NEXT GENERATION OPTIMIZATION METHODOLOGIES
FOR WIRELESS AND MICROWAVE CIRCUIT DESIGN

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J. W. Bandler and Q.J. Zhang

Simulation Optimization Systems Research Laboratory
and Department of Electrical and Computer Engineering
McMaster University, Hamilton, Canada L8S 4K1

bandler@mcmaster.ca
soya.sos.mcmaster.ca

Introduction

commercial CAE systems for high-speed, wireless and microwave circuits and systems are no longer regarded as complete without a variety of design automation capabilities

computer-integrated manufacturing, including CAD, CAM, information management and decision support systems will be a reality facing the design engineer in the next century

CAE practices such as active and passive device, circuit and system design are expected to be physically and electromagnetically based, to include electrical, mechanical and thermal effects

future developments in integrated CAE tools will concurrently link geometry, layout, physical, electromagnetic (EM) and process simulations, with performance, yield, cost, system specifications, manufacturability and testability in a manner transparent to the designer

Paper Outline

we review two exciting concepts:

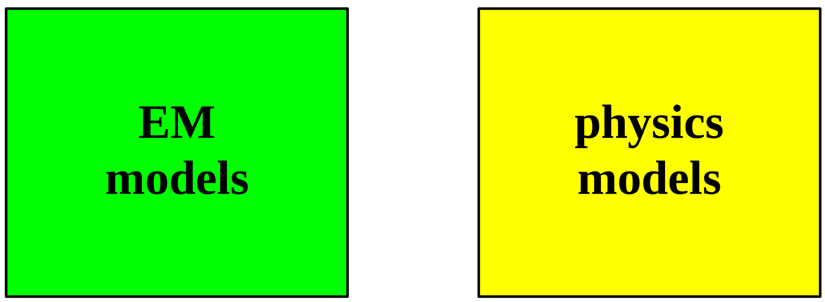
electronic device modeling through Artificial Neural Network technology

circuit optimization exploiting Space Mapping in the design parameter space

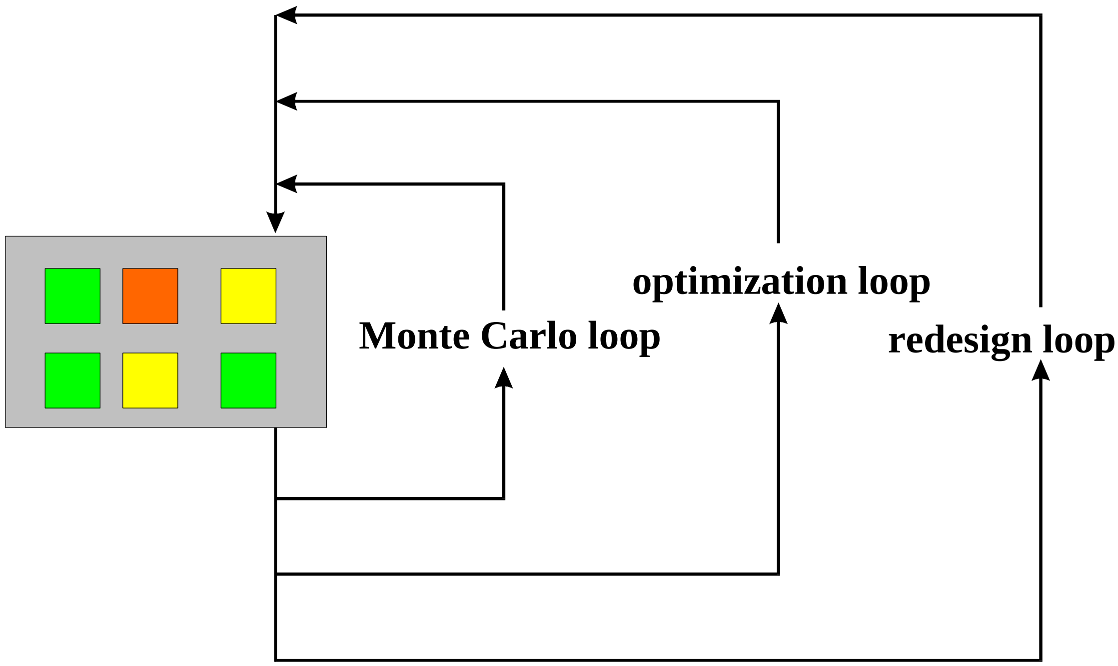
we elaborate on Knowledge Based Neural Network structures for enhanced modeling

we elaborate on Aggressive Space Mapping for efficient electromagnetic optimization

