The Design of C++0x

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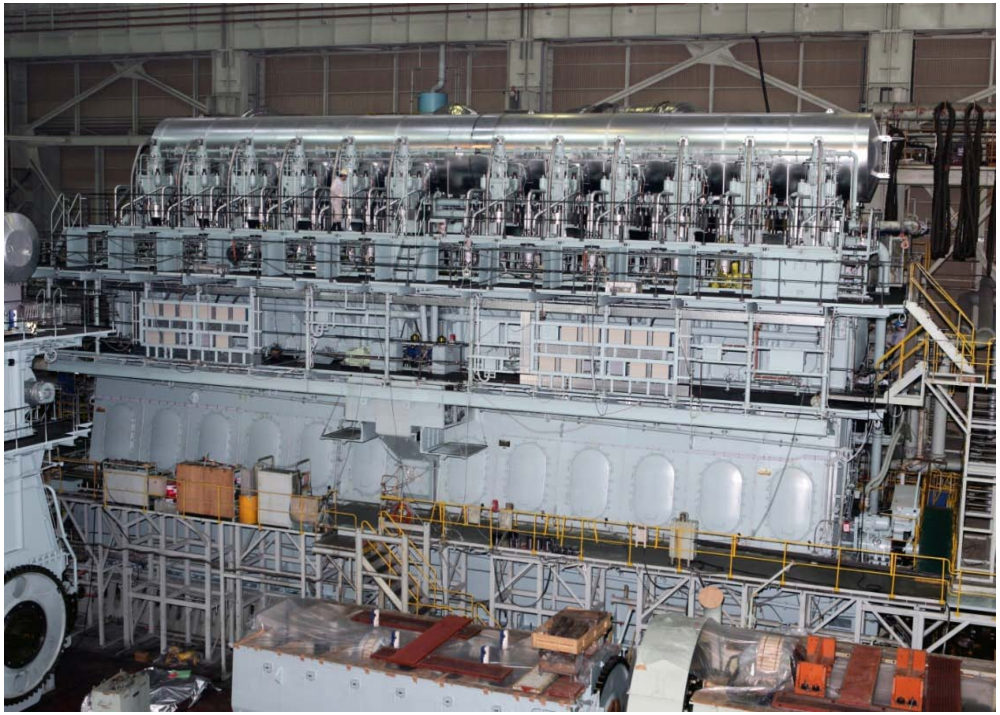
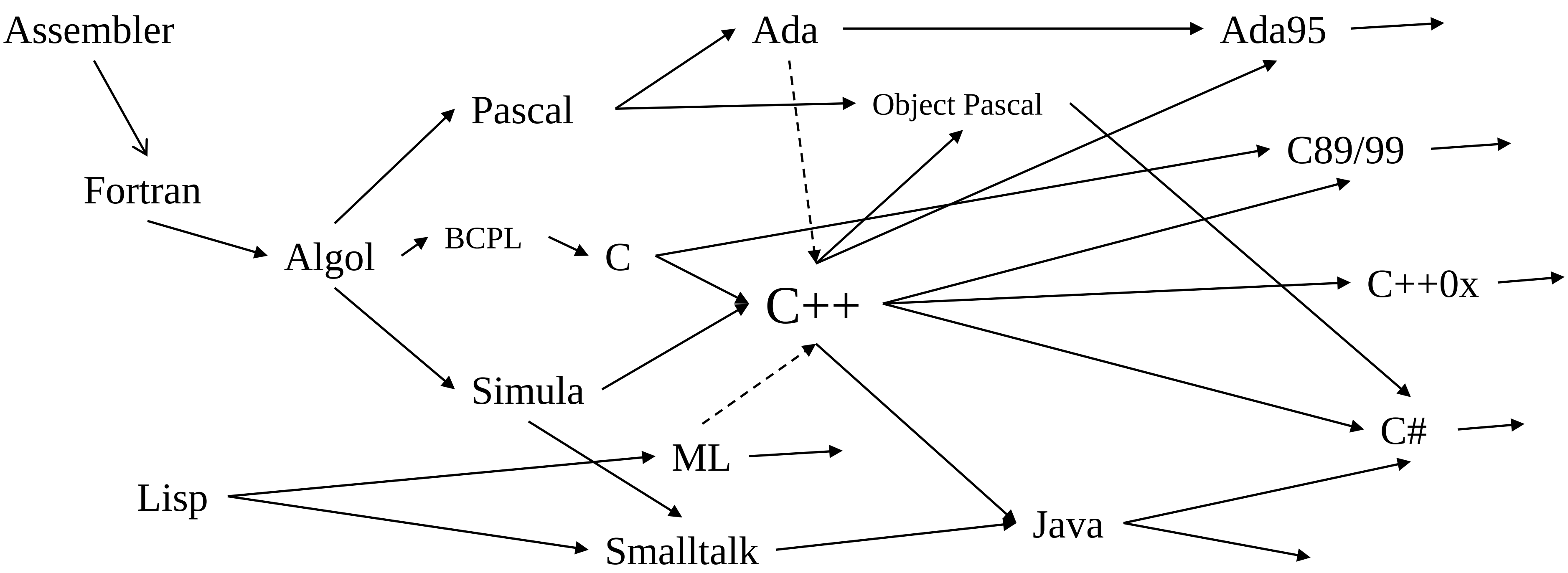
Overview

