Keynote:

Next Phase in ASML's Digital Engineering

Modular-Swift-Precision Modelling

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ASML D&E Mechanical Development Cluster

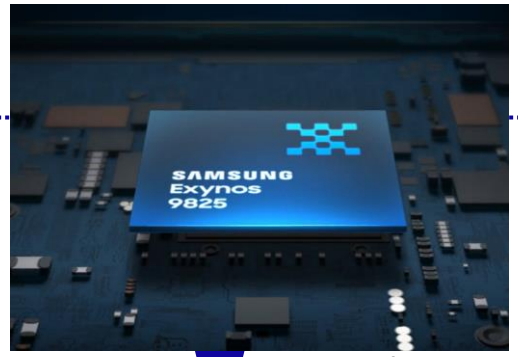
euspen

Special Interest Group Meeting: Thermal Issues

Mar 13th, 2024

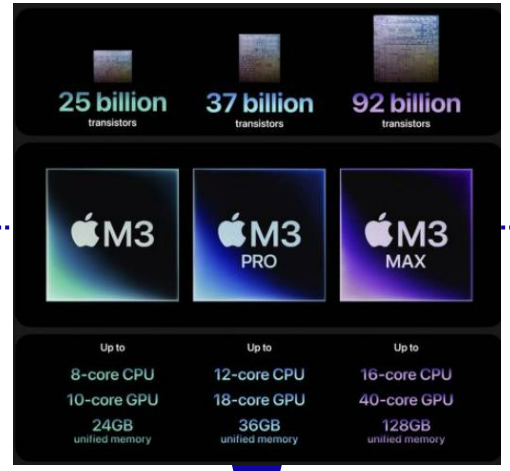
State of the world semiconductors → ASML's critical role in it

Node transitions ongoing with advancements in AI, Cloud Computing, Wearables, 5G, e-Mobility …



Courtesy of SAMSUNG

Courtesy of NVIDIA



Courtesy of Apple

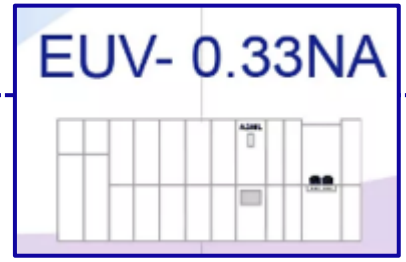
FOUNDRY NODES

7 nm

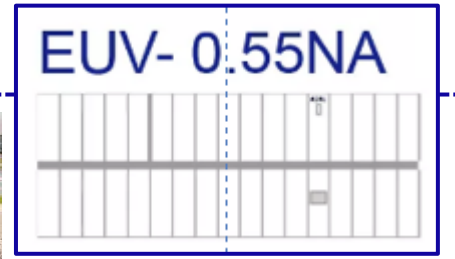
5 nm

3 nm

2 nm



1st High NA system shipped to Intel

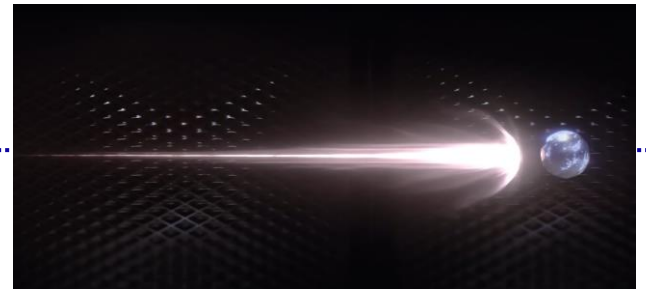


The reduction of feature and device size for high volume manufacturing

What does this mean for engineering the next ASML machines?