Models are Computationally Expensive



Repetitive Analysis is Expensive



Existing Modeling Approaches

original detailed simulations
- accurate
- but slow

empirical models
- limited accuracy and flexibility
- but fast

polynomial models

response surface models
- limited degree of nonlinearity
- but fast

table lookup models
- arbitrary nonlinearity
- fast
- but limited to low-dimensional problems

Neural Network Approach

multilayer perceptrons

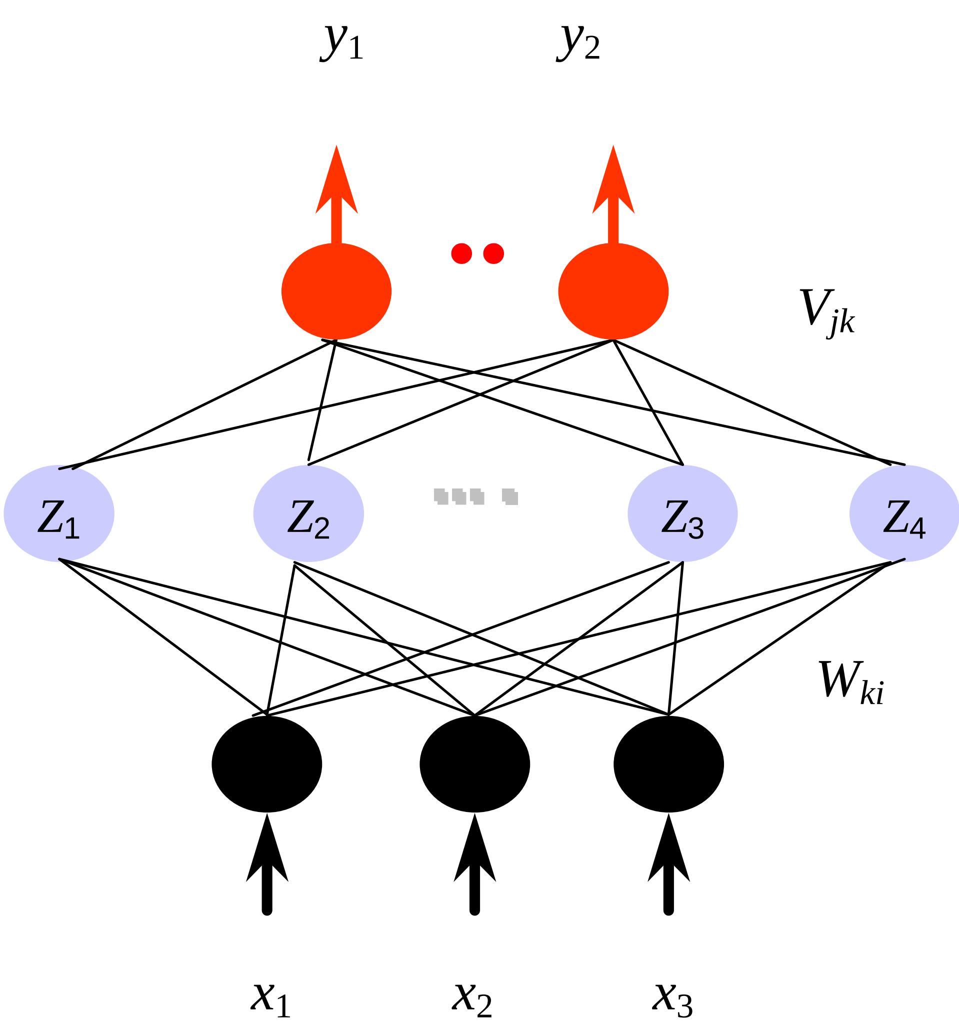
theoretically, models any degree of nonlinearity

