CSE 143
Lecture 25

Hashing

read 11.2

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Recall: ADTs (11.1)

- **abstract data type (ADT)**: A specification of a collection of data and the operations that can be performed on it.
  - Describes *what* a collection does, not *how* it does it.

- Java's collection framework describes ADTs with interfaces:
  - `Collection`, `Deque`, `List`, `Map`, `Queue`, `Set`, `SortedMap`

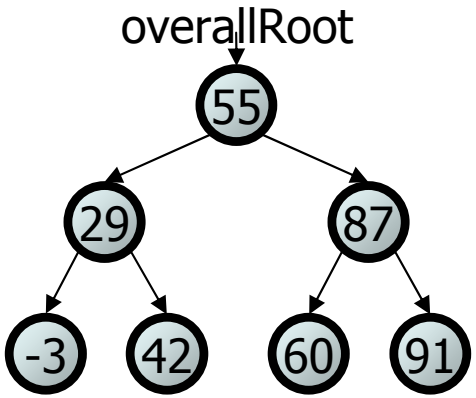
- An ADT can be implemented in multiple ways by classes:
  - `ArrayList` and `LinkedList` implement `List`
  - `HashSet` and `TreeSet` implement `Set`
  - `LinkedList` , `ArrayDeque`, etc. implement `Queue`

`SearchTree` as a set

- We implemented a class `SearchTree` to store a BST of `int`s:

- Our BST is essentially a set of integers.

  Operations we support:
  - `add`
  - `contains`
  - `remove`
  - …



- But there are other ways to implement a set…

How to implement a set?

- Elements of a `TreeSet` (`IntTree`) are in BST sorted order.
  - We need this in order to add or search in O(log *N*) time.

- But it doesn't really matter what order the elements appear in a set, so long as they can be added and searched quickly.

- Consider the task of storing a set in an array.
  - What would make a good ordering for the elements?

index	0	1	2	3	4	5	6	7	8	9
value	7	11	24	49	0	0	0	0	0	0

index	0	1	2	3	4	5	6	7	8	9
value	0	11	0	0	24	0	0	7	0	49

Hashing

- **hash**: To map a value to an integer index.
  - **hash table**: An array that stores elements via hashing.

- **hash function**: An algorithm that maps values to indexes.
  - one possible hash function for integers:

$$HF(I) \rightarrow I \ \% \ length$$

```
set.add(11);      // 11 % 10 == 1
set.add(49);      // 49 % 10 == 9
set.add(24);      // 24 % 10 == 4
set.add(7);       //  7 % 10 == 7
```

index	0	1	2	3	4	5	6	7	8	9
value	0	11	0	0	24	0	0	7	0	49

Efficiency of hashing

```
public static int HF(int i) {       // hash function
    return Math.abs(i) % elementData.length;
}
```

- Add: simply set `elementData[HF(i)] = i;`
- Search: check if `elementData[HF(i)] == i`
- Remove: set `elementData[HF(i)] = 0;`

- What is the runtime of `add`, `contains`, and `remove`?
  - **O(1)!** OMGWTFBBQFAST

- Are there any problems with this approach?

Collisions

- **collision**: When a hash function maps two or more elements to the same index.

```
set.add(11);
set.add(49);
set.add(24);
set.add(7);
set.add(54);  // collides with 24!
```

- **collision resolution**: An algorithm for fixing collisions.

index	0	1	2	3	4	5	6	7	8	9
value	0	11	0	0	54	0	0	7	0	49

Probing

- **probing**: Resolving a collision by moving to another index.
  - **linear probing**: Moves to the next index.

```
set.add(11);
set.add(49);
set.add(24);
set.add(7);
set.add(54);  // collides with 24
```

index	0	1	2	3	4	5	6	7	8	9
value	0	11	0	0	24	**54**	0	7	0	49

  - Is this a good approach?

Clustering

- **clustering**: Clumps of elements at neighboring indexes.
  - slows down the hash table lookup; you must loop through them.

