COMP1002
Data Structures and Algorithms

Lecture 10: DSA in Practice

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Department of Computing

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Copyright Warning

This Week

- Algorithm Selection
- Java Collections
- ADT selection

Algorithm Selection

- Computer Science has been developing and discovering algorithms for over 50 years
- Most problems have been attempted before
- First step should be to survey existing options

- e.g. for your assignment...
  - Graph algorithms: add vertices and edges, get adjacent...
  - Shortest paths
  - Nearby search
  - Sorting a linked list (possibly)

Algorithm Selection

- **What should we consider?**
- Type and size of data and sort keys
- Order – random, semi-sorted
- How often you will search / sort
- Time efficiency
- Space efficiency
- Understandability of algorithm
- How perfect the results have to be?
    - Is a good path as useful as the shortest path?

Algorithms in DSA

- Searching: Linear, Binary
- Sorting: Bubble, Selection, Insertion, Quicksort, Mergesort
- Binary Search Trees: Insert, Delete
- Graphs: Breadth/Depth First Search, Shortest Path
- Hash Tables: Linear/Quadratic/Double, Open Addr
- Heaps: Trickle-up/down, Heapify, Heapsort
- Advanced Trees: Insert, Delete, Split/Merge, "Balance"

More Sorting

– We looked at some excellent visualisations
– Clearly there are even better performing sorts
– How do we go beyond $O(N^{2)}$ and $O(N \log N)$?

– We have looked at "comparison-based" sorts
– There is a cost to every comparison

Visualisations

- Colour
  - https://www.youtube.com/watch?v=h-QYzgTmgVI
- Disparity
  - https://www.youtube.com/watch?v=IjIViETya5k

Shell Sort

- Developed by Donald Shell in 1959
- A variation of Insertion Sort
- Improves handling of values that are far from their final location
- Views the list as an interleaved bundle of lists
- Unstable
- Takes advantage of partially sorted data

Algorithm

– For each gap size (largest downto 1)
  - Consider each list is made up of the elements with a gap "h" between them
  - Sort each interleaved list using insertion sort
  - When all lists for gap "h" are sorted, the overall data is "h-sorted"

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}
Input data	62	83	18	53	07	17	95	86	47	69	25	28
After 5-sorting	17	28	18	47	07	25	83	86	53	69	62	95
After 3-sorting	17	07	18	47	28	25	69	62	53	83	86	95
After 1-sorting	07	17	18	25	28	47	53	62	69	83	86	95

- The first pass, 5-sorting, performs insertion sort on five separate subarrays (a1, a6, a11), (a2, a7, a12), etc
- The next pass, 3-sorting, performs insertion sort on the three subarrays (a1, a4, a7, a10), (a2, a5, a8, a11), etc
- The last pass, 1-sorting, is an ordinary insertion sort of the entire array (a1,..., a12).

https://en.wikipedia.org/wiki/Shellsort

	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}
Input data	62	83	18	53	07	17	95	86	47	69	25	28
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After 1-sorting	07	17	18	25	28	47	53	62	69	83	86	95

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https://en.wikipedia.org/wiki/Shellsort

Counting Sort

– Sorts keys in a specific range (small ranges preferred)

– Counts the number of occurrences of each key

– Then knows how much space those keys will take and slots them in

– Stable sort, but not in-place

– Takes advantage of duplicates

– O(n+k) – k=range... not a comparison sort

– Often used as a subroutine for other sorts (Radix)

http://www.geeksforgeeks.org/counting-sort/

Counting Sort - Algorithm

- Given array input[]
- Create Count[] and Result[]
- Fill Count[] with the count of each key in input[]
- Update Count[] to store the sum of the previous counts
  - This will give us the position for each group of keys
- Work through input[] backwards, slotting values into Result[], decrementing the count of each, each time

Counting Sort - Example

int input[] = { 2, 1, 4, 5, 7, 1, 7, 11, 8, 9, 10 };

Index	0	1	2	3	4	5	6	7	8	9	10	11
Count[]	0	2	1	0	1	1	0	2	1	1	1	1

Index	0	1	2	3	4	5	6	7	8	9	10	11
Modified Count[]	0	2	3	3	4	5	5	7	8	9	10	11

Count[i]=Count[i] + Count[i-1]

Result[]	0	1	1	2	4	5	7	7	8	9	10	11

Count[input[i]] will tell you the index position of input[i] in Result[]

http://algorithms.tutorialhorizon.com/counting-sort/

Radix Sort

- Counting Sort was limited to a small range of values
- If we have larger range of values, need to adjust...
- Radix Sort uses the Counting Sort as a function
- Works on each digit, sorting from Least Significant Digit (LSD) or Most Significant Digit (MSD)
- Stable sort, uses extra space (through Counting Sort)
- Tricky to calculate complexity – dependent on base (b)
- $O((n+b)*\log_b(k))$ – if $b=n$, $O(n)$

