PG4200: Algorithms And Data Structures

Lesson 06:
Hash Maps and Sets

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Hash Function

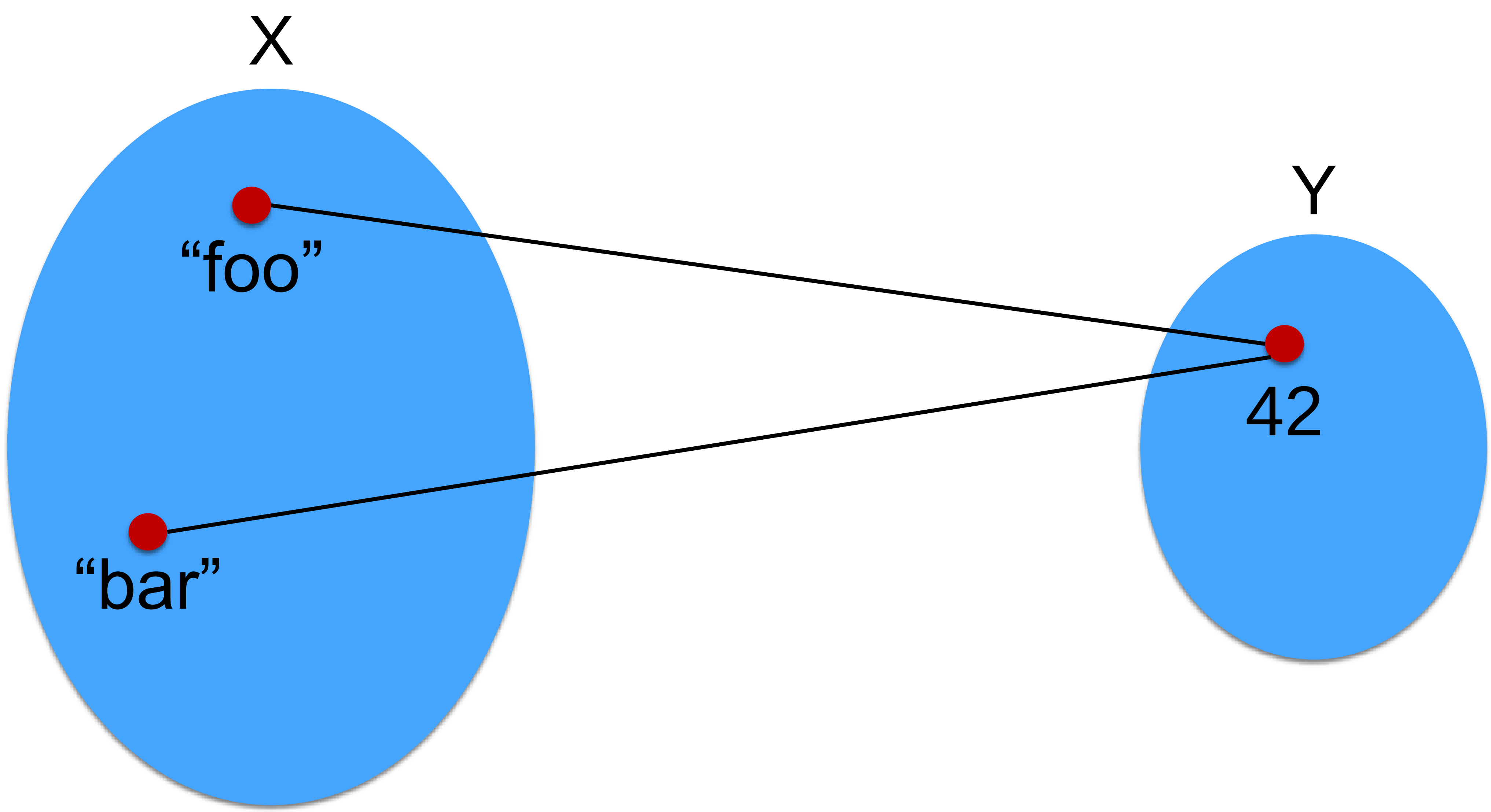
- A function that maps data from an arbitrary size to a specific size
  - eg, mapping strings to a int
- $h(x)=y$, mapping from domain X to a value in domain Y
- |X| is often much larger than |Y|

Hash Properties

- *Deterministic*: for a given input *x'*, should always get the same output *y'*
- *Uniform*: mapping from X to Y should be ideally spread uniformly over Y,
  - ie the number of elements in X that map to a specific *y'* should be close to |X|/|Y|
- *Performance*: either fast (in this course) or slow (security, eg hashing of passwords)

