C++

> Things to Look into more
>
> - Review POD types, class layouts as defined in the Class section.
> - Review how type traits are implemented for a variety of examples. Notably review the Cppcon video.
> - Review The containers in the standard library, from a performance and use case perspective
>   - Notably review the erase remove idiom.
> - Understand Placement new
> - Start collating a better understanding of template metaprogramming.
> - Cppcon
>   - Memory Allocators
>   - Type Erasure
>   - What is the C++ ABI
>   - Important C++ Optimisations

Misc

- Runtime vs Compile time

Basic Concepts

Move Semantics

Initialisation

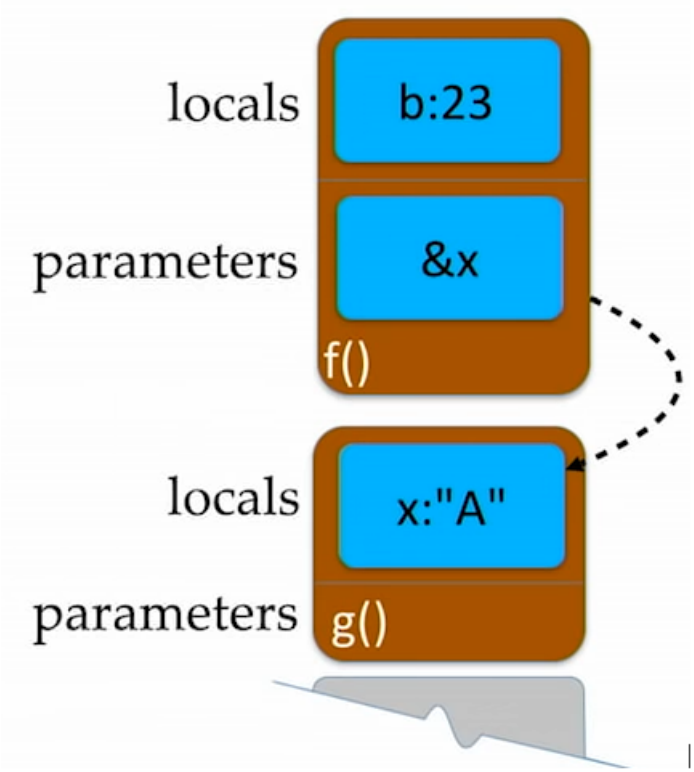
> Initialisation reference - https://en.cppreference.com/w/cpp/language/initialization

Summary

Copy & Move Elision

> cpp con talk - https://www.youtube.com/watch?v=IZbL-RGr_mk

- Compiler may generate some code. The compiler has the ability to elide copies that are not actually required.
- Returning a value defined in the calling function stack frame is not defined but rather moved directly into the address.




```
std::string f(){
    std::string a{"A"}; // not created on the stack frame as shown above

    int b{23};

    return a; // "A" is returned here, placed directly into the memory location
of x
}

void g(){
    std::string x{f()}; // f() takes &x as argument from where a is directly
placed into by compiler optimsaition.
}
```

Misc reminders:

- Statics initialisation order
- `Constinit` - `Constinit` - Ensure a variable is initialised at compile time before linking ensuring global variables being used as **external linkage** specifiers specified by `inline` `extern` or `global` are not used before the **corresponding definition** is generated.
    - ```
      #ifndef Fuck
      #define Fuck
      class FileSystem {
      public:
          [[nodiscard]] static std::size_t numDisks();
      };
      #endif

      inline constinit FileSystem tfs;
      ```
      ```

```
class Directory {
public:
    explicit Directory(int);
};

Directory::Directory(int) {
    std::size_t disks = tfs.numDisks(); // guaranteed to b
}
```

Idioms

> C++ Idioms

SFINAE

> SFINAE - wikibooks
>
> SFINAE Reference - cppreference

- Substitution failure is not an error.
- This rule applies during overload resolution of function templates: When substituting the explicitly specified or deduced type for the template parameter fails, the specialization is discarded from the overload set instead of causing a compile error.

Pimpl

> Pimpl Idiom

- Also called the **opaque pointer** idiom is a method of providing data and thus further implementation abstraction for Classes.

Erase-remove

- Erase remove idiom

```
// Use g++ -std=c++11 or clang++ -std=c++11 to compile.

#include <algorithm>  // remove and remove_if
#include <iostream>
#include <vector>

void Print(const std::vector<int>& vec) {
  for (auto val : vec) {
    std::cout << val << ' ';
  }
  std::cout << '\n';
}

int main() {
  std::vector<int> v = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9};
  Print(v);

  // Removes all elements with the value 5.
  v.erase(std::remove(v.begin(), v.end(), 5), v.end());
  Print(v);
```

```
  // Removes all odd numbers.
  v.erase(std::remove_if(v.begin(), v.end(), [](int val) { return val & 1; }),
          v.end());
  Print(v);
}

1 2 3 4 5
  2   4 >    13424
/*              ^
Output:
0 1 2 3 4 5 6 7 8 9
0 1 2 3 4 6 7 8 9
0 2 4 6 8
*/
```

- In C++20 We have the free function `std::free` which implements the erase remove idiom for us.

Operators

- Operator precedence - https://www.learncpp.com/cpp-tutorial/operator-precedence-and-associativity/

Operator overloading

Misc Reminders

- `->` operator:
  - overloading this essentially means we return some internal object from which we access its underlying values
  - If a pointer is returned we call the underlying operator, if this further calls another `->` then we repeat until we reach the end.

```
struct A {
    std::string* operator->(){
        return new std::string{"A string"};
    }
}

struct B {
    A operator->(){
        return A();
    }
}

int main(){
    B b;
    b->size();
}
```

- Comma `,` operator return type:
  - `auto func = [&](int x , int y) {return x + 1, y;} /* evalautes x+1 but returns y */`

Bit manipulation (review learncpp)

Misc reminders

- How bitwise OR represents flags
    - ```
      BINARY DECIMAL COLOR
      ------ ------- -----
         001       1  Red
         010       2  Green
         011       3  Red+Green
         100       4  Blue
         101       5  Blue+Red
         110       6  Blue+Green
         111       7  Blue+Green+Red
      ```
    - So `Red` is an integer and so is `Blue`
    - Bitwise OR `|` combines the two
    - Therefore when we bitwise AND `&` check it evaluates true for both `Red` and `Blue`, alternatively as shown above `101` is the value stored from the bitwise OR which is represented in the program.

