Informatik / Computer Science

C++ Test-driven Development

Unit Testing, Code Assistance and Refactoring

IFS INSTITUTE FOR SOFTWARE

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HSR HOCHSCHULE FÜR TECHNIK RAPPERSWIL

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Work Areas

- Refactoring Tools (C++, Scala, ...) for Eclipse
- Decremental Development (make SW 10% its size!)
- Modern Agile Software Engineering
- ISO C++ standardization committee

Pattern Books (co-author)

- Pattern-oriented Software Architecture Vol. 1
- Security Patterns

Background

- Diplom-Informatiker / MSc CS (Univ. Frankfurt/M)
- Siemens Corporate Research - Munich
- itopia corporate information technology, Zurich
- Professor for Software Engineering, HSR Rapperswil, Director IFS Institute for Software

Credo:

People create Software

- communication
- feedback
- courage

Experience through Practice

- programming is a trade
- Patterns encapsulate practical experience

Pragmatic Programming

- test-driven development
- automated development
- Simplicity: fight complexity

Software Quality

Software Quality

Software Quality
"An Elephant in the Room"

- **classic approach:**
  - manual testing after creation

But:
Small Cute Things

Peter Sommerlad

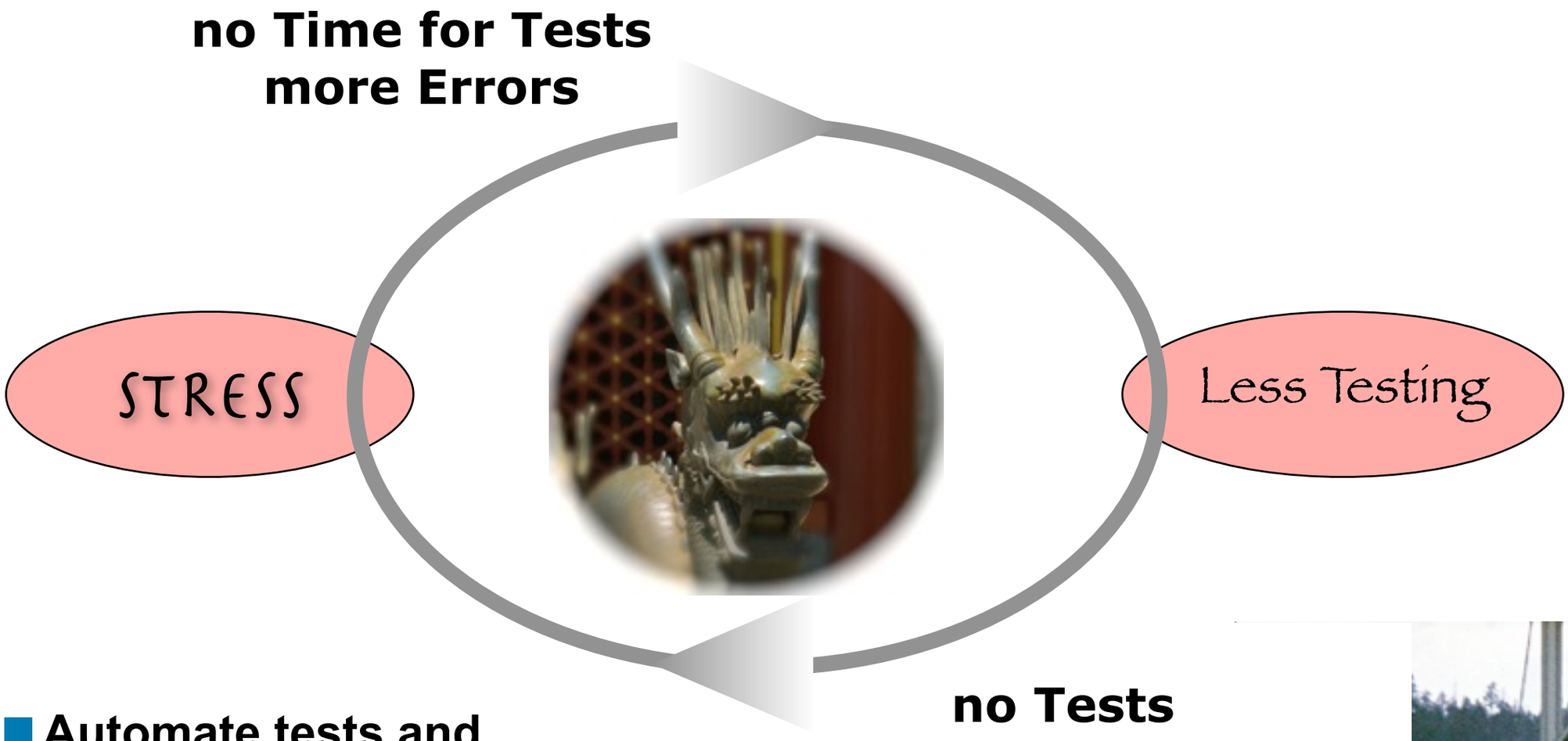
Grow to become larger Problems!

Is that Testing?

- **“it compiles!”**
  - no syntax error detected by compiler
- **“it runs!”**
  - program can be started
- **“it doesn’t crash!”**
  - …immediately with useful input
- **“it runs even with random input!”**
  - the cat jumped on the keyboard
- **“it creates a correct result!”**
  - a single use case is working with a single reasonable input

- **Automated (unit) testing gives you much more!**

Vicious Circle: Testing - Stress



- **Automate tests and run them often!**

C++ hello world (as generated by Eclipse CDT)

- **What is wrong here - and how can we test it?**

```
//============================================================================
// Name        : helloworld.cpp
// Author      :
// Version     :
// Copyright   : Your copyright notice
// Description : Hello World in C++, Ansi-style
//============================================================================

#include <iostream>
using namespace std;

int main() {
    cout << "!!!Hello World!!!" << endl; // prints !!!Hello World!!!
    return 0;
}
```

belongs into version management system

bad practice, very bad in global scope

ridiculous comment

redundant

inefficient, redundant

using global variable! really bad if not in main() :-(

A better (hello) world? How would it be?

- **Unit testable code mustn't use global (non-const) variables**
  - separate functionality from main() into a separate compilation unit or library
  - write unit tests against the library
  - make main() so simple, it cannot be wrong
- **using namespace pollutes namespace of compilation unit**
  - therefore never ever put "using namespace" in global scope within a header
  - prefer using declarations, like "using std::cout;" to name what you are actually using
    - functions and operators are automatically found when called, because of argument dependent lookup
- **ostream std::cout will flush automatically when program ends anyway**
  - use of std::endl most of the time a waste, because of flushing (except asking for input)

How can we test Hello World?

- **extract function with the functionality to be tested**
- **rid the function of dependencies you can not control (to std::cout)**
  - parameterize with std::ostream&
- **move function to a library that can be tested with unit tests to separate it from main**
- **write tests against the function**
- **run the tests**

A tested/testable hello world

Test:

```
#include "cute.h"
#include "ide_listener.h"
#include "xml_listener.h"
#include "cute_runner.h"
#include <sstream>
#include "sayHello.h"
void testSayHelloSaysHelloWorld() {
   std::ostringstream out;
   sayHello(out);
   ASSERT_EQUAL("Hello, world!\n",out.str());
}
void runAllTests(int argc, char const *argv[]){
    cute::suite s;
    s.push_back(CUTE(testSayHelloSaysHelloWorld));
    cute::xml_file_opener xmlfile(argc,argv);
    cute::xml_listener<cute::ide_listener<>> lis(xmlfile.out);
    cute::makeRunner(lis,argc,argv)(s, "AllTests");
}
int main(int argc, char const *argv[]){
    runAllTests(argc,argv);
    return 0;
}
```

Library:

```
#ifndef SAYHELLO_H_
#define SAYHELLO_H_

#include <iosfwd>
void sayHello(std::ostream &out);

#endif /* SAYHELLO_H_ */
```

```
#include "sayhello.h"
#include <ostream>
void sayHello(std::ostream &out){
   out << "Hello, world!\n";
}
```

Executable:

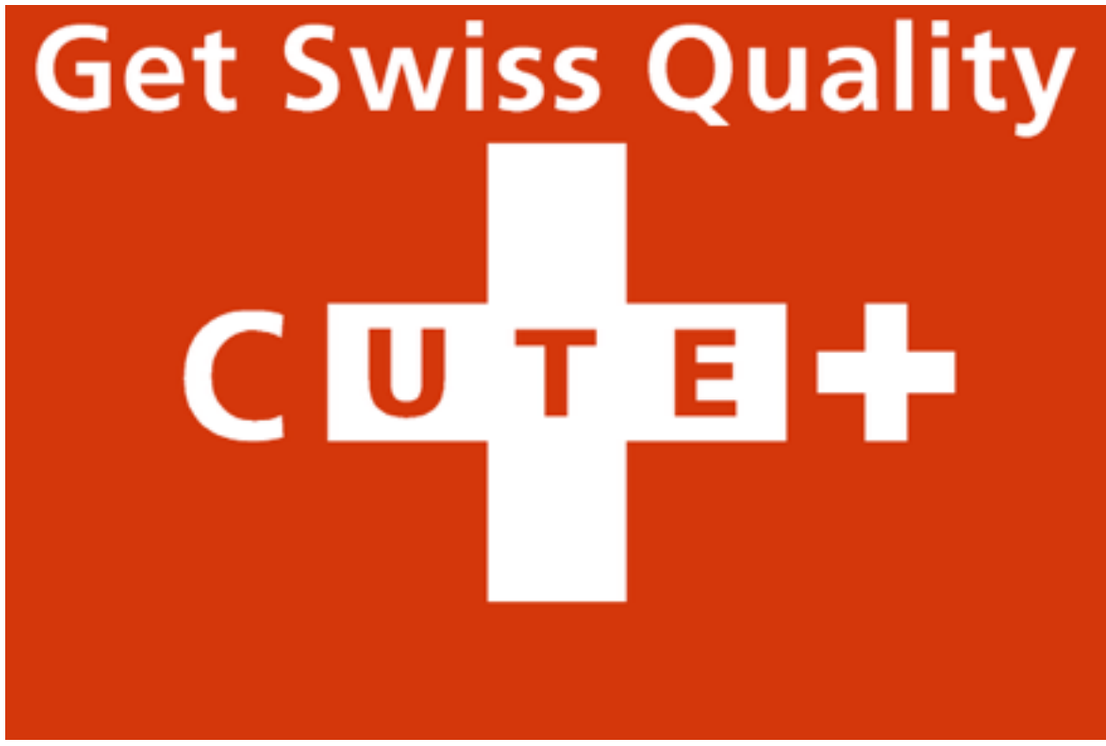
```
#include "sayhello.h"
#include <iostream>
int main(){
   sayHello(std::cout);
}
```

