Pushing the Performance Limit of NAND Flash Memory in Computing Systems

--- A True Device-Aware System Design Perspective

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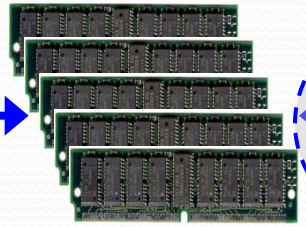
NSF HECURA (Sept. 2009 ~ Aug. 2012)

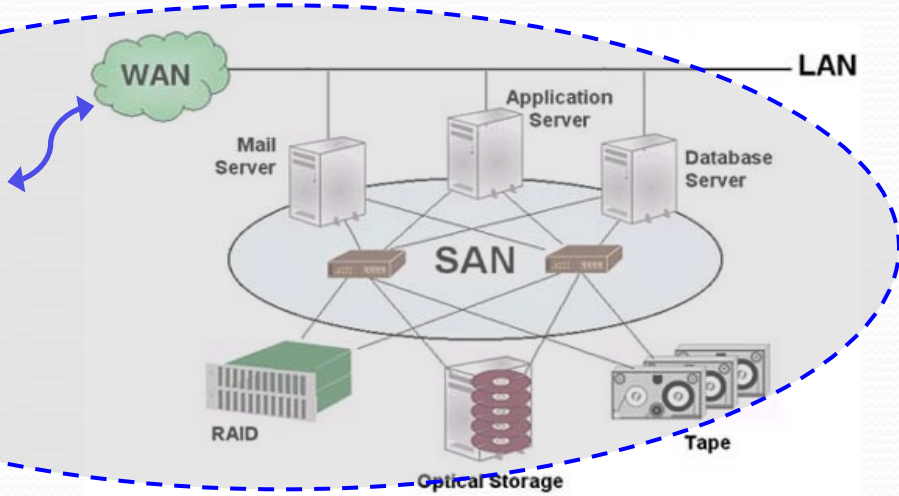
Hot Topic

CPU



Main memory

Hard disk



intel FUSION-IO SandForce SanDisk EMC² hp IBM ORACLE

Full Potential of NAND Flash Memory

True Device-Aware System Design

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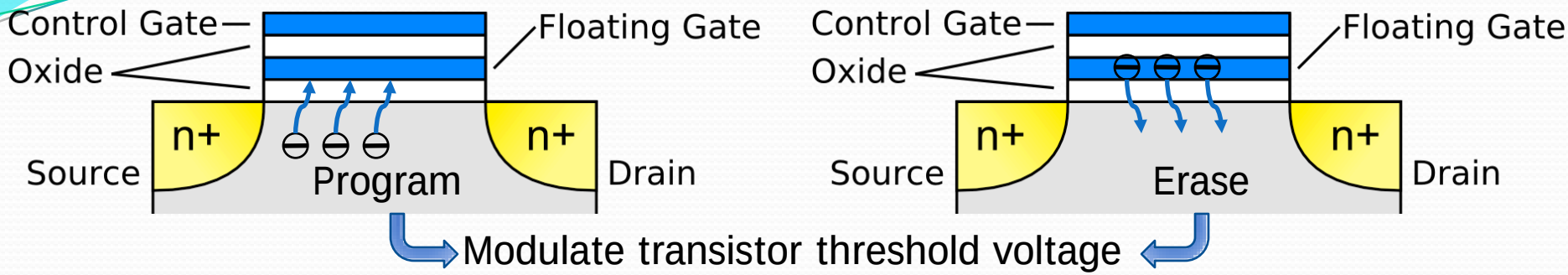
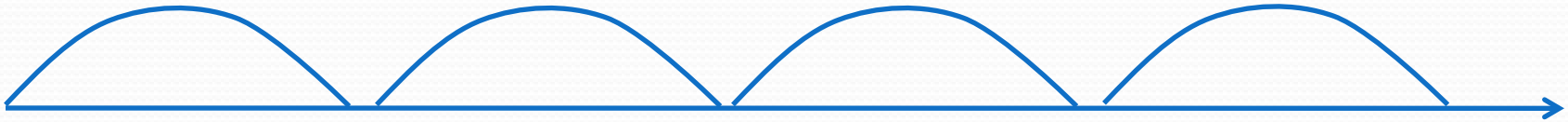


