Object-oriented Programming in C++

Stephane Redon

OneAngstrom
https://www.oneangstrom.com

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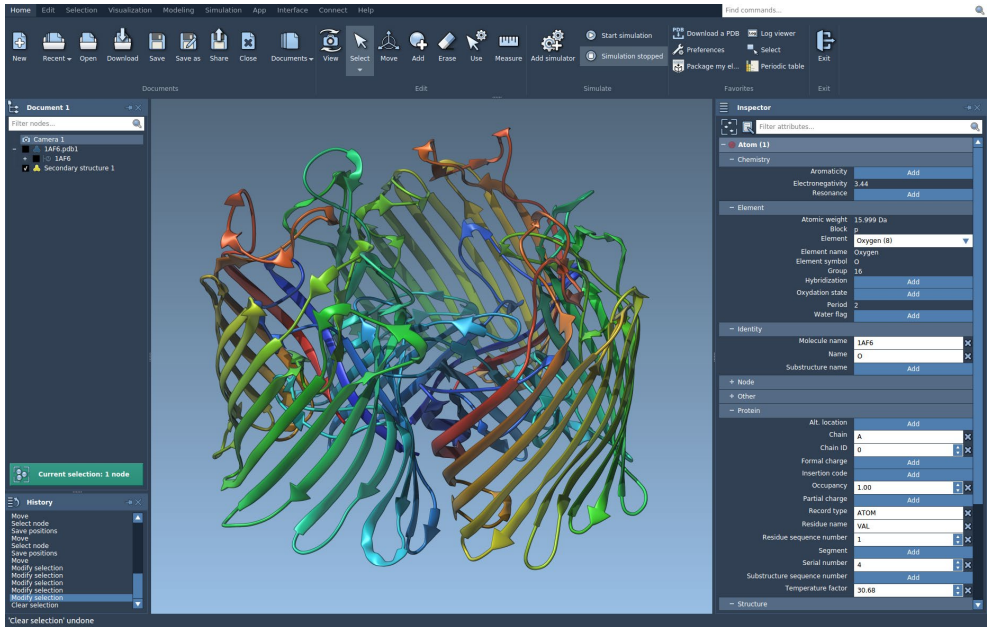
About this document

- This document is an introduction to C++ provided by OneAngstrom to help you kickstart development of modules for SAMSON, the open platform for molecular modeling available at https://www.samson-connect.net.



- This introduction can be read as a standalone, but the best way to learn is probably to head to the SAMSON developer guide at https://s-c.io/dg and use the present introduction to C++ when necessary.

Overview

Overview

- C++ is a **compiled language**: a program written in C++…

```
int main(int argc, char *argv[]) {
    // compute 10!
    int n=1;
    for (int i=1;i<10;i++) n=n*i;
    return n;
}
```

We will explain this program soon…

Overview

- C++ is a **compiled language**: … is turned into machine language

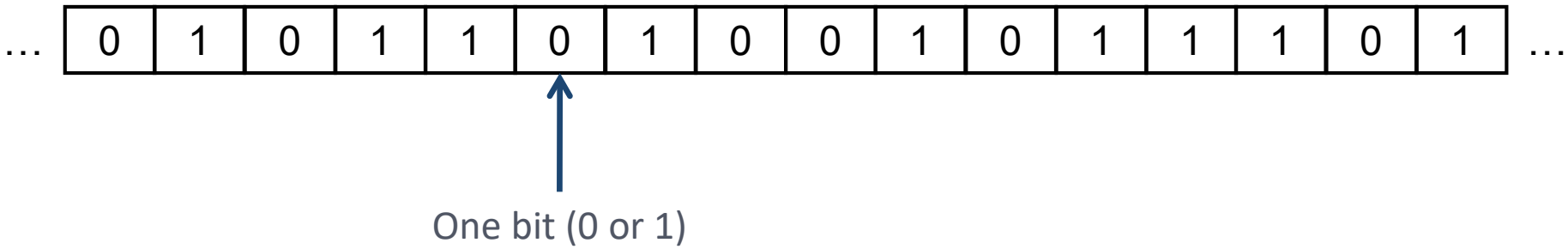
```
int main(int argc, char *argv[]) {
013113A0  push        ebp
013113A1  mov         ebp,esp
013113A3  sub         esp,0D8h
013113A9  push        ebx
013113AA  push        esi
013113AB  push        edi
013113AC  lea         edi,[ebp-0D8h]
013113B2  mov         ecx,36h
013113B7  mov         eax,0CCCCCCCCh
013113BC  rep stos    dword ptr es:[edi]

    // compute 10!

    int n=1;
013113BE  mov         dword ptr [n],1

    for (int i=1;i<10;i++) n=n*i;
013113C5  mov         dword ptr [ebp-14h],1
013113CC  jmp         main+37h (013113D7h)
013113CE  mov         eax,dword ptr [ebp-14h]
013113D1  add         eax,1
013113D4  mov         dword ptr [ebp-14h],eax
013113D7  cmp         dword ptr [ebp-14h],0Ah
013113DB  jge         main+49h (013113E9h)
013113DD  mov         eax,dword ptr [n]
013113E0  imul        eax,dword ptr [ebp-14h]
013113E4  mov         dword ptr [n],eax
013113E7  jmp         main+2Eh (013113CEh)

    return n;
013113E9  mov         eax,dword ptr [n]

}
```

… but not this one ;-)

Memory

Memory

- Memory can be modeled as a linear array



Memory

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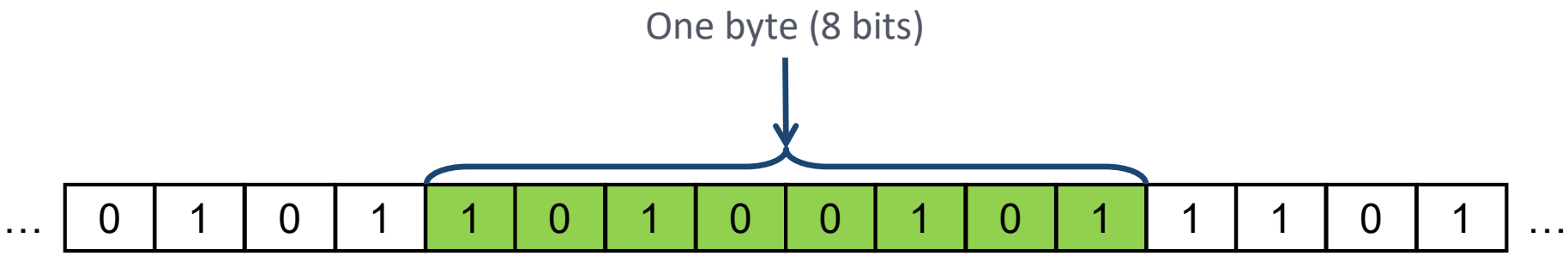
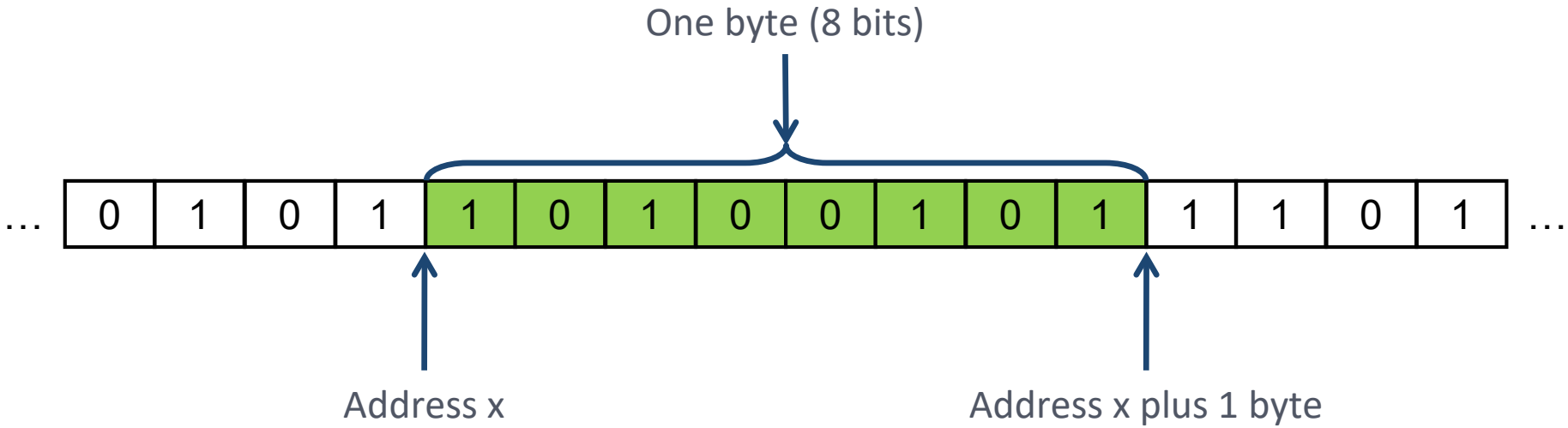


- 8 bits = 1 byte
- 1024 bytes = 1 kilobyte = 1 KB
- 1024 KB = 1 megabyte = 1MB
- 1024 MB = 1 gigabyte = 1GB
- 1024 GB = 1 terabyte = 1 TB
- …

Memory

- The memory cells have **addresses**



- On a 32-bit system, memory addresses are coded on 32 bits (4 bytes)
  - Maximum 4GB

- On a 64-bit system, memory addresses are coded on 64 bits (8 bytes)
  - Maximum 16 exbibytes = 2^64 bytes = 1 billion of gigabytes

Memory

- An executable uses three **memory segments**
  - Code segment
    - Stores the compiled program (the assembly code)
  - Stack segment
    - Memory allocated for functions
    - Function-level memory only lasts as long as the function lasts
  - Heap segment
    - Memory allocated for persistent data
    - Lasts until de-allocation, or when the executable ends
- More on this later

First programs

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The minimal program

The main function
(**has** to be called main)

Return type
(**has** to be int)

```
int main() {

    return 0;

}
```

The function **has** to return a value

The traditional Hello world! program

Input / output streams

Include a header file

End line
(more on this later)

```
#include <iostream>

int main() {

    std::cout << "Hello World!" << std::endl;

    return 0;

}
```

Standard output stream
(more on this later)

A string

Overloaded operator
(more on this later)

Comments

Comments

```
// This is a one-line comment

/* This is the first line of a multi-line comment
   This is the second line of a multi-line comment */

std::cout << "Hello" << std::endl; // comments may be placed after a statement

std::cout << "Hello" << /* and even inside a statement (please don't) */ std::endl;

/* comments may be used to de-activate parts of code
std::cout << "Hello" << std::endl;
*/
```

Comments

- **Extremely important**
- Used to document the code
  - Variables
  - Files
  - Functions
  - Algorithms
  - …
- Think about your collaborators
- Think about your **future you**

Fundamental data types

Fundamental data types

- bool (one bit): true or false

```
bool b=true;
```

- char (one byte): integer between -128 and 127

```
char c='A';
char d=65;   // 65 is the ASCII code of 'A', so d=c
```

- short (usually two bytes): integer between –32,768 and 32,767

```
short s=1203;
```

- int (usually four bytes): integer between –2,147,483,648 and 2,147,483,647

```
int i=0;
```

- long (usually eight bytes): –9,223,372,036,854,775,808 to 9,223,372,036,854,775,807

```
long l=12012930;
```

- char, int and long can be prefixed by ‘unsigned’

```
unsigned int i=4294967295;  // maximum unsigned int
unsigned short s=-1;        // s=65535
```

Fundamental data types

- float (four bytes): floating-point value (single precision)

```
float f1=1.0;                  // f1 is set to 1.0
float f2=1.000000000000001; // f2 is also set to 1.0!
```

- double (eight bytes): floating-point value (double precision)

```
double d1=1.0;                     // d1 is set to 1.0
double d2=1.000000000000001;       // d2 is set to 1.000000000000001
double d3=1.0000000000000001;      // d3 is set to 1.0!
```

- Declaration and assignment may be separate

```
int i;
i=2;
```

- C++ has rules for conversions between types
- **void**: the type that represents nothing (more on this later)

Arrays

Arrays

- Structure

  typeName variableName[size];

- Arrays are **not** initialized (saves time)

- Example

```
int i[10];  // an array of 10 integers
i[4]=65;    // affects 65 to the 5th element
std::cout << i[4] << std::endl; // prints 65
```

- In memory, array elements are contiguous

Streams

Streams

- We will use them to **print** and **read user input**

```
int i;                // i is an integer
double k;             // k is a double
unsigned char a[4];   // a is (a pointer to the first element of) an array of unsigned char
double d;             // d is a double

std::cin >> i; // affects to i the first number entered by the user
std::cin >> k; // affects to k the second number entered by the user
std::cin >> a; // affects to a the chars entered by the user
std::cin >> d; // affects to k the third number entered by the user

std::cout << i << std::endl; // prints the first number entered by the user
std::cout << k << std::endl; // prints the second number entered by the user
std::cout << a << std::endl; // prints the chars entered by the user
std::cout << d << std::endl; // prints the third number entered by the user
```

A slightly more friendly Hello world! program

Include the string header file

```
#include <iostream>
#include <string>

int main() {

    std::cout << "Hello! Please enter your name: ";

    std::string name;
    std::cin >> name;

    std::cout << "Hello " << name << "!" << std::endl;

    return 0;

}
```

name is a string variable

Standard **input** stream (more on this later)

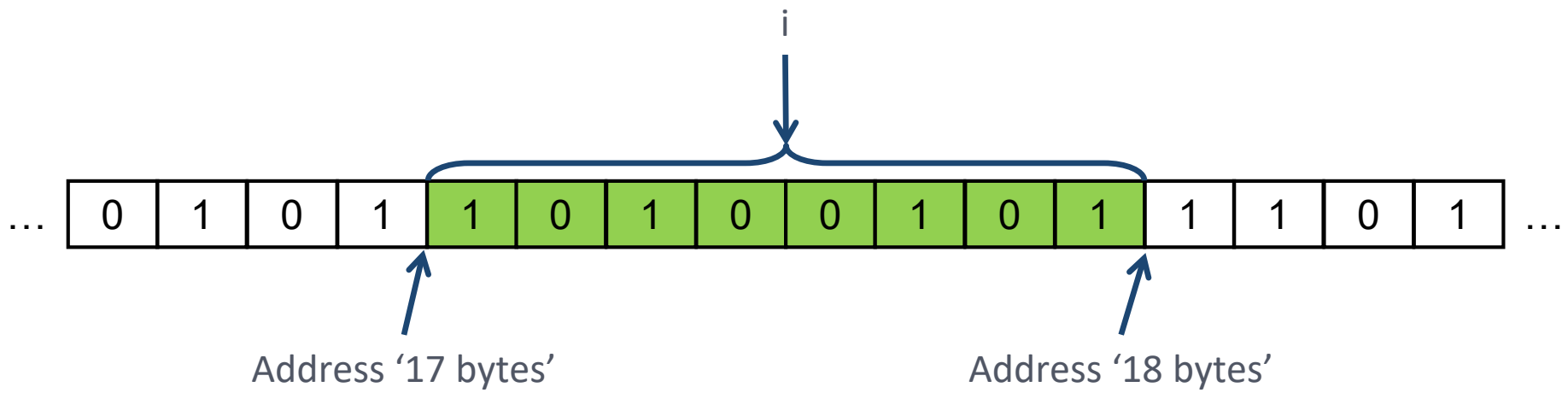
References and pointers

References and pointers

- Variables are stored in memory, at a given **address**

```
unsigned char i=165;
```

The variable i is stored at address 17



References and pointers

- A reference is a **supplementary name for a variable**

The reference **has to be assigned immediately**

Note the &

- Syntax: typeName& referenceName=variableName;

referenceName is a
supplementary name for the variable
with name ‘variableName’

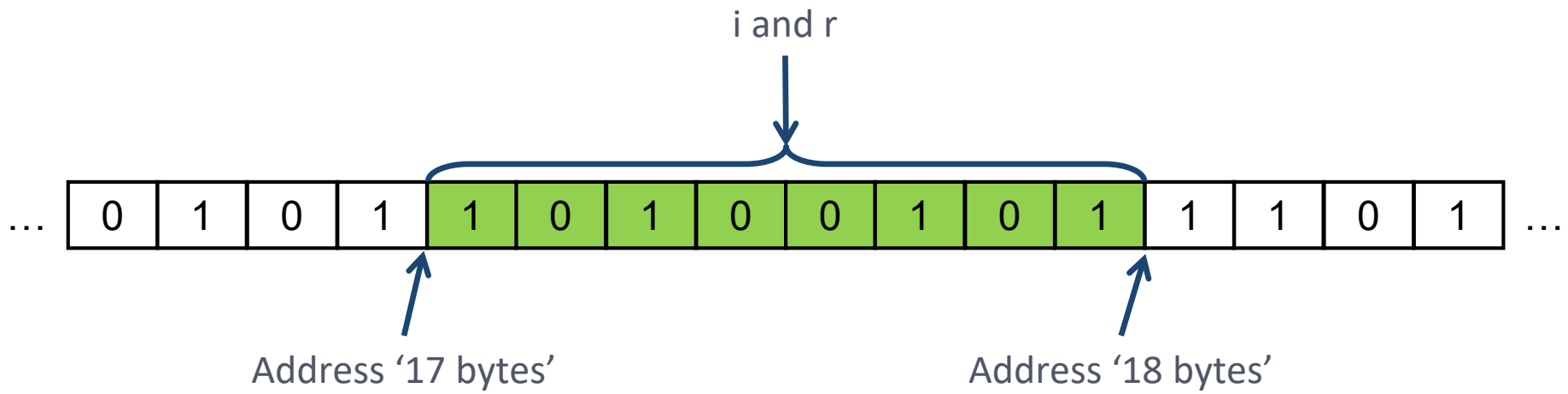
References and pointers

- Variables are stored in memory, at a given **address**

```
unsigned char i=165;
unsigned char& r=i;
```

