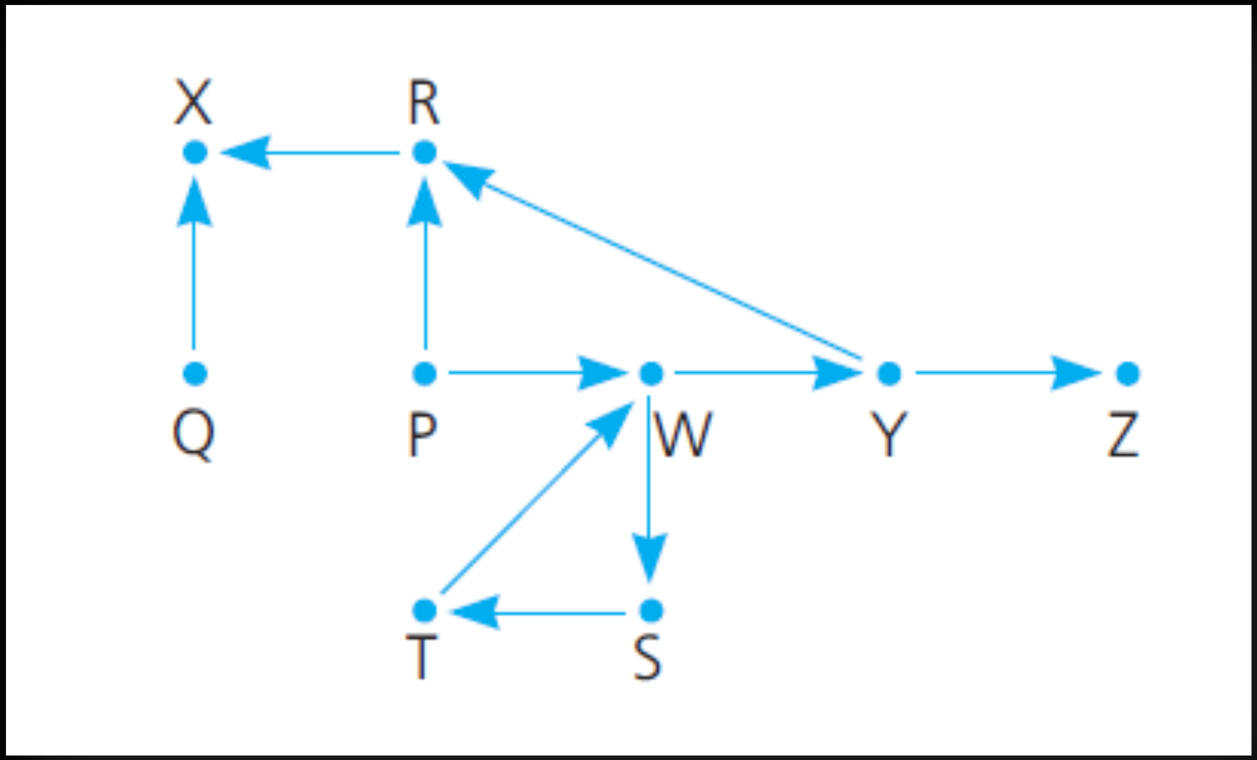

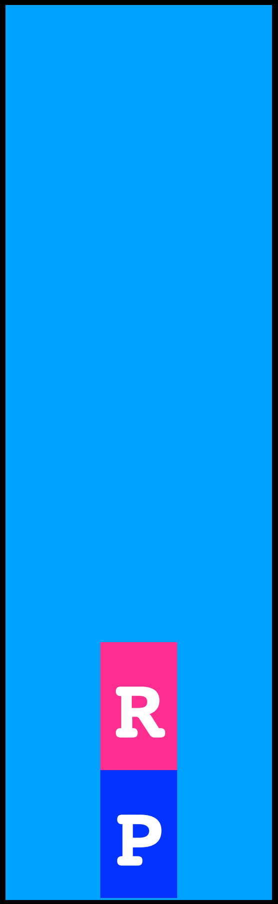

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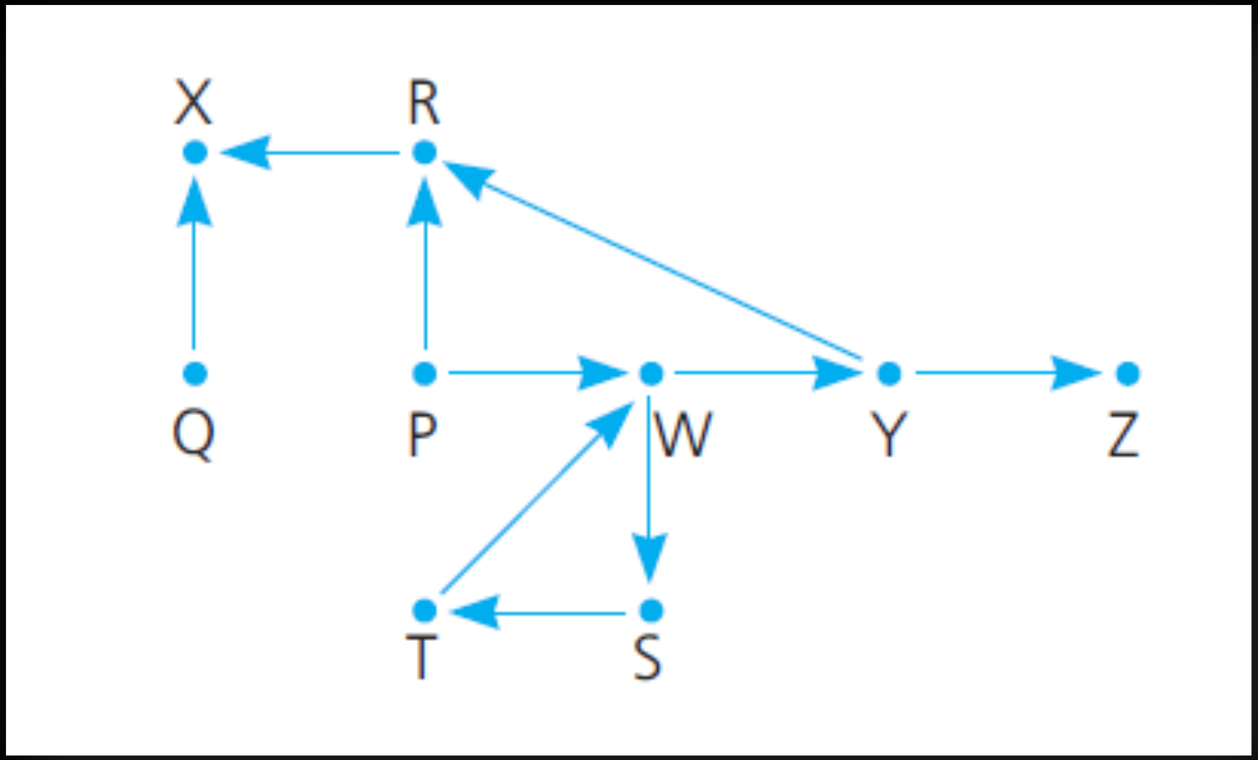

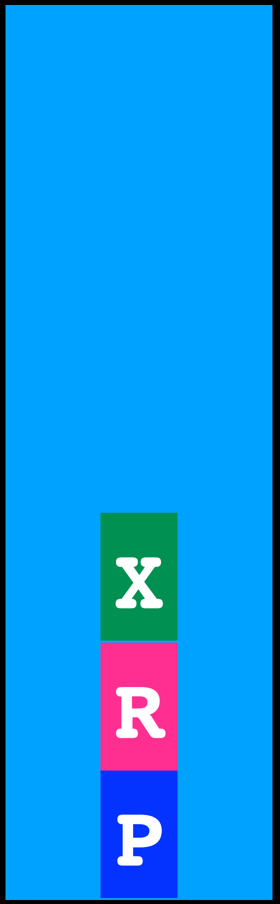

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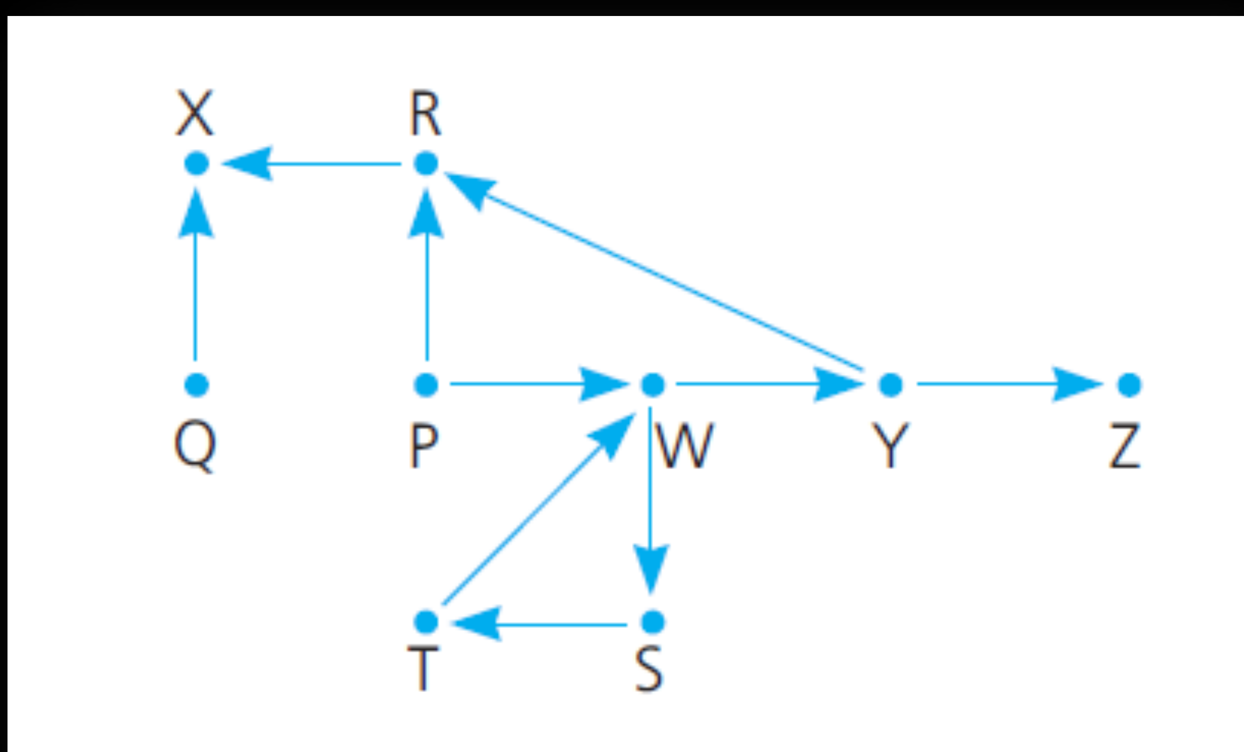
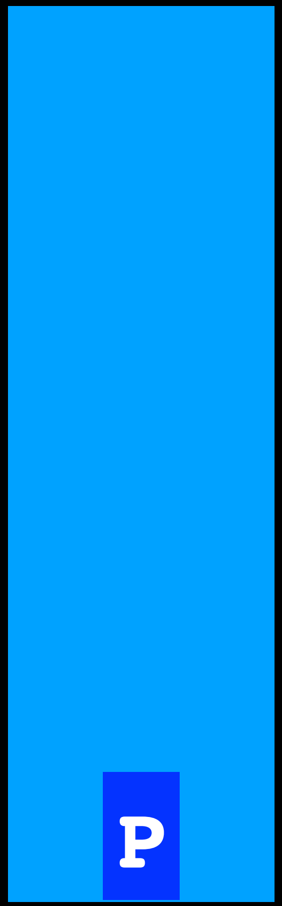


Backtracking



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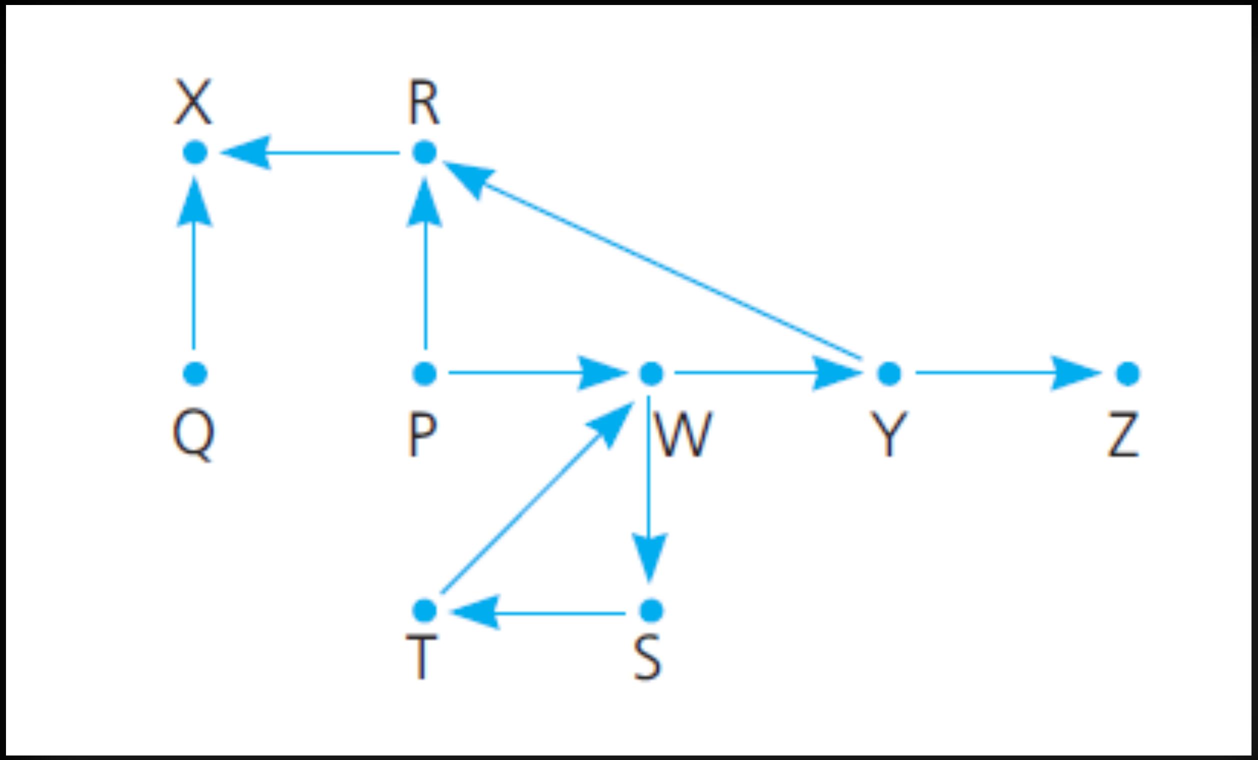
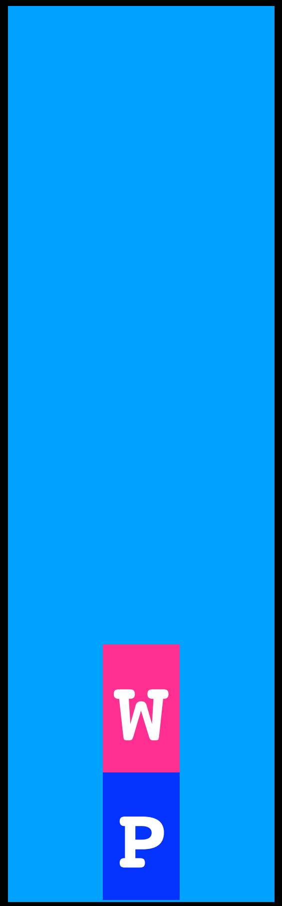


Backtracking



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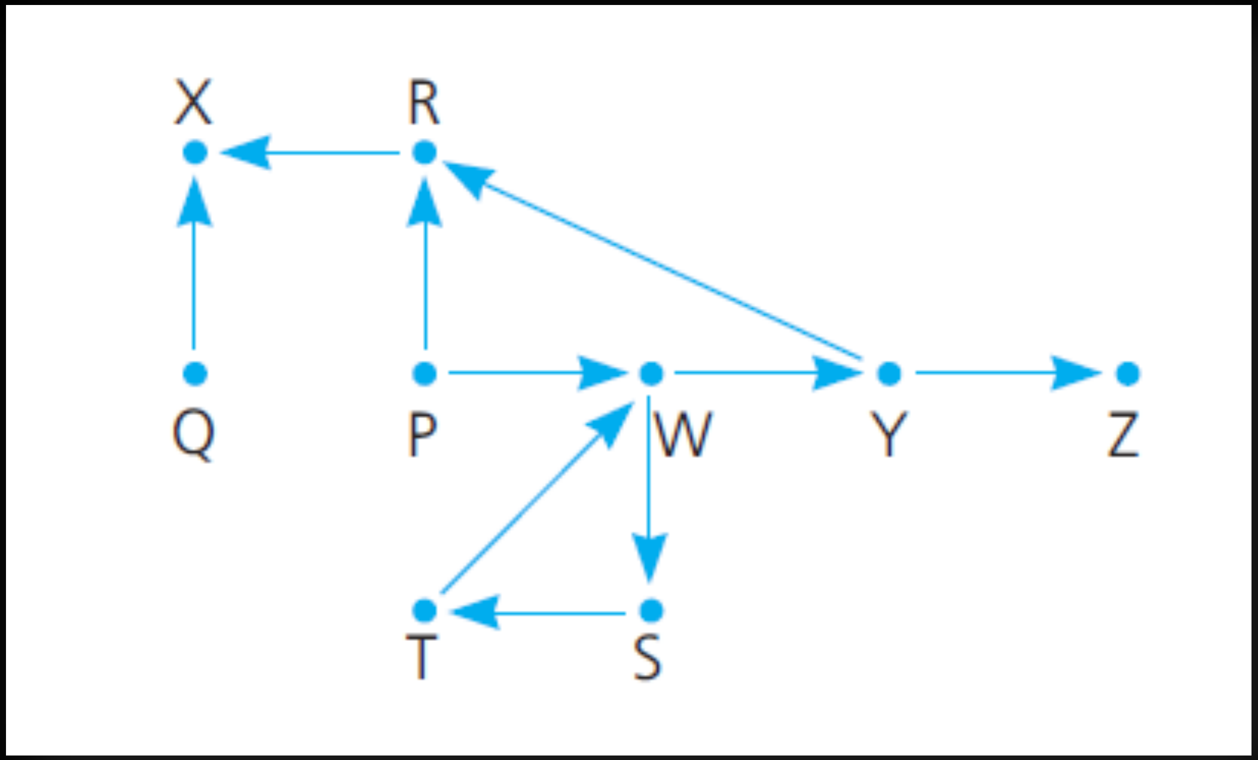

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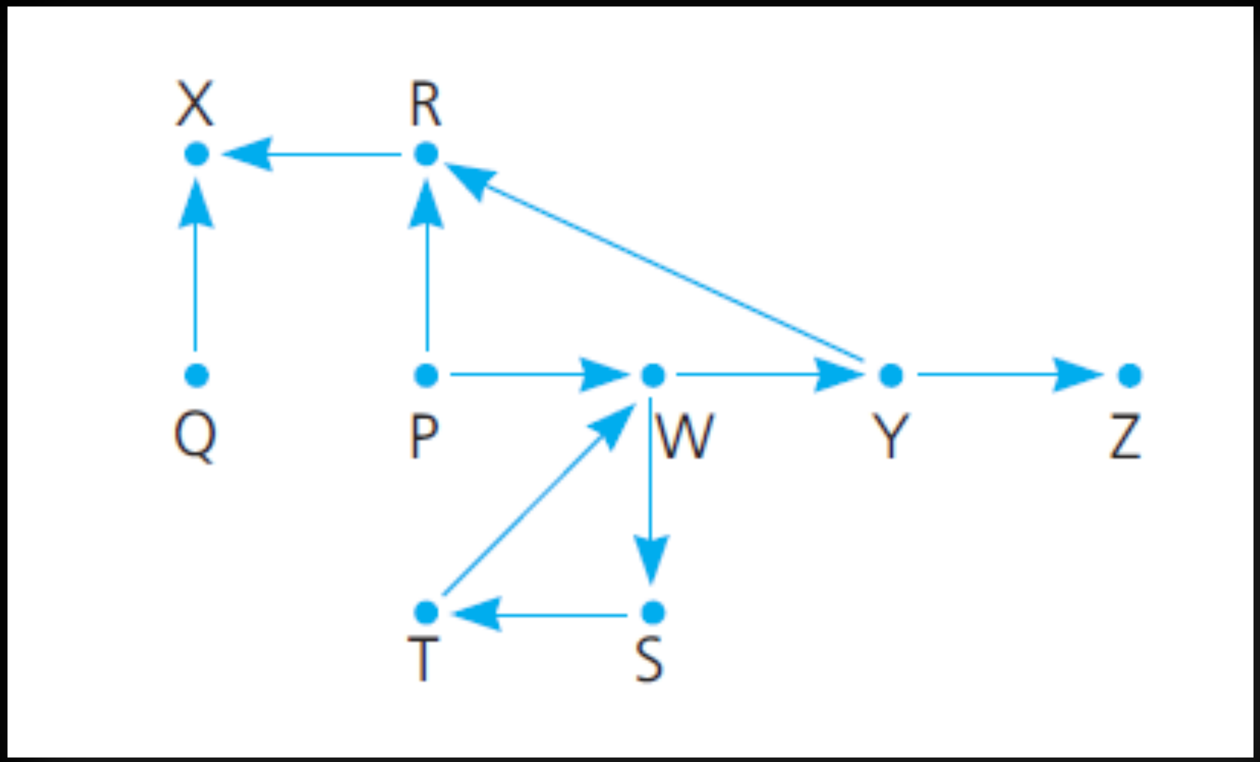

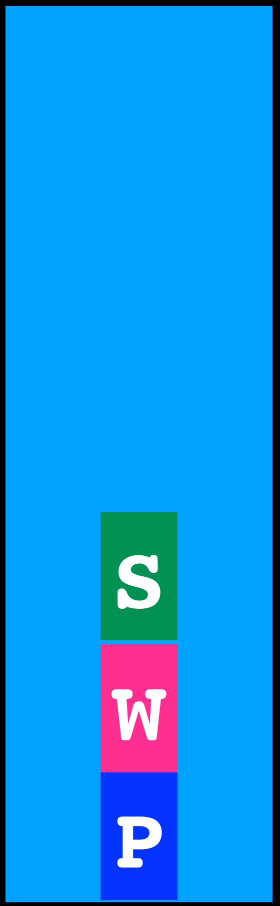

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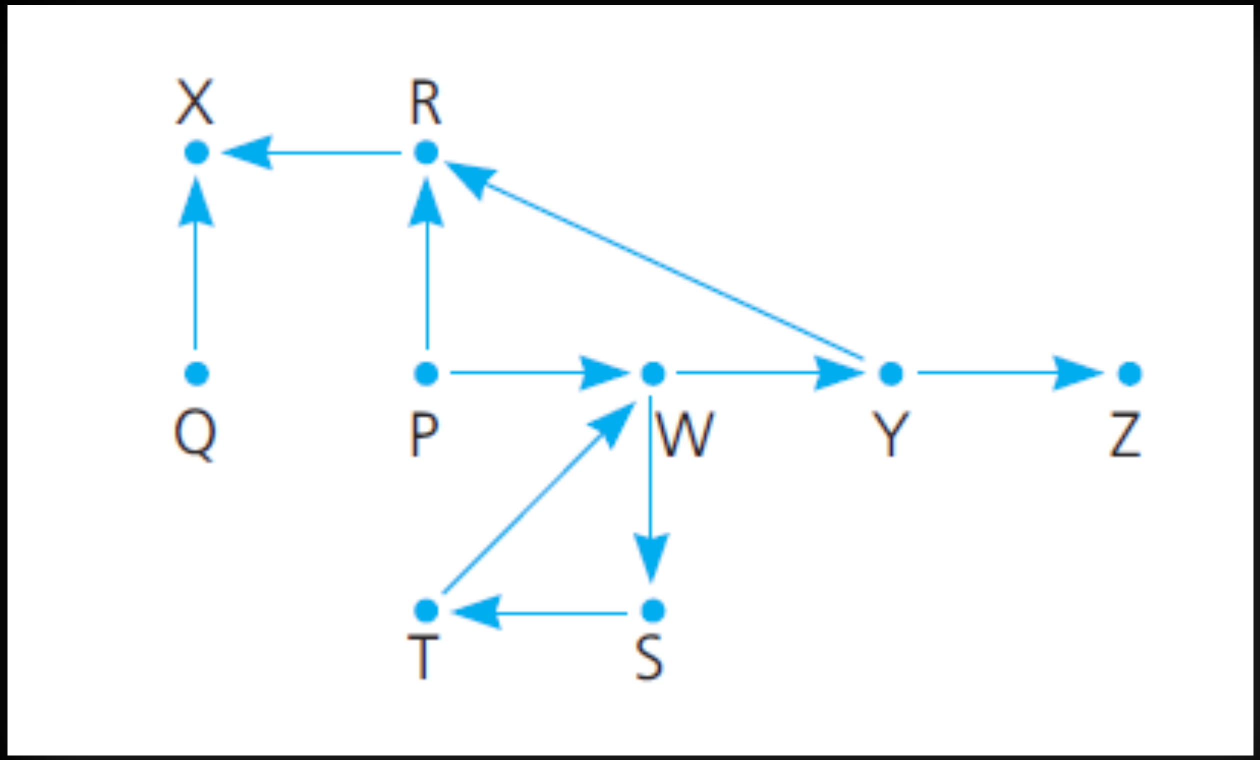

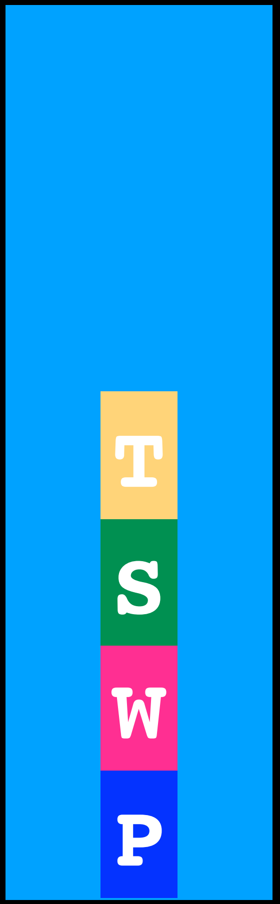

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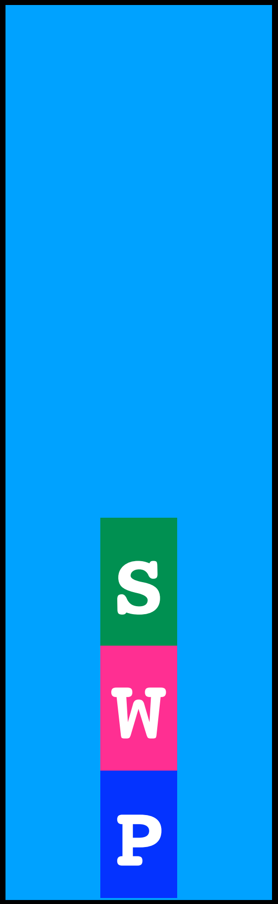

