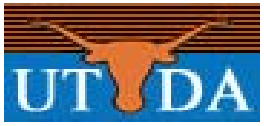

More Moore's Law through Computational Scaling -- and EDA's Role

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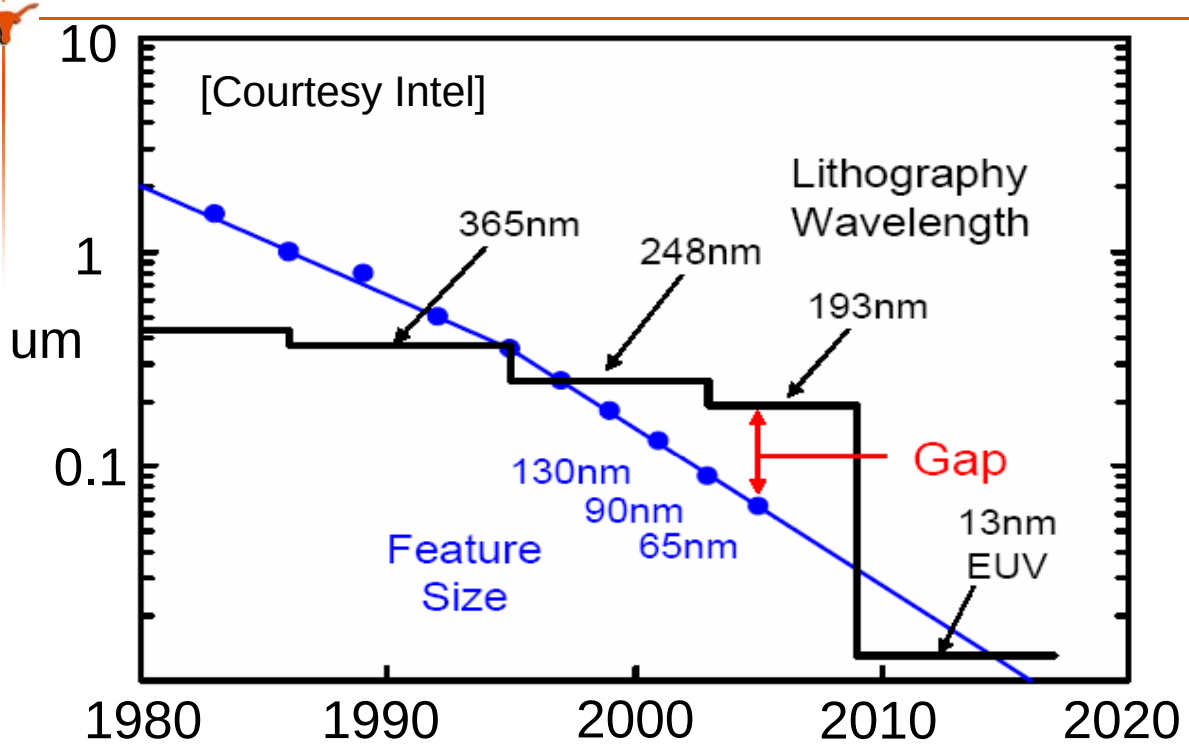
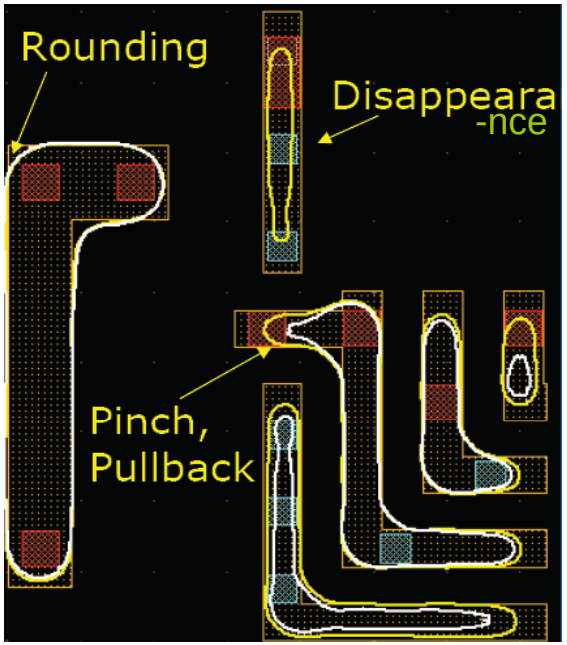
Scaling & Lithography Status

