CSE 373

Separate chaining; hash codes; hash maps

read: Weiss 5.1 - 5.2, 5.4, 5.5

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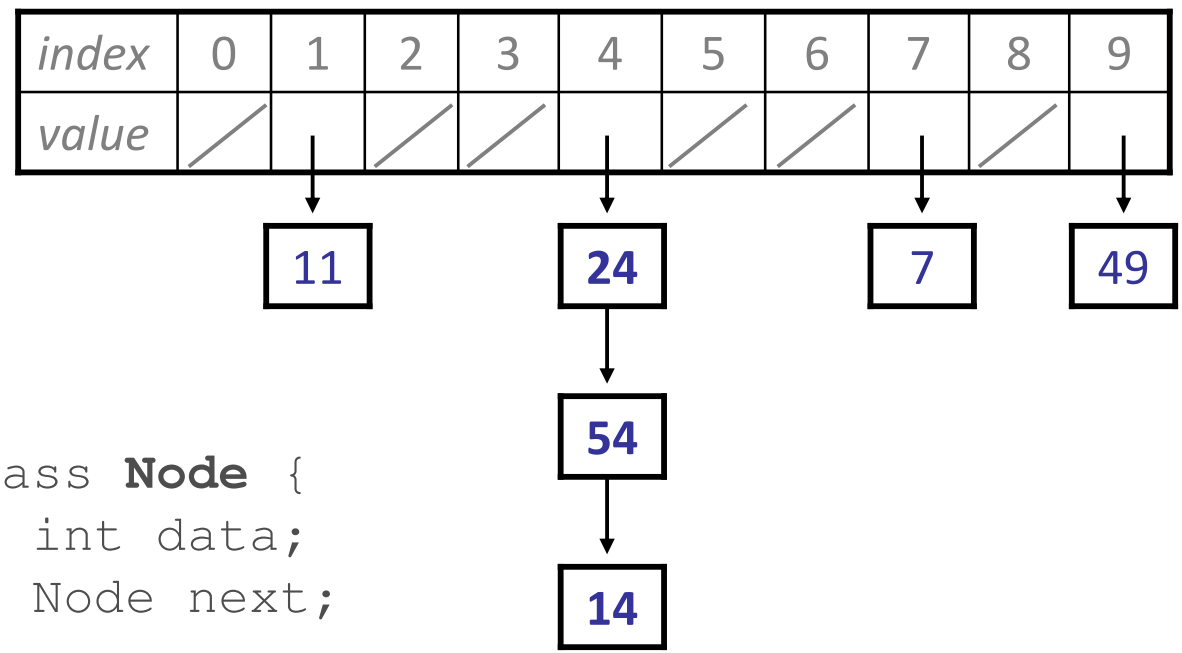
Separate chaining

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




```
private class Node {
    public int data;
    public Node next;
    ...
}
```

Implementing HashIntSet

- Let's implement a hash set of `int`s using separate chaining.

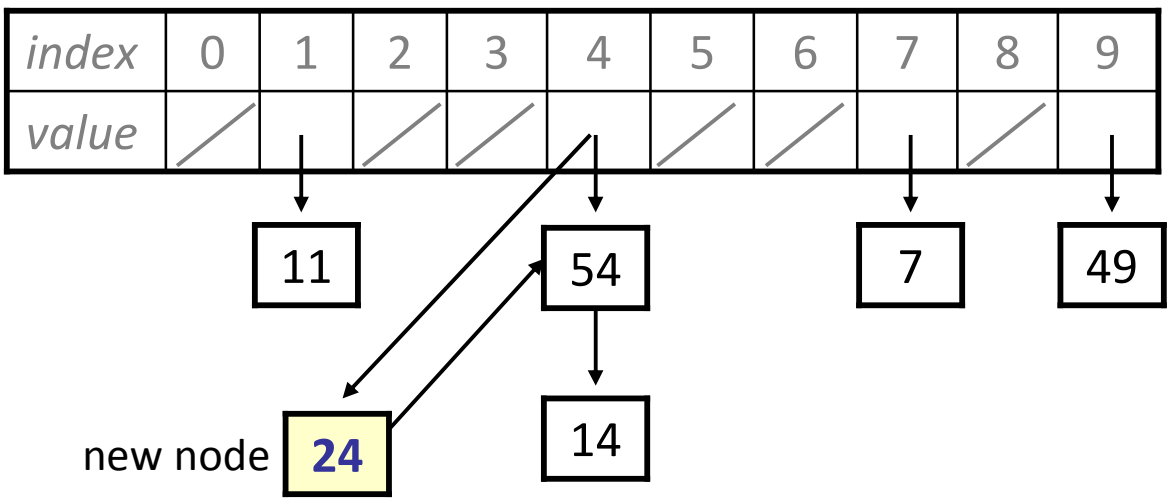
```
public class HashIntSet implements IntSet {
    // array of linked lists;
    // elements[i] = front of list #i (null if empty)
    private Node[] elements;
    private int size;

    // constructs new empty set
    public HashIntSet() {
        elements = new Node[10];
        size = 0;
    }

    // hash function maps values to indexes
    private int hash(int value) {
        return Math.abs(value) % elements.length;
    }
    ...
```

