Mechatronical engineering of production systems and its new challenges (also) for mathematical research

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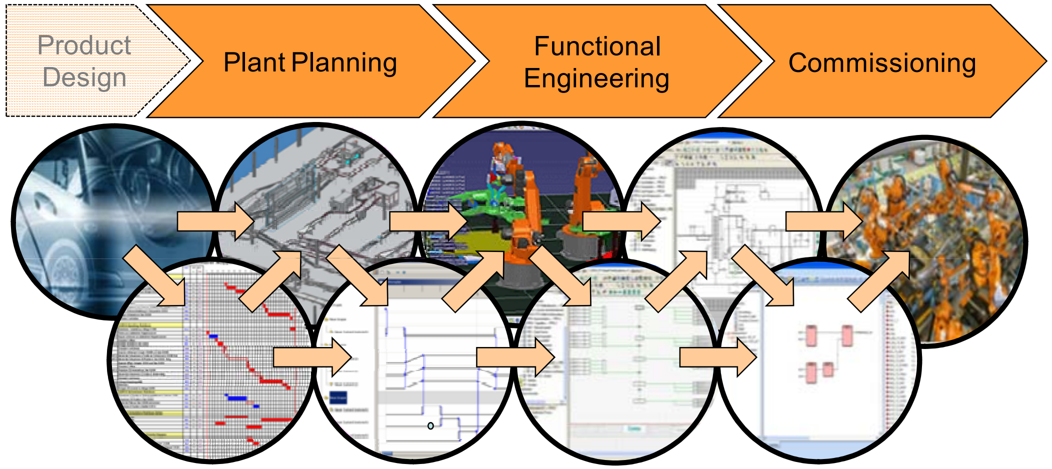
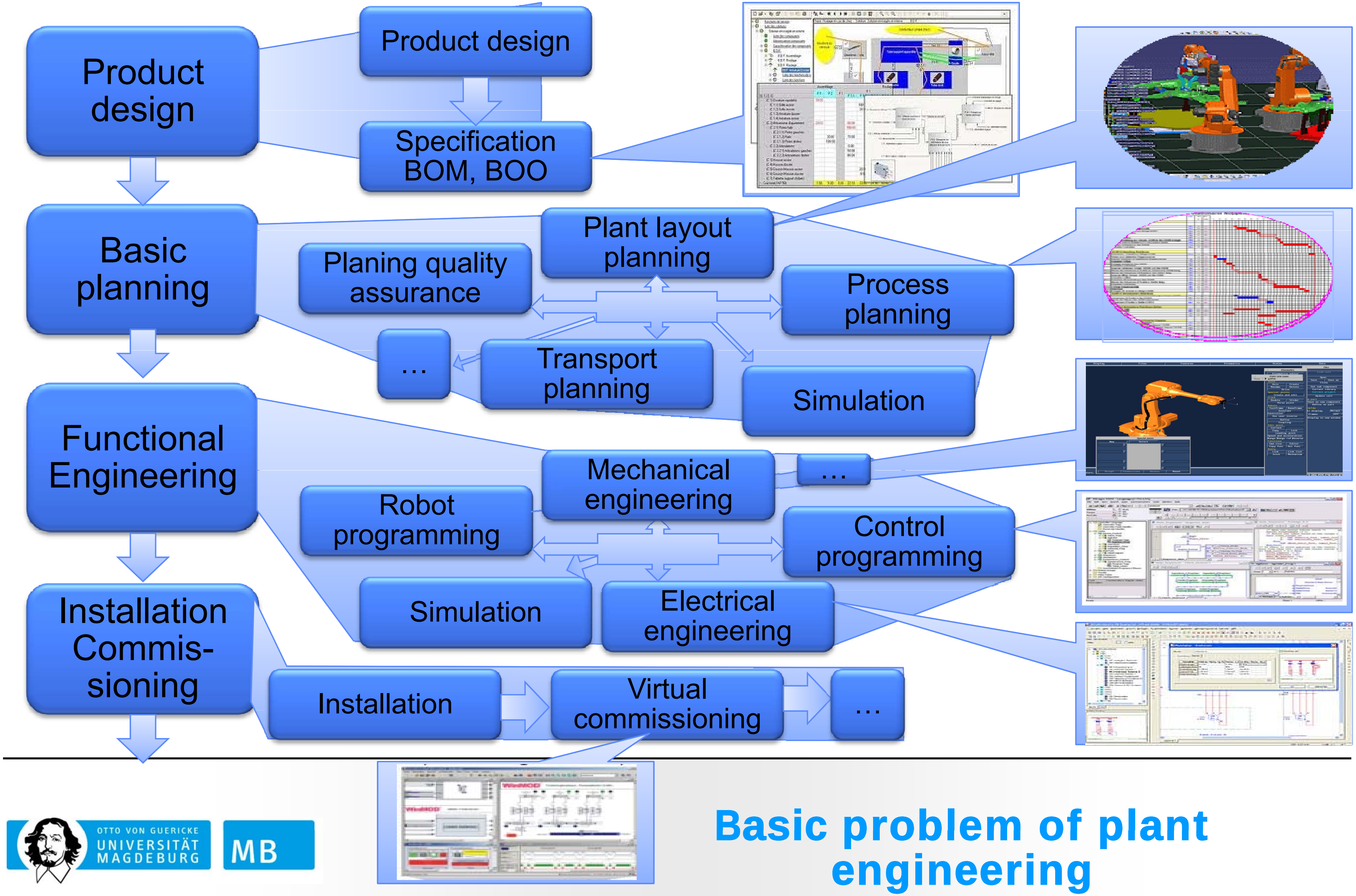
0. Some words about the speaker
1. Basic problem of plant engineering
2. Mechatronics – Terms and definitions
   - Mechatronical units
   - Mechatronical control architecture
3. Mechatronical engineering process for production systems
4. Benefits of mechatronical engineering
5. Challenges of mechatronical engineering
   - Engineering data consistency at model level
   - Distributed planning in distributed automation architectures
6. New research directions?

- **Companies face new challenges**
  - Increasing product variety
  - Reduced product life cycle
- **This results in**
  - Increase production system flexibility and, thus, complexity
  - Reduced production system lifetime
  - Increase production system reengineering frequency
- **But production system engineering involves various engineering disciplines**





