



UNIVERSITY OF  
RICHMOND



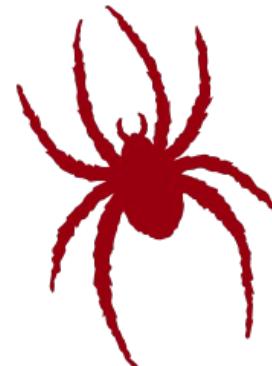
A photograph of a university campus. In the foreground, several students are walking away from the camera on a paved path. One student in the center-right has their back to the viewer, wearing a white shirt, black pants, and a red backpack. To their right, another student wears a blue shirt, blue jeans, and a blue backpack. On the left, two more students are visible, one in a dark jacket and another in a dark jacket and plaid shirt. The path is lined with large pine trees and a building with a red brick facade and arched windows. A pink flowering tree is prominent in the background. The overall atmosphere is bright and sunny.

# Memory & Pointers

CMSC 240 Software Systems Development

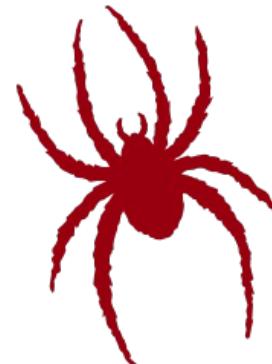
# Today

- Memory
- Pointers
- Garbage Values
- Memory Layout
- In-class exercise



# Today

- Memory
- Pointers
- Garbage Values
- Memory Layout
- In-class exercise



**char** 1 byte

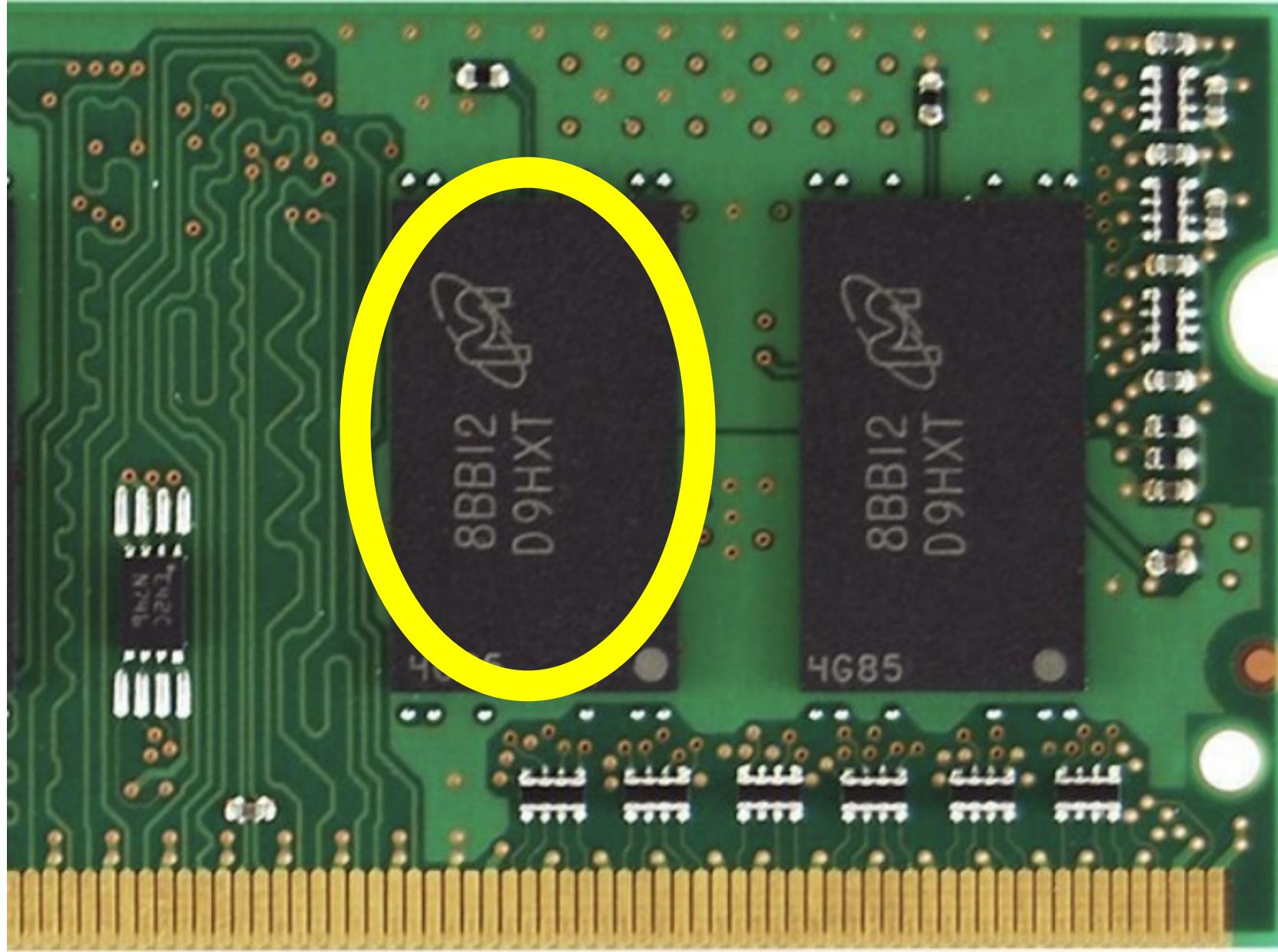
**int** 4 bytes

**long** 8 bytes

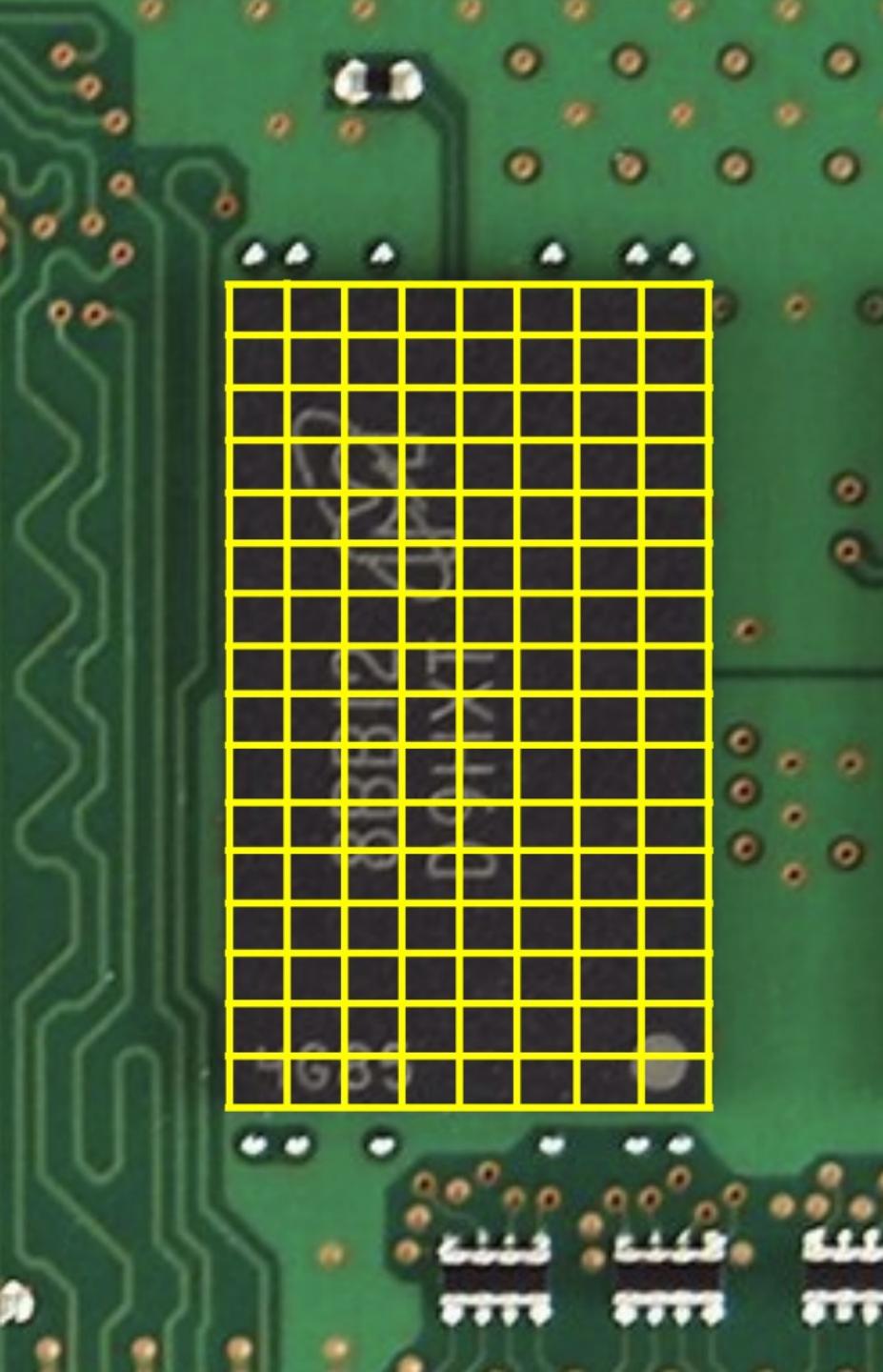
**float** 4 bytes

**double** 8 bytes

**string** ?

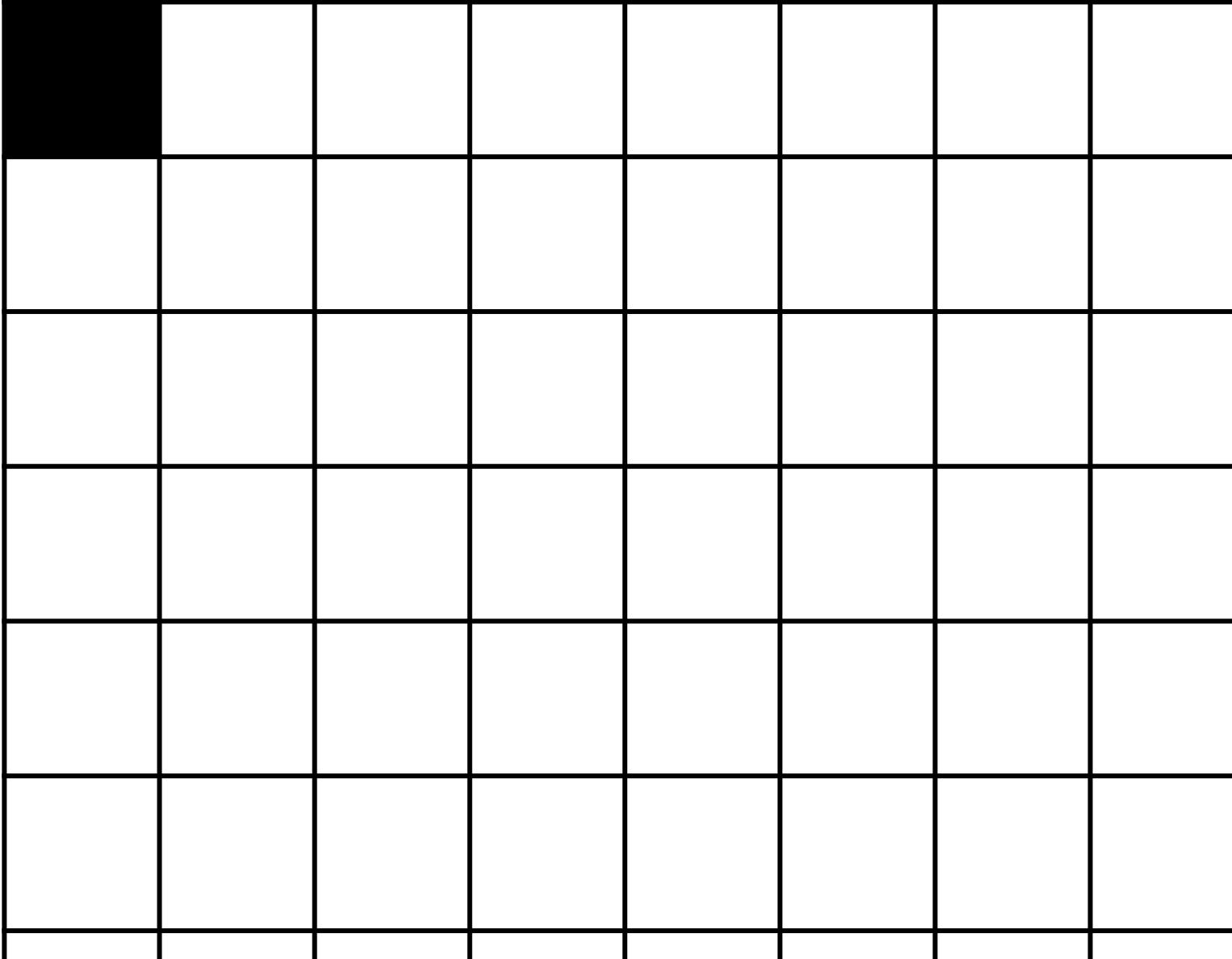
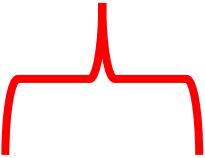




