Advanced T⚙pics *in* C⚙mpilers

NOELLE

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Outline

- Introducing NOELLE

- Building upon NOELLE

- Documentation

Software framework: NOELLE

- Git repo: https://github.com/arcana-lab/noelle

- You need to use LLVM 9.0.0
  - On hanlon.wot.eecs.northwestern.edu:
    ```
    LLVM_HOME= /home/software/llvm-9.0.0
    export PATH=$LLVM_HOME/bin:$PATH ;
    export LD_LIBRARY_PATH=$LLVM_HOME/lib:$LD_LIBRARY_PATH
    ```
  - On peroni.cs.northwestern.edu
    ```
    source /project/extra/llvm/9.0.0/enable
    ```

- Try to compile the framework
  ```
  $ git clone https://github.com/arcana-lab/noelle
  $ cd noelle
  $ make
  ```

Software framework: NOELLE

- Problem:
  - LLVM provides low-level and only code-centric APIs to middle-end passes
  - This makes the design of advanced code analyses and transformations hard

- Solution:
  - NOELLE complements LLVM by providing a dependence-centric (and more expensive, unfortunately) APIs at different granularities to middle-end passes
  - Even advanced code transformations (code parallelization, code vectorization, loop transformations) can be now implemented in a few lines of code (less than 1000!!!)
  - NOELLE's APIs are optional and you can combine them with LLVM's APIs
  - For most NOELLE's APIs:
    - You pay the cost of an API provided by NOELLE when you invoke that API

Current limitations of NOELLE

- You can analyze and/or transform a program, but not a library
  - The existence of main is assumed

- The IR code being analyzed/transformed using NOELLE has to be (at least) normalized using noelle-norm

- You keep track of which abstractions are no longer valid due to changes you have made to the code
  - Suggestion: use all abstractions you need to decide what to do, then do all changes at once
  - Suggestion: you can invoke your NOELLE-based transformation until a fixed-point is reached (learn how to use noelle-fixedpoint)

Compiling and installing NOELLE

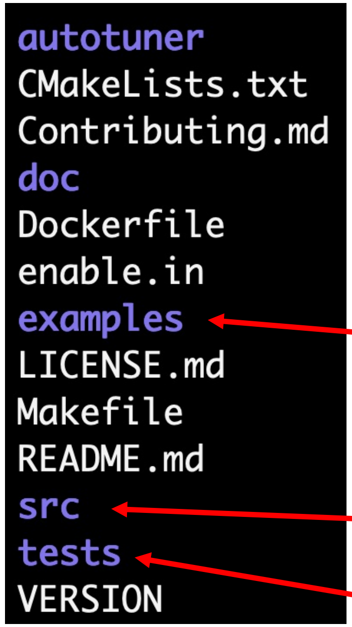
- NOELLE is configured to be compiled with
  SCAF, SVF, and LLVM alias analyses by default

- The installation directory is (by default)
  the sub-directory ./install of the NOELLE repository

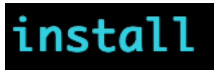
- If you want to change NOELLE's default configuration, please run:
  make menuconfig

- To compile and install NOELLE, run from the root directory of the repository:
  make

NOELLE structure



```
autotuner
CMakeLists.txt
Contributing.md
doc
Dockerfile
enable.in
examples
LICENSE.md
Makefile
README.md
src
tests
VERSION
```



```
install
```

