HETEROGENEOUS INTEGRATION ROADMAP

Modelling & Simulation

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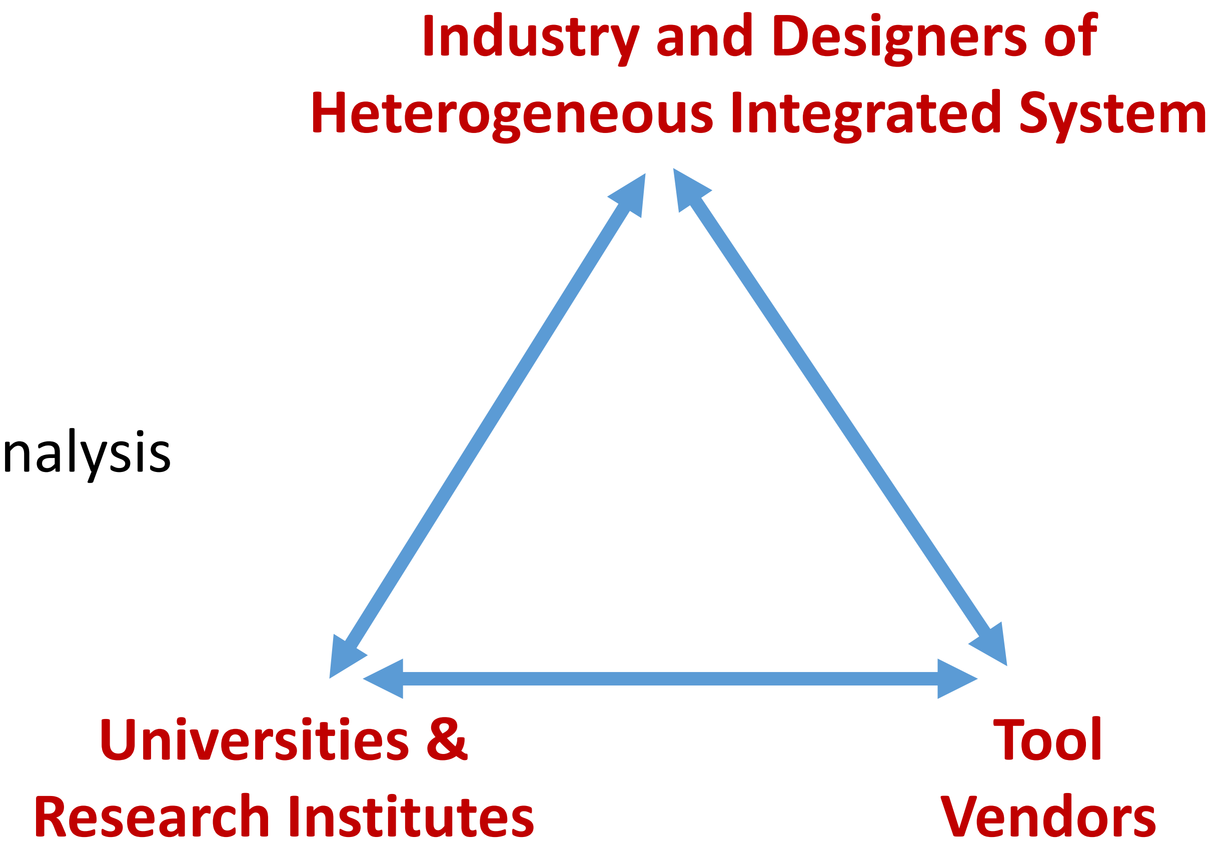
Co-Chairs

Scope

- Key Stakeholders
- Five sections
  - Electrical Analysis
  - Thermal Analysis
  - Materials Modelling
  - Mechanical & Multi-Physics Analysis
  - Reliability and Prognostics
- Chapter details
  - State of the Art
  - Challenges/Requirements
  - Potential solutions



