Department I - C Plus Plus

# Modern and Lucid C++ Advanced for Professional Programmers

## Week 14 – Rust and C++

Thomas Corbat / Felix Morgner

Rapperswil, 06.06.2023

FS2023

OST
Ostschweizer
Fachhochschule

# Agenda



- **Recap Week 13**
- **Intro to Rust**
- **Rust-like Features in C++**

# Goals



- **Participants should …**
  - … know how Rust provides increased lifetime safety
  - … know how to apply similar safety features using the Clang C++ compiler

# Recap Week 13

OST
Ostschweizer
Fachhochschule

# Motivating Example



- **Five libraries**
  - All depending on a common infrastructure library
- **Two executables**
  - Depend on some or all of the libraries
- **Two target-platforms**
  - Linux on x86_64 and armv7
  - OS X
- **Code will change owners**
- **4 months time-frame**

# Idea: Scripts!

- **Write a script that…**
  - Compiles each source file
  - Links all object files together
  - Repeats that for every target
- **DON’T! Because…**
  - … every source file get built every time!
  - … the commands tend to be platform specific
  - … build order must be managed manually
  - … scripts tend to become messy over time

```
#!/bin/bash

# Build libdabip
gcc -c parser.cpp
gcc -c generator
…
gcc -shared -o libdabip parser.o
…

# Build libdabdecode
gcc -c ensemble.cpp
gcc -c decoder.cpp
…
gcc -shared -o libdabdecode ensemble.o …

# Build <you get the idea>
```

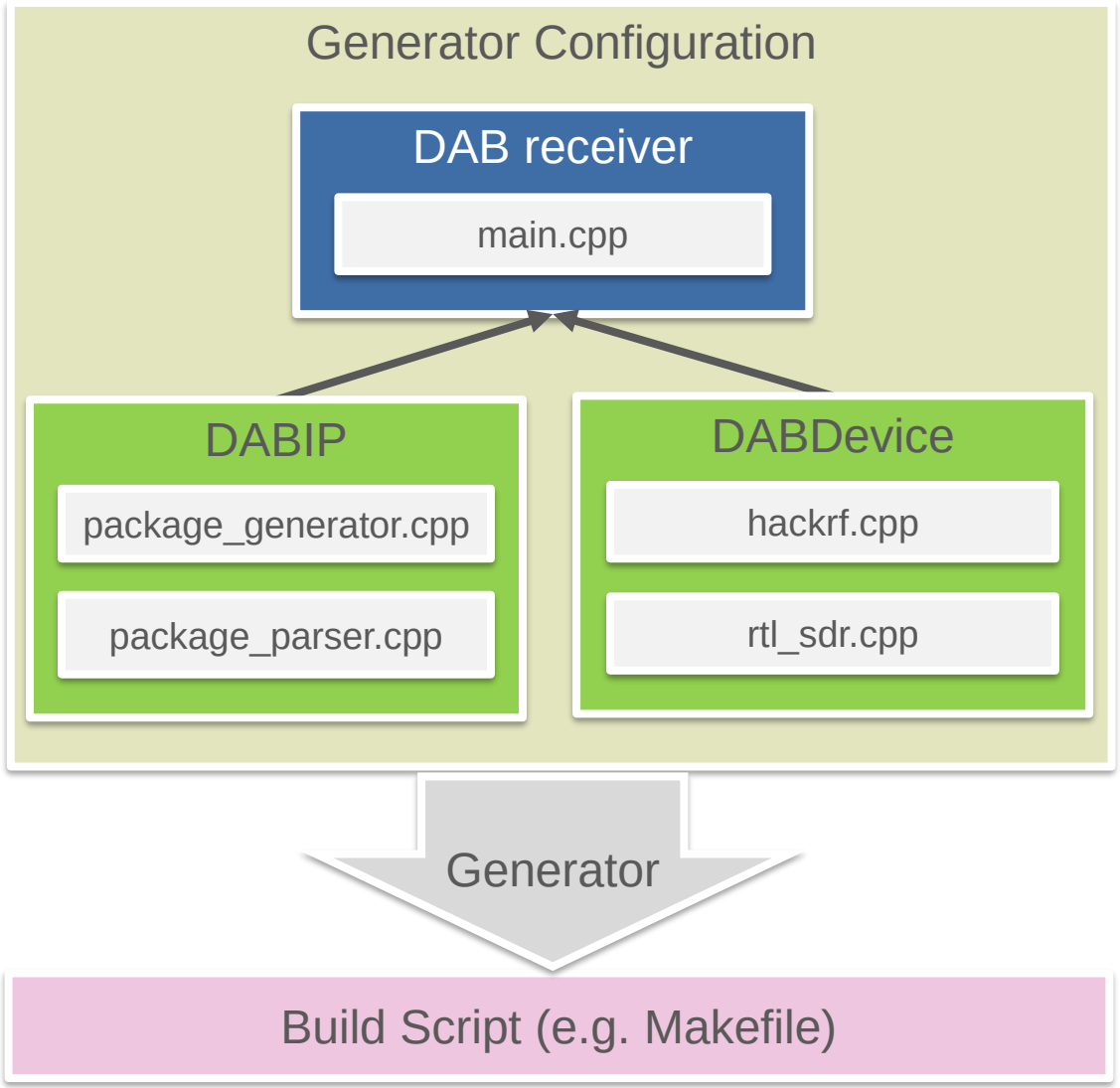
# Different Classes of Build Automation Software



