CSC 212: Data Structures and Abstractions

Hash Tables (part 2)

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Resizing a hash table

- Growing to a larger array when α exceeds a threshold
  - ✓ create a new table with larger capacity and rehash all the keys

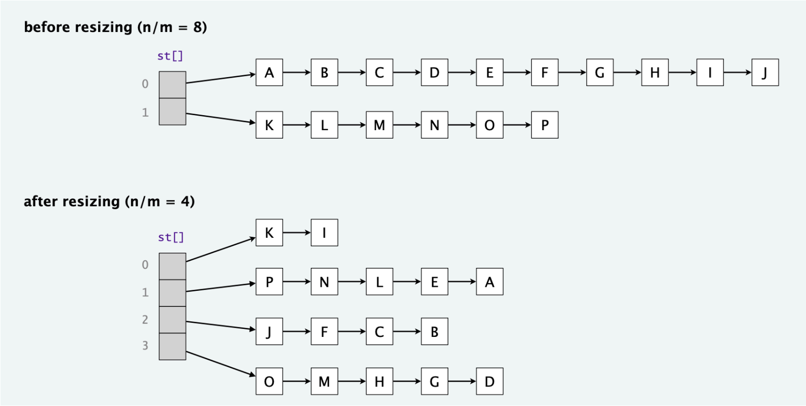

Image credit: COS 226 @ Princeton

Practice

- Insert the following keys into a hash of size M=4
  - 4, 2, 1, 10, 21, 32, 43, 3, 51, 71
- Resize the table to M=11

Open addressing

Open addressing

- Collision resolution mechanism
  - searching for next available slot (*probing*)
  - single-element per slot constraint, however requires careful deletion handling
  - assume duplicated keys are not allowed and $M \geq N$
- Core operations (assume a hash function h)
  - **insert**: if $h(key)$ is empty, place the new key (or key/value pair) there, otherwise, probe the table using a predetermined sequence until a slot is found
  - **search**: if $h(key)$ contains the key then return successfully, if not, probe the table using a predetermined sequence until either finding the key or an empty slot, which indicates that the key is not present in the table
  - **delete**: upon finding the key, **cannot mark the slot as empty**, as this would disrupt future search operations by prematurely terminating probe sequences, instead, mark the slot as deleted
- Comments
  - approach is more space-efficient than chaining, but it can be slower (better with $\alpha \approx 0.5$)

Probing

- m: table size
- i: probe number ($i = 0,1,2,\ldots$)
- $h'(k)$: initial hash value of key k
- $h(k,i)$: position for the i-th probe
- $h_2(k)$: secondary hash function

- Linear probing
  - probes next available index sequentially
  - $h(k,i) = (h'(k) + i) \mod m$
- Quadratic probing
  - probes next available index using a quadratic function
  - $h(k,i) = (h'(k) + i^2) \mod m$
- Double hashing
  - probes next available index using a secondary hash function h_2 (should not evaluate to 0)
  - $h(k,i) = (h'(k) + i \cdot h_2(k)) \mod m$

Practice

- Insert the following keys into a hash of size M=13
  - 4, 2, 1, 10, 21, 32, 43, 3, 51, 71, 17
  - use linear probing
  - use quadratic probing
  - use double hashing with $h_2(k) = 1 + (k \mod 10)$

Image credit: CS106B @ Stanford

Data Structure	Worst-case			Average-case			Ordered?
	insert at	**delete**	**search**	**insert at**	**delete**	**search**	
sequential (unordered)	O(n)	O(n)	O(n)	O(n)	O(n)	O(n)	No
sequential (ordered) binary search	O(n)	O(n)	O(log n)	O(n)	O(n)	O(log n)	Yes
BST	O(n)	O(n)	O(n)	O(log n)	O(log n)	O(log n)	Yes
2-3-4	O(log n)	O(log n)	O(log n)	O(log n)	O(log n)	O(log n)	Yes
Red-Black	O(log n)	O(log n)	O(log n)	O(log n)	O(log n)	O(log n)	Yes
Hash table (separate chaining)	O(n)	O(n)	O(n)	O(1)*	O(1)*	O(1)*	No
Hash table (open addressing)	O(n)	O(n)	O(n)	O(1)*	O(1)*	O(1)*	No

(*) assumes uniform hashing and appropriate load factor

Unordered associative containers (STL)

Unordered associative containers implement data structures that can be quickly searched – $O(1)$ average-case complexity

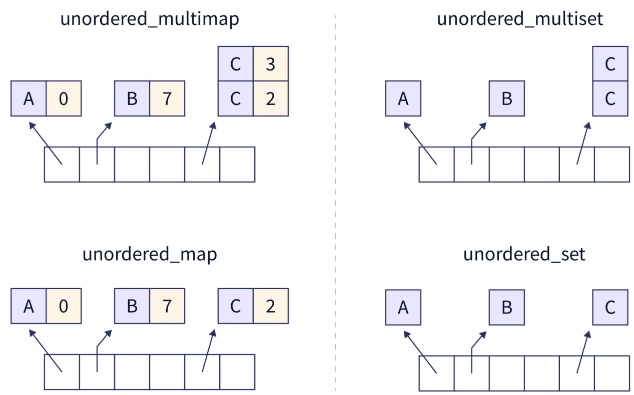

Image credit: https://www.scaler.com/topics/cpp/containers-in-cpp/