Robotics, Agents, and e-Work: The Emerging Future of Production

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Production, **R**obotics, and **I**ntegration **S**oftware for **M**fg. & **M**anagement
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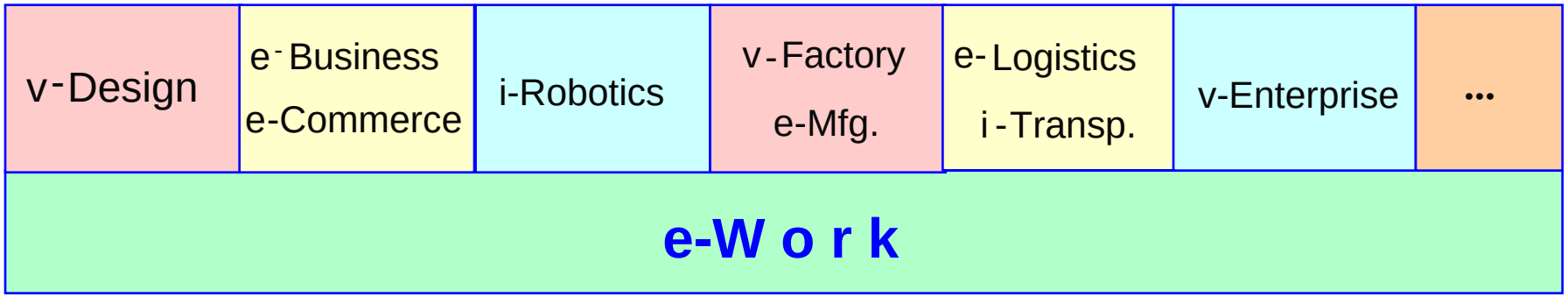
Outline

1. The influence of e-Work on enterprises and on society
2. Six key design principles and collaborative control theory
3. Network models and their emerging redesign counterparts
4. IMPACT: What does it mean? What do we really expect out of production?

e-Work Definitions

[PRISM Center. 1999]

- Collaborative, computer-supported, and communication-enabled work operations in highly distributed organizations of humans / robots / autonomous systems
- Our goal: Augment human abilities at work, and organizations' abilities to accomplish missions



- Challenges: • Complexity • Scalability • Dependence • Integrity • Communication • Coordination • Noise • Mismatch …

Problem: Potential promise of emerging e-work cannot materialized without collaboration support

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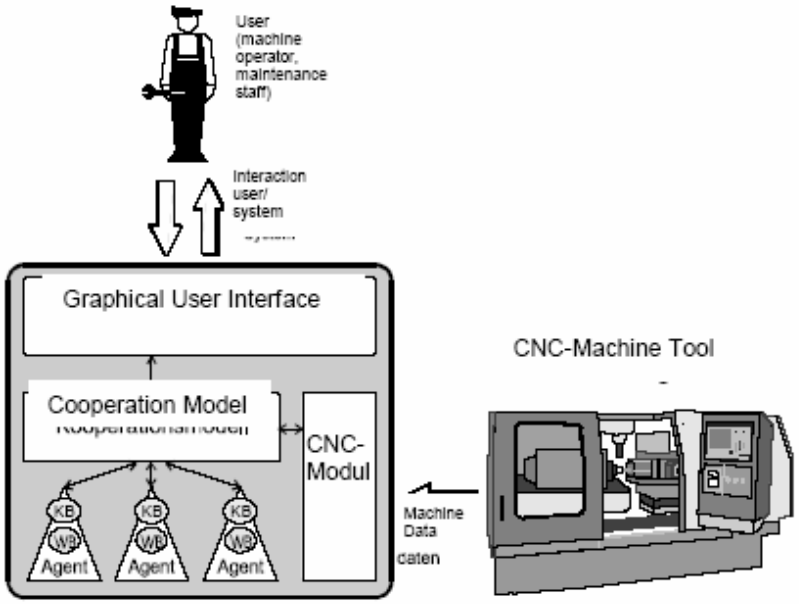
The transformative influence of e-Work

- We know: power fields, e.g., magnetic fields and gravitation
  - Influence bodies to organize and stabilize

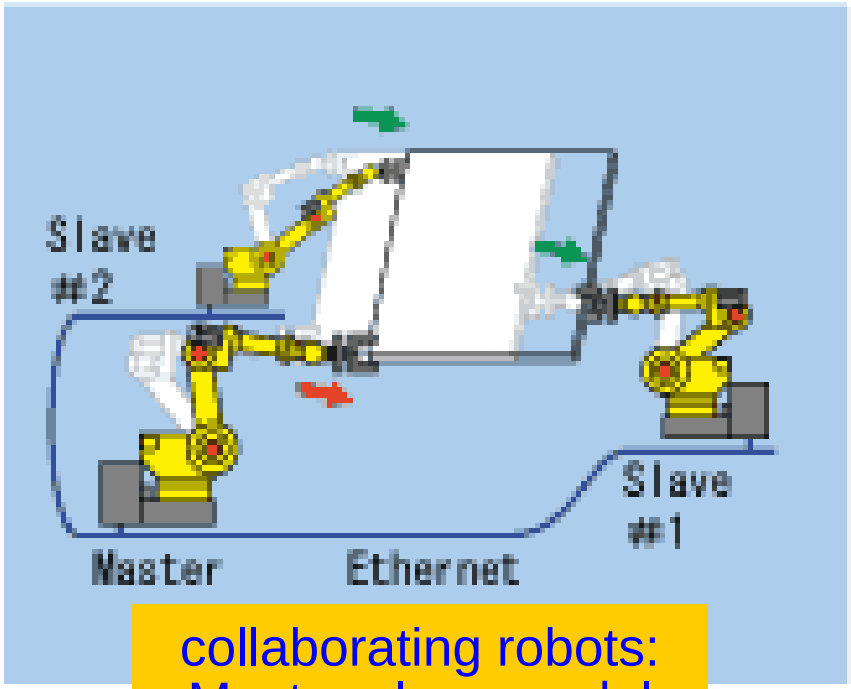
- So do cyber fields, e.g., IT and communication
  - Envelop us and influence us to organize our work systems in a different way
  - Purposefully, stabilize work to effectively produce desired outcomes

Survey of e-collaborative production - sample

(Jeong, 2005)



Multi-agent system architecture for machine tool automation



collaborating robots: Master-slave model

Fault Diagnosis of CNC-machines (Marzi & Timpe, TU-Berlin)
Virtual Labs (H. Erbe et al.)

"ROBOTLINK simultaneous motion" www.fanuc.co.jp

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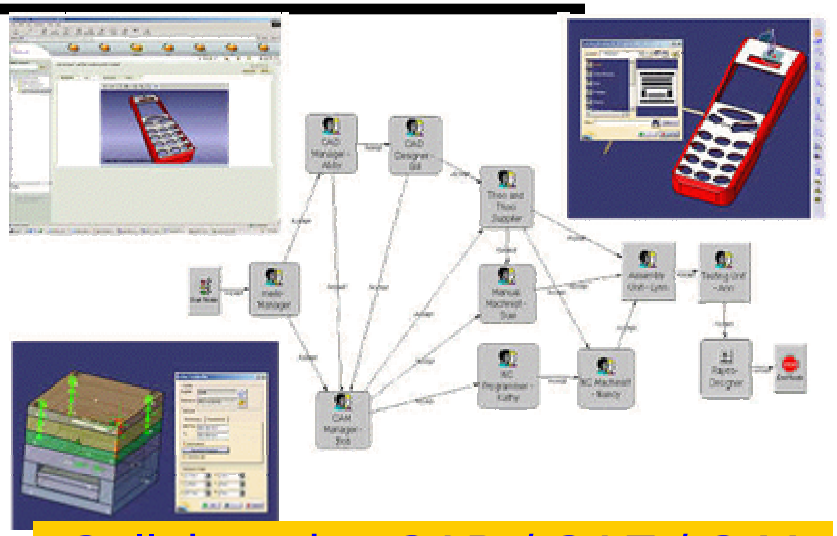
e-Collaborative design, engineering and manufacturing

