The 3rd Israeli Conference on Robotics

Collaborative Control Theory for Robots

Shimon. Y. Nof

PRISM Center
Production, **R**obotics, and **I**ntegration **S**oftware for **M**fg. & **M**anagement
Purdue University, W. Lafayette, IN, USA

10-11 November, 2010, Hertzlia, Israel

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PRISM Global Research Network

nof@purdue.edu

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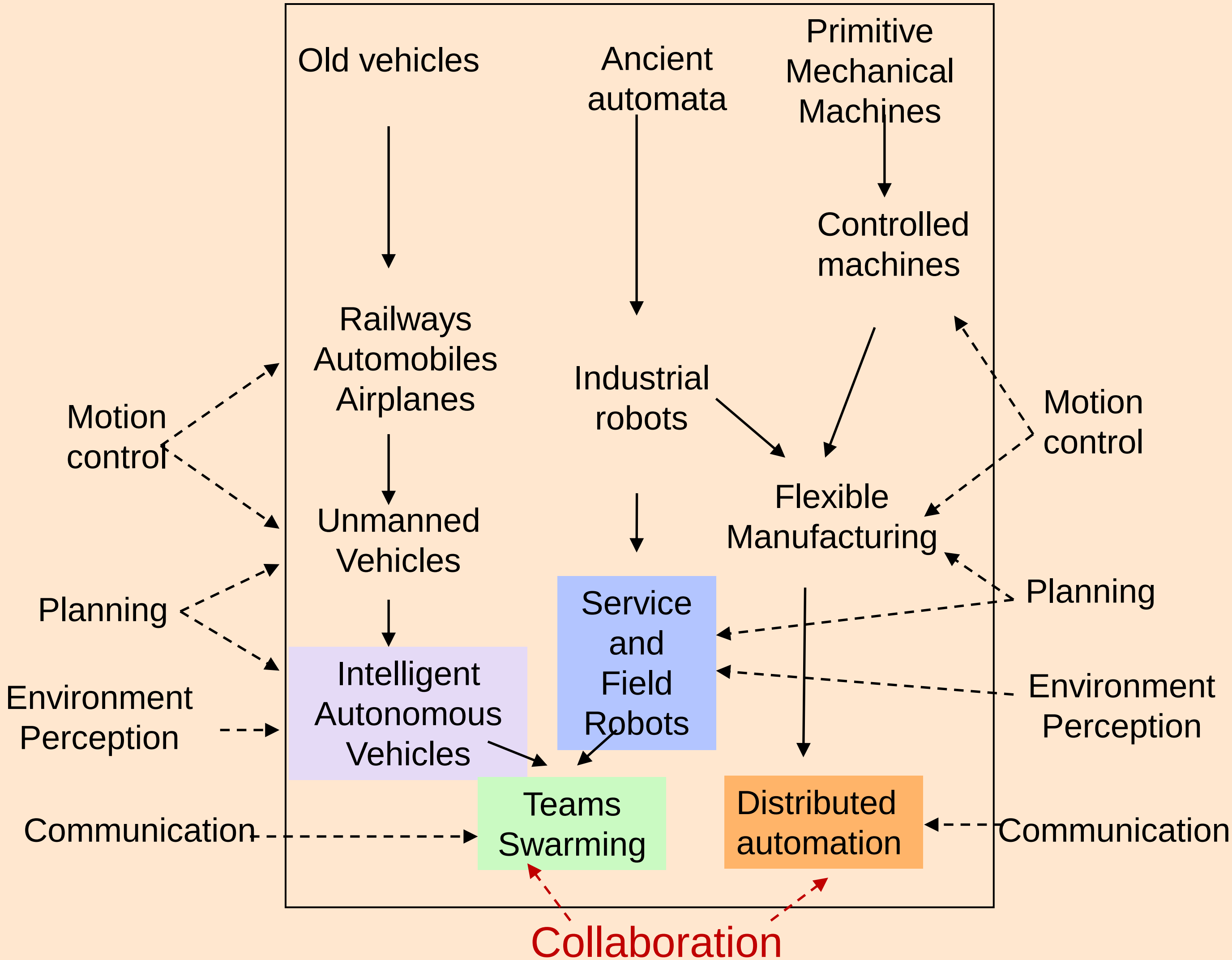
Robot Collaboration

- Collaboration revolution
- Co-Ro-Bots – Robot; Agent
- Collaborate: Why? Who? How?

Nature of Robot Collaboration: Alliance vs. adversary

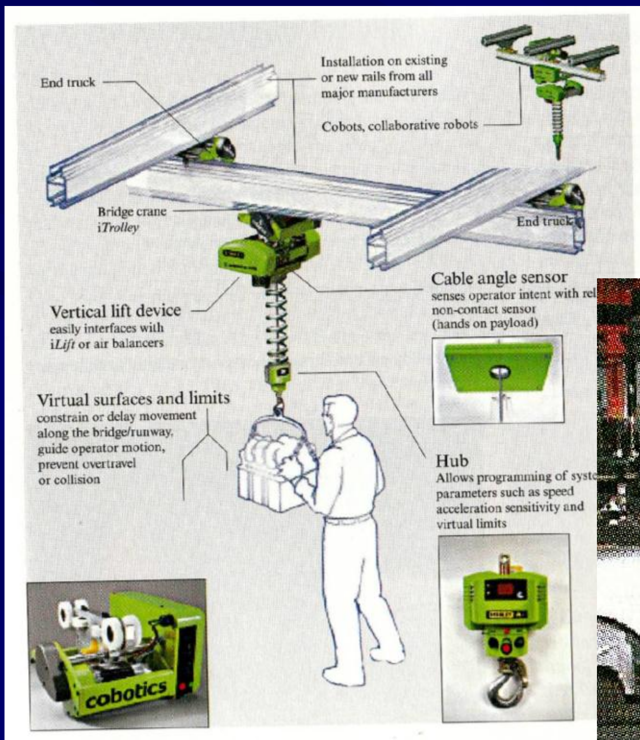
- CCT; Design recommendations for collaboration support
- Emerging trends
    - Evolutionary robotics
    - Bio-inspired robotics
    - Nano-robots
    - Social robotics
    - CI, Collaborative Intelligence

