A Comparison of Search Heuristics for Empirical Code Optimization

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International Workshop on Automatic Performance Tuning
Oct 1, 2008

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Motivation

- Can ATLAS-like techniques be applied to arbitrary code?

- What do we mean by ATLAS-like techniques?
  - Blocking
  - Loop unrolling
  - Data prefetch
  - etc.

- Referred to as *empirical optimization* or *autotuning*
  - Generate many variations
  - Pick the best implementation by measuring the performance

Motivation (cont)

- Why use empirical optimization?
  - Traditional compiler optimization can't extract full machine performance
  - Hand tuning is difficult and non-portable
  - Allows optimizing less common routines which have not been hand tuned

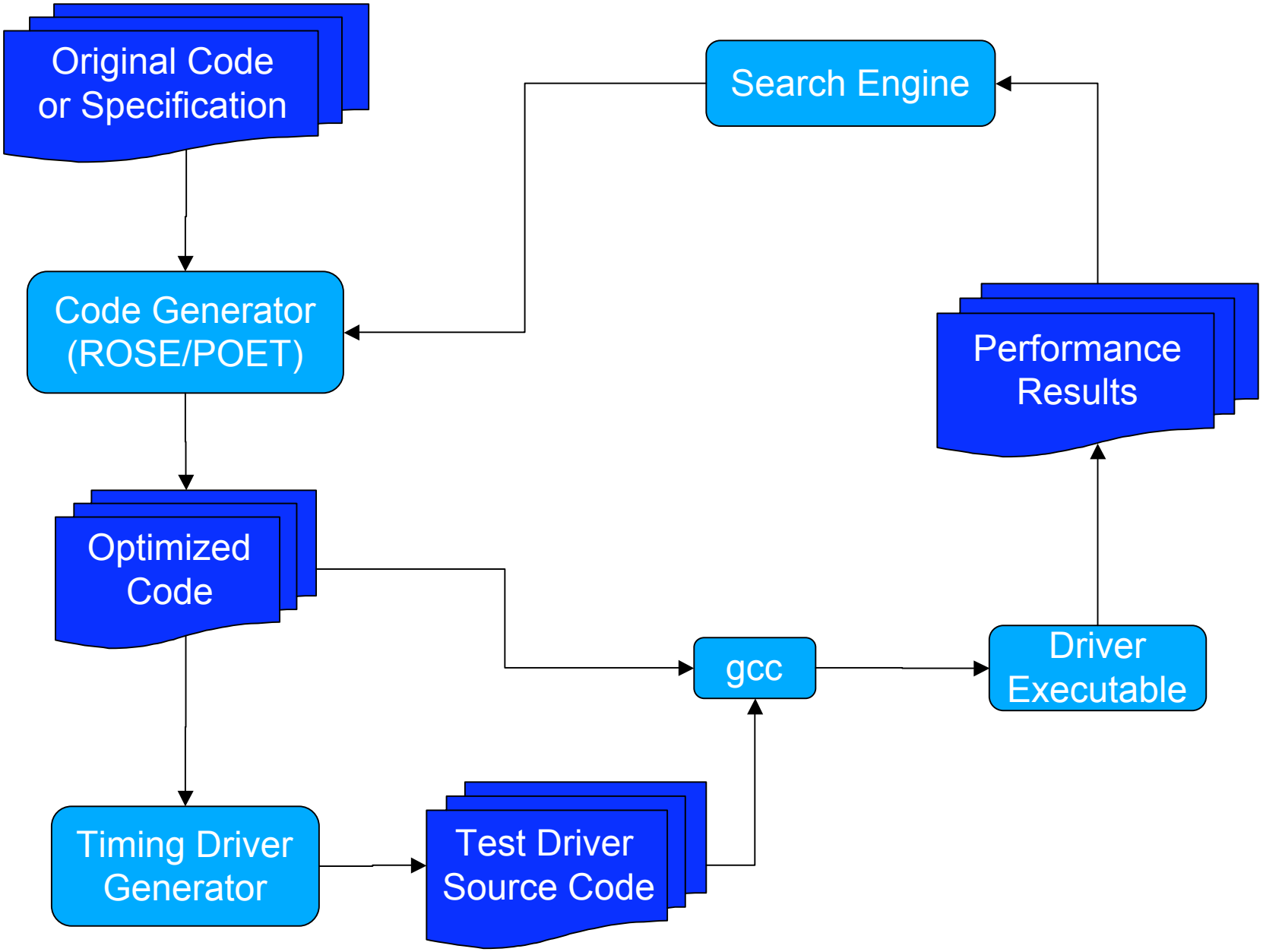
- Related Work
  - ATLAS
  - FFTW
  - PHiPAC
  - OSKI

Empirical Optimization Components

- Compiler infrastructure
  - Generates the various implementations
  - ROSE LoopProcessor from Lawrence Livermore National Lab (Yi, Q.; Quinlan, D.; Vuduc, R.)
  - POET - Parameterized Optimizations for Empirical Tuning (Yi, Q.; Seymour, K.; You, H.; Vuduc, R.; Quinlan, D.)

- Timing driver generator
  - Generates code to evaluate the performance

- Search engine
  - Can't exhaustively try implementations
  - Simplex
  - Genetic Algorithm
  - Random
  - Etc.


Original Code or Specification
Search Engine
Code Generator (ROSE/POET)
Performance Results
Optimized Code
gcc
Driver Executable
Timing Driver Generator
Test Driver Source Code

What is the user responsible for?