Radix Sort LSD - Example

– Original, unsorted list:

170, 45, 75, 90, 802, 24, 2, 66

– Sorting by least significant digit (1s place) gives:

170, 90, 802, 2, 24, 45, 75, 66

– Sorting by next digit (10s place) gives:

802, 2, 24, 45, 66, 170, 75, 90

– Sorting by most significant digit (100s place) gives:

2, 24, 45, 66, 75, 90, 170, 802

http://www.geeksforgeeks.org/radix-sort/

Visualisations

– Colour
    - https://www.youtube.com/watch?v=h-QYzgTmgVI

– Disparity
    - https://www.youtube.com/watch?v=IjIViETya5k

Choosing Abstract DataTypes

– We now have many ADTs we can work with

Linked Lists, Stacks, Queues,

BSTs, Graphs, Heaps, HashTables,

Red-Black Trees, 2-3-4 Trees, B-Trees

– There are many others

– There are many implementations

Choosing ADTs

- Know your data
- What do you want to use it for?
  - Unique values
  - Order important?
  - Search time important?
  - Static or changing data?
- Prototype – try them out

Java ADTs

– Beyond DSA, you can use the in-built ADTs
– You now know enough about ADTs to understand the collections and make choices
– Which class or interface to use?
– Extend using interfaces, or use Java implementations?
– Build your own?
– Source code is available

Java Collection Documentation

- Always look to the online documentation for up to date information
- These slides are based on the tutorial:
  - https://docs.oracle.com/javase/tutorial/collections/
- Some are taken directly from:
  - http://www.cs.nyu.edu/courses/fall07/V22.0102-002/lectures/JavaCollections.ppt
  - by Prof Evan Korth, NYU

Java Collections

- A collection — sometimes called a container — is simply an object that groups multiple elements into a single unit
- Collections are used to store, retrieve, manipulate, and communicate aggregate data.
- Typically, they represent data items that form a natural group:
  - a poker hand (a collection of cards), a mail folder (a collection of letters), or a telephone directory (a mapping of names to phone numbers).

Collections Framework

– A collections framework is a unified architecture for representing and manipulating collections.

– All collections frameworks contain the following:

- Interfaces: These are abstract data types that represent collections.

- Implementations: These are the concrete implementations of the collection interfaces. Reusable data structures.

- Algorithms: These are the methods that perform useful computations, such as searching and sorting, on objects that implement collection interfaces. (Polymorphic)

See also: C++ Standard Template Library (STL) and Smalltalk's collection hierarchy

Benefits

– Reduces programming effort:
  - By providing useful data structures and algorithms, the Collections Framework frees you to concentrate on the important parts of your program rather than on the low-level "plumbing" required to make it work.

– Increases program speed and quality:
  - Because you're freed from the drudgery of writing your own data structures, you'll have more time to devote to improving programs' quality and performance.

Benefits

- Allows interoperability among unrelated APIs:
  - The collection interfaces are the vernacular by which APIs pass collections back and forth. Our APIs will interoperate seamlessly, even though they were written independently.
- Reduces effort to learn and to use new APIs:
  - Many APIs naturally take collections on input and furnish them as output. In the past, each such API had a small sub-API devoted to manipulating its collections, with standard collection interfaces, the problem went away.

Benefits

– Reduces effort to design new APIs:

  - This is the flip side of the previous advantage. Designers and implementers don't have to reinvent the wheel each time they create an API that relies on collections; instead, they can use standard collection interfaces.

– Fosters software reuse:

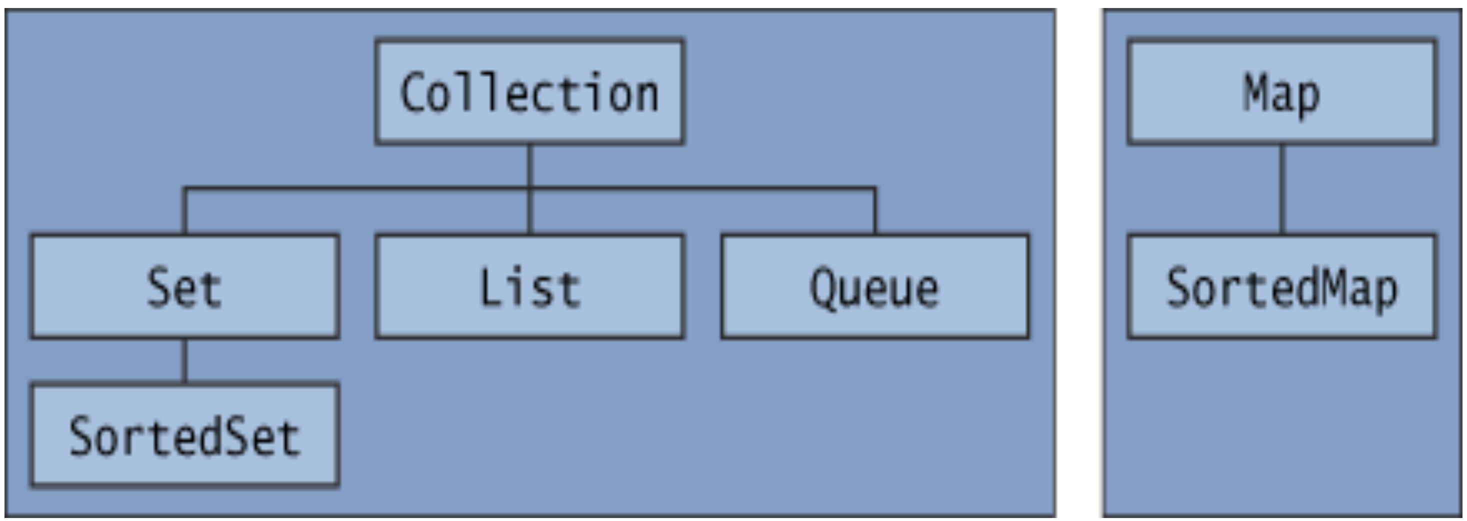
  - New data structures that conform to the standard collection interfaces are by nature reusable. The same goes for new algorithms that operate on objects that implement these interfaces.