2bits/cell

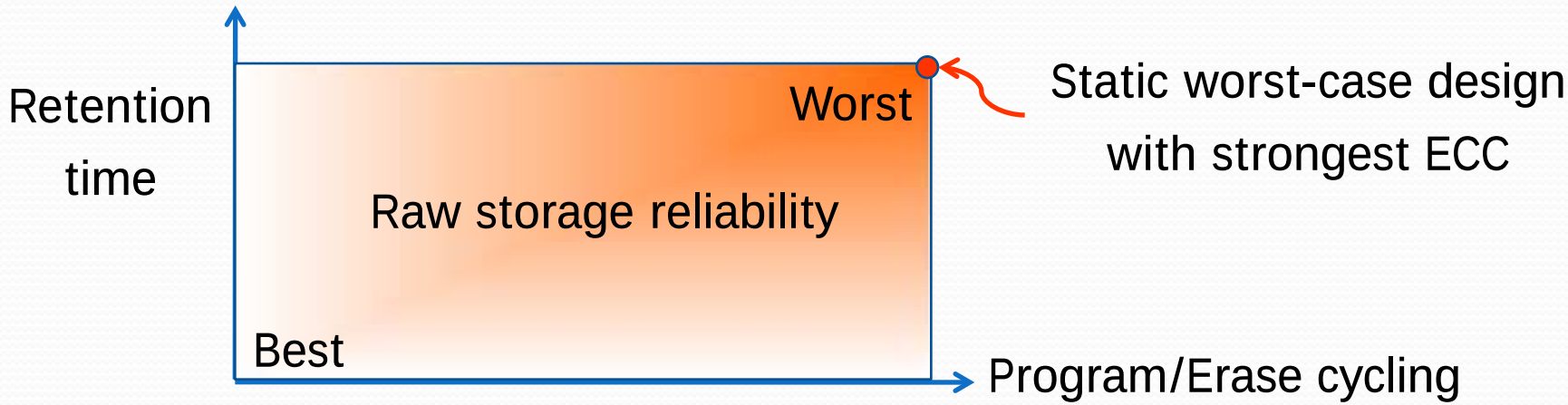
Threshold voltage (fresh memory cells)

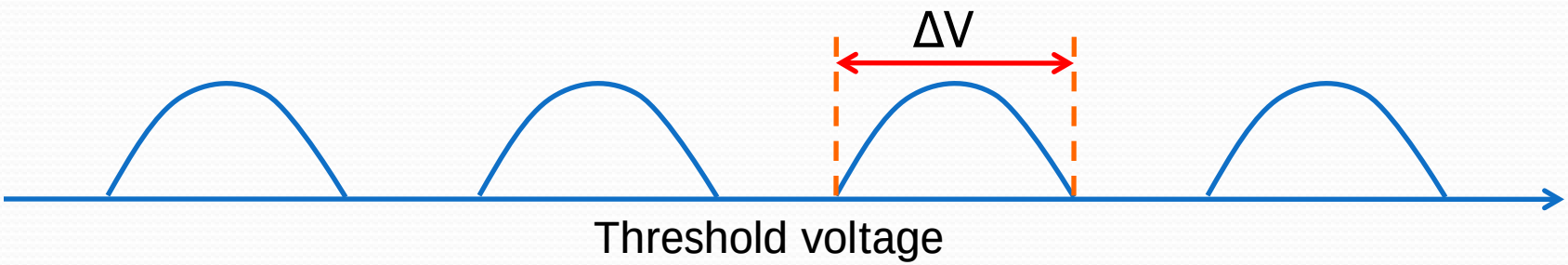
Threshold voltage (right after 10000 program/erase cycles)

