Direction for C++0x

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Abstract

A good programming language is far more than a simple collection of features. My ideal is to provide a set of facilities that smoothly work together to support design and programming styles of a generality beyond my imagination. Here, I outline rules of thumb (guidelines, principles) that are being applied in the design of C++0x. For example, generality is preferred over specialization, novices as well as experts are supported, library extensions are preferred over language changes, compatibility with C++98 is emphasized, and evolution is preferred over radical breaks with the past. Since principles cannot be understood in isolation, I very briefly present a few of the proposals such as concepts, generalized initialization, auto, template aliases, being considered in the ISO C++ standards committee.

Overview

- The problem
- Standardization
- Rules of thumb
- Examples
- If time permits:
  Generic programming and concepts
- Smmaries

ISO Standard C++

- C++ is a general-purpose programming language with a bias towards systems programming that
  - is a better C
  - supports data abstraction
  - supports object-oriented programming
  - supports generic programming

- A multi-paradigm programming language
  (if you must use long words)
  - The most effective styles use a combination of techniques

Problems

- C++ is immensely popular
  - well over 3 million programmers according to IDC
  - incredibly diverse user population
    - Application areas
    - Programmer ability
- Many people want improvements (of course)
  - For people like them doing work like them
  - “just like language XYZ”
  - And don’t increase the size of the language, it’s too big already
- Many people absolutely need stability
  - N*100M lines of code

Problems

- We can’t please everyone
  - The list of requested features in large and growing
    - See my C++ page
  - The language really is uncomfortably large and complex
- A language is far more than a simple collection of features
  - Designing a language feature to fit into a language is hard
    - Generality
    - Composability
  - Adding a feature can harm users
    - Performance
      - compile time, run time
    - Compatibility
      - Source, linkage, ABIs
    - Ease of learning

The (real) problems

- Help people to write better programs
  - Easier to write
  - Easier to maintain
  - Easier to achieve acceptable resource usage

C++ ISO Standardization

- Current status
  - ISO standard 1998, TC 2003,
  - Library TR 2005, Performance TR 2005
  - C++0x in the works – due 200x
- Membership
  - About 22 nations (8 to 12 represented at each meeting)
    - ANSI hosts the technical meetings
    - Other nations have further technical meetings
  - About 120 active members (50+ at each meeting)
    - About 200 members in all
    - Down ~40% from its height (1996), up again the last few years
- Process
  - formal, slow, bureaucratic, and democratic
  - “the worst way, except for all the rest” (apologies to W. Churchill)

Standardization – why bother?

- Directly affects millions
  - Huge potential for improvement
    - So much code is appallingly poor
- Defense against vendor lock-in
  - Only a partial defense, of course
  - I really don't like proprietary languages
- There are still many new techniques to get into use
  - They require language or standard library support to affect mainstream use
- For C++, the ISO standards process is central
  - C++ has no rich owner who dictates changes or controls a tame standards progress
    - And pays for marketing
  - The C++ standards committee is the central forum of the C++ community
  - For (too) many: "if it isn't in the standard it doesn't exist"
    - Unfair, but a reality

Why mess with a good thing?

- The ISO Standard is good
  - but not perfect
- ISO rules require review
  - Community demands consideration of new ideas
- We face increasingly difficult tasks
  - We == programmers and system designers
- The world changes
  - and poses new challenges
- We have learned a lot since 1996
  - When the last of the ISO C++ features was proposed
- Stability is good
  - but the computing world craves novelty
  - Without challenges, the best people will depart for greener pastures

Overall Goals

- Make C++ a better language for systems programming and library building
  - Rather than providing specialized facilities for a particular sub-community (e.g. numeric computation or Windows-style application development)
- Make C++ easier to teach and learn
  - Through increased uniformity, stronger guarantees, and facilities supportive of novices (there will always be more novices than experts)

Rules of thumb / Ideals

- Provide stability and compatibility
- Prefer libraries to language extensions
- Make only changes that changes the way people think
- Prefer generality to specialization
- Support both experts and novices
- Increase type safety
- Improve performance and ability to work directly with hardware
- Fit into the real world