- Aims, Ideals, and history
- C++
- Design rules for C++0x
  - With examples
- Case study
  - Concurrency



8000+ Programming Languages

- C++'s family tree (part of)



- And this is a gross oversimplification!

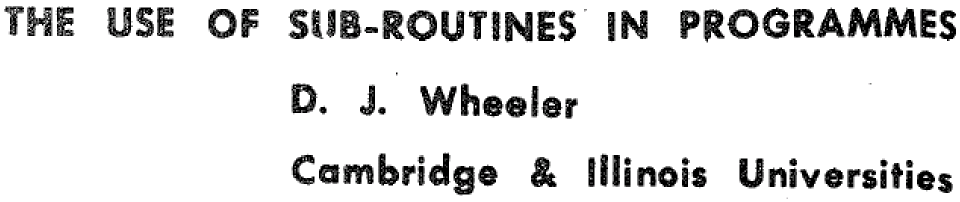
Programming languages

- A programming language exists to help people express ideas
- Programming language features exist to serve design and programming techniques
- The primary value of a programming language is in the applications written in it

- The quest for better languages has been long and must continue

Assembler –1951

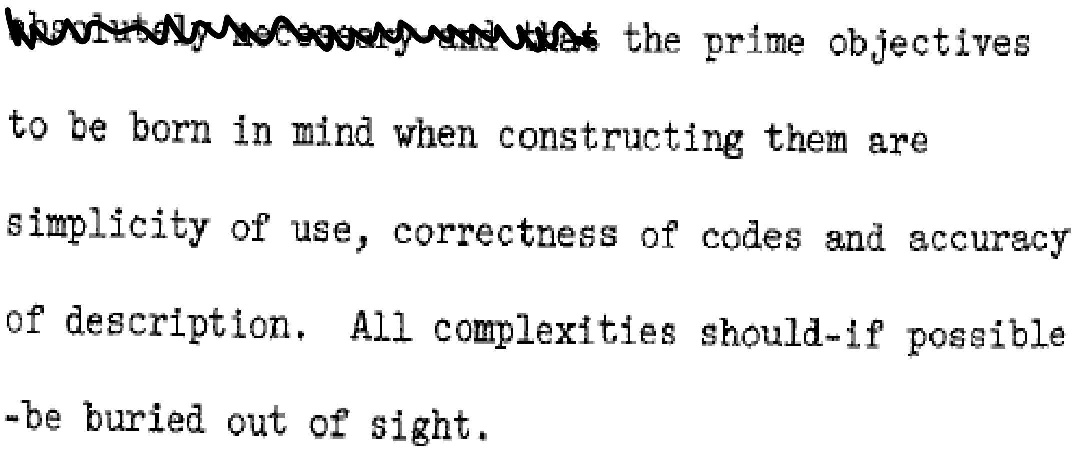
- Machine code to assembler and libraries
  - Abstraction
  - Efficiency
  - Testing
  - Documentation



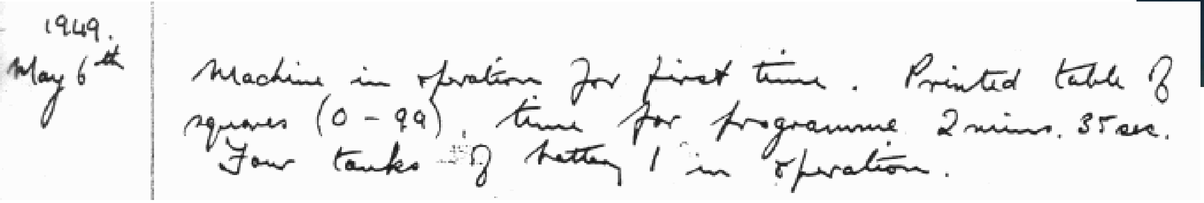
THE USE OF SUB-ROUTINES IN PROGRAMMES

D. J. Wheeler

Cambridge & Illinois Universities



~~absolutely necessary and that~~ the prime objectives to be born in mind when constructing them are simplicity of use, correctness of codes and accuracy of description. All complexities should-if possible -be buried out of sight.

