Generic Programming

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Introduction to Generic Programming
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Outline

1. Generic Programming
   - Introduction and Motivation
   - Concepts and Models
   - Traits Classes
   - Dispatching

2. STL - Standard Template Library
   - Containers and Iterators
   - Function Pointer and Function Objects

Generic Programming Paradigm

Definition (Generic Programming)

A discipline that consists of the gradual lifting of concrete algorithms abstracting over details, while retaining the algorithm semantics and efficiency.

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Translation:

- You do not want to write the same algorithm again and again !

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A discipline that consists of the gradual lifting of concrete algorithms abstracting over details, while retaining the algorithm semantics and efficiency.

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Translation:

- You do not want to write the same algorithm again and again !

$\Rightarrow$ You even want to make it independent from the used types.

See also: http://en.wikipedia.org/wiki/Generic_programming

Motivation - Generic Programming

Reasons to write generic code

- Laziness
  - you don’t want write code again and again
  - code is maintained at one place

Motivation - Generic Programming

Reasons to write generic code

- Laziness
  - you don't want write code again and again
  - code is maintained at one place
- Flexibility
  - others can use your code with their types
  - behavior of algorithm can be adjusted later

Outline

Trivial Example: swap

```
template <typename T> void swap(T& a, T& b)
{
  T tmp(a);
  a = b;
  b = tmp;
}
```

- announce that you write a template
- name the template arguments
- write template as if arguments where known types

Concept and Model (brief introduction)

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This code implies certain requirements on T

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- T must have an assignment operator that assigns

Or in formal words:

- T must be a Model of the Concept CopyConstructible
- T must be a Model of the Concept Assignable

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  - e.g. the return type of some required member function

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  - semantic guarantees, e.g., pre/post-conditions

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- Run-time Characteristics
  - semantic guarantees, e.g., pre/post-conditions
- Complexity Guarantees
  - maximum limits on execution time or required resources

Outline

Example: `normalize_rational` (I)

- Code for `leda::rational`

```
void normalize_rational(leda::rational& x) {
  leda::integer num   = x.numerator();
  leda::integer denom = x.denominator();
  leda::integer g     = leda::gcd(num,denom);
  x = leda::rational( num/g , denom/g );
}
```

Example: normalize_rational (I)

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  x = leda::rational( num/g , denom/g );
}
```

- Code for CORE::BigRat

```
void normalize_rational(CORE::BigRat& x) {
    CORE::BigInt num   = CORE::numerator(x);
    CORE::BigInt denom = CORE::denominator(x);
    CORE::BigInt g     = CORE::gcd(num,denom);
    x = CORE::BigRat( num/g , denom/g );
}
```

Example: `normalize_rational` (II)

Algorithm is actually clear:

- Take numerator and denominator.
- Compute the greatest common divisor (gcd).
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- Types are external and have different interface.
- How to get the type for integer ? (associated type)

Solution: Unify interface by using a traits class that you control!

Example: Rational_traits (I)

- a template version using a traits class:

```
template<class Rational>
void normalize_rational(Rational& x) {
  typedef Rational_traits<Rational> Traits;
  typedef typename Traits::Integer Integer;

  Integer num   = Traits::numerator(x);
  Integer denom = Traits::denominator(x);
  Integer g     = gcd(num,denom);
  x = Traits::make_rational( num/g , denom/g );
}
```

- use traits to get the integer type
- use traits to provide a unified interface

Example: Rational_traits (II)

```
template <typename T> struct Rational_traits{}; // default

// full specialization for leda::rational
template<> struct Rational_traits<leda::rational> {







};

// full specialization for CORE::BigRat
template<> struct Rational_traits<CORE::BigRat> {







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  static Integer numerator(const Rational& x){

  }

};

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  }
  // similar for denominator, make rational
};

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Traits class

Original definition:

- A traits class is a class template that associates information to compile-time entity, e.g., associated types or constants

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- may also provide unified interface

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Integer num   = Traits::numerator(x);
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Integer num   = Traits::numerator(x);
```

Sometimes the traits class is already used as the template argument:

- Advantage:
  provides all types and functionality the algorithm needs
  ⇒ usually only one template argument
- Disadvantage:
  this overload of the term *'traits'* may causes confusion

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Dispatching using Tags (I)

- Goal:
  - Provide a function `simplify` that is valid for any type.
  - If the argument is a rational it should normalize it.
  - Otherwise it should do nothing.
- Problem:
  - `normalize_rational` can only be instantiated for rationals.
  - This decision must be taken at compile time.

Dispatching using Tags (II)

First a small modification to `Rational_traits`:

```
struct Tag_false{}; // just two different classes
struct Tag_true{};

template <typename T> struct Rational_traits{ // default
  typedef Tag_false Is_rational;
};

template<> struct Rational_traits<leda::rational> {
  typedef Tag_true Is_rational;

  ... // the remaining definitions
};

template<> struct Rational_traits<CORE::BigRat> {
  typedef Tag_true Is_rational;

  ... // the remaining definitions
};
```

Dispatching using Tags (III)

Simplify some number:

