FLiT

Measuring and Locating Floating-Point Variability from Compiler Optimizations

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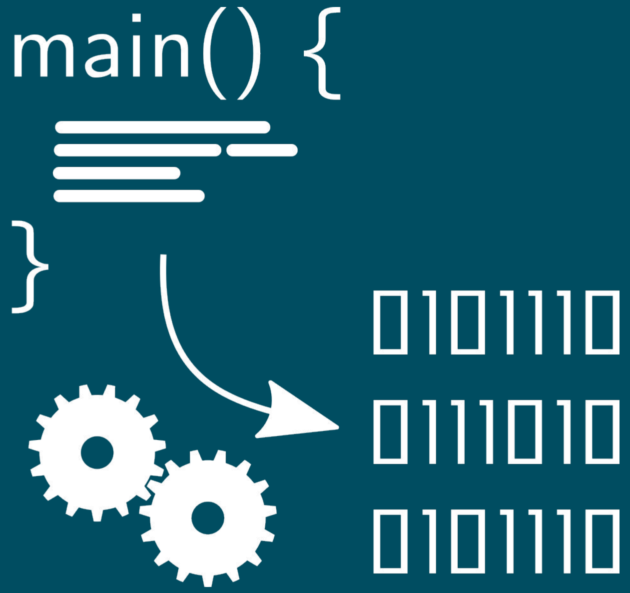
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 (LLNL-PRES-780623).

Compilers Can Induce Variability



Compilers have become so stable, we trust them almost implicitly.

I'm here to burst your bubble

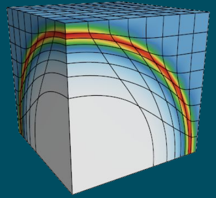
Two different compilations can give vastly different program results

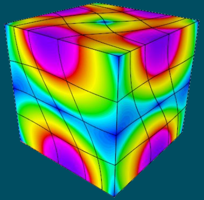
- Not because the compiler has a bug
- Not because the compiler did things wrong
- Not because the compiler doesn't understand

But because the compiler **thinks** you want it

Example of Compiler-Induced Variability

Laghos: A high-order Lagrangian hydrodynamics mini-application





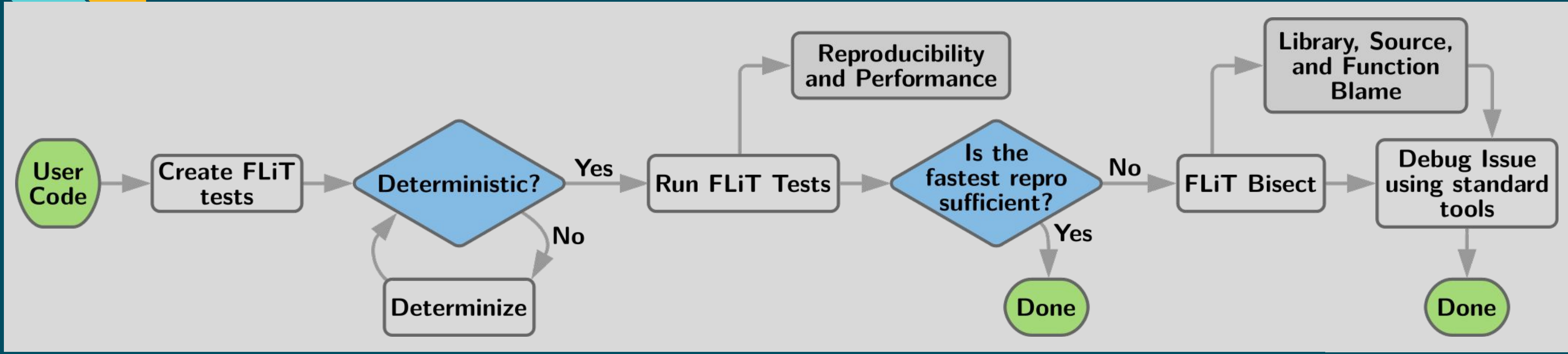
`xlc -O2` → `xlc -O3`

One iteration: **11.2%** relative error!

And speedup by a factor of **2.42**

What happened? How can I investigate it?

FLiT Workflow



Multiple Levels:

1. Determine variability-inducing compilations
2. Analyze the tradeoff of reproducibility and performance
3. Locate variability by identifying files and functions causing variability

