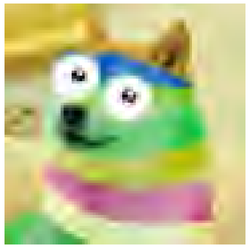
MDCC 2016 中国移动开发者大会 Mobile Developer Conference China 2016

把玩编译器，Clang 有意思^ ^

孙源 sunnyxx

自我介绍



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- 博客：http://blog.sunnyxx.com
- 微博：@我就叫Sunny怎么了
- GitHub：http://github.com/forkingdog

- 问：编译器可以编译程序，但编译器本身也是个程序，那它一定是由更早的编译器编译而成的，那...最早的一个编译器是哪儿来的?

Topics

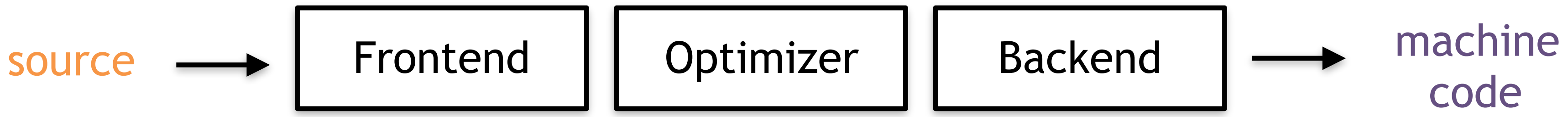
- ➡️ Apple 编译器 Clang-LLVM 架构初识
- 你的源码是如何一步步成为可执行文件的?
- 我们能用 Clang 做什么有意思的事情?

- LLVM - Low Level Virtual Machine
- Clang /ˈklæŋ/ - C Language Family Frontend for LLVM

GCC 用的好好的，Apple 为啥要自己搞一套?

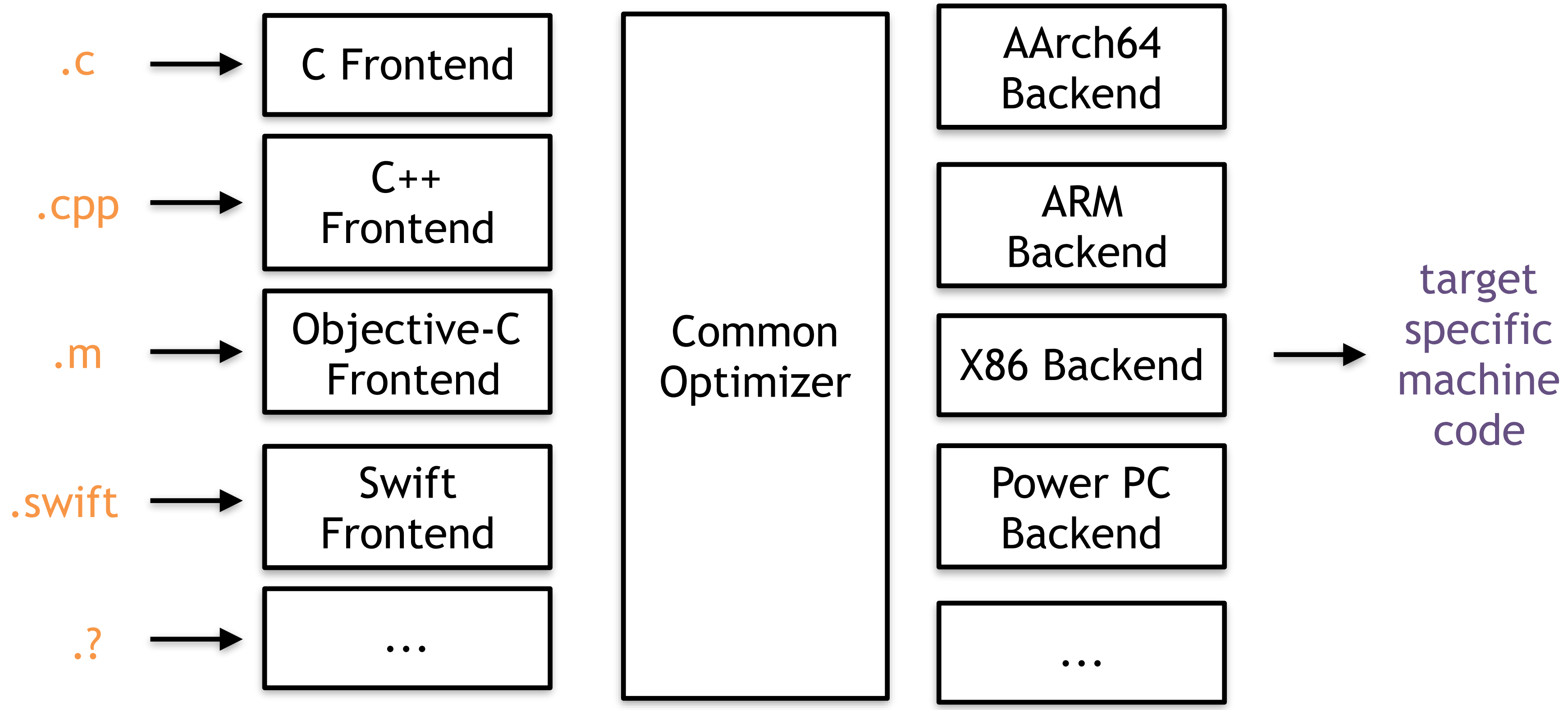
- GCC 的 Objective-C Frontend 不给力
- GCC 插件、工具、IDE 的支持薄弱
- GCC 编译效率和性能
- Apple 收回对工具链的控制（lldb, lld, swift...）