Examples of LLVM middle-end passes built upon NOELLE

NOELLE's internals

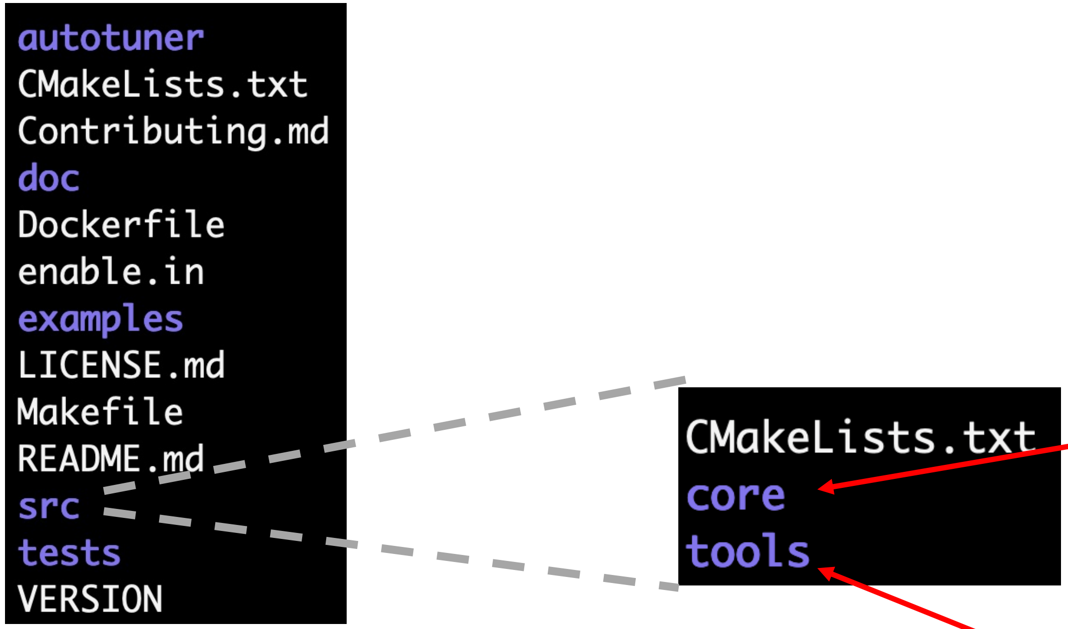
NOELLE's tests

- Unit tests

After you compile NOELLE, NOELLE's

- Binaries
- public APIs
- tools

NOELLE structure



```
autotuner
CMakeLists.txt
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src
tests
VERSION
```

