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Compilers Coursework Into

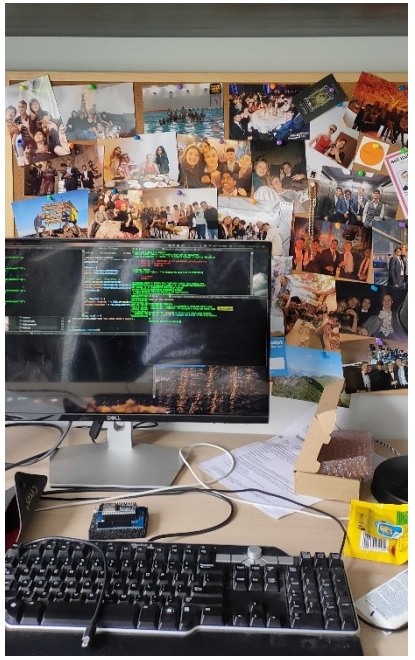
How to use a compiler to write your compiler

Simon Staal – 2026-02-12

Introduction

About me

- MEng Electronic & Information Engineering
- Graduated 2023 valedictorian
- Compilers TA for 5 years
- 7+ years of programming C++
- 2.5 years at Optiver, Amsterdam office



Agenda

1. OOP
2. Leveraging Type Information
3. RAII
4. Optiver

Optiver

What is OOP?

OOP in C++

virtual

```
2   class Shape
3   {
4   public:
5       virtual ~Shape() = default;
6       virtual double GetArea() const;
7   };
```

OOP in C++

virtual

```
 9  class Square : public Shape
10  {
11  public:
12      Square(double sideLength)
13          : mSideLength(sideLength)
14      {}
15
16      double GetArea() const
17      {
18          return mSideLength * mSideLength;
19      }
20  private:
21      double mSideLength;
22  };
```

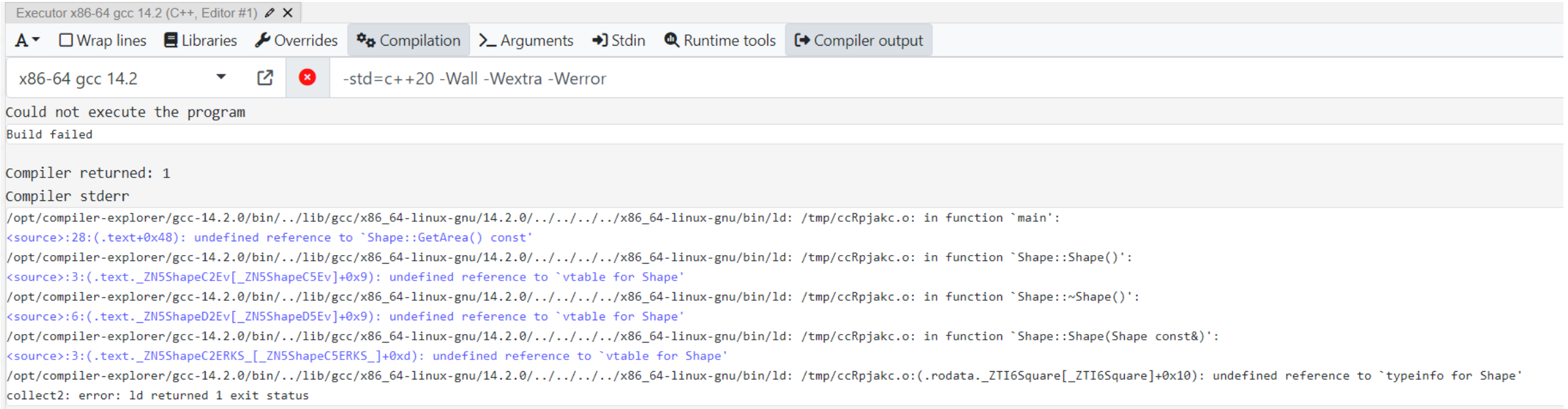
OOP in C++

What will the output be?

```
25  int main()
26  {
27      Shape s = Square{1.0};
28      std::cout << s.GetArea() << std::endl;
29  }
```

OOP in C++

What will the output be?



