EUROPEAN LLVM DEVELOPERS' MEETING 2019

DOE PROXY APPS: COMPILER PERFORMANCE ANALYSIS AND OPTIMISTIC ANNOTATION EXPLORATION

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OUTLINE

- Context (Proxy Applications)
- HPC Performance Analysis & Compiler Comparison
- Modelling Math Function Memory Access
- Information and the Compiler
- Optimistic Annotations
- Optimistic Suggestions

ECP PROXY APPLICATION PROJECT

Co-Design

- Improve the quality of proxies
- Maximize the benefit received from their use

ECP PathForward

Team

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- Hal Finkel, ANL
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- Robert Pavel, LANL
- Vinay Ramakrishnaiah, LANL
- Peter McCorquodale, LBL
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- Nikhil Jain, LLNL
- Bronson Messer, ORNL
- Tiffany Mintz, ORNL
- Shirley Moore, ORNL
- Jeanine Cook, SNL
- Courtenay Vaughan, SNL

Proxy Applications are used by Application Teams, Co-Design Centers, Software Technology Projects and Vendors

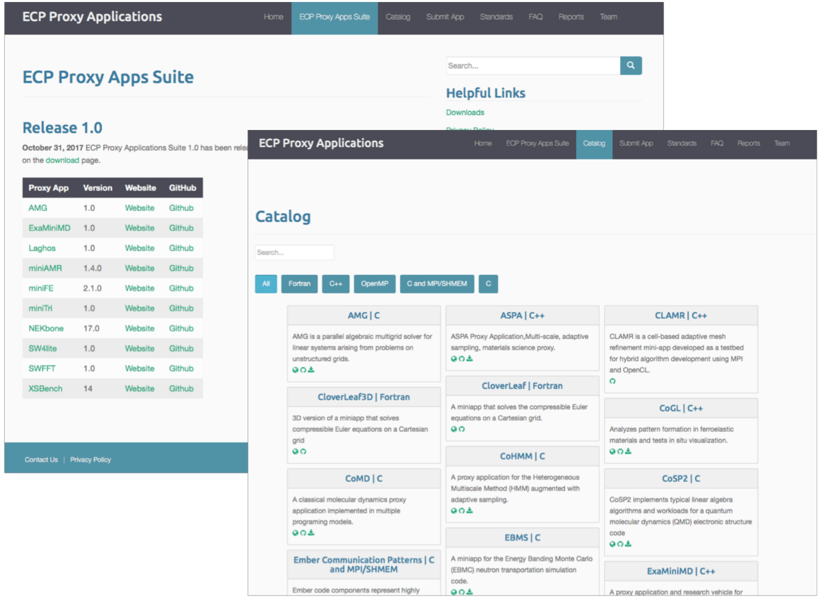
PROXY APPLICATIONS

– Proxy applications are models for one or more features of a parent application

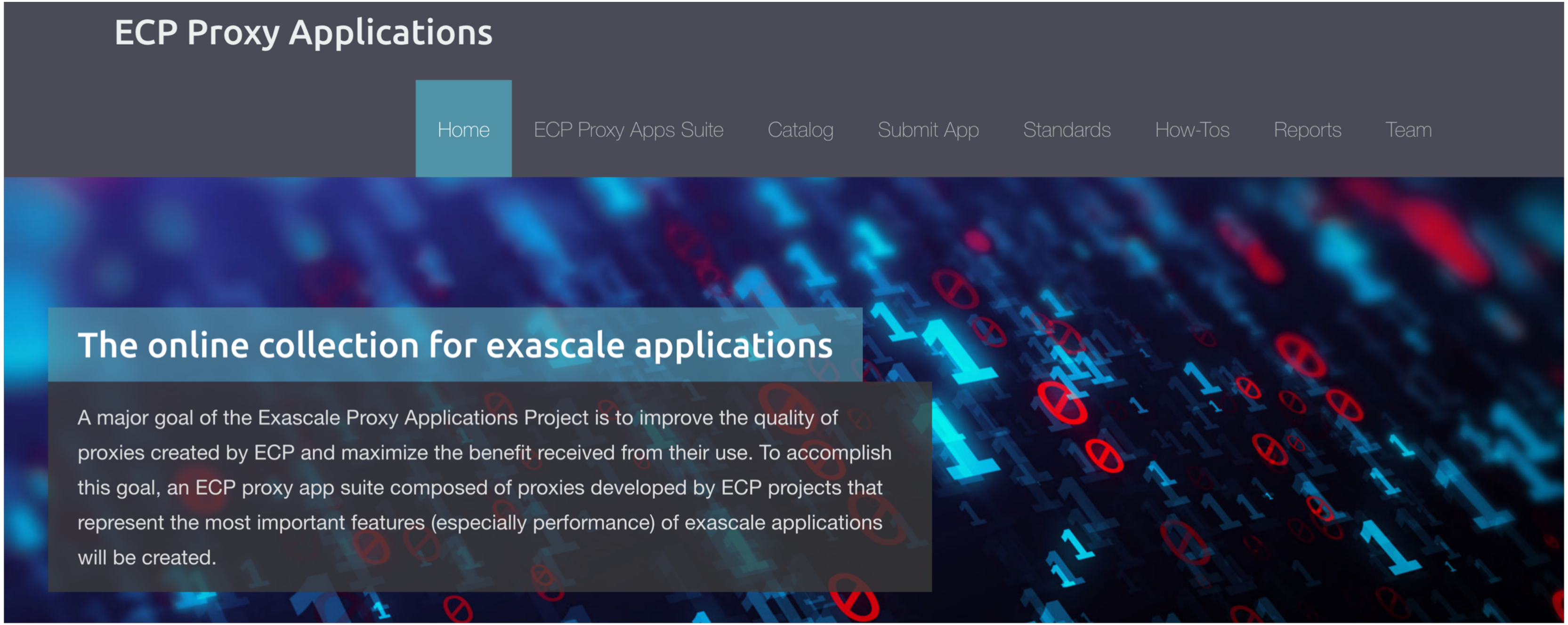
– Can model different parts
  - Performance critical algorithm
  - Communication patterns
  - Programming models

