

Precimonious Tuning Assistant for Floating- Point Precision Tuning



<http://fpanalysistools.org/>

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Ignacio Laguna, Harshitha Menon
Lawrence Livermore National Laboratory

Michael Bentley, Ian Briggs, Ganesh Gopalakrishnan
University of Utah

Cindy Rubio-González
University of California at Davis

Floating-Point Precision Tuning

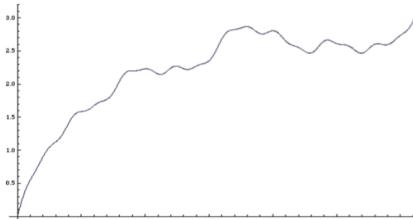
- Floating-point (FP) arithmetic used in variety of domains
- Reasoning about FP programs is difficult
 - Large variety of numerical problems
 - Most programmers are not experts in FP
- Common practice: use highest available precision
 - Disadvantage: more expensive!
- Goal: automated technique to assist in tuning floating-point precision



Example: Arc Length

- Consider the problem of finding the arc length of the function

$$g(x) = x + \sum_{0 \leq k \leq 5} 2^{-k} \sin(2^k x)$$



- Summing for $x_k \in (0, \pi)$ into n subintervals

$$\sum_{k=0}^{n-1} \sqrt{h^2 + (g(x_{k+1}) - g(x_k))^2} \quad \text{with } h = \pi/n \quad \text{and } x_k = kh$$

Precision	Slowdown	Result
double-double	20X	5.795776322412856
double	1X	5.795776322413031
mixed precision	< 2X	5.795776322412856

1
2
3

Example: Arc Length

```
long double g(long double x) {
    int k, n = 5;
    long double t1 = x;
    long double d1 = 1.0L;

    for(k = 1; k <= n; k++) {
        ...
    }
    return t1;
}

int main() {
    int i, n = 1000000;
    long double h, t1, t2, dppi;
    long double s1;
    ...
    for(i = 1; i <= n; i++) {
        t2 = g(i * h);
        s1 = s1 + sqrt(h*h + (t2 - t1)*(t2 - t1));
        t1 = t2;
    }
    // final answer stored in variable s1
    return 0;
}
```

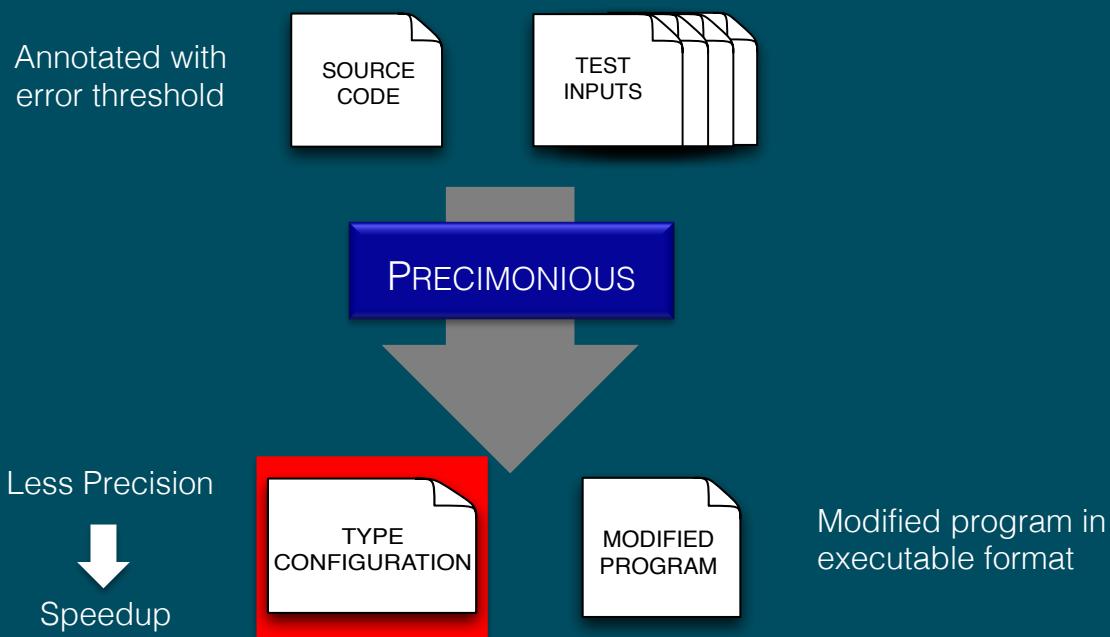


Mixed Precision
Program

Precimonious

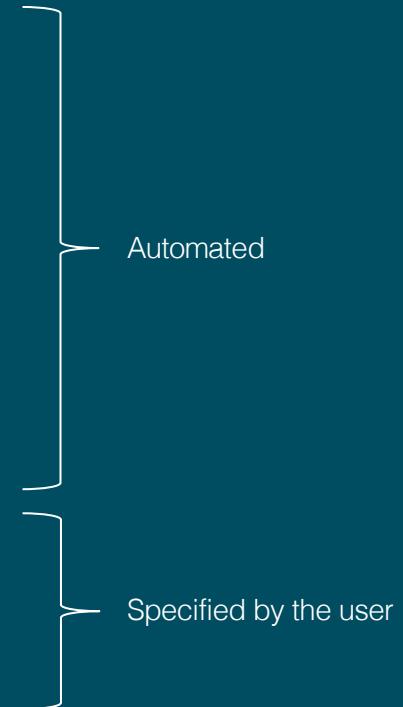
"Parsimonious or Frugal with Precision"

Dynamic Analysis for Floating-Point Precision Tuning



Challenges for Precision Tuning

- Searching efficiently over variable types and function implementations
 - Naïve approach -> exponential time
 - 19,683 configurations for arclength program (3^9)
 - 11 hours 5 minutes
 - Global minimum vs. Local minimum
- Evaluating type configurations
 - Less precision not necessarily faster
 - Based on runtime, energy consumption, etc.
- Determining accuracy constraints
 - How accurate must the final result be?
 - What error threshold to use?