Collection interfaces

– The core collection interfaces encapsulate different types of collections.

– They represent the abstract data types that are part of the collections framework.

– They are interfaces no implementation provided



public interface Collection<E> extends Iterable<E>

- **Collection** — the root of the collection hierarchy.
- A collection represents a group of objects known as its *elements*.
- The Collection interface is the common denominator that all collections implement and is used to pass collections around and to manipulate them when maximum generality is desired.
- Some types of collections allow duplicate elements, and others do not.
- Some are ordered and others are unordered.
- The Java platform doesn't provide any direct implementations of this interface

public interface Collection<E> extends Iterable<E>

```
public interface Collection<E> extends Iterable<E> {
    // Basic operations
    int size();
    boolean isEmpty();
    boolean contains(Object element);
    boolean add(E element);         //optional
    boolean remove(Object element); //optional
    Iterator<E> iterator();

    // Bulk operations
    boolean containsAll(Collection<?> c);
    boolean addAll(Collection<? extends E> c); //optional
    boolean removeAll(Collection<?> c);        //optional
    boolean retainAll(Collection<?> c);        //optional
    void clear();                              //optional

    // Array operations
    Object[] toArray();
    <T> T[] toArray(T[] a);
}
```

We already know about Iterators...

- An `Iterator` is an object that enables you to traverse through a collection and to remove elements from the collection selectively, if desired.
- You get an `Iterator` for a collection by calling its `iterator()` method.
- The following is the `Iterator` interface.

```
public interface Iterator<E> {
    boolean hasNext();
    E next();
    void remove(); //optional
}
```

public interface **Set<E>** extends Collection<E>

- **Set** — a collection that cannot contain duplicate elements.
- This interface models the mathematical set abstraction and is used to represent sets
- Examples: the cards comprising a poker hand, the courses making up a student's schedule, or the processes running on a machine.

public interface **Set<E>** extends Collection<E>

```
public interface Set<E> extends Collection<E> {
    // Basic operations
    int size();
    boolean isEmpty();
    boolean contains(Object element);
    boolean add(E element);         //optional
    boolean remove(Object element); //optional
    Iterator<E> iterator();

    // Bulk operations
    boolean containsAll(Collection<?> c);
    boolean addAll(Collection<? extends E> c); //optional
    boolean removeAll(Collection<?> c);        //optional
    boolean retainAll(Collection<?> c);        //optional
    void clear();                              //optional

    // Array Operations
    Object[] toArray();
    <T> T[] toArray(T[] a);
}
```

Note: nothing added to Collection interface – except no duplicates allowed

public interface **List<E>** extends Collection<E>

- **List** — an ordered collection (sometimes called a *sequence*).
- Lists can contain duplicate elements.
- The user of a List generally has precise control over where in the list each element is inserted and can access elements by their integer index (position).
- If you've used Vector, you're familiar with the general flavor of List.

public interface **List<E>**extends Collection<E>

```
public interface List<E> extends Collection<E> {
    // Positional access
    E get(int index);
    E set(int index, E element);    //optional
    boolean add(E element);         //optional
    void add(int index, E element); //optional
    E remove(int index);            //optional
    boolean addAll(int index,
        Collection<? extends E> c); //optional

    // Search
    int indexOf(Object o);
    int lastIndexOf(Object o);

    // Iteration
    ListIterator<E> listIterator();
    ListIterator<E> listIterator(int index);

    // Range-view
    List<E> subList(int from, int to);
}
```

A note on ListIterators

- The three methods that ListIterator inherits from Iterator (hasNext, next, and remove) do exactly the same thing in both interfaces.
- The **hasPrevious** and the **previous** operations are exact analogues of **hasNext** and **next**. The previous operation moves the cursor backward, whereas next moves it forward.
- The **nextIndex** method returns the index of the element that would be returned by a subsequent call to next, and **previousIndex** returns the index of the element that would be returned by a subsequent call to previous
- The **set** method overwrites the last element returned by **next** or **previous** with the specified element.
- The **add** method inserts a new element into the list immediately before the current cursor position.