The variable i is stored at address 17

r is just **another name** for i



References and pointers

- A pointer is a **variable which contains the address of another variable**

Note the *

- Declaration syntax: typeName* pointerName;

pointerName is a
variable which contains the address of another variable
of type 'typeName'

- **The address of a variable is obtained with &**

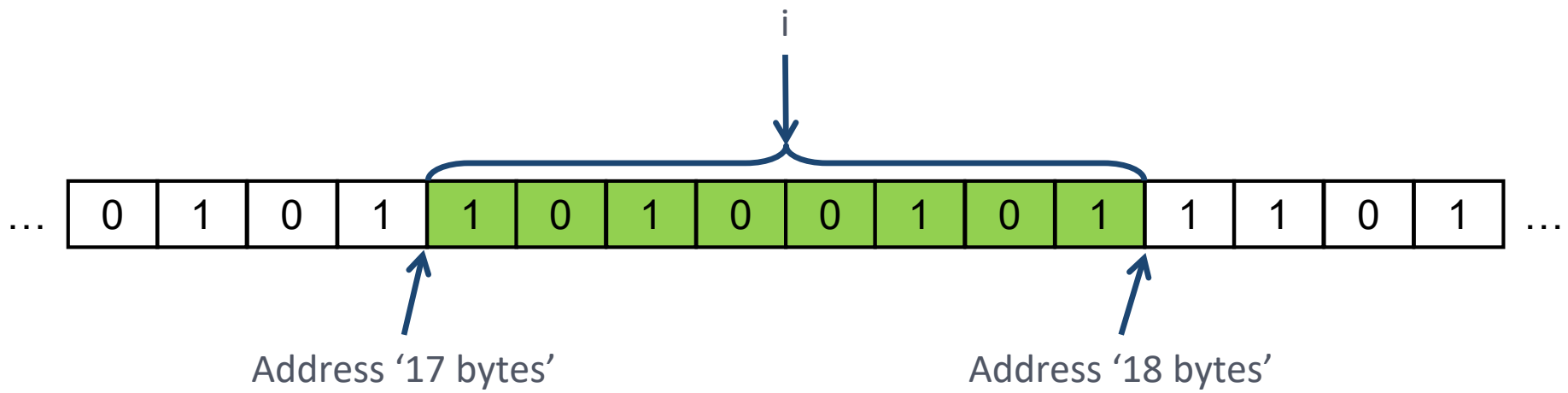
References and pointers

- Variables are stored in memory, at a given **address**

```
unsigned char i=165;
unsigned char* p=&i;
```

The variable i is stored at address 17

The variable p contains 17



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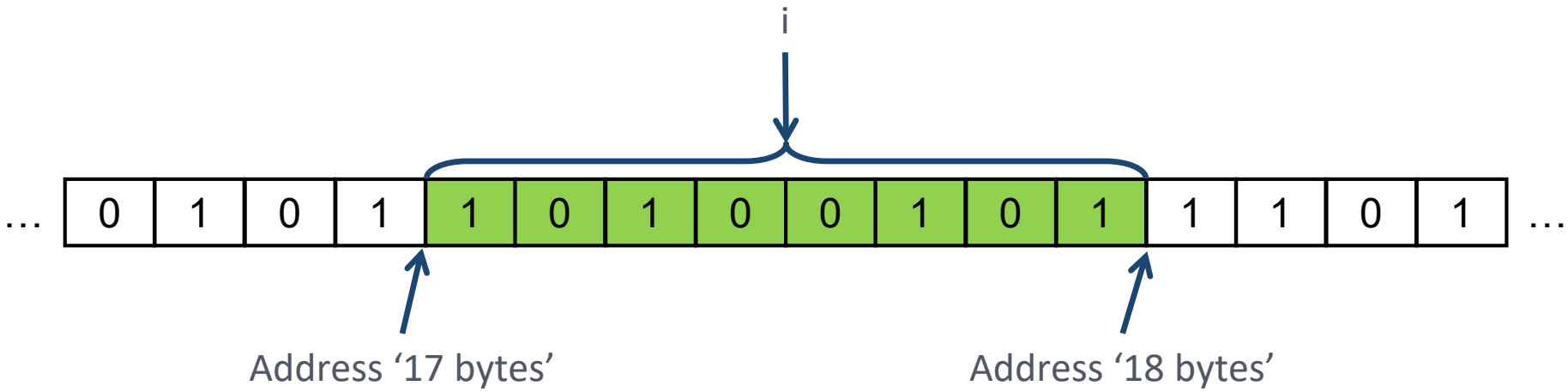


```
unsigned char* p; // p is an unsigned char*
unsigned char *p; // *p is an unsigned char
```

References and pointers

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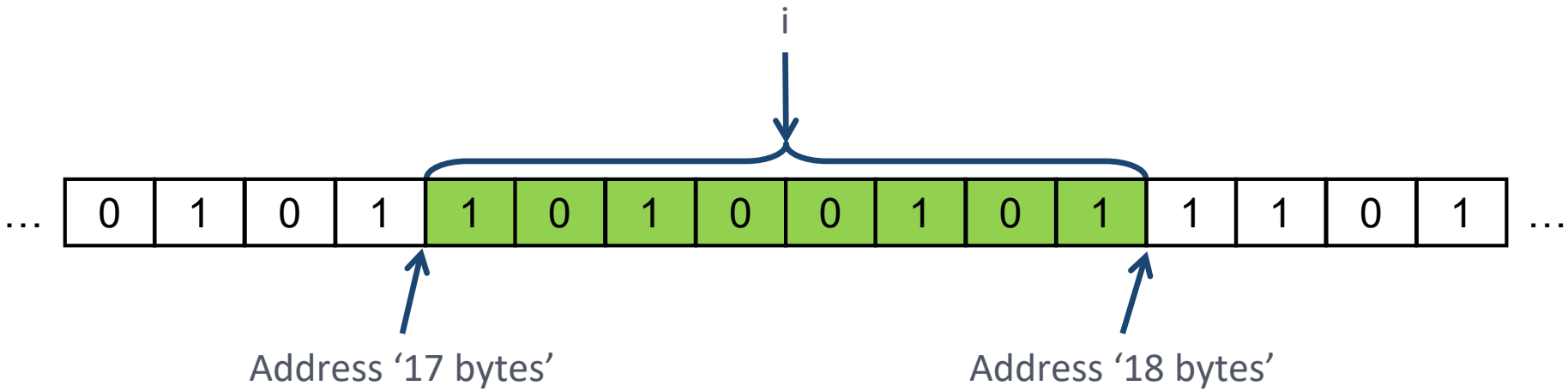

Dereferences ("depoints") pointer p

```
*p=65;                          // affects 65 to i
std::cout << *p << std::endl;   // prints A
```

References and pointers

- Variables are stored in memory, at a given **address**

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unsigned char* p=&i;
```

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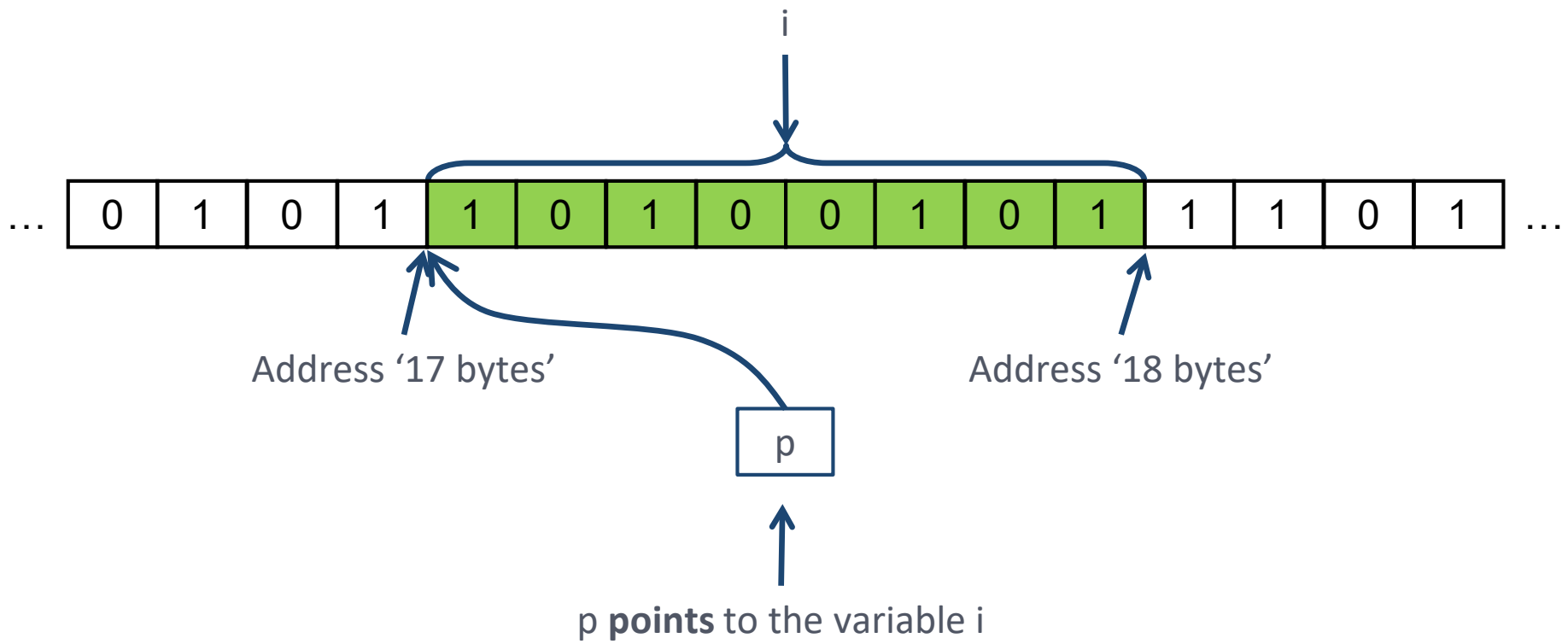
The variable p contains 17



References and pointers

- Variables are stored in memory, at a given **address**

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unsigned char i=165;
unsigned char* p=&i;
```
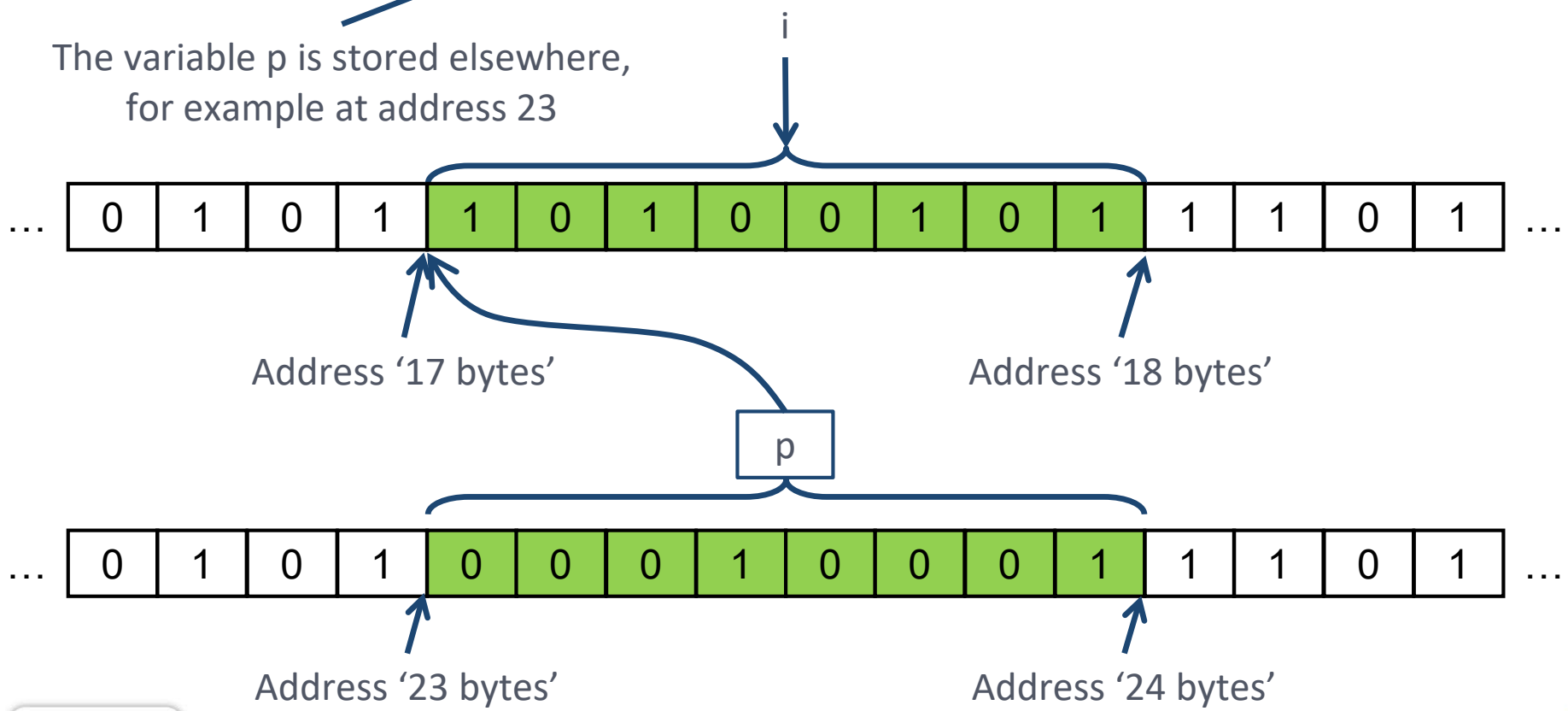

The variable i is stored at address 17

The variable p contains 17

The variable p is stored elsewhere,
for example at address 23



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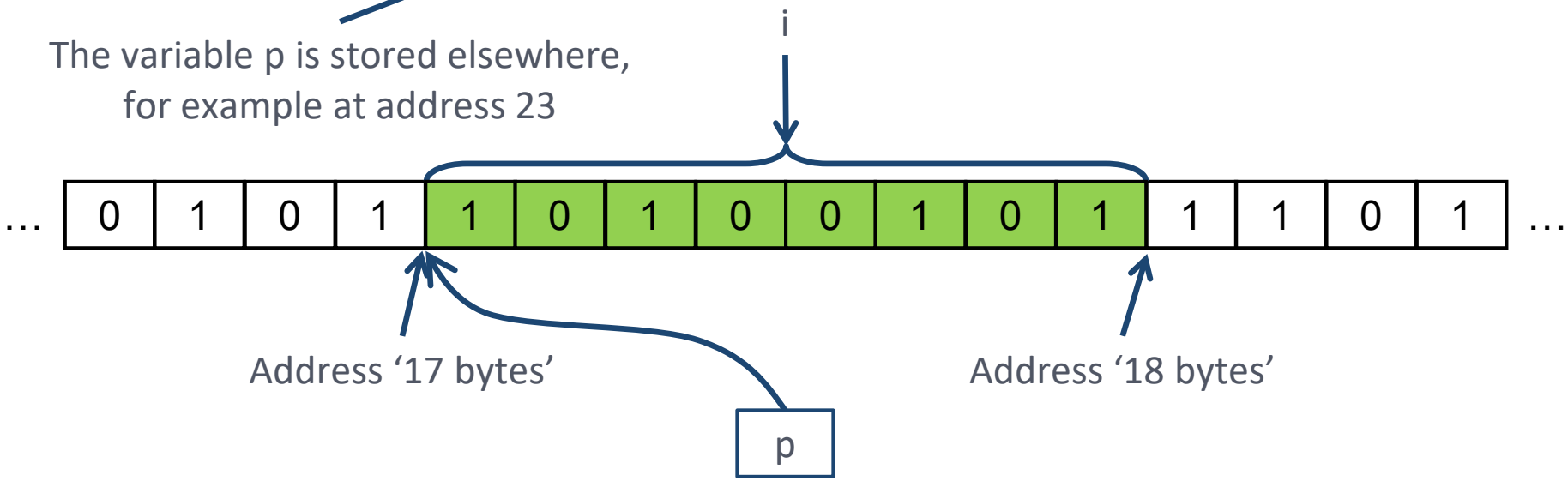