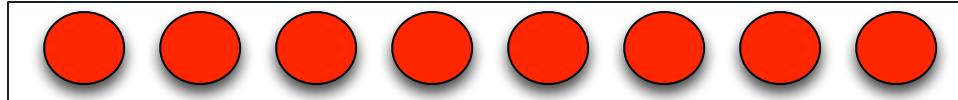


Precimonious Search Algorithm

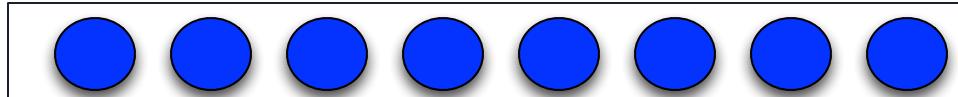
- Based on Delta Debugging Algorithm (TSE'?)
- Our definition of a change
 - Lowering the precision of a floating-point variable in the program
 - Example: double x -> float x
- Main idea
 - We can do better than making a change at the time
 - Start by dividing the change set into two equally sized subsets
 - Narrow the search to the subset that satisfies the success criteria
 - Otherwise, increase the number of subsets
- Our success criteria
 - Resulting program produces an answer within the given error threshold
 - Resulting program is faster than original program
- Find local minimum
 - Lowering the precision of any one more variable violates the success criteria