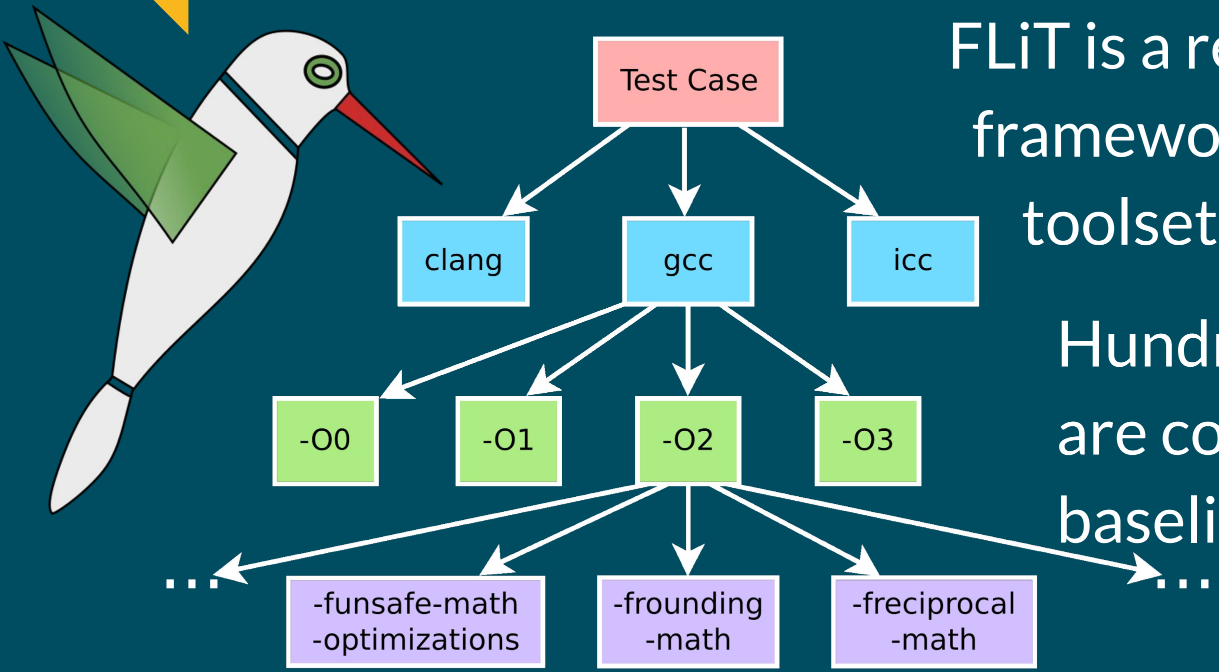
FLiT Installation

FLiT is easy to install

- Very few dependencies
- Use from repository or install on the system

```
 git $ git clone https://github.com/PRUNERS/FLiT.git
Cloning into 'FLiT'...
[...]
 git $ cd FLiT
 FLiT $ make
  src/timeFunction.cpp -> src/timeFunction.o
  src/flitHelpers.cpp -> src/flitHelpers.o
  src/TestBase.cpp -> src/TestBase.o
  src/flit.cpp -> src/flit.o
  src/FlitCsv.cpp -> src/FlitCsv.o
  src/InfoStream.cpp -> src/InfoStream.o
  src/subprocess.cpp -> src/subprocess.o
  src/Variant.cpp -> src/Variant.o
  src/fsutil.cpp -> src/fsutil.o
  mkdir lib
Building lib/libflit.so
 FLiT $ sudo make install
Installing...
  Generating /usr/share/flit/scripts/flitconfig.py
 FLiT $ sudo apt install python3-toml python3-pyelftools
[...]
```

Multi-Compilation Search



FLiT is a reproducibility test framework in the PRUNERS toolset (pruners.github.io).

Hundreds of compilations are compared against a baseline compilation.

Exercises

Exercises with FLiT

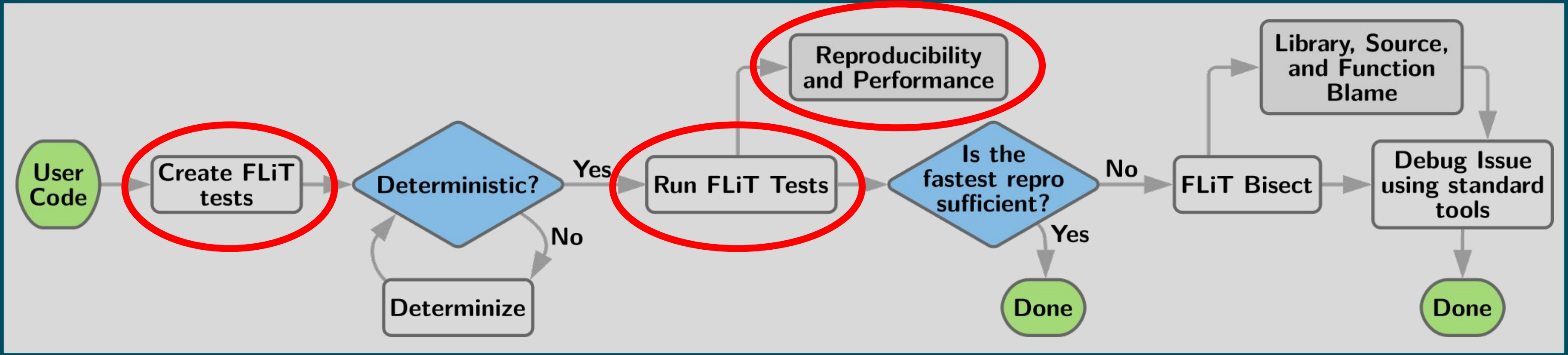
1. MFEM: many compilations and measure variability
2. MFEM: locate site of variability with FLiT Bisect
3. LULESH: auto-run many FLiT Bisects and Bisect-Biggest

Directory Structure

```
Module-FLiT/
├── exercise-1/
├── exercise-2/
├── exercise-3/
├── packages/
├── README.md
└── setup.sh
```

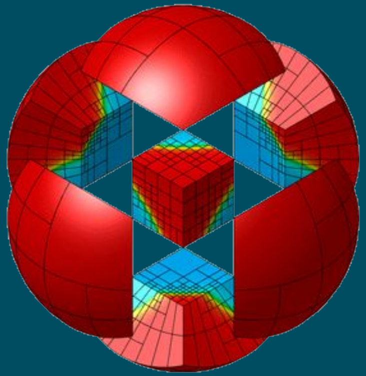
Exercise 1

Exercise 1 - Goal



1. Generate a FLiT test
2. Run the test with many compilations
3. Look at the results

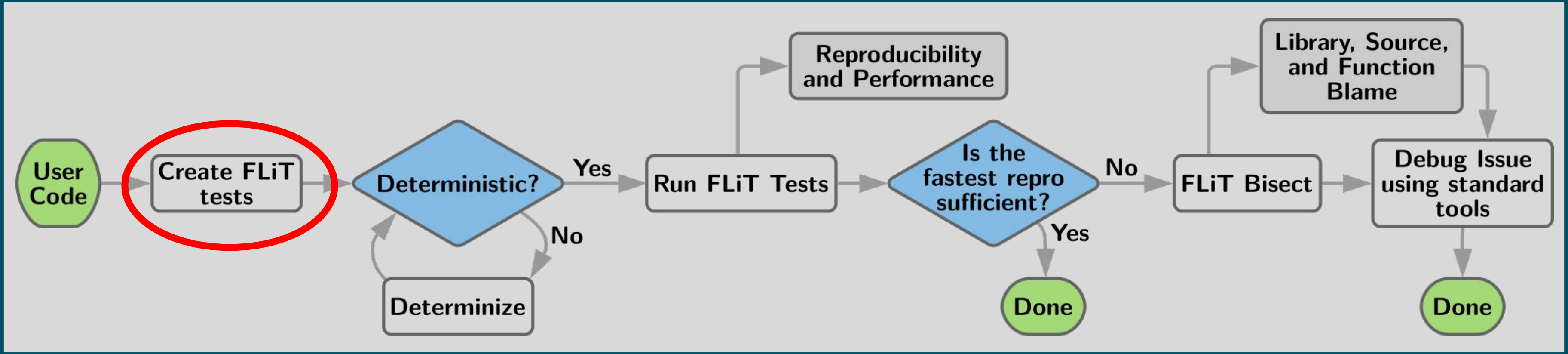
Application: MFEM



source files	97
average functions per file	31
total functions	2,998
source lines of code	103,205

