Seeds of SEED: H-CRAM: In-memory Homomorphic Search Accelerator using Spintronic Computational RAM

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University of Minnesota

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    - Sensitive databases, bioinformatics, biomarker search
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    - Encrypted computation accumulates noise on cyphertext
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- **H-CRAM**: SCAM in CRAM to accelerate homomorphic search

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- Plaintext comparison of *w*-bit *x* and *y*:

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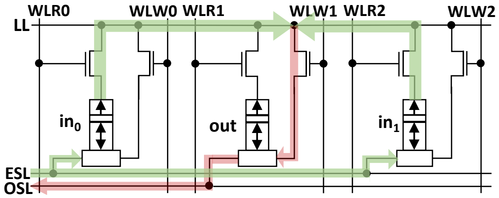
- Suffers from memory access overhead

CRAM Basics

2Transistor-1Magnet CRAM cells

- Logic Line (LL)
- Even/Odd Select Lines (E/OSL)
- Wordline Read/Write (WLR/W)



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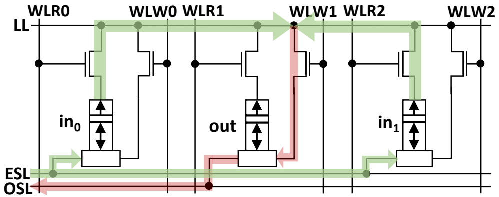

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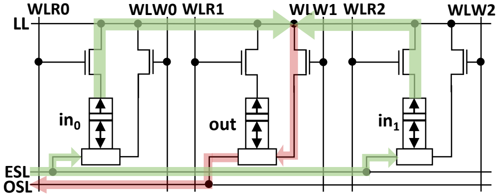

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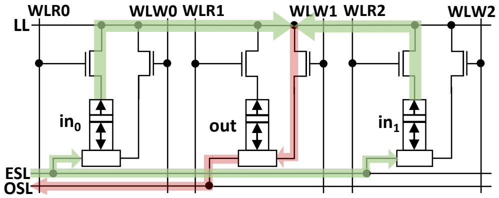

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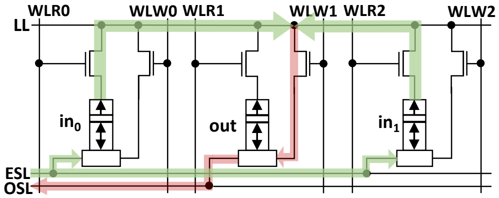

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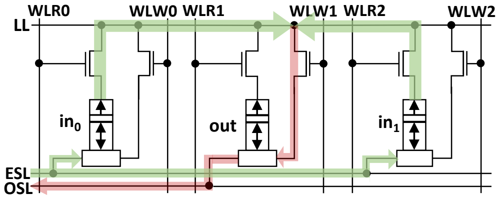

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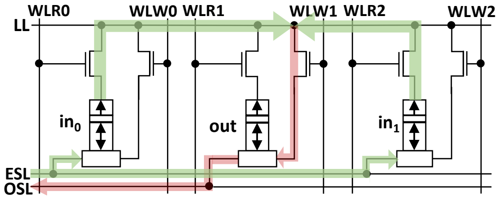

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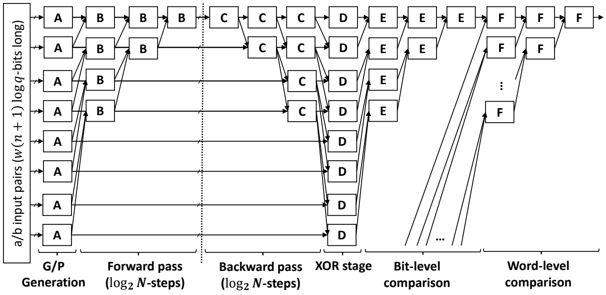
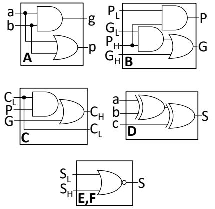
  - **Practically universal NAND gate!**

H-CRAM: SCAM in CRAM

- RCA: $O(n)$, CLA and others: $O(n \log n)$ ($O(\log n)$ depth)
- CLA adder based SCAM logic flow



a/b input pairs ($w(n+1)\log q$-bits long)
A
B
C
D
E
F
G/P Generation
Forward pass ($\log_2 N$-steps)
Backward pass ($\log_2 N$-steps)
XOR stage
Bit-level comparison
Word-level comparison



