Geostatistical-Inspired Metamodeling and Optimization of Nano-CMOS Circuits

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Outline of the talk

- Background and Motivation
- Related Prior Research
- Thermal Sensors
- Proposed Design Optimization Flow Methodology
- Experimental Results
- Conclusions and Future Research Directions

Issues in NanoCMOS Design

- Expensive Computer Simulations
- Pronounced effects of process variations in deep nanometer regions
  - Increase in design parameters
  - Current modeling techniques unable to capture effects of process variation

Background and Motivation

- Complex and High density designs
- Design for low power consumption
- Reliability issues
  - Thermal monitoring

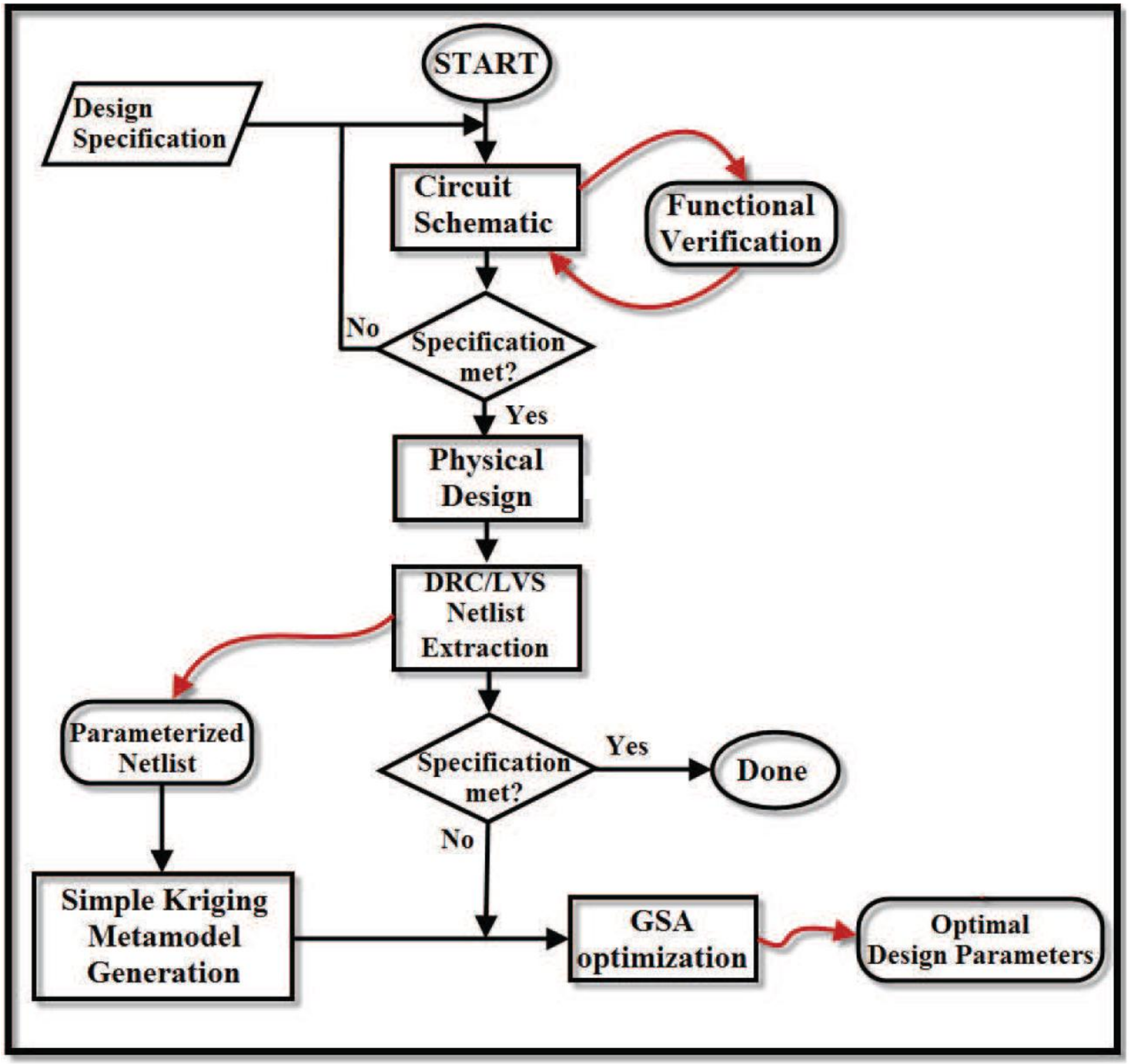
Novel Contributions

- Design flow methodology with geostatistical based metamodeling (kriging) and Gravitational Search algorithms (GSA) for nano-CMOS design optimization
- Implementation of GSA for nano-CMOS designs
- 45nm Thermal sensor designs

