From complexity to intelligence: Multi-paradigm modeling for next-generation CPS

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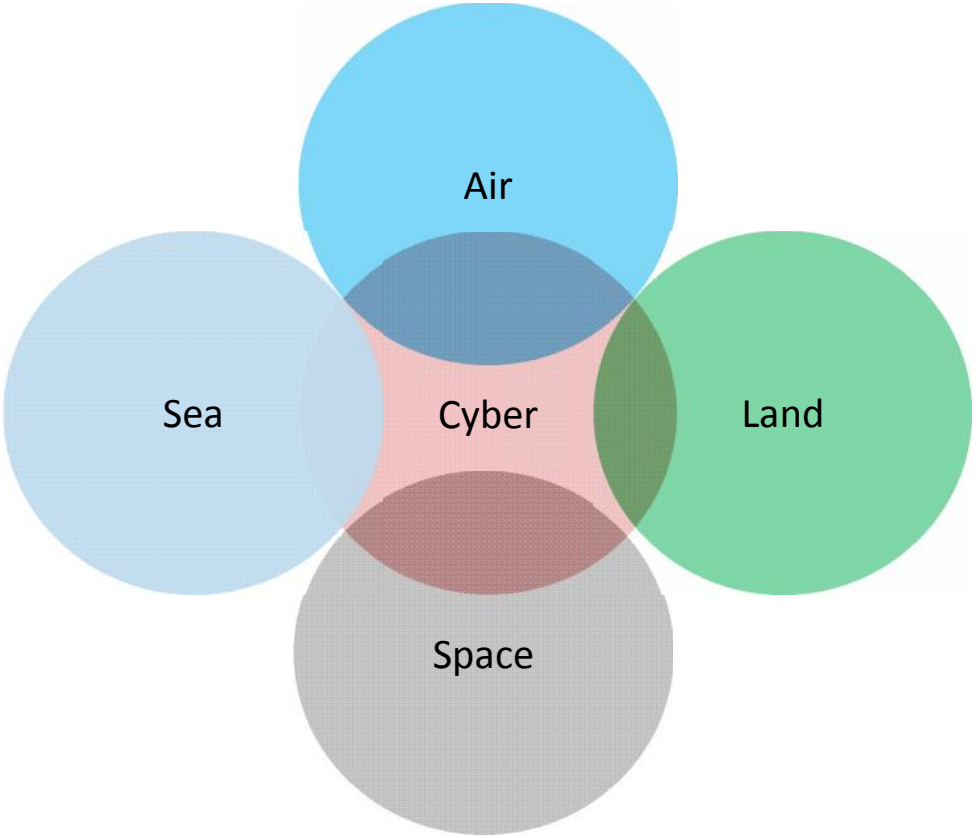
Prof.dr. Bedir Tekinerdogan

Wageningen University & Research
Chair Information Technology
Wageningen, The Netherlands

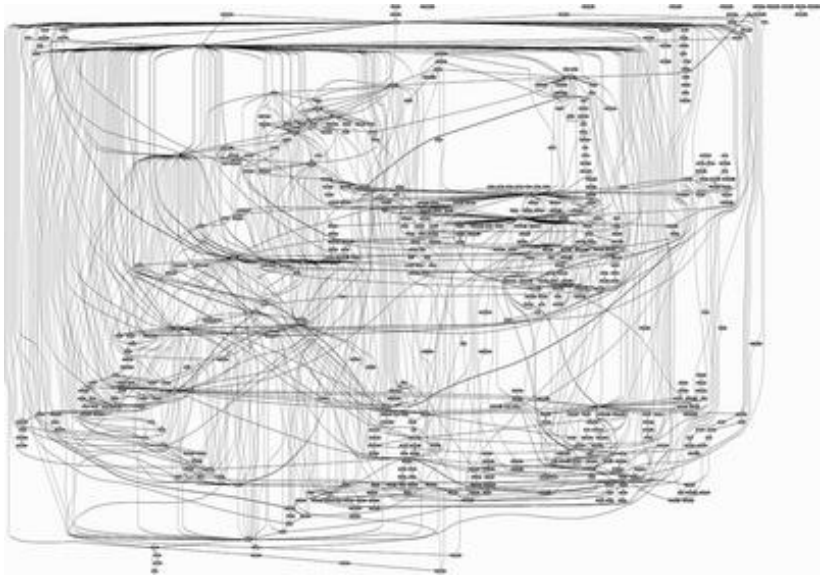
bedir.tekinerdogan@wur.nl
https://linkedin.com/in/bedir
https://www.researchgate.net/profile/Bedir-Tekinerdogan