– Come in different sizes
  - Kernels
  - Skeleton apps
  - Mini apps

https://proxyapps.exascaleproject.org



ECP PROXY APPLICATION PROJECT



WHY LOOK AT PROXY APPS

- Proxy applications aim to hit a balance of complexity and usability
- Represent the performance critical sections of HPC code
- Often have various versions (MPI, OpenMP, CUDA, OpenCL, Kokkos)

Issues

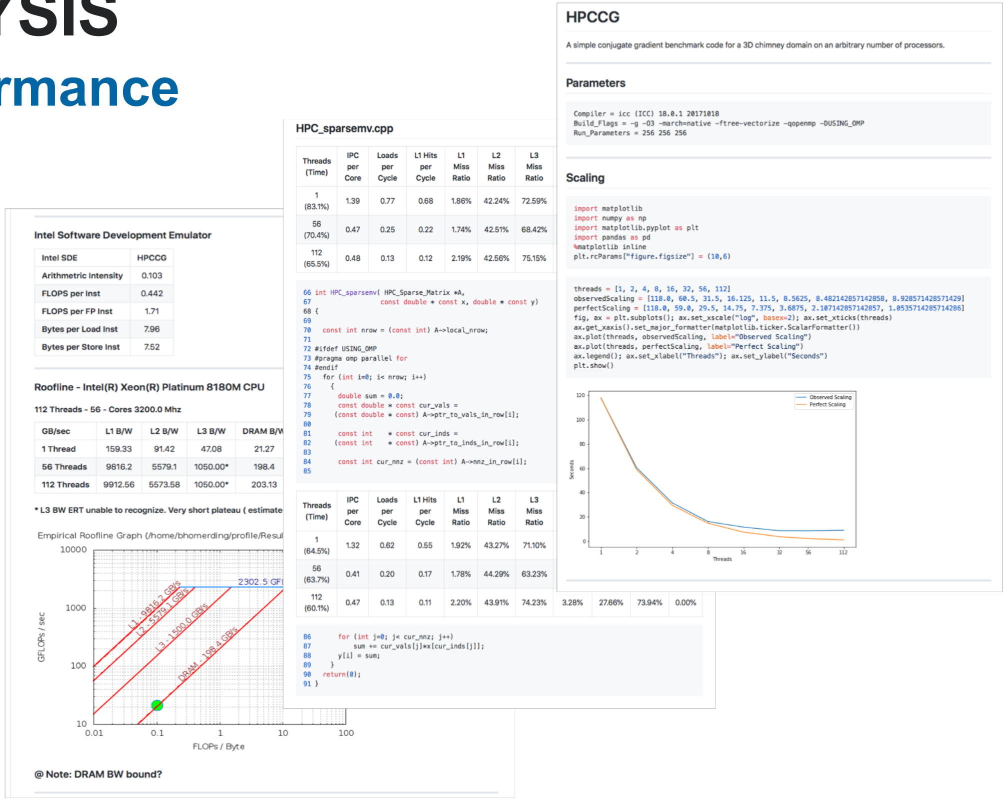
- They are designed to be experimented with, they are not benchmarks until the problem size is set
- No common test runner

HPC PERFORMANCE ANALYSIS & COMPILER COMPARISON

PERFORMANCE ANALYSIS

Quantifying Hardware Performance

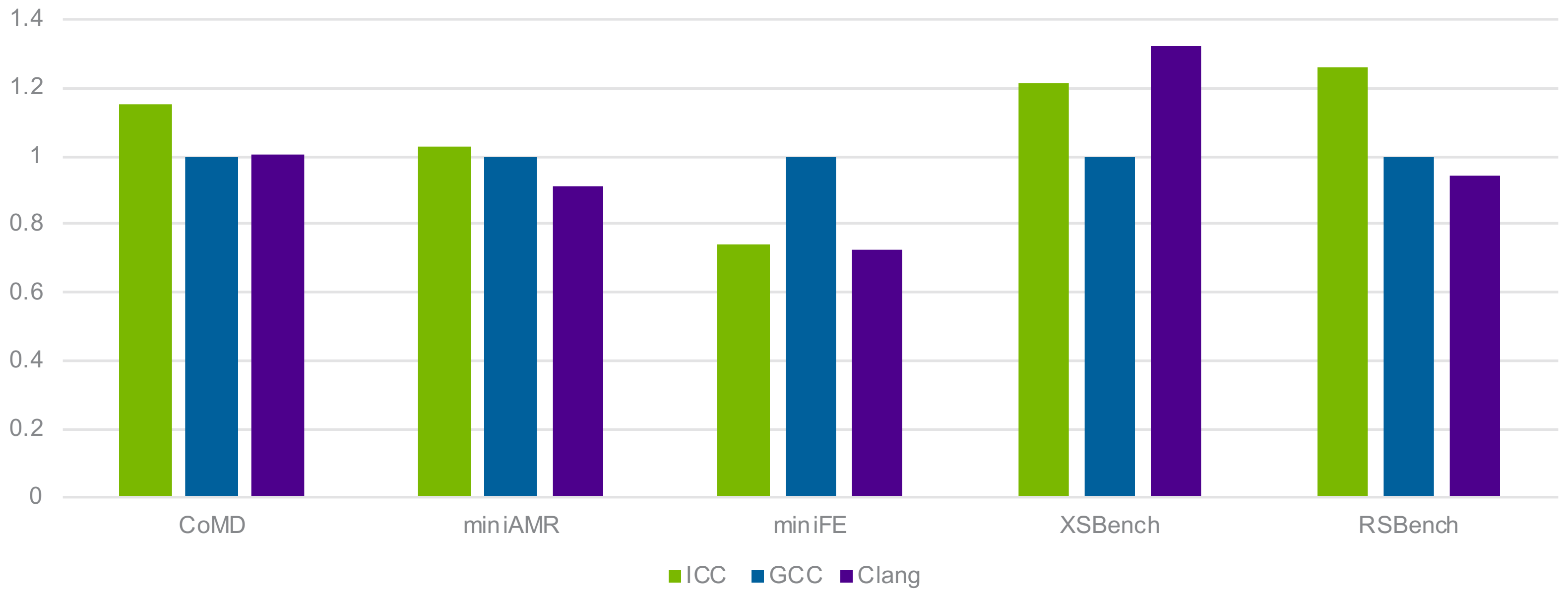
- Understand representative problem sizes
  - How to scale the problem to Exascale?
- What are the hardware characteristics of different classes of codes? (PIC, MD, CFD)
- Why is the compiler unable to optimize the code? Can we enable it to?