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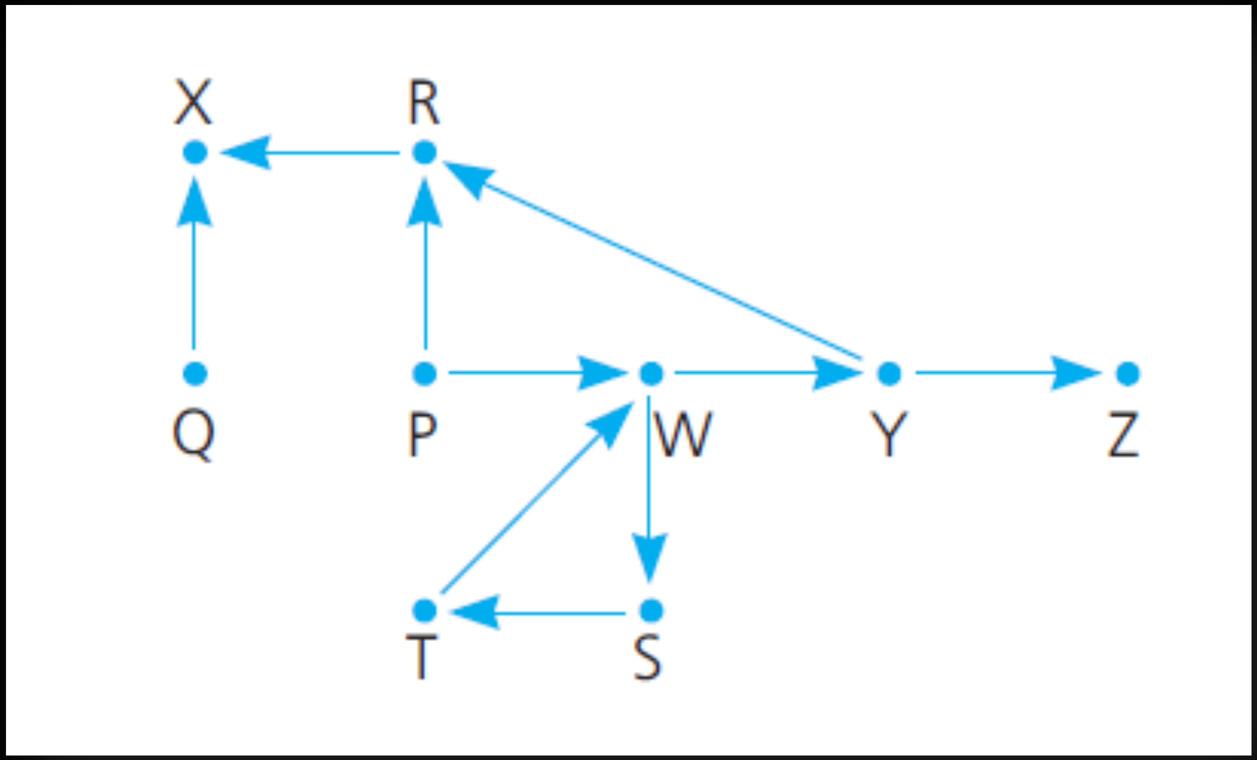

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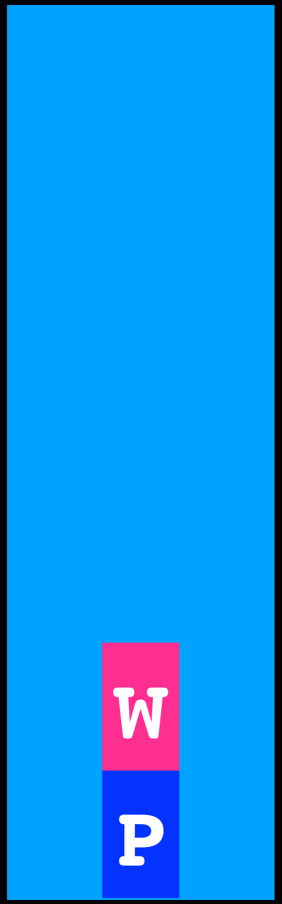

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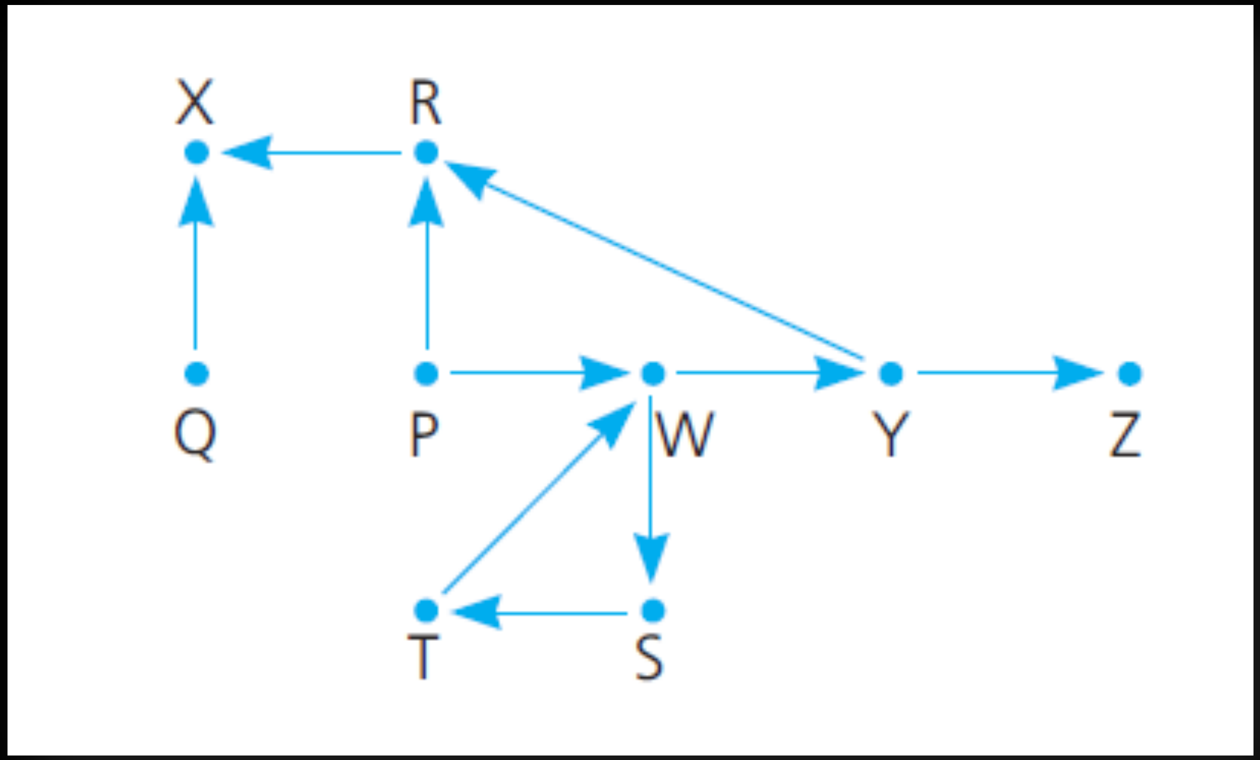

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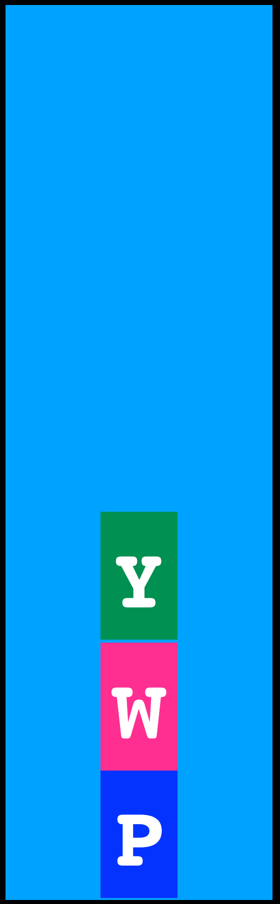

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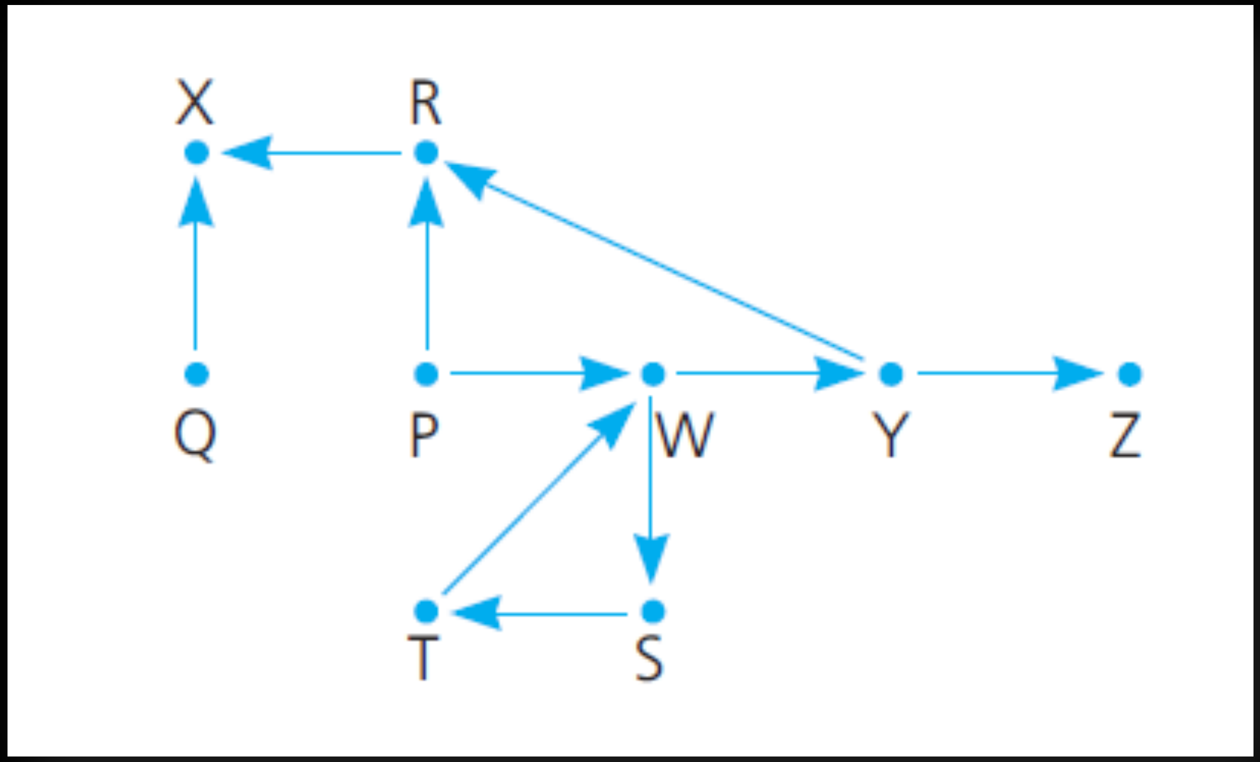

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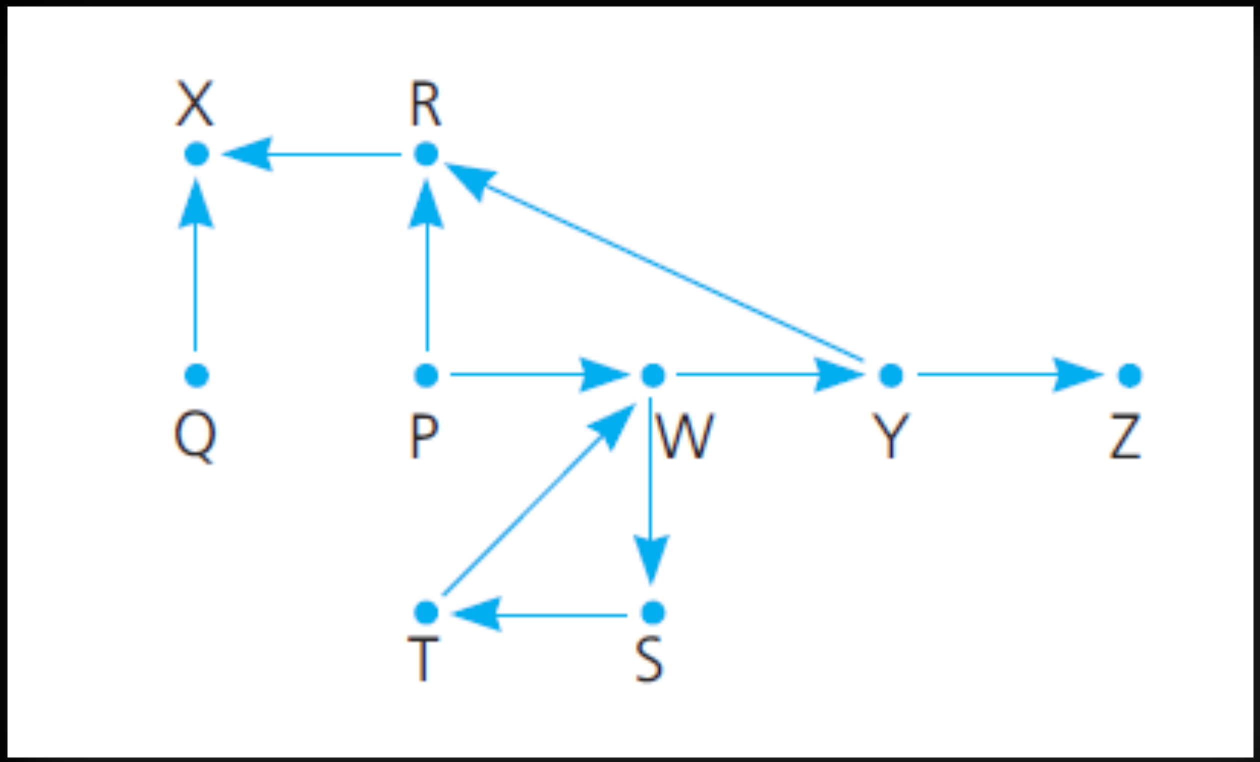

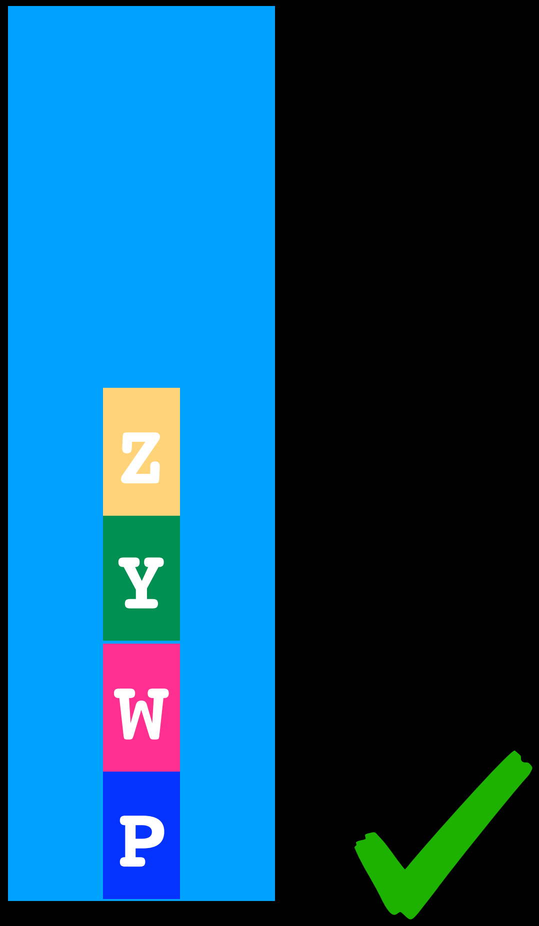

Backtracking

```
while(not found flights from origin to destination)
{
   if no flight exists from city on top of stack to
   unvisited destination
       pop the stack //BACKTRACK
   else
   {
       select an unvisited city C accessible from city
       currently at top of stack
       push C on stack
       mark C as visited
    }
}
```

Program Stack and Recursion

Recursion works because function waining for result/ return from recursive call are on program stack

Order of execution determined by **stack**

More Applications

Balancing anything!
- html tags (e.g <p> matches </p>)
- parsers in general

Reverse characters in a word or words in a sentence

Undo mechanism for editors or backups

Traversals (graphs / trees)

. . .

Stack ADT

```
#ifndef STACK_H_
#define STACK_H_

template<class T>
class Stack
{

public:
    Stack();
    void push(const T& new_entry); // adds an element to top of stack
    void pop(); // removes element from top of stack
    T top() const; // returns a copy of element at top of stack
    int size() const; // returns the number of elements in the stack
    bool isEmpty() const; // returns true if no elements on stack false otherwise

private:
          //implementation details here


};    //end Stack

#include "Stack.cpp"
#endif // STACK_H_`
```

Abstract Data Types

Bag

List

Stack

Queue

Queue

An ADT representing a waiting line

Objects can be enqueued to the back of the line

or dequeued from the front of the line

Queue

An ADT representing a waiting line

Objects can be enqueued to the back of the line

or dequeued from the front of the line

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Queue

An ADT representing a waiting line

Objects can be enqueued to the back of the line

or dequeued from the front of the line

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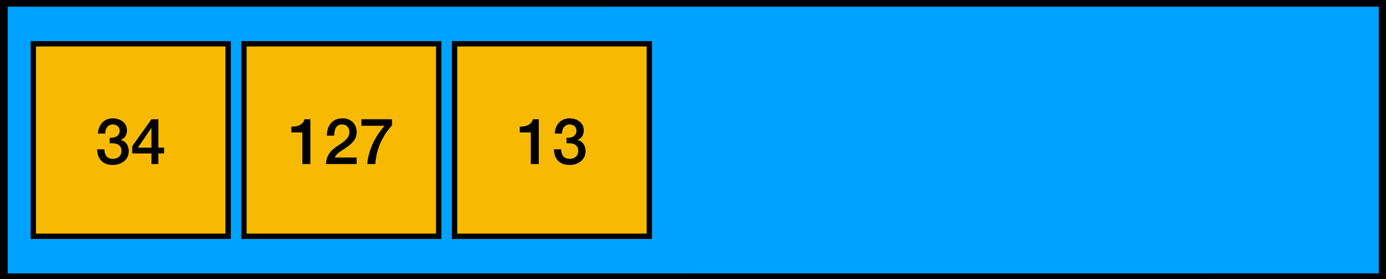

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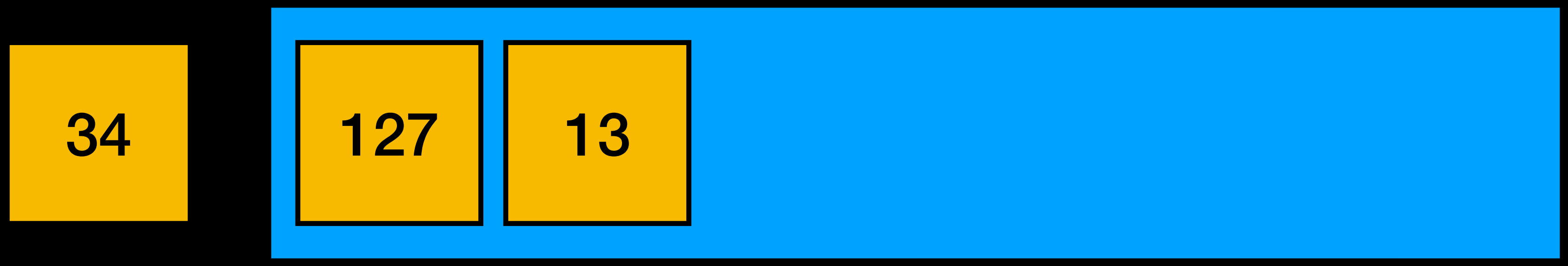

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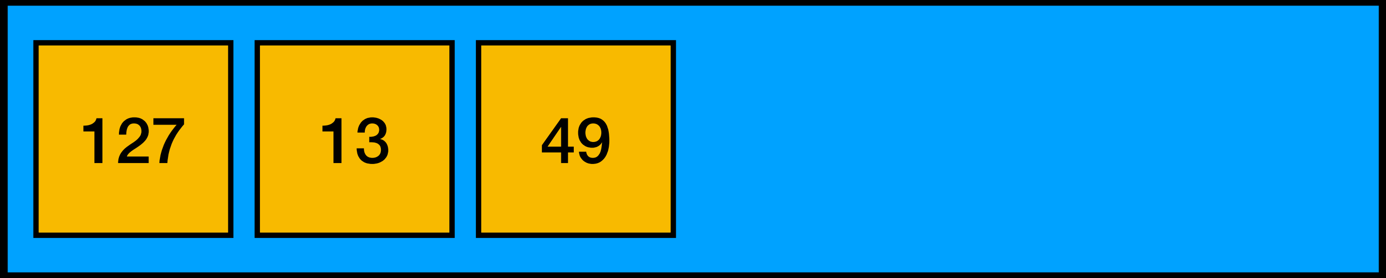

Queue

An ADT representing a waiting line

Objects can be enqueued to the back of the line

or dequeued from the front of the line

FIFO: First In First Out

Only front of queue is accessible (front), no other objects in the queue are visible

Queue Applications

Generating all substrings

Any waiting queue
- Print jobs
- OS scheduling processes with equal priority
- Messages between asynchronous processes
- . . .

Queue Applications

Generating all substrings

Any waiting queue
- Print jobs
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- Messages between asynchronous processes

. . .

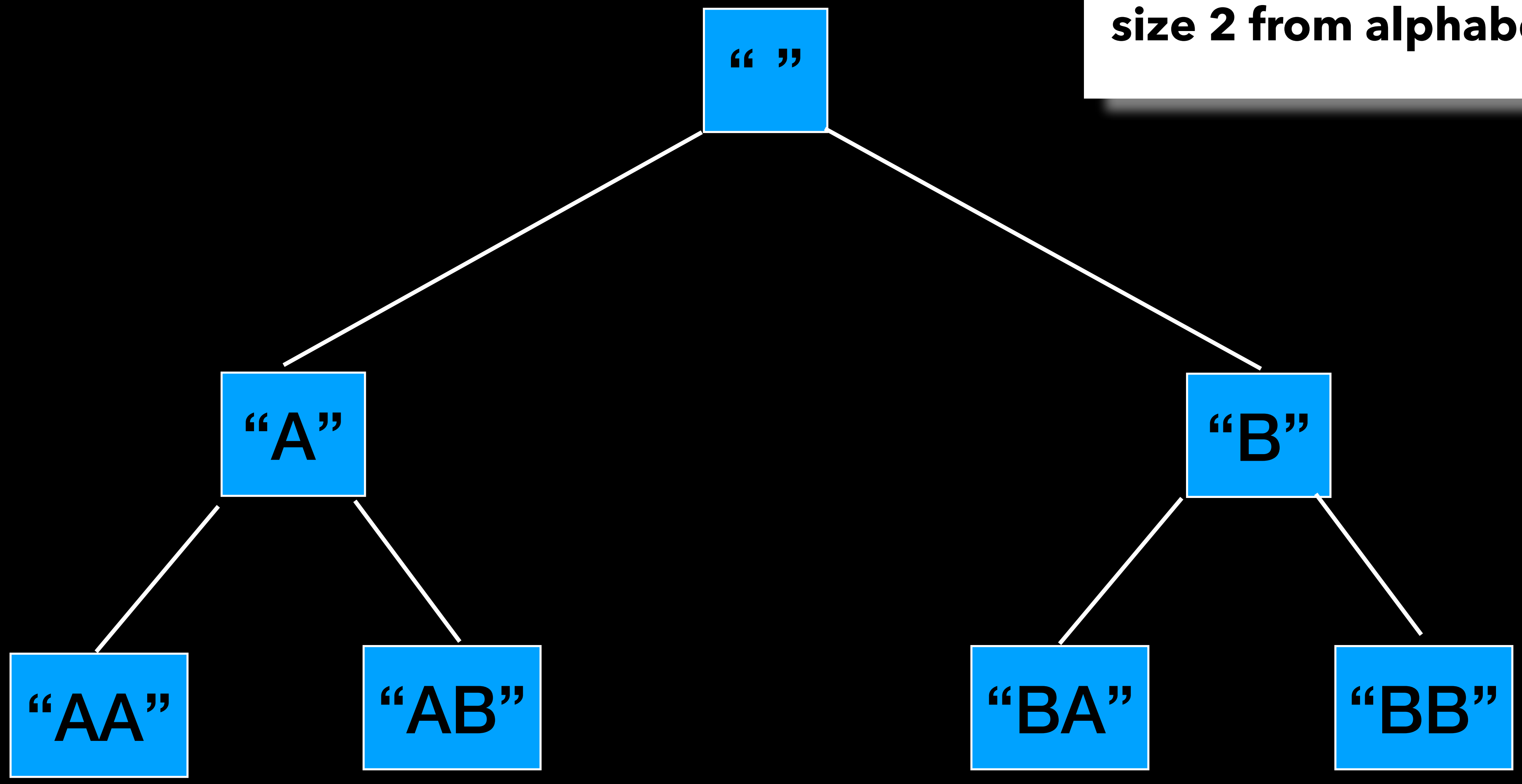
Generating all substrings

Generate all possible strings **up to** some fixed length **n with repetition (same character included multiple times)**

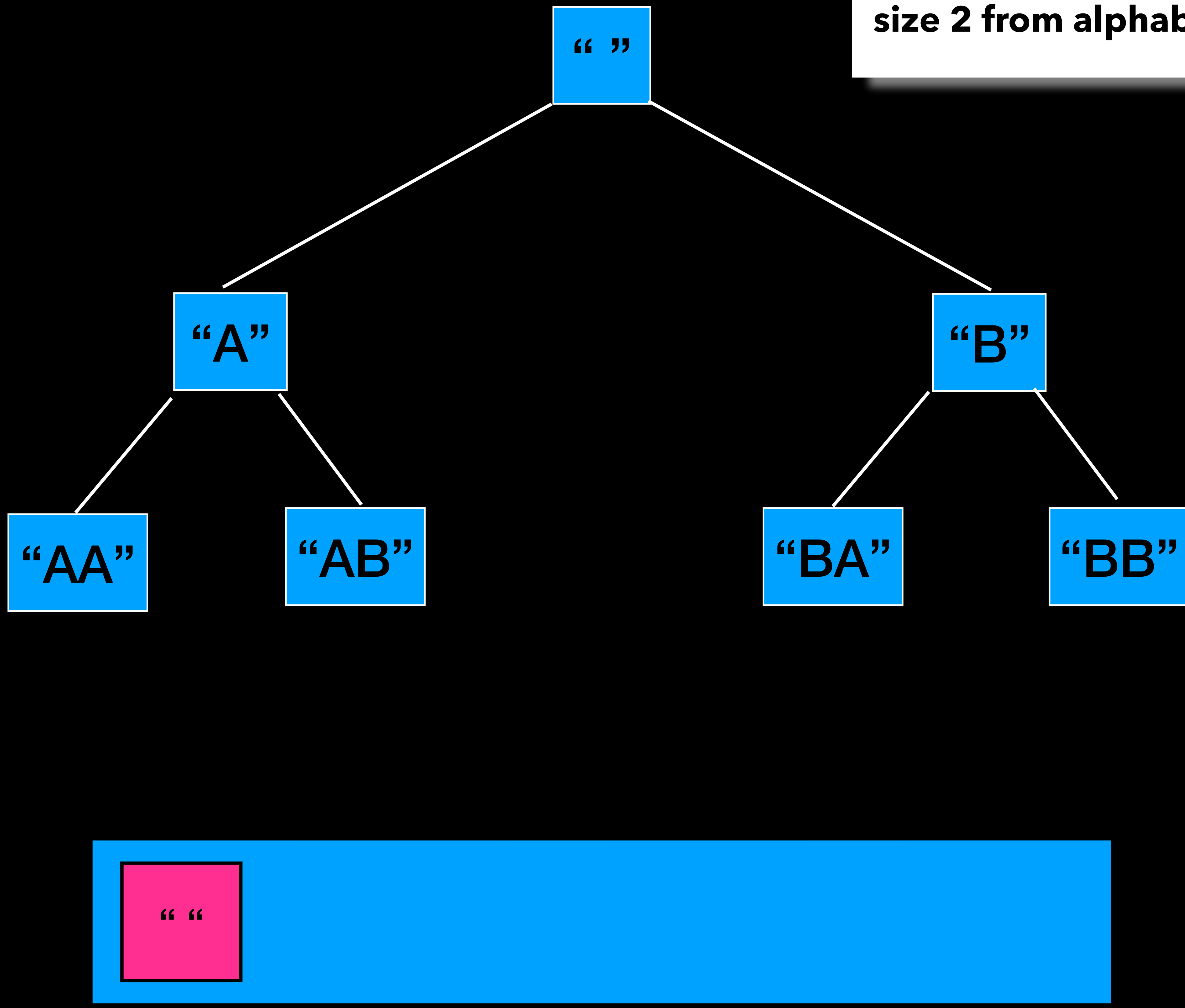
How might we do it with a queue?

