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Design Close to the Edge for Advanced Technology using Machine Learning & Brain-Inspired Algorithms

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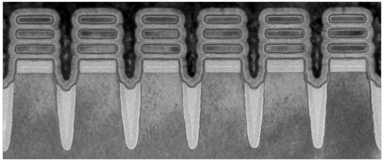
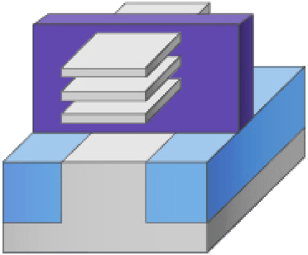
and Paul R. Genssler

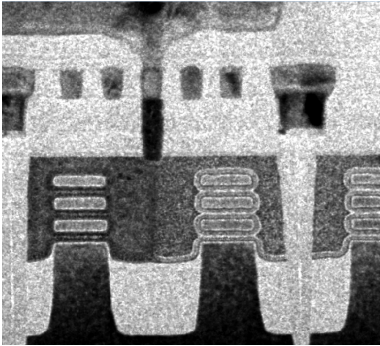
Scaling in Advanced Technology

- Transistor Technology close to fundamental limit
- TSMC 3 nm FinFET, 2 nm Nanosheet by IBM
- Less power, less area, higher clock speed, ...

→ But does your mobile run 30 % longer?







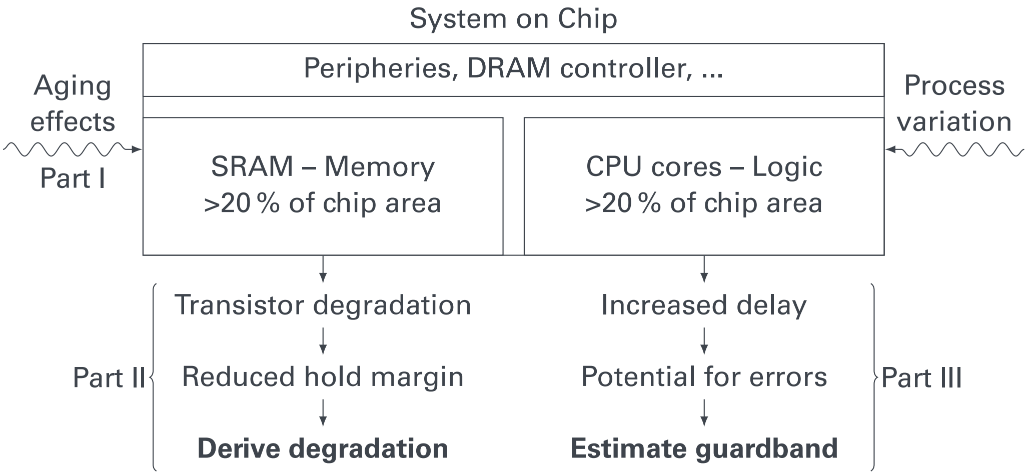
TSMC, ISSCC 2021; Samsung; IBM Research

Challenges with Advanced Technology

- Increased impact of degradation
- Increased variability due to quantum effects
- Increased demand for reliable chips
- SPICE simulations are expensive
- Assumption: Transistor model available
- Diminishing returns of scaling

➔ Move circuit design **close to the edge**

Our Multi-Level Approach



Background: Degradation

Design-time degradation

- key contributor: variation
- source: manufacturing
- Gaussian distribution
- constant over lifetime

Run-time degradation

- key contributor: aging (BTI, HCI)
- source: usage of circuit
- workload-dependent
- changes over lifetime

➔ change in electrical properties, most importantly ΔV_{th}

➔ **efficient guardband design** – small yet sufficient

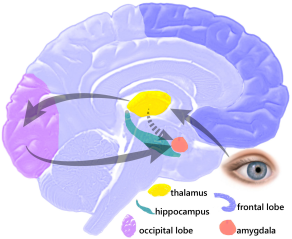
Background: Brain-Inspired Hyperdimensional Computing

