Understanding Application Data Movement Characteristics using Intel’s VTune Amplifier and Software Development Emulator tools

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Overview

- **Motivation -> Roofline Performance Model**
  - ➢Arithmetic Intensity: the ratio of total floating-point operations (FLOPs) to total data movement (bytes)
  - ➢Need a method to measure FLOPs and data movement
- **Software Development Environment Toolkit -> FLOPs and bytes (as seen by the L1)**
  - ➢Allows developers to gain familiarity with upcoming instruction set extensions using currently available compilers
  - ➢Built on Intel's Pin and XED tools
- **VTune Amplifier -> bytes (as seen by DRAM)**
  - ➢Intel's performance analysis and profiling tool

SDE Capability used in this Study

- **Dynamic instruction tracing**
  - ➢ Mix histogram tool: dynamic instructions executed, instruction length, instruction category, and ISA extension grouping
- **Invocation**
  - ➢ sde64 -hsw -d -iform 1 -omix my_mix.out -global_region -start_ssc_mark 111:repeat -stop_ssc_mark 222:repeat -- my_exe
- **Code instrumentation (Intel compiler only, no #include required)**

```
__SSC_MARK(0x111); // start SDE instruction tracing
for (k=0; k<NTIMES; k++) {
#pragma omp parallel for
        for (j=0; j<STREAM_ARRAY_SIZE; j++)
            a[j] = b[j]+scalar*c[j];
    }
__SSC_MARK(0x222); // stop SDE tracing
```

VTune Capabilities used in this Study

- **Uncore memory controller counters to determine DRAM bandwdith analysis**
- **Invocation**
  - ➢amplxe-cl -start-paused -data-limit=0 -collect bandwidth my_exe
- **Code instrumentation**

```
# include <ittnotify.h>

__itt_resume();    // start Vtune
for (k=0; k<NTIMES; k++) {
#pragma omp parallel for
        for (j=0; j<STREAM_ARRAY_SIZE; j++)
            a[j] = b[j]+scalar*c[j];
    }
__itt_pause();     // stop Vtune
```

Example SDE Output

```
# EMIT_GLOBAL_DYNAMIC_STATS    EMIT# 9
#
# $global-dynamic-counts
#
#       iform                       count
#
*mem-atomic                                                      403
*stack-read                                                  2583867
*stack-write                                                  589366
*iprel-read                                                  3961410
*iprel-write                                                      19
*mem-read-1                                                   566648
*mem-read-2                                                      659
*mem-read-4                                                  5654702
*mem-read-8                                                  7381945
*mem-read-16                                                      15
*mem-read-32                                              1000000000
*mem-write-1                                                     680
*mem-write-2                                                     180
*mem-write-4                                                    6968
*mem-write-8                                                  588745
*mem-write-32                                              500000000
```

