Modern C++ for Computer Vision and Image Processing

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Outline

Using pointers

Pointers are polymorphic

Pointer “this”

Using const with pointers

Stack and Heap

Memory leaks and dangling pointers

- Memory leak
- Dangling pointer
- RAII

Using pointers in real world

Using pointers for classes

- Pointers can point to objects of custom classes:

```
std::vector<int> vector_int;
std::vector<int>* vec_ptr = &vector_int;
MyClass obj;
MyClass* obj_ptr = &obj;
```

- Call object functions from pointer with `->`

```
MyClass obj;
obj.MyFunc();
MyClass* obj_ptr = &obj;
obj_ptr->MyFunc();
```

- `obj->Func()` ↔ `(*obj).Func()`

Pointers are polymorphic

- Pointers are just like references, but have additional useful properties:
  - Can be reassigned
  - Can point to “nothing” (`nullptr`)
  - Can be stored in a vector or an array
- **Use pointers for polymorphism**

```
Derived derived;
Base* ptr = &derived;
```

- **Example:** for implementing strategy store a pointer to the strategy interface and initialize it with `nullptr` and check if it is set before calling its methods

```cpp
#include <iostream>
#include <vector>
using std::cout;
struct AbstractShape {
  virtual void Print() const = 0;
};
struct Square : public AbstractShape {
  void Print() const override { cout << "Square\n"; }
};
struct Triangle : public AbstractShape {
  void Print() const override { cout << "Triangle\n"; }
};
int main() {
  std::vector<AbstractShape*> shapes;
  Square square;
  Triangle triangle;
  shapes.push_back(&square);
  shapes.push_back(&triangle);
  for (const auto* shape : shapes) { shape->Print(); }
  return 0;
}
```

`this` pointer

- Every object of a class or a struct holds a pointer to itself
- This pointer is called `this`
- Allows the objects to:
  - Return a reference to themselves: `return *this;`
  - Create copies of themselves within a function
  - Explicitly show that a member belongs to the current object: `this->x();`

Using const with pointers

- Pointers can **point to** a `const` variable:

```
// Cannot change value, can reassign pointer.
const MyType* const_var_ptr = &var;
const_var_ptr = &var_other;
```

- Pointers can **be** `const`:

```
// Cannot reassign ponter, can change value.
MyType* const var_const_ptr = &var;
var_const_ptr->a = 10;
```

- Pointers can do both at the same time:

```
// Cannot change in any way, read-only.
const MyType* const const_var_const_ptr = &var;
```

- Read from right to left to see which const refers to what

Stack and heap

Memory management structures

Working memory is divided into two parts:

Stack and **Heap**

stack
http://www.freestockphotos.biz

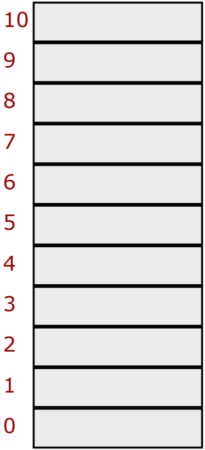
heap
https://pixabay.com

Stack memory

- **Static** memory
- Available for **short term** storage (scope)
- **Small / limited** (8 MB Linux typisch)
- Memory allocation is **fast**
- **LIFO** (**L**ast **i**n **F**irst **o**ut) structure
- Items added to top of the stack with **push**
- Items removed from the top with **pop**

Stack memory

stack frame




```
#include <stdio.h>
int main(int argc, char const* argv[]) {
  int size = 2;
  int* ptr = nullptr;
  {
    int ar[size];
    ar[0] = 42;
    ar[1] = 13;
    ptr = ar;
  }
  for (int i = 0; i < size; ++i) {
    printf("%d\n", ptr[i]);
  }
  return 0;
}
```

command: `2 x pop()`

Heap memory

- **Dynamic** memory
- Available for **long** time (program runtime)
- Raw modifications possible with `new` and `delete` (usually encapsulated within a class)
- Allocation is slower than stack allocations

Operators `new` and `new[]`

- User controls memory allocation (unsafe)
- Use `new` to allocate data:

```cpp
// pointer variable stored on stack
int* int_ptr = nullptr;
// 'new' returns a pointer to memory in heap
int_ptr = new int;

// also works for arrays
float* float_ptr = nullptr;
// 'new' returns a pointer to an array on heap
float_ptr = new float[number];
```

- `new` returns an address of the variable on the heap
- **Prefer using smart pointers!**

Operators `delete` and `delete[]`

- **Memory is not freed automatically!**
- User must remember to free the memory
- Use `delete` or `delete[]` to free memory:

```cpp
int* int_ptr = nullptr;
int_ptr = new int;
// delete frees memory to which the pointer points
delete int_ptr;

// also works for arrays
float* float_ptr = nullptr;
float_ptr = new float[number];
// make sure to use 'delete[]' for arrays
delete[] float_ptr;
```

- **Prefer using smart pointers!**

Example: heap memory

```
#include <iostream>
using std::cout; using std::endl;
int main() {
  int size = 2; int* ptr = nullptr;
  {
    ptr = new int[size];
    ptr[0] = 42; ptr[1] = 13;
  }  // End of scope does not free heap memory!
  // Correct access, variables still in memory.
  for (int i = 0; i < size; ++i) {
    cout << ptr[i] << endl;
  }
  delete[] ptr;  // Free memory.
  for (int i = 0; i < size; ++i) {
    // Accessing freed memory. UNDEFINED!
    cout << ptr[i] << endl;
  }
  return 0;
}
```

