CAUSE: Critical Application Usage-Aware Memory System using Non-volatile Memory for Mobile Devices

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User Experience in Mobile

User experience

Performance

Power

Processor speed

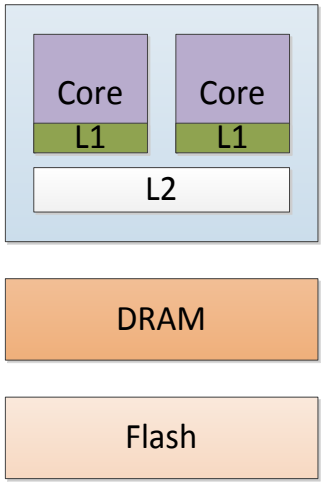
Memory bandwidth

Limited battery

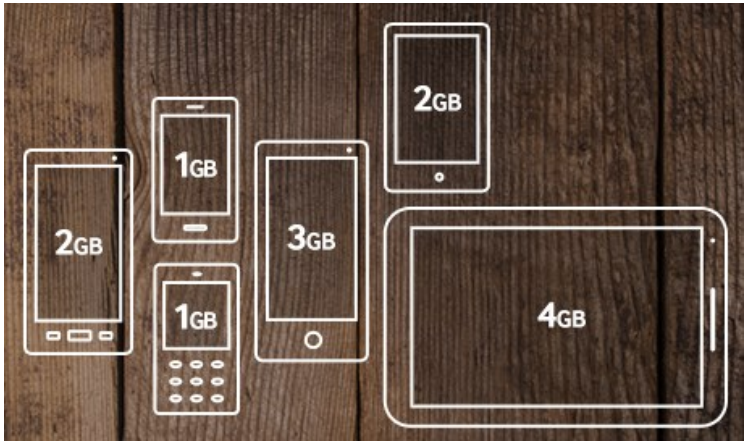
Launching Process (Angry Birds Rio)

Mobile, Applications and DRAM

- **Limited DRAM capacity**
  - State of the art mobile phones e.g 1G in iphone 6
  - 15% of applications close due to limited memory
  - Re-launching needs 10X slower [Wook et al. IEEE TECS14]



- **Problem caused by limited main memory**
  - Application termination
  - Launch time + energy overhead
  - Process service times

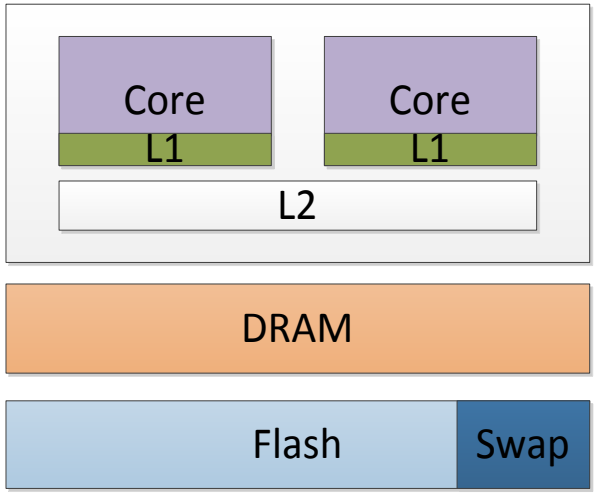


- **User experience degradation**

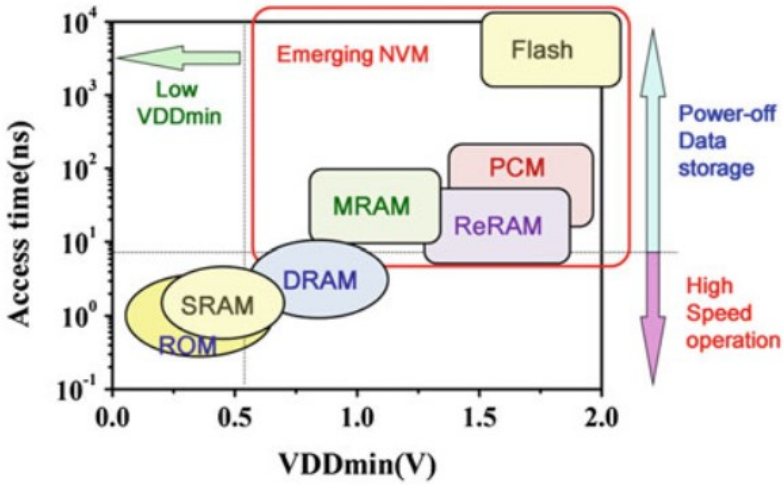
http://www.samsung.com/semiconductor/products/dram/mobile-dram/

Swap and Mobile Device

- **Swap Memory with Flash**
  - Energy
  - Latency
  - Endurance of eMMC flash



- **Emerging NVM technology**
  - Efficient read operation
  - Denser than DRAM (PCM ~2-4X)
  - **Low write performance!**