Searching for Type Configuration

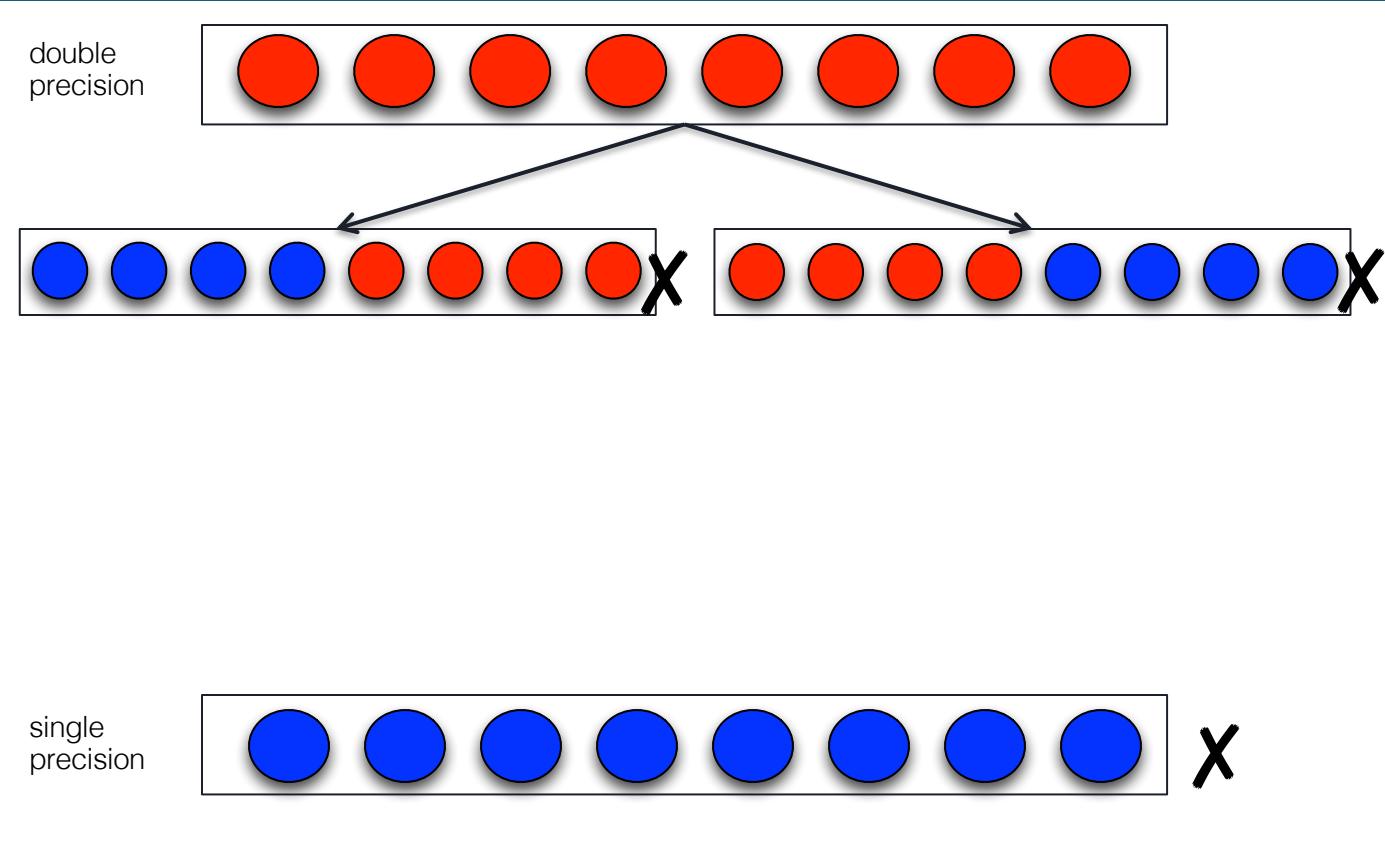
double
precision



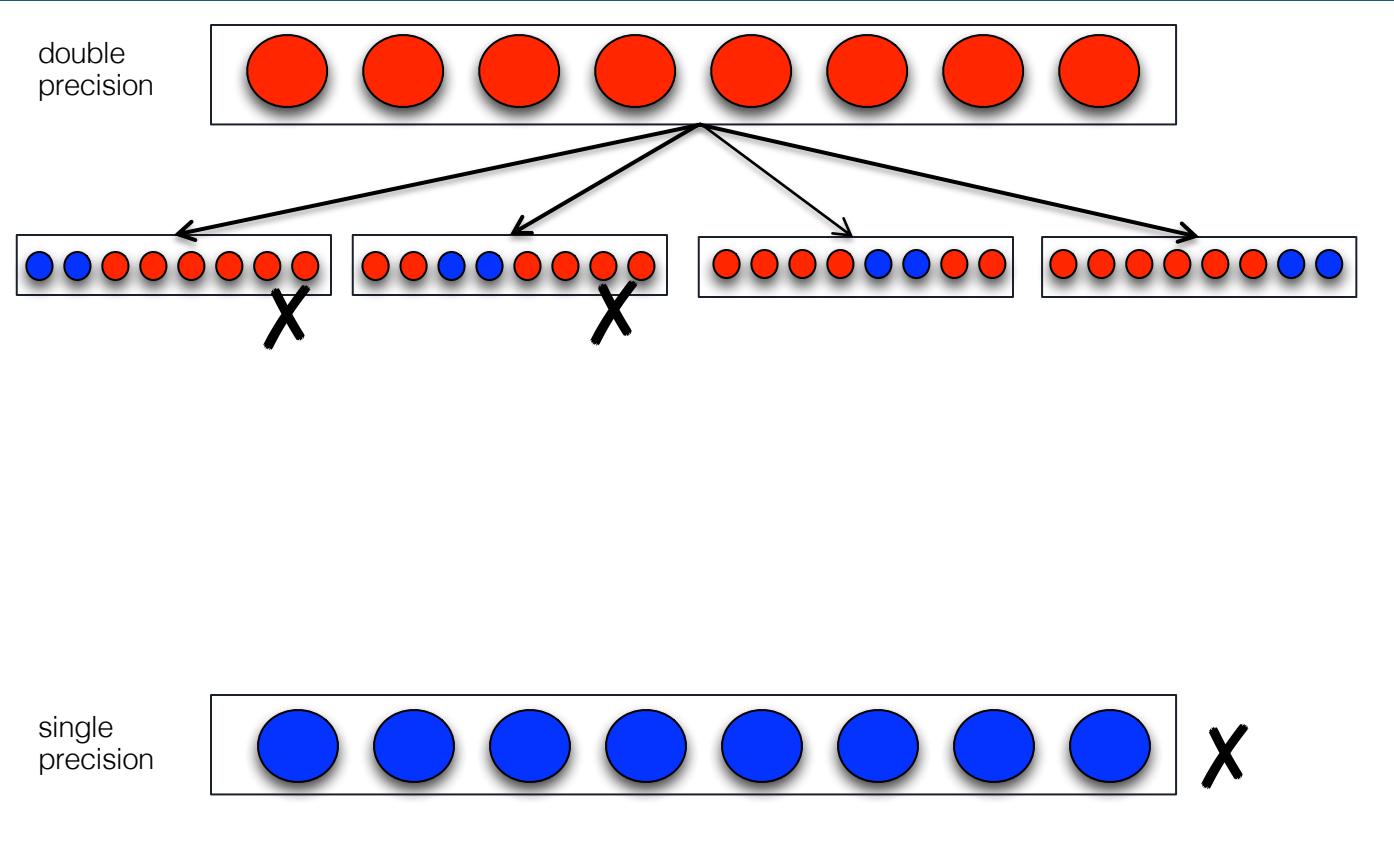
single
precision



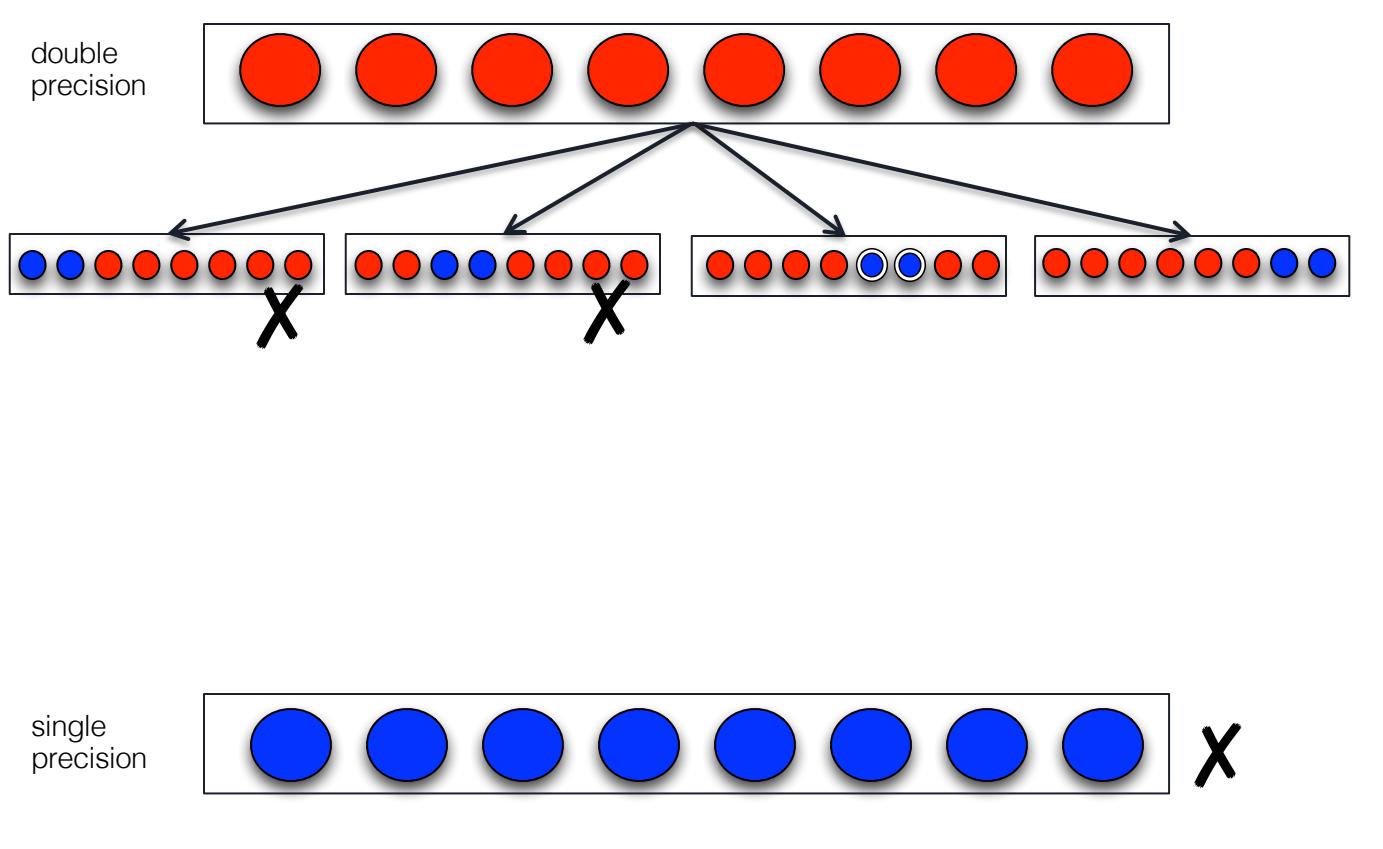
Searching for Type Configuration



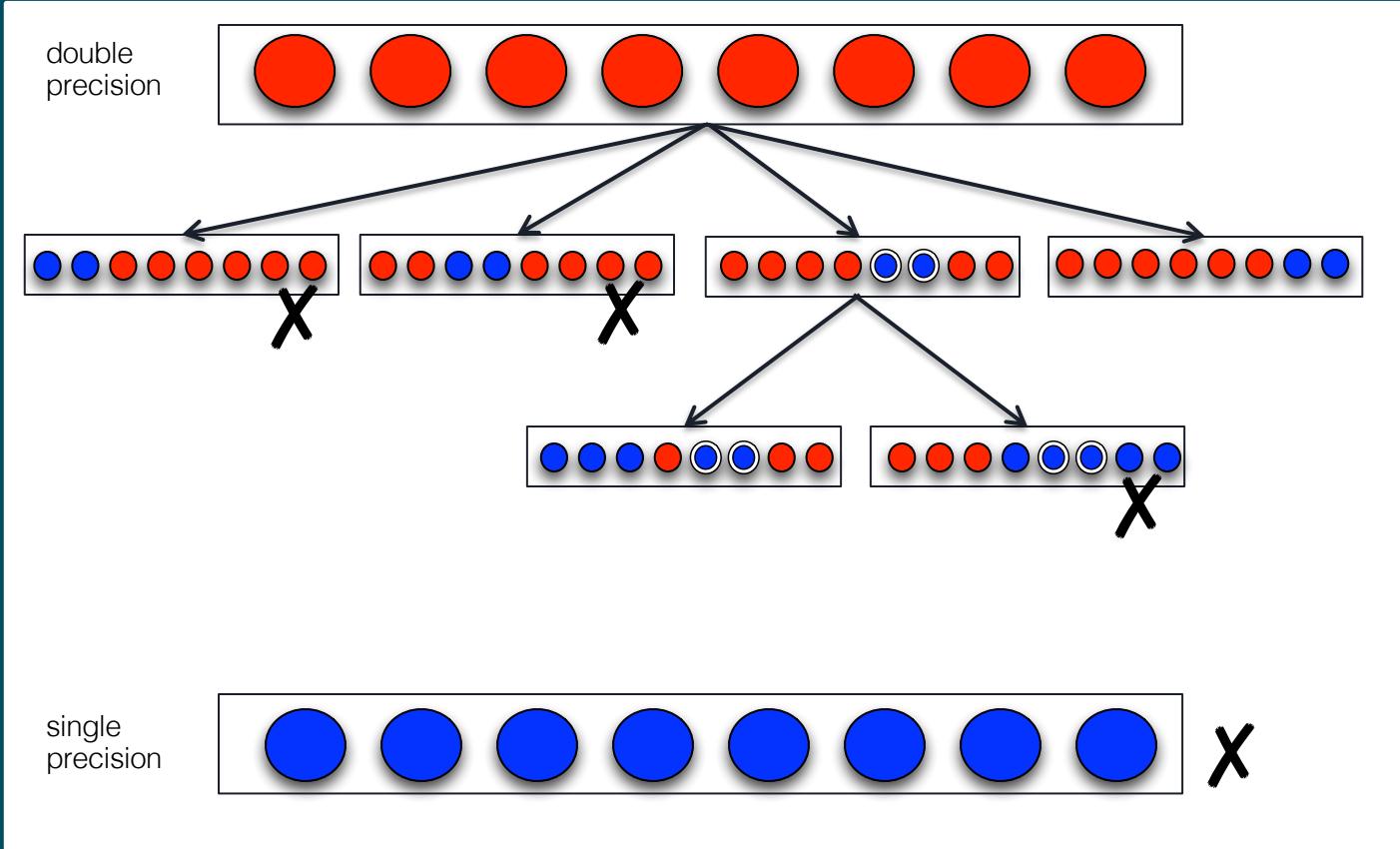
Searching for Type Configuration



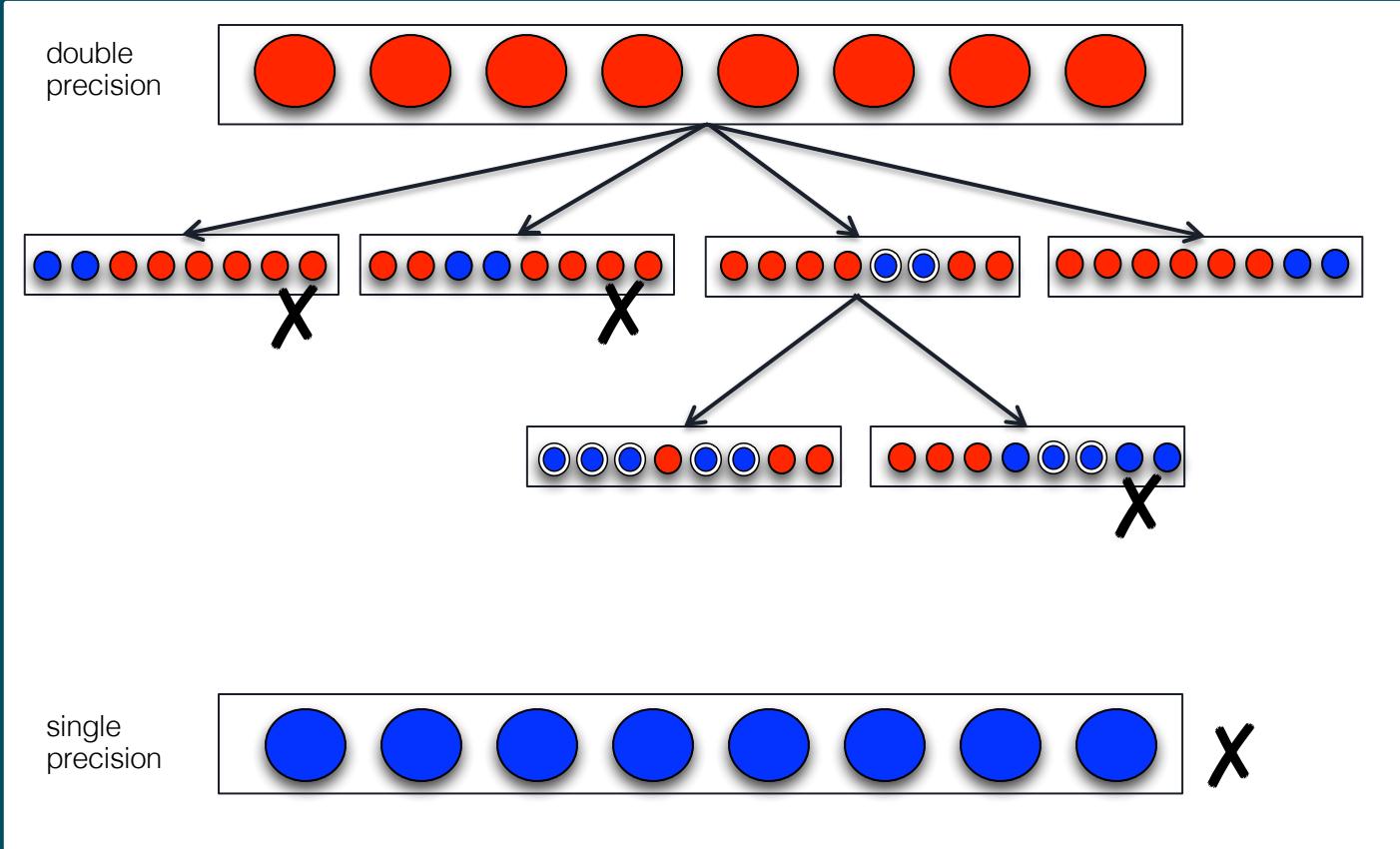
Searching for Type Configuration



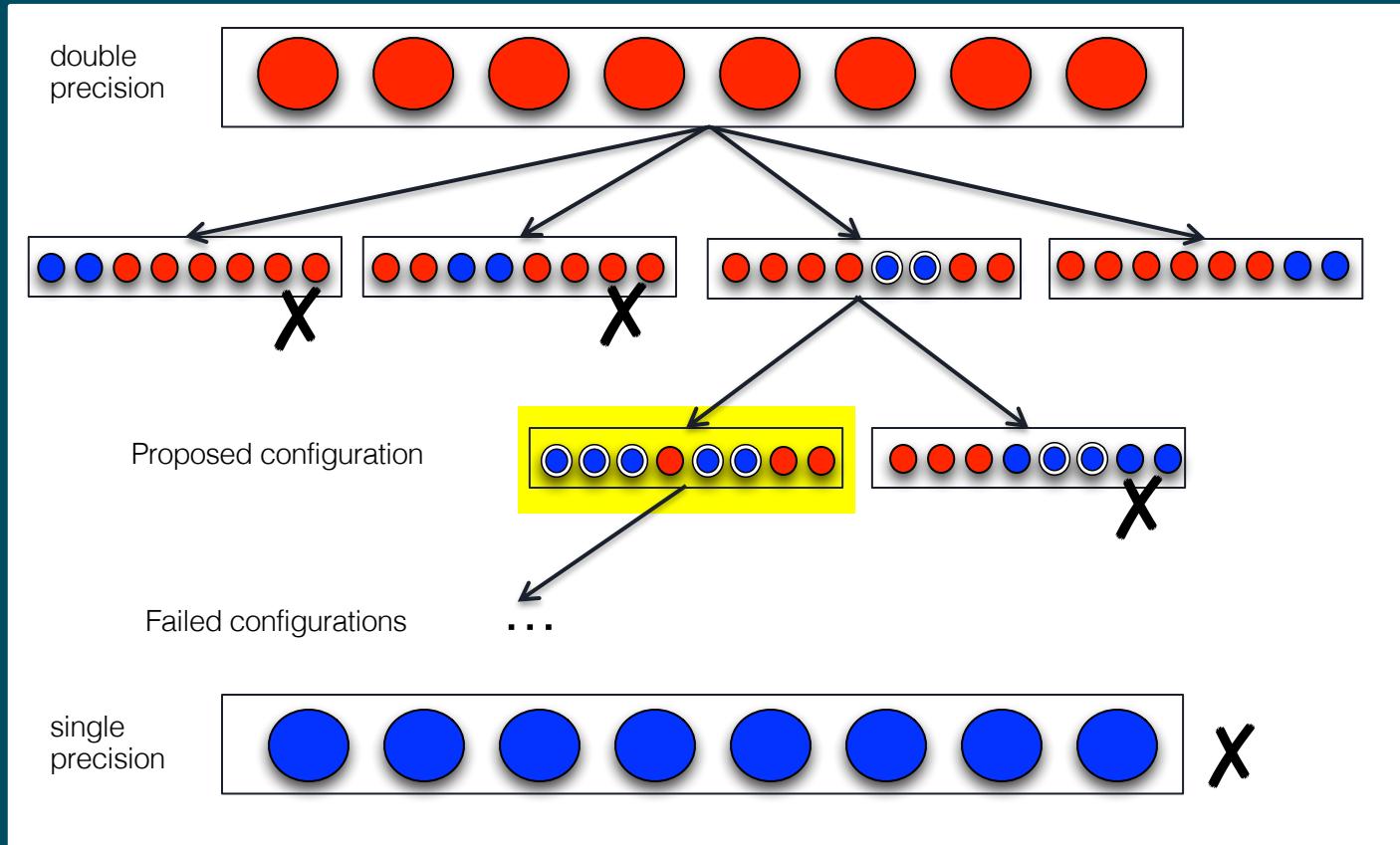
Searching for Type Configuration



Searching for Type Configuration



Searching for Type Configuration





Applying Type Configuration

- Automatically generate program variants
 - Reflect type configurations produced by the algorithm
- Intermediate representation
 - LLVM IR
- Transformation rules for each LLVM instruction
 - alloca, load, store, fadd, fsub, fpext, fptrunc, etc.
 - Changes equivalent to modifying the program at the source level
 - Clang plugin to provide modified source code (not discussed today)
- Able to run resulting modified program
 - Evaluate type configuration: accuracy & performance



Limitations

- Type configurations rely on inputs tested
 - No guarantees if worse conditioned input
 - Could be combined with input generation tools (e.g., S3FP)
- Getting trapped in local minimum
- Analysis scalability
 - Approach does not scale well for long-running applications
 - Need to reduce search space and reduce number of runs
 - Check out our follow up work on Blame Analysis (ICSE'16)
- Analysis effectiveness
 - Approach does not exploit relationship among variables
 - Check out our follow up work on HiFPTuner (ISSTA'18)

Source code available:
<https://github.com/corvette/precimonious>

Questions?

