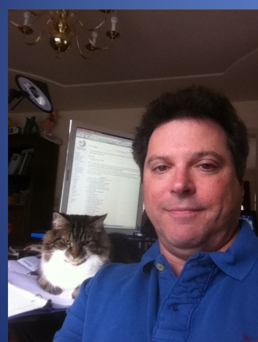
A Whirlwind Overview of C++11



Leor Zolman
BD Software
www.bdsoft.com
`leor@bdsoft.com`

C++ now

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Agenda

- C++ timeline
- Goals for the new C++
- Simpler language changes
- New facilities for class design
- Larger New language features
  - Initialization improvements
  - Rvalue references and move semantics
  - Lambdas
- Library additions
- Concurrency
- Not *all* of the new features are covered
  - at least not in detail
- Probably little or no time for questions ☹

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About the Code Examples

- Most code has been tested using:
  - TDM gcc 4.6.1 w/`just::thread` 1.7.3 (Preview)
  - TDM gcc 4.5.2 w/`just::thread` 1.7.0 (released)
- Code excerpts shown on slides are not 100% self-contained programs
  - Less clutter to just show the meat
  - Read the code *as if* the requisite `#include`s, `using` directives/declarations and/or `std::` qualifiers were there

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A Brief History of C++

- 1979: Bjarne invents *C With Classes*
- 1998: First ISO C++ Standard (C++98)
- 2003: Bug Fix update (C++03)
  - For the rest of this presentation, I'll use the term *Old C++* to mean "C++98 and C++03"
- 2005: TR1 specifies new lib. components
- 2005-2011: "C++0x" evolves
- 2011: C++11 ratified in August
- Next on the agenda (2012?): TR2…

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Goals for C++11

- Make C++ easier to teach, learn and use
- Maintain backward-compatibility
- Improve performance
- Strengthen library-building facilities
- Interface more smoothly with modern hardware

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"The pieces just fit together better than they used to and I find a higher-level style of programming more natural than before and as efficient as ever."

-Bjarne Stroustrup, from his C++11 FAQ

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Part I: The Simpler Core Language Features

- `auto`, `decltype`, trailing return types
- `nullptr`
- Range `for`
- `>>` in template specializations
- `static_assert`
- `noexcept`
- `extern template`

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Problem: Wordy declarations

```
// findNull: Given a container of pointers, return an
// iterator to the first null pointer (or the end
// iterator if none is found)

template<typename Cont>
typename Cont::const_iterator findNull(const Cont &c)
{
	typename Cont::const_iterator it;
	for (it = c.begin(); it != c.end(); ++it)
		if (*it == 0)
			break;

	return it;
}
```

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Using findNull in Old C++

```
int main()
{
   int a = 1000, b = 2000, c = 3000;
   vector<int *> vpi;
   vpi.push_back(&a);
   vpi.push_back(&b);
   vpi.push_back(&c);
   vpi.push_back(0);

   vector<int *>::const_iterator cit = findNull(vpi);
   if (cit == vpi.end())
      cout << "no null pointers in vpi" << endl;
   else
   {
      vector<int *>::difference_type pos = cit - vpi.begin();
      cout << "null pointer found at pos. " << pos << endl;
   }
}
```

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Using findNull in C++11

```
int main()
{
   int a = 1000, b = 2000, c = 3000;
   vector<int *> vpi { &a, &b, &c, nullptr };

   auto cit = findNull(vpi);

   if (cit == vpi.end())
      cout << "no null pointers in vpi" << endl;
   else
   {
      auto pos = cit - vpi.begin();
      cout << "null pointer found in position " <<
                   pos << endl;
   }
}
```

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What's the Return Type?

- Sometimes a return type simply cannot be expressed in the usual manner:

```
// Function template to return  product of two
// values of unknown types:

template<typename T, typename U>
??? product(const T &t, const U &u)
{
      return t * u;
}
```


decltype and Trailing Return Type

- In this case, a combination of `auto`, `decltype` and *trailing return type* provide the only solution:

```
// Function template to return  product of two
// values of unknown types:

template<typename T, typename U>
auto product(const T &t, const U &u) -> decltype (t * u)
{
      return t * u;
}
```

findNull in C++11
(First Cut)

```
// findNull: Given a container of pointers, return an
// iterator to the first null pointer (or the end
// iterator if none is found)

template<typename Cont>
auto findNull(const Cont &c) -> decltype(c.begin())
{
      auto it = c.begin();
      for (; it != c.end(); ++it)
            if (*it == nullptr) // nullptr: not your
                  break;        // father's NULL !

      return it;
}
```

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Non-Member begin/end

- New forms of begin() and end() even work for native arrays, hence are more generalized

```
bool strLenGT4(const char *s) { return strlen(s) > 4; }

int main()
{                          // Applied to STL container:
    vector<int> v {-5, -19, 3, 10, 15, 20, 100};
    auto first3 = find(begin(v), end(v), 3);

    if (first3 != end(v))
       cout << "First 3 in v = " << *first3 << endl;
                           // Applied to native array:
    const char *names[] {"Huey", "Dewey", "Louie"};
    auto firstGT4 = find_if( begin(names), end(names),
                             strLenGT4);
    if (firstGT4 != end(names))
       cout << "First long name: " << *firstGT4 << endl;
}
```

