Simulating Partial Specialization

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Overview

- **The focus is on solving problems using generative template metaprogramming in a shrink wrap software development environment.**

- **Will work through two sample problems that arise when implementing generic containers in C++**

- **Along the way will sketch two results from our research. One is a year old and one is a week old, so it is still somewhat rough.**

Context

- **Shrink wrap Software Development**
- **Deliver for Mac OS and Windows**
- **Associated SDK**
  - Software Is Developed in C++
  - Extensibility is critical
  - API mostly uses interface classes
  - Binary compatibility across releases is important
- **Microsoft compiler has limited support for standard C++**
  - In particular no support for partial specialization

Motivation

- **Would like to use generic containers from Standard Template Library**
  - Powerful, convenient, well documented framework
- **Couldn't use vendors implementations**
  - Existing STL implementations suffered from template code bloat under MSVC - no partial specialization
  - Binary compatibility across compiler versions would suffer
- **Existing Internal Container Libraries**
  - Optimized, limited template bloat
  - Non standard, not easy to use
  - Too many classes to choose from

Problem

- **Implementing part of a std::vector clone**

- **Two of the non-functional requirements**
  - Require no template code bloat
  - Require optimized std::copy, etc. for "plain old data" types, e.g. built-in types

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Naïve Approach Causes Code Bloat

```
/* Bloat: The compiler will instantiate separate code
for each vector of pointers even though the machine
instructions are the same.  */

template <typename T>
class SimpleVector
{ /* . . . */ };


/* This is often addressed by creating a separate
container template */

template <typename T>
class PtrVector : public SimpleVector<void *>
{/*Wrap base members with typecasts*/ };


/* But now clients must remember to select the
appropriate container template, PtrVector, if they are
using pointers. */
```

A Solution: Use a Vector Generator

- **We will define a container generating metafunction:**
  - ```
    template <typename T>
    struct VECTOR_GENERATOR {
      typedef /* . . . */ RET;};
    ```
- **`VECTOR_GENERATOR<T>::RET` will be the appropriate container**
  - `VECTOR_GENERATOR<int*>::RET` is of type `PtrVector<int*>`
  - `VECTOR_GENERATOR<std::string>::RET` is of type `SimpleVector<std::string>`
- **Can add some syntactic sugar using inheritance**
  - ```
    template <typename T>
    class Vector : public typename
    VECTOR_GENERATOR<T>::RET
    { /* implement delegating ctors */ }
    ```
  - Now client can write the code as if partial specialization was present without fear of template bloat e.g: `Vector<int*> v;`

Vector Generator Implementation

- **Create metafunction IS_PTR**
  - E.g. `IS_PTR<int *>::RET == 1`
- **Borrow template metafunction IF [CE2000]**
  - E.g. `IF<1+1 == 3,int,std::string> ::RET` is of type `std::string`
- **Then VECTOR_GENERATOR can be written:**
  - ```
    template <typename T>
    struct VECTOR_GENERATOR {
      typedef typename  IF<IS_PTR<T>::RET,
            PtrVector<T>,
            SimpleVector<T>
      >::RET RET;
    };
    ```

IS_PTR

- **There were existing versions of IS_PTR but all relied on partial template pointer specialization.**

- **We can subvert the function overload resolution mechanism instead.**

- **Alexandrescu pointed out the usefulness of `sizeof` in template programming. In particular `sizeof` can determine the size of any expression** at compile time**.**

IS_PTR implementation

```
/*Let us begin with IS_PTR. IS_PTR must discriminate
between pointer types and all others. We pass an instance
of T named t to a pair of overloaded functions. It helps
to think of t hese functions as discriminators.    Each
function has a uniquely sized return type so that sizeof
can determine which function was selected by the overload
resolution mechanism. So here is a simplified version of
IS_PTR (see Appendix or [2] for a m ore detailed
implementation).*/

 /* These are the discriminating functions. Note that
 only a declaration is required by sizeof. */

 char IsPtr(void*);
 int  IsPtr(...);

 // This template metafunction accepts a type T
 // then sets RET to true exactly when T is a
 // pointer.

