CSE 100:
MWTS AND TSTS

Goals for today

- Build Multi-way Tries and Ternary Search Trees
- Analyze the running time of MWTs, and list the advantage of a TST over a MWT
- Worksheet in the class

Tries: Efficient way to store/find keys that are sequences of digits/characters

Create the multi-way trie for the following keys:

apple

ape

applet

cape

tall

tap

tape

Does the structure of the trie depend on the order in which you inserted the words?

A. Yes B. No

apple, ape, applet, cape, tall, tap, tape

Tries: Efficient way to store/find keys that are sequences of digits/characters

Does the structure of the trie depend on the order in which you inserted the words?

A. Yes B. No

Properties of tries

Assume you insert 100 keys of length 5 digits into a multi-way trie.
In the worst case, how tall is your trie?

A. 5 B. 100 C. log2(100)

Properties of tries

If N is the number of keys you insert in your trie, and D is the length of the longest key, what is the maximum height of your trie in terms of N and/or D in the worse case?

A. N B. D C. log2(N)

Tries Vs. BST

Assume an alphabet of 6 characters, as above. From this alphabet, you can create $6^5 = 7776$ different keys (strings) of length 5. If you insert all 7776 of these strings into a MWT and a BST, which will be shorter? How tall is each? Is this true in general (consider different size alphabets, different length strings)? You can assume the BST is perfectly balanced.

Properties of tries

What is the main drawback of tries compared to BSTs?

A. They are difficult to implement
B. They often waste a lot of space
C. They are slow
D. There is no drawback of tries

Ternary search trees (tries) to the rescue!

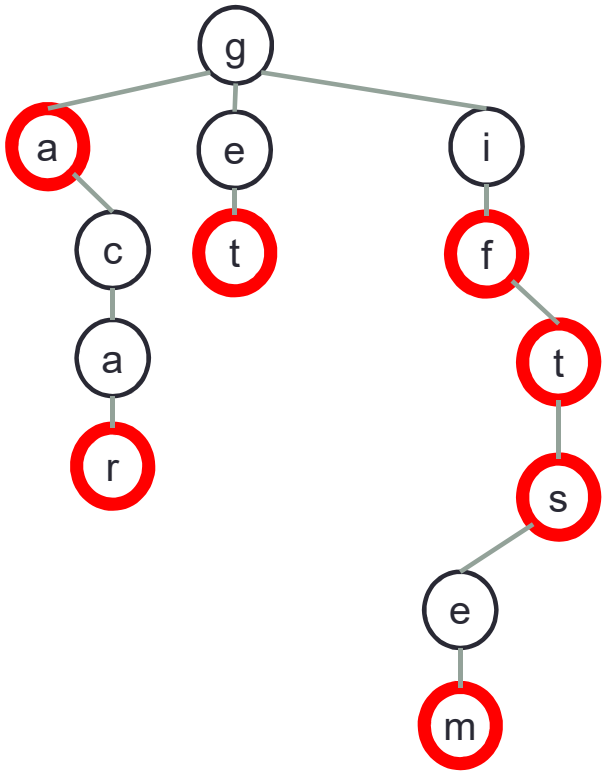
- Tries combine binary search trees with tries.
- Each node contains the following:
  - A key `digit` for search comparison
  - Three pointers:
    - `left` and `right`: for when the digit being considered is less than and greater than (respectively) the digit stored in the node (the BST part)
    - `middle`: for when the digit being considered is equal to the digit stored in the node (the trie part)
  - An `end` bit to indicate we've completed a key stored in the tree.

Ternary search trees (tries)

List all the words (strings) you can find in this TST

Are the following in the tree?
(A=yes, B=no)

- get
- if
- gif
- its
- gacar
- tsem



Draw the ternary search trie for the following (in this order)

apple, ape, applet, cape, tall, tap, tape

Draw the ternary search trie for the following (in this order)

How many nodes are added if I now add the word “ace”?

A. 0 B. 1 C. 2 D. 3

Draw the ternary search trie for the following (in this order)

Does the structure of the tree depend on the order in which keys were inserted?
A. Yes B. No

Goals for today

- Examine algorithms for tree search
- Explain the idea behind and advantages of hashing and hash tables
- Calculate collision probabilities in hash tables

New(ish)!

