

RAII. Smart Pointers

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Overview

RAII. Smart
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RAII

Smart pointers
in STL

1 RAII

2 Smart pointers in STL

- **RAII** = Resource Acquisition Is Initialization.
- **Resources**
 - E.g.: memory, files, sockets, database connections.
 - Resources are *acquired* before use and then *released* after one has finished working with them (preferably, they should be released as soon as possible).
 - Failing to release a resource can cause leaks and even crashes.
 - RAII is used to *avoid resource leaks* and to write *exception-safe code*.

Example of resource leak I

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```
void resourceLeak()
{
    try
    {
        int* a = new int{ 2 };
        throw std::exception{ "Hello! An exception
                               has occurred!\n" };
        delete a;
    }
    catch (std::exception& e)
    {
        cout << e.what();
    }
}
```

Example of resource leak II

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- How can this be solved?
- One solution (workaround): clean up in the `catch` block.
 ?
 Why is this not the best strategy?
- Another solution: using RAII.

The idea I

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- The compiler automatically calls:
 - constructors to initialize objects;
 - destructors, when the objects' scope is finished.
- When creating an object, we take responsibility for the resources in it. The constructor is responsible with resource allocation.
- The destructor does the clean up: the resource should be deallocated in the destructor.

The idea II

- As the compiler automatically calls constructors and destructors, the resource will be managed correctly.
- In this way, there will be no resource leaks.
- Advantages over garbage collection (from other programming languages):
 - RAII offers automatic management for different kinds of resources, not just memory.
 - The runtime environment is faster, as there is no separate mechanism involved (like the garbage collector).

The idea III

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The following are taken from [Bjarne Stroustrup: Constructors, Destructors, and Resource Acquisition Is Initialization \(RAII\), Lex Fridman Podcast 48](#). The entire podcast episode can be found here: [Bjarne Stroustrup: C++ — Lex Fridman Podcast 48](#).

Bjarne Stroustrup, when asked about the "most beautiful and nice and clean" feature of C++:

- "There is one clear answer: constructors-destructors."
- "The way a constructor can establish the environment for the use of a type, for an object and the destructor that cleans up any messes at the end of it. That is the key to C++."

The idea IV

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- "That's why we don't have to use garbage collection, that's how we can get predictable performance, that's how we get minimal overhead in many, many cases and have really clean types."
- "It's the idea of constructor-destructor pairs, sometimes it comes under the name RAII."
- "It's the best example why I shouldn't be in advertising. I get the best idea and I call it "Resource Acquisition Is Initialisation"... Not the greatest naming I've ever heard."
- Alternative names:
 - CADR: **C**onstructor **A**cquires, **D**estructor **R**eleases.
 - SBRM: **S**cope-**B**ound **R**esource **M**anagement.

How is it done?

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- Create a wrapper for your object using resource allocation: allocation in constructor, deallocation in destructor.
- Use the wrapper object (directly) wherever you need the object.
- The resource will be deallocated when the wrapper's scope is left.
- The lifetime of the resource that must be acquired before use is bound to the lifetime of the object.