- Open-source finite element library
  - Developed at LLNL
  - https://github.com/mfem/mfem.git
- Provides many example use cases
- Represents real-world code

Exercise 1 - Create MFEM Test



What does it take to create a FLiT test from an MFEM example?

Let’s find out!

Exercise 1 - Create MFEM Test

```
Module-FLiT $ cd exercise-1
```

Let's look at the test for MFEM example #13

`tests/Mfem13.cpp`

```
exercise-1 $ vim tests/MFEM13.cpp
```

or

```
exercise-1 $ pygmentize tests/Mfem13.cpp | cat -n
```

or whatever...

Exercise 1 - Create MFEM Test

tests/MFEM13.cpp

```
// Redefine main() to avoid name clash.  This is the function we will test
#define main mfem_13p_main
#include "ex13p.cpp"
#undef main
// Register it so we can use it in call_main() or call_mpi_main()
FLIT_REGISTER_MAIN(mfem_13p_main);
```

Things to notice:

- Include `ex13p.cpp` from MFEM without modification
- Rename `main()` to `mfem_13p_main()` to avoid name clash
- Register `mfem_13p_main()` with FLiT to be called as a separate process

Exercise 1 - Create MFEM Test

tests/MFEM13.cpp

```
template <typename T>
class Mfem13 : public flit::TestBase<T> {
public:
  Mfem13(std::string id) : flit::TestBase<T>(std::move(id)) {}
  virtual size_t getInputsPerRun() override { return 0; }
  virtual std::vector<T> getDefaultInput() override { return { }; }

  virtual long double compare(const std::vector<std::string> &ground_truth,
                              const std::vector<std::string> &test_results) const override {
    [...]
  }
```

- A simple test setup with no floating-point inputs
- `compare()` does L2 norm and returns % relative difference (skipped)

Exercise 1 - Create MFEM Test

tests/MFEM13.cpp

```cpp
// Only implement the test for double precision
template<>
flit::Variant Mfem13<double>::run_impl(const std::vector<double> &ti) {
  FLIT_UNUSED(ti);

  // Run in a temporary directory so output files don't clash
  std::string start_dir = flit::fsutil::curdir();
  flit::fsutil::TempDir exec_dir;
  flit::fsutil::PushDir pusher(exec_dir.name());
```

- Only double precision is implemented
- Create a temporary directory and go there (for out files)

Exercise 1 - Create MFEM Test

tests/MFEM13.cpp

```
// Run the example's main under MPI
auto meshfile = flit::fsutil::join(start_dir,"data", "beam-tet.mesh");
auto result = flit::call_mpi_main(
                     mfem_13p_main,
                    "mpirun -n 1 --bind-to none",
                    "Mfem13",
                    "--no-visualization --mesh "+ meshfile);
```

- Call `mfem_13p_main()` as a child process with MPI
- Command-line arguments for `mpirun` are given
- For this tutorial, only one MPI process, but can use many
- Command-line arguments for `mfem_13p_main()` are given

Exercise 1 - Create MFEM Test

tests/MFEM13.cpp

```
// Output debugging information
std::ostream &out = flit::info_stream;
out << id << " stdout: " << result.out << "\n";
out << id << " stderr: " << result.err << "\n";
out << id << " return: " << result.ret << "\n";
out.flush();

if (result.ret != 0) {
  throw std::logic_error("Failed to run my main correctly");
}
```

- Result from `call_mpi_main()` have `out`, `err`, and `ret`
- We check for an error using the return code, `ret`

Exercise 1 - Create MFEM Test

tests/MFEM13.cpp

```
// We will be returning a vector of strings that hold the mesh data
std::vector<std::string> retval;
  [...]
// Return the mesh and mode files as strings
return flit::Variant(retval);
```

- We skip the details here
- Return value is a `vector<string>` used by `compare()`

Exercise 1 - Create MFEM Test

```
tests/MFEM13.cpp

116 REGISTER_TYPE(Mfem13)
```

Finally, we register the test class with FLiT

Now, let's look at how the FLiT configuration looks
This has config about compilers and the search space

```
exercise-1 $ vim flit-config.toml
```

Exercise 1 - FLiT Configuration

flit-config.toml

```
[run]
enable_mpi = true
```

- Needed to get the compiler and linker flags for MPI
- Grabs the flags from `mpic++`

Exercise 1 - FLiT Configuration

flit-config.toml

```
[dev_build]
compiler_name = 'g++'
optimization_level = '-O3'
switches = '-mavx2 -mfma'

[ground_truth]
compiler_name = 'g++'
optimization_level = '-O2'
switches = ''
```

Defines the compilations for `make dev` and `make gt`

Exercise 1 - FLiT Configuration

flit-config.toml

```toml
[[compiler]]
binary = 'g++-7'
name = 'g++'
type = 'gcc'
optimization_levels = [
    '-O3',
]
switches_list = [
    '-ffast-math',
    '-funsafe-math-optimizations',
    '-mfma',
]
```

- Defines the “g++” compiler
- Defines the compilation search space

Exercise 1 - FLiT Configuration

flit-config.toml

```
[[compiler]]
binary = 'clang++-6.0'
name = 'clang++'
type = 'clang'
optimization_levels = [
    '-O3',
]
switches_list = [
    '-ffast-math',
    '-funsafe-math-optimizations',
    '-mfma',
]
```

