ScuDo

Scuola di Dottorato ~ Doctoral School

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XXXIV Cycle

Algorithms for the extraction of guaranteed stable and passive high-dimensional parameterized macromodels

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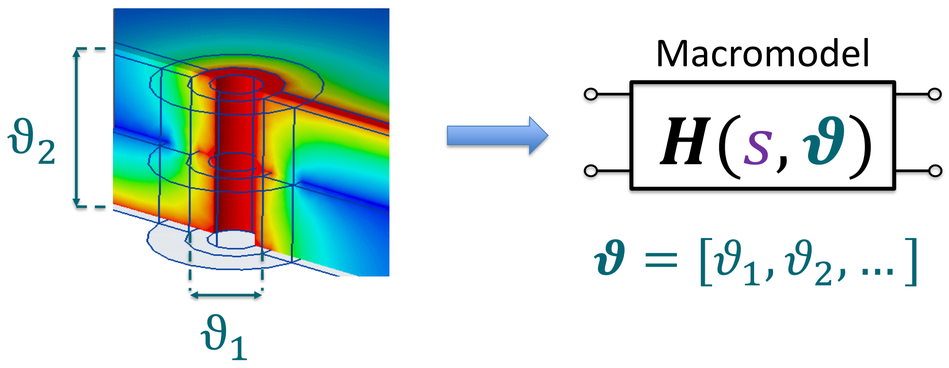
Research context and motivation

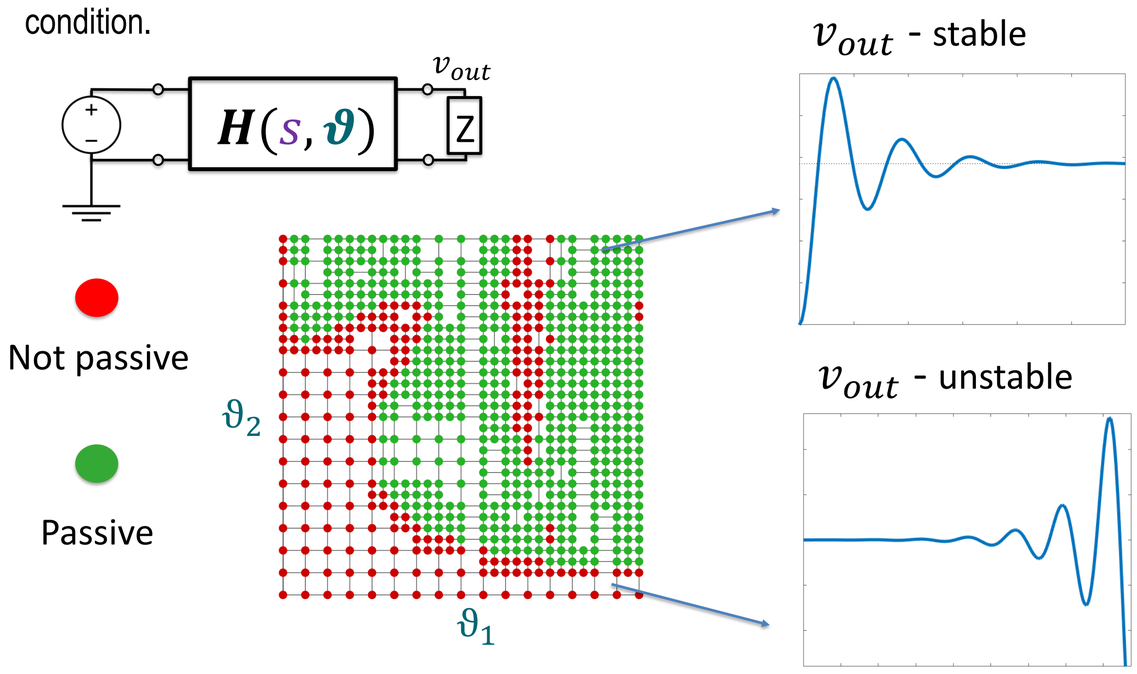
- In the last few years, the use of **numerical simulations** in electronics has become a common practice in most of the design workflows, mainly in **parameter optimization** and **design-centering** phases. However, as the design complexity increases, the required computational effort become intractable, preventing the use of these techniques for large scale problems.
- **Macromodels** are compact black-box surrogates that retain only the dominant dynamics of the phenomena under investigation. Thus, when used in place of first-principle simulators (e.g. FEM, Transistor Level SPICE), such models **drastically reduce** CPU and memory workload.



- We focus on **parameterized (linear)** - macromodels, that embed in closed form the dependence on several (10+) design parameters of interest ($\boldsymbol{\vartheta}$).
- Parametric macromodeling techniques exist, but they are restricted to a limited number of parameters.

