

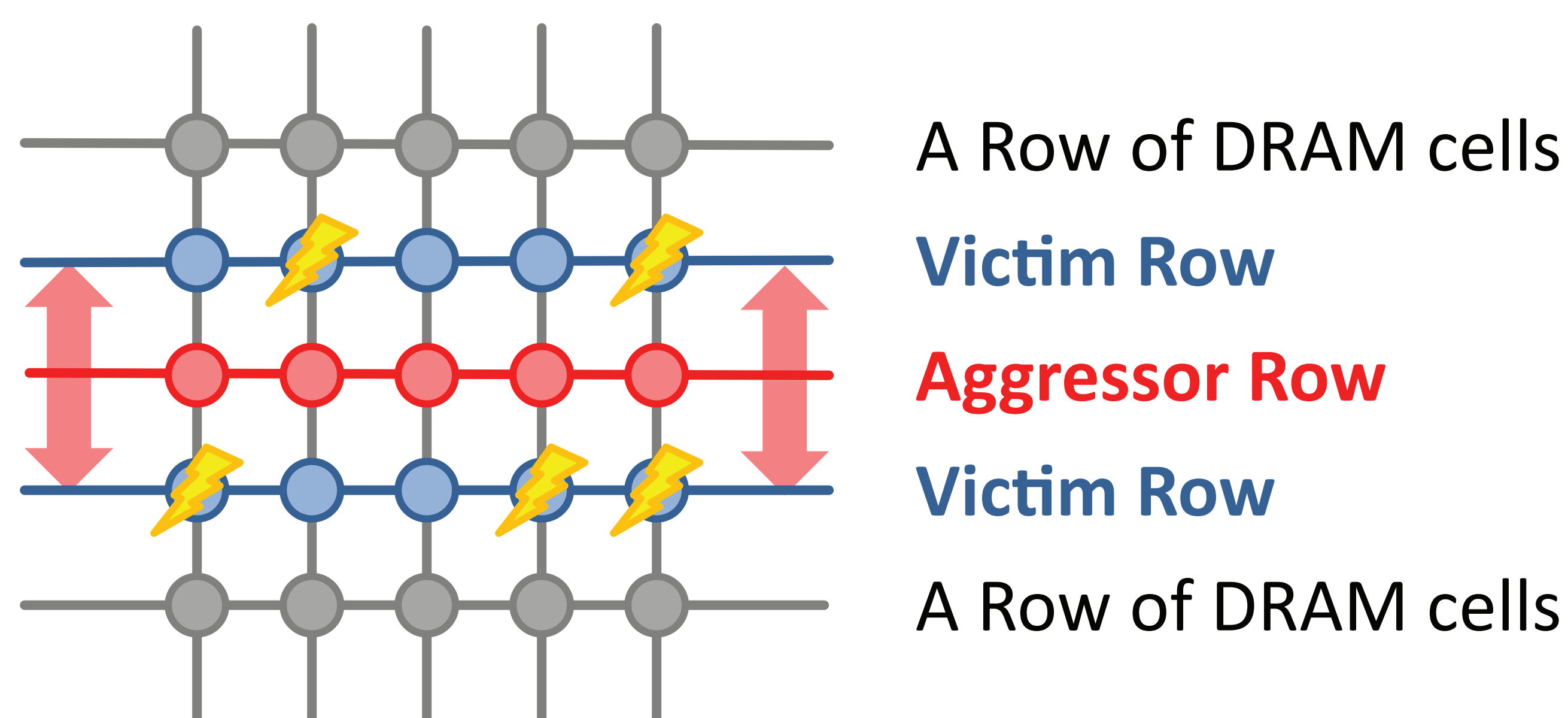
# Flipping Bits in Memory Without Accessing Them

Yoongu Kim\*, Ross Daly, Jeremie Kim\*, Chris Fallin, Ji Hye Lee\*, Donghyuk Lee\*,  
Chris Wilkerson (Intel Labs), Konrad Lai, Onur Mutlu\* (CMU\*)

[ISCA '14]

## OVERVIEW

- **Disturbance Error:** When an access to one memory address corrupts data stored in some other memory address(es)
- **Exposition:** Commodity DRAM modules from recent years exhibit disturbance errors
- **Pathology:** Repeatedly “opening” and “closing” a DRAM row causes cells in nearby rows to lose charge



## REAL SYSTEM DEMONSTRATION

```

1 disturb:
2  mov (X), %eax
3  mov (Y), %ebx
4  clflush (X)
5  clflush (Y)
6  mfence
7  jmp disturb

1 no-disturb:
2  mov (X), %eax
3  clflush (X)
4
5
6  mfence
7  jmp no-disturb
    
```