CUTE - A modern C++ Unit Testing Framework

C++ Unit Testing with CUTE in Eclipse CDT

TDD Test-Driven Development and Refactoring

- **CUTE http://cute-test.com - free!!!**
- **simple to use - test is a function**
  - understandable also for C programmers
- **designed to be used with IDE support**
  - can be used without, but a slightly higher effort
- **deliberate minimization of #define macro usage**
  - macros make life harder for C/C++ IDEs



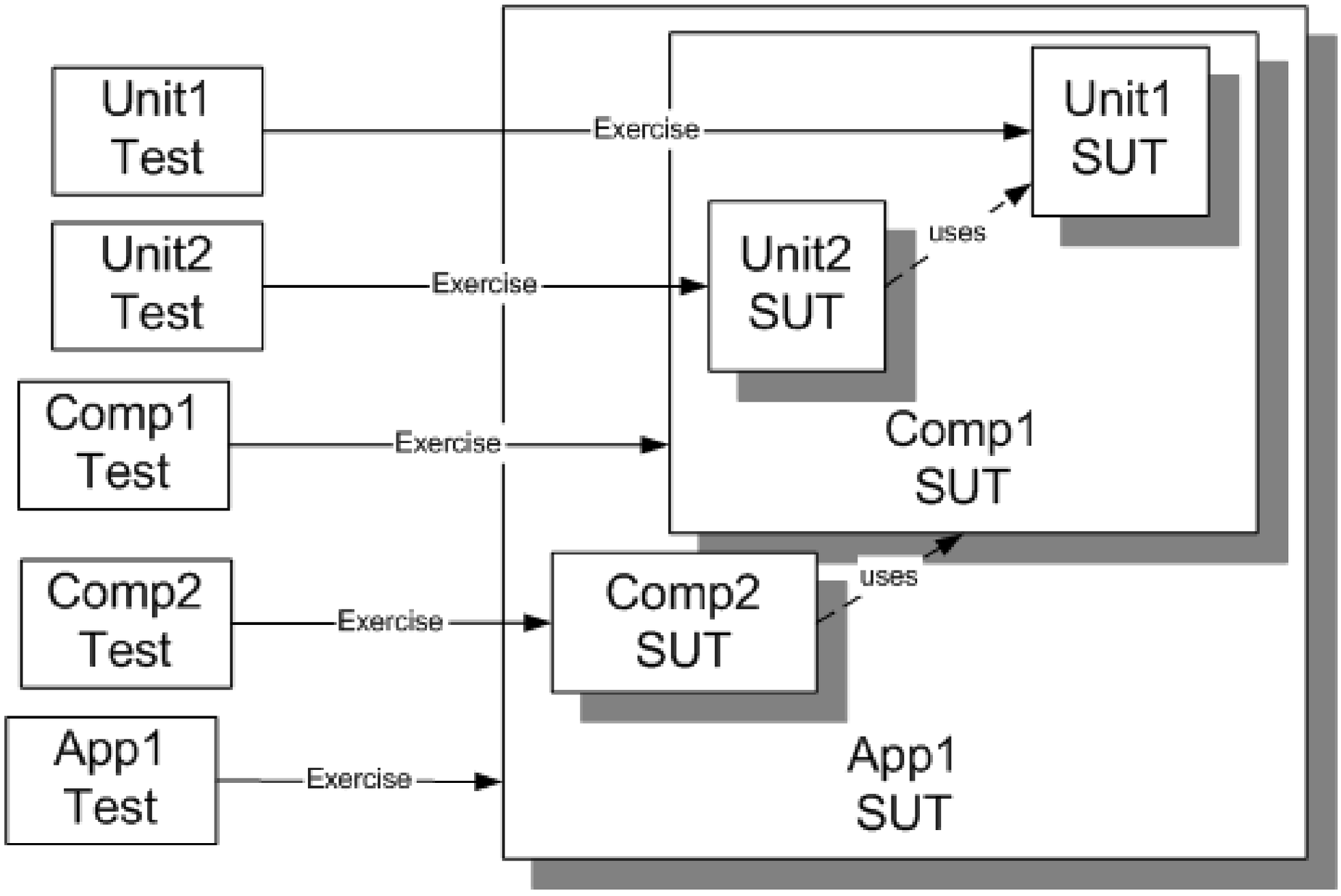
How do I write good Unit Tests?

- **If the code is correct, how would I know?**
- **How can I test this?**
- **What else could go wrong?**
- **Could a similar problem happen elsewhere?**

- **Writing good automated tests is hard.**
- **Beginners are often satisfied with “happy-path” tests**
  - error conditions and reactions aren’t defined by the tests
- **Code depending on external stuff (DB, IO, etc) is hard to test. How can you test it?**
- **Will good tests provide better class design?**
- **How can tests be designed well?**

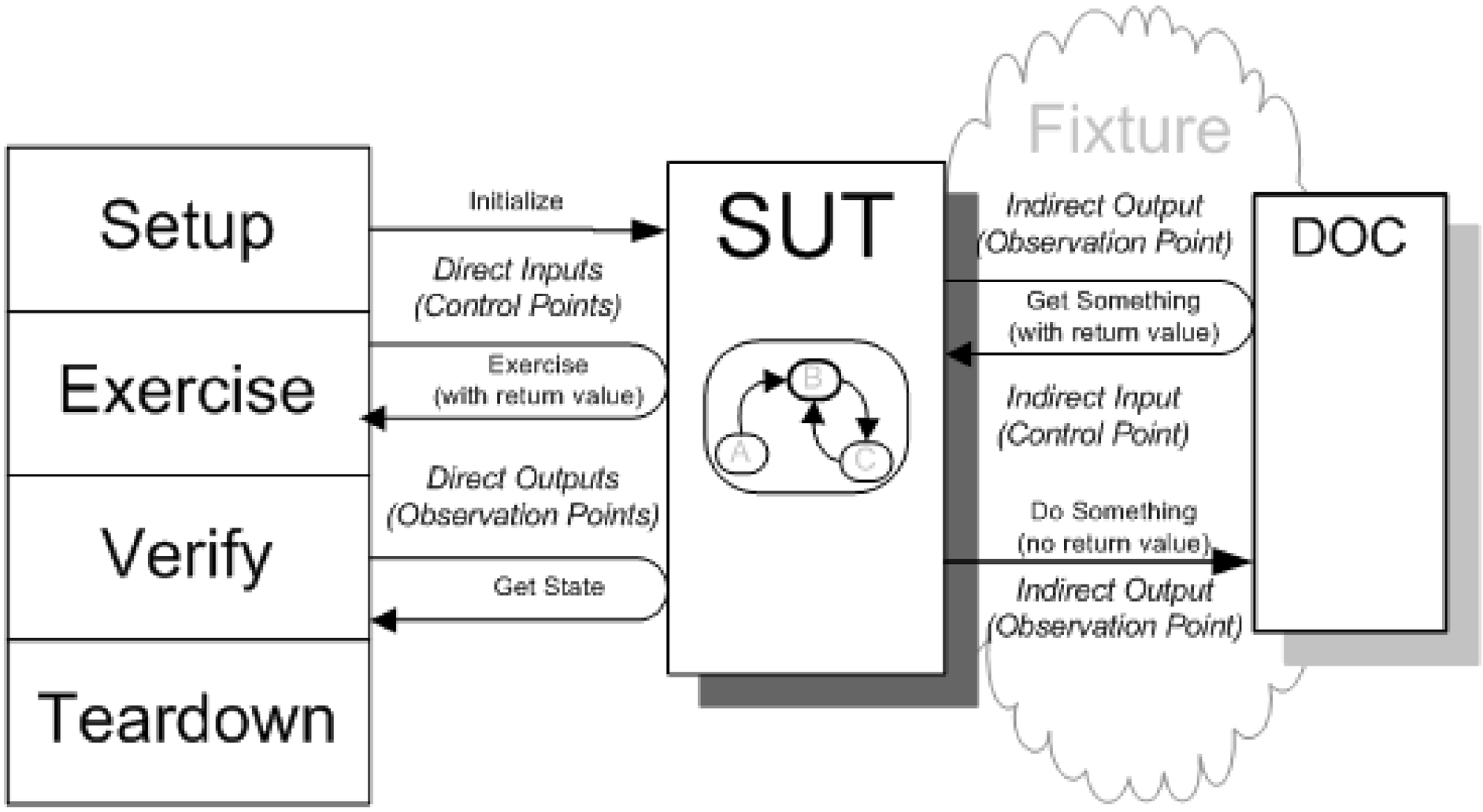
Some Terminology (source: xunitpatterns.com)

