Holonic Intelligence:
A Paradigm Shift

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April 10, 2010

Outline

Background

- Motivation for distributed intelligence
- Comparison with centralized intelligence
- How to achieve distributed intelligence

Technologies

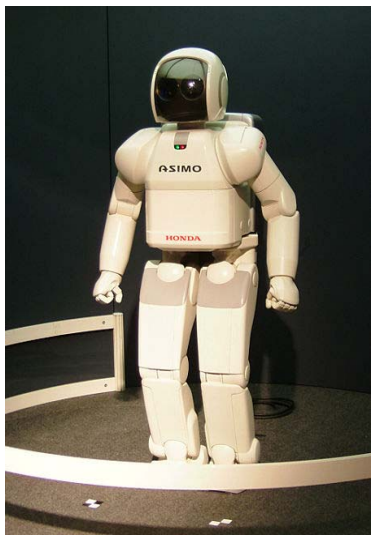
- Multi-agent and holonic systems
- Cooperation, collaboration, coordination
- Holonic intelligence system architecture
- Holonic intelligence network

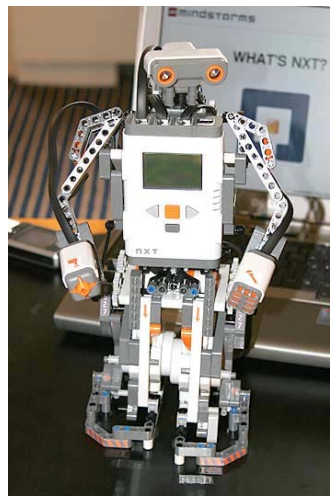
Applications

- Manufacturing automation, decision support
- Energy management, smart grid
- Smart home, digital services

Why is a paradigm change needed?

- Autonomous systems and robotic technologies are becoming pervasive
- Unmanned system capabilities are present in many space and combat systems
- Service robots are being developed for widespread use and varied applications





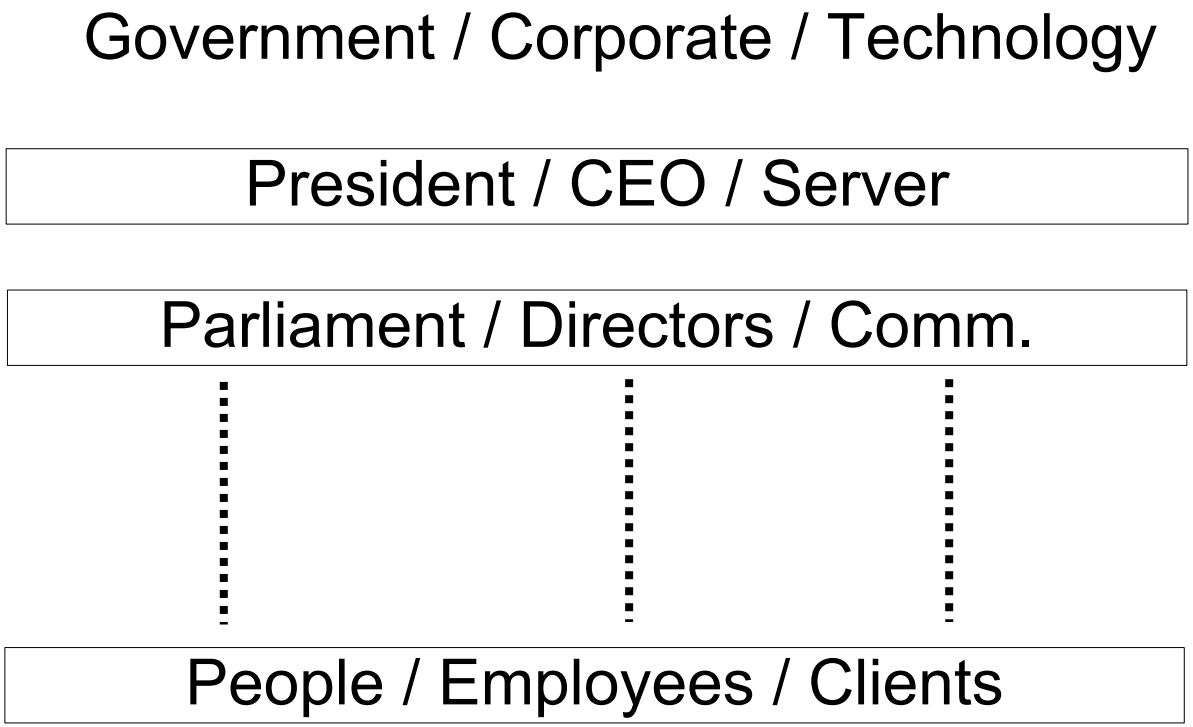
Why is a paradigm change needed?

- System of Systems (SoS)
- Availability of feature rich sensors, actuators, and controllers
- Increasing trend to network appliances and combine their controls and key functions

Distributed Intelligence in Nature

- Each ant has simple intelligence
  - distributed intelligence
- Communicates with other ants
  - distributed communications
- Uses pheromones to communicate
- Key decisions
  - food found, follow food found pheromone
  - food not found, find food elsewhere
  - return to colony

Centralized systems are everywhere …



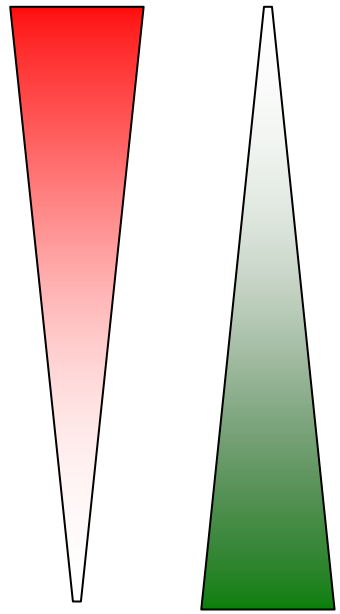
Control / Knowledge Imbalance

Government / Corporate / Technology

President / CEO / Server

Parliament / Directors / Comm.

People / Employees / Clients



Contradictory Nature of Technology

Internet:

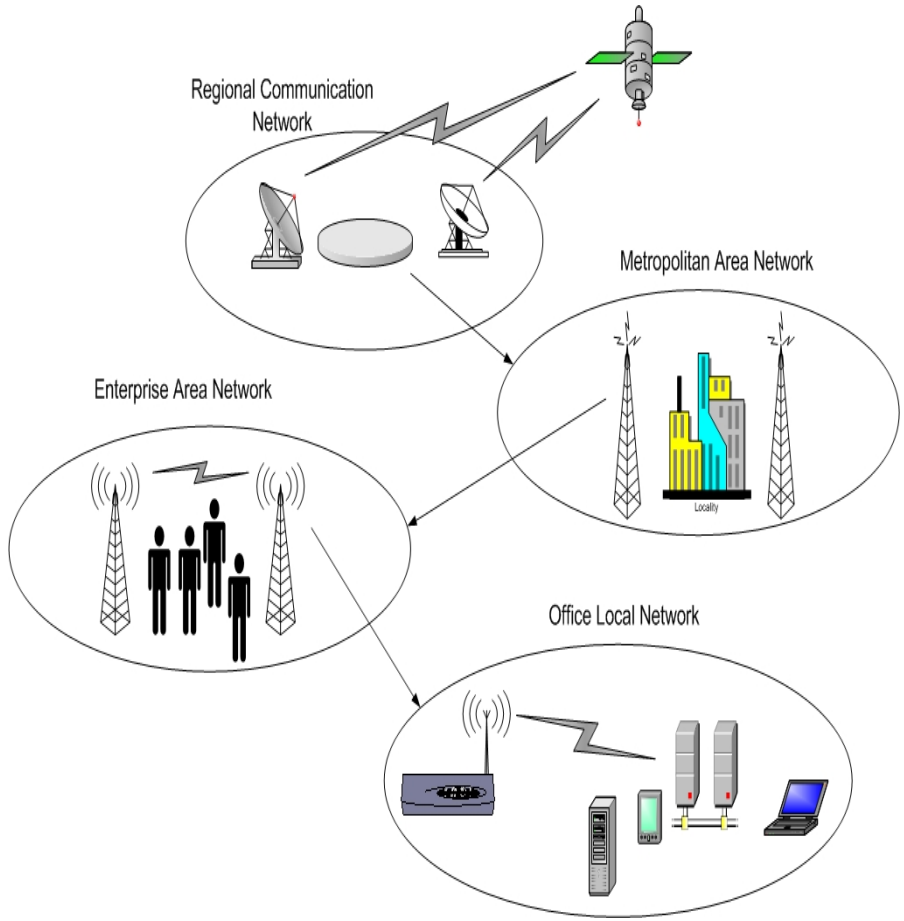
Designed for peer-to-peer communications but the Web has a client/server architecture

Wireless Communications:

Hierarchical infrastructure, but increasing demand for peer-to-peer applications

Information Systems:

Data, knowledge, information are concentrated but activities are distributed

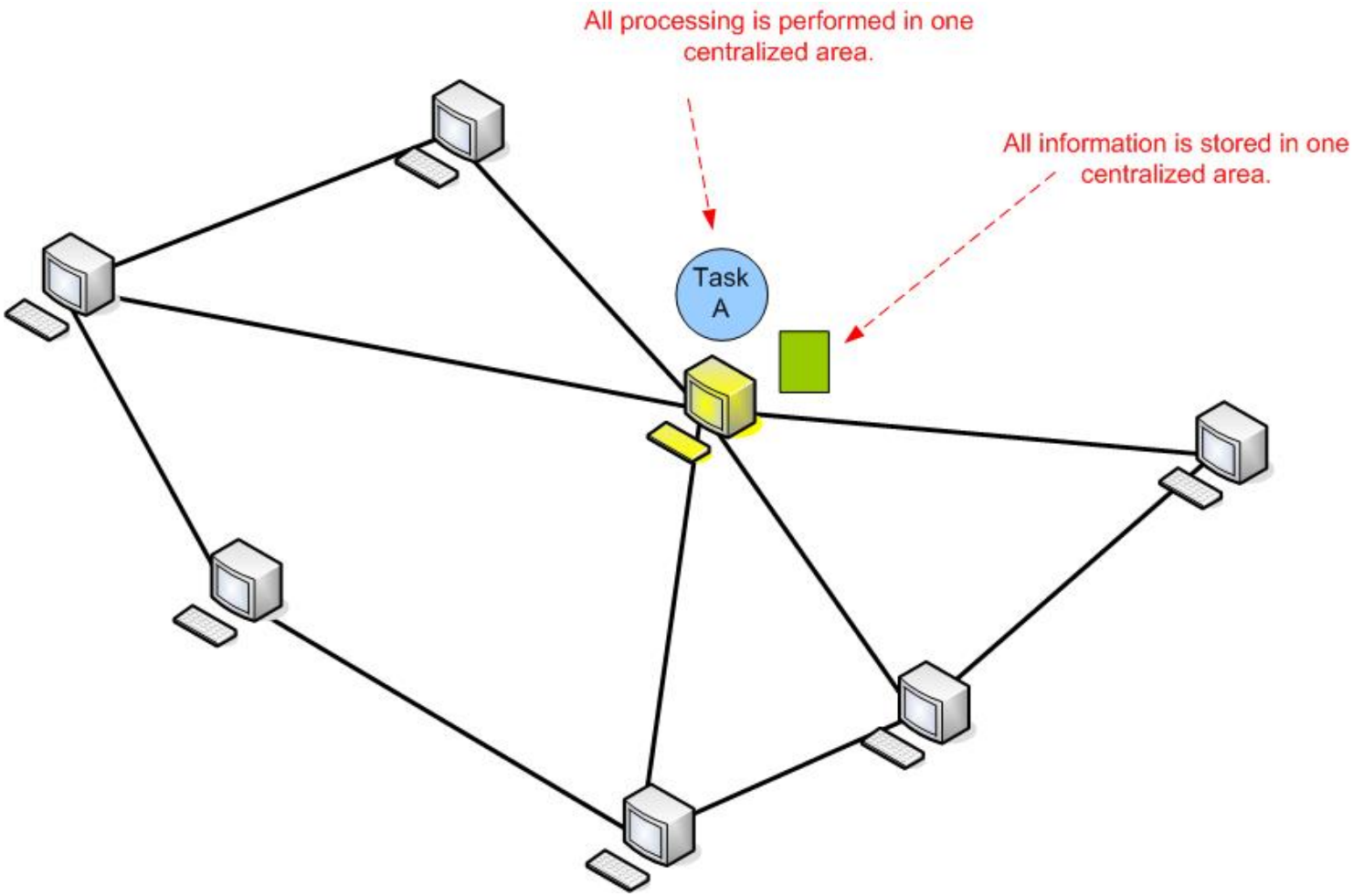


Hierarchical Organizational Model

"The work of every workman is fully planned out by the management at least one day in advance, and each man receives in most cases complete written instructions, describing in detail the task which he is to accomplish, as well as the means to be used in doing the work. … This task specifies not only what is to be done, but how it is to be done and the exact time allowed for doing it. … Scientific management consists very largely in preparing for and carrying out these tasks."

Frederick Taylor, *Principles of Scientific Management*, 1911

Centralized Systems



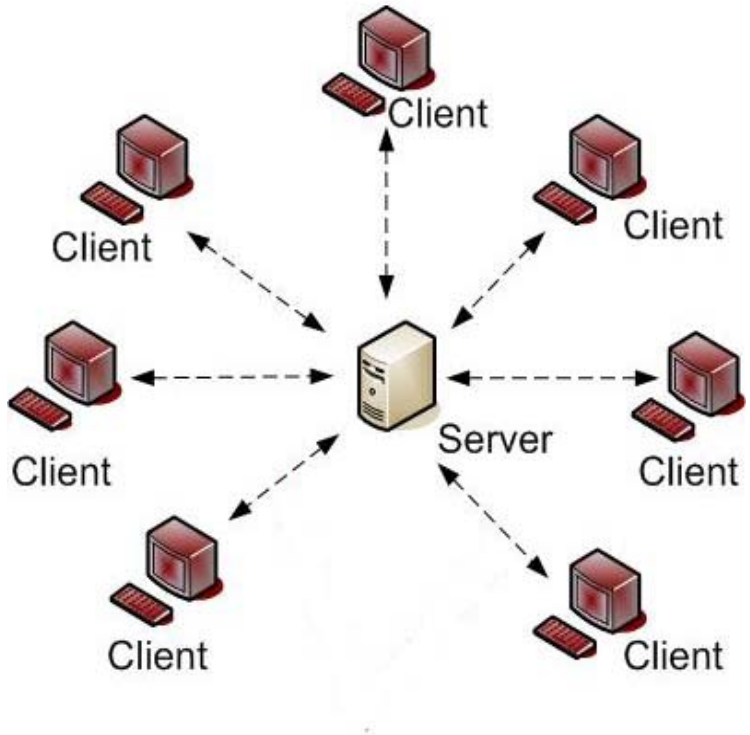
Disadvantages of Centralized Systems

Scalability
- Servers have finite storage and finite processing

Robustness
- Servers may not be able to respond to clients

Security
- Additional security needed to prevent unauthorized access

Communications
- Limited communication paths

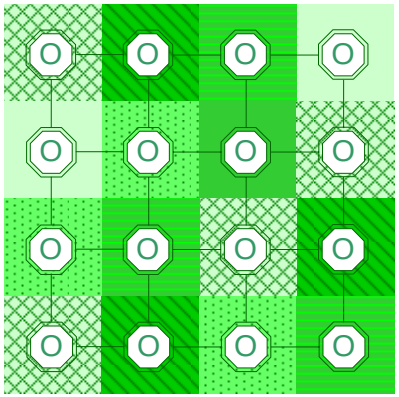


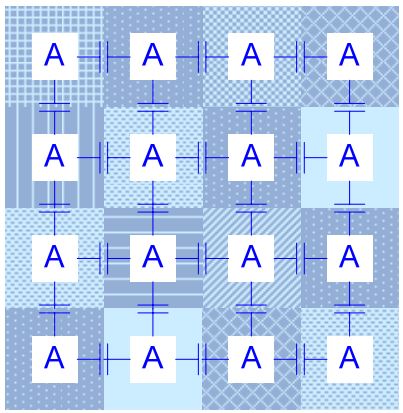
Distributed System

- each node contains a unique subset of the system information
- each node processes a unique subset of the system tasks

But where are we today?

OSI was designed for *point-to-point* connections in client/server applications.





RPC

Pipes

CORBA

Sockets

DCOM

RMI

.NET

FIPA ACL

ICM

April

KQML

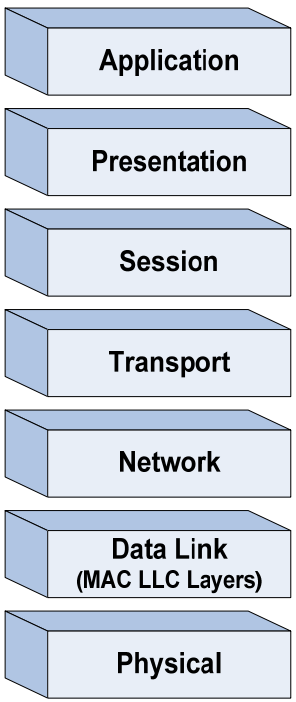
Object-Oriented Messaging

Agent Messaging

Solutions have been developed for many different kinds of system architectures, further complicating the development of distributed systems.

There are many environments for developing distributed systems, but they often complicate the problem instead of simplifying it.

