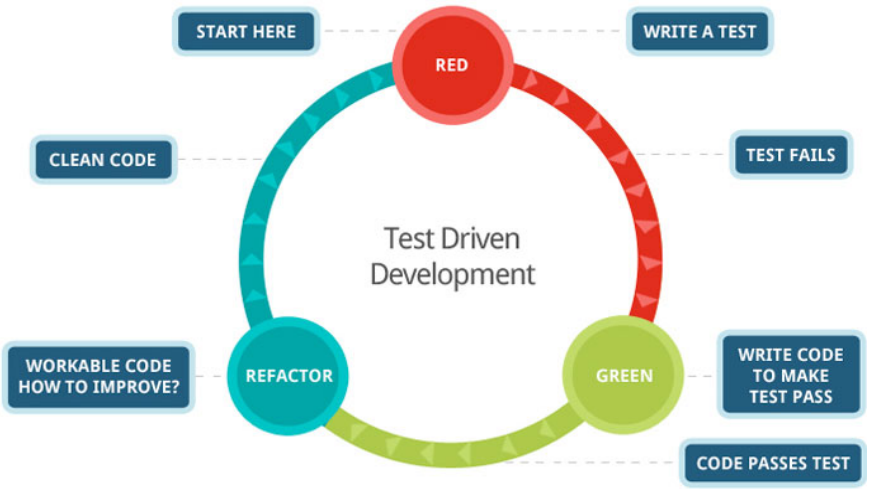
Test-driven development

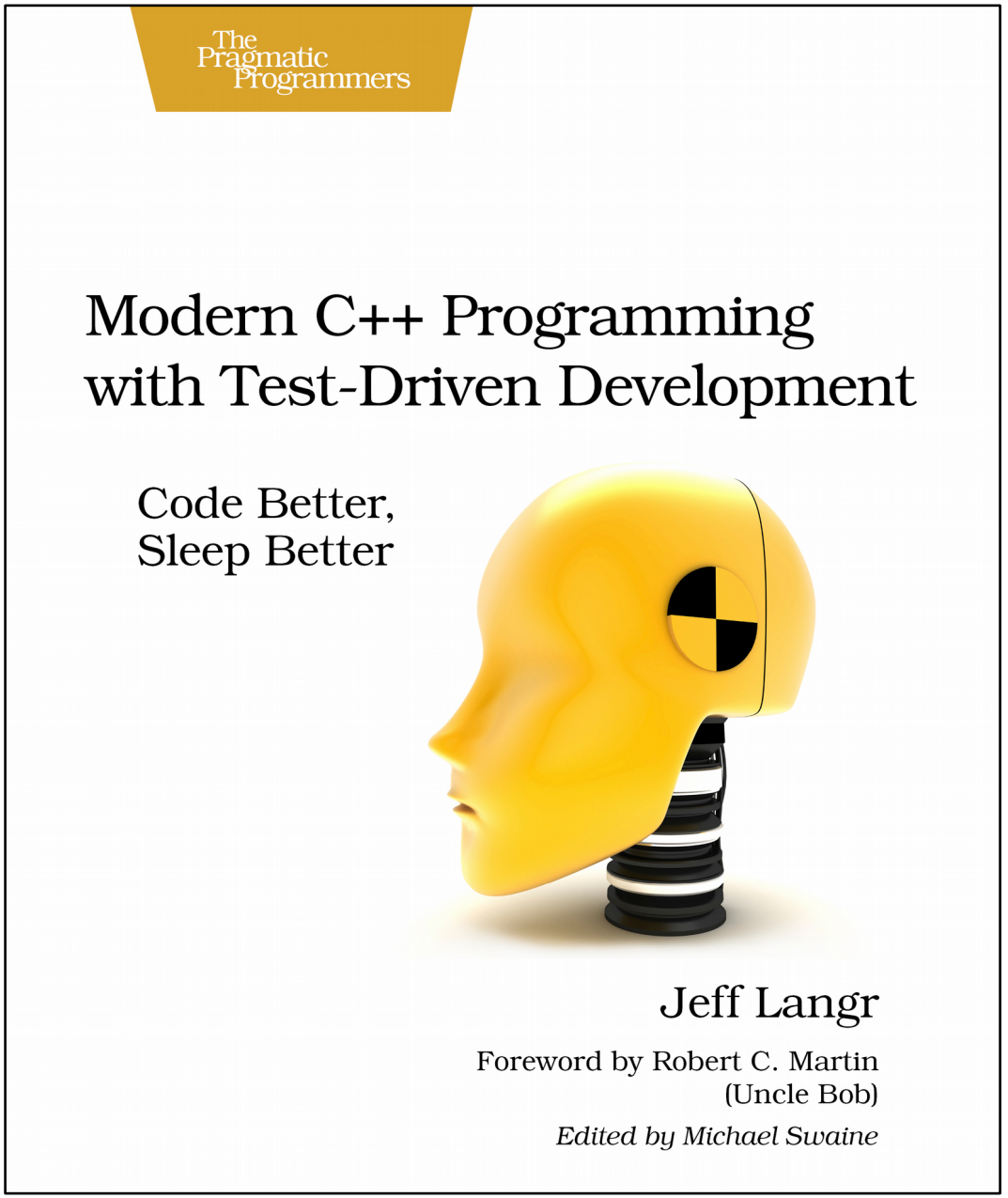
Richèl Bilderbeek



GitHub http://github.com/richelbilderbeek/CppPresentations

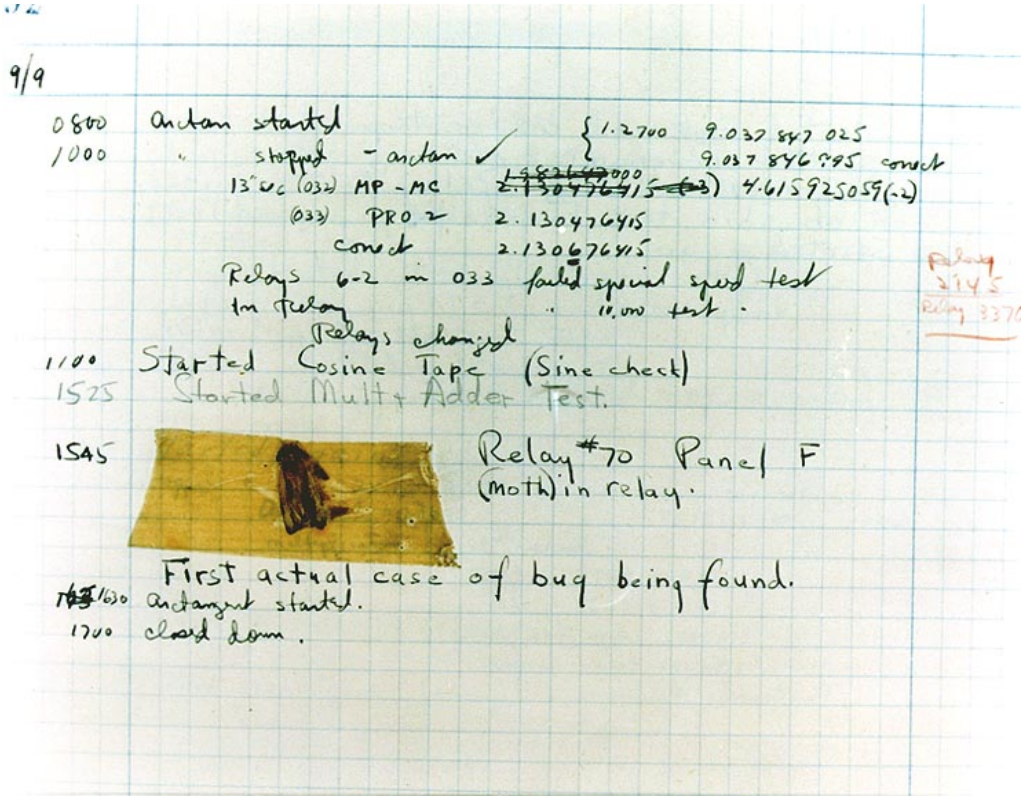
What is test-driven development?

- Developing code with the right amounts of tests



Why tests?

- Goal: code without bugs
- Untested code easily develops an error
- Code that cannot be tested has more errors