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`findNull` in C++11
(Final version)

```
template<typename Cont>
auto findNull(const Cont &c) -> decltype(begin(c))
{
	auto it = begin(c);
	for (; it != end(c); ++it)
		if (*it == nullptr)
			break;

	return it;
}
```

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More on `nullptr`

- In old C++, the concept of “null pointers” can be a source of confusion and ambiguity
  - How is NULL defined?
  - Does 0 refer to an int or a pointer?

```
void f(long) { cout << "f(long)\n"; }
void f(char *) { cout << "f(char *)\n";}

int main()
{
	f(0L);            // calls f(long)
	f(0);             // ERROR: ambiguous!
	f(static_cast<char *>(0)); // Oh, OK…
}
```

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More on `nullptr`

- Using `nullptr` instead of 0 disambiguates:

```
void f(long) { cout << "f(long)\n"; }
void f(char *) { cout << "f(char *)\n";}

int main()
{
        f(0L);           // calls f(long)
        f(nullptr);      // fine, calls f(char *)
}
```

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Iterating Over an Array or Container in Old C++

```
int main()
{
    int ai[] = { 10, 20, 100, 200, -500, 999, 333 };
    const int size = sizeof ai / sizeof *ai;    // A pain

    for (int i = 0; i < size; ++i)
        cout << ai[i] << " ";
    cout << endl;

    vector<int> vi { 10, 20, 100, 200, -500, 999, 333 };

    for (int i = 0; i < vi.size(); ++i)
        vi[i] += 100000;

    for (int i = 0; i < vi.size; ++i)
        cout << vi[i] << " ";
}
```

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Improvement: Range-Based `for` Loop

```
int main()
{
    int ai[] = { 10, 20, 100, 200, -500, 999, 333 };

    for (auto i : ai)
        cout << i << " "; // Don't need size
    cout << endl;

    vector<int> vi { 10, 20, 100, 200, -500, 999, 333 };
    for (auto &i : vi)
        i += 10000;       // Modify in place

    for (auto i : vi)
        cout << i << " ";
    cout << endl;

    for (auto i : { 100, 200, 300, 400})
        cout << i << " ";
}
```

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The ">> Problem"

- Old C++ requires spaces between consecutive closing angle-brackets of nested template specializations:

```
map<string, vector<string> > dictionary;
```

- C++11 permits you to omit the space:

```
map<string, vector<string>> dictionary;
```

- That's one less *gotcha*

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Compile-Time Assertions: `static_assert`

- The C library contributed the venerable `assert` macro for expressing run-time invariants:

```
int *pi = …;
assert (pi != NULL);
```

- C++11 provides direct compiler support for *compile-time* invariant validation and diagnosis:

```
static_assert(condition, “message”);
```

- Conditions may only be formulated from *constant* (compile-time determined) expressions

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`static_assert`

```
static_assert(sizeof(int) < 32,
      “This app requires ints to be at least 32-bits.");

template<typename R, typename E>
R safe_cast(const E& e)
{
   static_assert(sizeof (R) >= sizeof(E),
            “Possibly unsafe cast attempt.");
   return static_cast<R>(e);
}

int main()
{
   long lval = 50;
   int ival = safe_cast<int>(lval);   // OK iff long & int
                                      //    are same size
   char cval = safe_cast<char>(lval); // Compile error!
}
```

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Problem: Object File Code Bloat From Templates

- The industry has settled on the "template inclusion model"
  - Templates fully defined in header files
  - Each translation unit (module) #includes the header: all templates are instantiated in *each* module which uses them
  - At link time, all but one instance of each redundant instantiated function *is discarded*

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The Failed Solution: `export`

- Old C++ tried to address the problem with the `export` keyword
- The idea was to support *separately compiled templates*
- But even when implemented (AFAIK only EDG accomplished this), it didn't really improve productivity
  - Templates are just too complicated
    - (Due to two-phase translation)

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The C++11 Solution: `extern template`

- Declare the template `extern` and the compiler will not instantiate the template's member functions in that module:

```
#include <vector>
#include <Widget>
extern template class vector<Widget>;
```

- For `vector<Widget>`, the *class definition* is generated if needed (for syntax checking) but member functions are not instantiated
- Then, in just *one* module, explicitly instantiate the template:

```
template vector<Widget>;
```

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Problem: Exception Specifications

- In Java, methods declare exceptions they might throw, and callers are *required* to prove they're prepared for those exceptions
- In old C++, functions can declare exceptions they might throw…but callers need not attend to them!
- Plus, how can function templates possibly know what types of exceptions might be thrown?
- Thus the only exception specification Old C++ library components ever used is the *empty* one:

```
template<typename T>
class MyContainer {
public:
    …
    void swap(MyContainer &) throw();
…
```

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The C++11 Way: `noexcept`

- Exception specifications (even empty ones) can have non-trivial runtime cost
- C++11 provides the `noexcept` keyword as a more efficient alternative:

```
template<typename T>
class MyContainer {
public:
    …
    void swap(MyContainer &) noexcept;
    …
```

- `noexcept` clauses can be conditional on the "noexcept" status of sub-operations

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Problem: How Do You Write a Function to Average N Values?

