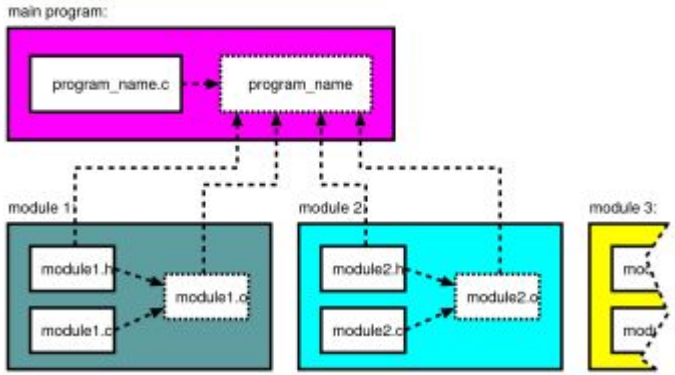
Yrkes
Akademin
Vi hjälper dig att lyckas!

Modularity and Software Testing

Programming and Development of Embedded Systems

Modularity

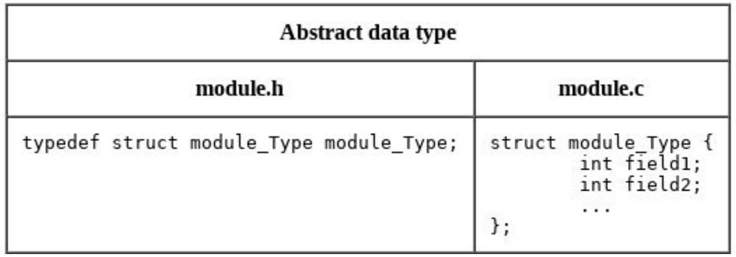
- A module is a self-contained part of a system that has
  - A well-defined interface and
  - An implementation which hides the code and any other private details to provide some functionalities for the system
- Modularity helps to
  - Organize large programs in smaller parts (modules)
  - Make testable, understandable and reusable code
  - Provide clear and flexible interfaces
  - Have separate compilation and make changes easier
  - Hide implementation and support operations on data structure
  - Encapsulate abstract data type and hide private data
    - An abstract data type is defined indirectly, only by the operations that may be done on it (e.g. **FILE**)



Modularity

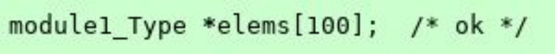
- Types of modules
  - Single-instance module
    - A module that has a single set of data to manage
    - To encapsulate the module’s private data, use **static** file scope variables
  - Multiple-instance module
    - A module that has to manage different sets of data for different clients
    - To encapsulate the module’s **abstract data type** and private data
      - Using **typedef** of a forward declared **struct** in the header (.h) file like

        typedef struct module_Type module_Type;
      - Inside the source (.c) file, define the struct elements for **module_Type**
      - A **Pointer** to the incomplete type can be passed around.
        - No code can dereference the pointer

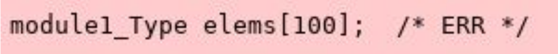


Abstract data type	
module.h	**module.c**

`typedef struct module_Type module_Type;`	`struct module_Type {`
	`int field1;`
	`int field2;`
	`...`
	`};`



```
module1_Type *elems[100];  /* ok */
```



```
module1_Type elems[100];  /* ERR */
```

Modularity and Software Testing

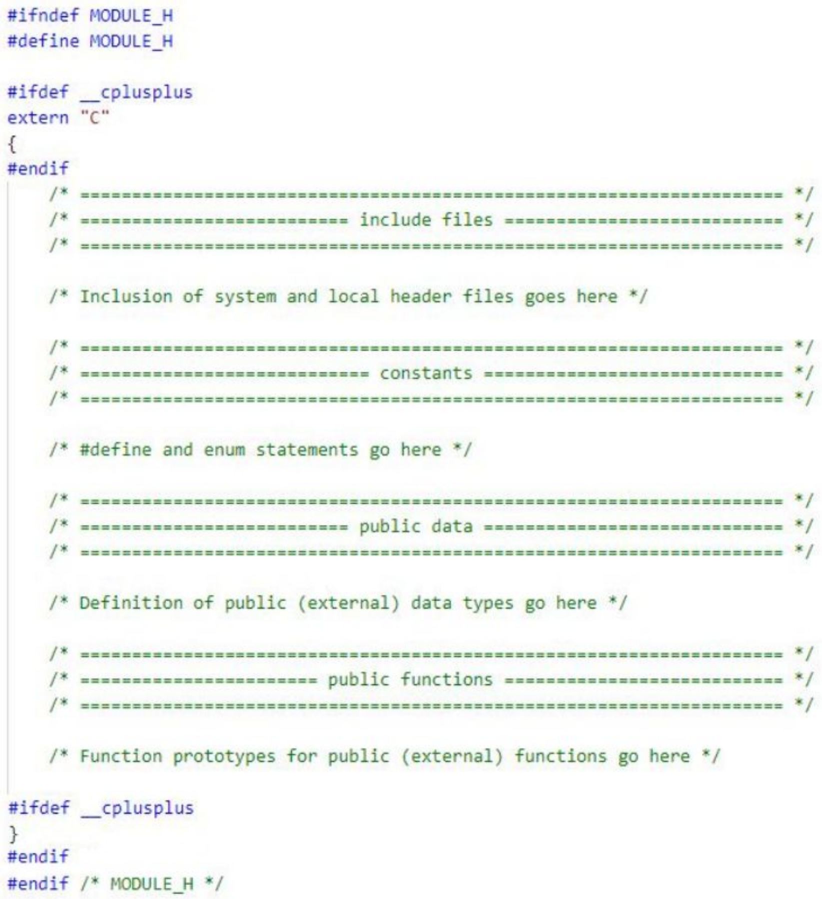
- To make a function in a module private, use **static** file scope in the .c file
- If it is required, make the private data accessible through the module's public interface
  - By defining a set of function prototypes in the header (.h) file
- To make a module private in another module, include it in the source file, otherwise in the header file
- When doing TDD to create modular C, we will use these files and conventions
  - The ***header file*** which defines the module's interface
    - For single-instance modules, the header file is made up of function prototypes
    - For abstract data types, in addition to function prototypes, a typedef is created for a pointer to a forward declared struct.
    - Hiding the struct hides the data details of the module
  - The ***source file*** contains the implementation of the interface
    - It includes any needed private helper functions and hidden data
    - For ADTs, the forward declared struct members are defined in the source file

