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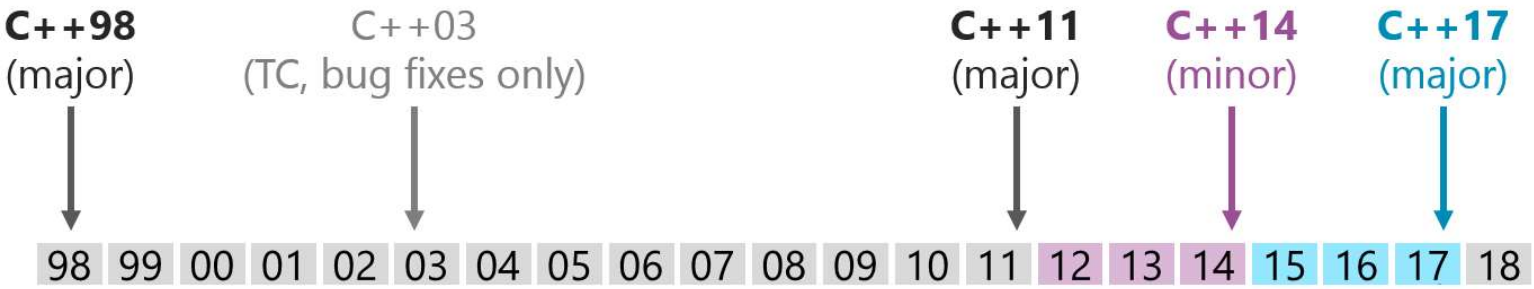
Modern C++: core features

For us

Modern C++

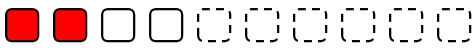
It is what is after C++98/03: C++11, C++14, and C++17



Core features

We shall see some of the core features which help us to at least read some modern C++ code:

- nullptr, auto, type aliases, initializer list, uniform initialization, scoped enumerations, range-based loops, constexpr, override and final.



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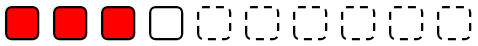
Prerequisites

To fully understand the course it is required:

- Basic knowledge of standard C++98



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Prerequisites: C++98

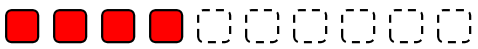
Very basic startup material:

- http://www.cplusplus.com/doc/oldtutorial/

Something more:

- Thinking in C++, Bruce Eckel

  https://www.micc.unifi.it/bertini/download/programmazione/TICPP-2nd-ed-Vol-one-printed.pdf
- Effective C++: 55 Specific Ways to Improve Your Programs and Designs, Scott Meyers



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Modern C++

- nullptr,
- auto,
- type aliases,
- initializer list,
- uniform initialization,
- range-based loops,
- constexpr,
- scoped enumerations,
- override and final.

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Use nullptr

Since C++11, we prefer the keyword nullptr over 0 or NULL to express a dummy pointer.

Use nullptr because:

- The literal 0 (NULL) is an int, not a pointer and could cause ambiguity in overloaded function resolution.
- It improves code clarity.

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Use nullptr

Example

```
void f(int a);
void f(char *a);
void test() {          // on compiler armclang w/ both -std=c++98/c++14/c++17
    f(0);              // calls f(int a)
    f(NULL);           // calls f(int a): it is not what we wanted
    f(nullptr);        // calls f(char *a)
    auto result = findRecord( /* arguments */ );
    if(nullptr == result) {    // there's no ambiguity:
        ....                   // result must be a pointer type
    }
}
```

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Use auto whenever possible

The new C++ standards allows the use of auto as a placeholder for types in various contexts and let the compiler deduce the actual type.

An actual term was coined for this by Andrei Alexandrescu and promoted by Herb Sutter: *almost always auto* (*AAA*).

