Degradation Stochastic Resonance (DSR) Concept: Benefits of Noise Injection

Delft University of Technology

Nivard Aymerich, Antonio Rubio and

Sorin Cotofana

7th International Conference on Unsolved Problems an Noise 13-17 July 2015. Barcelona

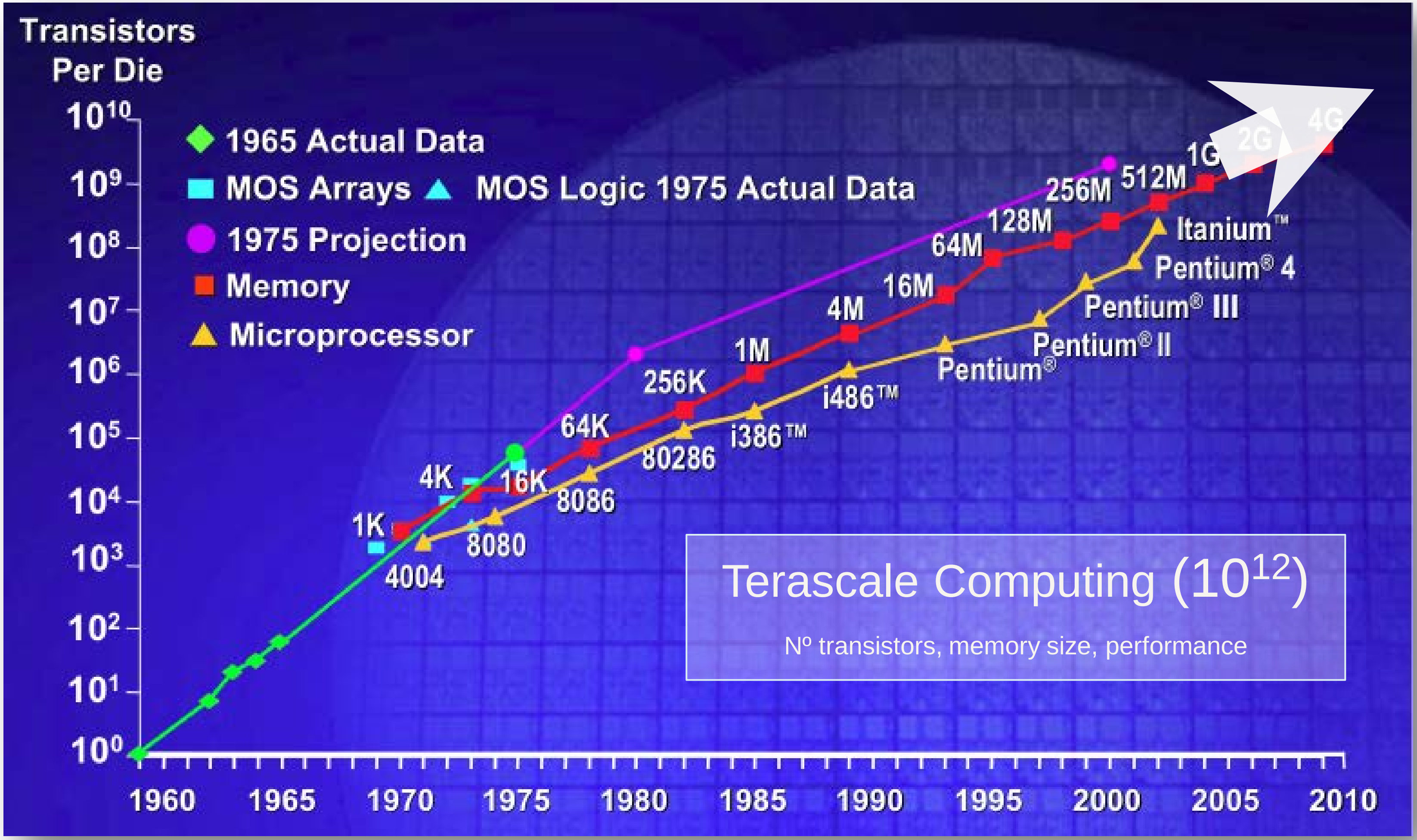
Both groups, we are working on the research and development of computing systems driven by noise.

In this case we will emphasizes on the unconventional fact that noise may benefit the reliability of hardware.

OUTLINE

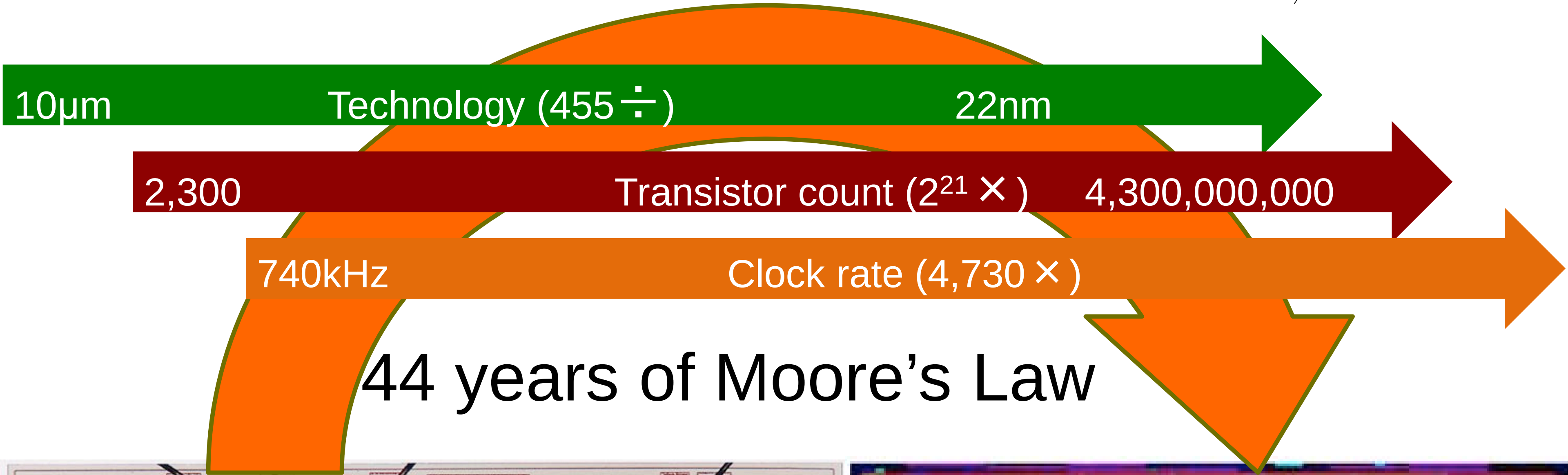
- MOTIVATION
- INTRODUCTION / THE ADAPTIVE AVERAGING CELL (AD-AVG)
- DEGRADATION STOCHASTIC RESONANCE (DSR) EFFECT
- BENEFITS OF INJECTING NOISE
- CONCLUSION