Modularity and Software Testing

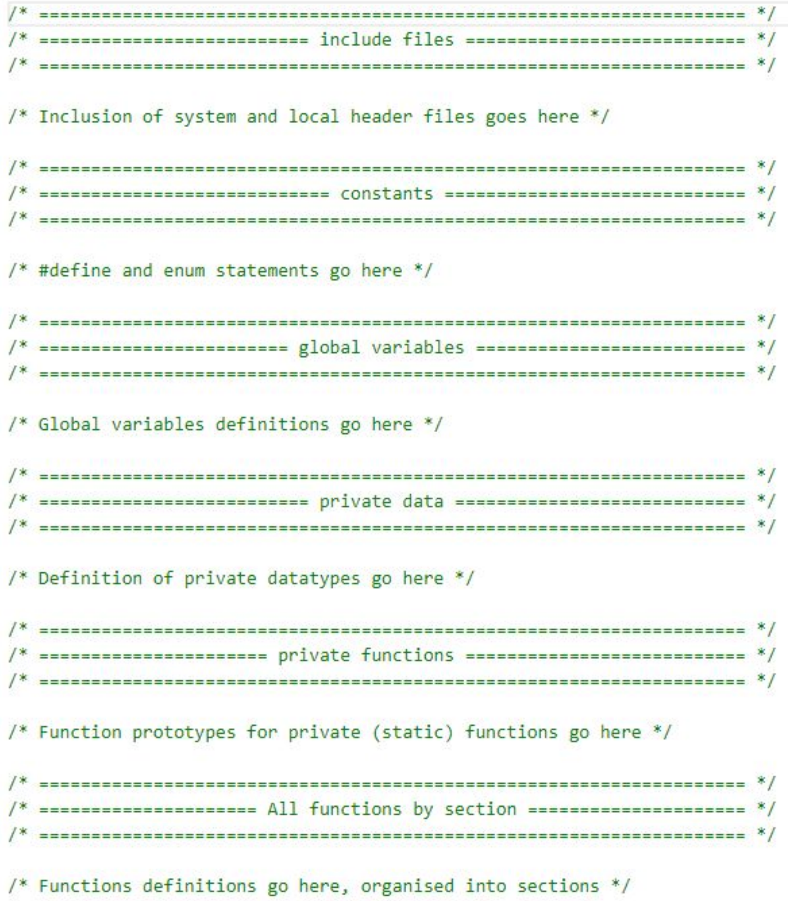
- When doing TDD to create modular C ...
  - The ***test file*** holds the test cases
    - Keep test code and production code separate
    - Each module has at least one test file
  - Module ***initialization*** and ***cleanup*** functions
    - Every module that manages hidden data should have initialization and cleanup functions
      - Like **Create** and **Destroy** functions for each module
      - ADTs certainly need them with their totally hidden internals
        - Memory for the data is allocated dynamically
    - Modules that is made up of stand-alone functions, like ***strlen*** and ***sprintf***, that keep no internal state won’t need initialization and cleanup

Modularity

- ❖ Module Example



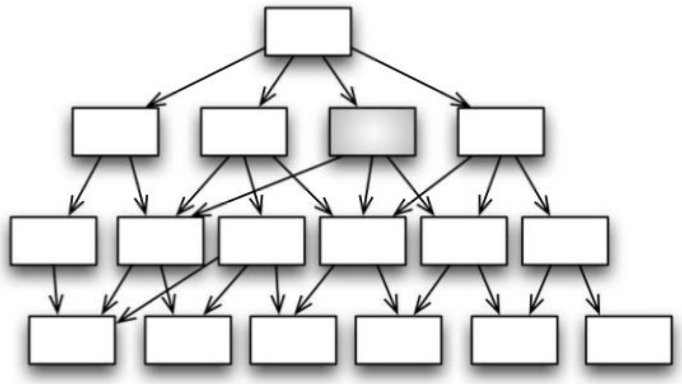
```c
#ifndef MODULE_H
#define MODULE_H

#ifdef __cplusplus
extern "C"
{
#endif
    /* ==================================================================== */
    /* ========================== include files =========================== */
    /* ==================================================================== */

    /* Inclusion of system and local header files goes here */

    /* ==================================================================== */
    /* ============================ constants ============================= */
    /* ==================================================================== */

    /* #define and enum statements go here */

    /* ==================================================================== */
    /* ========================== public data ============================= */
    /* ==================================================================== */

    /* Definition of public (external) data types go here */

    /* ==================================================================== */
    /* ======================= public functions =========================== */
    /* ==================================================================== */

    /* Function prototypes for public (external) functions go here */

#ifdef __cplusplus
}
#endif
#endif /* MODULE_H */
```



```c
/* ==================================================================== */
/* ========================== include files =========================== */
/* ==================================================================== */

/* Inclusion of system and local header files goes here */

/* ==================================================================== */
/* ============================ constants ============================= */
/* ==================================================================== */

/* #define and enum statements go here */

/* ==================================================================== */
/* ======================== global variables ========================== */
/* ==================================================================== */

/* Global variables definitions go here */

/* ==================================================================== */
/* ========================== private data ============================ */
/* ==================================================================== */

/* Definition of private datatypes go here */

/* ==================================================================== */
/* ====================== private functions =========================== */
/* ==================================================================== */

/* Function prototypes for private (static) functions go here */

/* ==================================================================== */
/* ===================== All functions by section ===================== */
/* ==================================================================== */

/* Functions definitions go here, organised into sections */
```

Modules & SOLID Design

- Five principles of the SOLID software design
  - **S**ingle Responsibility Principle
  - **O**pen Closed Principle
  - **L**iskov Substitution Principle
  - **I**nterface Segregation Principle
  - **D**ependency Inversion Principle



- Single Responsibility Principle (SRP)
  - The module should have a single responsibility
  - It should do one thing and do it well
  - It should have a single reason to change
  - It leads to modules with good cohesion and understandability

