accu 2022

CONTRACTUAL DISAPPOINTMENT IN C++

JOHN MCFARLANE

About Me

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johnmcfarlane.github.io/accu-2022

Background

Background

Work:

Background

Work: games,

Background

Work: games, servers,

Background

Work: games, servers, automotive

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Work: games, servers, automotive

Fun:

Background

Work: games, servers, automotive

Fun: numerics,

Background

Work: games, servers, automotive

Fun: numerics, workflow,

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Fun: numerics, workflow, word games

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C++:

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C++: low latency,

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C++: low latency, numerics,

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Work: games, servers, automotive

Fun: numerics, workflow, word games

C++: low latency, numerics, contracts

Definitions

Contracts

Contract Programming in C++(20)

Alisdair Meredith, CppCon 2018

> *A contract is an exchange of promises between a client and a provider.*

Disappointment

P0157R0: Handling Disappointment in C++

Lawrence Crowl, 2015

When a function fails to do what we want, we are disappointed. How do we report that disappointment to callers? How do we handle that disappointment in the caller?

Bugs and Errors

P0709R2: Zero-overhead deterministic exceptions: Throwing values

Herb Sutter, 2018

> *Programming bugs (e.g., out-of-bounds access, null dereference) and abstract machine corruption (e.g., stack overflow) cause a corrupted state that cannot be recovered from programmatically, and so they should never be reported to the calling code as errors that code could somehow handle.*

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- C++ API Contracts

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- C++ Standard

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Attributes

- Agreement
- Client
- Provider
- (Client) Violation

Contract Attributes

	C++ API	standard	end user	test user
agreement				
client				
provider				
violation				

Contract Attributes

	C++ API	**standard**	**end user**	**test user**
agreement	docs	ISO/IEC 14882	docs	docs
client	dev	dev	user	dev
provider	dev	implementer	dev	implementer
violation	bug	bug	error	error

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Contract Attributes

end user

client

user

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End User Contract

- The exchange of promises between the user and developer of a software product.
- It's expected that the user may violate the contract.
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- Such violations are *errors*.
- Errors should be handled by the program.

Errors

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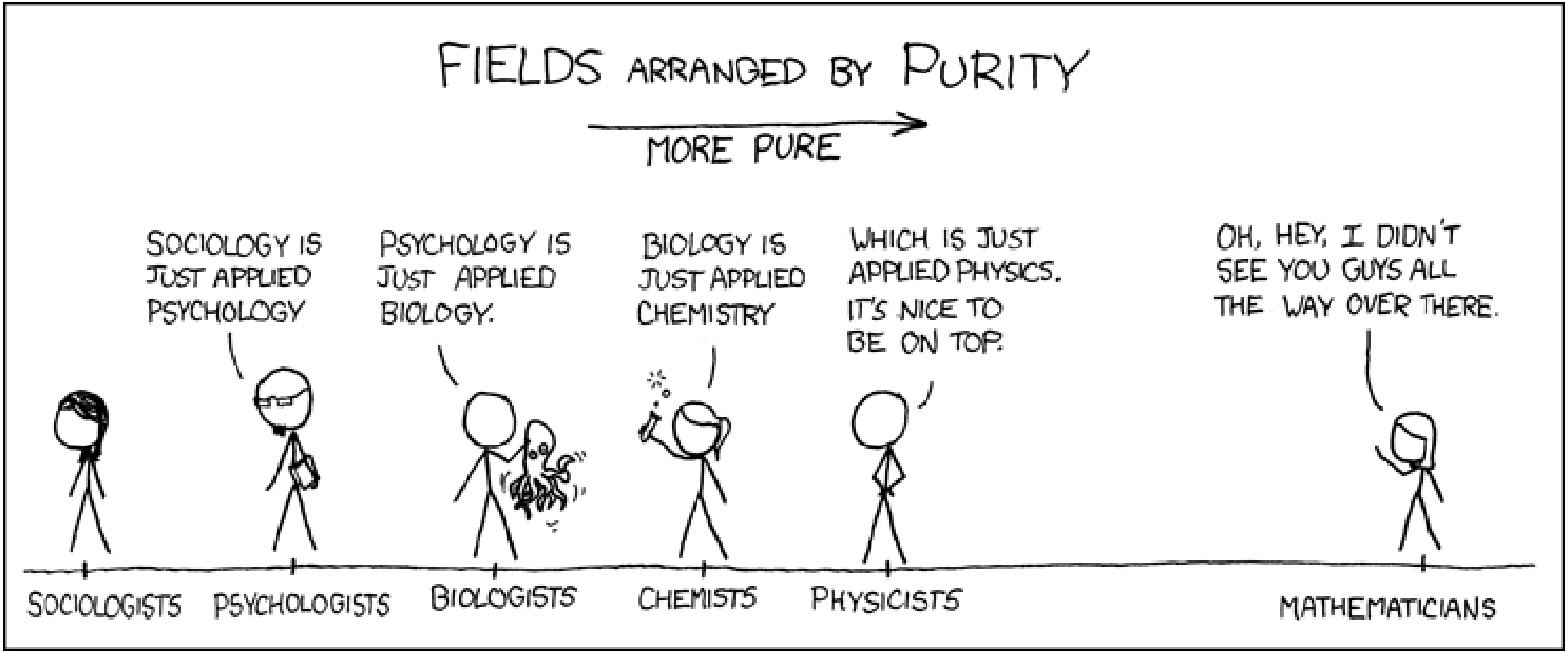
- are introduced through interfaces with the real world, e.g.:
  - `std::filesystem` and `std::string` are UI elements!
  - `std::chrono` models the real world and similarly 'messy'.

xkcd.com/435



errors errors errors errors errors bugs

Errors are things that can go wrong

- even in perfect programs.

Examples of Errors

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resource

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- parameter is out of range
- unexpected device type
- unexpected network packet size

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- The user needs to know about them in order to decide what to do next.
- The software must inform the user to this end.
- Be considerate!

$1,000,000 Question

How does your program handle errors?

$1,000,000 Answer

It depends.

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  - a console,
  - a GUI,
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  - something else, or
  - nothing at all?
- Is your program even a program, or reusable library?

