Efficiency

	add	remove	find
unsorted array	O(1)	O(n)	O(n)
sorted array	O(n)	O(n)	O(logN)
unsorted linked list	O(1)	O(n)	O(n)
sorted linked list	O(n)	O(n)	O(n)
binary search tree	O(logN)	O(logN)	O(logN)
hash table	O(1)	O(1)	O(1)

Hash Functions

- Maps a key to a number
  - result should be constrained to some range
  - passing in the same key should always give the same result
- Keys should be distributed over a range
  - very bad if everything hashes to 1!
  - should "look random"
- How would we write a hash function for String objects?

Hashing 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.
    - All classes come with a default version based on memory address.

String's hashCode

- The `hashCode` function inside `String` objects could look 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 Java examined only the first 16 characters. For some common data this led to poor hash table performance.

Collisions

- **collision**: When hash function maps 2 values to 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; must probe
```

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?
    - variation: **quadratic probing** moves increasingly far away

Clustering

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

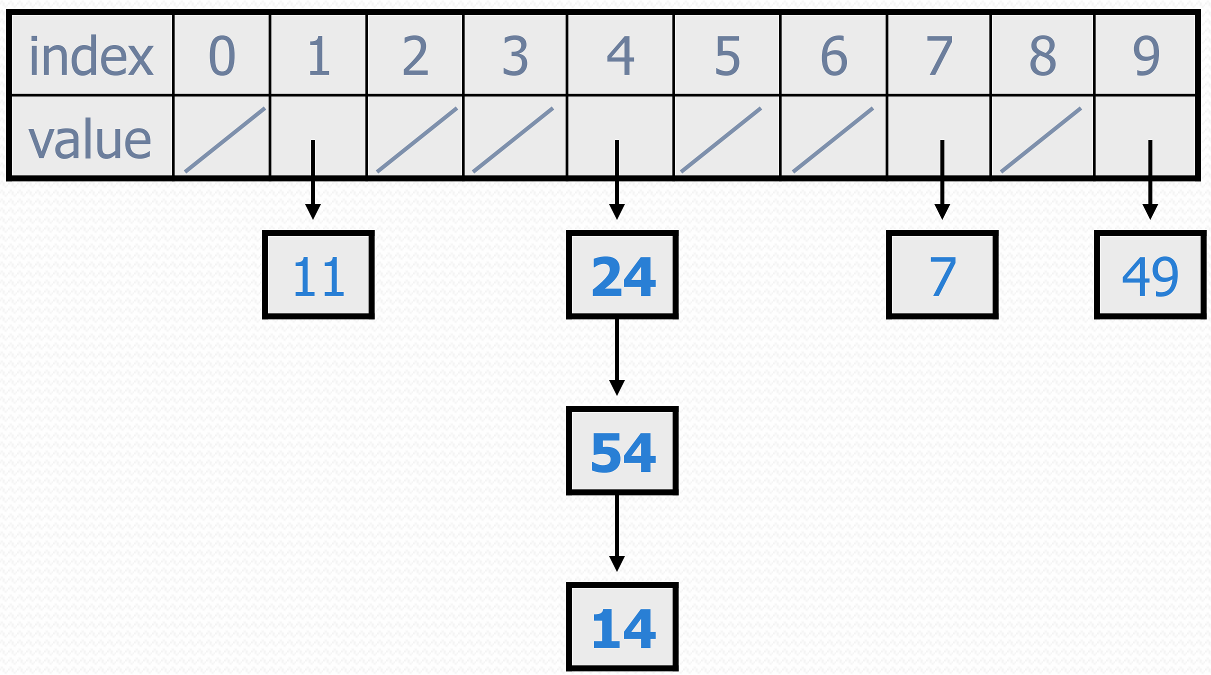
```
set.add(11);
set.add(49);
set.add(24);
set.add(7);
set.add(54);  // collides with 24
set.add(14);  // collides with 24, then 54
set.add(86);  // collides with 14, then 7
```

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

  - How many indexes must a lookup for 94 visit?

Chaining

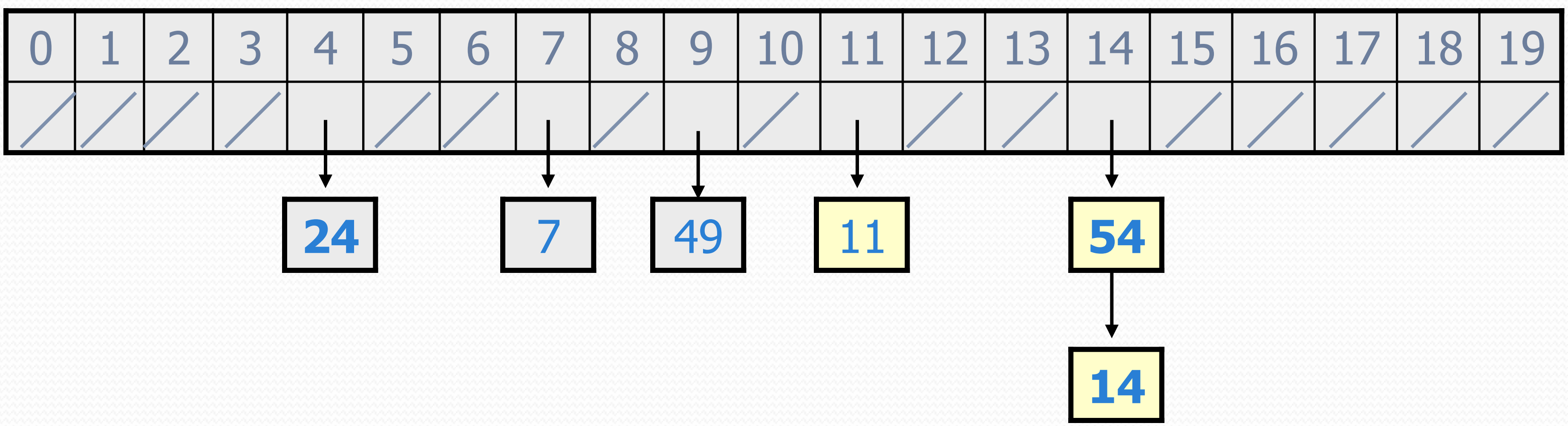
- **chaining**: Resolving collisions by storing a list at each index
  - add/search/remove must traverse lists, but the lists are short
  - impossible to "run out" of indexes, unlike with probing



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

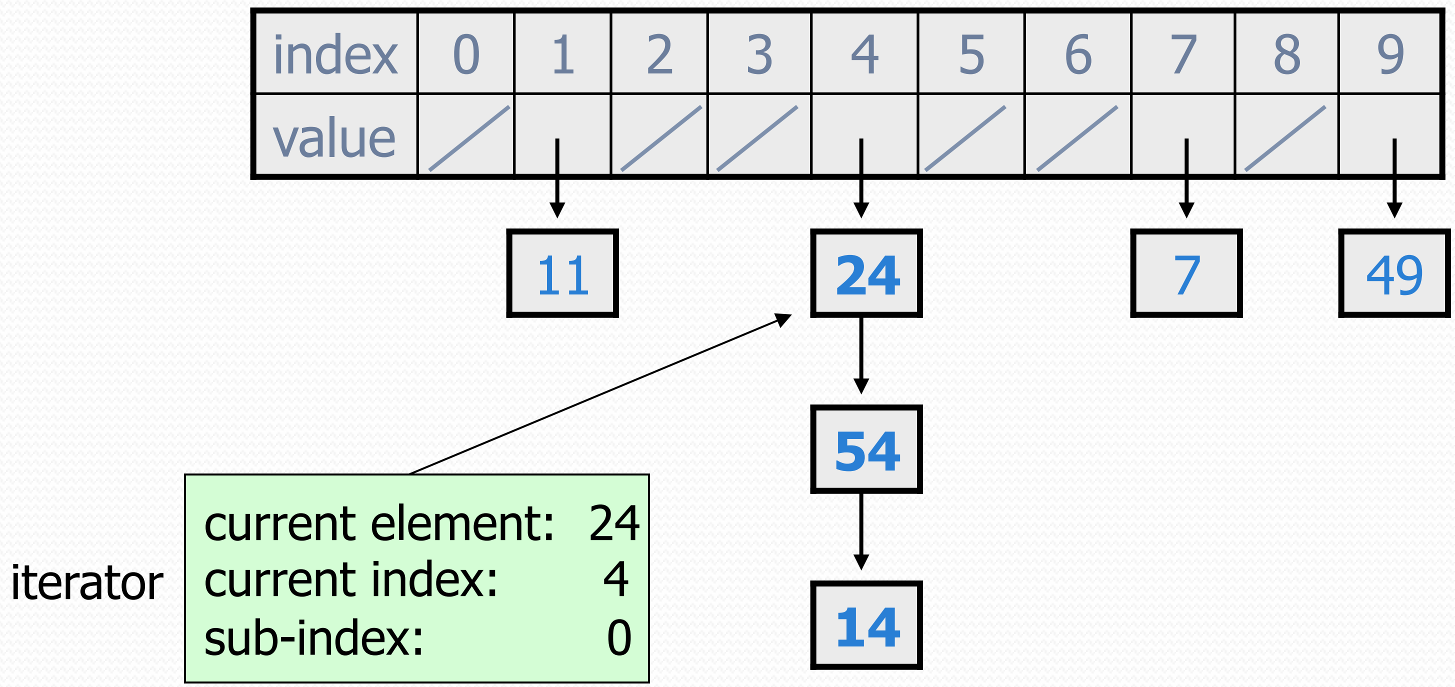


Rehashing code

