Mathematics
A key enabler for Digital Twins

Dirk Hartmann, 17 July 2019
Digital twin in a nutshell
Digital twins –
More than a digital hype?

Gartner Hype Cycle
for emerging technologies, 2018


Deloitte:
Expecting digital twins, 2018

Goldmann Sachs:
Double vision: Using ‘digital twins’ to pair virtual and physical worlds, 2018

MITsloan review:
Short video series on digital twin, 2018

Economist:
Millions of things will soon have digital twins, 2017

Forbes:
Why digital twins should be the CEO's best friend, 2018
Digitalization and associated innovations will change everything, selected trends affecting simulation and digital twin.

- **Mainframe computers**
  - Simulation for trouble shooting
  - CAx is a standard tool in engineering
- **Model-based systems engineering**
  - Machines program themselves in virtual worlds
  - Cloud and Exascale computing
- **Personal computers**
  - Additive manufacturing
- **Computational design**
  - Computational design goes multi-scale
  - Accurate Interactive CAx at scale
- **Digital twin**
  - Availability of experts limits CAE growth
  - Every product has an digital twin
- **Operations**
  - First time right design, prod. & commiss.
  - Lot size one production
  - Zero carbon emissions
- **Virtual worlds**
  - We live in virtual worlds
  - Machines engineer and operate better than humans
  - CAx on quantum computer

Use of Simulation and Digital Twin

Extrinsic Technology Driver / Pull

Trends affecting Simulation

Rough timeline is indicating first impacts
Therefore, simulation and digital twins …

“Requirements”

... must adapt speed and accuracy to purpose

... must be self-aware, self-adjusting, and autonomous

... must interact and adapt in heterogeneous contexts

... must adapt to hardware architectures

... must be user friendly

... must be specific and synchronized
Major leaps in electronics, mathematics, and computer science allow to challenge established paradigms.

## Technology Push / Major Game Changers

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<tr>
<th>Topic</th>
<th>Description</th>
<th>Source</th>
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<tbody>
<tr>
<td><strong>Computational power is exploding - More than Moore’s Law</strong></td>
<td>Computer and hardware architectures beyond scaling of chip performance and cloud, e.g. GPUs, reconfigurable computing, ubiquitous computing.</td>
<td>International Technology Roadmap for Semiconductors (2007), <a href="#">White Paper</a></td>
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<td><strong>Major breakthrough in mathematics and computer science achieved</strong></td>
<td>Exponential capability growth contributing significantly to efficiency, scalability, and usability of (simulation) model-based as well as data-based approaches.</td>
<td>SIAM CSE (2016), <a href="#">White Paper</a></td>
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<td><strong>Virtual and mixed reality is entering professional market</strong></td>
<td>Consumer technologies such as virtual or mixed reality becoming mainstream in industry and driving democratization of formerly expert centric tools.</td>
<td>Goldman Sachs (2016), <a href="#">Virtual and Augmented Reality</a></td>
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<td><strong>Semantic standards and knowledge graphs are maturing</strong></td>
<td>Knowledge graphs are entering rapidly the industrial domain allowing for efficient realization of ontologies putting semantic information access to a new level beyond general purpose interoperable standards.</td>
<td>Forbes (2016), <a href="#">Knowledge Graphs</a></td>
</tr>
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Digital Twins
Agenda

Digital product twin democratizes design
Digital twins improve development, production / construction, and operation.

Feedback insights derived from data

Push forward knowledge from models
Digital product twin ...  
... democratizes design.
Digital product twin …
… democratizes design.

Efficient discretization techniques
allowing lean codes, efficient memory access, easy parallelization, and
fast transfer to novel architectures

Optimal solver technology
exploiting achievements in computational science and engineering driving
exponential growth in algorithmic performance

Hardware-aware algorithms
leveraging next generation compute architectures, e.g. GPUs, TPUs, and
reconfigurable computing

- 1000x faster than today’s solvers
- 10x faster concept development boosting innovation
- Democratize CAE with 50M unaddressed users today

Sources:
D. Hartmann, S. Gavranovic (2017): Disrupting Computer Aided Engineering, GTC 2017
D. Hartmann, S. Gavranovic, P. Stelzig (2017): Accurate Interactive 3D Engineering Simulations, NWC 2017
3 Digital production twin enables robots to mill
Digital twins improve development, production / construction, and operation.

Feedback insights derived from data

Push forward knowledge from models

Digital Product Twin

Digital Production Twin

Digital Performance Twin
Digital production twin …
… enables robots to mill.

Source: new.siemens.com
Digital production twin …
… enables robots to mill.

Voxel-based milling process force models
using fine-resolution multiscale geometry models combined with simple heuristic force models

GPU parallelization
introducing state-of-the-art computer graphics libraries into manufacturing process simulation

Seamless NX CAM to control integration
leveraging and extending novel DF MC SINUMERIK module CC ROCO-Robot Accuracy as well as extending DF PL product NX CAM

- 10x higher part qualities enable use of robots for milling
- Enable lot-1 machining
- Novel markets with predicted growth rates of 16%/y

Sources: D. Hartmann, F. Schnös, S. Tauchmann (2018): Loading Robots with a Will to Mill, Siemens Stories

Source: new.siemens.com
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Digital performance twin boosts availability
Digital twins improve development, production / construction, and operation.

Feedback insights derived from data

Push forward knowledge from models

Digital Product Twin

Digital Production Twin

Digital Performance Twin

Infrastructure / buildings
Digital performance twin ... … boosts availability.

Source: https://youtu.be/86vkjykbHRM
new.siemens.com
Digital performance twin …  
… boosts availability.

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<th>Online capable simulation models</th>
<th>without add. effort</th>
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<td>Higher availability</td>
<td>by 20% reduction of stop times</td>
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<td>Save costs</td>
<td>of up to 200k€/h</td>
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Source: new.siemens.com
https://youtu.be/86vkjykbHRM
The age of pervasive digital twins is yet to come
Digital twins are not “new”. Simulation evolved from a trouble shooting tool to key business driver in the form of digital twins.

Scientific experts use models
- Understanding of phenomena
- Failure analysis

Computer aid in product design and engineering
- Design validation and design optimization
- Decision support

Key for communication across departments & companies
- Design driver
- Model-based systems engineering

Nexus of data and executable models accessible to everyone
- Business driver bridging different value chains
- Generative design closing the loop
If you like to know more …

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