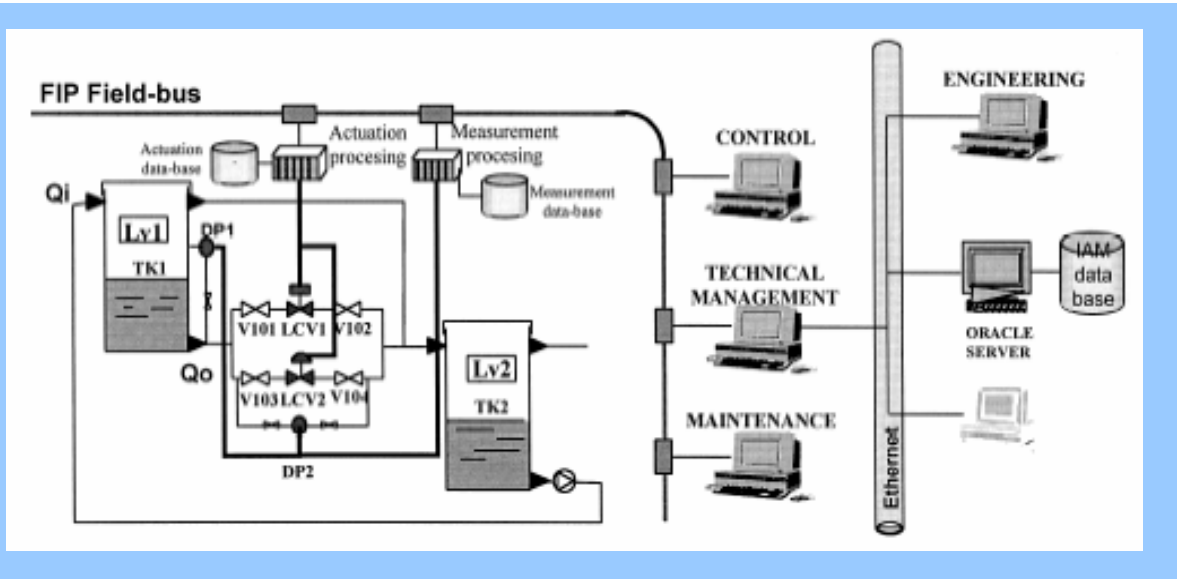


Collaborative CAD / CAE / CIM

Y.S. Wong; Singapore

Distributed actuation & measurement

Petin, Iung, Morel; France



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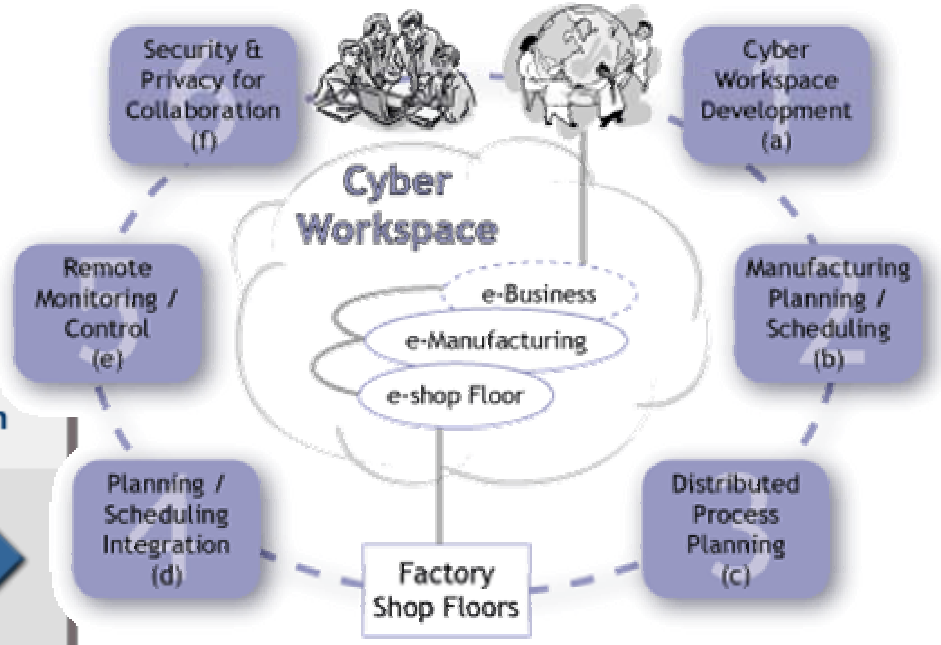
End-to-end processes: Collaborative, inter-operable, harmonized

Supply network harmonization

http://www. Apriso.com, FlexNet™



e-Collaborative e-Manufacturing

L. Korba, “e-Manufacturing” Canada

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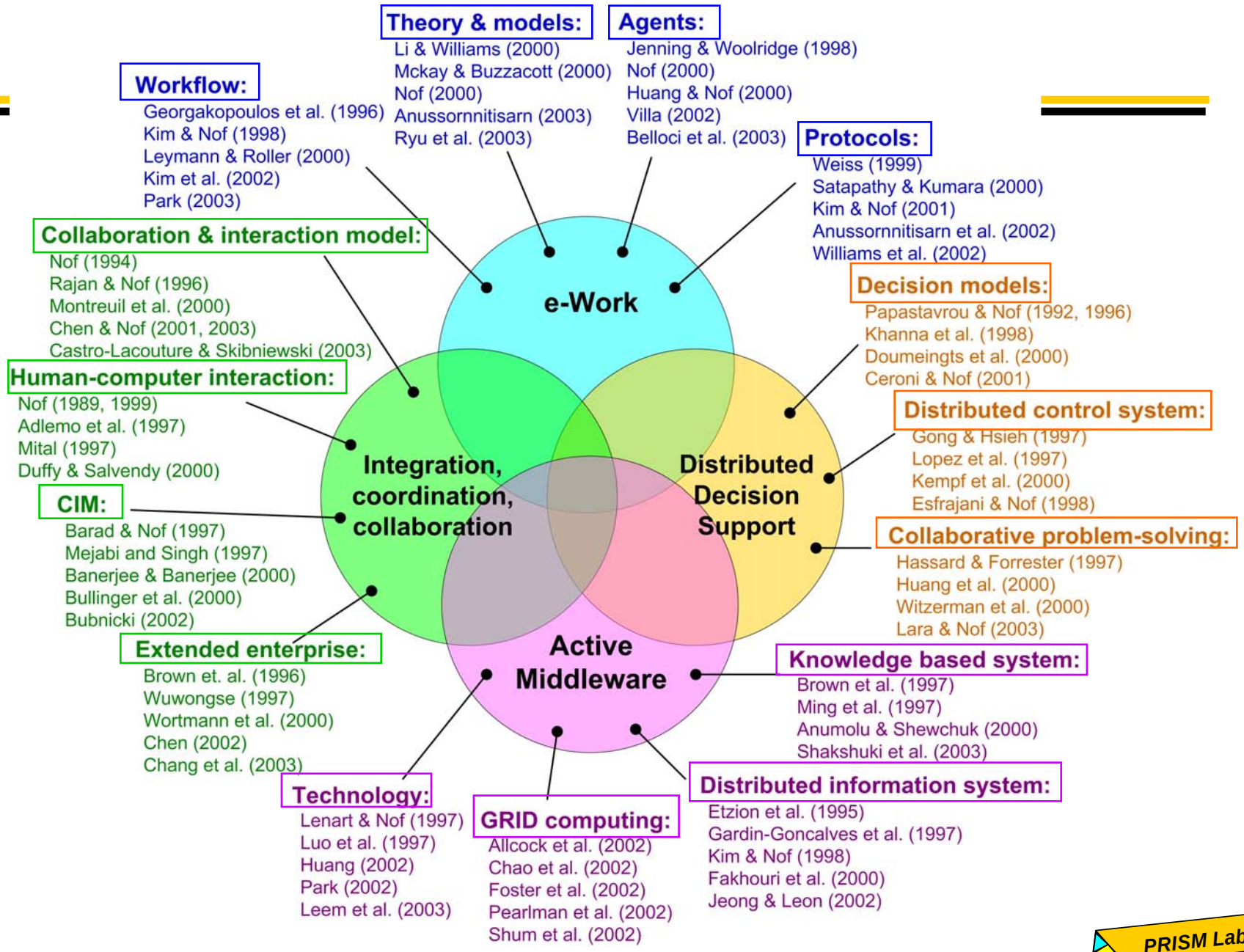
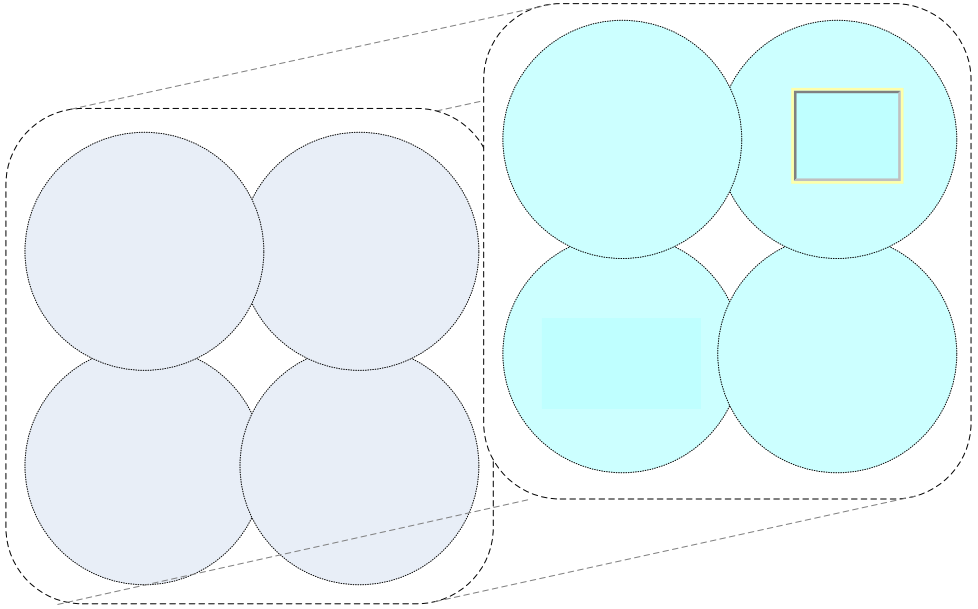
The 15 e-dimensions of collaborative e-Work