- Specifying the argument sizes:

```
/*$ATLAS ROUTINE DGEMM */
/*$ATLAS SIZE 400:400:50 */
/*$ATLAS ARG M           IN     int     $size */
/*$ATLAS ARG N           IN     int     $size */
/*$ATLAS ARG L           IN     int     $size */
/*$ATLAS ARG ALPHA       IN     double  1.0 */
/*$ATLAS ARG A[M][L]     IN     double  $rand */
/*$ATLAS ARG B[L][N]     IN     double  $rand */
/*$ATLAS ARG C[M][N]     INOUT  double  $rand */
```

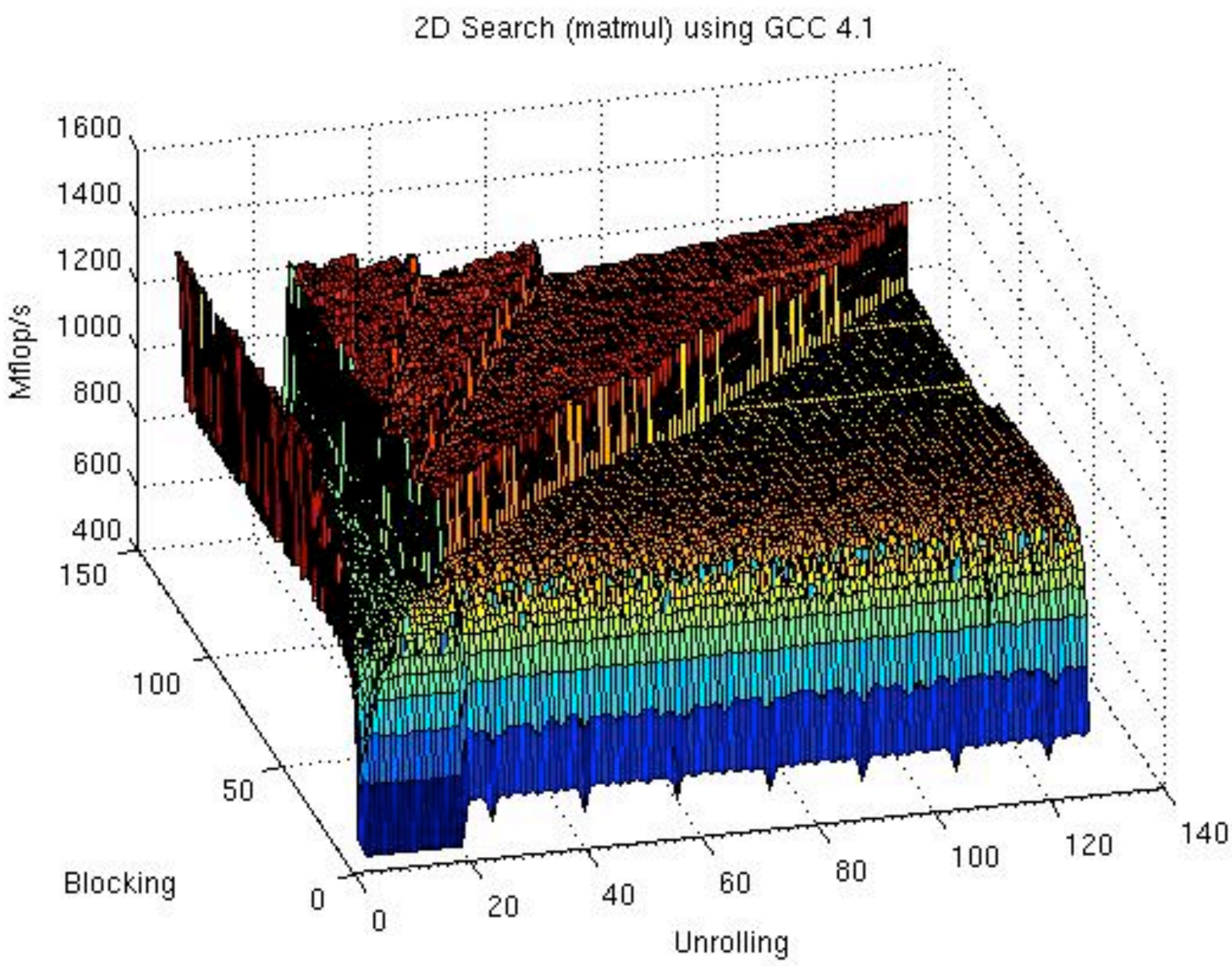
- Script that specifies the search bounds and evaluates a candidate:

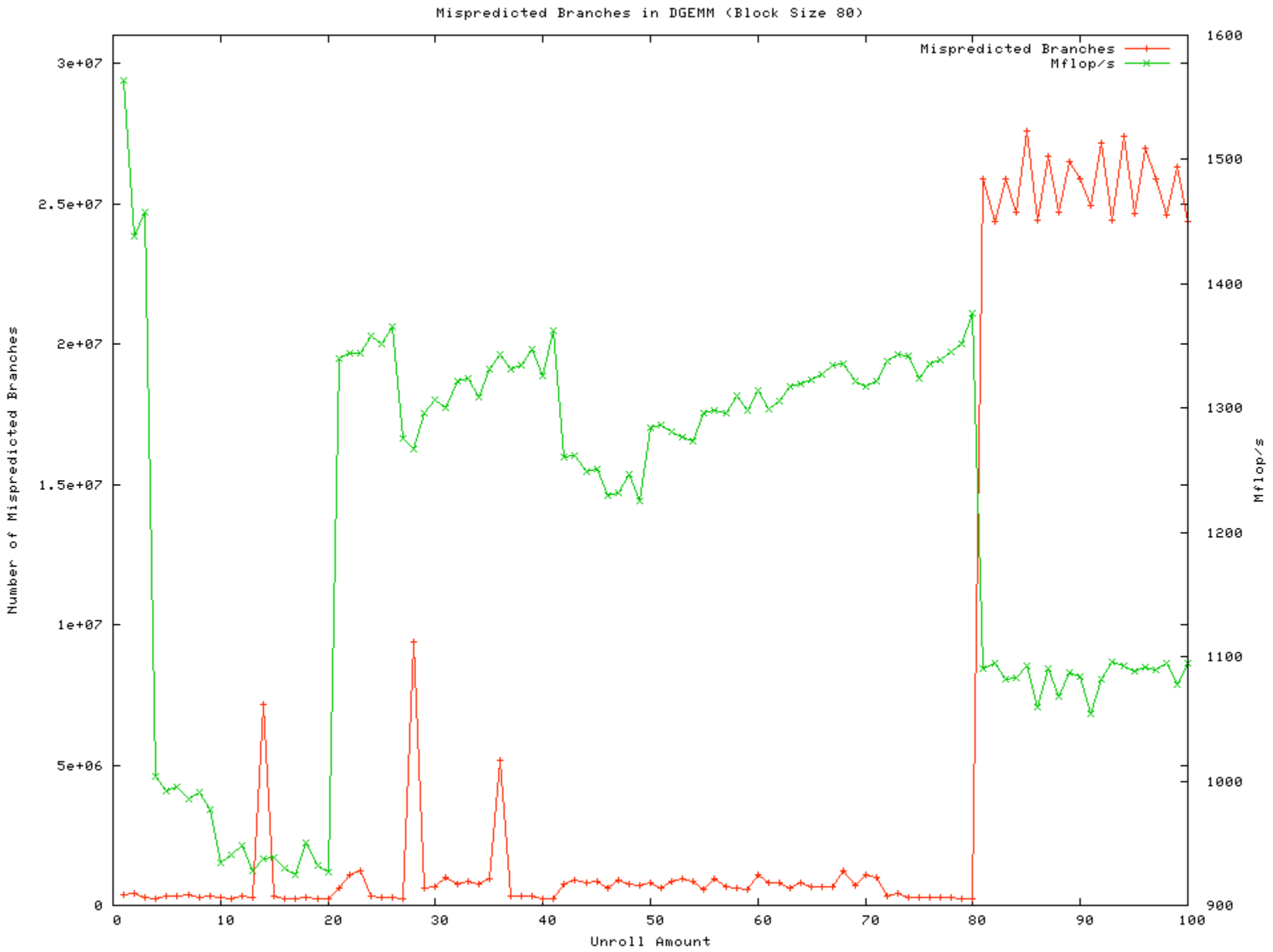
```
#DIM    5
#LB     2     2     2   2 1
#UB   128   128   128 128 6
#CONSTRAINT p1 < p2
#CONSTRAINT (p1 % 2) == 0
```

