# CS 228: Introduction to Data Structures
# Lecture 32

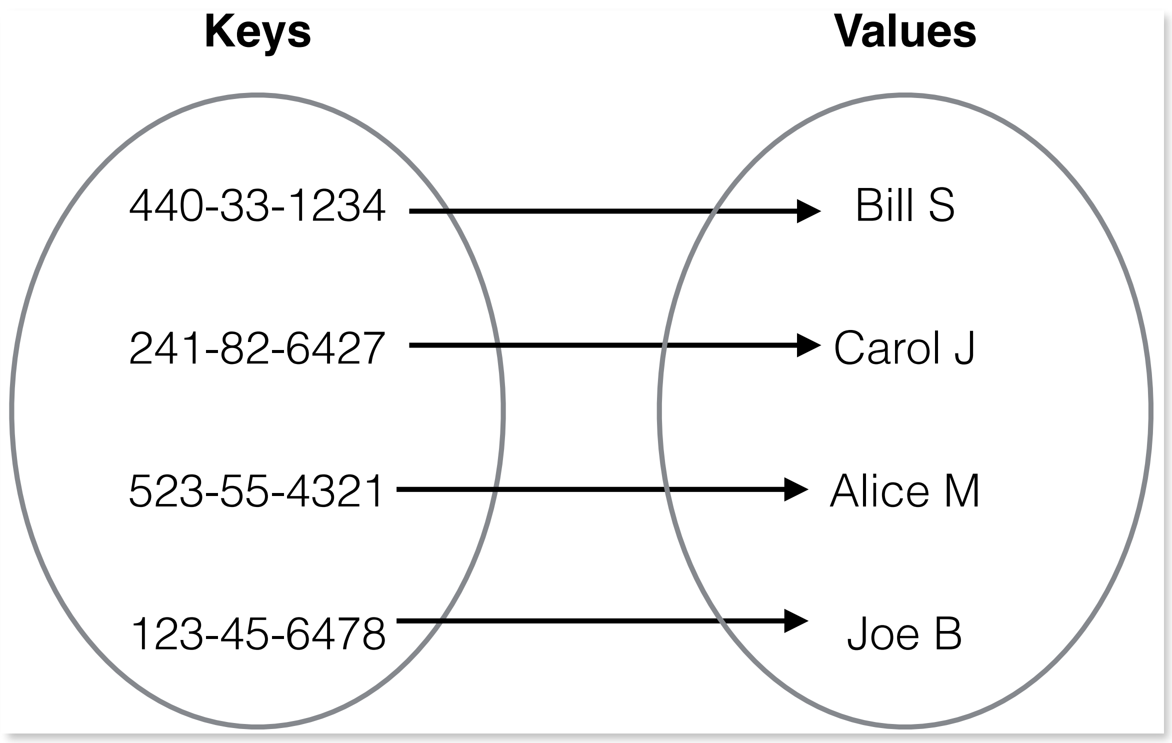
## Maps

A ***map*** is an object that maps a finite set of ***keys*** to a collection of ***values***. Each key can map to at most one value, and a map cannot contain duplicate keys. Maps correspond to the mathematical concept of a ***function***. Maps have many applications. Here are three.

- Dictionaries: The keys are words, the values are their definitions (e.g., as in Project 4). In fact, some authors call maps dictionaries, and the (now obsolete) predecessor of Java's `Map` class was called `Dictionary`.

- Associating social security numbers to people's names. The keys are 9-digit integers; the values are `String`s.

- Associating IP addresses (keys, `String`s) to host names (values, `String`s).



**The Java `Map<K,V>` Interface**

Java's `Map` interface specifies the methods of a mapping from a set of keys, of type K, to a set of values, of type V.

```
public interface Map<K,V>
```

Here is a partial list of the methods in the `Map` interface.

`boolean containsKey(Object key)`
Returns true if this map contains a mapping for `key`.

`boolean containsValue(Object value)`
Returns true if this map maps one or more keys to `value`.

`V get(Object key)`
Returns the value to which `key` is mapped, or null if this map contains no mapping for `key`.

`boolean isEmpty()`
Returns true if this map contains no key-value mappings.

`V put(K key, V value)`
Associates value with `key` in this map.

`V remove(Object key)`
Removes the mapping for `key` from this map if it is present.

`int size()`
Returns the number of key-value mappings in this map.

The `Map` interface provides three collection views, which allow a map's contents to be viewed as a set of keys, collection of values, or set of key-value mappings.

`Set<K> keySet()`
Returns a `Set` view of the keys contained in this map.

`Collection<V> values()`
Returns a `Collection` view of the values contained in this map.

`Set<Map.Entry<K,V>> entrySet()`
Returns a `Set` view of the mappings contained in this map.

The order of a map is defined as the order in which the iterators on the map's collection views return their elements. Some map implementations make specific guarantees as to their order; others do not.

