USING THE STANDARD TEMPLATE LIBRARY (STL)

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```
#include<algorithm>
#include<vector>

int main ( const int, const char** const ) {
  const unsigned short myArray[5] = { 4, 7, 1, 1, 42 };
  std::vector<unsigned short> myVec ( myArray, myArray+5 );
  std::shuffle ( myVec.begin(), myVec.end(), std::mt19937 ( 23 ) );
  std::vector<unsigned short>::const_iterator
    it = std::find ( myVec.begin(), myVec.end(), 42 );
  return ( EXIT_SUCCESS );
}
```

USING THE STANDARD TEMPLATE LIBRARY (STL)

1. Introduction
2. Concepts
3. Containers
4. Iterators
5. Algorithms and Utilities

1. Introduction

Contents

1. Introduction

Disclaimer

This talk is about …

- concepts of STL
- examples of STL usage
- examples should work with C++-11 (compiled on gcc-4.6.3, clang 3.6, and Visual Studio 2013)
- code examples available (incomplete excerpts in slides)
- Thanks to Hans M. for feedback!

1. Introduction

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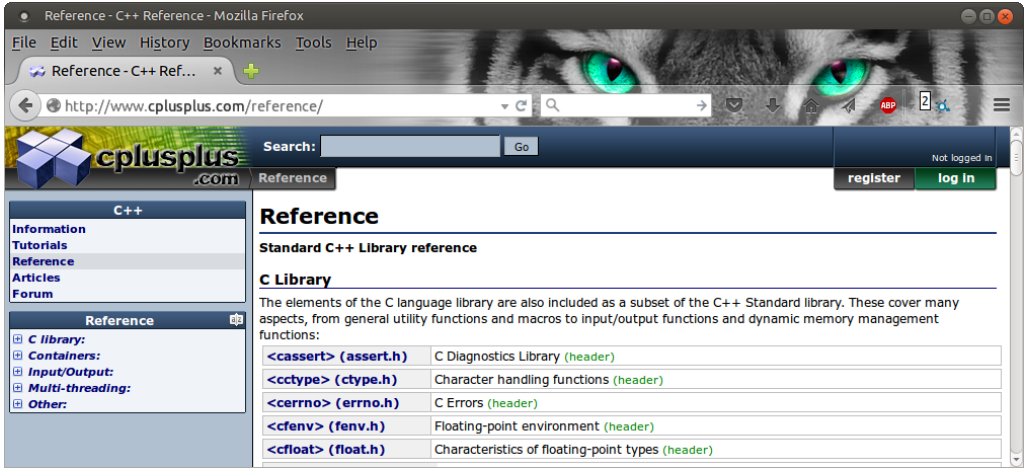
… but

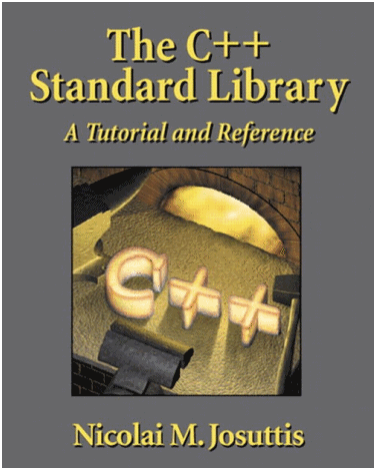
- I'm not a native STL speaker
- not exhaustive about STL
- no reference, see `http://www.cplusplus.com/reference` instead
- some observations may not be guaranteed
- boost or other libraries may offer better solutions for your needs
- example code quality not optimal
- not covered:
  - STL smart pointers
  - multithreading
  - exception handling
  - strings, stringstreams

1. Introduction

Further Reading



Further Reading



2. Concepts

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- algorithms and utilities **independent of containers**
- efficient (memory, time) if used correctly

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- `lowercase_names_with_underscores`
- data structures (containers) for specific use cases
- generic access by iterators
- algorithms and utilities **independent of containers**
- efficient (memory, time) if used correctly
- complexity guarantees

2. Concepts

First Example