The add operation

- How do we add an element to the hash table?
  - When you want to modify a linked list, you must either change the list's front reference, or the `next` field of a node in the list.
  - Where in the list should we add the new element?
  - Must make sure to avoid duplicates.



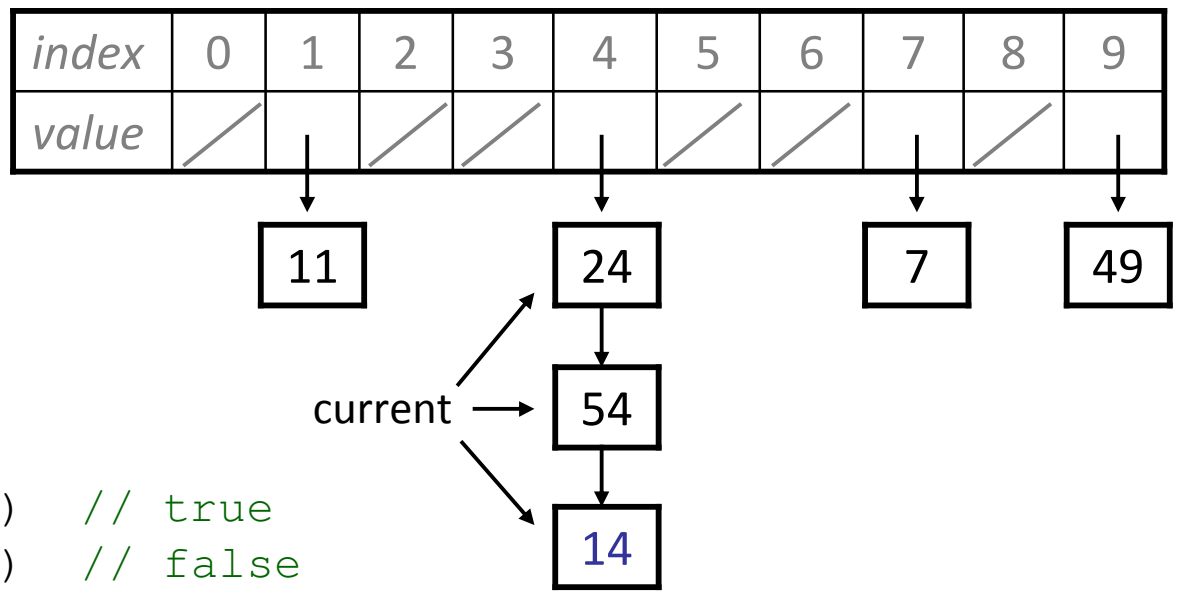
  - `set.add(24);`

Implementing add

```
public void add(int value) {
    if (!contains(value)) {
        int h = hash(value);              // add to front
        Node newNode = new Node(value);   // of list #h
        newNode.next = elements[h];
        elements[h] = newNode;
        size++;
    }
}
```

The contains operation

- How do we search for an element in the hash table?
  - Must loop through the linked list for the appropriate hash index, looking for the desired value.
  - Looping through a linked list requires a "current" node reference.




```
set.contains(14)   // true
set.contains(84)   // false
set.contains(53)   // false
```

