

Constant magic

- Constants in C++
- Const correctness
- Pointers to const
- Const member functions
- Const and mutable members
- STL const safety
- constexpr

Design goals of C++

- Type safety
- Resource safety
- Performance control
- Predictability
- Readability
- Learnability

Mapping semantic issues to syntax

```
#include <stdio.h>
int main()
{
    int fahr;
    for ( fahr = -100; fahr <= 400; fahr += 25 )
    {
        printf( "Fahr = %d,\tCels = %d\n", fahr, 5/9*(fahr-32) );
    }
    return 0;
}
```

Mapping semantic issues to syntax

```
#include <stdio.h>
int main()
{
    int fahr;
    for ( fahr = -100; fahr <= 400; fahr += 25 )
    {
        printf( "Fahr = %d,\tCels = %d\n", fahr, 5/9*(fahr-32) );
    }
    return 0;
}
```

```
$ ./a.out
Fahr = -100, Cels = 0
Fahr = -75, Cels = 0
Fahr = -50, Cels = 0
Fahr = -25, Cels = 0
Fahr = 0, Cels = 0
Fahr = 25, Cels = 0
```

Mapping semantic issues to syntax

```
#include <stdio.h>
int main()
{
    int fahr;
    for ( fahr = -100; fahr <= 400; fahr += 25 )
    {
        printf( "Fahr = %d,\tCels = %d\n", fahr, 5/9*(fahr-32) );
    }
    return 0;
}
```

```
$ ./a.out
Fahr = -100, Cels = 0
Fahr = -75, Cels = 0
Fahr = -50, Cels = 0
Fahr = -25, Cels = 0
Fahr = 0, Cels = 0
Fahr = 25, Cels = 0
```

Mapping semantic issues to syntax

```
#include <stdio.h>
int main()
{
    int fahr;
    for ( fahr = -100; fahr <= 400; fahr += 25 )
    {
        printf( "Fahr = %d,\tCels = %d\n", fahr, 5./9.*(fahr-32) );
    }
    return 0;
}
```

Mapping semantic issues to syntax

```
#include <stdio.h>
int main()
{
    int fahr;
    for ( fahr = -100; fahr <= 400; fahr += 25 )
    {
        printf( "Fahr = %d,\tCels = %d\n", fahr, 5./9.*(fahr-32) );
    }
    return 0;
}
```

```
$ gcc fahr2cels
```

```
2c.c: In function 'main':
```

```
2c.c:7:38: warning: format '%d' expects argument of type 'int', but
argument 3 has type 'double' [-Wformat=]
```

Mapping semantic issues to syntax

```
#include <stdio.h>
int main()
{
    int fahr;
    for ( fahr = -100; fahr <= 400; fahr += 25 )
    {
        printf( "Fahr = %d,\tCels = %d\n", fahr, 5./9.*(fahr-32) );
    }
    return 0;
}
```

```
$ ./a.out
Fahr = -100, Cels = 913552376
Fahr = -75, Cels = -722576928
Fahr = -50, Cels = -722576928
Fahr = -25, Cels = -722576928
Fahr = 0, Cels = -722576928
Fahr = 25, Cels = -722576928
```


Mapping semantic issues to syntax

```
#include <stdio.h>
int main()
{
    int fahr;
    for ( fahr = -100; fahr <= 400; fahr += 25 )
    {
        printf( "Fahr = %d,\tCels = %d\n", fahr, 5./9.*(fahr-32) );
    }
    return 0;
}
```

```
$ ./a.out
Fahr = -100, Cels = 913552376
Fahr = -75, Cels = -722576928
Fahr = -50, Cels = -722576928
Fahr = -25, Cels = -722576928
Fahr = 0, Cels = -722576928
Fahr = 25, Cels = -722576928
```

Mapping semantic issues to syntax

```
#include <iostream>
int main()
{
    for ( int fahr = -100; fahr <= 400; fahr += 25 )
    {
        std::cout << "Fahr = " << fahr << ", Cels = "
                  << 5./9.*(fahr - 32) << '\n';
    }
    return 0;
}
```

```
$ ./a.out
Fahr = -100, Cels = -73.333333
Fahr = -75, Cels = -59.444444
Fahr = -50, Cels = -45.555556
Fahr = -25, Cels = -31.666667
Fahr = 0, Cels = -17.777778
Fahr = 25, Cels = -3.888889
```

Mapping semantic issues to syntax

```
/* C language I/O */  
  
#include <stdio.h>  
int main()  
{  
    FILE *fp = fopen( "input.txt", "r");  
  
    . . .  
  
    fprintf( fp, "%s\n", "Hello input!");  
    return 0; /* not strictly necessary since C99 */  
}
```

- Runtime error!