Basic problem of plant engineering

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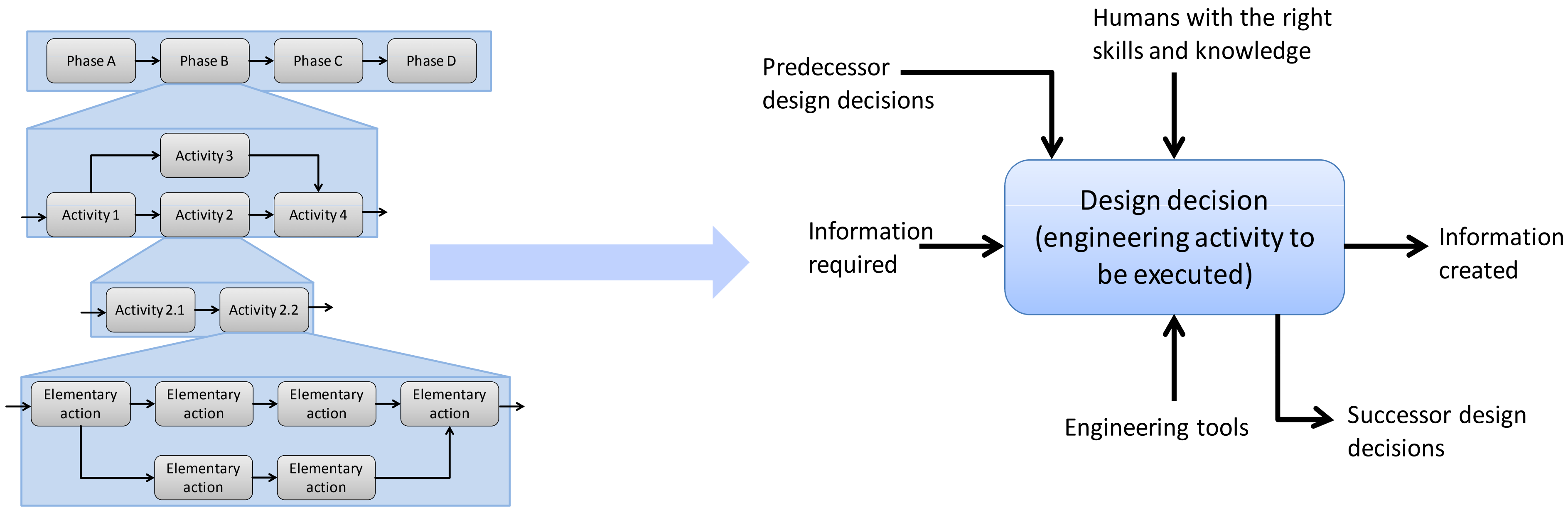
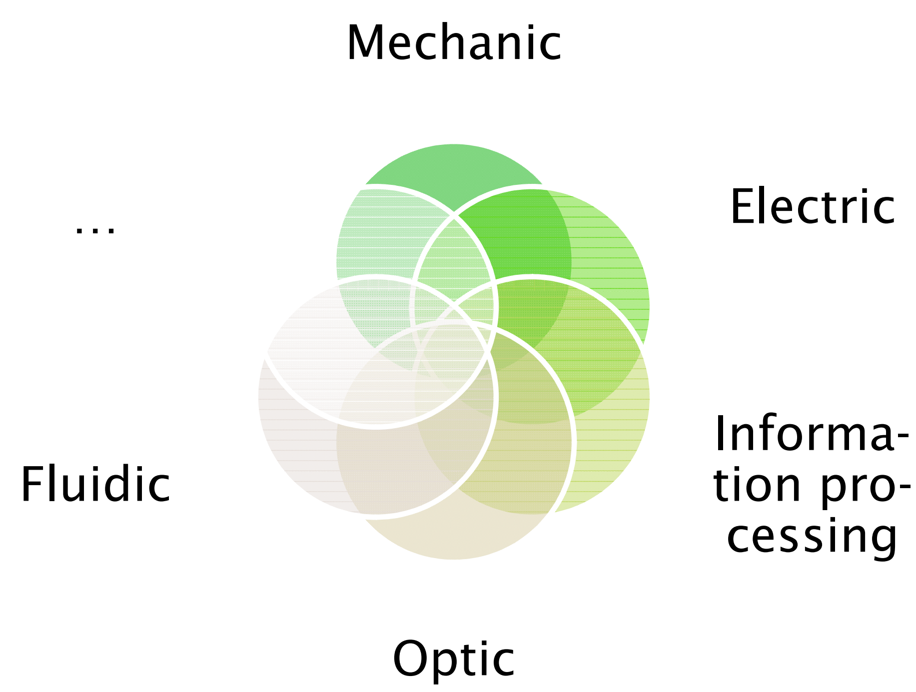
- **Engineering process**
  - **Consist of a hierarchy of engineering activities to make design decisions of different nature**
  - **Requires tools, engineering artifacts and human resources and creates engineering artifacts**



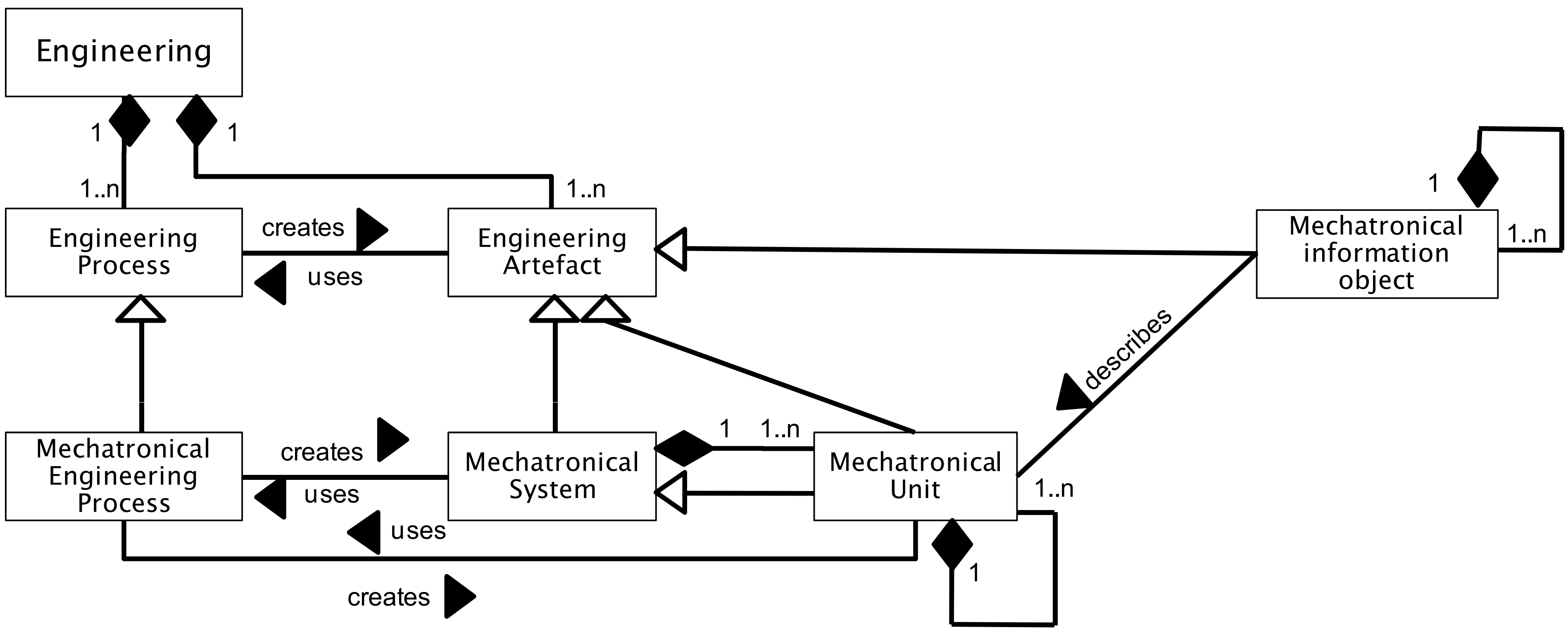
- **Within the engineering process several pitfalls need to be bypassed**
  - **Inconsistencies between engineering information of**
    - **Different engineering disciplines**
    - **Different engineering phases**
  - **Misinterpretations of engineering information in case of information exchange between**
    - **Different engineering tools**
    - **Different engineering disciplines**
    - **Different engineering phases**

- **Common concepts and models enabling an explicit representation of dependencies and model transformations are required**

- **Term Mechatronic emerges in 1970 in Japan**
  - **in Germany Feinwerktechnik is used in a similar way**
- **Today mechatronics is characterised by**
  - **Combination of mechanical, electrical, information and other sciences providing an added value beyond normal addition**
  - **Provision of a dedicated functionality**
- **Mechatronic is considered in application as well as in engineering**



- **A mechatronical engineering process**
  - is an engineering process where the involved engineering objects are mechatronical units and mechatronical systems.
- **A mechatronical unit (MU)**
  - Is a closed system realizing by actuators, sensors and controls a (physical) behavior within a manufacturing system
  - Is composed of software and hardware objects
  - Can be described by its functionality.
- **A mechatronical system**
  - Is composed of one or more mechatronical units
- **A mechatronical information object (MIO)**
  - Is an information oriented engineering artifact that combines the modeling of mechatronical units of a manufacturing system with its different characteristics like signals, electrical drawing, function blocks or devices in one object