Industry and Designers of Heterogeneous Integrated System

Universities & Research Institutes

Tool Vendors

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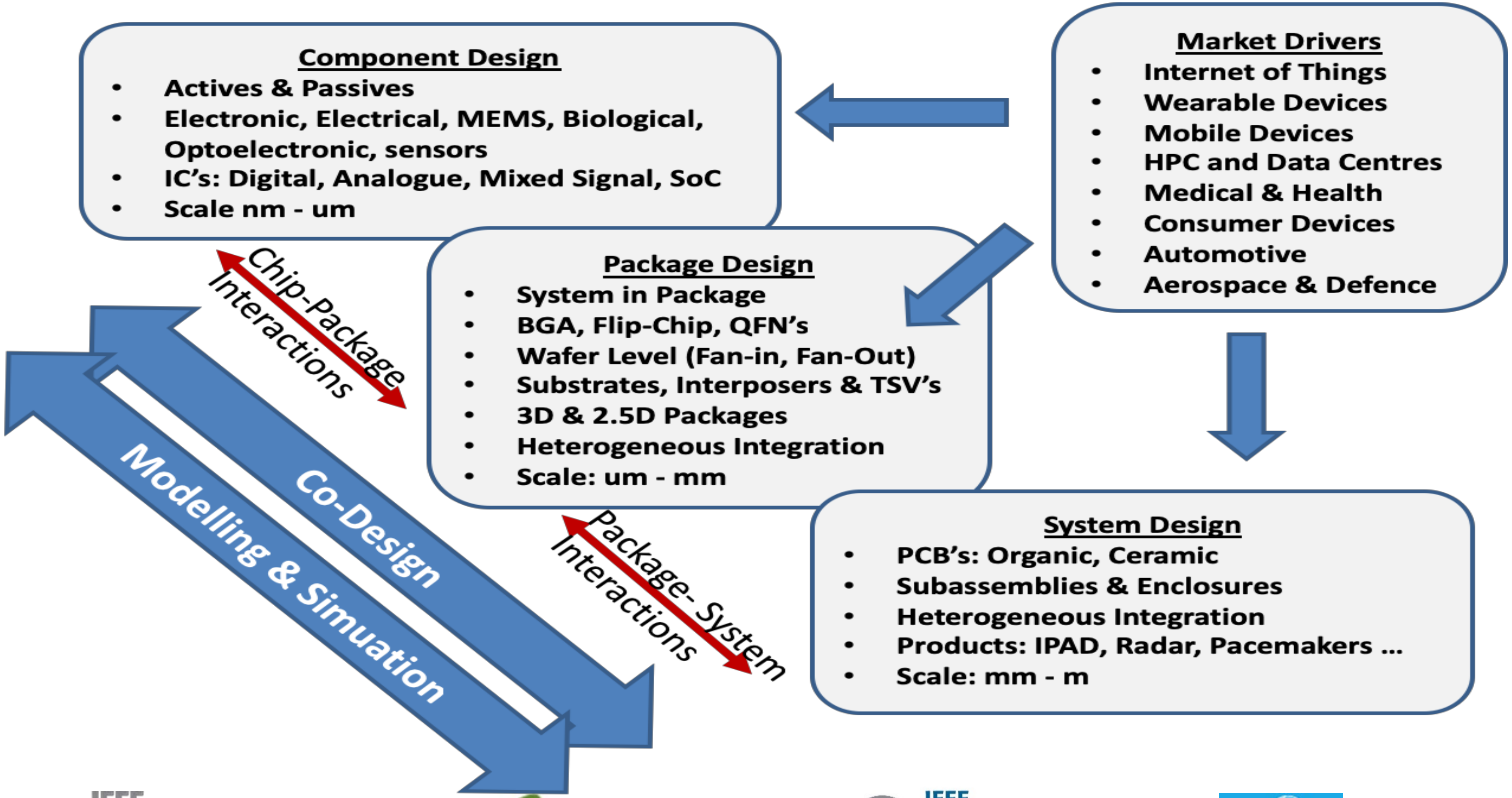
Supporting the Knowledge Base for HI



Component Design
- Actives & Passives
- Electronic, Electrical, MEMS, Biological, Optoelectronic, sensors
- IC's: Digital, Analogue, Mixed Signal, SoC
- Scale nm - um

Market Drivers
- Internet of Things
- Wearable Devices
- Mobile Devices
- HPC and Data Centres
- Medical & Health
- Consumer Devices
- Automotive
- Aerospace & Defence

Package Design
- System in Package
- BGA, Flip-Chip, QFN's
- Wafer Level (Fan-in, Fan-Out)
- Substrates, Interposers & TSV's
- 3D & 2.5D Packages
- Heterogeneous Integration
- Scale: um - mm

System Design
- PCB's: Organic, Ceramic
- Subassemblies & Enclosures
- Heterogeneous Integration
- Products: IPAD, Radar, Pacemakers …
- Scale: mm - m