OSI Model



HTTP, SMTP, SNMP, FTP, Telnet, SSH, Scp, NFS, RTSP

XDR, ASN.1, SMB, AFP

TLS, SSH, ISO 8327 / CCITT X.225, RPC, NetBIOS, ASP

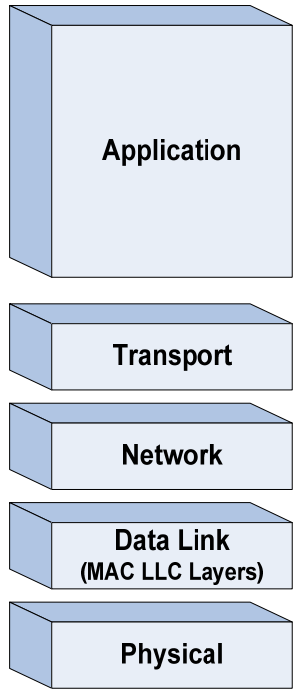
TCP, UDP, RTP, SCTP, SPX, ATP

IP, ICMP, IGMP, X.25, CLNP, ARP, RARP, BGP, OSPF, RIP, IPX, DDP

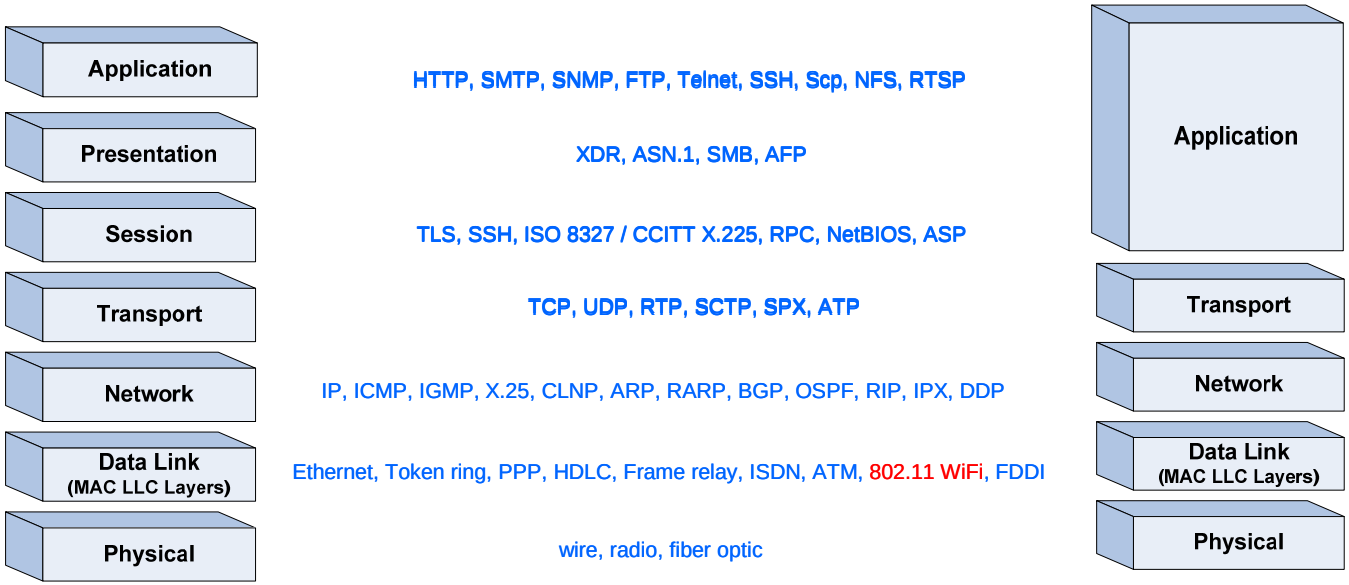
Ethernet, Token ring, PPP, HDLC, Frame relay, ISDN, ATM, 802.11 WiFi, FDDI