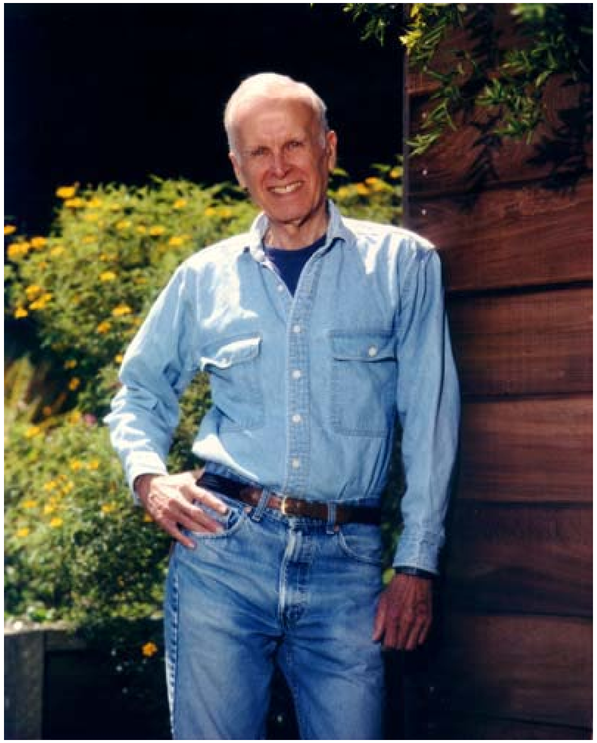


1949.
May 6th

Machine in operation for first time. Printed table of squares (0 - 99), time for programme 2 mins. 35 sec. Four tanks of battery 1 in operation.

Fortran –1956

- A notation fit for humans
  - For a specific application domain
    - **A(I) = B(I)+C*D(I)**
  - Efficiency a premium
  - Portability



Simula –1967

- Organize code to “model the real world”
  - Object-oriented design
- Let the users define their own types (classes)
  - In general: map concepts/ideas into classes (“data abstraction”)
- Organize classes into hierarchies
  - Object-oriented programming

C –1974

- An simple and general notation for systems programming
  - Direct mapping of objects and basic operations to machine
    - Performance becomes somewhat portable
  - Somewhat portable

C with Classes –1980

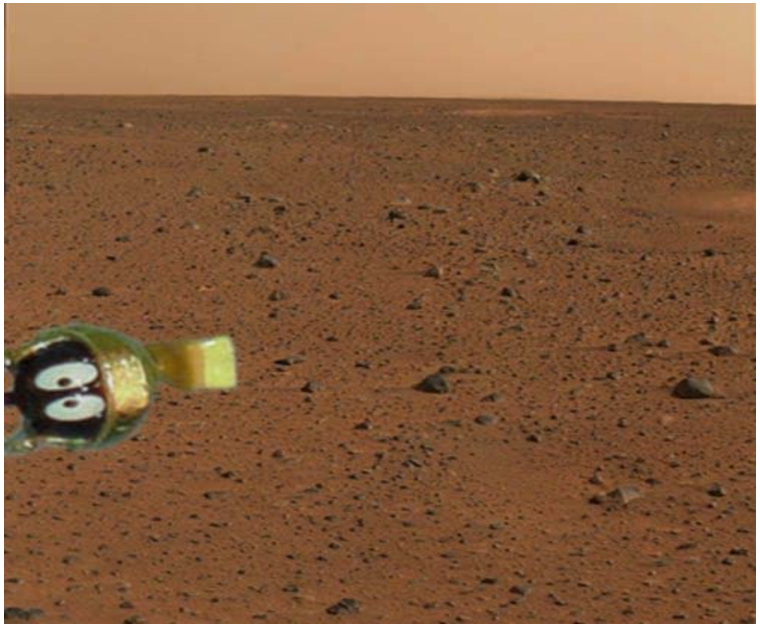
- General abstraction mechanisms to cope with complexity
  - From Simula
- General close-to-hardware machine model for efficiency
  - From C

