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Experiences and Perspectives from Applying MBSE in Manufacturing

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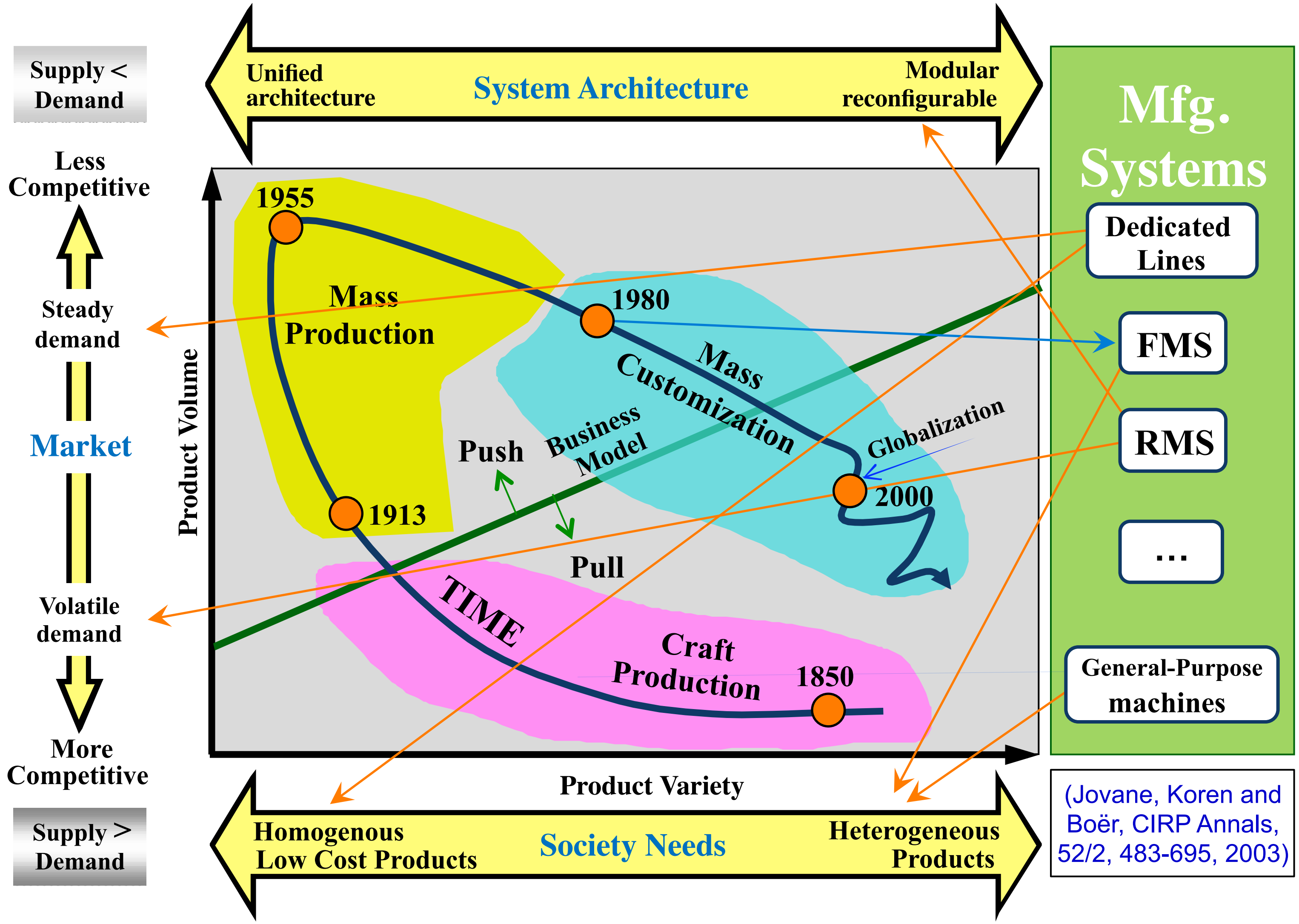
Presentation Outline

- Introduction to Manufacturing
- Life Cycle Data Integration
- Cyber- and Cloud-based Applications
  - Remote Monitoring and Control
  - Remote Assembly
  - Human-Robot Collaboration
- Conclusions

Manufacturing in a Nutshell

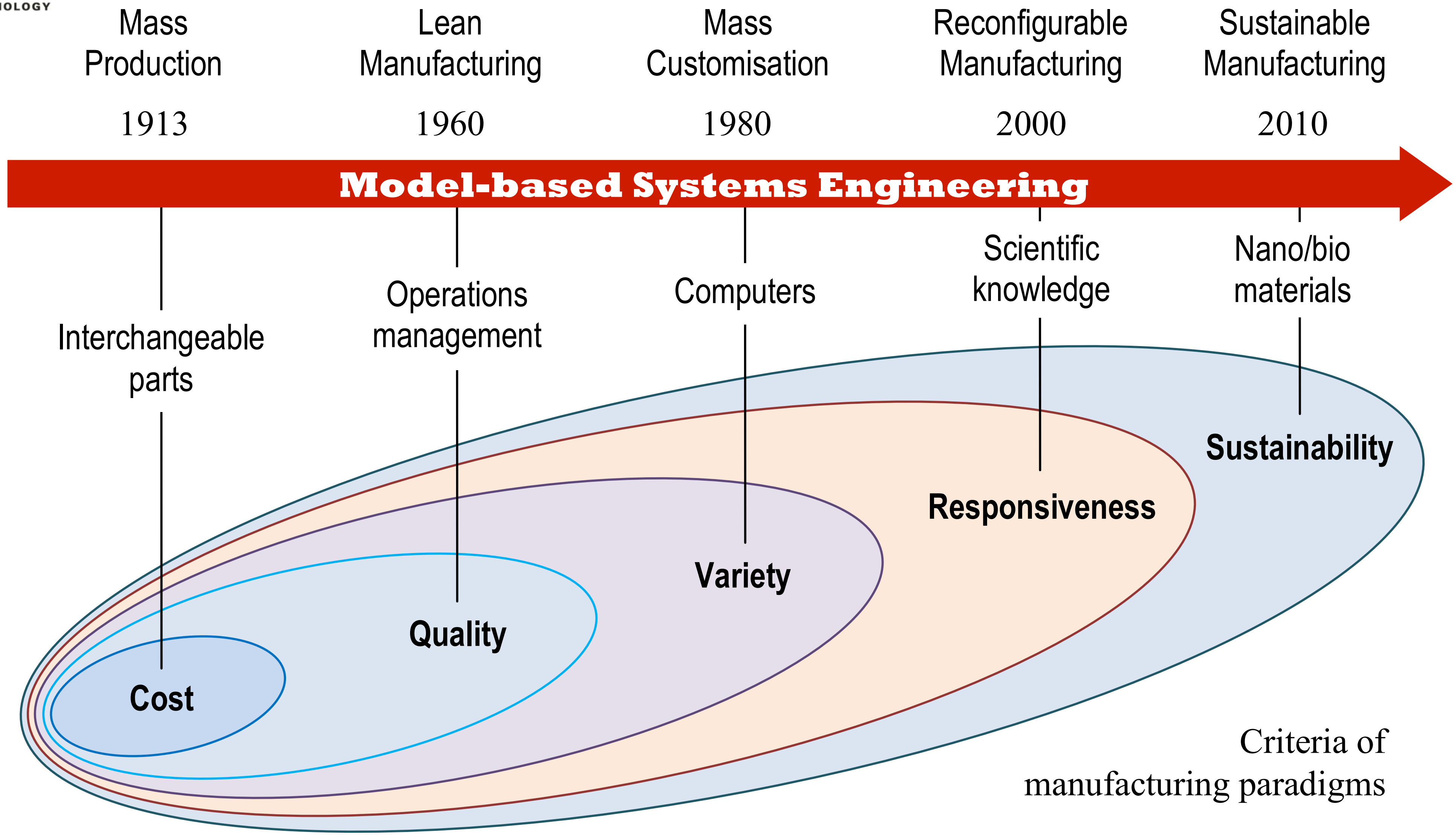


(Jovane, Koren and Boër, CIRP Annals, 52/2, 483-695, 2003)

Current Focus:

- Cyber-physical systems
- Cloud manufacturing
- Human-robot collaboration
- Programming-free machine control
- Additive manufacturing
- MBSE

Manufacturing Paradigms



(Adapted from Koren and Ulsoy, "Reconfigurable manufacturing systems," ERC/RMS, University of Michigan, 1997)

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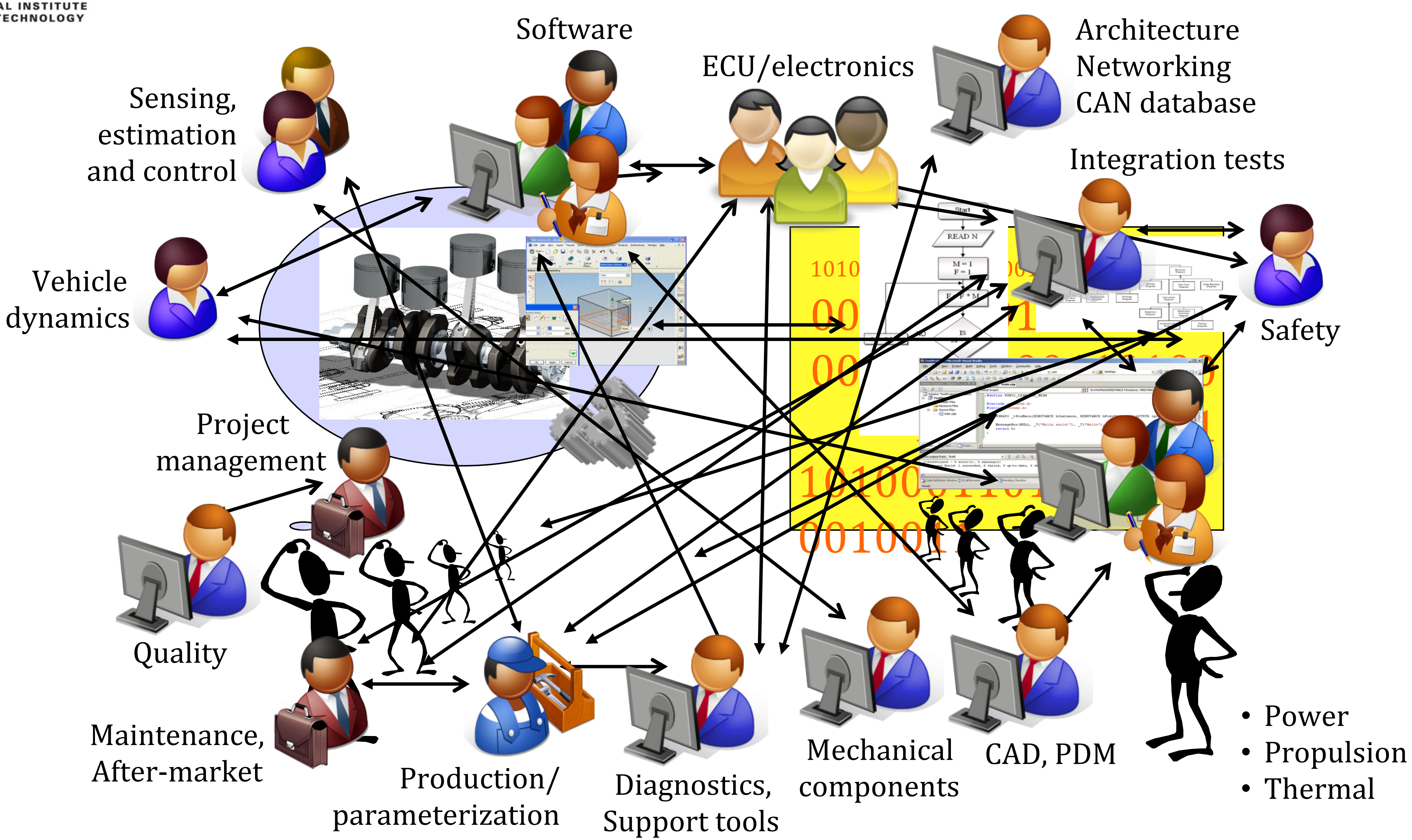
Model-based Engineering

MANY INSTANCES AND FLAVOURS OF MBD!!!