COMPILER FOCUS METHODOLOGY

- Get a performant version built with each compiler
- Identify room for improvement
- Collecting a wide array of hardware performance counters
- Utilize these hardware counters alongside specific code segments to identify areas where we are underperforming

RESULTS



1.4
1.2
1
0.8
0.6
0.4
0.2
0
CoMD
miniAMR
miniFE
XSBench
RSBench
ICC
GCC
Clang

RSBENCH MOTIVATING EXAMPLE

```
for( int i = 0; i < input.numL; i++ )
{
        phi = data.pseudo_K0RS[nuc][i] * sqrt(E);

        if( i == 1 )
                phi -= - atan( phi );
        else if( i == 2 )
                phi -= atan( 3.0 * phi / (3.0 - phi*phi));
        else if( i == 3 )
                phi -= atan(phi*(15.0-phi*phi)/(15.0-6.0*phi*phi));

        phi *= 2.0;

        sigTfactors[i] = cos(phi) - sin(phi) * _Complex_I;
}
```

GENERATED ASSEMBLY

Clang

```
callq   cos
vmovsd  %xmm0, 8(%rsp)                # 8-byte Spill
vmovsd  56(%rsp), %xmm0               # 8-byte Reload
                                      # xmm0 = mem[0],zero
callq   sin
vmovsd  .LCPI2_4(%rip), %xmm1         # xmm1 = mem[0],zero
vmovapd %xmm1, %xmm2
```

GCC

```
addq    $1, %rbx
addq    $16, %rbp
call    sincos
vpxord  %zmm1, %zmm1, %zmm1
vmovsd  40(%rsp), %xmm0
```

MODELING MATH FUNCTION MEMORY ACCESS

DESIGN

- Handle the special case
- Model the memory access of the math functions
- Expand Support in the backend
- Expose the functionality to the developer

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  - Combine sin() and cos() in SimplifyLibCalls
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  - Make use of the attribute – EarlyCSE with MSSA
  - Gain coverage of the attribute – Infer the attribute in FunctionAttrs
- Expose the functionality to the developer
  - Create an attribute in clang FE

INFORMATION AND THE COMPILER

QUESTIONS

- What information can we encode that we can’t infer?
- Does this information improve performance?
- If not, is it because the information is not useful or not used?
- How do I know what information I should add?
- How much performance is lost by information that is correct but that compiler cannot prove?

EXAMPLE

>> clang -O3

```
int *globalPtr;
void external(int*, std::pair<int>&);

int bar(uint8_t LB, uint8_t UB) {
    int sum = 0;
    std::pair<int> locP = {5, 11};
    external(&sum, locP);

    for (uint8_t u = LB; u != UB; u++)
        sum += *globalPtr + locP.first;
    return sum;
}
```

EXAMPLE

>> clang -O3

```
int *globalPtr;
void external(int*, std::pair<int>&)
__attribute__((pure));

int bar(uint8_t LB, uint8_t UB) {
  int sum = 0;
  std::pair<int> locP = {5, 11};
  external(&sum, locP);
  __builtin_assume(LB <= UB);
  for (uint8_t u = LB; u != UB; u++)
    sum += *globalPtr + locP.first; return
  sum;
}
```

EXAMPLE

>> clang -O3

```
int *globalPtr;
void external(int*, std::pair<int>&);

int bar(uint8_t LB, uint8_t UB) {
  int sum = 0;
  std::pair<int> locP = {5, 11};
  external(&sum, locP);

  return (UB - LB) * (*globalPtr + 5);
}
```

OPTIMISTIC ANNOTATIONS

IN A NUTSHELL

```
void baz(int *A);
```

>> clang -O3 ...

>> verify.sh --> Success

IN A NUTSHELL

```
void baz(__attribute__((readnone)) int *A);
```

```
>> clang -O3 ...
>> verify.sh --> Failure
```

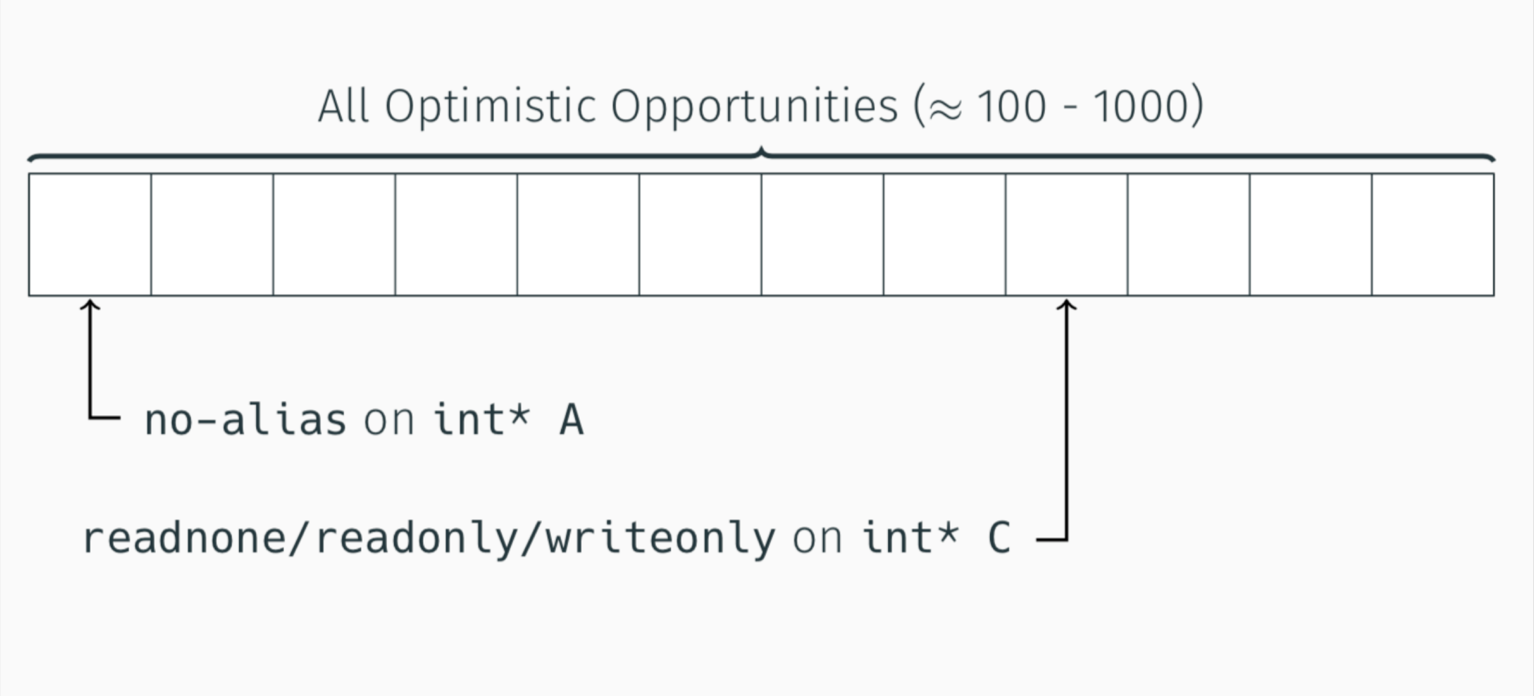
IN A NUTSHELL

```
void baz(__attribute__((readonly)) int *A);
```