- We can perform **pointer arithmetics**

References and pointers

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```

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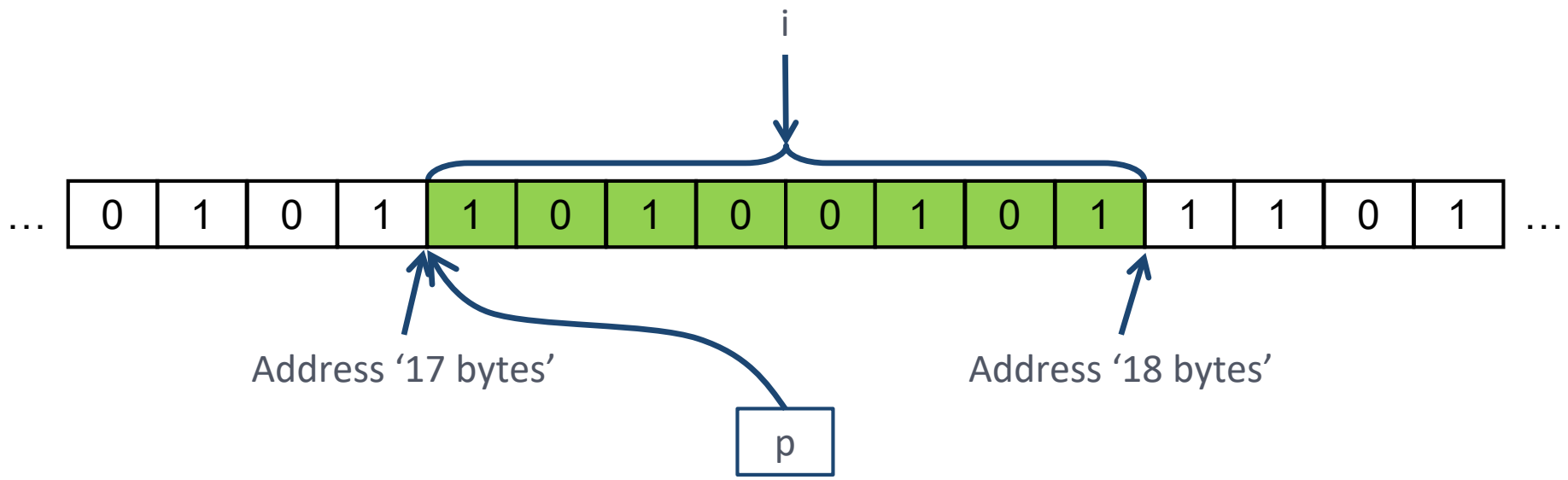
The variable p contains 17



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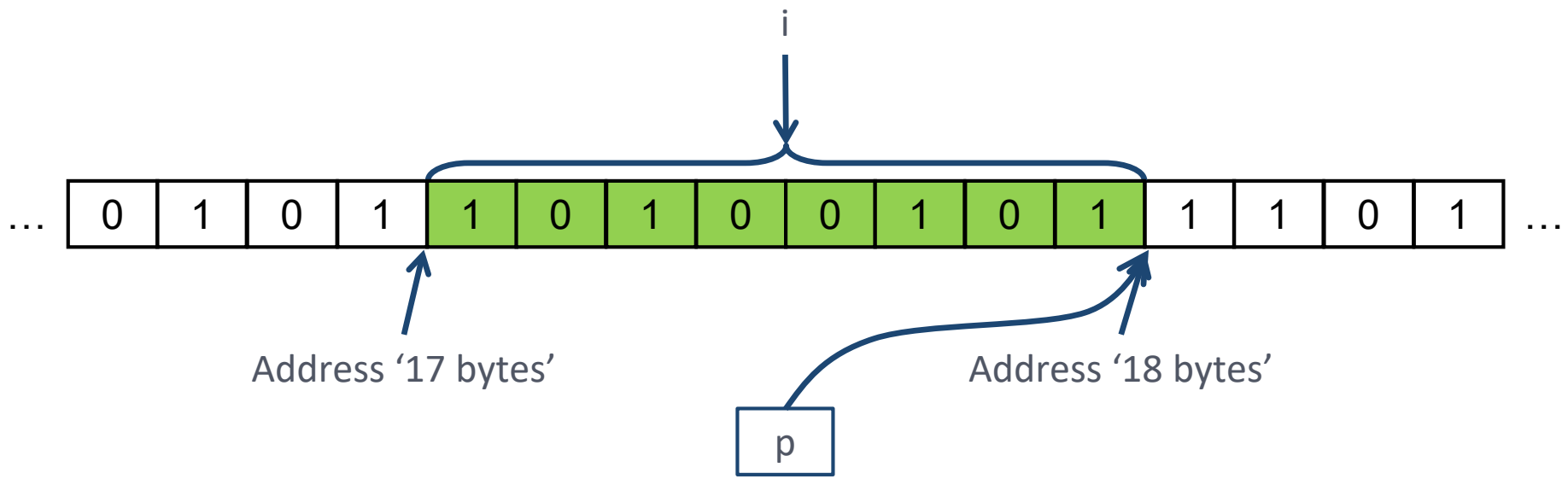


```
p++;
```

References and pointers

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unsigned char* p=&i;
```
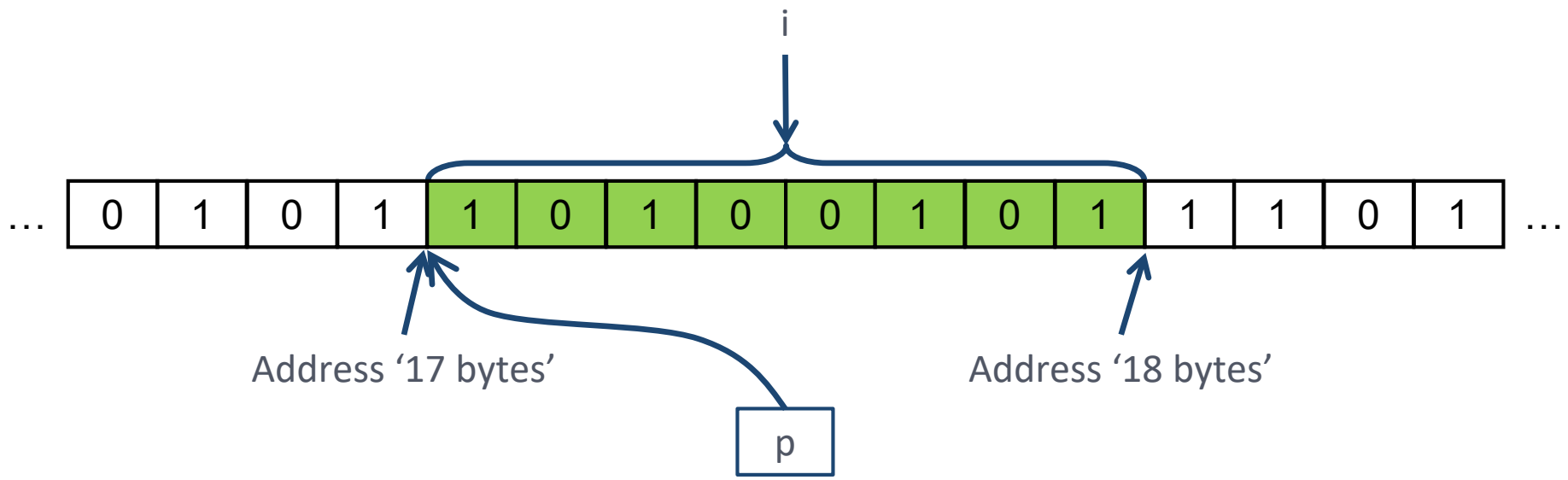

The variable i is stored at address 17

The variable p contains 17

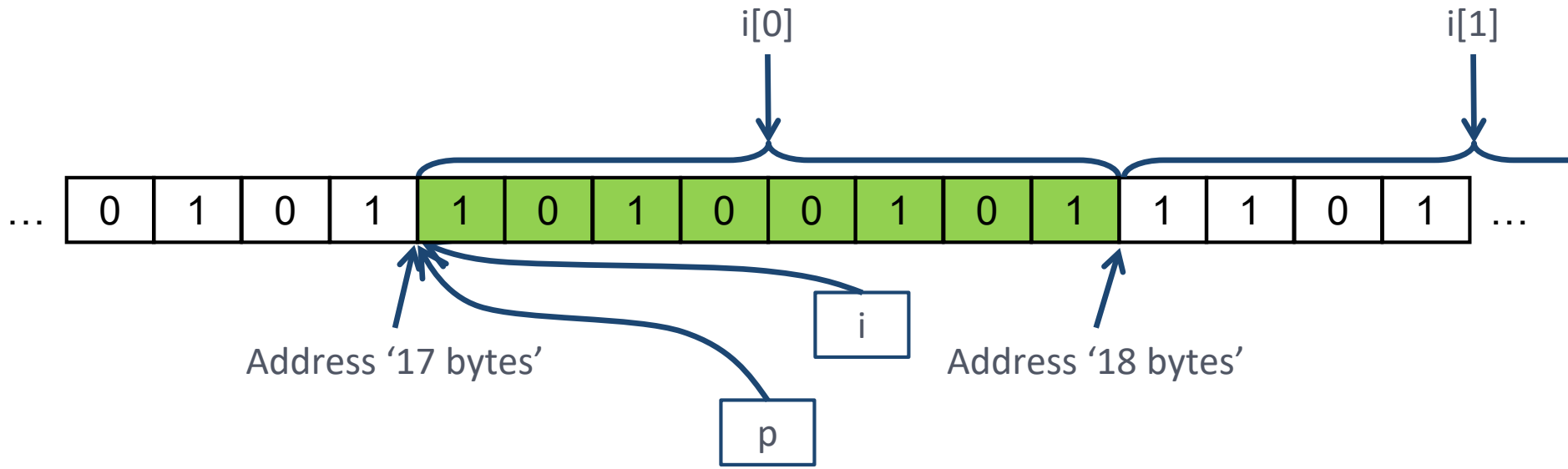



```
p--;
```

References and pointers

- A variable representing an array **“is” a pointer to the first element of the array**

```
unsigned char i[10]; // i is a pointer to the first element
unsigned char* p=i;  // p is equal to i
```



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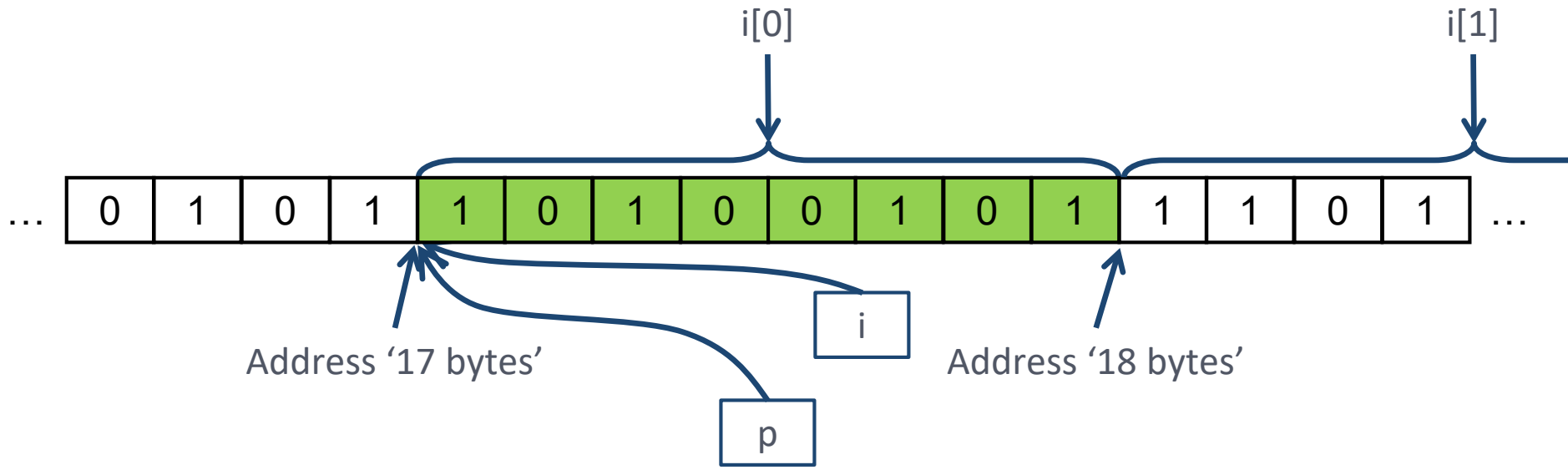


```
i[4]=65;     // affects 65 to the 5th element
std::cout << i[4] << std::endl; // prints A
```

References and pointers

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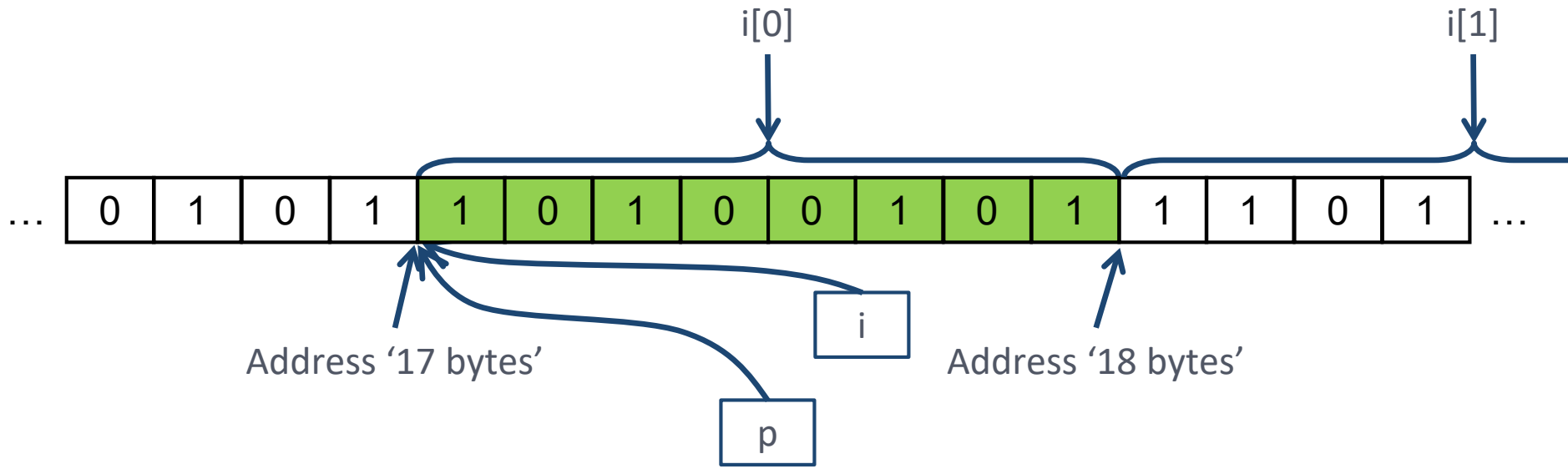
```




```
p[4]=65;     // affects 65 to the 5th element
std::cout << i[4] << std::endl; // prints A
```

References and pointers

- A variable representing an array **“is” a pointer to the first element of the array**

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unsigned char i[10]; // i is a pointer to the first element
unsigned char* p=i;  // p is equal to i
```
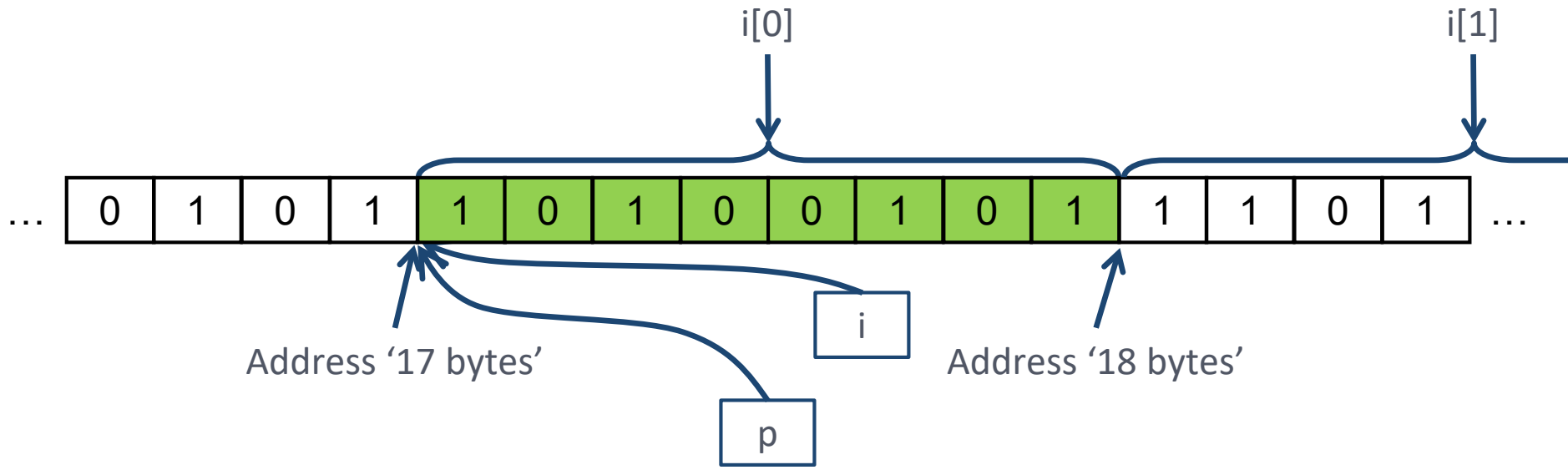




```
*(p+4)=65;  // affects 65 to the 5th element
std::cout << i[4] << std::endl; // prints A
```

Tests

Tests

- Structure

```
if (condition_statement) {

    statements

}
else {

    statements

}
```

The else block is optional

Tests

```
// check whether i is equal to 2

if (i==2) {

    std::cout << "i is equal to 2" << std::endl;

}
else {

    std::cout << "i is not equal to 2" << std::endl;

}
```

Tests

```
if ((i==2)&&(j==3)) { // && is the 'and' operator

    std::cout << "i is equal to 2" << std::endl;
    std::cout << "j is equal to 3" << std::endl;

}
else {

    std::cout << "i is not equal to 2" << std::endl;
    std::cout << "or j is not equal to 3" << std::endl;

}
```

Tests

```
if ((i==2)&(j==3)) { // evaluate both clauses before concluding

    std::cout << "i is equal to 2" << std::endl;
    std::cout << "j is equal to 3" << std::endl;

}
else {

    std::cout << "i is not equal to 2" << std::endl;
    std::cout << "or j is not equal to 3" << std::endl;

}
```

Tests

```
int i=3;
int j=3;

// test values

bool a=((i==2)&&(j==3));     // and: a is false
bool b=((i==2)||(j==3));     // or : b is true
bool c=!(i==2);              // not: c is true;
```

Loops

The for loop

- Structure

```
for (initial_statement; continuation_statement; iteration_statement) {
    statements
}
```

The for loop

```
// print hello ten times

for (int i=0;i<10;i++) std::cout << "Hello" << std::endl;

// print hello ten times

for (int i=10;i>0;i--) std::cout << "Hello" << std::endl;

// print hello ten times

for (int i=0;i<100;i=i+10) std::cout << "Hello" << std::endl;

// print hello ten times

for (double d=345.3;d<322370.45;d=-2.0*d+17.0875) std::cout << "Hello" << std::endl;
```

The for loop

```
// print hello ten times (no initial statement)

int i=0;

for (;i<10;i++) std::cout << "Hello" << std::endl;

// print hello ten times (no condition statement)

for (int i=0;;i++) {

    if (i>=10) break; // if i>=10, exit the for loop
    std::cout << "Hello" << std::endl;

}

// print hello ten times (no iteration statement)

for (int i=0;i<10;) {

    std::cout << "Hello" << std::endl;
    i++;

}
```

The for loop

```
// print hello ten times (no statements)

int i=0;

for (;;) {

    if (i>=10) break; // if i>=10, exit the for loop

    std::cout << "Hello" << std::endl;

    i++;

}
```

The for loop

```
// print hello ten times (imbricated for loops)
for (int i=0;i<2;i++) {
    for (int j=0;j<5;j++) std::cout << "Hello" << std::endl;
}
```

The while loop

- Structure

```
while (continuation_statement) {
    statements
}
```

The while loop

```
// print hello ten times
int i=0;
while (i<10) {
    std::cout << "Hello" << std::endl;
    i++;
}
```

The do-while loop

- Structure

Note: at least one iteration is performed!

