Testing Compile-time Constructs Within a Runtime Unit Testing Framework

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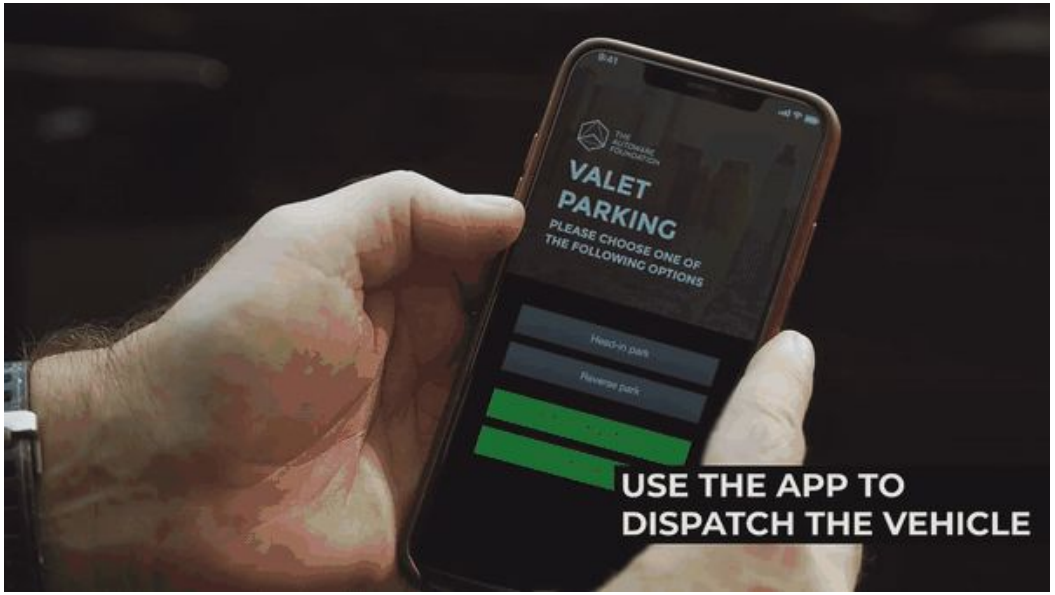
We use C++ (14) for safety-critical applications that we deliver to our customers



Errors have a high cost, so rigorous testing is a must

We use increasingly more compile-time polymorphism and checks

Question: how to test if something is compilable in a rigorous way?

Imagine designing a user-facing API

```
float get_half_of(float smth) {
  return smth / 2.0F;
}
```

Maybe a bit more generic

```
template<
  class T,
  class = std::enable_if_t<std::is_floating_point_v<T>>>
T get_half_of(T smth) {
  return smth / T{2};
}
```

Write a rigorous testing suite

```
#include <gtest/gtest.h>

TEST(TestMyApi, Halving) {
  EXPECT_FLOAT_EQ(21.0F, get_half_of(42.0F));
  EXPECT_DOUBLE_EQ(21.0, get_half_of(42.0));
}
```

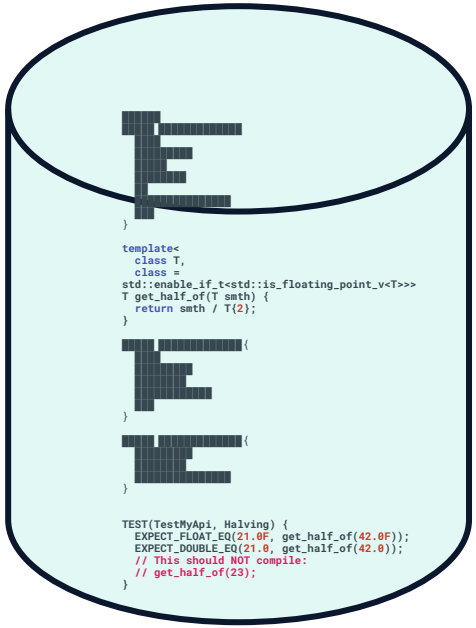
Even leave a helpful comment

```
#include <gtest/gtest.h>

TEST(TestMyApi, Halving) {
  EXPECT_FLOAT_EQ(21.0F, get_half_of(42.0F));
  EXPECT_DOUBLE_EQ(21.0, get_half_of(42.0));
  // This should NOT compile:
  // get_half_of(23);
}
```

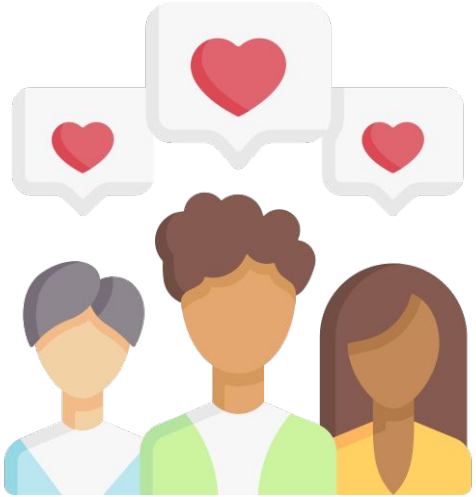
Now throw it into the rest of the code base

```
[redacted]
[redacted]{
  [redacted]
  [redacted]
  [redacted]
  [redacted]
  [redacted]
  [redacted]
  [redacted]
}

template<
  class T,
  class = std::enable_if_t<std::is_floating_point_v<T>>>
T get_half_of(T smth) {
  return smth / T{2};
}

[redacted] [redacted]{
  [redacted]
  [redacted]
  [redacted]
  [redacted]
  [redacted]
}

[redacted] [redacted]{
  [redacted]
  [redacted]
  [redacted]
  [redacted]
}

TEST(TestMyApi, Halving) {
  EXPECT_FLOAT_EQ(21.0F, get_half_of(42.0F));
  EXPECT_DOUBLE_EQ(21.0, get_half_of(42.0));
  // This should NOT compile:
  // get_half_of(23);
}
```

And deliver it to the customers



```
}

template<
  class T,
  class =
std::enable_if_t<std::is_floating_point_v<T>>>
T get_half_of(T smth) {
  return smth / T{2};
}

}

}


TEST(TestMyApi, Halving) {
  EXPECT_FLOAT_EQ(21.0F, get_half_of(42.0F));
  EXPECT_DOUBLE_EQ(21.0, get_half_of(42.0));
  // This should NOT compile:
  // get_half_of(23);
}
```