Why is collaboration needed? For better effectiveness & success



Evolution of automation in mobility and navigation
(Ollero, *Springer Handbook of Automation* 09)

Who collaborates? H:H, H:R, R:R, H:H:R, H:R:R; 1:1, 1:N, N:M, teams, swarms, networks



A cobot assisting a human in assembling a car

pHRI in human power amplifiers

Ergonomics, work optimization: Stronger, safer, faster, more precise, reach further

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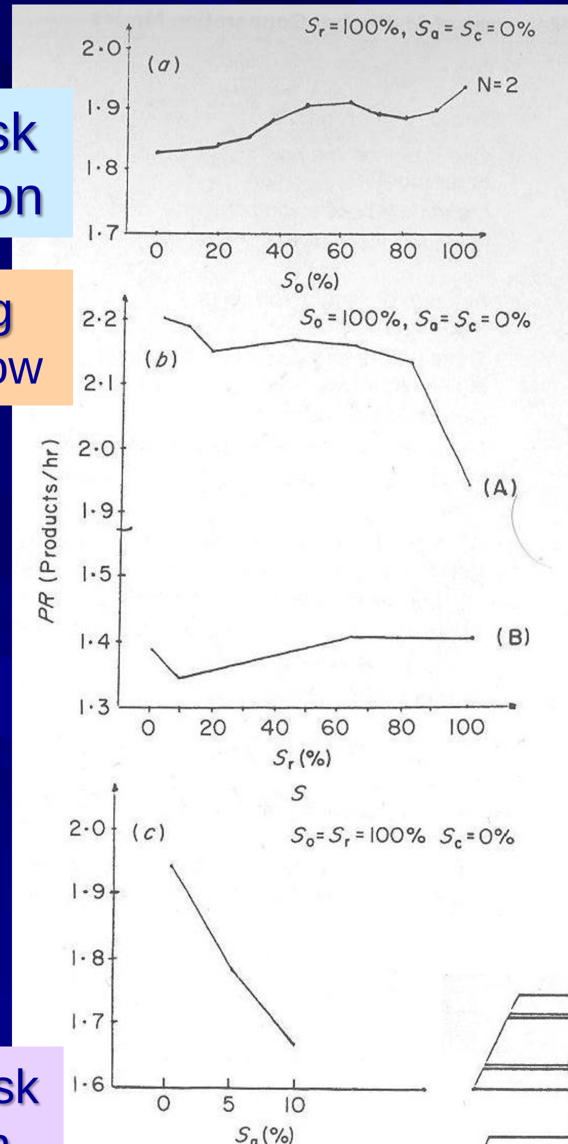
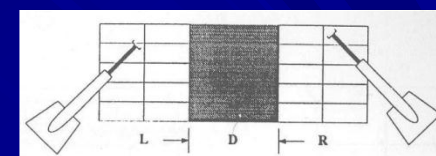
How to collaborate?

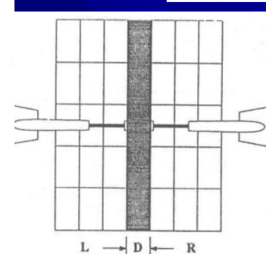
R:R:R,
H:R:R

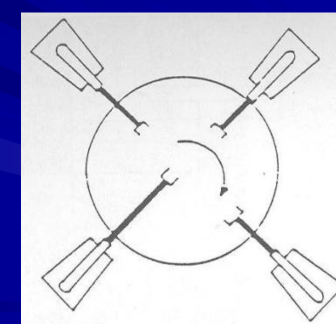
Optional Task Collaboration

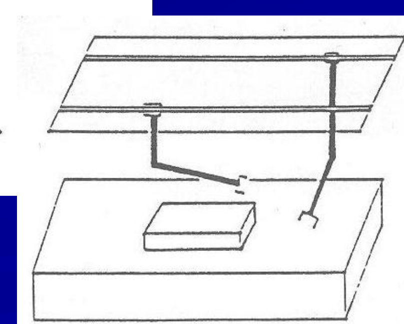
Level of Resource Sharing
Service load: (a) high, (b) low









