中山大學 SUN YAT-SEN UNIVERSITY

国家超级计算广州中心 NATIONAL SUPERCOMPUTER CENTER IN GUANGZHOU

Compiler Design
编 译 器 构 造 实 验

Lab 15： Project-4

张献伟、吴坎

xianweiz.github.io

DCS292, 5/26/2022

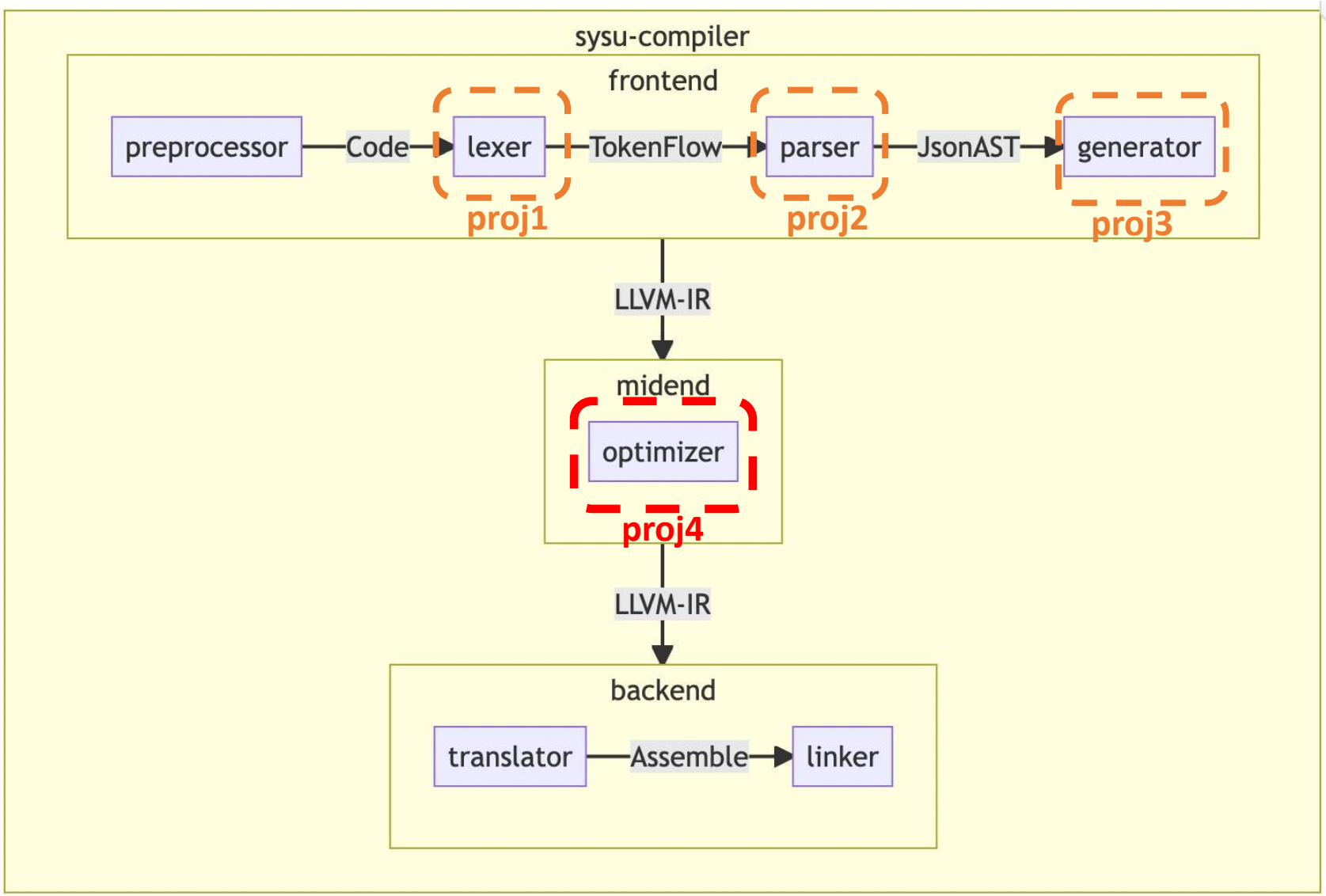
Project 4: What?