Example simplified to n = 2 and only letters A and B

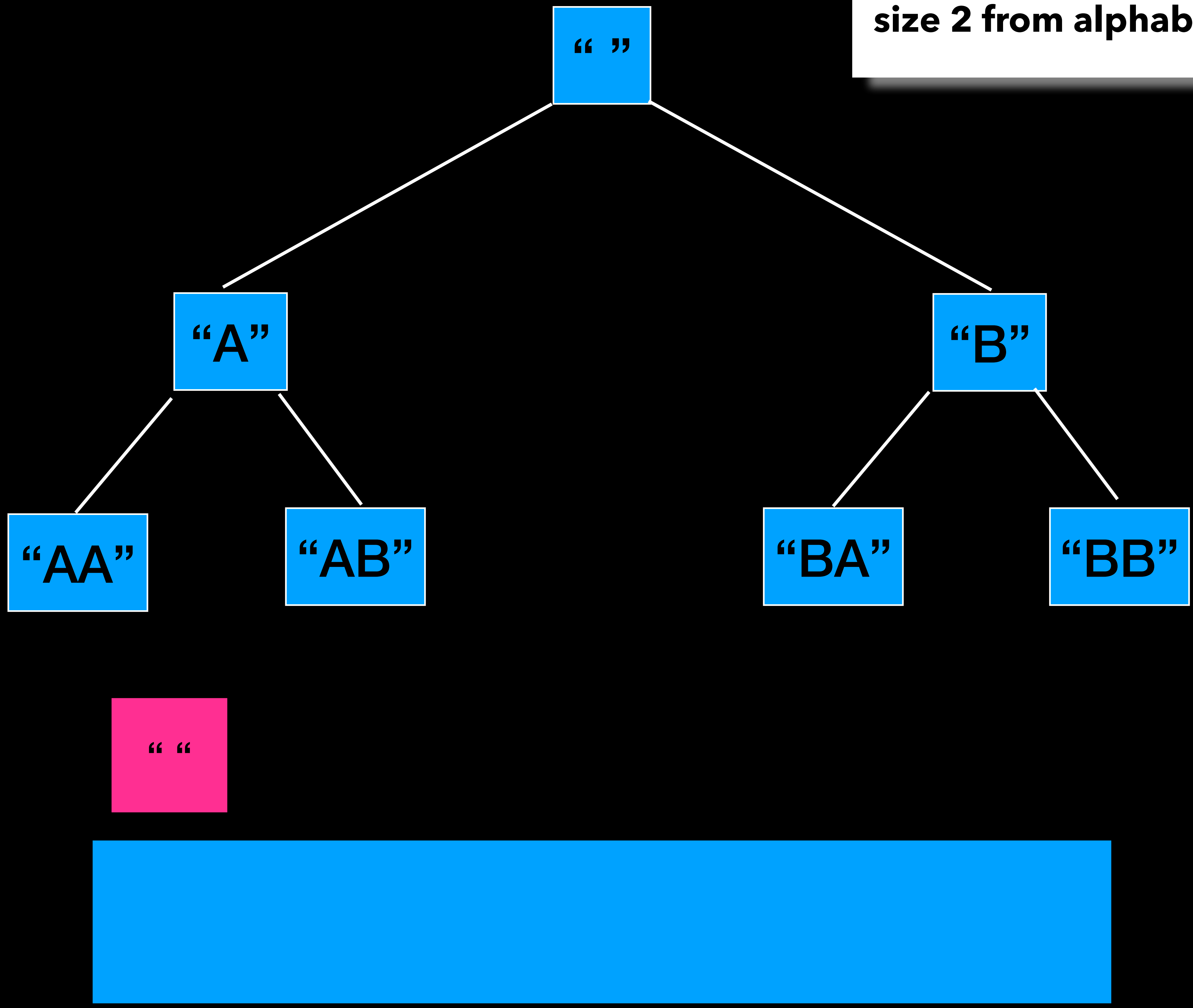
Generate all substrings of size 2 from alphabet {'A', 'B'}