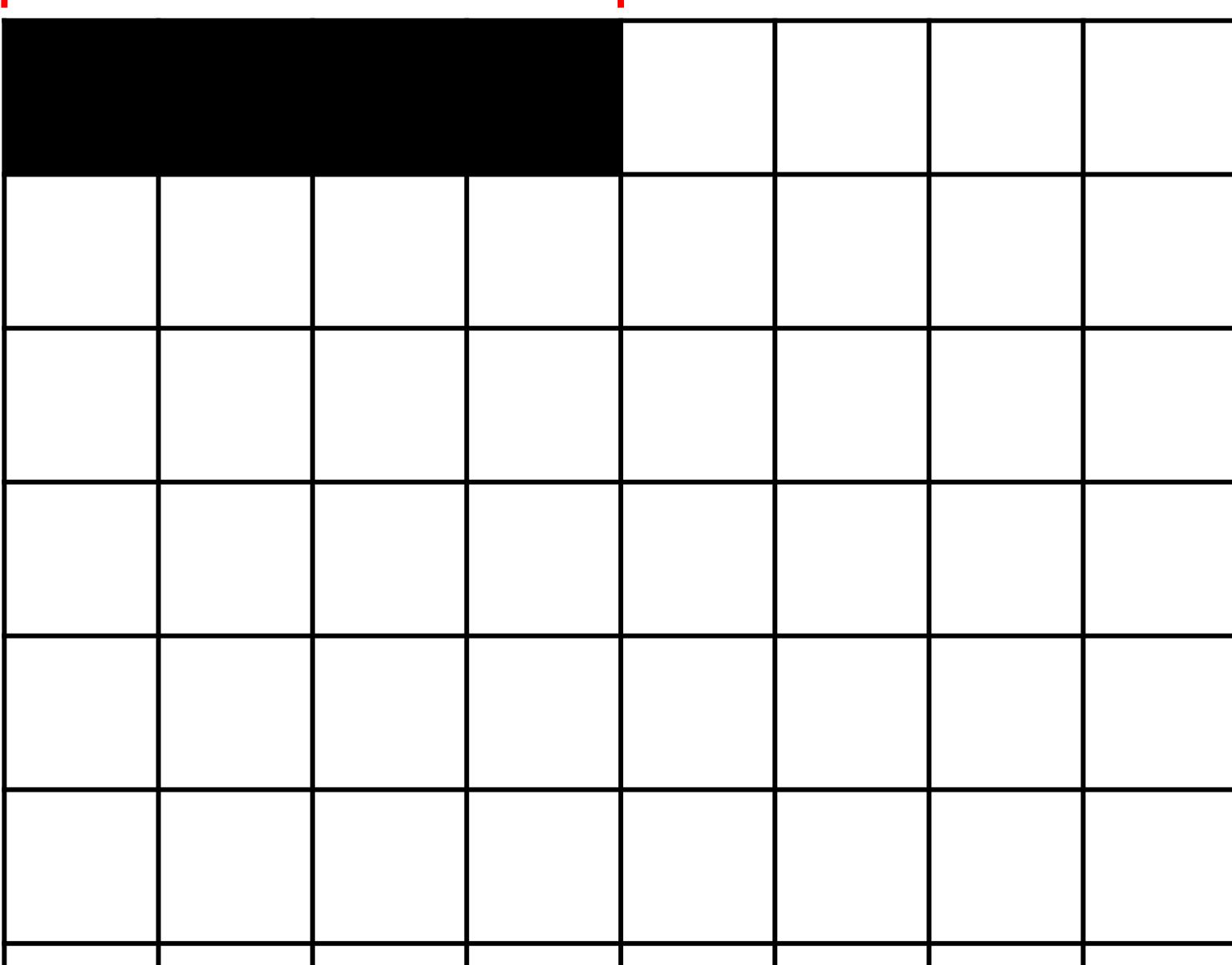




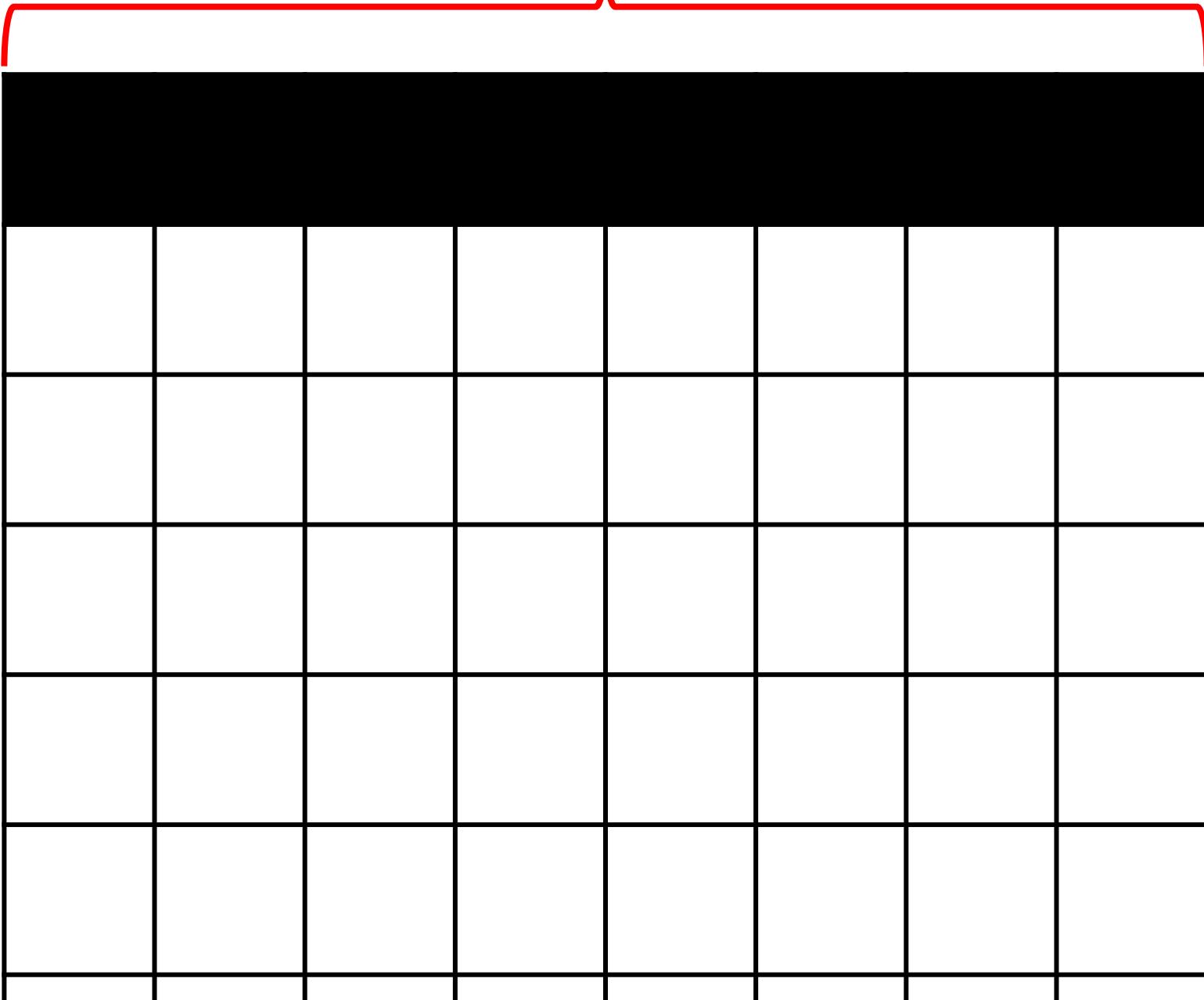
**char** 1 byte



`int` 4 bytes



**double** 8 bytes



```
int age1 = 42;
```

```
int age2 = 27;
```

```
int age3 = 19;
```

42

age1

<b>42</b> age1							

**27**  
age2

<b>42</b>	<b>27</b>
age1	age2
<b>19</b>	
age3	

age1

27

age2

**19**

age3

00000000000000000000000000000000101010	0000000000000000000000000000000011011
age1	age2
0000000000000000000000000000000011011	
age3	

age1

age2

age3







0 1

0 1 2 3 4 5 6 7 8 9

base-16

0 1 2 3 4 5 6 7 8 9 A B C D E F

Hexadecimal

$2^7$   $2^6$   $2^5$   $2^4$   $2^3$   $2^2$   $2^1$   $2^0$

**1111111**

128 64 32 16 8 4 2 1

**1111111111**

128 64 32 16 8 4 2 1

**1 1 1 1 1 1 1 1**

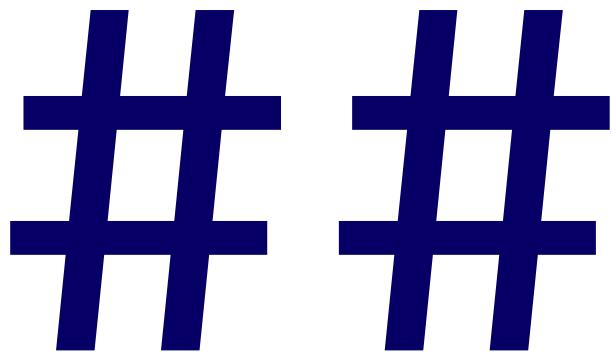
$(128 \times 1) + (64 \times 1) + (32 \times 1) + (16 \times 1) + (8 \times 1) + (4 \times 1) + (2 \times 1) + (1 \times 1)$

128 64 32 16 8 4 2 1

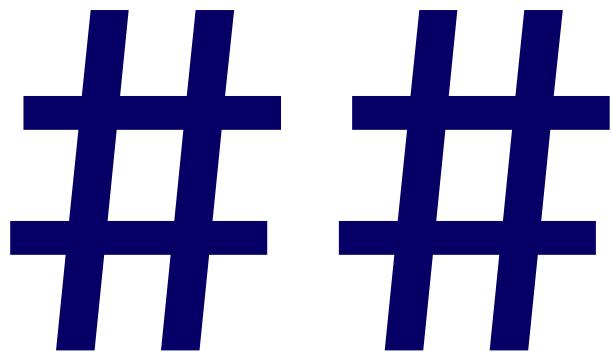
**1 1 1 1 1 1 1 1**

255

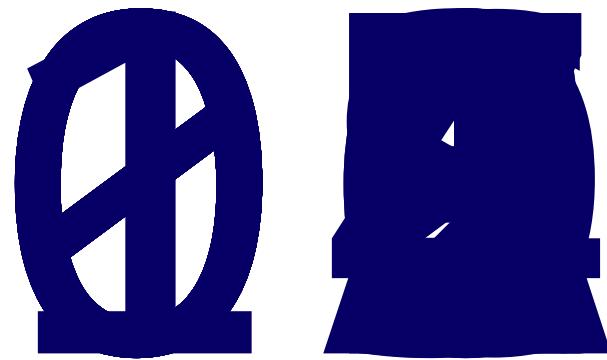
$16^1$      $16^0$



16 1



16 1



16 1

F F

16      1

F F

(16 × F) + (1 × F)

16      1

F F

$(16 \times 15) + (1 \times 15)$

16      1

F F

240 + 15

16 1

F F

255

128 64 32 16 8 4 2 1

**1 1 1 1 1 1 1 1**

255

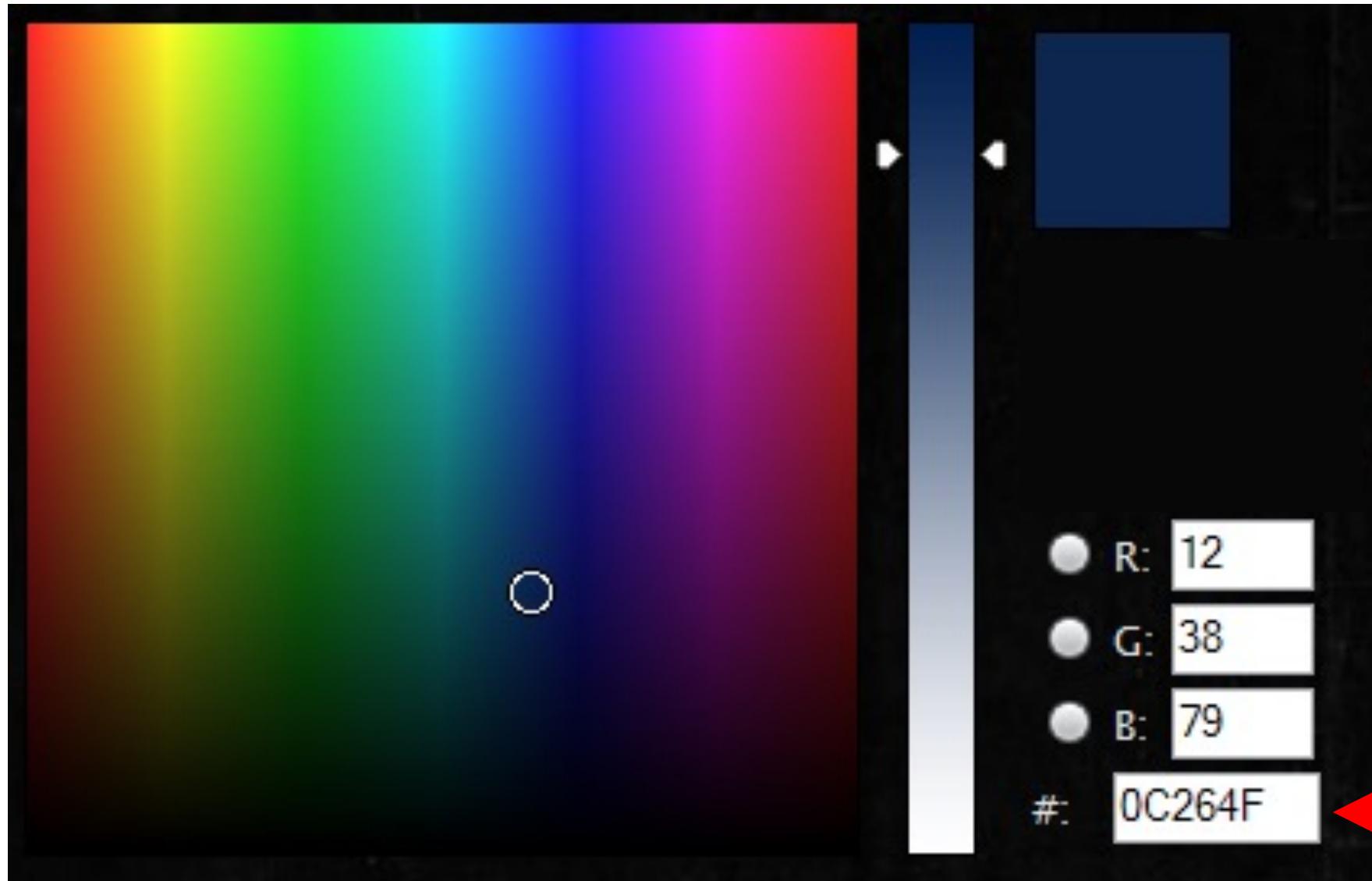
**11111111**

**1111**

**1111**

F

F



R: 12

G: 38

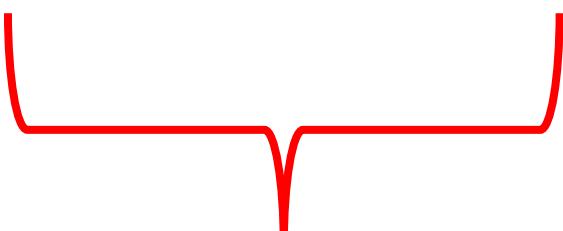
B: 79

#: 0C264F



0	1	2	3	4	5	6	7
8	9	A	B	C	D	E	F
10	11	12	13	14	15	16	17
18	19	1A	1B	1C	1D	1E	1F
20	21	22	23	24	25	26	27
28	29	2A	2B	2C	2D	2E	2F
30	31	32	33	34	35	36	37

