CSI:Rowhammer

Cryptographic Security and Integrity against Rowhammer

Jonas Juffinger, Lukas Lamster, Andreas Kogler, Moritz Lipp, Maria Eichlseder, Daniel Gruss

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Generic approach to data integrity protection

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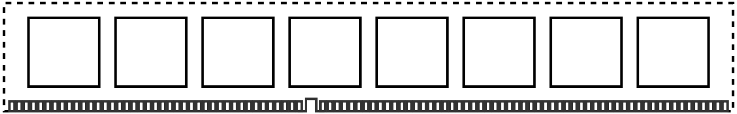
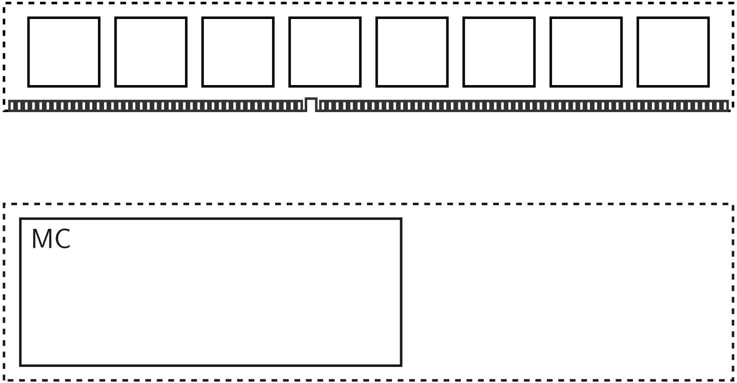
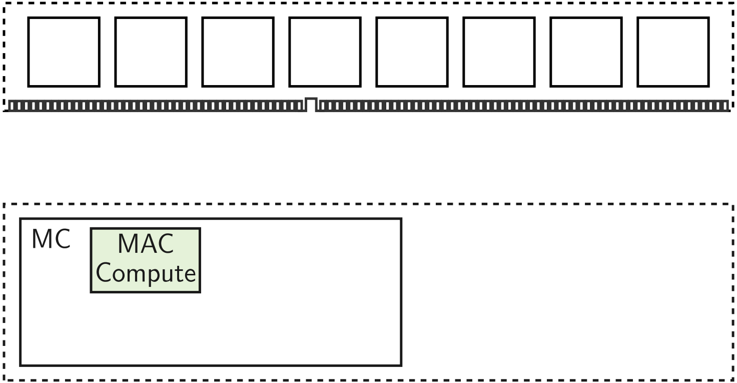
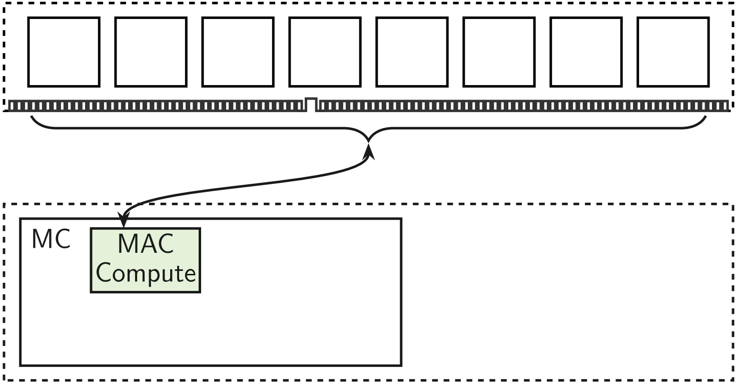
- **Generic** approach to data integrity protection
- Detect all data integrity failures with a MAC
- Best effort correction
- All Rowhammer attacks are DoS in the **worst case**





MC


MC
MAC Compute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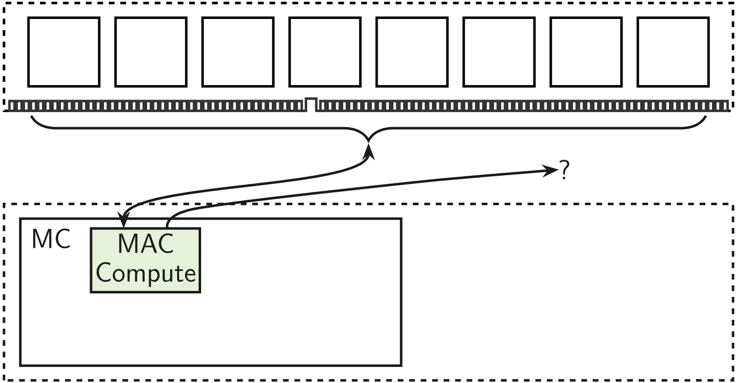
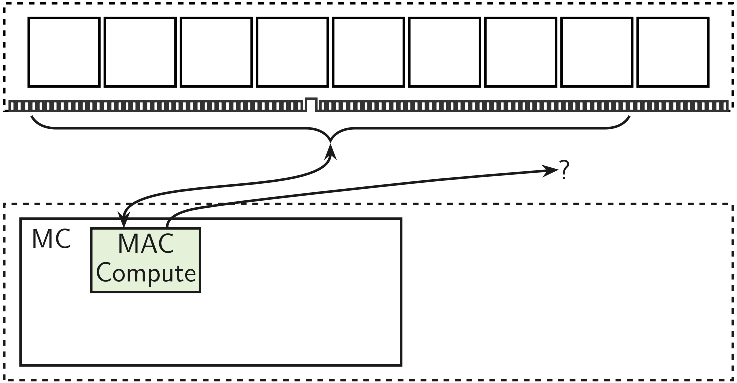
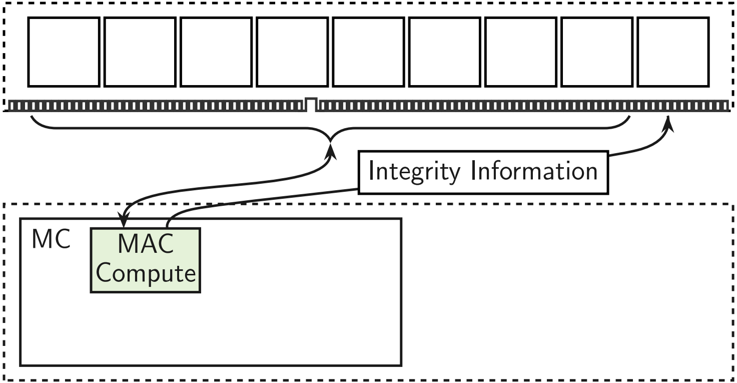
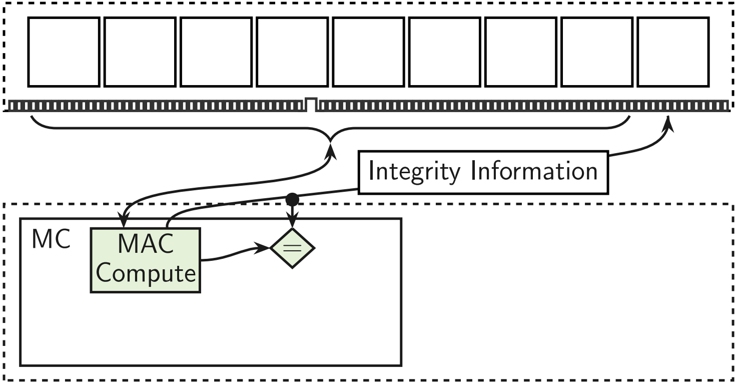
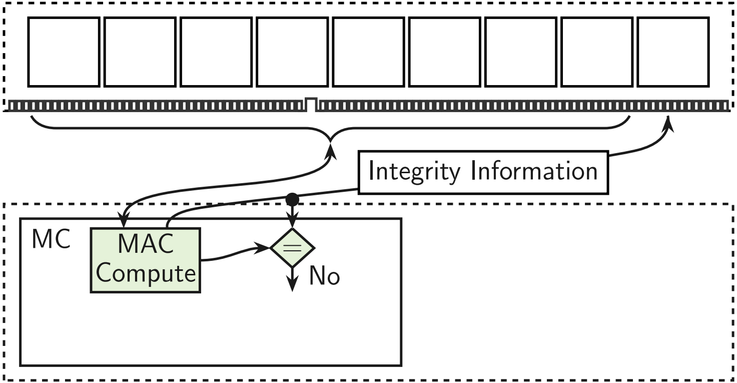
MAC Compute

