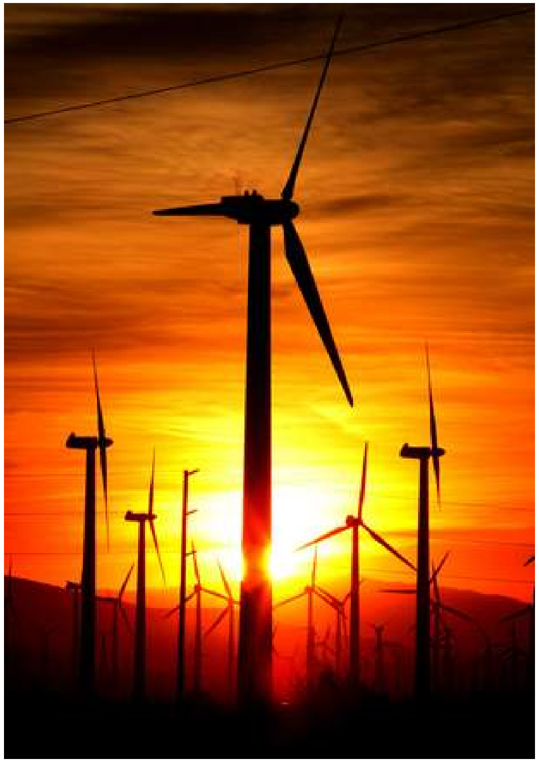
C++11
The Future is here

Bjarne Stroustrup
Texas A&M University
www.stroustrup.com

Parasol
Smarter computing.
Texas A&M University

Overview

- What is C++?
- Making simple things simple
  - Uniform and universal initialization
  - Auto
  - Range-for
  - …
- Resource Management
- Generic programming support
  - Lambdas
  - Variadic templates
  - Template aliases
  - …
- Concurrency



What is C++?

Template
meta-programming!

Class hierarchies

A hybrid language

Buffer
overflows

A multi-paradigm
programming language

It's C!

Classes

Embedded systems
programming language

Too big!

Low level!

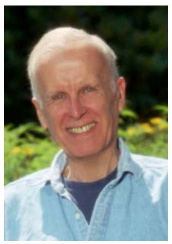
Generic programming

An object-oriented
programming language

A random collection
of features

Parasol
Smarter computing.
Texas A&M University

Programming Languages



Domain-specific abstraction

Fortran

Cobol

Simula

General-purpose abstraction

Java

C++

C++11

C#

Direct mapping to hardware

Assembler

BCPL

C

C++

A light-weight abstraction programming language

Key strengths:

- software infrastructure
- resource-constrained applications

Parasol
Smarter computing.
Texas A&M University

The ISO C++ Standard

- 1979 work on C with Classes starts
- 1985 first C++ commercial release
- 1990 work on an ANSI C++ standard starts
  - Based on “The ARM”
- 1998 first ISO C++ standard
- 2011 second ISO C++ standard
  - Compilers and libraries now available
- 2014 next ISO C++ revision

- No formal resources
  - No money, many volunteers
  - www.isocpp.org, The C++ Foundation
- 80 representatives present at meetings
  - 103+ in Bristol, April’13 – a new world record
- 250+ people involved
  - Much “electronic activity”
- Very democratic process
  - “herding cats”

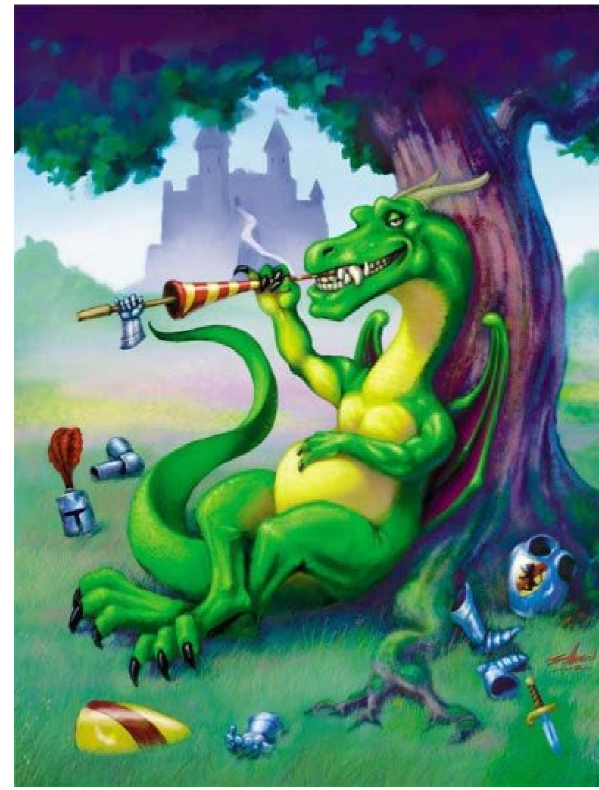
Lists of C++11 features

- You know where to find them
  - E.g. www.stroustrup.com/C++11FAQ.html
  - GCC 4.7, Clang 3.1, …
- What matter is how features work in combination