Modules & SOLID Design

- Open Closed Principle (OCP)
  - The module should be open for extension but closed for modification
  - It can be extended by adding new code, rather than modifying existing code
  - Like a USB port can be extended to be able to plug any compliant USB devices into the port (by providing different drivers) but does not need to be modified to accept a new device
- Liskov Substitution Principle (LSP)
  - A client modules should not care which kind of server module it is working with
  - Modules with the same interface should be substitutable without any special knowledge in the calling code
  - E.g. the **client** code should not behave differently when interacting with the **server's test double**

Modules & SOLID Design

- Interface Segregation Principle (ISP)
  - The client modules should not depend on fat interfaces
  - Interfaces should be tailored and very focused to the client’s needs
  - It limits dependencies, makes code more easily tested and ported
- Dependency Inversion Principle (DIP)
  - High-level modules shouldn’t depend on low-level modules
  - Dependencies should be broken with abstractions and interfaces
    - We hide the implementation details behind an interface
    - A client calls a server through a function pointer
    - A server calls a client back through a function pointer
    - An ADT hides the details of a data type

Modules & SOLID Design

- SOLID C Design Models
  - Single-instance module
    - Encapsulates a module’s internal state when only one instance of the module is needed
  - Multiple-instance module
    - Encapsulates a module’s internal state and create multiple instances of the module’s data
  - Dynamic interface
    - Allows a module’s interface functions to be assigned at runtime
    - Overriding the functions using function pointers
  - Per-type dynamic interface
    - Allows multiple types of modules with the same interface to have unique interface functions
    - E.g. By providing different drivers for a USB port

Exercise 13

- Using TDD develop a multiple instance unique and sorted linked list module.

Extra exercise

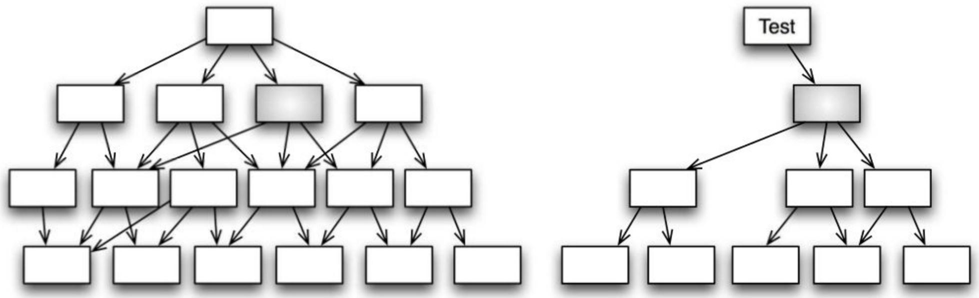
- Using TDD develop a multiple instance circular buffer module. Size of each buffer is specified during creation of the buffer.

Modules & Test Double

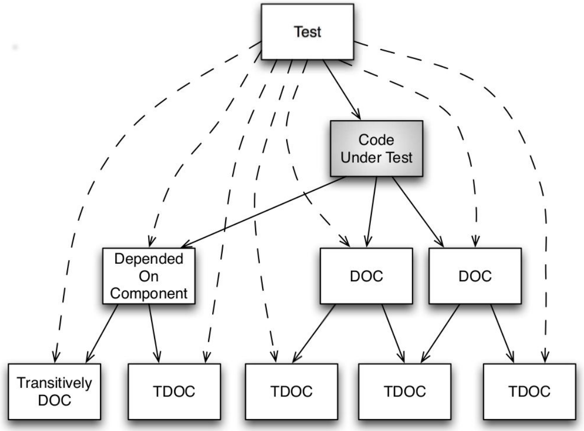
- **CUT** : Code Under Test
- A **dependency** is a function, data, module, library or device outside the CUT
  - Real code has dependencies. A module interacts with several others to do its job.
  - Dependencies make test automation difficult and expensive
- A **collaborator** is a dependency that the CUT depends upon
- A **test double** impersonates some dependencies during the test of the CUT
  - The CUT does not know it is using a test double
  - The CUT interacts with the double in the same way it interacts with the real collaborator
  - The test double is a stub taking the place of the actual production code
  - In TDD, the test doubles are used to facilitate automated testing

Modules & Test Double

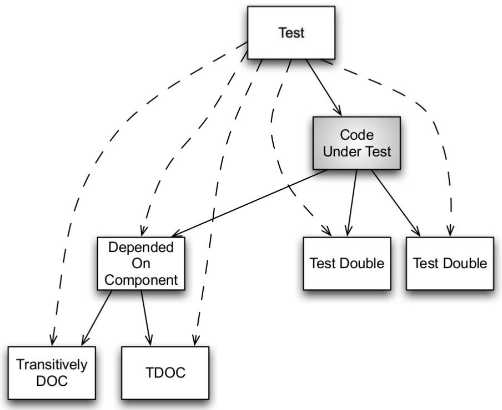
- ❖ Breaking Dependencies
  - ➢ Using of interfaces
  - ➢ Using of hierarchical design
  - ➢ Encapsulation and hiding data
  - ➢ Less reliance on unprotected global data



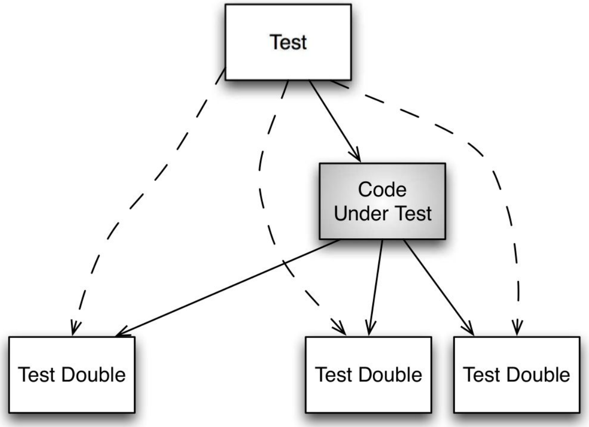
Dependencies of the gray module



Test Dependency Mess



Using test doubles and real collaborators



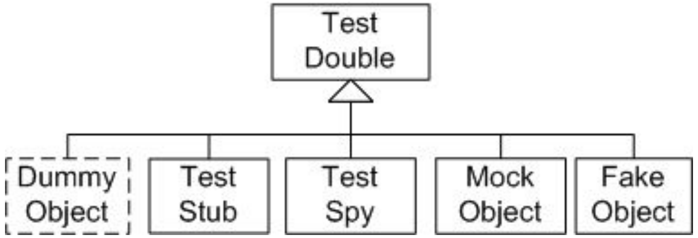
Manage test dependencies with test doubles