Physical Space and,…Cyberspace



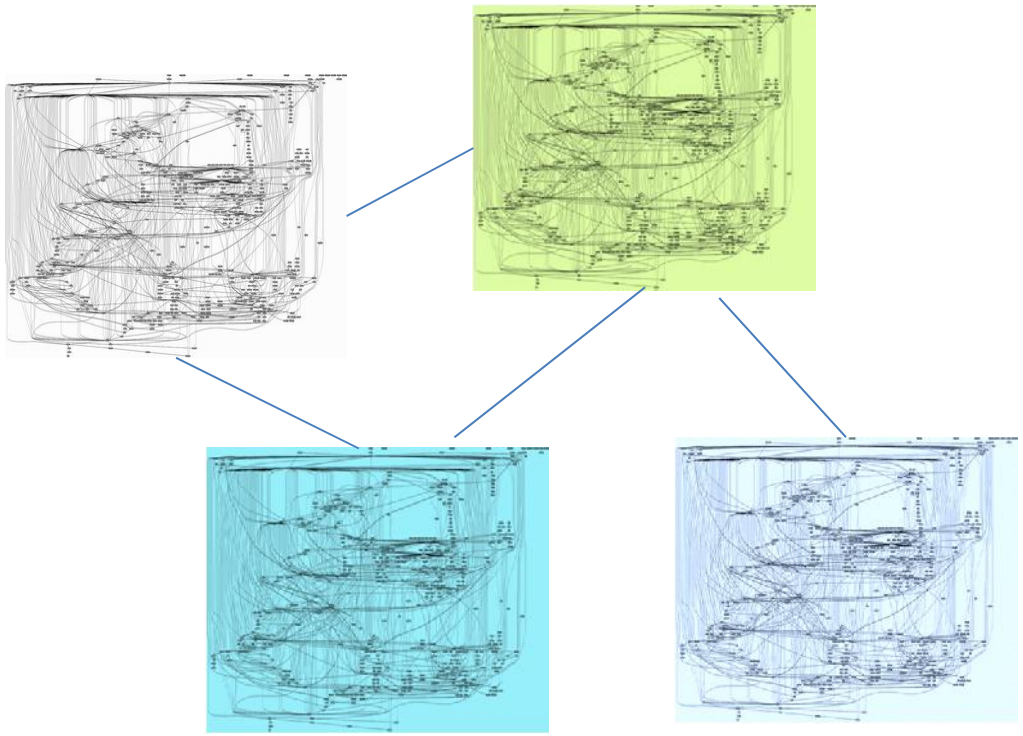
Complexity and Change

- **CPS is complex**
  - Accidental Complexity
  - Essential Complexity
- **CPS changes a lot**
  - To correct requirements
  - Or enhance the system for new requirements



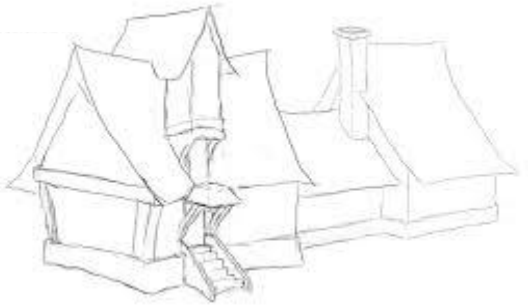
Complexity of CPS

- Inherent Complexity
  - Within a system
  - Across systems
- Accidental Complexity
  - Within a system
  - Across systems

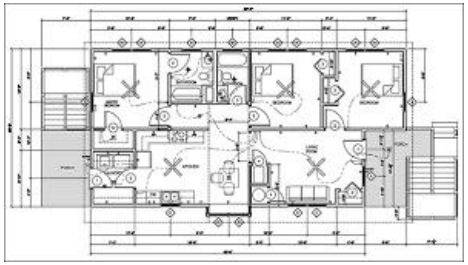


Maturity of Models…

- **Sketch** – simple drawing model; not precise or complete, nor is it intended to be. The purpose of the sketch is to try out an idea.



