Neural Space Mapping Methods for Modeling and Design of Microwave Circuits

José Ernesto Rayas-Sánchez

Simulation Optimization Systems Research Laboratory
McMaster University

presented at

Ph.D. Thesis Defence, McMaster University, Hamilton, Ontario, June 11, 2001

Outline

thesis general contribution

Space Mapping Based Neuromodeling

Neural Space Mapping (NSM) Optimization

EM-based Yield Optimization Via SM-Based Neuromodels

Neural Inverse Space Mapping (NISM) Optimization

publications

Outline

thesis general contribution

Space Mapping Based Neuromodeling

Neural Space Mapping (NSM) Optimization

EM-based Yield Optimization Via SM-Based Neuromodels

Neural Inverse Space Mapping (NISM) Optimization

publications

Outline

thesis general contribution

Space Mapping Based Neuromodeling

Neural Space Mapping (NSM) Optimization

EM-based Yield Optimization Via SM-Based Neuromodels

Neural Inverse Space Mapping (NISM) Optimization

publications

Outline

thesis general contribution

Space Mapping Based Neuromodeling

Neural Space Mapping (NSM) Optimization

EM-based Yield Optimization Via SM-Based Neuromodels

Neural Inverse Space Mapping (NISM) Optimization

publications

Outline

thesis general contribution

Space Mapping Based Neuromodeling

Neural Space Mapping (NSM) Optimization

EM-based Yield Optimization Via SM-Based Neuromodels

Neural Inverse Space Mapping (NISM) Optimization

publications

Outline

thesis general contribution

Space Mapping Based Neuromodeling

Neural Space Mapping (NSM) Optimization

EM-based Yield Optimization Via SM-Based Neuromodels

Neural Inverse Space Mapping (NISM) Optimization

publications

Outline

thesis general contribution

Space Mapping Based Neuromodeling

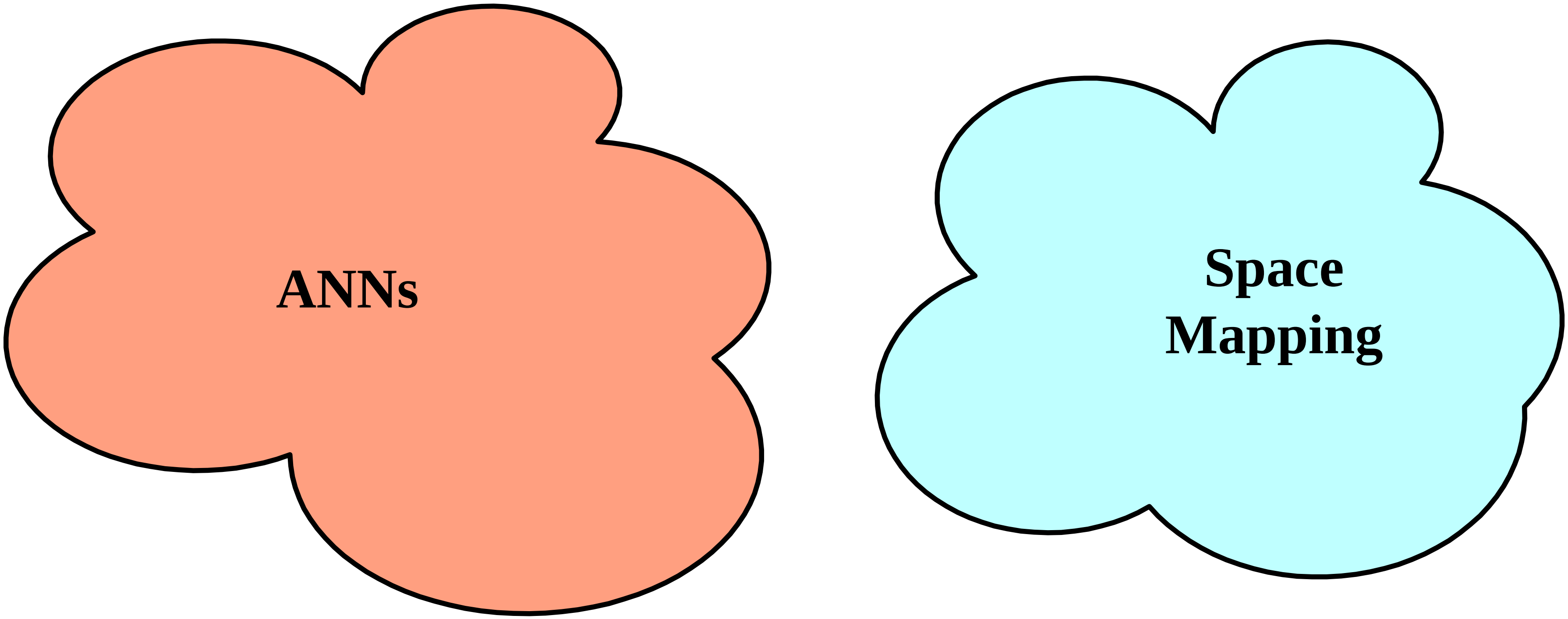
Neural Space Mapping (NSM) Optimization

EM-based Yield Optimization Via SM-Based Neuromodels

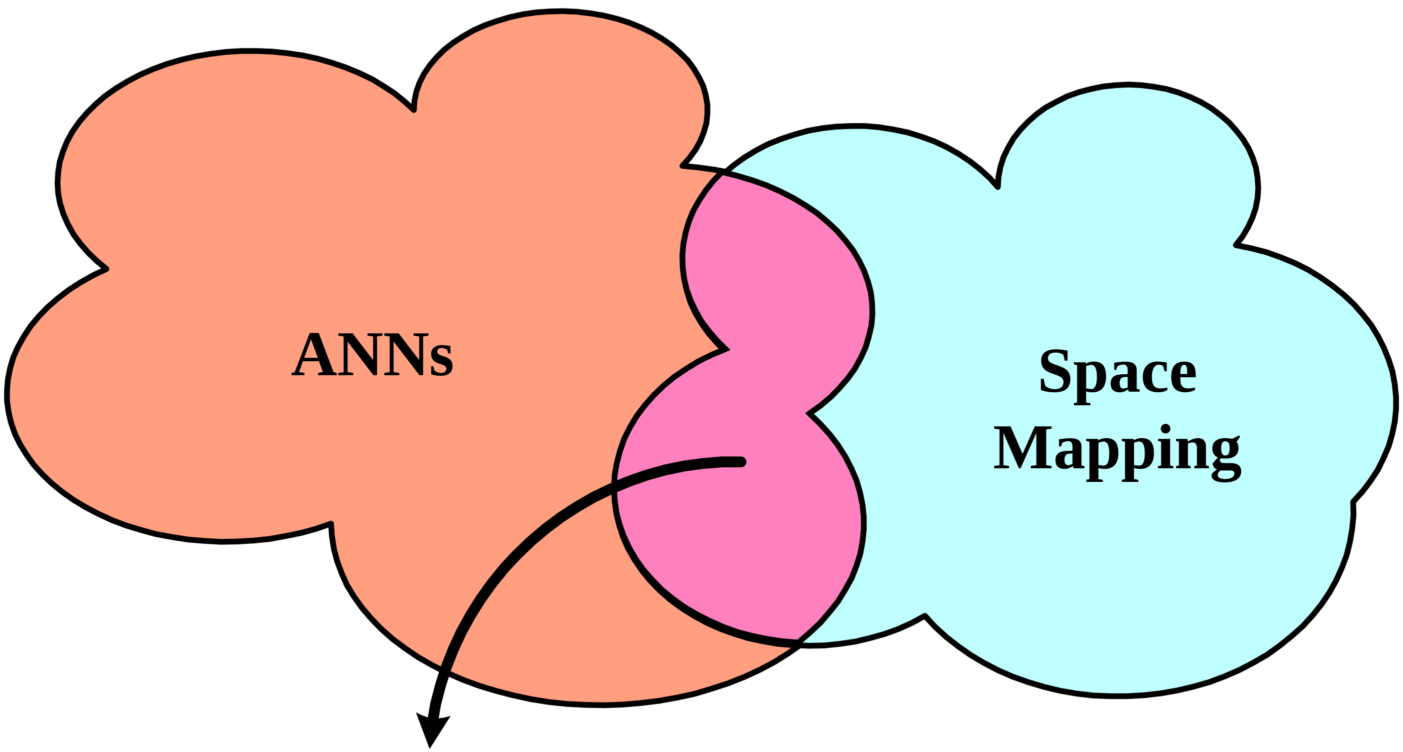
Neural Inverse Space Mapping (NISM) Optimization

