

## Modelling & Simulation Chapter

### Chapter 14



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## Highlights from M&S

- State of the art
  - High Fidelity Models: FEA, CFD, FDTD
  - Lower Fidelity Models: Compact models...
  - Point analysis tools
- Example of Challenges
  - Electrical – SI/PI die-die coupling, parasitics.
  - Thermal & Mechanical – Hot spots, Warpage..
  - Multi-physics – Mobility shifts, Migration
  - System-Level models – fast/accurate models
  - Reliability – Physics of Failure
  - Materials – Stochastic behavior



### Chapter 14: Modeling and Simulation

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## Modelling and Simulation Techniques

- Electrical analysis
- Thermal & thermomechanical
- Mechanics & multiphysics modeling
- Multi-scale modeling
- Machine learning/AI
- System-level modeling
- Material characterization

**Thermomigration**

Atomic Transport

Electron Wind

Stress Gradient

Temperature Gradient

Concentration Gradient

Self-diffusion

nonlinear analysis

linear analysis

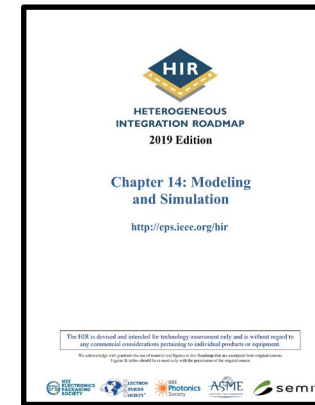
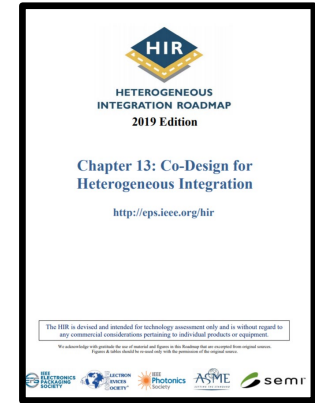
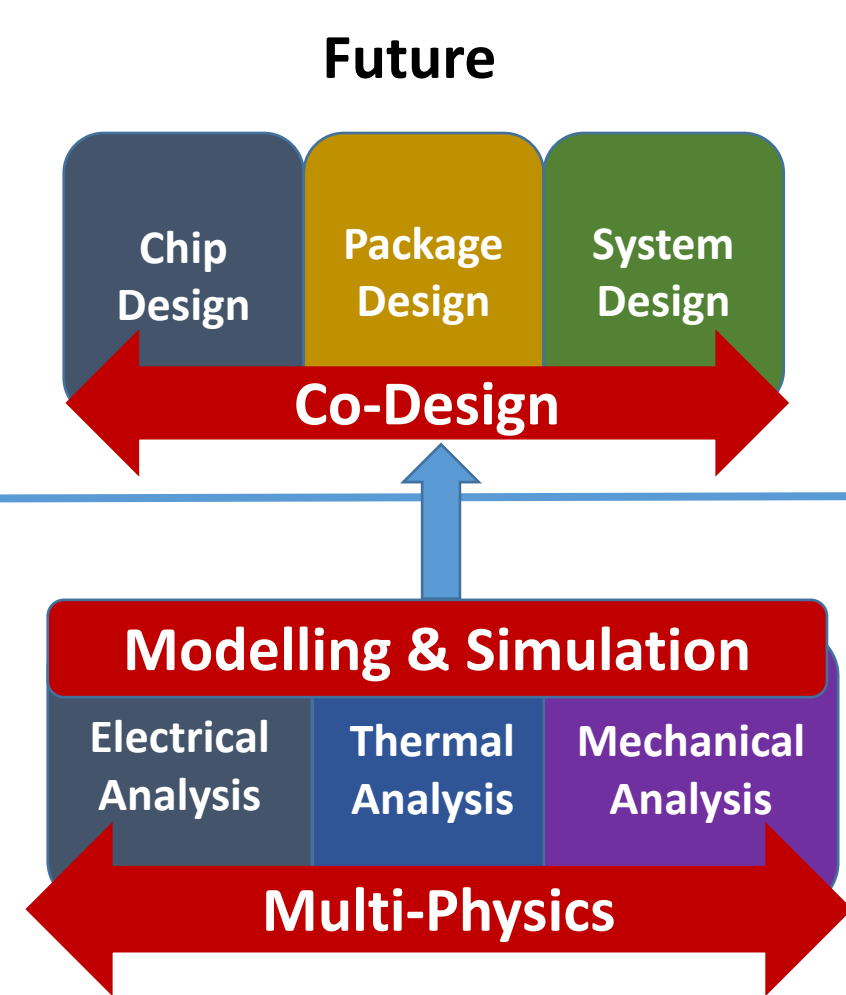
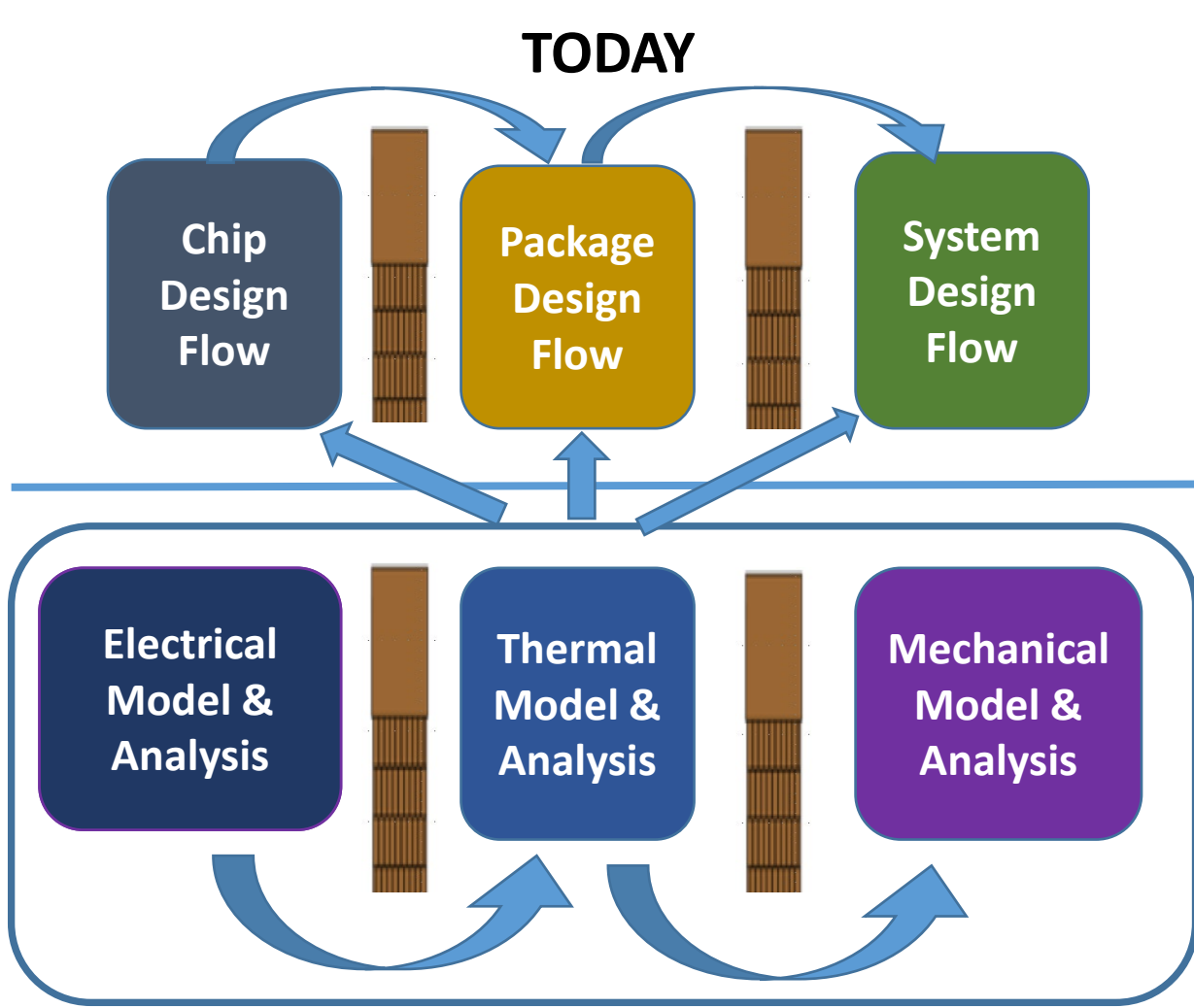
Machine Learning Algorithms

