Topic 20
Data Structure Potpourri: Hash Tables and Maps

"**hash collision** n.
[from the techspeak] (var. `hash clash') When used of people, signifies a confusion in associative memory or imagination, especially a persistent one (see **thinko**). True story: One of us was once on the phone with a friend about to move out to Berkeley. When asked what he expected Berkeley to be like, the friend replied: "Well, I have this mental picture of naked women throwing Molotov cocktails, but I think that's just a collision in my hash tables."

-The Hacker's Dictionary

Programming Pearls by Jon Bentley

- Jon was *senior programmer* on a large programming project.
- Senior programmer spend a lot of time helping junior programmers.
- Junior programmer to Jon: "I need help writing a *sorting algorithm*."

A Problem

- From *Programming Pearls (Jon in Italics)*

Why do you want to write your own sort at all? Why not use a sort provided by your system?
I need the sort in the middle of a large system, and for obscure technical reasons, I can't use the system file-sorting program.
What exactly are you sorting? How many records are in the file? What is the format of each record?
The file contains at most ten million records; each record is a seven-digit integer.
Wait a minute. If the file is that small, why bother going to disk at all? Why not just sort it in main memory?
Although the machine has many megabytes of main memory, this function is part of a big system. I expect that I'll have only about a megabyte free at that point.
Is there anything else you can tell me about the records?
Each one is a seven-digit positive integer with no other associated data, and no integer can appear more than once.

Questions

- When did this conversation take place?
- What were they sorting?
- How do you sort data when it won't all fit into main memory?
- Speed of file i/o?

A Solution

```
/* phase 1: initialize set to empty */
for i = [0, n)
    bit[i] = 0

/* phase 2: insert present elements into the set */
for each i in the input file
    bit[i] = 1

/* phase 3: write sorted output */
for i = [0, n)
    if bit[i] == 1 write i on the output file
```


Some Structures so Far

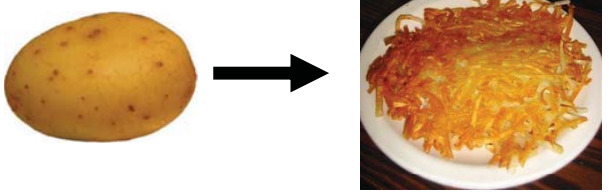
- ArrayLists
  - O(1) access
  - O(N) insertion (average case), better at end
  - O(N) deletion (average case)
- LinkedLists
  - O(N) access
  - O(N) insertion (average case), better at front and back
  - O(N) deletion (average case), better at front and back
- Binary Search Trees
  - O(log N) access if balanced
  - O(log N) insertion if balanced
  - O(log N) deletion if balanced

Why are Binary Trees Better?

- Divide and Conquer
  - reducing work by a factor of 2 each time
- Can we reduce the work by a bigger factor? 10? 1000?
- An ArrayList does this in a way when *accessing* elements
  - *but must use an integer value*
  - *each position holds a single element*

Hash Tables

- Hash Tables overcome the problems of ArrayList while maintaining the fast access, insertion, and deletion in terms of N (number of elements already in the structure.)



Hash Functions

- Hash: "From the French hatcher, which means 'to chop'. "
- *to hash* to mix randomly or shuffle (To cut up, to slash or hack about; to mangle)
- Hash Function: Take a large piece of data and reduce it to a smaller piece of data, usually a single integer.
  - A function or algorithm
  - The input need not be integers!

Hash Function

Simple Example

- Assume we are using names as our *key*
  - *take 3rd letter of name, take int value of letter (a = 0, b = 1, ...), divide by 6 and take remainder*
- What does "Bellers" hash to?
- L -> 11 -> 11 % 6 = 5

Result of Hash Function

- Mike = (10 % 6) = 4
- Kelly = (11 % 6) = 5
- Olivia = (8 % 6) = 2
- Isabelle = (0 % 6) = 0
- David = (21 % 6) = 3
- Margaret = (17 % 6) = 5 (uh oh)
- Wendy = (13 % 6) = 1
- This is an imperfect hash function. A perfect hash function yields a one to one mapping from the keys to the hash values.
- What is the maximum number of values this function can hash perfectly?