Choices, choices!

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C++ has too many error-handling facilities.

But part of the problem is its versatility.

An important consideration is to allow for versatility.

If you’re lucky

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```
namespace acme {
  // everything needed for program to do its thing;
  // well-formed and error-free
  struct sanitized_input {
    // ...
  };

  // safety boundary; untrusted input; trusted output
  std::optional<sanitized_input> digest_input(std::span<char const* const> arg

  // free from error handling
  std::string do_the_thing(sanitized_input in);
}

int main(int argc, char const* const* argv)
{
```

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  // variable binding: type safety FTW!
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int main(int argc, char const* const* argv)
{
  // variable binding; type safety FTW!
  auto const args{std::span{argv, argv+argc}};

  auto const input{acme::digest_input(args)};
  if (!input) {
    return EXIT_FAILURE;
```

If you're lucky

```
}

int main(int argc, char const* const* argv)
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  // variable binding; type safety FTW!
  auto const args{std::span{argv, argv+argc}};

  auto const input{acme::digest_input(args)};
  if (!input) {
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  std::cout << acme::do_the_thing(*input);
  return EXIT_SUCCESS;
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If you're lucky

```cpp
}

int main(int argc, char const* const* argv)
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Example 1: Print result, return success, log details

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```
// print file's size or return false
auto print_file_size(char const* filename)
{
  std::ifstream in(filename, std::ios::binary | std::ios::ate);
  if (!in) {
    std::cerr << std::format("failed to open file \"{}\"\n", filename);
    return false;
  }