“Computerized models used to support engineering throughout the life-cycle”

- Purposes: communication, documentation, analysis and synthesis
- Drivers: Complexity, ”Criticality” and ”Reuse”
- Requires appropriate methodology and strategy
  - Formalization comes at a cost

Viewpoints and Interrelations



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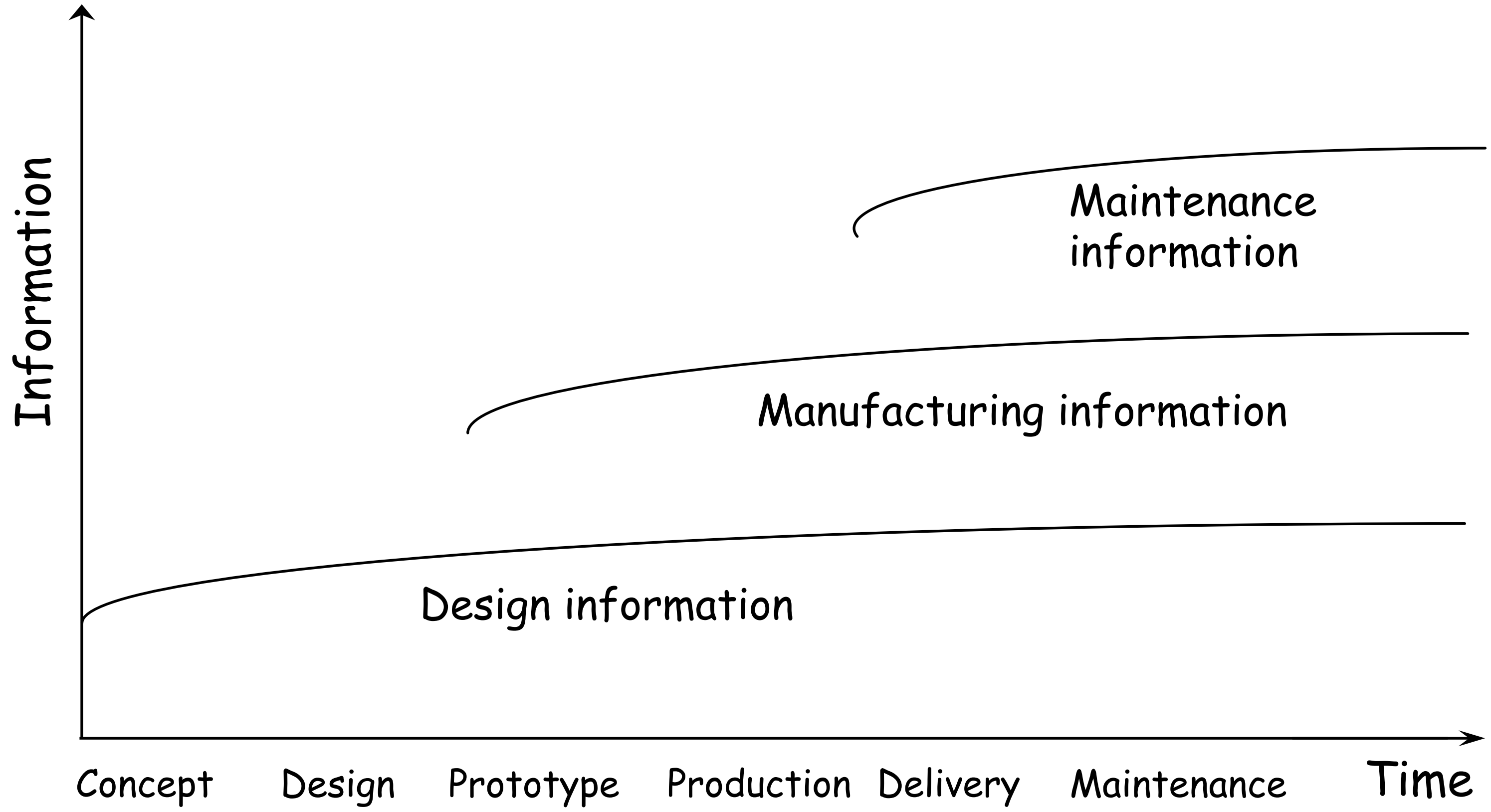
Product related "Information Mountain"



Fragmented storage in various specific IT systems (PLM, ALM, ERP, CRM etc.), resulting in "Inconsistency management"

Example case study: Information sharing in factory design

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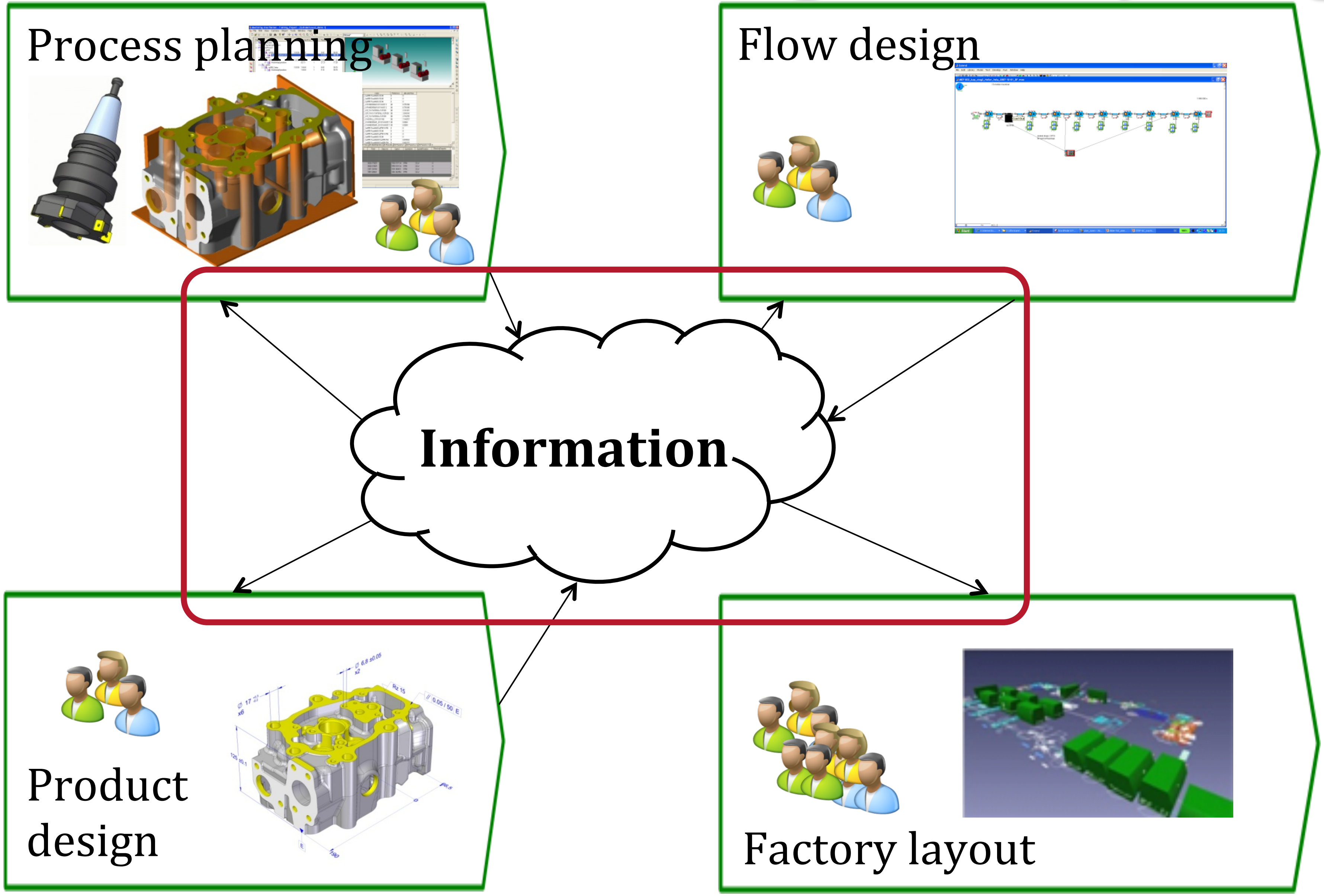


Model Integration and Decoupling

Basic relations: Coupled systems; Model Equivalence; Model abstraction/refinement

- But much more concerns involved!

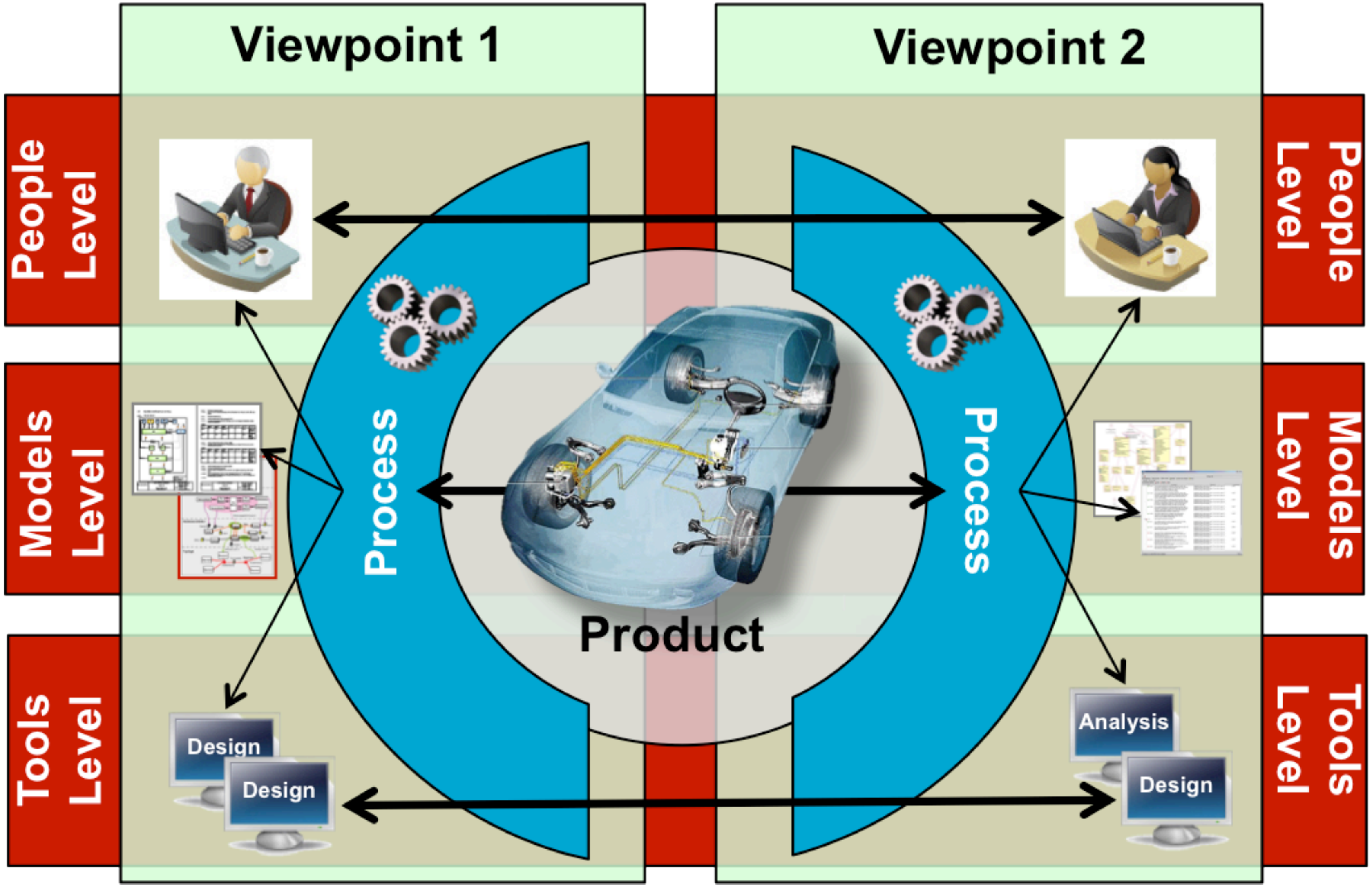
Multiple integration scenarios; Problems and Opportunities!

Challenge: Efficienctly dealing with change management, reuse, consistency, and leveraging added value services

Approach:

- Architecting engineering environments
- DSLs and code generators for data integration
- Viewpoint contracts and dependency modelling
- OSLC based integration and data warehousing

Multi-level Approach for Dealing with Viewpoint Interrelations



Example Contracts:
Control-Embedded SW with Timing Constraints

Agreement and obligations regarding functionalities and timing properties

- SW engineers: execute functions; meet timing requirements
- Control engineers: ensure correct closed-loop behaviour

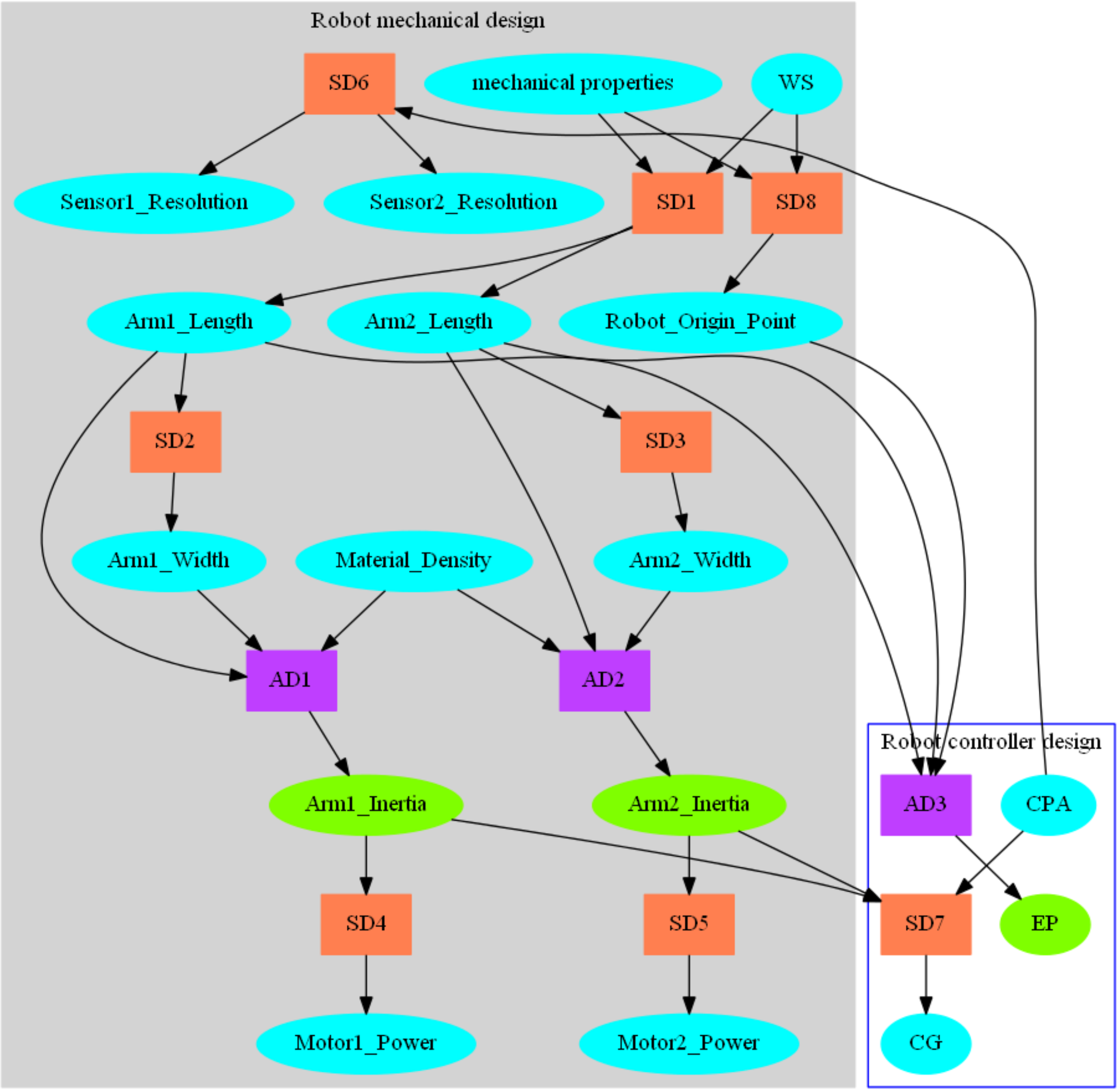
Example contracts:
- ’ZET’ ~ the synchronous approach
- ’LET’ ~ the PLC / Giotto approach
- ’BET’ ~ interpretation of FPS
- ’DET’ ~ deadline monotonic scheduling
- ’TOL’ ~ Tolerances on time variations