Scope, Duration and Linkage

Linkage

- **No Linkage**: Identifier refers only to itself.
    - Local variables.
    - Type definitions (e.g., enums, classes) inside a block.
- **Internal Linkage**: Accessible within the file where declared.
    - Static global variables (both initialized and uninitialized).
    - Static functions.
    - Const global variables.
    - Functions in unnamed namespaces.
    - Type definitions (e.g., enums, classes) in unnamed namespaces.
- **External Linkage**: - Accessible in the file where declared and in other files.
    - Functions.
    - Non-const global variables (both initialized and uninitialized).
    - Extern const global variables.
    - Inline const global variables.

Duration

- Variables with **automatic duration** are created at the point of definition, and destroyed when the block they are part of is exited. This includes:
    - Local variables
    - Function parameters
- Variables with **static duration** are created when the program begins and destroyed when the program ends. This includes:
    - Global variables
    - Static local variables
      ```

- Variables with **dynamic duration** are created and destroyed by programmer request. This includes:
    - Dynamically allocated variables

Variable scope, duration, and linkage summary

Type	Example	Scope	Duration	Linkage	Notes
Local variable	int x;	Block	Automatic	None	
Static local variable	static int s_x;	Block	Static	None	
Dynamic local variable	int* x { new int{} };	Block	Dynamic	None	
Function parameter	void foo(int x)	Block	Automatic	None	
External non-constant global variable	int g_x;	Global	Static	External	Initialized or uninitialized
Internal non-constant global variable	static int g_x;	Global	Static	Internal	Initialized or uninitialized
Internal constant global variable	constexpr int g_x { 1 };	Global	Static	Internal	Must be initialized
External constant global variable	extern const int g_x { 1 };	Global	Static	External	Must be initialized
Inline constant global variable (C++17)	inline constexpr int g_x { 1 };	Global	Static	External	Must be initialized

Forward declaration summary

Type	Example	Notes
Function forward declaration	void foo(int x);	Prototype only, no function body
Non-constant variable forward declaration	extern int g_x;	Must be uninitialized
Const variable forward declaration	extern const int g_x;	Must be uninitialized
Constexpr variable forward declaration	extern constexpr int g_x;	Not allowed, constexpr cannot be forward declared

Misc reminders

- Global scope = file scope = global namespace scope
- Classes / Types exempt from ODR
    - Types declared in a header file can have multiple definitions amongst the files its included in
    - They should be the same definitions otherwise its undefined.
- **Extern**
    - This comes in useful when you have global variables. You declare the *existence* of global variables in a header, so that each source file that includes the header knows about it, but you only need to "define" it once in one of your source files.
    - To clarify, using `extern int x;` tells the compiler that an object of type `int` called `x` exists *somewhere*. It's not the compilers job to know where it exists, it just needs to know the type and name so it knows how to use it. Once all of the source files have been compiled, the linker will resolve all of the references of `x` to the one definition that it finds in one of the compiled source files. For it to work, the definition of the `x` variable needs to have what's called "external linkage", which basically means that it needs to be declared outside of a function (at what's usually called "the file scope") and without the `static` keyword.
    - So we define the `extern` variable definition in one of the locations where the header is included and this compiles fine where each file including `header.h` can use the `global_x` without having to define it multiple times.

```
/* header.h */
#ifndef HEADER_H
#define HEADER_H

// any source file that includes this will be able to use "global_x"
extern int global_x;

void print_global_x();

#endif
```

```
/* main.cpp */

#include "header.h"

// since global_x still needs to be defined somewhere,
// we define it (for example) in this source file
int global_x;

int main()
{
    //set global_x here:
    global_x = 5;

    print_global_x();
}
```

```
/* header.cpp (definition for our header)*/
#include <iostream>
#include "header.h"

void print_global_x()
{
    //print global_x here:
    std::cout << global_x << std::endl;
}
```

- When to use static variable in C++
  - **Global scope statics** - for internal linkage, to avoid name conflicts between separate translation units
  - **Class scope statics** - internal class usage only, no conflicts between other classes.
  - Both Global and Class scope statics are *global*, given that for the class one you use `Class::`.
  - Another form of global variable , is just define a variable without `static` syntax. This becomes available to other files via the `extern` keyword.
- Extern C Video
  - `extern "c"` → use c header libraries and link them properly without name mangling
    - Where `func()` in c++ actually becomes a symbol `_Z3func` which would cause a
- How do inline variables work

    - Define a variable in a header as inline to be used amongst any translation unit, notably it solves the ODR (one definition rule) by its semantics.
- **Translation unit** - A single file that is comprised of headers and .cpp file that will be compiled to a .obj

