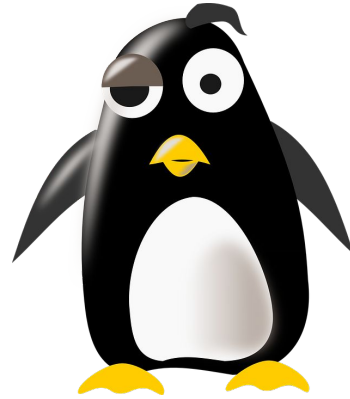


# Binary search algorithm

# Binary search algorithm

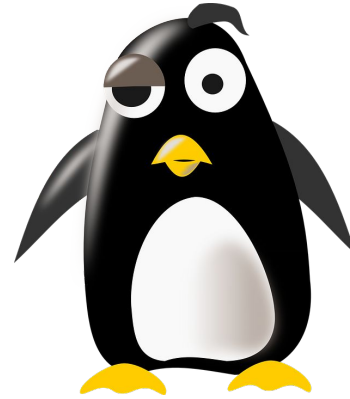
(only works with ordered arrays / lists)

index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71



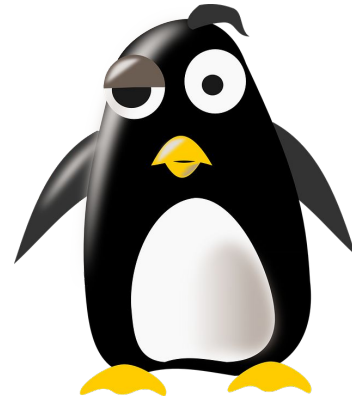
index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array  
contain number 44?



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

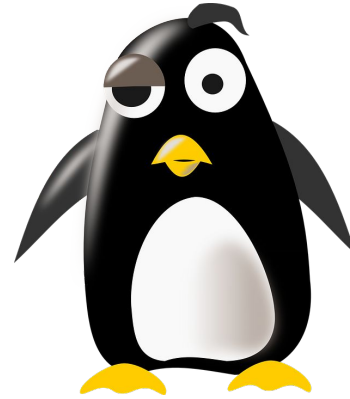
The execution of binary search begins with the middle value of the array.



Does the array contain number 44?

index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 44?

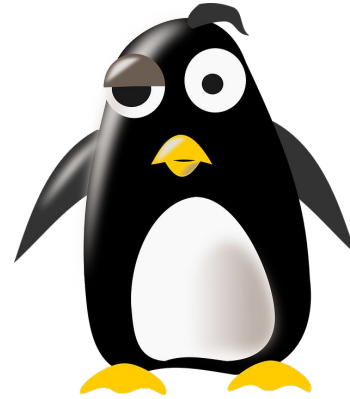


The execution of binary search begins with the middle value of the array.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 44?



The execution of binary search begins with the middle value of the array.

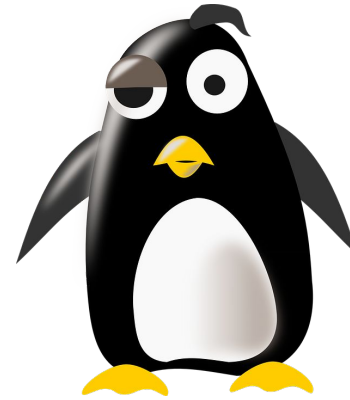
The index of interest contains 9. 44 is greater than 9, so this index or any lesser index cannot contain it.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71



Does the array contain number 44?



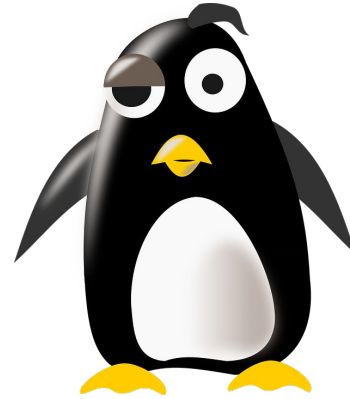
The execution of binary search begins with the middle value of the array.

The index of interest contains 9. 44 is greater than 9, so this index or any lesser index cannot contain it.



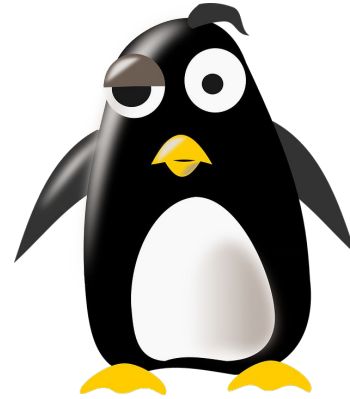
index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array  
contain number 44?



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 44?