- You can use a C variadic function:

  `int aver(int count, ...);`

  - Must write one for each type required
  - Must provide the argument count as 1st arg
  - Yechhhh
- Can't use C++ default arguments
  - Because we can't know the # of actual args
- Could use overloading and templates
  - That's ugly too

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Variadic Templates

```
// To get an average, we 1st need a way to get a sum…

template<typename T> // ordinary function template
T sum(T n)           // for the "terminal" case
{
      return n;
}
                     // variadic function template:
template<typename T, typename... Args>
T sum(T n, Args... rest)       // "parameter packs"
{
      return n + sum(rest...);
}

int main() {
      cout << sum(1,2,3,4,5,6,7);
      cout << sum(3.14, 2.718, 2.23606);
};
```

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Now For Average

- Another variadic function template can leverage the `sum()` template to give us average:

```
template<typename... Args>
auto avg(Args... rest) -> decltype(sum(rest...))
{
   return sum(rest...) / (sizeof... rest);
}

…
cout << avg(2.2, 3.3, 4.4) << endl; // works!
```

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String-Related Features

- Unicode string literals
  - UTF-8: `u8"This text is UTF-8"`
  - UTF-16: `u"This text is UTF-16"`
  - UTF-32: `U"This text is UTF-32"`
- Raw string literals
  - Can be clearer than lots of escaping:

```
string s = "backslash: \"\\\", single quote: \"'\"";
string t = R"(backslash: "\", single quote: "'")";

// Both strings set to:
//       backslash: "\", single quote: "'"
```

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Other Language Features

- `enum class`
  - "New" enums, strongly scoped and typed
  - Can specify underlying (integral) type
- `constexpr`
  - Forces compile-time evaluation of constant expressions and functions (including operators)
- `long long`
  - 64-bit (at least) ints

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Other Language Features

- template alias
  - The "template typedef" idea, w/clearer syntax
  - `using` aliases also provide a clearer alternative even for non-template typedefs
- `alignas` / `alignof`
  - query/ force boundary alignment

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Yet More Language Features

- Attributes
- Inline Namespaces
- Generalized Unions
- Generalized PODs
- Garbage Collection ABI
- User-defined Literals

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Part II: Features Specific to Class Design

- Generated functions: `default` / `delete`
- Override control: `override` / `final`
- Delegating constructors
- Inheriting constructors
- Increased flexibility for in-class initializers
- Explicit conversion operators

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Problem: How to Prevent Copying?

- There are two old C++ approaches to disallow the copying of objects
  - Either make the copy operations private:

```
class RHC       // some resource-hogging class
{     …
private:
      RHC(const RHC &);
      RHC &operator=(const RHC &);
};
```

  - Or inherit privately from a base class that does it for you:

```
class RHC : private boost::noncopyable
{
      …
```

  - Both approaches are problematic.

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C++11: =default, =delete

- These specifiers control function generation:

```
class T {
public:
      T() = default;
      T(const char *str) : s(str) {}
      T(const T&) = delete;
      T &operator=(const T&) = delete;
private:
      string s;
};

int main() {
      T t;              // Fine
      T t2("foo");      // Fine
      T t3(t2);         // Error!
      t = t2;           // Error!
}
```

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Problems With Overriding

- When limited to old C++ syntax, the “overriding interface” is quite ambiguous

```
class Base {
public:
      virtual void f(int);
      virtual int g() const;
      void h(int);
};

class Derived : public Base {
public:                  // Without looking at Base…
      void f(int);       // …is it virtual?
      virtual int g();   // …meant to override Base::g?
      void h(int);       // …overrides Base::h? Or… ?
};
```

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override / final

- C++11 lets you say what you really mean:

```
class Base {
   public:
      virtual void f(int);    // Nothing more needed;
      virtual int g() const;  // Here, either
      void h(int) final;      // Invariant over special-
};                            //                  ization

class Derived : public Base {
   public:
      void f(int) override;   // Base::f MUST be virtual
      int g() override;       // Error!
      void h(int);            // Error! GOOD THING!!
};
```

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Problem: Old C++ Ctors Can't use Other Ctors in the Class

```
class FluxCapacitor
{
public:
      FluxCapacitor() : capacity(0), id(nextId++) {}
      FluxCapacitor(double c) : capacity(c),
            id(nextId++) { validate(); }
      FluxCapacitor(complex<double> c) : capacity(c),
            id(nextId++) { validate(); }
      FluxCapacitor(const FluxCapacitor &f) :
            id(nextId++) {}
//    ...
private:
      complex<double> capacity;
      int id;
      static int nextId;
      void validate();
};
```

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C++11 Delegating Constructors

- C++11 ctors may call other ctors (à la Java)

```
class FluxCapacitor
{
public:
	FluxCapacitor() : FluxCapacitor(0.0) {}
	FluxCapacitor(double c) :
		FluxCapacitor(complex<double>(c)) {}
	FluxCapacitor(const FluxCapacitor &f) :
		FluxCapacitor(f.capacity) {}
	FluxCapacitor(complex<double> c) :
		capacity(c), id(nextId++) { validate(); }

private:
	complex<double> capacity;
	int id;
	static int nextId;
	void validate();
};
```

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In-Class Initializers

- In old C++, *only* const static integral members could be initialized in-class

```
class FluxCapacitor
{
public:
	static const size_t num_cells = 50;  // OK
	FluxCapacitor(complex<double> c) :
		capacity(c), id(nextId++) {}
	FluxCapacitor() : id(nextId++) {}    // capacity??
private:
	int id;
	static int nextId = 0;            // ERROR!
	complex<double> capacity = 100;   // ERROR!
	Cell FluxCells[num_cells];        // OK
};
```