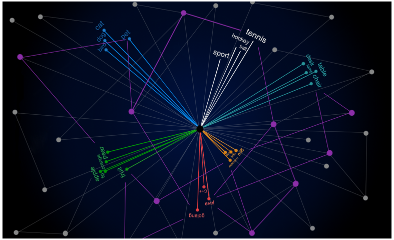
Human Brain

- Learning and pattern-based
- Distributed
- Embarrassingly parallel
- Unreliable Components

Hyperdimensional Computing

- Computing with patterns
- HD vectors as basic symbols
- Independent vector components
- Robust against failures





https://medium.com/dataseries/hyperdimensional-computing-and-its-role-in-ai-d6dc2828e6d6

Background: Concept of Hyperdimensional Vectors

- Random integer vectors A, B of dimension d
- Compute Cosine similarity $\cos(A, B)$
- Bundle multiple vectors as a set
- Bind vectors together

$$
\begin{array}{rcrrrr}
A & = & 0 & 1 & 0 & 1 \\
B & = & -1 & -1 & 1 & 1 \\
\hline
A \oplus B & = & -1 & 0 & 1 & 2
\end{array}
$$

Operation	Symbol	cos() with input	Implementation
Similarity	$\cos(A, B)$	–	Cosine similarity
Bundle	$A \oplus B$	0.7	component-wise addition
Bind	$A \otimes B$	0.0	component-wise multiplication
Permutation	$p(A)$	0.0	circular shift

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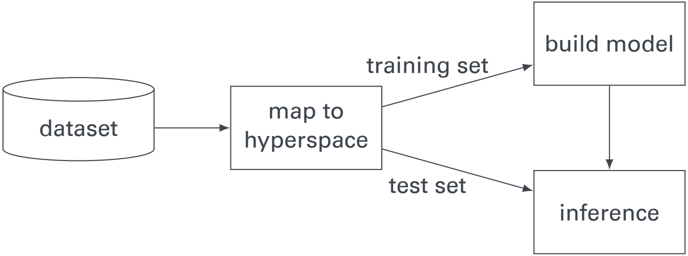
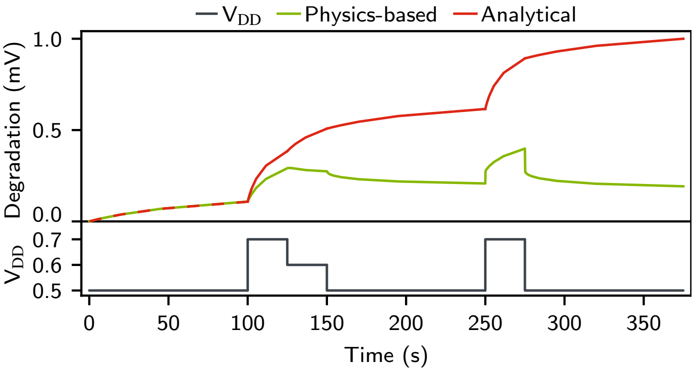
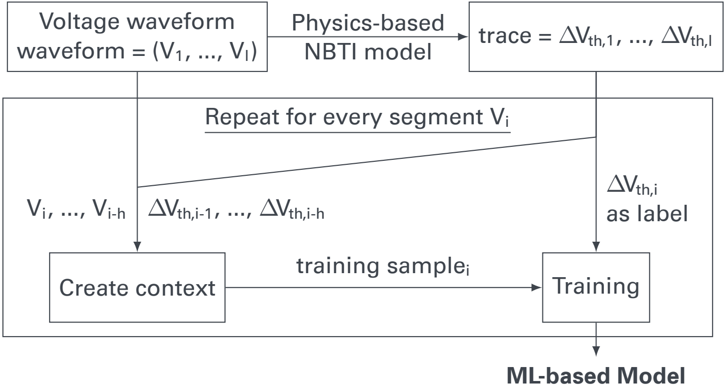