- 文档描述：https://github.com/arcsysu/SYsU-lang/tree/latest/optimizer
- 实现一个IR优化器
  - 输入：LLVM-IR（由Project 3或Clang提供）
  - 输出：LLVM-IR（优化版本）
- 总体流程
  - 引入Project3的IR（或使用clang）
  - 写analysis和transform passes
- 截止时间
  - **6/23/2022**

Project 4: How?

- 实现
  - $vim optimizer/optimizer.cc
- 编译
  - $cmake --build ~/sysu/build -t install
    - 输出：~/sysu/build/optimizer/
- 运行
  - (export PATH=~/sysu/bin:$PATH \ CPATH=~/sysu/include:$CPATH \ LIBRARY_PATH=~/sysu/lib:$LIBRARY_PATH \ LD_LIBRARY_PATH=~/sysu/lib:$LD_LIBRARY_PATH && clang -E ../tester/functional/000_main.sysu.c | **<THE_IR>** | sysu-optimizer)
    - Clang提供IR：<THE_IR> = clang -cc1 -O0 -S -emit-llvm
    - Project3提供IR： <THE_IR > = sysu-generator
  - sysu-optimizer
    - opt -S --enable-new-pm -load-pass-plugin= libsysuOptimizer.so -passes="sysu-optimizer-pass"

Where we are NOW?



LLVM Pass - Analysis vs Transformation

- A pass operates on some unit of IR (e.g. Module or Function)
  - Transformation pass will modify it
  - Analysis pass will generate some high-level information
- Analysis results are produced lazily
  - Another pass needs to request the results first
  - Results are cached
  - Analysis manager deals with a non-trivial cache (in)validation problem
- Transformation pass managers (e.g. FunctionPassManager) record what's preserved
  - Function pass can invalidate Module analysis results, and vice-versa

main.cc

```
38    // Create a module pass manager and add StaticCallCounterPrinter to it.
39    llvm::ModulePassManager MPM;
40    MPM.addPass(sysu::StaticCallCounterPrinter(llvm::errs()));
41
42    // Create an analysis manager and register StaticCallCounter with it.
43    llvm::ModuleAnalysisManager MAM;
44    MAM.registerPass([&] { return sysu::StaticCallCounter(); });
45
46    // Register all available module analysis passes defined in PassRegisty.def.
47    // We only really need PassInstrumentationAnalysis (which is pulled by
48    // default by PassBuilder), but to keep this concise, let PassBuilder do all
49    // the _heavy-lifting_.
50    llvm::PassBuilder PB;
51    PB.registerModuleAnalyses(MAM);
52
53    // Finally, run the passes registered with MPM
54    MPM.run(*M, MAM);
55
56    M->print(llvm::outs(), nullptr);
```

https://llvm.org/doxygen/classllvm_1_1PassManager.html

https://llvm.org/doxygen/classllvm_1_1AnalysisManager.html

注册所有的分析Pass

M: the IR module
MAM: the analysis manager

```
void PassBuilder::registerModuleAnalyses(
  ModuleAnalysisManager &MAM) {
#define MODULE_ANALYSIS(NAME, CREATE_PASS)
  MAM.registerPass([&] { return CREATE_PASS; });
#include "PassRegistry.def"

  for (auto &C : ModuleAnalysisRegistrationCallbacks)
    C(MAM);
}
```

e.g. PB.registerAnalysisRegistrationCallback

PassBuilder.cpp

https://llvm.org/doxygen/PassBuilder_8cpp_source.html

StaticCallCounterPrinter

optimizer.hh

```
27  class StaticCallCounterPrinter
28      : public llvm::PassInfoMixin<StaticCallCounterPrinter> {
29  public:
30    explicit StaticCallCounterPrinter(llvm::raw_ostream &OutS) : OS(OutS) {}
31    llvm::PreservedAnalyses run(llvm::Module &M,
32                                llvm::ModuleAnalysisManager &MAM);
33
34  private:
35    llvm::raw_ostream &OS;
36  };
```

