Memory & Pointers

CMSC 240 Software Systems Development

Today

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

RICHMOND

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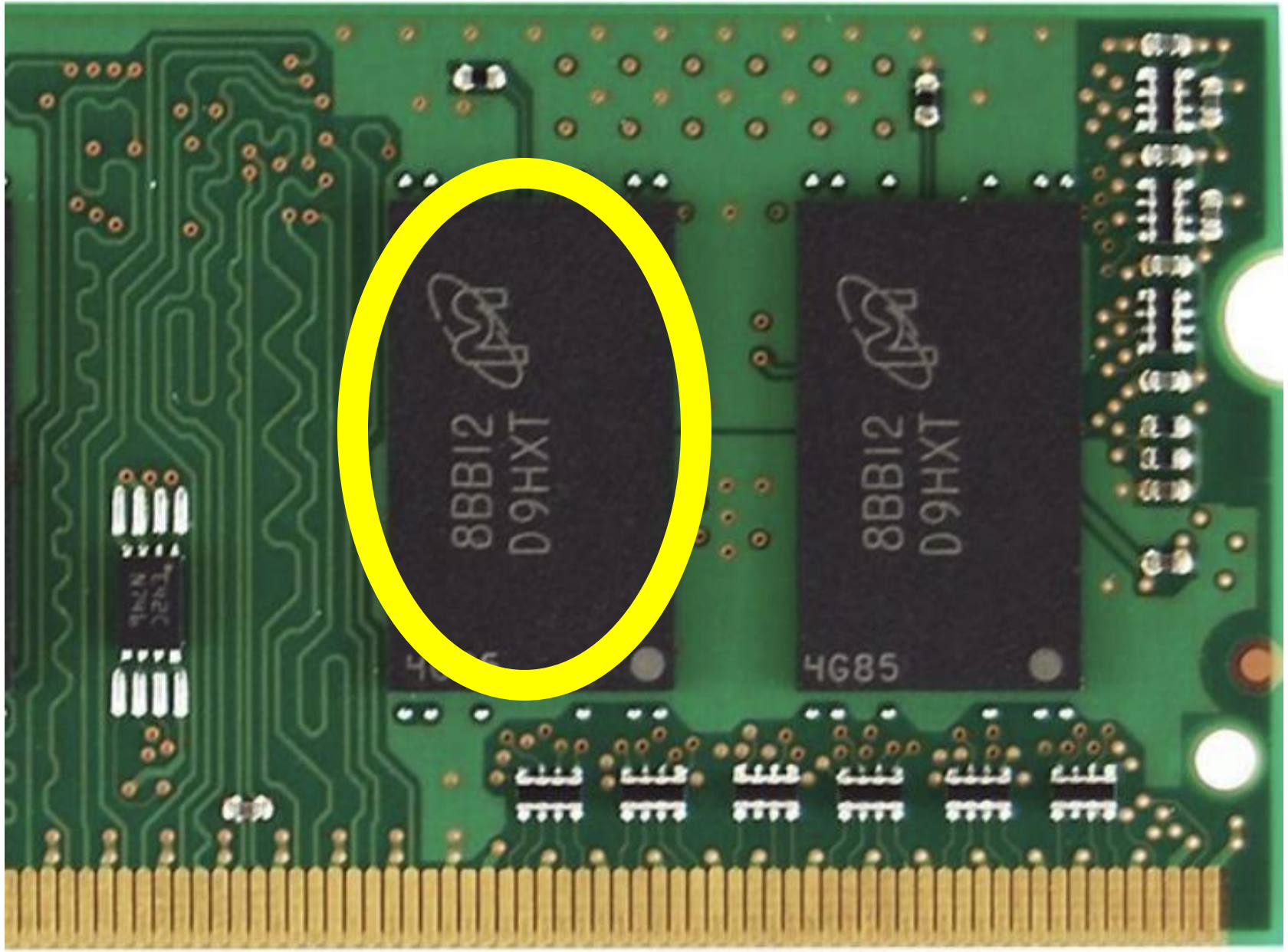
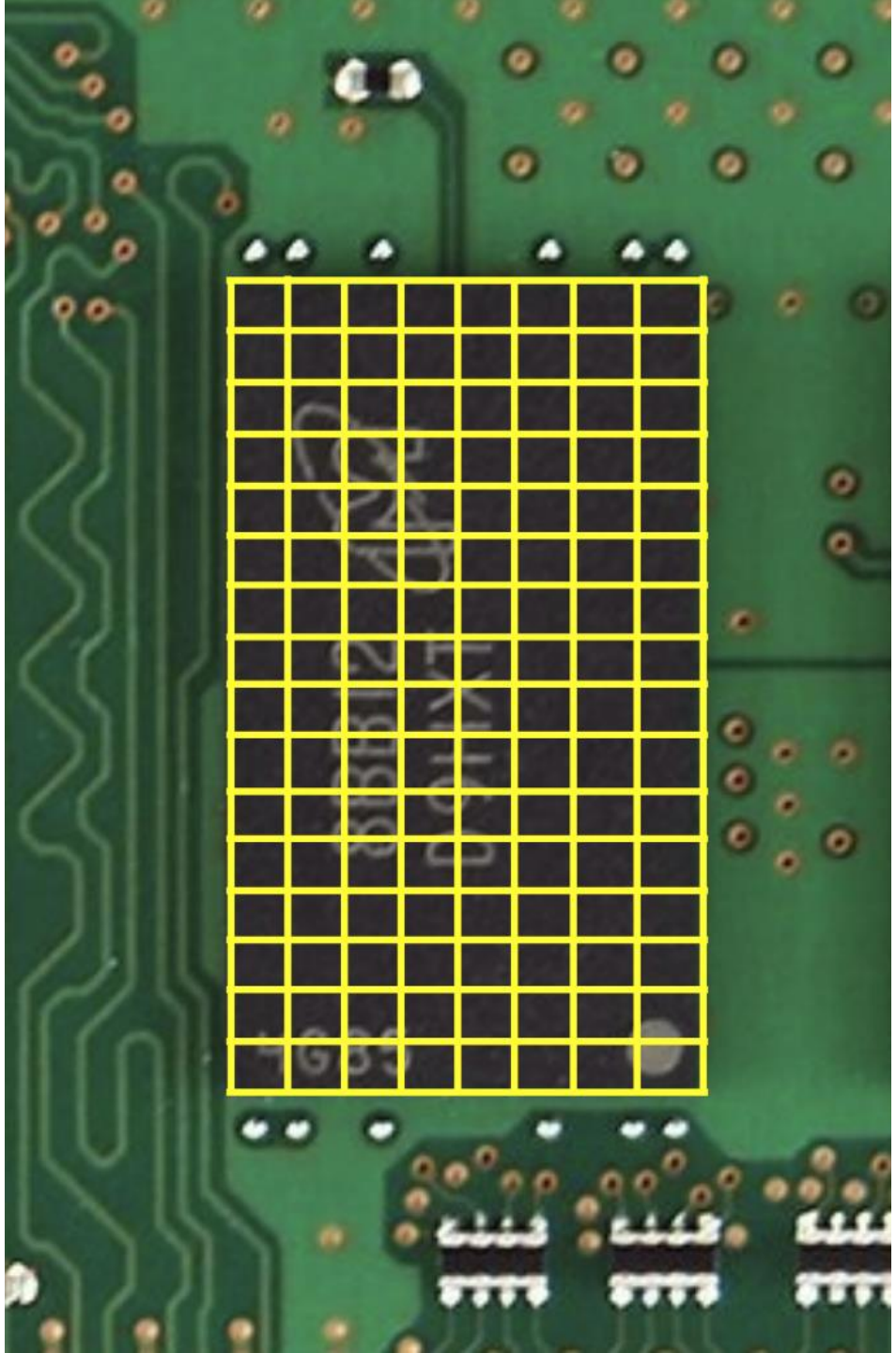
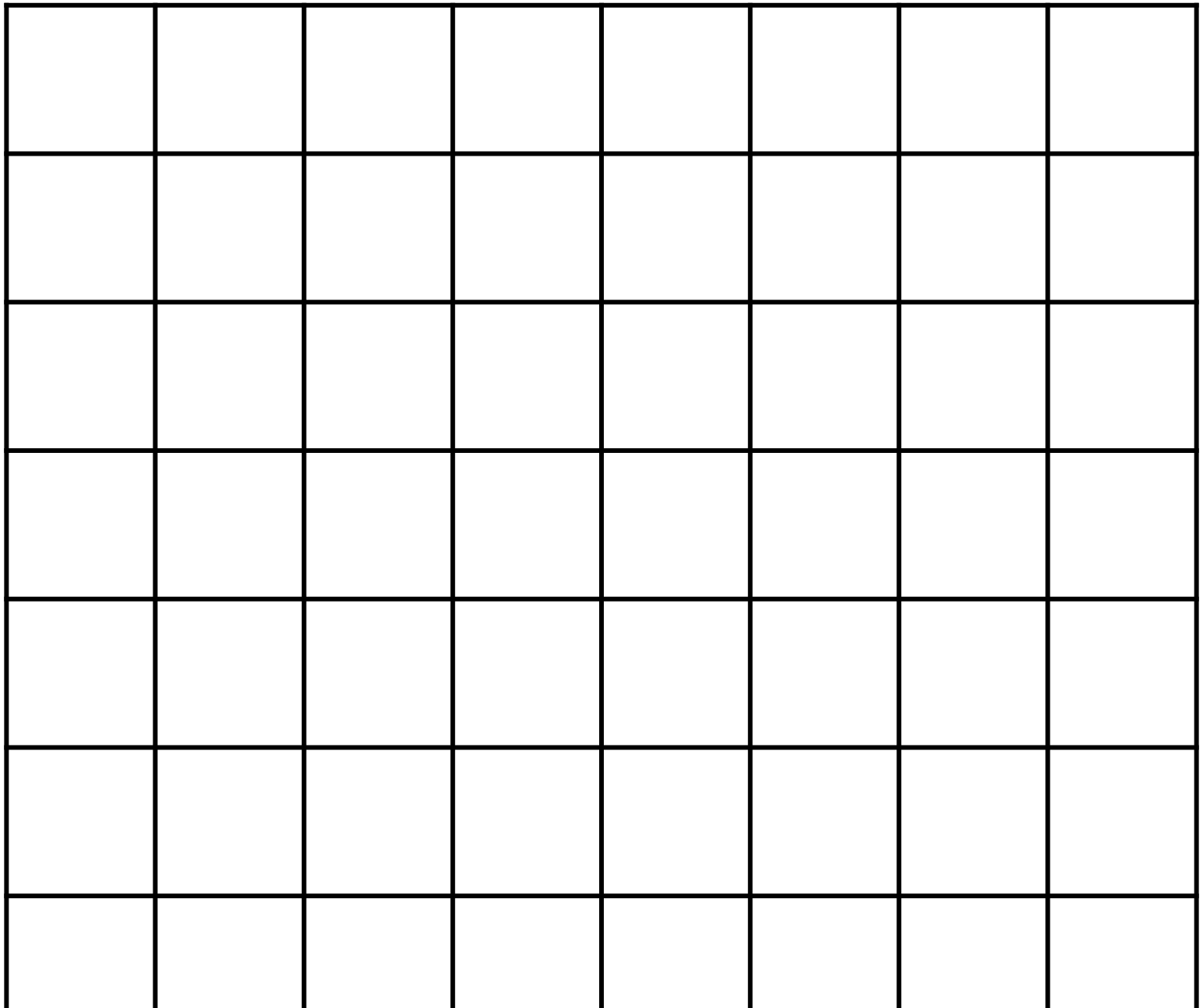
RICHMOND

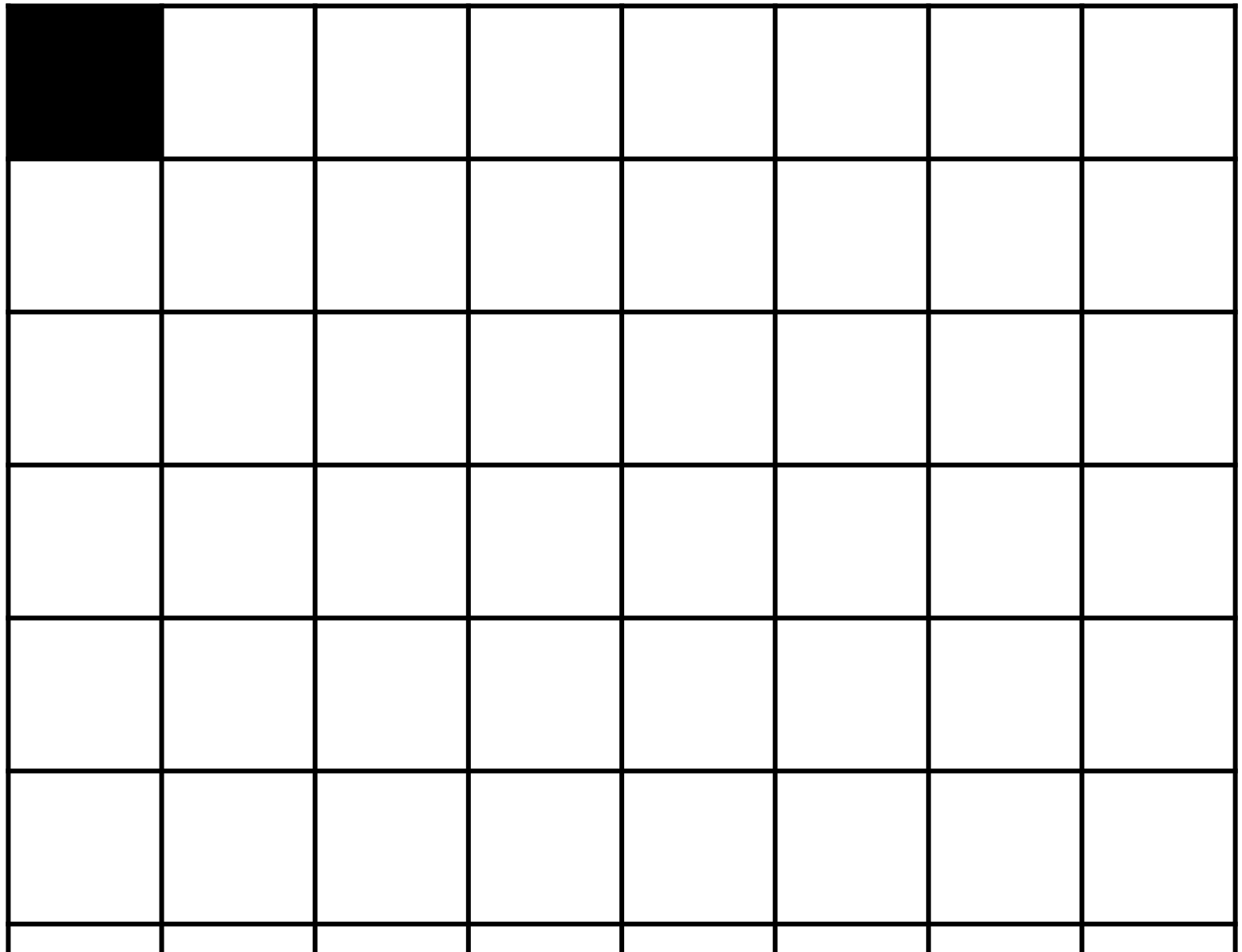
`char`	1 byte
`int`	4 bytes
`long`	8 bytes
`float`	4 bytes
`double`	8 bytes
`string`	?