publications

Thesis General Contribution



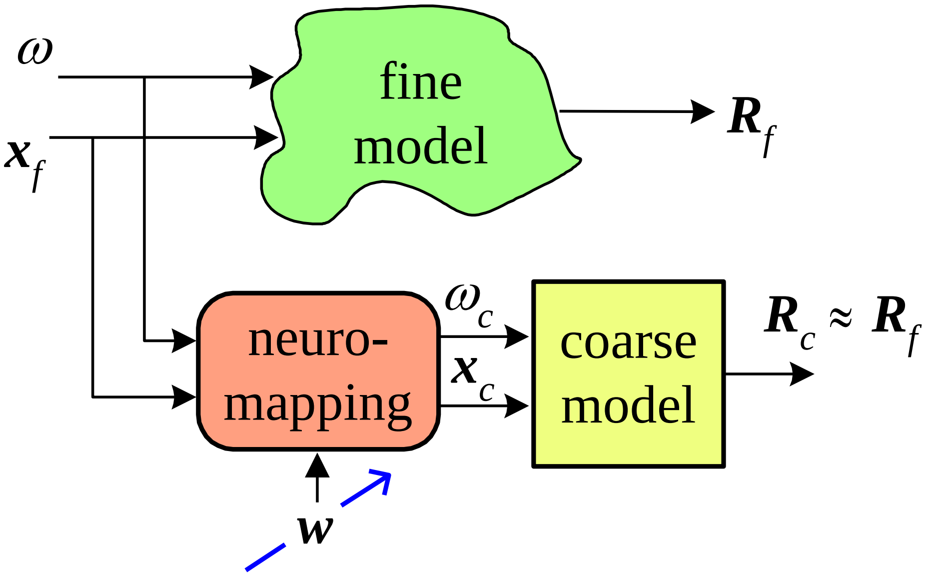
Thesis General Contribution

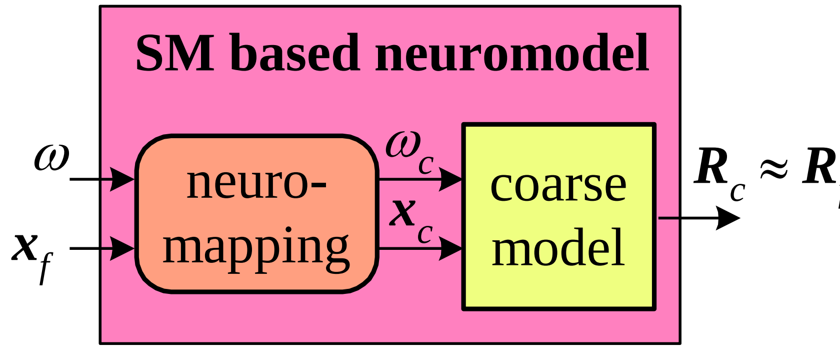


Neural Space Mapping Methods

modeling ***design***

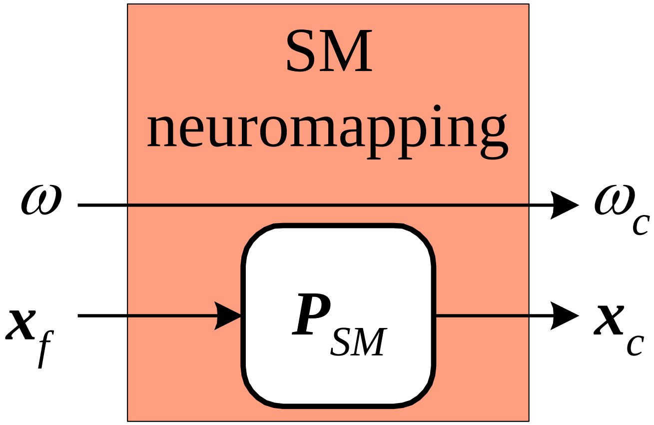
Space Mapping Based Neuromodeling



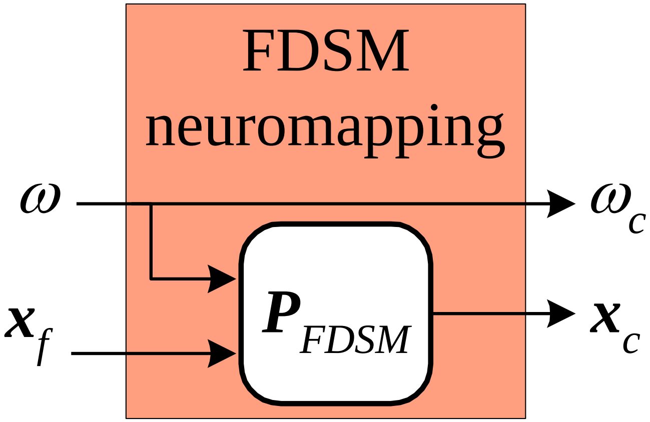


Neuromappings

Space Mapped neuromapping

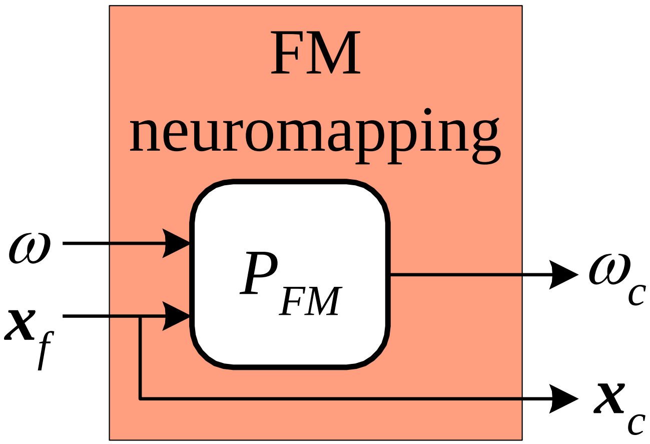


Frequency-Dependent Space Mapped neuromapping

