CSCI 136
Data Structures &
Advanced Programming

Hashtables & Collisions

Video Outline

- Hashtables
  - Recap “big picture”
- Collision resolution strategies
  - External chaining
  - Linear probing/open addressing

Hash Table Implementation

General idea: Use an array to represent "bins"

- `V get(K key)`:
  - use key's hashcode to identify bin (% array length)
  - Search bin for item with matching key
- `V put(K key, V val)`:
  - use key's hashcode to identify bin
  - Search bin for item with matching key:
    - If a match exists, replace old value with `val`
    - If no match exists, add new (key,value) pair

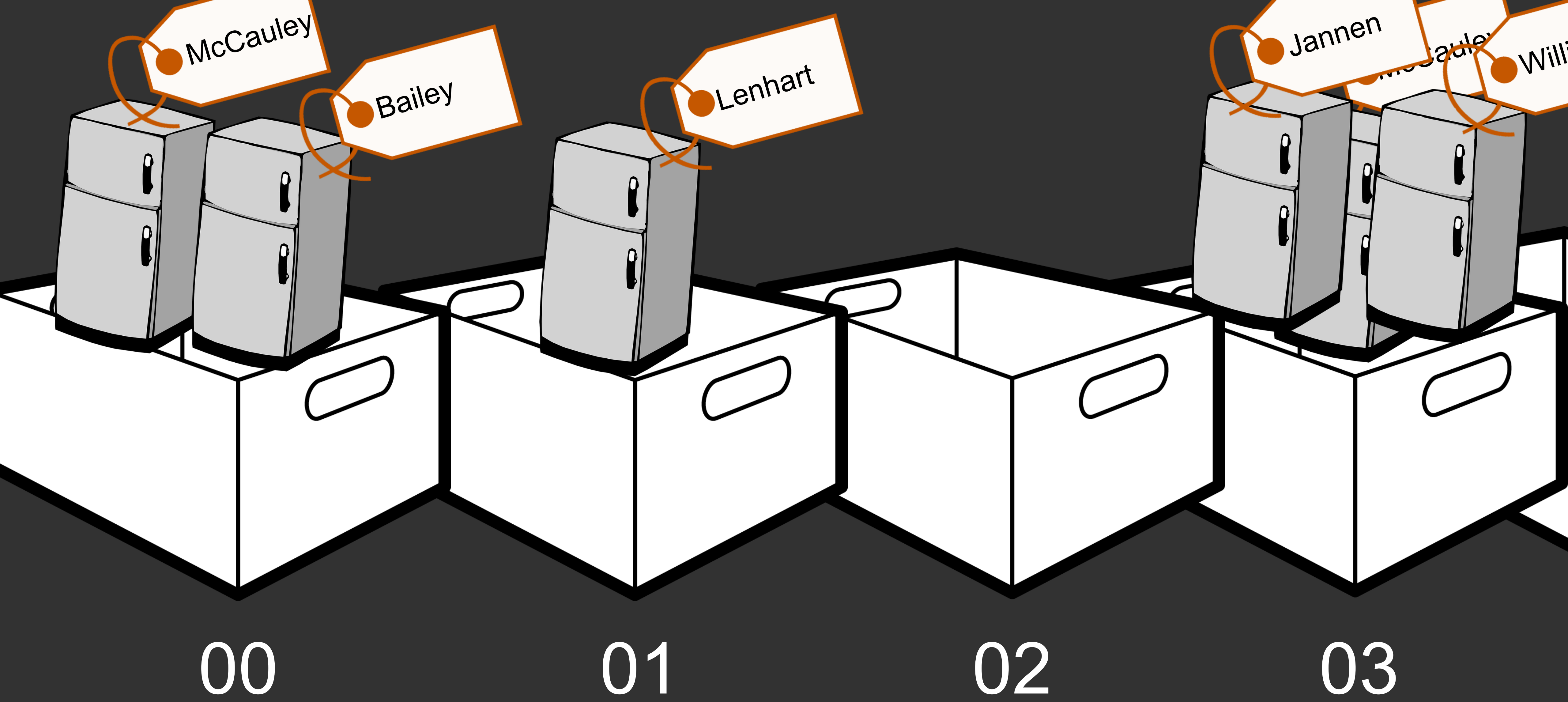
Notes on hashCode()

- We can use mod (%) to map an into to an array index
  - `array[o.hashCode() % array.length] = o;`
- What does a hashCode() return?
  - 32 bit integer
  - Can be negative!
  - This gives an array out of bounds exception
- Let's do the following:
  - `array[Math.abs(o.hashCode() % array.length)] = o;`