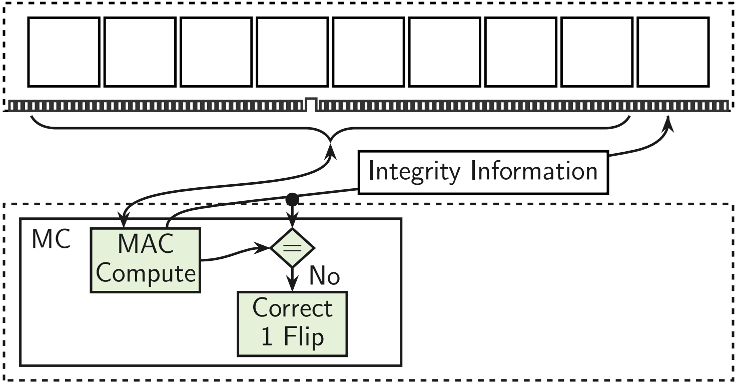

?
MC
MAC
Compute

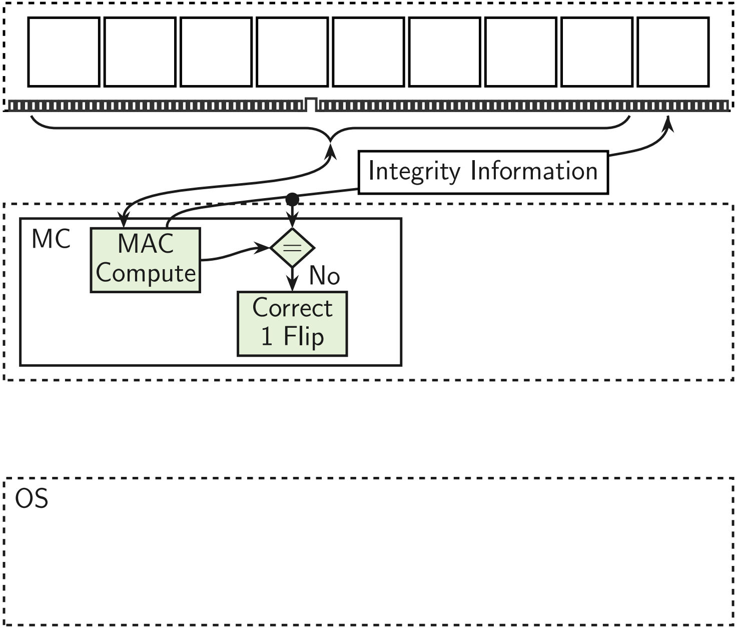

?
MC
MAC
Compute

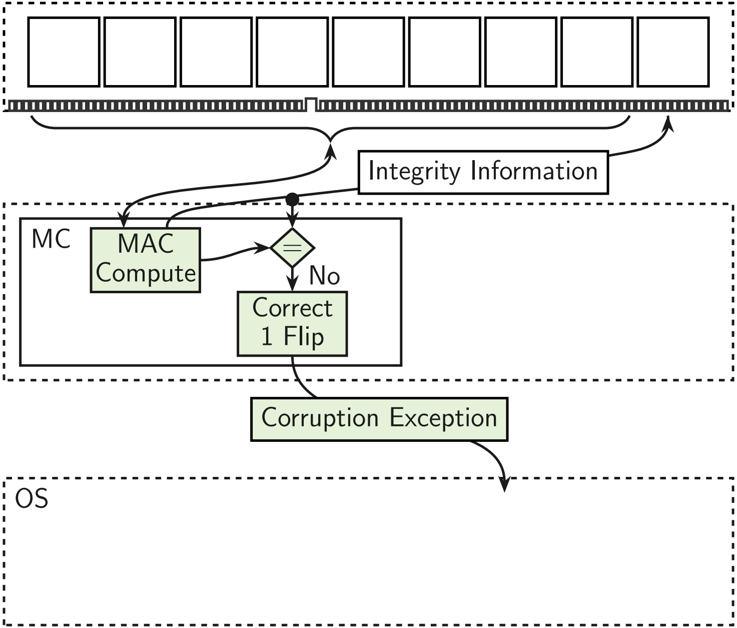

Integrity Information
MC
MAC
Compute

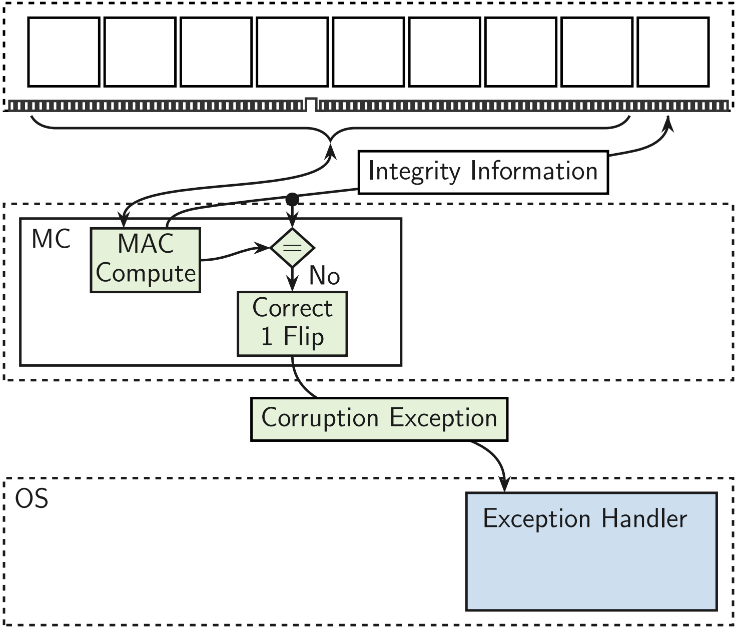

Integrity Information
MC
MAC
Compute
=

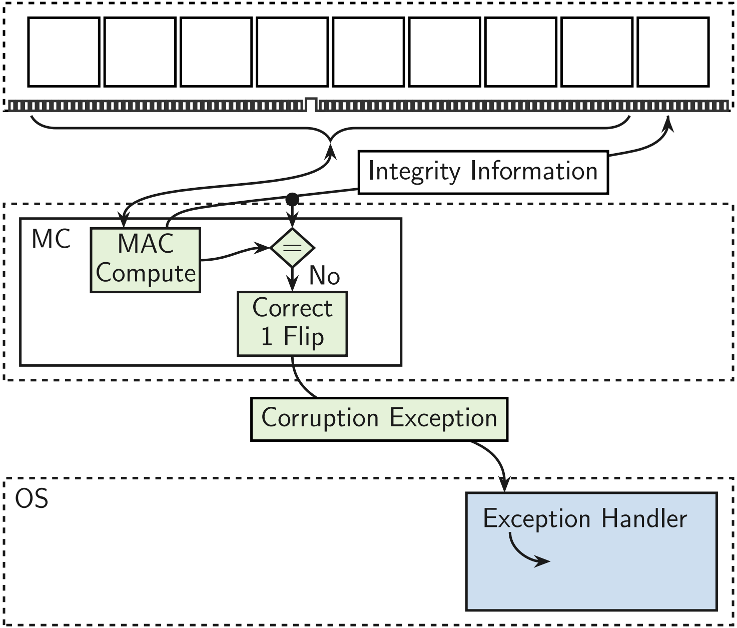

Integrity Information
MC
MAC
Compute
=
No

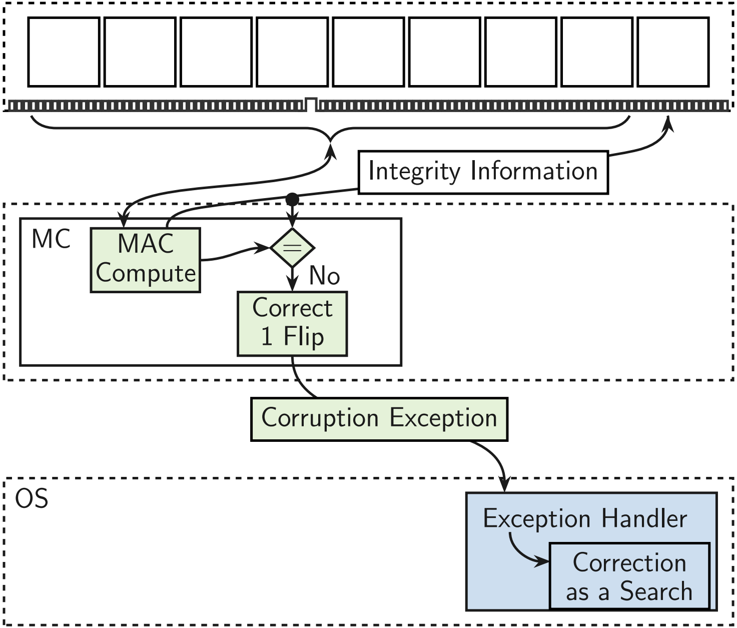

Integrity Information
MC
MAC Compute
=
No
Correct 1 Flip

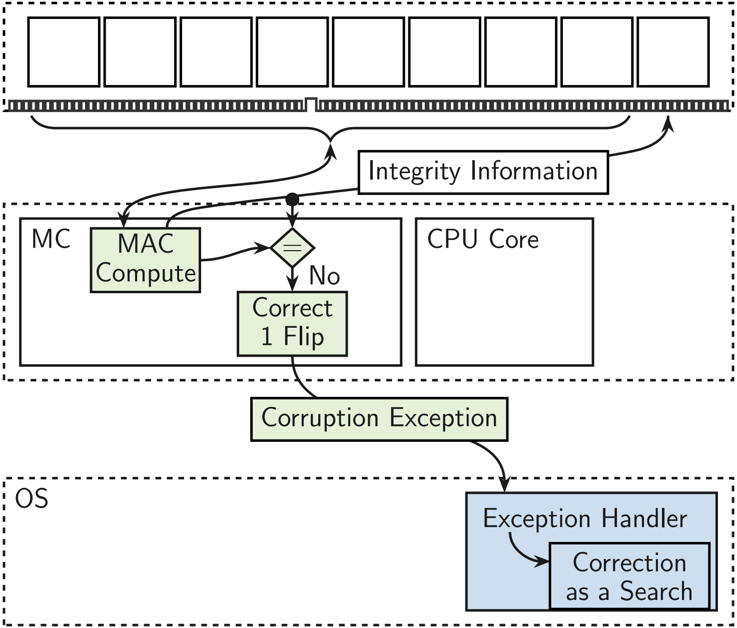

Integrity Information
MC
MAC Compute
=
No
Correct 1 Flip
OS

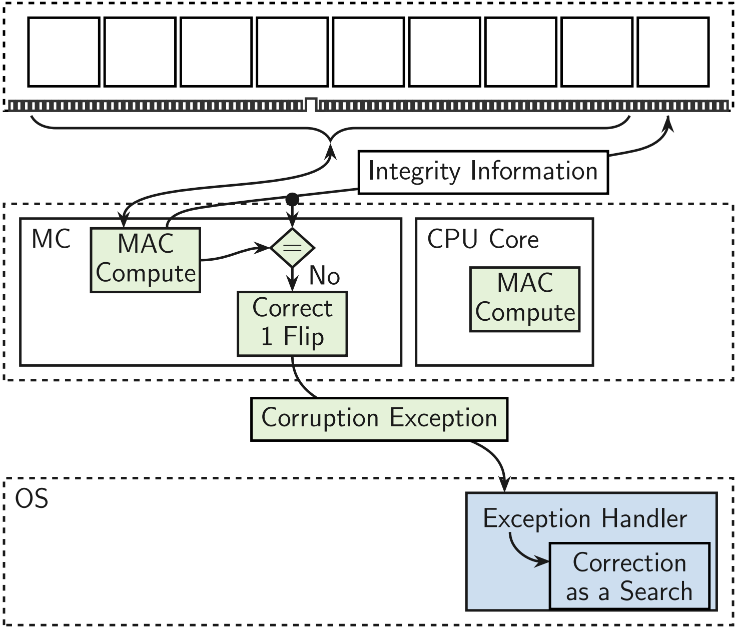

Integrity Information
MC
MAC Compute
=
No
Correct 1 Flip
Corruption Exception
OS

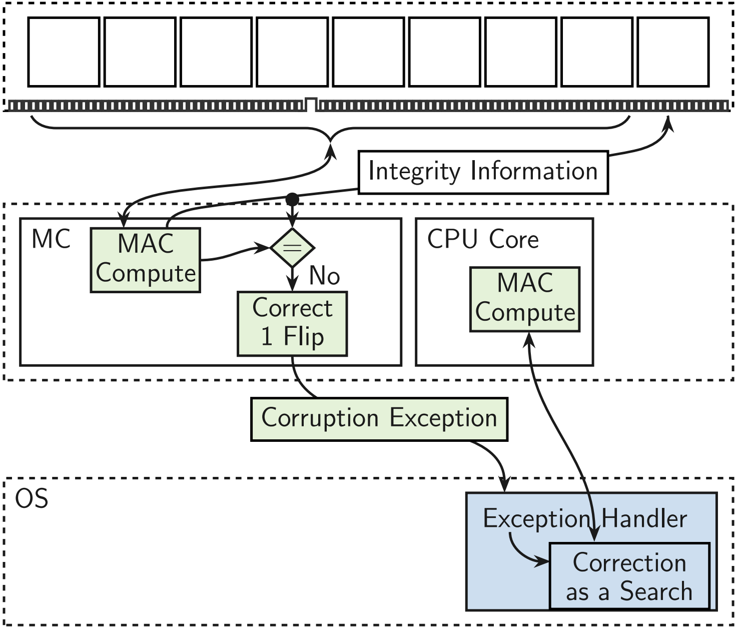