  std::cout << std::format("{}\n", in.tellg());
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auto print_config_file_size()
{
  if (!print_file_size("default.cfg")) {
```

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Example 3: Return result *or* failure, log details

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auto file_size(char const* filename)
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  std::ifstream in(filename, std::ios::binary | std::ios::ate);
  if (!in) {
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Example 4: Return result, abort on failure, log details

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```
// error handler function
template <typename... args>
[[noreturn]] void fatal(args&&... parameters)
{
  std::cerr << std::format(std::forward<args>(parameters)...);
  std::abort();
}

int main(int argc, char* argv[])
{
  auto const expected_num_params{3};
  if (argc != expected_num_params) {
    fatal(
        "Wrong number of arguments provided. Expected={}; Actual={}\n",
        expected_num_params, argc);
    return EXIT_FAILURE;
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There are zero or more obstacles and one finish line.

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```
auto do_something(auto param)
{
  // hurdle 1
  auto intermediate_thing1 = get_a_thing(param)
  if (!intermediate_thing1) {
    return failure;
  }

  // hurdle 2
  auto intermediate_thing2 = get_another_thing(intermediate_thing1)
  if (!intermediate_thing2) {
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  // finish line
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- Pros:

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- Pros:
  - versatile/scalable
  - very efficient normal path

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Contract Attributes

	C++ API	standard	end user	test user
agreement	docs	ISO/IEC 14882	docs	docs
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C++ API Contracts

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C++ API Contracts

- The exchange of promises between the developer(s) using and implementing a C++ API.
- Violations are *bugs*.
- Fixing bugs is as important as fixing compiler errors.

Bugs

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A program with a bug:

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- is incorrect

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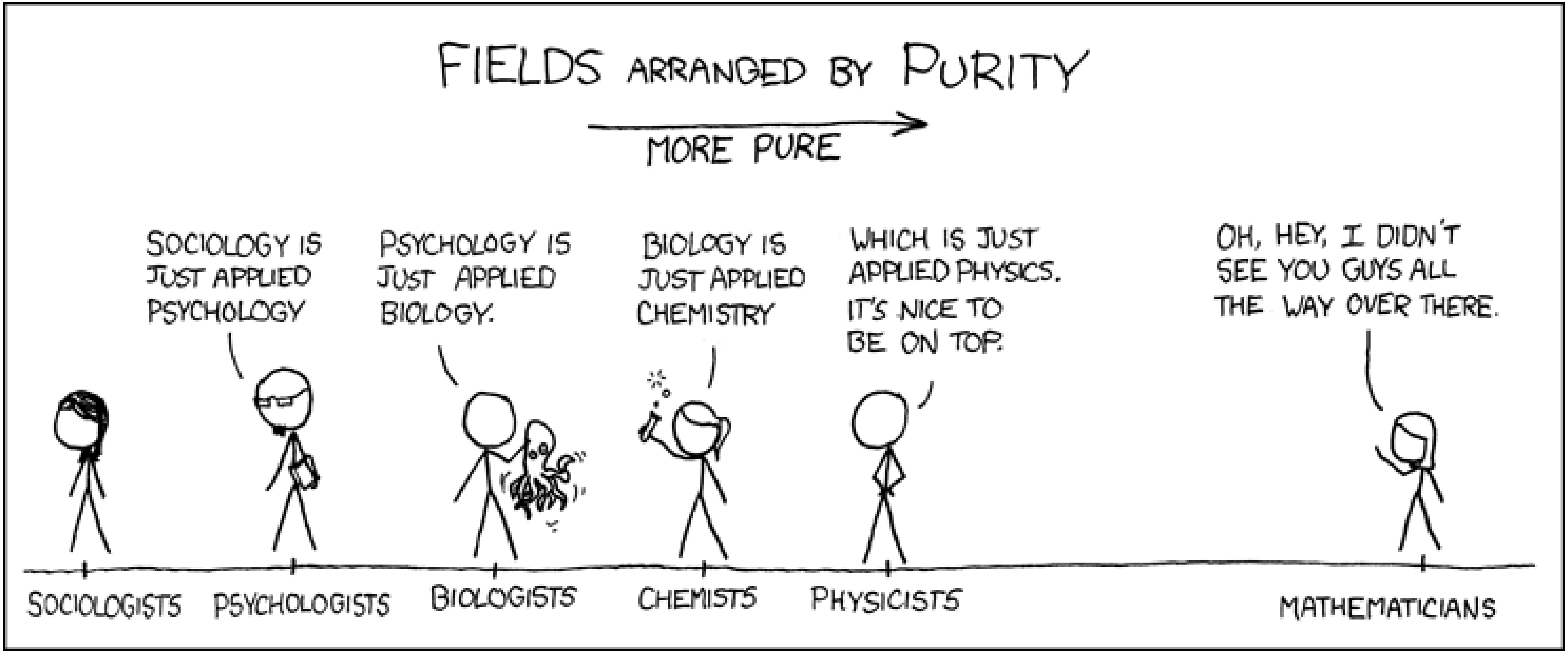
Bugs

A program with a bug:

- is incorrect
- contains undefined behaviour
- is vulnerable
- violates the *End User Contract*.

xkcd.com/435



errors errors errors errors errors bugs

Example of Client C++ API Contract Violation #1

PID Controller

PID controller

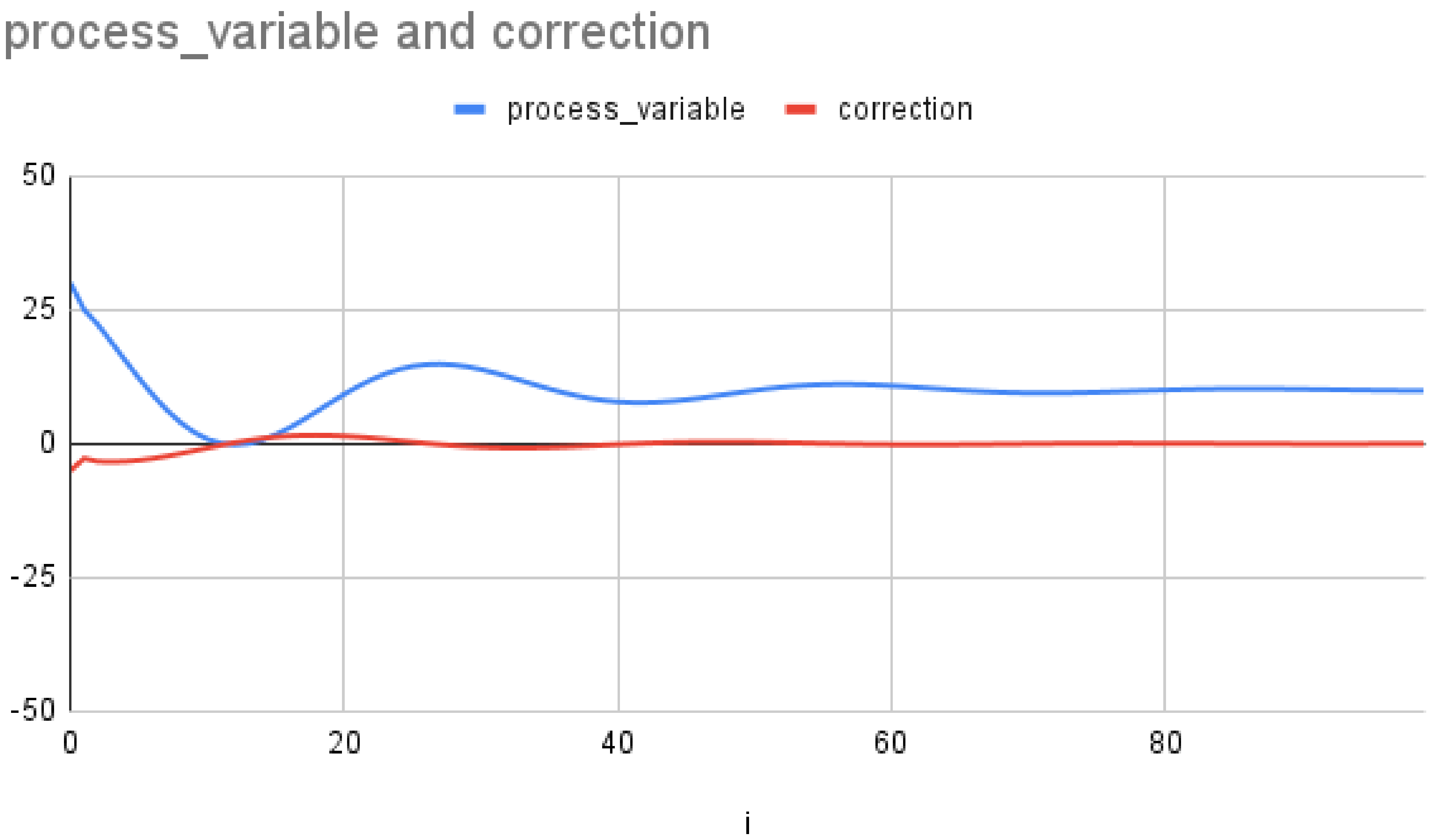
A **proportional–integral–derivative controller** (**PID controller** or **three-term controller**) is a control loop mechanism employing feedback that is widely used in industrial control systems and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an *error value* $e(t)$ as the difference between a desired setpoint (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively), hence the name.

In practical terms, PID automatically applies an accurate and responsive correction to a control function. An everyday example is the cruise control on a car, where ascending a hill would lower speed if constant engine power were applied. The controller's PID algorithm restores the measured speed to the desired speed with minimal delay and overshoot by increasing the power output of the engine in a controlled manner.

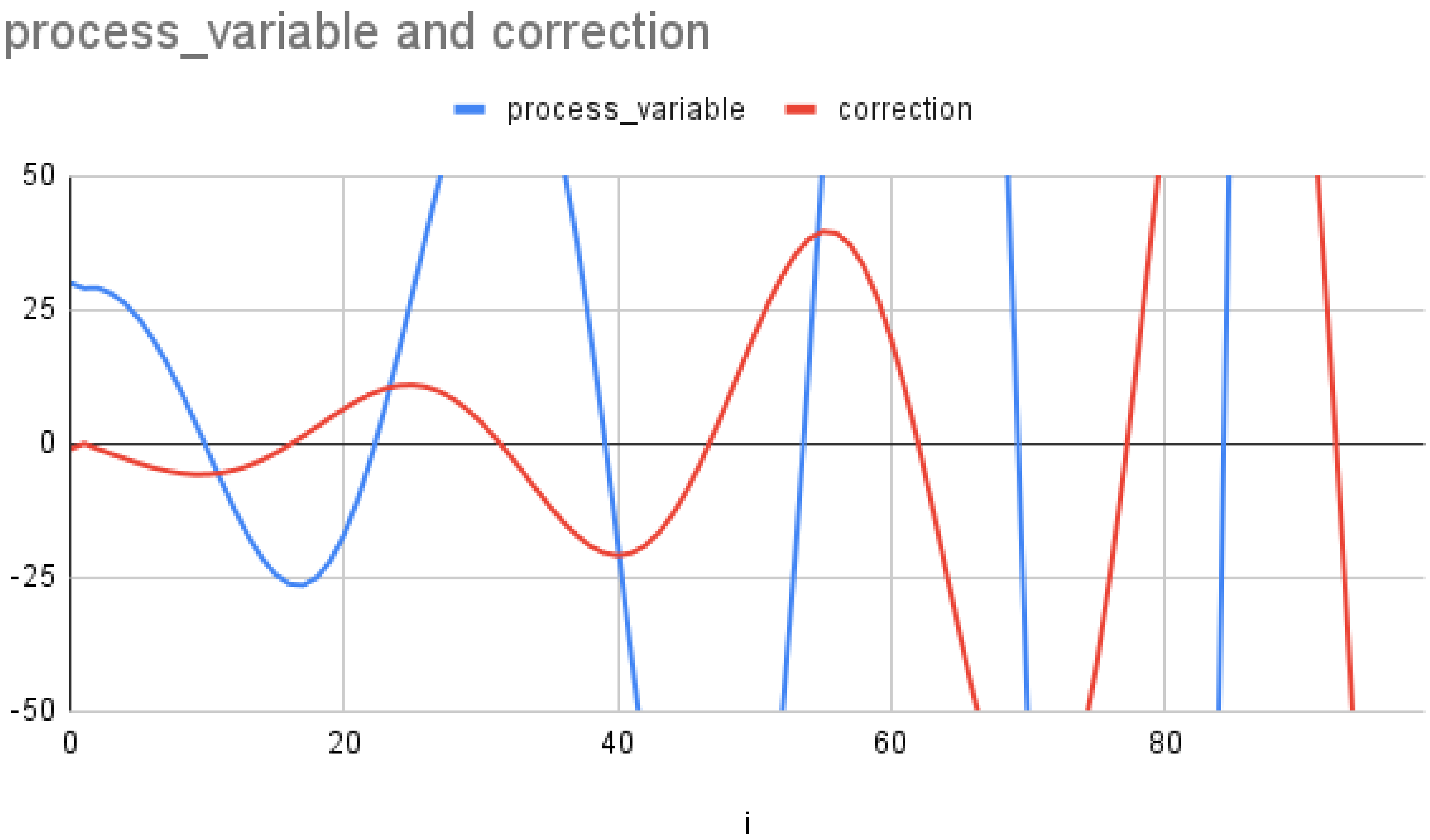
The first theoretical analysis and practical application of PID was in the field of automatic steering systems for ships, developed from the early 1920s onwards. It was then used for automatic process control in the manufacturing industry, where it was widely implemented in at first pneumatic and then electronic controllers. Today the PID concept is used universally in applications requiring accurate and optimized automatic control.

Contents

en.wikipedia.org/wiki/PID_controller



Kp=.1, Ki=.5, Kd=.01, setpoint=10, pv=30



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Contract from PID

Mathematical form [edit]

The overall control function $u(t) = K_\text{p} e(t) + K_\text{i} \int_0^t e(\tau)\,\mathrm{d}\tau + K_\text{d} \frac{\mathrm{d}e(t)}{\mathrm{d}t}$,

where K_p, K_i, and K_d, all non-negative, denote the coefficients for the proportional, integral, and derivative terms respectively (sometimes denoted *P*, *I*, and *D*).

In the *standard form* of the equation (see later in article), K_i and K_d are respectively replaced by K_p/T_i and $K_\text{p}T_\text{d}$; the advantage of this being that T_i and T_d have some understandable physical meaning, as they represent an integration time and a derivative time respectively. $K_\text{p}T_\text{d}$ is the time constant with which the controller will attempt to approach the set point. K_p/T_i determines how long the controller will tolerate the error being consistently above or below the set point.

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PID Controller (interface)

