Integrated Systems Engineering
Development, Modeling, and Optimization of Microelectronic Processes, Devices, Circuits, and Systems

Automatic BSIM3/4 Model Parameter Extraction with Penalty Function

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Outline

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- Extraction Approach
- Objective Function
- Penalty Functions
- Auto-Selection of Binning Parameters
- Experimental Results
- Summary

Introduction

- Difficulties of Traditional Extraction Approach
  - Poor convergence
  - Complicated extraction strategy
  - Need human interactions
  - Time consuming
- Solution: Extraction with optimization techniques

Extraction Approach

- Reliable optimization algorithm
  - Quasi-newton
- Objective function with penalties
- Sequence of extraction steps
  - Initial guess
  - Full optimization
  - Auto-selection of binning parameters procedure

Objective Function

$$F(X) = \sum_{devices} \sum_{curves} \left\{ \left(\frac{Id_{meas} - Id_{sim}}{Id_{meas}} \right)^2 + \Psi(P) \right\}$$

Penalty Function

$$\Psi(P) = \begin{cases} 0 & P \in feasible\ space \\ \sum_i \psi(P_i) & P \notin feasible\ space \end{cases}$$

P_i – parameter or intrinsic variable of the model

Penalty function guarantees physically correct parameters.

Example of Penalty Function

Mobility model for mobMod=2 (BSIM3)

$$\mu_{eff} = \frac{\mu_0}{1 + P_\mu}$$

$$P_\mu = \left(U_A + U_C \cdot Vbs_{eff}\right)\left(\frac{Vgs_{eff}}{Tox}\right) + U_B \cdot \left(\frac{Vgs_{eff}}{Tox}\right)^2$$

P_μ - Function of more than 100 model parameters

BSIM3 Constraint

$$P_\mu > -0.8$$

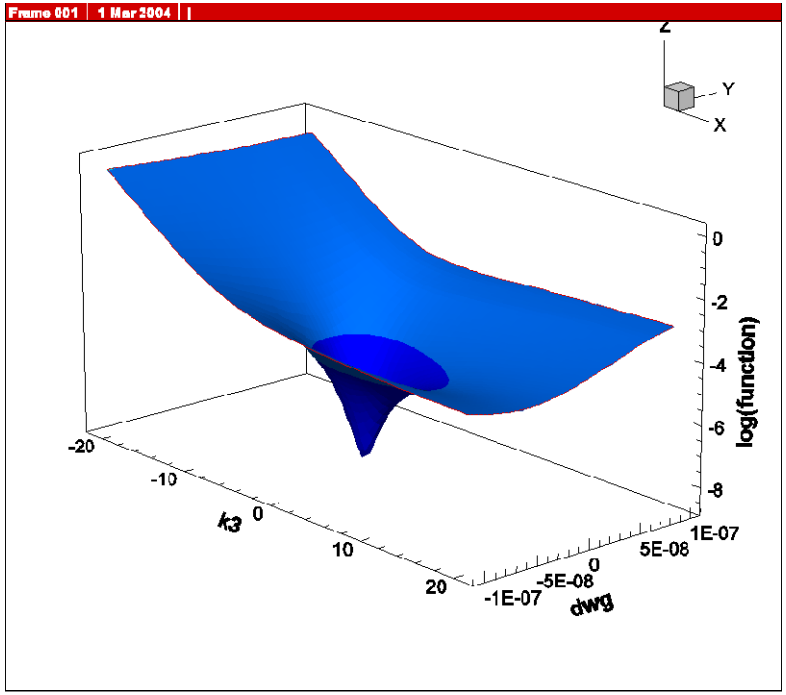
Penalty Function

$$\psi\left(P_\mu\right) = \begin{cases} 0 & P_\mu > -0.8 \\ \left(0.8 + P_\mu\right)^2 & P_\mu \le -0.8 \end{cases}$$