```
do {

   statements

}
while (condition_statement)
```

The do-while loop

```
// print hello ten times

int i=0;

do {

    std::cout << "Hello" << std::endl;

    i++;

}
while (i<10);
```

Functions

Functions

- Functions are used to **organize large programs**, and **avoid repetition**
- Structure

```
returnTypeName functionName(arguments) {

    statements

}
```

- A function receives **zero or more arguments**
- A function has a **single return type** (may be '**void**')
- When a function has to return something, the **return** keyword is used
- A function may **call other functions**, and even **call itself** ("**recursive function**")
- Two functions with the same name but different arguments **can co-exist**

Functions

This function returns nothing

This function has no arguments

```
void printHello() {

    std::cout << "Hello" << std::endl;

}
```

Even though the function **returns nothing**,
it still **prints** something on the console

Functions

This function returns nothing

This function receives one **argument**, a double called d

```
void printNumber(double d) {

    std::cout << d << std::endl;

}
```

Even though the function **returns nothing**, it still **prints** something on the console

Functions

This function returns a double

This function receives one **argument**, a double called d

```
double multiplyByTwo(double d) {

    double result=2*d;
    return result;

}
```

This time, the function **prints nothing**, but it **returns a double**

Functions

This function returns a double

This function receives one **argument**, a double called d

```
double multiplyByTwo(double d) {

    return 2*d;

}
```

In this version, the unnecessary temporary variable **has been removed**

Functions

```
void printNumber(double d) {

    std::cout << d << std::endl;

}

double multiplyByTwo(double d) {

    return 2*d;

}

void printNumberMultipliedByTwo(double d) {

    double dMultipliedByTwo=multiplyByTwo(d);
    printNumber(dMultipliedByTwo);

}
```

This function calls **two functions** to perform its task

Functions

```
void printNumber(double d) {

    std::cout << d << std::endl;

}

double multiplyByTwo(double d) {

    return 2*d;

}

void printNumberMultipliedByTwo(double d) {

    printNumber(multiplyByTwo(d));

}
```

This function calls **two functions** to perform its task

In this version, the unnecessary temporary variable **has been removed**

Functions

This function sometimes calls itself,
it is thus **recursive**

```
int factorial(int n) {

    if (n<=1) return 1;
    return n*factorial(n-1);

}
```

Stopping condition

General case

Functions

First overloaded version

```
int multiplyByTwo(int i) {

    return 2*i;

}
```

Second overloaded version

```
double multiplyByTwo(double d) {

    return 2*d;

}
```

Arguments **must differ**

(more on this in Session 3)

Argument passing

Argument passing

- Functions may receive arguments **by value** or **by reference**
- When an argument is **passed by value, a copy of it is made**

```
void increment(int a) {

    a++;

}

int main() {

    int i=65;                       // affects 65 to i
    increment(i);                   // pass i by value to increment
    std::cout << i << std::endl;    // prints 65

    return 0;

}
```

a is a **copy** of the passed argument

Argument passing

- Functions may receive arguments **by value** or **by reference**
- When an argument is **passed by value, a copy of it is made**

```
void increment(int i) {

    i++;

}

int main() {

    int i=65;                       // affects 65 to i
    increment(i);                   // pass i by value to increment
    std::cout << i << std::endl;    // prints 65

    return 0;

}
```

i is a **copy** of the passed argument, **even if it has the same name**

Argument passing

- Functions may receive arguments **by value** or **by reference**
- When an argument is **passed by reference, it may be accessed in the function**

```
void increment(int& r) {

    r++;

}

int main() {

    int i=65;                       // affects 65 to i
    increment(i);                   // pass i by value to increment
    std::cout << i << std::endl;    // prints 66

    return 0;

}
```

r is a **reference** to the passed argument (note the &)

Argument passing

- Functions may receive arguments **by value** or **by reference**
- When an argument is **passed by reference, it may be accessed in the function**

```
void increment(int& i) {

    i++;

}

int main() {

    int i=65;                       // affects 65 to i
    increment(i);                   // pass i by value to increment
    std::cout << i << std::endl;    // prints 66

    return 0;

}
```

i is a **reference** to the passed argument (note the &)

The stack

The stack

- Second type of memory segment associated to an executable
- The stack is used for temporary memory storage:
  - variables declared in the function
  - arguments passed by value to functions

The stack

- Second type of memory segment associated to an executable
- The stack is used for temporary memory storage:
  - variables declared in the function
  - arguments passed by value to functions

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                       // affects 65 to i
    i=addToInteger(i,2);            // add 2 to i
    std::cout << i << std::endl;    // prints 67

    return 0;

}
```

How many variables are stored in the stack?

The stack

- Second type of memory segment associated to an executable
- The stack is used for temporary memory storage:
  - variables declared in the function
  - arguments passed by value to functions

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                          // affects 65 to i
    i=addToInteger(i,2);               // add 2 to i
    std::cout << i << std::endl;       // prints 67

    return 0;

}
```

These variables are stored in the stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                       // affects 65 to i
    i=addToInteger(i,2);            // add 2 to i
    std::cout << i << std::endl;    // prints 67

    return 0;

}
```

The stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                       // affects 65 to i
    i=addToInteger(i,2);            // add 2 to i
    std::cout << i << std::endl;    // prints 67

    return 0;

}
```

main	**i**	

The stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                        // affects 65 to i
    i=addToInteger(i,2);             // add 2 to i
    std::cout << i << std::endl;     // prints 67

    return 0;

}
```

main	i	65

The stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                        // affects 65 to i
    i=addToInteger(i,2);             // add 2 to i
    std::cout << i << std::endl;     // prints 67

    return 0;

}
```

main	i	65

The stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                       // affects 65 to i
    i=addToInteger(i,2);            // add 2 to i
    std::cout << i << std::endl;    // prints 67

    return 0;

}
```

addToInteger	increment	
main	i	65

The stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                       // affects 65 to i
    i=addToInteger(i,2);            // add 2 to i
    std::cout << i << std::endl;    // prints 67

    return 0;

}
```

addToInteger	increment	2
main	i	65

The stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                       // affects 65 to i
    i=addToInteger(i,2);            // add 2 to i
    std::cout << i << std::endl;    // prints 67

    return 0;

}
```

addToInteger	result	
addToInteger	increment	2
main	i	65

The stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                       // affects 65 to i
    i=addToInteger(i,2);            // add 2 to i
    std::cout << i << std::endl;    // prints 67

    return 0;

}
```

addToInteger	result	67
addToInteger	increment	2
main	i	65

The stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                       // affects 65 to i
    i=addToInteger(i,2);            // add 2 to i
    std::cout << i << std::endl;    // prints 67

    return 0;

}
```

addToInteger	result	67
addToInteger	increment	2
main	i	65

The stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                       // affects 65 to i
    i=addToInteger(i,2);            // add 2 to i
    std::cout << i << std::endl;    // prints 67

    return 0;

}
```

main	i	67

The stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                        // affects 65 to i
    i=addToInteger(i,2);             // add 2 to i
    std::cout << i << std::endl;     // prints 67

    return 0;

}
```

main	i	67

The stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                       // affects 65 to i
    i=addToInteger(i,2);            // add 2 to i
    std::cout << i << std::endl;    // prints 67

    return 0;

}
```

main	i	67

The stack

The stack

- Example execution

```
int addToInteger(int& i, int increment) {

    int result=i+increment;
    return result;

}

int main() {

    int i=65;                       // affects 65 to i
    i=addToInteger(i,2);            // add 2 to i
    std::cout << i << std::endl;    // prints 67

    return 0;

}
```

The stack

The heap

The heap

- Third type of memory segment associated to an executable
- The heap is used to allocate memory that persists between functions
- In C++, the **operator new** is used to allocate on the heap
- In C++, the **operator delete** is used to de-allocate from the heap

```
int main() {

    int* i=new int;          // i points to an int in the heap
    *i=65;                   // affects 65 to *i

    char* a=new char[10];    // a points to an array of chars in the heap
    a[4]='A';                // affects 'A' to the 5th element of the array

    delete i;                // free the memory pointed by i
    delete[] a;              // free the memory pointed by a

    return 0;

}
```

Who is on the stack? Who is in the heap?

The heap

- Example execution

```
int main() {

    // i points to an int in the heap
    int* i=new int;

    // affects 65 to *i
    *i=65;

    // a points to an array of chars in the heap
    char* a=new char[10];

    // affects 'A' to the 5th element of the array
    a[4]='A';

    // free the memory pointed by i
    delete i;

    // free the memory pointed by a
    delete[] a;

    return 0;

}
```

The stack

The heap

The heap

- Example execution

```
int main() {

    // i points to an int in the heap
    int* i=new int;

    // affects 65 to *i
    *i=65;

    // a points to an array of chars in the heap
    char* a=new char[10];

    // affects 'A' to the 5th element of the array
    a[4]='A';

    // free the memory pointed by i
    delete i;

    // free the memory pointed by a
    delete[] a;

    return 0;

}
```

main	**i**	

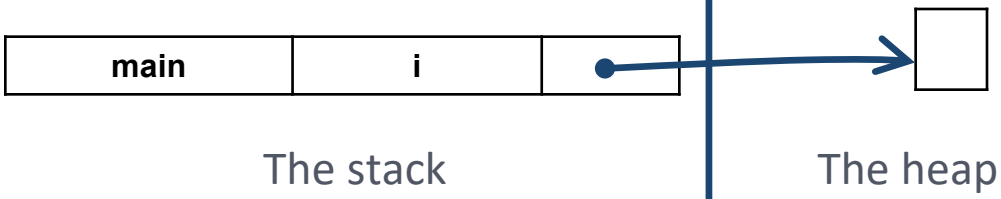
The stack

The heap

The heap

- Example execution

```
int main() {

    // i points to an int in the heap
    int* i=new int;

    // affects 65 to *i
    *i=65;

    // a points to an array of chars in the heap
    char* a=new char[10];

    // affects 'A' to the 5th element of the array
    a[4]='A';

    // free the memory pointed by i
    delete i;

    // free the memory pointed by a
    delete[] a;

    return 0;

}
```



The heap

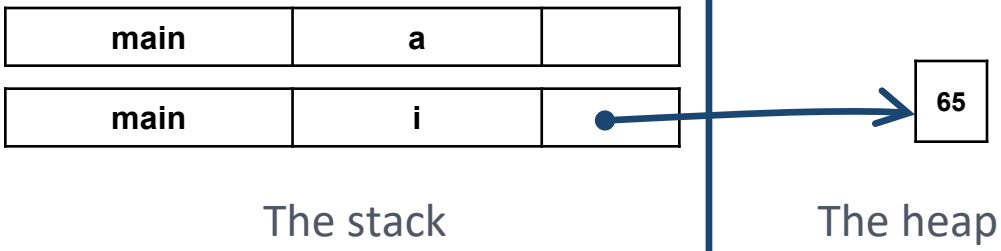
- Example execution

```
int main() {

    // i points to an int in the heap
    int* i=new int;

    // affects 65 to *i
    *i=65;

    // a points to an array of chars in the heap
    char* a=new char[10];

    // affects 'A' to the 5th element of the array
    a[4]='A';

    // free the memory pointed by i
    delete i;

    // free the memory pointed by a
    delete[] a;

    return 0;

}
```

The heap

- Example execution

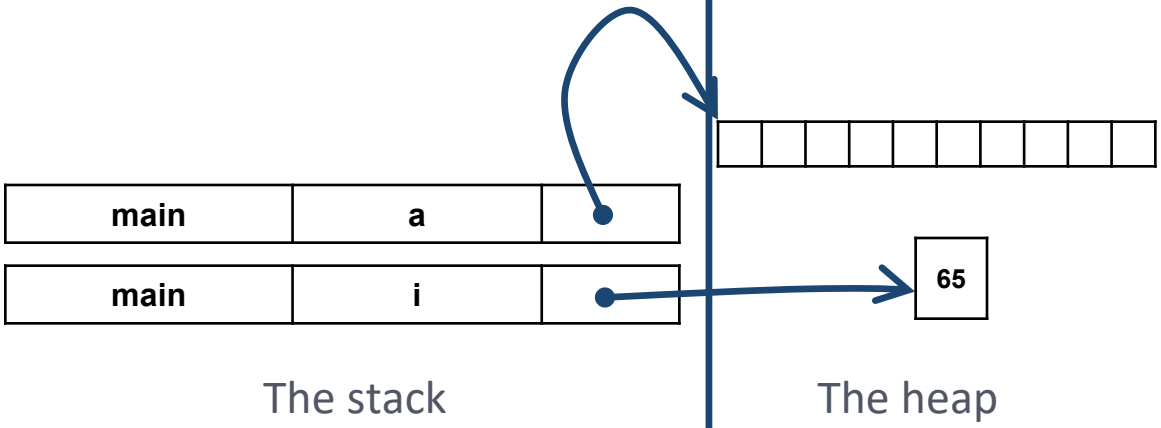
```
int main() {

    // i points to an int in the heap
    int* i=new int;

    // affects 65 to *i
    *i=65;

    // a points to an array of chars in the heap
    char* a=new char[10];

    // affects 'A' to the 5th element of the array
    a[4]='A';

    // free the memory pointed by i
    delete i;

    // free the memory pointed by a
    delete[] a;

    return 0;

}
```



The heap

- Example execution

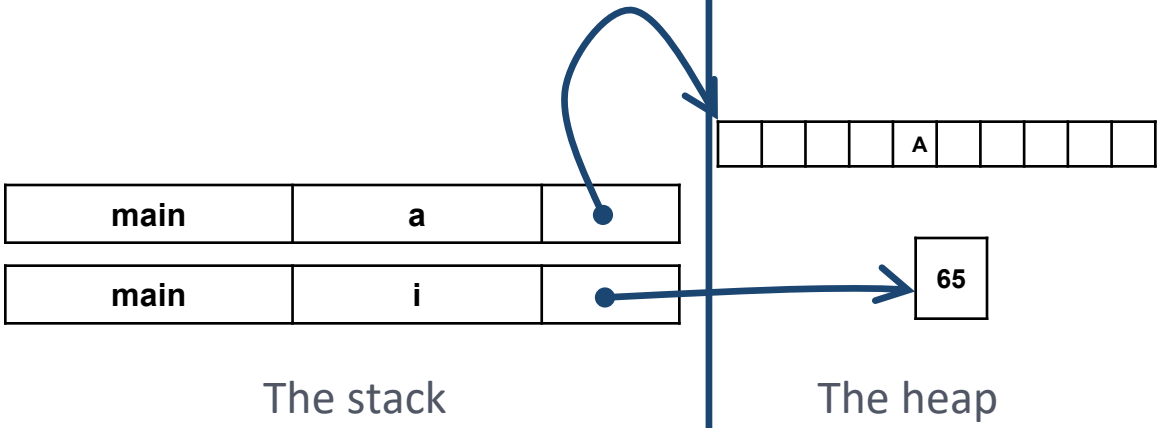
```
int main() {

    // i points to an int in the heap
    int* i=new int;

    // affects 65 to *i
    *i=65;

    // a points to an array of chars in the heap
    char* a=new char[10];

    // affects 'A' to the 5th element of the array
    a[4]='A';

    // free the memory pointed by i
    delete i;

    // free the memory pointed by a
    delete[] a;

    return 0;