Modules & Test Double

- The rule of thumb
  - Use the real code when you can and use a test double when you must
- When to Use a Test Double
  - Hardware independence
    - Testing independently from the hardware
    - Providing a wide variety of inputs into the core of the system that may be difficult to do it in the lab
  - Inject difficult to produce input(s)
    - Some computed or hardware-generated event scenarios may be difficult to produce
  - Speed up a slow collaborator
    - A slow collaborator, such as a database or a network service

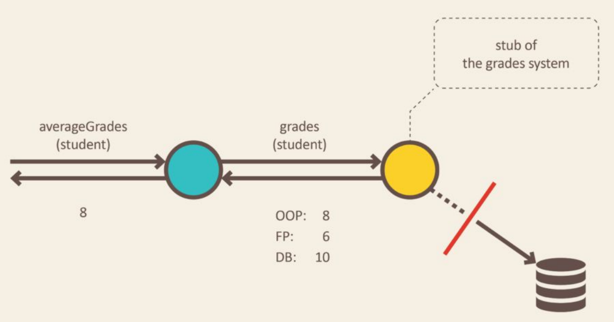
Modules & Test Double

- When to Use a Test Double ...
  - Dependency on something under development
  - Dependency on something volatile
    - Like an alarm clock.
    - You have an event that is supposed to get triggered at 03:42
  - Dependency on something that is difficult to configure
    - A database is an example of a DOC that you could test with but is difficult to set up
- Test Doubles Variations
  - There are different types of doubles like
    - Test Stub, Test Spy, Fake Object, Mock Object and etc.



Modules & Test Double Variations

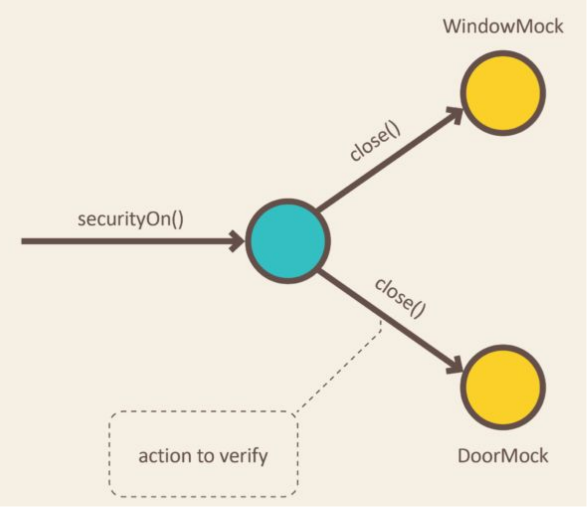
- Test dummy
  - It is provided to satisfy the compiler, linker or runtime dependency
- Test stub
  - It returns a value, as directed by the current test case
  - It holds predefined data and uses it to answer calls during tests
  - It is used when we cannot or don't want to involve objects that would answer with real data



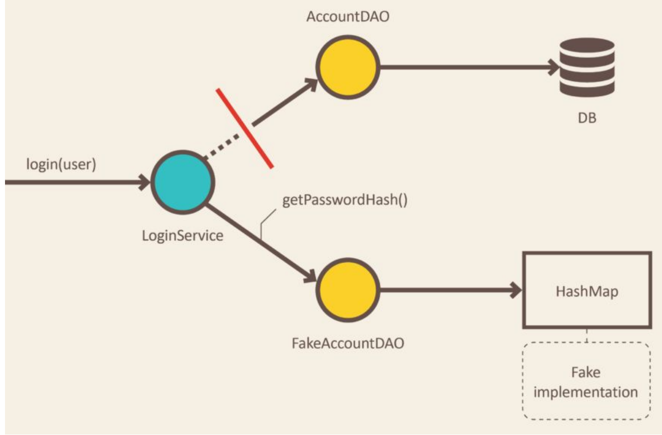
- Test spy
  - It captures the parameters passed from the CUT so the test can verify that the correct parameters have been passed to the CUT
  - It can also feed return values to the CUT just like a test stub

Modules & Test Double Variations

- **Mock Object**
  - It Verifies the functions called, the call order, and the parameters passed from the CUT to the DOC
  - It usually deals with a situation where multiple calls are made to it, and each call and response are potentially different

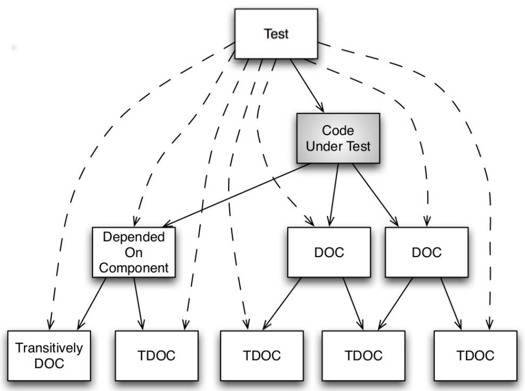


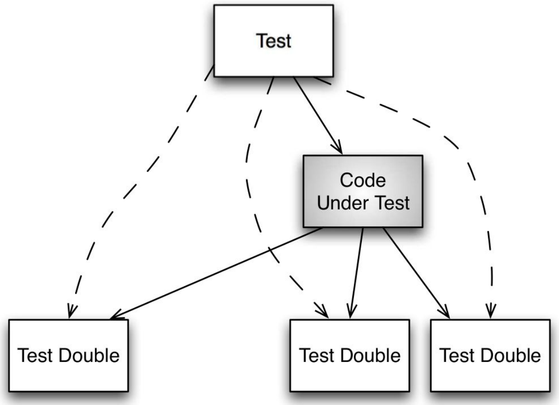
- **Fake Object**
  - It provides a partial and simplified version of the production code
  - It is used when the CUT depends on a component which makes testing difficult or slow



Faking in C

- Three primitive mechanisms to fake dependencies in C
  - Link-time substitution
  - Function pointer substitution
  - Preprocessor substitution