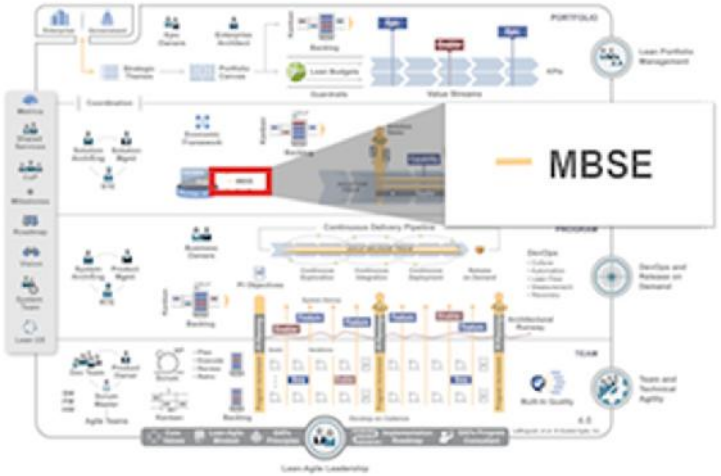
- **Blueprint** – document/design model describing properties needed to build the real thing. The blueprint is the embodiment of a plan for construction.



- **Executable** – software model that can be compiled and executed; can be automatically translated into other models or code

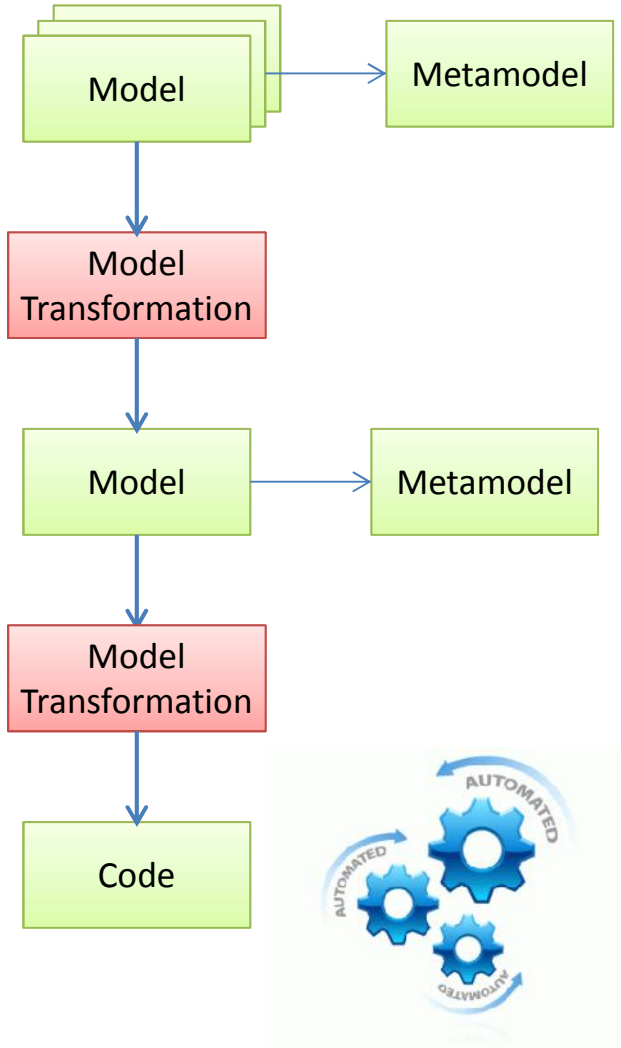
Model-***Based*** Engineering

- **Model-based Engineering** moves the record of authority from documents to digital models managed in a data rich environment