Navigating HashTable Collisions

- Problem: *collisions* occur when two unique items are mapped to the same bin
  - This is a problem in arrays, because we can only store one item per index
  - Thus, collision management isn't *just* a performance issue, it is a *correctness* issue

- We'll discuss two strategies to resolve collisions
  - External chaining
  - Linear probing (sometimes called open addressing)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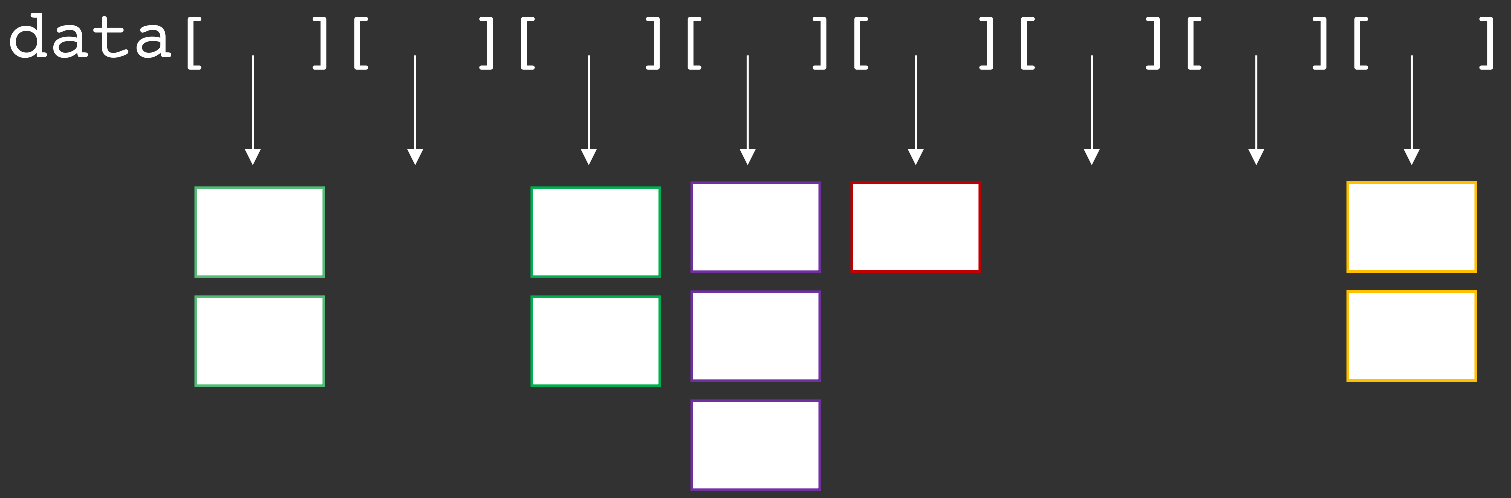
Idea 1: External Chaining

- Idea: Instead of mapping individual items to bins, we store a *list* in each bin



- `get()`, `put()`, and `remove()`, then, need to (a) identify the bin, then (b) check bin's list

Hash Table Implementation w/ External Chaining

```
public V get(K key) {
    int bin = Math.abs(key.hashCode() % table.length);
    // search for value in bin
    Association<K, V> temp = new Association<K,V>(key);
    Association<K, V> ret = table[bin].remove(temp);

    if (ret != null) { // if found, return value
        // restore value to bin so don't modify table
        table[bin].add(ret);
        // return the value we found
        return ret.getValue();
    }
    return null;
}
```

Hash Table Implementation w/ External Chaining

```
public V put(K key, V val) {
    int bin = Math.abs(key.hashCode() % table.length);
    // search for old value in bin and remove if found
    Association<K, V> toAdd = new Association<>(key, val);
    Association<K, V> old = table[bin].remove(toAdd);

    // add our new K,V pair
    table[bin].add(toAdd);

    if (old != null) {
        // if old value found, return val we're replacing
        return old.getValue();
    }
    // not found, return null
    return null;
}
```