Prior Related Research

- Exploration of optimization algorithms for NanoCMOS designs
  - Simulated annealing, swarm intelligence
- Efficient designs for thermal sensors
- Kriging based metamodels
  - O. Okobiah --- Ordinary and Simple kriging metamodels
  - G. Yu ---- Re-iterative pareto fronts
  - H. You --- Kriging metamodels

Proposed Design Flow Diagram



Kriging Fundamentals

- Kriging Fundamentals
  - Originally used in geostatics fields for mining purposes

$$y(\mathbf{x_0}) = \sum_{j=1}^{L} \lambda_j B_j(\mathbf{x}) + z(\mathbf{x})$$

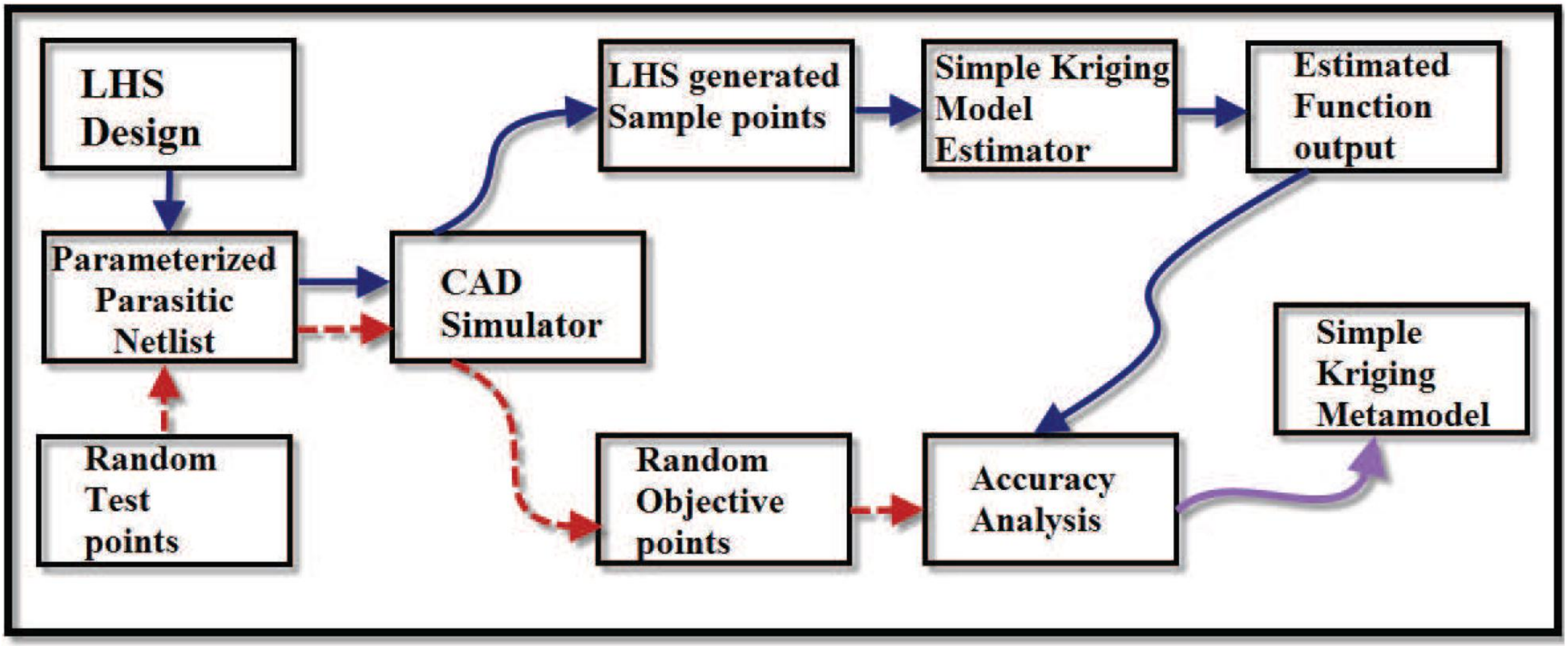
  - Each point is predicted with a set of unique weights (λ_j)