A2: Implementing dictionaries and autocomplete!

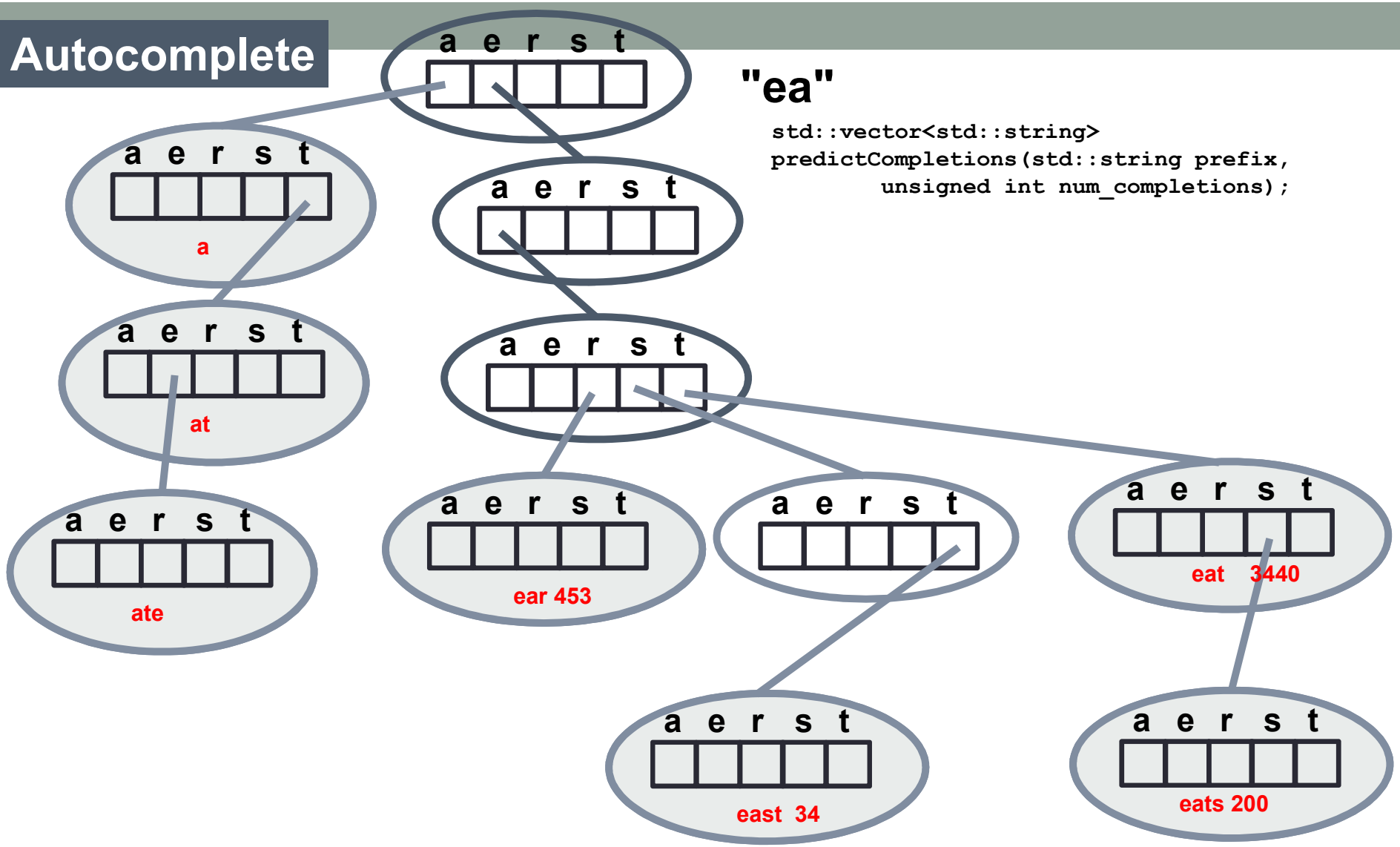
- Checkpoint: Implement string autocomplete
  - Autocomplete: Finds the top ‘n’ most frequently occurring words with a given prefix

“ap” → “apple”, “ape”, “apology”, …

You will use Tries!!

