Introduction to Programming

Week – *8*, Lecture – *3*

Stacks and Queues

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Example: How does a program execute?

```c
#include<stdio.h>
int main()
{
    int v1 = 5;
    f1(v1);
    return 0;
}
void f1(int v2)
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    f2();
    f3(v2);
    return;
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void f2()
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    printf("Hey !!");
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void f3(int v3)
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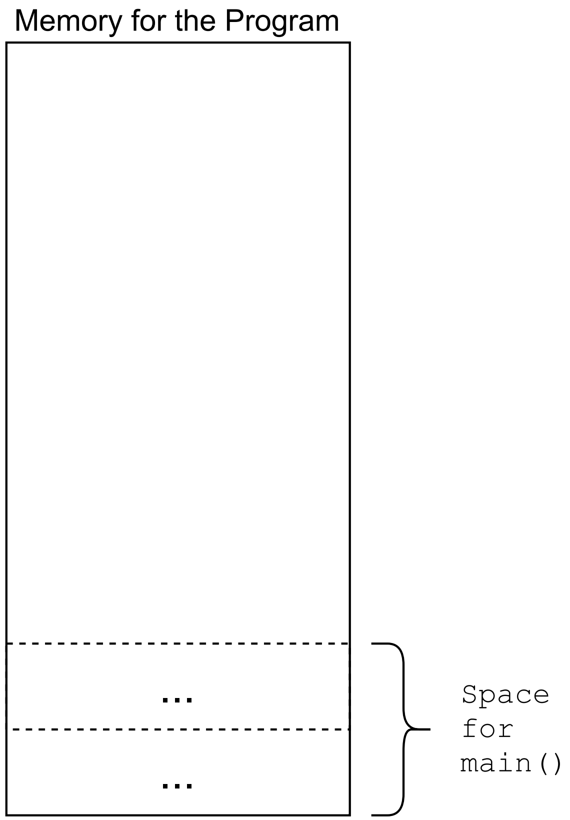

Assume that we are trying to execute this simple C program

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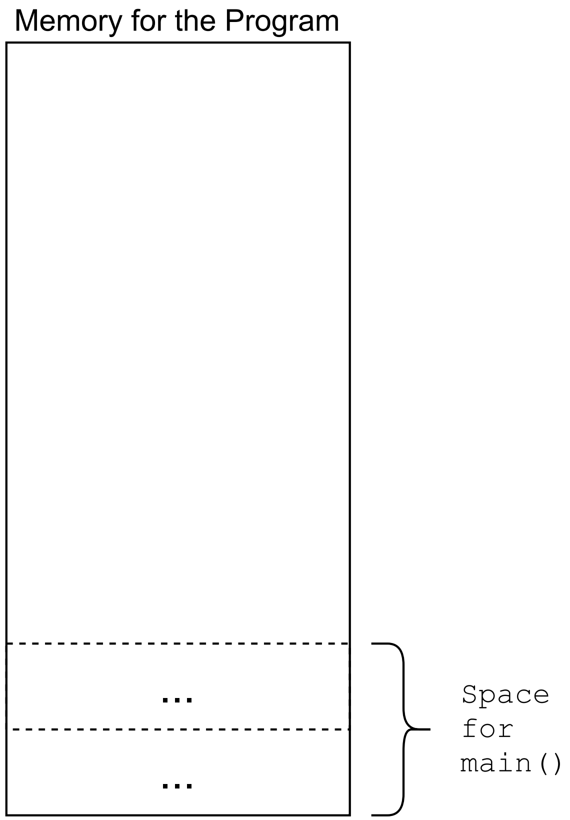

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It has four functions – `main()`, `f1()`, `f2()` and `f3()`

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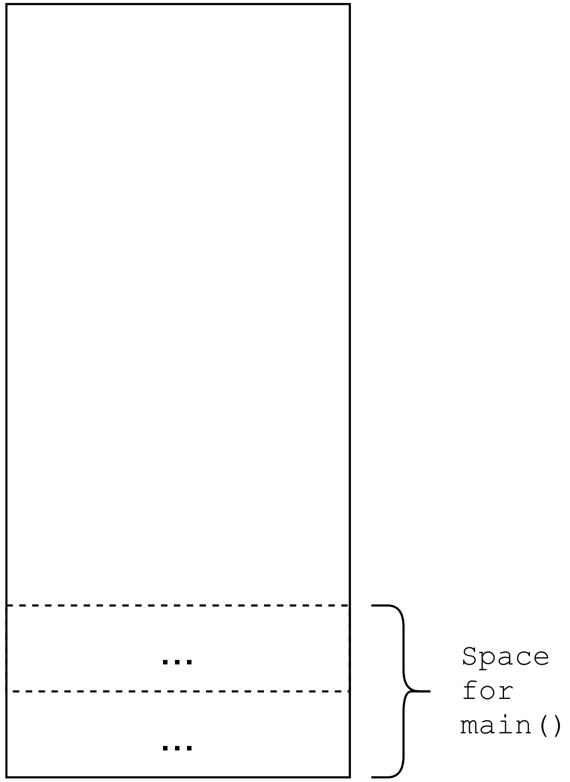
Memory for the Program



Assume that we are trying to execute this simple C program

It has four functions – `main()`, `f1()`, `f2()` and `f3()`

The execution starts from the first statement in `main()`

Example: How does a program execute?

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int main()
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```

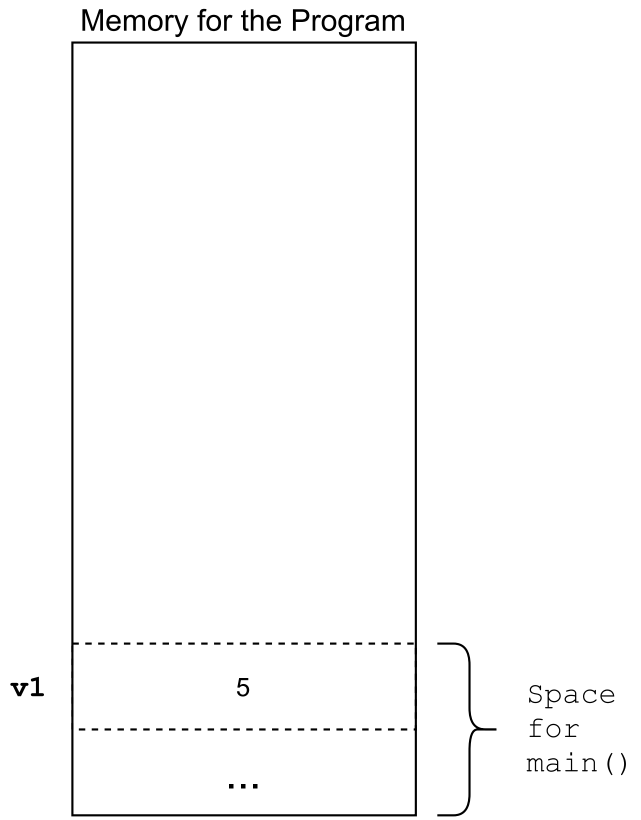

A variable called `v1` is allocated in some "designated" space in the Main Memory

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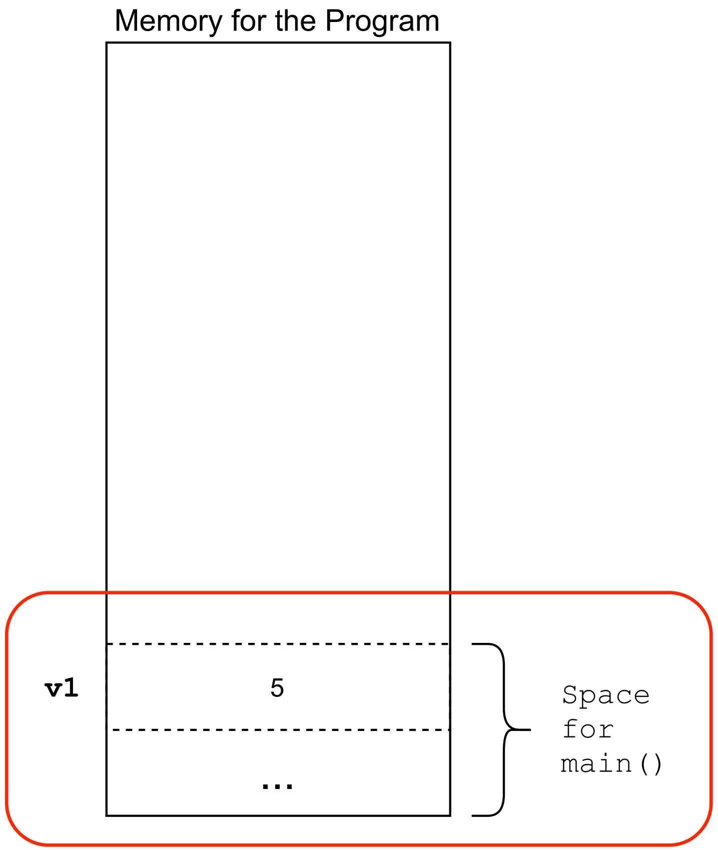

A variable called `v1` is allocated in some "designated" space in the Main Memory

This memory block is reserved for executing the `main()` function only

Example: How does a program execute?

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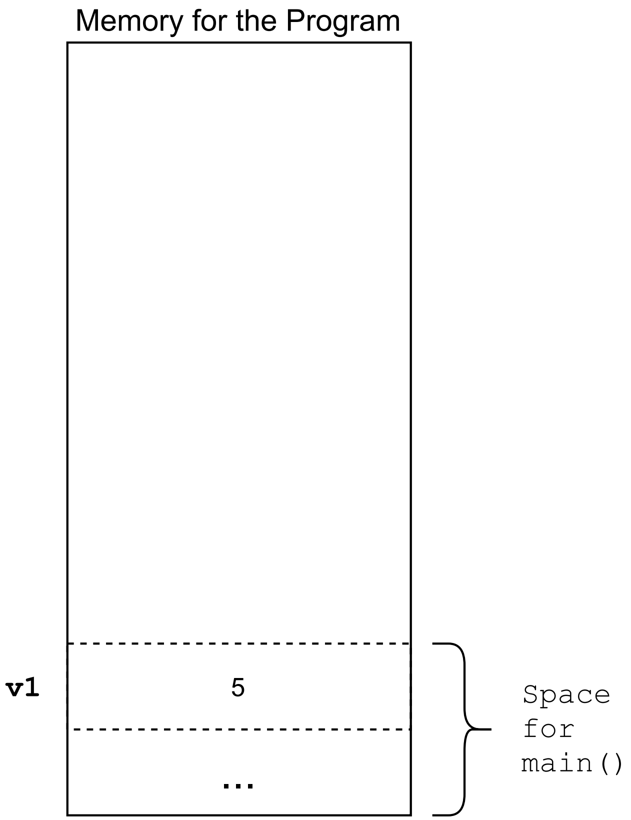

The next statement in `main()` is a call to the function `f1()`

Example: How does a program execute?

