Back to Basics:
const and constexpr

RAINER GRIMM

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Many Flavors of Constness

- Flavors
  - `const`
  - `const_cast`
  - `constexpr`
  - `consteval`
  - `constinit`
  - `is_constant_evaluated`

- Differences
  - Function Execution
  - Variable Initialization

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const

const correctness: Use the keyword `const` to prevent `const` objects from getting mutated.

➡ `const` is a quality attribute of your program.

`const` objects

- must be initialized.
- cannot be modified.
- cannot be victims of data races.
- can only invoke `const` member functions.

const

- `const` member functions cannot change the object.

```
struct Immutable {
    int val{12};
    void canNotModify() const {
        val = 13;       // ERROR
    }
};
```

- Distinguish physical and logical constness of an object.
  - Physical constness: The object is `const` and cannot be changed.
  - Logical constness: The object is `const` but could be changed.

➡ Declare members that can be changed in `const` member functions as `mutable`.

threadSafeCounter.cpp

`const`

- By default, pass pointers and references to `const`

```
void getCString(const char* cStr);
void getCppString(const std::string& cppStr);
```

  - Semantic:
    - Pointer and references do not pass ownership ➡ they borrow the resource from the caller
    - A pointer can be a null pointer ➡ you have to check it

- Exception for non-`const` pointers and references

```
void modifyCString(char* cStr);
void modifyCppString(std::string& cppStr);
```

➡ in/out parameter

`const`

The pointer and the pointee can be const.

- `const char* cStr`:
  - `cStr` points to a `char` that is `const`
  - The pointee cannot be modified, but the pointer can.
- `char* const cStr`:
  - `cStr` is a `const` pointer to `char`
  - The pointer cannot be modified, but the pointee can.
- `const char* const cStr:`
  - `cStr` is a `const` pointer to a `char` that is `const`
  - Neither the pointer nor the pointee can be modified.

Read the expressions from right to left.

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`const_cast`

`const_cast` allows it to remove or add the `const` or `volatile` qualifier to a variable.

Modifying a `const` declared object by removing its constness is undefined behavior.

Don't use a C-cast (`int i = (int) myValue;`), because is applies eventually a series of casts:

`static_cast` → `const_cast` → `reinterpret_cast`

[modifyingConst.cpp]()
[constCast.cpp]()

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constexpr

Constant expressions

- can be evaluated at compile time.
- give the compiler deep insight.
- are implicit thread-safe.

- Variables

```
constexpr double myDouble = 5.2;
const int myInt = 5;
```

- are implicit `const`.
- are implicit thread-safe. A data race requires shared mutable state.
- `const` variables are implicit `constexpr` when initialized with a constant expression.

`const/constexpr` variables make it easy to reason about your concurrent program.

constexpr

- Functions

```
constexpr int gcd(int a, int b) {
    while (b != 0){
        auto t = b;
        b = a % b;
        a = t;
    }
    return a;
}
```

  - must resolve each dependency at compile time.
  - can have variables that must be initialized by constant expressions.
  - cannot have `static` and `thread_local` variables.
  - have the potential to run at compile time. ➡ Must run at compile time when used in a constant expression.
  - are pure.

`constexpr`

- Pure Functions (Mathematical functions)
  - Produce the same result when given the same arguments (referential transparency).
  - Have no side-effects.
  - Don’t change the state of the program.

- Advantages
  - Easy to test and to refactor
  - The call sequence of functions can be changed
  - Automatically parallelizable
  - Results can be cached

constexpr

- User-defined types

```
struct MyDouble {
   double myVal;
   constexpr MyDouble(double v): myVal(v){}
   constexpr double getVal(){return myVal;}
};
```

  - must have at least one `constexpr` constructor.
  - can have `constexpr` and non-`constexpr` member functions.
  - `constexpr` objects can only invoke `constexpr` member functions.

constexpr

C++20 supports the `constexpr` containers `std::vector` and `std::string`.

- Memory allocated at compile time must also be released at compile time. Transient allocation

- The more than 100 algorithms of the STL are declared as `constexpr` in C++20.

If possible, declare user-defined types or functions as `constexpr`.

`constexprVector.cpp`

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consteval

`consteval` generates an *immediate* function.

- Every call of an *immediate* function generates a constant expression that is executed at compile time.

`consteval`

- cannot be applied to destructors.
- has the same requirements as a `constexpr` function.

```
consteval int sqr(int n) {
    return n * n;
}
constexpr int r = sqr(100);  // OK

int x = 100;
int r2 = sqr(x);             // Error
```

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`constinit`

`constinit` guarantees that a variable with static storage duration is initialized at compile time. This variable is still mutable.

