Part 3 - Memory

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Agenda

- Pointers
- Slices
- References
- Dynamic Memory
- The Standard Library

Pointers

Part 3

Pointers

- Pointers are an object that holds the numeric memory address of another object
- To access the value pointed to, the pointer must be dereferenced
- Because a pointer is a numeric value, you can perform any arithmetic operation on the pointer itself
- A pointer can be made polymorphic by being a `void` pointer
- You can a pointer to a constant object or a constant pointer to an object (or both!).
- You can also have pointer-to-pointers
- Pointers are easily misused as they can point to nothing

Pointers in Memory

Address	Value
0x00007fff59ae6ea4	…
0x00007fff59ae6e9d	0x00000004
0x00007fff59ae6e99	0x00009 1f5
0x00007fff59ae6e94	0x00007fff59ae6e94
0x00007fff59ae6e90	…

Pointers Example 1

```cpp
#include <iostream>
#include <memory>

auto main () -> int
{
    int a {4};
    int b {37365};
    int* pa {&a};
    int* pb {std::addressof(b)};

    std::cout << "a = " << a << std::endl;
    std::cout << "pa = " << pa << std::endl;
    std::cout << "*pa = " << *pa << std::endl;

    std::cout << "b = " << b << std::endl;
    std::cout << "pb = " << pb << std::endl;
    std::cout << "*pb = " << *pb << std::endl;

    return 0;
}
```

Pointers Example 2

```cpp
#include <iostream>
#include <memory>

auto main () -> int
{
    int a {4};
    int b {37365};
    const int* pa {&a};
    int* const pb {std::addressof(b)};

    std::cout << "*pa = " << *pa << std::endl;
    *pa += 3;  ///< Fails, comment out to run
    pa = std::addressof(b);
    std::cout << "*pa = " << *pa << std::endl;

    std::cout << "*pb = " << *pb << std::endl;
    *pb += 3;
    pb = std::addressof(a);  ///< Fails, comment out to run
    std::cout << "*pb = " << *pb << std::endl;

    return 0;
}
```

Pointers Example 3

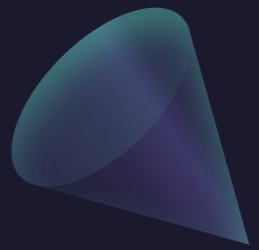
```cpp
#include <iostream>
#include <memory>

auto main () -> int
{
    int a {4};
    void* pa {std::addressof(a)};

    std::cout << "*pa = " << *static_cast<int*>(pa) << std::endl;
    std::cout << "*pa = " << *pa << std::endl;  ///< This will fail, comment out to run

    return 0;
}
```

Pointers Example 4

```cpp
#include <iostream>

auto main () -> int
{
    auto greeting {"Hello!"};
    const char* response {"Hi!!!"};

    for (auto i {0}; i < 7; ++i)
        std::cout << greeting[i];
    std::cout << std::endl;

    for (auto i {0}; i < 6; ++i)
        std::cout << *(response + i);
    std::cout << std::endl;

    /// These will have the same type
    std::cout << "typeid(greeting).name() = " << typeid(greeting).name() << std::endl;
    std::cout << "typeid(response).name() = " << typeid(response).name() << std::endl;

    for (auto i {0}; i < 6; ++i)
        std::cout << *(response++) << std::endl;

    std::cout << "response = " << response << std::endl;  ///< This now points to whatever is stored after `response`.

    return 0;
}
```

Pointers Example 5

```cpp
#include <iostream>

auto main () -> int
{
    int* p {nullptr};

    std::cout << "p = " << p << std::endl;      ///< p = 0

    /// Compiles (on Godbolt) but throws a runtime error (see return of program is not zero)
    std::cout << "*p = " << *p << std::endl;

    return 0;
}
```



Pointers Example 6

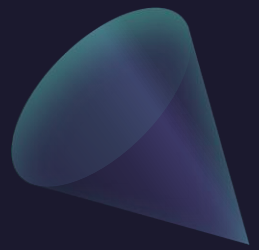
```cpp
#include <iostream>
#include <memory>

auto main () -> int
{
    int a {6};
    int* p {std::addressof(a)};
    int** pp {std::addressof(p)};

    std::cout << "pp = " << pp << std::endl;
    std::cout << "*pp = " << *pp << std::endl;
    std::cout << "**pp = " << **pp << std::endl;

    return 0;
}
```

Slices

Part 3

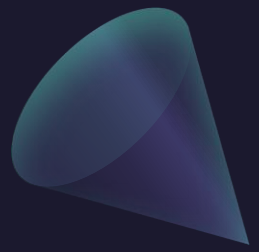
Slices

- Contiguous homogenous sequence of objects
- Size of slice must be known at compile time
- Indexed based access using [ ]
- Indexing starts at `0`
- Slices can decay into a pointer of the same type as the slice pointing to the first element of the slice
- String literals are slices of type *char*