- Defines the "`clang++`" compiler
- Defines the compilation search space

Exercise 1 - Makefile Configuration

A second configuration file: `custom.mk`

- FLiT autogenerates a `Makefile`
- `custom.mk` is included in the `Makefile`
- Tells FLiT how to compile your test(s)

```
exercise-1 $ vim custom.mk
```

Exercise 1 - Makefile Configuration

custom.mk

```
PACKAGES_DIR    := $(abspath ../packages)
MFEM_SRC        := $(PACKAGES_DIR)/mfem
HYPRE_SRC       := $(PACKAGES_DIR)/hypre
METIS_SRC       := $(PACKAGES_DIR)/metis-4.0

SOURCE          :=
SOURCE          += $(wildcard *.cpp)
SOURCE          += $(wildcard tests/*.cpp)

# Compiling all sources of MFEM into the tests takes too long for a tutorial
# skip it.  Instead, we link in the MFEM static library
#SOURCE          += $(wildcard ${MFEM_SRC}/fem/*.cpp)
#SOURCE          += $(wildcard ${MFEM_SRC}/general/*.cpp)
#SOURCE          += $(wildcard ${MFEM_SRC}/linalg/*.cpp)
#SOURCE          += $(wildcard ${MFEM_SRC}/mesh/*.cpp)

# just the one source file to see there is a difference
SOURCE          += ${MFEM_SRC}/linalg/densemat.cpp  # where the bug is
```

Exercise 1 - Makefile Configuration

custom.mk

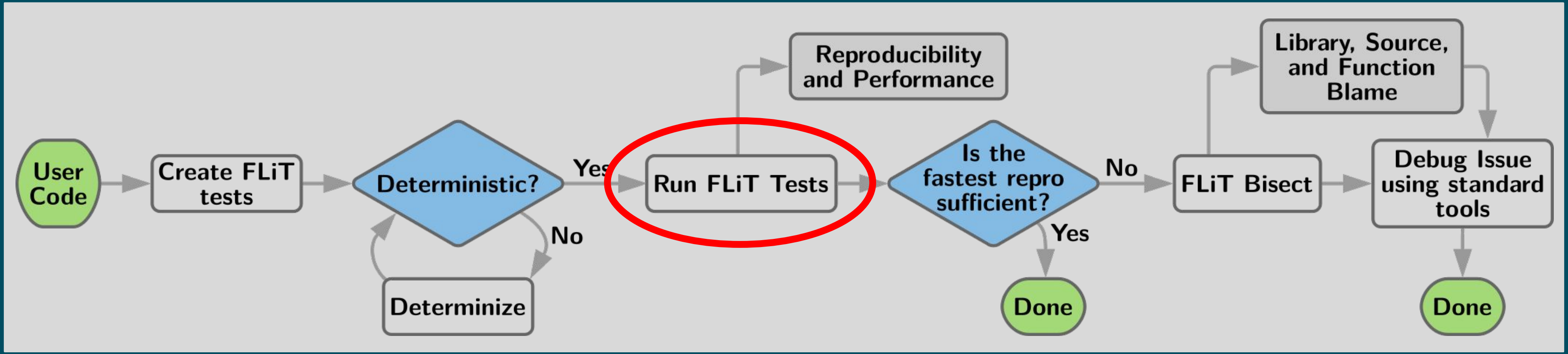
```
CC_REQUIRED     += -I${MFEM_SRC}
CC_REQUIRED     += -I${MFEM_SRC}/examples
CC_REQUIRED     += -isystem ${HYPRE_SRC}/src/hypre/include

LD_REQUIRED     += -L${MFEM_SRC} -lmfem
LD_REQUIRED     += -L${HYPRE_SRC}/src/hypre/lib -lHYPRE
LD_REQUIRED     += -L${METIS_SRC} -lmetis
```

That’s all there is to it

Let’s run it!

Exercise 1 - Run the MFEM Test



Each command has a script.

Run the script or the command from the slide - your choice

Exercise 1 - `./step-01.sh`

```
 exercise-1 $ flit update
Creating ./Makefile
```

- Auto-generate `Makefile`
- Since it is auto-generated, it is usually not committed in a repo

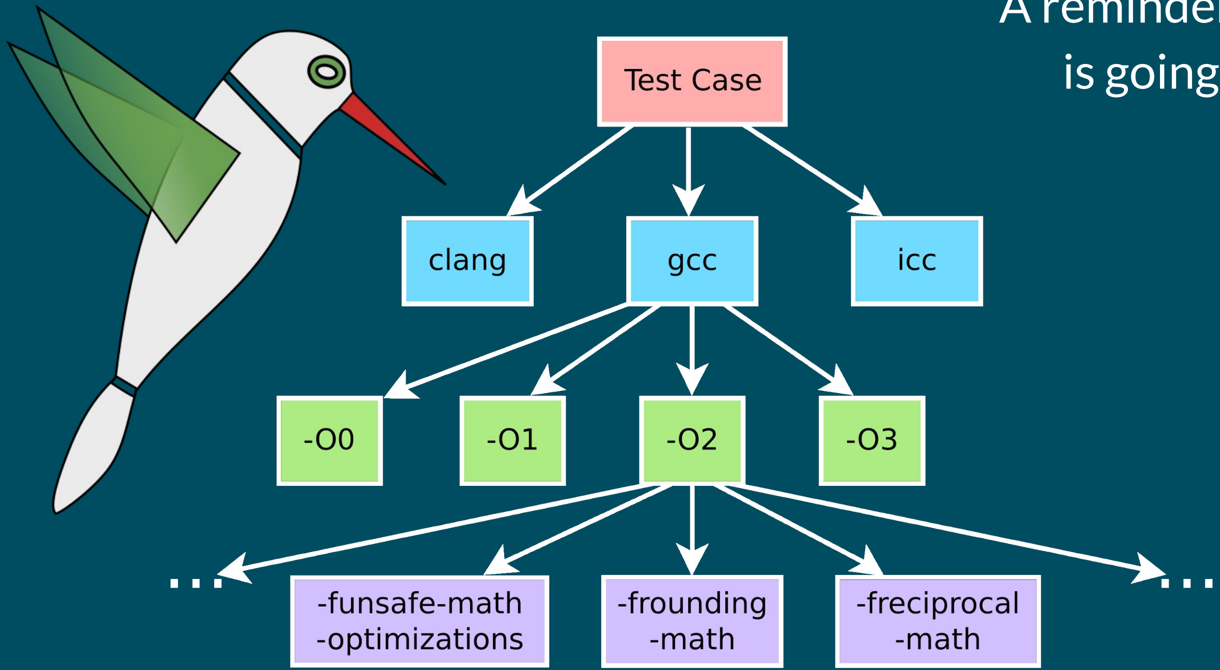
Exercise 1 - `./step-02.sh`

```
exercise-1 $ make runbuild -j1
  mkdir obj/gt
  /home/user1/Module-FLiT/packages/mfem/linalg/densemat.cpp -> obj/gt/densemat.cpp.o
  main.cpp -> obj/gt/main.cpp.o
  tests/Mfem13.cpp -> obj/gt/Mfem13.cpp.o
Building gtrun
  mkdir bin
  mkdir obj/GCC_ip-172-31-8-101_FFAST_MATH_O3
  /home/user1/Module-FLiT/packages/mfem/linalg/densemat.cpp ->
obj/GCC_ip-172-31-8-101_FFAST_MATH_O3/densemat.cpp.o
[...]
```