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Use auto …

To declare local variables when you do not want to commit to a specific type with the form:

```
auto name = expression
```

Example

```
auto i = 42; // int
auto d = 42.5; // double
auto s = "text"; // char const *
auto v = { 1, 2, 3 }; // std::initializer_list<int>
```


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Use auto …

To declare local variables when you need to commit to a specific type with the form:

```
auto name = type-id { expression }
```

Example

```
auto b = new char[10]{ 0 }; // char*
auto s1 = std::string {"text"}; // std::string
auto v1 = std::vector<int> { 1, 2, 3 }; // std::vector<int>
auto p = std::make_shared<int>(42); // std::shared_ptr<int>
```

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Use auto …

The auto can be used to specify the return type from a function. In C++11, this requires a trailing return type in the function declaration. In C++14, the type of the return value is deduced by the compiler.

Example

```
auto add(const int a, const int b) -> int { return a+b; }     // C++11

auto multiply(const int a, const int b) { return a*b; }       // C++14
```


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Use auto …

To declare named lambda functions, with the form:

```
auto name = lambda-expression
```

Example

```
auto half = [](const double v) { return v/2.0; };
auto result = half(8.0);
```

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Use auto …

To declare lambda parameters and return values (since C++14).

Examples

```
auto half = [](const auto a) { return a/2; };
constexpr double ninepointzero = 9.0;
constexpr int eleven = 11;
auto result1 = half(ninepointzero);        // it is 4.5 (double)
auto result2 = half(eleven);               // it is 5 (int)
```


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Benefits of auto

- It is not possible to leave a variable uninitialized.

```
auto ihaveavalue = 3;    // int
auto idonthaveavalue;  // ERROR: its content is unpredictable
```

- Ensures that you always use the correct type and that implicit conversion will not occur

```
auto v = std::vector<int>{ 1, 2, 3 };
int size1 = v.size();     // actually size() returns size_t ...
auto size2 = v.size(); // correct type size_t
```


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Benefits of auto

- It means less typing and less concern for types that we don't care about

```
std::map<int, std::string> m; // given this map …
// we just want to iterate
for (auto it = m.cbegin(); it != m.cend(); ++it)
{ /*…*/ }

// we don’t care about the type of the iterator it
for(std::map<int,std::string>::const_iterator it = m.cbegin();
it != m.cend(); ++it)
{ /*…*/ }
```


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Perils of auto

- The user may write obscure code

```
auto var = obtainit();
useit(var);
```

WHAT is var ????

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Almost always auto but

- Use auto wherever you believe it enhances code readability BUT … use it well and avoid it where it obscures the intent of the code

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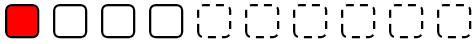
Use using

In C++, we can create synonyms for type name with a typedef declaration. However, typedef has some limitations (e.g., it cannot be used with templates).

Since C++11, there is a new using syntax for type aliases and alias templates.



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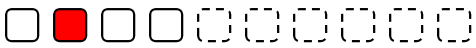
Use using

To create type aliases with the form:

Using alias-name = type-id

Example

```
using byte = unsigned char;
using array10b_t = byte[10];
using fpWorker = void (*)(void);
void dosomething() { static array10b_t data = {0}; data[0]++; }
void caller(fpWorker f) { f(); }
void f1() { caller(dosomething); }
```

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Use using

To create alias templates with the form :

```
template<template-params-list>
using alias-name = type-id
```

Example

```
template <typename T>
using vect_t = std::vector<T>;

vect_t<std::string> vs;
vect_t<int> vi;
```

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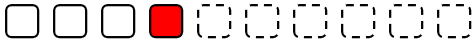
Use using

Example

```
// FP is a synonym for a pointer to a function taking an int and
// a const std::string& and returning nothing
typedef void (*FP)(int, const std::string&); // typedef

// same meaning as above
using FP = void (*)(int, const std::string&); // alias declaration
```

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Initializer list

An object of type std::initializer_list<T> is a lightweight proxy that provides access to an array of objects of type const T.