Three-Phase 编译器架构

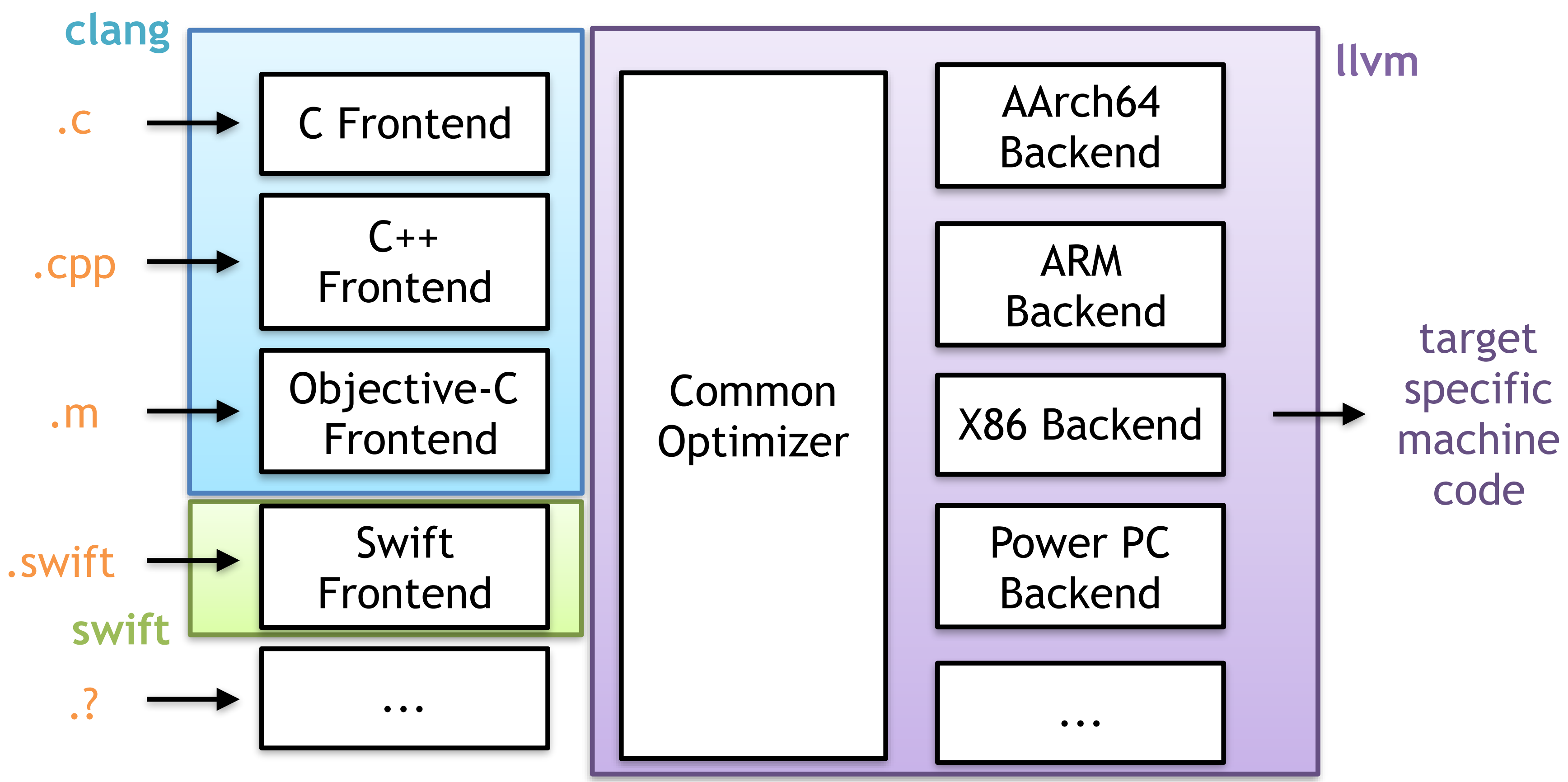


⚠️ **M (Language) * N (Target) = M * N Compilers**

Clang/Swift - LLVM 编译器架构



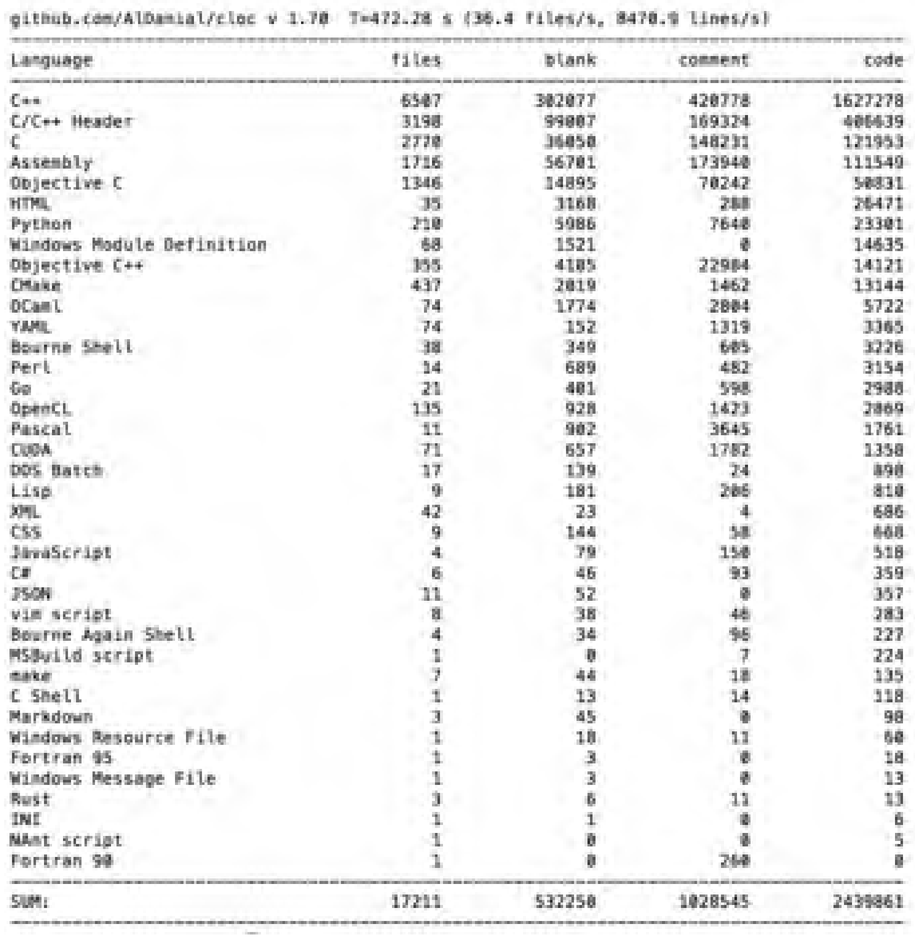
Clang/Swift - LLVM 编译器架构



PS: Swift Frontend 中还包含一层 SIL 及 Optimizer

Clang + LLVM 代码规模

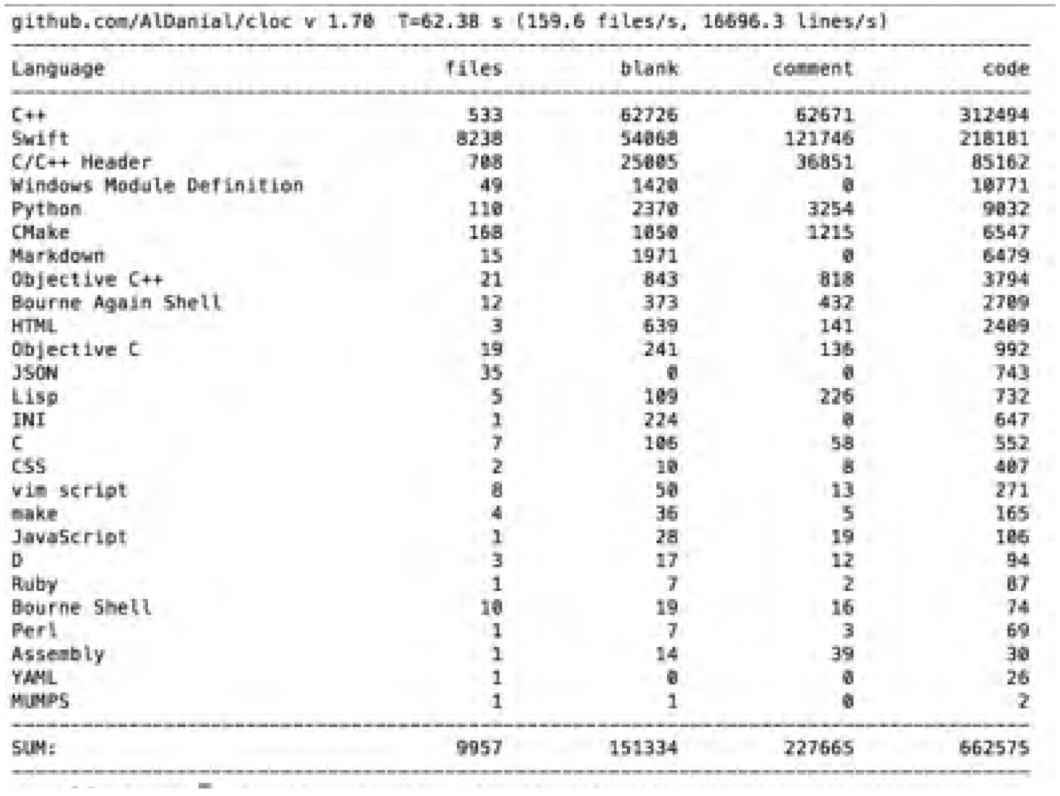
- Total 400W
- C++ 235W



```
github.com/AlDanial/cloc v 1.70  T=472.28 s (36.4 files/s, 8470.9 lines/s)
-------------------------------------------------------------------------------
Language                             files          blank        comment           code
-------------------------------------------------------------------------------
C++                                   6507         302077         420778        1627278
C/C++ Header                          3198          99007         169324         400639
C                                     2770          36050         148231         121953
Assembly                              1716          56701         173940         111549
Objective C                           1346          14895          70242          50831
HTML                                    35           3168            288          26471
Python                                 210           5986           7640          23301
Windows Module Definition               68           1521              0          14635
Objective C++                          355           4105          22984          14121
CMake                                  437           2019           1462          13144
OCaml                                   74           1774           2804           5722
YAML                                    74            152           1319           3365
Bourne Shell                            38            349            605           3226
Perl                                    14            689            482           3154
Go                                      21            401            598           2988
OpenCL                                 135            928           1423           2869
Pascal                                  11            902           3645           1761
CUDA                                    71            657           1782           1358
DOS Batch                               17            139             24            898
Lisp                                     9            181            206            810
XML                                     42             23              4            686
CSS                                      9            144             58            668
JavaScript                               4             79            150            518
C#                                       6             46             93            359
JSON                                    11             52              0            357
vim script                               8             38             48            283
Bourne Again Shell                       4             34             96            227
MSBuild script                           1              0              7            224
make                                     7             44             18            135
C Shell                                  1             13             14            118
Markdown                                 3             45              0             98
Windows Resource File                    1             18             11             60
Fortran 95                               1              3              0             18
Windows Message File                     1              3              0             13
Rust                                     3              6             11             13
INI                                      1              1              0              6
NAnt script                              1              0              0              5
Fortran 90                               1              0            260              0
-------------------------------------------------------------------------------
SUM:                                 17211         532250        1028545        2439861
-------------------------------------------------------------------------------
```

Swift Frontend 代码规模

- C++ 43W



```
github.com/AlDanial/cloc v 1.70  T=62.38 s (159.6 files/s, 16696.3 lines/s)
----------------------------------------------------------------------------------
Language                           files         blank       comment          code
----------------------------------------------------------------------------------
C++                                  533         62726         62671        312494
Swift                               8238         54068        121746        218181
C/C++ Header                         708         25005         36851         85162
Windows Module Definition             49          1420             0         10771
Python                               110          2370          3254          9032
CMake                                168          1050          1215          6547
Markdown                              15          1971             0          6479
Objective C++                         21           843           818          3794
Bourne Again Shell                    12           373           432          2709
HTML                                   3           639           141          2409
Objective C                           19           241           136           992
JSON                                  35             0             0           743
Lisp                                   5           109           226           732
INI                                    1           224             0           647
C                                      7           106            58           552
CSS                                    2            10             8           407
vim script                             8            50            13           271
make                                   4            36             5           165
JavaScript                             1            28            19           106
D                                      3            17            12            94
Ruby                                   1             7             2            87
Bourne Shell                          10            19            16            74
Perl                                   1             7             3            69
Assembly                               1            14            39            30
YAML                                   1             0             0            26
MUMPS                                  1             1             0             2
----------------------------------------------------------------------------------
SUM:                                9957        151334        227665        662575
----------------------------------------------------------------------------------
```

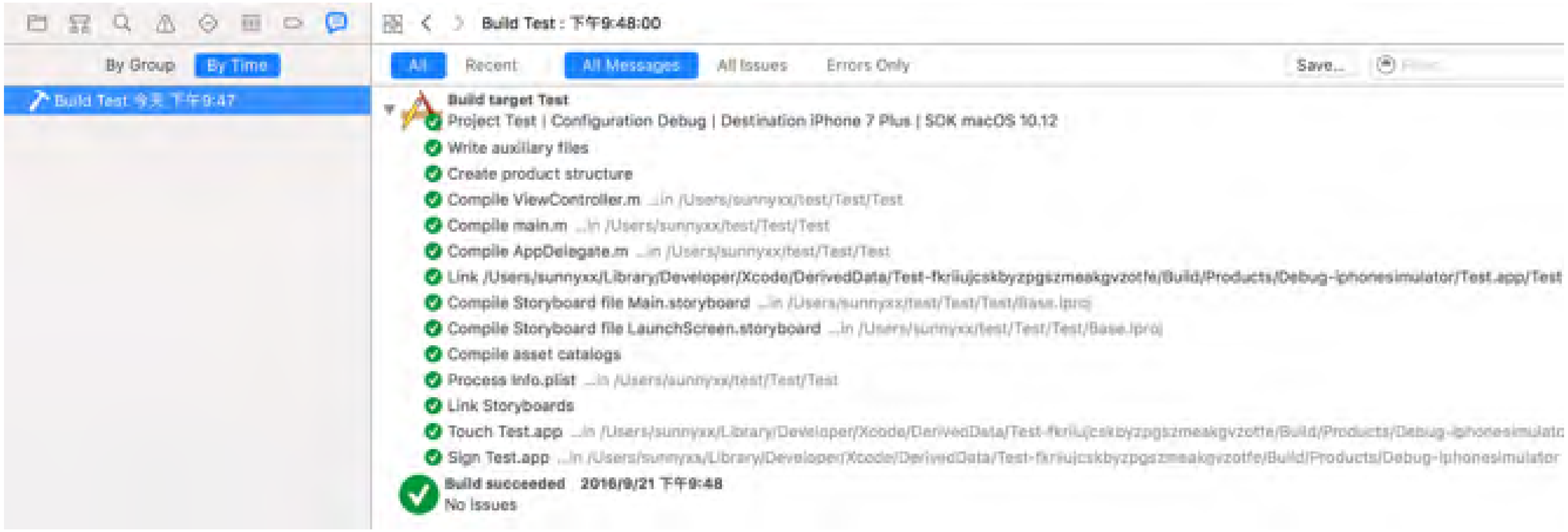
看 Clang-LLVM 源码的感受

- 代码巨多、需要一定 C++ 基础
- 远离安逸的 Xcode Build System，CMake Ninja 都比较陌生
- 目录明了、分层清晰、风格规范、注释覆盖度高 (~40%)
- 代码结构朴素但合理，均以 library 的形式整合，便于组合与复用

Topics

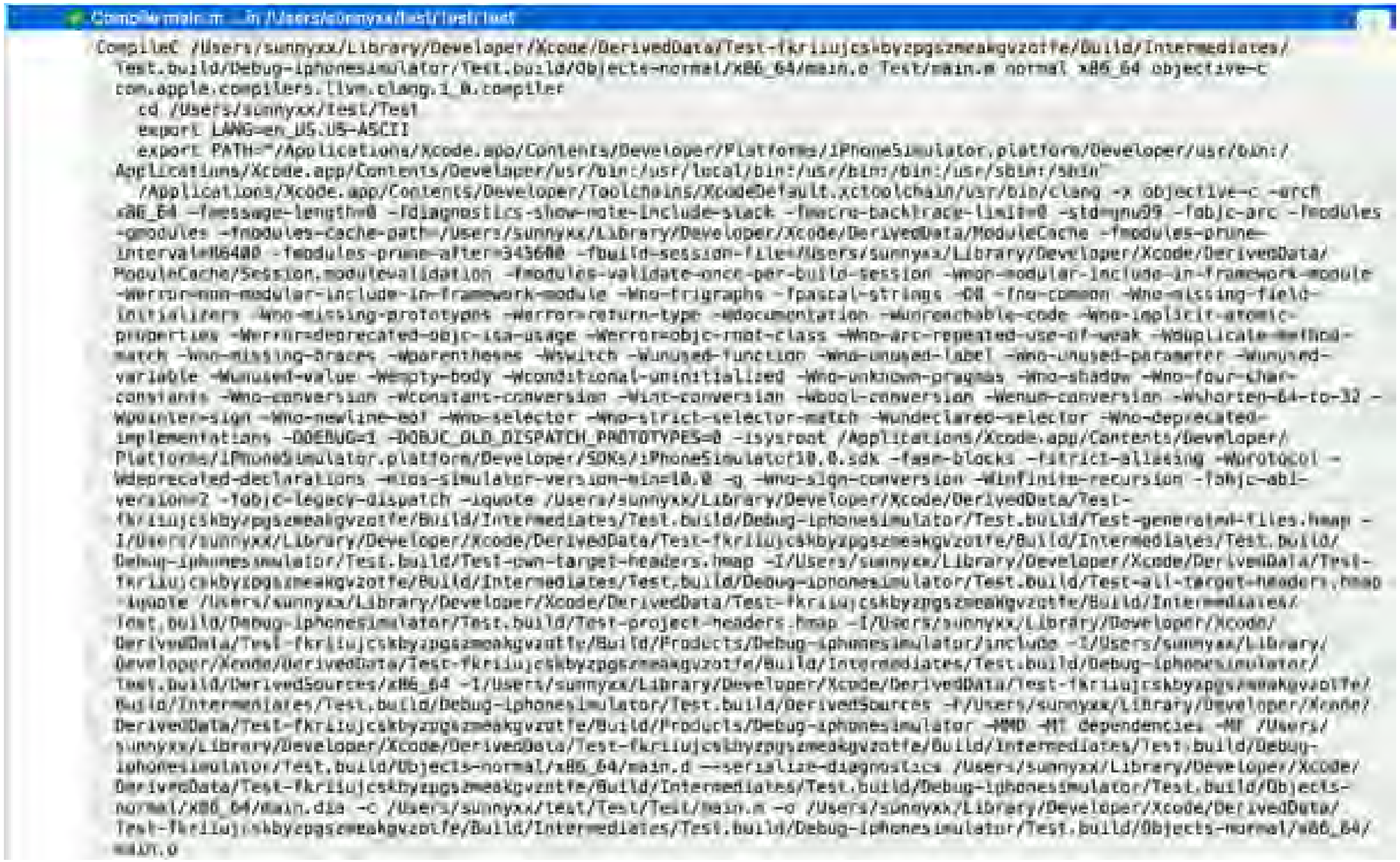
- ✅ Apple 编译器 Clang-LLVM 架构初识
- ➡️ 你的源码是如何一步步成为可执行文件的?
- 我们能用 Clang 做什么有意思的事情?