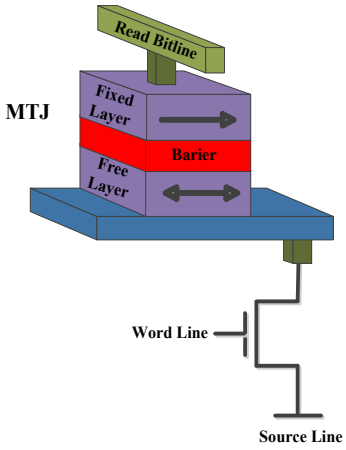


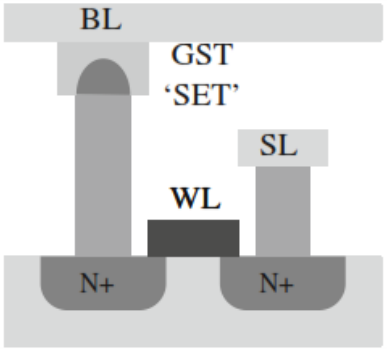
M-F. Chang, et al, IEEE ASPDAC, 2011.

Non-volatile Memory

- **STT-RAM**
  - Low leakage power
  - High endurance (10^{10}-10^{15})
  - Very fast in read
  - Write latency and energy!
  - Low scalability
- **PCM**
  - Low leakage power
  - Very high density
  - Scalable
  - Write latency and energy!
  - Low endurance (10^{6}-10^{7})

Solution?





Features	SRAM	eDRAM	STT-RAM	PCRAM
Density	Low	High	High	Very high
Speed	Very Fast	Fast	Fast for read; slow for write	Slow for read; very slow for write
Dynamic Power	Low	Medium	Low for read; very high for write	Medium for read; high for write
Leakage Power	High	Medium	Low	Low
Non-volatility	No	No	Yes	Yes

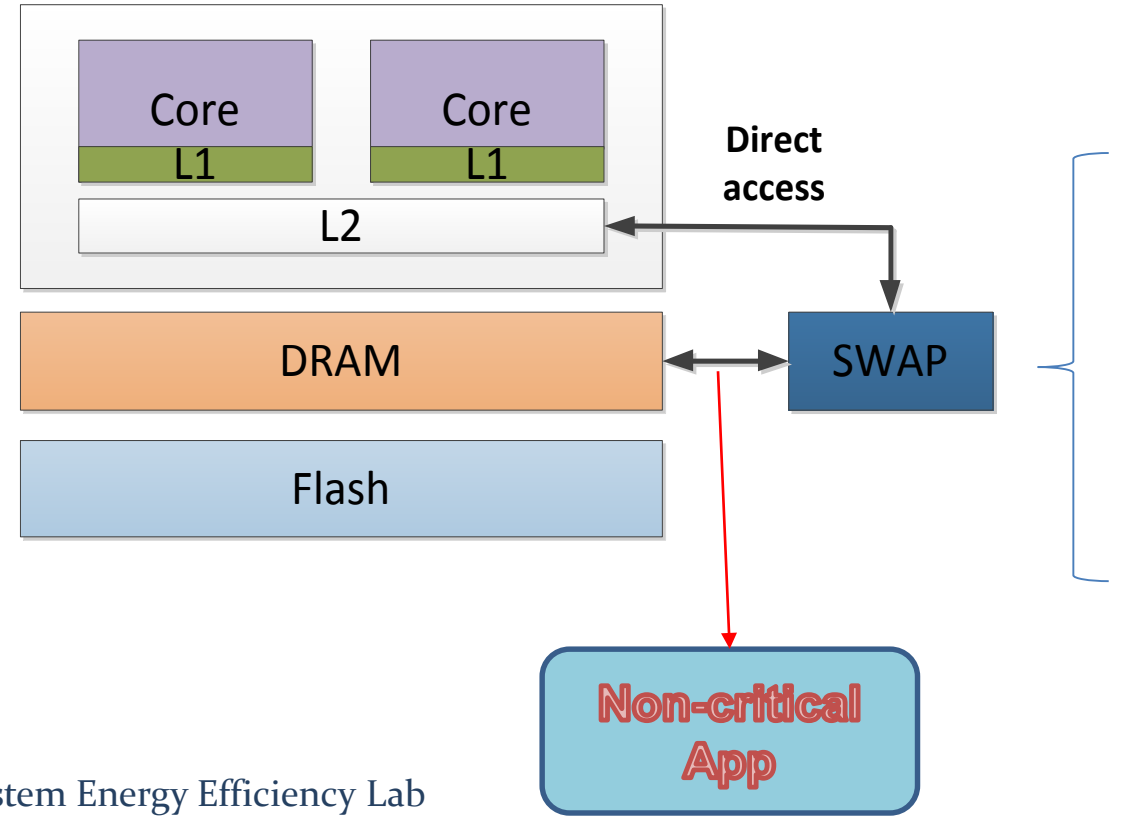
Challenges of NVM Based Swap Memory

- ***Software:***
  How to select apps which are good to be swapped?
  - Apps have different launching usage trends, resulting in distinct levels of criticality for user experience