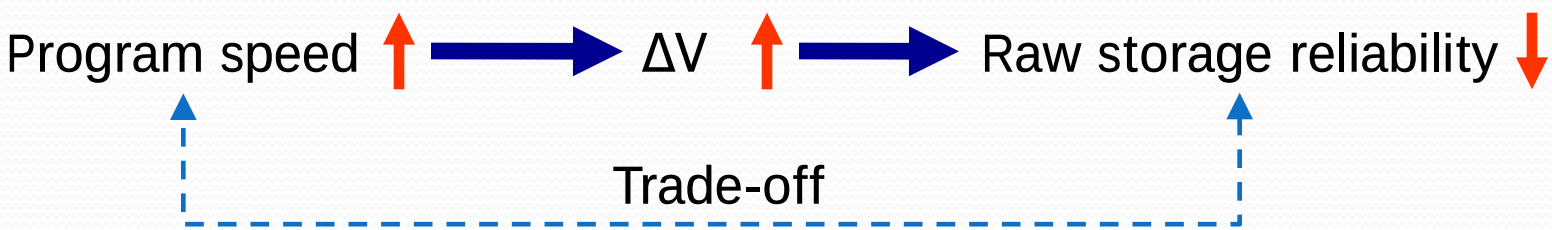


Threshold voltage (3 years after 10000 program/erase cycles)

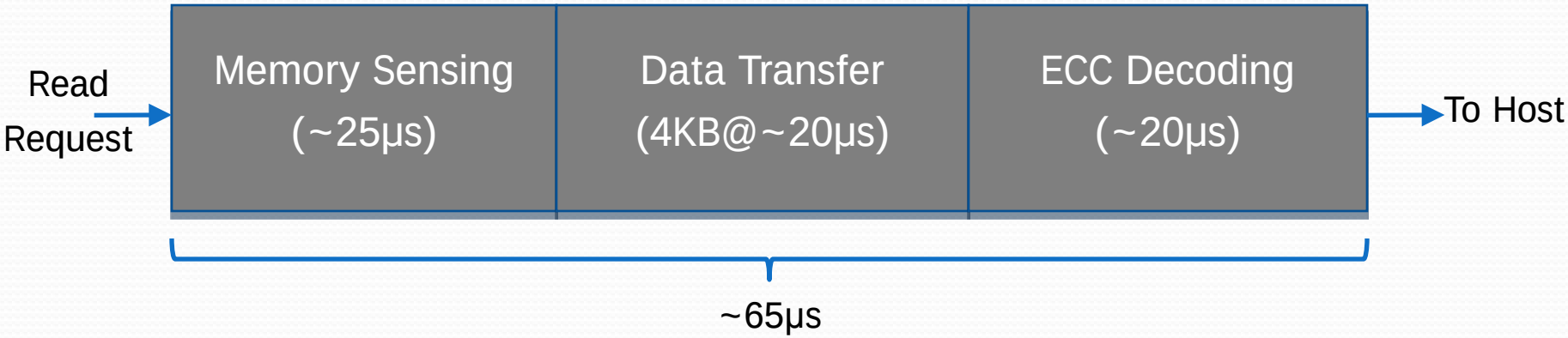
Strong dynamics of memory cell device characteristics