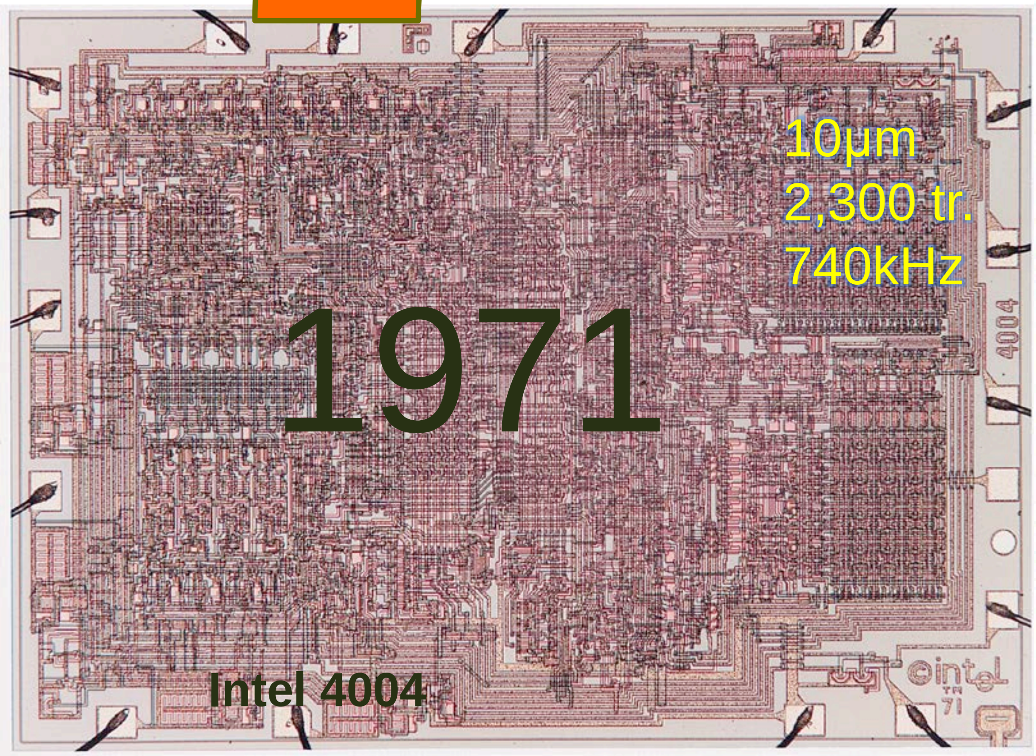
Motivation: Technology Evolution --- Moore’s Law