- ***Hardware:***
  How to design NVMs for swap?
  - Apps have different access characteristics according to their status, e.g., foreground app and background service

CAUSE

- Critical Application Usage-Aware Memory System
  - Fast app launch: Better user experience!
  - Better process service time: More memory space for foreground apps



Optimized NVM for swap

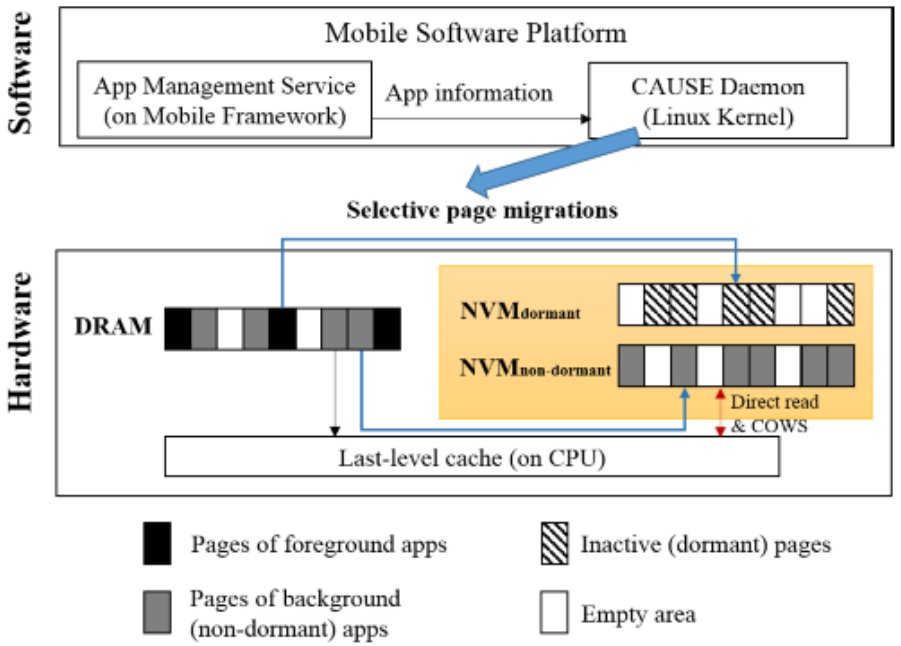
Low leakage power

Fast as DRAM

Memory Systems with NVM

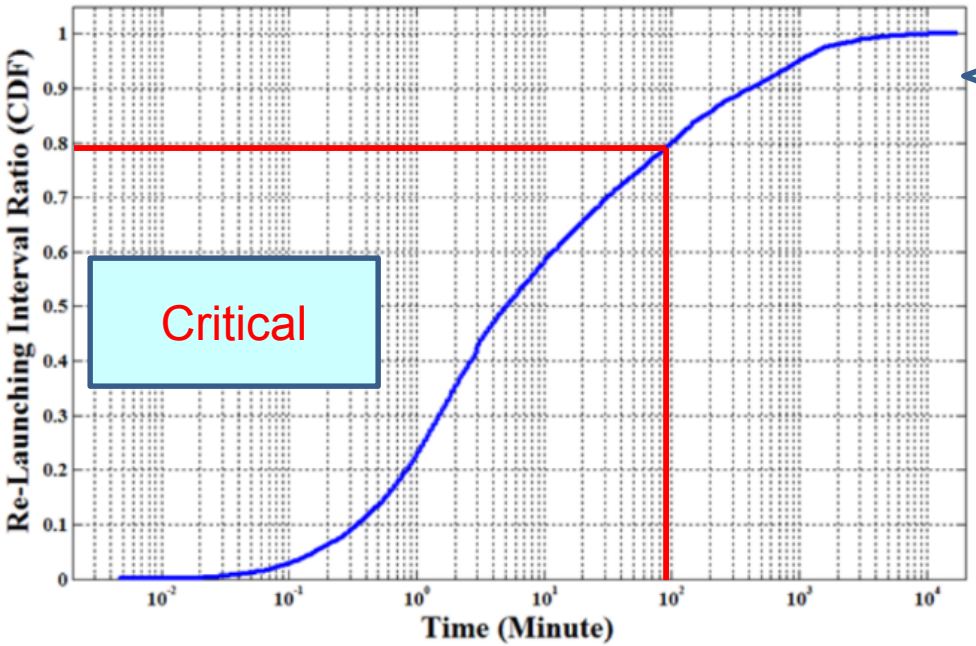
- **App management service:**
  - Recognizes applications launched by users
  - Tracks the applications recently launched in foreground
  - Sends the application information that is likely to be used in near future

- **Page characteristics:**
  - *Dormant:*
    - Foreground applications
    - Indeed not recently used
  - *Non-dormant:*
    - Likely to be accessed soon or periodically
    - Background applications and widget



Software: Application Launching Usage Trend

- Collected logs for two weeks from 10 users
- **Re-launching interval:** the time interval between two application launches for a certain application.
- 80% of applications were reused within 100 minutes!