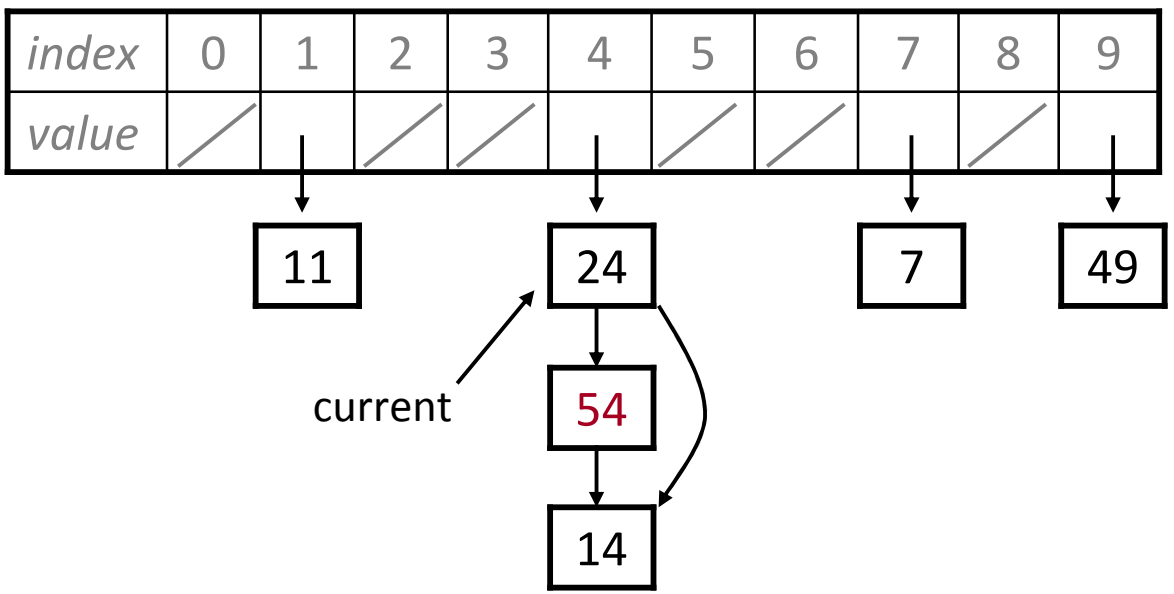
Implementing contains

```
public boolean contains(int value) {
    Node current = elements[hash(value)];
    while (current != null) {
        if (current.data == value) {
            return true;
        }
        current = current.next;
    }
    return false;
}
```

The remove operation

- How do we remove an element from the hash table?
  - Cases to consider: front (24), non-front (14), not found (94), null (32)
  - To remove a node from a linked list, you must either change the list's front reference, or the `next` field of the *previous* node in the list.

