Building Java Programs

Hashing

reading: 18.1

Data Structure Efficiency

	add	search	remove
Unsorted array	O(1)	O(n)	O(n)
Sorted array	O(n)	O(log n)	O(n)
Unsorted linked list	O(1)	O(n)	O(n)
Sorted linked list	O(n)	O(n)	O(n)
Binary search tree (balanced)	O(log n)	O(log n)	O(log n)
Hash Table	O(1)*	O(1)*	O(1)*

Arrays

- **Random access:** we have fast access if we know the index we are looking for in an array

- How would we add a value to an unsorted array of integers? How fast is this?

- How would we see if our unsorted array contains a particular value? How fast is this?

Hashing

- **hash**: To map a value to an integer index.
  - **hash table**: An array that stores elements via hashing.

- **hash function**: An algorithm that maps values to indexes.
  - one possible hash function for integers: **HF(I) = I % length**

```
set.add(11);        // 11 % 10 == 1
set.add(49);        // 49 % 10 == 9
set.add(24);        // 24 % 10 == 4
set.add(7);         //  7 % 10 == 7
```

index	0	1	2	3	4	5	6	7	8	9
value	0	11	0	0	24	0	0	7	0	49

Efficiency of hashing

```
public static int hashFunction(int i) {
    return Math.abs(i) % elementData.length;
}
```

- Add: set `elementData[HF(i)] = i;`
- Search: check if `elementData[HF(i)] == i`
- Remove: set `elementData[HF(i)] = 0;`

- What is the runtime of `add`, `contains`, and `remove`?
  - **O(1)**

- Are there any problems with this approach?

Hash Functions

- Maps an object to a number
  - result should be constrained to some range
  - passing in the same object should always give the same result

- Results from a hash function should be distributed over a range
  - very bad if everything hashes to 1!
  - should "look random"

- How would we write a hash function for String objects?

Hashing objects

- It is easy to hash an integer I (use index *I % length*).
  - How can we hash other types of values (such as objects)?

- All Java objects contain the following method:

  ```
  public int hashCode()
  ```

  Returns an integer hash code for this object.

  - We can call `hashCode` on any object to find its preferred index.

- How is `hashCode` implemented?
  - Depends on the type of object and its state.
    - Example: a String's `hashCode` adds the ASCII values of its letters.
  - You can write your own `hashCode` methods in classes you write.
    - All classes come with a default version based on memory address.

Hash function for objects

```
public static int hashFunction(E e) {
    return Math.abs(e.hashCode()) % elements.length;
}
```

- Add: set `elements[HF(o)] = o;`
- Search: check if `elements[HF(o)].equals(o)`
- Remove: set `elements[HF(o)] = null;`

String's hashCode

- The `hashCode` function inside `String` objects looks like this:

```
public int hashCode() {
    int hash = 0;
    for (int i = 0; i < this.length(); i++) {
        hash = 31 * hash + this.charAt(i);
    }
    return hash;
}
```

$$h(s) = \sum_{i=0}^{n-1} s[i] \cdot 31^{n-1-i}$$

- As with any general hashing function, collisions are possible.
  - Example: "Ea" and "FB" have the same hash value.
- Early versions of Java examined only the first 16 characters. For some common data this led to poor hash table performance.

Implementing generics

```
// a parameterized (generic) class
public class name<TypeParameter> {
    ...
}
```

- Forces any client that constructs your object to supply a type.
  - Don't write an actual type such as String; the client does that.
  - Instead, write a type variable name such as `E` (for "element") or `T` (for "type").
  - You can require multiple type parameters separated by commas.
- The rest of your class's code can refer to that type by name.

Collisions

- **collision**: When hash function maps 2 values to same index.

```
set.add(11);
set.add(49);
set.add(24);
set.add(7);
set.add(54);  // collides with 24! Where should it go?
```

- **collision resolution**: An algorithm for fixing collisions.

index	0	1	2	3	4	5	6	7	8	9
value	0	11	0	0	24	0	0	7	0	49

Probing

- **probing**: Resolving a collision by moving to another index.
  - **linear probing**: Moves to the next index.

```
set.add(11);
set.add(49);
set.add(24);
set.add(7);
set.add(54);   // collides with 24; must probe
```

index	0	1	2	3	4	5	6	7	8	9
value	0	11	0	0	24	**54**	0	7	0	49

  - Is this a good approach?
    - variation: **quadratic probing** moves increasingly far away

Clustering

- **clustering**: Clumps of elements at neighboring indexes.
  - slows down the hash table lookup; you must loop through them.