```
template <class T> inline
void simplify_(T& x, Tag_false){}

template <class T> inline
void simplify_(T& x, Tag_true){normalize_rational(x);}

template <class T> inline
void simplify(T& x){
    typedef Rational_traits<T> Traits;
    typedef typename Traits::Is_rational Is_rational;
    simplify_(x, Is_rational());
}
```

Outline

maximal_element (array version)

Compute the maximal element of an array:

```
template <typename T>
T maximal_element(T* elements, int size){
  T result = elements[0];
  for(int i = 1; i < size; i++){
    if (result < elements[i])
      result = elements[i];
  }
  return result;
}


// usage:
int main(){
  int A[3]={5,7,1};
  std::cout << maximal_element(A,3) << std::endl;
}
```

The `std::vector` Container (the better array)

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- For more details on vector see also: http://www.sgi.com/tech/stl/Vector.html

maximal_element (std::vector version)

Compute the maximal element of an std::vector:

```
template <typename T>
T maximal_element(std::vector<T> elements){ // size not given
  T result = elements[0];
  for(int i = 1; i<elements.size(); i++){ // query for size
    if (result < elements[i])
      result = elements[i];
  }
  return result;
}


// usage:
int main(){
  std::vector<int> V; // no fixed size
  V.push_back(5); // can grow as needed
  V.push_back(7);
  V.push_back(1);
  std::cout << maximal_element(V) << std::endl;
}
```

Containers and Iterators

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  - `std::list // connected via pointers`
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  - ...
  - see also: http://www.sgi.com/tech/stl/stl_index_cat.html

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- Can we provide one version of `maximal_element` for all ?
  Yes, using Iterators !

Iterators

- Are a generalization of pointers, i.e., pointers are iterators.
- Provide a way of specifying a position in a container.
- Every container c provides `c.begin()` and `c.end()`
  - `c.begin()` points to the *'first'* element in the container
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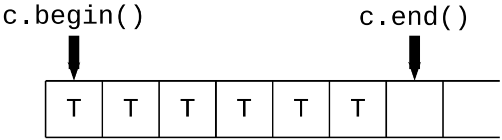

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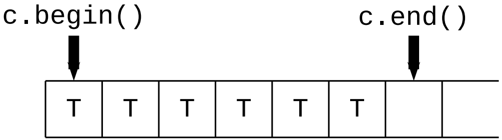

- Like pointers iterators can be
  - `*it` - dereferenced
  - `it1 == it2` - equality compared
  - `it++` - incremented (not all)
  - `it--` - decremented (not all)
  - `it[i]` - indexed (not all)

maximal_element (pointer version)

Compute the maximal element of a pointer range

```
template <typename T>
T* maximal_element(T* begin, T* end){
  T* result = begin;
  for(T* ptr = begin; ptr != end; ptr++){
    if (*result < *ptr)
      result = ptr;
  }
  return result;
}


// usage:
int main(){
  int A[3]={5,7,1};
  std::cout << *(maximal_element(A,A+3)) << std::endl;
}
```

maximal_element (iterator version)

Compute the maximal element of a pointer range

```
template <typename Iterator>
Iterator maximal_element(Iterator begin, Iterator end){
  Iterator result = begin;
  for(Iterator it = begin; it != end; it++){
     if (*result < *it)
      result = it;
  }
  return result;
}


// usage:
int main(){
  int A[3]={5,7,1};
  std::vector<int> V(A,A+3); // construction from 'iterator' range
  std::cout << *(maximal_element(A,A+3)) << std::endl;
  std::cout << *(maximal_element(V.begin(),V.end())) << std::endl;
}
```

see also: http://www.sgi.com/tech/stl/max_element.html

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  - Bidirectional Iterator // also decrementable
  - Random Access Iterator // operator[]
- There is `std::iterator_traits<Iterator>` providing `iterator_category` tag for dispatching.

see also: http://www.sgi.com/tech/stl/Iterators.html

Outline

Function Pointers

- Even more flexibility using function pointers:

```
template <typename Iterator, typename Comp>
Iterator maximal_element(Iterator begin, Iterator end, Comp comp){
  Iterator result = begin;
  for(Iterator it = begin; it != end; it++){
    if (comp(*result,*it))
      result = it;
  }
  return result;
}

bool less(const int& a, const int& b){return a<b;}
bool larger(const int& a, const int& b){return a>b;}

int main(){
  int A[3]={5,7,1};
  *(maximal_element(A,A+3,*less)) // returns 7
  *(maximal_element(A,A+3,*larger)) // returns 1
}
```

Function Objects

- Even more flexibility using function objects:

```
.. // definition of maximal_element as before

 template <typename T> struct Compare { // function object class

  bool m_less;  // carries a state
  Compare(bool less = true):m_less(less){}

  // make it look like a function
  bool operator()(const T& a, const T& b){
    if (m_less) return a < b;
    else return b < a;
  }
};

int main(){
  int A[3]={5,7,1};
  *(maximal_element(A,A+3,Compare<int>(true))) // returns 7
  *(maximal_element(A,A+3,Compare<int>(false))) // returns 1
}
```

- More flexibility due to carried state.

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Generic Programming & the STL Bibliography

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