- Final submission: Autocomplete, Document Generation
  - Document Generation:
    - Given previous text, produce similar new text
    - Markov Text Generation

Autocomplete



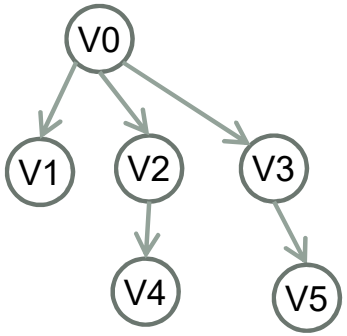
"ea"

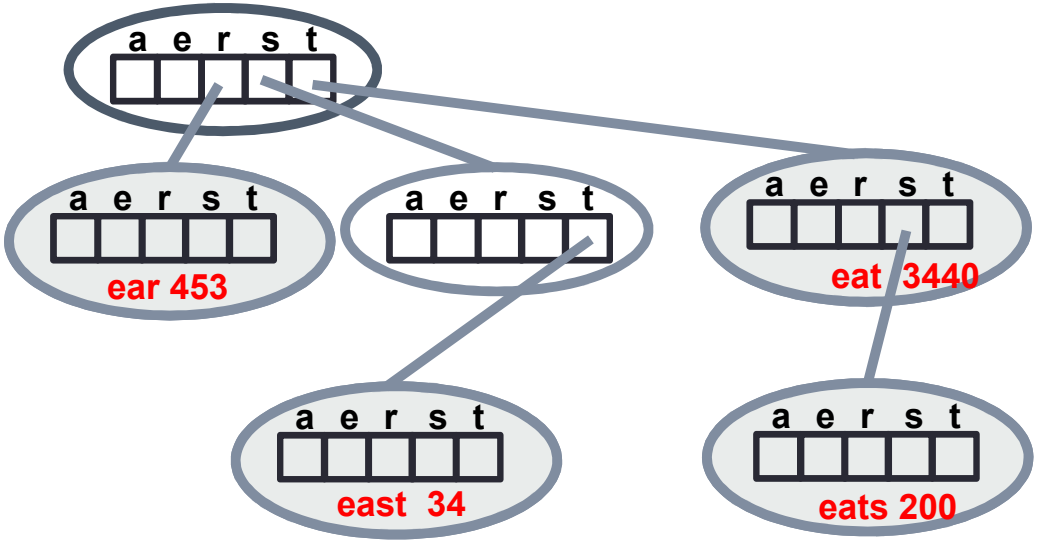
```
std::vector<std::string>
predictCompletions(std::string prefix,
        unsigned int num_completions);
```

Generic approach to graph (tree) search

Generic Goals:

- Find everything that can be explored
- Don't explore anything twice





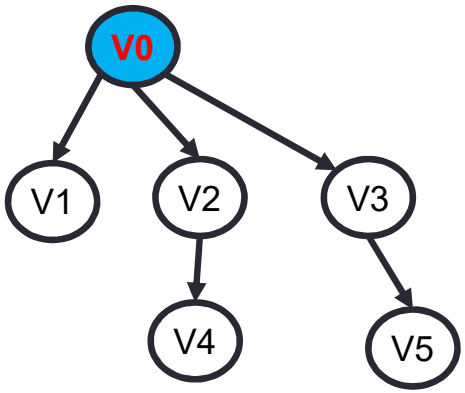
We will look at different graph (tree) search algorithms. Either can be used for PA2, at least at first

- Depth First Search
- Breadth First Search

Depth First Search for Tree Traversal

- Search as far down a single path as possible before backtracking

  Write the order of nodes explored, starting at V0 and assuming smaller numbers are selected first