```
#include<cstdlib>
#include<vector>

int main ( const int, const char** const ) {
  const unsigned int size = 10;
  std::vector<unsigned int> myVec(size);
  for ( unsigned int i = 0; i < size; ++i ) {
    myVec[i] = 42*i+23;
  }
  return ( EXIT_SUCCESS );
}
```

⇝ STLSimple.cpp

✘ not very STLish

3. Containers

Contents

3. Containers

Selected Containers

- `std::vector`
  - one-dimensional array
  - random access via index

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- `std::list`
  - bidirectionally linked list
  - cheap insertion
  - extension: `std::forward_list`

3. Containers

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- `std::list`
  - bidirectionally linked list
  - cheap insertion
  - extension: `std::forward_list`
- `std::set`
  - mathematical set: objects contained once
  - internally sorted
  - extensions: `std::multiset`, `std::unordered_set`

3. Containers

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- `std::set`
  - mathematical set: objects contained once
  - internally sorted
  - extensions: `std::multiset`, `std::unordered_set`
- `std::map`
  - “dictionary”, values for unique keys
  - internally sorted
  - extensions: `std::multimap`, `std::unordered_map`

3. Containers

Vectors

`std::vector<DataType>`

- one-dimensional array with dynamic size
- random access via index
- special `std::vector<bool>`

3. Containers

Vector 1

```
#include<vector>
// ...
std::vector<unsigned int> myVec(size); // create, 0-initialized

myVec[5] = 42; // random access
myVec.at(3) = 23; // random access with bounds checking

myVec.resize(12); // change size

myVec.push_back(23); // insert at (change size)
myVec.pop_back();    // remove last element

myVec.reserve(120); // allocation is logarithmic, but still ...

// iterate, note the ”auto” keyword (C++ 11)
for ( auto it = myVec.begin(); it != myVec.end(); ++it ) {
  std::cout << *it << std::endl;
}

myVec.clear(); // resize to 0
```

⇝ STLVector_Basic.cpp

3. Containers

Vector 2

```
#include<vector>
#include<algorithm>
// ...
std::vector<signed int> myVecA, myVecB;
// ... // fill vectors

// insert via iterator
std::vector<signed int>::iterator destPos = myVecA.begin();
++destPos; ++destPos;
myVecA.insert ( destPos, myVecB.rbegin(), myVecB.rend() );

// delete values (not indices) 60 (included) … 275 (excluded!)
signed int
  firstEntryToDelete = 60,
  firstEntryAfterDeletion = 275;
std::vector<signed int>::iterator
  rangeBegin = std::find ( myVecA.begin(), myVecA.end(), firstEntryToDelete ),
  rangeEnd = std::find ( myVecA.begin(), myVecA.end(), firstEntryAfterDeletion );
myVecA.erase ( rangeBegin, rangeEnd );
```

⇝ STLVector_Advanced.cpp

3. Containers

Lists

`std::list<DataType>`

- bidirectionally linked list
- no random access
- cheap insertion
- extension: `std::forward_list`

3. Containers

List 1

```
#include<list>

std::list<unsigned int> myList; // no size

for ( int i = 0; i < 12; ++i ) {
  myList.push_back ( 4 * i + 3 );
}

std::cout << ”myList␣is␣of␣size␣” << myList.size() << std::endl;
// iterate over list
for ( auto it = myList.begin(); it != myList.end(); ++it ) {
  std::cout << *it << std::endl;
}
```

3. Containers

List 2

```
std::list<unsigned int>::iterator it = myList.begin();
++it; ++it;
myList.insert ( it, 21859275 ); // insert new entry before it
                                // this is cheaper than for vectors
--it;
myList.erase ( it );

myList.push_front ( 4711 );
myList.push_back ( 28359 );

myList.pop_back();
myList.pop_front();

myList.clear(); // resize to 0
```

⇝ STLList_Basic.cpp

3. Containers

List 3

```
#include<list>

struct isOdd {
  template<typename IntegerType>
  bool operator() ( const IntegerType &Value ) {
    return ( ( Value % 2 ) == 1 );
  }
};

// in main program:
std::list<signed long int> myListA, myListB;

std::list<signed long int>::iterator myIt = myListA.begin();
std::advance ( myIt, 3 );
myListA.splice ( myIt, myListB );

myListA.sort();         // list-specific variants of generic
myListA.remove ( 65 );  // sort, remove, unique, remove_if
myListA.unique();
myListA.remove_if ( isOdd() );
```

⇝ STLList_Advanced.cpp

3. Containers

Vector vs. List 1

When using objects that are expensive to handle …

```
struct ExpensiveToCreate {
  ExpensiveToCreate ( ) : _val ( 0 ) {
    std::cout << ”␣␣EXPENSIVE␣create” << std::endl;
  }
  ExpensiveToCreate ( const size_t Val ) : _val ( Val ) {
    std::cout << ”␣␣EXPENSIVE␣create” << std::endl;
  }
  // ...
  // similar for destructor, copy constructor, operator=

  bool operator< ( const ExpensiveToCreate& Other ) const {
    return ( ( this->_val < Other._val ) );
  }

private:
  size_t _val;
};
```

3. Containers

Vector vs. List 2

… choose an efficient data structure!