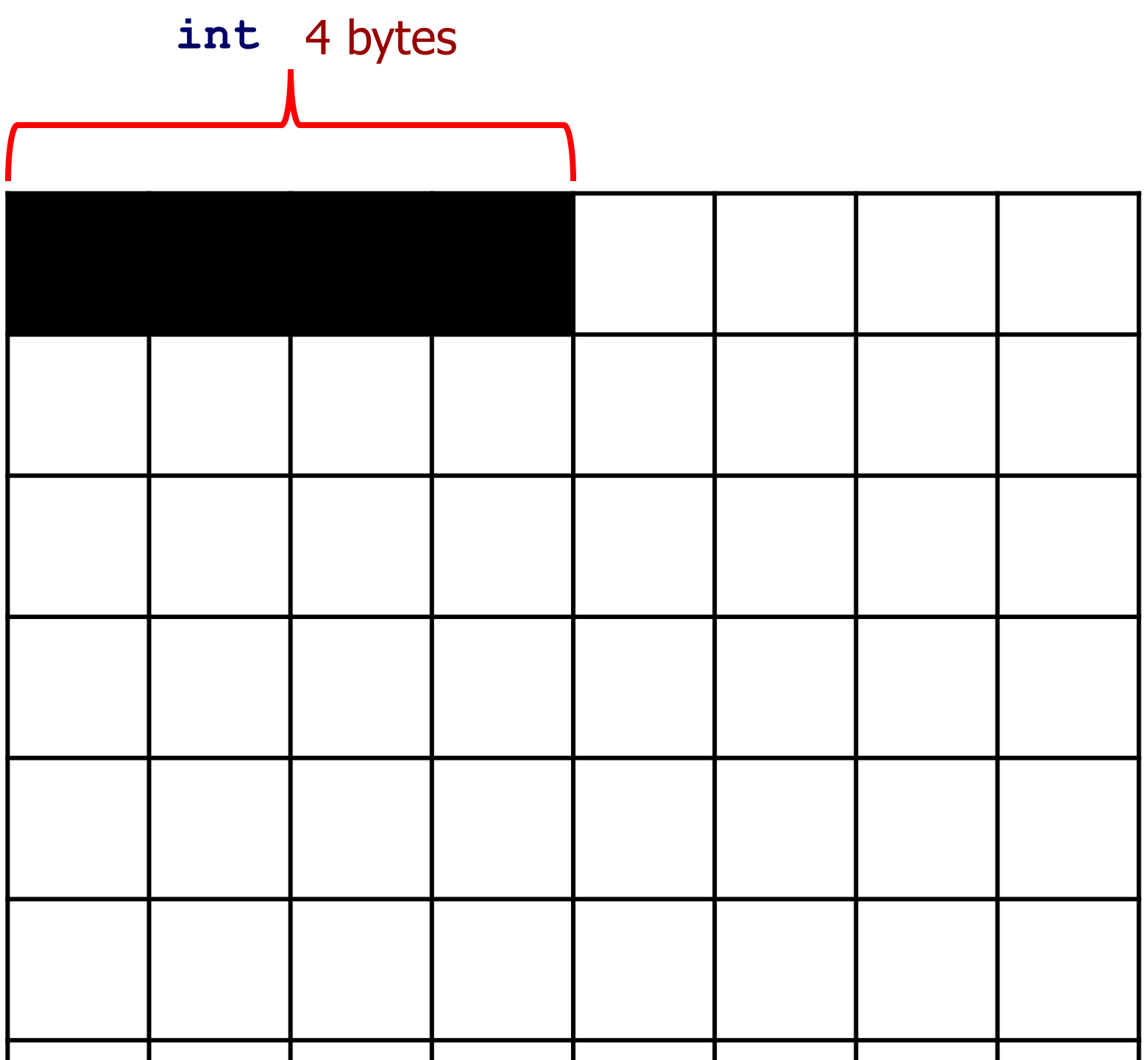


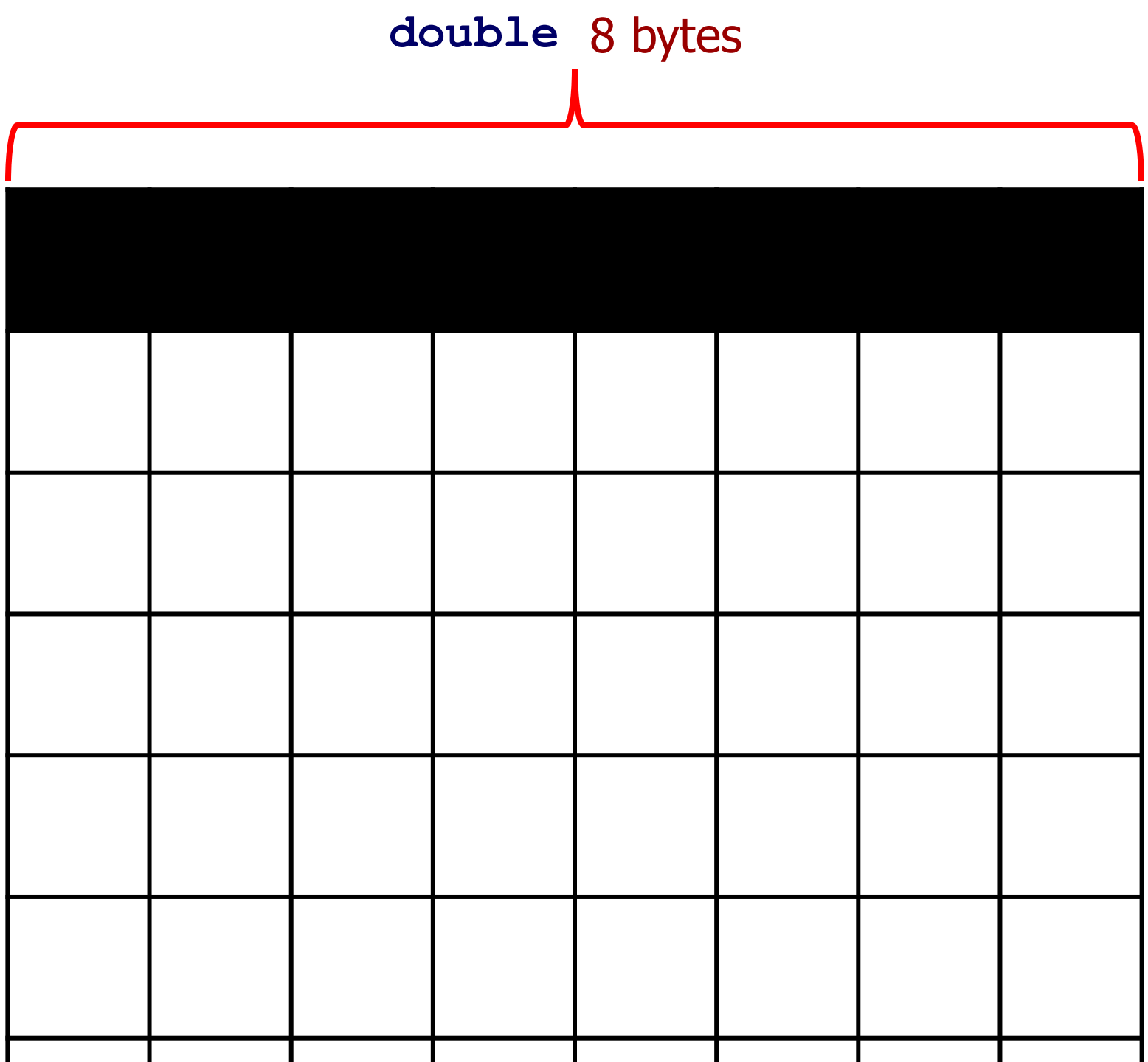




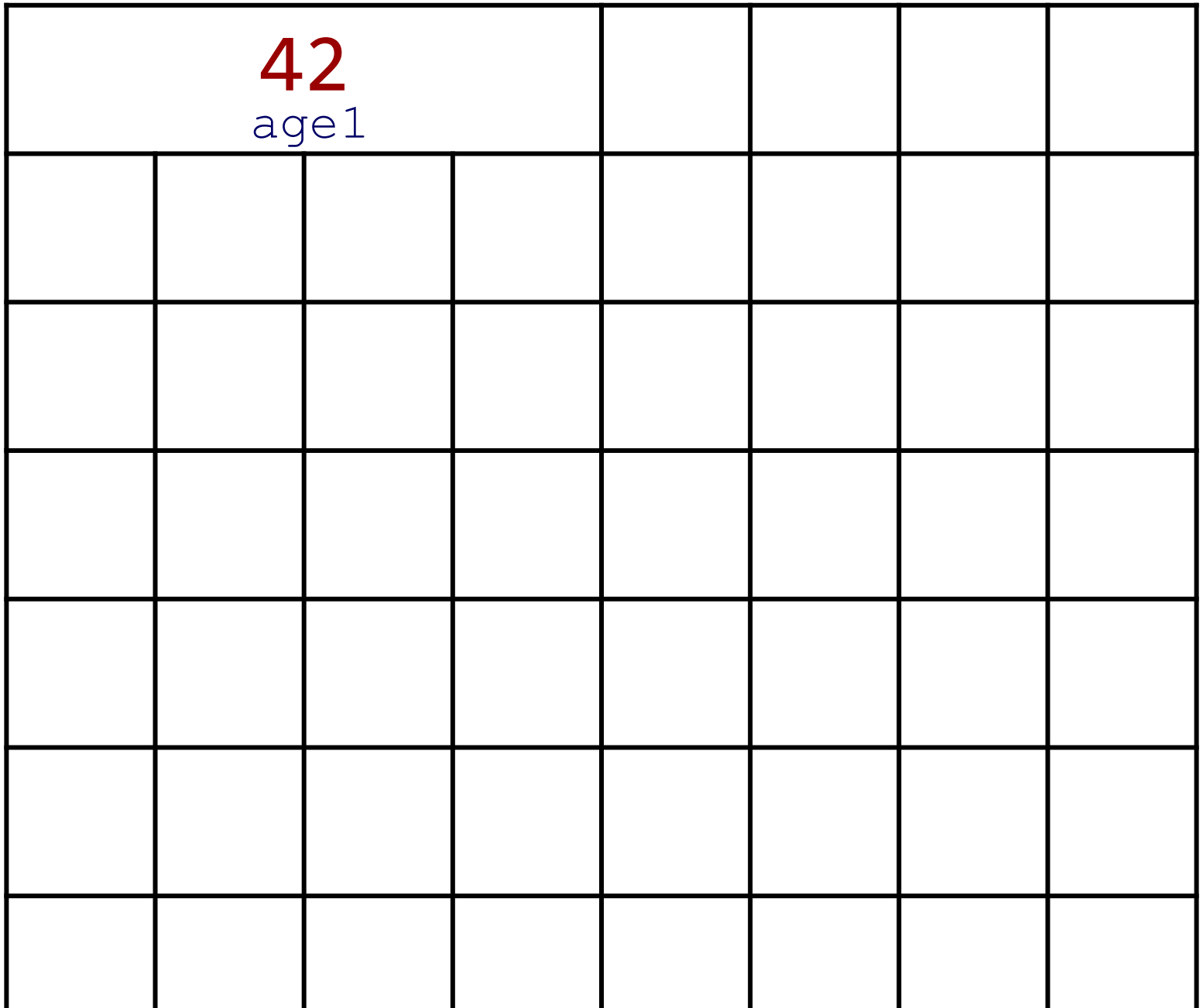
`char` 1 byte

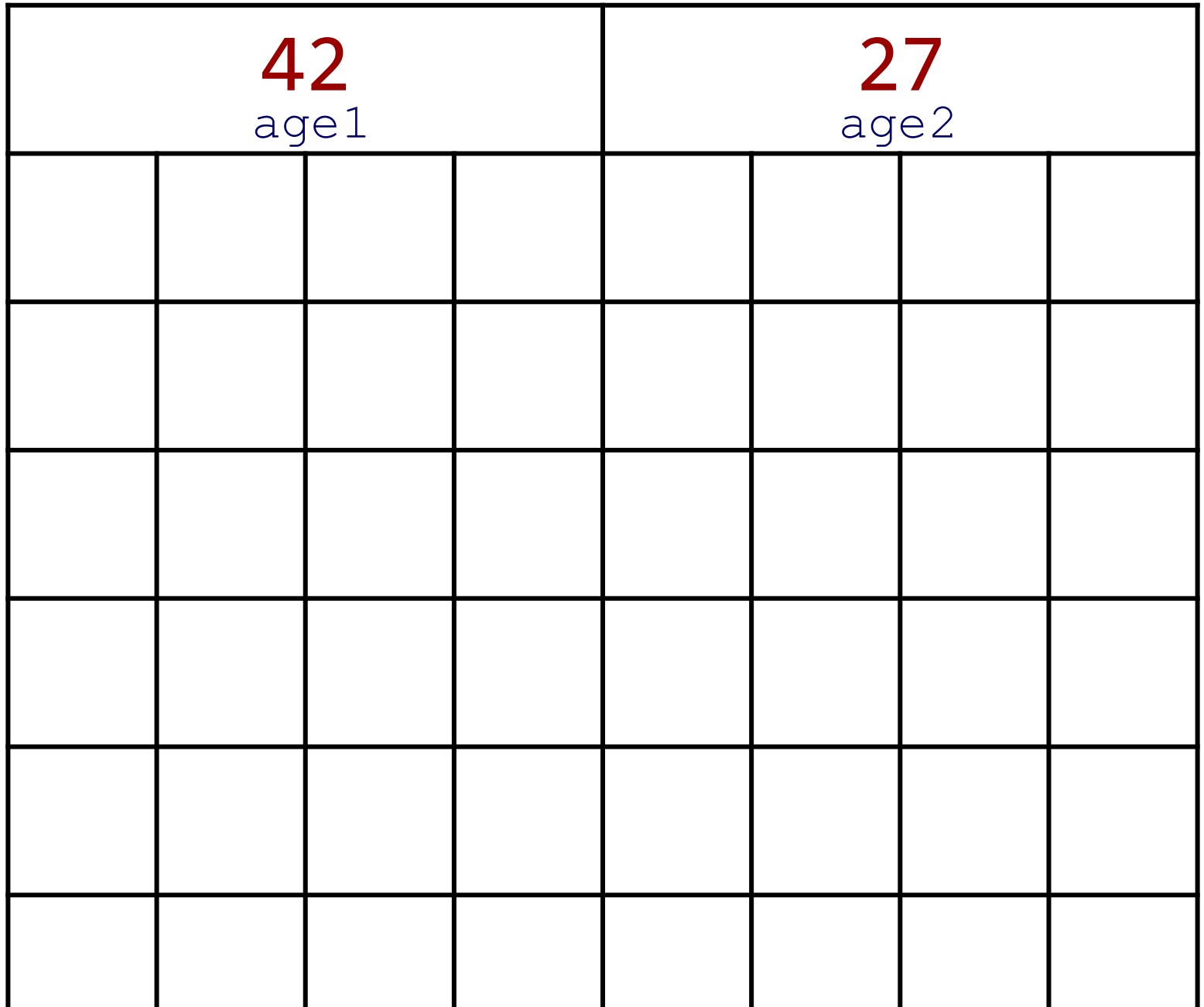


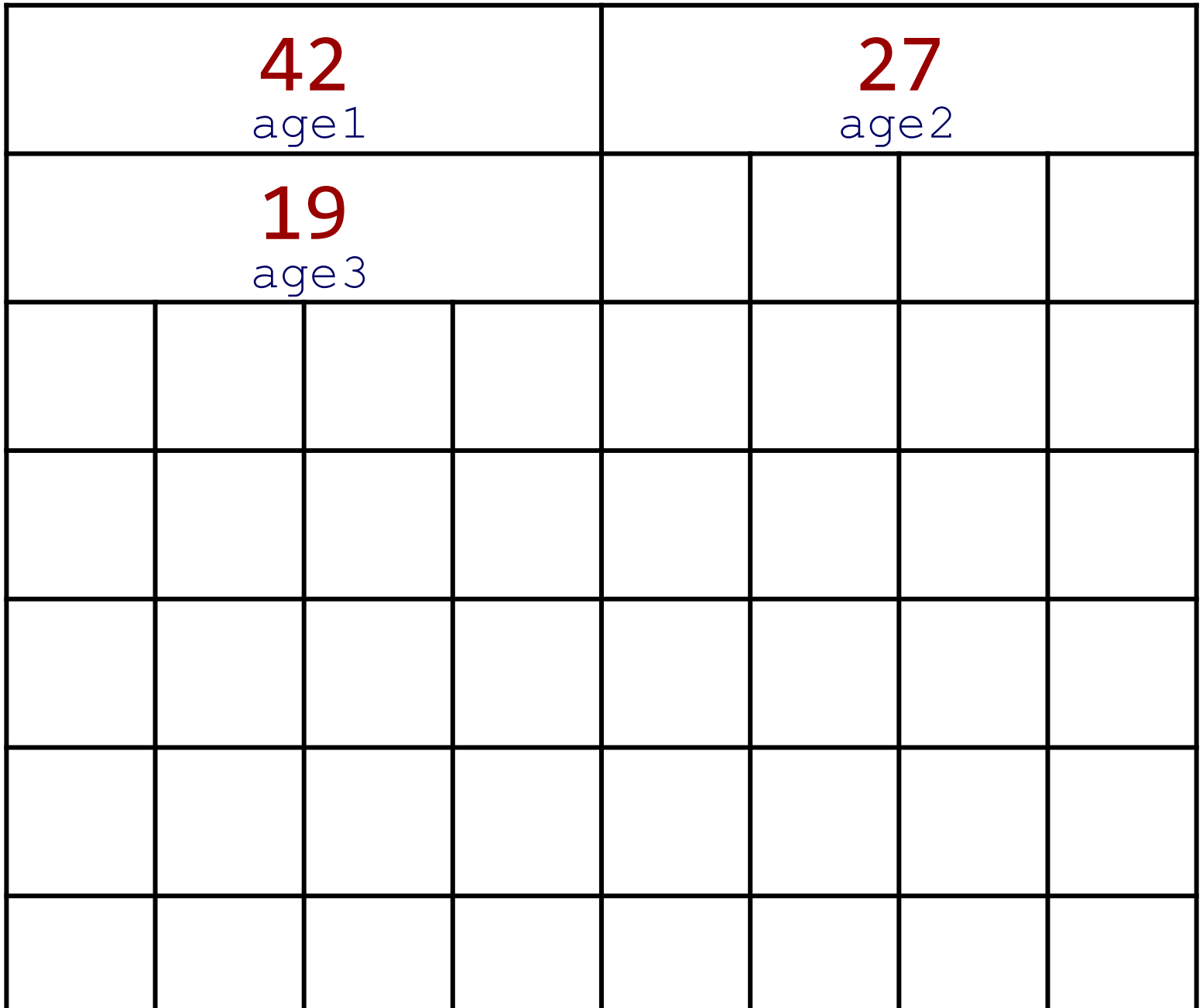

int
4 bytes

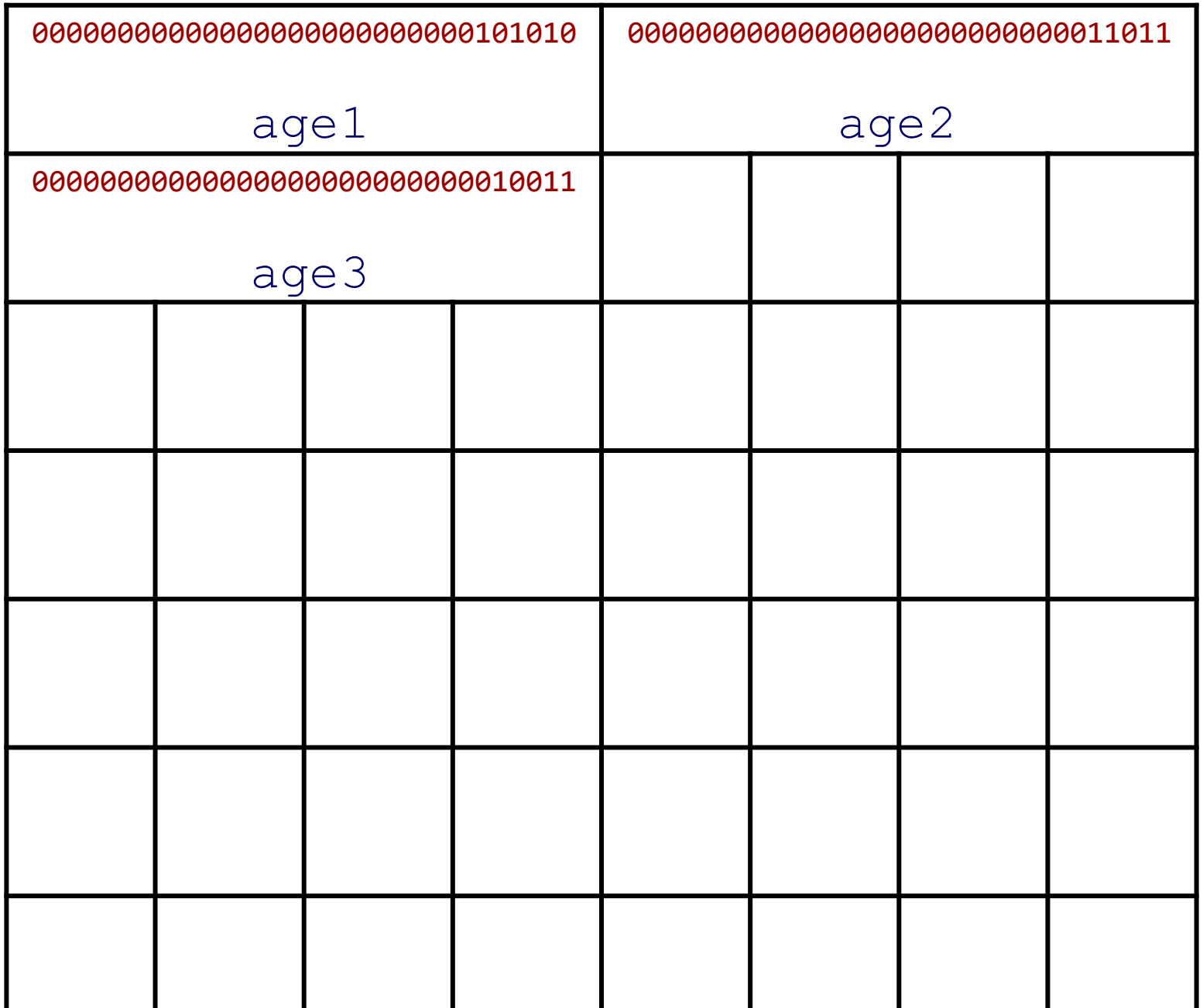

double 8 bytes

```
int age1 = 42;

int age2 = 27;

int age3 = 19;
```


42
age1


42
age1
27
age2


42
age1
27
age2
19
age3


00000000000000000000000000101010
age1
00000000000000000000000000011011
age2
00000000000000000000000000010011
age3

0	1	2	3	4	5	6	7
8	9	10	11	12	13	14	15

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

base-16

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

Hexadecimal

128 64 32 16 8 4 2 1

11111111

(128 × 1) + (64 × 1) + (32 × 1) + (16 × 1) + (8 × 1) + (4 × 1) + (2 × 1) + (1 × 1)

128 64 32 16 8 4 2 1

11111111

255

16 1

F F

(16 × 15) + (1 × 15)

16 1

F F

240 + 15

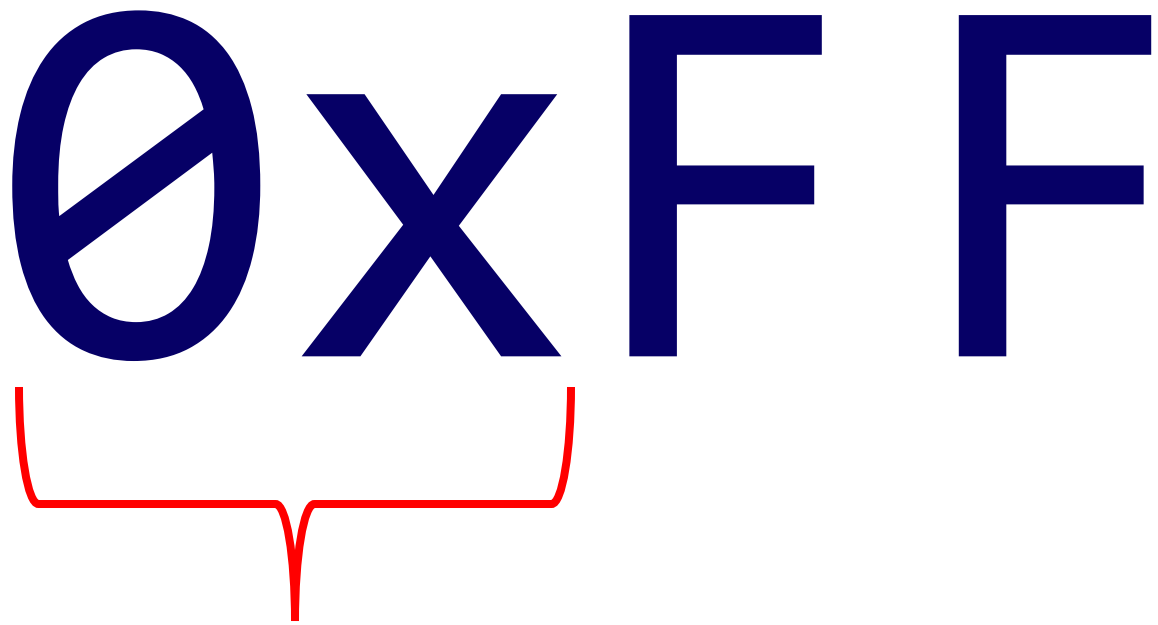
16 1

F F

255

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

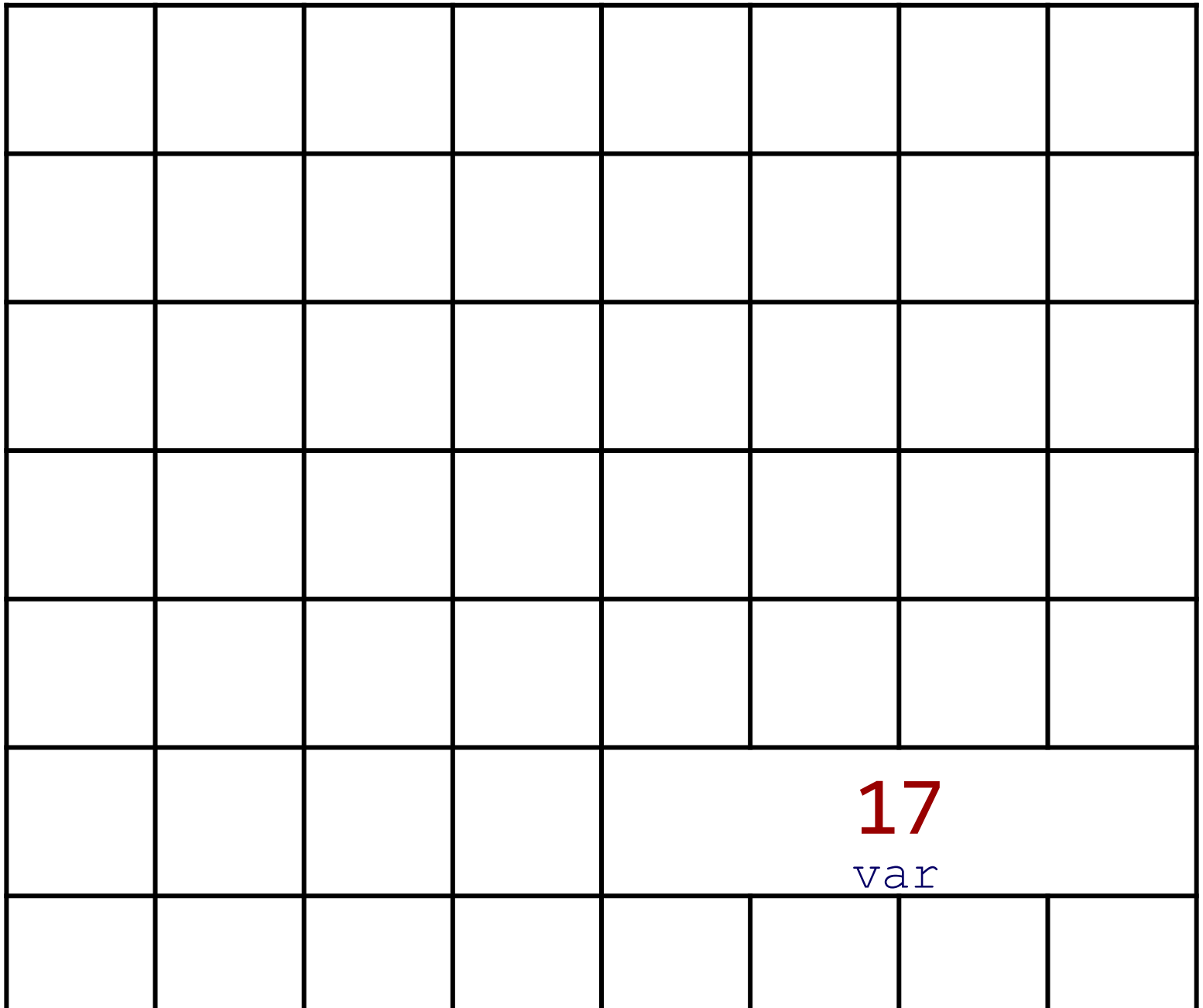
0	1	2	3	4	5	6	7
8	9	A	B	C	D	E	F
10	11	12	13	14	15	16	17
18	19	1A	1B	1C	1D	1E	1F
20	21	22	23	24	25	26	27
28	29	2A	2B	2C	2D	2E	2F
30	31	32	33	34	35	36	37