Integrity Information
MC
MAC Compute
=
No
Correct 1 Flip
Corruption Exception
OS
Exception Handler


Integrity Information
MC
MAC Compute
=
No
Correct 1 Flip
Corruption Exception
OS
Exception Handler


Integrity Information
MC
MAC Compute
=
No
Correct 1 Flip
Corruption Exception
OS
Exception Handler
Correction as a Search


Integrity Information
MC
MAC Compute
=
No
Correct 1 Flip
CPU Core
Corruption Exception
OS
Exception Handler
Correction as a Search


Integrity Information
MC
MAC Compute
=
No
Correct 1 Flip
CPU Core
MAC Compute
Corruption Exception
OS
Exception Handler
Correction as a Search


Integrity Information
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No
Correct 1 Flip
CPU Core
MAC Compute
Corruption Exception
OS
Exception Handler
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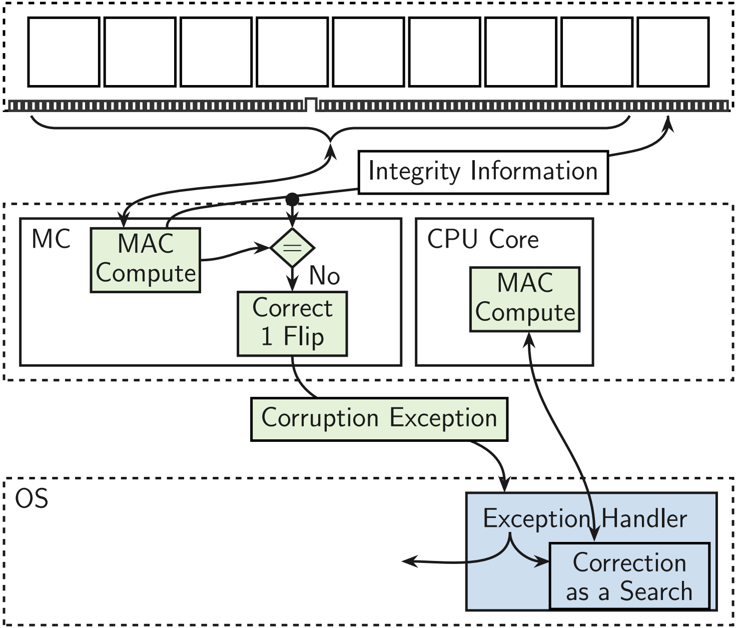
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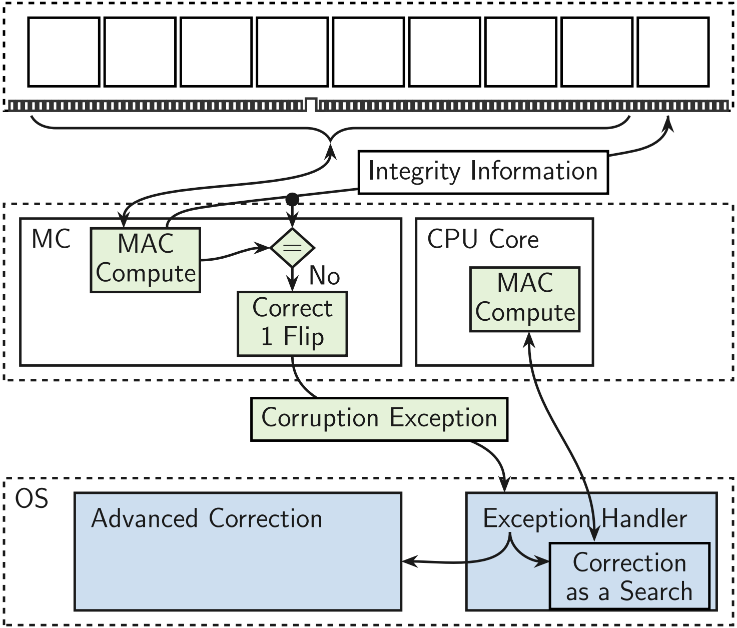
Integrity Information
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MAC Compute
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Corruption Exception
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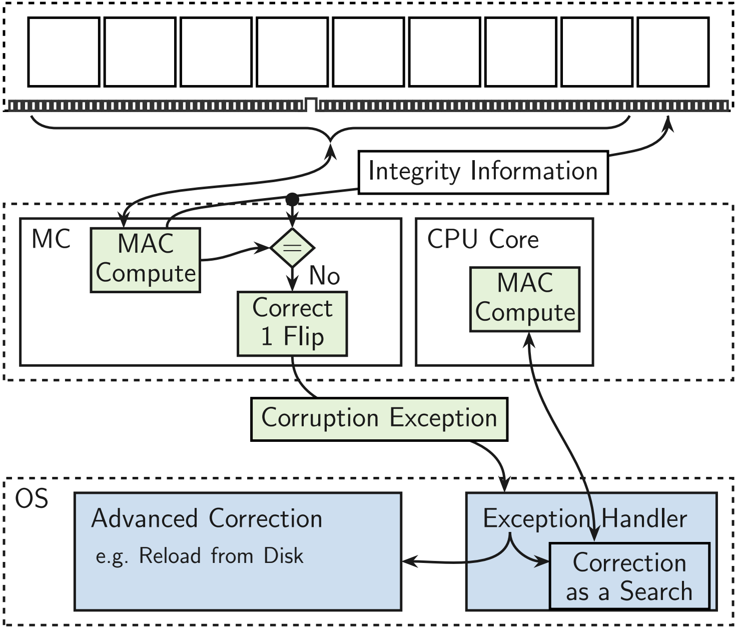
Integrity Information
MC
MAC Compute
=
No
Correct 1 Flip
CPU Core
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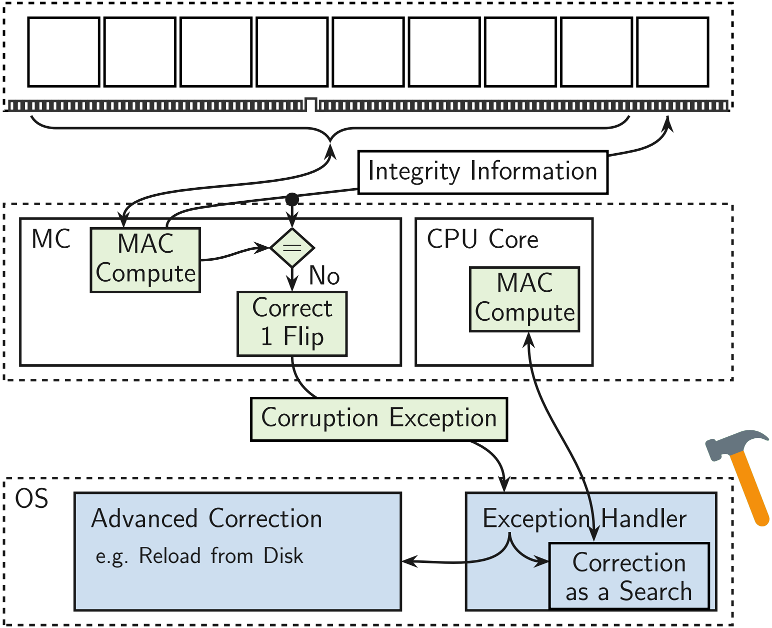
Corruption Exception
OS
Advanced Correction
e.g. Reload from Disk
Exception Handler
Correction as a Search


