Manage memory efficiently in your C++ code with smart pointers

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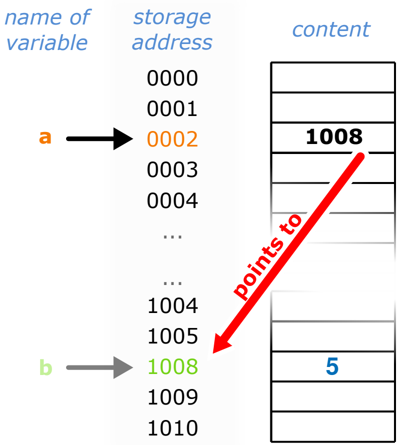
Outline

Introduction

What is a Pointer?



A pointer is an object whose value "points to" another value stored somewhere else in memory

- it contains a **memory address**
- **dereferencing**: obtaining the **value** stored at the pointed location
- very flexible and powerful tool

Using a Pointer

```
/* Defining a pointer */
int* a; // declares a pointer that can point to an integer value
//DANGER: the pointer points to a random memory portion!

int* b = nullptr; // OK, pointer is initialised to a null memory address

int* c = new int; // allocate memory for an integer value in the heap
//and assign its memory address to this pointer

int** d = &a; // this pointer points to a pointer to an integer value

MyObject* e = new MyObject(); // allocate memory for MyObject
// and assign its memory address to the pointer e

/* Using a pointer */
int f = *c; // dereferencing a pointer and assigning the pointed
// value to another integer variable

e->DoSomething(); // dereferencing a pointer and calling
// the method DoSomething() of the instance of MyObject
// pointed by e
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Why a raw pointer is hard to love

Memory leak

```
void MyAnalysisTask::UserExec()
{
  TLorentzVector* v = nullptr;
  for (int i = 0; i < InputEvent()->GetNumberOfTracks(); i++) {
    AliVTrack* track = InputEvent()->GetTrack(i);
    if (!track) continue;
    v = new TLorentzVector(track->Px(),
      track->Py(), track->Pz(), track->M());

    // my analysis here
    std::cout << v->Pt() << std::endl;
  }

  delete v;
}
```

What is the problem with this code?

Array or single value?

- A pointer can point to a single value or to an array $\rightarrow$ no way to infer it from its declaration
- Different syntax to destroy (= deallocate, free) the pointed object for arrays and single objects

```
AliVTrack* FilterTracks();

void UserExec()
{
  TLorentzVector *vect = new TLorentzVector(0,0,0,0);
  double *trackPts = new double[100];
  AliVTrack *returnValue = FilterTracks();

  // here use the pointers

  delete vect;
  delete[] trackPts;
  delete returnValue; // or should I use delete[] ??
}
```

Double deletes

- Each memory allocation should match a corresponding deallocation
- Difficult to keep track of all memory allocations/deallocations in a large project
- **Ownership** of the pointed memory is ambiguous: multiple deletes of the same object may occur

```
AliVTrack* FilterTracks();
void AnalyzeTracks(AliVTrack* tracks);

void MyAnalysisTask::UserExec()
{
  AliVTrack* tracks = FilterTracks();

  AnalyzeTracks(tracks);

  delete[] tracks; // should I actually delete it??
  //or was it already deleted by AnalyzeTracks?
}
```

Smart Pointers

Smart Pointers

- Clear (*shared* or *exclusive*) **ownership** of the pointed object
- **Automatic garbage collection**: memory is deallocated when the last pointer goes out of scope
- Available since C++11

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Exclusive-Ownership Pointers: `unique_ptr`

- Automatic garbage collection with **no additional CPU or memory overhead** (i.e. it uses the same resources as a raw pointer)
- `unique_ptr` **owns** the object it points
- Memory automatically released when `unique_ptr` goes out of scope or when its `reset(T* ptr)` method is called
- Only one `unique_ptr` can point to the same memory address

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unique_ptr example / 1

```
void MyFunction() {
  std::unique_ptr<TLorentzVector> vector(new TLorentzVector(0,0,0,0));
  std::unique_ptr<TLorentzVector> vector2(new TLorentzVector(0,0,0,0));

  // use vector and vector2

  // dereferencing unique_ptr works exactly as a raw pointer
  std::cout << vector->Pt() << std::endl;

  // the line below does not compile!
  // vector = vector2;
  // cannot assign the same address to two unique_ptr instances

  vector.swap(vector2); // however I can swap the memory addresses

  // this also releases the memory previously pointed by vector2
  vector2.reset(new TLorentzVector(0,0,0,0));