```
...
// Grows hash array to twice its original size.
private void rehash() {
    List<Integer>[] oldElements = elements;
    elements = (List<Integer>[])
                   new List[2 * elements.length];
    for (List<Integer> list : oldElements) {
        if (list != null) {
            for (int element : list) {
                add(element);
            }
        }
    }
}
```

Other questions

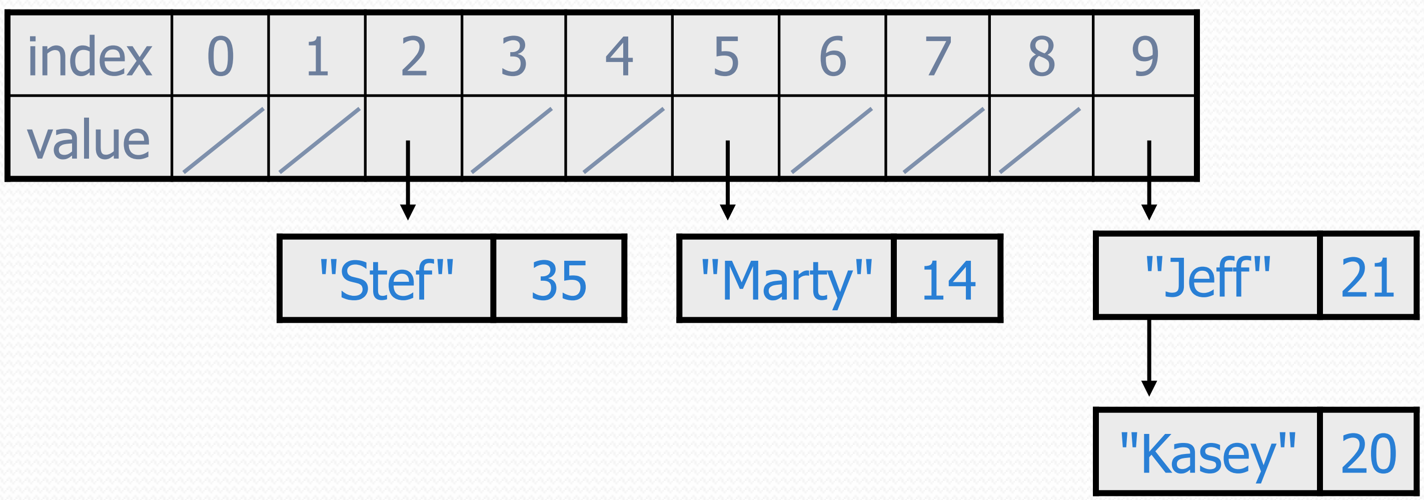
- How would we implement `toString` on a `HashSet`?



Implementing a hash map

- 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>