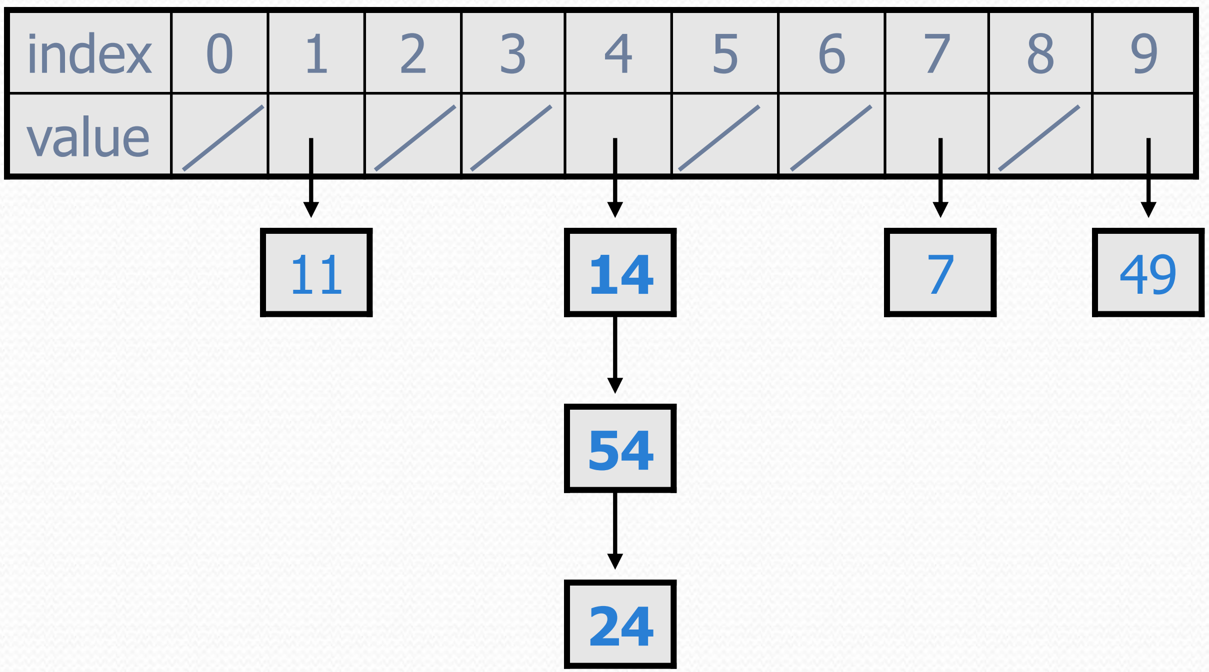
```
set.add(11);
set.add(49);
set.add(24);
set.add(7);
set.add(54);   // collides with 24
set.add(14);   // collides with 24, then 54
set.add(86);   // collides with 14, then 7
```

index	0	1	2	3	4	5	6	7	8	9
value	0	11	0	0	**24**	**54**	**14**	**7**	**86**	49

  - How many indexes must a lookup for 94 visit?

Chaining

- **chaining**: Resolving collisions by storing a list at each index
  - add/search/remove must traverse lists, but the lists are short
  - impossible to "run out" of indexes



Hash set code

```
import java.util.*;    // for List, LinkedList

public class HashIntSet {
    private static final int CAPACITY = 137;
    private List<Integer>[] elements;

    // constructs new empty set
    public HashSet() {
        elements = (List<Integer>[]) (new List[CAPACITY]);
    }

    // adds the given value to this hash set
    public void add(int value) {
        int index = hashFunction(value);
        if (elements[index] == null) {
            elements[index] = new LinkedList<Integer>();
        }
        elements[index].add(value);
    }

    // hashing function to convert objects to indexes
    private int hashFunction(int value) {
        return Math.abs(value) % elements.length;
    }
    ...
```