The real problems

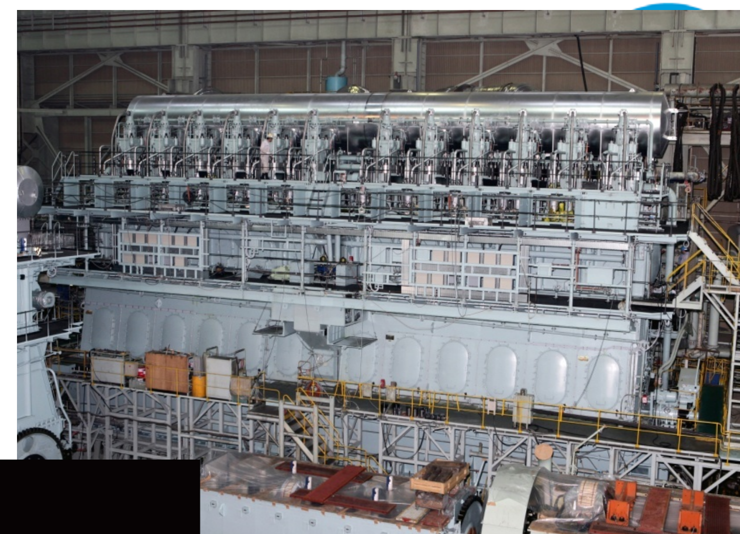
- Help people to write better programs
  - Easier to write
  - Easier to maintain
  - Easier to achieve acceptable resource usage

"...And that, in simple terms, is what's wrong with your software design."



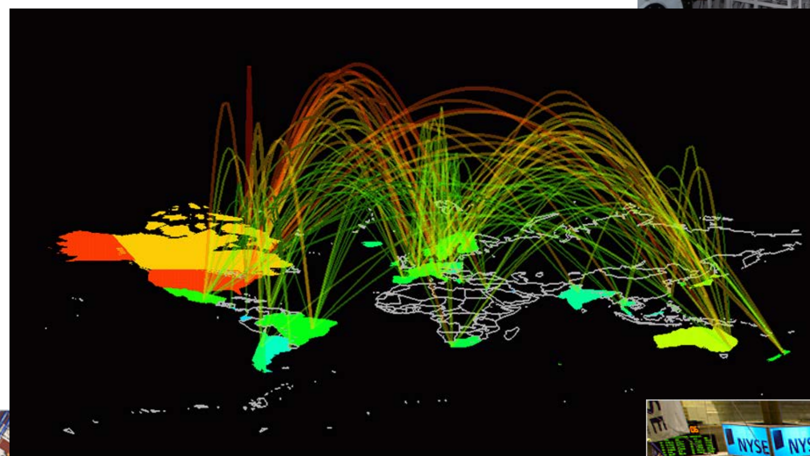
- The primary value of a programming language is in the applications written in it

C++ applications



OpenOffice.org

Microsoft .net

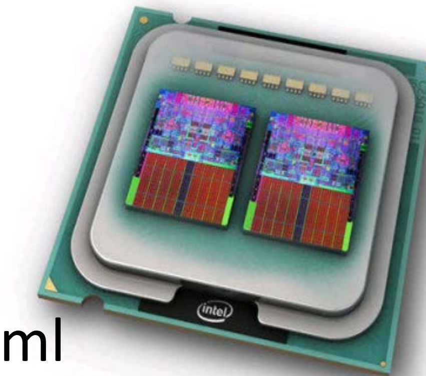


Java

C#

Google

C++ Applications



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

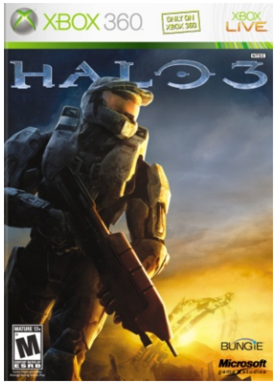
C++ Applications

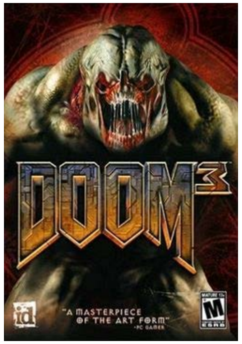
Parasol
Smarter computing.
Texas A&M University

