

Recap: basic data structures

Data Structures and Algorithms for Computational Linguistics III
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Overview

- Some basic data structures
 - Arrays
 - Lists
 - Stacks
 - Queues
- Revisiting searching a sequence

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Abstract data types and data structures

Introduction Abstract data types Algorithms

- An *abstract data type* (ADT), or abstract data structure, is an object with well-defined operations. For example a *stack* supports *push()* and *pop()* operations
- An abstract data type can be implemented using different *data structures*. For example a stack can be implemented using a linked list, or an array
- Sometimes the names and their usage are confusingly similar

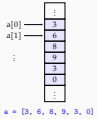
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Arrays

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- An array is simply a contiguous sequence of objects with the same size
- Arrays are very close to how computers store data in their memory
- Arrays can also be multi-dimensional. For example, matrices can be represented with 2-dimensional arrays
- Arrays support fast access to their elements through indexing
- On the downside, resizing and inserting values in arbitrary locations are expensive



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Arrays
in Python

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- No built-in array data structure in Python
- Lists are indexable
- For proper/faster arrays, use the *numpy* library

List indexing in Python

```
a = [3, 6, 8, 9, 3, 0]
a[0] = 3
a[-1] = 0
a[1:4] = [6, 8, 9]
a2d = [[3, 6, 8], [9, 3, 0]]
a2d[0][1] = 6
```

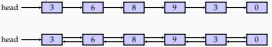
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Lists

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- Main operations for list ADT are
 - append (and prepend)
 - head (and tail)
- Lists are typically implemented using linked lists (but array-based lists are also common)



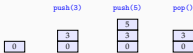
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Stacks

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- A stack is a last-in-first (LIFO) out data structure
- Two basic operations:
 - push
 - pop
- Stacks can be implemented using linked lists (or arrays)



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Queues

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- A queue is a first-in-first (FIFO) out data structure
- Two basic operations:
 - enqueue
 - dequeue
- Queues can be implemented using linked lists (or maybe arrays)



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Other common ADT

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- *Strings* are often implemented based on character arrays
- *Maps* or *dictionaries* are similar to arrays and lists, but allow indexing with (almost) arbitrary data types
 - Maps are generally implemented using hashing (later in this course)
- Sets implement the mathematical (finite) sets: a collection unique elements without order
- Trees are used in many algorithms we discuss later (we will revisit trees as data structures)

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Studying algorithms

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- In this course we will study a series of important algorithms, including
 - Sorting
 - Pattern matching
 - Graph traversal
- For any algorithm we design/use, there are a number of desirable properties
 - Correctness: an algorithm should do what it is supposed to do
 - Robustness: an algorithm should (correctly) handle all possible inputs it may receive
 - Efficiency: an algorithm should be light on resource usage
 - Simplicity: an algorithm should be as simple as possible
 - ...
- We will briefly touch upon a few of these issues with a simple case study

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A simple problem: searching a sequence for a value

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```
def linear_search(seq, val):
    answer = None
    for i in range(len(seq)):
        if seq[i] == val:
            answer = i
    return answer
```

Is this a good algorithm? Can we improve it?

Linear search: take 2

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```
def linear_search(seq, val):
    for i in range(len(seq)):
        if seq[i] == val:
            return i
    return None
```

Can we do even better?

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Linear search: take 3

```

1 def linear_search(seq, val):
2     n = len(seq) - 1
3     last = seq[n]
4     seq[n] = val
5     i = 0
6     while seq[i] != val:
7         i += 1
8     seq[n] = last
9     if i < n or seq[n] == val:
10        return i
11    else:
12        return None

```

- Is this better?
- Any disadvantages?
- Can we do even better?

Binary search

```

1 def binary_search(seq, val):
2     left, right = 0, len(seq)
3     while left <= right:
4         mid = (left + right) // 2
5         if seq[mid] == val:
6             return mid
7         if seq[mid] > val:
8             right = mid - 1
9         else:
10            left = mid + 1
11    return None

```

- We can do (much) better if the sequence is sorted.

Binary search

recursive version

```

1 def binary_search_recursive(seq, val, left=None, right=None):
2     if left is None:
3         left = 0
4     if right is None:
5         right = len(seq)
6     if left > right:
7         return None
8     mid = (left + right) // 2
9     if seq[mid] == val:
10        return mid
11    if seq[mid] > val:
12        return binary_search_recursive(seq, val, left, mid - 1)
13    else:
14        return binary_search_recursive(seq, val, mid + 1, right)

```

A note on recursion

- Some problems are much easier to solve recursively
- Recursion is also a mathematical concept, properties of recursive algorithms are often easier to prove
- Reminder:
 - You have to define one or more base cases (e.g., if `left > right` for binary search)
 - Each recursive step should approach the base case (e.g., should run on a smaller portion of the data)
- We will see quite a few recursive algorithms, it is time for getting used to if you are not

Exercise: write a recursive function for linear search.

Summary

- This lecture is a review of some basic data structure and algorithms
- We will assume you know these concepts, please revise your earlier knowledge if needed

Next:

- Analysis of algorithms (Reading: textbook (Goodrich, Tamassia, and Goldwasser, 2013) chapter 3)
- A few common patterns for designing (efficient) algorithms

An interesting historical anecdote

How difficult is the 'binary search'?

1946 suggested in a lecture by John Mauchly
 1960 first fix to the original version (by Derrick Henry Lehmer)
 1962 another fix/improvement was published (by Hermann Bottenbruch)
 2006 a bug was discovered in Java's binary search implementation

Although the basic idea of binary search is comparatively straightforward,
 the details can be surprisingly tricky.
 —Knuth (1973)

Another exercise

- Implement the abstract data types of stack and queue using
 - a list
 - an array
 as underlying data structure
- How do you do this in Python (where lists are actually arrays)?
- Which one is more efficient?
- Possible extension, implement a real singly-linked list structure in Python, repeat the above comparisons

Acknowledgments, credits, references

- The historical information on binary search development on Slide A.2 is from Wikipedia

-  Goodrich, Michael T., Roberto Tamassia, and Michael H. Goldwasser (2013). *Data Structures and Algorithms in Python*. John Wiley & Sons, Incorporated. isbn: 9781118426734.
-  Knuth, Donald E. (1973). *The Art of Computer Programming: Sorting and Searching*. Vol. 3. Pearson Education. isbn: 9780321635785.