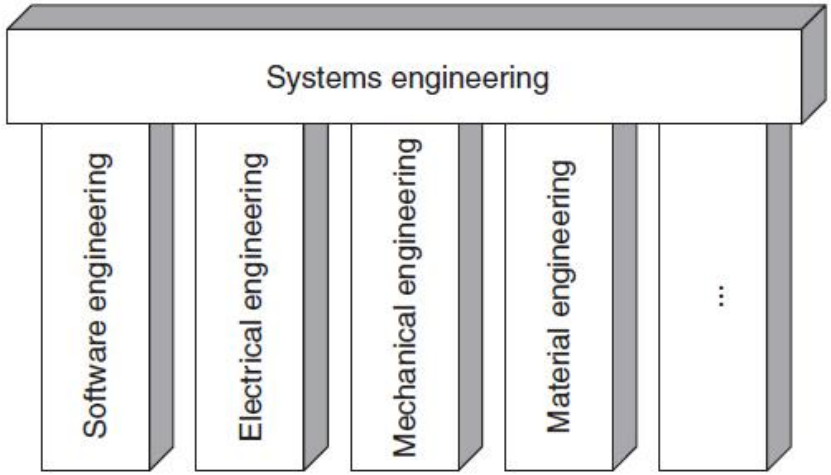
Model-***Driven*** Engineering

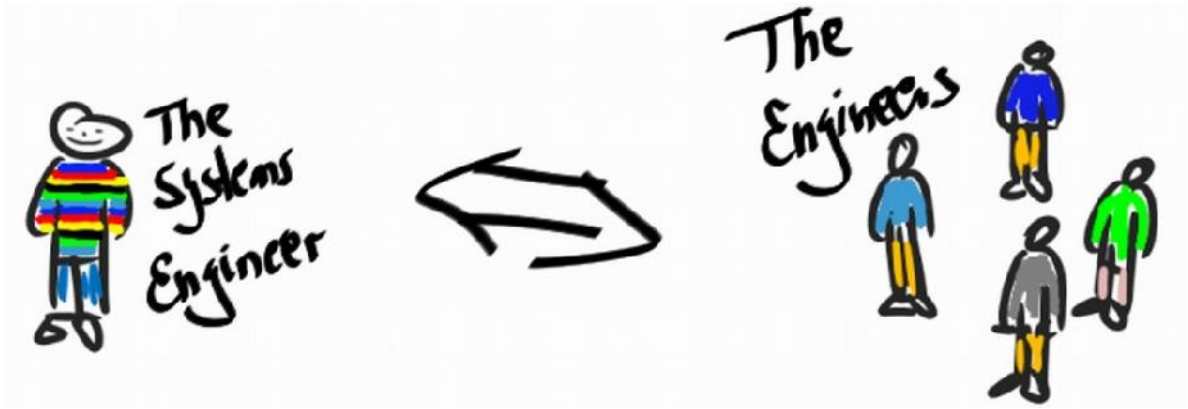
- Model-*Driven* Engineering adopts models as the basic abstraction.
- Models **do not constitute documentation**,
- but are **considered equal to code**
- as their implementation is **automated**.