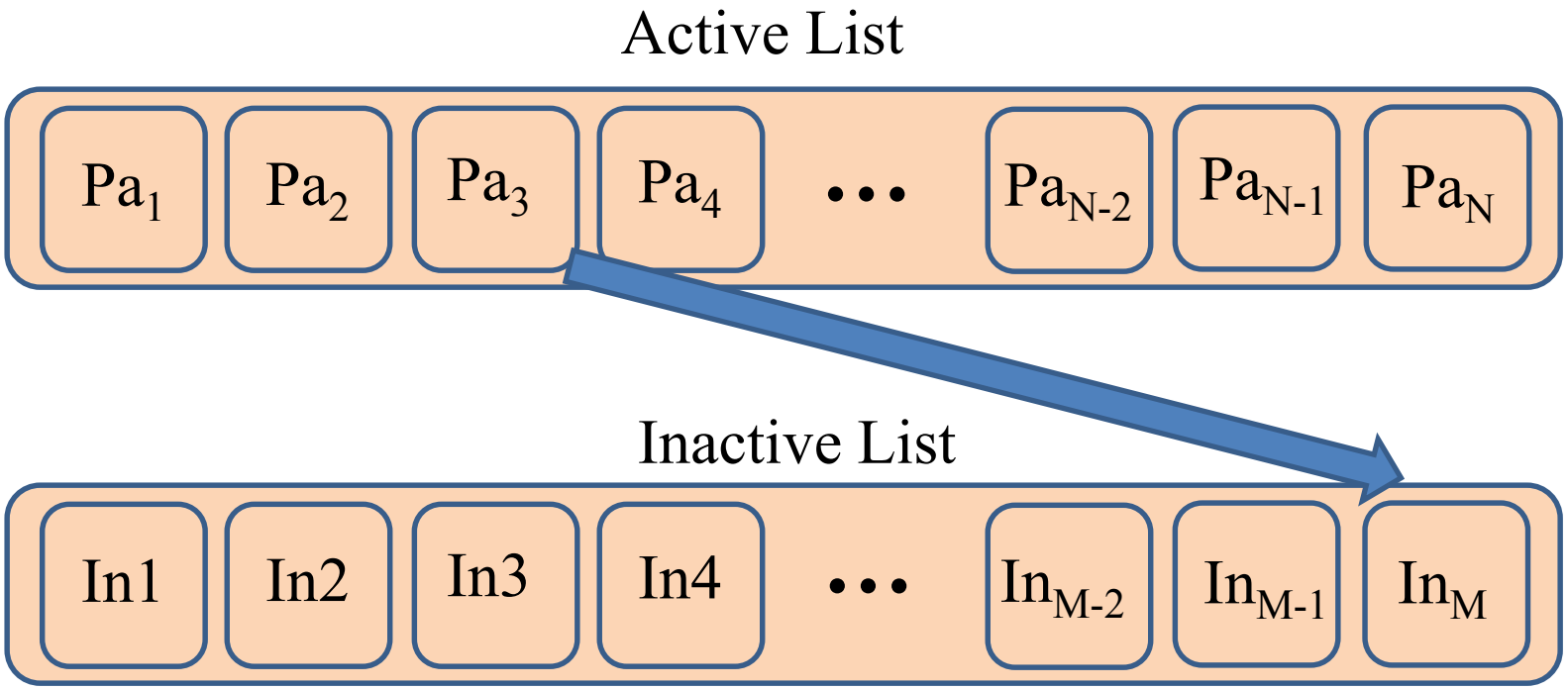
80% of app reused within 100 minutes!

