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U.S. DEPARTMENT OF ENERGY

Using Empirical Roofline Toolkit and Nvidia nvprof

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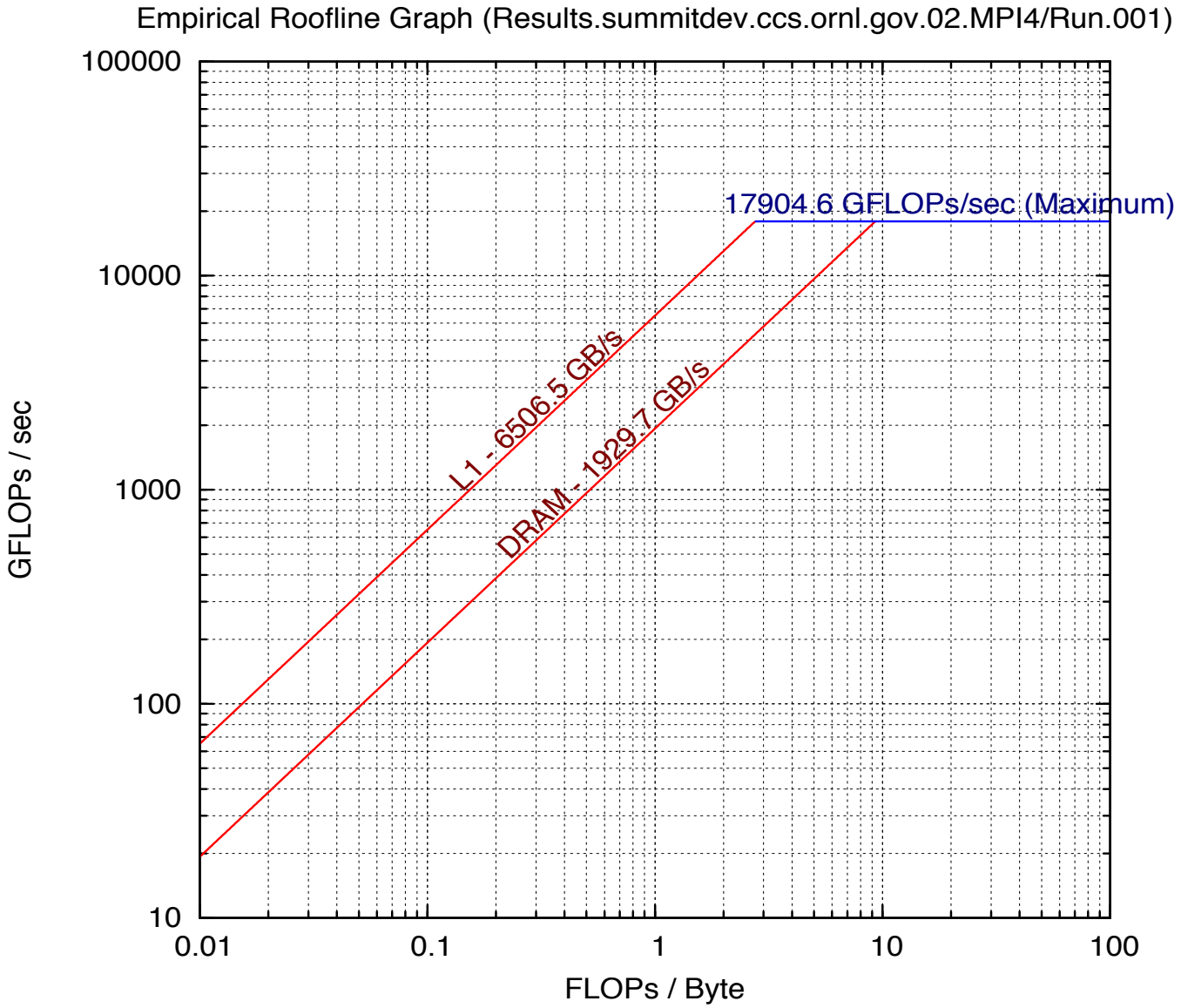
ERT Results from a SummitDev Node