OOP in C++

What is going on?

```
2   class Shape
3   {
4   public:
5       virtual ~Shape() = default;
6       virtual double GetArea() const;
7   };

25  int main()
26  {
27      Shape s = Square{1.0};
28      std::cout << s.GetArea() << std::endl;
29  }
```

Never defined

"slicing"

OOP in C++

How to fix: Pure virtual

```
3  class Shape
4  {
5  public:
6      virtual ~Shape() = default;
7      virtual double GetArea() const = 0;
8  };
```

```
<source>: In function 'int main()':
<source>:27:31: error: cannot allocate an object of abstract type 'Shape'
   27 |     const Shape s = Square{1.0};
      |                               ^
<source>:3:7: note:   because the following virtual functions are pure within 'Shape':
    3 | class Shape
      |       ^~~~~
<source>:7:20: note:     'virtual double Shape::GetArea() const'
    7 |     virtual double GetArea() const = 0;
      |                    ^~~~~~~
<source>:27:17: error: cannot declare variable 's' to be of abstract type 'Shape'
   27 |     const Shape s = Square{1.0};
      |                 ^
```

Compiler Flags

- Compiler errors are (mostly) good ☺
- Transforms runtime error you might miss into obvious issues
- Google / ChatGPT / Claude how to fix them

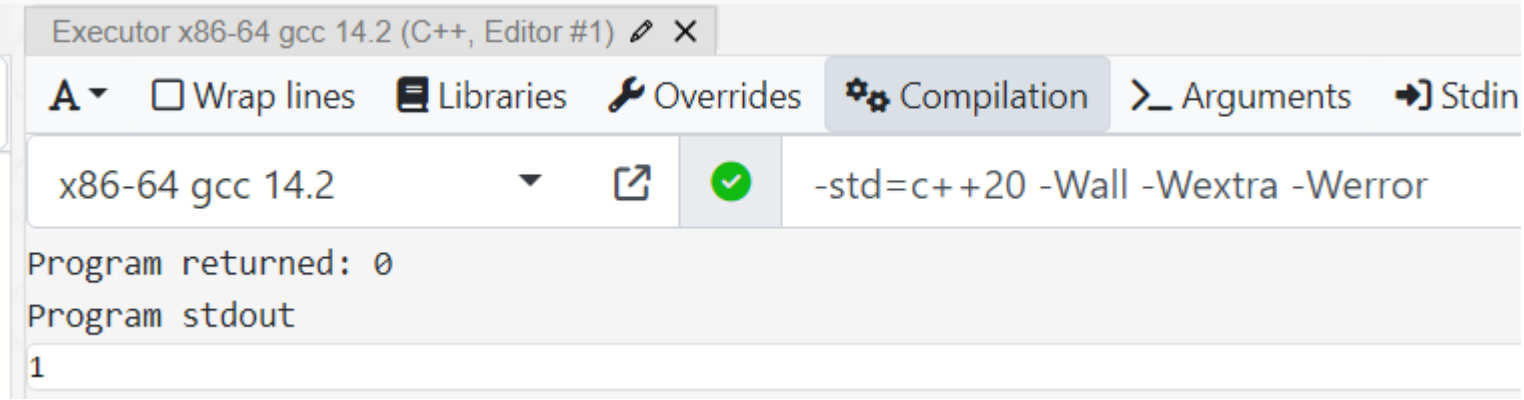
```
-std=c++23 -Wall -Wextra -Wsuggest-override -Werror
```

OOP in C++

How to fix: using pointers

Why does this help?

```
25  int main()
26  {
27      const Shape& s = Square{1.0};
28      std::cout << s.GetArea() << std::endl;
29  }
```



OOP in C?

virtual under the hood: function pointers

```
2   class Shape
3   {
4   public:
5       virtual ~Shape() = default;
6       virtual double GetArea() const;
7   };
```

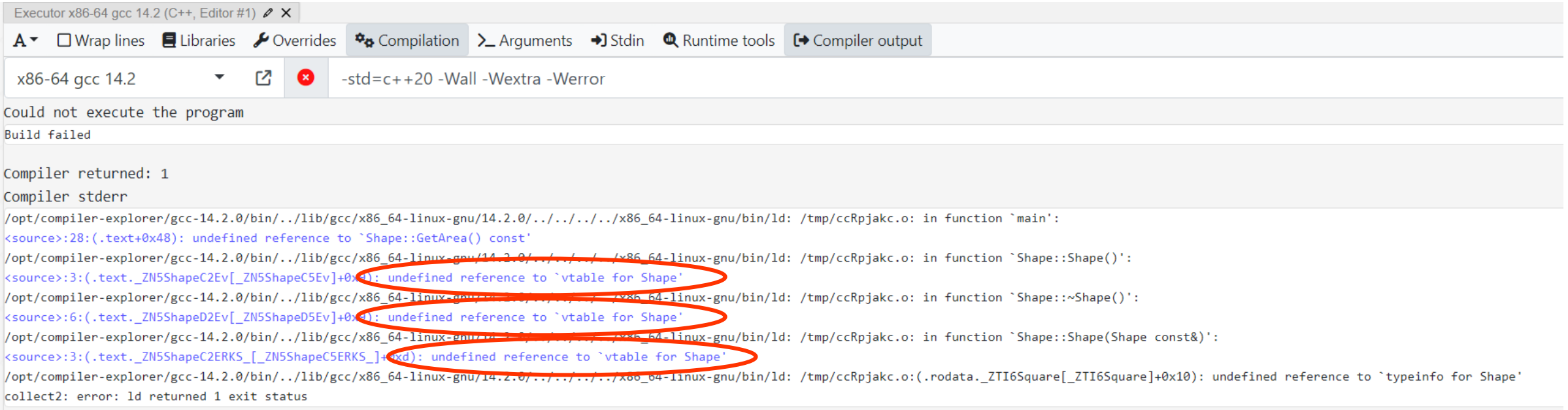
In C++ we call this a “vtable”

```
4   struct Shape
5   {
6       double (*GetArea)(const void* self);
7   };
```