  - Became C++ in 1984
  - Commercial release 1985
  - ISO standard 1998
  - 2nd ISO standard 200x (‘x’ is hex ☹)

C++ is everywhere

- http://www.research.att.com/~bs/applications.html

- Telecommunications
- Google
- Microsoft applications and GUIs
- Linux tools and GUIs
- Games
- PhotoShop
- Finance
- …



- Mars Rovers
- Marine diesel engines
- Cell phones
- Human genome project
- Micro electronics design and manufacturing
- …

C++ ISO Standardization

- Slow, bureaucratic, democratic, formal process
  - “the worst way, except for all the rest”
    - (apologies to W. Churchill)
- About 22 nations (5 to 12 at a meeting)
- Membership have varied
  - 100 to 200+
    - 200+ members currently
  - 40 to 100 at a meeting
    - ~60 currently
- Most members work in industry
- Most members are volunteers
  - Even many of the company representatives
- Most major platform, compiler, and library vendors are represented
  - E.g., IBM, Intel, Microsoft, Sun
- End users are underrepresented

C++0X

- We have a Final Draft Standard! (as on March 13, 2010)

Design?

- Can a committee design?
  - No (at least not much)
  - Few people consider or care for the whole language
- Is C++0x designed
  - Yes
    - Well, mostly
    - You can see traces of different personalities in C++0x
- Committees
  - Discuss
  - Bring up problems
  - “Polish”

Overall goals for C++0x

- 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)
  - Build directly on C++'s contributions to systems programming

- 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)

C++0x

- ‘x’ may be hex, but C++0x is not science fiction
  - Every feature is implemented somewhere
    - E.g. GCC 4.5: Rvalues, Variadic, Initializer lists, Static assertions, auto-typed variables, New function declarator syntax, Lambdas, Right angle brackets, Extern templates, Strongly-typed enums, Delegating constructors (patch), Raw string literals, Defaulted and deleted functions, Inline namespaces, Local and unnamed types as template arguments
  - Standard library components are shipping widely
    - E.g. GCC, Microsoft, Boost
  - The last design points have been settled
    - barring formal requests from National Standards Bodies
      - And they tend to be very conservative

Rules of thumb / Ideals

- Integrating features to work in combination is the key
  - And the most work
  - The whole is much more than the simple sum of its part

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

Maintain stability and compatibility

- “Don’t break my code!”
  - There are billions of lines of code “out there”
  - There are millions of C++ programmers “out there”

- “Absolutely no incompatibilities” leads to ugliness
  - We introduce new keywords as needed: **auto** (recycled), **decltype**, **constexpr**, **thread_local**, **nullptr**
  - Example of incompatibility:

    static_assert(4<=sizeof(int),"error: small ints");

- “Absolutely no incompatibilities” leads to absurdities

  _Bool *// C99 boolean type*

  typedef _Bool bool; *// C99 standard library typedef*

Support both experts and novices

- *Example*: minor syntax cleanup

  vector<list<int>> vl; *// note the “missing space”*

- *Example*: simplified iteration

  for (auto x : v) cout << x <<'\n';

- *Note*: Experts don’t easily appreciate the needs of novices
  - Example of what we couldn’t get just now

    string s = "12.3";

    double x = lexical_cast<double>(s); *// extract value from string*

Uniform initialization

- You can use **{}**-initialization for all types in all contexts

```
int a[] = { 1,2,3 };
vector<int> v { 1,2,3};

vector<string> geek_heros = {
    "Dahl", "Kernighan", "McIlroy", "Nygaard ", "Ritchie", "Stepanov"
};

thread t{}     // default initialization
               // remember “thread t();”  is a function declaration

complex<double> z{1,2};            // invokes constructor
struct S { double x, y; } s {1,2};  // no constructor (just initialize members)
```

Uniform initialization

- **{}**-initialization **X{v}** yields the same value of **X** in every context

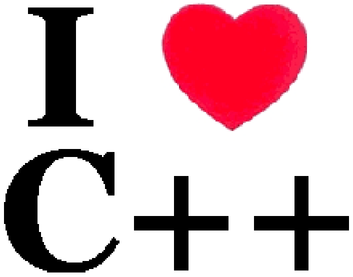
```
X x{a};
X* p = new X{a};
z = X{a};       // use as cast
f({a});         // function argument (of type X)
return {a};     // function return value (function returning X)
Y::Y(a) : X{a} /* … */ }          // base class initializer
```