Apps after 100min consider as inactive

CAUSE Management Policy

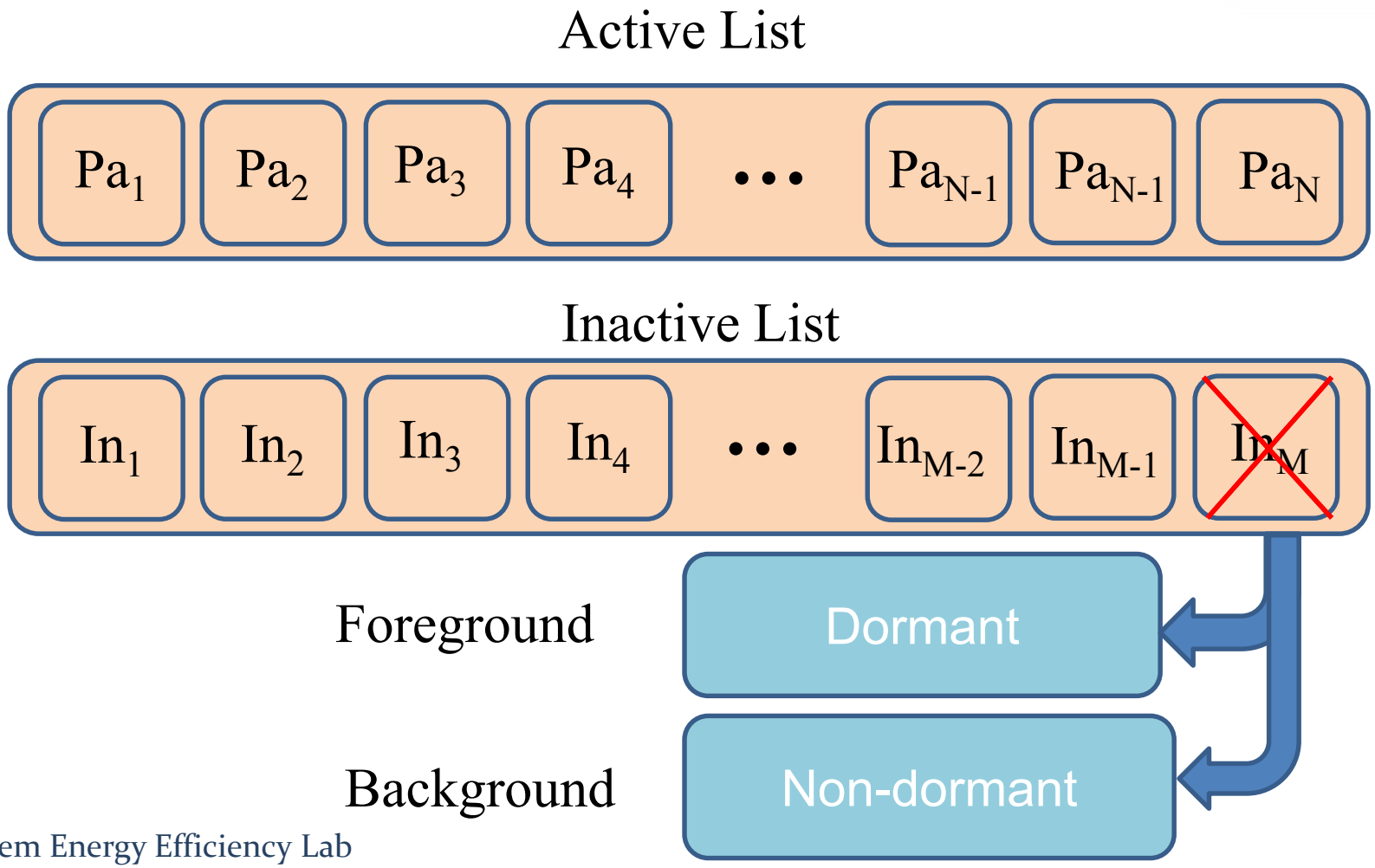
Active List Management

- Linux policy: balancing the number of active and inactive pages

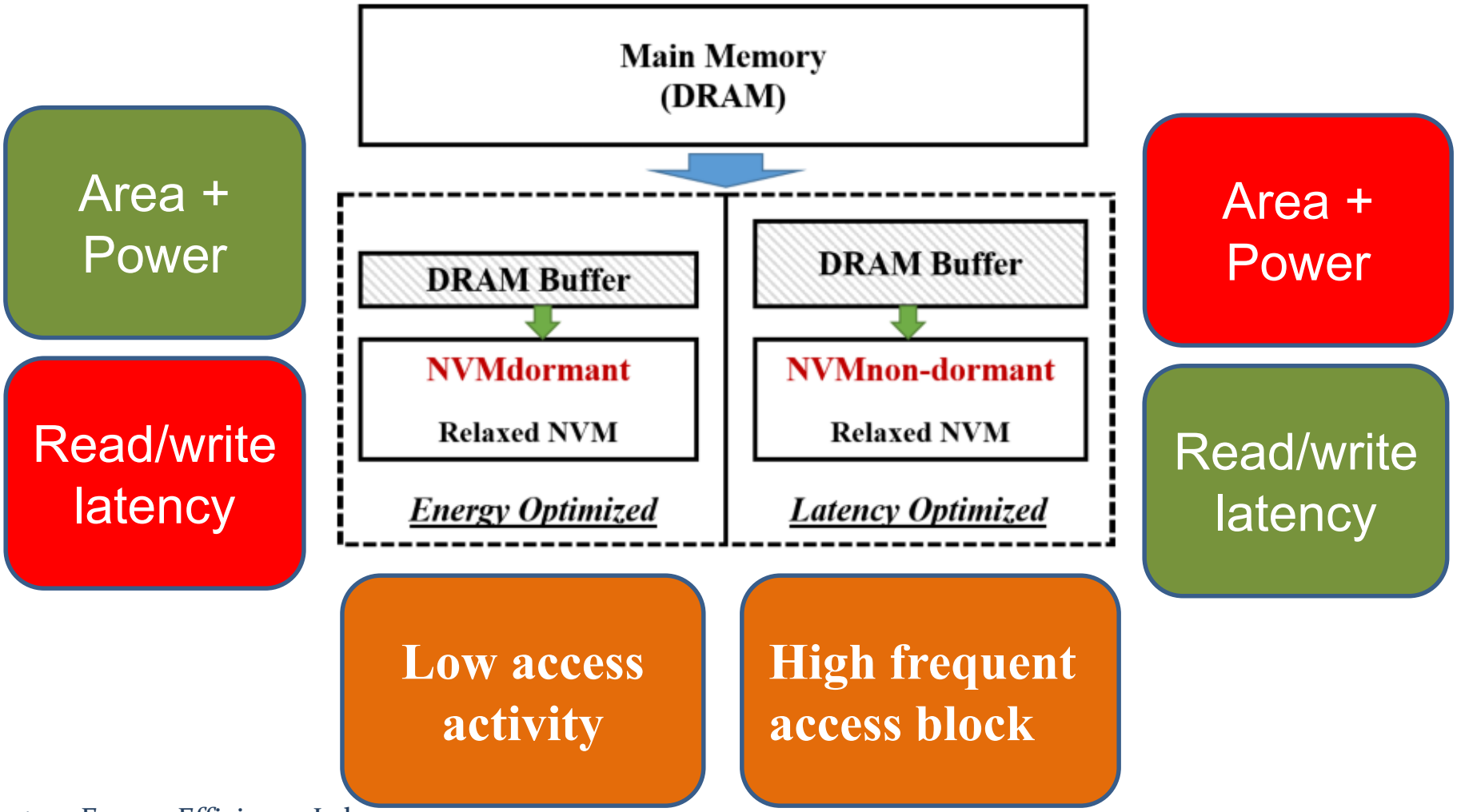


CAUSE Management Policy

Freeing memory pages