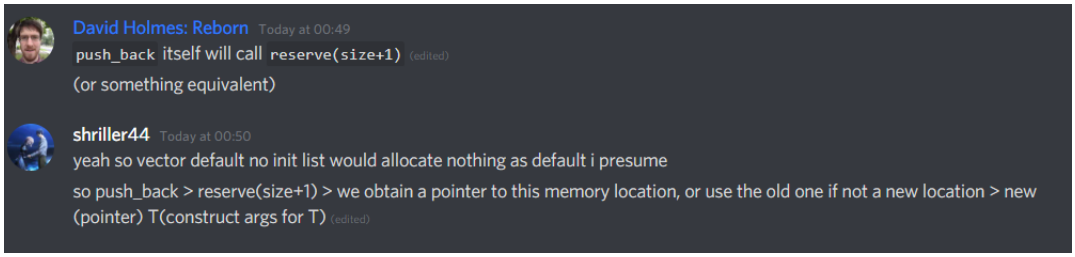
References, Pointers & Memory

Misc reminders

- Differences between references and pointers
- Shared Pointer vs Raw pointers
- Make Shared
    - Make Shared vs Normal shared
- References vs Pointers
- std:ref(T) vs T&
- `std::forward` - perfectly forwards the r value reference, l value reference inside a template.
- `std::unique_ptr` vs `std::shared_ptr` for pimpl idiom - https://stackoverflow.com/questions/5576922/should-i-use-shared-ptr-or-unique-ptr
- `std::unique_ptr` - generates a custom delete when there is no default destructor specified within the class its placed in.
- Placement New
    - Placement New use cases
    - Placement new explained as a memory pool calling explicit destructors
    - ```
      class Arena {
            public:
                  void* allocate(size_t);
                   void deallocate(void*);
                   // ...
       };

      void* operator new(size_t sz, Arena& a){
          return a.allocate(sz);
      }

              Arena a1(some arguments);
              Arena a2(some arguments);
      ```
    - Parameters to placement new
        - ```
          void* operator new(std::size_t, /* extra parameters*/){
              /* do something then return a pointer to at least size bytes */
          }
          ```
- Placement new in the context of `std::vector`

- 

- **Alignment**
  - How to use alignof, alignas
    - Alignment is a *restriction* on which *memory positions* some values *first byte* can be stored.
    - Alignment of `16` means the memory addresses that are **multiples** of `16` are the only valid addresses.
    - The `alignas` keyword forces alignment to the desired type of powers of `2` only
    - ```
      #include <cstdlib>
      #include <iostream>

      int main() {
          alignas(16) int a[4];
          alignas(1024) int b[4]; /* rather than taking up 16 bytes, each
      one now pads up to 1024 bytes.*/
          printf("%p\n", a);
          printf("%p", b);
      }
      ```
    - ```
      #include <iostream>

      /* the alignment is equal to the largest alignment data member
          every member must now follow this alignment rule and thus short
      would be padded 2 bytes to fit the
          4 byte alignment set by int
      */
      struct Foo2 /* alignment = 4 bytes, sizeof = 12 bytes for 3 members
      aligned to 4*/
      {
          short a{};/* 2 bytes*/
          /*2 padding bytes*/
          int b{}; /* 4 bytes*/
          short qq{}; /*2 bytes*/
         /*2 bytes*/
      };

      int main() {
          std::cout << sizeof(short) << std::endl;
          std::cout << sizeof(short) << std::endl;
          std::cout << sizeof(int) << std::endl;
          // total size of data members individually is 10 but as there
      must be padding to ensure proper alignment this changes.
          std::cout << sizeof(Foo2) << std::endl; // size is 12
      }
      ```

Classes, OOP, ...

Core

```
class T {                   // A new type
private:                    // Section accessible only to T's member functions
protected:                  // Also accessible to classes derived from T
public:                     // Accessible to all
    int x;                  // Member data
    void f();               // Member function
    void g() {return;}      // Inline member function
    void h() const;         // Does not modify any data members
    int operator+(int y);   // t+y means t.operator+(y)
    int operator-();        // -t means t.operator-()
    T(): x(1) {}            // Constructor with initialization list
    T(const T& t): x(t.x) {}// Copy constructor
    T(T&& t): x(t.x){ t.x = nullptr; } // Move constructor
    T& operator=(T&& t) {

        if (&t == this){
            return *th
        }

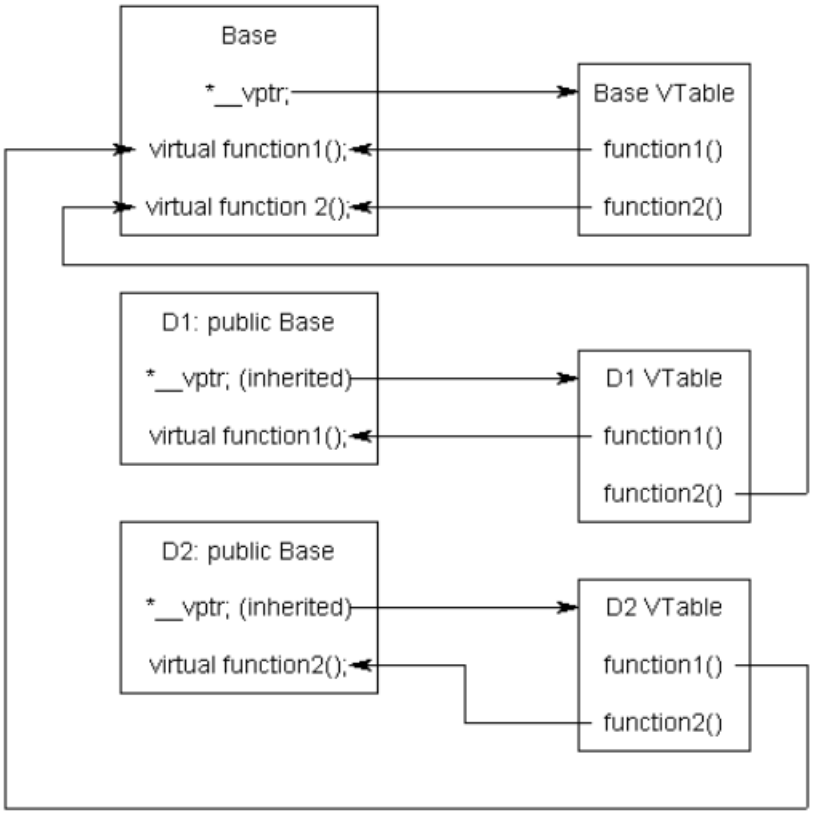
        x = t.x;
        t.x = nullptr;
    }
    T& operator=(const T& t)
    {x=t.x; return *this; } // Assignment operator
    ~T();                   // Destructor (automatic cleanup routine)
    explicit T(int a);      // Allow t=T(3) but not t=3
    T(float x): T((int)x) {}// Delegate constructor to T(int)
    operator int() const
    {return x;}             // Allows int(t)
    friend void i();        // Global function i() has private access
    friend class U;         // Members of class U have private access
    static int y;           // Data shared by all T objects
    static void l();        // Shared code.  May access y but not x
    class Z {};             // Nested class T::Z
    typedef int V;          // T::V means int
};
void T::f() {               // Code for member function f of class T
    this->x = x;}           // this is address of self (means x=x;)
int T::y = 2;               // Initialization of static member (required)
T::l();                     // Call to static member
T t;                        // Create object t implicit call constructor
t.f();                      // Call method f on object t

struct T {                  // Equivalent to: class T { public:
  virtual void i();         // May be overridden at run time by derived class
  virtual void g()=0; };    // Must be overridden (pure virtual)
class U: public T {         // Derived class U inherits all members of base T
  public:
  void g(int) override; };  // Override method g
class V: private T {};      // Inherited members of T become private
class W: public T, public U {};
```

```
                            // Multiple inheritance
class X: public virtual T {};
                            // Classes derived from X have base T directly
```