Generate all substrings of size 2 from alphabet {'A', 'B'}

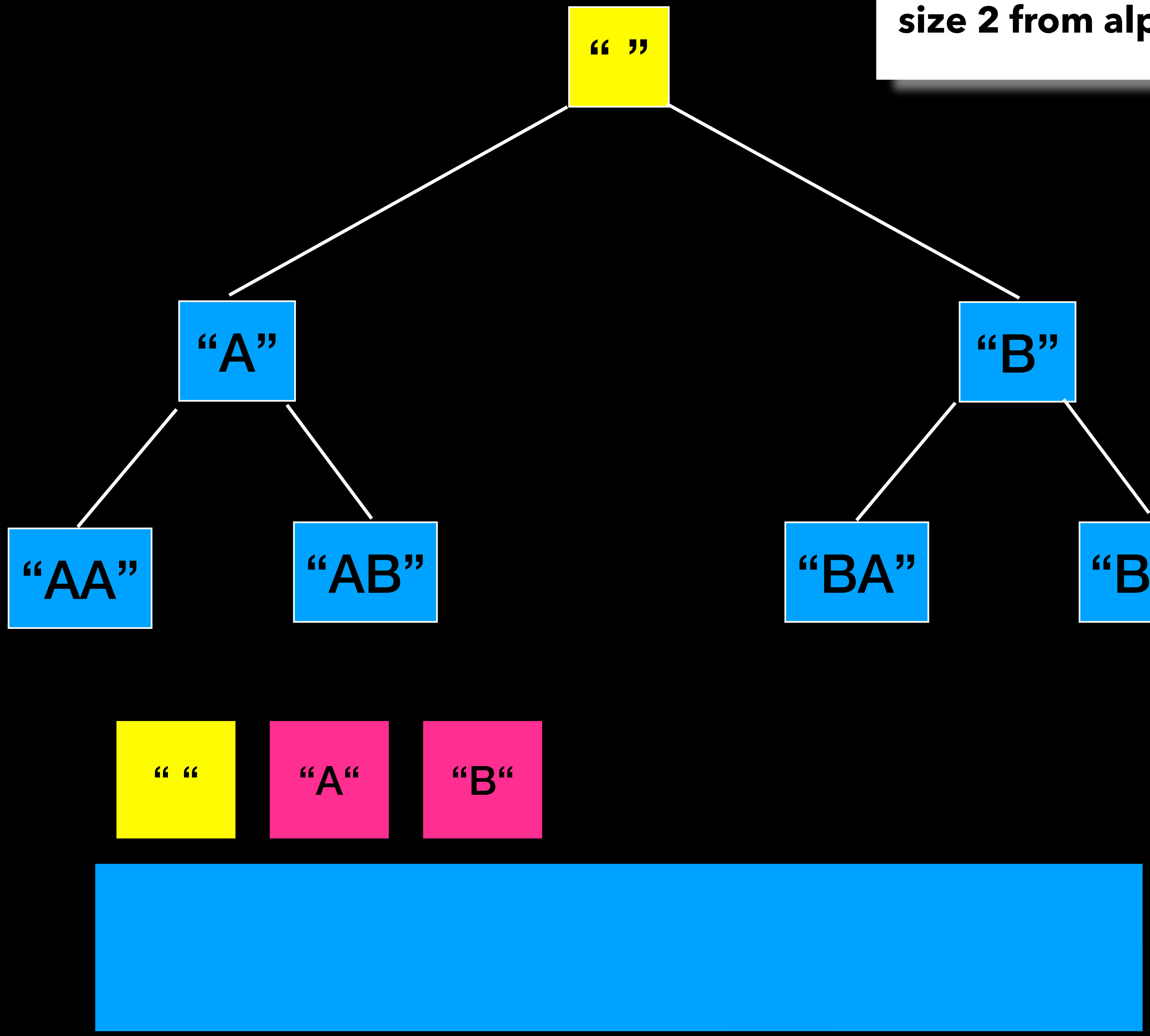


Generate all substrings of size 2 from alphabet {'A', 'B'}



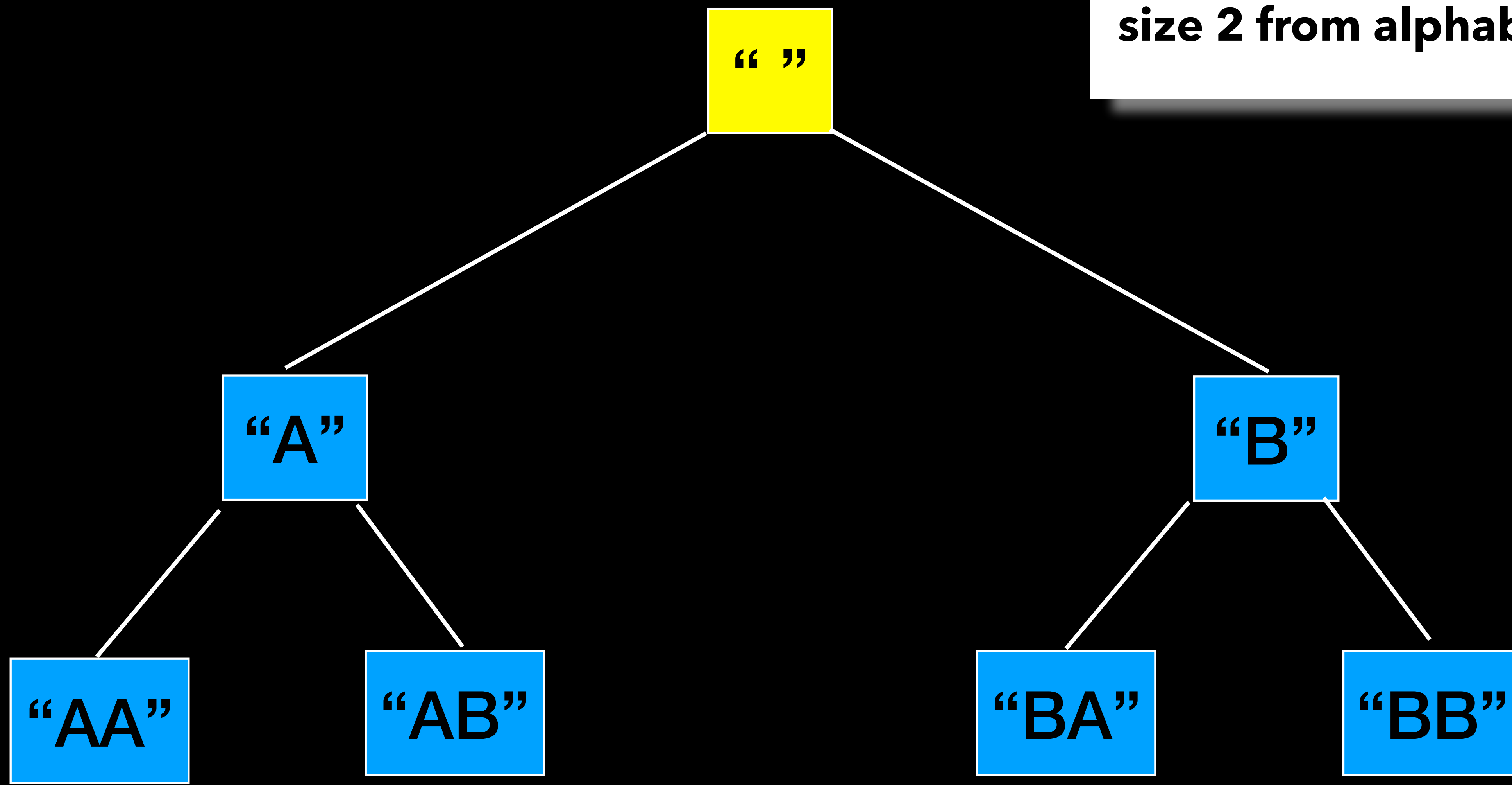
{ “”}

Generate all substrings of size 2 from alphabet {‘A’, ‘B’}



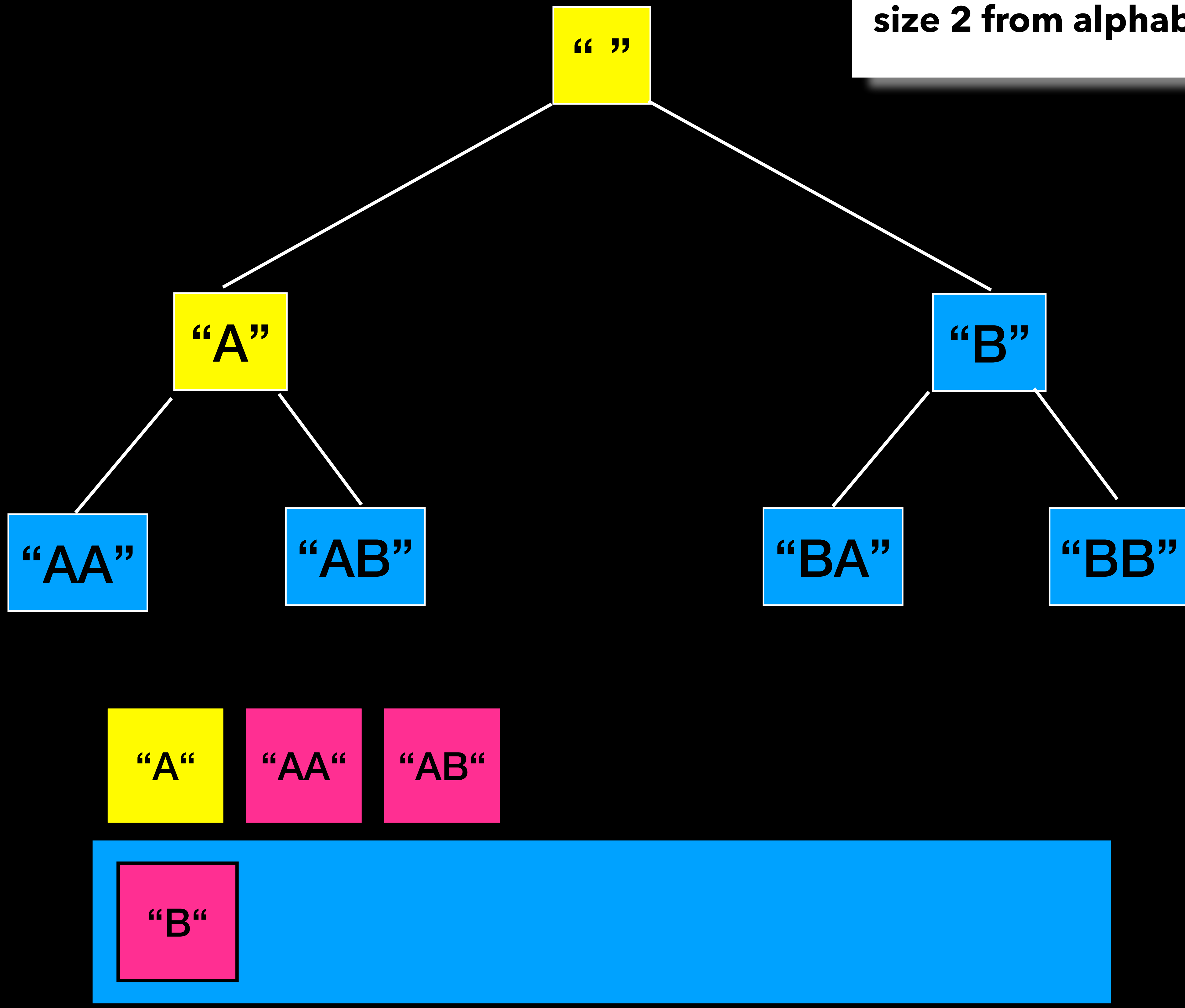
{ ""}

Generate all substrings of size 2 from alphabet {'A', 'B'}



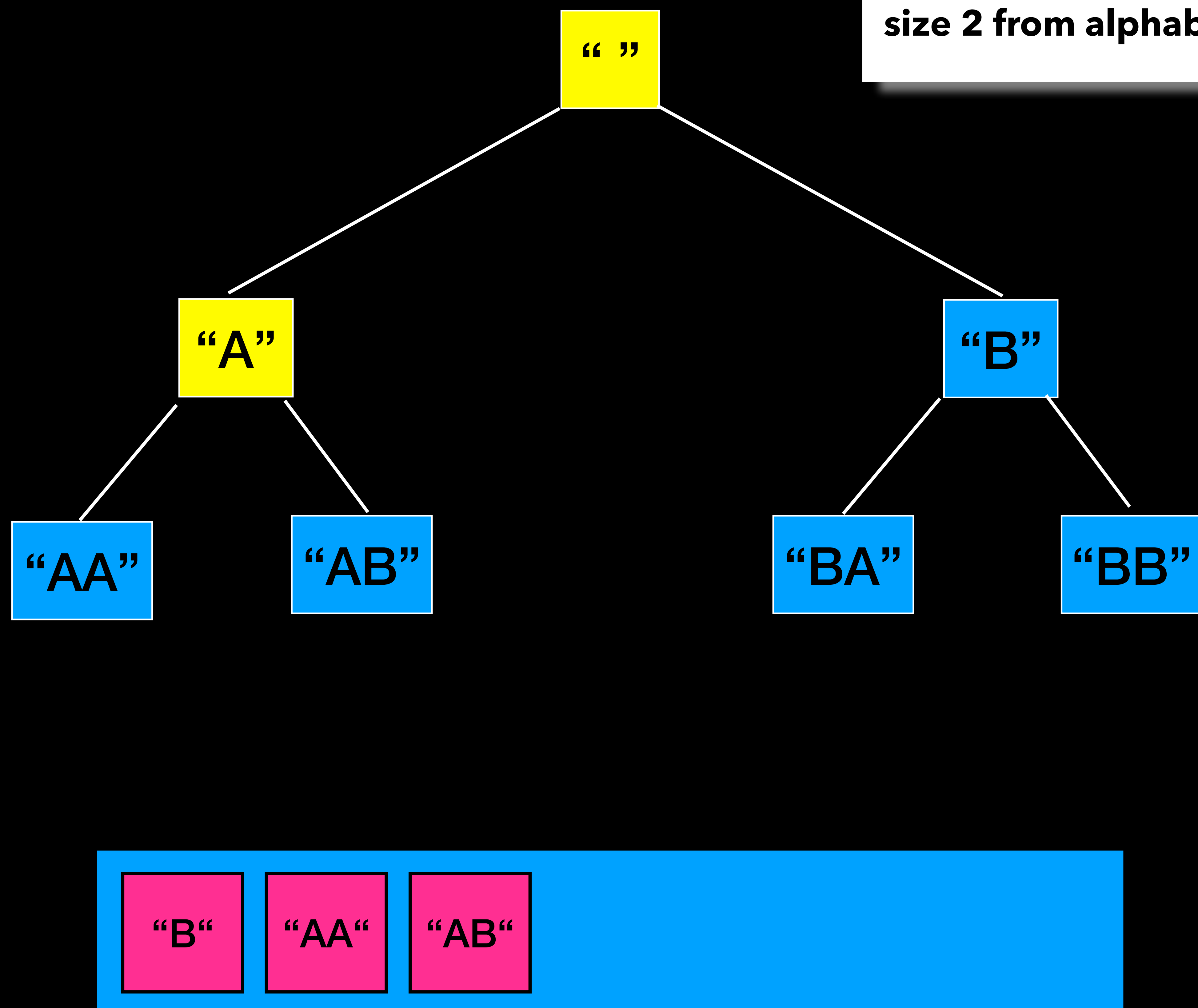
{ "", "A"}

Generate all substrings of size 2 from alphabet {'A', 'B'}



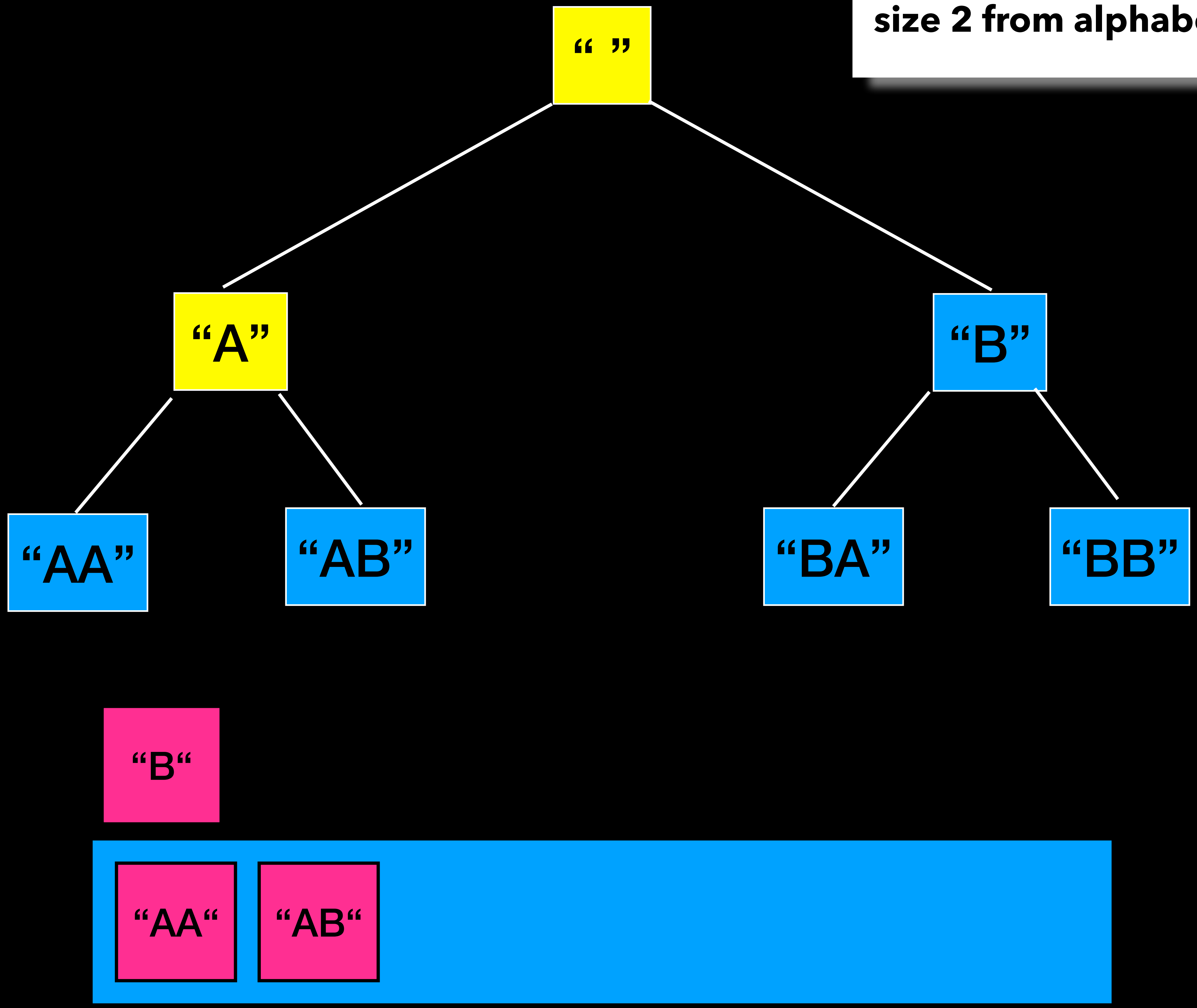
{ "", "A"}

Generate all substrings of size 2 from alphabet {'A', 'B'}



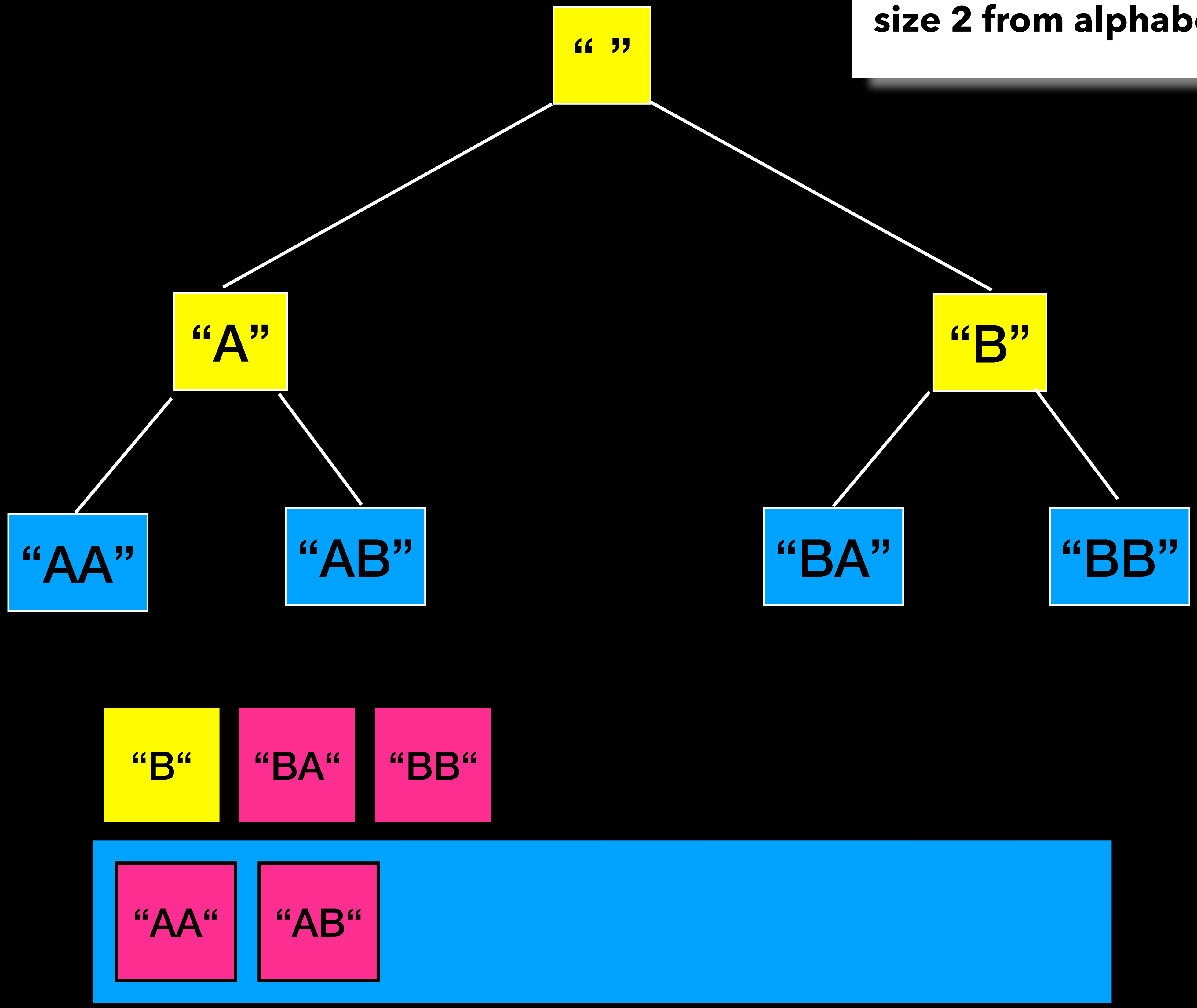
{ "", "A"}

Generate all substrings of size 2 from alphabet {'A', 'B'}



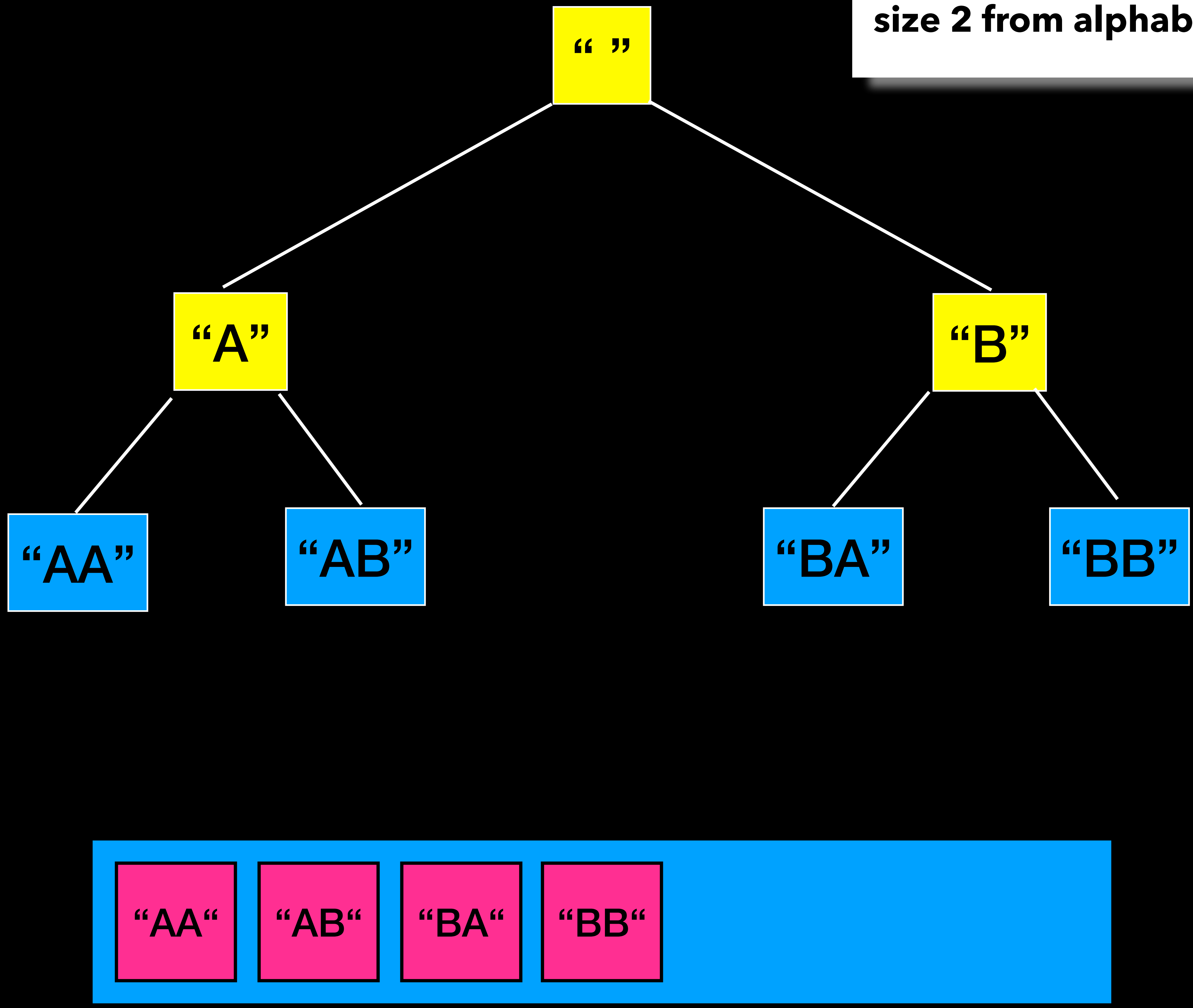
{ "", "A", "B"}

Generate all substrings of size 2 from alphabet {'A', 'B'}



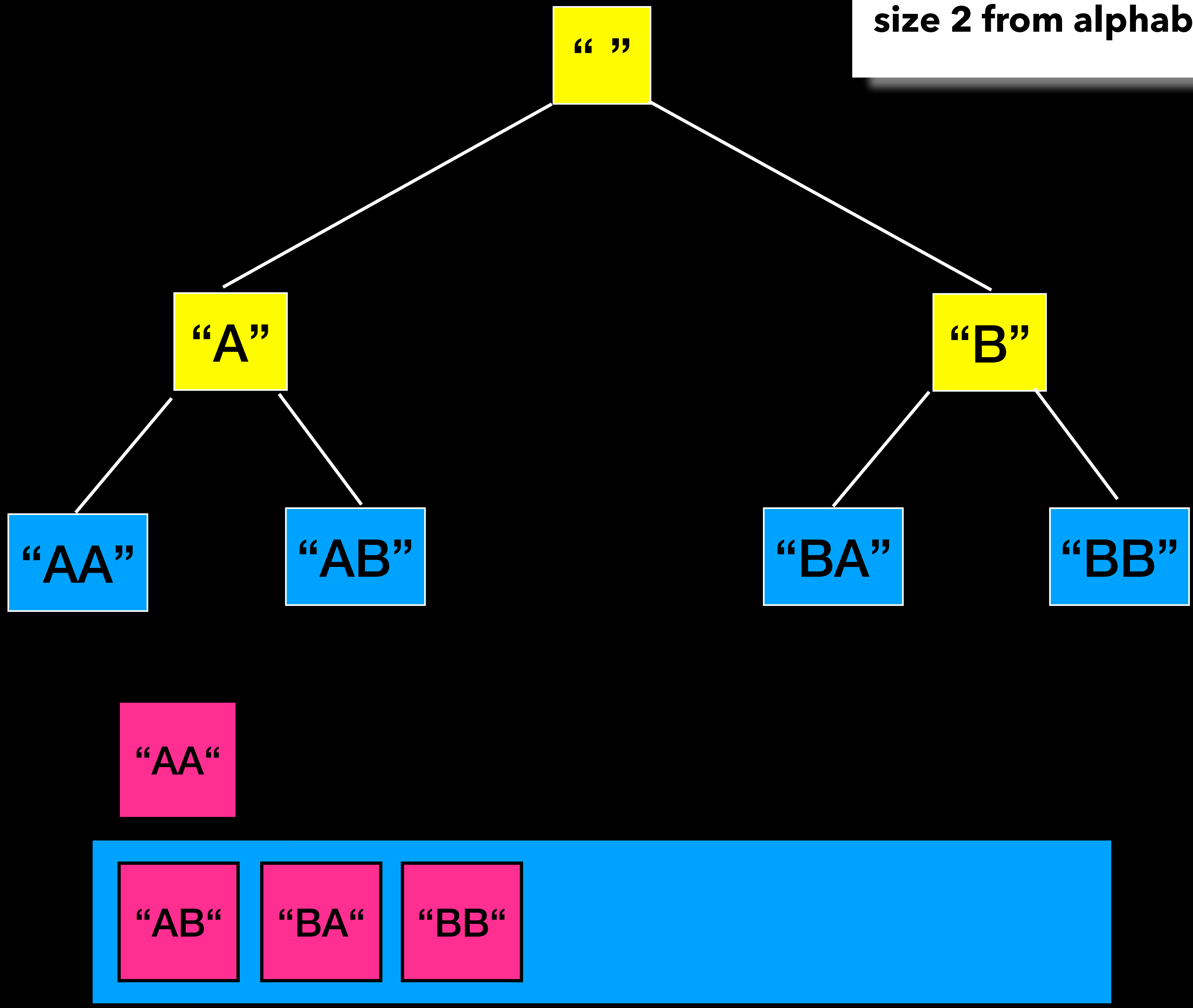
{ “”, “A”, “B”}

Generate all substrings of size 2 from alphabet {‘A’, ‘B’}



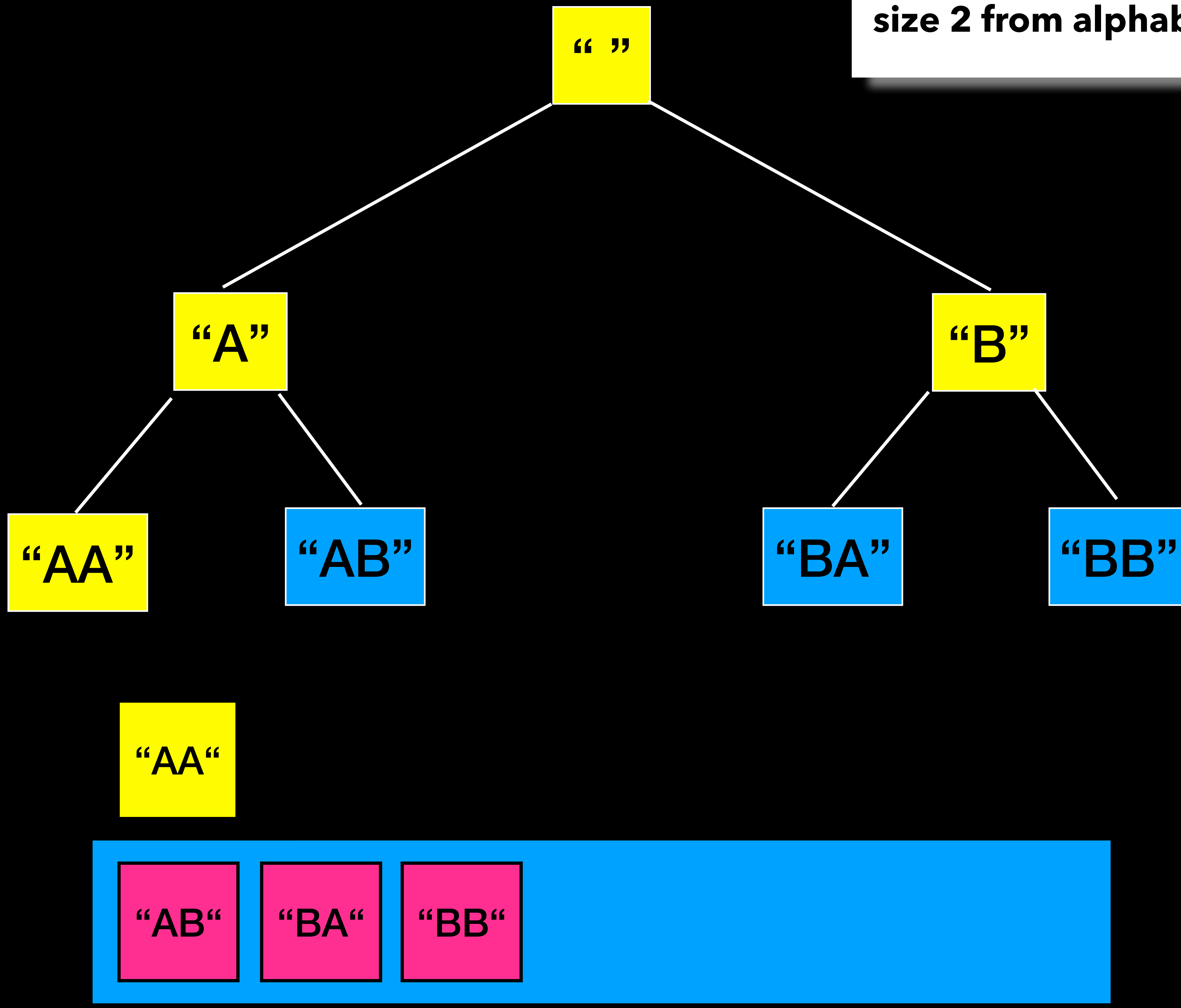
{ "", "A", "B"}

Generate all substrings of size 2 from alphabet {'A', 'B'}



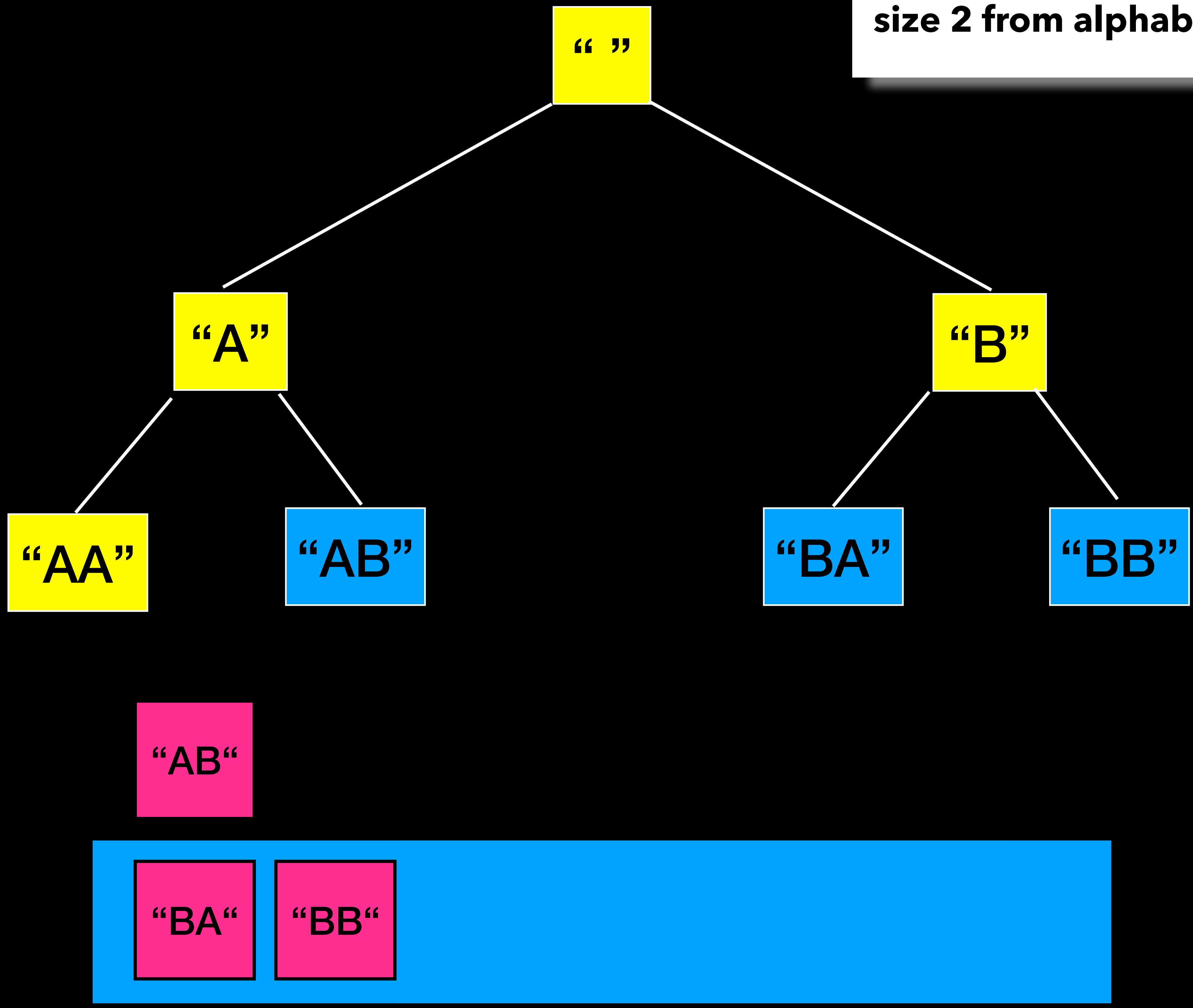
{ “”, “A”, “B”, “AA”}

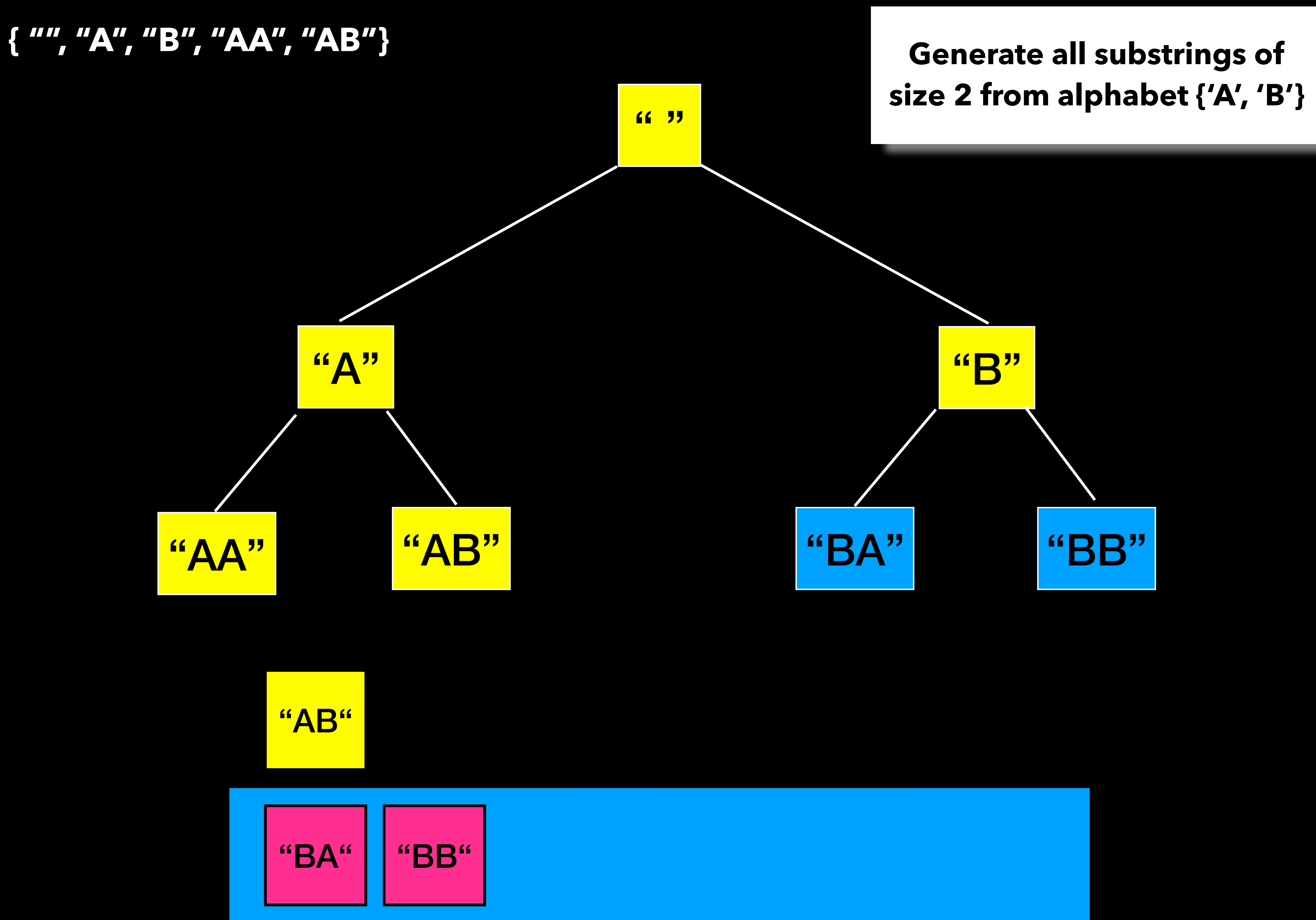
Generate all substrings of size 2 from alphabet {‘A’, ‘B’}



{ "", "A", "B", "AA"}

Generate all substrings of size 2 from alphabet {'A', 'B'}

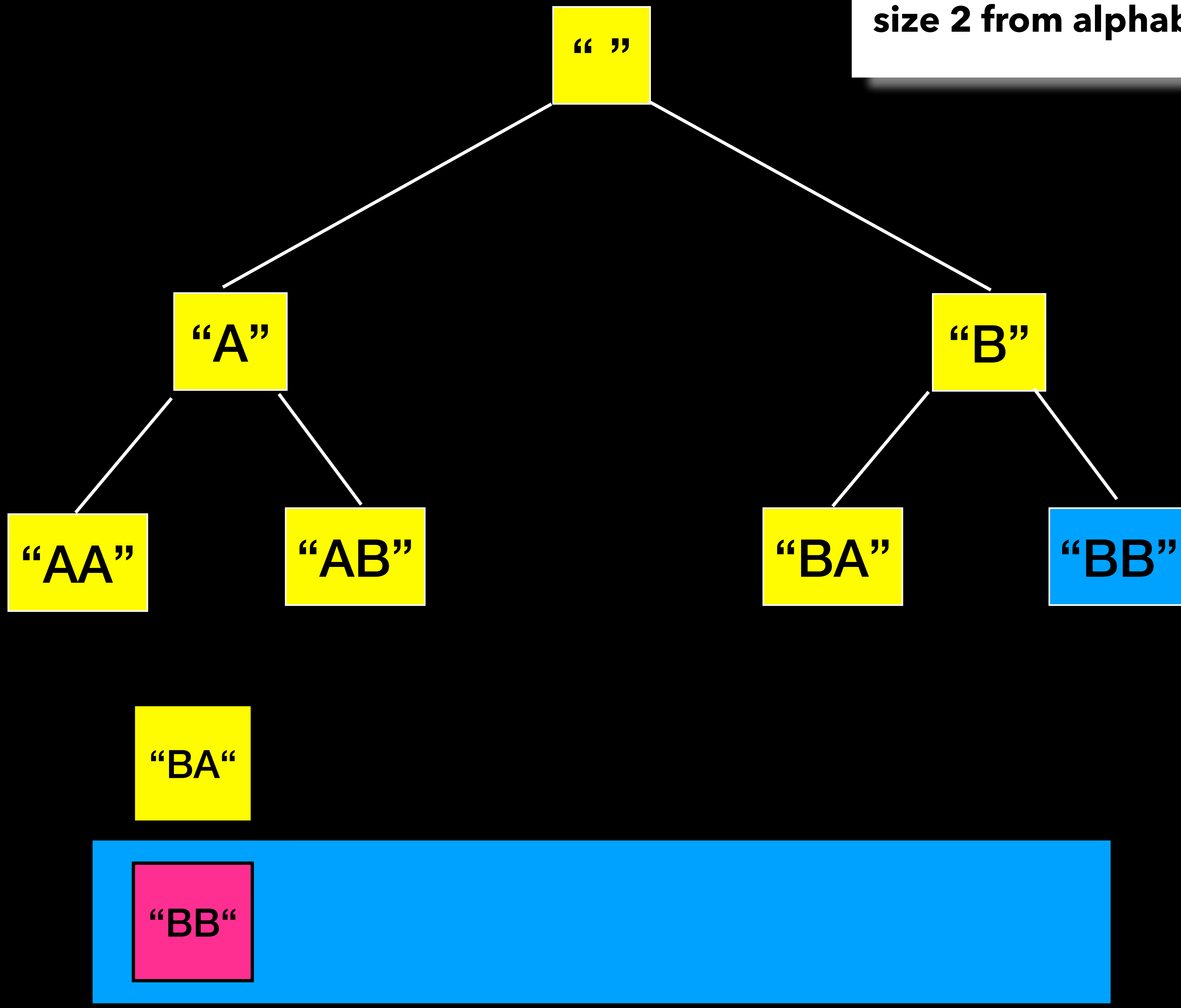




{ "", "A", "B", "AA", "AB"}
Generate all substrings of size 2 from alphabet {'A', 'B'}
" "
"A"
"B"
"AA"
"AB"
"BA"
"BB"
"AB"
"BA"
"BB"

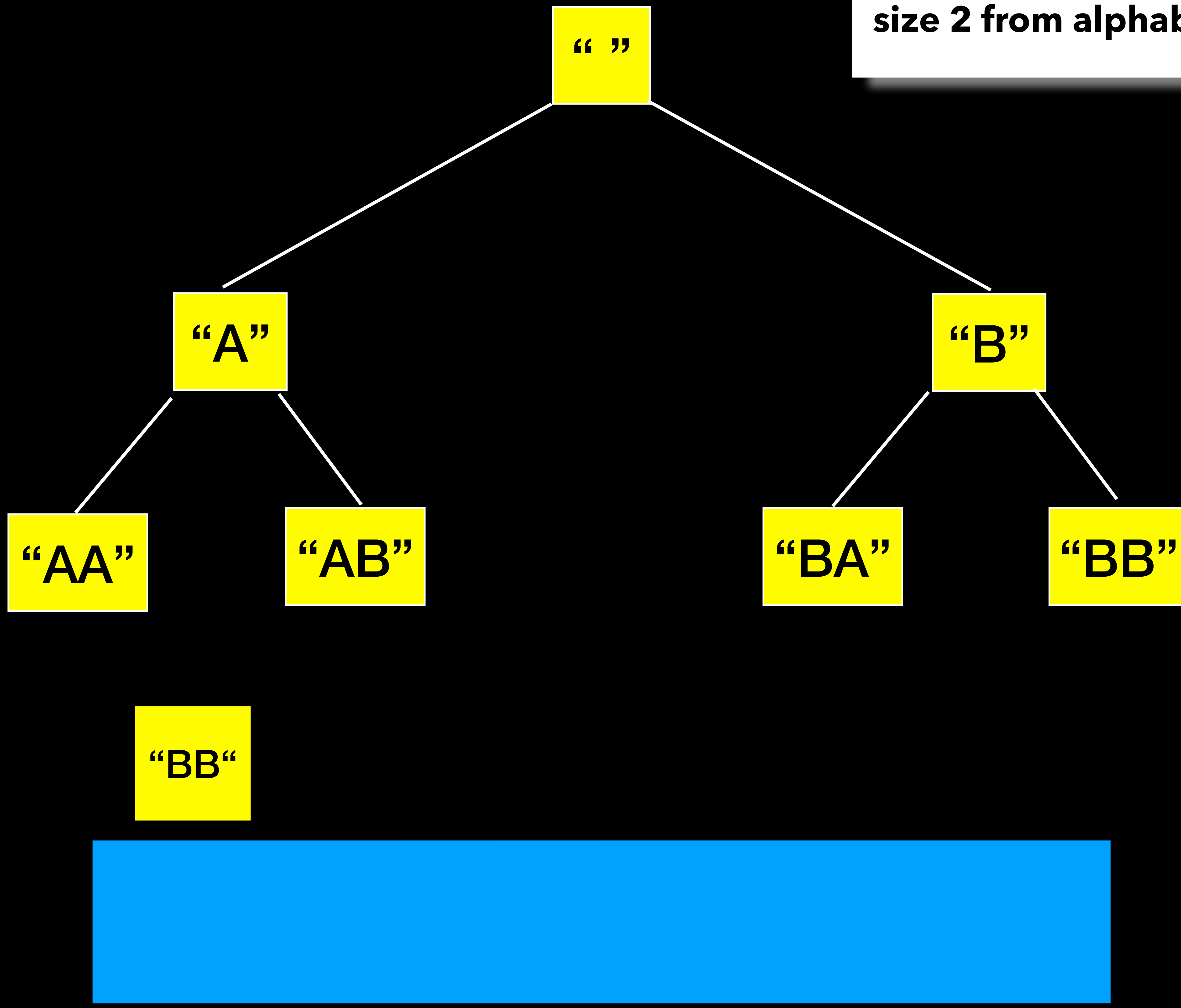
{ "", "A", "B", "AA", "AB", "BA"}

Generate all substrings of size 2 from alphabet {'A', 'B'}



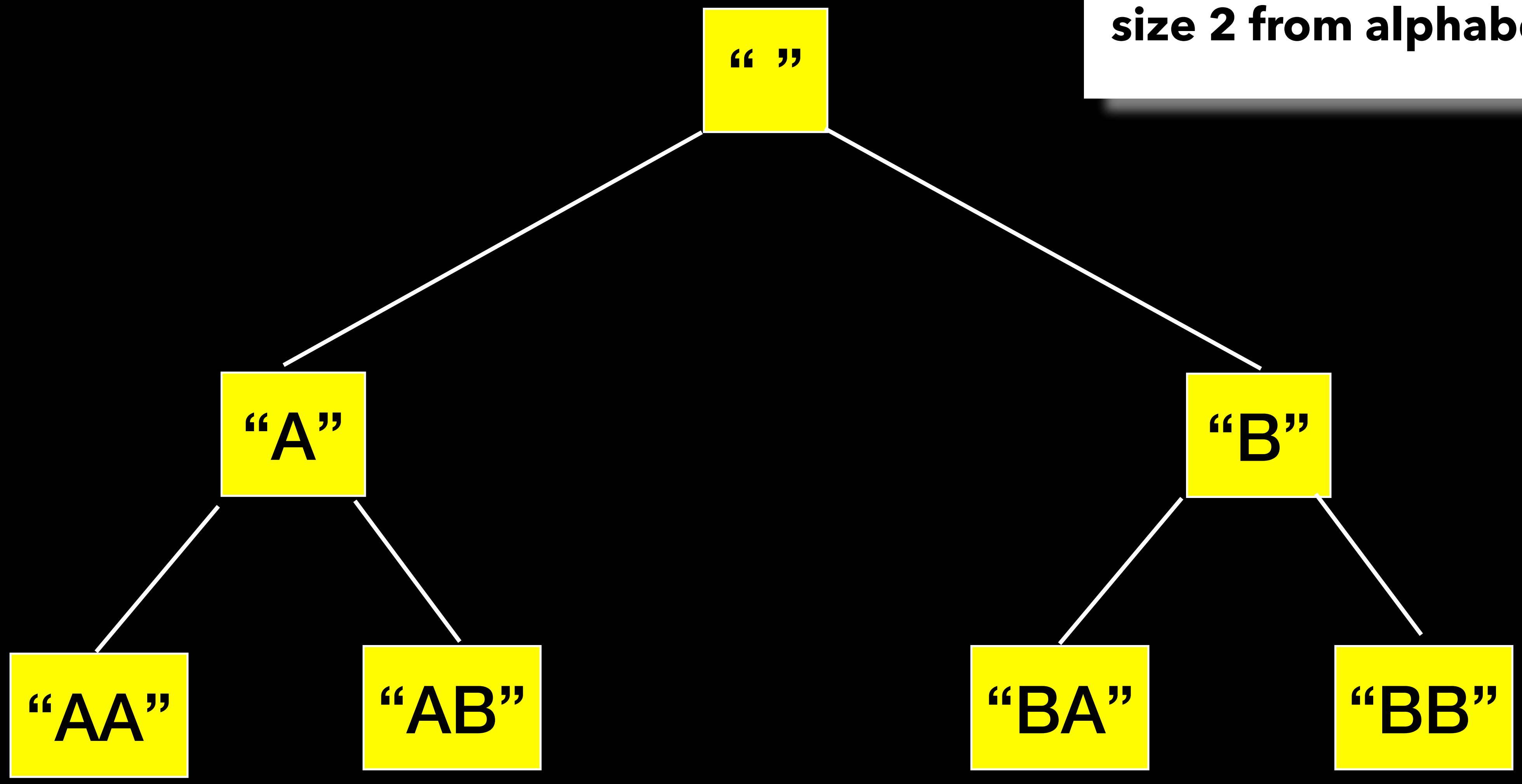
{ “”, “A”, “B”, “AA”, “AB”, “BA”, “BB” }

Generate all substrings of size 2 from alphabet {‘A’, ‘B’}



{ "", "A", "B", "AA", "AB", "BA", "BB" }

Generate all substrings of size 2 from alphabet {'A', 'B'}



Breadth-First Search

Applications

- Find shortest path in graph
- GPS navigation systems
- Crawlers in search engines
- . . .