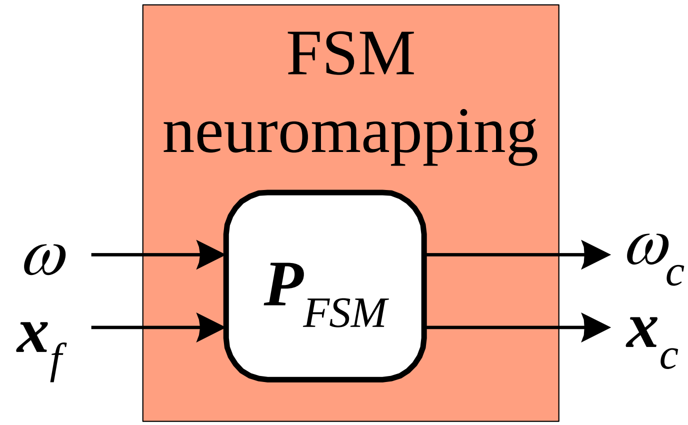


Neuromappings (continued)

Frequency Mapped neuromapping

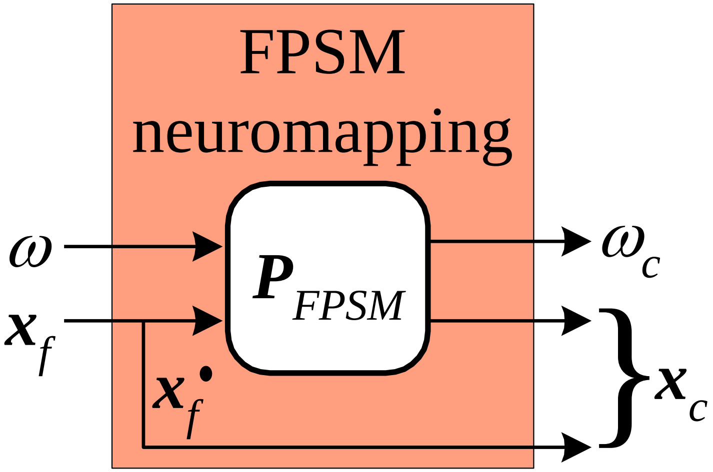


Frequency Space
Mapped neuromapping



Neuromappings (continued)

Frequency Partial-Space
Mapped neuromapping

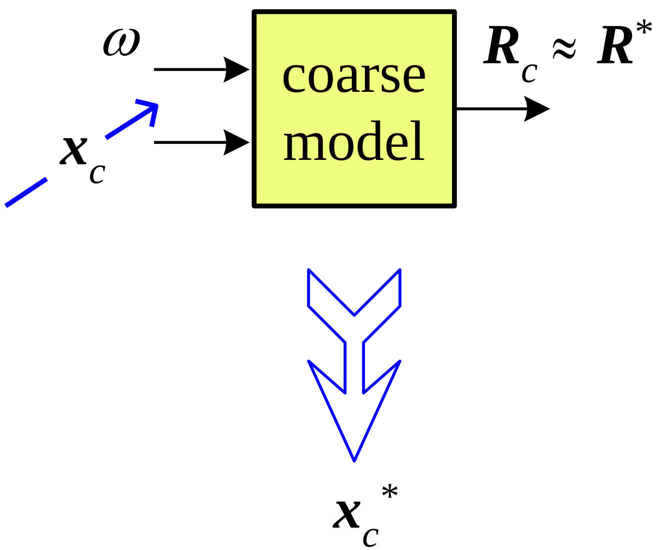


it is not always necessary to map the whole set of design parameters

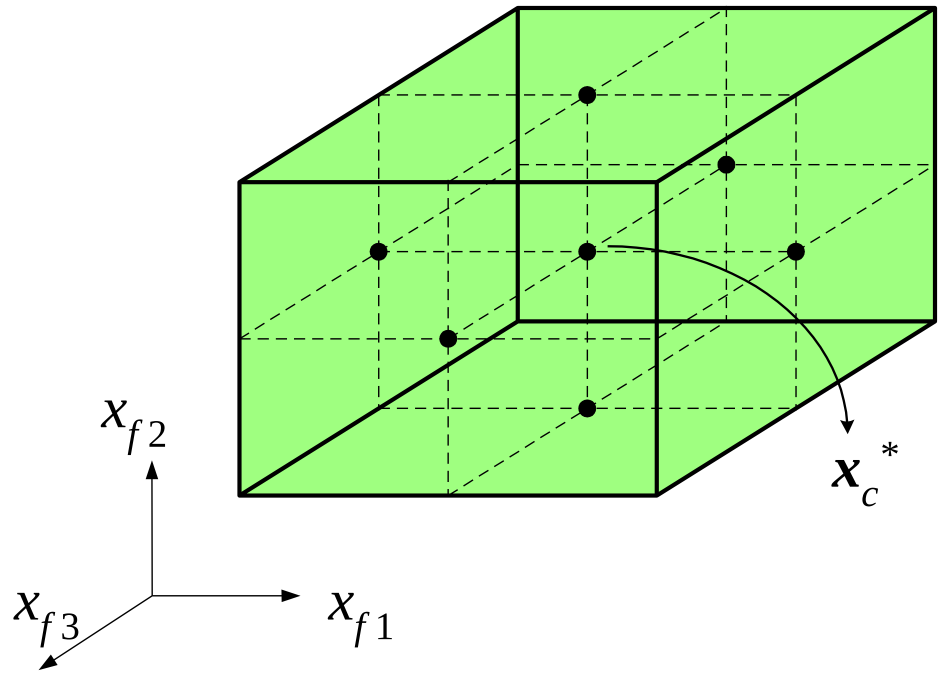
coarse model sensitivities can be used to select the mapped parameters