- **SUT System Under Test**



- **source: xunitpatterns.com - Gerard Meszaros**

Four Phase Test

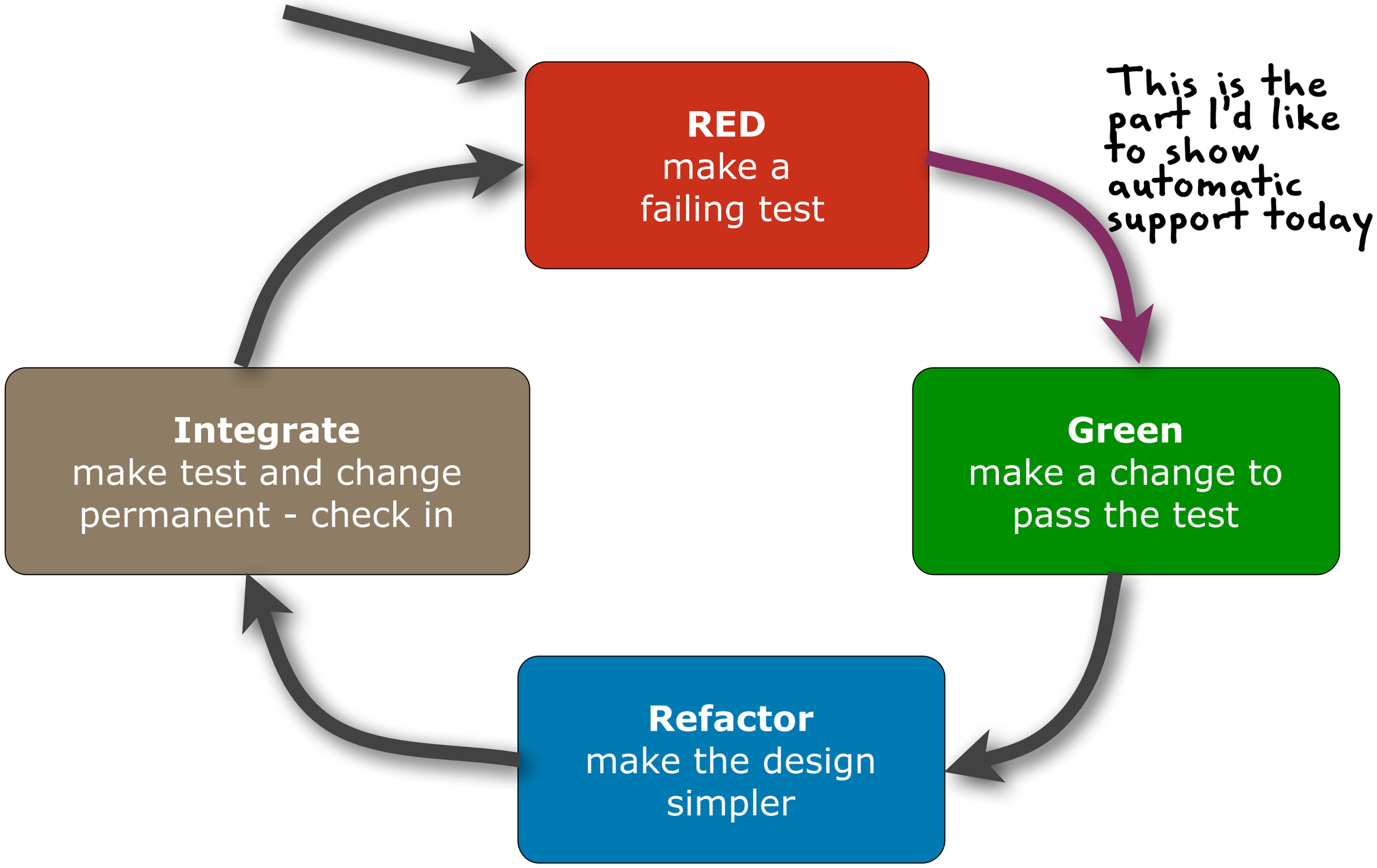


- **Setup: create locals needed for test**
- **Exercise: call function(s) which's behavior you want to check**
- **Verify: assert that results are as expected**
- **Teardown: usually trivial in C++, could mean to release external resources**

What are GUTs (Good Unit Tests)? (A. Cockburn)

- **are GOOD, DRY and Simple:**
  - no control structures, tests run linear
  - have the test assertion(s) in the end
- **test one thing at a time**
  - not a test per function/method, but a test per function call
  - a test per equivalence class of input values
- **have no (order) dependency**
  - leave no traces for others to depend on
- **all run successfully if you deliver**
- **have a good coverage of production code**
- **are often created Test-First —> Test-Driven Development**

TDD Cycle



Eclipse CDT TDD Support for CUTE and CUTE-plug-in features

- **get the cute plug-in from http://cute-test.com/updatesite or download Cevelop**

Download IDE at:
www.cevelop.com

- **create CUTE test project**
- **create test function**
- **create function definition from call (in test case)**
- **create type definition from usage (in test case)**
- **create variable definition from usage (in test case)**
- **move type definition into new header file (from test case file)**
- **toggle function definition between header and implementation (part of CDT)**

TDD Demo
Simulation of a Switch

- **Simulation of a Switch (class)**
  - alternative possible, if this seems too simple and time permits

