THE DYNAMIC GRANULARITY MEMORY SYSTEM

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MEMORY ACCESS GRANULARITY

• The size of block for accessing main memory
  – Often, equal to last-level cache line size

• Modern systems use coarse-grained (CG) memory access
  – 64B or larger
  – Amortize control & ECC overhead
  – Prefetching
CG ACCESS MAY WASTE BW

- Waste BW on unused data

GUPS microbenchmark

```c
for( i=0; i<N; i++ ) {
    a[ b[i] ] += x;
}
```

Buffer a

Initialized with random numbers
CAN WE WASTE BW?

• CG access often improves performance
  – Large cache lines reduce miss rate
due to prefetching

• Off-chip BW doesn’t scale with # cores
• Power is the limiting factor

• We shouldn’t waste the finite off-chip BW
HOW TO EFFICIENTLY UTILIZE OFF-CHIP BW?

• Prior work: AGMS [ISCA’11]
  – Combine CG and FG accesses
  – Need SW help for ECC support
    • Source code, compiler, OS, virtual memory, ...

• DGMS
  – HW-only variant of AGMS
  – Truly dynamic granularity adaptation
ADAPTIVE GRANULARITY MEMORY SYSTEM [ISCA’11]
AGMS [ISCA’11]

• Combine coarse-grained (CG) and fine-grained (FG) accesses

• CG for high spatial locality regions
• FG for low spatial locality regions

• Higher throughput
• Lower DRAM power
**SUB-RANKED DRAM MODULE**

- Independently control individual DRAM chips
- Access granularity = 8bit x burst 8 = 8B
8-bit data + 5-bit SEC-DED or 8-bit DEC

Burst 8

ABUS

Reg/Demux

x8 x8 x8 x8 x8 x8 x8 x8 x8

SR0 SR1 SR2 SR3 SR4 SR5 SR6 SR7 SR8
SOFTWARE SUPPORT IN AGMS

• Different data/ECC layouts for CG & FG

• Requires software help
  – Extend virtual memory interface
  – OS/runtime manages CG&FG pages
  – Programmer/compiler annotates preferred granularity

• Need to change every level of system hierarchy!
DYNAMIC GRANULARITY
MEMORY SYSTEM
DGMS

• **Unified data/ECC layout** for CG & FG
  – No SW support

• HW-only variant of AGMS
  – Comparable or better performance
  – **Easier to implement**

• Challenge:
  – **How to predict access granularity dynamically?**
### UNIFIED DATA/ECC LAYOUT

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- **E0-7**
  - E 0-15
  - E 16-23
  - E 24-31
  - E 32-39
  - E 40-47
  - E 48-55
  - E 56-63

- **Burst 8**
  - 64-bit data
  - 8-bit ECC (SEC-DED)
CG ACCESS

- Access the whole 72B

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Burst 8

E 0-7
E 8-15
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E 48-55
E 56-63
FG ACCESS

- Access 8B data and 8B ECC
AVOIDING CONTENTION ON ECC DRAM
DGMS DESIGN

Sector cache

Sub-ranked memory w/ unified data/ECC layout
Which words within a cache line will be used?
SPATIAL PATTERN PREDICTOR [CHEN; HPCA ’04]

L1 Data Cache

Request To L2

Load/Store

Update CPT

PC

DA

Tag Status Data

Used Idx

Status Idx Pattern

Evicted or Subsector miss

PHT hit

Default

PHT

00101101
01001011
00001000
10000000
00110000
11010001

01000000
00001000
00001110
01001100
11010001
01110000

01000000
00001000
00001110
01001100

11010001
01110000
SPP ACCURACY

- Not predicted, but Referenced
- Predicted & Referenced

SSCA2  canneal  em3d  mst  gups  mcf  omnetpp  lbm  OCEAN  s-cluster  stream
SPP LIMITATIONS

• Case 1)
  – Application accesses 5~7 words per cache line

• Case 2)
  – App1 has low spatial locality, MPKI is 1
  – App2 has high spatial locality, MPKI is 20

• Minimizing traffic doesn’t always improve performance
Ignore SPP if AvgRefWord > 3.75, or if row-buffer hirate > 0.8

Treat all requests are CG if CG requests are dominant (more than 80% of MC queue)

LPC & GPC prevent performance degradation in some CG-friendly apps
EVALUATION
EVALUATION

• Zesto simulator
  – 8 out-of-order x86 cores
  – Private caches: 32kB I/D L1, 256kB unified L2
  – Shared last-level cache: 8MB

• DrSim: detailed DDR3 DRAM model

• Memory intensive multiprogrammed workloads
LOW SPATIAL LOCALITY APPS

Weighted Speedup

SSCA2  canneal  em3d  mst  gups  mcf  omnetpp

CG  AGMS  DGMS
HIGH SPATIAL LOCALITY APPS

Weighted Speedup

Ibm  OCEAN  s-cluster  stream

CG  AGMS  DGMS
SYSTEM THROUGHPUT

Weighted Speedup

CG  AGMS  DGMS

SSCA2  canneal  em3d  mst  gups  mcf  omnetpp  lbm  OCEAN  s-cluster  stream  MIX1  MIX2  MIX3  MIX4  MIX5

32
MIXED CASES

MIX1: SSCA2 x2, mst x2, em3d x2, canneal x2
MIX2: SSCA2 x2, canneal x2, mcf x2, OCEAN x2
MIX3: canneal x2, mcf x2, bzip2 x2, hmmer x2
MIX4: mcf x4, omnetpp x4
MIX5: SSCA2 x2, canneal x2, mcf x2, streamcluster x2

Weighted Speedup

- CG
- AGMS
- DGMS
SYSTEM THROUGHPUT (NO ECC)

Weighted Speedup

SSCA2 canneal em3d mst gups mcf omnetpp Ibm OCEAN s-cluster stream MIX1 MIX2 MIX3 MIX4 MIX5

CG AGMS DGMS
CONCLUSIONS

• Dynamic Granularity Memory System
  – HW-only variant of AGMS
  – Truly dynamic granularity adaptation
    – Higher performance [31% vs. CG]
    – Lower DRAM power [13% vs. CG]

• More in the paper
  – Reg/demux and address/command bus bandwidth
  – LPC&GPC details
  – DGMS with chipkill-correct support
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