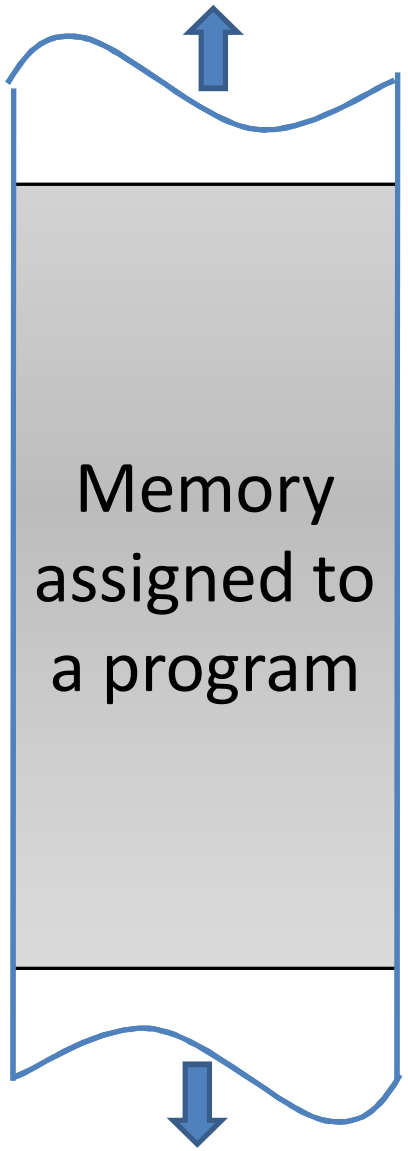
Dynamic Memory Allocation

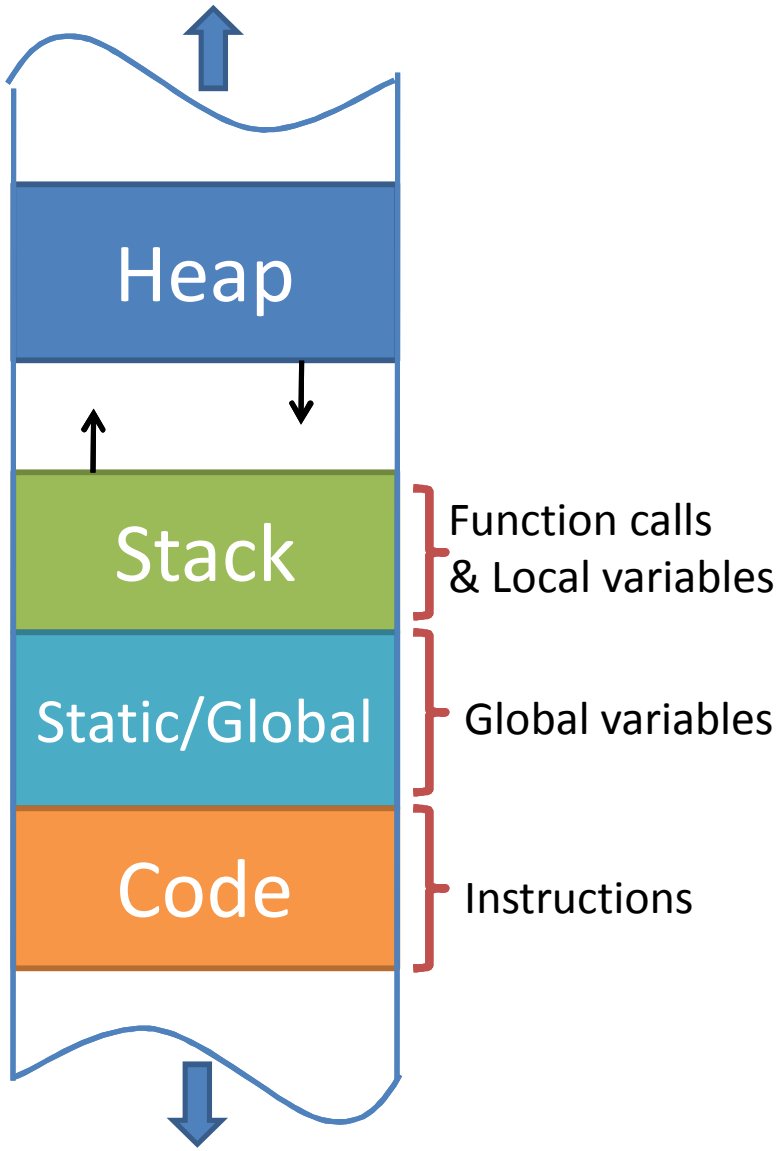
Memory of a Program

Whenever a program executes, the operating system allocates some space in memory for it.



Memory of a Program

The memory allocated to a program is divided into four parts.

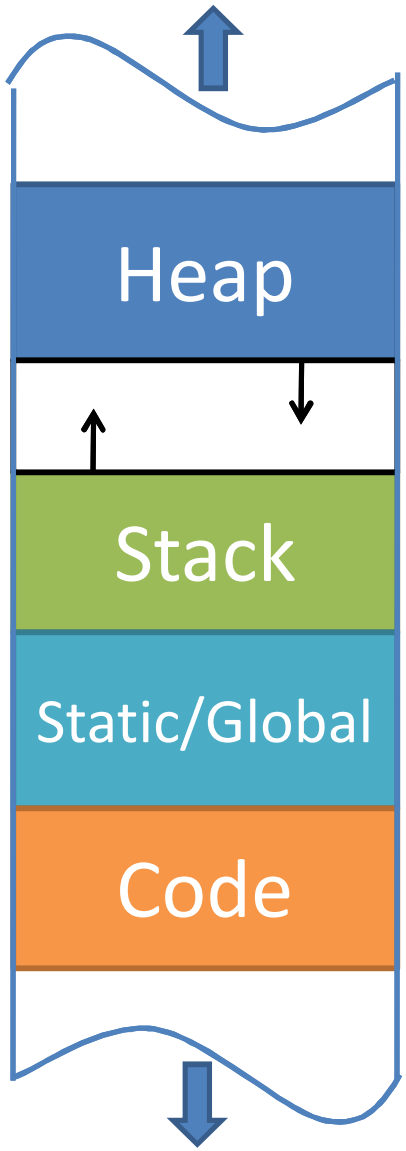


Memory of a Program

```
#include<stdio.h>
int total;
int Square(int x)
{
   return(x*x);
}

int SquareOfSum(int x,int y)
{
   int z = Square(x+y);
   return(z);
}

int main()
{
   int a=4, b=8;
   total = SquareOfSum(a,b);
   printf("Output=%d",total);
}
```



Use of Stack

```
#include<stdio.h>
int total;
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}

int SquareOfSum(int x,int y)
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int main()
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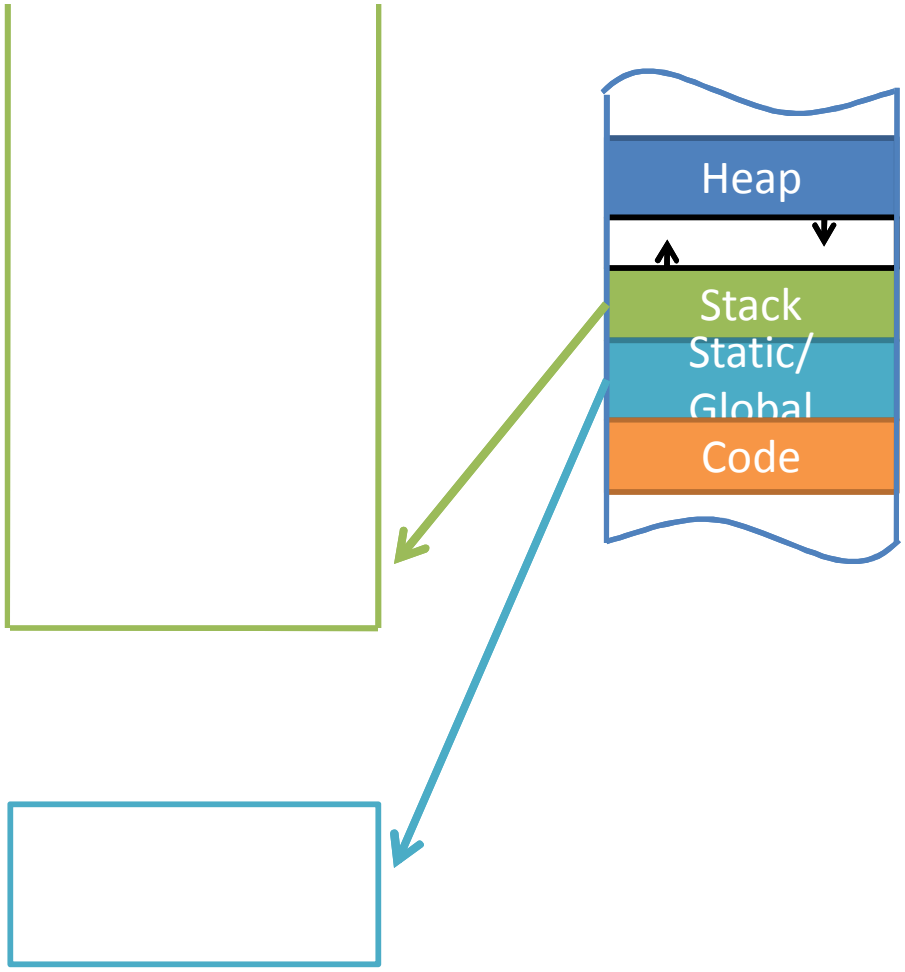
}
```



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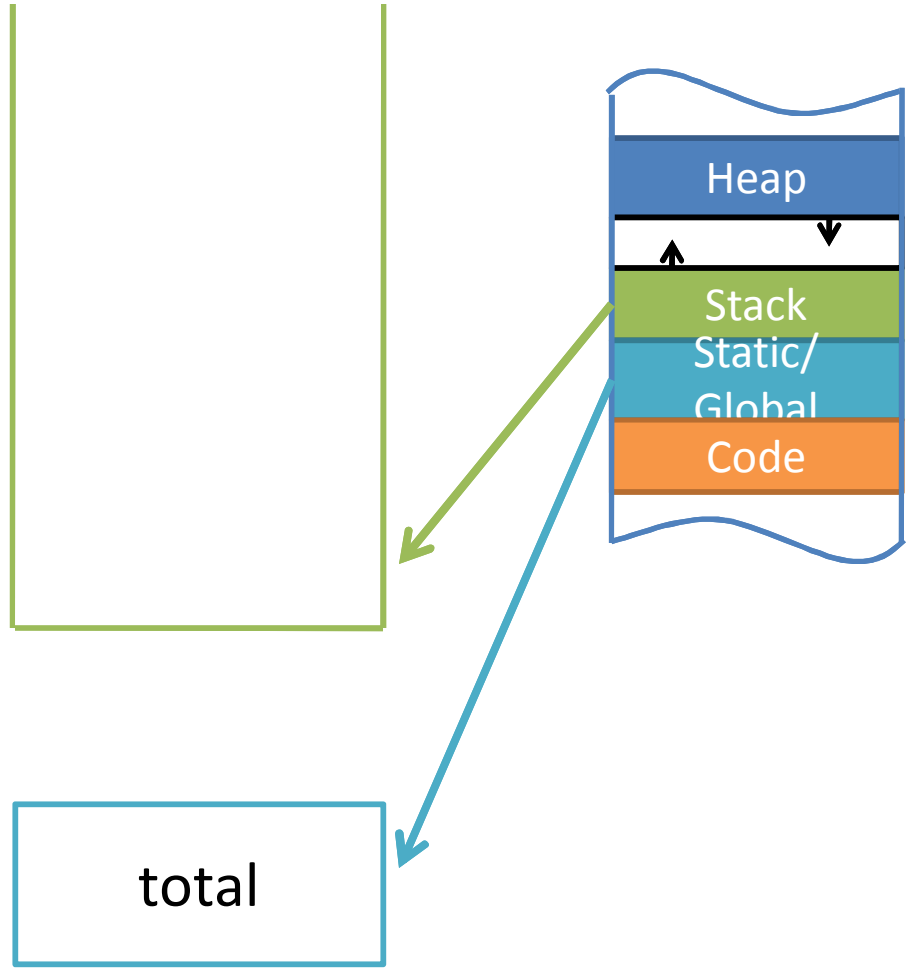
```



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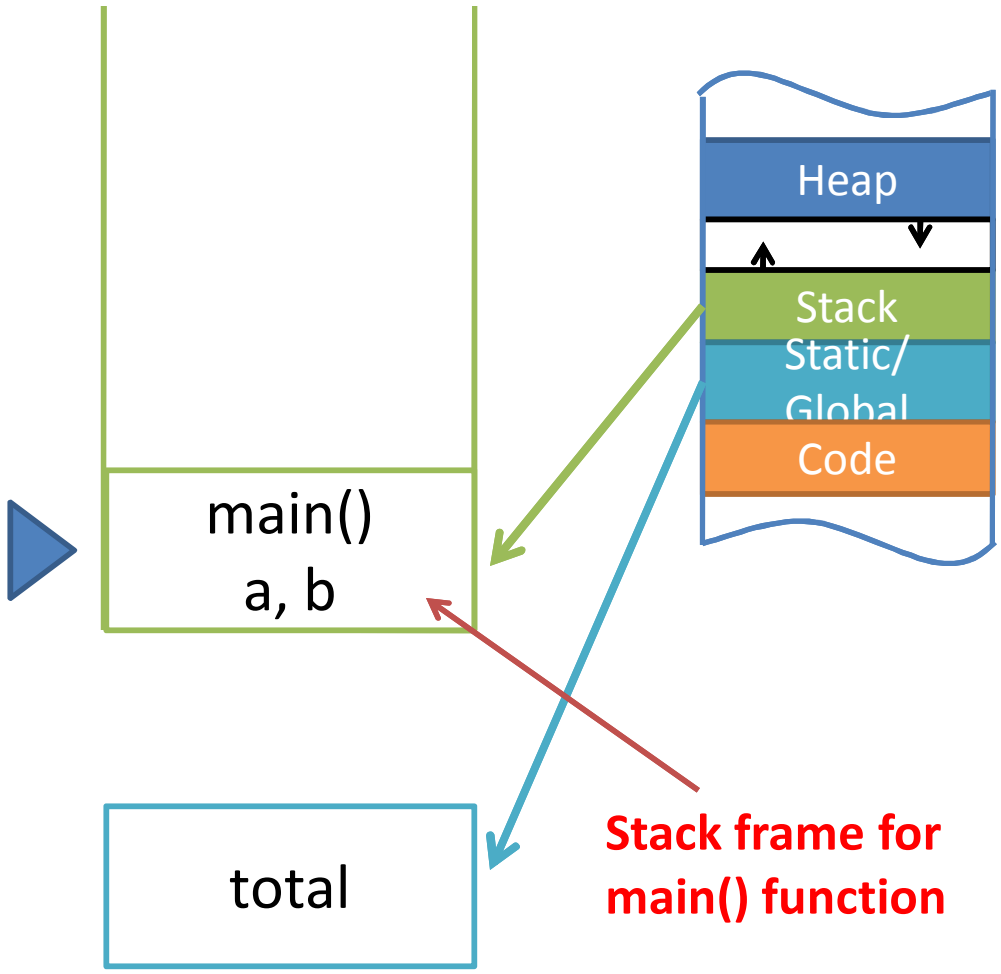

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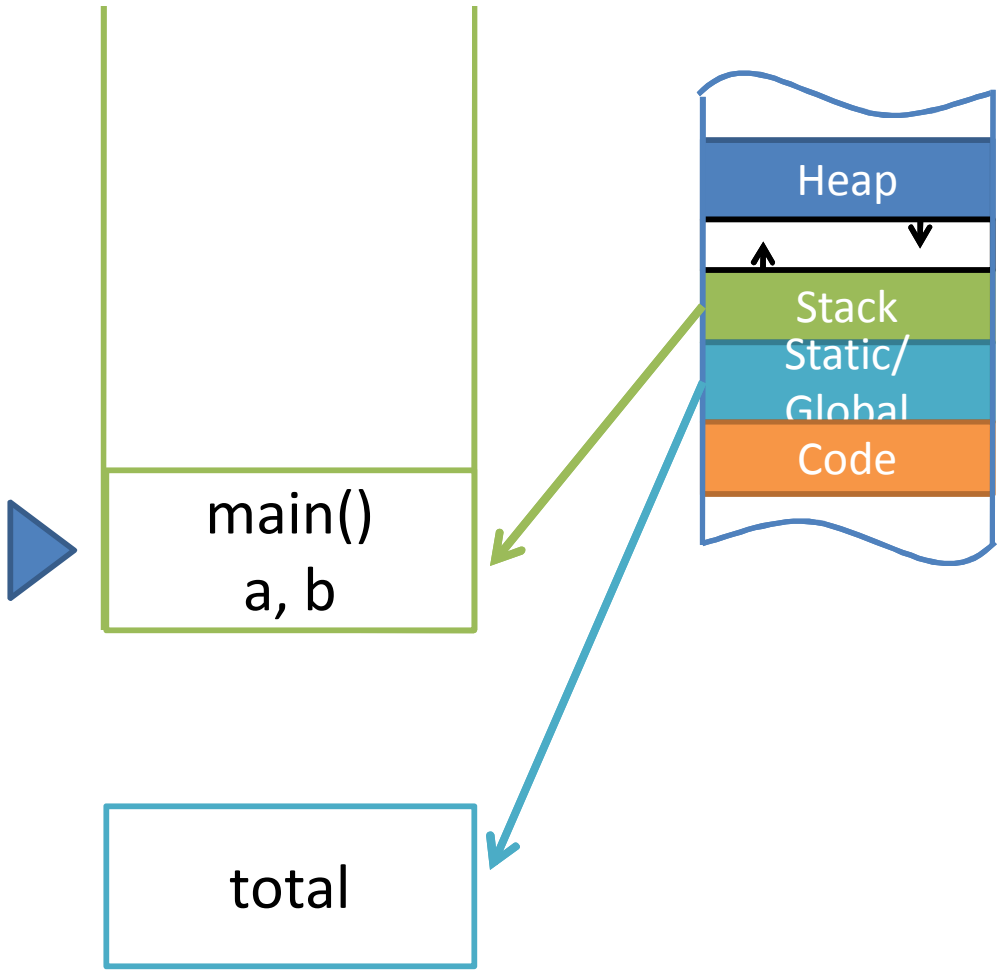

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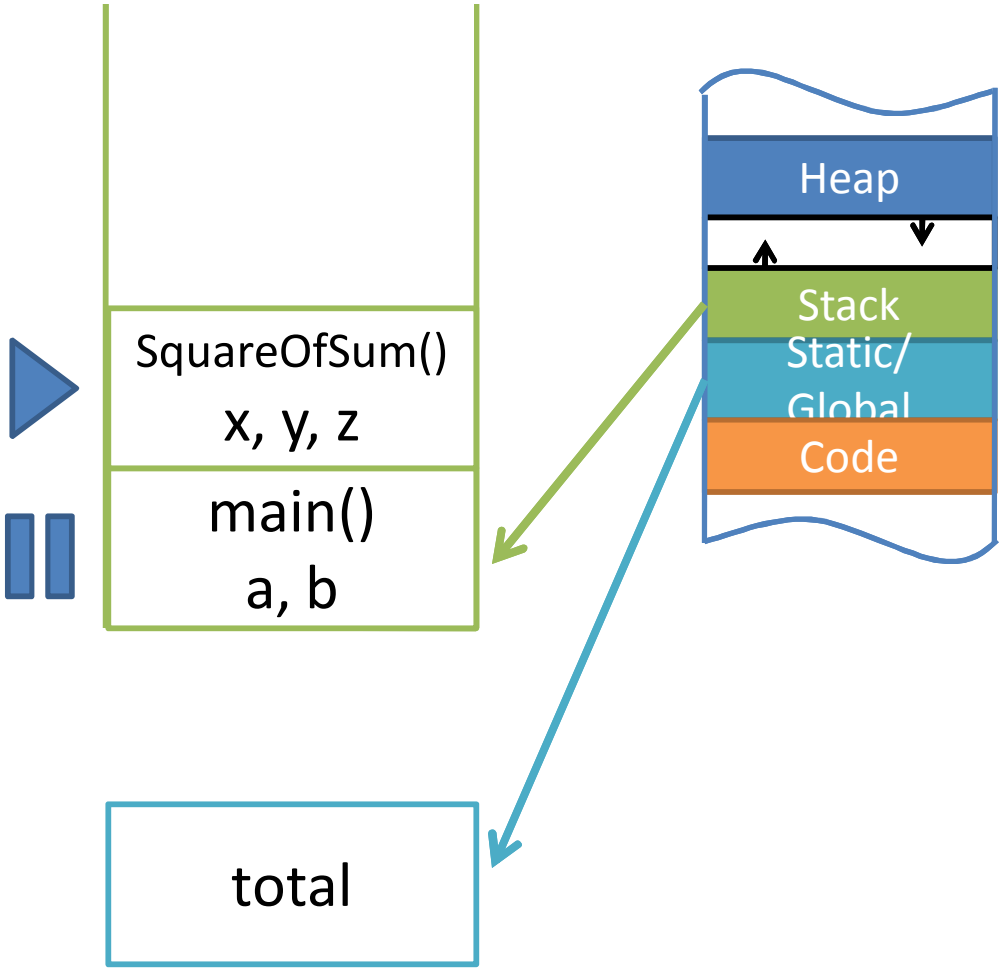
```



