

Modern C++ as Concurrent Assembly

Diego Perini

C++Now 2014

Overview

- > New Features of C++11/14
- > Doppl (a new language)
- > Compiled Doppl code (C++ code)

Materials: <http://goo.gl/Hw7oYS>

Modern C++

Features

Modern C++

- > Better functional programming support
- > Concurrency support in standard library
- > Better type resolution
- > More **readable** code for the same speed gain

Claim

Concurrency deserves its own type
of paradigms and languages

Why so few?

- > Concurrency + Safe code is hard

- > A Solution:

- Functional programming

- Immutable data structures

*"We all love Haskell but
only a few dare to code"*

Why so few?

- > Portable API for shared memory & message passing is hard to implement

Why so few?

Better Scalability vs Less utility code:

> Scalability always wins!

Claim

Modern C++ has necessary building blocks for a new concurrent language

Ingredients

> Standard library

```
#include <atomic>
```

```
#include <functional>
```

```
#include <future>
```

```
#include <thread>
```

Ingredients

> Parameter packs

```
template<typename C, typename... Ts>
auto call_when_I_need(C callable, Ts... args)
    -> std::future< decltype(callable(args...)) >
{
    return std::async(
        std::launch::deferred, callable, args...
    );
}
```

Ingredients

- > Lambdas

- > Suitable for asynchronous operations

- > Can capture environment

```
auto generic_add = [] (auto x, auto y) {  
    return x + y;  
}
```

Doppl

Data Oriented
Parallel Programming
Language

Doppl

- > Proof of concept
 - > Compiles to latest C++14 draft (thanks LLVM)
- > Natively parallel
- > Data oriented
- > Readability in mind

Doppl

Natively parallel:

- > Built-in parallel types
- > Built-in async support
- > Shared memory in user space

Doppl

Data oriented:

- > Minimal cache miss count
 - > Similar data are close to each other in memory
 - > Order of placement is the same as order of access
 - > **Structure of arrays** instead of array of structures

Doppl

Readability in mind:

```
task(1) HelloWorld {  
    init: {  
        output = "Hello World!\n"  
    }  
}
```

Apologies

Following Doppl code samples are
necessary for the sake of argument stated in
the beginning

Hello World Inspection

```
task(1) HelloWorld {  
    init: {  
        output = "Hello World!\n"  
    }  
}
```

Hello World Inspection

Keyword for defining tasks

```
task(1) HelloWorld {  
    init: {  
        output = "Hello World!\n"  
    }  
}
```

Hello World Inspection

Range literal

```
task(1) HelloWorld {  
    init: {  
        output = "Hello World!\n"  
    }  
}
```

Hello World Inspection

At least 1, at most 10 copies are allowed

```
task(1 10) HelloWorld {  
    init: {  
        output = "Hello World!\n"  
    }  
}
```

Hello World Inspection

Number of CPUs available during compilation

```
task(~) HelloWorld {  
    init: {  
        output = "Hello World!\n"  
    }  
}
```

Hello World Inspection

Task name

```
task(1) HelloWorld {  
    init: {  
        output = "Hello World!\n"  
    }  
}
```


Hello World Inspection

Reserved
keyword for
initial state

```
task(1) helloworld {  
    init: {  
        output = "Hello World!\n"  
    }  
}
```

Hello World Inspection

```
task(1) HelloWorld {  
    init: {  
        output = "Hello World!\n"  
    }  
}
```

Global binding for
standard output

States

```
task(2) HelloWorld {    #this is a line comment
    init: {
        output = "Hello "
        ->my_state
    }
    my_state: {
        output = "World!\n"
        -->init
    }
}    #infinite hello world loop!
```

States

```
task(2) HelloWorld {    #this is a line comment
    init: {
        output = "Hello "
        ->my_state
    }
    my_ "World!\n"
        -->init
    }
} #infinite hello world loop!
```



Blocking transition

States

```
task(2) HelloWorld {    #this is a line comment
    init: {
        output = "Hello "
        ->my_state
    }
    my_ Non-Blocking
        transition
        world!\n"
        -->init
    }
} #infinite hello world loop!
```

Members

```
task(10) Members {  
    my_int = int  
  
    init: {  
        my_int = 42  
        my_int = my_int + 1  
        finish  
    }  
}
```

Members

```
task(10) Members {
```

```
    my_int = int
```

Who owns this?

```
    init: {
```

```
        my_int = 42
```

```
        my_int = my_int + 1
```

```
        finish
```

```
    }
```

```
}
```