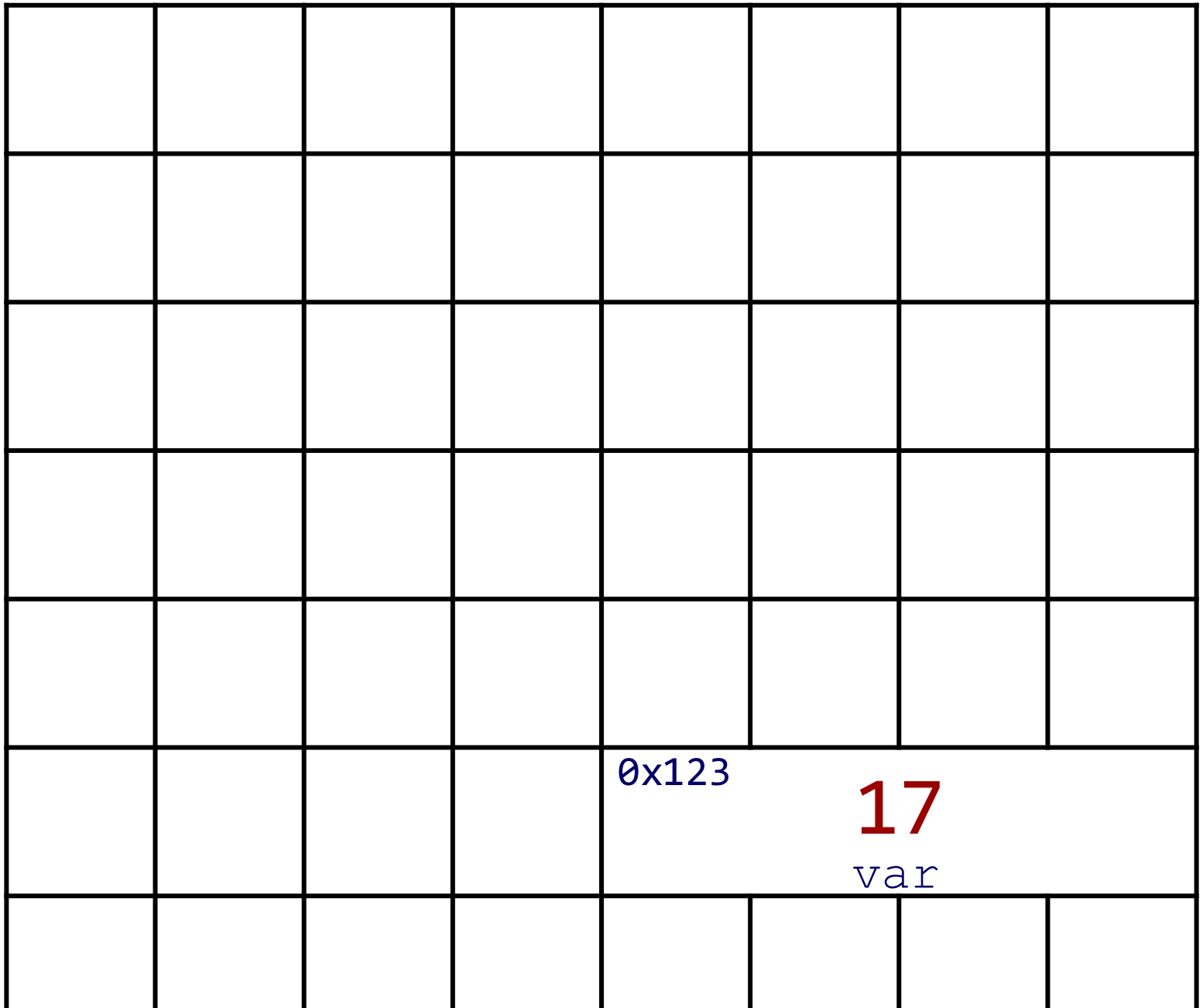


C++ convention that means the following number is a hexadecimal (base-16)

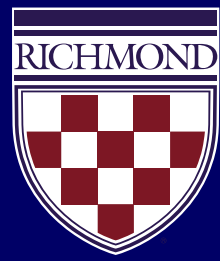
0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7
0x8	0x9	0xA	0xB	0xC	0xD	0xE	0xF
0x10	0x11	0x12	0x13	0x14	0x15	0x16	0x17
0x18	0x19	0x1A	0x1B	0x1C	0x1D	0x1E	0x1F
0x20	0x21	0x22	0x23	0x24	0x25	0x26	0x27
0x28	0x29	0x2A	0x2B	0x2C	0x2D	0x2E	0x2F
0x30	0x31	0x32	0x33	0x34	0x35	0x36	0x37

```
int var = 17;
```


17
var


0x123
17
var

Ask a question



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RICHMOND

A **pointer** is a variable that holds an address value.

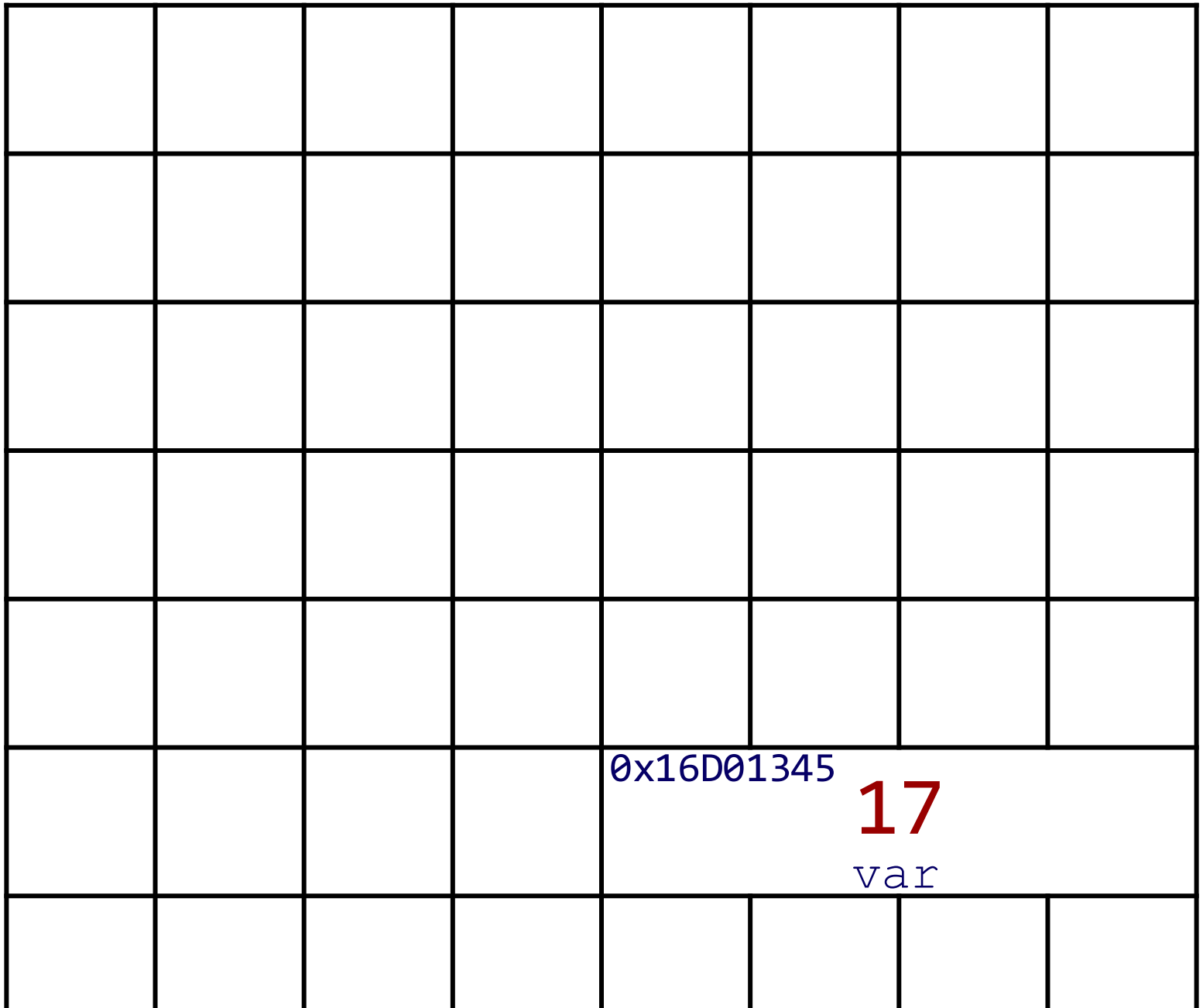
& "address of"

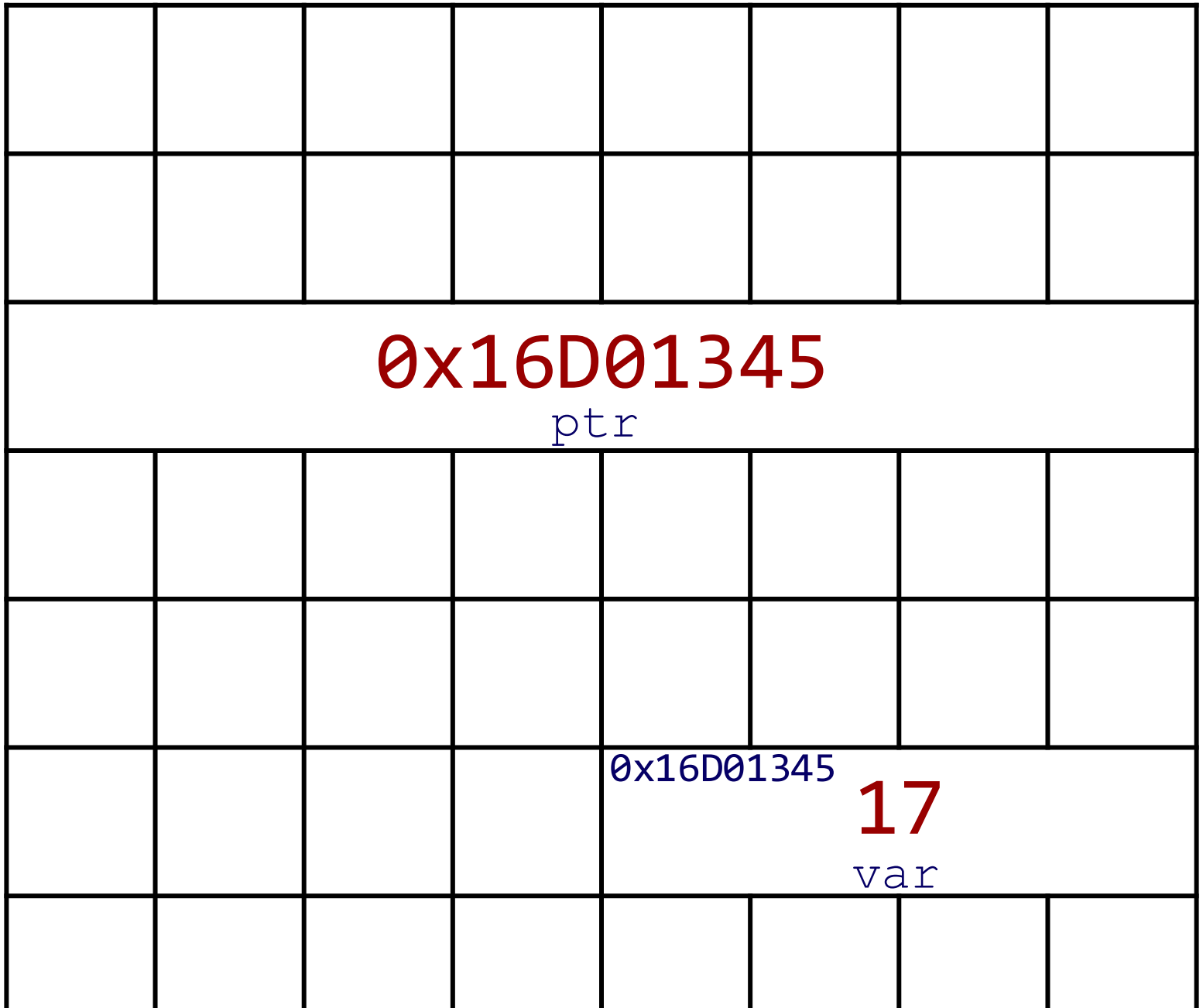
* "contents of"

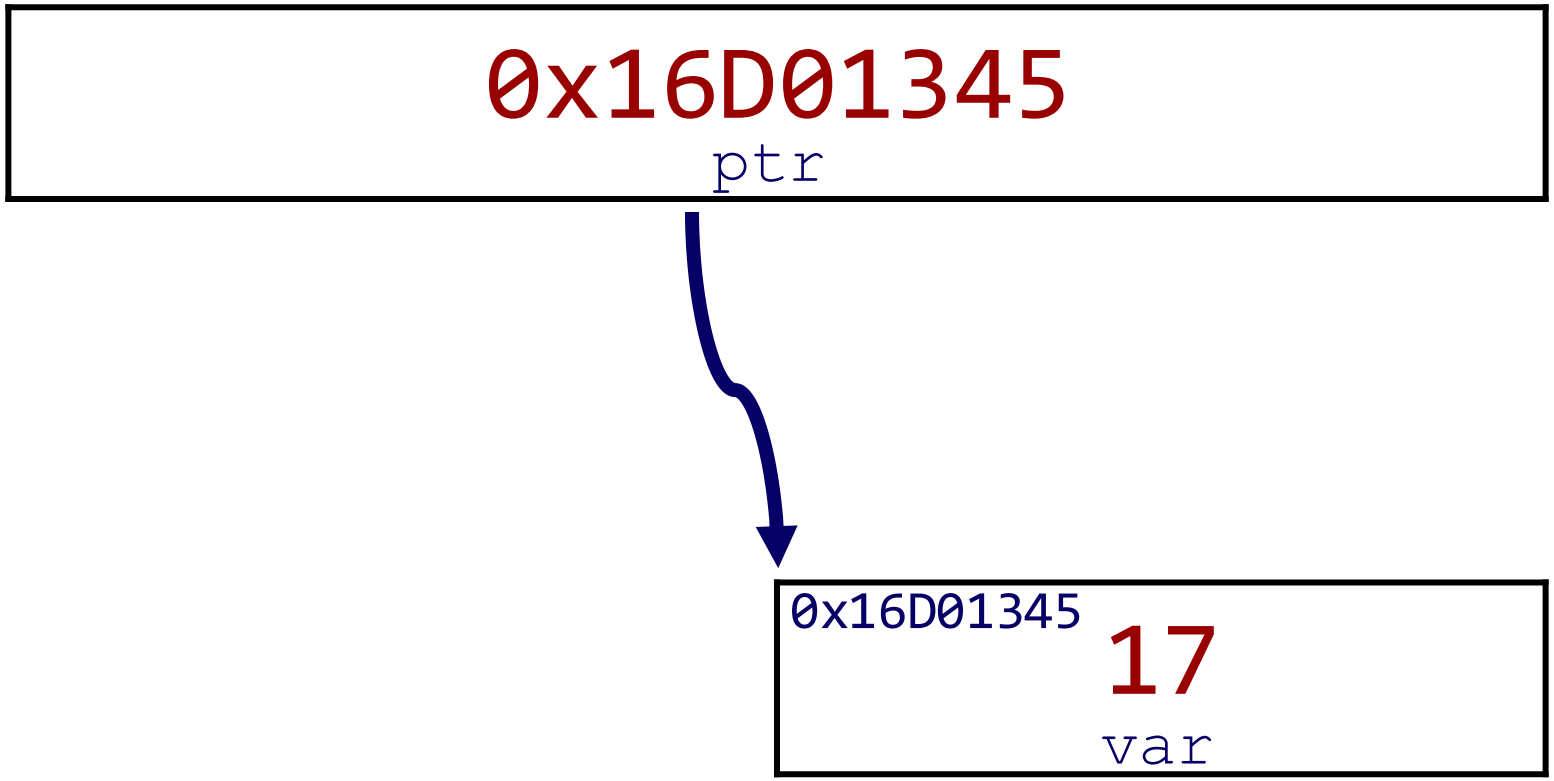
```
int var = 17;

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

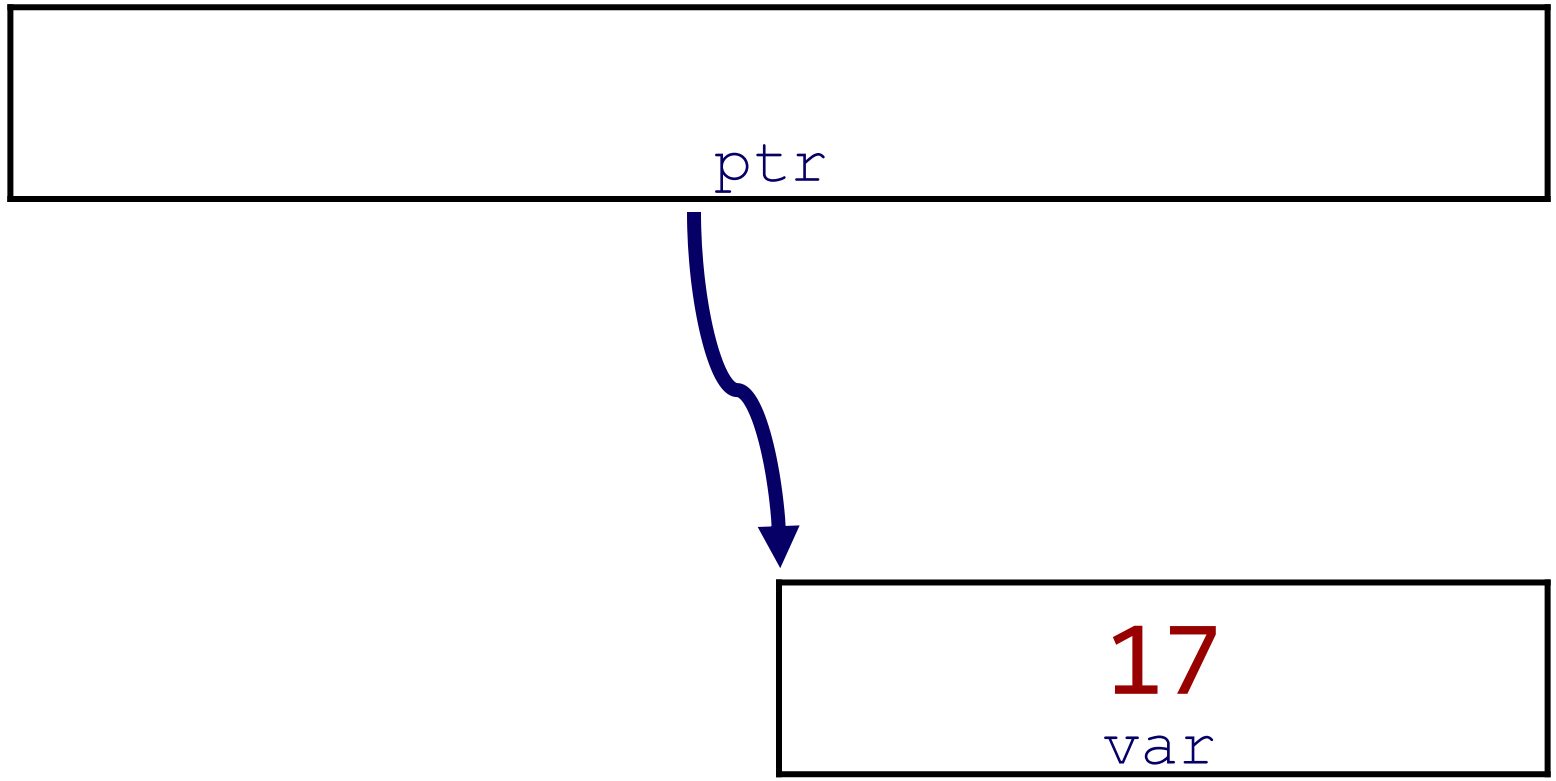
This new type is called an "**int pointer**" and is used to hold the address of an integer variable

The "**address of**" the integer `var`

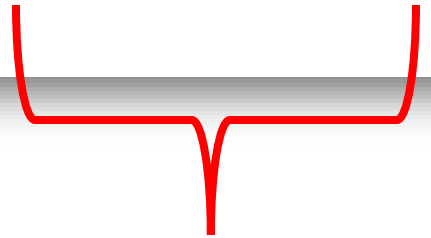

0x16D01345
17
var


0x16D01345
ptr
0x16D01345
17
var


0x16D01345
ptr
0x16D01345
17
var


ptr
17
var

