Project Codebase

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SWPP Practice Session

Seunghyeon Nam

Summary

- We will distribute the following before the project
  - Per-team upstream repository with swpp-compiler skeleton code
  - swpp-interpreter repository
  - swpp Docker image
  - Alive2 repository with swpp customization

swpp-interpreter

- Executes the program written in swpp assembly
- Automatically calculate the total execution cost
- Shows the cost analysis for every function and instruction ran
- Crashes with error message upon encountering illegal program
  - Invalid syntax, illegal memory address, etc

swpp-interpreter

- You can test your optimizations with the interpreter
  - If the interpreter starts to yield wrong output, your optimization might be wrong
  - Comparing the execution cost before and after the optimization can show the effectiveness of it.

swpp Docker Image

- Most details are in the 'Continuous-Integration' slides
- One important update: Alive2 will not be included in the image
  - It is hard to update the CI image in case of urgent update
  - We'll share the Alive2 repository instead
  - You can use `actions/checkout` to fetch the repository and build Alive2
  - You can use `actions/cache` to prevent frequent rebuilding

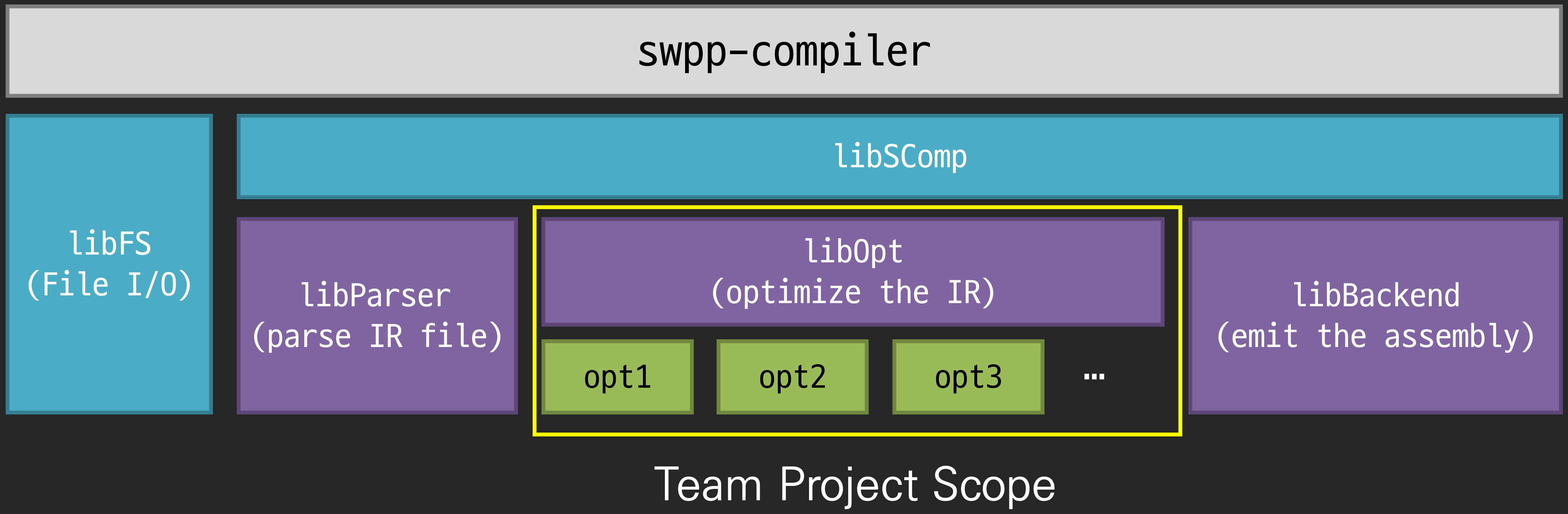
Alive2

- Verify the refinement between two LLVM IR programs
- Customizations are made to verify swpp-specific instructions
  - You cannot use the original Alive2 for the project
- Use small source and target program
  - It may fail to verify the optimization due to timeout
  - Or miss the incorrect optimization due to program complexity

swpp-compiler

- Your codebase for the team project
- Reads LLVM IR program from the file
- Applies your optimizations to the IR program
- Emits assembly from the optimized IR program
- Writes the emitted assembly back to file

swpp-compiler Overview



Codebase Characteristics

- Based on & makes extensive use of C++17 features
- Modularized structure
  - Don't worry about parser or backend during the project!
  - Your only concern should be IR-to-IR optimization
- CMake build system for easier configuration and testing
- In-source Doxygen documentation

Project Scope

- You're allowed to modify only a small fraction of the codebase
  - lib/opt.cpp
  - CMakeLists
- You can add new source files only inside lib/opt
- Modifying the source outside the scope will be penalized
  - Ask the TAs if you really think you have no choice but to modify them

