Hashing

Reading:
L&C 17.1, 17.3
Eck 10.3

Objectives

- Define hashing
- Discuss the problem of collisions in hash tables
- Examine Java's **`HashMap<K,V>`** implementation of hashing
- Look at **`HashMap`** example
- Save *serializable* objects to binary files

Hashing

So far, all of the collections that we have seen have made one of the following assumptions about the order of the elements in the collection:

- order is unimportant (sets)
- order is determined by the way elements are added (stacks, queues)
- order is determined by comparing the elements (sorted lists)

Hashing

- We looked at ways to search for a particular element in a collection, such as linear search and binary search.
- The efficiency of both of these search algorithms depends on the number of elements in the collection.

Hashing

- **Hashing** is a very clever way of determining the location of an element based on some function of the element itself.
- This way, the time it takes to find an element is independent of the number of elements being stored in the collection.

Hashing

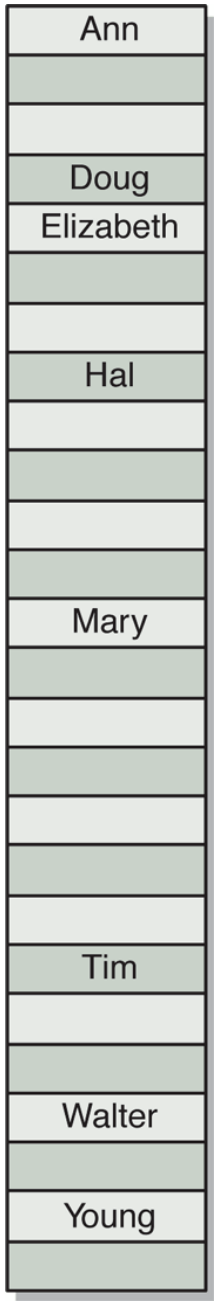
- Elements are stored in a **hash table** (or **hash map**), with their locations in the table determined by a **hashing function**.
- Each location in the hash table is called a **bucket**, or a **cell**.
- Elements are mapped to a bucket using a hashing function that calculates a hash code.
- To find an element in a hash table, you just have to compute the **hash code** of the key and go directly to the table location given by that hash code.

Hashing Example

- Consider an example where we want to store names.
- Our hash table will be an array.
- The buckets are indexes into the array.
- The elements are the names we want to store.

Hashing Example

- Suppose the hashing function uses the first letter of each name.
- A is mapped to position 0 (hash code 0), B is mapped to position 1, and so on up to Z, which is mapped to 25.



Hashing Example

- To locate elements in the hash table, we perform the hashing function to find the position.
- To find “Tim” in our example, we perform the hashing function

```
name.charAt(0) ⟶ 'T'
```

and get a hash code of 19 (remember that every character is represented as an `int`).

Hashing

- With hashing, we don't have to compare elements, we can find them directly, with each access taking a constant amount of time.
- However, this efficiency is only realized if each element maps to a unique position in the table.
- When two or more elements map to the same position, it is called a **collision**.
- E.g., “Andrew” also maps to position 0.

Perfect Hashing Function

- A hashing function that maps each element to a unique position in the table is called a **perfect hashing function**.
- It is not necessary to develop a perfect hashing function to use a hash table.
- A function that does a good job of distributing the elements in the table will still be more efficient than a linear search or binary search.

Hashing – Table Size

- Let's examine the issue of how to decide how large the table should be.
- Table size depends on two factors:
  - the number of elements to store (`n`)
  - whether or not we have a perfect hashing function
- Assuming that we know that **n** elements will be stored in the table:
  - if we have a perfect hashing function, the table size should be **n**.
  - if our hashing function is not perfect, it is recommended to make the table size **`n * 1.5`**

Hashing – Table Size

- Usually we don't know how many elements we will need to store in the table.
- In that case, we rely on **dynamic resizing**.
- Like resizing an array, resizing a hash table involves creating a larger table and inserting all of the elements of the old table into the new one.

Hashing – Table Size

- Luckily, the table resizing is done for us.
- We can, however, indicate when it should be done.
- When resizing an array, we wait until it is completely full.
- It is not a good idea to let a hash table get too full because the more full it is the less efficient it becomes.

Hashing – Load Factor

- A **load factor** is used to determine when to resize the table.
- The load factor indicates at what percentage occupancy the table should be resized.
  - a load factor of 0.5 indicates that the table should be resized when it is 50% full.
  - a load factor of 0.75 indicates that the table should be resized when it is 75% full.

