Precimonious

Tuning Assistant for Floating-Point Precision Tuning

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Floating-Point Precision Tuning

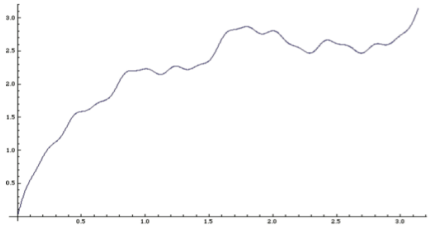
- Floating-point arithmetic used in variety of domains
- Reasoning about FP programs is difficult
  - Large variety of numerical problems
  - Most programmers are not experts in FP

- Common practice: use highest available precision
  - Disadvantage: more expensive!
- Goal: develop automated techniques to assist in tuning floating-point precision

Example: Arc Length

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

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



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

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

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

Example: Arc Length

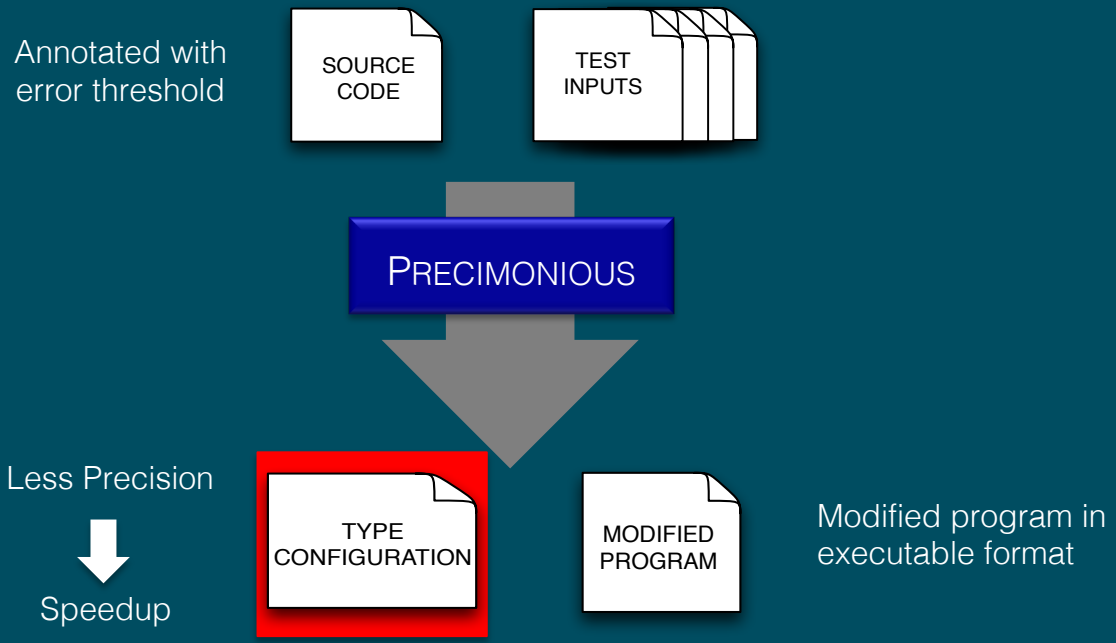