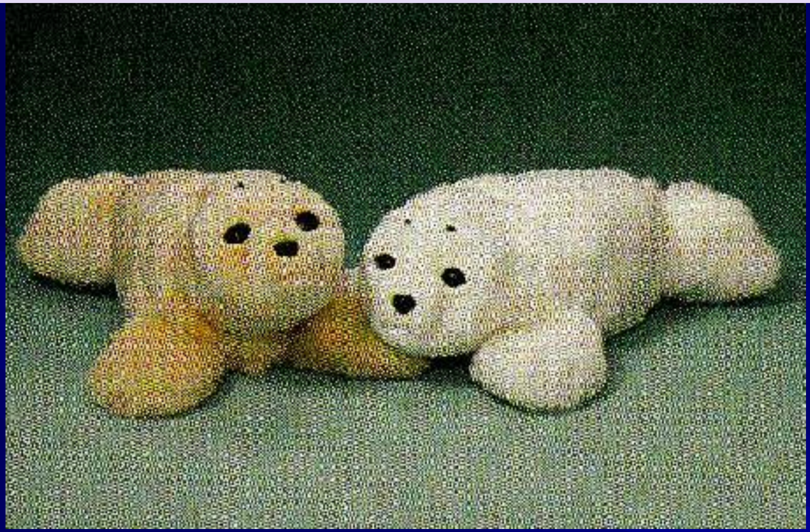


Mandatory Task Collaboration

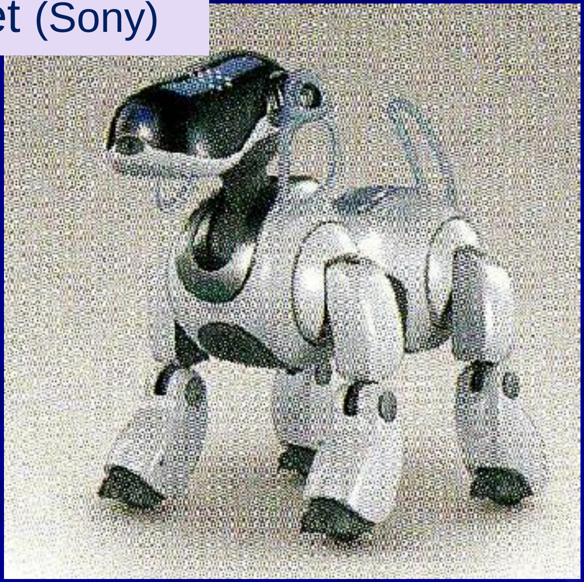
HBIR2 (Nof) Ch 32 Robot Ergonomics: Optimizing Robot Work

Who and How? H:R Bio-inspired sociable robots – attend, care, inform, act

PARO, therapeutical seal robots (AIST)



AIBO, robotic pet (Sony)



MEL, Conversational penguin robot (MERL)

Leonardo, media robot (MIT)

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Cooperate vs. Collaborate

Both: share space; time; information; knowledge; tools; capacity. In collaboration, share also in tasks execution

Cooperating robots:
"I can see what you cannot"

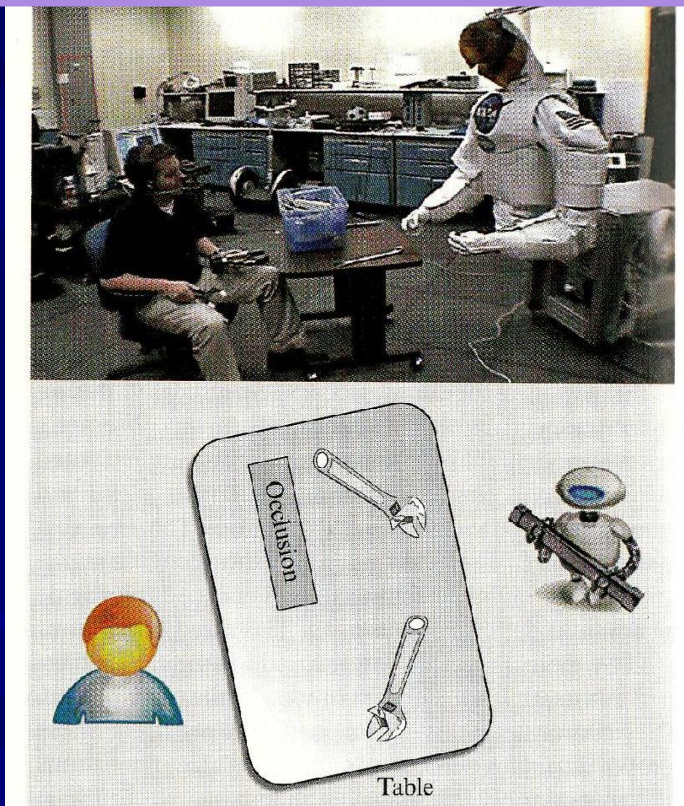
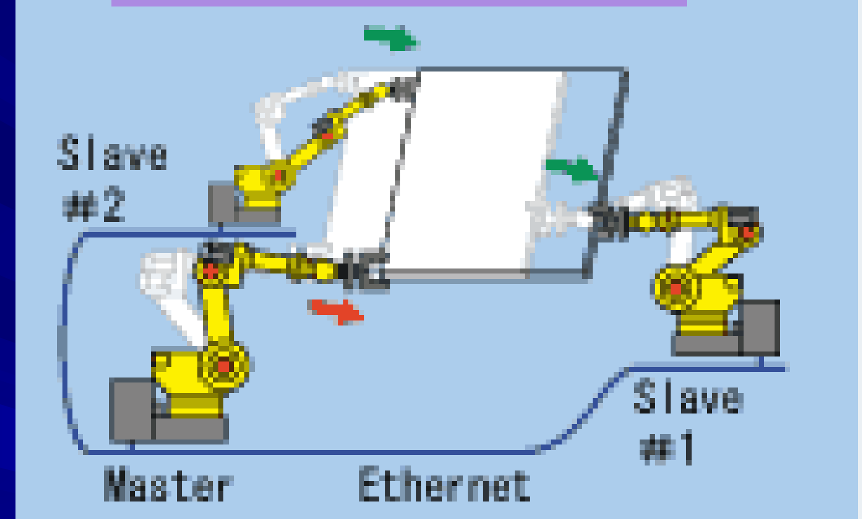


Fig. 58.13 Robonaut using visual perspective taking to disambiguate the intended referent when asked to *hand me the wrench*. The human can only see one wrench, but the robot can see both. The robot correctly hands the wrench that both can see