```
namespace pid {
  struct components {
    double proportional;
    double integral;
    double derivative;
  };

  // values kept constant throughout operation of a controller
  struct parameters {
    // non-negative factors used to generate PID terms
    components k;

    double dt;
  };

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};

```

PID Controller (interface)

```
struct input {
  // desired value
  double setpoint;

  // actual value
  double process_variable;
};

struct result {
  // corrective value to apply to system
  double correction;

  // to pass in to next iteration as input::previous state
  state current;
```

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  [[nodiscard]] auto calculate(parameters params, state previous, input in)
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PID Controller (implementation)

```
#include "pid.h"

#include "pid_assert.h"

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    -> result
{
  PID_ASSERT(params.k.proportional >= 0);
  PID_ASSERT(params.k.integral >= 0);
  PID_ASSERT(params.k.derivative >= 0);
  PID_ASSERT(params.dt > 0);

  auto const error = in.setpoint - in.process_variable;
  auto const next_integral{previous.integral + error * params.dt};
  auto const derivative = (error - previous.error) / params.dt;
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    return result{
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Example of Client C++ API Contract Violation #2

(Anecdotal) UID vs Bitmap

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typedef uid = std::uint32_t;
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public:
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UID vs Bitmap

Observations

- Sentinel values, e.g. `invalid_id`, are trouble!
- *Defensive* or *helpful* code is unwelcome complexity.
- Trap bugs as they hatch.