Scope of e-Production challenges and solutions

- **e-X ≠ X**. e-Work and e-Production / e-Business are not the same as work, production, and business.
- In general, **e-Work enables** e- Production / e-Business, and the latter require e-Work.
- Design objectives and benefits must respond to increasing needs of **sustainability** and **dependability** with a growing world population.
- **Emerging enablers**: Networks of demand & supply; smart teams, workflow interactions, decentralized decisions and automation, and collaborative control and management.

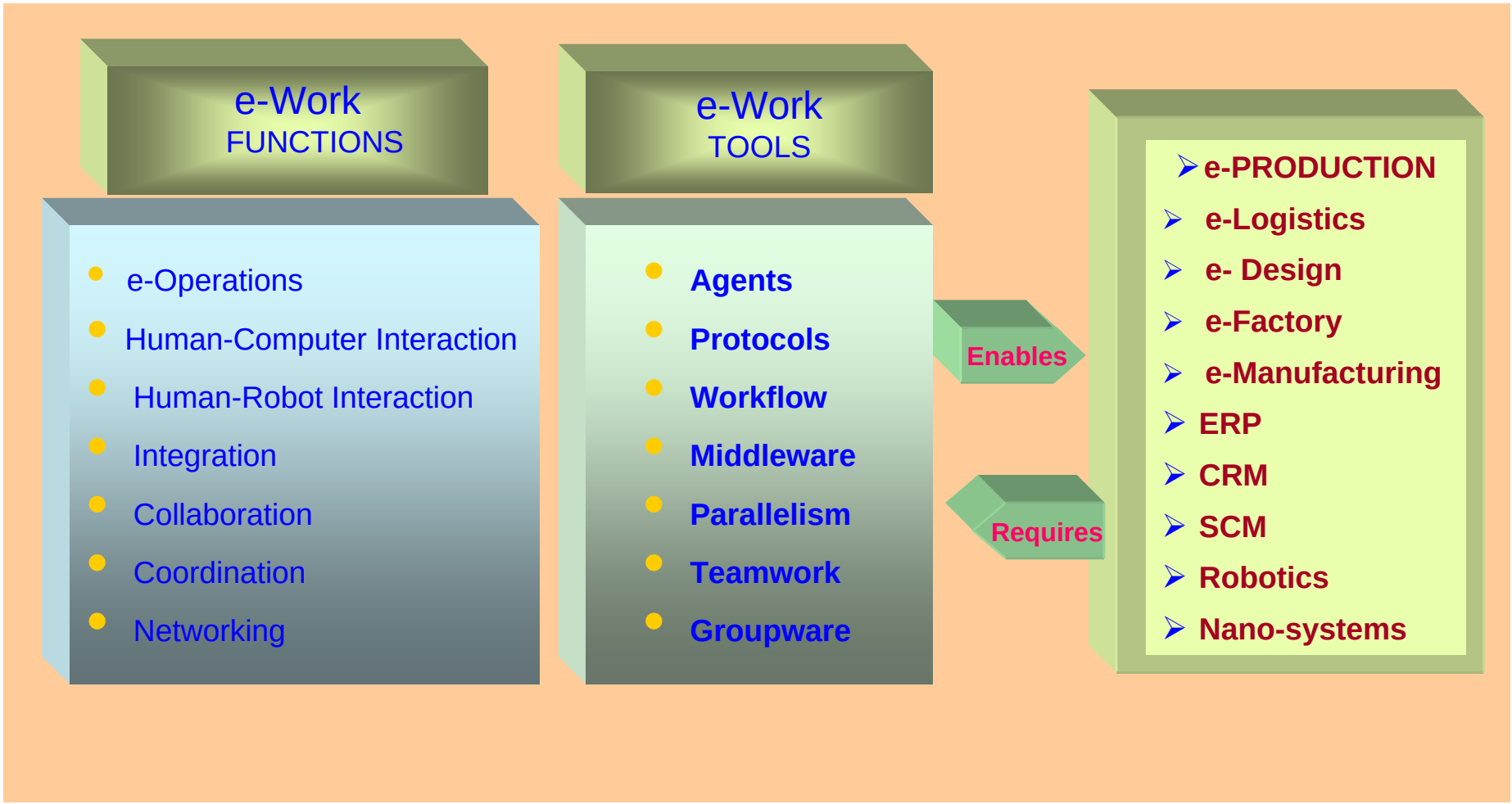


CHALLENGES

SOLUTION TRENDS

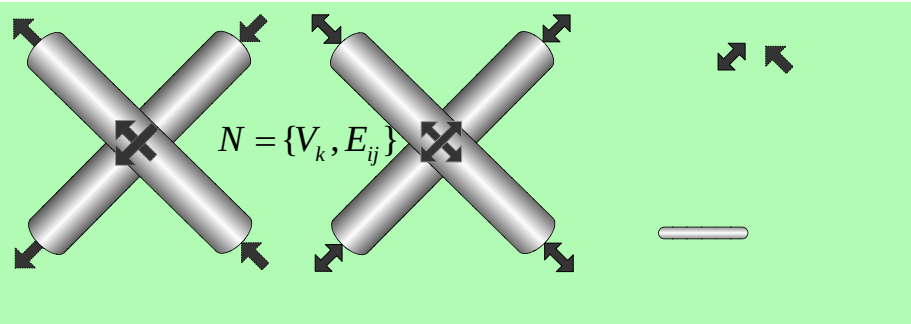
[IFAC-CC5 Milestone, 2005]

e-Work enables e-Production

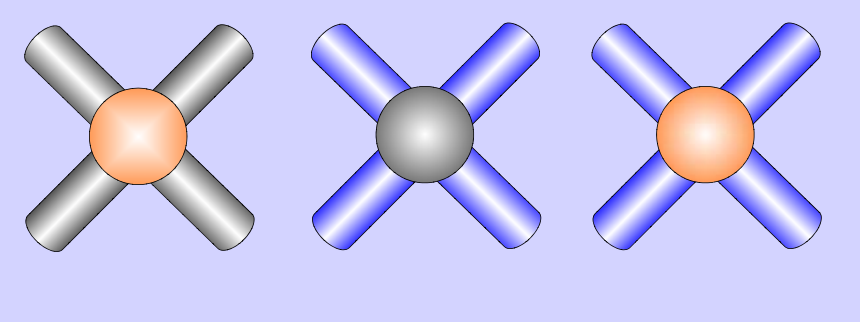


Emerging principles of collaborative control theory

- Collaborative control theory has been developed to support effective design of e-collaborative systems
- Network models applied to analyze/ optimize design
- A network model is defined as $N = \{V_k, E_{ij}\}$ where V is a vertex, or **node**; E is an edge, or **channel**.
- Network flow can be uni- or bi-directional; Nodes and/or edges (channels) *can be active*



