Binary Search

Efficient Searching Through Halves

Recap: Linear Search Complexity

- Best Case
  - target = **3**, List = [**3**, 6, 4, 9, 2]
  - O(1) → Constant time

Recap: Linear Search Complexity

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  - target = 3, List = [3, 6, 4, 9, 2]
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  - target = **2 or ?**, List = [3, 6, 4, 9, **2**]

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- Average Case
  - target = **4**, List = [3, 6, **4**, 9, 2]

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  - target = 3, List = [3, 6, 4, 9, 2]
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  - O(n) → Linear time
- Average Case
  - target = **4**, List = [3, 6, **4**, 9, 2]
  - n/2 ≈ O(n) → Linear time

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  - O(n) → Linear time
- **Average Case**
  - target = 4, List = [3, 6, 4, 9, 2]
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From Linear to Binary Search: A Faster Way

- **Recap Linear Search:**
  - Checks each element in a list one by one

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  - Imagine searching through 1 million records

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  - For 1 million items, Binary Search takes around **20 steps at most**
- **Setting up the Challenge:**
  - Let's explore this idea with a number guessing game
  - Imagine thinking of a number from a list of 16 sorted numbers
  - Can you guess it in no more than **4 attempts?**

Binary Search: Finding a Number in Sorted List

Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
List	3	7	12	18	23	27	30	35	40	45	50	54	60	65	70	72

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We are thinking of
12

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Calculate middle index
mid = (first + last) // 2

1. mid = (0 + 15) // 2 = **7**

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Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
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Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
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Is **12 == 35?** Yes, Greater, Less? **Less**

We are thinking of
12

Calculate middle index
mid = (first + last) // 2

1. mid = (0 + 15) // 2 = **7**

Binary Search: Finding a Number in Sorted List

Index	0	1	2	3	4	5	6
List	3	7	12	18	23	27	30

We are thinking of
12

Calculate middle index
mid = (first + last) // 2

1. mid = (0 + 15) // 2 = **7**

Is **12 == 35?** Yes, Greater, Less? **Less**

Binary Search: Finding a Number in Sorted List

Index	0	1	2	3	4	5	6
List	3	7	12	18	23	27	30

Is **12 == 35?** Yes, Greater, Less? **Less**

We are thinking of
12

Calculate middle index
mid = (first + last) // 2

1. mid = (0 + 15) // 2 = **7**

2. mid = (0 + 6) // 2 = **3**

Binary Search: Finding a Number in Sorted List

Index	0	1	2	3	4	5	6
List	3	7	12	18	23	27	30

Is **12 == 35?** Yes, Greater, Less? **Less**

We are thinking of
12

Calculate middle index
mid = (first + last) // 2

1. mid = (0 + 15) // 2 = **7**

2. mid = (0 + 6) // 2 = **3**

Binary Search: Finding a Number in Sorted List

Index	0	1	2	3	4	5	6
List	3	7	12	18	23	27	30

Is **12 == 18?** Yes, Greater, Less? **Less**

We are thinking of
12

Calculate middle index
mid = (first + last) // 2

1. mid = (0 + 15) // 2 = **7**

2. mid = (0 + 6) // 2 = **3**

Binary Search: Finding a Number in Sorted List

Index	0	1	2
List	3	7	12

Is **12 == 18?** Yes, Greater, Less? **Less**

We are thinking of
12

Calculate middle index
mid = (first + last) // 2

1. mid = (0 + 15) // 2 = **7**

2. mid = (0 + 6) // 2 = **3**

Binary Search: Finding a Number in Sorted List

Index	0	1	2
List	3	7	12

Is **12 == 18?** Yes, Greater, Less? **Less**

We are thinking of
12

Calculate middle index
mid = (first + last) // 2

1. mid = (0 + 15) // 2 = **7**

2. mid = (0 + 6) // 2 = **3**

3. mid = (0 + 2) // 2 = **1**

Binary Search: Finding a Number in Sorted List

Index	0	1	2
List	3	7	12

Is **12 == 18?** Yes, Greater, Less? **Less**

We are thinking of
12

Calculate middle index
mid = (first + last) // 2

1. mid = (0 + 15) // 2 = **7**

2. mid = (0 + 6) // 2 = **3**

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Binary Search: Finding a Number in Sorted List

Index	0	1	2
List	3	7	12

Is **12 == 7?** Yes, Greater, Less? **Greater**

We are thinking of
12

Calculate middle index
mid = (first + last) // 2

1. **mid** = (0 + 15) // 2 = **7**
2. **mid** = (0 + 6) // 2 = **3**
3. **mid** = (0 + 2) // 2 = **1**

Binary Search: Finding a Number in Sorted List

Index		2	
List		12	

Is **12 == 7?** Yes, Greater, Less? **Greater**

We are thinking of
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Calculate middle index
mid = (first + last) // 2

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Binary Search: Finding a Number in Sorted List

Index		2	
List		12	

Is **12 == 7?** Yes, Greater, Less? **Greater**

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12

Calculate middle index
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Binary Search: Finding a Number in Sorted List

Index		2
List		12

Is **12 == 7?** Yes, Greater, Less? **Greater**

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12

Calculate middle index
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Binary Search: Finding a Number in Sorted List

Index		2	
List		12	

Is **12 == 12?** Yes, Greater, Less? **Yes**

We are thinking of

12

Calculate middle index

mid = (first + last) // 2

1. **mid** = (0 + 15) // 2 = **7**
2. **mid** = (0 + 6) // 2 = **3**
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Binary Search: Finding a Number in Sorted List

Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
List	3	7	12	18	23	27	30	35	40	45	50	54	60	65	70	72

Input Size: **16**

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Input Size: **16**

Total Comparisons: **4**

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Binary Search: Finding a Number in Sorted List

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Linear Search: Comparisons $\propto$ Input Size

Binary Search: Finding a Number in Sorted List

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Linear Search: Comparisons ∝ Input Size

1

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1 **1**

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Binary Search: Comparisons **?** Input Size

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Linear Search: Comparisons $\propto$ Input Size

Comparisons	Input Size
1	**1**
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n	**n**

$\Rightarrow$ **O(n)**

Binary Search: Comparisons **?** Input Size

Comparisons	Input Size
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Linear Search: Comparisons ∝ Input Size

Comparisons	Input Size
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10	**10**
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Binary Search: Comparisons **?** Input Size

Comparisons	Input Size
4	**16**
?	**n**

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Linear Search: Comparisons $\propto$ Input Size

Comparisons	Input Size	
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10	**10**	
n	**n**	$\Rightarrow$ **O(n)**

Binary Search: Comparisons **?** Input Size

Comparisons	Input Size	
4	**16**	
?	**n**	$\Rightarrow$ $\boxed{\textbf{O(lgn)}}$

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Input Size: **16**

Total Comparisons: **4**

Linear Search: Comparisons ∝ Input Size

1 **1**

10 **10**

n **n** ⇒ **O(n)**

What is n?

