

Designing Reusable Software

by Chuck Allison

For software to be reusable, it must be usable in a variety of contexts. An important attribute of reusability at the code level is *genericity*. Generic software can operate, unmodified, on a variety of object types. Dynamically typed languages provide genericity naturally. Consider the following Python function that determines the smallest of whatever it receives as a parameter:

```
def smallest(stuff):
    assert len(stuff) > 0
    theMin = stuff[0]
    for x in stuff[1:]:
        if x < theMin: theMin = x
    return theMin
```

You can call this function with any type of sequence:

```
>>> smallest([1,2,3])
1
>>> smallest("cba")
a
```

The only constraints on the parameter `stuff` are that it is an iterable entity and that its contained objects support the less-than operator. Hence, `smallest` is a generic function.

Statically typed languages usually don't have such flexibility out of the box, but that is changing. Modern languages such as Eiffel, C++, Java, C#, and D have added generic programming capability while retaining the safety and efficiency that comes with static type checking.

Consider an everyday programming task: applying a series of transformations to data. Data transformations usually involve calling a series of functions on individual data elements. While it is simple to write separate functions and apply them in sequence, it can be even easier to assemble existing functions into a reusable, composite function. In other words, we want support for *function composition*.

In the November 2007 Code Craft, I used the following Python function:

```
def compose(*funs):
    return lambda x: reduce(lambda z,f: f(z), reversed(funs), x)
```

In case you forgot, `reduce` applies its first argument, a binary function that I'll call the *applicator*, to the first list element along with the initial value. That result and the next function in the list become input arguments to a second invocation of the applicator, and so on, until the list of functions is exhausted and the accumulated result is obtained. If you prefer a procedural rendering of `compose`, see listing 1.



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```
# Listing 1
def compose(*funs):
    def apply(x):
        result = x
        for f in reversed(funs):
            result = f(result)
        return result
    return apply
```

Listing 1

Both functions return a new, single-valued function representing the composition of the functions in the original list. So, if you have three like-typed functions, `f`, `g`, and `h`, you can compose them like this:

```
c = compose(f,g,h)
```

Every call to `c(x)` will compute `f(g(h(x)))`.

How can we accomplish this in C++? It won't be a one-liner, but there is a reasonable solution. But first, let's start with a non-generic version and then generalize it.

A Non-Generic Example

We'll assume the data type is `double` and will use C++'s `accumulate` algorithm, which works just like Python's `reduce`. Since we can't return functions in C++, we'll create a function object (a type implementing `operator()`), as shown in listing 2.

With a vector, `v`, of single-valued real functions, using their composition is straightforward:

```
// Listing 2: A non-generic C++ composer (for functions of doubles)
class Composer {
private:
    typedef double (*Fun)(double);
    vector<Fun> funs;
    static double apply(double sofar, double (*f)(double)) {
        return f(sofar);
    }
public:
    Composer(vector<Fun>& fs) : funs(fs) {
        reverse(funs.begin(), funs.end());
    }
    double operator()(double x) {
        return accumulate(funs.begin(), funs.end(), x, apply);
    }
};
```

Listing 2

```
// Listing 3: Generalizes the argument and sequence types
template<class T, class Iter>
class Composer {
private:
    typedef std::reverse_iterator<Iter> RevIter;
    RevIter beg, end;
    static T apply(T sofar, T (*f)(T)) {
        return f(sofar);
    }
public:
    Composer(Iter b, Iter e) : beg(RevIter(e)), end(RevIter(b)) {}
    T operator()(T x) {
        return accumulate(beg, end, x, apply);
    }
};
```

Listing 3

```
Composer comp(v);
cout << comp(x);
```

This class has two obvious deficiencies:

1. Only functions of real numbers can be composed.
2. Users must employ `std::vector` as the data structure.

A Generic Solution

The solution to both flaws is to use templates, as shown in listing 3.

Sequences in C++ are delimited by iterators, which can be pointers or objects of classes that implement pointer operations (`operator*`, `operator->`, `operator++`, etc.). Therefore, this version of `Composer` has two template parameters—one for the data type (`T`) and one for the iterator type (`Iter`). Since the functions need to be applied in the reverse of the order in which they appear, we use `std::reverse_iterator` to synthesize a reverse iterator type from `Iter`, which the `Composer` constructor initializes appropriately. The caller must provide