Collaborating robots:
Master-slave model



From rigid to bi-inspired control models:

- Autonomous / autonomic units (agents)
- Adaptability, evolutionary,
- Survivability (of fittest)
- Autonomous, collaborative systems
- Scalability, agility

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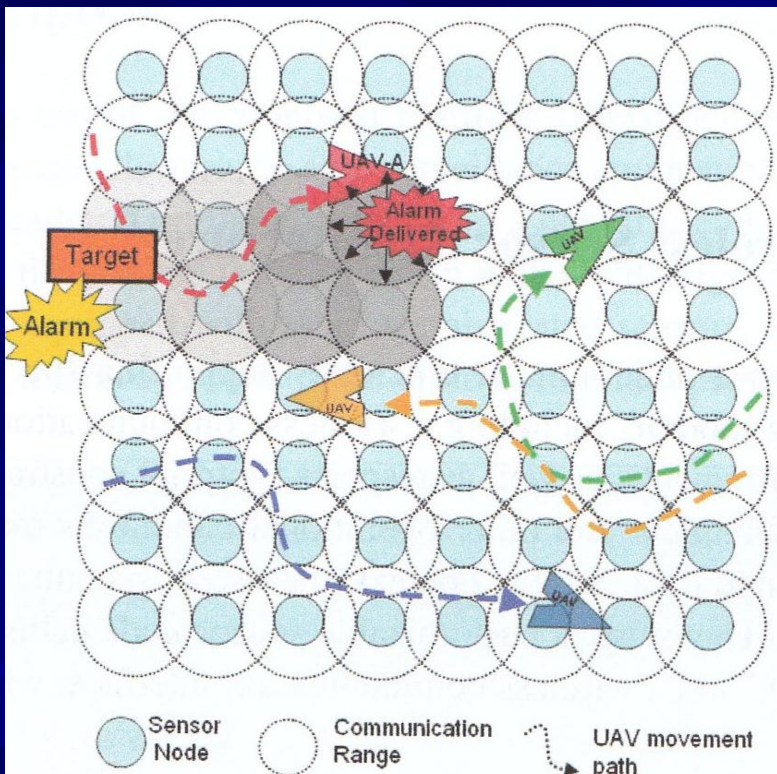
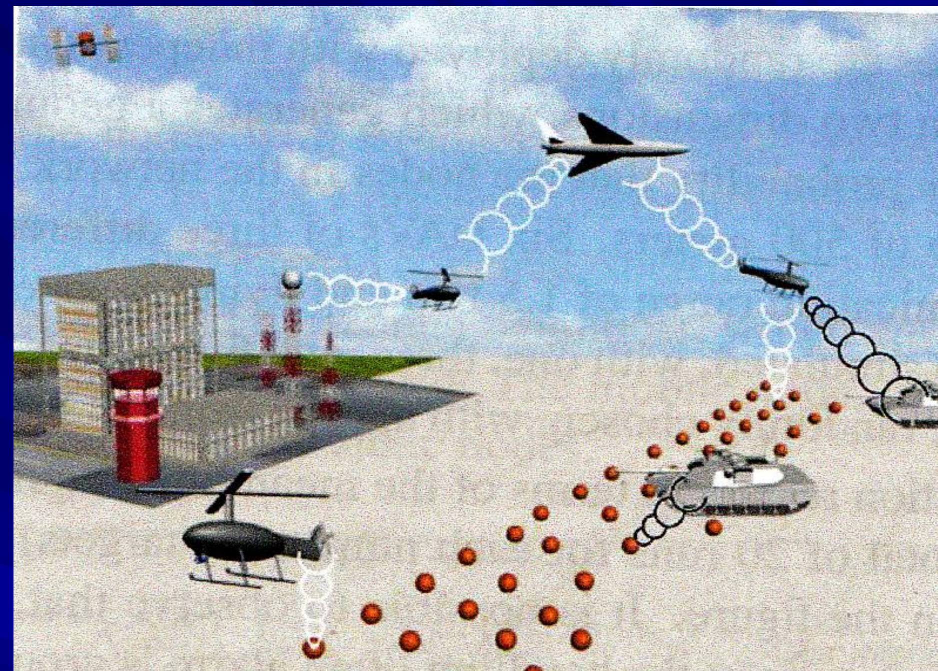
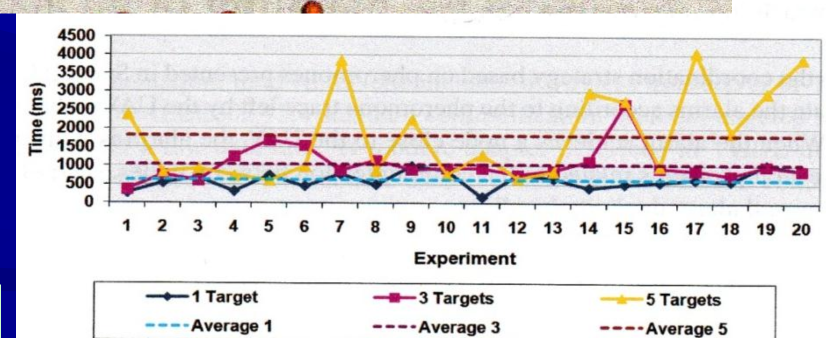
How? Comm. → Coordinate → Cooperate → Collaborate

H:R:R in sensor networks: Response quality by CCT logic

Co. to win: W-W; ZSG; MSG







Pheromone strategies with alarm response times achieved

de Fereitas et al. Coordinating aerial robots and sensors for intelligent surveillance. *IJCCC* 10, 52-70

Design Principles of Collaborative Control Theory (CCT)