TOMTOM

GARMIN

MySQL





PayPal

amazon

www.lextrait.com/vincent/implementations.html

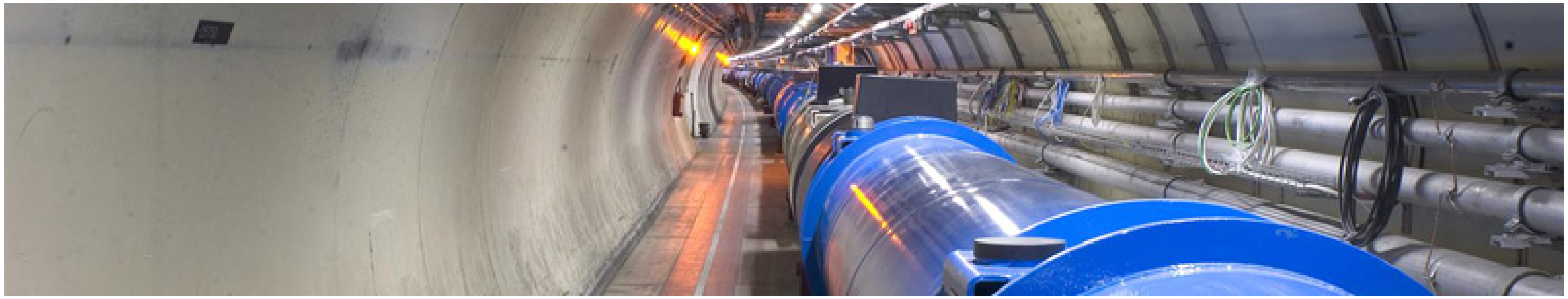
AMADEUS
Your technology partner

C++11

- Is a better approximation of my ideals for support of good programming
  - Significantly better than C++98
- Has tons of distracting “old stuff”
  - Going back to C in 1972
- We must focus on the essentials
  - And the “good stuff”
  - “Elegance ***and*** efficiency”
- C++11 is not the end, we can do much better still
  - Anyone who says *I have a perfect language* is a fool or a salesman
- Stability/compatibility is an important feature in itself
  - And not free

Make simple tasks simple

- Uniform and universal initialization
- Auto
- Range-for
- User-defined literals
- Constexpr



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

void f(X);
f({a});                   // function argument (of type X)

X g() {
    // …
    return {a};           // function return value (function returning X)
}

Y::Y(a) : X{a} { /* … */ };        // base class initializer
```

auto

- Deduce a type of an object from its initializer

```
auto x = 1;          // x is an int
auto y = 1.2;        // y is a double
```

- Most useful when types gets hard to type or hard to know

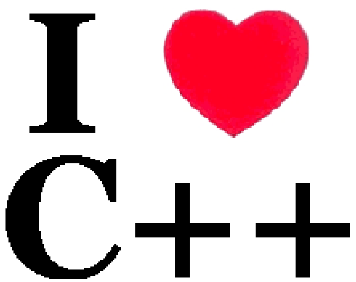
```
template<class C>
void use(C& c)
{
    for (auto p = c.begin(); p!=c.end(); ++p)      // p is a ???
            cout << *p << ‘\n’;
}
```

- Curio: The oldest C++11 feature
  - I implemented it in 1983/84

range-for

- Make the simplest loops simpler

```
template<class C>
void use(C& c)
{
        for (auto x : c)
                cout << x << '\n';
}

for(auto x : { 1, 2, 5, 8, 13})
        test(x);
```



User-Defined Literals

- Examples
  - **"Hello! "** **// const char***
  - **"Howdy! "s** **// std::string**
  - **2.3*5.7i** **//** “**i**” for “imaginary”: a **complex** number
  - **4h+6min+3s** **//** 4 hours, 6 minutes, and 3 seconds
- Can be used for type-rich programming
  - **Speed s = 100m/9s;** **//** very fast for a human
  - **Acceleration a1 = s/9s;** **//** OK
  - **Acceleration a2 = s;** **//** error: unit mismatch
- Definition
  - **complex<double> operator "" i(long double d) { return {0,d}; }**

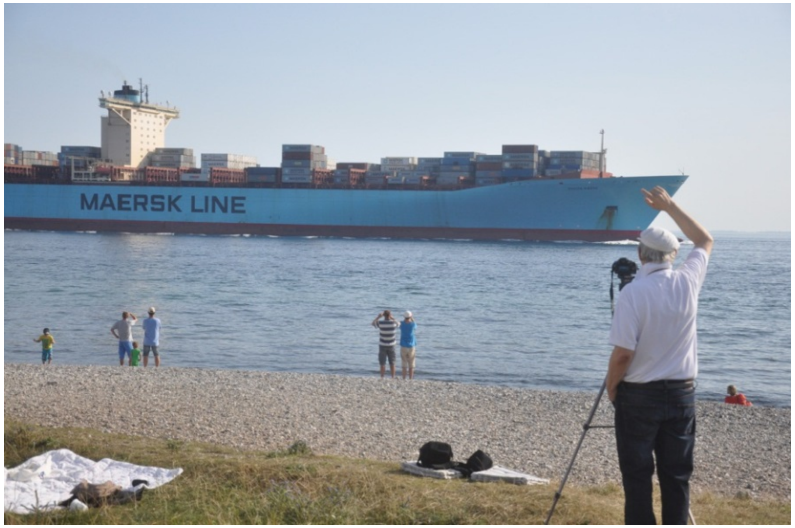
General constant expressions

- Think
  - ROM
  - concurrency
  - Compile-time computation (performance, compactness)
  - Type safety (reliability, maintainability)

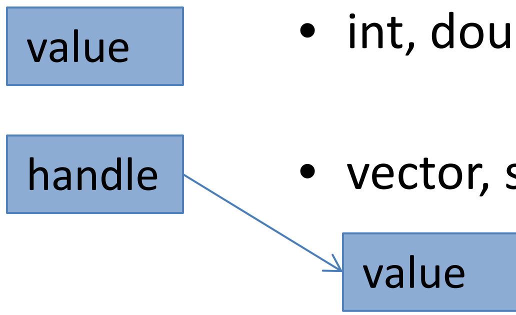
```
constexpr int abs(int i) { return (0<=i) ? i : -i; } // can be constant expression