DEMO

RAII for pointers (*Lecture_11* - SmartPointer, SmartPointerTemplate).

RAII in STL

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in STL

- You have already been using RAII.
- When an object of type `ifstream` or `ofstream`, the constructor acquires the resource (file handle) and will automatically open the file.
- When the object gets destroyed, the destructor automatically closes the file.
- The STL containers manage memory using the RAII programming idiom. Remember your dynamic vector?
- There are "smart pointers" defined in STL, which use RAII for "smart" memory management.

Smart pointers in STL I

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- In modern C++, raw pointers are used only in certain cases: "small code blocks of limited scope, loops, or helper functions where performance is critical and there is no chance of confusion about ownership". ([Microsoft: Smart pointers \(Modern C++\)](#)).
- Smart pointers are used instead.
- Smart pointers are class templates.
- A smart pointer object is declared on the stack and initialized with a raw pointer. When it goes out of scope, its destructor is invoked.

Smart pointers in STL II

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- The smart pointer owns the raw pointer \Rightarrow it is responsible for it (memory deallocation).
- Objects are automatically cleaned up when the smart pointers go out of scope or are set to point at something else or nothing - they get deleted when nobody is interested in them any more.
- STL smart pointers defined in the `std` namespace, in the header `<memory>`.

Smart pointers in STL III

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- There are 3 types of smart pointers in STL:
 - `std::unique_ptr`
 - `std::shared_ptr`
 - `std::weak_ptr`

std::unique_ptr I

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- Such a smart pointer *owns its object uniquely*.
- It retains *exclusive ownership* of the object, it does not share the object.
- It is impossible for two `unique_ptr` objects to own the same object.

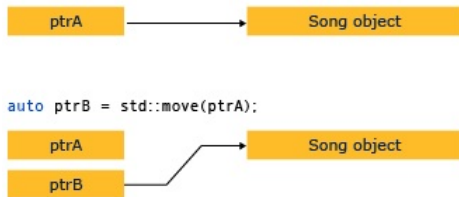
std::unique_ptr II

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Figure

source:

<https://docs.microsoft.com/en-us/cpp/cpp/how-to-create-and-use-unique-ptr-instances?view=msvc-160>

[how-to-create-and-use-unique-ptr-instances?view=msvc-160](https://docs.microsoft.com/en-us/cpp/cpp/how-to-create-and-use-unique-ptr-instances?view=msvc-160)

- It cannot be copied. **!** Careful consideration when passing such an object by value.
- It can be moved to a new owner: the resource is transferred to the new owner.

std::unique_ptr III

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- When it goes out of scope, the owned object is destroyed.
- It should be constructed with the `make_unique` function.

DEMO

`unique_ptr` (*Lecture_8_demo* - `exampleUniquePtr`).

std::shared_ptr |

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- Retains *shared ownership* of the object.
- Several `shared_ptr` objects may own the same object.
- Uses *reference counting*: when multiple shared pointers own the same object, these are keeping track of how many "copies" of the pointer there are.
- The owned object is deleted only when the last remaining owning `shared_ptr` is destroyed or has given up ownership (has been reset).

std::shared_ptr II

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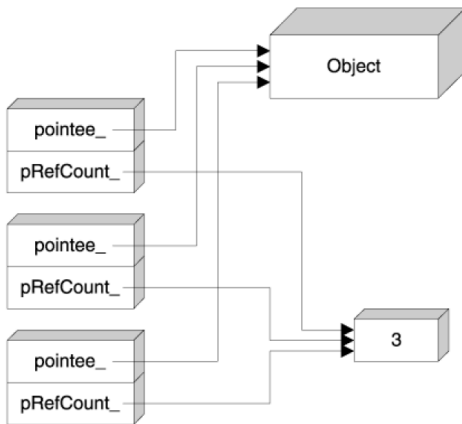


Figure source: [Reference counting](#)

std::shared_ptr III

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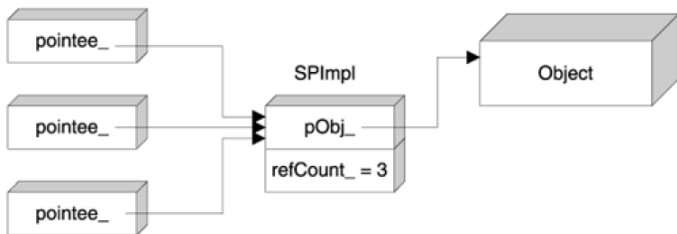


Figure source: [Reference counting](#)

std::shared_ptr IV

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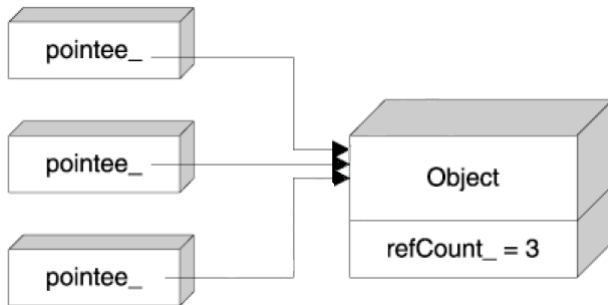