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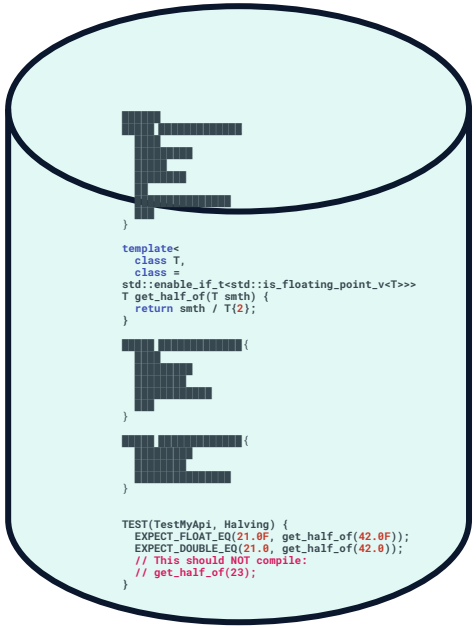
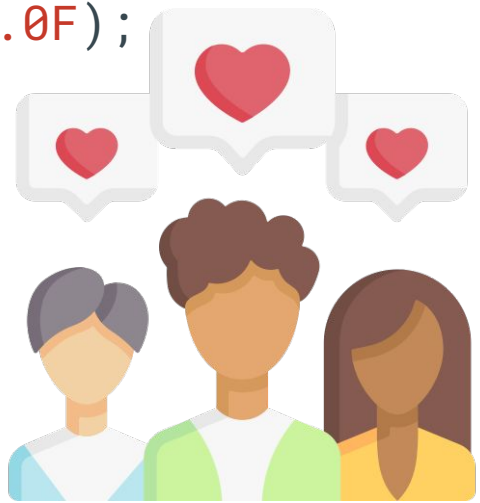
Correct requests get correct responses




```
float a = get_half_of(23.0F);
```

11.5F



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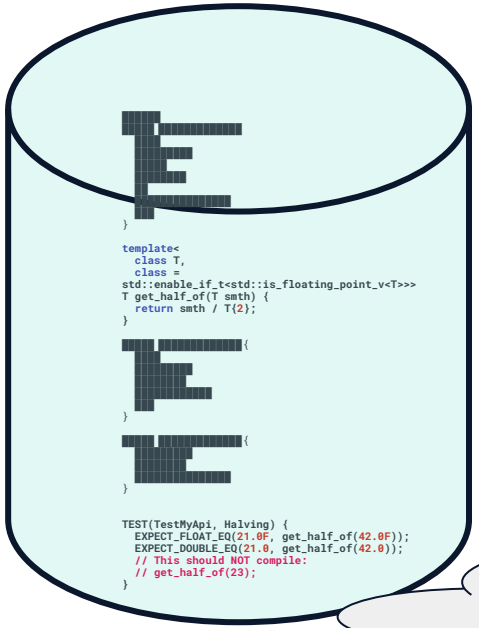
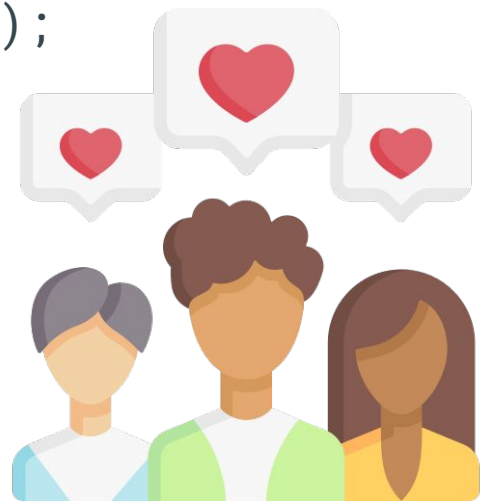
Wrong requests cause a compilation error




```
float a = get_half_of(23);
```

Compilation error



```
std::enable_if_t<
  std::is_floating_point_v<T>>
```

Code has a tendency to evolve with time

```
template<
  class T,
  class = std::enable_if_t<std::is_floating_point_v<T>>>
T get_half_of(T smth) {
  return smth / T{2};
}
```

image: Flaticon.com

Code has a tendency to evolve with time

```
template<
  class T,
  class = std::enable_if_t<std::is_floating_point_v<T>>>
T get_half_of(T smth) {
  return smth / T{2};
}
```

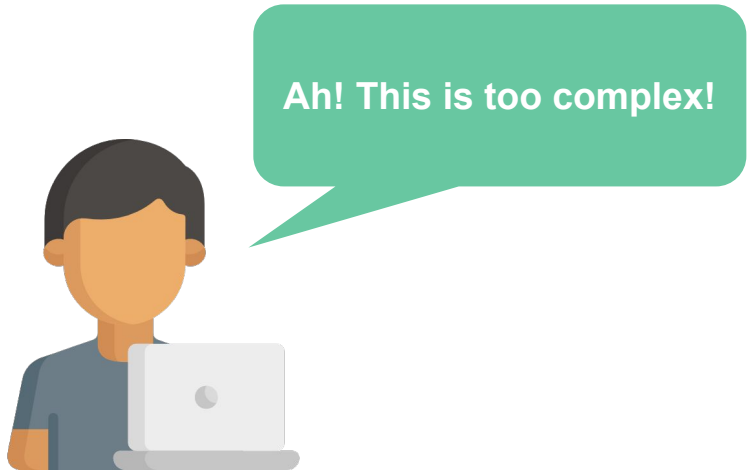


image: Flaticon.com

Code has a tendency to evolve with time

```
template<
  class T,
  class = std::enable_if_t<std::is_floating_point_v<T>>>
T get_half_of(T smth) {
  return smth / T{2};
}
```

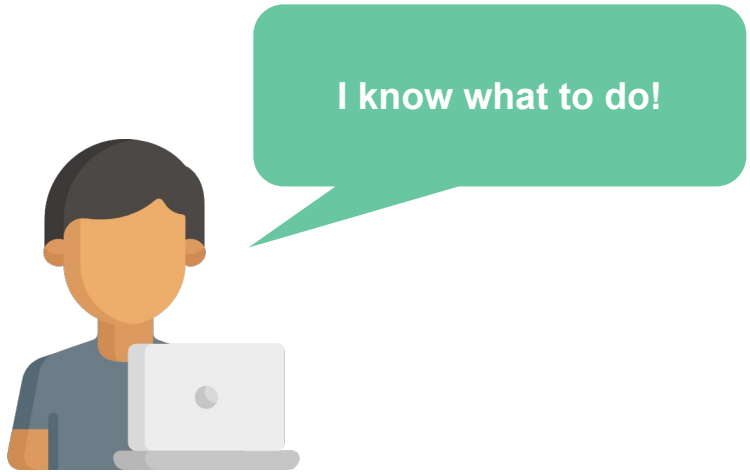


image: Flaticon.com

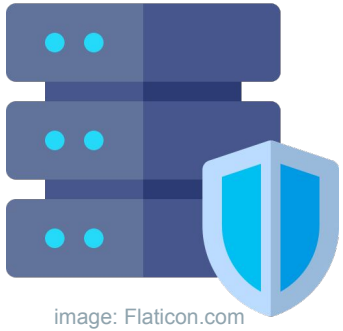
Code has a tendency to evolve with time

```
template<class T>
T get_half_of(T smth) {
  return smth / T{2};
}
```