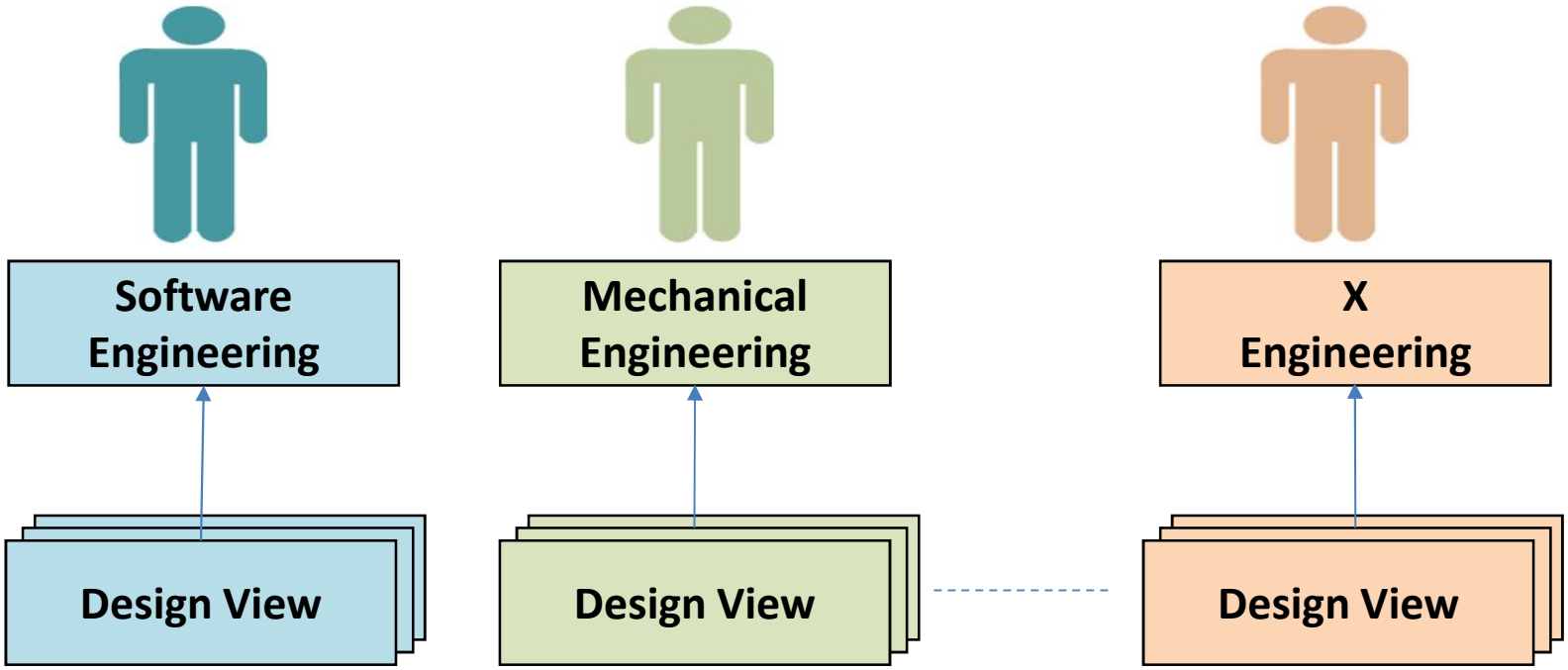
The CPS Engineer

- A CPS/system engineer is the connecting link between the disciplines in a project, which are sometimes very different.
- System/CPS engineers think along the line of the entire system, independent of software, hardware, or other specific views.