Engineering
1
1
1..n
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Engineering
Process
creates
uses
Engineering
Artefact
Mechatronical
information
object
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Mechatronical
Engineering
Process
creates
uses
Mechatronical
System
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Mechatronical
Unit
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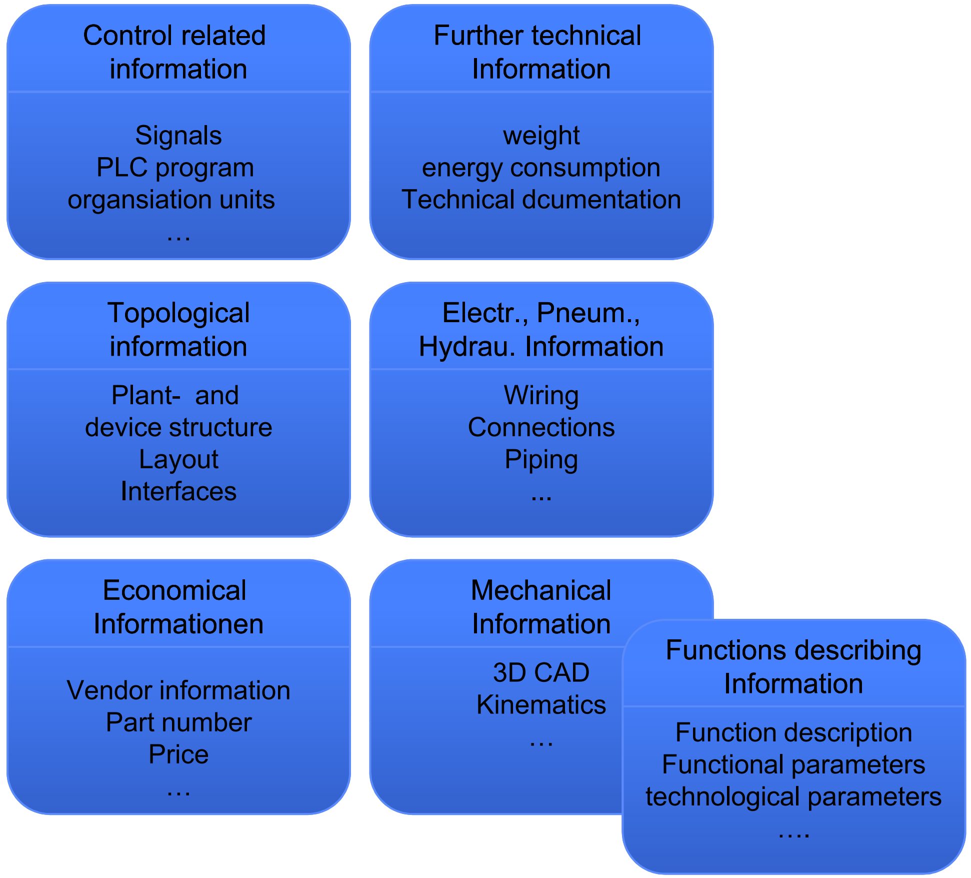
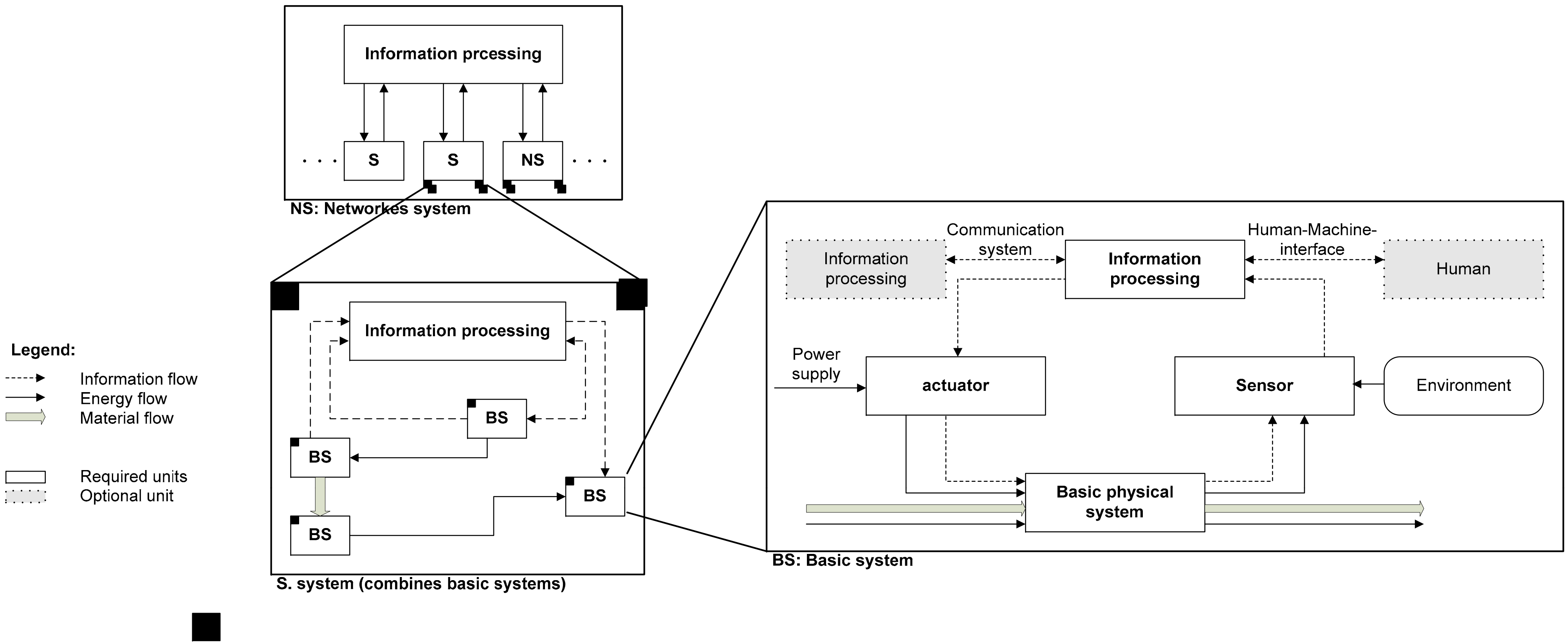
1
creates

Mechatronical information object

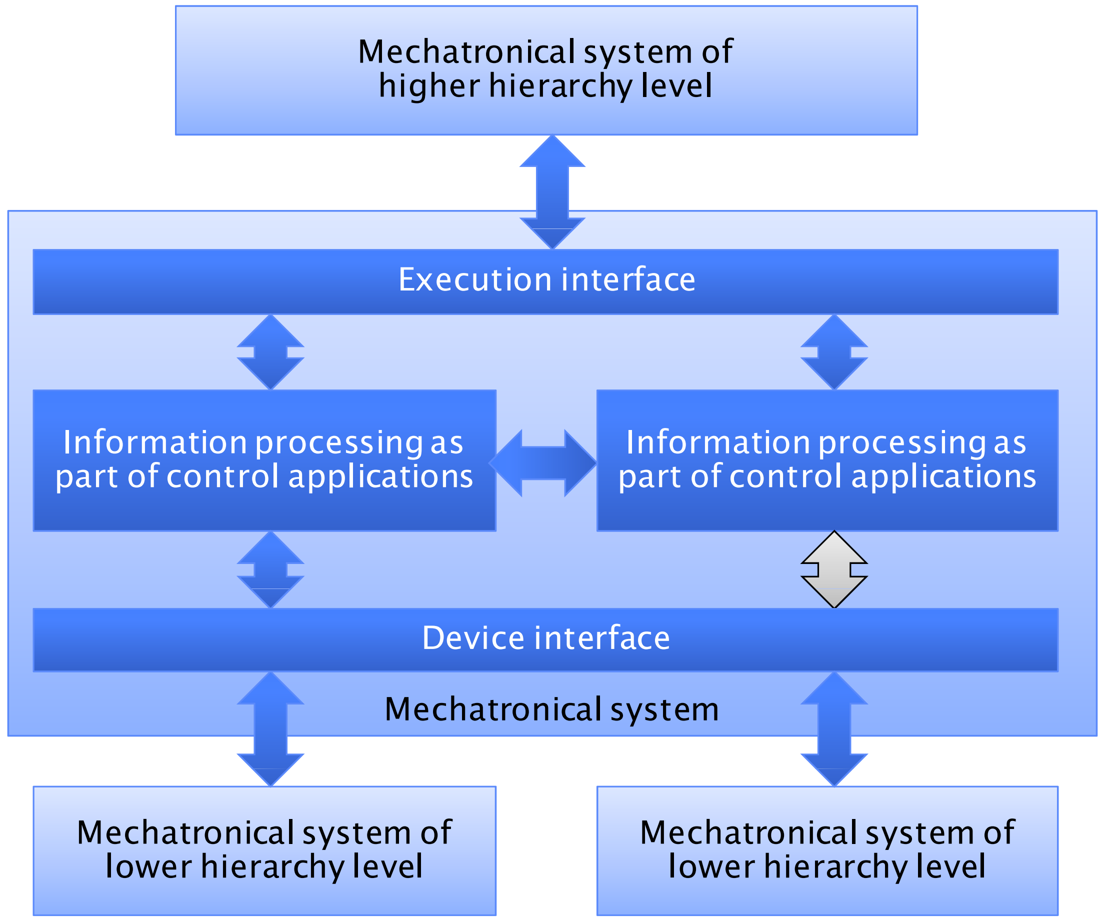
- **Represents the digital schadow of the mechatronical unit / system**
- **Contains**
  - **The different discipline related information / models / ...**
  - **The relations between information objects**
- **Can be treated like an ontology**