Binary Search: Comparisons **?** Input Size

4 **16**

? **n** ⇒ $\boxed{\textbf{O(lgn)}}$

Binary Search: Finding a Number in Sorted List

Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
List	3	7	12	18	23	27	30	35	40	45	50	54	60	65	70	72

We are thinking of
12

Calculate middle index
mid = (first + last) // 2

1. **mid** = (0 + 15) // 2 = **7**
2. **mid** = (0 + 6) // 2 = **3**
3. **mid** = (0 + 2) // 2 = **1**
4. **mid** = (2 + 2) // 2 = **2**

What is n? → **16**

Input Size: **16**

Total Comparisons: **4**

Linear Search: Comparisons ∝ Input Size

1 **1**

10 **10**

n **n** ⇒ **O(n)**

Binary Search: Comparisons **?** Input Size

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10 **10**

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Comparisons?

Binary Search: Comparisons **?** Input Size

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Linear Search: Comparisons ∝ Input Size

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10 **10**
n **n** ⇒ **O(n)**

What is n? → **16**
Comparisons? → **4**

Binary Search: Comparisons **?** Input Size

4 **16**
? **n** ⇒ $\boxed{\textbf{O(lgn)}}$

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Linear Search: Comparisons ∝ Input Size

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10 **10**

n **n** ⇒ **O(n)**

What is n? → **16**
Comparisons? → **4**
What is lgn → **lg16**?

Binary Search: Comparisons **?** Input Size

4 **16**

? **n** ⇒ $\boxed{\textbf{O(lgn)}}$

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Input Size: **16**

Total Comparisons: **4**

Linear Search: Comparisons ∝ Input Size

Comparisons	Input Size	
1	1	
10	10	
n	n	⇒ O(n)

What is n? → **16**
Comparisons? → **4**
What is lgn → **lg16**?
Must know base?

Binary Search: Comparisons **?** Input Size

Comparisons	Input Size	
4	16	
?	n	⇒ $\boxed{O(\lg n)}$

Binary Search: Finding a Number in Sorted List

Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
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Input Size: **16**
Total Comparisons: **4**

Linear Search: Comparisons ∝ Input Size

Comparisons	Input Size	
1	**1**	
10	**10**	
n	**n**	⇒ **O(n)**

What is n? → **16**
Comparisons? → **4**
What is lgn → **lg16**?
Must know base? → **2**

Binary Search: Comparisons **?** Input Size

Comparisons	Input Size	
4	**16**	
?	**n**	⇒ $\boxed{\textbf{O(lgn)}}$

Binary Search: Finding a Number in Sorted List

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Linear Search: Comparisons ∝ Input Size

1 **1**

10 **10**

n **n** ⇒ **O(n)**

Binary Search: Comparisons **?** Input Size

4 **16**

? **n** ⇒ $\boxed{\textbf{O(lgn)}}$

What is n? → **16**
Comparisons? → **4**
What is lgn → **lg16**?
Must know base? → **2**
What is lgn → $\mathbf{lg_2 16}$?

Binary Search: Finding a Number in Sorted List

Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
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Input Size: **16**

Total Comparisons: **4**

Linear Search: Comparisons ∝ Input Size

Comparisons	Input Size	
1	**1**	
10	**10**	
n	**n**	⇒ **O(n)**

Binary Search: Comparisons **?** Input Size

Comparisons	Input Size	
4	**16**	
?	**n**	⇒ $\boxed{\textbf{O(lgn)}}$

What is n? → **16**
Comparisons? → **4**
What is lgn → **lg16**?
Must know base? → **2**
What is lgn → **$lg_2 16$**? ⇒
What **power of base** (2) will give **16**?

Binary Search: Finding a Number in Sorted List

Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
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Linear Search: Comparisons ∝ Input Size

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10 **10**

n **n** ⇒ **O(n)**

Binary Search: Comparisons **?** Input Size

4 **16**

? **n** ⇒ $\boxed{\textbf{O(lgn)}}$

What is n? → **16**
Comparisons? → **4**
What is lgn → **lg16**?
Must know base? → **2**
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What **power of base** (2)
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Binary Search: Finding a Number in Sorted List

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Input Size: **16**
Total Comparisons: **4**

Linear Search: Comparisons ∝ Input Size

Comparisons	Input Size	
1	1	
10	10	
n	n	⇒ O(n)

Binary Search: Comparisons **?** Input Size

Comparisons	Input Size	
4	16	
?	n	⇒ $\boxed{O(\lg n)}$

What is n? → **16**
Comparisons? → **4**
What is lgn → **lg16**?
Must know base? → **2**
What is lgn → $\lg_2 16$? ⇒
What **power of base** (2) will give **16**? ⇒ **4**, i.e. $2^4 = 16$

Binary Search: Finding a Number in Sorted List

Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
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Input Size: **16**

Total Comparisons: **4**

Linear Search: Comparisons ∝ Input Size

Comparisons	Input Size
1	**1**
10	**10**
n	**n**

⇒ **O(n)**

Binary Search: Comparisons **?** Input Size

Comparisons	Input Size
4	**16**
?	**n**

⇒ $\boxed{O(\lg n)}$

What is n? → **16**
Comparisons? → **4**
What is lgn → **lg16**?
Must know base? → **2**
What is lgn → $\lg_2 16$? ⇒
What **power of base** (2) will give **16**? ⇒ **4**, i.e. $2^4 = 16$

$\therefore \lg_2 n = \lg_2 16 = 4$

Binary Search: Finding a Number in Sorted List

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Input Size: **16**
Total Comparisons: **4**

Linear Search: Comparisons ∝ Input Size

1 **1**
10 **10**
n **n** ⇒ **O(n)**

Binary Search: Comparisons **?** Input Size

4 **16**
? **n** ⇒ $\boxed{\textbf{O(lgn)}}$

log is also written as lg

What is n? → **16**
Comparisons? → **4**
What is lgn → **lg16**?
Must know base? → **2**
What is lgn → $\lg_2 16$? ⇒
What **power of base** (2) will give **16**? ⇒ **4**, i.e. $2^4 = 16$

$\therefore \lg_2 n = \lg_2 16 = 4$

Binary Search: Finding a Number in Sorted List

Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
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Input Size: **16**
Total Comparisons: **4**