Design Principle	Brief Definition	Robots/Agents
1. **CRP** I+II Collaboration Requirement Planning	Effective e-collaboration requires advanced planning and on-going re-planning	Operation plan and seq.; Adapt
2. Parallelism & KISS Parallelize and “Keep it simple, system!”	Optimally exploit the fact that work in cyber work-spaces and human work-spaces can and must be allowed to advance in parallel	Optimize DOP, {R}, TAP; KISS for H, R
3. **CEDP** Conflict & Error Detection and Prognostics	Minimize cost of resolving conflicts among collaborating agents by automated CSS, collaboration support systems	Id., detect, prevent, resolve errors, conflicts
4. **FTT** Fault-Tolerance by Teaming	Fault-tolerant collaboration can yield better results by a team of weak agents, than a single optimized and even flawless agent	Sensors and robots networks
5. **JLR** Join/Leave/ Remain in a CNO network	**An agent**: Decide when/ why to JLR a CNO by monitoring total participation gains/ costs. **A CNO:** Same, including more coordination, re each member	Dynamic team optimization
6. **LOCC** Lines of Command and Collaboration	Evolutionary mechanisms of interaction and organizational learning for effective ad-hoc decisions, improvisation, on-the-spot contact creation, best matching protocols pairing planners with executors	Alerts, backup and best matching TAPs

Nof, *ARC* 07;Velasquez & Nof, *SHBA* 09

Group/Swarm robotics

Model based control, MPC (Model Based Predictive Control) used for formation control. MAS, Multi Agent distributed control applies to autonomous agents

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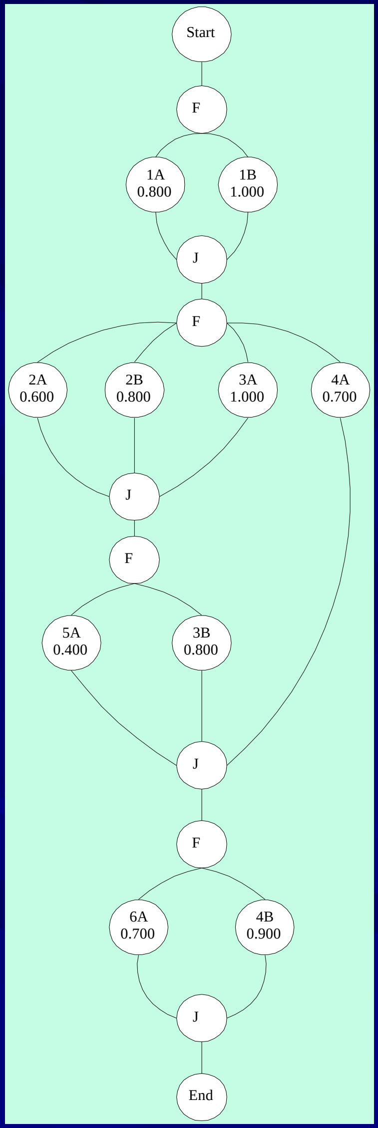
Collaborative parallelism



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

Summary: Local and Integrated Teams [Ceroni,00]

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

Optimize the DOP, Degree of Parallelism

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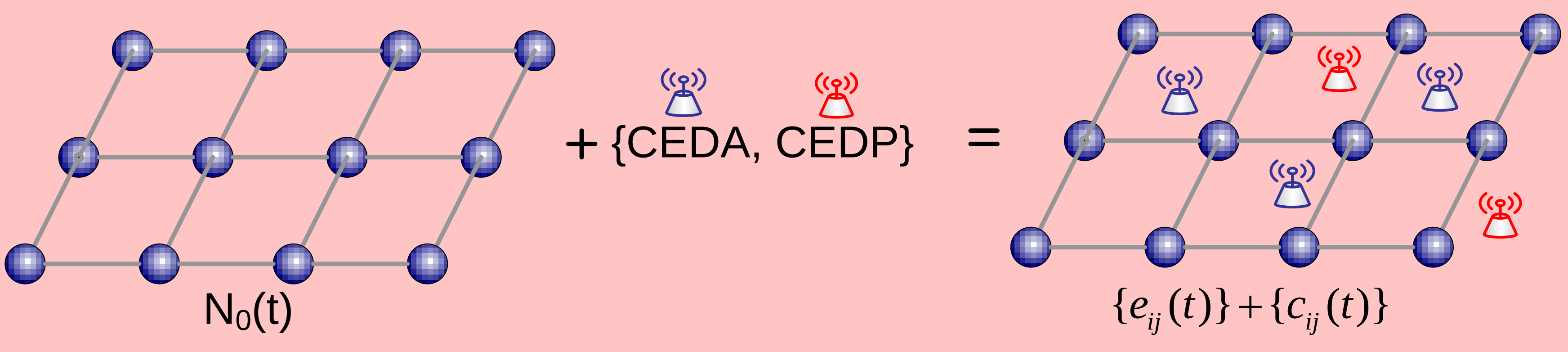
The Principle of Conflict Resolution in Collaborative e-Work

[Huang and Nof, 99; Chen and Nof, 09]