A note on ListIterators

```
public interface ListIterator<E> extends Iterator<E> {
    boolean hasNext();
    E next();
    boolean hasPrevious();
    E previous();
    int nextIndex();
    int previousIndex();
    void remove(); //optional
    void set(E e); //optional
    void add(E e); //optional
}
```

public interface **Queue<E>** extends Collection<E>

- **Queue** — a collection used to hold multiple elements prior to processing.
- Besides basic Collection operations, a Queue provides additional insertion, extraction, and inspection operations.

public interface **Queue<E>** extends Collection<E>

```
public interface Queue<E> extends Collection<E> {
    E element();                        //throws
    E peek();                      //null
    boolean offer(E e);  //add - bool
    E remove();                         //throws
    E poll();                      //null
}
```

public interface **Map<K,V>**

- **Map** — an object that maps keys to values.
- A Map cannot contain duplicate keys; each key can map to at most one value.
- Think about DSAHashTable - you're already familiar with the basics of Map.

public interface **Map<K,V>**

```
public interface Map<K,V> {

    // Basic operations
    V put(K key, V value);
    V get(Object key);
    V remove(Object key);
    boolean containsKey(Object key);
    boolean containsValue(Object value);
    int size();
    boolean isEmpty();

    // Bulk operations
    void putAll(Map<? extends K, ? extends V> m);
    void clear();

    // Collection Views
    public Set<K> keySet();
    public Collection<V> values();
    public Set<Map.Entry<K,V>> entrySet();

    // Interface for entrySet elements
    public interface Entry {
        K getKey();
        V getValue();
        V setValue(V value);
```

public interface **SortedSet<E>** extends Set<E>

- **SortedSet** — a Set that maintains its elements in ascending order.
- Several additional operations are provided to take advantage of the ordering.
- Sorted sets are used for naturally ordered sets, such as word lists and membership rolls.

public interface **SortedSet<E>** extends Set<E>

```
public interface SortedSet<E> extends Set<E> {
    // Range-view
    SortedSet<E> subSet(E fromElement, E toElement);
    SortedSet<E> headSet(E toElement);
    SortedSet<E> tailSet(E fromElement);

    // Endpoints
    E first();
    E last();

    // Comparator access
    Comparator<? super E> comparator();
}
```

Note on Comparator interface

– Comparator is another interface (in addition to Comparable) provided by the Java API which can be used to order objects.

– You can use this interface to define an order that is different from the Comparable (natural) order.

public interface **SortedMap<K,V>** extends Map<K,V>

- **SortedMap** — a Map that maintains its mappings in ascending key order.
- This is the Map analog of SortedSet.
- Sorted maps are used for naturally ordered collections of key/value pairs, such as dictionaries and telephone directories.

public interface **SortedMap<K,V>** extends Map<K,V>

```
public interface SortedMap<K, V> extends Map<K, V>{

    SortedMap<K, V> subMap(K fromKey, K toKey);
    SortedMap<K, V> headMap(K toKey);
    SortedMap<K, V> tailMap(K fromKey);
    K firstKey();
    K lastKey();

    Comparator<? super K> comparator();
}
```

General-purpose Implementations					
Interfaces	**Implementations**				
	Hash table	**Resizable array**	**Tree <u>(sorted)</u>**	**Linked list**	**Hash table + Linked list**
Set	**HashSet**		TreeSet **<u>(sorted)</u>**		LinkedHashSet
List		**ArrayList**		LinkedList	
Queue					
Map	**HashMap**		TreeMap **<u>(sorted)</u>**		LinkedHashMap

Note the naming convention

LinkedList also implements queue and there is a PriorityQueue implementation (implemented with heap)

Implementations

- Each of the implementations offers the strengths and weaknesses of the underlying data structure.
- What does that mean for:
  - Hashtable
  - Resizable array
  - Tree
  - LinkedList
  - Hashtable plus LinkedList
- **<u>Think about these tradeoffs when selecting the implementation!</u>**