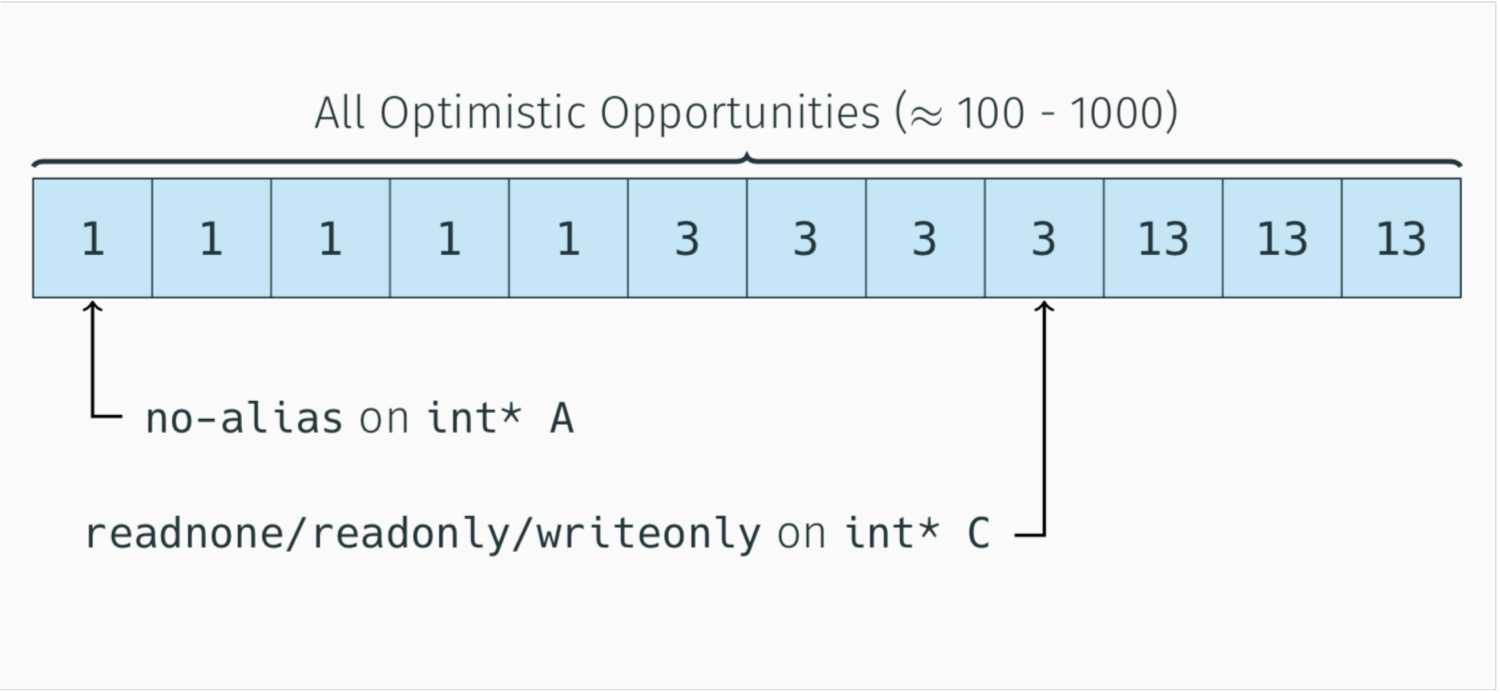
>> clang -O3 ...