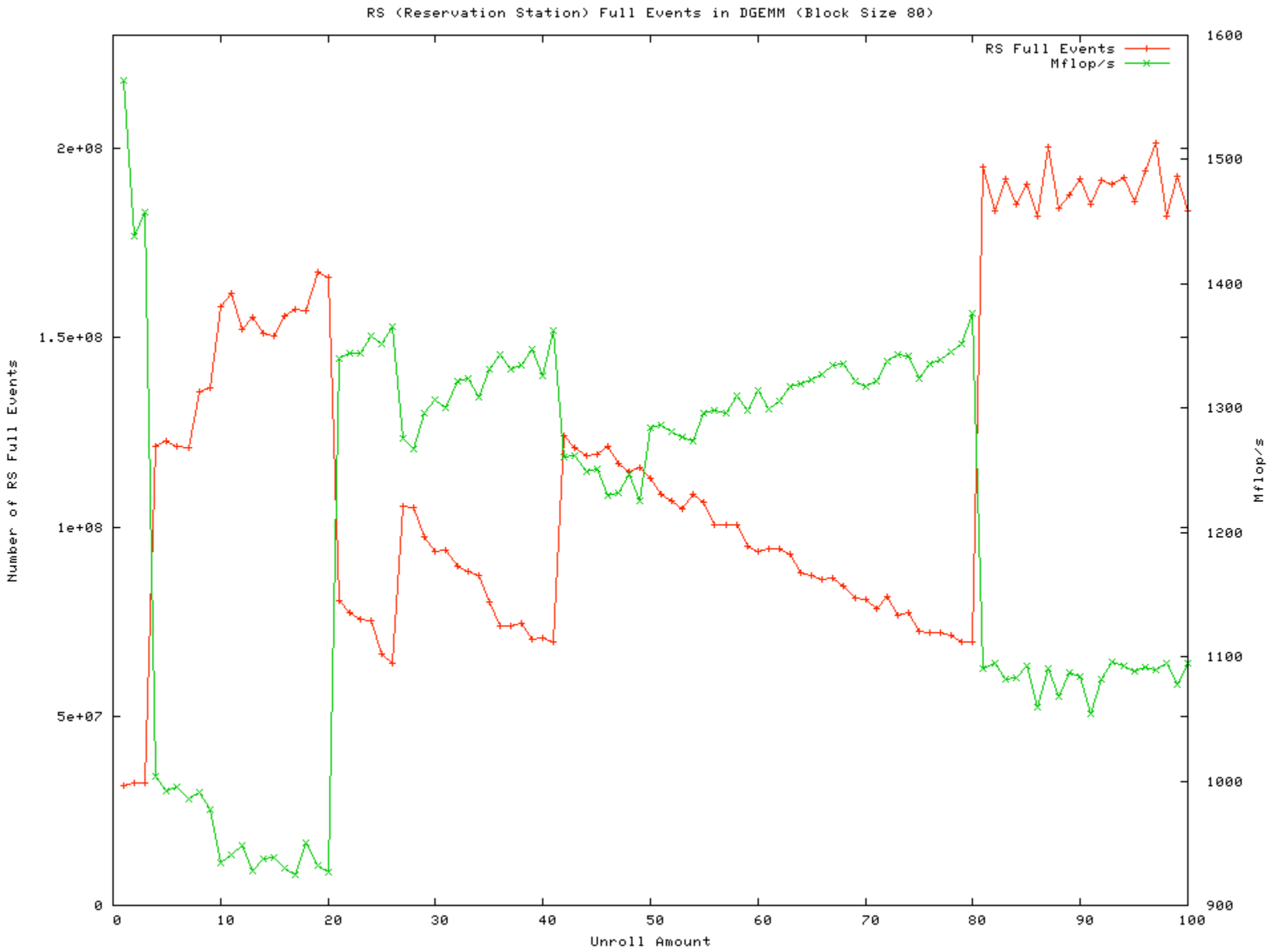
Test Environment

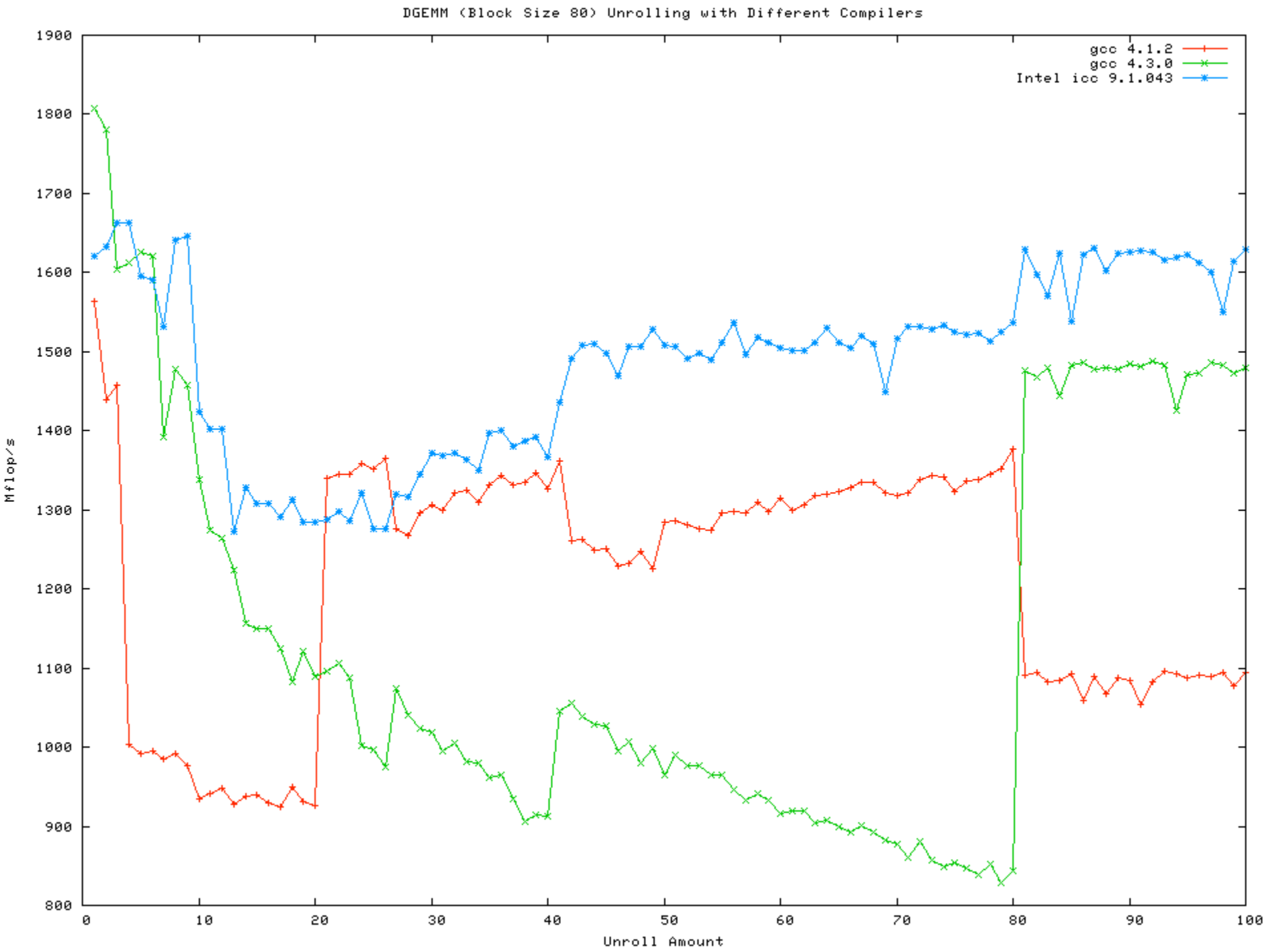
- 2.66GHz Intel Xeon X5355
- Fedora core 6 (kernel 2.6.22-10-perfctr)
- PAPI 3.6.0
- gcc 4.1.2

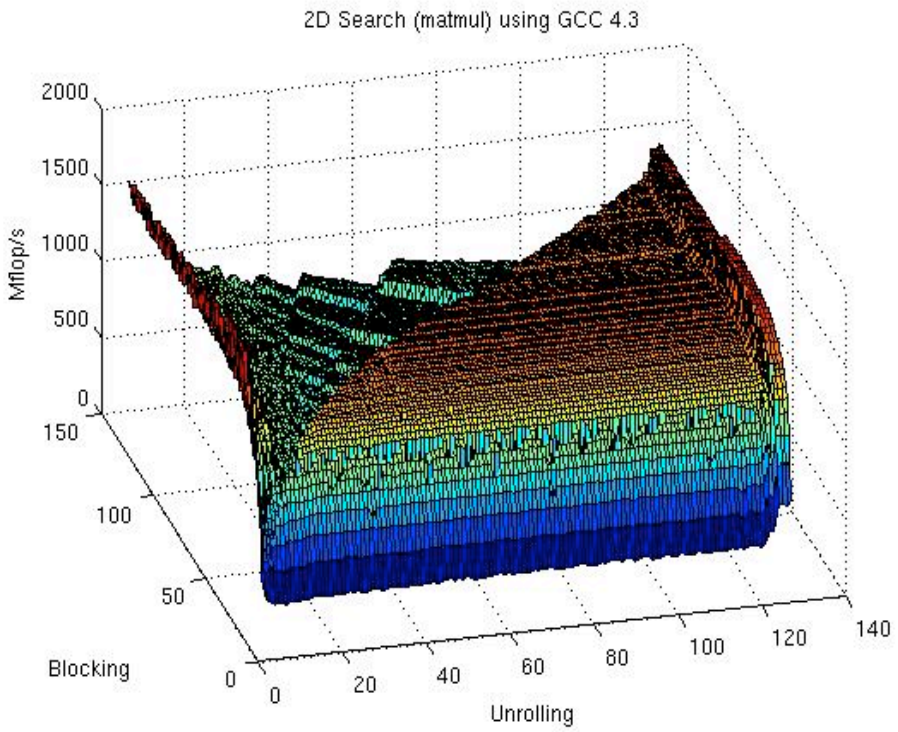
- Matrix multiply
  - 2d (blocking/unrolling)
  - 5d (multi-blocking/unrolling/loop order)
  - 21d (5d plus 16 dimensions of compiler flags)
- Matrix-vector multiply
  - 4d (multi-blocking/unrolling/loop order)


2D Search (matmul) using GCC 4.1
Mflop/s
1600
1400
1200
1000
800
600
400
Blocking
150
100
50
0
Unrolling
0
20
40
60
80
100
120
140