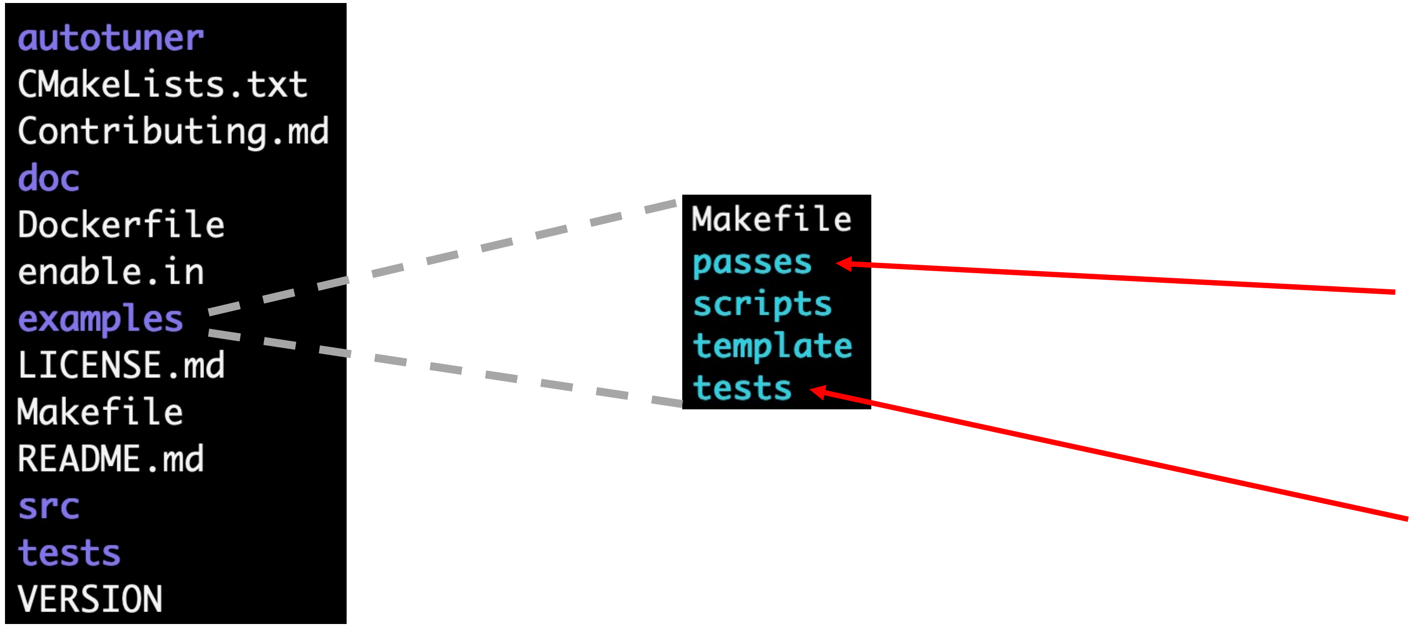
```
CMakeLists.txt
core
tools
```

Abstractions provided
by NOELLE
and their public APIs

All of them are within
the namespace arcana::noelle

Tools/analyses
built upon NOELLE

NOELLE structure



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```

```
Makefile
passes
scripts
template
tests
```

Simple examples of LLVM passes that use NOELLE's abstractions/APIs

Simple C/C++ programs that can be used to test the simple LLVM passes built using NOELLE

NOELLE commands

Code normalizations:

- noelle-norm
  normalize LLVM IR for NOELLE

- noelle-simplification
  run simple transformations that remove some redundancy (e.g., constant propagation) and then normalize LLVM IR for NOELLE

NOELLE commands

Metadata:

- noelle-meta-X-clean
  Remove metadata related to X from the given LLVM IR file

- noelle-meta-X-embed
  Embed metadata related to X into the given LLVM IR file

- The X can be:

loop	*about IDs of single loops*
pdg	*about the memory dependences needed to build a PDG*
prof	*about data generated by profilers*
scc	*about the composition of single SCCs*

NOELLE commands

Miscellaneous:

- noelle-prof-coverage
  Generate a binary with profiling instructions from a given LLVM IR file

- noelle-pdg
  Print the PDG of a given LLVM IR file

- noelle-load
  Replacement for opt to be used to run an LLVM pass built upon NOELLE (see next)

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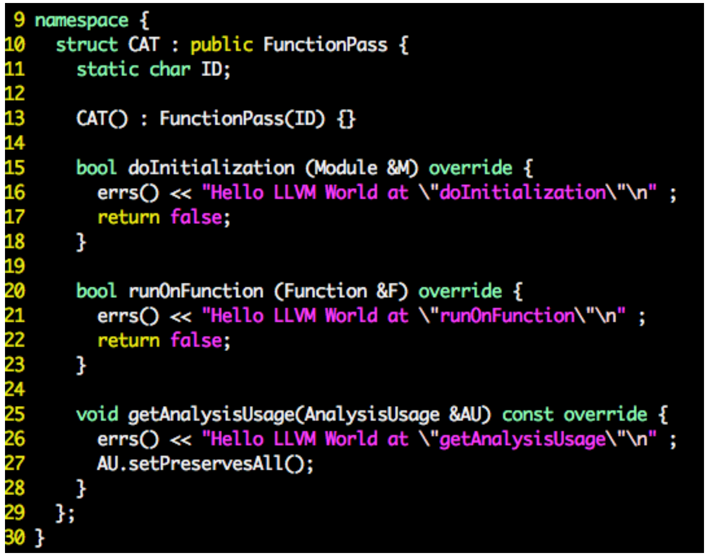
Middle-end pass

- Download the skeleton for an LLVM middle-end pass from here: https://github.com/scampanoni/LLVM_middleend_template



```
namespace {
  struct CAT : public FunctionPass {
    static char ID;

    CAT() : FunctionPass(ID) {}

    bool doInitialization (Module &M) override {
      errs() << "Hello LLVM World at \"doInitialization\"\n" ;
      return false;
    }

    bool runOnFunction (Function &F) override {
      errs() << "Hello LLVM World at \"runOnFunction\"\n" ;
      return false;
    }

    void getAnalysisUsage(AnalysisUsage &AU) const override {
      errs() << "Hello LLVM World at \"getAnalysisUsage\"\n" ;
      AU.setPreservesAll();
    }
  };
}
```

