# RowClone: Fast and Energy-Efficient In-DRAM Bulk Data Copy and Initialization

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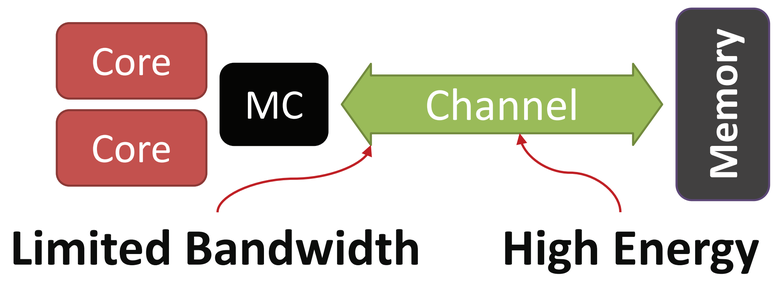
## Memory Bandwidth Bottleneck

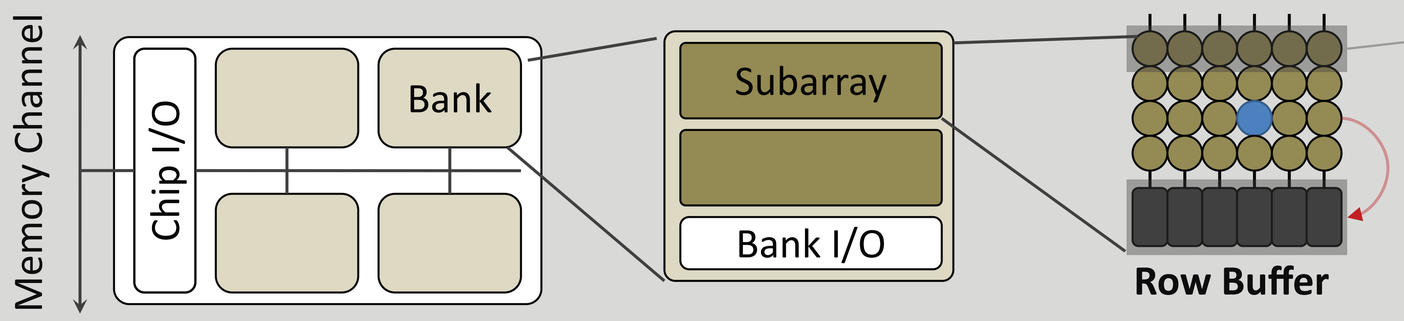



## Bulk Copy and Initialization


› Triggered frequently by many applications
› Consume high latency, bandwidth, and energy

**Our Approach: Perform them in DRAM**

## DRAM Chip Organization and Operation

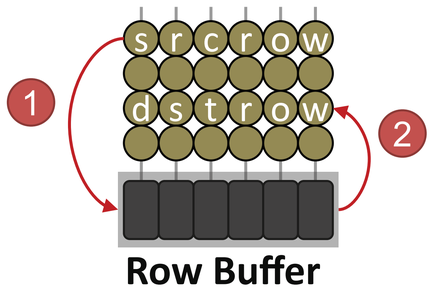


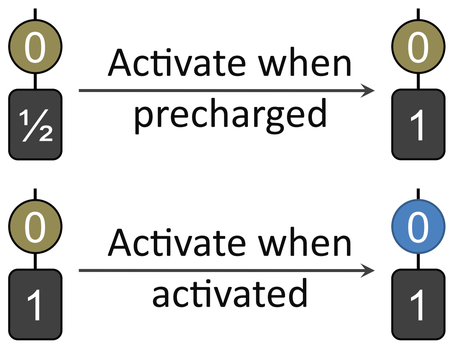

**Row of DRAM cells (8Kb)**

Even a single cell (orange) access transfers an entire row of data from the cells to the row buffer.