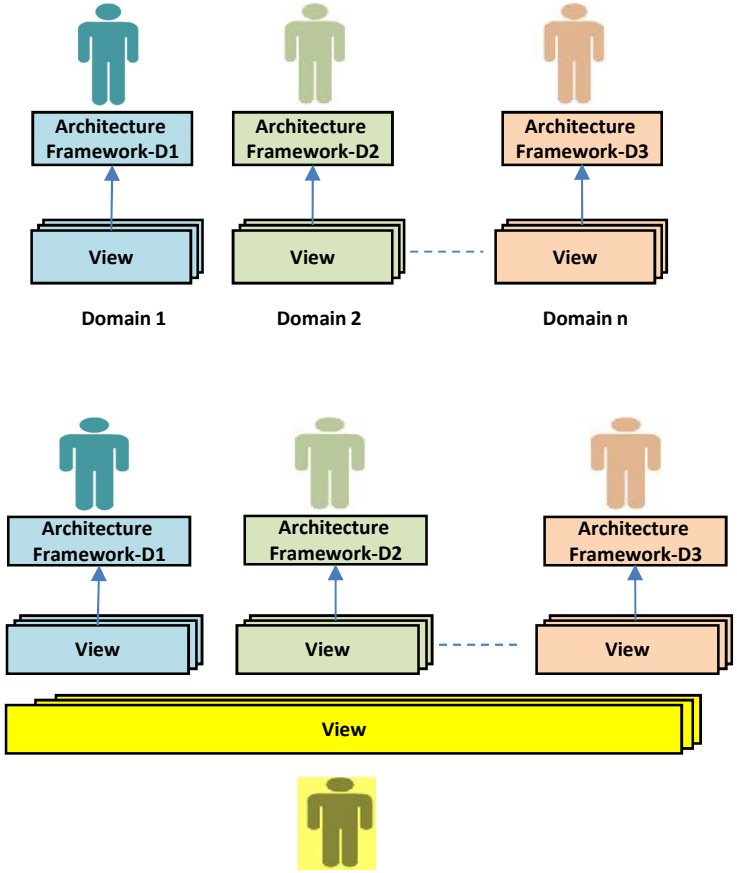


Multi-Paradigm Modeling



How to unify systematic design methods, techniques, and tools for SoS?

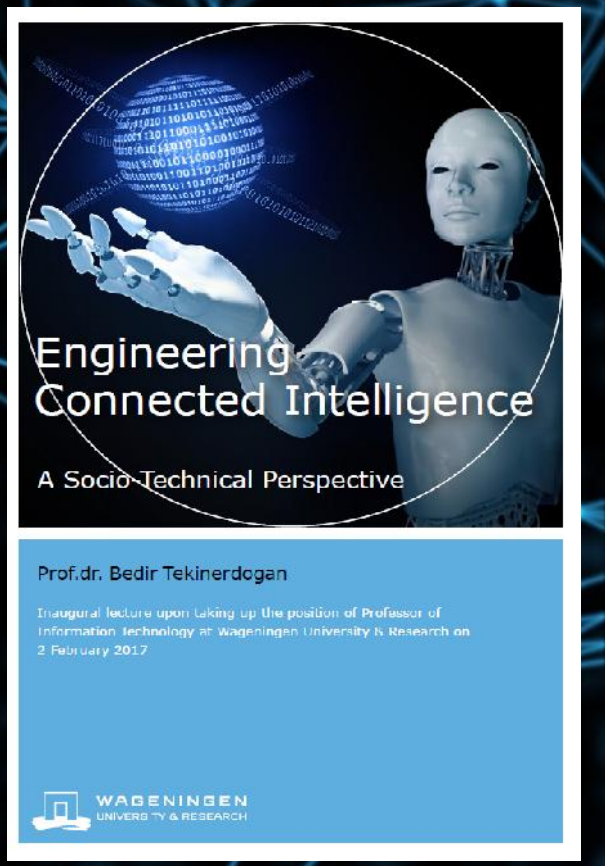
Alternatives



Challenges of Multi-Paradigm Modeling for CPS

- Integration of heterogeneous models
- Verification and validation of models
- Meeting real-time performance requirements
- Managing computational resources
- …

Systems get Smarter, and Connected



B. Tekinerdogan. Engineering Connected Intelligence: A Socio-Technical Perspective, Wageningen University, isbn 978-94-6343-049, doi 10.18174/401115, 2017

Smart Systems

Monitoring

1. Sensors and external data sources enable the comprehensive monitoring of:
   - the product's condition
   - the external environment
   - the product's operation and usage

   Monitoring also enables alerts and notifications of changes

Control

2. Software embedded in the product or in the product cloud enables:
   - Control of product functions
   - Personalization of the user experience

Optimization

3. Monitoring and control capabilities enable algorithms that optimize product operation and use in order to:
   - Enhance product performance
   - Allow predictive diagnostics, service, and repair