```
long double g(long double x) {
  int k, n = 5;
  long double t1 = x;
  long double d1 = 1.0L;

  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



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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?

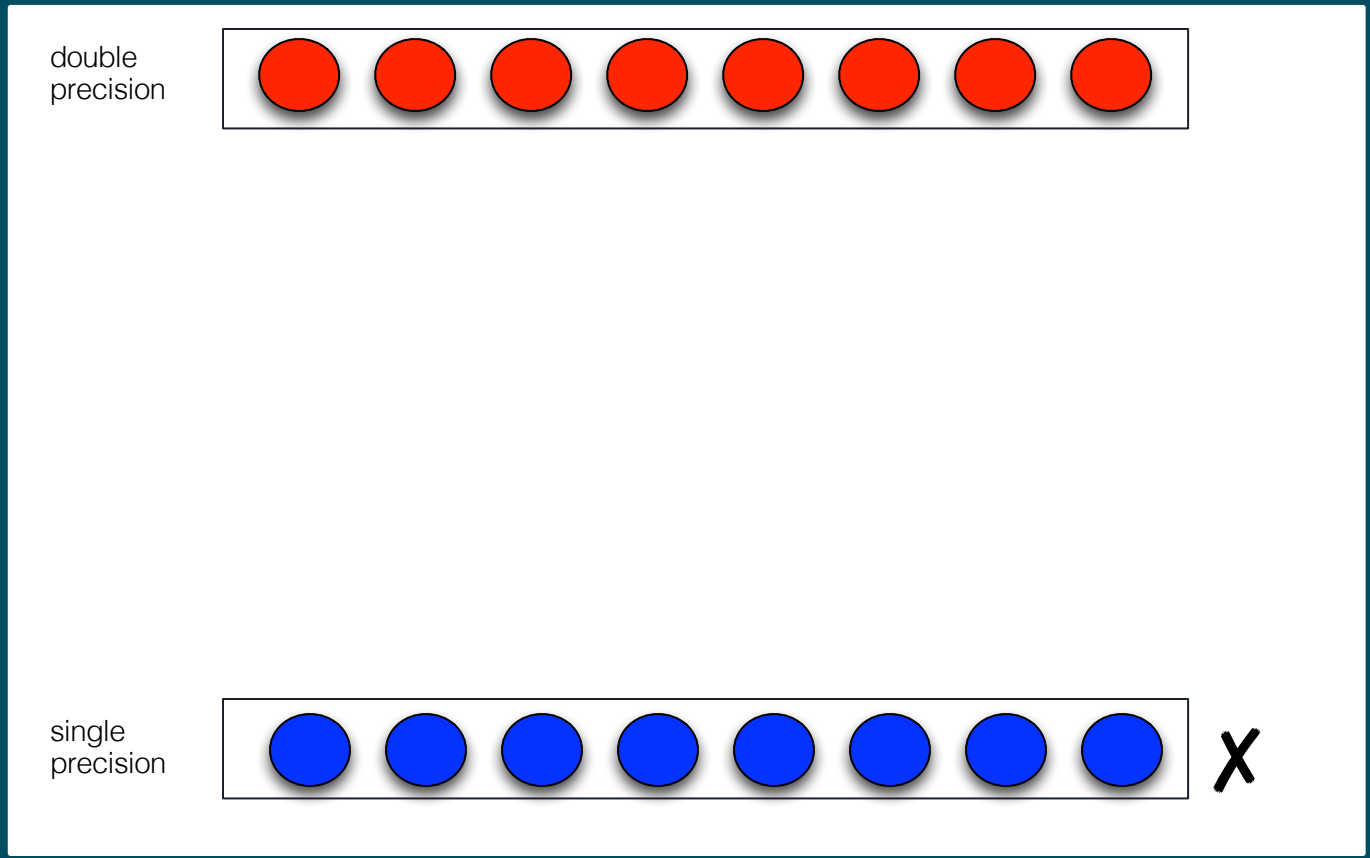
Automated

Specified by the user

Precimonious Search Algorithm

- 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 variable violates the success criteria