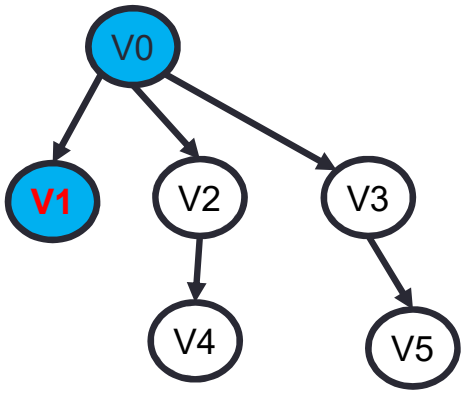


V0

Depth First Search for Tree Traversal

- Search as far down a single path as possible before backtracking

  Write the order of nodes explored, starting at V0 and assuming smaller numbers are selected first

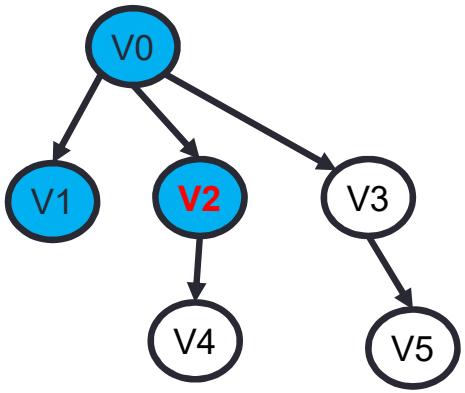


V0, V1

Depth First Search for Tree Traversal

- Search as far down a single path as possible before backtracking

  Write the order of nodes explored, starting at V0 and assuming smaller numbers are selected first

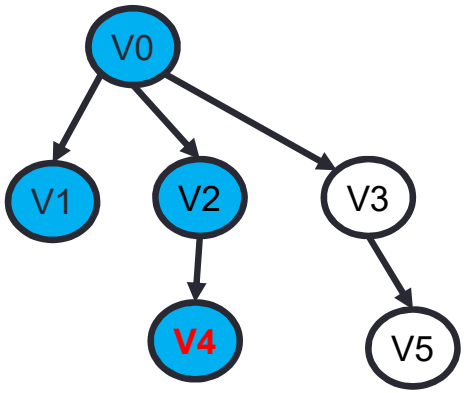


V0, V1, V2

Depth First Search for Tree Traversal

- Search as far down a single path as possible before backtracking

  Write the order of nodes explored, starting at V0 and assuming smaller numbers are selected first

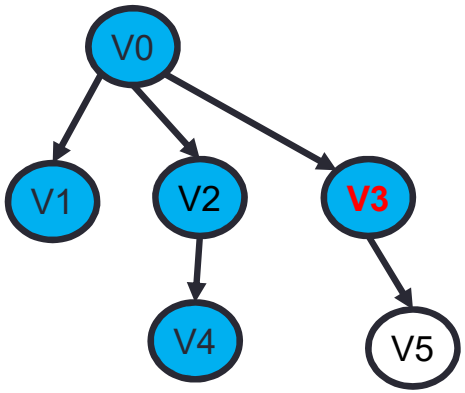


V0, V1, V2, V4

Depth First Search for Tree Traversal

- Search as far down a single path as possible before backtracking

  Write the order of nodes explored, starting at V0 and assuming smaller numbers are selected first

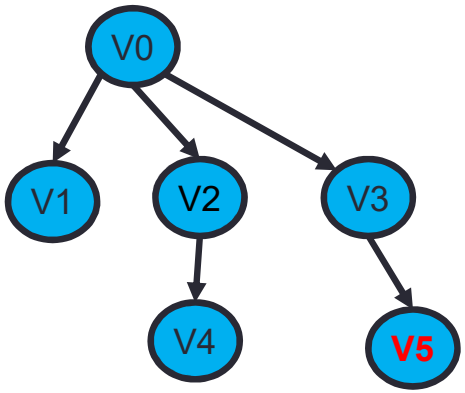


V0, V1, V2, V4, V3

Depth First Search for Tree Traversal

- Search as far down a single path as possible before backtracking

  Write the order of nodes explored, starting at V0 and assuming smaller numbers are selected first