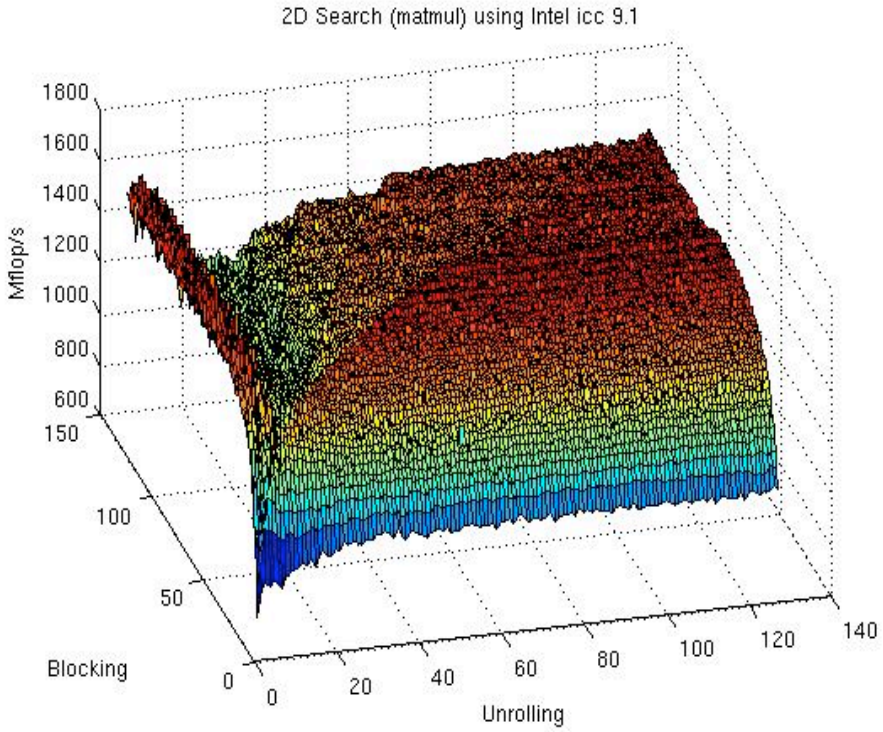

Mispredicted Branches in DGEMM (Block Size 80)
Mispredicted Branches
Mflop/s
Number of Mispredicted Branches
Mflop/s
Unroll Amount
0
5e+06
1e+07
1.5e+07
2e+07
2.5e+07
3e+07
900
1000
1100
1200
1300
1400
1500
1600
0
10
20
30
40
50
60
70
80
90
100


RS (Reservation Station) Full Events in DGEMM (Block Size 80)
RS Full Events
Mflop/s
Number of RS Full Events
Mflop/s
Unroll Amount
0
5e+07
1e+08
1.5e+08
2e+08
900
1000
1100
1200
1300
1400
1500
1600
0
10
20
30
40
50
60
70
80
90
100


DGEMM (Block Size 80) Unrolling with Different Compilers
gcc 4.1.2
gcc 4.3.0
Intel icc 9.1.043
Mflop/s
Unroll Amount
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
0
10
20
30
40
50
60
70
80
90
100