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C++11 In-Class Initializers

- Now, *any* data member can be (default) initialized in the class definition:

```
class FluxCapacitor
{
public:
      static const size_t num_cells = 50;  // still OK
      FluxCapacitor(complex<double> c) :
            capacity(c), id(nextId++) {}   // capacity c
      FluxCapacitor() : id(nextId++) {}    // capacity 100

private:
      int id;
      static int nextId = 0;            // Now OK!
      complex<double> capacity = 100;   // Now OK!
      Cell FluxCells[num_cells];        // Still OK
};
```

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Explicit Conversion Operators

- In Old C++, only constructors (one flavor of user-defined conversion) could be declared `explicit`
- User-defined conversion *operators* (e.g., `operator long()`) could not
- C++11 remedies that

```
class Rational {
public:
      // …
      operator double() const;           // Bad
      explicit operator double() const;  // Better
      double toDouble() const;           // Prob. best *
private:
      long num, denom;
};                          // * Editorial commentary…
```

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Part III: Larger Language Features

- Initialization
  - Initializer lists
  - Uniform initialization
  - Prevention of narrowing
- Lambdas
- Rvalue references and "move" semantics

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Problem: Limited Initialization of Aggregates in Old C++

```
int main()
{                                  // OK, array initializer
       int vals[] = { 10, 100, 50, 37, -5, 999};

       struct Point { int x; int y; };
       Point p1 = {100,100};       // OK, object initializer

       vector<int> v = { 5, 29, 37};     // ERROR in old C++!

       const int valsize = sizeof vals / sizeof *vals;

                                   // range ctor OK
       vector<int> v2(vals, vals + valsize);
}
```

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Initializer Lists

- C++11's `std::initializer_list` supports generalized initialization of aggregates
- It extends old C++'s array/object initialization syntax to *any* user-defined type

```
vector<int> v = { 5, 29, 37 };    // Fine in C++11
vector<int> v2 { 5, 29, 37 };     // Don't need the =

v2 = { 10, 20, 30, 40, 50 };      // not just for
                                  // "initialization" !
template<typename T>
class vector {              // A peek inside a typical STL
public:                     // container's implementation…
    vector(std::initializer_list<T>);    // (simplified)
    vector &operator=(std::initializer_list<T>);
    …
```

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More Initializer Lists

```
vector<int> foo()
{
        vector<int> v {10, 20, 30};
        v.insert(end(v), { 40, 50, 60 }); // use with algos,

        for(auto x : { 1, 2, 3, 4, 5 })    // with for loops,
                cout << x << " ";
        cout << endl;

        return { 100, 200, 300, 400, 500 }; // most anywhere!

}

int main()
{
        for (auto x : foo())               // note: foo()
                cout << x << " ";          // returns vector
        cout << endl;
}
```

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Old Initialization Syntax Can Be Confusing/Ambiguous

```
int main()
{
    int *pi1 = new int(10); // OK, initialized int
    int v1(10);             // OK, same
    int *pi2 = new int;     // OK, uninitialized
    int *pi3 = new int();   // Now initialized to 0
    int v2();               // oops...
    ...
    int foo(bar);           // what IS that?

    int i(5.5);             // legal, unfortunately
    double x = 10e19;
    int j(x);               // even if impossible!
}
```

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C++11 Uniform Initialization, Prevention of Narrowing

```
typedef int bar;

int main()
{
    int *pi1 = new int{10}; // initialized int
    int v1{10};             // same
    int *pi2 = new int;     // OK, uninitialized
    int v2{};               // Now it's an object!
    int foo(bar);           // func. declaration
    int foo{bar};           // ILLEGAL with braces
                            //    (as it should be)
    double x = 10e19;
    int j{x};               // ERROR: Narrowing when
                            //   using {}s is illegal
    int i{5.5};             // ERROR, fortunately!
}
```

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Problem: Algorithms Not Efficient When Used with Function Pointers

- Inlining rarely applies to function pointers

```
inline bool isPos(int n) { return n > 0; }

int main()
{
    vector<int> v {-5, -19, 3, 10, 15, 20, 100};
                    // Calls to isPos probably NOT inlined:
    auto firstPos = find_if(begin(v), end(v), isPos);
    if (firstPos != end(v))
       cout << "First positive value in v is: "
            << *firstPos << endl;

               // Old function object adaptors can eliminate
    firstPos = find_if(begin(v), end(v), // some functions,
        bind2nd(greater<int>(), 0) );    // but they're messy!
}
```

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Function Objects Improve Performance, But Not Clarity

```
// Have to define a separate class to create function
// objects from:

struct IsPos
{
      bool operator()(int n) { return n > 0; }
};

int main()
{
      vector<int> v {-5, -19, 3, 10, 15, 20, 100};

      auto firstPos =
                  find_if(begin(v), end(v), IsPos());
      if (firstPos != end(v))
            cout << "First positive value in v is: "
                        << *firstPos << endl;
}
```

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Lambda Expressions

- A *lambda expression* creates an on-demand function object
- Allows the logic to be truly localized
- Herb Sutter says: "Lambdas make the existing STL algorithms roughly 100x more usable."

```
int main()
{
    vector<int> v {-5, -19, 3, 10, 15, 20, 100};

    auto firstPos = find_if(begin(v)), end(v),
             [](int n){return n > 0;} );

    if (firstPos != end(v))
       cout << "First positive value in v is: "
             << *firstPos << endl;
}
```