Searching for Type Configuration



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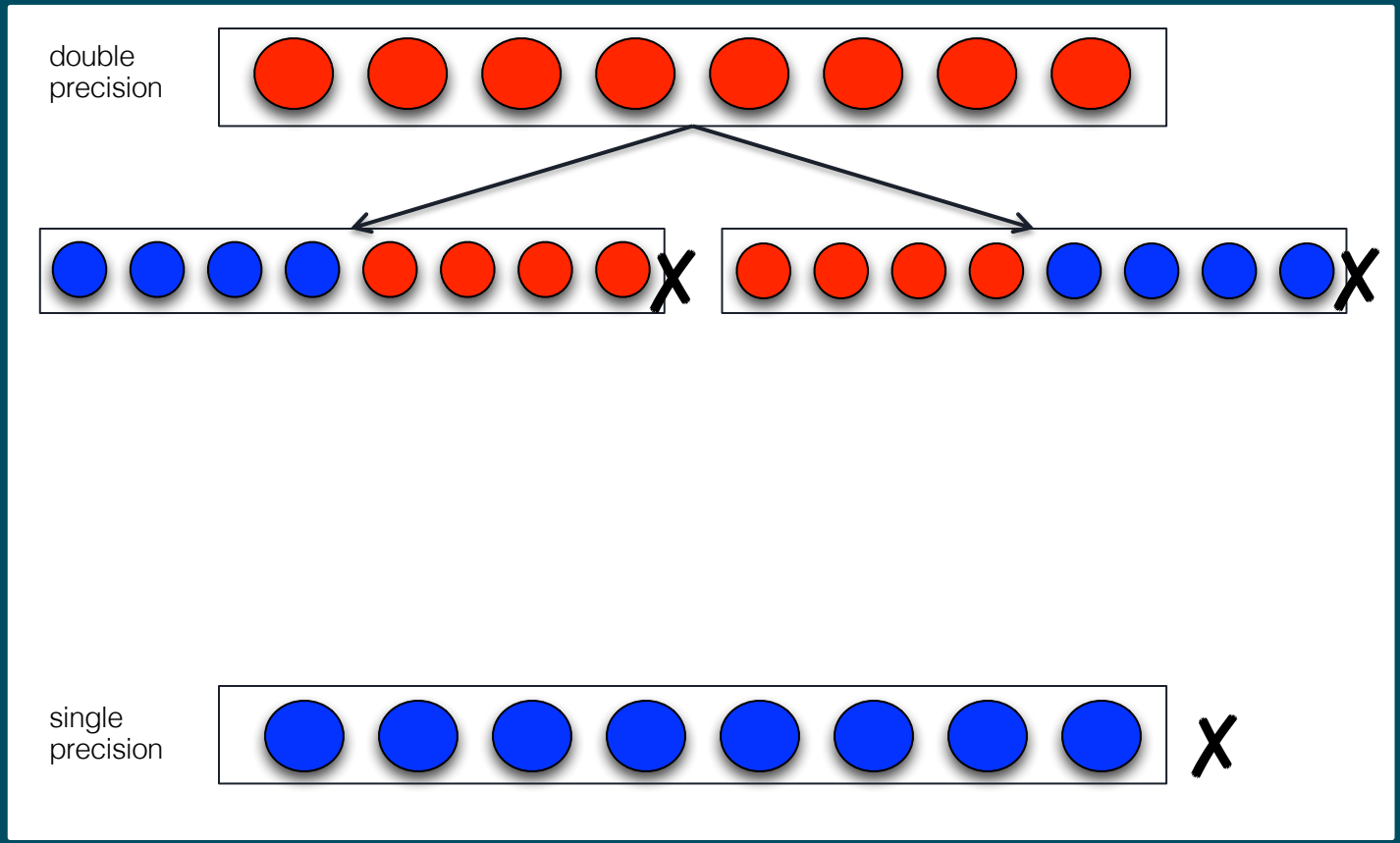
Searching for Type Configuration



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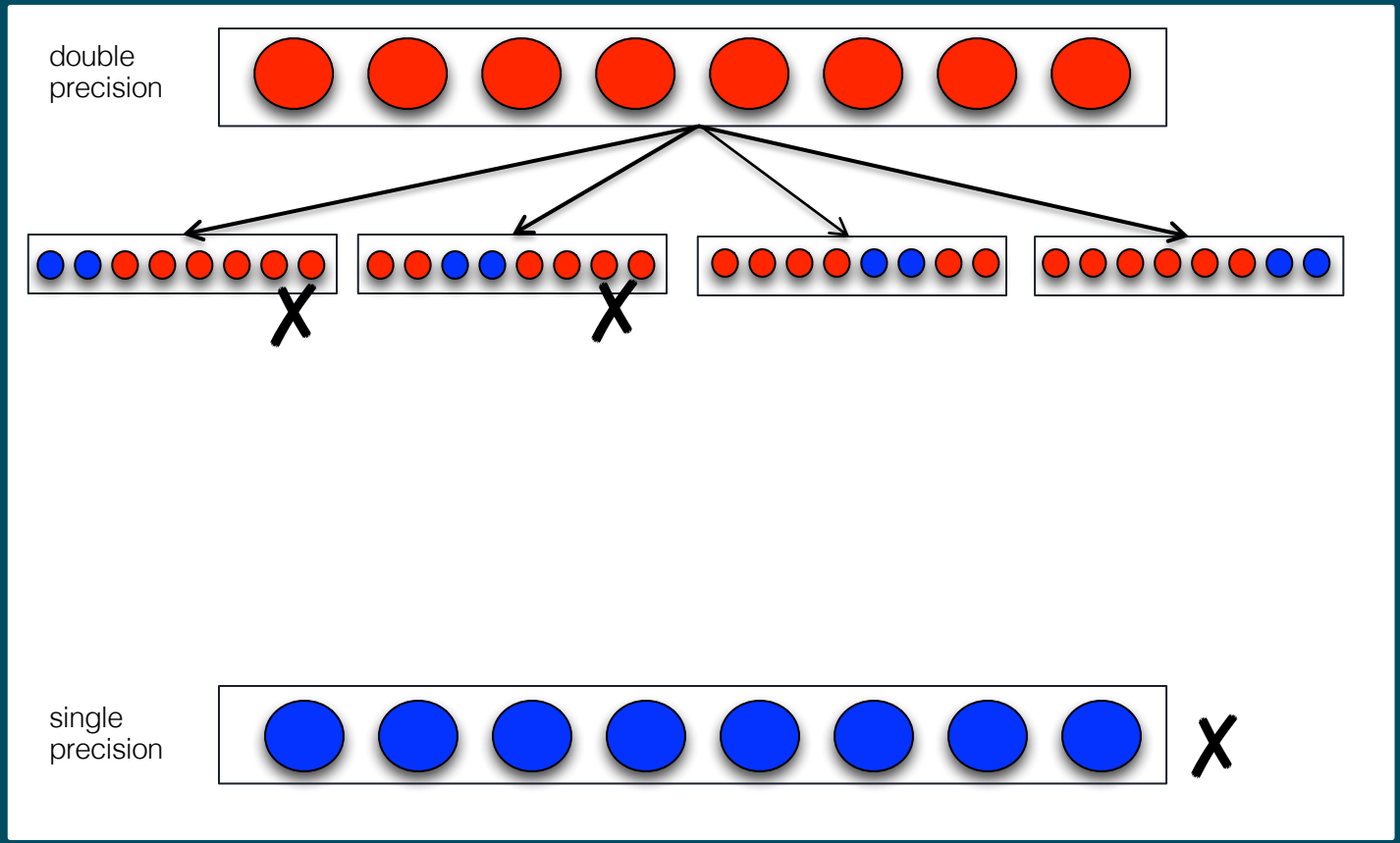
Searching for Type Configuration



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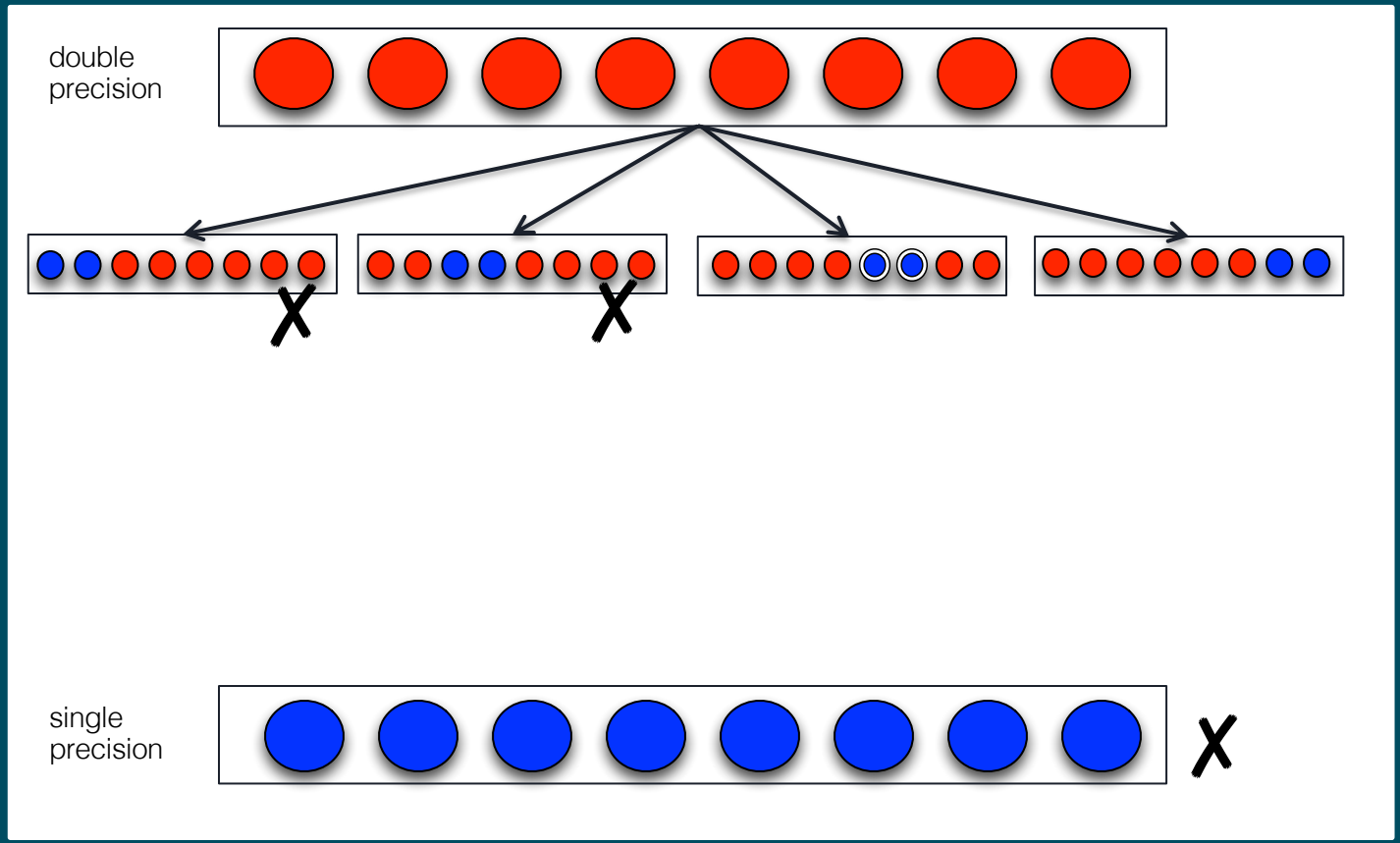