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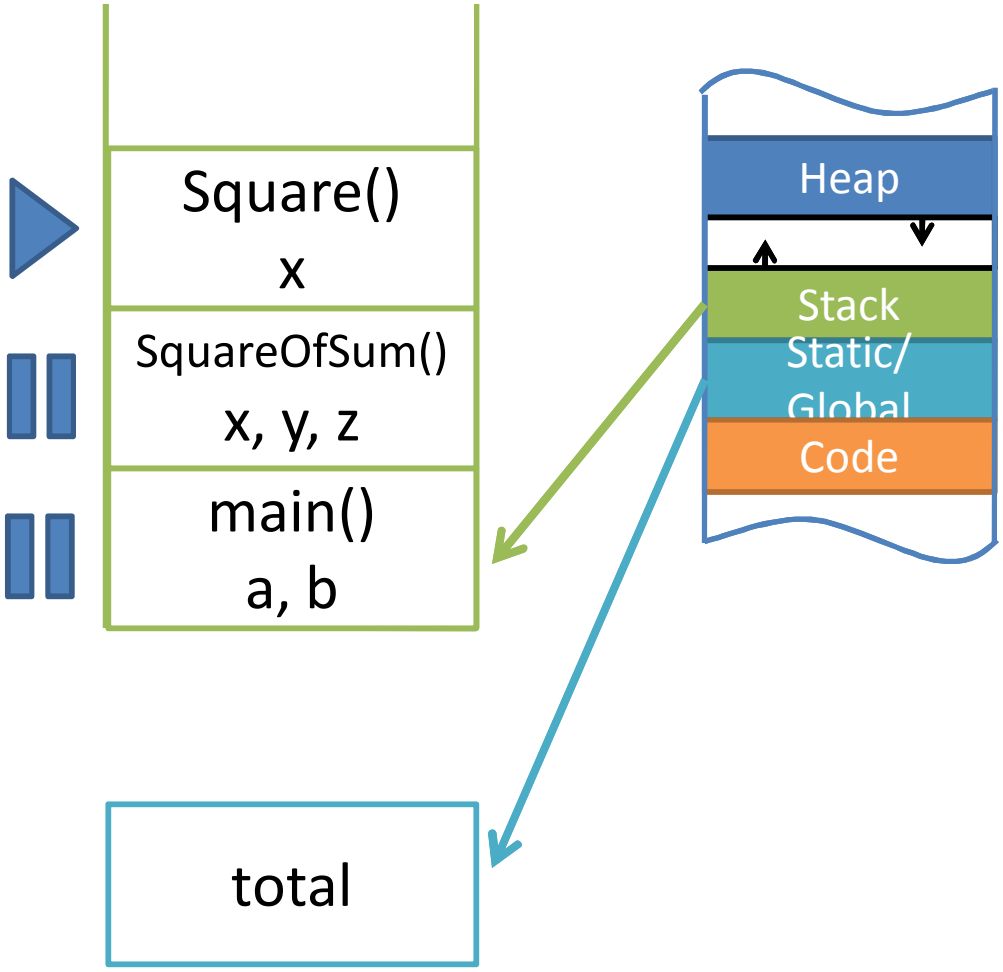

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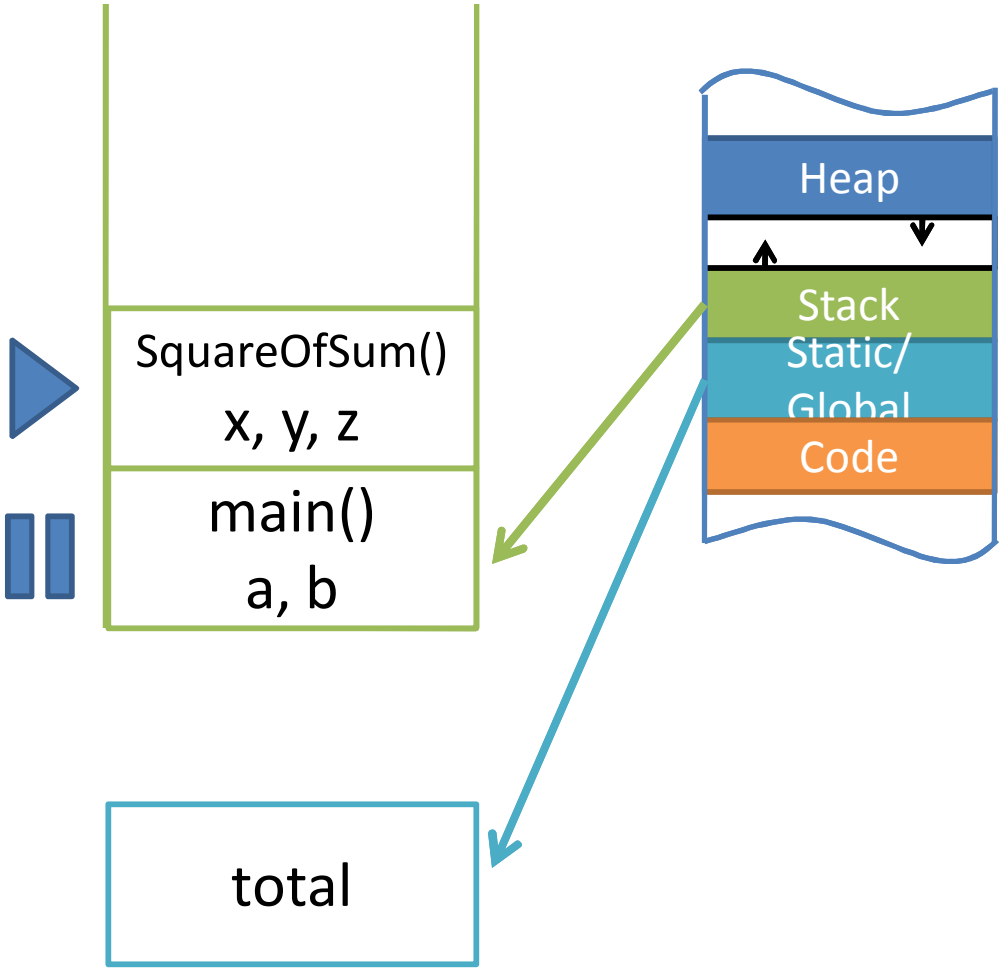

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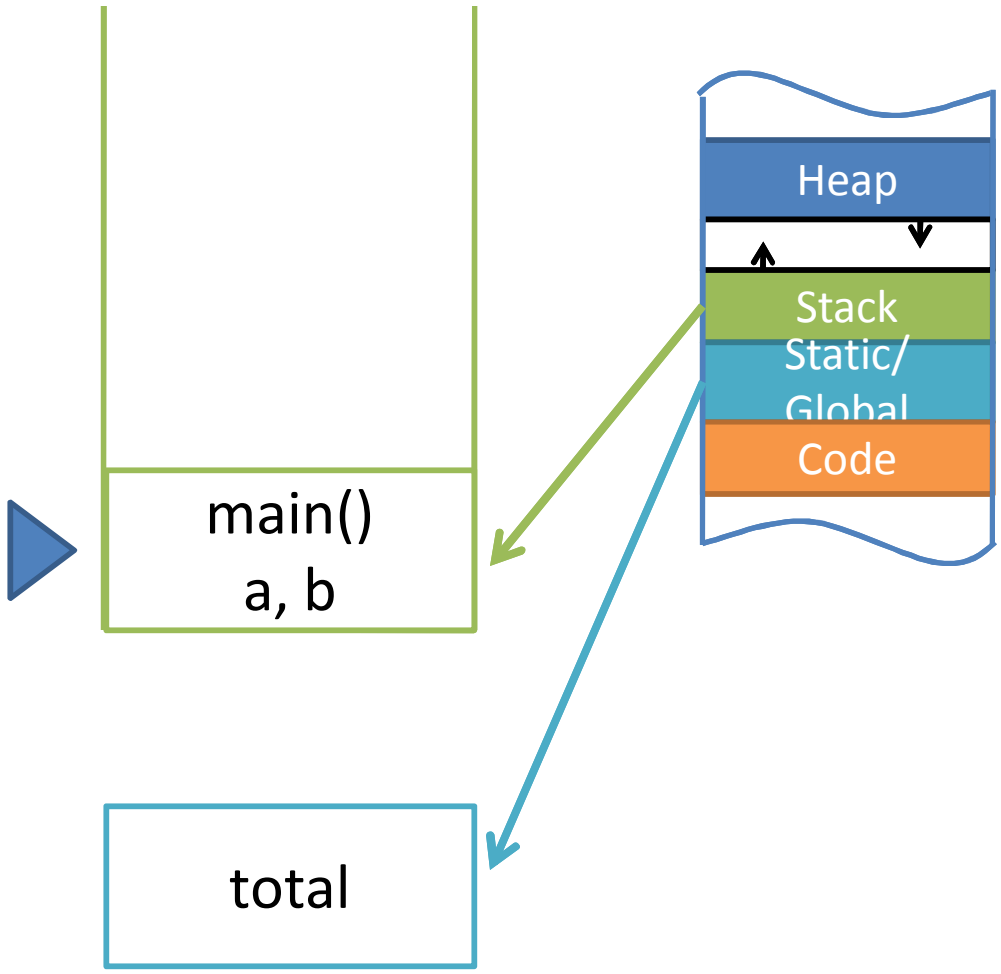

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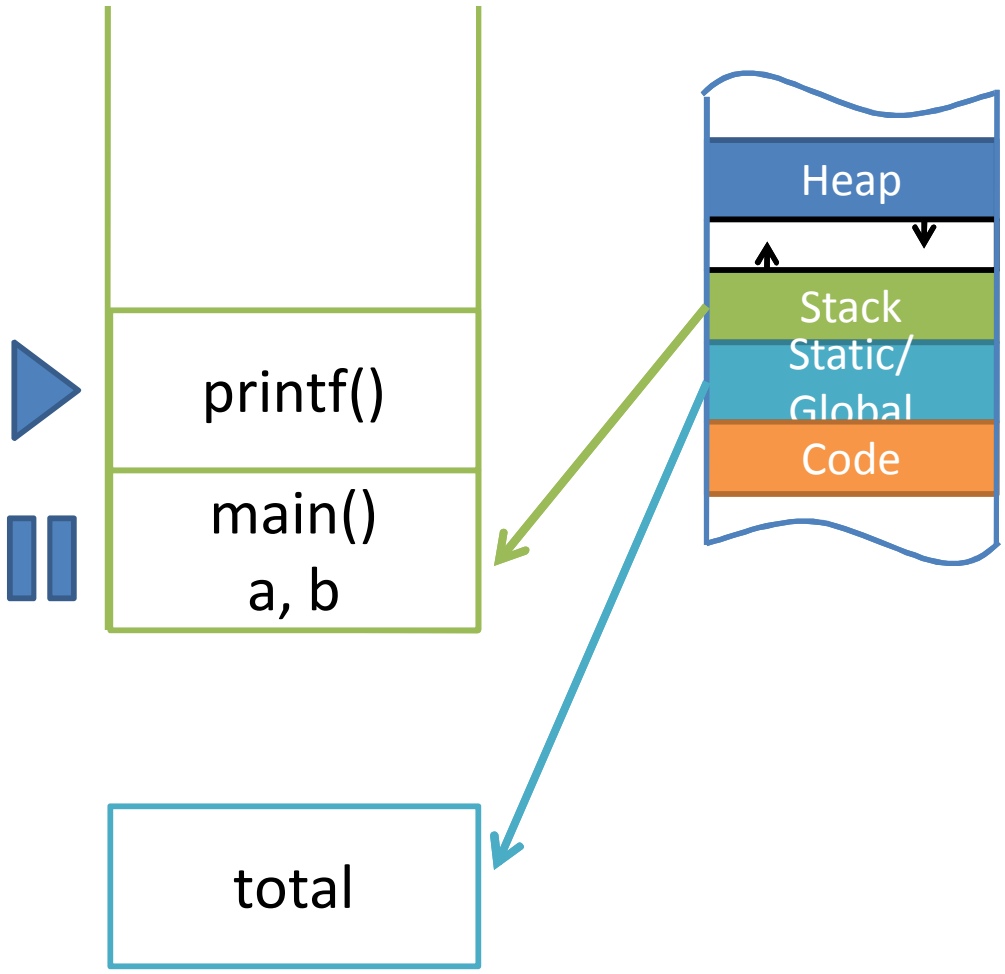
```



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    return(z);
}

int main()
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    total = SquareOfSum(a,b);
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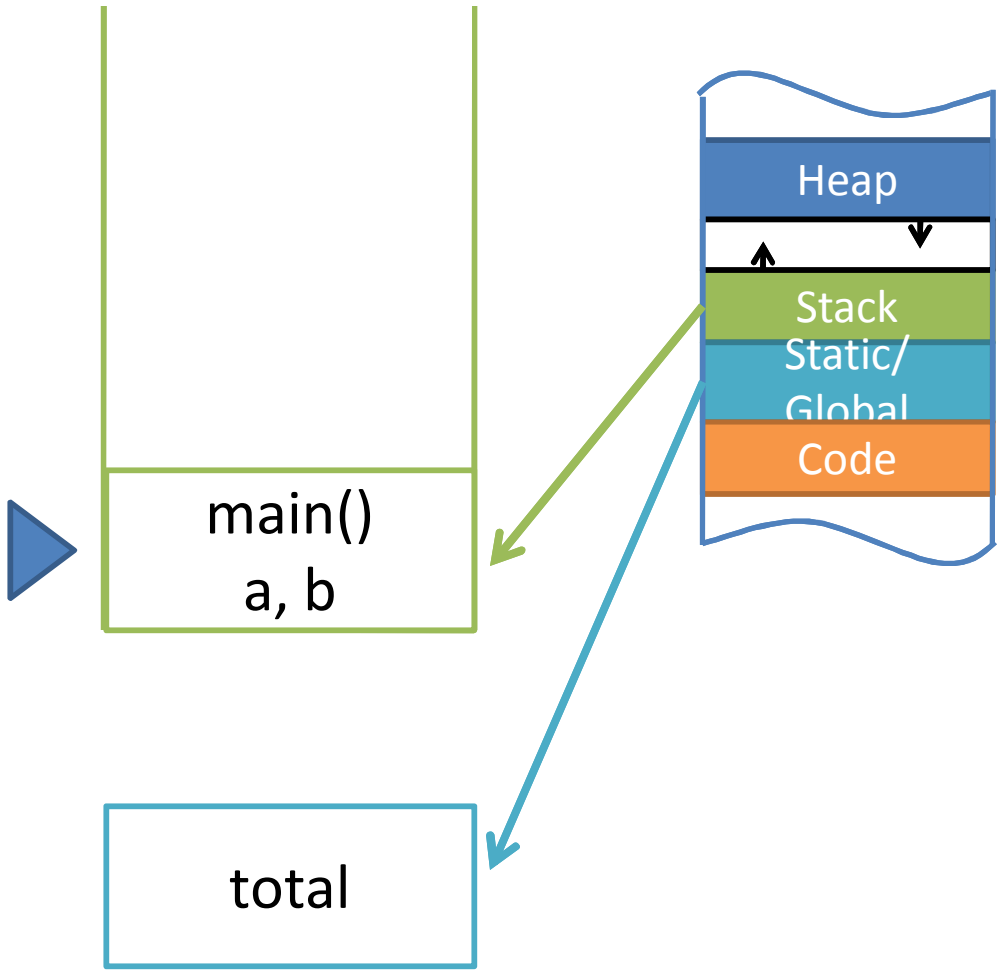
```



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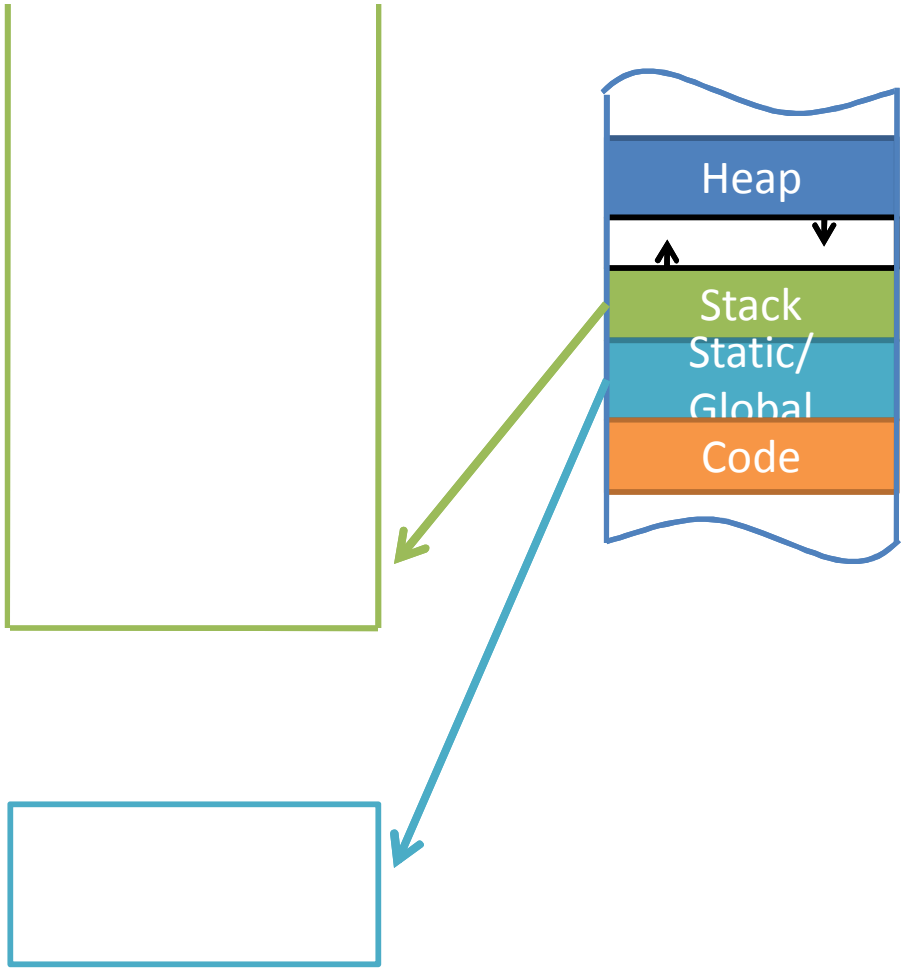

