Software and Safety

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Woven by Toyota
https://www.woven.toyota

November 2025

Definitions

Definitions

Safety Critical Software

The consequence for failure is injury or loss of life.

Definitions

Software with Safety Consequences

Failure can cause quality-of-life problems for users — e.g. loss of money, loss of work, loss of trust, exposure of personal details, identity theft.

Software for Dangerous Devices

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- Automotive control software — steering, brakes, engine control

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- Aircraft cockpit software

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Software for Dangerous Devices

- Automotive control software — steering, brakes, engine control
- Aircraft cockpit software
- Factory machinery control software
- Nuclear power plant control software

Software in Medical Devices

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- Pacemakers

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- Pacemakers
- Defibrilators

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- Pacemakers
- Defibrilators
- Artificial lungs

Software in Medical Devices

- Pacemakers
- Defibrilators
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- CT Scanners

Software Designed to Increase Safety

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- Driving assistance software

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- Automatic cut-off on cookers

Software Designed to Increase Safety

- Driving assistance software
- Automatic cut-off on cookers
- Fire alarm and sprinkler systems

Software for Management Tasks

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- Traffic light control software

Software for Management Tasks

- Traffic light control software
- Air traffic management software

Software for Management Tasks

- Traffic light control software
- Air traffic management software
- Railway management software

Personal Data Management

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Personal Data Management

- Payment software

Personal Data Management

- Payment software
- Banking software

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Personal Data Management

- Payment software
- Banking software
- Phone software

Personal Data Management

- Payment software
- Banking software
- Phone software
- Social Media

Incidental Software

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- Games

Incidental Software

- Games
- Internet-connected devices

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- Games
- Internet-connected devices
- Web browsers

Incidental Software

- Games
- Internet-connected devices
- Web browsers
- Spreadsheets

Software Development Standards

Safety Critical Software has Standards to conform to.

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The “baseline” standard is IEC 61508: “Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems”

Software Development Standards

There are also industry-specific standards:

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- ISO 26262 for automotive software

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- etc.

Software Development Standards

If your software is not “Safety Critical”, then these don’t apply.

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If your software is not “Safety Critical”, then these don’t apply.

You should still consider “safety”, and the potential impact of failure on your users.

Problem Causes

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A big cause of problems is circumstances the developers didn't expect to happen:

	Knowns	Unknowns
known	known Knowns	known Unknowns
unknown	unknown Knowns	unknown Unknowns

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- Events they thought "would never happen"

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Problem Causes

A big cause of problems is circumstances the developers didn't expect to happen:

- Events they thought "would never happen"
- Events they **didn't even consider as possibilities**

	Knowns	Unknowns
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We commonly call these cases **bugs**

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From a safety point of view, these are **design** issues.

Can we design the **system** to handle these?

Another Definition

undefined behavior

behavior for which this document imposes no requirements

— C++23 §3.65 [defns.undefined]

Another Definition

> ***undefined behavior***
> *behavior for which this document imposes no requirements*
>
> — *C++23 §3.65 [defns.undefined]*

"no requirements" means the code can do **anything at all**.

Undefined Behaviour

the implemented software unit shall be verified ...to provide evidence for ...confidence in the absence of unintended functionality

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Code with UB can do **anything at all**. This is likely **unintended functionality**, so must be avoided.

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Safety-Critical code **must provide evidence**.

Memory Safety?

There is a lot of publicity about the lack of Memory Safety being a **big problem**.

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Such problems are often an example of Undefined Behaviour:

- Lifetime errors
- Bounds errors

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Undefined Behaviour

Undefined behaviour is often a **consequence of an unexpected event**.

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known	known Knowns	known Unknowns
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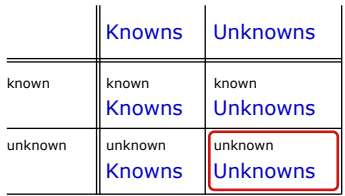
Undefined Behaviour

Undefined behaviour is often a **consequence of an unexpected event**.

If we are serious about “Safety”, we need to work hard to ensure we **eliminate unexpected events**.



Consequences

This all impacts how you develop software.

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In particular, it affects how you **specify** that software, and **test** that software.

Validating Input

A tester walks into a bar...

Validating Input

A tester walks into a bar...

- Orders 1 beer

Validating Input

A tester walks into a bar...

- Orders 1 beer
- Orders 99 beers

Validating Input

A tester walks into a bar...

- Orders 1 beer
- Orders 99 beers
- Orders an orange juice

Validating Input

A tester walks into a bar...

- Orders 1 beer
- Orders 99 beers
- Orders an orange juice
- Orders -1 beers

Validating Input

A tester walks into a bar...

- Orders 1 beer
- Orders 99 beers
- Orders an orange juice
- Orders -1 beers
- Orders four candles

Validating Input

A tester walks into a bar...

- Orders 1 beer
- Orders 99 beers
- Orders an orange juice
- Orders -1 beers
- Orders four candles
- Orders a `DROP TABLE DRINKS`

Validating Input

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This is a **design** problem.

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Decide on behaviour for invalid input.

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- What if the input is invalid?
- What if the input is valid **on its own**, but not **in the current system state**?
- What if the “input” is that something **external** isn’t working as expected?

Can you design the system so these are “expected” and handled gracefully?

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Malformed and invalid inputs can outnumber valid inputs.

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Usually it is impractical to test with all possible inputs.

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Fuzz testing can help fill holes.

Test all layers of your end product: low level libraries, middleware, application processes, the whole “system”

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One of the **most dangerous** consequences of UB is when **the code does exactly what you naively expected, in testing**.

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Memory Safety issues often fall into this category.