当我们按下 Run 之后...



```
Build target Test
Project Test | Configuration Debug | Destination iPhone 7 Plus | SDK macOS 10.12
Write auxiliary files
Create product structure
Compile ViewController.m ...in /Users/sunnyxx/test/Test/Test
Compile main.m ...in /Users/sunnyxx/test/Test/Test
Compile AppDelegate.m ...in /Users/sunnyxx/test/Test/Test
Link /Users/sunnyxx/Library/Developer/Xcode/DerivedData/Test-fkriiujcskbyzpgszmeakgvzotfe/Build/Products/Debug-iphonesimulator/Test.app/Test
Compile Storyboard file Main.storyboard ...in /Users/sunnyxx/test/Test/Test/Base.lproj
Compile Storyboard file LaunchScreen.storyboard ...in /Users/sunnyxx/test/Test/Test/Base.lproj
Compile asset catalogs
Process info.plist ...in /Users/sunnyxx/test/Test/Test
Link Storyboards
Touch Test.app ...in /Users/sunnyxx/Library/Developer/Xcode/DerivedData/Test-fkriiujcskbyzpgszmeakgvzotfe/Build/Products/Debug-iphonesimulatc
Sign Test.app ...in /Users/sunnyxx/Library/Developer/Xcode/DerivedData/Test-fkriiujcskbyzpgszmeakgvzotfe/Build/Products/Debug-iphonesimulator
Build succeeded   2016/9/21 下午9:48
No Issues
```

当我们按下 Run 之后...



Compile main.m ...in /Users/sunnyxx/test/Test/Test

```
CompileC /Users/sunnyxx/Library/Developer/Xcode/DerivedData/Test-fkriiujcskbyzpgszmeakgvzotfe/Build/Intermediates/
  Test.build/Debug-iphonesimulator/Test.build/Objects-normal/x86_64/main.o Test/main.m normal x86_64 objective-c
  com.apple.compilers.llvm.clang.1_0.compiler
    cd /Users/sunnyxx/test/Test
    export LANG=en_US.US-ASCII
    export PATH="/Applications/Xcode.app/Contents/Developer/Platforms/iPhoneSimulator.platform/Developer/usr/bin:/
  Applications/Xcode.app/Contents/Developer/usr/bin:/usr/local/bin:/usr/bin:/bin:/usr/sbin:/sbin"
    /Applications/Xcode.app/Contents/Developer/Toolchains/XcodeDefault.xctoolchain/usr/bin/clang -x objective-c -arch
  x86_64 -fmessage-length=0 -fdiagnostics-show-note-include-stack -fmacro-backtrace-limit=0 -std=gnu99 -fobjc-arc -fmodules
  -gmodules -fmodules-cache-path=/Users/sunnyxx/Library/Developer/Xcode/DerivedData/ModuleCache -fmodules-prune-
  interval=86400 -fmodules-prune-after=345600 -fbuild-session-file=/Users/sunnyxx/Library/Developer/Xcode/DerivedData/
  ModuleCache/Session.modulevalidation -fmodules-validate-once-per-build-session -Wnon-modular-include-in-framework-module
  -Werror=non-modular-include-in-framework-module -Wno-trigraphs -fpascal-strings -O0 -fno-common -Wno-missing-field-
  initializers -Wno-missing-prototypes -Werror=return-type -Wdocumentation -Wunreachable-code -Wno-implicit-atomic-
  properties -Werror=deprecated-objc-isa-usage -Werror=objc-root-class -Wno-arc-repeated-use-of-weak -Wduplicate-method-
  match -Wno-missing-braces -Wparentheses -Wswitch -Wunused-function -Wno-unused-label -Wno-unused-parameter -Wunused-
  variable -Wunused-value -Wempty-body -Wconditional-uninitialized -Wno-unknown-pragmas -Wno-shadow -Wno-four-char-
  constants -Wno-conversion -Wconstant-conversion -Wint-conversion -Wbool-conversion -Wenum-conversion -Wshorten-64-to-32 -
  Wpointer-sign -Wno-newline-eof -Wno-selector -Wno-strict-selector-match -Wundeclared-selector -Wno-deprecated-
  implementations -DDEBUG=1 -DOBJC_OLD_DISPATCH_PROTOTYPES=0 -isysroot /Applications/Xcode.app/Contents/Developer/
  Platforms/iPhoneSimulator.platform/Developer/SDKs/iPhoneSimulator10.0.sdk -fasm-blocks -fstrict-aliasing -Wprotocol -
  Wdeprecated-declarations -mios-simulator-version-min=10.0 -g -Wno-sign-conversion -Winfinite-recursion -fobjc-abi-
  version=2 -fobjc-legacy-dispatch -iquote /Users/sunnyxx/Library/Developer/Xcode/DerivedData/Test-
  fkriiujcskbyzpgszmeakgvzotfe/Build/Intermediates/Test.build/Debug-iphonesimulator/Test.build/Test-generated-files.hmap -
  I/Users/sunnyxx/Library/Developer/Xcode/DerivedData/Test-fkriiujcskbyzpgszmeakgvzotfe/Build/Intermediates/Test.build/
  Debug-iphonesimulator/Test.build/Test-own-target-headers.hmap -I/Users/sunnyxx/Library/Developer/Xcode/DerivedData/Test-
  fkriiujcskbyzpgszmeakgvzotfe/Build/Intermediates/Test.build/Debug-iphonesimulator/Test.build/Test-all-target-headers.hmap
  -iquote /Users/sunnyxx/Library/Developer/Xcode/DerivedData/Test-fkriiujcskbyzpgszmeakgvzotfe/Build/Intermediates/
  Test.build/Debug-iphonesimulator/Test.build/Test-project-headers.hmap -I/Users/sunnyxx/Library/Developer/Xcode/
  DerivedData/Test-fkriiujcskbyzpgszmeakgvzotfe/Build/Products/Debug-iphonesimulator/include -I/Users/sunnyxx/Library/
  Developer/Xcode/DerivedData/Test-fkriiujcskbyzpgszmeakgvzotfe/Build/Intermediates/Test.build/Debug-iphonesimulator/
  Test.build/DerivedSources/x86_64 -I/Users/sunnyxx/Library/Developer/Xcode/DerivedData/Test-fkriiujcskbyzpgszmeakgvzotfe/
  Build/Intermediates/Test.build/Debug-iphonesimulator/Test.build/DerivedSources -F/Users/sunnyxx/Library/Developer/Xcode/
  DerivedData/Test-fkriiujcskbyzpgszmeakgvzotfe/Build/Products/Debug-iphonesimulator -MMD -MT dependencies -MF /Users/
  sunnyxx/Library/Developer/Xcode/DerivedData/Test-fkriiujcskbyzpgszmeakgvzotfe/Build/Intermediates/Test.build/Debug-
  iphonesimulator/Test.build/Objects-normal/x86_64/main.d --serialize-diagnostics /Users/sunnyxx/Library/Developer/Xcode/
  DerivedData/Test-fkriiujcskbyzpgszmeakgvzotfe/Build/Intermediates/Test.build/Debug-iphonesimulator/Test.build/Objects-
  normal/x86_64/main.dia -c /Users/sunnyxx/test/Test/Test/main.m -o /Users/sunnyxx/Library/Developer/Xcode/DerivedData/
  Test-fkriiujcskbyzpgszmeakgvzotfe/Build/Intermediates/Test.build/Debug-iphonesimulator/Test.build/Objects-normal/x86_64/
  main.o
```

当我们按下 Run 之后...

```
/Applications/Xcode.app/Contents/Developer/
 Toolchains/XcodeDefault.xctoolchain/usr/bin/
 clang -x objective-c -fobjc-arc ...... main.m
 -o main.o
```

Clang 命令

- Clang 在概念上是编译器前端，同时，在命令行中也作为一个“黑盒”的 Driver
- 封装了编译管线、前端命令、LLVM 命令、Toolchain 命令等，一个 Clang 走天下
- 方便从 gcc 迁移过来

拆解编译过程

main.m

```
#import <Foundation/Foundation.h>

int main() {
    @autoreleasepool {
        id obj = [NSObject new];
        NSLog(@"Hello world: %@", obj);
    }
    return 0;
}
```

1. Preprocess - 预处理

- import 头文件
- macro 展开
- 处理 ‘#’ 打头的预处理指令，如 #if

1. Preprocess - 预处理

```
$clang -E main.m
```

```
...
...
...
# 181 "/Applications/Xcode.app/Contents/Developer/Platforms/MacOSX.platform/Developer/
SDKs/MacOSX10.12.sdk/System/Library/Frameworks/Foundation.framework/Headers/
Foundation.h" 2 3
# 1 "/Applications/Xcode.app/Contents/Developer/Platforms/MacOSX.platform/Developer/
SDKs/MacOSX10.12.sdk/System/Library/Frameworks/Foundation.framework/Headers/
FoundationLegacySwiftCompatibility.h" 1 3
# 185 "/Applications/Xcode.app/Contents/Developer/Platforms/MacOSX.platform/Developer/
SDKs/MacOSX10.12.sdk/System/Library/Frameworks/Foundation.framework/Headers/
Foundation.h" 2 3
# 6 "main.m" 2

int main() {
    @autoreleasepool {
        id obj = [NSObject new];
        NSLog(@"Hello world: %@", obj);
    }
    return 0;
}
```

1. Preprocess - 预处理

```
$clang -E -fmodules main.m
```

```
@import Foundation;
int main() {
    @autoreleasepool {
        id obj = [NSObject new];
        NSLog(@"Hello world: %@", obj);
    }
    return 0;
}
```

2. Lexical Analysis - 词法分析

- 词法分析，也作 Lex 或者 Tokenization
- 将预处理过的代码文本转化成 Token 流
- 不校验语义

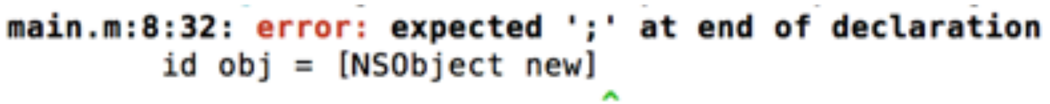
2. Lexical Analysis - 词法分析

```
$clang -fmodules -fsyntax-only -Xclang -dump-tokens main.m
```

```
int 'int'  [StartOfLine]  Loc=<main.m:7:1>
identifier 'main'   [LeadingSpace] Loc=<main.m:7:5>
l_paren '('     Loc=<main.m:7:9>
r_paren ')'     Loc=<main.m:7:10>
l_brace '{'   [LeadingSpace] Loc=<main.m:7:12>
at '@'  [StartOfLine]  [LeadingSpace]  Loc=<main.m:8:5>
identifier 'autoreleasepool'      Loc=<main.m:8:6>
l_brace '{'   [LeadingSpace] Loc=<main.m:8:22>
identifier 'id'  [StartOfLine]  [LeadingSpace]    Loc=<main.m:9:9>
identifier 'obj'    [LeadingSpace] Loc=<main.m:9:12>
equal '='  [LeadingSpace] Loc=<main.m:9:16>
l_square '['  [LeadingSpace] Loc=<main.m:9:18>
identifier 'NSObject'    Loc=<main.m:9:19>
identifier 'new'    [LeadingSpace] Loc=<main.m:9:28>
r_square ']'    Loc=<main.m:9:31>
semi ';'    Loc=<main.m:9:32>
...
```

3. Semantic Analysis - 语法分析

- 语法分析，在 Clang 中由 Parser 和 Sema 两个模块配合完成
- 验证语法是否正确
- **根据当前语言的语法，生成语意节点，并将所有节点组合成抽象语法树（AST）**