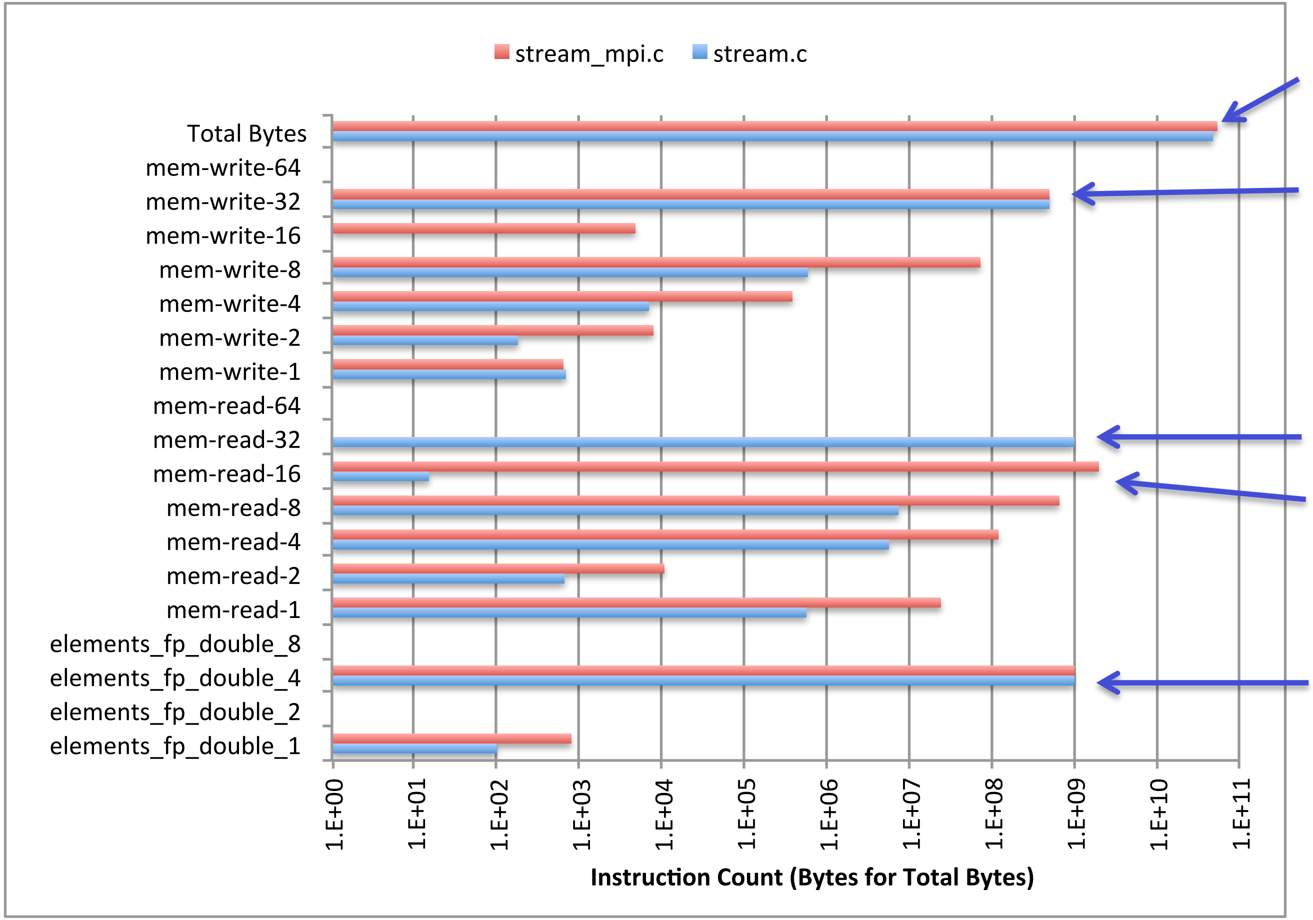
```
*isa-ext-AVX                                              1500001260
*isa-ext-BASE                                             2032342858
*isa-ext-LONGMODE                                               3989
*isa-ext-PAUSE                                               1129270
*isa-ext-SSE                                                     180
*isa-ext-SSE2                                                    314
*isa-ext-X87                                                     360
~ lots of output
*elements_fp_double_1                                            100
*elements_fp_double_4                                     1000000000
~ lots of output
# END_GLOBAL_DYNAMIC_STATS
```

Example VTune Output

```
Collection and Platform Info
----------------------------
Parameter                 r000bw
------------------------
---------------------------------------------------------------------
Application Command Line  ./stream_c.exe
~ lots of output
Average Bandwidth
-----------------
Package    Bandwidth, GB/sec:Self
---------  ----------------------
package_0                  63.542
package_1                     0.0
package_2                     0.0
package_3                   0.008
~ lots of output
```

```
Uncore Event summary
--------------------
Hardware Event Type                  Hardware Event Count:Self
----------------------------------  -------------------------
UNC_M_CAS_COUNT.RD[UNIT0]                             65792209
UNC_M_CAS_COUNT.RD[UNIT1]                             65712839
UNC_M_CAS_COUNT.RD[UNIT2]                             65752103
UNC_M_CAS_COUNT.RD[UNIT3]                             65713593
UNC_M_CAS_COUNT.RD[UNIT4]                             65803068
UNC_M_CAS_COUNT.RD[UNIT5]                             65837905
UNC_M_CAS_COUNT.RD[UNIT6]                             65776860
UNC_M_CAS_COUNT.RD[UNIT7]                             65769163
UNC_M_CAS_COUNT.WR[UNIT0]                             31446289
UNC_M_CAS_COUNT.WR[UNIT1]                             31333807
UNC_M_CAS_COUNT.WR[UNIT2]                             31339989
UNC_M_CAS_COUNT.WR[UNIT3]                             31356486
UNC_M_CAS_COUNT.WR[UNIT4]                             31437708
UNC_M_CAS_COUNT.WR[UNIT5]                             31337857
UNC_M_CAS_COUNT.WR[UNIT6]                             31349367
UNC_M_CAS_COUNT.WR[UNIT7]                             31348069
UNC_Q_TxL_FLITS_G0.DATA[UNIT0]                           82536
UNC_Q_TxL_FLITS_G0.DATA[UNIT1]                           72584
UNC_Q_TxL_FLITS_G0.NON_DATA[UNIT0]                   229393526
UNC_Q_TxL_FLITS_G0.NON_DATA[UNIT1]                   229423023
```