0xF F



C++ convention that means  
the following number is a  
hexadecimal (base-16)

0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7
0x8	0x9	0xA	0xB	0xC	0xD	0xE	0xF
0x10	0x11	0x12	0x13	0x14	0x15	0x16	0x17
0x18	0x19	0x1A	0x1B	0x1C	0x1D	0x1E	0x1F
0x20	0x21	0x22	0x23	0x24	0x25	0x26	0x27
0x28	0x29	0x2A	0x2B	0x2C	0x2D	0x2E	0x2F
0x30	0x31	0x32	0x33	0x34	0x35	0x36	0x37

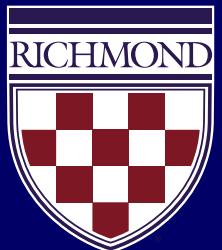
```
int var = 17;
```

17

var

					0x123 <b>17</b> var		

# Ask a question



# Today

- Memory
- Pointers
- Garbage Values
- Memory Layout
- In-class exercise



&

“address of”

\*

“contents of”

A **pointer** is an object that holds an address value.

```
int var = 17;
```

```
int* ptr = &var; // ptr holds the address of var
```

This new type is called an “**int pointer**” and is used to hold the address of an integer variable

The “**address of**” the integer `var`

					0x16D01345	17	var

<b>0x16D01345</b>							
ptr							
				<b>0x16D01345</b>	<b>17</b>		
					<b>var</b>		

**0x16D01345**

*ptr*



**0x16D01345**

**17**

*var*

A diagram illustrating a pointer variable. At the top, there is a horizontal rectangle with a black border. Inside the rectangle, the word "ptr" is written in purple. A dark blue arrow originates from the bottom edge of this rectangle and points downwards and to the right. This arrow points to the top edge of a second, smaller horizontal rectangle located below it. The number "17" is written in red inside the second rectangle, and the word "var" is written in purple below it.

ptr

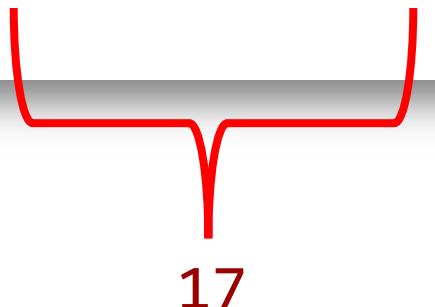
17

var

```
int var = 17;
```

```
int* ptr = &var; // ptr holds the address of var
```

```
int anotherVar = *ptr;
```



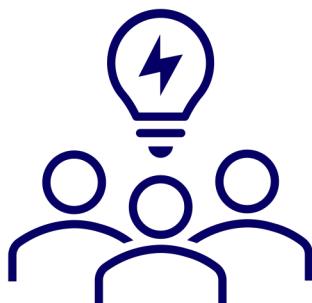
The “**contents of**” the  
pointer `ptr`  
(i.e., the value stored  
at the address)

```
int var = 17;
int* ptr = &var; // ptr holds the address of var

cout << "var == " << var << endl; // #1
cout << "'address of' var == " << &var << endl; // #2

cout << "ptr == " << ptr << endl; // #3
cout << "'contents of' ptr == " << *ptr << endl; // #4

cout << "'contents of' the 'address of' var == " << *&var << endl; // #5
```



```
int var = 17;
int* ptr = &var; // ptr holds the address of var

cout << "var == " << var << endl; // #1
cout << "'address of' var == " << &var << endl; // #2

cout << "ptr == " << ptr << endl; // #3
cout << "'contents of' ptr == " << *ptr << endl; // #4

cout << "'contents of' the 'address of' var == " << *&var << endl; // #5
```

```
var == 17
'address of' var == 0x16af27454
ptr == 0x16af27454
'contents of' ptr == 17
'contents of' the 'address of' var == 17
```

```
double pi = 3.14159;
```

```
double* ptr = &pi; // ptr holds the address of pi
```

This new type is called an  
**“double pointer”** and is  
used to hold the address of  
a variable of type double

The “**Address of**”  
the double pi

0x45FA1379	3.14159	pi					

3.14159  
pi

<b>0x45FA1379</b> ptr							
<b>0x45FA1379</b>							
<b>3.14159</b>							

ptr

**3.14159**

pi

**0x45FA1379**  
ptr

0x45FA1379

A blue arrow points from the bottom-left corner of the top box down to the left edge of the bottom box, indicating a pointer relationship.

**3.14159**  
pi

A diagram illustrating a pointer variable. At the top, there is a horizontal rectangle with a black border. Inside the rectangle, the word "ptr" is written in blue. A dark blue arrow originates from the bottom-left corner of this rectangle and points downwards and to the left. It then turns upwards and to the right, ending with an arrowhead that points to the bottom-left corner of a second horizontal rectangle below it. This second rectangle also has a black border. Inside, the number "3.14159" is written in red, and the letter "pi" is written in blue below it.

ptr

3.14159  
pi

MAN, I SUCK AT THIS GAME.  
CAN YOU GIVE ME  
A FEW POINTERS?

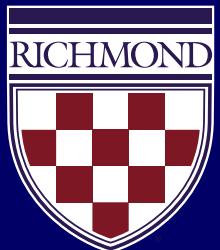


0x3A28213A  
0x6339392C,  
0x7363682E.

I HATE YOU.

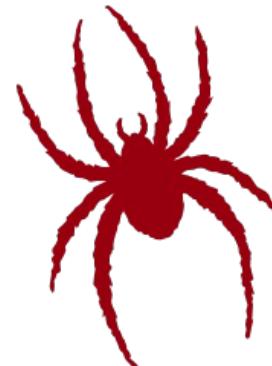


# Ask a question



# Today

- ~~Memory~~
- ~~Pointers~~
- Garbage Values
- Memory Layout
- In-class exercise



```
#include <iostream>
using namespace std;

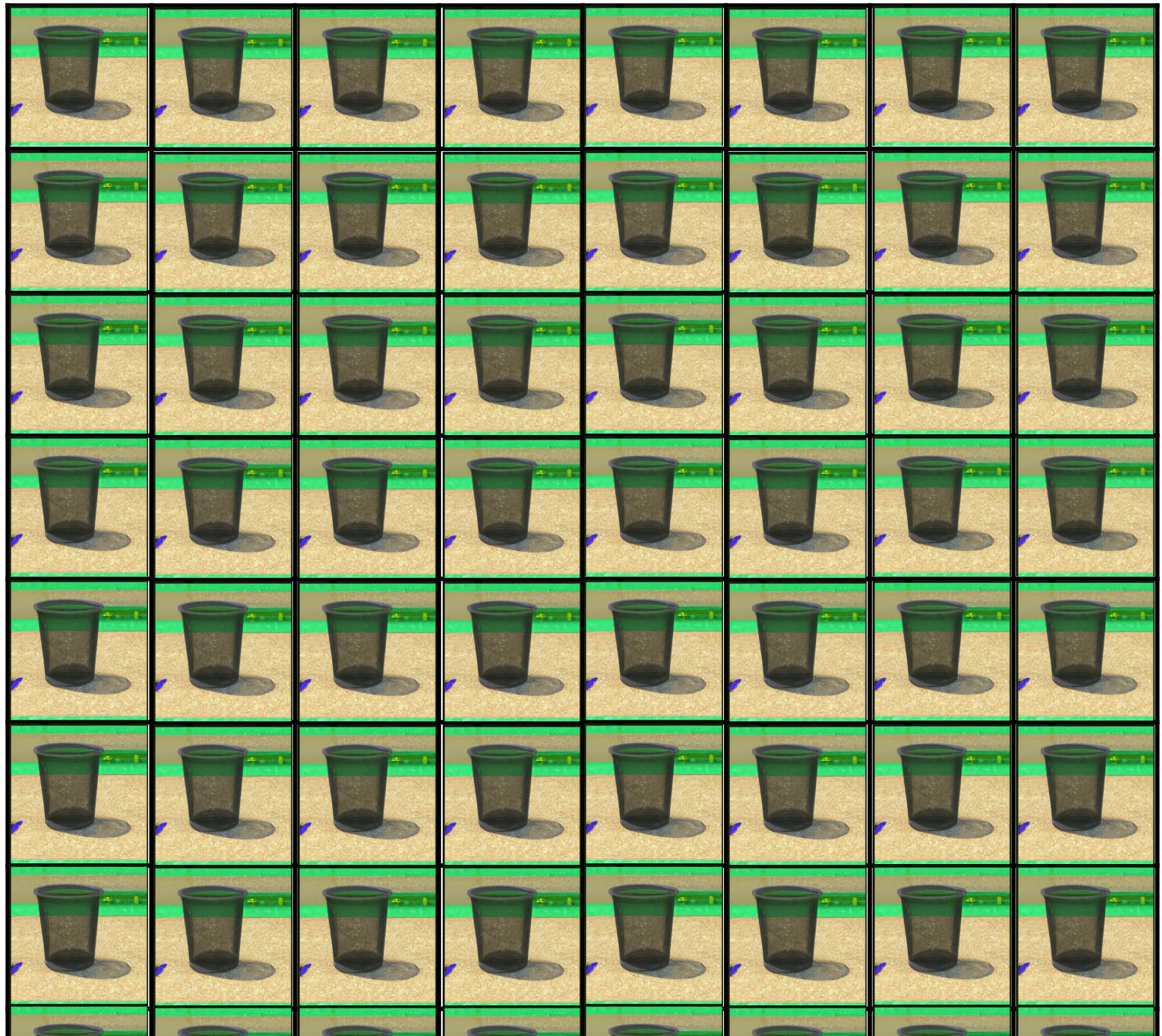
int main()
{
    int var1;           var1 == 1
    int var2;           var2 == 71282756
    int var3;           var3 == 1
    int var4;           var4 == 71319552
    int var5;           var5 == 1

    cout << "var1 == " << var1 << endl;
    cout << "var2 == " << var2 << endl;
    cout << "var3 == " << var3 << endl;
    cout << "var4 == " << var4 << endl;
    cout << "var5 == " << var5 << endl;
}
```

```
array<int, 10> numbers = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};  
  
cout << "numbers[323] == " << numbers[323] << endl; // Clearly out of array bounds!!
```

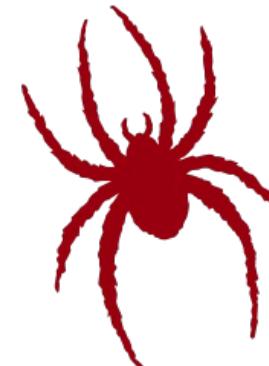
numbers[323] == 1966029422

0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7
0x8	0x9	0xA	0xB	0xC	0xD	0xE	0xF
0x10	0x11	0x12	0x13	0x14	0x15	0x16	0x17
0x18	0x19	0x1A	0x1B	0x1C	0x1D	0x1E	0x1F
0x20	0x21	0x22	0x23	0x24	0x25	0x26	0x27
0x28	0x29	0x2A	0x2B	0x2C	0x2D	0x2E	0x2F
0x30	0x31	0x32	0x33	0x34	0x35	0x36	0x37



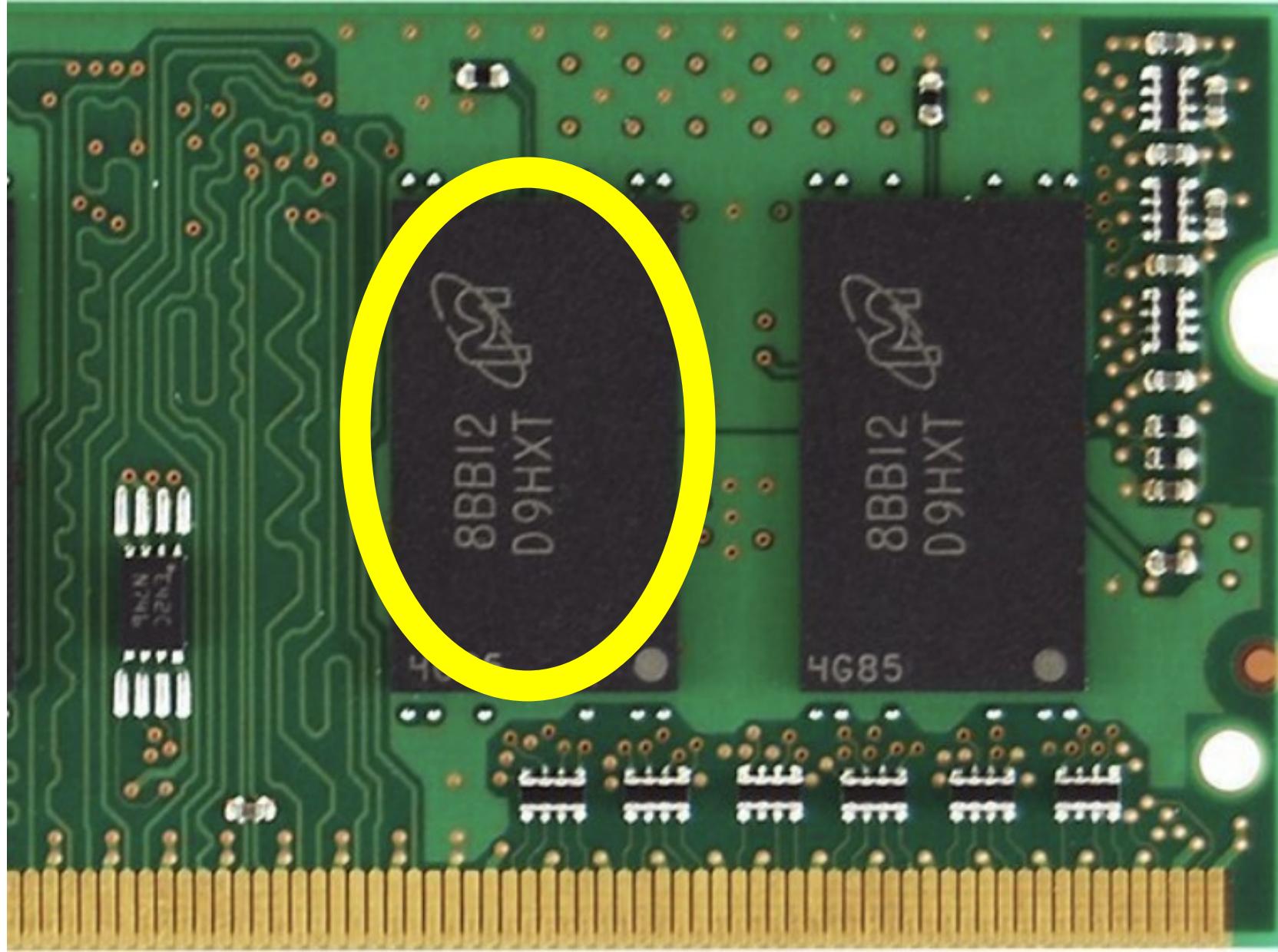
# Today

- ~~Memory~~
- ~~Pointers~~
- ~~Garbage Values~~
- Memory Layout
- In-class exercise