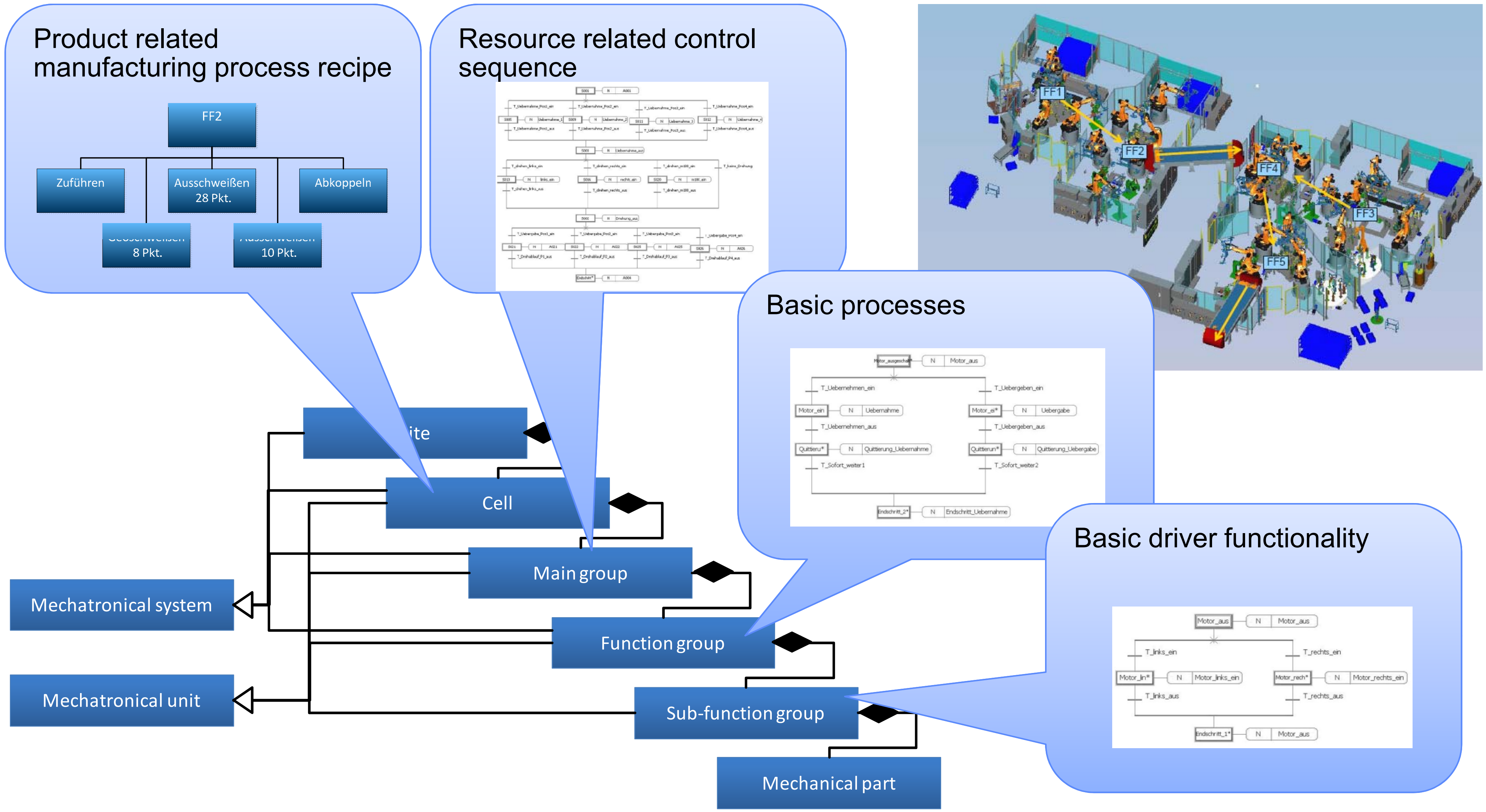
- **Mechatronical architecture following VDIU Guideline 2206**



- **Hierarchical mechatronical structure enables a hierarchical control structure**
  - **Provision of functions to higher layer mechatronical systems**
  - **Use of function of lower layer mechatronical systems to create own functions**
- **Enables clear structuring of manufacturing process control**



Mechatronical control architecture



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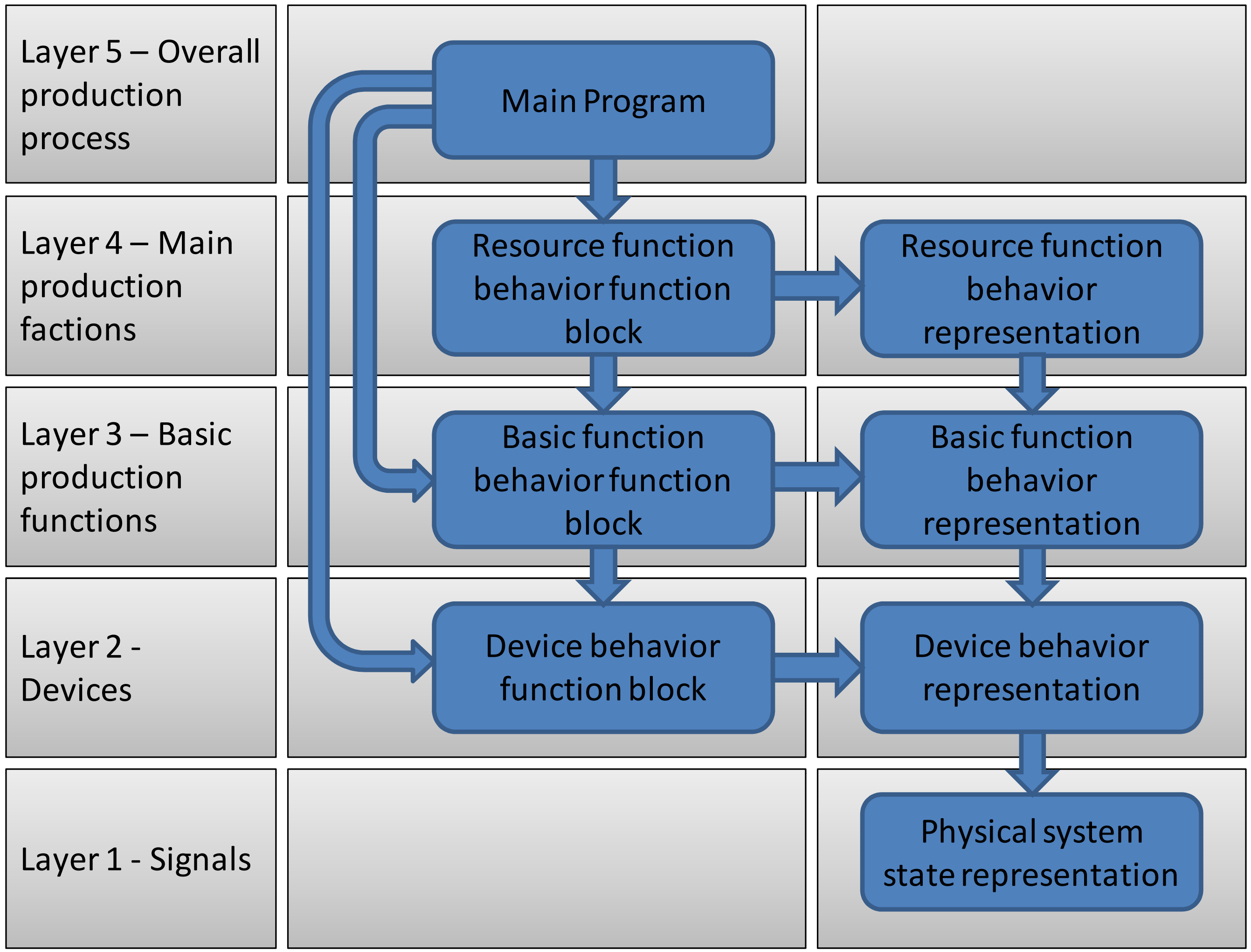
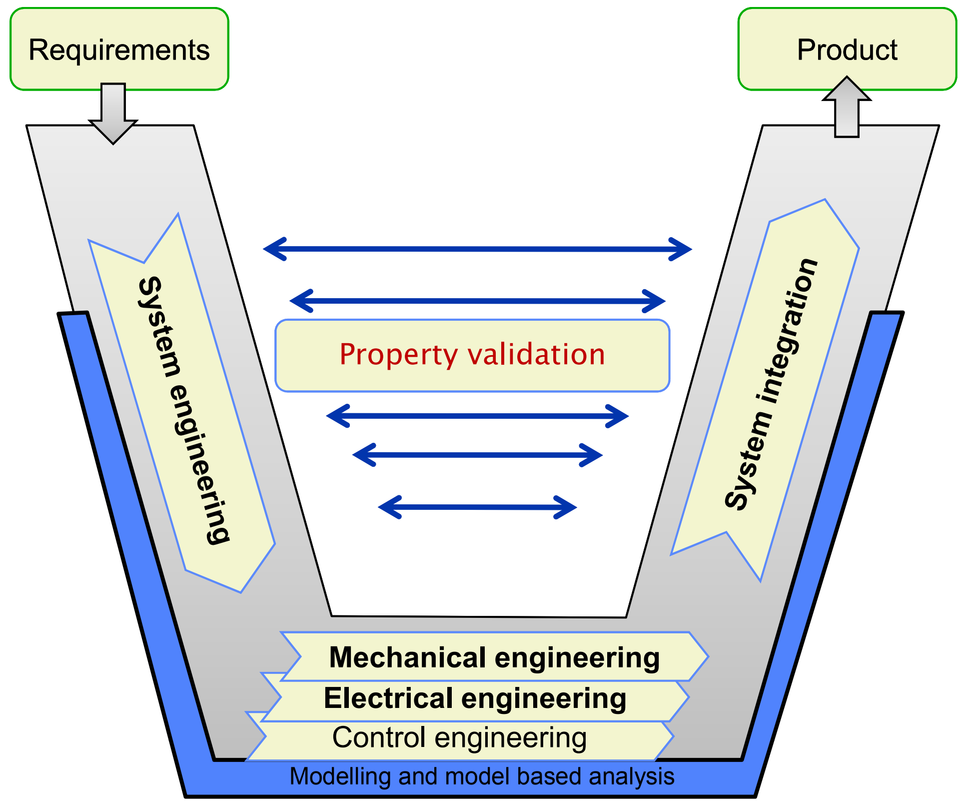