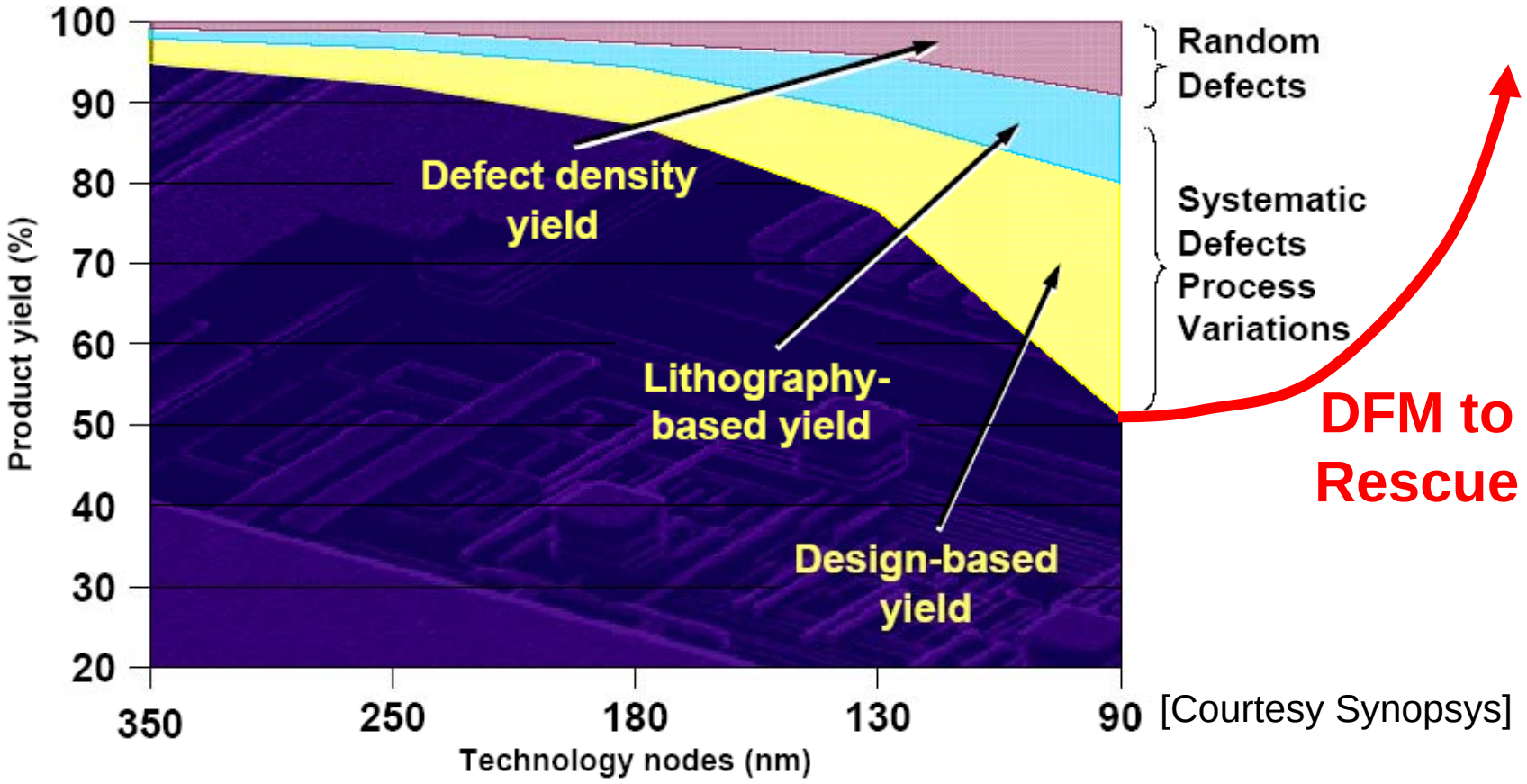




[Courtesy Intel, 2006]

- 193nm litho continues to push its limit
  - Immersion, extreme RET, DPL (Double Patterning Lithography)
- NGL - Next Generation Lithography, still next generation
  - Economical/material/technical challenges