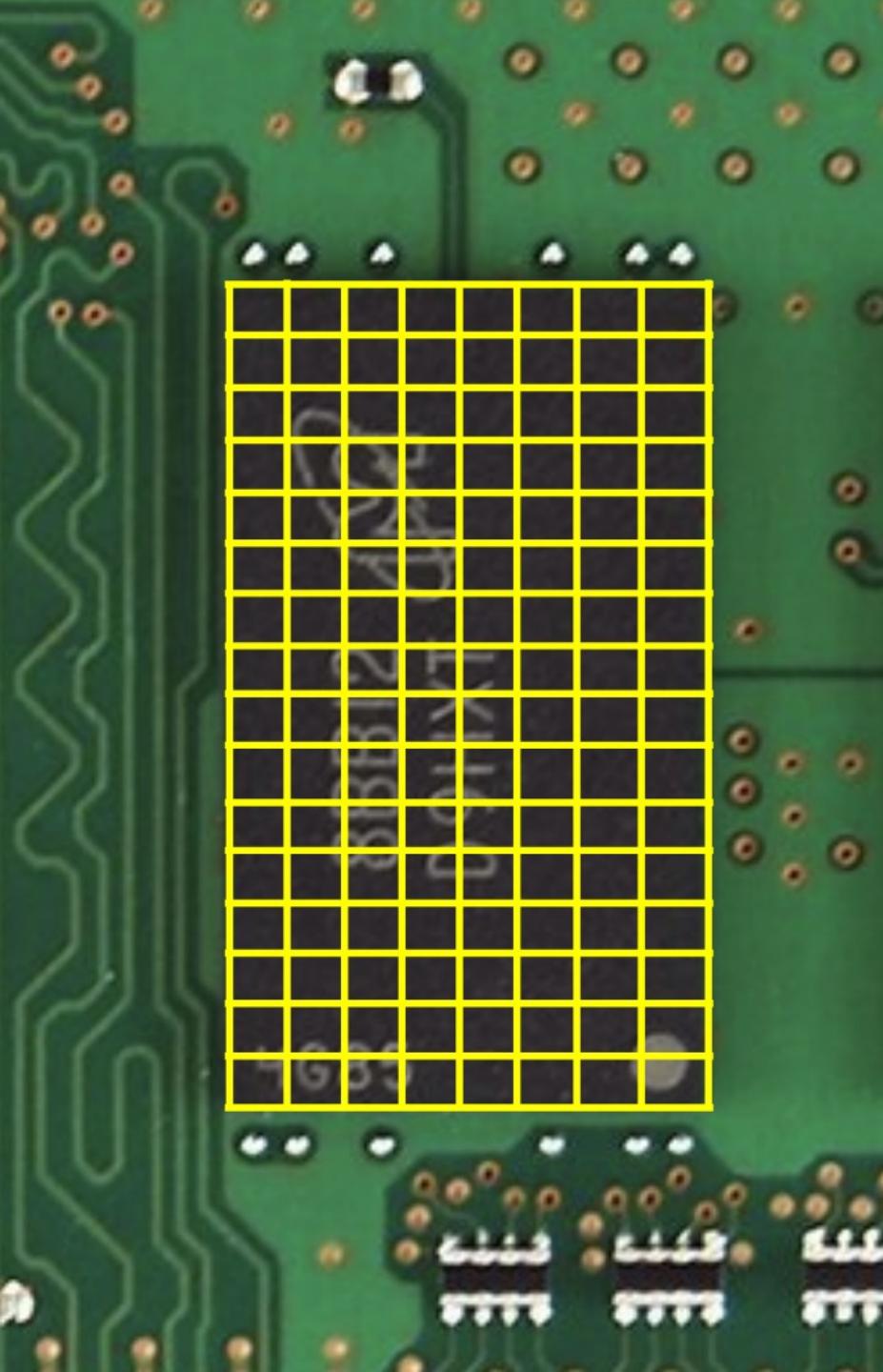


```
// Swap two int values.
void swap(int a, int b)
{
    int temp = a; // store a in temp
    a = b;         // put b into a
    b = temp;       // put temp a into b
}

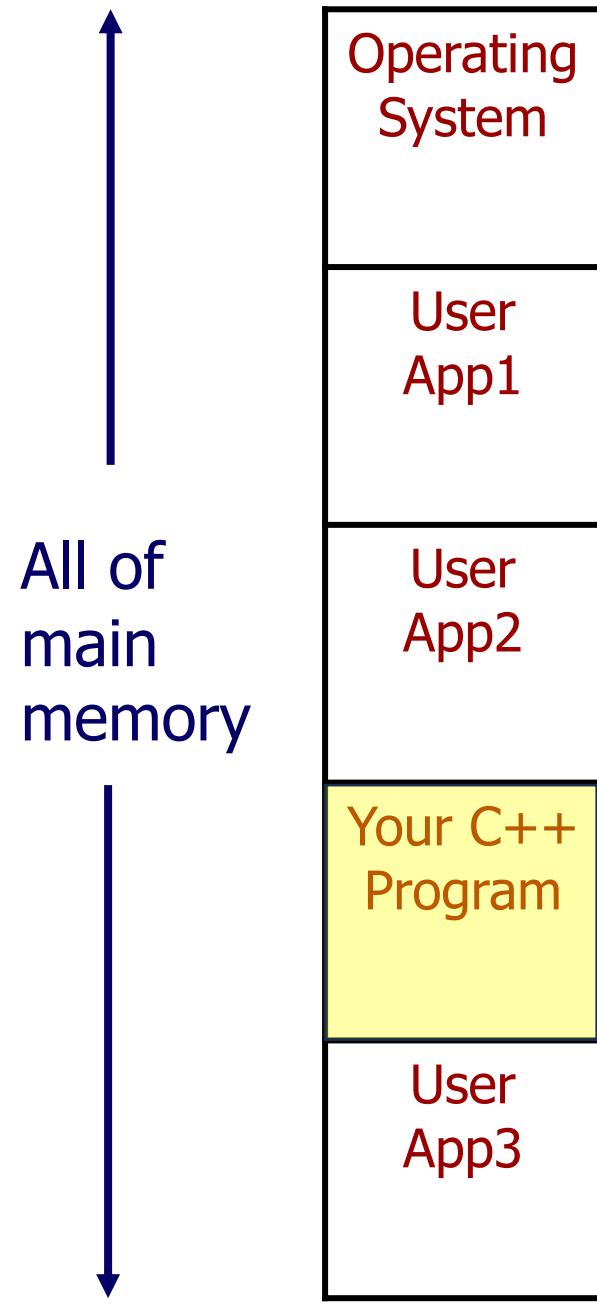
int main()
{
    int x = 12;
    int y = 33;
    swap(x, y);
    cout << "x == " << x << "  y == " << y << endl; // ?
    return 0;
}
```





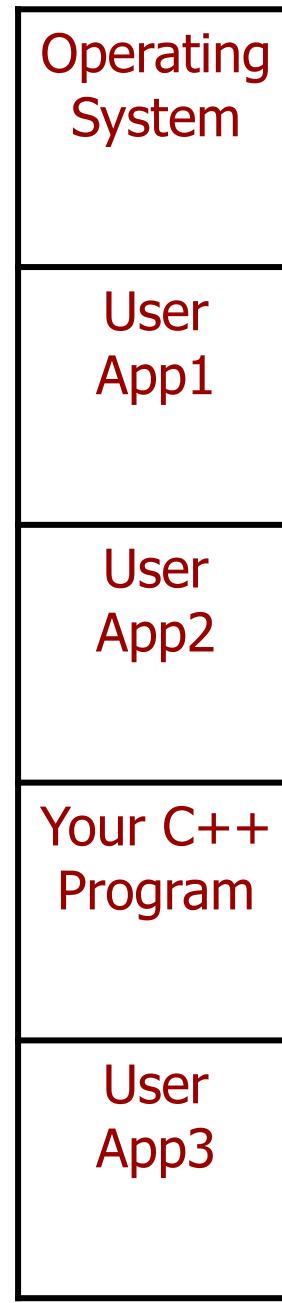


0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7
0x8	0x9	0xA	0xB	0xC	0xD	0xE	0xF
0x10	0x11	0x12	0x13	0x14	0x15	0x16	0x17
0x18	0x19	0x1A	0x1B	0x1C	0x1D	0x1E	0x1F
0x20	0x21	0x22	0x23	0x24	0x25	0x26	0x27
0x28	0x29	0x2A	0x2B	0x2C	0x2D	0x2E	0x2F
0x30	0x31	0x32	0x33	0x34	0x35	0x36	0x37
0x38	0x39	0x3A	0x3B	0x3C	0x3D	0x3E	0x3F
0x40	0x41	0x42	0x43	0x44	0x45	0x46	0x47
0x48	0x49	0x4A	0x4B	0x4C	0x4D	0x4E	0x4F

