CMPT 280

Tutorial: Hash Tables

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Collision Resolution using Open Addressing

- Hash array size: N
- Hash function: $h(k)$
- Probe increment: $p(j)$
- Location of j-th alternative array offset: $(h(k) + p(j)) \bmod N$

Collision Resolution using Open Addressing
Linear Probing

- Hash function: item value mod 10
- j-th probe increment: $p(j) = j$
- What does the hash array look like after insertion of 59, 42, 92, 102, 29, 39, 62.

0	1	2	3	4	5	6	7	8	9

Solution

Insert 59:

0	1	2	3	4	5	6	7	8	9
									59

Insert 42:

0	1	2	3	4	5	6	7	8	9
		42							59

Insert 92:

0	1	2	3	4	5	6	7	8	9
		42	92						59

Insert 102:

0	1	2	3	4	5	6	7	8	9
		42	92	102					59

Insert 29:

0	1	2	3	4	5	6	7	8	9
29		42	92	102					59

Insert 39:

0	1	2	3	4	5	6	7	8	9
29	39	42	92	102					59

Insert 62:

0	1	2	3	4	5	6	7	8	9
29	39	42	92	102	62				59

Collision Resolution using Open Addressing

Quadratic Probing

- Hash function: item value mod 10
- j-th probe increment: $p(j) = (-1)^{i-1}\left(\frac{i+1}{2}\right)^2$
- What does the hash array look like after insertion of 59, 42, 92, 102, 29, 39, 62.

0	1	2	3	4	5	6	7	8	9

Solution

	0	1	2	3	4	5	6	7	8	9
Insert 59:										59
Insert 42:			42							59
Insert 92:			42	92						59
Insert 102:		102	42	92						59
Insert 29:	29		42	92	102					59
Insert 39:	29		42	92	102				39	59
Insert 62:	29		42	92	102		62		39	59

Collision Resolution using Open Addressing
Double Hashing

- Hash function: item value mod 10
- j-th probe increment: $p(j) = (k \bmod 7 + 1)j$
- What does the hash array look like after insertion of 59, 42, 92, 102, 29, 39, 62.

0	1	2	3	4	5	6	7	8	9

Solution

Insert 59:

0	1	2	3	4	5	6	7	8	9
									59

Insert 42:

0	1	2	3	4	5	6	7	8	9
		42							59

Insert 92:

0	1	2	3	4	5	6	7	8	9
		42		92					59

Insert 102:

0	1	2	3	4	5	6	7	8	9
		42		92			102		59

Insert 29:

0	1	2	3	4	5	6	7	8	9
	29	42		92			102		59

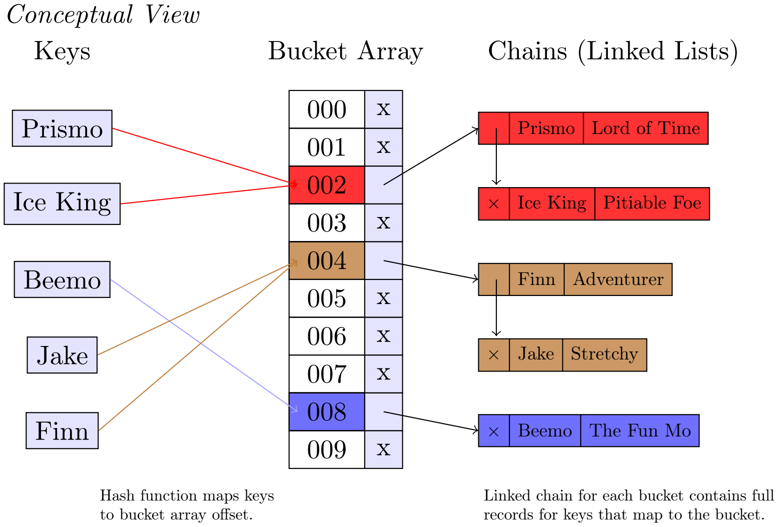
Insert 39: - Can't do it! Alternate location increments are $(39 \bmod 7+1) * j = 5, 10, 15, \ldots$. Since $h(39) = 9$, and it is occupied, the first alternative location will be $9 + 5 \bmod 10 = 4$. Which is occupied. The next alternate location is $9 + 10 \bmod 10 = 9$, which is occupied. The next alternative location is $9 + 15 \bmod 10 = 4$, which is still occupied, and so on. So offsets 4 and 9 are tried repeatedly, and the insertion cannot take place. Why did this happen?!? How can we avoid it? It happened because the hash table size of 10 was evenly divisible by the probe increment for key 39, which was 5. We can avoid it by making the hash table length N a prime number. Try repeating this exercise with $N = 11$.