A Famous (or Infamous?) Projection



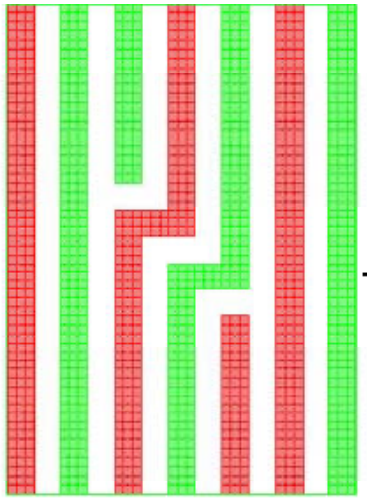
[Courtesy Synopsys]

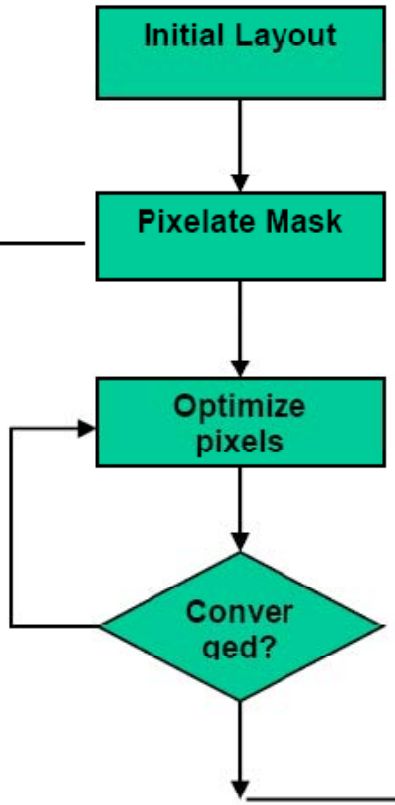
- Scaling, though challenged, still pushing!
- But more important role in computational scaling

Computational Scaling

- Not just by equipment advancement
- Computational scaling
  - Scaling enabled by massive computational power
  - Fast computers to help design faster computers
- Computational lithography for nanolithography systems
  - Computationally reverse-engineering
- Electronic design automation (EDA) eco-system to close the gaps
  - Synergistic Process-Layout-Circuit Co-Optimization
  - Parallel, multi-core, GPU, domain-specific, FPGA…

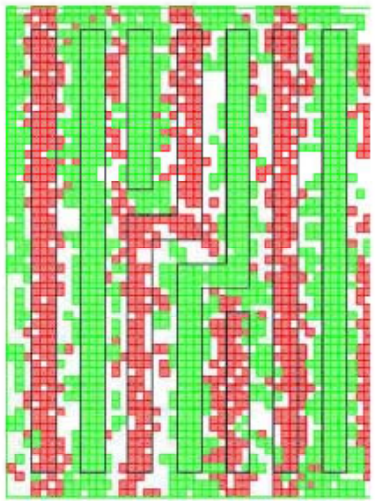
Computational Lithography





Intel's Pixelated Mask

[Singh+, SPIE'08)



- Other examples:
  - Variational litho-modeling [Yu+, DAC'06, JM3'07]
  - IBM: source mask optimization

Computational Nanolithography

- We do have massive computational power!
  - IBM BlueGene, Brion/ASMLTachyon (FPGA acceleration), Gauda (leveraging cheap GPU), …
- Make a trillion pixels dance [Singh+, SPIE'08]