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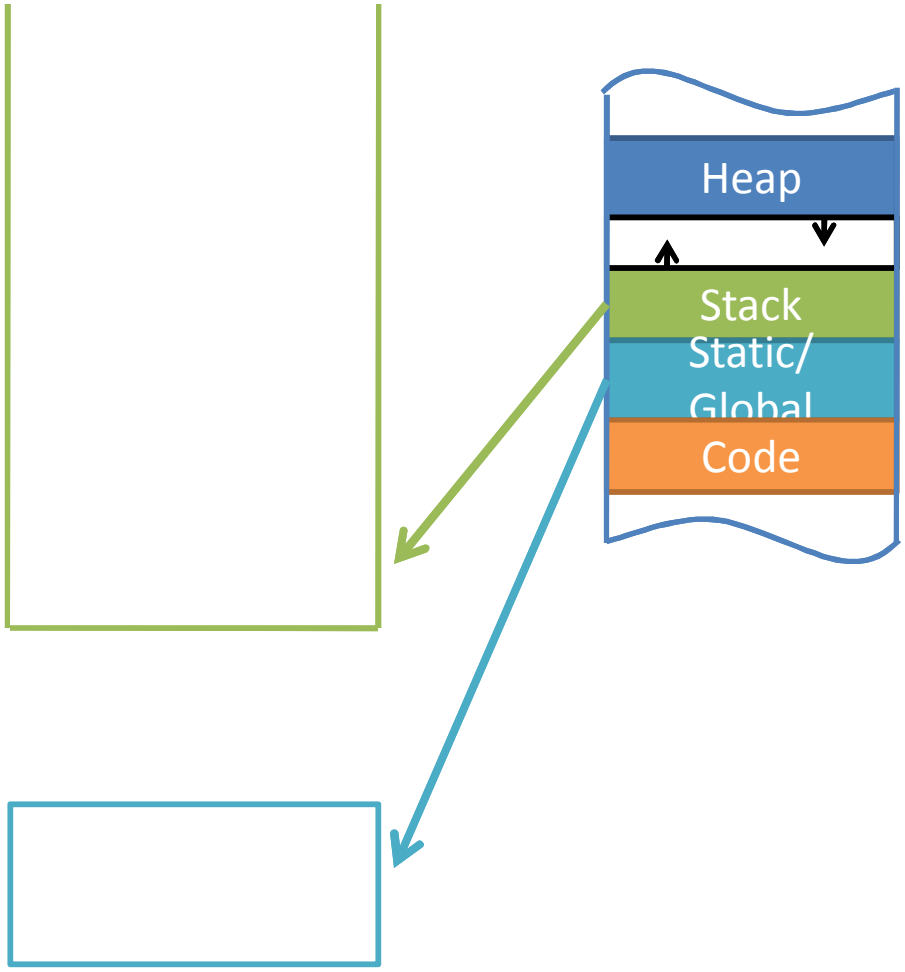


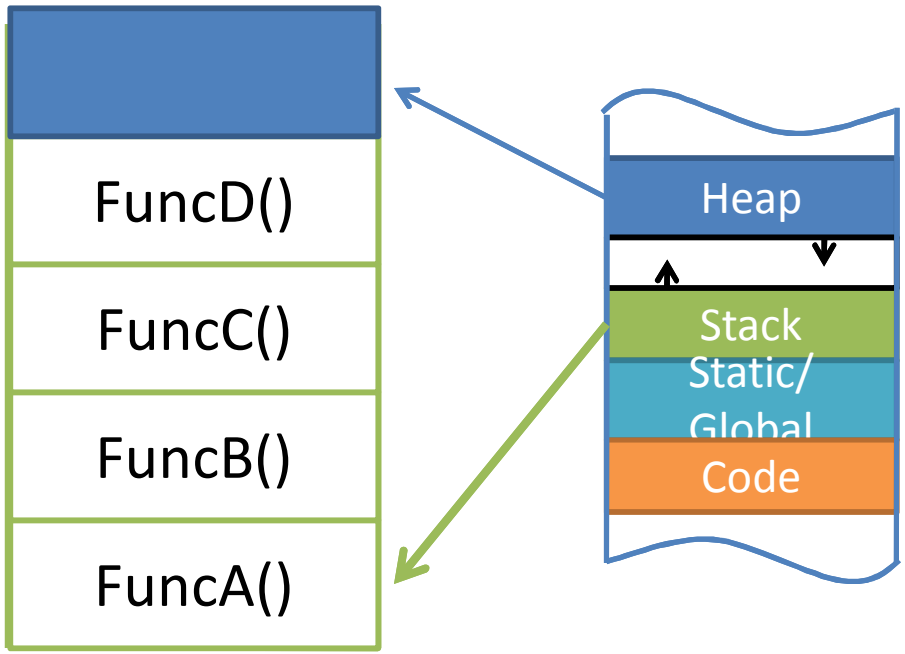
LIFO – Last In First Out

Limitation of Stack

```
#include<stdio.h>
int total;
int Square(int x)
{
   return(x*x);
}

int SquareOfSum(int x,int y)
{
   int z = Square(x+y);
   return(z);
}

int main()
{
   int a=4, b=8;
   total = SquareOfSum(a,b);
   printf("Output=%d",total);
}
```



Stack Overflow

Limitation of Stack

- Allocation and deallocation of stack memory are handled by Operating System. Programmer cannot control the lifetime of variables in stack memory.
    - **Allocation:** Function starts (Push onto stack)
    - **Deallocation:** Function finishes (Popped out of stack)

- Size of the **stack frame** for a function is known at the compile time.
- An array with **unknown size** (only known at run time) cannot be allocated in the stack memory.
    - For this, we need to use heap memory.

Heap Memory

- A programmer can define the size of an array at run time using **dynamic memory allocation.**
- All variables/array defined using dynamic memory allocation are allocated memory from heap.
- The programmer can decide how long the allocated memory to be kept.
- Heap can grow as long as the program does not run out of the memory allocated to it.
  - Sometimes dangerous if proper care is not taken.
- Heap is called a free pool/store of memory

Use of Heap
(Dynamic Memory Allocation)

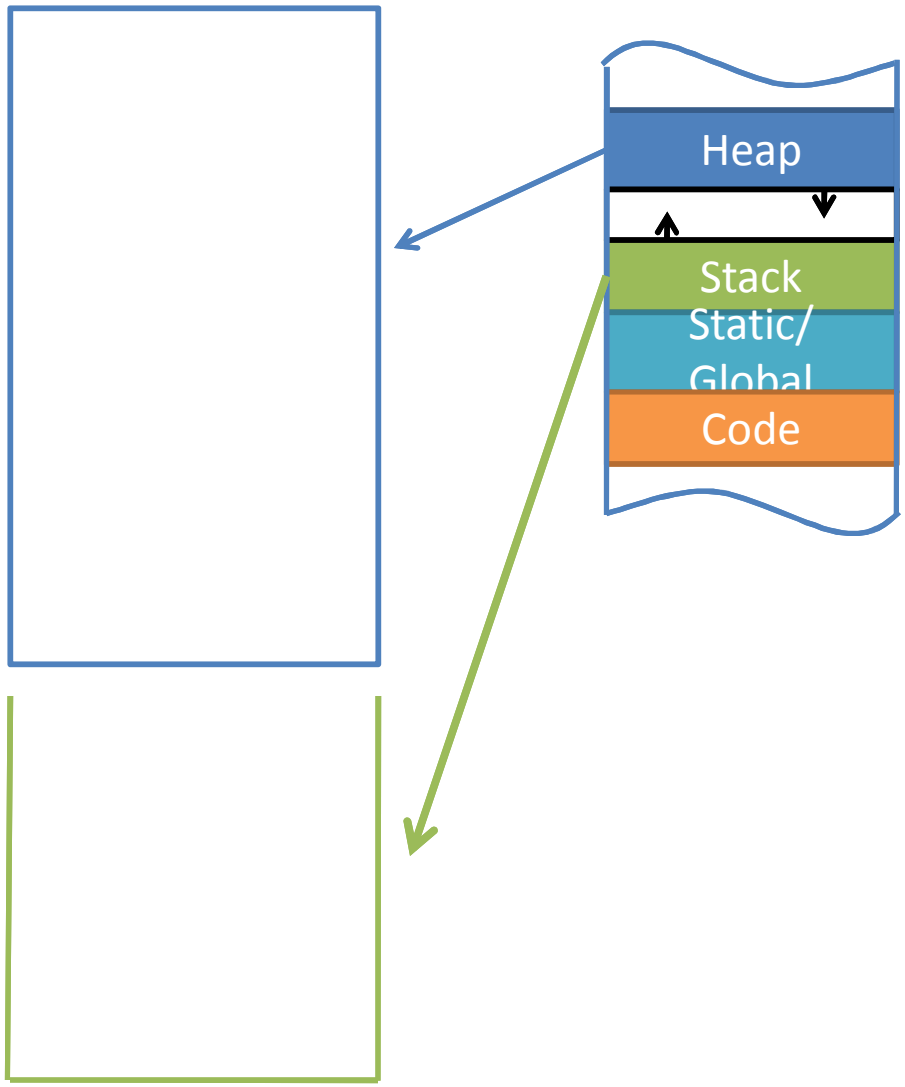
Dynamic Memory Allocation

C language

- **malloc()** – Allocates block of memory
- **calloc()** – Allocate multiple blocks and initialize to 0.
- **realloc()** – Reallocates block of memory
- **free()** – Frees up memory

C++ language

- **new** – Allocates block of memory
- **delete** – Frees up memory

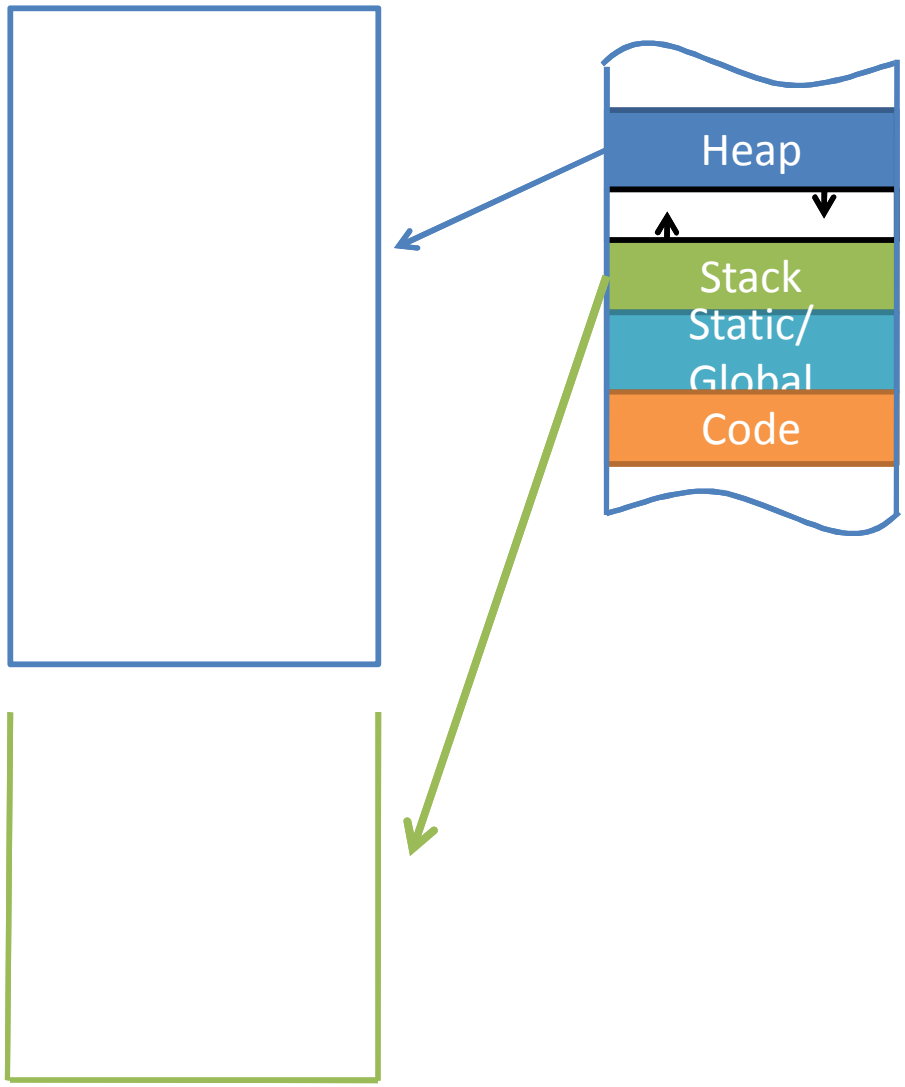


Use of Heap
(Dynamic Memory Allocation)

Dynamic Memory Allocation

C language (Example code)

```
#include<stdio.h>
#include<stdlib.h>
```

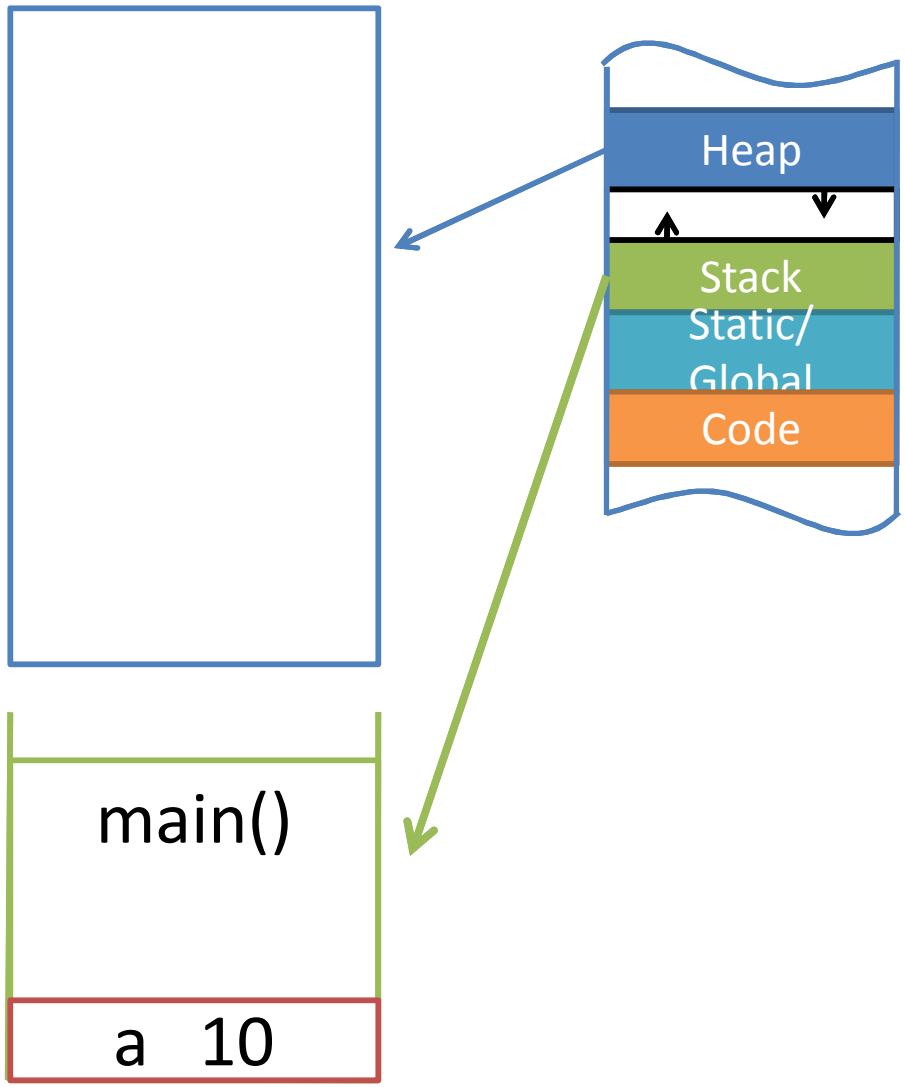


Use of Heap
(Dynamic Memory Allocation)

Dynamic Memory Allocation

C language (Example code)

```
#include<stdio.h>
#include<stdlib.h>
int main()
{
    int a=10;
```

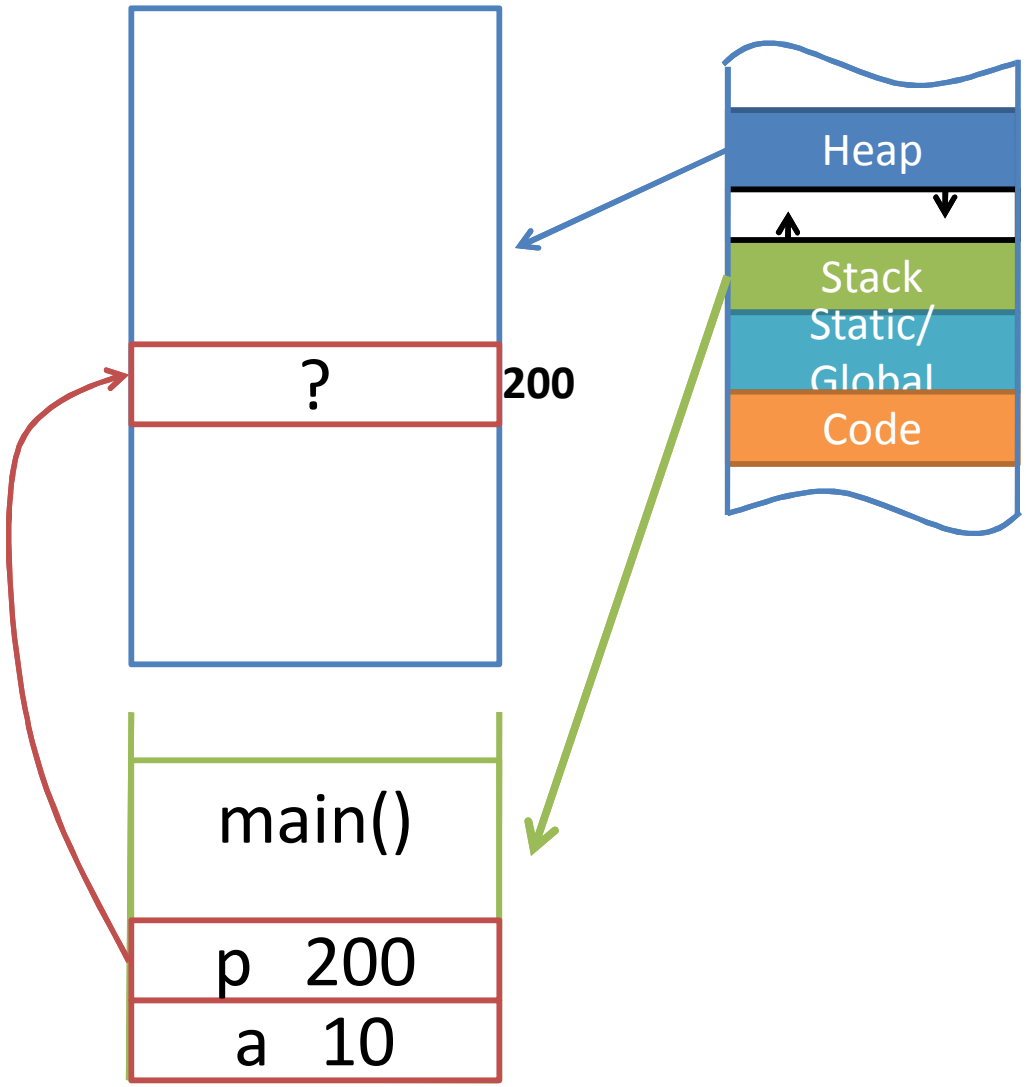


Use of Heap
(Dynamic Memory Allocation)

Dynamic Memory Allocation

C language (Example code)

```
#include<stdio.h>
#include<stdlib.h>
int main()
{
    int a=10;
    int *p;
    p = (int*)malloc(sizeof(int));
```

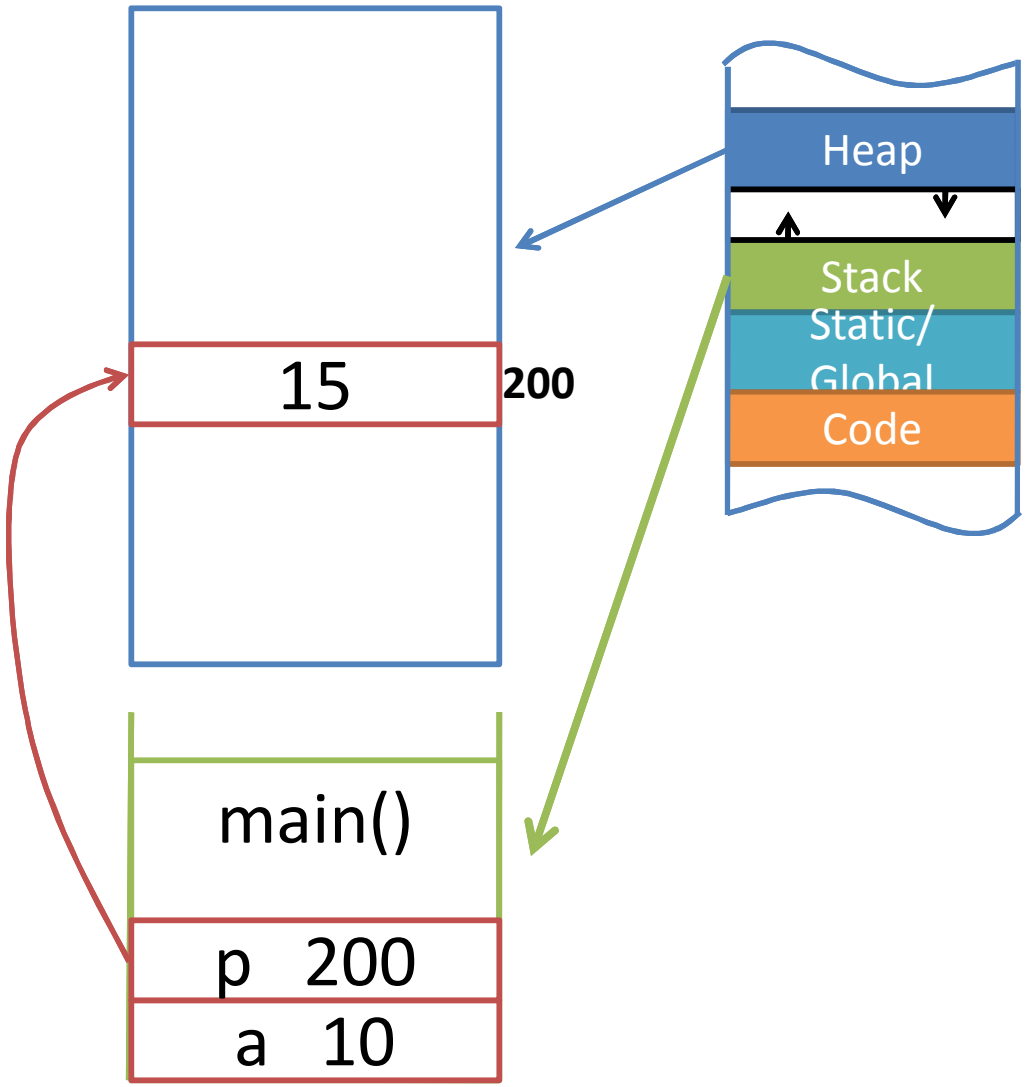


Use of Heap
(Dynamic Memory Allocation)

