0	{c : 40}
1	
2	{b : 70}
3	{f : ~~90~~} 100

f = b (false)

f = f (true)

```
Example:
Start buckets array with size 4, containing null
ASCII code as hash function ("a" = 97)

set("b", 70) # note 98 % 4 is 2
set("f", 90)
set("f", 100)
```

How many elements in bucket 1?
[✓ A: 0] B: 1 C: 2 D: 3 E: more than 3

How many elements in bucket 2?
A: 0 [✓ B: 1] C: 2 D: 3 E: more than 3

How many elements in bucket 3?
A: 0 [✓ B: 1] C: 2 D: 3 E: more than 3

How many entries are checked when doing `set("f", 100)`?
A: 0 B: 1 [✓ C: 2] D: 3 E: more than 3

What will the result of `get("f")` be after this sequence?
A: 70 B: 90 [✓ C: 100] D: null E: an error

Example continued...

`set("c", 40)`

Which bucket is "c" stored in?

A: 0 B: 1 C: 2 D: 3 [✓ E: it causes an error]

So we wrap around

```
A HashTable<Key, Value> using Linear Probing has:
  • size: an int
  • buckets: an array of Entries (not of lists of Entries!)
  • hash: a hash function for the Key type

An Entry is a single {key: value} pair.
                                              what if this was 1

void set(key, value):
  if loadFactor > 0.67: expandCapacity()
  hashed = hash(key)
  index = hashed % array length          for "f" this is 2
  while this.buckets[index] != null:       for "c" 3
    b = this.buckets[index]
    if b.key.equals(key):                ? f = c? false
      b.value = value
      return
    index += 1
    index = index % this.buckets.length

  // key not in table, add it at first index containing null
  this.buckets[index] = {key: value}
  size += 1


Value get(key):
  hashed = hash(key)
  index = hashed % this.buckets.length     - "f" will produce 2
  while this.buckets[index] != null:
    b = this.buckets[index]
    if b.key.equals(key): return b.value
    index += 1
    index = index % this.buckets.length

  // haven't found the key
  return null/throw exception


void expandCapacity():
  newEntries = new Entry[this.buckets.length * 2];
  oldEntries = this.buckets
  this.buckets = newEntries
  this.size = 0
  for each entry {k:v} in oldEntries:
    this.set(k, v)
```

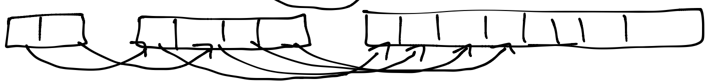
What about remove?

```
public class AList<E> implements List<E> {

  E[] elements;
  int size;

  @SuppressWarnings("unchecked")
  public AList() {
    this.elements = (E[])(new Object[2]);
    this.size = 0;
  }

  public void add(E s) {
    expandCapacity();
    this.elements[this.size] = s;
    this.size += 1;
  }

  @SuppressWarnings("unchecked")
  private void expandCapacity() {
    int currentCapacity = this.elements.length;
    if(this.size < currentCapacity) { return; }

    E[] expanded = (E[])(new Object[currentCapacity * 2]);

    for(int i = 0; i < this.size; i += 1) {
      expanded[i] = this.elements[i];
    }
    this.elements = expanded;
  }
}
```

we might expand

If we add 6 elements to an empty AList, what is the **sum of all the lengths of arrays created in (including constructor and expandCapacity)?**

A: 8 B: 10 C: 12 [✓ D: 14] E: 16



If we add 6 elements to an empty AList, what is the **total number of times an element is copied in expandCapacity?**

[✓ A: 6] B: 8 C: 10 D: 12 E: 16

2 + 4

If we add 20 elements to an empty AList, **how many times is expandCapacity ~~called~~?** executed?

A: 2 B: 3 [✓ C: 4] D: 5 E: 6

2 → 4   4 → 8   8 → 16   16 → 32

If we add 20 elements to an empty AList, **what is the length of the array created in each of those calls to expandCapacity?** (open-ended, no multiple-choice)

$$\sum_{i=1}^{n} 2^i$$

2   4   8   16   32

$\underbrace{2 \quad 4}_{6} < 8$

$\underbrace{\quad\quad}_{14} < 16$

$\underbrace{14+16}_{}$ 30 < 32

30 + 32

Amortized Analysis

A kind of "average" case,
counting across many operations

$(n-2) + n$
allocations / copies for n adds

$\frac{(n-2)+n}{n}$ is $O(1)$
per call to add()
on average

We say "add() is amortized constant time"