Misc reminders

- **Virtual destructors** - Use to call destructor of a derived classed pointed to by the base class type.
- **Virtual tables** - To implement virtual functions, C++ uses a special form of late binding known as the virtual table. The **virtual table** is a lookup table of functions used to resolve function calls in a dynamic/late binding manner. The virtual table sometimes goes by other names, such as *vtable*, *virtual function table*, *virtual method* table, or *dispatch table*.



- **Purpose of virtual functions**
- Virtual functions vs pure virtual functions

> A virtual function makes its class a *polymorphic base class*. Derived classes can override virtual functions. Virtual functions called through base class pointers/references will be resolved at run-time. That is, the *dynamic type* of the object is used instead of its *static type*

> A pure virtual function implicitly makes the class it is defined for *abstract* (unlike in Java where you have a keyword to explicitly declare the class abstract). Abstract classes **cannot be instantiated**. Derived classes **need to override/implement** all **inherited pure virtual functions**. If they **do not, they too will become abstract**. ends in `=0`

- Protected vs Private
- What is the override keyword
- `Explicit` Keyword

    - Explicit Keyword in C++ is **used to mark constructors to not implicitly convert types in C++**. It is optional for constructors that take exactly one argument and works on constructors(with single argument) since those are the only constructors that can be used in type casting.
    - Use explicit constructors to ensure the type being converted is not implicitly changing into the class type.
- **Implicit conversions**

```
class balls {
    operator int(){
        return ...
    }
}

int x = balls() /* runs our implicitly user defined function*/
```

- **Mutable keyword** - permits modificationof the class member declared mutable even if the containing object is declared const (i.e., the class member is mutable)
    - Declare an object mutable meaning the object that is const can act on member functions using these values
        - Basically some variables are mutable and can change even if the object they are instantiated within is declare

```
class X
{
    mutable const int* p; // OK
    mutable int* const q; // ill-formed
    mutable int&       r; // ill-formed
};
```

- Passing this context to a lambda within a class:
    - This gives the lambda access to the values of the class directly without having t

```
[this,session](const boost::system::error_code& ec) {
            if (ec.value() != 0) {
                session->m_ec = ec;
                onRequestComplete(session);
                return;
            }
```

- [C++11 POD Standard layout definition]
    - A standard-layout class is a class that - [https://en.cppreference.com/w/cpp/language/classes#Standard-layout_class]:

> 1. has no non-static data members of type non-standard-layout class (or array of such types) or reference,
> 2. has no virtual functions (10.3) and no virtual base classes (10.1),
> 3. has the **same access control** (Clause 11) for all non-static data members,
> 4. has no non-standard-layout base classes,

> 5. either has no non-static data members in the most derived class and **at most one base class with non-static data members**, or has no base classes with non-static data members, and
> 6. has no base classes of the **same type as the first non-static data member**.

- Enabled shared from this
- C++ non-standard-layout class layouts
    - You can cast a *standard layout class object* address to a pointer of its first member:

```
struct A {int x;};

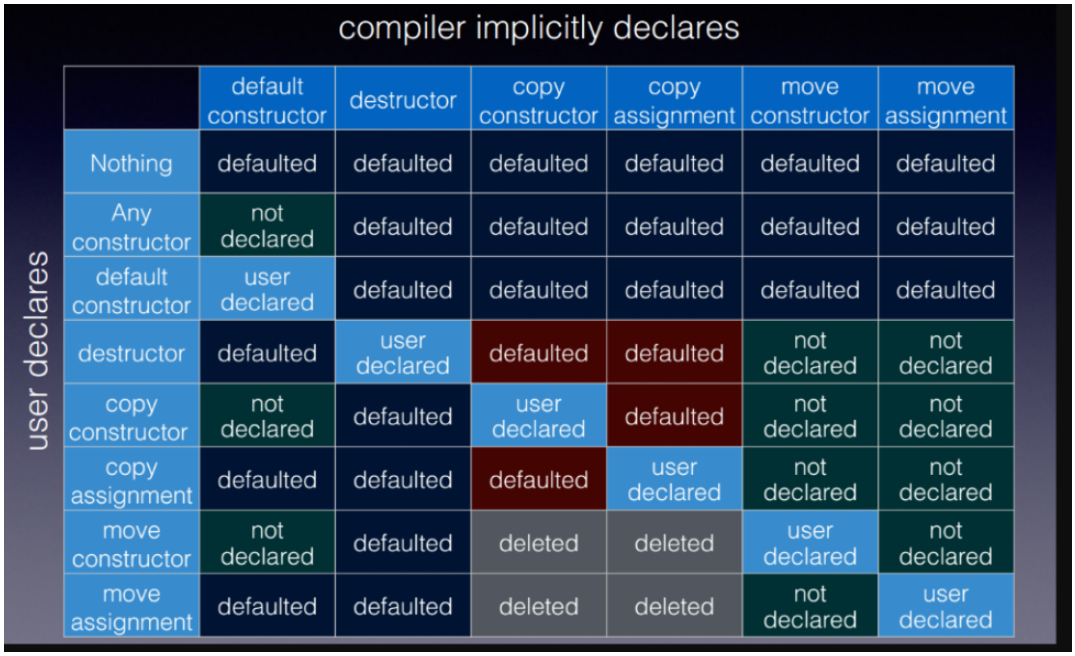
A a;

int *px = (int*) &a;

A *pa = (A*)px;
```

