Perspectives of Mfg. Automation under the Digital and Cyber Convergence

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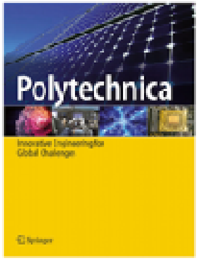

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Overview

Estou muito feliz e animado em conhecê-lo aqui nesta conferência especial

1. Digital & cyber convergence ⬌ mfg. automation
2. Role and challenges of cyber in collaborative automation
3. Role and challenges of product-service orientation
4. Examples
5. Challenges that bring exciting opportunities

Digital & Cyber in Mfg. Automation:

Augments abilities of workers, robots, and organizations

Increasing levels of computers, communication, mobility, and computational intelligence lead to higher levels of automation intelligence, and of resilience to internal and external disruptions.

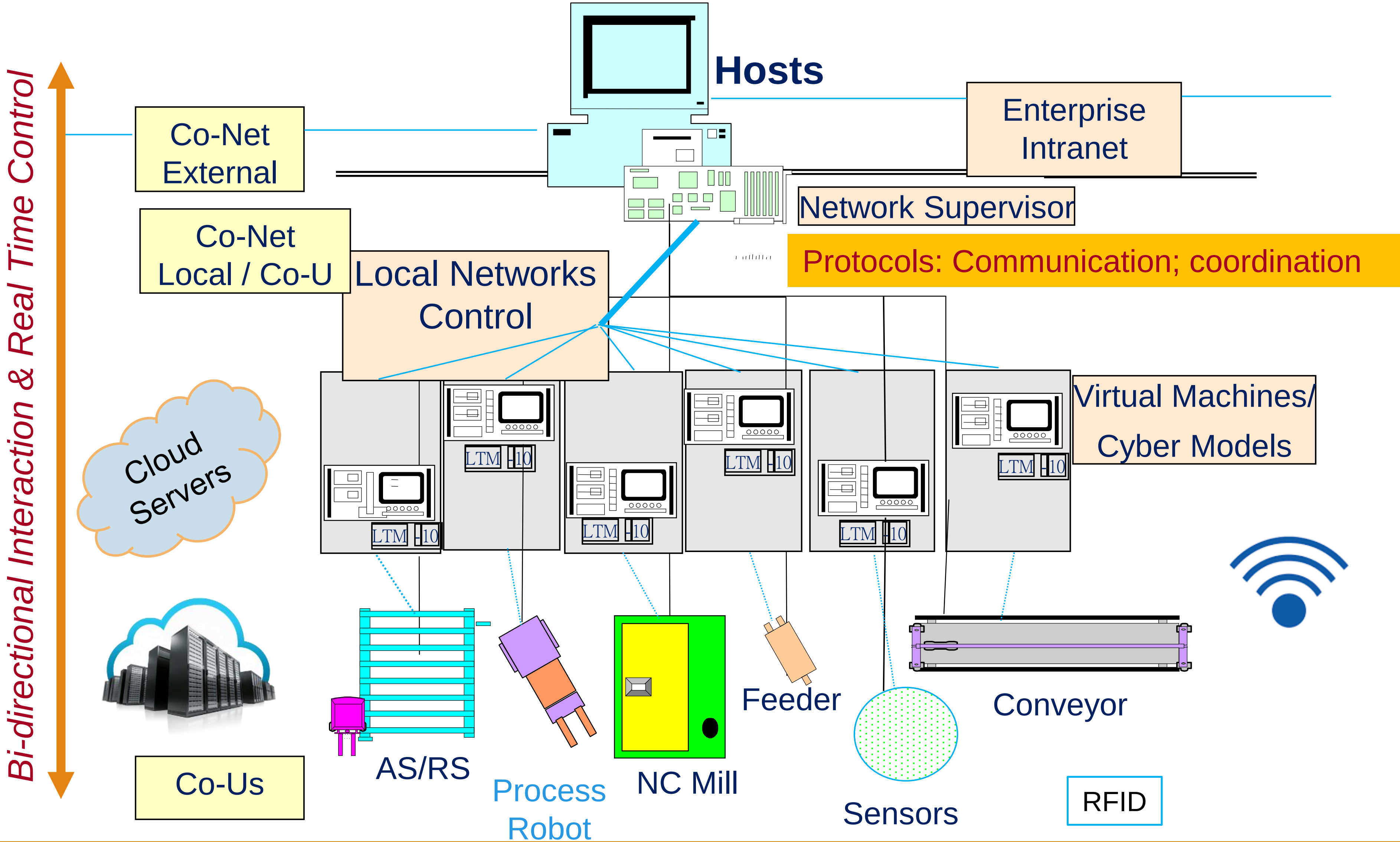
Digital & Cyber Augmentation	
1.0	Computerized
2.0	Computer Integrated
3.0	Internetworked + Mobile
4.0	Cloud-Based + Machine Learning
5.0	Cyber-Physical + Cybernetics