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Prominent C++ Standard contract violation bugs fall into two main categories

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- ~~leaks~~

Arithmetic Example 1: Divide by Zero

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int main()
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  return 1/0;
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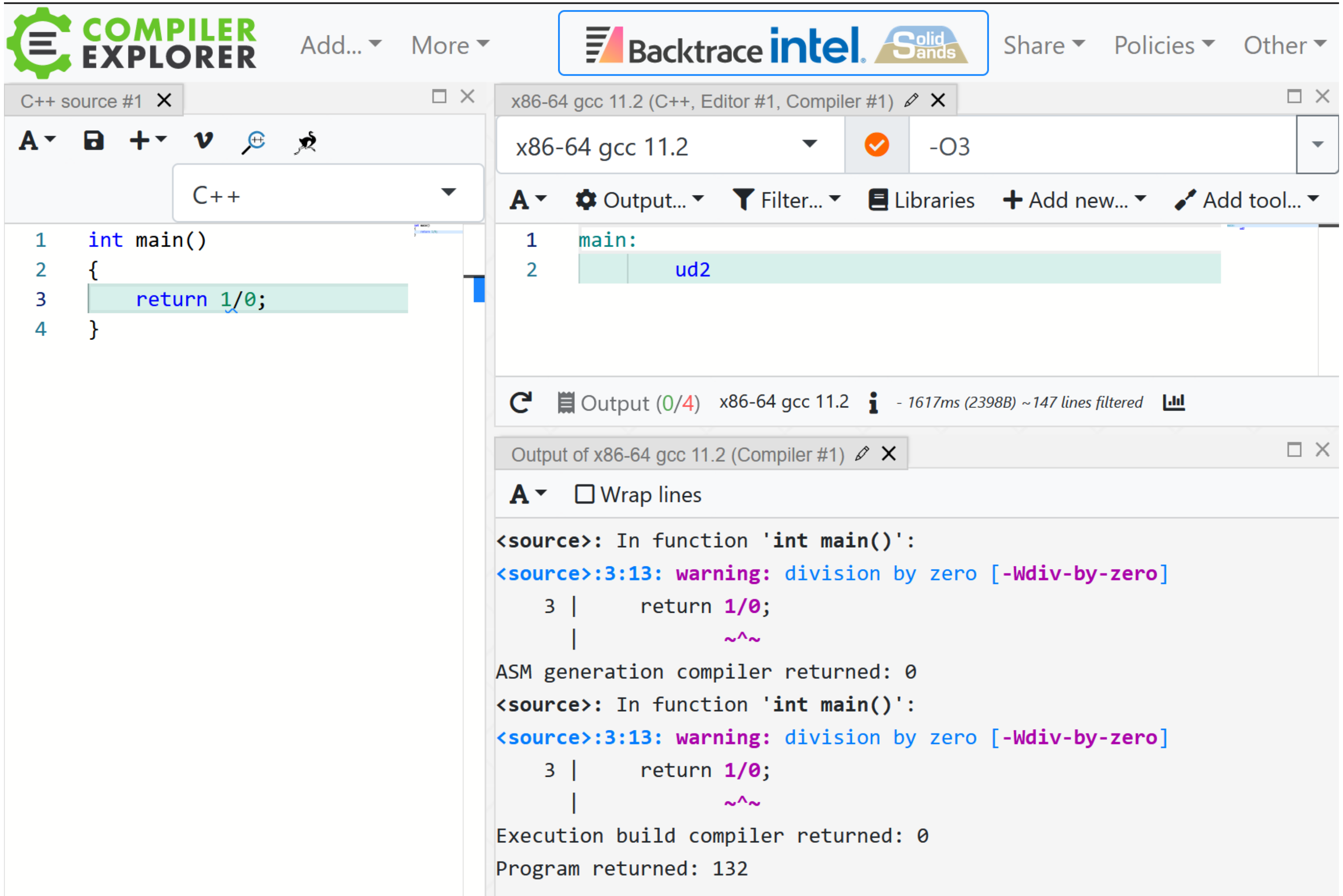
Tools to the Rescue!



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3. Instrumentation detects bugs in executing code.
4. Automated testing exercises the code.
5. Fuzz testing and coverage metrics guide testing.

Some Useful Flags

flag or `intrinsic`	Clang	GCC	MSVC	Description
-Werror	✓	✓		turn warnings into errors
/WX			✓	turn warnings into errors
-Wall, *-Wconversion*, *-Wextra* and *-Wpedantic*	✓	✓		enable many warnings
/W4			✓	enable many warnings
-D_LIBCPP_ENABLE_NODISCARD	✓			enable some warnings
-fsanitize=undefined,address etc.	✓	✓		flag C++ Standard user contract violations†
-fno-sanitize-recover=all	✓	✓		trap bugs flagged with *-fsanitize=*
-fsanitize-recover=all etc.	✓	✓		report bugs flagged with *-fsanitize=*, then continue
-ftrapv	✓	✓		avoid; broken on GCC
-D_LIBCPP_DEBUG=1	✓			trap Standard Library user contract violations
-D_GLIBCXX_ASSERTIONS		✓		trap Standard Library user contract violations
-D_GLIBCXX_DEBUG or *-D_GLIBCXX_DEBUG_PEDANTIC*		✓		enable libstdc++ debug mode
/D_ITERATOR_DEBUG_LEVEL=2			✓	trap Standard Library user contract violations
`__builtin_unreachable()`	✓	✓		flag Unambiguous Bugs to compiler‡
`__assume(false)`			✓	flag Unambiguous Bugs to compiler‡
-DNDEBUG	✓	✓	✓	disable `assert` macro
-O0	✓	✓		disable optimisations*
/Od			✓	disable optimisations*
-fwrapv	✓	✓		disable signed integer overflow
-O, *-O1*, *-O2*, *-O3*, *-Os*, *-Ofast* or *-Og*	✓	✓		optimise code
/O1, */O2*, */Os*, */Ot* or */Ox*			✓	optimise code

https://github.com/johnmcfarlane/papers/blob/main/cpp/contractual-disappointment.md#appendix-a---toolchain-specific-recommendations