- **[Effective C++ Item 9]** not call virtual functions within destructors, as the base class is created then derived therefore unexpected results could arise.
- We can use the concept of inline variables in a class to define a static variable in the class definition itself as opposed to on the outside.
    - ```
      // Pre C++17
      #include<iostream>
      using namespace std;
      class MyClass {
         public:
            MyClass() {
               ++num;
            }
            ~MyClass() {
               --num;
            }
            static int num;
      };
      int MyClass::num = 10;
      int main() {
         cout<<"The static value is: " << MyClass::num;
      }
      ```
    - ```
      // C++17 inline variables
      #include<iostream>
      using namespace std;
      class MyClass {
         public:
            MyClass() {
               ++num;
            }
            ~MyClass() {
               --num;
            }
            inline static int num = 10;
      ```

```
};
int main() {
   cout<<"The static value is: " << MyClass::num;
}
```

- Special Members that are declared based on user declarations in C++ for a class:
  - 

Unions

Misc reminders

- What is a union for in C and C++

Namespaces

```
namespace N {class T {};}   // Hide name T
N::T t;                     // Use name T in namespace N
using namespace N;          // Make T visible without N::
```

Misc reminders:

- Unnamed namespaces
- Namespace scope
- **Global namespace** - The top level namespace, accessed via just using the prepended :: operator - https://stackoverflow.com/questions/4269034/what-is-the-meaning-of-prepended-double-colon.

Declarations, Types

```
int x;                      // Declare x to be an integer (value undefined)
int x=255;                  // Declare and initialize x to 255
short s; long l;            // Usually 16 or 32 bit integer (int may be either)
char c='a';                 // Usually 8 bit character
unsigned char u=255;
signed char s=-1;           // char might be either
```

```
unsigned long x =
  0xffffffffL;              // short, int, long are signed
float f; double d;          // Single or double precision real (never unsigned)
bool b = true;                // true or false, may also use int (1 or 0)
int a, b, c;                // Multiple declarations
int a[10];                  // Array of 10 ints (a[0] through a[9])
int a[]={0,1,2};            // Initialized array (or a[3]={0,1,2}; )
int a[2][2]={{1,2},{4,5}};  // Array of array of ints
char s[]="hello";           // String (6 elements including '\0')
std::string s = "Hello"     // Creates string object with value "Hello"
std::string s = R"(Hello World)"; // Creates string object with value
"Hello\nWorld"
int* p;                     // p is a pointer to (address of) int
char* s="hello";            // s points to unnamed array containing "hello"
void* p=nullptr;            // Address of untyped memory (nullptr is 0)
int& r=x;                   // r is a reference to (alias of) int x
enum weekend {SAT,SUN};     // weekend is a type with values SAT and SUN
enum weekend day;           // day is a variable of type weekend
enum weekend{SAT=0,SUN=1};  // Explicit representation as int
enum {SAT,SUN} day;         // Anonymous enum
enum class Color {Red,Blue};// Color is a strict type with values Red and Blue
Color x = Color::Red;       // Assign Color x to red
typedef String char*;       // String s; means char* s;
const int c=3;              // Constants must be initialized, cannot assign to
const int* p=a;             // Contents of p (elements of a) are constant
int* const p=a;             // p (but not contents) are constant
const int* const p=a;       // Both p and its contents are constant
const int& cr=x;            // cr cannot be assigned to change x
int8_t,uint8_t,int16_t,
uint16_t,int32_t,uint32_t,
int64_t,uint64_t            // Fixed length standard types
auto it = m.begin();        // Declares it to the result of m.begin()
auto const param = config["param"];
                            // Declares it to the const result
auto& s = singleton::instance();
                            // Declares it to a reference of the result
volatile int x = 5; // x may be changed somewhere else, prevent compiler
optimizations.
```

Misc reminders

- What are cv qualifiers in C++
- Volatile keyword

```
int test {100};
volatile int test {100}; /* does not optimise.*/

while (test == 100){ /* optimize to while(true) may be undesirable*/
 ...
}
```

- `Using` vs `Typedef` in the context of function pointers.

```
typedef  void(*fp)(int); /* fp now alias to this function pointer*/
using fp = void(*)(int); /* fp now alias*/

// You can have calling conventions added too

using fp = void(__stdcall *)(int); // use msvc __stdcall calling convention


void func(int x){}
fp {&func};
```