Digital and Cyber Physical Divergence on Factory Work

Period	Technology Advancement	Human Work Augmented by	Fundamental Work System Principle	Engineering & Management Concerns	Work System Goal[1]
Before the Industrial Revolution	Hand-tools	Tooling	Manual and animal power	Work methods	Enable work functions
Before computers	Engines; Machines	Power; Motion; Moves	Human-machine systems	Work flow	Reduce muscle load
Computer Age	Computers; Communication; Robots	Control; Data Processing; Automation	Computer aided and computer integrated systems	Human-computer interaction; human-robot interaction	Reduce information overload
Information Age	Telecom; Internet; Mobility	Cognitive Skills; Collaboration	e-work; e-Mfg	e-work design; collaboration; parallelism	Reduce information and task[2] overload
Cyber-physical Age	IIoT; IIoS; AI; Brain Models	Collaborative Control Protocols & Collaborative Inteligence	c-work; c-Mfg Service Orientation	Humans-machines-robots harmony	Increase work quality[3]

Fundamental model of Cyber Physical distributed Mfg.

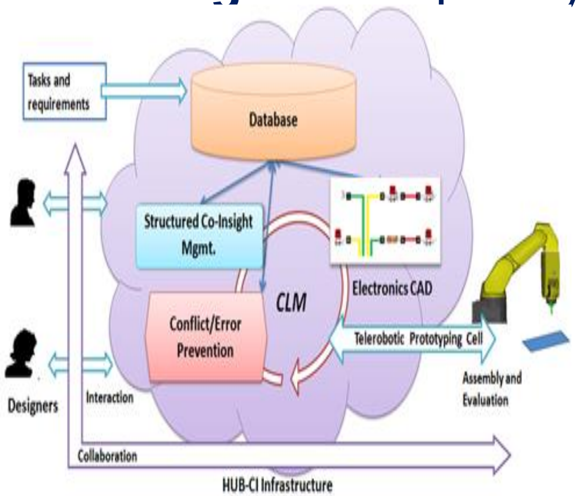
[Huang, 2016]



Five emerging cases of Cyber Physical Mfg. Automation

They are distributed systems: interactive • networked • autonomous • local/global → Must augment their collaboration with service orientation