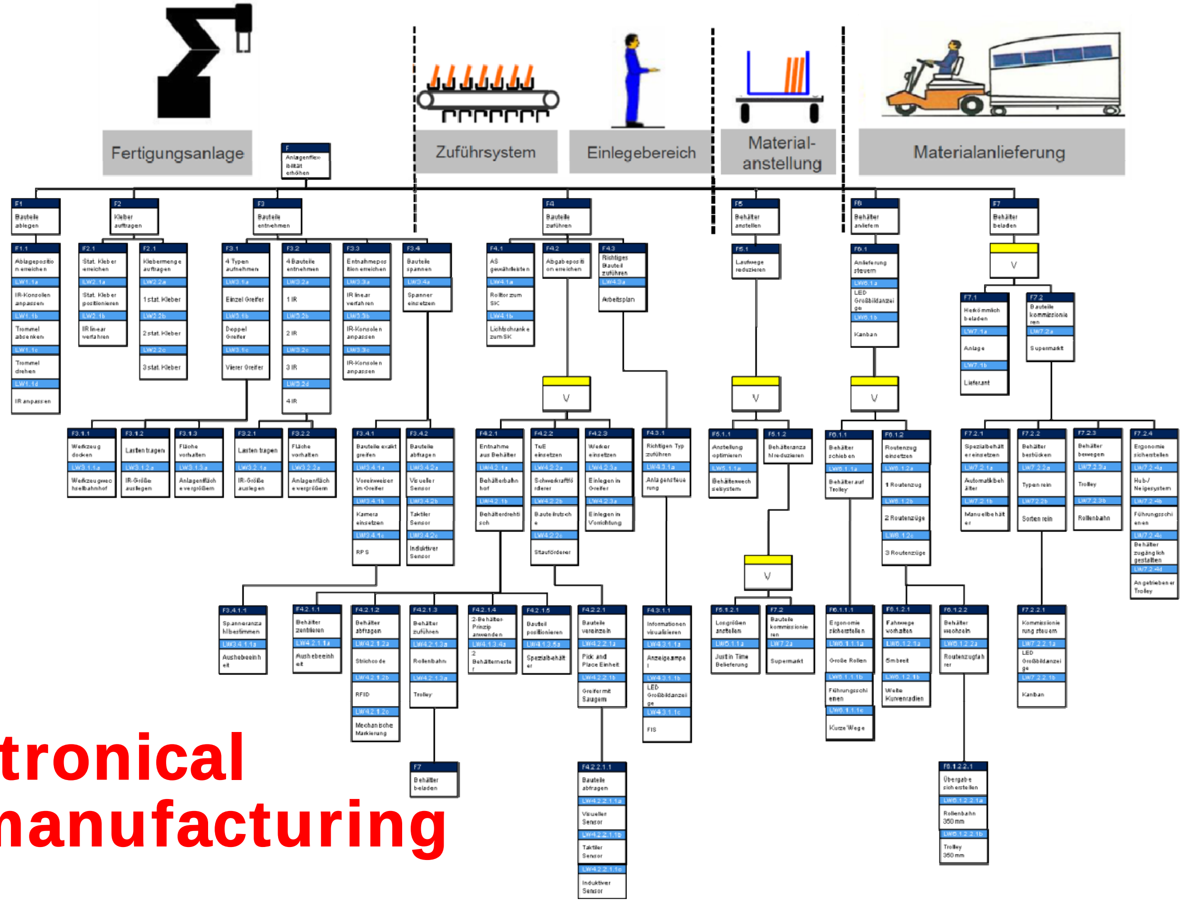
Mechatronical control architecture

- **VDI 2206 provides a process model for mechatronical engineering**
  - Different phases enabling the discipline crossing overall system design
  - Discipline specific system part engineering
  - Final system integration
  - Validation of requirements
- **Two main benefits for manufacturing system engineering**
  - Function orientation
  - System descomposition



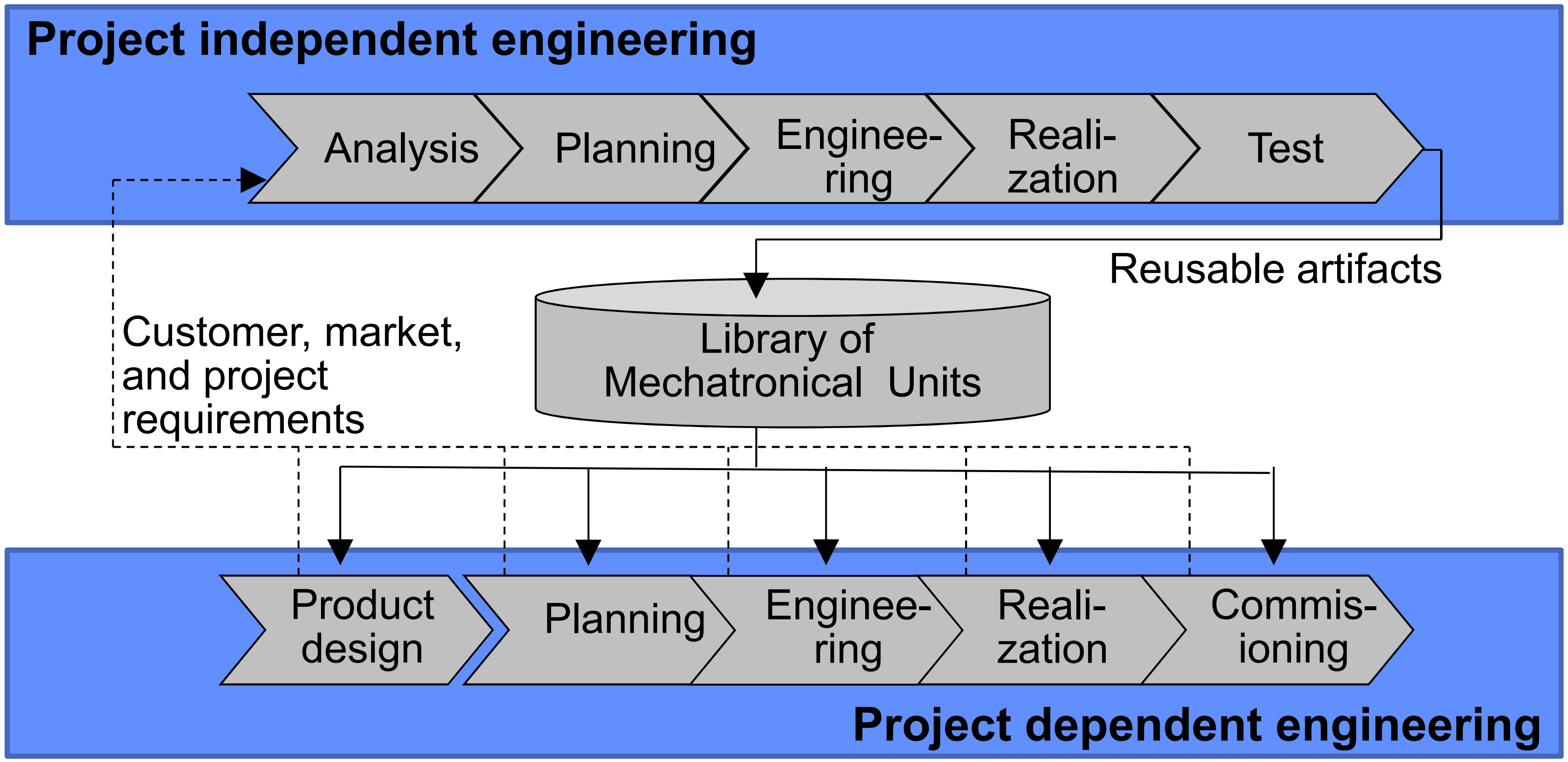
(Engineering process following VDI 2206)