Kriging Fundamentals: Ordinary Versus Simple

- Simple kriging assumes a known and local mean while ordinary kriging assumes a constant but unknown mean
- Ordinary kriging weights are biased,

$$\sum_{j=1}^{n} \lambda j = 1$$

Simple Kriging Metamodel Generation



Gravitational Search Algorithm …

- Part of Swarm Intelligence family
  - population based heuristic algorithms
- Based on gravitational laws of attraction and motion

$$F_{ij}^{d}(t) = G(t)\left(\frac{M_{pi}(t) \times M_{aj}(t)}{R_{ij}(t) + \epsilon}\right)\left(x_j^d(t) - x_i^d(t)\right)$$

  - Where $F^{d}_{ij}(t)$ is design objective, M is the qualitiy of solution at search location i or j, x_i is the set of design parameters at location i

Gravitational Search Algorithm

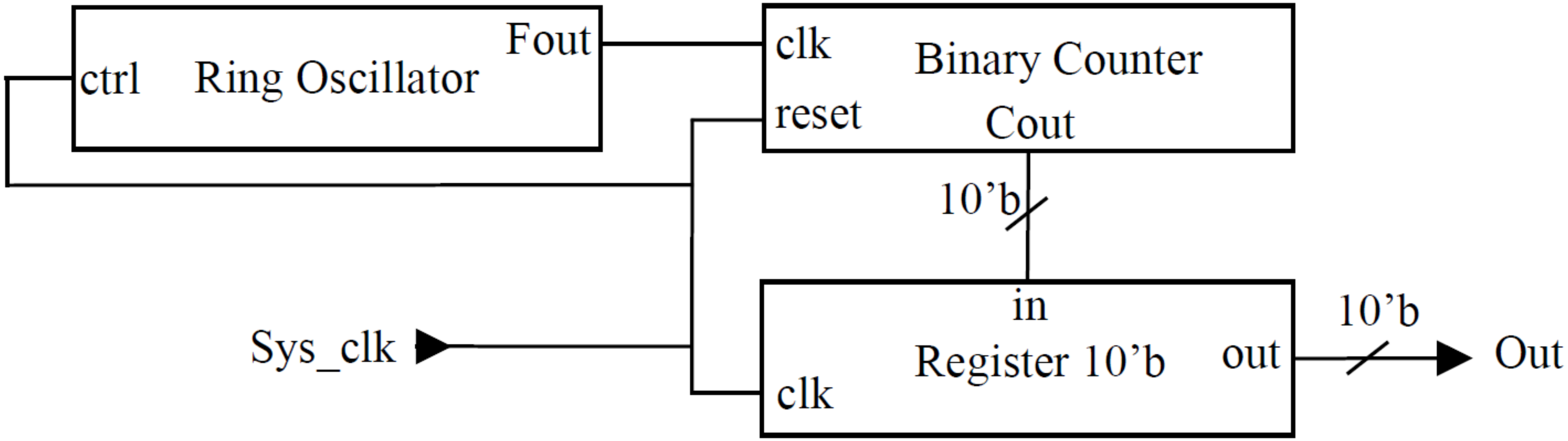
- Basic principles...
  - Heavier masses which correspond to better solutions attract search agents with poor solutions
  - Lighter masses move faster randomly -- exploring the search space
  - Heavier masses move slowly exploiting possible optimal locations

Gravitational Search Algorithm

Algorithm 1 Proposed Gravitational Search.