Flow through edges

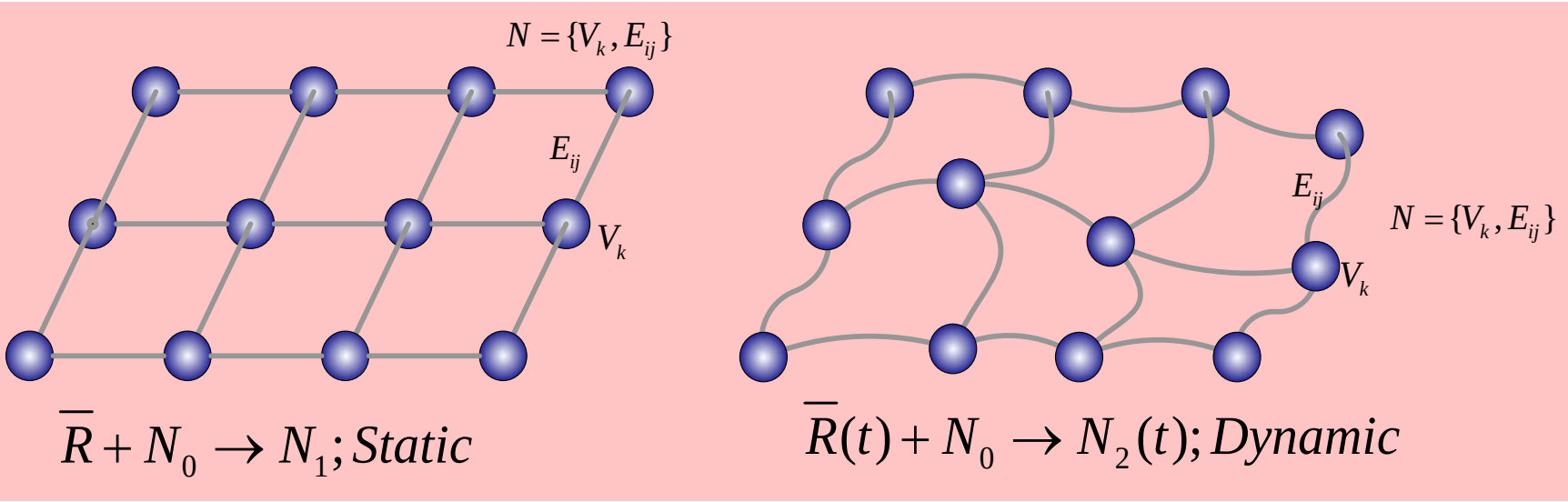


Activation of edges and/or vertices

(1) The Principle of Collaboration Requirement Planning, CRP

[Rajan and Nof, 1996]

- Effective e-collaboration requires advanced planning and on-going re-planning
  - CRP- I, plan *"who does what, how, and when"*
  - CRP-II, during execution, revise plan in real time, adapting to temporal and spatial changes and constraints



Network models for CRP on initial network N_0:
Static requirements $\overline{R}$; Dynamic $\overline{R}(t)$.

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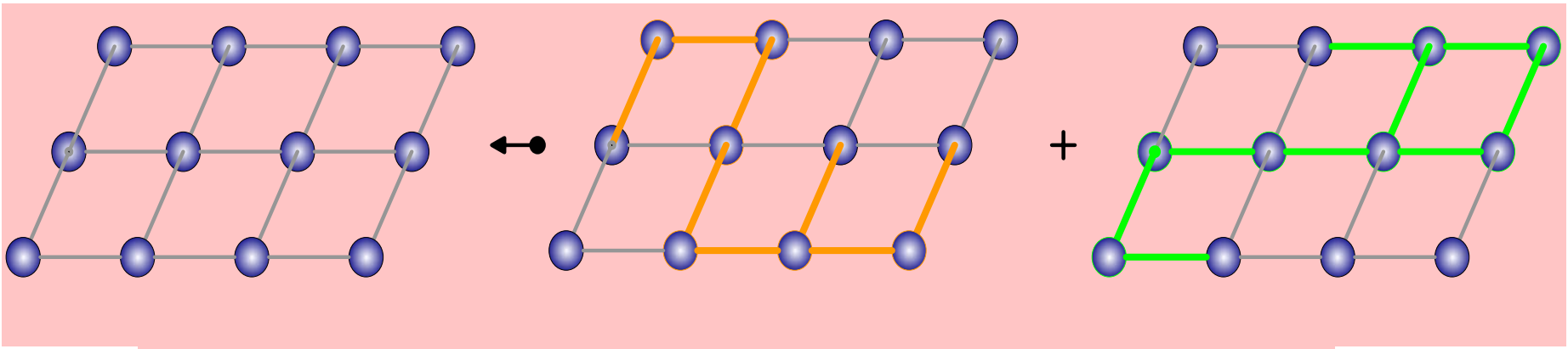
(2) The Principle of Collaborative e-Work Parallelism

[Ceroni and Nof, 1999]

- Optimally exploit the fact that work in **software work-spaces** and **human work-spaces** can and must be allowed to advance in parallel
  - To be effective, e-Work systems cannot be constrained by linear (sequential) precedence of tasks – delegate!
  - "KISS": Keep It Simple, System!



$$Tasks(t) + N_0 \rightarrow \{Tasks(t), n_a(t)\} + \{Tasks(t), n_b(t)\}$$

$$N_0 = \{n_a(t), n_b(t)\}$$

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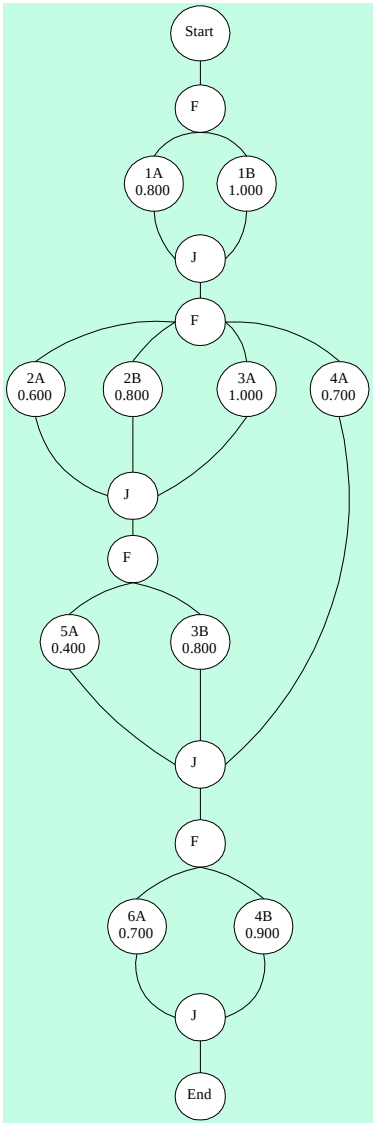
PIEM (centralized optimization algorithms) and DPIEM (optimization with distributed protocols) for planning the communication and coordination trade-offs in e-Work of design, mfg., logistics with parallelism



Summary: Local and Integrated Scenarios [Ceroni, 2000]

	Φ	Π	T	No. of Sub-tasks
Local Scenario (A+B)	1.9846	1.4239	0.5607	52
Enterprise A	1.3908	1.0350	0.3558	16
Enterprise B	0.5938	0.3889	0.2049	36
Integrated Scenario	1.8071	1.1666	0.6404	26

Optimize the DOP, Degree of Parallelism

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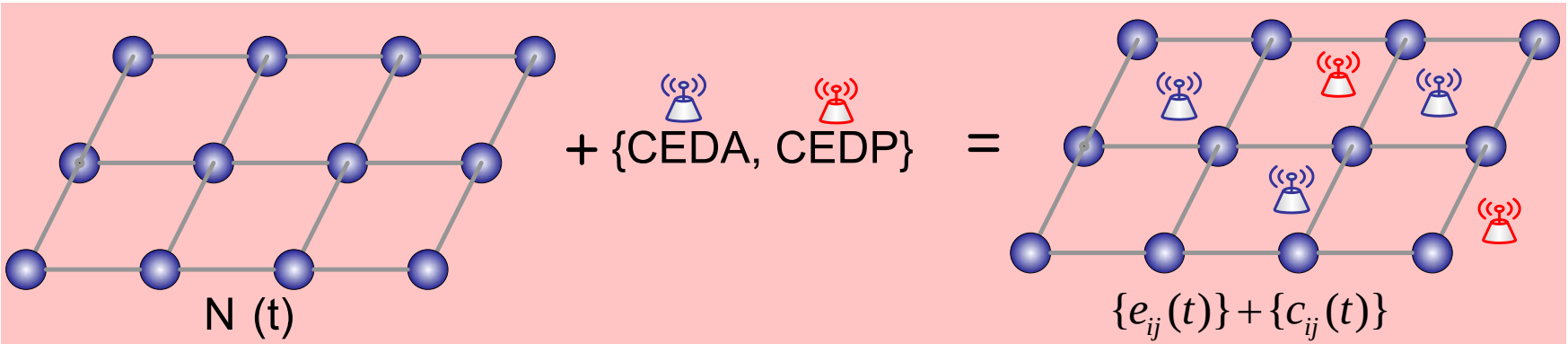
(3) The Principle of Conflict Resolution in Collaborative e-Work