wire, radio, fiber optic

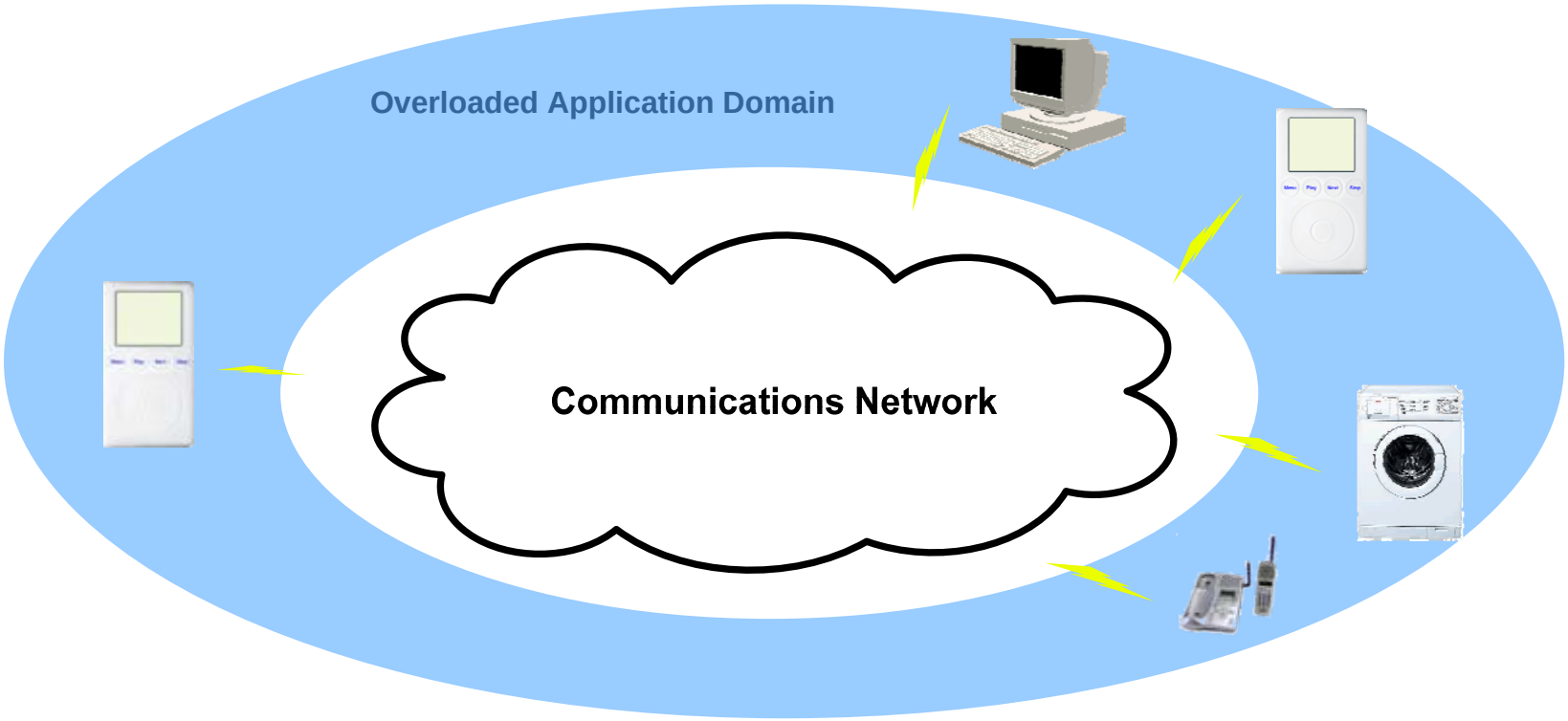
TCP/IP Model



Furthermore, there are too many protocols …

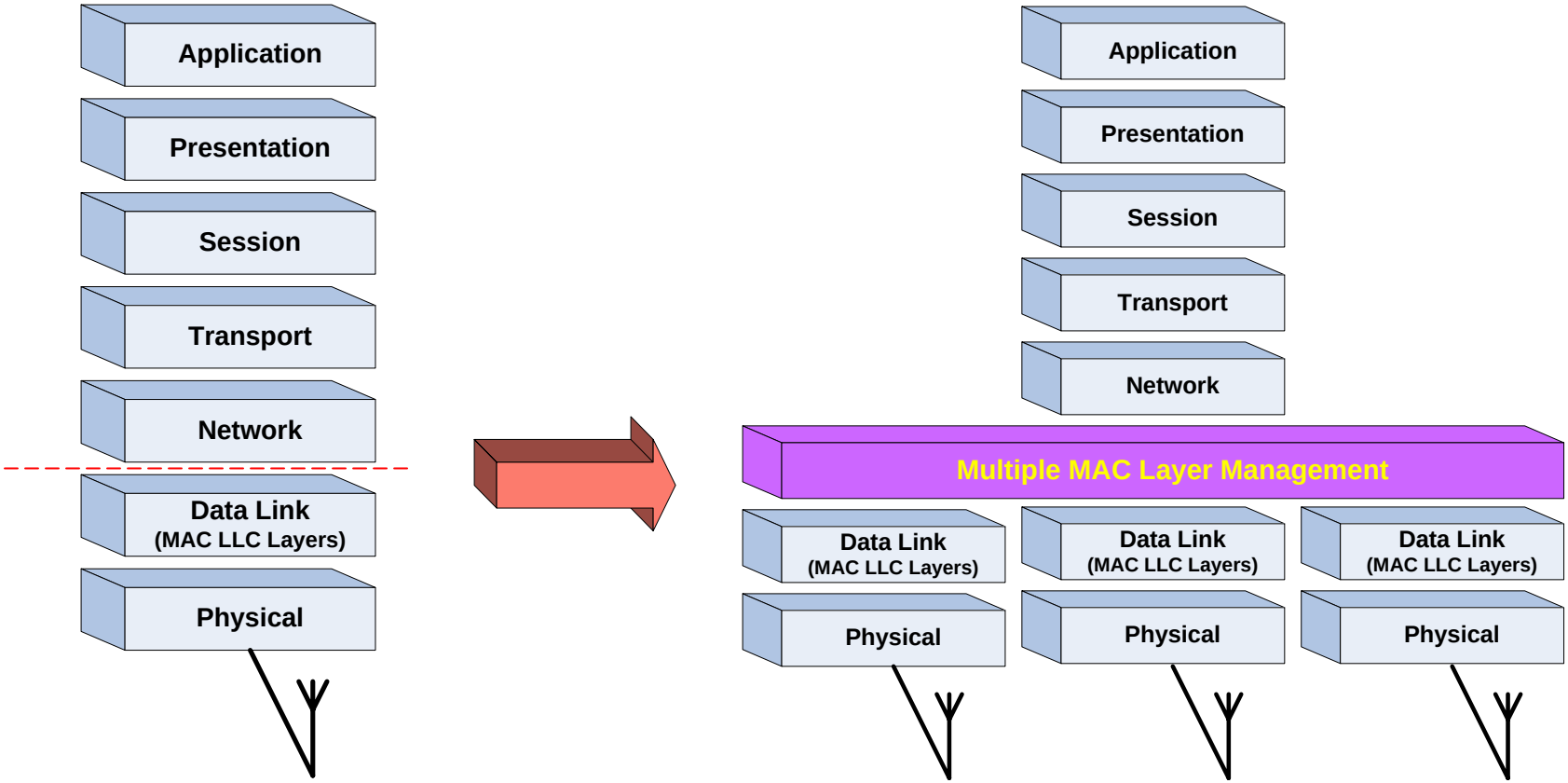


… that require more programming at the application level

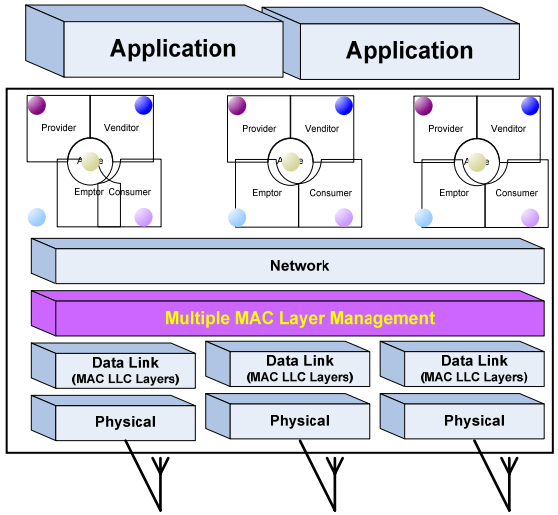


Because of limited intelligence in the lower layers of the OSI model, higher layers are needed to perform networking functions.

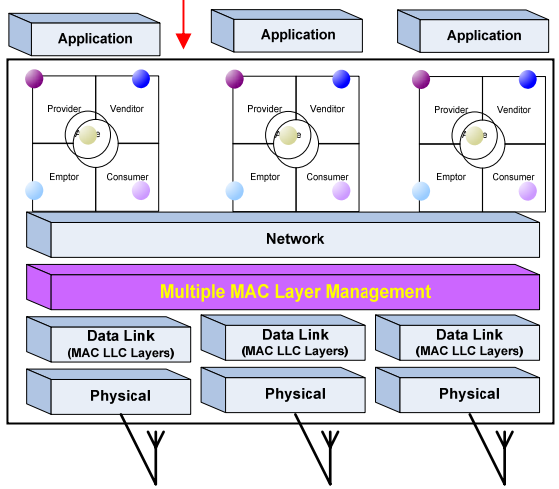
What’s the solution?

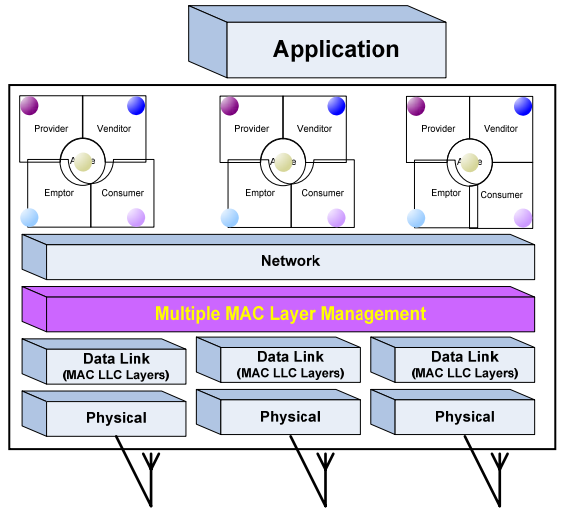


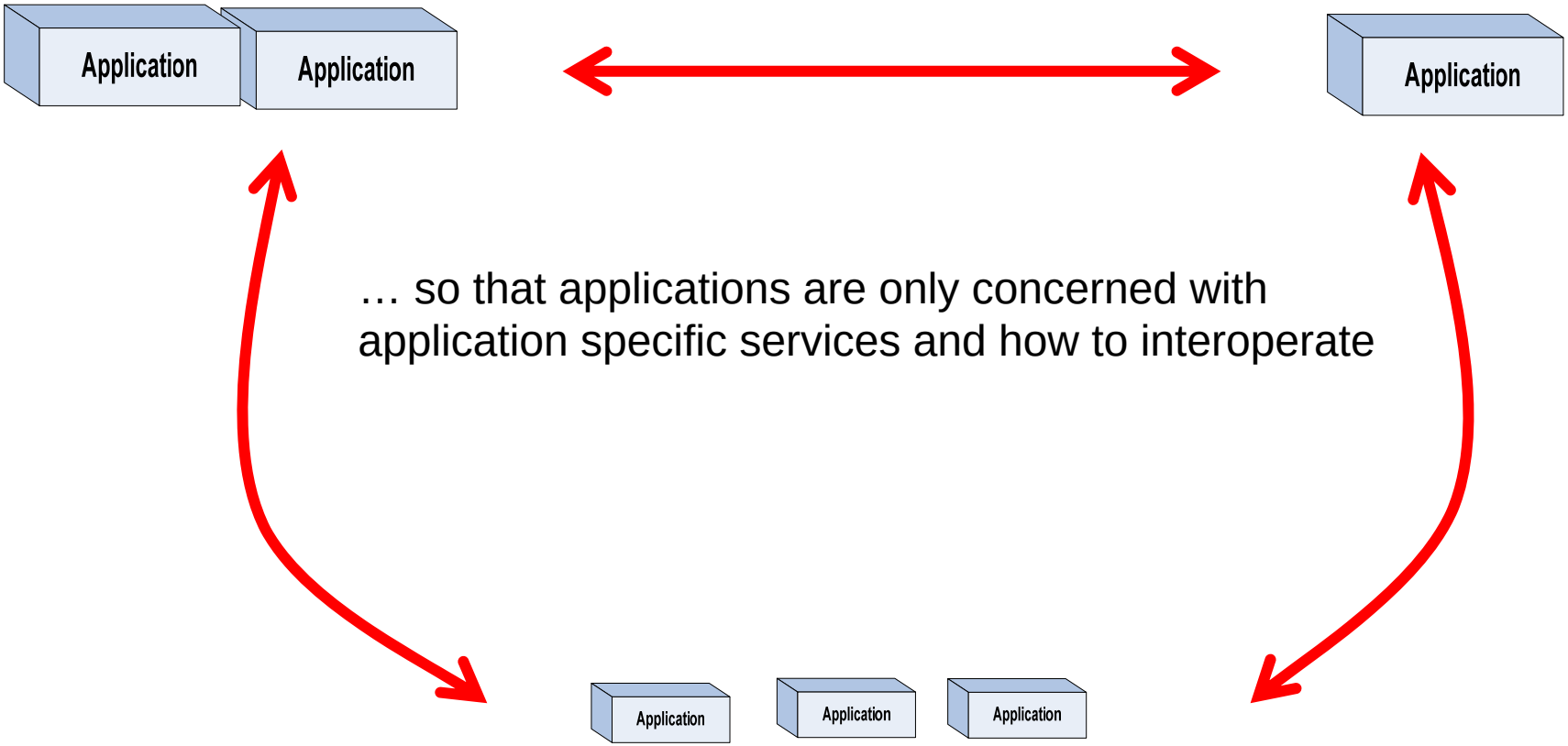
First, we need *multiple simultaneous connections* and *multi-hop* services



Next, we need *intelligent multi-agent systems* that can handle network services






Application
Application
Application
… so that applications are only concerned with application specific services and how to interoperate
Application
Application
Application

What technologies are needed to do this?