```
int var = 17;

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

int anotherVar = *ptr;
```



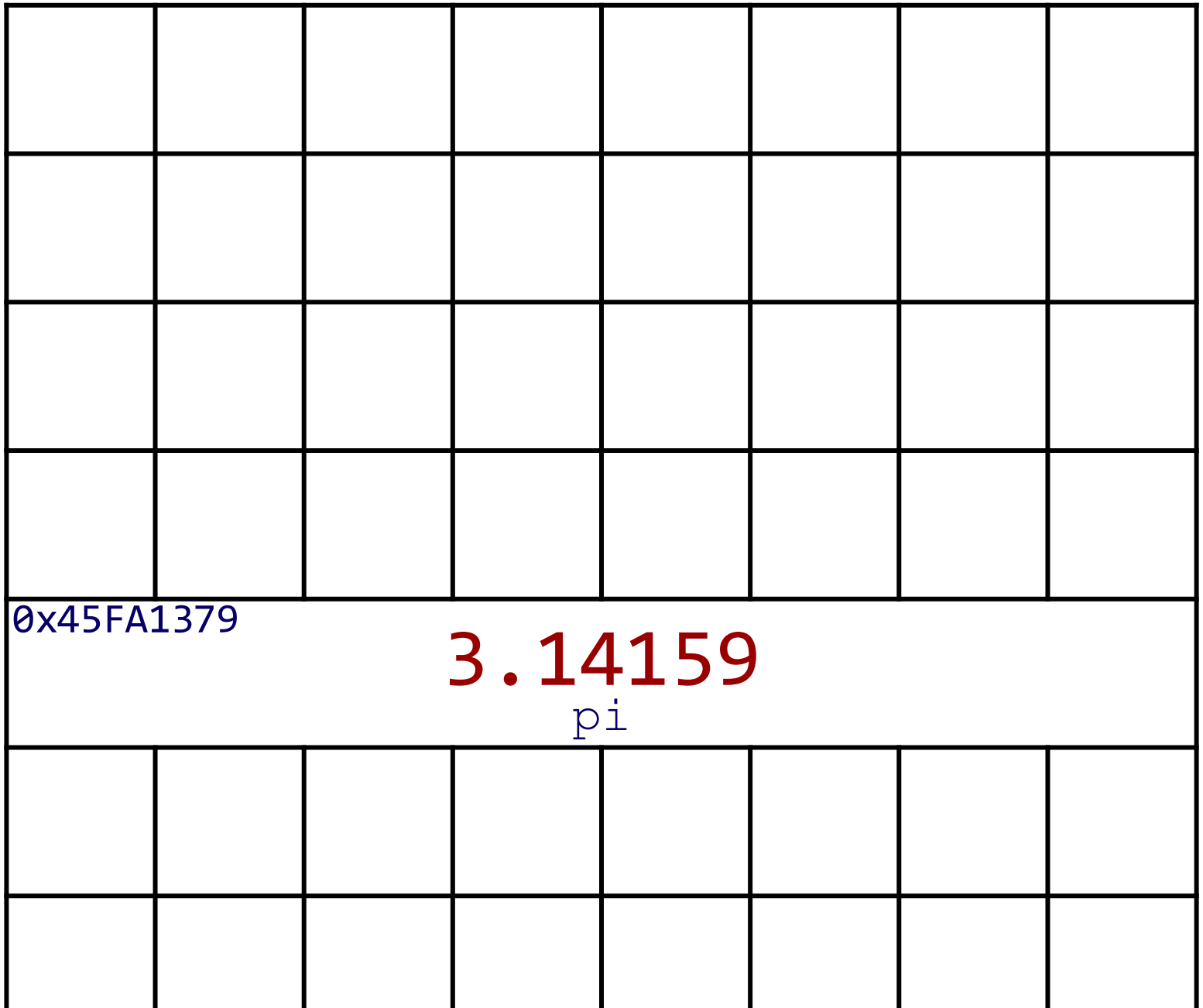
The "**contents of**" the pointer `ptr`
(i.e., the value stored at the address)

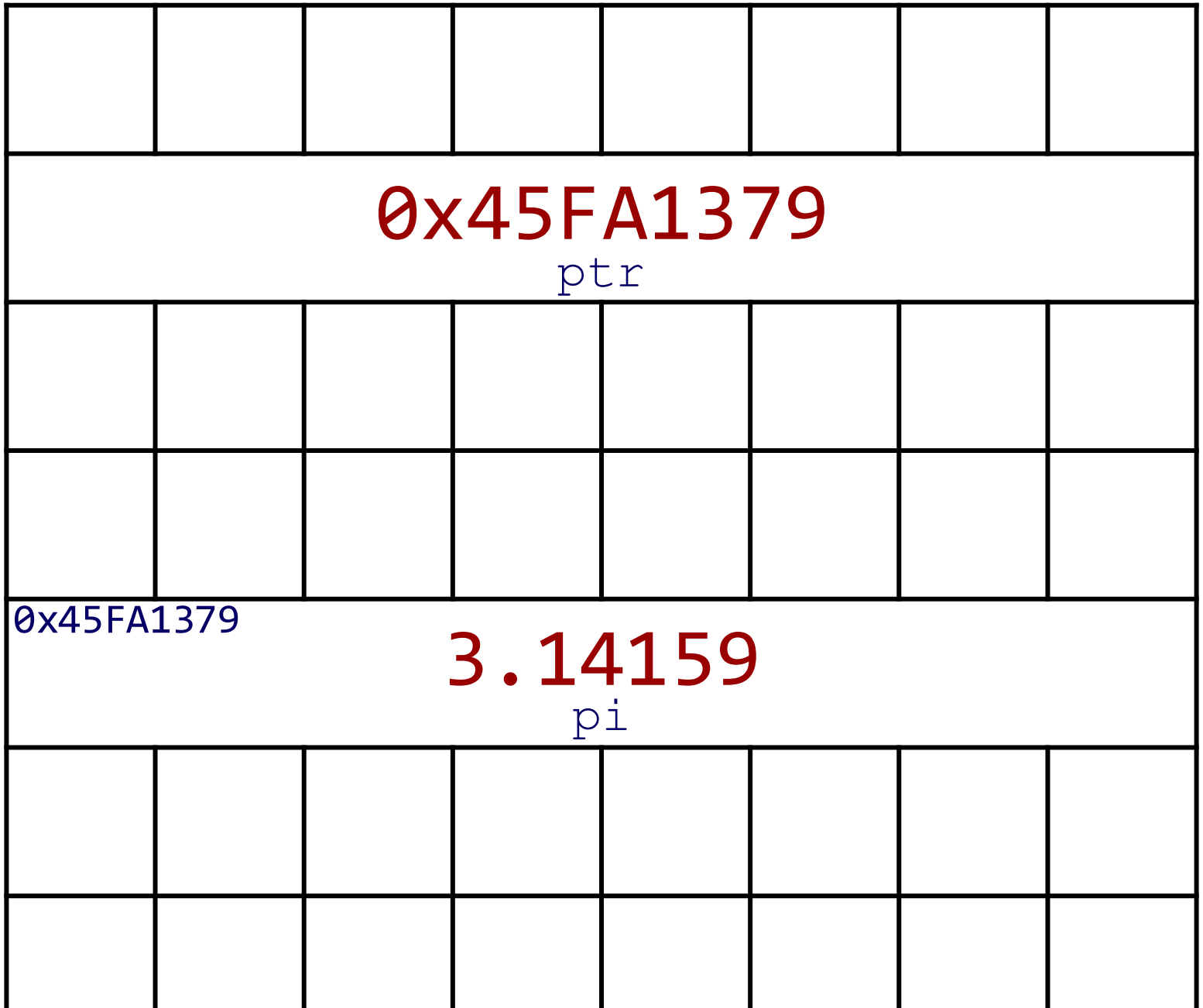
```
int var = 17;
int* ptr = &var;  // ptr holds the address of var

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
```

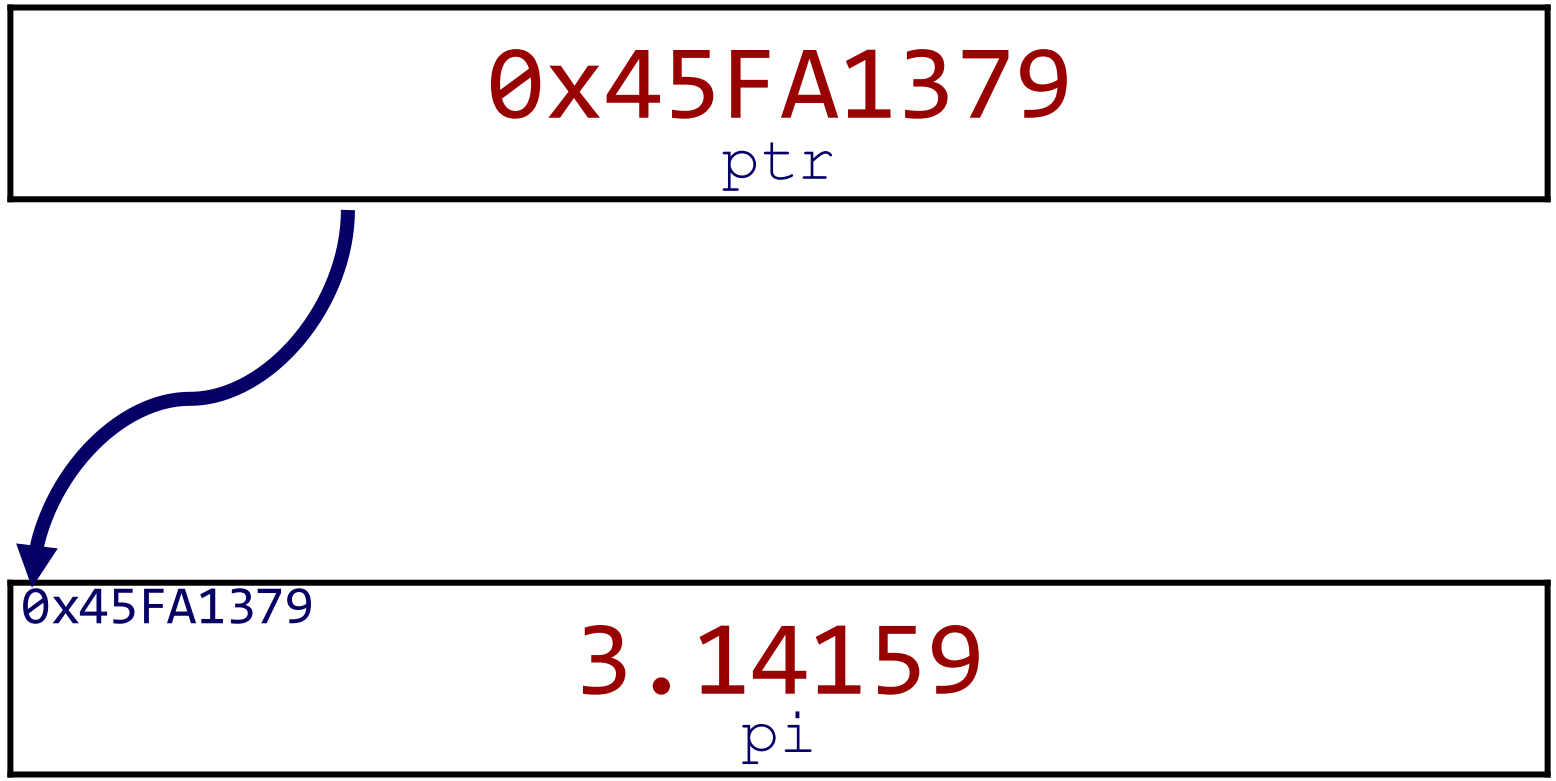
```
double pi = 3.14159;

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

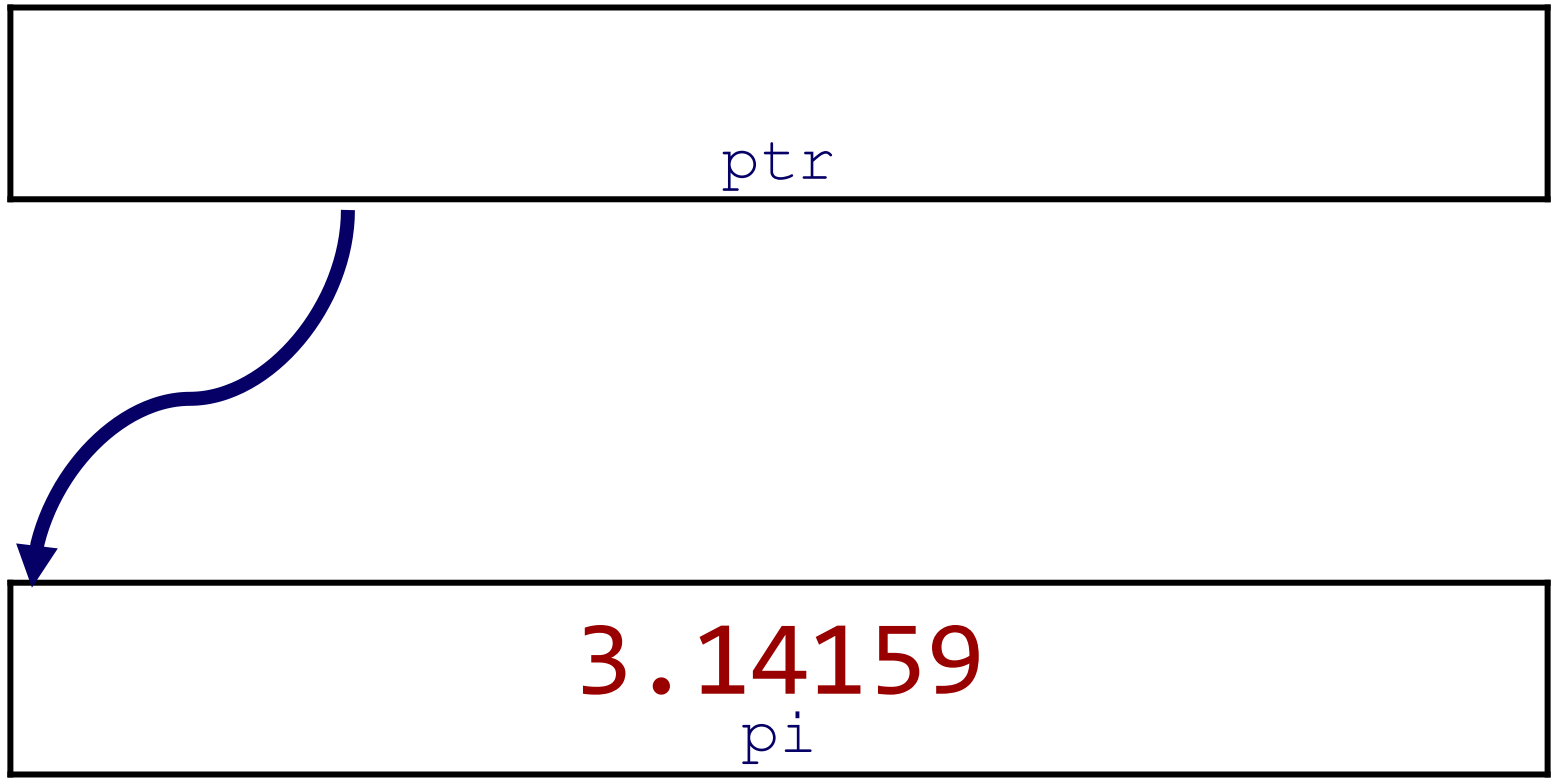
This new type is called an "**double pointer**" and is used to hold the address of a variable of type double

The "**Address of**" the double `pi`


0x45FA1379
3.14159
pi

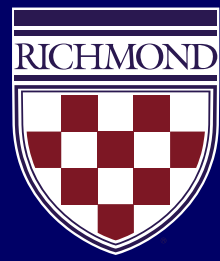

0x45FA1379
ptr
0x45FA1379
3.14159
pi


0x45FA1379
ptr
0x45FA1379
3.14159
pi


ptr
3.14159
pi

https://xkcd.com/138/

Ask a question



Today

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RICHMOND

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

int main()
{
    int var1;
    int var2;
    int var3;
    int var4;
    int var5;