Testing with Sanitizers is Left of Bug Reports

```
int main()
{
    auto v{std::vector{0, 1}};
    v.push_back(2);
    fmt::print("{}\n", v[3]);
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libstdc++: *-D_GLIBCXX_ASSERTIONS*

MSVC: */D_ITERATOR_DEBUG_LEVEL=1*?

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```cpp
// from https://discourse.cmake.org/t/tests-that-are-meant-to-abort/537/4
// This is a hack to implement death tests in CTest.
extern "C" void error_test_handle_abort(int /*unused*/)
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    std::exit(EXIT_FAILURE);  // NOLINT(concurrency-mt-unsafe)
}

int main()
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    if (std::signal(SIGABRT, error_test_handle_abort) == SIG_ERR) {
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    auto v{std::vector{0, 1}};
    v.push_back(2);
    fmt::print("{}\n", v[3]);
}
```

A Funny Thing Happened on the Way to the Repository

```cpp
// This is a hack to implement death tests in Ctest.
extern "C" void error_test_handle_abort(int /*unused*/)
{
    std::exit(EXIT_FAILURE);  // NOLINT(concurrency-mt-unsafe)
}

int main()
{
    if (std::signal(SIGABRT, error_test_handle_abort) == SIG_ERR) {
        std::abort();
    }

    auto v{std::vector{0, 1}};
    v.push_back(2);
    fmt::print("{}\n", v[3]);
}
```

A Funny Thing Happened on the Way to the Repository

```cpp
// from https://discourse.cmake.org/t/tests-that-are-meant-to-abort/537/4
// This is a hack to implement death tests in CTest.
extern "C" void error_test_handle_abort(int /*unused*/)
{
    std::exit(EXIT_FAILURE);  // NOLINT(concurrency-mt-unsafe)
}

int main()
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    if (std::signal(SIGABRT, error_test_handle_abort) == SIG_ERR) {
        std::abort();
    }

    auto v{std::vector{0, 1}};
    v.push_back(2);
    fmt::print("{}\n", v[3]);
```

death tests are hard

Contract Attributes

	C++ API	standard	end user	test user
agreement	docs	ISO/IEC 14882	docs	docs
client	dev	dev	user	dev
provider	dev	implementer	dev	implementer
violation	bug	bug	error	error

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Test User Contract

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- Provision is considered a nice-to-have, a 'quality of implementation' issue`.
- Client violations are ~~bugs~~ *errors*.
- These errors arise at the point where a bug is discovered.
- The user is a dev in need of feedback about correctness.
- One such tool is a good `assert`.

Trigger Warning: This Assertion Triggers UB!

```
// For testing coverage, assertions are not necessarily a concern.
#if defined(PID_DISABLE_ASSERTS)
#define PID_ASSERT(cond)

// In debug builds, fail fast and loud when an assertion is challenged.
#elif !defined(NDEBUG)
#define PID_ASSERT(cond) ((cond) ? static_cast<void>(0) : std::terminate())

// In optimised GCC builds, optimise/sanitize accordingly.
#elif defined(__GNUC__)
// NOLINTNEXTLINE(cppcoreguidelines-macro-usage)
#define PID_ASSERT(cond) ((cond) ? static_cast<void>(0) : __builtin_unreachabl

// In optimised MSVC builds, optimise/sanitize accordingly.
#elif defined(_MSC_VER)
#define PID_ASSERT(cond) __assume(cond)
```

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#endif
```

Simplicity, Uniformity, Versatility

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- The choice of how to handle bugs lies in the hands of the developer using the code.

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- All bugs stink.
- If you are unsure about correctness (which you should be) you are taking a risk by releasing your product to the client.
- If you are unsure about correctness (which you should be) you are taking a risk by enabling optimisations.
- The distinction between 'user bugs', 'language UB', 'hard UB', 'time travel UB' etc. is false.

Bugs is Bugs

```
// precondition: number is in range [1..26]
constexpr auto number_to_letter(int number)
{
  return char(number - 1 + 'A');
}

// signed integer overflow violates C++ Standard, is already UB
number_to_letter(0x7fffffff);
```

Bugs is Bugs

```cpp
// precondition: number is in range [1..26]
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// signed integer overflow violates C++ Standard, is already UB
number_to_letter(0x7fffffff);
```

Contracts Protect Interests

```cpp
constexpr auto number_to_letter(int number)
{
  constexpr auto lookup_table = "ABCDEFGHIJKLMNOPQRSTUVWXYZ";
  return lookup_table[number - 1];
}

// signed integer overflow violates C++ Standard, is already UB
number_to_letter(0x7fffffff);
```

Contracts Protect Interests

```
constexpr auto number_to_letter(int number)
{
  constexpr auto lookup_table = "ABCDEFGHIJKLMNOPQRSTUVWXYZ";
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```

Strategies

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- Trap Enforcement Strategy - Bugs are Fatal

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Strategies

- Trap Enforcement Strategy - Bugs are Fatal
- Non-enforcement Strategy - Struggle on
- Log-And-Continue Strategy - Bugs happens
- Prevention Enforcement Strategy - Bugs, what bugs?

Some Useful Flags, Again

flag or `intrinsic`	Clang	GCC	MSVC	Trap	Non	Log	Pre	Description
-Werror	✓	✓		✓	✓	✓	✓	turn warnings into errors
/WX			✓	✓	✓	✓	✓	turn warnings into errors
-Wall, *-Wconversion*, *-Wextra* and *-Wpedantic*	✓	✓		✓	✓	✓	✓	enable many warnings
/W4			✓	✓	✓	✓	✓	enable many warnings
-D_LIBCPP_ENABLE_NODISCARD	✓			✓	✓	✓	✓	enable some warnings
-fsanitize=undefined,address etc.	✓	✓		✓		✓		flag C++ Standard user contract violations[†]
-fno-sanitize-recover=all	✓	✓		✓				trap bugs flagged with *-fsanitize=*
-fsanitize-recover=all etc.	✓	✓				✓		report bugs flagged with *-fsanitize=*, then continue
-ftrapv	✓	✓						avoid; broken on GCC
-D_LIBCPP_DEBUG=1	✓			✓				trap Standard Library user contract violations
-D_GLIBCXX_ASSERTIONS		✓		✓				trap Standard Library user contract violations
-D_GLIBCXX_DEBUG or *-D_GLIBCXX_DEBUG_PEDANTIC*		✓		✓				enable libstdc++ debug mode
/D_ITERATOR_DEBUG_LEVEL=2			✓	✓				trap Standard Library user contract violations
`__builtin_unreachable()`	✓	✓		✓			✓	flag Unambiguous Bugs to compiler[‡]
`__assume(false)`			✓	✓			✓	flag Unambiguous Bugs to compiler[‡]
-DNDEBUG	✓	✓	✓		✓	✓	✓	disable `assert` macro
-O0	✓	✓			✓	✓		disable optimisations[*]
/Od			✓		✓	✓		disable optimisations[*]
-fwrapv	✓	✓			✓	✓		disable signed integer overflow
-O, *-O1*, *-O2*, *-O3*, *-Os*, *-Ofast* or *-Og*	✓	✓		✓			✓	optimise code
/O1, */O2*, */Os*, */Ot* or */Ox*			✓	✓			✓	optimise code