image: Flaticon.com

The code passes all checks and lands to the customer instance

commit
&
push



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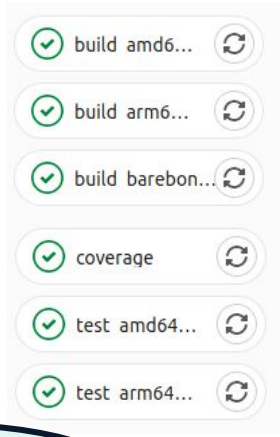
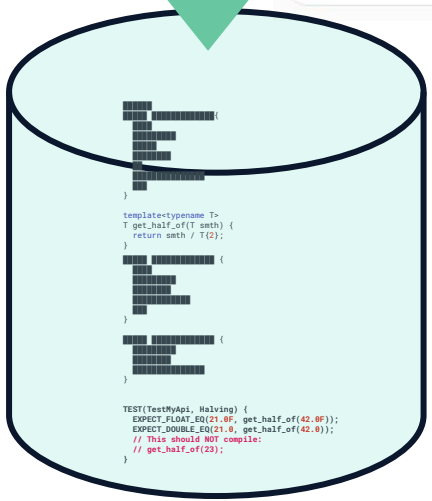
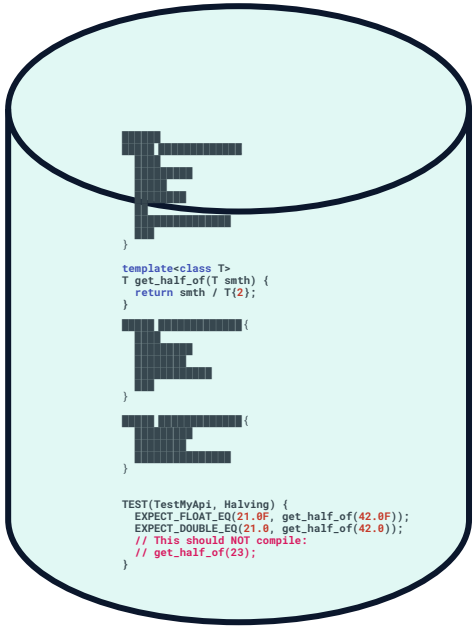
CI passes



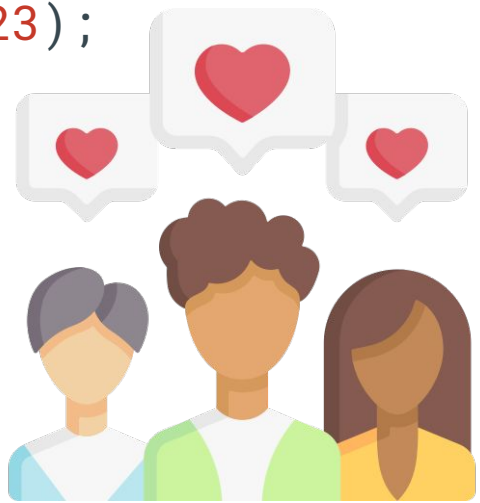


```
template<class T>
T get_half_of(T smth) {
  return smth / T{2};
}
```

After some time customers use the API




```
float a = get_half_of(23);
```



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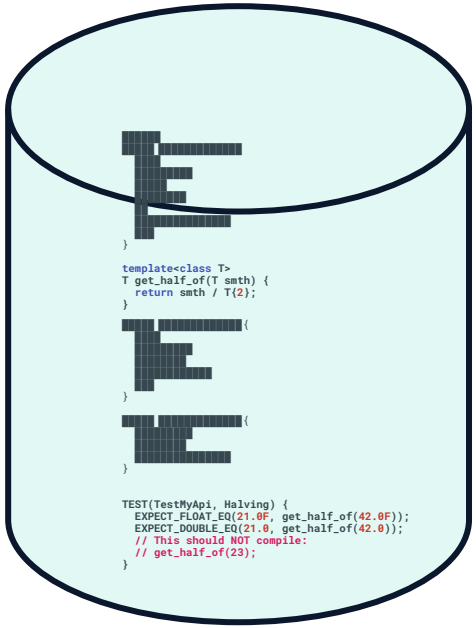
And receive a wrong response




```
float a = get_half_of(23);
```

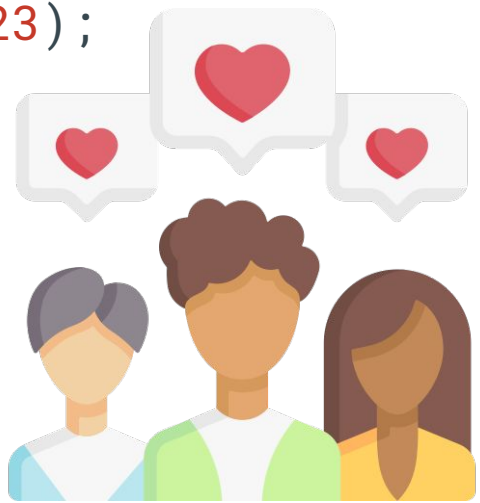


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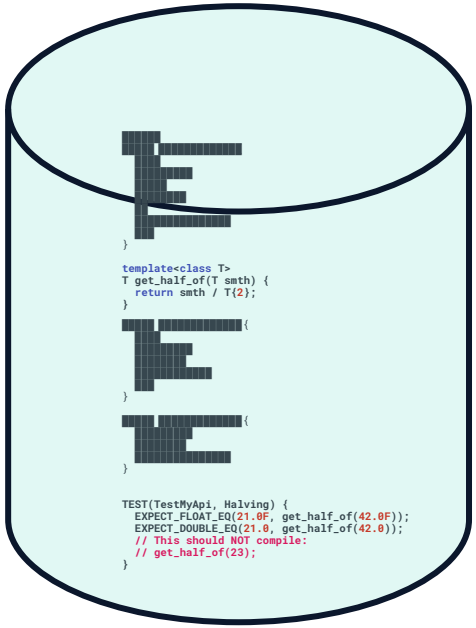
Image: Flaticon.com

```
return smth / T{2};
```

And they spend two weeks debugging the failure




```
float a = get_half_of(23);
```

11.0F

image: Flaticon.com

What went wrong? What can we do about it?

- We were relying on the code not being able to compile
- We missed the change at which the unwanted code started compiling
- Why did our test suite not help us?

```
#include <gtest/gtest.h>

TEST(TestMyLib, Halving) {
  EXPECT_FLOAT_EQ(21.0F, get_half_of(42.0F));
  EXPECT_DOUBLE_EQ(21.0, get_half_of(42.0));
  // This should NOT compile:
  // get_half_of(23);
}
```

What went wrong? What can we do about it?

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```
#include <gtest/gtest.h>

TEST(TestMyLib, Halving) {
  EXPECT_FLOAT_EQ(21.0F, get_half_of(42.0F));
  EXPECT_DOUBLE_EQ(21.0, get_half_of(42.0));
  // This should NOT compile:
  // get_half_of(23);
}
```

Would be really cool to enforce and test this!

We can do better!