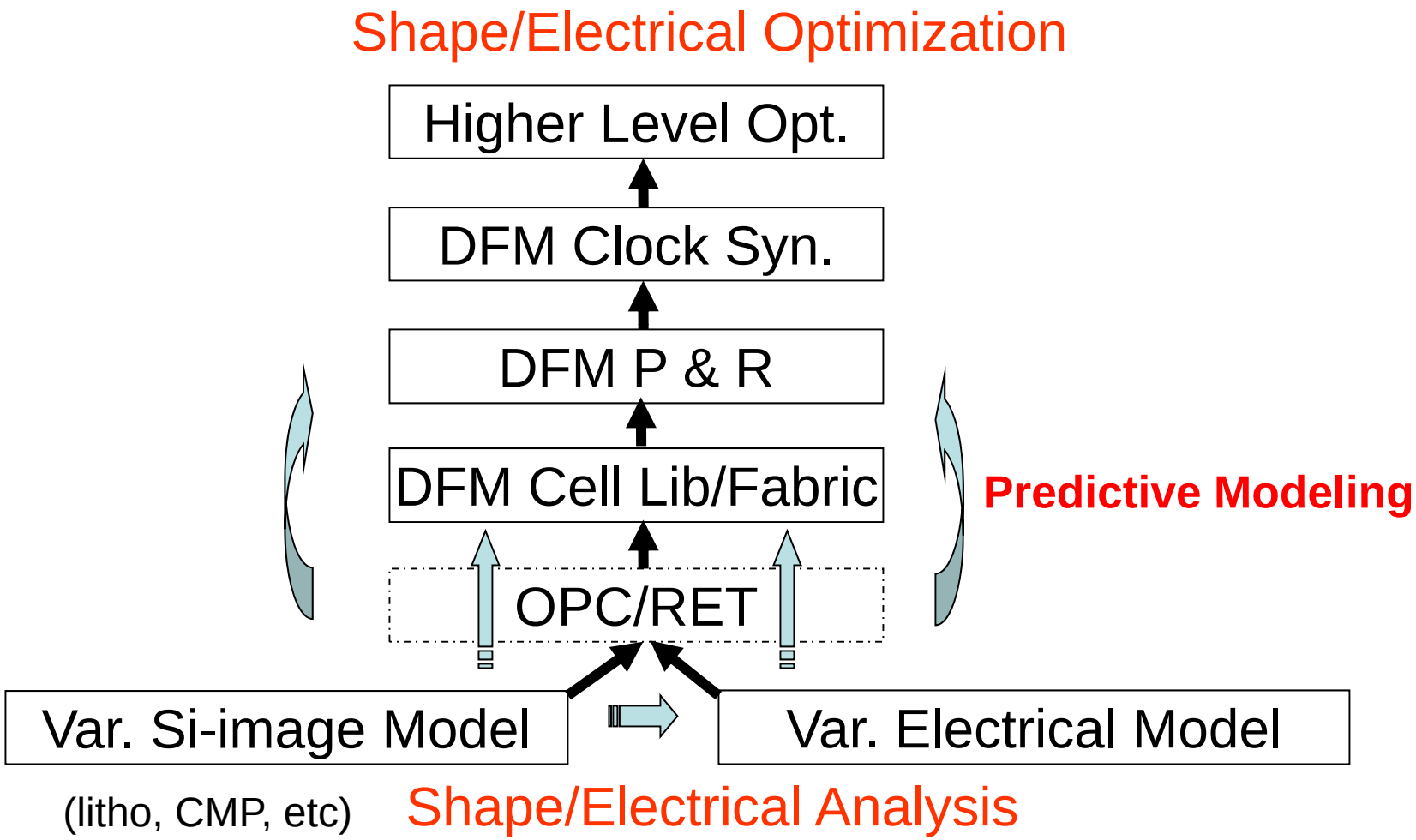
Still

There's Plenty of Room at the Bottom

- An Invitation to Enter a New Field of Physics

Richard P. Feynman, 1959

Synergistic Process-Layout-Ckt Co-Opt



Synergistic Optimizations

"Give me a lever, and I can optimize your billion transistor design." - EDA's Lever (model/rule)

Process Modeling

- How complicated?

$$I_I(x_1, y_1) = \iint\iint J_0(x_0 - x_0', y_0 - y_0') F(x_0, y_0) F^*(x_0', y_0') \times K(x_1 - x_0, y_1 - y_0) K^*(x_1 - x_0', y_1 - y_0') dx_0 dy_0 dx_0' dy_0'$$

