Aegis: Partitioning Data Block for Efficient Recovery of Stuck-at-Faults in Phase Change Memory

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Stuck-at Faults in PCM

- PCM has limited endurance (10^8).
- Stuck-at Fault occurs when memory cell fails to change it value and accumulates.
  - This type of faults is permanent.
  - Values in such faulty cells can still be read.
  - It is a major type of errors in PCM.
- Inversion-based correction schemes
  - Partition data block into a number of groups and exploit the fact that stuck-at values are still readable (e.g., SAFER).
  - Each group can tolerate one fault.
- **Proposal of a partition scheme efficiently separating faults into different groups.**

Comparing with SAFER

SAFER is the state-of-the-art inversion-based correction scheme

- Aegis has a larger set of candidate partition configurations for resolving fault collision to tolerate more faults.
  - A new configuration is demanded whenever two faults collide in a group.
  - SAFER has only $n+1$ partition configurations available for recovering continuous faults in a data block of 2^n bits.
- Aegis has a smaller number of groups in each configuration to reduce space overhead.
  - In SAFER, with increasing number of faults, the number of groups is increased exponentially.
- Aegis aggressively shuffles the bits among the groups attempting to uniformly distribute faults across different groups.

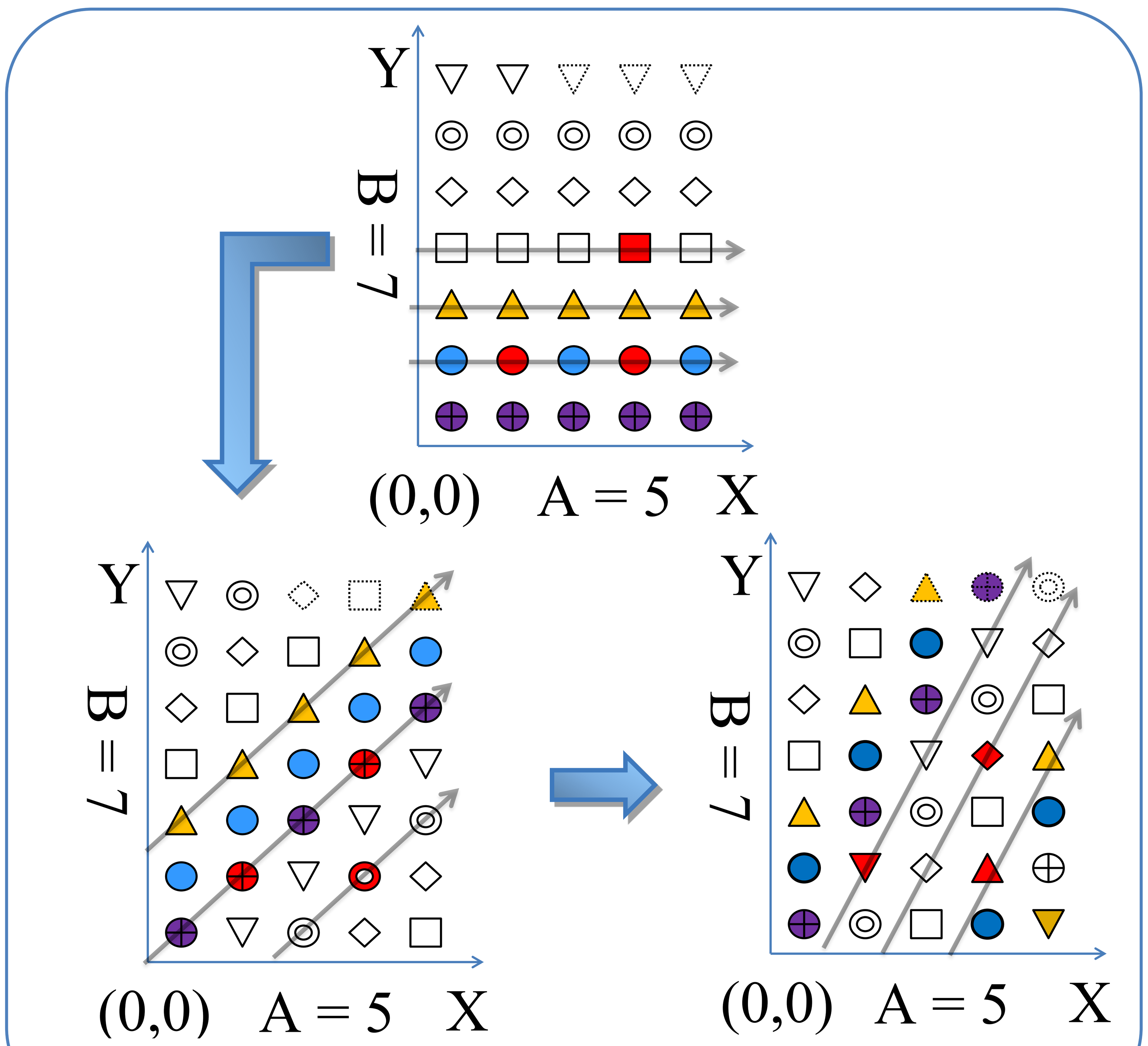
Design of Aegis

Structure

- Aegis arranges bits of an n-bit data block in a $A \times B$ rectangle on the Cartesian plane.