How does calling this work?

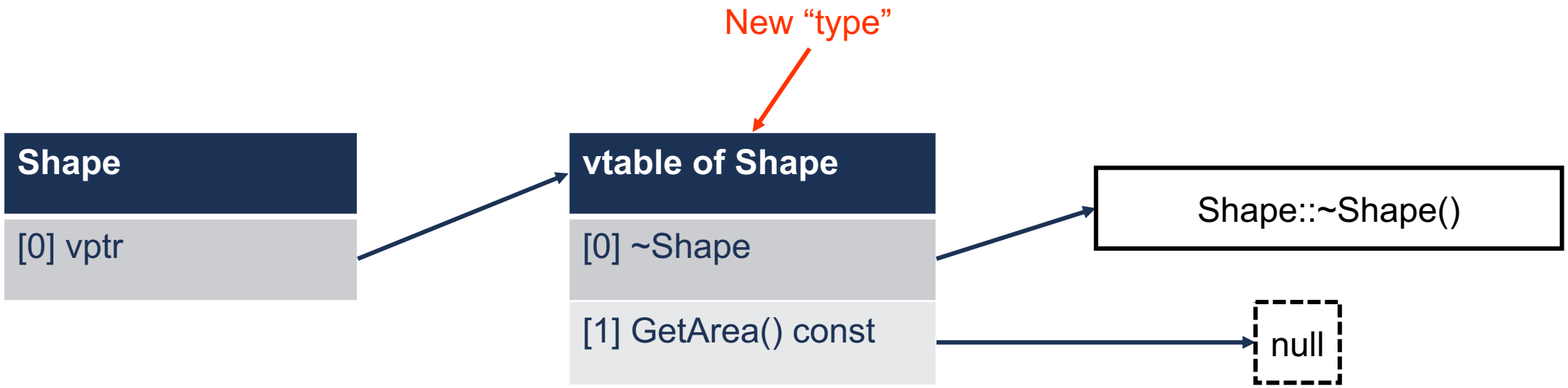
OOP in C++

Linker errors



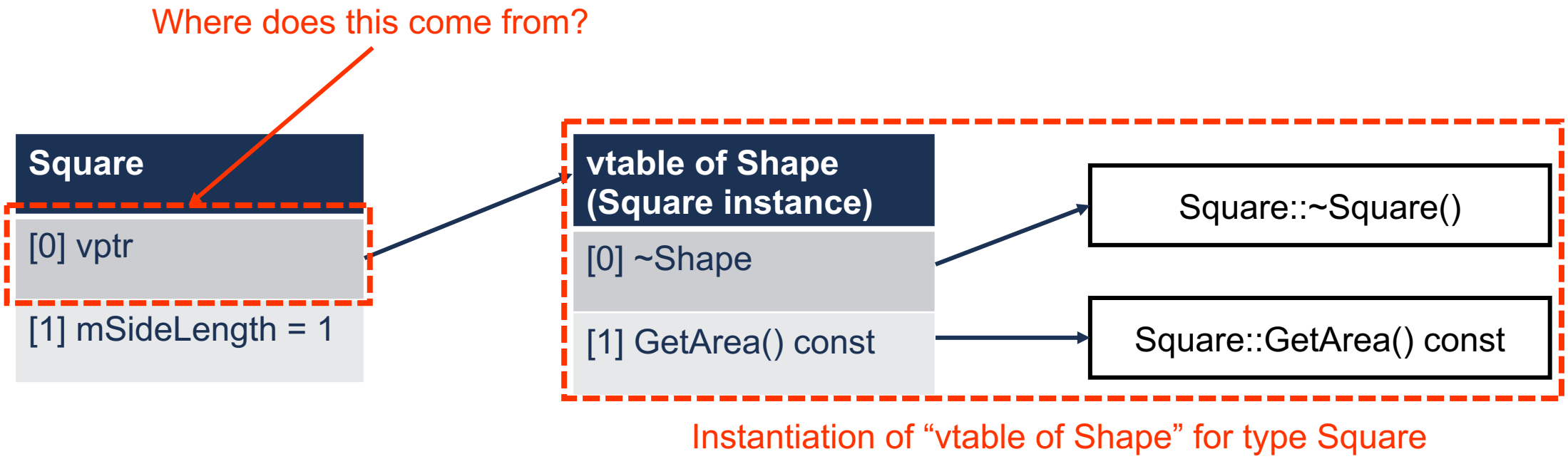
OOP in C++

virtual under the hood: base class



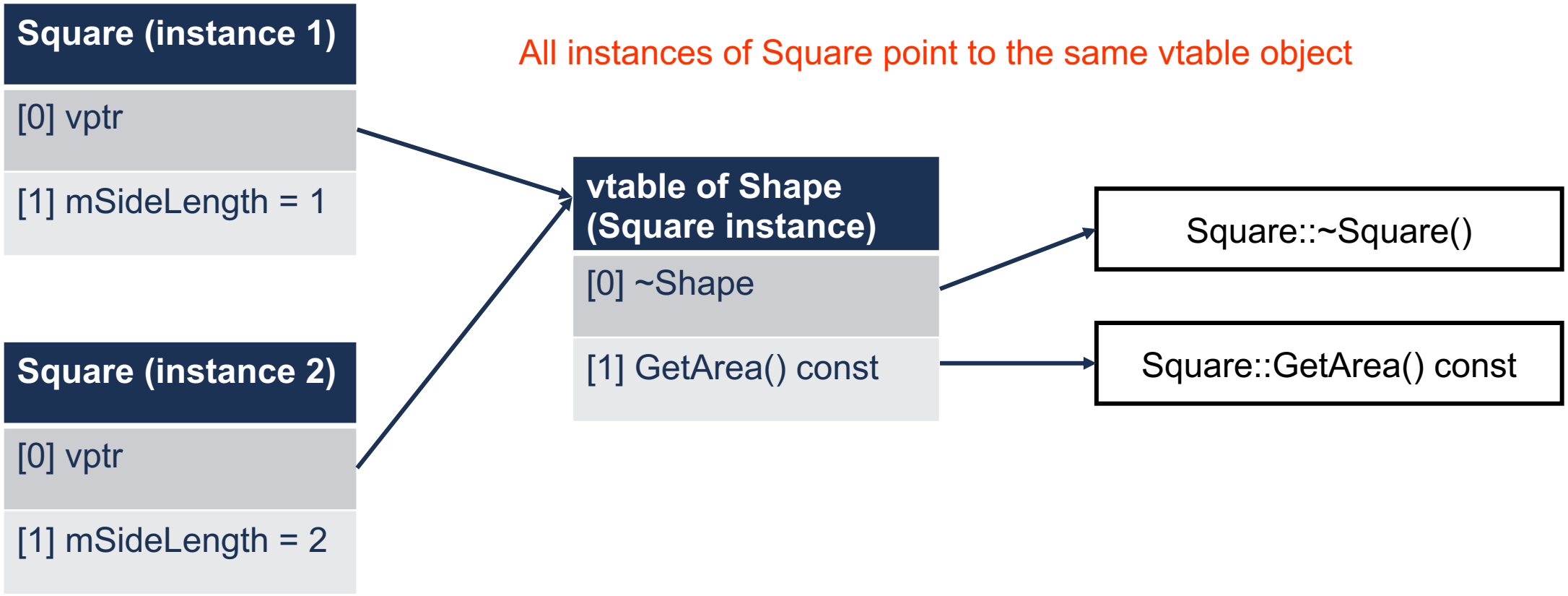
OOP in C++

virtual under the hood: derived class



OOP in C++

virtual under the hood: multiple instances



OOP in C?

Implementing inheritance

```
4  struct Shape
5  {
6      double (*GetArea)(const void* self);
7  };
```

OOP in C?

Implementing inheritance

```
 9  struct Square
10  {
11      struct Shape mBase;
12      double mSideLength;
13  };
14
15  double Square_GetArea(const void* self)
16  {
17      const struct Square* this = self;
18      return this->mSideLength * this->mSideLength;
19  }
20
21  // "Constructor", e.g. Square() in C++
22  struct Square* Square_Init(struct Square* this, double sideLength)
23  {
24      this->mBase.GetArea = &Square_GetArea; // In C++ the compiler will do this for you
25      this->mSideLength = sideLength;
26      return this;
27  }
```