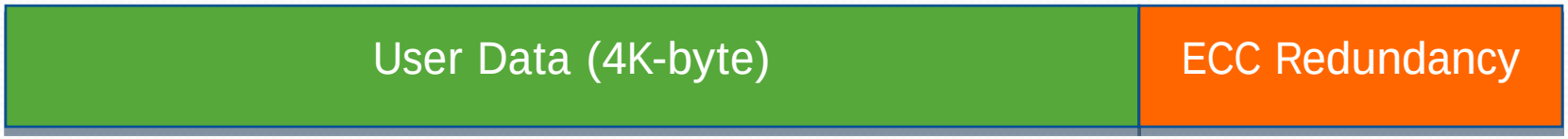


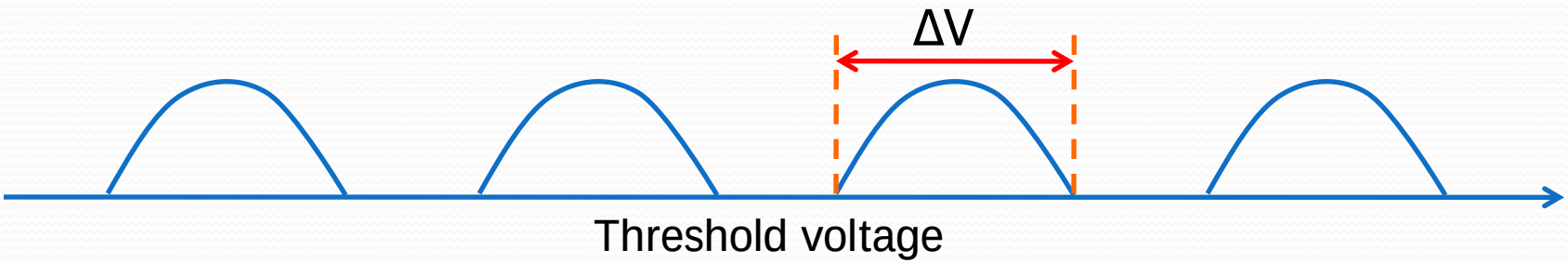




A Simple Example: Minimize Read Response Time







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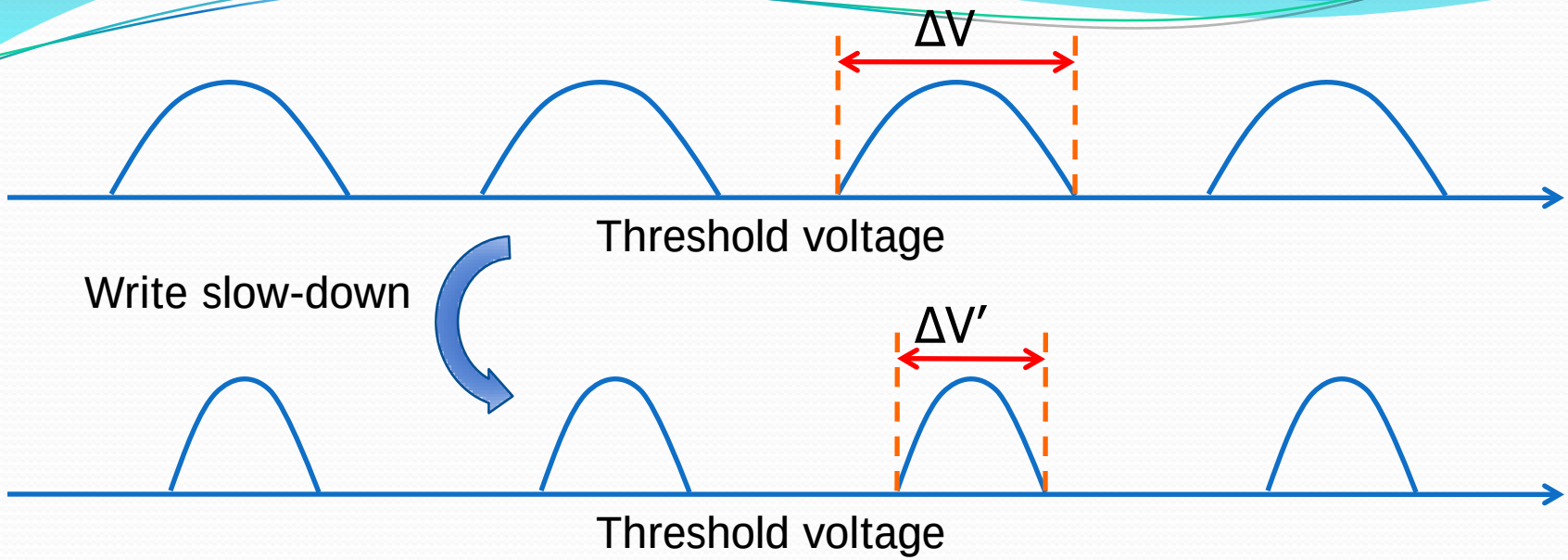
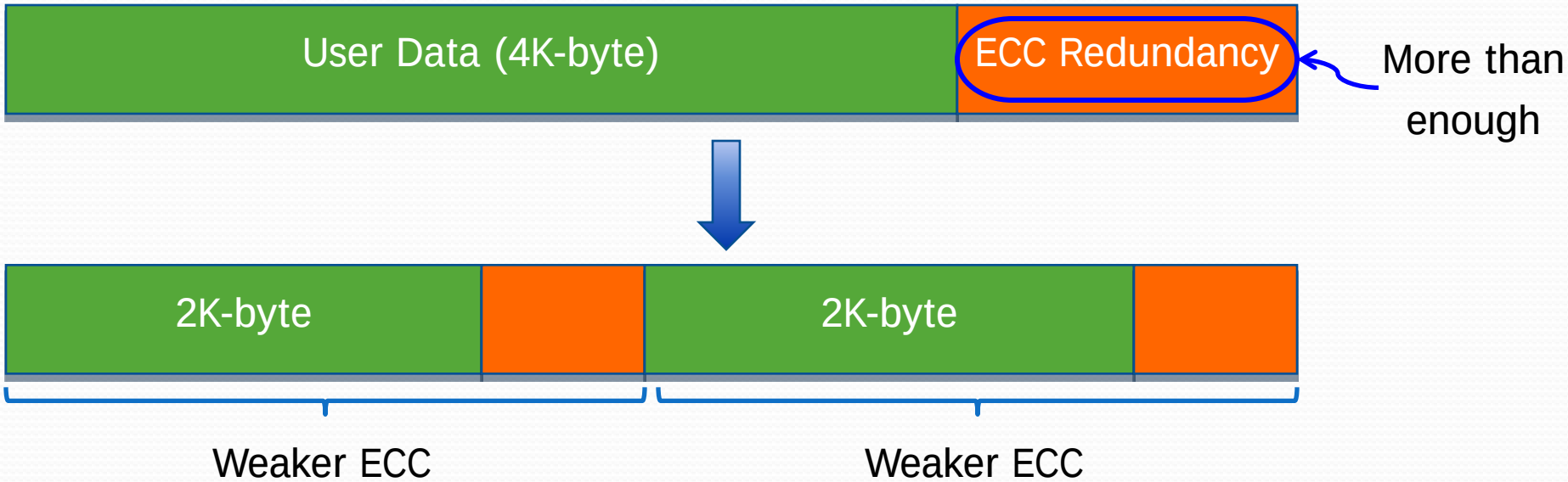
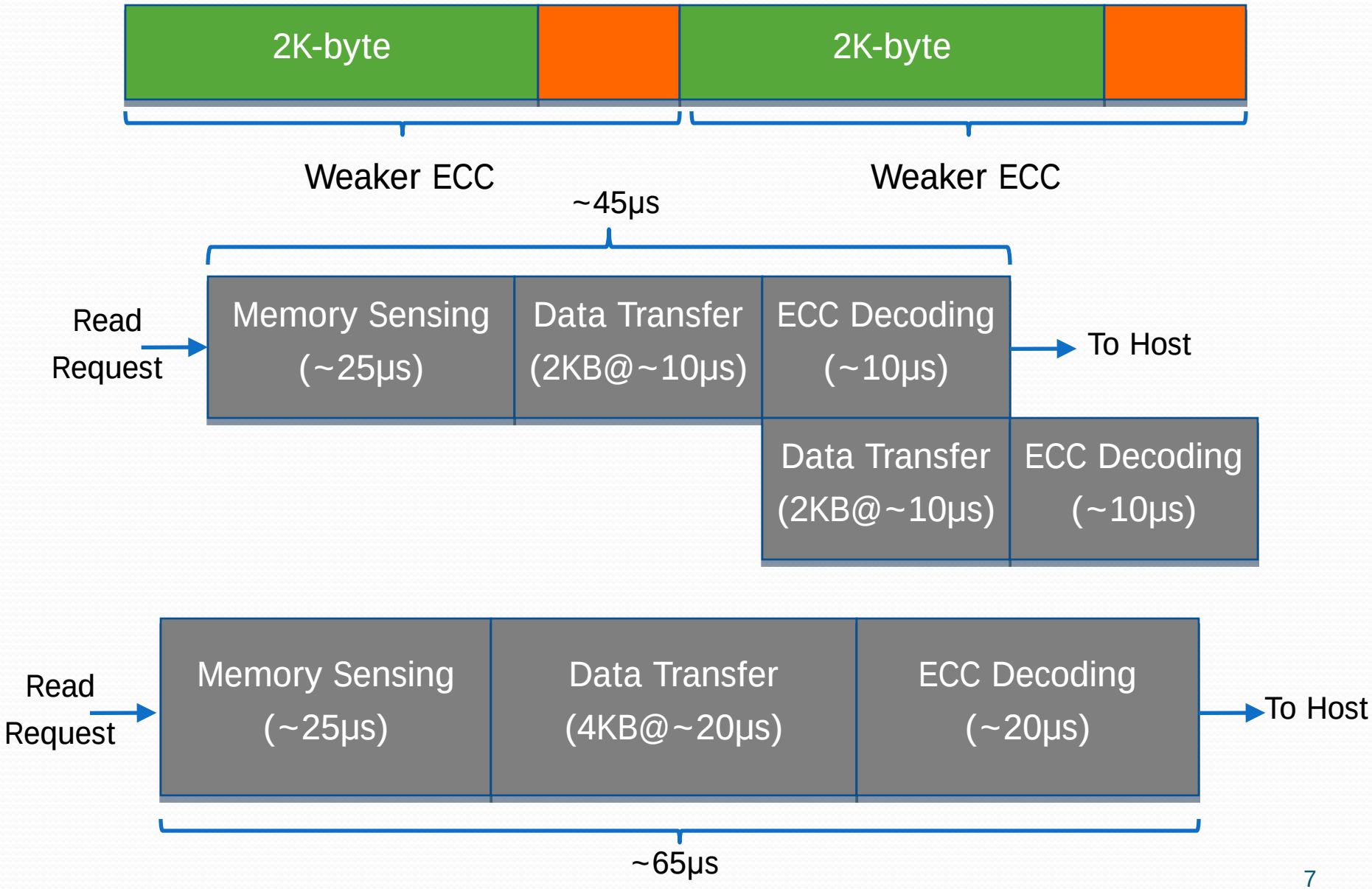