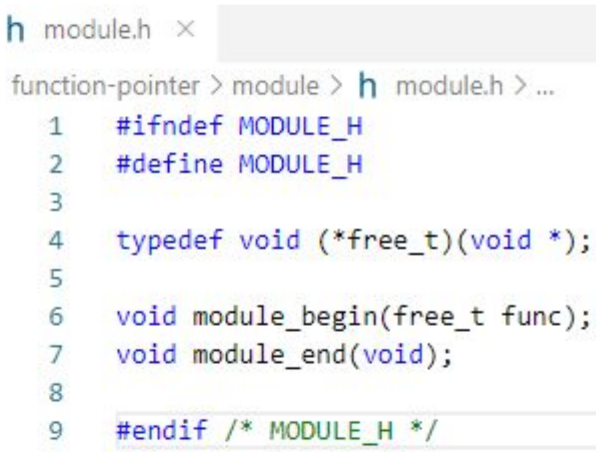




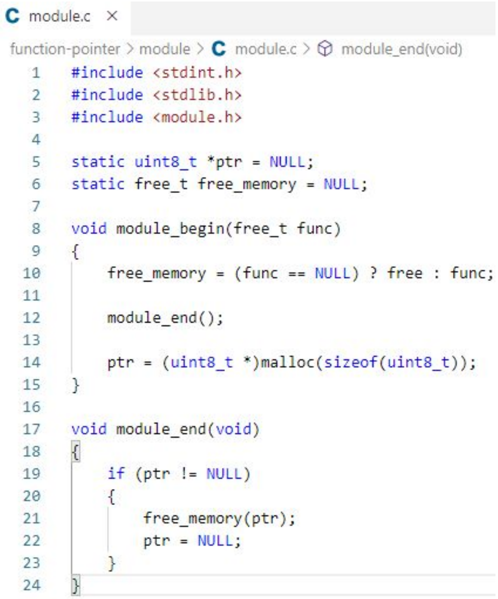
- Link-time substitution
  - Use it when you need to
    - Replace the DOC for the whole unit test,
    - Substitute a module where you do not control the interface
    - Eliminating dependencies on third-party libraries, hardware-dependent modules, or the OS
  - Instead of linking the real module, we need to make a test double for the DOC and link it

Faking in C

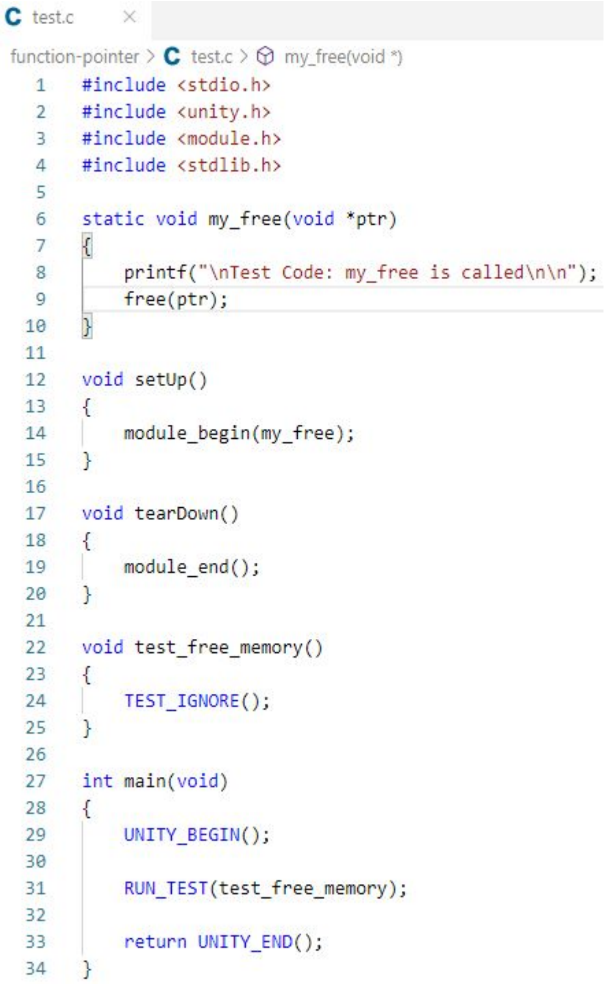
- ❖ Function pointer substitution
  - ➢ Use it when you want to replace the DOC for only some of the test cases
  - ➢ You can use it everywhere that you control the interface
  - ➢ It Uses some RAM, and compromises function declaration readability
  - ➢ It allows great control over where and when functions get overridden



```c
#ifndef MODULE_H
#define MODULE_H

typedef void (*free_t)(void *);

void module_begin(free_t func);
void module_end(void);

#endif /* MODULE_H */
```



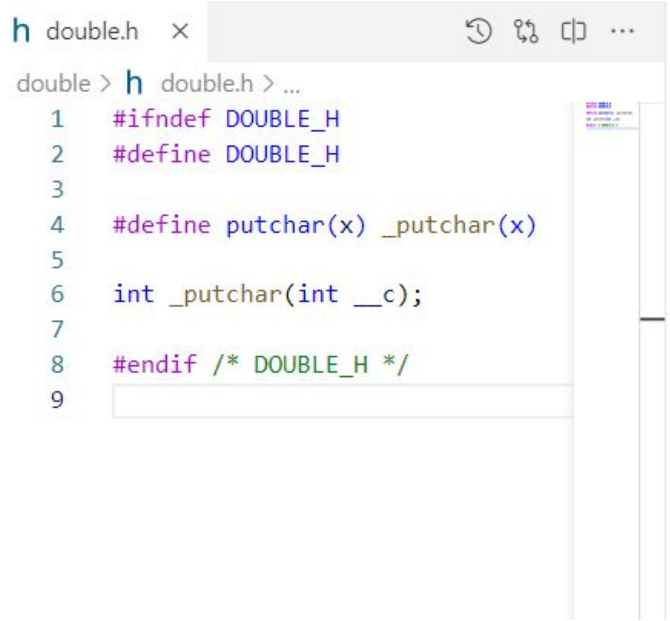
```c
#include <stdint.h>
#include <stdlib.h>
#include <module.h>

static uint8_t *ptr = NULL;
static free_t free_memory = NULL;

void module_begin(free_t func)
{
    free_memory = (func == NULL) ? free : func;

    module_end();

    ptr = (uint8_t *)malloc(sizeof(uint8_t));
}

void module_end(void)
{
    if (ptr != NULL)
    {
        free_memory(ptr);
        ptr = NULL;
    }
}
```



