122COM: Searching

David Croft

Coventry University

david.croft@coventry.ac.uk

2017

Overview

1 Introduction

2 Linear search

3 Binary search

4 String searching

5 Quiz

6 Recap

Introduction

I

Searching is used everywhere in computing.

- Obvious applications.
  - Text files.
  - Databases.
  - File systems.
  - Search engines.
- Hidden applications.
  - Computer games.
    - Field Of View (FOV) search for objects in view.
    - Path finding `https://www.youtube.com/watch?v=19h1g22hby8`.
  - Network routing.
  - Sat Nav.
  - Recommender systems.
    - Netflix What-to-watch.
    - Amazon recommended items.

Linear search

C

Simplest searching algorithm.

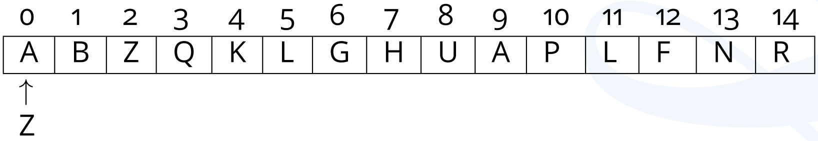
- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn’t in the sequence at all.
- ● $O(n)$
  - Will discuss $O()$ notation in a later week.

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn't in the sequence at all.
- ● $O(n)$
  - Will discuss $O()$ notation in a later week.



0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn’t in the sequence at all.

● *O*(*n*)
  - Will discuss *O*() notation in a later week.

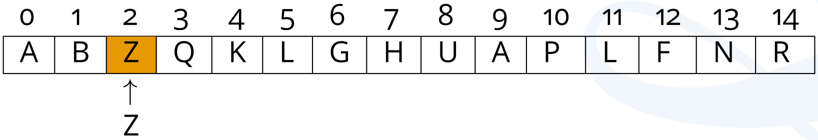
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R
	↑ Z													

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn't in the sequence at all.
- $O(n)$
  - Will discuss *O*() notation in a later week.



0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn't in the sequence at all.

● $O(n)$

  - Will discuss $O()$ notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

↑

R

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn’t in the sequence at all.
- ● $O(n)$
  - Will discuss $O()$ notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

↑

R

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn't in the sequence at all.

● $O(n)$

- Will discuss $O()$ notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

↑

R

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn't in the sequence at all.

● $O(n)$

- Will discuss $O()$ notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

↑
R

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn't in the sequence at all.

● $O(n)$

  - Will discuss $O()$ notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R
				↑										
				R										

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
    - Worst case if the value isn't in the sequence at all.

● *O*(*n*)

- Will discuss *O*() notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

↑
R

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
    - Worst case if the value isn't in the sequence at all.

● $O(n)$
- Will discuss *O*() notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

↑

R

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn't in the sequence at all.

● $O(n)$

  - Will discuss *O*() notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R
							↑ R							

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn't in the sequence at all.

● $O(n)$

  - Will discuss $O()$ notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

↑

R

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn’t in the sequence at all.

● $O(n)$

  - Will discuss $O()$ notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

↑

R

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
    - Worst case if the value isn't in the sequence at all.

● $O(n)$

- Will discuss $O()$ notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

↑

R

Coventry University

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn't in the sequence at all.

● $O(n)$

  - Will discuss $O()$ notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

↑

R

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn't in the sequence at all.

● $O(n)$
  - Will discuss $O()$ notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R
												↑ R		

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn't in the sequence at all.

● $O(n)$
  - Will discuss $O()$ notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

↑

R

Linear search

C

Simplest searching algorithm.

- Also called sequential search.
- Iterate over elements.
- Until found or until end of sequence.
- Potentially slow.
  - Worst case if the value isn't in the sequence at all.

● $O(n)$

  - Will discuss *O*() notation in a later week.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	Z	Q	K	L	G	H	U	A	P	L	F	N	R

↑

R

Binary search

I

A Divide & conquer algorithm.