Generally good when looking for the “shortest” or “best” way to do something => lists things in increasing order of “size” stopping at the “shortest” solution

Size of Substring

```
findAllSubstrings(int n)
{
    put empty string on the queue

    while(queue is not empty){
        let current_string = dequeue and add to result
        if(size of current_string < n){
            for(each character ch)//every character in alphabet
                append ch to current_string and enqueue it
        }
    }
    return result;
}
```

Analysis

Finding all substrings (with repetition) of size **up to n**

Assume alphabet (A, B, … , Z) of size 26

The empty string= 1= 26^0 ""

All strings of size 1 = 26^1 A B C . . . Z

All strings of size 2 = 26^2

AA	BA	CA	. . .	ZA
AB	BC	CB	. . .	ZB
. . .				
AZ	BZ	CZ	. . .	ZZ

. . .

All strings of size n = 26^n

With repetition: I have `26` options for each of the `n` characters

Size of Substring

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                append ch to current_string and enqueue it
        }
    }
    return result;
}
```

Analyze the worst-case time complexity of this algorithm assuming alphabet of size 26 and up to strings of length n

T(n) = ?

O(?)

Will stop when all strings have been removed from queue

```
findAllSubstrings(int n)
{
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        if(size of current_string < n){
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Will stop when all strings have been removed from queue

Removes 1 string from the queue

Adds 26 strings to the queue

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        }
    }
    return result;
}
```

Loop until queue is empty and dequeue only 1 each time.

So the question becomes:

How many strings are enqueued in total?

Will stop when all strings have been removed from queue

Removes 1 string from the queue

Adds 26 strings to the queue

```
findAllSubstrings(int n)
{
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        }
    }
    return result;
}
```

$$T(n) = 26^0 + 26^1 + 26^2 + ... 26^n$$

Will stop when all strings have been removed from queue

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Adds 26 strings to the queue

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$$T(n) = 26^0 + 26^1 + 26^2 + \ldots 26^n$$

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                append ch to current_string and enqueue it
        }
    }
    return result;
}
```
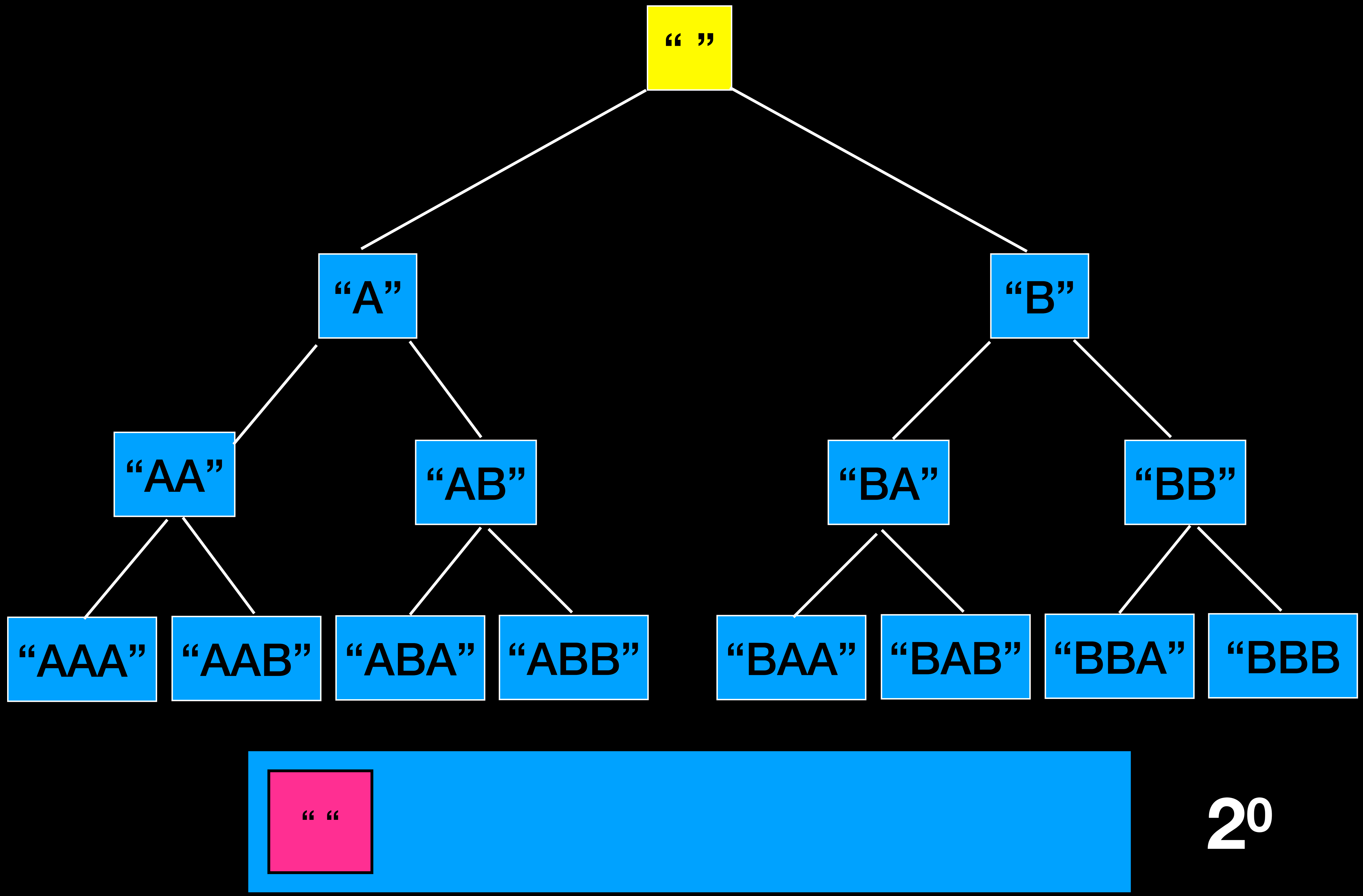
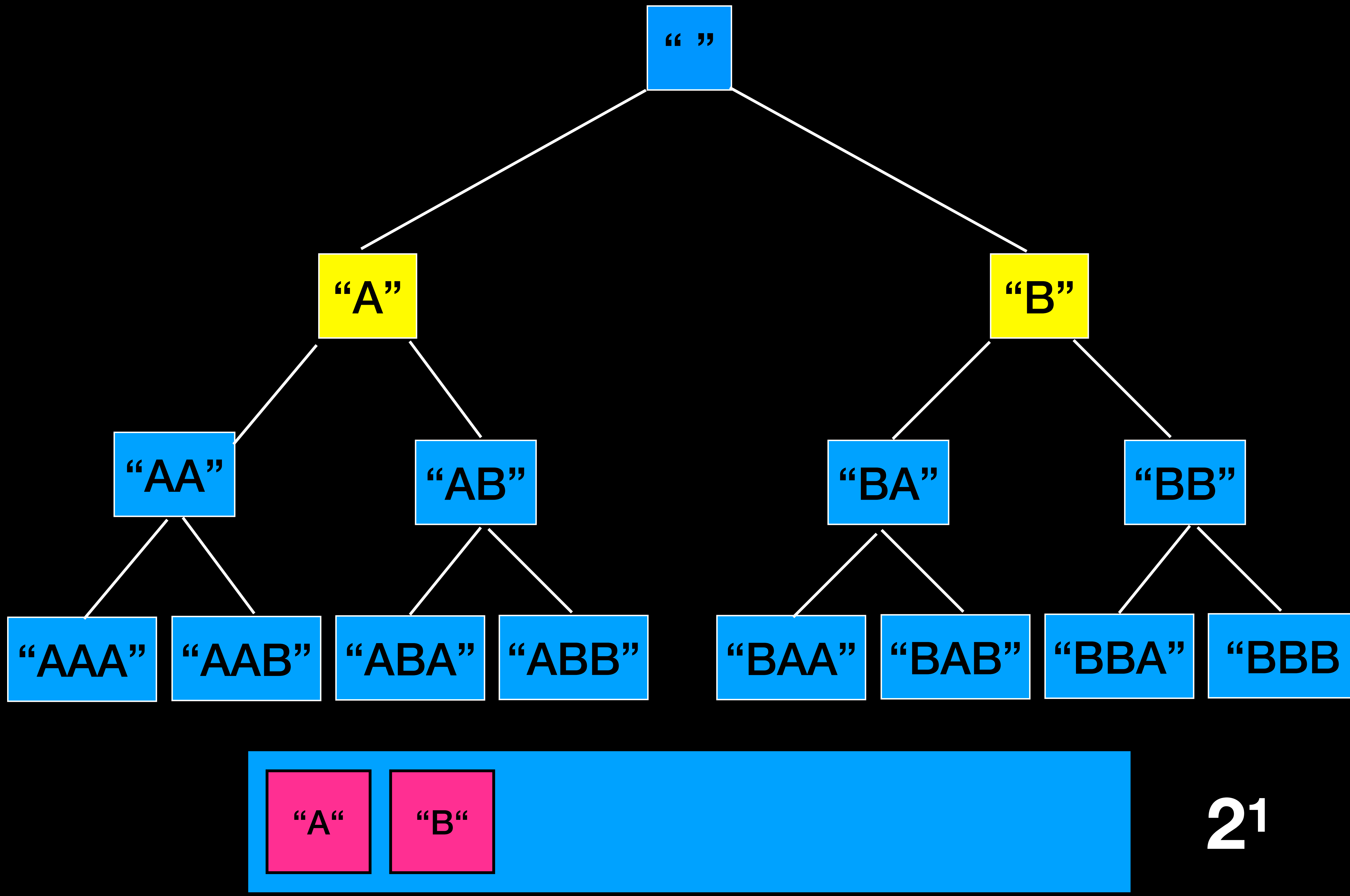

$O(26^n)$

Let n = 3, alphabet still {'A','B'}



2^0

Let n = 3, alphabet still {‘A’,’B’}



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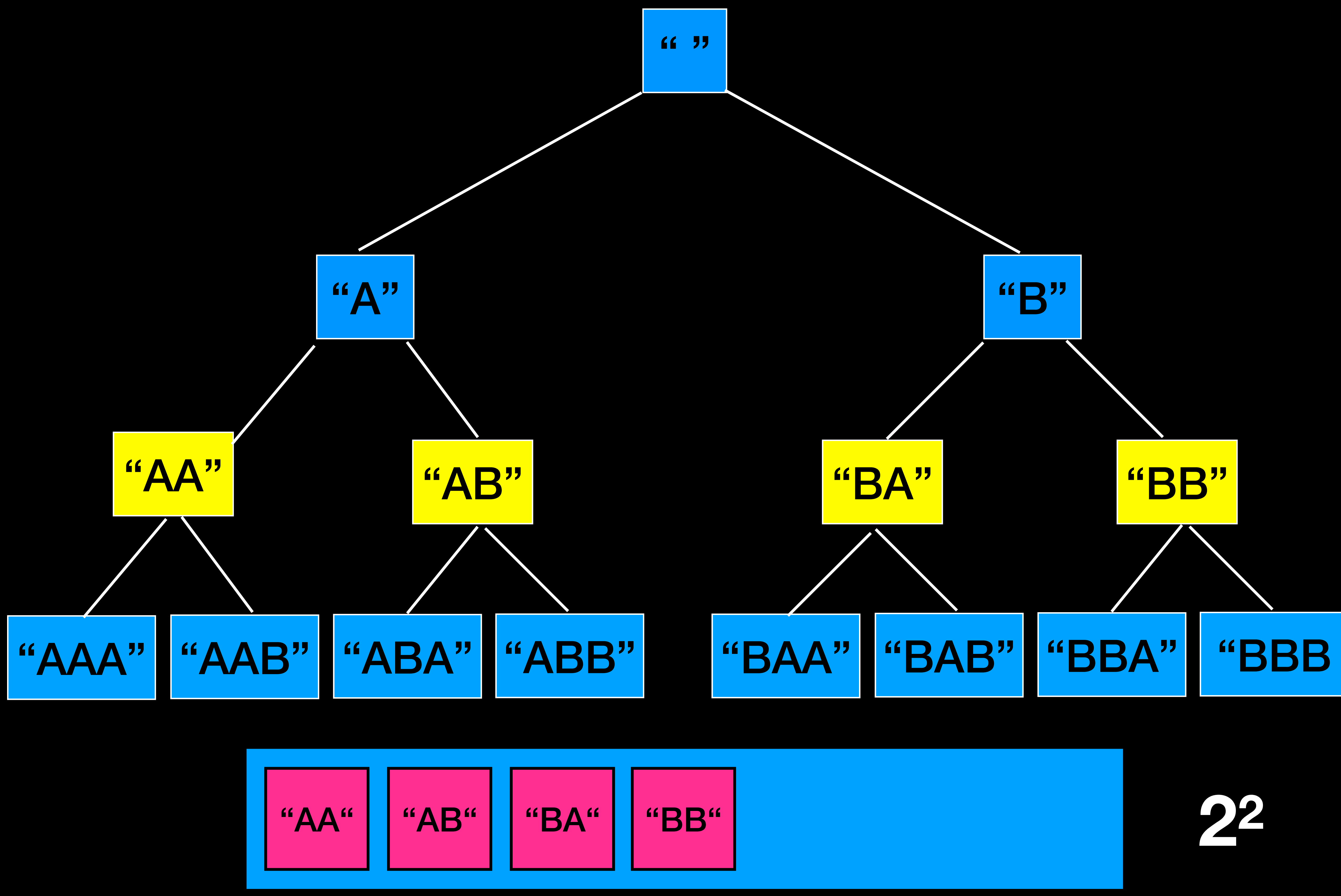

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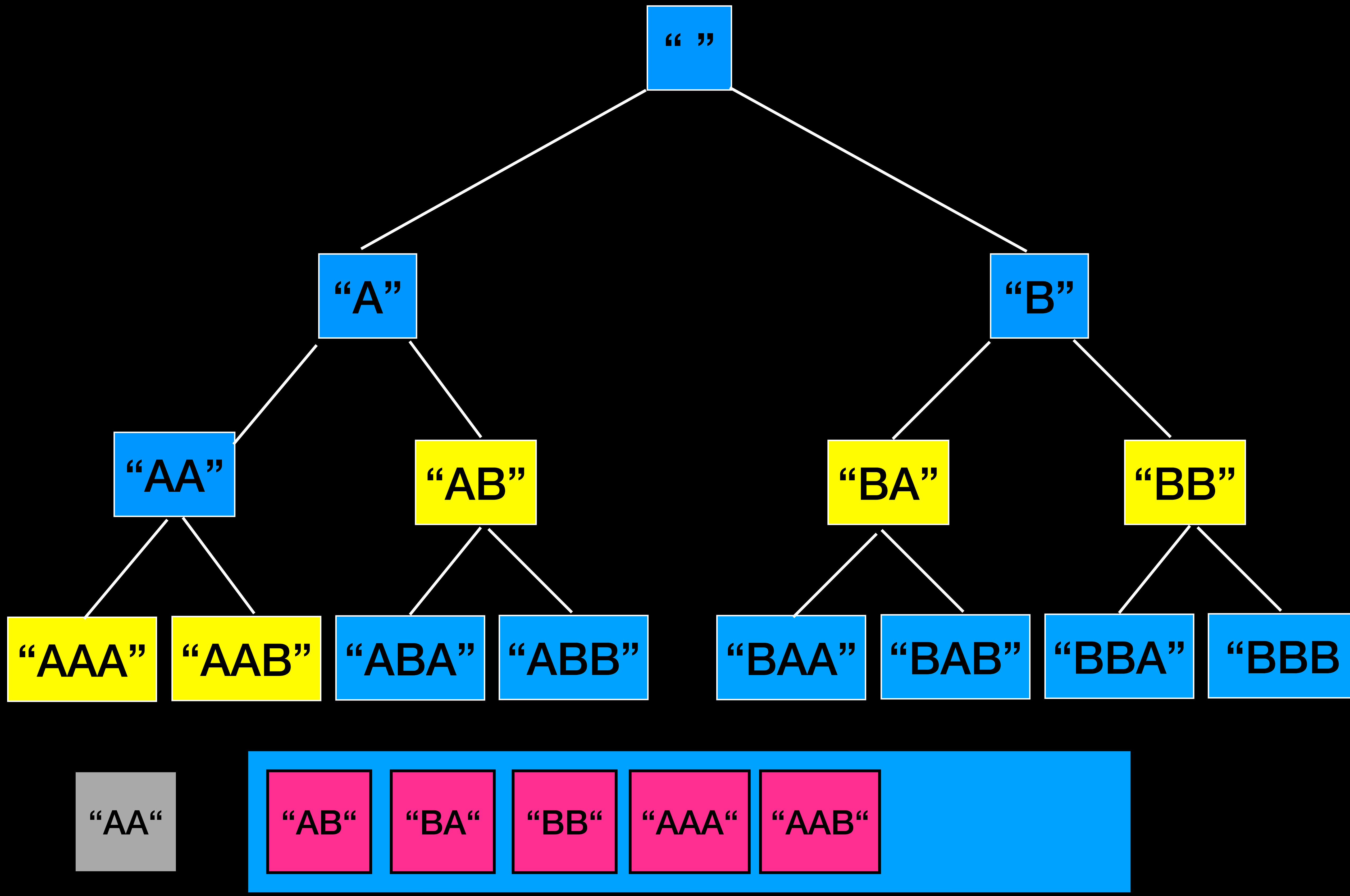

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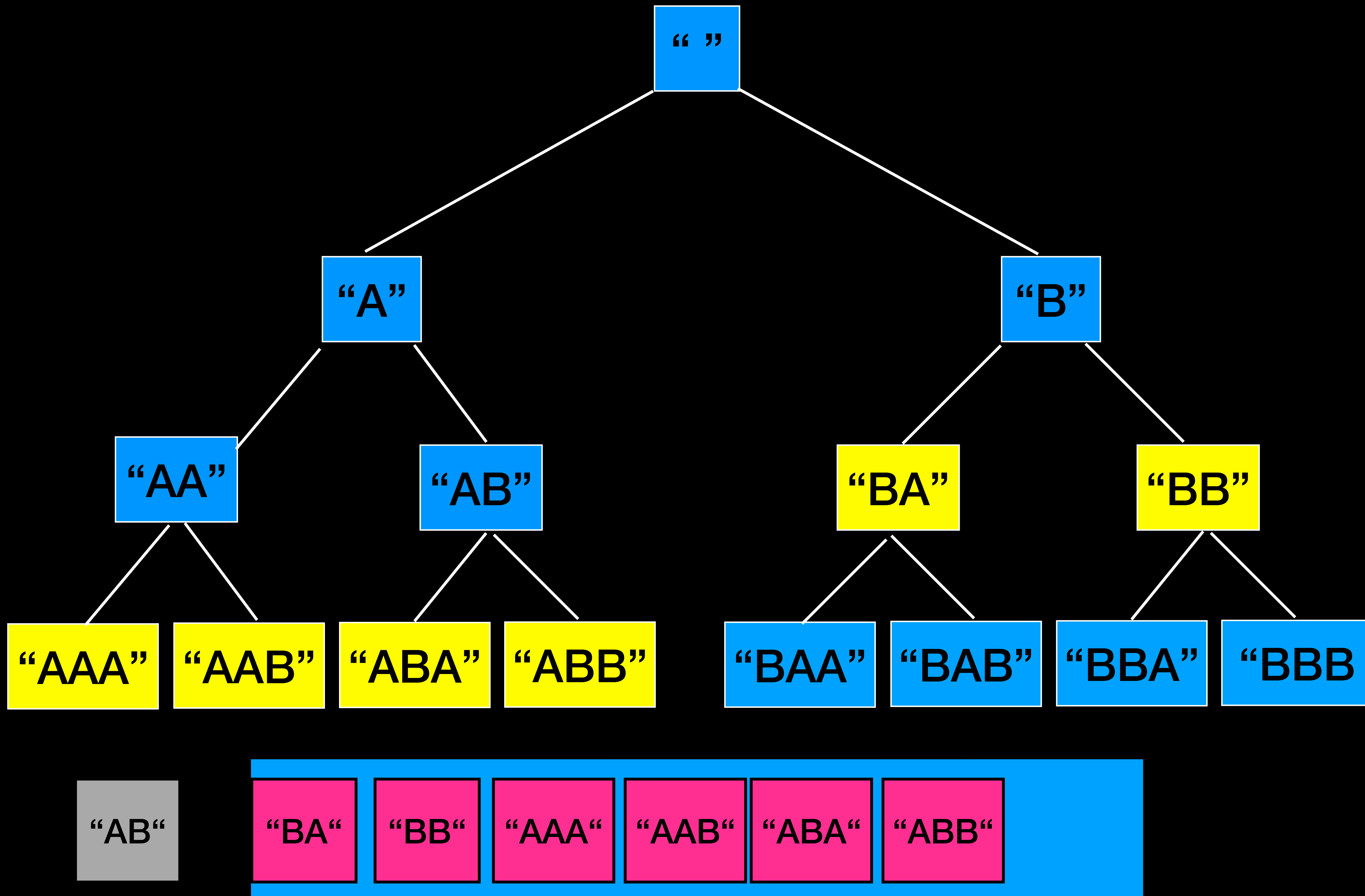
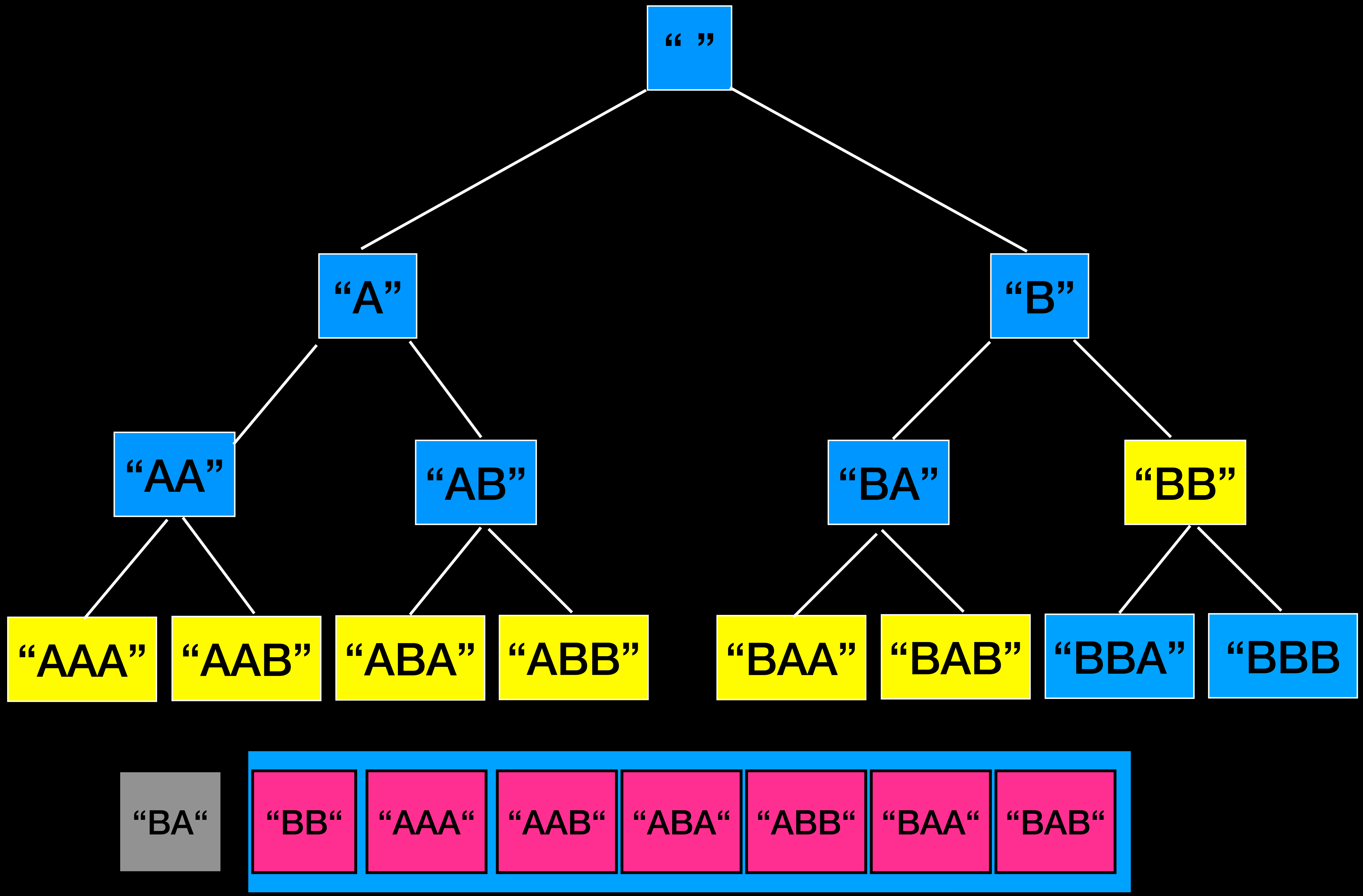
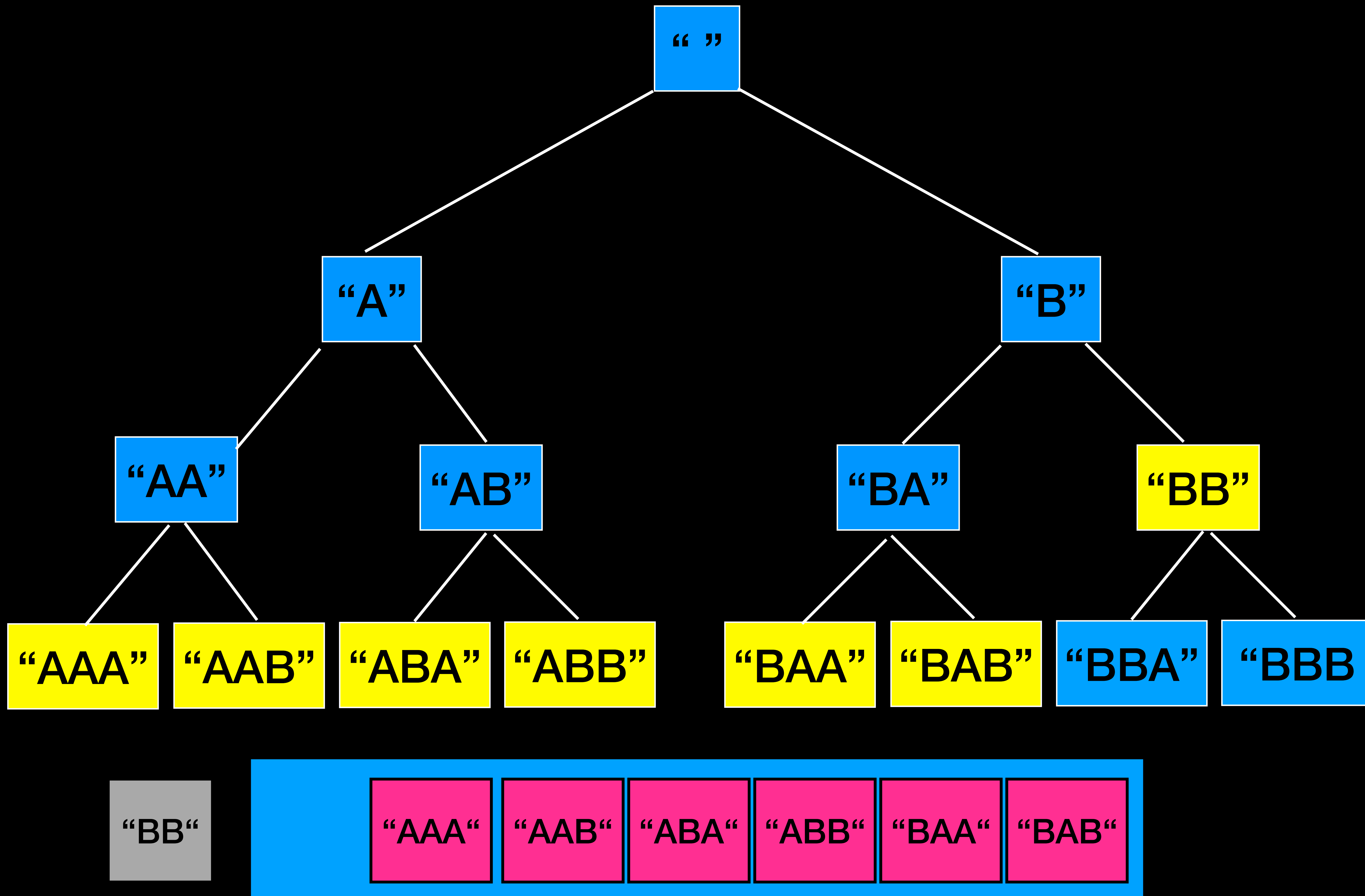