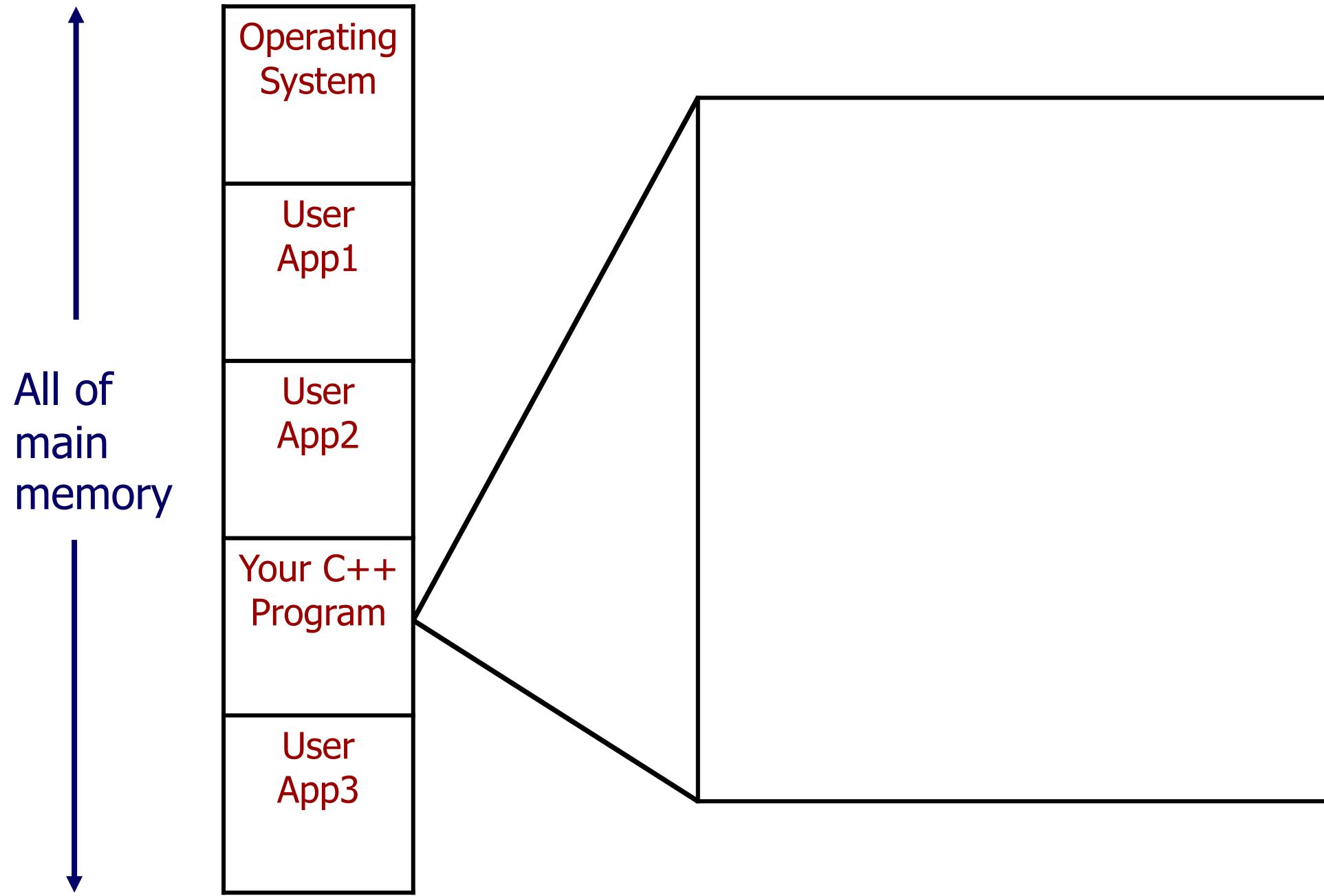


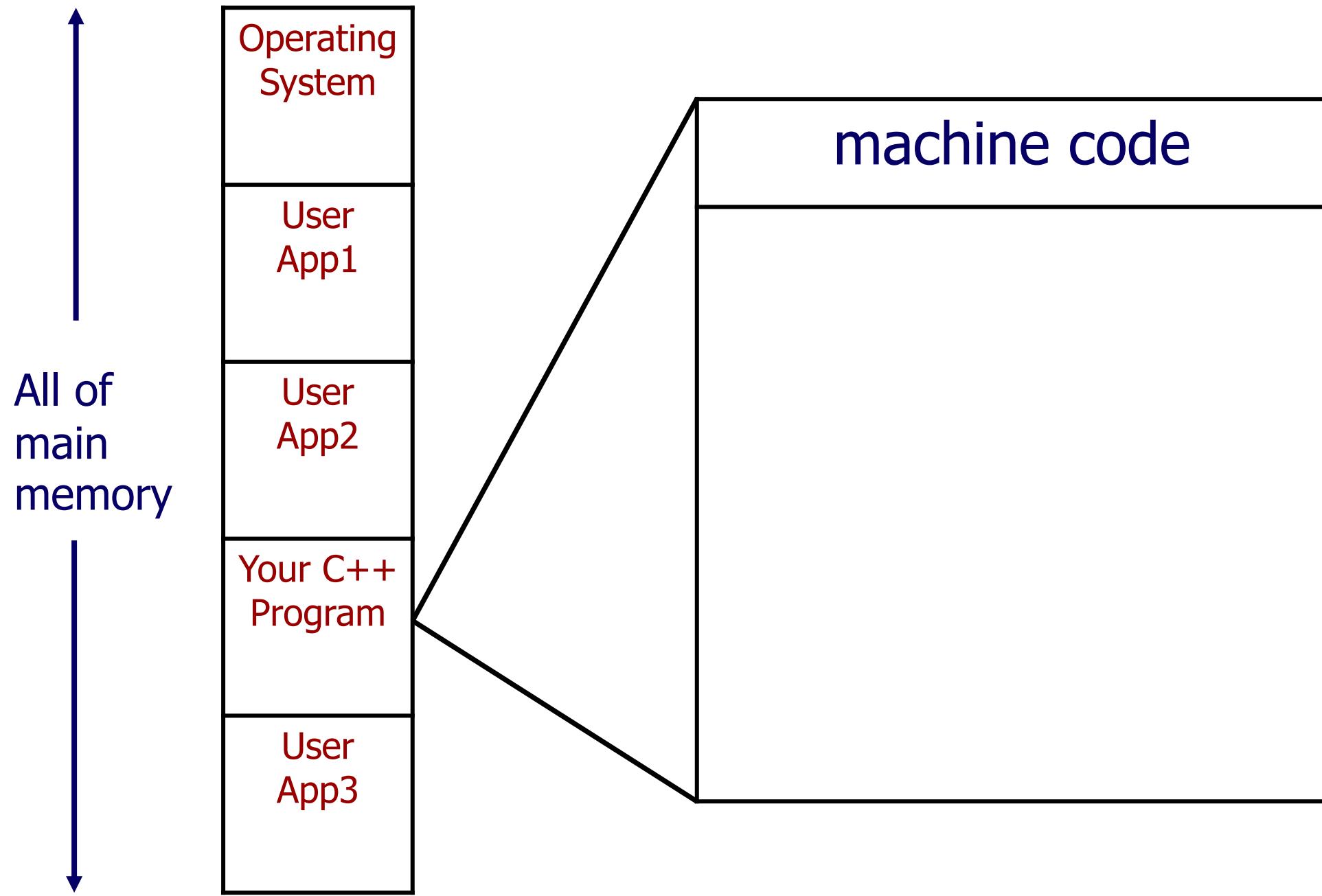
All of main memory

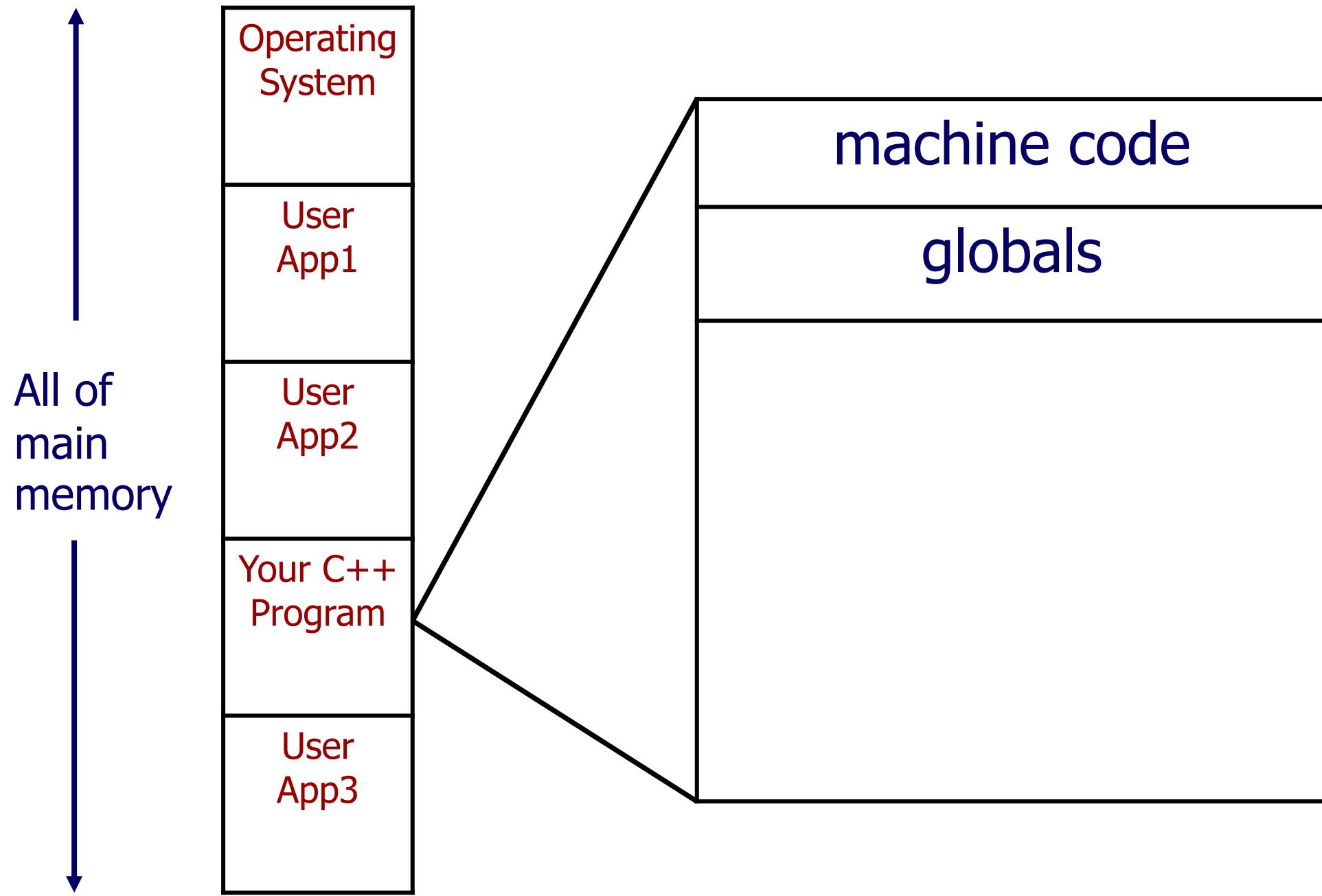
↑  
↓

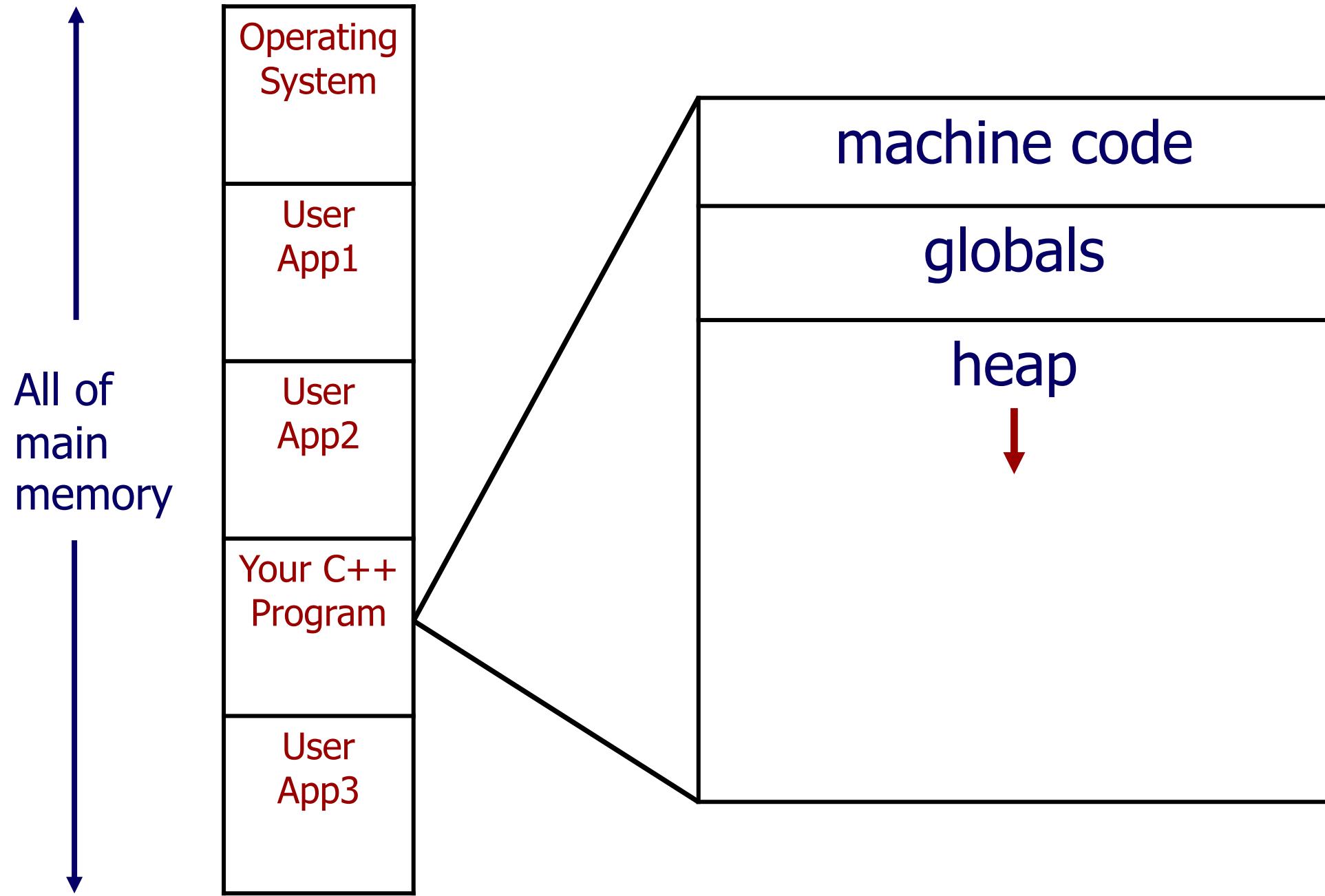


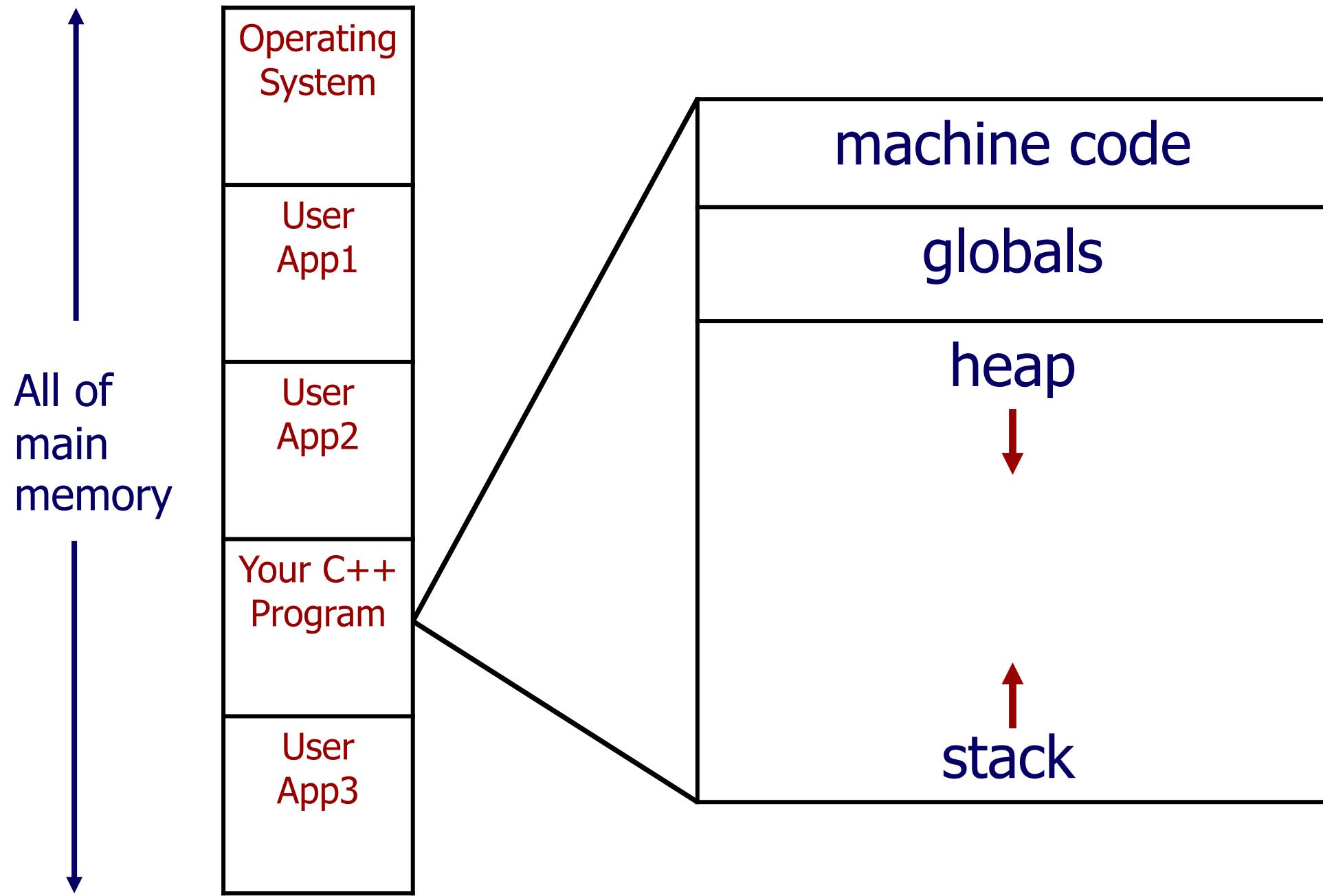
0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7
0x8	0x9	0xA	0xB	0xC	0xD	0xE	0xF
0x10	0x11	0x12	0x13	0x14	0x15	0x16	0x17
0x18	0x19	0x1A	0x1B	0x1C	0x1D	0x1E	0x1F
0x20	0x21	0x22	0x23	0x24	0x25	0x26	0x27
0x28	0x29	0x2A	0x2B	0x2C	0x2D	0x2E	0x2F
0x30	0x31	0x32	0x33	0x34	0x35	0x36	0x37
0x38	0x39	0x3A	0x3B	0x3C	0x3D	0x3E	0x3F
0x40	0x41	0x42	0x43	0x44	0x45	0x46	0x47
0x48	0x49	0x4A	0x4B	0x4C	0x4D	0x4E	0x4F