Design challenges: complexity • dynamicity • uncertainty • human role • trust



Human-Robot c-Design, c-Work, c-Assemble

Smart Warehouse

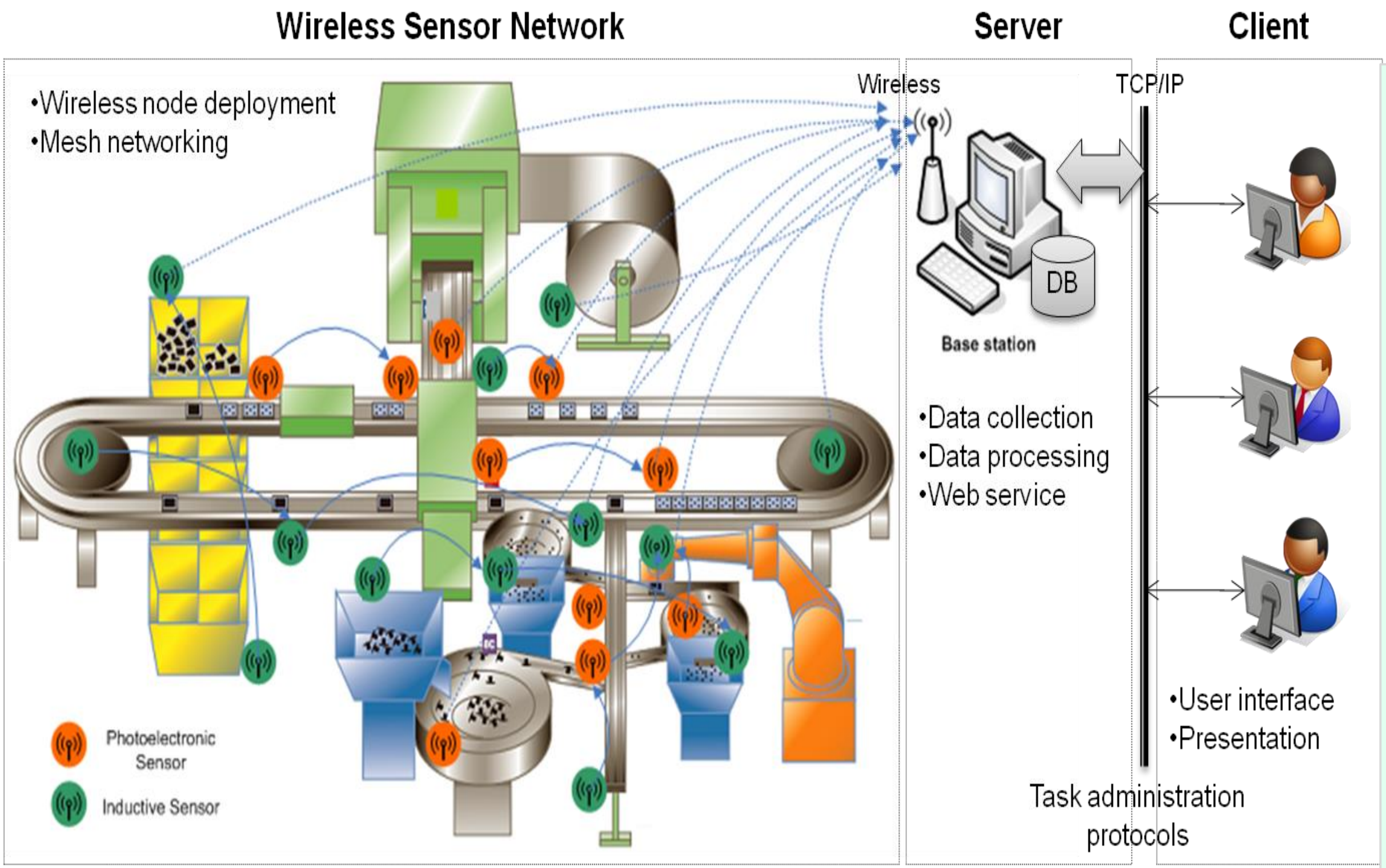
Drone distribution

Monitoring and repair c-Robots

Autonomous vehicles

Challenge: Resilience by Humans-Automation collaboration

Within and between production lines, and clients



Services

Cyber -
•Interface
•Middleware

To integrate sensors, machines, robots, and operators;

Understand each other;

Enable smooth, fast interactions, responses, harmony, predictions

- Fundamental models of mfg. collaboration services
- Service orientation challenge

Collaborative Control Theory (CCT)

Cyber augmented automation of collaboration among humans, robots, and software agents

- *CCT Motto:* ***Collaborate or Collapse; Collaborate & Conquer***

CCT enables Collaborative Automation Intelligence and resilience

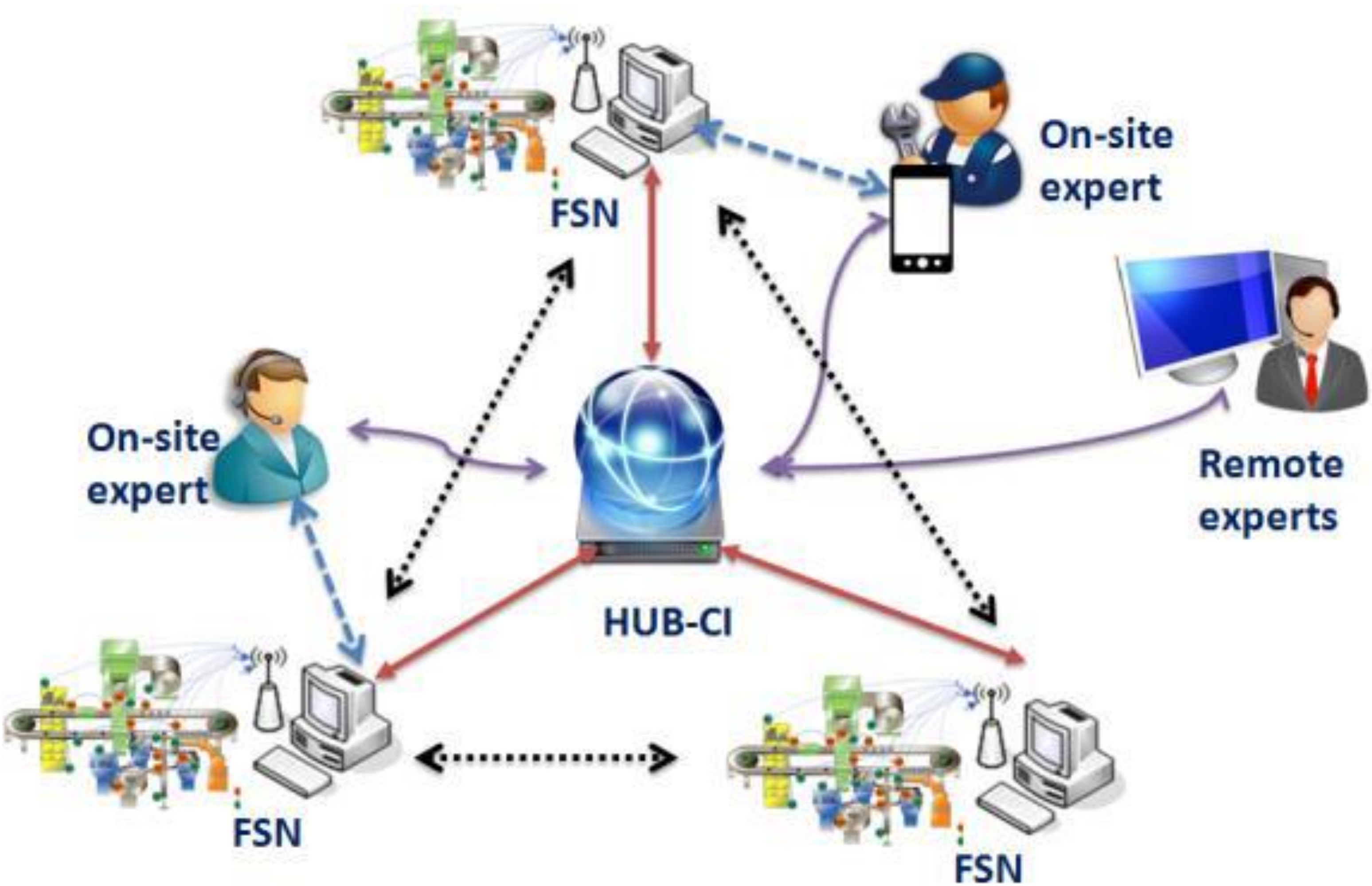
By CCT agents, algorithms, and protocols that