Searching for Type Configuration



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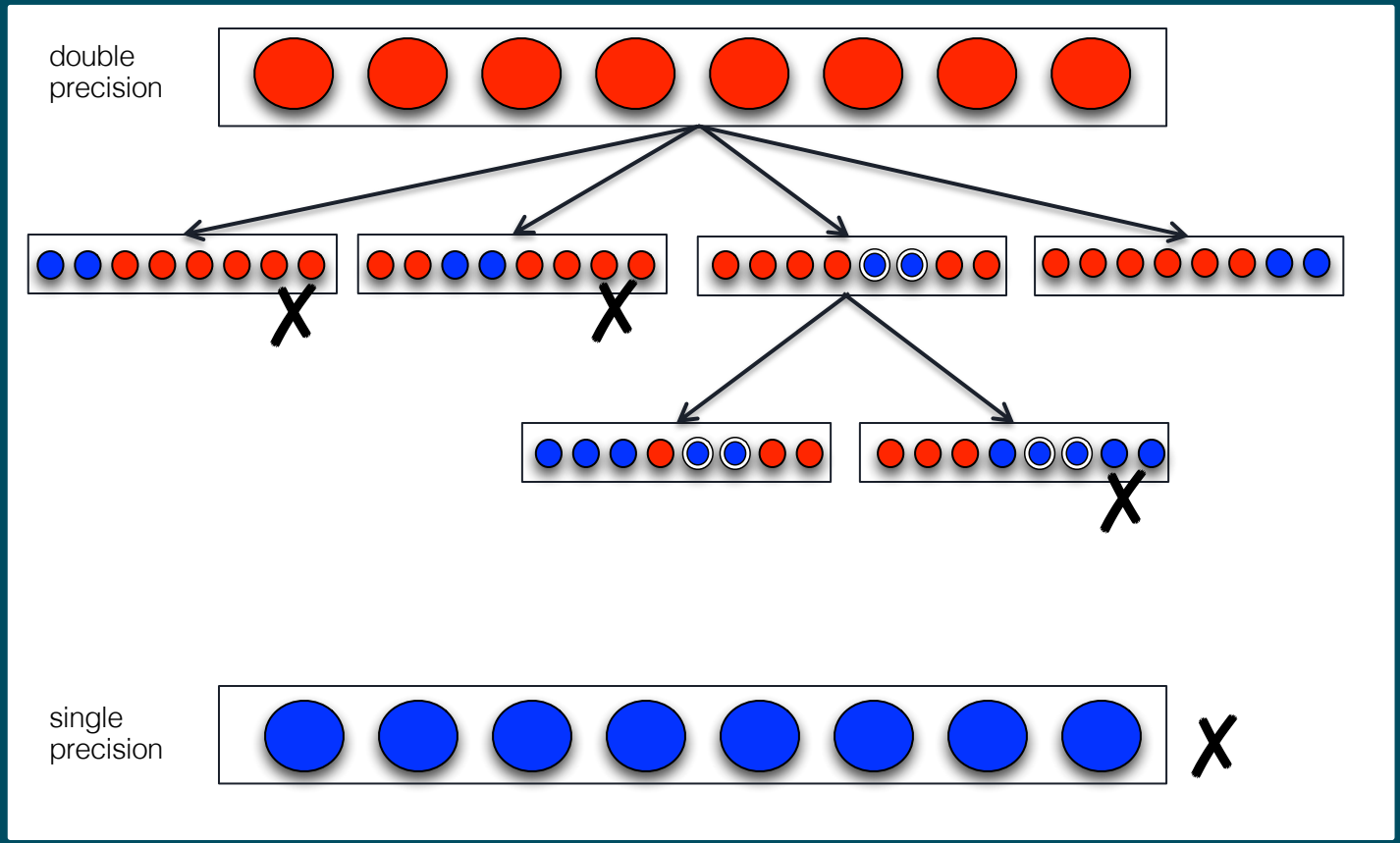
Searching for Type Configuration



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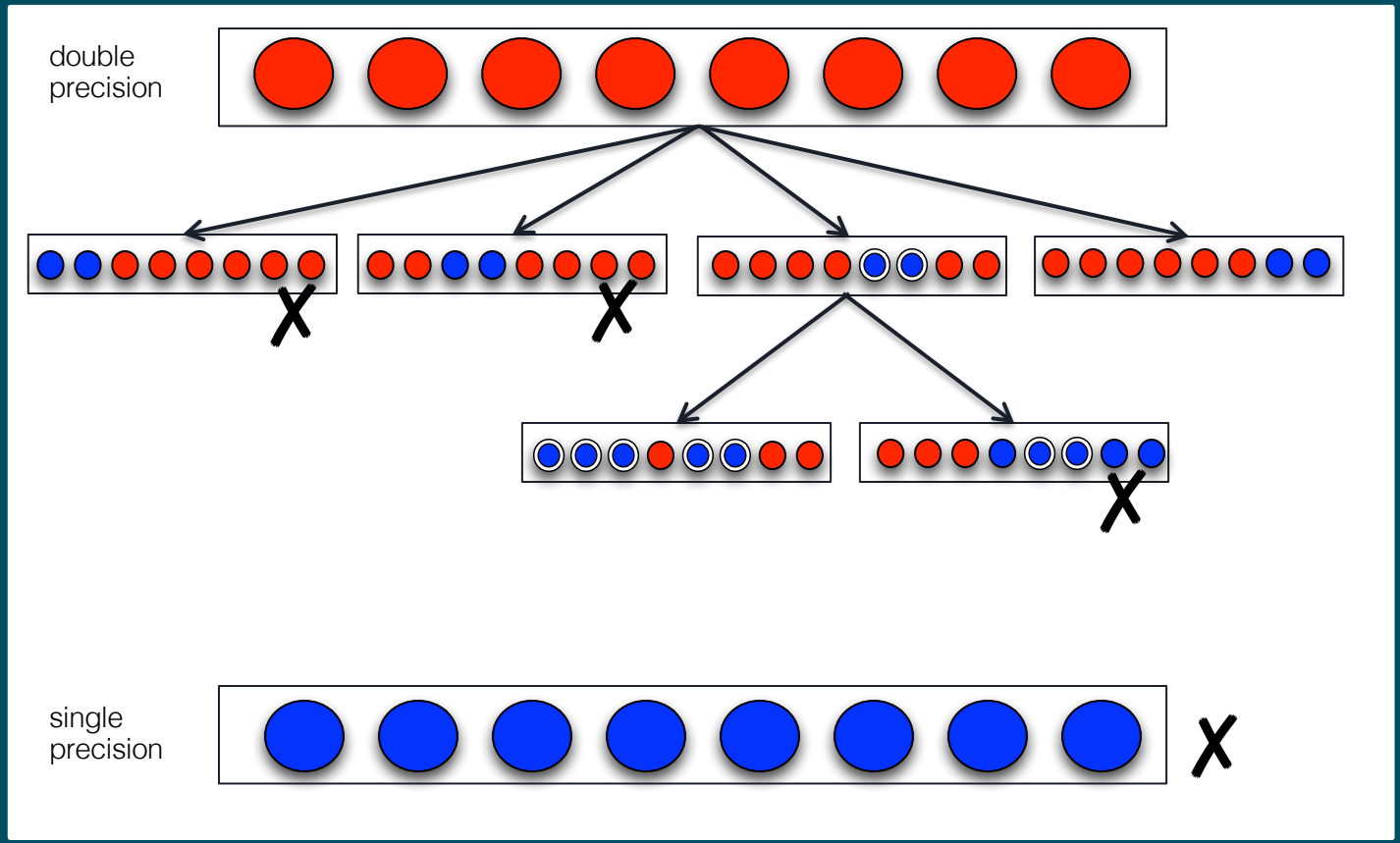
Searching for Type Configuration



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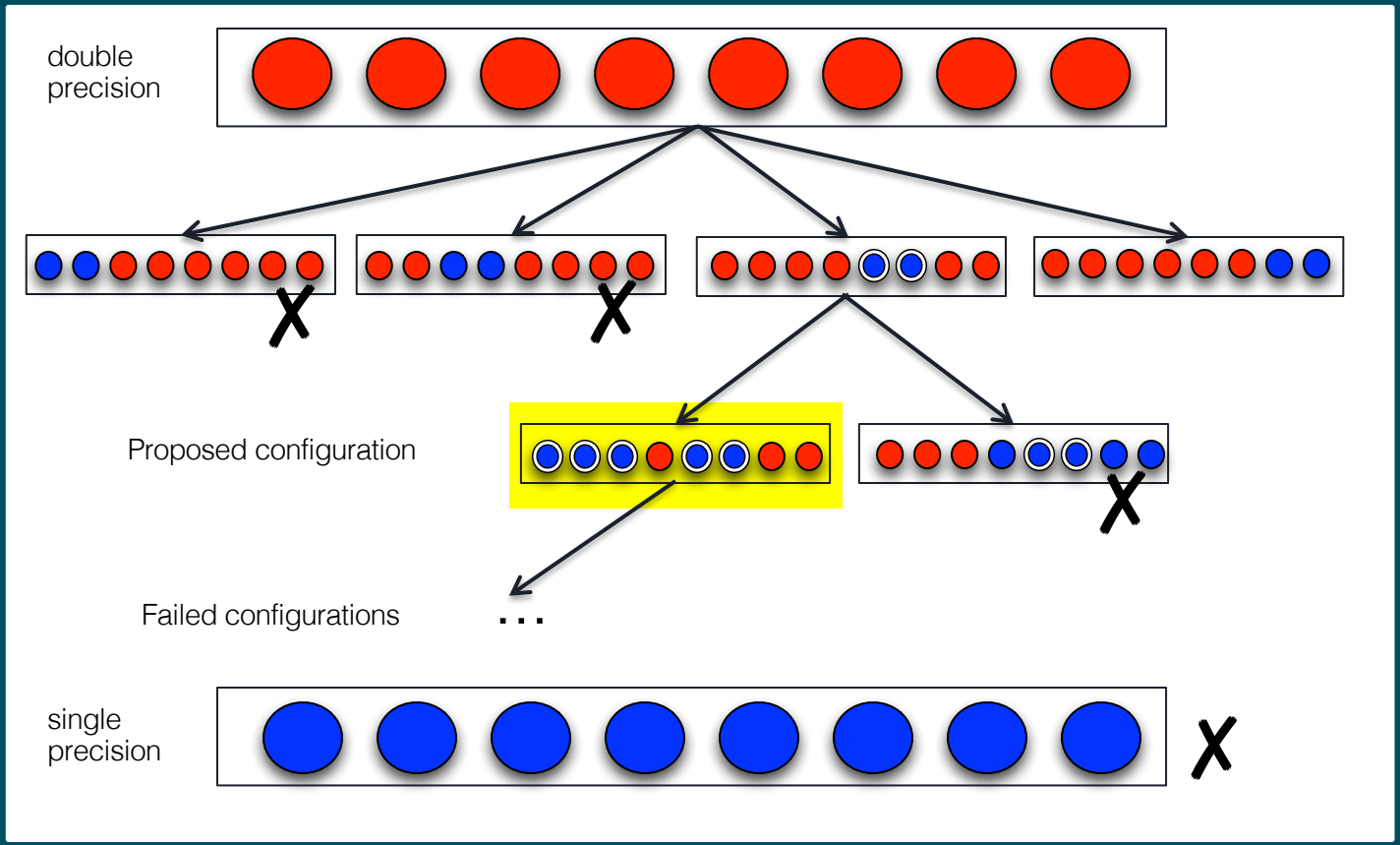
Searching for Type Configuration



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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
- Able to run resulting modified program

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/test1
1/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
   0.0090 (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/res
ult.out
Checking result value in file "src/tests/test11/result.out"
Touch("src/tests/test11/transformed.passed")
scons: done building targets.
```

