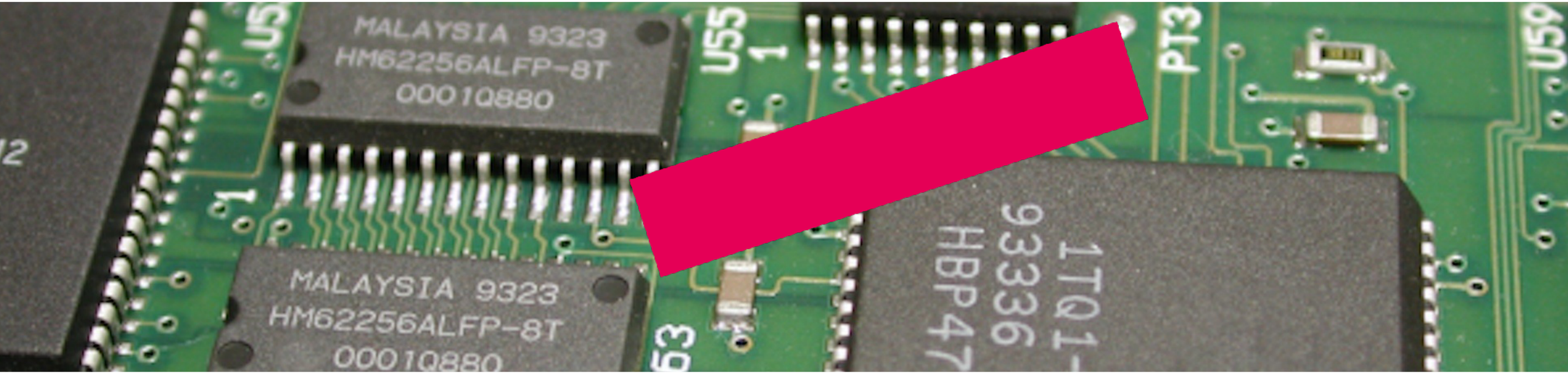
Embedded Systems Development - 2. Constructors, Lambdas and Open-Closed



Electrical Engineering / Embedded Systems
Faculty of Engineering

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V1.3 2024

HAN_UNIVERSITY
OF APPLIED SCIENCES

To begin with…

Attendance

Schedule (exact info see #OO and roster at insite.han.nl)

		C++	UML
Step 1	Single responsibility	Scope, namespaces, string	class diagram
Step 2	**Open-Closed Principle**	**Constructors, iterators, lambdas**	**Inheritance / Generalization**
Step 3	Liskov Substitution Principle	lists, inline functions, default params	
Step 4	Interface Segregation Principle	interfaces and abstract classes	
Step 5	Dependency Inversion Principle	threads, callback	
Step 6	Coupling and cohesion	polymorphism	
Step 7	n/a	n/a	n/a

Note: subject to changes as we go…

Constructors

- Constructors have the same name as the class itself
- Constructors don’t have a return type
- A constructor is automatically called when the object is created.
- If no constructor is defined, C++ compiler generates a default constructor:
    - with no parameters
    - with an empty body

C++ Language: Constructors

- default constructor
- copy constructor
- overloading instructors

- destructors

C++ Language: Copy Constructor

In Rectangle.cpp:

```
Rectangle::Rectangle(const Rectangle& rect) { cout << "Copy Constructor Called\n"; }
```

In Rectangle.h:

```
Rectangle(const Rectangle&);
```

```
int main()
{
   Rectangle r1;
   Rectangle r2{1.0, 3.0}; // Uniform initialization: { ..... }
   r1 = Rectangle(r2); // calls copy constructor
   return 0;
}
```

C++ Language: Destructor

In Rectangle.cpp:

```
Rectangle::~Rectangle() { cout << "Destructor Called\n"; }
```

In Rectangle.h:

```
~Rectangle(); // destructor
```

```
// Note: check output of your program to see when the destructor is called …
```

C++ Language: Constructors - Default Constructor

Either has:

- no parameters (arguments)

or:

- all parameters have default values

E.g. (in Rectangle.h):

```
Rectangle(double width, double height) : width_{width = 1.0}, height_{height = 1.0} {}

Rectangle(double width, double height) : width_{width}, height_{height} {}

Rectangle();
```

In Rectangle.cpp

```
Rectangle::Rectangle()
    : Rectangle{1.0, 1.0}   // Constructor delegation
{}
```