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

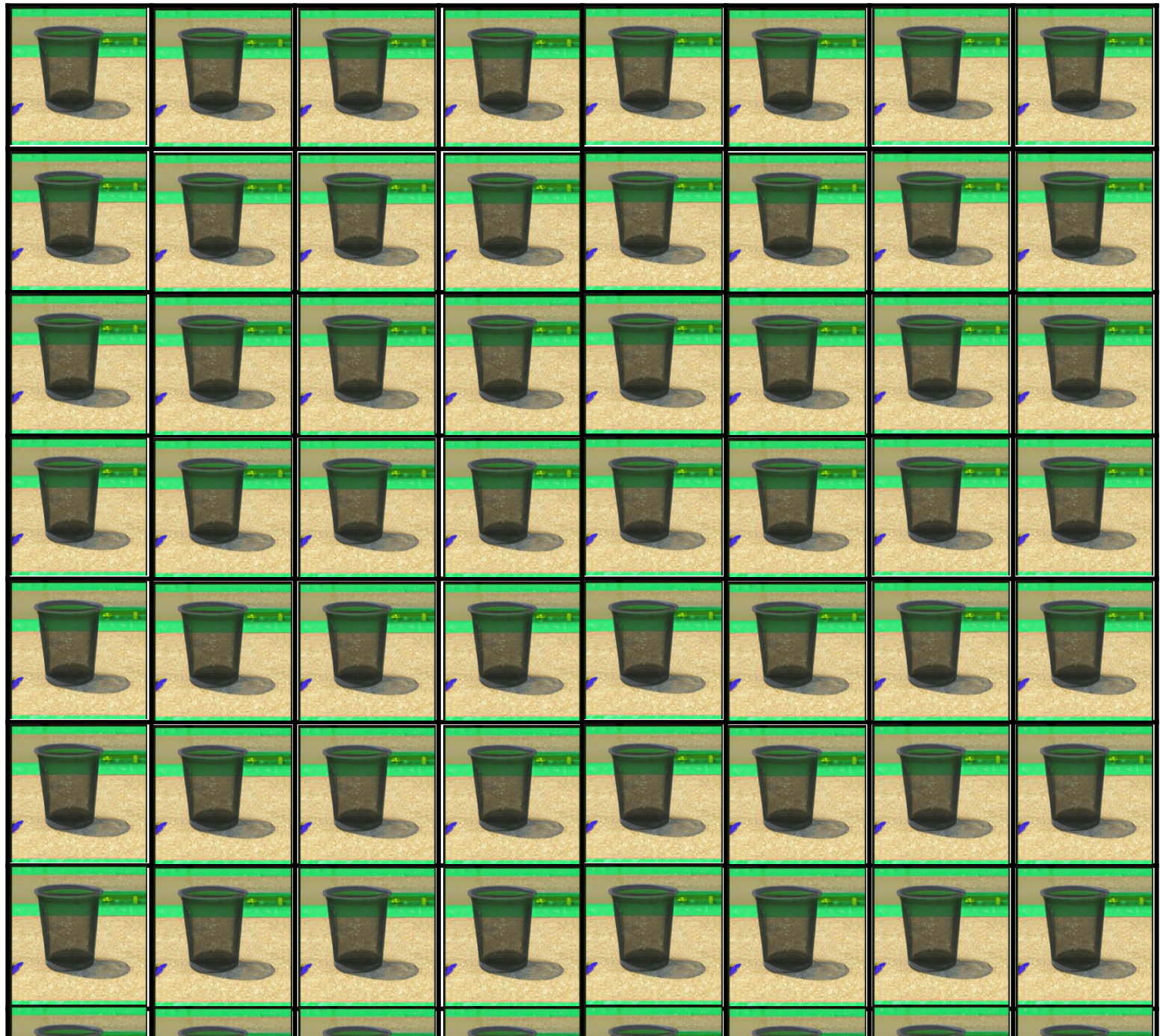
```
var1 == 1
var2 == 71282756
var3 == 1
var4 == 71319552
var5 == 1
```

```
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

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- ~~Garbage Values~~
- Memory Layout

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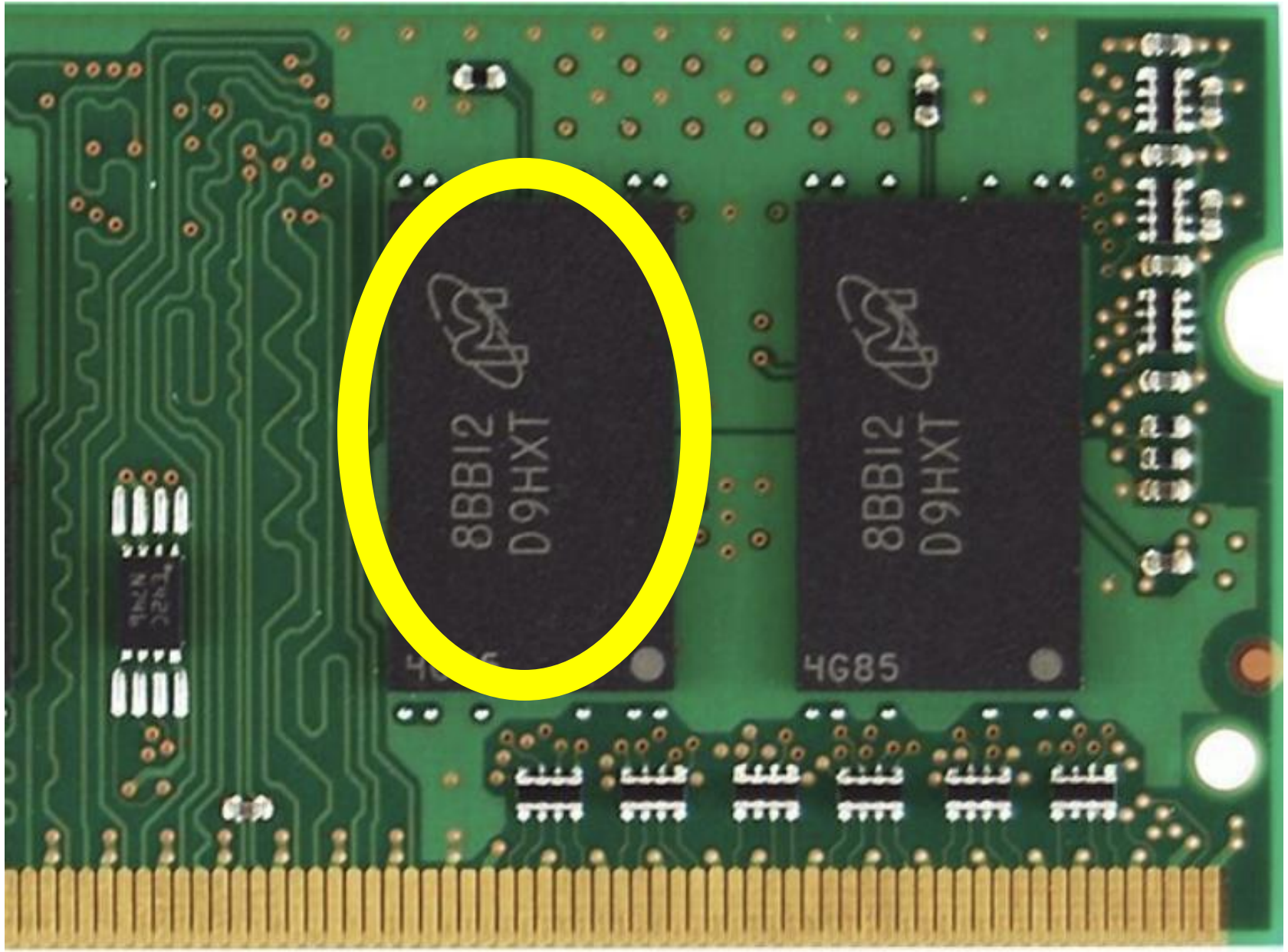
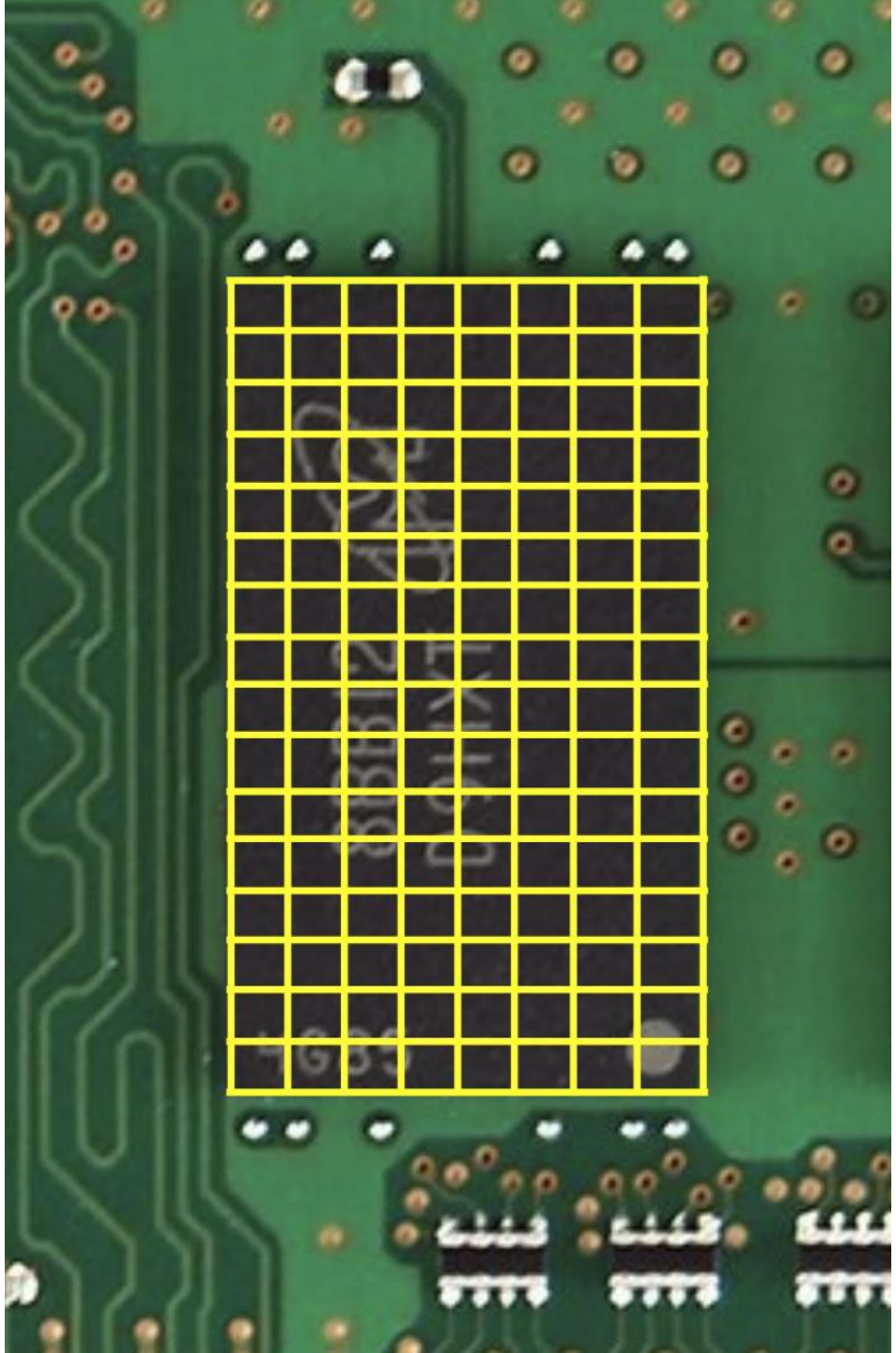
RICHMOND

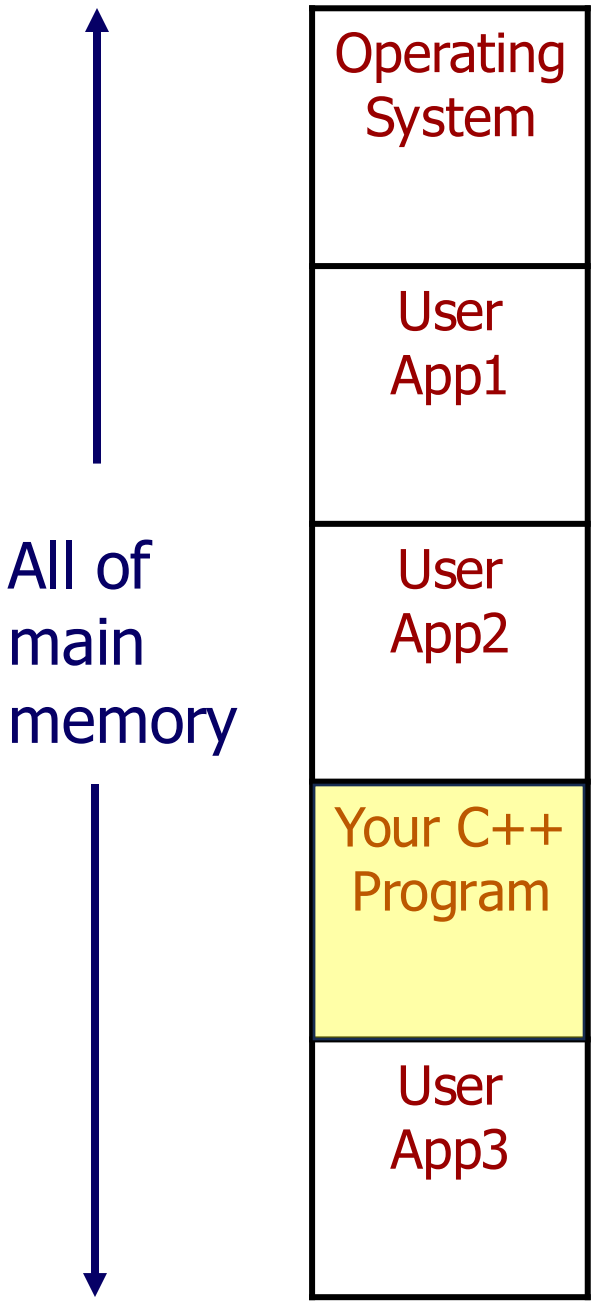
```
// Swap two int values.
void swap(int a, int b)
{
    int temp = a;  // store a in temp
    a = b;         // put b into a
    b = temp;      // put temp a into b
}