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1   #include<stdio.h>
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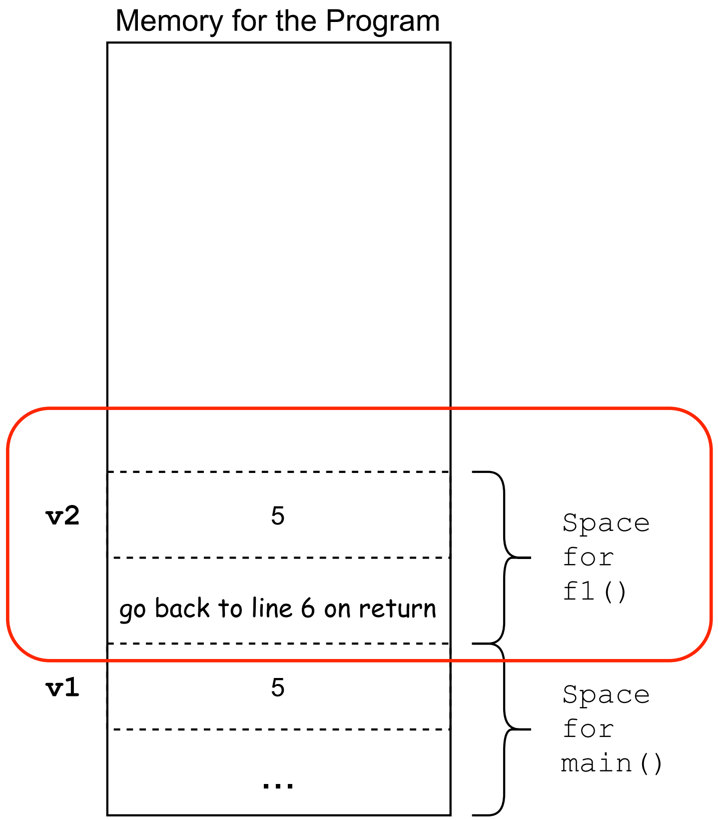

At this point, some space in the memory is allocated for executing `f1()`

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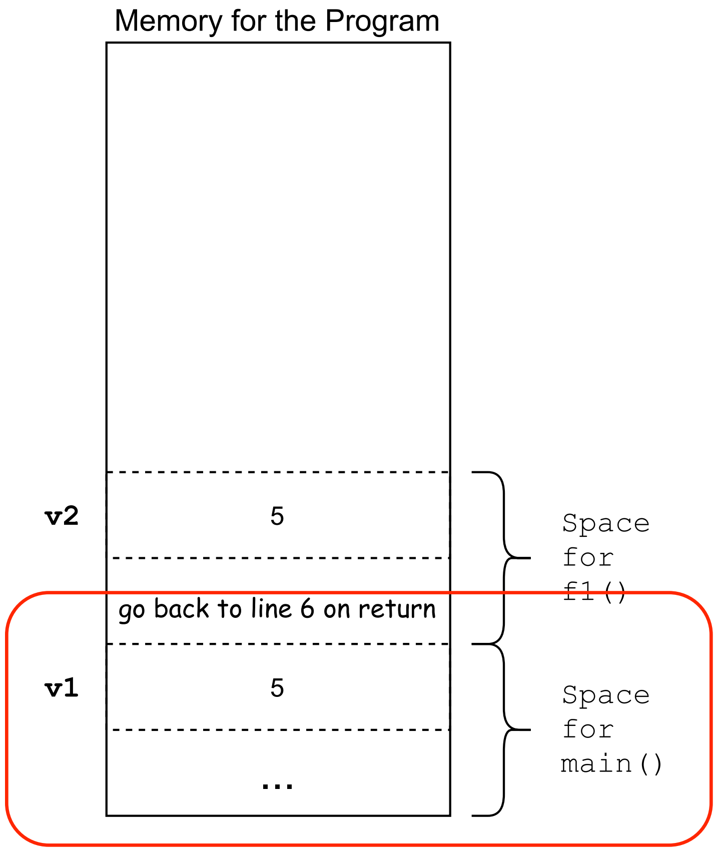

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The memory block for `main()` is also in the memory, but it is separated from this block

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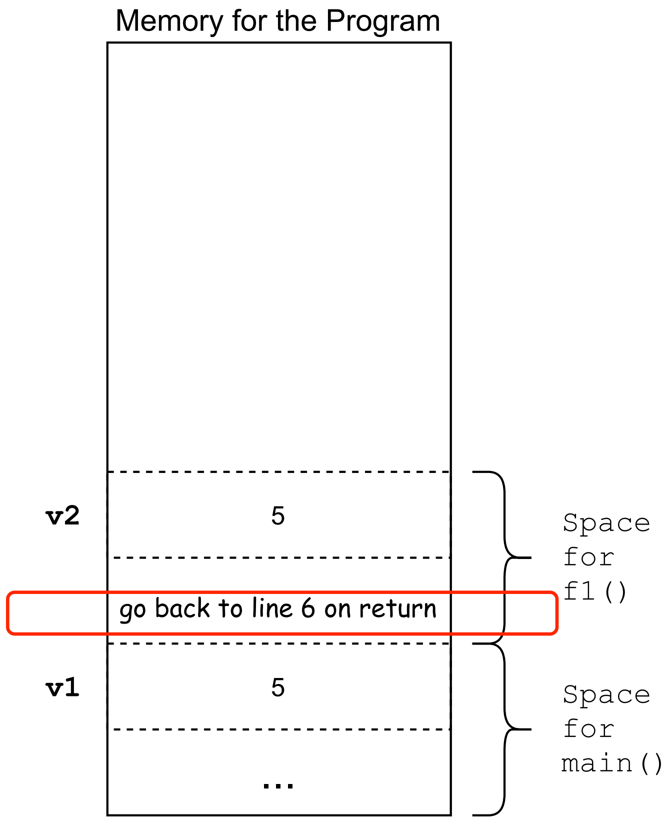

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Some information is saved in the block, for resumption of `main()` on return of `f1()`

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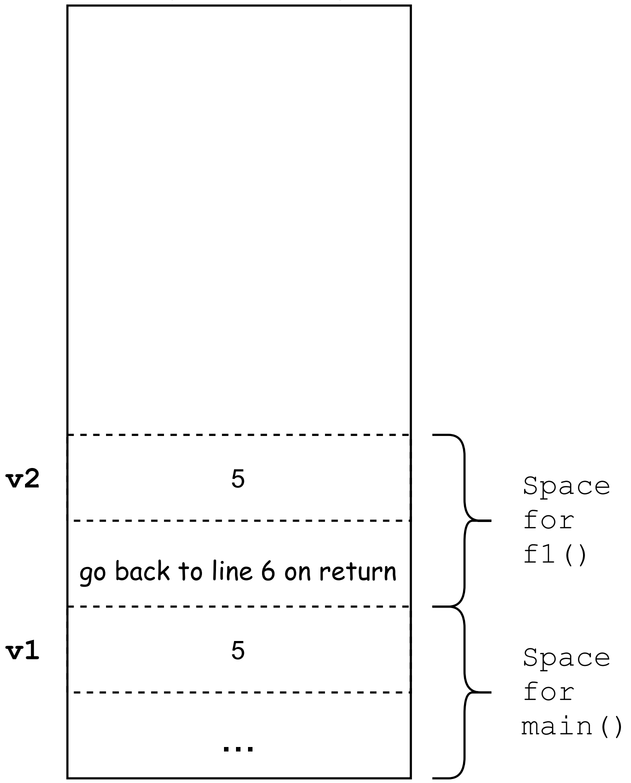

At this point, some space in the memory is allocated for executing `f1()`

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Local variable `v2`, which is a formal parameter for `f1()`, gets allocated in this block

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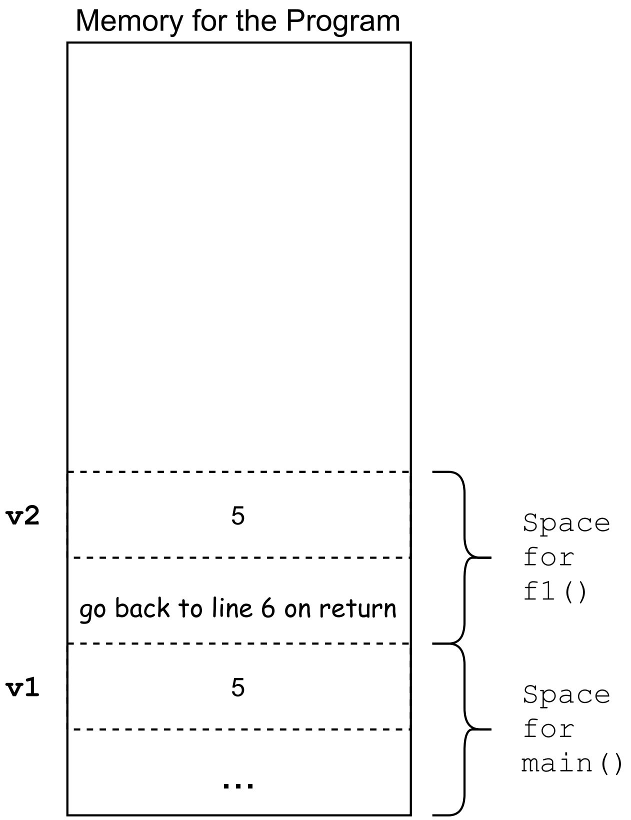

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Local variable `v2`, which is a formal parameter for `f1()`, gets allocated in this block

The first statement in `f1()` is a call to the function `f2()`

