CSCI 136
Data Structures &
Advanced Programming

Fall 2017

Lecture 33

The 2070567s

Administrative Details

Reminders

- No lab this week
- Final exam
  - Thursday, December 14 at 9:30 in TBL 112
  - Study guide, sample exam will be posted online
  - TAs available this weekend (see course calendar)
  - “Bills review” Tuesday from 1:30-2:30 in Physics 205

Last Time

- Prim's algorithm wrapup
- Hash tables
  - Object.hashCode() maps objects to bins
  - Linear probing to resolve collisions

Today's Outline

- External Chaining to resolve collisions
- Fun hashing applications (not on exam)
  - Cuckoo hashing
  - Bloom Filters
  - Verification/integrity
  - Deduplication

One Last Note on Graphs

- In an undirected graph, each edge connects two vertices
  - Which contributes 1 to the degree of each of those vertices
  - Since each edge will be counted by two vertices, the sum of all of the degrees of all vertices is twice the number of edges

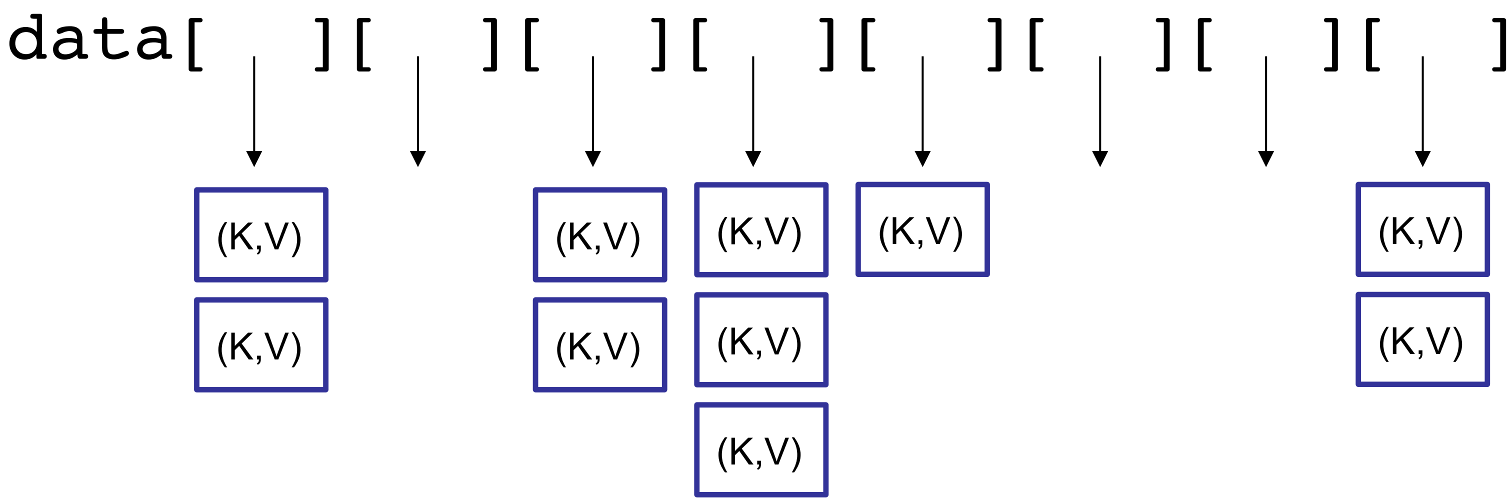
$$\sum \mathtt{deg(v)} = 2|\mathtt{E}|$$

Hashtable Core Concept

- A hash function maps a key to an index
- The index specifies the bin where the key-value pair should be stored
- If two keys hash to the same bin, we have a collision
- Linear probing scans and places the collided element in the first empty bin, creating a run
  - When we remove, must add a placeholder

External Chaining

- Instead of runs, we store a list in each bin



- Everything that hashes to bin_i goes into $list_i$
  - get(), put(), and remove() only need to check one slot's list
  - No placeholders!

Probing vs. Chaining

What is the performance of:

- `put(K, V)`
  - LP: O(1 + run length)
  - EC: O(1 + chain length)
- `get(K)`
  - LP: O(1 + run length)
  - EC: O(1 + chain length)
- `remove(K)`
  - LP: O(1 + run length)
  - EC: O(1 + chain length)

- Runs/chains are important. Ho do we control cluster/chain length?

Load Factor

- Need to keep track of how full the table is
  - Why?
  - What happens when array fills completely?
- Load factor is a measure of how full the hash table is
  - LF = (# elements) / (table size)
- When LF reaches some threshold, double size of array (typically threshold = 0.6)
  - Challenges?