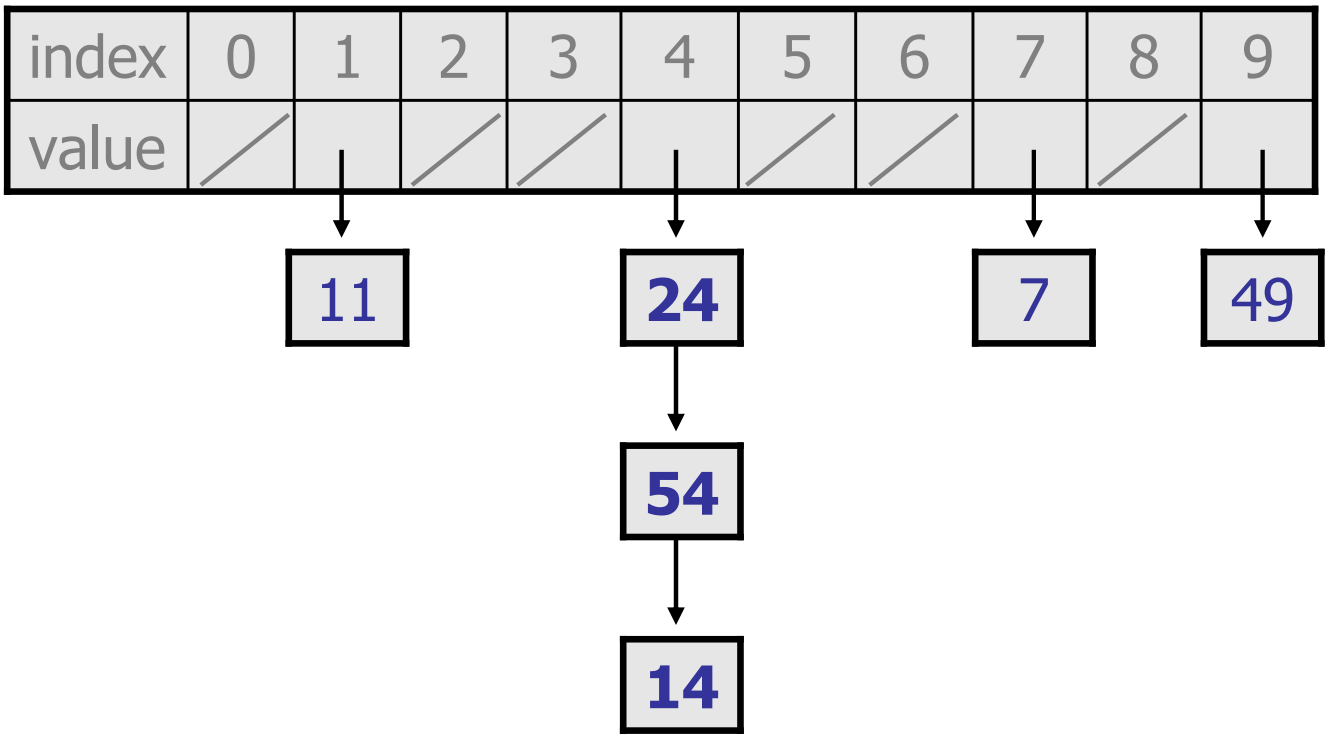
```
set.add(11);
set.add(49);
set.add(24);
set.add(7);
set.add(54);  // collides with 24
set.add(14);  // collides with 24, then 54
set.add(86);  // collides with 14, then 7
```

index	0	1	2	3	4	5	6	7	8	9
value	0	11	0	0	**24**	**54**	**14**	**7**	**86**	49

  - Now a lookup for 94 must look at 7 out of 10 total indexes.

Chaining

- **chaining**: Resolving collisions by storing a list at each index.
  - add/search/remove must traverse lists, but the lists are short
  - impossible to "run out" of indexes, unlike with probing



Hash set code

```
import java.util.*;   // for List, LinkedList

// All methods assume value != null;  does not rehash
public class HashIntSet {
    private static final int CAPACITY = 137;
    private List<Integer>[] elements;

    // constructs new empty set
    public HashSet() {
        elements = (List<Integer>[]) (new List[CAPACITY]);
    }

    // adds the given value to this hash set
    public void add(int value) {
        int index = HF(value);
        if (elements[index] == null) {
            elements[index] = new LinkedList<Integer>();
        }
        elements[index].add(value);
    }

    // hashing function to convert objects to indexes
    private int HF(int value) {
        return Math.abs(value) % elements.length;
    }
    ...
```

Final hash set code 2

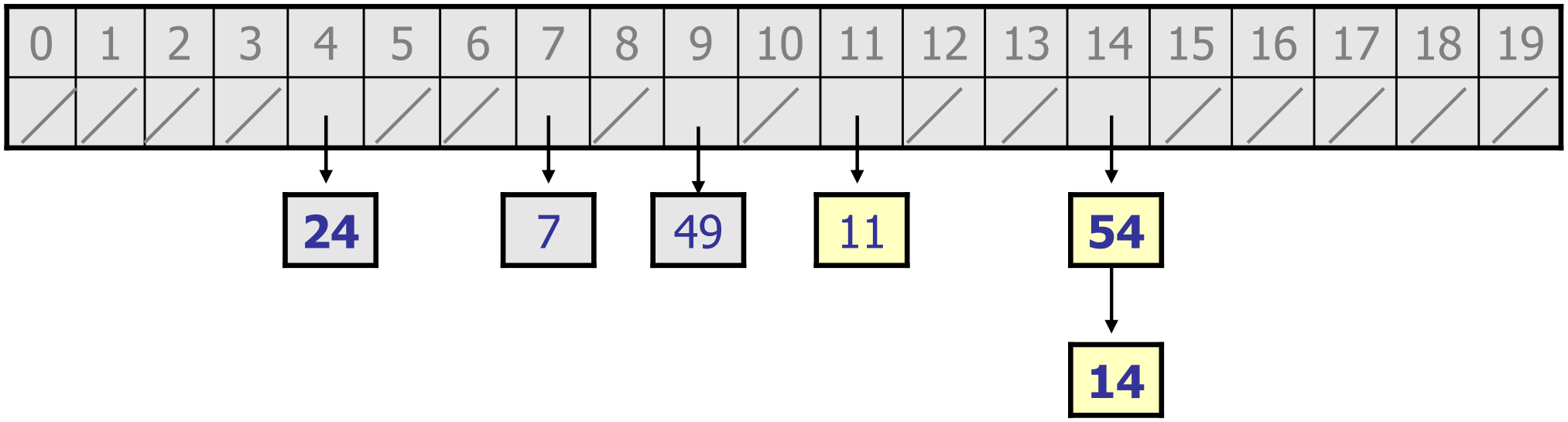
```
    ...
    // Returns true if this set contains the given value.
    public boolean contains(int value) {
        int index = HF(value);
        return elements[index] != null &&
               elements[index].contains(value);
    }

    // Removes the given value from the set, if it exists.
    public void remove(int value) {
        int index = HF(value);
        if (elements[index] != null) {
            elements[index].remove(value);
        }
    }
}
```