Members

```
task(10) Members {
```

```
    my_int = int
```

Who owns this?

```
    init: {
```

```
        my_int = 42
```

Is this synchronous?

```
        my_int = my_int + 1
```

```
        finish
```

```
    }
```

```
}
```


Members

```
task(10) Members {
```

```
    my_int = int
```

Who owns this?

```
    init: {
```

```
        my_int = 42
```

Is this synchronous?

```
        my_int = my_int + 1
```

Is this synchronous?

```
        finish
```

```
    }
```

```
}
```

Members

```
task(10) Members {
```

```
    my_int = int
```

Who owns this?

```
    init: {
```

```
        my_int = 42
```

Is this synchronous?

```
        my_int = my_int + 1
```

Is this synchronous?

```
        finish
```

```
    }
```

```
}
```

What if I want some code to be executed every time I accessed it?

Members

A member declaration clause:

scope	monadic	action	member	=	type
semantic	semantic	semantic	name		

Members

A member declaration clause:

scope	monadic	action	member	=	type
semantic	semantic	semantic	name		

Example:

private	just	data	my_int	=	int
---------	------	------	--------	---	-----

Members

scope	monadic	action	member	=	type
semantic	semantic	semantic	name		

Available semantics:

private	just	data	member	=	type
shared	maybe	future	name		
	once	state			
	sole	memory			
		element			

Members

scope	monadic	action	member	=	type
semantic	semantic	semantic	name		

Available semantics:

```
private      just      data      member      =      type
sh [REDACTED] name
```

If omitted, defaults are the first line (private, just, data)

element

Members

scope monadic action member = type
semantic semantic semantic name

Available semantics:

private
shared

just
maybe
once
sole

data
future
state

member = type
name

We are interested in these

Scope Semantics

```
task(10) ScopeSemantics {  
    private my_int = int           #there are 10 of these  
    shared  my_shared_int = int    #there is only 1 of this  
    init: {  
        my_int = 42  
        my_shared_int = 99  
        finish  
    }  
}
```


Monadic Semantics

```
task(10) MonadicSemantics {  
    just    my_int = int           #always a value, never null  
    maybe  maybe_int = int        #can be null sometimes  
    init: {  
        my_int = 42  
        maybe_int = null  
        maybe_int = my_int  
        finish  
    }  
}
```

Action Semantics

```
task(1) ActionSemantics {  
    data    my_data    = int  
    future  my_future  = int  
    state   my_state   = int
```

...

Action Semantics

```
init: {  
    my_data    = plus_forty_two(3)  
    my_future  = plus_forty_two(5)  
    my_state   = plus_forty_two(my_data)  
    finish  
}  
  
plus_forty_two(x = int): {  
    #some computation that takes time  
    yield 42 + x  
}
```

Action Semantics

```
init: {  
    my_data    = plus_forty_two(3)  
    my_future  = plus_forty_two(5)  
    my_state   = plus_forty_two(my_data)  
    finish  
}  
  
plus_forty_two(x = int): {  
    #some computation that takes time  
    yield 42 + x  
}
```

Synchronous

Asynchronous

Creates a closure
that can be used
later.
my_data is captured
by value

Action Semantics

```
init: {  
    my_data    = plus_forty_two(3)  
    my_future  = plus_forty_two(5)  
    my_state   = plus_forty_two(my_future)  
    finish  
}  
  
plus_forty_two(x = int): {  
    #some computation that takes time  
    yield 42 + x  
}
```



Is this synchronous?

Action Semantics

```
init: {  
    my_data    = plus_forty_two(3)  
    my_future  = plus_forty_two(5)  
    my_state   = plus_forty_two(my_future)  
    finish  
}  
  
plus_forty_two(x = int): {  
    #some computation that takes time  
    yield 42 + x  
}
```

NO! It's async

plus_forty_two
adapts its semantics
during capture

Compiling Doppl

C++ Code Generation

Compiler Features

- > Task range independent runtime
- > Scope semantics:
 - > private, shared
- > Action semantics:
 - > data, future, state
- > Concurrent stdin and stdout

Assignment and Member Access

- > We need a unified interface for any kind of assignment and member access
 - > Reason: Avoiding inheritance and pointer type casting

Assignment and Member Access

Assignment:

```
template<typename T, typename... Ts>  
void set(T& input, Ts&... args);
```

Member Access:

```
template<typename T>  
T get();
```

Assignment and Member Access

Assignment:

```
template<typename T, typename... Ts>  
void set(T& input, Ts&... args);
```

Member Access:

```
template<typename T>  
T get();
```

We are not putting these in a base class. They are merely concepts. Let's hope concepts become a thing in C++17 or sooner.