```
#include <gtest/gtest.h>


TEST(TestMyLib, Halving) {
  EXPECT_FLOAT_EQ(21.0F, get_half_of(42.0F));
  EXPECT_DOUBLE_EQ(21.0, get_half_of(42.0));
  // This should NOT compile:
  // get_half_of(23);
}
```

STATIC_TEST and SHOULD_NOT_COMPILE to the rescue!

```
#include <gtest/gtest.h>
#include <static_test/static_test.h>

TEST(TestMyLib, Halving) {
  EXPECT_FLOAT_EQ(21.0F, get_half_of(42.0F));
  EXPECT_DOUBLE_EQ(21.0, get_half_of(42.0));
}

STATIC_TEST(Halving) {
  SHOULD_NOT_COMPILE(get_half_of(23));
}
```

STATIC_TEST output when our bug is present

```
[----------] 1 test from StaticTest__Halving
[ RUN      ] StaticTest__SomeTest.Halving
[ COMPILE STATIC TEST ] Halving
ERROR: my_api/test_halving.cpp:35: must fail to compile.
my_api/test_halving.cpp:0: Failure
Some of the static tests failed. See above for error.
[              FAILED ] Halving
[  FAILED  ] StaticTest__Halving.Halving (1403 ms)
[----------] 1 test from StaticTest__SomeTest (1403 ms)
```

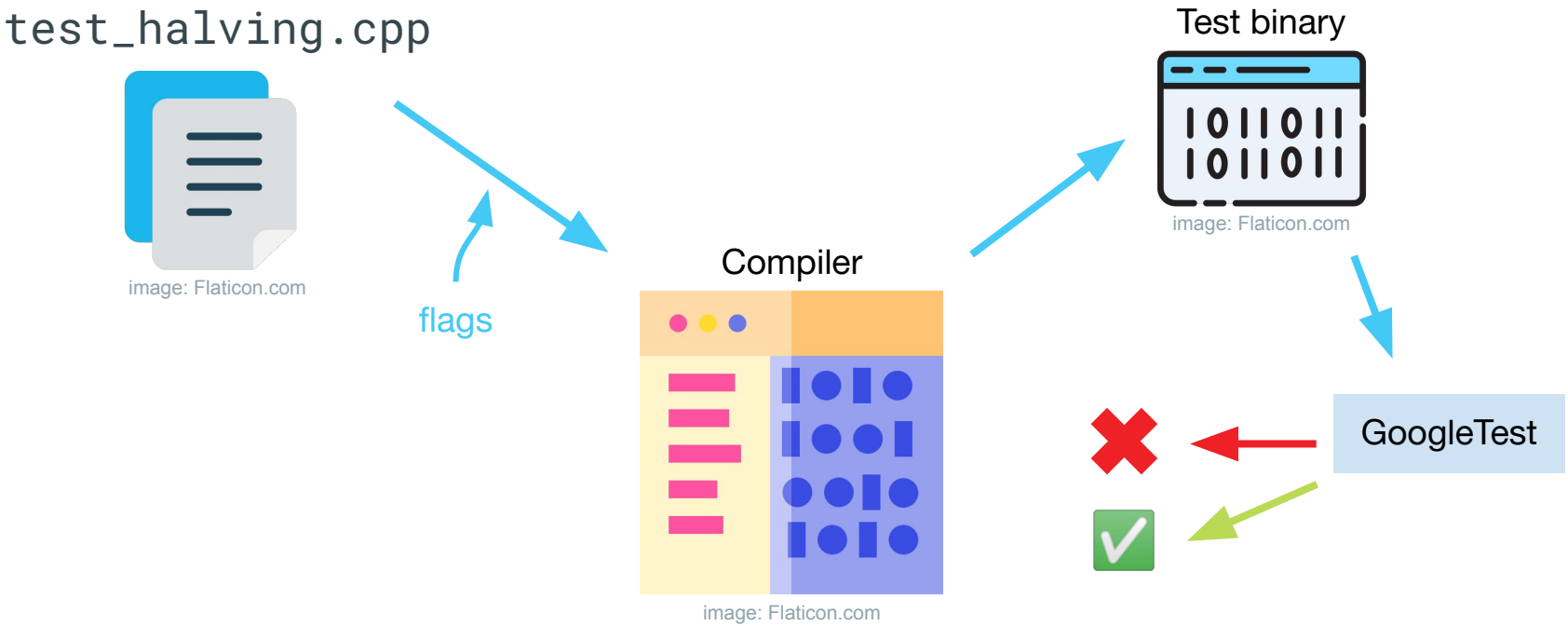
STATIC_TEST output when our bug is present

```
[----------] 1 test from StaticTest__Halving
[ RUN      ] StaticTest__SomeTest.Halving
[ COMPILE STATIC TEST ] Halving
ERROR: my_api/test_halving.cpp:35: must fail to compile.
my_api/test_halving.cpp:0: Failure
Some of the static tests failed. See above for error.
[              FAILED ] Halving
[  FAILED  ] StaticTest__Halving.Halving (1403 ms)
[----------] 1 test from StaticTest__SomeTest (1403 ms)
```

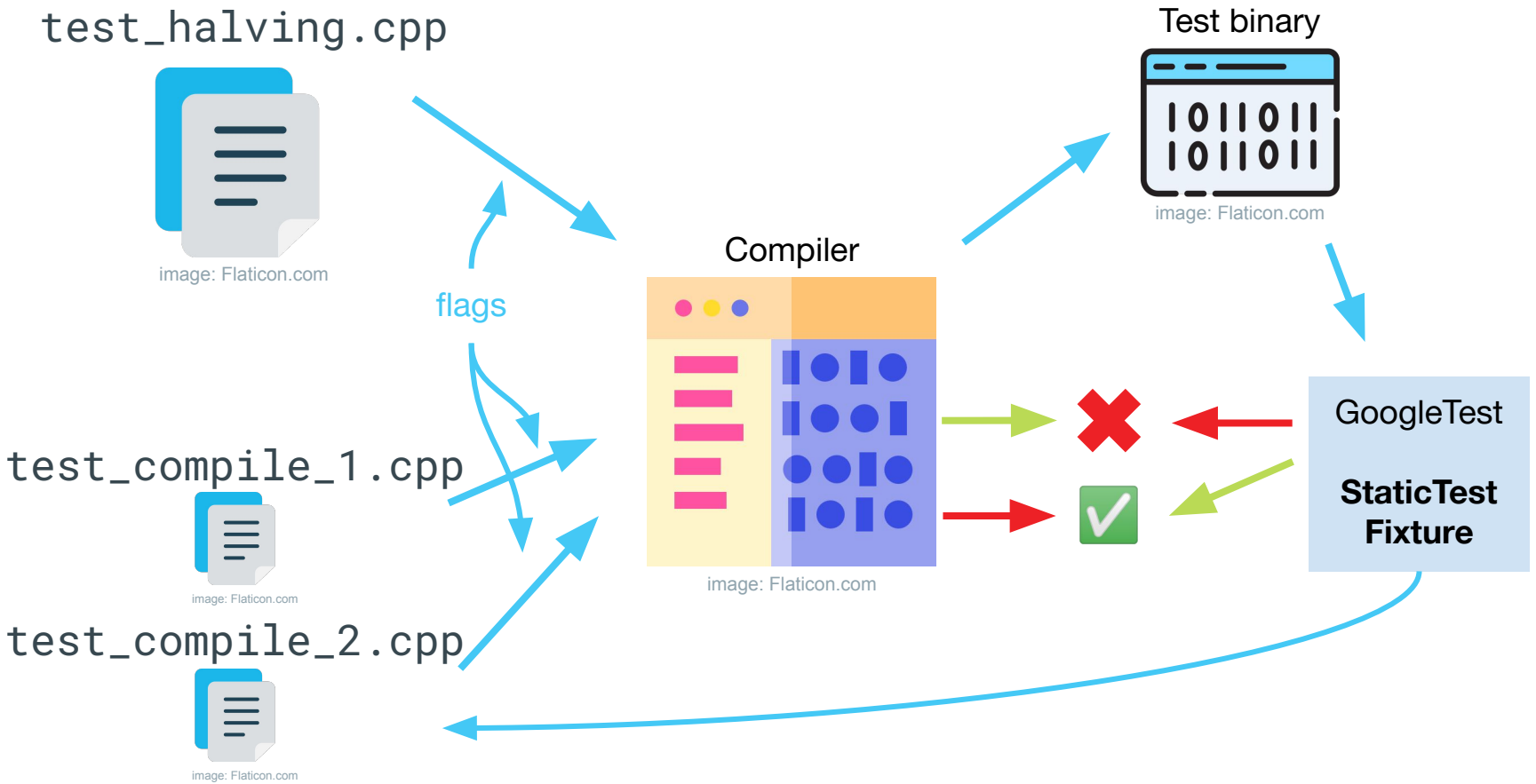
Once we fix the bug this is what we expect to see