- Pro: Muuuuuuch faster than linear search.
- Con: Only works on sorted sequences.
- The algorithm:
  1. Find middle value of the sequence.
  2. If search value == middle value then success.
  3. If search value is $<$ middle value then forget about the top half of the sequence.
  4. If search value is $>$ middle value then forget about the bottom half of the sequence.
  5. Repeat from step 1 until `len(sequence)==0`.

Binary search II

I

Find E.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

Binary search II

I

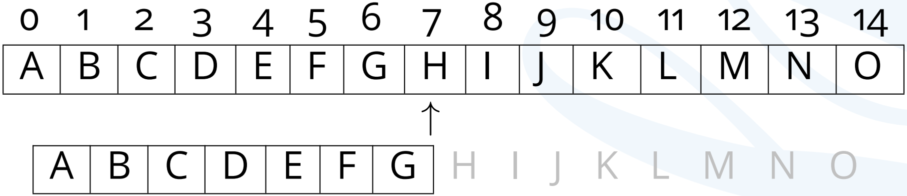
Find E.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
							↑							

Binary search II

I

Find E.



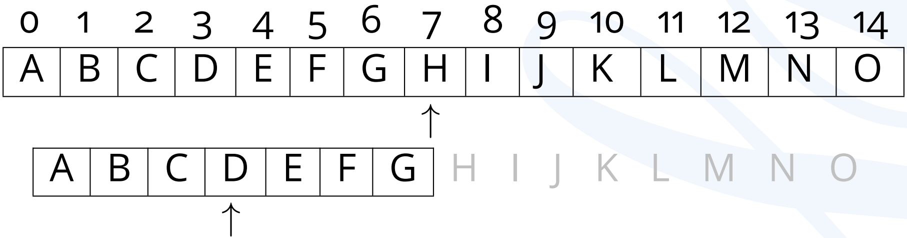
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

A B C D E F G H I J K L M N O

Binary search II

I

Find E.



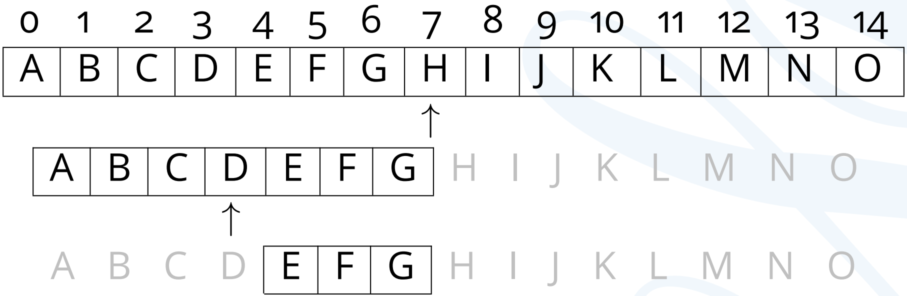
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
							↑							

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
			↑											

Binary search II

I

Find E.

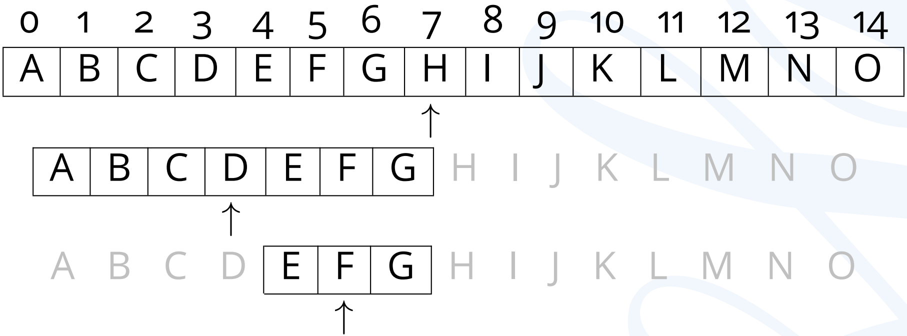


0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

Binary search II

I

Find E.