A. Augment people by cyber support for Collaborative Intelligence;

B. Enable better results with physical tools and infrastructure by applying cyber intelligence

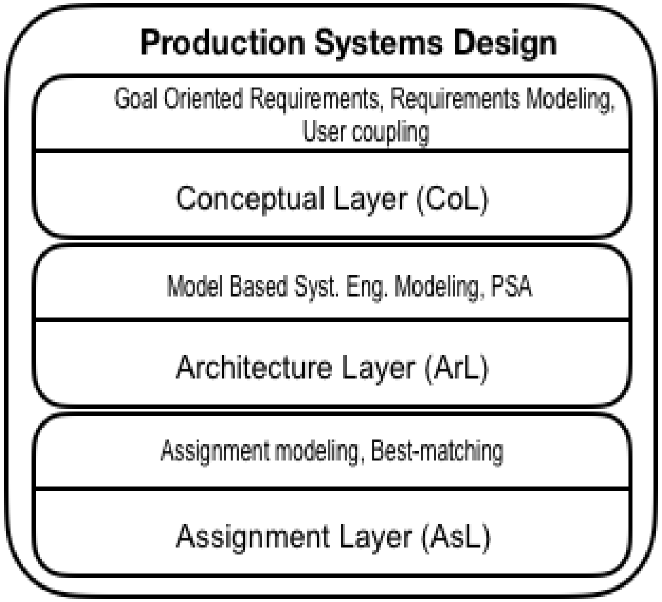
Nof et al., *Revolutionizing Collaboration through e-Work, e-Business, and e-Service,* Springer 2015

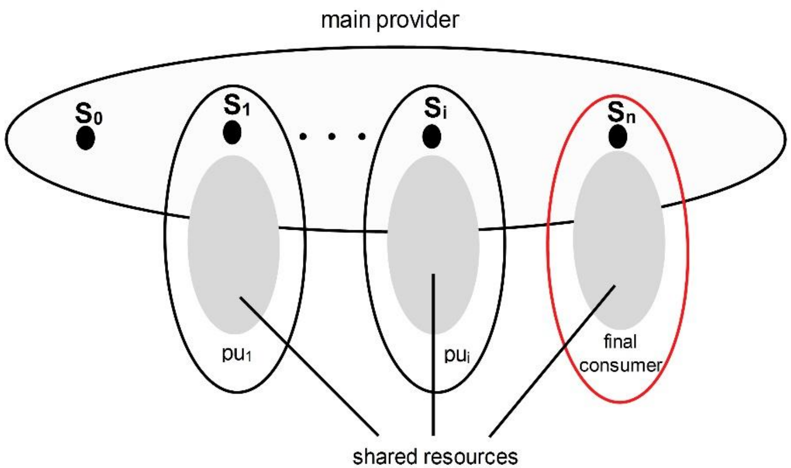
Challenge: Responsive Services for Automation and Resilience