(takes about 1 minute)

- For verbose output use `make VERBOSE=1 ...`
- Will make all compilations from search space into `bin/`
- Can do more parallelism (but not for this tutorial)

Exercise 1 - `./step-02.sh`



A reminder about what is going on here...

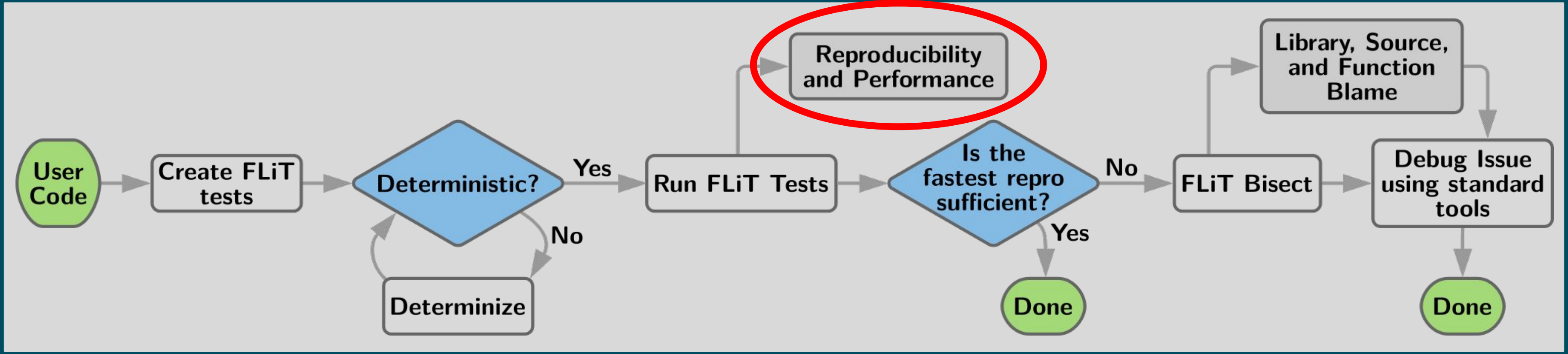
Exercise 1 - `./step-03.sh`

```
exercise-1 $ make run -j1
  mkdir results
  gtrun -> ground-truth.csv
  results/GCC_ip-172-31-8-101_FFAST_MATH_O3-out ->
results/GCC_ip-172-31-8-101_FFAST_MATH_O3-out-comparison.csv
  results/GCC_ip-172-31-8-101_FUNSAFE_MATH_OPTIMIZATIONS_O3-out ->
results/GCC_ip-172-31-8-101_FUNSAFE_MATH_OPTIMIZATIONS_O3-out-comparison.csv
  results/GCC_ip-172-31-8-101_MFMA_O3-out ->
results/GCC_ip-172-31-8-101_MFMA_O3-out-comparison.csv
  results/CLANG_ip-172-31-8-101_FFAST_MATH_O3-out ->
results/CLANG_ip-172-31-8-101_FFAST_MATH_O3-out-comparison.csv
  results/CLANG_ip-172-31-8-101_FUNSAFE_MATH_OPTIMIZATIONS_O3-out ->
results/CLANG_ip-172-31-8-101_FUNSAFE_MATH_OPTIMIZATIONS_O3-out-comparison.csv
  results/CLANG_ip-172-31-8-101_MFMA_O3-out ->
results/CLANG_ip-172-31-8-101_MFMA_O3-out-comparison.csv
  [...]
```

(takes about 1 minute)

- Runs the test and the `compare()` function

Exercise 1 - Analyze Results



Let us look at the generated results

They are in the `results/` directory

Exercise 1 - `./step-04.sh`

```
exercise-1 $ flit import results/*.csv
Creating results.sqlite
Importing results/CLANG_yoga-manjaro_FFAST_MATH_O3-out-comparison.csv
Importing results/CLANG_yoga-manjaro_FUNSAFE_MATH_OPTIMIZATIONS_O3-out-comparison.csv
Importing results/CLANG_yoga-manjaro_MFMA_O3-out-comparison.csv
Importing results/GCC_yoga-manjaro_FFAST_MATH_O3-out-comparison.csv
Importing results/GCC_yoga-manjaro_FUNSAFE_MATH_OPTIMIZATIONS_O3-out-comparison.csv
Importing results/GCC_yoga-manjaro_MFMA_O3-out-comparison.csv
```