Addressed research questions/problems

- **Find appropriate macromodel structure:** as the number of external parameters increase, the model complexity must be kept as small as possible.
- **Parametric macromodel synthesis:** develop efficient model identification algorithms, guaranteed to be uniformly (i.e. for any parameter combination) stable.
- **Guaranteeing uniform passivity:** if the structure under modeling is passive (i.e. unable to generate energy), the associated macromodel must be passive. If required, passivity must be checked and enforced to guarantee reliable time-domain simulations under any loading condition.

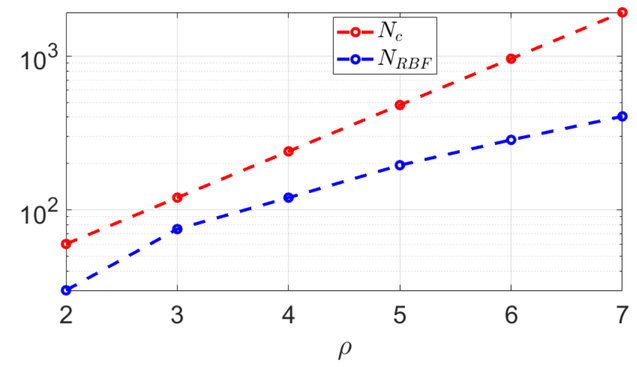


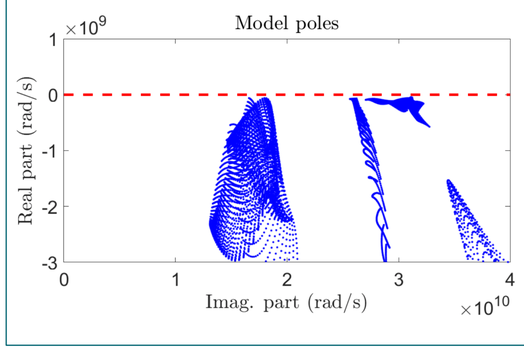
List of attended classes

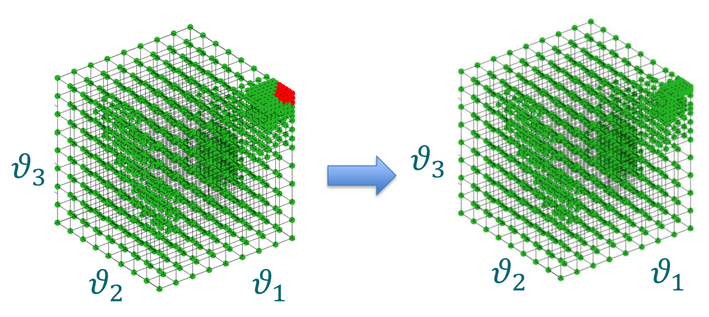
- 01QTEIU – Data mining concepts and algorithms (14/12/2018, 4 credits)
- 01ROCRT – Scomposizione di tensori: algebra, geometria e matematica computazionale (19/9/2019, 4 credits)
- 01TCORV – Surrogate and compact modeling: theory for the user (12/7/2019, 4 credits)
- 03SGVRV – Entrepreneurship and start-up creation from University Research(9/5/2019, 8 credits)

Novel contributions

- Adoption of high–dimensional **sparse model structure**, based on kernel (radial basis functions, RBF) expansions, providing major improvements with respect to standard techniques in terms of model complexity.
- Guaranteed **uniform stability**.
- Advanced **passivity verification and enforcement algorithms**, capable of handling models with many parameters (currently: only up to 3)





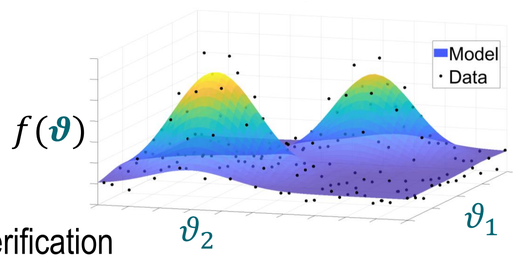


Adopted methodologies

- **Sparse** model representation based on multi-dimensional kernel expansion

$$f(\boldsymbol{\vartheta}) = \sum_n \alpha_n \cdot K_n(\boldsymbol{\vartheta} - \boldsymbol{\vartheta_n^0})$$

$$K_n(\boldsymbol{\vartheta}) = e^{-\varepsilon \cdot \|\boldsymbol{\vartheta}\|^2}$$