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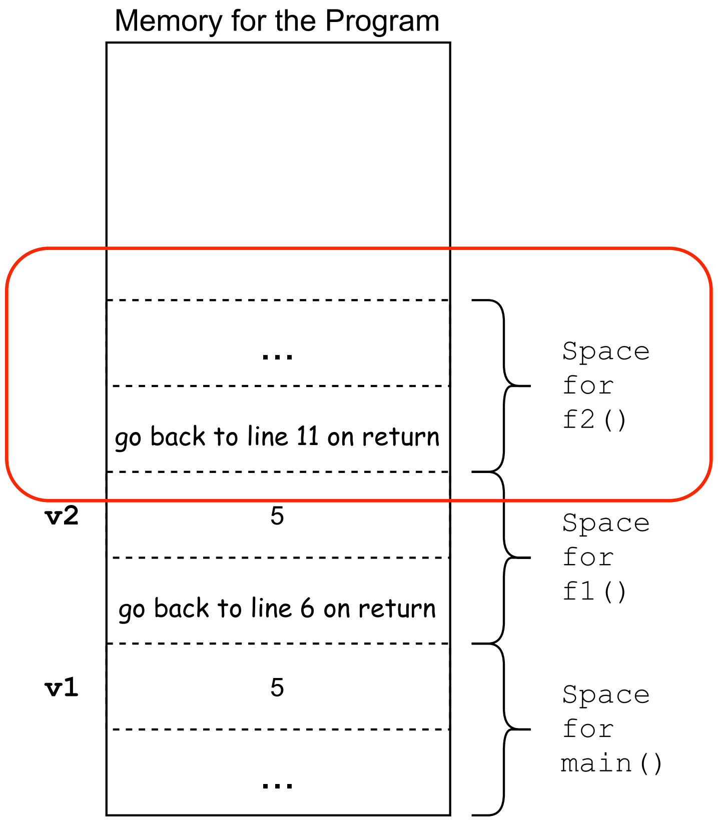

Again, another memory block is allocated, for executing `f2()` …

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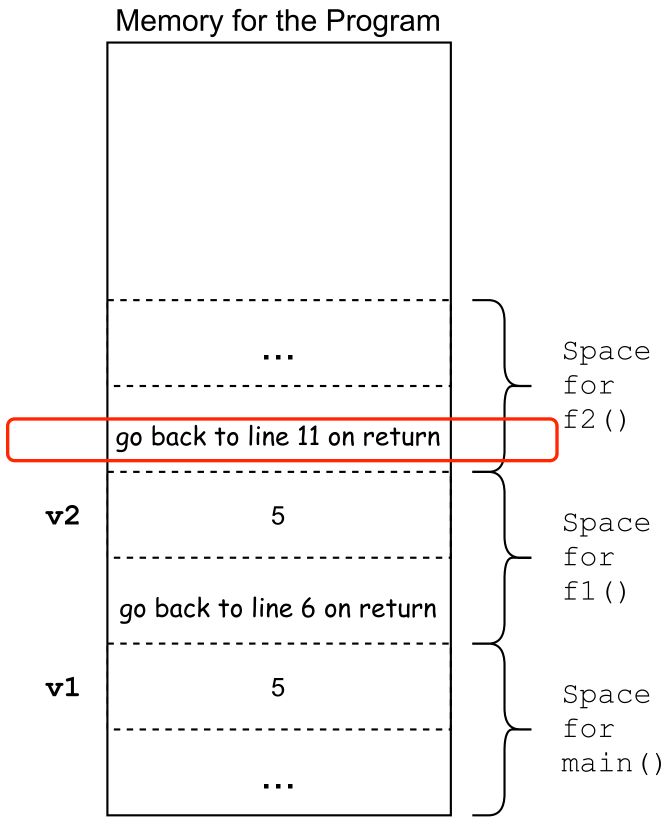

Again, another memory block is allocated, for executing `f2()` …

… and some information to return the control back to `f1()` is also stored

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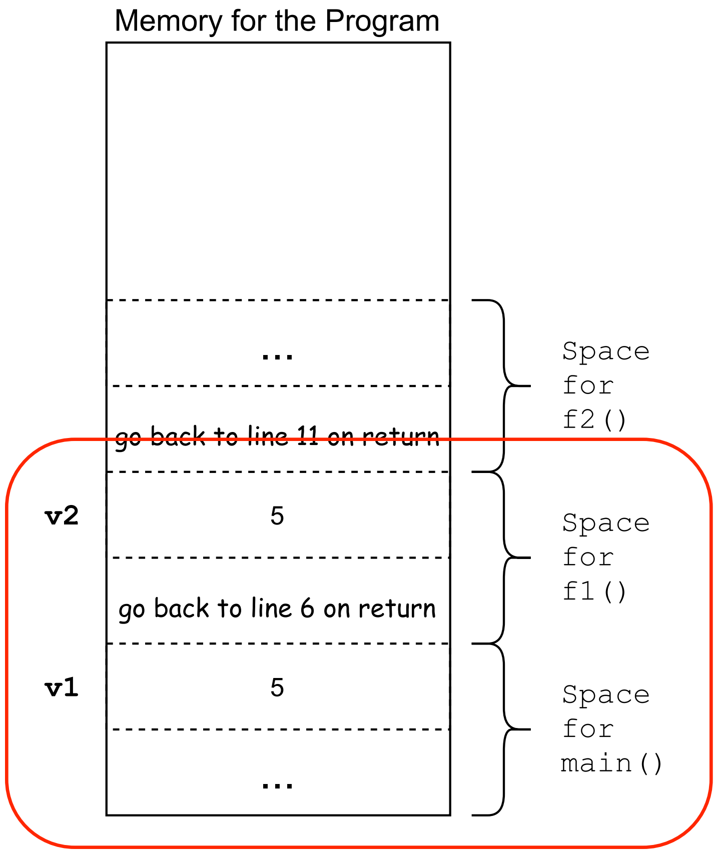

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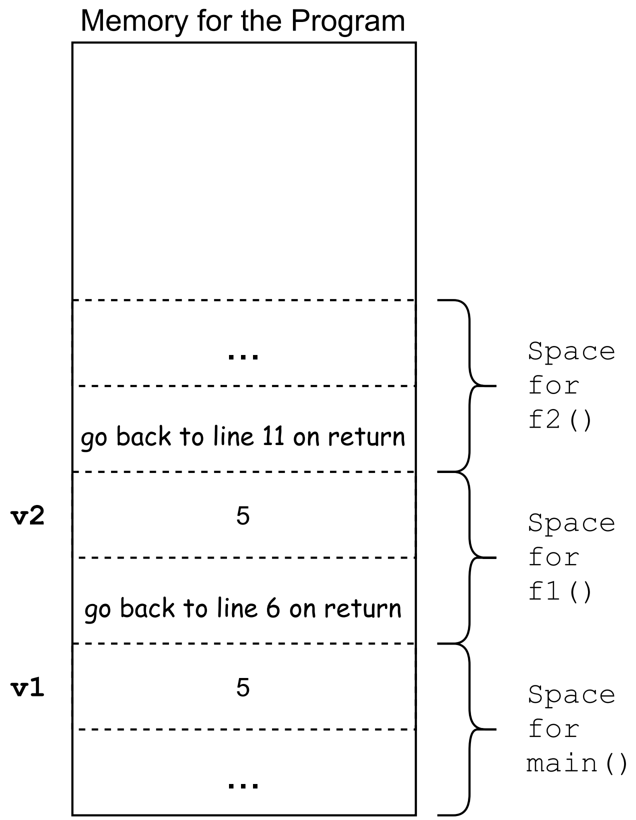

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The blocks for `f1()` and `main()` remain intact

The `printf()` statement executes, and since there are no other statements, `f2()` returns

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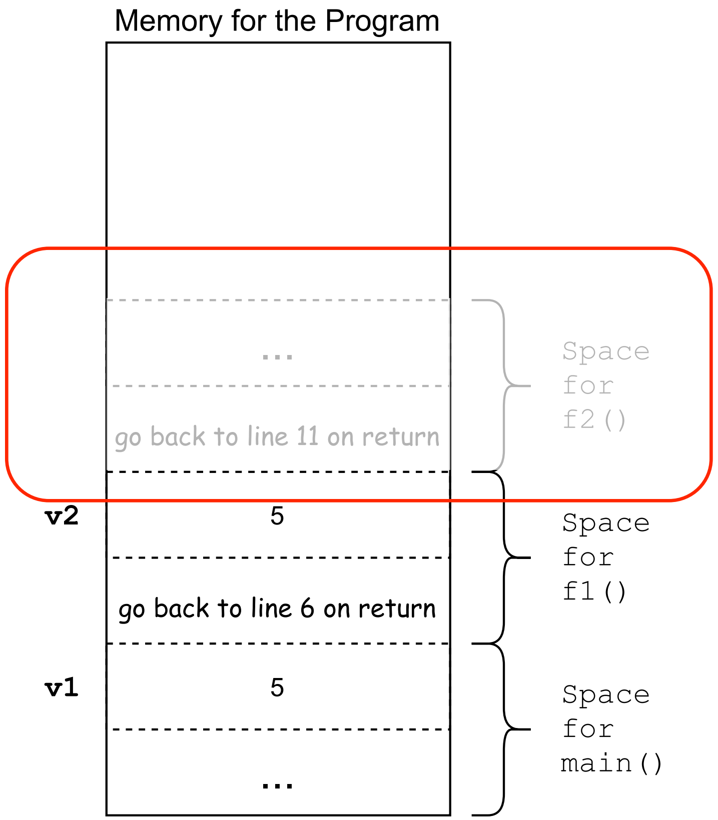

As soon as the return statement executes, the block for `f2()` gets freed

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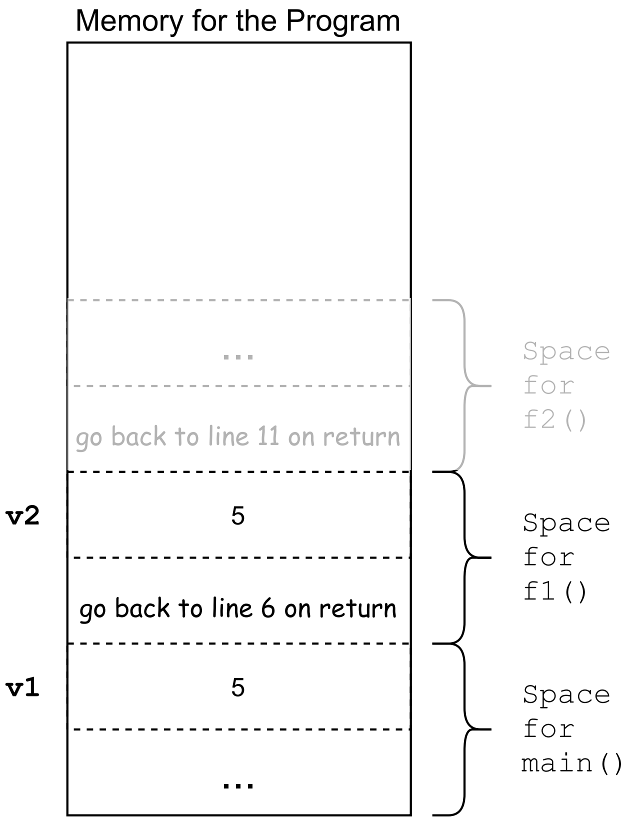

As soon as the return statement executes, the block for `f2()` gets freed

The return information is used at this point, to go back to the correct position in code

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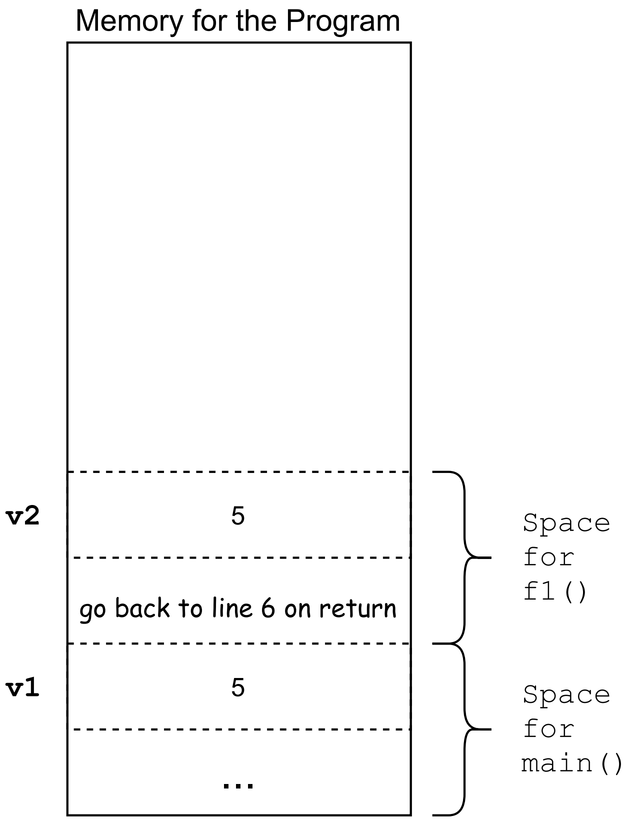

The control now returns to `f1()`