Mapping semantic issues to syntax

```
/* C++ language I/O */  
  
#include <iostream>  
#include <fstream>  
int main()  
{  
    std::ifstream f;  
  
    . . .  
  
    f << "Hello input!" << std::endl;  
    return 0;  
}
```

- Compile-time error!

Side note: Schwartz error

```
while ( cin >> i ) // 1st attempt: cin.operator int() Jerry Schwarz
```

```
std::istream& tempc = cin.operator>>(i);  
int tempi = tempc.operator int();  
while ( tempi )
```

```
while ( cin << i )
```

```
int tempi1 = cin.operator int();  
int tempi2 = tempi1 << i;  
while ( tempi2)
```

`operator bool()` is not better: `bool` -> `int` promotion

Side note: safe bool conversion

```
while ( cin >> i ) // 2nd attempt: cin.operator void*() Jerry Schwarz

std::istream& tempc = cin.operator>>(i);
void* tempptr = tempc.operator void*();
while ( tempi ) // contextually converted to bool

while ( cin << i )

void* tempi1 = cin.operator void*(); // no operator<<(void*,int)
delete std::cin; // delete ( operator void*(std::cin) )

// C++11 solution: explicit specifier
explicit operator bool() const; // not to use in implicit conversion
// works in if, while, etc...

// C++20
explicit (expr) operator bool() const; // explicit if expr is true
```

Const literals

```
char t1[] = {'H', 'e', 'l', 'l', 'o', '\\0'};
char t2[] = "Hello";
char t3[] = "Hello";

/* const */ char *s1 = "Hello"; // s1 points to 'H'
/* const */ char *s2 = "Hello"; // s2 points to the same place

// assignment to array elements ok:
*t1 = 'x'; *t2 = 'q'; *t3 = 'y';

// modifying string literal: can be segmentation error:
*s1 = 'w'; *s2 = 'z';
```

Preprocessor macro names

```
#define LOWER    -100
#define UPPER    400
#define STEP     40

int main()
{
    for( int fahr = LOWER; fahr <= UPPER; fahr += STEP )
    {
        std::cout << "fahr = " << std::setw(4) << fahr
            << ", cels = " << std::fixed << std::setw(7)
            << std::setprecision(2) << 5./9. * (fahr-32)
            << std::endl;
    }
    return 0;
}
```


Named constants

- ```
int f(int i) { return i; }
int main()
{
 const int c1 = 1; // initialized compile time
 const int c2 = 2; // initialized compile time
 const int c3 = f(3); // f() is not constexpr
 int t1[c1];
 int t2[c2];
int t3[c3]; // VLA (Variadic Length Array) is C99 not C++
 switch(i)
 {
 case c1: std::cout << "c1"; break;
 case c2: std::cout << "c2"; break;
 // case label c3 does not reduce to an integer constant
case c3: std::cout << "c3"; break;
 }
 return 0;
}
```

# When named const needs memory?

```
int f(int i) { return i; }

int main()
{
 const int c1 = 1; // initialized compile time
 const int c2 = 2; // initialized compile time
 const int c3 = f(3); // f() is not constexpr
 const int *ptr = &c2;
 return 0;
}
```

- Named pointers require storage when
  - Initialized at run-time (or)
  - Address is used

# Be careful with optimization!

```
int main()
{
 const int ci = 10;
 int *ip = const_cast<int*>(&ci);
 ++*ip;
 cout << ci << " " << *ip << endl;
 return 0;
}

$./a.out
```

# Be careful with optimization!

```
int main()
{
 const int ci = 10;
 int *ip = const_cast<int*>(&ci); // undefined behavior
 ++*ip;
 cout << ci << " " << *ip << endl;
 return 0;
}
```

```
$./a.out
10 11
```

# Be careful with optimization!

```
int main()
{
 volatile const int ci = 10;
 int *ip = const_cast<int*>(&ci); // undefined behavior
 ++*ip;
 cout << ci << " " << *ip << endl;
 return 0;
}
```

```
$./a.out
11 11
```