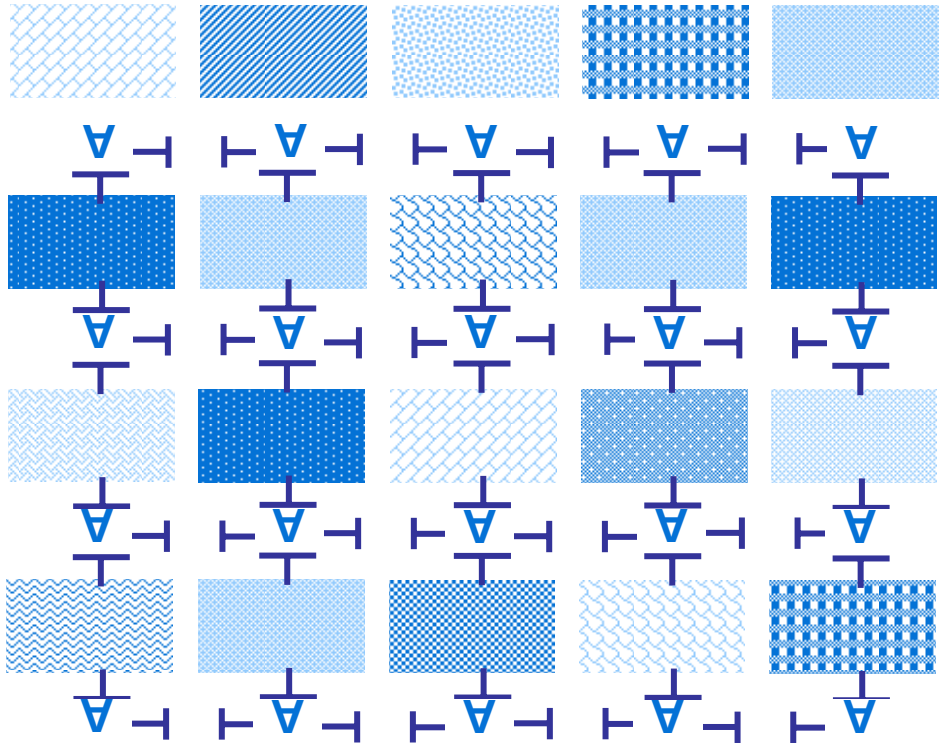
Local Intelligence

…the physics of emerging technology didn't work …[using centralized information systems] … so it is far more effective to put whatever computing power is required where the data are located. Efficiency considerations thus favor the distribution of technology, rather than the concentration of technology. The economics of information technology are the reverse of those of mechanical technology.

C. A. Mead
California Institute of Technology

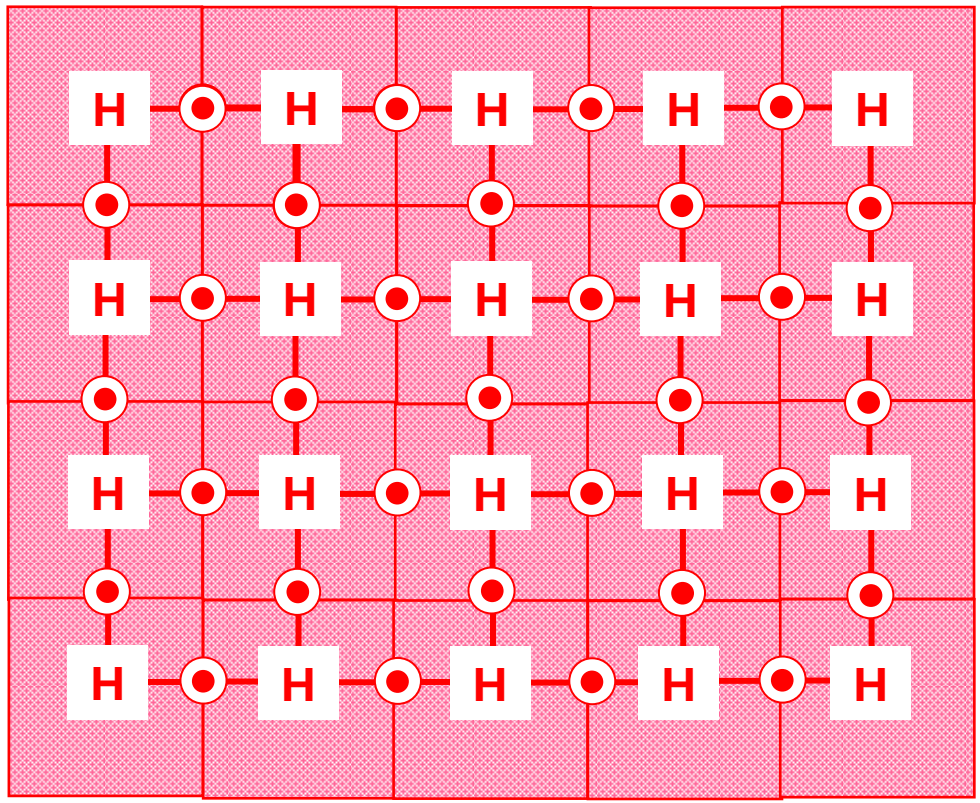
Multi-Agent System

- *Agent*: an autonomous entity
- Attempts to satisfy its local objectives with independent actions
- Can be functionally independent of other agents
- May be competitive
- Usually implemented in software



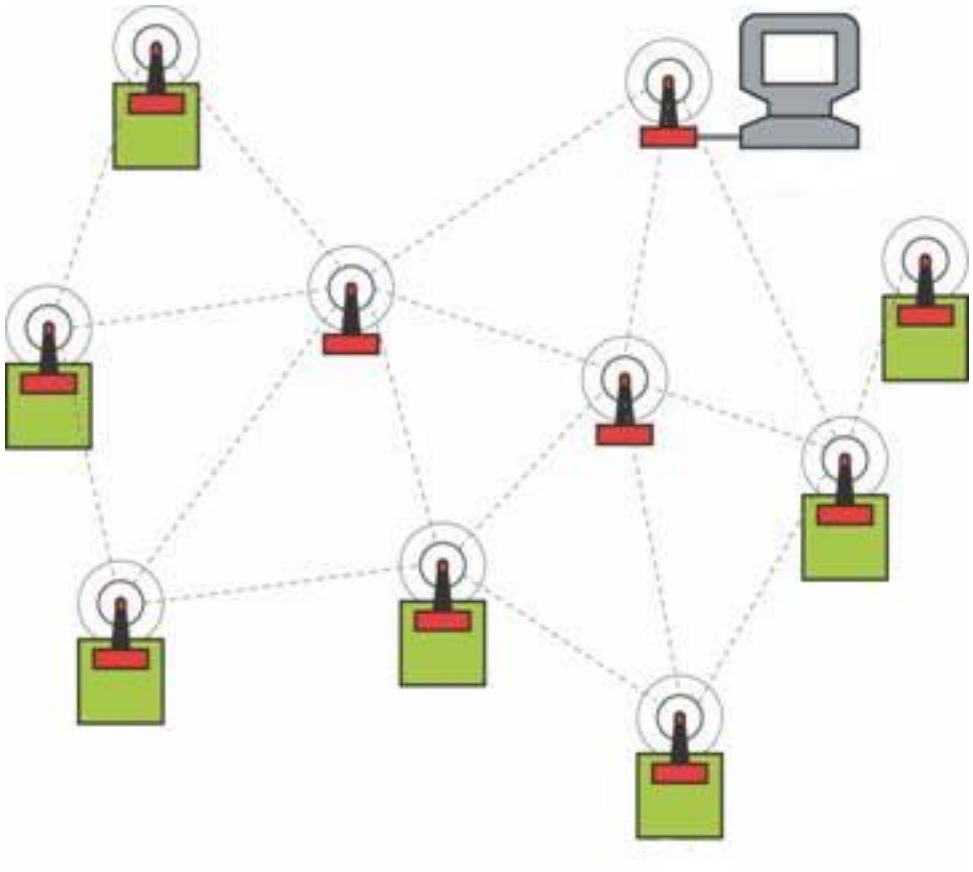
Holonic System

- *Holon*: self-contained element capable of functioning autonomously in a cooperative environment
- Enables collaboration among local tasks to achieve a global objective
- Consists of an information processing part and often a physical processing part
- Can form part of other holons ("whole-part" relationship)



Arthur Koestler, *The Ghost in the Machine*, Arkana Books,1967

Communication



for peer-to-peer networks

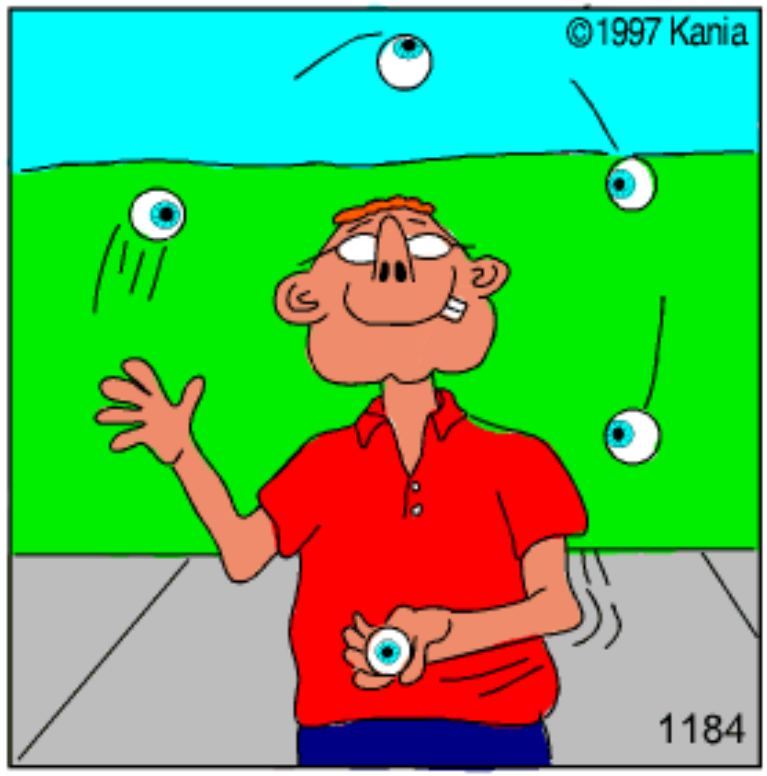
Cooperation

with different objectives …

Collaboration

with a global objective …

Coordination



… based on negotiation protocols

Holonic Technology Platform

Processor

– Processes information gathered by sensors (RFID, cameras, biometrics, motion)