>> verify.sh --> Success

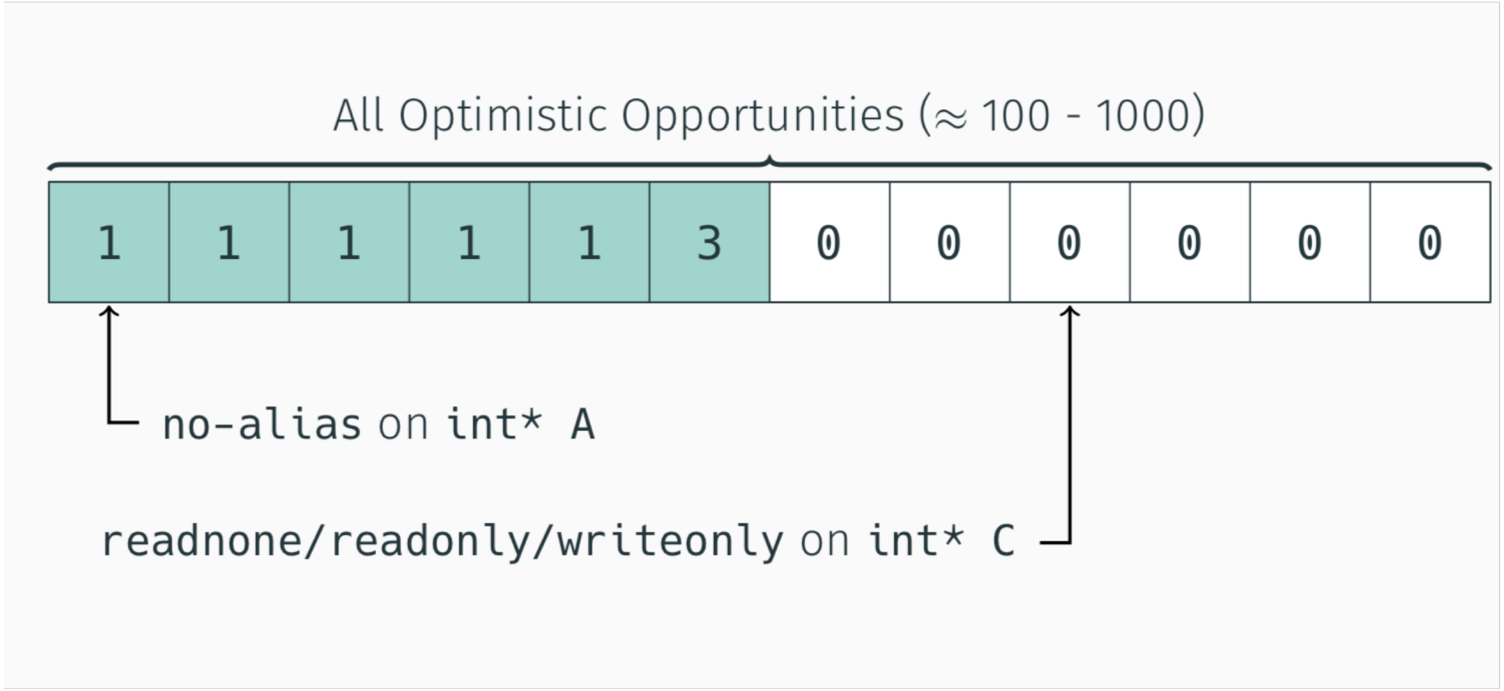
OPTIMISTIC OPPORTUNITIES



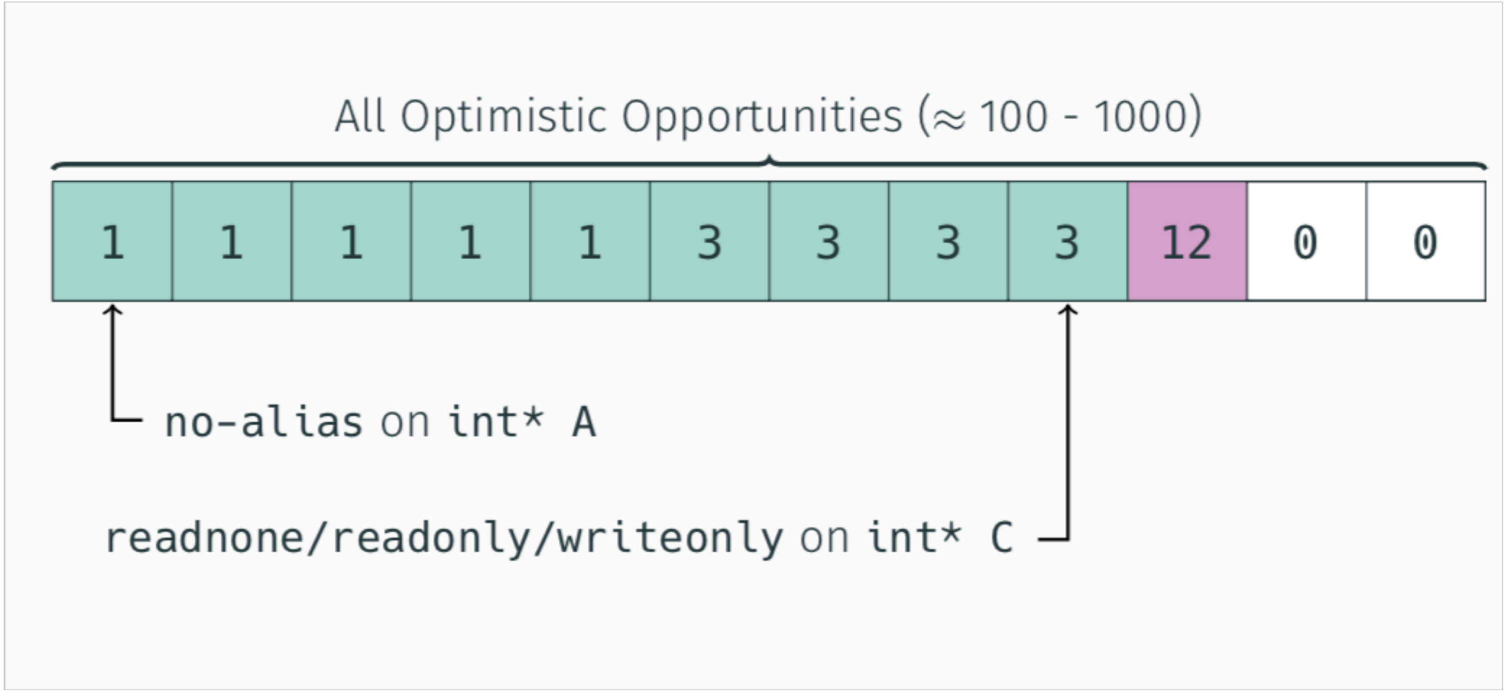
MARK THEM ALL OPTIMISTIC



SEARCH FOR VALID

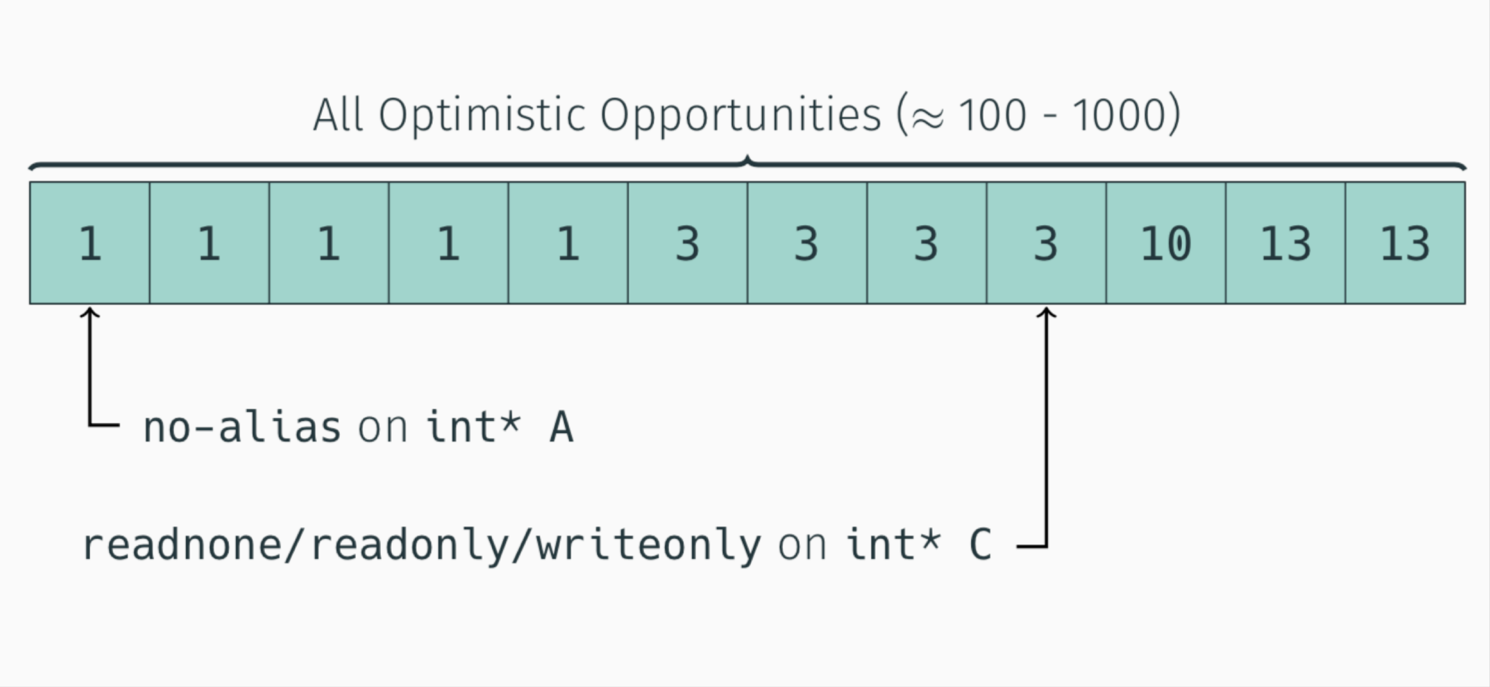


SEARCH



All Optimistic Opportunities (≈ 100 - 1000)
1
1
1
1
1
3
3
3
3
12
0
0
no-alias on int* A
readnone/readonly/writeonly on int* C

OPTIMISTIC CHOICES



OPPORTUNITY EXAMPLE – FUNCTION SIDE-EFFECTS

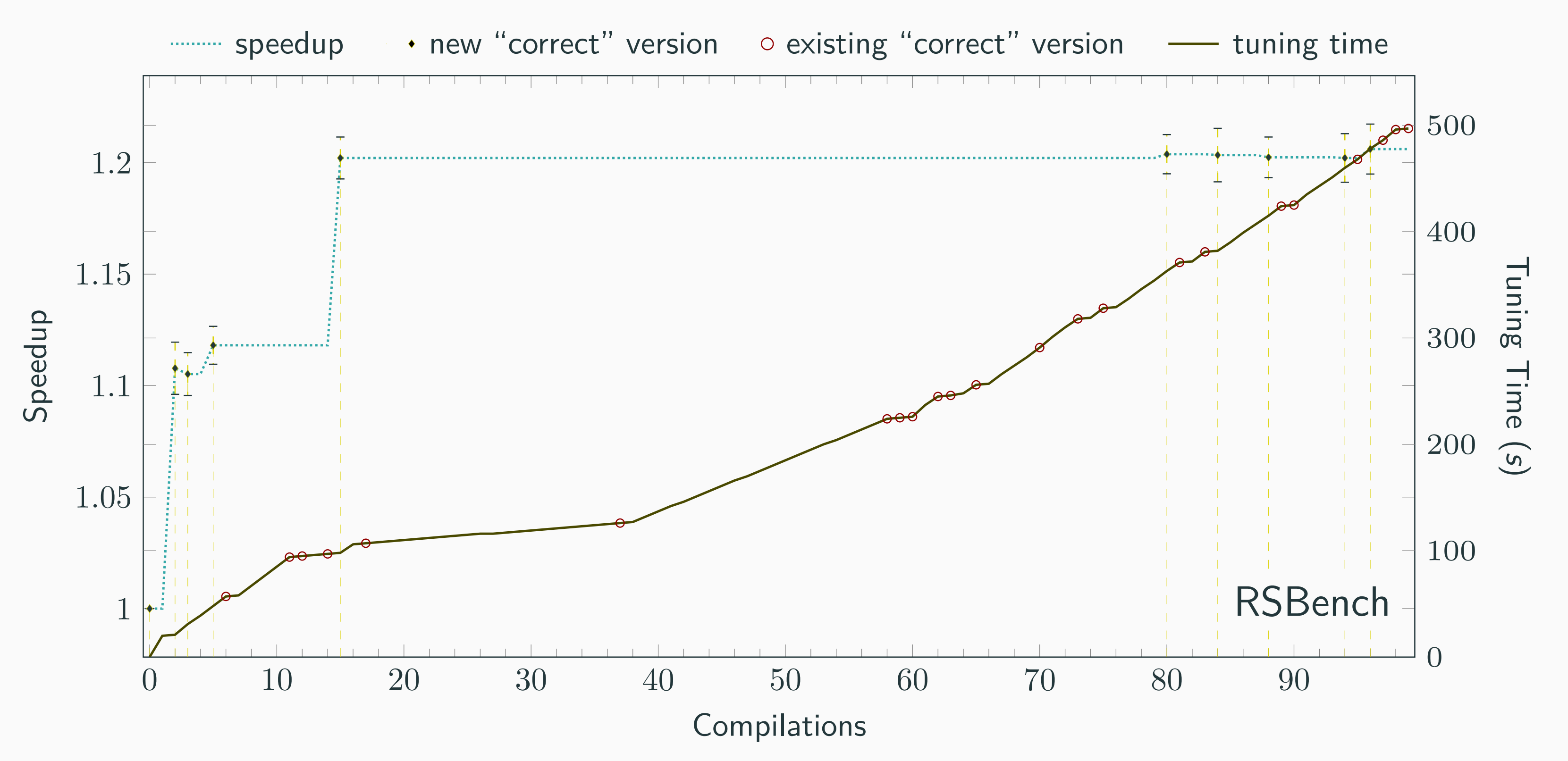
13. **speculatable** (and **readnone**)
12. **readnone**
11. **readonly** and **inaccessiblememonly**
10. **readonly** and **argmemonly**
9. **readonly** and **inaccessiblemem_or_argmemonly**
8. **readonly**
7. **writeonly** and **inaccessiblememonly**
6. **writeonly** and **argmemonly**
5. **writeonly** and **inaccessiblemem_or_argmemonly**
4. **writeonly**
3. **inaccessiblememonly**
2. **argmemonly**
1. **inaccessiblemem_or_argmemonly**
0. no annotation, original code

