Hybrid Memory Platform

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OpenPOWER Summit 2018
MGM Grand Las Vegas
March 19, 2018

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Outline

• The problem / The opportunity
• Project goals
• Roadmap - Sub-projects/Tracks
  • Performance Modeling
  • Hardware Prototyping
  • Heterogeneous Memory
• Industry Collaboration / Common Goals
• Summary
Moore’s Law is slowing—but the demand for cost effective capacity increases

Cost gap between DRAM and NAND continues to increase

Need cost-effective emerging memory to fill this gap.

Sources: IDC

Emerging memory
Big Opportunities Expected in Memory Systems:

Attachment strategies
- OpenCAPI
- DIMM Extension
- GenZ
- CCIX

Module Buffer Architectures
- DDIMM
- NVDIMM
- LRDIMM
- RDIMM

Emerging Memories
- RRAM
- MRAM
- PCM
- Flash
Mainstream Memories vs EM

* Projected information since EM is not in commercial volume production yet

<table>
<thead>
<tr>
<th></th>
<th>DRAM</th>
<th>NAND Flash</th>
<th>PCRAM</th>
<th>RRAM</th>
<th>MRAM</th>
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</thead>
<tbody>
<tr>
<td>Latency</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Endurance</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Write Energy</td>
<td>++</td>
<td>- -</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Cost per bit</td>
<td>++</td>
<td>- → + ?</td>
<td>- → + ??</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Capacity</td>
<td>+</td>
<td>- →</td>
<td>- →</td>
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- DRAM is hard to displace due to its low latency, write energy, high endurance, and relatively low cost
- DRAM will continue as a level of hierarchy in system memory
- EM offers the promise of continued cost per bit reduction

Projected information since EM is not in commercial volume production yet
Project Goals

- **Research:** Investigate future memory subsystem architectures around flash, emerging memories and attachment strategies. Specifically:
  - Multiple Memory types in a memory subsystem managed by hardware or software (Hybrid or Heterogeneous)
  - Multiple Memory attachment types including: Direct attach on common interface, Direct attached on unique interfaces, and Serially attached
  - Manage emerging and flash based memory to reduce cost / bit while optimizing performance in both persistent and volatile memory subsystems
  - Collaborate with industry partners to develop prototype solutions and explore the path forward for hybrid memory subsystems

Emerging Memories (RRAM, MRAM, PCM) and flash have the promise of lower cost / bit and thus could continue the $/GB improvement of memory systems. Many Emerging Memories have issues with latency, bandwidth and endurance that if unmanaged can greatly affect system performance.
Hybrid memory research roadmap

3 tracks to validate ideas and quantify management impact

Performance Modeling

• Results to date very promising
• Challenges: slow, limited scenarios, sim assumptions

Hardware Prototyping

• Custom Memory board and host board development
• Run real world applications
  • POWER9 CPU
  • OpenCAPI interface

Heterogeneous Memory

• Trace analysis
• Data placement
• Data movement
Memory Management Options

Hardware Managed (Hybrid Memory)

Software Managed (Heterogeneous Memory)

Direct Attached Management by CPU and buffers

Serial Attached Management by Media Controller/Buffer

- DDR 4/DDR 5/LPDDR 4/Flash/RRAM/MRAM/PCM

Simulation Research
Protoype Research

OpenCAPI

OpenPOWER
Hybrid Memory Simulation Results

- Performance Modeling of improved EM as main memory increase cost effective capacity
- Explored Multiple configurations for DRAM + Flash/EM
- Read performance and write performance evaluated
  - Flash device modifications identified
- Endurance is an issue as expected
  - Ongoing work on evaluating solutions

<table>
<thead>
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<th>Rambus techniques</th>
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Lower values better

**Issue**: Poor bandwidth, latency and endurance cause performance degradation in the absence of management

**Focus**: Management policies that enable improved performance at low cost per bit
Hardware Platform for Hybrid Memory Research

- **Processor**
  - IBM POWER9
  - Joint work to develop memory subsystem for research on hybrid memory
  - Demo planned in Q4 2018

- **Memory**
  - Low latency access from OpenCAPI
  - In conversation with several SCM providers
    - Looking for collaboration on SCM parts, specifications, and controllers

- **System**
  - Starting discussions with leading datacenter players
Hardware Platform for Hybrid Memory Research

- Low latency access from
  - OpenCAPI
- Memory Types
  - DDR4 DIMMs
  - Emerging Memory custom DIMMs
  - Enhanced Flash custom DIMMs
  - NVDIMM-P
- Management Policies: implemented in FPGA
Modularity for flexible and rapid experimentation
Potential Samsung Partnership

• Rambus Labs is looking for collaboration opportunities with key partners
• Including the use of Emerging Memories on the HW Platform to prove system benefit of DRAM and Emerging Memory
• Rambus is working to provide:
  • Hardware research platform access
  • Benchmarking
  • Management policies/algorithms
Common Research Goals Hybrid

**Rambus**
- Study IS protocols (OpenCAPI)
- Study any emerging memory and hybrid
- Run real world applications
- Study Serial vs direct attach

**Processor Leaders**
- Programming models
- Resource sharing / partitioning / provisioning
- Interface comparisons

**Memory Leaders**
- Analysis of EM types
- Demo Emerging Memories
- Estimate direct attach performance
- Real world application testing

**System Leaders**
- Functional testing of IS Protocols (OpenCAPI)
- Functional testing of NVDIMM
- Designs that can be modified to be a product
THANK YOU