Choosing the datatype

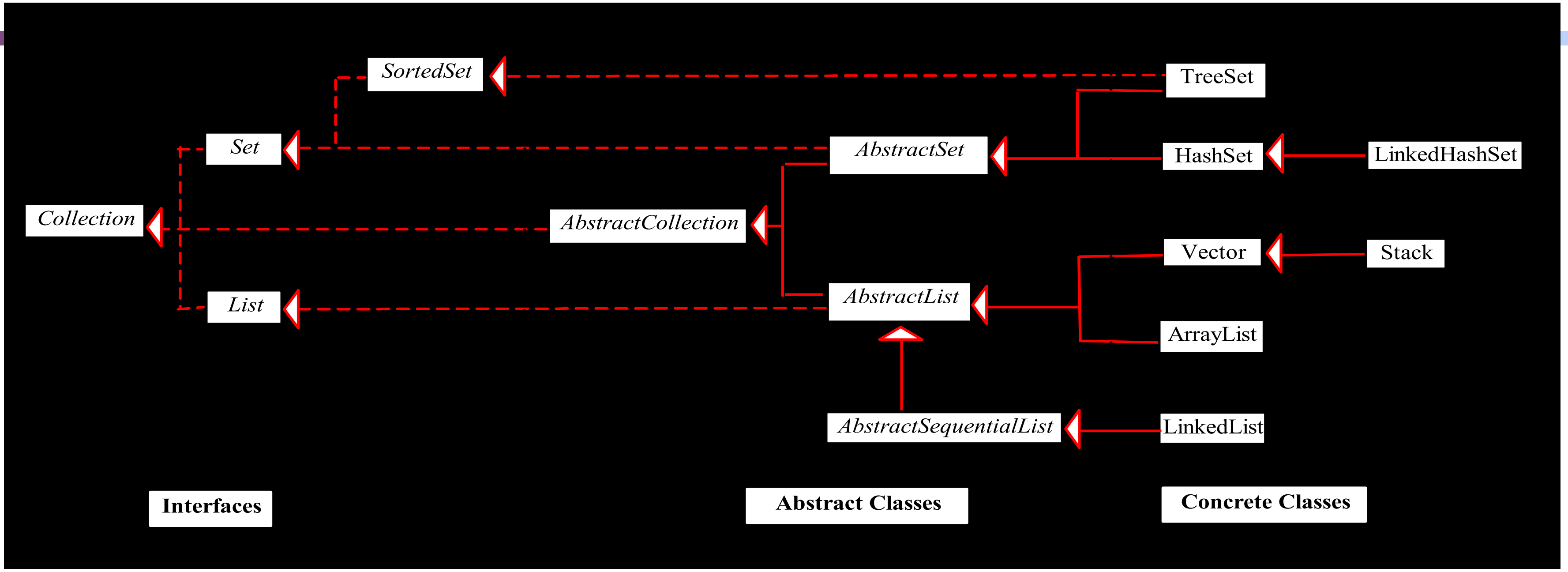
- When you declare a Set, List or Map, you should use Set, List or Map interface as the datatype instead of the implementing class.
- That will allow you to change the implementation by changing a single line of code!

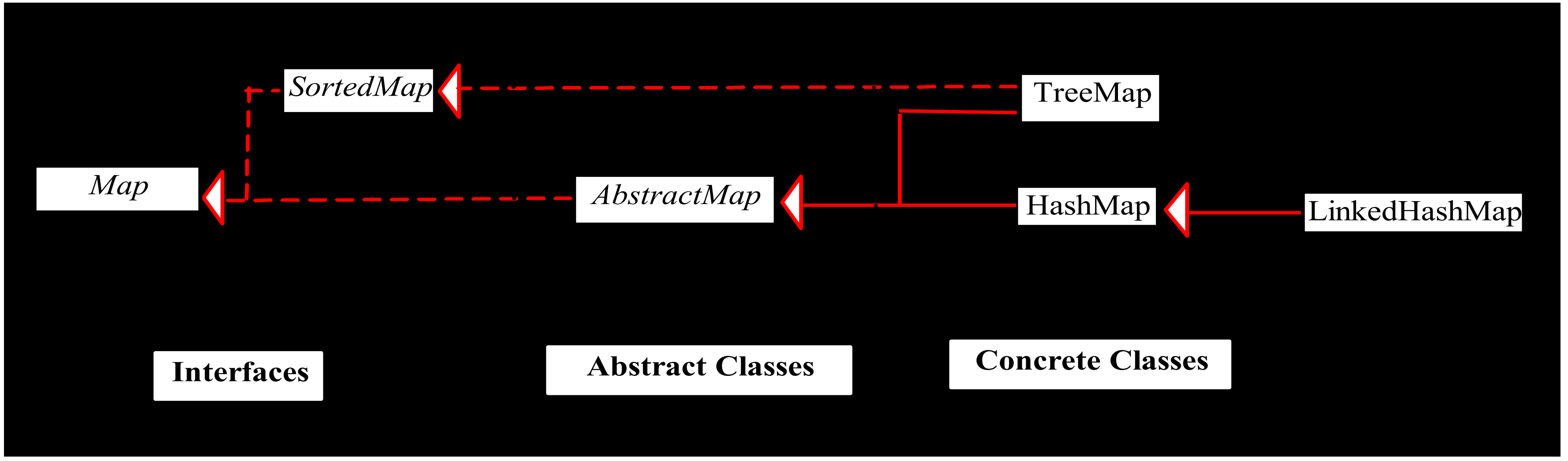
```
import java.util.*;

public class Test {
    public static void main(String[] args) {
        Set<String> ss = new LinkedHashSet<String>();

        for (int i = 0; i < args.length; i++)
            ss.add(args[i]);
        Iterator i = ss.iterator();
        while (i.hasNext())
            System.out.println(i.next());
    }
}
```

```
import java.util.*;

public class Test {

    public static void main(String[] args)
    {
        //map to hold student grades
        Map<String, Integer> theMap = new HashMap<String, Integer>();

        theMap.put("Korth, Evan", 100);
        theMap.put("Plant, Robert", 90);
        theMap.put("Coyne, Wayne", 92);
        theMap.put("Franti, Michael", 98);
        theMap.put("Lennon, John", 88);

        System.out.println(theMap);
        System.out.println("--------------------------------------");
        System.out.println(theMap.get("Korth, Evan"));
        System.out.println(theMap.get("Franti, Michael"));
    }
}
```

