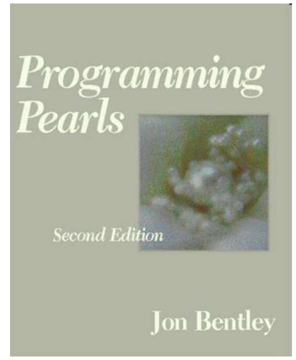
Topic 22
Hash Tables

"**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 people 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.

System Sort

```
pisces% cat simple.txt
zoo
apple
bee
Apple
Zoo
Yacht
Soccer
2410 Speedway
Dorr
!!
pisces%
```

```
pisces% sort simple.txt
!!
2410 Speedway
apple
Apple
bee
Dorr
Soccer
Yacht
zoo
Zoo
```

Starting Other Programs

getRuntime

`public static Runtime getRuntime()`

Returns the runtime object associated with the current Java application. Most of the methods of class `Runtime` are instance methods and must be invoked with respect to the current runtime object.

Returns:

the `Runtime` object associated with the current Java application.

Starting Other Programs

exec

`public Process exec(String command) throws IOException`

Executes the specified string command in a separate process.

This is a convenience method. An invocation of the form `exec(command)` behaves in exactly the same way as the invocation `exec(command, null, null)`.

Parameters:

`command` - a specified system command.

Returns:

A new `Process` object for managing the subprocess

Clicker 1 and 2

- When did this conversation take place?

A. circa 1965

B. circa 1975

C. circa 1985

D. circa 1995

E. circa 2005

- What were they sorting?

A. SSNs. B. Random values C. Street Addresses

D. Personal Incomes E. Phone Numbers

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 num_in_file in the input file
    bit[num_in_file] = 1

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

Some Structures so Far

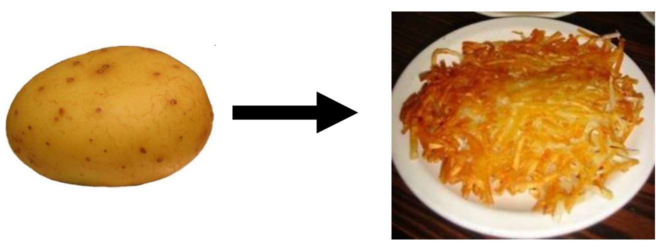
- ArrayLists
  - O(1) access
  - O(N) insertion (average case), better at end
  - O(N) deletion (average case)
- LinkedLists
  - O(N) access
  - O(N) insertion (average case), better at front and back
  - O(N) deletion (average case), better at front and back
- Binary Search Trees
  - O(log N) access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

Why are Binary Trees Better?

- Divide and Conquer - splitting problem into smaller problems
- Can we reduce the work by a bigger factor? 3? 10? More?
- An ArrayList does this in a way when *accessing* elements
  - *but must use an integer value*
  - *each position holds a single element*
  - ***given the index in an array, I can access that element rather quickly***
  - ***determining the address of the element requires a multiply op and an add op***

Hash Tables

- Hash Tables maintaining the fast access of arrays but improve the order for insertion, and deletion compare to array based lists.



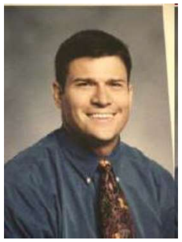
- Hash tables use an *array* and *hash functions* to determine the index for each element.

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 piece of data and transforms it to a different piece of data (typically smaller), usually a single integer.
  - A function or algorithm
  - The input need not be integers!

Hash Function

5/17/1971



555389085

Manchester, VT

"Mike Scott"

mscott61729@gmail.com

"Kelly"

"Olivia"

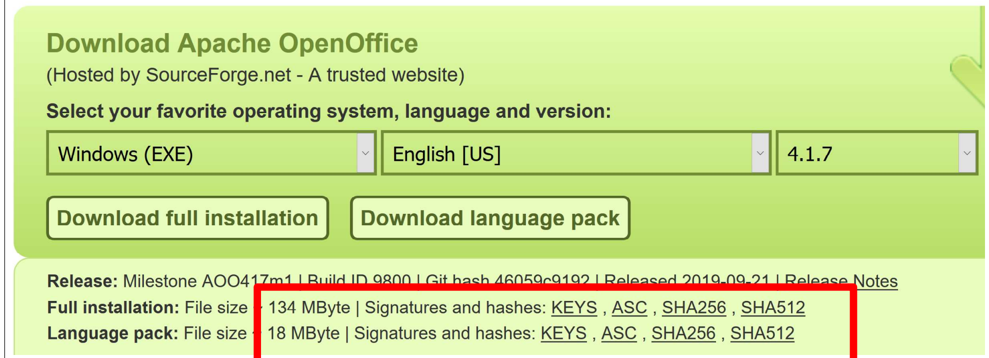
"Isabelle"