Dynamic Memory Allocation

C language (Example code)

```
#include<stdio.h>
#include<stdlib.h>
int main()
{
    int a=10;
    int *p;
    p = (int*)malloc(sizeof(int));
    *p=15;
```



Use of Heap
(Dynamic Memory Allocation)

Dynamic Memory Allocation

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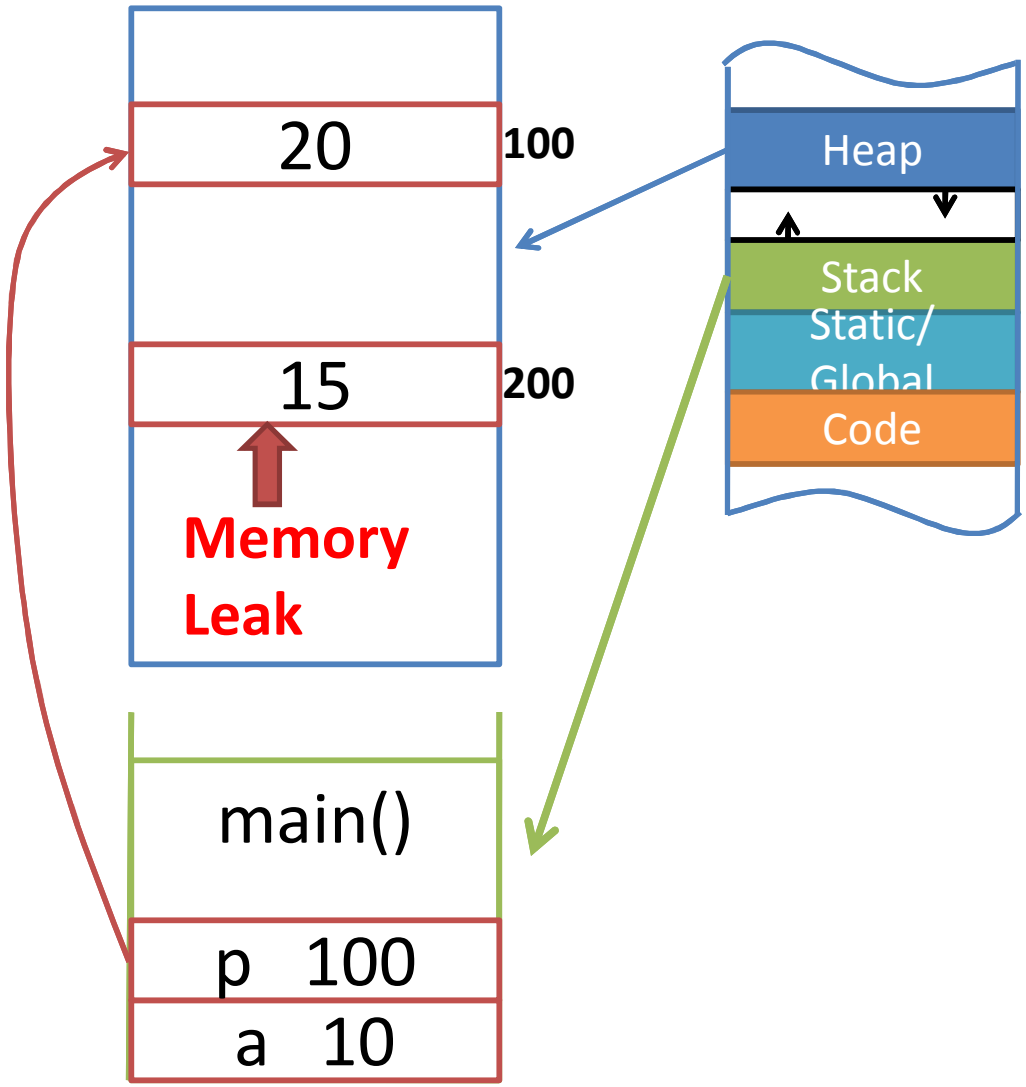
#include<stdio.h>
#include<stdlib.h>
int main()
{
    int a=10;
    int *p;
    p = (int*)malloc(sizeof(int));
    *p=15;

    p=(int*)malloc(sizeof(int));
    *p=20;
```

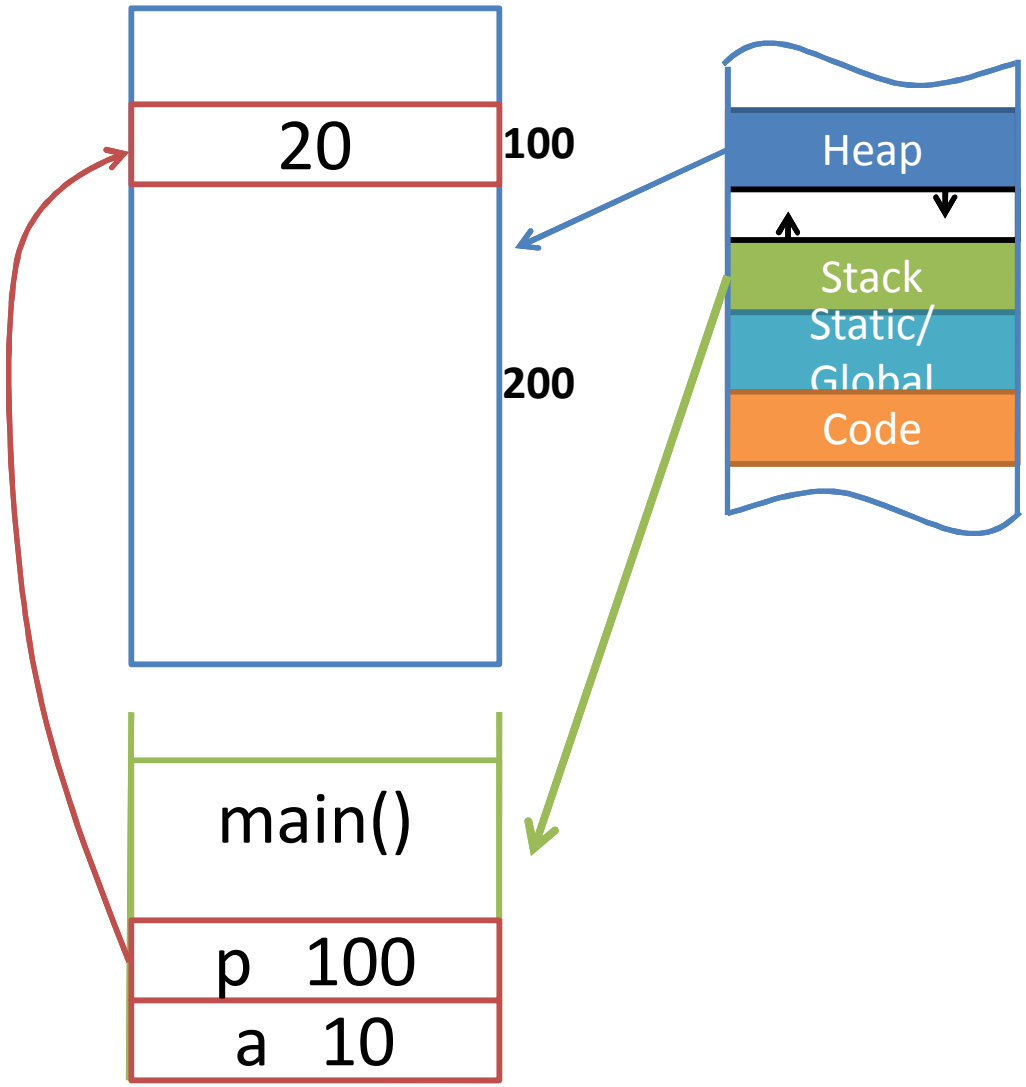


Use of Heap
(Dynamic Memory Allocation)

Dynamic Memory Allocation

C language (Example code)

```
#include<stdio.h>
#include<stdlib.h>
int main()
{
    int a=10;
    int *p;
    p = (int*)malloc(sizeof(int));
    *p=15;
    free(p);
    p=(int*)malloc(sizeof(int));
    *p=20;
}
```

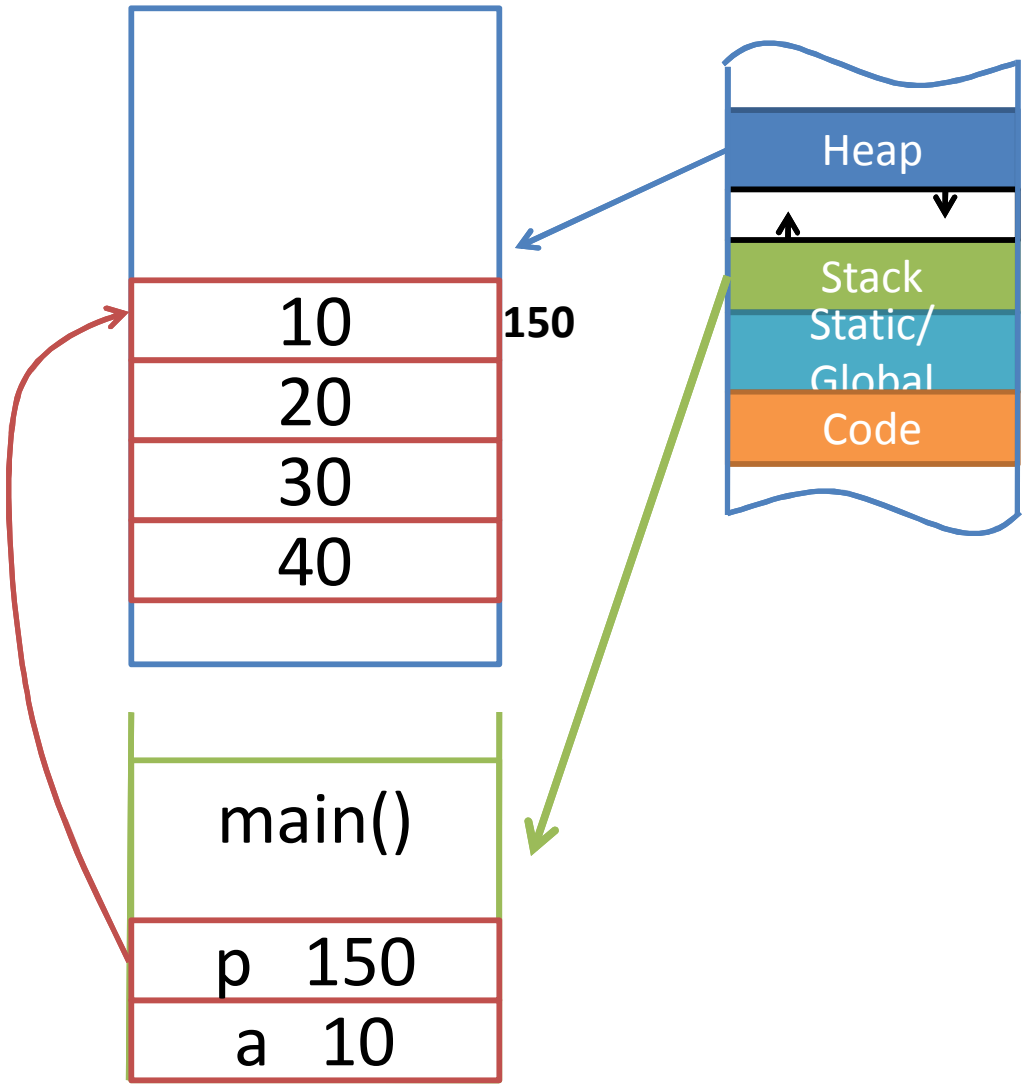


Use of Heap
(Dynamic Memory Allocation)

Dynamic Memory Allocation

C language (Example code)

```
#include<stdio.h>
#include<stdlib.h>
int main()
{
    int a=10;
    int *p;
    p = (int*)malloc(4*sizeof(int));
    p[0]=10;
    p[1]=20;
    *(p+2)=30;
    *(p+3)=40;
}
```

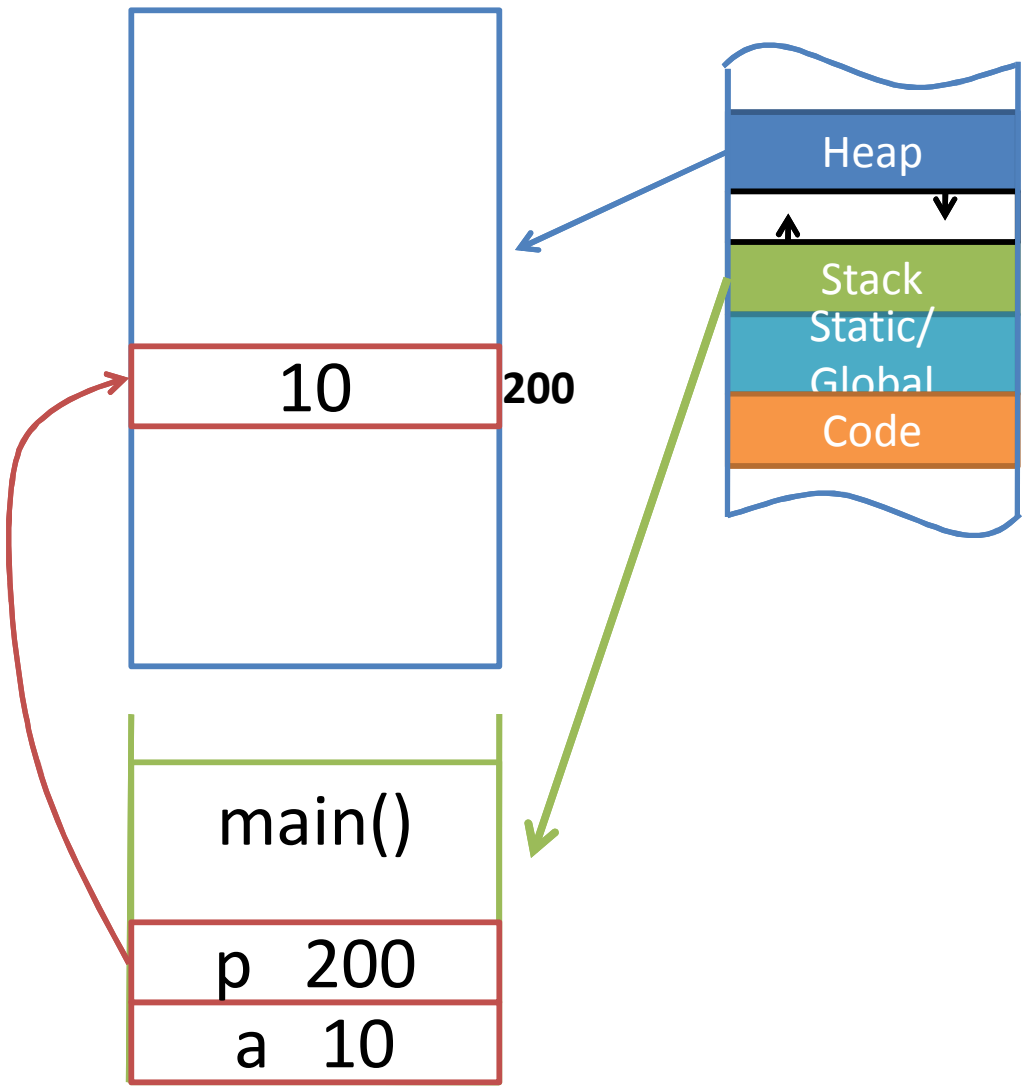


Use of Heap
(Dynamic Memory Allocation)

Dynamic Memory Allocation

C++ language (Example code)

```
#include<stdio.h>
#include<stdlib.h>
int main()
{
    int a=10;
    int *p;
    p = new int;
    *p=10;
```



Use of Heap
(Dynamic Memory Allocation)

Dynamic Memory Allocation

C++ language (Example code)