Equivalent to struct Square：public Shape

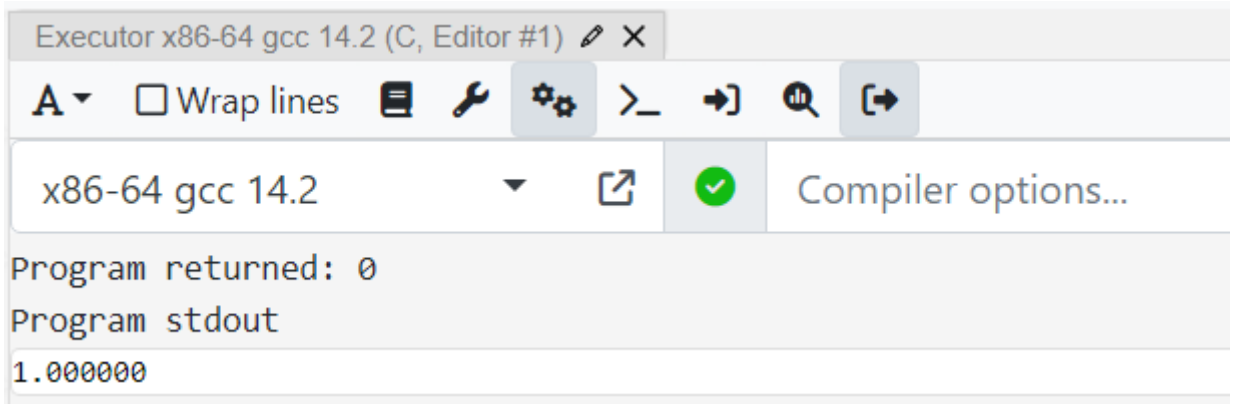
Equivalent to double GetArea() const override

OOP in C?

Inheritance in action

```
29  int main()
30  {
31      const struct Shape* shape = &Square_Init(malloc(sizeof(struct Square)), 1.0)->mBase;
32      printf("%f\n", shape->GetArea(shape));
33  }
```

Equivalent of new Square(1)



OOP in C?

What happens if we forget to init?

```
29  int main()
30  {
31      const stru                                  struct Square));
32      printf("%f
33  }
```

Why does slicing happen?

Compiler vs programmer managed memory

- Shape is using compiler managed stack memory
- Compiler will prevent you from making illegal memory access

```
15  double Square_GetArea(const void* self)
16  {
17      const struct Square* this = self;
18      return this->length * this->length;
19  }
```

- Shape& / Shape* is just an address, compiler (at call site) doesn't own the memory

OOP in C++

override and final specifiers

```
10  class Square final : public Shape
11  {
12  public:
13      Square(double sideLength)
14          : mSideLength(sideLength)
15      {}
16
17      double GetArea() const override
18      {
19          return mSideLength * mSideLength;
20      }
21  private:
22      double mSideLength;
23  };
```

Compiler API Design

AST Node

```
4  class Node
5  {
6      virtual ~Node() = default;
7      virtual void EmitRISC(std::ostream&, Context&) const = 0;
8      virtual void Print(std::ostream&) const = 0;
9  };
```

Compiler API Design

Implementing ReturnStatement

```
14  class ReturnStatement final : public Node
15  {
16  public:
17      ReturnStatement(NodePtr expression) : mExpression{expression} {}
18
19      void EmitRISC(std::ostream&, Context&) const override;
20      void Print(std::ostream&) const override;
21
22  private:
23      NodePtr mExpression;
24  };
```

Compiler API Design

Implementing ReturnStatement

```
31  void ReturnStatement::EmitRISC(std::ostream& out, Context& context) const
32  {
33      // Set destination register to return register
34      context.SetDestinationRegister("a0");
35
36      // Compile contained expression (into return register)
37      if (mExpression)
38          mExpression->EmitRISC(out, context);
39
40      // Exit function
41      out << "j " << context.GetFunctionEndLabel() << std::endl;
42  }
```

Compiler API Design

Is everything a Node?

- No! Only things that produce assembly are
- It’s okay to have plain old data types
- It’s okay to have more specialized interfaces
- Don’t try and shoehorn everything to be a Node

Type Safety

Plain old data: enum class

- Type-safe enum
- Perfect for representing a finite set of labelled values

```
4  enum class TypeSpecifier
5  {
6      INT,
7      // FLOAT,
8      // ...
9  };
```

Type Safety

Supporting new types

```
44  void ReturnStatement::EmitRISC(std::ostream& out, Context& context) const
45  {
46      // Set destination register to return register
47      switch(context.GetFunctionReturnType())
48      {
49          case TypeSpecifier::INT:
50              context.SetDestinationRegister("a0");
51              break;
52      }
```

```
<source>: In member function 'virtual void ReturnStatement::EmitRISC(std::ostream&, Context&) const':
<source>:47:11: error: enumeration value 'FLOAT' not handled in switch [-Werror=switch]
   47 |     switch(context.GetFunctionReturnType())
      |            ^
cc1plus: all warnings being treated as errors
```