```
[----------] 1 test from StaticTest__Halving
[ RUN      ] StaticTest__Halving.Halving
[ COMPILE STATIC TEST ] Halving
[                   OK ] Halving
[       OK ] StaticTest__Halving.Halving (966 ms)
[----------] 1 test from StaticTest__Halving (966 ms total)
```

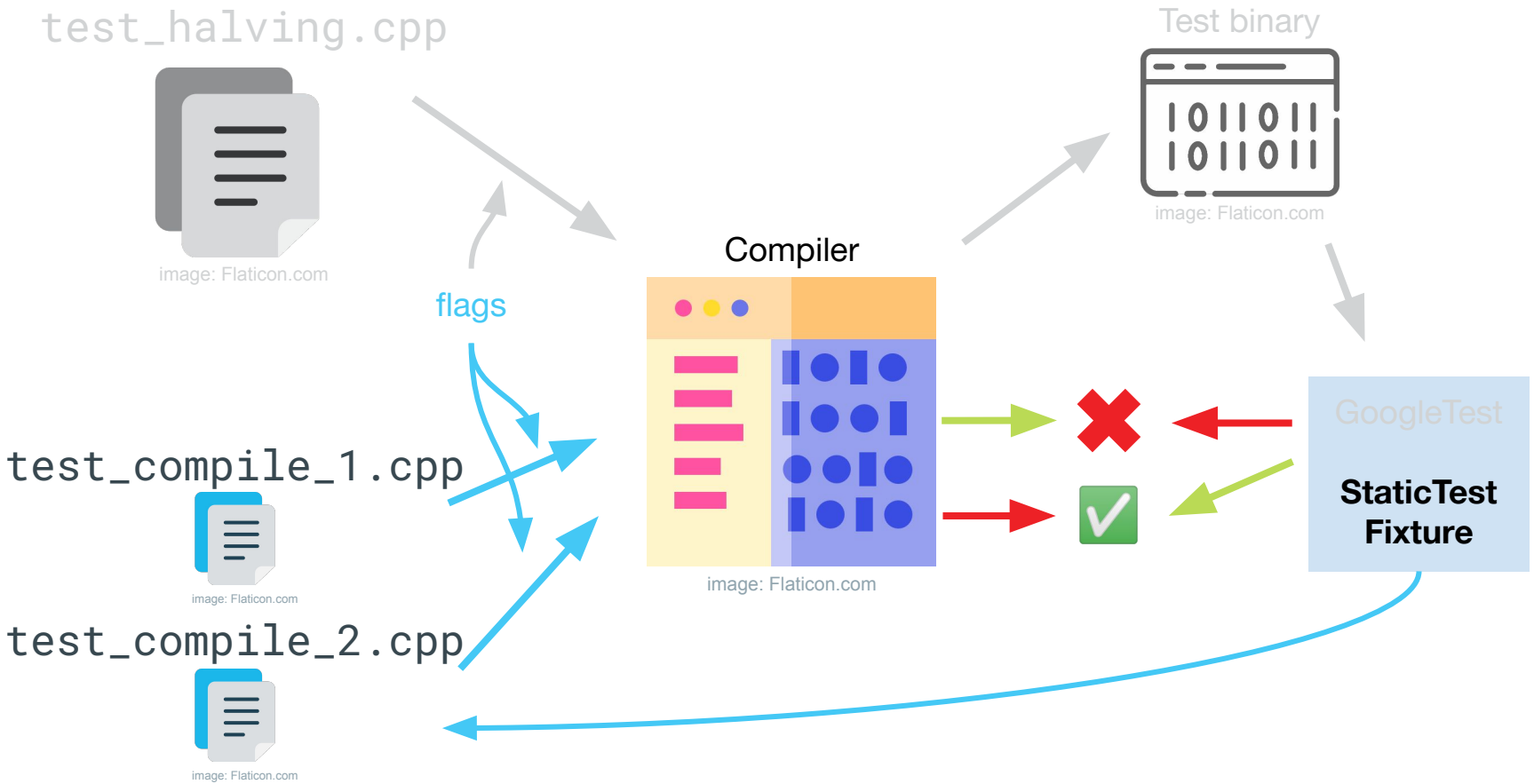
Standard testing pipeline



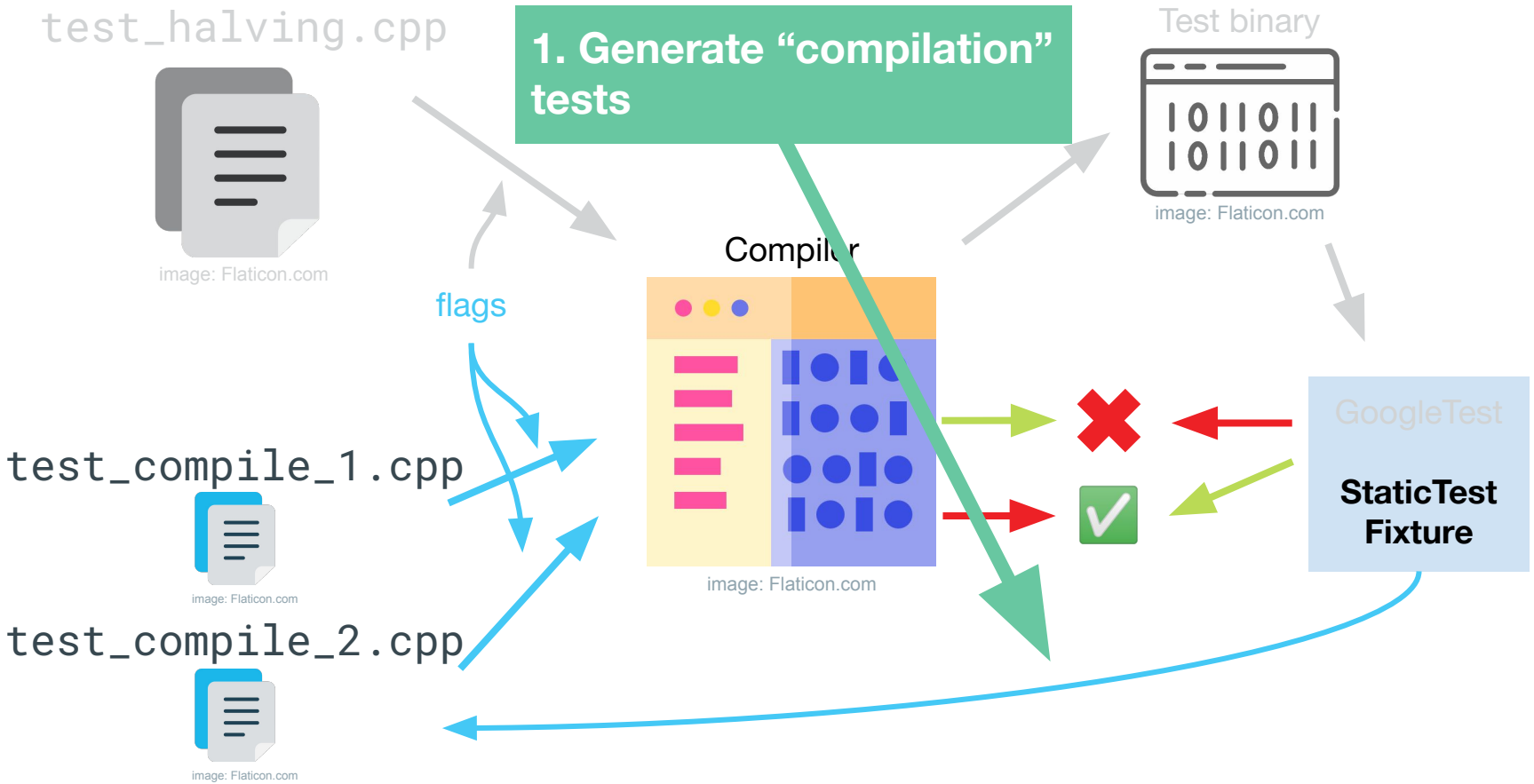
Proposed testing pipeline



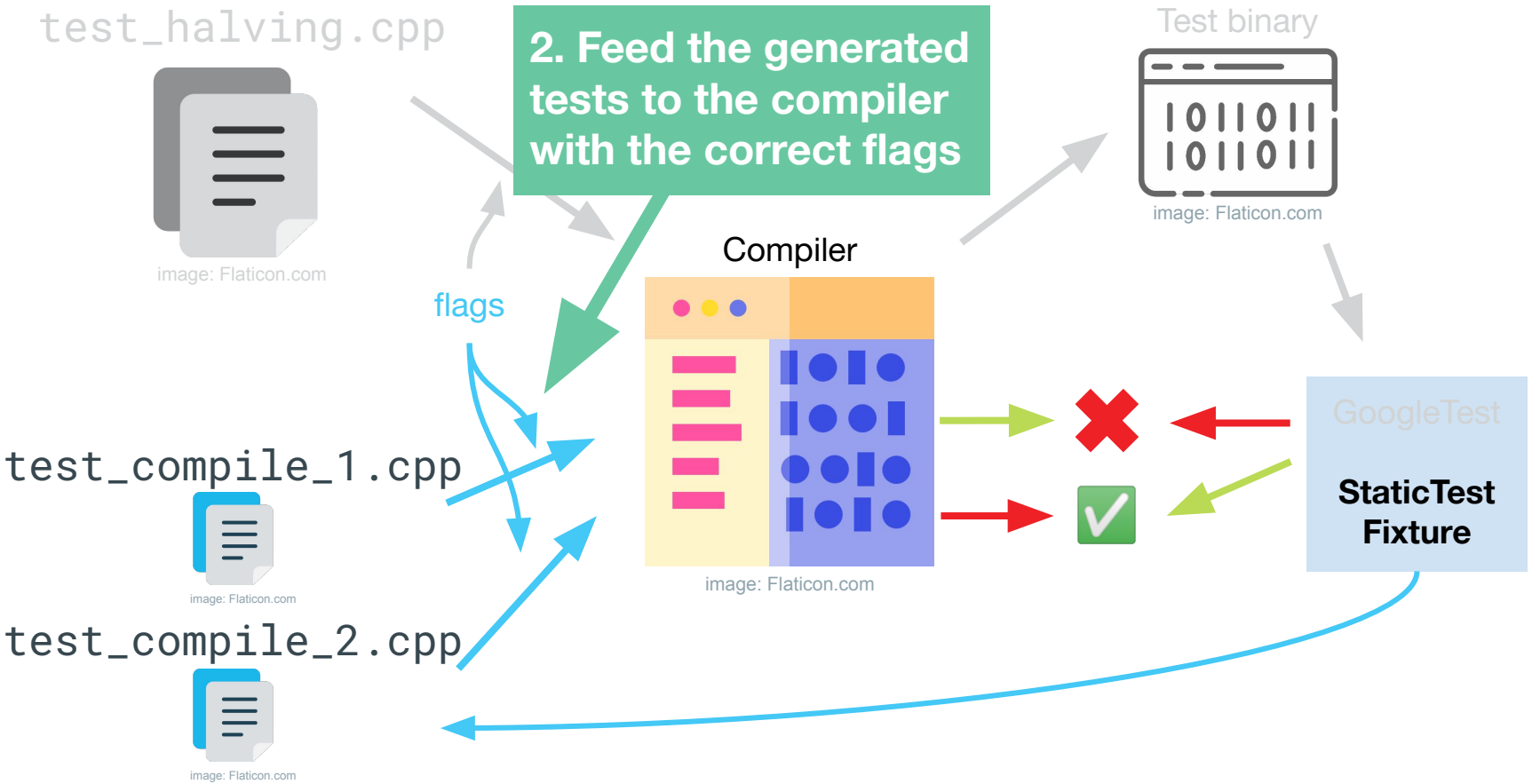
Things our library does



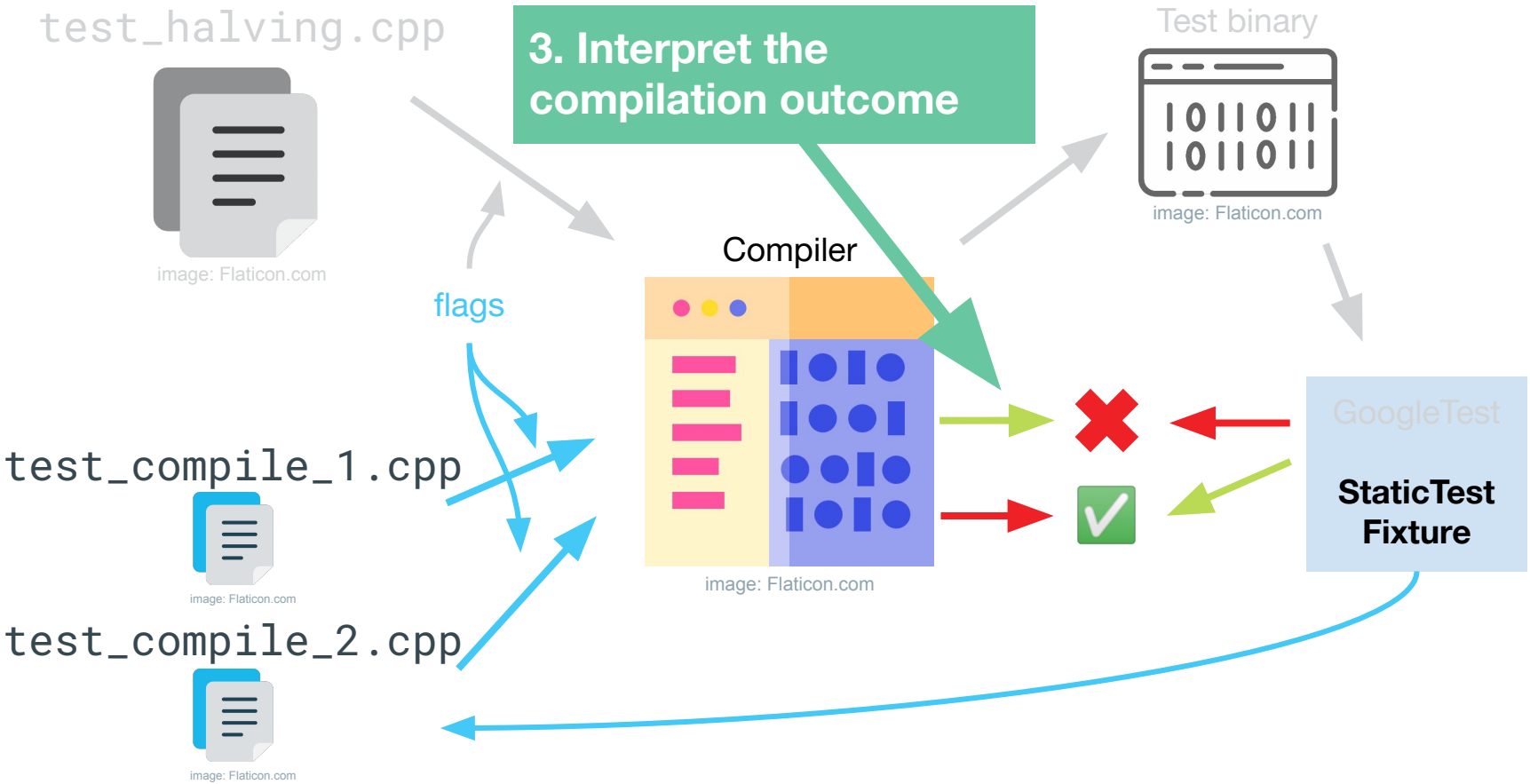
Things our library does



Things our library does



Things our library does



Integrate with the existing flow

- Build upon GoogleTest library by using a custom fixture
- Introduce the following macros:
  - `STATIC_TEST(foo) {}`
  - `SHOULD_NOT_COMPILE(code);`
  - `SHOULD_NOT_COMPILE_WITH_MESSAGE(code, message);`
- These macros hide calls to custom scripts that do all the work
- These scripts generate custom test files, feed them to the compiler and interpret the compilation results

STATIC_TEST
SHOULD_NOT_COMPILE
SHOULD_NOT_COMPILE_WITH_MESSAGE