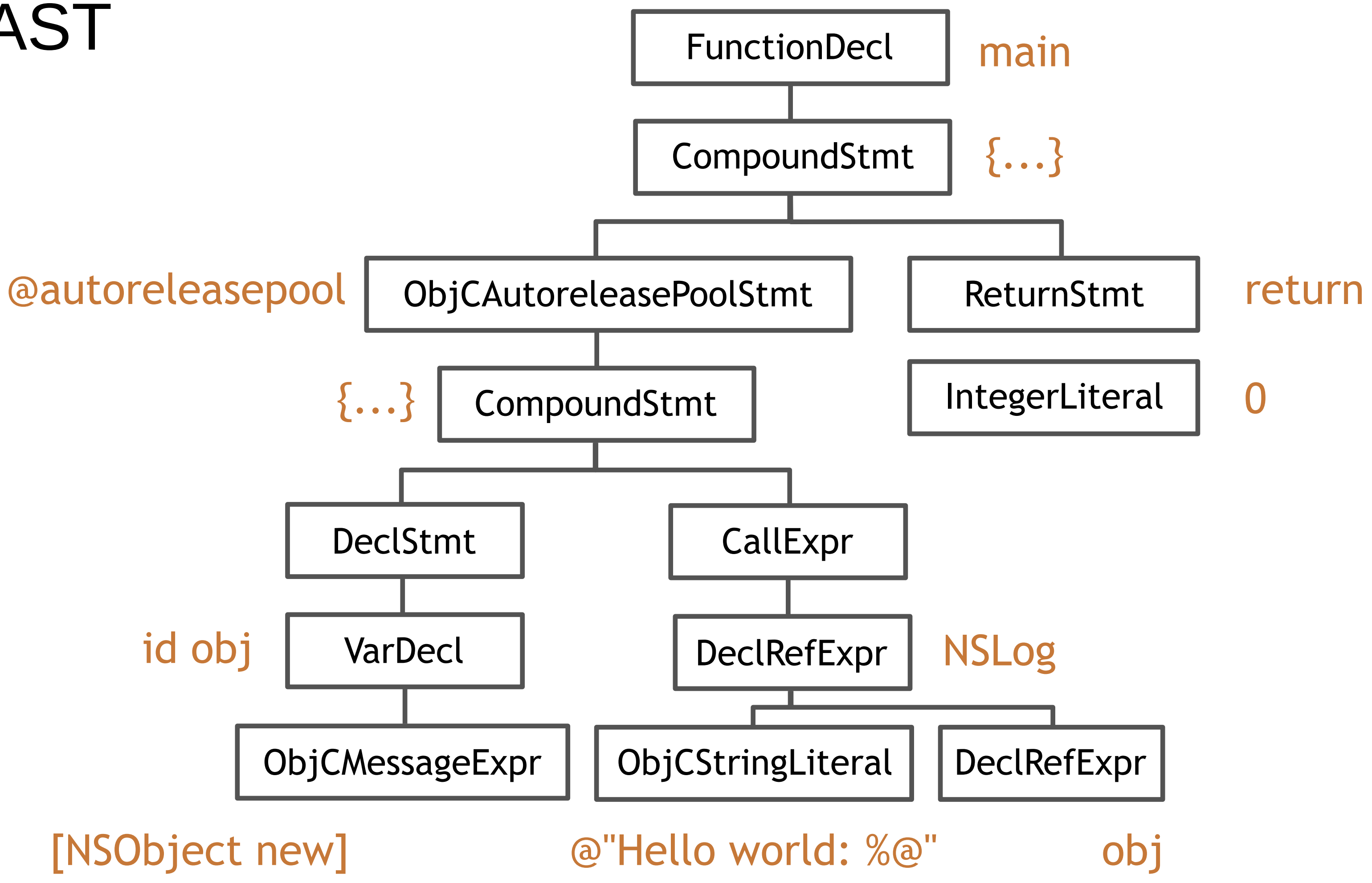
```
main.m:8:32: error: expected ';' at end of declaration
        id obj = [NSObject new]
                               ^
```

3. Semantic Analysis - 语法分析

```
$clang -fmodules -fsyntax-only -Xclang -ast-dump main.m
```

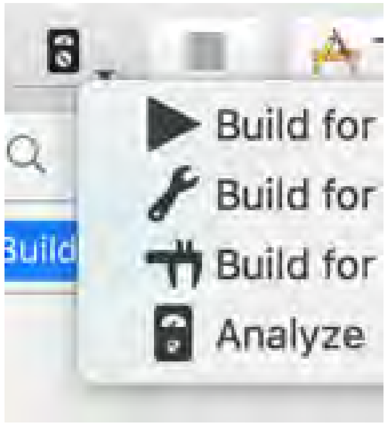
```
|-FunctionDecl 0x7fe881035b38 <line:6:1, line:12:1> line:6:5 main 'int ()'
| `-CompoundStmt 0x7fe88133ac28 <col:12, line:12:1>
|   |-ObjCAutoreleasePoolStmt 0x7fe88133abe0 <line:7:5, line:10:5>
|   | `-CompoundStmt 0x7fe88133abb8 <line:7:22, line:10:5>
|   |   |-DeclStmt 0x7fe88133a9e0 <line:8:9, col:32>
|   |   | `-VarDecl 0x7fe88132b728 <col:9, col:31> col:12 used obj 'id':'id' cinit
|   |   |   `-ImplicitCastExpr 0x7fe881327778 <col:18, col:31> 'id':'id' <BitCast>
|   |   |     `-ObjCMessageExpr 0x7fe881327748 <col:18, col:31> 'NSObject *'
selector=new class='NSObject'
|   |   `-CallExpr 0x7fe88133ab50 <line:9:9, col:38> 'void'
|   |     |-ImplicitCastExpr 0x7fe88133ab38 <col:9> 'void (*)(id, ...)'
<FunctionToPointerDecay>
|   |     | `-DeclRefExpr 0x7fe88133a9f8 <col:9> 'void (id, ...)' Function
0x7fe881327798 'NSLog' 'void (id, ...)'
|   |     |-ImplicitCastExpr 0x7fe88133ab88 <col:15, col:16> 'id':'id' <BitCast>
|   |     | `-ObjCStringLiteral 0x7fe88133aa90 <col:15, col:16> 'NSString *'
|   |     |   `-StringLiteral 0x7fe88133aa58 <col:16> 'char [16]' lvalue "Hello world:
%@"
|   |     `-ImplicitCastExpr 0x7fe88133aba0 <col:35> 'id':'id' <LValueToRValue>
|   |       `-DeclRefExpr 0x7fe88133aab0 <col:35> 'id':'id' lvalue Var 0x7fe88132b728
'obj' 'id':'id'
|   `-ReturnStmt 0x7fe88133ac10 <line:11:5, col:12>
|     `-IntegerLiteral 0x7fe88133abf0 <col:12> 'int' 0
```

AST


FunctionDecl
main
CompoundStmt
{...}
@autoreleasepool
ObjCAutoreleasePoolStmt
ReturnStmt
return
{...}
CompoundStmt
IntegerLiteral
0
DeclStmt
CallExpr
id obj
VarDecl
DeclRefExpr
NSLog
ObjCMessageExpr
ObjCStringLiteral
DeclRefExpr
[NSObject new]
@"Hello world: %@"
obj

Static Analysis - 静态分析

- 通过语法树进行代码静态分析，找出**非语法性错误**
- 模拟代码执行路径，分析出 control-flow graph (CFG)
- 预置了常用 Checker



4. CodeGen - IR 代码生成

- CodeGen 负责将语法树从顶至下遍历，翻译成 LLVM IR
- LLVM IR 是 Frontend 的输出，也是 LLVM Backend 的输入，前后端的桥接语言
- **与 Objective-C Runtime 桥接**

4. CodeGen - IR 代码生成 与 Objective-C Runtime 桥接

- Class / Meta Class / Protocol / Category 内存结构生成，并存放在指定 section 中 (如 Class：_DATA, _objc_classrefs)
- Method / Ivar / Property 内存结构生成
- 组成 method_list / ivar_list / property_list 并填入 Class

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4. CodeGen - IR 代码生成 与 Objective-C Runtime 桥接

- Non-Fragile ABI：为每个 Ivar 合成 OBJC_IVAR_$_ 偏移值常量
- 存取 Ivar 的语句 (_ivar = 123; int a = _ivar;) 转写成 base + OBJC_IVAR_$_ 的形式

4. CodeGen - IR 代码生成 与 Objective-C Runtime 桥接

- 将语法树中的 ObjCMessageExpr 翻译成相应版本的 objc_msgSend，对 super 关键字的调用翻译成 objc_msgSendSuper

4. CodeGen - IR 代码生成 与 Objective-C Runtime 桥接

- 根据修饰符 strong / weak / copy / atomic 合成 @property 自动实现的 setter / getter
- 处理 @synthesize

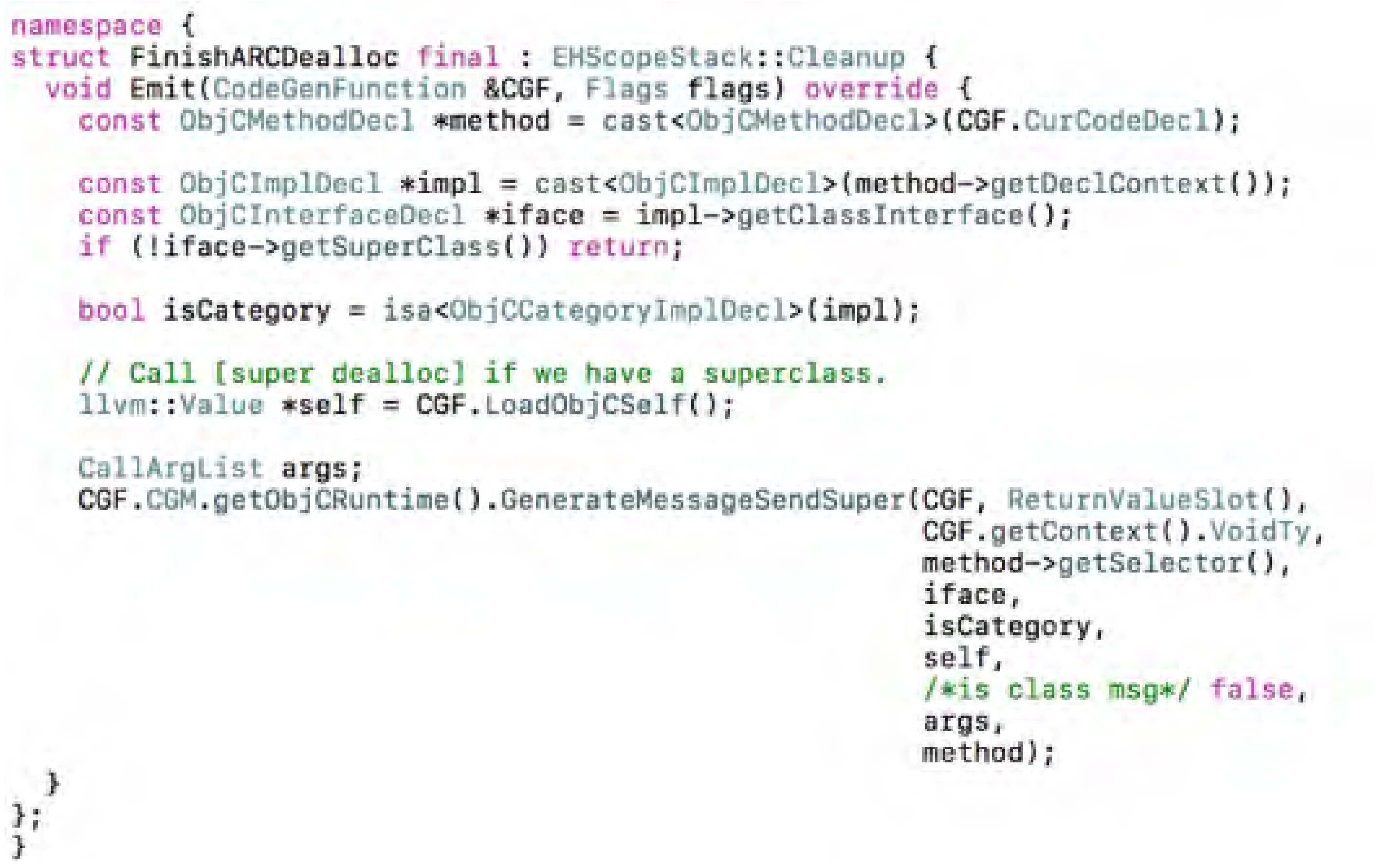
4. CodeGen - IR 代码生成 与 Objective-C Runtime 桥接