https://bitbucket.org/berkeleylab/cs-roofline-toolkit

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Components of the ERT

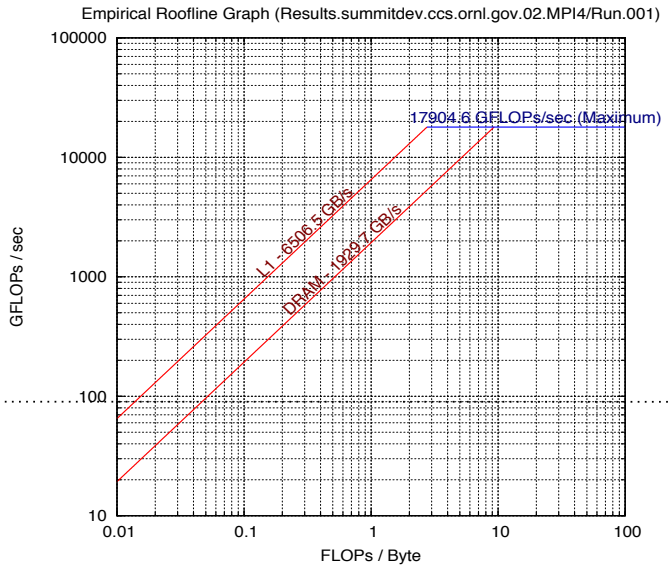
User Written ERT Script

```
ERT_RESULTS
Results.summitdev
ERT_DRIVER  driver1
ERT_KERNEL  kernel1
.....
```

ERT Driver

ERT Kernel

JSON file



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Driver

Driver

```
int main () {
  #pragma omp parallel private(id)
  {
  uint64_t n, t;
  initialize(&A[nid]);
  for (n = 16; n < SIZE; n *= 1.1) {
    for (t = 1; t < TRIALS; t *= 2) {
      // start timer here
      Kernel(n, t, &A[nid]);
      // stop timer here
      #pragma omp barrier
      #pragma omp master
      {
        MPI_Barrier(MPI_COMM_WORLD);
      }



}}}
```

Init

Compute

Sync

Kernel

Bandwidth

```
void Kernel (uint64_t size, unit64_t trials,
double * __restrict__ A) {
  double alpha = 0.5;
  uint64_t i, j;
  for (j = 0; j < trials; ++j ) {
    for (i = 0; i < nsize; ++i) {
      A[i] = A[i] + alpha;
    }
    alpha = alpha * 0.5;
}}
```