Basis for communication and agreements

Targets specific scenarios

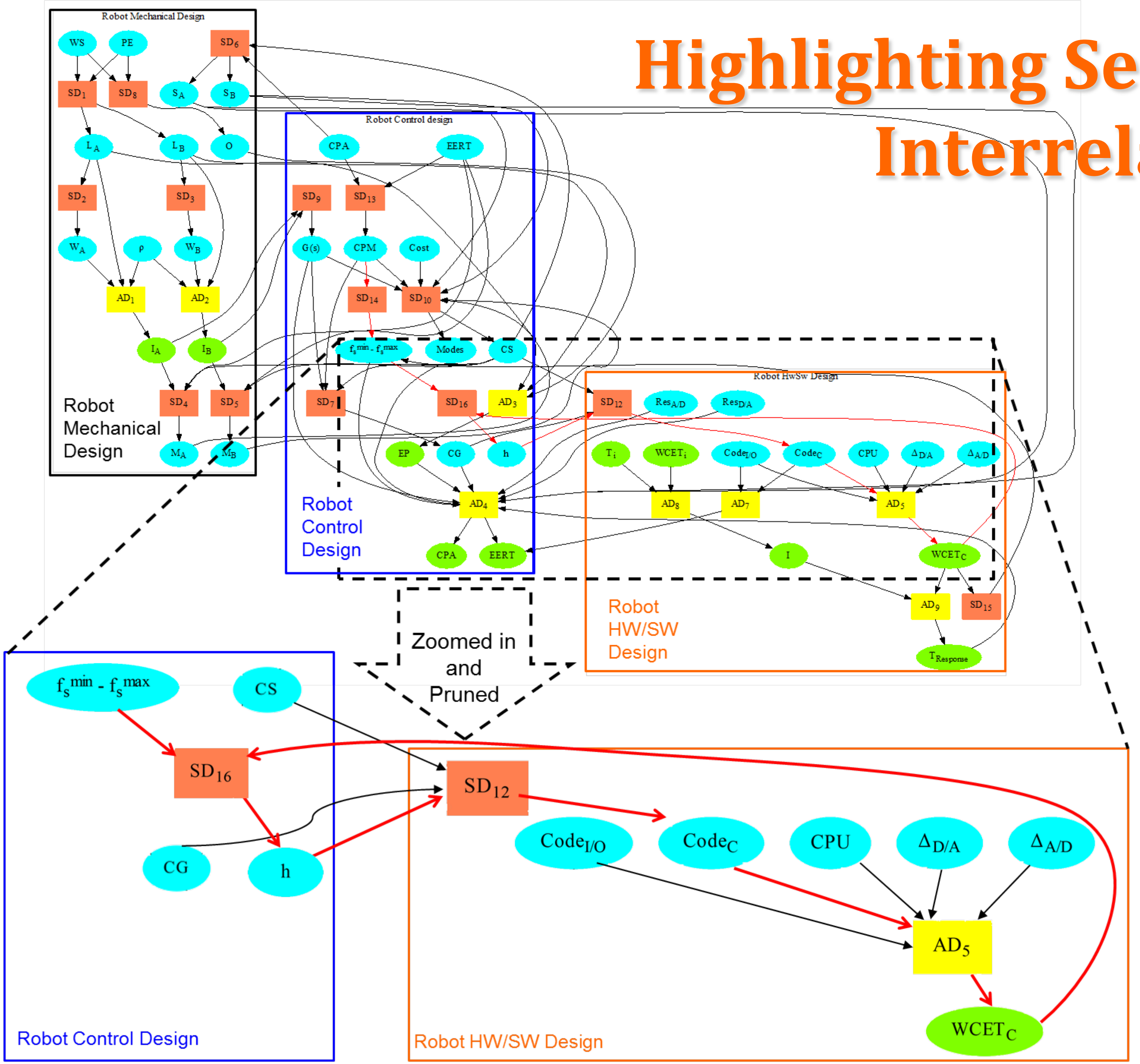
Support for modelling and simulation

Dependency Model Example

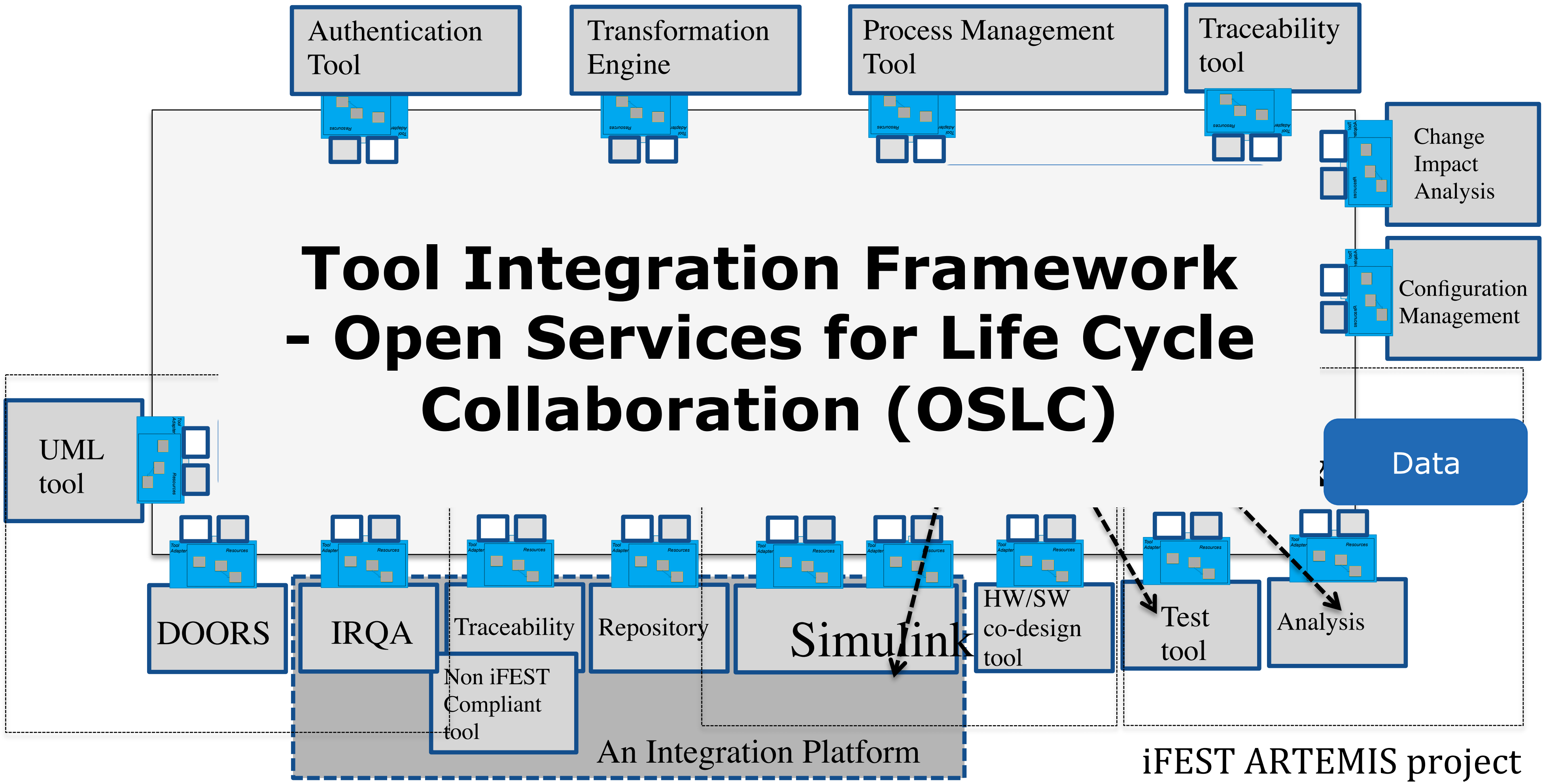


Courtesty of Ahsan Qamar
(KTH PhD)

Highlighting Selected Interrelations



Federated Tools and Data Exchange



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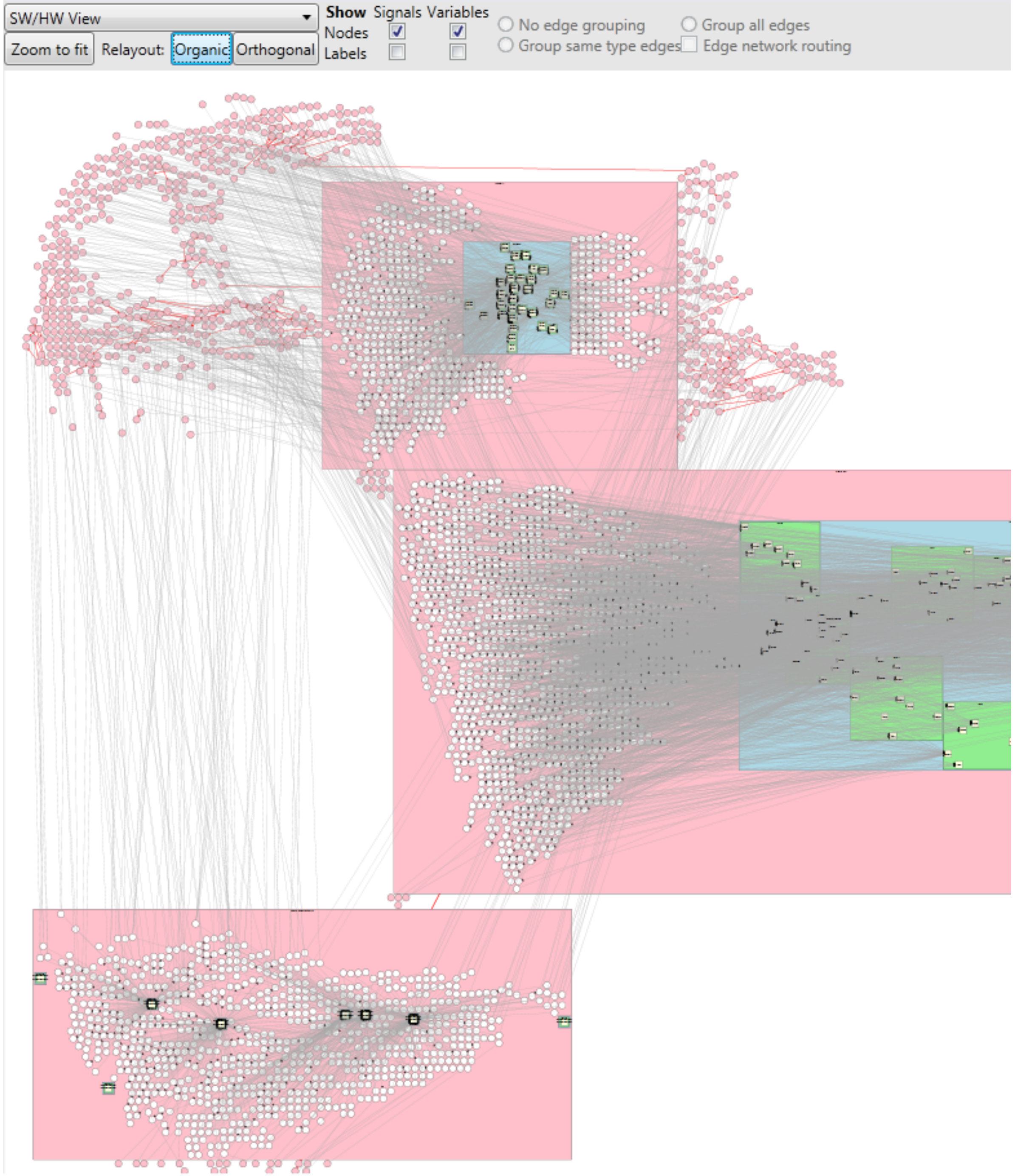
Architecture Browser for Automotive Embedded SW

Espresso Project Demonstrator (Scania and KTH)