- 生成 block_layout 的数据结构
- 变量的 capture (__block / __weak)
- 生成 _block_invoke 函数

4. CodeGen - IR 代码生成 与 Objective-C Runtime 桥接

- ARC：分析对象引用关系，将 objc_storeStrong/ objc_storeWeak 等 ARC 代码插入
- 将 ObjCAutoreleasePoolStmt 转译成 objc_autoreleasePoolPush/Pop
- 实现自动调用 [super dealloc]
- 为每个拥有 ivar 的 Class 合成 .cxx_destructor 方法来自动释放类的成员变量，代替 MRC 时代的 "self.xxx = nil"

4. CodeGen - IR 代码生成 与 Objective-C Runtime 桥接



```
namespace {
struct FinishARCDealloc final : EHScopeStack::Cleanup {
  void Emit(CodeGenFunction &CGF, Flags flags) override {
    const ObjCMethodDecl *method = cast<ObjCMethodDecl>(CGF.CurCodeDecl);

    const ObjCImplDecl *impl = cast<ObjCImplDecl>(method->getDeclContext());
    const ObjCInterfaceDecl *iface = impl->getClassInterface();
    if (!iface->getSuperClass()) return;

    bool isCategory = isa<ObjCCategoryImplDecl>(impl);

    // Call [super dealloc] if we have a superclass.
    llvm::Value *self = CGF.LoadObjCSelf();

    CallArgList args;
    CGF.CGM.getObjCRuntime().GenerateMessageSendSuper(CGF, ReturnValueSlot(),
                                                      CGF.getContext().VoidTy,
                                                      method->getSelector(),
                                                      iface,
                                                      isCategory,
                                                      self,
                                                      /*is class msg*/ false,
                                                      args,
                                                      method);
  }
};
}
```

合成 [super dealloc]

CodeGen - IR 代码生成

```
$clang -S -fobjc-arc -emit-llvm main.m -o main.ll
```

```
define i32 @main() #0 {
  %1 = alloca i32, align 4
  %2 = alloca i8*, align 8
  store i32 0, i32* %1, align 4
  %3 = call i8* @objc_autoreleasePoolPush() #3
  %4 = load %struct._class_t*, %struct._class_t**
@"OBJC_CLASSLIST_REFERENCES_$_", align 8
  %5 = load i8*, i8** @OBJC_SELECTOR_REFERENCES_, align 8, !invariant.load !7
  %6 = bitcast %struct._class_t* %4 to i8*
  %7 = call i8* bitcast (i8* (i8*, i8*, ...)* @objc_msgSend to i8* (i8*,
i8*)*)(i8* %6, i8* %5)
  %8 = bitcast i8* %7 to %0*
  %9 = bitcast %0* %8 to i8*
  store i8* %9, i8** %2, align 8
  %10 = load i8*, i8** %2, align 8
  notail call void (i8*, ...) @NSLog(i8* bitcast
(%struct.__NSConstantString_tag* @_unnamed_cfstring_ to i8*), i8* %10)
  call void @objc_storeStrong(i8** %2, i8* null) #3
  call void @objc_autoreleasePoolPop(i8* %3)
  ret i32 0
}
```

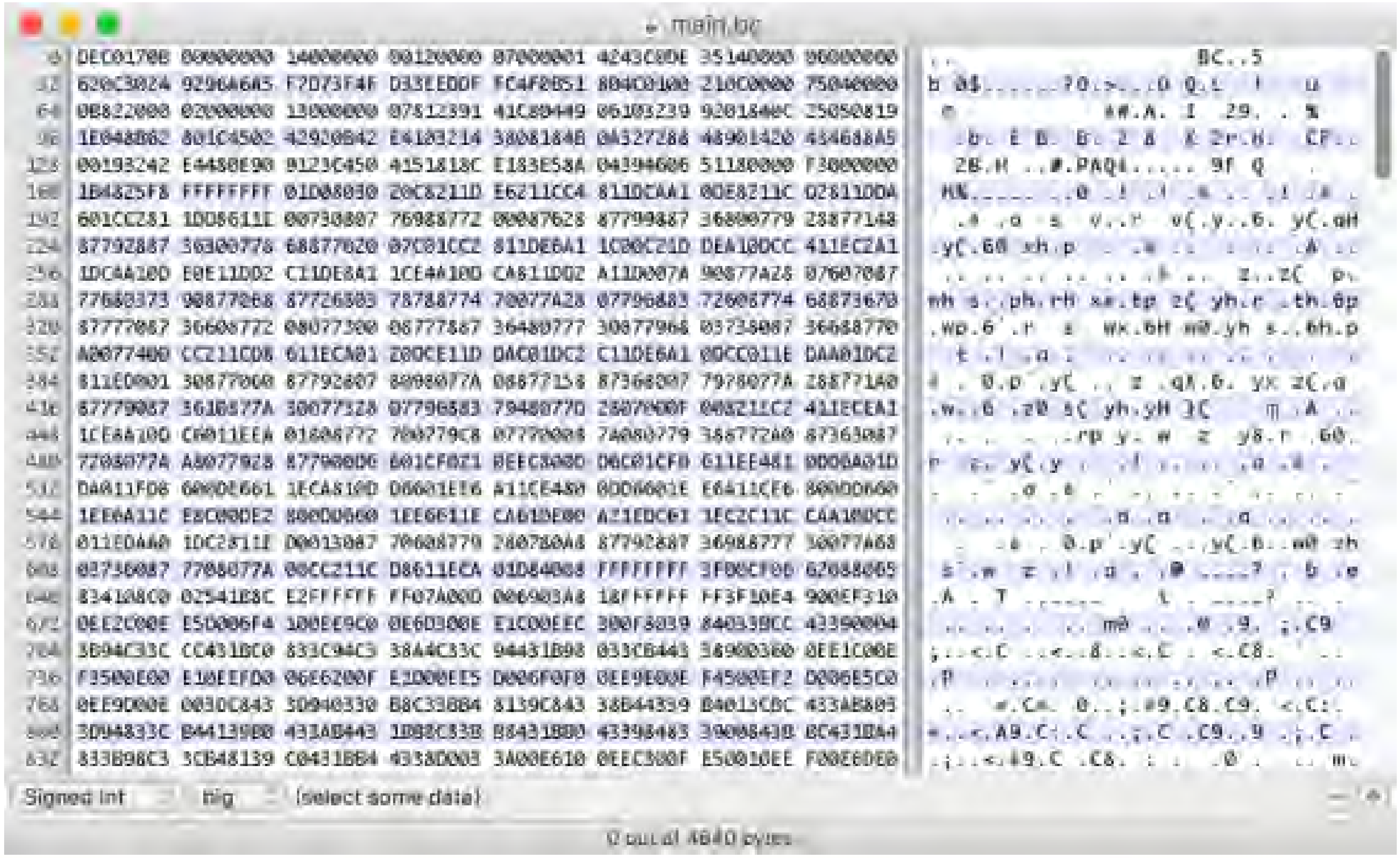
Optimize - 优化 IR

```
$clang -O3 -S -fobjc-arc -emit-llvm main.m -o main.ll
```

```
define i32 @main() #0 {
  %1 = tail call i8* @objc_autoreleasePoolPush() #3
  %2 = load i8*, i8** bitcast (%struct._class_t**
@"OBJC_CLASSLIST_REFERENCES_$_" to i8**), align 8
  %3 = load i8*, i8** @OBJC_SELECTOR_REFERENCES_, align 8, !invariant.load
!7
  %4 = tail call i8* bitcast (i8* (i8*, i8*, ...)* @objc_msgSend to i8*
(i8*, i8*)*)(i8* %2, i8* %3), !clang.arc.no_objc_arc_exceptions !7
  %5 = bitcast i8* %4 to %0*
  %6 = bitcast %0* %5 to i8*
  notail call void (i8*, ...) @NSLog(i8* bitcast
(%struct.__NSConstantString_tag* @_unnamed_cfstring_ to i8*), i8* %4), !
clang.arc.no_objc_arc_exceptions !7
  tail call void @objc_release(i8* %6) #3, !clang.imprecise_release !7
  tail call void @objc_autoreleasePoolPop(i8* %1) #3, !
clang.arc.no_objc_arc_exceptions !7
  ret i32 0
}
```

LLVM Bitcode - 生成字节码

```
$clang -emit-llvm -c main.m -o main.bc
```



main.bc

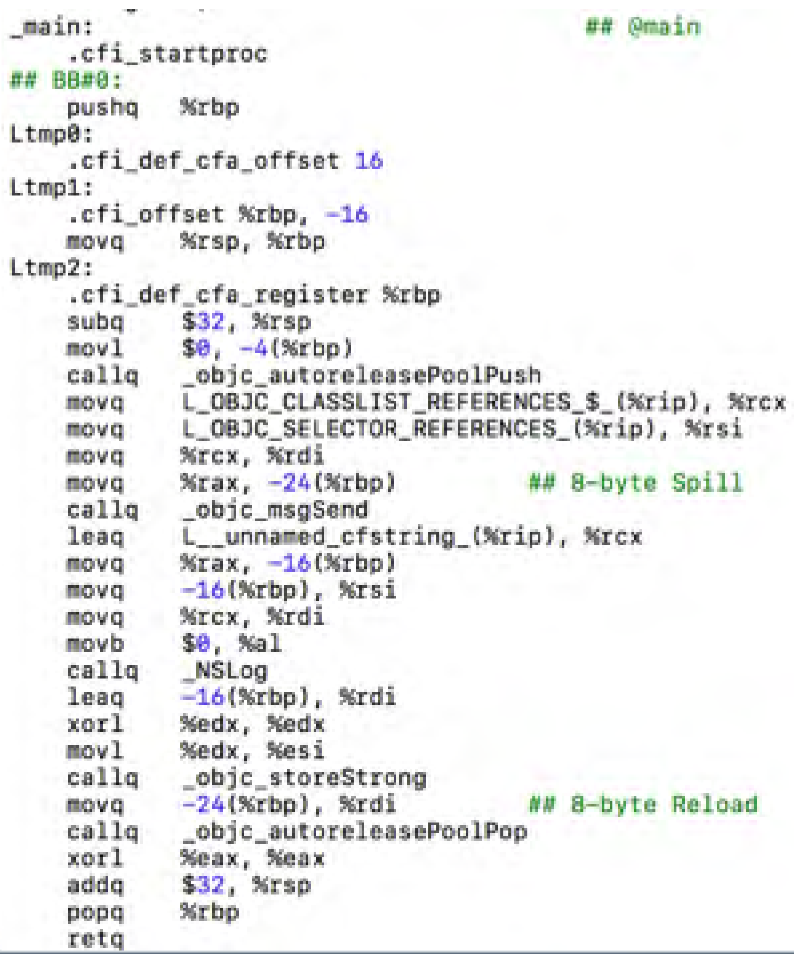
```
  0 DEC01700 00000000 14000000 00120000 07000001 4243C0DE 35140000 05000000
 32 620C3024 9296A6A5 F7D73F4F D33EEDDF FC4F2051 804C0100 210C0000 75040000
 64 0B822000 02000000 13000000 07812391 41C80449 06103239 9201840C 25050819
 96 1E048B82 801C4502 42920B42 E4103214 38081848 0A327288 48901420 43468AA5
128 00193242 E4480E90 91230450 4151818C E183E58A 04394606 51180000 F3000000
160 1B4825F8 FFFFFFFF 01D08030 20C8211D E6211CC4 8110CAA1 0DE8211C 0281100A
192 601CC281 1D08611E 00730807 76988772 00087628 87799887 36800779 28877148
224 87792887 36300778 68877020 07C01CC2 811DE6A1 1C00C21D DEA10DCC 411EC2A1
256 1DCAA10D E0E11D02 C11DE8A1 1CE4A10D CA611D02 A11D007A 90877A28 07607087
288 77680373 90877068 87726803 78788774 70077A28 07796883 72008774 68873670
320 87777087 36600772 00077300 08777487 36480777 30077968 03730087 36488770
352 A0077400 CC211C08 611ECA01 20DCE11D DAC01DC2 C11DE6A1 0DCC011E DAA01DC2
384 811ED001 30877000 87792807 0000077A 08877158 87360087 7978077A 288771A0
416 87779087 3610877A 30077328 07796883 79480770 2807000F 00821EC2 411EECA1
448 1CEAA10D C0011EEA 01A06772 700779C8 07770008 7A000779 38877280 87363087
480 7708077A A0077928 877000D0 601CF021 0EFC0000 D0C01CF0 611EE481 0D00A01D
512 DA011F08 000DE661 1ECA810D D0601E16 A11CE400 0DD0001E E6A11CE6 000DD000
544 1EE0A11C E8C000E2 000D0000 1EE6011E CA610E00 A21EDC01 1EC2C11C CAA100CC
576 011EDAA0 1DC2811E D0013087 70008779 280780A8 87792887 36988777 30077A03
608 03730087 7708077A 00CC211C D8611ECA 01D84008 FFFFFFFF 3F00CF06 62088005
640 834100C0 0254103C E2FFFFFF FF07A00D 006903A8 10FFFFFF FF3F10E4 900EF310
672 0EE2C00E E5D006F4 100EE9C0 0E6D300E E1C00EEC 300F8039 840330CC 43390004
704 3094C33C CC4310C0 833C94C3 3844C33C 94431098 033C8443 38900380 0EE1C00E
736 F3500E00 E10EEFD0 06E6200F E2D00EE5 D006F0F0 0EE9E00E F4500EF2 D006E5C0
768 0EE9D00E 0030C843 30940330 B8C338B4 8139C843 38B44339 B4013CBC 433AE805
800 30A4833C B4413900 431A0443 1082C338 884310B0 43398483 39008430 0C4310A4
832 833B98C3 3CB48139 C0431084 4338D003 3A00E610 0EEC300F E50010EE F00E60E0
```