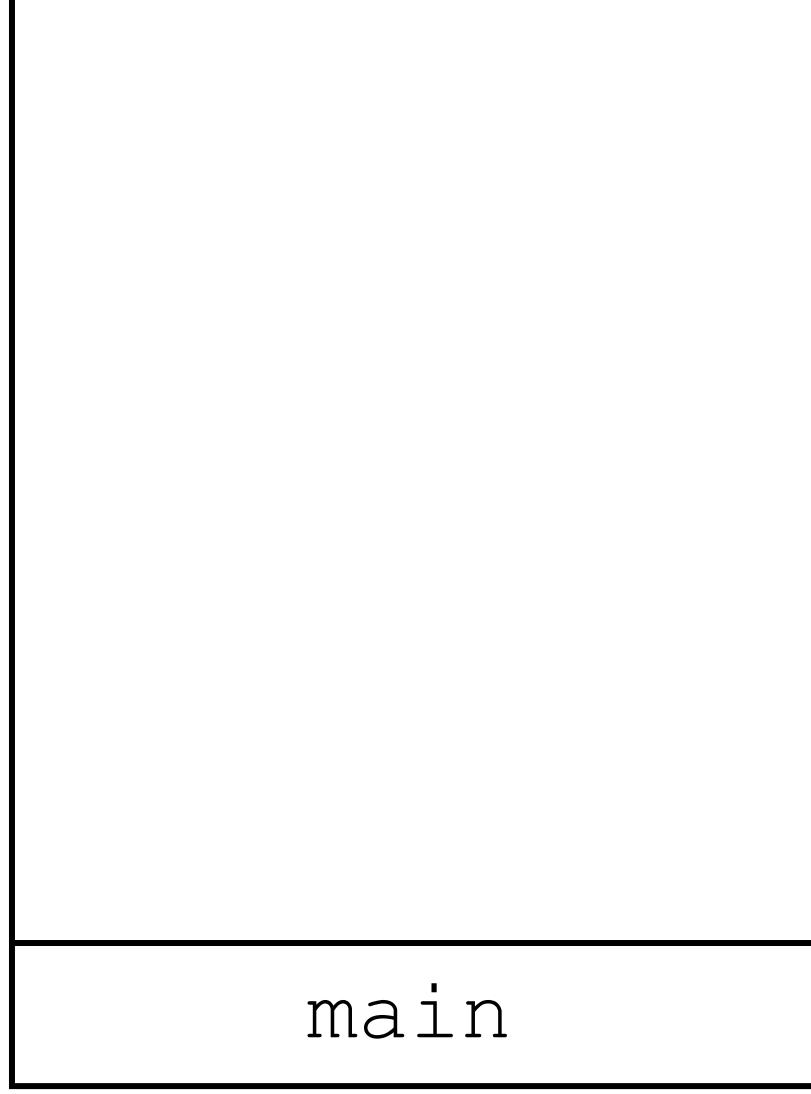




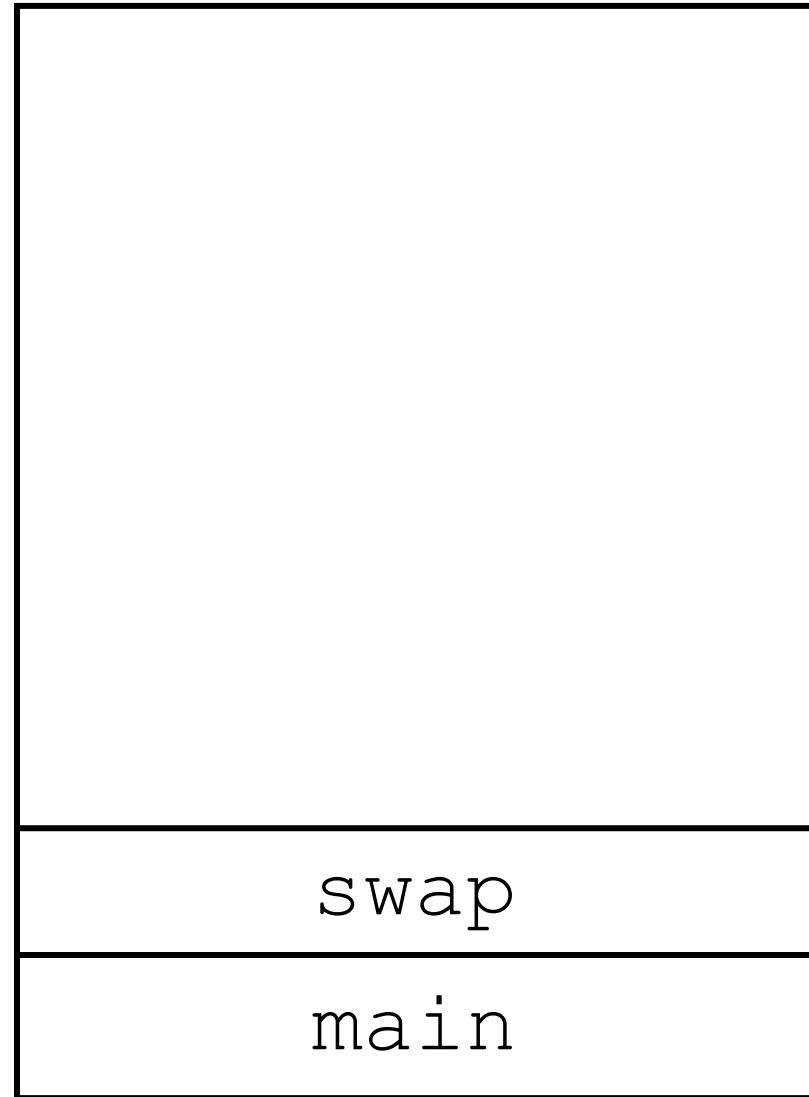


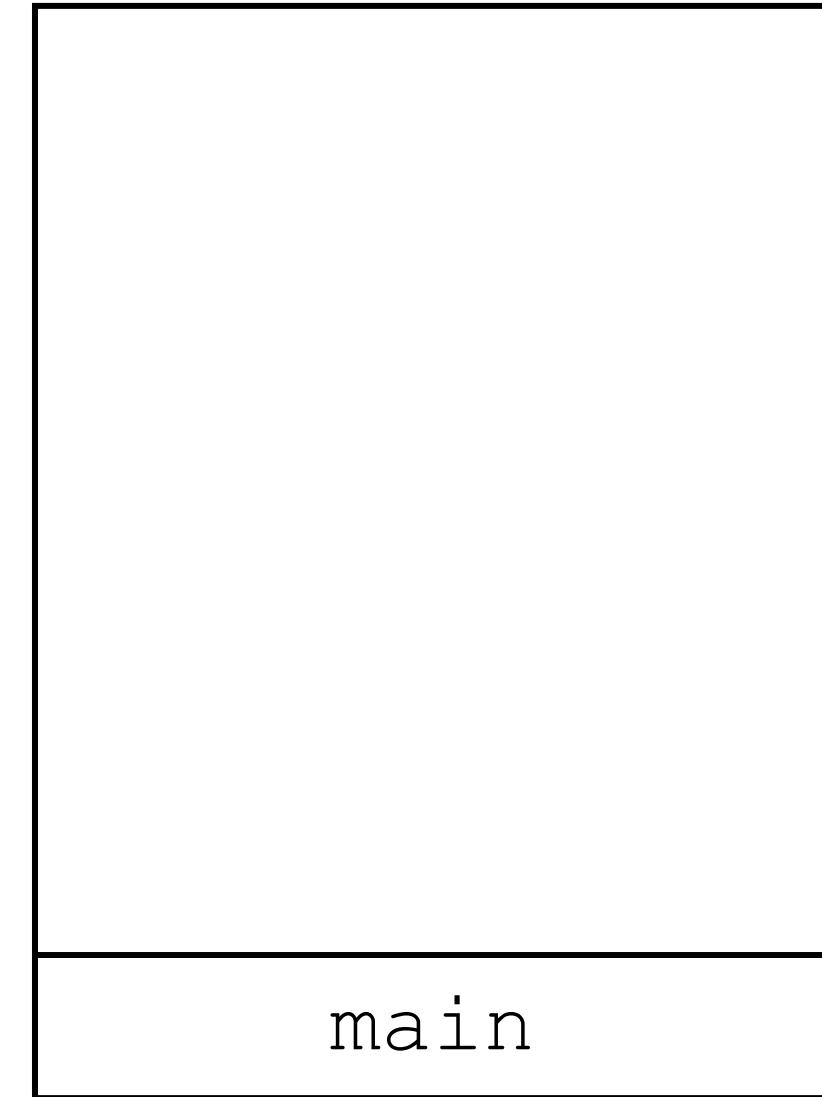
```
// Swap two int values.
void swap(int a, int b)
{
    int temp = a; // store a in temp
    a = b;         // put b into a
    b = temp;       // put temp a into b
}

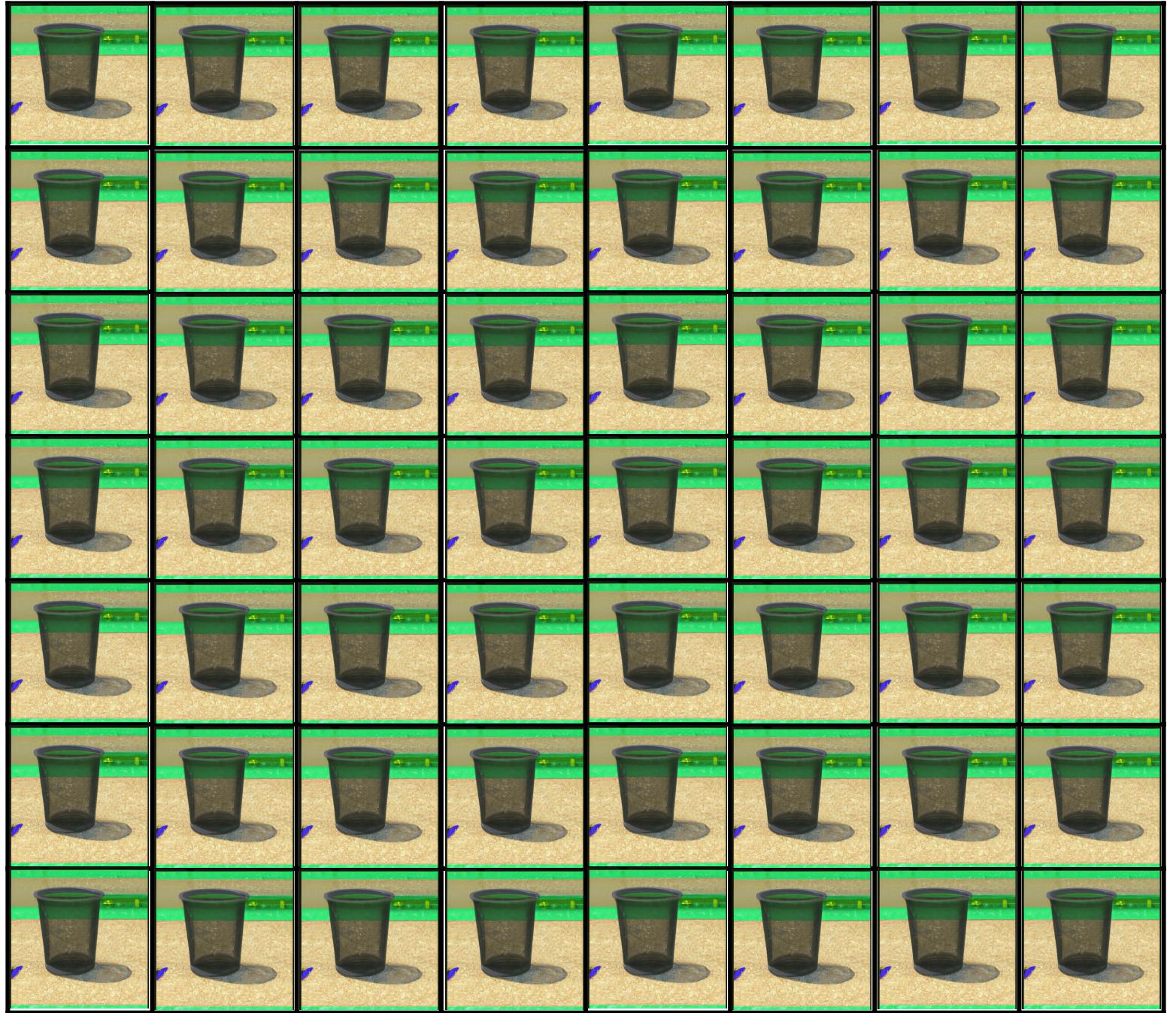
int main()
{
    int x = 12;
    int y = 33;
    swap(x, y);
    cout << "x == " << x << "  y == " << y << endl; // ?
    return 0;
}
```