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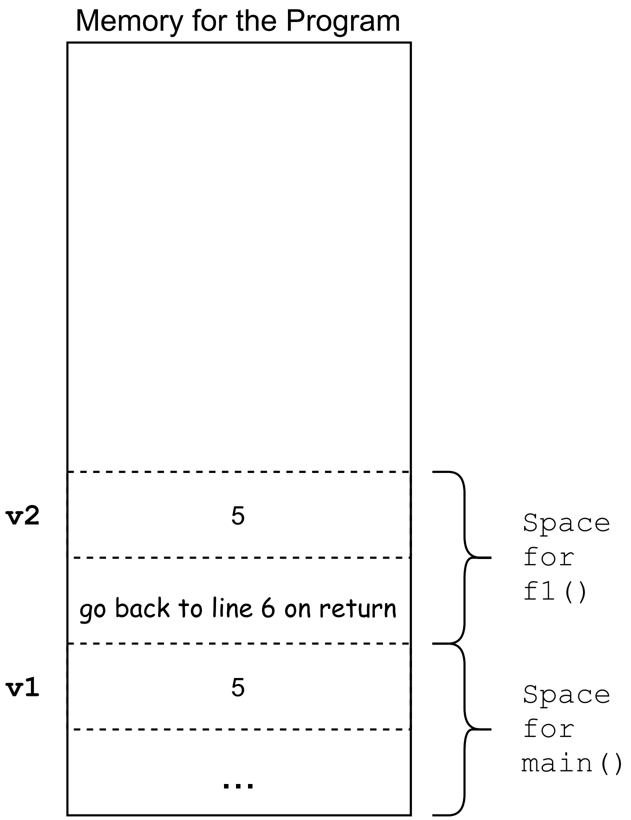

The control now returns to `f1()`

The next statement now, is a call to `f3()`

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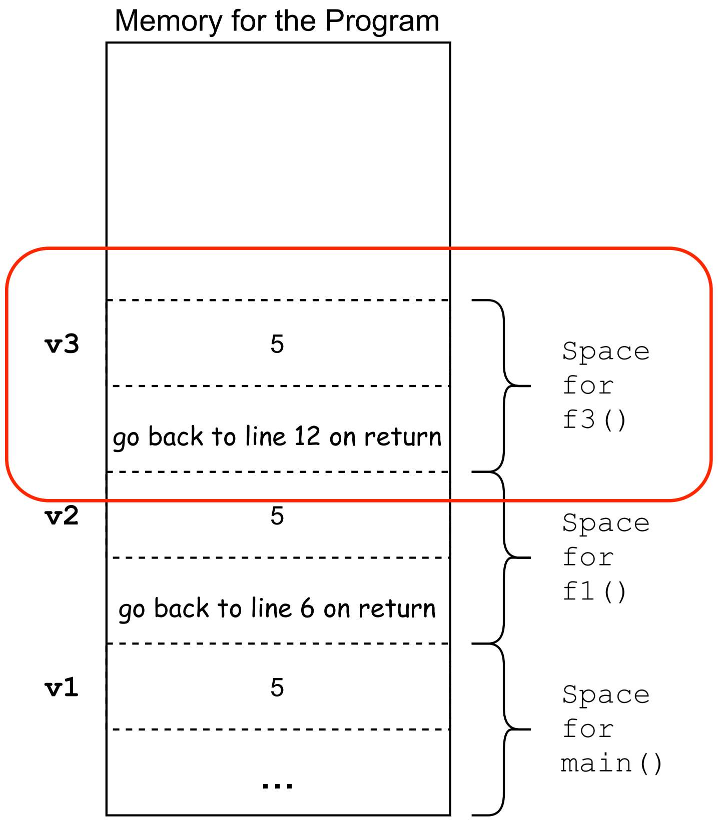

Another memory block gets allocated, this time for executing `f3()`

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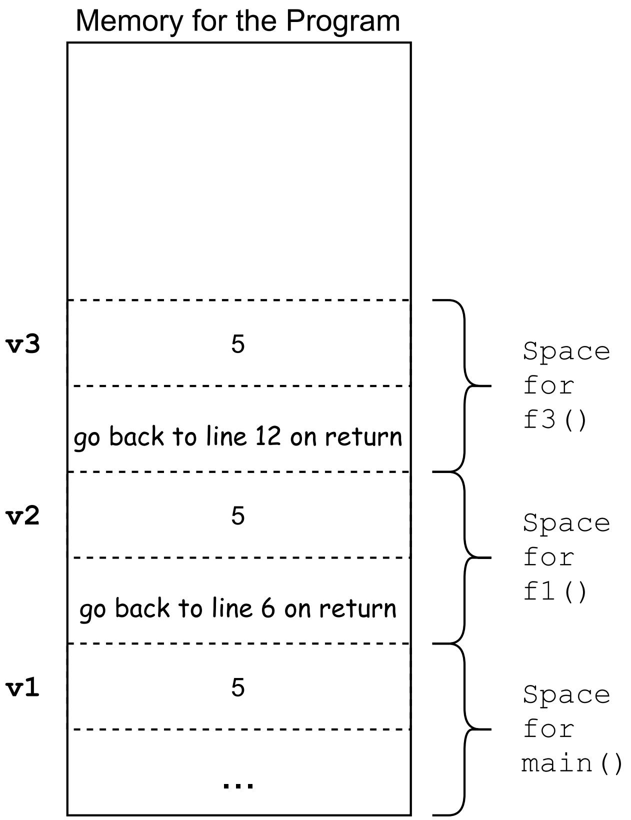

Another memory block gets allocated, this time for executing `f3()`

The formal parameter `v3`, is allocated in that block

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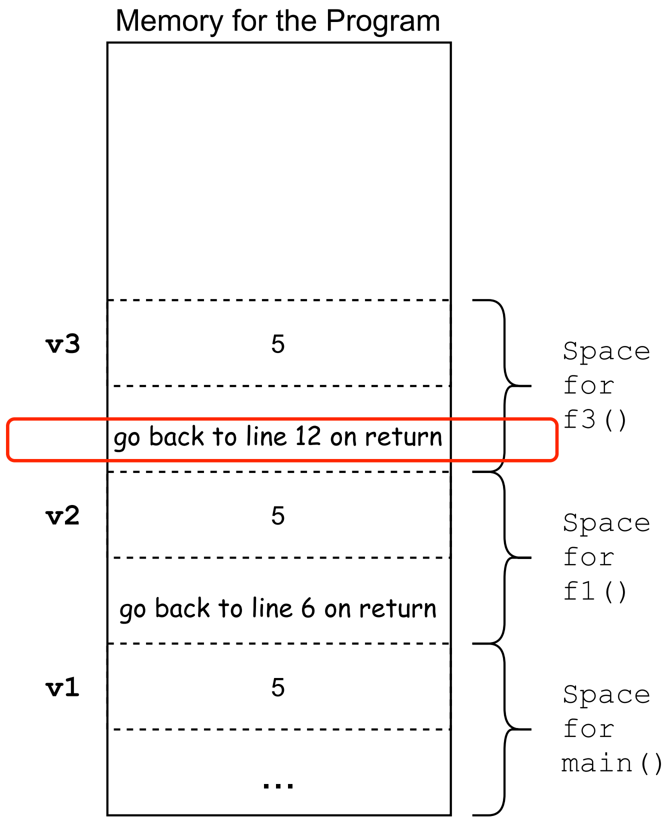

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The return address information is also stored

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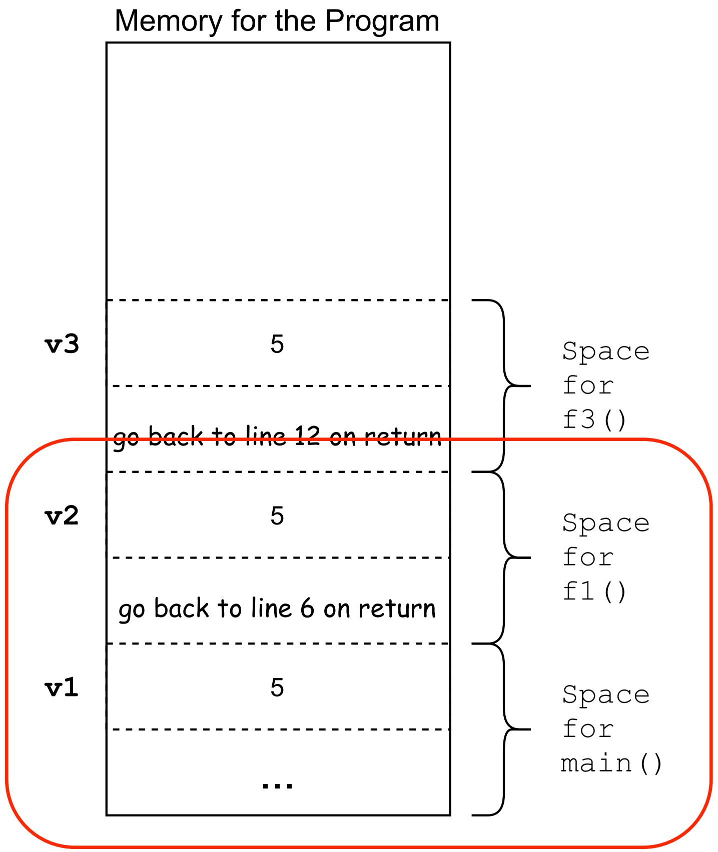

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The blocks for `f1()` and `main()` still remain intact

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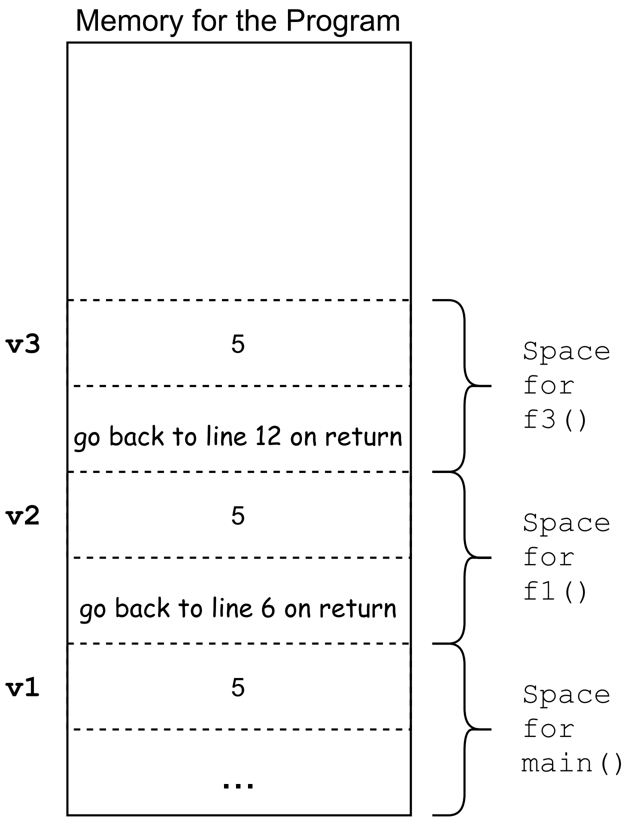

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The `printf()` statement executes, and since there are no other statements, `f3()` returns

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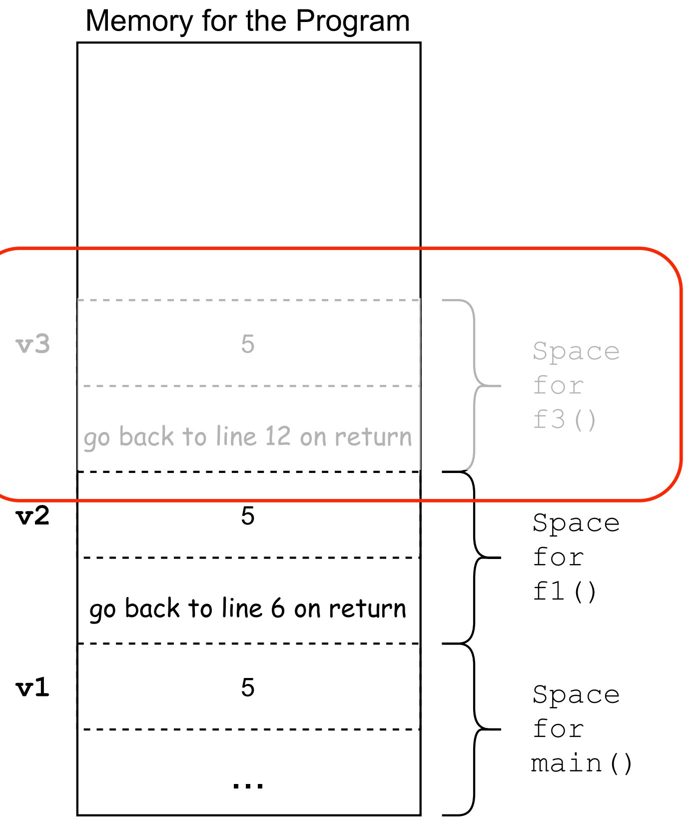

The memory block for `f3()`, too, is freed when the return statement is executed

Example: How does a program execute?