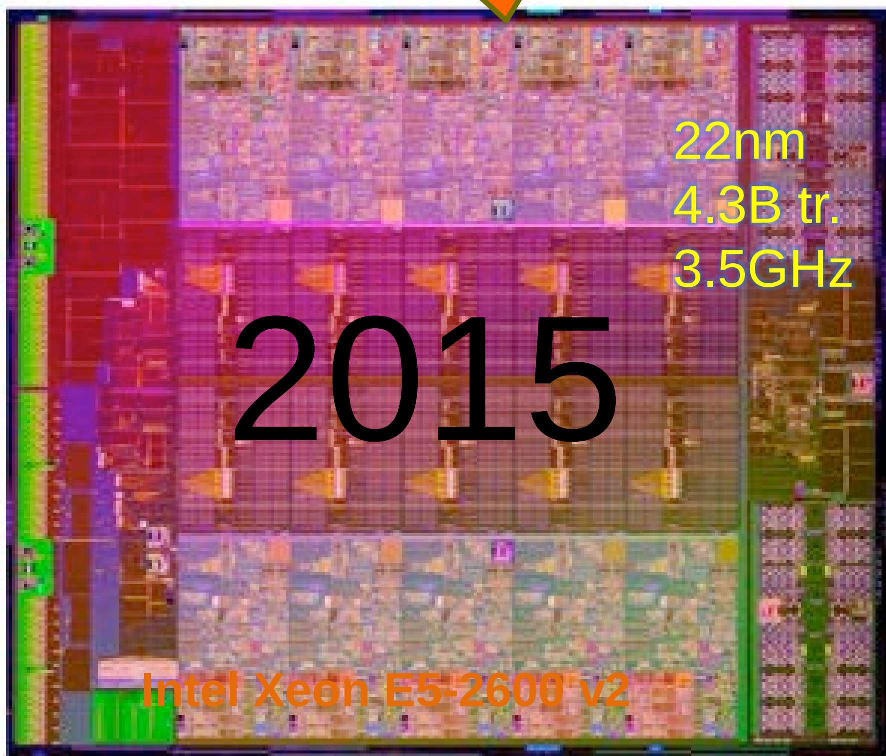


Moore's Law…

$$\frac{4,300,000,000}{2,300} \approx 2^{21}$$



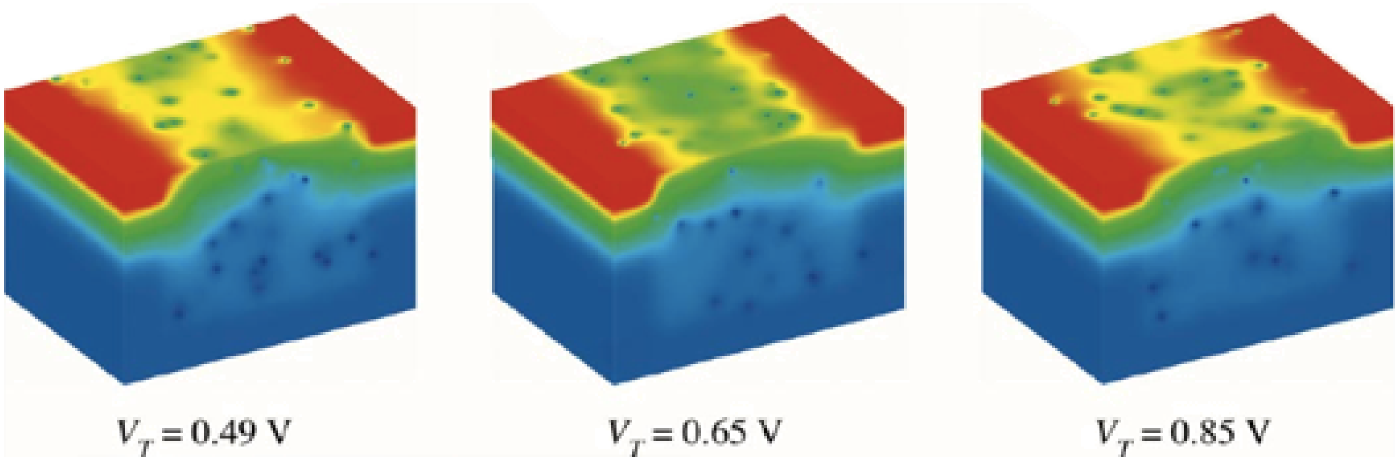




Scaling Limits

- **Fundamental:** thermodynamics, quantum mechanics, electromagnetic
- **Material:** breakdown, heat transfer, degradation
- **Manufacturing:** lithography limits,

variability



Situation nowadays

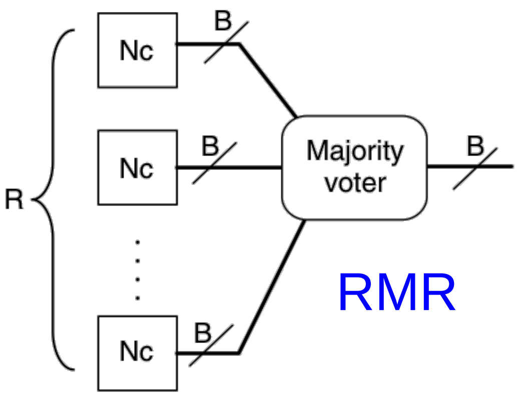
- Variability, manufacturing limitations and degradation are causing loss of performance enhancement. Making critical the technology progress.

- The manufacturing yield and lifetime is dramatically affected

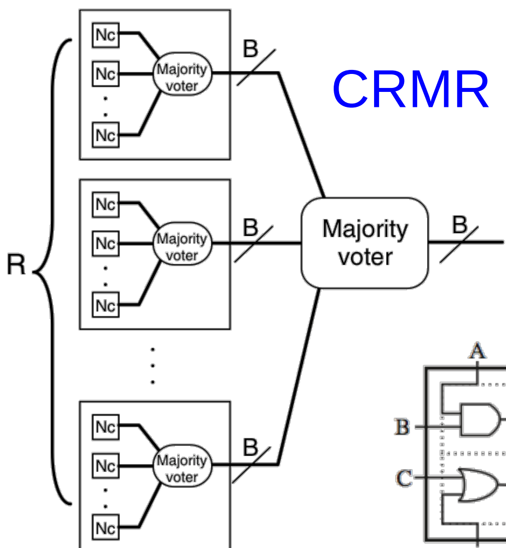
→ Need to introduce Fault Tolerance: Redundancy

Redundancy

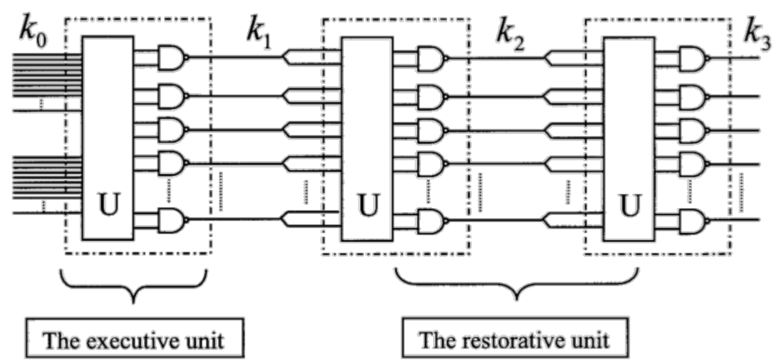
Design reliable systems from non-reliable components