# Const correctness

```
#include <iostream>

int my_strlen(char *s)
{
 char *p = s;
 while (! (*p = 0)) ++p;
 return p - s;
}

// This program likely cause run-time error
int main()
{
 char t[] = "Hello";
 std::cout << my_strlen(t) << std::endl;
 return 0;
}
```

# Const correctness

```
#include <iostream>

int my_strlen(char *s)
{
 char *p = s;
 while (! (*p = 0)) ++p; // FATAL ERROR
 return p - s;
}

// This program likely cause run-time error
int main()
{
 char t[] = "Hello";
 std::cout << my_strlen(t) << std::endl;
 return 0;
}
```

# Const correctness

```
#include <iostream>

int my_strlen(const char *s)
{
 const char *p = s;
 while (! (*p = 0)) ++p; // Compile-time error!
 return p - s;
}

int main()
{
 char t[] = "Hello";
 std::cout << my_strlen(t) << std::endl;
 return 0;
}
```



# Const correctness

```
#include <iostream>

int my_strlen(const char *s)
{
 const char *p = s;
 while (! (*p == 0)) ++p; // FIX
 return p - s;
}

// this program is fine
int main()
{
 char t[] = "Hello";
 std::cout << my_strlen(t) << std::endl;
 return 0;
}
```

# Side note on defensive programming

```
#include <iostream>

int my_strlen(char *s)
{
 char *p = s;
 while (! (0 = *p)) ++p; // compile-time error!
 return p - s; // "Yoda condition"
}

// This program likely cause run-time error
int main()
{
 char t[] = "Hello";
 std::cout << my_strlen(t) << std::endl;
 return 0;
}
```

# Const correctness and pointers

```
int i = 4; // not constant, can be modified:
 i = 5;

const int ci = 6; // const, must be initialized
 ci = 7; // syntax error, cannot be modified

int *ip;
 ip = &i;
 *ip = 5; // ok
```

# Const correctness and pointers

```
int i = 4; // not constant, can be modified:
 i = 5;

const int ci = 6; // const, must be initialized
 ci = 7; // syntax error, cannot be modified

int *ip;
 ip = &i;
 *ip = 5; // ok

if (input)
 ip = &ci; // ??

*ip = 7; // can I do this?
```

# Pointer to const

```
int i = 4; // not constant, can be modified:
 i = 5;
```

```
const int ci = 6; // const, must be initialized
 ci = 7; // syntax error, cannot be modified
```

```
const int *cip = &ci; // ok
 *cip = 7; // syntax error
int *ip = cip; // syntax error, C++ keeps const

 cip = ip; // ok, constness gained
 *cip = 5; // syntax error,
 // wherever cip points to
```

# Pointer constant

```
int i = 4; // not constant, can be modified:
 i = 5;
```

```
const int ci = 6; // const, must be initialized
 ci = 7; // syntax error, cannot be modified
```

```
int * const ipc = &i; // ipc is const, must initialize
 *ipc = 5; // OK, *ipc points is NOT a const
```

```
int * const ipc2 = &ci; // syntax error,
 // ipc is NOT a pointer to const
```

```
const int * const cccp = &ci; // const pointer to const
```

# const – pointer cheat sheet

- **const** keyword left to \* means pointer to **const**
  - Can point to **const** variable
  - Can be changed
  - Pointed element is handled as constant

```
const int ci = 10;
const int * cip = &ci;
int const * pic = &ci;
```

- **const** keyword right to \* means pointer is constant
  - Must be initialized
  - Can not be changed
  - Can modify pointed element

```
int i;
int * const ipc = &i;
```

# Const $X^{**} = X^{**}$

```
int main()
{
 int i = 42;
 int *ip = &i;
 int **ipp = &ip;

}
```



# Const X\*\* = X\*\*

```
int main()
{
 int i = 42;
 int *ip = &i;
 int **ipp = &ip;

 const int *cip = ip;
 const int **cipp = ipp;

}
```

# Const X\*\* = X\*\*

```
int main()
{
 int i = 42;
 int *ip = &i;
 int **ipp = &ip;

 const int *cip = ip;
const int **cipp = ipp; // error: invalid conversion
 // from 'int**' to 'const int*'

}
```