Hashing – Load Factor

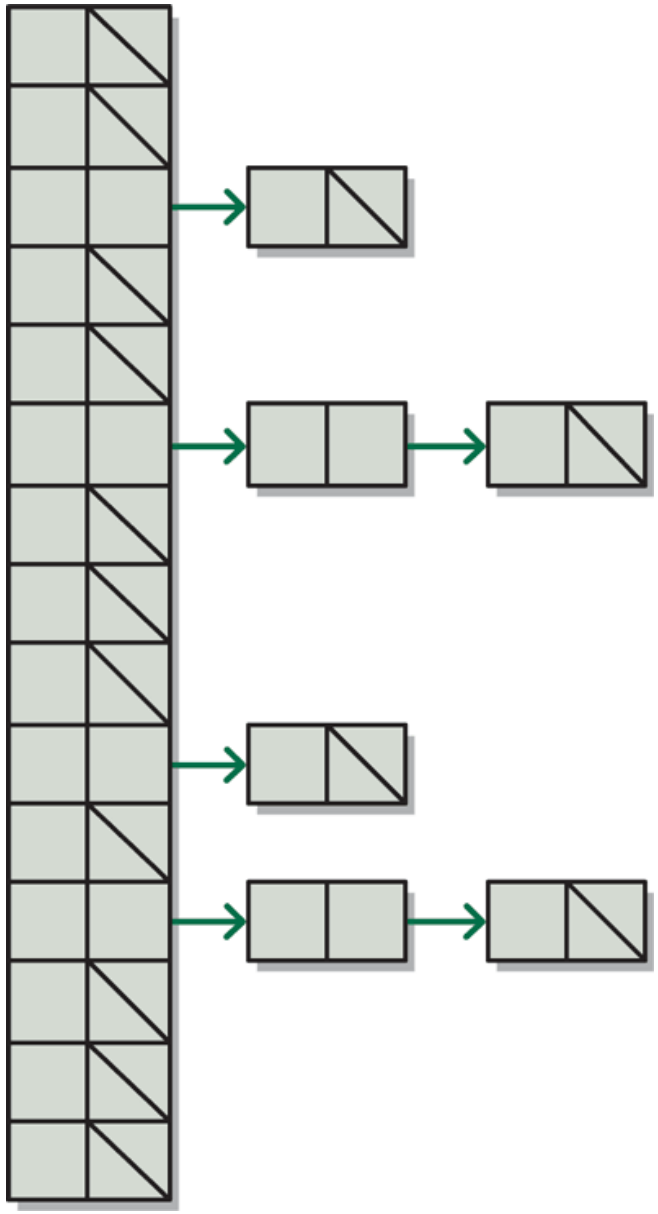
- The classes in the java library that implement hash tables have constructors that allow you to give an initial capacity and (optionally) a load factor as arguments.
- The default initial capacity is very small (16 for the **`HashMap`** class), so if you want to store more than 10 elements you should give a better initial capacity.
- The default load factor is 0.75, which should be ok in most cases.

Resolving Collisions – Chaining

- When more than one element map to the same table location (i.e., have the same hashcode), a collision occurs.
- The most common way of resolving collisions is by **chaining**.
- With chaining, each location in the table has a linked list of elements to be stored at that location.
- When an element is added to a location, it is simply appended to the linked list.

Resolving Collisions – Chaining

- When searching for an element, first the cell is identified by the hashing function, then the list at that location is searched.
- A good hashing function will keep the size of the linked lists small.



Resolving Collisions – Chaining

- Suppose we have a hashing function that just returns some constant, zero for example.
- Is this a good idea?
- Why or why not?

Resolving Collisions – Chaining

- It's NOT a good idea.
- All of the elements will be inserted at position 0.
- In effect we have turned our hash table into a linked list.
- Searching the linked lists is done linearly, using the **`equals`** method to determine if the element has been found.
- As we know, linear searching is not very efficient.

Hashing Functions

- There is a wide variety of hashing functions that provide good distribution of various types of data.
- Lewis&Chase discuss several ways of developing a hashing function.
- We will try to simplify our hash functions by combining existing hash codes.

equals and hashCode Methods

- Every object in Java has a hash code.
- The **`Object`** class defines the method **`hashCode()`**, which computes the hashcode and returns it as an **`int`**.
- All objects inherit the **`hashCode`** method from the **`Object`** class.

equals and hashCode Methods

- The **`hashCode`** method in the **`Object`** class, however, returns an integer based on the memory address of the object.
- Remember that the **`equals`** method in the **`Object`** class is also based on the memory address.
- For hashing to work, two objects that are considered equal by the **`equals`** method must also have the same hashcode.

equals and hashCode Methods

- Most of our classes override the **`equals`** method in the **`Object`** class, so that we can determine if the contents of the objects are equal, rather than just checking if they are aliases of each other.
- If we want to use these classes in a hash table, we must also override the **`hashCode`** method, so that objects that are equal also have the same hashcode.