- Bayesian
  - Naive Bayes
  - Averaged One-Dependence Estimators (AOOE)
  - Bayesian Belief Network (BBN)
  - Gaussian Naive Bayes
  - Multinomial Naive Bayes
  - Bayesian Network (BN)
- Decision Tree
  - Classification and Regression Tree (CART)
  - Iterative Dichotomiser 3 (ID3)
  - C4.5
  - CS.O
  - Chi-squared Automatic Interaction Detection (CHAID)
  - Decision Stump
  - Conditional Decision Trees
  - M5
- Dimensionality Reduction
  - Principal Component Analysis (PCA)
  - Partial Least Squares Regression (PLSR)
  - Sammon Mapping
  - Multidimensional Scaling (MDS)
  - Projection Pursuit
  - Principal Component Regression (PCR)
  - Partial Least Squares Discriminant Analysis
  - Mixture Discriminant Analysis (MDA)
  - Quadratic Discriminant Analysis (QDA)
  - Regularized Discriminant Analysis (RDA)
  - Flexible Discriminant Analysis (FDA)
  - Linear Discriminant Analysis (LDA)
- Instance Based
  - k-Nearest Neighbor (kNN)
  - Learning Vector Quantization (LVQ)
  - Self-Organizing Map (SOM)
  - Locally Weighted Learning (LWL)
- Clustering
  - k-Means
  - k-Medians
  - Expectation Maximization
  - Hierarchical Clustering
- Neural Networks
  - Perceptron
  - Back-Propagation
  - Hopfield Network
  - Ridge Regression
- Regularization
  - Least Absolute Shrinkage and Selection Operator (LASSO)
  - Elastic Net
  - Least Angle Regression (LARS)
  - Cubist
- Rule System
  - One Rule (OneR)
  - Zero Rule (ZeroR)
- Regression
  - Repeated Incremental Pruning to Produce Error Reduction (RIPPER)
  - Linear Regression
  - Ordinary Least Squares Regression (OLSR)
  - Stepwise Regression
  - Multivariate Adaptive Regression Splines (MARS)
  - Locally Estimated Scatterplot Smoothing (LOESS)
  - Logistic Regression

Graphs showing Stress (Mpa) vs Displacement (Angstrom) for CuO seeded interface. Parameters:  $N_{Cu} = 153380$ ,  $N_{CuO} = 143380$ ,  $C_{Cu} = 1714 \text{ J/m}^3$ .

Graphs showing  $e_i$  vs  $\theta_i$  for  $i=1, 2, 3$  and a plot of  $\Delta\omega_{obs}(\theta_1, \varphi_1)$  vs  $\omega_0$ .