Standard Input and Output

C++ Code Generation

Standard Input

```
class input_t {  
    private:  
        std::mutex m;  
  
    public:  
        const std::string get() {  
            std::lock_guard<std::mutex> lock(m);  
            std::string value;  
            std::cin >> value;  
            return value;  
        };  
};
```

Standard Output

```
class output_t {  
    private:  
        std::mutex m;  
  
    public:  
        void set(const std::string& value) {  
            std::lock_guard<std::mutex> lock(m);  
            std::cout << value;  
        };  
};
```

Scope Semantics

C++ Code Generation

Private Members

- > No encapsulation needed
- > Any encapsulation would probably be eliminated by the C++ compiler anyway

Shared Members

- > Shared members are bundled with their own mutex
- > Shared members forward their set() and get() once the mutex is passed

Attention: Literals must not become Lvalue references during encapsulation

Shared Members

```
template<typename T>  
class shared {  
private:  
    T member;  
    std::mutex m;
```

Shared Members

```
public:
```

```
    //Forward get
```

```
    auto get() -> decltype(member.get()) {  
        std::lock_guard<std::mutex> lock(m);  
        return member.get();  
    };
```

Shared Members

public:

//Assignment for member types

template<typename V, typename... Vs>

shared<T>& set(V& v, Vs&... args) {

std::lock_guard<std::mutex> lock(m);

member.set(v, args...);

return *this; //This is for chaining assignments

};

Shared Members

```
public:
```

```
    //Assignment for literals
```

```
    shared<T>& set(decltype(member.get())& v) {
```

```
        std::lock_guard<std::mutex> lock(m);
```

```
        member.set(v);
```

```
        return *this;
```

```
    };
```

```
};
```

Action Semantics

C++ Code Generation

Action Semantics

```
enum class semantic_action_specifier {  
    data,  
    future,  
    state/*,  
    memory,  
    element*/  
};
```

Forward Declarations

```
template<semantic_action_specifier S, typename T, typename... Ts>  
class task_member;
```

```
template<typename T>  
using DM = task_member<semantic_action_specifier::data, T>;  
template<typename T>  
using FM = task_member<semantic_action_specifier::future, T>;  
template<typename T, typename... Ts> //Ts is for parameterized states  
using SM = task_member<semantic_action_specifier::state, T, Ts...>;
```


Data Members

```
template<typename T>
```

```
using DM = task_member<semantic_action_specifier::data, T>;
```

> A template that can store any type

> set(DM<T>& input) is a copy assignment

> set(FM<T>& input) is a copy assignment, synchronizes input

> set(SM<T>& input) is a synchronous call

> set(T&& input) is a literal assignment

> get() is a synchronous value access

Data Members

```
template<typename T>
class task_member<semantic_action_specifier::data, T> {
private:
    T _data;
public:
    //Get value
    const T& get() {
        return _data;
    };
};
```

Data Members

```
//data = value  
DM<T>& set(T&& input) {  
    this->_data = input;  
    return *this;  
};
```

Data Members

```
//data = data  
DM<T>& set(DM<T>& input) {  
    this->_data = input._data;  
    return *this;  
};
```

Data Members

```
//data = state
template<typename... Ts>
DM<T>& set(SM<T, Ts...>& input, Ts&... args)
{
    FM<T> _future(input, true, args...);
    this->set(_future);
    return *this;
};
```

set() method of FM<T>
has an is_lazy flag for
lazy assignment

Data Members

```
//data = future  
DM<T>& set(FM<T>& input) {  
    this->_data = input.get();  
    return *this;  
};
```

Future Members

```
template<typename T>
```

```
using FM = task_member<semantic_action_specifier::future, T>;
```

- > Future members are interchangeable between threads

- > Encapsulates `std::shared_future<T>`

- > Value of internal T can be changed by current thread (Sync)

AND

- > Value of internal T can be changed by some other thread (Async)

- > Encapsulates `std::promise<T>` to retrieve its

- `std::shared_future`

Future Members

```
template<typename T>
```

```
using FM = task_member<semantic_action_specifier::future, T>;
```

> set(DM<T>& input) is forwarded to internal promise

> set(FM<T>& input) is forwarded to internal shared future

> set(SM<T>& input, **const bool** is_lazy) starts a call

> set(T&& input) is a literal assignment and forwarded to promise

> get() is a synchronous value access

Future Members

```
template<typename T>
class task_member<semantic_action_specifier::future, T> {
private:
    //Internal future and promise
    std::shared_future<T> _future;
    std::promise<T> _promise;

public:
    //Get value and sync
    const T& get() {
        return _future.get();
    };
};
```