- System engineering
  - Decomposition of system functions to a function hierarchy
  - Association of implementation components (functional units) to functions
  - Combination of functional units to complete system

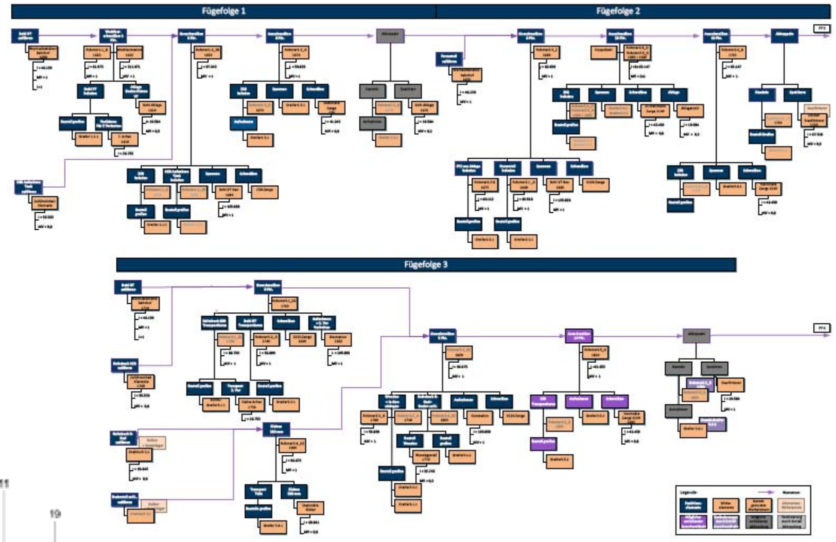


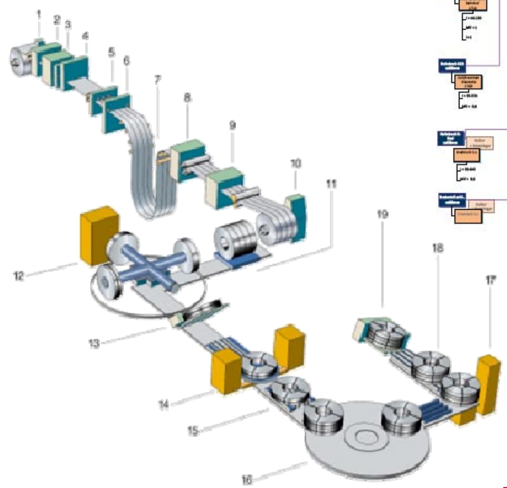
- Major benefit:
  - **Mapping of mechatronical units to required manufacturing system functions**

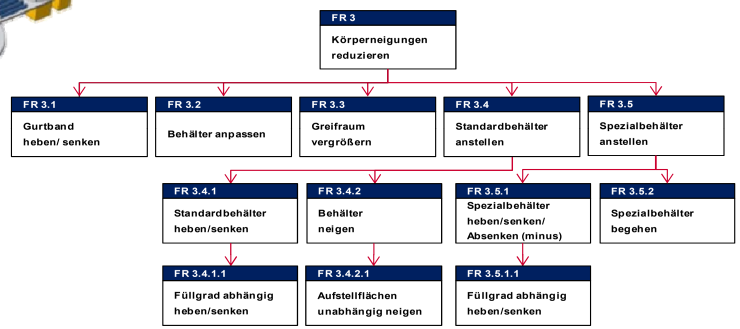
- **Engineering processes of manufacturing systems have got an new structure**
  - **Application of pre-designed and tested mechatronical units**
  - **Application of function descriptions for sellection**



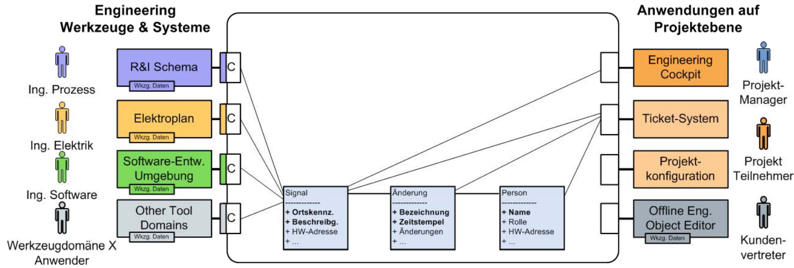
- **Ideas have been applied to**
  - Welding cells in car body manufacturing
  - Cutter systems in roller mills
  - Stone mills
  - Punching systems for metal sheet processing
  - Robot gripper design
  - …





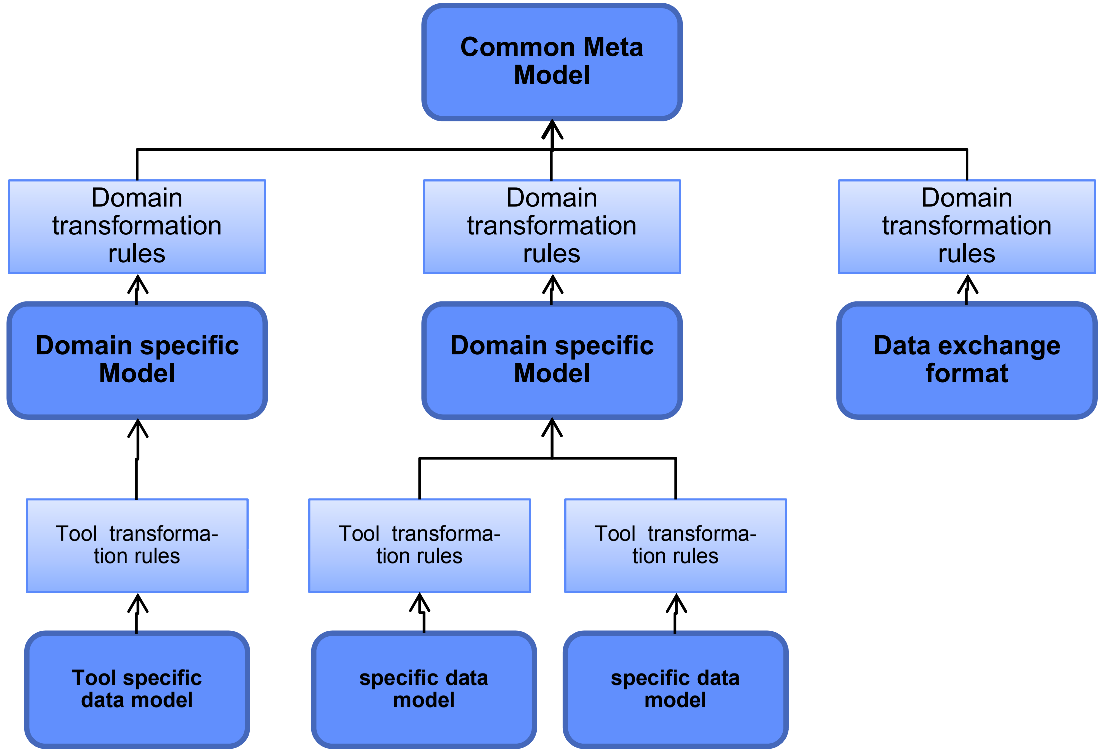


- **Development of common engineering concepts**
  - Mechatronical hierarchy enables the identification and use of common terms and entities within a production system
  - Examples:
    - Upcoming VDMA Guideline 66415
    - Typical drive application related machine components at Lenze
    - Signal within EngSB implementation for Hydro-Power-Station engineering
  - Engineers of different disciplines have a common dictionary