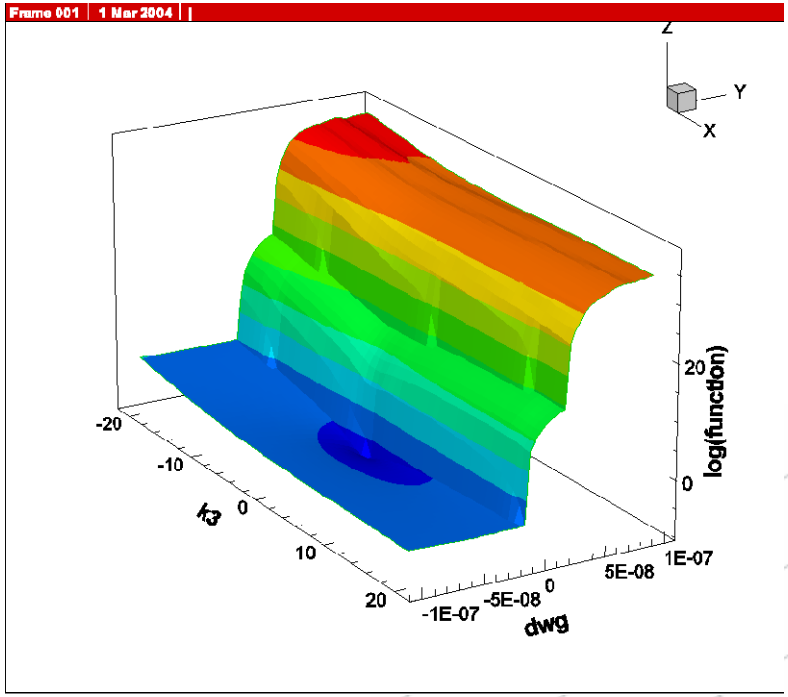
Objective Function Surface Plot, BSIM3

k3-dwg Surface Plot

No penalties

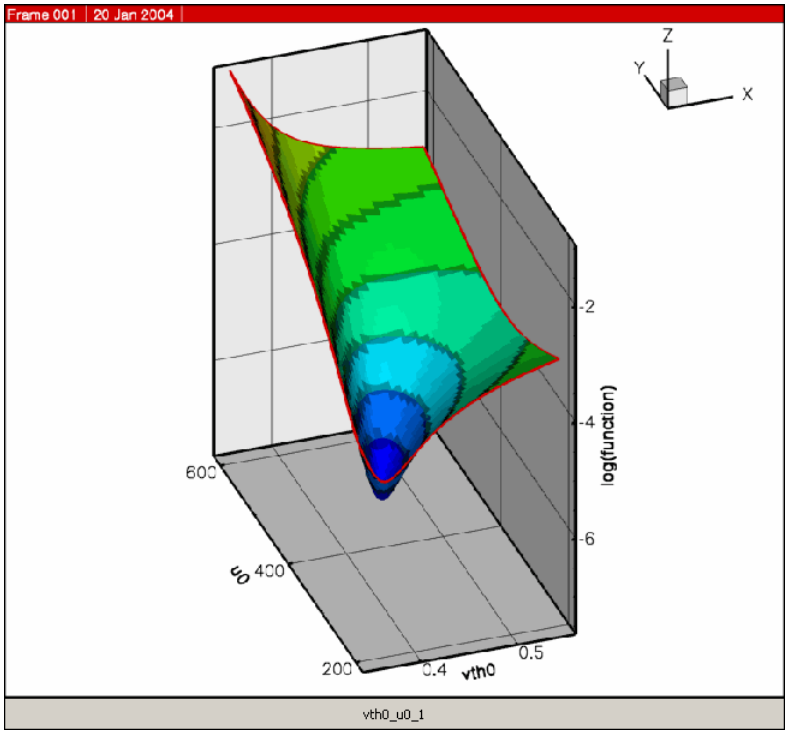


With Penalties



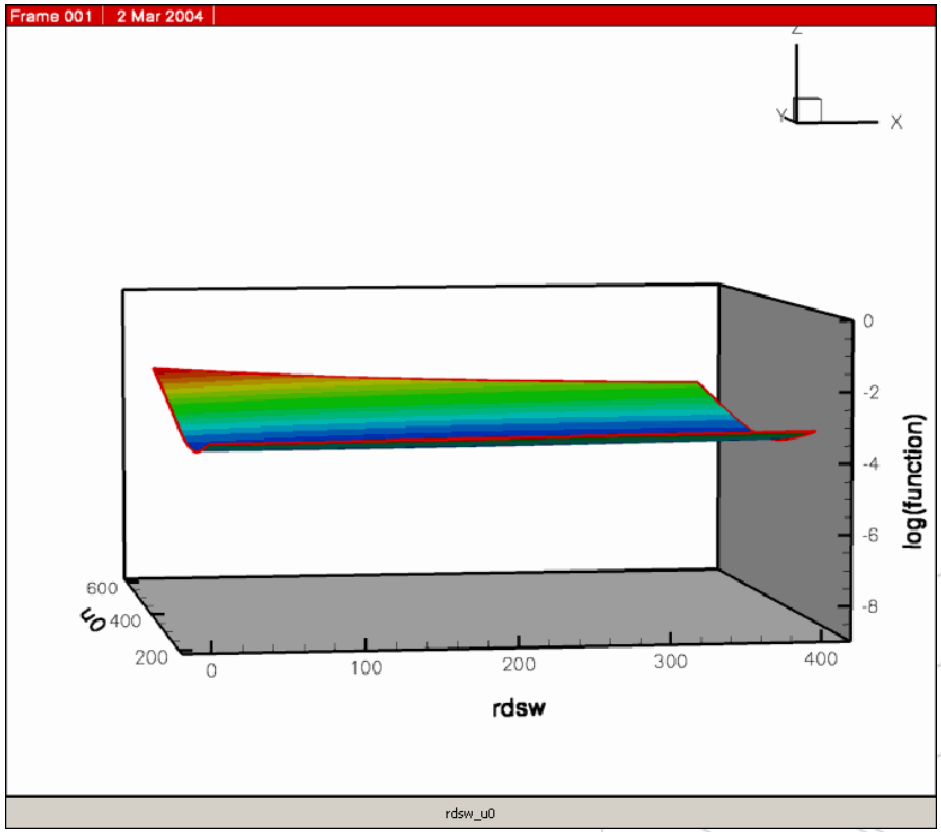