Doubling Array

- Cannot just copy values
  - Why?
  - Hash values may change
  - Example: suppose (`key.hashCode() == 11`)
    - 11 % 7 = 4;
    - 11 % 13 = 11;
- Result: must recompute all hash codes, reinsert into new array

Good Hashing Functions

- Important point:
  - All of this hinges on using "good" hash functions that spread keys "evenly"
- Good hash functions:
  - Are fast to compute
  - Distribute keys uniformly
- We almost always have to test "goodness" empirically

Example Hash Functions

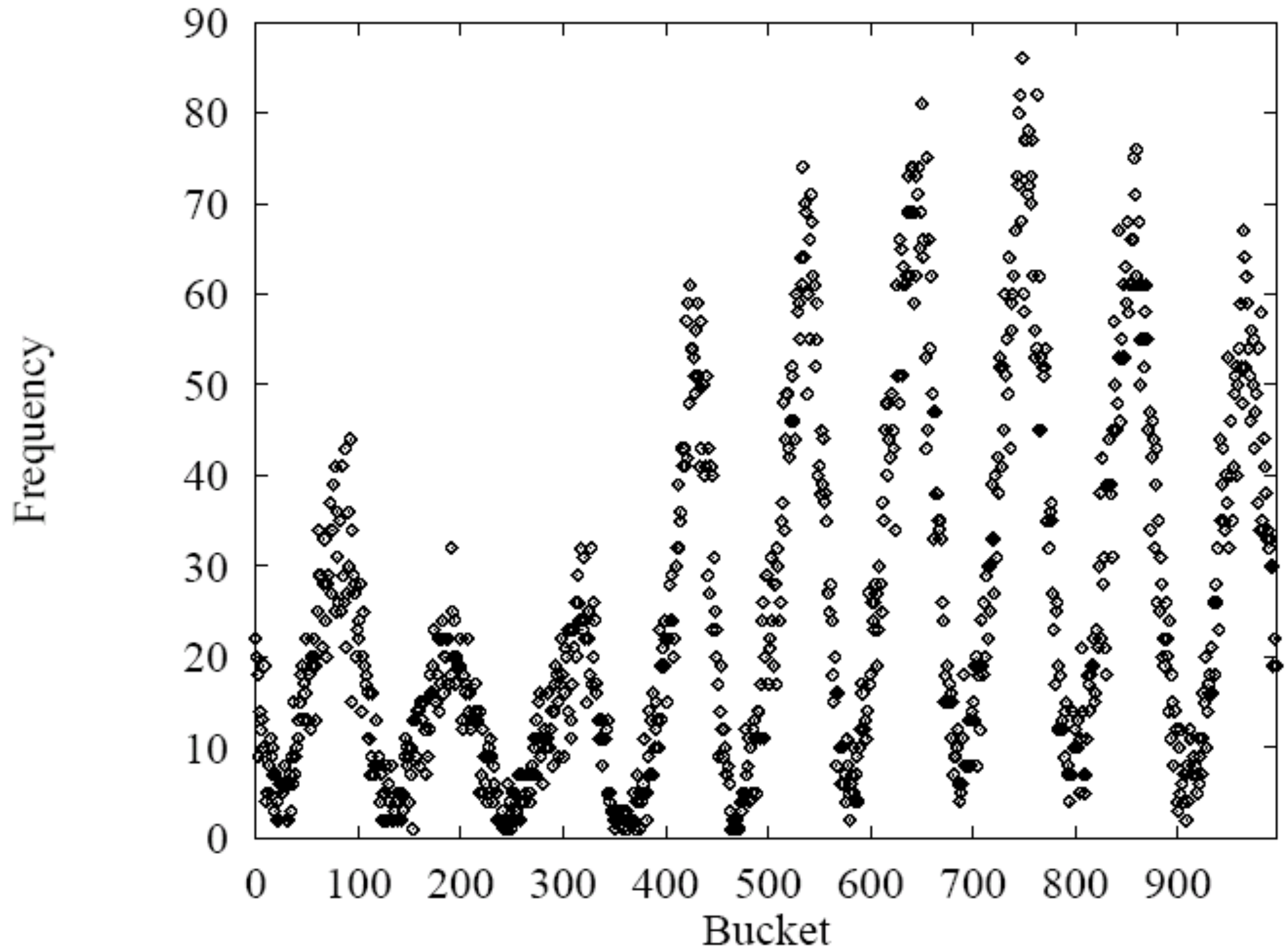
- What are some feasible hash functions for Strings?
  - First char ASCII value mapping
    - 0-255 only
    - Not uniform (some letters more popular than others)
  - Sum of ASCII characters
    - Not uniform - lots of small words
    - smile, limes, miles, slime are all the same