```
const size_t mySize = 4;

std::vector<ExpensiveToCreate> myVector ( mySize );
for ( size_t i = 0; i < mySize; ++i ) {
  myVector[i] = ExpensiveToCreate ( mySize - i );
}
std::sort ( myVector.begin(), myVector.end() );

std::list<ExpensiveToCreate> myList;
for ( size_t i = 0; i < mySize; ++i ) {
  myList.emplace_back ( i );
}
myList.sort();
```

⇝ STLVectorVsList.cpp

3. Containers

Benchmark: List vs. Forward List

```
std::list<signed long int> myListC;
fillWithSomeData ( myListC );
std::cout << ”Modifying␣list␣…␣” << std::flush;
std::chrono::high_resolution_clock::time_point
  t1 = std::chrono::high_resolution_clock::now();

for ( size_t i = 0; i < ListSize; ++i ) {
  typename std::list<signed long int>::iterator it = myListC.begin();
  ++it;
  myListC.insert ( it, 4711 );
}

std::chrono::high_resolution_clock::time_point
  t2 = std::chrono::high_resolution_clock::now();
const std::chrono::duration<double>
  timeSpan = std::chrono::duration_cast<std::chrono::duration<double>>(t2 - t1);
std::cout << ”done,␣took␣” << timeSpan.count() << std::endl;
```

Benchmark: List vs. Forward List

```
std::forward_list<signed long int> myListD;
fillWithSomeData ( myListD );
std::cout << ”Modifying␣forward␣list␣…␣” << std::flush;
std::chrono::high_resolution_clock::time_point
  t1 = std::chrono::high_resolution_clock::now();

for ( size_t i = 0; i < ListSize; ++i ) {
  typename std::forward_list<signed long int>::iterator it = myListD.begin();
  ++it;
  myListD.insert_after ( it, 4711 );
}

std::chrono::high_resolution_clock::time_point
  t2 = std::chrono::high_resolution_clock::now();
const std::chrono::duration<double>
  timeSpan = std::chrono::duration_cast<std::chrono::duration<double>>(t2 - t1);
std::cout << ”done,␣took␣” << timeSpan.count() << std::endl;
```

⇝ STLForwardList.cpp

3. Containers

A Note on Code Optimization

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2. make it **reproducible**
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3. Containers

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"More computing sins are committed in the name of efficiency (without necessarily achieving it) than for any other single reason—including blind stupidity." (William Wulf)

3. Containers

Sets

`std::set<DataType>`

- mathematical set: objects contained once
- internally sorted according to comparison
- no direct (write) access
- fast find
- extensions
  - `std::multiset<DataType>` can contain multiple instances
  - `std::unordered_set<DataType>` hashed, not sorted

3. Containers

Set 1

```
#include<set>
// ...
std::set<short int> mySet;
for ( int i = 0; i < 25; ++i ) {
  const short int val = ( 12 * i + 2 ) % 26;
  mySet.insert ( val );
}
std::cout << ”mySet␣is␣of␣size␣” << mySet.size() << std::endl;
// note: no random access

std::cout << ”␣Removed␣” << mySet.erase ( 12 ) << ”␣times␣entry␣12.” << std::endl
          << ”␣Removed␣” << mySet.erase ( 13 ) << ”␣times␣entry␣13.” << std::endl;
```

3. Containers

Set 2

```
// iterate over set, as before
for ( auto it = mySet.begin(); it != mySet.end(); ++it ) {
  std::cout << *it << std::endl;
}

std::set<short int>::iterator pos = mySet.find ( 16 );
std::cout << "16 found: " << *pos << std::endl;

std::set<short int>::iterator otherPos = mySet.find ( 23 );
if ( otherPos == mySet.end() ) {
  std::cout << "the following results in undefined behavior" << std::endl;
  std::cout << "23 not found: " << *otherPos << std::endl; // dereferencing undefined!
}
```

⇝ **STLSet_Basic.cpp**

3. Containers

Unordered Set and Multiset 1