Exercises



Exercises with Precimonious

1. Run Precimonious on sample program funarc
2. Run Precimonious on sample program simpsons

Directory Structure

```
/Module-Precimonious
|---/exercise-1
|---/exercise-2
```

Exercise 1

Step 1: Build Precimonious

- Open setup.sh file
- Precimonious uses LLVM and is built using scons
- Execute :
 - \$./setup.sh

```
clang -c -emit-llvm -o src/tests/test11/source.bc src/tests/test11/source.c
opt -load src/Passes.so -variables -adjust-operators --die --time-passes -include=src/tests/test11/include.txt -exclude=src/tests/test11/exclude.txt -json-config=src/tests/test11/source.json -output=src/tests/test11/transformed.bc src/tests/test11/source.bc > src/tests/test11/transformed.bc
** Changing precision of variables
    Variable a: double* -> float*
** Replacing function calls
=====
        ... Pass execution timing report ...
=====
Total Execution Time: 0.0000 seconds (0.0090 wall clock)

---Wall Time--- --- Name ---
0.0032 ( 35.3%) Dead Instruction Elimination
0.0017 ( 19.1%) Parse config file
0.0012 ( 13.0%) Adjusts the precision of operators depending on new types for operands
0.0008 ( 9.1%) Dominator Tree Construction
0.0008 ( 8.6%) Create bitcode with ids
0.0007 ( 7.7%) Bitcode Writer
0.0003 ( 3.5%) Module Verifier
0.0001 ( 1.7%) Preliminary module verification
0.0001 ( 1.3%) Change the precision of variables
0.0001 ( 0.7%) Replaces function calls
0.0000 (100.0%) Total

clang -c -emit-llvm -o src/tests/test11/expected.bc src/tests/test11/expected.c
lli src/tests/test11/expected.bc src/tests/test11/spec.cov
lli src/tests/test11/transformed.bc src/tests/test11/spec.cov src/tests/test11/log.cov src/tests/test11/result.out
Checking result value in file "src/tests/test11/result.out"
Touch("src/tests/test11/transformed.passed")
scons: done building targets.
```

Success building and running tests

<http://fpanalysistools.org/>

Step 2: Annotate Program (already done)

- Execute :

- \$ cd exercise-1
- \$ ls

The program we will tune:

```
root@2b744b834ee7:~/Module-Precimonious/exercise-1# ls
Makefile      funarc.c          reference    run-dependencies.sh
exclude.txt   include.txt      run-analysis.sh spec.csv
exclude_local.txt  include_global.txt run-config.sh
```

- Open funarc.c file

Accuracy logging & checking

Performance logging

```
***** BEGIN PRECIMONIOUS ACCURACY and PERFORMANCE LOGGING*****
threshold = result*pow(10, epsilon);

// cov_spec_log("spec.csv", threshold, 1, result);
cov_log("result", "log.csv", 1, result);
cov_check("log.csv", "spec.csv", 1);

FILE* file = fopen("score.csv", "w");
fprintf(file, "%ld\n", diff);
fclose(file);
***** END PRECIMONIOUS ACCURACY and PERFORMANCE LOGGING *****
```

Step 3: Compile Program with Clang

- Execute :
 - \$ make clean
 - \$ make

```
root@2b744b834ee7:~/Module-Precimonious/exercise-1# make
/root/llvm-3.0/bin/clang -emit-llvm -c -I/root/Module-Precimonious/precimonious/logging/ -Wno-unused-value funarc.c -o temp_funarc.bc
/root/llvm-3.0/bin/clang -emit-llvm -c /root/Module-Precimonious/precimonious/logging//cov_checker.c -o cov_checker.bc
/root/llvm-3.0/bin/clang -emit-llvm -c /root/Module-Precimonious/precimonious/logging//timers.c -o timers.bc
/root/llvm-3.0/bin/clang -emit-llvm -c /root/Module-Precimonious/precimonious/logging//cov_serializer.c -o cov_serializer.bc
/root/llvm-3.0/bin/clang -emit-llvm -c /root/Module-Precimonious/precimonious/logging//cov_log.c -o cov_log.bc
/root/llvm-3.0/bin/clang -emit-llvm -c /root/Module-Precimonious/precimonious/logging//cov_rand.c -o cov_rand.bc
/root/llvm-3.0/bin/llvm-link -o funarc.bc temp_funarc.bc cov_checker.bc cov_serializer.bc cov_log.bc cov_rand.bc timers.bc
/root/llvm-3.0/bin/opt -O2 funarc.bc -o original_funarc.bc
/root/llvm-3.0/bin/llc original_funarc.bc -o original_funarc.s
/root/llvm-3.0/bin/clang original_funarc.s -lm -o original_funarc.out
root@2b744b834ee7:~/Module-Precimonious/exercise-1#
```

- Creates LLVM bitcode file and optimized executable for later use

```
root@2b744b834ee7:~/Module-Precimonious/exercise-1# ls
Makefile           exclude_local.txt  original_funarc.out  spec.csv
cov_checker.bc     funarc.bc        original_funarc.s  temp_funarc.bc
cov_log.bc         funarc.c        reference          timers.bc
cov_rand.bc        include.txt    run-analysis.sh
cov_serializer.bc  include_global.txt run-config.sh
exclude.txt        original_funarc.bc run-dependencies.sh
root@2b744b834ee7:~/Module-Precimonious/exercise-1#
```