Example

```
void afun(const std::initializer_list<int> &l);
auto ilis = { 10, 20, 30 };  // the type of ilis is initializer_list<int>
afun(ilis);
auto ilistr = { “hello”, “world” } ;
```

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Initializer list

The std::initializer_list<T> is used as a constructor for the std containers. As such, it has wide use in modern C++.

Example

```
std::array<int, 3> a3 = {1, 2, 3};
std::map<int, std::string> mm1 = { {1, "one"}, {2, "two"} };
std::map<int, std::string> mm2{ {3, “three"}, {4, “four"} };
```


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Initializer list

Example

```
template <class T>
struct S {
    std::vector<T> v;
    (std::initializer_list<T> l) : v(l) {  std::cout << “size = " << l.size();    }
    void append(std::initializer_list<T> l) { v.insert(v.end(), l.begin(), l.end()); }
};

S<int> s = {1, 2, 3, 4, 5}; // copy list-initialization
s.append({6, 7, 8}); // list-initialization in function call
```


Initializer list

Actual use in YARP

YARP_OS: add initializer_list constructor for Property.

Example:

```
Property p {{"one", Value(1)},
            {"two", Value(2.0)},
            {"string", Value("foo")}
            };
```

devel (#2007)

Nicogene committed 29 days ago

```
60  60
    61  +       /**
    62  +        * @brief Initializer list constructor.
    63  +        * @param[in] values, list of std::pair with which initialize the Property.
    64  +        */
    65  +       Property(std::initializer_list<std::pair<std::string, yarp::os::Value>> values);
```

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Initializer list

Actual use in embedded software of iCub

```
162
163  static void start_evt_based(void)
164  {
165      // pulse led one at 1 hertz
166      embot::app::theLEDmanager &theleds = embot::app::theLEDmanager::getInstance();
167      theleds.init( { embot::hw::LED::one, embot::hw::LED::two } );
168      theleds.get(embot::hw::LED::one).pulse(embot::common::time1second);
169
```

```
class theLEDmanager
{
public:
    static theLEDmanager& getInstance();

    bool init(const std::initializer_list<embot::hw::LED> &leds);
    bool deinit(const std::initializer_list<embot::hw::LED> &leds);
    bool deinit();

    bool initialised(embot::hw::LED led) const;
    LEDhandle & get(embot::hw::LED led) const;

    ~theLEDmanager();

private:
    theLEDmanager();
    struct Impl;
    std::unique_ptr<Impl> pImpl;
};
```


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Uniform-initialization

C++11 has a uniform syntax that can be used anywhere, the braced-initialization: { }

It can be used in direct initiatialization and also in copy initialization:

direct initialization

```
int i{2};
int[] ai{2,3};
vector<int> vi{1, 2, 3};
```

copy initialization

```
int i = {2};
int ai[] = {2, 3};
vector<int> vi = {1, 2, 3};
```


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Uniform-initialization

Example w/ built-in types and arrays:

```
int i { 42 }; double d { 1.2 };
int arr1[3] { 1, 2, 3 };  int* arr2 = new int[3]{ 1, 2, 3 };
```

Example w/ standard containers:

```
std::vector<int> v { 1, 2, 3 };
std::vector<int> v1 {};
std::map<int, std::string> m { {1, "one"}, { 2, "two" } };
```

In C++98, it is possible only w/ std::vector and integral types:

```
int arr[] = {3, 9, 27, 81};
std::vector<int> vec98 (arr, arr + sizeof(arr) / sizeof(arr[0]) );
```

{}

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Uniform-initialization

Example w/ user-defined types:

```
class FAQ {
    std::string question {“*"};
    int answer {42};
public:
    FAQ() = default;
    FAQ(const std::string &q, int a) : question(q), answer(a) {}
};
void test() {
        FAQ f0{};
        FAQ f2{ “what?”, 42};
}
```

{}

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Uniform-initialization

All standard containers have an additional constructor in C++11 that takes an argument std::initializer_list<T>