SDE Summary for Stream



MPI version moves 1.13x more aggregate than OpenMP version

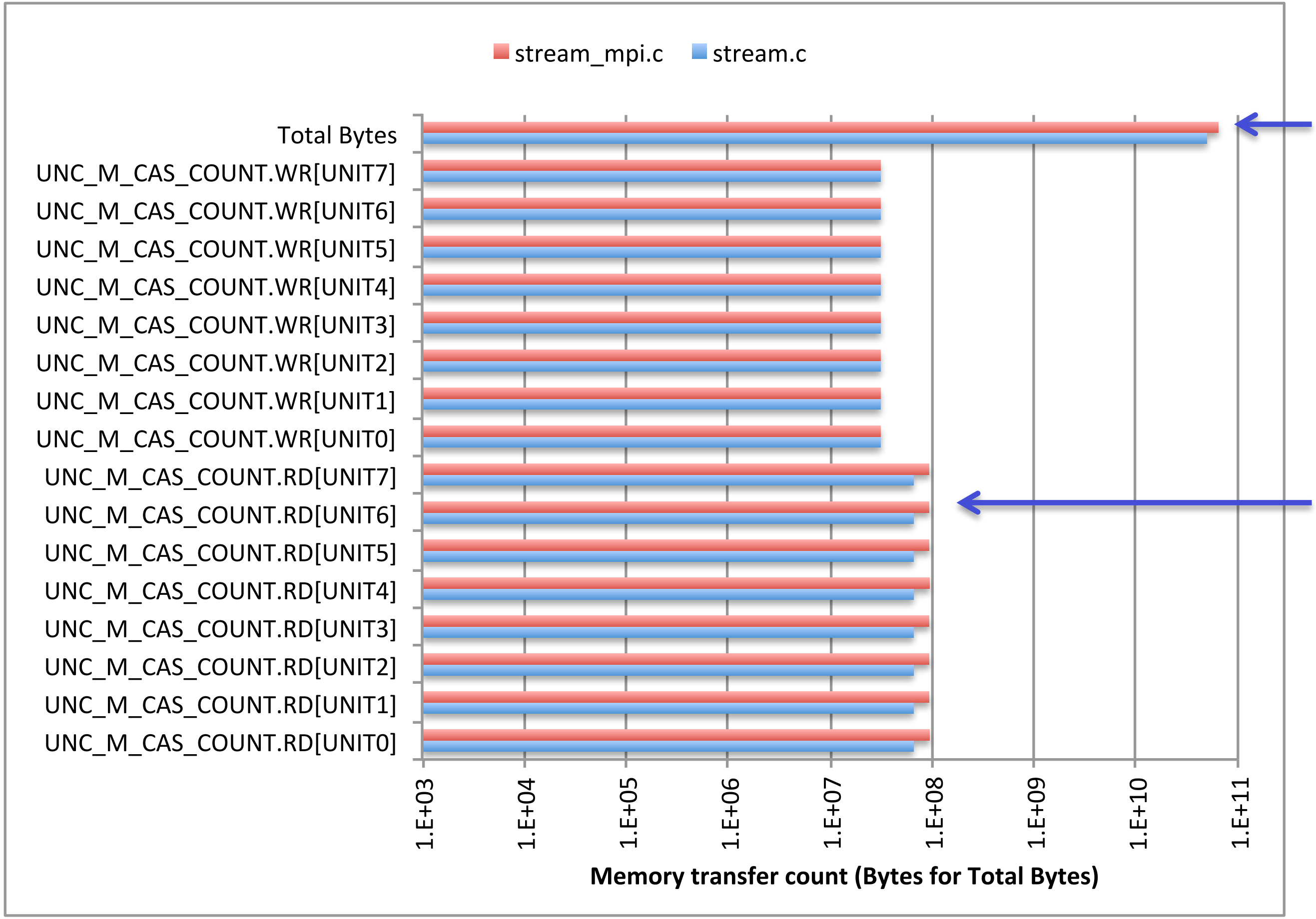
Writes are equivalent

OpenMP version does 32 byte reads

MPI version does 16 byte reads

Both use 256-bit AVX to full extent

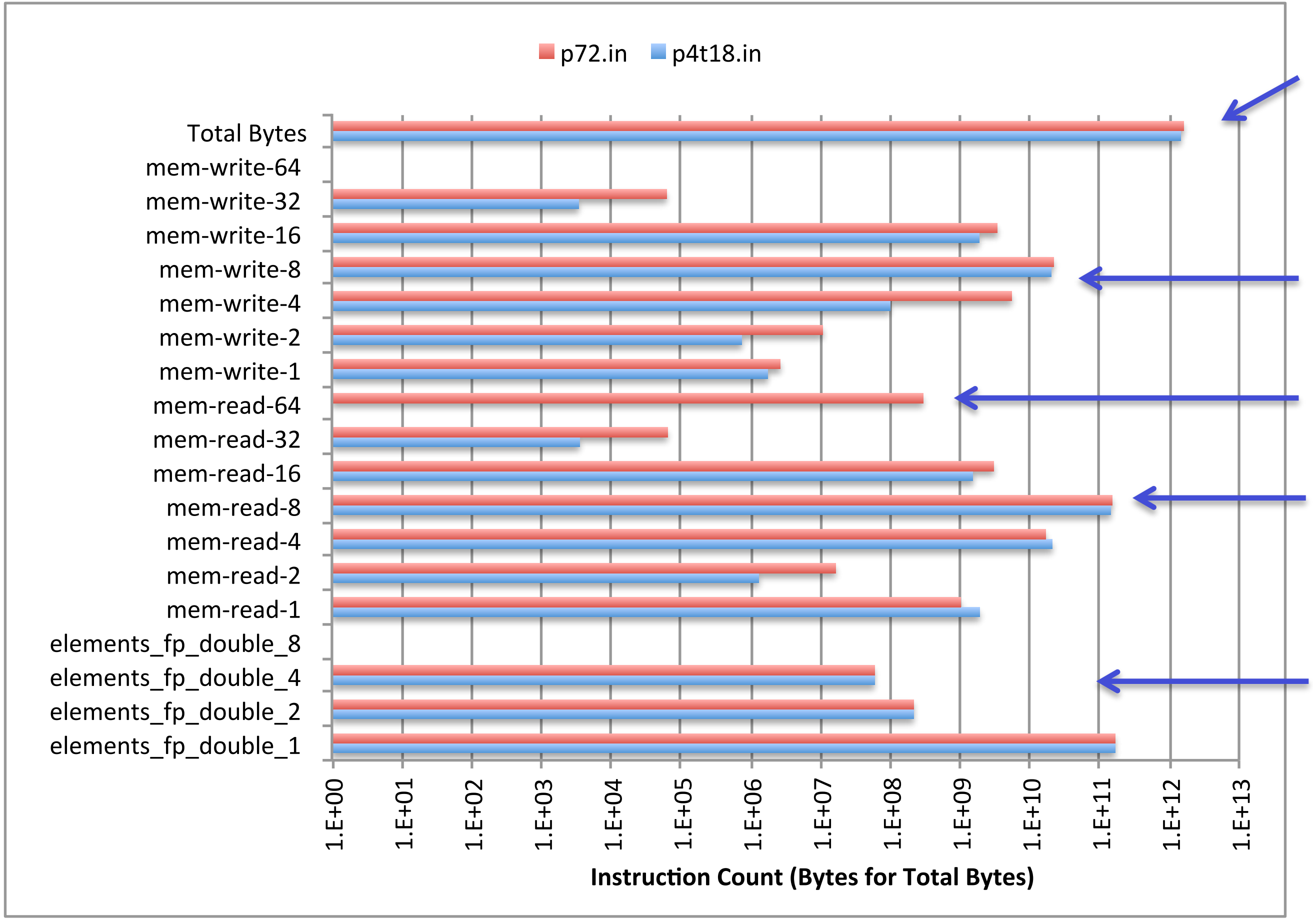
VTune Summary for Stream



MPI version moves 1.29x more data

Higher read rate for MPI is visible at the DRAM interface

SDE Summary for MILC



MPI version moves 1.10x more aggregate than OpenMP version

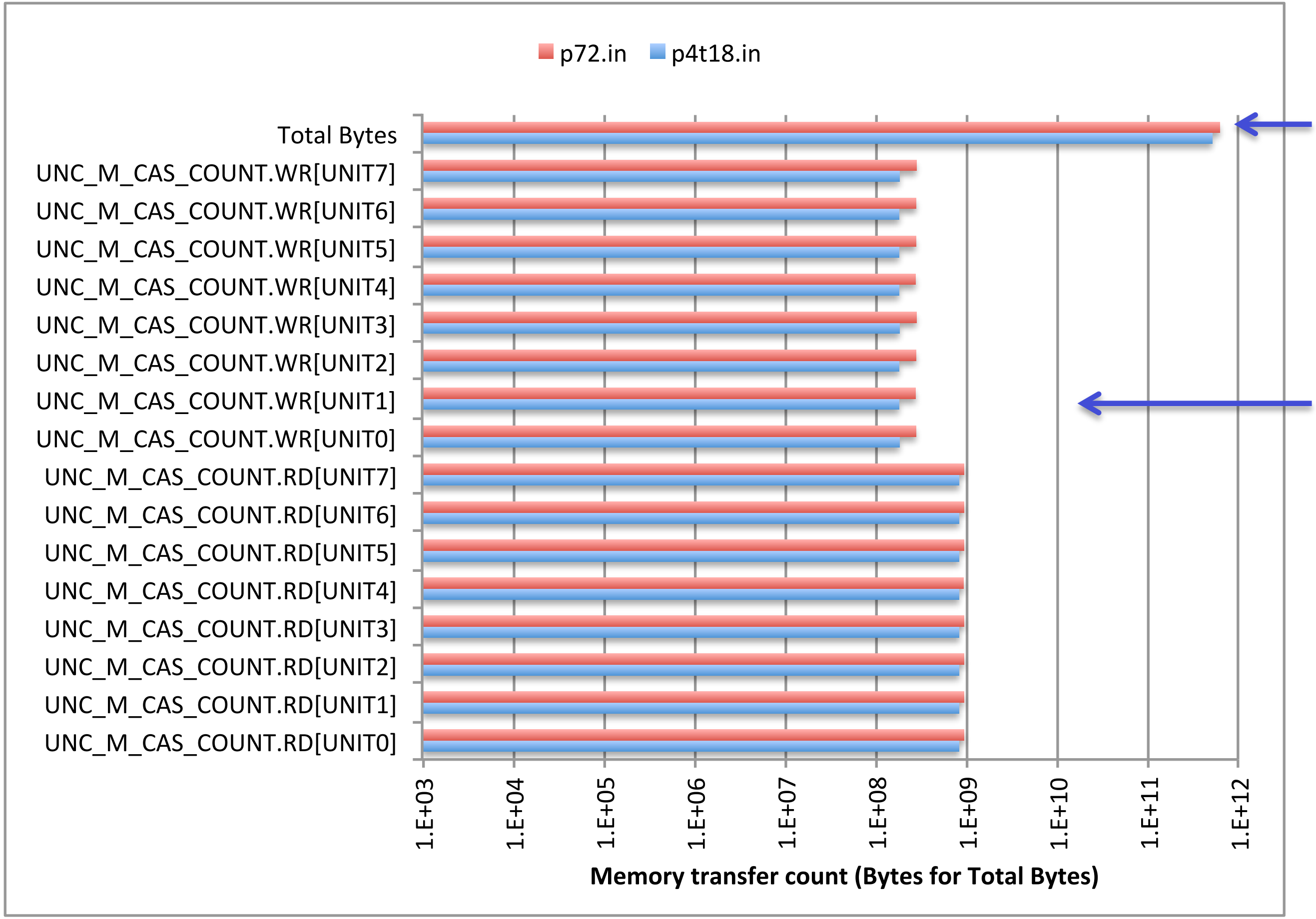
In general, MPI write traffic > OpenMP

MPI version does 64-bit reads

In general, MPI read traffic > OpenMP

Both have equivalent FLOPs

VTune Summary for MILC



MPI version moves 1.21x more data

Higher read and write rates for MPI is visible at the DRAM interface

Insights & Summary

- **Using a well known micro-benchmark, the differences in data movement between an MPI and an OpenMP implementation was demonstrated**
  - ➢ This method has been applied to the applications GTC-P and MILC and similar characteristics were observed; More to be analyzed in the future
- **SDE provides a wealth of information that will allow you to better understand your application**
  - ➢ Started using SDE to count floating-point operations
  - ➢ Found SDE can also be used to better understand data movement
  - ➢ This study only focused on memory and floating-point instructions
  - ➢ Future efforts will delve into function-level specific counters, larger instruction mix analysis, etc
  - ➢ SDE output can consist of multiple files and is lengthy; I developed my own script to parse out data of interest
- **VTune can be used to analyze uncore data movement**

Other interesting tips

- **Generate a VTune report per package/socket as opposed to aggregating all memory controller counters across all sockets**
  - ➢amplxe-cl –R hw-events –group-by=package –r r000bw
- **VTune report with per function counter data**
  - ➢amplxe-cl –R hw-events –r r000bw

Thank You

- Special thanks to Matthew Cordery who initially developed the methodology

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