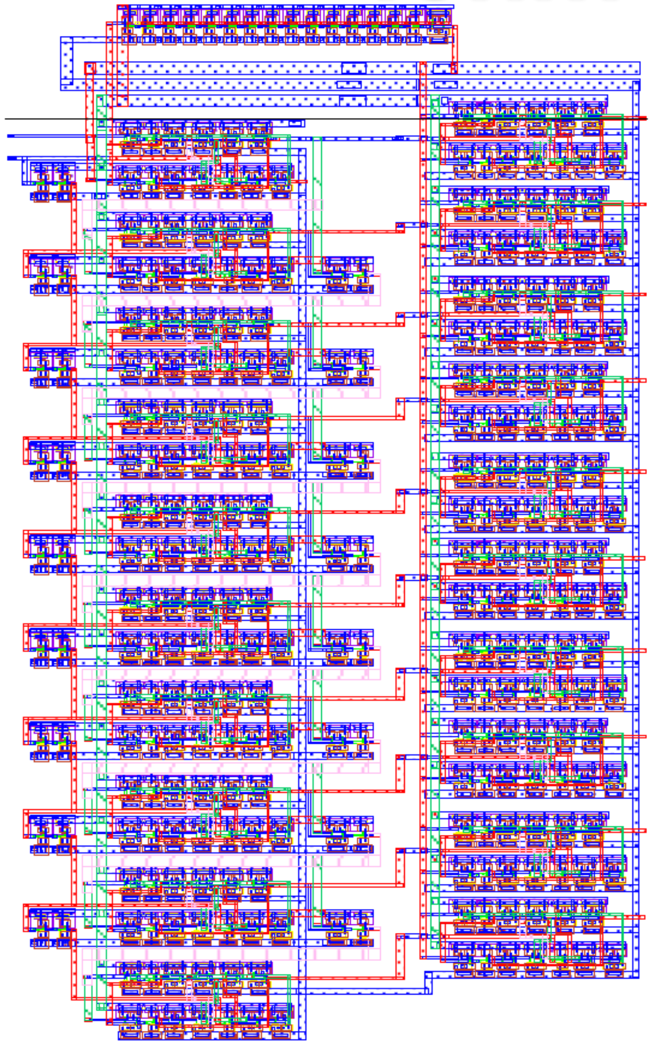
Initialize iteration counter: $counter \leftarrow 0$.
Initialize max iteration Max_{iter}.
Initialize number of search agents η gravity constant G, and velocity ν.
Generate η random search nodes (design parameter sets).
Consider the objective of interest Power_{TS_i}.
$counter \leftarrow max\_Iteration$.
while $(counter < Max_{iter})$ **do**
  Evaluate objective of interest (Power_{TS_i}) for each search node.
  Update best and worst solution per function objective.
  Update the gravity constant G.
  Calculate M and a for each search node.
  Update ν for each search node.
  Update search nodes by applying velocity on M.
  $counter \leftarrow counter + 1$.
end while
return $bestsolution$.