## Implementation

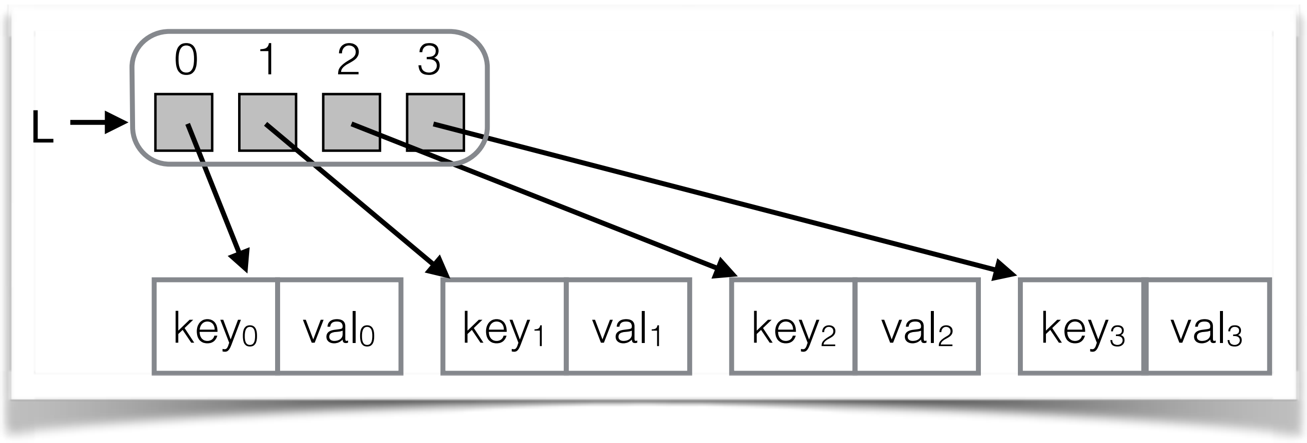
Implementing the full Java `Map` interface can be overwhelming, so we will not attempt to do it here. To give you an idea of how an implementation might look, we will study how to implement the following stripped-down version of the `Map` interface called `SimpleMap`.

```
public interface SimpleMap<K, V>
{
  public V put(K key, V value);
  public V get(K key);
  public V remove(K key);
  public boolean containsKey(K key);
  public int size();
  public Iterator<K> keyIterator();
}
```

Most methods in `SimpleMap` match the `Map` API. One exception is `keyIterator()`, which is equivalent to calling `keySet().iterator()` in the `Map` API. The `keySet()` method returns a “set view” of the keys; i.e., a `Set` consisting of all the keys. This `Set` comes with its own iterator.

## List Implementation

An easy way to implement `SimpleMap` is to use a `List` of `MapEntry` objects, which are key/value pairs.



For encapsulation, the list and the `MapEntry` type are private.

```
public class ListBasedMap<K, V>
implements SimpleMap<K, V>
{
  private List<MapEntry> list =
    new LinkedList<MapEntry>();

  private class MapEntry
  {
    public K key;
    public V value;

    public MapEntry(K key, V value)
    {
      this.key = key;
      this.value = value;
    }
  }
```

To `put()` a `key`/`value` pair into the map, we first do a linear scan to check if `key` is already being used. If it is, we replace `key`'s old value with the new `value`, returning the old value. Otherwise, we just `add()` the `key`/`value` pair to the list.

```
  public V put(K key, V value)
  {
    if (key == null)
      throw new IllegalArgumentException();
    for (MapEntry entry : list)
    {
      if (entry.key.equals(key))
      {
        V ret = entry.value;
        entry.value = value;
        return ret;
      }
    }
    list.add(new MapEntry(key, value));
    return null;
  }
```

The `get()` method also requires a linear scan through the list in search of the key. The `contains()` and `remove()` work similarly. You can find the details on Blackboard.

Because of the need for linear scans, `put()`, `get()`, `contains()`, and `remove()` take O(n) time in the worst case, where n is the size of the map.

**Iterators.** Note that we have to iterate over the set of keys, not over the key/value pairs. The details are hidden within a `KeyIterator` inner class.

Suppose m is the map represented using `list` and `kIter = m.keyIterator()`. Then `kIter` is implemented using an iterator `iter` over `list` (generated using `list.iterator()`). Since `iter` iterates over `MapEntry` objects, a call to `iter.next()` would return a pair. Thus, `kIter.next()` returns `iter.next().key`.

```
public Iterator<K> keyIterator()
{
  return new KeyIterator();
}

private class KeyIterator
implements Iterator<K>
{
  private Iterator<MapEntry> iter =
    list.iterator();

  @Override
  public boolean hasNext()
  {
    return iter.hasNext();
  }

  @Override
  public K next()
  {
    return iter.next().key;
  }

  @Override
  public void remove()
  {
    iter.remove();
  }
}
```

## Binary Search Tree Implementation

If the keys have a natural ordering, we can represent maps using a BST consisting of `MapEntry` objects. To make `MapEntry` objects comparable by key, we need to override `compareTo()` appropriately. You will find the details in the class `BSTMap`, posted on Blackboard.

On a BST implementation, the running times of `get()`, `put()`, `containsKey()`, and `remove()` are all O(height(T)), where T is the underlying tree. Therefore, if we use ***balanced*** BSTs, the running time of all those methods is O(log n). In fact, Java's `TreeMap` class[1] uses red-black trees (a kind of balanced BST) to represent `Map` objects. In Project 5, you will implement a simplified version of `Map` that uses "$\alpha$-balanced" trees as the backing store; in this implementation `get()`, `put()`, `containsKey()`, and `remove()` take O(log n) ***amortized*** time. You can also achieve O(log n) amortized time using splay trees.

1 https://docs.oracle.com/javase/8/docs/api/java/util/TreeMap.html