Neural Space Mapping (NSM) Optimization

step 1



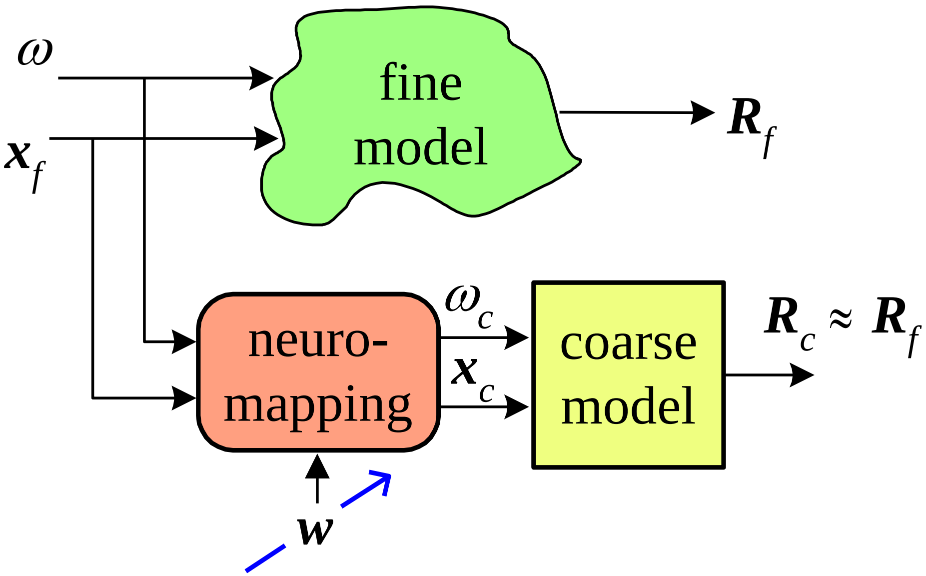
step 2



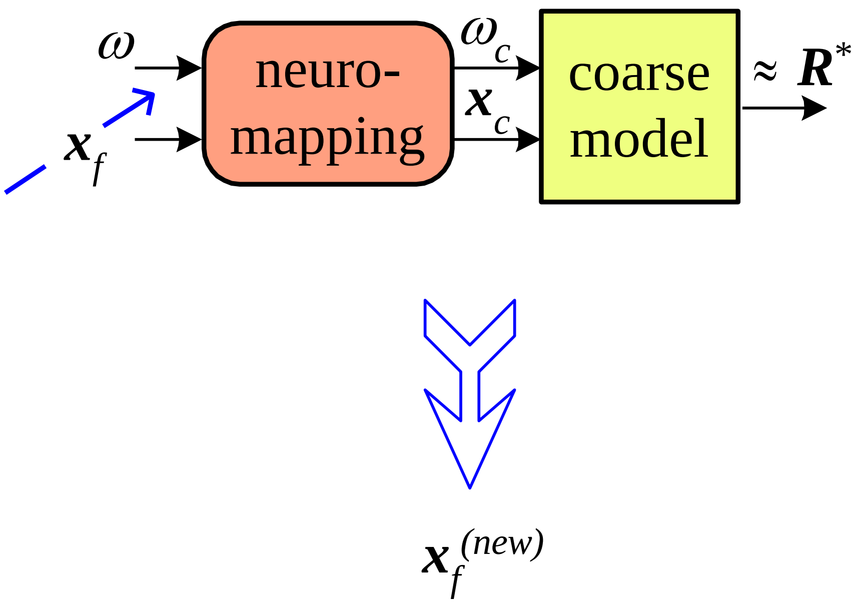
(2n + 1 learning base points for a microwave circuit with n design parameters)

Neural Space Mapping (NSM) Optimization (continued)

step 3



step 4



EM-based Yield Optimization Via SM-Based Neuromodels
(Bandler et. al., 2001)

the SM-based neuromodel responses are given by

$$\boldsymbol{R}_{SMBN}(\boldsymbol{x}_f, \omega) = \boldsymbol{R}_c(\boldsymbol{x}_c, \omega_c)$$

with

$$\begin{bmatrix} \boldsymbol{x}_c \\ \omega_c \end{bmatrix} = \boldsymbol{P}(\boldsymbol{x}_f, \omega)$$

where the mapping function ***P*** is implemented by a neuromapping variation (SM, FDSM, FSM, FM or FPSM)

