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Industry 4.0 – a view on data and communication

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Aim of the Talk

- *It’s only an attempt to define I4.0, point out some technical challenges and what kind of research is still necessary .*

- *This is not a prediction about business opportunities through Industry 4.0 (I4.0)*
  - Business opportunities, social issues, and consequences for working environment are highly important and part of the I4.0 initiative, but not discussed here.
  - "Prediction is very difficult, especially if it's about the future." [Mark Twain/Niels Bohr]

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Industry 4.0: déjà-vu?

Precursor

- Computer Integrated Manufacturing (CIM)
  - ⇨ J. Harrington, CIM, Industrial Press, 1974
  - ⇨ Hype started ~ 1984
  - ⇨ Subsystems: CAx, CNC, PPS, plant data collection

CIM = I4.0?

Not really

- CIM: Manufacturing is controlled by Computer Systems, but not necessarily flexible; products are still “dumb”
- I4.0: Covers the full life cycle of a product, production is highly flexible, machines/products are “intelligent”
- Promise of I4.0: 4^{th} Industrial revolution[1)]

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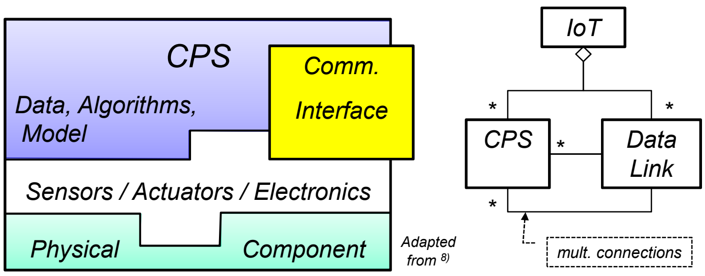
CPS: Definition

Cyber Physical System (CPS)[6)]

- Is a physical system with built-in, interacting software and communication capabilities
  - ⇨ Building blocks of “Internet of Things” (IoT)
- CPS are called “intelligent” as they “know” about themselves and about their environment.
  - ⇨ Model is always in sync with phys. Component



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Industry 4.0: Definition

Industry 4.0 (I4.0)

- Is the name for a fully digitalized, automated, and flexible product lifecycle, notably production technology,
  e.g. using CPS to build a “smart factory”
  - ⇨ I4.0 covers the whole product lifecycle [1,7)]
  - ⇨ Production is adaptive (modular, flexible) with
    - interoperable, autonomous CPSs
    - CPSs take decentralized decisions (in real-time!)
    - products itself are also a kind of CPS[2)], i.e.
    - I4.0 lies the grounds for machines that create new (and better) machines to replace themselves.

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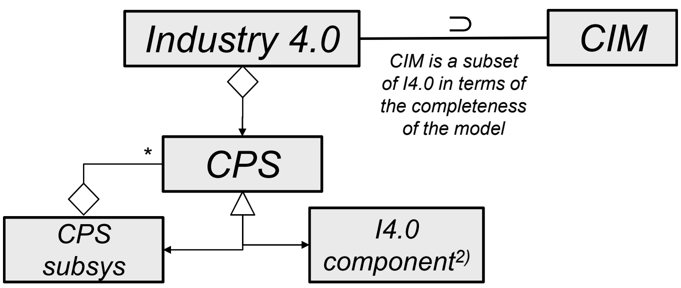
Industry 4.0 vs CPS vs CIM

- *I4.0 refers to a digitalized, flexible production with autonomous manufacturing machines and business services.*
  Products know about itself during the whole life cycle
- *CPS relates to physical things with computing and communication capabilities which can be components of I4.0*
- *CIM is a computer supported manufacturing with hierarchical control*



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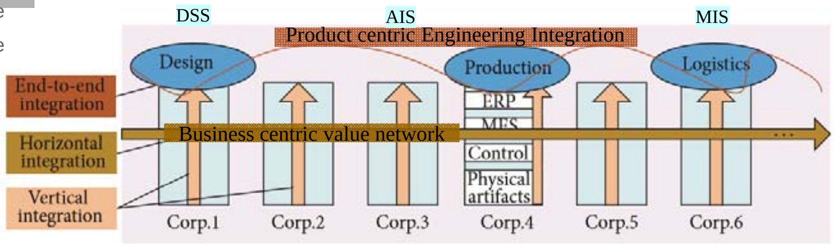
I4.0 Design Principals