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{p1.y,abs(x)};       // ok?: is x is a constant expression?
```

Simplify Resource management and error handling

- Resources
  - A resource is something you acquire and must release
    - Release can (and should be implicit)
  - Never leak a resource
- RAII
  - Simplify code structure
  - Integrate resource management and error handling
- Move
  - Simplify interfaces
  - Don’t waste cycles

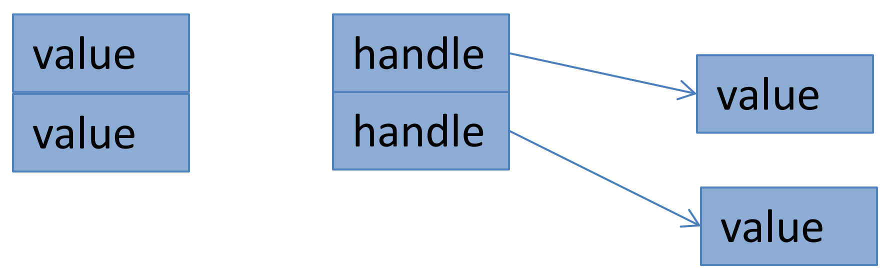


C++ Basics



- int, double, complex<double>, Date, …
- vector, string, thread, Matrix, …

- Objects can be composed by simple concatenation:
  - Arrays
  - Classes/structs

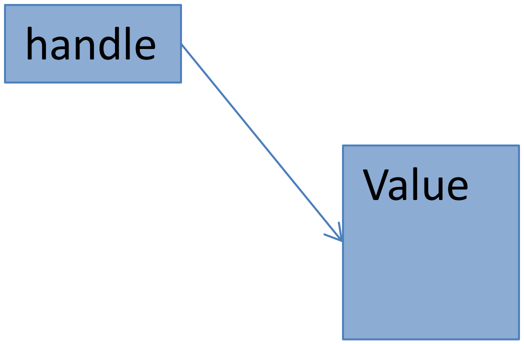


- If you understand **int** and **vector**, you understand C++
  - The rest is “details” (1300 pages of details)

Resource management

- A resource should be owned by a "handle"
  - A "handle" should present a well-defined and useful abstraction
    - E.g. a vector, string, file, thread
- Use constructors and a destructor

```
class Vector {                                   // vector of doubles
        Vector(initializer_list<double>);  // acquire memory; initialize elements
        ~Vector();                              // destroy elements; release memory
        // …
private:
        double* elem;          // pointer to elements
        int sz;                   // number of elements
};

void fct()
{
        Vector v {1, 1.618, 3.14, 2.99e8};          // vector of doubles
        // …
}
```



Resource management

- A resource should be owned by a "handle"
  - A "handle" should present a well-defined and useful abstraction
    - E.g. a vector, string, file, thread
- Use constructors and a destructor

```
Vector::Vector(initializer_list<double> lst)
        :elem {new double[lst.size()]}, sz{lst.size()};        // acquire memory
{
        uninitialized_copy(lst.begin(),lst.end(),elem);      // initialize elements
}