Integrity Information
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MAC Compute
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CPU Core
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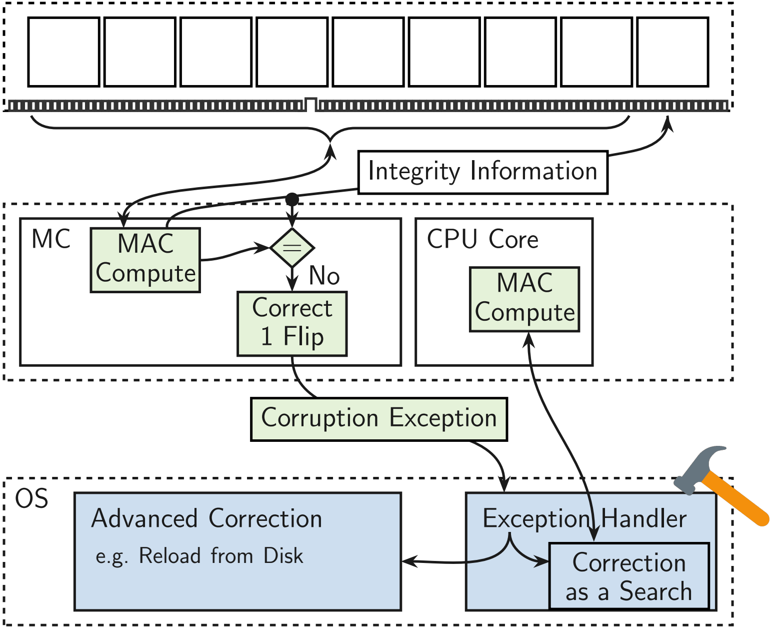
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CPU Core
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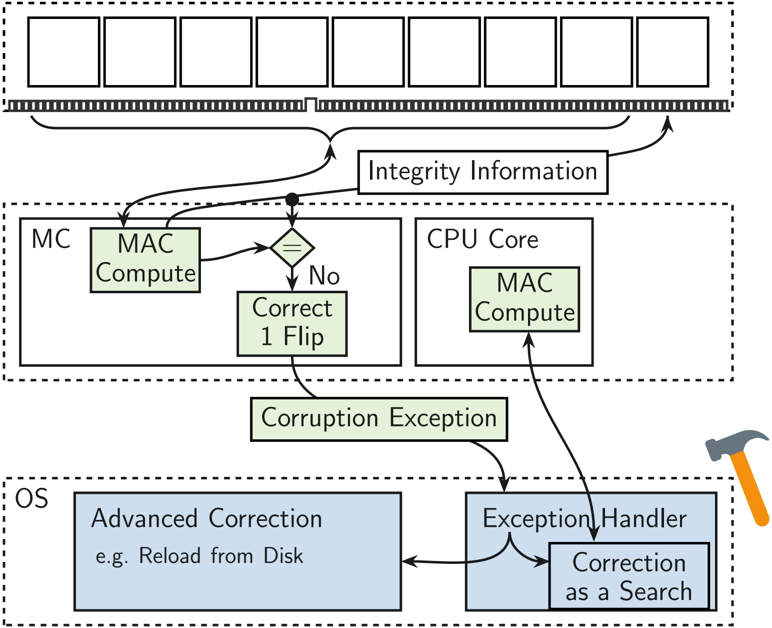
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MC
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No
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CPU Core
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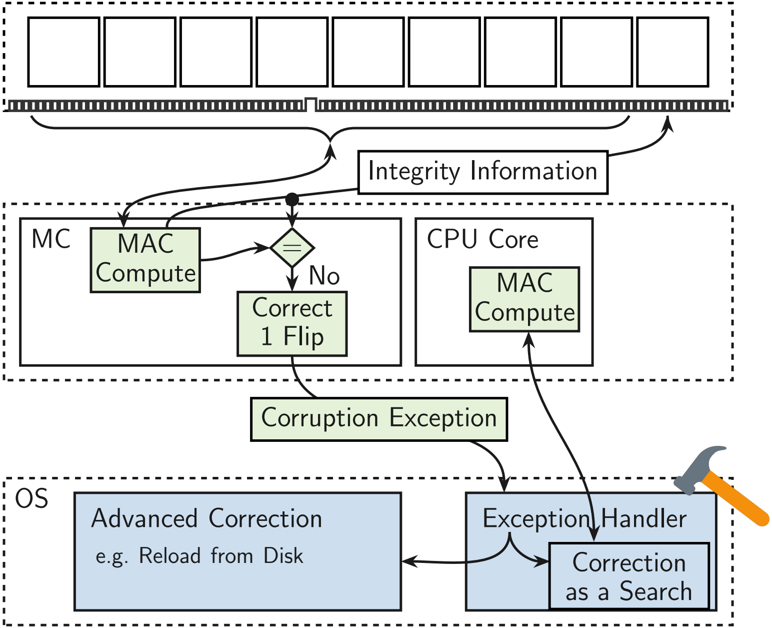