THE LIST FOR CLASS SWITCH

1. CREATE,GETSTATE → OFF
2. TURNON,GETSTATE → ON
3. TURNOFF,GETSTATE → OFF

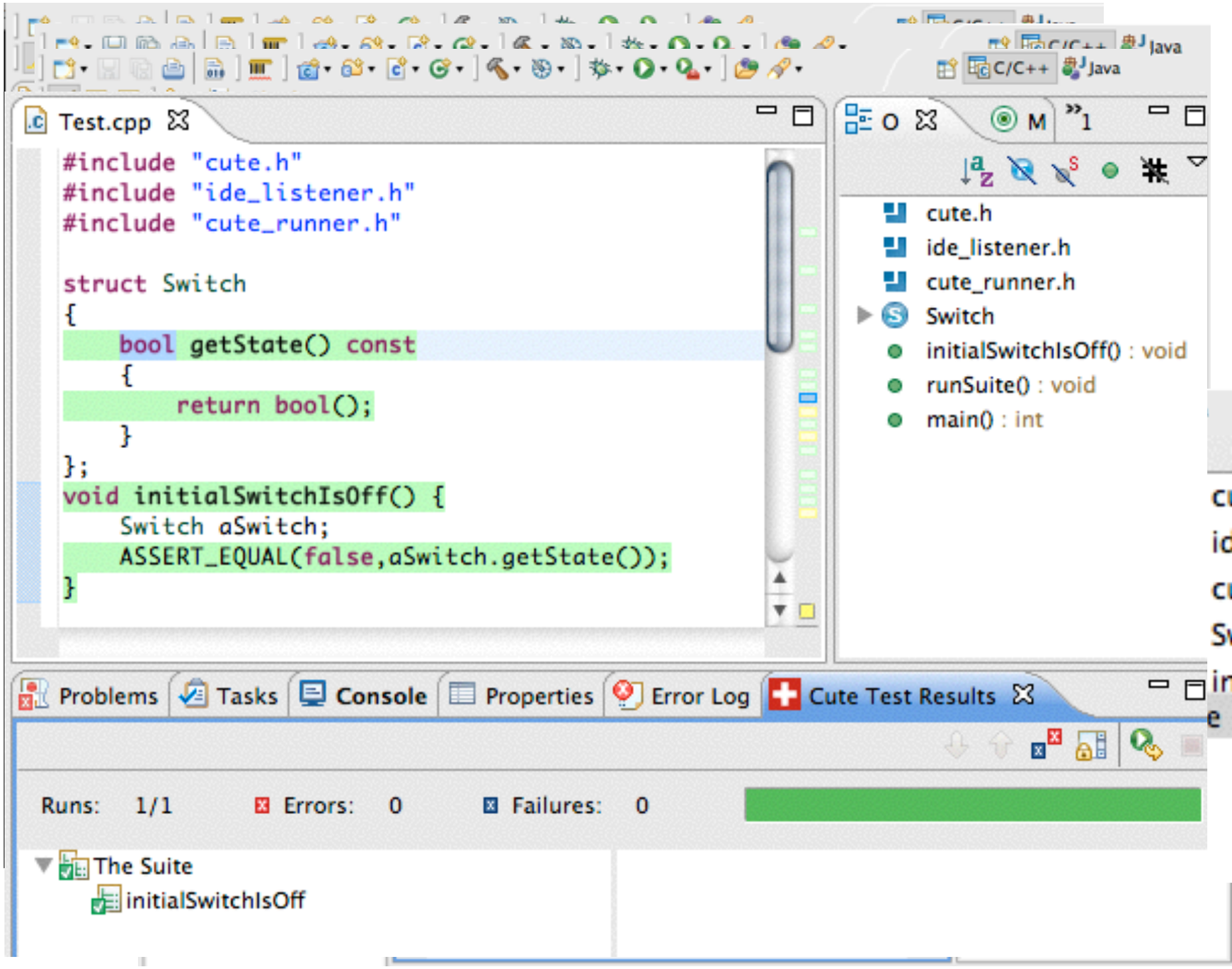
Demo 

TDD habits/patterns - Writing Tests

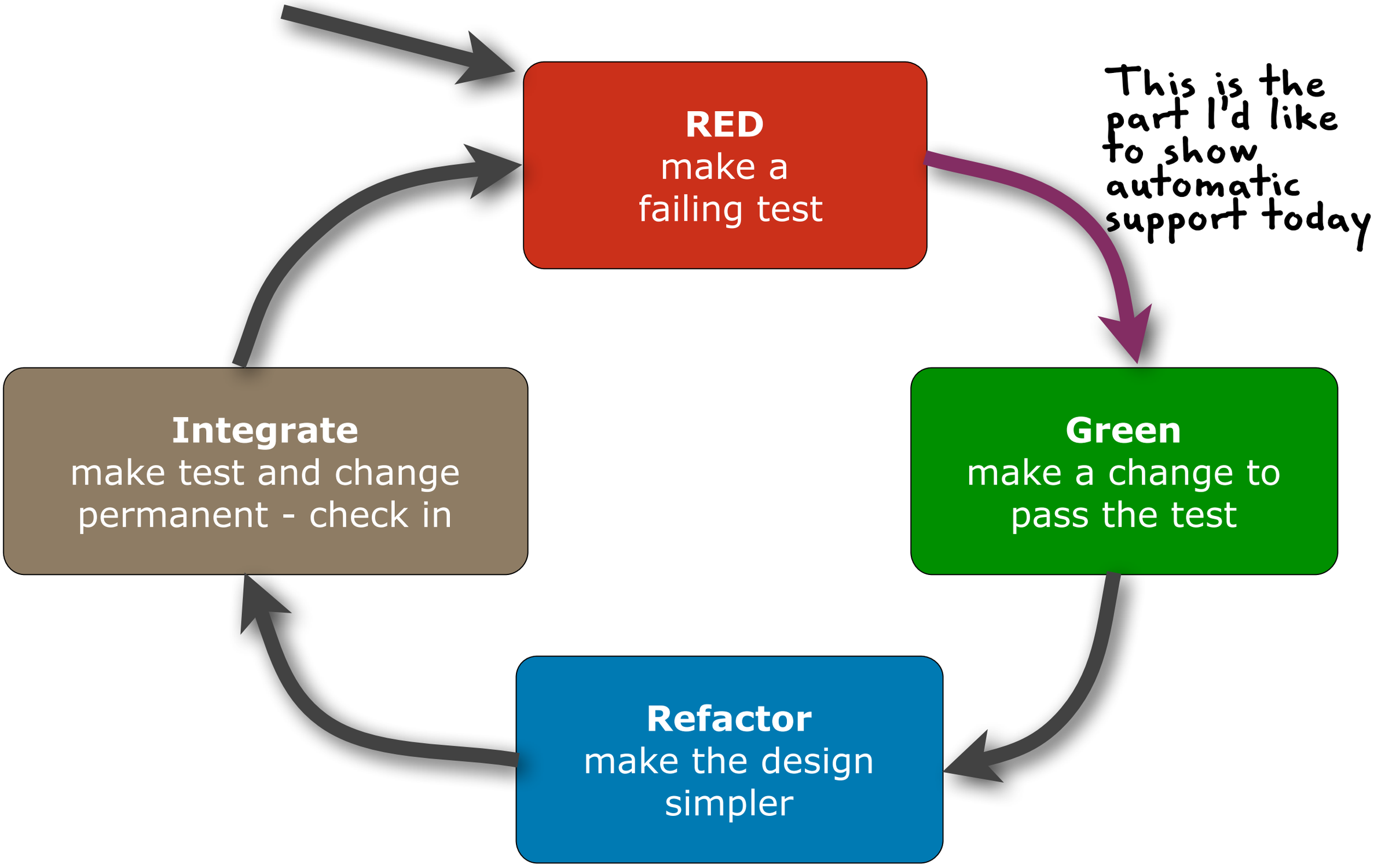
- **Isolated Tests**
  - write tests that are independent of other tests
- **Test List**
  - use a list of to-be-written tests as a reminder
  - only implement one failing test at a time
- **Test First**
  - write your tests before your production code
- **Assert First**
  - start writing a test with the assertion
  - only add the acting and arrangement code when you know what you actually assert

Demo

- **New C++ Project**
  - CUTE Test Project
- **Run as CUTE Test**
- **Fix Failing Test**
  - write first "real" test
    - rename test case function
    - write test code
    - make it compile through TDD quick-fixes (2x)
      - create type
      - create function
- **Run Tests**
  - green bar
- **iterate...**



TDD Cycle



What is Refactoring?

- **Ongoing cleaning**
  - “Clean Code”
- **Assure long-term quality**
  - code is always used longer than expected
- **Find better design**
  - understandability - habitable code
- **Remove duplication**
  - maintainability

TDD habits/patterns - “red bar” patterns

- **How do I find the tests I need to write?**

- **One Step Test**
  - solve a development task test-by-test
    - no backlog of test code, only on your test list
    - select the simplest/easiest problem next
- **Starter Test**
  - start small, e.g., test for an empty list
  - refactor while growing your code
- **Explanation Test**
  - discuss design through writing a test for it
- **Learning Test**
  - understand existing code/APIs through writing tests exercising it
  - Important, when you have to deal with legacy code base without GUTs

TDD habits/patterns: Green Bar patterns (how to make tests work)

- **Fake It ('Til You Make It)**
  - It is OK to “hack” to make your test succeed.
  - BUT: Refactor towards the real solution ASAP
- **Triangulate**
  - How can you select a good abstraction?
  - try to code two examples, and then refactor to the “right” solution
- **Obvious Implementation**
  - Nevertheless, when it’s easy, just do it.
- **One to Many (or zero, one, many)**
  - Implement functions with many elements first for one element (or none) correctly
- **Regression Test**
  - For every bug report write tests showing the bug
- **Break (Enough breaks are important! e.g. drink water while coding)**
- **Do Over (delete code when you are stuck and restart)**

TDD Demo
(3+4)*6 → 42

- **Expression Evaluator for simple Arithmetic**
- **Test-First Development with CUTE**
- **Incremental Requirements Discovery**

THE LIST FOR EVAL (V0)

"" → ERROR

"0" → 0

"2" → 2

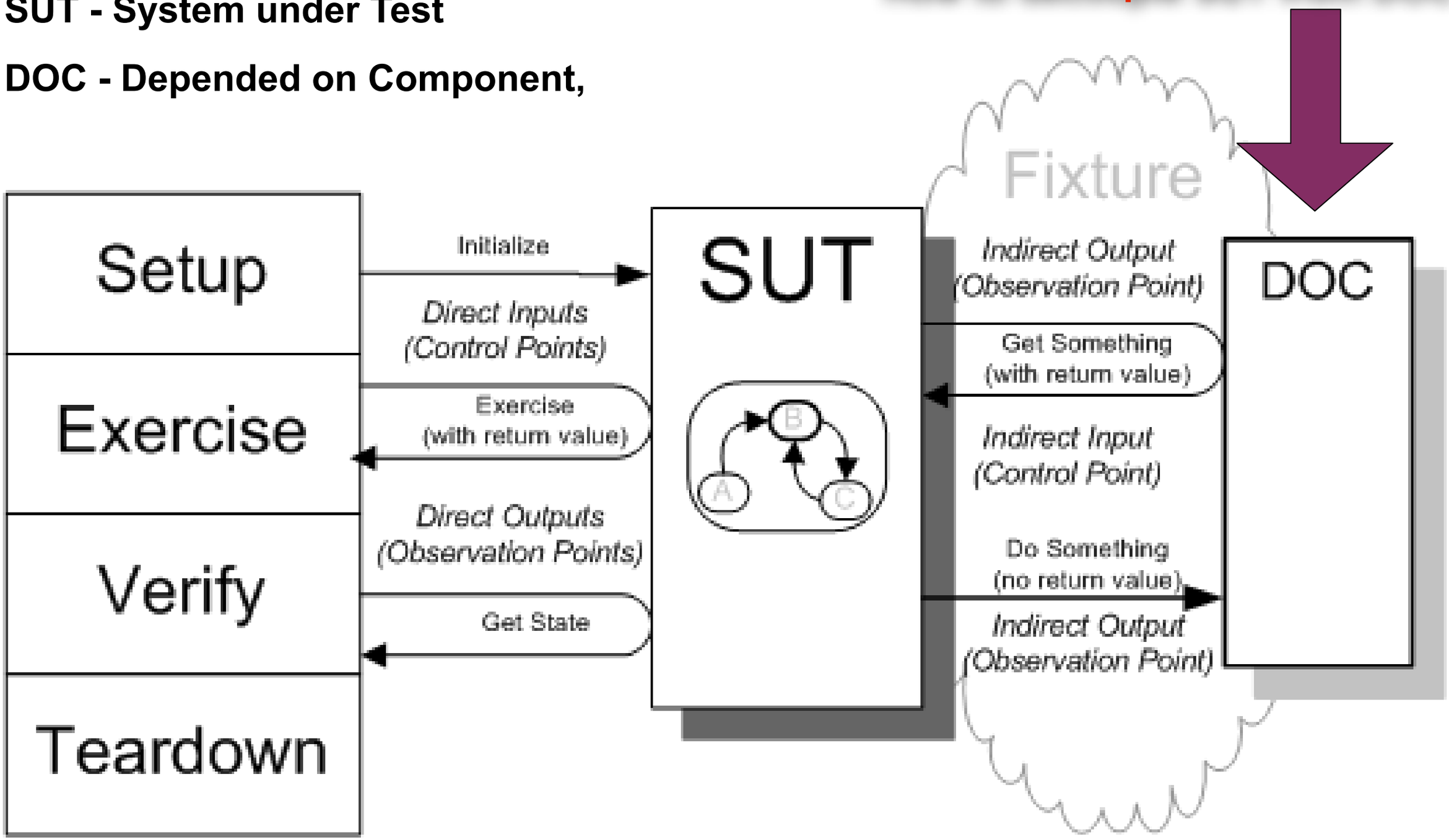
"1+1" → 2

Demo 

Four Phase Test Case
Setup, Exercise, Verify, Teardown

- **SUT - System under Test**
- **DOC - Depended on Component,**

How to decouple SUT from DOC?



- **source: xunitpatterns.com - Gerard Meszaros**

Mockator

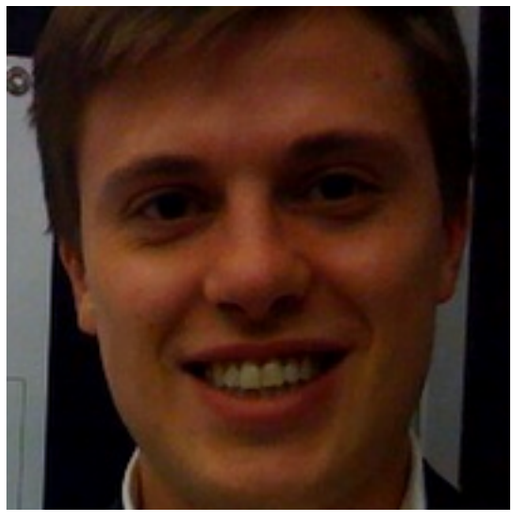
C++ Legacy Code Refactoring enabling Unit Testing

Seam Introduction
- Object Seam
- Compile Seam
- Link Seam
- Preprocessor Seam

Test Double generation

Mock Object generation

Function Tracer generation



Master Thesis by Michael Rüegg

inspired and supervised by Prof. Peter Sommerlad
soon to be released on http://mockator.com
beta at http://sinv–56033.edu.hsr.ch/mockator/repo

Principle of Mock objects

- **A unit/system under test (SUT) depends on another component (DOC) that we want to separate out from our test.**
- **Reasons**
  - real DOC might not exist yet
  - real DOC contains uncontrollable behavior
  - want to test exceptional behavior by DOC that is hard to trigger
  - using the real DOC is too expensive or takes to long
  - need to locate problems within SUT not DOC
  - want to test usage of DOC by SUT is correct

Why the need for Mock Objects?