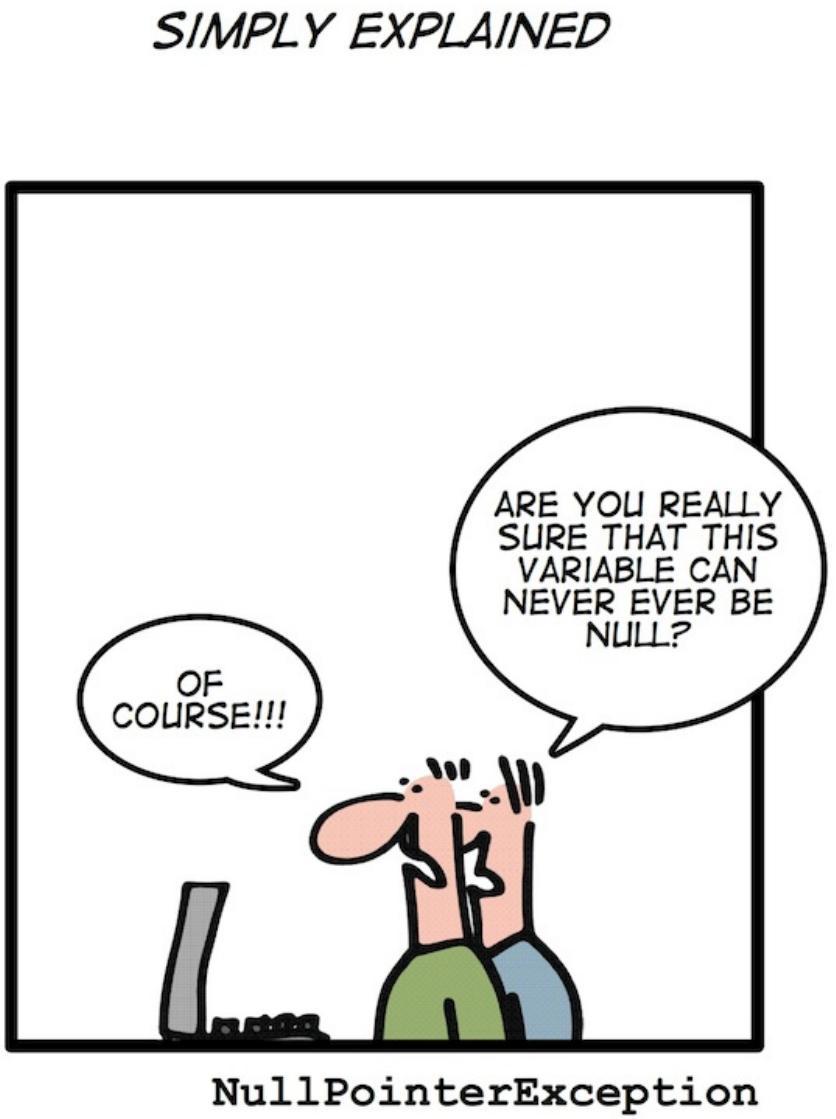


How much tests?

- “Testing can be used to show the presence of errors, never their absence!” Edsger Dijkstra
- Too few: many errors are not discovered
- Too much: many correctnesses are checked multiple times
- What is the balance?

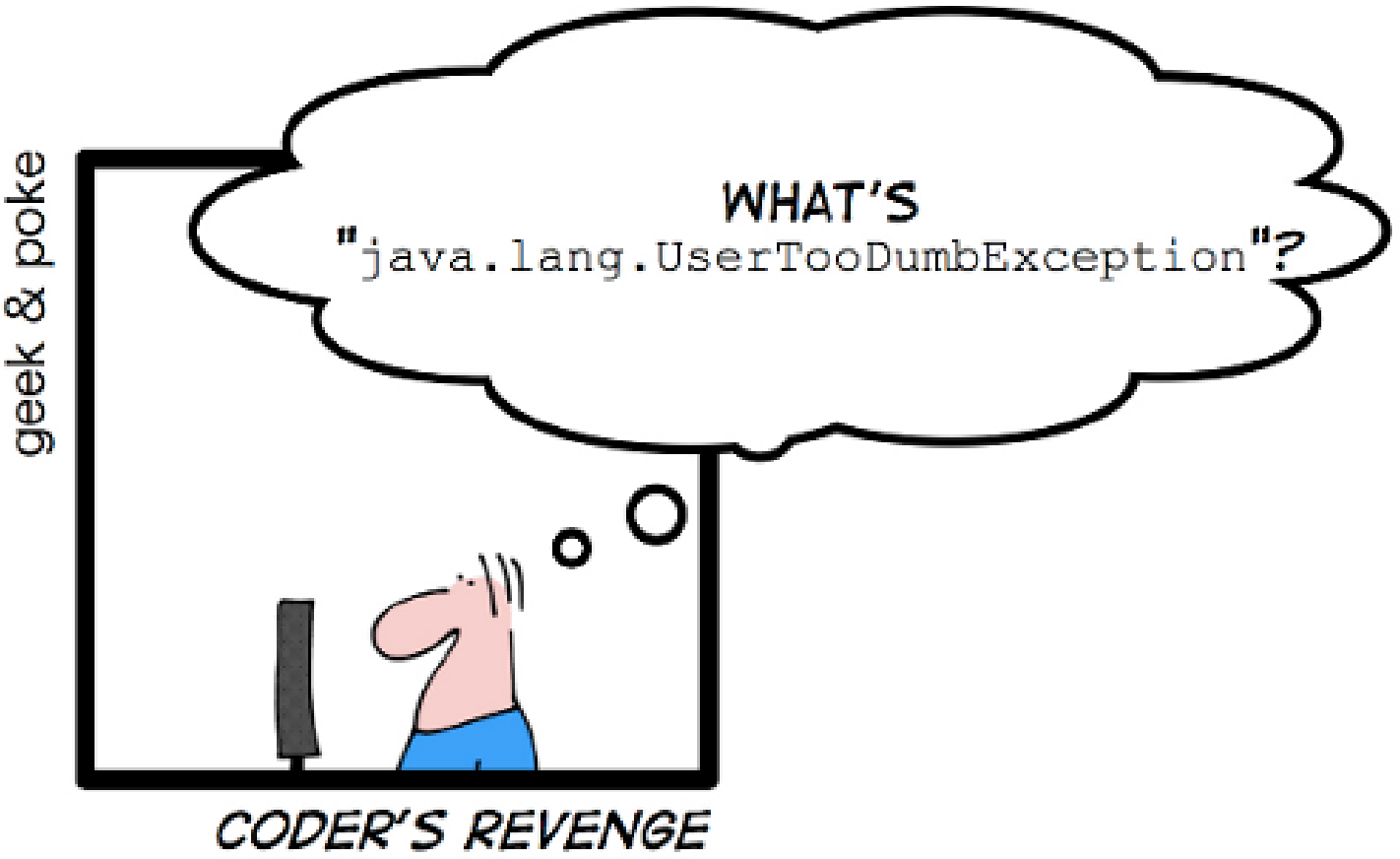
What is an error?