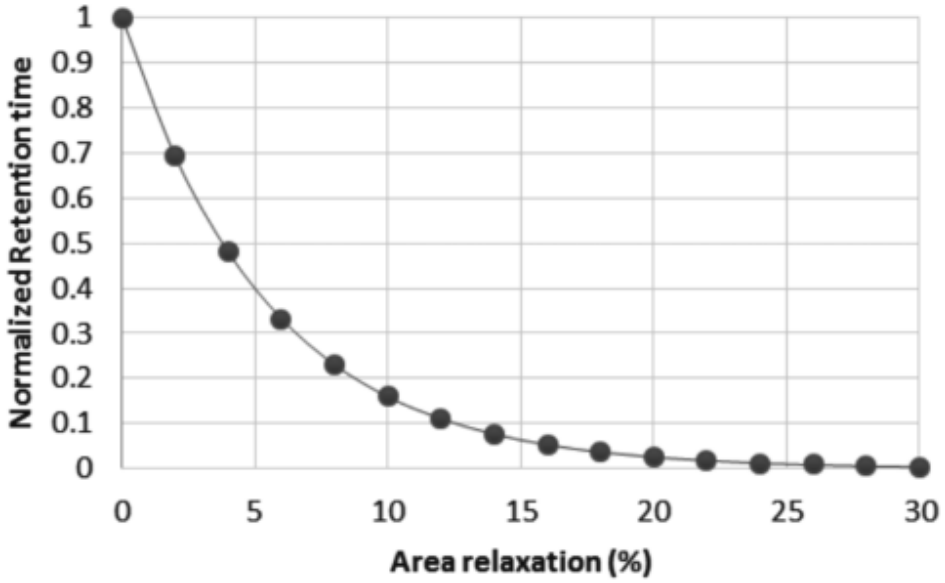


Hardware:
Buffer Optimization



Retention Relaxation

- **STT-RAM retention** [Smullen et al, HPCA 2011]
  - 20% MTJ area relaxation
  - 83% write latency improvement
  - Retention time from 20 years to 1 month
  - Possibility of refresh