Kernel

GFlops

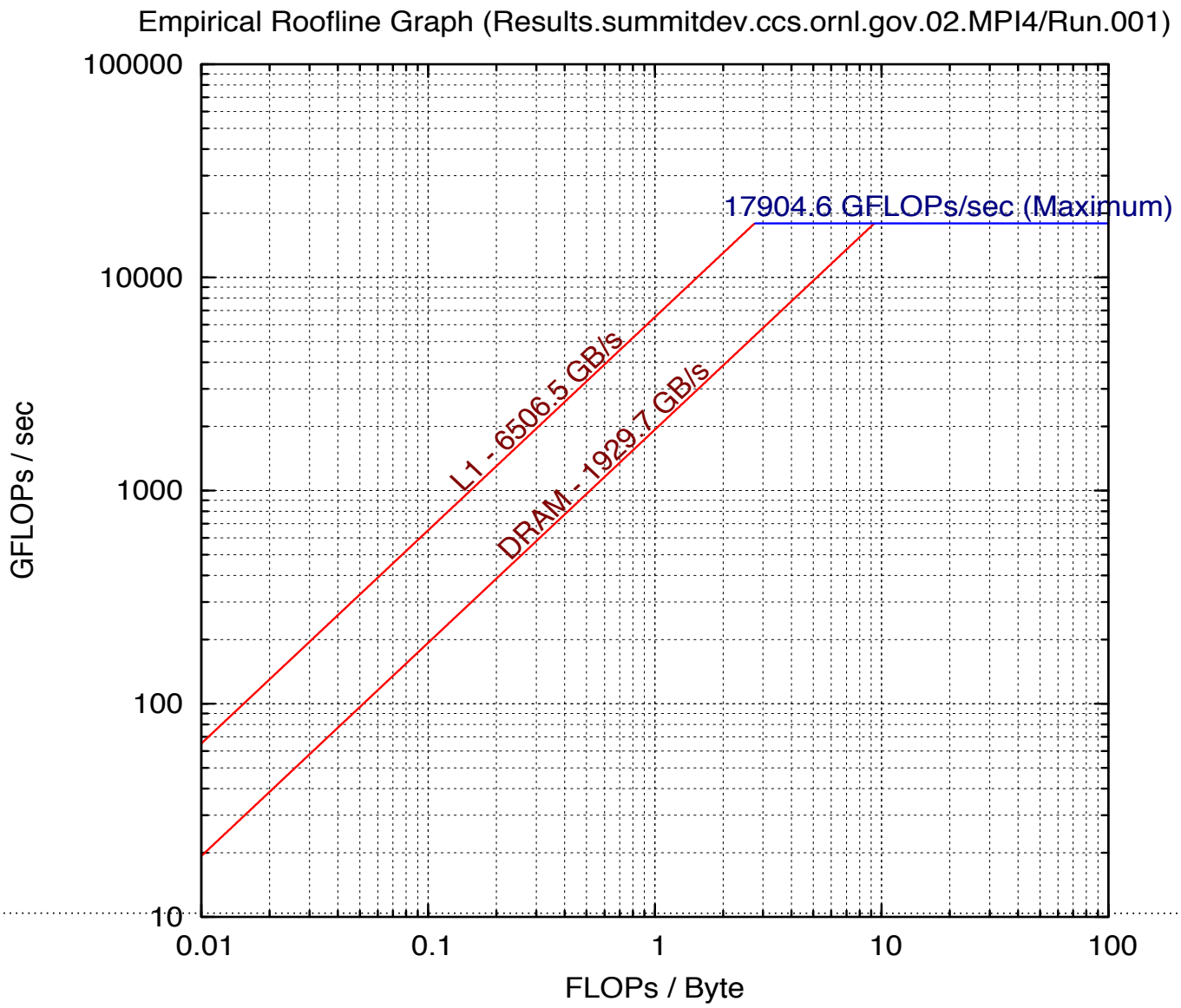
```
void Kernel (uint64_t size, unit64_t trials,
double * __restrict__ A) {
  double alpha = 0.5;
  uint64_t i, j;
  for (j = 0; j < trials; ++j ) {
    for (i = 0; i < nsize; ++i) {
      double bete = 0.8;
      #if FLOPPERITER == 2
      beta = beta * A[i] + alpha;
          #elif FLOPPERITER == 4
      beta = beta * A[i] + alpha;
      beta = beta * A[i] + alpha;
      #elif FLOPPERITER == 8
      …
      #endif
      A[i] = beta;
    }
    alpha = alpha * 0.5;
}}
```

Configuration Script for SummitDev

```
ERT_RESULTS Results.summitdev
ERT_DRIVER  driver1
ERT_KERNEL  kernel1

ERT_GPU         True
ERT_GPU_CFLAGS  -x cu

ERT_MPI True
ERT_FLOPS   1,2,4,8,16,32,64,128,256
ERT_ALIGN   32

ERT_CC      nvcc
ERT_CFLAGS  -O3 -gencode code=sm_60 ...
ERT_LD      mpicc
ERT_LDFLAGS ...

ERT MPI_PROC 4

ERT_RUN   mpirun -np ERT_MPI_PROCS -map-by
ppr:4:node --bind-to none -gpu -display-map
ERT_CODE
```

```
ERT_BLOCKS_THREADS 28672
ERT_GPU_BLOCKS     28,56,112,224,448
ERT_GPU_THREADS    64,128,256,512,1024


ERT_NUM_EXPERIMENTS 1
ERT_MEMORY_MAX 1073741824
ERT_WORKING_SET_MIN 128
ERT_TRIALS_MIN 1


ERT_GNUPLOT gnuplot
```

ERT Results from a SummitDev Node



AI of using Nvidia nvprof

Nvidia nvprof enables the collection of a timeline of CUDA-related activities on both CPU and GPU, including kernel execution, memory transfers, memory set and CUDA API calls

AI of using Nvidia nvprof

To plot roofline (AI) data for a kernel, we need:

```
Number of floating-point operations executed
```

```
Data-volume to and from DRAM or cache
```

```
The runtime in seconds
```

Runtime of Kernel

command: nvprof --print-gpu-trace ./build/bin/hpgmg-fv 6 8

output:

Time	Calls	Avg	Min	Max
2.52256s	1764	1.4300ms	1.4099ms	1.4479ms

Name

void smooth_kernel<int=7,int=16,int=4,int=16>
(level_type, int, int, double, double, int, double*, double*)