Linear Search: Comparisons ∝ Input Size

Comparisons	Input Size	
1	1	
10	10	
n	n	⇒ O(n)

lgn vs lgn +1

Binary Search: Comparisons **?** Input Size

Comparisons	Input Size	
4	16	
?	n	⇒ $\boxed{O(\lg n)}$

log is also written as lg

What is n? → **16**
Comparisons? → **4**
What is lgn → **lg16**?
Must know base? → **2**
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What **power of base** (2) will give **16**? ⇒ **4**, i.e. $2^4 = 16$

$\therefore \lg_2 n = \lg_2 16 = 4$

Linear vs. Binary Search: Comparing Steps with Input Growth

Input Size (n)	Linear Search	Binary Search
8	8	$\lg_2 8$ = **3**
16	16	$\lg_2 16$ =
32	32	$\lg_2 32$ =
64	64	$\lg_2 64$ =
...	...	...
1024	1024	$\lg_2 1024$ =
2048	2048	$\lg_2 2048$ =
...	...	...
1048576	1048576	$\lg_2 1048576$ =

Linear vs. Binary Search: Comparing Steps with Input Growth

Input Size (n)	Linear Search	Binary Search
8	8	$\lg_2 8$ = **3**
16	16	$\lg_2 16$ =
32	32	$\lg_2 32$ =
64	64	$\lg_2 64$ =
...	...	...
1024	1024	$\lg_2 1024$ =
2048	2048	$\lg_2 2048$ =
...	...	...
1048576	1048576	$\lg_2 1048576$ =

Linear vs. Binary Search: Comparing Steps with Input Growth

Input Size (n)	Linear Search	Binary Search
8	8	$\lg_2 8 =$ **3**
16	16	$\lg_2 16 =$ **4**
32	32	$\lg_2 32 =$ **5**
64	64	$\lg_2 64 =$ **6**
…	…	…
1024	1024	$\lg_2 1024 =$
2048	2048	$\lg_2 2048 =$
…	…	…
1048576	1048576	$\lg_2 1048576 =$

Linear vs. Binary Search: Comparing Steps with Input Growth

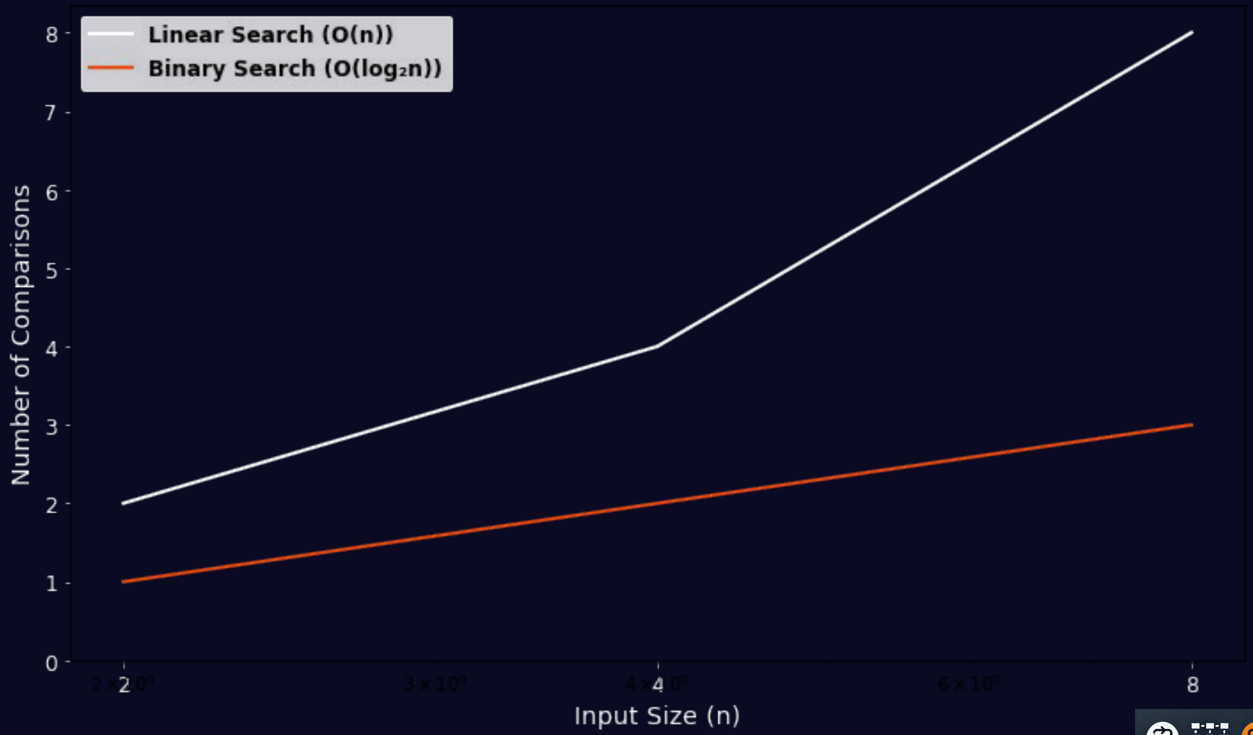
Input Size (n)	Linear Search	Binary Search
8	8	$lg_2 8 =$ **3**
16	16	$lg_2 16 =$ **4**
32	32	$lg_2 32 =$ **5**
64	64	$lg_2 64 =$ **6**
…	…	…
1024	1024	$lg_2 1024 =$ **10**
2048	2048	$lg_2 2048 =$ **11**
…	…	…
1048576	1048576	$lg_2 1048576 =$

Linear vs. Binary Search: Comparing Steps with Input Growth

Input Size (n)	Linear Search	Binary Search
8	8	$lg_2 8$ = **3**
16	16	$lg_2 16$ = **4**
32	32	$lg_2 32$ = **5**
64	64	$lg_2 64$ = **6**
…	…	…
1024	1024	$lg_2 1024$ = **10**
2048	2048	$lg_2 2048$ = **11**
…	…	…
1048576	1048576	$lg_2 1048576$ = **20**