Rehashing

- **rehash**: Growing to a larger array when the table is too full.
  - Cannot simply copy the old array to a new one. (Why not?)

- **load factor**: ratio of (*# of elements*) / (*hash table length*)
  - many collections rehash when load factor ≅ .75
  - can use big prime numbers as hash table sizes to reduce collisions



Hashing objects

- It is easy to hash an integer I (use index *I % length*).
  - How can we hash other types of values (such as objects)?

- All Java objects contain the following method:

  ```
  public int hashCode()
  ```

  Returns an integer hash code for this object.

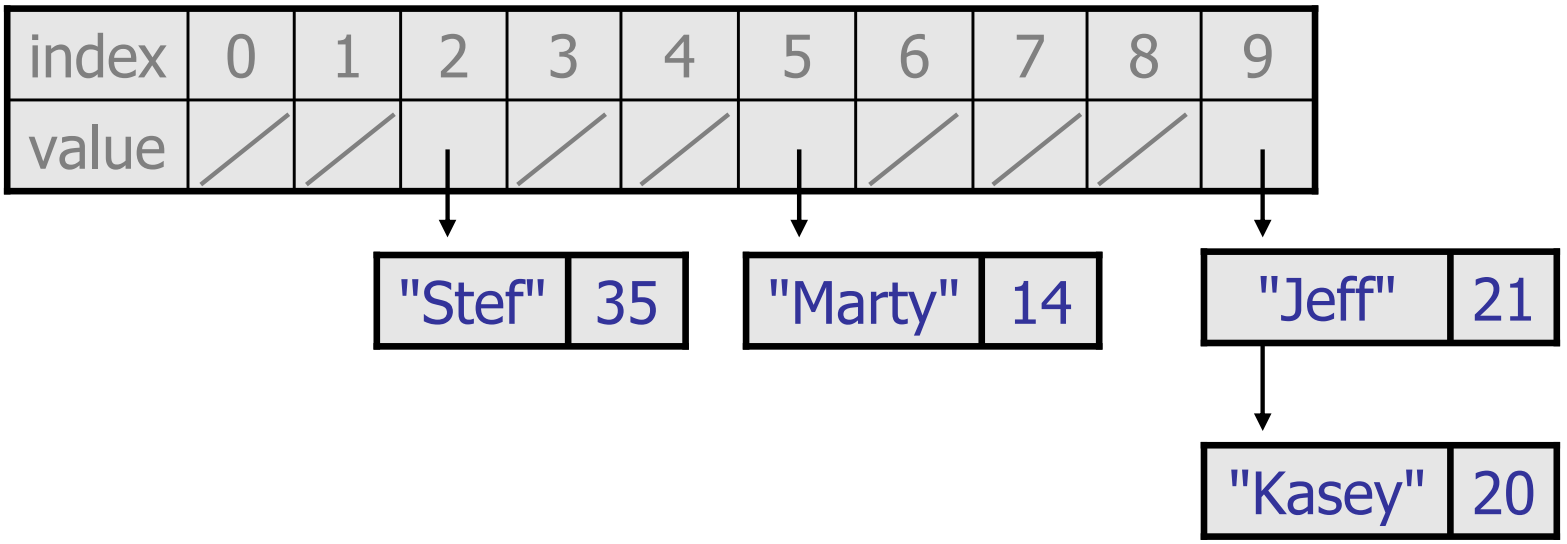
  - We can call `hashCode` on any object to find its preferred index.

- How is `hashCode` implemented?
  - Depends on the type of object and its state.
    - Example: a String's `hashCode` adds the ASCII values of its letters.
  - You can write your own `hashCode` methods in classes you write.

Implementing hash maps

- A hash map is just a set where the lists store key/value pairs:

```
//          key     value
map.put("Marty", 14);
map.put("Jeff",  21);
map.put("Kasey", 20);
map.put("Stef",  35);
```



  - Instead of a `List<Integer>`, write an inner `Entry` node class with `key` and `value` fields; the map stores a `List<Entry>`