Nvidia nvprof is used in the gpu-trace mode

Using nvprof to Collect Metrics

Use the nvprof metric summary mode to collect:

Flops

DRAM read/write throughput

DRAM read/write transactions

```
command: nvprof  --kernels  "smooth_kernel”
         --metrics flop_count_dp
         --metrics dram_read_throughput
         --metrics dram_write_throughput
         --metrics dram_read_transactions
         --metricsdram_write_transactions
         ./build/bin/hpgmg-fv 6 8
```

Using nvprof to Collect Metrics

```
command: nvprof  --kernels  "smooth_kernel”
         --metrics flop_count_dp
         --metrics dram_read_throughput
         --metrics dram_write_throughput
         --metrics dram_read_transactions
         --metricsdram_write_transactions
         ./build/bin/hpgmg-fv 6 8
```

Kernel: void smooth_kernel<int=7, int=32, int=4, int=16>(level_type, int, int, double, double, int, double*, double*)

Invocations	Metric Name	Min	Max	Avg
1764	flop_count_dp	240648192	240648192	240648192
1764	dram_read_throughput	299.98 GB/s	307.48GB/s	303.72 GB/s
1764	dram_write_throughput	40.102GB/s	41.099GB/s	40.578GB/s
1764	dram_read_transactions	4537918	4599890	4567973
1764	dram_write_transactions	606387	611691	610299

Computing Arithmetic Intensity

Method 1

FP / (DR + DW) * (size of transaction = 32 Bytes)