```
typedef string (*Fun)(string);
Fun funs[] = {f,g,h};
Composer<string, Fun*> comp(funs, funs+3);
cout << comp(x) << endl;
```

Listing 4

the template arguments and iterators. The sample code in listing 4 uses an array to hold pointers to the functions `f`, `g`, and `h`. The iterator type is therefore a *pointer* to such pointers-to-functions, as shown in listing 4.

Is more generalization possible? Yes, if we use a forthcoming feature of C++0x (the imminent update of standard C++), namely, `function`. The `function` class template wraps anything that is callable as a function. This way we can use function objects as well as function pointers, and even mix the two in the same sequence. This feature is available today as `Boost.function` (see the [StickyNotes](#) for a link). We also will use other template features of the current version of C++.

All we will require of users is to declare their sequences to hold compatible instances of `function`. The new implementa-

ISO standards for programming languages are eligible for renewal every ten years. C++ was standardized in 1998, and work began on a new version in 2003. The new version is expected to be complete before 2010, hence the “C++0x” moniker. C++0x will contain many enhancements and simplifications, including template constraints (a.k.a. “concepts”), lambda functions, and a regular expression library. Work on a concurrency model is also in progress.

```
// Listing 5: Generalizes the callable type
template<class Iter>
class Composer {
private:
    // Deduce function and return/argument types
    typedef typename iterator_traits<Iter>::value_type Fun;
    typedef typename Fun::result_type T;

    // Declare reverse iterators (see constructor for use)
    typedef reverse_iterator<Iter> RevIter;
    RevIter beg, end;

    // The function called by accumulate
    static T apply(T sofar, Fun f) {
        return f(sofar);
    }
public:
    Composer(Iter b, Iter e) : beg(RevIter(e)), end(RevIter(b)) {}
    T operator()(T x) {
        return accumulate(beg, end, x, apply); // Function Applicator
    }
};
```

Listing 5

```
// Listing 6
typedef function<double(double)> Fun;
std::list<Fun> funs;
funs.push_back(bind2nd(divides<double>(), 3.0));
funs.push_back(&f); // A plain double (*)(double) function
funs.push_back(bind2nd(plus<double>(), 1.0));
transform(nums, nums+4, ostream_iterator<double>(cout, " "),
    compose(funs.begin(), funs.end()));
```

Listing 6

tion of `Composer` also uses `iterator_traits`, a C++ feature that deduces the type to which an iterator points, as shown in listing 5.

We are assuming that the type pointed to, `Fun`, is an instance of function, which happens to have a `result_type` member. We use this as the argument type since we expect the functions we compose to have the same argument and return type.

To make things convenient for the user, we'll create a function template that deduces the iterator type from its arguments:

```
template<class Iter>
Composer<Iter> compose(Iter b, Iter e) {
    return Composer<Iter>(b,e);
}
```

This allows users to embed calls to `compose` in other contexts, as you can see in the sample code in listing 6, which composes two function objects along with a plain function pointer.

The first line defines the type `Fun` as `function<double(double)>`, which matches anything that is callable with a single `double` argument and returns a `double`. The first function, which we create on the fly, divides its argu-

ment by three. The `divides` function object comes with the standard C++ library, as does the `bind2nd` function-object adaptor, which converts `divides` into a single-arg function by fixing its second argument as the value 3. (See the September 2007 Code Craft article for more on standard function objects and `bind2nd`).

The call to `transform` processes an array of four doubles, `nums` (declaration not shown), applies the composition of the three given functions, and prints the result to standard output—all in one statement.

Summary

Let's review what we have accomplished—we have created a reusable class for function composition, which can come in handy in data processing, and we have gained some experience in designing generic software. The final version of `Composer` is generic in

that it can compose an arbitrary number of unary, single-valued functions or function objects of compatible types, and those functions can reside in an array or in any standard sequence container. `Composer` itself has reused the standard generic types and functions: `accumulate`, `reverse_iterator`, `iterator_traits`, and `function`. **{end}**

Chuck Allison developed software for twenty years before becoming a professor of computer science at Utah Valley State College. He was senior editor of the C/C++ Users Journal and is founding editor of The C++ Source. He is also the author of two C++ books and gives onsite training in C++, Python, and Design Patterns. Chuck is a technical editor for Better Software magazine.

Sticky Notes

For more on the following topic go to www.StickyMinds.com/bettersoftware.

■ Boost.function



Is defining for reuse on your list of priorities? Do you routinely use generics?

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