handles more variables than, e.g., lookup table models

valid across a larger space than polynomial models

is ultra fast

Structure and Parameters of Multilayer Perceptrons



$$y_j = \sum_k V_{jk} Z_k$$

$$Z_k = \tanh\left(\sum_i W_{ki} X_i\right)$$

x_i

Model Building: Learning Mode

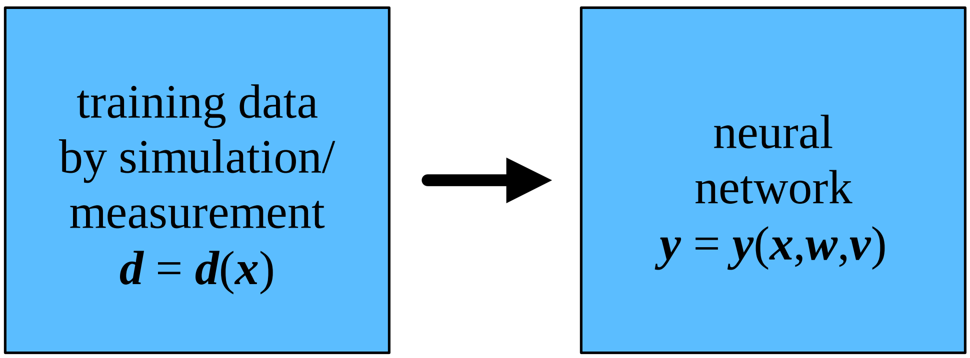
perform detailed device/circuit simulations/measurements
to obtain data

use the data to train the neural network

this procedure could be very slow

it can be performed off-line

Neural Network Training



objective:

to adjust neural network internal weights ***w***,***v*** such that

$$\underset{\mathbf{w},\mathbf{v}}{\text{minimize}} \quad \sum_{x} (y - d)^2$$

Model Usage

given a set of input parameters to the neural network it will predict corresponding outputs

this recalling procedure is very fast and is done on-line during optimization

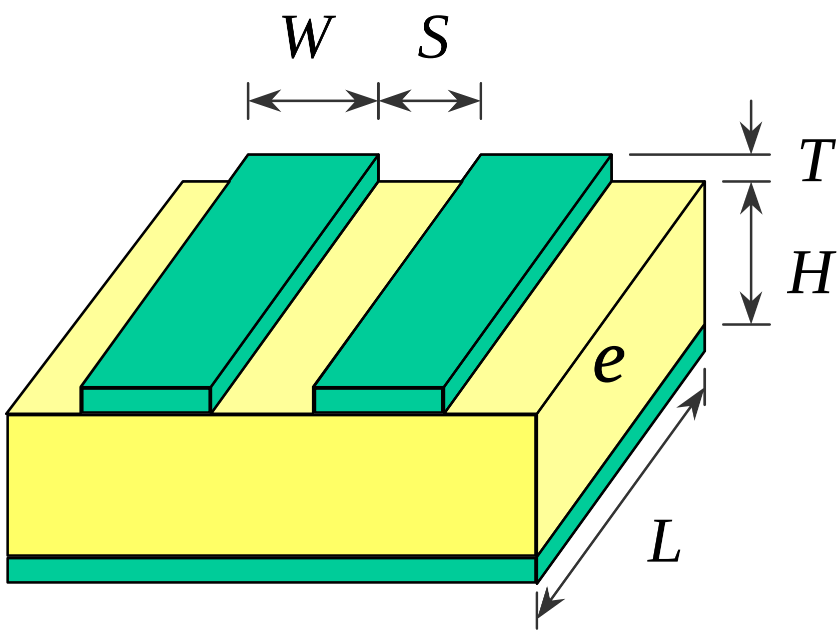
Neural Network Model for Iterative Design