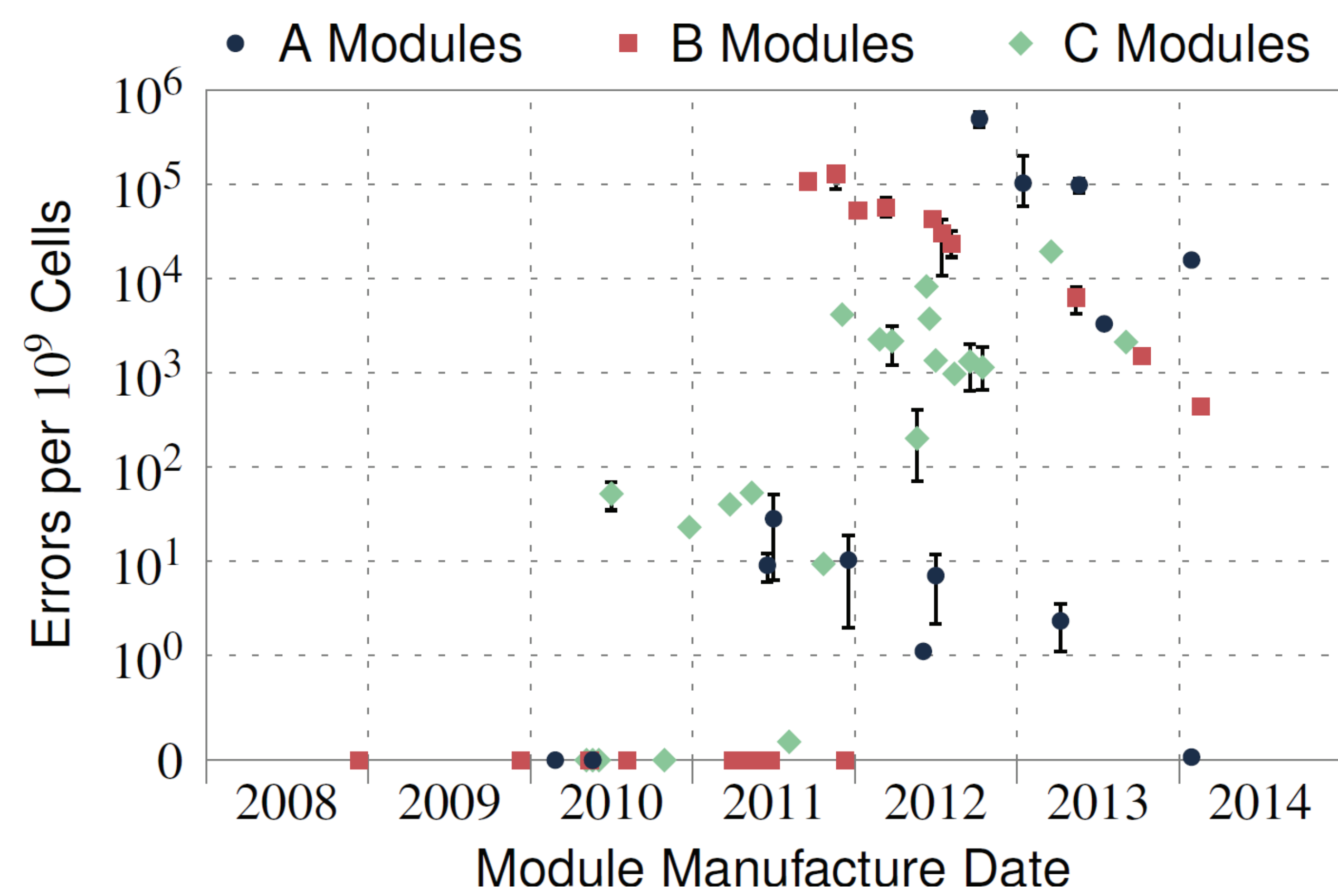
- Addresses X and Y must map to *different* rows in the same bank
- Alternating accesses to different rows cause both of them to be opened and closed
- Number of errors induced using a 2GB module:

Bit-Flips	Intel SNB	Intel IVB	Intel HSW	AMD PLD
'0' → '1'	7,992	10,273	11,404	47
'1' → '0'	8.125	10,449	11,467	12

## CHARACTERIZATION METHODOLOGY

- 8 FPGAs programmed with customized test engine
- 129 DDR3 DRAM modules (972 DRAM chips)
- Heat chamber regulated to  $50 \pm 2^\circ\text{C}$
- Row is opened/closed once every 55ns for 128ms

## DISTURBANCE ERRORS ARE WIDESPREAD



- 110 out of 129 modules are affected
- As many as 1 out of every 1.7K cells is affected
- As few as 139K accesses induce an error
- To eliminate all errors, requires  $\sim 8x$  refresh rate
- As many as 4 errors per 64-bit word

## SUMMARY OF OTHER FINDINGS IN PAPER

- Most aggressors induce errors in two rows or less
- Almost all errors are attributed to charge loss
- *RowStripe* data has 100x more errors than *Solid*
- For a given victim cell, errors are highly repeatable
- Victim cells  $\neq$  Weak cells
- Errors are not strongly affected by temperature

## OUR SOLUTION

- Every time a row is closed, refresh its neighbors with some low probability
- We call it PARA (*probabilistic adjacent row activation*)