Future Members

```
//future = data  
FM<T>& set(DM<T>& input) {  
    std::promise<T> p;  
    _future = p.get_future();  
    p.set_value(input.get());  
    return *this;  
};
```

Future Members

```
//future = value  
FM<T>& set(T&& input) {  
    std::promise<T> p;  
    _future = p.get_future();  
    p.set_value(input);  
    return *this;  
};
```

Future Members

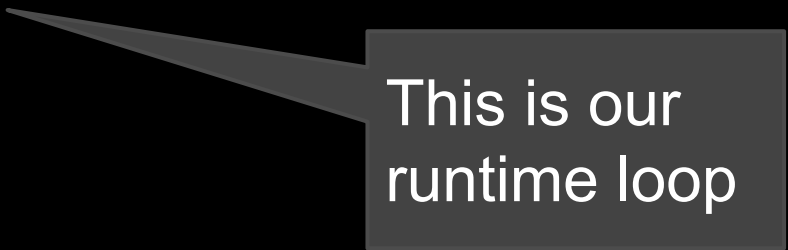
```
//future = future  
FM<T>& set(FM<T>& input) {  
    this->_future = input._future;  
    return *this;  
};
```

Future Members

```
//future = state
template<typename... Ts>
FM<T>& set(SM<T, Ts...>& input, const bool is_lazy, Ts&... args) {
    _promise = std::promise<T>();
    _future = _promise.get_future();
    auto f = std::async(
        is_lazy ? std::launch::deferred : std::launch::async,
        [&] () { task_loop<T, Ts...>()(input, _promise, args...); }
    );
    if(is_lazy) f.get();
    return *this;
};
```

Future Members

```
//future = state
template<typename... Ts>
FM<T>& set(SM<T, Ts...>& input, const bool is_lazy, Ts&... args) {
    _promise = std::promise<T>();
    _future = _promise.get_future();
    auto f = std::async(
        is_lazy ? std::launch::deferred : std::launch::async,
        [&] () { task_loop<T, Ts...>()(input, _promise, args...); }
    );
    if(is_lazy) f.get();
    return *this;
};
```



This is our
runtime loop

Future Members

```
//future = state
template<typename... Ts>
FM<T>& set(SM<T, Ts...>& input, const bool is_lazy, T
    _promise = std::promise<T>();
    _future = _promise.get_future();
    auto f = std::async(
        is_lazy ? std::launch::deferred : std::launch::async,
        [&] () { task_loop<T, Ts...>()(input, _promise, args...); }
    );
    if(is_lazy) f.get();
    return *this;
};
```

This is for
yield

This is our
runtime loop

State Members

```
template<typename T, typename... Ts>  
using SM = task_member<semantic_action_specifier::state, T, Ts...>;
```

- > Stores a callable
- > Stored callable must be able to transform into a value (yield)
- > Stored callable must be able to set the next callable (transition)
 - > Encapsulates std::function
- > Stored callable must be able to capture some environment
 - > Two template instances (captured and uncaptured)

SM<T>

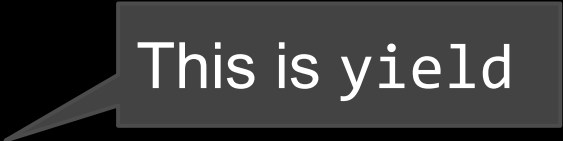
SM<T, Ts...>

State Members

```
template<typename T>
class task_member<semantic_action_specifier::state, T> {
private:
    std::function<
        void(std::promise<T>&, SM<T>&, SM<T>&)
        > _state;
public:
    auto get() -> decltype(_state) {
        return _state;
    };
};
```

State Members

```
template<typename T>
class task_member<semantic_action_specifier::state, T> {
private:
    std::function<
        void(std::promise<T>&, SM<T>&, SM<T>&)
        > _state;
public:
    auto get() -> decltype(_state) {
        return _state;
    };
};
```



This is yield

State Members

```
template<typename T>
class task_member<semantic_action_specifier::state, T> {
private:
    std::function<
        void(std::promise<T>&, SM<T>&, SM<T>&)
        > _state;
public:
    auto get() -> decltype(_state) {
        return _state;
    };
};
```

This is yield

This is next
state that we
set to
transition

State Members

```
template<typename T>
class task_member<semantic_action_specifier::state,
private:
    std::function<
        void(std::promise<T>&, SM<T>&, SM<T>&)
        > _state;
public:
    auto get() -> decltype(_state) {
        return _state;
    };
};
```