- Global objects, or objects declared with `static` or `extern`, have static storage duration.
- Objects with a static storage duration are allocated at the program start and deallocated at its end.

`constinit`

Static Initialization Order Fiasco: The initialization order of static variables between translation units is not specified.

- Initialization of static happens in two steps.
  - Compile time. Statics that are not const-initialized are zero-initialized.
  - Run-time: The zero-initialized statics are dynamic initialized at run time.

➡ `constinit` solves the static initialization order fiasco.

constinit

```
// sourceSIOF1.cpp
int square(int n) {
  return n * n;
}
auto staticA = square(5);
```

```
// mainSOIF1.cpp
#include <iostream>

extern int staticA;
auto staticB = staticA;

int main() {
  std::cout << "staticB: " << staticB;
}
```

rainer : bash — Konsole

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```
rainer@seminar:~> g++ -c mainSIOF1.cpp
rainer@seminar:~> g++ -c sourceSIOF1.cpp
rainer@seminar:~> g++ mainSIOF1.o sourceSIOF1.o -o mainSource
rainer@seminar:~> g++ sourceSIOF1.o mainSIOF1.o -o sourceMain
rainer@seminar:~> mainSource

staticB: 0

rainer@seminar:~> sourceMain

staticB: 25

rainer@seminar:~>
```

constinit

```cpp
// sourceSIOF3.cpp
constexpr int quad(int n) {
  return n * n;
}

constinit auto staticA  = quad(5);
```

```cpp
// mainSOIF3.cpp
#include <iostream>

extern constinit int staticA;
auto staticB = staticA;

int main() {
    std::cout << "staticB: " << staticB;
}
```

Windows PowerShell

```
C:\Users\rainer>clang++ -std=c++20 -c mainSIOF3.cpp

C:\Users\rainer>clang++ -std=c++20 -c sourceSIOF3.cpp

C:\Users\rainer>clang++ mainSIOF3.o sourceSIOF3.o -o mainSource.exe

C:\Users\rainer>clang++ sourceSIOF3.o mainSIOF3.o -o sourceMain.exe

C:\Users\rainer>mainSource.exe

staticB: 25


C:\Users\rainer>sourceMain.exe

staticB: 25


C:\Users\rainer>
```

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std::is_constant_evaluated

`std::is_constant_evaluated` determines whether the function is executed at compile time or run time.

```
constexpr double power(double b, int x) {
    if (std::is_constant_evaluated() && !(b == 0.0 && x < 0)) {
        if (x == 0) return 1.0;
        double r = 1.0, p = x > 0 ? b : 1.0 / b;
        auto u = unsigned(x > 0 ? x : -x);
        while (u != 0) {
            if (u & 1) r *= p;
            u /= 2;
            p *= p;
        }
        return r;
    }
    else return std::pow(b, double(x));  // not declared constexpr
}   // https://en.cppreference.com/w/cpp/types/is_constant_evaluated
```

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Function Execution

```
#include <iostream>

int sqrRunTime(int n) { return n * n; }
consteval int sqrCompileTime(int n) { return n * n; }
constexpr int sqrRunOrCompileTime(int n) { return n * n; }

int main() {
    constexpr int prod1 = sqrRunTime(100);        // ERROR
    constexpr int prod2 = sqrCompileTime(100);
    constexpr int prod3 = sqrRunOrCompileTime(100);

    int x = 100;
    int prod4 = sqrRunTime(x);
    int prod5 = sqrCompileTime(x);                 // ERROR
    int prod6 = sqrRunOrCompileTime(x);
}
```

consteval.cpp

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Variable Initialization

```
#include <iostream>

constexpr int constexprVal = 1000;
constinit int constinitVal = 1000;

int main() {
    auto val = 1000;
    const auto res = ++val;

    std::cout << "res: " << ++res << '\n';                   // ERROR
    std::cout << "++constexprVal: " << ++constexprVal << '\n’; // ERROR
    std::cout << "++constinitVal: " << ++constinitVal << '\n';

    constexpr auto localConstexpr = 1000;
    constinit auto localConstinit = 1000;                     // ERROR
}
```

constexprConstinit.cpp

Variable Initialization

Initialization of a local non-`cost` variable at compile time.

```
consteval auto doubleMe(auto val) {
    return 2 * val;
}

int main() {

    auto res = doubleMe(1010);  // compile-time initialization
    ++res;              // 2021    // non-const

}
```

compileTimeInitializationLocal.cpp

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