3 - Dynamic Arrays

16:25

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Dynamic Arrays

Dynamic Arrays are much more common and useful because of their ability to be resized. In JavaScript and Python, these are the default — they are not strictly typed languages.

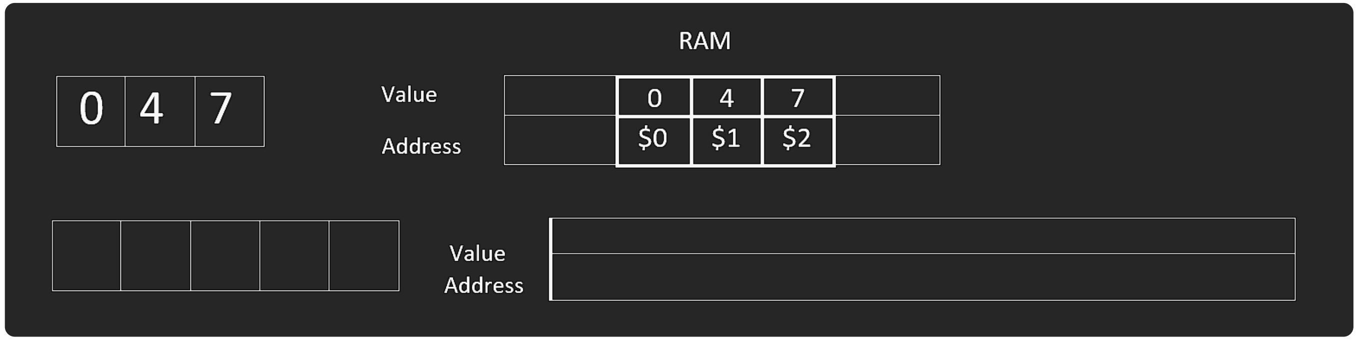
The difference between static and dynamic arrays is that we don't have to specify a size upon initialization.

In different languages, dynamic arrays maybe assigned a default size - Java being 10 and C# being 4. Regardless, these are resized dynamically by the operating system.

Mechanics of dynamic arrays

When inserting into a dynamic array, the operating system finds the next empty space and pushes the element into it. For the sake of an example, let's take an array of size 3 and push elements into it until we run out of space. The pseudocode and visual below demonstrate this.

```
fn pushback(n):
   if length has reached capacity:
       resize the array by doubling its size
   arr[length] = n
   length++
```



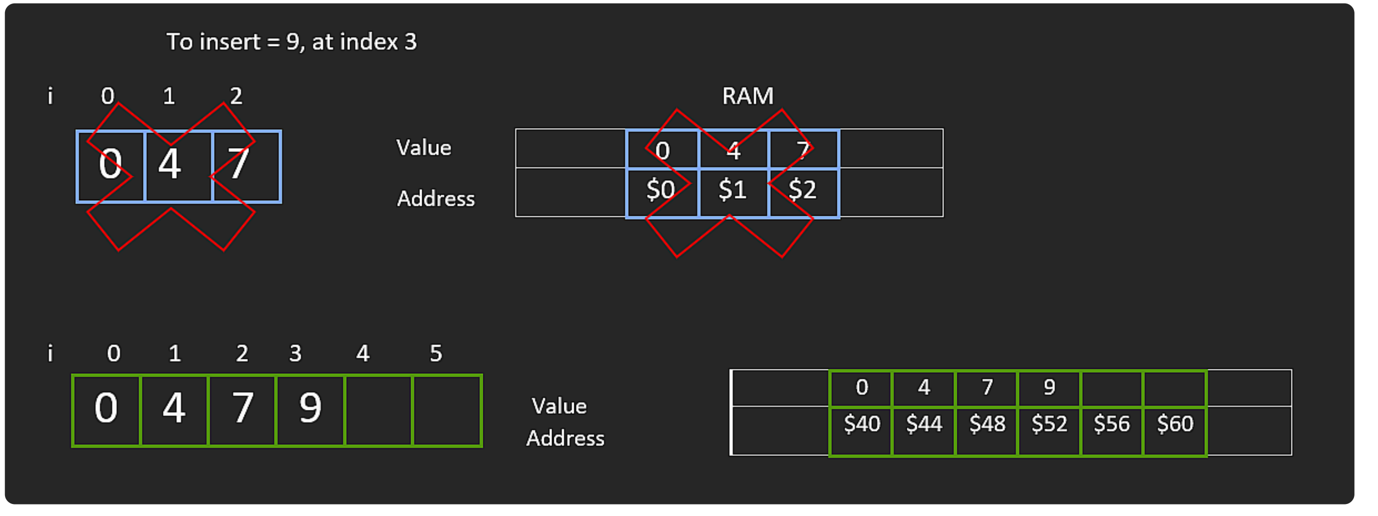
Since the array is dynamic, adding another element when we run out of capacity is achieved by copying over the values to a new array that is double the original size - this means that the resulting array will be of size 6 and will have new space allocated for it in memory. The following visual and pseudocode demonstrates this.

```
fn resize(capacity, arr, length):
   // Create new array of double capacity
```

```
    capacity = 2 * capacity
    //declare an array newArr with updated capacity

    // Copy elements to newArr
    for i = 0 to length:
        newArr[i] = arr[i]

    // update the original array
    arr = newArr
```