```
#include<stdio.h>
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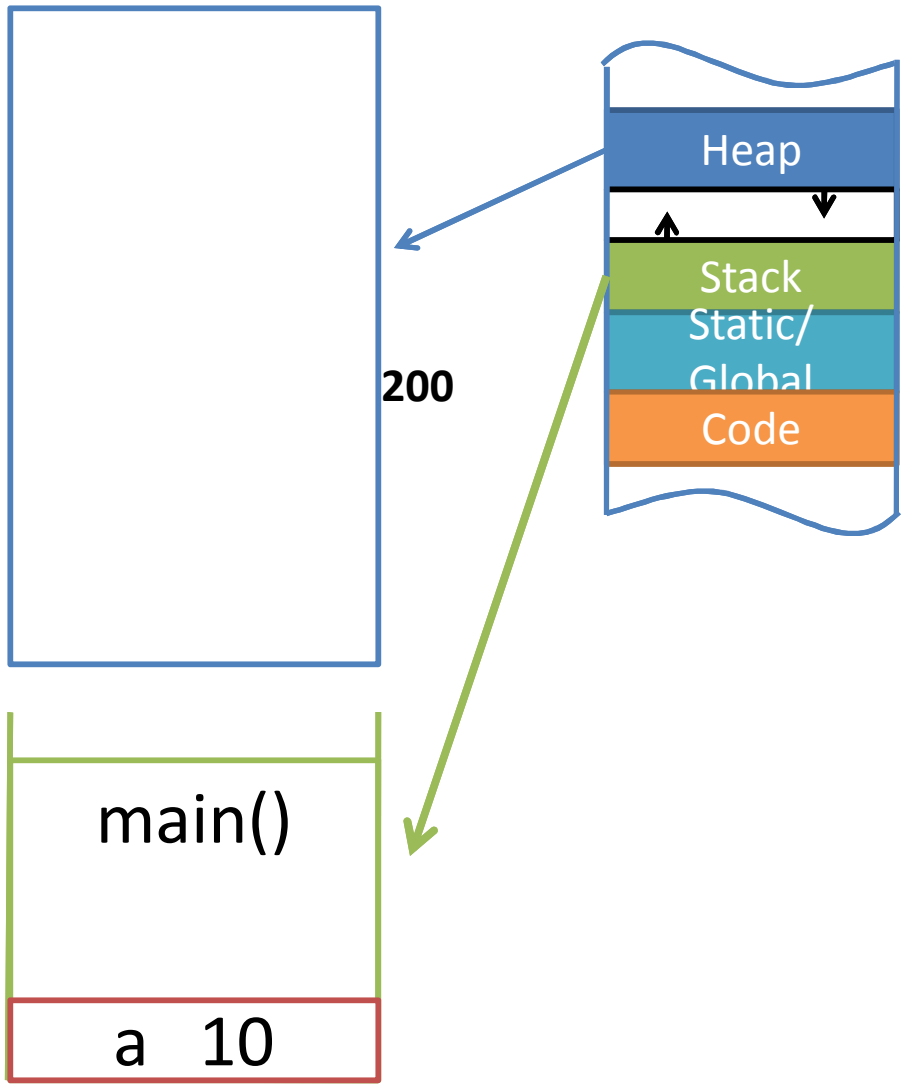
int main()
{
    int a=10;
    int *p;
    p = new int;
    *p=10;
    delete p;
```

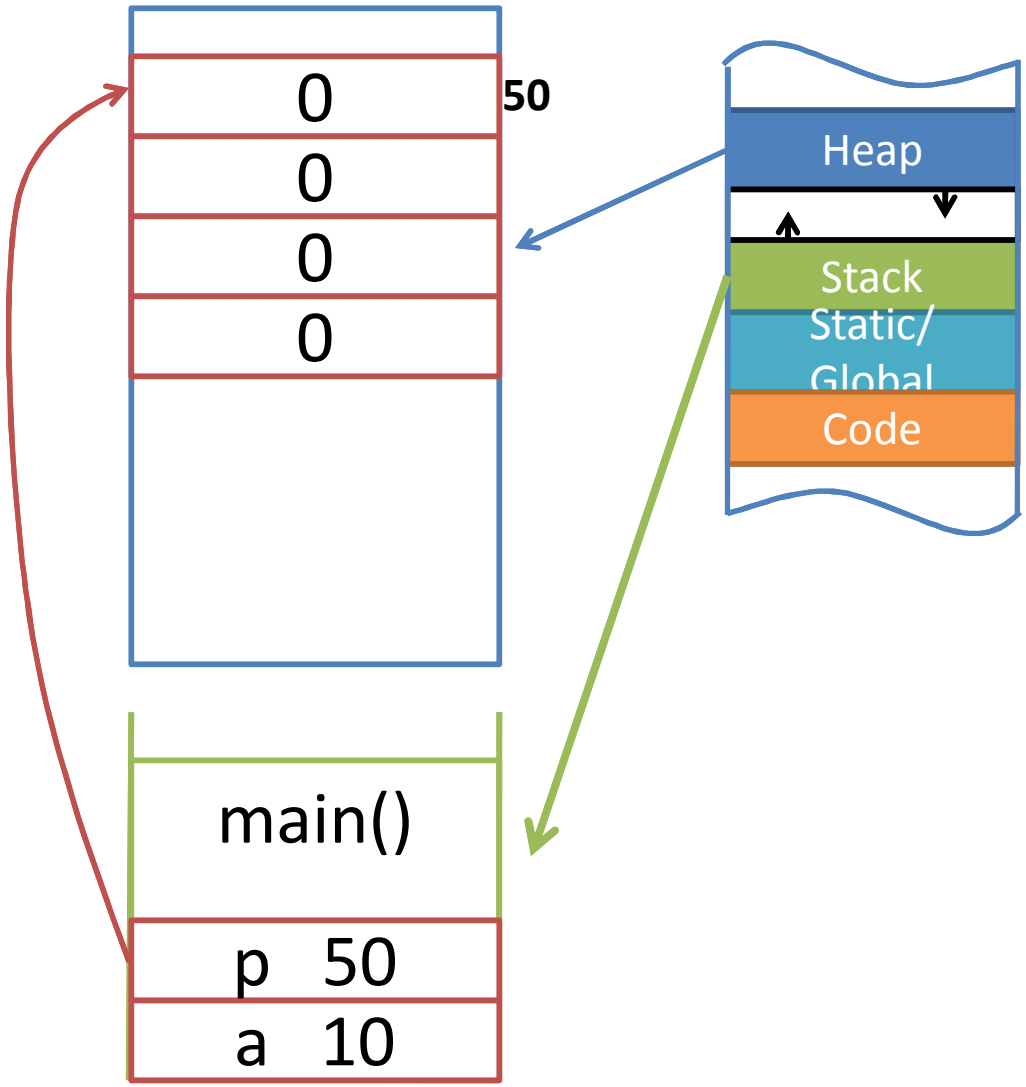


Use of Heap
(Dynamic Memory Allocation)

Dynamic Memory Allocation

C++ language (Example code)

```
#include<stdio.h>
#include<stdlib.h>
int main()
{
    int a=10;
    int *p;
    p = new int;
    *p=10;
    delete p;
    p = new int[4];
    for(int i=0;i<4;i++)
       p[i]=0;
```

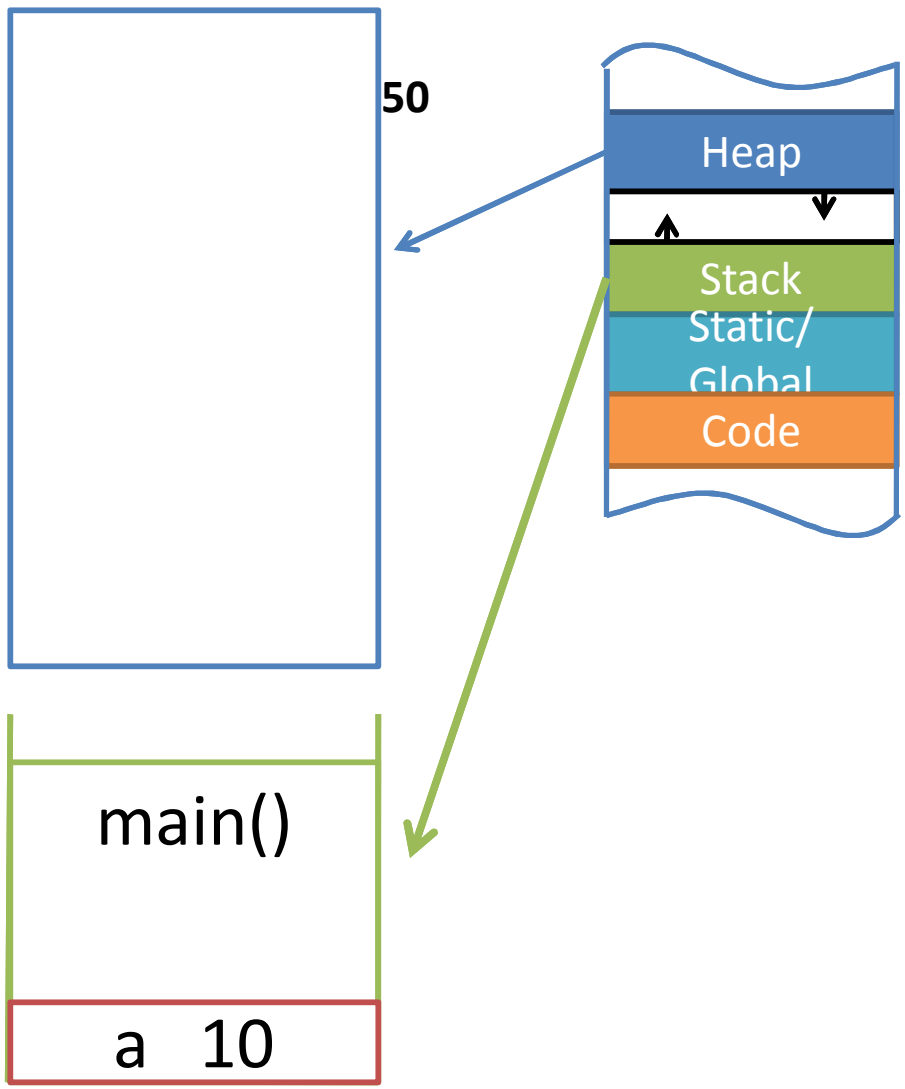


Use of Heap
(Dynamic Memory Allocation)

Dynamic Memory Allocation

C++ language (Example code)

```
#include<stdio.h>
#include<stdlib.h>
int main()
{
    int a=10;
    int *p;
    p = new int;
    *p=10;
    delete p;
    p = new int[4];
    for(int i=0;i<4;i++)
       p[i]=0;
    delete[ ] p;
}
```

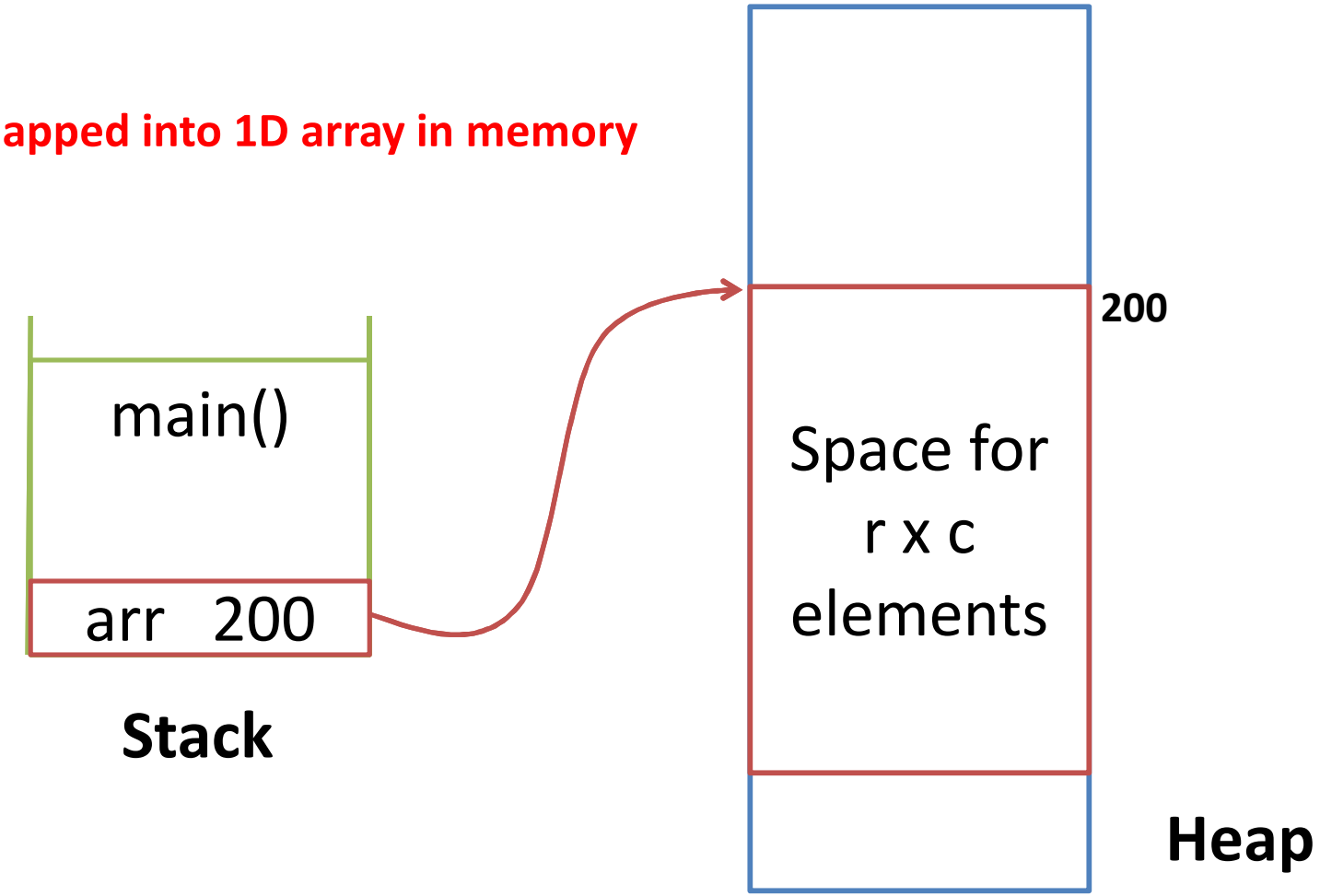


Dynamic 2D Array Allocation in C
Using single pointer

```c
#include <stdio.h>
#include <stdlib.h>

int main()
{
    int r = 3, c = 4;
    int *arr = (int *)malloc(r * c * sizeof(int));

    int i, j, count = 0;
    for (i = 0; i < r; i++)
    for (j = 0; j < c; j++)
        *(arr + i*c + j) = ++count;

    for (i = 0; i < r; i++)
    for (j = 0; j < c; j++)
        printf("%d ", *(arr + i*c + j));

/* Code for further processing and free the
    dynamically allocated memory */

return 0;
}
```

Dynamic 2D Array Allocation in C
Using single pointer

2D array mapped into 1D array in memory

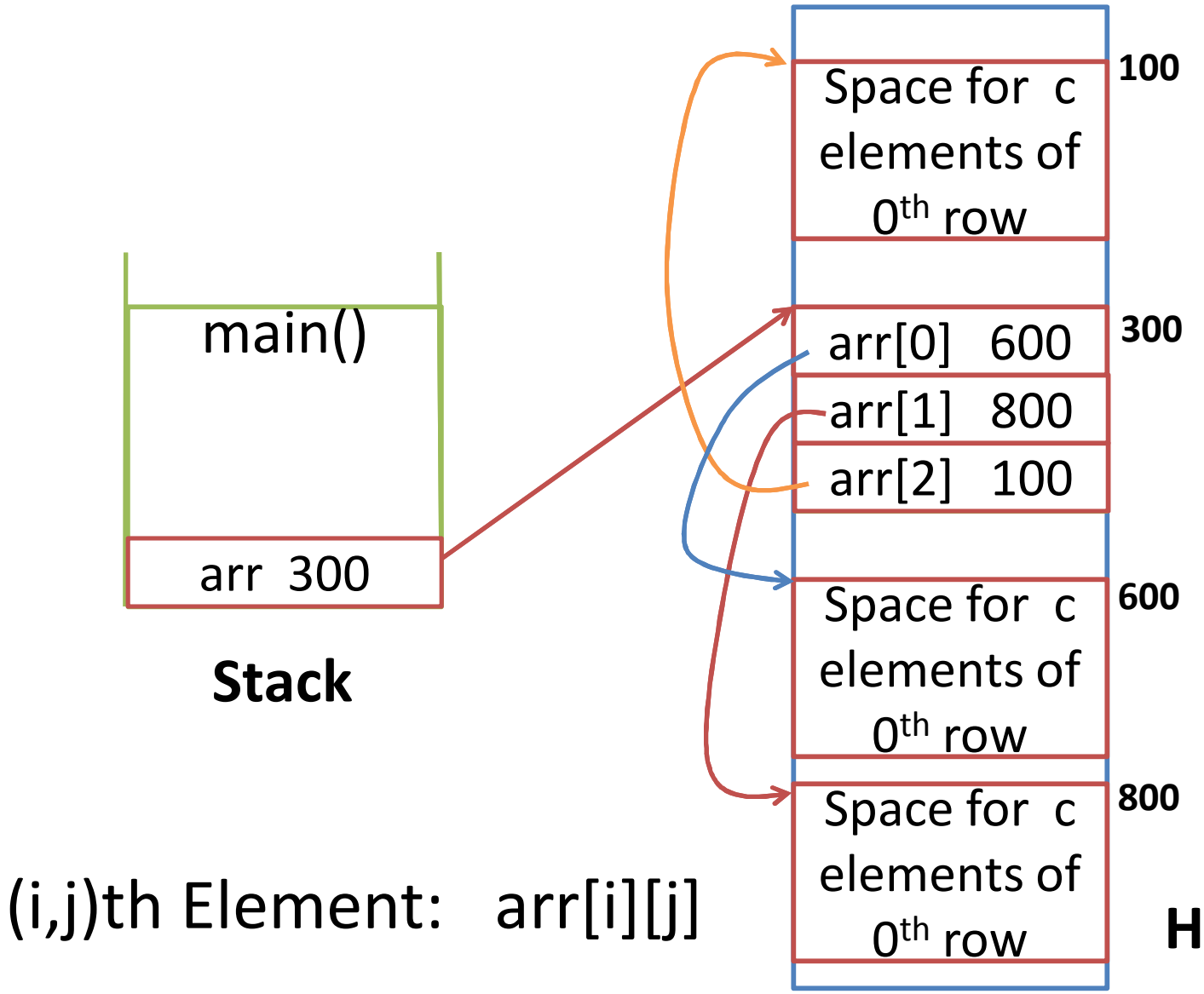


(i,j)th Element: *(arr+i*c+j) or arr[i*c+j]

Dynamic 2D Array Allocation in C
Using array of pointers

```c
#include <stdio.h>
#include <stdlib.h>

int main()
{
    int r = 3, c = 4, i, j, count;

    int **arr = (int **)malloc(r * sizeof(int *));
    for (i=0; i<r; i++)
        arr[i] = (int *)malloc(c * sizeof(int));

    // Note that arr[i][j] is same as *(*(arr+i)+j)
    count = 0;
    for (i = 0; i < r; i++)
    for (j = 0; j < c; j++)
        arr[i][j] = ++count; // OR *(*(arr+i)+j) = ++count

    for (i = 0; i < r; i++)
    for (j = 0; j < c; j++)
        printf("%d ", arr[i][j]);