Figure source: [Reference counting](#)

std::shared_ptr V

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- It can be copied and moved (move transfers ownership).
- `shared_ptr` has more overhead than `unique_ptr` (because of the internal reference counting), therefore, **whenever possible, prefer `unique_ptr`**.
- It should be constructed with the `make_shared` function.

DEMO

`shared_ptr` (*Lecture_8_demo* - `exampleSharedPtr`).

std::weak_ptr |

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- Used to access the underlying object of a `shared_ptr` without causing the reference count to be incremented.
- It allows "observing" the object managed by the `shared_ptr`, without taking ownership of it.
- Is usually used to avoid dependency cycles (circular references).

std::weak_ptr ||

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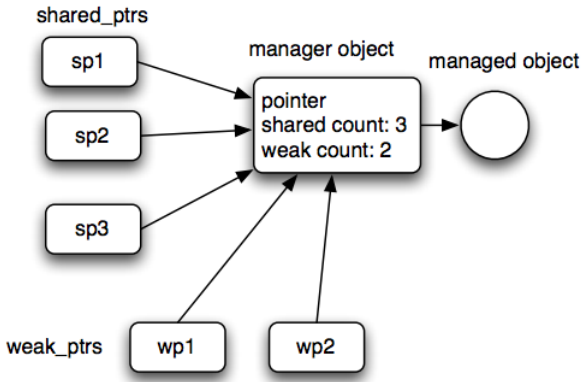


Figure source: <https://ix.cs.uoregon.edu/~norris/cis330/index.cgi?n=Main.W10D1ex>

std::weak_ptr III

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E.g.: 2 classes - Team and Member

- A team has pointers to its members.
- Each member can have a pointer to the team it belongs to.
- **?** If all pointers (to members and to team) are `shared_ptr`, what happens when the team goes out of scope? (Answer: memory leak - but how and why?)
- Therefore, the members should have a weak pointer to their team.

std::weak_ptr IV

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- The underlying object in a `weak_ptr` can still be deleted even though there is a `weak_ptr` reference to it.
- `weak_ptr` can be used to create a `shared_ptr`.

DEMO

`weak_ptr` (*Lecture_8_demo* - `teamMembersSharedPtr`, `exampleWeakPtr`).

Advantages of smart pointers

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- Smart pointers increase productivity and improve the robustness of the program.
- The programmer does not need to be concerned with memory management (provided the smart pointers are used correctly).
- They help in avoiding memory leaks and writing exception-safe code.

Homework I

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- Write an application to keep the aircraft evidence in a country.
- Each aircraft has a **unique identifier** and a **model**, *is suitable* only for certain activities (e.g. public transportation, medical emergencies, leisure time, military) and can reach a certain *maximum altitude*.
- An aircraft can be one of the following three: helicopter, plane or hot air balloon.

Homework II

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- A helicopter:
 - has the following additional characteristic: **isPrivate**, specifying whether the helicopter belongs to the state or to a private entity.
 - is suitable for activities like: military, medical emergencies, public transportation and leisure time (only if it is private).
 - can reach a maximum altitude of 12 km.
- A plane:
 - has the following additional characteristics: **isPrivate**, specifying whether the plane belongs to the state or to a private entity and **main wings** (the plane can be either monoplane or biplane).
 - is suitable for activities like: military, public transportation and leisure time (only if it is biplane).
 - can reach a maximum altitude of 26 km.

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- A hot air balloon:
 - has the following additional characteristics: **weight limit**, specifying the maximum weight limit for the balloon.
 - is suitable for activities like: leisure time.
 - can reach a maximum altitude of 21 km.
- The application should allow the following:
 - Add any type of aircraft.
 - Display all aircraft which can be used for a certain activity and save them to a file having the activity's name.
 - Display all aircraft which can reach at least a given altitude.