```
#define STATIC_TEST(NAME)                                                    \
  class StaticTest__##NAME : public StaticTest {                             \
  public:                                                                    \
    StaticTest__##NAME() noexcept : StaticTest{#NAME, __FILE__} {}           \
  };                                                                         \
  /* Create a test that uses this fixture and wraps the user code.*/         \
  TEST_F(StaticTest__##NAME, NAME)

#define SHOULD_NOT_COMPILE(IGNORED_CODE)

#define SHOULD_NOT_COMPILE_WITH_MESSAGE(IGNORED_CODE, IGNORED_MESSAGE)
```

STATIC_TEST
SHOULD_NOT_COMPILE
SHOULD_NOT_COMPILE_WITH_MESSAGE

```
#define STATIC_TEST(NAME)                                                    \
  class StaticTest__##NAME : public StaticTest {                             \
  public:                                                                    \
    StaticTest__##NAME() noexcept : StaticTest{#NAME, __FILE__} {}           \
  };                                                                         \
  /* Create a test that uses this fixture and wraps the user code.*/         \
  TEST_F(StaticTest__##NAME, NAME)

#define SHOULD_NOT_COMPILE(IGNORED_COD

#define SHOULD_NOT_COMPILE_WITH_MESSAG
```

Our custom `GoogleTest` fixture that hides the code to generate, compile, run the compilability tests and interpret the compilation results

STATIC_TEST
SHOULD_NOT_COMPILE
SHOULD_NOT_COMPILE_WITH_MESSAGE

```
#define STATIC_TEST(NAME)                                                    \
  class StaticTest__##NAME : public StaticTest {                             \
  public:                                                                    \
    StaticTest__##NAME() noexcept : StaticTest{#NAME, __FILE__} {}           \
  };                                                                         \
  /* Create a test that uses this fixture and wraps the user code.*/         \
  TEST_F(StaticTest__##NAME, NAME)

#define SHOULD_NOT_COMPILE(IGNORED_CODE)

#define SHOULD_NOT_COMPILE_WITH_MESSAGE(IGNORED_CODE, IGNORED_MESSAGE)
```

STATIC_TEST
SHOULD_NOT_COMPILE
SHOULD_NOT_COMPILE_WITH_MESSAGE

```
#define STATIC_TEST(NAME)                                                    \
  class StaticTest__##NAME : public StaticTest {                             \
  public:                                                                    \
    StaticTest__##NAME() noexcept : StaticTest{#NAME, __FILE__} {}           \
  };                                                                         \
  /* Create a test that uses this fixture and wraps the user code.*/         \
  TEST_F(StaticTest__##NAME, NAME)

#define SHOULD_NOT_COMPILE(IGNORED_CODE)