- RTTI + Microsoft MSVC RTTI
- `constexpr` functions are *implicitly inline*
    - Because constexpr functions may be evaluated at compile-time, the compiler must be able to see the full definition of the constexpr function at all points where the function is called.
    - This means that a constexpr function called in multiple files needs to have its definition included into each such file -- which would normally be a violation of the one-definition rule. To avoid such problems, constexpr functions are implicitly inline, which makes them exempt from the **one-definition rule**.
- When is a function ran at compile time
    - According to the C++ standard, a `constexpr` function that is eligible for compile-time evaluation *must* be evaluated at compile-time if the return value is used where a constant expression is required. Otherwise, the compiler is free to evaluate the function at either compile-time or runtime.
    - ```
      #include <iostream>

      constexpr int greater(int x, int y)
      {
          return (x > y ? x : y);
      }

      int main()
      {
          constexpr int g { greater(5, 6) };            // case 1: evaluated at compile-time
          std::cout << g << "is greater!";

          int x{ 5 }; // not constexpr
          std::cout << greater(x, 6) << " is greater!"; // case 2: evaluated at runtime

          std::cout << greater(5, 6) << " is greater!"; // case 3: may be evaluated at either runtime or compile-time

          return 0;
      }
      ```

- `consteval`
      ```

- Notes that the function must be evaluated at compile time, otherwise it results in an error.
- ```
  #include <iostream>

  consteval int greater(int x, int y) // function is now consteval
  {
      return (x > y ? x : y);
  }

  int main()
  {
      constexpr int g { greater(5, 6) };            // ok: will evaluate at compile-time
      std::cout << greater(5, 6) << " is greater!"; // ok: will evaluate at compile-time

      int x{ 5 }; // not constexpr
      std::cout << greater(x, 6) << " is greater!"; // error: consteval functions must evaluate at compile-time

      return 0;
  }
  ```
- ```
  #include <iostream>

  // Uses abbreviated function template (C++20) and `auto` return type to make this function work with any type of value
  // See 'related content' box below for more info (you don't need to know how these work to use this function)
  consteval auto compileTime(auto value)
  {
      return value;
  }

  constexpr int greater(int x, int y) // function is constexpr
  {
      return (x > y ? x : y);
  }

  int main()
  {
      std::cout << greater(5, 6);              // may or may not execute at compile-time
      std::cout << compileTime(greater(5, 6)); // will execute at compile-time

      int x { 5 };
      std::cout << greater(x, 6);              // we can still call the constexpr version at runtime if we wish

      return 0;
  ```

Expressions

```
T::X                        // Name X defined in class T
N::X                        // Name X defined in namespace N
::X                         // Global name X

t.x                         // Member x of struct or class t
p-> x                       // Member x of struct or class pointed to by p
a[i]                        // i'th element of array a
f(x,y)                      // Call to function f with arguments x and y
T(x,y)                      // Object of class T initialized with x and y
x++                         // Add 1 to x, evaluates to original x (postfix)
x--                         // Subtract 1 from x, evaluates to original x
typeid(x)                   // Type of x
typeid(T)                   // Equals typeid(x) if x is a T
dynamic_cast<T>(x)          // Converts x to a T, checked at run time.
static_cast<T>(x)           // Converts x to a T, not checked
reinterpret_cast<T>(x)      // Interpret bits of x as a T
const_cast<T>(x)            // Converts x to same type T but not const

sizeof x                    // Number of bytes used to represent object x
sizeof(T)                   // Number of bytes to represent type T
++x                         // Add 1 to x, evaluates to new value (prefix)
--x                         // Subtract 1 from x, evaluates to new value
~x                          // Bitwise complement of x
!x                          // true if x is 0, else false (1 or 0 in C)
-x                          // Unary minus
+x                          // Unary plus (default)
&x                          // Address of x
*p                          // Contents of address p (*&x equals x)
new T                       // Address of newly allocated T object
new T(x, y)                 // Address of a T initialized with x, y
new T[x]                    // Address of allocated n-element array of T
delete p                    // Destroy and free object at address p
delete[] p                  // Destroy and free array of objects at p
(T) x                       // Convert x to T (obsolete, use ..._cast<T>(x))

x * y                       // Multiply
x / y                       // Divide (integers round toward 0)
x % y                       // Modulo (result has sign of x)

x + y                       // Add, or \&x[y]
x - y                       // Subtract, or number of elements from *x to *y
x << y                      // x shifted y bits to left (x * pow(2, y))
x >> y                      // x shifted y bits to right (x / pow(2, y))

x < y                       // Less than
x <= y                      // Less than or equal to
x > y                       // Greater than
x >= y                      // Greater than or equal to

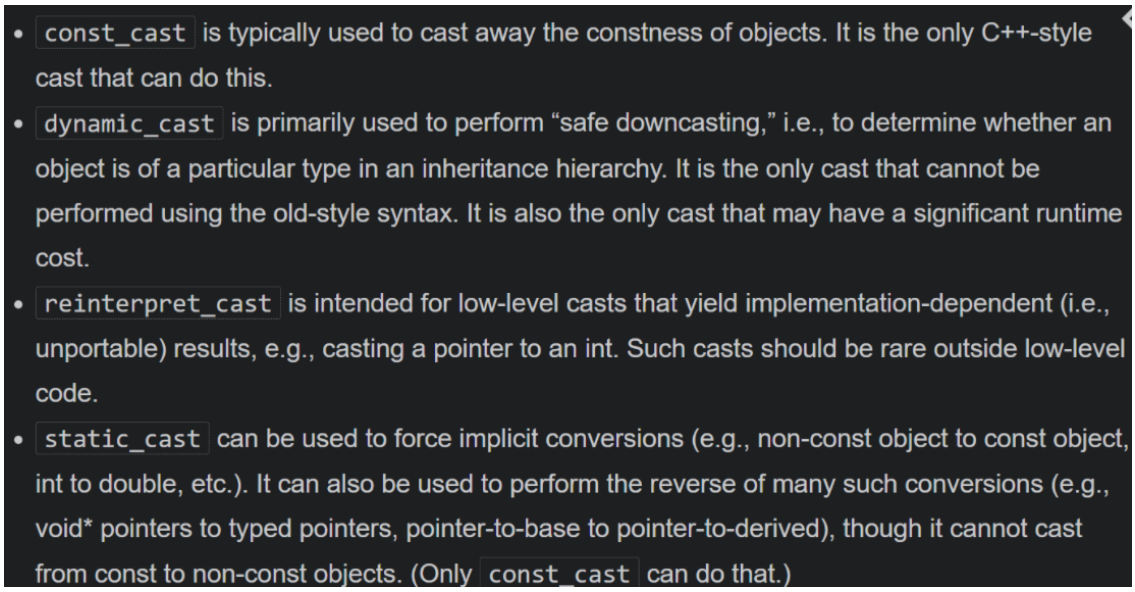
x & y                       // Bitwise and (3 & 6 is 2)
x ^ y                       // Bitwise exclusive or (3 ^ 6 is 5)
x | y                       // Bitwise or (3 | 6 is 7)
x && y                      // x and then y (evaluates y only if x (not 0))
```

```
x || y                      // x or else y (evaluates y only if x is false (0))
x = y                       // Assign y to x, returns new value of x
x += y                      // x = x + y, also -= *= /= <<= >>= &= |= ^=
x ? y : z                   // y if x is true (nonzero), else z
throw x                     // Throw exception, aborts if not caught
x , y                       // evaluates x and y, returns y (seldom used)
```