Uniform initialization

- **{}**-initialization does not narrow

```
int x1 = 7.9;  // x1 becomes 7
int x2 {7.9};  // error: narrowing conversion

Table phone_numbers = {
    { "Donald Duck", 2015551234 },
    { "Mike Doonesbury", 9794566089 },
    { "Kell Dewclaw", 1123581321 }
};
```



Prefer libraries to language extensions

- Libraries deliver more functionality
- Libraries are immediately useful
- *Problem*: Enthusiasts prefer language features
  - see library as 2nd best
- *Example*: New library components
  - **std::thread**, **std::future**, …
    - Threads ABI; not thread built-in type
  - **std::unordered_map**, **std::regex**, …
    - Not built-in associative array

- *Example*: Mixed language/library extension
  - The new **for** works for every type with **std::begin()** and **std::end()**
  - The new initializer lists are based on **std::initializer_list<T>**

```
vector<string> v = { "Nygaard ", "Ritchie" };
for (auto& x : {y,z,ae,ao,aa}) cout << x <<'\n';
```

Prefer generality to specialization

- *Example*: Prefer improvements to abstraction mechanisms over separate new features
  - Inherited constructor

```
template<class T> class Vector : std::vector<T> {
        using vector::vector<T>;                  // inherit all constructors
        // …
};
```

  - Move semantics supported by rvalue references

```
template<class T>  class vector {
        // …
        void push_back(T&& x);                    // move x into vector
                                                  // avoid copy if possible
};
```

- *Problem*: people love small isolated features

Not a reference

Move semantics

- Often we don’t want two copies, we just want to move a value

```
vector<int> make_test_equence(int n)
{
    vector<int> res;
    for (int i=0; i<n; +=i) res.push_back(rand_int());
    return res; // move, not copy
}

vector<int> seq = make_test_sequence(1000000);          // no copies
```

- New idiom for arithmetic operations:
  - **Matrix operator+(const Matrix&, const Matrix&);**
  - **a = b+c;** *// no copies*

Increase type safety

- Approximate the unachievable ideal
  - *Example*: Strongly-typed enumerations

```
enum class Color { red, blue, green };
int x = Color::red;         // error: no Color->int conversion
Color y = 7;                // error: no int->Color conversion
Color z = red;              // error: red not in scope
Color c = Color::red;       // fine
```

  - *Example*: Support for general resource management
    - **std::unique_ptr** (for ownership)
    - **std::shared_ptr** (for sharing)
    - Garbage collection ABI

Move semantics in the standard library

- Prefer unique ownership to shared ownership

```
void f(shared_ptr<X>);
void g(unique_ptr<X>);

f(shared_ptr<X>(new X(1,2,3));          // manipulate (shared) use count
                                        // 0->1->2->1
g(unique_ptr<X>(new X(1,2,3));          // zero overhead
```

Improve performance and the ability to work directly with hardware

- Embedded systems programming is very important
  - *Example*: address array/pointer problems
    - **array<int,7> s;** *// fixed-sized array*
  - *Example*: Generalized constant expressions (think ROM)

```
constexpr int abs(int i) { return (0<=i) ? i : -i; } // can be constant expression

struct Point {
    int x, y;
    constexpr Point(int xx, int yy) : x{xx}, y{yy} { }        // “literal type”
};

constexpr Point p1{1,2};          // must be evaluated at compile time: ok
constexpr Point p2{1,abs(x)};  // ok?: is x is a constant expression?
```

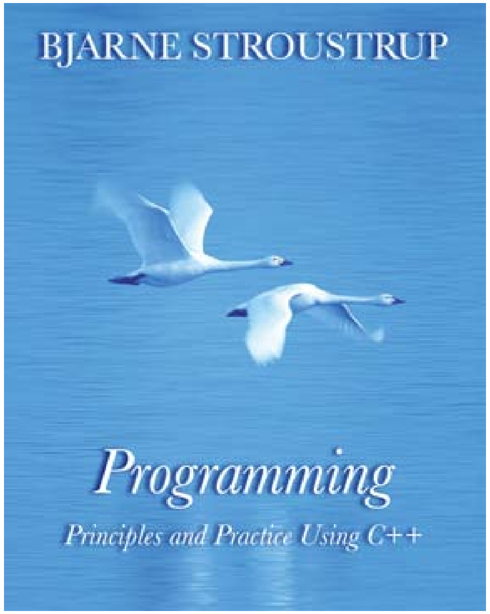
Make only changes that change the way people think