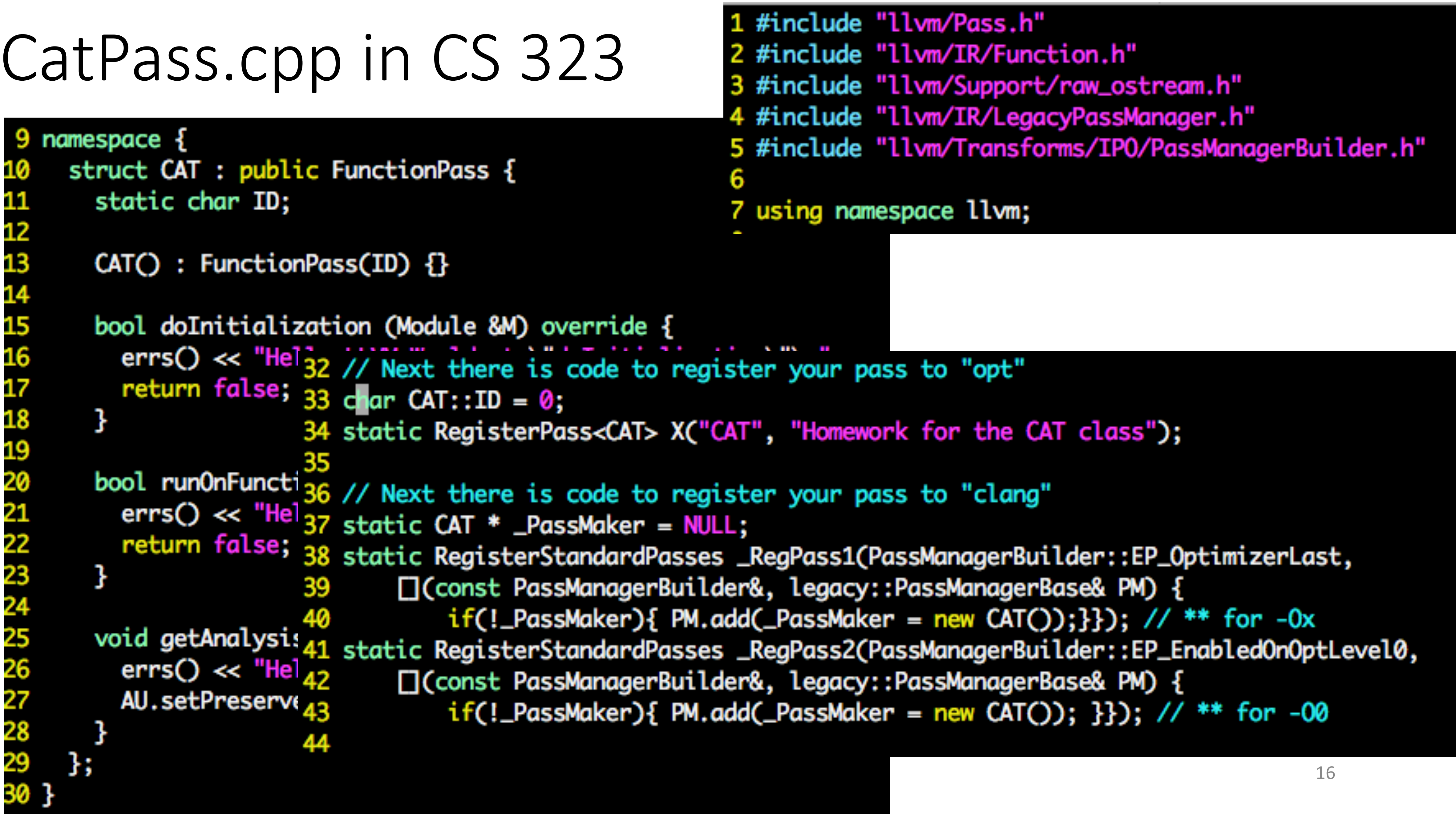
- You need to (see next slides):

1. Extend/change this skeleton (src/CatPass.cpp) to implement your middle-end pass upon NOELLE
2. Declare NOELLE to cmake (src/CMakeLists.txt)