Objective Function Surface Plot, BSIM3

- vth0-u0 Surface Plot Animation



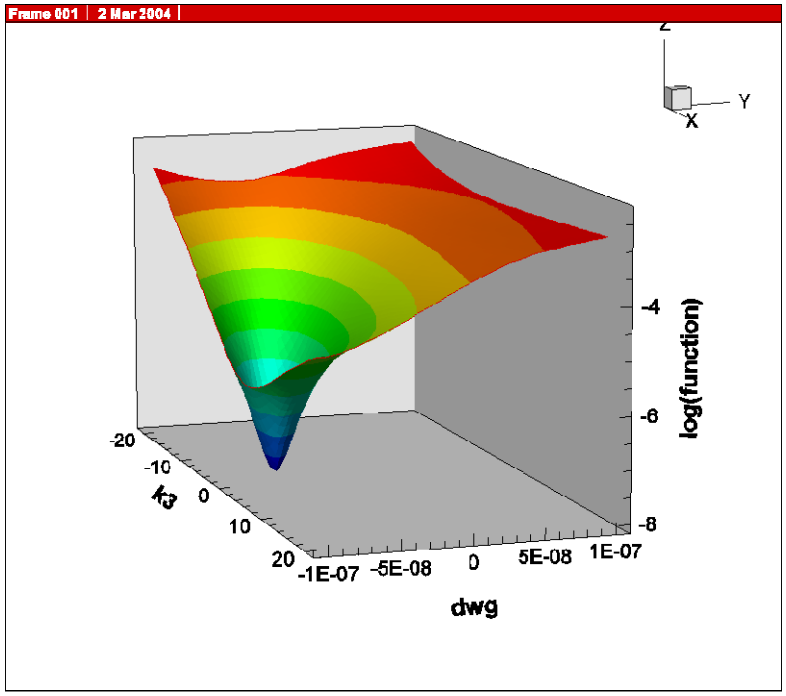
Objective Function Surface Plot, BSIM3

- rdsw-u0 Surface Plot Animation

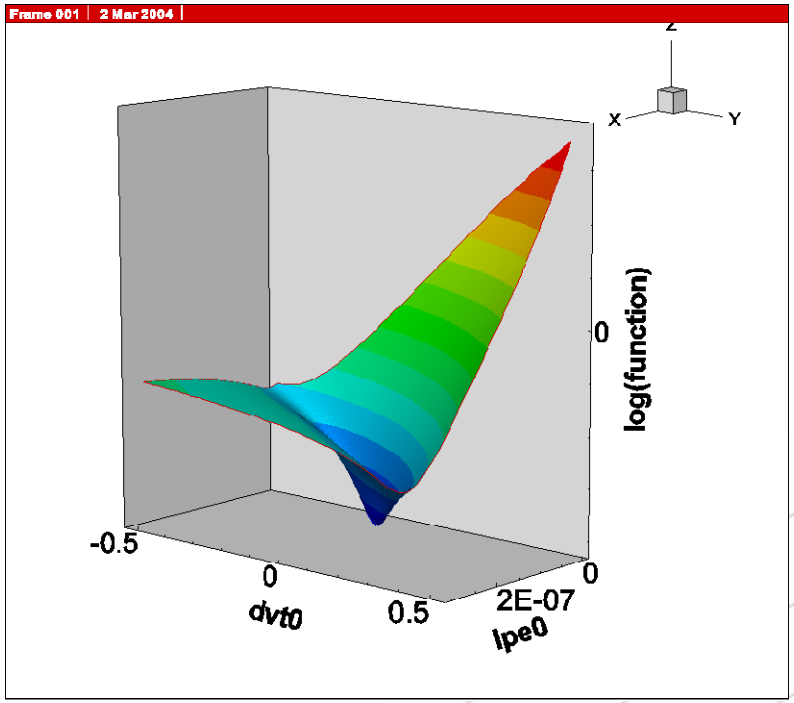