```
template<typename SetType>
void fillAndPrint ( ) {
  SetType mySet;

  for ( int i = 0; i < 25; ++i ) {
    const short int val = ( 12 * i + 2 ) % 26;
    std::cout << ”inserting␣” << val << std::endl;
    mySet.insert ( val );
  }

  std::cout << ”mySet␣is␣of␣size␣” << mySet.size() << std::endl;

  for ( auto it = mySet.begin(); it != mySet.end(); ++it ) {
    std::cout << *it << std::endl;
  }
  std::cout << std::endl;
}
```

3. Containers

Unordered Set and Multiset 2

```
#include<set>
#include<unordered_set>
// ...
std::cout << ”Multiset:␣” << std::endl;
fillAndPrint < std::multiset<short int> > ();

std::cout << ”Unordered␣Set:␣” << std::endl;
fillAndPrint < std::unordered_set<short int> > ();

std::cout << ”Unordered␣Multiset:␣” << std::endl;
fillAndPrint < std::unordered_multiset<short int> > ();
```

Unordered Set: More about Hashing

```
#include<set>
#include<unordered_set>
// ...

std::unordered_set<std::string> myUnorderedSet;

for ( int i = 0; i < 25; ++i ) {
  std::string number = ”Number␣” + std::to_string ( i );
  std::cout << ”inserting␣” << number << ”␣with␣hash␣”
            << myUnorderedSet.hash_function() ( number ) << std::endl;
  myUnorderedSet.insert ( number );
}

std::cout << ”Load␣factor␣is␣” << myUnorderedSet.load_factor()
          << ”,␣there␣are␣” << myUnorderedSet.bucket_count() << ”␣buckets.” << std::endl;

std::string num23 ( ”Number␣23” );
std::cout << num23 << ”␣is␣in␣bucket␣” << myUnorderedSet.bucket ( num23 ) << std::endl;
```

⇝ STLSet_Extensions.cpp

3. Containers

Maps

`std::map<KeyType, ValueType>`

- “dictionary”, values for unique keys
- internally sorted according to comparison
- fast lookup
- access via `operator[]` somewhat tricky
- extensions
  - `std::multimap<KeyType, ValueType>` can contain multiple value per key
  - `std::unordered_map<KeyType, ValueType>` hashed, not sorted

3. Containers

Map 1

```
#include<map>
#include<string>
// ...
std::map<short int, std::string> myMap;
myMap[1] = ”One”; // inserting elements works via operator[]
myMap.insert ( std::pair<short int, std::string> ( 2, ”Two” ) );
myMap.insert ( std::make_pair ( 3, ”Three” ) );

std::cout << ”1:␣” << myMap[1] << std::endl; // access also works via operator[]

std::cout << ”4:␣” << myMap[4] << std::endl;
                  // there is no const access, default object created instead!

auto it = myMap.find ( 1 );
std::cout << it->first << ”␣” << it->second << std::endl; // iterator points to pair

it = myMap.find ( 5 );
std::cout << ( it == myMap.end() ) << std::endl;
```

3. Containers

Map 2

```
#include<map>
#include<string>
// ...
std::map< std::string, short int>
  myOtherMap = { { ”Zero␣”, 0 },
                 { ”One␣␣”, 1 },
// ...
                 { ”Eight”, 8 },
                 { ”Nine␣”, 9 } };
// alternative form of initialization

// this is how one can iterate over a map
for ( auto it = myOtherMap.begin(); it != myOtherMap.end(); ++it ) {
  std::cout << it->first << ”␣” << it->second << std::endl;
} // note: the map is sorted
```

⇝ STLMap_Basic.cpp

3. Containers

Map 3

```
#include<map>
#include<string>
// ...
std::map<short int, std::string> myMap;
myMap[1] = ”One”; // inserting elements works via operator[]
myMap[2] = ”Two”;
std::string dwarf = myMap[3];

// access including existence check and const access via at()
for ( short int i = 0; i < 5; ++i ) {
  std::string myString;
  try {
    myString = myMap.at ( i );
  } catch ( std::exception &ex ) {
    std::cout << ”exception␣caught:␣” << ex.what() << std::endl;
    myString = ”not␣found”;
  }
  std::cout << i << ”:␣” << myString << std::endl;
}
```

Unordered Map