Middle-end pass

1. Extend/change this skeleton (src/CatPass.cpp) to implement your middle-end pass upon NOELLE

CatPass.cpp in CS 323



```
#include "llvm/Pass.h"
#include "llvm/IR/Function.h"
#include "llvm/Support/raw_ostream.h"
#include "llvm/IR/LegacyPassManager.h"
#include "llvm/Transforms/IPO/PassManagerBuilder.h"

using namespace llvm;
```

```
namespace {
  struct CAT : public FunctionPass {
    static char ID;

    CAT() : FunctionPass(ID) {}

    bool doInitialization (Module &M) override {
      errs() << "Hel
      return false;
    }

    bool runOnFuncti
      errs() << "Hel
      return false;
    }

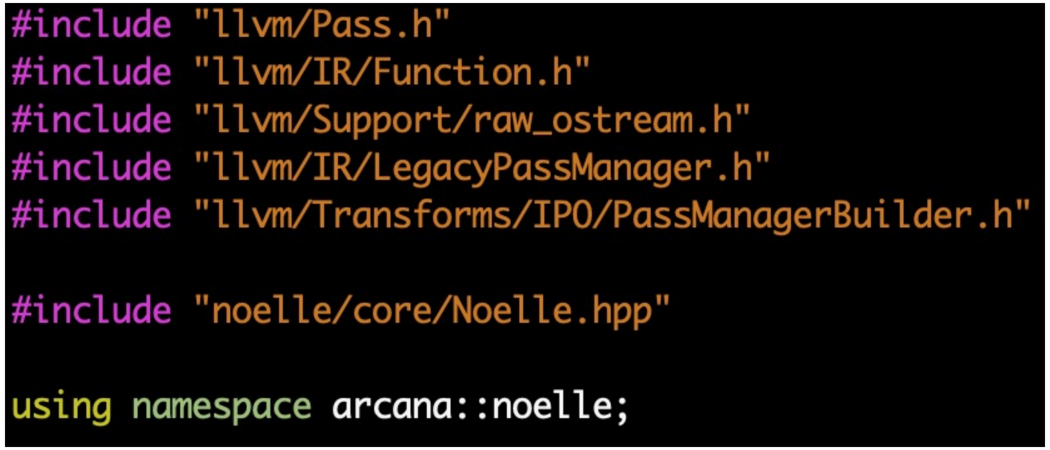
    void getAnalysis
      errs() << "Hel
      AU.setPreserve
    }
  };
}
```

```
// Next there is code to register your pass to "opt"
char CAT::ID = 0;
static RegisterPass<CAT> X("CAT", "Homework for the CAT class");

// Next there is code to register your pass to "clang"
static CAT * _PassMaker = NULL;
static RegisterStandardPasses _RegPass1(PassManagerBuilder::EP_OptimizerLast,
    □(const PassManagerBuilder&, legacy::PassManagerBase& PM) {
        if(!_PassMaker){ PM.add(_PassMaker = new CAT());}}); // ** for -Ox
static RegisterStandardPasses _RegPass2(PassManagerBuilder::EP_EnabledOnOptLevel0,
    □(const PassManagerBuilder&, legacy::PassManagerBase& PM) {
        if(!_PassMaker){ PM.add(_PassMaker = new CAT()); }}); // ** for -O0