## Moving towards a New Paradigm





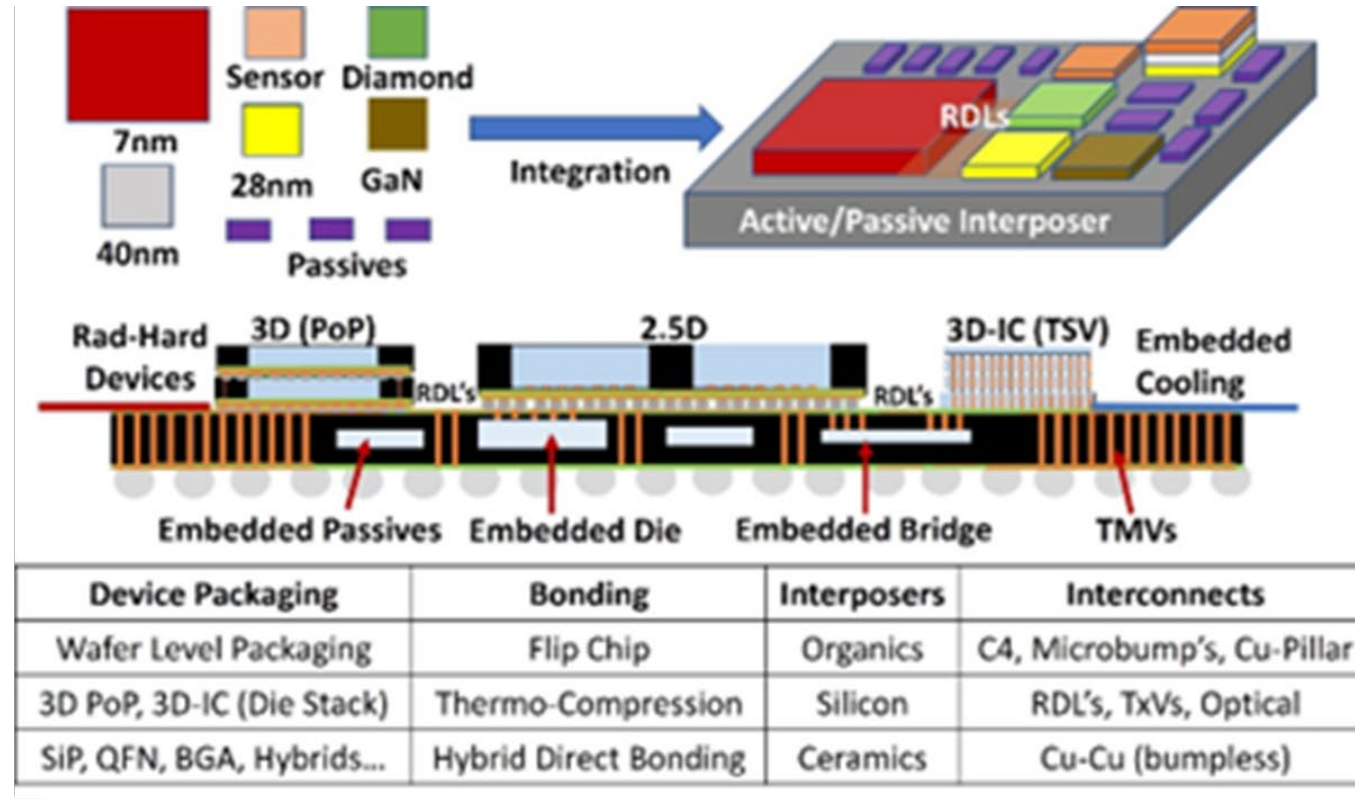
## Moving towards chiplets

Design

Materials

Processes

Environments



Electrical

Performance

Thermal

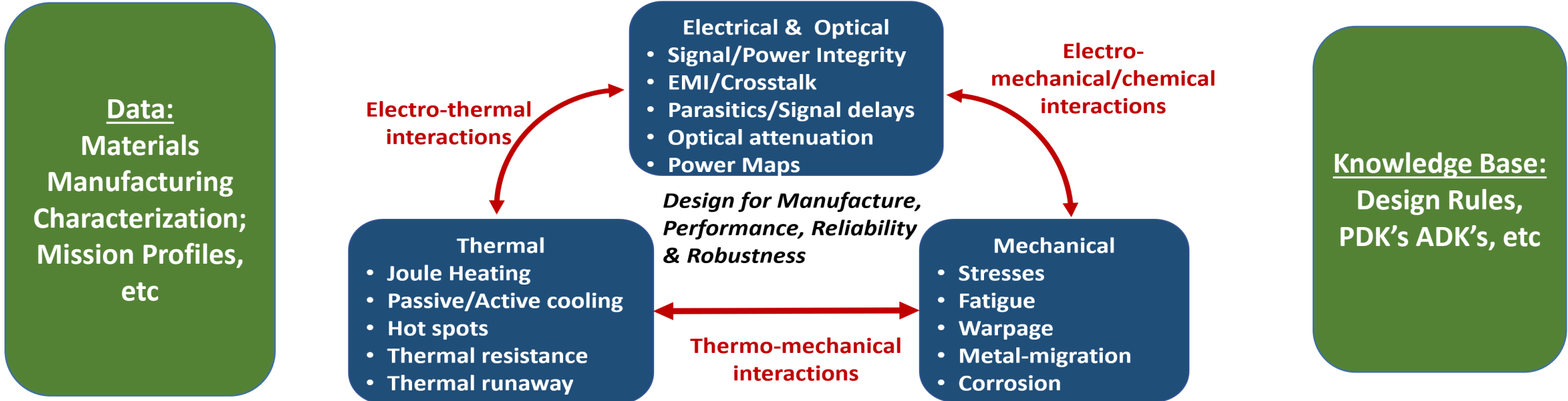
Mechanical

Reliability

- Multi-domain/co-simulation requirements
- Large design space for multi-objective optimization