Creates `results.sqlite`

Exercise 1 - `./step-05.sh`

```
 exercise-1 $ sqlite3 results.sqlite
SQLite version 3.28.0 2019-04-16 19:49:53
Enter ".help" for usage hints.
sqlite> .tables
runs   tests
sqlite> .headers on
sqlite> .mode column
sqlite> select * from runs;
id          rdate                       label
----------  --------------------------  ------------------
1           2019-07-08 23:05:19.358055  First FLiT Results
```

Two tables in the database:

1. `runs`: has our label and the date and time of importing
2. `tests`: test results with timing

Exercise 1 - `./step-06.sh`

```
sqlite> select compiler, optl, switches, comparison, nanosec from tests;
compiler      optl        switches      comparison  nanosec
------------  ----------  ------------  ----------  ----------
clang++-6.0   -O3         -ffast-math   0.0         2857386994
clang++-6.0   -O3         -funsafe-ma   0.0         2853588952
clang++-6.0   -O3         -mfma         0.0         2858789982
g++-7         -O3         -ffast-math   0.0         2841191528
g++-7         -O3         -funsafe-ma   0.0         2868636192
g++-7         -O3         -mfma         193.007351  2797305220
sqlite> .q
```

One compilation had 193% relative error!

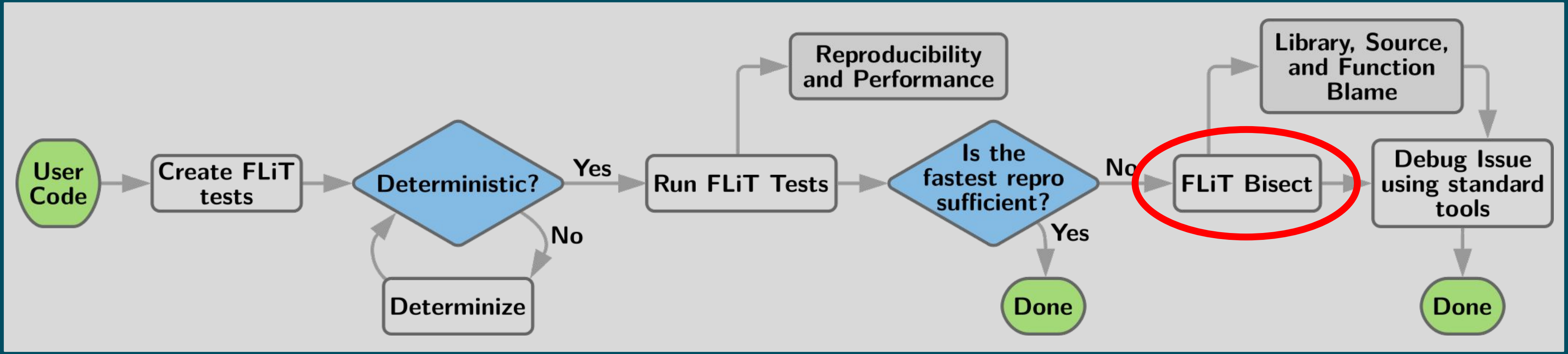
The others had no error.

Now to find the sites in the source code

Exercise 2

```
exercise-1 $ cd ../exercise-2
```

Exercise 2 - FLiT Bisect



We want to find the file(s)/function(s) where FMA caused 193% relative error

Compilation: `g++-7 -O3 -mfma`

Exercise 2 - `./step-07.sh`

What's Different?

```
exercise-2 $ diff -u ../exercise-1/custom.mk ./custom.mk
--- ../exercise-1/custom.mk 2019-07-01 16:09:39.239923037 -0600
+++ custom.mk 2019-07-01 16:07:41.090571010 -0600
@@ -17,9 +17,15 @@
 #SOURCE         += $(wildcard ${MFEM_SRC}/linalg/*.cpp)
 #SOURCE         += $(wildcard ${MFEM_SRC}/mesh/*.cpp)

-# just the one source file to see there is a difference
 SOURCE         += ${MFEM_SRC}/linalg/densemat.cpp  # where the bug is

+# a few more files to make the search space a bit more interesting
+SOURCE         += ${MFEM_SRC}/linalg/matrix.cpp
+SOURCE         += ${MFEM_SRC}/fem/gridfunc.cpp
+SOURCE         += ${MFEM_SRC}/fem/linearform.cpp
+SOURCE         += ${MFEM_SRC}/mesh/point.cpp
+SOURCE         += ${MFEM_SRC}/mesh/quadrilateral.cpp
+
 CC_REQUIRED    += -I${MFEM_SRC}
 CC_REQUIRED    += -I${MFEM_SRC}/examples
 CC_REQUIRED    += -isystem ${HYPRE_SRC}/src/hypre/include
```

Exercise 2 - `./step-08.sh`

Again, we need to regenerate the `Makefile`

```
exercise-2 $ flit update
Creating ./Makefile
```

Before we bisect, remember which compilation caused a problem:

`g++-7 -O3 -mfma`

Exercise 2 - `./step-09.sh`

```
 exercise-2 $ flit bisect --precision=double “g++-7 -O3 -mfma” Mfem13
Updating ground-truth results - ground-truth.csv - done
Searching for differing source files:
  Created ./bisect-04/bisect-make-01.mk - compiling and running - score 193.00735125466363
  Created ./bisect-04/bisect-make-02.mk - compiling and running - score 193.00735125466363
  Created ./bisect-04/bisect-make-03.mk - compiling and running - score 0.0
  Created ./bisect-04/bisect-make-04.mk - compiling and running - score 193.00735125466363
    Found differing source file /home/user1/Module-FLiT/packages/mfem/linalg/densemat.cpp: score
193.00735125466363
[...]
All variability inducing symbols:
  /home/user1/Module-FLiT/packages/mfem/linalg/ densemat.cpp:3692
_ZN4mfem13AddMult_a_AAtEdRKNS_11DenseMatrixERS0_ --  mfem::AddMult_a_AAt(double, mfem::DenseMatrix
const&, mfem::DenseMatrix&) (score 193.00735125466363)
```