- Logic error
  - The programmer makes an incorrect reasoning
  - Example: a division by zero
- Runtime error
  - Hardware encounters a limit
  - Example: memory is full



What is not an error?

- The user gives incorrect/nonsense input
- Example: a command that does not exist



Logic error

- The programmer makes an incorrect reasoning
- Example: a function that returns the wrong answer
- Test:
  - call the function with different arguments
  - see if it returns the expected results

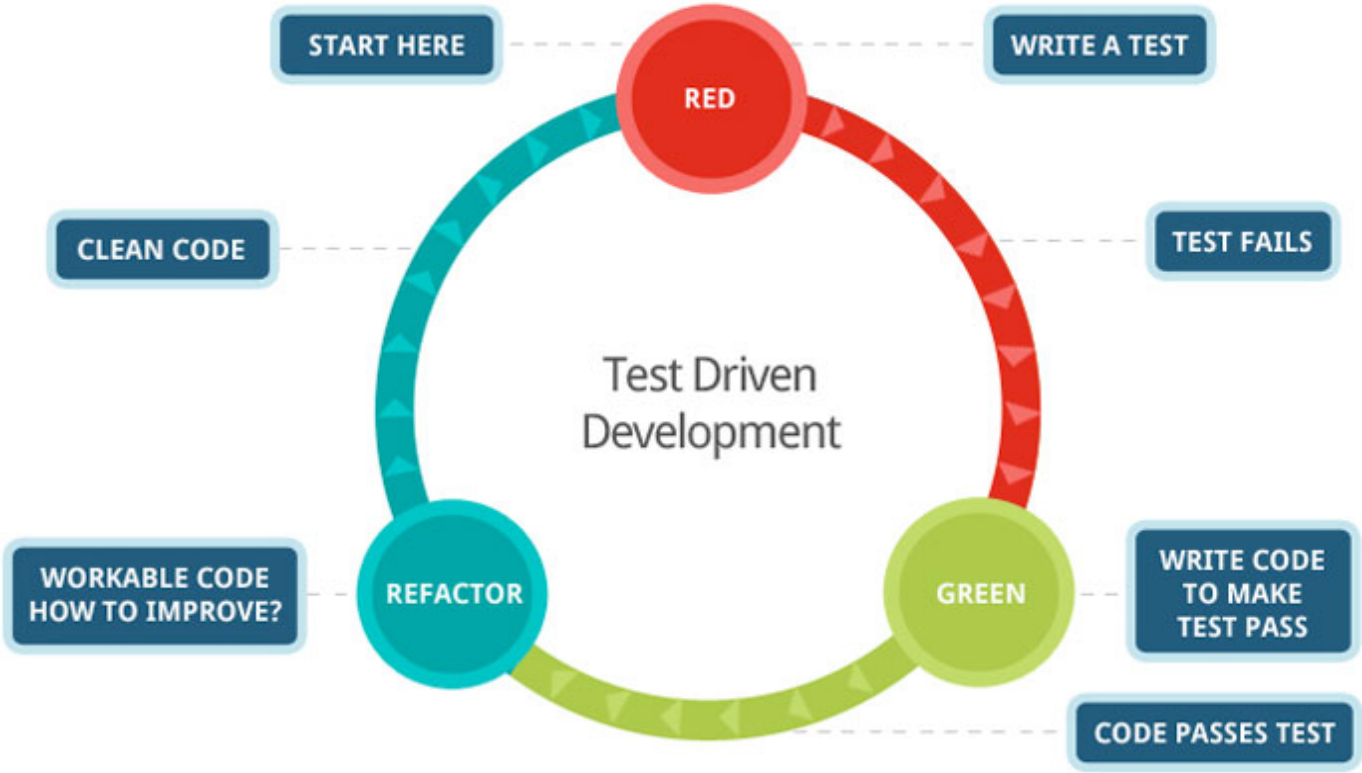
Example

```
bool IsPrime(const int x)
{
  /* calculation */
  /* return true or false */
}
```


```
IsPrime <- function(x)
{
  # calculation
  # return TRUE or FALSE
}
```

