Lecture 21: Hashing

08/12/22

Upcoming

- Checkpoint 8 due Sunday 8/14 @ 11:59pm
- A6 Resubmission due Tuesday 8/16 @ 11:59pm
- A8 due Tuesday 8/16 @ 11:59pm
  - Cannot be resubmitted!
  - Late days allowed, but the last day of IPL is Wednesday, 8/17

Runtime Efficiency of `contains`

- Array, ArrayList, LinkedList:

- TreeSet:

- HashSet:

Runtime Efficiency of `contains`

- Array, ArrayList, LinkedList: O(N)

- TreeSet: O(log N)

- HashSet: O(1)

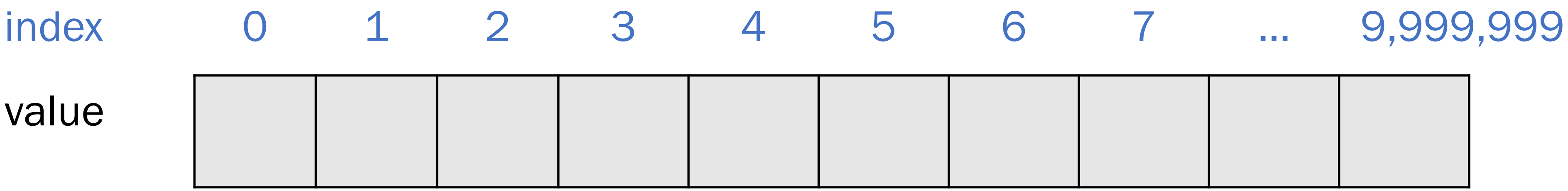
Arrays

- **Random access:** we can jump straight to any index in an array

index	0	1	2	3	4	5	6	7	8	9
value	0	11	5	-1	24	2	3	7	0	49

Really Big Array – my idea ☺

- Store Set of student ids: 0 – 9,999,999
  - add(id)
  - contains(id)



index	0	1	2	3	4	5	6	7	…	9,999,999
value										

Hashing

- hash: To map a value to an integer index.
- hash table: An array that stores elements via hashing.
- hash function: A function that maps values to indexes.

Hashing Example

- Hash function: `h(x) = x % 10`
- Add: 3, 16, 24, 300
- Contains: 16, 27

index	0	1	2	3	4	5	6	7	8	9
value										

Bad Hash Functions (why?)

- `h(x) = 1`

- `h(x) = rand.nextInt()`

Bad Hash Functions (why?)

- `h(x) = 1`

Everything hashes to the same index – lots of collisions!

- `h(x) = rand.nextInt()`

Not consistent – we can’t find our elements after we put them in our set!

Good Hash Functions

- Maps a value to a number
  - passing in the same value should always give the same result

- Results from a hash function should be distributed over a range
  - very bad if everything hashes to 1!
  - should "look random"

- Should be “fast”

Hashing Objects

- `Object` class – superclass of everything
    - `public String toString()`
    - `public int hashCode()`
        - This is a built-in hash function!

Hashing Strings

- How would we write a hash function for String objects?

String's hashCode

- The `hashCode` function inside `String` objects looks 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.

Let’s implement our own HashSet!

Collisions

- **collision:** When hash function maps 2 values to same index.

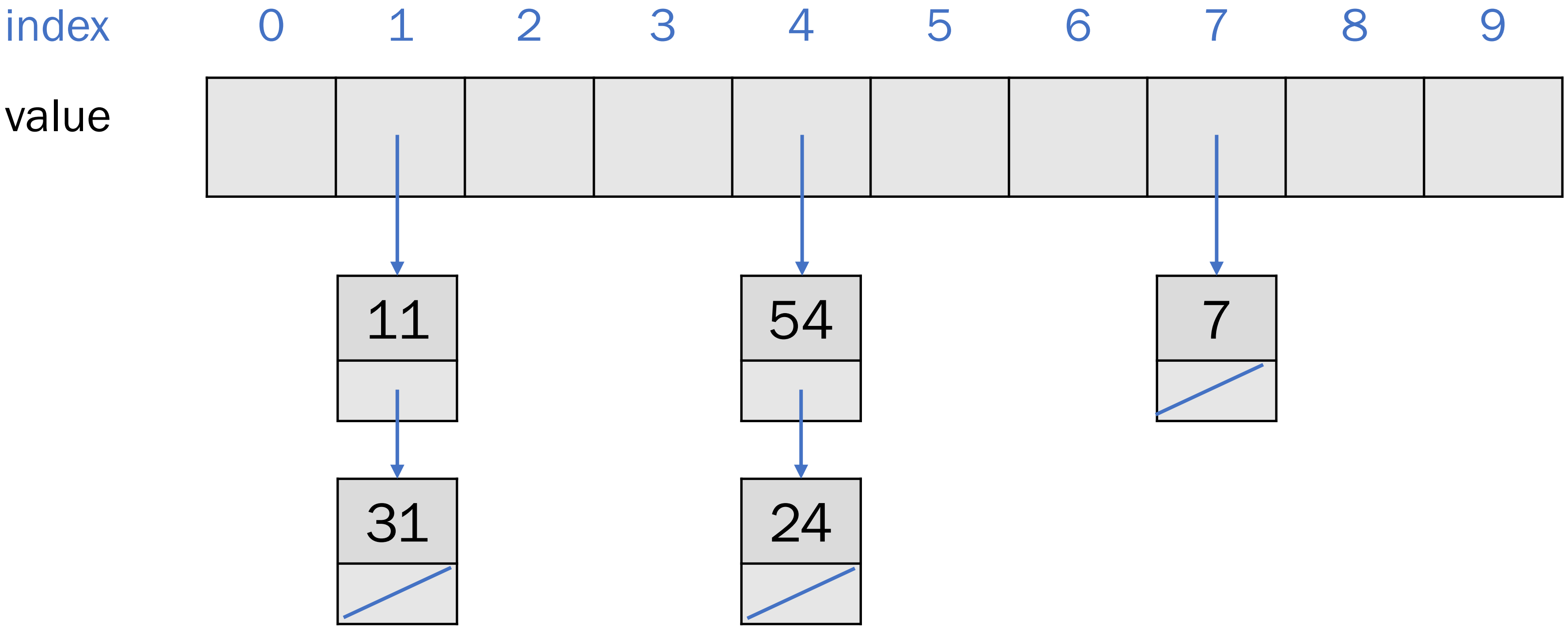
Example: `h(x) = x % 10`

```
set.add(24);
set.add(7);
set.add(54);
```

index	0	1	2	3	4	5	6	7	8	9
value										

Separate Chaining

- **chaining**: Resolving collisions by storing a list at each index.
  - add/contains/remove must traverse lists, but the lists are short



Practical points

- Use known hash functions – don’t reinvent the wheel!
- When you override `hashCode()` you must always override `equals()` as well! (and vice versa)
- Use prime numbers for table sizes
- Rehash when the hash table gets too crowded

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