```

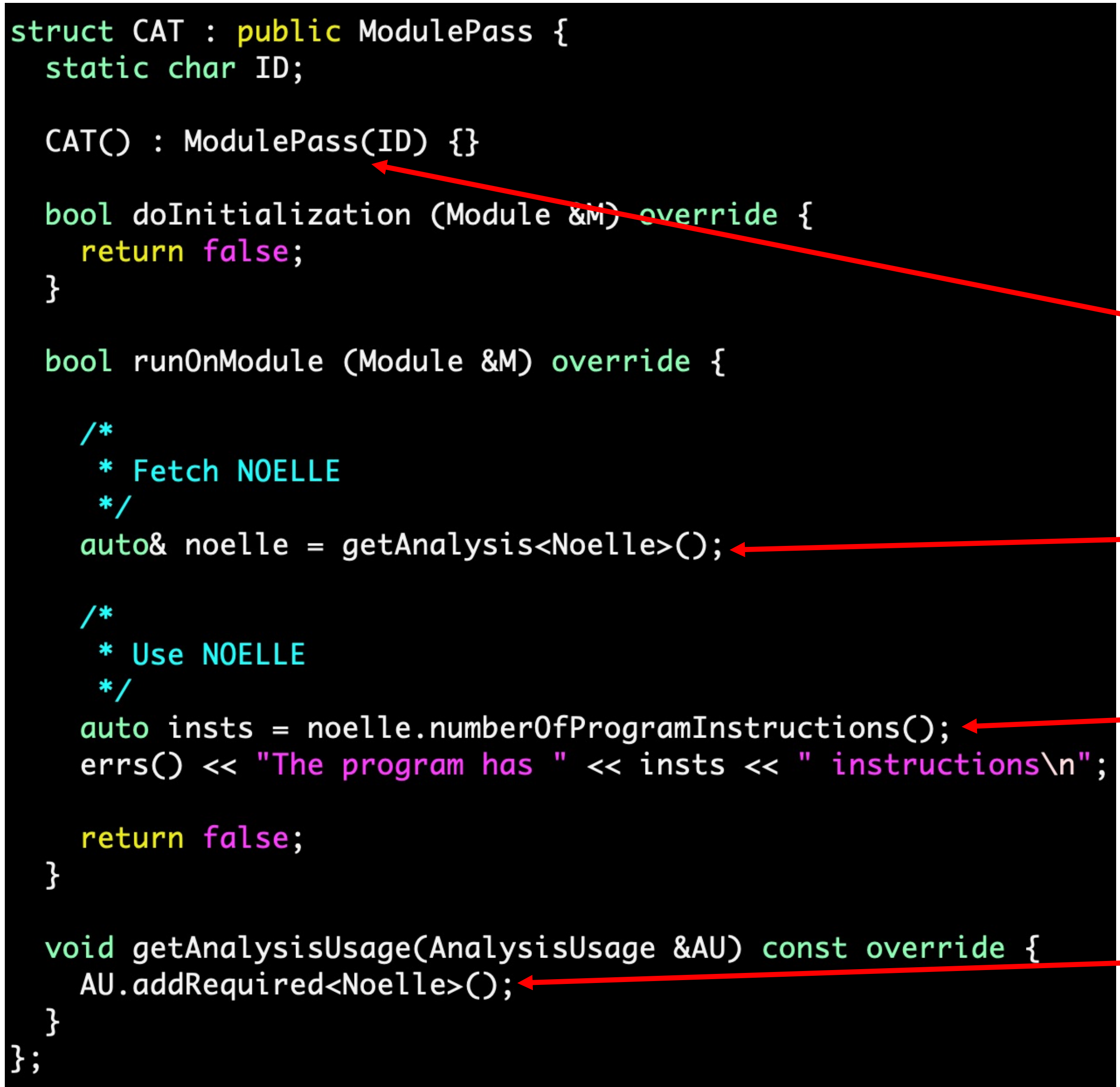
CatPass.cpp using NOELLE



```
#include "llvm/Pass.h"
#include "llvm/IR/Function.h"
#include "llvm/Support/raw_ostream.h"
#include "llvm/IR/LegacyPassManager.h"
#include "llvm/Transforms/IPO/PassManagerBuilder.h"

#include "noelle/core/Noelle.hpp"

using namespace arcana::noelle;
```



```
struct CAT : public ModulePass {
  static char ID;

  CAT() : ModulePass(ID) {}

  bool doInitialization (Module &M) override {
    return false;
  }

  bool runOnModule (Module &M) override {

    /*
     * Fetch NOELLE
     */
    auto& noelle = getAnalysis<Noelle>();

    /*
     * Use NOELLE
     */
    auto insts = noelle.numberOfProgramInstructions();
    errs() << "The program has " << insts << " instructions\n";

    return false;
  }

  void getAnalysisUsage(AnalysisUsage &AU) const override {
    AU.addRequired<Noelle>();
  }
};
```

It has to be a ModulePass

Fetch NOELLE

Simple example
of using NOELLE

Declare to LLVM that
your pass depends on NOELLE

Middle-end pass

1. Extend/change this skeleton (src/CatPass.cpp) to implement your middle-end pass upon NOELLE
2. Declare NOELLE to cmake (src/CMakeLists.txt)

Declaring NOELLE to cmake

- Put NOELLE in your environment:
  source MY_NOELLE/enable

- Find out where is the include directory of your installed NOELLE
  noelle-config –include

- Copy the directory printed above (e.g., MY_NOELLE/install/include)
  and paste it into src/CMakeLists.txt
  include_directories(${LLVM_INCLUDE_DIRS} MY_NOELLE/install/include)