Developing IsPrime

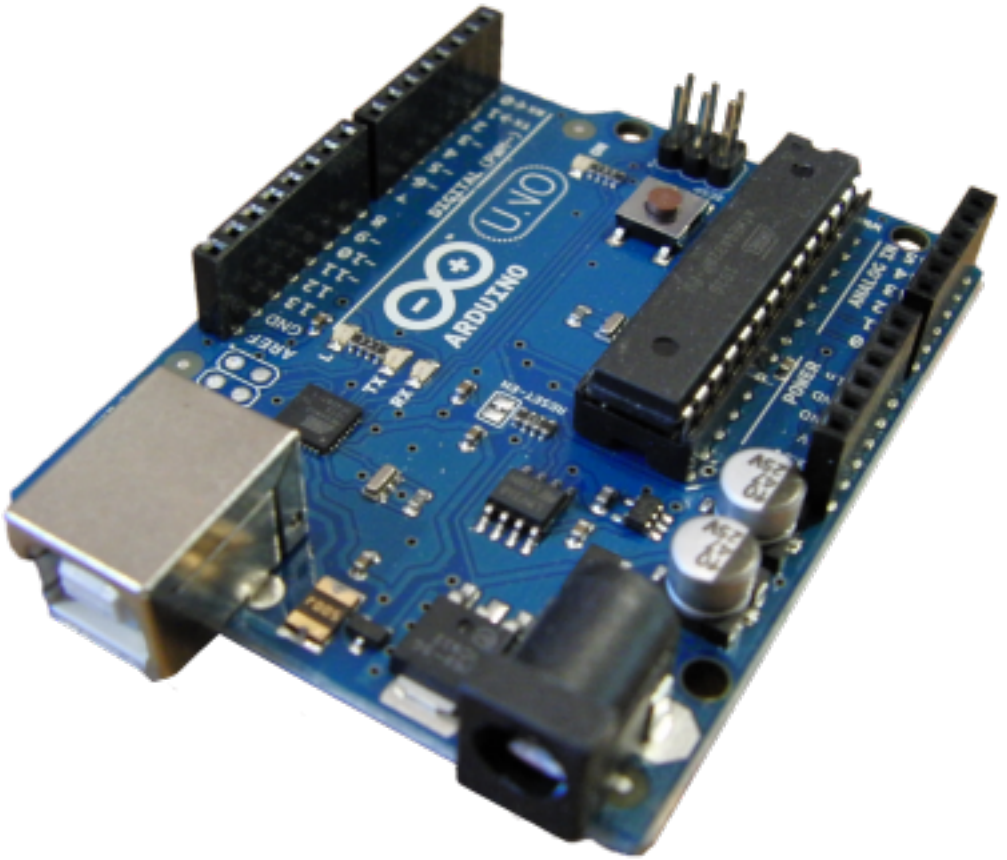
- Cycle test-driven development:
  - Red: write a test that fails
  - Green: pass the test
  - Refactor: improve the new code, clean up mess, check in code



Development IsPrime

- As small steps as possible
- One step at a time

C++ on Arduino



Testing environment Arduino

```
void setup()
{
  Serial.begin(9600);
  if (/* */) {
    Serial.println(“Test failed!”);
  }
}
```

Red: write a test that fails

```
void setup() {
  Serial.begin(9600);
  if (!IsPrime(2)) {
    Serial.println(
      “Two must be prime”
    );
  }
}
```

Green: pass the test

```
bool IsPrime(const int x) {
  return true;
}

void setup() {
  Serial.begin(9600);
  if (!IsPrime(2)) {
    Serial.println("Two must be prime");
  }
}
```

Refactor

- Checking in

```
git add --all :/
git commit -m
   "IsPrime: 2 is prime"
```

Red: write a test that fails

```
void setup() {
  // Previous code
  if (IsPrime(4)) {
    Serial.println(
      “Four is not prime”
    );
  }
}
```

Green: pass the test

```
bool IsPrime(const int x) {
  for (int i=2; i!=x; ++i)
  {
    if (x % i == 0) return false;
  }
  return true;
}


void setup() { /* */ }
```

Refactor

- Check in

```
git add --all :/
git commit -m
   "IsPrime: 4 is not prime"
```

Red: write a test that fails

```
void setup() {
  // Previous code
  if (IsPrime(1)) {
    Serial.println(
      “One is not prime”
    );
  }
}
```

Green: pass the test

```
bool IsPrime(const int x) {
   if (x == 1) return false;
   // rest of the code
}
```

Refactor

- Check in

```
git add --all :/
git commit -m
   “IsPrime: 1 is not prime”
```

Red: write a test that fails

```
void setup() {
  // Previous code
  if (IsPrime(0)) {
    Serial.println(
      “Zero is not prime”
    );
  }
}
```

Green: pass the test

```
bool IsPrime(const int x) {
   if (x <= 1) return false;
   // rest of the code
}
```