An initializer list always takes precedence over other constructors where brace-initialization is used.

```
struct fee {
   std::array<int, 2> a {0, 0};
   fee() = default;
   fee(int v1, int v2 = 1) : a{v1, v2} {} // useless
   fee(std::initializer_list<int> l) { if(l.size() == 2){ … } }
};
fee f{ 1, 2 }; // calls constructor with initializer_list<int>;
```

{}

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Uniform-initialization

Caveat:

- The precedence of std::initializer_list<> may lead to bugs:

```
std::vector<int> v {5, 1}; // a vector of 2 elements: 5 and 1
std::vector<int> v (5, 1); // a vector of 5 elements with value 1
```

- brace-initialization does not allow narrowing conversion:

```
int i{ 1.2 };                 // error
double d = 47 / 13;
float f1{ d };                // error
float f2{47/13};              // OK
```

{}

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Modern C++

- Hidden track: std::array<>

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std::array<>

The std::array is a container that encapsulates fixed size arrays.

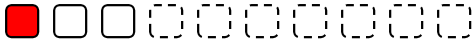
- std::array<T, N> an aggregate type with the same semantics as a struct holding a C-style array T[N] as its only non-static data member.

```
std::array<int, 2> data0 {1, 2};

int value = data0[1];
```

```
struct ARRAY {
    int memory[2];
    // other code
};
ARRAY data1 {1, 2};

int value = data1.memory[1];
```

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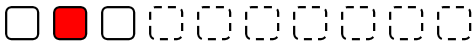
std::array<>

- the struct combines the performance and accessibility of a C-style array with the benefits of a standard container, such as knowing its own size, supporting assignment, random access iterators, etc.

```
std::array<int, 4> data0;

size_t pos = getpositionsomewhere();
if(pos < data0.size())
{
   data0[pos]++;
}
```