Stability and compatibility

- The aim for C++0x is evolution constrained by a strong need for compatibility.
- The aim of that evolution is to provide major real-world improvements.
  - Not fiddling with minor details
- 100% compatibility is too constraining
  - E.g. new keyword
    - **static_assert**
  - We avoid extreme circumlocution
    - **#define static_assert __Static_assert**

Libraries and language features

- Prefer libraries to language extensions
- A major aim of the language is to support better library building
  - Well-defined machine model
  - Better support for generic programming
  - Move semantics
- New library component examples
  - Unordered_map (hash_map; Library TR 2004)
  - Regexp (Library TR – 2004)
  - “smart” pointers (Library TR – 2004)
  - File manipulation
  - Threads

Prefer generality to specialization

- The aim for C++0x is to supply general language mechanisms that can be used freely in combination and to deliver more specialized features as standard library facilities built from language features available to all.
- Examples
  - Better generic programming support
  - Improve initialization facilities
  - Provide user-defined constant expressions (ROMable)
- C++ will remain a general-purpose language
  - Not, a specialized
    - web language,
    - a Windows application language
    - embedded systems programming language
  - We'll be better in all of those application areas – and more

Support novices

- C++ has become too “expert friendly”
- Most of us are novices at something most of the time

- Have you ever written something like this?

```
vector<vector<double>> v;
```

or this?

```
int i = extract_int(s);          // s is a string, e.g. “12.37”
```

or this?

```
vector<int>::iterator p = find(tbl.begin(), tbl.end(), x);
```

Better (C++0x)

- This'll work

```
vector<vector<double>> v;    // no space between the >s

auto p = find(tbl.begin(), tbl.end(), x);
 // tbl is a const vector<int>
 // p becomes vector<int>::const_iterator
```

- The >> and **auto** solutions have been approved for C++0x
- "Supporting novices of all backgrounds" requires work on both the language and the standard library.
- Concerns for education will be central for that
  - E.g., "Learning Standard C++ as a new Language" [Stroustrup, 1999].
- Overloading based on concepts, will allow a further simplification

```
auto p = find(tbl, x);  // tbl is some container
```

Type safety

- For correctness, safety and security, and convenience
  - complex, dangerous code:

```
void get_input(char* p)
{
        char ch;
        while (cin.get(ch) && !iswhite(ch)) *p++ = ch;
        *p = 0;
}
```

  - Better, much better:

```
string s;
cin >> s;
```

Type safety

- For performance
  - Messy, slow code:

```
struct Link {
   Link* link;
   void* data;
};

void my_clear(Link* p, int sz)      // clear data of size sz
{
   for (Link* q = p; q!=0; q = q->link) memset(q->data,0,sz);
}
```

  - Simpler, faster code:

```
template<class In> void my_stl_clear(In first, In last)
   {
         while (first!=last) *first++ = 0;
   }
```

Areas of language change

- Machine model and concurrency
- Modules and libraries
- Concepts and other type stuff
  - Auto, decltype, template aliases,“strong enums”
  - initialization
- Etc.
  - >>, static_assert, long long, for each, C99 character types

C++98 example

- Initialize a vector
  - clumsy

```
template<class T> class vector {
   // …
   void push_back(const T&) { /* … */ }
   // …
};

vector<double> v;
v.push_back(1.2);
v.push_back(2.3);
v.push_back(3.4);
```

C++98 example

- Initialize a vector
  - Awkward
  - Spurious use of (unsafe) array

```
template<class T> class vector {
   // …
   template <class Iter>
         void vector(Iter first, Iter last) { /* … */ }
   // …
};

int a[ ] = { 1.2, 2.3, 3.4 };
vector<double> v(a, a+sizeof(a)/sizeof(int));
```

  - Important principle (currently violated):
    - Support user-defined types as well as built-in types

C++0x version

```
template<Value_type T> class vector {      // note: T is typed
        // …
        vector(Sequence<T>);     // sequence constructor
        // …
    };
vector<double> v = { 1.2, 2.3, 3.4 };
```

- Exactly how should the sequence constructor be defined?

Will this happen?