Downsides to External Chaining

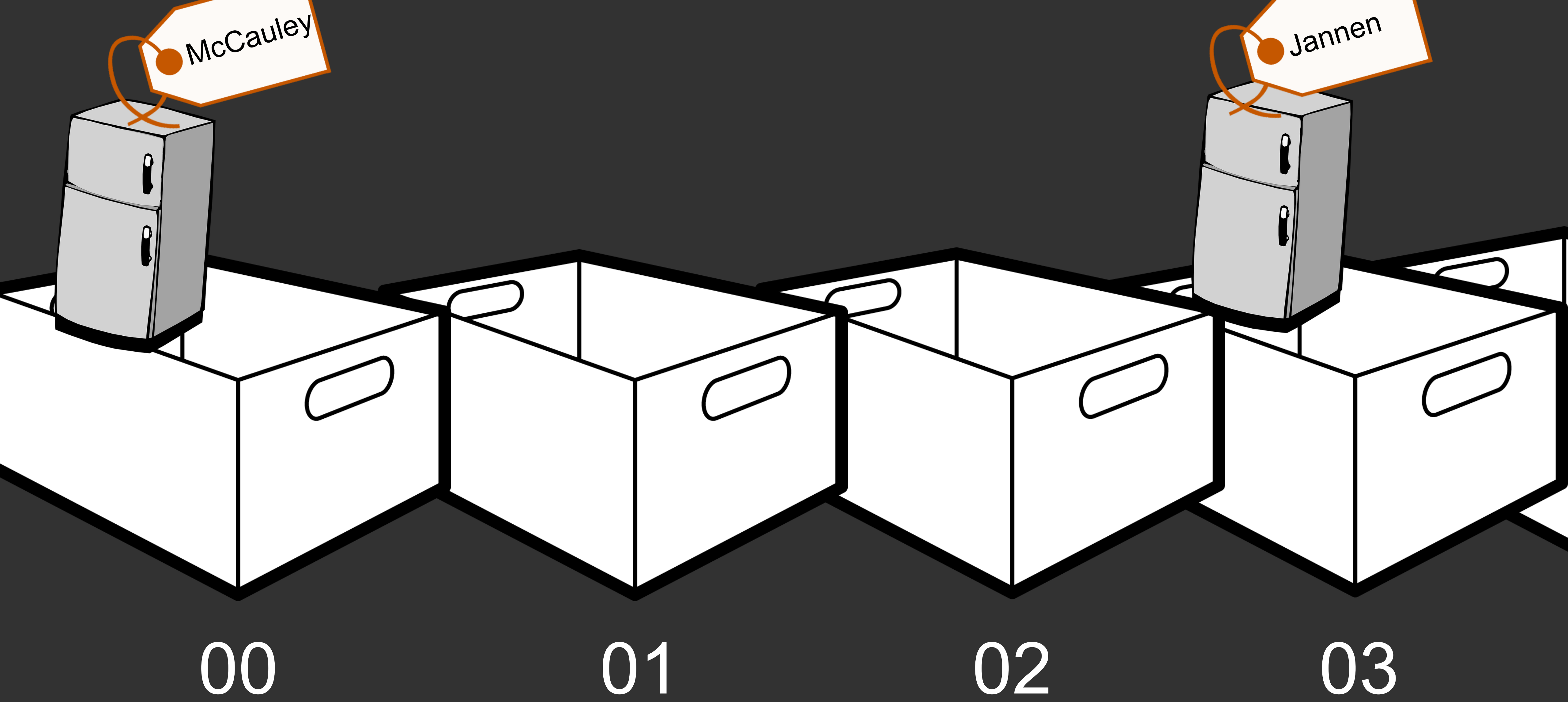
- Each slot in our Hashtable's array stores a list, even if the slot is empty
  - This consumes extra space
- Potentially poor *locality*
  - Not something we've talked about so far in this course, but a general rule of thumb: it is faster to access things that are near to each other than it is to access things that are far away.
    - Array elements are always contiguous (near)
    - List elements may be scattered throughout mem (far)

Rethinking Collisions

- Let's define an item's canonical slot as the place where the item belongs *ignoring collisions*
  - If no two items map to the same canonical slot, we don't have any problems
  - If multiple items do map to the same canonical slot, we need to figure out:
    - Among the set of colliding items, which one belongs in the canonical slot
    - Where do the "losing" items belong so that we still can find them in the future?