Step 2: Annotate Program (already done)

- Execute :
  - $ cd exercise-1
  - $ ls

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

- Open funarc.c file

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

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

FILE* file = fopen("score.cov", "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.cov
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

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

```
** 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@2b744b834ee7:~/Module-Precimonious/exercise-1#
```

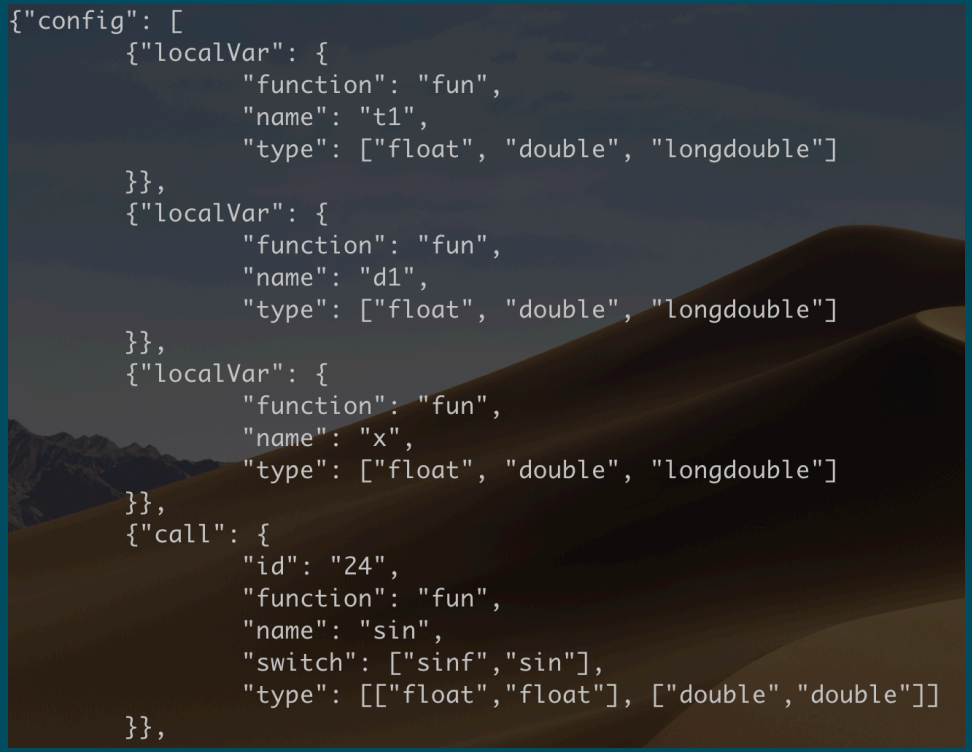
Step 4: Run Analysis – Configuration File