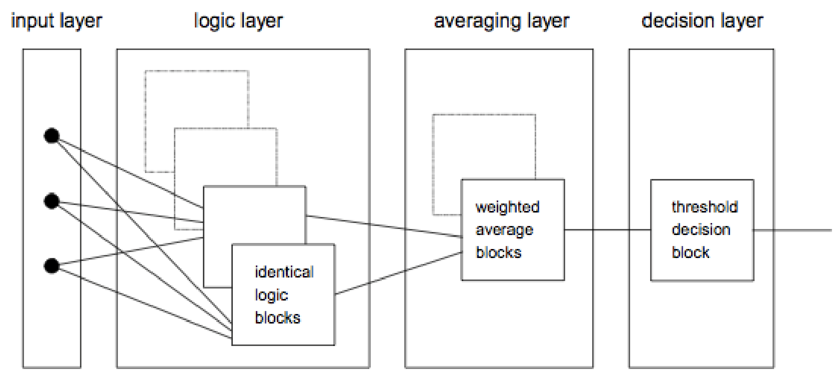
RMR



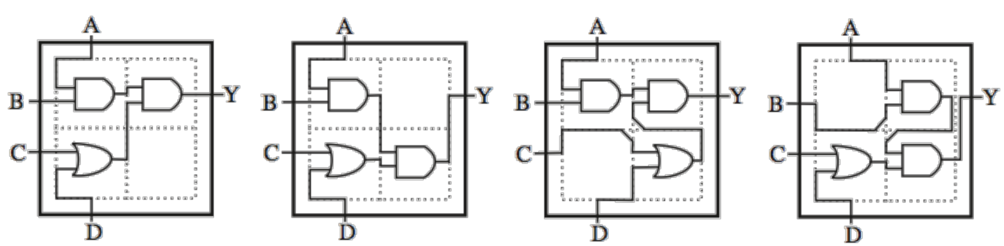
CRMR



NAND
multiplexing

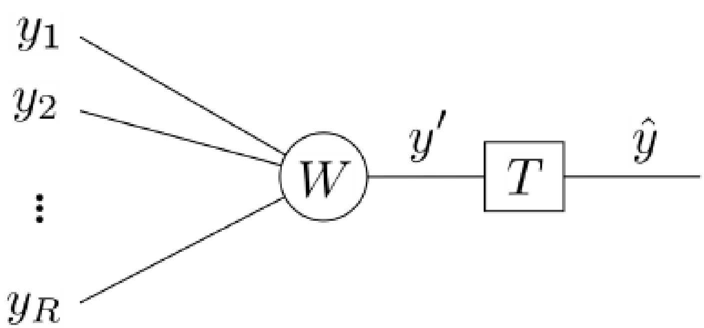


Averaging Cell



Reconfiguration

INTRODUCTION – **THE ADATIVE AVERAGING CELL (AVG)**

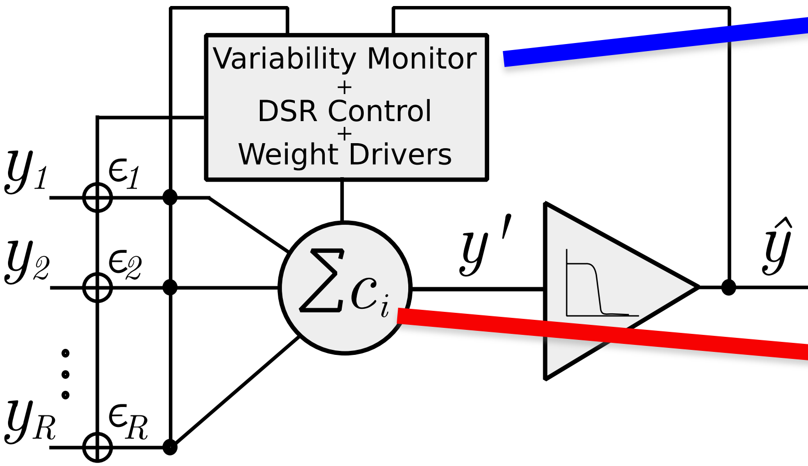


$$y' = W(y_1, ..., y_R) = \frac{1}{\sum_{i=1}^{R} k_i} \sum_{i=1}^{R} k_i y_i$$

$$\hat{y} = T(y') = \begin{cases} V/2 & \text{if } y' > 0 \\ -V/2 & \text{if } y' < 0 \end{cases}$$

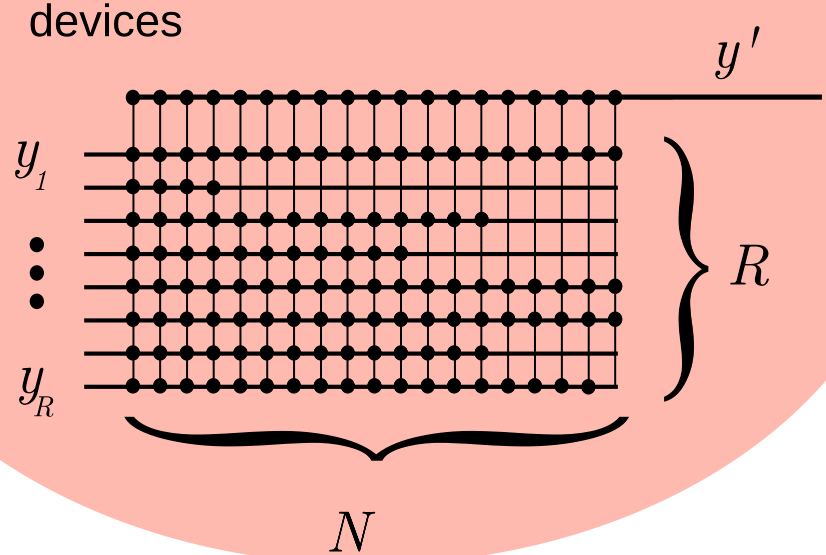
Heterogeneous-aware Reliable Design: ADAPTIVE-AVG cell

