CSE 373: Hash Tables
(applications & collisions)

Chapter 5

Hash Table Sets: Use

Hash tables can be used to store sets

e.g., the set of all departments represented in CSE 373

```
typedef enum {ACMS, ECON, EE, MATH, …} dept;
HashTable<dept> D;
```

Approach: Just store the departments themselves in the hash table:

- to add a new department, `insert()` it
- to see if a department is represented, `find()` it

Hash Table Sets: Implementation

Data Structure:

```
template <class HashedObj>
class HashTable {
  private:
    int tablesize;
    HashedObj* data;
};
```

Sample Operation:

`HashTable::insert(HashedObj& key)`

- hash **key** to get an index, I
- check whether data[I] is empty (or already storing **key**)
- if so, set data[I] = **key**
- otherwise deal with the conflict

Hashing Records

Goal: store the CSE 373 class list as a Hash Table

```
class student {
  name first, last;
  int UWID;
  name email;
  dept major;
  int year;
};
```

Implementation:

Use a hash table of students rather than departments:

```
HashTable<student> studentSet;
```

Hashing Records: Design Decisions

Design Decisions:

What to hash on?

- last name?
- first name?
- student ID?
- email?
- some combination thereof?

How to look someone up?

- supply entire record?
- supply just a single field?

Food For Thought

Question: How to implement a simple database?

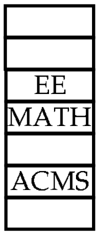
Goals:

- store records as in class list example
- be able to search based on *any* field
- minimize space requirements

Load Factor

Load Factor: Density of hash table, λ

λ = # of stored elements / table size



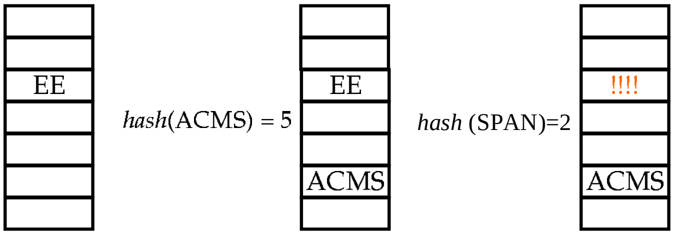
$\lambda = 3/7$

Ideally, we'd like $\lambda \approx 1.0$

Dealing with Collisions

What can we do when two keys hash to the same slot?

`D.insert(EE)` **`D.insert(ACMS)`** **`D.insert(SPAN)`**



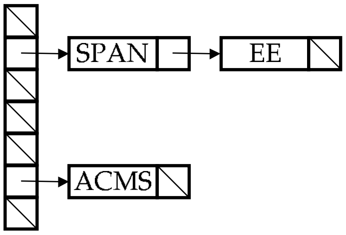
hash(EE) = 2

hash(ACMS) = 5

hash (SPAN)=2

Solution: Separate Chaining

Idea: At each position, store a list of the keys that hash to that position



Separate Chaining: Implementation

```
template <class HashedObj>
class HashTable {
  private:
    int tablesize;
    List<HashedObj>* datalist;
};
```

`HashTable::insert(HashedObj& key)`

- hash key (`i = hash(key)`)
- see if key is already in list (`datalist[i].find(key)`)
- if not, insert into the list (`datalist[i].insert(key)`)

(Note that we could replace lists with BSTs, hash tables)

Solution 2: Rehashing

Grow the size of the hash table as it gets full

But when?

- whenever there is a collision?
- whenever λ reaches 1.0?
- whenever λ reaches k?
- whenever n% of the slots are in use?

Can we simply resize the data array and copy values over as we did with lists and stacks?

Running Time of Rehashing

Assume that we'll rehash whenever $\lambda = 1.0$…

- starting with an array of size 11
- approximately doubling the size of the array
  (use the next prime larger than $2 \times$ tablesize)
- what is the total running time of inserting n keys?

Solution 3: Open Addressing

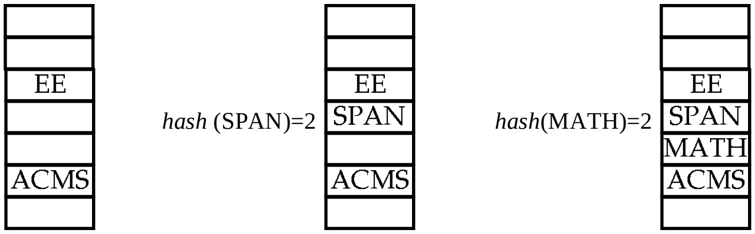
Goal: Use available space in table to store collisions rather than lists or resizing

- linear probing
- quadratic probing
- double hashing

Linear Probing

If there's a collision, insert data in next blank slot:

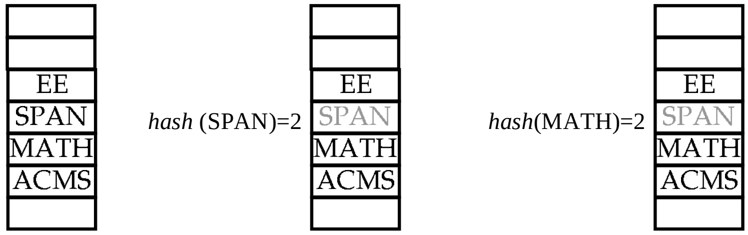
`D.insert(SPAN)` `D.insert(MATH)`



Note that if there is an open slot in the table, linear probing will always find it (eventually)

Finding, Deleting w/ Linear Probing

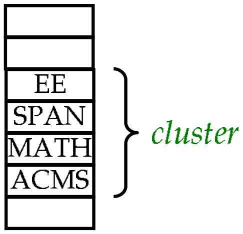
`D.find(SPAN)` `D.remove(SPAN)` `D.find(MATH)`



Primary Clustering

Linear probing has the tendency to result in clusters of data in the table

- increases search time for values hashing to that area



Open Addressing Requirements

- The selection of alternate slots must be recomputable and deterministic
  - so that we can `find()` data that we've inserted
- Deletion from the table must be "lazy"
  - similar to binary search trees
  - don't remove data, simply mark it as being deleted

Open Addressing: General Form

Open addressing is generally expressed as:

(hash(**key**) + $f(i)$) mod **tablesize**, for $i = 0, 1, 2, \ldots$

The hashing procedure is therefore:

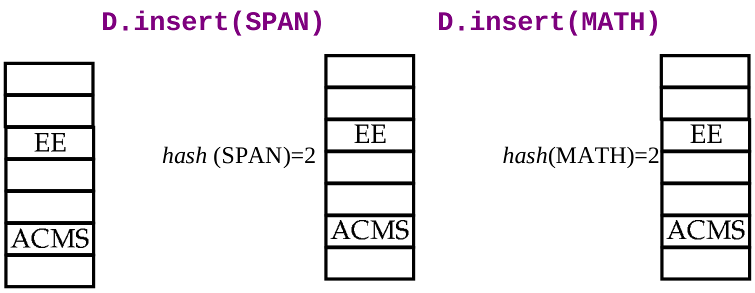
1) Try (hash(**key**) + $f(0)$) mod **tablesize**
2) If it's full, try (hash(**key**) + $f(1)$) mod **tablesize**
3) Continue until you find an empty slot

Design decision: what to use for $f()$?

- Linear probing uses $f(i) = i$

Quadratic Probing

Uses $f(i) = i^2$



Quadratic Probing: Evaluation

- *Intuition:* spreads things out more, so primary clustering should not be as much of a problem
- It can be proven that quadratic probing is guaranteed to find a free slot if…
  - – number of slots is prime
  - – table is less than half full
  - – (therefore, resize when $\lambda = 0.5$)

Double Hashing

$f(i) = i \cdot \text{hash}_2(\mathbf{key})$

Intuition: since good hash functions result in fairly random distributions, this spreads values out in a less predictable pattern

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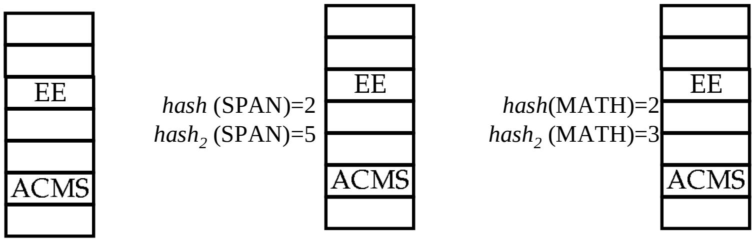
Quadratic Probing

Uses $f(i) = i^2$

`D.insert(SPAN)` `D.insert(MATH)`



hash (SPAN)=2
$hash_2$ (SPAN)=5

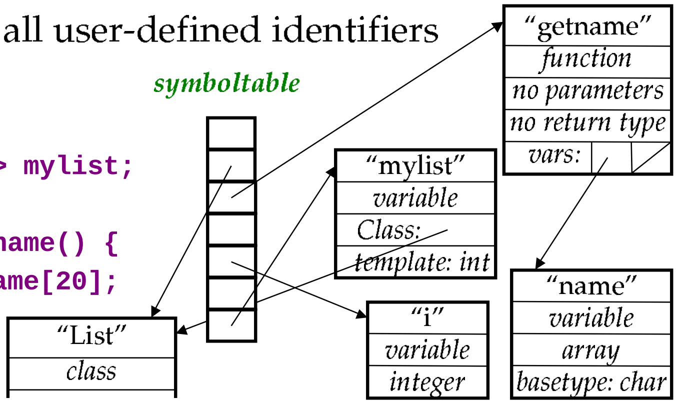
hash(MATH)=2
$hash_2$ (MATH)=3

Applications: Compilers

Compilers use hash tables to store information about all user-defined identifiers

```
int i;
List<int> mylist;

void getname() {
  char name[20];
  …
}
```



Applications: AI

- Create a hash function for a game's "position"
- Store "good moves" from each position as they are discovered
- While playing, can quickly check if there is a known good move from the current position