Memory

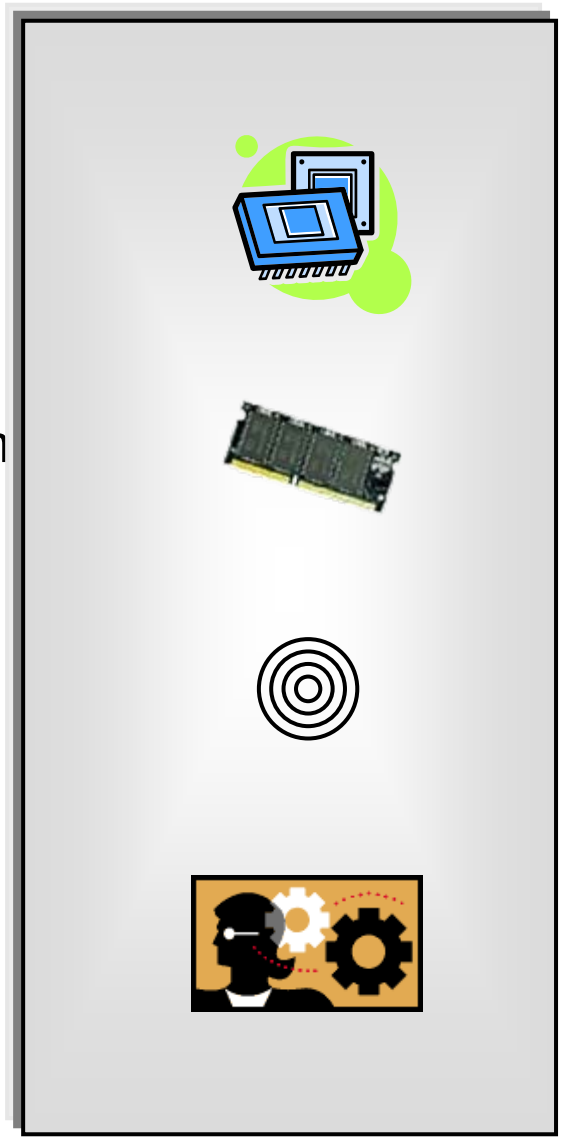
– Stores information, applications, and system software at each node

Transceiver

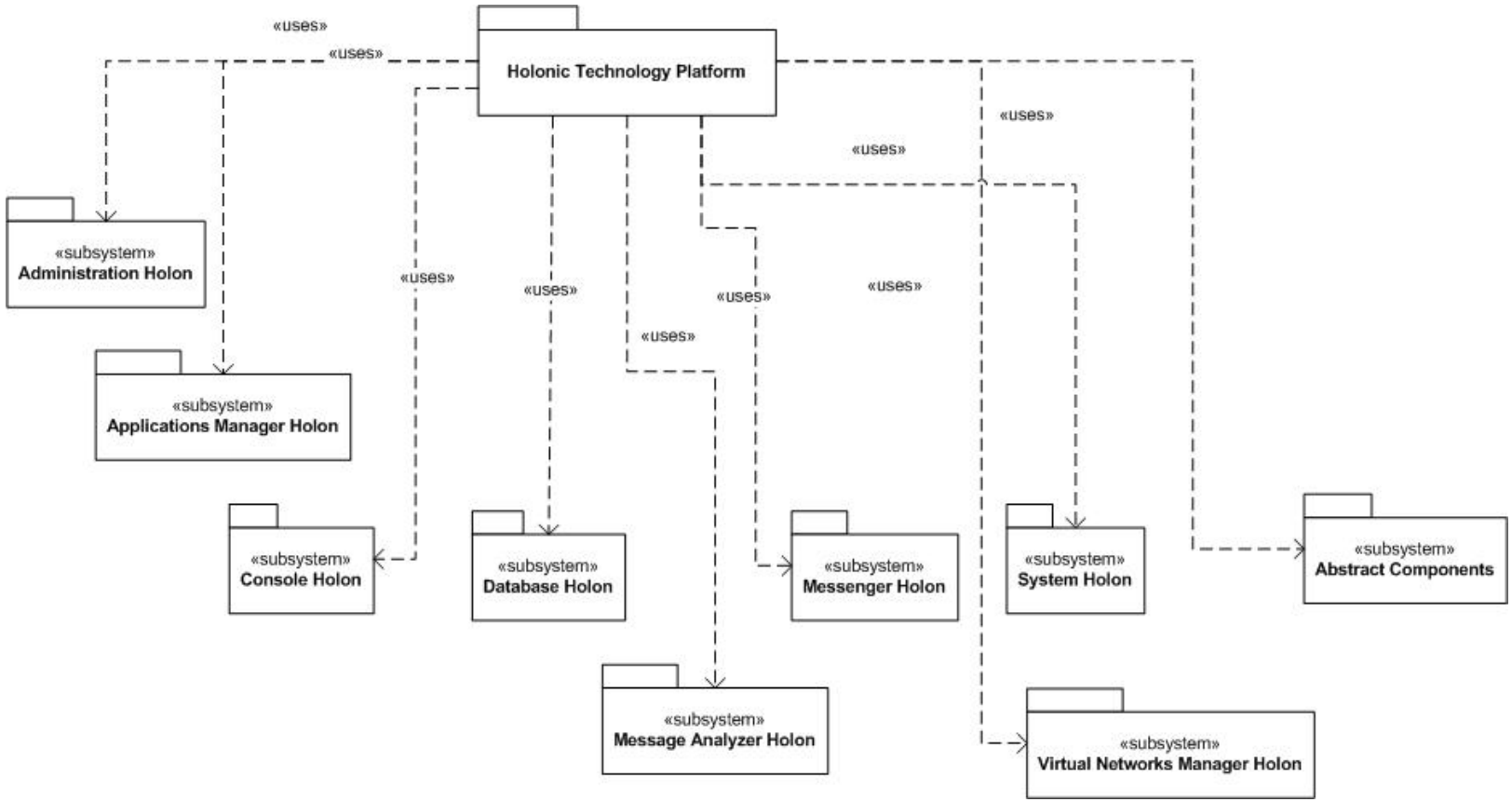
– Establishes wireless communications with other nodes

Systems Software

– Intelligent routing of data
– Local decision support
– Distributed processing



System Architecture



C. Ng, Z. Alibhai, D. Sabaz, O. Uncu, and W. A. Gruver, "Framework for developing distributed systems in a peer-to-peer environment," *Proc. of the IEEE International Conference on Systems, Man, and Cybernetics*, Taipei, Taiwan, October 2006

System Software

- User applications developed in an agent framework
- System services developed in a holonic framework
- Implemented in Java running under Ubuntu Linux O/S
- Uses UDP/IP to provide a message based infrastructure for devices to interconnect
- Services include send and receive messages, event-to-event triggering, virtual network topologies, yellow-pages, remote agent/holon monitoring and configuration.
- Holons facilitate system objectives including communication routing, where agents should reside for service delivery, and system security.

Prototype Hardware: 2nd Generation

Processors: Intel PXA270 (640 MHz)
Cirrus ARM920T(200 Mhz)

FPGA: Altera 8256 LUT Cyclone II

Memory: 512Mb SDRAM, 1Gb NOR,
512Mb NAND flash (customizable)

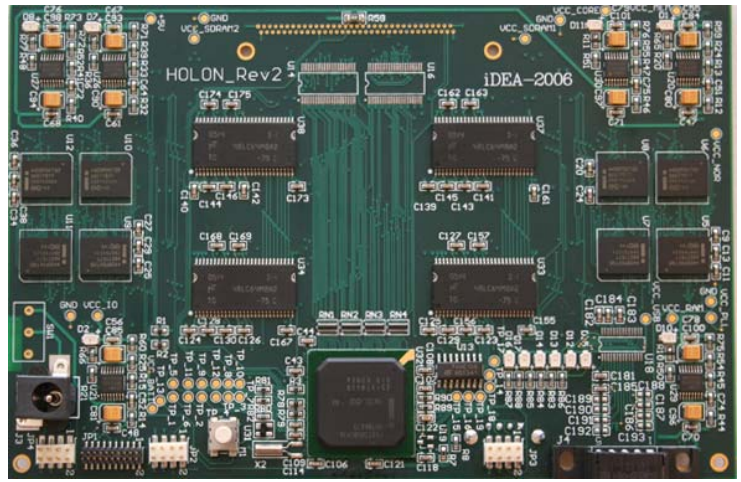
Wireless Transceiver: IEEE 802.11b/g
2.402 - 2.497 GHz, 3 antennas,
100-300 meter range