[Huang and Nof, 1999]

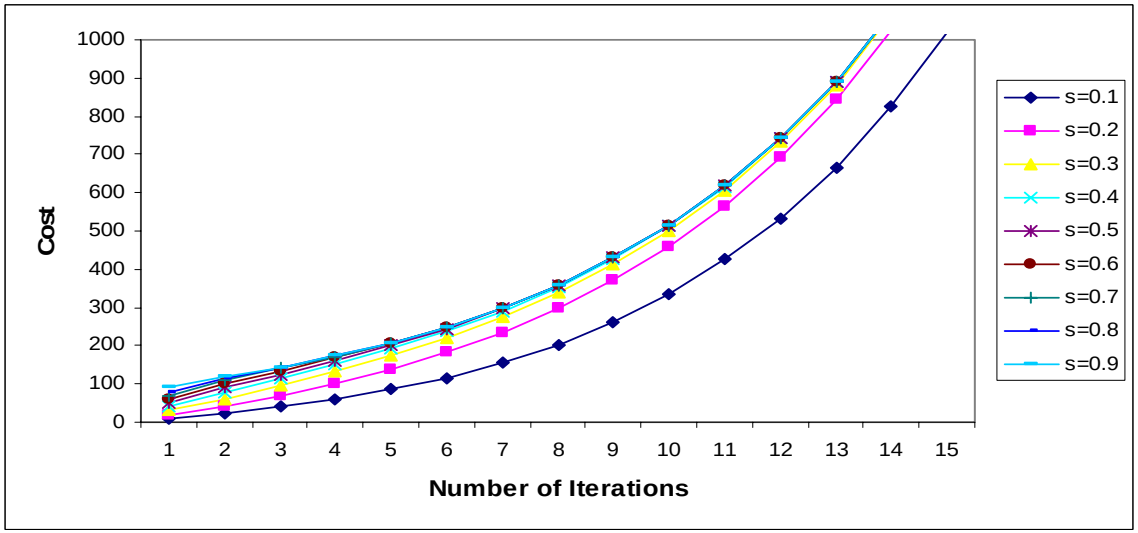
- Minimize the cost of resolving conflicts among collaborating e-Workers by automated EWSS (e-Work support systems)
  - Beyond reducing information and task overloads, e-Work must be designed to automatically prevent and overcome as many errors and conflicts as required to be effective

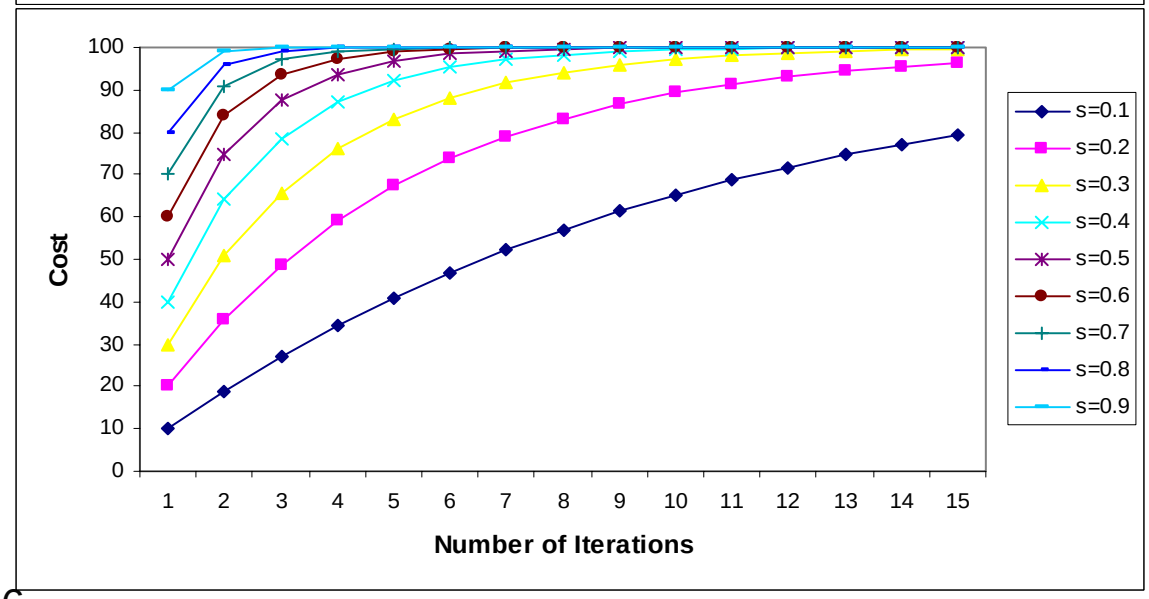


Conflict & Error Detection Agents (CEDA) and Protocols (CEDP) are assigned to Network $N_0(t)$

Critical Cost of Error Recovery / Conflict Resolution

(C-Y Huang, 2001)





Increases exponentially when human communications and operations are applied (assuming *q*=0.2)

Reaches an upper bound when IT is Applied (assuming *q*=0.0)

q *= % of human involvement*

S *= rate of conflicts*

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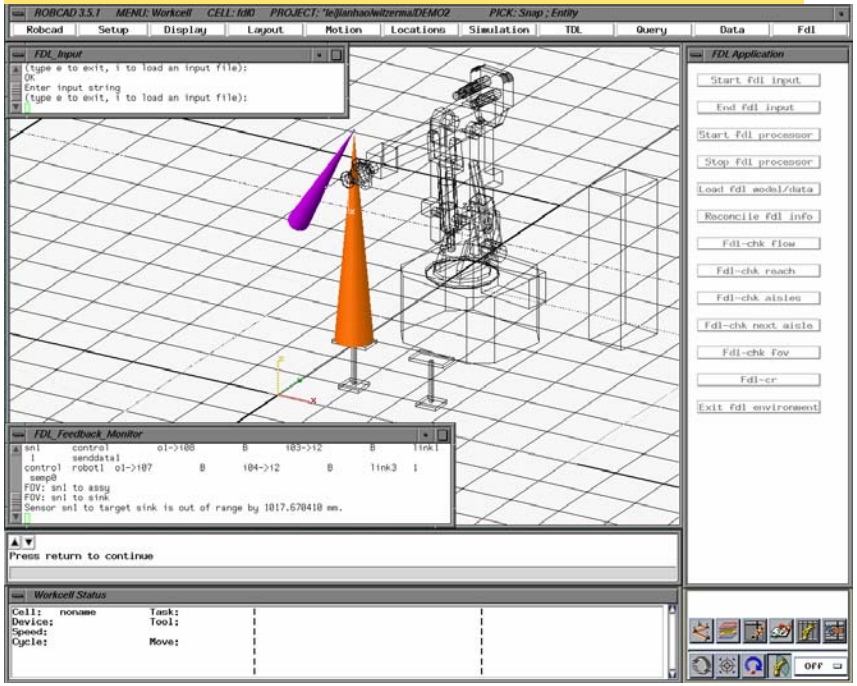
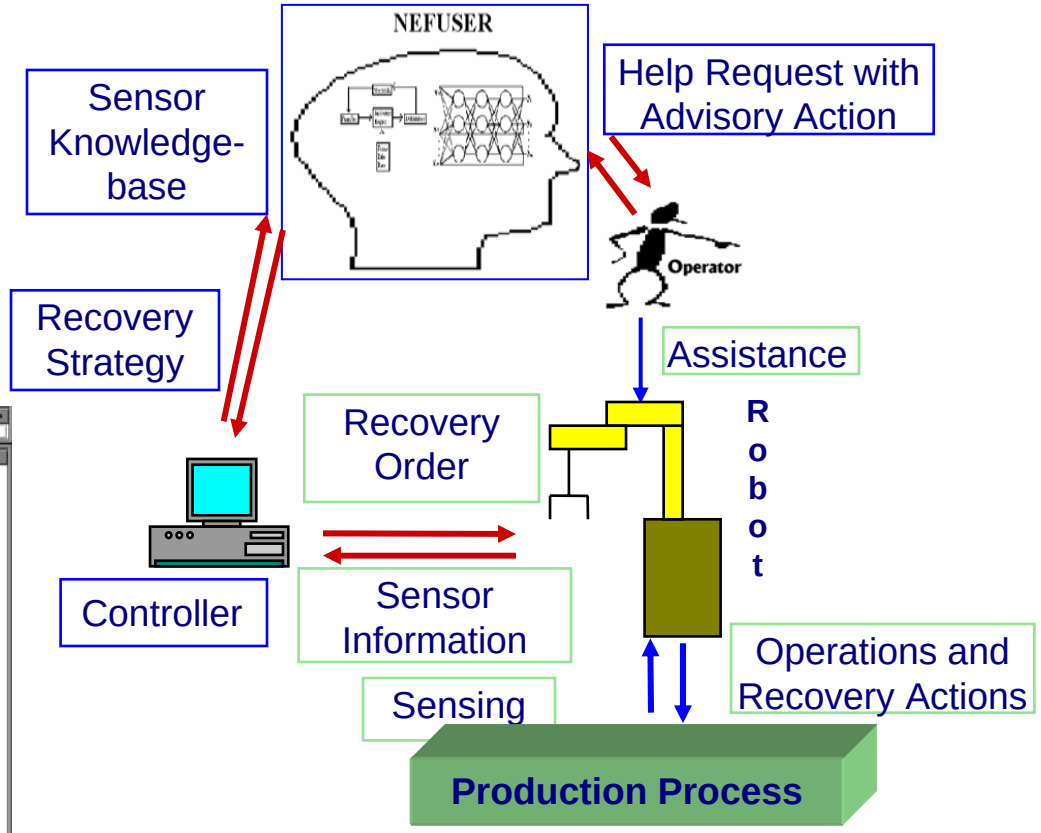
Solutions for e-diagnostics, e-recovery, e-resolution