- **Make-style Build Tools**
  - Run build scripts
  - Produce your final products
  - Often verbose
  - Use a language agnostic configuration language
- **Build Script Generators**
  - Generate configurations for Make-style Build Systems or Build Scripts
  - Configuration independent of actual build tool
  - Advanced features (download dependencies, etc.)

# Build Script Generators

- **Idea: Take a step back**
  - Define what we want to achieve, not how to do it
  - Work on a higher level
  - Let the create the actual build configurations
- **Platform independent build specification**
- **Tool Independent**
  - Often can generate IDE projects
  - Support multiple build tools



- **CMake includes CTest**
  - Enable CTest using `enable_testing()`
  - Create a “Test Runner” executable
    - Make sure to include your suite sources!
  - Configure build environment:

```
$ cmake ..
```

  - Build the project:

```
$ cmake --build .
```

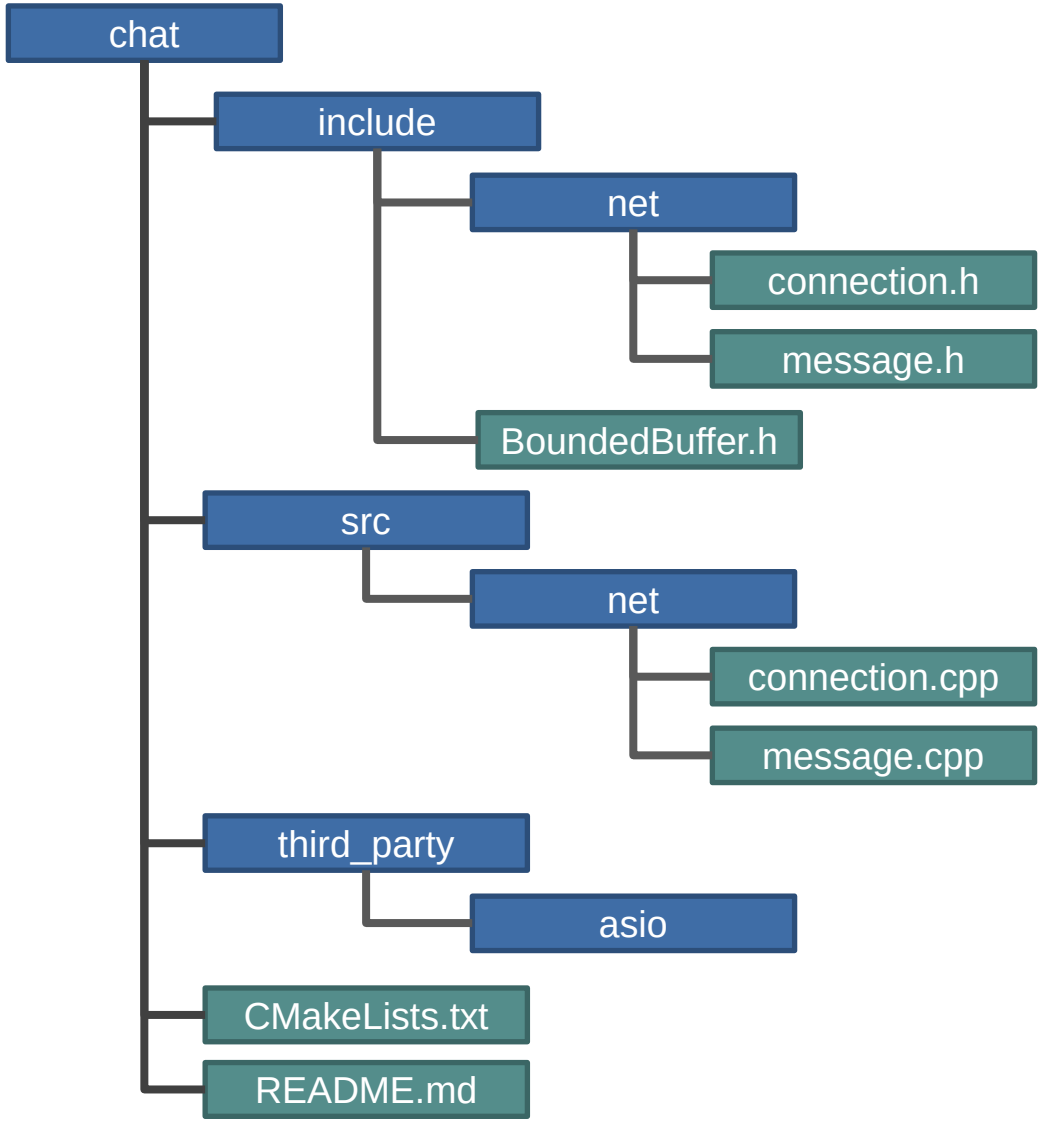
  - Run `ctest`

```
$ ctest --output-on-failure
```

```
cmake_minimum_required(VERSION "3.12.0")

project("answer" LANGUAGES CXX)

enable_testing()

add_library("${PROJECT_NAME}"
  "answer.cpp"
)

add_executable("test_runner"
  "Test.cpp"
)

target_link_libraries("test_runner" PRIVATE
  "answer“
)

target_include_directories("test_runner" SYSTEM PRIVATE
  "cute“
)

add_test("tests" "test_runner")
```

# Project Layout (General)

- **Headers live in the “include” folder**
  - Add subfolders for separate subsystems if needed
- **Implementation files live in the “src” folder**
  - Make sure that subfolder layout matches the “include” folder (**consistency**)
- **Put third-party projects/sources in a “third_party” or “lib” folder**
- **Test resource live in the “test” folder**
  - The test folder will have src, include, and third_party subfolders if required
- **Build configuration files should live in the root of your project**