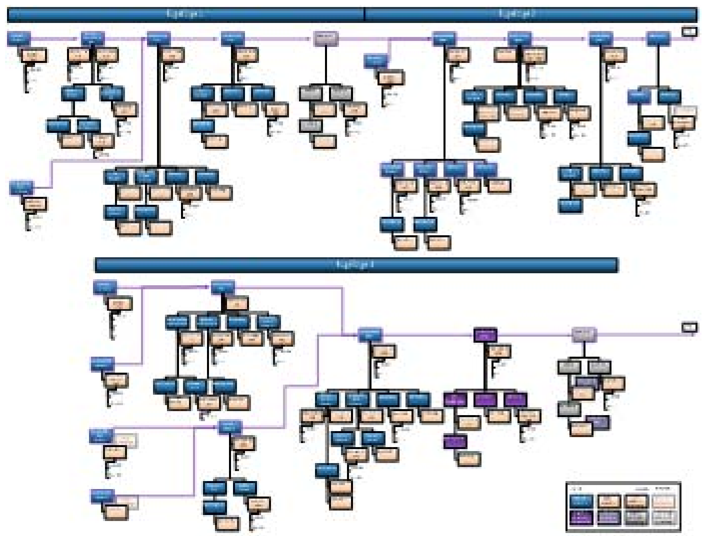


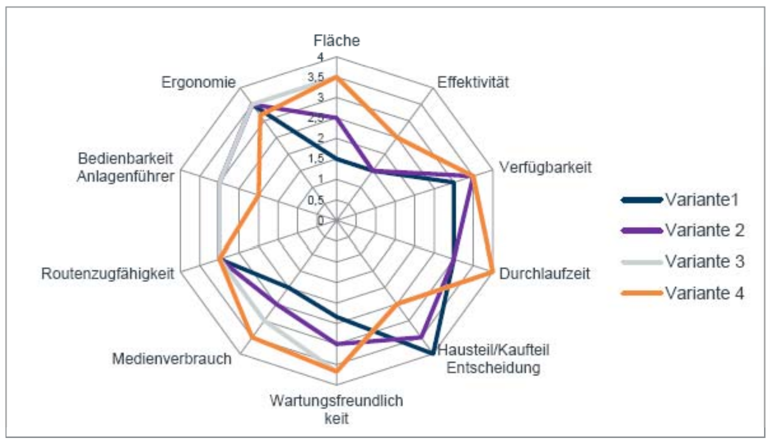
Benefits of mechatronical engineering

- **Identification of counter parts within different engineering models**
  - **Identification of redundant information, definition of information owner**
- **Identification of dependencies between information sets**
  - **Explicit representation of dependencies**
  - **Easy identification of problems and progress**



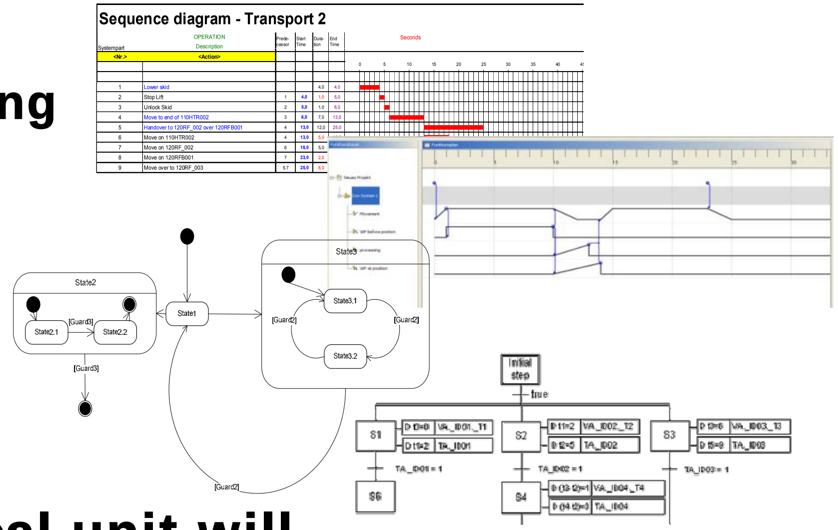
- **Function oriented engineering**
  - **Modeling of production system functions based on “Bill of operations”**
  - **Implementation technology independent plant design following ideas of Model Driven Engineering**
  - **Late freeze of implementation technology mapping**
  - **Possibility of optimization of resource allocation**





Engineering data consistency at model level

- Within different phases different types of models are applied
- Example: Control engineering related behavior information
  - Process planning ➔ Gantt Charts
  - Mechanical and electrical engineering ➔ Impuls Diagrams
  - Resource design ➔ State charts
  - Control programming ➔ PLC code
  - Virtual commissioning ➔ Differential equation systems
- How can be ensured, that models representing the same mechatronical unit will model the same behavior



➔ **Mathematical research can provide mapping and consistency rules for different types of models**

