Mathematics and Engineering: A Clash Of Cultures?

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... all of IBM Research
Straw poll
Decision point

- Talk 1: for a preponderance of mathematicians
- Talk 2: for a preponderance of engineers
Outline

- Integrated circuit design methodology
  - a series of optimization steps!
- Paradise for formal mathematical algorithms? No!
- Barriers to making better use of mathematics in chip design methodology
  - characteristics of the problems to be solved
  - mess vs. elegance, practical vs. theoretical
  - people issues: biases and cultural traits
- Elegant or not, mathematical or not, chip design will march on!
- The evolution of a new species: the “mingineer”
  - mingineer traits
- Opportunities looking ahead
Chip design methodology

High-level design → Logic design → Floor-planning → Circuit design

Test → Manufacturing → Routing → Layout

High-level design → Test → Manufacturin → Routing → Layout

High-level design → Logic design → Circuit design → Manufacturin → Routing

High-level design → Logic design → Floor-planning → Layout
Recent trends
Mathematical optimizers’ paradise?
Or wishful thinking?

That’s the most irrational thing I’ve heard...

You’re dual degenerate!!!
Increasing and inevitable variability

249,403,263 Si atoms, 68,743 donors, 13,042 acceptors

*D. J. Frank et al, Symp. VLSI Tech., 1999

Litho-induced variability

Random dopant effects

Oxide thickness

Interconnect CMP effects
End of scaling means more tool opportunities!

Is this worth a huge investment?
Barriers to use of math. methods in chip design

- **Problem types**
  - n-p or #p complete problems
  - “messy” problems

- **Theoretical vs. practical, messy vs. elegant**

- **Biases and cultural traits?**
  - different languages
  - different priorities
  - different approaches
  - different software techniques
  - different conferences and journals
## Deft definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Engineer</th>
<th>Mathematician</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimum</td>
<td>“Good enough”</td>
<td>“The one and only best solution”</td>
</tr>
<tr>
<td>Optimal</td>
<td>“The best that I can do”</td>
<td>“The best solution in an irrelevantly small neighborhood”</td>
</tr>
<tr>
<td>Global convergence</td>
<td>“Global optimum, right?”</td>
<td>“Local optimum, starting from anywhere”</td>
</tr>
<tr>
<td>Numerical noise</td>
<td>“Part of life”</td>
<td>“Irrelevant”</td>
</tr>
<tr>
<td>Finite-precision arithmetic</td>
<td>“Death, taxes and finite-precision”</td>
<td>“Irrelevant”</td>
</tr>
</tbody>
</table>
The human side of optimization

- “I’ve been designing circuits for 20 years; surely I can do better than a machine!”

- The problem of tacit constraints

- What optimization promises
  - a shift to a higher level of thinking
  - automation of grunt work
  - more productive design
  - faster/smaller/smarter designs
Software techniques... the “other” language problem

- C++ vs. Fortran
- DLLs vs. static linking
- Slave vs. master
- Scripting: Tcl or Perl
- APIs vs. tokenized files
- Throw-away code
- “Output” and reports – relevance of slack variables, for example
Case study: transistor sizing

- **Convergence**
  - whose fault is it?
- **Mixed integer/discrete problems**
  - fingers
  - low and high $V_t$
  - pin swapping
- **What is the objective function?**
- **4th version... and counting?**
- **When is a project complete?**
Visualization example

Courtesy of Phillip Restle
Visualization example #2

Red = critical
Green = non-critical
Curvature = sensitivity
Thickness = transistor size

Delay

Logic stages

Pls by criticality

Time

Gate
Power4 clock distribution visualization

Clock Grid

- Tuned wiring trees
- Buffer level 4
- Buffer level 3
- Buffer level 2
- Clock source
- Loads

Courtesy of Phillip Restle
Error found through visualization

- Significant delays noticed “between” wires
- Via resistances calculated wrong (~10X)
Errors found through visualization

- Summary of 3 common errors in one voltage/current animation

- Missing Vias
- Floating Wire
- Vdd-Gnd short (high resistance)
Other issues

- Good move – bad move – 2-step updating!
- (In)significance of asymptotics
- Mathematics is a grand unifier across disciplines and fields
- Mixed discrete/continuous problems are ubiquitous
- Even if only small problems can be solved formally, they can be used to calibrate heuristics
  - example: synthetic benchmarks with known optimal solutions
- Preconditioners are a good example of a combination of engineering intuition and mathematical rigor
- The penchant for using simulated annealing and genetic algorithms
Chip design: a juggernaut (theory is behind practice!)
Evolution of a new species: the “mingineer”

- Applied mathematicians
- Engineers
- “Curious” engineers
Traits of a “mingineer” from the engineering side

- Not scared of equations
- Well-versed in basic mathematical methods
- Willing to dig into mathematical literature and at home in mathematics conferences
- Can “abstract” the problem at hand and hold a conversation with mathematicians
- Interested in “general solutions” rather than heuristics and hacks and band-aids
- Under no illusions about his/her limitations
- Has fewer tacit requirements
- Willing to take a sabbatical in a mathematics department
Traits of a “mingineer” from the mathematics side

- Patient
- Willing to “get his/her hands dirty”
- Practical
- Willing to dig into engineering literature/conferences
- Can translate mathematical statements into a language understandable by engineers
- Software-savvy
- Willing to compromise research goals to achieve engineering success
- Under no illusions about his/her limitations
- Willing to take a sabbatical in an engineering department
Conclusions

- Chip design is a series of optimization tasks
- The penetration of mathematical algorithms in mainstream design automation and chip design methodology is negligible thus far
- Part of the reason is that we don’t have enough people with mingineering skills
  - cultural and other biases must be overcome
- Huge potential if we are successful
Some inspiration

- “Do not worry about your difficulties in mathematics, I assure you that mine are greater.”
- “As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality.”
- “God does not care about our mathematical difficulties. He integrates empirically.”
- “Since the mathematicians have invaded the theory of relativity, I do not understand it myself anymore.”