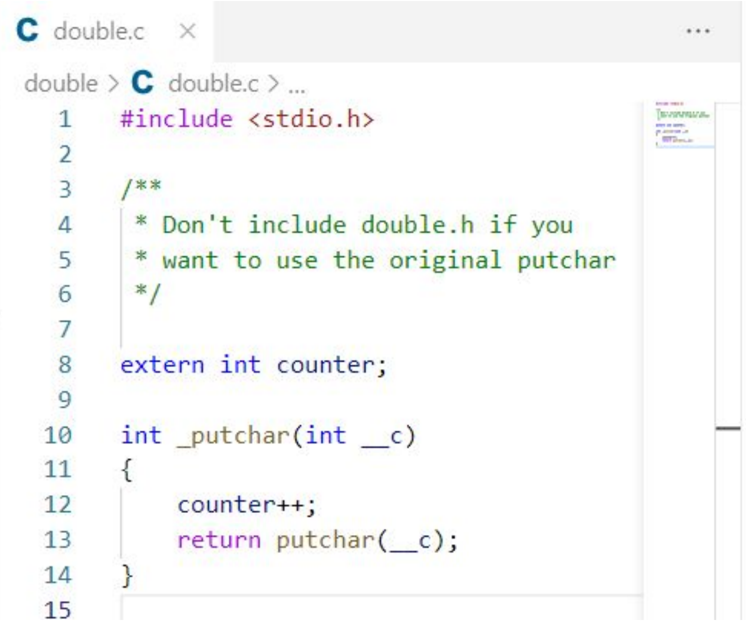
```c
#include <stdio.h>
#include <unity.h>
#include <module.h>
#include <stdlib.h>

static void my_free(void *ptr)
{
    printf("\nTest Code: my_free is called\n\n");
    free(ptr);
}

void setUp()
{
    module_begin(my_free);
}

void tearDown()
{
    module_end();
}

void test_free_memory()
{
    TEST_IGNORE();
}

int main(void)
{
    UNITY_BEGIN();

    RUN_TEST(test_free_memory);

    return UNITY_END();
}
```

Faking in C

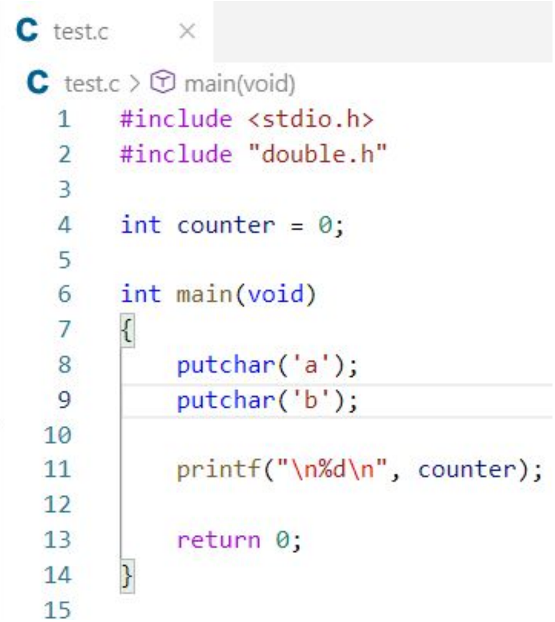
- Preprocessor substitution
  - Use it when linker and function pointer substitutions can’t do the job
  - You can break a chain of unwanted includes with preprocessors
  - You can also use it selectively or temporarily to override names



```c
#ifndef DOUBLE_H
#define DOUBLE_H

#define putchar(x) _putchar(x)

int _putchar(int __c);

#endif /* DOUBLE_H */

```



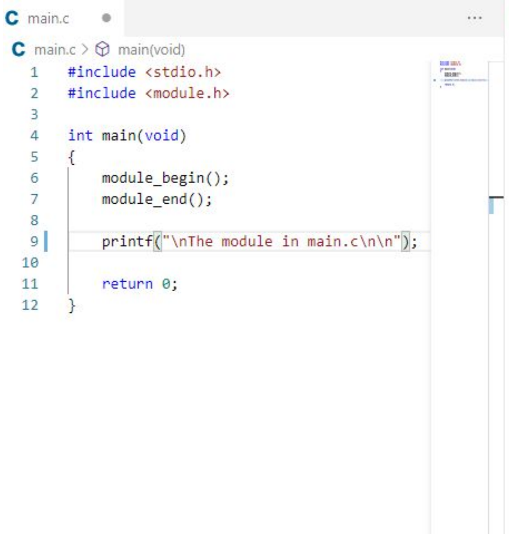
```c
#include <stdio.h>

/**
 * Don't include double.h if you
 * want to use the original putchar
 */

extern int counter;

int _putchar(int __c)
{
    counter++;
    return putchar(__c);
}

```



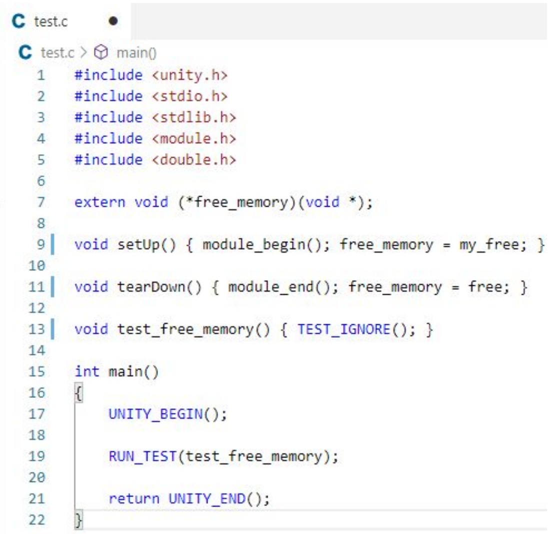
```c
#include <stdio.h>
#include "double.h"

int counter = 0;

int main(void)
{
    putchar('a');
    putchar('b');

    printf("\n%d\n", counter);

    return 0;
}