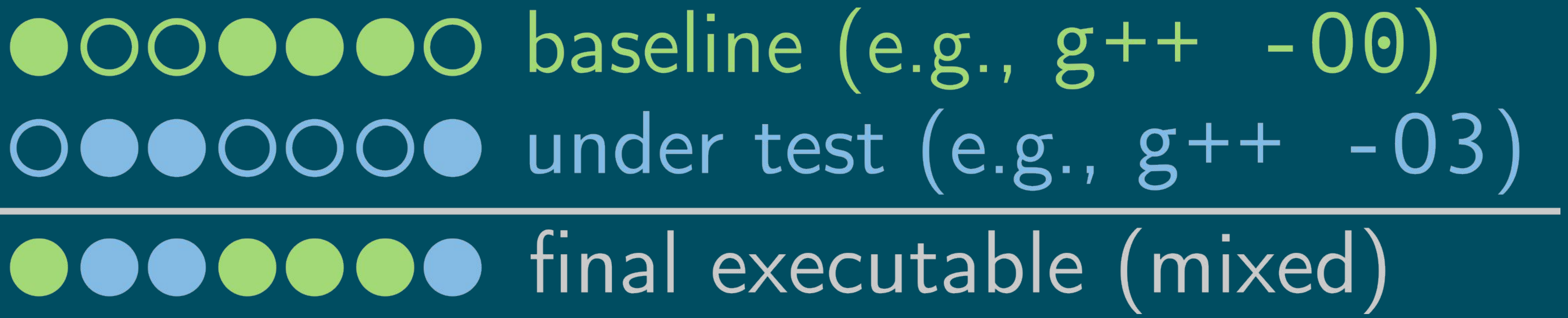
(takes approximately 1 minute 30 seconds)

- Finds the file: `densemat.cpp`
- Finds the function: `mfem::AddMult_a_AAt()`

Exercise 2 - Bisect Details

First locate variability files

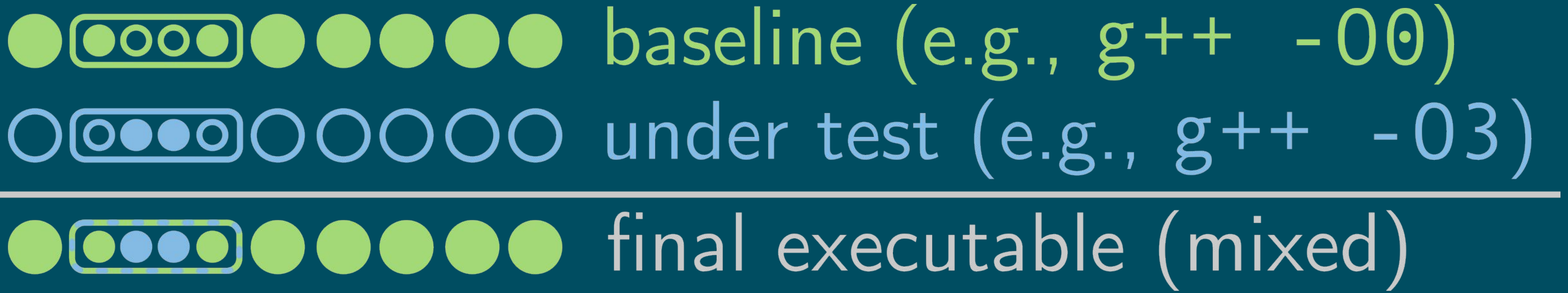
Approach: combine object files from the two compilations



Exercise 2 - Bisect Details

Approach: combine symbols **after compilation**

Convert function symbols into weak symbols



Downside: Requires recompiling with `-fPIC`

Exercise 2 - `./step-10.sh`

```
exercise-2 $ cat -n ../packages/mfem/linalg/densemat.cpp | tail -n +3688 | head -n 24
void AddMult_a_AAt(double a, const DenseMatrix &A, DenseMatrix &AAt)
{
  double d;

  for (int i = 0; i < A.Height(); i++)
  {
     for (int j = 0; j < i; j++)
     {
        d = 0.;
        for (int k = 0; k < A.Width(); k++)
        {
           d += A(i,k) * A(j,k);
        }
        AAt(i, j) += (d *= a);
        AAt(j, i) += d;
     }
     d = 0.;
     for (int k = 0; k < A.Width(); k++)
     {
        d += A(i,k) * A(i,k);
     }
     AAt(i, i) += a * d;
  }
}
```

Computes

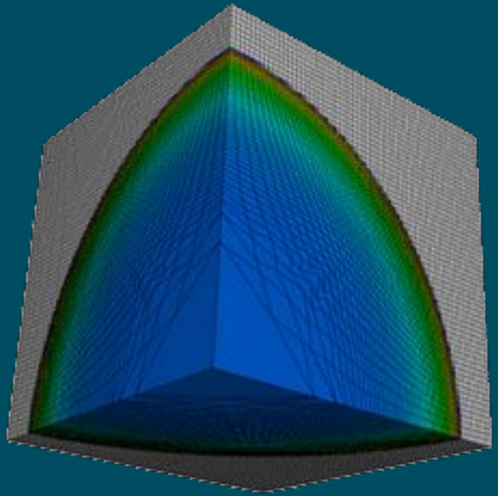
$$M = M + aAA^\top$$

Exercise 3

```
exercise-2 $ cd ../exercise-3
```

Exercise 3 Application: LULESH

- Proxy application developed at LLNL
- Models a shock hydrodynamics problem



Goal: explore more FLiT Bisect functionality

- Auto-Bisect all from `results.sqlite`
- Bisect-Biggest instead of Bisect-All

Exercise 3 - `./step-11.sh`

```
 exercise-3 $ sqlite3 results.sqlite
SQLite version 3.22.0 2018-01-22 18:45:57
Enter ".help" for usage hints.
sqlite> .headers on
sqlite> .mode column
sqlite> select compiler, optl, switches, comparison, nanosec from tests;
compiler      optl        switches             comparison            nanosec
------------  ----------  -------------------  --------------------  ----------
clang++-6.0   -O3         -freciprocal-math    5.52511478433538e-05  432218541
clang++-6.0   -O3         -funsafe-math-opt    5.52511478433538e-05  432185456
clang++-6.0   -O3                              0.0                   433397072
g++-7         -O3         -freciprocal-math    5.52511478433538e-05  441362811
g++-7         -O3         -funsafe-math-opt    7.02432004920159      436202864
g++-7         -O3         -mavx2 -mfma         1.02330009691563      416599918
g++-7         -O3                              0.0                   432654778
sqlite> .q
```

Five variability compilations.