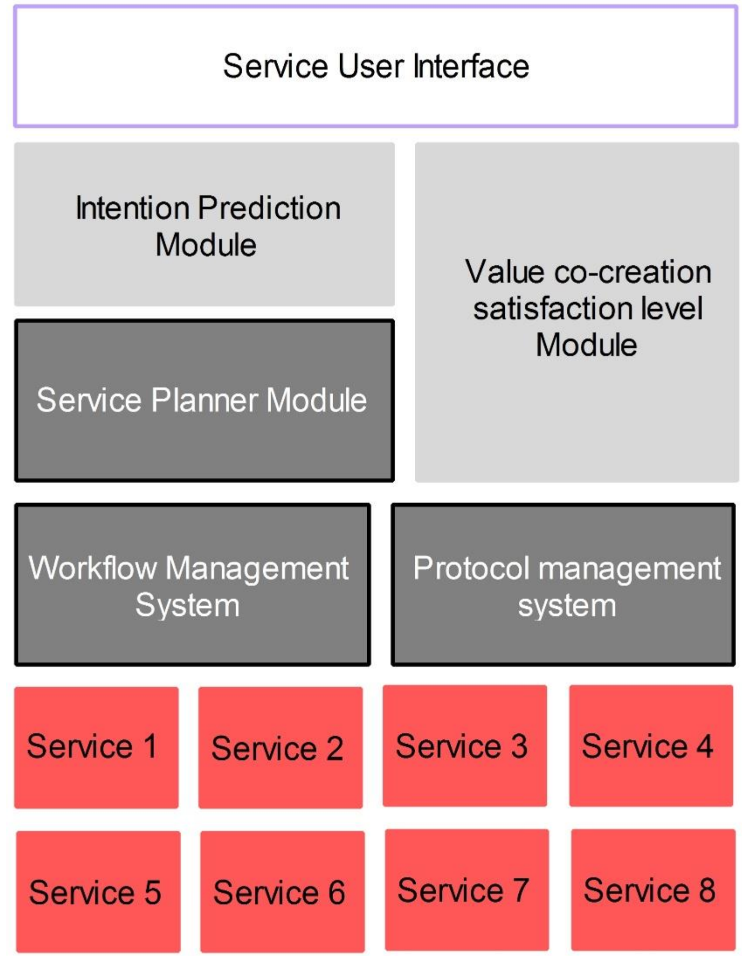


[Zhong, Nof, Filip, 2014]

Layered Systems and Services Design with Product-Service Architecture (PSA)

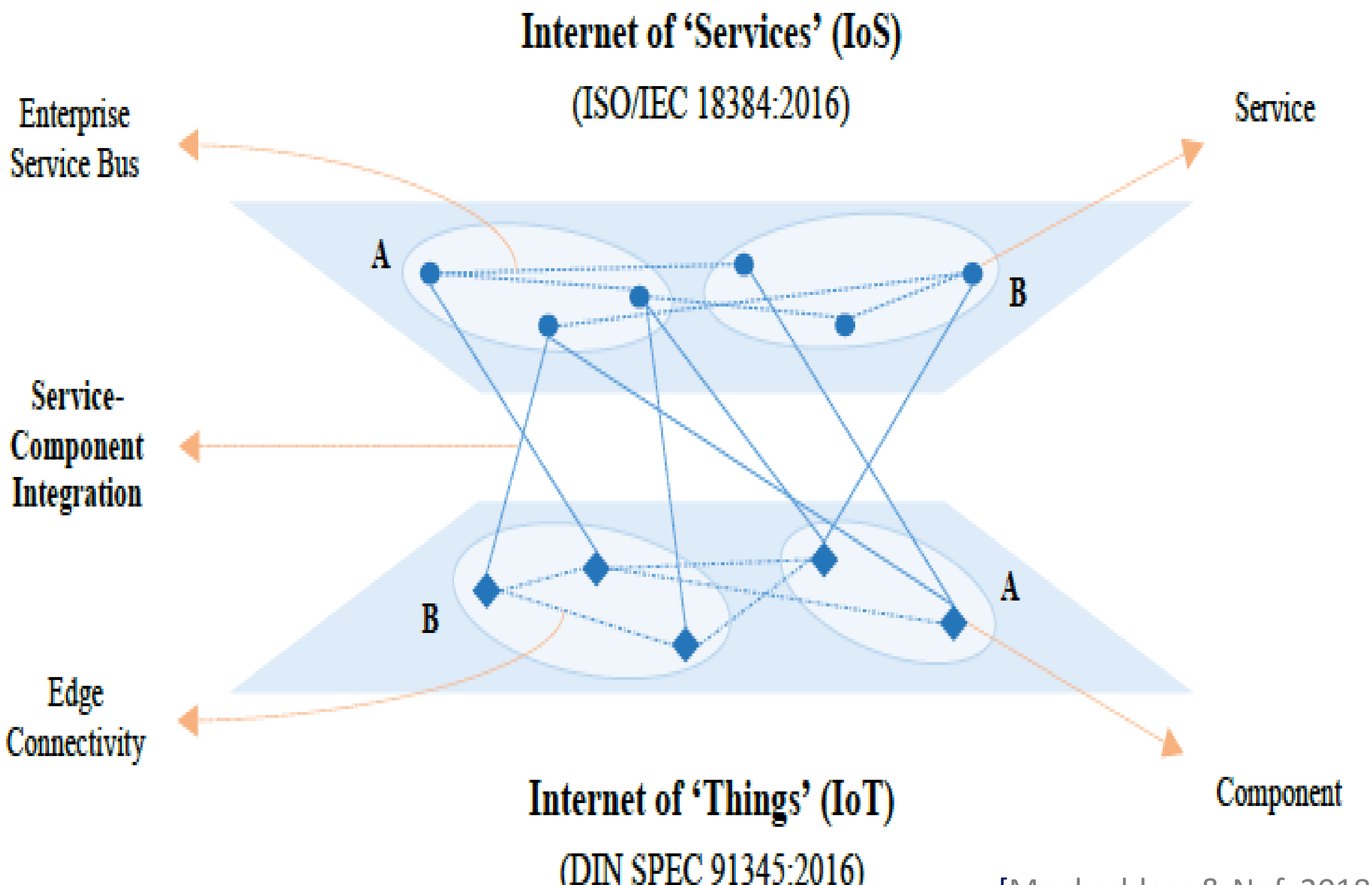






[JR Silva, 2014; Silva et al., 2018]