Value Categories

Misc reminders

- **Static cast** - This is the simplest type of cast which can be used. It is a **compile time cast**. It does things like implicit conversions between types (such as int to float, or pointer to void*), and it can also call explicit conversion functions (or implicit ones).
    - `static_cast<int>(x) vs int(x)` - (https://stackoverflow.com/questions/103512/why-use-static-castintx-instead-of-intx)
- **Types of casting**



Functions

```
int f(int x, int y);        // f is a function taking 2 ints and returning int
void f();                   // f is a procedure taking no arguments
void f(int a=0);            // f() is equivalent to f(0)
f();                        // Default return type is int
inline f();                 // Optimize for speed
f() { statements; }         // Function definition (must be global)
T operator+(T x, T y);      // a+b (if type T) calls operator+(a, b)
T operator-(T x);           // -a calls function operator-(a)
T operator++(int);          // postfix ++ or -- (parameter ignored)
extern "C" {void f();}      // f() was compiled in C
```

Misc reminders

- When to use inline functions
  - When the compiler inline-expands a function call, the function's code gets inserted into the caller's code stream (conceptually similar to what happens with a `#define` macro). This can, depending on a zillion other things, improve performance, because the optimizer can procedurally integrate the called code — optimize the called code into the caller.
- Overload Resolution - https://en.cppreference.com/w/cpp/language/overload_resolution
  - Argument dependent lookup (ADL)
  - What exactly is ADL
- `inline` functions vs preprocessor macros
- **Mutable lambdas**

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

void myInvoke(const std::function<void()>& fn)
{
    fn();
}

int main()
{
    int i{ 0 };

    // Increments and prints its local copy of @i.
    auto count{ [i]() mutable {
      std::cout << ++i << '\n';
    } };

    myInvoke(count); // 1
    myInvoke(count); // 2
    myInvoke(count); // 3

    return 0;
}
```

- Comma operator return type:

```
auto func = [&](int x , int y) {return x + 1, y;} /* evalautes x+1 but returns y */
```

- `std::bind` - What is std::bind in C++

```
void add(int first, int second, const char* string ) {

    std::cout << "first: " << first << "| second : " << second << std::endl;
    std::cout << "word :" << string << std::endl;

}
auto func = std::bind(&add, std::placeholders::_1, std::placeholders::_2,
"test");

/* can call func, using our default "test" string on each value*/
```

Arrays (std::array & C style arrays)

Misc reminders

- Raw C arrays vs std::array performance
- C style array used in templates:
    - ```
      template<typename T, size_t size>
      size_t GetSize(T(&arr)[size])
      {
          return size;
      }

      double arr[] = { 5.0, 6.0, 7.0, 8.0 };
      std::cout << GetSize<double>(arr) << std::endl;
      ```
    - Templated version using normal C++
    - ```
      #include <iostream>
      #include <array>

      template<typename T>
      size_t GetSize(T& arr)
      }
          return std::size(arr);
      }

      int main() {
          double arr[] = { 5.0, 6.0, 7.0, 8.0 };
          /* arr > decays to pointer > reference taken in by template */
          std::cout << GetSize(arr) << std::endl;

      }
      ```
- Passing C++ Arrays to function by reference
- Note on arrays memory address being reference to a `char [5]`
    - ```
      //'array' is a reference to char [5]
      char (&array) [5];
      ```
    - ```
      //Alias of a char[5]
      using FiveCharCode = char[5];
      ```

```
//'code' is a char(&)[5]

/* reference to a char[5] identfied as code*/
void Bar(const FiveCharCode& code) {
 for(char c : code) { //range-based-for loop works
  std::cout << c << "\n";
 }
}


int main() {
 char code[5] = {'A','B','C','D','E'};
  //Call Bar
 Bar(code); //No explicit length passed
 return 0;
}
```

- Using generic return type and collection type. This notably uses the idea that they all can use ranged based for loops to operate.