```

Faking in C

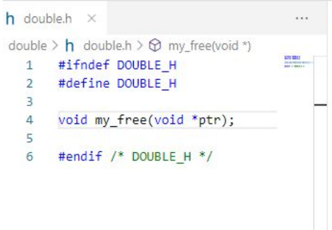
- ❖ Combination of link-time and function pointer substitutions
  - ➢ We can combine link-time and function pointer substitution to work together
  - ➢ A link-time stub can be created that contains a function pointer initialized to NULL
  - ➢ A test case can override the NULL pointer and provide exactly the stub function
  - ➢ You want the flexibility of the function pointers but not to change the interface of the DOC



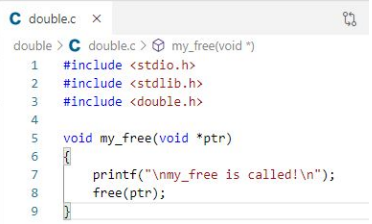
```c
#include <stdio.h>
#include <module.h>

int main(void)
{
    module_begin();
    module_end();

    printf("\nThe module in main.c\n\n");

    return 0;
}
```



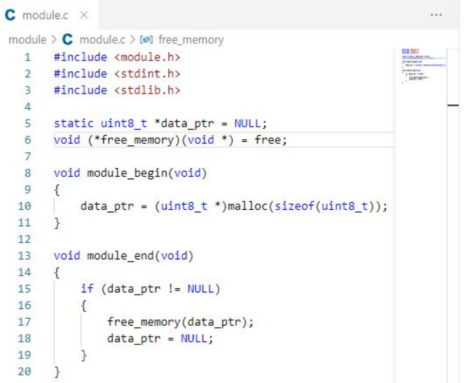
```c
#include <unity.h>
#include <stdio.h>
#include <stdlib.h>
#include <module.h>
#include <double.h>

extern void (*free_memory)(void *);

void setUp() { module_begin(); free_memory = my_free; }

void tearDown() { module_end(); free_memory = free; }

void test_free_memory() { TEST_IGNORE(); }

int main()
{
    UNITY_BEGIN();

    RUN_TEST(test_free_memory);

    return UNITY_END();
}
```



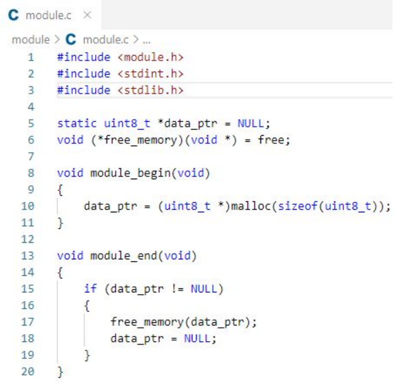
```c
#ifndef DOUBLE_H
#define DOUBLE_H

void my_free(void *ptr);

#endif /* DOUBLE_H */
```



```c
#include <stdio.h>
#include <stdlib.h>
#include <double.h>

void my_free(void *ptr)
{
    printf("\nmy_free is called!\n");
    free(ptr);
}
```



```c
#include <module.h>
#include <stdint.h>
#include <stdlib.h>

static uint8_t *data_ptr = NULL;
void (*free_memory)(void *) = free;

void module_begin(void)
{
    data_ptr = (uint8_t *)malloc(sizeof(uint8_t));
}

void module_end(void)
{
    if (data_ptr != NULL)
    {
        free_memory(data_ptr);
        data_ptr = NULL;
    }
}
```



```c
#include <module.h>
#include <stdint.h>
#include <stdlib.h>

static uint8_t *data_ptr = NULL;
void (*free_memory)(void *) = free;

void module_begin(void)
{
    data_ptr = (uint8_t *)malloc(sizeof(uint8_t));
}

void module_end(void)
{
    if (data_ptr != NULL)
    {
        free_memory(data_ptr);
        data_ptr = NULL;
    }
}
```

Dual-Targeting Strategy

- Dual-targeting means that the code is designed to run on at least two platforms:
  - The final target hardware
  - The development system
- Dual-targeting strategy is used because of:
  - The target hardware is expensive
  - Target hardware is not ready until late in the project
  - When target hardware is finally available, it may have bugs of its own
  - Long target build or upload times waste valuable time during the edit, compile, and test cycle
  - Compilers for the target hardware are considerably more expensive than native compilers
  - And etc.
- Concurrent hardware and software development is a reality for many projects

Dual-Targeting Strategy

- Benefits of Dual-Targeting
  - It allows you to overcome the hardware restrictions
  - Dual-targeting, like TDD, produces more modular and hardware independence designs
- Risks of Dual-Target Testing
  - The riska are because of differences between the development and target environments
  - Compilers may support different language features
  - The runtime libraries may be different
  - Primitive data types might have different sizes
  - The target compiler may have bugs
  - Byte ordering and data structure alignments may be different

Dual Targeting & Link-Time Faking Techniques

- If you want to test your module **ONLY** on your **PC**
  - Make a test double using the link-time substitution technique for Arduino.
    - The test double shall have Arduino.h and optionally Arduino.cpp to implement the fake functions
  - In this technique your modules will be dependent of Arduino
    - We have to include Arduino.h in modules and directly use Arduino functions

- If you want to follow the dual targeting strategy and make portable modules
  - Make an abstraction layer over Arduino in order to make your modules independent of Arduino. In this way your modules don’t directly depend on Arduino.
  - Use the link-time faking technique to make test doubles for the modules in the abstraction layer
  - In the modules of the abstraction layer you can use Arduino functions and macros

Dual Targeting & Function Pointer Faking Techniques

- If you want to test your module on **ONLY** your **PC**
  - Generally avoid using the function pointer substitution technique to make test doubles.
    - The readability of your code is decreased.
- If you want to follow dual targeting and test your module on your **PC** and the **µC** without needing to create an abstraction layer over Arduino, use the function pointer technique. Even if you need to abstract a module or a framework, you can use the function pointer technique to make test doubles for the abstracted modules.