C++ Language: Iterators

CONTAINER	TYPES OF ITERATOR SUPPORTED
Vector	Random-Access
List	Bidirectional
Deque	Random-Access
Map	Bidirectional
Multimap	Bidirectional
Set	Bidirectional
Multiset	Bidirectional
Stack	No iterator Supported
Queue	No iterator Supported
Priority-Queue	No iterator Supported

C++ Language: Iterators

```cpp
// for_each example
#include <iostream>     // std::cout
#include <algorithm>    // std::for_each
#include <vector>       // std::vector

void myfunction (int i) {  // function:
  std::cout << ' ' << i;
}

struct myclass {           // function object type:
  void operator() (int i) {std::cout << ' ' << i;}
} myobject;

int main () {
  std::vector<int> myvector;
  myvector.push_back(10);
  myvector.push_back(20);
  myvector.push_back(30);

  std::cout << "myvector contains:";
  for_each (myvector.begin(), myvector.end(), myfunction);
  std::cout << '\n';

  // or:
  std::cout << "myvector contains:";
  for_each (myvector.begin(), myvector.end(), myobject);
  std::cout << '\n';

  return 0;
}
```

C++ Language: Iterators

https://www.geeksforgeeks.org/introduction-iterators-c/

Note: in C++ 20 changes were made in iterator implementation

(Version 20 was released Feb. 2020)

Tip: it might be interesting to also see changes for C++ 2023

https://en.wikipedia.org/wiki/C%2B%2B23

C++ Language: Lambda functions

Aka: anonymous function (function literal, lambda abstraction, or lambda expression)

In other languages: closure

[capture clause] (parameters) -> return-type

{

definition of method

}

C++ Language: Lambda functions

+ Conciseness and Readability
+ Improved Locality
+ Functional Programming Style
+ Flexibility
+ Performance

C++ Language: Lambda functions

+ Conciseness and Readability

  Lambda functions allow you to define small, anonymous functions directly at the point of use. This eliminates the need to declare a separate named function elsewhere, keeping the code related to a specific task together and improving readability.

+ Improved Locality
+ Functional Programming Style
+ Flexibility
+ Performance

C++ Language: Lambda functions

+ Conciseness and Readability
+ Improved Locality

  Lambdas can capture variables from their surrounding scope, allowing you to work with data directly without passing it explicitly as arguments. This enhances code locality and reduces the need for helper functions or global variables.

+ Functional Programming Style
+ Flexibility
+ Performance

C++ Language: Lambda functions

+ Conciseness and Readability
+ Improved Locality
+ Functional Programming Style

Lambdas are a core component of functional programming, enabling you to express algorithms and operations in a declarative manner. This can lead to more concise and expressive code, especially when working with algorithms like std::sort, std::for_each, or std::transform.

+ Flexibility
+ Performance

C++ Language: Lambda functions

+ Conciseness and Readability
+ Improved Locality
+ Functional Programming Style
+ Flexibility

Lambdas can be stored in variables, passed as arguments to functions, and returned from functions, offering a high degree of flexibility in how you organize and reuse code.

+ Performance

C++ Language: Lambda functions

+ Conciseness and Readability
+ Improved Locality
+ Functional Programming Style
+ Flexibility
+ Performance

Modern C++ compilers can often optimize lambda functions aggressively, sometimes even inlining them directly at the call site. This can lead to performance gains compared to using traditional function pointers or function objects.

C++ Language: Lambda functions

+ Conciseness and Readability
+ Improved Locality
+ Functional Programming Style
+ Flexibility
+ Performance

Common Use Cases:

Callbacks and Event Handling: ideal for defining concise callback functions that respond to events or user interactions.
Custom Sorting and Filtering: clean way for custom comparison/filtering for algorithms like std::sort or std::find_if.

Asynchronous Programming: define tasks or continuations in asynchronous programming frameworks, making the code more readable and maintainable.

Lazy Evaluation: Lambdas can be used to implement lazy evaluation, where computations are deferred until their results are actually needed.