Project Scope

- No restrictions on new test files, scripts, or CI scripts
  - As long as they are not related to the compiler code, it’s okay

swpp Intrinsics

- The swpp assembly language have some unique instructions
  - `aload, sum, incr, decr`
- They don't have the corresponding LLVM IR counterparts
- You have to use the intrinsics to emit those instructions
  - Compiler backend will convert these intrinsics into instructions

swpp Intrinsics

- Intrinsics can be called like ordinary LLVM IR functions
  - Ex) `%2 = call i64 @incr_i64(i64 %1)`
  - This will be converted to `r_ = incr r_ 64`
- Intrinsics must be 'declared' prior to its use
  - This is a restriction due to LLVM IR grammar
  - Note that you don't have to 'define' these instructions

CMakeLists.txt

- Build script used by CMake
- Always update the CMakeLists when you add a new file
- There's a helper function inside for easier registration
  - Your passes will be built as an independent shared library
  - You can use the shared library to test with LLVM opt
  - See also: Assignment 3

Doxygen

- In–source documentation utility
- Converts the comments into documentation webpage
- Our codebase will include Doxygen documentation
- You're not required to documentize your passes with Doxygen
  - But it looks fancy ☺

Modern C++

- std::optional<T>, std::variant<T, Ts…>, std::string_view
- std::function<T(P…)>, lambda expressions
- std::transform, std::accumulate
- decltype, auto
- std::move, rvalue reference, std::unique_ptr<T>

`std::optional<T>`

- Concept: A container that may or may not contain an object
- The contained object is accessible via dereference operator (*)
- Trying to access an empty optional results in exception
- More on cppreference.com

`std::variant<T, Ts...>`

- Concept: A container that contains one of the specified types
- Can specify any number of types without duplicates
  - Except zero, of course
- Helper functions such as `std::get<T>` or `std::visit()`
- Trying to access as a different type results in exception
- More on cppreference.com

`std::string_view`

- Concept: A read-only reference to part of the string
- Make a substring without copying the contents
- `string` must not be modified or deleted while view is alive
  - Dangling reference!
- More on cppreference.com

`std::function<T(Ts...)>`

- Concept: A function object
  - Functions can be tossed around like ordinary objects!
  - Includes lambda expressions
- Often used in higher-order functions (next slides)
- More on cppreference.com

std::transform()

- Concept: Apply a function to every element in the iteration
- Accepts a transformer function and input/output iterator
  - Function type should be outputT(inputT)
  - Using constant input iterator is a good practice
  - Input/output iterators should not overlap
- More on cppreference.com

`std::accumulate()`

- Concept: Apply a function to every element in the iteration
- Accepts an accumulator function, init value and input iterator
  - Accumulator function type should be outputT(outputT, inputT)
  - Using constant input iterator is a good practice
- More on cppreference.com

Lambda Expression

- Concept: Defining a function to use in a very narrow scope
  - A function that will be used once and never don’t really need a name
- Weird syntax!
  - `[captures](args) { definition }`
- Context can be ‘captured’ when creating a lambda.
- More on [cppreference.com]()

Keyword `decltype`

- Concept: Type of an object
- Useful when hiding a very long typename
    - In large codebase, typenames can get extremely long…
- More on cppreference.com

Keyword `auto`

- Concept: Deduce the type from the RHS expression
  - You can't use auto when there's no RHS to deduce type from!
  - Notable exception is lambda's arguments
- Useful when hiding a very long typename
  - Using auto is enough for most of the cases
- More on cppreference.com

Problems with Copying

- Assigning from one variable to another is done via copying
- But copying can be extremely costly
  - A string of 1M+ characters
  - A vector of a very large struct with more than 100 member variables
- Don’t copy unless you really need a separate copy!

Implicit Copy

- Detecting the copy operations in the code is very hard
  - At least one assignment, construction, or function call in every LOC
- Missing a single copy can open up a ‘copy hell’
  - Overhead due to repetitive or recursive copying
- Can be a potential performance bottleneck

Deleted Operations

- You can forbid copying the objects
  - To enforce explicit ownership, prevent implicit copy, etc
  - Construction: `T(const T&) = delete;`
  - Assignment: `T& operator=(const T&) = delete;`
- Most LLVM API types forbid copying
  - You should rely on reference or pointers for most of the times