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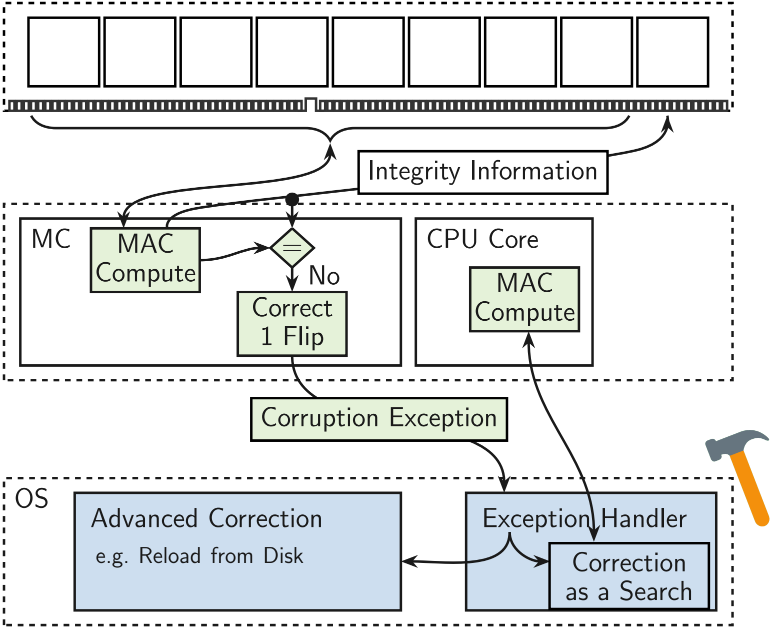
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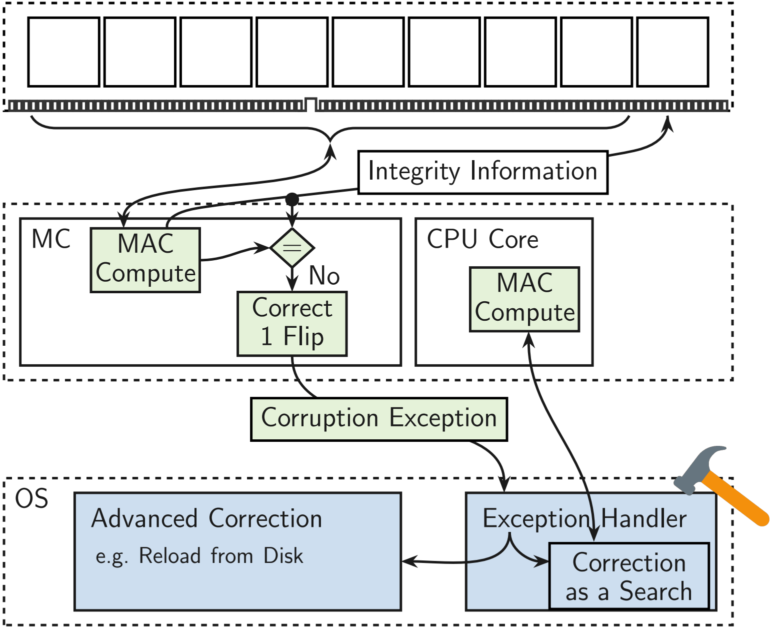
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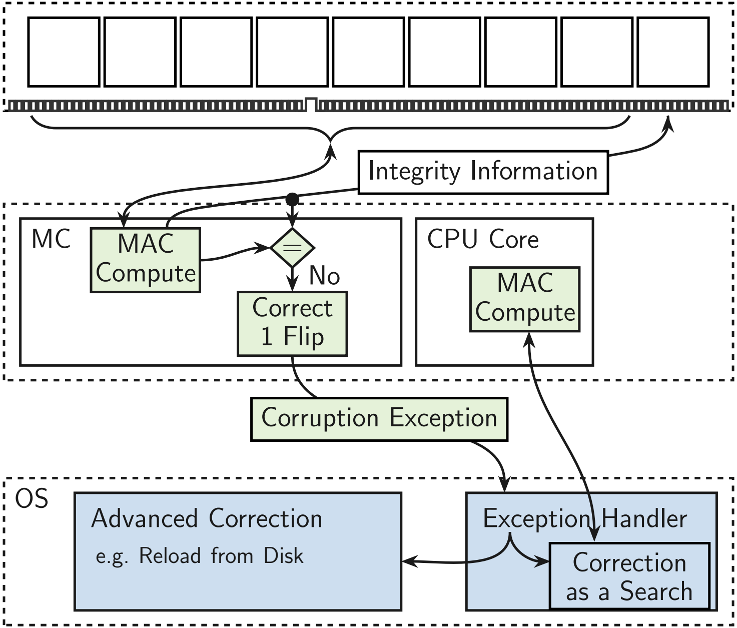
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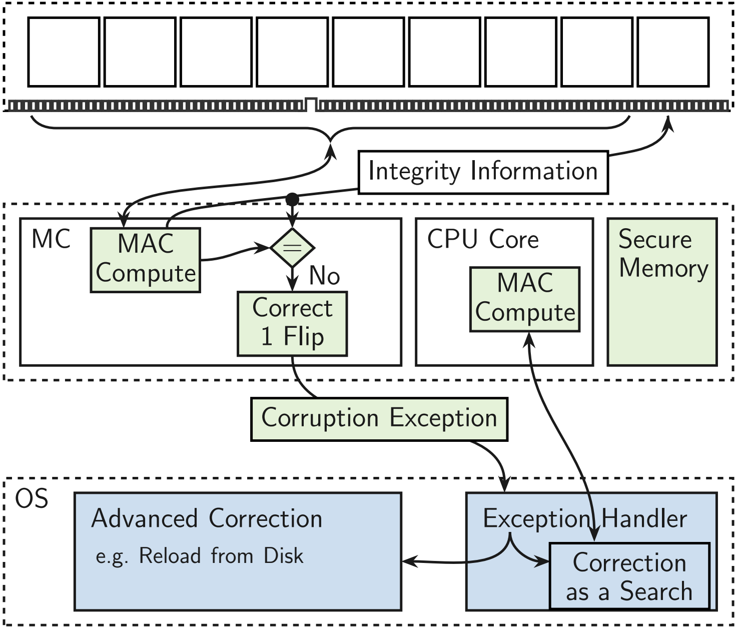
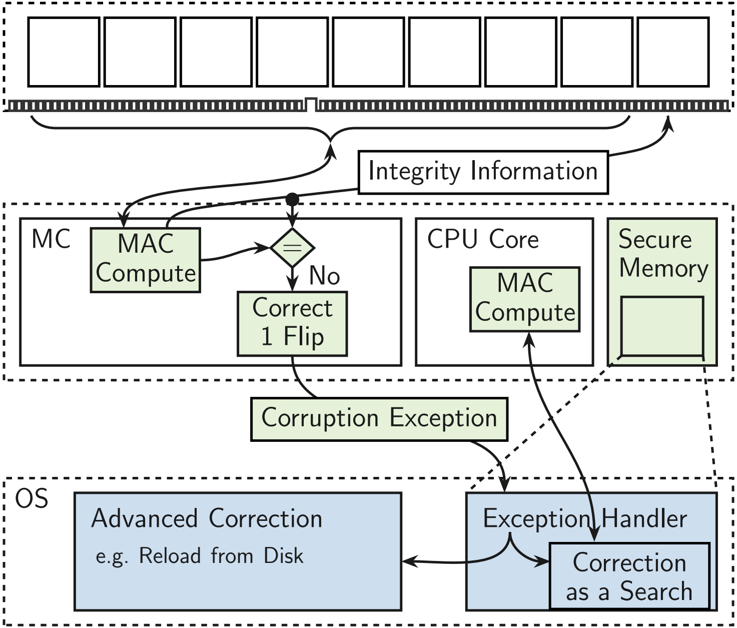
MC
MAC Compute
=
No
Correct 1 Flip
CPU Core
MAC Compute
Corruption Exception
OS
Advanced Correction
e.g. Reload from Disk
Exception Handler
Correction as a Search