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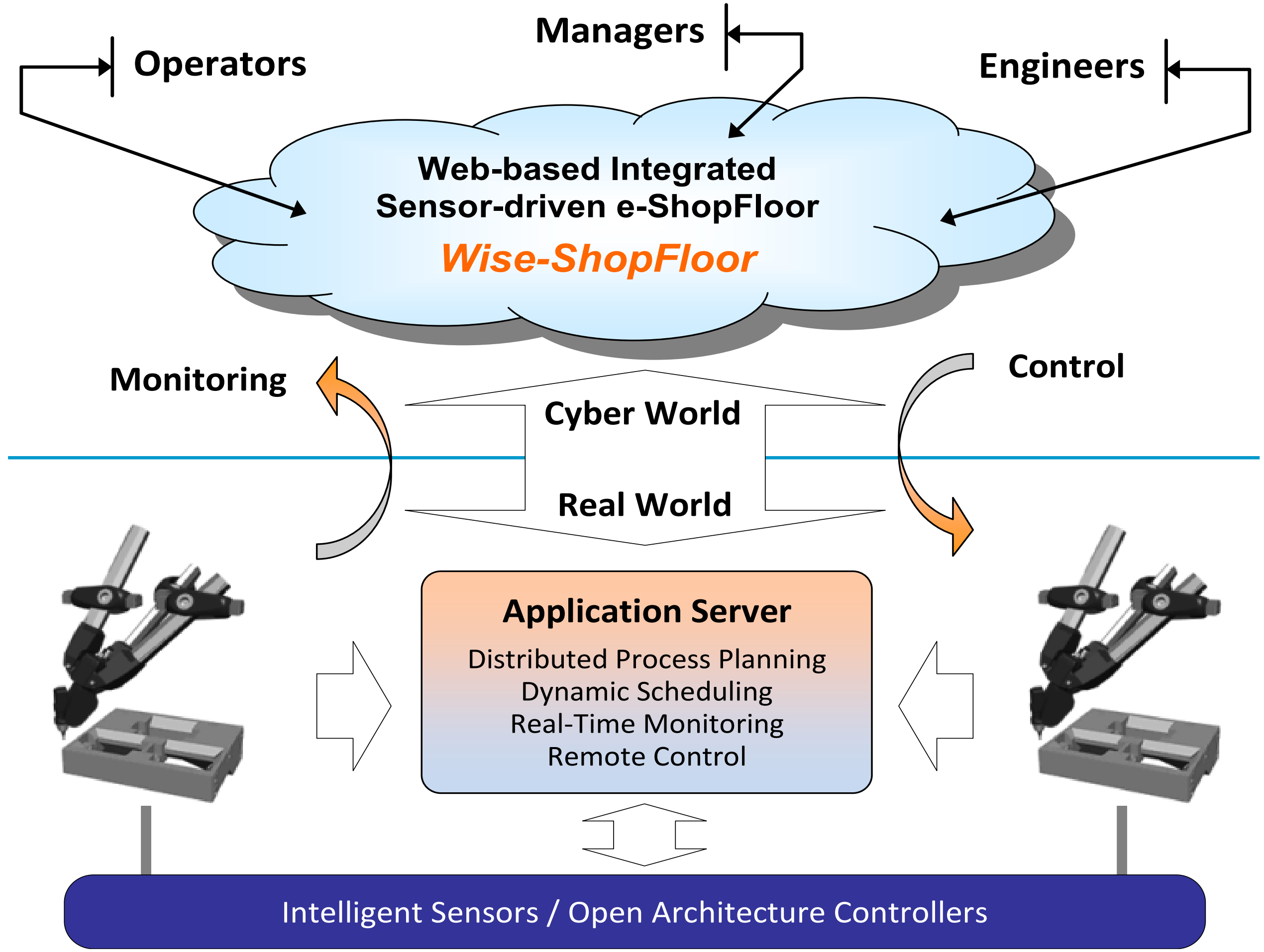
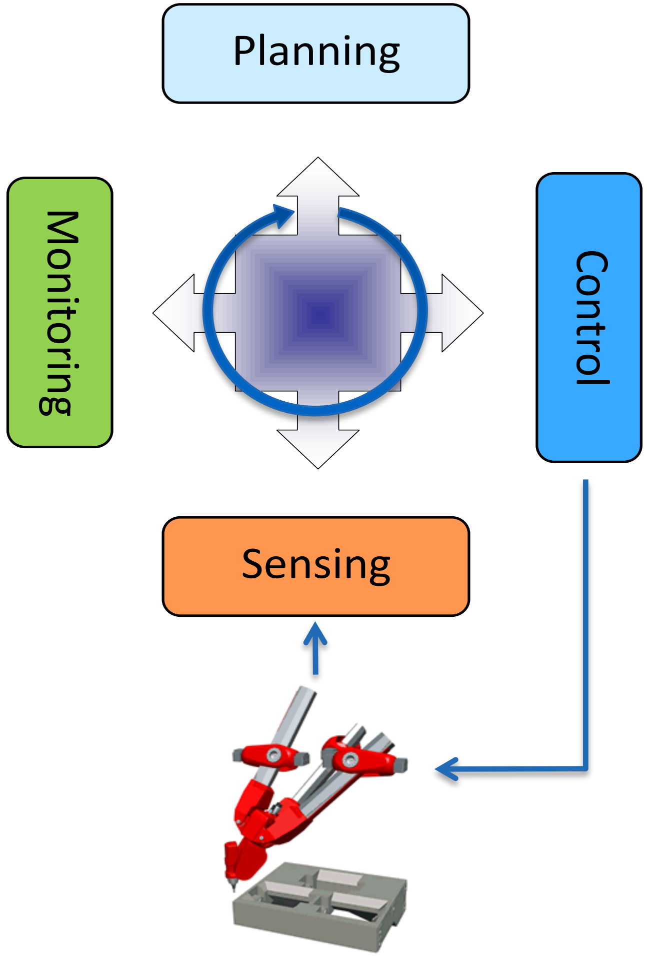
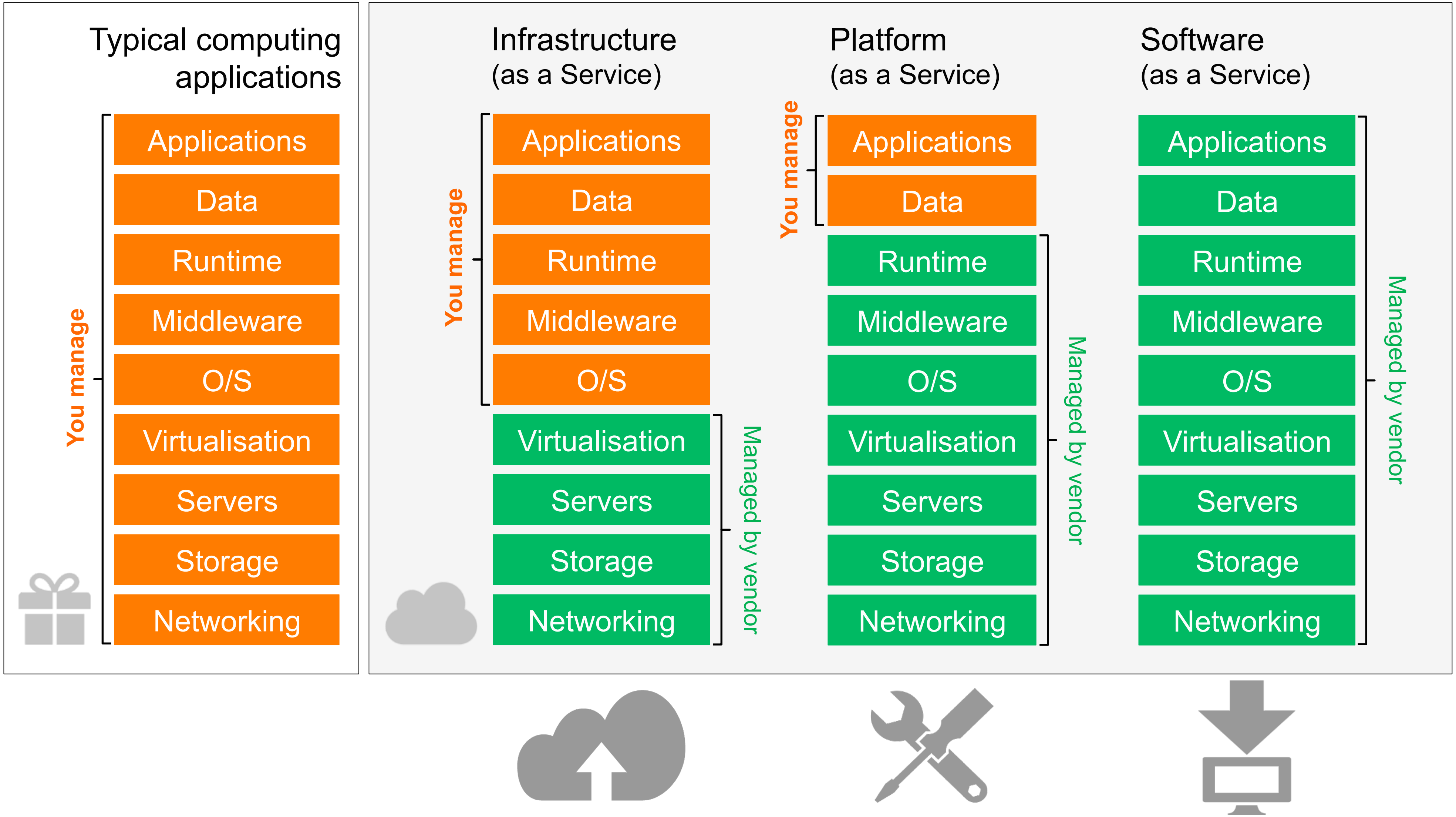
Cyber vs. Cloud Manufacturing

Cyber-Physical → Dynamic → Adaptive





Service Levels in the Cloud



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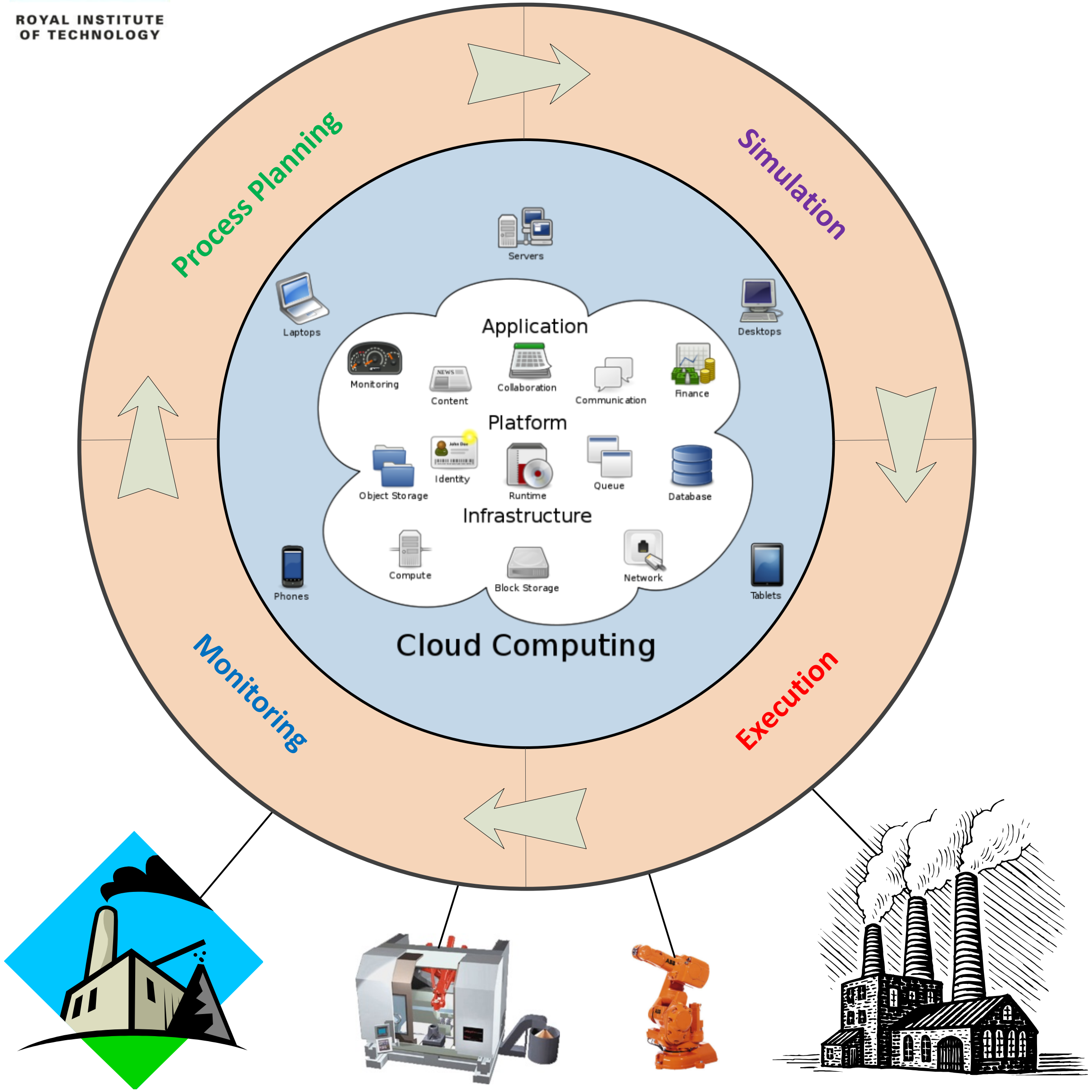
Benefits of Using Cloud

ELASTIC	Scale up or down based on demand – quickly!
BROAD ACCESS	The resources are always available and can be instantly accessed and deployed from anywhere, any time.
FAULT TOLERANT	Degree of replication including geo-replication provides fault tolerance. High availability.
COST-EFFECTIVE	Pay only for what we use. Economies of scale allow cost reduction.

Cloud Manufacturing Concept



→ **Cloud computing** – provides services (IaaS, PaaS, SaaS, AssS) with high reliability, dynamic scalability, and availability over the Internet

→ **Cloud manufacturing** – is based on cloud computing and offers adaptive, secure and on-demand manufacturing services over the Internet of Things

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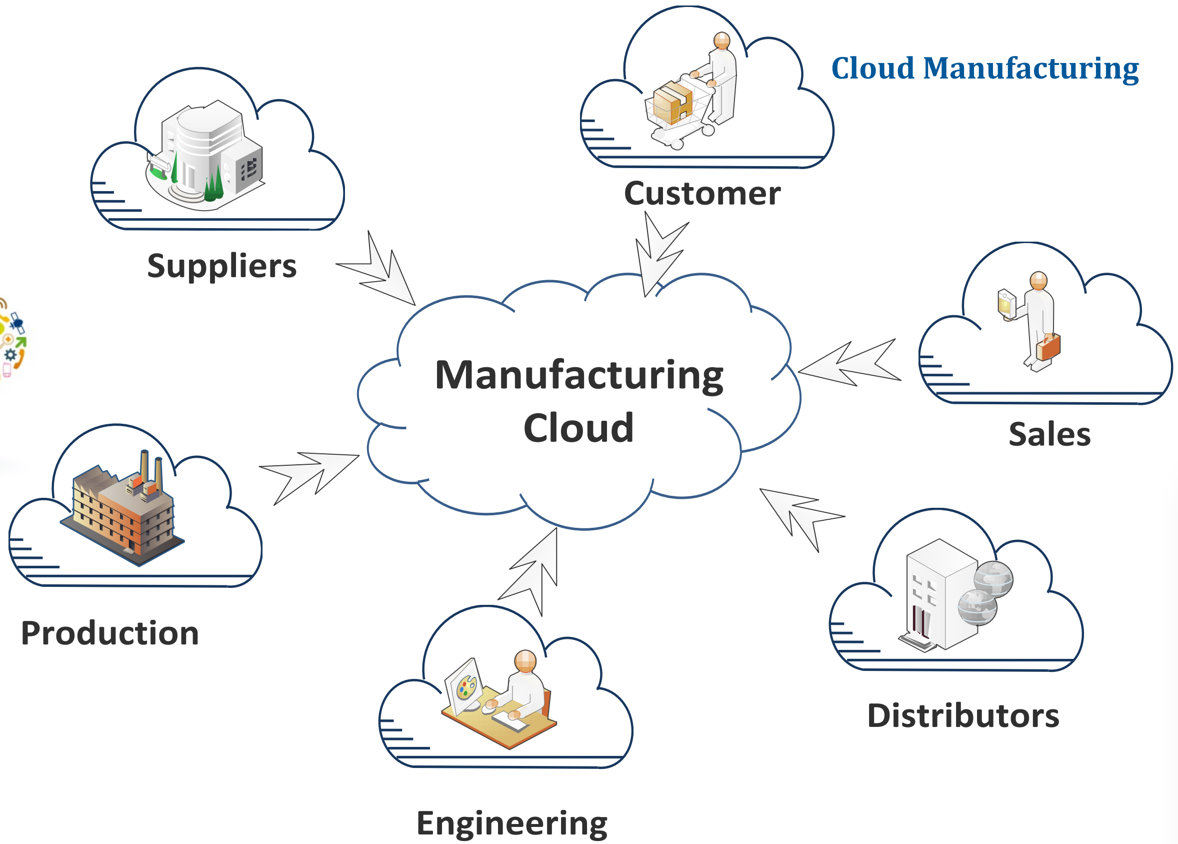
What Is Cloud Manufacturing?

