THE C++ ABI FOR DUMMIES

Louis Dionne <@LouisDionne>

C++ Standard Library Engineer @ Apple

OUTLINE

- Why you care about ABI
- What's in the ABI?
- How source changes impact ABI
- Controlling the ABI
- Useful tools

DISCLAIMER

This talk assumes Unix and Itanium ABI

But concepts mostly transfer

WHY IS ABI STABILITY IMPORTANT?

- Ship libraries to a system and update them without
  - recompiling other system libraries
  - recompiling all applications
- Allows shipping static archives

BREAKING IT MEANS YOU NEED TO REBUILD

COSTS OF ABI STABILITY

1. Harder to evolve language and library
2. Performance improvements may be hindered

WHAT IS AN ABI?

Wikipedia:

An ABI defines how data structures or computational routines are accessed in machine code, which is a low-level, hardware-dependent format [...]

[...] in contrast, an API defines this access in source code, which is a relatively high-level, hardware-independent, often human-readable format.

SO ABI IS LIKE API FOR MACHINE CODE

THE ITANIUM C++ SPECIFICATION

https://github.com/itanium-cxx-abi/cxx-abi

CONVENTION FOLLOWED BY VENDORS

DESCRIBES THE ABI FOR C++ CONSTRUCTS

LAYERED ON TOP OF THE UNDERLYING C ABI

A FEW EXAMPLES

PASSING ARGUMENTS IN C

1. Arguments are passed in registers
2. Or via the stack

PASSING ARGUMENTS IN C++

1. Same as C for trivial types
2. For non-trivial types:
    1. Space allocated on the stack
    2. Caller invokes copy-constructor
    3. Address passed as a normal argument
    4. Caller invokes destructor

LAYING OUT BASE CLASSES

- Do base class members come before or after the derived class members?
- Multiple inheritance: left-to-right, right-to-left, something else?

HOW IT WORKS

- Base classes in declaration order
- Non-static data members in declaration order
- Virtual bases in inheritance graph order

THIS IS WHERE EBO TAKES PLACE

NAME MANGLING IN C

```
void foo(int); // just 'foo'
```

NAME MANGLING IN C++

Consider overloading, namespaces, etc.

Linker has to know which one to call

```
namespace hello {
  void foo(int); // mangled as '_ZN5hello3fooEi'
  void foo(long); // mangled as '_ZN5hello3fooEl'
}
```

ABI STABILITY

Software compiled against one version of a library doesn't need to be recompiled in order to use a newer version of the library

EXAMPLE OF BREAKING ABI

LIBRARY VERSION 1

```
template <typename First, typename Second>
struct pair {
  First first;
  Second second;

  pair(First const& f, Second const& s)
    : first(first), second(s)
  { }

  ~pair() { }
};

void foo(pair<int, int>); // defined in a .cpp
```

LIBRARY VERSION 2

```
template <typename First, typename Second>
struct pair {
  First first;
  Second second;

  pair(First const& f, Second const& s)
    : first(first), second(s)
  { }

  ~pair() = default;
};

void foo(pair<int, int>); // defined in a .cpp
```

APPLICATION

```cpp
#include "library.hpp"

int main() {
  pair<int, int> x = {3, 5};
  foo(x);

  // ...
}
```

WHAT'S THE PROBLEM?

- `pair` version 2 is trivial when `First` and `Second` are trivial
- Passed in registers instead of on the stack

EVEN SEEMINGLY INNOCUOUS CHANGES CAN BREAK ABI!

GENERAL GUIDELINES

(non-exhaustive)

Taken from:

- KDE ABI Guidelines: https://bit.ly/2ka1ITz
- Android ABI Stability docs: https://bit.ly/2lIleac

SAFE (1/3)

- add new non-virtual functions
- add a new enum to a class.
- append new enumerators to an existing enum
  - make sure the underlying type doesn't change

SAFE (2/3)

- define an inline function out-of-line
  - it must be OK for the program to call the old OR the new implementation
- remove private non-virtual functions or static members
  - must not have been used by a function in headers

SAFE (3/3)

- add new static data members
- change default arguments to a method
  - existing calls will use the old default arguments until recompiled
- add new classes
- add or remove friend declarations