Identifying Undefined Behaviour

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Use sanitizers in testing and hardened libraries in testing and production.

Contracts

Preconditions specify what is required to be true when you use a function or class.

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Preconditions specify what is required to be true when you use a function or class.

Postconditions specify what will be true when a function returns.

Checking Contracts: if

You can often check preconditions in code:

```
// precondition: ptr must not be null
void foo(bar* ptr) {
  if(ptr == nullptr) { // contract check
    precondition_violated();
  }
  do_something(*ptr);
}
```

Checking Contracts: macros

You can often check preconditions in code:

```
// precondition: ptr must not be null
void foo(bar* ptr) {
  PRECONDITION(ptr != nullptr);


  do_something(*ptr);
}
```

Checking Contracts: C++26

You can often check preconditions in code:

```
// precondition: ptr must not be null
void foo(bar* ptr)
  pre(ptr != nullptr) { // C++26 syntax


  do_something(*ptr);
}
```

Checking Contracts: Static Analysis

You can often check preconditions in code:

```
// precondition: ptr must not be null
void foo(bar* ptr) {
  /*@ requires @*/        // CodeQL Annotation
  assert(ptr != nullptr);

  do_something(*ptr);
}
```

Checking Contracts: Performance

A checked contract requires evaluating the condition, and branching to the handler on failure.

```
void foo(bar* ptr) {
  PRECONDITION(ptr != nullptr);
  do_something(*ptr);
}
```

```
"foo(bar*)":
  test rdi, rdi
  je .L3
  jmp "do_something(bar&)"
"foo(bar*) [clone .cold]":
.L3:
  push rax
  call "violation_handler"
```

Checking Contracts: Performance

Compilers are good at optimizing out redundant checks.

```
void baz(bar* ptr){
  PRECONDITION(ptr!=nullptr);
  foo(ptr);
  foo(ptr);
}
```

```
"baz(bar*)":
  sub rsp, 24
  test rdi, rdi
  je .L9
  mov QWORD PTR [rsp+8], rdi
  call "do_something(bar&)"
  mov rdi, QWORD PTR [rsp+8]
  add rsp, 24
  jmp "do_something(bar&)"
"baz(bar*) [clone .cold]":
.L9:
  call "violation_handler"
```

Checking Contracts: Performance

Compilers are good at optimizing out redundant checks.

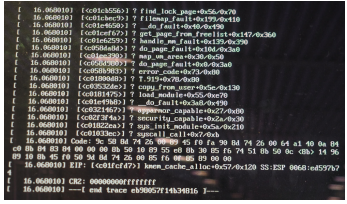
```
void loop(){
  bar values[10]{};

  for(unsigned i=0;i<10;++i) {
    baz(&values[i]);
  }
}
```

```
"loop()":
  push rbx
  sub rsp, 16
  lea rbx, [rsp+6]
.L12:
  mov rdi, rbx
  call "do_something(bar&)"
  mov rdi, rbx
  add rbx, 1
  call "do_something(bar&)"
  lea rax, [rsp+16]
  cmp rax, rbx
  jne .L12
  add rsp, 16
  pop rbx
  ret
```

Violated Contracts

If a contract is violated, **you have a bug**.



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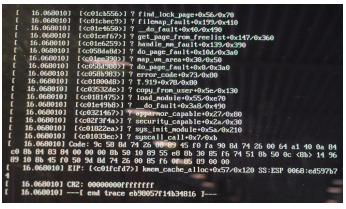

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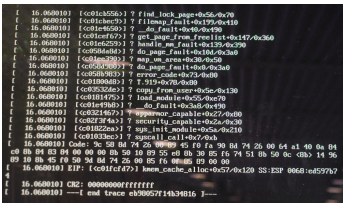

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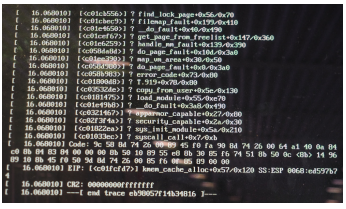

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- Stack trace and core dump

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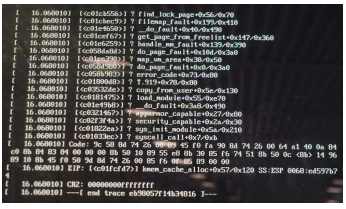

- Break into debugger
- Stack trace and core dump
- Custom logging of state

Violated Contracts

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Including continuing.

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- Use checked functions like `at`
- Use `span` and `string_view` rather than raw pointers
- Use range-based `for` loops rather than indexing
- Use RAII to manage lifetimes

Defense in Depth

Use the “Swiss Cheese” approach:

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- Use contracts

Software and Safety

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- Use “Swiss Cheese” defense in depth

Announcement

Arene Base Library

Woven by Toyota is releasing our foundation-level C++ library for Safety-Critical Systems as Open Source.

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It will be released under the Apache License 2.0 with LLVM exception.

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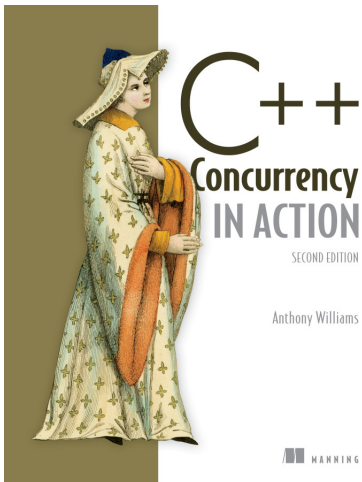
- Provides backports of more recent library features such as `string_view`, `span` and `mdspan`
- Includes enforced preconditions for bounds checks

My Book



C++ Concurrency in Action
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Covers C++17 and the
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