0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

↑

A B C D E F G H I J K L M N O

↑

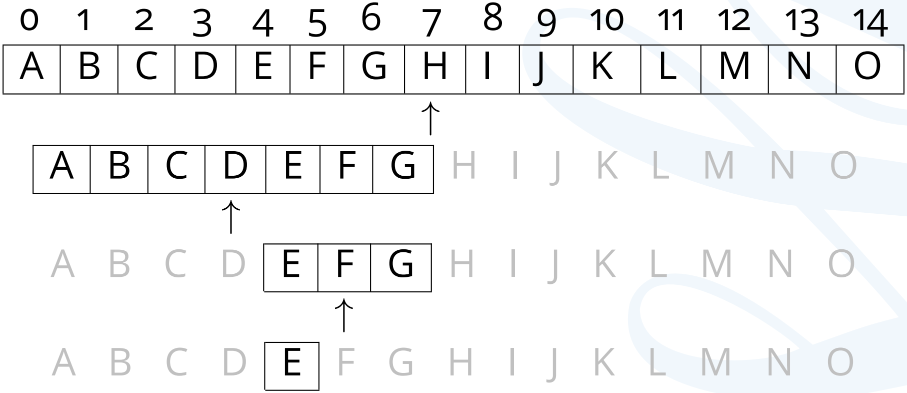
A B C D E F G H I J K L M N O

↑

Binary search II

I

Find E.



0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

↑

A B C D E F G H I J K L M N O

↑

A B C D E F G H I J K L M N O

↑

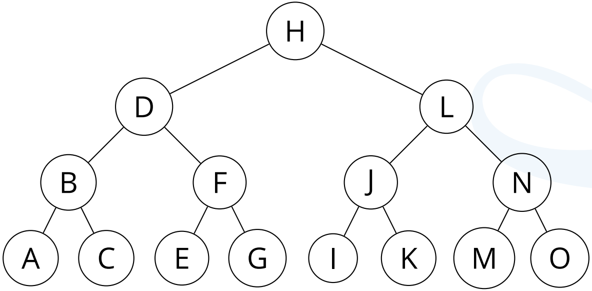
A B C D E F G H I J K L M N O

Complexity

A

Maximum number of comparisons needed? Binary Search Trees.

- How many times can we divide our sequence in half?

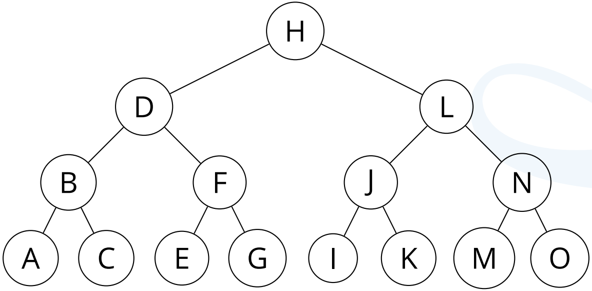


Complexity

A

Maximum number of comparisons needed? Binary Search Trees.

- How many times can we divide our sequence in half?
- Ideal depth of the tree is $\log_2(n)$
  - $n = 15$ in this example.
  - $\log_2(15) = 3.9 \Rightarrow 3$

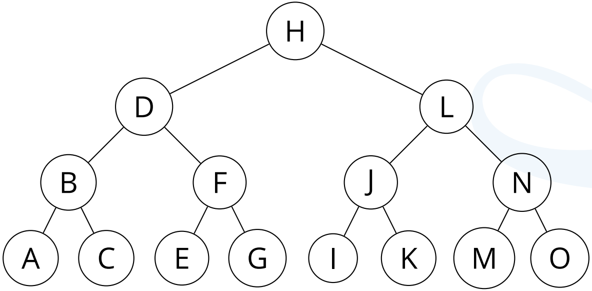


Complexity

A

Maximum number of comparisons needed? Binary Search Trees.

- How many times can we divide our sequence in half?
- Ideal depth of the tree is $\log_2(n)$
  - $n = 15$ in this example.
  - $\log_2(15) = 3.9 \Rightarrow 3$
- Binary search has a complexity of $O(\log n)$.
  - Will cover $O()$ complexity in later week.