  - `set.remove(54);`

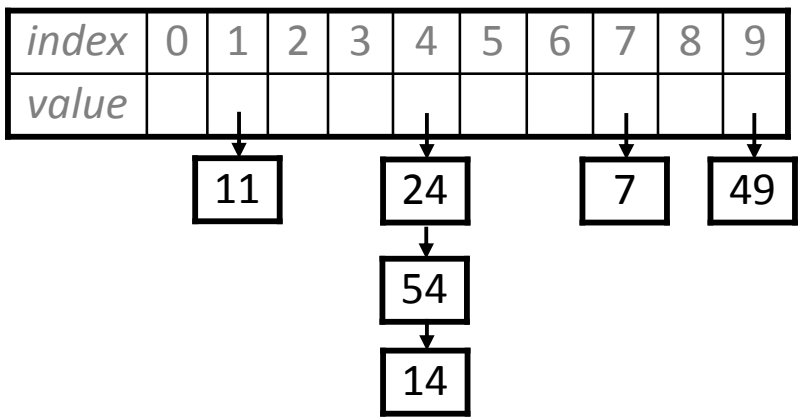


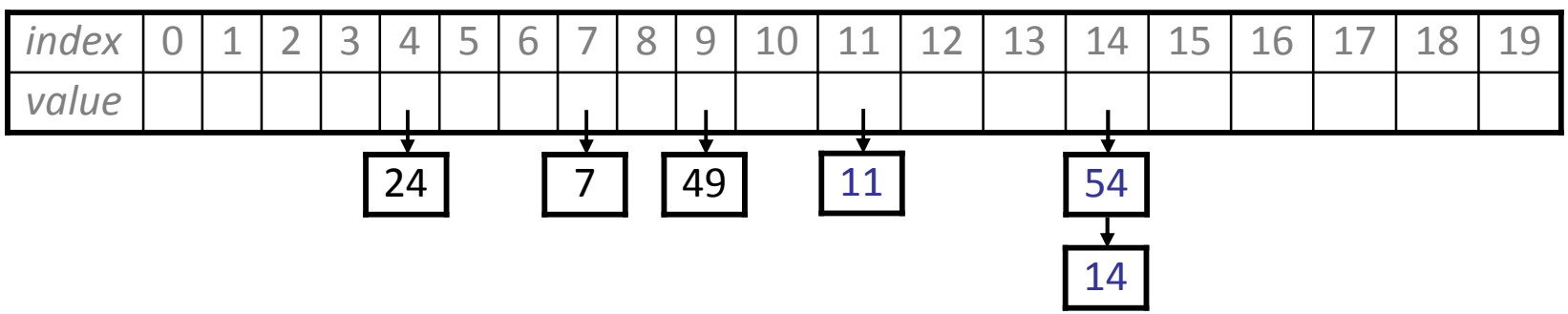
Implementing remove

```
public void remove(int value) {
    int h = hash(value);
    if (elements[h] != null && elements[h].data == value) {
        elements[h] = elements[h].next;  // front case
        size--;
    } else {
        Node current = elements[h];      // non-front case
        while (current != null && current.next != null) {
            if (current.next.data == value) {
                current.next = current.next.next;
                size--;
                return;
            }
            current = current.next;
        }
    }
}
```

Rehashing w/ chaining

- Separate chaining handles rehashing similarly to linear probing.
  - Loop over the list in each hash bucket; re-add each element.
  - An optimal implementation re-uses node objects, but this is optional.





Hash set of objects

```
public class HashSet<E> implements Set<E> {
    ...
    private class Node {
        public E data;
        public Node next;
    }
}
```

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

The hashCode method

- 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.
  - `HashSet`, `HashMap`, and the other built-in "hash" collections call `hashCode` internally on their elements to store the data.

- We can modify our set's hash function to be the following:

```
private int hash(E e) {
    return Math.abs(e.hashCode()) % elements.length;
}
```

Issues with generics

- You must make an unusual cast on your array of generic nodes:

```
public class HashSet<E> implements Set<E> {
    private Node[] elements;
    ...
    public HashSet() {
        elements = (Node[]) new HashSet.Node[10];
    }
```

- Perform all element comparisons using `equals`:

```
public boolean contains(int value) {
    ...
     // if (current.data == value) {
        if (current.data.equals(value)) {
            return true;
        }
        ...
```

Implementing hashCode

- You can write your own `hashCode` methods in classes you write.
  - All classes come with a default version based on memory address.
  - Your overridden version should somehow "add up" the object's state.
    - Often you scale/multiply parts of the result to distribute the results.

```
public class Point {
    private int x;
    private int y;
    ...
    public int hashCode() {
        // better than just returning (x + y);
        // spreads out numbers, fewer collisions
        return 137 * x + 23 * y;
    }
}
```

Good hashCode behavior

- A well-written `hashCode` method has:
  - *Consistently with itself* (must produce same results on each call):

    `o.hashCode() == o.hashCode()`, if **`o`**'s state doesn't change

  - *Consistently with equality*:

    `a.equals(b)` must imply that **`a.hashCode() == b.hashCode()`**,

    `!a.equals(b)` does NOT necessarily imply that

    `a.hashCode() != b.hashCode()` *(why not?)*

    - When your class has an `equals` or `hashCode`, it should have both.

  - *Good distribution of hash codes*:
    - For a large set of objects with distinct states, they will generally return unique hash codes rather than all colliding into the same hash bucket.