https://github.com/johnmcfarlane/papers/blob/main/cpp/contractual-disappointment.md#appendix-a---toolchain-specific-recommendations

Don’t Optimise Until You Sanitize!

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Don’t Optimise Until You Sanitize!

- Test your code before you release it.
- Make sure it's all tested (coverage).
- Make sure it's all *really* tested (fuzzing).
- Get your 9's.

Testing Isn't Debugging

.github/workflows/toolchains/linux-gcc.cmake

```
set(CMAKE_CXX_FLAGS_INIT
    "-Wall -Werror -Wextra -Wno-maybe-uninitialized -Wno-restrict -pedantic")
set(CMAKE_CXX_FLAGS_COVERAGE_INIT
    "-coverage -fno-exceptions -DPID_DISABLE_ASSERTS")
set(CMAKE_CXX_FLAGS_TEST_INIT
    "-D_GLIBCXX_ASSERTIONS -DNDEBUG -O3 -fsanitize=address,undefined -fno-sanit
```

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```

Testing Isn't Debugging

.github/workflows/toolchains/linux-gcc.cmake

```
#!/usr/bin/env bash

set -euo pipefail

PROJECT_DIR=$(cd "$(dirname "$0")"/../../..; pwd)

conan install \
  --build=missing \
  --env CONAN_CMAKE_TOOLCHAIN_FILE="${PROJECT_DIR}/.github/workflows/toolchains/linux-gcc.cmake"
  --settings build_type=Test \
  "${PROJECT_DIR}" \
  "$@"

conan build \
  "${PROJECT_DIR}"
```

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conan build \
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```

Discussion

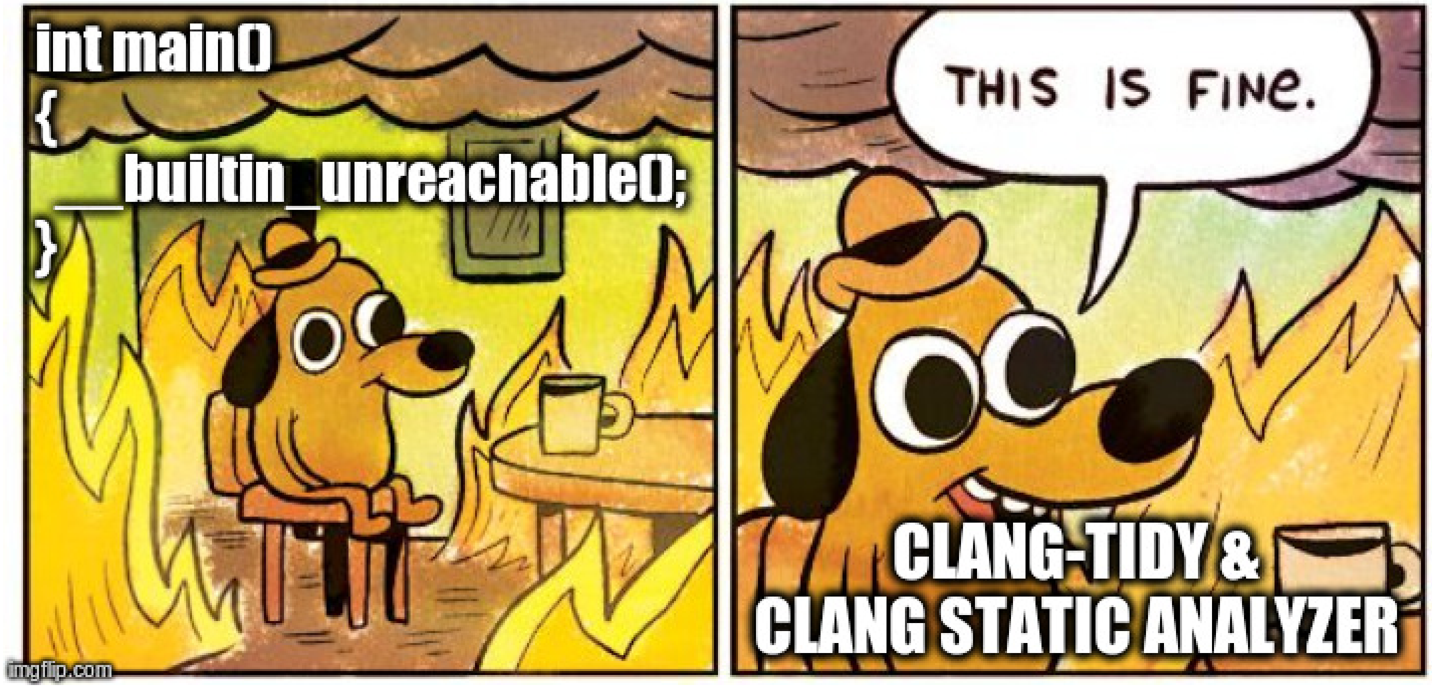
Mars Code, Gerard J. Holzmann, 2014

- Mars Science Laboratory, written in C
- four static analysers run nightly
- used dynamic thread analysis tool
- warnings enabled and enforced in compiler
- all mission-critical code
  - had to be 2% assertions
  - had to remain enabled after testing

Mars Code, Gerard J. Holzmann, 2014

A failing assertion is now tied in with the fault-protection system and by default places the spacecraft into a predefined safe state where the cause of the failure can be diagnosed carefully before normal operation is resumed.