Vector::~Vector()
{
        delete[] elem;        // destroy elements; release memory
};
```

Resource management

- What about errors?
  - A resource is something you acquire and release
  - A resource should have an owner
  - Ultimately “root” a resource in a (scoped) handle
  - “Resource Acquisition is Initialization” (RAII)
    - Acquire during construction
    - Release in destructor
  - Throw exception in case of failure to construct (acquire)
  - Never throw while holding a resource ***not*** owned by a handle

Resource management

- For all resources
  - Memory (done by **std::string**, **std::vector**, **std::map**, …)
  - Locks (e.g. **std::unique_lock**), files (e.g. **std::fstream**), sockets, threads (e.g. **std::thread**), …

```
std::mutex mtx;          // a resource
int sh;                  // shared data

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

Resource Handles and Pointers

- Many (most?) uses of pointers in local scope are not exception safe

```
void f(int n, int x)
{
        Gadget* p = new Gadget{n};          // look I'm a java programmer! ☺
        // …
        if (x<100) throw std::runtime_error{"Weird!"};        // leak
        if (x<200) return;                                    // leak
        // …
        delete p;                     // and I want my garbage collector! ☹
}
```

  – "Naked New"! (bad idea)
  – But, why use a "naked" pointer?

Resource Handles and Pointers

- A **std::shared_ptr** releases its object at when the last **shared_ptr** to it is destroyed

```
void f(int n, int x)
{
        shared_ptr<Gadget> p {new Gadget{n}};     // manage that pointer!
        // …
        if (x<100) throw std::runtime_error{"Weird!"};        // no leak
        if (x<200) return;                                    // no leak
        // …
}
```

  – **shared_ptr** provides a form of garbage collection
    - For good ***and*** bad
  – But I'm not sharing anything
    - use a **unique_ptr**

Resource Handles and Pointers

- But why use a pointer at all?
- If you can, just use a scoped variable

```
void f(int n, int x)
{
        Gadget g {n};
        // …
        if (x<100) throw std::runtime_error{"Weird!"};        // no leak
        if (x<200) return;                                     // no leak
        // …
}
```

Why do we use pointers?

- And references, iterators, etc.

- To represent ownership
  - Don’t! use handles
- To reference resources
  - from within a handle
- To represent positions
  - Be careful
- To pass large amounts of data (into a function)
  - E.g. pass by **const** reference
- To return large amount of data (out of a function)
  - Don’t

How to move a resource

- Common problem:
  - How to get a lot of data cheaply out of a function
- Idea #1:
  - Return a pointer to a **new**'d object

```
Matrix* operator+(const Matrix&, const Matrix&);
Matrix& res = *(a+b);          // ugly! (unacceptable)
```

- Who does the **delete**?
  - there is no good general answer

How to move a resource

- Common problem:
  - How to get a lot of data cheaply out of a function
- Idea #2
  - Return a reference to a **new**'d object

```
Matrix& operator+(const Matrix&, const Matrix&);
Matrix res = a+b;        // looks right, but …
```

- Who does the **delete**?
  - What **delete**? I don't see any pointers.
  - there is no good general answer

How to move a resource

- Common problem:
  - How to get a lot of data cheaply out of a function
- Idea #3
  - Pass an reference to a result object

```
void operator+(const Matrix&, const Matrix&, Matrix& result);
Matrix res = a+b;                  // Oops, doesn't work for operators
Matrix res2;
operator+(a,b,res2);               // Ugly!
```

  - We are regressing towards assembly code

How to move a resource

- Common problem:
  - How to get a lot of data cheaply out of a function
- Idea #4
  - Return a **Matrix**

```
Matrix operator+(const Matrix&, const Matrix&);
Matrix res = a+b;
```

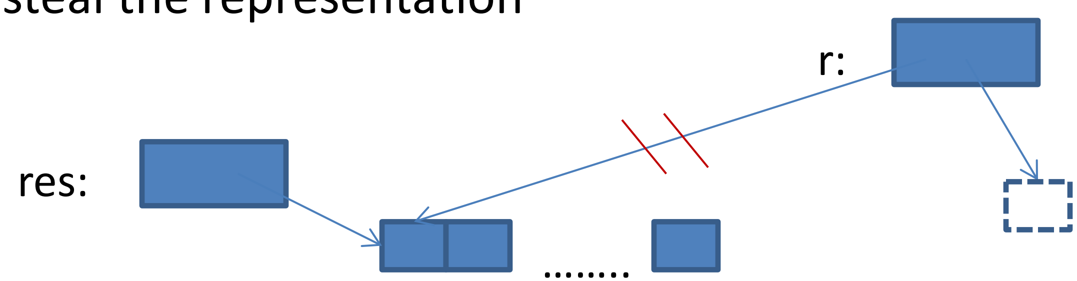
- Copy?
  - expensive
- Use some pre-allocated “result stack” of **Matrix**es
  - A brittle hack
- Move the **Matrix** out
  - don’t copy; “steal the representation”
  - Directly supported in C++11 through move constructors