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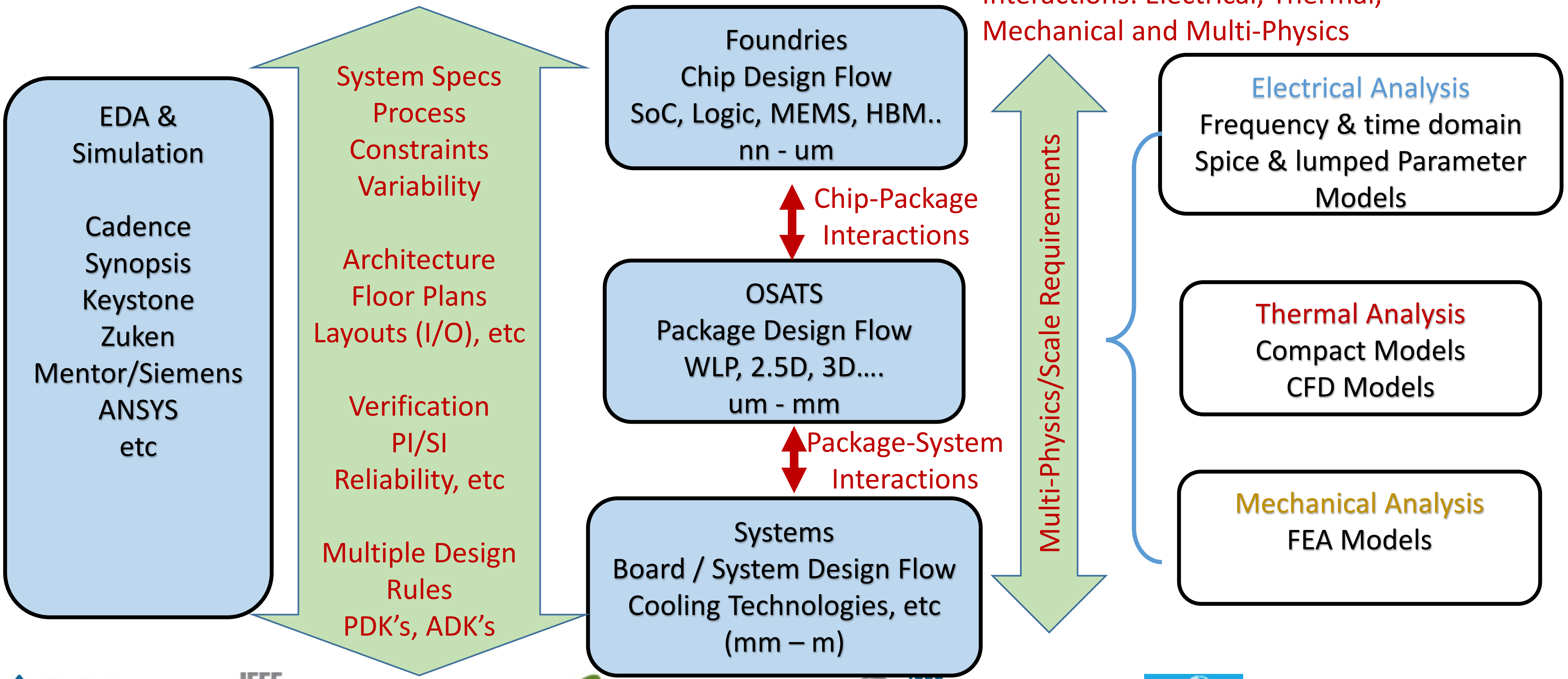
HI Design and Simulation Environment



Interactions: Electrical, Thermal,
Mechanical and Multi-Physics

EDA &
Simulation

Cadence
Synopsis
Keystone
Zuken
Mentor/Siemens
ANSYS
etc

System Specs
Process
Constraints
Variability

Architecture
Floor Plans
Layouts (I/O), etc

Verification
PI/SI
Reliability, etc

Multiple Design
Rules
PDK's, ADK's

Foundries
Chip Design Flow
SoC, Logic, MEMS, HBM..
nn - um

Chip-Package
Interactions

OSATS
Package Design Flow
WLP, 2.5D, 3D….
um - mm

Package-System
Interactions

Systems
Board / System Design Flow
Cooling Technologies, etc
(mm – m)