- You can now compile your pass built upon NOELLE.
  To do so, run the following script from your LLVM pass root directory:
  ./run_me.sh

Running NOELLE based passes

- noelle-load **rather than** opt

- In CS 323:
  - opt –load ~/CAT/lib/CAT.so -CAT A.bc –o B.bc

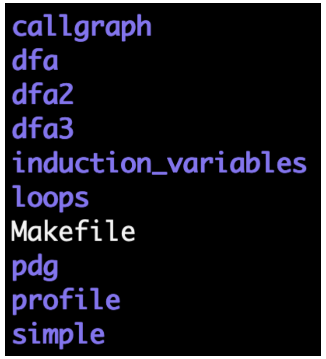
- Now:
  - noelle-load –load ~/CAT/lib/CAT.so -CAT A.bc –o B.bc

It will print the invocation to opt with all arguments if you invoke it with “--noelle-verbose=1” (or 2, 3)

```
opt -load /nfs-scratch/simonec/parallelism/parallelization/NOELLEs/2/install/lib/CallGraph.so
     …
   -load /home/simonec/CAT/lib/MYPASS.so -MYPASS A.bc -o B.bc
```

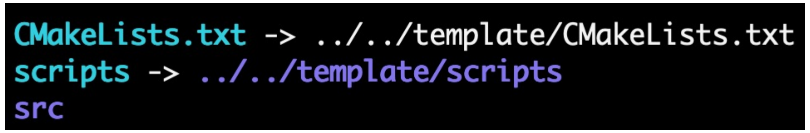
Let’s compile a simple example of code transformation built upon NOELLE

- cd examples/passes



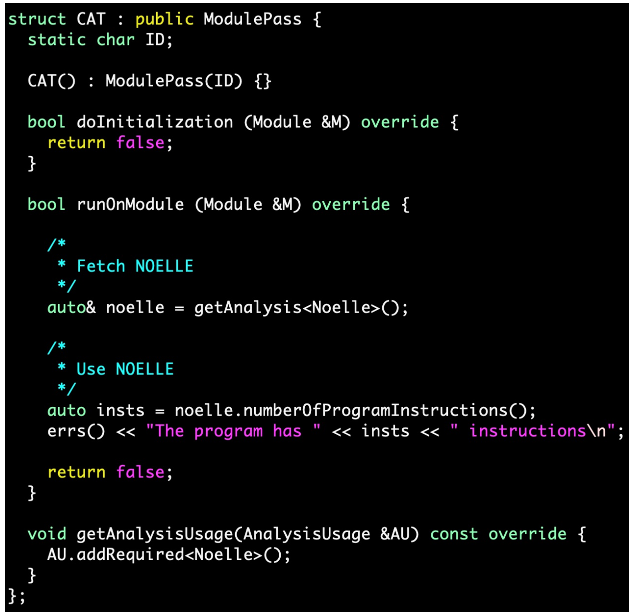
```
callgraph
dfa
dfa2
dfa3
induction_variables
loops
Makefile
pdg
profile
simple
```

- make links ; cd simple



```
CMakeLists.txt -> ../../template/CMakeLists.txt
scripts -> ../../template/scripts
src
```

- ./scripts/run_me.sh
  It will compile and install the pass to ~/CAT
  (like in 323)



```
struct CAT : public ModulePass {
  static char ID;

  CAT() : ModulePass(ID) {}

  bool doInitialization (Module &M) override {
    return false;
  }

  bool runOnModule (Module &M) override {

    /*
     * Fetch NOELLE
     */
    auto& noelle = getAnalysis<Noelle>();

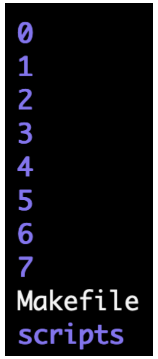
    /*
     * Use NOELLE
     */
    auto insts = noelle.numberOfProgramInstructions();
    errs() << "The program has " << insts << " instructions\n";

    return false;
  }

  void getAnalysisUsage(AnalysisUsage &AU) const override {
    AU.addRequired<Noelle>();
  }
};
```