Yield Optimization Via SM-Based Neuromodels (continued)

$$\boldsymbol{R}_f(\boldsymbol{x}_f, \omega) \approx \boldsymbol{R}_{SMBN}(\boldsymbol{x}_f, \omega)$$

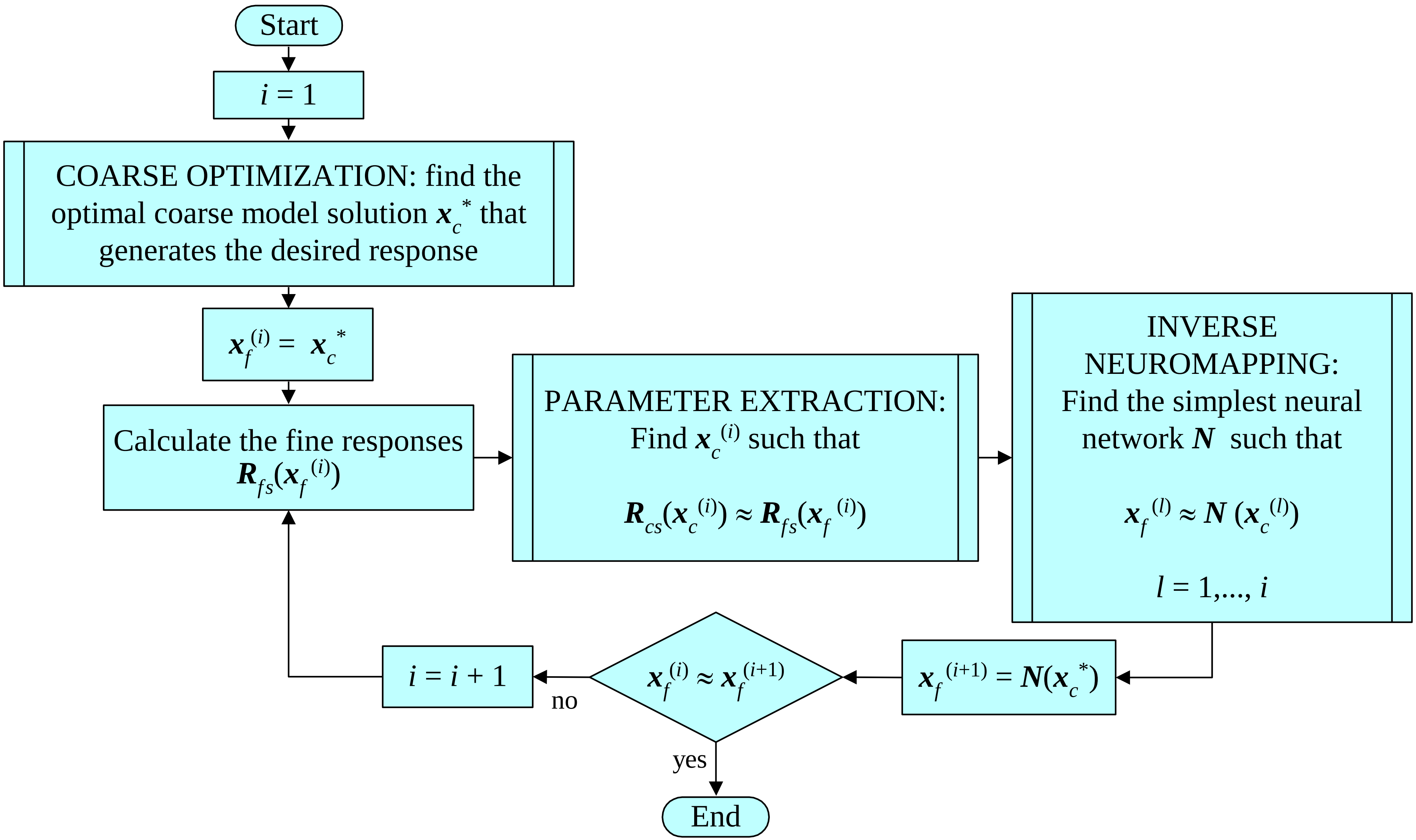
for all $\boldsymbol{x}_f$ and ω in the training region

we can show that

$$\boldsymbol{J}_f \approx \boldsymbol{J}_c \, \boldsymbol{J}_P$$

$\boldsymbol{J}_f \in \Re^{r \times n}$	Jacobian of the fine model responses w.r.t. the fine model parameters
$\boldsymbol{J}_c \in \Re^{r \times (n+1)}$	Jacobian of the coarse model responses w.r.t. the coarse model parameters and mapped frequency
$\boldsymbol{J}_P \in \Re^{(n+1) \times n}$	Jacobian of the mapping function w.r.t. the fine model parameters