Cloud Computing

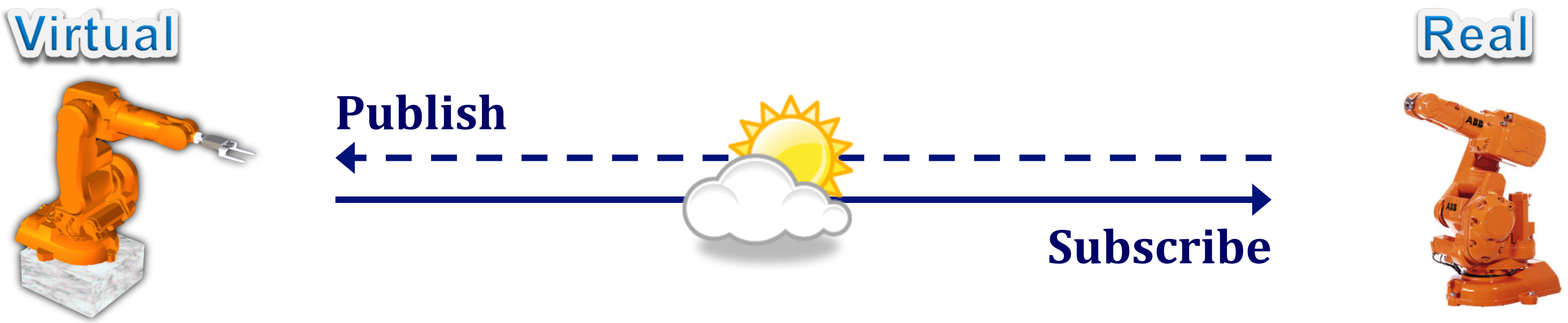


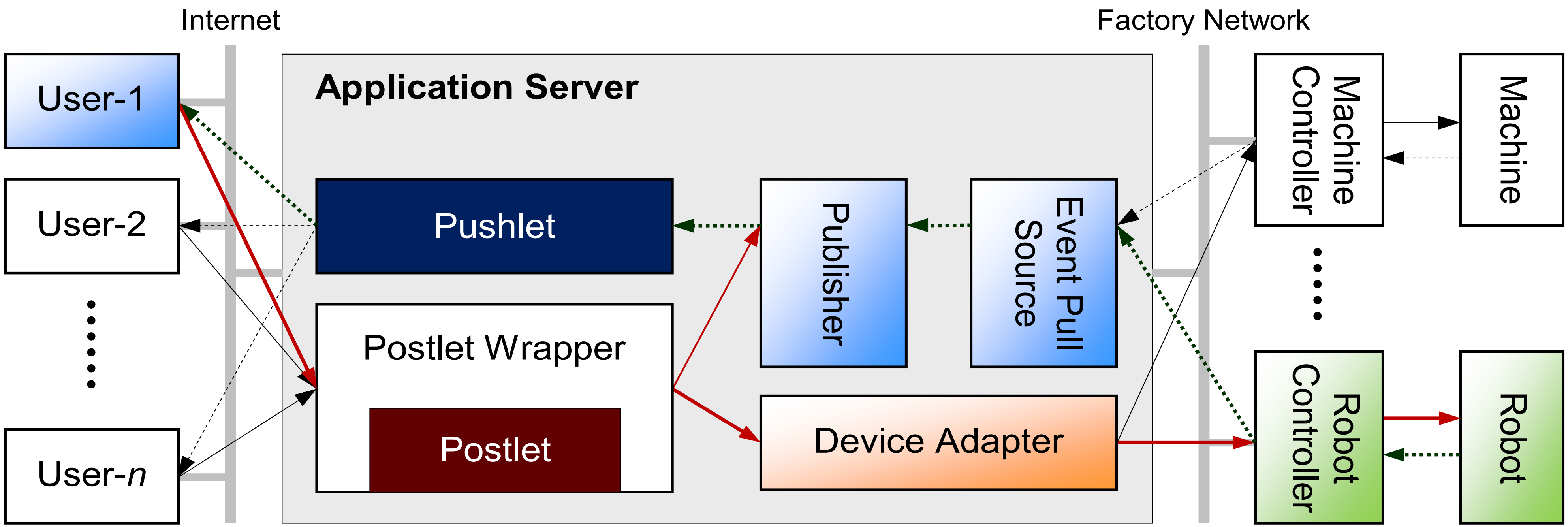
Cyber-Physical System

- "is an integrated cyber-physical system that can provide on-demand manufacturing services digitally and physically to best utilise manufacturing resources."

– L. Wang et al., "A cloud-based approach for WEEE remanufacturing," *CIRP Annals – Manufacturing Technology*, Vol.63, No.1, pp.409-412, 2014

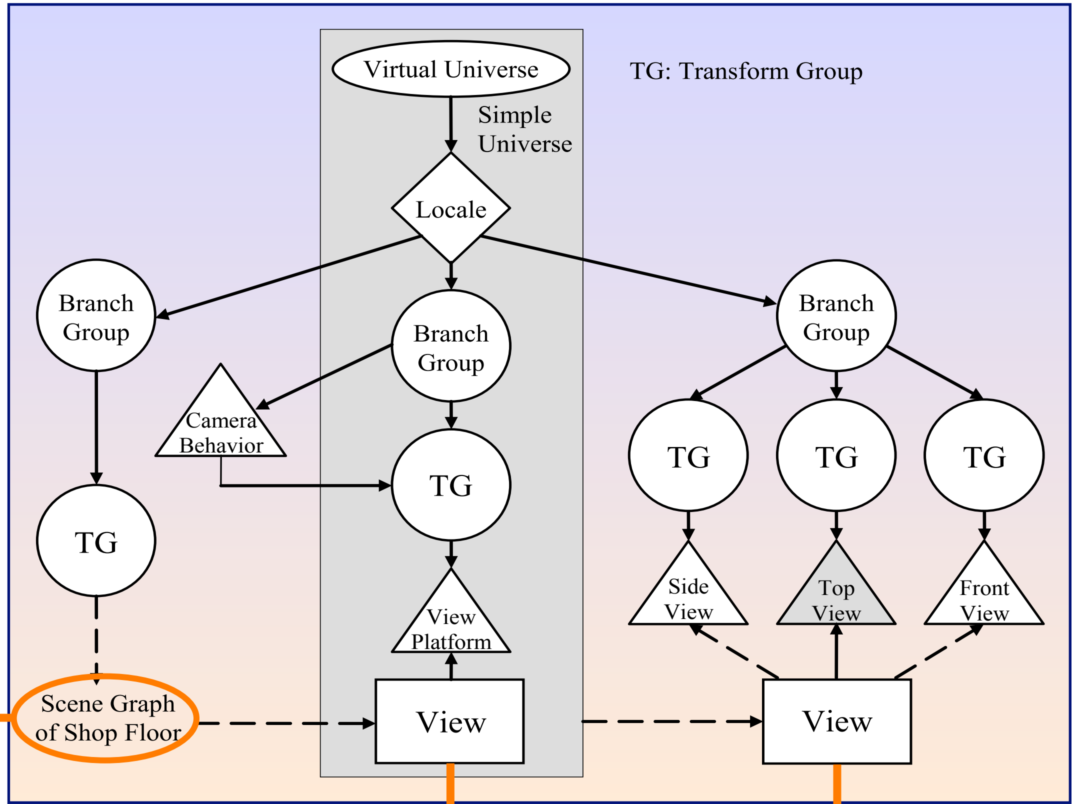
Virtual to Real via Cloud

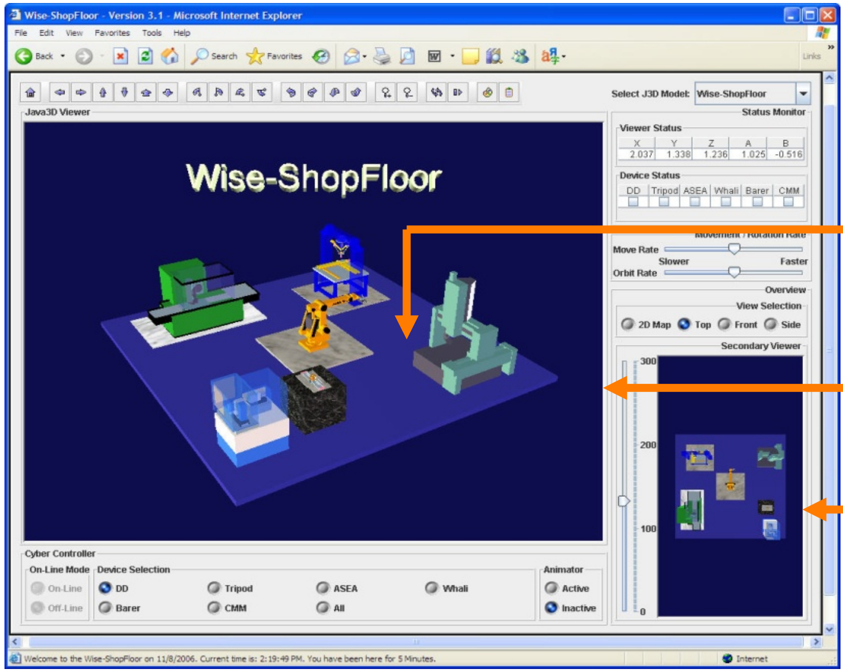




Model-based Remote Monitoring

- Java 3D uses scene graphs to represent models.
- A scene graph must have a virtual universe as a base to hold graphical components.
- It may have many branches.





- Three scene graph branches are used to generate a Wise-ShopFloor.

A Mini Robotic Assembly Cell

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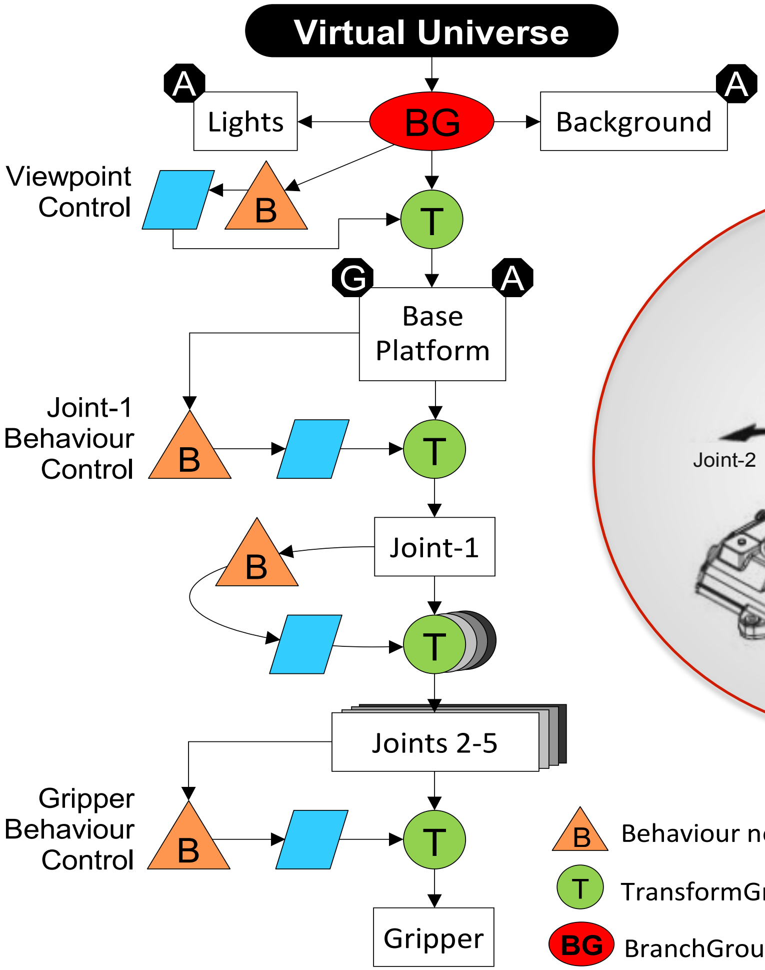