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Lambdas and Local Variables

- Variables local to the function outside the lambda may be *captured* in the lambda's `[]`s
  - The resulting (anon.) function object is called a *closure*

```
int main()
{
    vector<double> v { 1.2, 4.7, 5, 9, 9.4};
    double target = 4.9;
    double epsilon = .3;

    auto endMatches = stable_partition(begin(v), end(v),
             [target,epsilon] (double val)
             { return fabs(target - val) < epsilon; });

    cout << "Values within epsilon: ";
    for_each(begin(v), endMatches,
              [](double d) { cout << d << ' '; });
}                                  // output: 4.7 5
```

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Problem: Excessive Copying

- In old C++, objects are (or might be) *copied* when replication is neither needed nor wanted
  - The "extra" copying can sometimes be optimized away (e.g., the RVO), but often not

```
class Big { ... };           // expensive to copy

Big makeBig() { return Big(); } // return by value
Big operator+(const Big &, const Big&); // arith. op.

                             // This may cost up to 3
Big bt = makeBig();          // ctors and 2 dtors!

Big x(…), y(…);
Big sum = x + y;  // extra copy of ret val from op+ ?
```

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Old C++ Solutions are Fragile

- The functions *could* be re-written to return:
  - References – but how is memory managed?
  - Raw pointers – prone to leaks, bugs
  - Smart pointers – more syntax to deal with
  - (`operator=` doesn't even have those options)
- But if we know the returned object is a *temporary*, we know its data will no longer be needed after "copying" from it
- The solution is a new kind of reference…

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C++11 Rvalue References

- An *rvalue reference* (declared with &&) binds *only* to unnamed, temporary objects

```
int fn();                    // Note: return val is rvalue
int main()
{
   int i = 10, &ri = i;      // ri is ordinary lvalue ref
   int &&rri = 10;           // OK, rvalue ref to temp
   int &&rri2 = i;           // ERROR, attempt to bind
                             //    lvalue to rvalue ref
   int &&rri3 = i + 10;      // Fine, i + 10 is a temp

   int &ri2 = fn();          // ERROR, attempt to bind
                             //    rvalue to lvalue ref
   const int &ri3 = fn(); // OK, lvalue ref-to-const

   int &&rri4 = fn();        // Fine, ret. val is a temp
}
```

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Copy vs. Move Operations

- C++ has always had the "copy" operations--the *copy constructor* and *copy assignment operator*:

```
T::T(const T&);             // copy ctor
T &operator=(const T&);   // copy assign.
```

- C++11 adds "move" operations—the *move constructor* and *move assignment operator*:

```
T::T(T &&);           // move ctor
T &operator=(T &&); // move assignment
```

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"Big" Class with Move Operators

- So there are now six canonical functions per class (used to be four) that compilers may generate

```
class Big {
public:
   Big();                              // default ctor
   ~Big();                             // dtor
   Big(int x);                         // (non-canonical)

   Big(const Big &);                   // copy ctor
   Big &operator=(const Big &);        // copy assignment
   Big(Big &&);                        // move ctor
   Big &operator=(Big &&);             // move assignment
private:
   BigBlog *bbp;
};
```

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Move Operations In Action

```
Big operator+(const Big &, const Big &);
Big munge(const Big &);
Big makeBig()  { return Big(); }

int main()
{
   Big x, y;
   Big a;

   a = makeBig();        // 1 Big created *
   Big b(x + y);         // 1 Big created *
   a = x + y;            // 1 Big created *
   a = munge(x + y);     // 2 Bigs created *
   std::swap(x,y);       // 0 Bigs created! (C++11 only)
}

// *: Return value's contents moved to destination obj
```

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Move Operations: Not Always Automatic

- Consider the old C++-style implementation of the `std::swap` function template:

```
template<typename T>
void swap(T &x, T &y)     // lvalue refs
{
     T tmp(x);       // copy ctor
     x = y;          // copy assignment
     y = tmp;        // copy assignment
}
```

- Even when applied to objects (e.g., `Big`) with *move support*, that support won't be used!

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Forcing Move Operations

- Here's a C++11 version of `std::swap`:

```
template<typename T>
void swap(T &x, T &y)     // still lvalue refs
{
     T tmp(move(x));      // move ctor
     x = move(y);         // move assignment
     y = move(tmp);       // move assignment
}
```

- Note the signature is still the same as for the old `swap`, but we've forced source objects to be treated as *rvalues*…favoring move ops.

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Part IV: New Library Components

- New Function/Function Object Facilities
  - `std::function`
  - `std::bind`
- Smart Pointers
  - `std::unique_ptr`
  - `std::shared_ptr`
- Fixed-length Array
  - `std::array`
- Hash-based Containers
  - `std::unordered_*`
- Performance enhancements
- Note: Most new components originated in Boost!