AD-AVG Implementation



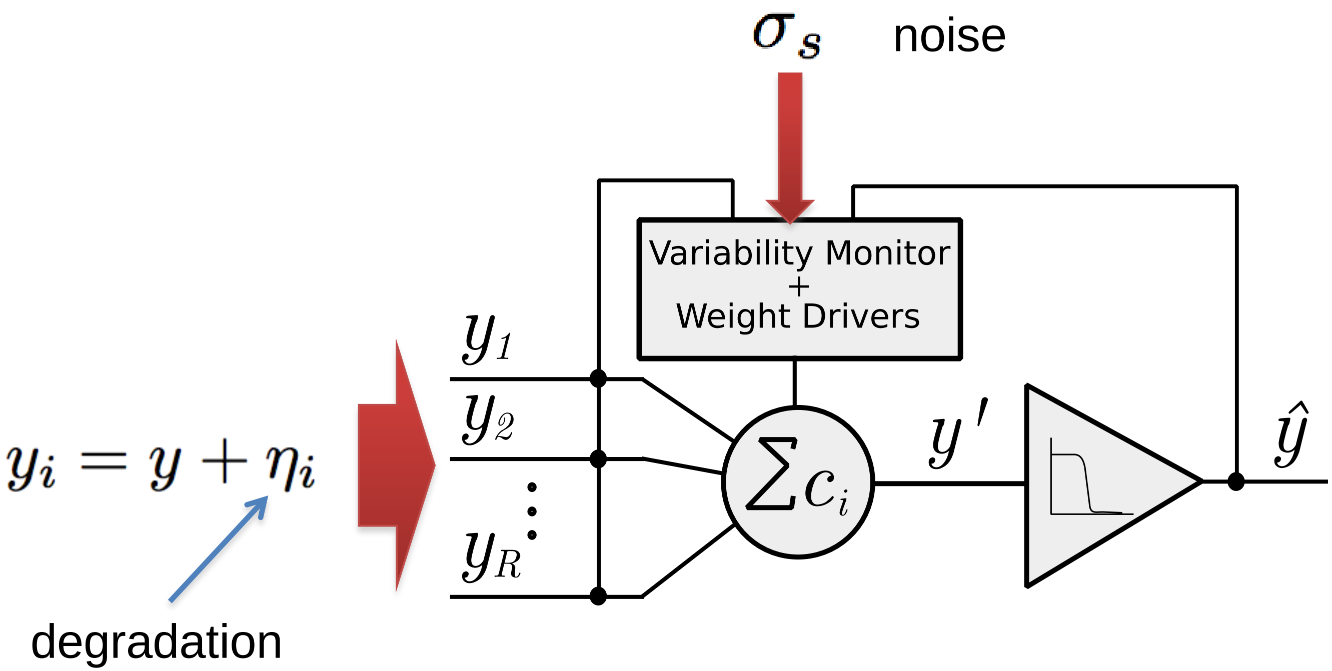
Variability Monitor based on a disagreement detector between the AD-AVG output $\hat{y}$ and the signal provided by each replica y_i

Averaging Scheme based on a crossbar of switching resistive devices



- Implements an adaptive algorithm to maximize reliability.
- Able to cope with non-homogeneous variability and time-varying effects.

DEGRADATION **IMPACT ON AD-AVG**

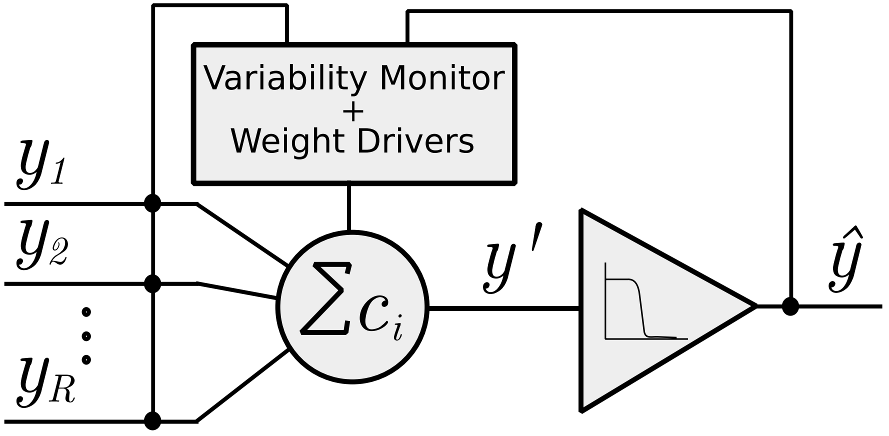


MOTIVATION

Analyzing the reliability of the Adaptive Averaging Cell (AD-AVG) against noise and degradation we observed that…