## Modeling & Simulation

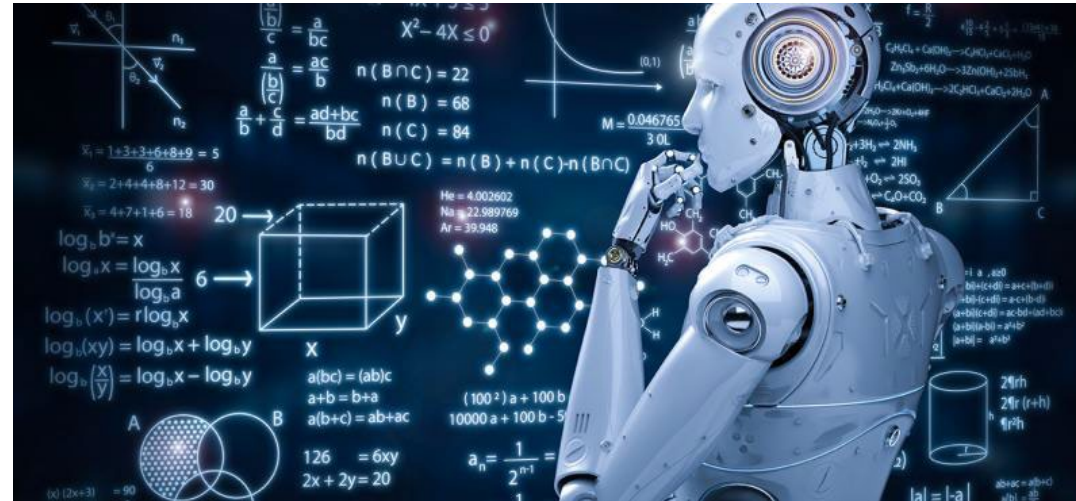
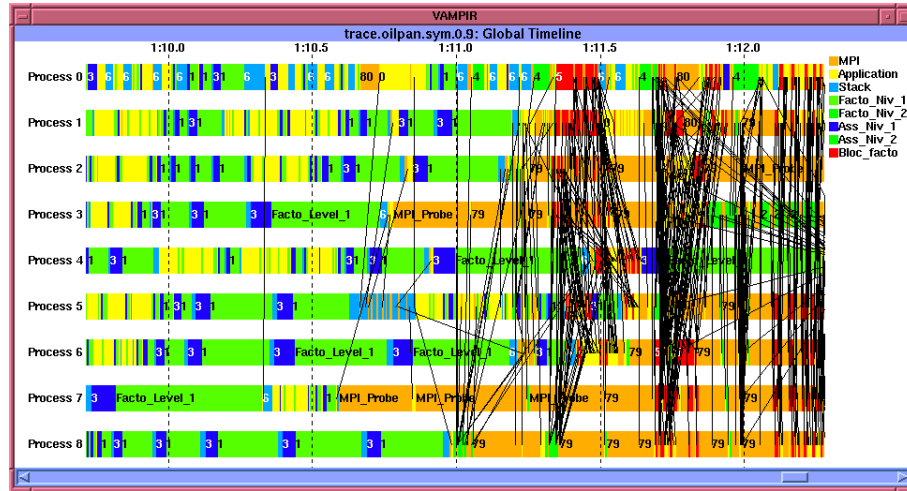
**Scale:**      Devices (nm)      Packages(um-mm)      Boards (mm-cm)      Systems (cm-m)



**Model Fidelity:**      Analytical      Circuit/Network      Compact/Response Surface      MOR      MD/FEA/CFD

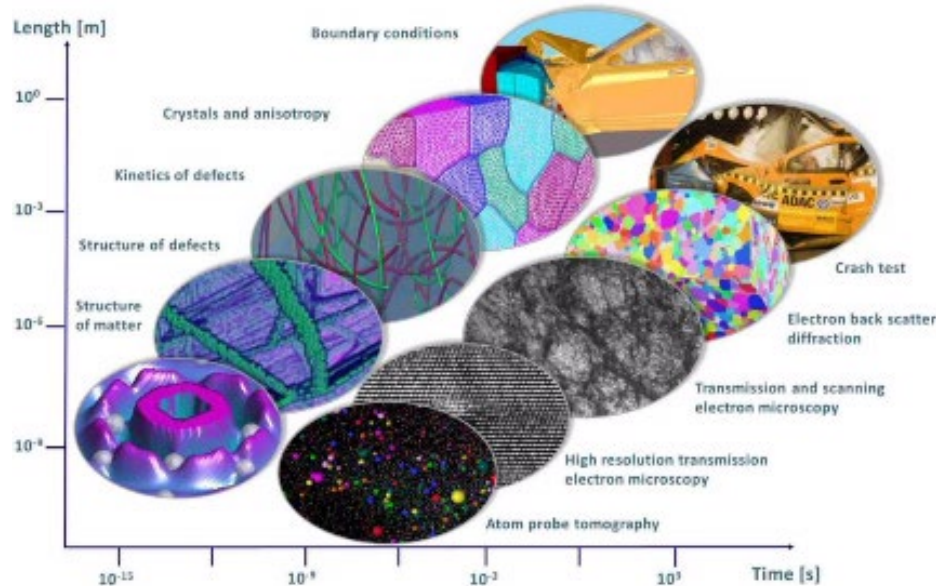
Model based Optimization; Big Data Analytics; Physics of Failure Models; Prognostics; etc.