Integrity Information
MC
MAC Compute
=
No
Correct 1 Flip
CPU Core
MAC Compute
Secure Memory
Corruption Exception
OS
Advanced Correction
e.g. Reload from Disk
Exception Handler
Correction as a Search


Integrity Information
MC
MAC Compute
=
No
Correct 1 Flip
CPU Core
MAC Compute
Secure Memory
Corruption Exception
OS
Advanced Correction
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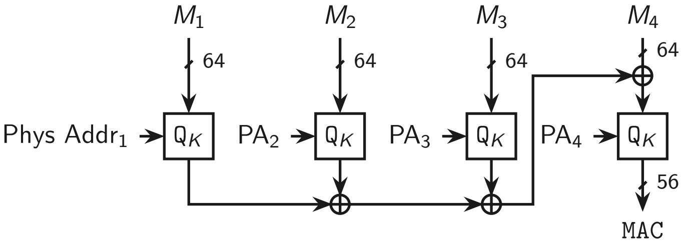
Exception Handler
Correction as a Search

CSI:Rowhammer – MAC Design



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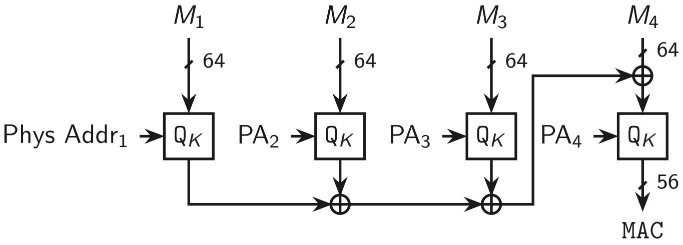
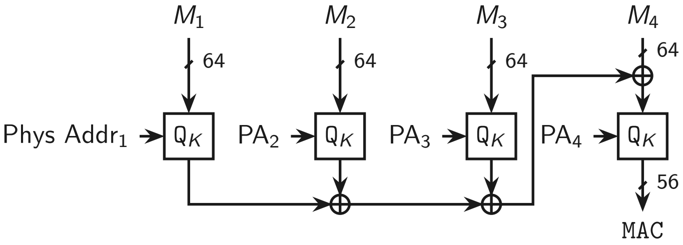


- PMAC construction

CSI:Rowhammer – MAC Design



- PMAC construction
- QARMA$_5$-64-σ_0 block cipher [Ava17]

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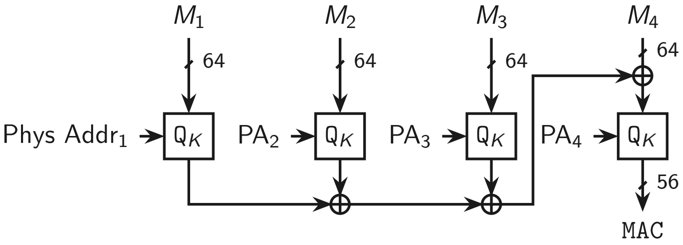

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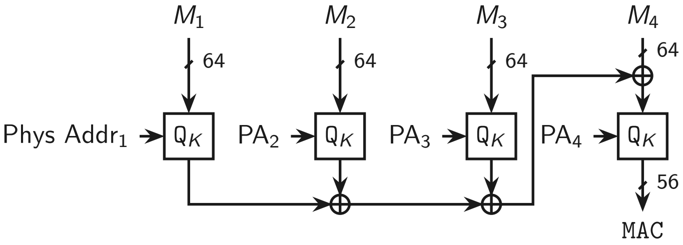

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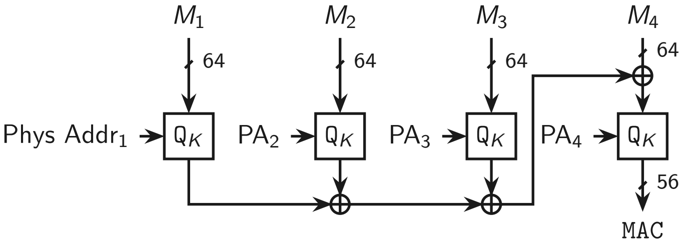

- PMAC construction
- QARMA$_5$-64-σ_0 block cipher [Ava17]
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- 5.13 ns 256-bit
- 6.60 ns 512-bit