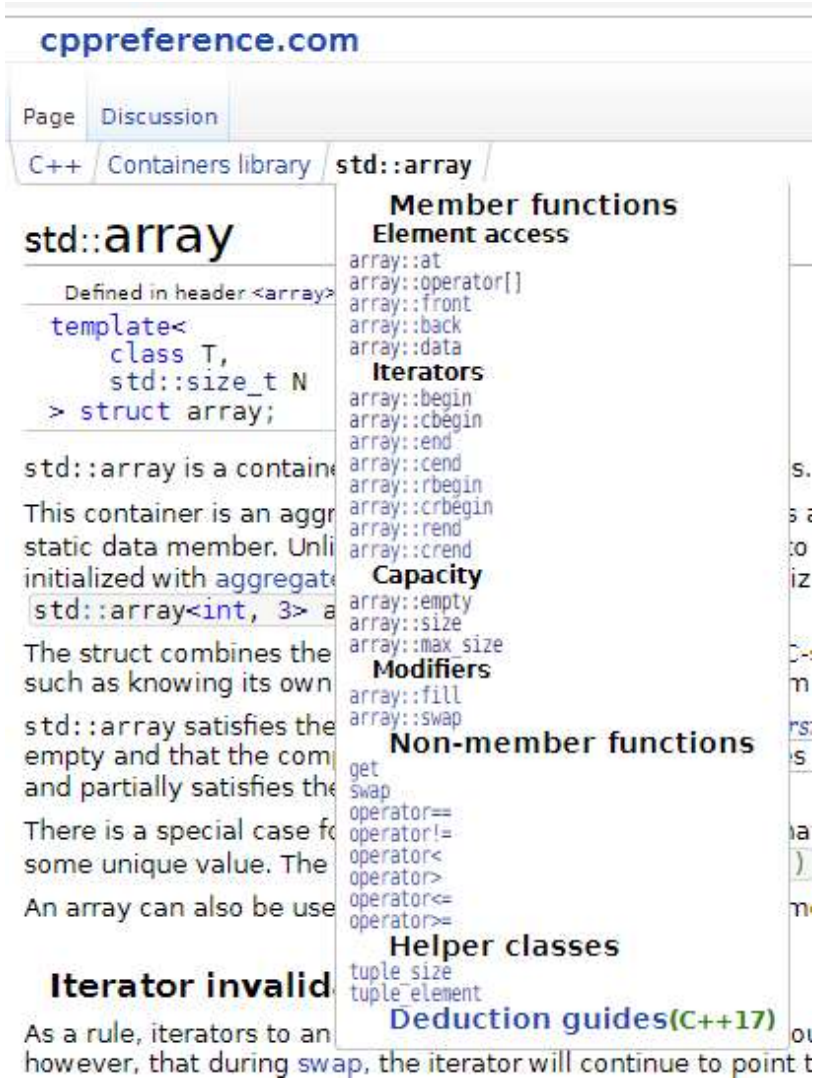



std::array<>

```
std::array<int, 4> data0 {};

Data0.fill(41);

for(auto &v : data0)
{
   v++;
}
```



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Range-based loops

In C++11, a range-based for loop has the following general syntax:

```
for ( decl : expr ) stmt;
```

Example

```
std::vector<int> fibo {0, 1, 1, 2, 3, 5, 8, 13};
std::vector<std::string> names {};
for(const auto &a : fibo) {
    names.push_back(std::to_string(a));
}
```


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Range-based loops

A loop can be non mutating:

```
for (int i : fibo) std::cout << i;
for (const int i : fibo) std::cout << i; // It is OK, but prefer the const &
for (const std::string &s : names) std::cout << s;
```

Or mutating:

```
for (int &i : fibo) i++;
```

Also, it can automatically infer the type:

```
for (auto i : fibo) std::cout << i;
for (const auto i : fibo) std::cout << i; // It is OK, but prefer the const &
for (const auto &s : names) std::cout << s;
for (auto &i : fibo) i++;
```

for (decl : expr) stmt;

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Range-based loops

It works on any *expr* whose type, or decltype(expr):

- has begin() / end() member functions (as the STL containers);

```
std::vector<int> fibo{0, 1, 1}; for(const auto &a : fibo) { … }
```

- or: is of array type;

```
int set[] = {1, 2, 3, 4};
for(auto &item : set) item++;
```

- or: has existing begin(decltype(*expr*)) and end(decltype(*expr*)) functions, found exclusively via argument-dependent lookup.

```
MySet set;
for(const auto &item : set) { /* use the item set */ }
// it works if we have MySet::begin() / ::end() / related operators ++ and !=
```


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Range-based loops

The expression for (*decl* : *expr*) stmt; expands to:

```
{
    auto&& __range = expr;          // it is a universal reference
    auto __b = begin(__range);
    auto __e = end(__range);
    for ( ; __b != __e; ++__b ) {
        decl = *__b;
        stmt;
    }
}
```


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Range-based loops

Example (compiled w/ armclang and executed)

```
volatile int ciao[] = {1, 2, 3, 4, 5, 6, 7, 8};  // placed in RAM @ 0x2000A9B4
// for(auto &item : ciao) item++; // is equivalent to following code:
{
    auto && __range = ciao;      // it is a ref to int[8] and points 0x2000A9B4
    auto __b = std::begin(__range); // it is a int * = 0x2000A9B4
    auto __e = std::end(__range); // it is a int * = 0x2000A9D4
    for ( ; __b != __e; ++__b ) {
        auto &item = *__b; // is the reference to each value inside ciao[]
        item++;
    }
}
```

for (decl : expr) stmt;

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Range-based loops

Example (yarp vector TODO)

```
volatile int ciao[] = {1, 2, 3, 4, 5, 6, 7, 8};  // placed in RAM @ 0x2000A9B4
// for(auto &item : ciao) item++; // is equivalent to following code:
{
    auto && __range = ciao;      // it is a ref to int[8] and points 0x2000A9B4
    auto __b = std::begin(__range); // it is a int * = 0x2000A9B4
    auto __e = std::end(__range); // it is a int * = 0x2000A9D4
    for ( ; __b != __e; ++__b ) {
        auto &item = *__b; // is the reference to each value inside ciao[]
        item++;
    }
}
```

for (decl : expr) stmt;

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constexpr

The keyword constexpr (short for constant expression) can be used to declare compile-time constant objects and functions.