- Think/remember:
  - – Object-oriented programming
  - – Generic programming
  - – Concurrency
  - – …
- But, most people prefer to fiddle with details
  - – So there are dozens of small improvements
    - All useful somewhere
    - **long long**, **static_assert**, raw literals, **thread_local**, unicode types, …
  - – *Example*: A null pointer keyword

```
void f(int);
void f(char*);
f(0);             // call f(int);
f(nullptr);       // call f(char*);
```

Fit into the real world

- *Example*: Existing compilers and tools must evolve
  - Simple complete replacement is impossible
  - Tool chains are huge and expensive
  - There are more tools than you can imagine
  - C++ exists on *many* platforms
    - So the tool chain problems occur N times
      - (for each of M tools)
- *Example*: Education
  - Teachers, courses, and textbooks
    - Often mired in 1970s thinking (“C is the perfect language”)
    - or 1980s thinking (OOP: Rah! Rah!! Rah!!!)
  - “We” haven’t completely caught up with C++98!
    - “legacy code breeds more legacy code”



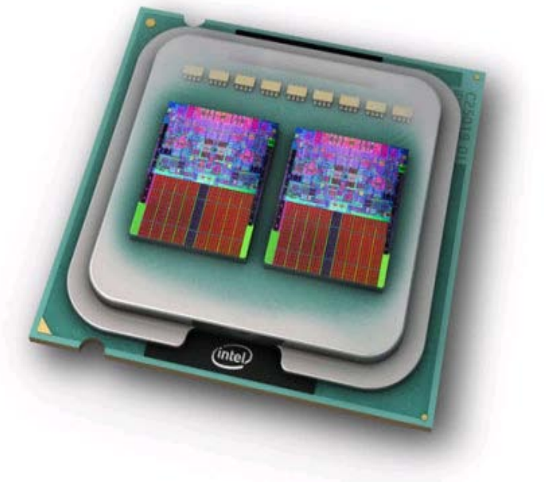
BJARNE STROUSTRUP

Programming

Principles and Practice Using C++

Areas of language change

- Machine model and concurrency Model
  - Threads library (**std::thread**)
  - Atomic ABI
  - Thread-local storage (**thread_local**)
  - Asynchronous message buffer (**std::future**)
- Support for generic programming
  - (no concepts ☹)
  - uniform initialization
  - **auto**, **decltype**, lambdas, template aliases, move semantics, variadic templates, range-**for**, …
- Etc.
  - **static_assert**
  - improved **enums**
  - **long long**, C99 character types, etc.
  - …



Standard Library Improvements

- New containers
  - Hash Tables (**unordered_map**, etc.)
  - Singly-linked list (**forward_list**)
  - Fixed-sized array (**array**)
- Container improvements
  - Move semantics (e.g. **push_back**)
  - Intializer-list constructors
  - Emplace operations
  - Scoped allocators
- More algorithms (just a few)
- Concurrency support
  - **thread**, **mutex**, **lock**, …
  - **future**, **async**, …
  - Atomic types
- Garbage collection ABI

Standard Library Improvements

- Regular Expressions (**regex**)
- General-purpose Smart Pointers (**unique_ptr**, **shared_ptr**, …)
- Extensible Random Number Facility
- Enhanced Binder and function wrapper (**bind** and **function**)
- Mathematical Special Functions
- Tuple Types (**tuple**)
- Type Traits (lots)

What is C++?

Template meta-programming!

A hybrid language

A multi-paradigm programming language

Buffer overflows

It’s C!

Embedded systems programming language

Too big!

Supports generic programming

Low level!