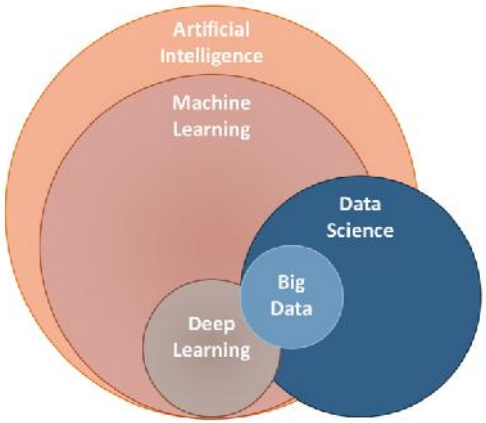
Autonomy

4. Combining monitoring, control, and optimization allows:
   - Autonomous product operation
   - Self-coordination of operation with other products and systems
   - Autonomous product enhancement and personalization
   - Self-diagnosis and service

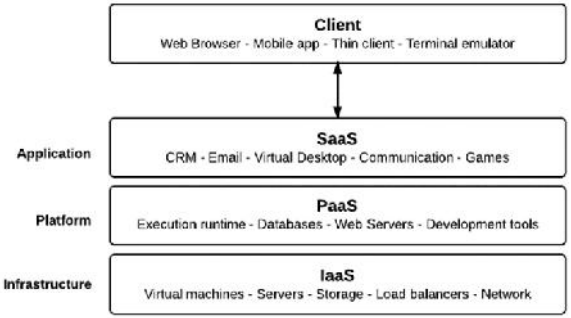
Michael E. Porter and James E. Heppelmann. How Smart, Connected Products Are Transforming Competition, Harvard Business Reviews, 2014

