# Data Structures

## Hash Tables and Applications

Design and Analysis of Algorithms I

NEXTCORE AI

# Hash Table: Supported Operations

Purpose : maintain a (possibly evolving) set of stuff.
(transactions, people + associated data, IP addresses, etc.)

Insert : add new record

Delete : delete existing record

Lookup : check for a particular record
( a "dictionary" )

Using a "key"

AMAZING GUARANTEE
All operations in O(1) time ! *

* 1. properly implemented 2. non-pathological data

# Application: De-Duplication

Given : a "stream" of objects.

- Linear scan through a huge file
- Or, objects arriving in real time

Goal : remove duplicates (i.e., keep track of unique objects)

-e.g., report unique visitors to web site

- avoid duplicates in search results

Solution : when new object x arrives

- lookup x in hash table H
- if not found, Insert x into H

# Application: The 2-SUM Problem

Input : unsorted array A of n integers. Target sum t.

Goal : determine whether or not there are two numbers x,y in A with

x + y = t

Naïve Solution : $\theta(n^2)$ time via exhaustive search

Better : 1.) sort A ( $\theta(n \log n)$ time ) 2.) for each x in A, look for t-x in A via binary search

$\theta(n)$ *time* $\theta(n \log n)$

Amazing : 1.) insert elements of A into hash table H 2.) for each x in A, Lookup t-x $\theta(n)$ *time*

# Further Immediate Applications

- Historical application : symbol tables in compilers

- Blocking network traffic

- Search algorithms (e.g., game tree exploration)
    - Use hash table to avoid exploring any configuration (e.g., arrangement of chess pieces) more than once

- etc.

# Data Structures

## Hash Tables: Some Implementation Details

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# High-Level Idea

Setup : universe U [e.g., all IP addresses, all names, all chessboard configurations, etc. ]
[ generally, REALLY BIG ]

Goal : want to maintain evolving set $S \subseteq U$
[ generally, of reasonable size ]

Solution : 1.) pick n = # of "buckets" with
(for simplicity assume |S| doesn't vary much)
2.) choose a hash function $h : U \rightarrow \{0, 1, 2, ..., n-1\}$
3.) use array A of length n, store x in A[h(x)]

Naïve Solutions

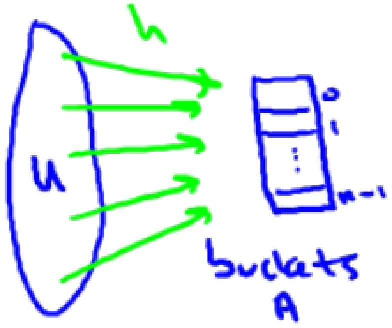
1. Array-based solution
   [ indexed by u]
   - O(1) operations but $\theta(|U|)$ space
2. List –based solution
   - $\theta(|S|)$ space but $\theta(|S|)$ Lookup

Consider $n$ people with random birthdays (i.e., with each day of the year equally likely). How large does $n$ need to be before there is at least a 50% chance that two people have the same birthday?

- ○ 23 ← 50 %
- ○ 57 ← 99 %
- ○ 184 ← 99.99....%
- ○ 367 ← 100%

BIRTHDAY "PARADOX"

# Resolving Collisions




Collision: distinct $x, y \in U$ such that $h(x) = h(y)$

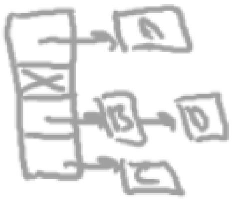
Solution # 1 : (separate) chaining

-keep linked list in each bucket

- given a key/object x, perform Insert/Delete/Lookup in the list in A[h(x)]

Linked list for x

Bucket for x



Solution #2 : open addressing. (only one object per bucket)

-Hash function now specifies probe sequence $h_1(x), h_2(x), ..$

(keep trying till find open slot)

Use 2 hash functions

- Examples : linear probing (look consecutively), double hashing

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# What Makes a Good Hash Function?

Note : in hash table with chaining, Insert is $\theta(1)$

$\theta(list\ length)$ for Insert/Delete.

Insert new object x at front of list in A[h(x)]

Equal-length lists

could be anywhere from m/n to m for m objects

All objects in same bucket

Point : performance depends on the choice of hash function!

(analogous situation with open addressing)

Properties of a "Good" Hash function

1. Should lead to good performance => i.e., should "spread data out" (gold standard – completely random hashing)
2. Should be easy to store/ very fast to evaluate.

# Bad Hash Functions

Example : keys = phone numbers (10-digits). $|u| = 10^{10}$

-Terrible hash function : $h(x) = 1^{st}$ 3 digits of x choose $n = 10^3$

(i.e., area code)

- mediocre hash function : h(x) = last 3 digits of x

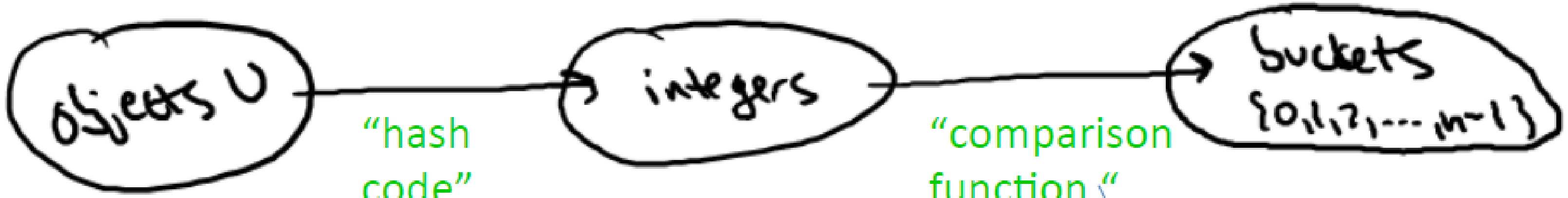
[still vulnerable to patterns in last 3 digits ]

Example : keys = memory locations. (will be multiples of a power of 2)

-Bad hash function : h(x) = x mod 1000 (again $n = 10^3$)

=> All odd buckets guaranteed to be empty.

# Quick-and-Dirty Hash Functions




"hash code"

e.g., subroutine to convert strings to integers

"comparison function "

like the mod n function

<u>How to choose n = # of buckets</u>

1. Choose n to be a prime ( within constant factor of # of objects in table)
2. Not too close to a power of 2
3. Not too close to a power of 10