Neural Inverse Space Mapping Optimization



Statistical Parameter Extraction

(1)

$$\boldsymbol{x}_c^{(i)} = \arg\min_{\boldsymbol{x}_c} \; U_{PE}(\boldsymbol{x}_c)$$

$$U_{PE}(\boldsymbol{x}_c) = \| \boldsymbol{e}(\boldsymbol{x}_c) \|_2^2$$

$$\boldsymbol{e}(\boldsymbol{x}_c) = \boldsymbol{R}_{fs}(\boldsymbol{x}_f^{(i)}) - \boldsymbol{R}_{cs}(\boldsymbol{x}_c)$$

(2)

$$\Delta_{\max} = \frac{\delta_{PE}}{\left\| \nabla U_{PE}(\boldsymbol{x}_c^{*}) \right\|_\infty}$$

(3)

$$\Delta x_k = \Delta_{\max}(2 rand_k - 1)$$

$$k = 1 \ldots n$$

begin

solve (1) using $\boldsymbol{x}_c^{*}$ as starting point

while $\left\| \boldsymbol{e}(\boldsymbol{x}_c^{(i)}) \right\|_\infty > \varepsilon_{PE}$

calculate $\Delta\boldsymbol{x}$ using (2) and (3)

solve (1) using $\boldsymbol{x}_c^{*} + \Delta\boldsymbol{x}$ as starting point

end

Inverse Neuromapping

(4)

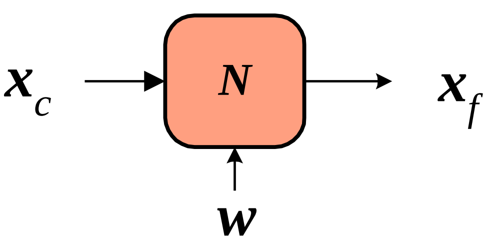
$$\boldsymbol{w}^* = \arg\min_{\boldsymbol{w}} \; U_N(\boldsymbol{w})$$

$$U_N(\boldsymbol{w}) = \left\| \begin{bmatrix} \cdots & \boldsymbol{e}_l^T & \cdots \end{bmatrix}^T \right\|_2^2$$

$$\boldsymbol{e}_l = \boldsymbol{x}_f^{(l)} - \boldsymbol{N}(\boldsymbol{x}_c^{(l)}, \boldsymbol{w})$$

$$l = 1, \ldots, i$$

ANN (2LP or 3LP)



begin

solve (4) using a 2LP

$h = n$

while $U_N(\boldsymbol{w}^*) > \varepsilon_L$

solve (4) using a 3LP

$h = h + 1$

end

Publications

work published

[1] J.W. Bandler, J.E. Rayas-Sánchez and Q.J. Zhang, “Space mapping based neuromodeling of high frequency circuits,” *Micronet Annual Workshop* (Ottawa, ON), 1999, pp. 122-123.

[2] 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. Digest* (Anaheim, CA), 1999, pp. 149-152.

[3] 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,” (invited), *IEEE AP-S Int. Symp. Digest* (Orlando, FL), 1999, pp. 2572-2575.

[4] J.W. Bandler, J.E. Rayas-Sánchez and Q.J. Zhang, “Neural modeling and space mapping: two approaches to circuit design,” (invited), *XXVI URSI General Assembly* (Toronto, ON), 1999, p. 246.

[5] J.W. Bandler, N. Georgieva, M.A. Ismail, J.E. Rayas-Sánchez and Q.J. Zhang, “A generalized space mapping tableau approach to device modeling,” *European Microwave Conf.* (Munich, Germany), vol. 3, 1999, pp. 231-234.

[6] J.W. Bandler, M.A. Ismail, J.E. Rayas-Sánchez and Q.J. Zhang, “Neuromodeling of microwave circuits exploiting space mapping technology,” *IEEE Trans. Microwave Theory Tech.*, vol. 47, 1999, pp. 2417-2427.

[7] J.W. Bandler, J.E. Rayas-Sánchez, F. Wang and Q.J. Zhang, “Realizations of Space Mapping based neuromodels of microwave components,” (invited) *AP2000 Millennium Conf. on Antennas & Propagation* (Davos, Switzerland), vol. 1, 2000, pp. 460.

[8] J.W. Bandler, J.E. Rayas-Sánchez and Q.J. Zhang, “Software implementation of space mapping based neuromodels of microwave components,” *Micronet Annual Workshop* (Ottawa, ON), 2000, pp. 67-68.

Publications

work published (continued)

[9] M.H. Bakr, J.W. Bandler, K. Madsen, J.E. Rayas-Sánchez and J. Søndergaard, “Space mapping optimization of microwave circuits exploiting surrogate models,” *IEEE MTT-S Int. Microwave Symp. Digest* (Boston, MA), 2000, pp. 1785-1788.