Collisions

- If |X| > |Y|, you cannot avoid $h(x')=h(x'')$, two different values in X mapping to the same value in Y
- Ideally, if uniform, no more than |X|/|Y| collisions per element



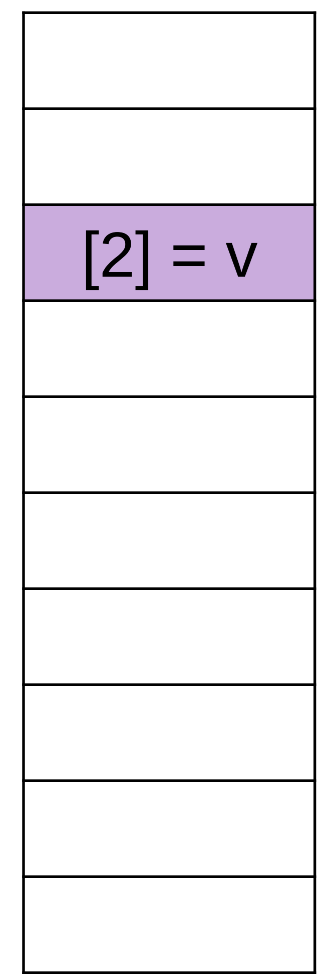
Hash Maps

- Still a map from a K key to a V value
- No requirement on ordering of K keys, just being able to compute an *hash* of it
- In Java, all objects inherits from *java.lang.Object*, which defines a *hashCode()* method
- Hash code used as an index for an internal array

Example

- *put("foo", v)*
- *h("foo")=42*
- *h("foo")%10 = 2*
- Benefit: operations (insert/search/etc) have cost due to hash independent of size N of the collection

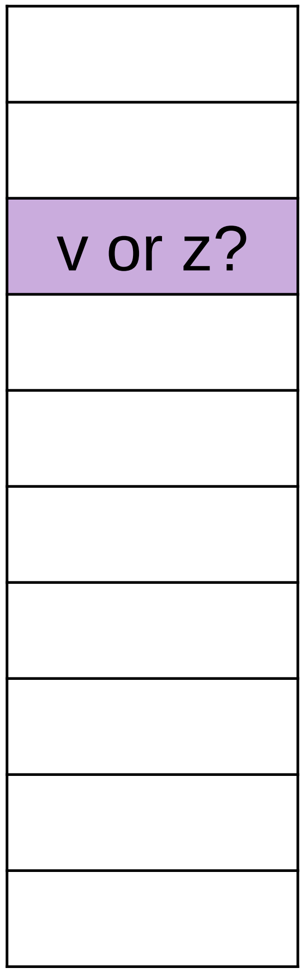
Internal array buffer of size M=10



What About Collisions?

- *put("foo", v)*
- *put("bar", z)*
- *h("foo")=h("bar")*
  - ie, collision due to same hash
- *h("foo")%10 = 2*
- What to do?