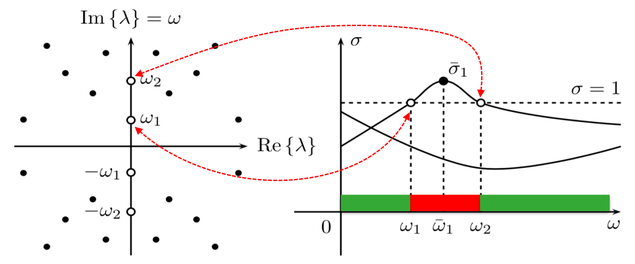


- Parametric **Hamiltonian–based** passivity verification

$$\boldsymbol{H}(s,\boldsymbol{\vartheta}) \Longrightarrow \begin{aligned} \dot{\boldsymbol{x}} &= \boldsymbol{A}(\boldsymbol{\vartheta})\boldsymbol{x} + \boldsymbol{B}\boldsymbol{u} \\ \boldsymbol{y} &= \boldsymbol{C}(\boldsymbol{\vartheta})\boldsymbol{x} + \boldsymbol{D}\boldsymbol{u} \end{aligned}$$

$$\boldsymbol{\mathcal{M}}(\boldsymbol{\vartheta}) = \begin{pmatrix} \mathbf{A}(\boldsymbol{\vartheta})^T & \mathbf{B}\mathbf{B}^T \\ -\mathbf{C}(\boldsymbol{\vartheta})^T\mathbf{C}(\boldsymbol{\vartheta}) & -\mathbf{A}(\boldsymbol{\vartheta})^T \end{pmatrix}, \quad \boldsymbol{\mathcal{K}} = \begin{pmatrix} \mathbf{E} & \mathbf{0} \\ \mathbf{0} & \mathbf{E}^T \end{pmatrix}$$

$$\lambda(\boldsymbol{\vartheta}) = eig(\boldsymbol{\mathcal{M}}(\boldsymbol{\vartheta}), \boldsymbol{\mathcal{K}})$$



Future work

- Select the most appropriate sparse model representation.
- **Stabilize** kernel-based identification methods. The resulting fitting problem may become strongly ill-conditioned.
- Formulation of advanced passivity verification algorithms, hopefully immune from the curse of dimensionality.

Submitted and published works

1. **Journal**: A. Zanco, S. Grivet-Talocia, T. Bradde, M. De Stefano. "*Enforcing passivity of parameterized LTI macromodels via Hamiltonian-driven multivariate adaptive sampling*". IEEE TCAD, 2018 (early access), pp. 1-14.
2. **Journal:** E. Fevola, A. Zanco, S. Grivet-Talocia, T. Bradde, M. De Stefano. "*An Adaptive Sampling Process for Automated Multivariate Macromodeling Based on Hamiltonian-Based Passivity Metrics*". IEEE TCPMT, 2019 (early access), pp. 1-14.
3. **Conference**: A. Zanco, S. Grivet-Talocia, T. Bradde, M. De Stefano. "*Multivariate macromodeling with stability and passivity constraints*". In: IEEE SPI2018, Brest, 22-25 May 2018. pp. 1-4.
4. **Conference**: A. Zanco, S. Grivet-Talocia, T. Bradde, M. De Stefano, "*On stabilization of parameterized macromodeling*". In: IEEE SPI 2019, Chambery, 18-21 June 2019. pp. 1-4. **BEST STUDENT PAPER AWARD**
5. **Conference**: E. Fevola, A. Zanco, S. Grivet-Talocia, T. Bradde, M. De Stefano," *A 3D passivity-based adaptive algorithm for automated parameterized macromodeling of electromagnetic structures".* ICEAA 2019, Granada, 9-13 September 2019, pp. 1-4.
6. **Conference**: T. Bradde, S. Grivet-Talocia, M. De Stefano, A. Zanco," *A Scalable Reduced-Order Modeling Algorithm for the Construction of Parameterized Interconnect Macromodels from Scattering Responses*". IEEE EMC SI- PI 2018. Long Beach, 30 July – 3 August 2018. pp. 650-655. **BEST PAPER AWARD**
7. **Conference**: M. De Stefano, S. Grivet-Talocia, T. Bradde, A. Zanco, "*A framework for the generation of guaranteed stable small-signal bias-dependent behavioral models*". In: IEEE EuMIC 2018, Madrid, 23-25 September 2018. pp. 142-145.
8. **Conference**: T. Bradde, P. Toledo, M. De Stefano, A. Zanco, S. Grivet-Talocia, P. Crovetti, "*Enabling fast power integrity transient analysis through parameterized small-signal macromodels*", EMC Europe, Barcelona, 2-6 September 2019, pp.1-6
9. **Conference:** A. Zanco, S. Grivet-Talocia, *High-dimensional parameterized macromodeling with guaranteed stability*, accepted for oral presentation at 28th EPEPS, 2019, Montreal, 6-9 October, pp.1-3.

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