Linear Probing

- General idea: store each key-value pair in the first open slot on or after its canonical slot
- Insertion: If a collision occurs at a given bin, just scan forward (linearly) until an empty slot is available, and store it there
  - We "wrap around" at the end of the array
  - We will call a contiguous region of full bins a *run*
- Lookup: To find a KV-pair, scan linearly through the run until you find it or reach the end of the run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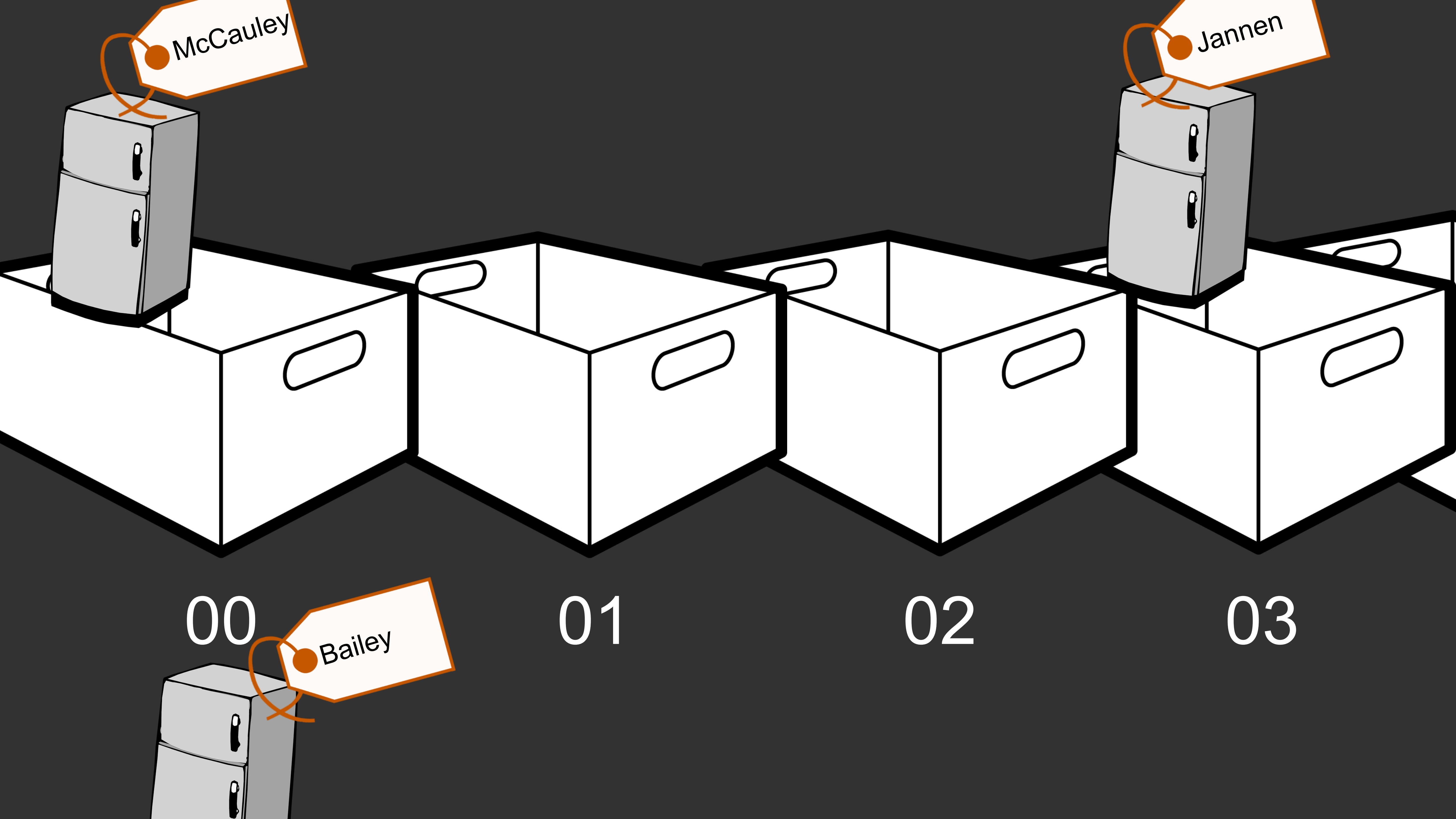
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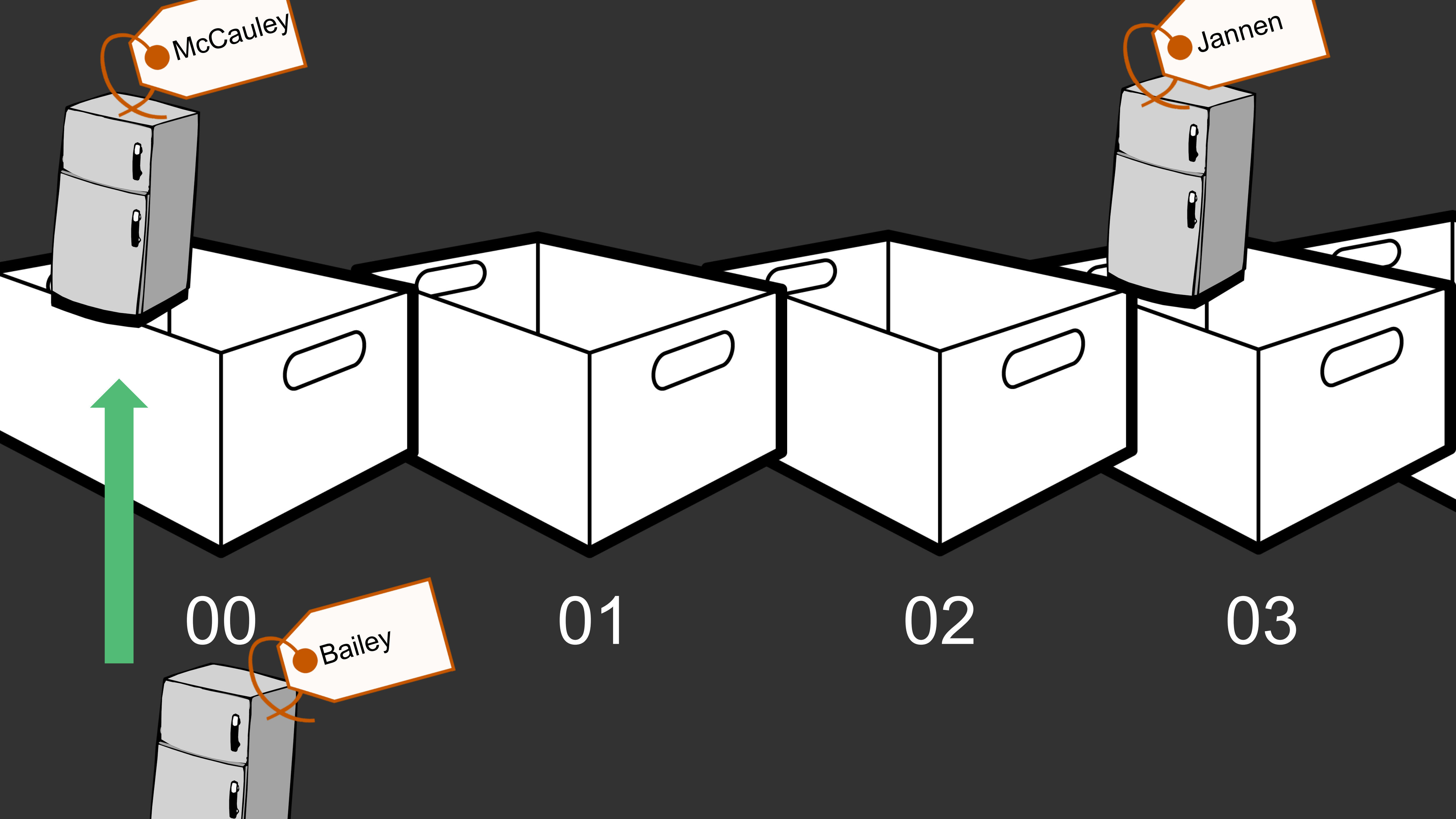
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