Part I: Brain-inspired Transistor Degradation Model

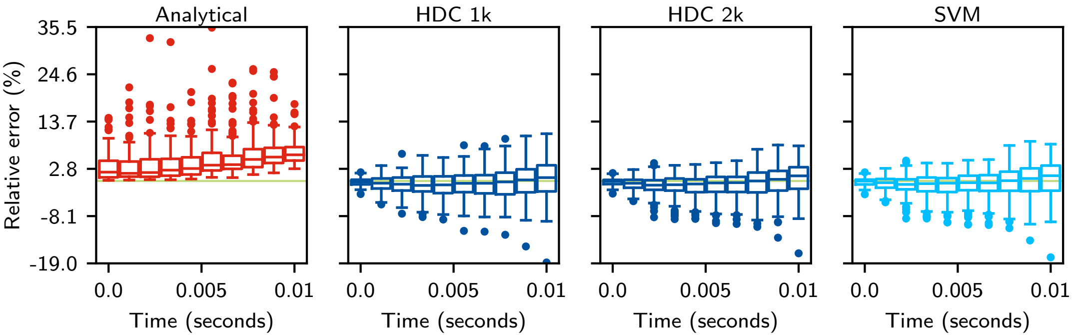
- Predict workload-dependent aging per transistor
- Created by foundry, utilized by circuit designers
- Solves confidentiality problem



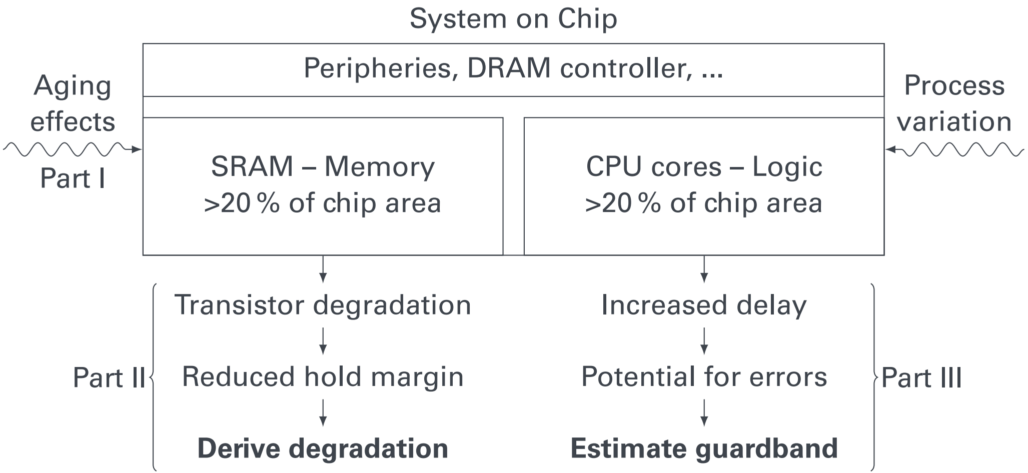
Creating a Brain-inspired Degradation Model



Results for Transistor Degradation Prediction

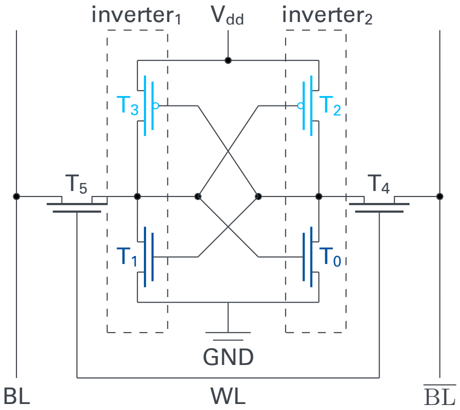


Our Multi-Level Approach



Part II: Noise Resiliency in SRAM

- Dominant on-chip memory
- Static noise margin (SNM)
- Measure "butterfly curve"
- Infer ΔV_{th} through SNM



