Recap: basic data structures

Data Structures and Algorithms for Computational Linguistics III
ISCL-BA-07

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Seminar für Sprachwissenschaft

Winter Semester 2023-2024

version: dad9c9f+ @2023-10-25

Overview

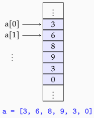
- Some basic data structures
  - Arrays
  - Lists
  - Stacks
  - Queues
- Revisiting searching a sequence

Abstract data types and data structures

- 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

Arrays

- 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



Arrays
in Python

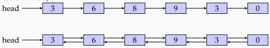
- No built-in array data structure in Python
- Lists are indexable
- For proper/faster arrays, use the `numpy` library

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
```


Lists

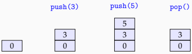
- Main operations for list ADT are
  - append (and prepend)
  - head (and tail)
- Lists are typically implemented using linked lists (but array-based lists are also common)



- Python lists are array-based

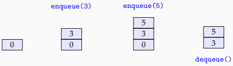
Stacks

- 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)



Queues

- 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)



Other common ADT

- *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)

Studying algorithms

- 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 algorithms 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

A simple problem: searching a sequence for a value

```
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

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

Can we do even better?

Linear search: take 3

```python
def linear_search(seq, val):
    n = len(seq) - 1
    last = seq[n]
    seq[n] = val
    i = 0
    while seq[i] != val:
        i += 1
    seq[n] = last
    if i < n  or seq[n] == val:
      return i
    else:
      return None
```

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

Binary search

```python
def binary_search(seq, val):
    left, right = 0, len(seq)
    while left <= right:
        mid = (left + right) // 2
        if seq[mid] == val:
            return mid
        if seq[mid] > val:
          right = mid - 1
        else:
          left = mid + 1
    return None
```

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

Binary search

recursive version

```python
def binary_search_recursive(seq, val, left=None, right=None):
    if left is None:
        left = 0
    if right is None:
        right = len(seq)
    if left > right:
      return None
    mid = (left + right) // 2
    if seq[mid] == val:
        return mid
    if seq[mid] > val:
      return binary_search_recursive(seq, val, left, mid - 1)
    else:
      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)

Acknowledgments, credits, references

- Some of the slides are based on the previous year's course by Corina Dima.
- The historical information on binary search development on Slide 1 is from Wikipedia

Goodrich, Michael T., Roberto Tamassia, and Michael H. Goldwasser (2013). *Data Structures and Algorithms in Python*. John Wiley & Sons, Incorporated. ISBN: 9781118476734.

Knuth, Donald E. (1973). *The Art of Computer Programming: Sorting and Searching*. Vol. 3. Pearson Education. ISBN: 9780321635785.