C++ Language: Lambda function to variable

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

int main()
{

    // Assign lambda expression that adds two numbers to an auto variable.
    auto f1 = [](int x, int y) { return x + y; };

    std::cout << f1(2, 3) << std::endl;

}
```

C++ Language: Lambda function to variable

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

int main()
{

    // Assign the same lambda expression to a function object.
    function<int(int, int)> f2 = [](int x, int y) { return x + y; };

    std::cout << f2(3, 4) << std::endl;
}
```

C++ Language: Lambda function to variable

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

int main()
{

    // Assign the same lambda expression to a function object.
    auto sum = [](int a, int b) {
      return a + b;
    };
    std::cout << sum(2, 4) << std::endl;
}
```

Why is it an anonymous function?

C++ Language: Lambda function to variable

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

int main()
{

    // Assign the same lambda expression to a function object.
    auto sum = [](int a, int b) {
      return a + b;
    };
    std::cout << sum(2, 4) << std::endl;
}
```

Why is it an anonymous function?

There is no function name in the implementation just the Variable you assign the function to (“auto sum” in this case)…

C++ Language: Lambda functions - Embedded

+ Conciseness and Readability
+ Improved Locality
+ Functional Programming Style
+ Flexibility
+ Performance

- Memory Overhead
- Runtime Performance
- Code Size
- Debugging and Profiling

C++ Language: Lambda functions - Embedded

- Memory Overhead

  Capturing variables within a lambda can lead to increased memory usage, as the compiler might need to generate a functor object to store the captured values.

  This can be problematic in resource-constrained embedded systems with limited memory.

- Runtime Performance
- Code Size
- Debugging and Profiling

C++ Language: Lambda functions - Embedded

- Memory Overhead
- Runtime Performance

  While modern compilers can often optimize lambda functions well, there's still a potential for runtime overhead compared to traditional function pointers or carefully hand-optimized code. This can be critical in embedded systems where real-time performance is paramount.

- Code Size
- Debugging and Profiling

C++ Language: Lambda functions - Embedded

- Memory Overhead
- Runtime Performance
- Code Size

  Lambdas can contribute to increased code size, especially if used extensively or if they capture many variables. This can be an issue in embedded systems with limited flash memory.

- Debugging and Profiling

C++ Language: Lambda functions - Embedded

- Memory Overhead
- Runtime Performance
- Code Size
- Debugging and Profiling

Lambdas can sometimes make debugging and profiling more challenging, as they can introduce additional layers of indirection and make it harder to track the flow of execution.

C++ Language: Lambda functions - Embedded

Possible Embedded solutions:

Use Non-Capturing Lambdas: Non-capturing lambdas are generally safe to use in embedded systems, as they are often convertible to simple function pointers and don't incur additional memory overhead.

Minimize Capturing: If you need to capture variables, try to capture by value whenever possible to avoid potential lifetime issues and reduce memory usage.

Consider Alternatives: In performance-critical (real-time) sections or when memory is extremely tight, consider using traditional function pointers or hand-optimized code instead of lambdas.

Profile and Measure: Always profile and measure the impact of using lambdas in your embedded system to ensure they don't introduce unacceptable performance or memory overhead.

C++ Language: More on Lambda functions

https://docs.microsoft.com/en-us/cpp/cpp/examples-of-lambda-expressions?view=vs-2019

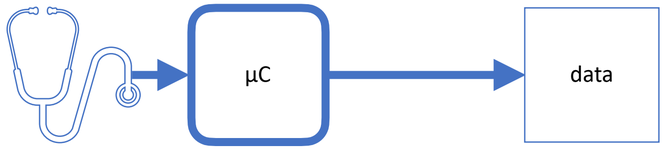
SOLID: Open-Closed Principle

“A software artifact should be open for extension but closed for modification." - Meyer 1988

(From: Clean Architecture, R.C. Martin, 2018)

SOLID: Open-Closed Principle

Embedded Software Context:



Imagine your application needs to send sensor data to an SD-card…

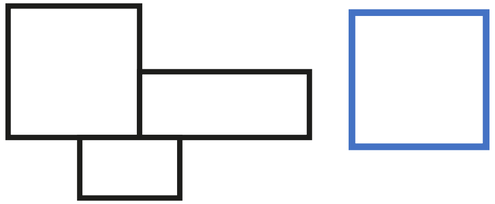
How hard will it be to react to changing requirements? E.g. UART (maybe Bluetooth) / SPI / i2c…

SOLID: Open-Closed Principle

You'd better: *"Design for change!"*.