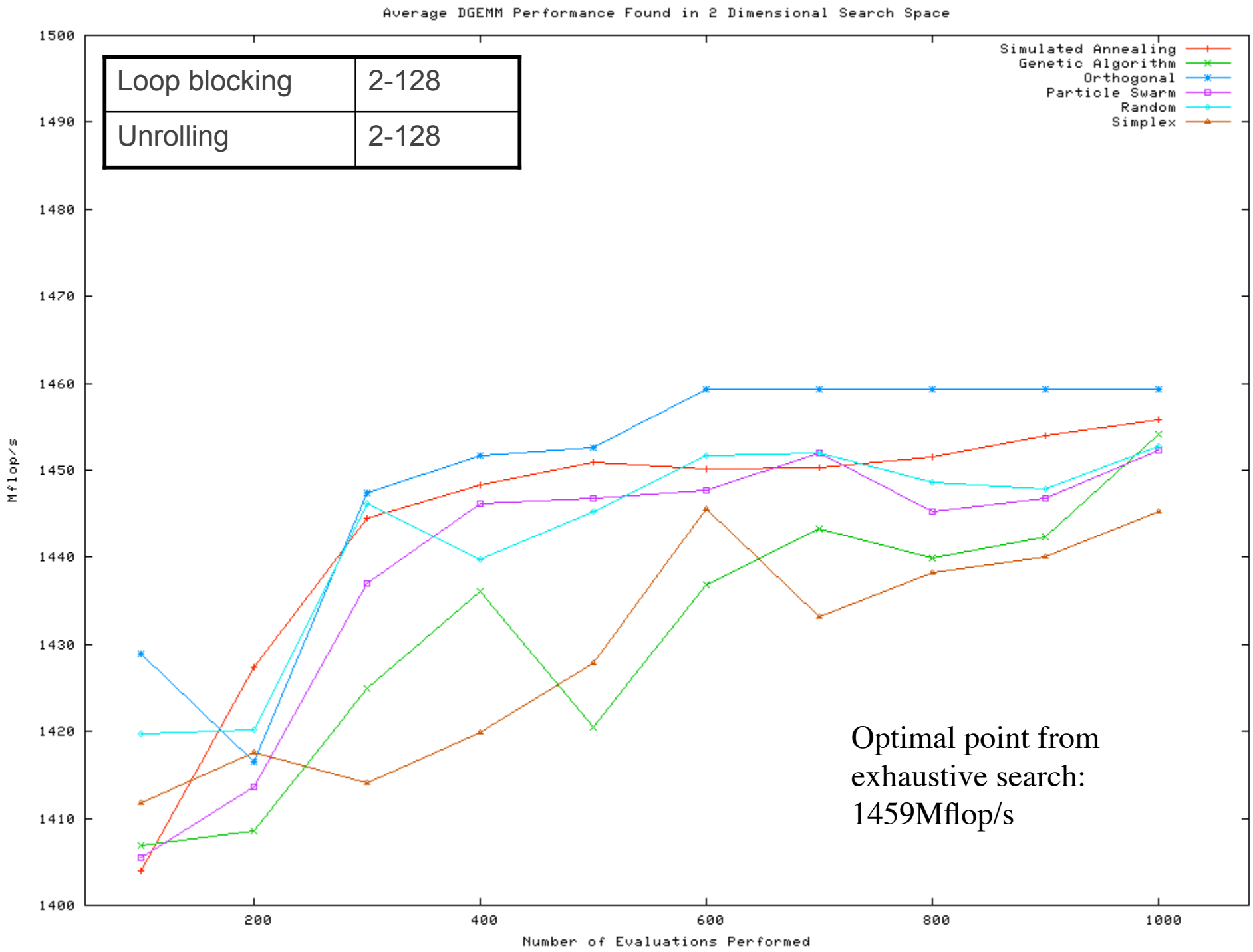
GCC 4.3

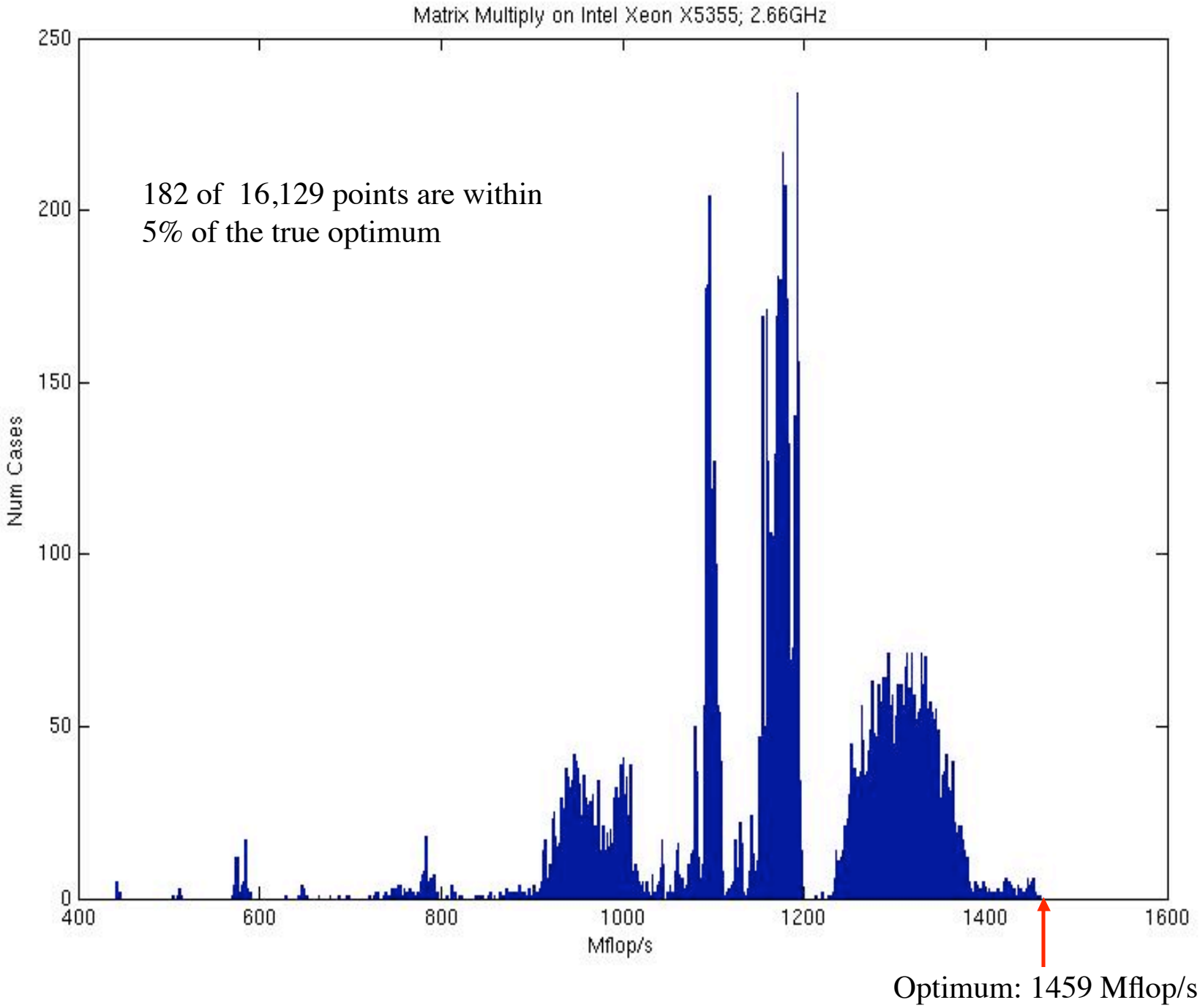


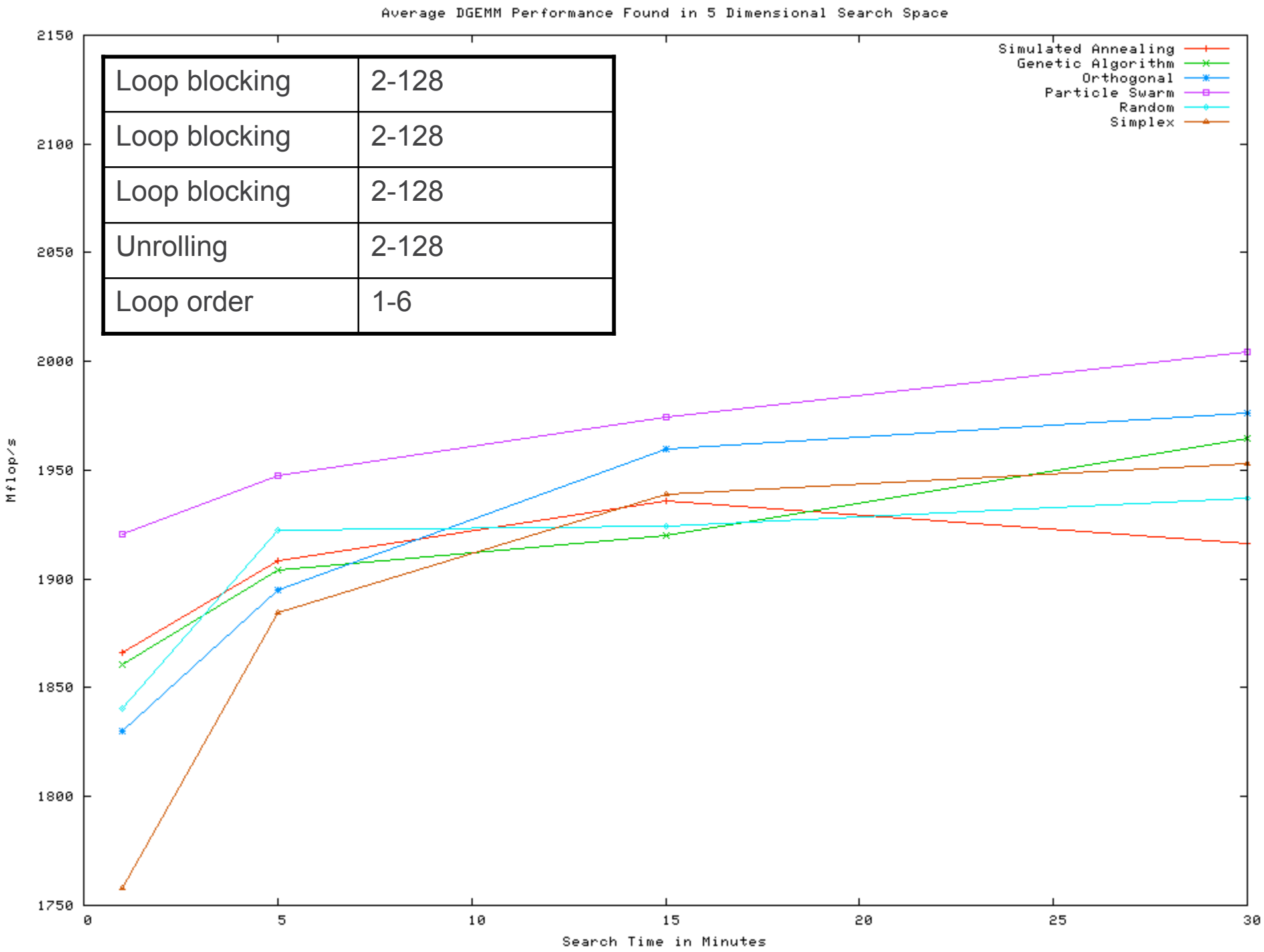
Intel icc 9.1

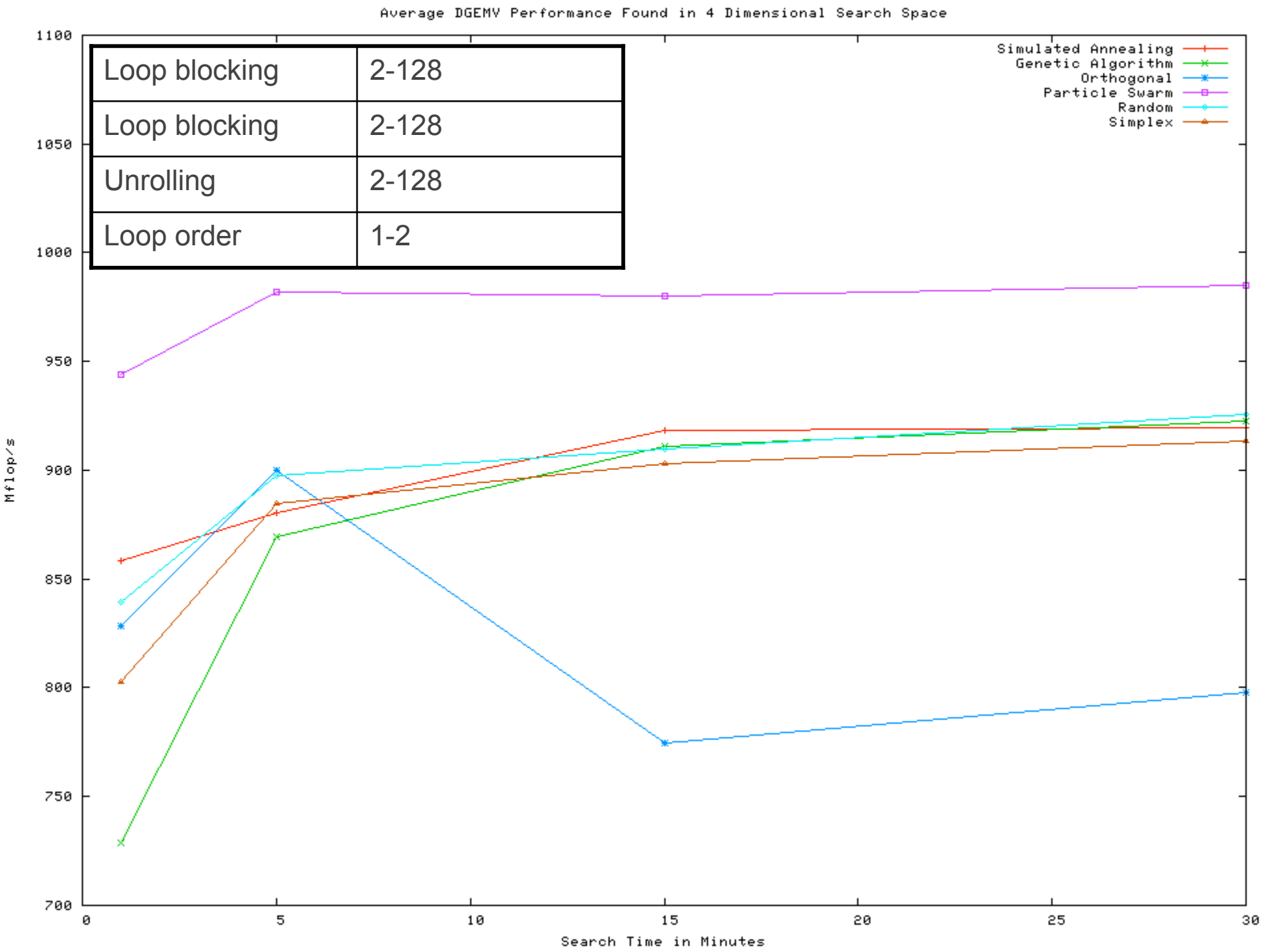
Search Techniques

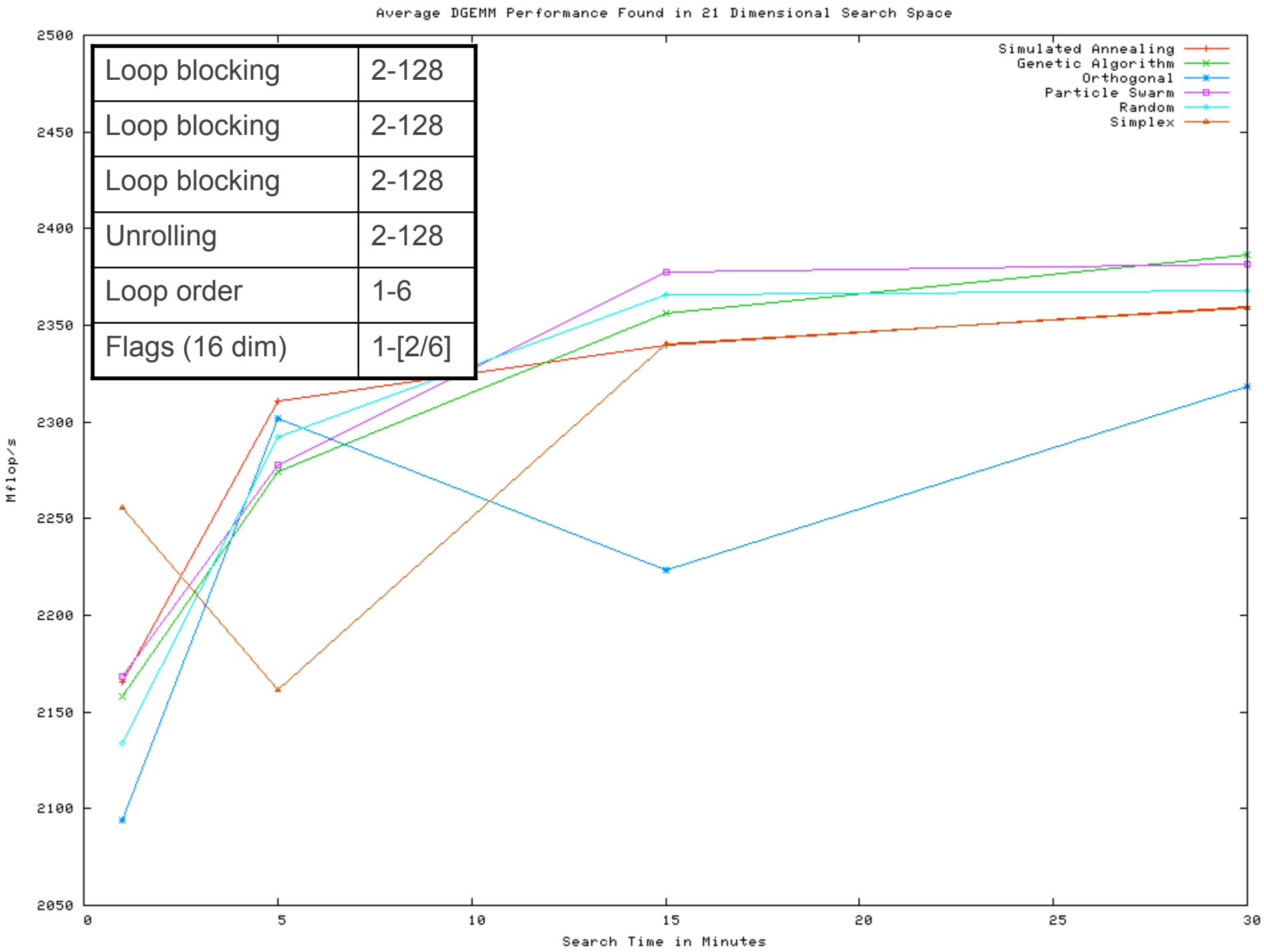
- Simplex
  - Set of vertices that contracts to an optimum by *reflection*, *expansion*, *contraction*, and *shrink*
- Orthogonal
  - Fully search one dimension at a time
- Genetic Algorithm
  - Adapt a population of candidates via natural selection (selection, mutation, crossover)
- Simulated Annealing
  - Based on annealing of substances such as metals – go through heating/cooling cycles until the characteristics change
- Particle Swarm Optimization
  - Based on flocking of birds – allow a population of particles to fly through the space, attracted to better performing areas
- Random


Average DGEMM Performance Found in 2 Dimensional Search Space
Loop blocking 2-128
Unrolling 2-128
Simulated Annealing
Genetic Algorithm