Multi-Physics/Scale Requirements

Electrical Analysis
Frequency & time domain
Spice & lumped Parameter
Models

Thermal Analysis
Compact Models
CFD Models

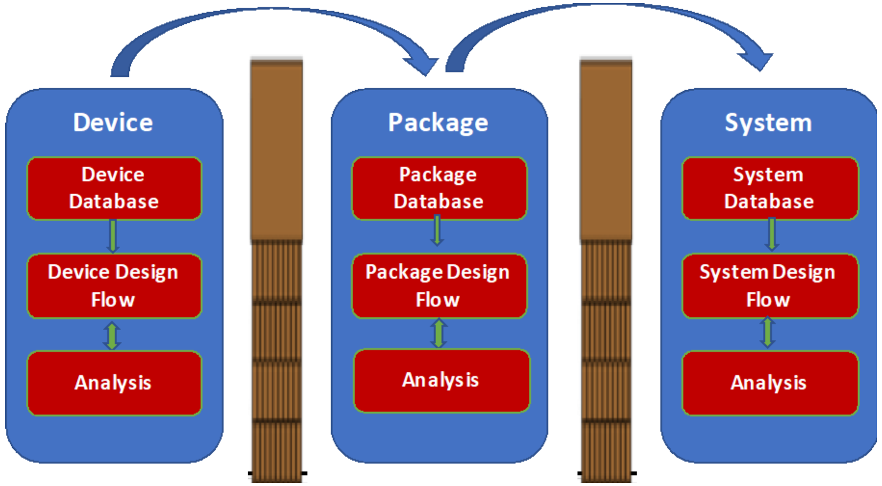
Mechanical Analysis
FEA Models

Moving towards a new Paradigm

Chip Design → Package Design → System Design

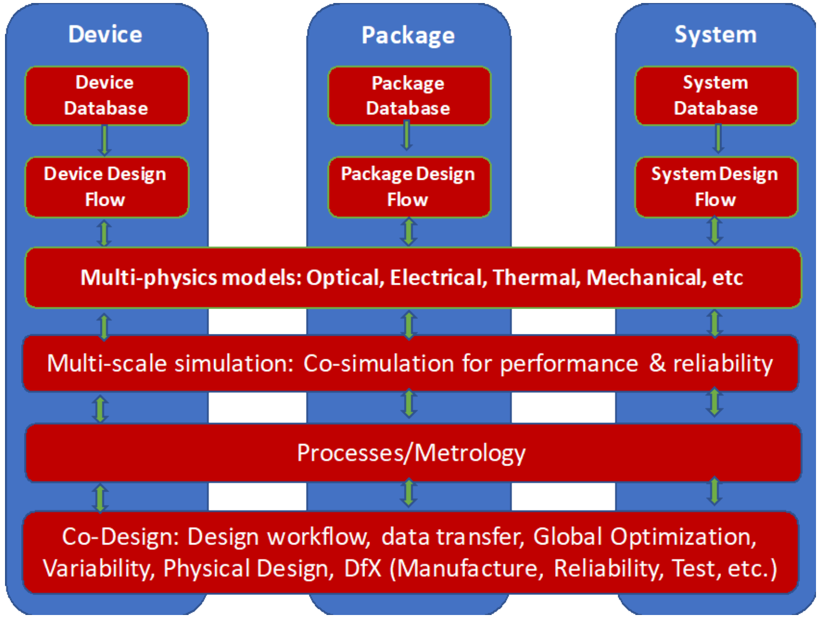
2 Years · 6 Months · 12 Months

Today (Generally)



- Different design flows / Tools
- EDA (Spice Models, PDK's)
- Packaging (ADK's);Therma/Mechanical – System level