Let n = 3, alphabet still {‘A’,’B’}



Let n = 3, alphabet still {‘A’,’B’}



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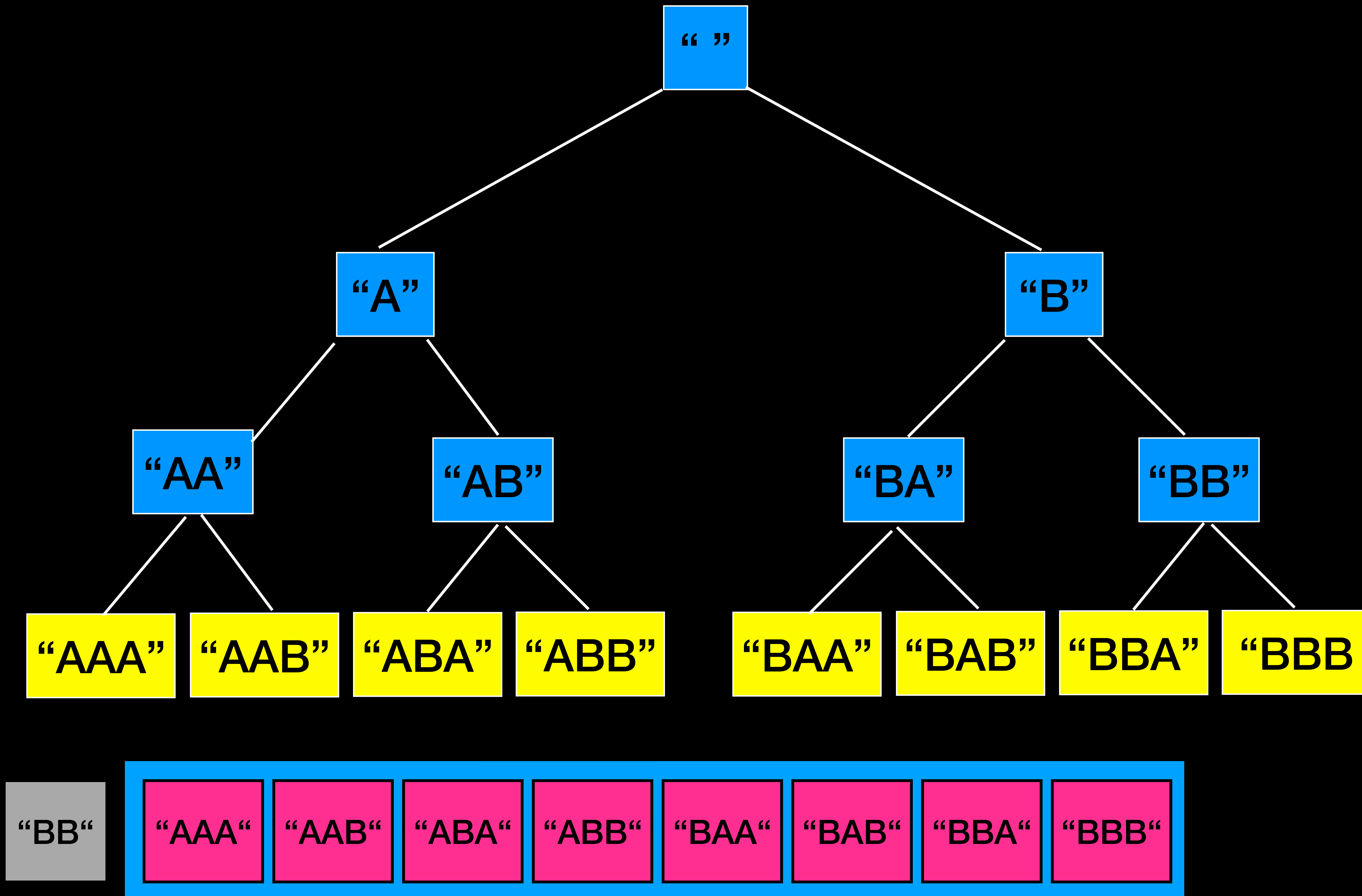
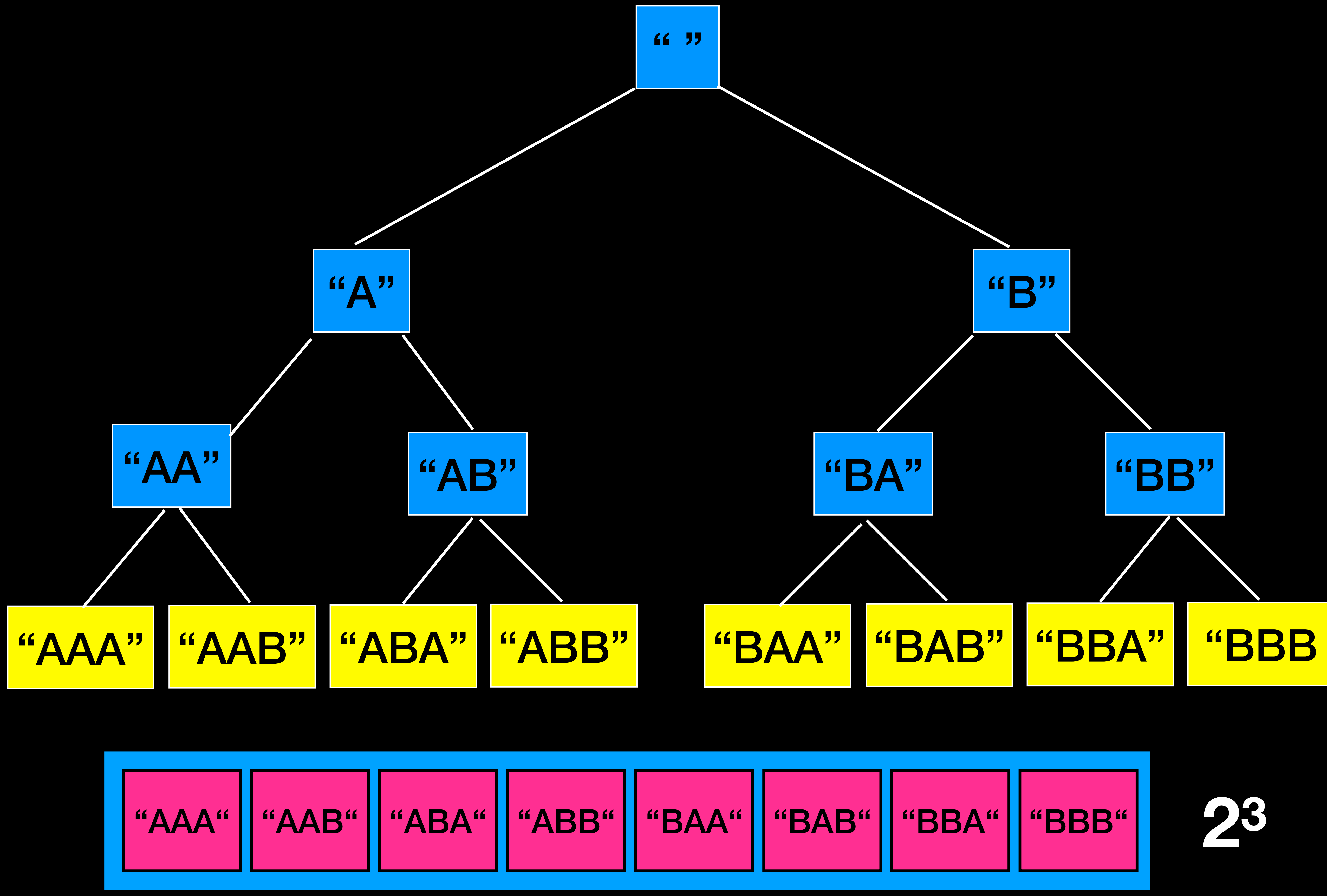


Let n = 3, alphabet still {‘A’,’B’}



2^3

Memory Usage

With alphabet {'A', 'B', …, 'Z'}, at some point we end up with **26^n** strings in memory

Size of string on my machine = 24 bytes

Running this algorithm for n = 7 (≈ 193GB) is the maximum that can be handled by a standard personal computer

For n = 8 ≈ 5TB

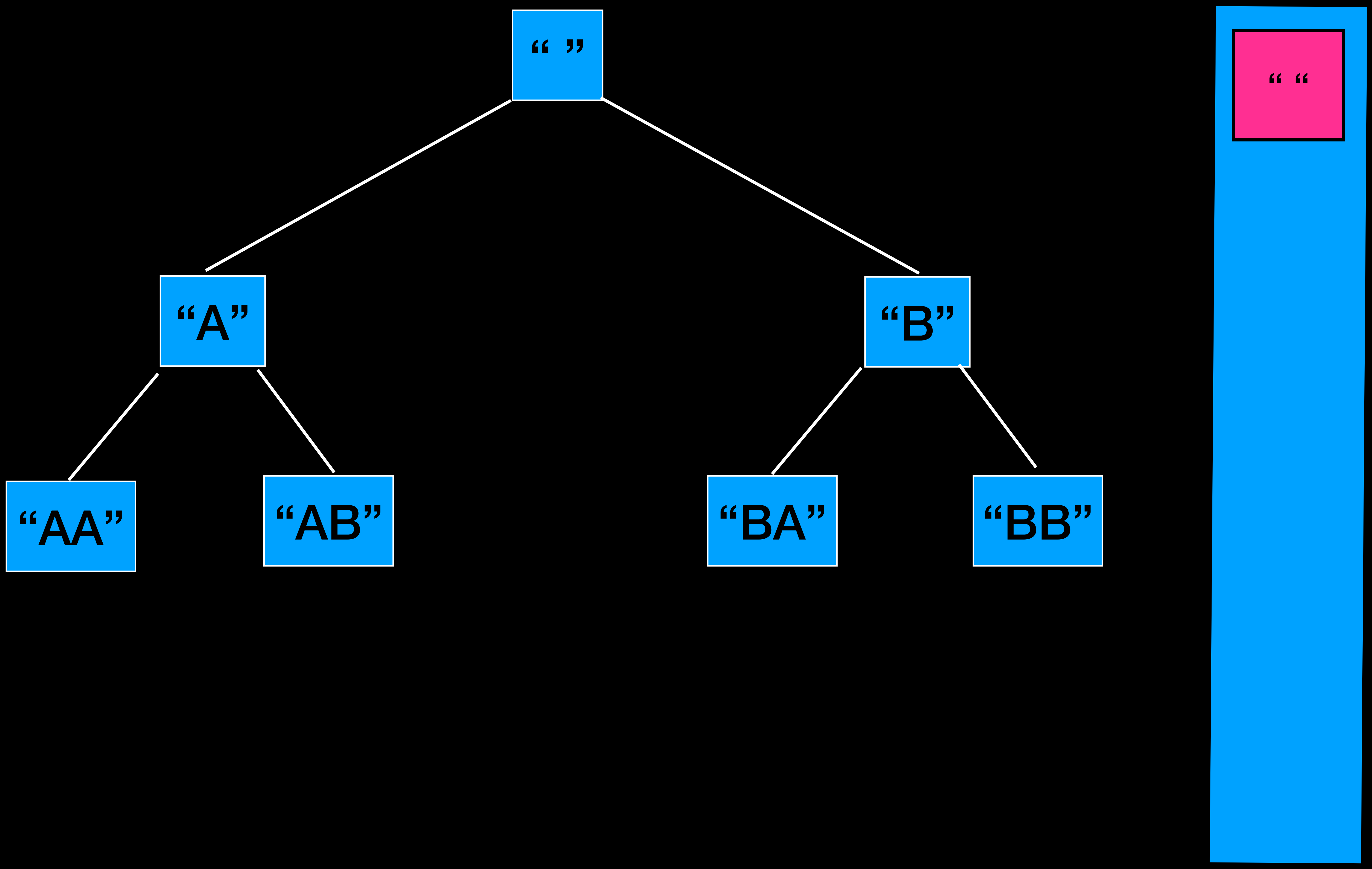
Massive space requirement

What if we use a stack?

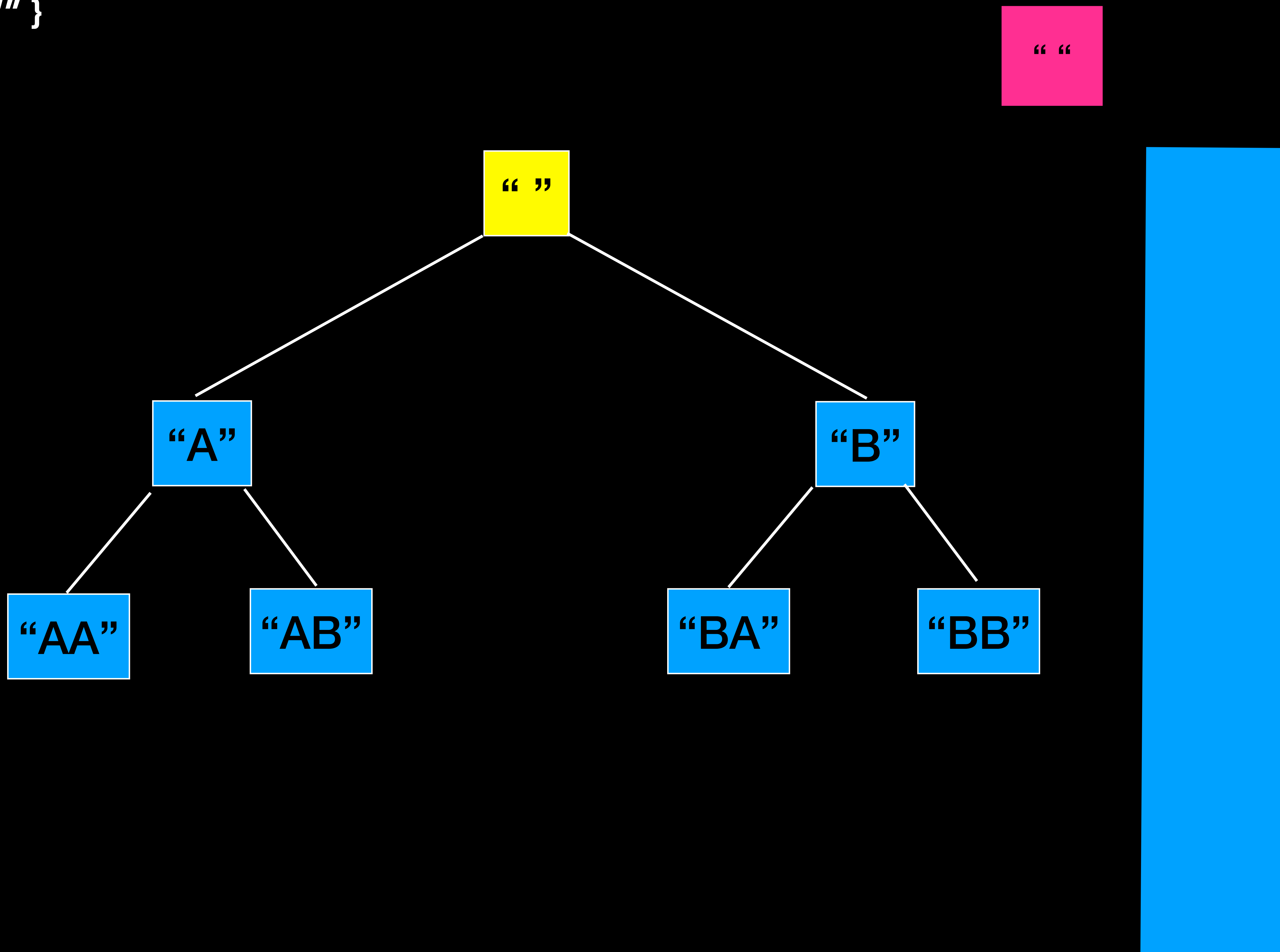
```
findAllSubstrings(int n)
{
    push empty string on the stack

    while(stack is not empty){
        let current_string = pop and add to result
        if(size of current_string < n){
            for(each character ch)//every character in alphabet
                append ch to current_string and push it
        }
    }
    return result;
}
```

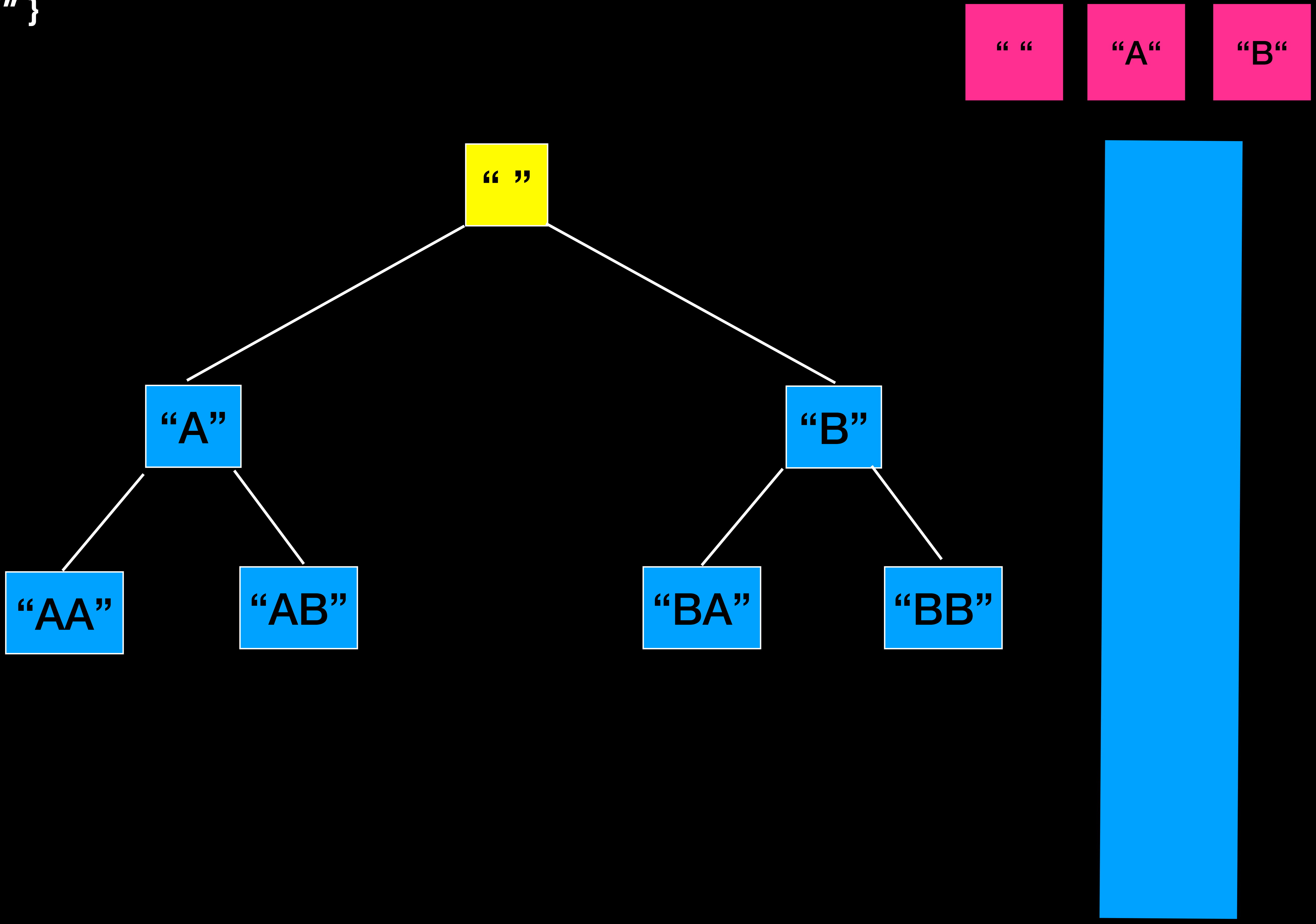
$O(26^n)$


“ ”
“A”
“B”
“AA”
“AB”
“BA”
“BB”
“ “

{ “” }

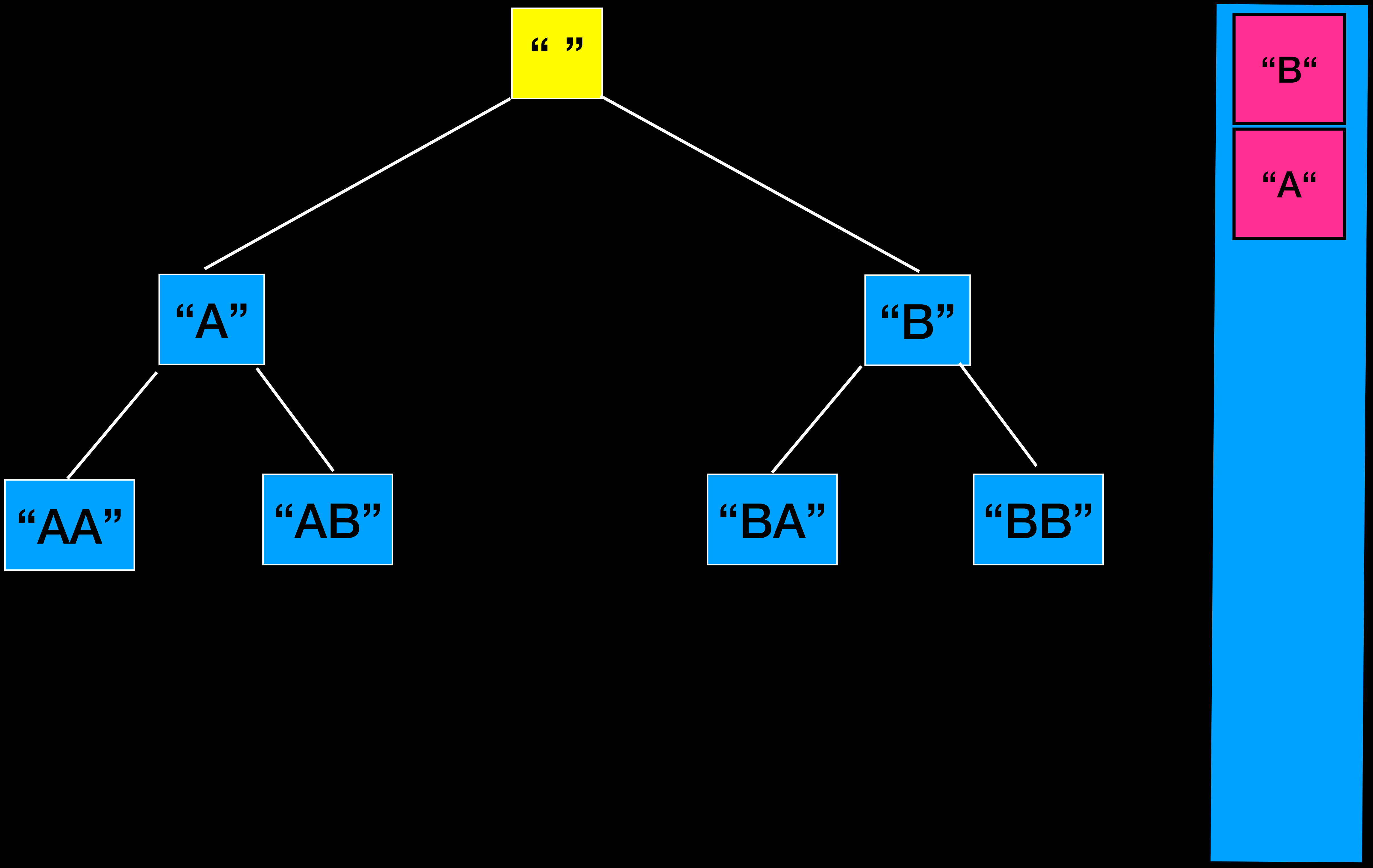

“ “
“ ”
“A”
“B”
“AA”
“AB”
“BA”
“BB”

