Hash Tables and Hashing

CS 214, Fall 2019

Dictionary data structures we have seen, with lookup times and a special case

- (Balanced) binary search tree — $\mathcal{O}(\log n)$
- Sorted array — $\mathcal{O}(\log n)$
- List of associations — $\mathcal{O}(n)$

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- (Balanced) binary search tree — $\mathcal{O}(\log n)$
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- List of associations — $\mathcal{O}(n)$
- An array using keys (0, 1, …, $k-1$) as indices — $\mathcal{O}(1)$

The last of these is sometimes called "direct addressing"

A direct addressing example

Suppose we want to map digits to their names in English:

```
let digits = ['zero', 'one', 'two', 'three', 'four',
              'five', 'six', 'seven', 'eight', 'nine']

def get_digit_name(name: int?) -> str?:
    digits[name]
```

Non-direct addressing example: phone book

A phone book is a dictionary where the keys are names and the values are phone numbers

How can we use names (strings) as keys?

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How can we use names (strings) as keys?

Let's map strings to small integer keys by using the value of the first character

The first-character hash

(bucket)	name	phone
(0)	`"Alice"`	555–1212
(1)	⊘	⊘
(2)	`"Carol"`	555–1214
(3)	⊘	⊘
	⋮	
(24)	`"Yves"`	555–1215
(25)	⊘	⊘

The first-character hash

(bucket)	name	phone
(0)	"Alice"	555–1212
(1)	⊘	⊘
(2)	"Carol"	555–1214
(3)	⊘	⊘
	⋮	
(24)	"Yves"	555–1215
(25)	⊘	⊘

What happens when we want to add Charles to the phonebook?

Hash collision!

The function that maps names to numbers is called a *hash function*:

$$h(\texttt{"Alice"}) = 0$$
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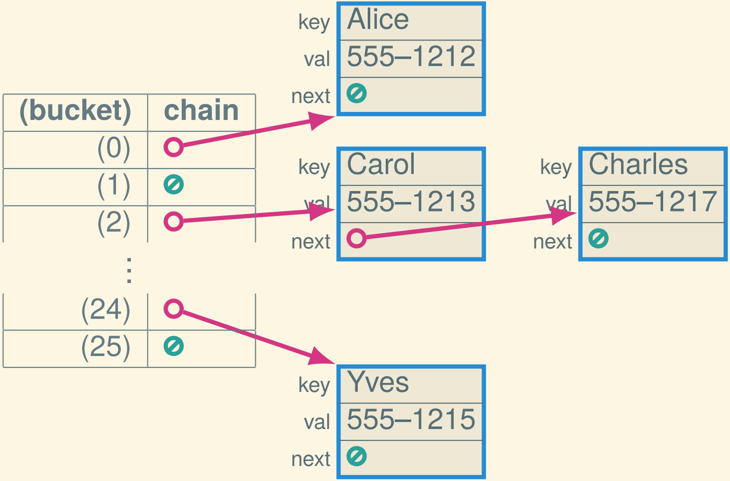
$$h(\texttt{"Charles"}) = 2$$

How do we resolve it?

Two solutions to hash collision

1. Store a linked list in each bucket (*separate chaining*)
2. Use the next free bucket instead (*open addressing*)

Separate chaining hash table



Open addressing hash table

(bucket)	name	phone
(0)	"Alice"	555–1212
(1)	⊘	⊘
(2)	"Carol"	555–1214
(3)	"Charles"	555–1217
(4)	⊘	⊘
⋮		
(24)	"Yves"	555–1215
(25)	⊘	⊘

What happens as the table fills up

- Separate chaining: the length of the chains is $\mathcal{O}(n)$
- Open addressing: the length of the scan is $\mathcal{O}(n)$

Thus, it's important to have enough buckets

Our hash function sucks

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Here's a better hash function:

Input: A string *str* and number of buckets *buckets*
Output: A hash code between 0 and $\textit{buckets} - 1$

$\textit{hash} \leftarrow 1$;

for each character *c* in *str* do
| $\textit{hash} \leftarrow 31 \times \textit{hash} + c$
end

return *hash* % *buckets*

What makes a good hash function?

Hash functions are big topic—what you need to know:

- deterministic (not random)
- uniform (not clustery)

Load

For good performance, we can't let the table get too full

One way to think of this is the *load factor*:

$$\text{load factor} = \frac{n}{k}$$

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For separate chaining, we should keep the load factor < 2

For open addressing, we should keep the load factor < 0.75

Resizing

When the load factor gets too high, we need to grow the table

- Requires rehashing everything!
- Doubles in size (like dynamic array)

Next time: Big-O notation