Move semantics

- Return a **Matrix**

```
Matrix operator+(const Matrix& a, const Matrix& b)
{
        Matrix r;
        // copy a[i]+b[i] into r[i] for each i
        return r;
}
Matrix res = a+b;
```

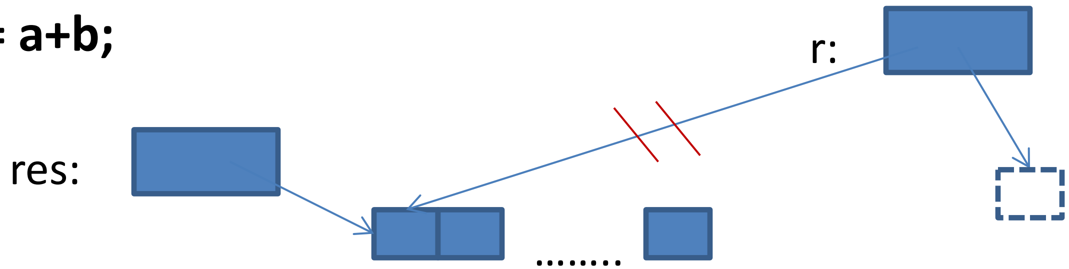
- Define move a constructor for **Matrix**
  - don’t copy; “steal the representation”



Move semantics

- Direct support in C++11: Move constructor

```
class Matrix {
        Representation rep;
        // …
        Matrix(Matrix&& a)          // move constructor
        {
                rep = a.rep;        // *this gets a's elements
                a.rep = {};         // a becomes the empty Matrix
        }
};

Matrix res = a+b;
```

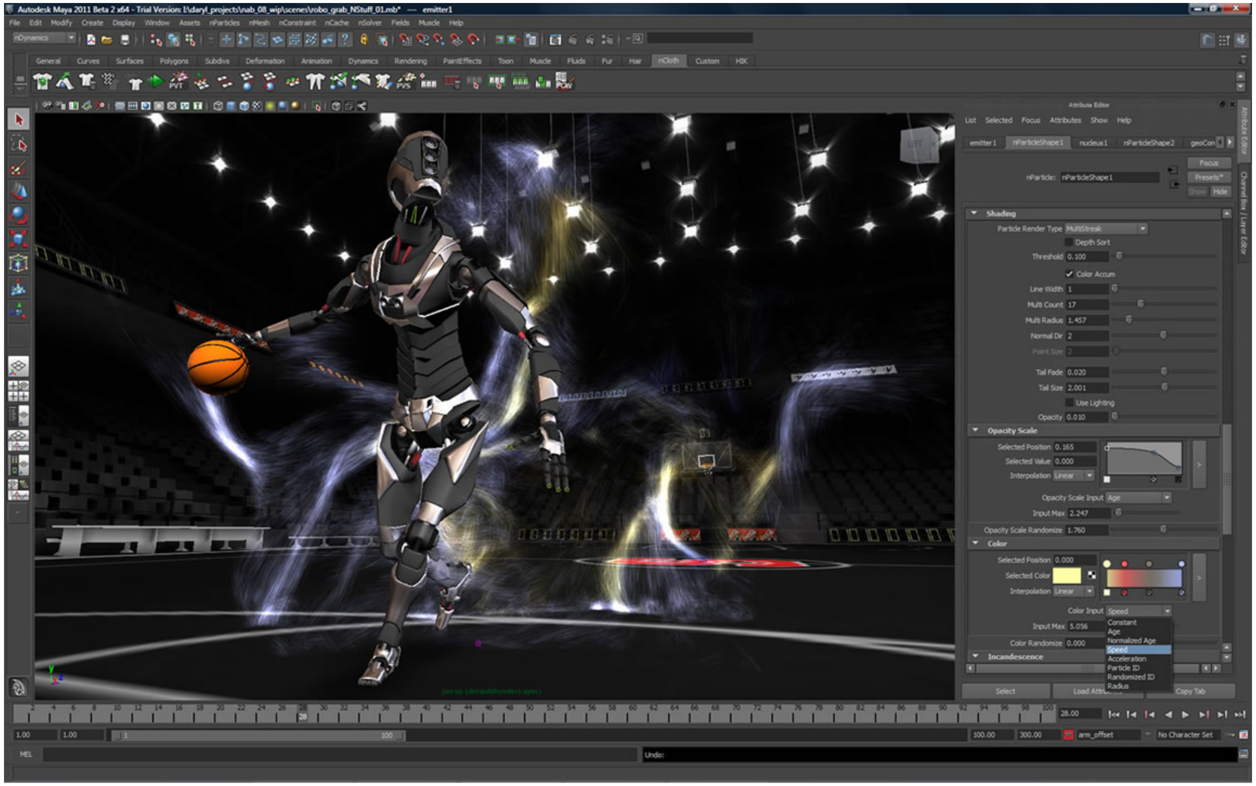


RAII and Move Semantics

- All the standard-library containers provide it
  - **vector**
  - **list, forward_list** (singly-linked list), …
  - **map, unordered_map** (hash table),…
  - **set, multi_set, …**
  - …
  - **string**
- So do other standard resources
  - **thread, lock_guard, …**
  - **istream, fstream, …**
  - **unique_ptr, shared_ptr**
  - …