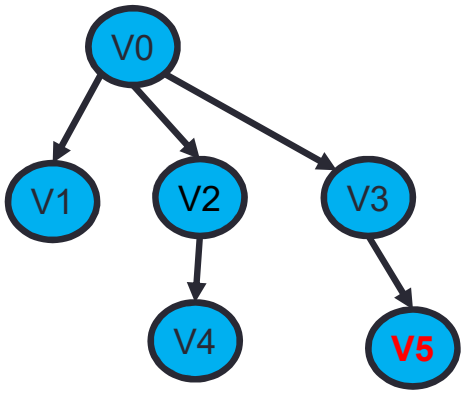
V0, V1, V2, V4, V3, V5

Depth First Search for Tree Traversal

- Search as far down a single path as possible before backtracking

Write the order of nodes explored, starting at V0 and assuming smaller numbers are selected first

How to keep track of where to search next?

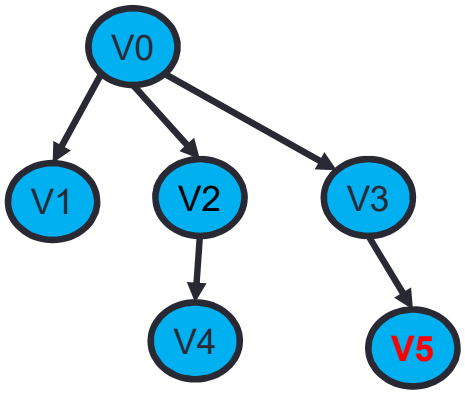


V0, V1, V2, V4, V3, V5

Depth First Search for Tree Traversal

- Search as far down a single path as possible before backtracking

Write the order of nodes explored, starting at V0 and assuming smaller numbers are selected first



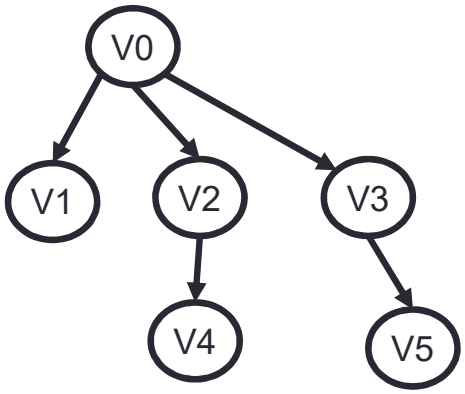
How to keep track of where to search next?
A Stack! (LIFO)

V0, V1, V2, V4, V3, V5

Depth First Search for Tree Traversal

- Search as far down a single path as possible before backtracking

Write the order of nodes explored, starting at V0 and assuming smaller numbers are selected first

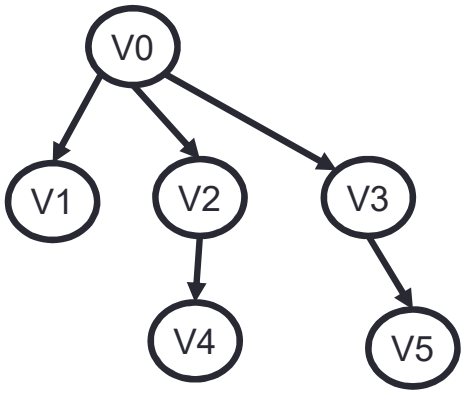



```
DFS(Start):
    Initialize stack
    Push Start onto the stack
    while stack is not empty:
        pop node curr from top of stack
        visit curr
        for each of curr's children, n
            push n onto the stack
 // When we get here then we're done exploring
```

Recursive Depth First Search for Tree Traversal

- Search as far down a single path as possible before backtracking

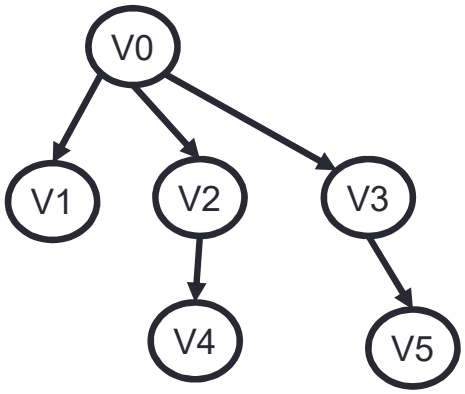
Write the order of nodes explored, starting at V0 and assuming smaller numbers are selected first




```
DFS(Start S):
  for each of S's neighbors, n:
    "visit" n
    DFS(n)
```

What happens when we switch from a stack to a queue?