## RowClone – Fast Parallel Mode (FPM)

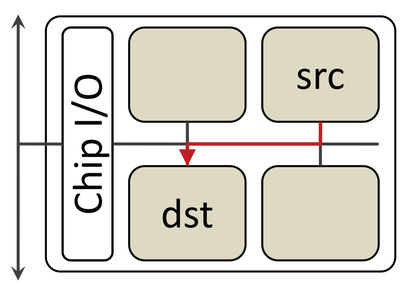
**2-step row-to-row copy**




+ **11.6X** latency reduction, **74.4X** energy reduction
– src and dst in same subarray, only full row copy

## Pipelined Serial Mode (PSM)




**Bank-to-Bank Cache Line Copy**

› Overlap read/write using shared bus
› 1.9X latency, 3.2X energy reduction

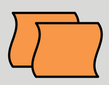
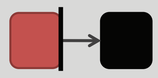
**Overall DRAM area cost = 0.01%**

## System Design

› **ISA**: memcpy and meminit
› **µArch**: manage coherence
› **OS**: smart page mapping

## Primitives and Applications Accelerated by RowClone

**Copy-on-Write**

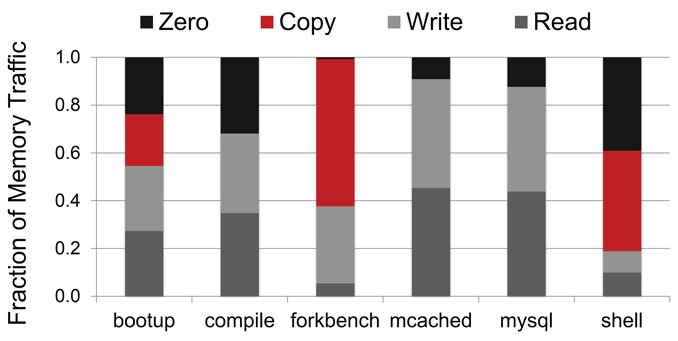
**Forking**  **Checkpoint** 

**Bulk Zeroing**

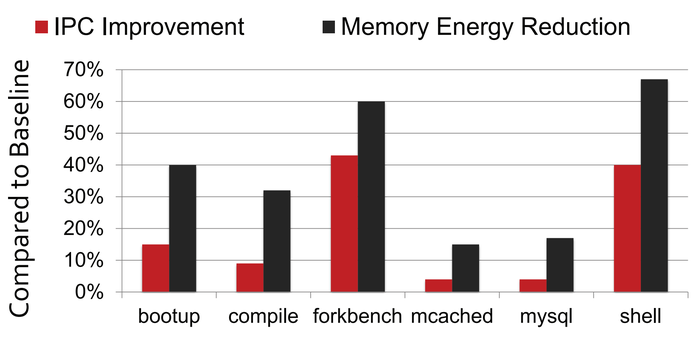
**Page zero** 

**VM Cloning** 

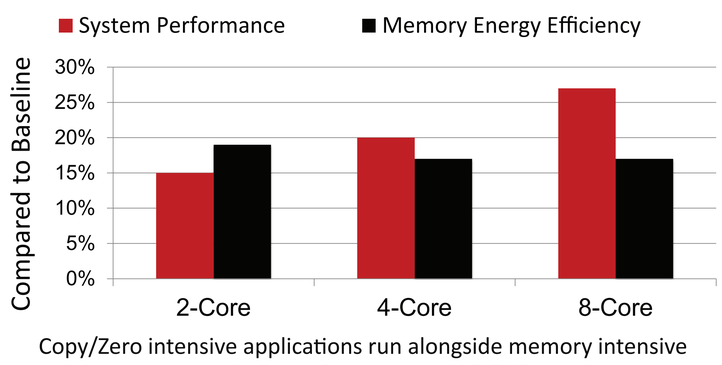
## Copy/Zero Intensive Apps




## Single Core Results




## Multi-Core Results




Copy/Zero intensive applications run alongside memory intensive applications from SPEC CPU 2006

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