Open-Closed Principle: Problem

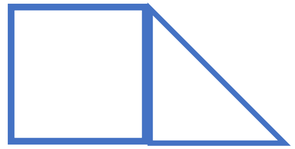
```cpp
// Rectangle.cpp
#include "Rectangle.h"

Rectangle::Rectangle(double width, double height)
{
    this->width = width;
    this->height = height;
}

double Rectangle::getSurfaceArea() const
{
    return width * height;
}

void Rectangle::setWidth(double width)
{
   this->width = width;
}

void Rectangle::setHeight(double height)
{
   this->height = height;
}
```



```cpp
// Rectangle.h
#include <iostream>

class Rectangle
{

public:
   Rectangle(double width, double height);
   double getSurfaceArea() const;
   void setHeight(double height);
   void setWidth(double height);

private:
   double width;
   double height;
};
```

Open-Closed Principle: Problem

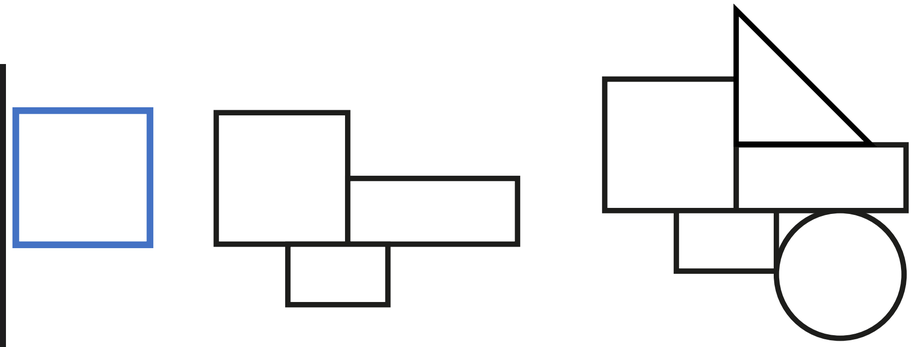
```cpp
// Triangle.cpp
#include "Triangle.h"

Triangle::Triangle(double width, double height)
{
    this->width = width;
    this->height = height;
}

double Triangle::getSurfaceArea() const
{
    return (width * height) / 2;
}

void Triangle::setWidth(double width)
{
   this->width = width;
}

void Triangle::setHeight(double height)
{
   this->height = height;
}
```

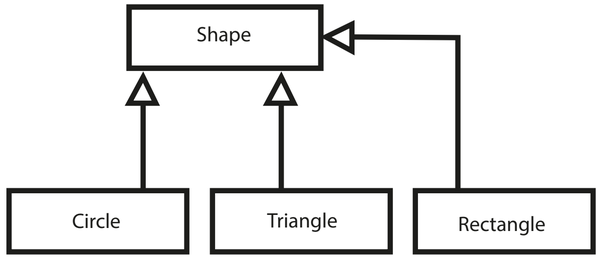


```cpp
// Triangle.h
#include <iostream>

class Triangle
{

public:
   Triangle(double width, double height);
   double getSurfaceArea() const;
   void setHeight(double height);
   void setWidth(double height);

private:
   double width;
   double height;
};
```

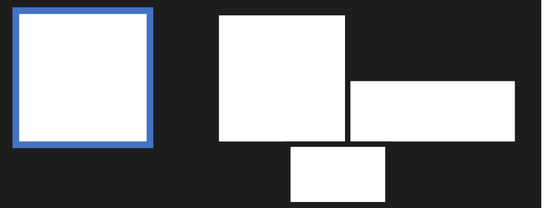
Open-Closed Principle: Solution

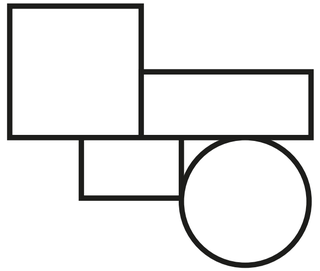
```
// Base class
class Shape {
   public:
      // pure virtual function providing
      interface framework.
      virtual int getArea() = 0;
      void setWidth(int w) {
         width = w;
      }

      void setHeight(int h) {
         height = h;
      }

   protected:
      int width;
      int height;
};
```

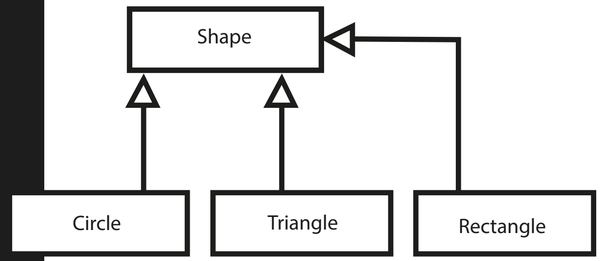




```
#include <math.h>

// Derived classes
class Rectangle: public Shape {
   public:
      int getArea() {
         return (width * height);
      }
};

class Triangle: public Shape {
   public:
      int getArea() {
         return (width * height)/2;
      }
};

class Circle: public Shape {
   public:
      double radius;
     void setRadius(int r) {
         width = r*2;
        height = r*2;
        radius = r;
      }


      int getArea() {
         return (radius * radius * M_PI);
      }
};
```