Clang-Tidy Avoids Unreachable Paths



godbolt.org/z/oWjPfrKds

"Doesn't look like anything to me"

Thank You

John McFarlane

Jaguar Land Rover, Shannon, Ireland

github.com/johnmcfarlane/accu-2022-examples

twitter.com/JSAMcFarlane

johnmcfarlane.github.io/slides/2022-accu

The Stuff I Didn't Get To

Naming

- Names matter to contracts
- If the meaning of an element changes, consider changing the name

Bug or Error?

```
int f(int const* p, int a, int b)
{
  // Are we good?
  int r = 0;
  for (int i = a; i <= b; i ++)
  {
    r += p[i];
  }
  return r;
}

int g(int const* p)
{
  // Is this OK?
  return f(p, -1, 1);
}
```

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```

maybe a bug, maybe not

Bug?

```cpp
int accumulate(int const* numbers, int first, int last)
{
  // Are we good?
  int r = 0;
  for (int i = first; i <= last; i ++)
  {
    r += numbers[i];
  }
  return r;
}

int g(int const* p)
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  }
  return r;
}

int g(int const* p)
{
  // Is this OK?
  return accumulate(p, -1, 1);
}
```

it's a bug!

Bug!

```
int accumulate(int const* numbers, int first, int last)
{
  assert(first >= 0);
  int r = 0;
  for (int i = first; i <= last; i ++)
  {
    r += numbers[i];
  }
  return r;
}

int g(int const* p)
{
  // Bug: -1 isn't in sequence that starts with p
  return accumulate(p, -1, 1);
}
```

Bug!

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int g(int const* p)
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```

but...

Bug?

```cpp
int sample(int const* center, int first, int last)
{
  // Are we good?
  int r = 0;
  for (int i = first; i <= last; i ++)
  {
    r += center[i];
  }
  return r;
}

int g(int const* p)
{
  // Is this OK?
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Bug?

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  }
  return r;
}

int g(int const* p)
{
  // Is this OK?
  return sample(p, -1, 1);
}
```

what about now?

No Bug!

```
int sample(int const* center, int first, int last)
{
  // First might be anything.
  int r = 0;
  for (int i = first; i <= last; i ++)
  {
    r += center[i];
  }
  return r;
}

int g(int const* p)
{
  // center is not necessarily the start of the sequence.
  return sample(p, -1, 1);
}
```

No Bug!

```
int sample(int const* center, int first, int last)
{
  // First might be anything.
  int r = 0;
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  return r;
}

int g(int const* p)
{
  // center is not necessarily the start of the sequence.
  return sample(p, -1, 1);
}
```

Naming

- Problem:
  - Two functions use the same algorithm
  - But they have different contracts
  - How do you test different contracts from the same function?
- Solution:
  - Different functions?

Naming

```
int accumulate_neighborhood(int const* position, int offset_first, int offset_
{
  int r = 0;
  for (int i = offset_first; i <= offset_last; i ++)
  {
    r += position[i];
  }
  return r;
}

int sample(int const* center, int first, int last)
{
  return accumulate_neighborhood(center, first, last);
}

int accumulate_subrange(int const* numbers, int first, int last)
```

Naming

```
  {
    r += position[i];
  }
  return r;
}

int sample(int const* center, int first, int last)
{
  return accumulate_neighborhood(center, first, last);
}

int accumulate_subrange(int const* numbers, int first, int last)
{
  assert(first >= 0);
  return accumulate_neighborhood(numbers, first, last);
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{
  assert(first >= 0);
  return accumulate_neighborhood(numbers, first, last);
}
```

Naming

```
int accumulate_neighborhood(int const* position, int offset_first, int offset_
{
  int r = 0;
  for (int i = offset_first; i <= offset_last; i ++)
  {
    r += position[i];
  }
  return r;
}

int sample(int const* center, int first, int last)
{
  return accumulate_neighborhood(center, first, last);
}

int accumulate_subrange(int const* numbers, int first, int last)
```

what about now?

Surgery is Now Open

- Q: My project doesn't use analysis tools or modern, quality toolchains.
- A: Sorry about that. Consider running tests against nice tools.

Surgery is Now Open

- Q: A million things would break if I enabled checks.
- A: Disable checks and exclude all files. Then slowly fix things one check/file at a time until all the checks you want are applied to all files.

Surgery is Now Open

- Q: My project doesn't test the code.
- A: You're problems are beyond the specialty of this doctor.

Surgery is Now Open

- Q: My dependencies trigger warnings/errors
- A: Think about the contract between you and your dependency provider; try `-isystem`.

Surgery is Now Open

- Q: This stuff gets hard in big, old projects maintained by big, young teams
- A: Agreed. There is no silver bullet.

Surgery is Now Open

- Q: My project doesn't need to be safe/secure. I don't need to worry about this stuff, right?
- A: ...

On Correctness

- Correctness is a consequence of generally-good practices:
  - using modern features (std::print, std::optional, std::vector, owning pointers)
  - testing code
  - using tools
  - healthy team dynamics (mentoring, pairing, reviewing)
  - avoiding accidental complexity

On Correctness

- Correctness gives you
  - quality - your software works better sooner
  - productivity - less time wasted testing changes, debugging, fixing
  - knowledge - tools teach you how to avoid mistakes
  - safety & security guarantees

In Defence of Simplicity

- Keep all your software simple and correct, including:
  - Functional (production) code
  - Automated tests
  - Documentation
  - Build system
- Avoid control flow, especially `if` statements
- Don't over-engineer or write code you don't need (YAGNI)

Coding Standards

- Commit to modern practices and conventions, e.g.:
  - C++ Core Guidelines
  - Modern CMake
  - Linux-flavour Git commit descriptions
- Enforce with tools, tools, tools!

Keep Your Friends Close; Keep Your Errors Closer

- Minimise distance (in space and time) between bug location (source code that needs fixing) and point of failure (crash, trap, unwanted behaviour)
- Being explicit and strict about C++ API Contracts helps this enormously
- Accordingly assertions help. Language feature will help too.