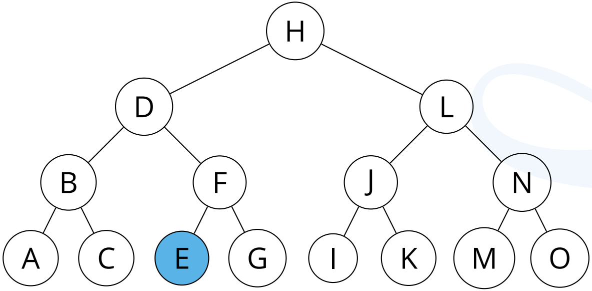


Complexity

A

Maximum number of comparisons needed? Binary Search Trees.

- How many times can we divide our sequence in half?
- Ideal depth of the tree is $\log_2(n)$
  - $n = 15$ in this example.
  - $\log_2(15) = 3.9 \Rightarrow 3$
- Binary search has a complexity of $O(\log n)$.
  - Will cover $O()$ complexity in later week.
- Find E.

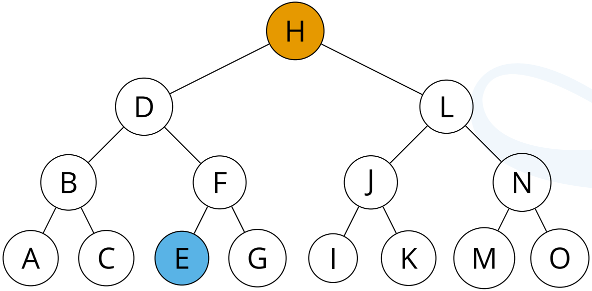


Complexity

A

Maximum number of comparisons needed? Binary Search Trees.

- How many times can we divide our sequence in half?
- Ideal depth of the tree is $\log_2(n)$
  - $n = 15$ in this example.
  - $\log_2(15) = 3.9 \Rightarrow 3$
- Binary search has a complexity of $O(\log n)$.
  - Will cover $O()$ complexity in later week.
- Find E.

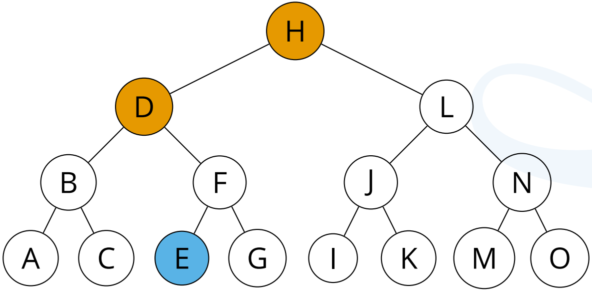


Complexity

A

Maximum number of comparisons needed? Binary Search Trees.

- How many times can we divide our sequence in half?
- Ideal depth of the tree is $\log_2(n)$
  - $n = 15$ in this example.
  - $\log_2(15) = 3.9 \Rightarrow 3$
- Binary search has a complexity of $O(\log n)$.
  - Will cover $O()$ complexity in later week.
- Find E.

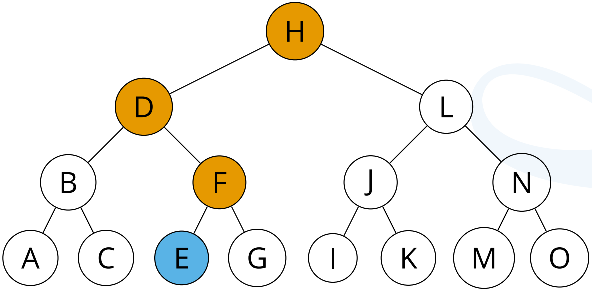


Complexity

A

Maximum number of comparisons needed? Binary Search Trees.

- How many times can we divide our sequence in half?
- Ideal depth of the tree is $\log_2(n)$
  - $n = 15$ in this example.
  - $\log_2(15) = 3.9 \Rightarrow 3$
- Binary search has a complexity of $O(\log n)$.
  - Will cover $O()$ complexity in later week.
- Find E.



It’s HOW much faster?!?!!

I

Clearly much faster than linear search.