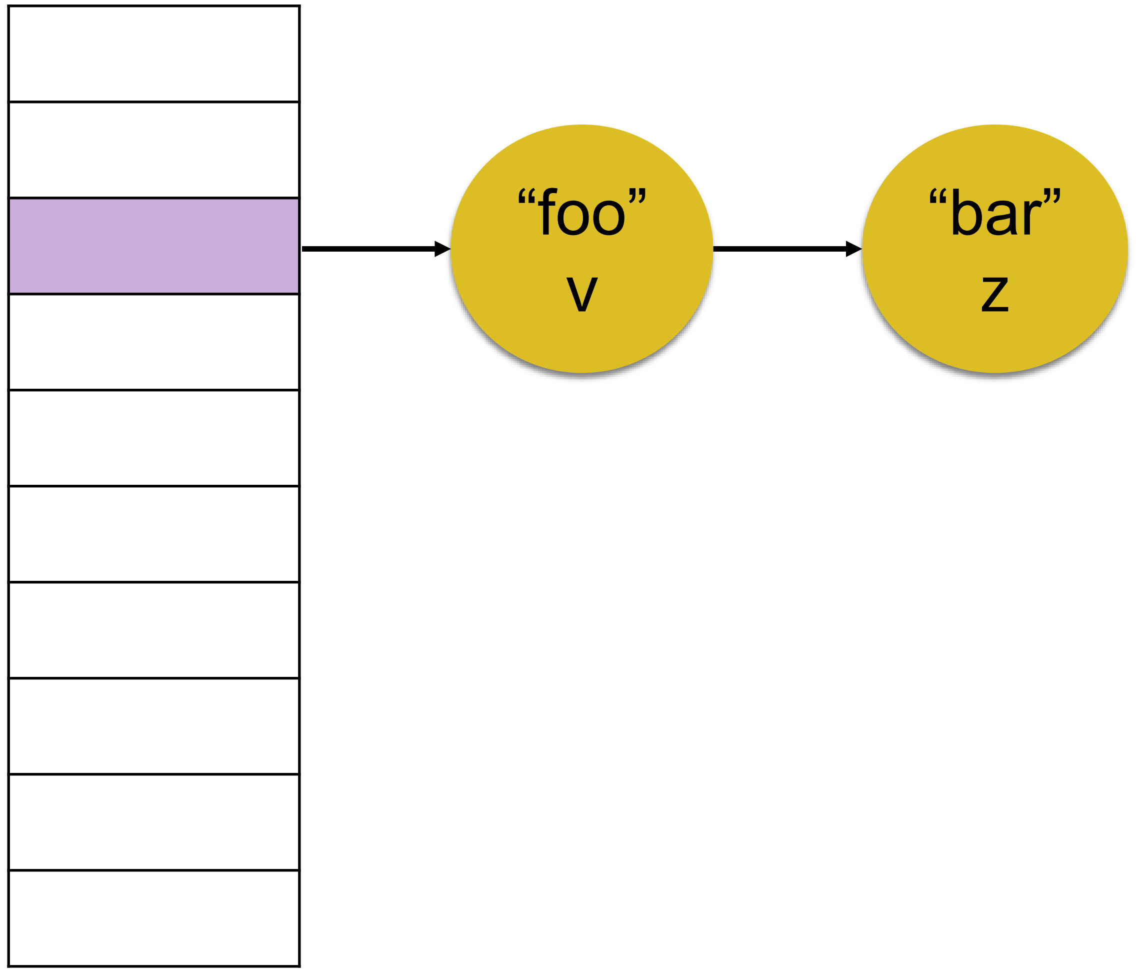
Internal array buffer of size M=10



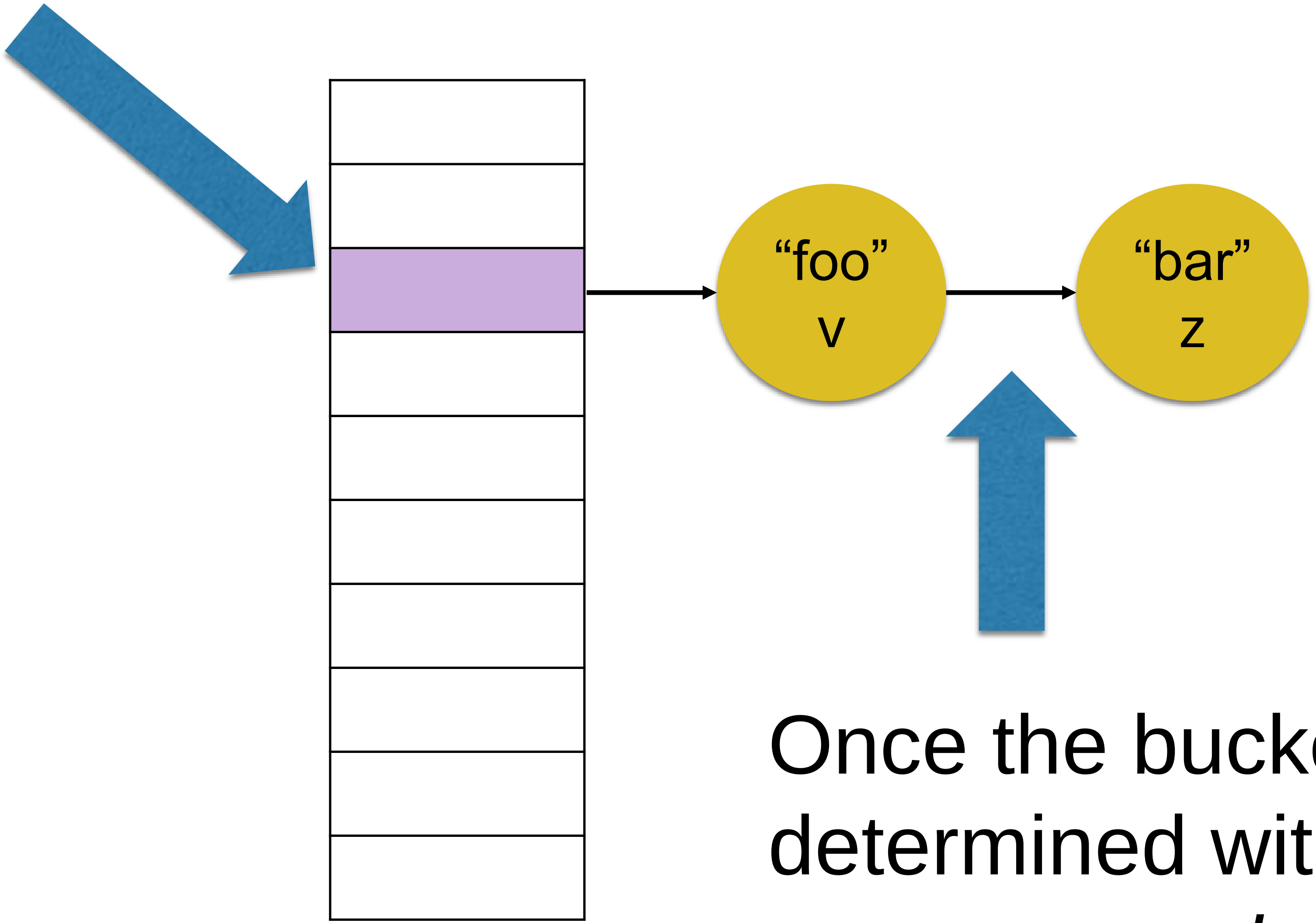
Different Strategies

- *put("foo", v)*
- *put("bar", z)*
- *h("foo")=h("bar")*
    - ie, collision due to same hash
- Use list at each position sharing same hash
- Nodes containing keys and values

Internal array buffer of size M=10



hashCode() computed on the keys to determine their bucket. In this example, assuming *“foo”.hashCode()==“bar”.hashCode()*, because same bucket. However, *“foo”.equals(“bar”)* is false



Once the bucket is determined with *hashCode()*, we use *equals()* on the *keys* in the list (one at a time), to see if there is a match

java.lang.Object

- *Object* does define two methods: *hashCode()* and *equals()*
- Those methods will depend on the internal fields of the object
- *Important*: if two objects are equals, then they **MUST** have same hash code
  - *A.equals(B)* implies *A.hashCode()==B.hashCode()*
  - The vice-versa is not necessarily true, ie *A.hashCode()==B.hashCode()* does not imply *A.equals(B)*, although that could happen
- What if constraint is not satisfied? Expect weird bugs when using maps and sets…

Cost

- Worst case: **O(N)** if all elements end up in same "bucket" (ie same value for *h()%M*), the map would be equivalent to a list
  - operations to search on list would be O(N), albeit insert would be O(1)

- But, **if** M large enough compared to N, and hash function is uniform enough, you can have a **O(1)** cost in many cases
  - even if you have some collisions, it will not be a problem, as you would have a small number of elements in the list

Hash or RBT?

- Hash Maps is the most popular and widely used
- If you know how much data you ll insert at most, can choose a good large enough M
- So in most cases, we are in *O(1)* Hash vs *O(log N)* RBT
- But Hash can be *O(N)* in worst case, vs RBT **guarantees** *O(log N)* in all cases
  - eg, in critical systems where you MUST guarantee a response within a certain amount of time, might want to use RBT
- Hash does not need ordering of keys

Set

- In mathematics, a *set* is a collection of elements where:
  - 1) *ordering is not important*: ie {1,2,3} is equivalent to {2,3,1}
  - 2) *no repetitions*: ie {1,2} is the same as {2,1,1,2,2,1,1,2,1}
- How to implement a Set in Java?
- Easy: use an internal *Map*<*K,V*> were your values in the set are the keys *K*, and you just ignore the values *V*