}
```



The heap

- Example execution

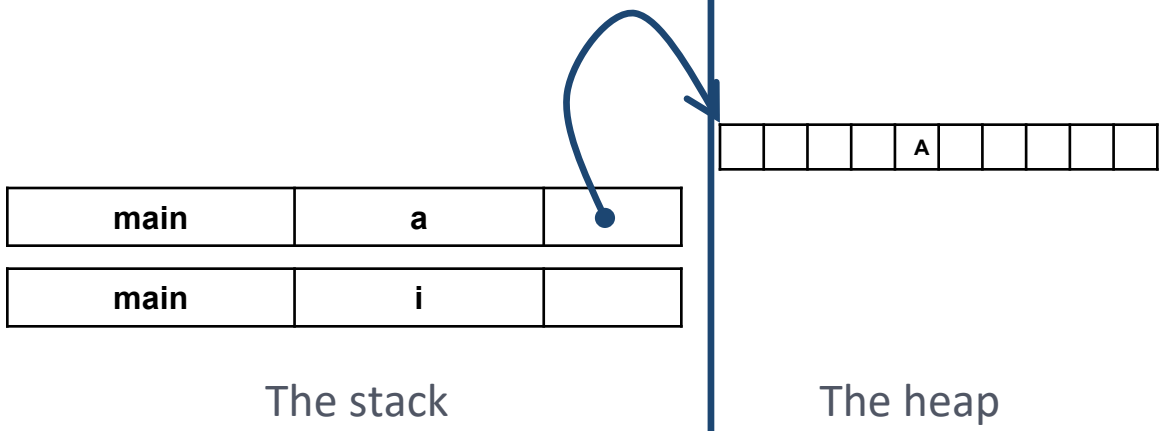
```
int main() {

    // i points to an int in the heap
    int* i=new int;

    // affects 65 to *i
    *i=65;

    // a points to an array of chars in the heap
    char* a=new char[10];

    // affects 'A' to the 5th element of the array
    a[4]='A';

    // free the memory pointed by i
    delete i;

    // free the memory pointed by a
    delete[] a;

    return 0;

}
```



The heap

- Example execution

```
int main() {

    // i points to an int in the heap
    int* i=new int;

    // affects 65 to *i
    *i=65;

    // a points to an array of chars in the heap
    char* a=new char[10];

    // affects 'A' to the 5th element of the array
    a[4]='A';

    // free the memory pointed by i
    delete i;

    // free the memory pointed by a
    delete[] a;

    return 0;

}
```



The heap

- Example execution

```
int main() {

    // i points to an int in the heap
    int* i=new int;

    // affects 65 to *i
    *i=65;

    // a points to an array of chars in the heap
    char* a=new char[10];

    // affects 'A' to the 5th element of the array
    a[4]='A';

    // free the memory pointed by i
    delete i;

    // free the memory pointed by a
    delete[] a;

    return 0;

}
```

main	**a**	
main	**i**	

The stack

The heap

The heap

- Example execution

```
int main() {

    // i points to an int in the heap
    int* i=new int;

    // affects 65 to *i
    *i=65;

    // a points to an array of chars in the heap
    char* a=new char[10];

    // affects 'A' to the 5th element of the array
    a[4]='A';

    // free the memory pointed by i
    delete i;

    // free the memory pointed by a
    delete[] a;

    return 0;

}
```

main	**a**	
main	**i**	

The stack

The heap

The heap

- Example execution

```
int main() {

    // i points to an int in the heap
    int* i=new int;

    // affects 65 to *i
    *i=65;

    // a points to an array of chars in the heap
    char* a=new char[10];

    // affects 'A' to the 5th element of the array
    a[4]='A';

    // free the memory pointed by i
    delete i;

    // free the memory pointed by a
    delete[] a;

    return 0;

}
```

The stack

The heap

Classes

Classes

- **Motivation: organize data and algorithms in large programs**

- **Objects** are data structures that may contain
  - Data members
  - Member functions

- The word "**Class**" is used to mean "**Class of objects**"
  - All objects of the same class have the same structure
  - Only **one class** with a given name, but **many objects** of the same class

- **First**, you define a class of objects, **then** you create objects of this class

- Fancy sentences:
  - "Object a is an **instance** of class A" (note the (arbitrary) capitalization)
  - "The **type of** "a" is "A""

The minimal class

The class **name**

The **class** keyword

```
class A {

};
```

There **has** to be a ;

A simple class

Access
(more on this later)

Member function

Data member

```
class A {
public:
    int i;
    void print() {
        std::cout << i << std::endl;
    }
};
```

Classes

- Declaring a class means **making a new type** (like **int**, **float**, etc.)

```
int i;          // The type of i is int
A a;            // The type of a is A
```

The type name

The variable name

Data members

Data members

Data member

```
class A {
public:
    int i;
    void print() {
        std::cout << i << std::endl;
    }
};
```

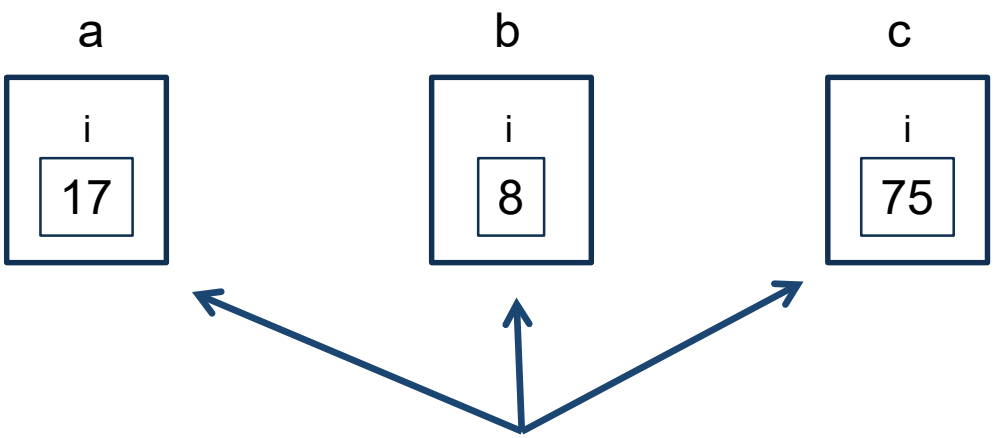
- If a class has data members, then objects of this class **each have their own instances of these variables**

```
A a;    // a has its own int i
A b;    // b has its own int i
A c;    // c has its own int i
```

- In other words, an object “contains” data

Data members

```
A a;    // a has its own int i
A b;    // b has its own int i
A c;    // c has its own int i
```

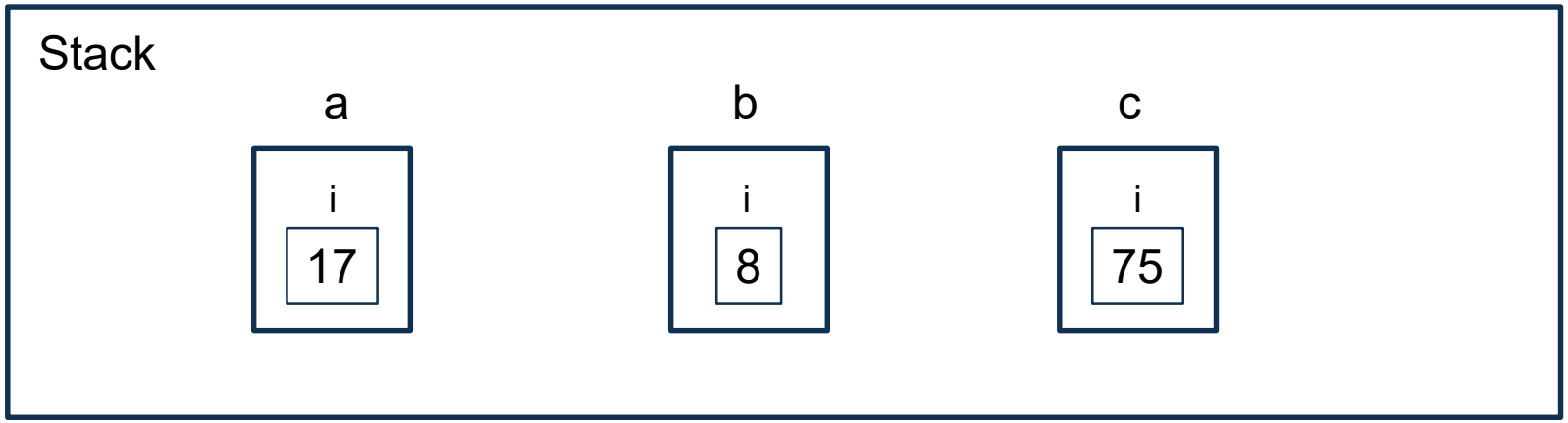


Some memory has been allocated for each object and its variables

Question: which type of memory has been used in this example?

Data members

```
A a;    // a has its own int i
A b;    // b has its own int i
A c;    // c has its own int i
```



Answer: these objects have been allocated **on the stack** ❗
(since **new** hasn't been used) (more on this later)

Data members

See the dot?

- From **outside**, data members are accessed with **.**

What about here, see the dot?

```
a.i=10; // assigns 10 to i of a
std::cout << a.i << std::endl; // outputs 10
```

Look Ma', there's a dot!

Data members

- Data members **may be objects** (this is called **composition**)

```
class A {
public:

    int i;

};

class B {
public:

    A a;

};

int main() {

    B b;
    b.a.i=10;                           // assigns 10 to i of A
    std::cout << b.a.i << std::endl;    // outputs 10

    return 0;

}
```

Data members

- An object cannot contain itself (more on this later)

```
class A {
public:

    A a;

};
```

Compilation error

Member functions

Member functions

- Member functions **have access to data members**

```
class A {

public:

    int i;

    void print() {

        std::cout << i << std::endl;

    }

};
```

This member function has access to data members

This i is the one belonging to the objects

Member functions

- From **outside**, data members **and member functions** are accessed with **.**

```
a.i=10; // assigns 10 to i of a
a.print(); // outputs 10
```

a.print() has access to a.i

Member functions

- From **outside**, data members **and member functions** are accessed with **.**

```
A a;
A b;

a.i=10; // assigns 10 to i of a
b.i=17; // assigns 17 to i of b

a.print(); // outputs 10
b.print(); // outputs 17
```

Member functions

- Example execution

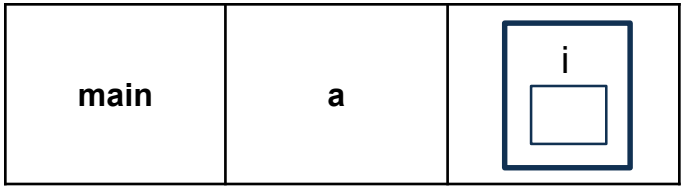
```
class A {

public:

    int i;

    void print() {

        std::cout << i << std::endl;

    }

};

int main() {

    A a;
    a.i=10; // assigns 10 to i of a
    a.print(); // outputs 10

    return 0;

}
```

The stack

Member functions

- Example execution

```
class A {

public:

    int i;

    void print() {

        std::cout << i << std::endl;

    }

};

int main() {

    A a;
    a.i=10; // assigns 10 to i of a
    a.print(); // outputs 10

    return 0;

}
```

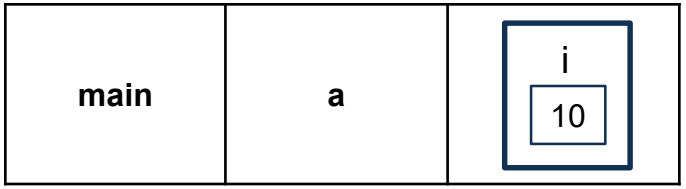


The stack

Member functions

- Example execution

```
class A {

public:

    int i;

    void print() {

        std::cout << i << std::endl;

    }

};

int main() {

    A a;
    a.i=10; // assigns 10 to i of a
    a.print(); // outputs 10

    return 0;

}
```

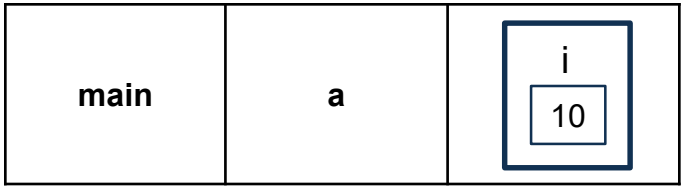


The stack

Member functions

- Example execution

```
class A {

public:

    int i;

    void print() {

        std::cout << i << std::endl;

    }

};

int main() {

    A a;
    a.i=10; // assigns 10 to i of a
    a.print(); // outputs 10

    return 0;

}
```

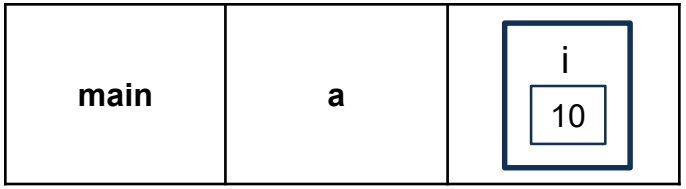


The stack

Member functions

- Example execution

```
class A {

public:

    int i;

    void print() {

        std::cout << i << std::endl;

    }

};

int main() {

    A a;
    a.i=10; // assigns 10 to i of a
    a.print(); // outputs 10

    return 0;

}
```



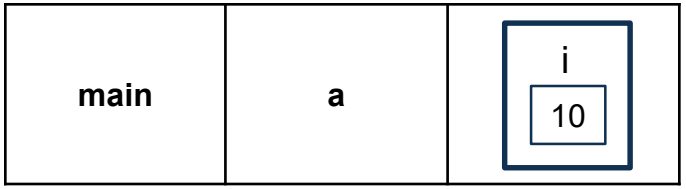
The stack

Member functions

Since we called print() of a, this is i of a

- Example execution

```
class A {

public:

    int i;

    void print() {

        std::cout << i << std::endl;

    }

};

int main() {

    A a;
    a.i=10; // assigns 10 to i of a
    a.print(); // outputs 10

    return 0;

}
```

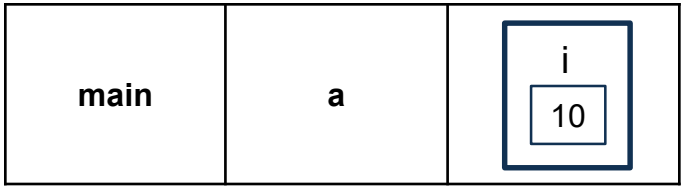


The stack

Member functions

- Example execution

```
class A {

public:

    int i;

    void print() {

        std::cout << i << std::endl;

    }

};

int main() {

    A a;
    a.i=10; // assigns 10 to i of a
    a.print(); // outputs 10

    return 0;

}
```

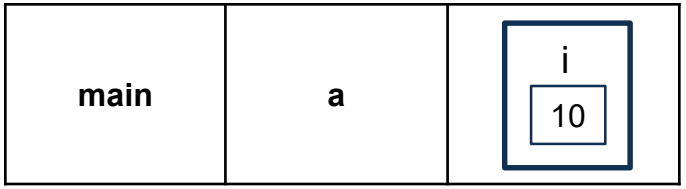


The stack

Member functions

- Example execution

```
class A {

public:

    int i;

    void print() {

        std::cout << i << std::endl;

    }

};

int main() {

    A a;
    a.i=10; // assigns 10 to i of a
    a.print(); // outputs 10

    return 0;

}
```



The stack

Member functions

- Example execution

```
class A {

public:

    int i;

    void print() {

        std::cout << i << std::endl;

    }

};

int main() {

    A a;
    a.i=10; // assigns 10 to i of a
    a.print(); // outputs 10

    return 0;

}
```

The stack

Member functions

- Member functions may also be used to **modify** data members

```
class A {

public:

    int i;

    void add(int j) { i=i+j; }
    void print() { std::cout << i << std::endl; }

};

int main() {

    A a;
    a.i=10;      // assigns 10 to i of a
    a.add(4);    // adds 4 to i of a
    a.print();   // outputs 14

    return 0;

}
```

Member functions

- Member functions may be **overloaded**

Overloaded functions

```
class A {

public:

    int i;

    void add(int j) { i=i+j; }
    void add(int j, int k) { i=i+j+k; }
    void print() { std::cout << i << std::endl; }

};

int main() {

    A a;
    a.i=10;      // assigns 10 to i of a
    a.add(4);    // adds 4 to i of a
    a.add(5,6); // adds 11 to i of a
    a.print();   // outputs 25

    return 0;

}
```

Access modifiers

Access modifiers

- Access modifiers are used to specify **who** can access data and functions
  - **public** : anyone outside the class has access
  - **private** : nobody outside the class has access
  - (more on a **third modifier** later)

- Modifiers may be used in **zero or more places**
  - **If no modifier is specified, everything is private**

Access modifiers

```
class A {
public:

    int i;

};

int main() {

    A a;
    a.i=10;                          // assigns 10 to i of A
    std::cout << a.i << std::endl;   // outputs 10

    return 0;

}
```

Everything below **public** is **accessible** from outside

Access modifiers

```
class A {
private:

    int i;

};

int main() {

    A a;
    a.i=10;                          // assigns 10 to i of A
    std::cout << a.i << std::endl;   // outputs 10

    return 0;

}
```

Everything below **private** is **inaccessible** from outside

Compiler errors

Access modifiers

```
class A {
public:

    void setI(int a) { i=a; }
    int  getI() { return i; }

private:

    int i;

};

int main() {

    A a;
    a.setI(10);                          // assigns 10 to i of A
    std::cout << a.getI() << std::endl; // outputs 10

    return 0;