声明run()方法，which actually runs the pass

run(): 接收一些IR单元和一个分析管理器，返回类型为 PreservedAnalyses

LLVM:

```
template <typename DerivedT> struct PassInfoMixin {
  static StringRef name() {
    // (...)
  }
};

template <typename IRUnitT,
          typename AnalysisManagerT = AnalysisManager<IRUnitT>,
          typename... ExtraArgTs>
class PassManager : public PassInfoMixin<
    PassManager<IRUnitT, AnalysisManagerT, ExtraArgTs...>> {

    PreservedAnalyses run(IRUnitT &IR, AnalysisManagerT &AM,
      ExtraArgTs... ExtraArgs) {
      // Passes is a vector of PassModel<> : PassConcept
      for (unsigned Idx = 0, Size = Passes.size(); Idx != Size; ++Idx) {
        PreservedAnalyses PassPA = P->run(IR, AM, ExtraArgs...);

        AM.invalidate(IR, PassPA);
      }
  } // end of run
} // end of PassManager
```

llvm/include/llvm/IR/PassManager.h

https://llvm.org/devmtg/2019-10/slides/Warzynski-WritingAnLLVMPass.pdf

StaticCallCounterPrinter (cont.)

optimizer.cc

```
5   llvm::PreservedAnalyses
6   sysu::StaticCallCounterPrinter::run(llvm::Module &M,
7                                       llvm::ModuleAnalysisManager &MAM) {
8
9     auto DirectCalls = MAM.getResult<sysu::StaticCallCounter>(M);
10
11    OS << "================================================\n";
12    OS << "sysu-optimizer: static analysis results\n";
13    OS << "================================================\n";
14    const char *str1 = "NAME", *str2 = "#N DIRECT CALLS";
15    OS << llvm::format("%-20s %-10s\n", str1, str2);
16    OS << "------------------------------------------------\n";
17
18    for (auto &CallCount : DirectCalls) {
19      OS << llvm::format("%-20s %-10lu\n",
20                         CallCount.first->getName().str().c_str(),
21                         CallCount.second);
22    }
23
24    OS << "------------------------------------------------\n\n";
25    return llvm::PreservedAnalyses::all();
26  }
```

实现run()方法

Get the result of an analysis pass for a given IR unit

你可以：
获取分析Pass的结果，然而优化修改代码

StaticCallCounter

optimizer.hh

```
15  class StaticCallCounter : public llvm::AnalysisInfoMixin<StaticCallCounter> {
16  public:
17    using Result = llvm::MapVector<const llvm::Function *, unsigned>;
18    Result run(llvm::Module &M, llvm::ModuleAnalysisManager &);
19
20  private:
21    // A special type used by analysis passes to provide an address that
22    // identifies that particular analysis pass type.
23    static llvm::AnalysisKey Key;
24    friend struct llvm::AnalysisInfoMixin<StaticCallCounter>;
25  };
```

```
struct AnalysisInfoMixin : PassInfoMixin<DerivedT> {
  /// Returns an opaque, unique ID for this analysis type.
  ///
   static AnalysisKey *ID() {
     static_assert(std::is_base_of<AnalysisInfoMixin, DerivedT>::value,
                   "Must pass the derived type as the template argument!");
     return &DerivedT::Key;
   }
};
```

llvm/include/llvm/IR/PassManager.h

StaticCallCounter (cont.)