Service-component matching and integration in Cloud Mfg. for Organizations A and B



[Moghaddam & Nof, 2018]

Cyber-Supported Collaborative Factory of the Future*

1. Value of service orientation to cyber-augmented distributed mfg., robotics
2. Service collaboration models can overcome resilience challenges:
   - Protocols resolve conflicts, negotiate agreements, prevent errors
   - Fault tolerance by teaming and back-up control algorithms
   - Optimized sharing of resources, handling, transportation, reuse.
3. Cyber augmentation with service orientation enables distributed systems-of-systems achieve better performance and sustainability through collaboration.
4. HUBs (of Industrial Internets) enable **CI, Collaborative Intelligence** focused on augmenting human ability to collaborate effectively

* Moghaddam and Nof, *The Collaborative Factory of the Future,* IJCIM, 2017

Conclusions, Challenges

1. Convergence -- digital, cyber, and technological -- is the polytechnic confluence realized after significant technological disruptions, leading to acceptance, stability, regulation, and standardization.
2. Careful assessment of risks and benefits using techniques such as PSA and Best Matching, will have to guide researchers and industry in their challenging design for effective and sustainable solutions.
3. CCT and Collaborative Intelligence (CI) integrate collective knowledge from diverse sources for better design of products-services; needed for timely and predictive responses during the life of the factory.
4. Service-oriented architectures with cyber-augmented collaborative control protocols (C3P) will be needed to harmonize product-service components' interactions among allied suppliers and customers.
5. Further research and industry studies are needed in the polytechnic approaches to advance benefits of cyber-augmented service-product interactions to accelerate and ameliorate learning, decision-making, emergency response, and other social and cultural services.

Acknowledgement

This research has been developed with partial support from the Production, Robotics, and Integration Software for Manufacturing & Management (PRISM) Center at Purdue University.

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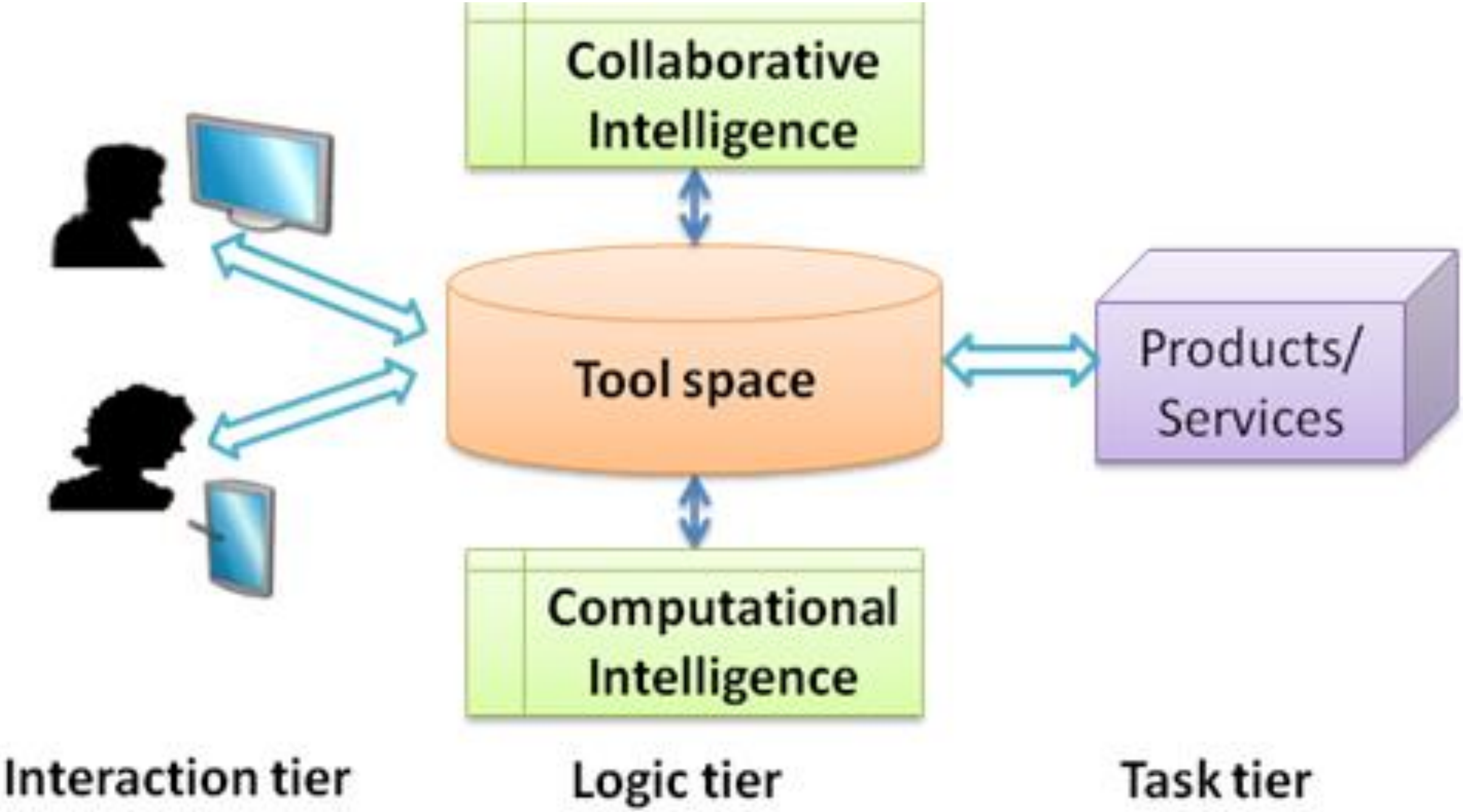
Collaborative Control Theory (CCT) Principles, Augmentation