{ "" }



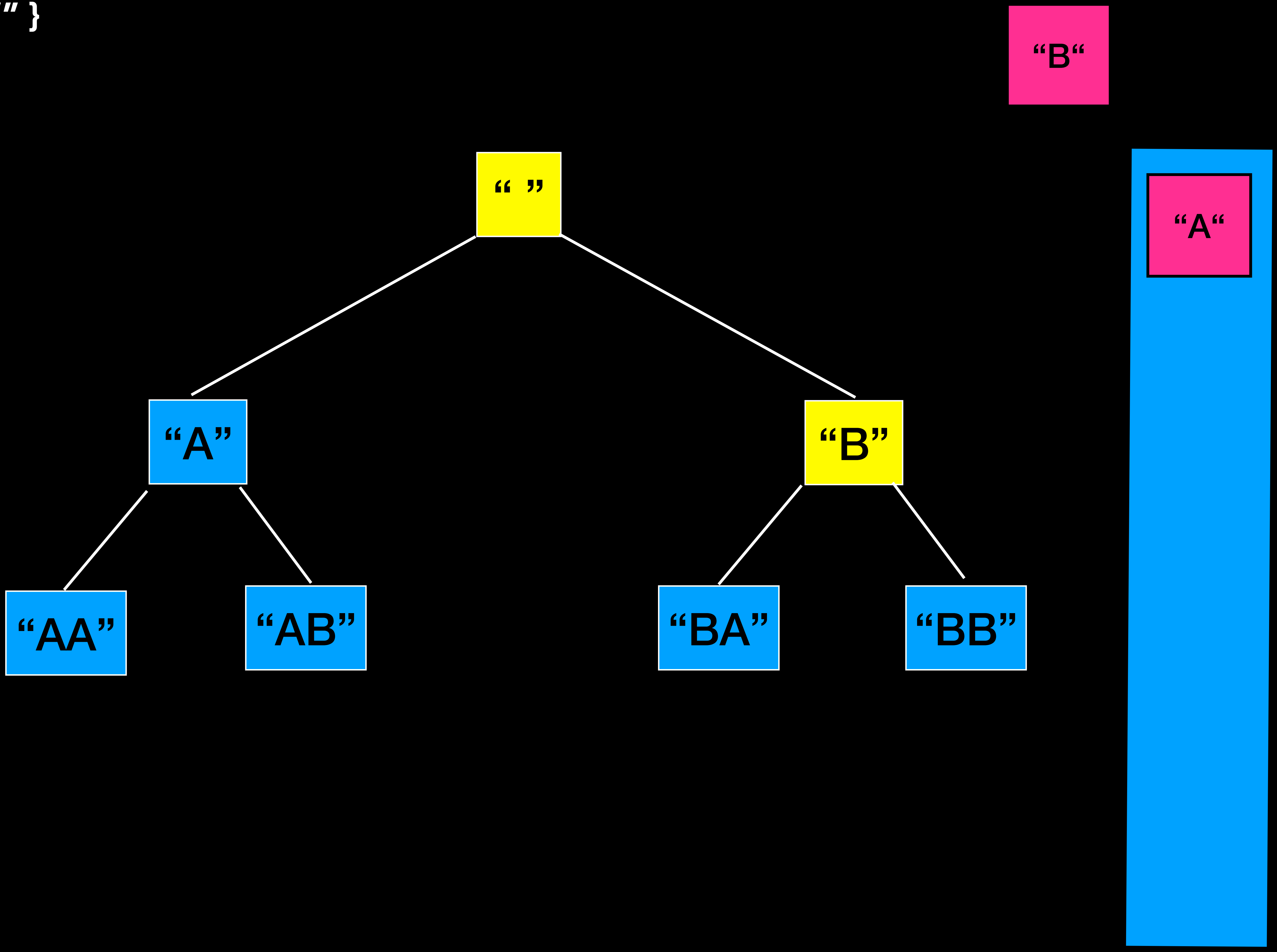
" "
"A"
"B"
" "
"A"
"B"
"AA"
"AB"
"BA"
"BB"

{ "" }

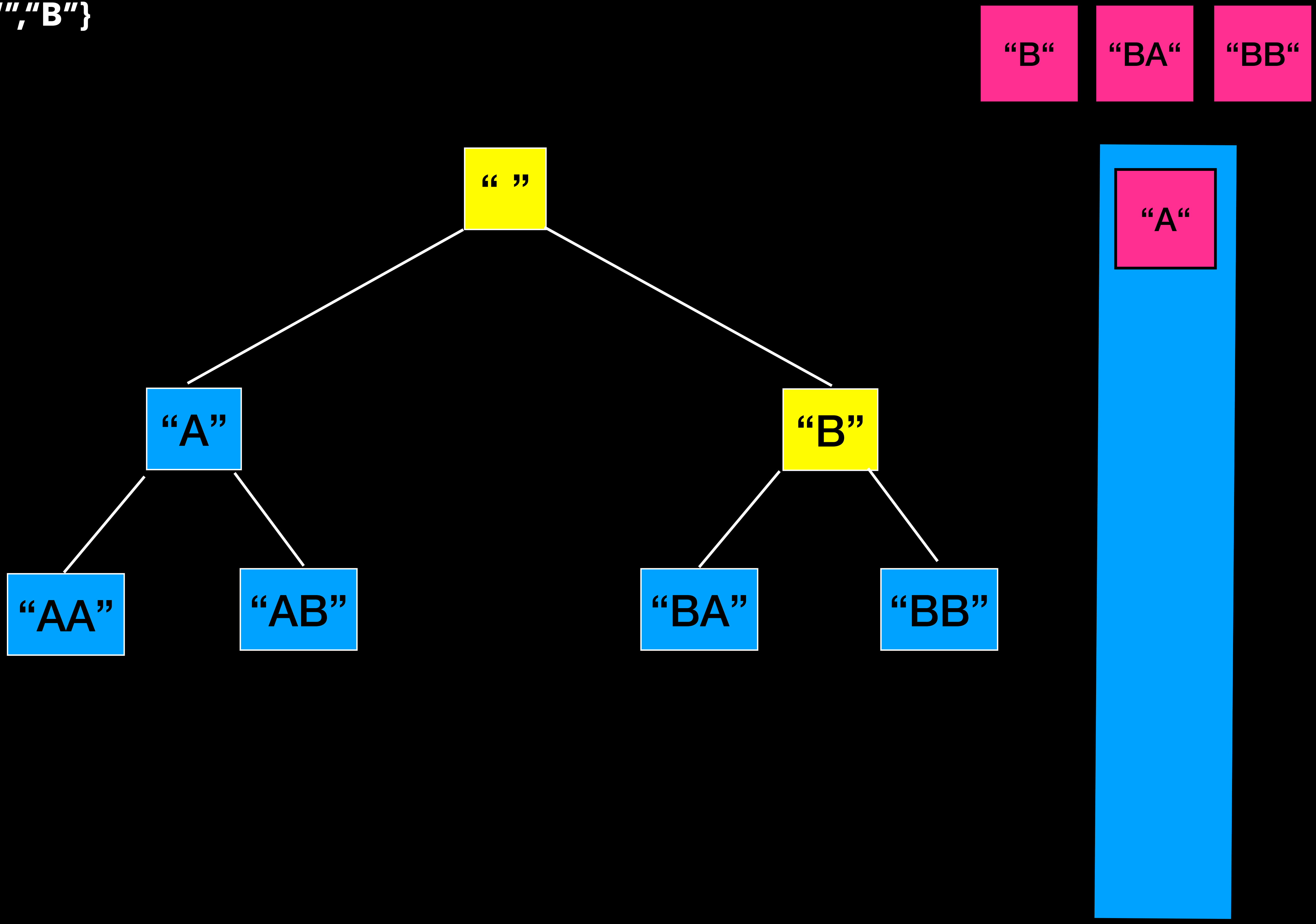


“ ”
“A”
“B”
“AA”
“AB”
“BA”
“BB”
“B“
“A“

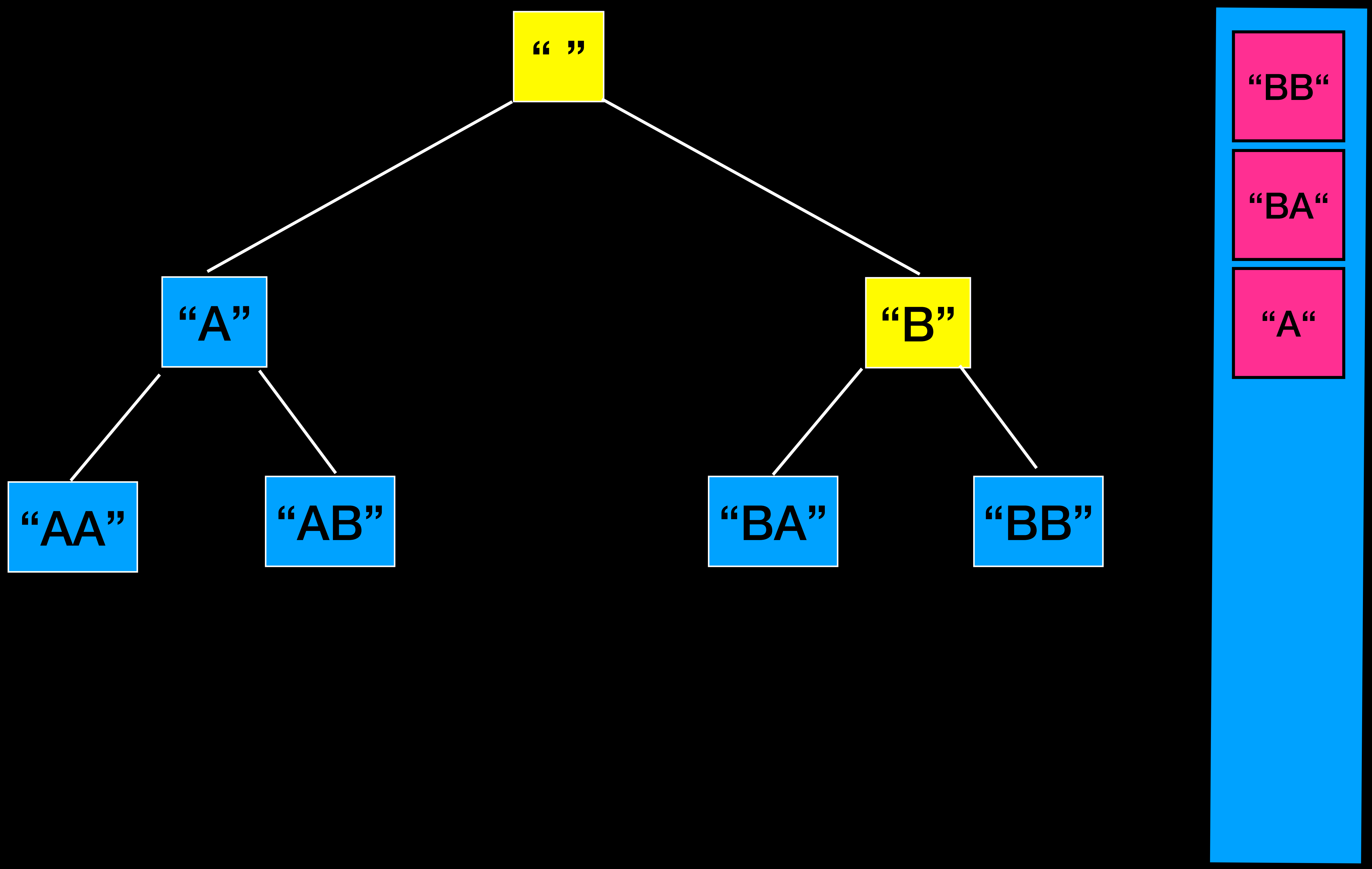
{ “” }


“B“
“ ”
“A“
“A”
“B”
“AA”
“AB”
“BA”
“BB”

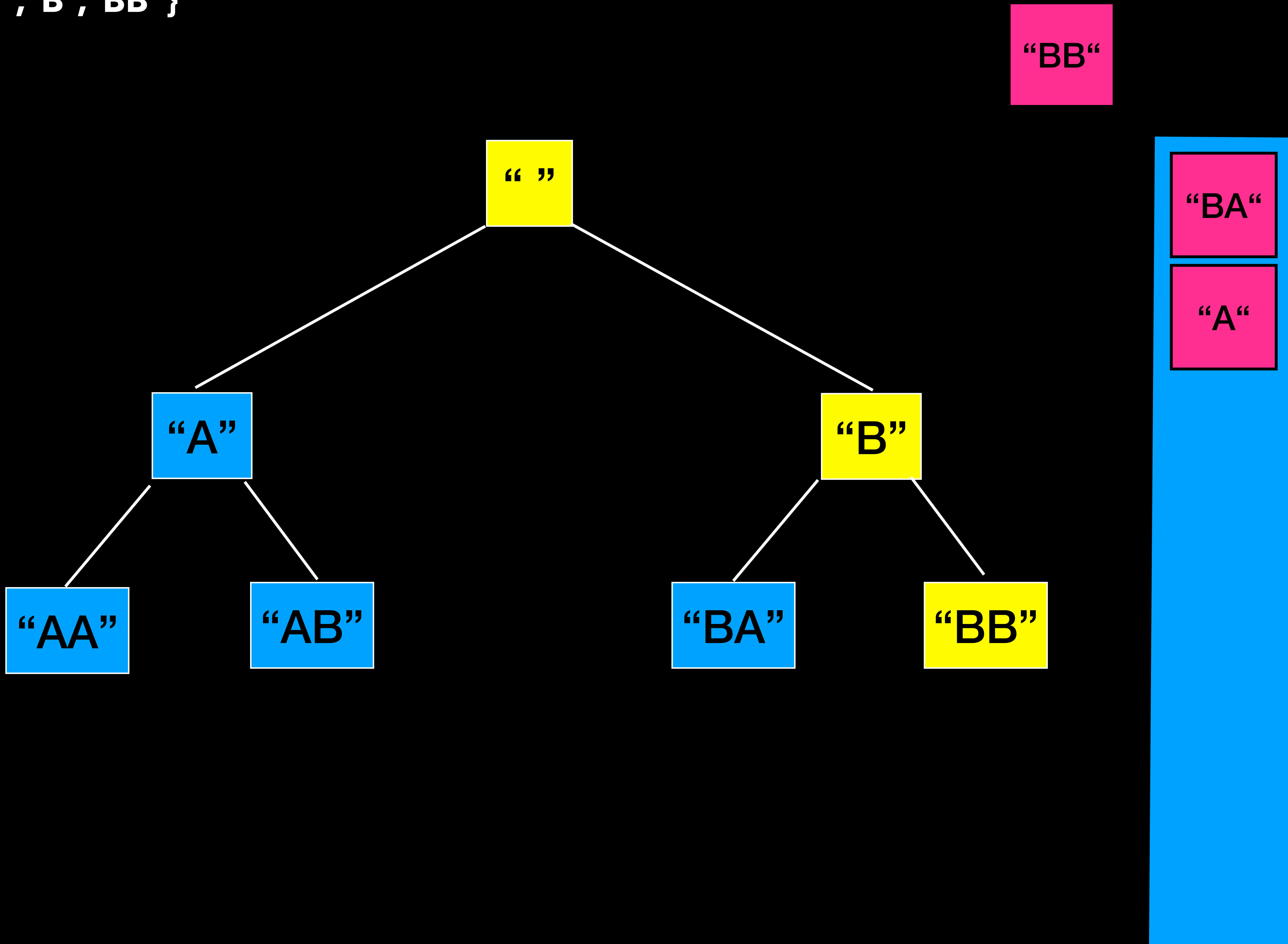
{ “”,“B”}



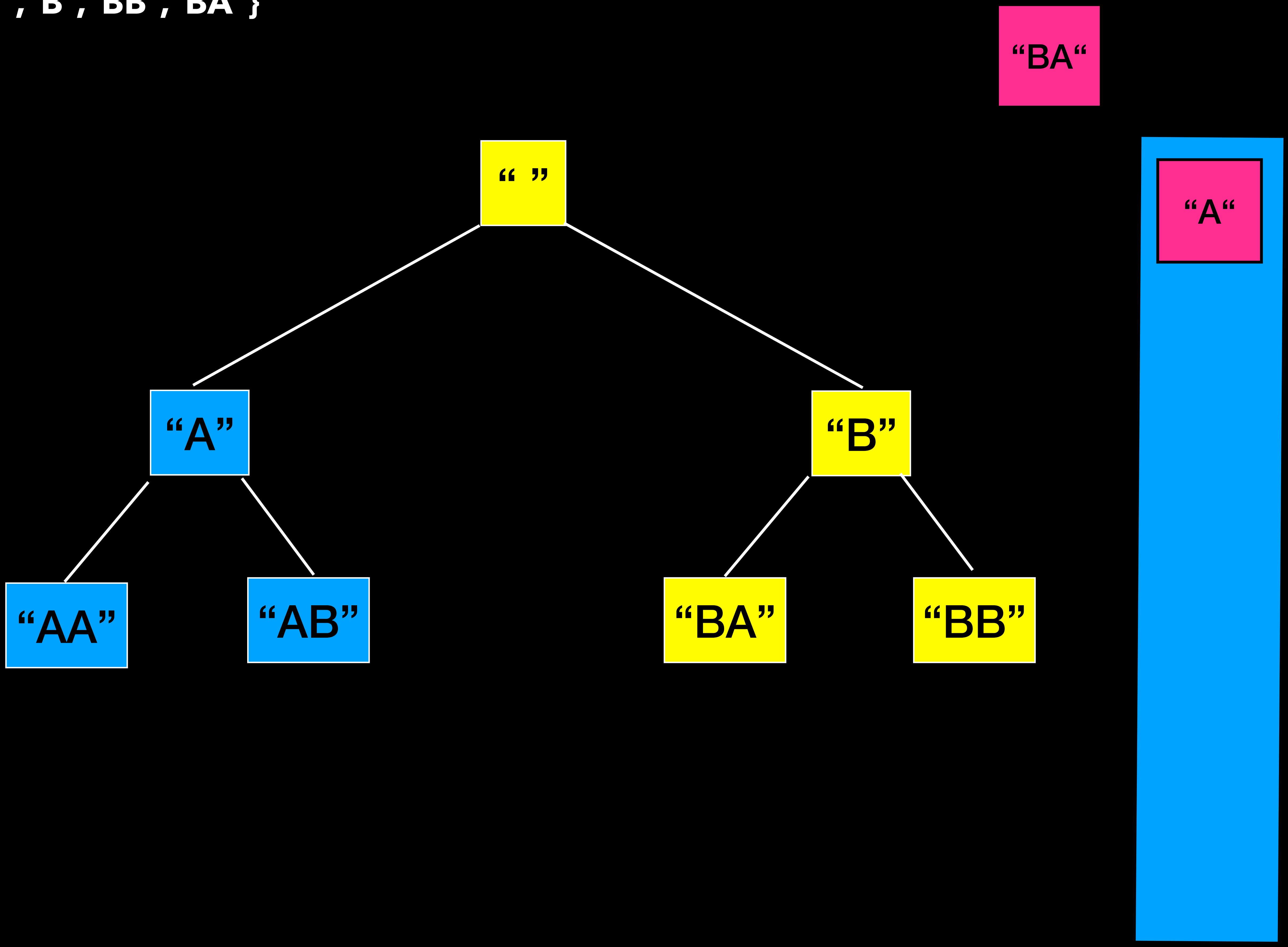
{ “”,”B”}

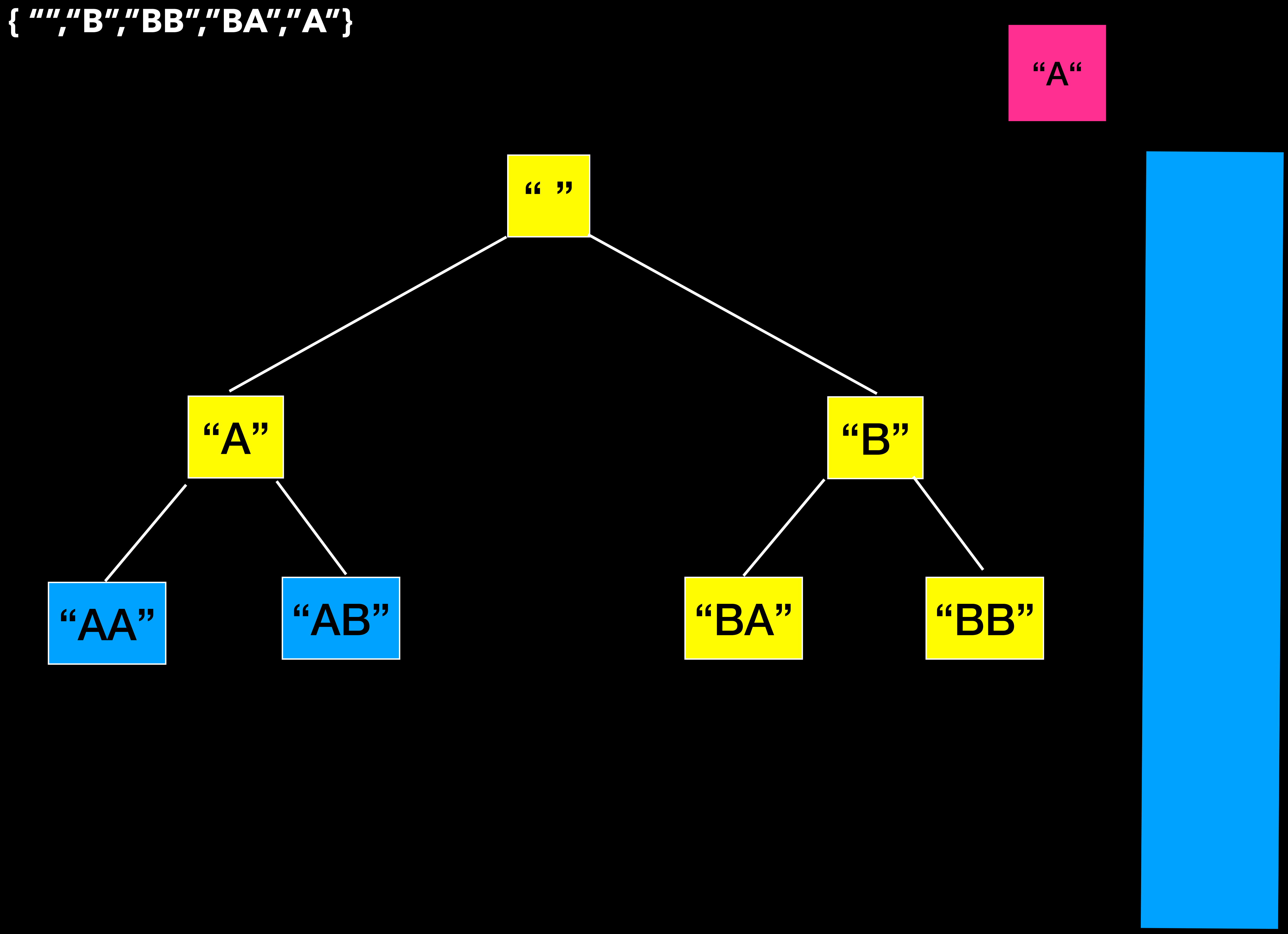


{ "","B","BB"}

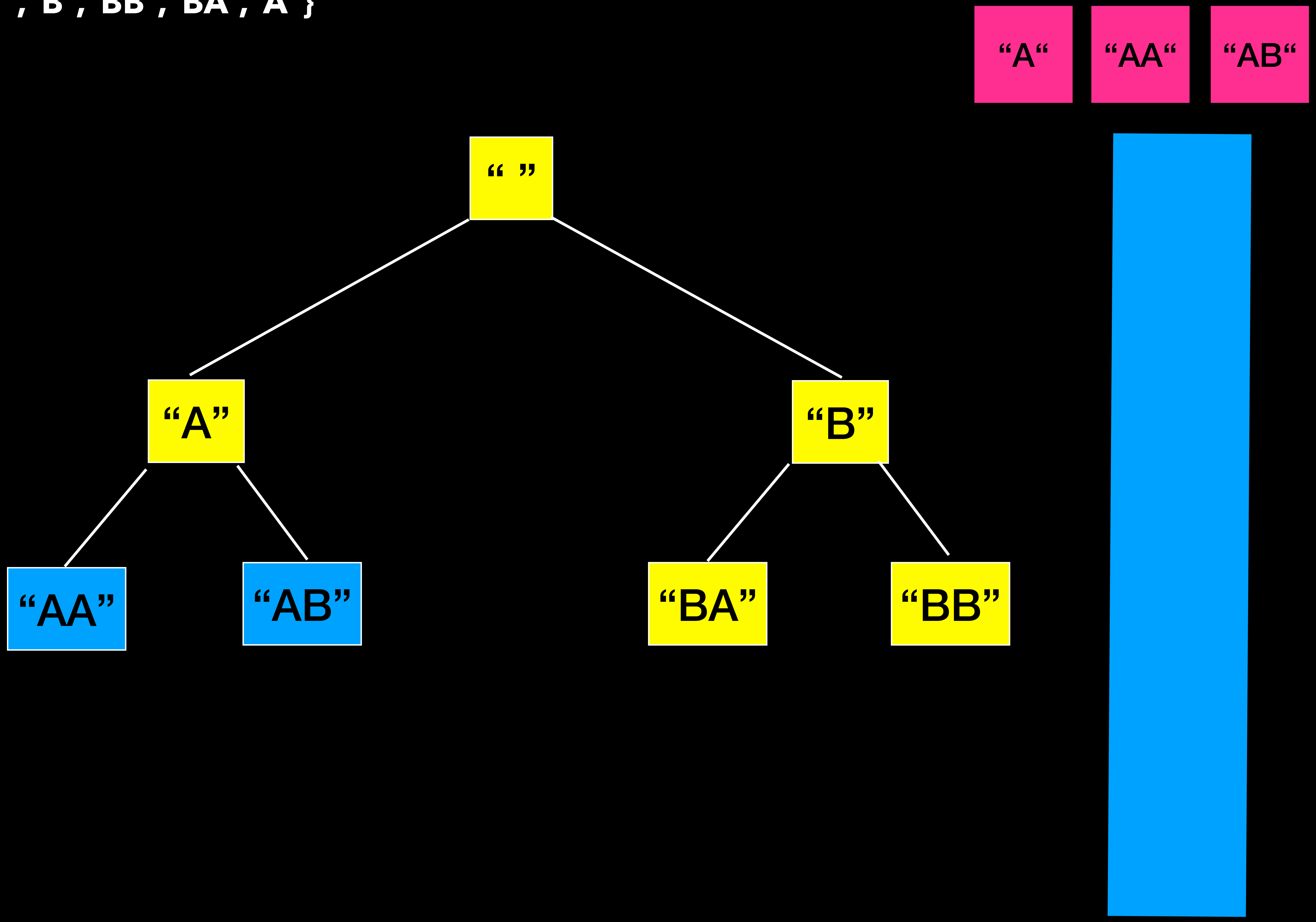


{ "","B","BB","BA"}

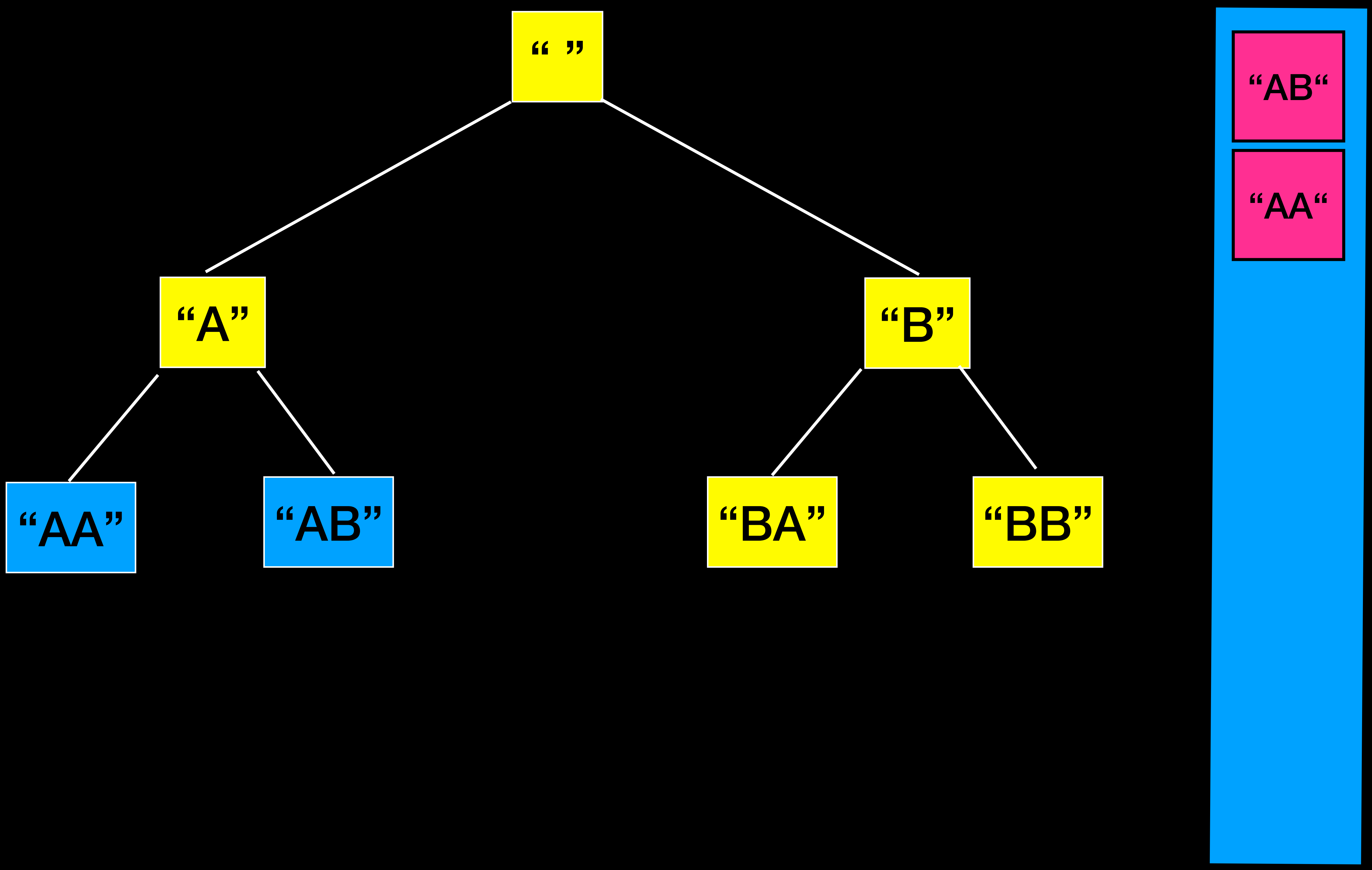



{ "","B","BB","BA","A"}
"A"
" "
"A"
"B"
"AA"
"AB"
"BA"
"BB"