```
1  #include<stdio.h>
2  int main()
3  {
4      int v1 = 5;
5      f1(v1);
6      return 0;
7  }
8  void f1(int v2)
9  {
10     f2();
11     f3(v2);
12     return;
13 }
14 void f2()
15 {
16     printf("Hey !!");
17     return;
18 }
19 void f3(int v3)
20 {
21     printf("%d", v3);
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23 }
```

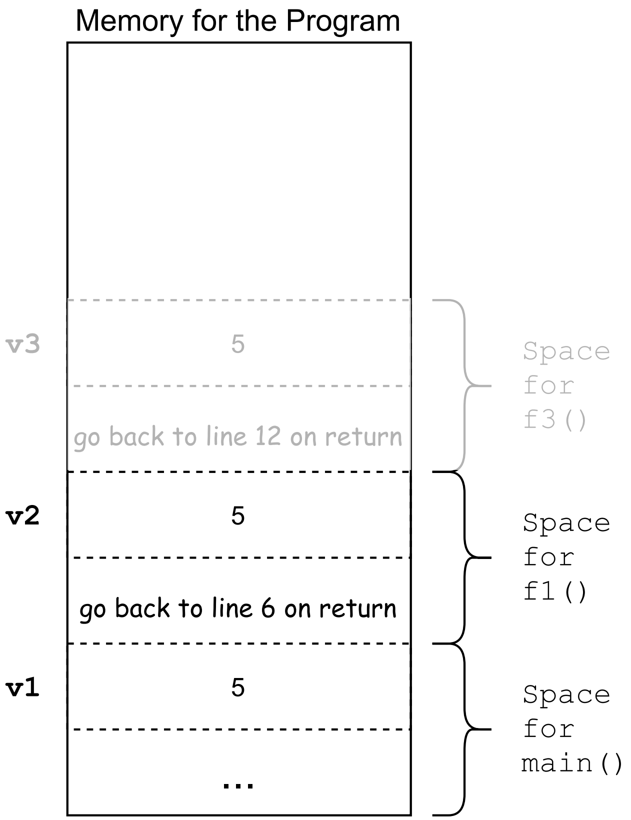

The memory block for `f3()`, too, is freed when the return statement is executed

Again, the return information helps in taking the control back to `f1()`

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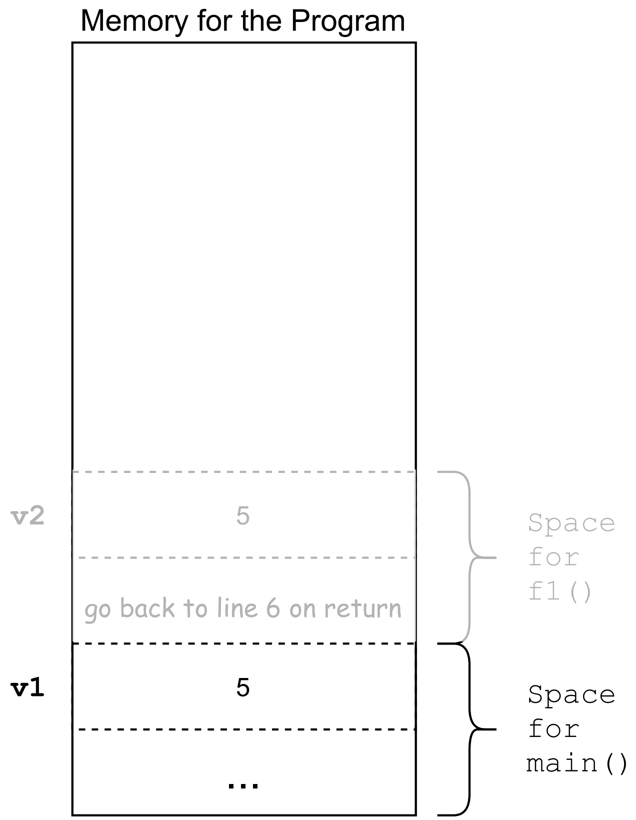

Now, `f1()` too, has completed execution, and can now return

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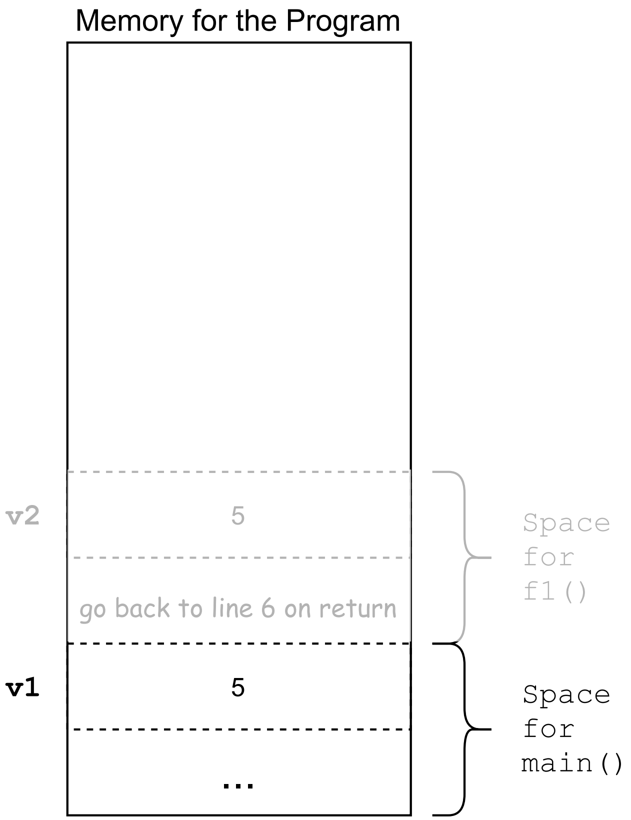

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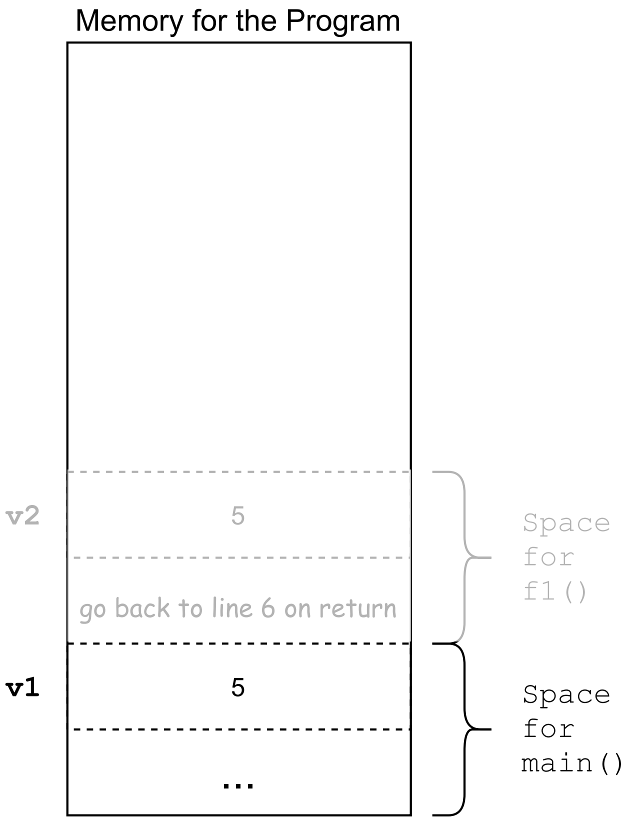

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With the help of the return information, control can now go back to `main()`

Example: How does a program execute?