Future

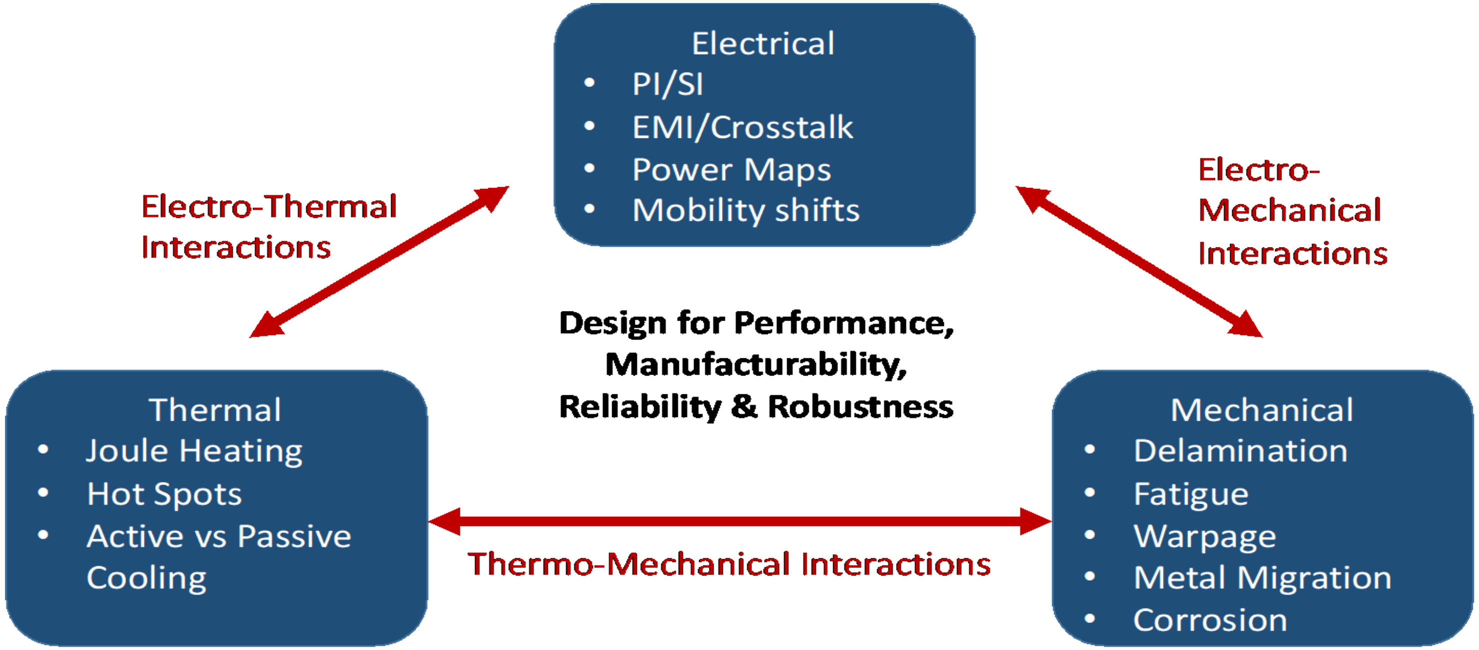


- Design flow that captures Multi-Physics/Scale Interactions
- Collaborative Design
- System aware design

Multi-Physics/Scale Domains

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

Data:
Materials
Manufacturing
Characterization;
Mission Profiles,
Industry 4.0, etc



Electrical
- PI/SI
- EMI/Crosstalk
- Power Maps
- Mobility shifts

Electro-Thermal Interactions

Electro-Mechanical Interactions

Design for Performance, Manufacturability, Reliability & Robustness

Thermal
- Joule Heating
- Hot Spots
- Active vs Passive Cooling

Mechanical
- Delamination
- Fatigue
- Warpage
- Metal Migration
- Corrosion

Thermo-Mechanical Interactions

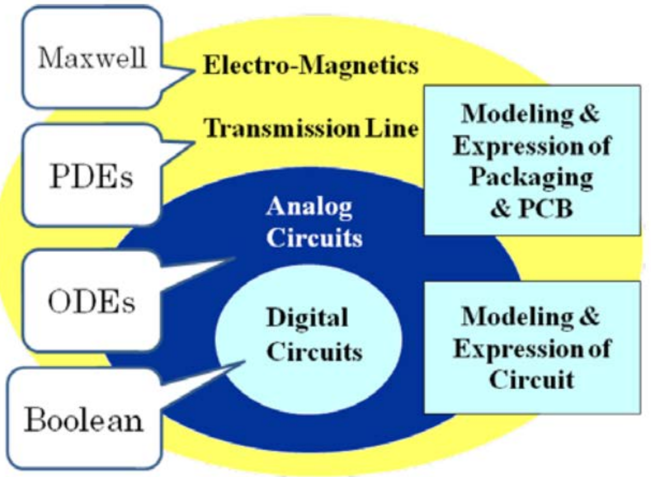
Knowledge Base:
Design Rules,
PDK's ADK's, etc