[10] J.W. Bandler, M.A. Ismail and J.E. Rayas-Sánchez, “Broadband physics-based modeling of microwave passive devices through frequency mapping,” *IEEE MTT-S Int. Microwave Symp. Digest* (Boston, MA), 2000, pp. 969-972.

[11] M.H. Bakr, J.W. Bandler, M.A. Ismail, J.E. Rayas-Sánchez and Q.J. Zhang, “Neural space mapping optimization of EM microwave structures,” *IEEE MTT-S Int. Microwave Symp. Digest* (Boston, MA), 2000, pp. 879-882.

[12] M.H. Bakr, J.W. Bandler, M.A. Ismail, J.E. Rayas-Sánchez and Q.J. Zhang, “Neural space mapping optimization for EM-based design of RF and microwave circuits,” *First Int. Workshop on Surrogate Modeling and Space Mapping for Engineering Optimization* (Lyngby, Denmark), November 2000.

[13] J.W. Bandler, M.A. Ismail and J.E. Rayas-Sánchez, “Microwave device modeling exploiting generalized space mapping,” *First Int. Workshop on Surrogate Modeling and Space Mapping for Engineering Optimization* (Lyngby, Denmark), November 2000.

[14] M.H. Bakr, J.W. Bandler, M.A. Ismail, J.E. Rayas-Sánchez and Q.J. Zhang, “Neural space mapping optimization for EM-based design,” *IEEE Trans. Microwave Theory Tech.*, vol. 48, 2000, pp. 2307-2315.

[15] M.H. Bakr, J.W. Bandler, K. Madsen, J.E. Rayas-Sánchez and J. Søndergaard, “Space mapping optimization of microwave circuits exploiting surrogate models,” *IEEE Trans. Microwave Theory Tech.*, vol. 48, 2000, pp. 2297-2306.

[16] J.W. Bandler, N. Georgieva, M.A. Ismail, J.E. Rayas-Sánchez and Q.J. Zhang, “A generalized space mapping tableau approach to device modeling,” *IEEE Trans. Microwave Theory Tech.*, vol. 49, 2001, pp. 67-79.

Publications

work published (continued)

[17] J.W. Bandler, J.E. Rayas-Sánchez and Q.J. Zhang, "Space mapping based neuromodeling of high frequency circuits," *Micronet Annual Workshop* (Ottawa, ON), 2001, pp. 69-70.

[18] J.W. Bandler, M.A. Ismail, J.E. Rayas-Sánchez and Q.J. Zhang, "Neural inverse space mapping EM-optimization," *IEEE MTT-S Int. Microwave Symp. Digest* (Phoenix, AZ), 2001, pp. 1007-1010.

[19] J.W. Bandler, M.A. Ismail and J.E. Rayas-Sánchez, "Expanded space mapping design framework exploiting preassigned parameters," *IEEE MTT-S Int. Microwave Symp. Digest* (Phoenix, AZ), 2001, pp. 1151-1154.

[20] M.H. Bakr, J.W. Bandler, Q.S. Cheng, M.A. Ismail and J.E. Rayas-Sánchez, "SMX—A novel object-oriented optimization system," *IEEE MTT-S Int. Microwave Symp. Digest* (Phoenix, AZ), 2001, pp. 2083-2086.

[21] J.W. Bandler, M.A. Ismail and J.E. Rayas-Sánchez, "Broadband physics-based modeling of microwave passive devices through frequency mapping," *Int. J. RF and Microwave CAE*, 2001, vol. 11, pp. 156-170.

work accepted

[22] J.W. Bandler and J.E. Rayas-Sánchez, "Neural space mapping methods for device modeling and optimal design," *1st. Annual McMaster Optimization Conf.* (Hamilton, Ontario), 2001.

[23] J.W. Bandler, J.E. Rayas-Sánchez and Q.J. Zhang, "Yield driven EM optimization using space mapping-based neuromodels," *European Microwave Conf.* (London, England), 2001.

Publications

work submitted

[24] J.W. Bandler, M.A. Ismail and J.E. Rayas-Sánchez, "Expanded space mapping design framework exploiting preassigned parameters," ***IEEE Trans. Microwave Theory Tech*****., December 2001.**

[25] J.W. Bandler, M.A. Ismail, J.E. Rayas-Sánchez and Q.J. Zhang, "Neural inverse space mapping (NISM) optimization for EM-based design of microwave structures," ***IEEE Trans. Microwave Theory Tech*****., December 2001.**

[26] J.W. Bandler, J.E. Rayas-Sánchez and Q.J. Zhang, "Yield-driven electromagnetic optimization via space mapping-based neuromodels," ***Int. J. RF and Microwave CAE*****, 2001, December 2001.**

Publications (continued)

main author of…

12 conference papers

4 journal papers

co-author of…

6 conference papers

4 journal papers