Other implementations in the API

- Wrapper implementations delegate all their real work to a specified collection but add (or remove) extra functionality on top of what the collection offers.
  - Synchronization Wrappers
  - Unmodifiable Wrappers
- Convenience implementations are mini-implementations that can be more convenient and more efficient than general-purpose implementations when you don't need their full power
  - List View of an Array
  - Immutable Multiple-Copy List
  - Immutable Singleton Set
  - Empty Set, List, and Map Constants


SortedSet
TreeSet
Set
AbstractSet
HashSet
LinkedHashSet
Collection
AbstractCollection
Vector
Stack
List
AbstractList
ArrayList
AbstractSequentialList
LinkedList
Interfaces
Abstract Classes
Concrete Classes


SortedMap
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Making your own implementations

- Most of the time you can use the implementations provided for you in the Java API.
- In case the existing implementations do not satisfy your needs, you can write your own by extending the abstract classes provided in the collections framework.

Algorithms

– The Java collections framework also provides polymorphic versions of algorithms you can run on collections...

- Sorting
- Shuffling
- Routine Data Manipulation
  - » Reverse
  - » Fill copy
  - » etc.
- Searching
  - » Binary Search
- Composition
  - » Frequency
  - » Disjoint
- Finding extreme values
  - » Min / Max

Python Built-Ins

- For DSA, we have specifically avoided built-ins that were covered in FOP
- We can now revisit these standard library options to see how they align with our DSA topics:
  - Sorting
  - Sets
  - Stacks and Queues
  - Heaps – priority queues
  - Hash Tables

https://dbader.org/blog/fundamental-data-structures-in-python

Python Built-ins: Sorting

- If you have a list, there is a sort method available
- Most types can be converted into a list, sorted and sent back
- Pandas and numpy provide sorting methods for dataframes and arrays
  - `sorted_list = old_list.sort( )`
  - `sorted(old_list)    # sorts the original list`
  - `rev_list = old_list.sort(reverse=True)`

Python Built-ins: Sets

- A *set* is an unordered collection of objects that does not allow duplicate elements.
- **Functionality**: test a value for **membership** in the set, **insert** or **delete** new values from a set, and to compute the **union** or **intersection** of two sets.
- In a "proper" set implementation, membership tests are expected to run in $O(1)$ time. Union, intersection, difference, and subset operations should be $O(n)$.
- The set implementations in Python match this performance.

Python Built-ins: Sets

– Examples of using sets in Python:

```
>>> vowels = {'a', 'e', 'i', 'o', 'u'}
>>> 'e' in vowels
True
>>> letters = set('alice')
>>> letters.intersection(vowels) {'a', 'e', 'i'}
>>> vowels.add('x')
>>> vowels {'i', 'a', 'u', 'o', 'x', 'e'}
>>> len(vowels)
6
>>> squares = {x * x for x in range(10)}
```