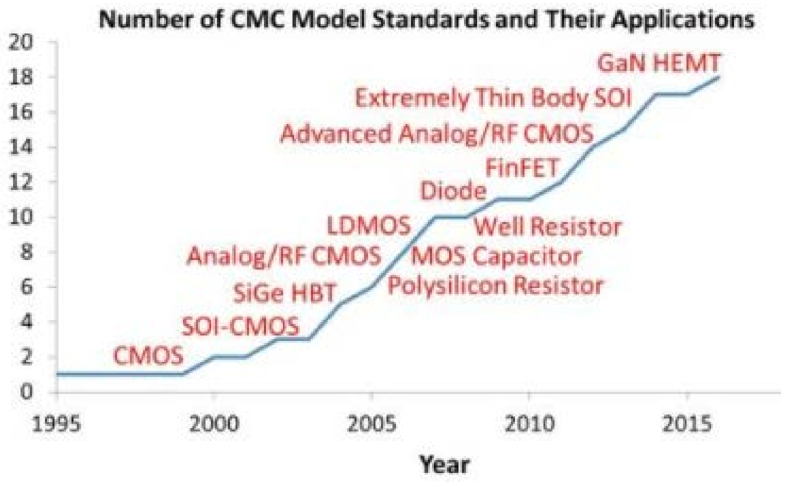
Model Fidelity: Analytical Circuit/Network Compact/Response Surface MOR MD/FEA/CFD

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

Electrical Analysis

- State of the art
  - Solvers: SPICE, IBIS, MoMaxwell Solvers (FDTD), etc.
  - Customised solutions for die, package and system
- Challenges/Requirements
  - Accurate simulations for scale of features (die <-> package <–> System)
  - Standardisation of interface files between tools
- Potential Solutions
  - Compact models for co-analysis
  - Integrated solutions for Power and Signal Integrity / EMC, etc
  - Application of machine learning for generating fast models for use in HI EDA design flows

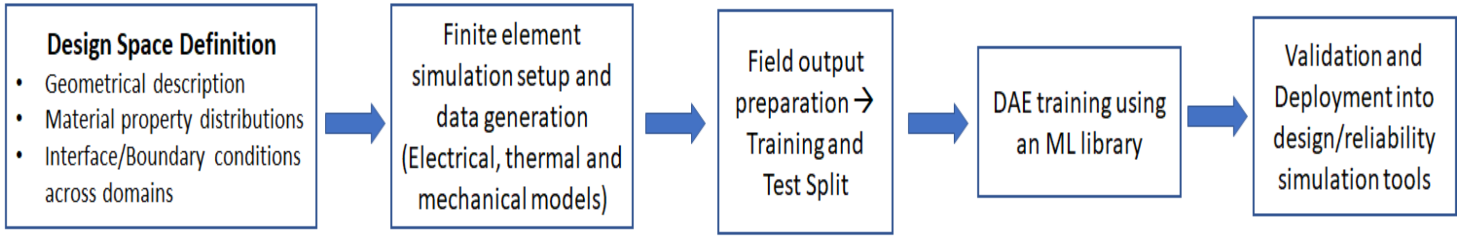




The CMC has been developing modeling standards for nearly two decades.

Thermal Analysis

- State of the art
  - CFD/FEM: Complex set-up
- Challenges/Requirements
  - Self heating - Localised hot-spots
  - Ability to predict temperatures across the length scales
  - Accurate models for active cooling
- Potential Solutions
  - Probabilistic input parameters to CFD
  - Use CFD models for machine learning training for deep autoencoders (DAE)
  - Use DAE in HI EDA design flows



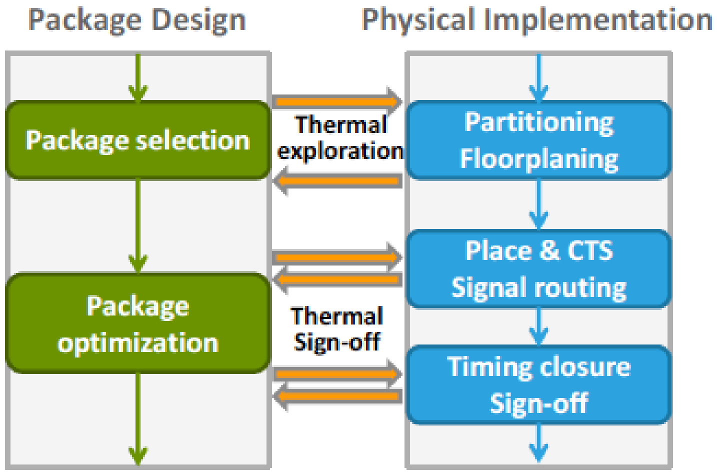
Design Space Definition
- Geometrical description
- Material property distributions
- Interface/Boundary conditions across domains