Computer-Supported Conflict Resolution: FDL's Field-of-View function [Lara, 2001]





NEFUSER: Neuro-Fuzzy Error Recovery with human-robot recovery interactions [Avila, 2002]

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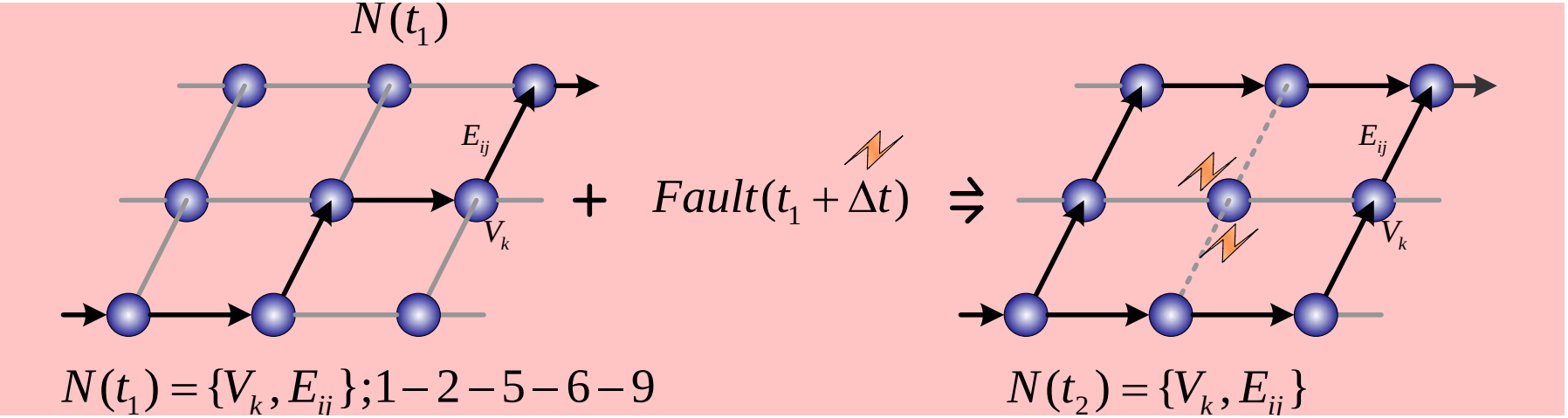
(4) The Principle of Collaborative Fault-Tolerance

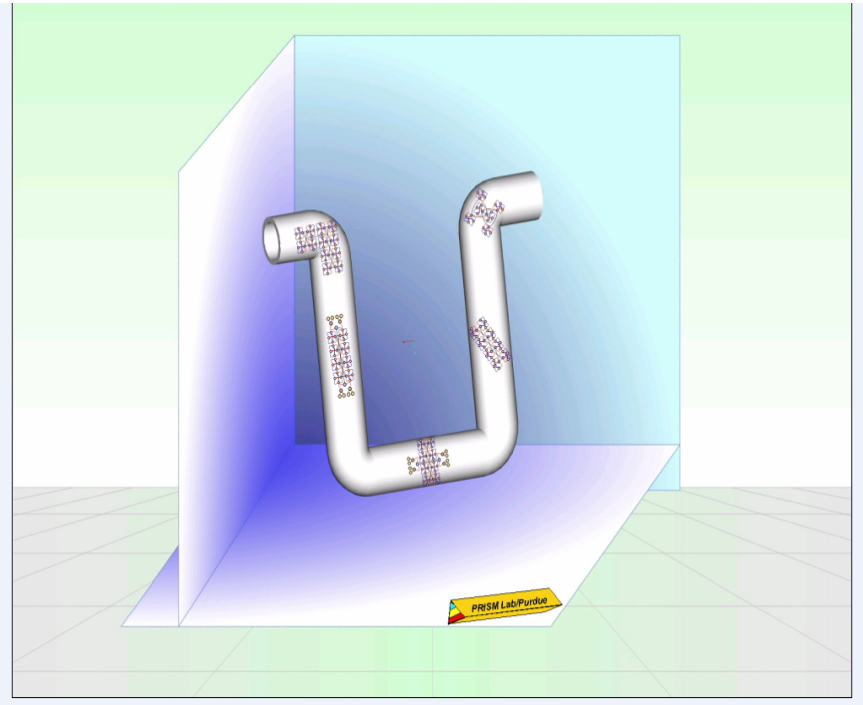
[Jeong and Nof, 2005]

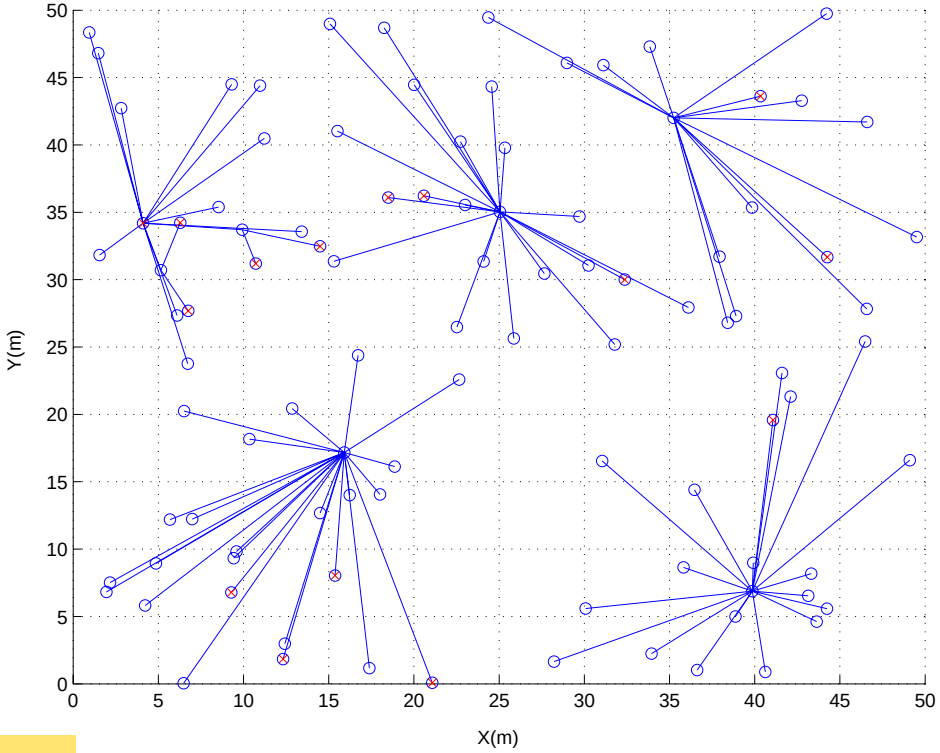
- Fault-tolerant collaboration can yield better results from a team of weak agents, relative to a single optimized and even flawless agent
- Ancient synergy lesson: “A collaborative team is better than the sum of the individuals”; this principle: ***How*** to achieve this advantage by smart automation, even with some faulty agents/channels