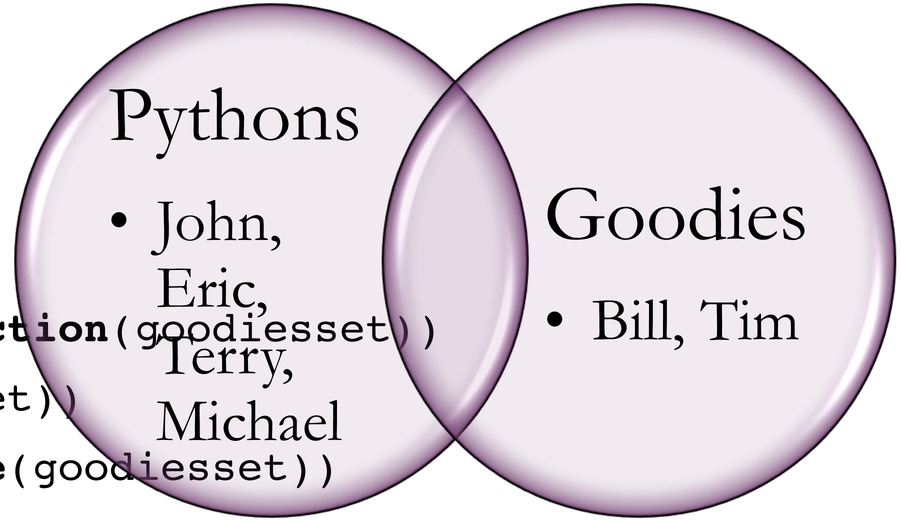
Set creation and operations (from FOP)

```
pythonlist = ['John', 'Eric', 'Graham', 'Terry', 'Michael', 'Terry']
pythonset = set(pythonlist)
goodieslist = ['Bill', 'Graham', 'Tim']
goodiesset = set(goodieslist)
print(pythonset)
print(goodiesset)
print('Intersection = ', pythonset.intersection(goodiesset))
print('Union = ', pythonset.union(goodiesset))
print('Difference = ', pythonset.difference(goodiesset))
print('Difference = ', goodiesset.difference(pythonset))
```

```
{'Eric', 'John', 'Michael', 'Terry', 'Graham'}
{'Tim', 'Bill', 'Graham'}
Intersection =  {'Graham'}
Union =  {'John', 'Michael', 'Tim', 'Bill', 'Eric', 'Terry', 'Graham'}
Difference =  {'Eric', 'John', 'Terry', 'Michael'}
Difference =  {'Bill', 'Tim'}
```

Set creation and operations (from FOP)

```
pythonlist = ['John', 'Eric', 'Graham', 'Terry', 'Michael', 'Terry']
pythonset = set(pythonlist)
goodieslist = ['Bill', 'Graham', 'Tim']
goodiesset = set(goodieslist)
print(pythonset)
print(goodiesset)
print('Intersection = ', pythonset.intersection(goodiesset))
print('Union = ', pythonset.union(goodiesset))
print('Difference = ', pythonset.difference(goodiesset))
print('Difference = ', goodiesset.difference(pythonset))
```




```
{'Eric', 'John', 'Michael', 'Terry', 'Graham'}
{'Tim', 'Bill', 'Graham'}
Intersection =  {'Graham'}
Union =  {'John', 'Michael', 'Tim', 'Bill', 'Eric', 'Terry', 'Graham'}
Difference =  {'Eric', 'John', 'Terry', 'Michael'}
Difference =  {'Bill', 'Tim'}
```

Python Built-ins: Multi-Sets

– Multiset (or bag) type allows multiple occurrences of elements in the set

```
>>> from collections import Counter
>>> inventory = Counter()
>>> loot = {'sword': 1, 'bread': 3}
>>> inventory.update(loot)
>>> inventory
Counter({'bread': 3, 'sword': 1})
>>> more_loot = {'sword': 1, 'apple': 1}
>>> inventory.update(more_loot)
>>> inventory
Counter({'bread': 3, 'sword': 2, 'apple': 1})
```

Python Built-ins: Queues

– Could use a List to provide queue behaviour, but the performance is poor:

```
# How to use Python's list as a FIFO queue:
q = []
q.append('eat')
q.append('sleep')
q.append('code')
>>> q
['eat', 'sleep', 'code']
# Careful: This is slow!
>>> q.pop(0)
'eat'
```

Python Built-ins: Queues (deque)

– The deque class implements a double-ended queue that supports adding and removing elements from either end in *O(1)* time.

– deque objects are implemented as doubly-linked lists

  - excellent performance for enqueuing and dequeuing
  - poor *O(n)* performance for randomly accessing elements in the middle of the queue.

– Because deques support adding and removing elements from either end equally well, they can serve both as queues and as stacks.

Python Built-ins: Queues (deque)

```
# How to use collections.deque as a FIFO queue:
from collections import deque
q = deque()
q.append('eat')
q.append('sleep')
q.append('code')
>>> q                          deque(['eat', 'sleep', 'code'])
>>> q.popleft()                'eat'
>>> q.popleft()                'sleep'
>>> q.popleft()                'code'
>>> q.popleft()
IndexError: "pop from an empty deque"
```

Python Built-ins: Priority Queue (Heap)

- Priority queue is a modified queue:
  - instead of retrieving by insertion time, retrieve by *highest-priority*
- The priority of individual elements is decided by the ordering applied to their keys.

```
from queue import PriorityQueue
q = PriorityQueue()
q.put((2, 'code'))
q.put((1, 'eat'))
q.put((3, 'sleep'))
while not q.empty():
    next_item = q.get()
    print(next_item)
```

Result:

```
(1, 'eat')
(2, 'code')
(3, 'sleep')
```

Python Built-ins: Dictionary (Hashtable)