Let’s investigate!

Exercise 3 - `./step-12.sh`

```
exercise-3 $ flit update
Creating ./Makefile
```

Nothing surprising here...

Exercise 3 - `./step-13.sh`

```
 exercise-3 $ flit bisect --auto-sqlite-run results.sqlite --parallel=1 --jobs=1
Before parallel bisect run, compile all object files
  (1 of 5) clang++ -O3 -freciprocal-math:  done
  (2 of 5) clang++ -O3 -funsafe-math-optimizations:  done
  (3 of 5) g++ -O3 -freciprocal-math:  done
  (4 of 5) g++ -O3 -funsafe-math-optimizations:  done
  (5 of 5) g++ -O3 -mavx2 -mfma:  done
Updating ground-truth results - ground-truth.csv - done

Run 1 of 5
flit bisect --precision double "clang++ -O3 -freciprocal-math" LuleshTest
Updating ground-truth results - ground-truth.csv - done
Searching for differing source files:
[...]
```

(takes approximately 3 min 10 sec)

Will automatically run all rows with `comparison > 0.0`

Let's look at the Bisect algorithm

How to Perform the Search

- **Problem:** search space is exponential
- **Problem:** floating-point errors combine in non-intuitive ways

Assumption 1: errors do not exactly cancel

- **Delta Debugging:** old but good idea $O(n \log n)$

Assumption 2: variability sites act alone

- **Linear Search:** simple $O(n)$
- **Logarithmic Search:** find one at a time $O(k \log n)$

Bisect Algorithm

- Simple divide and conquer
- Guaranteed to have no false positives
- False negatives identified automatically

Algorithm 1 Bisect Algorithm

```
procedure BisectAll(Test, items)
    found ← { }
    T ← Copy(items)
    while Test(T) > 0 do
        G, next ← BisectOne(Test, T)
        found ← found ∪ next
        T ← T \ G
    assert Test(items) = Test(found)
    return found
```

```
procedure BisectOne(Test, items)
    if Size(items) = 1 then                          ▷ base case
        assert Test(items) > 0
        return items, items
    Δ1, Δ2 ← SplitInHalf(items)
    if Test(Δ1) > 0 then
        return BisectOne(Test, Δ1)
    else
        G, next ← BisectOne(Test, Δ2)
        return G ∪ Δ1, next
```

Exercise 3 - `./step-14.sh`

```
exercise-3 $ head -n 3 auto-bisect.csv
testid,bisectnum,compiler,optl,switches,precision,testcase,type,name,return
1,1,clang++,-O3,-freciprocal-math,double,LuleshTest,completed,"lib,src,sym",0
1,1,clang++,-O3,-freciprocal-math,double,LuleshTest,src,"('tests/LuleshTest.cpp',
0.33294020544031533)",0
```

Results are placed in a CSV file for easy access

Exercise 3 - Bonus

Exercise 3 - efficiency

The 4th run (from auto-run) took 34 compilation / run steps.

```
Run 4 of 5
flit bisect --precision double "g++ -O3 -funsafe-math-optimizations" LuleshTest
  [...]
All variability inducing symbols:
  ../packages/LULESH/lulesh-init.cc:16 _ZN6DomainC1Eiiiiiiiii -- Domain::Domain(int, int, int,
int, int, int, int, int, int) (score 2.3302358973548727)
  ../packages/LULESH/lulesh-init.cc:219 _ZN6Domain9BuildMeshEiii -- Domain::BuildMesh(int, int,
int) (score 1.4315005606175104)
  ../packages/LULESH/lulesh.cc:1362 _Z14CalcElemVolumePKdS0_S0_ -- CalcElemVolume(double const*,
double const*, double const*) (score 0.9536115035892543)
  ../packages/LULESH/lulesh.cc:1507 _Z22CalcKinematicsForElemsR6Domaindi --
CalcKinematicsForElems(Domain&, double, int) (score 0.665781828022106)
  ../packages/LULESH/lulesh.cc:2651 _Z11lulesh_mainiPPc -- lulesh_main(int, char**) (score
0.3328909140110529)
```

Can we do better?

What if we only want the **top contributing function**?

Exercise 3 - `./step-15.sh`

```
exercise-3 $ flit bisect --biggest=1 --precision=double "g++-7 -O3 -funsafe-math-optimizations"
LuleshTest
Updating ground-truth results - ground-truth.csv - done
Looking for the top 1 different symbol(s) by starting with files
  [...]
    Found differing source file ../packages/LULESH/lulesh-init.cc: score 3.7609285311270604
    Searching for differing symbols in: ../packages/LULESH/lulesh-init.cc
      [...]
        Found differing symbol on line 16 -- Domain::Domain(int, int, int, int, int, int, int,
int, int) (score 2.3302358973548727)
  [...]
  Created ./bisect-06/bisect-make-20.mk - compiling and running - score 0.022750390077923448
    Found differing source file tests/LuleshTest.cpp: score 0.022750390077923448
[...]
The 1 highest variability symbol:
  ../packages/LULESH/lulesh-init.cc:16 _ZN6DomainC1Eiiiiiiiii --  Domain::Domain(int, int, int,
int, int, int, int, int, int) (score 2.3302358973548727)
```

- Found the same highest variability function: `Domain::Domain()`
- Found it in 20 compile/run cycles instead of 34
- Searches for symbols after each file

Thank You!

Questions?

pruners.github.io/flit