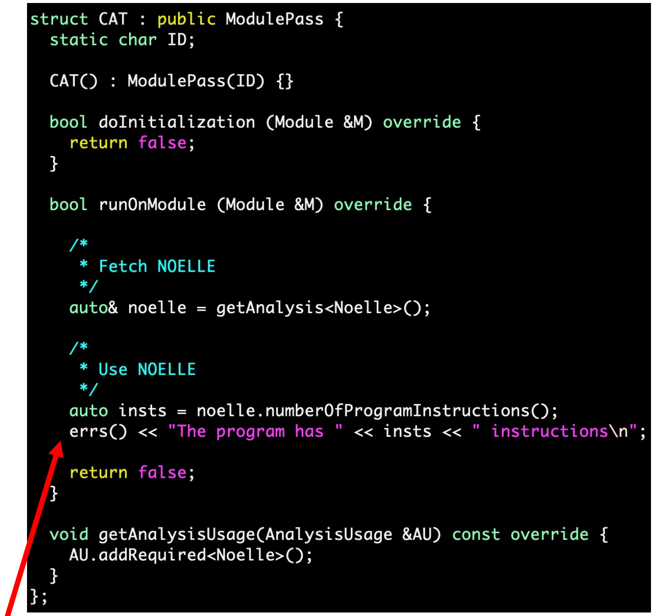
Let’s run a simple example of code transformation built upon NOELLE

- cd examples/tests



```
0
1
2
3
4
5
6
7
Makefile
scripts
```

- source ../../enable ;
- cd 0 ;
- make -f Makefile_no_profile



```
struct CAT : public ModulePass {
  static char ID;

  CAT() : ModulePass(ID) {}

  bool doInitialization (Module &M) override {
    return false;
  }

  bool runOnModule (Module &M) override {

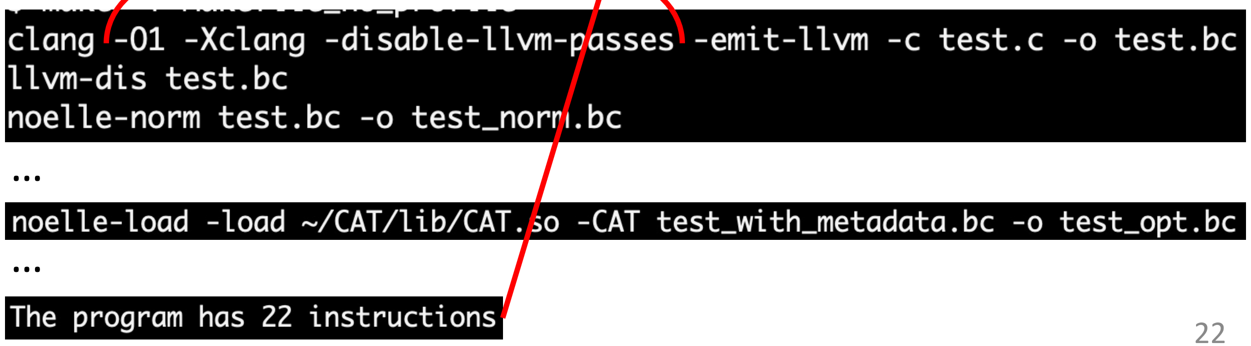
    /*
     * Fetch NOELLE
     */
    auto& noelle = getAnalysis<Noelle>();

    /*
     * Use NOELLE
     */
    auto insts = noelle.numberOfProgramInstructions();
    errs() << "The program has " << insts << " instructions\n";

    return false;
  }

  void getAnalysisUsage(AnalysisUsage &AU) const override {
    AU.addRequired<Noelle>();
  }
};
```

To generate unoptimized IR with intrinsic calls



```
clang -O1 -Xclang -disable-llvm-passes -emit-llvm -c test.c -o test.bc
llvm-dis test.bc
noelle-norm test.bc -o test_norm.bc
```

…

```
noelle-load -load ~/CAT/lib/CAT.so -CAT test_with_metadata.bc -o test_opt.bc
```

…

```
The program has 22 instructions
```

You have to normalize the code before invoking NOELLE

Outline

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- Documentation

Documentation of NOELLE

- Entry point: README.md
- All links to other documentation/videos/slides are reachable from the entry point
- Please read the documentation (most questions can be answered by reading the documentation)

Always have faith in your ability

Success will come your way eventually

Best of luck!