Collision Resolution using Open Addressing

- More examples of linear and quadratic probing and double hashing on chalkboard as needed...

Chained Hash Tables

Conceptual View



Chained Hash Tables in `lib280`

In Assignment 4 you will use `lib280`'s `KeyedChainedHashTable280` class.

```java
public class KeyedChainedHashTable280<K extends Comparable<? super K>,
     I extends Keyed280<K> >
     extends HashTable280<I>
     implements KeyedDict280<K, I>
```

- Two type paramters: `K` and `I`.
- Extends abstract class `HashTable280`.
- Implements `KeyedDict280<K,I>`.

Keyed Dictionaries

- Recall: Dictionaries allow adding, querying, and deleting of elements.
- `OrderedSimpleTree280`, is a dictionary, but not a keyed dictionary. If you want to to query or delete from a non-keyed dictionary, you need to already have the entire item that you are querying or deleting.
- A keyed dictionary is one in which every item has a unique key, and items can be looked up in the dictionary using **only** their key to obtain the entire item with that key.

`KeyedChainedHashTable280` is a keyed dictionary.

- Since `KeyedChainedHashTable280` is a keyed dictionary (it implements the `KeyedDict280` interface) supports operations like:
  - `obtain(k)` - get the entire item that has key `k`.
  - `delete(k)` - delete the item with key `k` from the hash table.
- But it also still supports the non-keyed dictionary operations like:
  - `obtain(i)` - get the item that matches item `i`
  - `delete(i)` - delete the item that matches item `i`
  - `insert(i)` - insert the item `i`

  (this is because it inherits `Dict280` via `HashTable280` – `HashTable280` enforces a requirement that all hash tables be at least non-keyed dictionaries).

Type parameters for `KeyedChainedHashTable280<K,I>`

```java
public class KeyedChainedHashTable280<K extends Comparable<? super K>,
     I extends Keyed280<K> >
     extends HashTable280<I>
     implements KeyedDict280<K, I>
```

- The type parameter `K` is the type of the keys of the items to be stored.
- Since instances of type `K` must be comparable other instances of type `K`, it is required that type `K` be one that implements the `Comparable` interface.

Type parameters for `KeyedChainedHashTable280<K,I>`

```java
public class KeyedChainedHashTable280<K extends Comparable<? super K>,
     I extends Keyed280<K> >
     extends HashTable280<I>
     implements KeyedDict280<K, I>
```

- The type parameter `I` is the type of the items that may be stored in the hash table.
- Note that `I` must extend `Keyed280<K>`. This forces the type `I` to implement a method called `key()` which returns the item's key, which must be of type `K`.
- In summary: the hash table stores items of type `I` whose keys are of type `K`.

Internal Data Structure for `KeyedChainedHashTable280<K,I>`

```java
// Array to store linked lists for separate chaining.
protected LinkedList280<I>[] hashArray;
```

- The hash table implementation is an array of linked lists (the array of buckets on slide 3) containing items of type `I`.
- A function called `hashPos`, defined in `HashTable280` is used to take an item and map it to one of the offsets of the linked-list array.
- The `hashPos` function calls the `hashCode` method of the given item (which, if not overridden, is found in `Object`) and converts the integer result to a number between 0 and `hashArray.length-1` using the modulus operator.

Other features of `KeyedChainedHashTable280<K,I>`

- The internal array starts at a default length, and increases in size if the hash tables *load factor* gets too large. This is why you do not have to specify an array size in the hash table's constructor.
- The load factor is the number of items in the hash table divided by the length of the array.
- The hash table also has an internal cursor that can be used to iterate over all of the items in the table. It supports the usual cursor methods like `goFirst()`, `itemExists()`, `goForth()`, etc.
- You can look at the code for `KeyedChainedHashTable280<K,I>` if you want to see how all of this works.