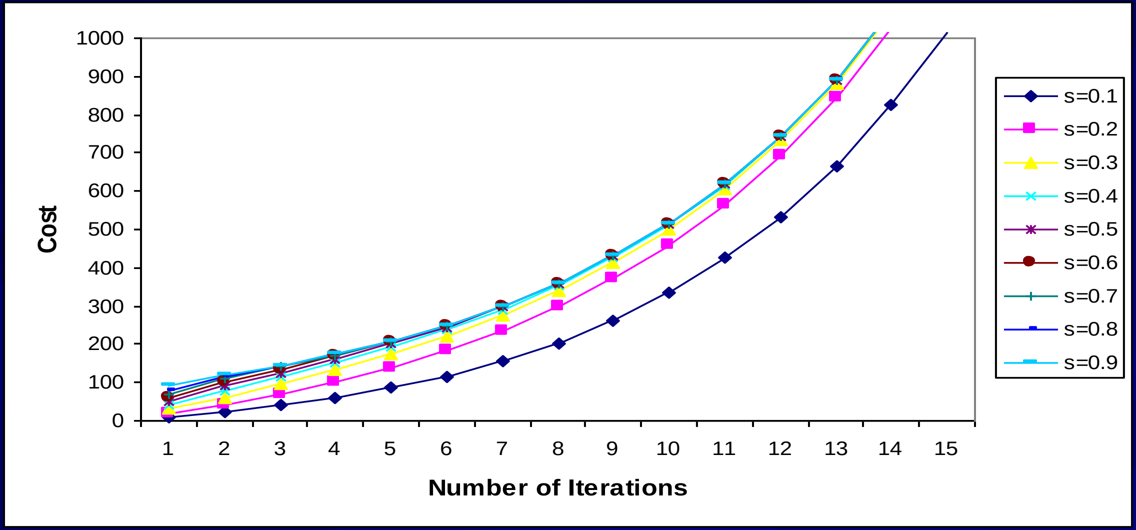
- Minimize the cost of resolving conflicts among collaborating agents by automated CSS (collaboration support systems)
  - Beyond reducing information and task overloads, agents must be designed to automatically prevent and overcome as many errors and conflicts as required to be effective

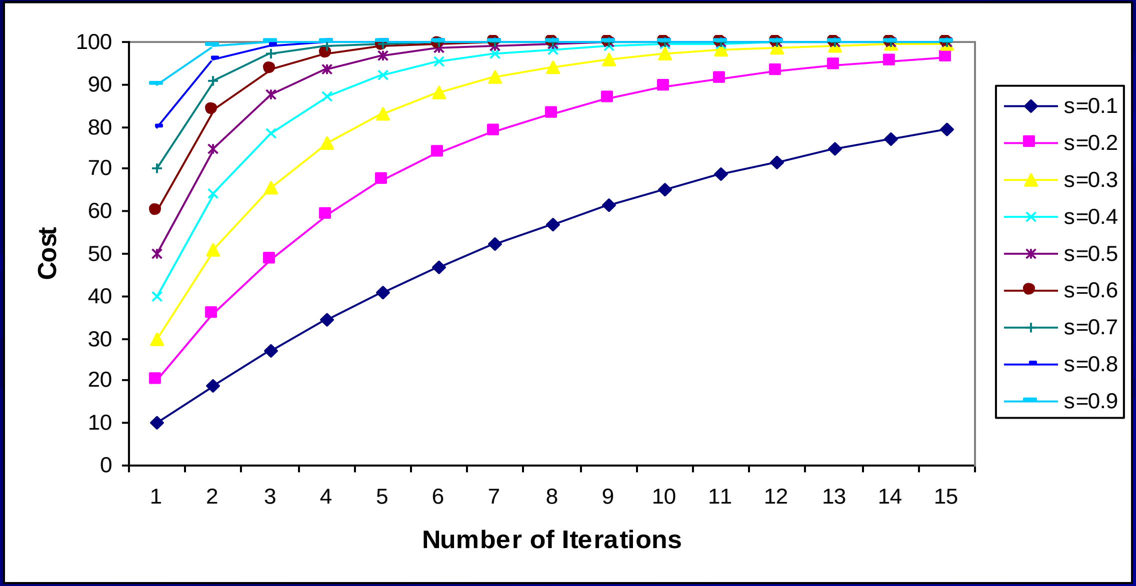


Conflict & Error Detection Agents (CEDA) and Protocols (CEDP) are assigned to Network $N_0(t)$

Ex. Elimination of faults in inspection, testing, security

Critical Cost of Error Recovery / Conflict Resolution





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)

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q *= % of human involvement*