Type Safety

Supporting new types

```
40  void ReturnStatement::EmitRISC(std::ostream& out, Context& context) const
41  {
42      // Set destination register to return register
43      switch(context.GetFunctionReturnType())
44      {
45          case TypeSpecifier::INT:
46              context.SetDestinationRegister("a0");
47              break;
48          case TypeSpecifier::FLOAT:
49              context.SetDestinationRegister("fa0");
50              break;
51      }
```

Type Safety

Alternative: No type safety

- Consider using a `std::string` instead

```
40  void ReturnStatement::EmitRISC(std::ostream& out, Context& context) const
41  {
42      // Set destination register to return register
43      if (context.GetFunctionReturnType() == "INT")
44      {
45          context.SetDestinationRegister("a0");
46      }
47      // Compiler cannot help you when you want to add FLOAT support
```

- Will just generate incorrect assembly
- Relies on sufficient test case coverage to catch
- You will loose marks on silly mistakes like this

Compiler API Evolution

BinaryAdd: Sample implementation

- Sometimes you will need to expose more information. Consider:

```
34  class BinaryAdd final : public Node
35  {
36  public:
37      void EmitRISC(std::ostream&, Context&) const override;
38      void Print(std::ostream&) const override;
39
40  private:
41      NodePtr mLeft;
42      NodePtr mRight;
43  };
```

Compiler API Evolution

BinaryAdd: Sample implementation

```
50  void BinaryAdd::EmitRISC(std::ostream &out, Context &context) const
51  {
52      // Acquire a register for the left operand
53      auto leftReg = context.AcquireRegister();
54      mLeft->EmitRISC(out, context);
55
56      // Acquire a register for the right operand
57      auto rightReg = context.AcquireRegister();
58      mRight->EmitRISC(out, context);
59
60      // Perform the add into the current destination register
61      out << "add " << context.GetDestinationRegister() << ", "
62          << leftReg << ", " << rightReg << "\n";
63
64      // Release temporary registers
65      context.ReleaseRegister(leftReg);
66      context.ReleaseRegister(rightReg);
67  }
```

Compiler API Evolution

BinaryAdd: How to deal with pointer arithmetic?

- We need to be able to check if one of the operands is a pointer to implement pointer arithmetic
- Do NOT add this to `Node`
  - Does it make sense for a `FunctionDefinition` to implement this? Or a `ForLoop`?
- Update types in parser file and the compiler will tell you what needs to be changed
  - Avoid `dynamic_cast` (or C-style casting) as much as possible

```
31  class Expression : public Node
32  {
33  public:
34      virtual bool IsPointerType() const = 0;
35  };
```

Compiler API Evolution

BinaryAdd: Update API

```
39  class BinaryAdd final : public Expression
40  {
41  public:
42      void EmitRISC(std::ostream&, Context&) const override;
43      void Print(std::ostream&) const override;
44      bool IsPointerType() const override;
45
46  private:
47      ExpressionPtr mLeft;
48      ExpressionPtr mRight;
49  };
```

Compiler API Evolution

BinaryAdd: Update implementation

```
54  void BinaryAdd::EmitRISC(std::ostream &out, Context &context) const
55  {
56      // Acquire registers and compile operands
57      ...
58
59      // Scale the non-pointer operand by 4 (32-bit architecture)
60      if (mLeft->IsPointerType() && !mRight->IsPointerType()) {
61          out << "  slli " << rightReg << ", " << rightReg << ", 2\n";
62      } else if (mRight->IsPointerType() && !mLeft->IsPointerType()) {
63          out << "  slli " << leftReg << ", " << leftReg << ", 2\n";
64      }
65
66      // Perform the add into the current destination register
67      out << "add " << context.GetDestinationRegister() << ", "
68          << leftReg << ", " << rightReg << "\n";
69
70      // Release temporary registers
71      context.ReleaseRegister(leftReg);
72      context.ReleaseRegister(rightReg);
73  }
```

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What is RAII?