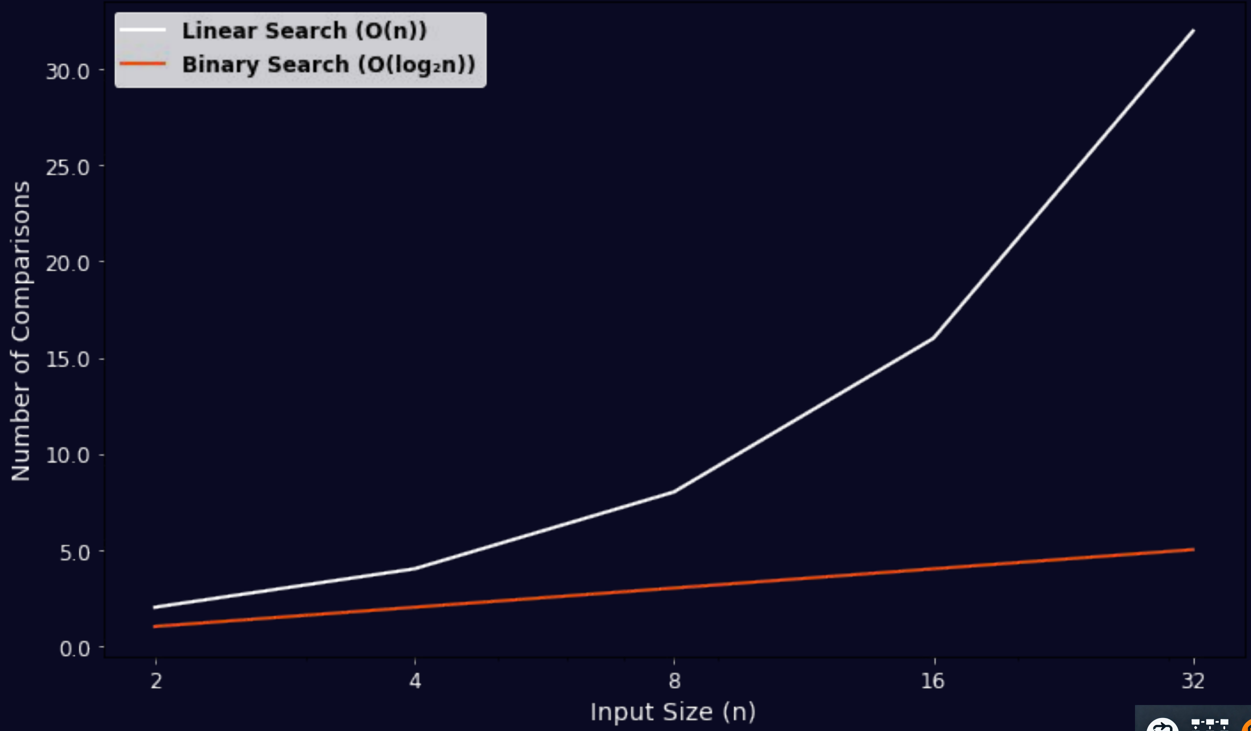
Linear vs. Binary Search: Comparing Steps with Input Growth

Input Size (n)	Linear Search	Binary Search
8	8	$\lg_2 8 =$ **3**
16	16	$\lg_2 16 =$ **4**
32	32	$\lg_2 32 =$ **5**
64	64	$\lg_2 64 =$ **6**
...	...	...
1024	1024	$\lg_2 1024 =$ **10**
2048	2048	$\lg_2 2048 =$ **11**
...	...	...
1048576	1048576	$\lg_2 1048576 =$ **20**



Linear vs. Binary Search: Comparing Steps with Input Growth

Input Size (n)	Linear Search	Binary Search
8	8	$\lg_2 8$ = **3**
16	16	$\lg_2 16$ = **4**
32	32	$\lg_2 32$ = **5**
64	64	$\lg_2 64$ = **6**
...	...	...
1024	1024	$\lg_2 1024$ = **10**
2048	2048	$\lg_2 2048$ = **11**
...	...	...
1048576	1048576	$\lg_2 1048576$ = **20**



Linear vs. Binary Search: Comparing Steps with Input Growth

Input Size (n)	Linear Search	Binary Search
8	8	$\lg_2 8$ = **3**
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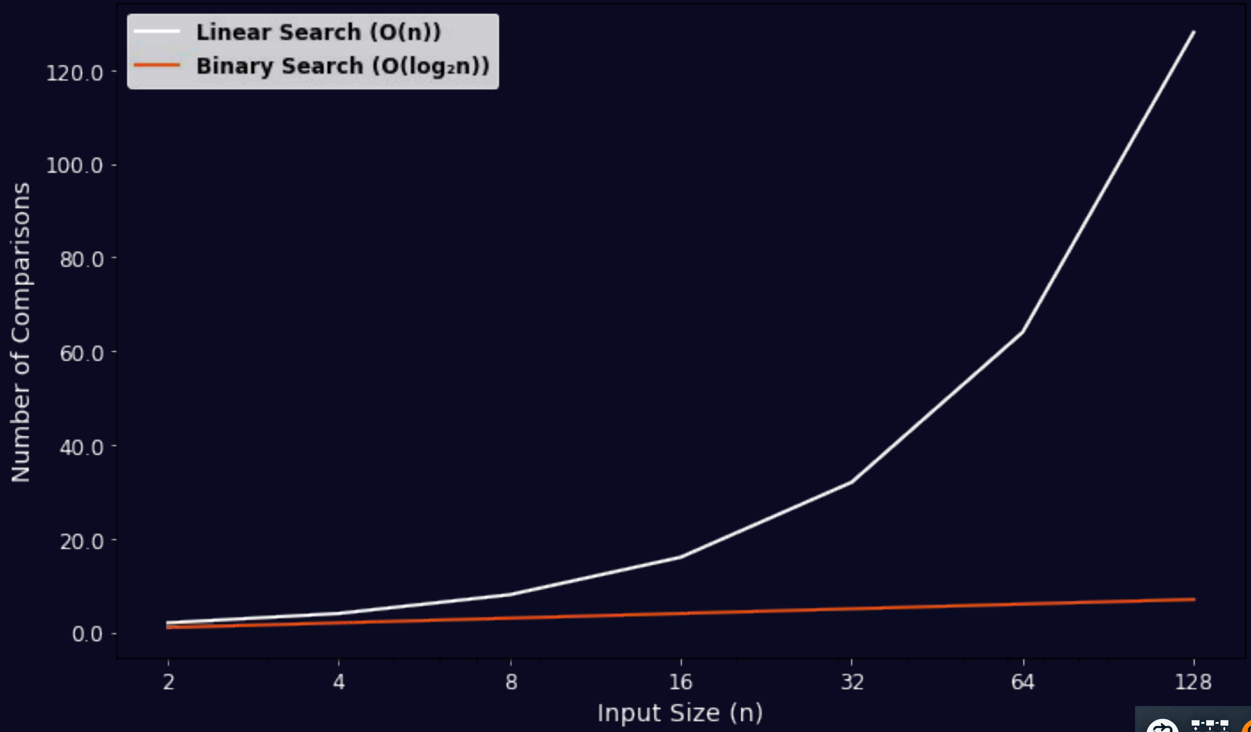
64	64	$\lg_2 64$ = **6**
...	...	...
1024	1024	$\lg_2 1024$ = **10**
2048	2048	$\lg_2 2048$ = **11**
...	...	...
1048576	1048576	$\lg_2 1048576$ = **20**