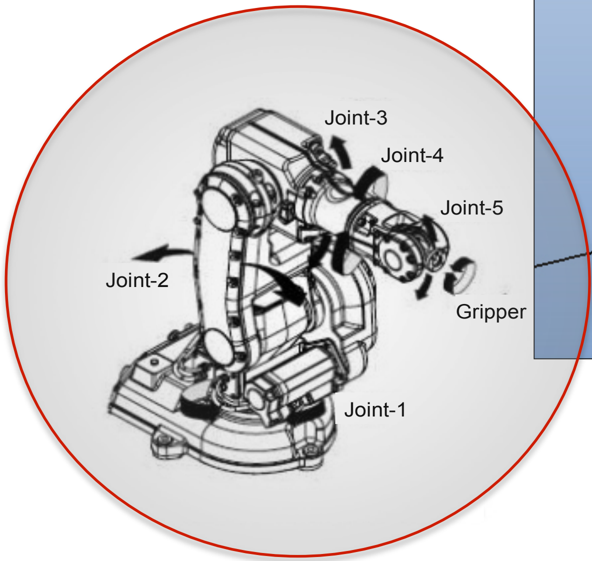

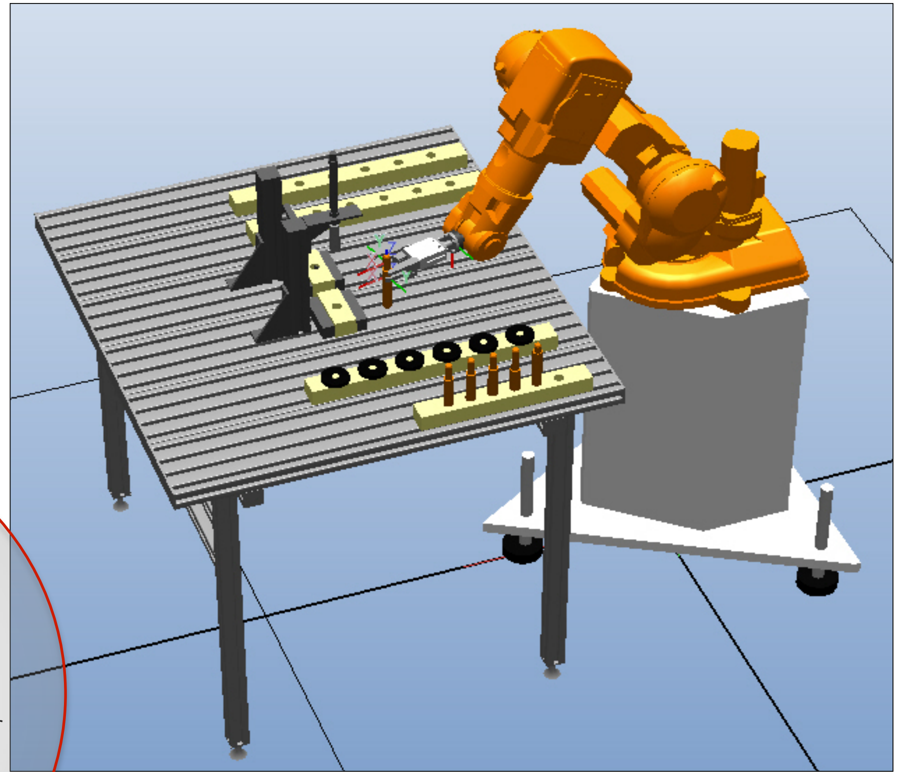

A mini robotic assembly cell

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Remote Robotic Assembly

(L. Wang et al., "A Sensor-Driven 3D Model-Based Approach to Remote Real-Time Monitoring," CIRP Annals – Manufacturing Technology, Vol.60, No.1, pp.493-496, 2011.)

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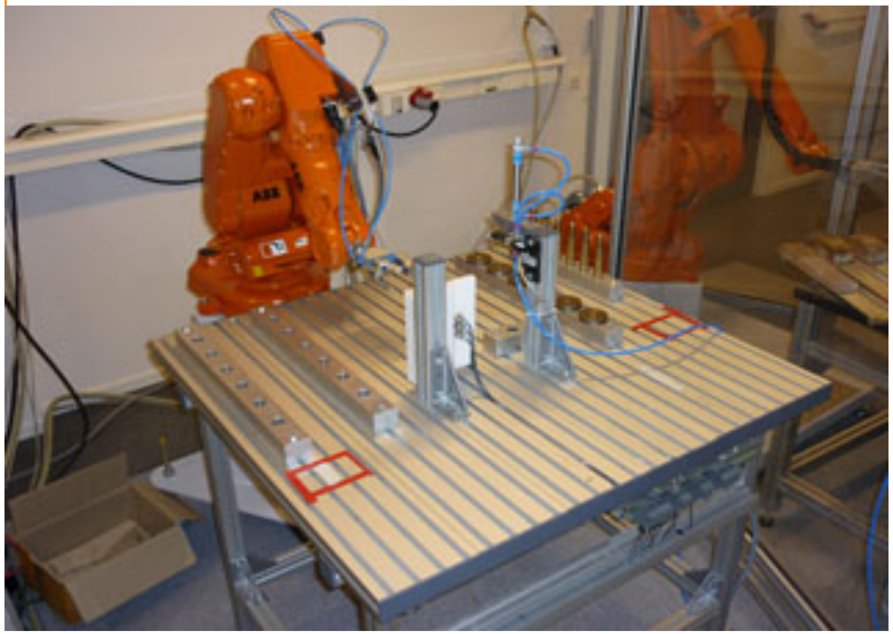
Data Size Comparison

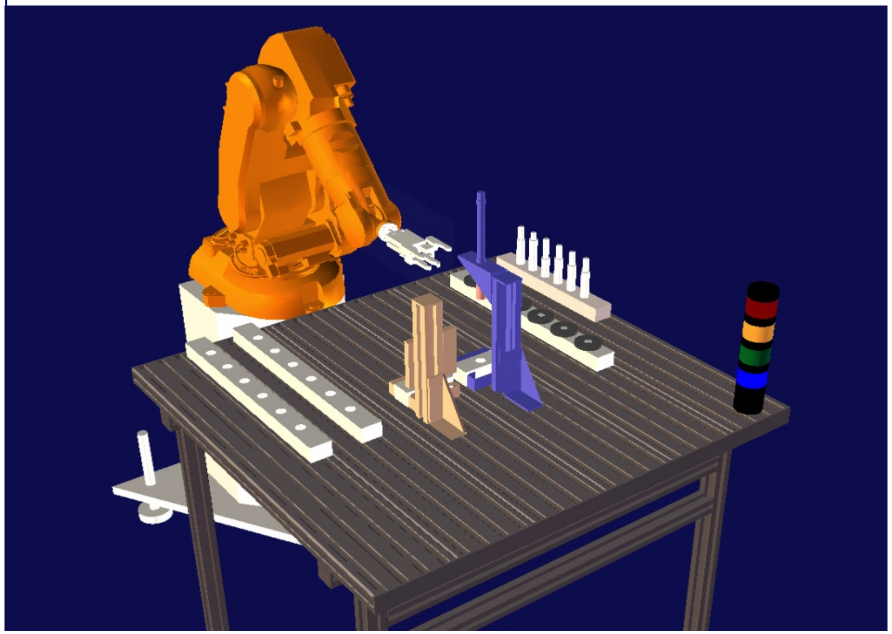
1	2	3	4	5	6	7	8	9	10	11	12	13
Relative position of 6 joints						Absolute position of 6 joints						CW

0.017%

100%

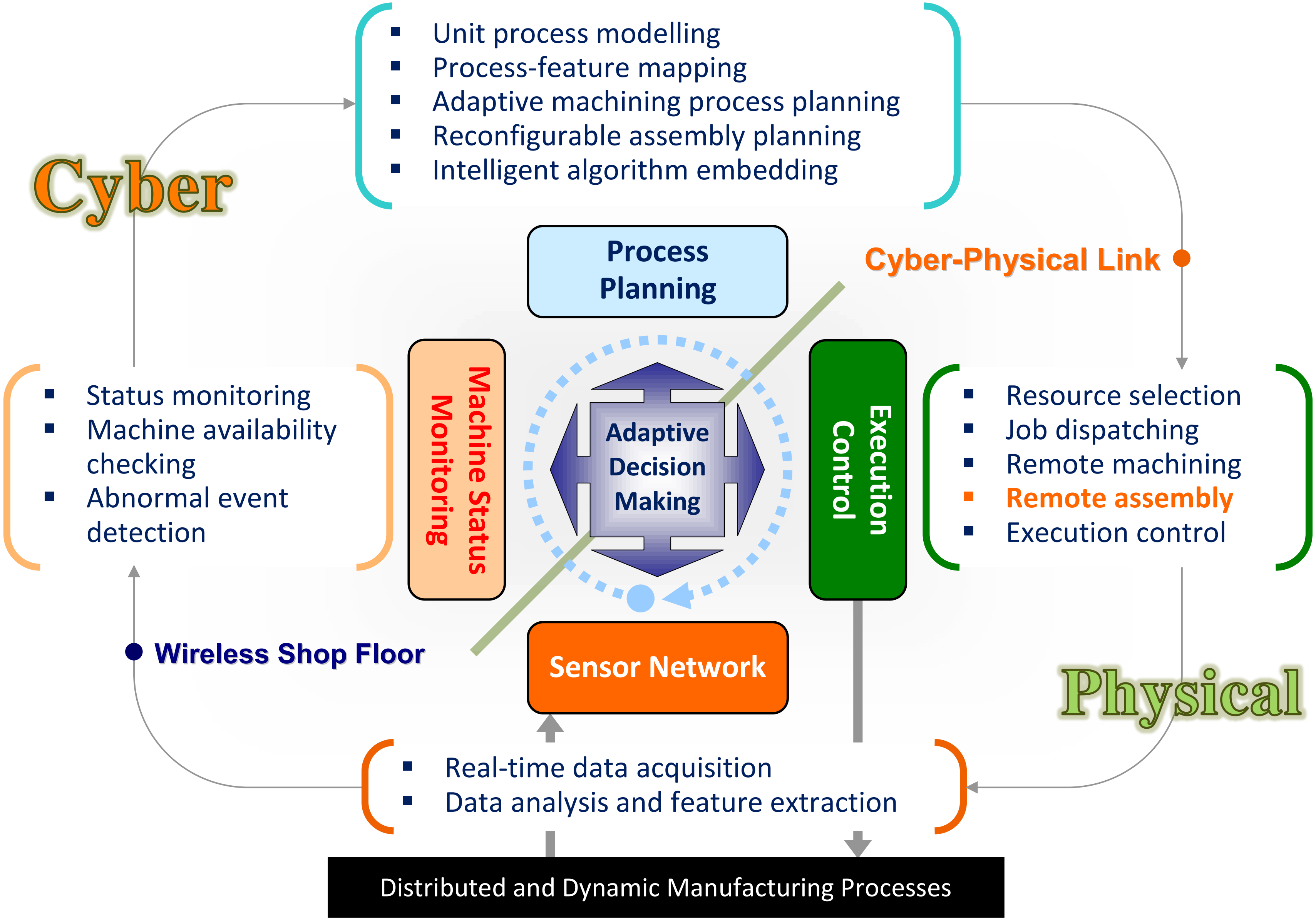


An 8-bit VGA Camera Image
640×480 (307,200 bytes)



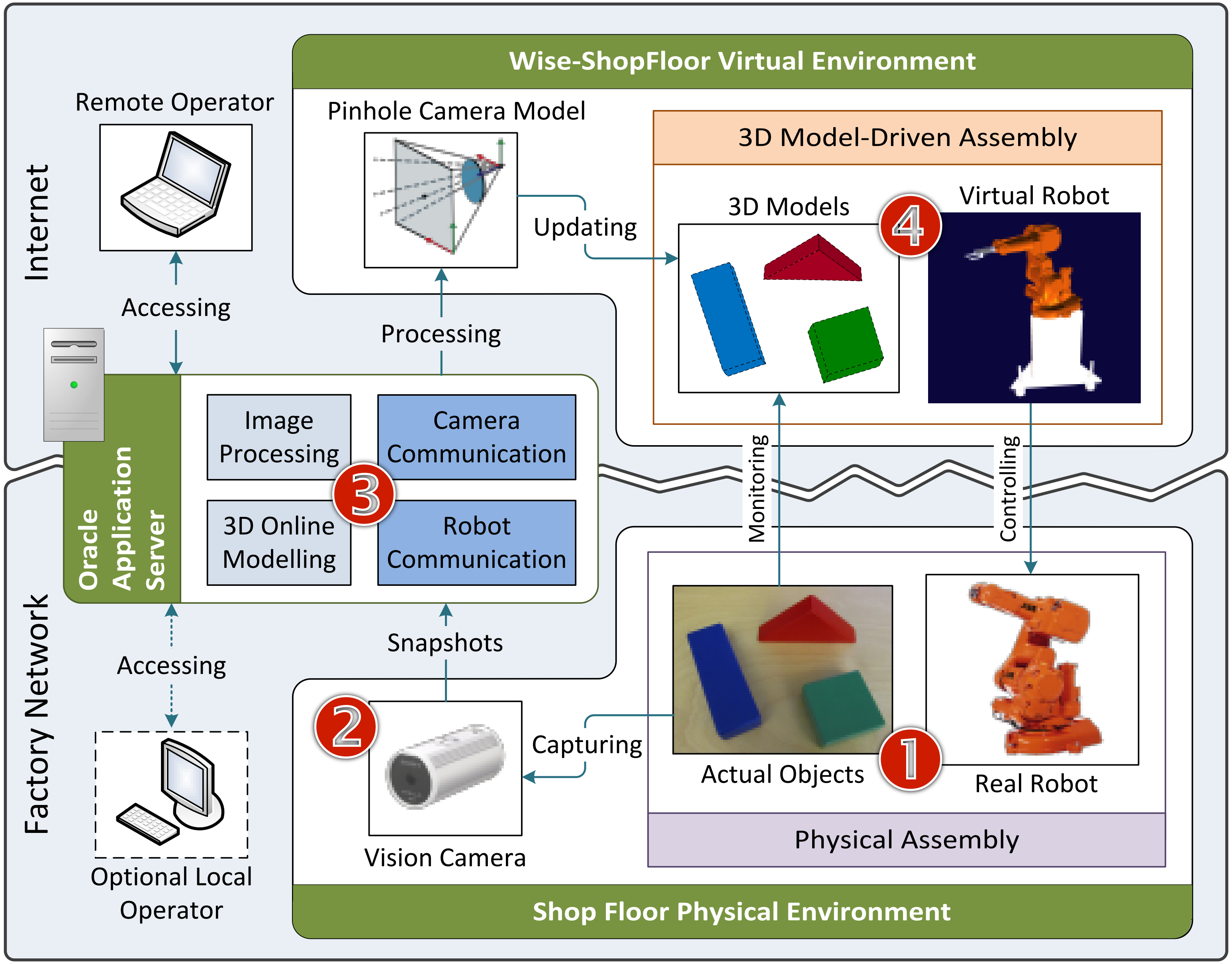
One Scene in Java 3D
Any size (52 bytes)