RAII

Introduction

- RAII: Resource Allocation Is Initialisation
- Acquires necessary resources on construction
- Relinquishes necessary resources on destruction
- Moves responsibility of resource management from programmer to compiler (for stack variables)
- Originated from C++11
- E.g. `std::vector` de-allocates the heap memory it owns when it's destructed

RAII

std::unique_ptr

- Memory is an example of a “resource”
- We want to avoid “leaking” memory
- Compiler can do the work for us!
- *Ideally*: never use new or delete again*

```
108  void example()
109  {
110      int* raw = new int(1);
111      std::unique_ptr<int> smart = std::make_unique<int>(3); // allocates own memory
112      std::unique_ptr<int> alsoSmart{ new int(2) }; // takes ownership of "existing" memory
113  } // `delete` called on smart's underlying pointer by smart's destructor, raw gets leaked
```

RAII

std::unique_ptr: How it works

- What happens if we made a copy of smart?

```
108  void example()
109  {
<source>: In function 'void example()':
<source>:112:38: error: use of deleted function 'std::unique_ptr<_Tp, _Dp>::unique_ptr(const std::unique_ptr<_Tp, _Dp>&)
  112 |     std::unique_ptr<int> smartCopy = smart;
      |                                      ^~~~~
113  }  // What w      ere?
```

- If we can't copy std::unique_ptr how can we pass them around?

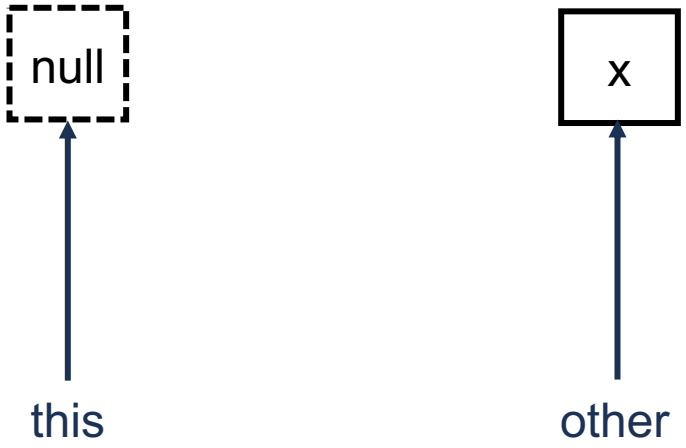
RAII

Move semantics

```
108  class MyUniquePtr {
109  public:
110      MyUniquePtr(int* raw) : mOwned(raw) {}
111      ~MyUniquePtr() { delete mOwned; }
112      MyUniquePtr(const MyUniquePtr& other) = delete;
113      MyUniquePtr(MyUniquePtr&& other) {
114          std::swap(mOwned, other.mOwned); // "steal" other's resource
115      }
116      MyUniquePtr& operator=(const MyUniquePtr& other) = delete;
117      MyUniquePtr& operator=(MyUniquePtr&& other) {
118          std::swap(mOwned, other.mOwned);
119          return *this;
120      }
121  private:
122      int* mOwned = nullptr;
123  };
```

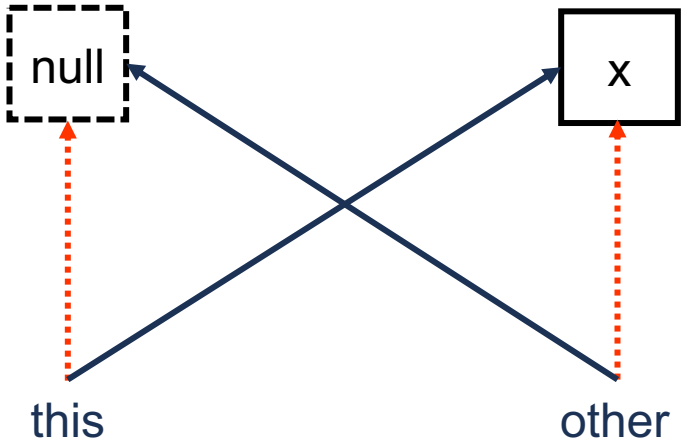
RAII

Move semantics



RAII

Move semantics



RAII

Move semantics

```
108  class MyUniquePtr {
109  public:
110      MyUniquePtr(int* raw) : mOwned(raw) {}
111      ~MyUniquePtr() { delete mOwned; }
112      MyUniquePtr(const MyUniquePtr& other) = delete;
113      MyUniquePtr(MyUniquePtr&& other) {
114          std::swap(mOwned, other.mOwned); // "steal" other's resource
115      }
116      MyUniquePtr& operator=(const MyUniquePtr& other) = delete;
117      MyUniquePtr& operator=(MyUniquePtr&& other) {
118          std::swap(mOwned, other.mOwned);
119          return *this;
120      }
121  private:
122      int* mOwned = nullptr;
123  };
```

Move Semantics

l-values and r-values

- In a nutshell:
- T& is an l-value: represents a variable
- T&& is an r-value: represents a temporary
- std::move(x) casts its argument into an r-value
  - Does not “move” anything – just a cast
- How could we convert an r-value into an l-value?
- const T& accepts both types of values. Why can it do this?