- Avoid using the preprocessor technique to make test doubles. It affects the CUT
  - But preprocessor substitution can be useful when we only want to change function names

Code Coverage

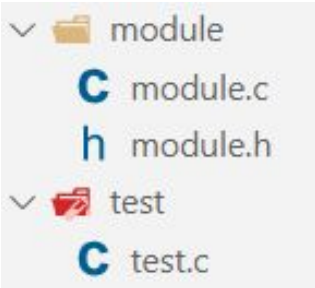
- What is Code Coverage?
  - Is the percentage of the code which is covered by automated tests
  - Determines which parts of the code is executed through a test run, and which parts is not
- Why Measure Code Coverage?
  - To know how well our tests actually test the production code
  - To know whether we have enough testing in place
  - To maintain the test quality over the lifecycle of the project
- Types of Coverage measured
  - **Statement coverage**: measures whether each statement is executed
  - **Condition coverage**: measures whether each sub-expression evaluated both to true and false
  - **Branch coverage**: measures which branches (e.g. if-else) in flow control structures are followed
  - **Function coverage**: measures whether each function in the program been called

Code Coverage

- **Code instrumentation** refers to insert code in programs to monitor
  - Code tracing, debugging, analyzing, performance measuring, data logging and etc.
- Mainly there are three code Instrumentation approaches
  - **Source-code** instrumentation: Add the instrumentation code to the source code and compile the it with the compilation tool chain to produce an instrumented program.
    - Is done by developers and processed in the preprocessor step.
  - **Compile-time** instrumentation: Is done during compilation of source files, and the instrumentation is performed by the compiler.
    - E.g. debugging(-g), profiling(-pg), code coverage(--coverage), and etc.
  - **Runtime** instrumentation: The instrumentation code and data are inserted into the executable binary files during execution. It is done during runtime.
    - E.g. Dynamic binary instrumentation tools like Intel Pin Tool

Code Coverage in C

- We need to use **gcov** to instrument coverage code in files
  - **gcov** is the code coverage library for **gcc/g++**.
  - Compile source files with **--coverage**, and link against **-lgcov**
    - For **.cpp** projects, you can use **g++** compiler or link **-lstdc++** if you use **gcc**.
  - Run the test to produce .gcda and .gcno files
- To generate code coverage reports:
  - On Linux you can use **lcov**(a graphical front-end for gcov) and **genhtml**(html report generator).
  - Or you can use **gcovr**(a python package). For more info about gcovr look at the documentation
  - Run **gcovr -r <*root-directory*> --html-details -o <*output-directory*>/index.html**
    - Specify root-directory and the output-directory of your project. Look at the options of gcovr
- Example
  - mkdir -p build; gcc --coverage ./test/test.c ./module/module.c -lunity -lgcov -o ./build/test;
  - ./build/test;   gcovr -r . --html-details -o build/index.html



```
module
  module.c
  module.h
test
  test.c
```

Modularity and Software Testing - Exercises

- Exercise 14: Develop a multiple-instance **stack** module
  - Size of instances are set during runtime when we create them.
  - The module shall be fully tested using the TDD technique on **YOUR PC** and **ESP32**
  - To make a test double for the dependency use the function pointer faking thechnique

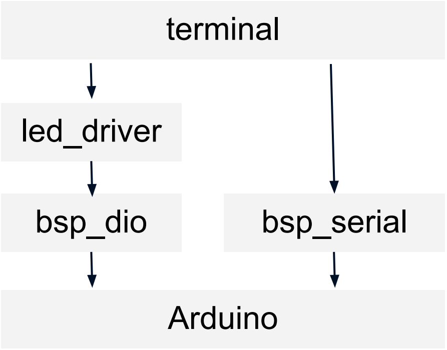
- Exercise 15: Develop a multiple-instance module (**mmetro**) like the **Metro** library
  - The module shall be fully tested using the TDD technique on **YOUR PC** and **Teensy**
  - The module shall be able to measure microseconds and milliseconds
    - Using **millis**() and **micros**() in Arduino
  - To make a test double for the dependency use the function pointer faking thechnique

Modularity and Software Testing - Exercises

- Connect your LDR series with a 4.7kΩ resistor to an analog pin and a LED series with 120Ω to a PWM pin on Teensy. Specify a range of resistance for light intensity in your room
  - E.g. for max. light the LDR resistance is 2 kΩ and for min. light it is 50 kΩ
- Make a driver module (**ldr_driver**) for the LDR to read the light intensity in percent
  - Means that the max. resistance is equivalent to 0% and min. resistance is equivalent to 100%
- Make a driver module (**led_driver**) for a LED to change its brightness in percent
  - You need to use PWM. Means that 0% is equivalent to 0 and 100% of brightness is equivalent to 255.
- Make a program to read the light intensity in percentage every 100ms and apply it to the LED.
  - For timing use an **interval timer**.
- Use the **TDD** technique to test your modules. (Code coverage shall be 100%)
- **Exercise 16**: Use the link-time faking technique to develop the modules on your computer
- **Exercise 17**: Follow the **dual targeting strategy**. Test your modules on Teensy.
  - Create an abstraction layer over Arduino to make your modules independent of Arduino.

Modularity and Software Testing - Exercises

- **Exercise 18**: Make a program for ESP32 to control the built-in LED in a terminal.
- The program shall have a menu system with two options
  - An option to turn the LED on and an option to turn the LED off
- You shall develop a driver module(led_driver) for the LED
- You shall develop an application module(terminal) for user interaction.
- Your modules shall be independent of Arduino
  - Create an abstraction layer over Arduino(bsp_dio and bsp_serial modules)
- Use TDD and dual targeting strategy to test your modules.
  - Do unit and integration testing.
  - The code coverage for your tests shall be 100%
- Use the link-time faking technique to make the test doubles



Modularity and Software Testing

- Some useful links
  - Modular Programming in C
  - Modular Approach in Programming
  - Effective Tests: Test Doubles
  - Test Doubles — Fakes, Mocks and Stubs
  - Test Double
  - Linker Substitution in C
  - Function pointers vs. Preprocessor vs. Link-time substitution
  - SOLID Agile Development
  - SOLID Principles made easy
  - SOLID Principle in Programming
  - SOLID Principles: Explanation and examples
  - gcovr documentation
  - About Code Coverage
  - Instrumentation (computer programming)
  - The Ultimate List of Code Coverage Tools
  - Code Coverage Using GNU Gcov and Lcov
  - Code Coverage in C with gcov and lcov
  - Using gcov and lcov
  - Code instrumentation