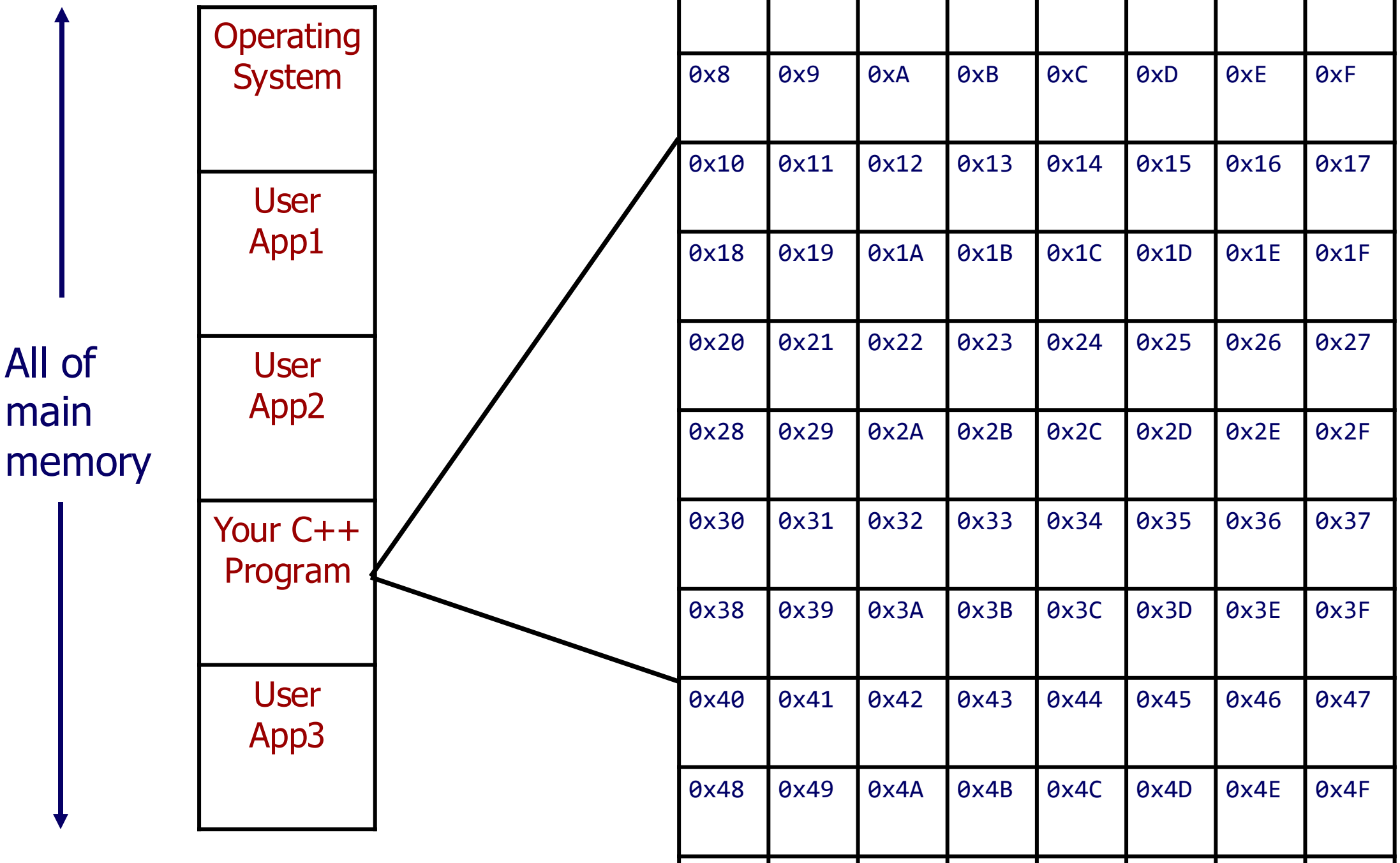
int main()
{
    int x = 12;
    int y = 33;
    swap(x, y);
    cout << "x == " << x << "  y == " << y << endl;    // ?
    return 0;
}
```

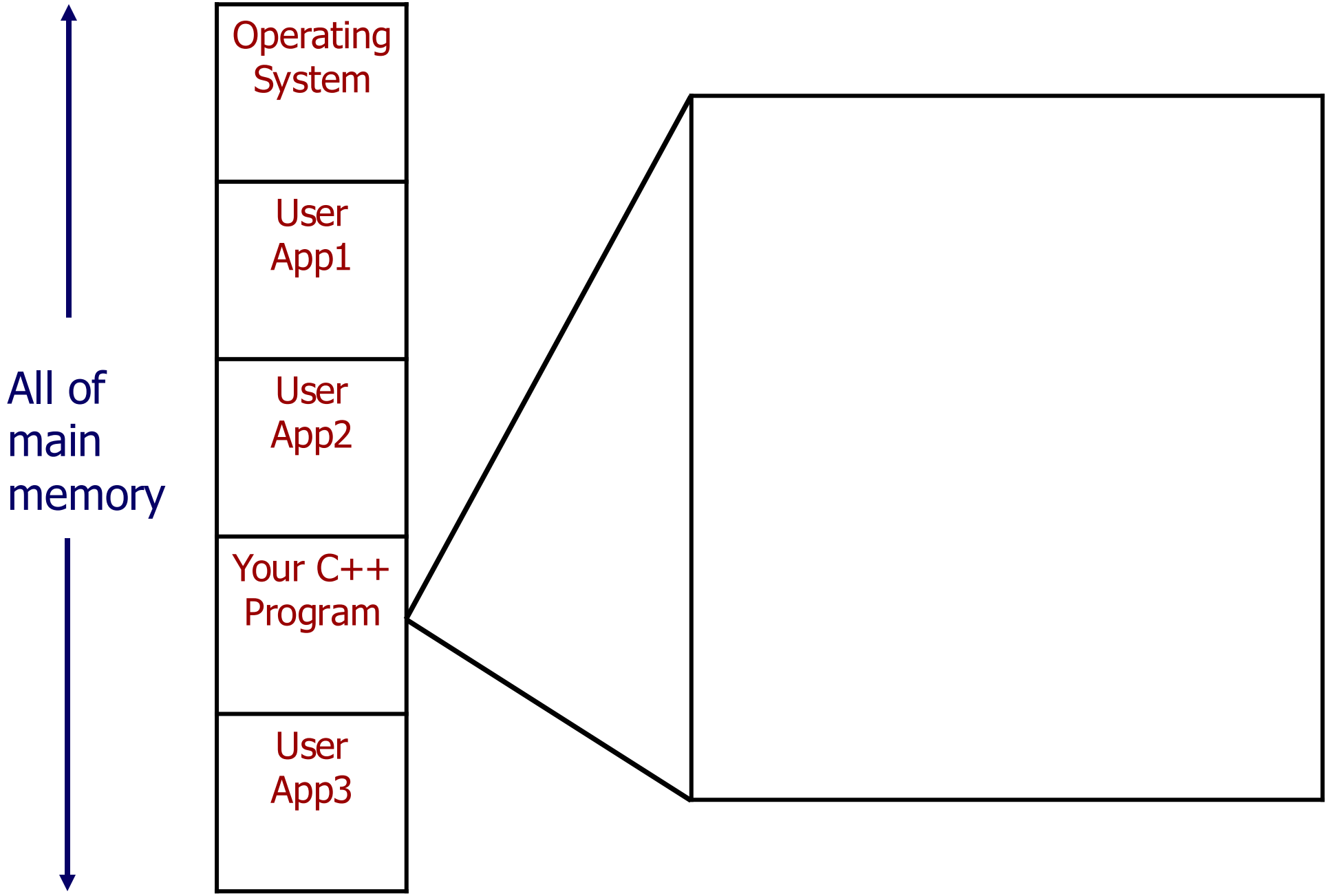


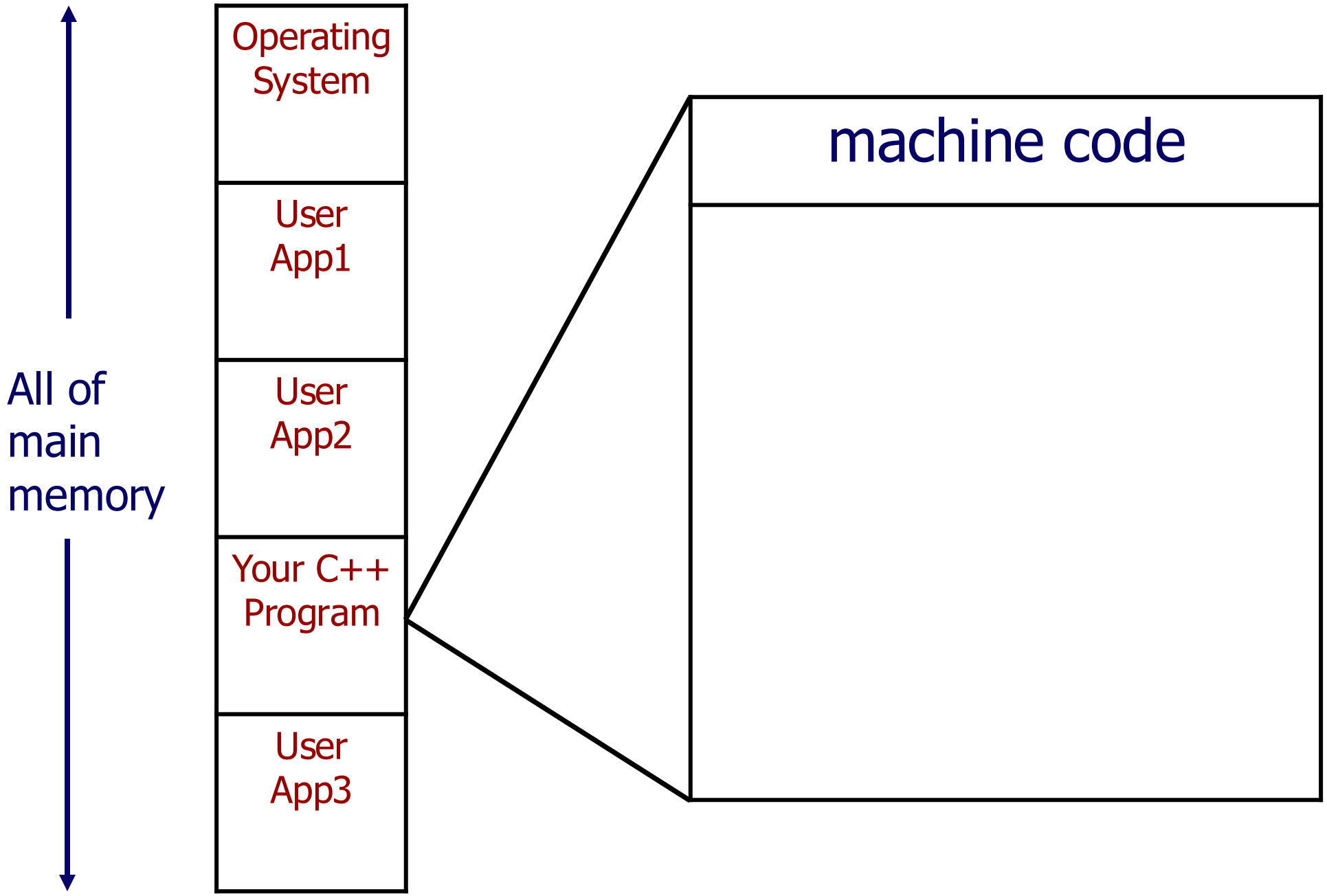


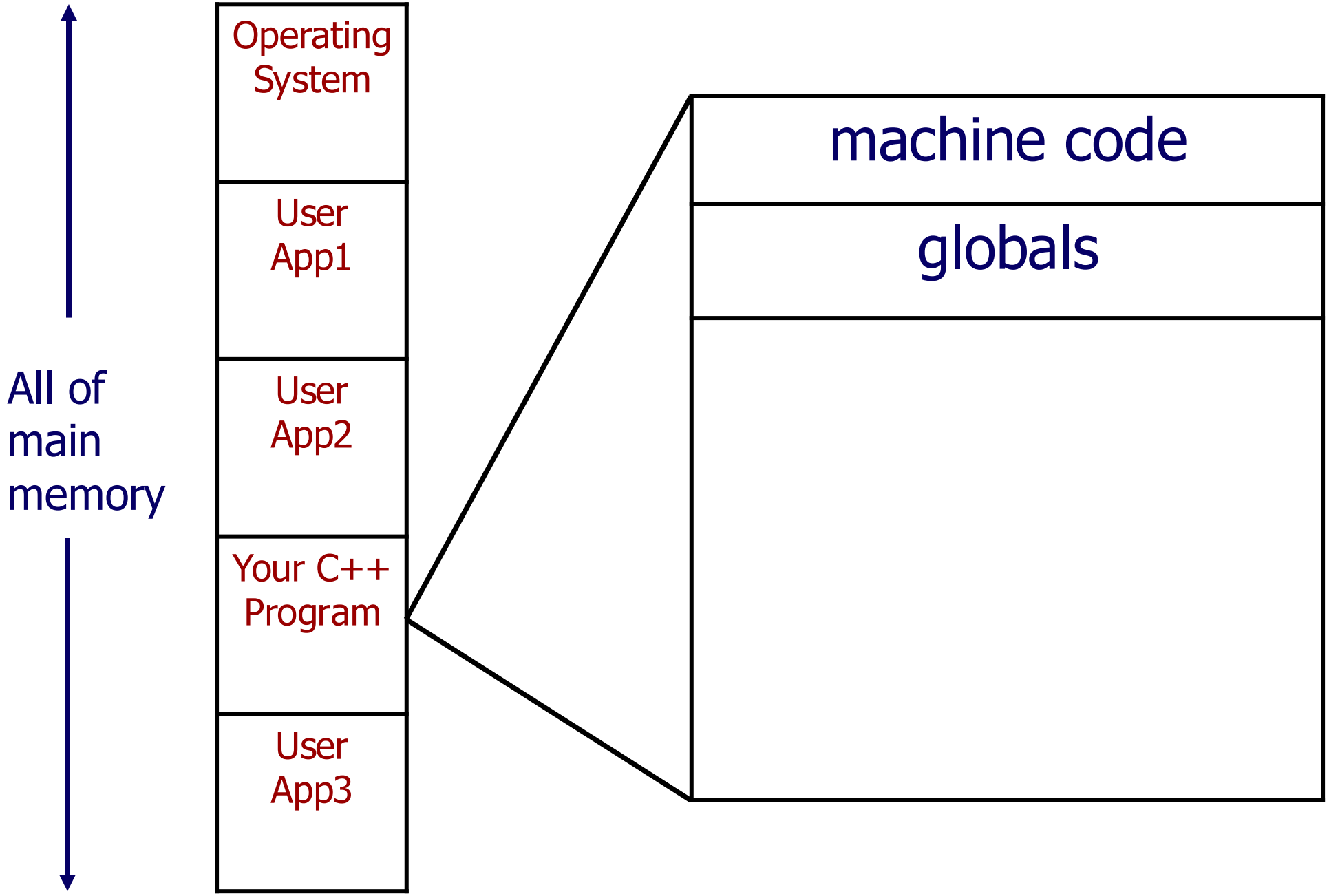
0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7
0x8	0x9	0xA	0xB	0xC	0xD	0xE	0xF
0x10	0x11	0x12	0x13	0x14	0x15	0x16	0x17
0x18	0x19	0x1A	0x1B	0x1C	0x1D	0x1E	0x1F
0x20	0x21	0x22	0x23	0x24	0x25	0x26	0x27
0x28	0x29	0x2A	0x2B	0x2C	0x2D	0x2E	0x2F
0x30	0x31	0x32	0x33	0x34	0x35	0x36	0x37
0x38	0x39	0x3A	0x3B	0x3C	0x3D	0x3E	0x3F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

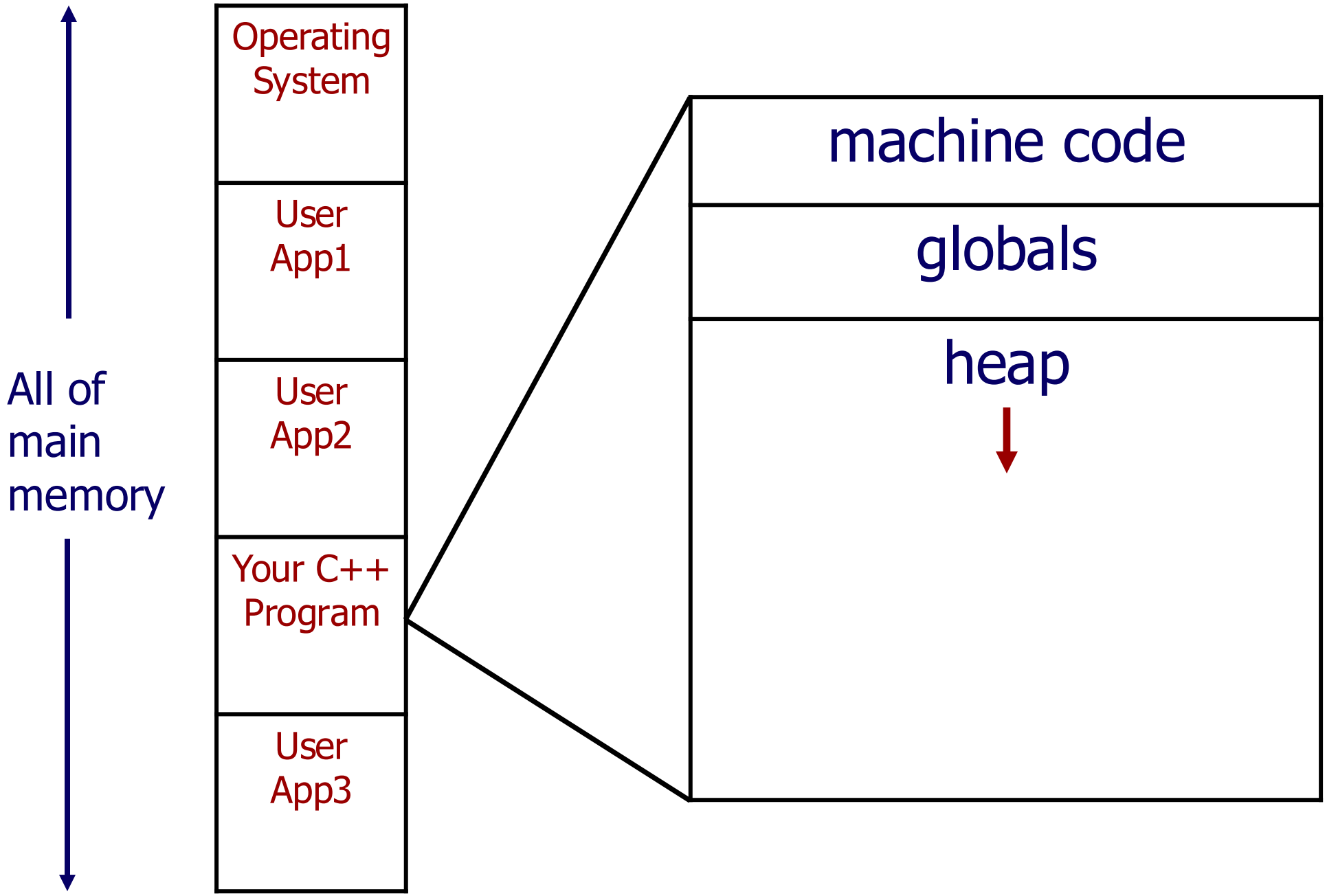

All of main memory
Operating System
User App1
User App2
Your C++ Program
User App3

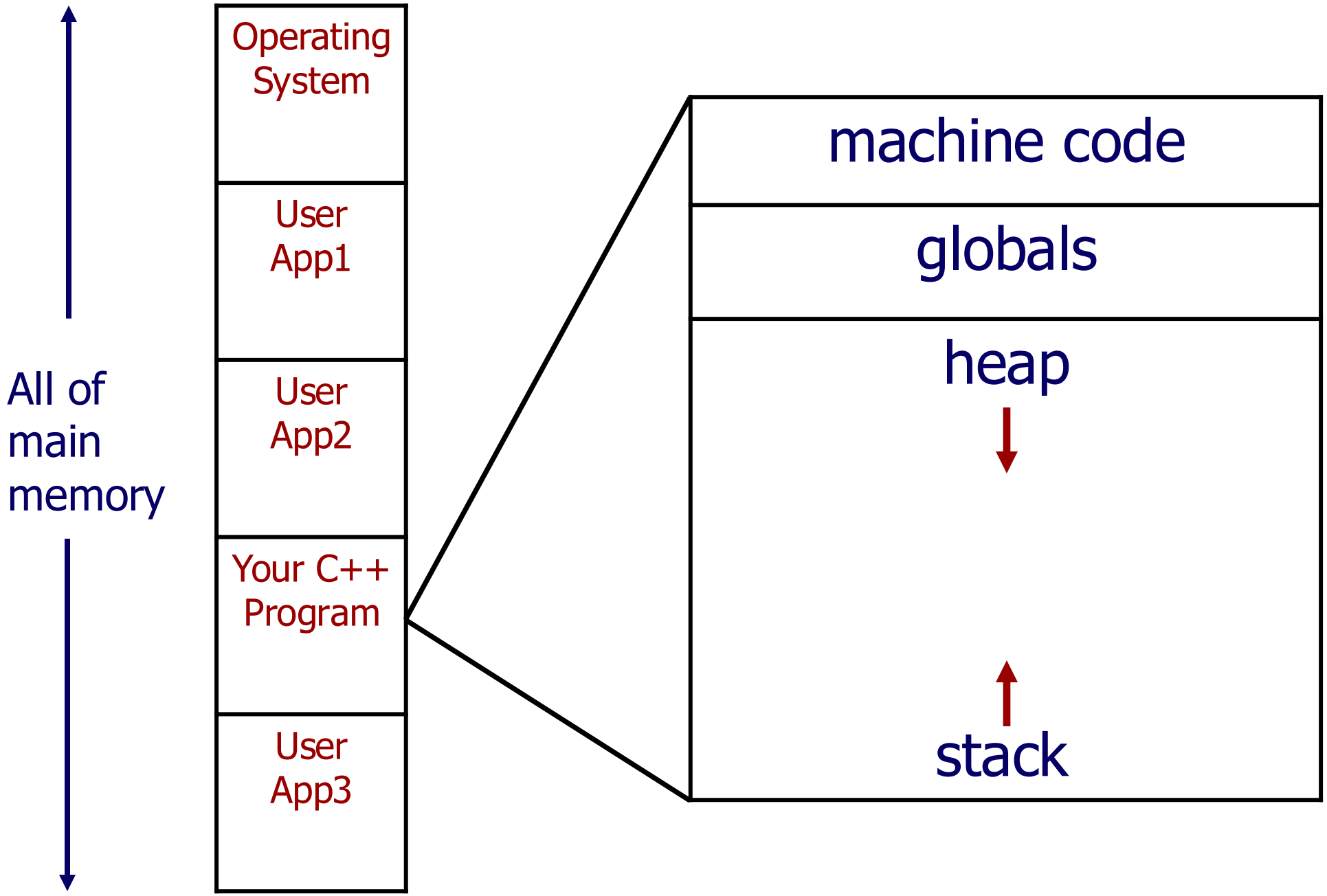

All of main memory
Operating System
User App1
User App2
Your C++ Program
User App3
0x0 0x1 0x2 0x3 0x4 0x5 0x6 0x7
0x8 0x9 0xA 0xB 0xC 0xD 0xE 0xF
0x10 0x11 0x12 0x13 0x14 0x15 0x16 0x17
0x18 0x19 0x1A 0x1B 0x1C 0x1D 0x1E 0x1F
0x20 0x21 0x22 0x23 0x24 0x25 0x26 0x27
0x28 0x29 0x2A 0x2B 0x2C 0x2D 0x2E 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
Operating System
User App1
User App2
Your C++ Program
User App3


All of main memory
Operating System
User App1
User App2
Your C++ Program
User App3
machine code

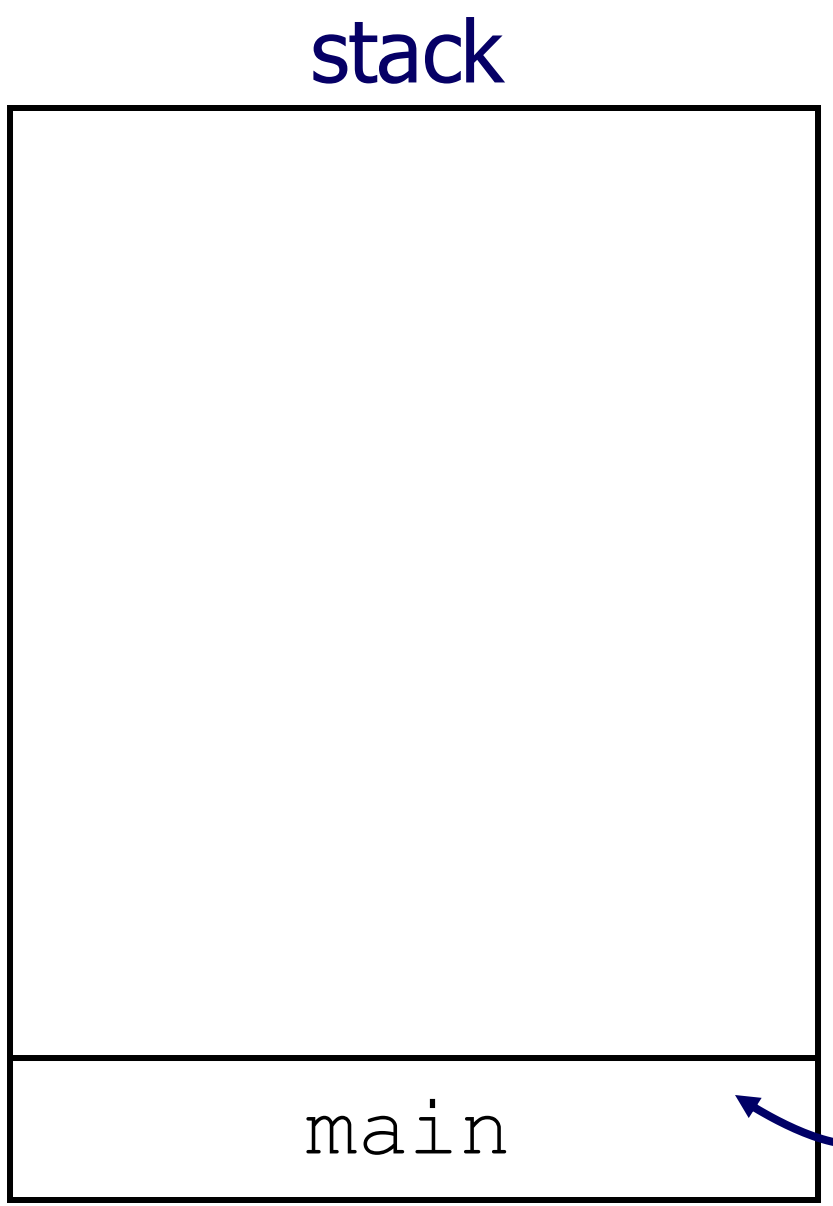

All of main memory
Operating System
User App1
User App2
Your C++ Program
User App3
machine code
globals


All of main memory
Operating System
User App1
User App2
Your C++ Program
User App3
machine code
globals
heap


All of main memory
Operating System
User App1
User App2
Your C++ Program
User App3
machine code
globals
heap
stack

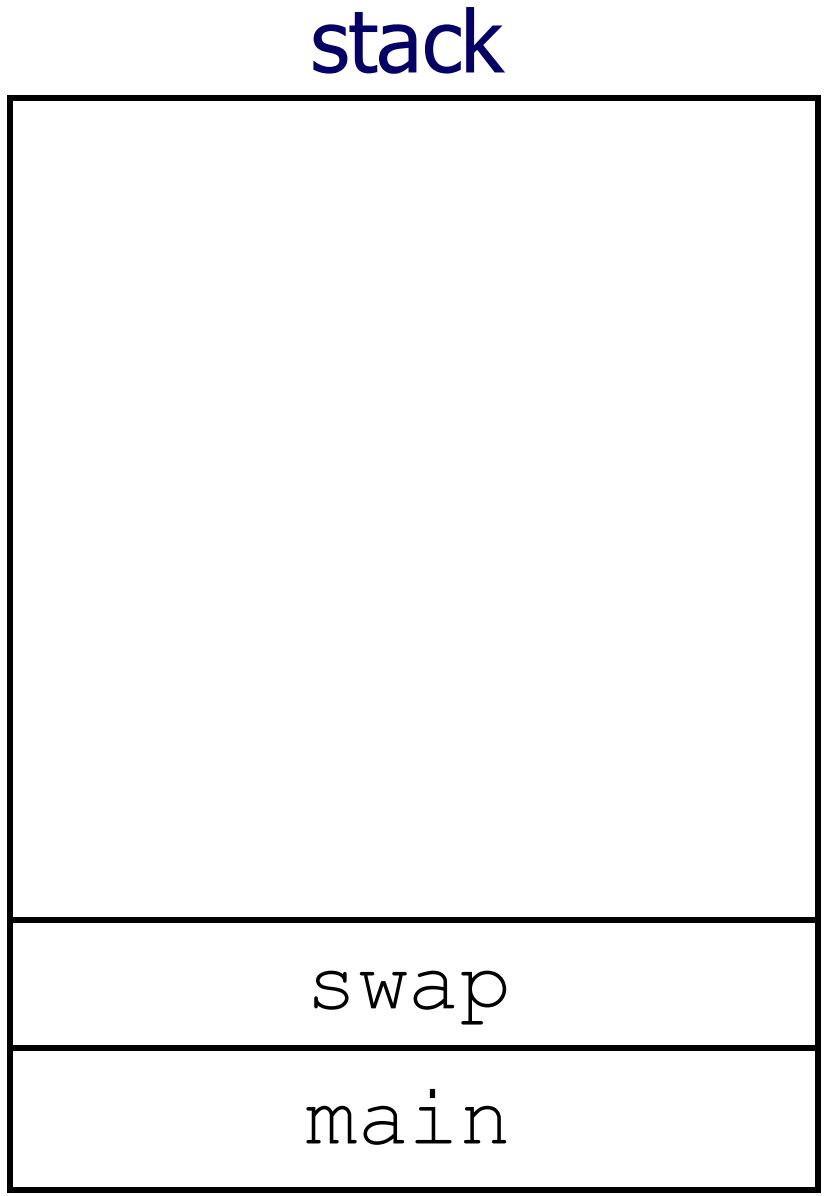
```
// Swap two int values.
void swap(int a, int b)
{
    int temp = a;  // store a in temp
    a = b;         // put b into a
    b = temp;      // put temp a into b
}