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Representing Function Objects

- We know templates can be written to support things that "act like a function":
  - ```
    template<typename In, typename Pred>
    In find_if(In begin, In end, Pred p);
    ```
    - `p` can be either a function pointer *or* a function object
- But how do we represent these "function-like" objects when they're not playing the role of function template parameters?

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    ```

std::function

```
size_t str_length(const string &s) { return s.length(); }

int main()
{
   string s("Hello, Dolly!");
   cout << s.length() << endl;

   function<int (const string &)> fn;

   fn = str_length;              // non-member function
   cout << fn(s) << endl;

   fn = &string::length;         // member function
   cout << fn(s) << endl;
                                 // lambda:
   fn = [](const string &s) { return s.length();};
   cout << fn(s) << endl;
}
```

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Old C++ Binders

- Special-purpose 1-off functions are lame:

```
bool greaterThan5(int n) { return n > 5;}
… = find_if(v.begin(), v.end(), greaterThan5);
```

- Old C++ had `bind1st`, `bind2nd` to "fix" one argument of a binary function:

```
… = find_if(v.begin(), v.end(),
      bind2nd(std::greater_than<int>(), 5))
```

  – Some of the drawbacks to `bind1st` / `bind2nd`:
    - Limited to two arguments (one each)
    - Requires "adaptable" function object

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std::bind

- C++11 provides the more flexible `std::bind`:

```
… = find_if(begin(v), end(v),
        bind(greater<int>(), _1, 5));
```

- However, lambdas are often better yet:

```
… = find_if(begin(v), end(v),
        [](int n) { return n > 5; });
```

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Problem: Resource Leaks

- Memory and other resources managed by raw pointers are easily "leaked":

```
Widget *getWidget();
void crunch()
{
        int *ia = new int[1000];   // dyn. array of int
        Widget *wp = getWidget();  // Widget factory

        //  Insert lots of code here, including
        //  function calls, conditionals, etc...

        delete wp;                 // Release the Widget
        delete[] ia;               // Release array of ints
}
```

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Solution: Smart Pointers

- *Smart Pointers* are objects that
  - are initialized with a resource (the *RAII* idiom)
  - are used with the syntax of pointers
  - release that resource automatically upon destruction
- Typically, they are class templates specialized on the type of resource being managed
- Old C++ provided a single, zero-cost, smart pointer template, `auto_ptr`:

```
{
        auto_ptr<int> api(new int);
        *api = 10;
        // …
} // pointer deleted
```

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Applying auto_ptr ?

```
Widget *getWidget();
void crunch2()
{
        auto_ptr<Widget> wp(getWidget());       // Fine.
        auto_ptr<int> ia (new int[1000]);       // Mistake!

    //  Regardless of exceptions and/or returns out of
    //  this section of code, Widget automatically
    //  released…
    //  Unfortunately, undefined behavior for the array!
}
```

- `auto_ptr` also has strange semantics – *copying* an `auto_ptr` means *transferring* the resource!
  - Thus, `auto_ptr` has been deprecated for C++11

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The C++11 Solution: `unique_ptr`

```
Widget *getWidget();
unique_ptr<Widget> getWidget2();

void crunch2()
{
   unique_ptr<Widget> wp(getWidget());   // init from ptr
   unique_ptr<int[]> ia (new int[1000]); // arrays too!

   unique_ptr<FILE, int (*)(FILE *)>    // custom deleter!
      fp(fopen("file.txt", "r"), fclose); // (not 0-cost)

   unique_ptr<Widget> wp2;   // copying from another
   wp2 = getWidget2();       // unique_ptr means "move"…
   wp = wp2;                 // ERROR! (…but rvalues only)
                             // All resources released OK
}
```

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Reference-Counted Smart Pointer: `shared_ptr`

- Introduced in TR1
  - Not "Zero Cost", but still a great value!

```
class Widget {
public:
      Widget(int, double);
};

void crunch2()
{                                     // initialize from ptr:
   shared_ptr<Widget> spw(new Widget(10, 2.23));

   vector<shared_ptr<Widget>> vw;
   list<shared_ptr<Widget>> lw;

   vw.push_back(spw);      // copy shared_ptr, NOT Widget
   lw.push_back(spw);      // another copy of shared_ptr
}     // The ONE Widget is destroyed before return
```

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An Optimization: `make_shared`

- A single memory allocation suffices for both the resource *and* the `shared_ptr`'s reference count:

```
class Widget {
public:
      Widget(int, double);
};

void crunch2()
{     // allocate Widget AND ref. count in one fell swoop:
   auto spw = make_shared<Widget>(10, 2.23);

   vector<shared_ptr<Widget>> vw;
   list<shared_ptr<Widget>> lw;

   vw.push_back(spw);
   lw.push_back(spw);
}
```

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The `array` template: Arrays as First-Class Objects

- Another component introduced in TR1
  - Another "nail in the coffin" of built-in arrays?

```
void f1(int a[]);
void f2(vector<int> v);
void f3(array<int, 5> a);

int main()
{
      int ai[] {5, -3, 25, 0, -2};
      vector<int> vi { 3, -19, 0, 6, 5};
      array<int, 5> ai2 {35, -5, 13, -20, 6};

      f1(ai);      // just passing pointer
      f2(vi);      // passing vi by value
      f3(ai2);     // passing ai2 by value
}
```

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Templates, However, Can Still Be Quite Generalized!