# Const X\*\* = X\*\*

```
int main()
{
 int i = 42;
 int *ip = &i;
 int **ipp = &ip;

 const int *cip = ip;
const int **cipp = ipp;
 const int **cipp = &cip; // OK
 **cipp = 43;
}
```

# Const X\*\* = X\*\*

```
int main()
{
 int i = 42;
 int *ip = &i;
 int **ipp = &ip;

 const int *cip = ip;
const int **cipp = ipp;
 const int **cipp = &cip; // OK
**cipp = 43; // error: assignment of read-only location
}
```

# Const X\*\* = X\*\*

```
int main()
{
 int i = 42;
 int *ip = &i;
 int **ipp = &ip;

 const int *cip = ip;
const int **cipp = ipp;

 int *const *pcip = ipp; // OK
}
```

# Const X\*\* = X\*\*

```
int main()
{
 int i = 42;
 int *ip = &i;
 int **ipp = &ip;

 const int *cip = ip;
const int **cipp = ipp;

 int *const *pcip = ipp; // OK
 **pcip = 43; // OK?
}
```

# Const X\*\* = X\*\*

```
int main()
{
 int i = 42;
 int *ip = &i;
 int **ipp = &ip;

 const int *cip = ip;
const int **cipp = ipp;

 int *const *pcip = ipp; // OK
 **pcip = 43; // OK?
*pcip = &j; // assignment of read-only location
}
```

# Const X\*\* = X\*\*

```
int main()
{
 int i = 42;
 int *ip = &i;
 int **ipp = &ip;

 const int *cip = ip;
const int **cipp = ipp;

 const int *const *pcip = ipp; // OK
*pcip = &j; // assignment of read-only location
**pcip = 43; // assignment of read-only location
}
```



# Const X\*\* = X\*\*

```
int main()
{
 int i = 42;
 int *ip = &i;
 int **ipp = &ip;

 const int *cip = ip;
const int **cipp = ipp;

 const int *const *pcip = ipp; // OK
*pcip = &j; // assignment of read-only location
**pcip = 43; // assignment of read-only location
 pcip = &jp; // OK
}
```

# Const X\*\* = X\*\*

```
int main()
{
 int i = 42;
 int *ip = &i;
 int **ipp = &ip;

 const int *cip = ip;
const int **cipp = ipp;

 const int *const *const pcip = ipp; // OK
*pcip = &j; // assignment of read-only location
**pcip = 43; // assignment of read-only location
pcip = &jp // assignment of read-only location
}
```

# Base\*\* = Derived\*\*

```
class Vehicle { https://isocpp.org/wiki/faq/proper-inheritance#derivedptrptr-to-baseptrptr
public:
 virtual ~Vehicle() { }
 virtual void startEngine() = 0;
};

class Car : public Vehicle {
public:
 virtual void startEngine();
 virtual void openGasCap();
};

class NuclearSubmarine : public Vehicle {
public:
 virtual void startEngine();
 virtual void fireNuclearMissile();
};

int main()
{
 Car car;
 Car* carPtr = &car;
 Car** carPtrPtr = &carPtr;
Vehicle** vehiclePtrPtr = carPtrPtr; // This is an error in C++

 NuclearSubmarine sub;
 NuclearSubmarine* subPtr = ⊂
 *vehiclePtrPtr = subPtr; // carPtr to point to Submarine
 carPtr->openGasCap(); // This might call fireNuclearMissile()!
}
```

# User-defined types

```
class Date
{
public:
 Date(int year, int month = 1, int day = 1);
 // ...
 int getYear();
 int getMonth();
 int getDay();
 void set(int y, int m, int d);
 // ...
private:
 int year;
 int month;
 int day;
};
const Date my_birthday(1963,11,11); // const can be initialized
 Date curr_date(2015,7,10);

 curr_date = my_birthday; // ok, const can be read
my_birthday = curr_date; // compile-time error: write const
```

# User-defined types

```
class Date
{
public:
 Date(int year, int month = 1, int day = 1);
 // ...
 int getYear();
 int getMonth();
 int getDay();
 void set(int y, int m, int d);
 // ...
private:
 int year;
 int month;
 int day;
};

const Date my_birthday(1963, 11, 11);
 Date curr_date(2015, 7, 10);

int x = my_birthday.getYear(); // can I read ??
my_birthday.set(2015, 7, 10); // can I write ??
```