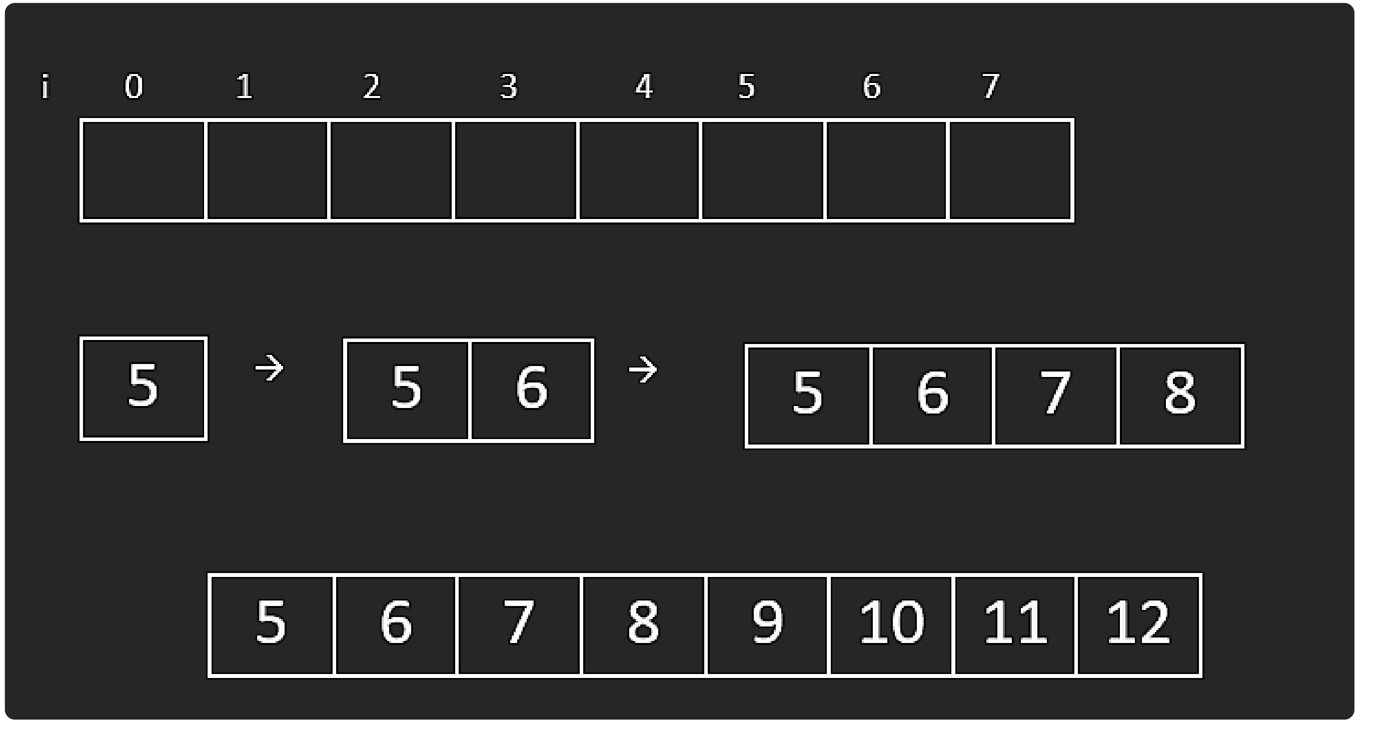


> *When all the elements from the first array have been copied over, it does not make sense to keep it in memory - this space will be deallocated.*

This operation will run in ***amortized*** $O(1)$. Amortized time complexity is the average time taken per operation, that once it happens, it won't happen again for so long that the cost becomes “amortized”. This makes sense because it is not always that the array needs to be resized, in which case we would perform $O(n)$ operations.

Why double the capacity?

Let’s dig a little bit deeper into why we double the size of the initial array when we run out of space. This can be proven mathematically, so let’s go over a high level overview. Don't worry, we will not be using any fancy equations. The visual below shows a resulting array of size 8. Now imagine that we wanted to dynamically fill it up and we started with a size 1 array. We would add 5, double the space to add 6, double that space to add 7 and 8, double that space to add 9, 10, 11 and 12.



The size of the above array went from `1 -> 2 -> 4 -> 8`. And this makes sense because in order to create the resulting array observed in the visual, we had to create 4 spaces, and then insert 4 elements, which is a total of 8 operations. Additionally, we also have to take into consideration the ***sum of all the operations*** that occured before the last one since we would not have gotten to the resulting array without these operations.

The pattern here is that the last term (the dominating term) is always less than or equal to the sum of all the terms before it. In this case, $1 + 2 + 4 = 7$, and $7 < 8$. Add in the 8 to the 7, we get a total of 15 operations to create the resulting array of size 8. Generally, the formula is that for any array size n, it will take at most $2n$ operations to create, which would belong to $O(n)$.

> *When we are talking about the asymptotic analysis, we are more concerned with an unusually large input size, meaning in the worst case, if our input size was extremely large, say, we built an array of size 150,000, asymptotically, there would be no difference between $O(2n)$ and $O(n)$ because if the algorithm performs exactly $2n$ operations, it surely performs **at least** $O(n)$ operations. Therefore, we drop the constants.*

Closing Notes

Operation	**Big-O Time**	**Notes**
Access	$O(1)$	
Insertion	$O(1)*$	$O(n)$ if insertion in the middle since shifting will be required
Deletion	$O(1)*$	$O(n)$ if deletion in the middle since shifting will be required

Other operations in pseudocode

```
// Remove the last element in the array
fn popback(length):
    if length > 0:
        length--


// Get value at ith index
fn get(i, length):
    //if the index exists
    if i < length:
        return arr[i]

// if the index is out of bounds
```

```
        return -1

    // Insert n at ith index
    fn insert(i, n):
        // If index is reachable
        if i < length:
            arr[i] = n
            return
        // if the index is out of bounds
        return

    // print values of the array
    fn print(length):
        for i = 0 to length:
            print arr[i]
```

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