Recap: basic data structures

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

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Overview

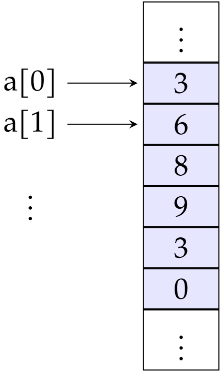
- Some basic data structures
  - Arrays
  - Lists
  - Stacks
  - Queues
- Revisiting searching a sequence

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




```
a = [3, 6, 8, 9, 3, 0]
```

Arrays
in Python

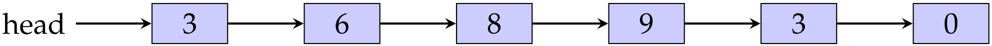
- No built-in array data structure in Python
- Lists are indexable
- For proper/faster arrays, use the `numpy` library

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

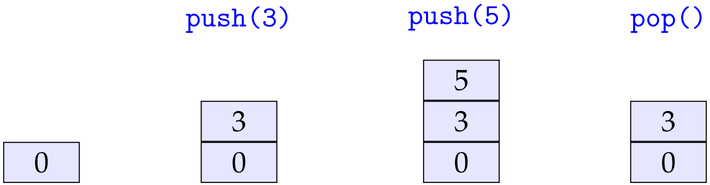
- Main operations for list ADT are
  - append (and prepend)
  - head (and tail)
- Lists are typically implemented using linked lists (but array-based lists are also common)



- Python lists are array-based

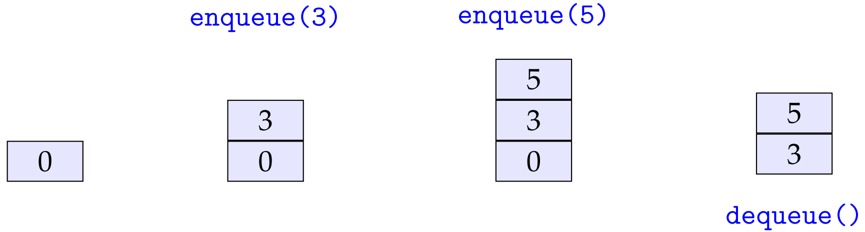
Stacks

- 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 case*s (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

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Exercise: write a recursive function for linear search.

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- 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

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Next:

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

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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

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

Acknowledgments, credits, references

- The historical information on binary search development on Slide A.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.