- 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"]
        }},
```

Step 4: Run Analysis – Search File

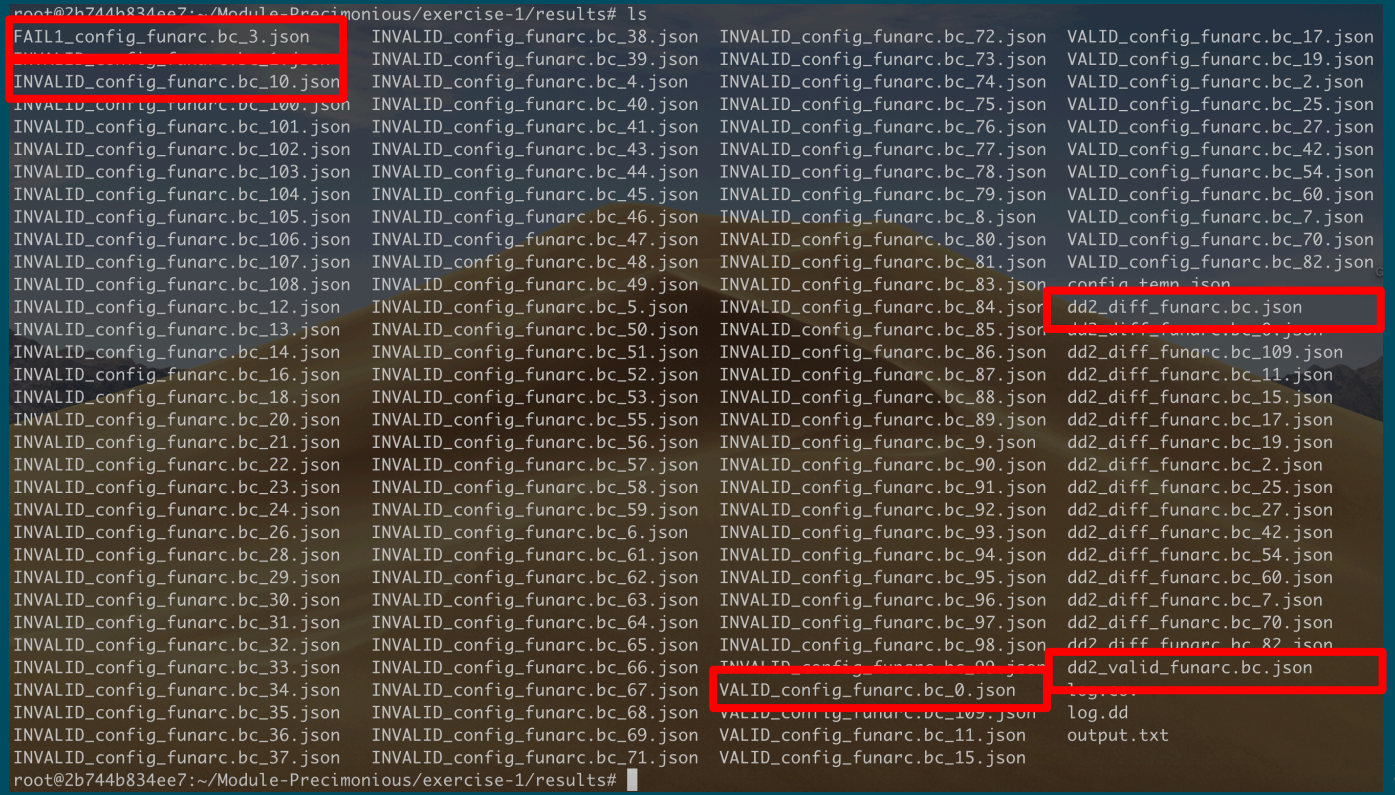
- Open search_funarc.json
- Search space file



```
{"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



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