```
template<class C>         // C is any container or array
auto min_elt(const C &cont) -> decltype(begin(cont))
{
       return min_element(begin(cont), end(cont));
}

int main()
{
       int ai[] {5, -3, 25, 0, -2};
       vector<int> vi { 3, -19, 0, 6, 5};
       array<int, 5> ai2 {35, -5, 13, -20, 6};

       cout << "min val in vi = " <<
                     *min_elt(vi) << endl;      // -19
       cout << "min val in ai2 = " <<
                     *min_elt(ai2) << endl;     // -20

       cout << *min_elt(ai) << endl;            // -3
}
```

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Hash-based Associative Containers

- Original associative containers
  - `set`, `multiset`, `map`, `multimap`
  - b-tree based, always remain sorted
  - Insert/delete/lookup speed is $O(\log_2 N)$
- TR1 / C++11 hash-based associative containers
  - `unordered_set`, `unordered_map`, etc.
  - Data structure based on hash table
  - *No* inherent sort order
  - Insert/delete/lookup speed *typically* faster…
    - …But not always. Issues can be complex. Rule of thumb: the larger the size of the container, the more likely a hash-based version will yield better overall performance.

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Library Performance Improvements

- Containers' interfaces benefit from move operations and variadic templates:
  - `push_back` overloaded for rvalue refs
  - `emplace_back` accepts ctor argument list
- Internally, sequence containers employ move operations in lieu of copying
  - E.g., `vector` memory reallocation
- Algorithms, e.g. `sort` win by moving
- Initializer lists, lambdas streamline the use of algorithms

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Library Components We Didn't Cover

- Larger Library Components
  - Regular expressions
  - Tuples
- Smaller Library Components
  - `std::weak_ptr`
  - `std::forward_list`
  - `std::result_of`
  - Wrapper References
  - Type Traits (for TMP)
  - New algorithms
    - `copy_if`, `all_of`, `any_of`, `none_of`
    - `iota` (anyone remember APL?)
    - A bunch of others…

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Some Omissions, Some Remedies

- The Old C++ Standard makes no mention of several useful aspects of modern software design, e.g.:
  - GUIs
  - Garbage Collection
  - `finally` blocks in exception handling
  - multithreading
- "Hooks" now exist in C++11 to support GC
- Arguably the most far-reaching new aspect of C++11, however, is support for *concurrency*

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Part V: Concurrency

- Threads
- Passing arguments to threads
- Synchronization with mutexes and locking
- Returning values from threads using futures
- Atomics

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A Quick Intro to Concurrency

- Multi-threading is *complicated*
- Current on-line concurrency tutorials have 8-9 parts… *and aren't even finished*
- As with exception handling:
  - The language/lib support for concurrency is significant
  - Understanding best practices / idioms requires both study and experience
    - Reading at least one good book on the subject can help
      - Such as C++ *Concurrency In Action* (Williams, Manning Press)
  - All we can do here is scratch the surface

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Threads

- `main` runs in one single thread of execution
  - Pre-C++11, single-threaded execution was all the Standard recognized
- In C++11, additional concurrent threads are launched by instantiating a `std::thread`
  - On multi-core / multi-processor systems, multiple threads can truly be *concurrent*
  - On single-core systems, they are time-sliced
  - Both scenarios are coded the same way

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Starting a New Thread, 1st Attempt

```
void hello()
{
     cout << "Hello from new thread\n";
}

int main()
{
     thread t0(hello);
     cout << "Hello from main!\n";
}
```

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Starting a New Thread, 2nd Attempt

```
void hello()
{
     cout << "Hello from new thread\n";
}

int main()
{
     thread t0(hello);
     cout << "Hello from main!\n";
     t0.join();     // wait 'til t0 done
}
```

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Functors, Lambdas as Threads

```
void hello();                       // function, as before

class Hello {                       // function object (functor)
public:
   void operator()() { cout << "Hello from functor\n"; }
};

int main() {
   thread t1(hello);                // function pointer

   Hello aHello;
   thread t2a(aHello);              // named function object
   thread t2b{Hello()};             // anonymous functor

   thread t3([]{ cout << "Hello from lambda!\n"; });

   t1.join(); t2a.join();
   t2b.join();
   t3.join();
}
```

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Arguments and Threads: `bind`

```
void hello(const string &greeting, int n) {
      cout << greeting << "," << n << endl;
}

class Hello {
public:
      void operator()(const string &g)
      { cout << "Hello from " << g << endl; }
};

int main() {
      thread t1(bind(hello, "hello from function", 42));

      Hello aHello;
      thread t2a(bind(aHello, "named functor"));
      thread t2b(bind(Hello(), "anonymous functor"));

      t1.join(); t2a.join(); t2b.join();
}
```

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Variadic `thread` Constructor

```
int main()
{
//     thread t1(bind(hello, "hello from function", 42));

                                          // Look Ma, no bind!
       thread t1(hello, "hello from function", 42);

       Hello aHello;

//     thread t2a(bind(aHello, "hello from named functor"));
       thread t2a(aHello, "hello from named functor");

//     thread t2b(bind(Hello(), "anonymous functor"));
       thread t2b(Hello(), "Hello from anon. functor");

       t1.join(); t2a.join(); t2b.join();
}
```

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A Synchronization Issue

- Running either of the previous two examples reveals a problem
- Statements such as

  `cout << greeting << "; n = " << n << endl;`

  are composed of multiple interdependent expressions / function calls
- A thread context switch can occur anywhere within that statement, mixing output up between different lines in separate threads

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Mutexes