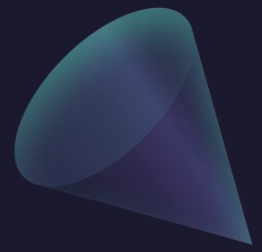
Slices Example 1

```cpp
#include <iostream>

void print(int arr[], std::size_t s)
{
    std::cout << "[ ";
    for (auto i {0}; i < s; ++i)
        std::cout << arr[i] << ", ";
    std::cout << "]" << std::endl;
}

auto main () -> int
{
    int nums[] { 1, 2, 3, 4, 5 };

    print(nums, 5);

    return 0;
}
```



Slices Example 2

```cpp
#include <iostream>

void print(int* arr, std::size_t s)
{
    std::cout << "[ ";
    for (auto i {0}; i < s; ++i)
        std::cout << arr[i] << ", ";
    std::cout << "]" << std::endl;
}

auto main () -> int
{
    int nums[] { 1, 2, 3, 4, 5 };

    print(nums, 5);

    return 0;
}
```



Dynamic Memory

Part 3

Dynamic Memory

- There are two memory sources in C++, the stack and the heap
- Stack resources are ones used by variables and objects in a C++ program
- Heap resources are allocated memory from the free store of the computer
- Heap memory must be explicitly requested and returned to and from the OS
- `new` and `delete` are used to allocate and free memory respectively from the heap in C++
- Memory for slices can also be allocated and freed respectively from the heap using `new[]` and `delete[]`

Dynamic Memory Example 1

```cpp
#include <iostream>

auto main () -> int
{
    int* ip = new int(7);   ///< Creates an `int` initialised with the value `7` on the heap

    std::cout << "ip = " << ip << std::endl;
    std::cout << "*ip = " << *ip << std::endl;

    delete ip;
    ip = nullptr;

    return 0;
}
```

Dynamic Memory Example 2

```cpp
#include <iostream>

void print(int arr[], std::size_t s)
{
    std::cout << "[ ";
    for (auto i {0}; i < s; ++i)
        std::cout << arr[i] << ", ";
    std::cout << "]" << std::endl;
}

auto main () -> int
{
    int* nums = new int[]{ 1, 2, 3, 4, 5 }; ///< Creates a slice of `int` initialised with brace list

    print(nums, 5);

    delete[] nums;
    nums = nullptr;

    return 0;
}
```

References

Part 3

References

- Act as an alias to an existing object
- Any operations on a reference act upon the referred object without the need for dereferencing
- References cannot refer to nothing, ie. Must be bound to an existing object
- References are always constant meaning they cannot be rebound to alias a different object
- A constant reference means the object it aliases is constant

Pointers vs References

Pitfall	Pointers	References	Meaning
Nullable	☑	✗	Pointers can point to nothing, references cannot
Dereferencable	☑	✗	You cannot dereference a reference
Rebindable	☑	✗	A reference cannot be rebound to a new value. Operations done on the reference affect the underlying value, even assignment.
Multiple levels of indirection	☑	✗	You cannot have a reference of a reference.
Pointer arithmetic	☑	✗	You cannot increment (etc.) a reference like a pointer

References Example 1

```cpp
#include <iostream>

auto main () -> int
{
    int i {7};
    int& ir {i};

    std::cout << "i = " << i << std::endl;
    std::cout << "ir = " << ir << std::endl;

    ir += 6;
    std::cout << "i = " << i << std::endl;

    i -= 4;
    std::cout << "ir = " << ir << std::endl;

    return 0;
}
```

References Example 2

```cpp
#include <iostream>

auto main () -> int
{
    int i {7};
    int& ir {i};
    const int& cir {i};

    std::cout << "i = " << i << std::endl;
    std::cout << "ir = " << ir << std::endl;
    std::cout << "cir = " << cir << std::endl;

    ir += 6;
    std::cout << "i = " << i << std::endl;

    i -= 4;
    std::cout << "ir = " << ir << std::endl;

    cir += 7;   ///< Fails, `cir` is read-only
    std::cout << "i = " << i << std::endl;

    return 0;
}
```

The Standard Library

Part 3

The C++ Standard Library

- The C++ Standard Library is home to a very large collection of features available to C++ programmers from containers and algorithms to concurrency and random number generation.
- Any non-language specific feature in C++ can be found in the Standard Library
- Library components are stored in headers and are imported into source files using `#include` directives

Standard Library Types

SEQUENCES

- `std::initializer_list` - A concrete type for the constructor sequences using
- `std::array` - C++'s array type
- `std::span` - A view over any contiguous sequence of homogenous elements
- The type of any sequence must be known or deducible at compile time

STRINGS

- `std::string` - C++'s string type
- `std::string_view` - A view over a character slice or string
- `""s` - Creates a string from a character or string literal
- There are other string types that hold different character types e.g. `std::wstring`

SMART POINTERS

- `std::unique_ptr` - Assumes unique ownership of a dynamic memory resource
- `std::shared_ptr` - Assumes shared ownership of a dynamic memory resource. Only when the last owner is deleted will the resource
- `std::weak_ptr` - Assumes temporary shared ownership of a dynamic memory resource
- All smart pointers automatically delete the dynamic memory resource when the smart pointer goes out of scope