- **Simpler Tests and Design**
  - especially for external dependencies
  - promote interface-oriented design
- **Independent Testing of single Units**
  - isolation of unit under testing
  - or for not-yet-existing units
- **Speed of Tests**
  - no external communication (e.g., DB, network)
- **Check usage of third component**
  - is complex API used correctly
- **Test exceptional behavior**
  - especially when such behavior is hard to trigger

Types of Mock Objects [Dave Astels]

- **There exist different categories of Mock objects and different categorizers.**

- **Stubs**
  - substitutes for “expensive” or non-deterministic classes with fixed, hard-coded return values
- **Fakes**
  - substitutes for not yet implemented classes
- **Mocks**
  - substitutes with additional functionality to record function calls, and the potential to deliver different values for different calls

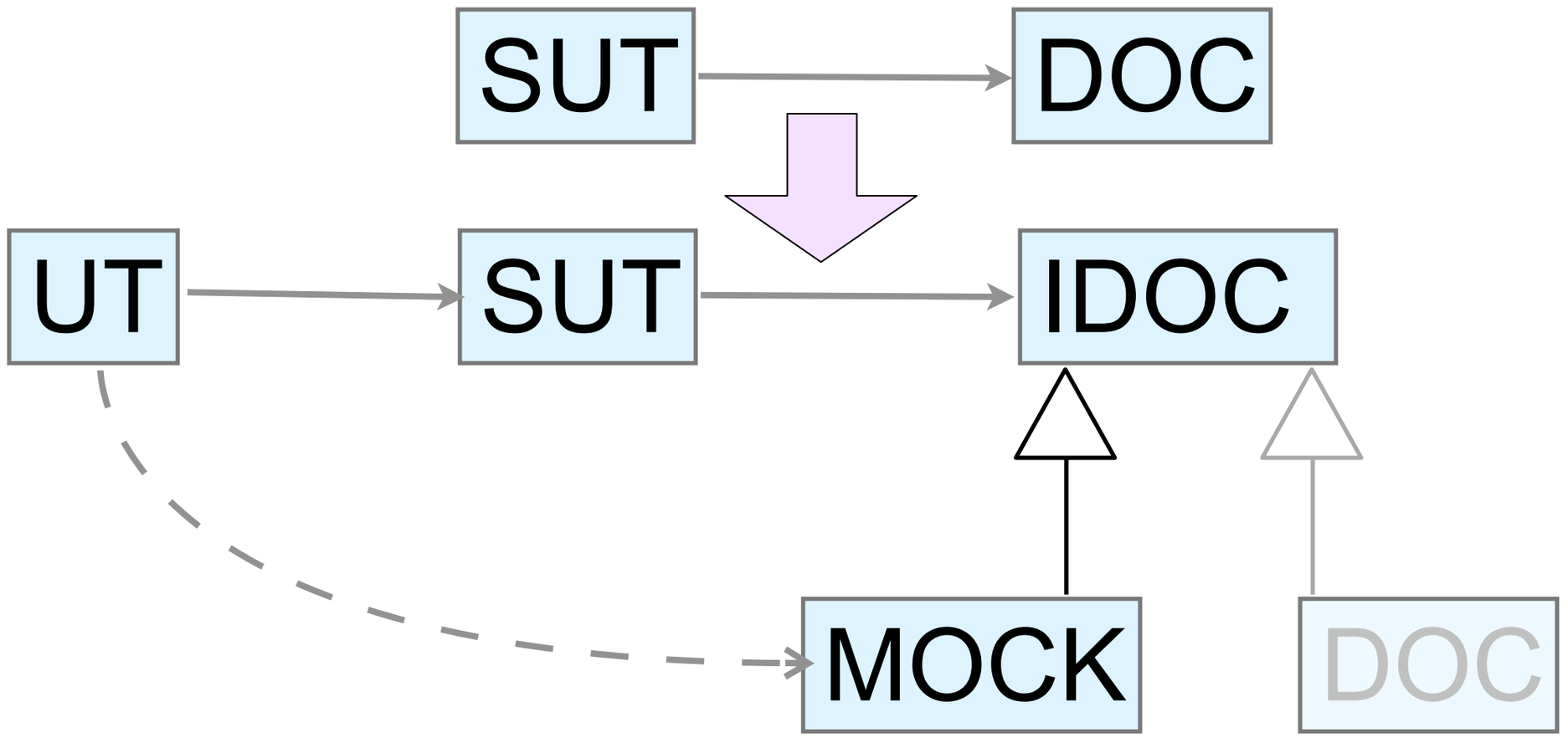
Seams!

How to decouple SUT from DOC?

- **Introduce a Seam:**
  - makes DOC exchangeable!
  - C++ provides different mechanisms
- **Object Seam (classic OO seam)**
  - Introduce Interface - Change SUT to use Interface instead of DOC directly
    - introduces virtual function lookup overhead
  - Pass DOC as a (constructor) Argument
  - Pass Test Double as Argument for Tests
- **Compile Seam (use template parameter)**
  - Make DOC a default template Argument

Introduce an Object Seam

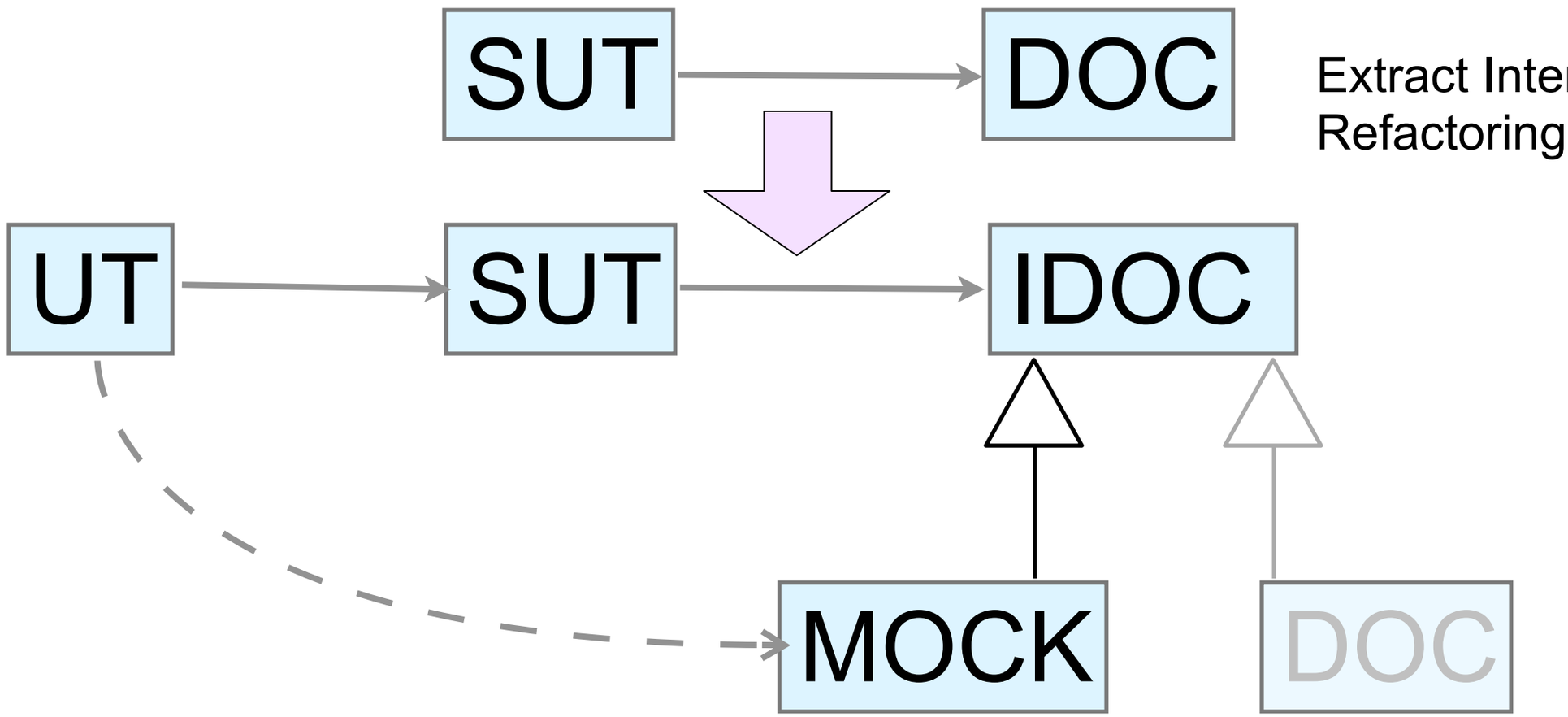
- **classic inheritance based mocking**
  - extract interface for DOC -> IDOC
  - make SUT use IDOC
  - create MOCK implementing IDOC and use it in UT



  - in C++ this means overhead for DOC (virtual functions)!