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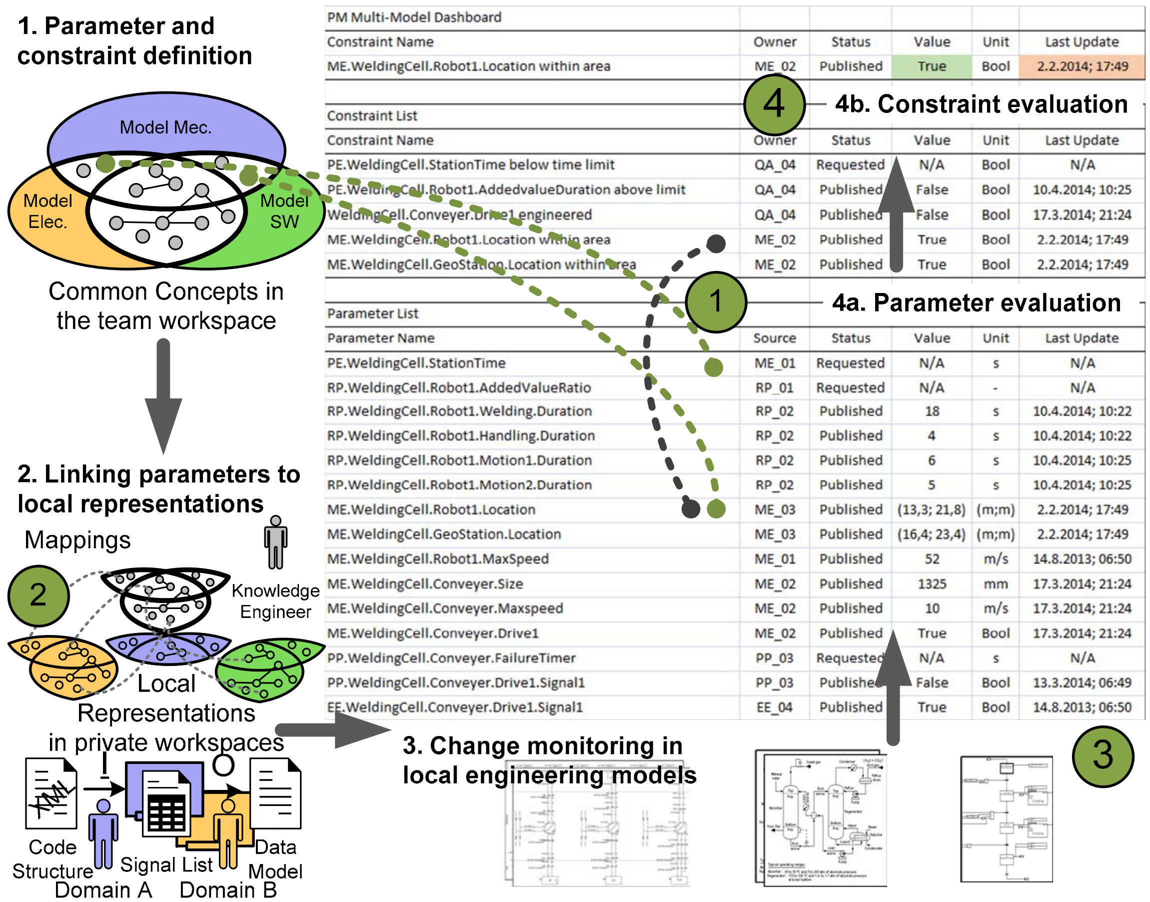
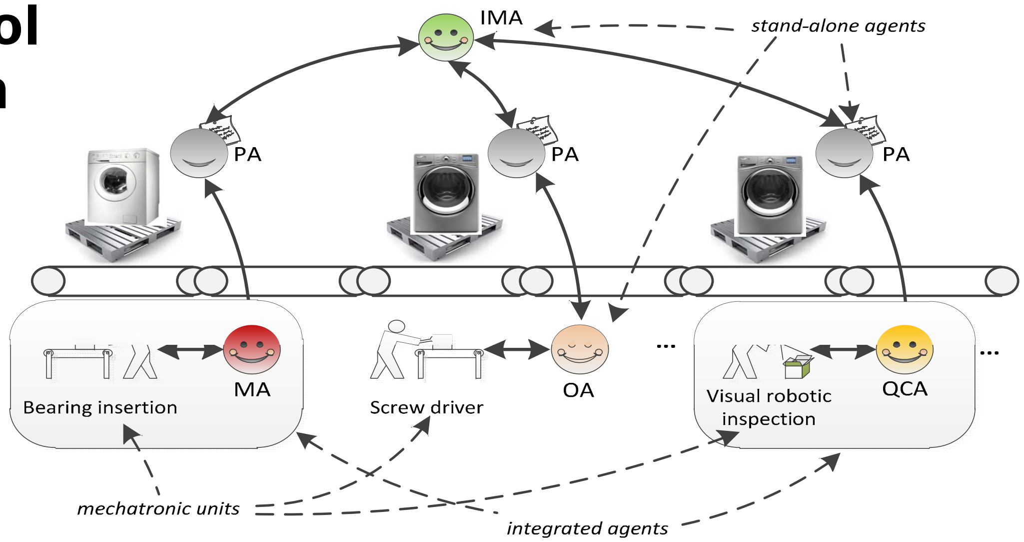
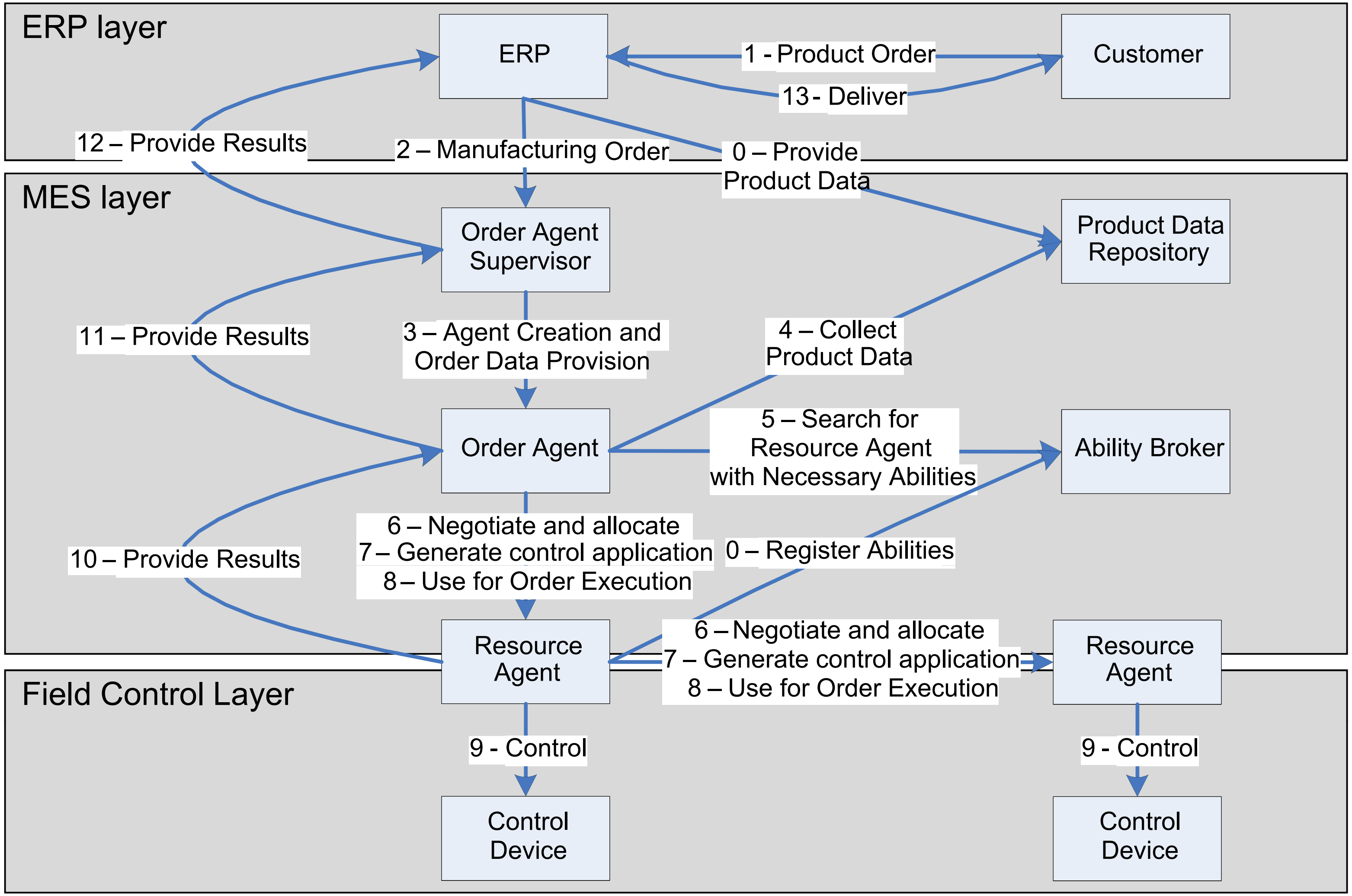
- **Most interesting types of models are**
  - Sequence oriented process models
  - Geometry and kinematic models of mechanical engineering
  - Dynamic models of electrical engineering
  - Automaton based (partially hybrid) models of control engineering
  - Timing models communication systems
  - Automation based (usually hybrid) models of physical plant behavior
- **Such model transformations should be based on data exchange technologies**

- **Possible application → Multi-Model Dashboard**
  - **Identification of information of common interest**
  - **Identification of information in local models**
  - **Modeling of dependencies as formulas**
  - **Automatic evaluation of dependencies to ensure correctness**
- **Improvement of engineering process quality**



- **Distributed planning in distributed automation architectures**
  - **Mechatronic oriented control systems tend to ensure distributed control**
  - ➔ **Entities control its own behavior independently but cooperative**
  - **Example: Distributed control at Manufacturing Execution Control level**




ERP layer
MES layer
Field Control Layer
ERP
Customer
1 - Product Order
13 - Deliver
12 – Provide Results
2 – Manufacturing Order
0 – Provide Product Data
Order Agent Supervisor
Product Data Repository
11 – Provide Results
3 – Agent Creation and Order Data Provision
4 – Collect Product Data
Order Agent
5 – Search for Resource Agent with Necessary Abilities
Ability Broker
10 – Provide Results
6 – Negotiate and allocate
7 – Generate control application
8 – Use for Order Execution
0 – Register Abilities
Resource Agent
6 – Negotiate and allocate
7 – Generate control application
8 – Use for Order Execution
Resource Agent
9 - Control
9 - Control
Control Device
Control Device

- **Essential problem: Distributed scheduling of resources**
  - **Current algorithms postulate the completely informed planner**
  - → **This is not given in distributed control**
  - **Instead:**
    - **Each control entity knows only its own requirements and bordering conditions**
    - **Control entities can interact via interaction protocols**
  - **Currently:**
    - **First come first served planning**
    - **Priority integration can result in snowball effects**

→ **Mathematical research can provide improved scheduling algorithms implementable in distributed control systems**

- **An essential capability for control system improvement is the increasing calculation power of modern embedded systems**
  - **Enable the direct application of model driven approaches and the execution of model based control systems**
  - **Enable implementation independent modeling of controlled behavior and its execution in an interpreter like way**

➔ **Behavior models can be designed, improved and executed along the plant life cycle integrating product related models and resource related models**

➔ **Success of Industry 4.0 initiative is based on such models**

➔ **Open question: How to enrich model content step by step while preserving model consistency in an automatic way?**

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- Model transformation
- Model consistency rules
- Model integration

- **Most relevant model types:**
  - Systems of interacting (hybrid) automatons were automaton states may contain differential equation systems to represent parameter trends
  - Systems of hierarchical automatons

Der einzige Weg, die Grenzen des Möglichen zu finden, ist, ein klein wenig über diese hinaus in das Unmögliche vorzustoßen.

Arthur C. Clarke