$$CD = k_1 \bullet \lambda / NA$$

Availability — **Throughput**

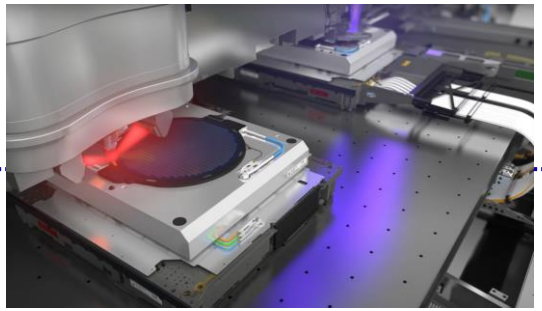


Courtesy of TRUMPF

New EUV Light Source

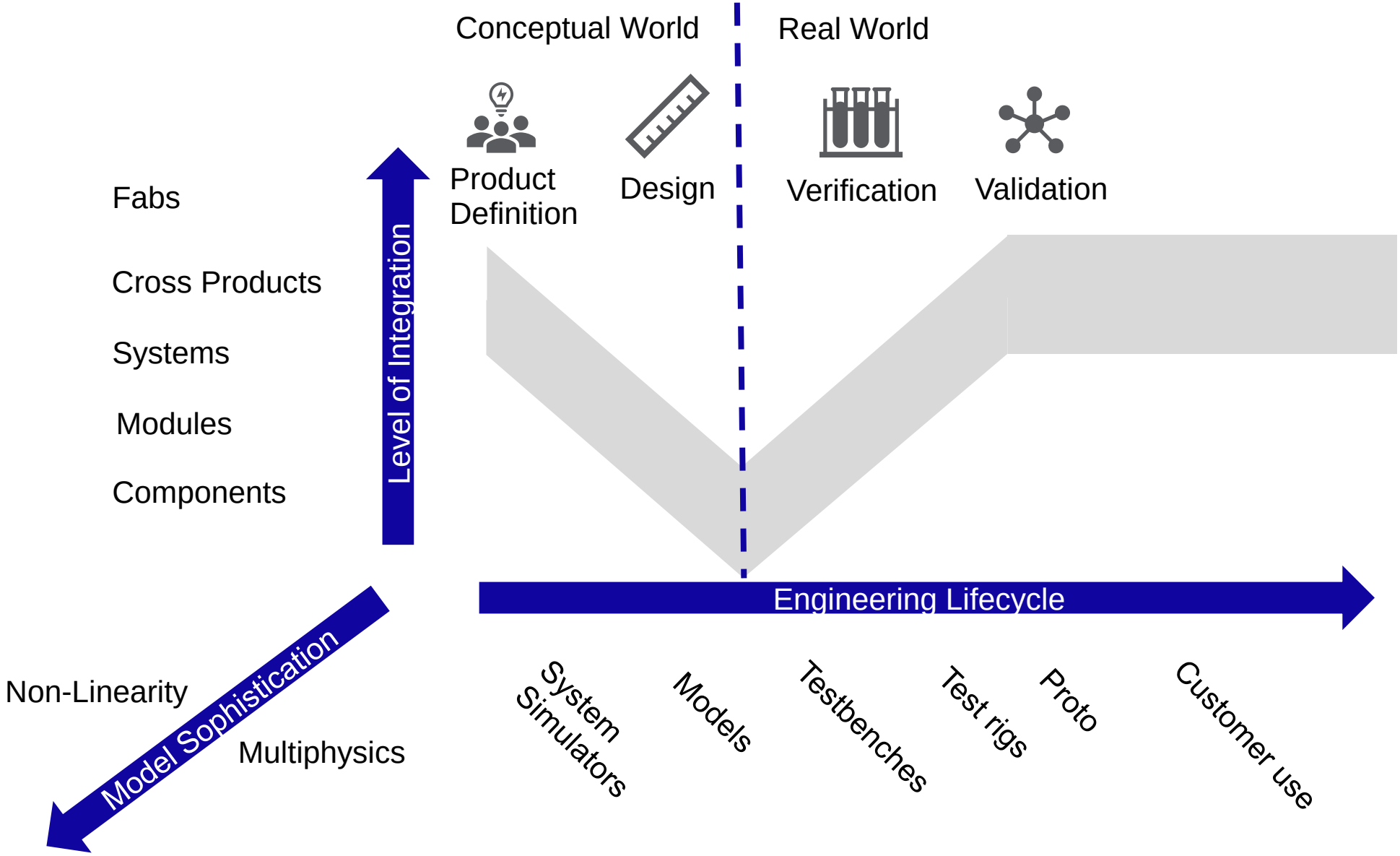
with ambitious power ramp, dose stability, spectral content and lifetime needs.

Larger mirrors with higher NA and ultrasmooth, multilayer surfaces



High accelerations in Wafer & Reticle Stages with ultra-precision positioning control needs

What are dimension of complexity for modelling and simulations?