- Probably
  - Lillehammer meeting adopted schedule aimed at ratified standard in 2009 (feature complete late 2007)
  - With the feature set as described here
    - We'll be flooded with new request before August 2005 "proposal freeze"
    - We'll slip up a few times – this really is hard
  - Ambitious, but
    - We'll work harder
    - We have done it before

Generic programming: The language is straining

- Late checking
  - At template instantiation time
- Poor error messages
  - Amazingly so
    - Pages!
- Too many clever tricks and workarounds
  - Works beautifully for correct code
    - Uncompromising performance is usually achieved
      - After much effort
  - Users are often totally baffled by simple errors
  - The notation can be very verbose
    - Pages for things that’s logically simple

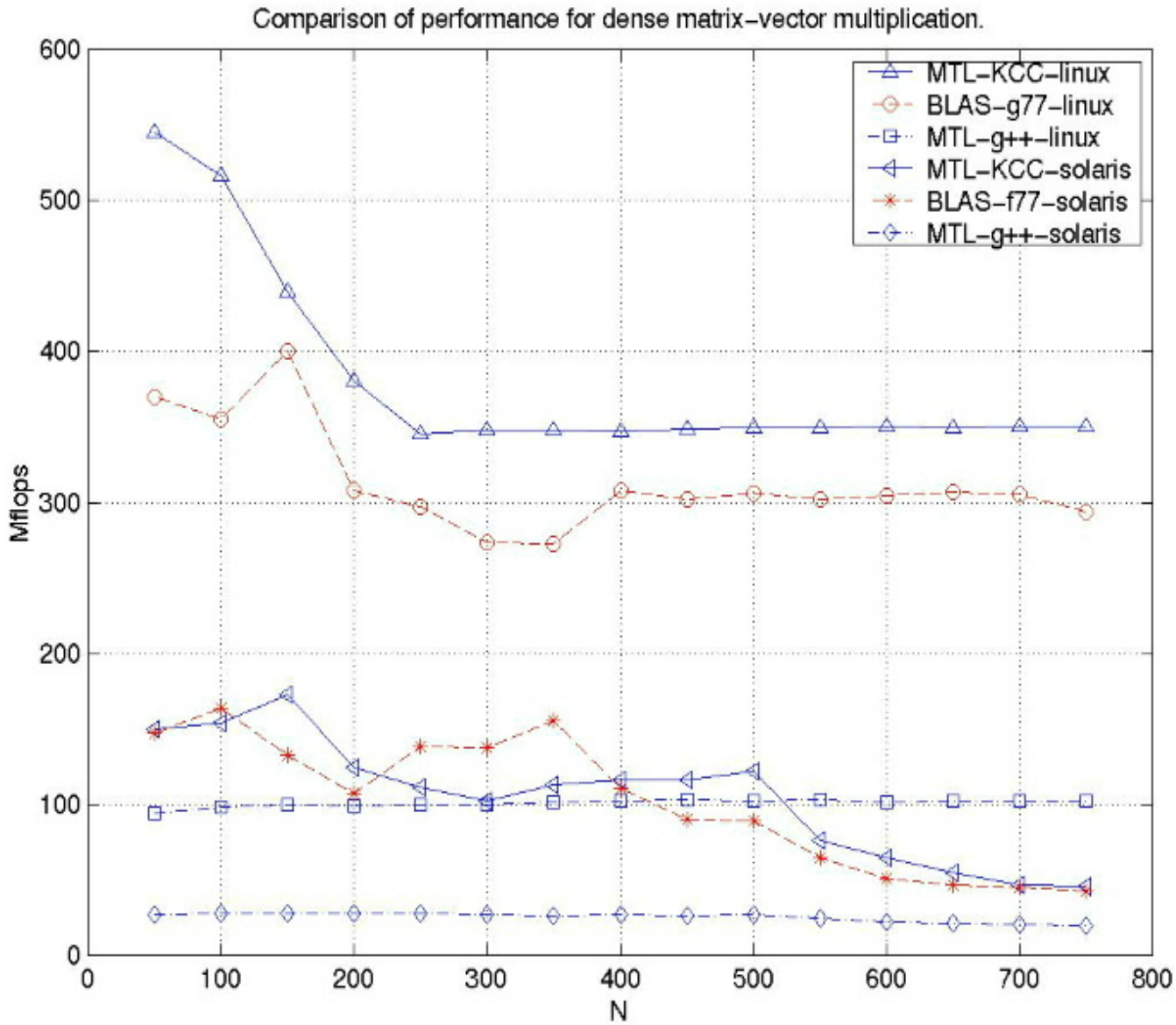
What's wrong?