the neural network model is trained off-line only once

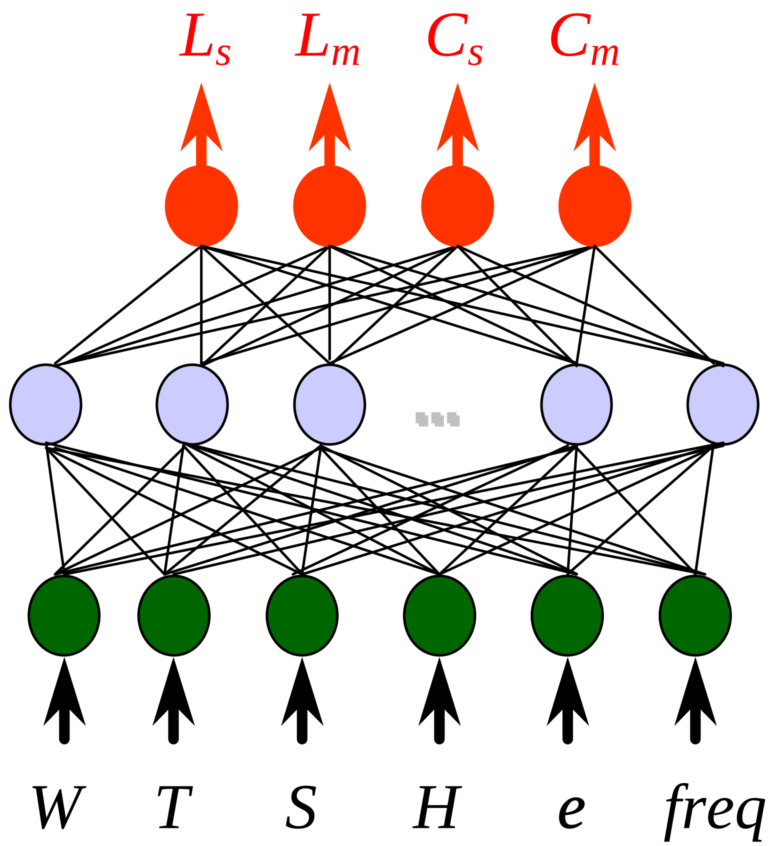
the model can then be used many times for different purposes