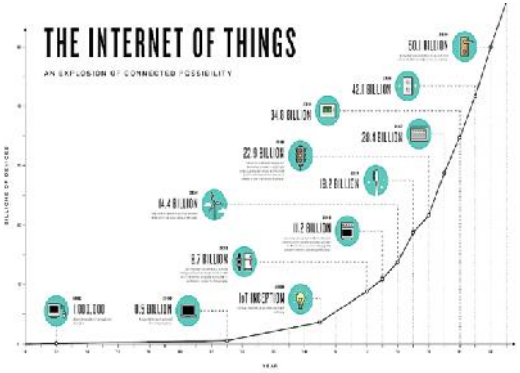
IT Trends…

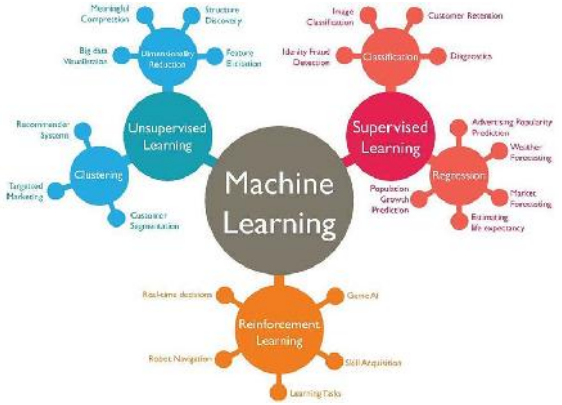

Cloud
Computing


Artificial
Intelligence
Machine
Learning
Data
Science
Big
Data
Deep
Learning

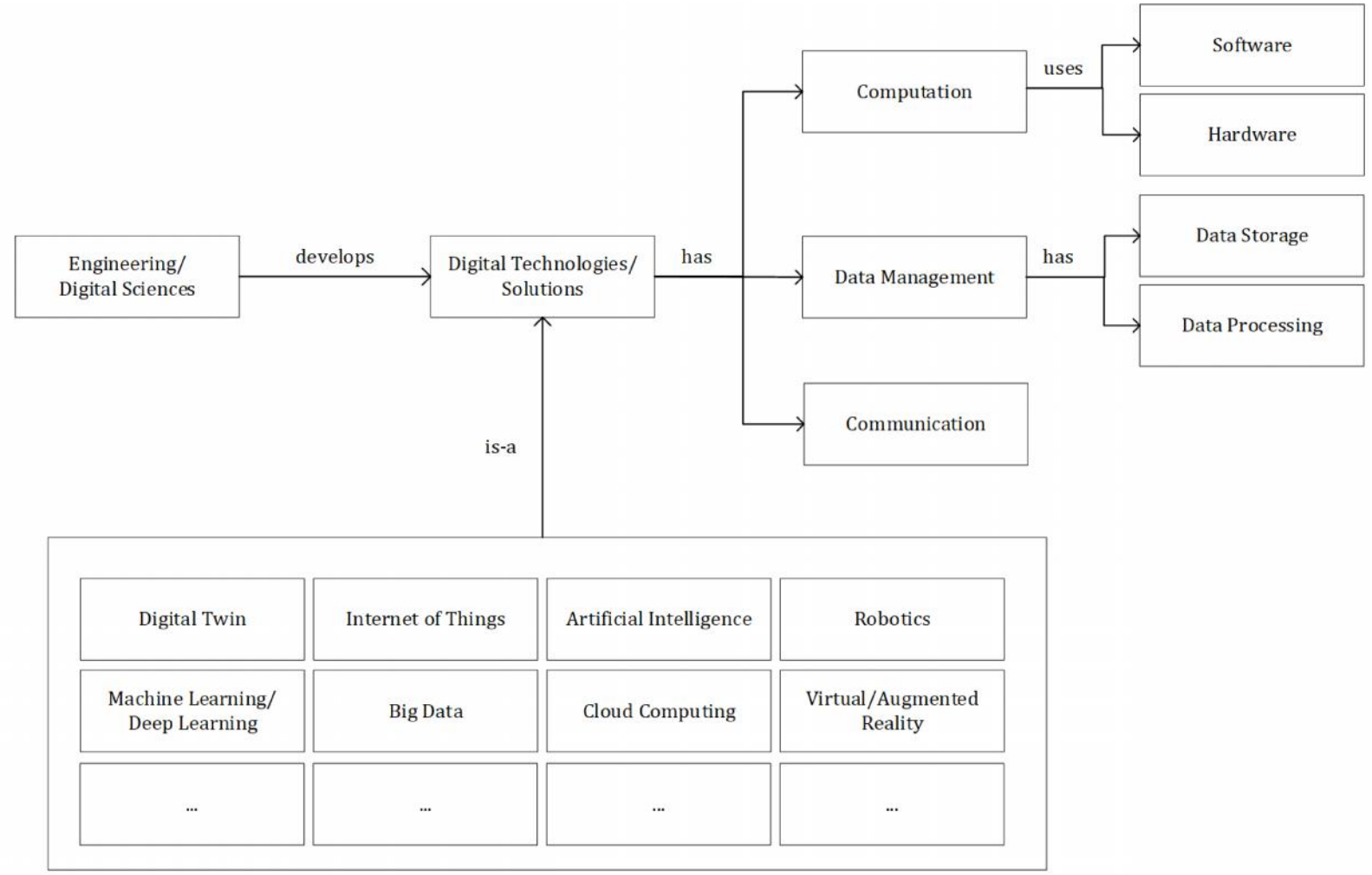

BLOCKCHAIN
Block
Ledger
Distribution
Transaction
Confirmation
Proof of work
Result


Client
Web Browser - Mobile app - Thin client - Terminal emulator
Application
SaaS
CRM - Email - Virtual Desktop - Communication - Games
Platform
PaaS
Execution runtime - Databases - Web Servers - Development tools
Infrastructure
IaaS
Virtual machines - Servers - Storage - Load balancers - Network


THE INTERNET OF THINGS


Machine
Learning
Unsupervised
Learning
Supervised
Learning
Reinforcement
Learning
Clustering
Regression
Classification

Digital Technologies



Position Statements

- CPS requires **multi-paradigm modeling**
- Multi-paradigm modeling for CPS is dynamic and depending on the required domains
- Multi-paradigm modeling for CPS is **inherently complex** due to the increasing **scale** and **scope**
- With this, CPSs become **smarter** and **connected**
- This provides new opportunities but **adds to the existing inherent complexity**
- **Novel methods, abstractions and tools** are required to cope with the trend from **complexity to intelligence**