

Topic 23

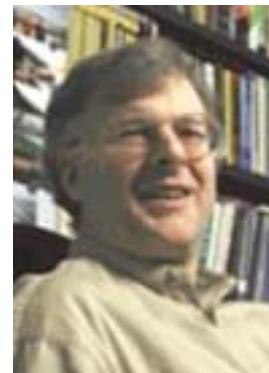
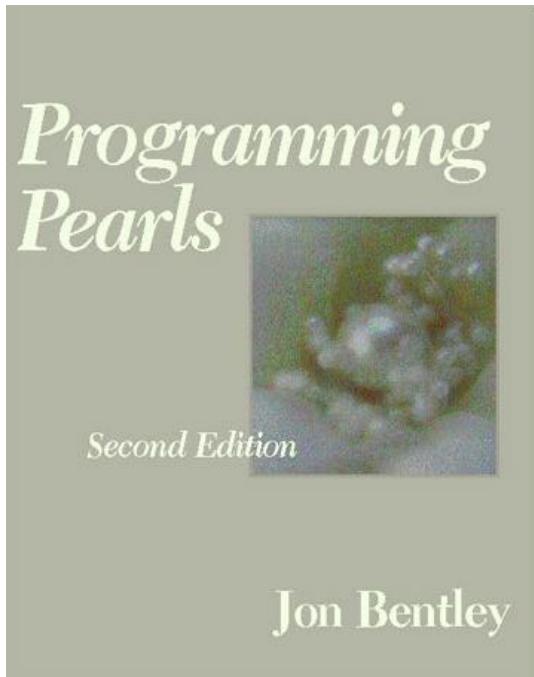
Hash Tables

"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?
 - circa 1965
 - circa 1975
 - circa 1985
 - circa 1995
 - circa 2005
- ▶ What were they sorting?
 - SSNs.
 - Random values
 - Street Addresses
 - Personal Incomes
 - 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

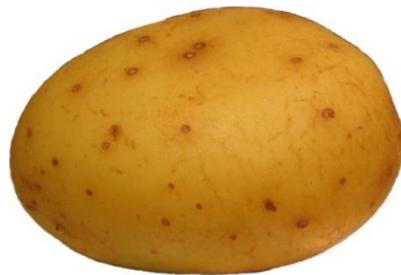
- ▶ **ArrayLists**
 - $O(1)$ access
 - $O(N)$ insertion (average case), better at end
 - $O(N)$ deletion (average case)
- ▶ **LinkedLists**
 - $O(N)$ access
 - $O(N)$ insertion (average case), better at front and back
 - $O(N)$ deletion (average case), better at front and back
- ▶ **Binary Search Trees**
 - $O(\log N)$ 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.

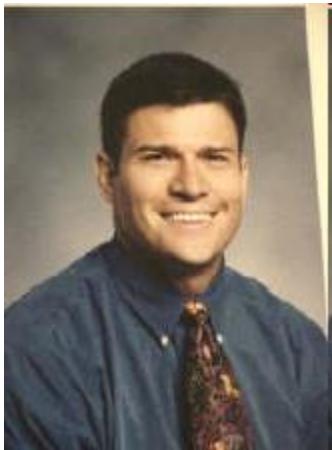


- ▶ Hash tables use an *array* and *hash functions* to determine the index for each element.

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"



hash
function

Hash Functions

- ▶ Like a fingerprint

Download Apache OpenOffice

(Hosted by SourceForge.net - A trusted website)

Select your favorite operating system, language and version:

Windows (EXE)

English [US]

4.1.7

[Download full installation](#)

[Download language pack](#)

Release: Milestone AOO417m1 | Build ID 9800 | Git hash 46059c9192 | Released 2019-09-21 | [Release Notes](#)

Full installation: File size ~ 134 MByte | Signatures and hashes: [KEYS](#) , [ASC](#) , [SHA256](#) , [SHA512](#)

Language pack: File size ~ 18 MByte | Signatures and hashes: [KEYS](#) , [ASC](#) , [SHA256](#) , [SHA512](#)

- ▶ 134 Megabytes

Hash Function

- ▶ SHA 512 Hash code

c3e6ef13fb80e349813047547174a35367fb19ee
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 static 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

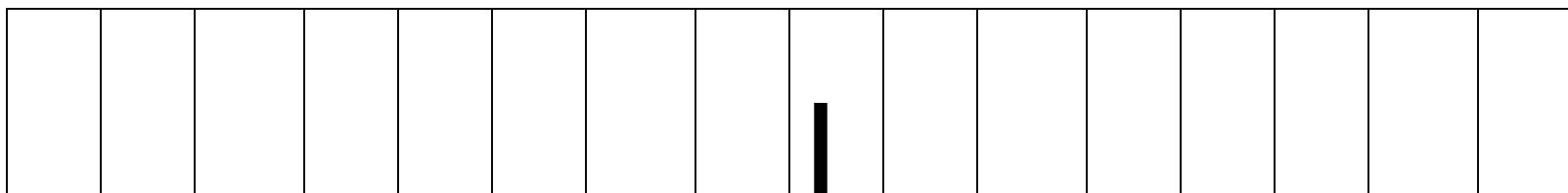
Mapping Results

"Isabelle" \longrightarrow 230492619

hashCode
method

$$230492619 \% 997 = 177$$

0 1 2 3 177 996



"Isabelle"

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?

- HashSet TreeSet HashTable314 BST
- HashSet HashTable314 TreeSet BST
- TreeSet HashSet BST HashTable314
- HashTable314 HashSet BST TreeSet
- None of these