Objective Function Surface Plot, BSIM4

k3-dwg Surface Plot



dvt0-lpe0 Surface Plot

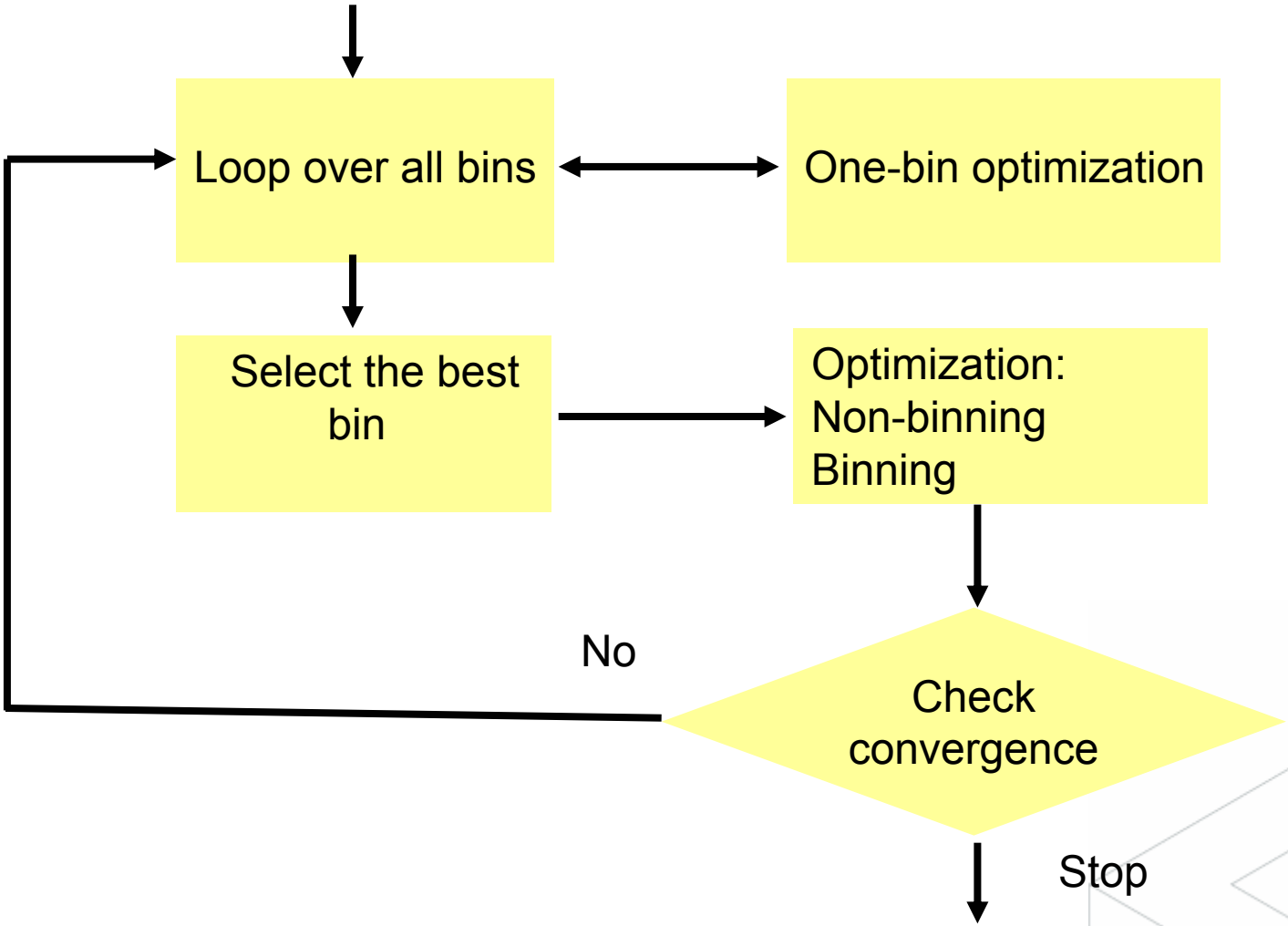


Conclusions from the Surface Plots

In our implementation of objective function calculation