ANNOTATION OPPORTUNITIES

- Potentially aliasing pointers
- Potentially escaping pointers
- Potentially overflowing computations
- Potential runtime exceptions in functions
- Potentially parallel loops
- Externally visible functions
- Potentially non-dereferenceable pointers
- Unknown pointer alignment
- Unknown control flow choices
- Potentially invariant memory locations
- Unknown function return values
- Unknown pointer usage
- Potential undefined behavior in functions
- Unknown function side-effects

OPTIMISTIC TUNER RESULTS

Proxy Application	Problem Size / Run Configuration	# Successful Compilations	# New Versions	Optimistic Opportunities Taken
RSBench	-p 300000	32	9 (28.1%)	225/240 (93.8%)
XSBench	-p 500000	47	5 (10.6%)	129/141 (91.5%)
PathFinder	-x 4kx750.adj_list	62	22 (35.5%)	264/299 (88.3%)
CoMD	-x 40 –y 40 –z 40	49	13 (26.5%)	179/194 (92.3%)
Pennant	leblancbig.pnt	69	12 (17.4%)	610/689 (88.5%)
MiniGMG	6 2 2 2 1 1 1	16	4 (25.0%)	479/479 (100%)

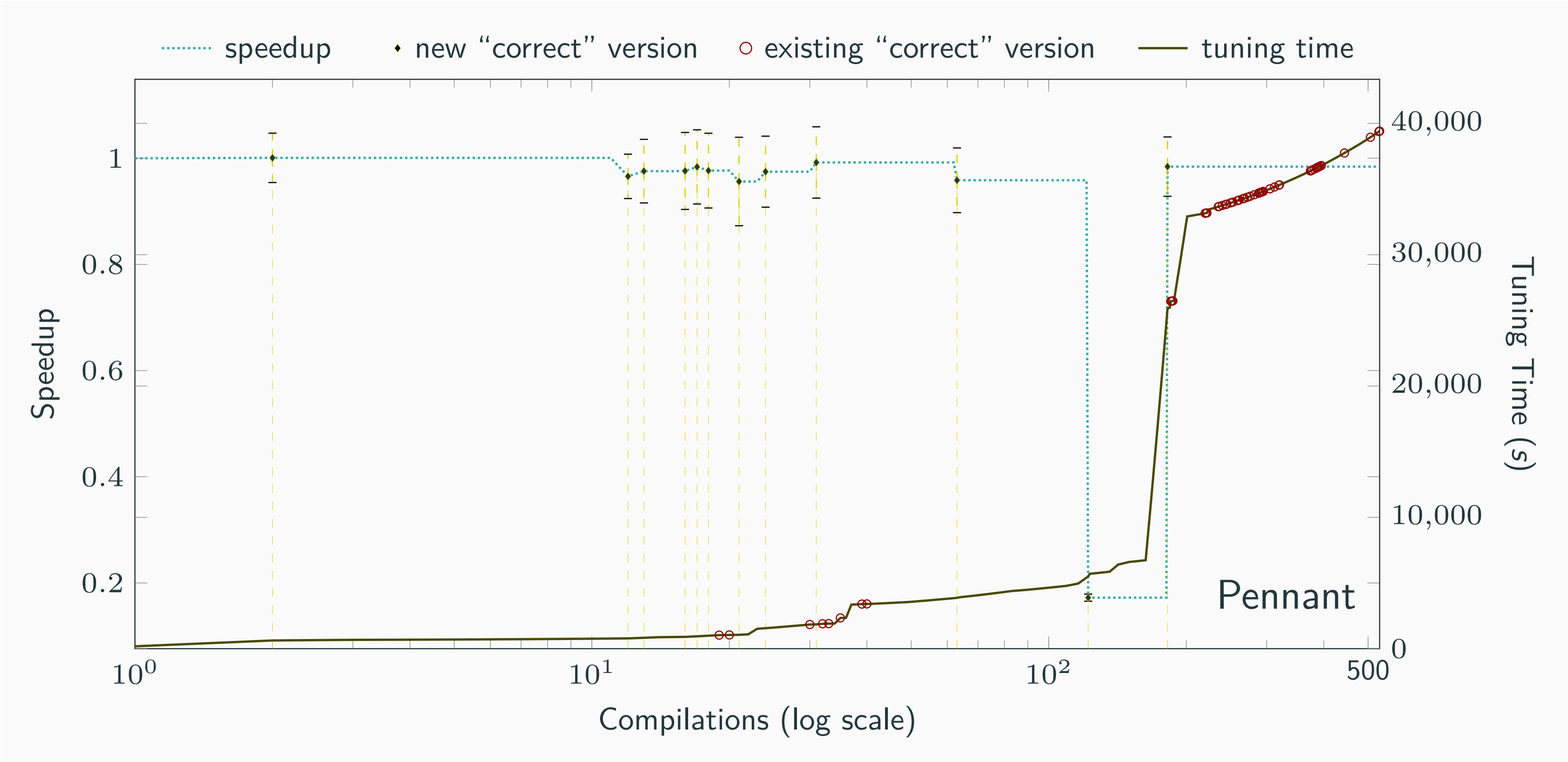


speedup
new “correct” version
existing “correct” version
tuning time
Speedup
1.2
1.15
1.1
1.05
1
Tuning Time (s)
500
400
300
200
100
0
RSBench
0
10
20
30
40
50
60
70
80
90
Compilations