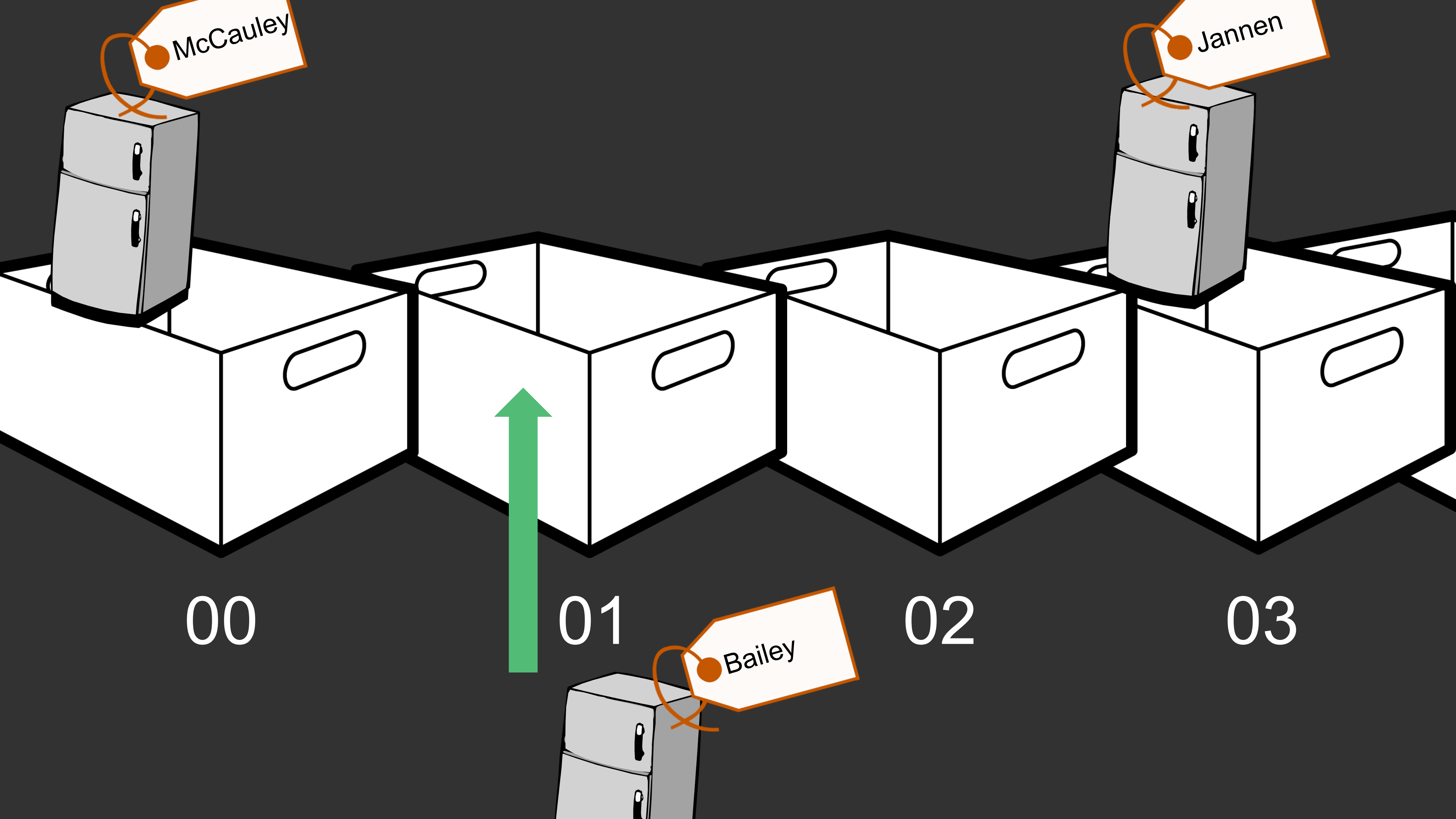
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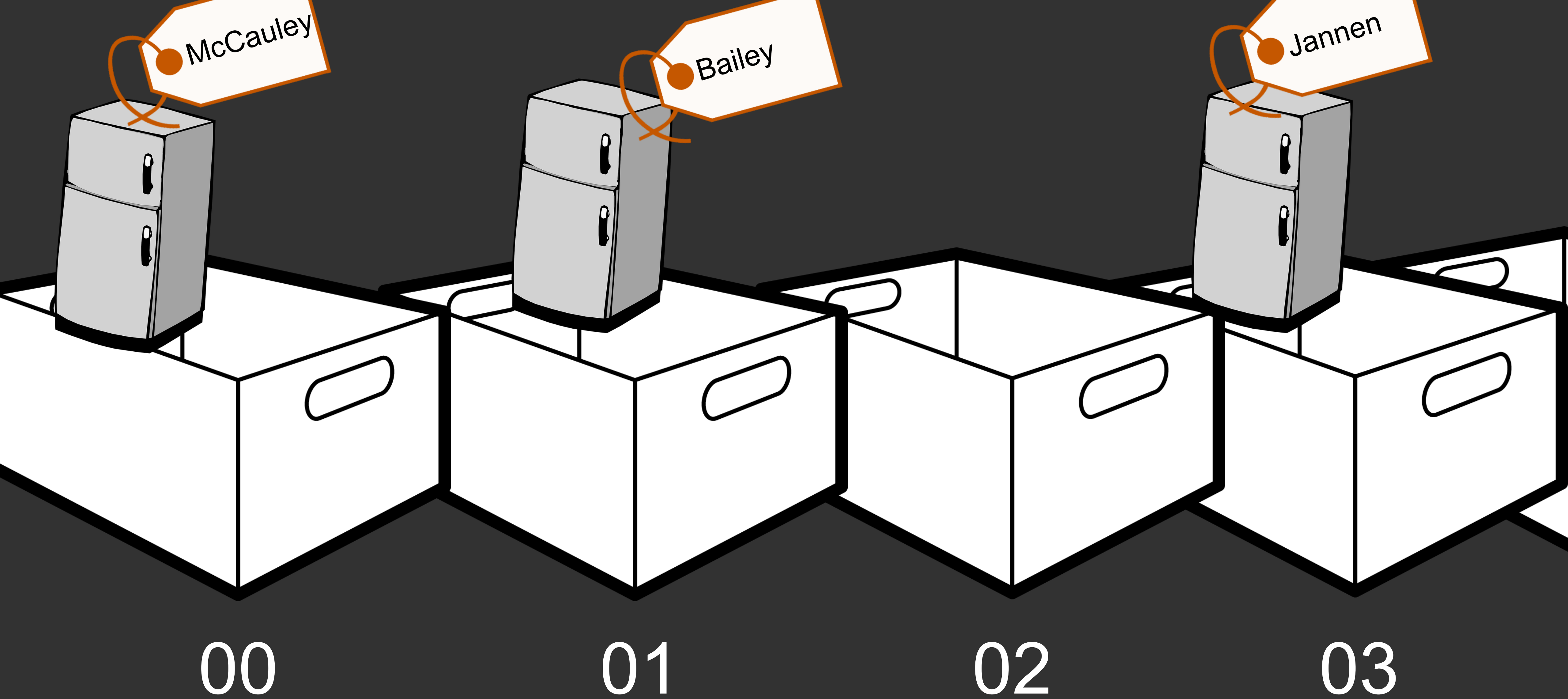
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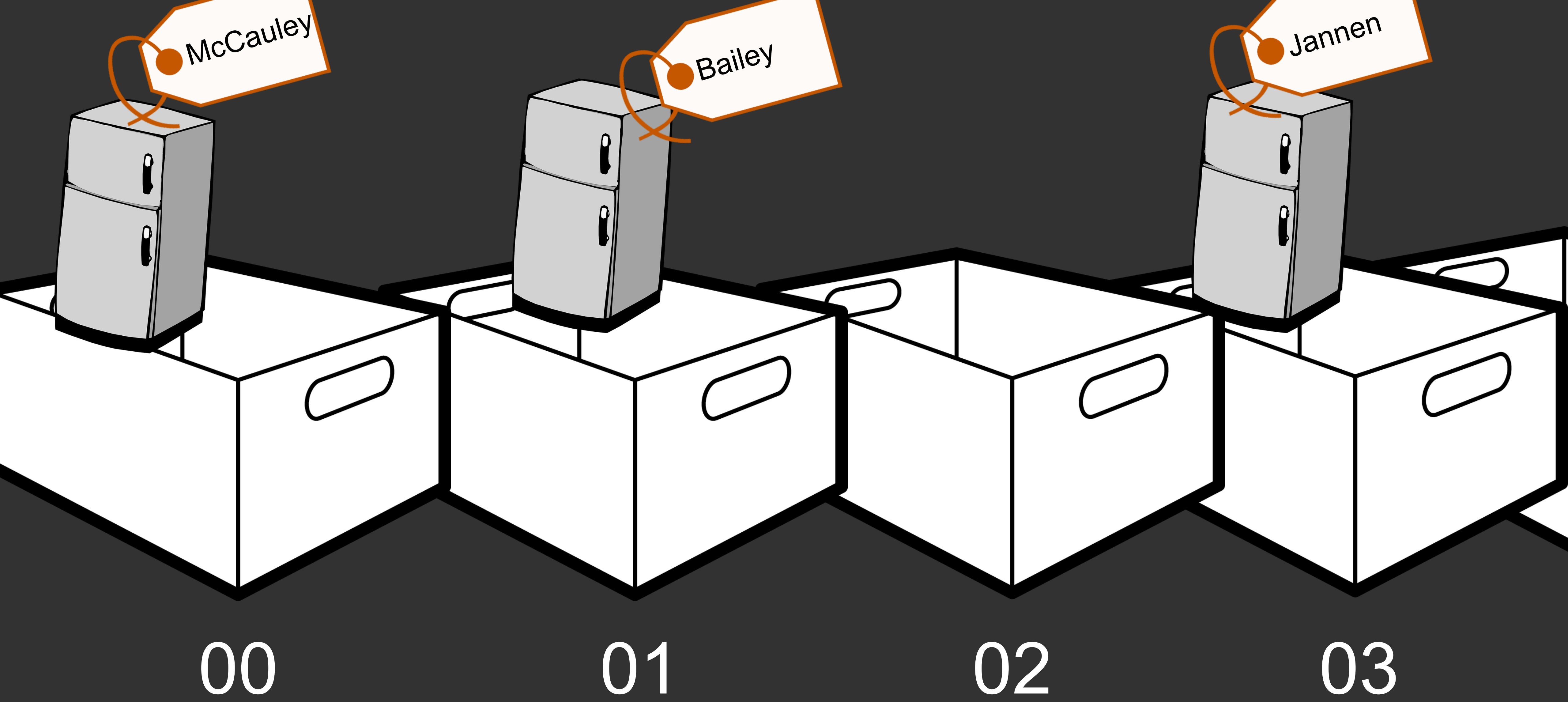