Step 4: Run Analysis on Program

- Execute :
 - \$./run-analysis.sh funarc

Type changes are listed for each explored configuration

Suggested type configuration
<http://fpanalysistools.org/>

Sample output:

```
** Exploring configuration #108
** Changing precision of variables
  Variable t1: x86_fp80 -> double
  Variable d1: x86_fp80 -> float
  Variable s1: x86_fp80 -> double
  Variable t1: x86_fp80 -> double
  Variable t2: x86_fp80 -> double
  Variable h: x86_fp80 -> float
  Variable dppi: x86_fp80 -> float
** Replacing function calls
  Function call: acos ->acosf
  Function call: sqrt ->sqrtf
** Result is NOT within error threshold

** Exploring configuration #109
** Changing precision of variables
  Variable t1: x86_fp80 -> double
  Variable d1: x86_fp80 -> float
  Variable s1: x86_fp80 -> double
  Variable t1: x86_fp80 -> double
  Variable t2: x86_fp80 -> double
  Variable h: x86_fp80 -> double
  Variable dppi: x86_fp80 -> float
** Replacing function calls
  Function call: acos ->acosf
  Function call: sqrt ->sqrtf
** Result is within error threshold

Check dd2_valid_funarc.bc.json for the valid configuration file
root@ZD744D834EE7:~/Module-Precimontous/exercise-1#
```

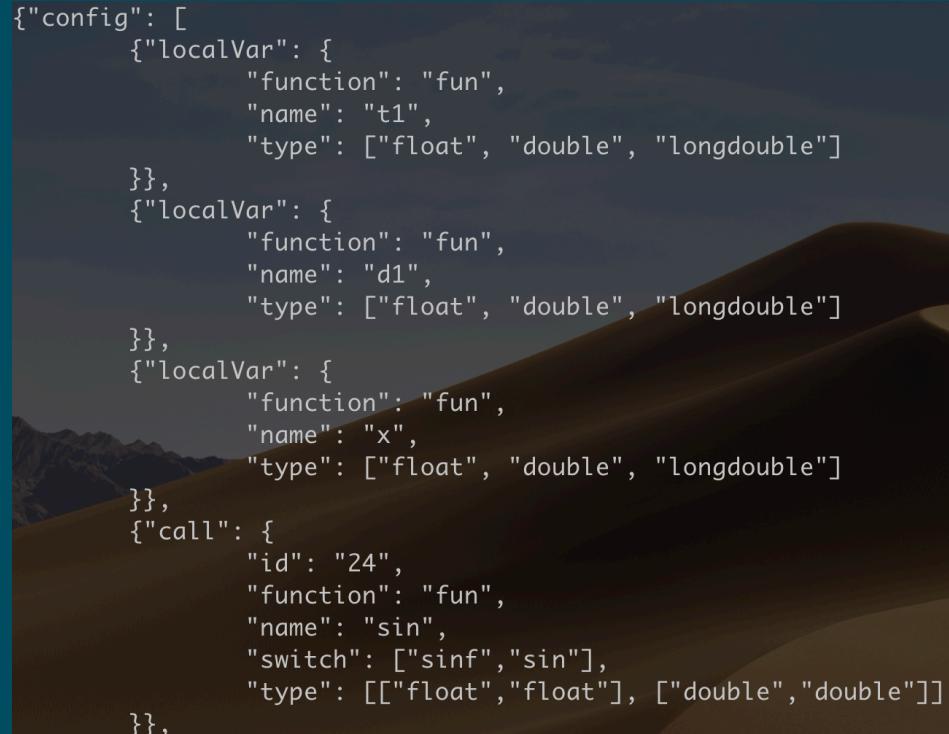
Step 4: Run Analysis – Configuration File

- Open config_funarc.json
- Original type configuration

```
{"config": [    {"localVar": {        "function": "fun",        "name": "t1",        "type": "longdouble"    }},    {"localVar": {        "function": "fun",        "name": "d1",        "type": "longdouble"    }},    {"localVar": {        "function": "fun",        "name": "x",        "type": "longdouble"    }},    {"call": {        "id": "24",        "function": "fun",        "name": "sin",        "switch": "sin",        "type": ["double", "double"]    }}],    "global": {        "function": "sin",        "name": "sin",        "type": "longdouble"    }}
```

Step 4: Run Analysis – Search File

- Open search_funarc.json
- Search space file
- To exclude functions edit exclude.txt
- To exclude variables edit exclude_local.txt
- Or you can directly edit search file prior to analysis



```
{"config": [    {"localVar": {        "function": "fun",        "name": "t1",        "type": ["float", "double", "longdouble"]    }},    {"localVar": {        "function": "fun",        "name": "d1",        "type": ["float", "double", "longdouble"]    }},    {"localVar": {        "function": "fun",        "name": "x",        "type": ["float", "double", "longdouble"]    }},    {"call": {        "id": "24",        "function": "fun",        "name": "sin",        "switch": ["sinf", "sin"],        "type": [[["float", "float"], ["double", "double"]]]    }}],
```

Step 4: Run Analysis – Output Files

- Execute :