equals and hashCode Methods

- Most of the classes included in the Java library have correctly defined **`equals`** and **`hashCode`** methods. In particular, the **`String`** class has well-defined **`equals`** and **`hashCode`** methods.
- If **`Strings`** are being used, you don't need to do anything extra.

hashCode()

- The **`hashCode`** method in a class you define yourself should include all of the instance variables that the **`equals`** method uses.
- Let's look at some examples using a **`Word`** class.

hashCode() for Word1

```
public class Word1 {
   private String form;
   private int frequency;
   < constructors, etc >

   public boolean equals(Object otherObj) {
      // two words are equal if they have same form
      if (otherObj == null)
         return false;

      if (getClass() != otherObj.getClass())
         return false;

      Word1 otherWord = (Word1) otherObj;
      return form.equals(otherWord.form);
   }
}
```

hashCode() for Word1

```
public class Word1 {
   private String form;
   private int frequency;
   < constructors, etc >

   < equals method based on form only >

   public int hashCode() {
      return form.hashCode();
   }
}
```

hashCode() for Word2

```
public class Word2 {
   private String form;
   private int frequency;
   < constructors, etc >

   public boolean equals(Object otherObj) {
      // two words are equal if they have same form
      // and the same frequency
      if (otherObj == null)
         return false;

      if (getClass() != otherObj.getClass())
         return false;

      Word2 otherWord = (Word2) otherObj;
      return (form.equals(otherWord.form) &&
              (frequency == otherWord.frequency));
   }
}
```

hashCode() for Word2

```
public class Word2 {
   private String form;
   private int frequency;
   < constructors, etc >

   < equals method based on form AND frequency >

   public int hashCode() {
      return form.hashCode() + frequency;
      // or: form.hashCode() * frequency;
   }
}
```

Maps

- A **map** is a kind of generalized array, sometimes also called an **associative array**.
- In an array, we use an integer index to access elements: `int x = myArray[5];`
- In a map, we use an object (a **key**) to access elements.
- Each **key** is associated with a **value**.

Maps

- The keys are used to determine a position in the map.
- Objects used as keys must have well-defined **`equals`** and **`hashCode`** methods.
- A value is associated with a key.
- Objects used as values do not necessarily need to override the **`equals`** and **`hashCode`** methods.

HashMap<K,V>

- Let's take a look at Java's **`HashMap<K,V>`** class (in package **`java.util`**) and an example of how it can be used.
- Suppose we want to store some names and phone numbers in a hash map.
- We will use a person's name as the key and their phone number as the value.
- We will use strings for both the name and the phone number.

HashMap<K,V>

- Our phonebook will most likely contain about 100 entries.
- Let's look at our choices for constructors in the **`HashMap`** class and create an empty **`HashMap`**.

HashMap<K,V> - Constructors

- **`HashMap()`**

  Constructs an empty **`HashMap`** with the default initial capacity (16) and the default load factor (0.75).

- **`HashMap(int initialCapacity)`**

  Constructs an empty **`HashMap`** with the specified initial capacity and the default load factor (0.75).

- **`HashMap(int initialCapacity, float loadFactor)`**

  Constructs an empty **`HashMap`** with the specified initial capacity and load factor.

HashMap<K,V> - Example

- A load factor of 75% is usually ok, but the default initial capacity of 16 is too small.
- We'll use the second constructor with an initial capacity of 150, which is 150% of our estimated data size of 100:

```
HashMap<String, String> phonebook =
        new HashMap<String, String>(150);
```

- A **`HashMap`** has two *type parameters* (both of type **`String`** in this example):
  - the first one specifies the type of the keys
  - the second specifies the type of the values

HashMap<K,V> - put

- Let's add some entries to our phonebook:

```
HashMap<String, String> phonebook =
        new HashMap<String, String>(150);

phonebook.put(“Joe”, “12345”);
phonebook.put(“Sam”, “54321”);
phonebook.put(“Kathy”, “11111”);
```

HashMap<K,V> - get

- Get Sam's and Tim's number:

```
HashMap<String, String> phonebook =
        new HashMap<String, String>(150);

phonebook.put(“Joe”, “12345”);
phonebook.put(“Sam”, “54321”);
phonebook.put(“Kathy”, “11111”);

String samsNumber = phonebook.get(“Sam”);
// samsNumber is now “54321”

String timsNumber = phonebook.get(“Tim”);
// timsNumber is now null
```

HashMap<K,V> - containsKey

- Find out if “Mike” is in phonebook:

```
HashMap<String, String> phonebook =
        new HashMap<String, String>(150);

phonebook.put(“Joe”, “12345”);
phonebook.put(“Sam”, “54321”);
phonebook.put(“Kathy”, “11111”);

if (phonebook.containsKey(“Mike”))
    // do something
```