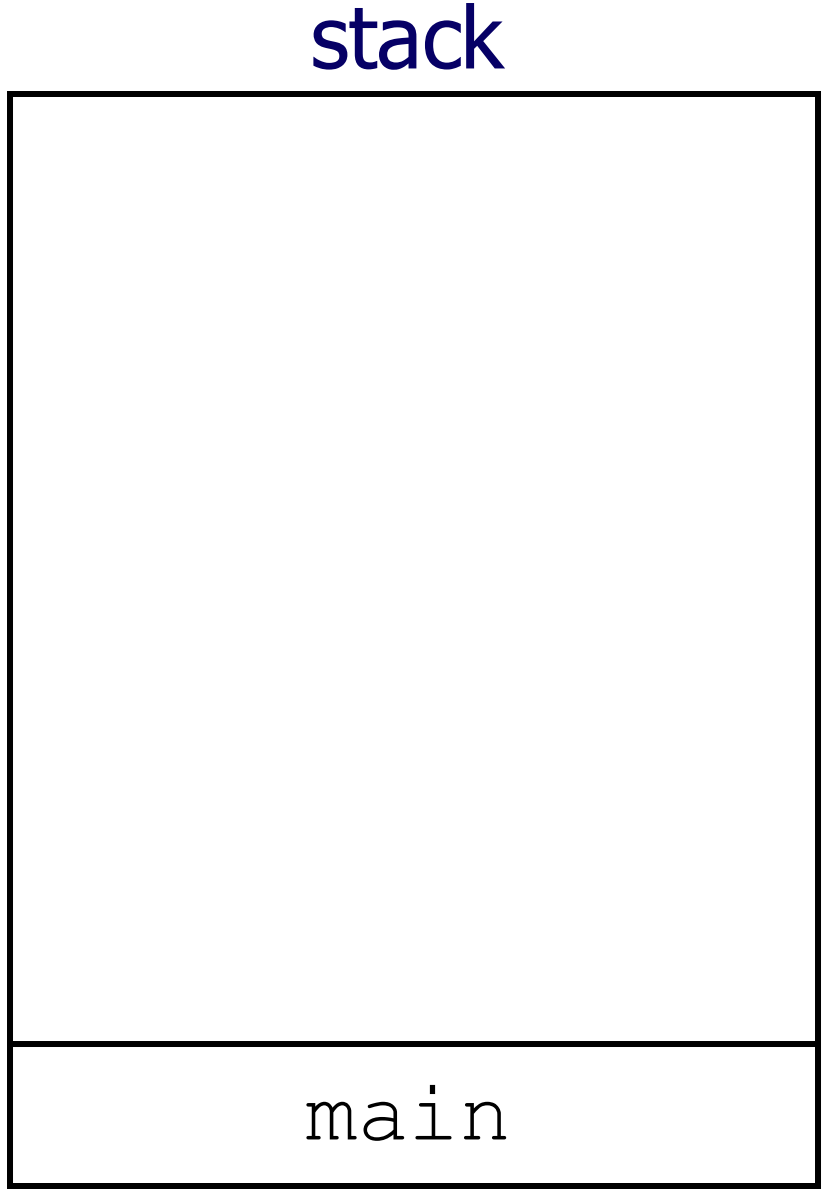
int main()
{
    int x = 12;
    int y = 33;
    swap(x, y);
    cout << "x == " << x << "  y == " << y << endl;    // ?
    return 0;
}
```

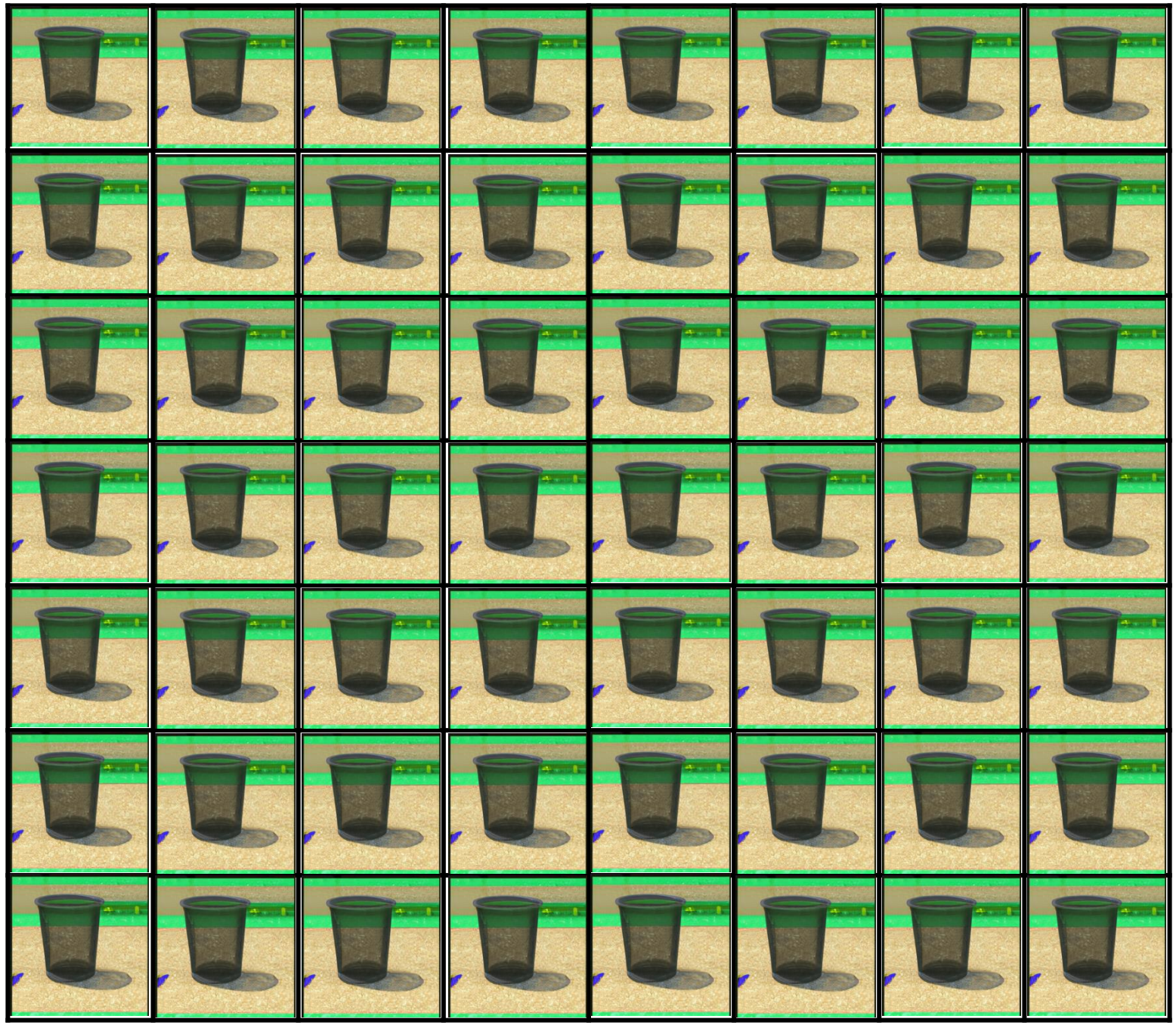


Stack Frame

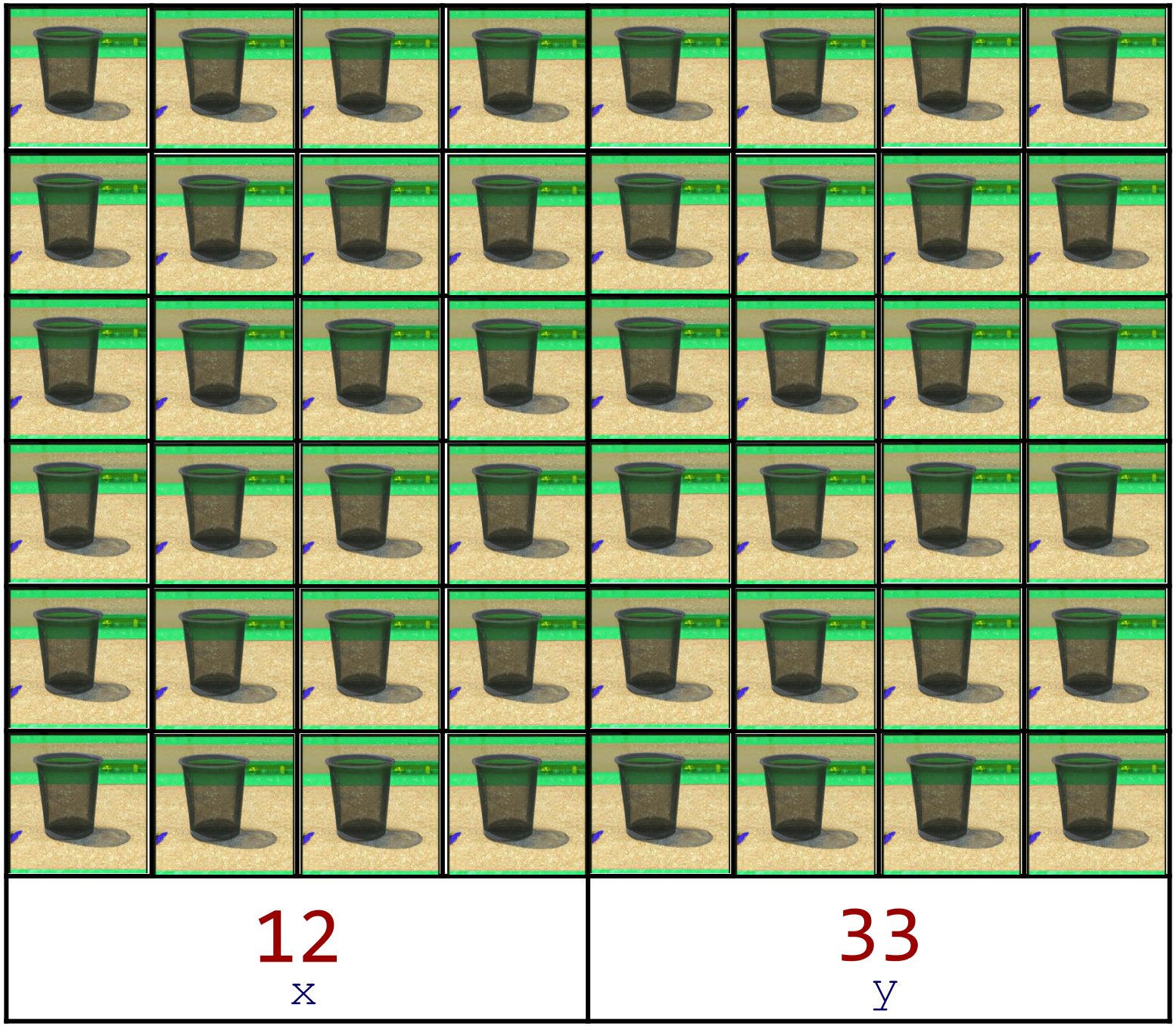
- function arguments
- local variables
- return address

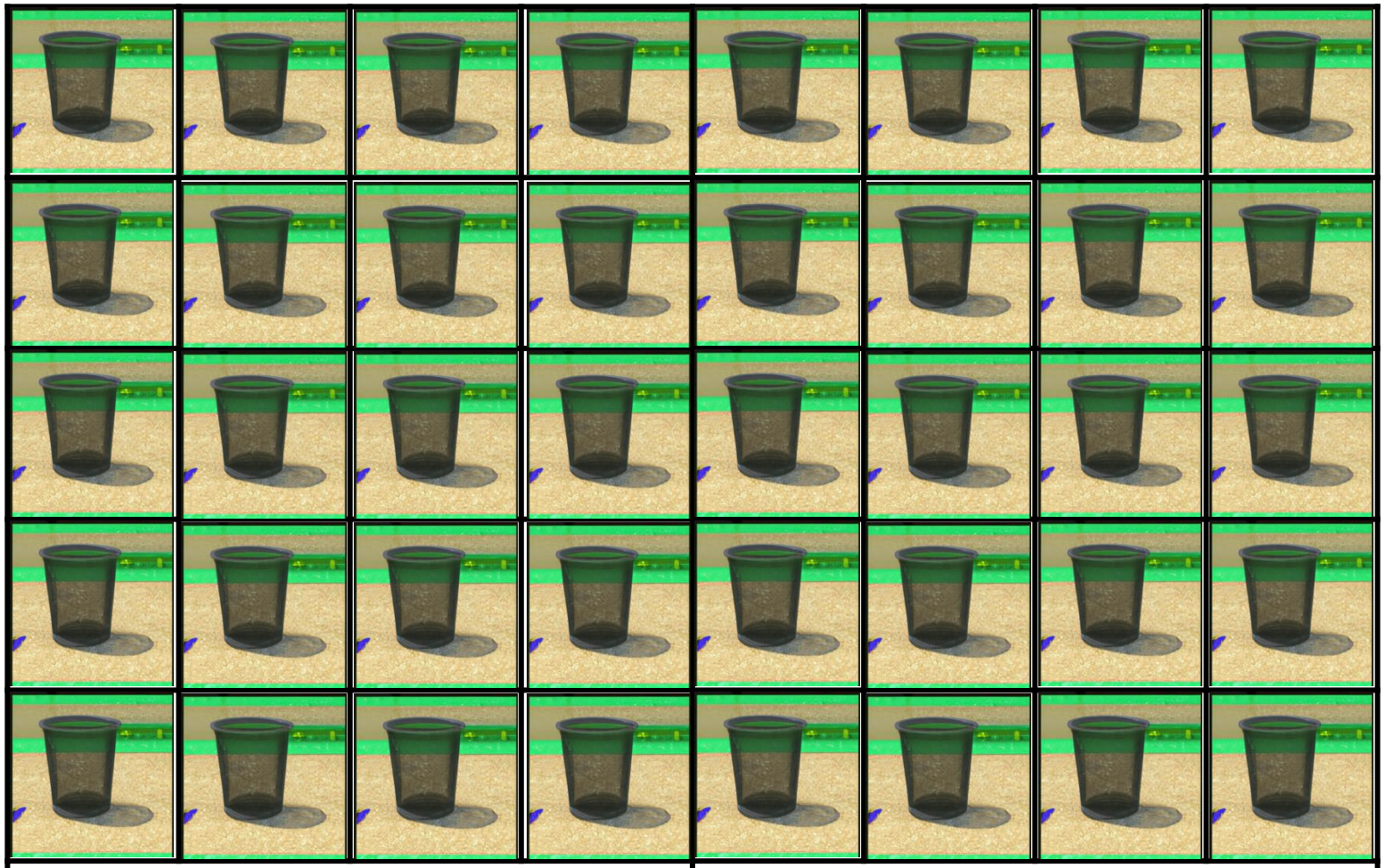

stack
swap
main


stack
main



main





swap		
	12 a	33 b
main	12 x	33 y

swap

main

12 temp	
12 a	33 b
12 x	33 y

swap

12 temp	
33 a	33 b

main

12 x	33 y

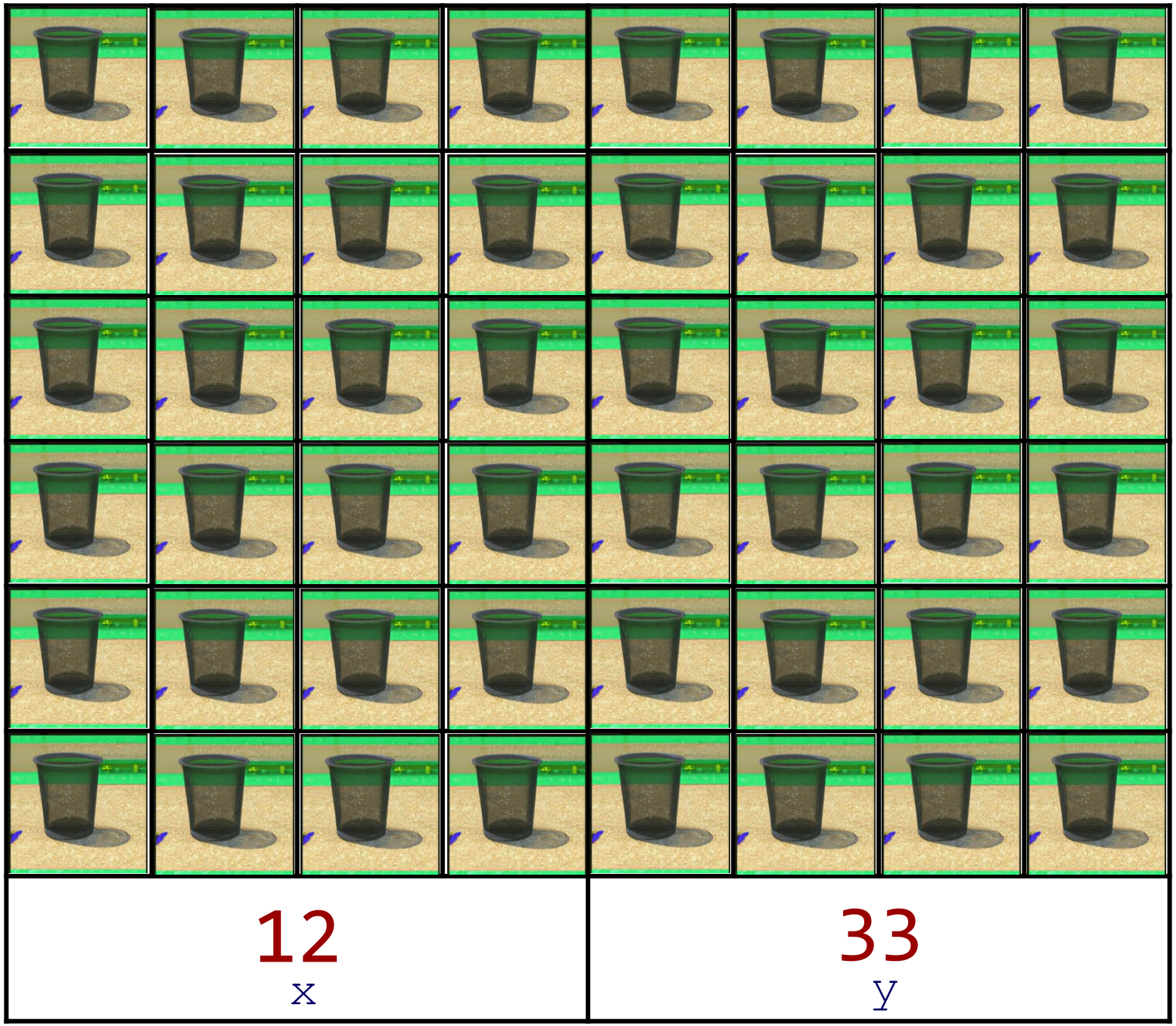
swap

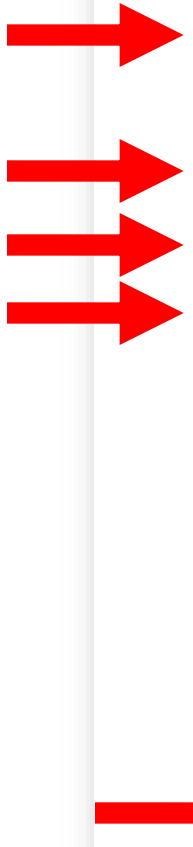
12 temp	
33 a	12 b

main

12 x	33 y

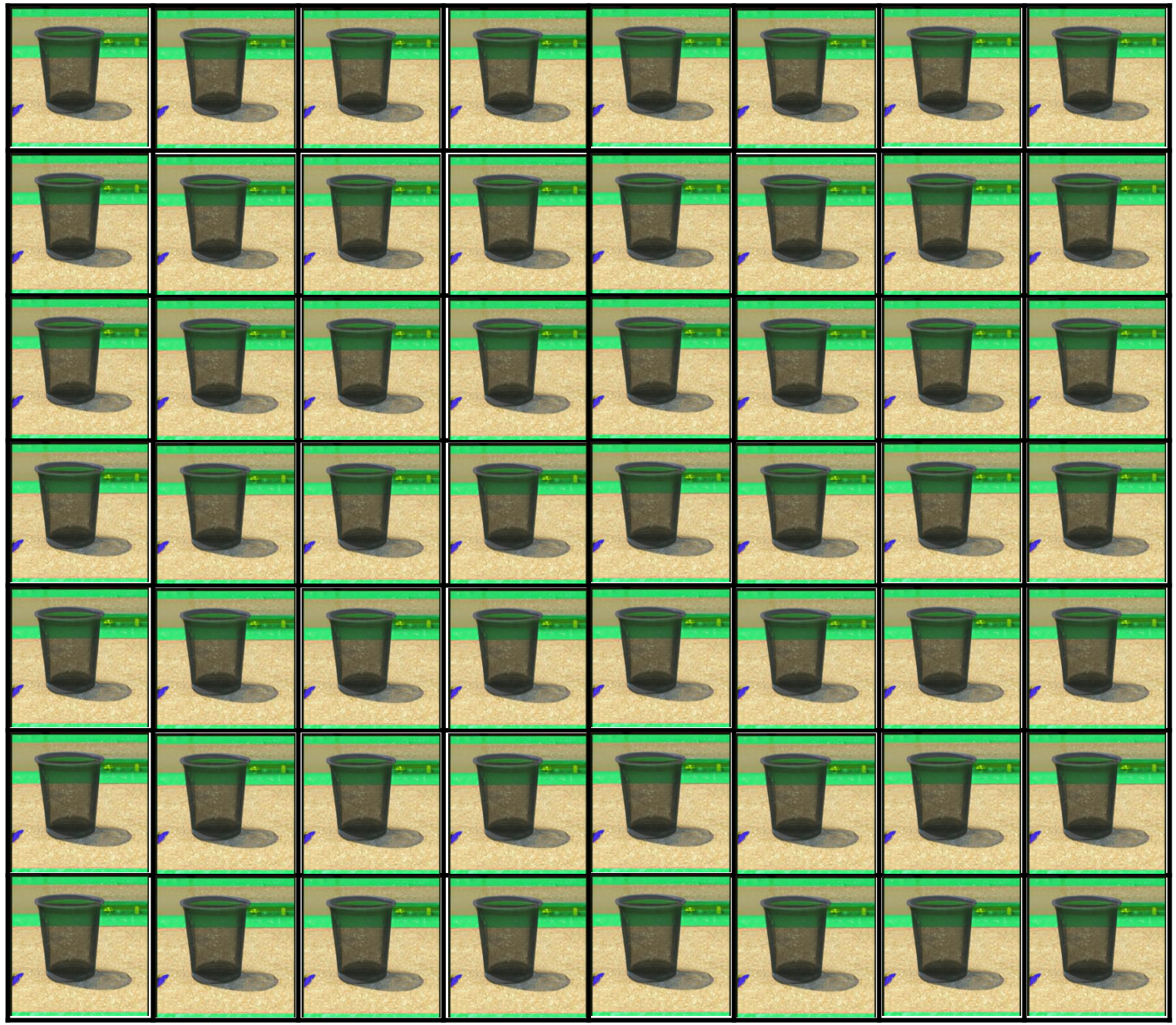
main



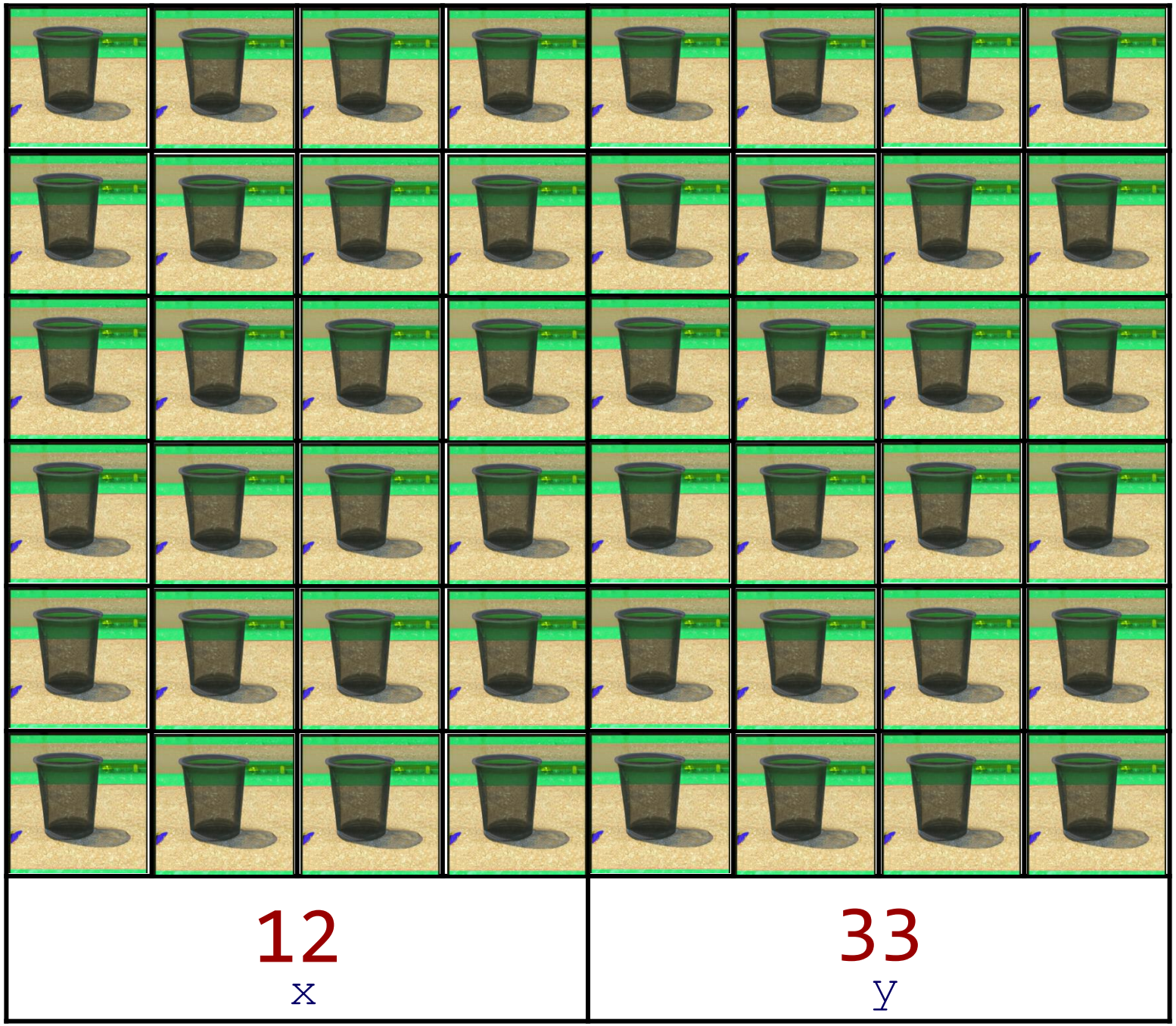