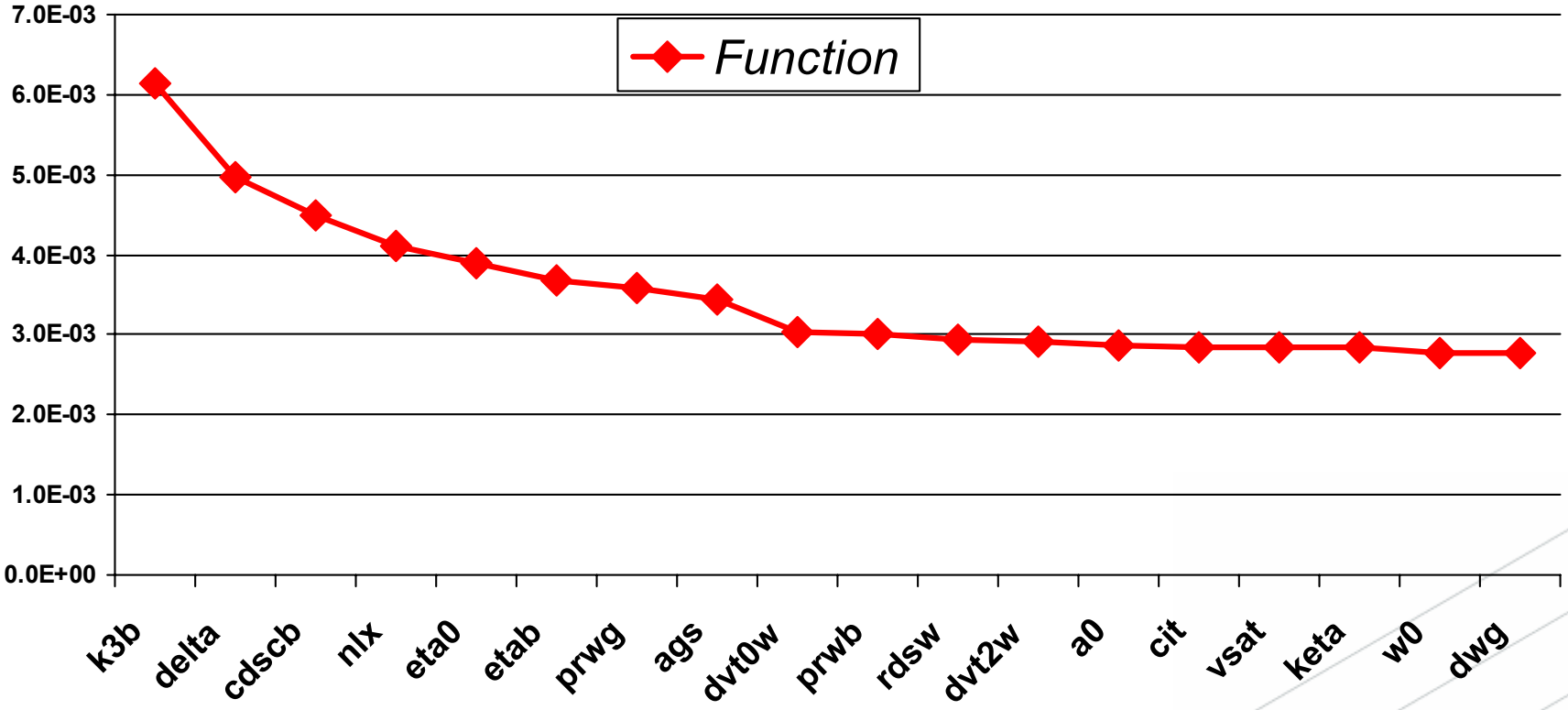
- Objective Function – smooth
- No multiextremum behavior
- Gradient algorithms of optimization – preferable
- Random search algorithms – not necessary