```
/* specify collection type and then pass the collection*/
template<typename _Ret, typename _Coll> typ_Ret Sum(const _Coll& c) {

 _Ret sum = 0;
 for(auto& v : c)
    sum += v;
 return sum;
}

int main() {
 //With regular array. Passed as reference
 int arr[] = {1,2,3,4,5};
 std::cout << Sum<int64_t>(arr) << "\n"; //15

 //With vector
 std::vector<int> vec = {1,2,3,4,5};
 std::cout << Sum<int64_t>(vec) << "\n"; //15
 return 0;
}
```

- When you use `sizeof(arr)` the `arr` does not get converted to a pointer therefore this operation correctly obtains the size of bytes the array occupies in total.

Standard Library

I/O

- Basic file reading

```
#include <fstream>
#include <iostream>
#include <cstdlib>
```

```
int main(){
    std::ofstream output;

    if (!output){
        std::cerr << "error when attempting to open a stream" << "\n";
        exit(1); /* exit from cstdlib */
    }

    int num[5] { 1,2,3,4,5 };

    for (int i = 0; i < 5; i++){
        output << num[i] << "\n";
    }

    output.close();

}
```

- String comparison

```
#include <iostream>
template<typename T>
T max_t(T a, T b)
{
    return b < a ? "first string" : "second string"; // Note that z > a for
string comparison
}
int main() {
    const std::string str1 { "b" };
    const std::string str2 { "a" };
    constexpr auto ret = max_t(str1, str2);
    std::cout << ret << "\n";
}
```

- Converting strings to integers - https://en.cppreference.com/w/cpp/string/basic_string/stol
- Filestreams
- std::flush
- istreambuf_iterator vs istream_iterator
- Iterator default initial value

```
#include <iostream>
#include <iterator>
#include <algorithm>
#include <sstream>
int main()
{
    std::istringstream stream("1 2 3 4 5");
    std::copy(
        std::istream_iterator<int>(stream),
        std::istream_iterator<int>(), /* default constructor just sets to end of
the file.*/
        std::ostream_iterator<int>(std::cout, " ")
    );
}
```

Misc reminders

- Checking an iterator against null
- std::fixed
- When floatfield is set to fixed, floating-point values are written using fixed-point notation: the value is represented with exactly as many digits in the decimal part as specified by the *precision field* (precision) and with no exponent part.
- **std::variant**
    - Alternative to runtime polymorphism

```
#include <iostream>

struct make_string_functor {
    std::string operator()(const std::string& x) const {return x;}
    std::string operator()(int x){return std::to_string(x);}
}

int main(){
    const std::variant<int, std::string> v = "hello";

    std::cout << std::visit(make_string_functor(), v) << '\n';

    std::visit([](const auto&x){std::cout << x;}, v);
    std::cout << '\n';
}
```

- **std::ranges::generate**

```
for (auto& arr : datasets) {
        std::ranges::generate(arr, f);
    }

/* fills each value of the container with the f being called at each o*/
```

- **Remove specific item** from `std::vector`

```
std::vector<int> items{ 1,2,3,4 };

/* remove the item at 4 by incrementing the start pointer */
items.erase(items.begin() + 3);
```

- **Float value between a and b**

```
std::random_device rd;
std::default_random_engine gen(rd());
/* replace with a and b and make a function, also set option for a custom
generator */
std::uniform_real_distribution<> distr(0, 1);

for (int n = 0; n < 5; ++n) {
    std::cout << std::setprecision(10) << distr(gen)<< "\n";
}
```

C++11

C++14

C++17

- **Structured bindings**
  - https://stackoverflow.com/questions/62871344/using-structured-binding-declaration-in-range-based-for-loop
- https://en.cppreference.com/w/cpp/language/structured_binding
- **[[nodiscard]]**
  - Why not use no discard everywhere

C++20

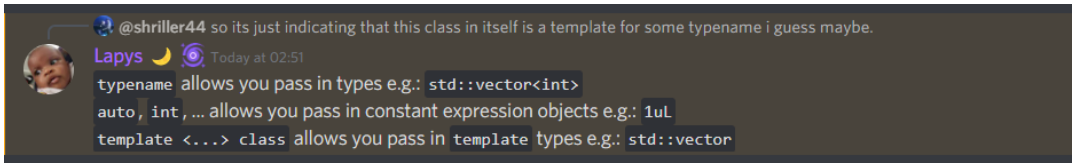
C++23

Performant C++

Templates

Misc reminders

- Type traits primer in C++ - https://www.internalpointers.com/post/quick-primer-type-traits-modern-cpp
- Type traits - `is_standard_layout` - https://en.cppreference.com/w/cpp/types/is_standard_layout
- Explicit template initialisation use cases
- Character traits (char_traits)
- Inline keyword for templates
- Passing types to templates

- 


- ```
  template<template<typename> class F,class T>
  struct Crapdaptor
  {
      bool operator()( const std::unique_ptr<T>& pl,const
  std::unique_ptr<T>& pr ) const
      {
          return F<T>{}( *pl,*pr );
      }
  };
  ```

Abbreviated function templates

```
auto max(auto x, auto y)
{
    return (x > y) ? x : y;
}

/* equivalent too*/

template <typename T, typename U>
auto max(T x, U y)
{
    return (x > y) ? x : y;
}
```

Simple Variadic Template example

```

/* used for when the parameter pack is empty.*/
void print() {
}

/* takes in generic type and generic number of items*/
template<typename T, typename... Types>

/* takes in the first item, then the second item is the parameter pack (...)
denoted args*/
void print(T firstarg, Types... args) {
    std::cout << firstarg << "\n";
    /* pass the parameter pack recurisvely to repeat this process to operate on
each value*/
    print(args...);
}

int main(){
   /* generic printing is a common application of template metaprogramming*/
   print(1, "fuck", false) // 1, "fuck" ,0
}
```
```

User defined deduction guides

- ```
  template <typename T, typename U>
  struct pair
  {
      T first{};
      U second{};
  };

  /* this tells us that when we initialise a pair with some values T,U the
  type deduced should be pair<T,U>*/
  template <typename T, typename U>
  pair(T, U) -> pair<T, U>;

  int main()
  {
      pair<int, int> p1{ 1, 2 };
      pair p2{ 1, 2 };

      return 0;
  }
  ```

Template external

Concurrency

Misc reminders

- **std::atomic**

Networking

Graphics

Architecture

Misc reminders

- Data oriented design summary
  ```