Hash Tables

In pursuit of *O(1)* searches

- Define what a key value pair is
- Define what a hash function is
- State the big O for:

  1. Linear array searches
  2. Hashing a key
  3. Addressing an array by numeric index.

- Use hash tables for fast data lookups in *O(1)* time

Case study

- Count word frequency in a large document
- Compare different storage and search strategies

  1. Unsorted linear array
  2. Hash table

- Compare execution time with data of non-trivial size.

Key value pairs

Key	Value
"apple"	3
"orange"	2
"pear"	4

An array, with hypothetcial address in memory

Address	Key	Value
0x7fff5d8ccc00	"apple"	3
0x7fff5d8ccc32	"orange"	2
0x7fff5d8ccc64	"pear"	4

...and so on

Method 1: Linear search through an array

Given a list of words `parsed_words` parsed of a document, and an array `word_counts` like the previous slide.

- for each `word` in `parsed_words`
  1. if `word_counts` contains `word` then increment the count by 1
  2. else append `word` to `word_counts` and set the initial value to 1

NB: `word` can only appear once in the `word_counts` array.

```
[[word1, count1], [word2, count2], ... , [wordN, countN]]
```

Discuss with neighbors

- What is the Big O of traversing a list of words.
- What is the Big O of directly indexing into an array by its address?
- What is the Big O of inserting or modifying a word count in the array.

Direct address into array is:

$$O(1)$$

Hence, a linear search through an unsorted array would be (dropping constant 1)

$$O(N)$$

Even if you sorted it, and did a binary search you would still have

$$O(logN)$$

Discuss with neighbors

If you were to do a binary search:

- You could not simply append to the list. What do you need to do instead?
- How would that slow insertion?

But we can do better by using
hash tables and hash functions

What's a hash function? Part 1

$$h(k) \to address$$

Where

- k is a key, such a string, in our case a word to count.
- address is a memory address in an array in which to store the value
- h(k) runs in constant time

What's a hash function? Part 2

Keys can collide

- `h('kiwi') -> 0x7fff5d8ccc96`
- `h('new zealand') -> 0x7fff5d8ccc96`

A couple ways to deal with this.

- Chained hash table (we'll discuss this)
- linear probing

Livin' the O(1) dream

Since

- *h(k)* is constant and
- Array address indexing is constant

then you get constant time access into your hash table!

JS implements hash tables with objects.

Method 2: Using a hash table

Given a list of words `parsed_words` parsed of a document, and an array `word_counts` like the previous slide.

- for each `word` in `parsed_words`
    1. if `word_counts` contains key of `word` then increment the value by 1
    2. else add key `word` to `word_counts` and set the initial value to 1

`{word1: count1, word2: count2, ... , wordN: countN}`

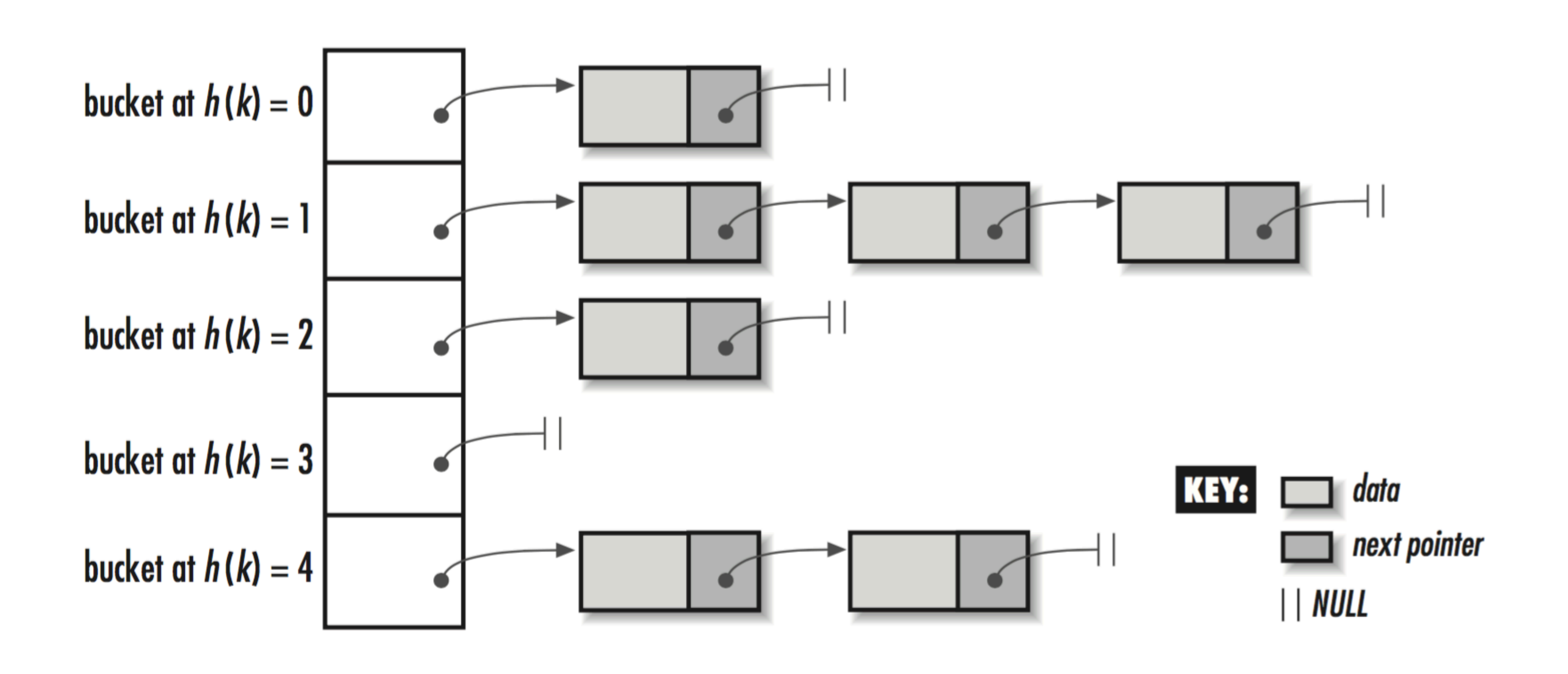
Discuss with neighbors

- What is the Big O of traversing a given list of words?
- What is the Big O of insertion into the hash table.

Now let's take a deep dive...

- Hash tables can have many considerations.
- Most of these are abstracted away from you.
- But more in depth thought is good CS and systems architecture practice.

When *h(k)* collides: chained hash tables [100]



[100] Loudon, K. Mastering Algorithms in C. Pg. 143

Discuss with neighbors

What are the data structures in this diagram?

Where are the bottle necks?

Big O for chained hash tables, part 1:

Given the following variables, we obtain [101]:

- k Table size (the size of the array)
- n Number of keys

$$O(1 + \frac{n}{k})$$

[101] Wikipedia on hash table performance analysis

Big O for chained hash tables, part 2:

In the case of a huge table, we have

$$k >> n$$

which yields

$$\frac{n}{k} \approx 0$$

But if you have

- A crappy hash function
- A small table
- A lot of collisions

Then this means something is wrong and once again, you will get.

$$O(n)$$

A truly sad day indeed. But you don't need to worry about that.

Thankfully

this is taken care of for you!

The point is that I wanted you to see that the analysis can go deep.

- Defined what a key value pair is
- Defined what a hash function is
- Stated the big O for:
  1. Linear array searches
  2. Hashing a key
  3. Addressing an array by numeric index.
- Used hash tables for fast data lookups in *O(1)* time
- Saw Rigorous Big O analysis on complex data structures