Finite element simulation setup and data generation (Electrical, thermal and mechanical models)

Field output preparation → Training and Test Split

DAE training using an ML library

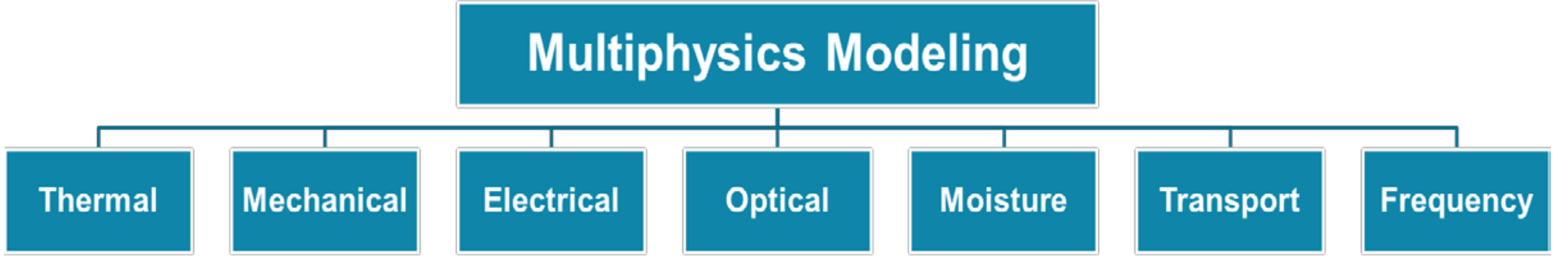
Validation and Deployment into design/reliability simulation tools



Package-Die Thermal Design Flow

DAC Designer Track 2017 | ***Pascal Vivet***

Mechanical & Multi-Physics



- State of the art
  - Finite Element tools
  - Compute intensive tools
- Challenges/Requirements
  - Stress in die due to package constraints
  - Stochastic Models for Materials
  - Multi-physics aware floor-planning/placement
- Potential Solutions
  - Fast accurate ROM models for stress/warpage
  - Combined physics models with machine learning
  - Integrate into HI EDA design flow