Repositioning Modeling & Simulation in engineering lifecycle:
Enabling earlier decisions and predictability at higher system levels

FASTER

EARLIER

SLOW

LATE

Model-based system engineering

Opportunity: model re-use at system & solution level

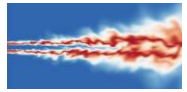
… to reduce integration problems for FCs

Diagnostics

Virtual pre-integration

Software verification

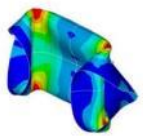
Design cycles are iterations on models



Everything that is specified is modeled

Most Functional Clusters (FC) work completely model-driven

Models are used to verify implementations



Models are used to make design decisions

Implementation is the realization of models

The predicted challenges on this path

PHYSICS

- Machine functions are multi-physics driven. Naturally complex
- There are many non-linearities existing in system behavior.
- Various multi-domain modelling tools exist in ASML ecosystem.

INTERFACES

- Functional Clusters (FCs) use different technologies for their modeling (Python, MATLAB, Julia, …)
- Standardized model architecture to match functional decomposition with interface management
- model interoperability with other models and SW interceptors

CONFIGURATION & TRACEABILITY

- Creating models without governance will lead to chaos
- Simulation Governance tooling needed: simulation process data management (SPDM) systems linked to PLM
- Proper configuration management to track unique machine variants
- models, requirements, assumptions, parameters→

  linked system objects space

VERIFICATION & VALIDATION

- How do we verify that the simulated performance is representative for the real machine? i.e. Model Credibility assessment as an identity data attached to models
- Parameter variance and their impact on output parameter space

Why do we need a modular-swift-precision modelling concept?

To manage complexity + verify control characteristics + produce predictive outputs

MODULARITY

- ASML machine development is divided into functional modularity.
- For scaling from simpler modules to large complex systems in the machine
- Plug&Play

X
IN-THE-LOOP

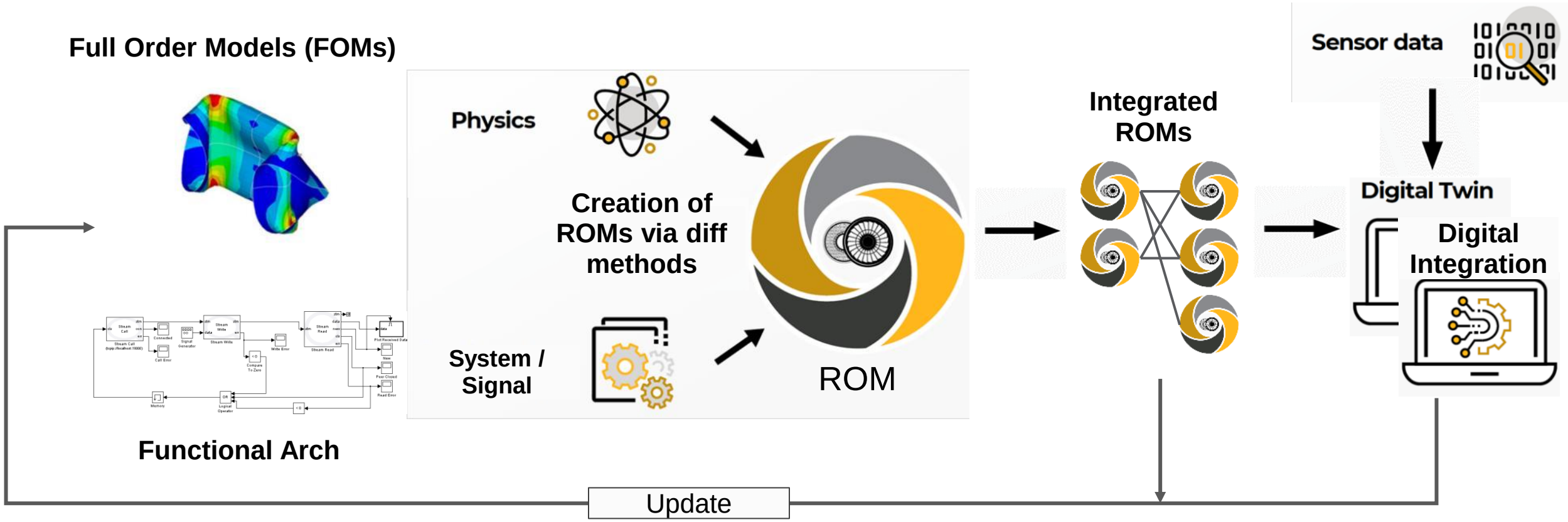
- ASML machines are continuously under position, temperature, acceleration, flow control to meet customer Overlay & throughput requirements.
- Software drives actuation at high kHz frequency rates.

PRECISION

- Parameter variance and their effect on functional outputs
- Specs from uK to hundreds of K's, from pm to m. Range is large for the whole machine.