Auto-Selection of Binning Parameters



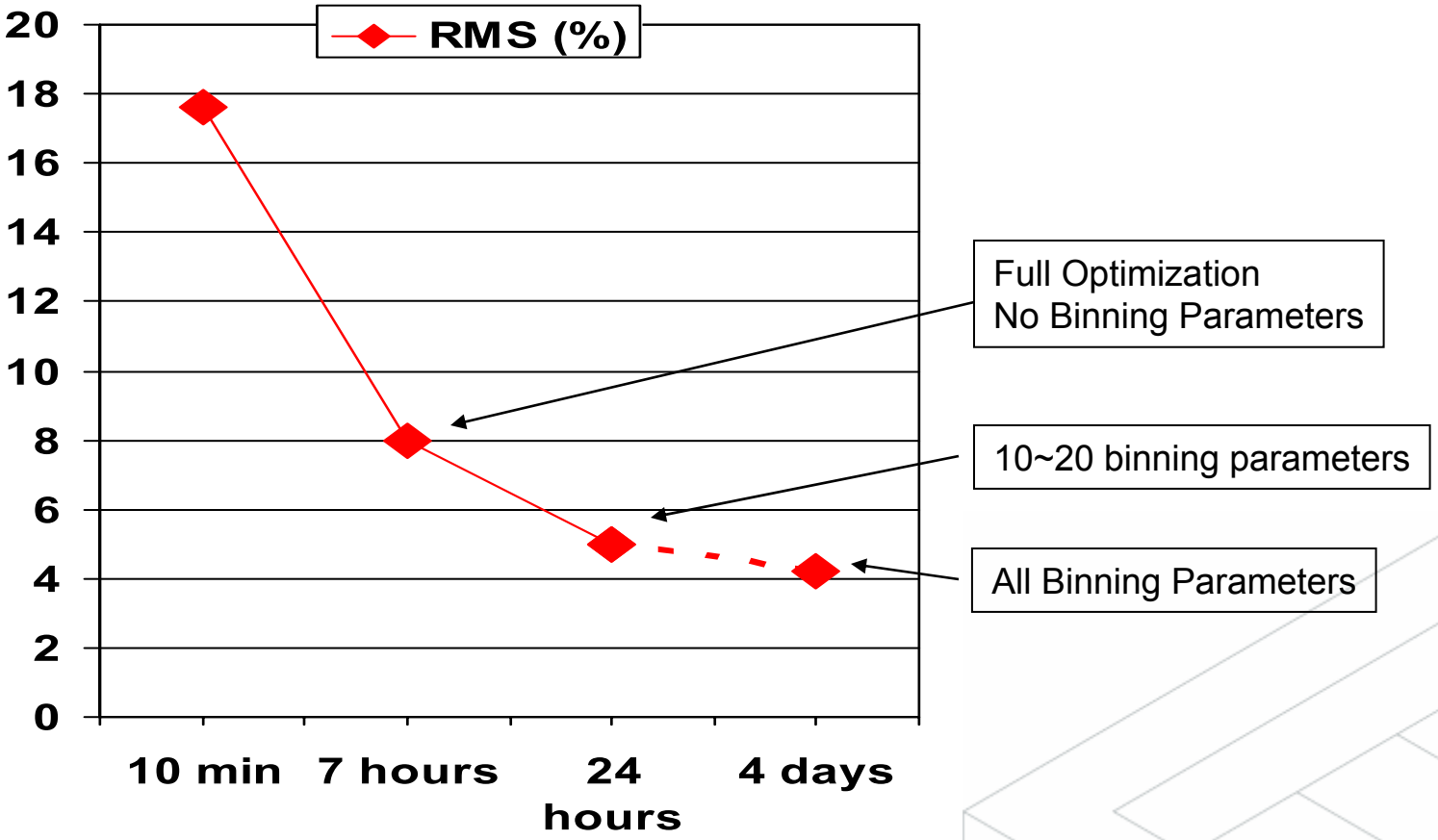
Auto-Selection of Binning Parameters

Example: Objective Function Evolution



Auto-Selection of Binning Parameters