- repeated simulations
- optimization
- re-optimization

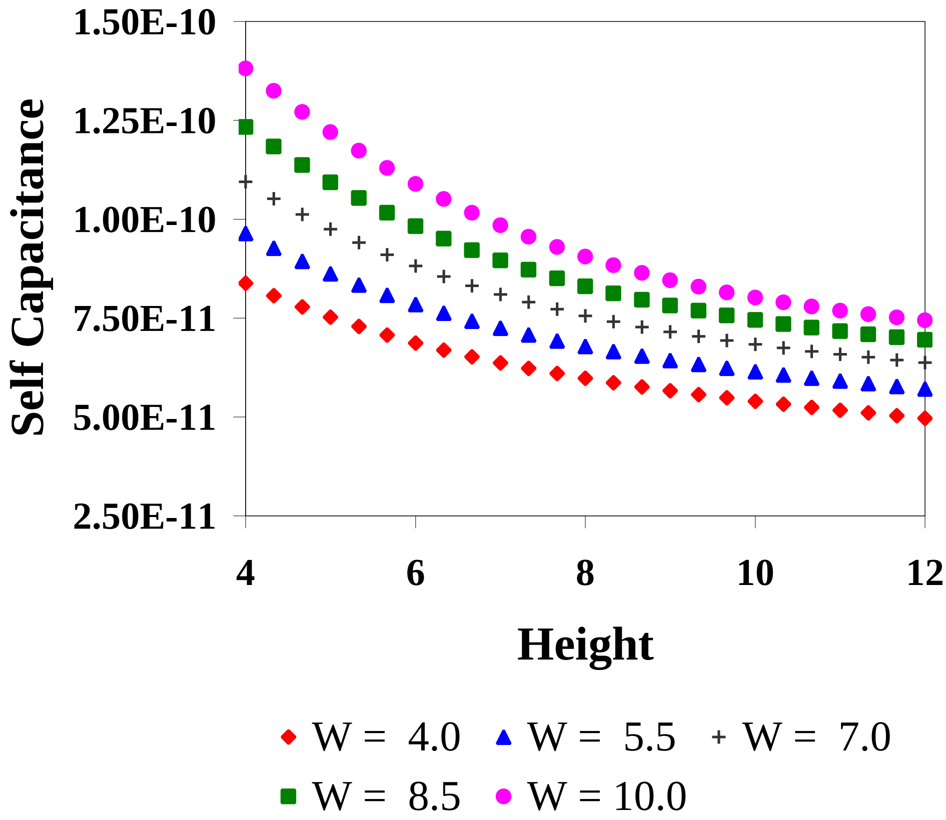
2-Conductor Microstrip Line



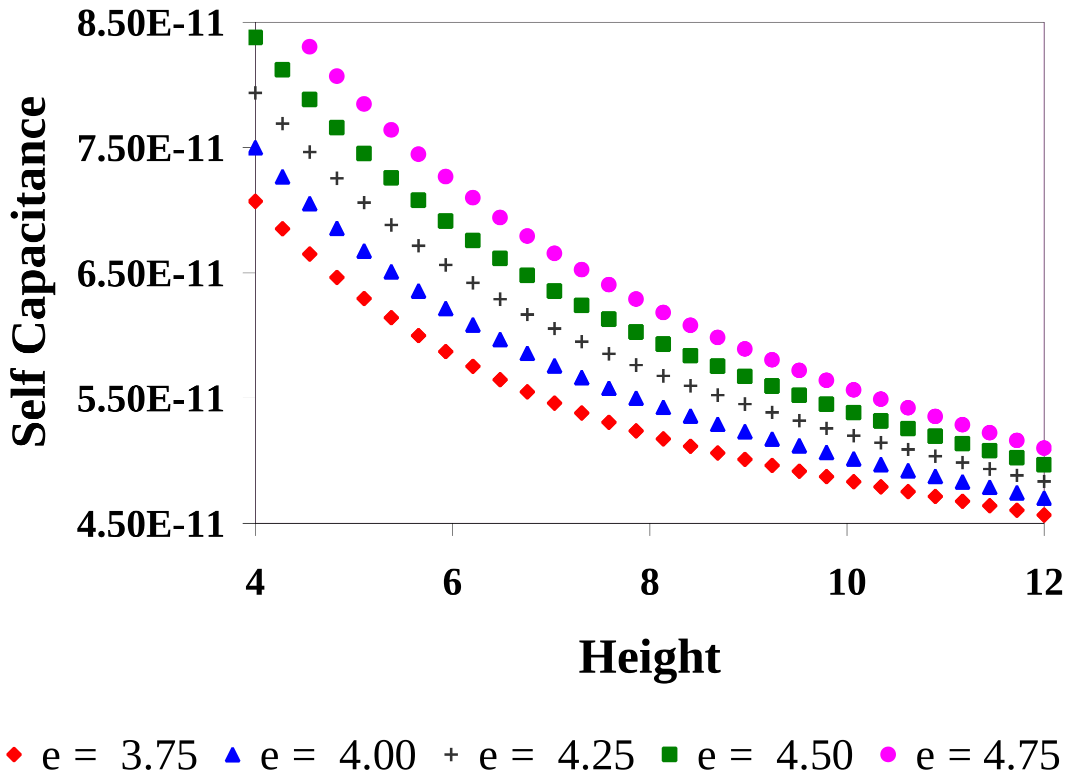
Neural Model for Microstrip Line



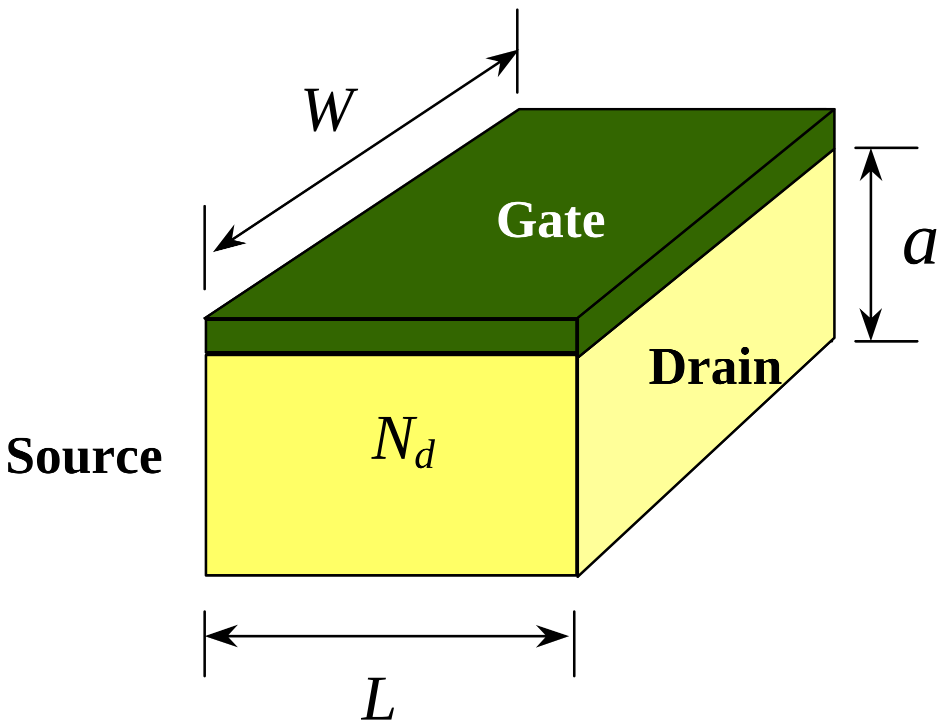
Neural Model for Self Capacitance of Microstrip Line