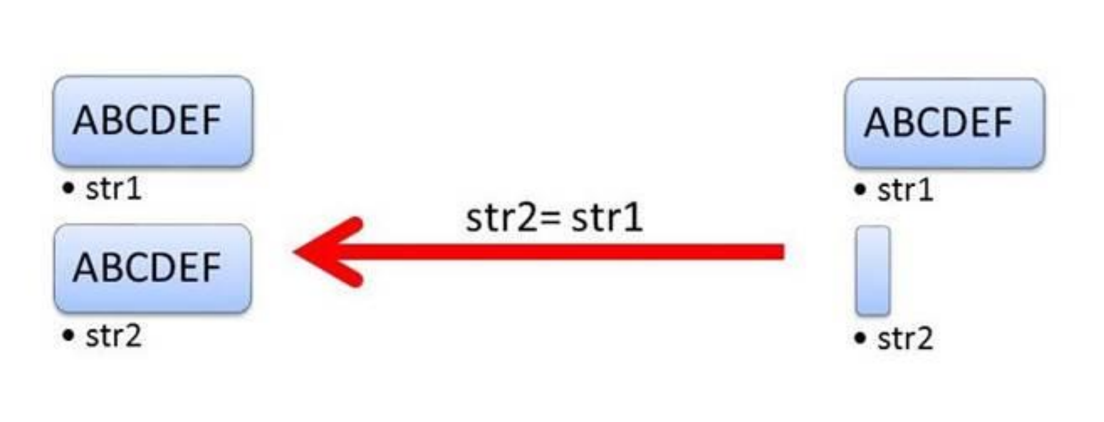
Deleted Operations

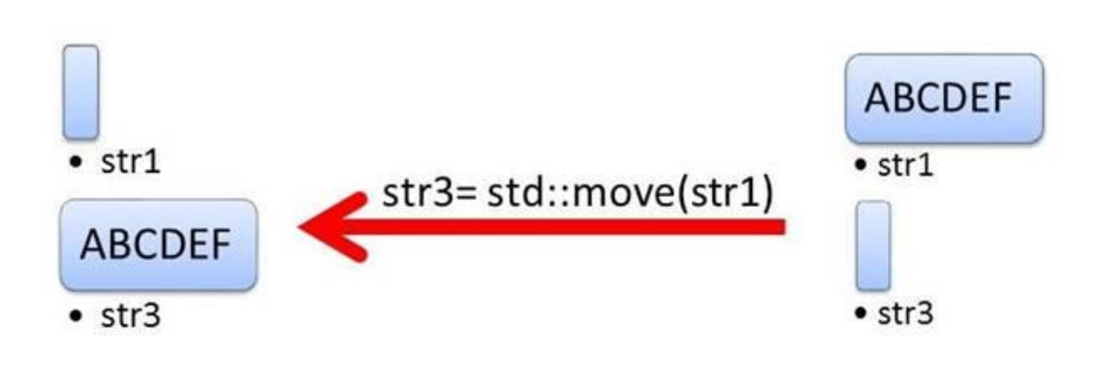
- Programming without assignment is virtually impossible
  - You cannot store the return value of a function
  - You cannot alias the variables for readability
- What if there's a way to assign a value without copying?

Move Semantics

- Concept: Transfer the ownership of data instead of copying
- Moving is cheaper than copying in most of the cases
  - Move operations should be implemented for actual benefit
  - If not, the behavior defaults to copying

Move Semantics





Move Semantics

- There are many C++ idioms you should know in order to implement your own move operations
- Following slides will be hard to understand at the first glance
- Understanding only the colored sentences should be sufficient for most of the cases
  - You can always look more into the reference page though

rvalue Reference (&&)

- Concept: An object that might be moved instead of copying
- Despite the syntax, it is not reference of reference
- Used to distinguish when to copy and when to move
  - Move operations are specialization for rvalue operand(s)
  - If operations are not specialized, your object will be copied
- More on cppreference.com (warning: very technical)

`std::move()`

- Concept: Cast an object into an rvalue reference
- The name is terribly misleading
  - It does not actually move your object
  - Object won't be 'moved' unless move operations are defined
- More on cppreference.com

`std::unique_ptr<T>`

- Concept: Exclusive ownership of an object
- Copying is forbidden
  - You have to `std::move()` the `unique_ptr` to transfer the ownership
  - Or you can only take the reference of the contained object
- Usually created using `std::make_unique()`

std::unique_ptr<T>

- Concept: Automated resource management
- When `unique_ptr` gets out of scope, the contained object is automatically deleted
  - No more leaking memories you forgot to `delete`!
- More on cppreference.com
- See also: RAII, shared_ptr⟨T⟩

Implementing Move Operations

- Implement move constructor
  - `T(T&& other)`
- Implement move assignment operator
  - `T& operator=(T&& other)`
- Copy constructor and copy AOp will be automatically deleted
  - You can manually re-implement them if you want to

Implementing Move Operations

- Simply copy pointer or integral types
  - Copying such small types have negligible overhead
- Use `std::move()` for standard library types
  - Most of them have well-implemented move operations
- Heap-allocate large structs or classes using `unique_ptr`
  - Moving only the `unique_ptr` can be cheaper

Implementing Move Operations

- Or just use the default implementation!
  - `T(T&& other) = default;`
  - `T& operator=(T&& other) = default;`
- Default implementation will ‘try to’ move every member
  - If you have a lot of member variables, use the `unique_ptr` trick

Implementing Move Operations

- The state of ‘moved from’ object is unspecified
  - Unspecified means the behavior depends on implementation
  - Each type may show different behavior or state
  - Behaviors of standard library types are specified in the reference
- It is your responsibility to correctly implement your type’s behavior after the move