```
mutex m;

void hello2(const string &greeting, int n)
{
   m.lock();              // "critical" section
   cout << greeting << "; n = " << n << endl;
   m.unlock();
}

class Hello {
   public:
      void operator()(const string &g)
      {     m.lock();   // critical section
            cout << g << endl;
            m.unlock();
      }
};

// BUT…what about exceptions in critical sections?
```

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lock_guard

```
mutex m;

void hello2(const string &greeting, int n)
{
   lock_guard<mutex> lck(m);  // example of RAII
   cout << greeting << "; n = " << n << endl;
}                         // guaranteed unlocking

class Hello {
   public:
      void operator()(const string &g)
      {
            lock_guard<mutex> lck(m);
            cout << g << endl;
      }                   // guaranteed unlocking
};
```

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Returning values from threads

- Consider a system for predicting the weather. We begin with a Forecast class:

```
class Forecast {
   public:
      Forecast(int n) : weather(n) {}
      string describe() const { return forecasts[weather]; }
      static int last() { return forecasts.size() - 1; }
   private:
      static vector<string> forecasts;
      int weather;
};

vector<string> Forecast::forecasts = {
   "hurricane", "noreaster", "tropical_storm", "heavy_rain",
   "light_rain", "cloudy", "partly_cloudy", "sunny" };

ostream &operator<<(ostream &os, const Forecast &f) {
   return os << f.describe(); }
```

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Predicting the Weather

```
Forecast predict_weather(system_clock::time_point t)
{   // using the C++ random number generator facilities...
    static uniform_int_distribution<int>
                    dist(0, Forecast::last());
    static mt19937 engine;
    int n = dist(engine);

    return Forecast(n);
}

int main()
{
    for (int i = 0; i < 100; ++i)
       cout << "Forecast is for " <<
           predict_weather(system_clock::now() + hours(96))
              << endl;     // Above, C++11 time facilities
}
```

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Futures and async()

```
int main()
{
   future<Forecast> theForecast =
      std::async(predict_weather,
            system_clock::now() + hours(96));

   cout << "Doing stuff while predicting" << endl;
   cout << "Doing more stuff while predicting" << endl;

   cout << "Weather prediction is for: "
            << theForecast.get() << endl;
}
```

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Atomics

- We've seen how critical sections of code have to be synchronized
- The same principle applies to operations on primitives if they're shared among threads…

```
int global_int = 10;
atomic<int> ai(10);

int function()
{
    ++global_int;           // OK only if not shared

    ai.fetch_add(1);        // thread-safe (instead of ++ai)

    cout << ai << endl;     // prints 11
}
```

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C++11 Resources

For live links to resources listed here and more, please visit my "links" page at BD Software:

`www.bdsoft.com/links.html`

- The C++ Standards Committee:
  `www.open-std.org/jtc1/sc22/wg21`
  (Draft C++ Standard available for free download)
- Scott Meyers' Summary of Feature Availability in MSVC and gcc:
  `www.aristeia.com/C++11/C++11FeatureAvailability.htm`
  (Note the 'tabs' at the bottom of the page!)

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Overviews of C++11

- Bjarne Stroustrup's C++11 FAQ:
  `www2.research.att.com/~bs/C++0xFAQ.html`
- Wikipedia C++11 page:
  `en.wikipedia.org/wiki/C++0x`
- Elements of Modern C++ Style (Herb Sutter):
  `herbsutter.com/elements-of-modern-c-style/`
- Scott Meyers' *Overview of the New C++ (C++11)*
  `http://www.artima.com/shop/`
  `overview_of_the_new_cpp`

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Video Presentations

- Herb Sutter
  - "Why C++?" (keynote talk from *C++ and Beyond 2011*):
    `channel9.msdn.com/posts/C-and-Beyond-2011-Herb-Sutter-Why-C`
  - "Writing modern C++ code: how C++ has evolved over the years":
    `channel9.msdn.com/Events/BUILD/BUILD2011/TOOL-835T`
- Going Native 2012 (@ µSoft) Talks
  - Bjarne, Herb, Andre, "STL", many others:
    `http://channel9.msdn.com/Events/GoingNative/GoingNative-2012`

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Concurrency Resources

- Tutorials
  - Book: *C++ Concurrency in Action* (Williams)
  - Tutorial article series by Williams: *Multithreading in C++0x (parts 1-8)*
  - *C++11 Concurrency Series* (9 videos, Milewski)
- `just::thread` Library Reference Guide
  - `www.stdthread.co.uk/doc`

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Where to Get Compilers / Libraries

- Twilight Dragon Media (TDM) gcc compiler for Windows
  `tdm-gcc.tdragon.net/start`
- Visual C++ 2010 Express compiler
  `www.microsoft.com/visualstudio/en-US/products/2010-editions/visual-cpp-express`
- Boost libraries
  `www.boost.org`
- Just Software Solutions (just::thread library)
  `www.stdthread.co.uk`
- If running under Cygwin, a Wiki on building the latest gcc distro under that environment:
  `http://cygwin.wikia.com/wiki/How_to_install_a_newer_version_of_GCC`

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"There are only two kinds of languages: the ones people complain about and the ones nobody uses."
-Bjarne Stroustrup

Thanks for attending!
(And enjoy all the drilling-down yet to come this week!)

Leor Zolman
`leor@bdsoft.com`
For all links cited, please visit:
`www.bdsoft.com/links.html`

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