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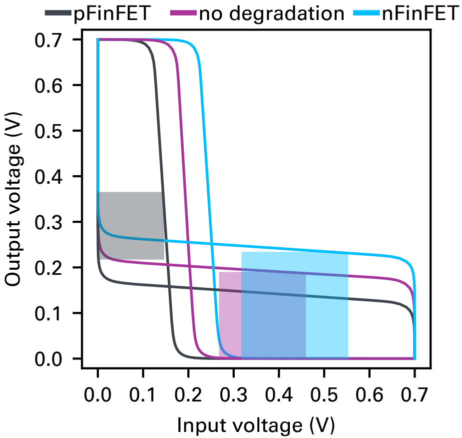
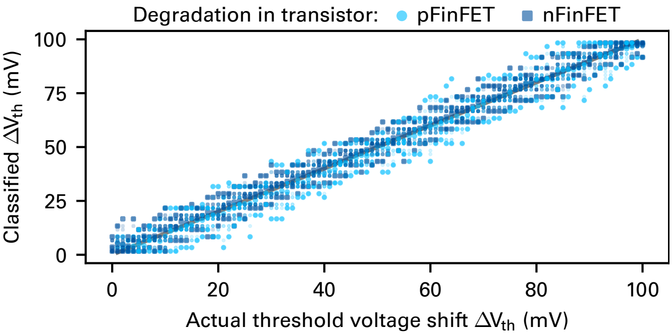


Inferring Degradation through SNM



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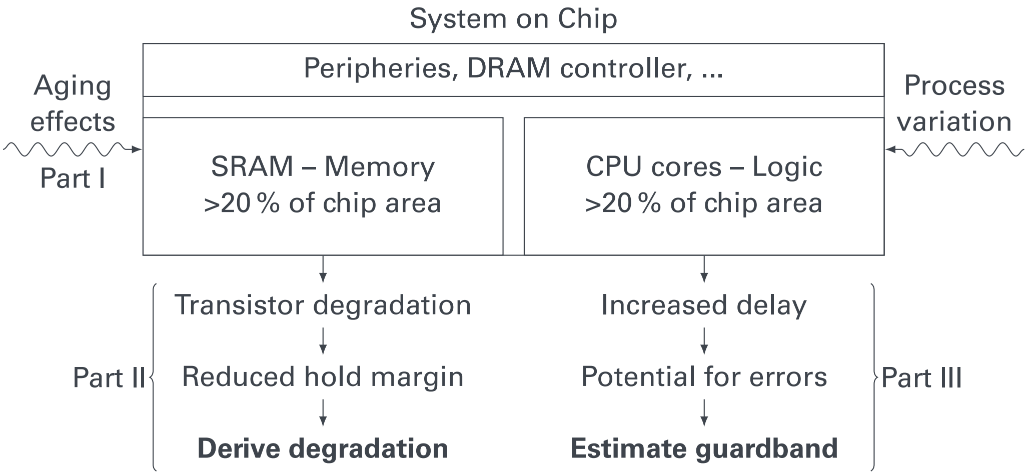
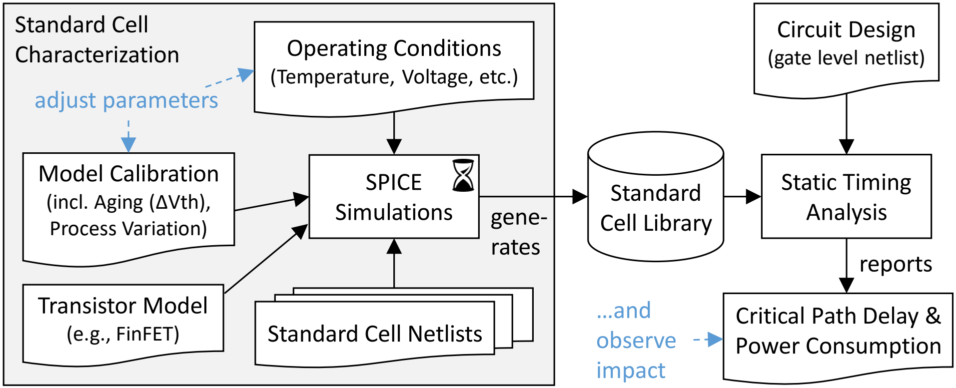
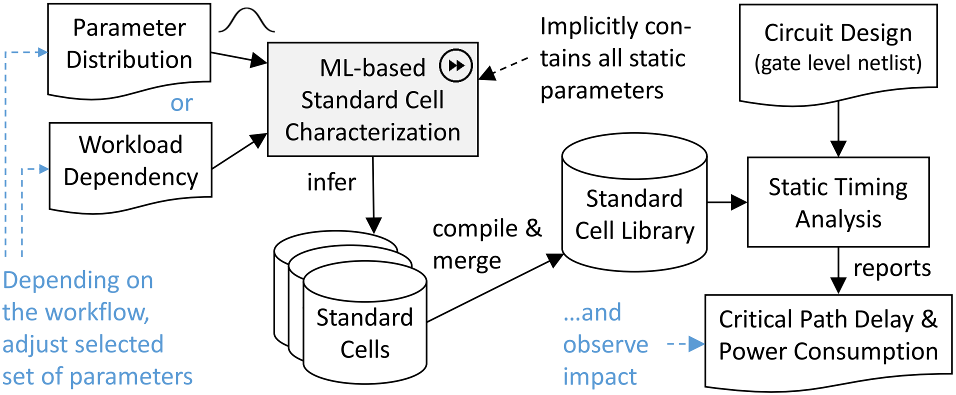