/* Code for further processing and free the
    dynamically allocated memory */

return 0;
}
```

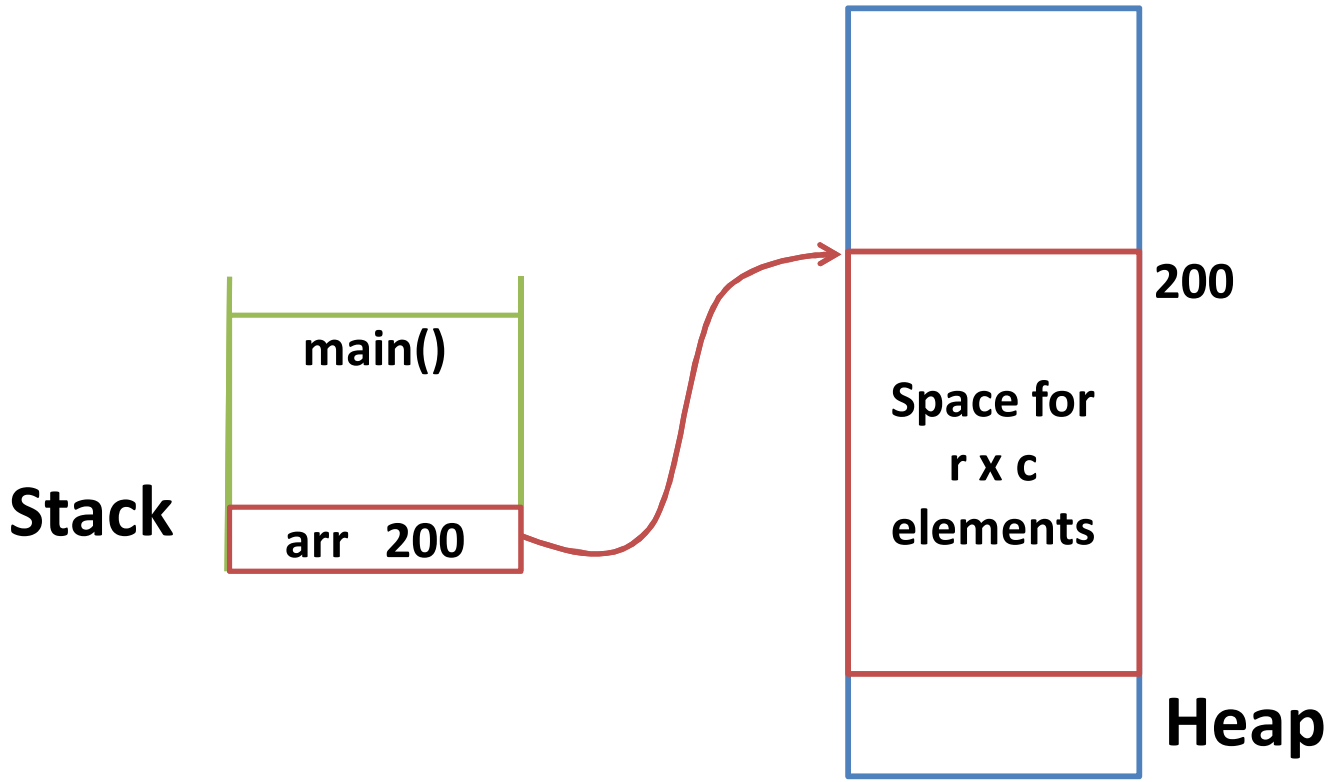
Dynamic 2D Array Allocation in C
Using single pointer



(i,j)th Element: arr[i][j]

Freeing Dynamic 2D Array in C

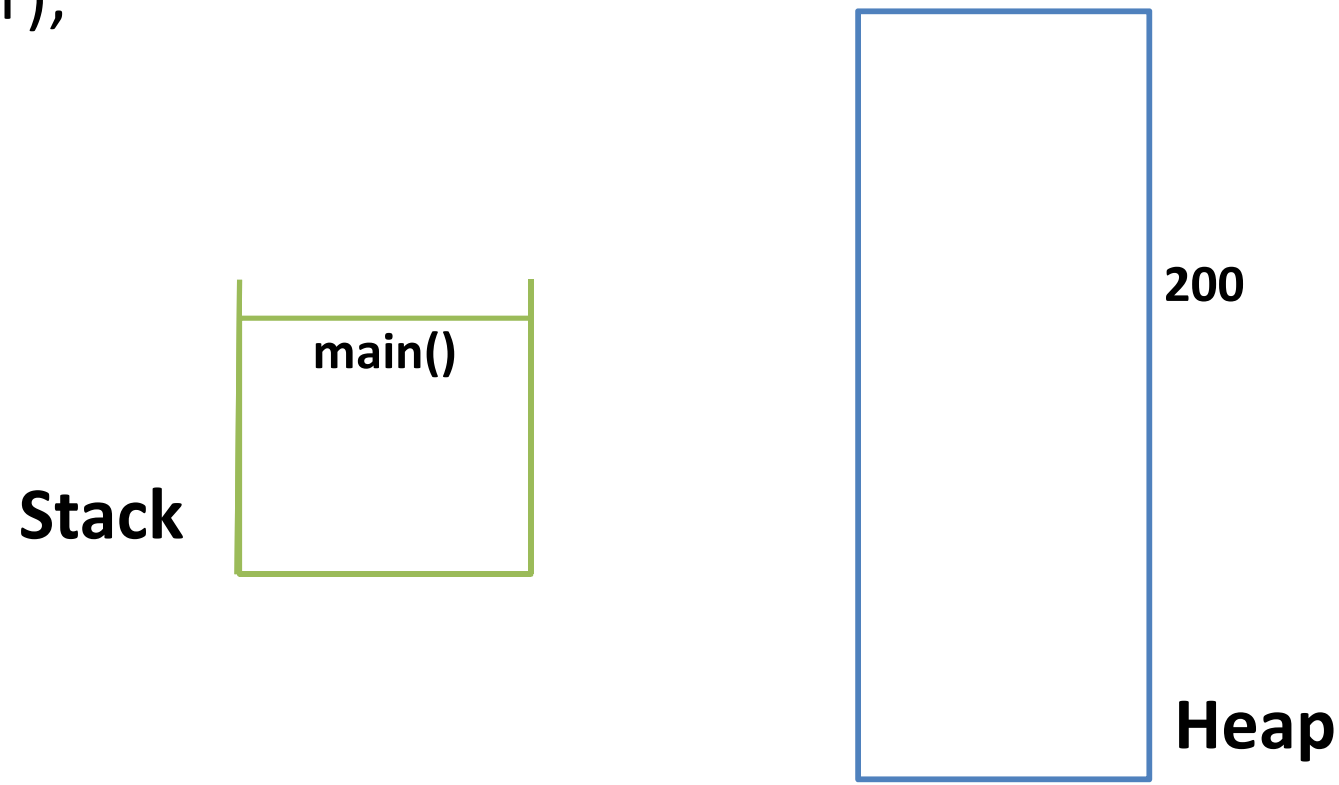
- **For single pointer:**



Freeing Dynamic 2D Array in C

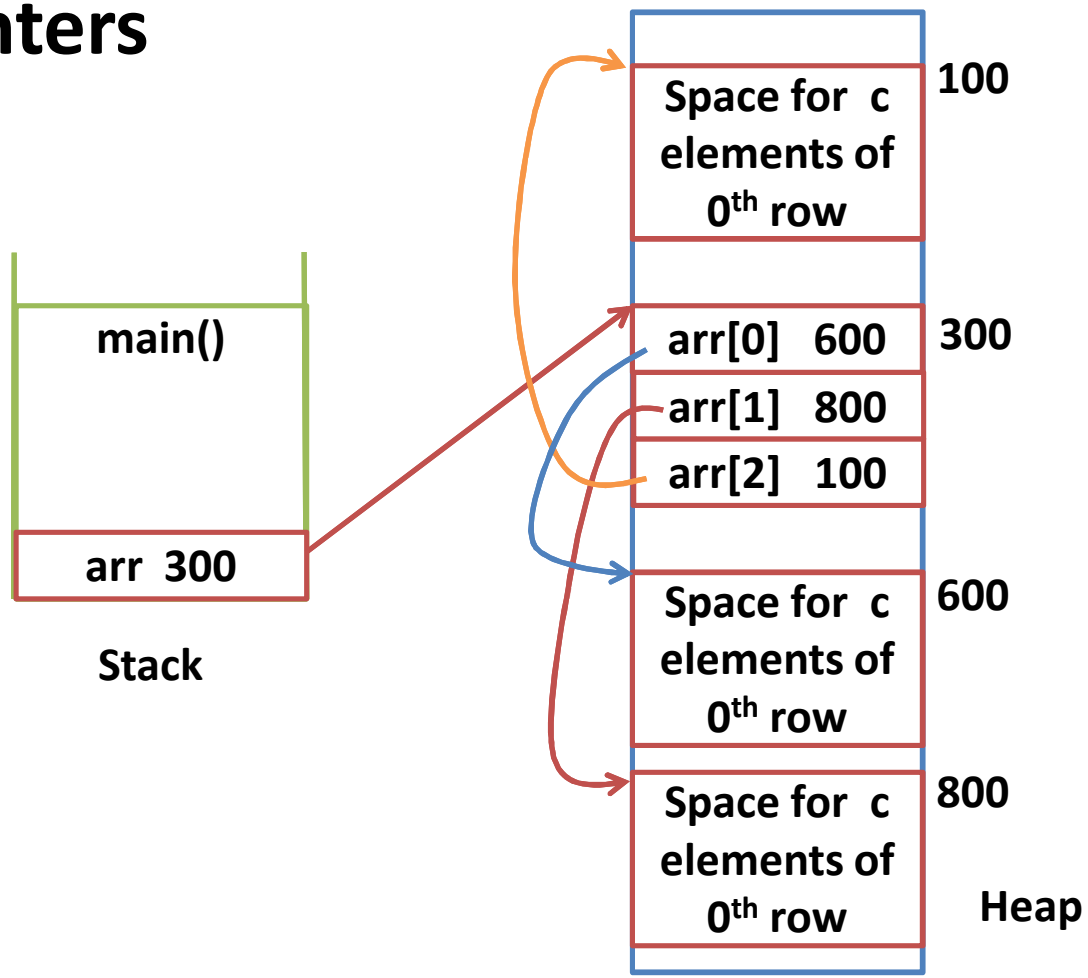
- **For single pointer:**

  free(arr);



Freeing Dynamic 2D Array in C

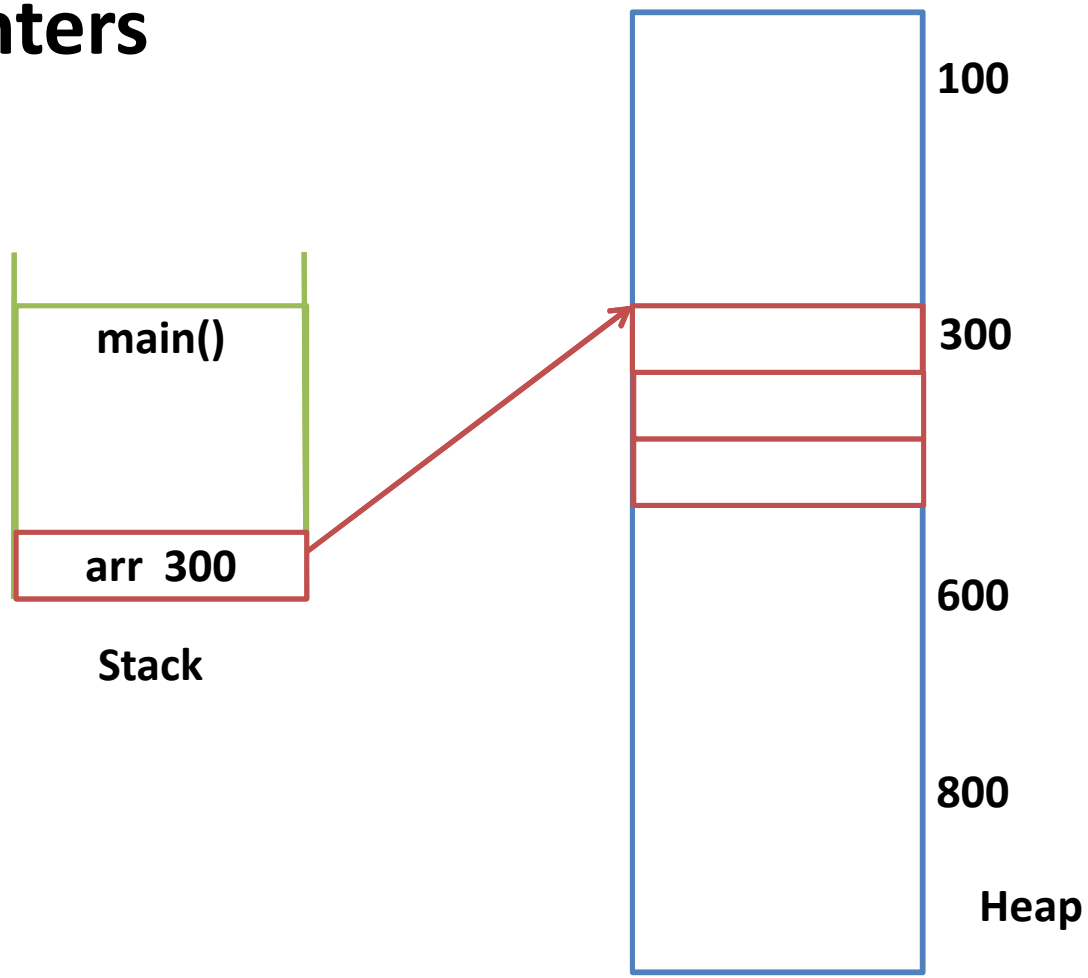
- **For array of pointers**



Freeing Dynamic 2D Array in C

- **For array of pointers**

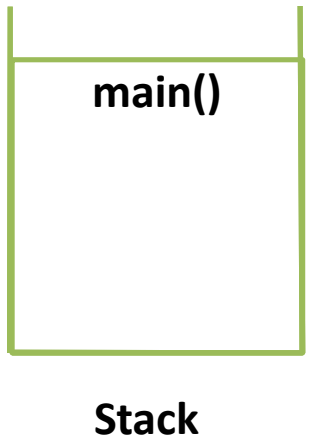
```
for(i=0;i<r;i++){
    free(arr[i]);}
```

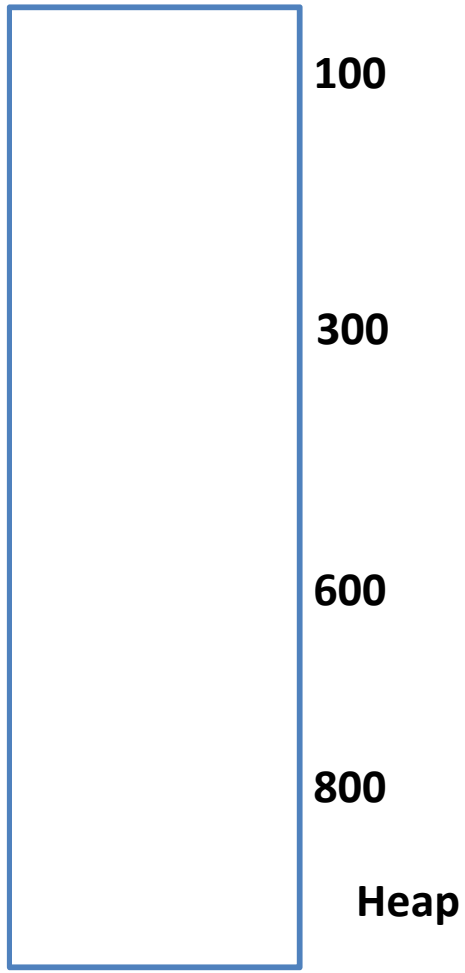


Freeing Dynamic 2D Array in C

- **For array of pointers**

```
for(i=0;i<r;i++){
    free(arr[i]);}
free(arr);
```





Dynamic 2D Array Allocation and Freeing in C++
Using single pointer

```
int r=3, c=4;
int** arr = new int[r*c];
```

$(i,j)^{th}$ element can be accessed by *(arr + i*c+j) or arr[i*c+j]

For freeing memory:

```
delete[] arr;
```

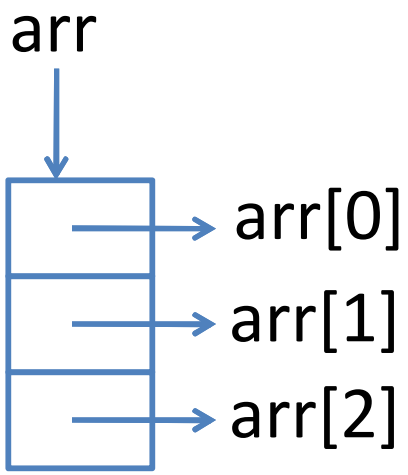
Dynamic 2D Array Allocation and Freeing in C++
Using array of pointers

```
int r=3, c=4;
int** arr = new int*[r];
for(i=0;i<r;i++)
    arr[i] = new int[c];
```

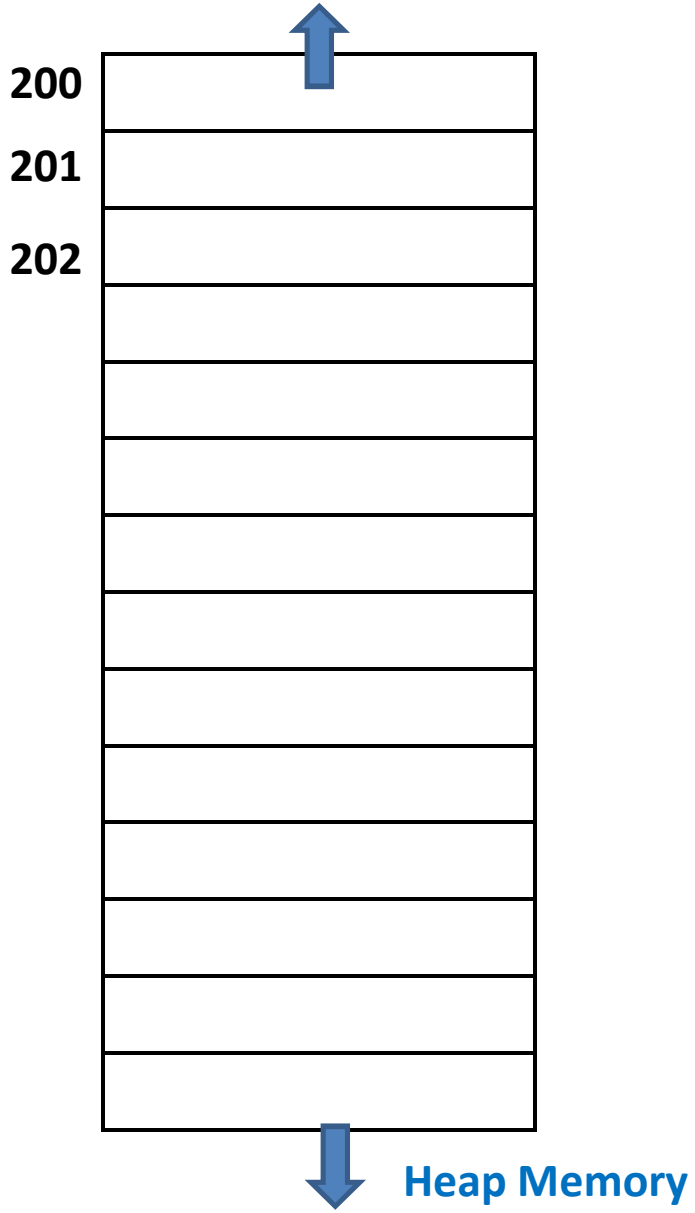
$(i,j)^{th}$ element can be accessed by arr[i][j];

For freeing memory:

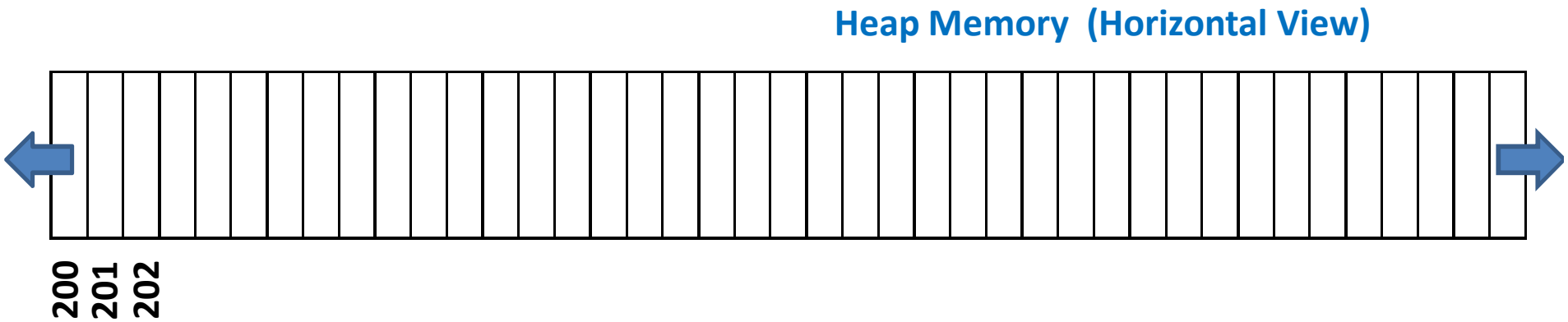
```
 for(i=0;i<r;i++){
        delete[] arr[i]);}

delete[] arr;
```



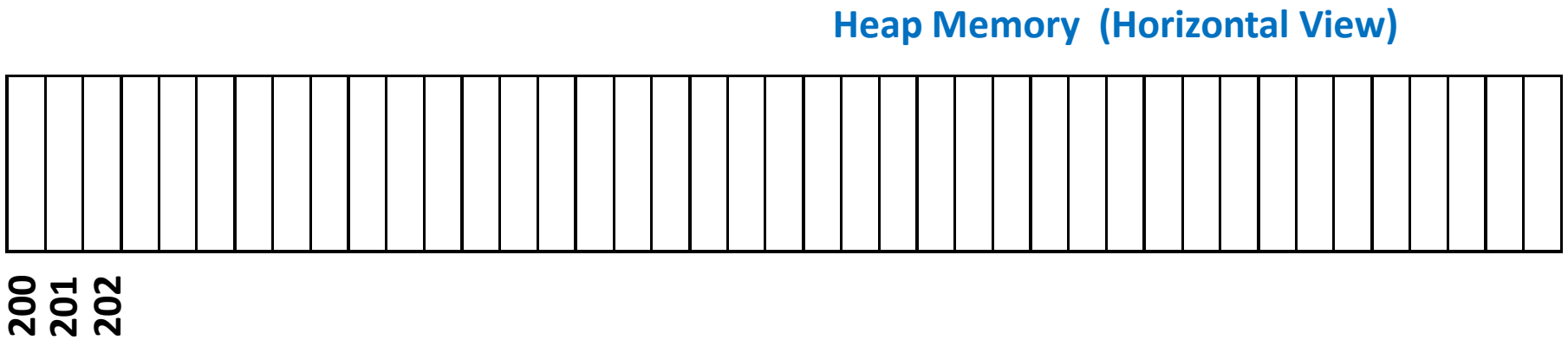
Limitations of Dynamic Array



Limitations of Dynamic Array

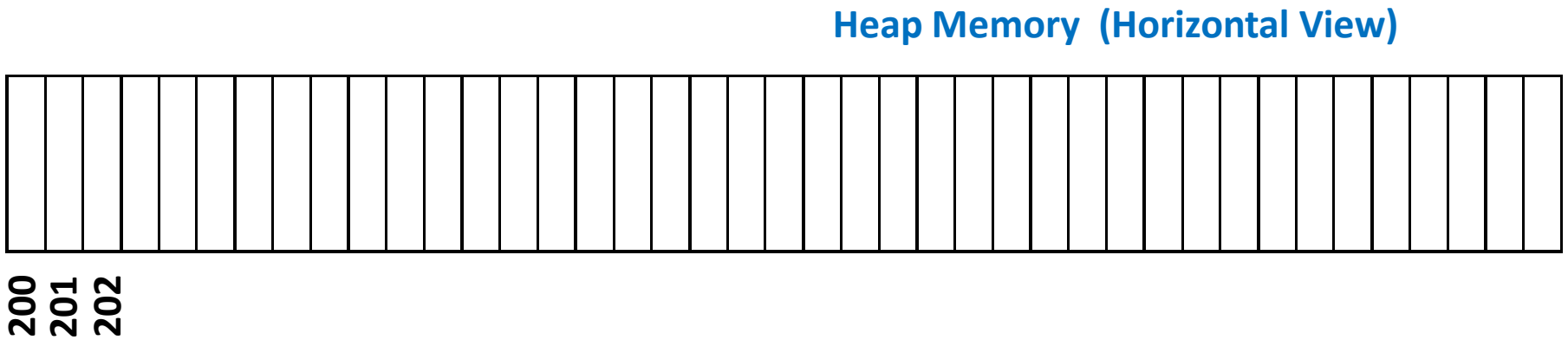


Limitations of Dynamic Array



- Memory Manager (A part of operating systems) manages the memory.
  - Keeps track of free space
  - Allocates space on request from the programs

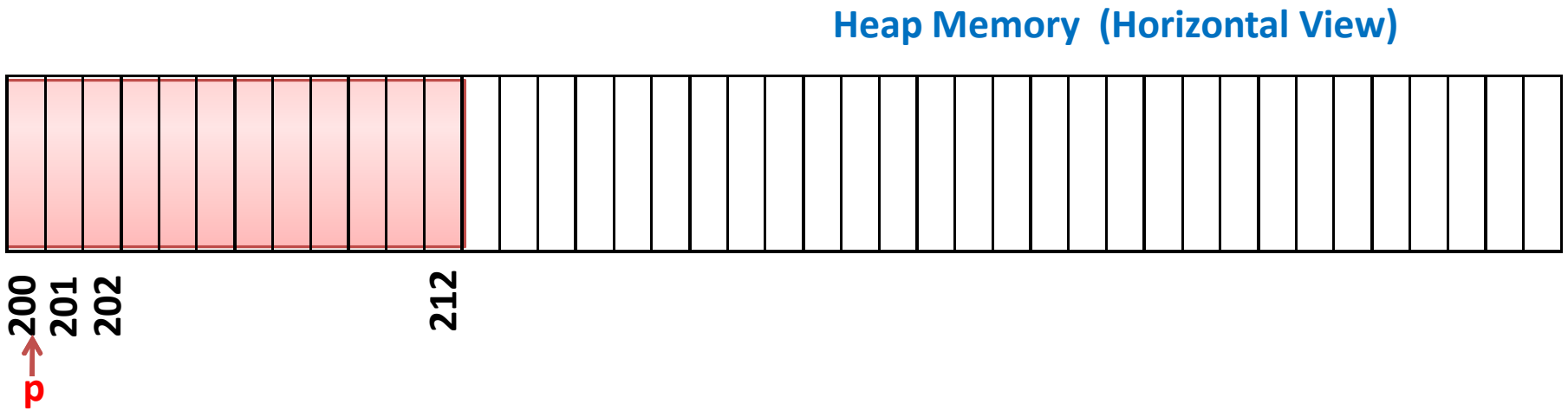
Limitations of Dynamic Array



Consider a program segment:

```
int *p=(int*)malloc(3*sizeof(int));
```

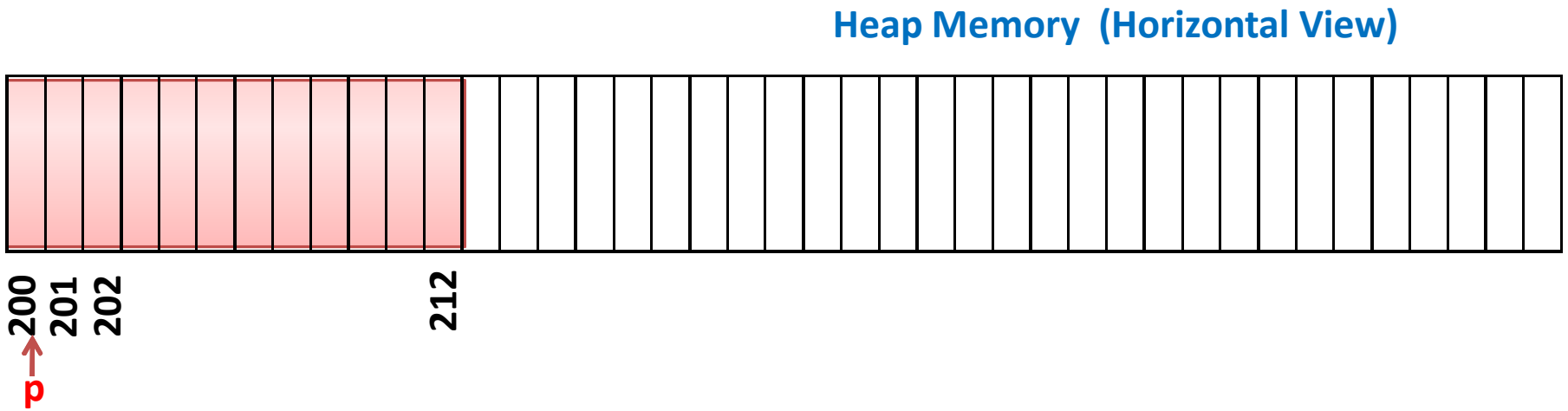
Limitations of Dynamic Array



Consider a program segment:

```
int *p=(int*)malloc(3*sizeof(int));   // int size is 4 bytes
```

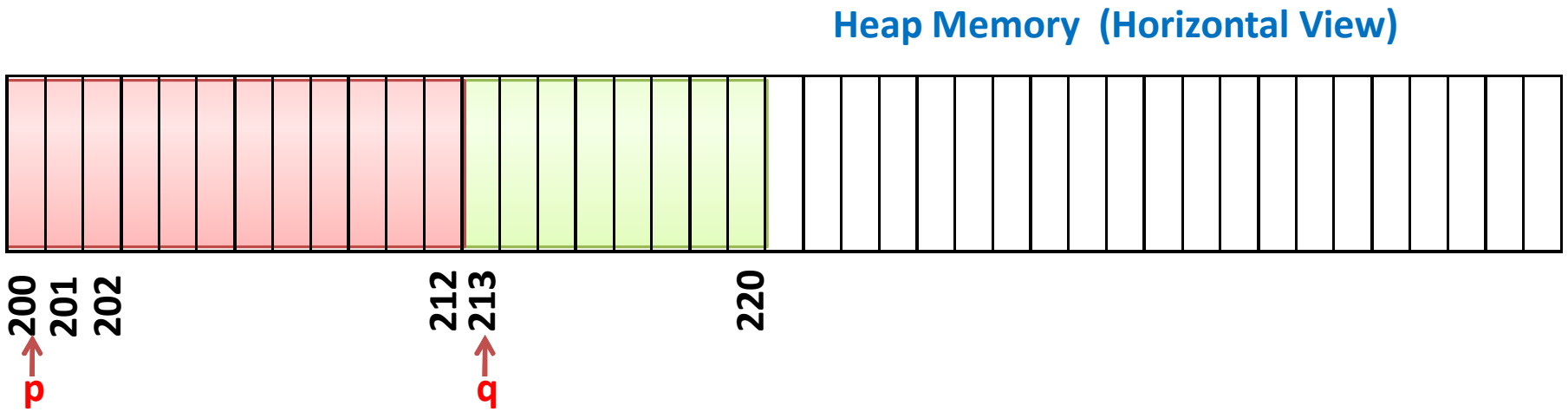
Limitations of Dynamic Array



Consider a program segment:

```
int *p=(int*)malloc(3*sizeof(int));   // int size is 4 bytes
float *q=(float*)malloc(sizeof(float));   // float size is 8 bytes
```

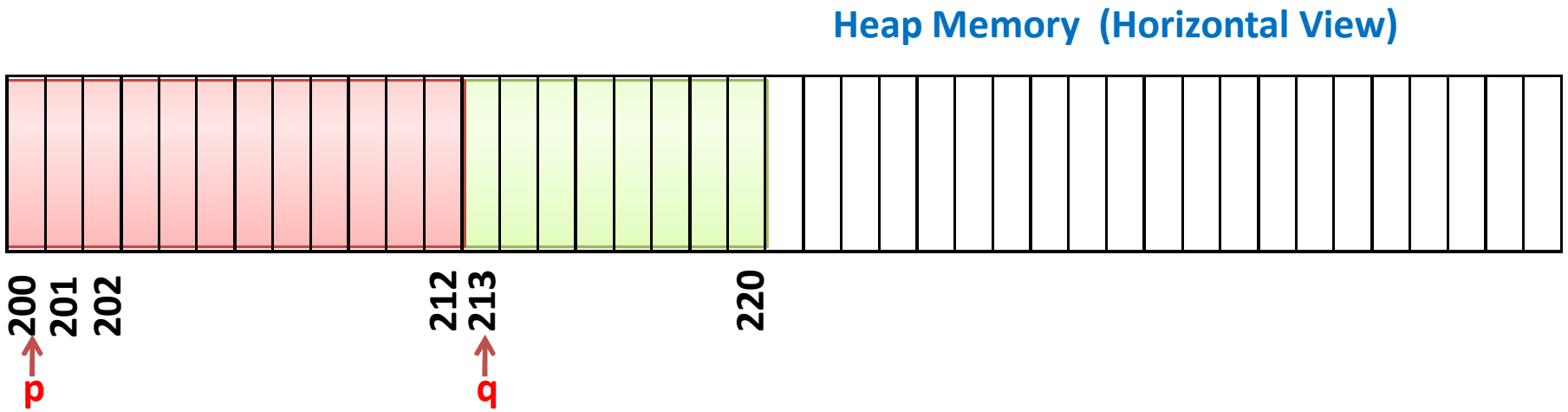
Limitations of Dynamic Array



Consider a program segment:

```
int *p=(int*)malloc(3*sizeof(int));   // int size is 4 bytes
float *q=(float*)malloc(sizeof(float));   // float size is 8 bytes
```

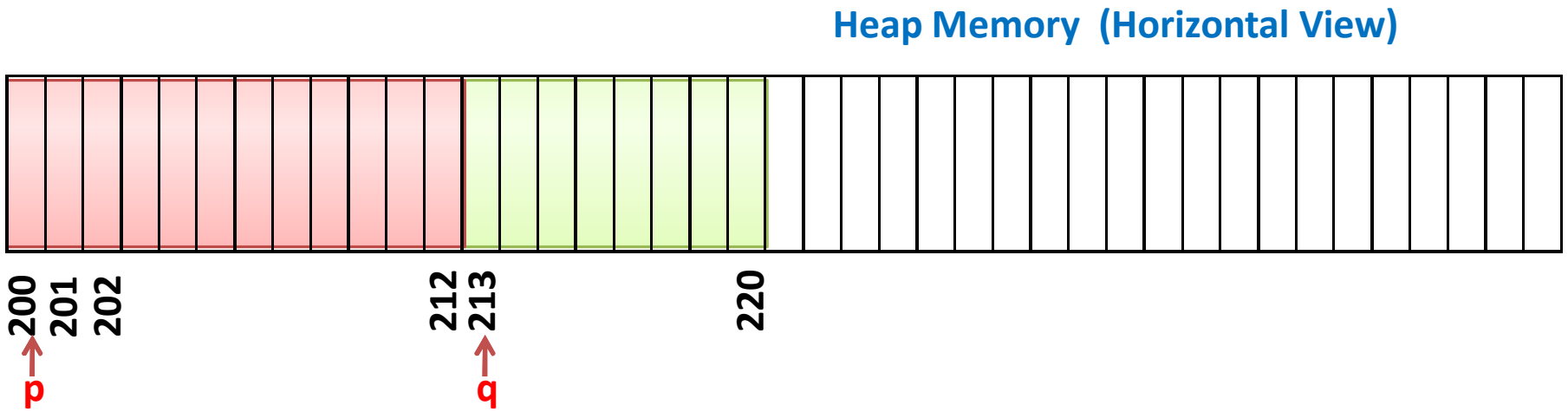
Limitations of Dynamic Array



Consider a program segment:

```
int *p=(int*)malloc(3*sizeof(int));   // int size is 4 bytes
float *q=(float*)malloc(sizeof(float));   // float size is 8 bytes
int *r=(int*)malloc(4*sizeof(int)); // int size is 4 bytes
```

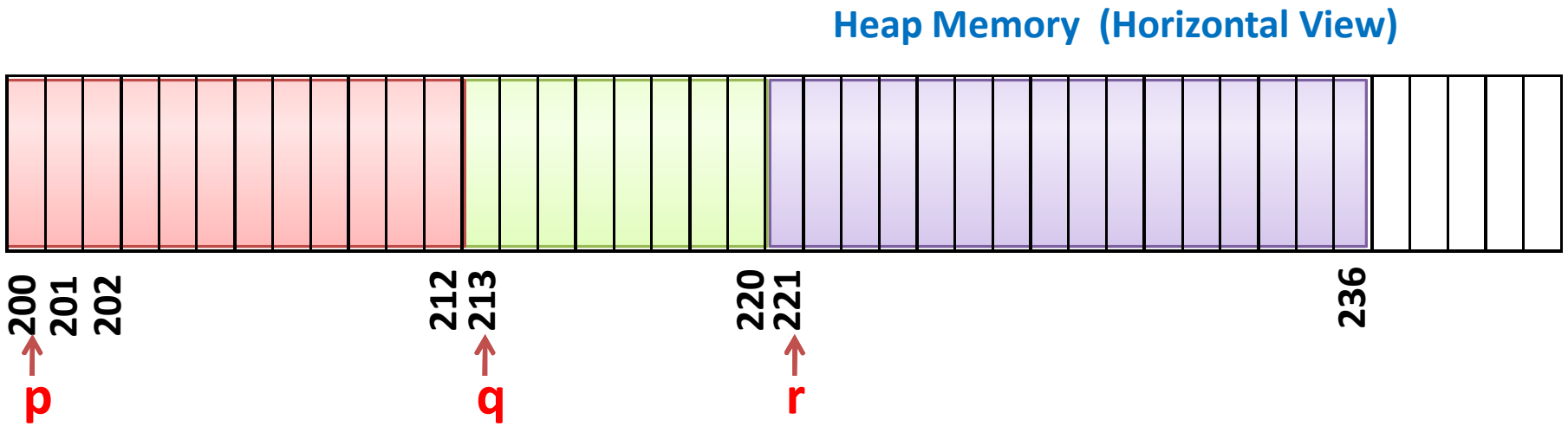
Limitations of Dynamic Array



Consider a program segment:

```
int *p=(int*)malloc(3*sizeof(int));   // int size is 4 bytes
float *q=(float*)malloc(sizeof(float));   // float size is 8 bytes
int *r=(int*)malloc(4*sizeof(int)); // int size is 4 bytes
```

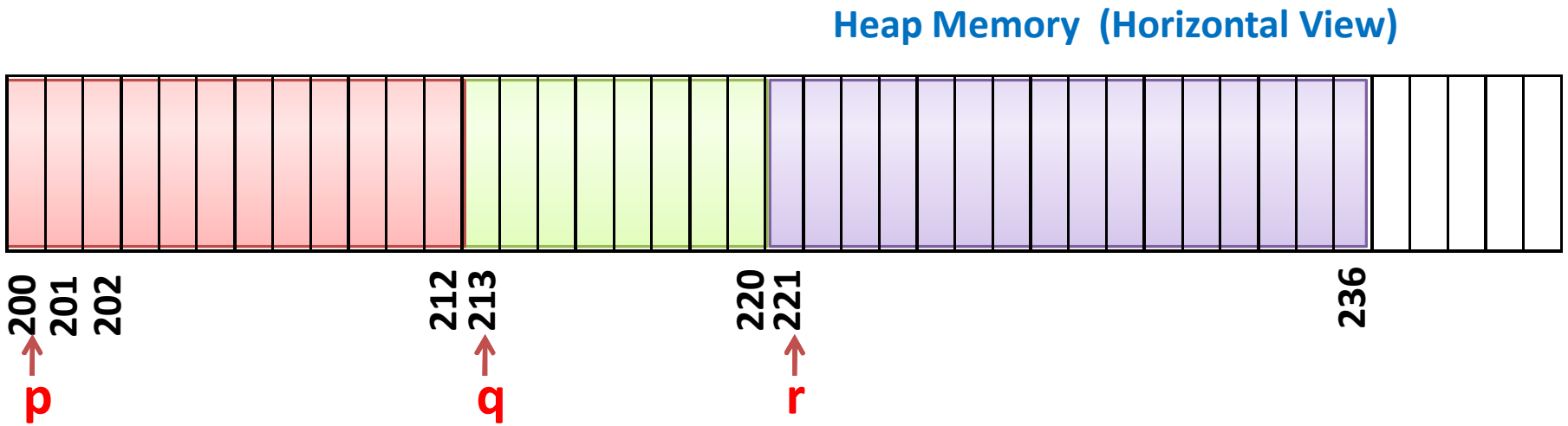
Limitations of Dynamic Array



Consider a program segment:

```
int *p=(int*)malloc(3*sizeof(int));   // int size is 4 bytes
float *q=(float*)malloc(sizeof(float));   // float size is 8 bytes
int *r=(int*)malloc(4*sizeof(int)); // int size is 4 bytes
```

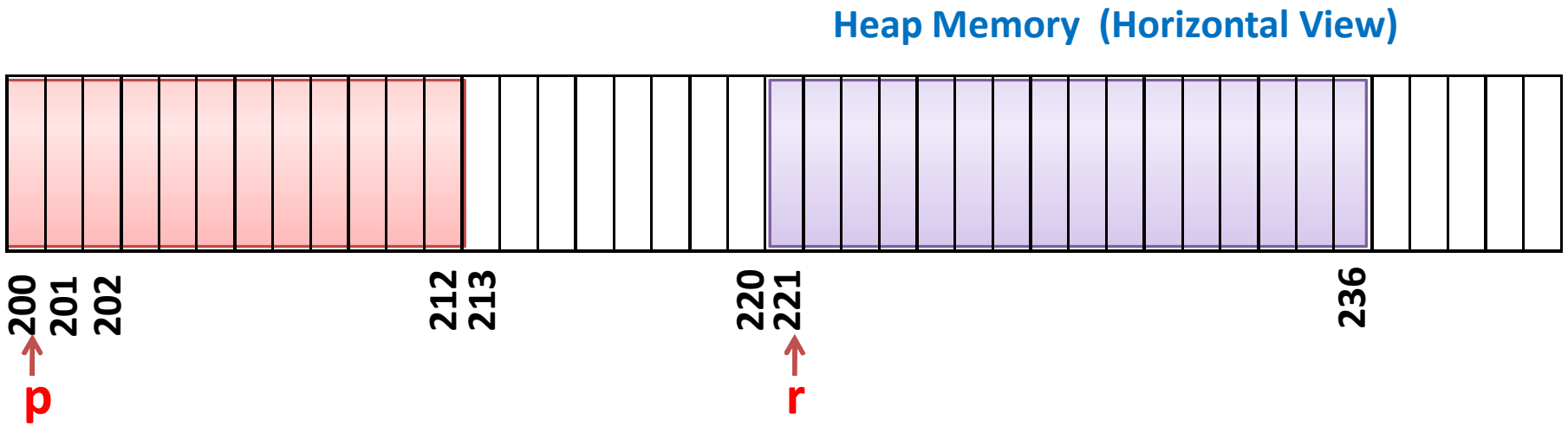
Limitations of Dynamic Array



Consider a program segment:

```
int *p=(int*)malloc(3*sizeof(int));   // int size is 4 bytes
float *q=(float*)malloc(sizeof(float));   // float size is 8 bytes
int *r=(int*)malloc(4*sizeof(int)); // int size is 4 bytes
free(q)
```

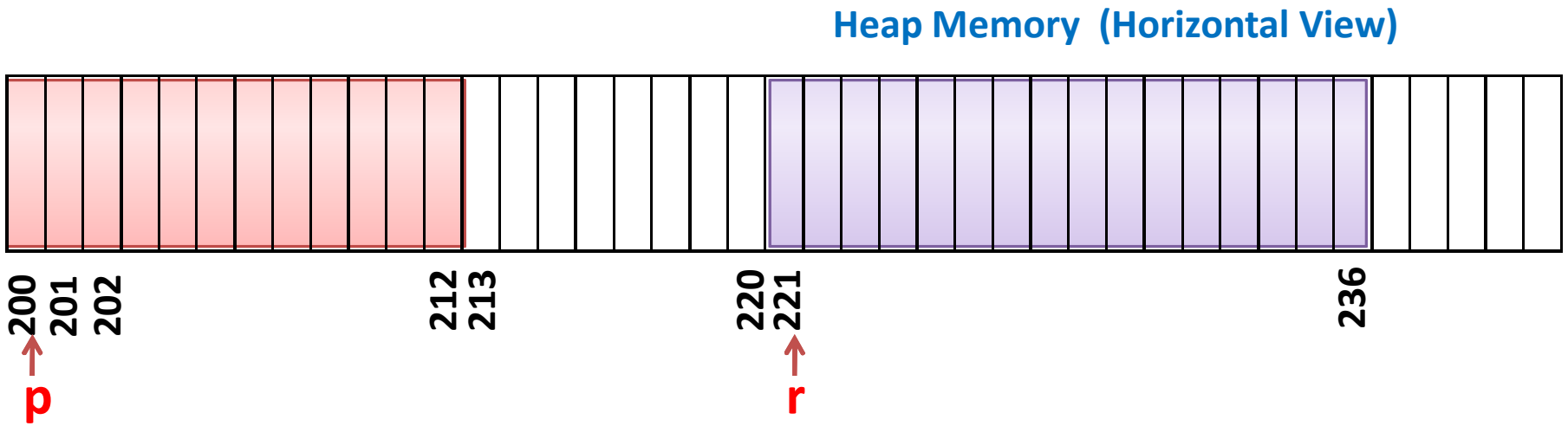
Limitations of Dynamic Array



Consider a program segment:

```
int *p=(int*)malloc(3*sizeof(int));   // int size is 4 bytes
float *q=(float*)malloc(sizeof(float));   // float size is 8 bytes
int *r=(int*)malloc(4*sizeof(int)); // int size is 4 bytes
free(q)
```

Limitations of Dynamic Array

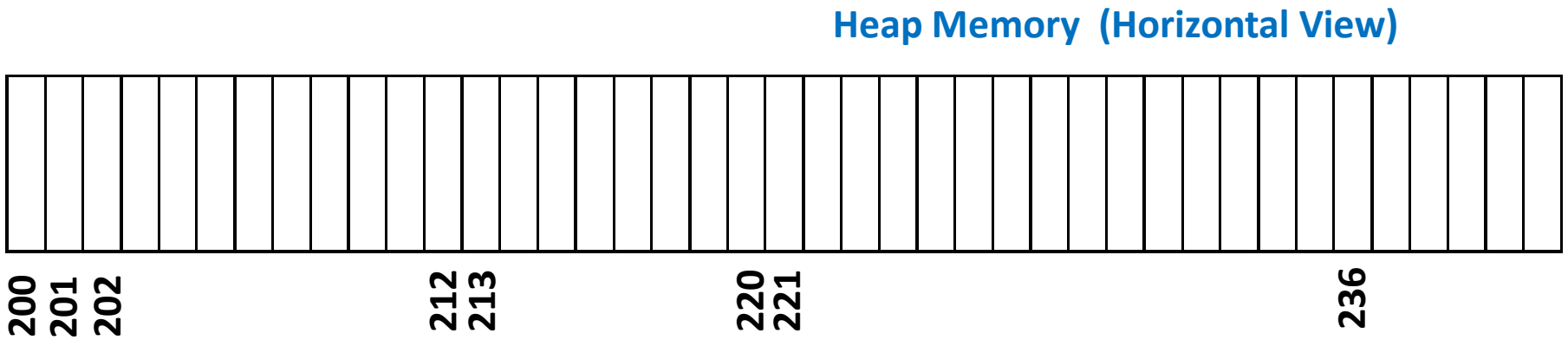


Consider a program segment:

```
int *p=(int*)malloc(3*sizeof(int));   // int size is 4 bytes
float *q=(float*)malloc(sizeof(float));   // float size is 8 bytes
int *r=(int*)malloc(4*sizeof(int)); // int size is 4 bytes
free(q)
int *s=(int*)malloc(3*sizeof(int));   // int size is 4 bytes
```

Although free memory is more than required 3 x 4 = 12 bytes, yet it cannot be allocated as it is not contiguous. Returns a null pointer.

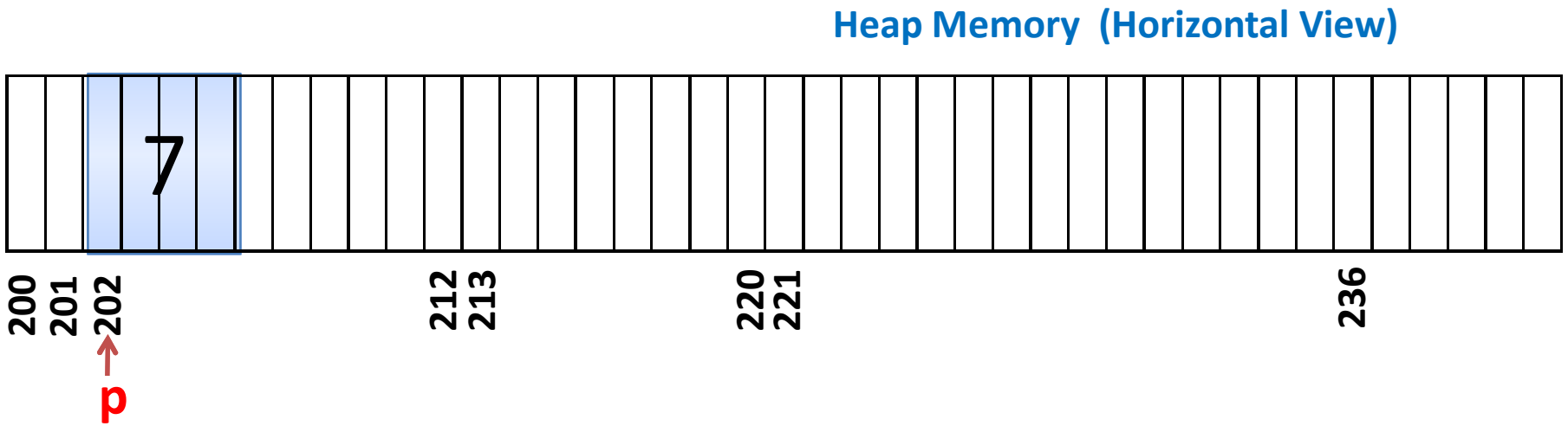
Solution: Linked List



Suppose we need to store a list of 4 integers: 7, 10, 5, 9.

Instead of asking memory manager for an integer array of 4 elements, these 4 integers can be stored one at a time in memory in different places.

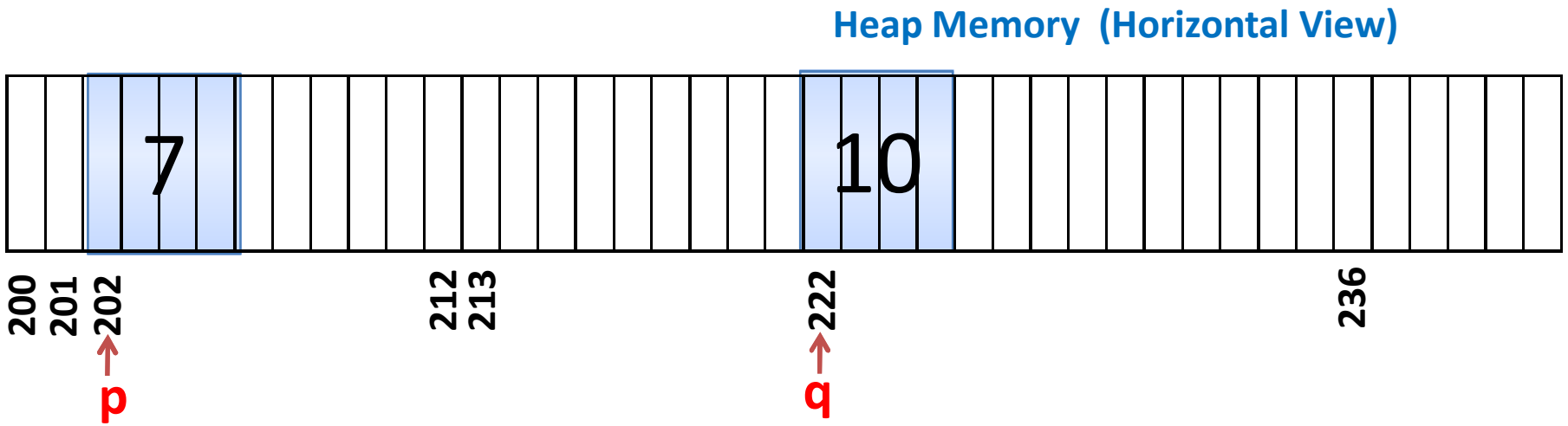
Solution: Linked List



Suppose we need to store a list of 4 integers: 7, 10, 5, 9.

```
int *p=(int*)malloc(sizeof(int));    *p=7;
```

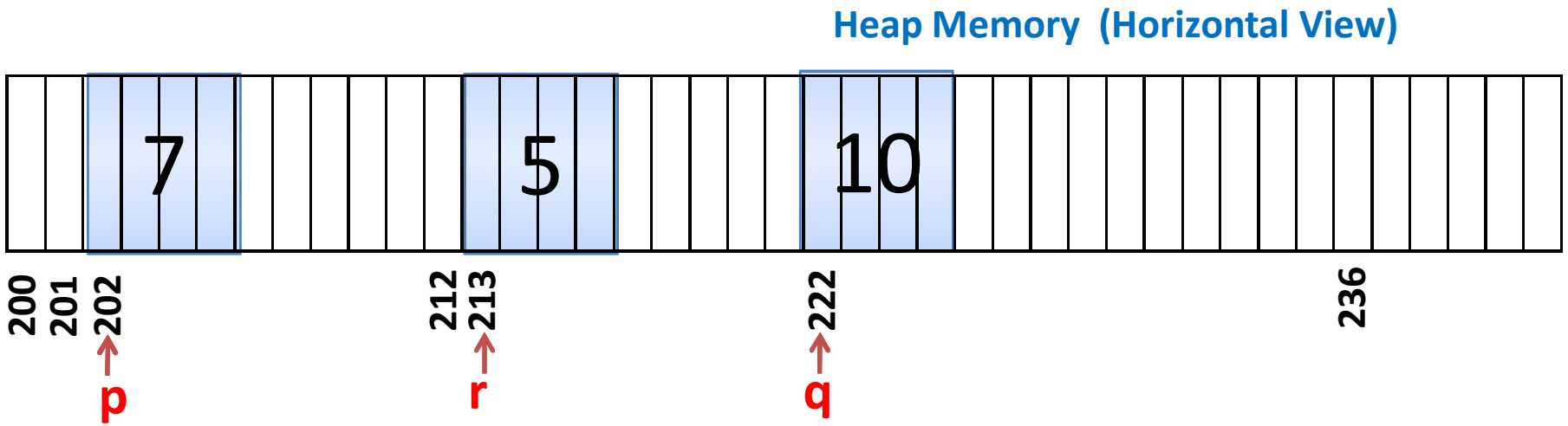
Solution: Linked List



Suppose we need to store a list of 4 integers: 7, 10, 5, 9.

```
int *p=(int*)malloc(sizeof(int));    *p=7;
int *q=(int*)malloc(sizeof(int));    *q=10;
```

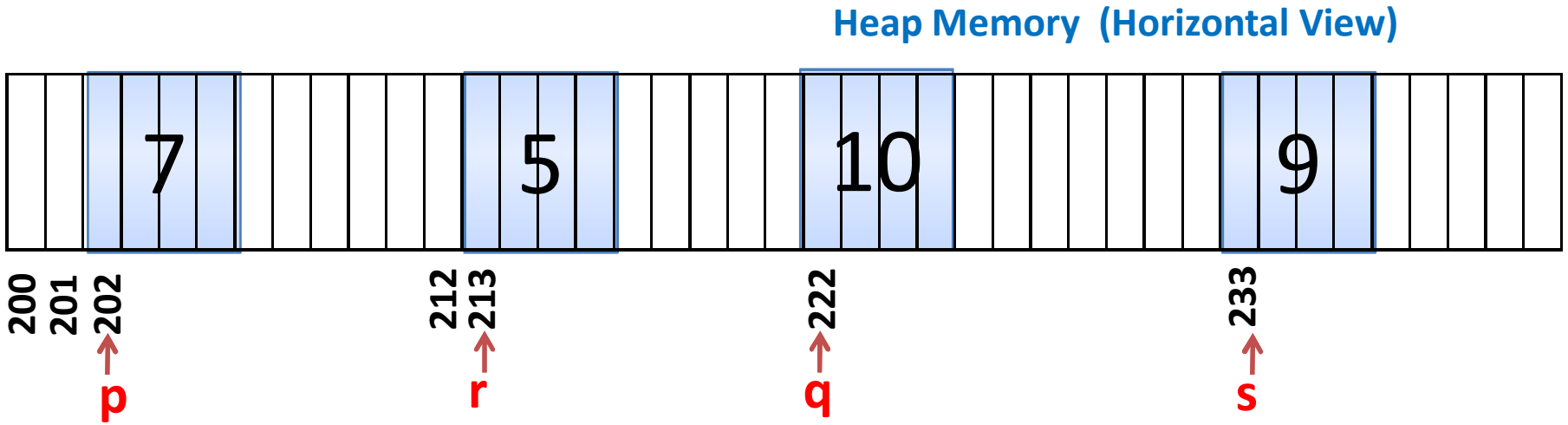
Solution: Linked List



Suppose we need to store a list of 4 integers: 7, 10, 5, 9.

```
int *p=(int*)malloc(sizeof(int));    *p=7;
int *q=(int*)malloc(sizeof(int));    *q=10;
int *r=(int*)malloc(sizeof(int));    *r=5;
```

Solution: Linked List

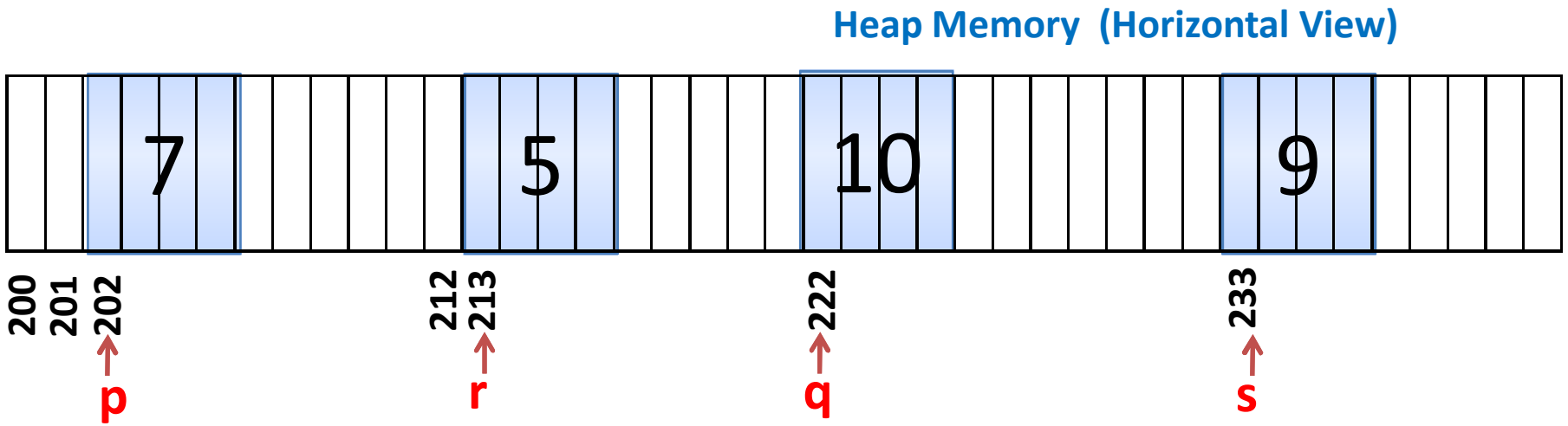


Suppose we need to store a list of 4 integers: 7, 10, 5, 9.

```
int *p=(int*)malloc(sizeof(int));    *p=7;
int *q=(int*)malloc(sizeof(int));    *q=10;
int *r=(int*)malloc(sizeof(int));    *r=5;
int *s=(int*)malloc(sizeof(int));    *s=9;
```

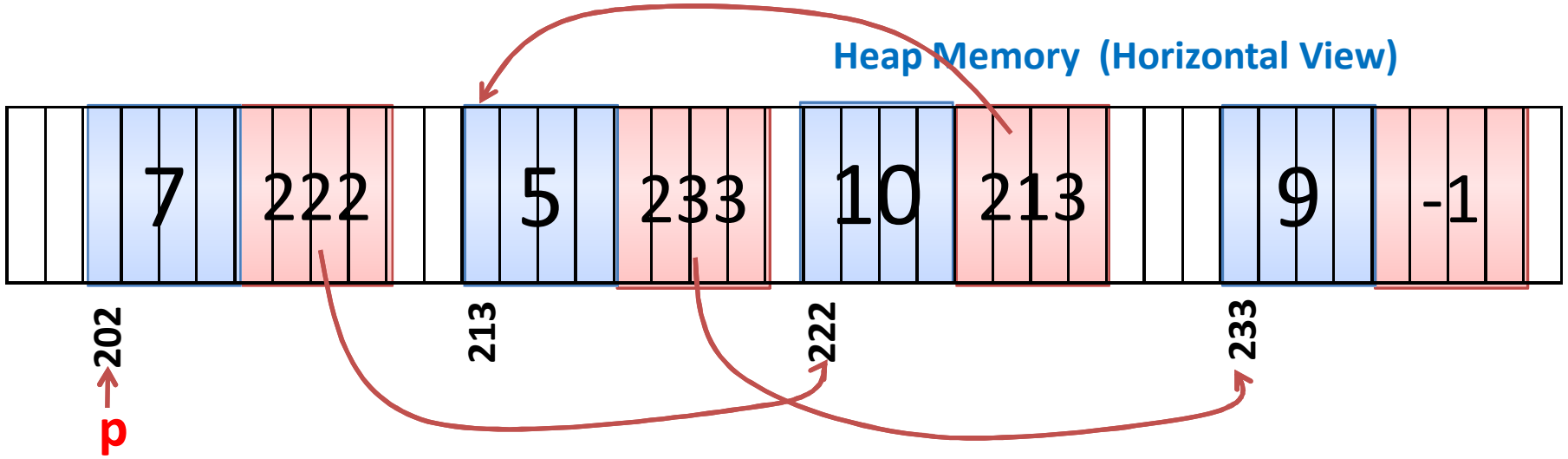
Non-contiguous allocation: Hence it is not possible to traverse the list directly as done in array.

Solution: Linked List



To traverse the elements of the list, one should store the address of the next element in the list with each element.

Solution: Linked List

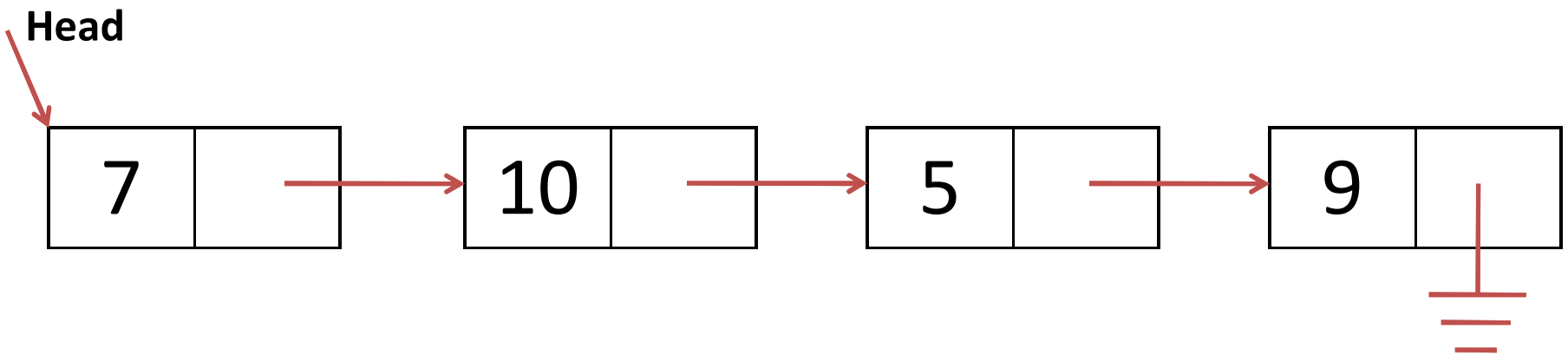


To traverse the elements of the list {7, 10, 5, 9}, one should store the address of the next element (**pointer to next element**) in the list with each element.

It is sufficient to know the address of (pointer to) the first node (also called as head node) to retrieve all the elements of the list.

The last node points to null (represented by -1 here).

Logical View of Linked List



Structure of each node

```
struct node
{
int val;
struct node* next;
}
```