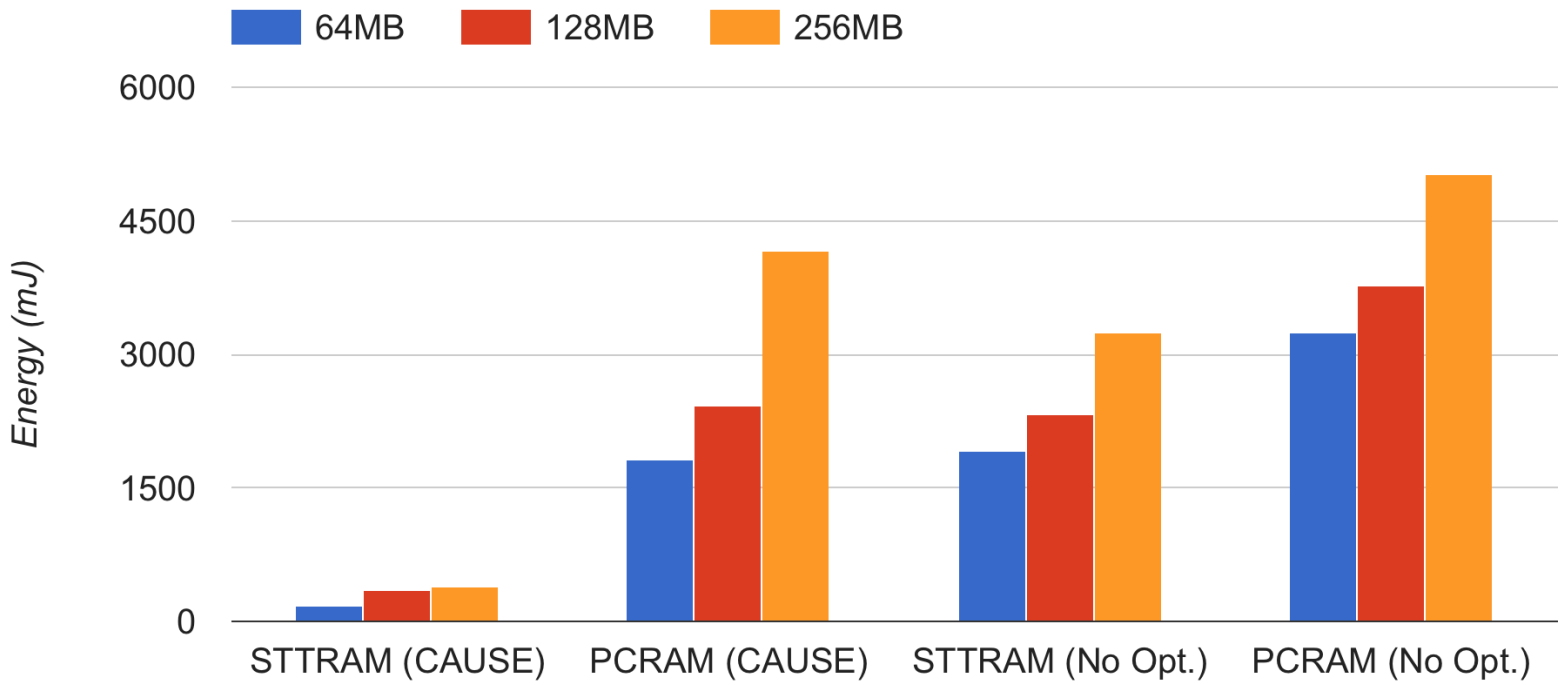


Experimental Setup

- Qualcomm MSM8660 smartphone
  - Running Android 4.1 with Linux kernel 3.0.6
  - 1GB Main memory; 768MB DRAM; 64KB-256KB NVM
- HSPICE for circuit level simulation
  - Retention time relaxation
  - Circuit level optimization
- NVsim & NVmain simulators for energy estimation
  - DRAM buffer
  - Buffer design
- 10 users launch 20 apps for 2 weeks
  - Scale down the executed time to 20 mins