Refactor

- Check in

```
git add --all :/
git commit -m
   "IsPrime: zero and lower not prime"
```

IsPrime end result

```
bool IsPrime(const int x) {
  if (x <= 1) return false;
  for (int i=2; i!=x; ++i)
  {
    if (x % i == 0) return false;
  }
  return true;
}
```

All IsPrime tests

```
void setup()
{
  if (!IsPrime(2)) { /* ERROR */ }
  if ( IsPrime(4)) { /* ERROR */ }
  if ( IsPrime(1)) { /* ERROR */ }
  if ( IsPrime(0)) { /* ERROR */ }
}
```

C++ on a desktop PC

Testing environment desktop

```
#include <cassert>


int main()
{
  assert(/* something */);
}
```

Red: write a test that fails

```
#include <cassert>


int main()
{
   assert(IsPrime(2));
}
```

Green: pass the test

```
bool IsPrime(const int x) {
   return true;
}


int main()
{
   assert(IsPrime(2));
}
```

Refactor

- Checking in

```
git add --all :/
git commit -m
   "IsPrime: 2 is prime"
```

Red: write a test that fails

```
int main()
{
   // Previous code
   assert(!IsPrime(4));
}
```

Green: pass the test

```
bool IsPrime(const int x) {
  for (int i=2; i!=x; ++i)
  {
    if (x % i == 0) return false;
  }
  return true;
}


int main() { /* */ }
```

Refactor

- Check in

```
git add --all :/
git commit -m
   "IsPrime: 4 is not prime"
```

Red: write a test that fails

```
int main()
{
   // Previous code
   assert(!IsPrime(1));
}
```

Green: pass the test

```
bool IsPrime(const int x) {
   if (x == 1) return false;
   // rest of the code
}
```

Refactor

- Check in

```
git add --all :/
git commit -m
   “IsPrime: 1 is not prime”
```

Red: write a test that fails

```
int main()
{
   // Previous code
   assert(!IsPrime(0));
}
```

Green: pass the test

```
bool IsPrime(const int x) {
   if (x <= 1) return false;
   // rest of the code
}
```

Refactor

- Check in

```
git add --all :/
git commit -m
   "IsPrime: zero and lower not prime"
```

IsPrime end result

```
bool IsPrime(const int x) {
  if (x <= 1) return false;
  for (int i=2; i!=x; ++i)
  {
    if (x % i == 0) return false;
  }
  return true;
}
```

All IsPrime tests

```
int main()
{
  assert( IsPrime(2));
  assert(!IsPrime(4));
  assert(!IsPrime(1));
  assert(!IsPrime(0));
}
```

R on a desktop PC

Testing environment desktop

```
library(testit)


assert(
   # something
)
```

Red: write a test that fails

```
library(testit)


assert(IsPrime(2))
```

Green: pass the test

```
library(testit)


IsPrime <- function(x)
{
   return (TRUE)
}


assert(IsPrime(2))
```

Refactor

- Checking in

```
git add --all :/
git commit -m
   "IsPrime: 2 is prime"
```

Red: write a test that fails

```
# Previous code

assert(!IsPrime(4))
```

Green: pass the test

```
IsPrime <- function(x)
{
  if (x == 2) return (TRUE)
  for (i in seq(2,x-1))
  {
    if (x %% i == 0) return (FALSE);
  }
  return (TRUE)
}
```

Refactor

- Check in

```
git add --all :/
git commit -m
   "IsPrime: 4 is not prime"
```

Red: write a test that fails

```
assert(!IsPrime(“Two”))
```

Green: pass the test

```
is_integer <- function(N){
  !grepl(
    "[^[:digit:]]",
    format(N,  digits = 20, scientific = FALSE)
  )
}

IsPrime <- function(x)
{
  if (!is_integer(x)) return (FALSE)
  # Rest of code
}
```

Refactor

- Check in

```
git add --all :/
git commit -m
   "IsPrime: words are not prime"
```

IsPrime end result

```
library(testit)

is_integer <- function(N) {
  !grepl("[^[:digit:]]", format(N,  digits = 20, scientific = FALSE))
}

IsPrime <- function(x)
{
  if (!is_integer(x)) return (FALSE)
  if (x == 2) return (TRUE)
  for (i in seq(2,x-1))
  {
    if (x %% i == 0) return (FALSE);
  }
  return (TRUE)
}
```

All IsPrime tests

```
assert(IsPrime(2))

assert(!IsPrime(4))

assert(!IsPrime(“Two”))
```