Linear vs. Binary Search: Comparing Steps with Input Growth

Input Size (n)	Linear Search	Binary Search
8	8	$\lg_2 8$ = **3**
16	16	$\lg_2 16$ = **4**
32	32	$\lg_2 32$ = **5**
64	64	$\lg_2 64$ = **6**
…	…	…
1024	1024	$\lg_2 1024$ = **10**
2048	2048	$\lg_2 2048$ = **11**
…	…	…
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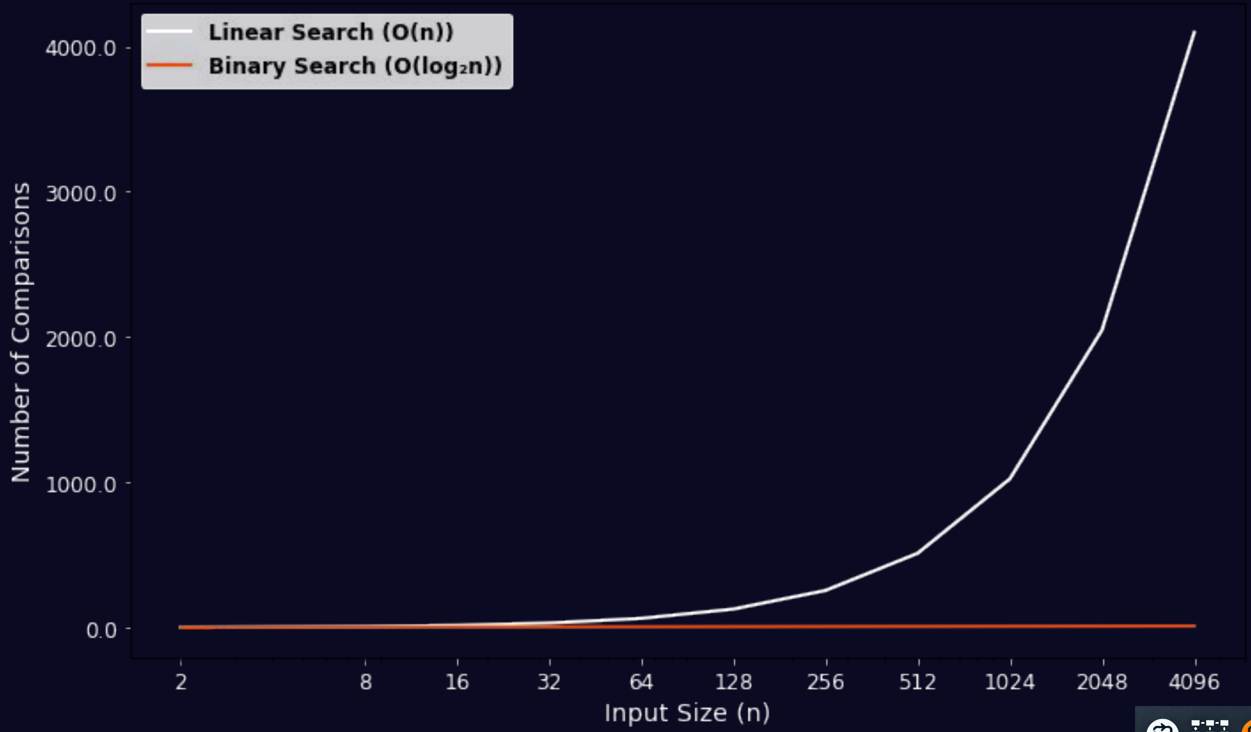
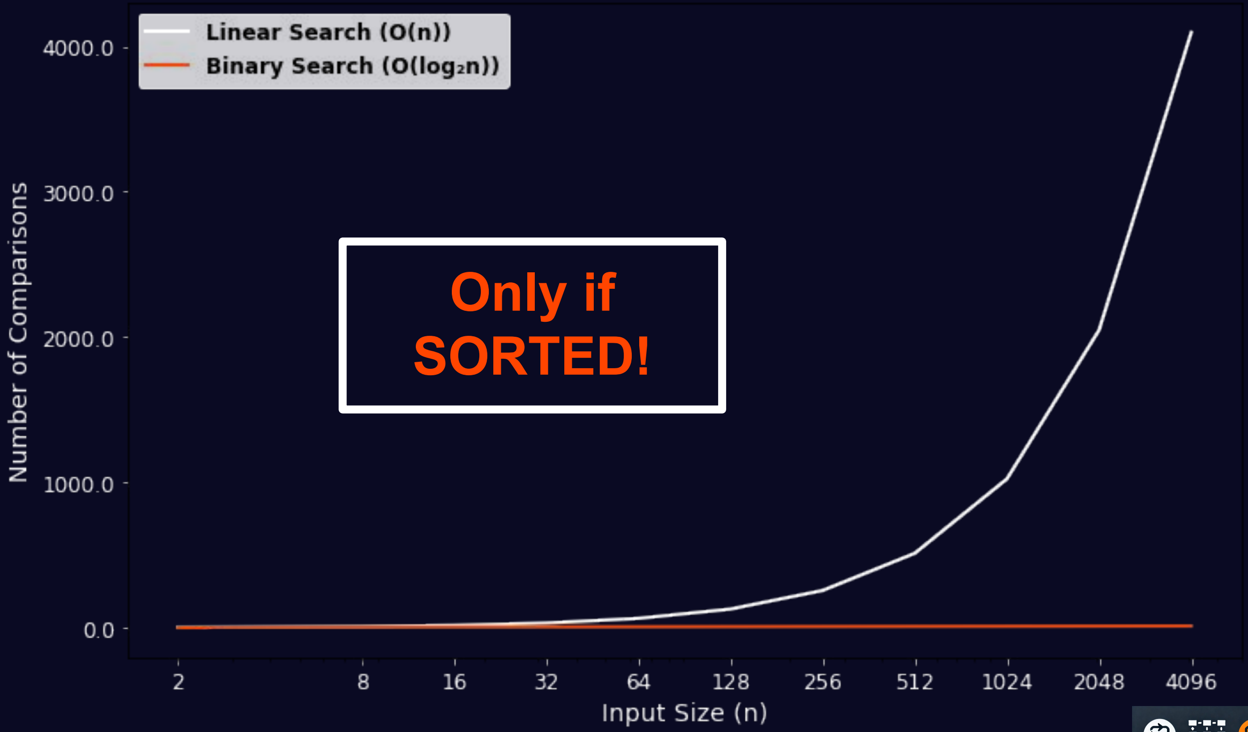