Digital Assets: Reduced Order Models → Fast-Accurate multiphysics models

ROMs bring cost-effective predictability for large complex systems



Comprehensive, Accurate, Slow, Costly

Simpler, Faster, Predictive, Scalable

Reduced Order Models

Both physics-based and data-based are investigated per sub-system dynamic behavior

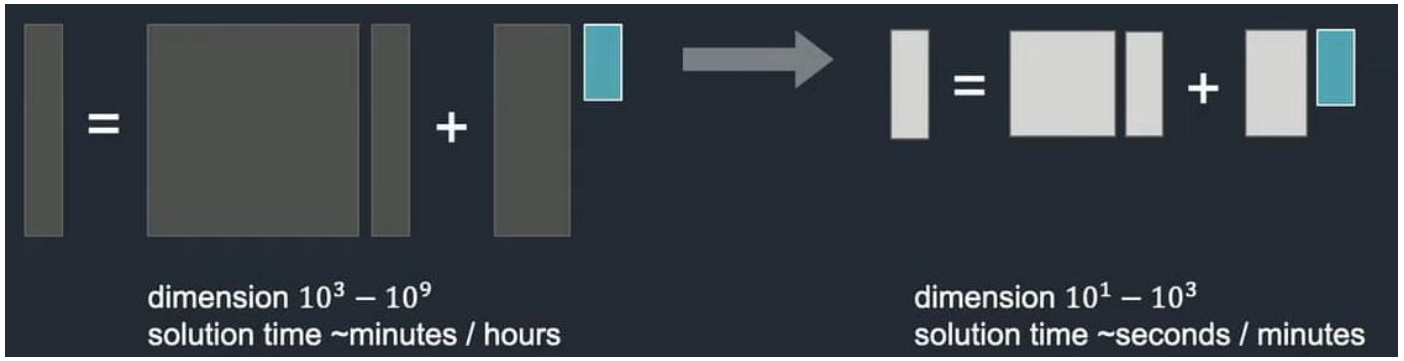


Illustration by Prof. Karen E Willcox
Oden Institute, U of Texas

Physics Based ROMs

!

$$\rho c_p \frac{\partial T}{\partial t} - \nabla \cdot (k \nabla T) = \dot{q}_V$$

Start with underlying system partial differential equations

1st Principles Models: 0D Lumped

Craig Brampton

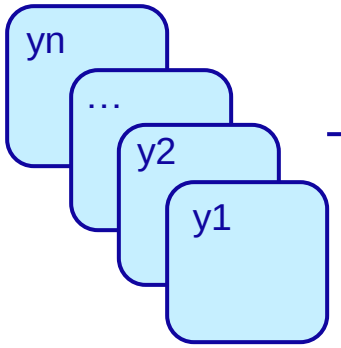
Proper Orth Decomp

⋮

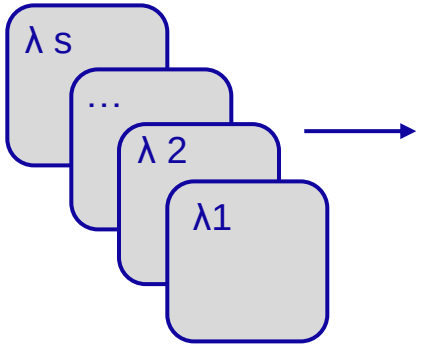
$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

Continuous /Discrete State Space

Data Based ROMs



Snapshots in time



DMD modes
System Identification
ML based methods?