Write the order of nodes explored, starting at V0 and assuming smaller numbers are selected first



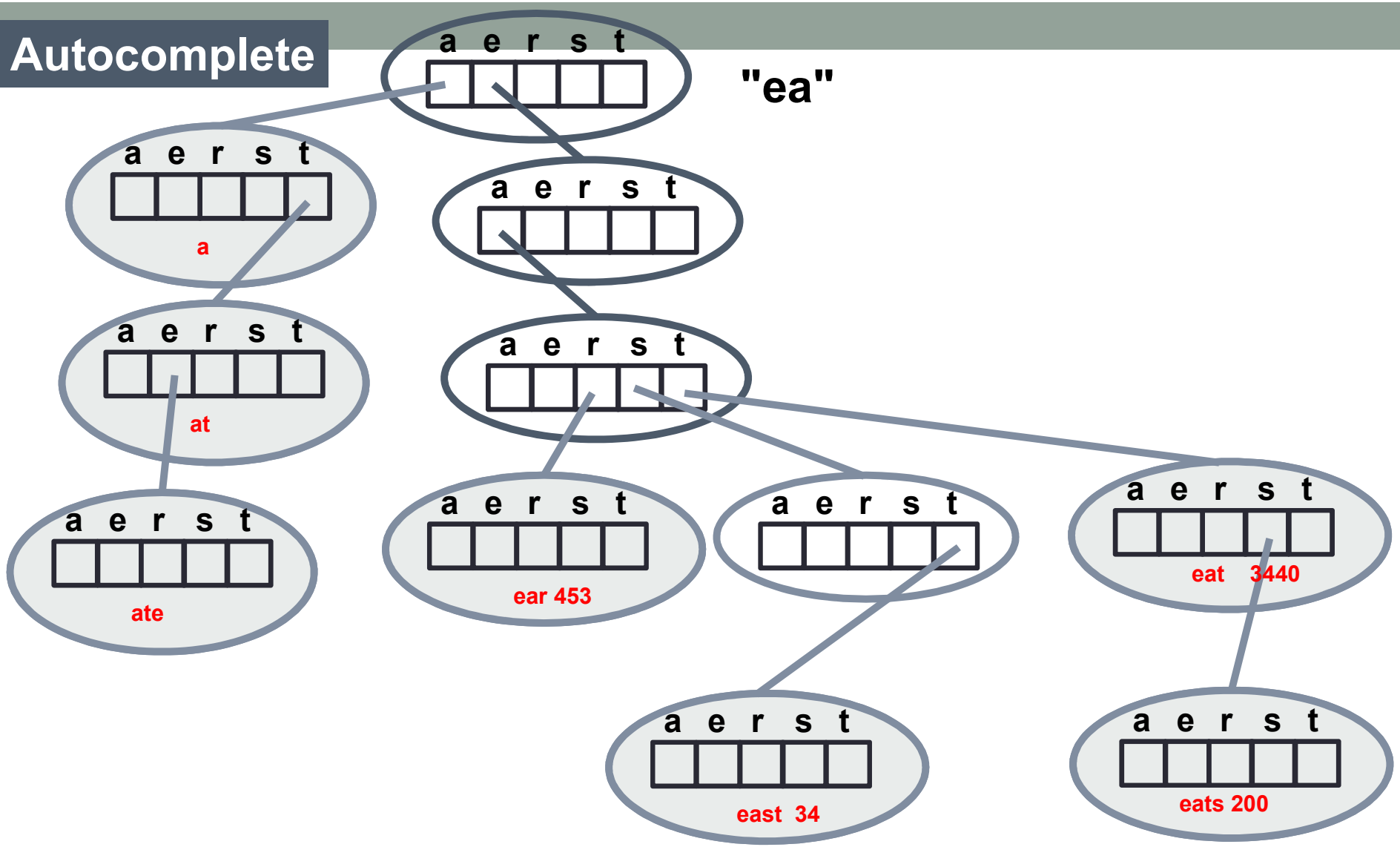

```
Mystery(Start):
    Initialize queue
    Push Start onto the queue
    while queue is not empty:
        pop node curr from front of queue
        visit curr
        for each of curr's children, n
            push n onto the queue
 // When we get here then we're done exploring
```

PA2: Things to work out

- Which search algorithm should be used for predict_completions on PA2?