Original flow 1-2-5-6-9 adapts to link or node failures → backup flow 1-4-7-8-9 or 1-2-3-6-9, depending on energy and response-time constraints

Collaborative fault-tolerance TAP design





Principles 1-4 at work:
Alternative MEMS and nano sensor arrays / networks optimized along an artery for measurement and control

6 Faulty sensor routed communication by a time-based control [Jeong, 2006]

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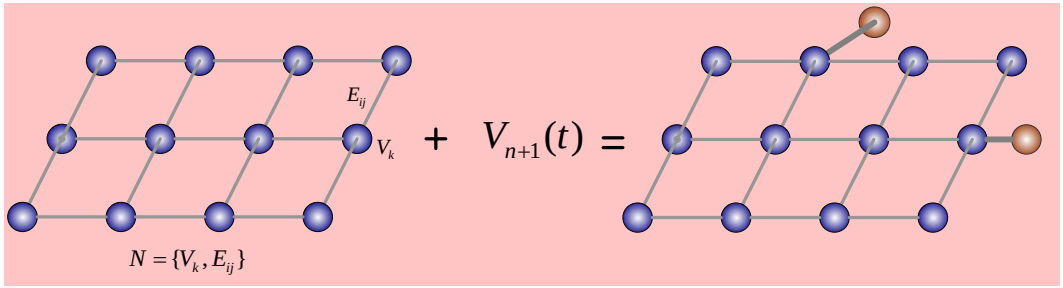
(5) The Join/Leave/Remain (JLR) Principle in Collaborative Organizations

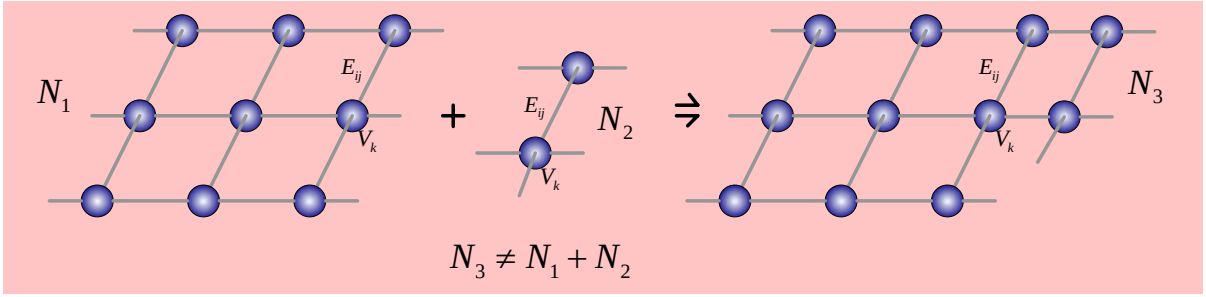
[Chituc and Nof, 2005]

- Individual organizations: Decide repeatedly when and why to JLR a given CNO based on measured total participation gains and costs, 3-D {Agility; Payoff; Cost}
- For a CNO: Same (including increased coordination) relative to each member organization

(a)



(b)



The JLR model: (a) Two nodes join a network. (b) Larger and small organizations unite, transform the original network.

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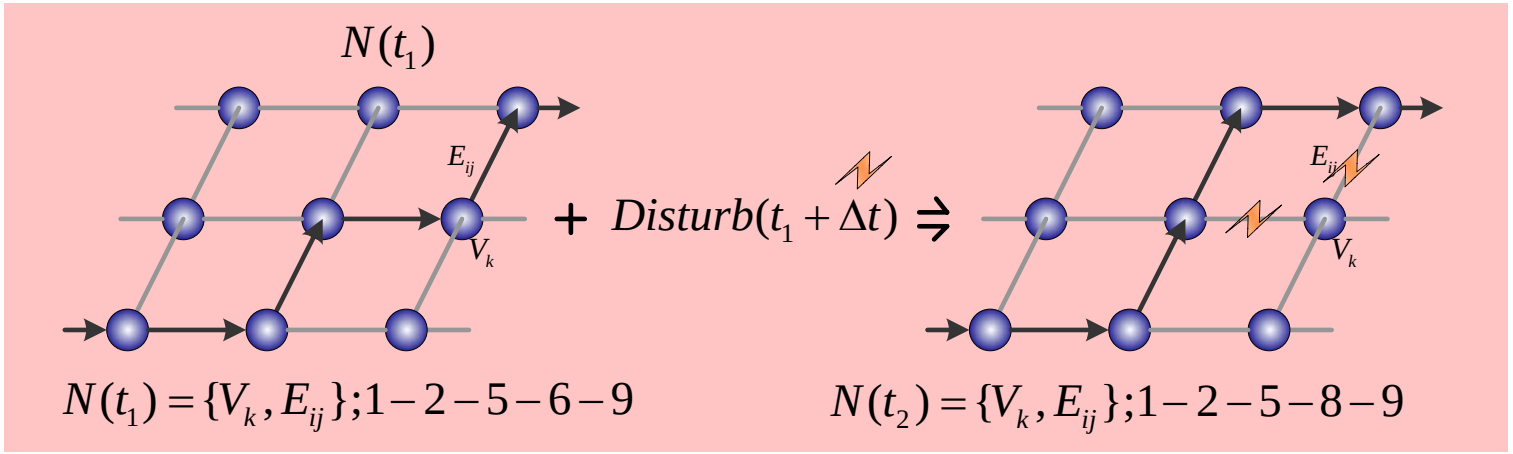
(6) The Principle of Emergent Lines of Collaboration and Command, LOCC [Velasquez and Nof, 2006]

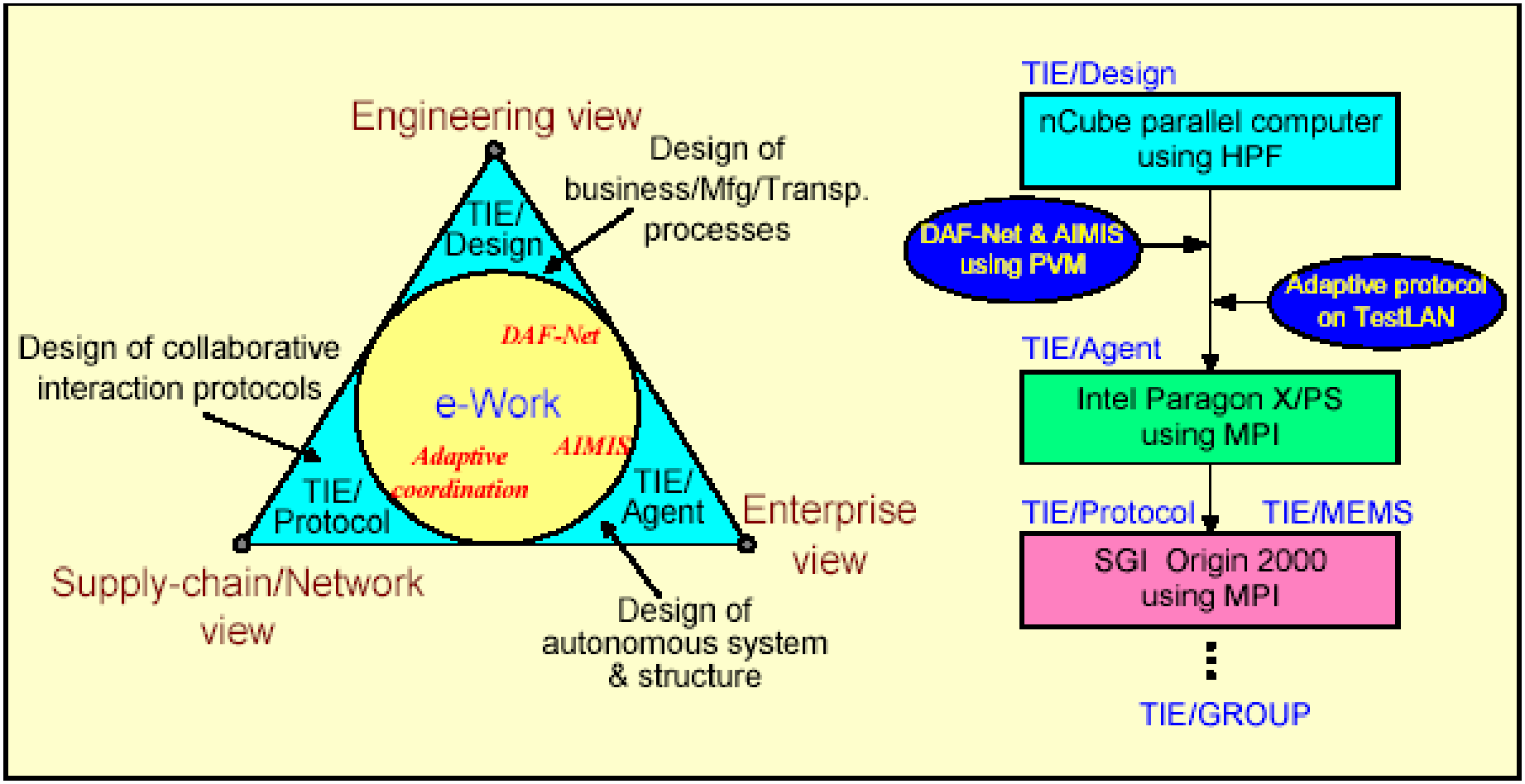
- Design evolutionary mechanisms of interaction and organizational learning for better ad-hoc decisions, effective improvisation, on-the-spot contact creation, and best matching protocols to pair decision makers and executors