Linear vs. Binary Search: Comparing Steps with Input Growth

Input Size (n)	Linear Search	Binary Search
8	8	$lg_2 8$ = **3**
16	16	$lg_2 16$ = **4**
32	32	$lg_2 32$ = **5**
64	64	$lg_2 64$ = **6**
...	...	...
1024	1024	$lg_2 1024$ = **10**
2048	2048	$lg_2 2048$ = **11**
...	...	...
1048576	1048576	$lg_2 1048576$ = **20**



Binary Search Algorithm

Algorithm BinarySearch

Binary Search Algorithm

Algorithm BinarySearch
Input: A sorted list A, a target value

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Input: A sorted list A, a target value

Index	0	1	2	3	4	5	6	7
List	3	7	12	18	23	27	30	35

Target to Search: **13**

Binary Search Algorithm

Algorithm BinarySearch
Input: A sorted list A, a target value
Output: Index of target in A, or -1 if target is not found

Index	0	1	2	3	4	5	6	7
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Target to Search: **13**

Binary Search Algorithm

Algorithm BinarySearch
Input: A sorted list A, a target value
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Index	0	1	2	3	4	5	6	7
List	3	7	12	18	23	27	30	35

Target to Search: **13**
Expected Output: **-1**

Binary Search Algorithm

Algorithm BinarySearch
Input: A sorted list A, a target value
Output: Index of target in A, or -1 if target is not found

1. Initialize low ← 0, high ← length(A) - 1

low high

Index	0	1	2	3	4	5	6	7
List	3	7	12	18	23	27	30	35

Target to Search: **13**
Expected Output: **-1**
Length of List: **8**

Binary Search Algorithm

low

high

Index	0	1	2	3	4	5	6	7
List	3	7	12	18	23	27	30	35

Algorithm BinarySearch
Input: A sorted list A, a target value
Output: **Index** of **target** in A, or -1 if target is not found

1. Initialize low ← 0, high ← length(A) - 1
2. While low ≤ high do:

Target to Search: **13**
Expected Output: **-1**
Length of List: **8**

Binary Search Algorithm

low high

Index	0	1	2	3	4	5	6	7
List	3	7	12	18	23	27	30	35

Algorithm BinarySearch
Input: A sorted list A, a target value
Output: Index of target in A, or -1 if target is not found

1. Initialize low ← 0, high ← length(A) - 1
2. While low ≤ high do:
    a. Set mid ← (low + high) // 2

Target to Search: **13**
Expected Output: **-1**
Length of List: **8**

Binary Search Algorithm

Algorithm BinarySearch
Input: A sorted list A, a target value
Output: Index of target in A, or -1 if target is not found

1. Initialize low ← 0, high ← length(A) - 1
2. While low ≤ high do:
    a. Set mid ← (low + high) // 2

low mid high

Index	0	1	2	**3**	4	5	6	7
List	3	7	12	18	23	27	30	35

Target to Search: **13**
Expected Output: **-1**
Length of List: **8**

1. mid = (0 + 7) // 2 = **3**

Binary Search Algorithm

low mid high

Index	0	1	2	**3**	4	5	6	7
List	3	7	12	**18**	23	27	30	35

Algorithm BinarySearch
Input: A sorted list A, a target value
Output: **Index** of **target** in A, or **-1** if target is not found

1. Initialize low ← 0, high ← length(A) - 1
2. While low ≤ high do:
    a. Set mid ← (low + high) // 2

Target to Search: **13**
Expected Output: **-1**
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Binary Search Algorithm

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1. Initialize low ← 0, high ← length(A) - 1
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   b. If A[mid] = target then
      return mid

low mid high

Index	0	1	2	**3**	4	5	6	7
List	3	7	12	**18**	23	27	30	35

Target to Search: **13**
Expected Output: **-1**
Length of List: **8**

1. mid = (0 + 7) // 2 = **3**

Binary Search Algorithm

low mid high

Index	0	1	2	3	4	5	6	7
List	3	7	12	**18**	23	27	30	35

Algorithm BinarySearch
Input: A sorted list A, a target value
Output: **Index** of **target** in A, or **-1** if target is not found

1. Initialize low ← 0, high ← length(A) - 1
2. While low ≤ high do:
   a. Set mid ← (low + high) // 2
   b. If A[mid] = target then
      return mid

Is 18 == 13?

Target to Search: **13**
Expected Output: **-1**
Length of List: **8**

1. mid = (0 + 7) // 2 = **3**

Binary Search Algorithm

low　　　mid　　　high

Index	0	1	2	3	4	5	6	7
List	3	7	12	**18**	23	27	30	35

Algorithm BinarySearch
Input: A sorted list A, a target value
Output: **Index** of **target** in A, or **-1** if target is not found

1. Initialize low ← 0, high ← length(A) - 1
2. While low ≤ high do:
   a. Set mid ← (low + high) // 2
   b. If A[mid] = target then
      return mid
   c. Else If A[mid] > target then
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Target to Search: **13**
Expected Output: **-1**
Length of List: **8**

1. mid = (0 + 7) // 2 = **3**

Binary Search Algorithm

low mid high

Index	0	1	2	**3**	4	5	6	7
List	3	7	12	**18**	23	27	30	35

Algorithm BinarySearch
Input: A sorted list A, a target value
Output: **Index** of **target** in A, or **-1** if target is not found

1. Initialize low ← 0, high ← length(A) - 1
2. While low ≤ high do:
   a. Set mid ← (low + high) // 2
   b. If A[mid] = target then
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Is 18 > 13?, YES

Target to Search: **13**
Expected Output: **-1**
Length of List: **8**

1. mid = (0 + 7) // 2 = **3**

Binary Search Algorithm

Algorithm BinarySearch
Input: A sorted list A, a target value
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1. Initialize low ← 0, high ← length(A) - 1
2. While low ≤ high do:
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   b. If A[mid] = target then
      return mid
   c. Else If A[mid] > target then
      high ← mid - 1

Is 18 > 13?, YES

low high

Index	0	1	2
List	3	7	12

Target to Search: **13**
Expected Output: **-1**
Length of List: **8**

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Binary Search Algorithm

Index	0	1	2
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Binary Search Algorithm

Index	0	1	2
List	3	7	12

low → 0, mid → 1, high → 2

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Binary Search Algorithm

	low	mid	high
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List	3	**7**	12

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Input: A sorted list A, a target value
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Is 7 == 13?

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Expected Output: **-1**
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Binary Search Algorithm

mid	low		high

Index	0	1	2
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Is 7 > 13?