Needs of Remote Assembly



System Configuration

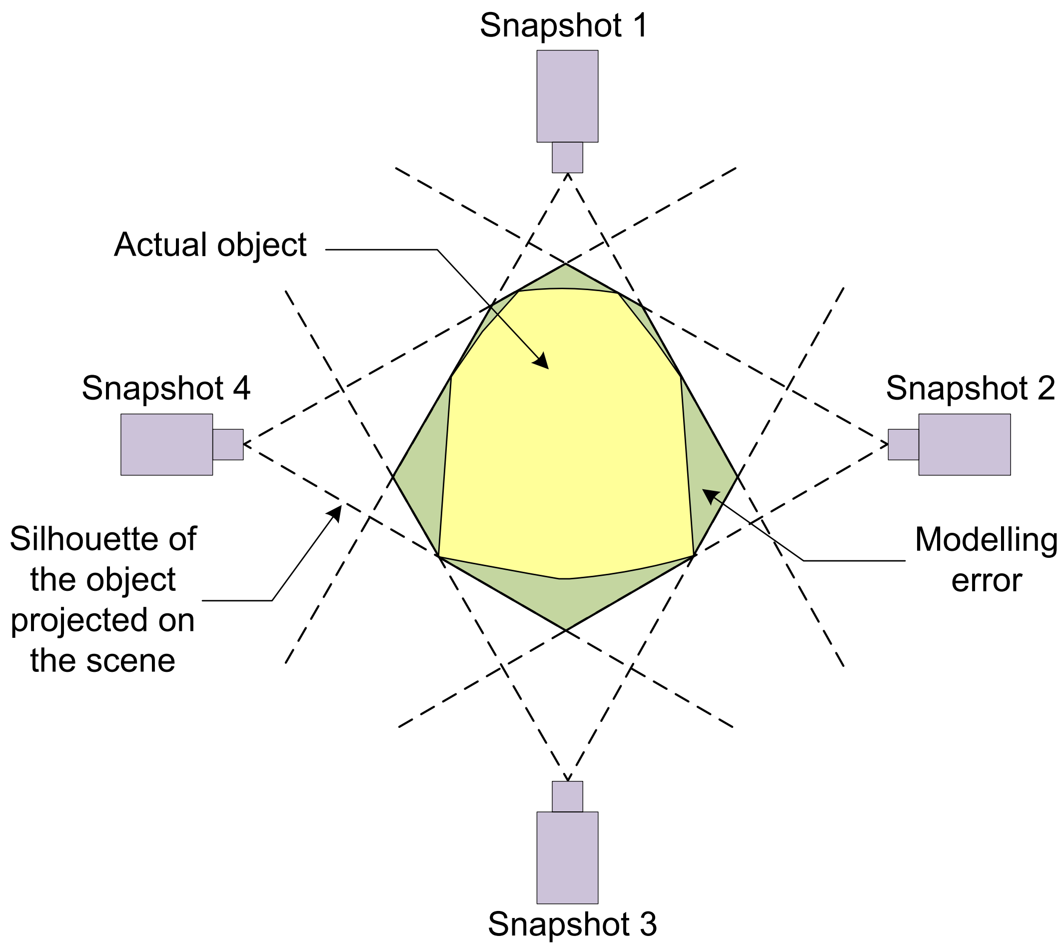
An Integrated Solution



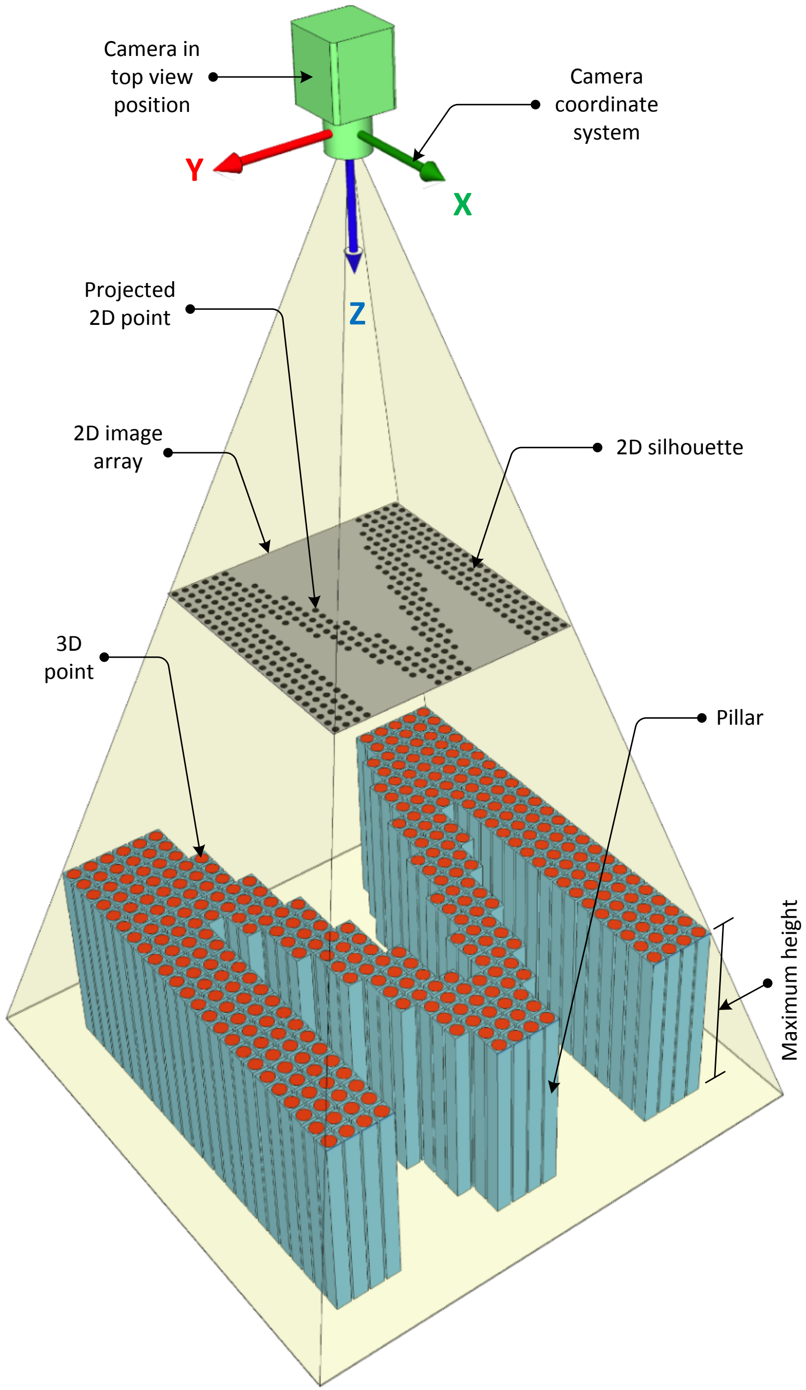
Shape Approximation by Trimming

- The system convert the silhouettes of the objects in the top-view snapshot to a set of vertical pillars with a default height.

- The camera is then used to take a sequence of new snapshots of the objects from other angles. Projecting the silhouettes of each snapshot back to the 3D scene creates a number of trimmed pillars.



Pillars Construction

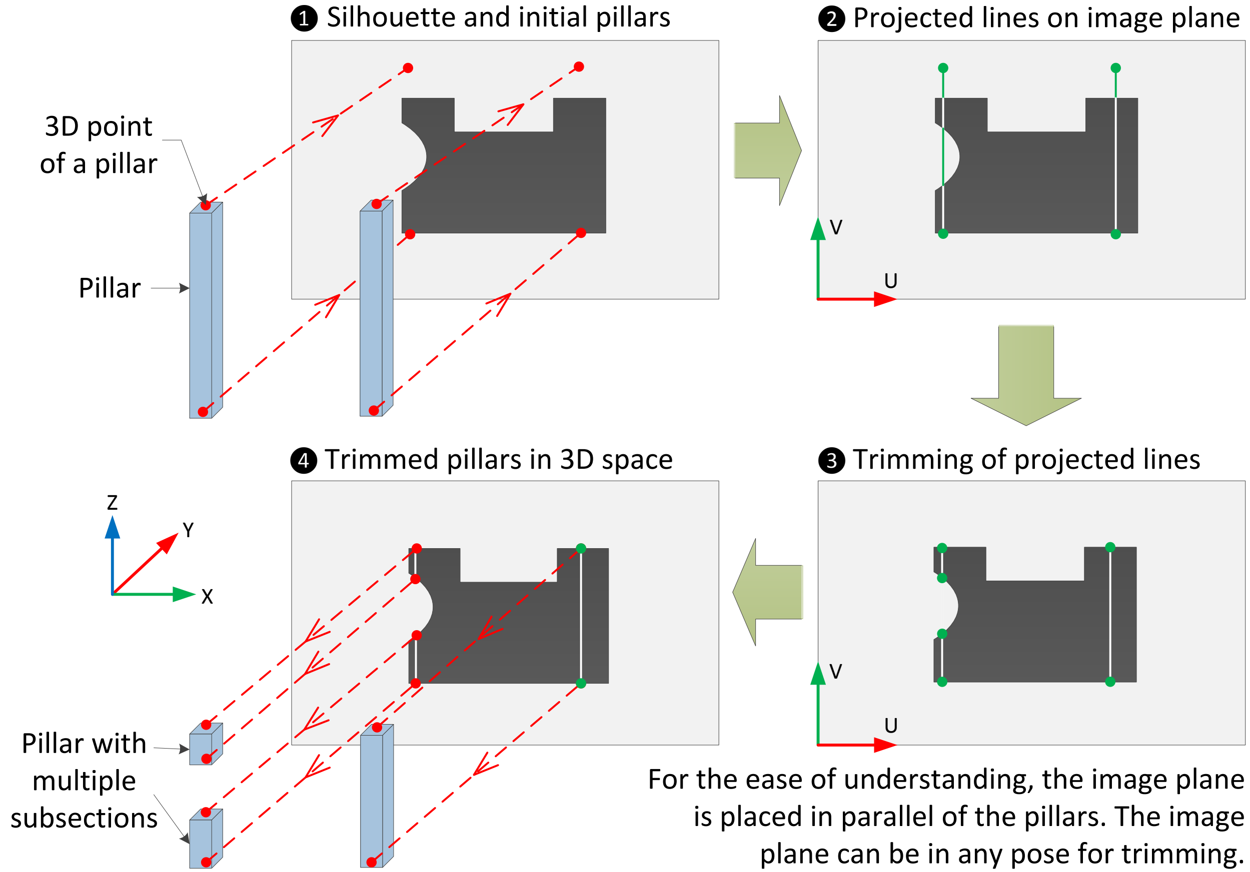


- The first snapshot taken by a camera provides the top view of the objects.
- The captured image helps the system to construct an initial representation of the 3D models based on the extracted silhouettes of the objects.

Trimming of the Pillars

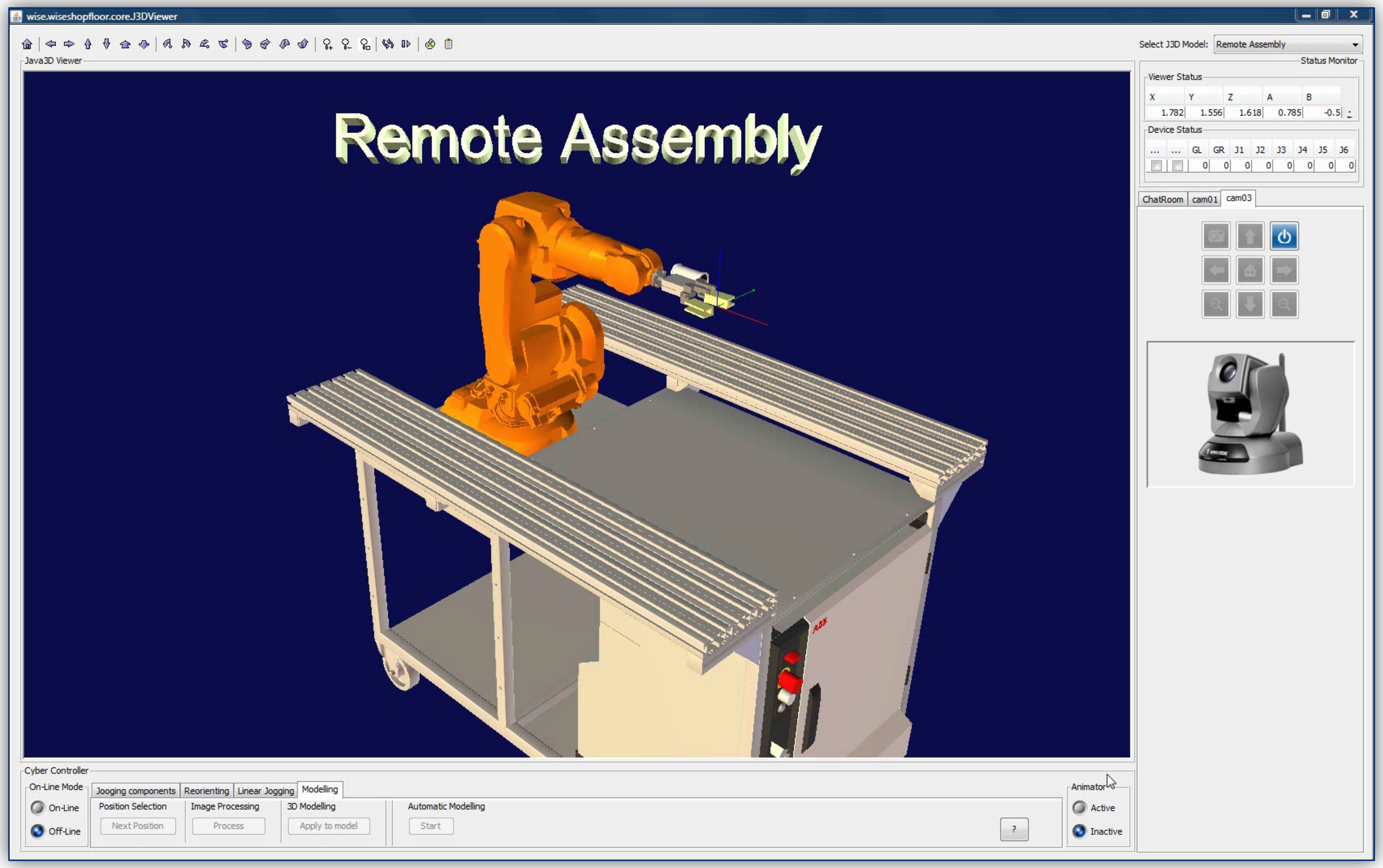
Trimming process:

- Projecting the pillars one by one from the 3D space to the image plane as 2D line.
- Extracting the pixels that are shared by the projected line and the silhouette of the object, which reveals a trimmed line.
- Projecting back the trimmed 2D line to the 3D space to replace the old pillar, resulting in a trimmed new pillar.