CONTROLLING YOUR ABI

SYMBOL VISIBILITY

(for dynamic libraries)

```
#define HIDDEN_VISIBILITY \
  __attribute__((__visibility__("hidden")))

HIDDEN_VISIBILITY void foo();
```

CONTROLLING LINKAGE

(for static libraries)

```
#define INTERNAL_LINKAGE \
  __attribute__((internal_linkage))

INTERNAL_LINKAGE void foo();
```

CONTROLLING VTABLE AND RTTI VISIBILITY

Today

```
// in header
class __attribute__((__type_visibility__("default"))) Widget {
public:
  virtual void draw();
};

// in library
void Widget::draw() { /* ... */ } // vtable and RTTI implicitly here
```

CONTROLLING VTABLE AND RTTI VISIBILITY

Wish (http://wg21.link/p1263)

```
// in header
class Widget {
public:
  virtual void draw();
};

// in library
// control where and how vtable is instantiated
extern __attribute__((__visibility__("default"))) Widget::virtual;
void Widget::draw() { /* ... */ }
```

WILL THESE ATTRIBUTES EVER BE STANDARDIZED?

- People have tried and failed, so far
- Different platforms are too different (Windows/Unix)

TOOLS

LOOKING AT EXPORTED SYMBOLS

(and their type)

```
$ nm -gmU /usr/lib/libc++.dylib
[...]
(indirect)      external __ZNKSt13bad_exception4whatEv
                         (for __ZNKSt13bad_exception4whatEv)
(indirect)      external __ZNKSt13runtime_error4whatEv
                         (for __ZNKSt13runtime_error4whatEv)
(__TEXT,__text) external __ZNKSt16nested_exception14rethrow_nestedEv
(__TEXT,__text) external __ZNKSt18bad_variant_access4whatEv
(__TEXT,__text) external __ZNKSt19bad_optional_access4whatEv
(indirect)      external __ZNKSt20bad_array_new_length4whatEv
                         (for __ZNKSt20bad_array_new_length4whatEv)
[...]
```

PROTIP: `c++filt`

Will demangle anything

```
$ nm -gmU /usr/lib/libc++.dylib | c++filt
[...]
(indirect)      external std::bad_exception::what() const
                        (for std::bad_exception::what() const)
(indirect)      external std::runtime_error::what() const
                        (for std::runtime_error::what() const)
(__TEXT,__text) external std::nested_exception::rethrow_nested() const
(__TEXT,__text) external std::bad_variant_access::what() const
(__TEXT,__text) external std::bad_optional_access::what() const
(indirect)      external std::bad_array_new_length::what() const
                        (for std::bad_array_new_length::what() const)
[...]
```

libabigail

```
$ abidiff libtest-v0.so libtest-v1.so
Functions changes summary: 0 Removed, 1 Changed, 0 Added function
Variables changes summary: 0 Removed, 0 Changed, 0 Added variable

1 function with some indirect sub-type change:

  [C]'function void foo(S0*)' has some indirect sub-type changes:
        parameter 0 of type 'S0*' has sub-type changes:
          in pointed to type 'struct S0':
            size changed from 32 to 64 bits
            1 base class insertion:
              struct type_base
            1 data member change:
             'int S0::m0' offset changed from 0 to 32
```

ANDROID ABI CHECKER

EXTRACTS ABI INFORMATION FROM HEADERS

```
$ header-abi-dumper foo.cpp -o foo.sdump
$ header-abi-linker foo.sdump -o libfoo.lsdump
```

ALLOWS DIFFING ABI INFORMATION

```
$ header-abi-diff -old libfoo_old.lsdump \
                  -new libfoo_new.lsdump \
                  -o libfoo.abidiff
```

OUTPUT

```
$ cat libfoo.abidiff
record_type_diffs {
  fields_diff {
    old_field {
      referenced_type: "foo"
      field_offset: 0
      field_name: "mfoo"
      access: public_access
    }
    new_field {
      referenced_type: "foo *"
      field_offset: 0
      field_name: "mfoo"
      access: public_access
    }
  }
}
```

THANK YOU

Louis Dionne <@LouisDionne>

C++ Standard Library Engineer @ Apple