Litho model: Hopkins eqn

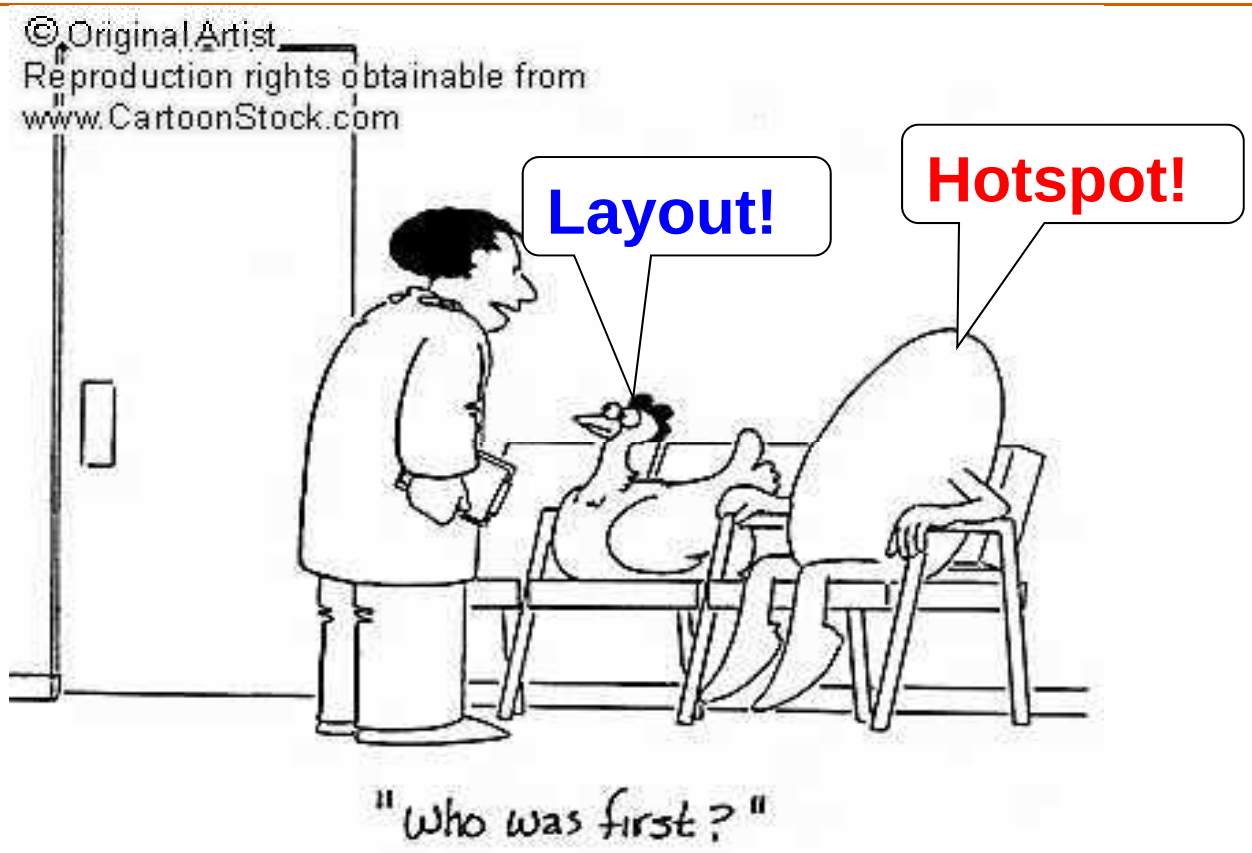
- or simple can it be?

$$Cu\_Thickness = \alpha * (1 - \frac{Metal\_density^2}{\beta})$$

CMP model: [Cho+, ICCAD'06]

- Key Issues:
  - Accuracy vs. Fidelity (Elmore-like)
  - Design-oriented vs. process-oriented

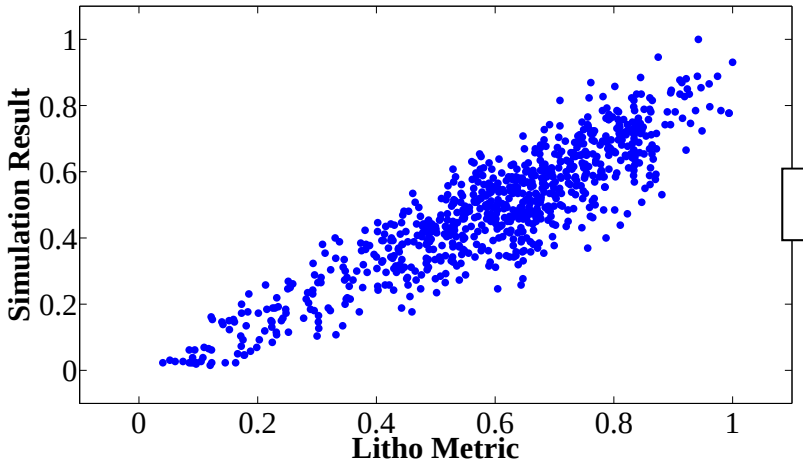
Prediction & Prescription



- **Prediction: e.g., statistical modeling [Cho+, DAC'08], machine learning [Ding+, ICICDT'09]**
- **Prescription: only work with patterns that are printable**