Final remarks

- Run-time speed
- Collaboration
- Limitation

Run-time speed

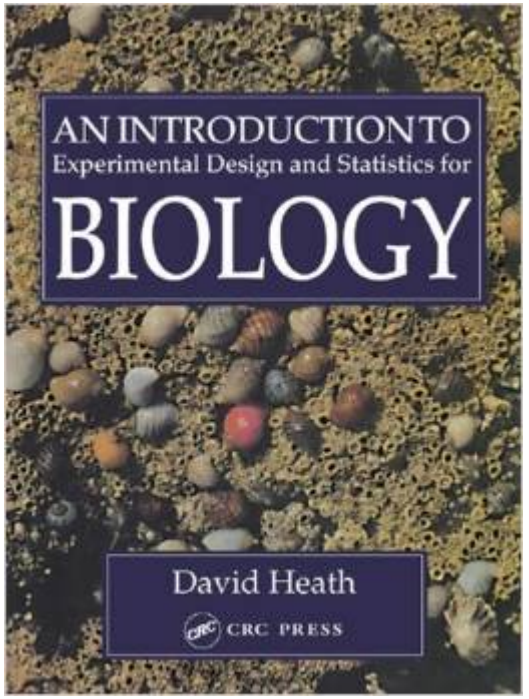
It is far, far easier
to make a correct program fast
than it is
to make a fast program correct.

Herb Sutter, C++ expert

- You can test if your new function is faster and gives the same correct results

Collaboration

- Tests can be used as a mean to let others contribute
- Example:
  - I implemented a Wilcoxon's signed rank test, especially a function to get the rank of each value, following Heath
  - Later, Senbong G contacted me and helped us fix my function
- In this example, syntax is not important



C++ tests

```
values   = { 10.0, 20.0, 30.0 };
expected = {  1.0,  2.0,  3.0 };
results = GetRanks(values);
assert(expected == results);
```

```
values   = { 30.0, 10.0, 20.0 };
expected = {  3.0,  1.0,  2.0 };
results = GetRanks(values);
assert(expected == results);
```

C++ tests

```
//From Heath, page 263
values   = { 0.6, 1.4, 4.0, 13.0, 14.5, 9.4, 11.4, 12.6, 4.0 };
expected = { 1.0, 2.0, 3.5,  8.0,  9.0, 5.0,  6.0,  7.0, 3.5 };
results = GetRanks(values);
// Heath, page 263, no zero value
assert(expected == results);
```

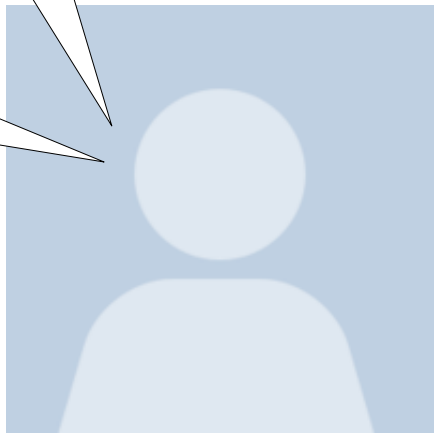
```
//From Heath, page 263, now with zero added
values   = { 0.6, 1.4, 0.0,  4.0, 13.0, 14.5, 9.4, 11.4, 12.6, 4.0 };
expected = { 1.0, 2.0, 0.0,  3.5,  8.0,  9.0, 5.0,  6.0,  7.0, 3.5 };
results = GetRanks(values);
// Heath, page 263, with zero value
assert(expected == results);
```

Email from Senbong G

I think I found a bug

How can that be?
Can you convince me with a test?

Sure, the tests on the next slide all fail



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Senbong G

C++ tests

```
values   = { 1.0, 1.0, 1.0, 2.0, 2.0, 3.0, 3.0, 3.0};
expected = { 2.0, 2.0, 2.0, 4.5, 4.5, 7.0, 7.0, 7.0};
results = GetRanks(values);
assert(expected == results);
```

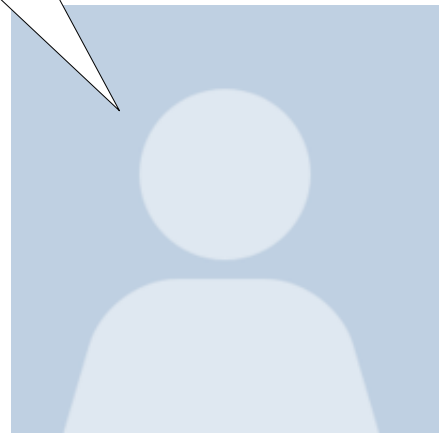
```
values   = { 0.0, 0.0, 0.0 };
expected = { 0.0, 0.0, 0.0 };
results = GetRanks(values);
assert(expected == results);
```

Email from Senbong G

Blimey, you're right!
I'll fix it within a week

No need to,
I already did,
here is the code

Thanks!



