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

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Scaling & Lithography Status

- 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
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

Other examples:

› Variational litho-modeling [Yu+, DAC’06, JM3’07]
› IBM: source mask optimization

Intel’s Pixelated Mask
[Singh+, SPIE’08]
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

Shape/Electrical Optimization

- DFM Clock Syn.
- DFM P & R
- DFM Cell Lib/Fabric
- OPC/RET

Predictive Modeling

- Var. Si-image Model
- Var. Electrical Model

(litho, CMP, etc)

Shape/Electrical Analysis
Synergistic Optimizations

“Give me a lever, and I can optimize your billion transistor design.” - EDA’s Lever (model/rule)
Process Modeling

♦ How complicated?

\[ I_I(x_1, y_1) = \iiint J_0(x_0 - x'_0, y_0 - y'_0) F(x_0, y_0) F^*(x'_0, y'_0) \times K(x_1 - x_0, y_1 - y_0) K^*(x'_1 - x'_0, y'_1 - y'_0) dx_0 dy_0 dx'_0 dy'_0 \]

Litho model: Hopkins eqn

♦ or simple can it be?

\[ Cu\_Thickness = \alpha \ast (1 - \frac{\text{Metal}\_density^2}{\beta}) \]

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]

Higher correlation in more macro level,

\[ R = 0.90, \text{16x16um}^2 \]

\[ R = 0.95, \text{32x32um}^2 \]

*Very high macro-level fidelity*
Moving Up: System/High-Level and Logic/Physical-Level Co-design

- System profiling
- Co-design
- Variation modeling

- Design guidance from physical reality
- Synthesis planning

- Variation budgeting with system-level profiling
Moving Down: Design for Equipment

Equipment Characteristics

- Timing optimization using ASML dose mapper [Jeong, Kahng+ DAC’08]
- Combine DFM and APC (advanced process control) [Pan+, JPC’08]
There is still plenty of life for Moore’s Law
Bigger role of Computational Scaling and EDA to extend the Moore’s Law

NO EXPONENTIAL IS FOREVER…
BUT
WE CAN DELAY “FOREVER”

Moore’s Law Amendment [Moore 2003]

[Moore 1965]