```
#include<unordered_map>
#include<string>
// ...
std::unordered_map< std::string, short int>
  myOtherMap = { { ”Zero␣”, 0 },
                 { ”One␣␣”, 1 },
                 { ”Two␣␣”, 2 },
                 { ”Three”, 3 },
                 { ”Four␣”, 4 },
                 { ”Five␣”, 5 },
                 { ”Six␣␣”, 6 },
                 { ”Seven”, 7 },
                 { ”Eight”, 8 },
                 { ”Nine␣”, 9 } };
// alternative form of initialization

// iteration as usual (for maps)
for ( auto it = myOtherMap.begin(); it != myOtherMap.end(); ++it ) {
  std::cout << it->first << ”␣” << it->second << std::endl;
}
```

3. Containers

Multimap 1

```
#include<map>
#include<string>
// ...
std::multimap<unsigned int, std::string>
  myMap = { { 1, ”one” },
            { 1, ”eins” },
// ...
            { 3, ”three” },
            { 3, ”drei” } };
// no access via operator[]
for ( auto it = myMap.begin(); it != myMap.end(); ++it ) {
  std::cout << it->first << ”␣” << it->second << std::endl;
}
```

Multimap 2

```
std::cout << ”number␣of␣occurences␣of␣1␣and␣4:␣”
          << myMap.count ( 1 ) << ”␣” << myMap.count ( 4 ) << std::endl;

// here’s how to iterate over values with the same key
typedef std::multimap<unsigned int, std::string>::const_iterator citType;
std::pair< citType, citType >
  range = myMap.equal_range ( 2 );
for ( citType it = range.first; it != range.second; ++it ) {
  std::cout << it->first << ”␣” << it->second << std::endl;
}
```

⇝ STLMap_Advanced.cpp

Caution: Set and Map with Floating Point Numbers

```
const double
  oneThirdA = 1.0/3.0f,
  oneThirdB = A::getOneOverThirty() / 2 + 9.5f * A::getOneOverThirty(),
  oneThirdC = 10.0f * A::getOneOverThirty();

std::map<double, std::string> myMap;
myMap [ oneThirdA ] = ”one␣third␣A”;
myMap [ oneThirdB ] = ”one␣third␣B”;

std::cout << ”should␣be␣oneThird␣A␣or␣B:␣”
          << myMap [ 10.0f * A::getOneOverThirty() ] << std::endl;

myMap [ oneThirdC ] = ”one␣third␣C”;

for ( auto it = myMap.begin(); it != myMap.end(); ++it ) {
  std::cout << it->first << ”␣” << it->second << ”␣”;
  printAsHex ( it->first );
  std::cout << std::endl;
}
```

⇝ STLMap_HowNotTo.cpp

4. Iterators

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- `reverse_iterator` vs. `iterator`
  - `for ( std::vector<...>::reverse_iterator it = vec.rbegin(); it != myVec.rend(); ++it )`

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  - `for ( std::vector<...>::reverse_iterator it = vec.rbegin(); it != myVec.rend(); ++it )`
- `const_iterator` vs. `iterator`

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  - `for ( std::vector<...>::reverse_iterator it = vec.rbegin(); it != myVec.rend(); ++it )`
- `const_iterator` vs. `iterator`
  - prevent modifying container contents

Iterators

- iterators can be used similarly for different containers
- replacable by pointers (see sorting example later) or anything that behaves like an iterator
- unidirectional vs. bidirectional vs. random access iterators
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- `const_iterator` vs. `iterator`
  - prevent modifying container contents
  - `const_iterator`s can still be incremented
- iterators (pointers, references) may survive container modification or not

5. Algorithms and Utilities

Contents

5. Algorithms and Utilities

Debugging Support

compiler define `_GLIBCXX_DEBUG`:

```
g++ -std=c++0x -g -D_GLIBCXX_DEBUG
  -lm -o STLDebugging.bin_d STLDebugging.cpp
```