Example: String hashCode

- The `hashCode` function inside a `String` object looks like this:

```
public int hashCode() {
    int hash = 0;
    for (int i = 0; i < this.length(); i++) {
        hash = 31 * hash + this.charAt(i);
    }
    return hash;
}
```

$$h(s) = \sum_{i=0}^{n-1} s[i] \cdot 31^{n-1-i}$$

  - As with any general hashing function, collisions are possible.
    - Example: "Ea" and "FB" have the same hash value.
  - Early versions of the Java examined only the first 16 characters. For some common data this led to poor hash table performance.

hashCode tricks

- If one of your object's fields is an object, call its `hashCode`:

```
public int hashCode() {          // Student
    return 531 * firstName.hashCode() + ...;
```

- To incorporate a `double` or `boolean`, use the `hashCode` method from the `Double` or `Boolean` wrapper classes:

```
public int hashCode() {          // BankAccount
    return 37 * Double.valueOf(balance).hashCode() +
     Boolean.valueOf(isCheckingAccount).hashCode();
```

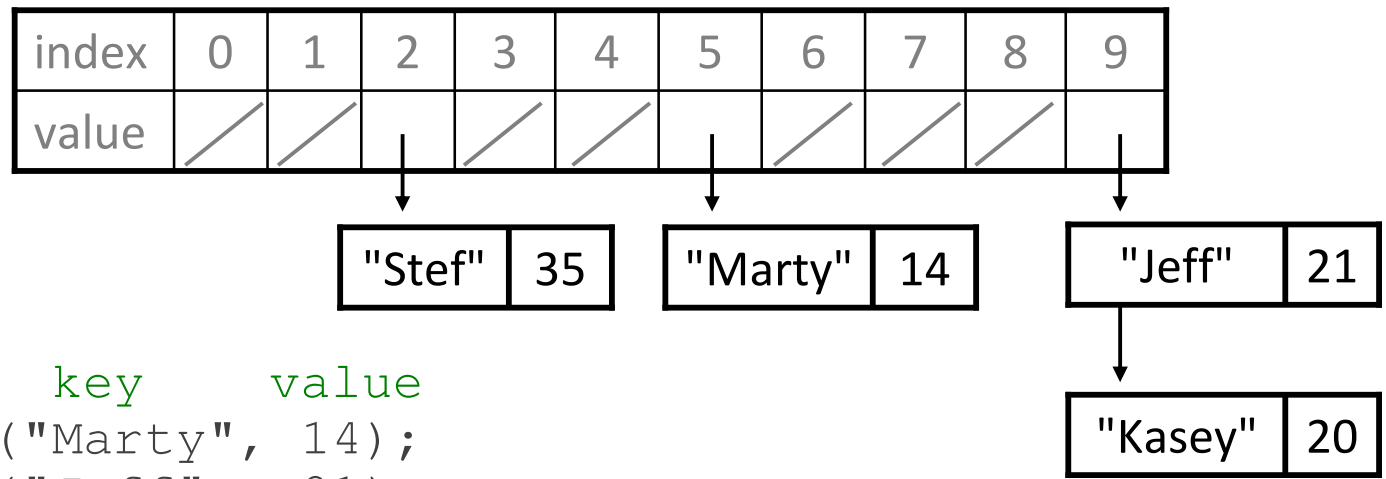
- Guava includes an `Objects.hashCode(...)` method that takes any number of values and combines them into one hash code.

```
public int hashCode() {          // BankAccount
    return Objects.hashCode(name, id, balance);
```

Implementing a hash map

- A hash map is like a set where the nodes store key/value pairs:

```
public class HashMap<K, V> implements Map<K, V> {
    ...
}
```




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

  - Must modify your Node class to store a key *and* a value

Map ADT interface

- Let's think about how to write our own implementation of a map.
  - As is (usually) done in the Java Collection Framework, we will define map as an ADT by creating a Map interface.
  - Core operations: put (add), get, contains key, remove

```
public interface Map<K, V> {
    void clear();
    boolean containsKey(K key);
    V get(K key);
    boolean isEmpty();
    void put(K key, V value);
    void remove(int value);
    int size();
}
```

Hash map vs. hash set

- The hashing is always done on the keys, *not* the values.
- The `contains` method is now `containsKey`; there and in `remove`, you search for a node whose key matches a given key.
- The `add` method is now `put`; if the given key is already there, you must replace its old value with the new one.
  - `map.put("Bill", 66);  // replace 49 with 66`