Signed Int | big | (select some data)

0 out of 4640 bytes

Assemble - 生成 Target 相关汇编

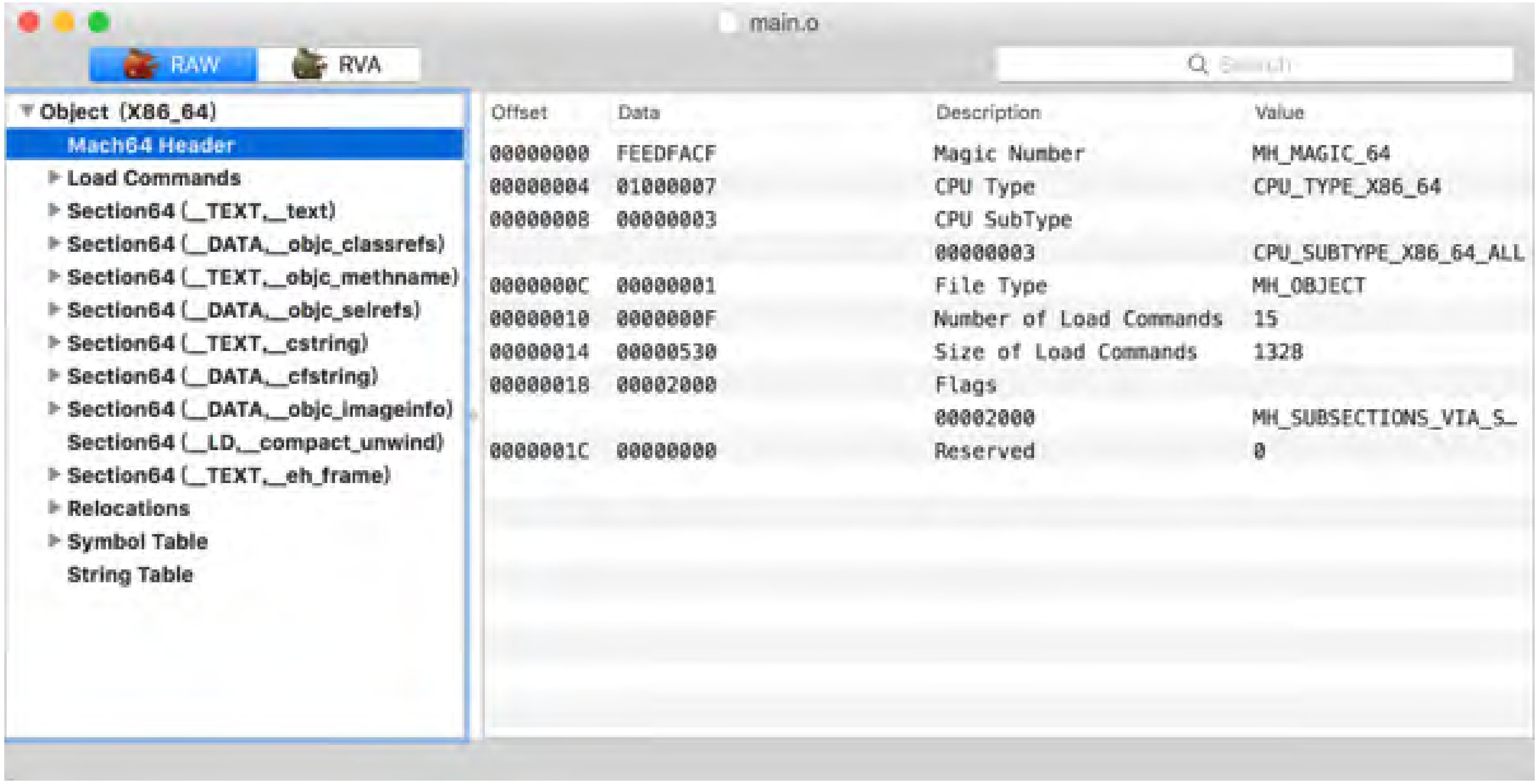
$clang -S -fobjc-arc main.m -o **main.s**



```
_main:                                  ## @main
        .cfi_startproc
## BB#0:
        pushq   %rbp
Ltmp0:
        .cfi_def_cfa_offset 16
Ltmp1:
        .cfi_offset %rbp, -16
        movq    %rsp, %rbp
Ltmp2:
        .cfi_def_cfa_register %rbp
        subq    $32, %rsp
        movl    $0, -4(%rbp)
        callq   _objc_autoreleasePoolPush
        movq    L_OBJC_CLASSLIST_REFERENCES_$_(%rip), %rcx
        movq    L_OBJC_SELECTOR_REFERENCES_(%rip), %rsi
        movq    %rcx, %rdi
        movq    %rax, -24(%rbp)         ## 8-byte Spill
        callq   _objc_msgSend
        leaq    L__unnamed_cfstring_(%rip), %rcx
        movq    %rax, -16(%rbp)
        movq    -16(%rbp), %rsi
        movq    %rcx, %rdi
        movb    $0, %al
        callq   _NSLog
        leaq    -16(%rbp), %rdi
        xorl    %edx, %edx
        movl    %edx, %esi
        callq   _objc_storeStrong
        movq    -24(%rbp), %rdi         ## 8-byte Reload
        callq   _objc_autoreleasePoolPop
        xorl    %eax, %eax
        addq    $32, %rsp
        popq    %rbp
        retq
```

Assemble - 生成 Target 相关 Object (Mach-O)

```
$clang -fmodules -c main.m -o main.o
```


main.o
RAW
RVA
Search
Object (X86_64)
Mach64 Header
Load Commands
Section64 (__TEXT,__text)
Section64 (__DATA,__objc_classrefs)
Section64 (__TEXT,__objc_methname)
Section64 (__DATA,__objc_selrefs)
Section64 (__TEXT,__cstring)
Section64 (__DATA,__cfstring)
Section64 (__DATA,__objc_imageinfo)
Section64 (__LD,__compact_unwind)
Section64 (__TEXT,__eh_frame)
Relocations
Symbol Table
String Table

```
Offset    Data      Description                 Value
00000000  FEEDFACF  Magic Number                MH_MAGIC_64
00000004  01000007  CPU Type                    CPU_TYPE_X86_64
00000008  00000003  CPU SubType
                    00000003                    CPU_SUBTYPE_X86_64_ALL
0000000C  00000001  File Type                   MH_OBJECT
00000010  0000000F  Number of Load Commands     15
00000014  00000530  Size of Load Commands       1328
00000018  00002000  Flags
                    00002000                    MH_SUBSECTIONS_VIA_S…
0000001C  00000000  Reserved                    0
```

MDCC2016

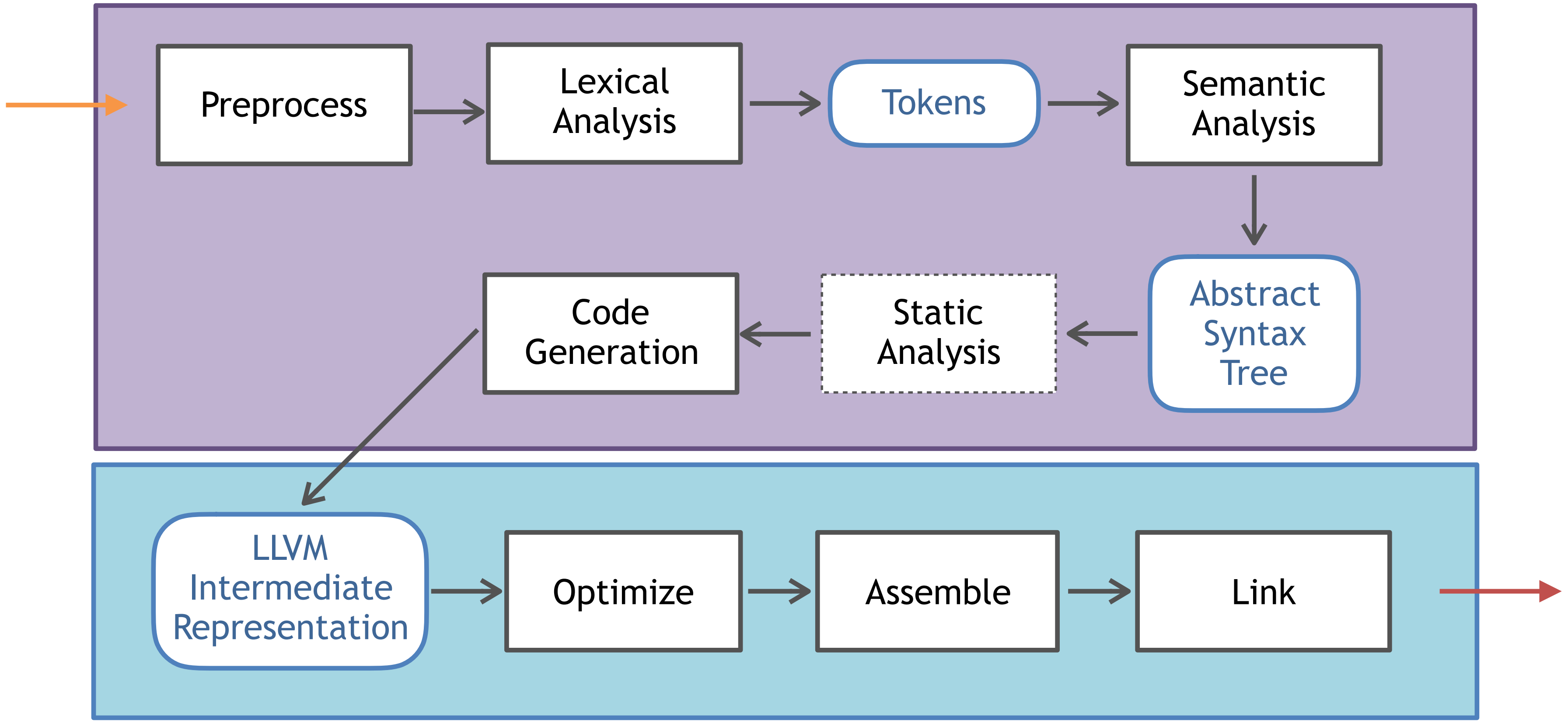
Link 生成 Executable

```
$clang main.m -o main
```

```
$./main
```

```
main[13595:2214602] Hello world: <NSObject: 0x7f9b01506700>
```

总结：Clang-LLVM 下，一个源文件的编译过程



Topics

- ✅ Apple 编译器 Clang-LLVM 架构初识
- ✅ 你的源码是如何一步步成为可执行文件的?
- ➡️ 我们能用 Clang 做什么有意思的事情?

我们能在 Clang 上做什么?