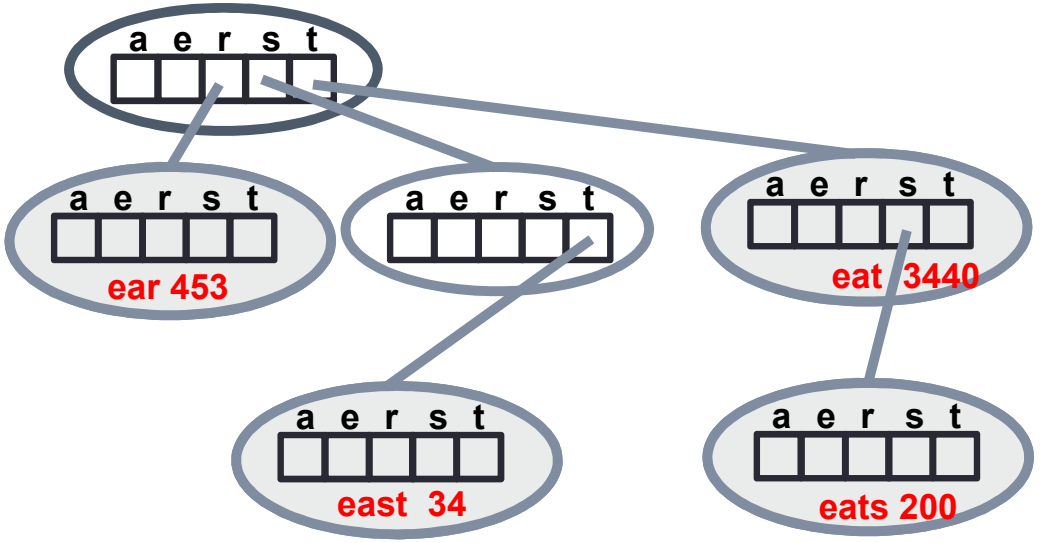
A. DFS
B. BFS
C. Either one, it doesn't matter

Autocomplete



Search for PA2: things to work out

```
DFS(S, G, other_args):
    for each of S's children, n:
        figure out what to do with n
        DFS(n, G, other_args)
```




```
vector<string> predictCompletions(string prefix) ;
```

Tree Search: Thought questions

- Which search algorithm will take longer for predict-completions (return the N most frequent completions)?

A. DFS
B. BFS
C. They will take the same

- If you ignore frequencies, which search algorithm will find words in increasing order of length in a MWT?

A. DFS
B. BFS
C. both
D. neither

- Which search algorithm will find words in increasing order of frequency in a MWT?