External Interfaces: USB 2.0, RS232, VGA

Operating System: Debian Linux

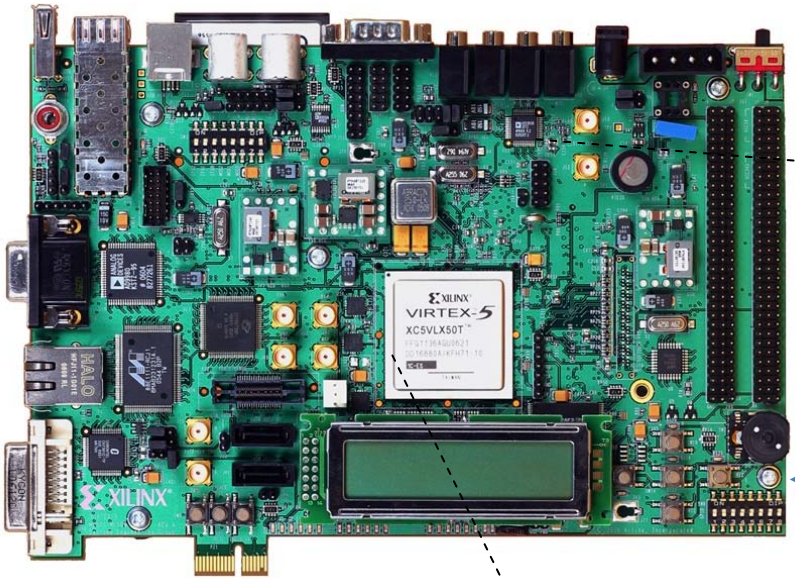
Power Requirements: 5 VDC @ 1.4 A

Dimensions: 8" x 6" x 2“



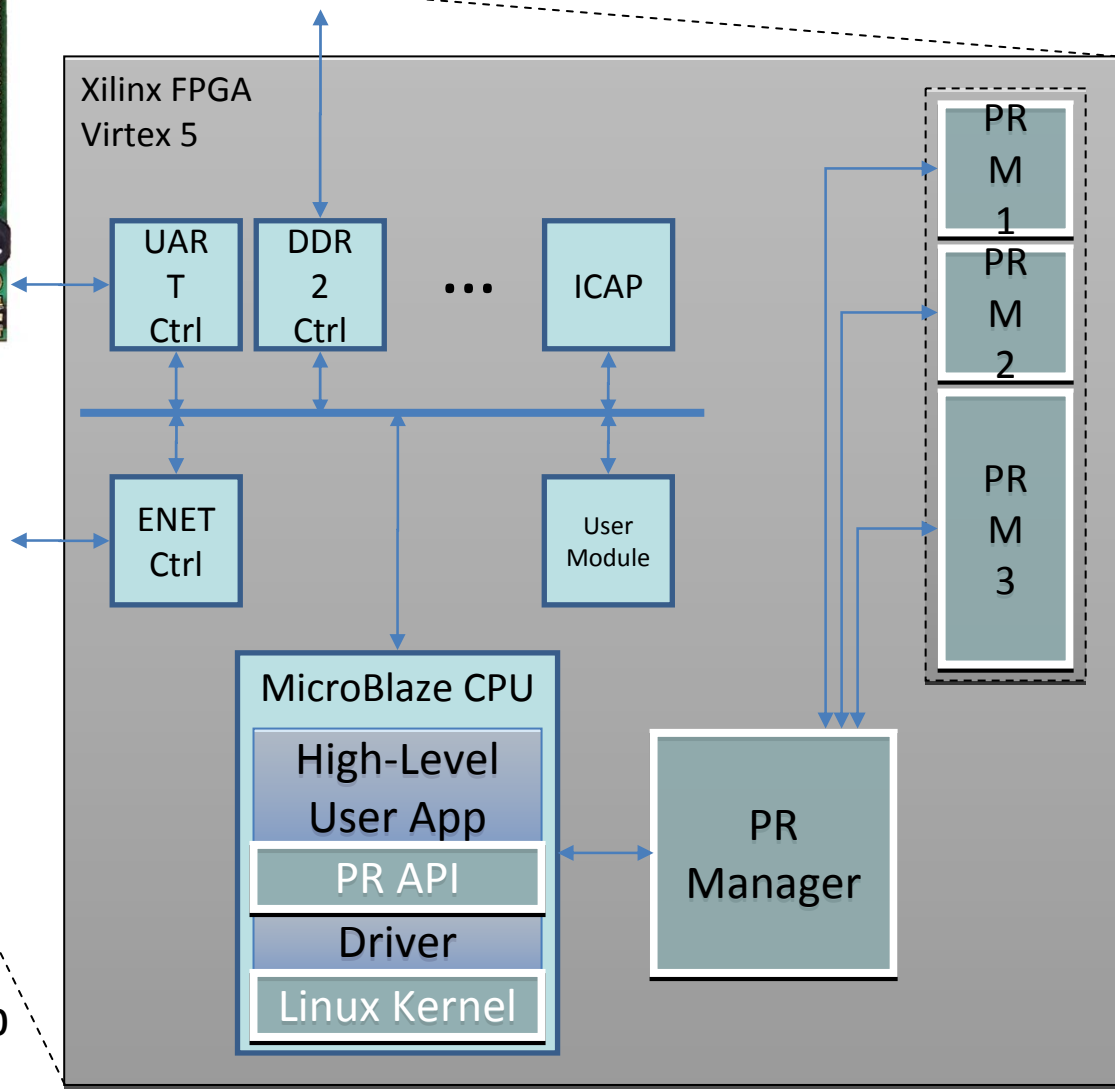
S. Ovcharenko, Z. Alibhai, C. Ng, W. A. Gruver, and D. Sabaz, “Implementation of a wireless distributed intelligent system,” *Proc. of the 2006 IEEE International Workshop on Intelligent Distributed Systems*, Prague, Czech Republic, June 2006

Prototype System: 3rd Generation



- High-level software controls partially reconfigurable user modules via API
- Linux kernel
- Xilinx Virtex 5 Dev board, MicroBlaze Soft Processor

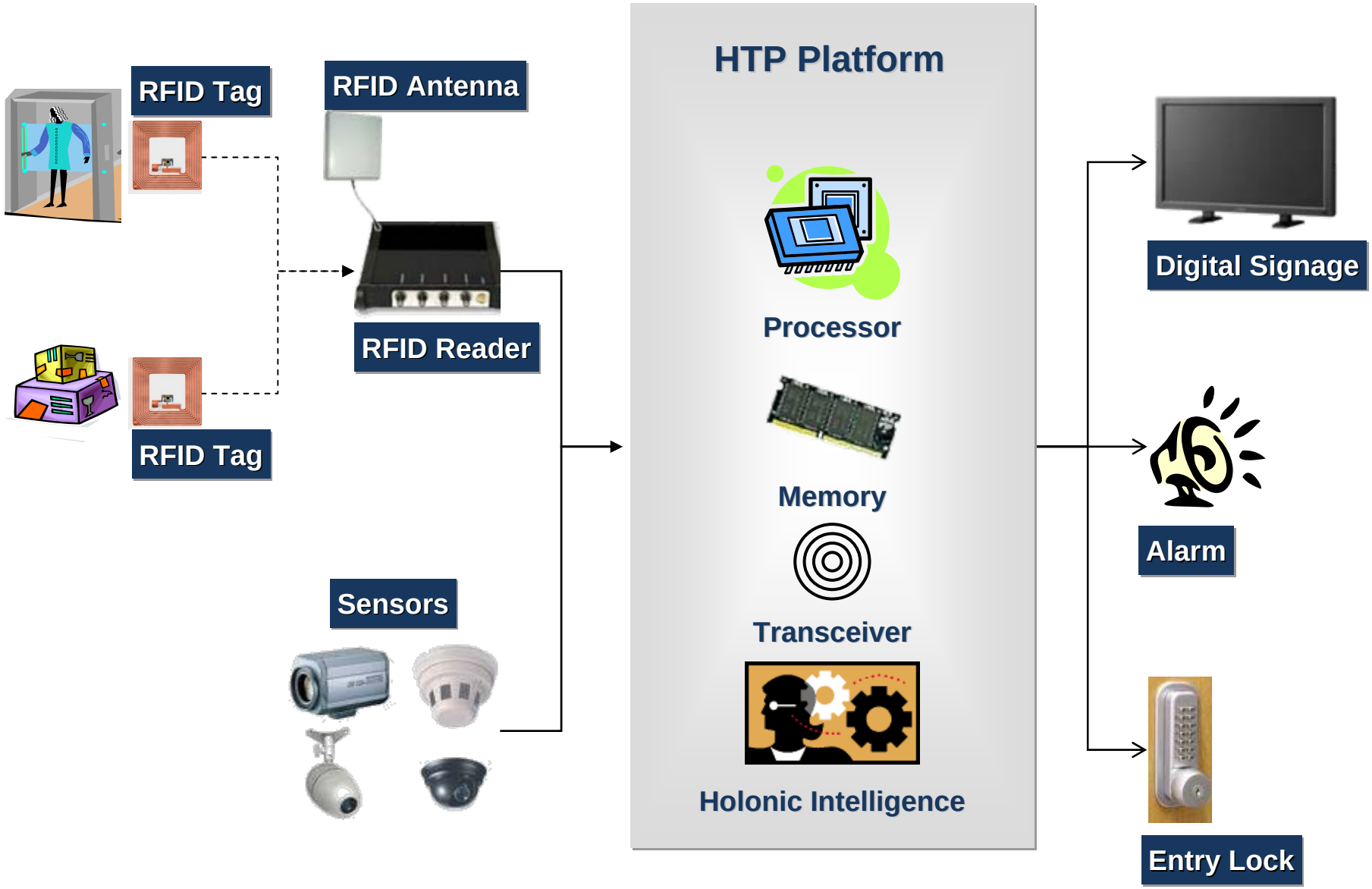
Edward Chen and Victor Gusev, PhD/MASc students in iDEA Lab