Experimental Results: 45nm Thermal Sensor

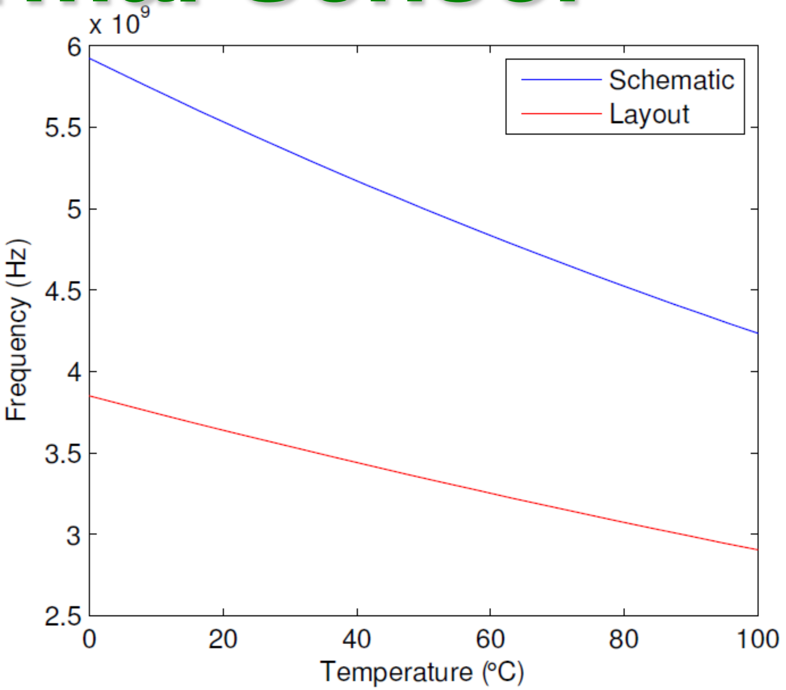


- Ring Oscillators for sensing
- Binary Counter
- Register

45nm Thermal Sensor



45nm thermal sensor physical design



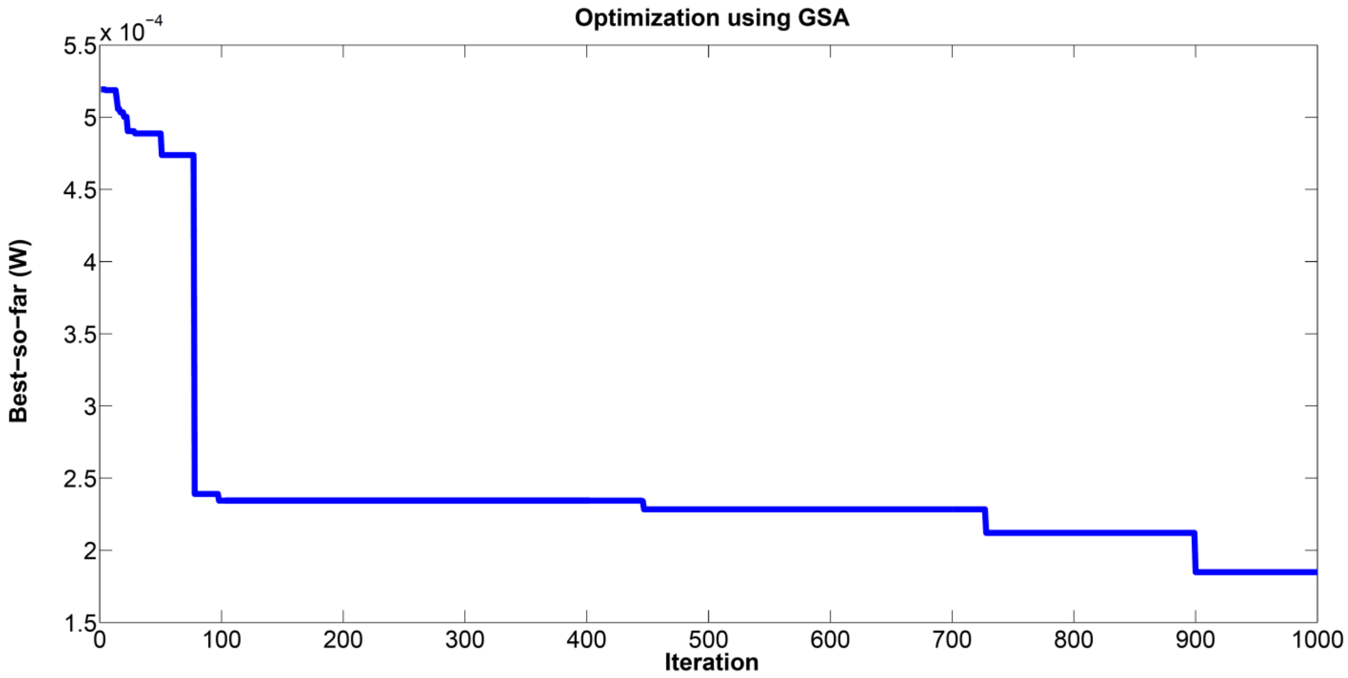
Frequency response vs temperature for 45nm thermal sensor

Design	Avg Pwr	Sensitivity	Area
Schematic	293.1µW	16.88MHz/°C	-
Layout	379.4µW	9.42MHz/°C	1221.37µm^2
% Change	+29%	-44%	

Experimental Results

Accuracy Analysis of Simple Kriging Metamodel

Metric	Value
MSE	4.36×10^{-18}
RMSE	2.09×10^{-09}
R_2	0.9934



Optimal Design Results

Design	Average Power	Sensitivity	Area
Schematic	293.1µW	16.88MHz/°C	-
Layout	379.4µW	9.42MHz/°C	1221.37µm^2
Final	+29%	9.42MHz/°C	1770.98µm^2*
% Change	36.9%	44.2%	45%*

Conclusions

- A novel design flow methodology incorporating simple kriging and GSA was presented.
- Average power consumption was reduced by 36.9%
- Reduced design space exploration by 90%
- Current techniques will be explored for process variation effects and statistical optimization.

Thank you !!!