Better Support for Generic Programming

- Lambdas
- Variadic templates
- Template aliases
- Type traits



Lambda expressions

- A lambda expression (“a lambda”) is a use-once function object

```
template<class C, class Oper>
void for_all(C& c, Oper op)          // assume that C is a container of pointers
{
    for (auto& x : c)
        op(*x);    // pass op() a reference to each element pointed to
}

void user()
{
    vector<unique_ptr<Shape>> v;
    while (cin)
        v.push_back(read_shape(cin));          // read shape from input

    for_all(v, [](Shape& s){ s.draw(); });          // draw_all()
    for_all(v, [](Shape& s){ s.rotate(45); });      // rotate_all(45)
}
```

Variadic templates

- Any number of arguments of any types

```
template <class F, class ...Args>            // thread constructor
    explicit thread(F&& f, Args&&... args); // argument types must
                                             // match the operation's
                                             // argument types

void f0();              // no arguments
void f1(int);           // one int argument

thread t1 {f0};
thread t2 {f0,1};                     // error: too many arguments
thread t3 {f1};                       // error: too few arguments
thread t4 {f1,1};
thread t5 {f1,1,2};                   // error: too many arguments
thread t3 {f1,"I'm being silly"};     // error: wrong type of argument
```

Template aliases

- Notation matters
- C++98 exposes all details when we use templates

```
typename iterator_traits<For>::value_type x;
```

- C++11 allows us to hide details

```
template<typename Iter>
using Value_type<T> = typename std::iterator_traits<For>::value_type;
// …
Value_type<For> x;
```

- Had I had an initializer, I could have used **auto**

```
auto x = *p;
```

Range for and move

- As ever, what matters is how features work in combination

```
template<typename C, typename V>
vector<Value_type<C>*> find_all(C& c, V v)  // find all occurrences of v in c
{
        vector<Value_type<C>*> res;
        for (auto& x : c)
                if (x==v)
                        res.push_back(&x);
        return res;
}

string m {"Mary had a little lamb"};
for (const auto p : find_all(m,'a'))   // p is a char*
        if (*p!='a')
                cerr << "string bug!\n";
```

Don't start from the bare language

- Some standard-library components
  - Type-safe concurrency
    - Conventional treads and locks
    - Futures and async()
  - Regular expressions
  - Hash tables
    - Yes, they weren't standard until C++11
  - Random numbers
  - STL
    - Many "small" improvements
      - New algorithms, containers, functions
      - Move semantics

Concurrency

- There are many kinds
- Stay high-level
- Stay type-rich

Type-Safe Concurrency

- Programming concurrent systems is hard
  - We need all the help we can get
  - C++11 offers
    - A memory model for concurrency
    - Support for lock-free programming
    - type-safe programming at the threads-and-locks level
    - One simple higher-level model (futures and async task launching)
  - Type safety is hugely important

- threads-and-locks
  - is an unfortunately low level of abstraction
  - is necessary for current systems programming
    - That's what the operating systems offer
  - presents an abstraction of the hardware to the programmer
  - can be the basis of other concurrency abstractions

Threads

```
void f(vector<double>&);              // function

struct F {                            // function object
    vector<double>& v;
    F(vector<double>& vv) :v{vv} { }
    void operator()();
};

void code(vector<double>& vec1, vector<double>& vec2)
{
    std::thread t1 {f,vec1};          // run f(vec1) on a separate thread
    std::thread t2 {F{vec2}};         // run F{vec2}() on a separate thread
    t1.join();
    t2.join();
    // use vec1 and vec2
}
```