## Potential Solutions

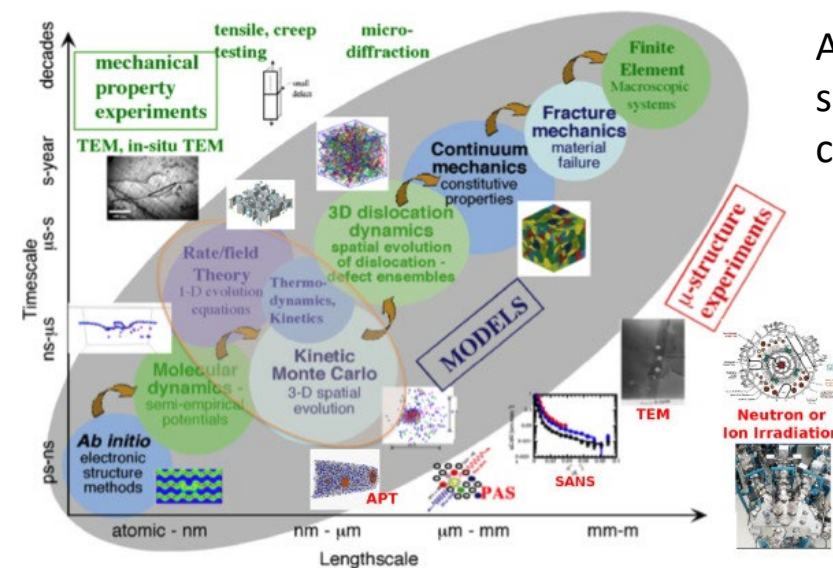


AI/ML applications

Advanced solvers  
(CPU, CPU-GPU,  
Cloud AWS, and  
DSA).



Multi-scale  
modeling

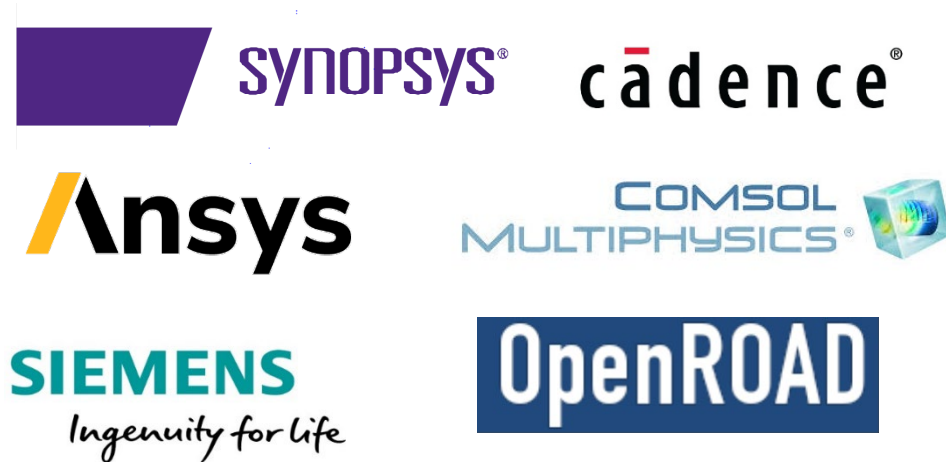


Advanced multi-scale  
material  
characterization.



## Potential Solutions - Tools

EDA suppliers are enabling multiphysics and system co-design solutions through on-going developments:



- No single tool can do it all.
- Modular architecture to 3<sup>rd</sup> party simulation tools
- Open access data formats
- 3D-ADK's

Rajen Murugan (Texas Instruments, EuroSimE 2021, HIR Panel)



- Chip-package-board interactions
  - Floor planning, Shielding
  - TxV locations
  - Design of cooling structures
  - Chip-package interactions
  - Package Board interactions
- Multi-physics aware design
  - Electro-thermal
  - Thermo-mechanical
  - Physics of Failure
- AI enhanced design space exploration