- B must be a prime number, $A \leq B, A \times (B-1) < n \leq A \times B$
- Any two bits in the same line will not be in the same line once slope of the lines is changed.
- Aegis has B slopes and tolerates at least f faults that satisfies $\binom{f}{2} + 1 \leq B$.
- Aegis can be improved by
  - Tolerating more faults in a group (Aegis-rw)
    - Multiple R faults or multiple W faults can be in the same group.
    - To tolerate $f = f_w + f_r$ faults, it needs $f_w \times f_r + 1$ slopes
  - Using pointers to indicate faulty groups (Aegis-rw-p)
    - It use "Pigeonhole Principle" and only $\lfloor f/2 \rfloor$ group pointers to record the inverted groups.

Basic Observation

- A Cartesian plane any two different points on a line uniquely determine slope of the line.
- Aegis considers all points on a line as a group.



*Red symbols represent the faulty bits

While it is possible that two faults that were in different groups can move into the same group after a re-partition, we guarantee that a collision-free configuration exists and can be efficiently identified.

Hard Fault Tolerance Capability

Cost Per Block

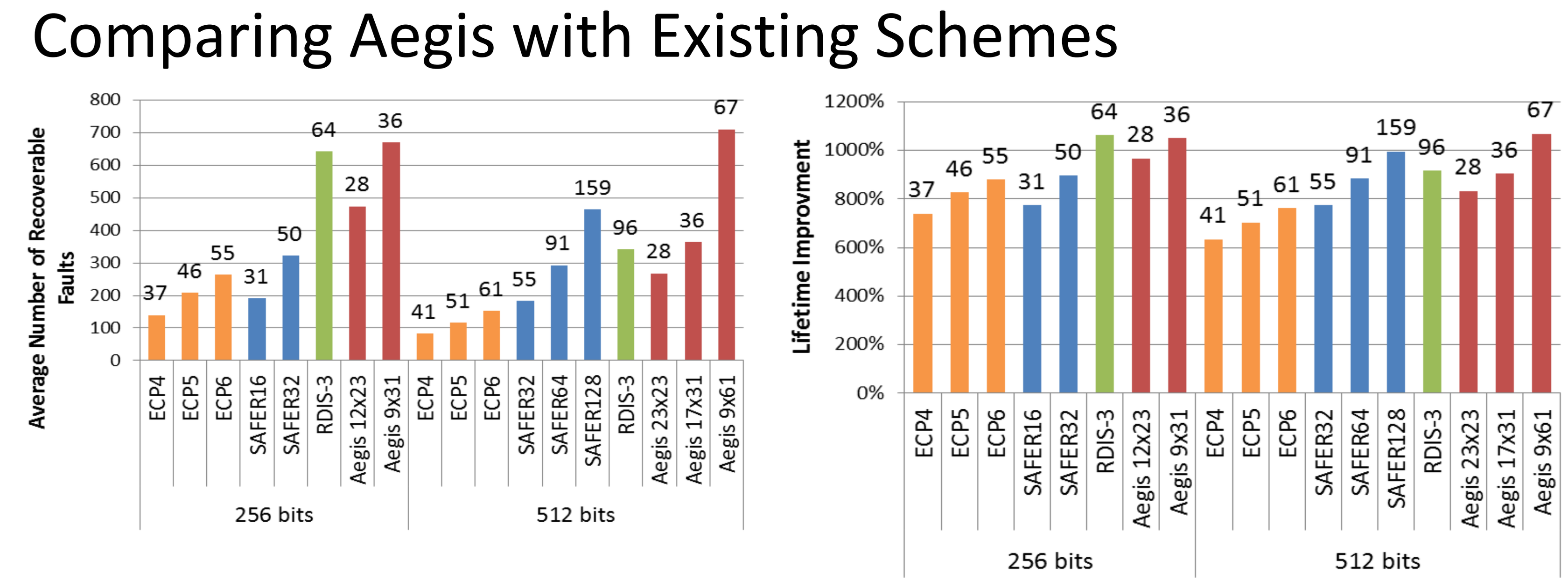
- For each n-bit data block Aegis needs a slope counter of $\lfloor log_2(f+1) \rfloor$ bits and $\binom{f}{2} + 1 < B$ and an inversion vector of B bits.
- The cost of Aegis and Aegis-rw are $\lfloor log_2(f+1) \rfloor + B$
- the hardware cost for Aegis-rw-p is $log_2\left(\min\left(\left\lfloor \frac{f}{2} \right\rfloor \times \left\lceil \frac{f}{2} \right\rceil + 1, B\right)\right) + \left\lfloor \frac{f}{2} \right\rfloor \times \lceil log_2 B \rceil + 2$

