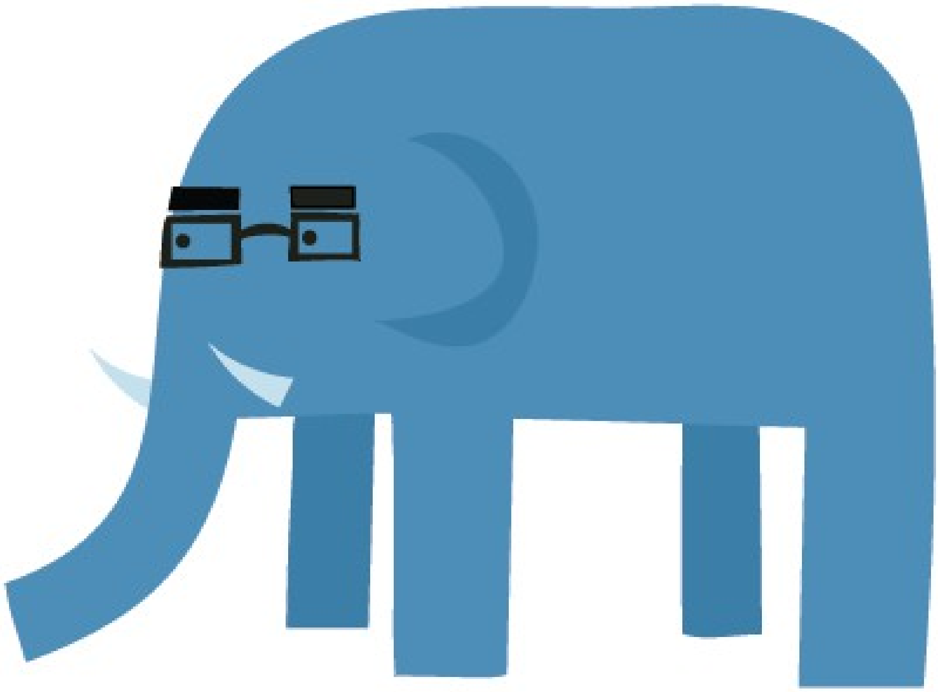
Making New Pseudo-Languages with C++

Build You a C++ For Great Good



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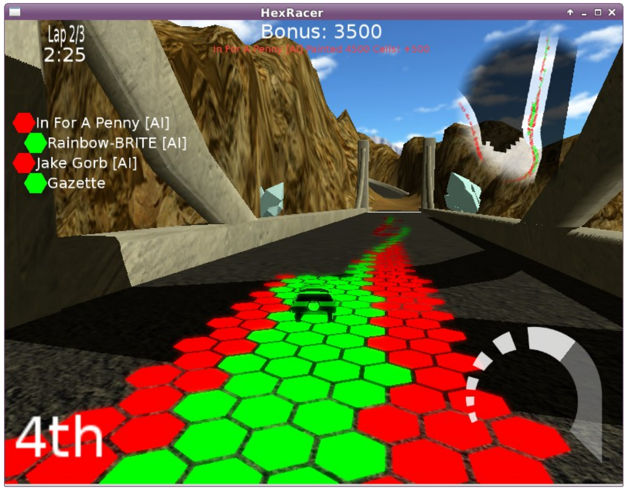
A 10,000 Metre Talk by David Williams-King

Agenda

1/4 Introduction
2/4 Polymorphism & Multimethods
3/4 Changing the Behaviour of C++
4/4 Metaprogramming & Frontends

Introduction

- About me
  - CBoard member for nearly 10 years http://cboard.cprogramming.com/
  - C++ game engine developer



- Most large-scale C++ projects have their own idioms, and invent their own “dialect” of C++
- Thinking about this explicitly is useful

C++ Language Specifications

- Pre-standard: iostream.h, ad-hoc libraries
- C++98: first standard
- TR1 (C++03): regular exp, smart pointers, hash tables, etc (just library changes)
  - Boost: major C++ library which influenced TR1
- C++11 (C++0x): second major standard, syntax changes (template >>), auto type inference, etc
- C++14 (upcoming): auto return types, better lambdas, etc.

C++ ecosystems

- Major C++ compilers
  - Borland C++ Builder
  - Microsoft Visual Studio C++ (MSVC)
  - GNU Compiler Collection (g++)
  - LLVM (clang)
  - IBM's xlc++, Intel's icc, EDG front-end (Coverity...)
- Boost: high-quality C++ libraries
  - Atomics, message-passing, serialization, regexes, preprocessors (Wave), co-routines, random number generators, shared pointers, embedded Python, ...