Orthogonal
Particle Swarm
Random
Simplex
Mflop/s
Number of Evaluations Performed
1500
1490
1480
1470
1460
1450
1440
1430
1420
1410
1400
200
400
600
800
1000
Optimal point from exhaustive search: 1459Mflop/s


Matrix Multiply on Intel Xeon X5355; 2.66GHz
182 of 16,129 points are within
5% of the true optimum
Num Cases
Mflop/s
0
50
100
150
200
250
400
600
800
1000
1200
1400
1600
Optimum: 1459 Mflop/s


Average DGEMM Performance Found in 5 Dimensional Search Space
Loop blocking 2-128
Loop blocking 2-128
Loop blocking 2-128
Unrolling 2-128
Loop order 1-6
Simulated Annealing
Genetic Algorithm
Orthogonal
Particle Swarm
Random
Simplex
Mflop/s
2150
2100
2050
2000
1950
1900
1850
1800
1750
0
5
10
15
20
25
30
Search Time in Minutes


Average DGEMV Performance Found in 4 Dimensional Search Space
Loop blocking 2-128
Loop blocking 2-128
Unrolling 2-128
Loop order 1-2
Simulated Annealing
Genetic Algorithm
Orthogonal
Particle Swarm
Random
Simplex
Mflop/s
Search Time in Minutes
1100
1050
1000
950
900
850
800
750
700
0
5
10
15
20
25
30


Average DGEMM Performance Found in 21 Dimensional Search Space
Loop blocking 2-128
Loop blocking 2-128
Loop blocking 2-128
Unrolling 2-128
Loop order 1-6
Flags (16 dim) 1-[2/6]
Simulated Annealing
Genetic Algorithm
Orthogonal
Particle Swarm
Random
Simplex
Mflop/s
2500
2450
2400
2350
2300
2250
2200
2150
2100
2050
0
5
10
15
20
25
30
Search Time in Minutes

Recent Work

- Uniform distributions for population based methods (GA, PSO)
  - Halton and Faure sequences
- Hybrid Particle Swarm / Simulated Annealing
- Orthogonal search modifications
  - Hybrid random/orthogonal search
  - Sort dimensions based on size
- Application to different kinds of problems

Conclusions

- Performance can be improved with a modest amount of search time
- Random search is pretty good!
  - Is the search space too easy?
- Otherwise PSO seems to have the slight edge
- Non-architectural features (e.g. compiler behavior) can have a huge effect