Sequences Example 1

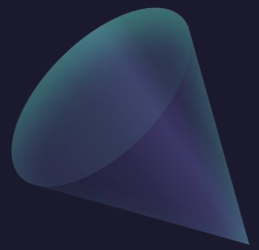
```cpp
#include <iostream>
#include <array>

void print(std::array<int, 6> arr)
{
    std::cout << "[ ";
    for (auto i {0}; i < arr.size(); ++i)
        std::cout << arr[i] << ", ";
    std::cout << "]" << std::endl;
}

auto main () -> int
{
    auto a = std::array<int, 6>{ 1, 2, 3, 4, 5, 6 };
    auto b = std::to_array<int>({ -1, -2, -3, -4, -5, -6});  ///< Size can be deduced

    print(a);
    print(b);

    return 0;
}
```

Sequences Example 2

```cpp
#include <array>
#include <iostream>
#include <span>

void print(std::span<int> span)
{
    std::cout << "[ ";
    for (auto& e : span)
        std::cout << e << ", ";
    std::cout << "]" << std::endl;
}

auto main () -> int
{
    auto array = std::to_array<int>({ 1, 2, 3, 4, 5, 6 });
    int slice[] = {4, 46, 57};

    print(array);
    print(slice);

    return 0;
}
```

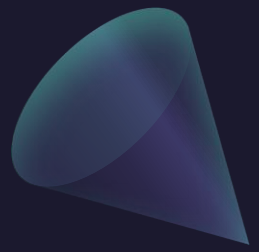
Strings Example 1

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

auto main () -> int
{
    auto str1 {"Hello"};
    auto str2("Goodbye");

    std::cout << str1 << std::endl;
    std::cout << str2 << std::endl;

    return 0;
}
```



Strings Example 2

```cpp
#include <iostream>
#include <string_view>

void print(std::string_view s)
{ std::cout << s << std::endl; }

auto main () -> int
{
    print("Hello");

    return 0;
}
```



Strings Example 3

```cpp
#include <iostream>
#include <string>
#include <string_view>

using namespace std::literals;

void print(std::string_view s)
{ std::cout << s << std::endl; }

auto main () -> int
{
    print("Hello"sv);

    std::cout << typeid("Hello").name() << std::endl;
    std::cout << typeid("Hello"s).name() << std::endl;
    std::cout << typeid("Hello"sv).name() << std::endl;

    return 0;
}
```

Smart Pointers Example 1

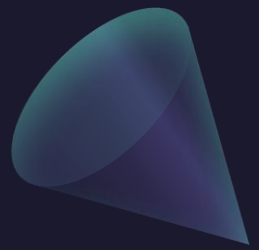
```cpp
#include <iostream>
#include <memory>

void print(std::unique_ptr<int>& ptr)
{
    std::cout << ptr << std::endl;
    std::cout << *ptr << std::endl;
}

void add_magic(std::unique_ptr<int>& ptr)
{ *ptr += 42; }

auto main () -> int
{
    std::unique_ptr<int> p1(new int(6));
    auto p2 = std::make_unique<int>(7);
    auto p3 = std::unique_ptr<int>{nullptr};

    print(p1);
    print(p2);

    add_magic(p1);
    // add_magic(p3);  ///< Would fail

    print(p1);
    // print(p3);  ////< Would fails

    return 0;
}
```

Smart Pointers Example 2

```cpp
#include <iostream>
#include <memory>

void print(std::shared_ptr<int> ptr)
{
    std::cout << "ptr = " << ptr << std::endl;
    std::cout << "*ptr = " << *ptr << std::endl;
    std::cout << "ptr.use_count() = " << ptr.use_count() << std::endl;
}

void add_magic(std::shared_ptr<int>& ptr)
{ *ptr += 42; }

auto main () -> int
{
    auto p = std::make_shared<int>(7);

    std::cout << "p.use_count() = " << p.use_count() << std::endl;

    print(p);
    add_magic(p);

    return 0;
}
```

Smart Pointers Example 3

```cpp
#include <iostream>
#include <memory>

void print(std::weak_ptr<int> ptr)
{
    std::cout << "ptr.use_count() = " << ptr.use_count() << std::endl;

    if (auto sp = ptr.lock())
    {
        std::cout << "sp.use_count() = " << sp.use_count() << std::endl;
        std::cout << "sp = " << sp << std::endl;
        std::cout << "*sp = " << *sp << std::endl;
    }
    else
        std::cout << "ptr is expired" << std::endl;
}

auto main () -> int
{
    auto p = std::make_shared<int>(7);

    std::cout << "p.use_count() = " << p.use_count() << std::endl;

    print(p);

    return 0;
}
```



Discussion

- Any questions?
- Need help?
- Open discussion.
- Concerns?

Next Week

- Advanced Functions
- Functional Programming
- Namespaces
- Chrono
- Unions
- Enumerations

Summary

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Thank You

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https://github.com/MonashDeepNeuron/HPP