# User-defined types

```
class Date
{
public:
 Date(int year, int month = 1, int day = 1);
 // ...
 int getYear() const;
 int getMonth() const ;
 int getDay() const;
 void set(int y, int m, int d);
 // ...
private:
 int year;
 int month;
 int day;
};

const Date my_birthday(1963, 11, 11);
 Date curr_date(2015, 7, 10);

int x = my_birthday.getYear(); // works
my_birthday.set(2015, 7, 10); // compile error
```

# User-defined types

```
class Date
{
public:
 Date(int year, int month = 1, int day = 1);
 // ...
 int getYear() const; -> _ZNK4Date7getYearEv(const Date* this);
 int getMonth() const;
 int getDay() const;
 void set(int y, int m, int d); -> _ZN4Date3setEiii(Date *this,int y,int m,int d)
 // ...
private:
 int year;
 int month;
 int day;
};

const Date my_birthday(1963,11,11);
 Date curr_date(2015,7,10);

int x = my_birthday.getYear(); // ok
my_birthday.set(2015,7,10); // compile-time error!
```

# Overloading on const

```
template <typename T, ... >
class vector
{
public:
 T& operator[](size_t i);
 const T& operator[](size_t i) const;
 // ...
};
int main()
{
 std::vector<int> iv;
 const std::vector<int> civ;
 // ...
 iv[i] = 42; // non-const
 int i = iv[5];
 int j = civ[5] // const
 // ...
}
```



# Const members

```
class Msg
{
public:
 Msg(const char *t);
 int getId() const { return id; }
private:
 const int id;
 std::string txt;
};

Msg m1("first"), m2("second");
m1.getId() != m2.getId();

MSg::Msg(const char *t)
{
 txt = t;
 id = getNextId(); // syntax error, id is const
}

//initialization list works
MSg::Msg(const char *t) : id(getNextId()), txt(t) { }
```

# Const members

```
class Msg
{
public:
 Msg(const char *t);
 int getId() const { return id; }
private:
 const int id = getNewId(); // since C++11
 std::string txt;
};
```

# Mutable members

```
struct Point
{
 void getXY(int& x, int& y) const;
 double xcoord;
 double ycoord;
 mutable int read_cnt;
};

void f()
{
 const Point a;
 ++a.read_cnt; // ok, Point::read_cnt is mutable
}

void Point::getXY(int& x, int& y) const
{
 // ...
 ++read_cnt; // ok, Point::read_cnt is mutable
};
```

# Mutexes are usually mutables

```
#include <mutex>
```

- ```
struct Point
{
public:
    void getXY(int& x, int& y) const;
    // ...
private:
    double xcoord;
    double ycoord;
    mutable std::mutex m;
};
```

```
void getXY(int& x, int& y) const // atomic read of point
{
    std::lock_guard< std::mutex > guard(m); // locking of m
    x = xcoord;
    y = ycoord;
} // unlocking m
```

Static const

```
// x.h
```

```
class X
```

```
{
```

```
    static const int c1 = 7;    // ok, scalar
```

```
    static      int i2 = 8;    // error: not const
```

```
    const      int c3 = 9;    // C++11: ok
```

```
    static const int c4 = f(2); // error: non-const init.
```

```
    static const float f = 3.14; // ok, scalar
```

```
};
```

```
// x.cpp
```

```
const int X::c1; // initializer is here xor in-class
```

STL is const safe

```
template <typename It, typename T>
It find( It begin, It end, const T& t)
{
    while (begin != end) {
        if ( *begin == t )
            return begin;
        ++begin;
    }
    return end;
}

const char t[] = { 1, 2, 3, 4, 5 };
const char *p = std::find( t, t+sizeof(t), 3)
if ( p != t+sizeof(t) )
{
    std::cout << *p; // ok to read
    // syntax error: *p = 6;
}
const std::vector<int> v(t, t+sizeof(t));
std::vector<int>::const_iterator i = std::find( v.begin(), v.end(), 3);
if ( v.end() != i )
{
    std::cout << *i; // ok to read
    // syntax error: *i = 6;
}
```