An object-oriented programming language

A random collection of features

C++0x

- It *feels* like a new language
  - Compared to C++98
- How can I categorize/characterize it?
- It’s *not* just “object oriented”
  - Many of the key user-defined abstractions are not objects
    - Types
    - Classifications and manipulation of types (types of types)
      - I miss “concepts”
    - Algorithms (generalized versions of computation)
    - Resources and resource lifetimes
- The pieces (language features) fit together much better than they used to

C++

A language for building software infrastructures and resource-constrained applications

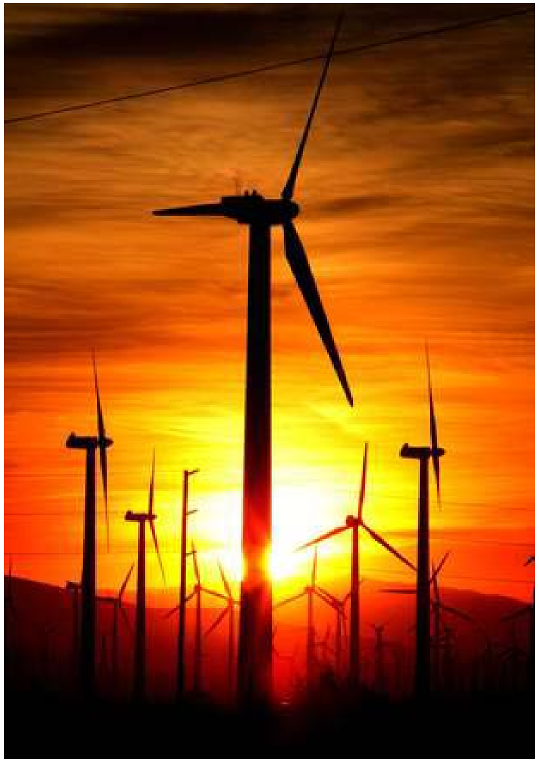
A light-weight abstraction programming language

Case study

- Concurrency
  - “driven by necessity”
  - More than ten years of experience

Case study: Concurrency

- What we want
  - Ease of programming
    - Writing correct concurrent code is hard
  - Portability
  - Uncompromising performance
  - System level interoperability
- We can’t get everything
  - No one concurrency model is best for everything
  - De facto: we can’t get all that much
  - “C++ is a systems programming language”
    - (among other things) implies serious constraints



Concurrency: std::thread

```
#include<thread>

void f() { std::cout << "Hello "; }

struct F { void operator()() { std::cout << "parallel world "; } };


int main()
{
    std::thread t1{f};        // f() executes in separate thread
    std::thread t2{F()};      // F()() executes in separate thread

    t1.join();      // wait for t1
    t2.join();      // wait for t2
}  // spot the bug
```

Thread – pass arguments

- Use bind() or variadic constructor

```
void f(vector<double>&);
struct F {
    vector<double>& v;
    F(vector<double>& vv) :v{vv} { }
    void operator()();
};

int main()
{
    std::thread t1{std::bind(f,some_vec)};        // f(some_vec)
    std::thread t2{f,some_vec};                   // f(some_vec)
    t1.join(); t2.join();
}
```

Mutual exclusion: std::mutex

- A **mutex** is a primitive object use for controlling access in a multi-threaded system.
- A **mutex** is a shared object (a resource)
- Simplest use:

```
std::mutex m;
int sh; // shared data
// …
m.lock();
        // manipulate shared data:
        sh+=1;
m.unlock();
```

Mutex – try_lock()

- Don’t wait unnecessarily

```
std::mutex m;
int sh; // shared data
// …
if (m.try_lock()) { // manipulate shared data:
    sh+=1;
    m.unlock();
else {
    // maybe do something else
}
```

RAII for mutexes: std::lock

- A lock represents local ownership of a resource (the **mutex**)

```
std::mutex m;
int sh; // shared data

void f()
{
    // ...
    std::unique_lock lck(m);    // grab (acquire) the mutex
    // manipulate shared data:
    sh+=1;
}   // implicitly release the mutex
```

Potential deadlock

- Unstructured use of multiple locks is hazardous:

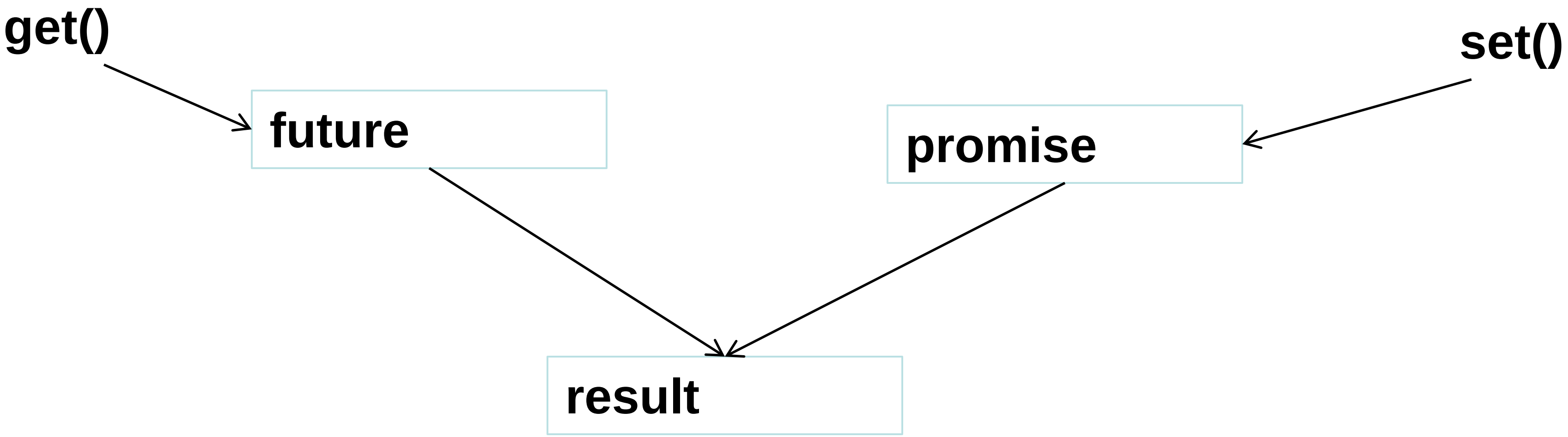
```
std::mutex m1;
std::mutex m2;
int sh1; // shared data
int sh2;
// …
void f() {
    // …
    std::unique_lock lck1(m1);
    std::unique_lock lck2(m2);
    // manipulate shared data:
    sh1+=sh2;
}
```

RAII for mutexes: std::lock

- We can safely use several locks

```
void f() {
    // ...
    std::unique_lock lck1(m1,std::defer_lock);  // make locks but don't yet
                                                 // try to acquire the mutexes
    std::unique_lock lck2(m2,std::defer_lock);
    std::unique_lock lck3(m3,std::defer_lock);
    // …
    lock(lck1,lck2,lck3);
    // manipulate shared data
}   // implicitly release the mutexes
```

Future and promise



- future+promise provides a simple way of passing a value from one thread to another
    - No explicit synchronization
    - Exceptions can be transmitted between threads

Future and promise

- Get an X from a **future<X>**:

```
X v = f.get();// if necessary wait for the value to get
```

- Put an X to a **promise<X>**:

```
try {
      X res;
      // compute a value for res
      p.set_value(res);
} catch (...) {
      // oops: couldn't compute res
      p.set_exception(std::current_exception());
}
```

async()

- Simple launcher using the variadic template interface

```
double accum(double* b, double* e, double init);

double comp(vector<double>& v) // spawn many tasks if v is large enough
{
    if (v.size()<10000) return accum(&v[0], &v[0]+v.size(), 0.0);

    auto f0 = async(accum, &v[0], &v[v.size()/4], 0.0);
    auto f1 = async(accum, &v[v.size()/4], &v[v.size()/2], 0.0);
    auto f2 = async(accum, &v[v.size()/2], &v[v.size()*3/4], 0.0);
    auto f3 = async(accum, &v[v.size()*3/4], &v[0]+v.size(), 0.0);

    return f0.get()+f1.get()+f2.get()+f3.get();
}
```

Thanks!

- C and Simula
  - Brian Kernighan
  - Doug McIlroy
  - Kristen Nygaard
  - Dennis Ritchie
  - …
- ISO C++ standards committee
  - Steve Clamage
  - Francis Glassborow
  - Andrew Koenig
  - Tom Plum
  - Herb Sutter
  - …
- C++ compiler, tools, and library builders
  - Beman Dawes
  - David Vandevoorde
  - …
- Application builders

More information

- My HOPL-II and HOPL-III papers
- The Design and Evolution of C++ (Addison Wesley 1994)
- My home pages
  - Papers, FAQs, libraries, applications, compilers, …
    - Search for “Bjarne” or “Stroustrup”
    - “What is C++0x ?” paper
  - C++0x FAQ
- The ISO C++ standard committee’s site:
  - All documents from 1994 onwards
    - Search for “WG21”
- The Computer History Museum
  - Software preservation project’s C++ pages
    - Early compilers and documentation, etc.
      - http://www.softwarepreservation.org/projects/c_plus_plus/
      - Search for “C++ Historical Sources Archive”