HashMap<K,V> - remove

- Remove “Joe” from the phonebook:

```
HashMap<String, String> phonebook =
        new HashMap<String, String>(150);

phonebook.put(“Joe”, “12345”);
phonebook.put(“Sam”, “54321”);
phonebook.put(“Kathy”, “11111”);

phonebook.remove(“Joe”);
```

HashMap<K,V> - change a value

- Change Kathy's phone number:

```
HashMap<String, String> phonebook =
        new HashMap<String, String>(150);

phonebook.put(“Joe”, “12345”);
phonebook.put(“Sam”, “54321”);
phonebook.put(“Kathy”, “11111”);

phonebook.put(“Kathy”, “222222”);
// Kathy's phone number is replaced
```

HashMap<K,V> - change a value

- Add an extension to Kathy's number:

```
HashMap<String, String> phonebook =
        new HashMap<String, String>(150);

phonebook.put(“Joe”, “12345”);
phonebook.put(“Sam”, “54321”);
phonebook.put(“Kathy”, “11111”);

String value = phonebook.get(“Kathy”);
if (value != null) {
    value += “-32”;
    phonebook.put(“Kathy”, value);
   // Kathy's number is now “11111-32”
}
```

HashMap<K,V> - toString

- We could use **`toString`** to print:

```
HashMap<String, String> phonebook =
        new HashMap<String, String>(150);

phonebook.put(“Joe”, “12345”);
phonebook.put(“Sam”, “54321”);
phonebook.put(“Kathy”, “11111”);

System.out.println(phonebook);
```

- The output is not well formatted.
- It is better to print each entry on a separate line.
- We'll do this with iteration.

HashMap<K,V> - Iterating

- The **`HashMap`** class does not provide an **`iterator`** method.
- There are three common ways of iterating a **`HashMap`**:
  - **`keySet()`**: get a **`Set`** of the keys in the map and iterate it.
  - **`entrySet()`**: get a **`Set`** of the entries in the map and iterate it.
  - **`values()`**: get a **`Collection`** of the values and iterate it.
- Either way is fine – just pick one.

HashMap<K,V> - Iterating

- Note that the order in which we get the elements back from either of these methods is unpredictable.
- This is because an element's position depends on the hashcode and the table size.
- The table size can change as we add elements.

HashMap<K,V> - Iterating (keySet)

- Print all entries:

```
HashMap<String, String> phonebook =
        new HashMap<String, String>(150);
String value;

phonebook.put(“Joe”, “12345”);
phonebook.put(“Sam”, “54321”);
phonebook.put(“Kathy”, “11111”);

// for each key in the map's keyset
for (String key : phonebook.keySet()) {
   value = phonebook.get(key);
   System.out.println(key + “ “ + value);
}
```

HashMap<K,V> - Iterating (entrySet)

- Print all entries:

```
HashMap<String, String> phonebook =
        new HashMap<String, String>(150);
String key, value;

phonebook.put(“Joe”, “12345”);
phonebook.put(“Sam”, “54321”);
phonebook.put(“Kathy”, “11111”);

// for each entry in the map
for (Map.Entry<String,String> entry : phonebook.entrySet()) {
   key = entry.getKey();
   value = entry.getValue();
   System.out.println(key + “ “ + value);
}
```

Saving to a Binary File

- In Java, it is possible to save any s*erializable* object to a binary file.
- **`ArrayLists`**, **`LinkedLists`**, **`and HashMaps`** are all serializable (to name a few), i.e., they implement the **`Serializable`** interface.
- The **`writeObject`** method of the **`ObjectOutputStream`** class is used to store the data

Saving to a Binary File

```
try {
    ObjectOutputStream out = new ObjectOutputStream(
                             new FileOutputStream("myFile"));
    out.writeObject(myHashMap);
    out.close();
} catch (IOException e) {
    System.out.println(e.getMessage());
}
```

Retrieving the Object from a File

- To retrieve the object from the file, use the **`readObject`** method of the **`ObjectInputStream`** class.

Retrieving the Object from a File

```
File inputFile = new File("myFile");
try {
   if (inputFile.exists()) {

      ObjectInputStream in = new ObjectInputStream(
                             new FileInputStream(inputFile));

      myHashMap = (HashMap<String,String>) in.readObject();
      in.close();

   }
} catch (IOException e) {
   System.out.println(e.getMessage());
} catch (ClassNotFoundException e) {
   System.out.println(e.getMessage());
}
```

Serializable

- You can make your own classes serializable by having them implement the **`Serializable`** interface:

```
public class MyClass implements Serializable { ... }
```

- The **`Serializable`** interface has no methods that need to be implemented, so that's it!