optimizer.cc

```
28  sysu::StaticCallCounter::Result
29  sysu::StaticCallCounter::run(llvm::Module &M, llvm::ModuleAnalysisManager &) {
30    llvm::MapVector<const llvm::Function *, unsigned> Res;
31
32    for (auto &Func : M) {
33      for (auto &BB : Func) {
34        for (auto &Ins : BB) {
35
36          // If this is a call instruction then CB will be not null.
37          auto *CB = llvm::dyn_cast<llvm::CallBase>(&Ins);
38          if (nullptr == CB) {
39            continue;
40          }
41
42          // If CB is a direct function call then DirectInvoc will be not null.
43          auto DirectInvoc = CB->getCalledFunction();
44          if (nullptr == DirectInvoc) {
45            continue;
46          }
47
48          // We have a direct function call - update the count for the function
49          // being called.
50          auto CallCount = Res.find(DirectInvoc);
51          if (Res.end() == CallCount) {
52            CallCount = Res.insert({DirectInvoc, 0}).first;
53          }
54          ++CallCount->second;
55        }
56      }
57    }
58
59    return Res;
60  }
```

Pass Registration

optimizer.cc

```
65  llvm::PassPluginLibraryInfo LLVM_ATTRIBUTE_WEAK llvmGetPassPluginInfo() {
66    return {LLVM_PLUGIN_API_VERSION, "sysu-optimizer-pass", LLVM_VERSION_STRING,
67            [](llvm::PassBuilder &PB) {
68              // #1 REGISTRATION FOR "opt -passes=sysu-optimizer-pass"
69              PB.registerPipelineParsingCallback(
70                  [&](llvm::StringRef Name, llvm::ModulePassManager &MPM,
71                      llvm::ArrayRef<llvm::PassBuilder::PipelineElement>) {
72                    if (Name == "sysu-optimizer-pass") {
73                      MPM.addPass(sysu::StaticCallCounterPrinter(llvm::errs()));
74                      return true;
75                    }
76                    return false;
77                  });
78              // #2 REGISTRATION FOR
79              // "MAM.getResult<sysu::StaticCallCounter>(Module)"
80              PB.registerAnalysisRegistrationCallback(
81                  [](llvm::ModuleAnalysisManager &MAM) {
82                    MAM.registerPass([&] { return sysu::StaticCallCounter(); });
83                  });
84            }};
85  }
```

LLVM:

```
struct PassPluginLibraryInfo {
  /// The API version understood by this plugin
  uint32_t APIVersion;
  /// A meaningful name of the plugin.
  const char *PluginName;
  /// The version of the plugin.
  const char *PluginVersion;

  /// Callback for registering plugin passes with PassBuilder
  void (*RegisterPassBuilderCallbacks)(PassBuilder &);
};
```

include/llvm/Passes/PassPlugin.h

```
// Load requested pass plugins and let them register pass
// builder callbacks
bool runPassPipeline(...) {
                          from CL option
  for (auto &PluginFN : PassPlugins ) {
    auto PassPlugin = PassPlugin::Load(PluginFN);
                    FPMHook from HelloWorld.cpp
    PassPlugin->registerPassBuilderCallbacks(PB);
  }
}
```

tools/opt/NewPMDriver.cpp

https://llvm.org/devmtg/2019-10/slides/Warzynski-WritingAnLLVMPass.pdf

References

- https://github.com/arcsysu/SYsU-lang/blob/latest/optimizer/README.md
- Using the New Pass Manager
  - https://llvm.org/docs/NewPassManager.html
- Writing an LLVM Pass: 101 (LLVM 2019 tutorial)
  - https://llvm.org/devmtg/2019-10/slides/Warzynski-WritingAnLLVMPass.pdf
- Writing an LLVM Pass
  - https://llvm.org/docs/WritingAnLLVMNewPMPass.html
- LLVM's Analysis and Transform Passes
  - https://www.llvm.org/docs/Passes.html
- Getting Started with LLVM Core Libraries
  - https://faculty.sist.shanghaitech.edu.cn/faculty/songfu/course/spring2018/CS131/llvm.pdf