- \$ cd results
- \$ ls

```
root@2b744b834ee7:~/Module-Precimonious/exercise-1/results# ls
FAIL1_config_funarc.bc_3.json      INVALID_config_funarc.bc_38.json    INVALID_config_funarc.bc_72.json    VALID_config_funarc.bc_17.json
INVALID_config_funarc.bc_4.json      INVALID_config_funarc.bc_39.json    INVALID_config_funarc.bc_73.json    VALID_config_funarc.bc_19.json
INVALID_config_funarc.bc_10.json     INVALID_config_funarc.bc_40.json    INVALID_config_funarc.bc_74.json    VALID_config_funarc.bc_2.json
INVALID_config_funarc.bc_100.json    INVALID_config_funarc.bc_41.json    INVALID_config_funarc.bc_75.json    VALID_config_funarc.bc_25.json
INVALID_config_funarc.bc_101.json    INVALID_config_funarc.bc_43.json    INVALID_config_funarc.bc_76.json    VALID_config_funarc.bc_27.json
INVALID_config_funarc.bc_102.json    INVALID_config_funarc.bc_44.json    INVALID_config_funarc.bc_77.json    VALID_config_funarc.bc_42.json
INVALID_config_funarc.bc_103.json    INVALID_config_funarc.bc_45.json    INVALID_config_funarc.bc_78.json    VALID_config_funarc.bc_54.json
INVALID_config_funarc.bc_104.json    INVALID_config_funarc.bc_46.json    INVALID_config_funarc.bc_79.json    VALID_config_funarc.bc_60.json
INVALID_config_funarc.bc_105.json    INVALID_config_funarc.bc_47.json    INVALID_config_funarc.bc_8.json     VALID_config_funarc.bc_7.json
INVALID_config_funarc.bc_106.json    INVALID_config_funarc.bc_48.json    INVALID_config_funarc.bc_80.json    VALID_config_funarc.bc_70.json
INVALID_config_funarc.bc_107.json    INVALID_config_funarc.bc_49.json    INVALID_config_funarc.bc_81.json    VALID_config_funarc.bc_82.json
INVALID_config_funarc.bc_108.json    INVALID_config_funarc.bc_5.json     INVALID_config_funarc.bc_83.json    config_temp.json
INVALID_config_funarc.bc_12.json    INVALID_config_funarc.bc_50.json    INVALID_config_funarc.bc_84.json    dd2_diff_funarc.bc.json
INVALID_config_funarc.bc_13.json    INVALID_config_funarc.bc_51.json    INVALID_config_funarc.bc_85.json    dd2_diff_funarc.bc_0.json
INVALID_config_funarc.bc_14.json    INVALID_config_funarc.bc_52.json    INVALID_config_funarc.bc_86.json    dd2_diff_funarc.bc_109.json
INVALID_config_funarc.bc_16.json    INVALID_config_funarc.bc_53.json    INVALID_config_funarc.bc_87.json    dd2_diff_funarc.bc_11.json
INVALID_config_funarc.bc_18.json    INVALID_config_funarc.bc_55.json    INVALID_config_funarc.bc_88.json    dd2_diff_funarc.bc_15.json
INVALID_config_funarc.bc_20.json    INVALID_config_funarc.bc_56.json    INVALID_config_funarc.bc_89.json    dd2_diff_funarc.bc_17.json
INVALID_config_funarc.bc_21.json    INVALID_config_funarc.bc_57.json    INVALID_config_funarc.bc_9.json     dd2_diff_funarc.bc_19.json
INVALID_config_funarc.bc_22.json    INVALID_config_funarc.bc_58.json    INVALID_config_funarc.bc_90.json    dd2_diff_funarc.bc_2.json
INVALID_config_funarc.bc_23.json    INVALID_config_funarc.bc_59.json    INVALID_config_funarc.bc_91.json    dd2_diff_funarc.bc_25.json
INVALID_config_funarc.bc_24.json    INVALID_config_funarc.bc_6.json     INVALID_config_funarc.bc_92.json    dd2_diff_funarc.bc_27.json
INVALID_config_funarc.bc_26.json    INVALID_config_funarc.bc_61.json    INVALID_config_funarc.bc_93.json    dd2_diff_funarc.bc_42.json
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INVALID_config_funarc.bc_32.json    INVALID_config_funarc.bc_66.json    INVALID_config_funarc.bc_98.json    dd2_diff_funarc.bc_82.json
INVALID_config_funarc.bc_33.json    INVALID_config_funarc.bc_67.json    INVALID_config_funarc.bc_99.json    dd2_valid_funarc.bc.json
INVALID_config_funarc.bc_34.json    INVALID_config_funarc.bc_68.json    log_dd
INVALID_config_funarc.bc_35.json    INVALID_config_funarc.bc_69.json    output.txt
INVALID_config_funarc.bc_36.json    INVALID_config_funarc.bc_71.json    VALID_config_funarc.bc_105.json
INVALID_config_funarc.bc_37.json    INVALID_config_funarc.bc_72.json    VALID_config_funarc.bc_11.json
root@2b744b834ee7:~/Module-Precimonious/exercise-1/results#
```

Step 4: Run Analysis – Output Files

- Open dd2_valid_funarc.bc.json: suggested configuration file in JSON format
- Open dd2_diff_funarc.bc.json: summary of type changes

```
localVar: d1  at fun longdouble -> float
localVar: s1  at main longdouble -> double
localVar: t1  at main longdouble -> double
localVar: t2  at main longdouble -> double
localVar: h   at main longdouble -> double
localVar: dppi  at main longdouble -> float
call: acos at mainacos -> acosf
call: sqrt at mainsqrt -> sqrtf
```

Step 5: Apply Result Configuration & Compare Performance

- Execute :

- \$./run-config.sh funarc

- Execute :

- \$ time ./original_funarc.out
 - \$ time ./tuned_funarc.out

```
root@2b744b834ee7:~/Module-Precimonious/exercise-1# ./run-config.sh funarc
** Applying precimonious configuration
** Changing precision of variables
    Variable t1: x86_fp80 -> double
    Variable d1: x86_fp80 -> float
    Variable s1: x86_fp80 -> double
    Variable t1: x86_fp80 -> double
    Variable t2: x86_fp80 -> double
    Variable h: x86_fp80 -> double
    Variable dppi: x86_fp80 -> float
** Replacing function calls
    Function call: acos -> acosf
    Function call: sqrt -> sqrtf
** Result is within error threshold

Run the following to compare performance:
time ./original_funarc.out
time ./tuned_funarc.out
root@2b744b834ee7:~/Module-Precimonious/exercise-1#
```

Exercise 2



Exercise 2: Run Precimonious on simpsons program

- Open exercise-2/simpsons.c to see annotated program
- Execute :
 - cd .../exercise-2
 - make clean
 - make
 - ./run-analysis.sh simpsons
 - ./run-config.sh simpsons
- Open results/dd2_valid_simpsons.bc.json to see configuration in JSON format
- Open results/dd2_diff_simpsons.bc.json to see difference between original program and proposed configuration

Collaborators

University of California, Berkeley



Cuong
Nguyen



Diep
Nguyen



Ben
Mehne



James
Demmel



William
Kahan



Koushik
Sen

Lawrence Berkeley National Lab



Costin
Iancu



David
Bailey



Wim
Lavrijsen

Oracle



David
Hough

Source code available:
<https://github.com/corvette/precimonious>

Questions?