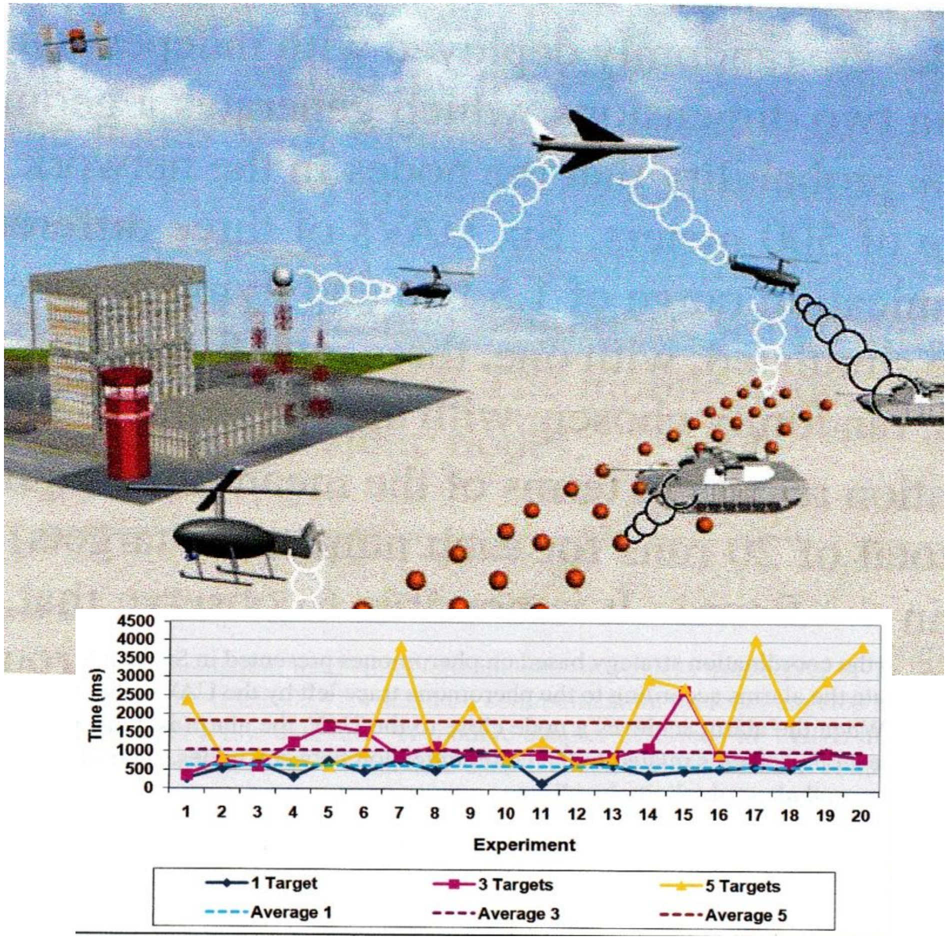
CCT Principle	Augmentation by Cyber Tools	Rational
1. **CRP** Collaboration Requirement Planning	Advanced planning and on-going re-planning enable effective e-collaboration	"Think before you act"
2. Parallelism & KISS Parallelize + "Keep it simple, system!"	Optimal parallelism of autonomous agents with simple interfaces and smooth interactions allow efficient delivery of results	"Divide and conquer"
3. **CEDP** Conflict & Error Detection and Prevention	Increase security, safety, gains by preventing or resolving errors and conflicts	"Learn from mistakes"
4. **FTT** Fault-Tolerance by Teaming	Fault-tolerant collaboration of weak agents team can outperform a single strong agent	"Team for synergy"
5. **JLR** Join/Leave/ Remain in a network	Ensure resilience by monitoring, reorganizing & reconfiguring a collaborative network	"Be selective"
6. **LOCC** Lines of Command & Collaboration	Overcome disruptions by adaptive interactions and ad-hoc best matching	"Trust the backup"