Example Hash Functions

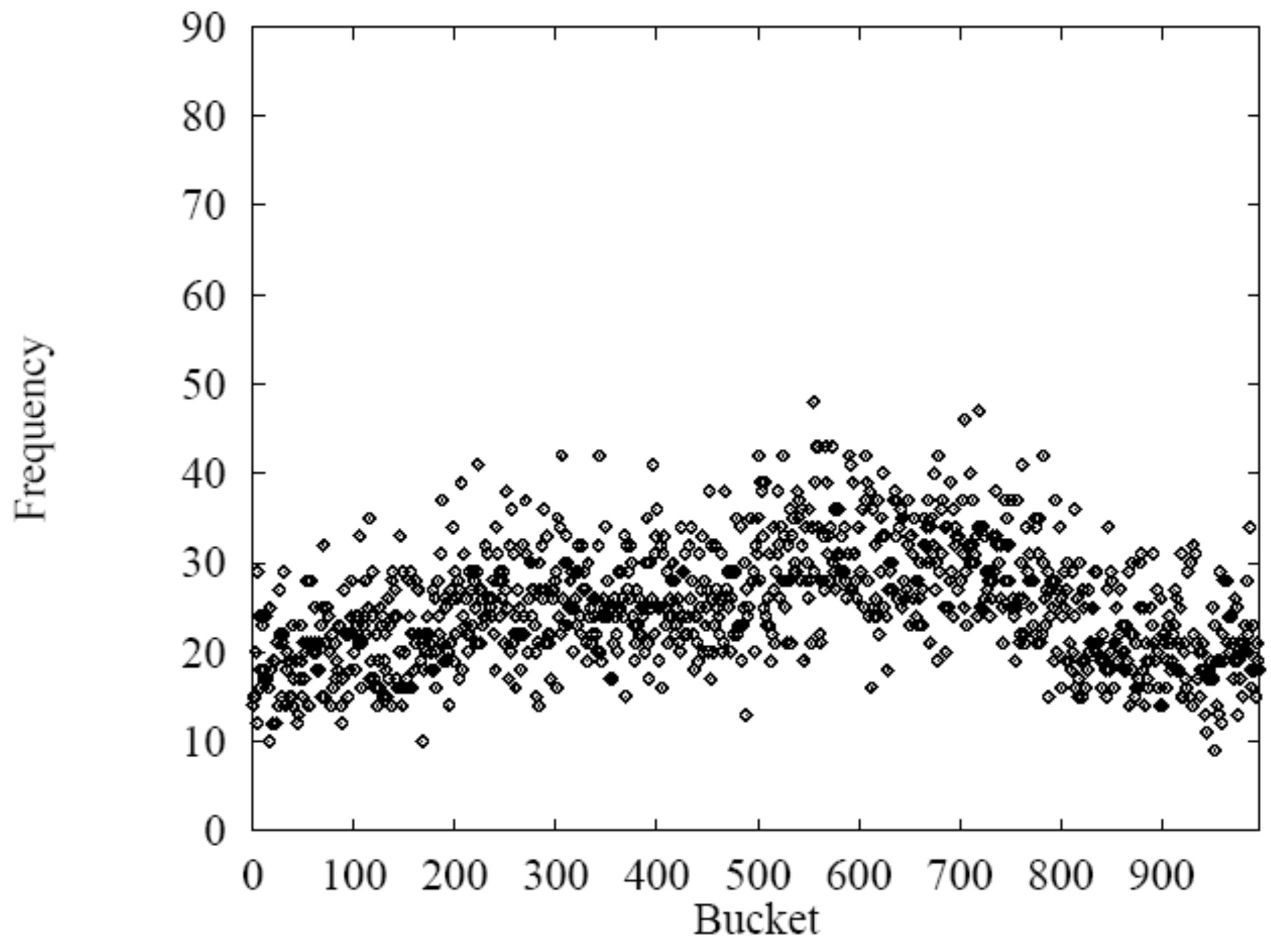
- String hash functions commonly use weighted sums
  - Character values weighted by position in string
    - Long words get bigger codes
    - Distributes keys better than non-weighted sum
  - Let's look at different weights…

$$\sum_{i=0}^{n=s.length()} s.charAt(i)$$

Hash of all words in UNIX spelling dictionary (997 buckets)