- To search a trillion elements linearly could mean a trillion comparisons.
- Binary search does it in 39.

But...

- Have to sort the list first.
- Sorting lists can be expensive.
  - Will cover sorting in a later week.
- Can’t always sort sequences.
- Ordering can be important.
  - E.g. Words in text documents.
  - E.g. Genes in genetic chromosomes.

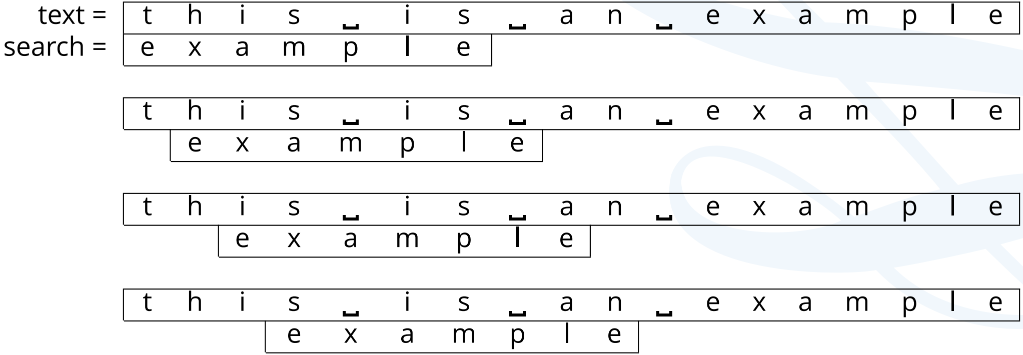
Break

String searching

C

I.e. Text searching.

- Finding one sequence in another sequence.
- Naive search.
  - Like linear search but with multiple values to compare.
  - Is very slow.



```
  text = t h i s ␣ i s ␣ a n ␣ e x a m p l e
search = e x a m p l e

         t h i s ␣ i s ␣ a n ␣ e x a m p l e
           e x a m p l e

         t h i s ␣ i s ␣ a n ␣ e x a m p l e
             e x a m p l e

         t h i s ␣ i s ␣ a n ␣ e x a m p l e
               e x a m p l e
```

etc, etc, etc.

Quiz

Q1

By what other name is linear search known?

1. Divide & Conquer.
2. Binary search.
3. Sequential search.
4. Path finding.

Q1

By what other name is linear search known?

1. Divide & Conquer.
2. Binary search.
3. Sequential search.
4. Path finding.

Q2

What is the downside of binary search compared to linear?

1. Can only search sequences.
2. Can only search numbers.
3. Can only search sorted sequences.
4. Can only search an even number of things.

Q2

What is the downside of binary search compared to linear?

1. Can only search sequences.
2. Can only search numbers.
3. Can only search sorted sequences.
4. Can only search an even number of things.

Q3

Binary search is faster than linear search because ______.

1. No it isn’t.
2. It only searches 1s and 0s.
3. It only searches two things.
4. It’s a divide & conquer algorithm.

Q3

Binary search is faster than linear search because ______.

1. No it isn't.
2. It only searches 1s and 0s.
3. It only searches two things.
4. It's a divide & conquer algorithm.

Q4

The $O()$ complexity of binary search is _____.

1. $O(n)$
2. It depends on how many elements are being searched.
3. $O(\log n)$
4. $O(n!)$

Q4

The $O()$ complexity of binary search is ____.

1. $O(n)$
2. It depends on how many elements are being searched.
3. $O(\log n)$
4. $O(n!)$

Why do I care?

Everyone

- Searching algorithms are key to understanding many data type.
    - I.e. sets and maps/dicts.
- Key to writing efficient code.
- Key to understanding memory/processor trade offs.

Recap

- 🟢 Searching
  - Applications everywhere.
- 🟢 Linear search.
  - Simple.
  - Slow.
- 🟡 Binary search.
  - Ordered sequence.
  - Very fast.
  - Divide & Conquer.
- 🟢 String searching.
  - Finding subsequence in sequence.
  - 🔴 Boyer-Moore.

The End