# Project Layout (Libraries)

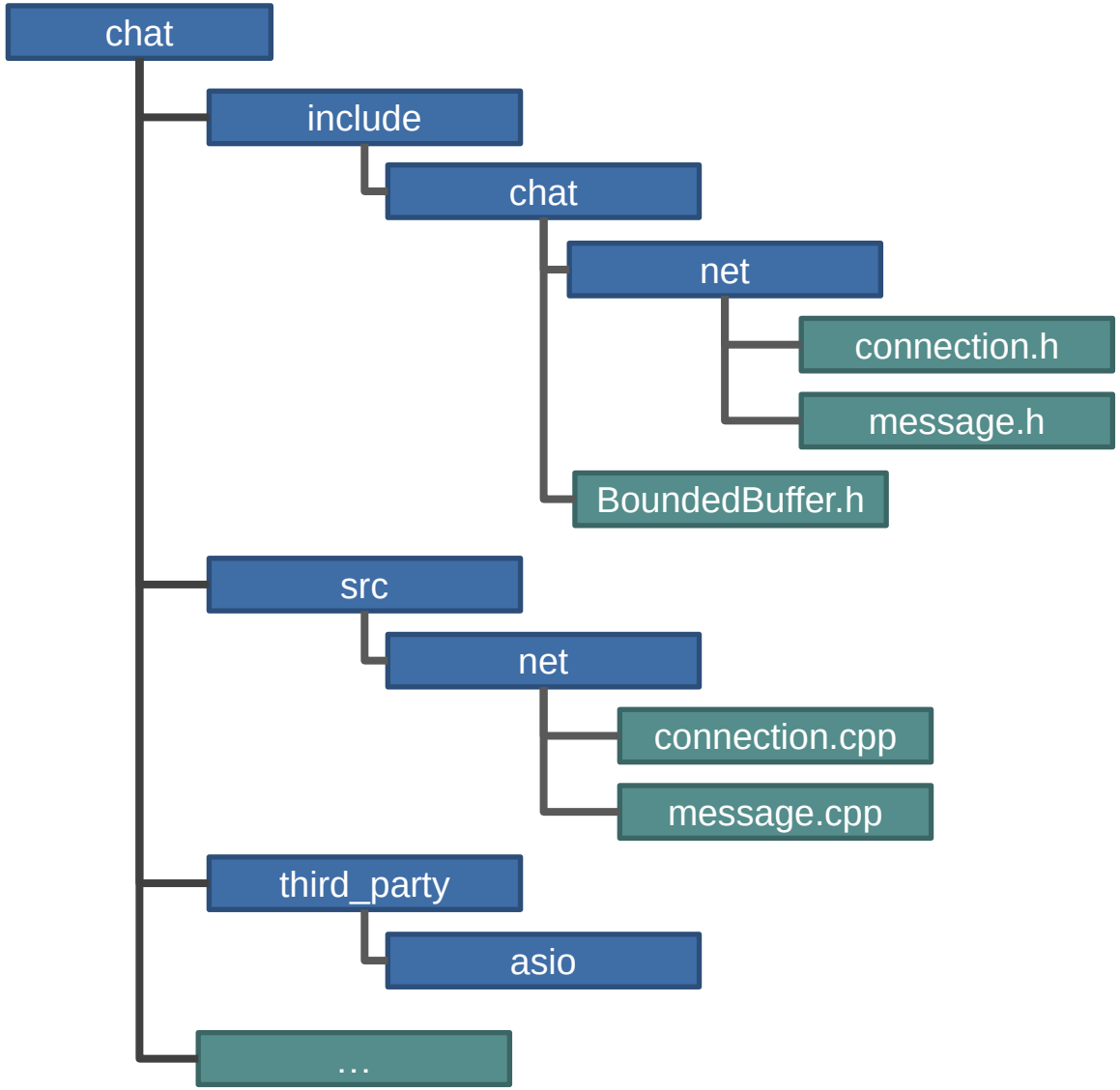
- **Libraries may benefit from a slightly different layout**
  - You will need to ship your headers
  - Your headers might have very generic names
- **Idea: Introduce another nesting level for your headers**
  - Use the name of your project

```
#include “message.h”
```

… becomes …

```
#include “chat/message.h”
```

  - Helps avoid filename clashes



# Intro to Rust

OST
Ostschweizer
Fachhochschule

- **Multiplayer Game**
  - Focused on Survival Gameplay
  - First Released in December 2012
  - Inspired by S.T.A.L.K.E.R
- **Implementation**
  - Built on top of Unity
  - Most likely C#
- **Online-only**

- **Multi-paradigm Programming Language**
  - Functional
  - Imperative
  - Generic
  - …
- **Strong focus on safety**
  - Ownership
  - Memory Safety
- **Designed by Mozilla in 2010**
  - Now “The Rust Foundation”

- **Rustc**
  - Compiler
  - Built on top of LLVM
- **Cargo**
  - Quick-start for projects
  - Build system and package manager
  - https://crates.io as primary repository
- **Rustfmt**
  - Formatter

# Live Coding Demo

# Ownership



- **Every Object has an Owner**
  - Ownership can be Transferred
  - Scope is Bound to Owner
- **Ownership has *reader-writer-lock* semantics**
  - Multiple immutable references
  - Only one mutable reference
- **Value semantics still apply when …**
  - … copying the object
  - … moving the object

```
struct Number {
    value: u32
}

fn consume(num: Number) -> u32 {
    num.value
}

pub fn main() {
    let num = Number{ value: 32 };
    consume(num);
    println!("num.value == {0}", num.value);
}
```