Thread – pass argument and result

```
double* f(const vector<double>& v);          // read from v return result
double* g(const vector<double>& v);          // read from v return result

void user(const vector<double>& some_vec)         // note: const
{
    double res1, res2;
    thread t1 {[&]{ res1 = f(some_vec); }};     // lambda: leave result in res1
    thread t2 {[&]{ res2 = g(some_vec); }};     // lambda: leave result in res2
    // …
    t1.join();
    t2.join();
    cout << res1 << ' ' << res2 << '\n';
}
```

async() – pass argument and return result

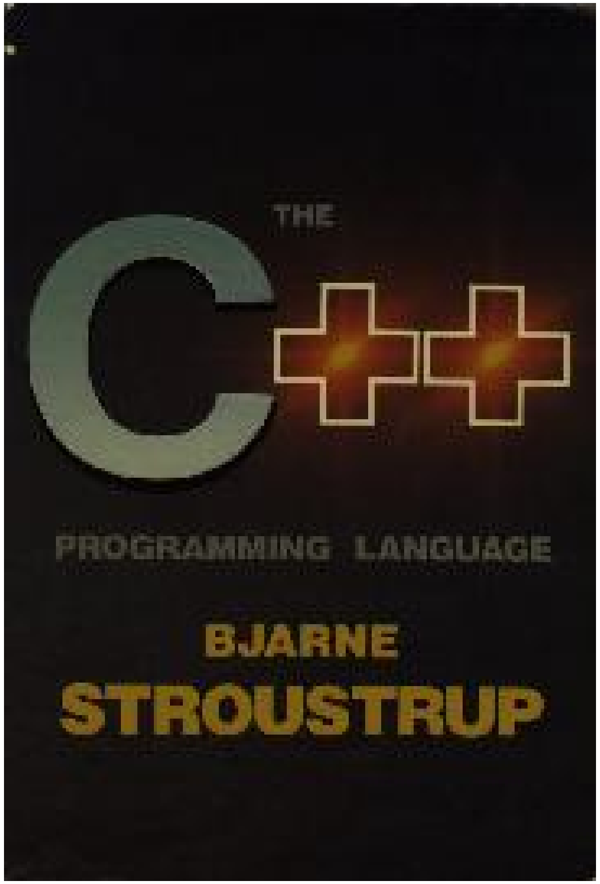
```
double* f(const vector<double>& v);    // read from v return result
double* g(const vector<double>& v);    // read from v return result

void user(const vector<double>& some_vec)          // note: const
{
    auto res1 = async(f,some_vec);
    auto res2 = async(g,some_vec);
    // ...
    cout << *res1.get() << ' ' << *res2.get() << '\n';     // futures
}
```

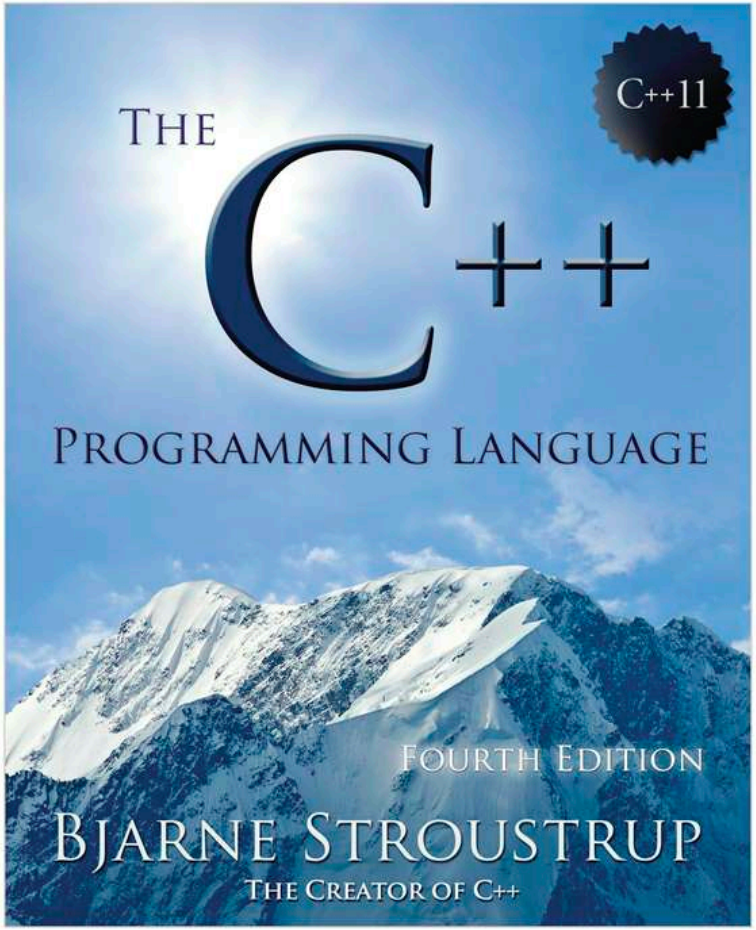
- Much more elegant than the explicit thread version
  - And most often faster

When? – Now!

- The compilers are getting good
  - Much faster adoption than C++98
- Use will lag for years
  - Decades?
  - Developers are very busy and can be very conservative
  - Teaching materials (even “new” ones)
  - Courses
  - Tools
- Fight FUD!
  - Start with the “low-hanging fruit” to gain credibility

Questions?





- Stroustrup: “A Tour of C++” http://isocpp.org/tour