```c
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int main()
{
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    f1(v1);
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    return;
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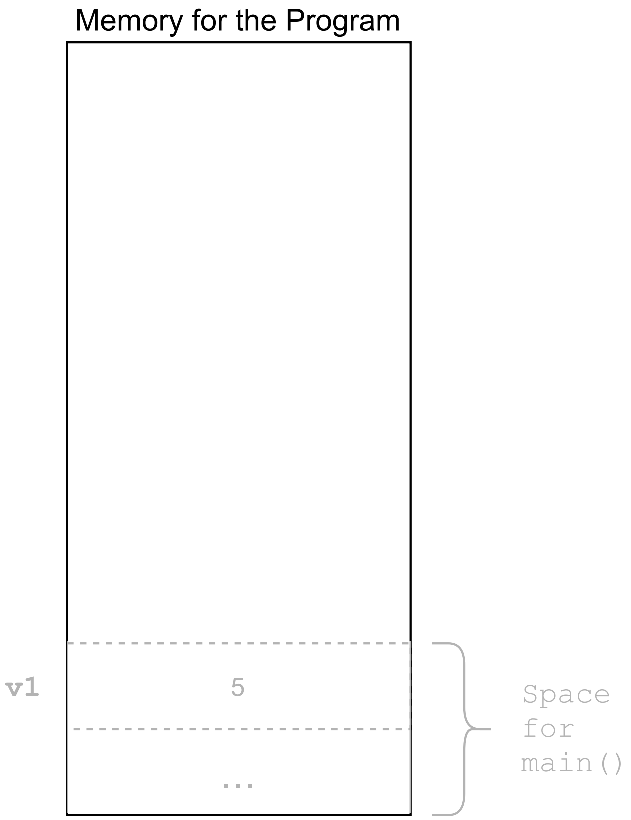
```



Finally, the `main()` too, completes and returns

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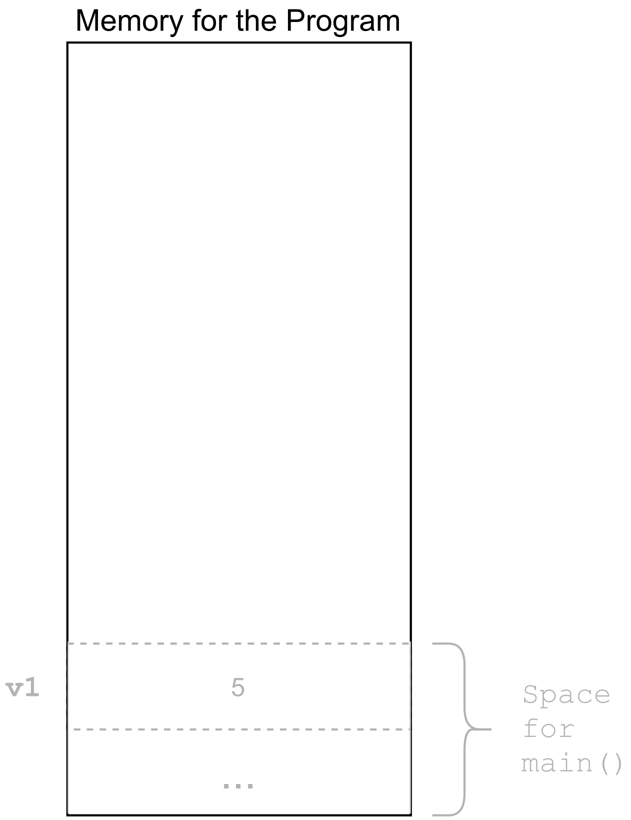

Finally, the `main()` too, completes and returns

At this point, the execution of the program ends, and the memory allocated to the respective process is freed in totality

The concept of a Stack

One aspect of the memory blocks that we saw, is that they follow a *last in first out* pattern…

- … i.e. the block for the function which was called most recently in the function call chain, is freed first

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The operation to add an element to a stack is called *push()* and it takes the element as argument

The operation to delete an element from a stack is called *pop()* and it returns the deleted element

Example: Stack using an array

0	1	2	3	4
12	x	x	x	x

top = 0

Assume that we have a single element in the stack right now

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The `top` right now points to index `0`

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0	1	2	3	4
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`push(21)`

0	1	2	3	4
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If we push an element, `21`, it is inserted at position `1`

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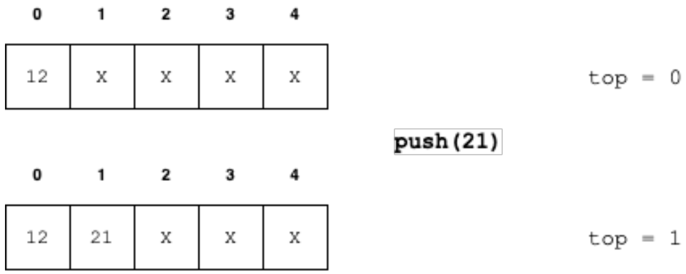

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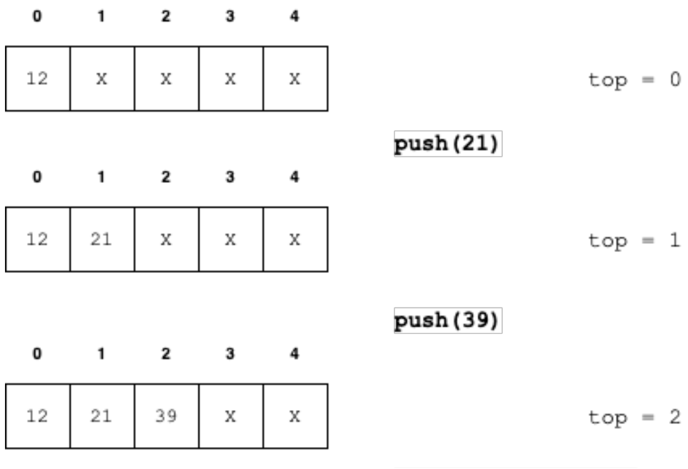

If we push another element, 39, it is inserted at position 2

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0	1	2	3	4
12	21	39	X	X

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If we push another element, `39`, it is inserted at position `2`

The `top` now points to index `2`

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`top = 0`

`push(21)`

0	1	2	3	4
12	21	X	X	X

`top = 1`

`push(39)`

0	1	2	3	4
12	21	39	X	X

`top = 2`

`pop() [returns 39]`

0	1	2	3	4
12	21	X	X	X

`top = 1`

If we pop an element, the element at index `top` is removed

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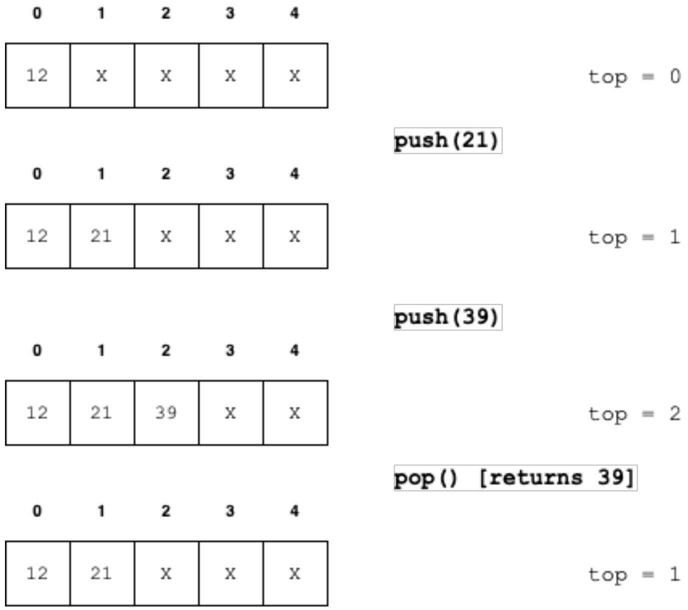

If we pop an element, the element at index `top` is removed

The removed element, i.e., `39`, is returned, and `top` now points to `1`

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0	1	2	3	4
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top = 0

`push(21)`

0	1	2	3	4
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0	1	2	3	4
12	21	39	X	X

top = 2

`pop() [returns 39]`

0	1	2	3	4
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Another pop will remove `21` from the stack

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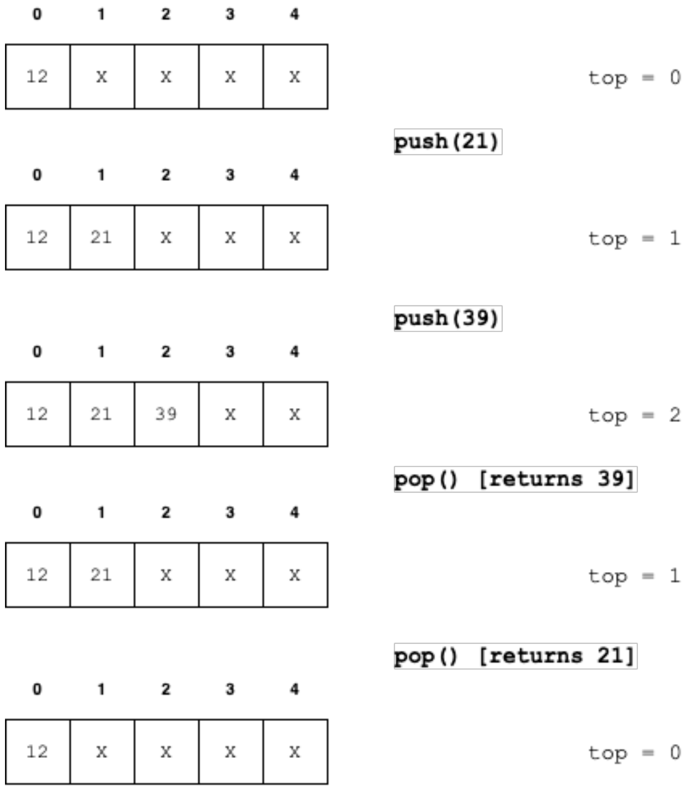

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12	21	39	x	x

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`pop() [returns 39]`