→ 12

hash function

Hash Functions

- Like a fingerprint



- 134 Megabytes

Hash Function

- SHA 512 Hash code

```
c3e6ef13fb80e34981304754717 4a35367fb19ee
0ba704a27ab748ed99a6463671bcd1bef348bb42
a5e883301ef786970fe303d0fd3f677f8d0a8fd0
4aeba798
*Apache_OpenOffice_4.1.7_Win_x86_install
_en-US.exe
```


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?

Clicker 3 - Hash Function

- Assume the hash function for String adds up the Unicode value for each character.

```
public int hashCode(String s) {
    int result = 0;
    for (int i = 0; i < s.length(); i++)
        result += s.charAt(i);
    return result;
}
```

- Hashcode for "DAB" and "BAD"?

A.	301	103
B.	4	4
C.	412	214
D.	5	5
E.	199	199

More on Hash Functions

- transform the key (which may not be an integer) into an integer value
- 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

Shifting

- 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 && value.length > 0) {
       char[] val = value;
       for (int i = 0; i < val.length; i++) {
            h = 31 * h + val[i];
       }
       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

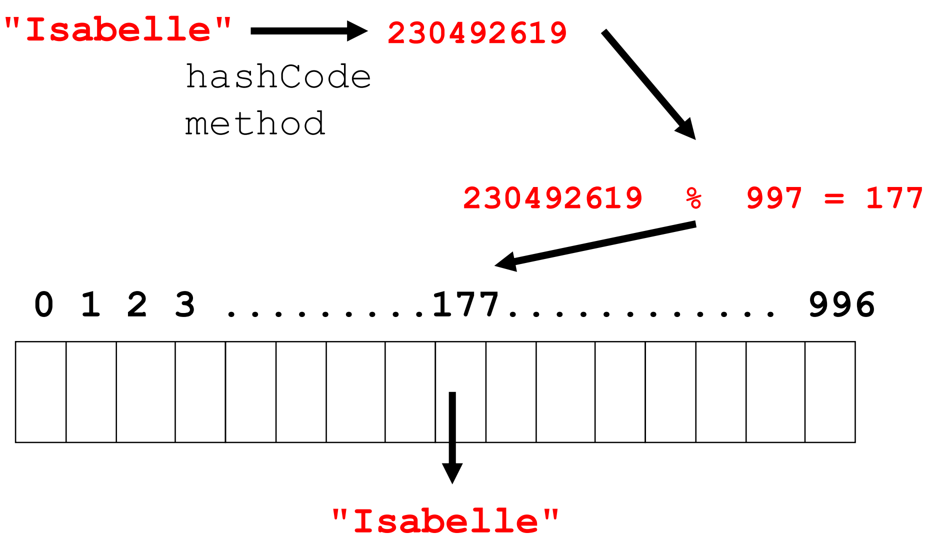
index = key mod n

n is size of hash table

empirical evidence shows a prime number is best

10 element hash table, move up to 11 or 13 elements

Mapping Results



Handling Collisions

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

Open Addressing

- 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

Closed Addressing: 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
- 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`
- Overriding one of `equals` and `hashCode`, but not the other, can cause logic errors that are difficult to track down if objects added to hash tables.

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

Comparison

- Compare these data structures for speed:
- Java HashSet
- Java TreeSet
- our naïve Binary Search Tree
- our HashTable
- Insert random ints

Clicker 4

- What will be order from fastest to slowest?

A. HashSet TreeSet HashTable314 BST

B. HashSet HashTable314 TreeSet BST

C. TreeSet HashSet BST HashTable314

D. HashTable314 HashSet BST TreeSet

E. None of these