The possibility to evaluate expressions at compile time improves runtime execution because there is less code to run and the compiler can perform additional optimizations.

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constexpr

Use constexpr to define non-member functions that can be evaluated at compile time.

```
constexpr unsigned int factorial(const unsigned int n)
{
    return n > 1 ? n * factorial(n-1) : 1;
}
```


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constexpr

Use constexpr to define constructors that can be executed at compile time to initialize constexpr objects.

```
struct P3D {
   double const x_; double const y_; double const z_;
   constexpr P3D(const double x = 0, const double y = 0,
                 const double z = 0) : x_{x}, y_{y}, z_{z} {}
   constexpr double get_x() const {return x_;}
   constexpr double get_y() const {return y_;}
   constexpr double get_z() const {return z_;}
};
```


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constexpr

Use constexpr to define variables that can have their values evaluated at compile time.

```
constexpr P3D origin { 1.3, 1.5, 1.7 };
constexpr unsigned int size = factorial(6);
char buffer[size] {0};
constexpr P3D p {0, 1, 2};
constexpr auto x = p.get_x();
```


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constexpr

Use in embedded software in iCub

```
69 namespace embot { namespace hw { namespace bsp {
70
71     struct SUPP
72     {
73         std::uint32_t       supportedmask;
74
75         constexpr SUPP(std::uint32_t m) : supportedmask(m) {}
76
77         template <typename T>
78         constexpr bool supported(T v) const
79         {
80             return embot::binary::bit::check(supportedmask, embot::common::tointegral(v));
81         }
82     };
83
84 }}} // namespace embo
```

```
4
5  namespace embot { namespace hw { namespace bsp { namespace pga308 {
6
7      struct PROP
8      {
9          embot::hw::GPIO poweron;
0      };
1
2      struct BSP : public embot::hw::bsp::SUPP
3      {
4          constexpr static std::uint8_t maxnumberof = embot::common::tointegral(embot::hw::PGA308
5          constexpr BSP(std::uint32_t msk, std::array<const PROP*, maxnumberof> pro) : SUPP(msk),
6          constexpr BSP() : SUPP(0), properties({0}) {}
7
8          std::array<const PROP*, maxnumberof> properties;
9          constexpr const PROP * getPROP(embot::hw::PGA308 h) const { return supported(h) ? prope
0          void init(embot::hw::PGA308 h) const;
1      };
2
3      const BSP& getBSP();
```


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constexpr

Use in embedded software in iCub

```
578 namespace embot { namespace hw { namespace bsp { namespace pga308 {
579
580     #if defined(STM32HAL_BOARD_STRAIN2)
581
582     constexpr PROP prop { .poweron = {embot::hw::GPIO::PORT::B, embot::hw::GPIO::PIN::fifteen} };
583
584     constexpr BSP thebsp {
585         // maskofsupported
586         mask::pos2mask<uint32_t>(PGA308::one)   | mask::pos2mask<uint32_t>(PGA308::two)  |
587         mask::pos2mask<uint32_t>(PGA308::three) | mask::pos2mask<uint32_t>(PGA308::four) |
588         mask::pos2mask<uint32_t>(PGA308::five)  | mask::pos2mask<uint32_t>(PGA308::six),
589         // properties
590         {{
591             &prop, &prop, &prop, &prop, &prop, &prop
592         }}
593     };
594
595     void BSP::init(embot::hw::PGA308 h) const {}
596
597     #else
598
599     constexpr BSP thebsp { };
600     void BSP::init(embot::hw::PGA308 h) const {}
601
602     #endif
603
604     const BSP& getBSP()
605     {
606         return thebsp;
607     }
608
609 }}}} // namespace embot { namespace hw { namespace bsp {  namespace pga308 {
610
```