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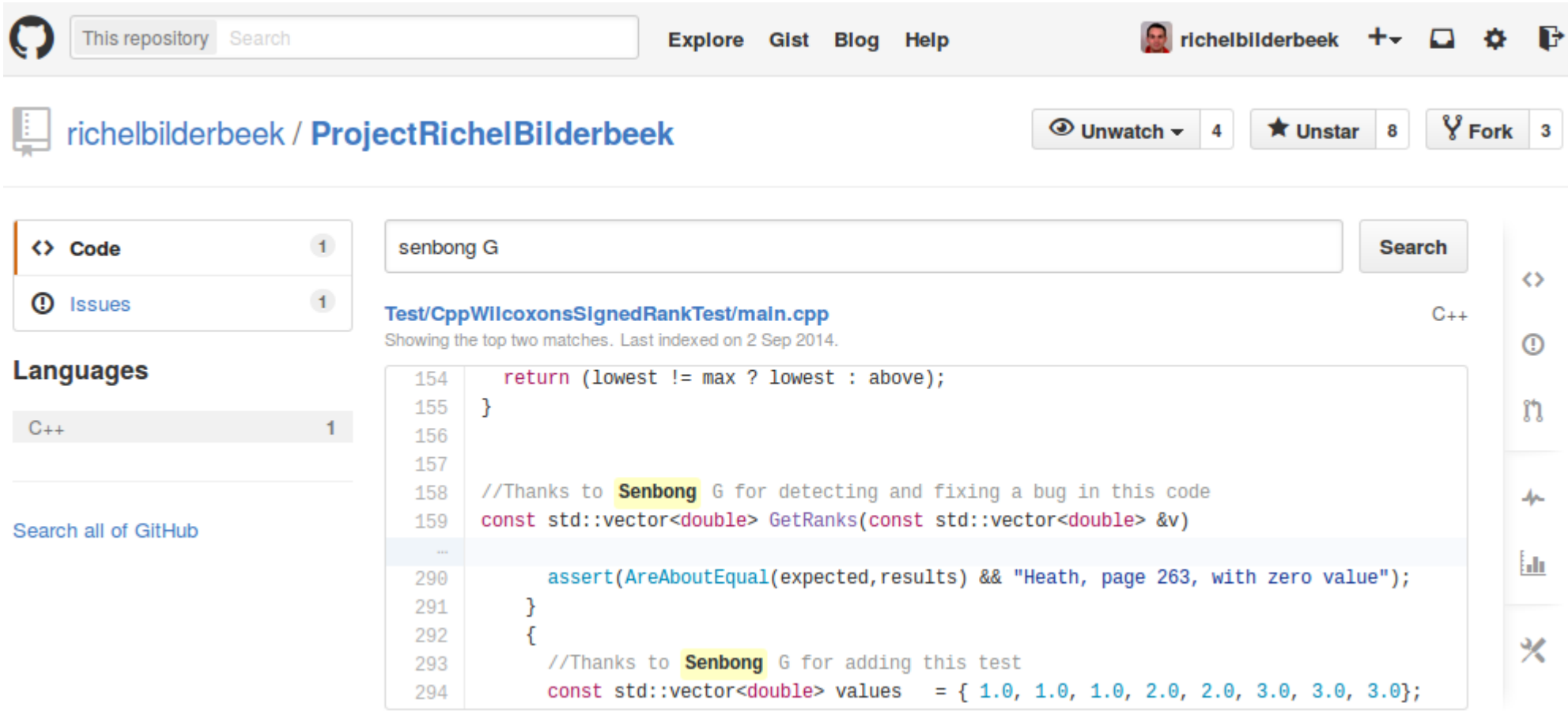
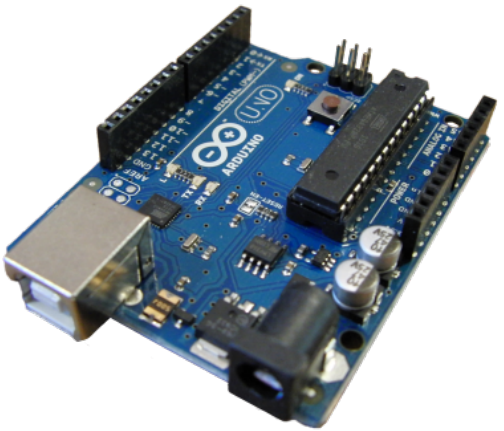
Senbong G

Eternal glory



Limitations on Arduino

- You cannot test everything on Arduino:
  - Is the text displayed on the LCD screen?
  - Is the servo motor moving?
- What you can test:
  - What is the text I send to the LCD screen?
  - What is the angle I send to the servo motor?
- It is not doable to add sensors to test everything, as these sensors must also be tested



Limitations C++ on desktop PC

- Few
- So it is too easy to make brute force tests, just to be sure
- Solution:
  - Limit tests to 100 msec per class

Limitations R on desktop PC

- R does not have a debug and release mode
- Tests is functions will also slow down your released code!
- Solution:
  - Write no tests in function
  - Put tests in separate files
  - You will need more tests thanks to this

Conclusion

- Test-driven development
  - uses a systematic approach
  - delivers testable code
  - delivers code that has been tested to be correct
  - does not test more than needed
  - facilitates collaboration