 template <typename T>
 struct IS_PTR {
   static T t; //definition not required.
   enum { RET = (sizeof(IsPtr(t)) == sizeof(char)) };
 };
```

"Associated" Type Recovery

- We would also like to recover the underlying value type. That is we would like to be able to write something like `REMOVE_PTR<T>::RET` **otherwise known as** `std::iterator_traits<T>::value_type`

- We know of no way to do so for pointers without partial specialization. But we don't always need to completely recover the underlying type. Sometimes it suffices to "ask it a question".

- In those cases we can turn our client code "inside out". If we have some work to carry out we can create a metafunction to be executed with the underlying type as its argument. The restriction is that the metafunction can only return an enum not a type.

Applying a metafunction to an Associated Type

- As an example suppose we have the metafunction `IS_POD` which detects whether a type `T` is "plain old data". Lets say we want to detect whether T points to plain old data. That is we would like to have a metafunction IS_PTR_TO_POD. If we had REMOVE_PTR we might be able to use IS_POD<typename REMOVE_PTR<T>::RET>::RET. Instead we can ask IS_POD to be evaluated in the context of the underlying type.

Applying a metafunction to an Associated Type (cont.)

- **Note that we are not limited to recovering value types from pointers. We can apply the same technique to arbitrary type relationships. Nor are we limited to single argument metafunctions. For example we can ask:**

    - `IS_VECTOR_OF_LIST_OF_POD<T>`

    - `IS_PTR_TO_SAME<T,U>`

Applied Inside Out Type Recovery

- **As an example once we have our IS_PTR_TO_POD we can implement our other non-functional requirement - an optimized std::copy.**

```
        template <typename InputIter, typename ForwardIter>
        inline ForwardIter
        FastCopy<InputIter, ForwardIter>::copy(
         InputIter first, InputIter last, ForwardIter result)
        {

          META_ASSERT<
             IS_PTR_TO_POD<InputIter>::RET
             && IS_PTR_TO_POD<ForwardIter>::RET
             && IS_PTR_TO_SAME_TYPE<InputIter,ForwardIter>::RET,
             FastCopy_on_bad_types>();

          ptrdiff_t count = last - first;
          memmove(result, first, count*sizeof(*first));
          return result + count;
        }


        template <typename InputIter, typename ForwardIter>
        inline ForwardIter copy( InputIter first,
         InputIter last, ForwardIter result)
        {
          return IF<IS_PTR_TO_POD<InputIter>::RET
                      && IS_PTR_TO_POD<ForwardIter>::RET
                      && IS_PTR_TO_SAME_TYPE<InputIter,
                             ForwardIter
                           >::RET,
                    FastCopy<InputIter, ForwardIter>,
                    SafeCopy<InputIter, ForwardIter>
                  >::RET::copy(first, last, result);
        }
```

IS_PTR_TO_POD implementation

```
/* For IS_PTR_TO_POD we again make use of the function
overload resolution mechanism. But this time we use it to
"remove" the pointer before applying the IS_POD
metafunction. The key point is that we can give the
IS_POD metafunction access to the underlying type by
using it in the return type of our discriminator. */

 template <typename T>
 struct IS_POD {
  enum {RET = /* see Appendix */ };
 };

 template <typename T>
 struct IS_PTR_TO_POD
 {
  /* The IF below is one way to convert the enum returned
by IS_POD into a type suitable for passing to sizeof. */

    template <typename V>
    IF<IS_POD<V>::RET, char, int>::RET RemovePtr(V*);
    int                               RemovePtr (…);

    enum {RET = sizeof(RemovePtr(t) )== sizeof(char) };
    static T t;
 };
```

Related Work

- **The IF for broken compilers appeared in [CE2000].**

- **IS_PTR existed for some time for compilers that support partial specialization, see boost::type_traits for example.**

- **In September 2000 Jesse Jones and I published an implementation for "broken" compilers using properties of the sizeof operator pointed out by Alexandrescu.**

- **These "workarounds" were refined by John Maddock into boost::type_traits for is_pointer and similar metafunctions.**

- **Last week when preparing this paper I uncovered the "inside out" type recovery technique.**

Discussion ideas

- **Why aren't explicit control constructs (IF, SWITCH, WHILE, etc.) used more widely by the template metaprogramming community. This style from [CE2000] seems more readable than template specialization. In addition it can guide us in writing metaprograms that would otherwise seem too complex or escape our notice.**

- **We can avoid some uses of std::iterator_traits<T> ::value_type by turning calculations inside out to "recover the associated type". Where else might it be this technique be useful.**

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