- LibClang
- LibTooling
- ClangPlugin

LibClang

- 😊 C API 来访问 Clang 的上层能力，如获取 Tokens、遍历语法树、代码补全、获取诊断信息
- 😊 API 稳定，不受 Clang 源码更新影响
- 😡 只有上层的语法树访问，不能获取到全部信息

LibClang - 如何使用

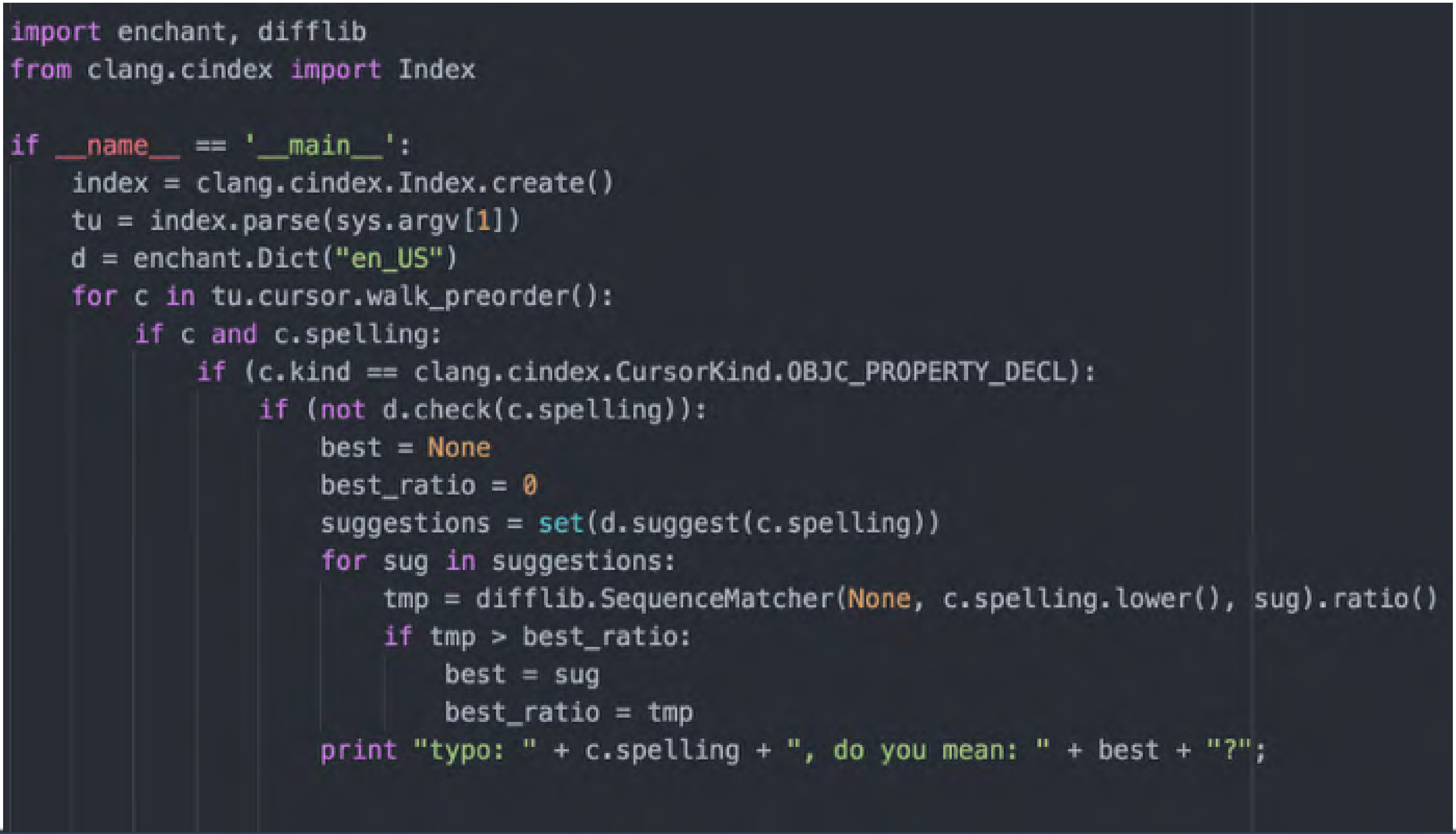
- 使用原始 C API
- 脚本语言：使用官方提供的 python binding 或开源的 node-js / ruby binding
- Objective-C：开源库 ClangKit

LibClang - Demo

```
@interface Sark : NSObject

@property (nonatomic, strong) id passWord;
@property (nonatomic, strong) id nickName;
@property (nonatomic, strong) id netWorking;
@property (nonatomic, strong) id suuny;
@property (nonatomic, strong) id backgrond;

@end
```

用 LibClang 的 Python Binding 实现一个 Property Name Linter

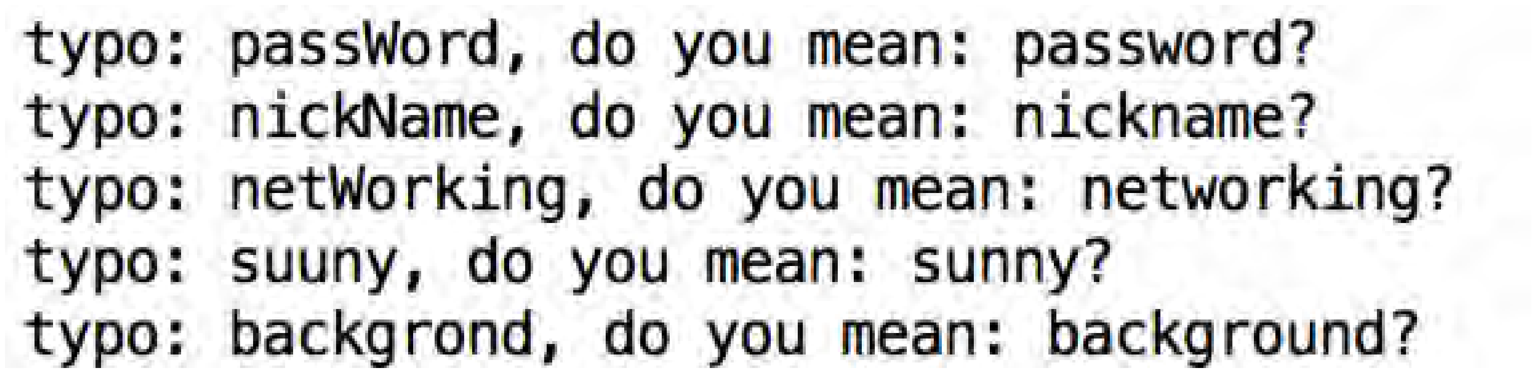
LibClang - Demo



```python
import enchant, difflib
from clang.cindex import Index

if __name__ == '__main__':
    index = clang.cindex.Index.create()
    tu = index.parse(sys.argv[1])
    d = enchant.Dict("en_US")
    for c in tu.cursor.walk_preorder():
        if c and c.spelling:
            if (c.kind == clang.cindex.CursorKind.OBJC_PROPERTY_DECL):
                if (not d.check(c.spelling)):
                    best = None
                    best_ratio = 0
                    suggestions = set(d.suggest(c.spelling))
                    for sug in suggestions:
                        tmp = difflib.SequenceMatcher(None, c.spelling.lower(), sug).ratio()
                        if tmp > best_ratio:
                            best = sug
                            best_ratio = tmp
                    print "typo: " + c.spelling + ", do you mean: " + best + "?";
```

LibClang - Demo

```
$python property-linter.py main.m
```



```
typo: passWord, do you mean: password?
typo: nickName, do you mean: nickname?
typo: netWorking, do you mean: networking?
typo: suuny, do you mean: sunny?
typo: backgrond, do you mean: background?
```

LibTooling

- 😊 对语法树有完全的控制权
- 😊 **可作为一个 standalone 命令单独的使用，如 clang-format**
- 😡 需要使用 C++ 且对 Clang 源码熟悉

LibTooling - Demo

```
@interface Sark : NSObject
@property (nonatomic, copy) NSString *name;
- (void)becomeGay;
@end
```

实现一个简易 Objective-C -> Swift 源码转换器

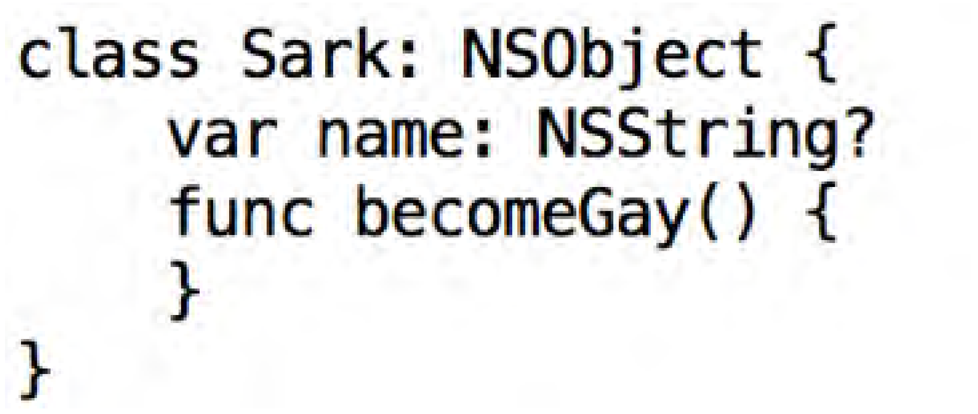
LibTooling - Demo

```
|-ObjCInterfaceDecl 0x7ff94185dca0 <line:7:1, line:10:2> line:7:12 Sark
| |-super ObjCInterface 0x7ff9411a4608 'NSObject'
| |-ObjCPropertyDecl 0x7ff9411a24e0 <line:8:1, col:39> col:39 name 'NSString
*' readwrite copy nonatomic
| |-ObjCMethodDecl 0x7ff9411a2600 <line:9:1, col:18> col:1 - becomeGay
'void'
| |-ObjCMethodDecl 0x7ff9411a2688 <line:8:39> col:39 implicit - name
'NSString *'
| `-ObjCMethodDecl 0x7ff9411a2710 <col:39> col:39 implicit - setName: 'void'
|   `-ParmVarDecl 0x7ff9411a2798 <col:39> col:39 name 'NSString *'
```

创建 RecursiveASTVisitor，在 AST 中重写感兴趣节点的 Visit 方法

LibTooling - Demo

```
$objc2swift test.m -- -fsyntax-only -fmodules
```

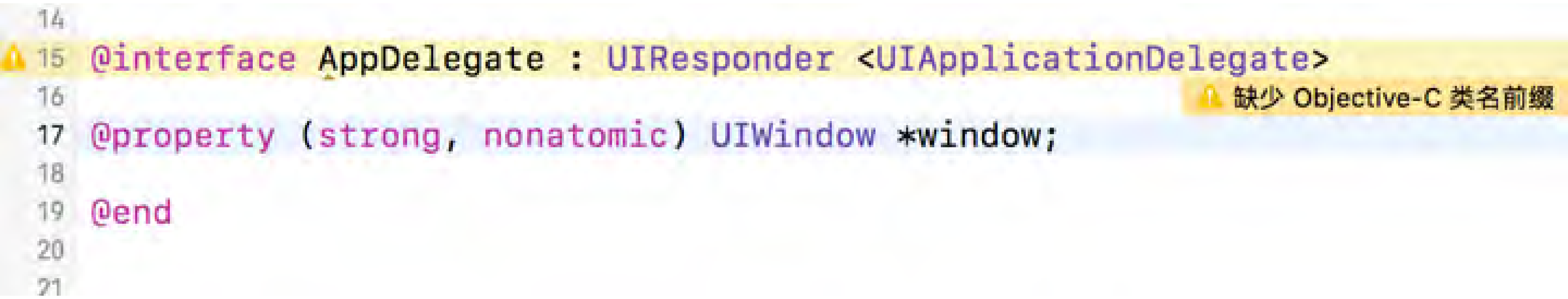


```
class Sark: NSObject {
    var name: NSString?
    func becomeGay() {
    }
}
```

ClangPlugin

- 😊 对语法树有完全的控制权
- 😊 **作为插件注入到编译流程中，可以影响 build 和决定编译过程**
- 😡 需要使用 C++ 且对 Clang 源码熟悉