STL is const safe

```
// C++11

std::vector<int> v1(4,5);
auto i = std::find( v1.begin(), v1.end(), 3);
// i is vector<int>::iterator

const std::vector<int> v2(4,5);
auto j = std::find( v2.begin(), v2.end(), 3);
// j is vector<int>::const_iterator

auto k = std::find( v1.cbegin(), v1.cend(), 3);
// k is vector<int>::const_iterator
```

STL is const safe

```
// C++11
```

```
std::vector<int> v1(4,5);  
auto i = std::find( std::begin(v1), std::end(v1), 3);  
// i is vector::iterator  
  
const std::vector<int> v2(4,5);  
auto j = std::find( std::begin(v2), std::end(v2), 3);  
// j is vector::const_iterator  
  
auto k = std::find( std::cbegin(v1), std::cend(v1), 3);  
// k is vector::const_iterator
```


Constexpr objects in C++11

- Const objects having value known at translation time.
- translation time = compilation time + linking time
- They may have placed to ROM
- Immediately constructed or assigned
- Must contain only literal values, constexpr variables and functions
- The constructor used must be constexpr constructor

Constexpr in C++11

```
enum Flags { good=0, fail=1, bad=2, eof=4 };
```

```
constexpr int operator|(Flags f1, Flags f2)  
{  
    return Flags(int(f1)|int(f2));  
}
```

```
void f(Flags x)  
{  
    switch (x)  
    {  
        case bad:          /* ... */ break;  
        case eof:         /* ... */ break;  
        case bad|eof:     /* ... */ break;  
        default:         /* ... */ break;  
    }  
}
```

Constexpr in C++11

```
include <cstdio>
```

```
size_t constexpr length(const char* str)
{
    return *str ? 1 + length(str + 1) : 0;
}
```

```
void f()
{
    printf("%d %d", length("abcd"), length("abcdefgh"));
}
```

- Pattern matching + recursion == Turing complete

Constexpr functions in C++11/14

- Can produce constexpr values when called with compile-time constants.
- Otherwise can run with non-constexpr parameters
- Must not be virtual
- Return type must be literal type
- Parameters must be literal type
- Since C++14 they can be more than a return statement
 - if / else / switch
 - for / ranged-for / while / do-while

Constexpr in C++14

```
#include <iostream>
```

```
constexpr int strlen(const char *s)
```

```
{
```

```
    const char *p = s;
```

```
    while ( '\0' != *p ) ++p;
```

```
    return p-s;
```

```
}
```

```
int main()
```

```
{
```

```
    std::cout << strlen("Hello") << std::endl;
```

```
    return 0;
```

```
}
```

```
constexpr int pow( int base, int exp) noexcept
```

```
{
```

```
    auto result = 1;
```

```
    for (int i = 0; i < exp; ++i) result *= base;
```

```
    return result;
```

```
}
```

Constexpr in C++14

```
class Point
{
public:
    constexpr Point(double xVal=0, double yVal=0) : x(xVal),y(yVal) noexcept {}
    constexpr double xValue() const noexcept { return x; }
    constexpr double yValue() const noexcept { return y; }

    // can be constexpr since C++14
    constexpr void setX(double newX) noexcept { x = newX; }
    constexpr void setY(double newY) noexcept { y = newY; }
private:
    double x, y;
};

constexpr Point p1(42.0, -33.33); // fine, constexpr ctor during compilation
constexpr Point p2(25.0, 33.3); // also fine

constexpr Point midpoint(const Point& p1, const Point& p2) noexcept
{
    return { (p1.xValue() + p2.xValue()) / 2, // call constexpr
            (p1.yValue() + p2.yValue()) / 2 }; // member funcs
}

constexpr auto mid = midpoint(p1, p2); // init constexpr object with
// result of constexpr
```

Constexpr lambda in C++17

- Constexpr lambda (+ template lambda)
- Closure objects are literal types (as long as captured members are literal types)

```
template <typename I>
constexpr auto adder(I i) {
    //use a lambda in constexpr context
    return [i](auto j){ return i + j; };
}
```

```
//constexpr closure object
constexpr auto add5 = adder(5);
constexpr auto add15 = adder(15);
```

```
template <unsigned N>
class X{};
```

```
int foo()
{
    //use in a constant expression
    X<add5(22)> x27;
    int t25[add15(10)];
}
```