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

Continuous /Discrete State Space

ROMs are **critical enablers** for system level predictive modelling

System Sim Demo No.01: EXE5000 Level Sensor Thermal Drift

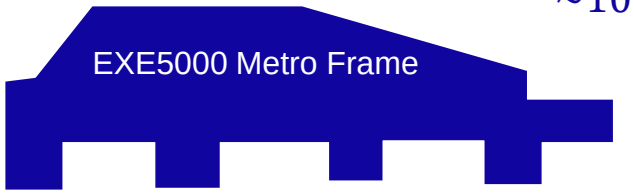
TWINSCAN
Machine Software

CPD Test Outputs

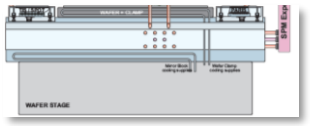
Reduced Order Model

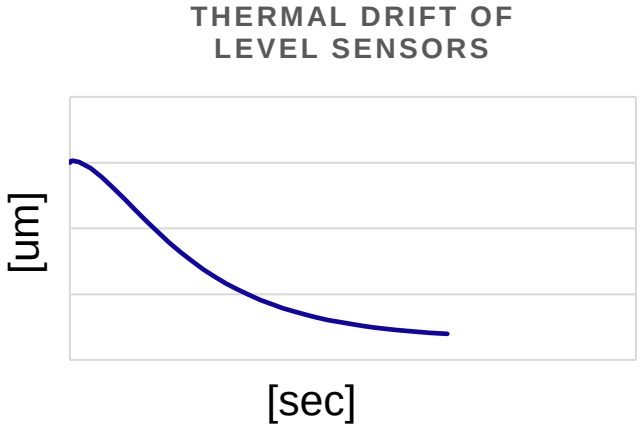
ROM deployed in TwinSim

$\sim 10^4 x\ Faster$



Wafer Stage Heat





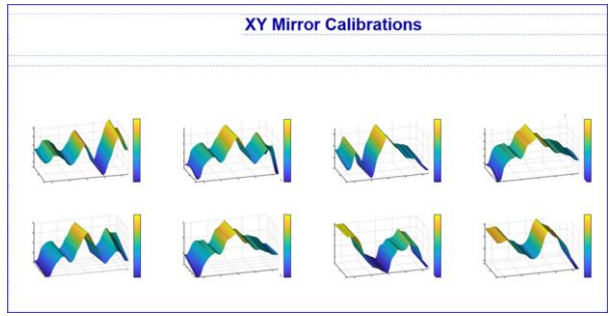
This digital verification can **save >50 hours of test time** on a physical proto for each HW/ SW design iteration