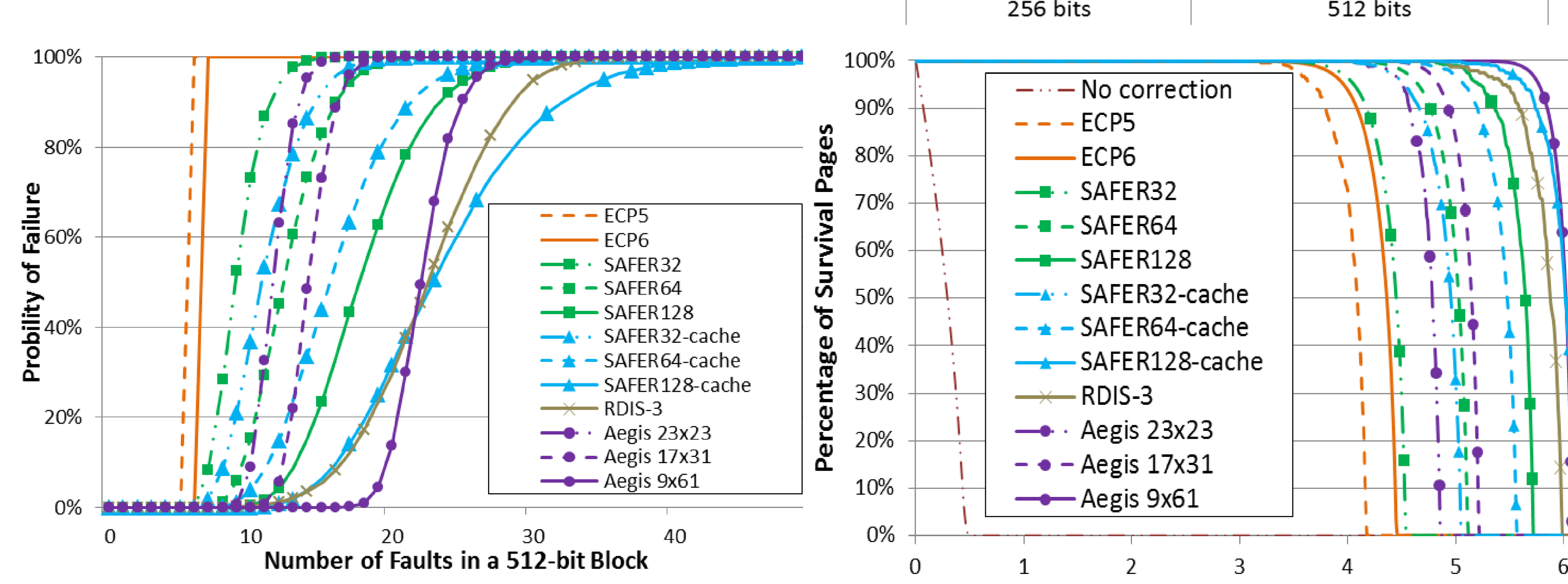
The hardware cost used to tolerate a given number of faults (HFT) for each 512-bit block.

Hard FTC	1	2	3	4	5	6	7	8	9	10
ECP	11	21	31	41	51	61	71	81	91	101
SAFER	1	7	14	22	35	55	91	159	292	552
No. of group (for SAFER)	1	2	4	8	16	32	64	128	256	512
Aegis	23	24	25	26	27	27	28	34	43	53
$A \times B$ (for Aegis)	23×23							18×29	14×37	11×47
Aegis-rw	23	24	25	26	26	27	27	28	28	34
Aegis-rw-p	1	8	9	15	15	21	21	27	27	32
$A \times B$ (for Aegis-rw/rw-p)	23×23									18×29

Soft Fault Tolerance Capability

Comparing Aegis with Existing Schemes





* Number of bits required for protecting each block are shown above respective bars.