- The dictionary abstract data type is one of the most frequently used and most important data structures in computer science.
- Because of this importance Python features a robust dictionary implementation as one of its built-in data types (dict).
- Python's dictionaries are indexed by keys of any hashable type.
- A hashable object has a hash value which never changes in its lifetime (__hash__), and can be compared (__eq__).

```
>>> phonebook = {'bob': 7387, 'alice': 3719, 'jack': 7052}
>>> phonebook['alice']
3719
```

Python Built-ins: Dictionary (Hashtable)

– Python dictionaries are based on a well-tested and finely tuned hash table implementation that provides the performance characteristics you'd expect:
  - *O(1)* time complexity for lookup, insert, update, and delete operations in the average case.

– Can map to objects for hash table entries:

```
>>> items = {'AAA' : [4, 5, 6, 7],
    'BBB' : [10,20,30,40], 'CCC': [100,50,-30,-50]}
>>> items['AAA']
[4, 5, 6, 7]
```

Dictionary – The Meaning of Liff

```
liff = {'Duddo': 'The most deformed potato in any given
collection of potatoes.',
        'Fring': 'The noise made by a lightbulb that has
just shone its last.',
        'Tonypandy': ' The voice used by presenters on
children\'s television programmes.'}
liff['Wawne'] = 'A badly supressed yawn.'
liff['Woking'] = 'Standing in the kitchen wondering what you
came in here for.'
print(liff)
print(liff['Duddo'])
print(liff['Fring'])
print(liff.keys())
del liff['Fring']
print(liff.keys())
```

The Meaning of Liff and
The Deeper Meaning of Liff,
by Douglas Adams and John Lloyd

http://liff.hivemind.net/

Dictionary – The Meaning of Liff

```
OUTPUT
{'Fring': 'The noise made by a lightbulb that has just shone
its last.', 'Wawne': 'A badly supressed yawn.', 'Duddo': 'The
most deformed potato in any given collection of potatoes.',
'Tonypandy': " The voice used by presenters on children's
television programmes.", 'Woking': 'Standing in the kitchen
wondering what you came in here for.'}

The most deformed potato in any given collection of potatoes.

The noise made by a lightbulb that has just shone its last.
dict_keys(['Woking', 'Fring', 'Wawne', 'Tonypandy', 'Duddo'])
dict_keys(['Woking', 'Wawne', 'Tonypandy', 'Duddo'])
```

Dictionaries

– Maps that create a set of relationships between keys and values.

```
pops = {'New South Wales': 7757843,
        'Victoria' : 6100877,
        'Queensland' : 4860448,
        'South Australia' : 1710804,
        'Western Australia' : 2623164,
        'Tasmania': 519783,
        'Northern Territory' : 245657,
        'Australian Capital Territory': 398349}

print(pops['Victoria'])          6100877
print(pops['Queensland'])        4860448
```

Australian Demographic Statistics, Sep 2016
http://www.abs.gov.au/ausstats/abs@.nsf/mf/3101.0

Dictionaries

– We can list the keys, or the values, or both...

```
for p in pops:
    print(p)
```

```
Tasmania
Western Australia
…
Australian Capital Territory
New South Wales
```

```
for k in pops.keys():
    print(pops[k])
```

```
519783
2623164
...
7757843
```

```
for k in pops.keys():
    print(k, ': ', pops[k])
```

```
Tasmania:  519783
Western Australia:  2623164
…
New South Wales:  7757843
```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Dictionary: Word Frequencies…

– Find the frequency of each of the words in a text…

```
import sys

punctuation = '~!@#$%^&*()_+{}|:"<>?`=[]\\;\',./'

if len(sys.argv) <2 :
    filename = 'grimm.txt'
else:
    filename = sys.argv[1]

book = open(filename).read()
bookP = book.translate(str.maketrans('','',punctuation))
words = bookP.lower().split()
print(len(words))
print(words[:10])
```

```
1139
['rumpelstiltskin', 'by',
'the', 'side', 'of', 'a',
'wood', 'in', 'a', 'country']
```

Dictionary: Word Frequencies…

– Then calculate frequencies using a dictionary…

```
wordfreq = {}                     # empty dictionary
for word in words:                # for each word
    if word not in wordfreq:      # if it's not in dict
        wordfreq[word] = 0        # create a key/val pair
    wordfreq[word] += 1           # increment count[word]

print(len(wordfreq))              # 390 unique, 1139 total
print(wordfreq)
```

– There are many alternative packages with extensive support for analysing text (e.g. nltk) – but this is a good starting point

Conclusion: What now?

- For the exam, you should not use Built-ins
- Beyond that, explore them, compare them, use them
- Now that you get ADTs and algorithms, you can use them (or not) from a point of understanding
- You should be confident that you can research and select algorithms and ADTs, and beyond that APIs
- You can then write code to work with and extend on the work of others