More on Hash Functions

- Normally a two step process
  - transform the key (which may not be an integer) into an integer value
  - Map the resulting integer into a valid index for the hash table (where all the elements are stored)
- The transformation can use one of four techniques
  - mapping, folding, shifting, casting

Hashing Techniques

- Mapping
  - As seen in the example
  - integer values or things that can be easily converted to integer values in key
- Folding
  - partition key into several parts and the integer values for the various parts are combined
  - the parts may be hashed first
  - combine using addition, multiplication, shifting, logical exclusive OR

More Techniques

- Shifting
  - an alternative to folding
  - A fold function

```
int hashVal = 0;
int i = str.length() - 1;
while(i > 0){
   hashVal += (int) str.charAt(i);
   i--;
}
```

results for "dog" and "god" ?

Shifting and Casting

- More complicated with shifting

```
int hashVal = 0;
int i = str.length() - 1;
while(i > 0)
{ hashVal = (hashVal << 1) + (int) str.charAt(i);
  i--;
}
```

different answers for "dog" and "god"

Shifting may give a better range of hash values when compared to just folding

Casts

- Very simple
  - essentially casting as part of fold and shift when working with chars.

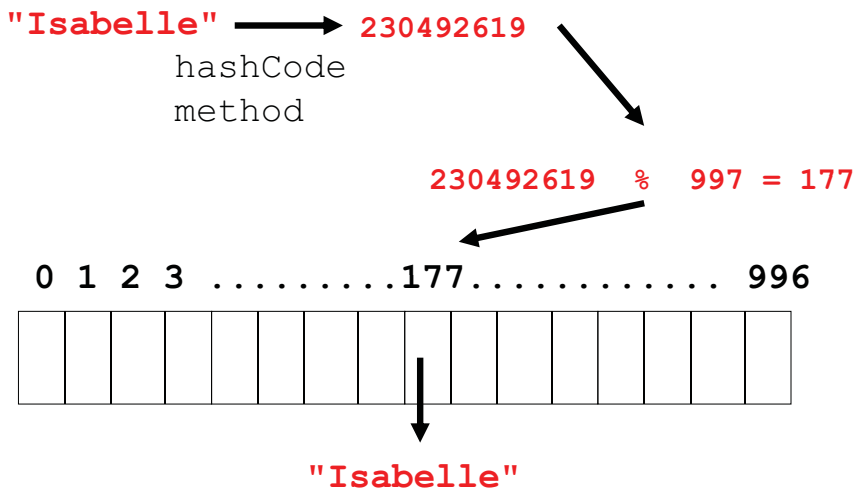
The Java String class hashCode method

```
public int hashCode()
{    int h = hash;
     if (h == 0)
     {    int off = offset;
          char val[] = value;
          int len = count;
           for (int i = 0; i < len; i++)
           {    h = 31*h + val[off++];
           }
           hash = h;
     }
     return h;
}
```

Mapping Results

- Transform hashed key value into a legal index in the hash table
- Hash table is normally uses an array as its underlying storage container
- Normally get location on table by taking result of hash function, dividing by size of table, and taking remainder
  - index = key mod n
  - n is size of hash table
  - empirical evidence shows a prime number is best
  - 1000 element hash table, make 997 or 1009 elements

Mapping Results



Handling Collisions

- What to do when inserting an element and already something present?

Open Address Hashing

- Could search forward or backwards for an open space
- Linear probing:
  - move forward 1 spot. Open?, 2 spots, 3 spots
  - reach the end?
  - When removing, insert a blank
  - null if never occupied, blank if once occupied
- Quadratic probing
  - 1 spot, 2 spots, 4 spots, 8 spots, 16 spots
- Resize when *load factor* reaches some limit

Chaining

- Each element of hash table be another data structure
  - linked list, balanced binary tree
  - More space, but somewhat easier
  - everything goes in its spot
- Resize at given load factor or when any chain reaches some limit: (relatively small number of items)
- What happens when resizing?
  - Why don't things just collide again?