~1 man-month to create Data-driven ROM

System Sim Demo No.02: EXE5000 Mirror Deformations

TWINSCAN
Machine Software

CPD Test Outputs



ROM deployed in TwinSim

$\sim 10^4 x\ Faster$

EXE5000
Long Stroke

EXE5000
Mirror Block

Multiple inputs

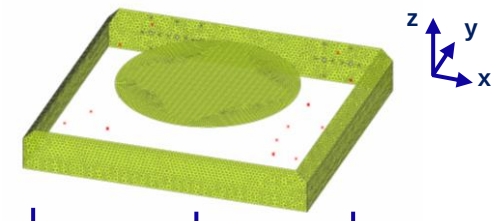
Heat Load params

EXE5000
SS

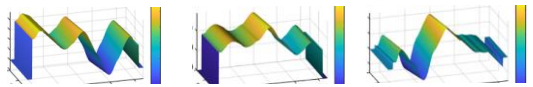
Output

Thermo-mech Deformations

Mirror Maps created at ~real time



Snapshots of Mirror maps at t1, t2…

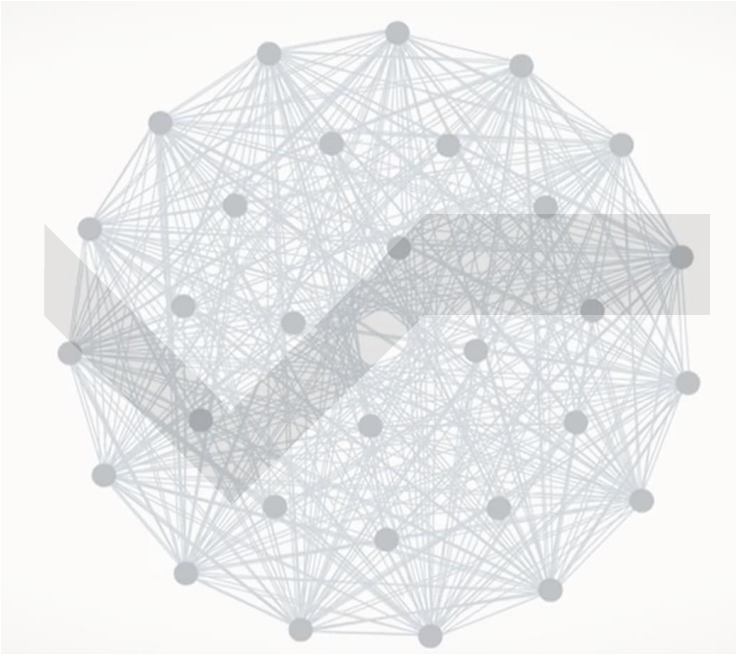


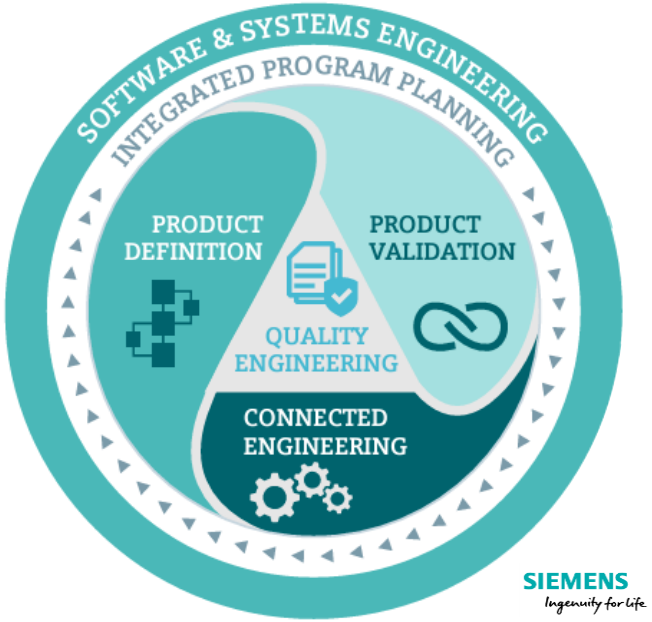
~1 man-month to create Physics-driven ROM

This digital verification can **save >25 hours of test time** on a physical proto for each HW/ SW design iteration

Virtual Verification Management + SPDM (Simulation Process& Data Mng)

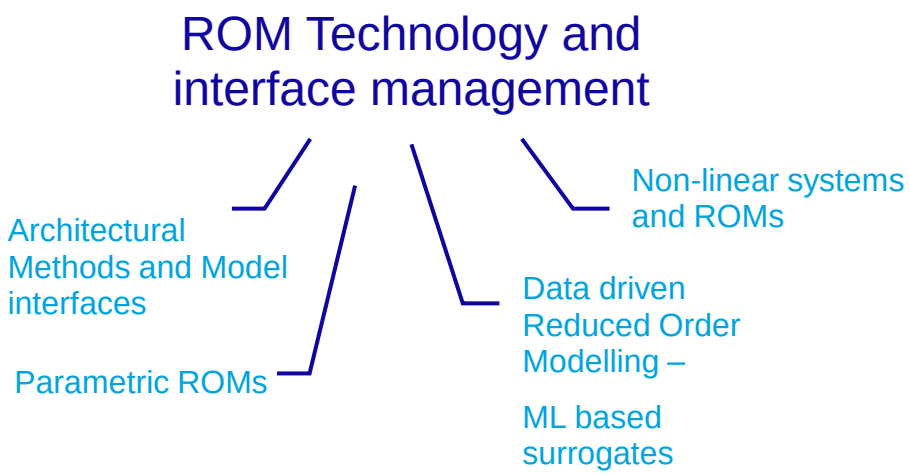
Simulation governance end to end: Traceable + Configurable + Modular + Secure

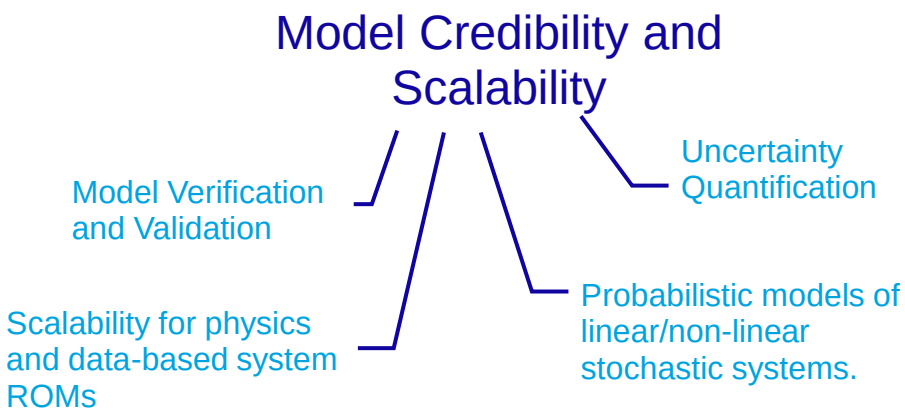




Working closely with our Product Lifecycle Management (PLM) partner to pull all digital threads together

Ecosystem - Collaboration with suppliers & universities





Areas of interest for Internships / Partnerships :

- Developing in house ROM and model verification tooling
- Investigation on commercial codes for state-of-the-art ROM methods
- Statistical & Stochastic parameter sensitivity for FOM and ROMs
- AI/ML based methods for non-linear system representation

Thanks

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Veldhoven

Q&A