Design principals[9] are

- Decentralized decisions
- Interconnection and integration
- Information transparency
- Technical assistance for humans

I4.0 product lifecycle and 3 kinds of integration[3]:



Problem: End-to-End and Horizontal integration are not orthogonal
→ some elements are entangled

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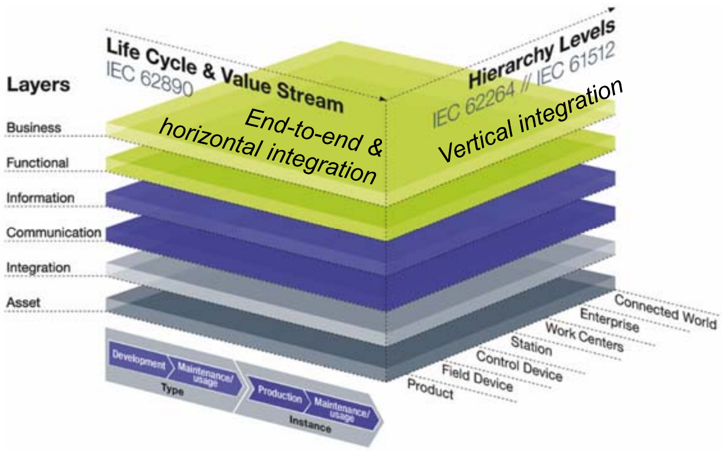
Reference Architecture Model Industry 4.0 (RAMI 4.0)

The 3-dimensional framework RAMI 4.0[2]

- Covers different aspects (layers), product life cycle, and the position of I 4.0 elements in the Industry hierarchy



Problem: Many crosscutting functions, aspects and elements exist
→ „separation of concerns“ is not always possible

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Example: flexible Production with lot size 1

Smart factory production system

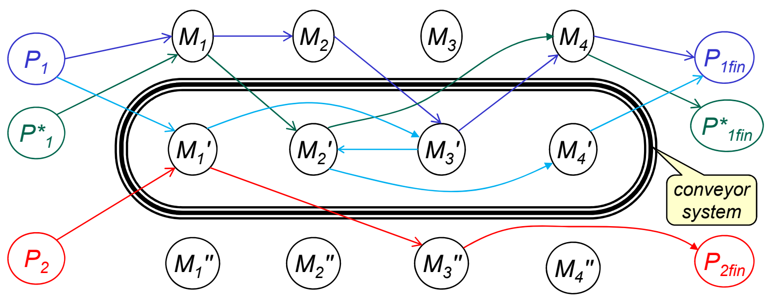

Figure adapted and extended from [3)]

Legend: $P_{x[fin]}$ = [final] Product x, P^*_x = Variant of Product x
$M_x^{['['']]}$ = Machines x ['['']] with the same capabilities

Multiple routes:

- *standard route A,*
- *alternative route B (e.g. if M_1 is broken and all M2 are in use (only possible if process steps of M2 and M3 are interchangeable),*
- *route A* for product variant P*1 (step M3 (e.g. painting) is skipped),*
- *route C for other product P2*

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Real World Example

Trumpf

- World leading company for advanced, high precision, industrial Machine Tools, Laser Technology, and Electronics
- Is a protagonist of I4.0 technology in Germany
  - Develops and uses I4.0 Technology for its own “smart factory”
  - Member of Allianz I4.0, I4.0 working group of BMBF, and Smart Data Innovation
- I4.0 related products
  - TruConnect: Digitized, networked, and automated order processing
  - SYNCHRO: Just-in-time production control and Continuous Improvement Process (Kaizen)
- www.trumpf.com
- https://www.youtube.com/watch?v=ewjIVIUri1s