Move Semantics

l-values and r-values: example

```
108  void test(int& x) { std::cout << "l-value\n"; }
109  void test(int&& x) { std::cout << "r-value\n"; }
110
111  int main()
112  {
113      test(1);
114      int x = 2;
115      test(x);
116      test(std::move(x));
117      std::cout << x << '\n'; // What is the value of x here?
118  }
```

Move Semantics

Passing around std::unique_ptr

```
111  void example(std::unique_ptr<int>&& x)
112  {
113      // Note: x is an l-value of type "r-value reference to std::unique_ptr"
114      std::unique_ptr<int> mine = std::move(x); // another std::move is required here
115  }
116
117  int main()
118  {
119      example(std::unique_ptr<int>{}); // invoke directly with temporary
120      auto x = std::make_unique<int>(1);
121      example(x); // compile-error: x is an l-value
122      example(std::move(x)); // casts x to r-value
123  }
```

RAII

For your compiler

- Try your best not to leak memory (good practice)
  - Unfortunately, you need to use raw pointers in bison parser
  - Don’t use std::shared_ptr
  - using NodePtr = std::unique_ptr<const Node>
- Can you think of any other applications?

```
54  void BinaryAdd::EmitRISC(std::ostream &out, Context &context) const
55  {
56      // Acquire a register for the left operand
57      auto leftReg = context.AcquireRegister();
58      mLeft->EmitRISC(out, context);
59
60      // Acquire a register for the right operand
61      auto rightReg = context.AcquireRegister();
62      mRight->EmitRISC(out, context);
63
64      ...
65
66      // Release temporary registers
67      context.ReleaseRegister(leftReg);
68      context.ReleaseRegister(rightReg);
69  }
```

Wrap-up

Summary

- Keep your code as simple as possible (avoid branches)
- Reuse your code as much as possible (no copy-pasting)
- Let the compiler help catch your mistakes (make your intent explicit)
- Don’t be afraid to make simplifying assumptions
  - Try to ensure these are very “visible” so you can potentially fix them later
- Good opportunity to explore other std library classes
- Learn :)

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Questions?

Simon Staal
Software Engineer

simonstaal@optiver.com

What we do

Three tracks, choose yours

Trading

Analyse live markets, weigh risk and reward, and adapt strategies in real time.

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Build and optimise the systems that power our trading – from low-latency pricing engines to advanced FPGA hardware.

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Programmes: Discover your fit

Applications Open

- 5-day immersive experience in trading, technology or research
- Work with our teams on real-world challenges
- Learn how your skills translate into market impact
- Meet our teams and explore different career paths

Opportunities in 2026

Future Focus (Quants) - closed

Career Kickstarter (Trading)

Career Kickstarter (Tech)

Career Kickstarter (Women in Tech) - closed

Internships: Real projects, real impact

Applications Open

- Paid, full-time summer experience in Amsterdam
- Structured training and close collaboration with experienced teams
- Ownership of projects with measurable business impact
- Pathway to a full-time offer
- **Applications closing in a few weeks**

Opportunities in 2026

Quantitative Research Internship - closed

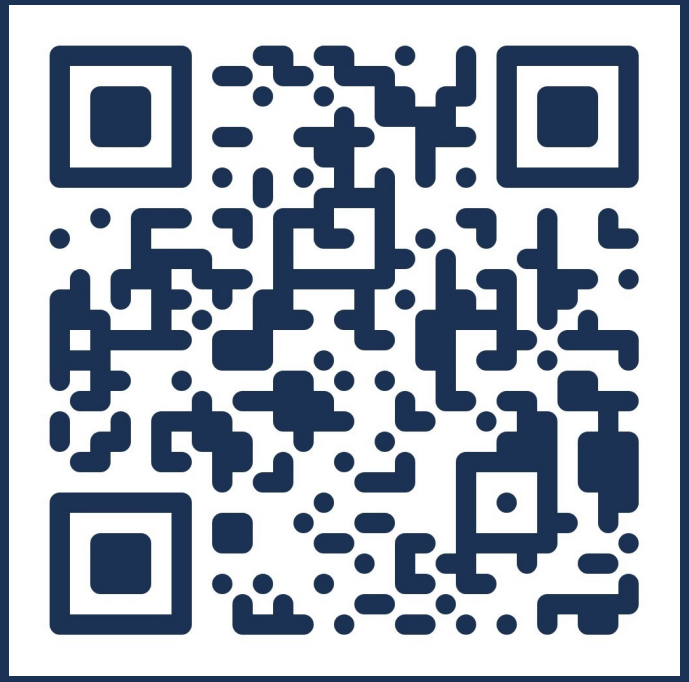
Software Engineering Internship

FPGA Engineering Internship - closed

Quantitative Trading Internship - closed

Links

Compilers coursework intro



Applications

Lecture feedback