Bailey’s phone number ended in 00, but his freezer winds up in 01

First Attempt: put(K)

```
public V put (K key, V value) {
   int bin = Math.abs(key.hashCode() % data.length);
   while (true) {
      Association<K,V> slot = (Association<K,V>) data[bin];
      if (slot == null) { // Found an empty bin!
         data[bin] = new Association<K,V>(key,value);
         return null;
      }
      if (slot.getKey().equals(key)) { // already exists!
         V old = slot.getValue();
         slot.setValue(value);
         return old;
      }
      // Bin filled. Check the next bin…
      bin = (bin + 1) % data.length;
   }
}
```

First Attempt: get(K)

```
public V get (K key) {
   int bin = Math.abs(key.hashCode() % data.length);
   while (true) {
      Association<K,V> slot = (Association<K,V>) data[bin];
      if (slot == null) // Found an empty bin. End of the run
         return null;

      if (slot.getKey().equals(key))
         return slot.getValue();

      bin = (bin + 1) % data.length;
   }
}
```

Linear Probing Gotchas

- Let’s look at NaiveProbing.java
  - We specify a dummy hash function: index of first letter of word
  - Initial array size = 8
  - Add “atlanta” to hash table
  - Add “detroit”
  - Add “queens”
- What happens when we remove “atlanta”, and then lookup “queens”?
  - Our *run* was broken up!
  - Now get() won’t work correctly

Linear Probing Challenge

- When we delete an element from a run, we create a “hole”
  - Challenge: How do we tell if the run has ended, or if the hole is from a deletion?
  - Solution: Insert a “placeholder”
    - If we see the placeholder during a lookup, we treat it as a collision, and keep scanning until we find a true hole
    - If we see the placeholder during insertion, we treat it as an open spot
      - (We must still scan the whole run to see if our key is present)

HashAssociation.java

```
public class HashAssociation<K,V> extends Association<K,V>
{
    protected boolean reserved;
    /*...*/
    public boolean reserved()
    {
        return reserved;
    }

    public void reserve()
    {
        Assert.pre(!reserved,"HashAssociation reserved twice.");
        reserved = true;
    }
```

Hashtable.java

```
protected int locate(K key) {
        // initial hash code
        int hash = Math.abs(key.hashCode() % data.size());
        // keep track of first unused slot, in case we need it
        int reservedSlot = -1;
        boolean foundReserved = false;
        while (data.get(hash) != null) {
                // loop until end of run OR find target key
                if (data.get(hash).reserved()) {
                        // remember reserved slot if we fail to locate value
                        if (!foundReserved) {
                                reservedSlot = hash;
                                foundReserved = true;
                        }
                } else {
                        // value located? return the index in table
                        if (key.equals(data.get(hash).getKey())) return hash;
                }
                hash = (1+hash)%data.size();
        }
        // return first empty slot we encountered
        if (!foundReserved)
                return hash;
        else
                return reservedSlot;
}
```

Hashtable.java

```java
public V get(K key) {
        // find bin where key lives (after resolving collisions)
        int hash = locate(key);

        // if the key is not found, the resulting location
        // is either null or “RESERVED”
        if (data.get(hash) == null || data.get(hash).reserved())
                return null;

        // key was found, so return associated
        return data.get(hash).getValue();
}
```

Hashtable.java

```
public V remove(K key) {
        // find bin where key lives (after resolving collisions)
        int hash = locate(key);

        // if the key is not found, the resulting location
        // is either null or “RESERVED”
        if (data.get(hash) == null ||
            data.get(hash).reserved())
               return null;

        // key was found, so remove, then return old value
        count--;
        V oldValue = data.get(hash).getValue();
        data.get(hash).reserve();
        return oldValue;
}
```

Linear Probing Observations

- Code becomes more complicated, but manageable
- The length of a run dictates the performance
- Reserving elements does not “shrink” the run–it defers the work to other operations
  - Keeping our runs small is important, so we may want to reexamine design decisions if we expect a lot of deletions

Linear Probing Observations

- Downsides of linear probing?
  - What if array is almost full?
    - Loooong runs for every lookup…
    - Items out of place if we don't re-index after removing (placeholders are correct, but they defer work)
- Does external chaining avoid these problems?
  - Recall, *External chaining* "groups" objects with the same hash value together in same bin in a `Collection` (usually a SLL)
    - Only scan collisions, not an entire run
    - Never scans more items than linear probing
    - Worse cache behavior (locality)

Summary: Probing vs. Chaining

What is the performance of:

- `put(K, V)`
  - LP: O(1 + run length)
  - EC: O(1 + chain length)
- `get(K)`
  - LP: O(1 + run length)
  - EC: O(1 + chain length)
- `remove(K)`
  - LP: O(1 + run length)
  - EC: O(1 + chain length)
- Parting Question: how do we control cluster/chain length?