- Poor separation between template definition and template arguments
  - But that's essential for optimal code
  - But that's essential for flexible composition
  - So we must **improve separation** as much as possible without breaking what's essential
- We have to say too much (explicitly)
  - So we must find ways to **abbreviate and make implicit**
- The template name lookup rules are too complex
  - But we can't break masses of existing code
  - So find ways of saying things that **avoid the complex rules**

What's right?

- Parameterization doesn't require hierarchy
  - Less foresight required
    - Handles separately developed code
  - Handles built-in types beautifully
- Parameterization with non-types
  - Notably integers
- Uncompromised efficiency
  - Near-perfect inlining
- Compile-time evaluation
  - Template instantiation is Turing complete

We try to strengthen and enhance what works well


Comparison of performance for dense matrix−vector multiplication.
MTL−KCC−linux
BLAS−g77−linux
MTL−g++−linux
MTL−KCC−solaris
BLAS−f77−solaris
MTL−g++−solaris
Mflops
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C++0x proposals related to generic programming

- **Concept**s
  - Type checking for template arguments
  - Overloading based on template types
  - Unified call syntax
  - Unified template declaration syntax
- **auto/decltype**
  - Simplified notation
  - Perfect forwarding (also using move semantics)
- Template aliases
- Generalized initializers

Example

```
template<Forward_iterator For, Value_type V>
    where Assignable<For::value_type,V>
void fill(For first, For last, const V& v)
{
    while (first!=last) { *first = v; ++first; }
}

int i = 0;
int j = 9;
fill(i, j, 9.9);        // error: int is not a Forward_iterator

int* p= &v[0];
int* q = &v[9];
fill(p, q, 9.9);        // ok
```

Alternate (explicit predicate) notation

A “concepts” is a predicate on one or more types
(or types and integer values)

```
template<class For, class V>
    where Forward_iterator<For>
    && Value_type<V>
    && Assignable<For::value_type,V>
void fill(For first, For last, const V& v)
{
    while (first!=last) { *first = v; ++first; }
}
```

template<class T> means “for all types **T**”

template<C T> means “for all types **T,** such that **C<T>**”

Example

```
template<Forward_iterator For, Value_type V>
    where Assignable<For::value_type,V>
void fill(For first, For last, const V& v)
{
    while (first!=last) {
        *first = v;
        first = first+1;     // error: no + defined for Forward_iterator
    }
}

int* p= &v[0];
int* q = &v[9];
fill(p, q, 9.9);
```

In a template definition you can use only the operations defined for the concept in the way they are specified in the concept

Yet another example

```
template<Value_type T> class vector {
    // …
    vector(size_type n, const value_type& x = value_type());
    template<Input_iterator Iter> vector(Iter first, Iter last);
};

vector<int> v1(100,1);      // call 1st constructor
int* p = …
int* q = …
vector<int> v2(p,q);        // call 2nd constructor
```

- Important principle (currently violated):
- the C++ standard library should be written in C++
  - and preferably reasonably obvious and good C++ because people do read it and copy its style

Defining concepts

```
concept Forward_iterator<class Iter>{
    Iter p;                     // uninitialized
    Iter q =p;                  // copy initialization
    p = q;                      // assignment

    Iter& q = ++p;              // can pre-increment, result usable as an Iter&
    const Iter& cq = p++;       // can post-increment, result convertible to Iter

    bool(p==q);                 // equality comparisons,  result convertible to bool
    bool(p!=q);

    Value_type Iter::value_type;   // Iter has a member type value_type,
                                   // which is a Value_type
    Iter::value_type = *p;         // *p is an lvalue of Iter's value type
    *p = v;
};
```