Introduce an Object Seam

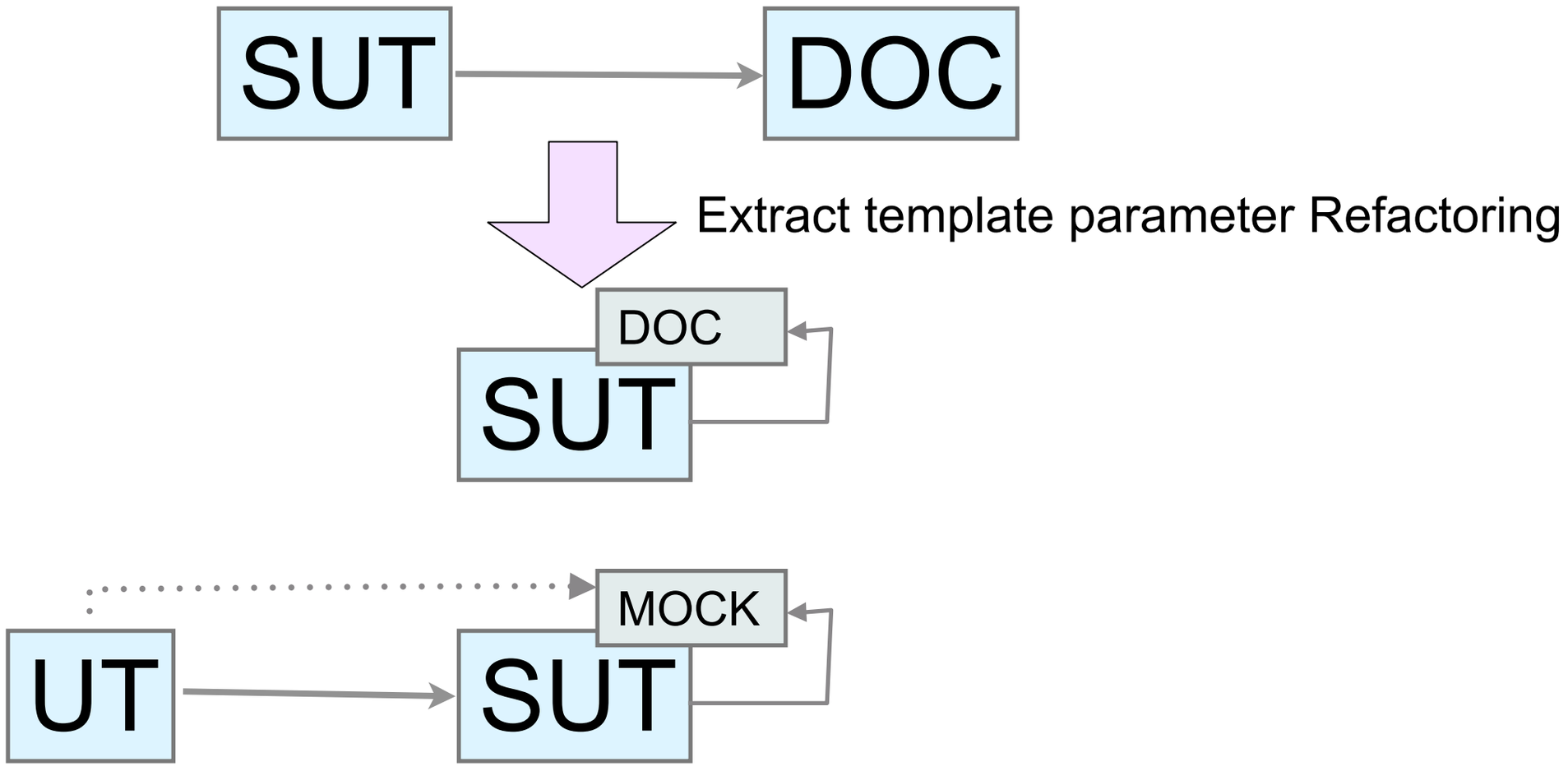
- **classic inheritance based mocking**
  - extract interface for DOC -> IDOC
  - make SUT use IDOC, edit constructor
  - create MOCK implementing IDOC and use it in UT



- in C++ this means overhead for DOC (virtual functions)!

Introduce a Compile Seam

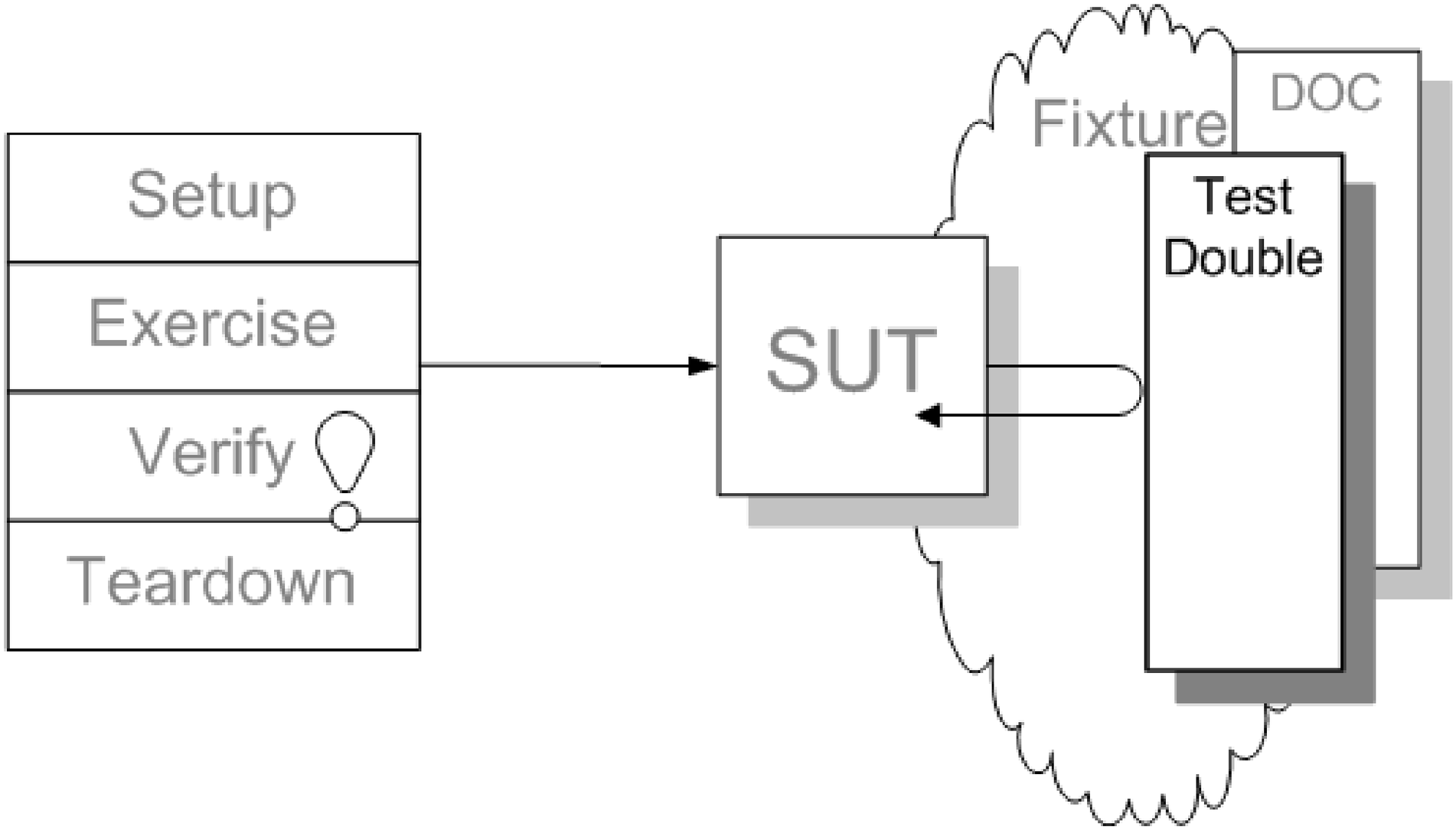
- **C++ template parameter based mocking**
  - make DOC a default template argument of SUT



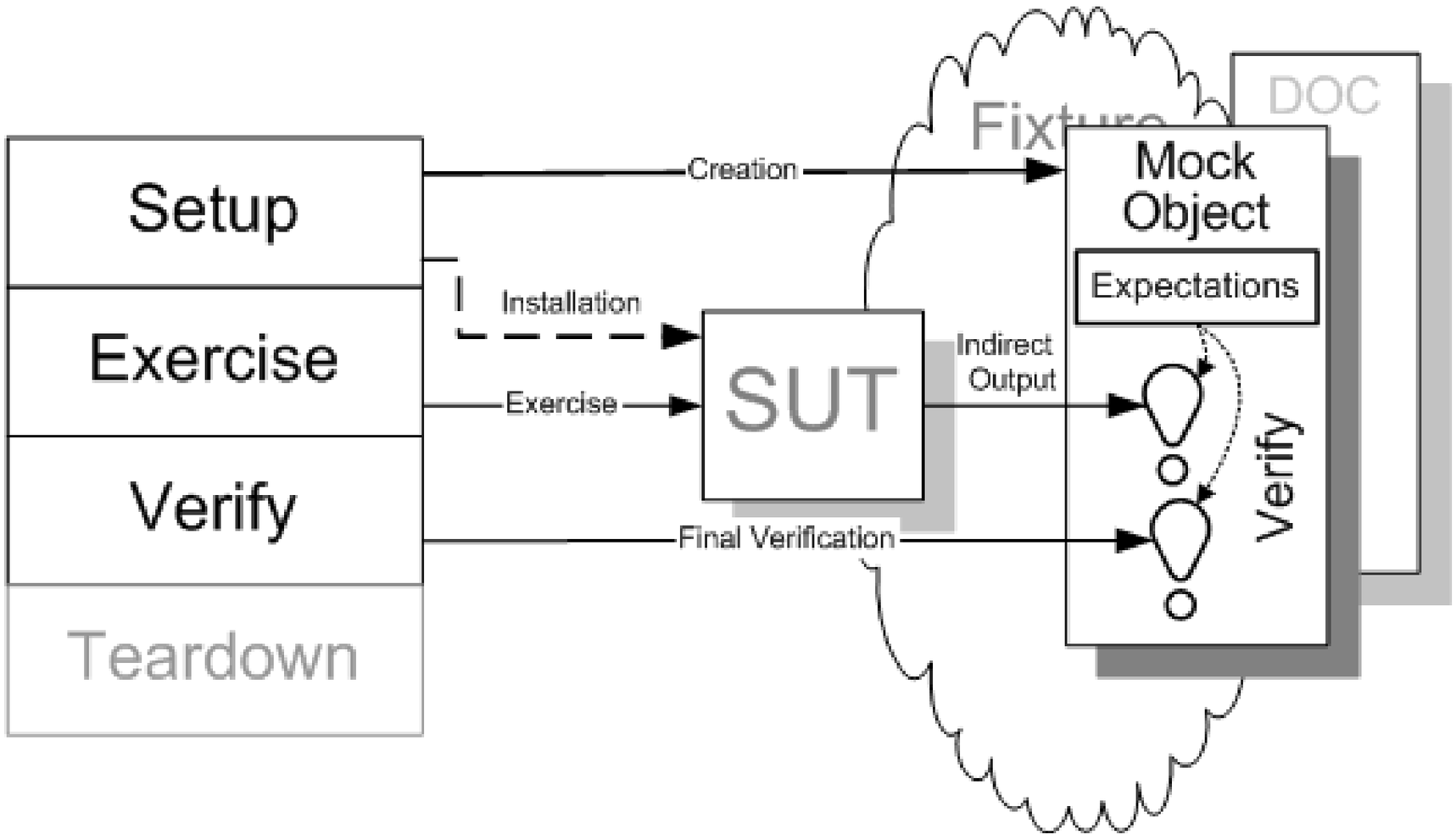
C/C++ specifics: Link Seam, Preprocessor