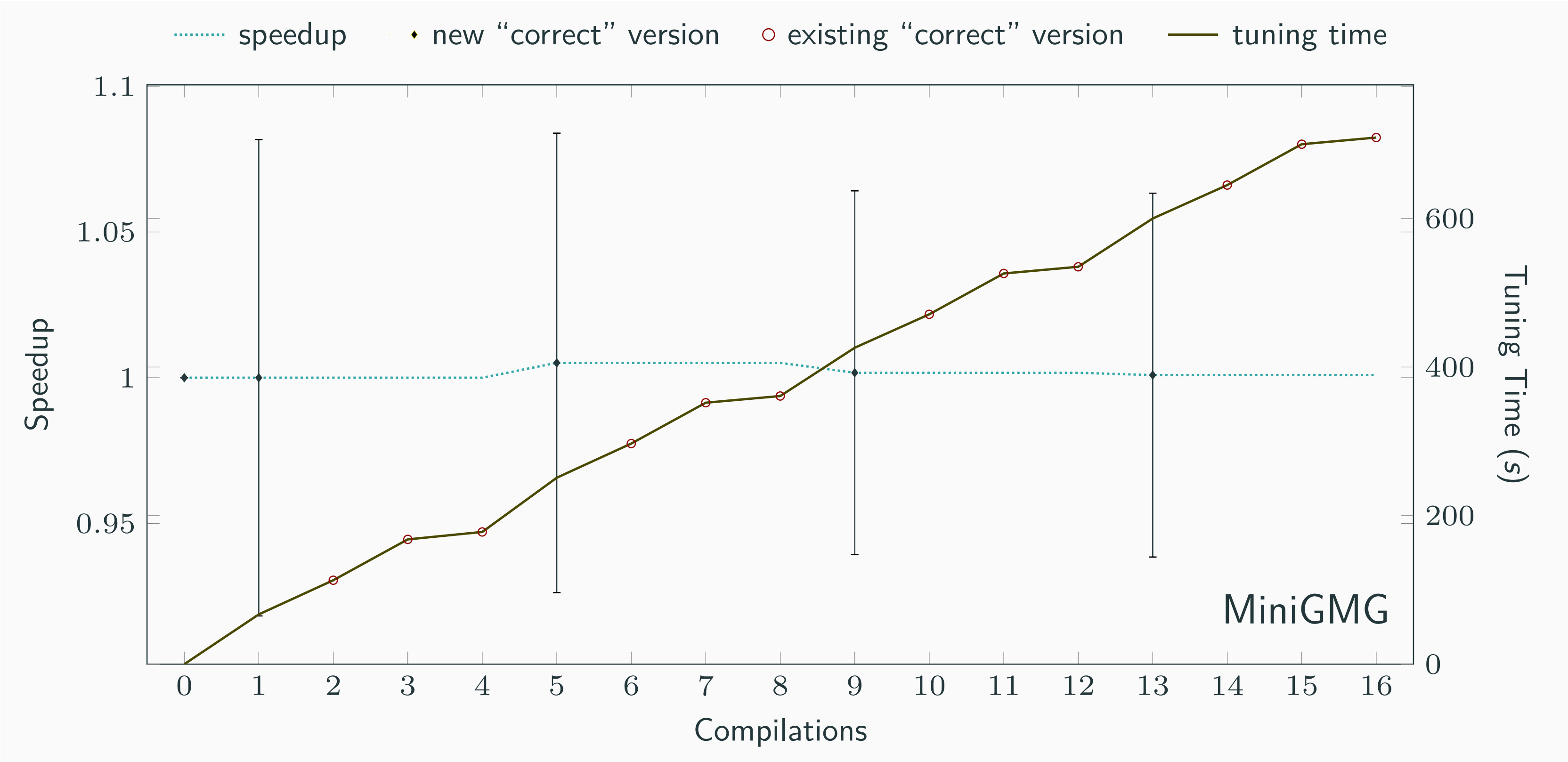

speedup
new “correct” version
existing “correct” version
tuning time
Speedup
Tuning Time (s)
Compilations
XSBench
1.2
1.15
1.1
1.05
1
400
300
200
100
0
10
20
30
40
50
60
70
80
90

speedup
new “correct” version
existing “correct” version
tuning time
Speedup
1.2
1.15
1.1
1.05
1
0.95
Tuning Time (s)
4,000
3,000
2,000
1,000
0
0
20
40
60
80
100
120
140
160
180
200
220
240
Compilations
PathFinder


speedup
new "correct" version
existing "correct" version
tuning time
Speedup
Tuning Time (s)
Compilations
CoMD
1.06
1.04
1.02
1
0.98
0.96
0.94
2,500
2,000
1,500
1,000
500
0
0
10
20
30
40
50
60
70
80
90
100
110
120



speedup
new “correct” version
existing “correct” version
tuning time
Speedup
1
0.8
0.6
0.4
0.2
Tuning Time (s)
40,000
30,000
20,000
10,000
0
Compilations (log scale)
10^0
10^1
10^2
500
Pennant


speedup
new "correct" version
existing "correct" version
tuning time
Speedup
1.1
1.05
1
0.95
Tuning Time (s)
600
400
200
0
MiniGMG
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Compilations

COMPARISON TO LTO

Performance Gap with LTO as Baseline

Proxy Application	LTO	thin-LTO
RSBench	2.86%	5.68%
XSBench	14.03%	41.23%
PathFinder	3.67%	4.79%
CoMD	4.75%	4.48%
Pennant	-1.13%	-1.14%
MiniGMG	0.73%	0.79%

OPTIMISTIC SUGGESTIONS

OPTIMISTIC OPPORTUNITIES WITH CHOICES MADE

RSBench

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	0	0	0
1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	1	3	1	3	0	7	0	7	7				

PERFORMANCE CRITICAL OPTIMISTIC CHOICES

RSBench

0	0	0	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0				

SUGGESTION EXAMPLES

```
xs_kernel.c:6:1: remark: internalize the function,
                 e.g., through 'static' or 'namespace { ... }'.
double complex fast_nuclear_W(double complex Z) {
^

In file included from xs_kernel.c:1:
rsbench.h:94:16: remark: provide better information on function memory
                 effects, e.g., through '__attribute__((pure))' or
                 '__attribute__((const))'
complex double fast_cexp( double complex z );
```

FUTURE WORK

- Improvements to the tool (suggestions and search)
- Additional results
- Identify information that causes regressions

- Understand if information was not useful or not used
- Collect statistics on addition information that does/does not change the binary

ACKNOWLEDGEMENTS

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THANK YOU