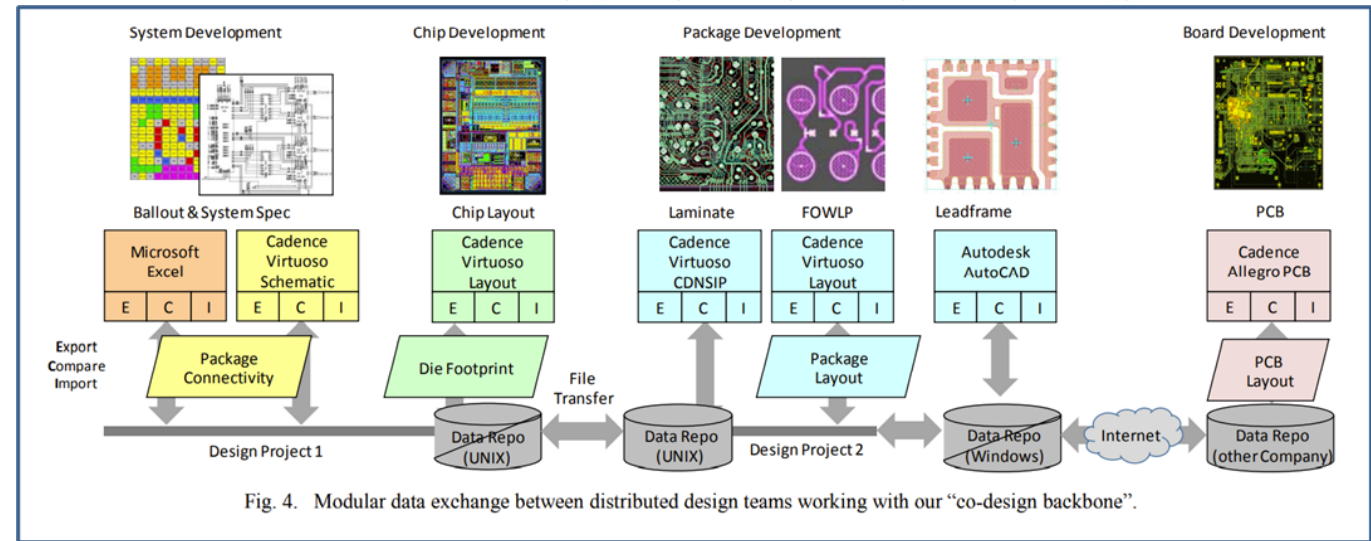
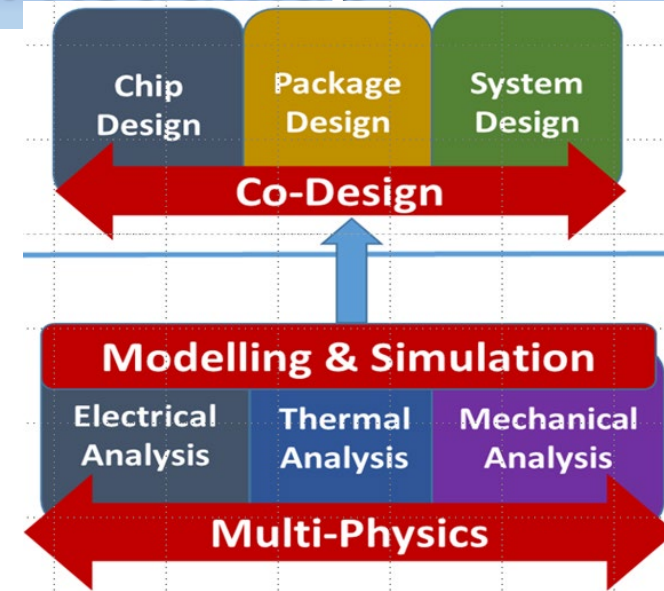
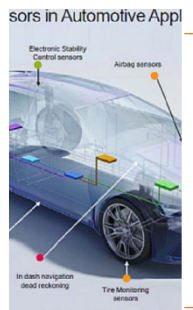


Fig. 4. Modular data exchange between distributed design teams working with our "co-design backbone".

T. Brandtner et-al, "Chip/Package/Board Co-Design Methodology Applied to Full-Custom Heterogeneous Integration," ECTC, 2020

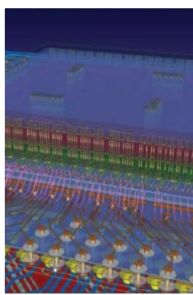
## Applications



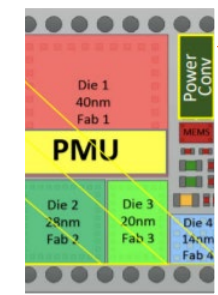
MEMS



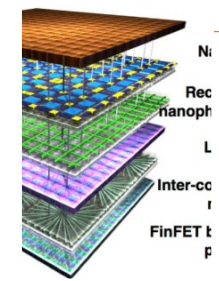
Reliability



Manufacturing Process



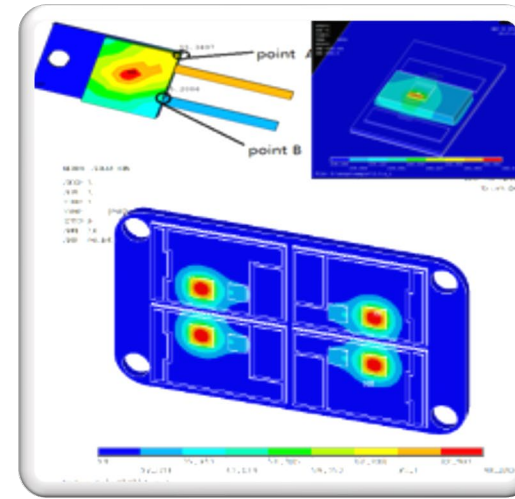
Composite Materials



Digital Twin

## Digital Twin

In-situ Data-monitoring and updating



- Digital Twin is the ultimate aim of product design, reliability and lifetime management.
- Modeling and Simulation plays a vital role in digital twin realization.