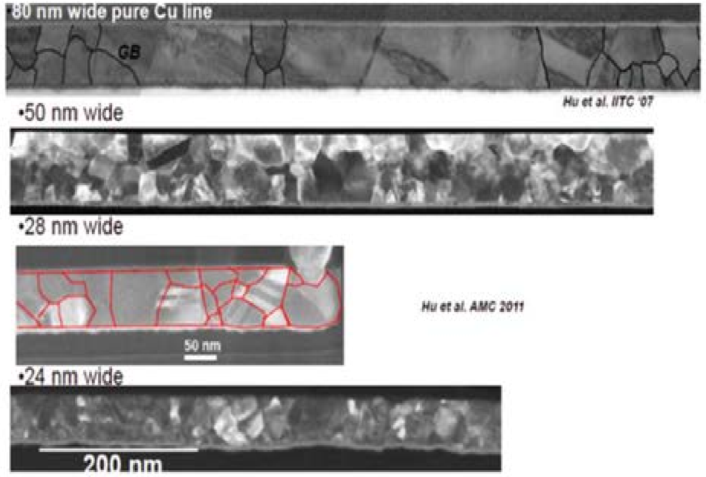


Fig. 7 Copper metal line scaling over the past generations of CMOS technology

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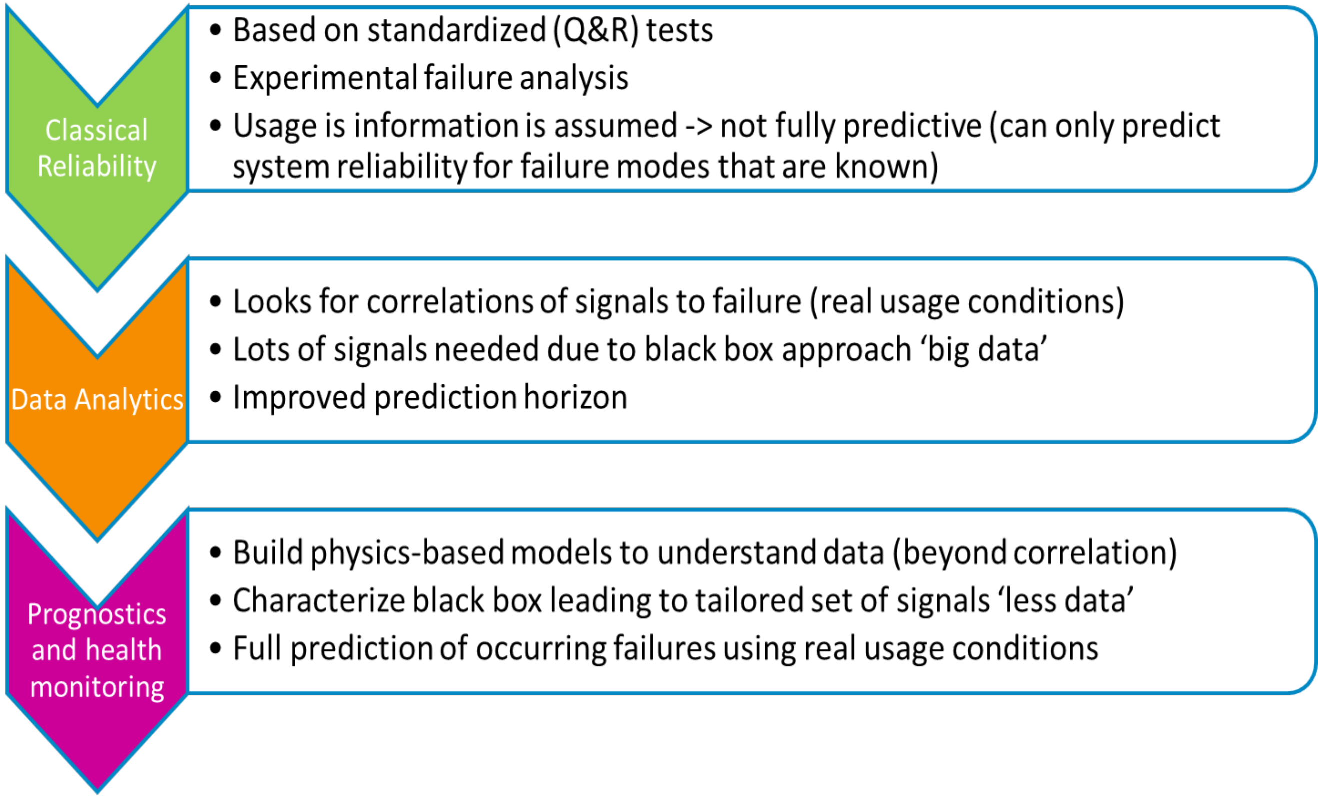
Reliability & Prognostics

- State of the art
  - Classical reliability
  - Physics of failure (PoF) models
- Challenges/Requirements
  - New failure mechanisms/modes
  - System health management
  - Smart Testing
- Potential Solutions
  - New PoF models
  - Prognostics (Data and model driven)
  - Combined physics models with machine learning for integration into HI EDA design flows



Classical Reliability

- Based on standardized (Q&R) tests
- Experimental failure analysis
- Usage is information is assumed -> not fully predictive (can only predict system reliability for failure modes that are known)

Data Analytics

- Looks for correlations of signals to failure (real usage conditions)
- Lots of signals needed due to black box approach 'big data'
- Improved prediction horizon

Prognostics and health monitoring

- Build physics-based models to understand data (beyond correlation)
- Characterize black box leading to tailored set of signals 'less data'
- Full prediction of occurring failures using real usage conditions

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Metrics

Metric	5 years	10 years	15 years
Concept to Product	5 years	3 years	18 months
DfR (Accuracy)	200%	150%	110%
Product validation in Virtual Environment	50%	70%	100%
AI/Machine Learning	Use of Machine Learning - - single package and physics	Use of Machine Learning - multiple packages and single physics	Use of Machine Learning - for multiple packages and physics
Multi-Physics	Electro-thermal analysis at single package level (chip-package co-design)	Accurate multi-physics analysis for chip-package co-design	Accurate multi-physics analysis for whole system
Data Sharing	Interfaces between tools and ADK's and PDK's	Data and model sharing through supply chain	

Acknowledgements and Status

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  - Chris Bailey (University of Greenwich)
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- Status
  - Version 1 complete
  - Editing taken place
  - Some minor additions expected
    - Reliability section
    - Metrics
  - Ready for peer review
  - Version 2
    - Closer alignment with Co-Design Chapter
    - Optical analysis
    - Materials Characterisation for models