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constexpr

Use in embedded software in iCub

main-strain2-application.cpp | embot_hw_bsp.cpp | embot_hw_bsp.h | embot_hw_pga308.cpp* | embot_app_canprotocol.h | embot_app_application_theSTRA

```
146         return resOK;
147     }
148
149     result_t init(PGA308 a, const Config &config)
150     {
151         if(false == embot::hw::bsp::pga308::getBSP().supported(a))
152         {
153             return resNOK;
154         }
155
156         if(true == initialised(a))
157         {
158             return resOK;
159         }
160
161         // init chip
162         embot::hw::bsp::pga308::getBSP().init(a);
163
164         s_privatedata.config[embot::common::tointegral(a)] = config;
165
166         // init onewire. i dont check vs correct config apart from correct gpio
167         if(false == config.onewireconfig.gpio.isvalid())
168         {
169             return resNOK;
170         }
171
172         const embot::hw::bsp::pga308::PROP * prop = embot::hw::bsp::pga308::getBSP().getPROP(embot::hw::PGA308::one);
173
174         if(false == prop->poweron.isvalid())
175         {
176             return resNOK;
177         }
178
```


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Modern C++

- nullptr,
- auto,
- type aliases,
- initializer list,
- uniform initialization,
- range-based loops,
- constexpr,
- scoped enumerations,
- override and final.

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Scoped enumerators

Enumerators declared with enum class or enum struct are called *scoped enumerators*.

```
enum color { Black, White, Red }; // unscoped, C++98
enum class Color { black, white, red }; // scoped, C++11
```

From Effective Modern C++, Scott Meyers:

[item 10]: Prefer scoped enums to unscoped enums

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OK, but why enums at all?

From Effective C++, Scott Meyers:

[item 2]: Prefer consts, enums, and inlines to #defines

Or: "prefer the compiler to the preprocessor," because #define may be treated as if it's not part of the language per se.

- The enum can be scoped by a namespace, the macro (#define) cannot.
- The macro can be redefined, the enum cannot
- The enum can be used as a type for an argument passing.

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Why not just unscoped enum?

The unscoped enums suffer two main problems that the scoped enum have solved:

- nothing else in their scope may have the same name, hence they do scope pollution;
- they implicitly convert to integral types and, from there, to floating-point types.

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Reasons for scoped enum

They don't do scope pollution.

```
enum color { Black, White, Red }; // they are in same scope as color
enum class Color { black, white, red }; // they are scoped by Color


auto White = false;  // error! White already declared in this scope
auto white = false; // fine, no other white in scope
Color c = white; // error! no enumerator named white in this scope
Color c = Color::white; // fine
auto c = Color::white; // also fine
enum class LED { one, two, three };
enum class SPI { one, two, three };
```


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Reasons for scoped enum

They don’t convert to integral types:

```
enum color { Black, White, Red = 2};
enum class Color { black, white, red = 2 };
std::vector<std::size_t> primeFactors(std::size_t x);
color c = Red; // Red but also = 2
if (c < 14.5) { // compare Color to double (!)
        auto factors = primeFactors(c); // SIC! prime factors of a color
}
Color c = Color::red;
if (c < 14.5) { // error! can't compare Color and double
        auto factors = primeFactors(c); // error! can't pass Color to size_t
}
```


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Underlying types of enum

Since C++11, we can specify an underlying type for enums so that they occupy a given size:

```
enum color : std::uint8_t { Black, White, Red = 1000 }; // error!
enum class Color : std::uint8_t { black, white, red = 2 };
static_assert(sizeof(Color) == 1, "underlying type is not 8 bits");
```

To retrieve the value of the underlying type, use:

```
template<typename E>              // // C++14 [Meyers, pag. 73]
constexpr auto toUType(E enumerator) noexcept {
        return static_cast<std::underlying_type_t<E>>(enumerator);
}
primeFactors(toUType(Color::red)); // Color -> std::uint8_t -> std::size_t
```