```
#include<cstdlib>
#include<iostream>
#include<vector>

int main ( const int, const char** const ) {
  const unsigned int size = 2;
  std::vector<unsigned int> myVec(size);
  myVec.clear();
  myVec[1] = 42;
  // myVec.at(1) = 42;
  return ( EXIT_SUCCESS );
}
```

⇝ **STLDebugging.cpp**

5. Algorithms and Utilities

Predicates

- functions returning Boolean value
- always return same value (no internal state)
- e.g., comparison for sorting

```
bool isDivisibleByFour ( const int &Arg ) {
  return ( ( ( Arg % 4 ) == 0 ) );
}
```

5. Algorithms and Utilities

Functors (Function Objects)

- object with `operator()`
- behave like a function, but more general

```
class UniqueNumberGenerator {
public:
  UniqueNumberGenerator() : _num ( 0 ) {
  }

  int operator()() {
    _num += 3;
    return ( _num );
  }

private:
  int _num;
};
```

5. Algorithms and Utilities

Algorithms

- some examples of container methods seen above
- STL offers **generic** algorithms independent of STL data structures
- access via iterators or iterator-likes

5. Algorithms and Utilities

Pairs

```
#include<list>
#include<limits>

template<typename T>
std::pair<T, unsigned int> findMaximumAndItsPosition ( std::list<T> &Arg ) {
  std::pair<T, unsigned int> res ( - std::numeric_limits<T>::infinity(),
                                   std::numeric_limits<unsigned int>::max() );
  unsigned int i = 0;
  for ( typename std::list<T>::const_iterator it = Arg.begin();
        it != Arg.end(); ++it, ++i ) {
    if ( (*it) > (res.first) ) {
      res.first  = (*it);
      res.second = i;
    }
  }
  return ( res );
}
// ...
std::pair<double, unsigned int> maxAndPos = findMaximumAndItsPosition ( myList );
```

⇝ **STLUtilities_Pair.cpp**

5. Algorithms and Utilities

Min, Max, Swap

```
#include<cstdlib>
#include<iostream>

int main ( const int, const char** const ) {
  int a = 23, b = 42;
  std::cout << ”Maximum␣is␣” << std::max ( a, b) << std::endl;
  std::cout << ”Maximum␣is␣” << std::min ( a, b) << std::endl;

  std::swap ( a, b );
  std::cout << ”Now␣a␣=␣” << a << ”,␣b␣=␣” << b << std::endl;

  return ( EXIT_SUCCESS );
}
```

⇝ **STLUtilities_MinMaxSwap.cpp**

5. Algorithms and Utilities

Maximum with Comparator

```
int weightedTimeSinceMeal ( const int Hour ) {
  static const int hPD = 24; // hours per day

  const int hour = Hour % hPD;
       if ( hour <  8 ) { return ( ( ( hPD + hour - 20 ) % hPD ) / 2 ); }
  else if ( hour < 12 ) { return ( 2 * ( hour - 8 ) );                  }
  else if ( hour < 20 ) { return ( ( hour - 12 ) );                     }
  else {                  return ( ( ( hour - 20 ) % hPD ) / 2 );       }

}

bool hungerCompare ( const int HourA, const int HourB ) {
  return ( weightedTimeSinceMeal ( HourA ) < weightedTimeSinceMeal ( HourB ) );
}
// ...

const int timeA = 11, timeB = 14;

std::cout << "Comparing " << timeA << " and " << timeB
          << ", more hungry at " << std::max ( 11, 14, hungerCompare ) << std::endl;
```

⇝ STLUtilities_Compare.cpp

5. Algorithms and Utilities

Sorting 1

```
#include<vector>
#include<set>
#include<algorithm>

const size_t mySize = 8;
const float myArray[mySize] = { 0.2, 0.8, 1.9, 1.7, 0.3, 1.1, 1.5, 0.4 };

std::vector<float> myVector ( myArray, myArray+mySize );
std::sort ( myVector.begin(), myVector.end() );

std::sort ( myVector.begin(), myVector.end(), std::greater<float>() );

std::set<float, std::greater<float> > mySet ( myArray, myArray+mySize );
```

5. Algorithms and Utilities

Sorting 2

```
#include<vector>
#include<algorithm>

template<typename FloatDataType>
struct lessAsInt {
  bool operator() ( const FloatDataType A, const FloatDataType B ) const {
    return ( ( static_cast<int> ( A ) < static_cast<int> ( B ) ) );
  }
};

std::vector<float> myVectorB ( myArray, myArray+mySize );
std::sort ( myVectorB.begin(), myVectorB.end(), lessAsInt<float>() );

std::sort ( myArray, myArray+mySize ); // sort C array
```

⇝ STLAlgorithms_Sorting.cpp

5. Algorithms and Utilities

Generators 1