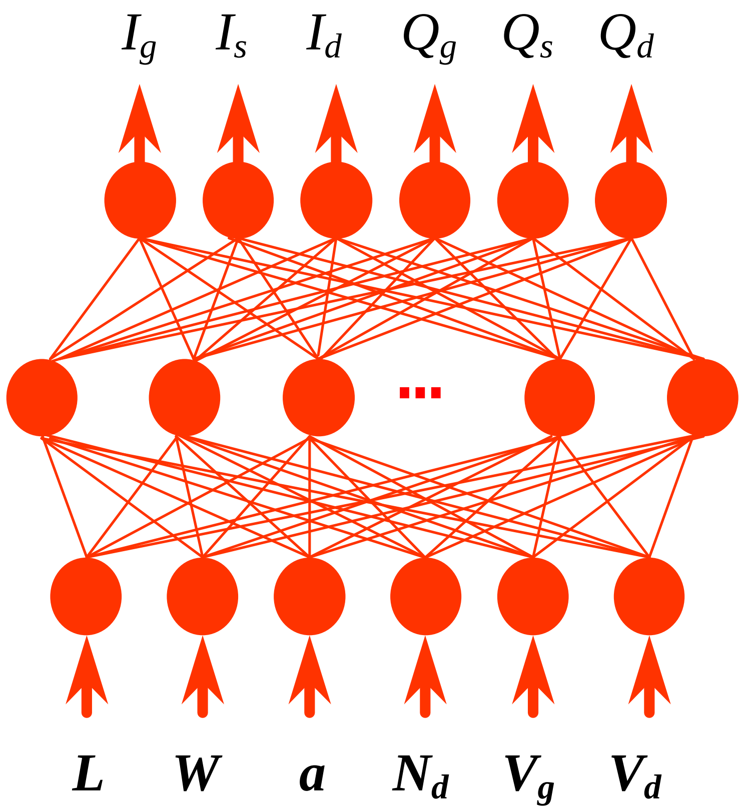
Neural Model for Self Capacitance of Microstrip Line