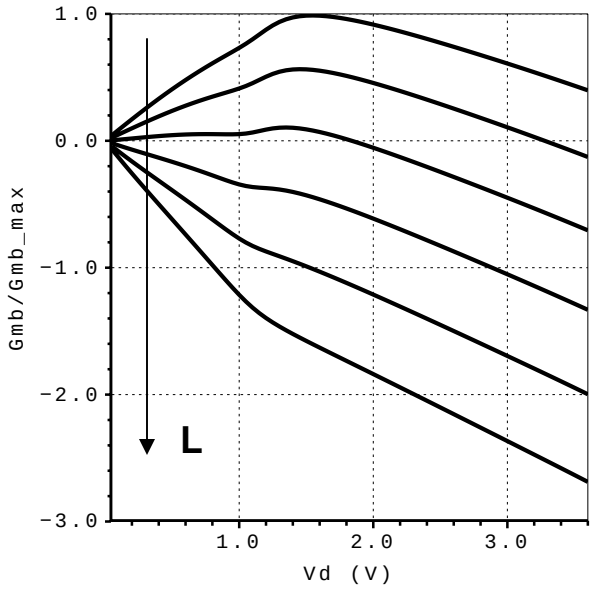
RMS Error vs. Time Consumption, 1 CPU



Experimental Results

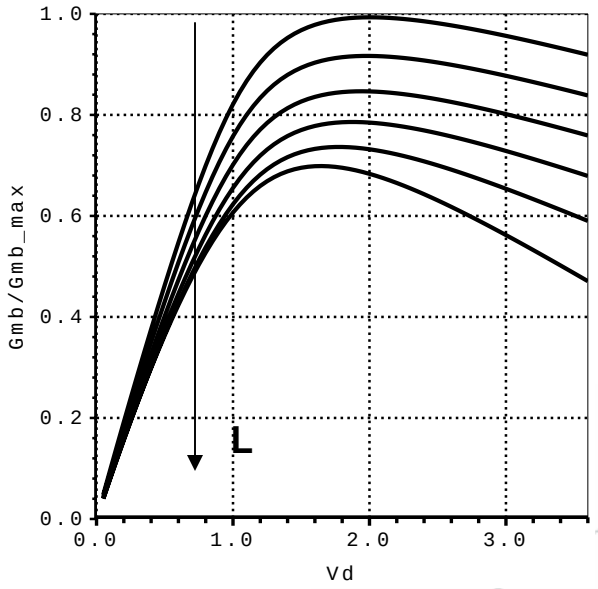
- BSIM3 model. HV 0.13 technology
- L = 0.34, 0.32, 0.30, 0.28, 0.26, 0.24