```
// Swap two int values.
void swap(int* a, int* b)
{
    int temp = *a;    // store contents of a in temp
    *a = *b;          // put contents of b into a
    *b = temp;        // put temp a into b
}

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;
}
```

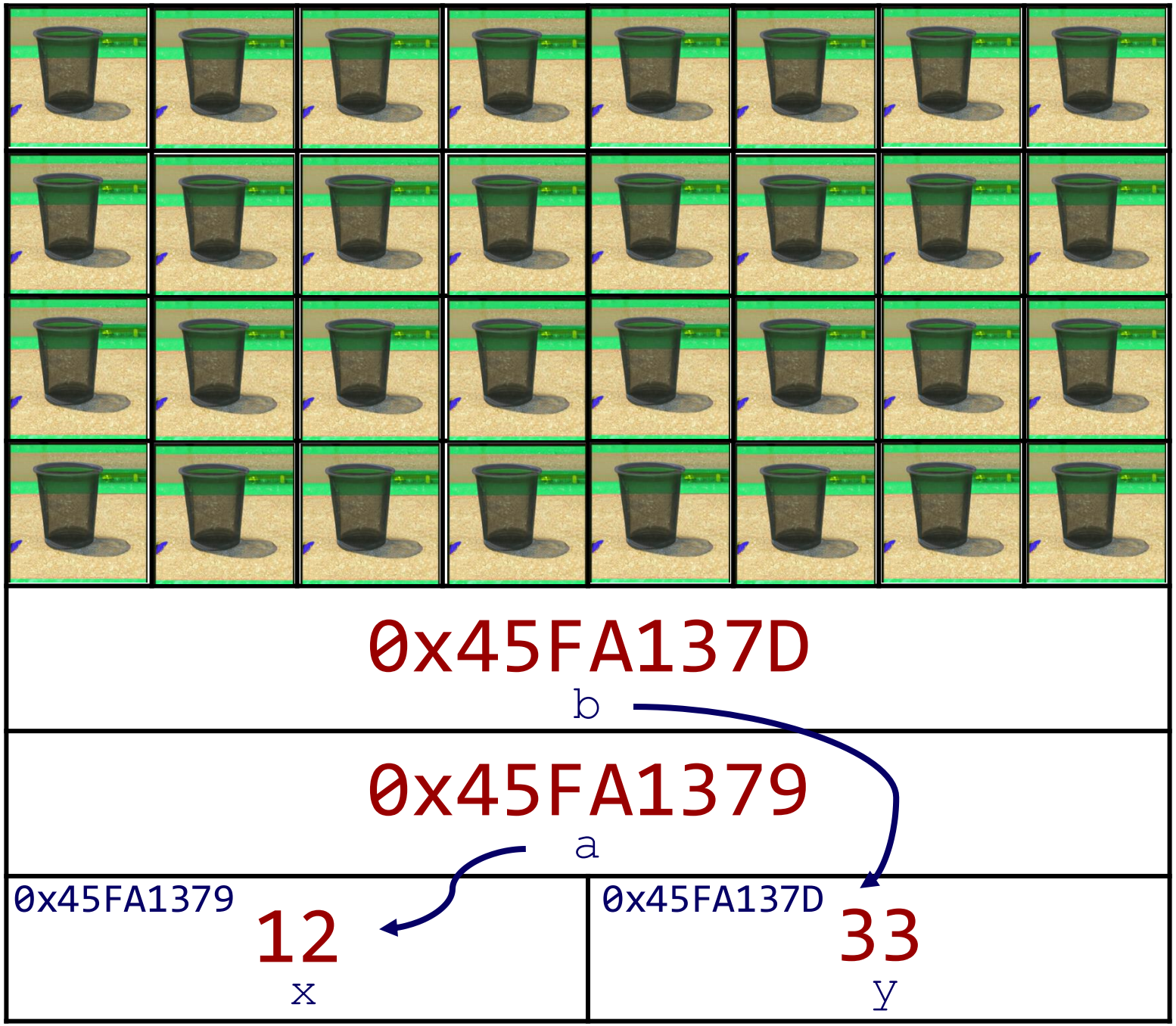


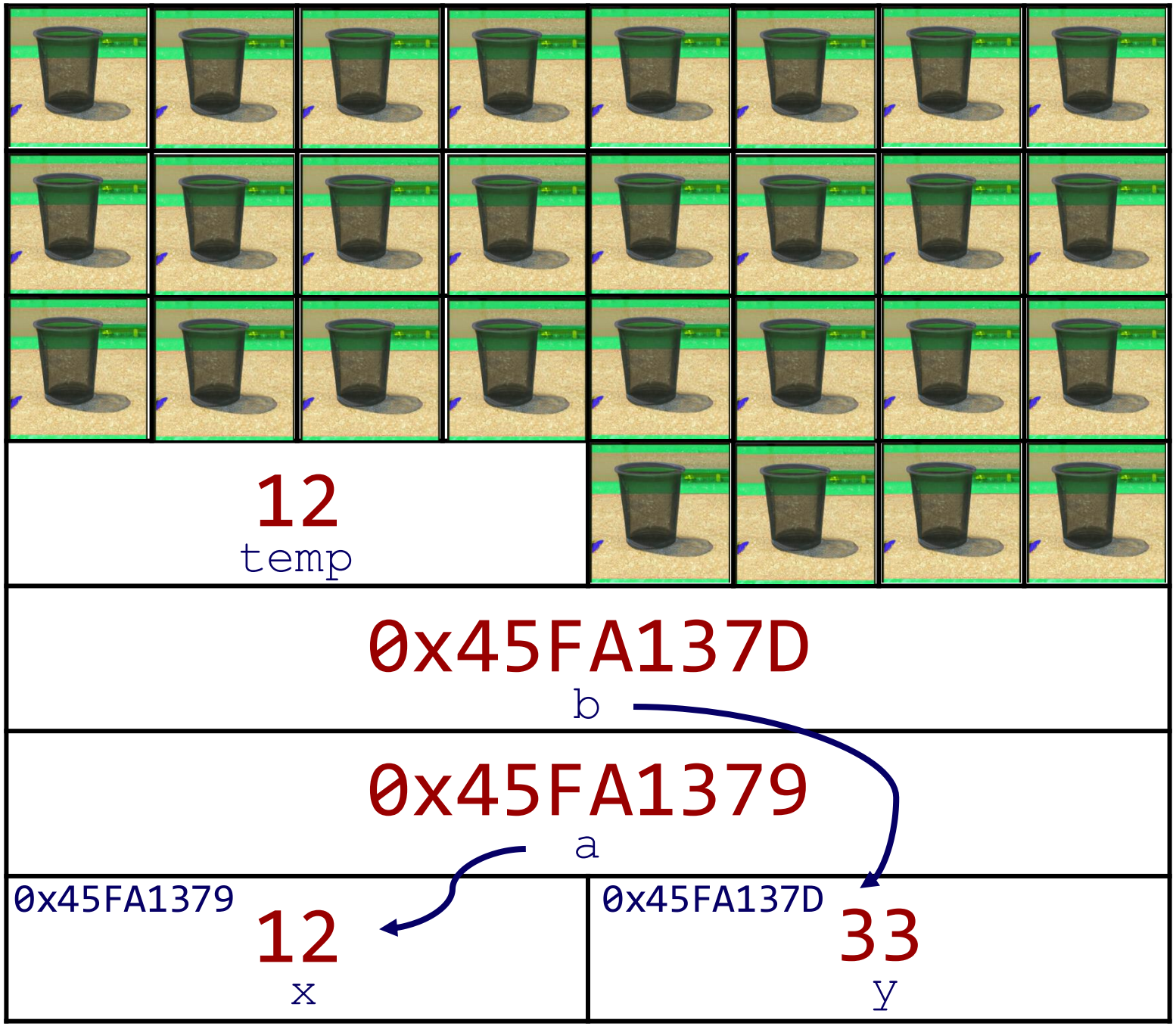
main



swap

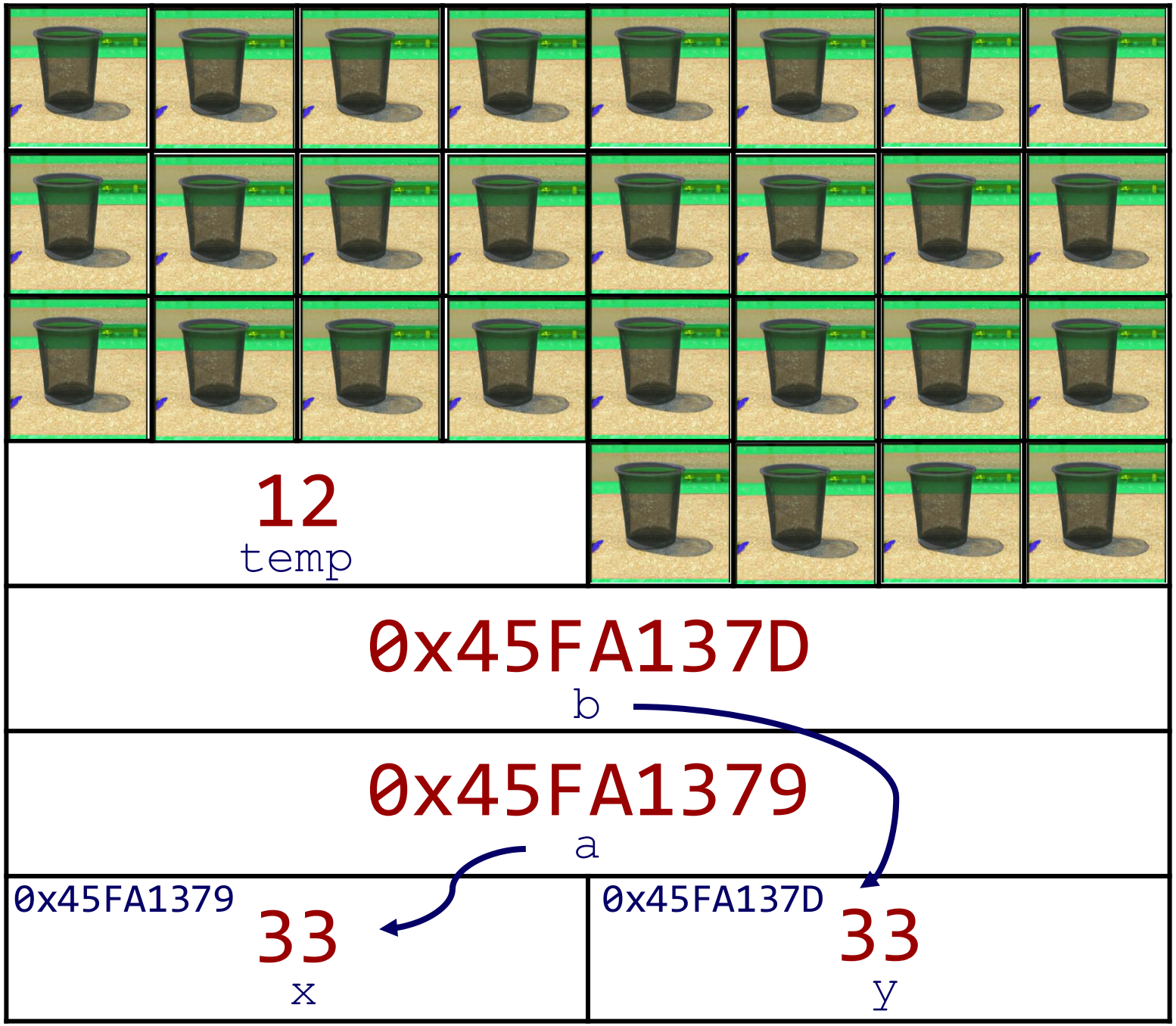
main




12
temp
0x45FA137D
b
0x45FA1379
a
0x45FA1379
12
x
0x45FA137D
33
y
swap
main

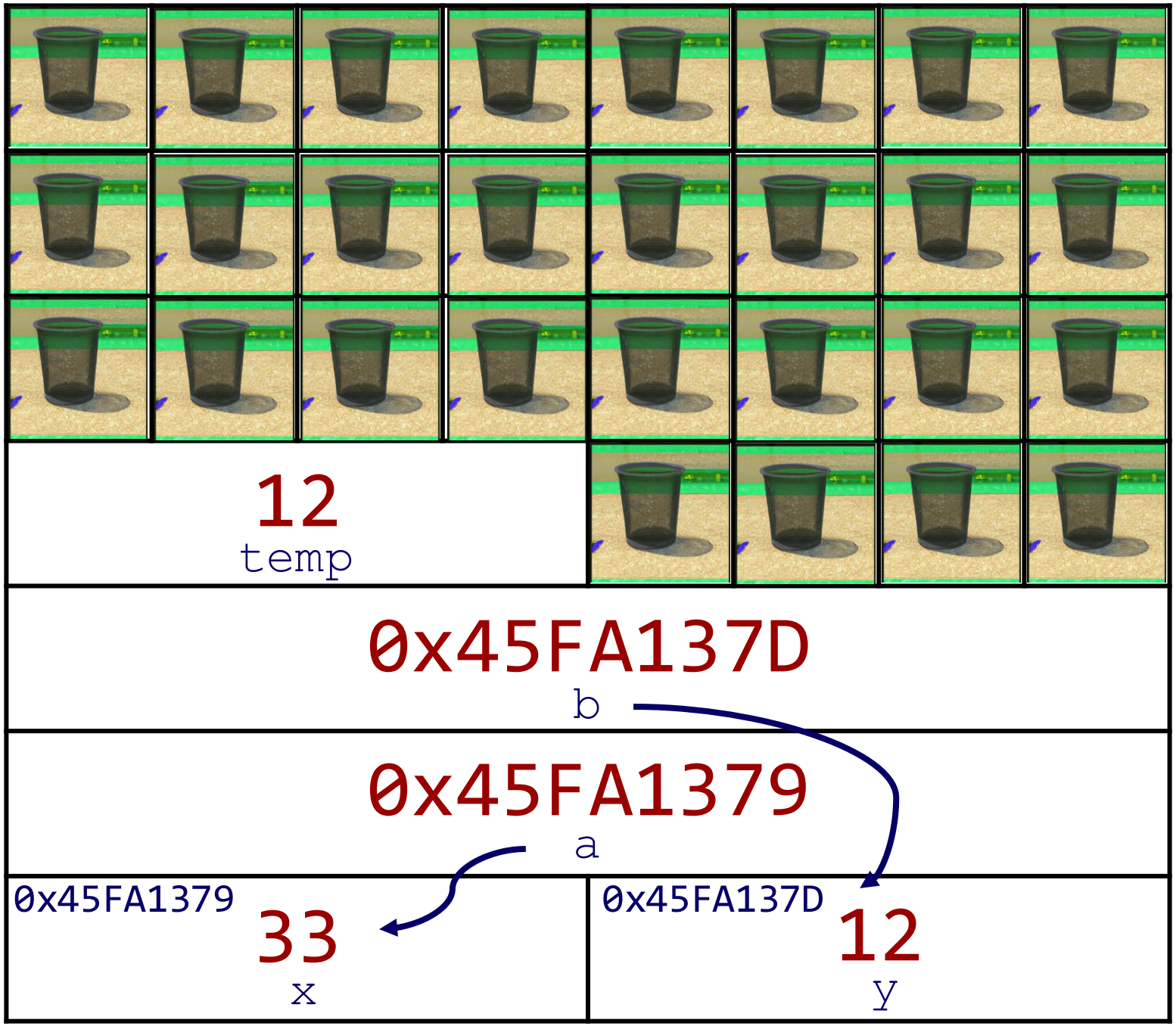
swap

main

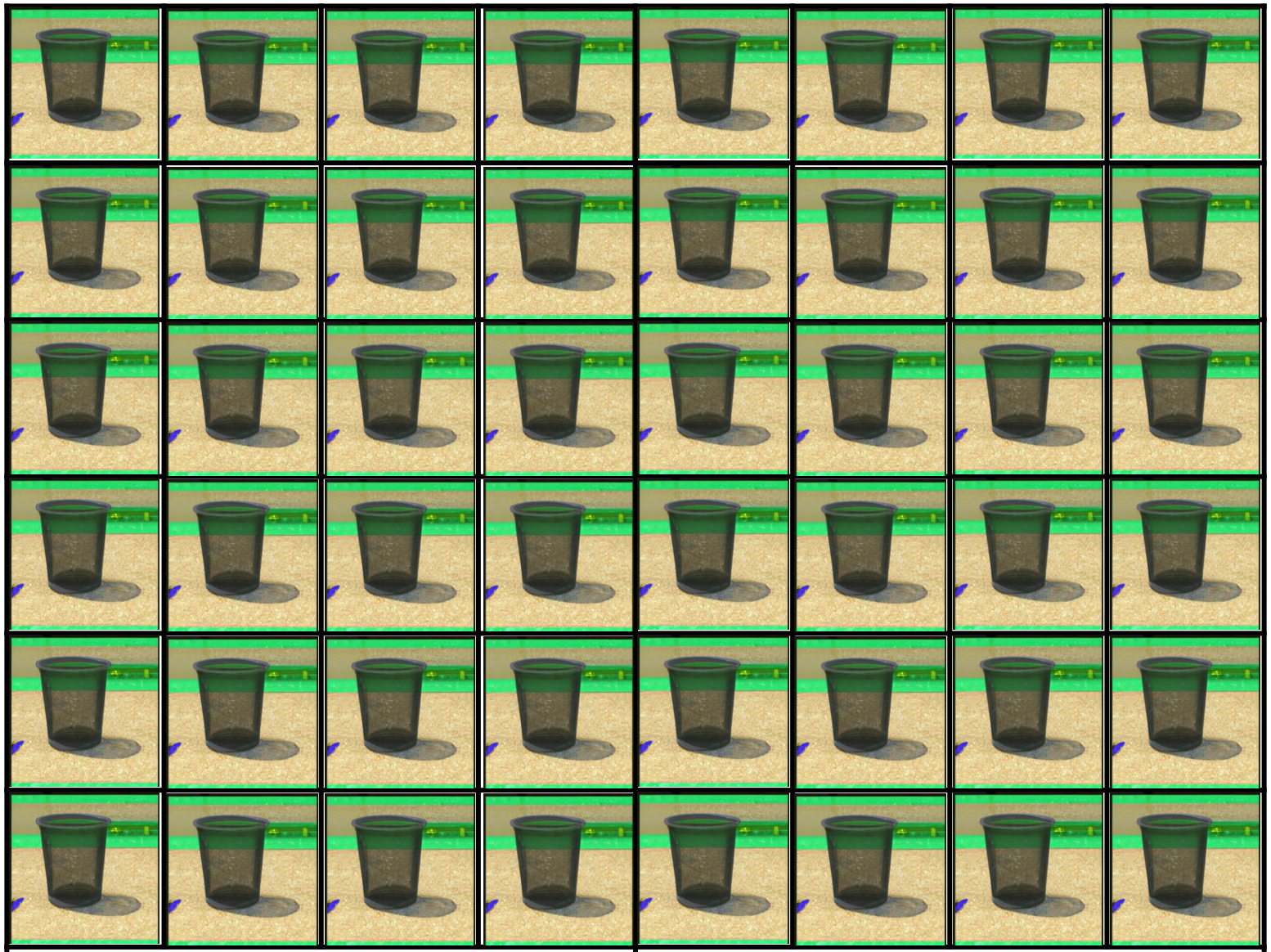

12
temp
0x45FA137D
b
0x45FA1379
a
0x45FA1379
33
x
0x45FA137D
33
y

swap

main

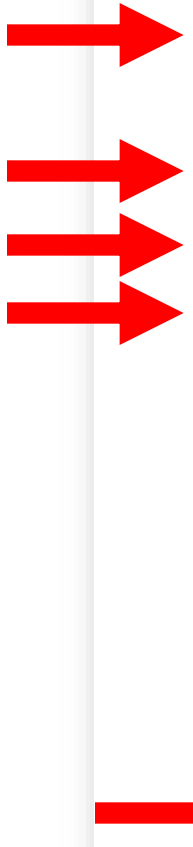

12
temp
0x45FA137D
b
0x45FA1379
a
0x45FA1379
33
x
0x45FA137D
12
y

main



33
x

12
y



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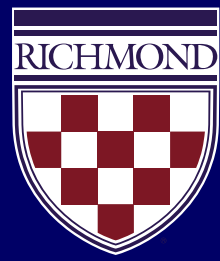
    int y = 33;
    swap(&x, &y);  // pass by reference (the addresses of x and y)
    cout << "x == " << x << "  y == " << y << endl;
    return 0;
}
```

Ask a question



Today

- ~~Memory~~
- ~~Pointers~~
- ~~Garbage Values~~
- ~~Memory Layout~~

- In-class exercise

RICHMOND

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