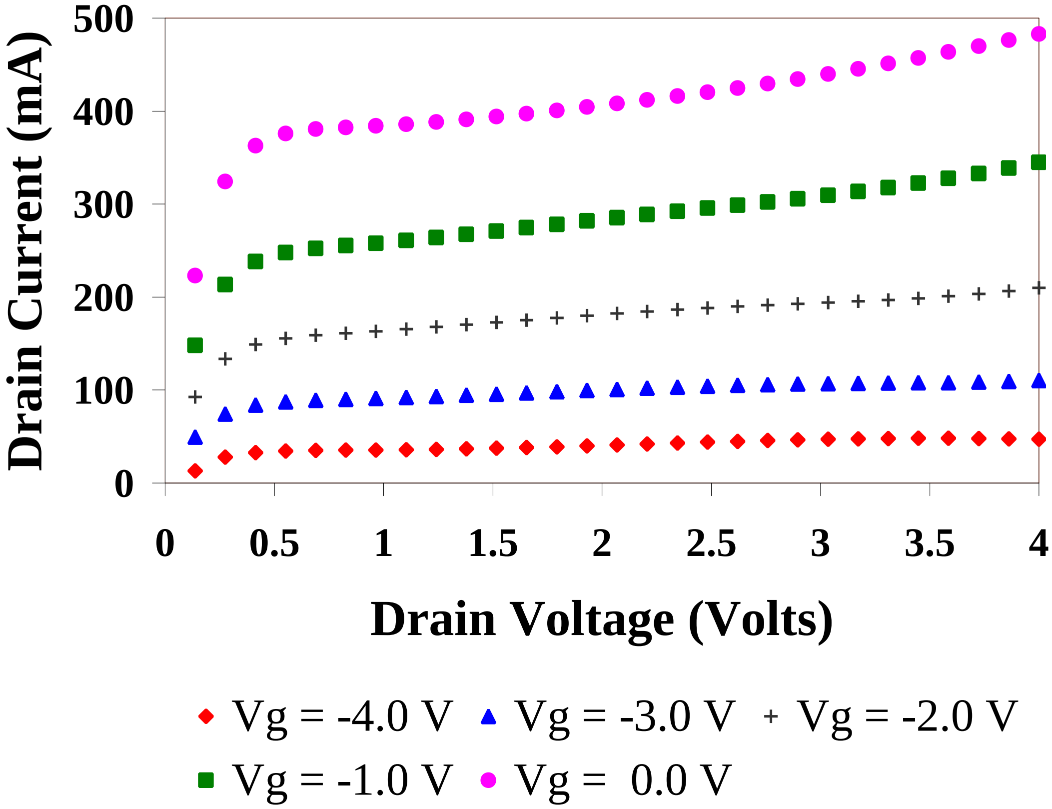
Physics-Based MESFET



Neural Model for MESFET



FET I-V Curve Neural Network Model



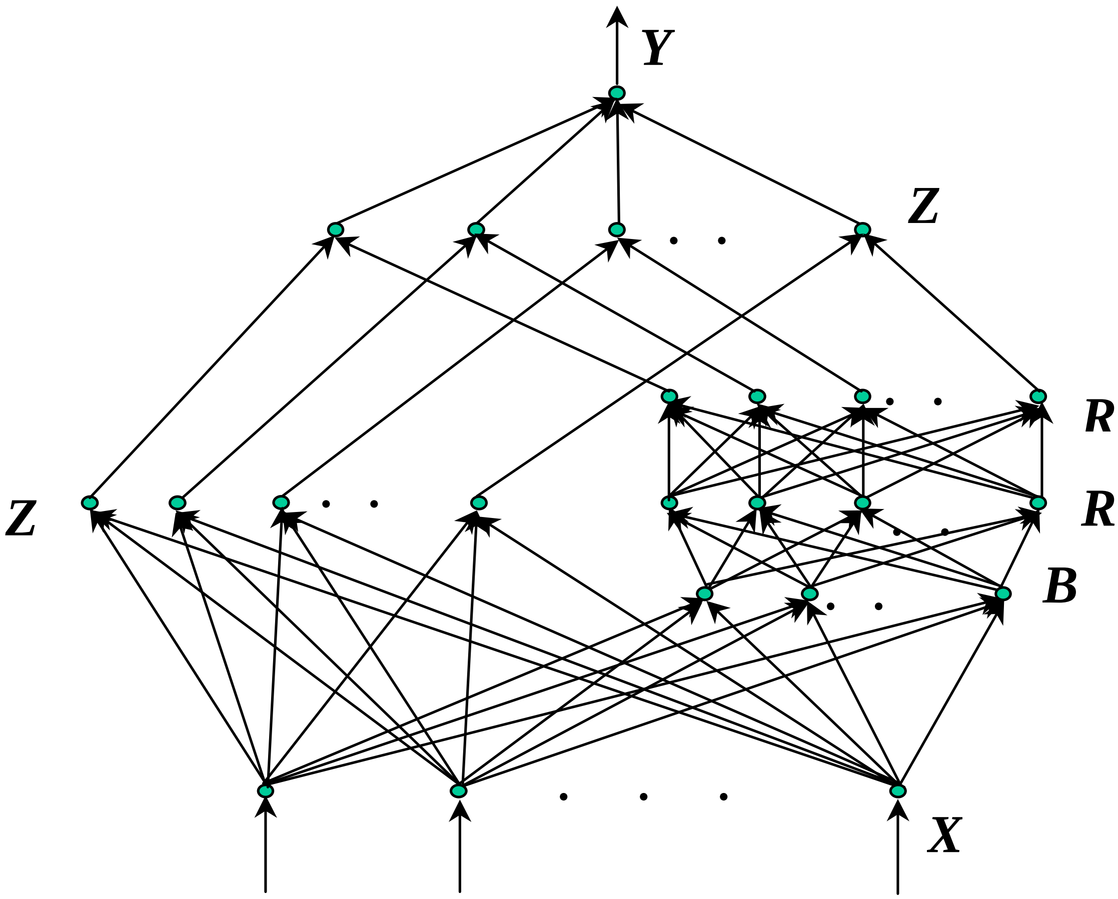
Knowledge Based Neural Networks (KBNN)