- **absolutely no change on existing code of SUT needed!**
- **remove Dependency on system/library functions**
  - shadowing through providing an alternative implementation earlier in link sequence
    - avoid dependency on system or non-deterministic functions, e.g. rand(), time(), or "slow" calls
  - wrapping of functions with GNU linker --wrap option, allows calling original also
    - good for tracing, additional checks (e.g., valgrind)
  - wrapping functions within dynamic libraries with dlopen/dlsym&LD_PRELOAD
  - problem: C++ name mangling if done by hand (solved by Mockator)
- **replace calls through #define preprocessor macro**
  - as a means of last resort, many potential problems

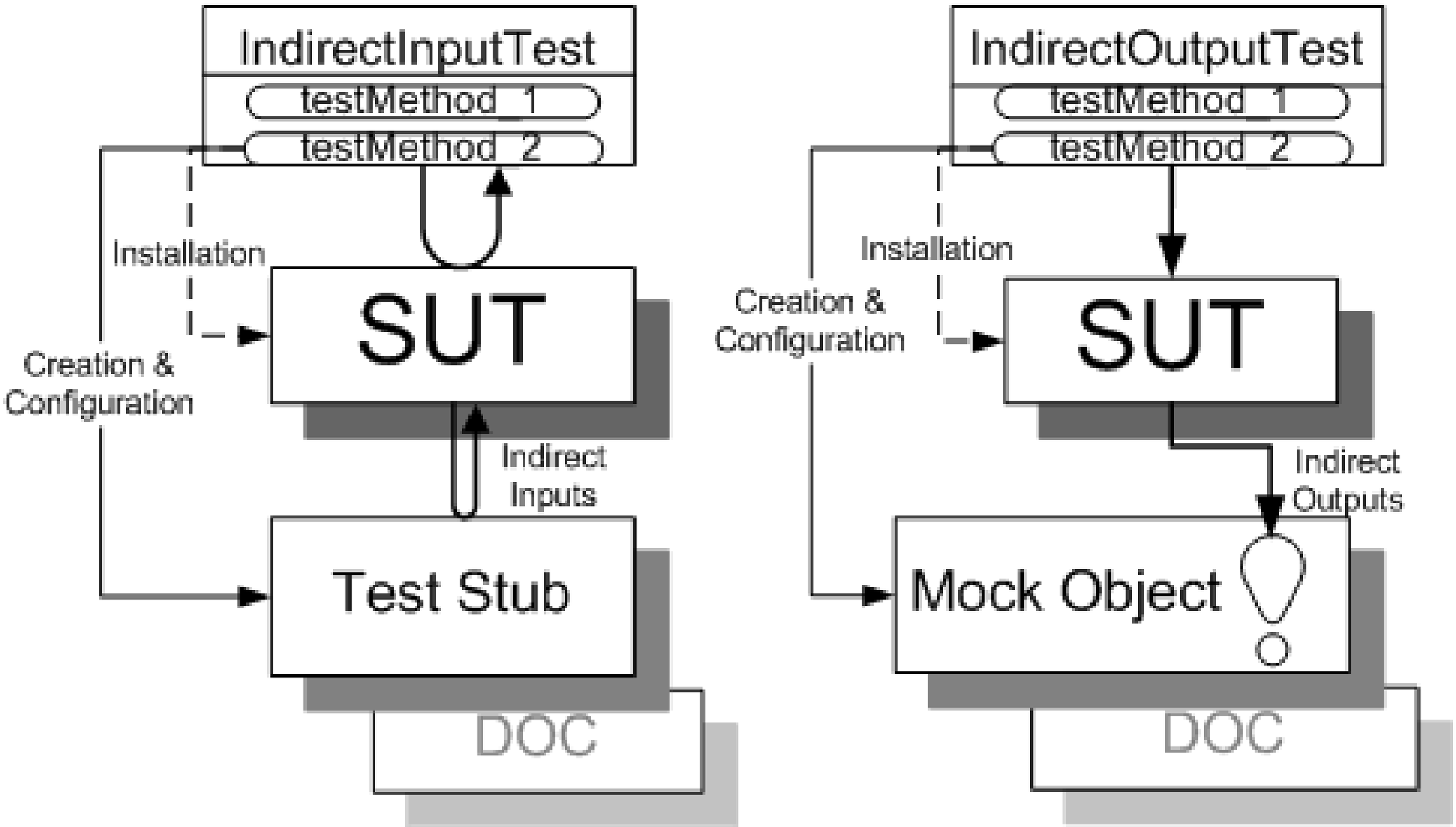
- **How can we verify logic independently when code it depends on is unusable?**
- **How can we avoid slow tests?**



- **How do we implement behavior verification for indirect outputs of the SUT?**



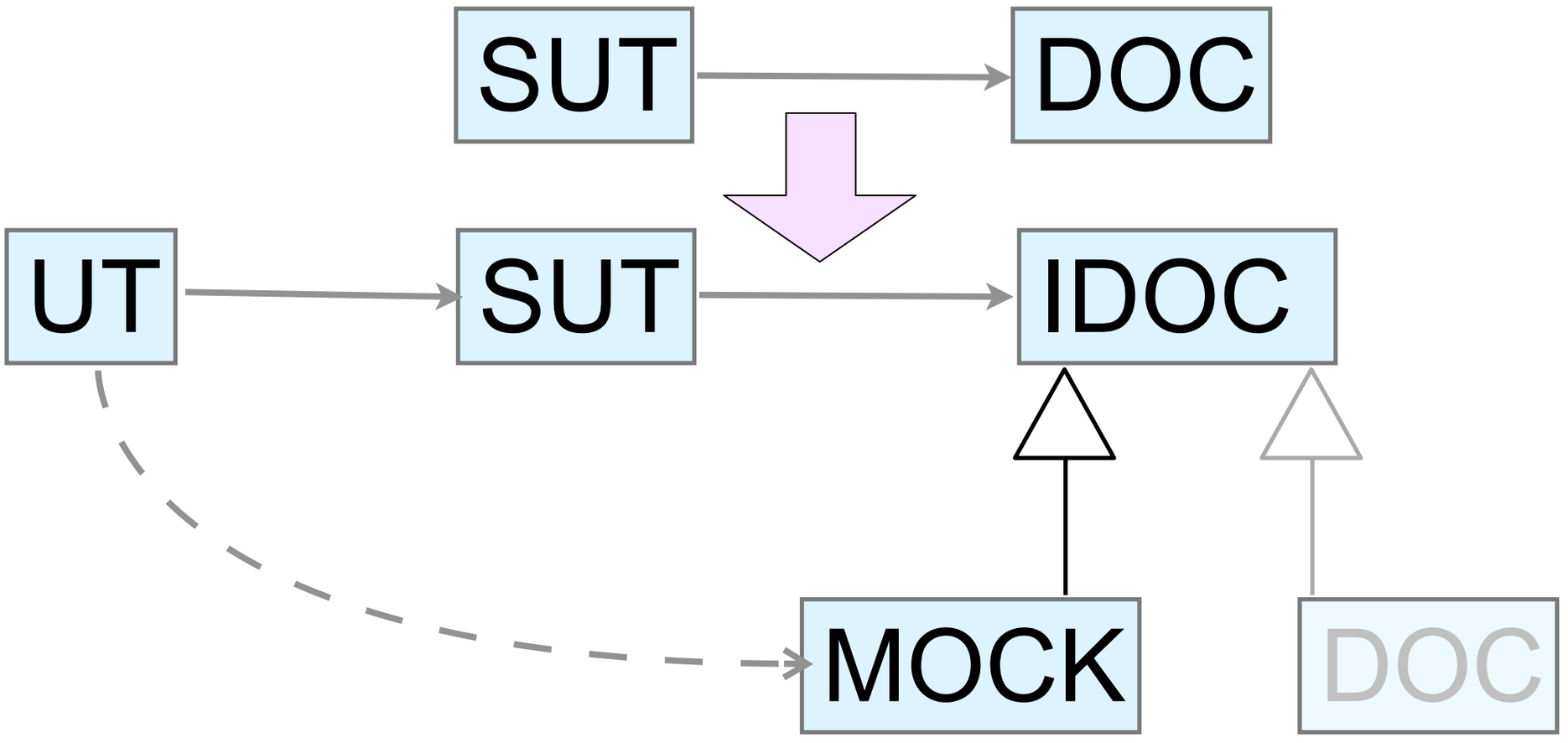
Difference between Test-Stub and Mock-Object



- **xunitpatterns.com**

Interface-oriented Mock

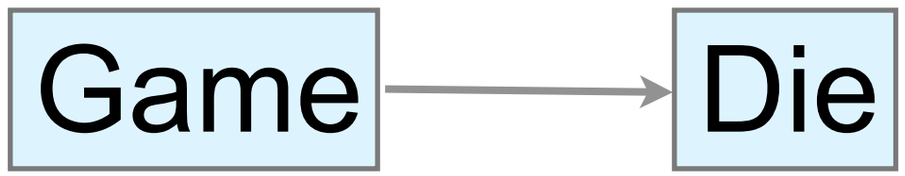
- **classic inheritance based mocking**
  - extract interface for DOC -> IDOC
  - make SUT use IDOC
  - create MOCK implementing IDOC and use it in UT



  - in C++ this means overhead for DOC (virtual functions)!