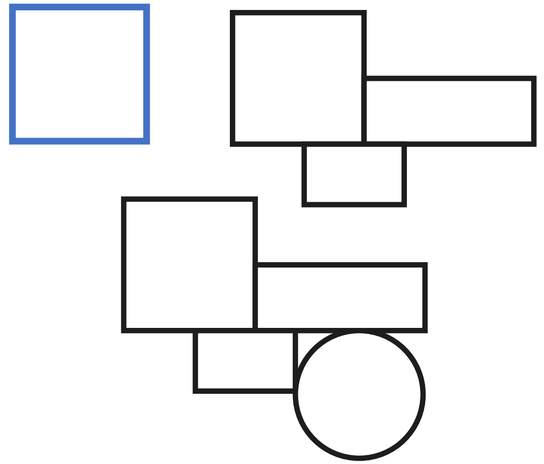


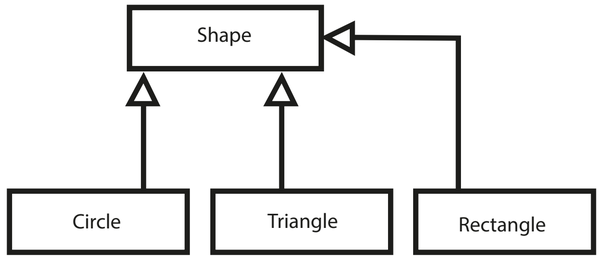




Open-Closed Principle: Solution

```
// Some main to test your code.

int main(void) {
   Rectangle rectangle;
   Triangle  triangle;

   rectangle.setWidth(5);
   rectangle.setHeight(7);

   // Print the area of the object.
   cout << "Total Rectangle area: " << rectangle.getArea() << endl;

   triangle.setWidth(5);
   triangle.setHeight(7);

   // Print the area of the object.
   cout << "Total Triangle area: " << triangle.getArea() << endl;

   return 0;
}
```





Patterns: Delegation

Jos put in his example “constructor delegation”

What is delegation:

- you delegate a task to some other method or even class

We might touch delegation later on, in protocol oriented languages delegation is key.

Delegation also helps to sustain the Single Responsibility principle.

Typical Sensor Library

https://www.arduino.cc/reference/en/libraries/category/sensors/

Issues with libraries:
https://github.com/DFRobot/DFRobot_VL6180X/blob/master/DFRobot_VL6180X.cpp

Can you spot the violation of Single Responsibility?

What about this one?
https://github.com/pololu/lis3mdl-arduino/blob/master/LIS3MDL.cpp

Typical Sensor Library

So:

- Wire is the i2c helper object for Arduino
- SAMDx1 e.g. uses custom / multiple wires, is that possible with previous libraries?
- What of you use multiple sensors of the same or other type on the same bus?

Solution:

You could inject the Wire-object of choice using dependency injection.

Also:

Beware of side-effects, who is in control of the i2c bus, your sensor library or you main program (or even something in between, maybe some helper class).

Patterns: Dependency Injection

- UML is not an annoying extra: it is a way to keep your thinking structured and document your software in a visual way also for non-programmers.

- Even though Design Patterns are sometimes abstract really abstract (and initially maybe somewhat confusing) they help you to keep your software structured.

- Uncle Bob has excellent views on Software Craftsmanship so please listen to his advices.

Links

https://www.tutorialspoint.com/compile_cpp_online.php

https://www.visual-paradigm.com/guide/uml-unified-modeling-language/what-is-class-diagram/

https://github.com/ksvbka/design_pattern_for_embedded_system/blob/master/design-patterns-for-embedded-systems-in-c-an-embedded-software-engineering-toolkit.pdf

Visual Studio Code Terminals Configuration:

https://www.youtube.com/watch?v=E9C3M0XIndM

Tomorrow

- Compressions and Ventilations OO

- Compression sensor library for Arduino (ToF sensor)

Any questions?