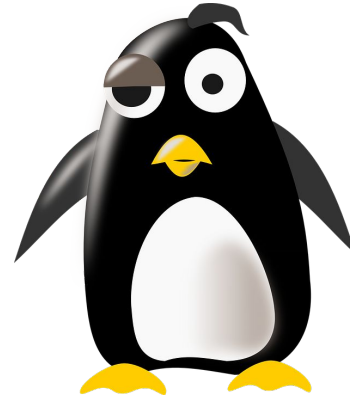


The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 44?

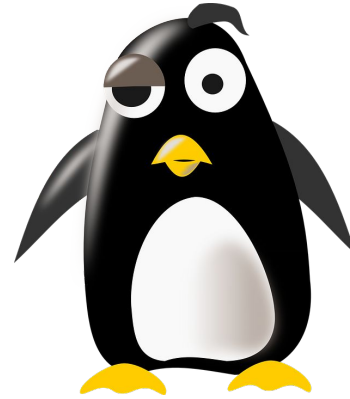


The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 44?



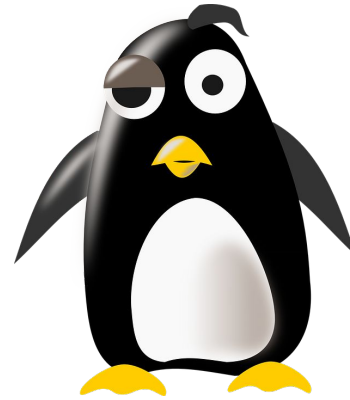
The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The index of interest contains number 31. 44 is greater than 31, so this index or any lesser index cannot contain the searched value.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 44?



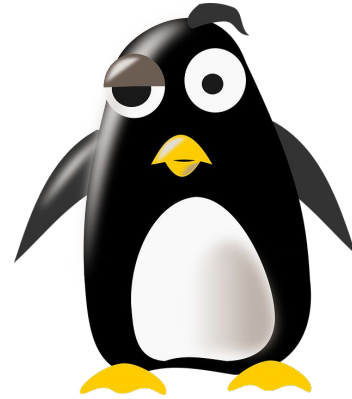
The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The index of interest contains number 31. 44 is greater than 31, so this index or any lesser index cannot contain the searched value.



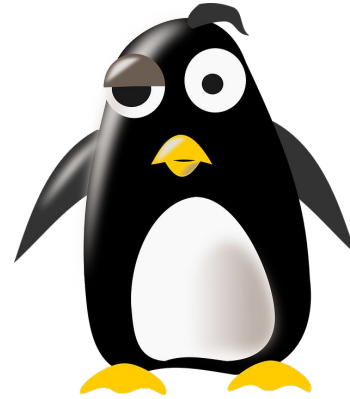
index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array  
contain number 44?



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 44?



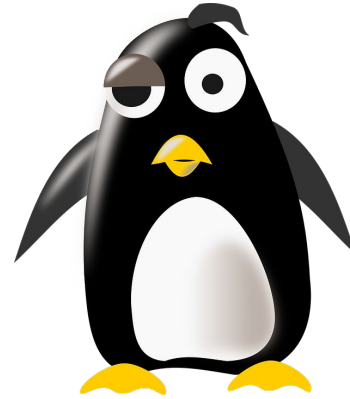
The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71



Does the array contain number 44?

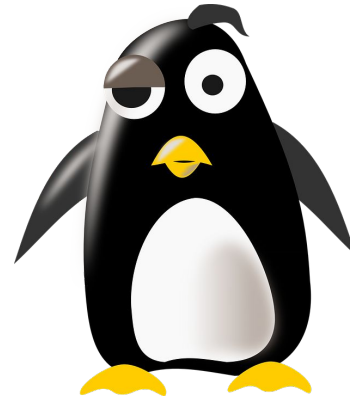


The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 44?



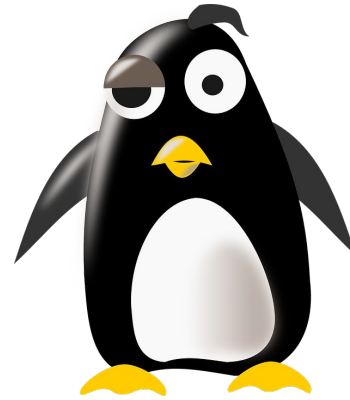
The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The index of interest contains 45, which is greater than 44. So that index or greater indices cannot contain 44.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 44?