Possible issues with memory

Memory leak

- Can happen when working with Heap memory if we are not careful
- **Memory leak**: memory allocated on Heap access to which has been lost

Memory leak (delete)

```
#include <iostream>
using std::cout; using std::endl;
int main() {
  double *ptr_1 = NULL;
  double *ptr_2 = NULL;
  int size = 10;
  // Allocate memory for two arrays on the heap.
  ptr_1 = new double[size];
  ptr_2 = new double[size];
  cout << "1: " << ptr_1 << " 2: " << ptr_2 << endl;
  ptr_2 = ptr_1;
  // ptr_2 overwritten, no chance to access the memory.
  cout << "1: " << ptr_1 << " 2: " << ptr_2 << endl;
  delete[] ptr_1;
  delete[] ptr_2;
  return 0;
}
```

Error: double free or corruption

```
ptr_1: 0x10a3010, ptr_2: 0x10a3070
ptr_1: 0x10a3010, ptr_2: 0x10a3010
*** Error: double free or corruption (fasttop): 0
    x00000000010a3010 ***
```

- The memory under address `0x10a3070` is **never** freed
- Instead we try to free memory under `0x10a3010` **twice**
- Freeing memory twice is an error

Memory leak example

CODING HORROR

```cpp
#include <iostream>
#include <cmath>
#include <algorithm>
using std::cout; using std::endl;
int main() {
  double *data = nullptr;
  size_t size = pow(1024, 3) / 8;  // Produce 1GB
  for (int i = 0; i < 5; ++i) {
    // Allocate memory for the data.
    data = new double[size];
    std::fill(data, data + size, 1.23);
    // Do some important work with the data here.
    cout << "Iteration: " << i << " done!" << endl;
  }
  // This will only free the last allocation!
  delete[] data;
  int unused; std::cin >> unused;  // Wait for user.
  return 0;
}
```

Memory leak example

- If we run out of memory an `std::bad_alloc` error is thrown
- Be careful running this example, everything might become slow

```
Iteration: 0 done!
Iteration: 1 done!
Iteration: 2 done!
Iteration: 3 done!
terminate called after throwing an instance of 'std::
    bad_alloc'
  what():  std::bad_alloc
```

Dangling pointer

```
int* ptr_1 = some_heap_address;
int* ptr_2 = some_heap_address;
delete ptr_1;
ptr_1 = nullptr;
// Cannot use ptr_2 anymore! Behavior undefined!
```

Dangling pointer

- **Dangling Pointer**: pointer to a freed memory
- Think of it as the opposite of a memory leak
- Dereferencing a dangling pointer causes **undefined behavior**

Dangling pointer example

```cpp
#include <iostream>
using std::cout; using std::endl;
int main() {
  int size = 5;
  int *ptr_1 = new int[size];
  int *ptr_2 = ptr_1;  // Point to same data!
  ptr_1[0] = 100;      // Set some data.
  cout << "1: " << ptr_1 << " 2: " << ptr_2 << endl;
  cout << "ptr_2[0]: " << ptr_2[0] << endl;
  delete[] ptr_1;  // Free memory.
  ptr_1 = nullptr;
  cout << "1: " << ptr_1 << " 2: " << ptr_2 << endl;
  // Data under ptr_2 does not exist anymore!
  cout << "ptr_2[0]: " << ptr_2[0] << endl;
  return 0;
}
```

Even worse when used in functions

```cpp
#include <stdio.h>
// data processing
int* GenerateData(int size);
void UseDataForGood(const int* const data, int size);
void UseDataForBad(const int* const data, int size);
int main() {
  int size = 10;
  int* data = GenerateData(size);
  UseDataForGood(data, size);
  UseDataForBad(data, size);
  // Is data pointer valid here? Should we free it?
  // Should we use 'delete[]' or 'delete'?
  delete[] data;  // ?????????????
  return 0;
}
```

Memory leak or dangling pointer

CODING HORROR

```
void UseDataForGood(const int* const data, int size) {
  // Process data, do not free. Leave it to caller.
}
void UseDataForBad(const int* const data, int size) {
  delete[] data;    // Free memory!
  data = nullptr;   // Another problem - this does nothing!
}
```

- **Memory leak** if nobody has freed the memory
- **Dangling Pointer** if somebody has freed the memory in a function

RAII

- **R**esource **A**llocation **I**s **I**nitialization.
- New object → allocate memory
- Remove object → free memory
- Objects **own** their data!

```
class MyClass {
 public:
  MyClass() { data_ = new SomeOtherClass; }
  ~MyClass() {
    delete data_;
    data_ = nullptr;
  }
 private:
  SomeOtherClass* data_;
};
```

- Still cannot copy an object of `MyClass`!!!

CODING HORROR

```cpp
struct SomeOtherClass {};
class MyClass {
 public:
  MyClass() { data_ = new SomeOtherClass; }
  ~MyClass() {
    delete data_;
    data_ = nullptr;
  }
 private:
  SomeOtherClass* data_;
};
int main() {
  MyClass a;
  MyClass b(a);
  return 0;
}
```

```
*** Error in `raii_example':
double free or corruption: 0x0000000000877c20 ***
```

Shallow vs deep copy

- **Shallow copy:** just copy pointers, not data
- **Deep copy:** copy data, create new pointers
- Default copy constructor and assignment operator implement shallow copying
- RAII + shallow copy → **dangling pointer**
- RAII + Rule of All Or Nothing → **correct**
- **Use smart pointers instead!**