Constexpr in C++20

- Union (also needed for constexpr string)
- Try and catch (throw not allowed, so catch works only runtime)
- `dynamic_cast` and `typeid` (since we have virtual functions)
- Constexpr allocation
 - Transient: deallocated before evaluation completes
 - Non-transient: not (yet)
- Virtual calls in constexpr, constexpr virtual functions/overrides
- Library: constexpr vector and string

constexpr in C++20

```
// C++20
```

```
constexpr auto naiveSum(unsigned int n)
{
    auto p = new int[n]; // transient allocation C++20

    // iota is constexpr in C++20
    std::iota(p, p+n, 1);

    // accumulate is constexpr in C++20
    auto tmp = std::accumulate(p, p+n, 0);

    delete [] p; // compiler detects delete/delete[] issues
    return tmp;
}
```

Consteval in C++20/23

- Immediate function: always evaluated in compiler time
 - Constexpr can be evaluated in run-time

```
constexpr int sqr(int n)
{
    return n*n;
}
constexpr int r = sqr(100); // Okay.
int x = 100;
int r2 = sqr(x); // Error: Call does not produce a constant.

if ( std::is_constant_evaluated() ) { } else { } // C++20

if constexpr { } else { } // C++23, the same as above
if !constexpr { } else { } // always compound statement
```

Consteval in C++2c?

- Consteval variables
- Immediate variables: replacement for MACROs
 - Never seen by the compiler back-end / code generation

```
constexpr int RN = 42;  
int LN = 42;  
  
int f(int const&);  
  
int r1 = f(LN); // Direct reference binding.  
int r2 = f(RN); // Not a direct binding (temporary created).
```

Constinit in C++20

- A variable to be constant initialized but can be mutable
 - Solves the problem of Static Initialization Order Fiasco
 - Local static: no need for mutex on initialization
- Should be applied for static storage duration
- Requires constant initializer

```
// Foo.h
struct Foo {
    constinit static int x;
};
// Foo.cpp
int Foo::x = 42;
int Foo::x = f(); // error

void g()
{
    ++Foo::x; // ok
}
```

Static IF in C++17

- Evaluate conditional expression in compile time
- The compiler eliminates the false branch(es)
- The rest of the code should be syntactically correct (compiler should parse)
- ... but the compiler does not compile it

```
template <class T>
auto foo(T t) {
    if constexpr(std::is_same_v<T, X>) {
        return t.a_function_that_exists_only_for_X();
    }
    else {
        std::cout << "Not T\n";
        return; // returns void if T is not int
    }
}
void bar() {
    X x;
    auto i = foo(x); // calls x.a_function_that_exists_only_for_X();
    foo(23); // would be compile error for non-static if
}
```

Static IF in C++17

- Before C++17: overloading, SFINAE, enable_if
- Since C++17 we can write common code

```
template <typename T>
auto get_value(T t)
{
    if constexpr (std::is_pointer_v<T>)
        return *t;
    else
        return t;
}
```

```
template <class Head, class... Tail>
void print(Head const& head, Tail const&... tail)
{
    std::cout << head;
    if constexpr (sizeof...(tail) > 0)
    {
        std::cout << ", ";
        print(tail...);
    }
}
```

Fibonacci with static IF

```
// before C++17
template<int N>
constexpr int fibonacci() {return fibonacci<N-1>() + fibonacci<N-2>(); }

template<>
constexpr int fibonacci<1>() { return 1; }

template<>
constexpr int fibonacci<0>() { return 0; }

// since C++17
template<int N>
constexpr int fibonacci()
{
    if constexpr (N >= 2)
        return fibonacci<N-1>() + fibonacci<N-2>();
    else
        return N;
}

int main()
{
    constexpr int fib12 = fibonacci<12>(); // 144
}
```

More on constants

- C++Now 2019 Daveed Vandevorde “C++ constants”
<https://www.youtube.com/watch?v=m9tcmTjGeho>
- C++Now 2017 Ben Deane & Jason Turner: “constexpr ALL the things!”
<https://www.youtube.com/watch?v=HMB9oXFobJc>
- C++Now 2021 David Sankel: “Don’t constexpr ALL the things!”
<https://www.youtube.com/watch?v=NNU6cbG96M4>
- C++Weekly Jason Turner: “C++23 if constexpr”
https://www.youtube.com/watch?v=AtdlMB_n2pl