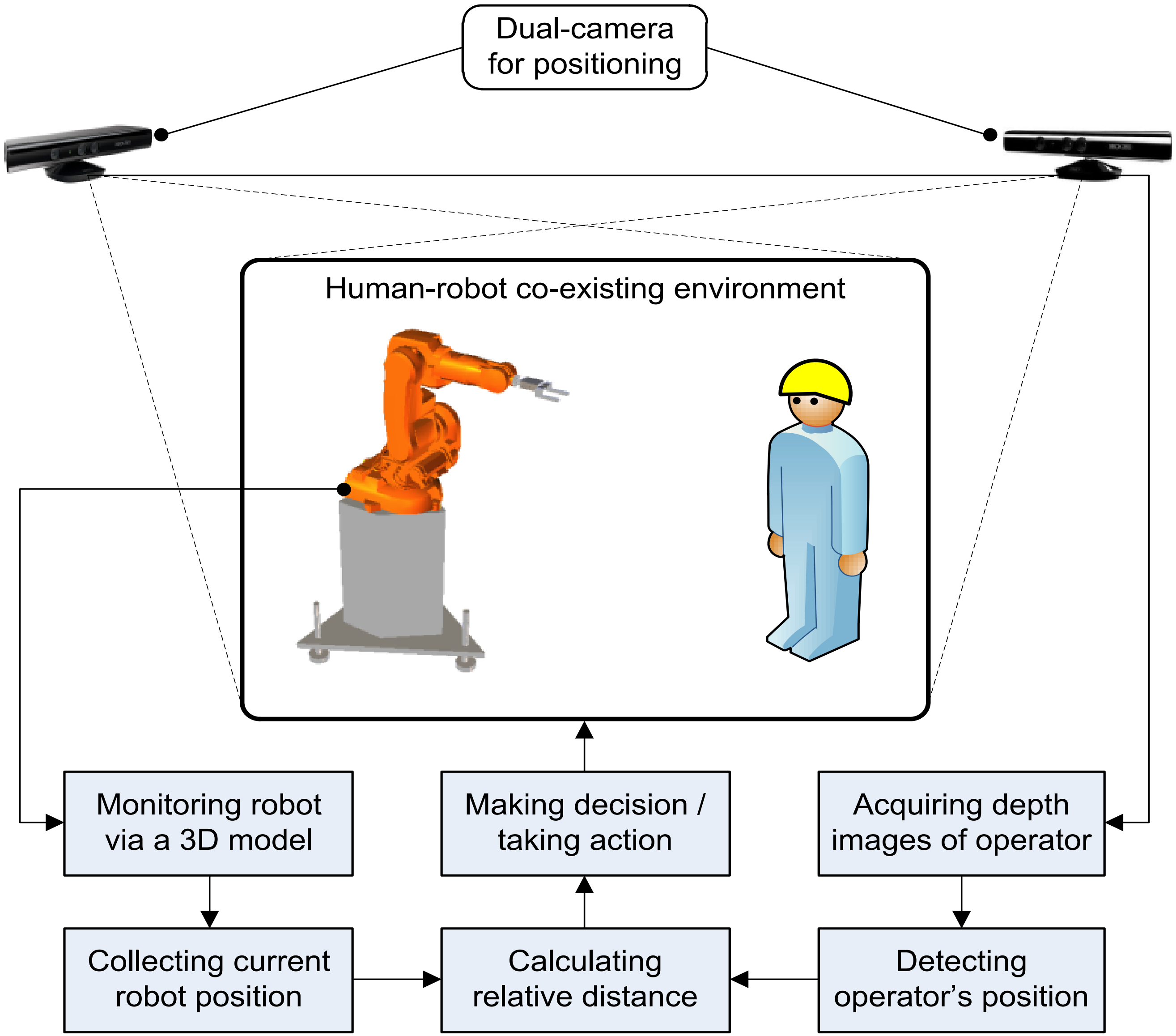
For the ease of understanding, the image plane is placed in parallel of the pillars. The image plane can be in any pose for trimming.

A Recorded Demo



(L. Wang et al., "Remote Robotic Assembly Guided by 3D Models Linking to a Real Robot," CIRP Annals – Manufacturing Technology, Vol.63, No.1, pp.1-4, 2014.)

Active Collision Avoidance



Safety Policies

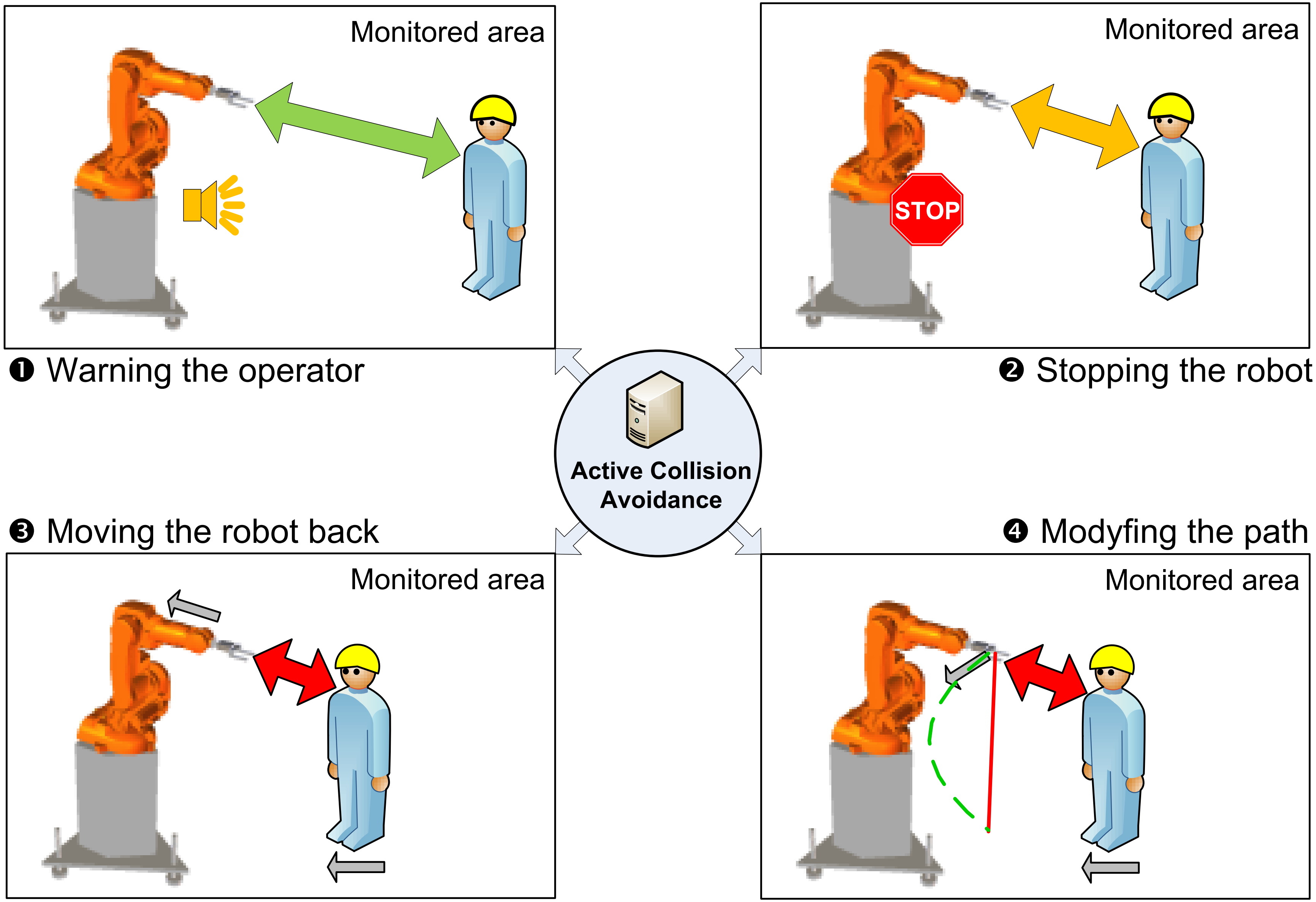
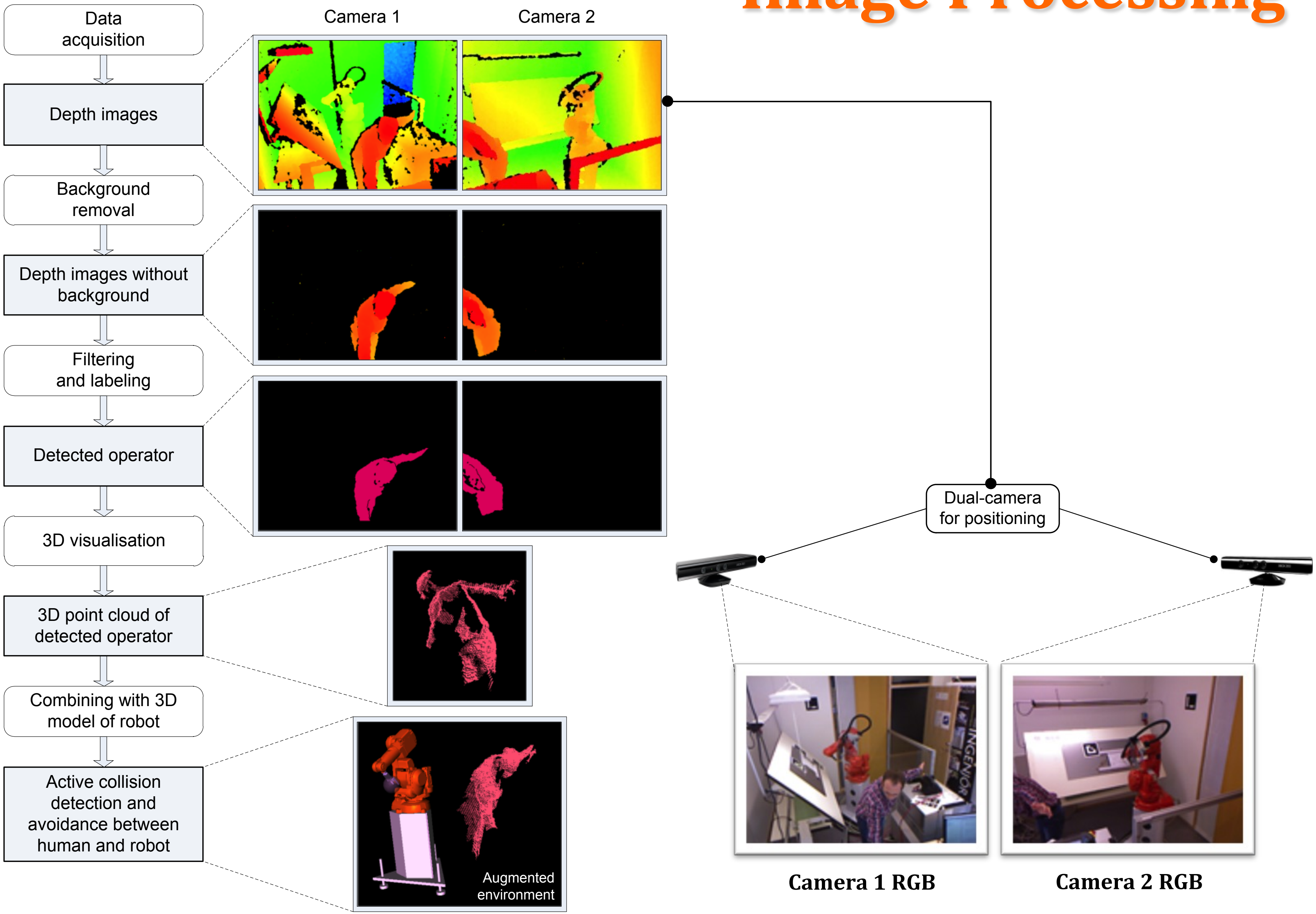


Image Processing



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Safety without a Fence

Conclusions

- Models as necessary and intrinsic part of manufacturing systems life-cycle
- Models of different types (geometrical, kinematic, dynamic and control) playing important roles in CPS and cloud manufacturing
- Real-time constraint, security and uncertainty
- Viewpoint interrelations
  - Architecting and model-based approaches to engineering environments
  - Viewpoint contracts and dependency modelling
  - OSLC based integration and data warehousing

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Questions?

Further reading if interested:

- Martin Törngren, Ahsan Qamar, Matthias Biehl, Frederic Loiret, Jad Elkhoury. Integrating Viewpoints in the Development of Mechatronic Products. Journal of Mechatronics, special issue on Model-based mechatronic system-design, Elsevier Dec. 2013, (http://dx.doi.org/10.1016/j.mechatronics.2013.11.013).
- Patricia Derler, Edward Lee, Martin Törngren, Stavros Tripakis. Cyber-Physical System Design Contracts, ICCPS '13: ACM/IEEE 4th Int. Conf. on Cyber-Physical Systems, 2013.
- Matthias Biehl, Jad El-Khoury, Frederic Loiret, Martin Törngren. On the Modeling and Generation of Service-Oriented Tool Chains. J. of Software and Systems Modeling, Dec 2012.
- L. Wang, A. Mohammed and M. Onori, "Remote Robotic Assembly Guided by 3D Models Linking to a Real Robot," CIRP Annals – Manufacturing Technology, Vol.63, No.1, pp.1-4, 2014.
- L. Wang, M. Givehchi, G. Adamson and M. Holm, "A Sensor-Driven 3D Model-Based Approach to Remote Real-Time Monitoring," CIRP Annals – Manufacturing Technology, Vol.60, No.1, pp.493-496, 2011.