```
int consecutiveNumber() {
  static int counter = 0;
  return ( counter++ );
}

class UniqueNumberGenerator {
public:
  UniqueNumberGenerator() : _num ( 0 ) {
  }

  int operator()() {
    _num += 3;
    return ( _num );
  }

private:
  int _num;
};
```

5. Algorithms and Utilities

Generators 2, Transform, Accumulate

```
#include<vector>
#include<algorithm>
#include<functional>
// ...
const size_t mySize = 10;
std::vector<int> myVectorA ( mySize );
std::generate ( myVectorA.begin(), myVectorA.end(), consecutiveNumber );

std::vector<int> myVectorB ( mySize );
std::generate ( myVectorB.begin(), myVectorB.end(), UniqueNumberGenerator() );

std::vector<int> myVectorC ( mySize );
std::transform ( myVectorA.begin(), myVectorA.end(),
                 myVectorB.begin(), myVectorC.rbegin(), std::plus<int>() );
const int
  init = 50,
  result = std::accumulate ( myVectorA.begin(), myVectorA.end(),
                             init, std::minus<int>() );
std::cout << "result␣=␣" << result << std::endl;
```

⇝ **STLAlgorithms_Generate.cpp**

Find and Iterator Arithmetics

```
#include<vector>
#include<algorithm>

typedef unsigned short ushort;
const size_t mySize = 10;

// std::find works with C arrays as well as STL data structures

const ushort myArray[mySize] = { 0, 2, 4, 6, 8, 10, 12, 14, 12, 12 };
const ushort* p = std::find ( myArray, myArray+mySize, 12 );
if ( ( p - myArray ) < mySize ) {
  std::cout << "Found " << *p << " at position " << p - myArray << std::endl;
} // else, p == myArray+mySize indicating not found

std::vector<ushort> myVector ( myArray, myArray+mySize );
std::vector<ushort>::iterator
  pos = std::find ( myVector.begin(), myVector.end(), 14 );
if ( pos != myVector.end() ) {
  std::cout << "Found " << *pos << " at position "
            << pos - myVector.begin() << std::endl; // iterator difference
} // else not found
```

5. Algorithms and Utilities

Count, Shuffle and Minmax_Element

```
#include<ctime>
#include<random>
// ...

const int numCount = std::count ( myArray, myArray+mySize, 12 );
std::cout << ”12␣is␣contained␣” << numCount << ”␣times.” << std::endl;

unsigned int mySeed = static_cast<int> ( std::time(0) );
std::shuffle ( myVector.begin(), myVector.end(), std::mt19937 ( mySeed ) );

std::pair< std::vector<ushort>::iterator,
           std::vector<ushort>::iterator >
  minMax = std::minmax_element ( myVector.begin(), myVector.end() );

std::cout << ”Minimum␣of␣” << * ( minMax.first  )
          <<  ”␣at␣” << minMax.first  - myVector.begin() << ”,␣”
          << ”maximum␣of␣” << * ( minMax.second )
          <<  ”␣at␣” << minMax.second - myVector.begin() << std::endl << std::endl;
```

similarly: **std::count_if**, **std::min_element**, **std::max_element**

5. Algorithms and Utilities

Partitioning and Binary Search

```
bool isDivisibleByFour ( const ushort &Arg ) {
  return ( ( ( Arg % 4 ) == 0 ) );
}

bool veryExpensiveComparison ( const ushort &A, const ushort &B ) {
  std::cout << "VERY EXPENSIVE COMPARISON" << std::endl;
  return ( ( A < B ) );
}

// ...

std::vector<ushort> myVector2 ( myVector );

std::partition ( myVector2.begin(), myVector2.end(), isDivisibleByFour );

std::stable_partition ( myVector.begin(), myVector.end(), isDivisibleByFour );

bool found = std::binary_search ( myVector.begin(), myVector.end(),
                                  14, veryExpensiveComparison );
```

⇝ STLAlgorithms_Misc.cpp

6. Summary

1. Introduction
2. Concepts
3. Containers
4. Iterators
5. Algorithms and Utilities

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6. Summary

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