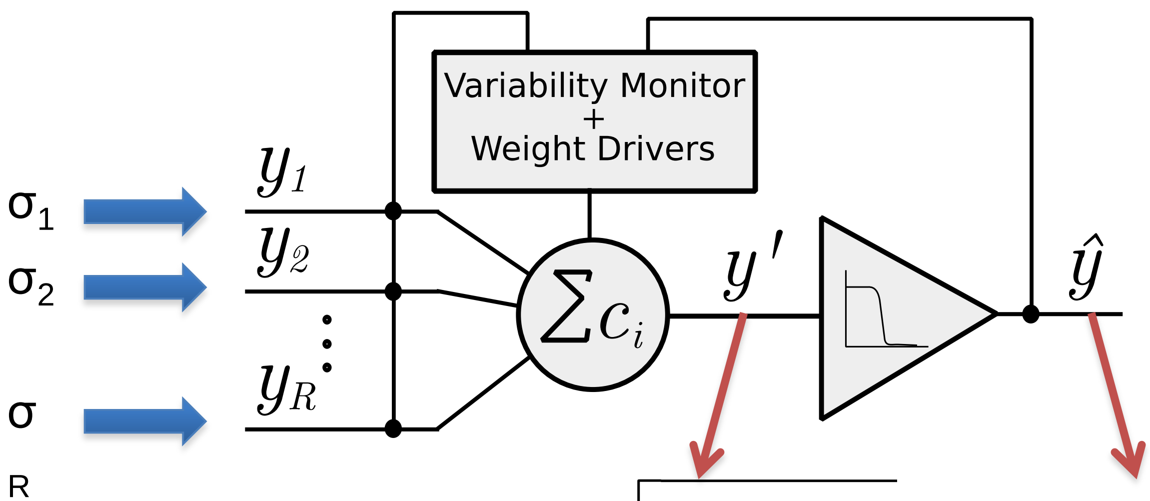
SOMETIMES, HARDWARE DEGRADATION DOES NOT MEAN A LOSS OF RELIABILITY

- AD-AVG architecture



INTRODUCTION – **YIELD MEASUREMENT**

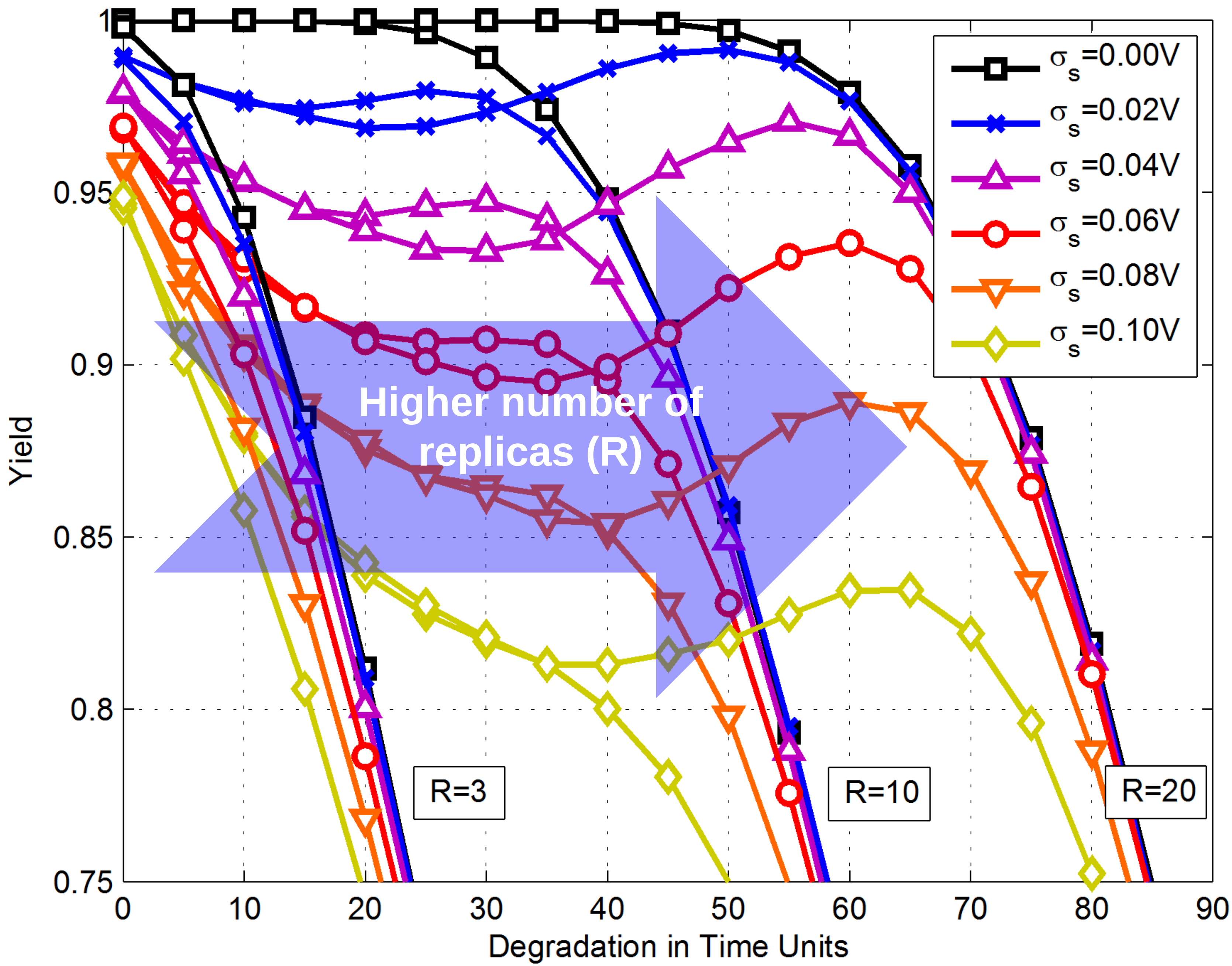
- **AD-AVG YIELD =** % of circuits in a MC simulation that satisfy the reliability requirement Pe < 10^{-4}.