main







main

12  
x

33  
y



swap

main



12  
a

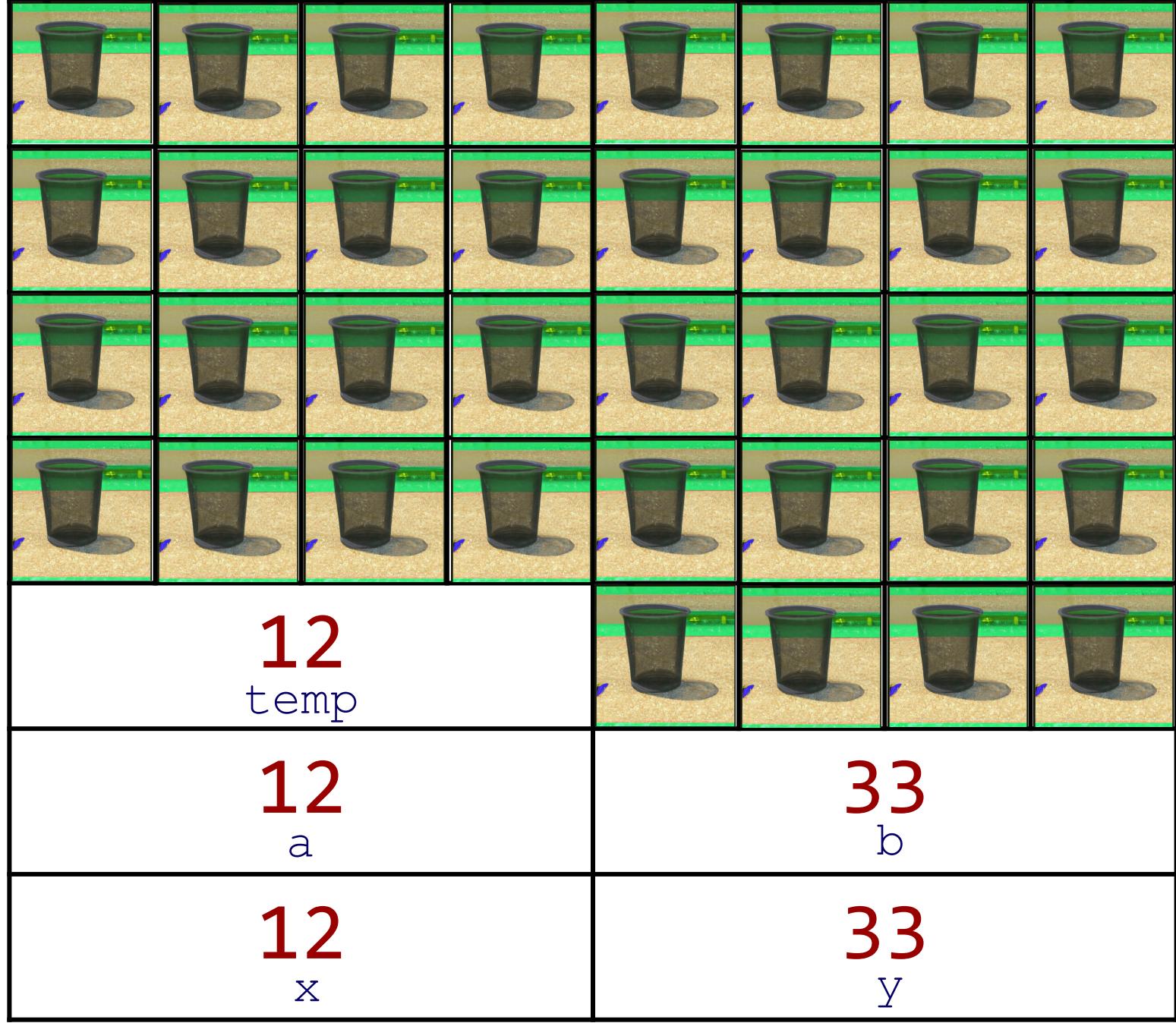
12  
x

33  
b

33  
y

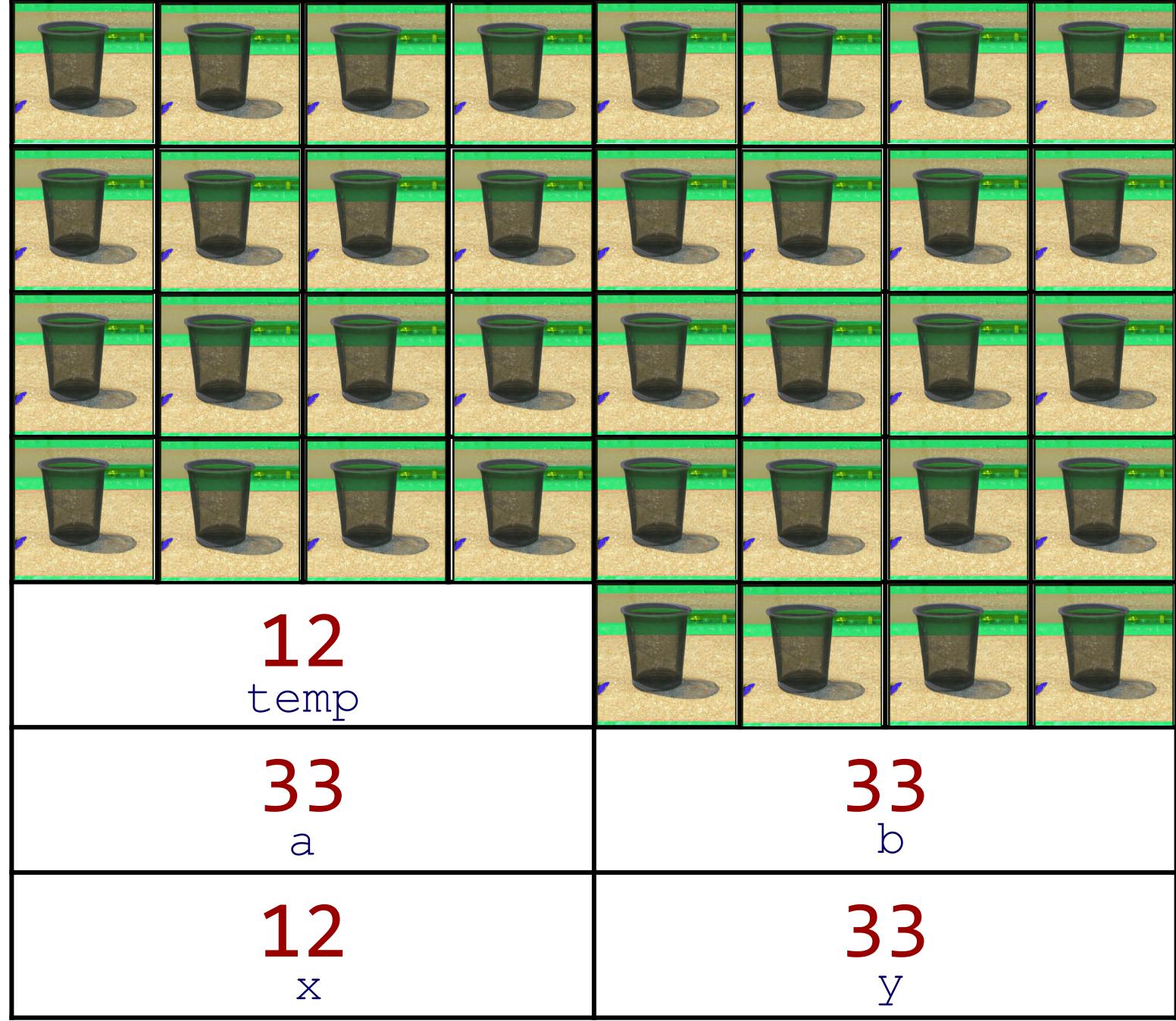
swap

main



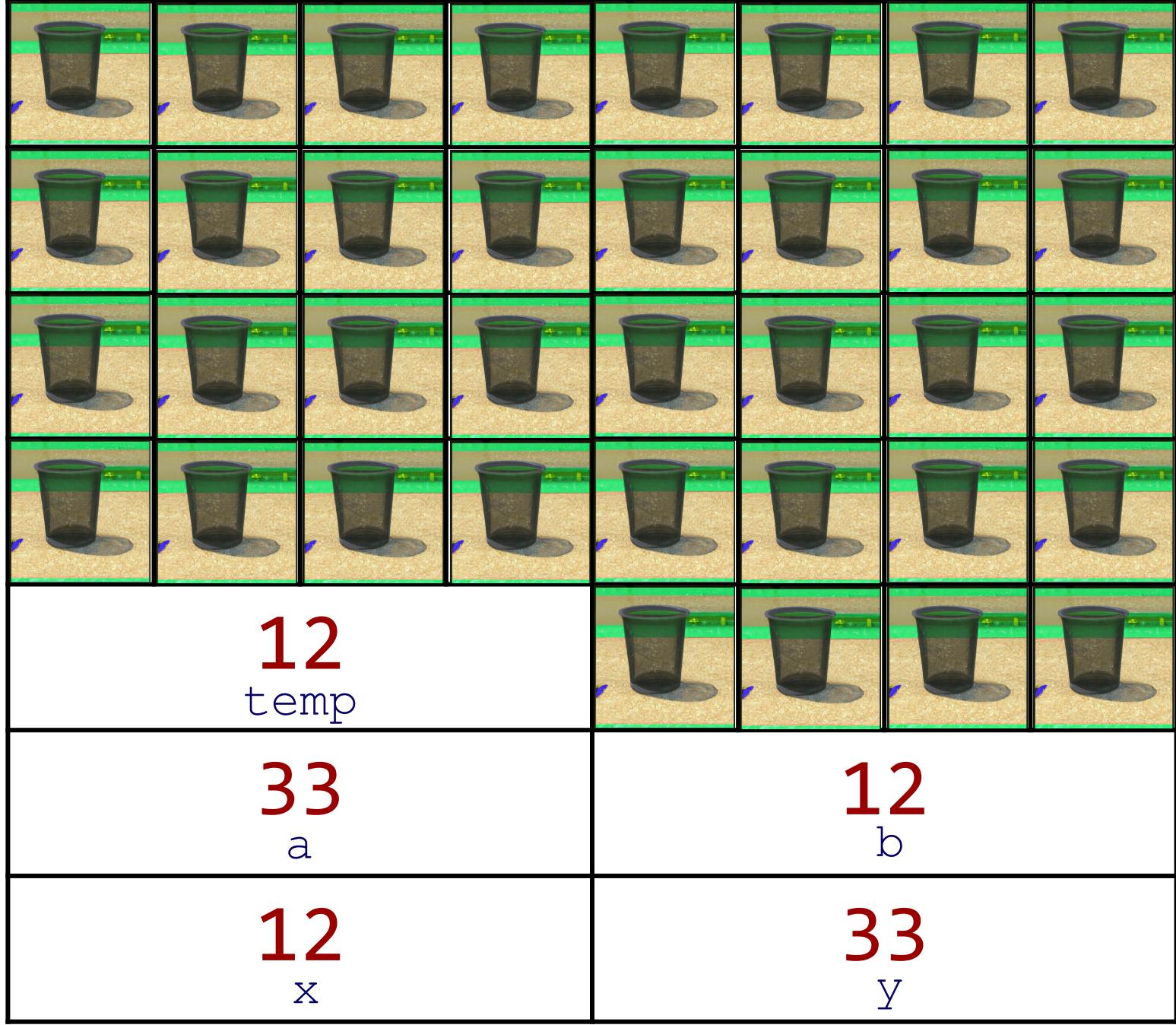
swap

main



swap

main



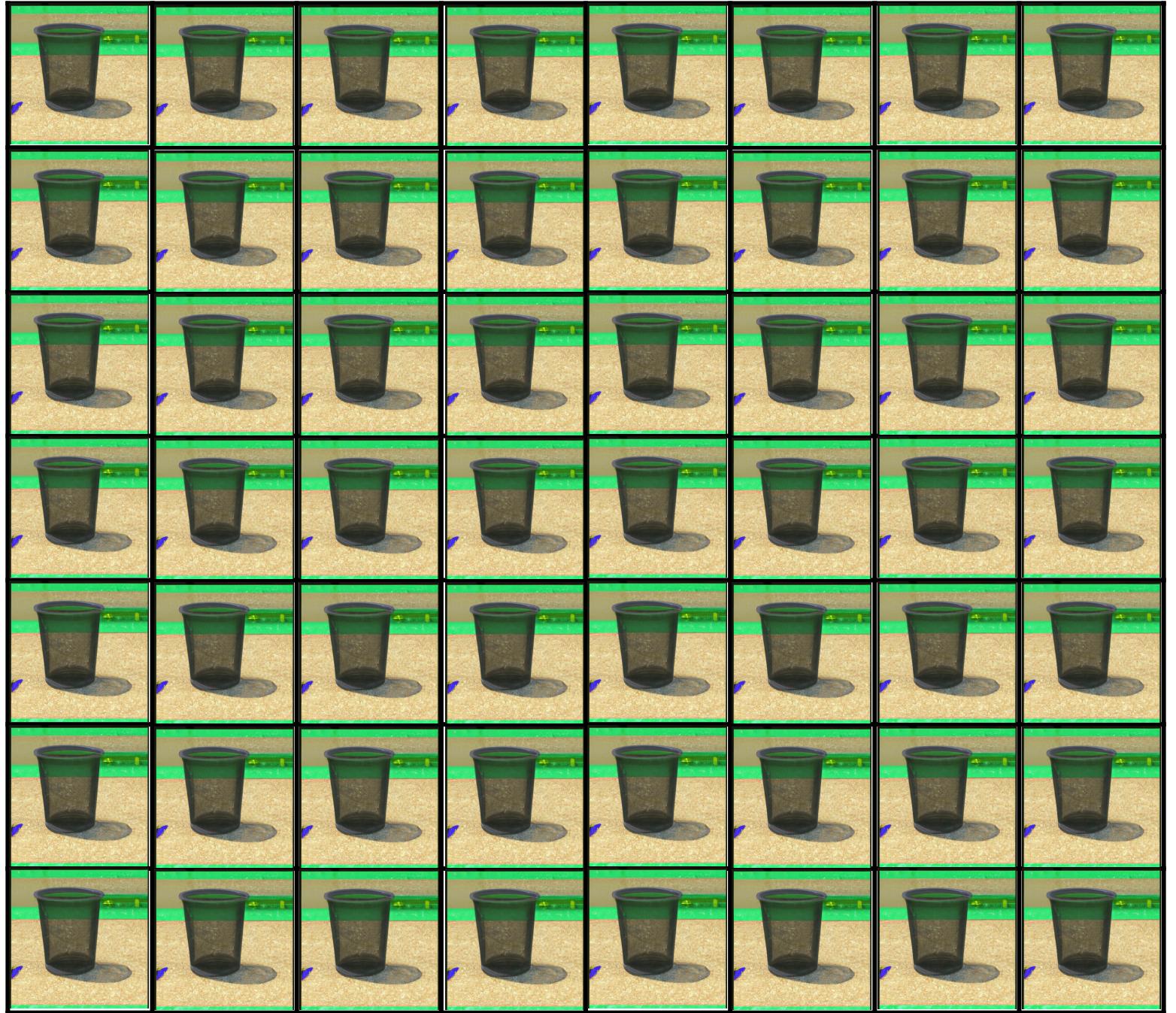
main

12  
x

33  
y



```
// Swap two int values.  
void swap(int* a, int* b)  
{  
    int temp = *a;      // store contents of a in temp  
    *a = *b;            // put contents of b into a  
    *b = temp;          // put temp a into b  
}  
  
int main()  
{  
    int x = 12;  
    int y = 33;  
    swap(&x, &y);    // pass by reference (the addresses of x and y)  
    cout << "x == " << x << "  y == " << y << endl;  
    return 0;  
}
```