}
```

A public **interface** is used to access data

Implementation details are **hidden from clients** (i.e. users)

This

This

- In each class, there is a **reserved** (hidden but usable) variable called **this**
- If the class name is **A**, the type of **this** is **A*** (pointer to an object of the class)
- The (constant) value of **this** is **the address of the object**

This

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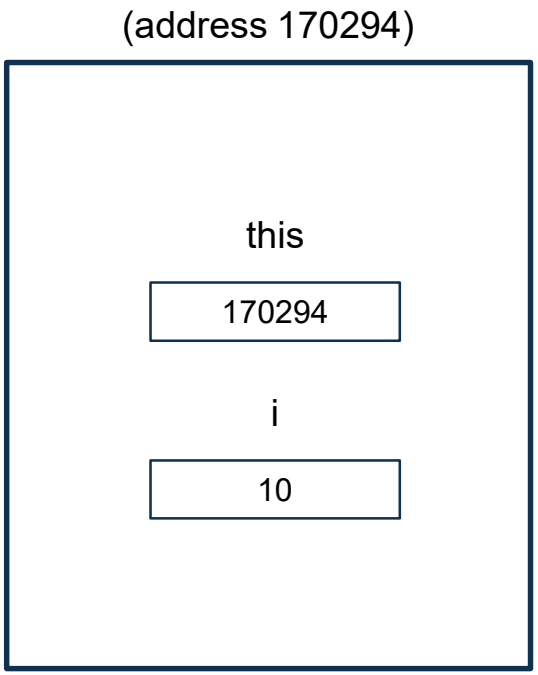
- If the class name is **A**, the type of **this** is **A*** (pointer to an object of the class)
- The (constant) value of **this** is **the address of the object**

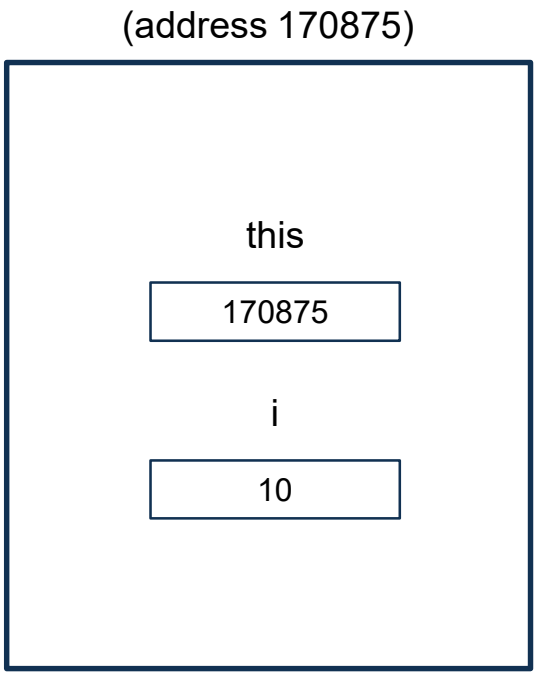
```
class A {
public:

    void setI(int a) { i=a; }
    int  getI() { return i; }

private:

    int i;

};

int main() {

    A a;
    a.setI(10);
    std::cout << a.getI() << std::endl;

    return 0;

}
```



This

- In each class, there is a **reserved** (hidden but usable) variable called **this**
- If the class name is **A**, the type of **this** is **A*** (pointer to an object of the class)
- The (constant) value of **this** is **the address of the object**

```
class A {
public:

    void setI(int a) { i=a; }
    int  getI() { return i; }

private:

    int i;

};

int main() {

    A* a=new A();
    a->setI(10);
    std::cout << a->getI() << std::endl;

    return 0;

}
```



This

- **this** may be used when there is an ambiguity between a data member and a member function argument

```
class A {
public:

    void setI(int i) { i=i; }
    int  getI() { return i; }

private:

    int i;

};
```

This

- **this** may be used when there is an ambiguity between a data member and a member function argument

If we forget **this**,
the i of the object is not changed!
(the argument has priority)

```
class A {
public:

    void setI(int i) { i=i; }
    int  getI() { return i; }

private:

    int i;

};
```

This

- **this** may be used when there is an ambiguity between a data member and a member function argument

If we forget **this**,
the i of the object is not changed!
(the argument has priority)

```
class A {
public:

    void setI(int i) { i=i; }
    int  getI() { return i; }

private:

    int i;

};
```

Here, **this** is not necessary

This

- **this** may be used when there is an ambiguity between a data member and a member function argument

this is used as a regular pointer

```
class A {
public:

    void setI(int i) { (*this).i=i; }
    int  getI() { return i; }

private:

    int i;

};
```

Here, **this** is not necessary

This

- **this** may be used when there is an ambiguity between a data member and a member function argument

this is used as a regular pointer

```
class A {
public:

    void setI(int i) { this->i=i; }
    int  getI() { return i; }

private:

    int i;

};
```

Here, **this** is not necessary

Constructors and destructors

Constructors

- Constructors are **special member functions**
  - They have the **same name as the class**
  - They have **no return type** (not even void)

- Constructors are used to initialize ("construct") objects

No return type
(not even void)

Same as the class name

```
class A {

public:

    A() { // constructor

        i=0;

    }

    int i;

};
```

Constructors

- Constructors are called automatically the first time objects are declared

```
A a;          // The constructor A() is called
```

- As other functions, constructors may have parameters

```
class A {

public:

    A()         { i=0;  } // default constructor
    A(int a)    { i=a;  } // ninja constructor

    int i;

};
```

Constructors

- Using non-default constructors may be used to simplify code

```
// using the default constructor

A a;          // The constructor A() is called
a.i=10;

// using the non-default constructor

A a(10);      // The constructor A(int a) is called
```

- The compiler automatically determines which constructor to call, **based on the arguments types**

Constructors

- If you program **no** constructors, the compiler makes a default one for you
  - (no guarantee on what it does though)

```
A a;                              // calls the implicit default constructor
std::cout << a.i << std::endl;    // outputs a random variable
```

On some compilers, this doesn't even compile
(the compiler complains that 'a' has not been initialized properly)

Destructors

- Destructors are **special member functions**
  - They have the **same name as the class, preceded with ~ (tilde)**
  - They have **no return type**

- Destructors are **called just before the object memory is released**

- Destructors are typically **used to clean up memory**

```
class A {

public:

    int* i;

    A()  { i=new int[10]; }
    ~A() { delete [] i; }

};
```

Destructors

```
class A {

public:

    int* i;

    A()  { i=new int[10]; }
    ~A() { delete [] i; }

};

int main() {

    A a; // A() is called

    for (int i=0;i<10;i++)
        std::cout << a.i[i] << std::endl;

    return 0;

} // ~A() is called
```

Destructors

```
class A {

public:

    int* i;

    A()  { i=new int[10]; }
    ~A() { delete [] i; }

};

int main() {

    A a; // A() is called

    for (int i=0;i<10;i++)
        std::cout << a.i[i] << std::endl;

    return 0;

} // ~A() is called
```

What is created on the stack?
What is created on the heap?

Destructors

The i of a (a.i) is on the stack
(since a is on the stack)

```
class A {

public:

    int* i;

    A()  { i=new int[10]; }
    ~A() { delete [] i; }

};

int main() {

    A a; // A() is called

    for (int i=0;i<10;i++)
        std::cout << a.i[i] << std::endl;

    return 0;

} // ~A() is called
```

The array is **on the heap!**
(since we use **new**)
(even though i of a, on the stack, contains its address)

a is on the stack

i is on the stack

Destructors

- There can be at most **one** destructor per class
- A destructor cannot take any arguments
- If no destructor is programmed, one is automatically written for you
- Beware of **memory leaks (= memory that cannot be deleted anymore)**

Organizing files – Part 1

Organizing files

- For large projects, **class declarations** are separated from **class definitions**
- One **header file** (e.g. A.hpp) and one **source file** (e.g. A.cpp) per class (e.g. A)

Header file: A.hpp

```
#pragma once

class A {
public:
    A();
    ~A();
    int getI();
    void setI(int i);

private:
    int i;
};
```

So that the compiler includes this file at most once

Organizing files

- For large projects, **class declarations** are separated from **class definitions**
- One **header file** (e.g. A.hpp) and one **source file** (e.g. A.cpp) per class (e.g. A)

Include A.hpp
so the compiler knows
what A means

Source file: A.cpp

```
#include "A.hpp"

A::A() {
    i=0;
}

A::~A() {
    i=0;
}

int A::getI() { return i; }
void A::setI(int i) { this->i=i; }
```

Member function definition syntax:
returnType className::functionName(arguments) {
  statements…
}

Organizing files

- For large projects, **class declarations** are separated from **class definitions**
- One **header file** (e.g. A.hpp) and one **source file** (e.g. A.cpp) per class (e.g. A)

Include A.hpp
so the compiler knows
what A means

Header file: B.hpp

```
#pragma once

#include "A.hpp"

class B {
public:
    B();
    ~B();
    A getA();
    void setA(A a);

private:
    A a;
};
```

Organizing files

- For large projects, **class declarations** are separated from **class definitions**
- One **header file** (e.g. A.hpp) and one **source file** (e.g. A.cpp) per class (e.g. A)

Include B.hpp
so the compiler knows
what B means

Source file: B.cpp

```
#include "B.hpp"

A B::getA() { return a; }
void B::setA(A a) { this->a = a; }
```

Member function definition syntax:
returnType className::functionName(arguments) {
  statements…
}

It is not necessary to include A.hpp (it is included by B.hpp)

Organizing files

- For large projects, **class declarations** are separated from **class definitions**
- One **header file** (e.g. A.hpp) and one **source file** (e.g. A.cpp) per class (e.g. A)

Source file: main.cpp

B cool →

```
#include "B.hpp"
#include <iostream>

void main() {

    A a;
    a.setI(10); // a.i = 10

    B b;
    b.setA(a);  // b.a = a

    std::cout << b.getA().getI() << std::endl;  // outputs 10

}
```

It is not necessary to include A.hpp (it is included by B.hpp)

Static members

Static data members

- Static data members do **not** depend on a specific object
- Only **one version** of a static data member exists in memory
- Static data members are **shared** among all objects

```
class A {

public:

    static int i;

};

int A::i;
```

i of A has to be defined outside the class (so that it exists somewhere in memory)

The name of the variable

The type of the static variable

The name of the class

:: is the **scope operator** (indicates where i is declared)

Static data members

```
class A {

public:

    static int i;
    void print() { std::cout << i << std::endl; }

};

int A::i;

int main() {

    A a;
    A b;

    a.i=10;      // assigns 10 to i of A
    b.print();   // outputs 10

    return 0;

}
```

Static member functions

- Static member functions do **not** depend on a specific object

- Static member functions **may only access static data members**
  (since they are common to all objects, they are not part of any **specific** object)

```
class A {
public:
    int i;
    static void print() { std::cout << i << std::endl; }
};
```

Error, i is not static

Static member functions

- Static member functions do **not** depend on a specific object

- Static member functions **may only access static data members**
  (since they are common to all objects, they are not part of any **specific** object)

```
class A {
public:
    static int i;
    static void print() { std::cout << i << std::endl; }
};
```

OK, i is static

Creating arrays of objects

Creating arrays of objects

- As with fundamental types, arrays can be created

```
A a[10];          // calls the default constructor 10 times
a[4].i=17;        // assigns 17 to the 5th object in the array
(a[4]).i=17;      // assigns 17 to the 5th object in the array
```

The dot is used to access members

The parentheses are optional

Creating objects on the heap

1Å

Creating objects on the heap

- Like fundamental variables or arrays, objects **may be created on the heap**

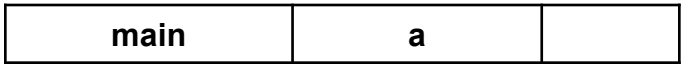
```
class A {
public:

    void setI(int a) { i=a; }
    int  getI() { return i; }

private:

    int i;

};

int main() {

    A* a=new A();                          // a is a pointer
    (*a).setI(10);                         // assigns 10 to i of A
    std::cout << (*a).getI() << std::endl; // outputs 10

    return 0;

}
```

a is a **pointer to an object** of class A

Dereferencing operator

Creating objects on the heap

```
class A {
public:

    void setI(int a) { i=a; }
    int  getI() { return i; }

private:

    int i;

};

int main() {

    A* a=new A();
    (*a).setI(10);
    std::cout << (*a).getI() << std::endl;

    return 0;

}
```

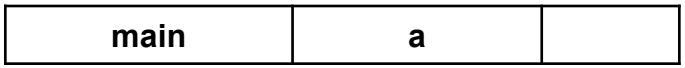


The stack

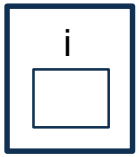
The heap

Creating objects on the heap

```
class A {
public:

    void setI(int a) { i=a; }
    int  getI() { return i; }

private:

    int i;

};

int main() {

    A* a=new A();
    (*a).setI(10);
    std::cout << (*a).getI() << std::endl;

    return 0;

}
```



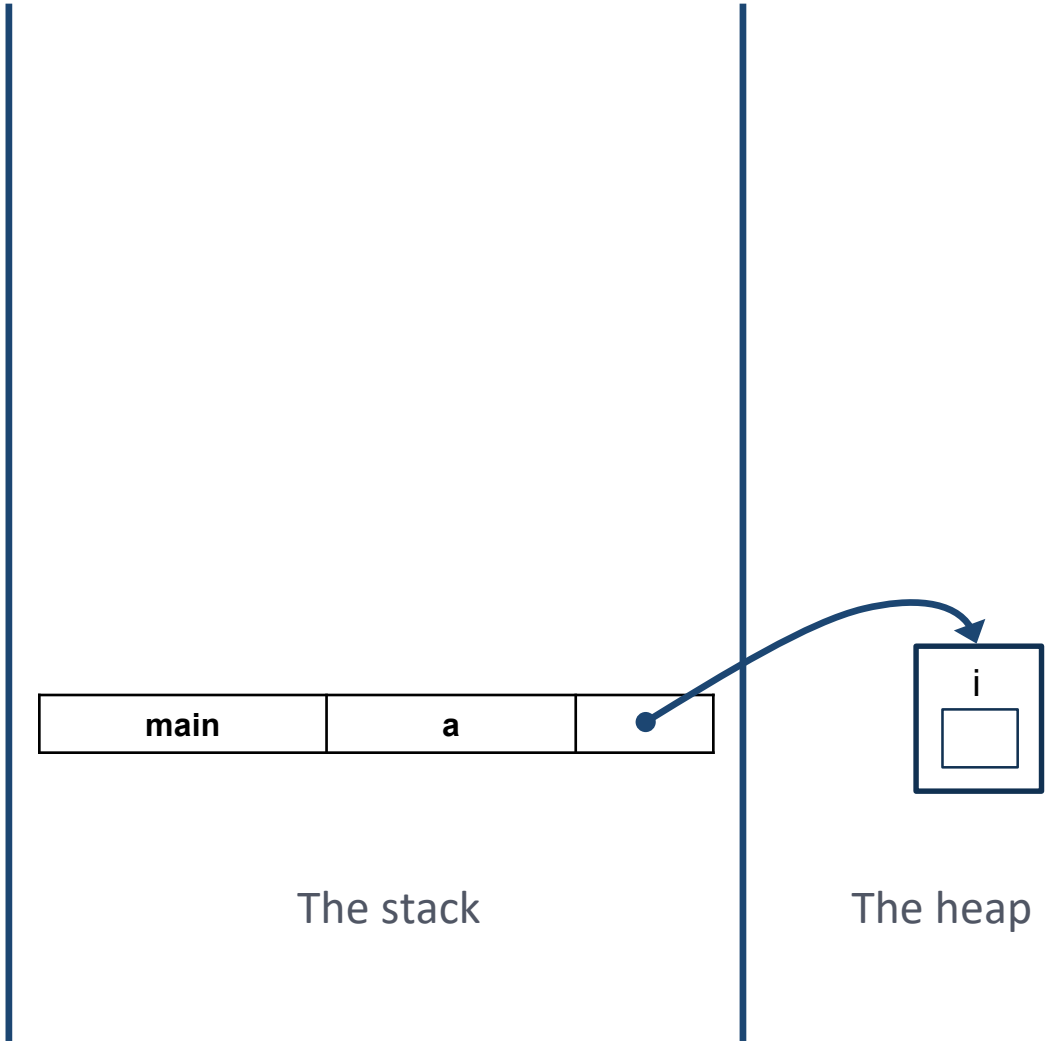
The stack



The heap

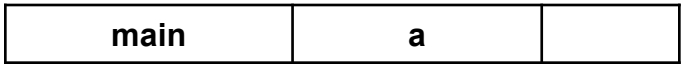
Creating objects on the heap

```
class A {
public:

    void setI(int a) { i=a; }
    int  getI() { return i; }

private:

    int i;

};

int main() {

    A* a=new A();
    (*a).setI(10);
    std::cout << (*a).getI() << std::endl;

    return 0;

}
```

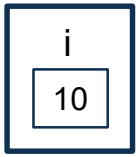


Creating objects on the heap

```
class A {
public:

    void setI(int a) { i=a; }
    int  getI() { return i; }

private:

    int i;

};

int main() {

    A* a=new A();
    (*a).setI(10);
    std::cout << (*a).getI() << std::endl;

    return 0;

}
```



The stack



The heap

Creating objects on the heap

- Like fundamental variables or arrays, objects **may be created on the heap**

```
class A {
public:

    void setI(int a) { i=a; }
    int  getI() { return i; }

private:

    int i;

};

int main() {

    A* a=new A();                          // a is a pointer
    (*a).setI(10);                         // assigns 10 to i of A
    std::cout << (*a).getI() << std::endl; // outputs 10

    return 0;

}
```

a is a **pointer to an object** of class A

Dereferencing operator

Creating objects on the heap

- Like fundamental variables or arrays, objects **may be created on the heap**

```
class A {
public:

    void setI(int a) { i=a; }
    int  getI() { return i; }

private:

    int i;

};

int main() {

    A* a=new A();                          // a is a pointer
    *a.setI(10);                           // assigns 10 to i of A
    std::cout << *a.getI() << std::endl;   // outputs 10

    return 0;