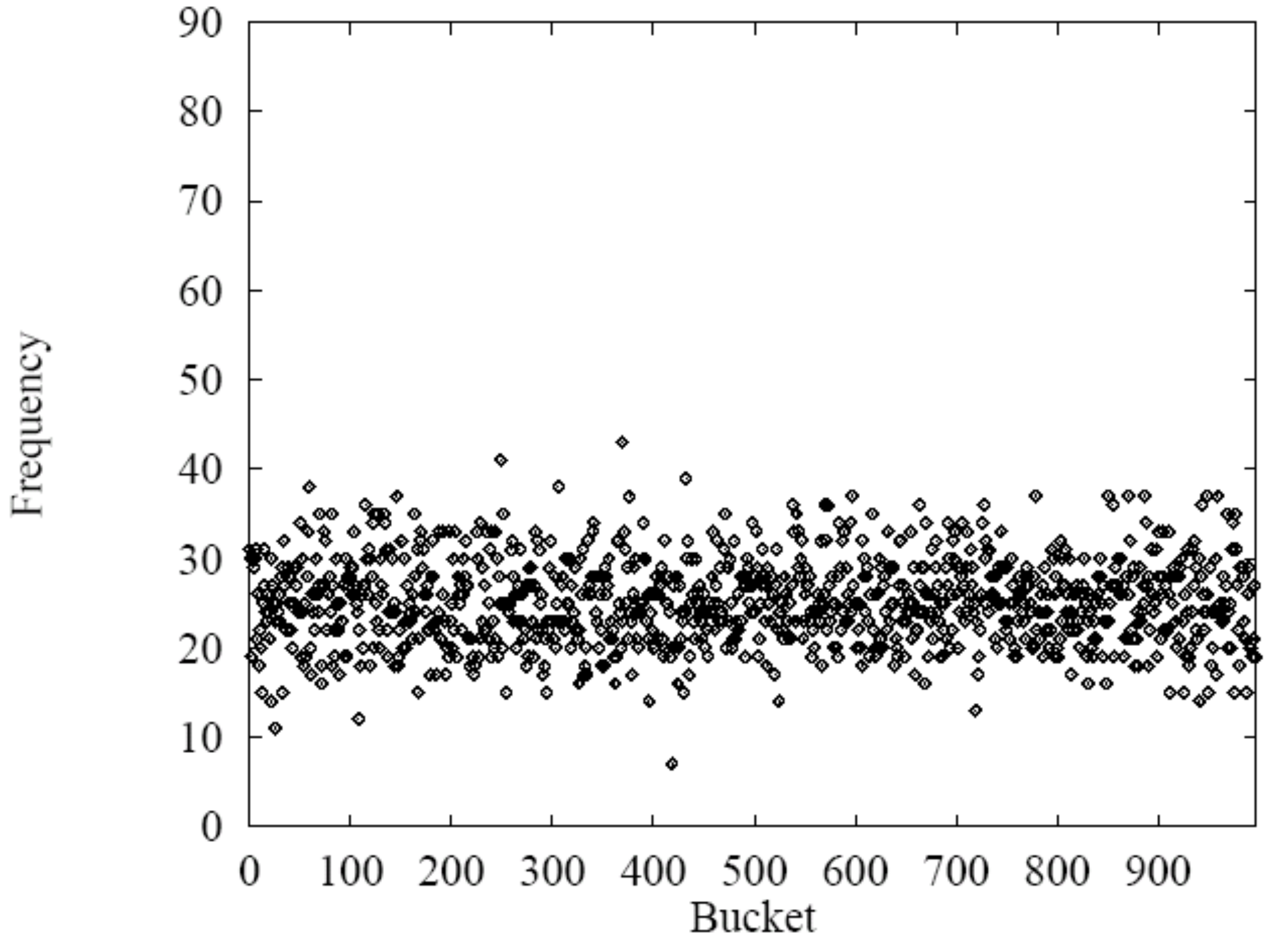


$$\sum_{i=0}^{n} s.charAt(i) * 2^{i}$$



$$\sum_{i=0}^{n} s.charAt(i) * 256^{i}$$

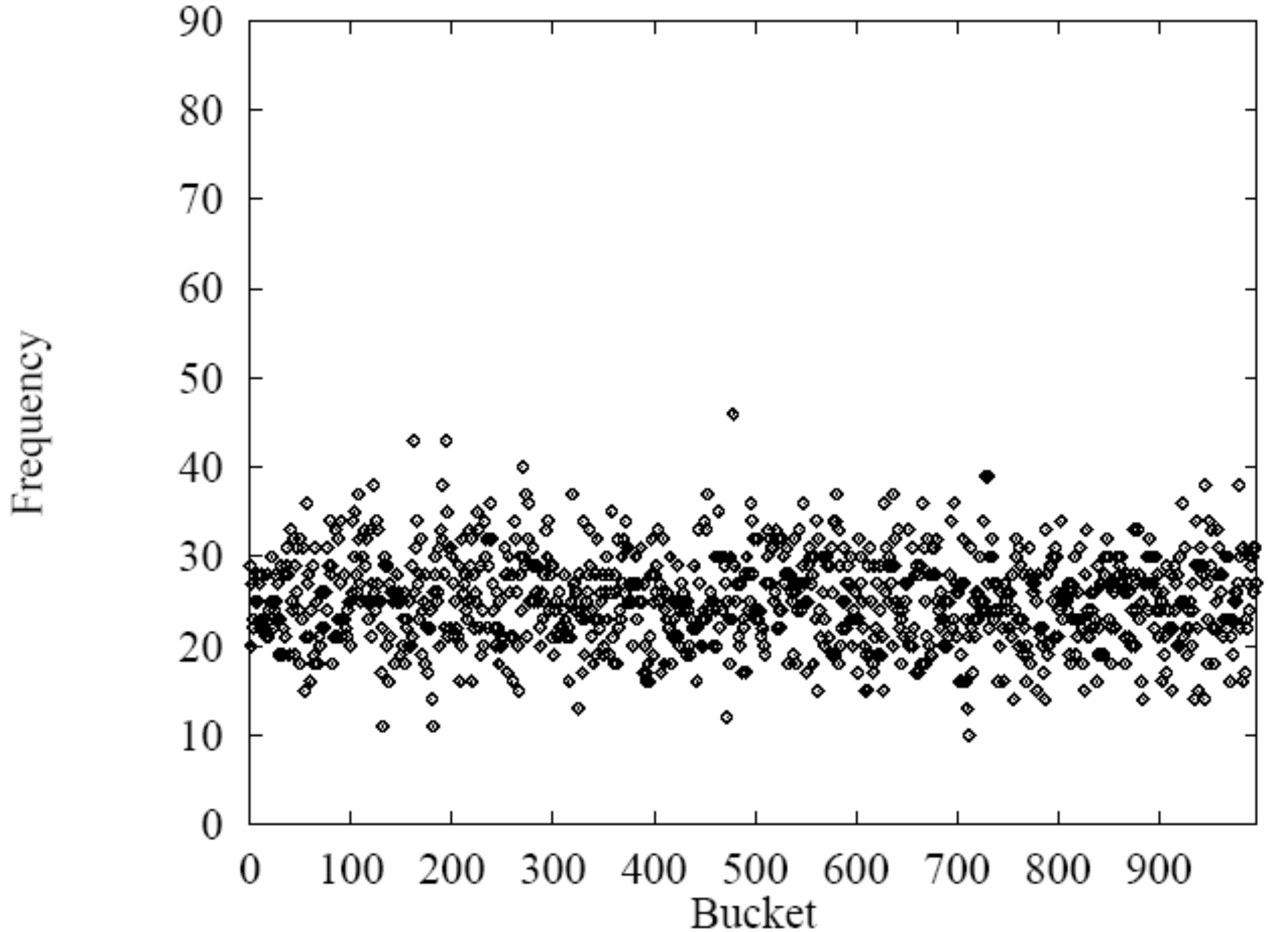
This looks pretty good, but 256^i is big…



$$\sum_{i=0}^{n} s.charAt(i) * 31^{i}$$

Java uses:

$$\sum_{i=0}^{n} s.charAt(i) * 31^{(n-i-1)}$$



Hashtables: O(1) operations?

- How long does it take to compute a String's hashCode?
  - O(s.length())
- Given an object's hash code, how long does it take to find that object?
  - O(run length) or O(chain length) PLUS cost of .equals() method
- Conclusion: for a good hash function (fast, uniformly distributed) and a low load factor (short runs/chains), we *say* hashtables are O(1)

Summary

	put	get	space
unsorted vector	O(n)	O(n)	O(n)
unsorted list	O(n)	O(n)	O(n)
sorted vector	O(n)	O(log n)	O(n)
balanced BST	O(log n)	O(log n)	O(n)
array indexed by key	O(1)	O(1)	O(key range)