S *= rate of conflicts*

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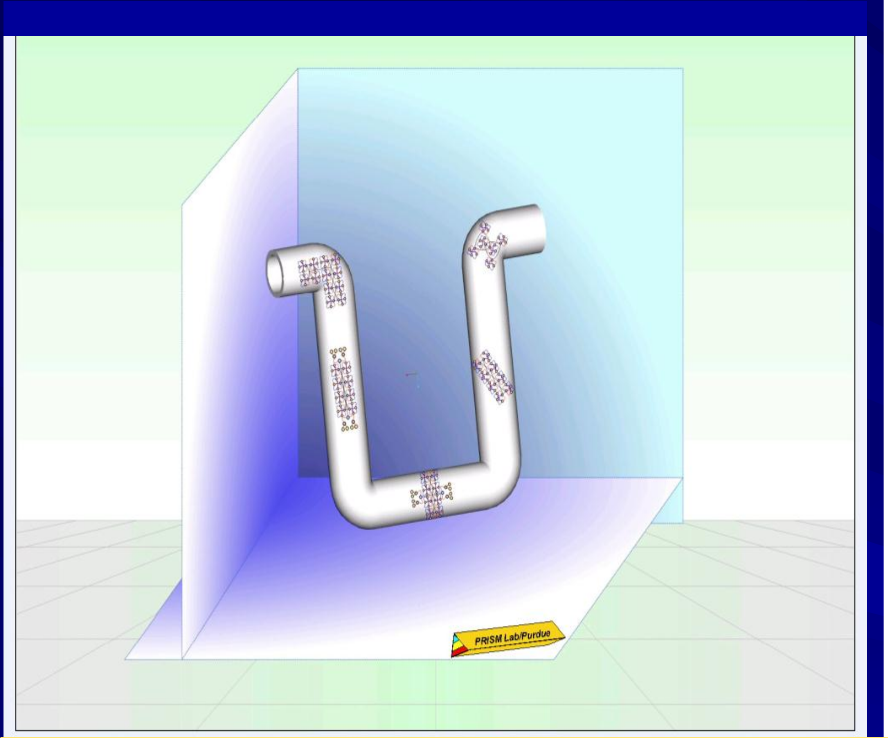
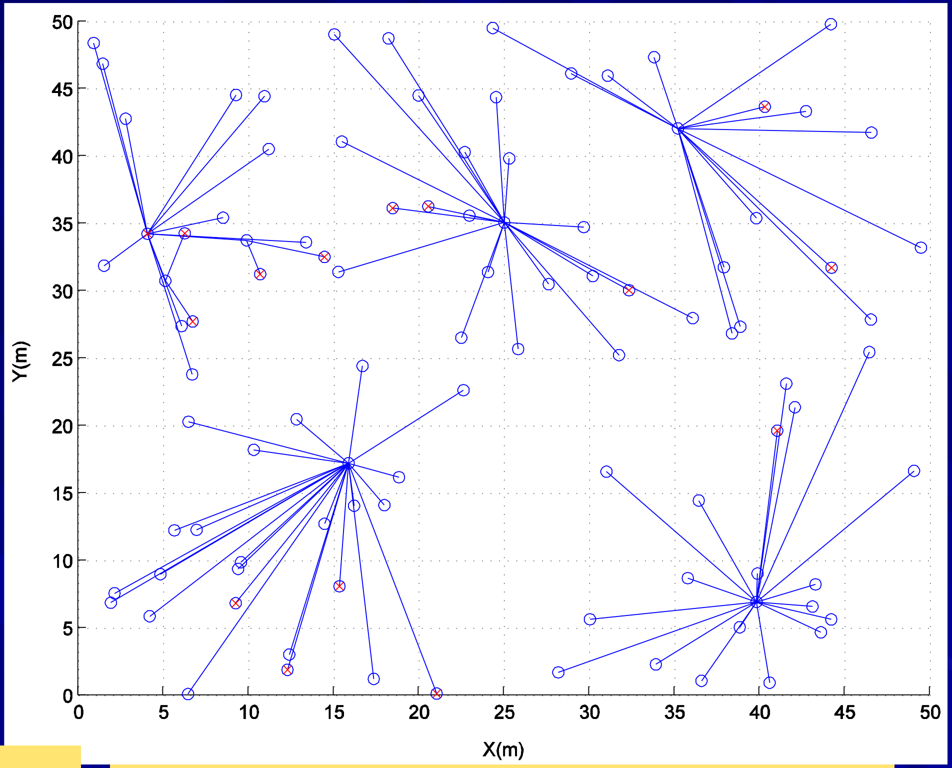
Collaborative fault-tolerance TAP design in sensor/agent networks



Principles 1-6 at work:
Alternative MEMS and nano sensor arrays / networks optimized along an artery for measurement and control



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

TAP: Task Administration Protocols for complex workflow

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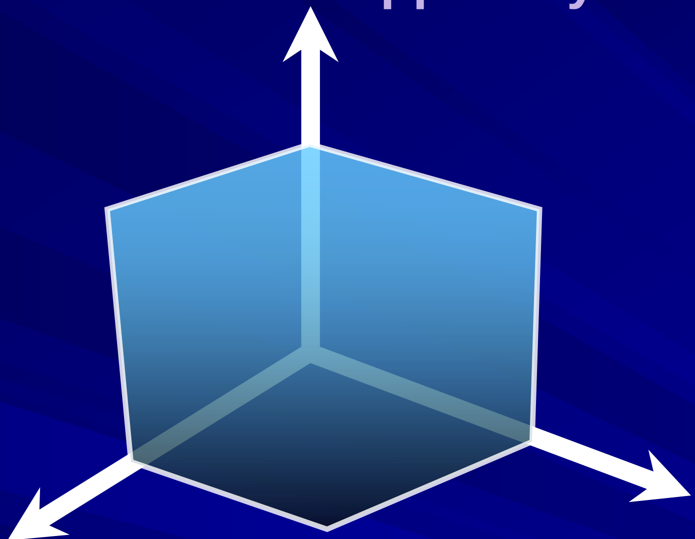
Summary, Emerging Trends, open challenges

1. CCT contributions continue and expand in networks of supply, knowledge supply, decision and policy making, healthcare delivery, cyber security, physical security, etc.
2. Modeling for CCT: Network theory; Network-aware models; bio-inspired models; swarm intelligence; game theory models (bargaining)
3. Collaborative Intelligence, CI
4. Collaborating with humanoids

Purdue IE Collaboratorium Initiative (2009 -)
for Collaborative Intelligence

Collaboration Science = Collaborative Control Theory + Collaboration Support Systems