ClangPlugin - Demo



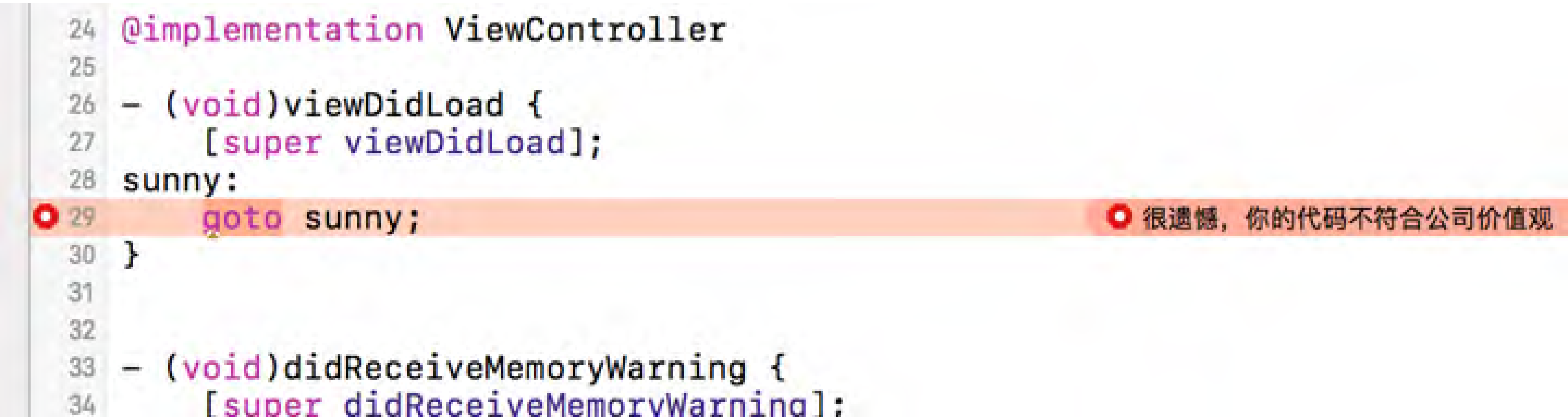
```
@interface AppDelegate : UIResponder <UIApplicationDelegate>
                                                  缺少 Objective-C 类名前缀

@property (strong, nonatomic) UIWindow *window;

@end

```

可以嵌入 Xcode 的 Linter，提供可识别的诊断信息

ClangPlugin - Demo

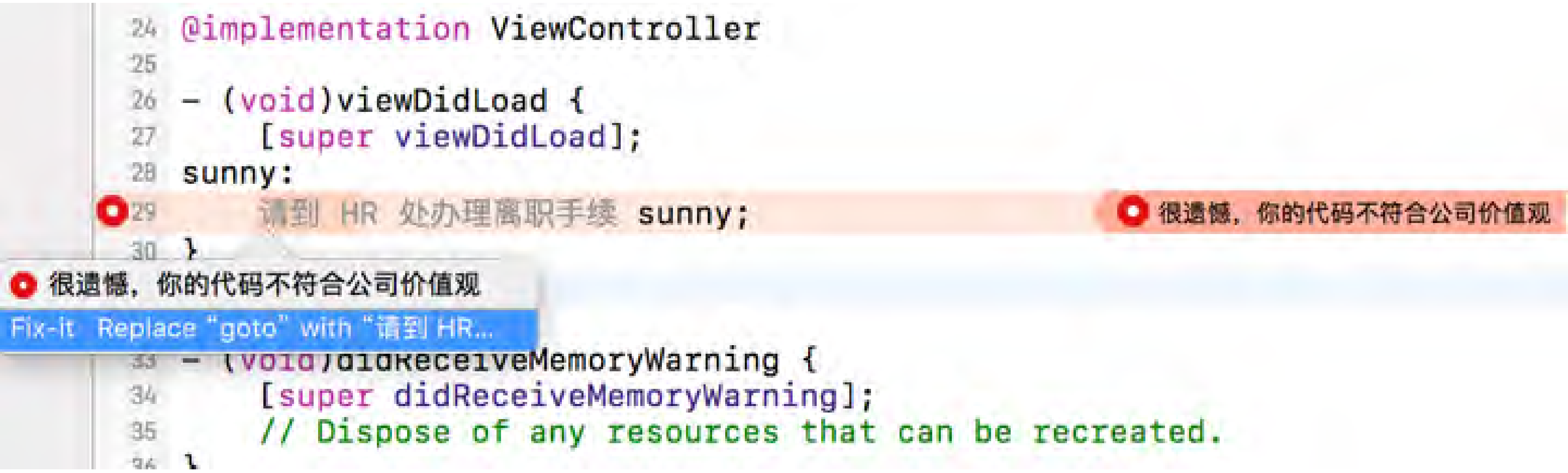
```
bool VisitObjCInterfaceDecl(clang::ObjCInterfaceDecl *D) {
    const clang::SourceManager &SM = Context->getSourceManager();
    clang::FullSourceLoc loc = Context->getFullLoc(D->getLocStart());
    if (!SM.isInSystemHeader(loc)) {
        std::string name = D->getName();
        clang::DiagnosticsEngine &DE = *Diagnostics;
        if (std::islower(name[0]) || std::islower(name[1])) {
            unsigned int id = 
DE.getCustomDiagID(clang::DiagnosticsEngine::Warning, "缺少 Objective-C 
类名前缀");
            DE.Report(loc.getLocWithOffset(11), id);
        }
    }
    return true;
}
```

ClangPlugin - Demo

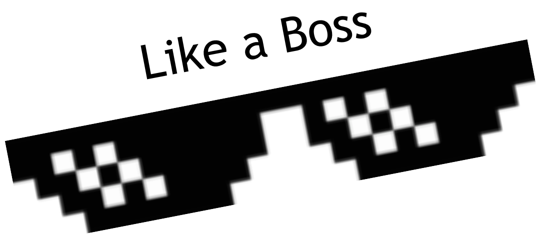


```
@implementation ViewController

- (void)viewDidLoad {
    [super viewDidLoad];
sunny:
    goto sunny;                                很遗憾，你的代码不符合公司价值观
}


- (void)didReceiveMemoryWarning {
    [super didReceiveMemoryWarning];
```

ClangPlugin - Demo



```
@implementation ViewController

- (void)viewDidLoad {
    [super viewDidLoad];
sunny:
    请到 HR 处办理离职手续 sunny;        很遗憾，你的代码不符合公司价值观
}
很遗憾，你的代码不符合公司价值观
Fix-it  Replace “goto” with “请到 HR...
- (void)didReceiveMemoryWarning {
    [super didReceiveMemoryWarning];
    // Dispose of any resources that can be recreated.
}
```



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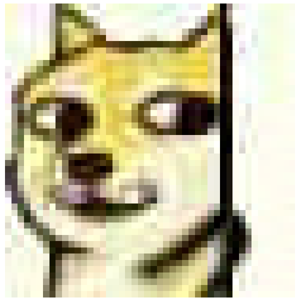
- ✅ 你的源码是如何一步步成为可执行文件的?
- ✅ 我们能用 Clang 做什么有意思的事情?

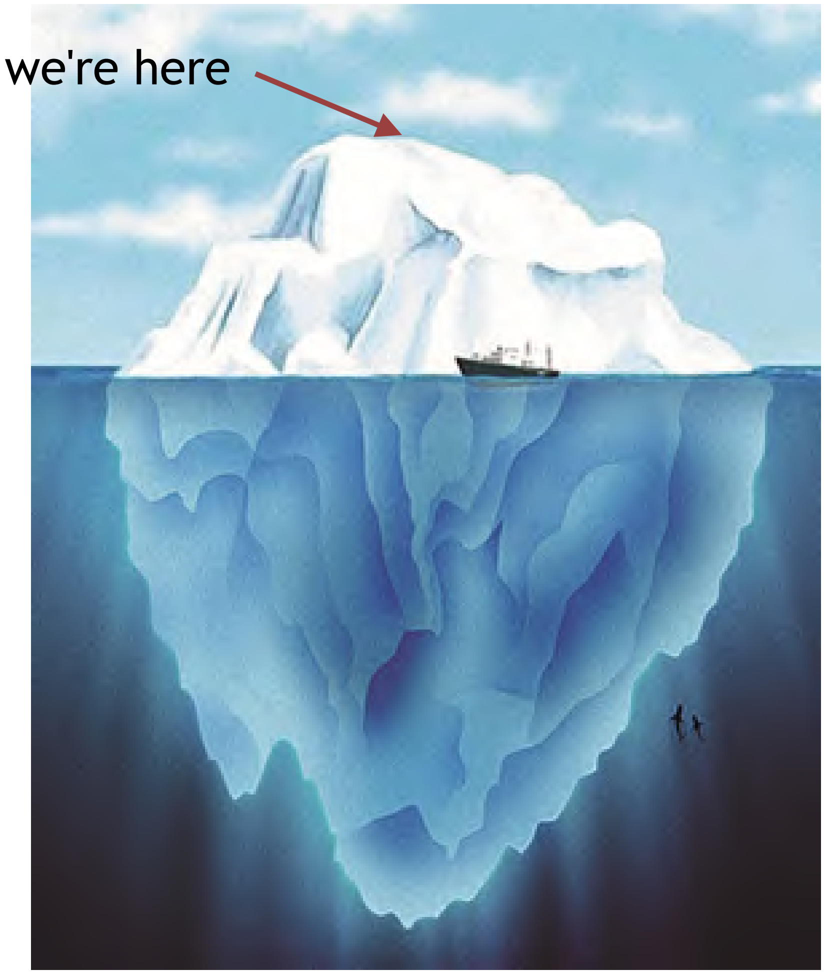
Clang-LLVM 相关资料

- http://clang.llvm.org/docs/index.html
- http://blog.llvm.org/
- https://www.objc.io/issues/6-build-tools/compiler/
- http://llvm.org/docs/tutorial/index.html
- https://github.com/loarabia/Clang-tutorial
- http://lowlevelbits.org/getting-started-with-llvm/clang-on-os-x/
- https://kevinaboos.wordpress.com/2013/07/23/clang-tutorial-part-i-introduction/
- http://szelei.me/code-generator/
- 《Getting Started with LLVM Core Libraries》
- 《LLVM Cookbook》

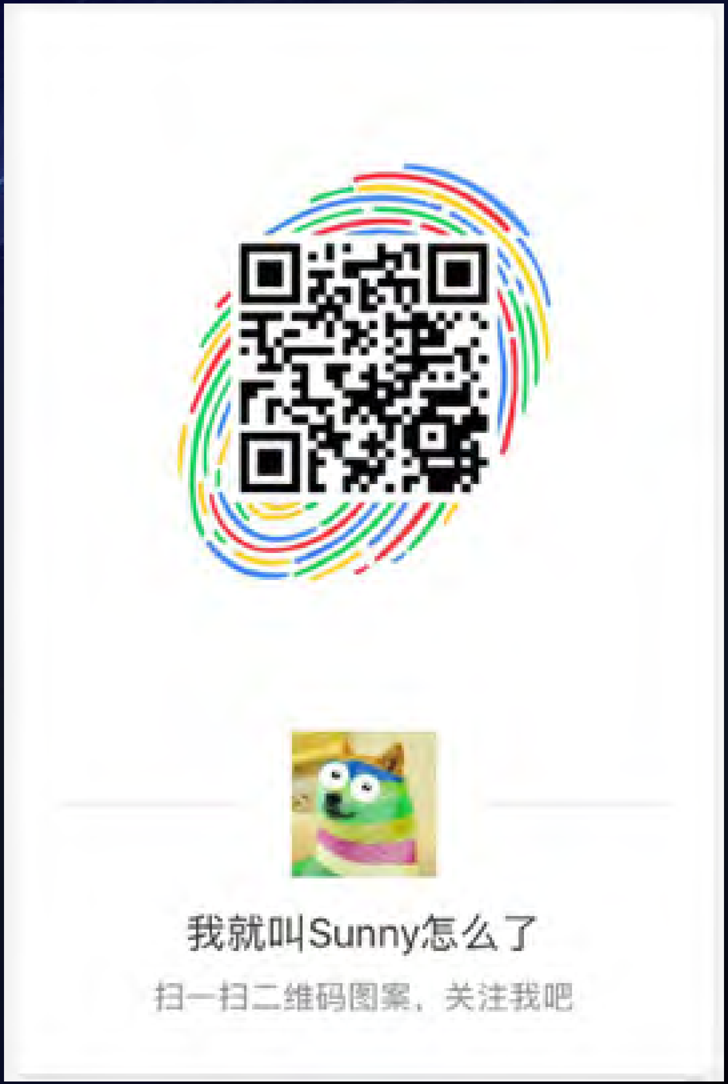
- 问：编译器可以编译程序，但编译器本身也是个程序，那它一定是由更早的编译器编译而成的，那...最早的一个编译器是哪儿来的?

手写机器码?




we're here

Q



A