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Binary Search Algorithm

mid

low high

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Is 7 < 13?, **YES**

Binary Search Algorithm

	low	mid	high
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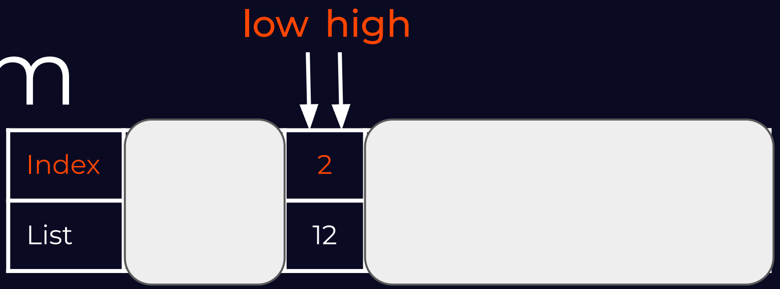
Binary Search Algorithm



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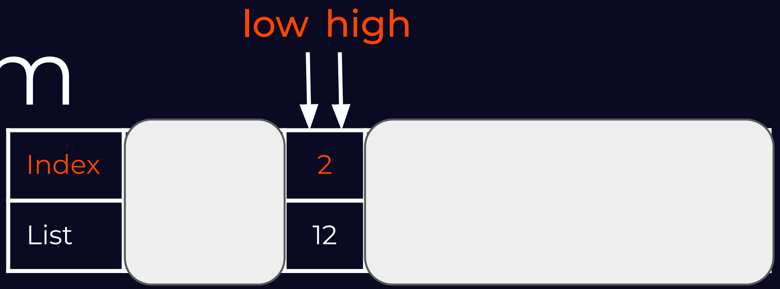
Binary Search Algorithm



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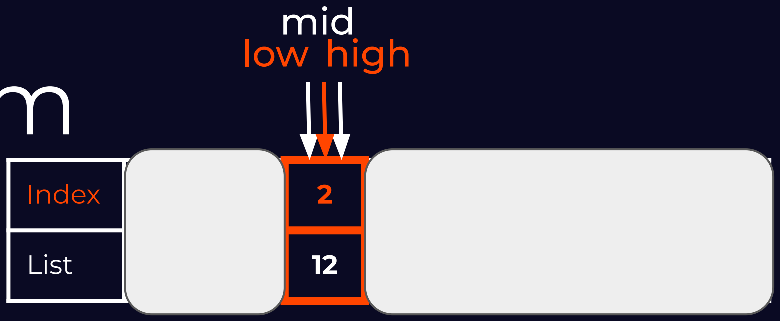
Binary Search Algorithm



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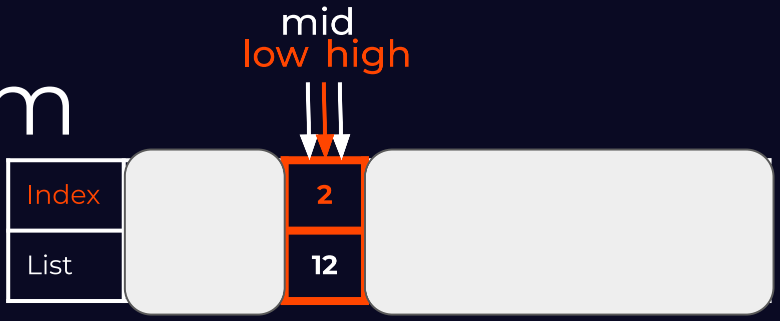

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Is 12 == 13?

Target to Search: **13**
Expected Output: **-1**
Length of List: **8**

1. mid = (0 + 7) // 2 = **3**
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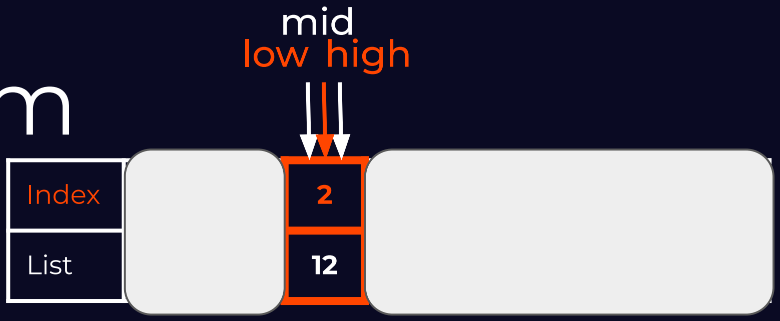
Binary Search Algorithm



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Is 12 > 13?

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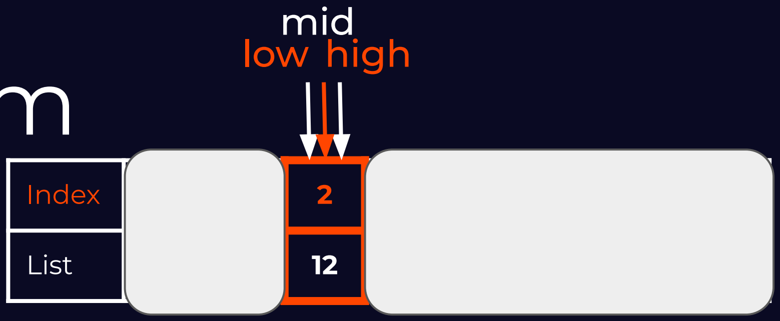
Binary Search Algorithm



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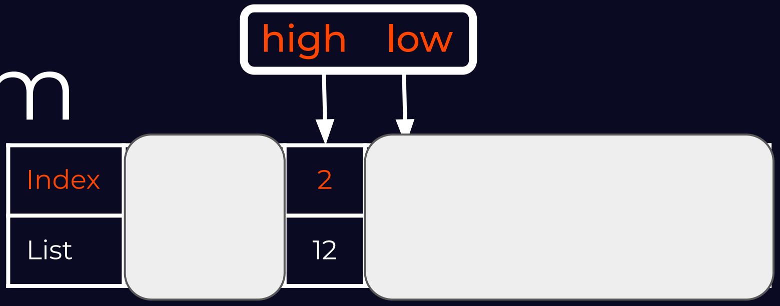

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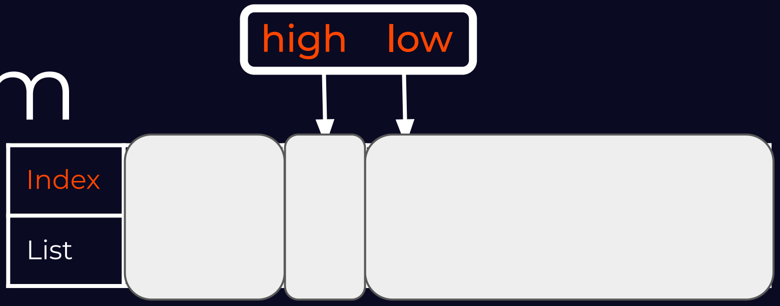

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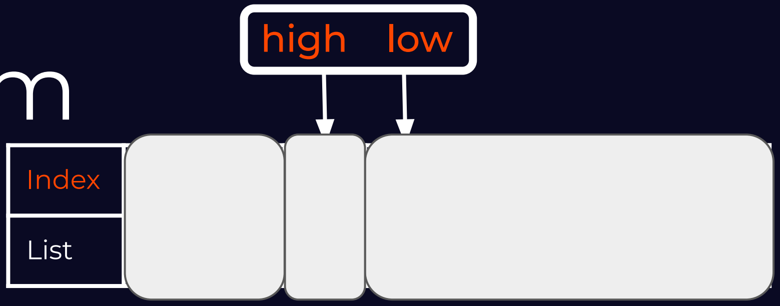

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Binary Search in Python

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def binary_search(A, target):
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Recursion: An Alternative to Iteration

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Factorial of a number **n** is the **product** of all positive integers from **1 to n**.