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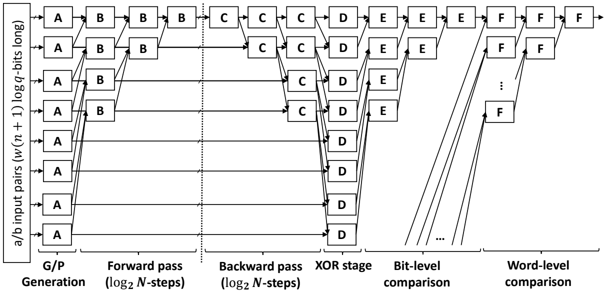

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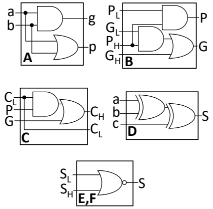
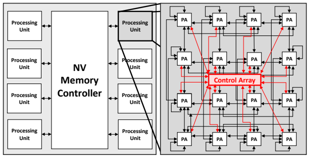
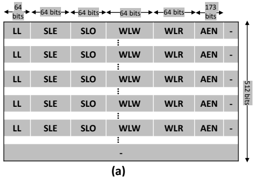


- Mapped to **Processing** and **Control** arrays
- De Bruijn graph topology for inter-array connectivity

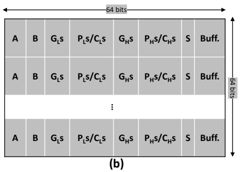




64 bits
64 bits
64 bits
64 bits
64 bits
173 bits
512 bits

LL	SLE	SLO	WLW	WLR	AEN	-
LL	SLE	SLO	WLW	WLR	AEN	-
LL	SLE	SLO	WLW	WLR	AEN	-
LL	SLE	SLO	WLW	WLR	AEN	-
LL	SLE	SLO	WLW	WLR	AEN	-
			⋮			
			-			

(a)

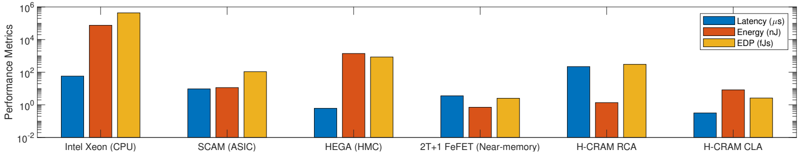


64 bits
64 bits

A	B	G_Ls	P_Ls/C_Ls	G_Hs	P_Hs/C_Hs	S	Buff.
A	B	G_Ls	P_Ls/C_Ls	G_Hs	P_Hs/C_Hs	S	Buff.
			⋮				
A	B	G_Ls	P_Ls/C_Ls	G_Hs	P_Hs/C_Hs	S	Buff.

(b)

Results



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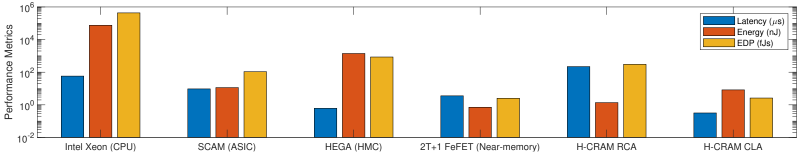

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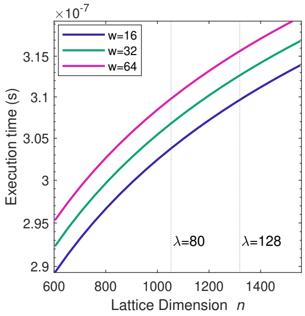

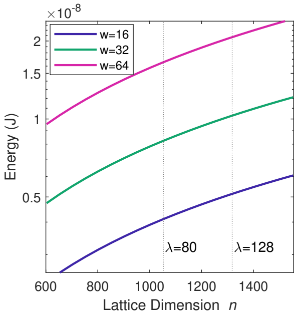

H-CRAM scales efficiently with word size!

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  - Multi-grain parallelism
  - Memory access overhead elimination
  - True processing in-memory semantics, tight coupling of memory&compute

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- Future work: general purpose homomorphic computing
  - How to extend H-CRAM to more complex homomorphic computation without bootstrapping?

Thank you!
Questions?