  // objects pointed by vector and vector2 are deleted here
}
```

unique_ptr example / 2

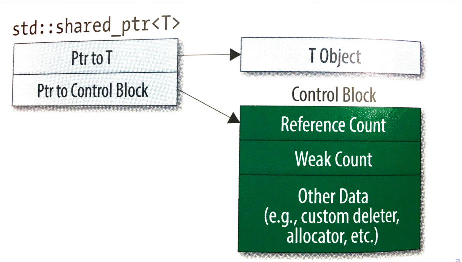
```
void MyAnalysisTask::UserExec()
{
  for (int i = 0; i < InputEvent()->GetNumberOfTracks(); i++) {
    AliVTrack* track = InputEvent()->GetTrack(i);
    if (!track) continue;
    std::unique_ptr<TLorentzVector> v(new TLorentzVector(track->Px(),
      track->Py(), track->Pz(), track->M()));

    // my analysis here
    std::cout << v->Pt() << std::endl;
    // no need to delete
    // v is automatically deallocated after each for loop
  }
}
```

No memory leak here! :)

Shared-Ownership Pointers: `shared_ptr`

- Automatic garbage collection with some CPU and memory overhead
- The pointed object is *collectively owned* by one or more `shared_ptr` instances
- Memory automatically released the last `shared_ptr` goes out of scope or when it is re-assigned



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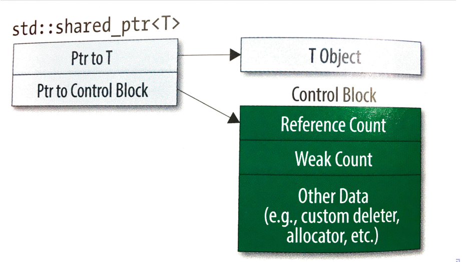

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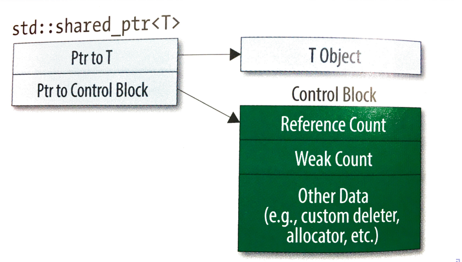

shared_ptr example / 1

```
void MyFunction() {
  std::shared_ptr<TLorentzVector> vector(new TLorentzVector(0,0,0,0));
  std::shared_ptr<TLorentzVector> vector2(new TLorentzVector(0,0,0,0));

  // dereferencing shared_ptr works exactly as a raw pointer
  std::cout << vector->Pt() << std::endl;

  // assignment is allowed between shared_ptr instances
  vector = vector2;
  // the object previously pointed by vector is deleted!
  // vector and vector2 now share the ownership of the same object

  // object pointed by both vector and vector2 is deleted here
}
```

shared_ptr example / 2

```
class MyClass {
  public:
    MyClass();
  private:
    void MyFunction();
    std::shared_ptr<TLorentzVector> fVector;
};

void MyClass::MyFunction() {
  std::shared_ptr<TLorentzVector> vector(new TLorentzVector(0,0,0,0));

  // assignment is allowed between shared_ptr instances
  fVector = vector;
  // the object previously pointed by fVector (if any) is deleted
  // vector and fVector now share the ownership of the same object

  // here vector goes out-of-scope
  // however fVector is a class member so the object is not deleted!
  // it will be deleted automatically when this instance of the class
  // is deleted (and therefore fVector goes out-of-scope) :)
}
```

Some word of caution on shared_ptr

```
void MyClass::MyFunction() {
  auto ptr = new TLorentzVector(0,0,0,0);

  std::shared_ptr<TLorentzVector> v1 (ptr);
  std::shared_ptr<TLorentzVector> v2 (ptr);

  // a double delete occurs here!
}
```

What is the problem with the code above?

Some word of caution on `shared_ptr`

```
void MyFunction() {
  auto ptr = new TLorentzVector(0,0,0,0);

  std::shared_ptr<TLorentzVector> v1 (ptr);
  std::shared_ptr<TLorentzVector> v2 (ptr);

  // a double delete occurs here!
}
```

- `v1` does not know about `v2` and viceversa!
- Two control blocks have been created for the same pointed objects

Some word of caution on `shared_ptr`

```
void MyFunction() {
  std::shared_ptr<TLorentzVector> v1 (new TLorentzVector(0,0,0,0));
  std::shared_ptr<TLorentzVector> v2 (v1);

  // this is fine!
}
```

- Solution: use raw pointers only when absolutely needed (if at all)

Usage Notes for ALICE Software

- Can be used in the implementation files of **AliPhysics** (*.cxx files)
- In the header files (*.h) need to hide them from CINT (therefore cannot be used as non-transient class members)

```
#if !(defined(__CINT__) || defined(__MAKECINT__))
// your C++11 code goes here
#endif
```

- Cannot be used anywhere in **AliRoot**

Conclusions

Final remarks

- When the extra-flexibility of a pointer is not needed, do not use it
- Alternative to pointers: arguments by reference (not covered here)
- Avoid raw pointers whenever possible!
- Smart pointers (`unique_ptr` and `shared_ptr`) should cover most use cases and provide a much more robust and safe memory management

References

Effective modern C++, Scott Meyers (O'Reilly 2015)
http://en.cppreference.com/