Hash Tables in Java

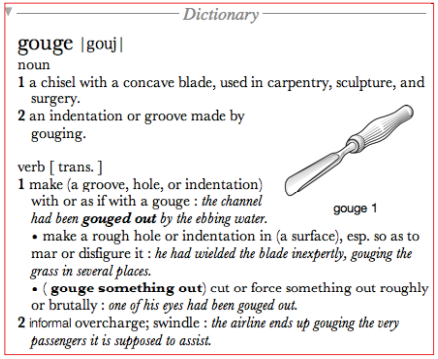
- `hashCode` method in `Object`
- `hashCode` and `equals`
  - "If two objects are equal according to the equals (`Object`) method, then calling the `hashCode` method on each of the two objects must produce the same integer result. "
  - if you override `equals` you need to override `hashCode`

Hash Tables in Java

- HashTable class
- HashSet class
  - implements Set interface with internal storage container that is a HashTable
  - compare to TreeSet class, internal storage container is a Red Black Tree
- HashMap class
  - implements the Map interface, internal storage container for keys is a hash table

Maps (a.k.a. Dictionaries)

```
A -> 65
```



Dictionary

gouge |gouj|
noun
1 a chisel with a concave blade, used in carpentry, sculpture, and surgery.
2 an indentation or groove made by gouging.

verb [trans.]
1 make (a groove, hole, or indentation) with or as if with a gouge : *the channel had been* ***gouged out*** *by the ebbing water.*
• make a rough hole or indentation in (a surface), esp. so as to mar or disfigure it : *he had wielded the blade inexpertly, gouging the grass in several places.*
• (**gouge something out**) cut or force something out roughly or brutally : *one of his eyes had been gouged out.*
2 informal overcharge; swindle : *the airline ends up gouging the very passengers it is supposed to assist.*

gouge 1

Maps

- Also known as:
  - table, search table, dictionary, associative array, or associative container
- A data structure optimized for a very specific kind of search / access
  - with a *bag* we access by asking "is X present"
  - with a *list* we access by asking "give me item number X"
  - with a *queue* we access by asking "give me the item that has been in the collection the longest."
- In a *map* we access by asking "give me the *value* associated with this *key."*

Keys and Values

- Dictionary Analogy:
  - The *key* in a dictionary is a word: *foo*
  - The *value* in a dictionary is the definition: *First on the standard list of metasyntactic variables used in syntax examples*
- A key and its associated value form a pair that is stored in a map
- To retrieve a value the key for that value must be supplied
  - A List can be viewed as a Map with integer keys

More on Keys and Values

- Keys must be unique, meaning a given key can only represent one value
  - but one value may be represented by multiple keys
  - like synonyms in the dictionary. Example: *factor: n.See coefficient of X*
  - *factor* is a key associated with the same value (definition) as the key *coefficient of X*

The Map<K, V> Interface in Java

- `void clear()`
  - Removes all mappings from this map (optional operation).
- `boolean containsKey(Object key)`
  - Returns true if this map contains a mapping for the specified key.
- `boolean containsValue(Object value)`
  - Returns true if this map maps one or more keys to the specified value.
- `Set<K> keySet()`
  - Returns a Set view of the keys contained in this map.

The Map Interface Continued

- `V get(Object key)`
  - Returns the value to which this map maps the specified key.
- `boolean isEmpty()`
  - Returns true if this map contains no key-value mappings.
- `V put(K key, V value)`
  - Associates the specified value with the specified key in this map

The Map Interface Continued

- `Vremove(Object key)`
  - Removes the mapping for this key from this map if it is present
- `int size()`
  - Returns the number of key-value mappings in this map.
- `Collection<V> values()`
  - Returns a collection view of the values contained in this map.

Implementing a Map

- Two common implementations of maps are to use a binary search tree or a hash table as the internal storage container
  - HashMap and TreeMap are two of the implementations of the Map interface
- `HashMap` uses a hash table as its internal storage container.
  - keys stored based on hash codes and size of hash tables internal array

TreeMap implementation

- Uses a Red - Black tree to implement a Map
- relies on the `compareTo` method of the keys
- somewhat slower than the HashMap
- keys stored in sorted order

Sample Map Problem

Determine the frequency of words in a file.

```
File f = new File(fileName);
Scanner s = new Scanner(f);
Map<String, Integer> counts =
      new Map<String, Integer>();
while( s.hasNext() ){
  String word = s.next();
  if( !counts.containsKey( word ) )
    counts.put( word, 1 );
  else
    counts.put( word,
        counts.get(word) + 1 );
}
```