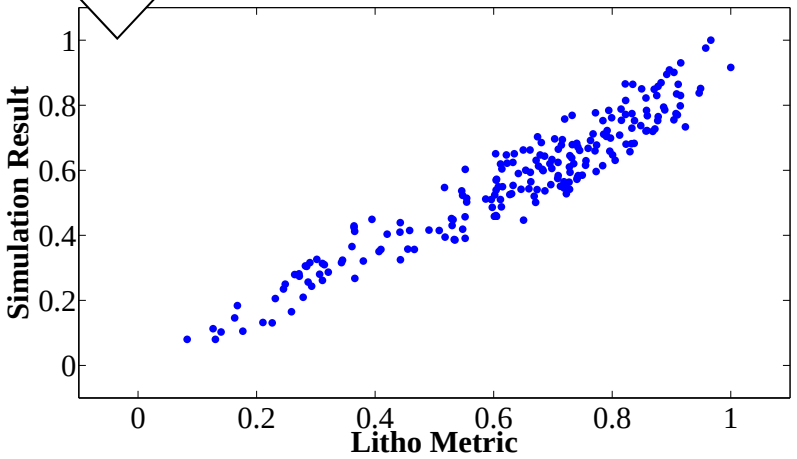
E.g., Post-OPC Predictive Modeling

[Cho+, DAC'08]



R=0.90, 16x16um²

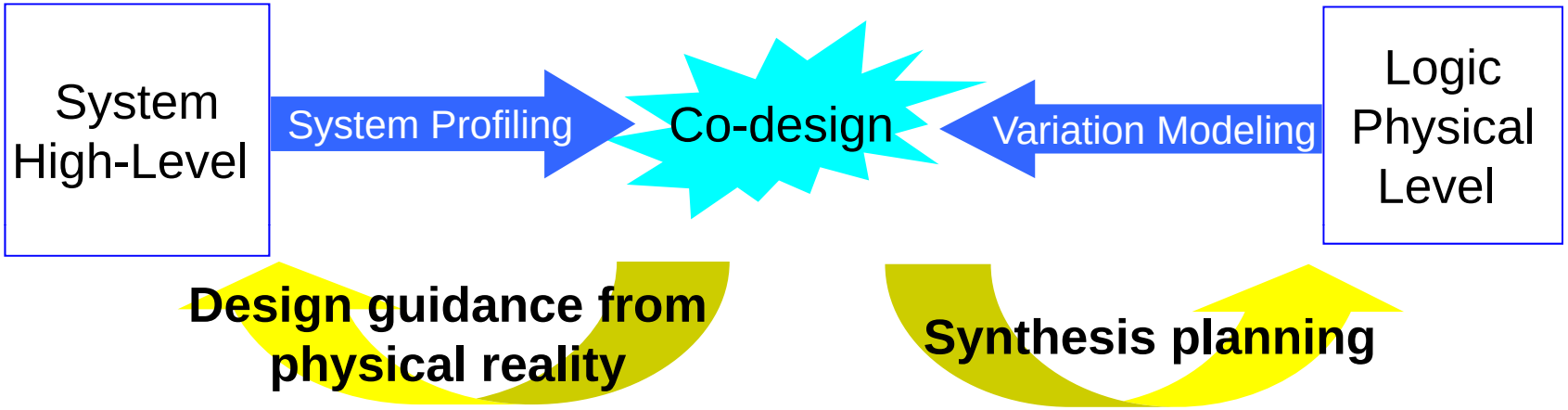
Higher correlation in more macro level,



R=0.95, 32x32um²

- **Very high macro-level fidelity**

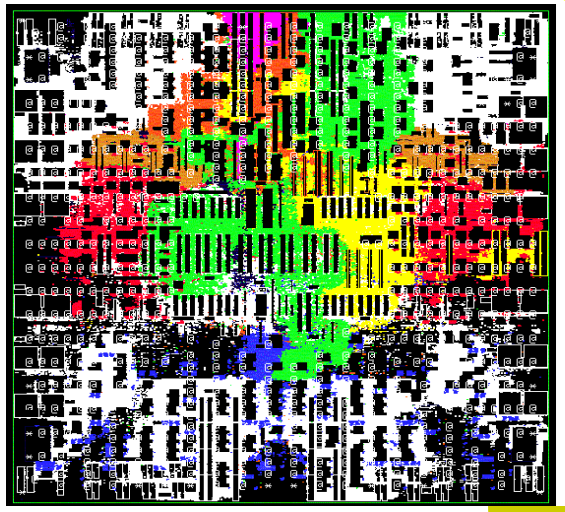
Moving Up: System/High-Level and Logic/Physical-Level Co-design