}
```

Parentheses are necessary (* has low priority)

Creating objects on the heap

- Like fundamental variables or arrays, objects **may be created on the heap**

```
class A {
public:

    void setI(int a) { i=a; }
    int  getI() { return i; }

private:

    int i;

};

int main() {

    A* a=new A();                          // a is a pointer
    a->setI(10);                           // assigns 10 to i of A
    std::cout << a->getI() << std::endl;   // outputs 10

    return 0;

}
```

This is **an arrow that points to the content of *a**

Creating objects on the heap

- Like fundamental variables or arrays, objects **may be created on the heap**

```
class A {
public:

    void setI(int a) { i=a; }
    int  getI() { return i; }

private:

    int i;

};

int main() {

    A* a=new A();                          // a is a pointer
    a->setI(10);                           // assigns 10 to i of A
    std::cout << a->getI() << std::endl;   // outputs 10

    return 0;

}
```

The variable a **points to an object of class A**

Argument passing

Argument passing

- Objects may be passed to functions (member or not) **by value** or **by reference**

- When an object is **passed by value, a copy of it is made (might be slow)**

```
class A {
public:

    A(int i) { this->i=i; }
    int i;

};

void increment(A o) {
    o.i++;
}

int main() {

    A a(10);                        // a.i=10
    increment(a);                   // does nothing to a
    std::cout << a.i << std::endl;  // outputs 10
    return 0;

}
```

o is a **copy** of the passed argument

o is **destroyed** when we exit increment

Argument passing

- Objects may be passed to functions (member or not) **by value** or **by reference**

- When an object is **passed by value, a copy of it is made (might be slow)**

```
class A {
public:

    A(int i) { this->i=i; }
    int i;

};

void increment(A a) {
    a.i++;
}

int main() {

    A a(10);                        // a.i=10
    increment(a);                   // does nothing to a
    std::cout << a.i << std::endl;  // outputs 10
    return 0;

}
```

Even if the argument 'a' has the same name, it is **still a copy**

The copy 'a' is **destroyed** when we exit increment

Argument passing

- Objects may be passed to functions (member or not) **by value** or **by reference**
- When an object is **passed by value, a copy of it is made (might be slow)**

```
class A {
public:

    A(int i) { this->i=i; }
    int i;

};

void increment(A& r) {
    r.i++;
}

int main() {

    A a(10);                        // a.i=10
    increment(a);                   // increments a.i
    std::cout << a.i << std::endl;  // outputs 11
    return 0;

}
```

'r' is a **reference to** (another name for) the passed argument

This modifies 'a'

The reference 'r' is **forgotten** when we exit increment

Overloading operators

Overloading operators

```
class A {
public:

    A(int i) { this->i=i; }
    A plus(A a) { return A(i+a.i); }
    int getI() { return i; }

private:
    int i;
};

int main() {

    A a(10);                              // a.i=10
    A b(10);                              // b.i=10
    A c=a.plus(b);                        // c.i=a.i+b.i
    std::cout << c.getI() << std::endl; // outputs 20
    return 0;

}
```

Overloading operators

getI() is not necessary here!
('plus' and 'i' belong to the same class)

```
class A {
public:

    A(int i) { this->i=i; }
    A plus(A a) { return A(i+a.i); }
    int getI() { return i; }

private:
    int i;
};

int main() {

    A a(10);                              // a.i=10
    A b(10);                              // b.i=10
    A c=a.plus(b);                        // c.i=a.i+b.i
    std::cout << c.getI() << std::endl; // outputs 20
    return 0;

}
```

Overloading operators

```
class A {
public:

    A(int i) { this->i=i; }
    A plus(A a) { return A(i+a.i); }
    int getI() { return i; }

private:
    int i;
};

int main() {

    A a(10);                                // a.i=10
    A b(10);                                // b.i=10
    A c=a.plus(b);                          // c.i=a.i+b.i
    std::cout << c.getI() << std::endl; // outputs 20
    return 0;

}
```

Asymmetric syntax

Overloading operators

```
class A {
public:

    A(int i) { this->i=i; }
    A operator+(A a) { return A(i+a.i); }
    int getI() { return i; }

private:
    int i;
};

int main() {

    A a(10);                                // a.i=10
    A b(10);                                // b.i=10
    A c=a+b;                                // c.i=a.i+b.i
    std::cout << c.getI() << std::endl; // outputs 20
    return 0;

}
```

Symmetric syntax!

Overloading operators

Object passed by reference (more efficient)

```
class A {
public:

    A(int i) { this->i=i; }
    A operator+(A& a) { return A(i+a.i); }
    int getI() { return i; }

private:
    int i;
};

int main() {

    A a(10);                                // a.i=10
    A b(10);                                // b.i=10
    A c=a+b;                                // c.i=a.i+b.i
    std::cout << c.getI() << std::endl; // outputs 20
    return 0;

}
```

Inheritance

Inheritance

- Inheritance is a C++ mechanism that makes it possible to reuse functionality

- Inheritance **should mean 'is a'**

A is a **base class** of B

B is a **derived class** of A

```
class A {
public:

    int i;
};

class B : public A {
public:

    int j;

};

int main() {

    B b;
    b.i=10; // assigns 10 to b.i
    b.j=20; // assigns 20 to b.j

    return 0;

}
```

B **inherits** A
(everything public in A is public in B)

An object of class B is an object of class A,
with something more

Inheritance

- Inheritance is a C++ mechanism that makes it possible to reuse functionality

- Inheritance **should mean 'is a'**

```
class A {
public:
    int i;
    int getI() { return i; }
};

class B : public A {
public:
    int j;
    int getJ() { return j; }
};

int main() {

    B b;
    b.i=10;                                  // assigns 10 to b.i
    b.j=20;                                  // assigns 20 to b.j
    std::cout << b.getI() << std::endl; // outputs 10
    return 0;

}
```

Public functions of A are public in B

Inheritance

- Inheritance is a C++ mechanism that makes it possible to reuse functionality

- Inheritance **should mean 'is a'**

```
class A {
public:
    int getI() { return i; }
private:
    int i;
};

class B : public A {
public:
    int j;
    void print() { std::cout << i << std::endl; }
};
```

i is private in A, so this does not compile

Inheritance

- Inheritance is a C++ mechanism that makes it possible to reuse functionality

- Inheritance **should mean 'is a'**

```
class A {
public:
    int getI() { return i; }
private:
    int i;
};

class B : public A {
public:
    int j;
    void print() { std::cout << getI() << std::endl; }
};
```

getI() is public in A, so this compiles

Inheritance

- Inheritance is a C++ mechanism that makes it possible to reuse functionality

- Inheritance **should mean 'is a'**

```
class A {
public:
    int getI() { return i; }
protected:
    int i;
};

class B : public A {
public:
    int j;
    void print() { std::cout << i << std::endl; }
};
```

i is **protected**, so is accessible through **public inheritance**

Inheritance

- When constructing a derived object, a base constructor is called first
- When destructing a derived object, the base destructor is called after

```
class A {
public:
    A() { i=0; }
    ~A() {}
protected:
    int i;
};

class B : public A {
public:
    B() { j=0; }
    ~B() {}
protected:
    int j;
};

int main() {

    B b;        // calls A(), then B()
    return 0;

} // calls ~B(), then ~A()
```

Virtual functions

Virtual functions

- A function that is redefined in a derived class **hides** the base class function

```
class A {
public:
    void print() { std::cout << "A" << std::endl; }
};

class B : public A {
public:
    void print() { std::cout << "B" << std::endl; }
};

int main() {

    B b;
    b.print(); // outputs B
    return 0;

}
```

Virtual functions

- A function that is redefined in a derived class **hides** the base class function

```
class A {
public:
    void print() { std::cout << "A" << std::endl; }
};

class B : public A {
public:
    void print() { std::cout << "B" << std::endl; }
};

int main() {

    A* b=new B();
    b->print(); // outputs A
    return 0;

}
```

Virtual functions

- The code of a virtual function is **located at runtime**, based on the object type (and not based on the variable type)

virtual keyword

```
class A {
public:
    virtual void print() { std::cout << "A" << std::endl; }
};

class B : public A {
public:
    virtual void print() { std::cout << "B" << std::endl; }
};

int main() {

    A* b=new B();
    b->print(); // outputs B
    return 0;

}
```

Virtual functions

- The code of a virtual function is **located at runtime**, based on the object type (and not based on the variable type)

virtual keyword

```
class A {
public:
    virtual void print() { std::cout << "A" << std::endl; }
};

class B : public A {
public:
    virtual void print() { std::cout << "B" << std::endl; }
};

int main() {

    A* b=new B();
    b->print(); // outputs B
    return 0;

}
```

Organizing files – Part 2

Organizing files

- For large projects, **class declarations** are separated from **class definitions**

A.hpp

So that the compiler includes this file at most once

```
#pragma once

class A {
public:
    A();
    ~A();
    int getI();
    void setI(int i);

protected:
    int i;
};
```

Organizing files

- For large projects, **class declarations** are separated from **class definitions**

  Syntax: returnType className::functionName(arguments) { statements }

A.cpp

```
#include "A.hpp"

A::A() {
    i=0;
}

A::~A() {
    i=0;
}

int A::getI() { return i; }
void A::setI(int i) { this->i=i; }
```

Organizing files

- For large projects, **class declarations** are separated from **class definitions**

So that the compiler includes this file at most once

B.hpp

Include the declaration of class A

```
#pragma once

#include "A.hpp"

class B : public A {
public:
    int getJ();
    void setJ(int j);

protected:
    int j;
};
```

Organizing files

- For large projects, **class declarations** are separated from **class definitions**

B.cpp

```
#include "B.hpp"

int B::getJ() { return j; }
void B::setJ(int j) { this->j=j; }
```

Organizing files

- For large projects, **class declarations** are separated from **class definitions**

main.cpp

```
#include "A.hpp"
#include "B.hpp"

#include <iostream>

int main() {

    A* b=new B();
    b->setI(10);                            // b.i=10
    std::cout << b->getI() << std::endl;    // outputs 10
    return 0;

}
```

Organizing files

- To prevent **#include** cycles, **forward declarations might be necessary**

A.hpp

```
#pragma once

class B;

class A {
public:
    A();
    ~A();
    int getI();
    void setI(int i);

protected:
    int i;
    B* b;
};
```

Forward declaration
(tells the compiler that B is a valid symbol)

Inheritance (Ninja)

1Å

Inheritance (Ninja)

```
class A {
public:

    int i;
};

class B : public A {
public:

    int j;

};

int main() {

    B b;
    b.i=10; // assigns 10 to b.i
    b.j=20; // assigns 20 to b.j

    return 0;

}
```

Public inheritance

Everything public in A is public in B

Inheritance (Ninja)

Base class modifier	Type of inheritance		
	Public	Protected	Private
Public	Public	Protected	Private
Protected	Protected	Protected	Private
Private	Hidden (not accessible)	Hidden (not accessible)	Hidden (not accessible)

Ninja tricks

Typedef

- The **typedef** keyword may be used to **define types**

```
class A {
public:
    int i;
};

typedef A B;

int main() {

    B b;                            // b is an object of class B=A
    b.i=10;                         // assigns 10 to b.i
    std::cout << b.i << std::endl;  // outputs 10

    return 0;

}
```

B is just another name for the class (the type) A

Constness

- The **const** keyword may be used to **specify constant values**

```
int main() {

    const int i = 17;
    i = 12;

    return 0;

}
```

This does not compile:
the value of i cannot be changed

Constness

- The **const** keyword may be used to **specify constant values**

```
int multiplyByTwo(const int i) {

    i *= 2;
    return i;

}

int main() {

    int i = 12;
    i = multiplyByTwo(i);

    return 0;

}
```

This does not compile:
the value of i cannot be changed
(the i of multiplyByTwo)

Constness

- The **const** keyword may be used to **specify constant values**

```
int multiplyByTwo(int& i) {

    return 2 * i;

}

int main() {

    int a = 17;
    int b = 8;
    int c = multiplyByTwo(a+b);

    return 0;

}
```

This does not compile:
we cannot pass a reference to the
non-const temporary value a+b

Constness

- The **const** keyword may be used to **specify constant values**

```
int multiplyByTwo(const int& i) {

    return 2 * i;

}

int main() {

    int a = 17;
    int b = 8;
    int c = multiplyByTwo(a+b);

    return 0;

}
```

This compiles:
even though a+b is a temporary value, the compiler knows we will not modify it, since the i of multiplyByTwo is a reference to a const value

Constness

- The **const** keyword may be used to **specify non-modifying functions**

```
class A {

public:

    void setI(int i) { this->i = i; }
    int getI() const { return i; }

private:

    int i;

};
```

The function getI cannot change the value of I
(this helps the compiler optimize code,
and is useful information for class clients)

Namespaces

- Namespaces may be used to **organize code** and **avoid name conflicts**

```
namespace MyNameSpace {

    class A {
    public:
        int i;
    };

}

int main() {

    MyNameSpace::A a;                // a is an object of class MyNameSpace::A
    a.i=10;                          // assigns 10 to a.i
    std::cout << a.i << std::endl;   // outputs 10

    return 0;

}
```

Namespace declaration

The scope operator :: indicates to which namespace the class belongs

Namespaces

- Namespaces may be used to **organize code** and **avoid name conflicts**

```
namespace MyNameSpace {

    class A {
    public:
        int i;
    };

}

int main() {

    A a;                          // a is an object of class MyNameSpace::A
    a.i=10;                       // assigns 10 to a.i
    std::cout << a.i << std::endl; // outputs 10

    return 0;

}
```

Namespace declaration

If the namespace is not specified, the program does not compile

Namespaces

- Namespaces may be used to **organize code** and **avoid name conflicts**

```
namespace MyNameSpace {

    class A {
    public:
        int i;
    };

}

using namespace MyNameSpace;

int main() {

    A a;                          // a is an object of class MyNameSpace::A
    a.i=10;                       // assigns 10 to a.i
    std::cout << a.i << std::endl; // outputs 10

    return 0;

}
```

Namespace declaration

The 'using' keyword specifies namespaces that the programmer wants to use

A is found in the used namespace, so there is no compiler error

Namespaces

- Namespaces may be defined in several parts

A.hpp

```cpp
#pragma once

namespace MyNameSpace {

    class A {
    public:
        int i;
    };

}
```

B.hpp

```cpp
#pragma once

#include "A.hpp"

namespace MyNameSpace {

    class B : public A {
    public:
        int j;
    };

}
```

Namespaces

main.cpp

```cpp
#include <iostream>

#include "A.hpp"
#include "B.hpp"

using namespace MyNameSpace;

int main() {

    B b;    // b is an object of class MyNameSpace::B
    b.i=10; // assigns 10 to b.i
    b.j=20; // assigns 20 to b.j

    return 0;

}
```

Namespaces

- Namespaces may be **nested**

```
namespace MyNameSpace {

    namespace MySubNameSpace1 {

        class A {
        public:
            int i;
        };

    }

    namespace MySubNameSpace2 {

        class B {
        public:
            int i;
        };

    }

}
```

First sub-namespace

Second sub-namespace

Namespaces

- Namespaces may be **nested**

Don’t hold your breath

```
int main() {

    MyNameSpace::MySubNameSpace1::A a;  // a is an object of class MyNameSpace::MySubNameSpace1::A
    MyNameSpace::MySubNameSpace2::B b;  // b is an object of class MyNameSpace::MySubNameSpace2::B

    return 0;

}
```

Namespaces

- Namespaces may be **nested**

The compiler looks for class names inside MyNameSpace

```
using namespace MyNameSpace;

int main() {

    MySubNameSpace1::A a;   // a is an object of class MyNameSpace::MySubNameSpace1::A
    MySubNameSpace2::B b;   // b is an object of class MyNameSpace::MySubNameSpace2::B

    return 0;

}
```

OK, MySubNameSpace1::A and MySubNameSpace2::B are defined in MyNameSpace

Namespaces

- Namespaces may be **nested**

The compiler looks for class names inside MyNameSpace::MySubNameSpace1

```
using namespace MyNameSpace::MySubNameSpace1;

int main() {

    A a;                    // a is an object of class MyNameSpace::MySubNameSpace1::A
    MySubNameSpace2::B b;   // b is an object of class MyNameSpace::MySubNameSpace2::B

    return 0;

}
```

The type MySubNameSpace1::B is not found inside MyNameSpace::MySubNameSpace1

Nested classes

- Classes may be **nested** (defined within other classes)

```
class A {
public:
    class B {
    public:
        int i;
    };
    B b;
};

int main() {

    A a;          // a is an object of class A
    A::B b;       // a.b is an object of class A::B
    a.b.i=10;     // a.b.i is the i of the b in a

}
```

B is defined inside A

Enumerations

- The **enum** keyword is used to assign **readable values to integers**

```
enum MyEnum {
    MyFirstValue=17,
    MySecondValue=8,
    MyThirdValue=75
};

int main() {

    MyEnum v=MyFirstValue;  // v=17

    return 0;

}
```

There **has** to be a ;

Enumerations

- The **enum** keyword is used to assign **readable values to integers**

```
class A {
public:
    enum MyEnum {
        MyFirstValue=17,
        MySecondValue=8,
        MyThirdValue=75
    };
};

int main() {

    A::MyEnum v=A::MyFirstValue;    // v=17

    return 0;

}
```

There **has** to be a ;

Function templates

Function templates

- Reminder: functions may be overloaded

```
int max(int a, int b) {

    if (a>b) return a;
    return b;

}

double max(double a, double b) {

    if (a>b) return a;
    return b;