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Example: **4!** = 4 × 3 × 2 × 1 = 24

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Example: **4!** = 4 × 3 × 2 × 1 = 24

```
def iterative_factorial(n):
```

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Factorial of a number **n** is the **product** of all positive integers from **1 to n**.

Mathematically: **n!** = n × (n - 1) × (n - 2) × ... × 1

Example: **4!** = 4 × 3 × 2 × 1 = 24

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def iterative_factorial(n):
    result = 1
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Recursion: An Alternative to Iteration

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Alternative:

Factorial(**n**)

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Alternative:

Factorial(**n**)

n * Factorial(**n-1**)

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Factorial(**n**)

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(**n-1) *** Factorial(**n-2**)

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Alternative:

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Factorial(n)
  n * Factorial(n-1)
    (n-1) * Factorial(n-2)
              …
      (n-n-2) * Factorial(1)
        return 1
```

Recursion: An Alternative to Iteration

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Alternative:

Factorial(**n**)

n * Factorial(**n-1**)

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…

(**n-n-2) *** Factorial(**1**)

return **1**

Alternative:

Factorial(**4**)

Recursion: An Alternative to Iteration

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Alternative:

Factorial(**4**)

4 * Factorial(**3**)

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Alternative:

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(**n-1**) * Factorial(**n-2**)

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4 * Factorial(**3**)

3 * Factorial(**2**)

2 * Factorial(**1**)

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Recursive Case

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Alternative:

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n * Factorial(**n-1**)

(**n-1**) * Factorial(**n-2**)

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Alternative:

Factorial(4)

4 * Factorial(3)

3 * Factorial(2)

Recursive Case

2 * Factorial(1)

return **1**

Base Case

Recursion: An Alternative to Iteration

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Alternative:

Factorial(**4**)

4 * Factorial(**3**)

3 * Factorial(**2**)

2 * → **1 = 2**

~~return 1~~

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(**n-n-2) *** Factorial(**1**)

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Factorial(**4**)

4 * Factorial(**3**)

3 * Factorial(**2**)

2 * → **1 = 2**

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Alternative:

Factorial(**4**)

4 * Factorial(**3**)

3 * **→ 2 = 6**

2 * ~~Factorial(1)~~ **→ 1 = 2**

~~return 1~~

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Alternative:

Factorial(**4**)

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3 * [redacted] → **2 = 6**

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Alternative:

Factorial(**4**)

4 * [redacted] **→ 6 = 24**

3 * ~~Factorial(2)~~ **→ 2 = 6**

2 * ~~Factorial(1)~~ **→ 1 = 2**

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Alternative:

$\boxed{\text{Factorial(4)}}$

4 * → **6 = 24**

3 * ~~Factorial(2)~~ → **2 = 6**

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Alternative:

Factorial(**n**)

n * Factorial(**n-1**)

(**n-1**) * Factorial(**n-2**)

…

(**n-n-2**) * Factorial(**1**)

return **1**

Alternative:

[redacted] → **24**

4 * ~~Factorial(3)~~ → **6 = 24**

3 * ~~Factorial(2)~~ → **2 = 6**

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Recursion: An Alternative to Iteration

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Alternative:

Factorial(**4**)

4 * Factorial(**3**)

3 * Factorial(**2**)

Recursive Case

2 * Factorial(**1**)

return **1**

Base Case

```
def recursive_factorial(n):
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Recursion: An Alternative to Iteration

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Alternative:

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Factorial(n)
  n * Factorial(n-1)
    (n-1) * Factorial(n-2)
      ...
        (n-n-2) * Factorial(1)
          return 1
```

Alternative:

```
Factorial(4)
  4 * Factorial(3)
    3 * Factorial(2)
      2 * Factorial(1)
        return 1
```

Recursive Case

Base Case

```
def recursive_factorial(n):
    if n == 1:
        return 1
```

Recursion: An Alternative to Iteration

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Alternative:

Factorial(**n**)
n * Factorial(**n-1**)
(**n-1**) * Factorial(**n-2**)
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Alternative:

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4 * Factorial(**3**)
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Recursive Case

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Factorial(**n**)
  n * Factorial(**n-1**)
    (**n-1**) * Factorial(**n-2**)
      …
        (**n-n-2**) * Factorial(**1**)
          return **1**

Alternative:

Factorial(**4**)
  4 * Factorial(**3**)
    3 * Factorial(**2**)

Recursive Case

      2 * Factorial(**1**)
        return **1**

Base Case

```
def recursive_factorial(n):
    if n == 1:
        return 1
    else:
        return n * recursive_factorial(n - 1)
```

Base Case

Recursive Case

Recursion: An Alternative to Iteration

Factorial of a number **n** is the **product** of all positive integers from **1 to n**.

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Factorial(**n**)
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(**n-1**) * Factorial(**n-2**)
...
(**n-n-2**) * Factorial(**1**)
return **1**

Alternative:

Factorial(**4**)
4 * Factorial(**3**)
3 * Factorial(**2**)
2 * Factorial(**1**)
return **1**

Recursive Case

Base Case

```
def recursive_factorial(n):
    if n == 1:
        return 1
    else:
        return n * recursive_factorial(n - 1)
```

Base Case

Recursive Case

Recursion: An Alternative to Iteration

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  - Typically requires fewer lines of code and can make complex problems easier to express.
  - Function calls and can lead to stack overflow if the depth of recursion is too large.

Converting Iterative Binary Search to Recursive

```
def binary_search(A, target):
    low = 0
    high = len(A) - 1
    while low <= high:
        mid = (low + high) // 2

        if A[mid] == target:
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#A[mid] < target:
(mistake in video)

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Recursive Cases

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Focus: Exploring foundational sorting techniques and their importance in efficient data organization

Thank You for Watching!