A. DFS
B. BFS
C. both
D. neither

Finding data fast

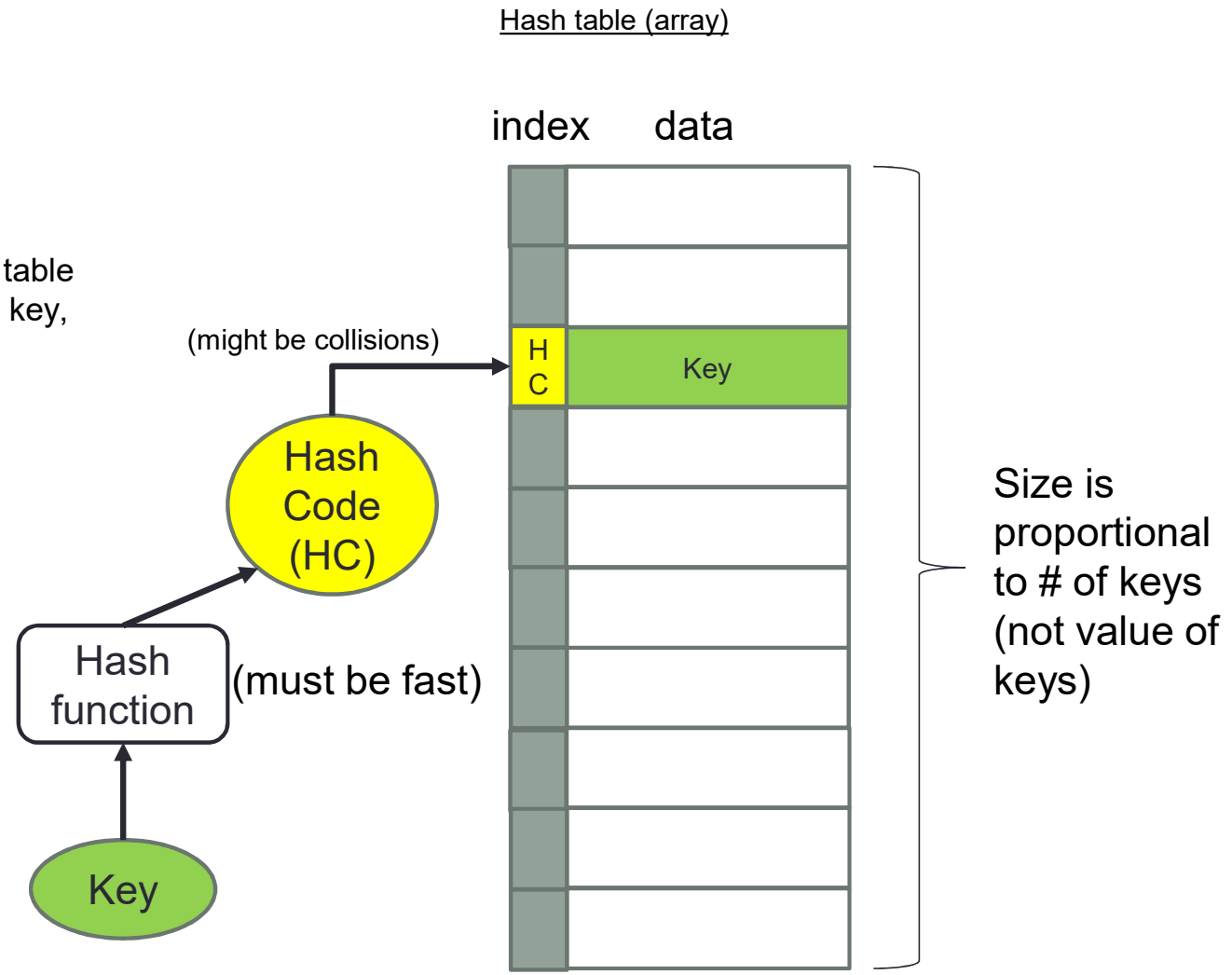
Imagine that you want to store integers between 0 and 1,000,000. You want to be able to find out whether an element is present in your set. You know you can do this with a BST with average running time of O(logN). But you decide to use an array with 1,000,000 Boolean values to store your data to try to make this faster. An entry will be true if the item is in your structure, and false otherwise.

What is the (Big-O) running time to "insert" an item into this proposed structure?

A. O(N)
B. O(logN)
C. O(1)

Hashing

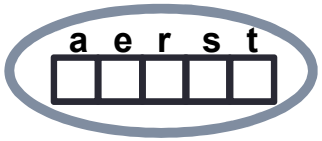
- Let's modify our array-based look up table
- Need a hash-function h(x): takes in a key, returns an index in the array
- gold standard: random hash function



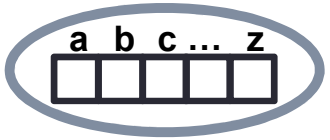
“Hashing” and MWTs

- The idea of hashing was at the heart of the MWT data structure we looked at. We mapped chars to ints to get their position in the array.

The hash function was:
H(‘a’) = 0
H(‘e’) = 1
H(‘r’) = 2
H(‘s’) = 3
H(‘t’) = 4



What is the hash function you would use for your PA if you implement a MWT with a vector? (ignore spaces for now)



H(c) = _____

This hash function has no collisions!