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Example of scoped enum + constexpr

Example

```
enum class Led : std::uint8_t { red = 0, green = 1, blue = 63, max = blue };

template<typename E, E max>
  struct eMap {
     static_assert(toUType(max) < (8*sizeof(unsigned long long)), "size error");
     std::bitset<toUType(max)+1> map;
     constexpr eMap(const std::initializer_list<E> &li) {
        unsigned long long m = 0;
        for(auto &e : li) m |= (static_cast<unsigned long long>(1) << toUType(e));
        map = m;
     }
     constexpr bool available(E e) const { return map[toUType(e)]; }
  };
```


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Example of scoped enum + constexpr

Example (continued)

```
enum class Led : std::uint8_t { red = 0, green = 1, blue = 2, white = 63, max = white };
constexpr eMap<Led, Led::max> theLEDs {Led::red, Led::blue}; // resolved at compile…

void init()
{
    if(theLEDs.available(Led::green) {   // resolved at compile time.
        dosomething();                   // on armclang compiler with 0 optimization …
    }                                    // no code is generated.

    if(theLEDs.available(Led::red) {     // resolved at compile time.
        doit();                          // on armclang compiler with 0 optimization …
    }                                    // only code for doit() is generated.
}
```


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Modern C++

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Use override

Use the keyword override to prevent mistakes in the design of virtual functions.

I will use Scott Meyers's words from his book *Effective Modern C++* (Item 12: Declare overriding functions override):

'The world of object-oriented programming in C++ revolves around classes, inheritance, and virtual functions. Among the most fundamental ideas in this world is that virtual function implementations in derived classes *override* the implementations of their base class counterparts. It's disheartening, then, to realize just how easily virtual function overriding can go wrong '

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Use override

Example (bad design, but OK so far)

```
class Base {
public:
        virtual int get() { return b; }              // base class virtual function
        …
};
class Derived: public Base {
public:
         virtual int get() { return d*d; }           // overrides Base::get()
        …                                            // ("virtual" is optional here)
};

Base * p = new Derived;
p->get();          // OK: called Derived::get() through a Base *
```


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Use override

Example (bad design, incorrect behaviour)

```
class Base {
public:
        virtual int get() const { return b; }        // someone changes signature
        …
};
class Derived: public Base {                         // but forgets the Derived class
public:
         virtual int get() { return d*d; }           // it DOES NOT override Base::get()
        …                                            // anymore
};

Base * p = new Derived;
p->get();          // ERROR: called Base::get() now
```


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Use override

Example (better design)

```
class Base {
public:
        virtual int get() { return b; }                 // base class virtual function
        …
};
class Derived: public Base {
public:
         virtual int get() override { return d*d; } // overrides Base::get()
        …                                                       // ("virtual" is optional here)
};

Base * p = new Derived;
p->get();          // OK: called Derived::get() through a Base *
```


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Use override

Example (the error is catched at compile time)

```
class Base {
public:
        virtual int get() const { return b; }          // someone changes signature
        …
};
class Derived: public Base {                           // but forgets the Derived class
public:
         virtual int get() override { return d*d; }  // it DOES NOT compile
        …
};

Base * p = new Derived;
p->get();          // OK: always calls Base::get()
```


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There is also final

In C++11 we have the keyword final which is used to terminate inheritance.

```
struct Point final { int x, y; };
struct IperPoint : public Point { int i; }:                    // does not compile
class Polygon final : public std::vector<Point> { ... };       // it compiles

class Derived: public Base {                          // but forgets the Derived class
public:
        int get() const override final { return d*d; }  // cannot further derive get()
};

class Derived2 : public Derived {     // I can further derive the class as long as
…                                     // I don't derive get() any further
};
```


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EMPTY

Bla bla bla typedef sssss.

dece, typedef cercwercver.

- Some etxt.

  Soem code // given this map …