main

12  
x

33  
y



swap

main



0x45FA137D

b

0x45FA1379

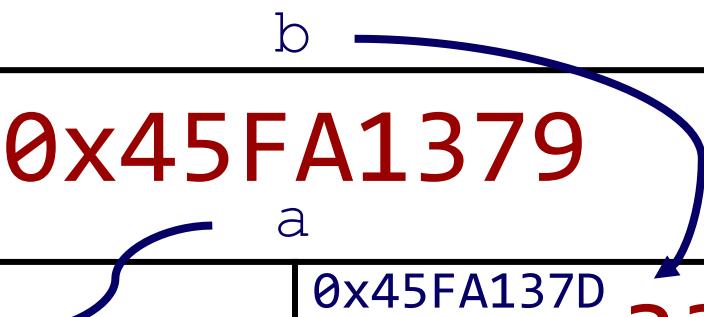
a

0x45FA1379

12  
x

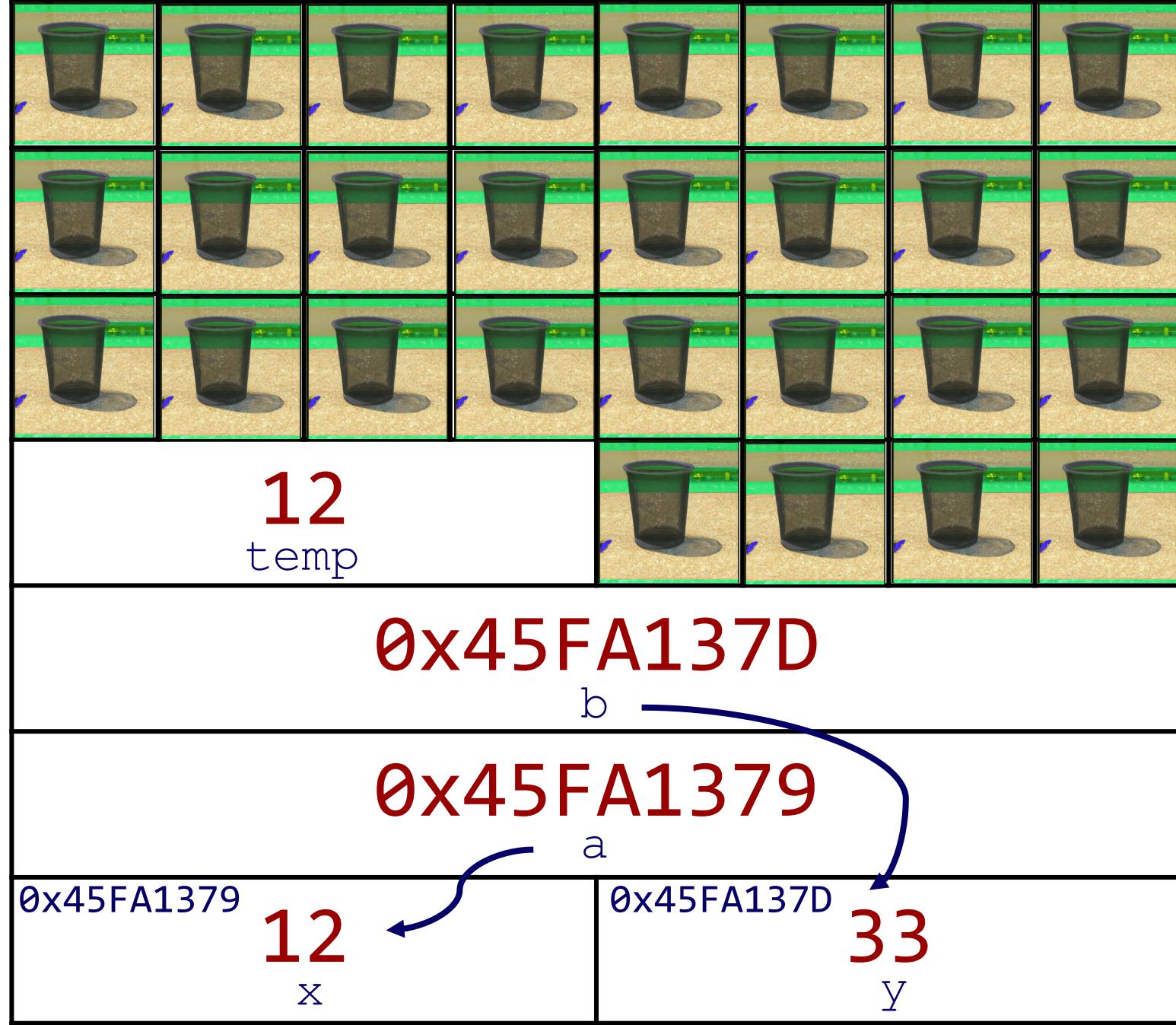
0x45FA137D

33  
y



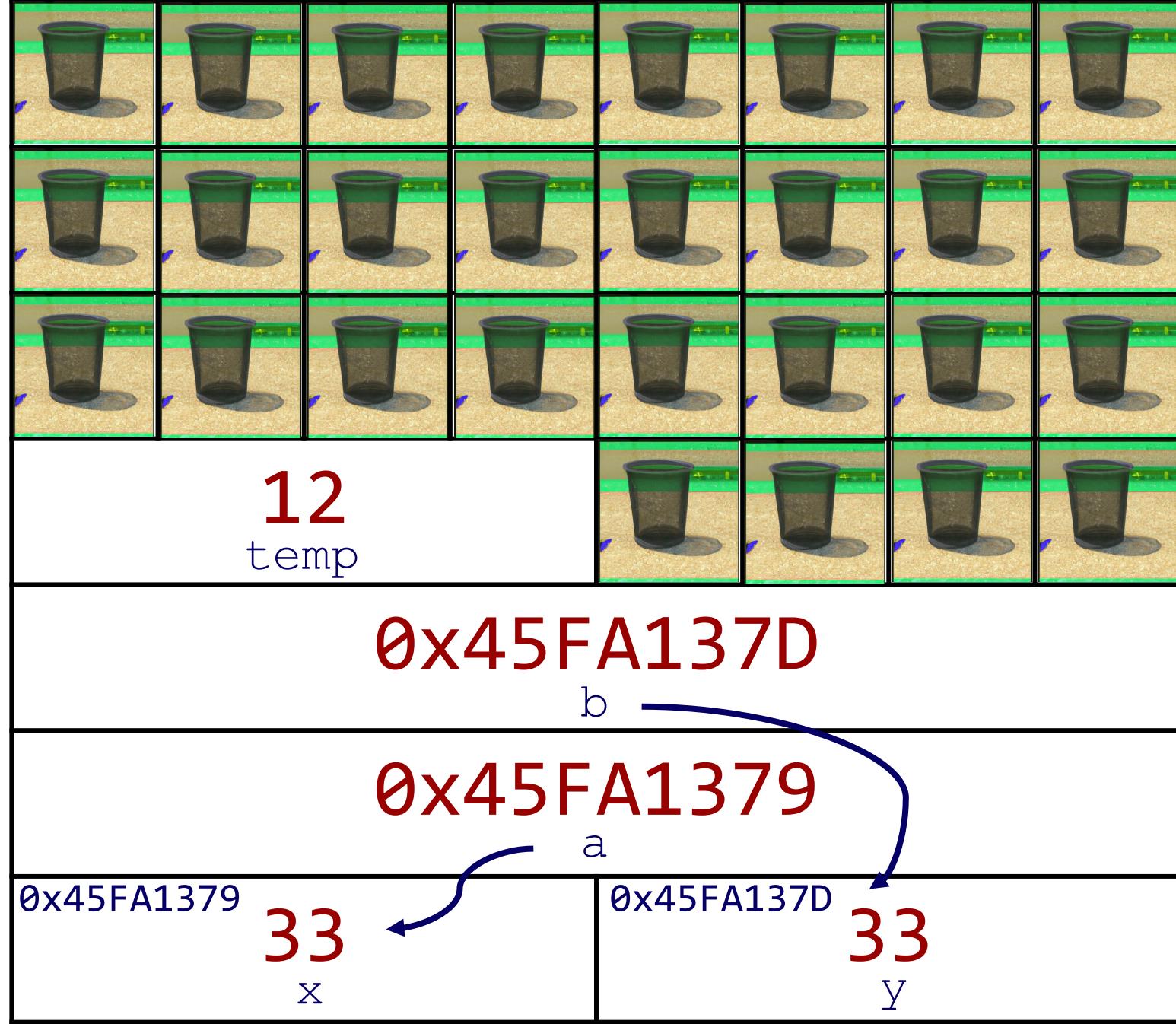
swap

main



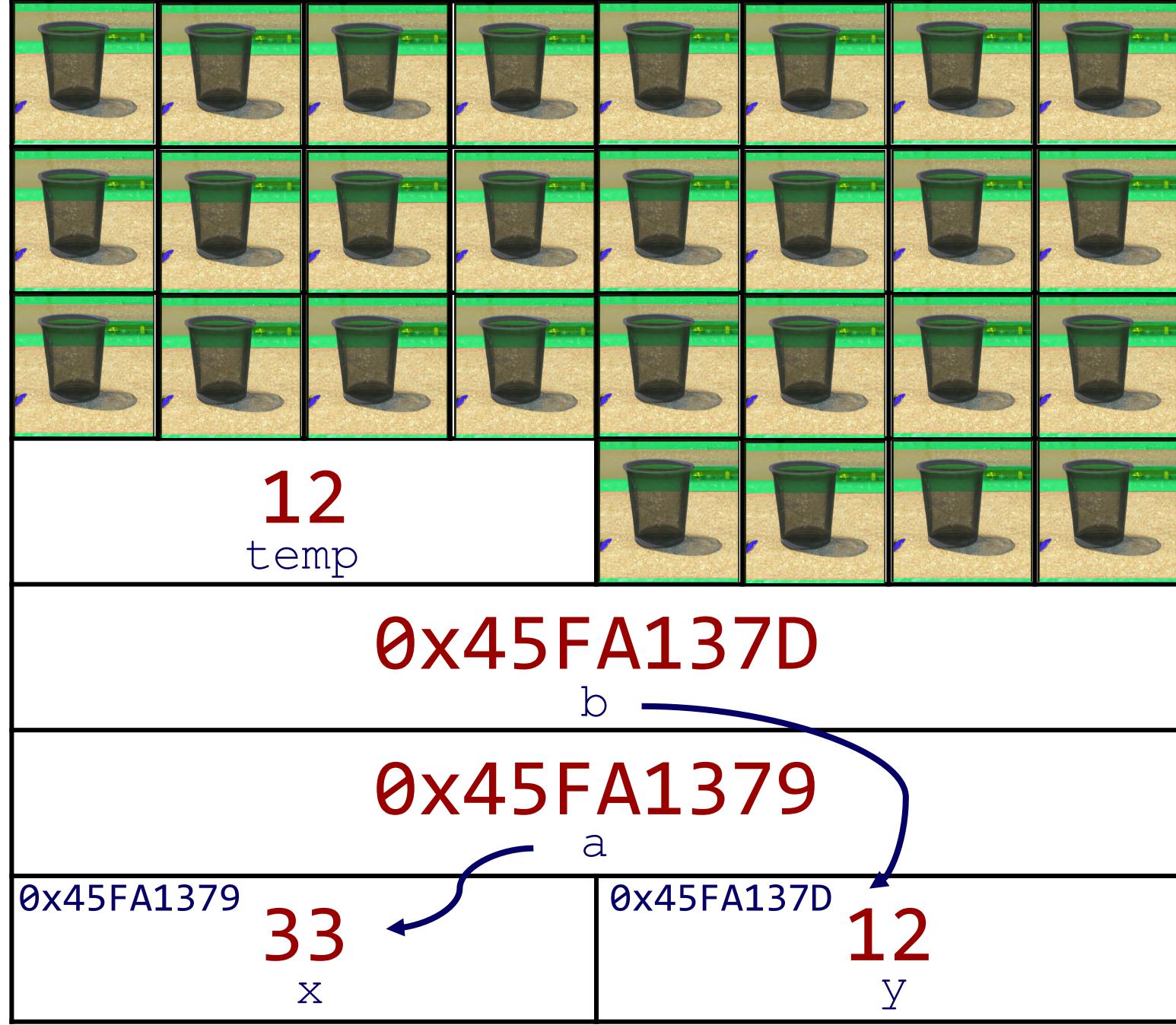
swap

main



swap

main



main

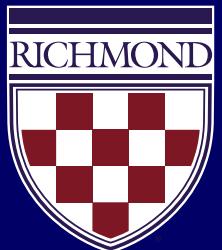
33  
x

12  
y



```
// Swap two int values.  
void swap(int* a, int* b)  
{  
    int temp = *a;      // store contents of a in temp  
    *a = *b;            // put contents of b into a  
    *b = temp;          // put temp a into b  
}  
  
int main()  
{  
    int x = 12;  
    int y = 33;  
    swap(&x, &y);    // pass by reference (the addresses of x and y)  
    cout << "x == " << x << "  y == " << y << endl;  
    return 0;  
}
```

# Ask a question



# Today

- ~~Memory~~
- ~~Pointers~~
- ~~Garbage Values~~
- ~~Memory Layout~~
- In-class exercise



# Credits

- Malan CS50 
  - Computer memory image and yellow grid
  - Lecture materials
- Open-AI  DALL·E
  - 3-D rendered garbage can image
- xkcd.com
  - Pointers comic: <https://xkcd.com/138/>
- Unsplash.com
  - Image of post office boxes