Using a type (obvious match of concept)

```
class Ptr_to_int {
    typedef int value_type;
    Ptr_to_int& operator++();       // ++p
    Pter_to_int operator++(int);    // p++
    int& operator*();               // *p
    // …
};

bool operator==(const Ptr_to_int&, const Ptr_to_int&);
bool operator!=(Ptr_to_int, Ptr_to_int);

const int max = 100;
int a[max];
Ptr_to_int pi(a);
Ptr_to_int pi2(a+100);
fill(pi, pi2, 77);
```

Using a type (not so obvious match of concept)

```
const int max = 100;
int a[max];
fill(a, a+max, 77);
```

- Obviously, we want an **int*** to be a **Forward_iterator**
  - But what about the member type **value_type**?

Explicit concept asserts

- we can say “unless **Ptr_to_int** is a **Forward_iterator** the compilation should fail”

  static_assert Forward_iterator<Ptr_to_int>;

- The exact details are under vigorous debate
  - I think that static asserts are necessary but their use must be optional

Explicit concept asserts

```
// when uses as an argument for a Forward_iterator concept parameter,
// value_type should be considered a member of T* with the “value” int:
static_assert template<Value_type T>  Forward_iterator<T*> {
    typedef T* pointer_type;          // auxiliary name for predicate argument
    typedef  T pointer_type::value_type;
};


// clearer, but would involve syntax extensions
static_assert template<Value_type T>  Forward_iterator<T*> {
    using T*::value_type = T;
};
```

Core language suggestions (Lots!)

- **decltype/auto –** type deduction from expressions
- Template alias
- **#nomacro**
- Extern template
- Dynamic library support
- Allow local classes as template parameters
- Move semantics
- **nullptr** - Null pointer constant
- Static assertions
- Concepts (a type system for types)
- Solve the forwarding problem
- Variable-length template parameter lists
- Simple compile-time reflection
- GUI support (e.g. slots and signals)
- Defaulting and inhibiting common operations
- Class namespaces
- **long long**
- >> (without a space) to terminate two template specializations
- …

Library TR

- Hash Tables
- Regular Expressions
- General Purpose Smart Pointers
- Extensible Random Number Facility
- Mathematical Special Functions

- Polymorphic Function Object Wrapper
- Tuple Types
- Type Traits
- Enhanced Member Pointer Adaptor
- Reference Wrapper
- Uniform Method for Computing Function Object Return Types
- Enhanced Binder

What's out there? (Lots!)

Library building is the most fertile source of ideas

- Libraries
- Core language

- Boost.org – libraries loosely based on the standard libraries
- ACE – portable distributed systems programming platform
- Blitz++ – the original template-expression linear-algebra library
- SI – statically checked international units
- Loki – mixed bag of very clever utility stuff
- Endless GUIs and GUI toolkits
  - GTK+/gtkmm, Qt, FOX Toolkit, eclipse, FLTK, wxWindows, ...
- … much, much more …

see the C++ libraries FAQ

- Link on http://www.research.att.com/~bs/C++.html

What’s out there? Boost.org

- Filesystem Library – Portable paths, iteration over directories, etc
- MPL added – Template metaprogramming framework
- Spirit Library – LL parser framework
- Smart Pointers Library –
- Date-Time Library –
- Function Library – function objects
- Signals – signals & slots callbacks
- Graph library –
- Test Library –
- Regex Library – regular expressions
- Format Library added – Type-safe 'printf-like' format operations
- Multi-array Library added – Multidimensional containers and adaptors
- Python Library – reflects C++ classes and functions into Python
- uBLAS Library added – Basic linear algebra for dense, packed and sparse matrices
- Lambda Library – **for_each(a.begin(), a.end(), std::cout << _1 << ' ');**
- Random Number Library
- Threads Library
- …

Performance TR

- The aim of this report is:
  - to give the reader a model of time and space overheads implied by use of various C++ language and library features,
  - to debunk widespread myths about performance problems,
  - to present techniques for use of C++ in applications where performance matters, and
  - to present techniques for implementing C++ language and standard library facilities to yield efficient code.
- Contents
  - Language features: overheads and strategies
  - Creating efficient libraries
  - Using C++ in embedded systems
  - Hardware addressing interface