# Live Coding Demo

```
struct Number {
    value: u32
}

fn consume(num: Number) -> u32 {
    num.value
}

pub fn main() {
    let num = Number{ value: 32 };
    consume(num);
    println!("object.value == {0}", num.value);
}
```

```
error[E0382]: borrow of moved value: `num`
  --> <source>:13:37
   |
11 | let num = Number{ value: 32 };
   | --- move occurs because `num` has type `Number`, which does not implement the `Copy` trait
12 | consume(num);
   | --- value moved here
13 | println!("object.value == {0}", num.value);
   | ^^^^^^^^^ value borrowed here after move
```

# Live Coding Demo

# Either Copy or use References



```
#[derive(Clone, Copy)]
struct Number {
    value: u32
}

fn consume(num: Number) -> u32 {
    num.value
}

pub fn main() {
    let num = Number{ value: 32 };
    consume(num);
    println!("object.value == {0}", num.value);
}
```

```
struct Number {
    value: u32
}

fn consume(num: & Number) -> u32 {
    num.value
}

pub fn main() {
    let num = Number{ value: 32 };
    consume(&num);
    println!("object.value == {0}", num.value);
}
```

- **Every Object has an Owner**
  - The Compiler Enforces Validity
  - Moved-from values cannot be used anymore
- **Primary use: Multithreading!**
  - Move values into closure
  - All Accesses After Move are Invalid!
  - No data-race possible!

# Live Coding Demo

```rust
use std::thread;

pub fn main() {
    let v = vec![1, 2, 3];

    let handle = thread::spawn(|| {
        println!("{:?}", v);
    });

    handle.join().unwrap();
}
```

```
error[E0373]: closure may outlive the current function, but it borrows `v`, which is owned by the
current function
 --> <source>:6:32
  |
6 | let handle = thread::spawn(|| {
  | ^^ may outlive borrowed value `v`
7 | println!("{:?}", v);
  | - `v` is borrowed here
```

```rust
use std::thread;

pub fn main() {
    let v = vec![1, 2, 3];

    let handle = thread::spawn(move || {
        println!("{:?}", v);
    });

    handle.join().unwrap();
}
```

# Rust-like Features in C++

OST
Ostschweizer
Fachhochschule

# C++ Extensions



- **Compilers Support Extensions**
  - “Playground” for Future Language Features
  - Support for Library Specific Features
  - GNU C++ Dialect
- **Clang has Rust-like Ownership Extensions**
  - Specific Warning Category
    - `-Wconsumed`

# Consumed Annotation Checking



- **Classes Must be Marked Using `consumable` Attribute**
  - `[[clang::consumable(…)]]`
- **Functions and Parameters Are Marked with Specific Attributes**
  - `[[clang::callable_when(…)]]`
  - `[[clang::return_typestate(…)]]`
  - `[[clang::set_typestate(…)]]`
  - `[[clang::param_typestate(…)]]`
- **Typestates:**
  - unconsumed, consumed, unknown

```
struct Number {
    unsigned value() const {
        return m_value;
    }

    unsigned m_value;
};

auto main() -> int {
    auto num = Number{32};

    auto fut = std::async(std::launch::async, [num = std::move(num)]{
        std::cout << num.value() << '\n';
    });

    std::cout << num.value() << '\n';
}
```

# Live Coding Demo

```
struct [[clang::consumable(unconsumed)]] Number
{
    [[clang::callable_when(unconsumed)]]
    unsigned value() const {
        return m_value;
    }

    unsigned m_value;
};
```

```
<source>:50:22: error: invalid invocation of method 'value' on object 'num' while it is in
the 'consumed' state [-Werror,-Wconsumed]
std::cout << num.value() << '\n';
```

# Live Coding Demo

# Let's try to do it the Rust way



```
auto main() -> int {
    auto num = Number{32};

    auto fut = std::async(std::launch::async, [num = std::move(num)]{
        std::cout << num.value() << '\n';
    });

    num = Number{42};

    std::cout << num.value() << '\n';
}
```

# Summary



- **Rust has a powerful mechanism to prevent invalid use of objects**
  - There can only ever be one owner for an object
  - Together with memory safety features makes making mistakes very hard
- **Efforts in the Clang C++ compiler to try and provide similar guarantees in C++**
  - Currently no effort of standardizing this mechanism
  - Must see the body of the functions