The Function Concept

An empirical study

Daniel Lincke (Potsdam Institute for Climate Impact Research)
and
Sibylle Schupp (Hamburg University of Technology)

Nov. 5, 2009

Function Types in Programming

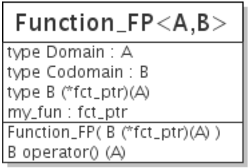
- Functional programmers are used to function *types*
- For instance in Haskell: `A -> B`
- Imperative languages lack native support for function types
- However, they are the base of generic programming
- Higher-order functions, for instance, require function types
- We investigate function types in C++, as this is the imperative language with the best support for generic programming

Comparing Function Types in C++

- How do the existing implementations compare?
- Surprisingly, it was not clear at all how they compare
- In many situations an evaluation is useful
- What about a function concept? How does it compare to other approaches?
- Measure it! Evaluate it!

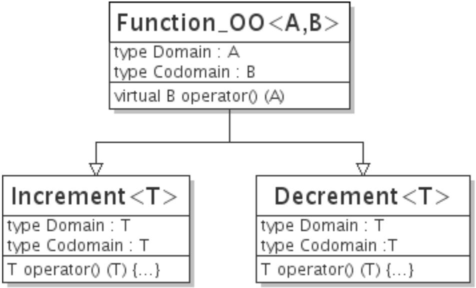
	no optimization	optimization level 3 (-O3)
FPtr	-	-
OO	59.41	**43.05**
Boost	284.25	**123.74**
FC++	88.63	**72.86**
Concept	11.60	1.00

Function Pointers



- Small template class, directly supported
- Internally, a function pointer is stored as a member
- Application operator resolves the function pointer at runtime (overhead!)

Object-Oriented Programming

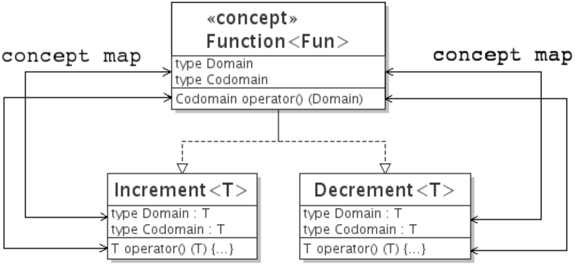


- Function is an abstract base class
- One class for every concrete function; inherits from the abstract base class, dynamic binding
- Application operator resolves virtual call at runtime (overhead!)

Libraries

- Several libraries provide function datatypes
- Most prominent: Boost
- In addition, we picked the FC++ library
- How to use: create an instance of a library object and pass along

Concepts



- The concept models a static interface
- One class for every concrete function, declared as a model of the function class with a `concept_map`; static binding
- Application operator resolved in the `concept_map` at compile time (no overhead!)

The Function Concept

```
concept Concept_Function<class F> {
    typename Domain;
    typename Codomain;

    Codomain operator()(F&, Domain);
};

template<class T>
concept_map Concept_Function<Increment<T> >  {
     typedef T Domain; ++
     typedef T Codomain;
}
```

Function Application: A measurement

Evaluation

- Function application is the basic operation for functions
- Important to have no overhead for the application operator
- A simple test: repeated function application. Results:

	no optimization	optimization level 3 (-O3)
Fptr	5.37	2.56
OO	3.84	1.06
Boost	8.91	8.59
FC++	12.42	5.24
Concept	3.73	1.00

Function Application: A Measurement

Some interpretations:

- As expected: the concept has no overhead
- The function class for the object-oriented case is as fast as the function object
- Function pointer wrappers suffer from pointer indirection costs
- Library datatypes use a complicated machinery with pointer indirections and virtual calls

Higher-order Functions: Performance

- Higher-order functions are a main reason for introducing function datatypes
- Function application for higher-order functions should be efficient
- A simple test: repeated higher-order function application. Results:

	no optimization	optimization level 3 (-O3)
Fptr	17.18	5.45
OO	13.82	6.18
Boost	25.19	16.76
FC++	34.50	10.55
Concept	12.92	1.00

Higher-order Functions: Performance

Some interpretations:

- As expected: concept performs best
- The object-oriented solution resolves the virtual application operator call, which leads to an overhead
- Function pointer wrappers and library datatypes: as before

Other Evaluation Criteria

- We are looking further: operations on function types like composition, currying are needed
- Questions: can these operations be implemented at all?
- And if so, can they be implemented efficiently?
- Interestingly, it turns out that not all of them are expressive enough
- A simple function pointer wrapper, for instance, cannot support composition

Example: Partial Application

- We also tested the performance of function application for curried, partially applied functions
- Results show surprisingly big differences in terms of performance:

	no optimization	optimization level 3 (-O3)
Fptr	-	-
OO	59.41	43.05
Boost	284.25	123.74
FC++	88.63	72.86
Concept	11.60	1.00

- Once again, the function concept performs best

Type Declarations

- The function concept performs very good in all performance evaluations
- So, where is the rub?
- The function concept leads to difficult type declarations, compared with other solutions:

```
boost::function<B, A> f1 = ...;
boost::function<C, B> f2 = ...;
boost::function<C, A> f1_f2 = boost_compose(f1,f2);
```

Type Declarations

- With function objects and concepts:

```
Test_Function1 f1;  // f1 : A->B
Test_Function2 f2;  // f2 : B->C
Composed_Function<Test_Function1,
                  Test_Function2>
f1_f2 = concept_compose(f1,f2);
```

- Hard to understand for nested composition / currying

Evaluation Summary

Feature	Fptr	OO	FC++	Boost	Concept
Application operator	+	−	−	−	+
Higher-order functions	+	−	−	−	+
Function composition	−	+	+	+	+
Function comp., efficiency	−	−	−	−	+
Partial application	−	+	+	+	+
Partial appl., efficiency	−	−	−	−	+
Pretty function types	+	+	+	+	−