Physical world



Virtual world

Adaptive Design, Plan, Decision and Strategy Feedback

## Plans for next edition

- Plans for next edition
  - Expand/revise current sections
  - Strong theme for Chiplets
  - New section on photonics
  - New Section on Process Modelling
- Current linkages with TWG's
  - Co-Design (Need for fast analysis)
  - Single and Multi-Chip
  - Automotive
  - MemS and Sensors
  - Reliability
  - Thermal
  - Supply Chains



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## Ensuring Roadmaps Align

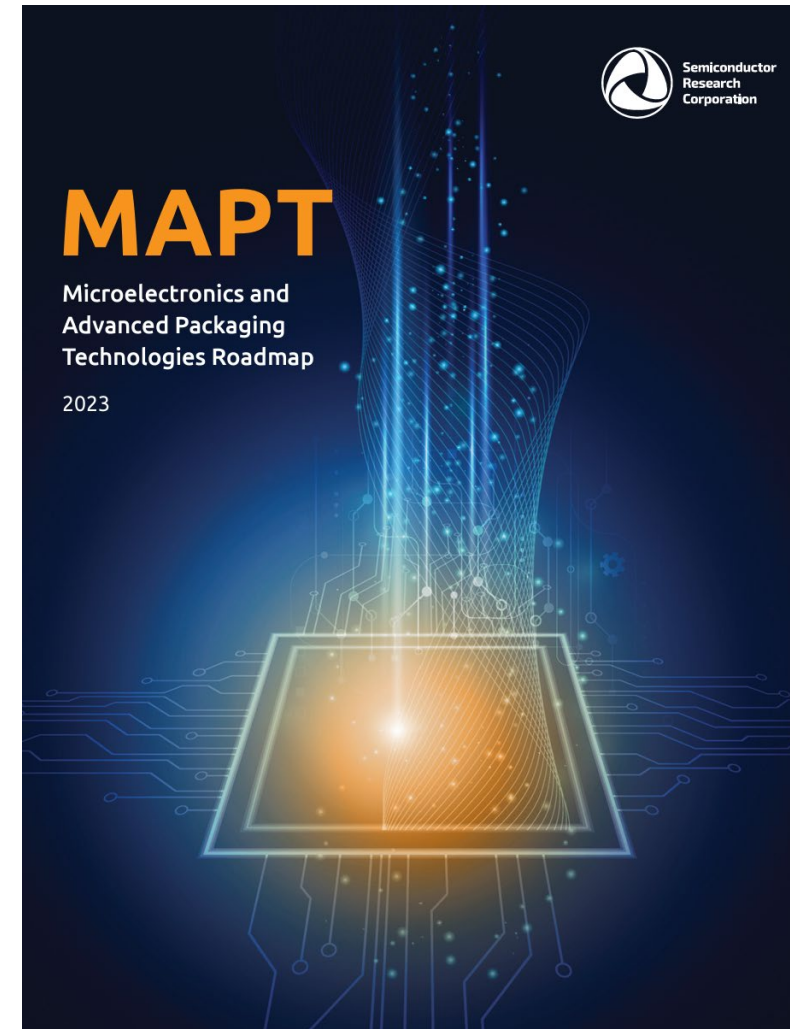


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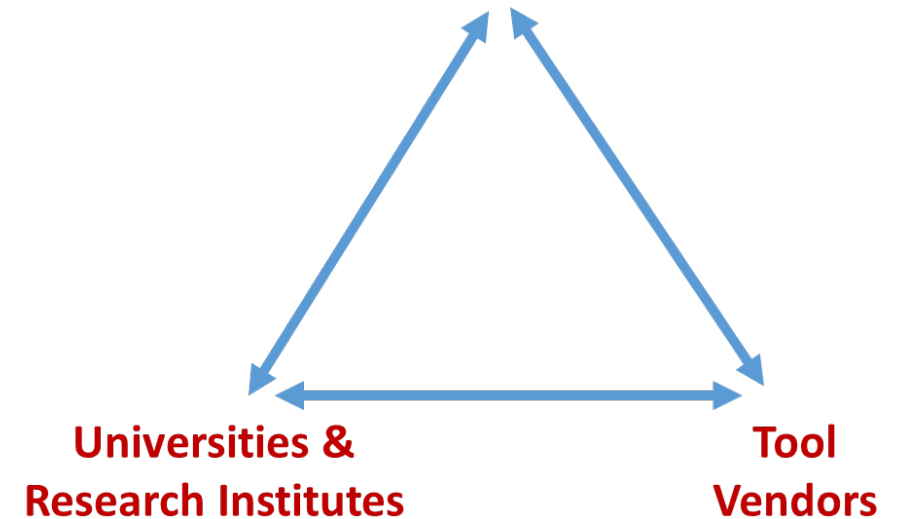


## Thank You

### TWG Members & Contributors

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- Kouchi Zhang (TU Delft)

**Industry and Designers of  
Heterogeneous Integrated System**



**We welcome new participants**

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