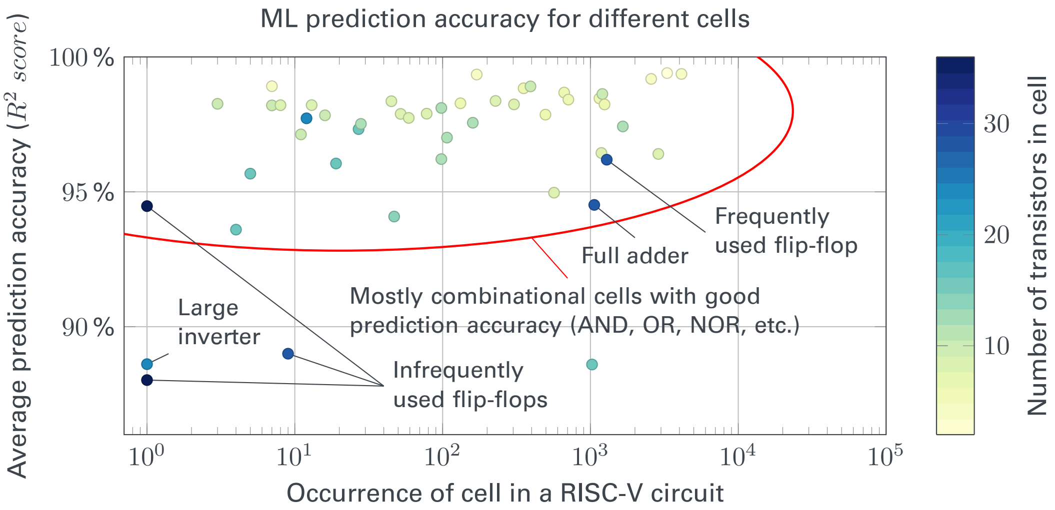
Part III: Cell Library Characterization - Traditional Approach