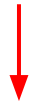
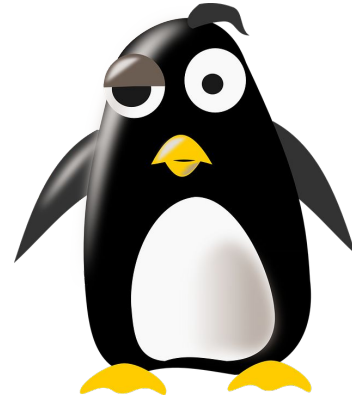
The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The index of interest contains 45, which is greater than 44. So that index or greater indices cannot contain 44.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

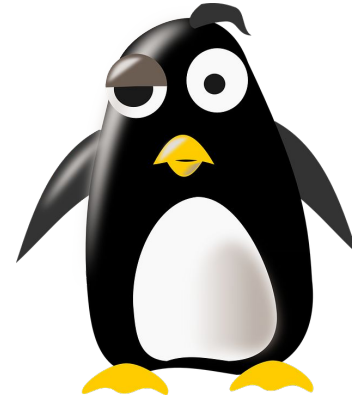
Does the array  
contain number 44?



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

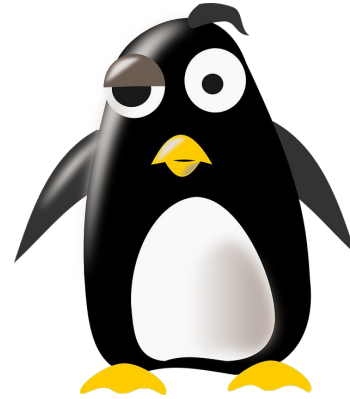
Does the array contain number 44?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 44?

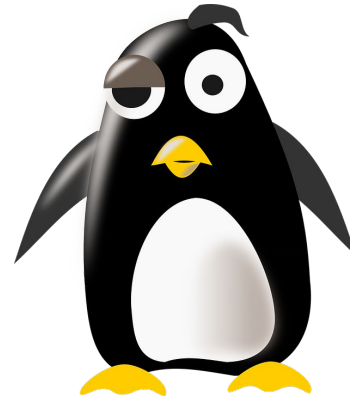


The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 44?



The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The index we are examining contains 44. This is the value we are searching for, so let's return the index.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The index we are examining contains 44. This is the value we are searching for, so let's return the index.

Does the array contain number 44?



Here I am, at index 12!

index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71



The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The index we are examining contains 44. This is the value we are searching for, so let's return the index.

Number 44 is at index 12!



Here I am, at index 12!

index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array  
contain number 2?



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The execution of binary search begins with the middle value of the array.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?



The execution of binary search begins with the middle value of the array.

The examined index contains the value 9. 2 is smaller 9, so this index or any greater index cannot contain number 2.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?



The execution of binary search begins with the middle value of the array.

The examined index contains the value 9. 2 is smaller 9, so this index or any greater index cannot contain number 2.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71



Does the array  
contain number 2?

The binary search continues with the  
index at the middle of the remaining  
area (rounding down, if there is no  
single middle value).



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The examined index contains value 0, which is smaller than 2. So number 2 cannot be at this index or any smaller index.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The examined index contains value 0, which is smaller than 2. So number 2 cannot be at this index or any smaller index.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The examined index contains value 5, which is greater than 2. Number 2 cannot be at this index or any greater index.



↓

index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The examined index contains value 5, which is greater than 2. Number 2 cannot be at this index or any greater index.



↓

index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71



Does the array contain number 2?



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The examined index contains value 1, which is smaller than 2. The number 2 cannot be at this index or any smaller index.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

The examined index contains value 1, which is smaller than 2. The number 2 cannot be at this index or any smaller index.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

There is no remaining space, so the value cannot be found. We'll return -1 to indicate that there is no index for the number that was searched for.



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

Does the array contain number 2?

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

There is no value, so the return is -1.

Not found, returning -1



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71



Lukua 2 ei löytynyt.

The binary search continues with the index at the middle of the remaining area (rounding down, if there is no single middle value).

There is no value in the array, so the return value is -1.

Not found, returning -1



index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
value	-22	-9	-3	0	1	5	7	9	11	16	22	31	44	45	62	71

# Idea of binary search

- Data is searched in an ordered array or list.
- Search begins in the middle.
- The the value of the examined middle point is not the value that is searched for, we exclude half of the previous search are and move to examine the middle point of the remaining area.
- If the examined middle value is the value that is searched for, we return the index of that middle point.
- If the search area does not exist anymore (every index has been excluded from the list of possinilities), the value of -1 is returned. It indicates that the value in question cannot be found.

# Binary search

- Halves the search area after each round.
- The number of examined places is a logarithmically connected to the size of the array / list; for instance, searching a list of 4294967296 elements can be accomplished by examining 32 indices ( $\log_2 4294967296 \sim 32$ ).
- Also works with strings; in this case the algorithm compares the order of individual characters in a string. Individual characters can be represented as char ttype numeric values.
- Your own classes and objects need to be defined an ordering. We'll return to this issue in the advanced programming course.