incorporate electrical knowledge into neural networks to

reduce the amount of training data
required for model development

improve the accuracy and reliability
of the neural network model

KBNN Structure



Conclusions (Neural Networks)

a novel neural based modeling technique has been developed

the feasibility and efficiency of neural models have been demonstrated

the proposed KBNN combines engineering empirical knowledge with the learning power of neural networks

with ultra fast recalling speed, neural models will have significant impact on the development of interactive CAD tools

NeuroModeler is the first tool of its kind dedicated to RF and microwave engineering

NeuroModeler is available from Dr. Q.J. Zhang (Carleton University)

Conclusions (Space Mapping Optimization)

ASM has been applied to a number of design examples exploiting full wave EM simulators

Sonnet's ***em*** has been used to optimize various filters, including the design of a high temperature superconducting filter

finite element solvers Ansoft and HP HFSS have been used to design various 3D structures such as waveguide transformers and filters

coarse models exploited coarse grid EM models or circuit-theoretic/analytical models

coarse models, decomposed into subnetworks, have even consisted of a mixture of EM based subnetworks and empirical elements connected through circuit theory

A new ASM algorithm called TRASM (Trust Region Aggressive Space Mapping) automates the selection of fine model points used in a multi-point parameter extraction process

References

Q.J Zhang, "Neural network paradigm for microwave modeling, simulation and optimization," *IEEE MTT-S Int. Microwave Symp.*, Workshop on Applications of ANN to Microwave Design (Denver, CO, 1997).

F.Wang and Q.J. Zhang, "Knowledge based neural models for microwave design," *IEEE Trans. Microwave Theory Tech.*, vol. 45, 1997, pp. 2333-2343.

J.W. Bandler, R.M. Biernacki, S.H. Chen, R.H. Hemmers and K. Madsen, "Electromagnetic optimization exploiting aggressive space mapping," *IEEE Trans. Microwave Theory Tech.*, vol. 43, 1995, pp. 2874-2882.

M.H. Bakr, J.W. Bandler, R.M. Biernacki, S.H. Chen and K. Madsen, "A trust region aggressive space mapping algorithm for EM optimization," *IEEE Trans. Microwave Theory Tech.*, vol. 46, 1998, pp. 2412-2425.

New Results

M.H. Bakr, J.W. Bandler, N. Georgieva and K. Madsen, "A hybrid aggressive space mapping algorithm for EM optimization," *IEEE MTT-S Int. Microwave Symp.* (Anaheim, CA, June 1999).

M.H. Bakr, J.W. Bandler and N. Georgieva, "An aggressive approach to parameter extraction," *IEEE MTT-S Int. Microwave Symp.* (Anaheim, CA, June 1999).

M.H. Bakr, J.W. Bandler and N. Georgieva, "Modeling of microwave circuits exploiting space derivative mapping," *IEEE MTT-S Int. Microwave Symp.* (Anaheim, CA, June 1999).

J.W. Bandler, M.A. Ismail, J.E. Rayas-Sánchez and Q. J. Zhang, "Neuromodeling of microwave circuits exploiting space mapping technology," *IEEE MTT-S Int. Microwave Symp.* (Anaheim, CA, June 1999).

J.W. Bandler, M.A. Ismail, J.E. Rayas-Sánchez and Q. J. Zhang, "New directions in model development for RF/microwave components utilizing artificial neural networks and space mapping," *IEEE AP-S Int. Symp.* (Orlando, FL, July 1999).

J.W. Bandler, J.E. Rayas-Sánchez and Q.J. Zhang, "Neural modeling and space mapping: two approaches to circuit design," *XXVI URSI General Assembley* (Toronto, ON, Aug. 1999).