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2/4 Polymorphism & Multimethods

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Partially-Specified Behaviour

- Polymorphism through template types

```
// from GCC 4.9's bits/stl_set.h
namespace std
{
  template<typename _Key, typename _Compare = std::less<_Key>,
       typename _Alloc = std::allocator<_Key> >
    class set
    {  // ...
```

- Polymorphism through inheritance, interface specification, composition, etc
- Polymorphism through virtual functions!

Virtual Functions

- Overriding a method with a new version
  - crops up in C code, in the runtime linker, etc.
  - Some languages do this everywhere (Smalltalk, Java, etc.)
  - C++ lets you opt in with “virtual”
- Normal function calls are bound statically; virtual function calls are bound dynamically

Multimethods

- Call a function polymorphically based on the types of multiple different classes
  - e.g. collisions in a game
  - a.k.a. multiple dispatch (double dispatch)
- “Report on language support for Multi-Methods and Open-Methods for C++” -- Stroustrup
- Can emulate with visitor design pattern
  - polymorphic source method creates a visitor class which has accept(Foo), accept(Bar), etc
  - Target class hierarchy has polymorphic visit(Visitor)

Visitor Design Pattern

```
struct Visitor {
    virtual ~Visitor() {}
    virtual void visit(const Foo1 &f) = 0;
    virtual void visit(const Foo2 &f) = 0;
};

struct Foo {
    virtual void accept(Visitor &v) { v.visit(*this); }
    virtual void collide(const Foo &other);
};
class Foo1 : public Foo {};
class Foo2 : public Foo {};

void Foo1::collide(const Foo &other) {
    struct NewFooFunction : public Visitor { /* ... */ } f;
    other.accept(f);
    // one level of polymorphism because collide is virtual;
    // another level because of the visitor's overloading
}
```

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Operator overloading

- Simple operator overloading

```
Point operator + (const Point &other) const
    { return Point(x + other.x, y + other.y); }
```

- External operator overloading

```
std::ostream &operator << (std::ostream &o, const Foo &f) {
    o << f.getName(); return o;
}
```

- Type-conversion overloading

```
operator std::string () const
    { return StreamAsString() << x << ',' << y; }
```

StreamAsString

- Use << operator anywhere a string is expected

```
void print(const std::string &s);
print(StreamAsString() << “Answer: “ << 42);
```

- How?
  - std::ostringstream
  - template operator <<
  - operator std::string()

StreamAsString

```
#include <sstream>
#include <string>

class StreamAsString {
private:
    std::ostringstream stream;
public:
    template <typename T>
    StreamAsString &operator << (const T &data) {
        stream << data;
        return *this;
    }

    operator std::string() const {
        return stream.str();
    }
};
```

Memory Management

- C-style arrays, unchecked accesses, unsafe
- New Standard Template Library containers like std::vector, std::map, std::unordered_map, etc.
  - they can do bounds-checking and auto-resizing
- Automatic memory management with smart pointers and reference counting (C++03/Boost)
- Program-wide memory management with allocator pools

Smart Pointers

- How to write a smart pointer implementation:
  - catch dereferences (operator *, operator ->)
  - catch copying (operator =, copy constructor)
  - provide comparisons, conversions (operator bool)
- std::shared_ptr, std::weak_ptr
  - shared_ptr does ref counting
  - weak_ptr can be converted to shared but doesn't count towards the reference count

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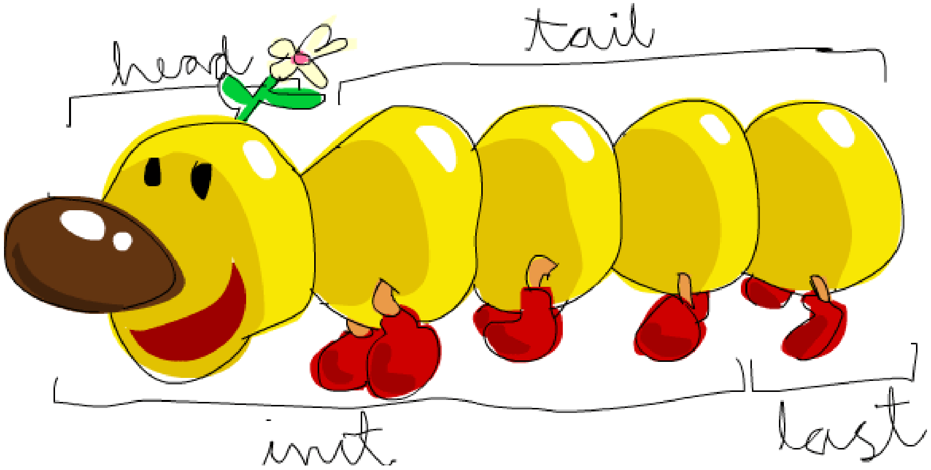
Metaprogramming