Hash set code 2

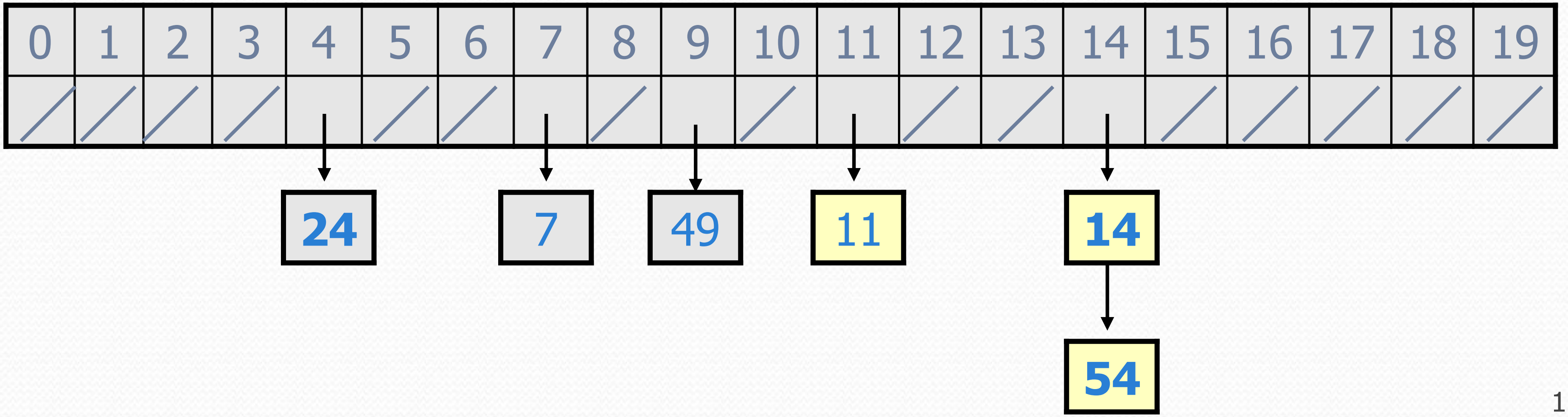
```
    ...
    // Returns true if this set contains the given value.
    public boolean contains(int value) {
        int index = hashFunction(value);
        return elements[index] != null &&
               elements[index].contains(value);
    }

    // Removes the given value from the set, if it exists.
    public void remove(int value) {
        int index = hashFunction(value);
        if (elements[index] != null) {
            elements[index].remove(value);
        }
    }
}
```

Rehashing

- **rehash**: Growing to a larger array when the table is too full.
  - Cannot simply copy the old array to a new one. (Why not?)

- **load factor**: ratio of (*# of elements*) / (*hash table length*)
  - many collections rehash when load factor ≅ .75
  - can use big prime numbers as hash table sizes to reduce collisions