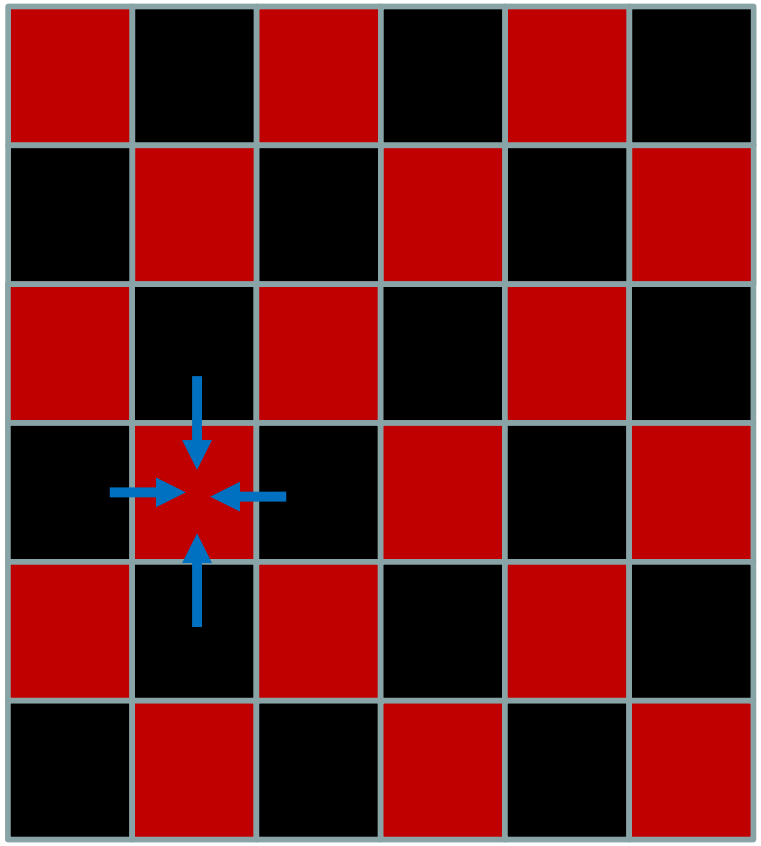
Method 2

FP / (TR + TW) * time taken by kernel

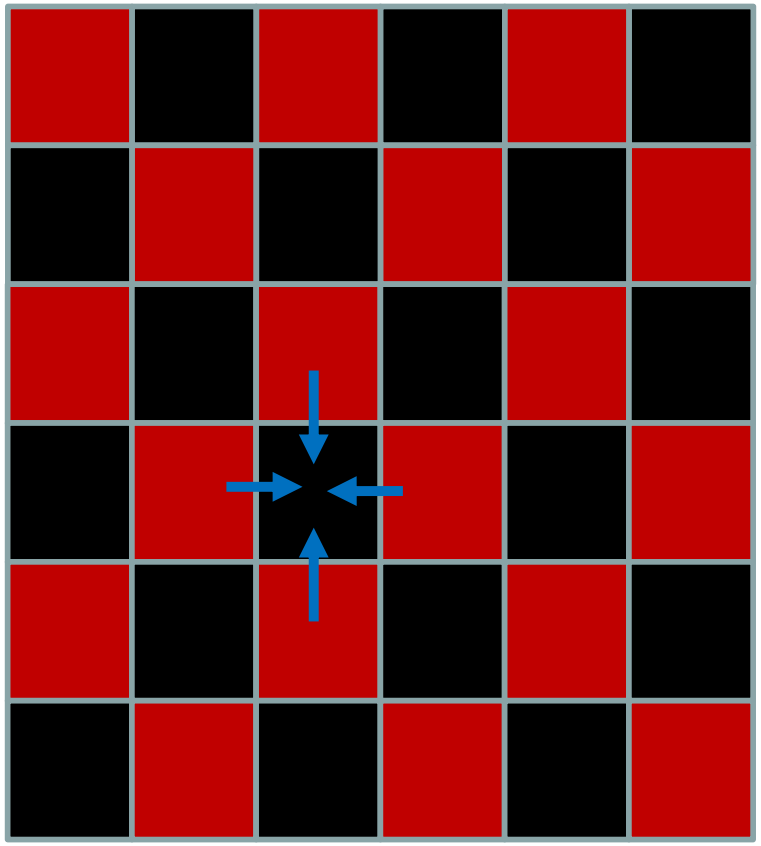
FP = double precision ops
DR/DW= dram read/write transactions
TR/TW= dram read/write throughput

Gauss-Seidel Red-Black (GSRB)

Red Sweep: update red points



Black Sweep: update black points



Two Flavors of GSRB (GSRB_BRANCH)

```
template<intLOG_DIM_I,intBLOCK_I,intBLOCK_J,intBLOCK_K>
__global__ void smooth_kernel(…){

int i=ilo+threadIdx.x;
int j=jlo+threadIdx.y;

for (k=klow; k<klow+kdim; k++){
int ijk = i+j*jStride+k*kStride;
if ((i^j^k^color^1)&1){
        double Ax=apply_op_ijk(); //7-point VC stencil
        double lambda=Dinv_ijk();
        xo[ijk]=X(ijk)+lambda*(rhs[ijk]-Ax);

}}
```

The if-condition blocks unnecessary computation

Two Flavors of GSRB (GSRB_FP)

```
template<intLOG_DIM_I,intBLOCK_I,intBLOCK_J,intBLOCK_K>
__global__ void smooth_kernel(…){

int i=ilo+threadIdx.x;
int j=jlo+threadIdx.y;

for (k=klow; k<klow+kdim; k++){
        Int ijk = i+j*jStride+k*kStride;
        double* RedBlack=level.RedBlack_FP
                +ghosts*(1+jStride)
                +((k^color000)&1)*kStride;
        double Ax=apply_op_ijk(); //7-point VC stencil
        double lambda=Dinv_ijk();
        xo[ijk]=X(ijk)+RedBlack [ij] lambda*(rhs[ijk]-Ax);

}}
```

RedBlack mask is used to block unnecessary writes

Results from GSRB on SummitDev GPUs

```
Thread Block (I=32, J=4)
```

	flops executed	Read Transactions	Write Transactions	Data Movement (Bytes)
GSRB_FP	240648192	4566618	610123	165655712
GSRB_BRANCH	120061952	9306276	613283	317425888

```
ERT BANDWIDTH : 497 GB/s
```

```
GSRB_FP READ+WRITE THROUGHPUT: 371 GB/s
```

Results from GSRB on SummitDev GPUs

`Thread Block (I=32, J=4)`

	flops executed	Read Transactions	Write Transactions	Data Movement (Bytes)
GSRB_FP	240648192	4566618	610123	165655712
GSRB_BRANCH	120061952	9306276	613283	317425888

	flops (requisite)	Ratio	Data Movement (Bytes) Requisite	Ratio
GSRB_FP	119537664	2.013157895	128798208	1.286164727
GSRB_BRANCH	119537664	1.004385965	110398464	2.875274497

`Requisite flops computed for GSBR_branch`

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