- C++ is Turing-complete (obviously)
  - So is the preprocessor: http://stackoverflow.com/questions/3136686/is-the-c99-preprocessor-turing-complete
  - So are templates (see Modern C++ Design by Andrei Alexandrescu -- the library is called Loki)
- Basic ideas like singleton, factories, pools
- But also typelists, traits, multimethods, functors



Object Messages/Event Systems

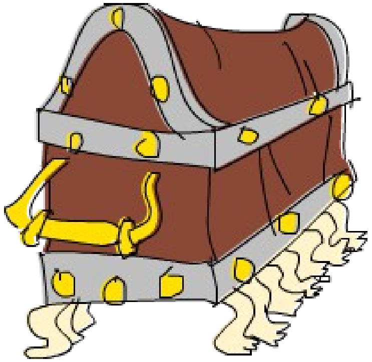
- A class wants to announce a state change without knowing who is interested
  - common in GUI toolkits and game engines
- Ways of implementing this:
  - observer design pattern (quite klunky)
  - event class with functors (Boost.Signals, templates)
  - global event managing system (my favourite)
  - separate pre-processing pass (e.g. Qt moc)

Serialization/Marshalling

- Turn an object into a string and back again (for sending over a network, storing on disk, etc)
- Boost.Serialization example:

```
class C {
private:
    friend class boost::serialization::access;

    template <typename Archive>
    void serialize(Archive &ar, const unsigned ver) {
        ar & x;  // like << and >> combined together
        ar & y;
    }
private:
    int x, y;
};
```



Reflection

- Want the ability to query the functions of an unknown class, call a function by name, instantiate a class by name at runtime
  - powerful when combined with serialization
- One example: Qt's Meta-Object Compiler (moc)
  - extra pre-processing pass that constructs a meta-object for relevant classes
  - also generates plumbing for object messages

Synthesis

- add events to objects (Boost.Signals, etc)
- store events in templated thread-safe queues
- automatically serialize and deserialize events (Boost.Serialization)
- send events over the network asynchronously (Boost.Asio)
- manage memory with shared pointers
- define events in XML or Lua ....

The End.

References (1/3)

- More about C++ in general
  - CBoard http://cboard.cprogramming.com/
  - C++11 http://www.learncpp.com/cpp-tutorial/b-1-introduction-to-c11/
  - Boost! Learn it!! http://boost.org/
  - Misc: function pointers http://www.newty.de/fpt/
- Slide references
  - Images from Learn You a Haskell for Great Good http://learnyouahaskell.com/

References (2/3)

- Metaprogramming and language extensions
  - Book: Modern C++ Design by Andrei Alexandrescu (will turn you into a template wizard!)
    - Or get the code online http://loki-lib.sourceforge.net/index.php?n=Main.ModernCDesign
  - Qt Meta-Object system http://qt-project.org/doc/qt-4.8/metaobjects.html
  - Boost http://boost.org/
    - Especially Boost.Signals, for event systems: http://www.boost.org/doc/libs/1_56_0/doc/html/signals/tutorial.html#idp426643280
  - My rant about Qt signals/slots (Boost is much better!) http://elfery.net/blog/signals.html

References (3/3)

- Serialization
  - Google's protocol buffers https://github.com/google/protobuf/
- Multimethods
  - “Report on language support for Multi-Methods and Open-Methods for C++” http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2007/n2216.pdf
  - For stuff that actually exists, see “Multiple Dispatch” on Wikipedia http://en.wikipedia.org/wiki/Multiple_dispatch
- Design patterns
  - Visitor, Observer, Composition; Event Notifier:
    - http://www.marco.panizza.name/dispenseTM/slides/exerc/eventNotifier/eventNotifier.html

(backup slides)

Undefined Functions

- Convention: prototype a method but don't define the function body (to create an abstract class)
- C++ canonized this with pure virtual functions

```
class C {
public:
    virtual void foo() = 0;
}
```

- Effective way to define abstract classes

C++11 Virtual Function Features

- New virtual function controls
  - override: this function must override a base-class function (like Java 5's @Override annotation)
  - final: can't be overridden (like Java's final)
  - default: use default code for default constructor, copy-constructor, assignment operator, or destructor
  - delete: prevent function from being called

```
virtual void foo() override;
virtual void foo() final;
virtual void foo() = default;
virtual void foo() = delete;
```

Function Pointers

- http://www.newty.de/fpt/
- Original C function pointers are straightforward:

```
void print(const char *s) {
    puts(s);
}

void (*func)(const char *) = &print;
func(“Hello”);
(*func)(“Hello”);
```

Function Pointers

- Pointers to member functions must specify scope

```
class C {
public:
    int add(int i) const { return i+i; }
    int mul(int i) const { return i*i; }
};

int (C::*func)(int) = &C::add;
C c, *p = &c;
int result1 = (c.*func)(5);
int result2 = (p->*func)(5);
int result3 = (*this.*func)(5);
```