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Real World Example

Festo

- Leading world-wide supplier of automation technology, robotic (bionic), and technical education (didactic learning and simulation factory)
- Is a protagonist of I4.0 technology in Germany
  - Develops valves, pneumatic and servo drives, controller and sensors for factory and process automation
  - Coauthored chap. 6 of [2] and contributor to [1]
- I4.0 related products and projects
  - “Intelligent” components: self configuring pneumatic conveyor (WaveHandling,) produced at Scharnhausen I4.0 Technology Plant: 66k m^2, 1200 employees
  - MetamoFAB[12]: developing solutions to enable a metamorphosis into intelligent and networked factories
  - OPAK: open engineering platform for autonomous, mechatronic automation components
  - BionicANTs: cooperative behavior, highly integrated individual systems used to solve a common task → SmartBird
- www.festo.com;
  www.festo.com/group/de/cms/10225.htm
  www.youtube.com/watch?v=3SKiH8N8D6w

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1. Challenge: (Wireless) Interconnection in Real-time

Collaborating machines/robots need real-time response guaranties.

- Direct links
  - How to master the many to many links? → O(n^2) problem
  - Wireless LAN → signal collisions, no resp.-time guaranty
- Internet protocols are not designed for real-time communication
  - How can hard real-time limits be assured?
    - Protocols on top of TCP/IP deliver only “soft” real-time.
    - Synchronous protocols like ProfiNet IRT (1 ms cycle) are not compatible with CSMA/CD. (see [10])
- In production environments there is a high level of EMI (electro-magnetic interference)
  - How can EMI disturbances be mastered in production environment? → mobile assistance systems produce additional interferences

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2. Challenge: The Data Integration Problem

Taming the data flood

- I4.0 recommendations:
  - ⇨ Administrative data should be stored with scalable cloud technology.
  - ⇨ Operative/machine data should be stored locally.
- Data from many dispersed sources need to be integrated. This requires a consolidated data model.
  - ⇨ Is there an enterprise data model? → semantic of data
- Many decisions need support from big data analysis
  - ⇨ Can the data flood be analyzed in time? → data stream analysis
- Workflow and Process data need transactional reliability. Not only storing (logging) of data but also structuring and high performance transactional processing is required. Distributed decision is needed in real-time.
  - ⇨ Are the traditional protocols (locking, 2PC, buffering, etc) sufficient for the performance?

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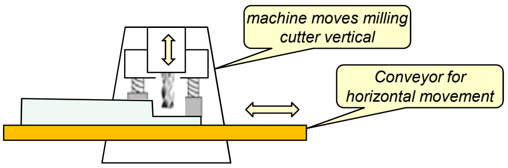
3. Challenge: Decentralized Intelligence

Where and how is the knowledge distributed?

- Machines/Robots have to collaborate to achieve a joint function or to take a decentralized decision
  - ⇨ Who knows about the joint functions/possibilities?
    - Example: Planning with a milling machine and a conveyor

      the milling machine has limited movement, with the help of a conveyer a part can be planed for arbitrary length
  - ⇨ the knowledge about this joint function needs to be stored somewhere (the conveyor is “misused” as a traverse feed in this case)



  - ⇨ What are the strategies for creating joint functions?
    → is there a voting, a judge in case of draw, a priority, try-and-error?

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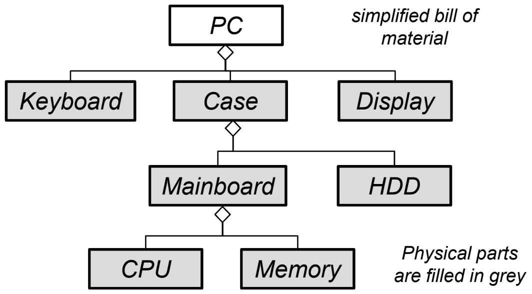
4. Challenge: Aggregated Knowledge

- *A product knows about itself (properties, purpose, etc.)*
  - Where is this information located?
    → it needs to be attached to a physical part[4)] (the PC is an aggregate, not a physical part).
  - What if the information is distributed? → parts can be used for many different products



  - What happens if the product is disassembled?
  → is the product information lost? BoM stored?

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Conclusion

- *Industry 4.0*
  - Makes a lot size of 1 possible (not always desirable)
    - ⇨ Questionable business value for (cheap) mass products
  - allows new business models
  - Is more an evolution of CIM than an industrial revolution
    - ⇨ See [5)] and [11)] for critical voices
  - Research still necessary
  - Substantial investment needed
  - Huge social impact on employees
- *Industry 4.0 hype seems to increase with “additive production” (3D-Printing)*

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Discussion

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