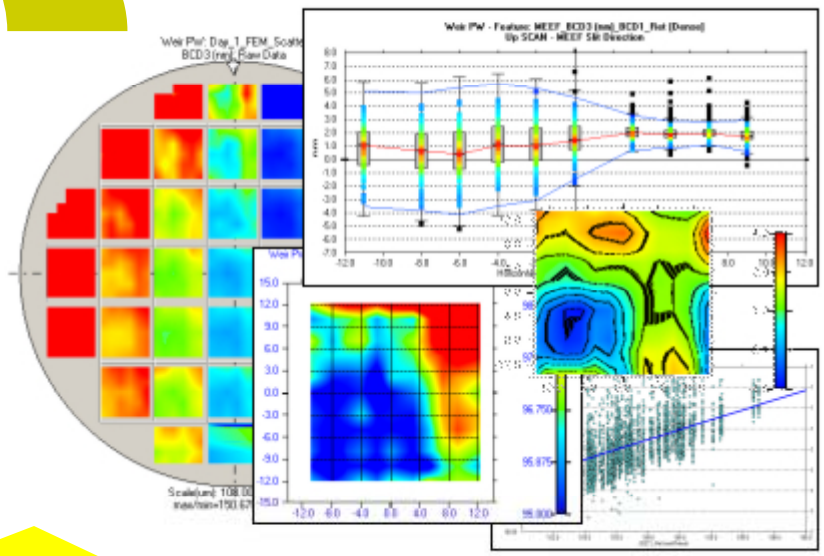


- Variation budgeting with system-level profiling

Moving Down: Design for Equipment

Equipment Characteristics



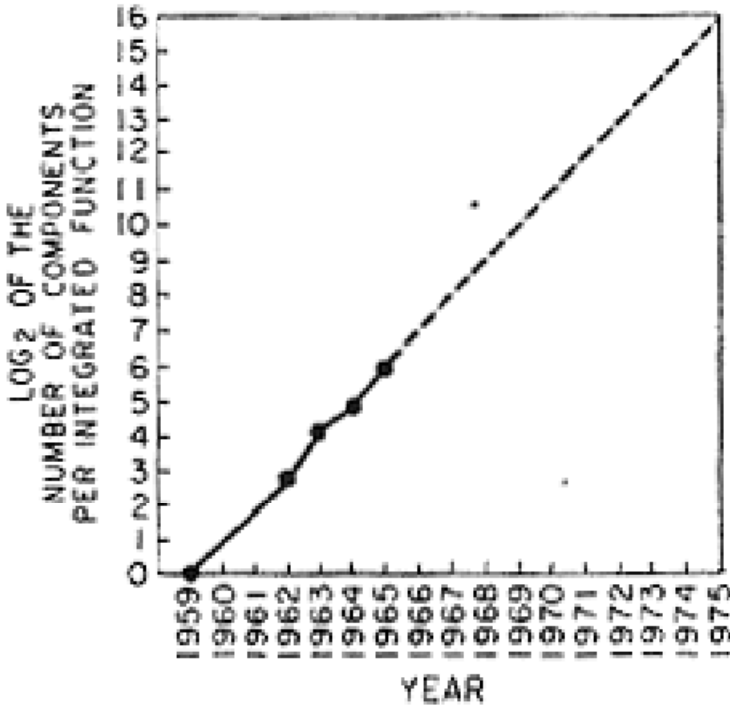


Tunable Parameters

- Timing optimization using ASML dose mapper [Jeong, Kahng+ DAC'08]
- Combine DFM and APC (advanced process control) [Pan+, JPC'08]

The Moore, The Better

- There is still plenty of life for Moore's Law
- **Bigger role of Computational Scaling and EDA** to extend the Moore's Law



[Moore 1965]

- **NO EXPONENTIAL IS FOREVER…**
- **BUT**
- **WE CAN DELAY "FOREVER"**

Moore's Law Amendment [Moore 2003]