Gmb < 0 , old results



No Gmb penalty

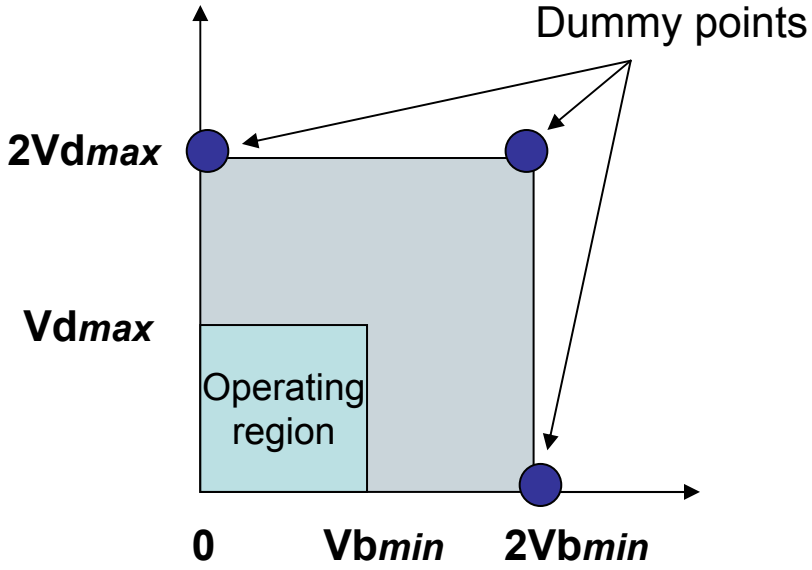
Gmb > 0 , new results

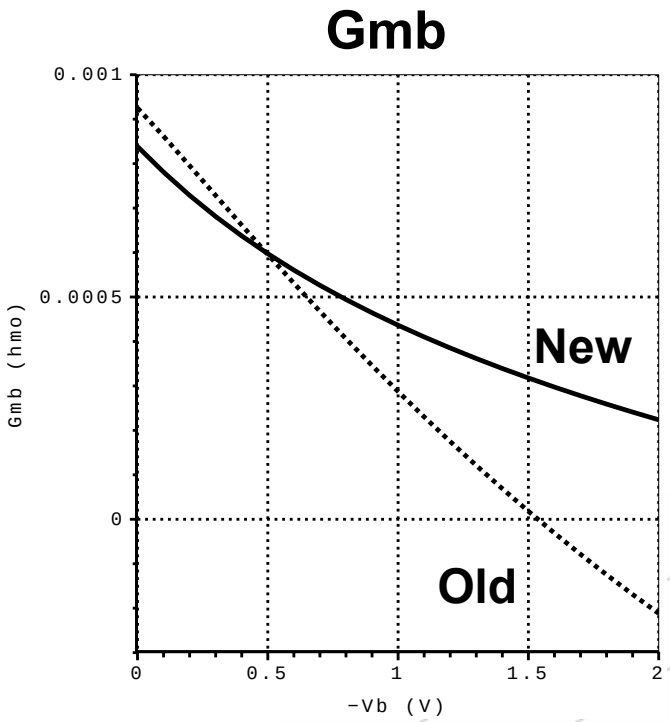


Gmb penalty turn on

Experimental Results

- BSIM4 model. 0.09 technology. Small device.





- Dummy Points
  - Do not optimize drain current
  - Keep under control the penalty functions
- $\Rightarrow$ Gmb is positive within twice the range

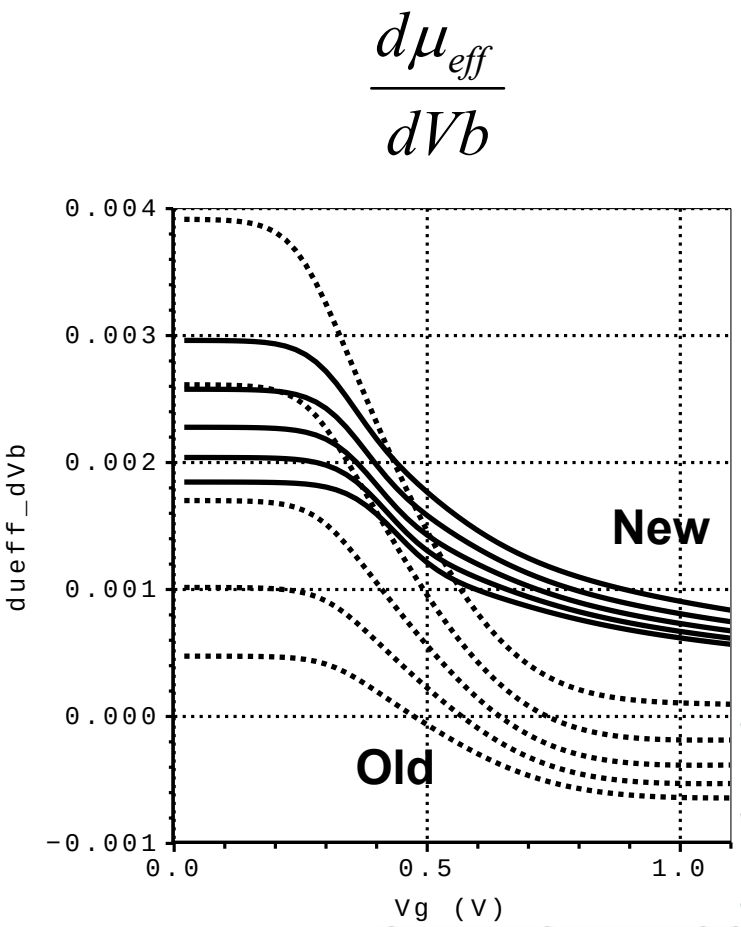
Experimental Results

BSIM4 model.

0.09 technology. Small device.

- No penalty - $\frac{d\mu_{eff}}{dVb}$ may change sign
- Penalty for $\frac{d\mu_{eff}}{dVb}$ is turned

  on - $\frac{d\mu_{eff}}{dVb}$ always positive



Summary

- Objective function with penalties demonstrates smooth behavior
- Gradient optimization algorithm is preferable
- Auto-selection of binning parameters helps to find the needed bins
- Model parameters within physical range is guaranteed by penalty functions
- No human interactions
- Reliable model card