$$y_i = y + \eta_i$$
$$\eta_i \sim N(0, \sigma_i)$$

$$\sigma_{y'} = \sqrt{\sum_{i=1}^{R} c_i^2 \sigma_i^2}$$

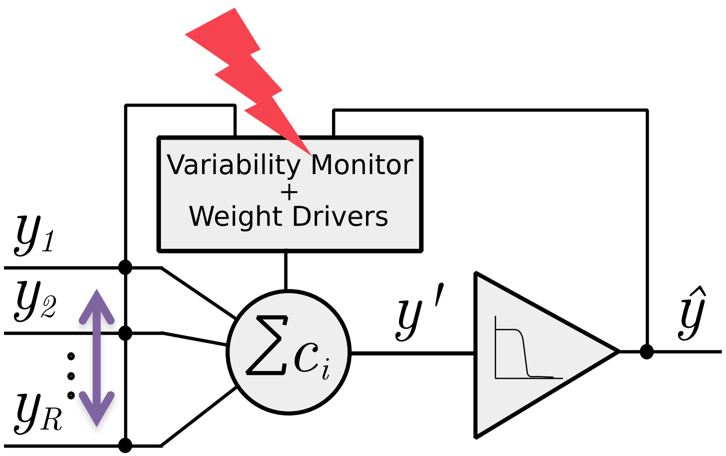
$$P_e = \frac{1}{2} \times \operatorname{erfc}\left(\frac{V_{cc}}{\sqrt{8}\sigma_{y'}}\right)$$



Yield
Degradation in Time Units
Higher number of replicas (R)
R=3
R=10
R=20
σs=0.00V
σs=0.02V
σs=0.04V
σs=0.06V
σs=0.08V
σs=0.10V
1
0.95
0.9
0.85
0.8
0.75
0
10
20
30
40
50
60
70
80
90