}

int main() {

    std::cout << max(1,2) << std::endl;     // calls max(int,int) and outputs 2
    std::cout << max(1.5,2.5) << std::endl; // calls max(double,double) and outputs 2.5

    return 0;

}
```

Function templates

- Reminder: functions may be overloaded

```
int max(int a, int b) {

    if (a>b) return a;
    return b;

}

double max(double a, double b) {

    if (a>b) return a;
    return b;

}

int main() {

    std::cout << max(1,2) << std::endl;     // calls max(int,int) and outputs 2
    std::cout << max(1.5,2.5) << std::endl; // calls max(double,double) and outputs 2.5

    return 0;

}
```

Problem: how do we avoid writing functions for all useful arguments?

Function templates

- Reminder: functions may be overloaded

```
int max(int a, int b) {

    if (a>b) return a;
    return b;

}

double max(double a, double b) {

    if (a>b) return a;
    return b;

}

int main() {

    std::cout << max(1,2) << std::endl;     // calls max(int,int) and outputs 2
    std::cout << max(1.5,2.5) << std::endl; // calls max(double,double) and outputs 2.5

    return 0;

}
```

Solution: use **function templates**

Function templates

The **template** keyword

An abstract **type name** T

```
template <typename T> T max(T a, T b) {

    if (a>b) return a;
    return b;

}
```

Function templates

- The compiler **instantiates** specialized versions of the functions templates, i.e. generates specialized code **where necessary**

```
template <typename T> T max(T a, T b) {

    if (a>b) return a;
    return b;

}

int main() {

    std::cout << max(1,2) << std::endl;     // calls max(int,int) and outputs 2
    std::cout << max(1.5,2.5) << std::endl; // calls max(double,double) and outputs 2.5

    return 0;

}
```

In this example, the template is **instantiated twice**
(once for int, once for double)

Function templates

- The compiler **instantiates** specialized versions of the functions templates, i.e. generates specialized code **where necessary**

```
template <typename T> T max(T a, T b) {

    if (a>b) return a;
    return b;

}

int main() {

    std::cout << max<int>(1.5,2.5) << std::endl; // calls max(int,int) and outputs 2

    return 0;

}
```

The specialization may be **forced**
(here, the compiler generates a warning because of the conversion of the arguments)

Function templates

- If the template is not used, its code is not compiled

```
#include <iostream>

template <typename T> void function(T t) {

    the compiler does not care

}

int main() {

    std::cout << "Hello World!" << std::endl;
    return 0;

}
```

This is **not compiled**

This program compiles **just fine**

Function templates

- **If the template is not used, its code is not compiled**

```
#include <iostream>

template <typename T> void function(T t) {

    the compiler finds 15 errors in the program

}

int main() {

    std::cout << "Hello World!" << std::endl;
    function(1.0);
    return 0;

}
```

The compiler attempts to compile this

The compiler instantiates 'function' and tries to compile the instantiated version

Function templates

The **template** keyword

An abstract **type name** T

```
template <typename T> T max(T a, T b) {

    if (a>b) return a;
    return b;

}
```

In this example, the programmer assumes that the template will be used with **types for which operator > is well defined**

Function templates

```
class A {
public:
    A(int i) { this->i=i; }
    int i;
};

int main() {

    int i=max(1,2);          // calls max(int,int) and assigns 2 to i
    double d=max(1.5,2.5);   // calls max(double,double) and assigns 2.5 to d

    A a(1);
    A b(2);
    A c=max(a,b);            // does not compile ("A does not define >")

    return 0;

}
```

A does not define operator >

Function templates

A defines operator >

```
class A {
public:
    A(int i) { this->i=i; }
    int i;
    bool operator>(const A& a) { return (i>a.i); }
};

int main() {

    int i=max(1,2);          // calls max(int,int) and assigns 2 to i
    double d=max(1.5,2.5);   // calls max(double,double) and assigns 2.5 to d

    A a(1);
    A b(2);
    A c=max(a,b);            // calls max(A,A) and assigns 2 to c.i

    return 0;

}
```

Function templates

- Function templates may have several **template parameters**

- Structure

```
template <template parameters> returnType functionName(arguments) {

    statements

}
```

These may depend on template parameters

Function templates

- Function templates may have several **template parameters**

```
template <typename T1, typename T2> void print(T1 a, T2 b) {

    std::cout << a << " " << b << std::endl;

}

int main() {

    print(1,2.0);                // calls print(int,double) and outputs 1 2
    print("The answer is",42);   // calls print(char*,int) and outputs The answer is 42

    while(1);
    return 0;

}
```

Function templates

- Function templates may be **explicitly specialized**

```
template <typename T> void print(T t) {

    std::cout << "General case: " << t << std::endl;

}

template <> void print<int>(int t) {

    std::cout << "Special case for int: " << t << std::endl;

}

int main() {

    print(2.0); // calls print(double) and outputs General case: 2
    print(2);   // calls print(int) and outputs Special case for int: 2

    return 0;

}
```

Explicit specialization

Function templates

- If a regular function with matching signature exists, **it has priority**

```
#include <iostream>

template <typename T> void print(T t) {

    std::cout << "Generic template version: " << t << std::endl;

}

template <> void print<int>(int t) {

    std::cout << "Specialized template version: " << t << std::endl;

}

void print(int i) {

    std::cout << "Regular version: " << i << std::endl;

}

int main() {

    print(1.0);     // outputs Generic template version: 1
    print(1);       // outputs Regular version: 1
    print<int>(1);  // outputs Specialized template version: 1

}
```

Function templates

- Function template parameters may be **integers**

Integer template parameter

```
#include <iostream>

template <int numberOfPrints, typename T> void print(T t) {

    for (int i=0;i<numberOfPrints;i++) std::cout << t << std::endl;

}

int main() {

    print<10,int>(5); // outputs 5 ten times

    return 0;

}
```

Function templates

- To be reusable, templates definitions are typically placed in **header files** (since the compiler needs the definition to instantiate the template)

Print.hpp

```
#pragma once

#include <iostream>

template <typename T1, typename T2> void print(T1 a, T2 b) {

    std::cout << a << " " << b << std::endl;

}
```

Class templates

Class templates

- Like function templates, class templates are used to write **generic classes**

- Structure

```
template <template parameters> class className {

    statements

};
```

These may depend on template parameters

Class templates

- Template classes are **instantiated where necessary**

```
template <typename T> class A {
public:
    T t;
};

int main() {

    A<int> a;              // a.t is an int
    a.t=10;                // assigns 10 to a.t

    A<char*> b;            // b.t is a char*
    b.t=new char[10];      // assigns to b.t the address of a char array

    return 0;

}
```

The template parameter is **obligatory**

Class templates

- Template parameters **may be classes**

```
class A {
public:
    A(int i) { this->i=i; }
    int i;
};

template <typename T> class B {
public:
    B(T a) : t(a) {}
    T t;
};

int main() {

    B<A> b(A(10)); // b.t is an A, whose i is an int equal to 10
    std::cout << b.t.i << std::endl; // outputs 10

    return 0;

}
```

Class templates

- Template parameters **may be template classes**

```
template <typename T> class A {
public:
    A(T a) : t(a) {}
    T t;
};

int main() {

    A< A<int> > a(A<int>(10)); // a.t is an A<int>, whose t is an int equal to 10
    std::cout << a.t.t << std::endl; // outputs 10

    return 0;

}
```

Class templates

- Template parameters **may be template classes**

```
template <typename T> class A {
public:
    A(T a) : t(a) {}
    T t;
};

int main() {

    A< A<int> > a(A<int>(10)); // a.t is an A<int>, whose t is an int equal to 10
    std::cout << a.t.t << std::endl; // outputs 10

    return 0;

}
```

Always add a space between two consecutive '>'
(some compilers read 'operator>>')

The standard template library

Where we show a few examples of template classes and algorithms

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The standard template library (STL)

- The standard template library
  - **Standard**: provided
  - **Template**: customizable
  - **Library**: include appropriate header files to use

```
#include <iostream>

#include <string>

int main() {

    std::string s="Hello World!";    // s in a string
    std::cout << s << std::endl;     // outputs Hello World!

    return 0;

}
```

The header that declares the string class

The STL is in the namespace **std**

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The header that declares the string class

The STL is in the namespace **std**

string **is** a template class (inside 'xstring')

```
typedef basic_string<char, char_traits<char>, allocator<char> >
    string;
```

The standard template library (STL)

- The standard template library defines several useful **data structures**…
  - Lists: **std::list<T>**
  - Strings: **std::string<T>**
  - Vectors: **std::vector<T>**
  - …
- … **functionals** (e.g. objects that perform specific functions)
  - **greater<T>**
  - …
- … and **algorithms**
  - **for_each**
  - **replace**
  - **sort**
  - …

std::list<T>

- **std::list<T>** implements a **doubly-linked list**
  - O(1) push and pop (**front and back**)
  - O(n) access inside

The header that declares the list template class

```
#include <list>

int main() {

    std::list<int> l;    // l is an empty list of int
    l.push_back(20);     // l={20}
    l.push_back(30);     // l={20,30}
    l.push_front(10);    // l={10,20,30}
    l.pop_back();        // l={10,20}
    l.pop_front();       // l={10}

    return 0;

}
```

std::string

- **std::string** implements a **string of char**

The header that declares the string class

```
#include <iostream>
#include <string>

int main() {

    std::string girl; // a girl has no name
    std::cin >> girl;
    std::cout << girl << std::endl;

    return 0;

}
```

std::vector<T>

- **std::vector<T>** implements an **extensible array of elements**
  - Amortized O(1) push and pop (**back only**)
  - O(1) access inside

The header that declares the vector template class

```
#include <vector>
#include <iostream>

int main() {

    std::vector<int> v;                                  // v is an empty vector of int
    v.push_back(10);                                     // v={10}
    v.push_back(20);                                     // v={10,20}
    v.pop_back();                                        // v={10}
    v.push_back(30);                                     // v={10,30}

    std::cout << v[0] << " " << v[1] << std::endl;  // outputs 10 30

    return 0;

}
```

std::vector<T> **implements operator[]** to access vector elements

Combining templates

```
#include <list>
#include <string>
#include <vector>

int main() {

    std::string s;                                  // s is an empty string
    std::vector< std::string > v;                   // v is an empty vector of strings
    std::list< std::vector< std::string > > l;      // l is an empty list of vectors of strings

    s.push_back('a');    // s="a"
    v.push_back(s);      // v={"a"}
    l.push_back(v);      // l={{"a"}}
    l.push_back(v);      // l={{"a"},{"a"}}

    return 0;

}
```

The STL template classes have 'uniform' designs

The push_back calls insert **copies** !

Iterators

- Iterators are objects that are used to **access (iterate over) STL classes**
- They are defined inside the classes themselves

```
#include <list>
#include <iostream>

int main() {

    std::list<int> l;    // l is an empty list of int
    l.push_back(10);     // l={10}
    l.push_back(20);     // l={10,20}
    l.push_back(30);     // l={10,20,30}

    for (std::list<int>::iterator i=l.begin();i!=l.end();i++) {

        std::cout << (*i) << std::endl;

    }

    return 0;

}
```

Iterators

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```
#include <list>
#include <iostream>

int main() {

    std::list<int> l;    // l is an empty list of int
    l.push_back(10);     // l={10}
    l.push_back(20);     // l={10,20}
    l.push_back(30);     // l={10,20,30}

    for (std::list<int>::iterator i=l.begin();i!=l.end();i++) {

        std::cout << (*i) << std::endl;

    }

    return 0;

}
```

i is an **iterator**

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```
#include <list>
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int main() {

    std::list<int> l;    // l is an empty list of int
    l.push_back(10);     // l={10}
    l.push_back(20);     // l={10,20}
    l.push_back(30);     // l={10,20,30}

    for (std::list<int>::iterator i=l.begin();i!=l.end();i++) {

        std::cout << (*i) << std::endl;

    }

    return 0;

}
```

l.begin() and l.end() are **iterators**

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```
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#include <iostream>

int main() {

    std::list<int> l;    // l is an empty list of int
    l.push_back(10);     // l={10}
    l.push_back(20);     // l={10,20}
    l.push_back(30);     // l={10,20,30}

    for (std::list<int>::iterator i=l.begin();i!=l.end();i++) {

        std::cout << (*i) << std::endl;

    }

    return 0;

}
```

The iterator **implements operator++** (which moves to the next element)

Iterators

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```
#include <list>
#include <iostream>

int main() {

    std::list<int> l;    // l is an empty list of int
    l.push_back(10);     // l={10}
    l.push_back(20);     // l={10,20}
    l.push_back(30);     // l={10,20,30}

    for (std::list<int>::iterator i=l.begin();i!=l.end();i++) {

        std::cout << (*i) << std::endl;

    }

    return 0;

}
```

The iterator **implements the dereferencing operator**

Iterators

- Iterators are objects that are used to **access (iterate over) STL classes**
- They are defined inside the classes themselves

```
#include <list>
#include <iostream>

int main() {

    std::list<int> l;    // l is an empty list of int
    l.push_back(10);     // l={10}
    l.push_back(20);     // l={10,20}
    l.push_back(30);     // l={10,20,30}

    for (std::list<int>::iterator i=l.begin();i!=l.end();i++) {

        std::cout << (*i) << std::endl;

    }

    return 0;

}
```

The type of i is std::list<int>::iterator, so the type of *i is int

Iterators

- Iterators are objects that are used to **access (iterate over) STL classes**
- They are defined inside the classes themselves

```
#include <list>
#include <iostream>

int main() {

    std::list<int> l;    // l is an empty list of int
    l.push_back(10);     // l={10}
    l.push_back(20);     // l={10,20}
    l.push_back(30);     // l={10,20,30}

    for (std::list<int>::iterator i=l.begin();i!=l.end();i++) {

        std::cout << (*i) << std::endl;

    }

    return 0;

}
```

Think of iterators as **pointers that know how to move within the data structure**

std::greater<T>

- std::greater<T> is a **functional** (a structure which contains a function)

```
#include <iostream>
#include <functional>

int main() {

    int i=10;   // this should be clear
    int j=20;   // this should be clear as well

    std::greater<int> g;    // g is a functional (a structure which contains a function)
    bool result=g(i,j);     // result=(i>j)

    return 0;

}
```

for_each

- **for_each** is a template algorithm used to apply operations to ranges

Structure

```
template<typename IteratorType, typenameFunctionType> FunctionType
    for_each(IteratorType first, IteratorType last, FunctionType function );
```

for_each

- **for_each** is a template algorithm used to apply operations to ranges

```
#include <list>
#include <algorithm>
#include <iostream>

class Printer {
public:
    void operator()(int i) { std::cout << i << " "; }
};

int main() {

    Printer p;                      // p is a Printer
    std::list<int> l;               // l is an empty list of int
    l.push_back(10);                // l={10}
    l.push_back(20);                // l={10,20}
    l.push_back(30);                // l={10,20,30}
    for_each(l.begin(),l.end(),p);  // outputs 10 20 30

    return 0;

}
```

for_each is defined here

for_each **needs a definition of operator()**

for_each

Temporary object (slow)

```
#include <list>
#include <algorithm>
#include <iostream>
#include <functional>

template <typename T> class ComparisonPrinter {
public:
    ComparisonPrinter(T a) : t(a) {}
    void operator()(T i) { std::cout << std::greater<T>()(t,i) << " "; }
    T t;
};

int main() {

    ComparisonPrinter<int> p(15);   // p is a ComparisonPrinter<int> and p.t=15
    std::list<int> l;               // l is an empty list of int
    l.push_back(10);                // l={10}
    l.push_back(20);                // l={10,20}
    l.push_back(30);                // l={10,20,30}

    for_each(l.begin(),l.end(),p);  // outputs 1 0 0

    return 0;

}
```

replace

- replace is a template algorithm used to replace elements in ranges

```
#include <list>
#include <algorithm>

int main() {

    std::list<int> l;                    // l is an empty list of int
    l.push_back(10);                     // l={10}
    l.push_back(20);                     // l={10,20}
    l.push_back(10);                     // l={10,20,10}
    l.push_back(30);                     // l={10,20,10,30}
    replace(l.begin(),l.end(),10,15);    // l={15,20,15,30}

    return 0;

}
```

replace is defined here

sort

- sort is a template algorithm used to sort values in ranges

```
#include <vector>
#include <algorithm>

int main() {

    std::vector<int> v;                    // v is an empty vector of int
    v.push_back(10);                       // v={10}
    v.push_back(40);                       // v={10,40}
    v.push_back(20);                       // v={10,40,20}
    v.push_back(30);                       // v={10,40,20,30}
    sort(v.begin(),v.end());               // v={10,20,30,40}

    return 0;

}
```

sort is defined here

sort

- sort is a template algorithm used to sort values in ranges

```
#include <vector>
#include <algorithm>

class A {
public:
    A(int i) { this->i=i; }
    int i;
};

bool compare(A a, A b) { return (a.i<b.i); }

int main() {

    std::vector<A> v;                    // v is an empty vector of A
    v.push_back(A(10));                  // v={A(10)}
    v.push_back(A(30));                  // v={A(10),A(30)}
    v.push_back(A(20));                  // v={A(10),A(30),A(20)}
    v.push_back(A(40));                  // v={A(10),A(30),A(20),A(40)}
    sort(v.begin(),v.end(),compare);     // v={A(10),A(20),A(30),A(40)}

    return 0;

}
```

Comparison function

That’s all, folks!

- Congratulations!
- To apply what you’ve learned, head to the documentation center of the SAMSON platform for molecular modeling, create apps and distribute them on SAMSON Connect!

https://documentation.samson-connect.net