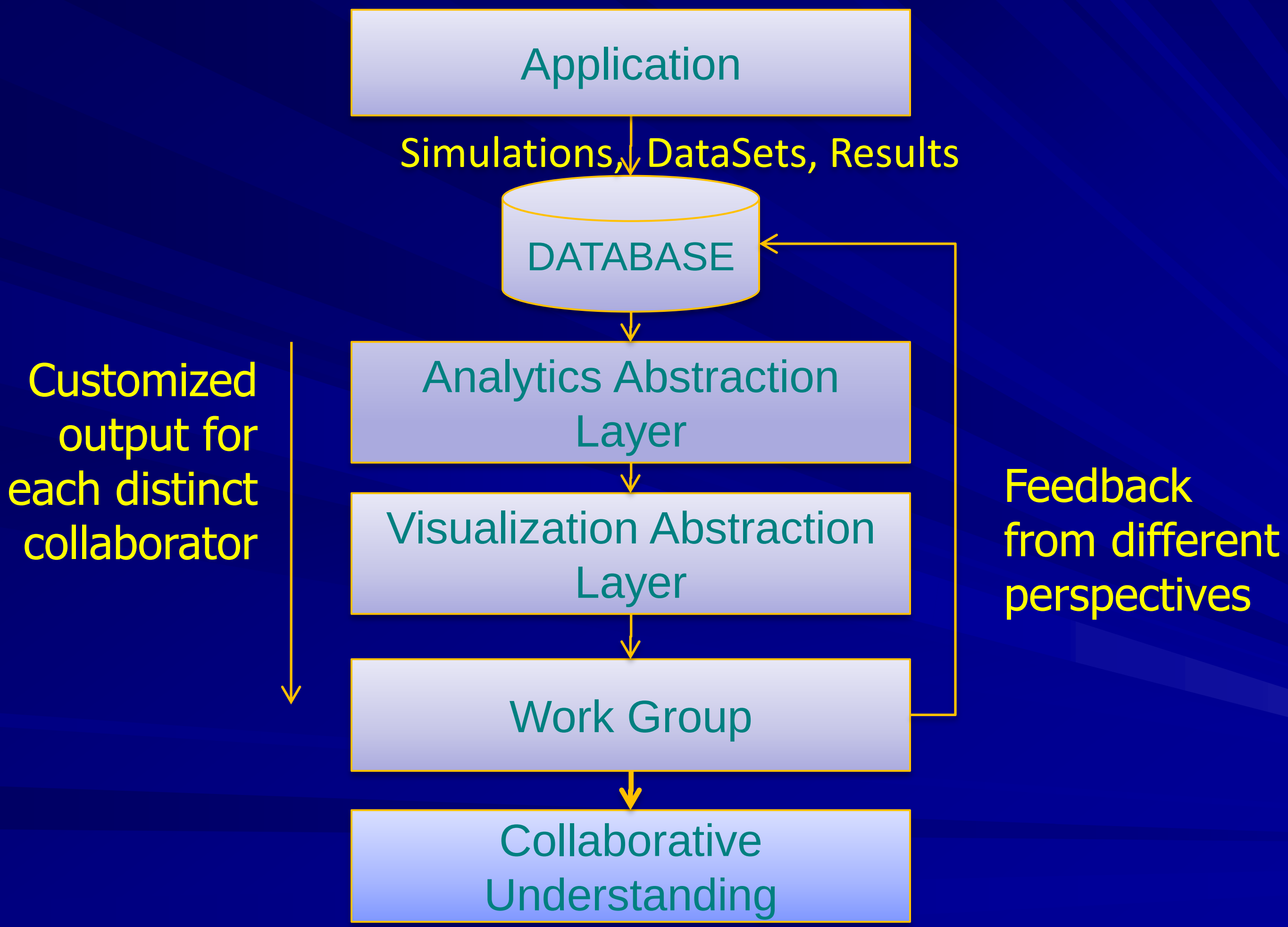
Access
+
Interaction Science
e.g., human visualization

HUBzero.org
Domain Knowledge
Contents and Tools

Collaboratorium quality impact: How well it facilitates

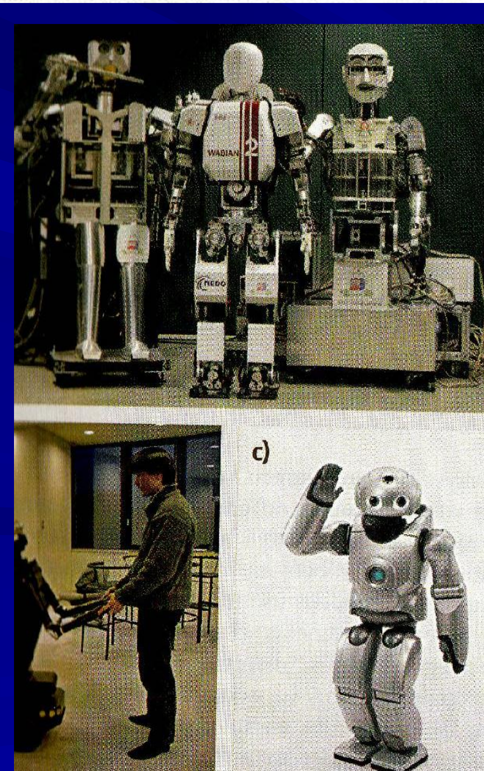
1. Significantly accelerated and better synthesis and integration of knowledge and discoveries;
2. Understanding the dynamics of interactive-collaborative work;
3. Timely delivery of critically needed discoveries and shared knowledge.

Abstraction Scheme for Collaborative Visualization
Co – Viz / Co-insight Approach (Ozsoy, 10)



Collaborating with Humanoids

Dancing with humanoids



Socially interactive humanoid robots

Springer Handbook of Robotics, 08

Acknowledgement

- Research reported in this plenary presentation has been developed at the PRISM Center with NSF, Indiana 21st Century fund for Science and Technology, and industry support.
- Special thanks to my colleagues, Visiting Scholars and students at the PRISM Lab and the PRISM Global Research Network, and in IFAC Committee CC5 for Manufacturing and Logistics Systems, who have collaborated with me to develop the collaborative control and robotics knowledge.