0	1	2	3	4
12	21	x	x	x

top = 1

`pop() [returns 21]`

0	1	2	3	4
12	x	x	x	x

top = 0

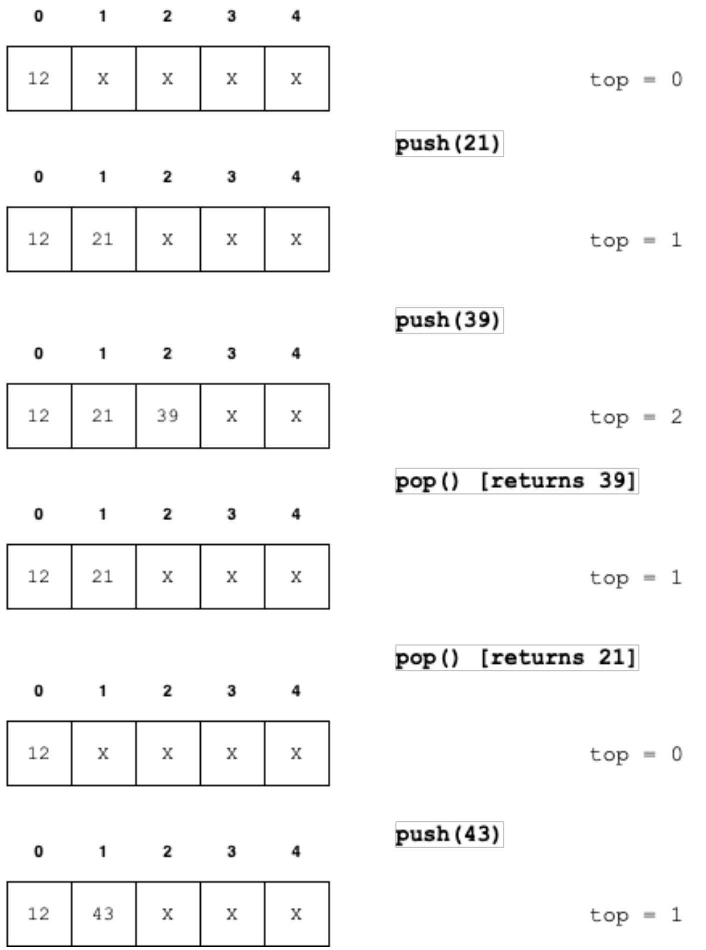
`push(43)`

0	1	2	3	4
12	43	x	x	x

top = 1

Another push operation, say with element `43`, adds it to index `1`

Example: Stack using an array



Another push operation, say with element `43`, adds it to index `1`

The `top` again increases to index `1`

A counterpart of Stack – Queue

With stack, the insertions and deletions are restricted at just one end

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In a queue, insertions and deletions are still restricted to ends, but they occur at different ends

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The end where insertions are done, is called the rear end…

- … and a variable that points to the index of the last inserted element is called *rear*

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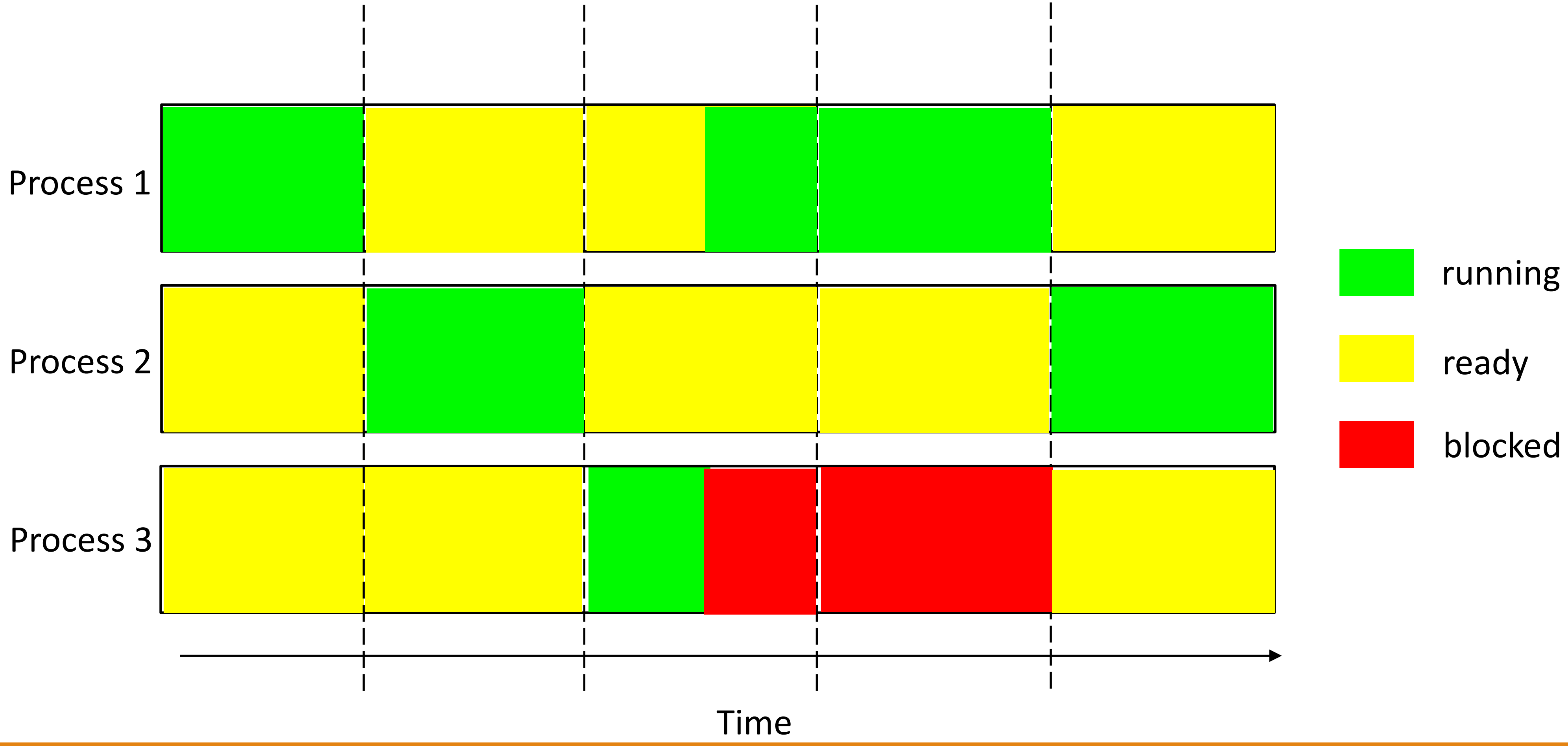
The counterparts of push() and pop() are called *enqueue()* and *dequeue()* respectively

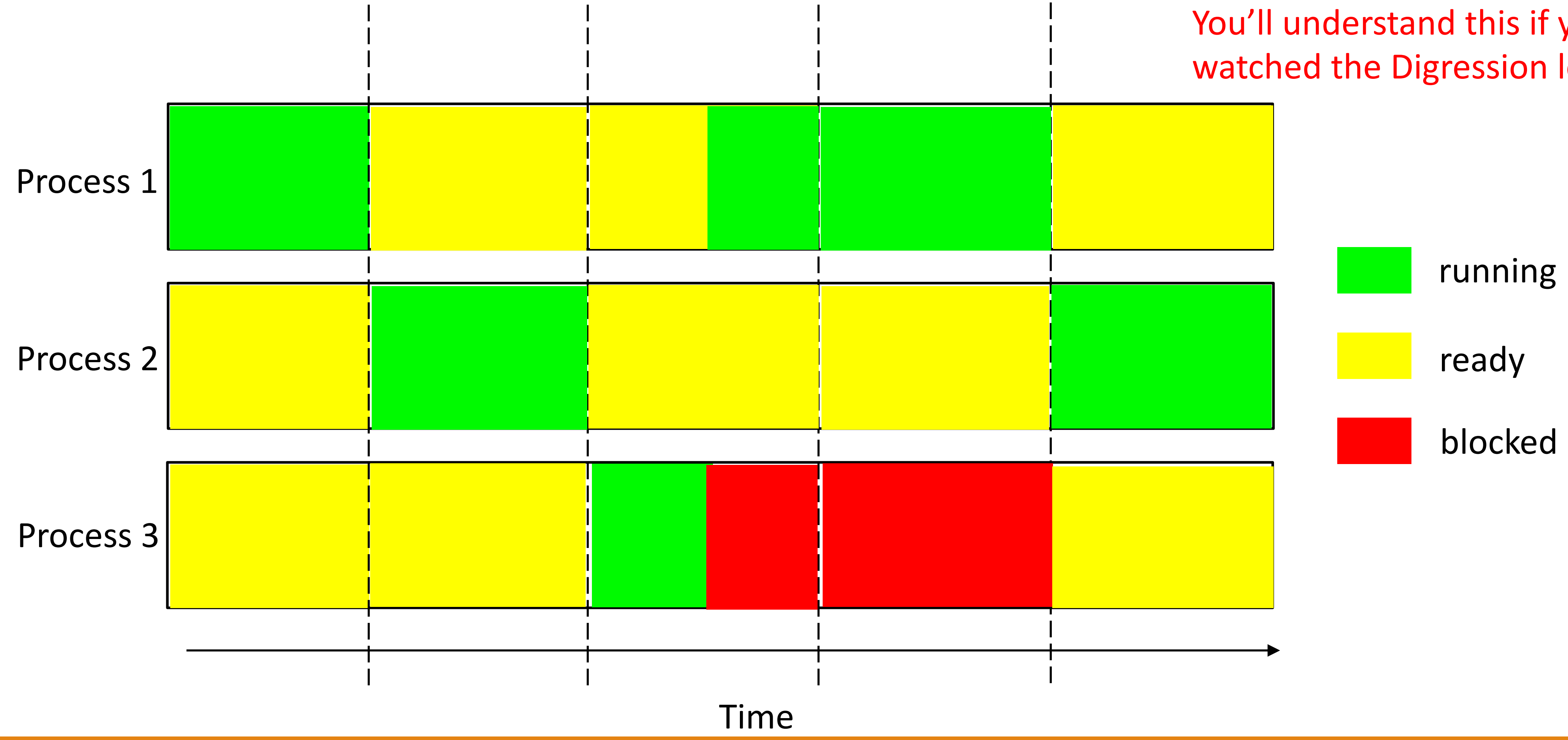
Queues are often used in holding details for processes, so that they can be scheduled judiciously

Example: Scheduling Processes



Example: Scheduling Processes

You’ll understand this if you watched the Digression lecture :P



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0	1	2	3	4
12	x	x	x	x

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rear = 0
front = 0
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Assume that we have a single element in the queue right now

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12	x	x	x	x

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rear = 0
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```

Assume that we have a single element in the queue right now

Both `rear` and `front` point to index `0`

Example: Queue using an array

0	1	2	3	4
12	X	X	X	X

rear = 0
front = 0

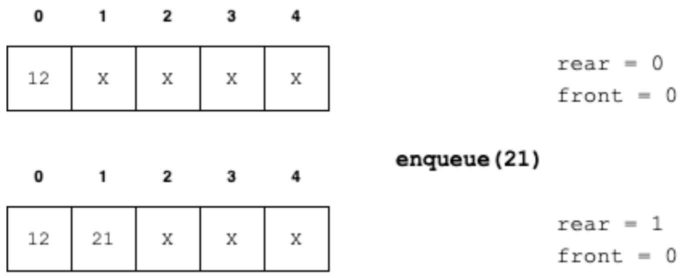
enqueue(21)

0	1	2	3	4
12	21	X	X	X

rear = 1
front = 0

If we enqueue an element, `21`, in the queue, it is added at index `1`

Example: Queue using an array



If we enqueue an element, `21`, in the queue, it is added at index `1`

While `rear` now points to index `1`, `front` remains unchanged

Example: Queue using an array

0	1	2	3	4
12	X	X	X	X

```
rear = 0
front = 0
```

enqueue(21)

0	1	2	3	4
12	21	X	X	X

```
rear = 1
front = 0
```

enqueue(39)

0	1	2	3	4
12	21	39	X	X

```
rear = 2
front = 0
```

Another enqueue request, for element `39`, is then executed

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enqueue(21)

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Another enqueue request, for element `39`, is then executed

The element is added at index `2`

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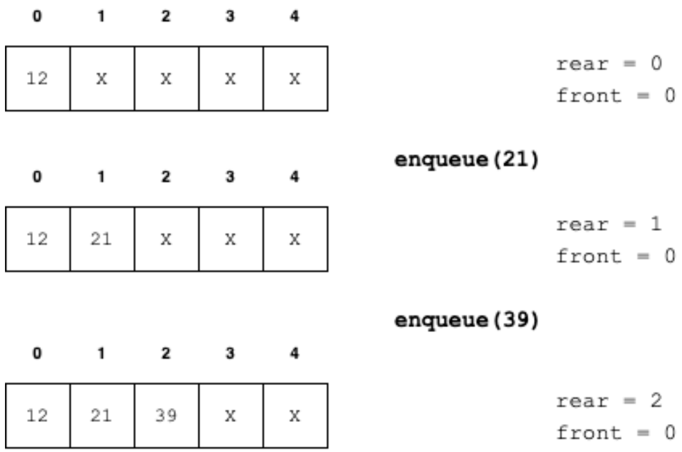


Another enqueue request, for element `39`, is then executed

The element is added at index `2`

It means `rear` now points to `2`; `front` remains at `0`

Example: Queue using an array

0	1	2	3	4
12	X	X	X	X

```
rear = 0
front = 0
```

enqueue(21)

0	1	2	3	4
12	21	X	X	X

```
rear = 1
front = 0
```

enqueue(39)