A Simple Example: Minimize Read Response Time



A Simple Example: Minimize Read Response Time

Direct memory write slow-down → System performance degradation

Run-time data access workload **variability**

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Opportunistic NAND flash write slow-down

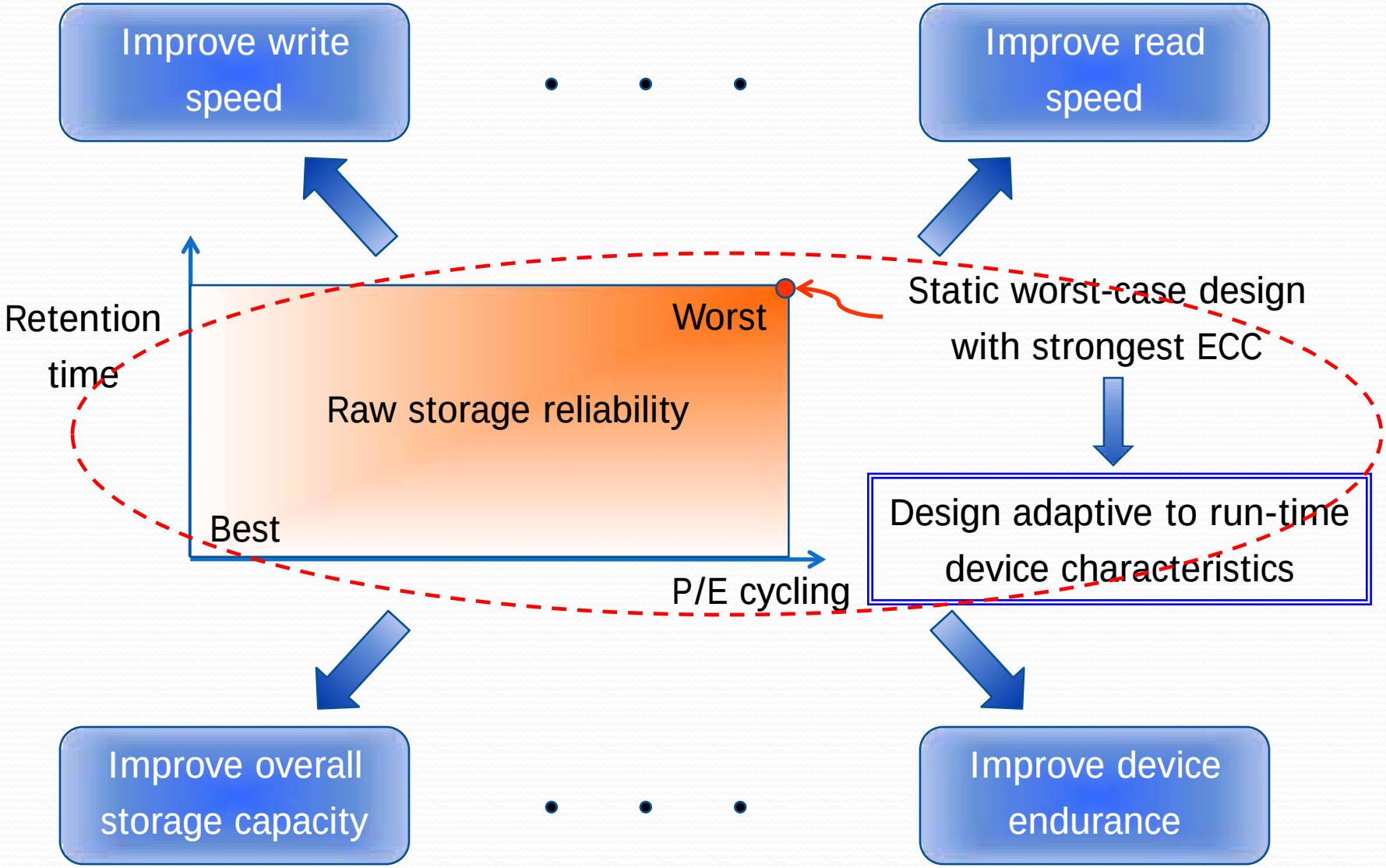
A buffer queue scheduling policy

BCH code design & analysis

→ Effectiveness well demonstrated using several server disk traces

Best paper candidate, IEEE/ACM International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems (MASCOTS), Aug. 2010

NAND flash device characteristics + System workload characteristics ⇒ True Device-Aware System Design


Improve write speed
Improve read speed
Retention time
Worst
Raw storage reliability
Best
P/E cycling
Static worst-case design with strongest ECC
Design adaptive to run-time device characteristics
Improve overall storage capacity
Improve device endurance

A Simple Example

Threshold voltage (early life-time)

Threshold voltage (late life-time)

Inherent dynamics over device lifetime → Adaptive NAND flash operation

Program → Erase

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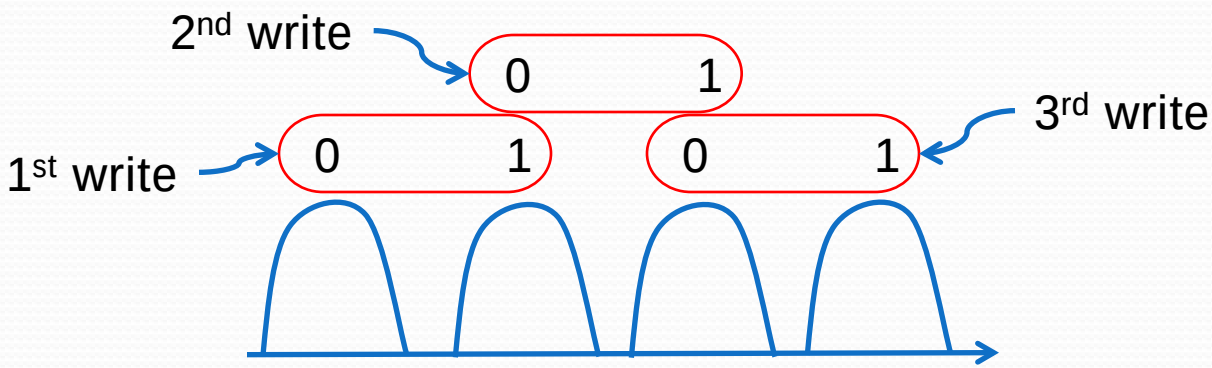
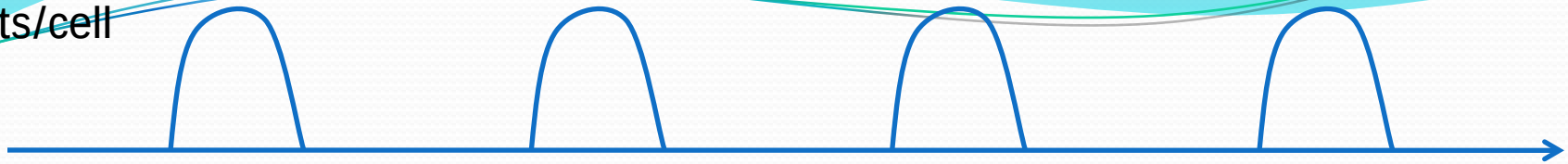
Multiple-Program → Erase