Data Correction

CSI:Rowhammer – Correction as a Search

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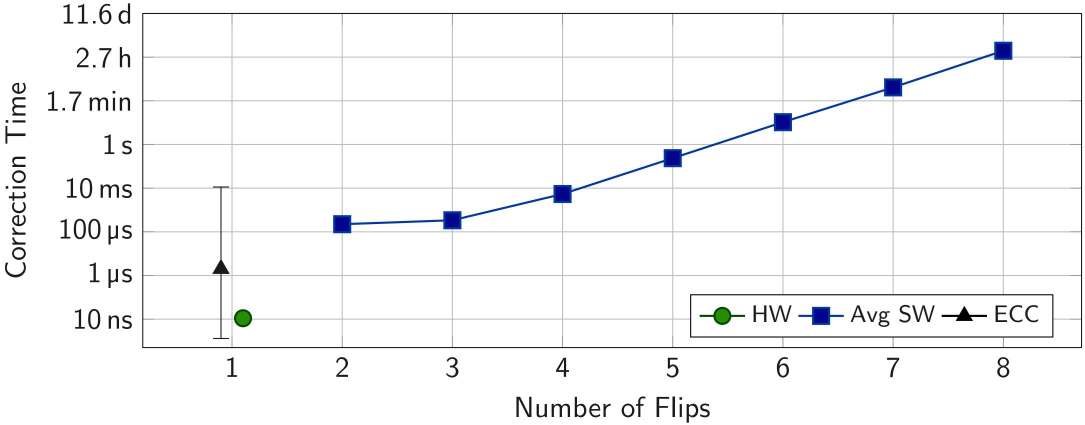
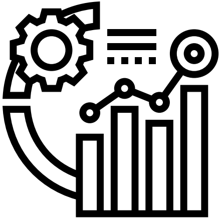
$$\texttt{MAC from DRAM} \longrightarrow \texttt{01010010} \checkmark$$

- Parity bits to shrink search space

CSI:Rowhammer – Correction Time



CSI:Rowhammer – Advanced Error Correction



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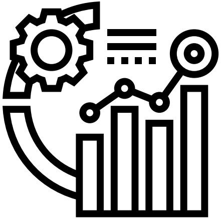

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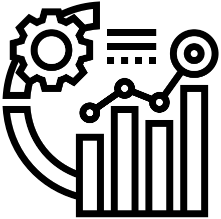

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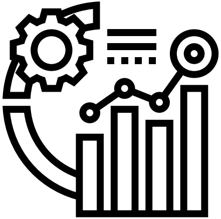
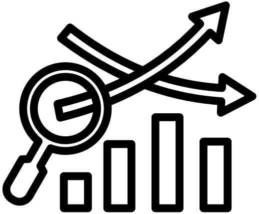


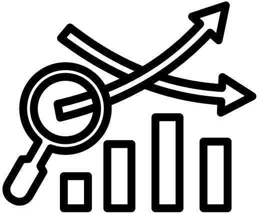
- OS has some **knowledge** about the corrupted data
- Reload disk backed data instead of correcting
- Recompute data (page tables)

Evaluation

CSI:Rowhammer – Evaluation

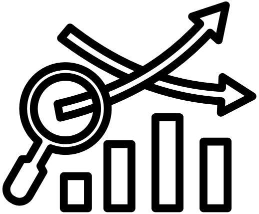


CSI:Rowhammer – Evaluation



- Implemented CSI:Rowhammer in **gem5**

CSI:Rowhammer – Evaluation



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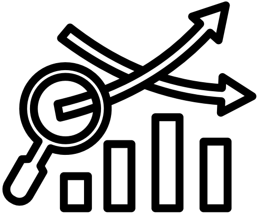
CSI:Rowhammer – Evaluation



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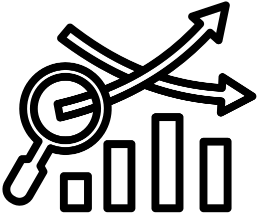
CSI:Rowhammer – Evaluation



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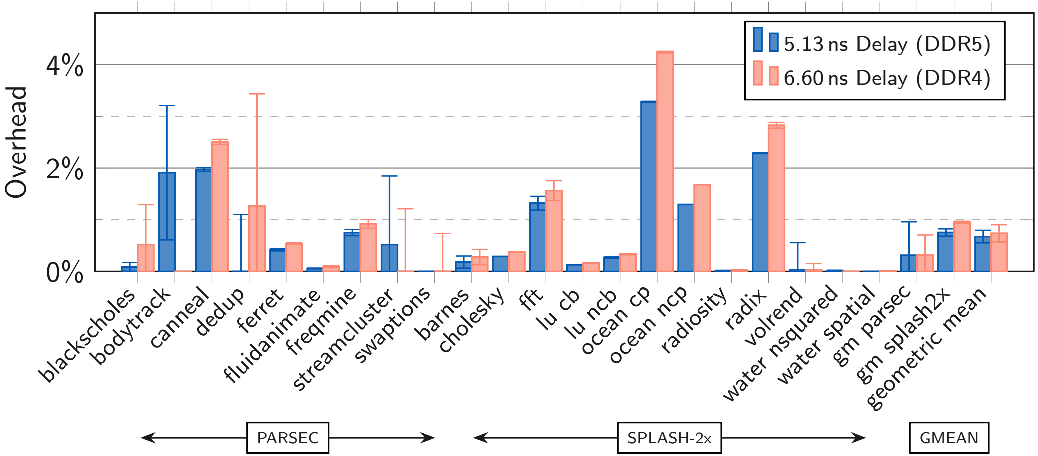
- Evaluated performance overhead

CSI:Rowhammer – Performance Overhead



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Data Flips	$\log_2(\#$ Correction Tries$)$	Ignored Flips	MAC Strength
5	26.0	3	41.2
6	31.5	2	45.4
7	38.8	1	50.2
8	42.4	0	56.0

CSI:Rowhammer – Security Evaluation

- **Approximate Equality**

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CSI:Rowhammer – Security Evaluation

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- Silent Data Corruption rate less than once per 10^9 billion years.

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- **Approximate Equality**
- Silent Data Corruption rate less than once per 10^9 billion years.
- Rowhammer second preimage after one year: $9.75 \cdot 10^{-5}\,\%$

Data Flips	$\log_2(\#$ Correction Tries$)$	Ignored Flips	MAC Strength
5	26.0	3	41.2
6	31.5	2	45.4
7	38.8	1	50.2
8	42.4	0	56.0

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- Corruption exception **nesting detection**

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- Detailed security evaluation

CSI:Rowhammer

Cryptographic Security and Integrity against Rowhammer

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PoC: github.com/CSIRowhammer/CSIRowhammerPoC

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