Demo/Exercise
Code in need for Mocking

- **A very simple game, roll dice, check if you've got 4 and you win, otherwise you loose.**



- **We want to test class Die first:**

```
#include <cstdlib>

struct Die
{
   int roll() { return rand()%6 + 1; }
};
```

How to test Game?


```
#include "Die.h"
class GameFourWins
{
   Die die;
public:
   GameFourWins();
   void play();
};
```

```
void GameFourWins::play(){
   if (die.roll() == 4) {
      cout << "You won!" << endl;
   } else {
      cout << "You lost!" << endl;
   }
}
```

```
#include "Die.h"
#include <iostream>

class GameFourWins
{
   Die die;
public:
   GameFourWins();
   void play(std::ostream &os = std::cout);
};
```

```
void GameFourWins::play(std::ostream &os){
   if (die.roll() == 4) {
      os << "You won!" << endl;
   } else {
      os << "You lost!" << endl;
   }
}
```

Test with a Mock ostream

- **We now can use a ostrstream to collect the output of play() and check that against an expected value:**

```
void testGame() {
   GameFourWins game;
   std::ostringstream os;
   game.play(os);
   ASSERT_EQUAL("You lost!\n",os.str());
}
```

- **What is still wrong with that test?**

Simulation Mocks
Interface-oriented

- **deliver predefined values**
  - we need that for our Die class
- **Introduce an Interface**

```
struct DieInterface
{
   virtual ~DieInterface(){}
   virtual int roll() =0;
};

struct Die: DieInterface
{
   int roll() { return rand()%6+1; }
};
```

- **now we need to adjust Game as well to use DieInterface& instead of Die**
- **Mockator Pro plug-in will make those code conversions automatic (Summer 2012)**

Simulation Mocks
preparing SUT

- **Changing the interface, need to adapt call sites**
- **theDie must live longer than Game object**

```
class GameFourWins
{
   DieInterface &die;
public:
   GameFourWins(DieInterface &theDie):die(theDie){}
   void play(std::ostream &os = std::cout);
};
```

- **now we can write our test using an alternative implementation of DieInterface**
- **would using pointer instead of reference improve situation? what's different?**

- **This way we can also thoroughly test the winning case:**

```
struct MockWinningDice:DieInterface{
   int roll(){return 4;}
};

void testWinningGame() {
   MockWinningDice d;
   GameFourWins game(d);
   std::ostringstream os;
   game.play(os);
   ASSERT_EQUAL("You won!\n",os.str());
}
```

A C++ alternative using templates

- **advantages: no virtual call overhead, no extra Interface extraction**
  - transformation provided by our "Introduce Typename Template Parameter" Refactoring
- **drawback: inline/export problem potential**

```
template <typename Dice=Die>
class GameFourWinsT
{
   Dice die;
public:
   void play(std::ostream &os = std::cout){
     if (die.roll() == 4) {
     os << "You won!" << std::endl;
     } else {
       os << "You lost!" << std::endl;
     }
   }
};
typedef GameFourWinsT<Die> GameFourWins;
```

Mock via template parameter

- **The resulting test looks like this:**

```
struct MockWinningDice{
   int roll(){return 4;}
};
void testWinningGame() {
   GameFourWins<MockWinningDice> game;
   std::ostringstream os;
   game.play(os);
   ASSERT_EQUAL("You won!\n",os.str());
}
```

- **should we also mock the ostream similarly?**

Call Tracing Mocks

- **We want also to count how often our dice are rolled. How to test this?**

```
struct MockWinningDice:DieInterface{
   int rollcounter;
   MockWinningDice():rollcounter(0){}
   int roll(){++rollcounter; return 4;}
};
void testWinningGame() {
   MockWinningDice d;
   GameFourWins game(d);
   std::ostringstream os;
   game.play(os);
   ASSERT_EQUAL("You won!\n",os.str());
   ASSERT_EQUAL(1,d.rollcounter);
   game.play(os);
   ASSERT_EQUAL(2,d.rollcounter);
}
```

Using C++ template Parameters for Mocking

- **C++ template parameters can be used for mocking without virtual member function overhead and explicit interface extraction.**
  - no need to pass object in as additional parameter
  - unfortunately no default template parameters for template functions (yet)
- **You can mock**
  - Member Variable Types
  - Function Parameter Types
- **Mocking without template inline/export need is possible through explicit instantiations**

Mockator Demo - Compile Seam using Templates

- **Extract Template Parameter**
  - part of CUTE plug-in
- **Use Template in Test**
  - introduce Mock object for DIE
    - create test double class...
    - add missing member function
    - implement test double code
- **Add Mock Object Support**
  - check for expected calls (C++11)
- **additional features**
  - dependency injection through
    - templates
    - abstract interface classes

```
void testWinningGame(){
    INIT_MOCKATOR();
    static std::vector<calls> allCalls(1);
    struct WinningDie
    {
        const int mock_id;
        WinningDie()
        :mock_id(++mockCounter_)
        {
            allCalls.push_back(calls());
            allCalls[mock_id].push_back(call{"WinningDie()"});
        }

        int roll() const
        {
            allCalls[mock_id].push_back(call{"roll() const"});
            return 4;
        }

    };
    GameT<WinningDie> game;
    ASSERTM("Winning Game", game.play());
    calls expected = {{"WinningDie()"}, {"roll() const"}};
    ASSERT_EQUAL(expected,allCalls[1]);
}
```

Mockator - Preprocessor Seam

- **mockator_malloc.h**

```
#ifndef MOCKATOR_MALLOC_H_
#define MOCKATOR_MALLOC_H_
#include <cstdlib >
int mockator_malloc(size_t size, const char *fileName, int lineNumber);
#define malloc(size_t size) mockator_malloc((size),__FILE__,__LINE__)
#endif
```

- **mockator_malloc.c**

```
#include "mockator_malloc.h"
#undef malloc
int mockator_malloc(size_t size, const char * fileName, int lineNumber) {
//TODO your tracing code here
   return malloc(size);
}
```

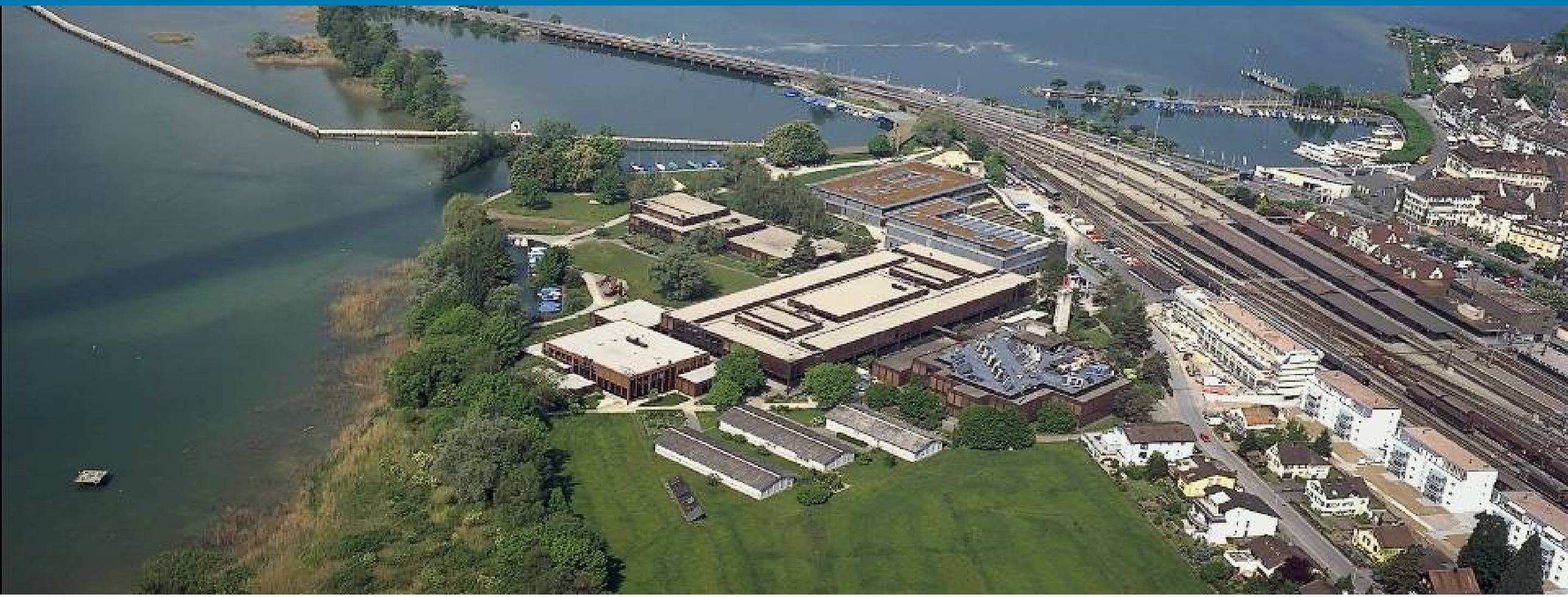
- **Generating trace functions like this one is easy: Ctrl+Alt+T (on Linux)**
  - Mockator passes mockator_malloc.h to the GNU compiler by using its -include option

Mockator - Link Seam - Shadowing & Wrapping Library Functions

- **Shadowing on Linux only using GCC Linker**
- **Allows wrapping of functions in shared libraries**
  - Both Linux and MacOS X supported
- **Mockator does all the hard work like**
  - creating a shared library project,
  - adding dependencies to the dl library,
  - creating run-time configurations with the following env values, etc.,
    - Linux: LD PRELOAD=libName.so MacOS X:
    - DYLD FORCE FLAT NAMESPACE=1
    - DYLD INSERT LIBRARIES=libName.dylib

```
int foo(int i) {
  static void *gptr = nullptr;
  if(!gptr)  gptr = dlsym(RTLD_NEXT,"_Z3fooi");
  typedef int (*fptr)(int);
  fptr  my_fptr = reinterpret_cast<fptr>(gptr);
  // TODO  put your code here
  return my_fptr(i);
}
```

Questions ?



- http://cute-test.com - Unit Testing
- http://mockator.com - Seams and Mocks
- http://linticator.com - Lint Integration
- http://includator.com - #include optimization
- http://sconsolidator.com - SCons integration

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