Threshold voltage (early life-time)

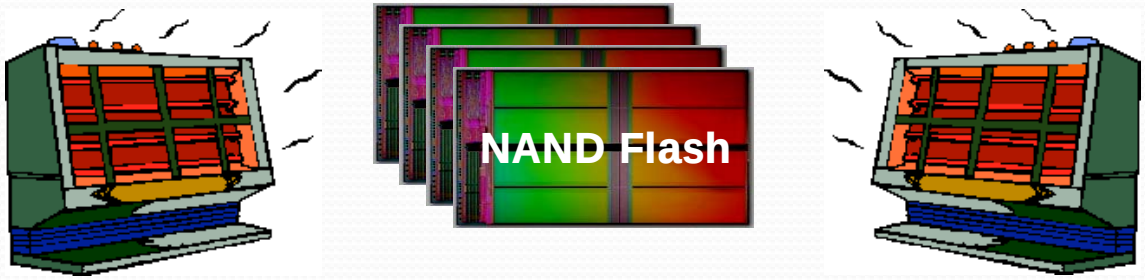
How to best exploit it from the system perspective?

2bits/cell



Threshold voltage (fresh memory cells)

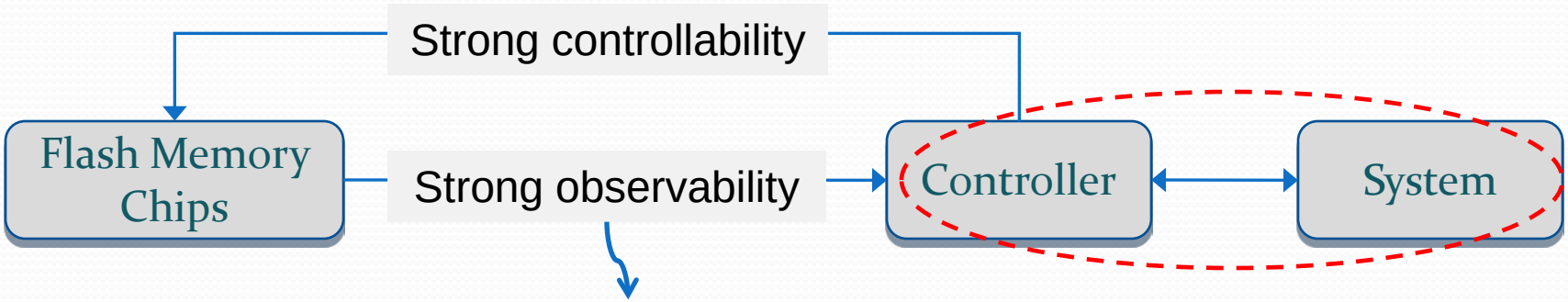
Threshold voltage (after 10000 program/erase cycles)



Threshold voltage (recovered, ready for another ~10000 program/erase cycles)

Self-healing solid-state drives?

True Device-Aware System Design



Matches to a clear trend of NAND flash memory manufacturers

A research framework with big potential impact!

True inter-disciplinary research collaborations