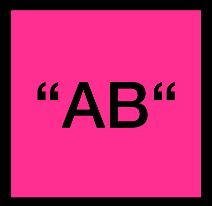
{ “”,”B”,”BB”,”BA”,”A”}

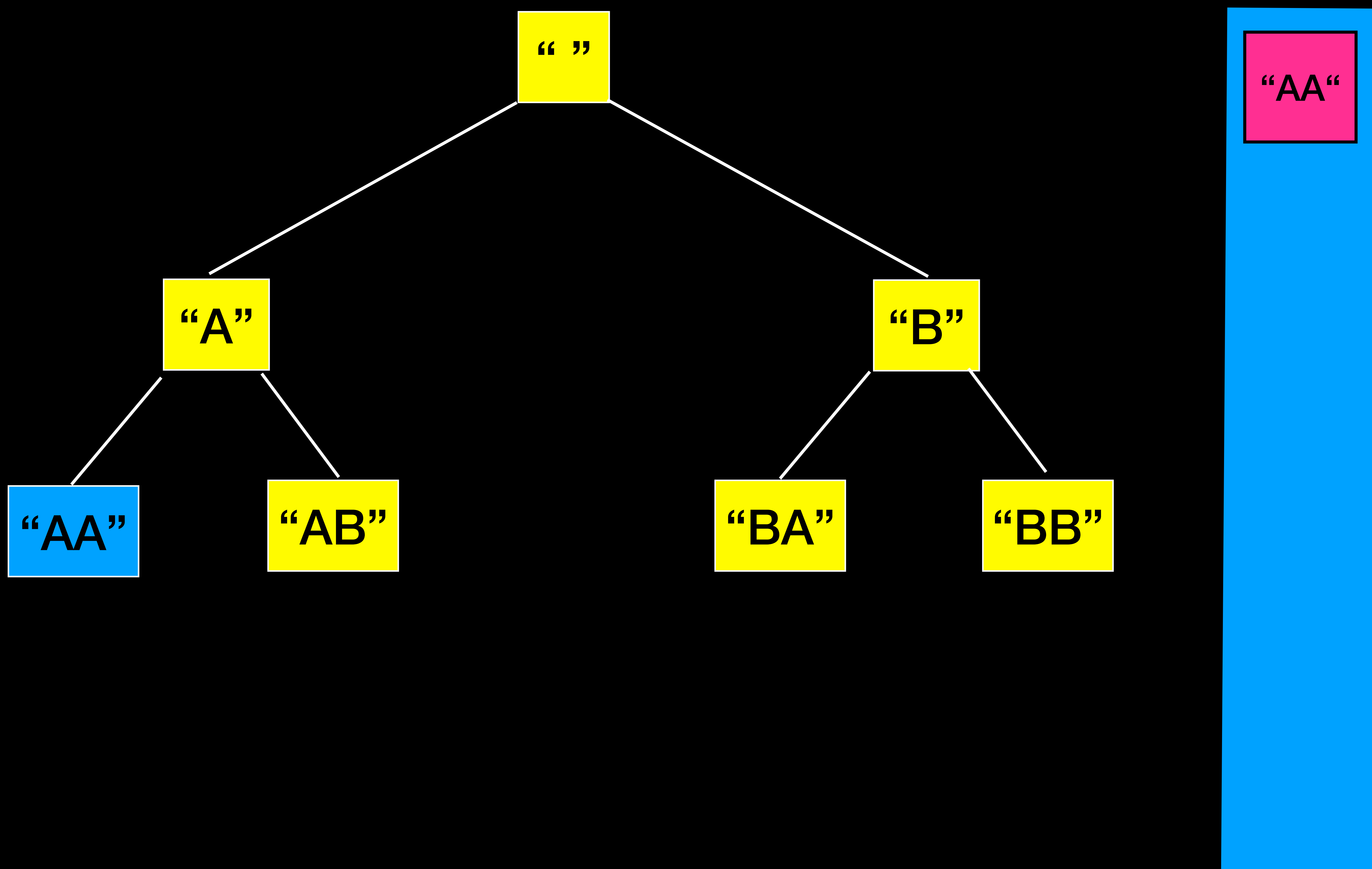


{ “”,”B”,”BB”,”BA”,”A”}

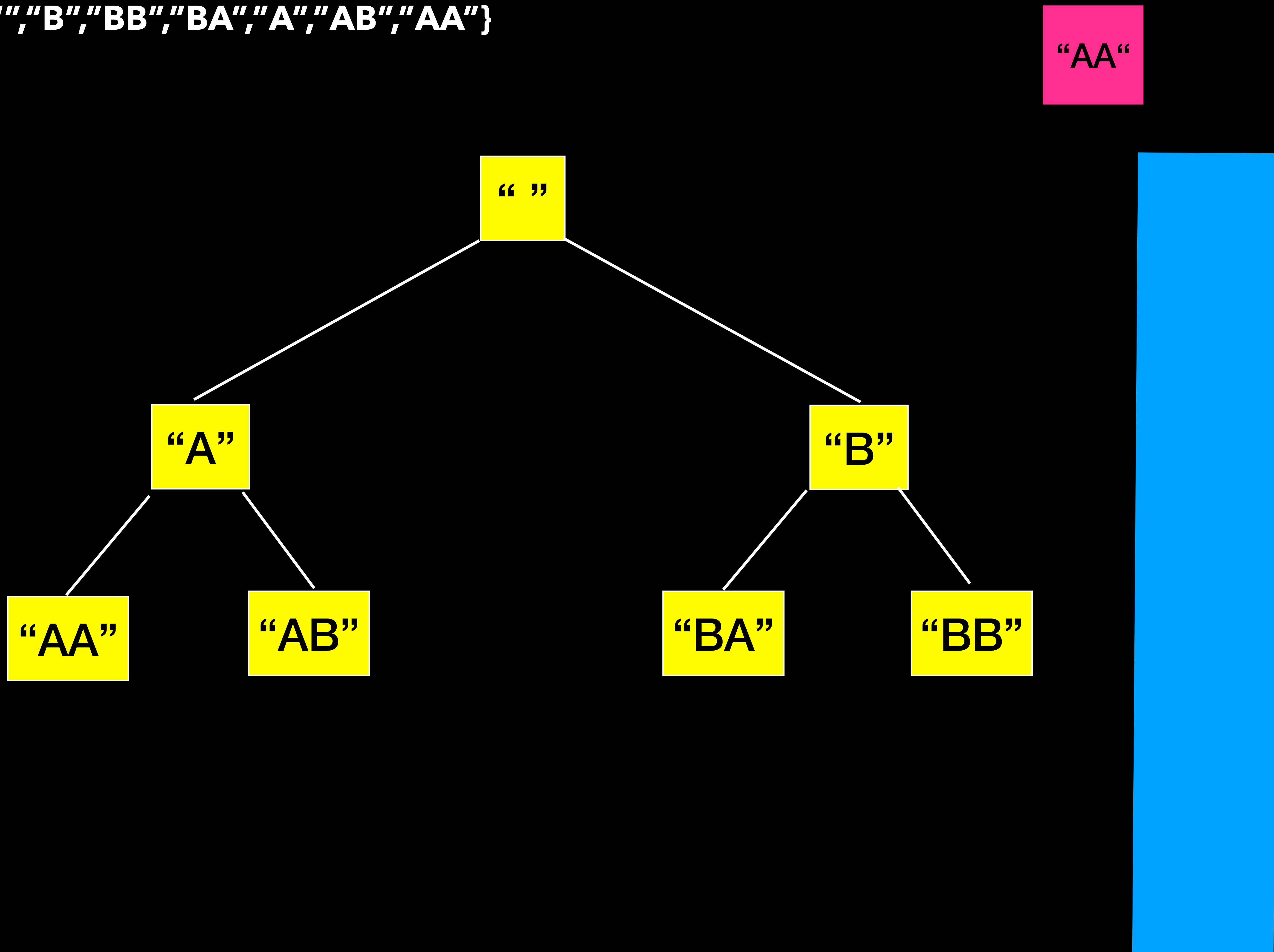


{ "","B","BB","BA","A","AB"}

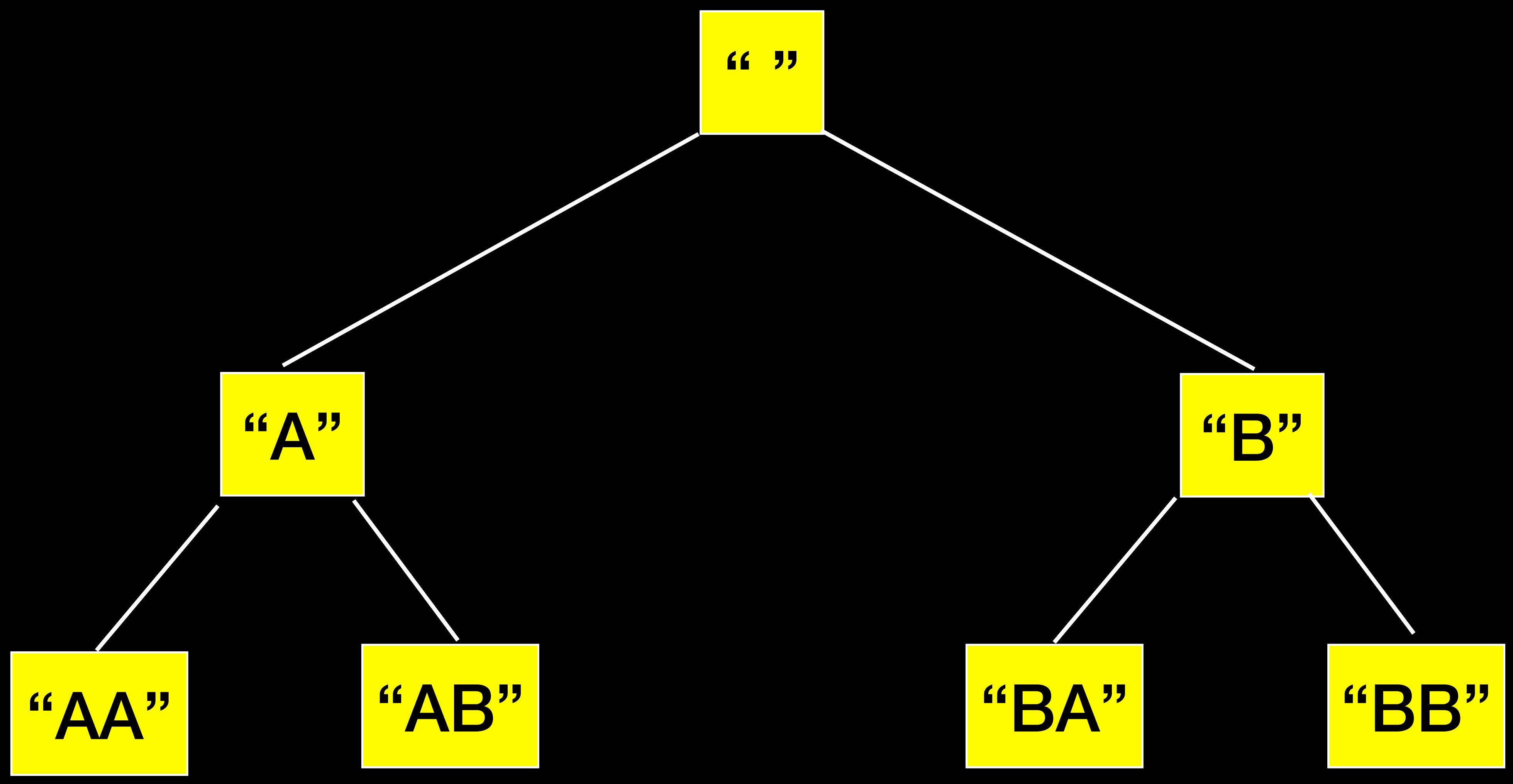




{ "","B","BB","BA","A","AB","AA"}



{ "","B","BB","BA","A","AB","AA"}



What’s the difference?

Depth-First Search

Applications

- Detecting cycles in graphs
- Path finding
- Finding strongly connected components in graph
- . . .

Same worst-case runtime analysis

More space efficient than previous approach

Does not explore options in increasing order of size

Comparison

Breadth-First Search
(using a queue)

Time O(26^n)

Space O(26^n)

Good for exploring options in increasing order of size when expecting to find "shallow" or "short" solution

Memory inefficient when must keep each "level" in memory

Depth-First Search
(using a stack)

Time O(26^n)

Space O(n)

Explores each option individually to max size - does NOT list options by increasing size

More memory efficient

Queue ADT

```
#ifndef QUEUE_H_
#define QUEUE_H_

template<class T>
class Queue
{

public:
    Queue();
    void enqueue(const T& new_entry); // adds an element to back queue
    void dequeue(); // removes element from front of queue
    T front() const; // returns a copy of element at the front of queue
    int size() const; // returns the number of elements in the queue
    bool isEmpty() const; // returns true if no elements in queue, false otherwise

private:
            //implementation details here


};    //end Queue

#include "Queue.cpp"
#endif // QUEUE_H_ `
```

Other ADTs

Deque

Double ended queue (deque)

Can add and remove to/from front and back

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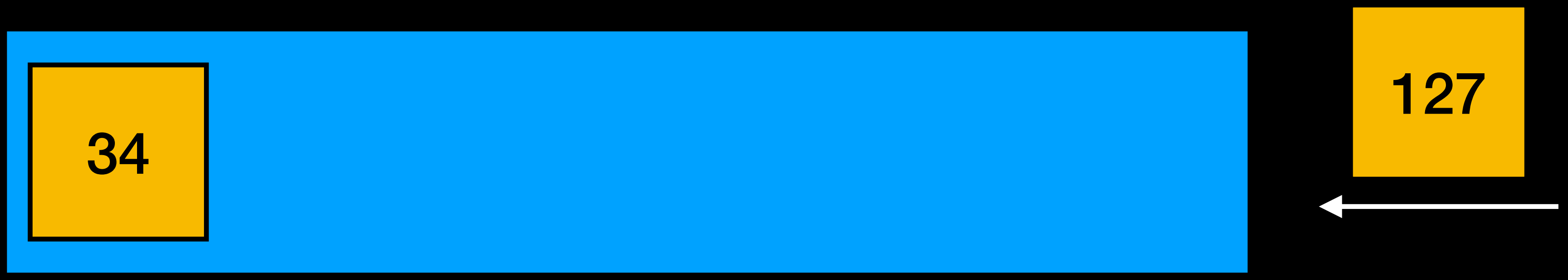

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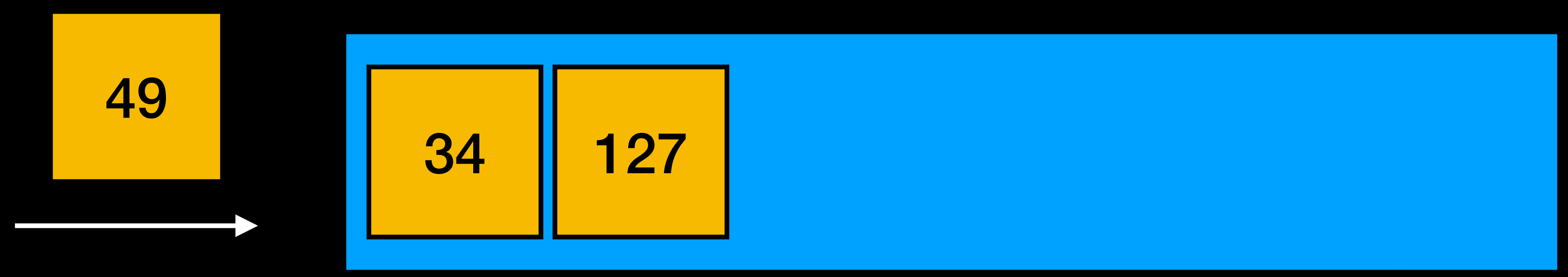

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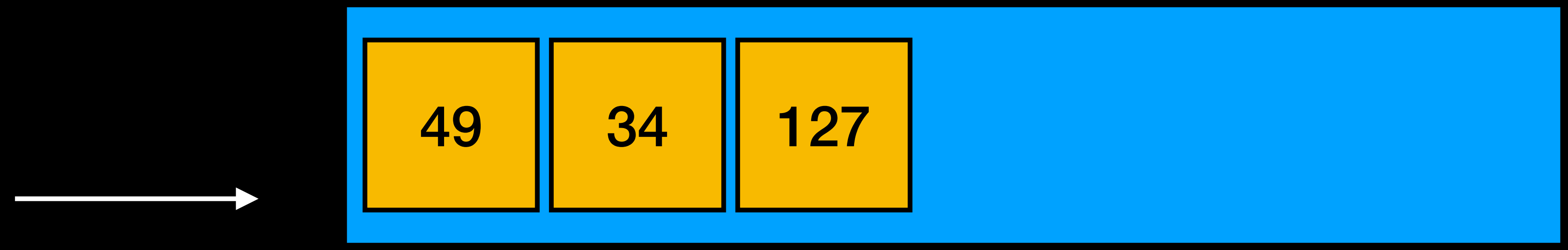

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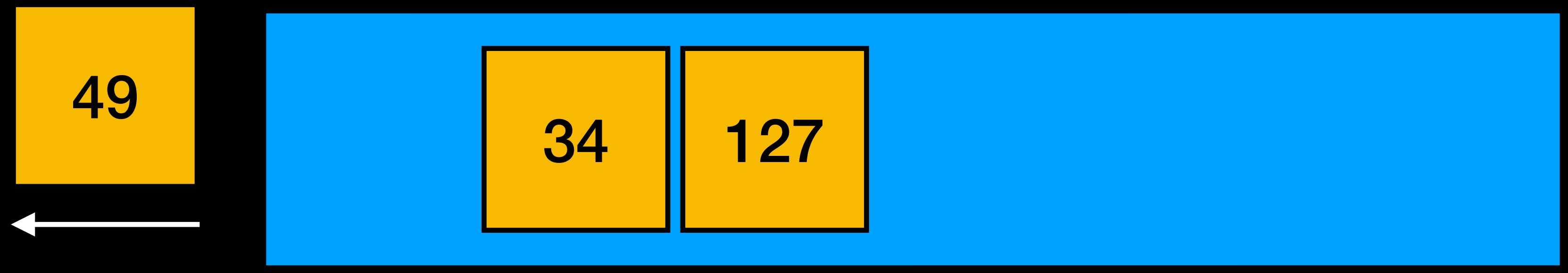

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- grows more efficiently than vector

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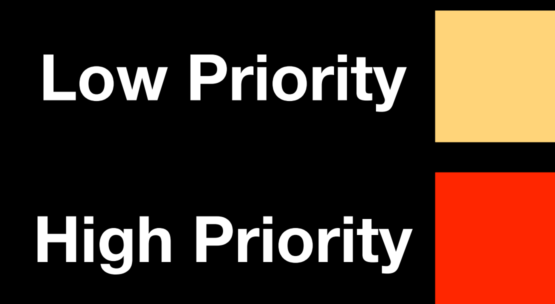
In STL stack and queue are *adapters* of deque

STL standardized the use of language “push” and “pop”, adapting with “push_back”, “push_front” etc. for all containers

Priority Queue



A queue of items “sorted” by priority

Priority Queue

Low Priority

High Priority

A queue of items “sorted” by priority

Priority Queue

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Priority Queue

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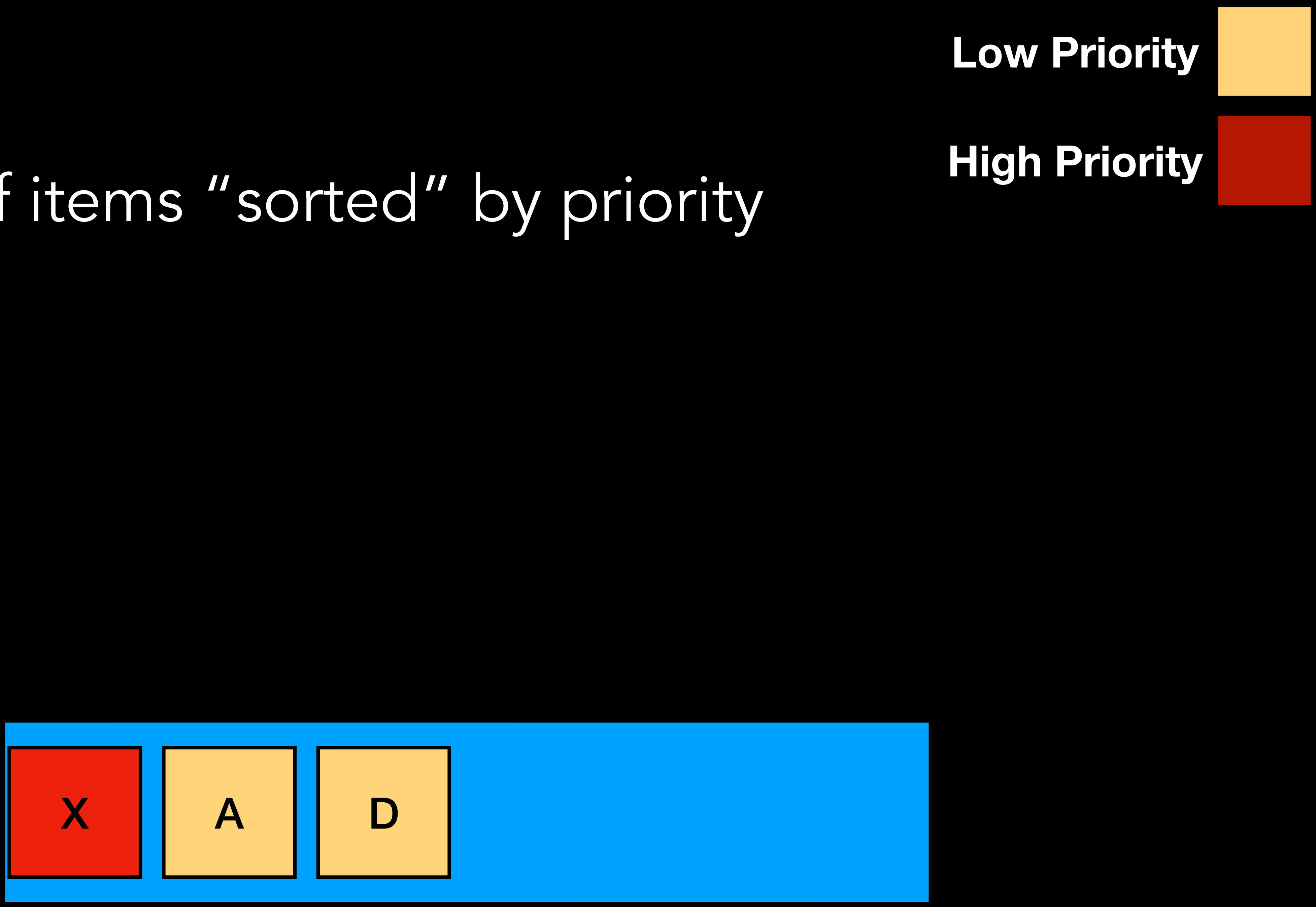

Priority Queue

Low Priority

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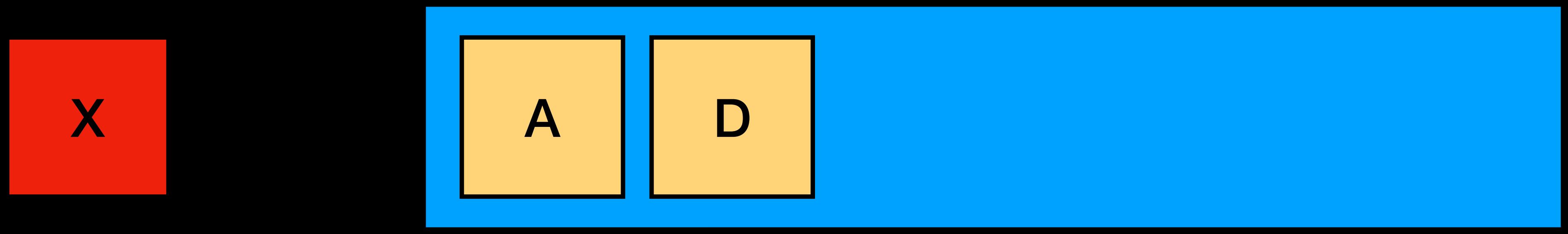

Priority Queue

Low Priority

High Priority

A queue of items "sorted" by priority

If value indicates priority, it amounts to a sorted list that accesses/removes the "highest" items first

Priority Queue

Orders elements by priority => removing an element will return the element with highest priority value

Elements with same priority kept in queue order (in some implementations)

Priority Queue

Spoiler Alert!!!!

Often implemented with a Heap

Will tell you what it is in a few weeks… but here is another example of ADT vs data structure

Explore the STL

It's time to get to know it!!!

C++ Interlude 8 in your textbook

`https://en.cppreference.com/w/cpp/standard_library`

`https://en.cppreference.com/w/cpp/container`

`https://en.cppreference.com/w/cpp/algorithm`

You should use STL stack and queue for Project 6

Explore as you learn about new ADTs and algorithms.

Main Components

Containers

Algorithms

Functions

Iterators

Main Components

Containers

Algorithms

Functions

Iterators

Sequence Containers

`array`

`vector`

`deque`

`forward_list` (singly linked)

`list` (doubly linked)

Contiguous memory

Fixed size

Grow and Shrink

Also allows access to any location with [ ]

Non-contiguous memory
Growing and shrinking more efficient

Container Adaptors

Impose a different interface for the underlying container

`stack`

`queue`

`priority_queue`

For Project 6

```
#include <stack>
#include <queue>

std::queue<Attack> attack_queue_;
std::stack<Creature*> alien_stack_;
std::stack<Creature*> undead_stack_;
std::stack<Creature*> mystical_stack_;
std::stack<Creature*> unknown_stack_;

attack_queue_.push(attack);
//uses stack language but always adds
// to the back of the queue

attack_queue_.pop();
//uses stack language but always removes from the
//front of the queue, does NOT return
// the popped item
```

Algorithms

```
#include <algorithm>
```

Search and Compare Algorithms examples

```
    for_each() // applies a function to a range in container
    count() // counts the occurrences of an item within a range
    max_element() // returns the max value within a range
```

Sequence Modification Algorithms examples

```
    copy() //copies items within a range starting at given position
           within same or different container
    fill() // sets all entries within a range to give value
```

Sorting and Searching Algorithms examples

```
    sort() // sorts entries within a range in ascending order –
              typically some variation of QuickSort
    stable_sort() // “” – typically MergeSort may vary
    binary_search() // determines if an item exist in a given range
                       in a sorted container
```

. . . much more!!!