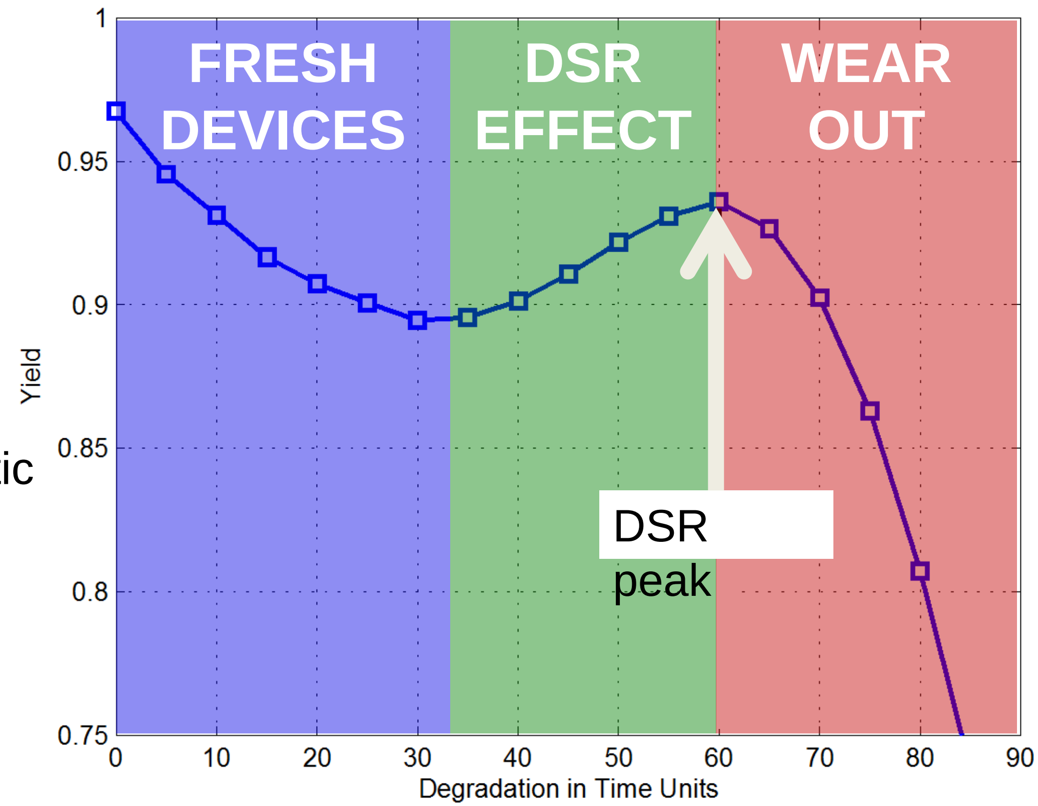
Heterogeneous-aware Reliable Design

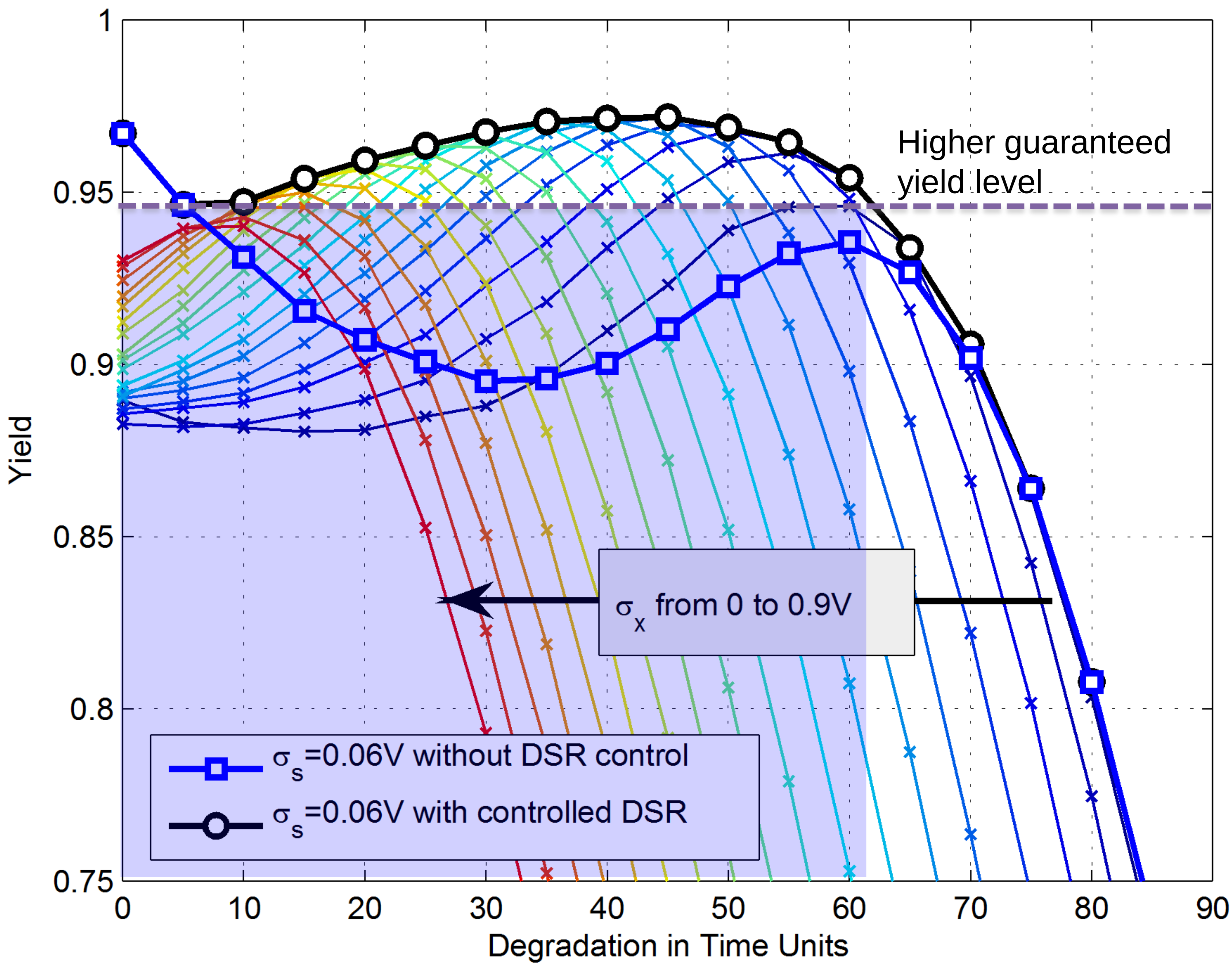
Degradation Stochastic Resonance



R: nº of replicas

Related to Suprathreshold Stochastic Resonance (SSR) effect

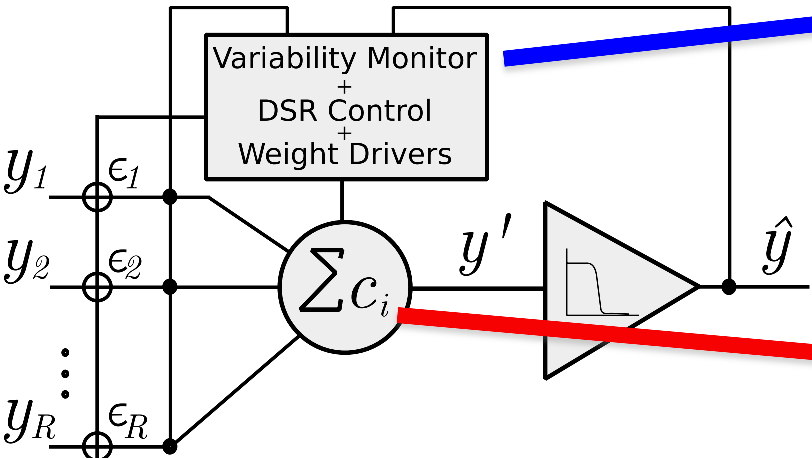




Yield
Degradation in Time Units
Higher guaranteed
yield level
σx from 0 to 0.9V
σs=0.06V without DSR control
σs=0.06V with controlled DSR
1
0.95
0.9
0.85
0.8
0.75
0
10
20
30
40
50
60
70
80
90

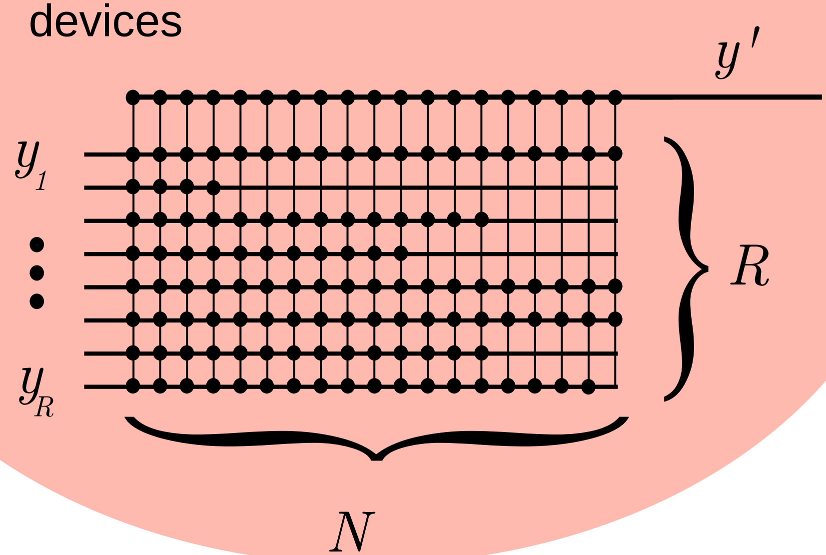
Heterogeneous-aware Reliable Design

AD-AVG Implementation



Variability Monitor based on a disagreement detector between the AD-AVG output $\hat{y}$ and the signal provided by each replica y_i

Averaging Scheme based on a crossbar of switching resistive devices



Noise injectors based on diodes designed to work through avalanche breakdown

CONCLUSION

- Noise combined with degradation produces the DSR effect in highly replicated FT AD-AVG.

- Controllable noise added to each of the input replicas can improve the FT hardware yield under specific degradation conditions.