Keys and Immutability

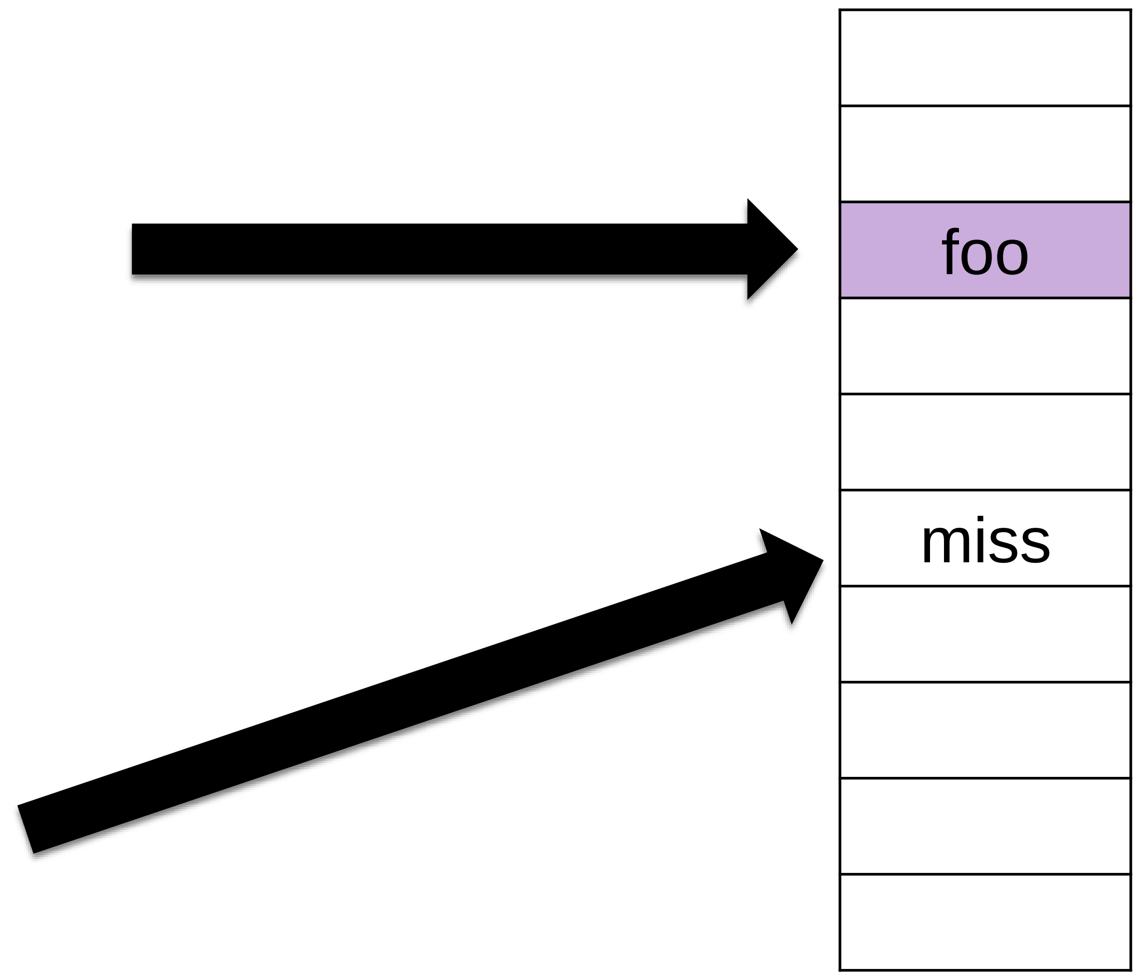
- *Immutable Object*: an object whose state cannot be changed once created

- Example: Strings are immutable
  - eg, concatenation with + and methods like *toUpperCase()* and *substring()* do NOT change the String, but rather *create* a NEW one

- Keys in a Map/Set **MUST** be *immutable*… why?

Different Hash

```
Foo foo = new Foo();

set.add(foo);

assertTrue(set.contains(foo));

// h(foo) = 42  ,  42 % M = 2

foo.setSomeVariable(…);

// h(foo) = 55  ,  55 % M = 5

assertFalse(set.contains(foo));
```



Using Maps and Sets

- Can only use a *Set* for **immutable** types
- What if you need a collection of mutable types <*X*>?
  - creating a *Set*<*X*> would wrong!
- Option 1: rather use a list, eg *List*<*X*>
  - however, it would allow duplicates
- Option 2: use a map *Map*<*K,X*> where the key is an immutable field derived from *X*
  - eg, if mutable *User*, *map.put(user.getId(), user)*, where the id could be a String (recall strings are immutable)

Homework

- Study Book Chapter 3.4 and 3.5
- Study code in the *org.pg4200.les06* package
- Do exercises in *exercises/ex06*
- Extra: do exercises in the book