#define SHOULD_NOT_COMPILE_WITH_MESSAGE(IGNORED_CODE, IGNORED_MESSAGE)
```

Our custom `StaticTest` fixture

```
class StaticTest : public ::testing::Test {
 public:
  StaticTest(const string &name, const string &file) {
    const auto cmd = "command " + name + " " + file;
    const auto exit_status = std::system(cmd.c_str());
    if (exit_status != 0) {
      GTEST_MESSAGE_AT_(file_.c_str(), 0,
        "Some of the static tests failed. See above.",
        ::testing::TestPartResult::kNonFatalFailure);
    }
  }
};
```

Our custom `StaticTest` fixture

```
class StaticTest : public ::testing::Test {
 public:
  StaticTest(const string &name, const string &file) {
    const auto cmd = "command " + name + " " + file;
    const auto exit_status = std::system(cmd.c_str());
    if (exit_status != 0) {
      GTEST_MESSAGE_AT_(file_.c_str(), 0,
        "Some of the static test
        ::testing::TestPartResu
    }
  }
};
```

Construct a command string to call the external script

Our custom `StaticTest` fixture

```
class StaticTest : public ::testing::Test {
 public:
  StaticTest(const string &name, const string &file) {
    const auto cmd = "command " + name + " " + file;
    const auto exit_status = std::system(cmd.c_str());
    if (exit_status != 0) {
      GTEST_MESSAGE_AT_(file_.c_str(), 0,
        "Some of the static tests failed. See above.",
        ::testing::TestPartResu                      );
    }
  }
};
```

Run the external script

Our custom `StaticTest` fixture

```
class StaticTest : public ::testi
 public:
  StaticTest(const string &name,
    const auto cmd = "command " + name +
    const auto exit_status = std::system(cmd.c_str());
    if (exit_status != 0) {
      GTEST_MESSAGE_AT_(file_.c_str(), 0,
        "Some of the static tests failed. See above.",
        ::testing::TestPartResult::kNonFatalFailure);
    }
  }
};
```

If the command failed - insert a GoogleTest error that will be shown to the user

Let’s talk about that external script

- We use an external script that gets called from the fixture
- This script does the following:
  a. parses the original test file as text
  b. generates new test files from `STATIC_TEST`s in the original test file
  c. gets proper flags for the original test file
  d. feeds the generated test files to the compiler
  e. interprets the results and returns an error code to the fixture
- The script can be written in any language as long as it can be called from within our `StaticTest` fixture

Let’s look at a concrete example

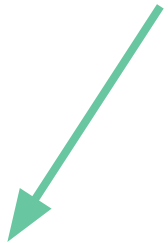
```
#include <gtest/gtest.h>
#include "foo/foo.h"

STATIC_TEST(Halving) {
  SHOULD_NOT_COMPILE(get_half_of(23));
  SHOULD_NOT_COMPILE_WITH_MESSAGE(
    get_half_of(”23”),
    "no matching function for call");
}
```

Copy everything not within a STATIC_TEST to all generated files

```
#include <gtest/gtest.h>
#include "foo/foo.h"

STATIC_TEST(Halving) {
  SHOULD_NOT_COMPILE(get_half_of(23));
  SHOULD_NOT_COMPILE_WITH_MESSAGE(
    get_half_of("23"),
    "no matching function for call");
}
```

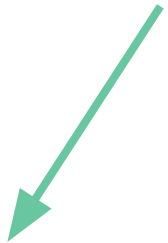


```
#include <gtest/gtest.h>
#include "foo/foo.h"
```

Each STATIC_TEST generates a main function

```
#include <gtest/gtest.h>
#include "foo/foo.h"

STATIC_TEST(Halving) {
  SHOULD_NOT_COMPILE(get_half_of(23));
  SHOULD_NOT_COMPILE_WITH_MESSAGE(
    get_half_of("23"),
    "no matching function for call");
}
```



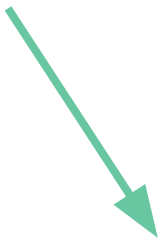
```
#include <gtest/gtest.h>
#include "foo/foo.h"
int main() {


}
```

Each SHOULD_NOT_COMPILE is copied to a new file

```
#include <gtest/gtest.h>
#include "foo/foo.h"

STATIC_TEST(Halving) {
  SHOULD_NOT_COMPILE(get_half_of(23));
  SHOULD_NOT_COMPILE_WITH_MESSAGE(
    get_half_of("23"),
    "no matching function for call");
}
```



```
#include <gtest/gtest.h>
#include "foo/foo.h"
int main() {
  get_half_of(23);
  return 0;
}
```

```
#include <gtest/gtest.h>
#include "foo/foo.h"
int main() {
  get_half_of("23");
  return 0;
}
```

Feed the generated files to the compiler

Compiler

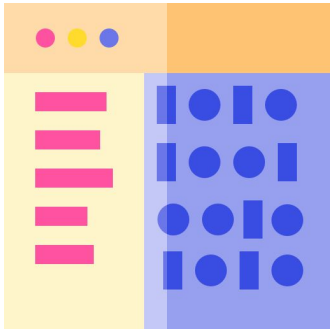


image: Flaticon.com

Our library compiles the generated files and parses the compilation result

test_compile_1.cpp

```
#include <gtest/gtest.h>
#include "foo/foo.h"
int main() {
  get_half_of(23);
  return 0;
}
```

test_compile_2.cpp

```
#include <gtest/gtest.h>
#include "foo/foo.h"
int main() {
  get_half_of("23");
  return 0;
}
```

How to get proper compilation flags?

- Compilation highly depends on the compilation flags provided by the user
- We derive the compilation flags for the generated files from the original test file in which the `STATIC_TEST`s are written
- We will compile all the generated files with the same set of flags
- There are 2 broad ways of how to get flags:
  - By using strings stored in the original test binary compiled with `-frecord-gcc-switches`
  - By parsing a compilation database that can be generated on the fly or beforehand

Interpreting the compilation results

- The script passes files to the compiler and receives the compilation output
- For `SHOULD_NOT_COMPILE`:
  - If compilation is successful - **fail** the `STATIC_TEST` and print the line of code in the original test file to notify the user
  - If compilation fails - print the `STATIC_TEST` **success** message
- For `SHOULD_NOT_COMPILE_WITH_MESSAGE`:
  - If compilation is successful - **fail** the `STATIC_TEST` and print the line of code in the original test file to notify the user
  - If compilation fails check that the output matches a specified pattern:
    - If pattern matches - the `STATIC_TEST` is **successful**
    - If not - the static test has **failed**

Summary

- We can test the compilability of the code
- We must use the compiler in the loop
- We integrate with GoogleTest library to run our tooling
- We generate custom tests that compile generated code
  - If this compilation succeeds the static test fails
  - If this compilation fails the static test succeeds
- Most of the functionality lives in an external script called by a fixture
- This allows catching bugs that were impossible to catch before
- The final product is more safe to use
- A proof of concept implementation is incoming

Questions?

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