This is yield

This is
finish state
to end the call

This is next
state that we
set to
transition

State Members

public:

```
SM<T>& set(SM<T>& input) { //state = state (input is a closure)
    this->_state = input._state;
    return *this;
};
```

```
SM<T>& set(decltype(_state) input) { //state = function literal
    _state = input;
    return *this;
};
```

State Members

```
//state = state (input is bound to args to create a closure)
template<typename... Ts, typename... As>
SM<T>& set(SM<T, Ts...>& input, As&... args) {
    this->_state =
        [&] (std::promise<T>& p, SM<T>& n, SM<T>& f) {
            input.get()(p, n, f, args...);
        };
    return *this;
};
```

State Members

```
template<typename T, typename... Ts>
class task_member<semantic_action_specifier::state, T, Ts...> {
private:
    std::function<void(std::promise<T>&, SM<T>&, SM<T>&, Ts...)> _state;

public:
    //Get callable
    auto get() -> decltype(_state) {
        return _state;
    };
};
```

State Members

```
//state = state
SM<T, Ts...>& set(SM<T, Ts...>& input) {
    this->_state = input._state;
    return *this;
};
```

```
//state = function literal
SM<T, Ts...>& set(decltype(_state) input) {
    _state = input;
    return *this;
};
```

```
};
```


Runtime (aka Task Loop)

C++ Code Generation

Task Loop

- > A loop that handles state transition
- > A loop that never throws exceptions
- > Its initial state should accept parameters

Task Loop

- > Other than some internal handles, it should not pollute its creators' stack
 - > Reason: We should be able to create task loops as many as we want without worry during runtime
 - > Reason: Temporarily cloned tasks (remember `future=state` assignments) must use its creators' members `without copy`.

Task Loop

```
template<typename T, typename... Ts>
```

```
class task_loop {
```

```
private:
```

```
    SM<T> initial_state;
```

```
    SM<T> next_state;
```

```
    SM<T> finish_state;
```

```
    std::future<void> current_state_future;
```

Yield type

Arguments
for initial
state

Task Loop

```
public:
int operator() (SM<T, Ts...>& init, std::promise<T>& yield,
               Ts&... args) {
    //Set init
    initial_state.set(init, args...);

    //Infinite loop escape trigger
    bool is_running = true;
    finish_state.set(
        [&is_running] (std::promise<T>& yield, SM<T>& next, SM<T>& finish)
            { is_running = false; } );
```

Task Loop

```
//Default next state assignment
next_state.set(finish_state);

//Initial state assignment (lazy)
current_state_future = std::async(
    std::launch::deferred,
    [&] () {
        initial_state.get()(yield, next_state, finish_state);
    }
);
```

Task Loop

```
//Program loop
try {
    while(is_running) {
        //Run lazily assigned state code
        current_state_future.get();
        //Set next state (lazy)
        current_state_future = std::async(
            std::launch::deferred, [&] () {
                next_state.get()(yield, next_state, finish_state);
            });
    }
}
```

Task Loop

```
//Error  
catch(std::exception& e) {  
    return 1; //Or abort, dunno :)  
}  
  
return 0;  
};
```


Future Members (previous slide)

```
//future = state
template<typename... Ts>
FM<T>& set(SM<T, Ts...>& input, const bool is_lazy, T
    _promise = std::promise<T>();
    _future = _promise.get_future();
    auto f = std::async(
        is_lazy ? std::launch::deferred : std::launch::async,
        [&] () { task_loop<T, Ts...>()(input, _promise, args...); }
    );
    if(is_lazy) f.get();
    return *this;
};
```

This is for
yield

This is our
runtime loop

```
int main()
```

C++ Code Generation

Pseudo Code

- > Declare *range* as *const int*
- > Declare stdin and stdout as *input_t* and *output_t*
- > Declare shared members as *shared*
- > Declare *std::array<T, range>* for each private member
- > Declare *task_body* as *lambda*
 - > Declare a *task_loop*
 - > Declare states
 - > Declare local members
 - > Insert program code
 - > Start declared loop
- > Call *std::async(task_body) range* times

Future Studies

Wrapping Other Modern C++ Components

Future Studies

- > Partially applied closures: `std::bind`
- > Native tuple type: `std::tuple` (see project site)
- > Collections: `std::array`, `std::vector` ...
- > Element members: `Iterators`
- > Memory members: `std::shared_ptr`, `std::unique_ptr`
- > Once members: `std::call_once` (see project site)
- > Sole members: `std::lock_guard`

Doppl

> Website:

doppl.org

> Presentation Materials and Doppl runtime:

github.com/diegoperini

> Contact:

diego@dperini.com

Questions?

Thank you!