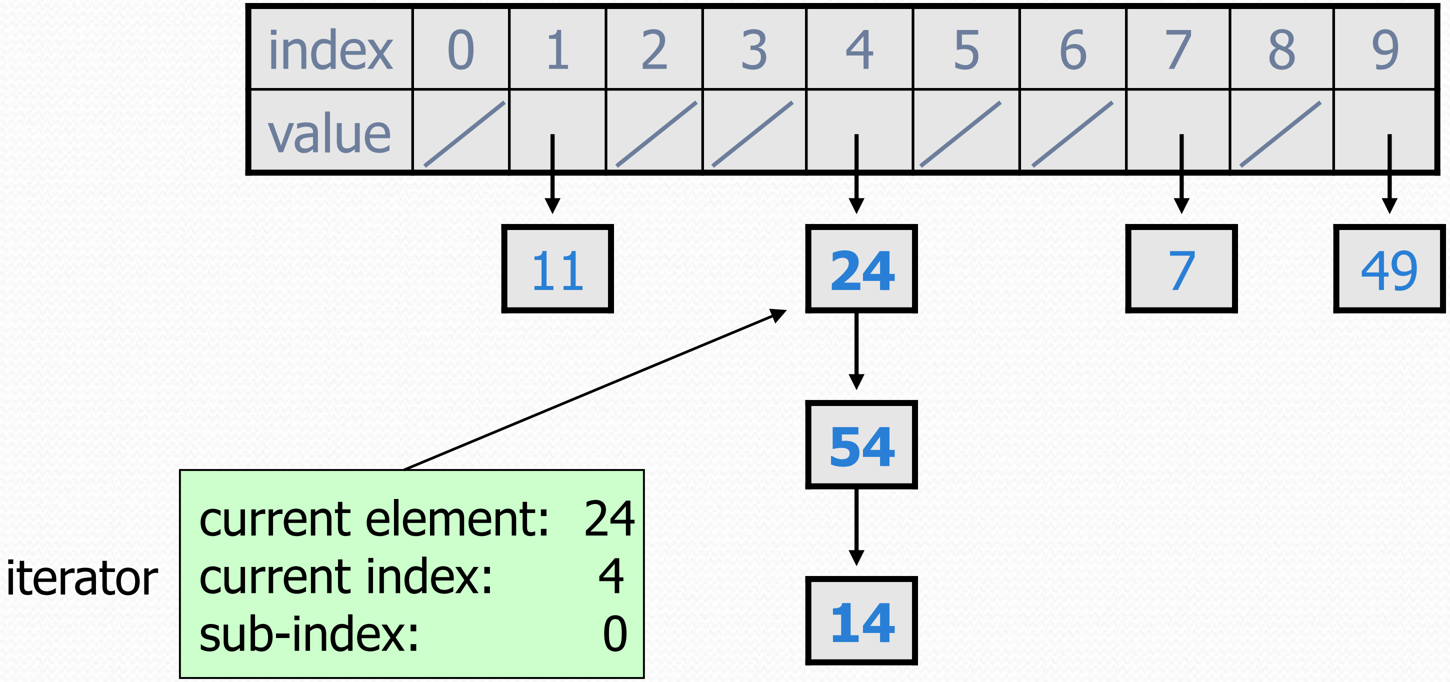


Rehashing code

```
...
// Grows hash array to twice its original size.
private void rehash() {
    List<Integer>[] oldElements = elements;
    elements = (List<Integer>[])
                   new List[2 * elements.length];
    for (List<Integer> list : oldElements) {
        if (list != null) {
            for (int element : list) {
                add(element);
            }
        }
    }
}
```

Other questions

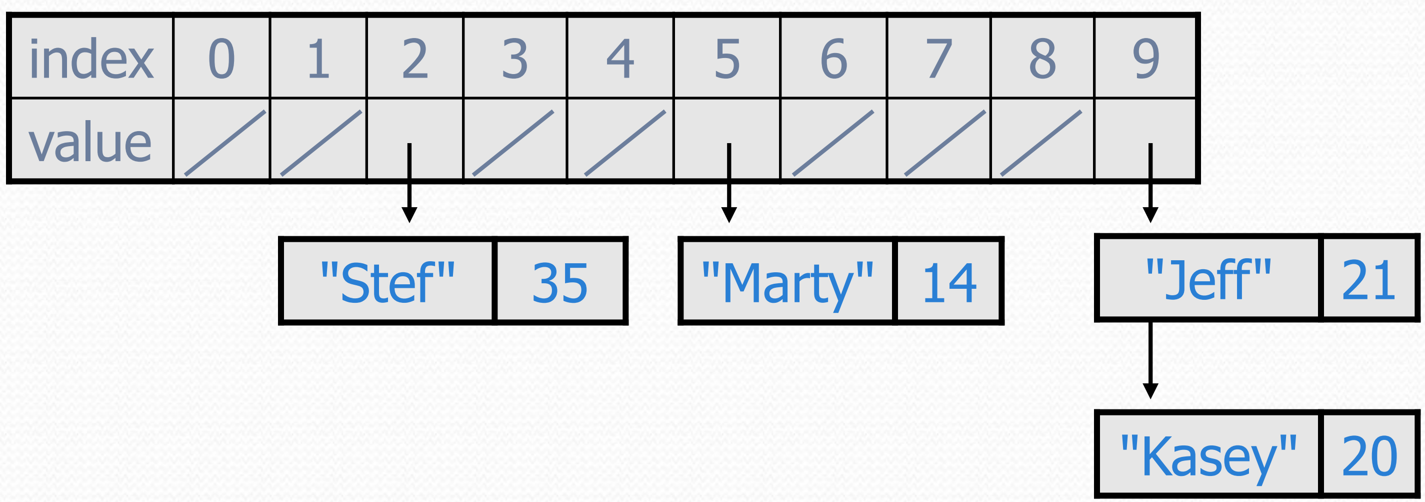
- How would we implement `toString` on a `HashSet`?



Implementing a hash map

- A hash map is just a set where the lists store key/value pairs:

```
//           key      value
map.put("Marty", 14);
map.put("Jeff",  21);
map.put("Kasey", 20);
map.put("Stef",  35);
```



  - Instead of a `List<Integer>`, write an inner `Entry` node class with `key` and `value` fields; the map stores a `List<Entry>`