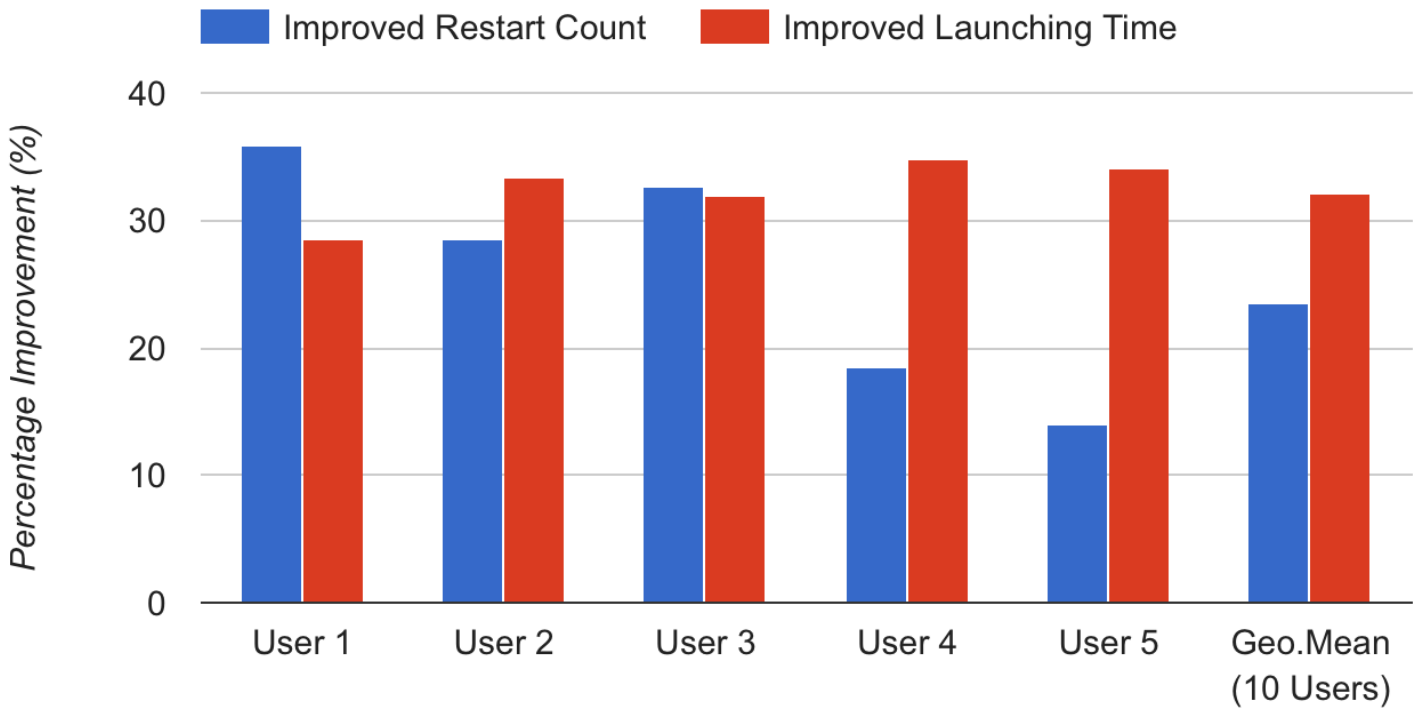
CAUSE Energy Consumption

- Comparison of energy consumption with different memory technologies
  - 90% and 44% energy savings for STT-RAM and PCM



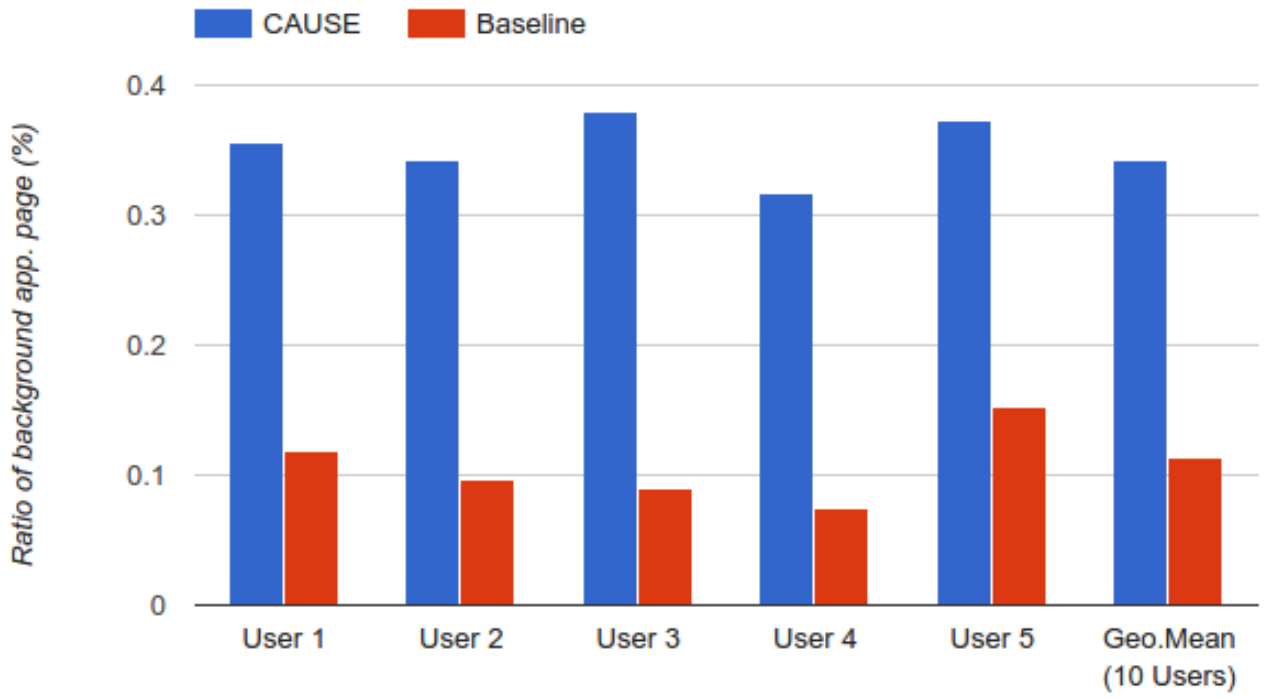
Launch Experience

- 32% launching time speed up
  - Better user experience ☺



Background Page Balancing

- 23% more background page migration
  - Provides space for foreground applications
  - Better process service time ☺



Summary

- Addressed limited main memory capacity of mobile devices
- Proposed new swap architecture to save the inactive pages based on applications and users
- Proposed & optimized dormant and non-dormant memory components for background and foreground applications
- 23% more background migrations + better process service time
- 32% launching time speed up + better user experience