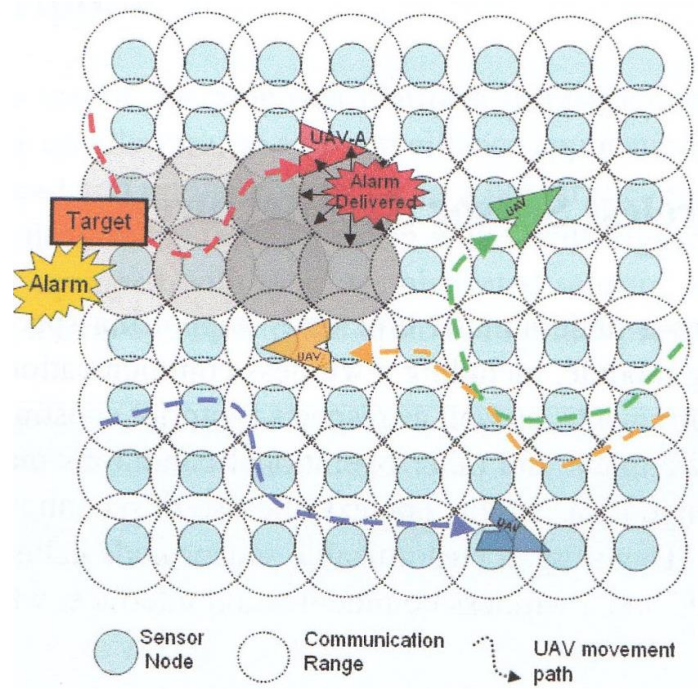
Resilience by the HUB-CI infrastructure with cyber-collaborative best matching



c-Work Augmentation: Comm.→Coordinate→Cooperate→Collaborate

H:R:R:Sensor networks -- Response quality by CCT logic





Pheromone strategies with alarm response times achieved

EP de Fereitas, T Heimfarth, RS Allgayer, FR Wagner, T Larsson, CE Pereira, AM Ferreira. Coordinating aerial robots and sensors for intelligent surveillance. *IJCCC* 2010, 52-70

CACAS: Define; Design; Case Studies

Cyber:

1. Computing
2. Communication
3. Real Time Control
4. Brain models (cybernetics)

IoS / IoT / Industrial Internet:

1. Internet
2. Services/Industrial systems
3. Connected

Industry 4.0:

1. Sensors
2. Cloud
3. Big data analytics
4. Integration (Interoperability)

CACAS*:

1. Cyber
2. Physical items
3. Networked

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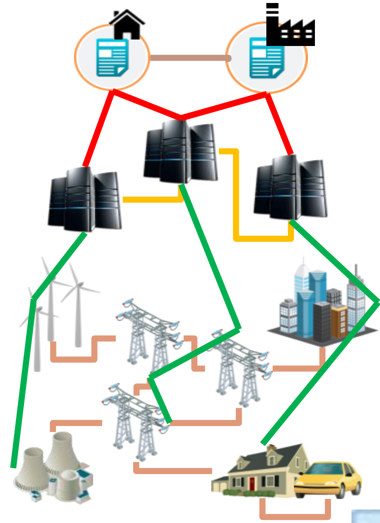
* Cyber-Augmented Collaborative Automation Systems

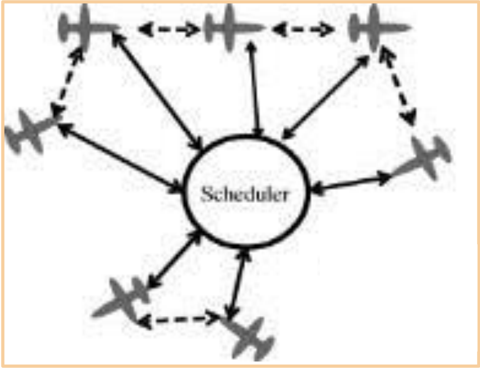
Automation 5.0:

5. **Cyber-supported, smart, augmented collaboration**
6. **c-Work, c-Robotics, c-Service**
7. **CI, collaborative intelligence for better results**

Resilience by Conflict/Error Detection and Prevention (CEDP)

e-Work networks with intelligent protections





Objectives

1. Conflicts and errors models in diverse complex systems
2. Reduce diagnosis and prognosis time
3. Prevent cascading failures and damages
4. Adaptive intelligent CEDP logic in different systems
5. Efficient mitigation & recovery strategies by dynamic lines of collaboration (DLOC)