0	1	2	3	4
12	21	39	X	X

```
rear = 2
front = 0
```

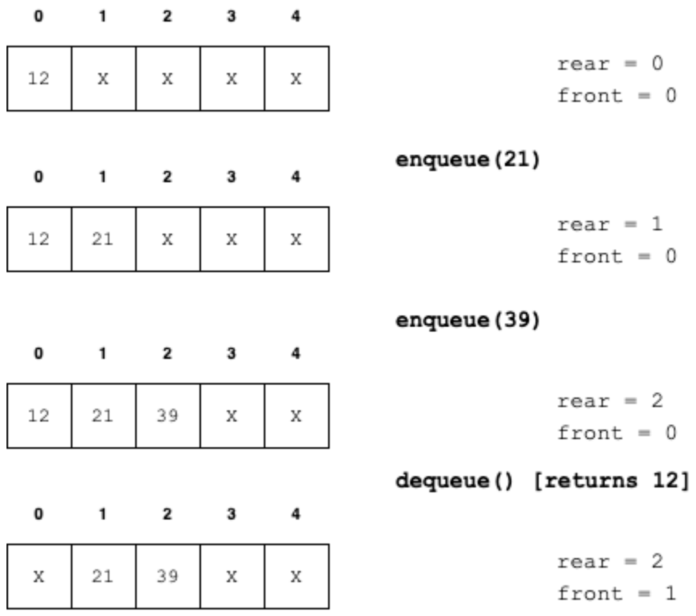
dequeue() [returns 12]

0	1	2	3	4
X	21	39	X	X

```
rear = 2
front = 1
```

On receiving a dequeue request, element `12` is removed from the queue and returned

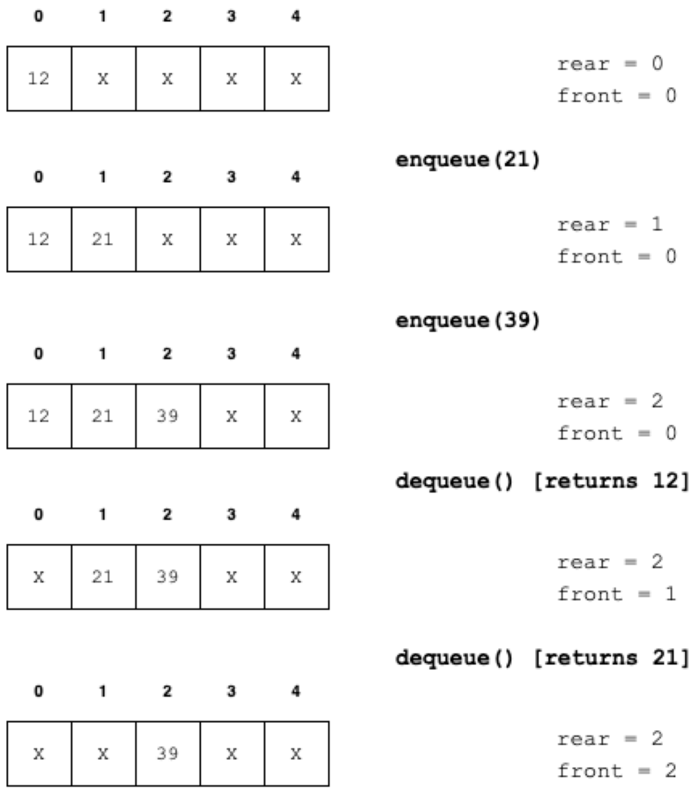
Example: Queue using an array



On receiving a dequeue request, element `12` is removed from the queue and returned

The `front` now moves to index `1`, while `rear` points to the same index as before

Example: Queue using an array



One more dequeue request removes `21` this time the queue, and the same is returned

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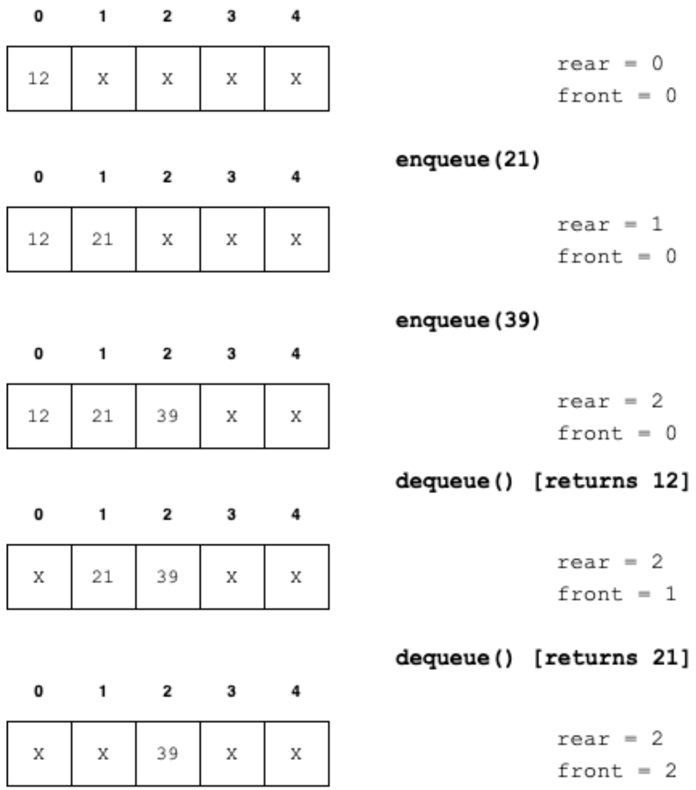
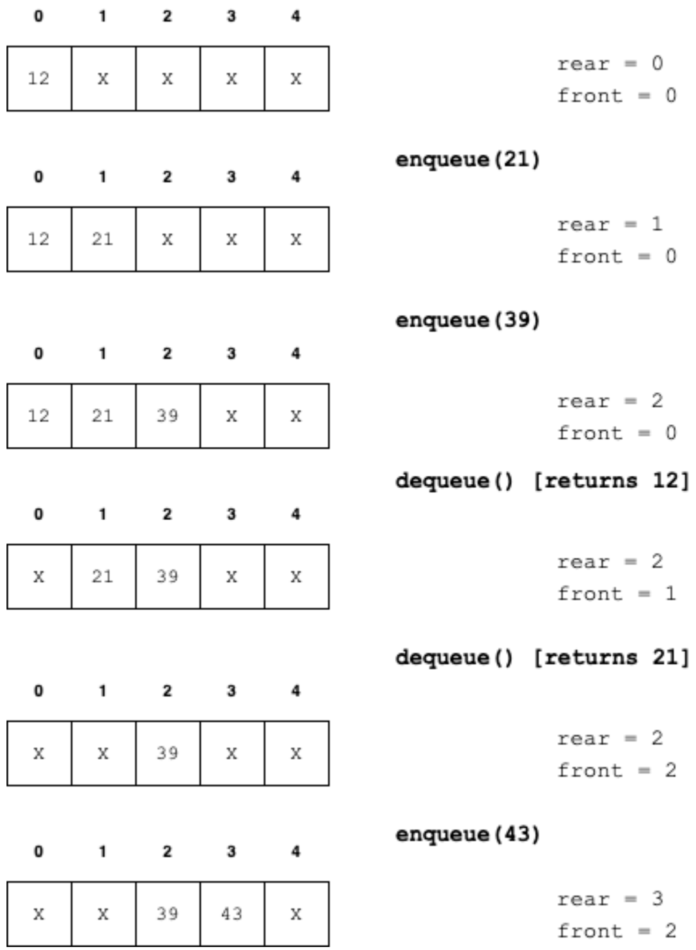


One more dequeue request removes `21` this time the queue, and the same is returned

The `front` moves further to index `2`, joining `rear`

Example: Queue using an array



And again, another enqueue operation, this time for element `43`, results in its addition in the queue at index `3`

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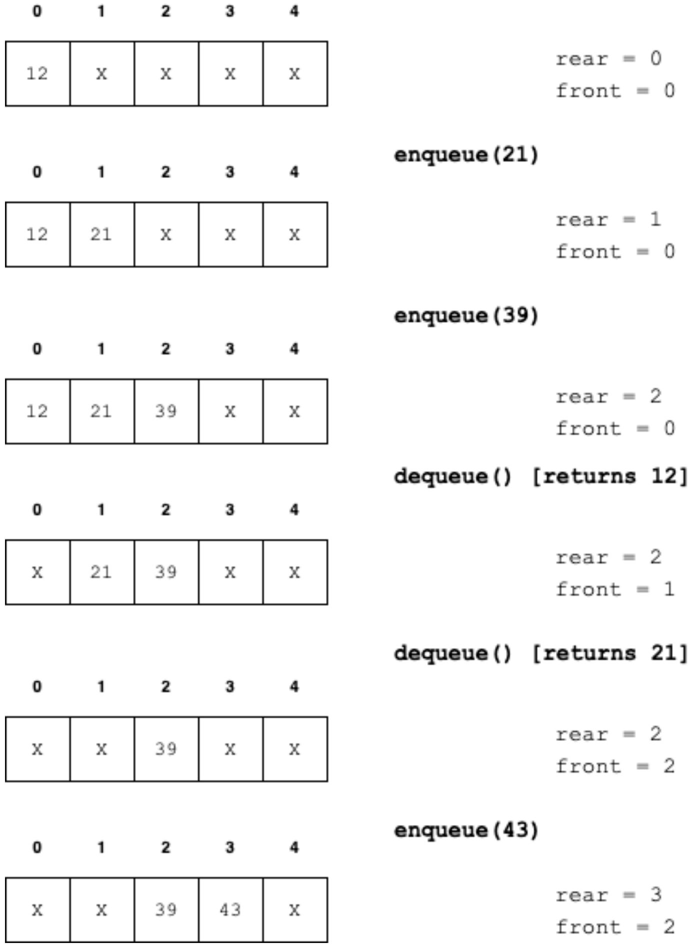

And again, another enqueue operation, this time for element `43`, results in its addition in the queue at index `3`

This results in advancement of `rear` to index `3`, leaving `front` at index `2`

Uses of Stacks and Queues

We saw how stacks are used to implement a system for chains of function calls

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Queues are used for many purposes in Computer Science

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- A common example is usage in any type of message delivery system

Uses of Stacks and Queues

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- … and for performance reasons, you want to convert it to an iterative solution…
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However, the formulation of queues that we saw in this lecture is seldom used

- It is because we will not be able to enqueue any new element, when `rear` reaches the end of the array
- Usually, the queues that are used more practically, are *circular* in nature (see **Additional Reading** slide)

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This was just an introduction to two most common data structures

- We will have a look at one more important data structure – *linked lists* – in the next week

Homework !!

Revisit the program called `BasicArrayOperations.c` from Week 5

- Change it to create two programs – `StackOperations.c` and `QueueOperations.c`
- Modify the code to emulate the working of a stack and a queue respectively
- See if you can handle the problem with formulation of a queue that we discussed
  Hint: May be shifting elements of the array could lead to a solution

Additional Reading

A more practical version of queue is called *circular queue*

- A circular queue allows the rear and the front variables to "wrap-around"…
- … i.e., they can go from 0 to size-1 and vice versa, if applicable

Read more about circular queues

- You may start here: https://www.geeksforgeeks.org/circular-queue-set-1-introduction-array-implementation/