- Critical under all hazards emergency situations
- Ex. real-time KBS for monitoring and diagnosing dynamic processes



LOCC model: Line 1-2-5-6-9 evolves after disturbance (emergency) to 1-2-5-8-9

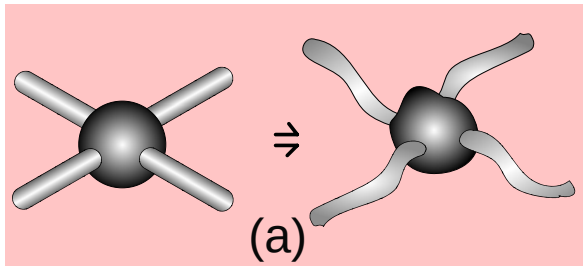
TIE, **T**eamwork **I**ntegration **E**valuators: Parallel/distributed interactions and engagements

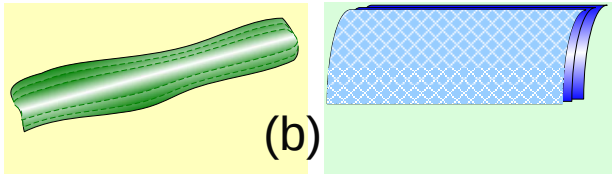


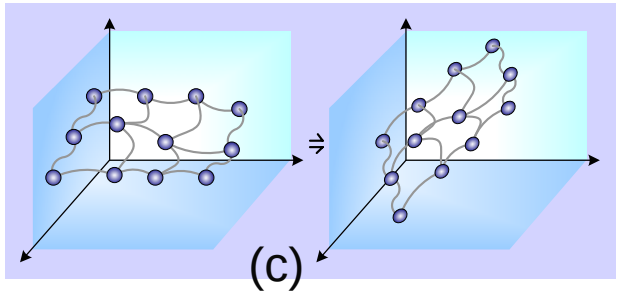
New measures needed: XXXability – e.g., viability, interoperability, detect-ability, scalability, dependability, reachability, integration-ability, recover-ability, learn-ability, resolvability, integrity, trust-ability, …..

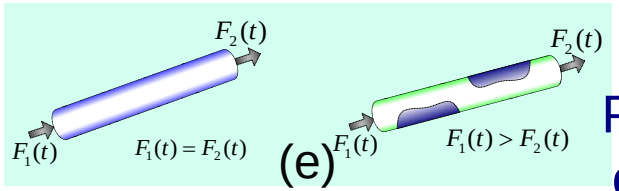
Challenge:

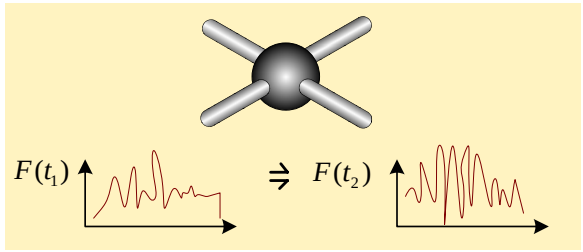
Bio-inspired collaborative node and channel behaviors

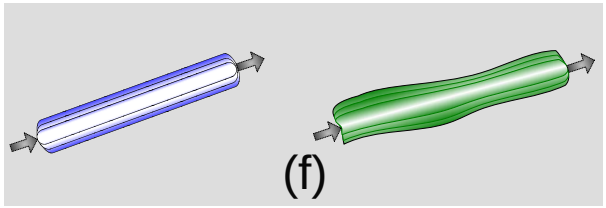




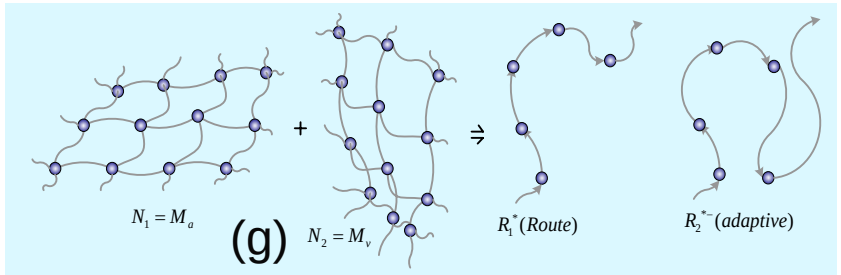


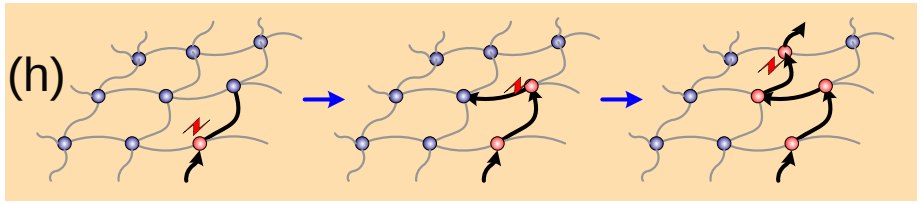


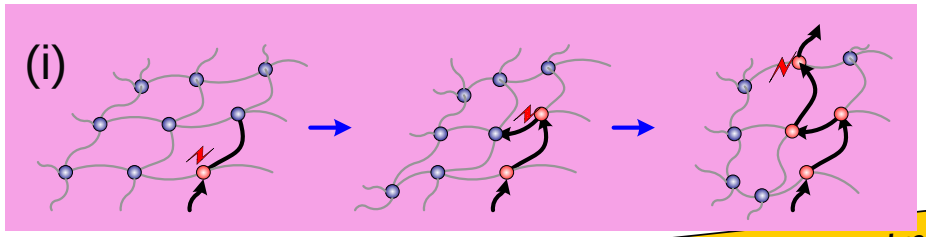




Physical, electrical, and bio-chemical dynamic changes in neural/brain activities enable survival, collaboration, interactions







Bio-inspired network models: (g) Survival maps; (h) propagation; (i) same, both nodes & channel variations

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Summary 1/2
Collaborative e-Work and e-Production – Our Future

Emerging: Smart parallel teams will be able to interact better; Collaborative control EWSS will enable production effectiveness, harmony

Trend 1. Collaborative Coordination Control Theory

Why? Optimized coordination of e-Work interactions is critical

Trend 2. Smart protocols will prevent and manage errors, conflicts, reorganization, and interactions

Why? Complexity, dependency among distributed teams increases

Trend 3. Smart protocols for fault-tolerant collaboration

Why? Future e-production will depend on cheaper, redundant, disposable arrays/networks/teams

Summary 2/2

IMPACT: What does it mean? What do we really expect out of production?

- Over half the world population does not yet enjoy the benefits of production – important changes are emerging
- Food, transportation, security, medical & healthcare services, education, civilization -- all depend on production
- Emerging production analogous to dramatic productivity transformation in agriculture
- The emerging future of production enterprises depends on our understanding of how effective e-Work can be designed
- Interesting questions: dynamic reorganization? optimal clustering? profitability vs. sustainability? Topology-based performance? Bio-inspired network behavior?
- Most important: Let's collaborate wisely!

Acknowledgement

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