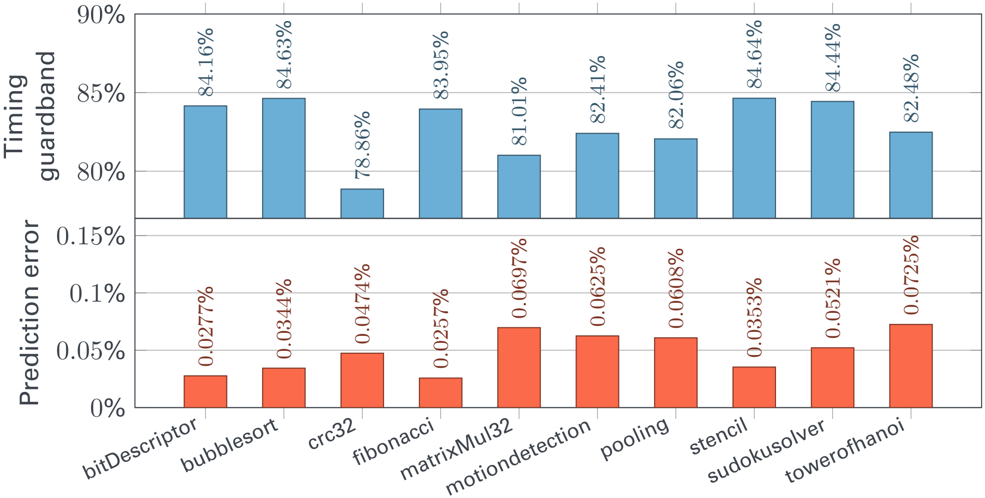
Our ML approach towards Cell Library Characterization



Prediction Results

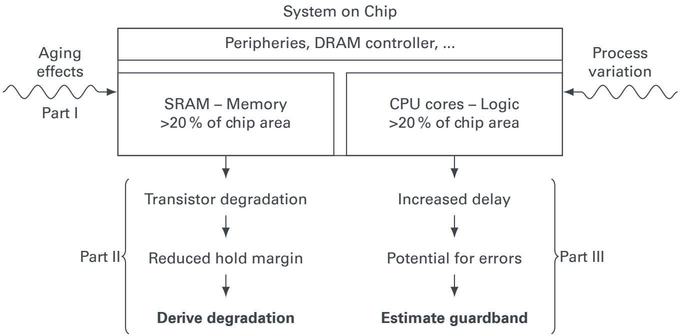


Achievable Timing Guardband Reduction

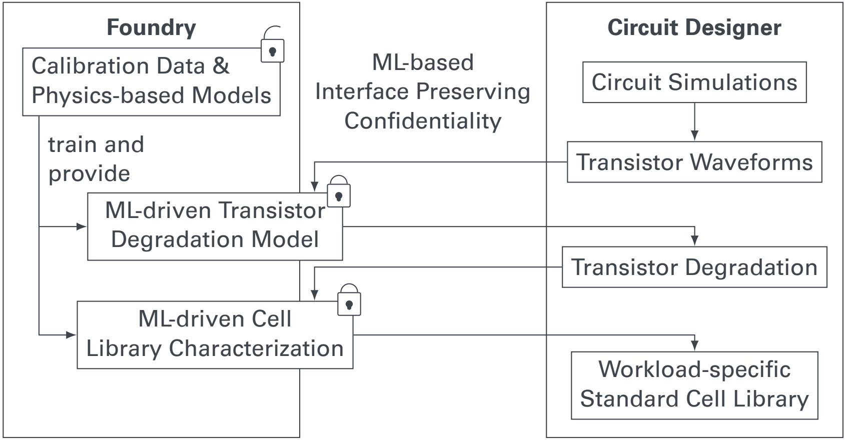


Summary

- Advanced technology challenges pessimistic workflow
- ML-based and brain-inspired methods for close-to-the-edge design



Perspective on ML-based Design Flow



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