SYSTEMS ENGINEERING AND RESEARCH

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Highest earning exports of The Netherlands (released 5 Nov 2019)
ESI at a glance

Mission: *Embedding leading edge methodologies into the Dutch high-tech systems industry to cope with the ever increasing complexity of their products.*

**Synopsis**
- Foundation ESI started in 2002
- ESI acquired by TNO per January 2013
- ~55 staff members, many with extensive industrial experience
- 5 Part-time Professors
- Working at industry locations
- From embedded systems innovation to embedding innovation

**Focus**
Managing complexity of high-tech systems through
- system architecting,
- system reasoning and
- model-driven engineering

delivering
- methodologies validated in cutting-edge industrial practice

**Partner Board**

An initiative of industry, academia and TNO.
Systems, Systems Engineering and Research

**Bottom line:**
(High-tech) Systems

**Realization:**
Systems engineering & architecting

**Research:**
Into SE and SA methodologies

**Scientific foundation:**
Methods to research SE & SA methodologies

Based on: Gerrit Muller PhD Thesis, 2004
Bottom line: (High-tech) Systems

Realization: Systems engineering & architecting

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High-tech Systems

- Semiconductor manufacturing equipment
- Medical systems
- Food processing
- Agricultural robots
- Traffic management
- Electron microscopes
- Building control
- Robotized warehousing
- Combat management systems
- Industrial printers
- Automotive
- Residential heating/cooling
Main drivers of complexity into the 2020’s

**Continuously Evolving Systems**
The system has both the capability and the need to evolve over time

**Autonomous Systems**
System operates without human in the loop, human interaction moves to higher level

**X-as-a-Service Systems**
Not the machine, but the service it provides is the manufacturer’s value proposition

**Series-of-one Systems**
High level of customization of each system delivered, no two systems alike

**Systems of Systems**
The system is an integral part of a larger system without any control of that system

**Parameters-times-10 Systems**
All design parameters (e.g. interfaces, LoC) get one (or more) orders more demanding
Systems, Systems Engineering and Research

meta⁰

Bottom line:
(High-tech) Systems

meta¹

Realization:
Systems engineering & architecting

meta²

Research:
Into SE and SA methodologies

meta³

Scientific foundation:
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Systems engineering: applying methodologies to better design and realize complex systems

I can’t be bothered by some crazy technology idea, I have a war to fight!

Example: Digital Twin
The digital twin as central asset for adaptation and evolution

Digital twins are software representations of assets and processes that are used to understand and diagnose systems, and predict and optimize their performance, allowing us to perform the critical evaluation and by which the system becomes better fitted to perform and last in its environment.

The digital thread sets up full traceability across a whole lifecycle, addressing the key concern of availability of engineering and system knowledge.
Digital twin – with hardware in the loop
Case study – ASML lithography scanner

System requirement

- Very high throughput
- Extreme (nanometer) precision

- Requirement: no hiccups
- Exposure is carried out as sequence of concatenated Step/Scan actions
Digital Twin to diagnose timing bottlenecks in large-scale component-based software

**Domain**
Lithography scanners
Industrial partners: ASML

How to measure and exploit the measured data to automatically diagnose timing bottleneck in existing large-scale component-based software?

**Problem**

**Technology**

**Approach**
- Formalization of subset of Message Sequence Charts (based on international standards)
- SW code instrumentation with probes at strategic places in middleware
- Digital twin
- Fully automated Message Sequence Chart inference from measurements
- Fully automated critical path analysis
Automatic diagnosis of timing bottlenecks

Measurement-based approach to get insight in timing bottlenecks based on Timed Message Sequence Charts (TMSCs)

1. Code instrumentation
2. Automated inference of digital representation creating a digital twin in the form of TMSC
3. Replay measured sequence: automated critical-path analysis to detect timing bottlenecks

Scalability
- 396 components
- 48.7 million events
- 24.3 million function executions
- 60.4 million timing constraints
- 11.7 million messages
Digital twin research challenges

• Digital twin fit for purpose
• Reducing the effort of constructing digital twins
• Use of machine learning and process mining to create models and digital twins
• (much) faster than RT digital twins
• Digital twins for adaptive cyber-physical systems of systems

• ESI position paper: https://www.esi.nl/home/leaflets.dot
Systems, Systems Engineering and Research

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meta^2

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Research into improving the System Engineering Methodologies

Example: Research into effective design methodologies

“We only have two demands! Why don’t people just give us what we want?”

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Example: Ongoing research in more effective and robust system design methods

• **Traditional V-model:**
  • Presupposes completing design and spec in all details
  • Only then engineering can start
  • Leads to many iterations – (hardware) prototypes

• **System architecting approach of decomposition (divide and conquer) allows concurrent work on components**
  • Individual parallel Vs
  • Followed by integration
  • In complex systems requires super-hero architect
  • Often goes foul
Desired: a way to do team-based phased engineering

Elements
• Determining criticals, essentials and others
• Keep track of decision impact at all levels
• Team-based decision and sharing

Benefits
• Shorter engineering cycles
• Less physical iterations
• Improved quality and better fit to market
Daarius methodology

- **Daarius** is a structured, scalable, and team-based system design methodology providing traceable underpinning for key design decisions and leveraging the abundance of simple executable models in systems engineering.
  - Team-architecting (replacing super-hero architect)
  - Dilemma handling
  - Trade-off handling
- **CAFCR based solution space analysis**
- **Allows to stepwise fill and track solution space**
  - First: criticals
  - Then: essentials
  - Finally: others

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Daarius: research in progress

Research questions:

• Methods to determine criticals, essentials and others
• How much detail is needed for taking decision at specific levels
• How to determine the right levels
• Inclusion of quantified degrees of uncertainty and unknowns in method
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Meta$^3$: reflecting on the way to do SE research
An approach to SE Research: Industry-as-a-Lab

- Philips - Best
- ASML - Veldhoven
- DAF - Eindhoven
- Océ - Venlo
- Thermo Fisher - Acht
- NXP - Eindhoven
- Vanderlande - Veghel
- Signify - Eindhoven
- Nexperia - Nijmegen
- Thales - Hengelo

Full access to industry background

Generic results

Industry specific validation results
Learning from each other
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THANK YOU!