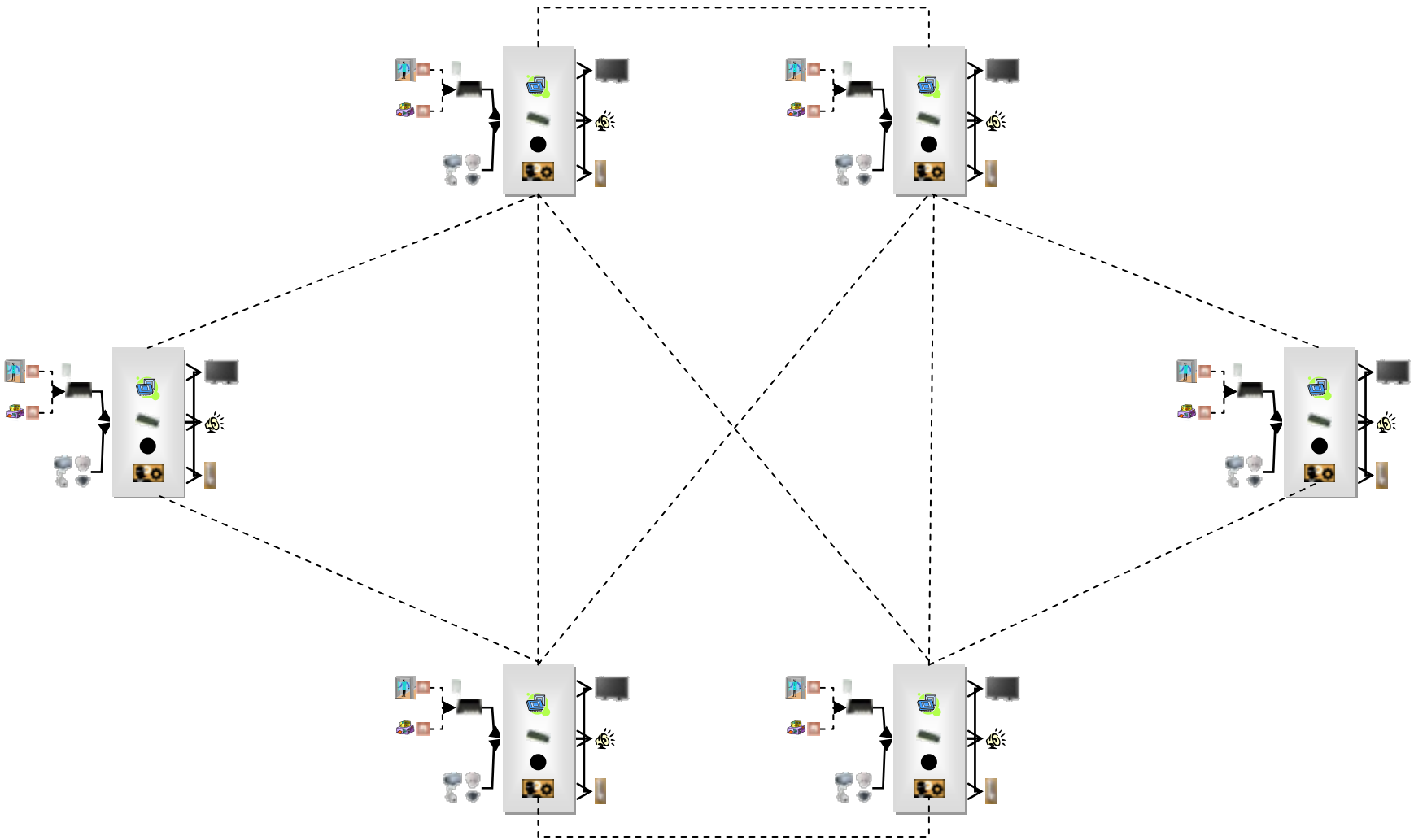
Dynamic Partial Reconfiguration

- Partially reconfigurable FPGA enables dynamic reconfiguration without shut down
- High-level PR hardware abstraction allows easier management from user space
- Linux provides standard facilities for networking, device management, etc.
- Reduces product cost
- Reduces footprint
- Reduces power consumption
- Increase performance
- Faster configuration time

Holonic Intelligence Node



Holonic Intelligence Network



HMS Project (1995-2004)

5 Regions

- Australia, Canada, European Union, Japan, USA

40 Organizations

Industry

- Intelligent Robotics, DaimlerChrysler, Fanuc, GM Holden, Hitachi, Rockwell Automation, Toshiba, Yaskawa Electric, BHP Billiton, ANAYAK, ATOS, ATS Spartec, Blastman Robotics, Okuma, Softing

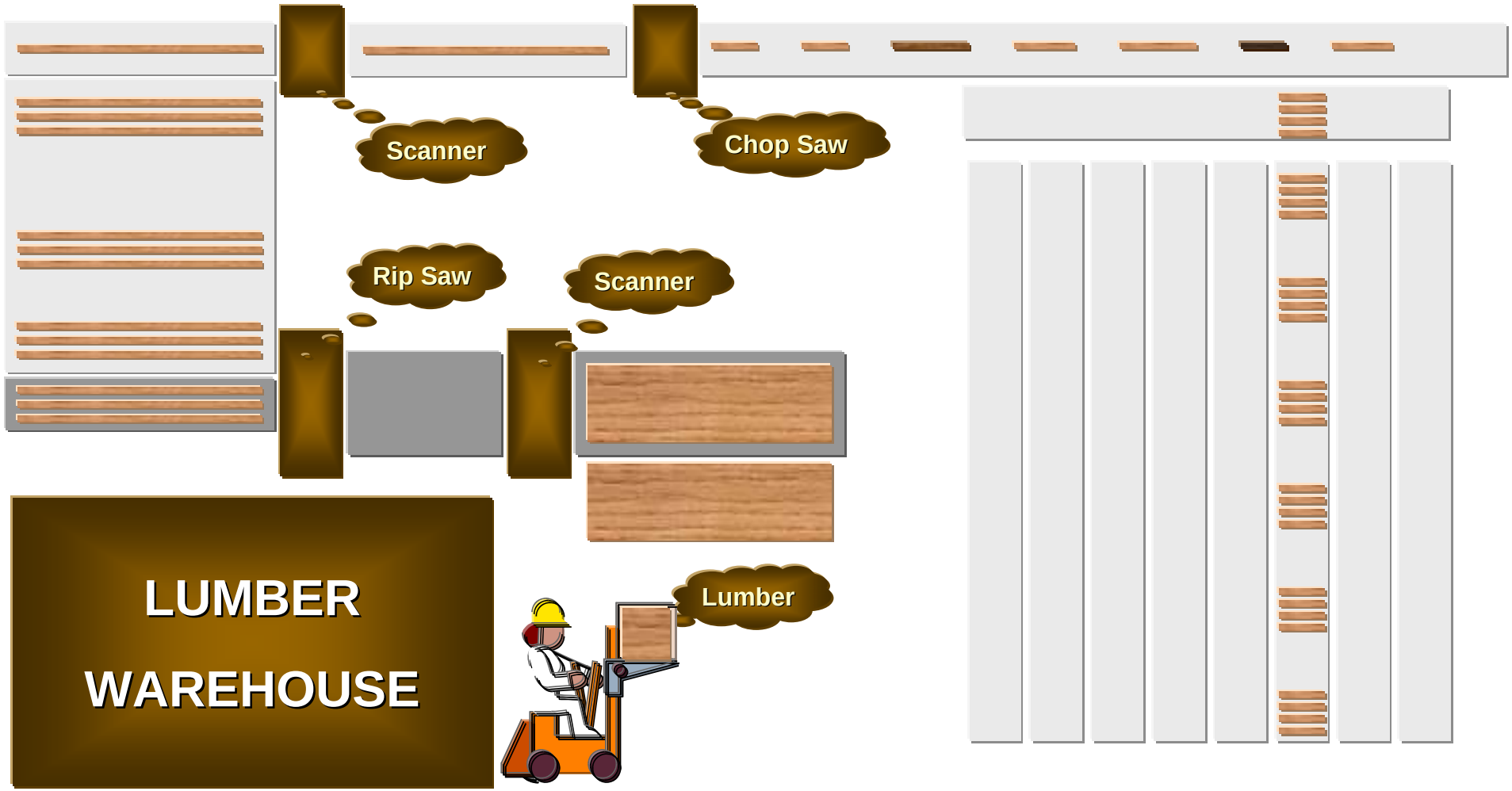
R&D Labs

- Fraunhofer IPA, NRC Canada, CSIRO, Profactor, Tekniker, VTT

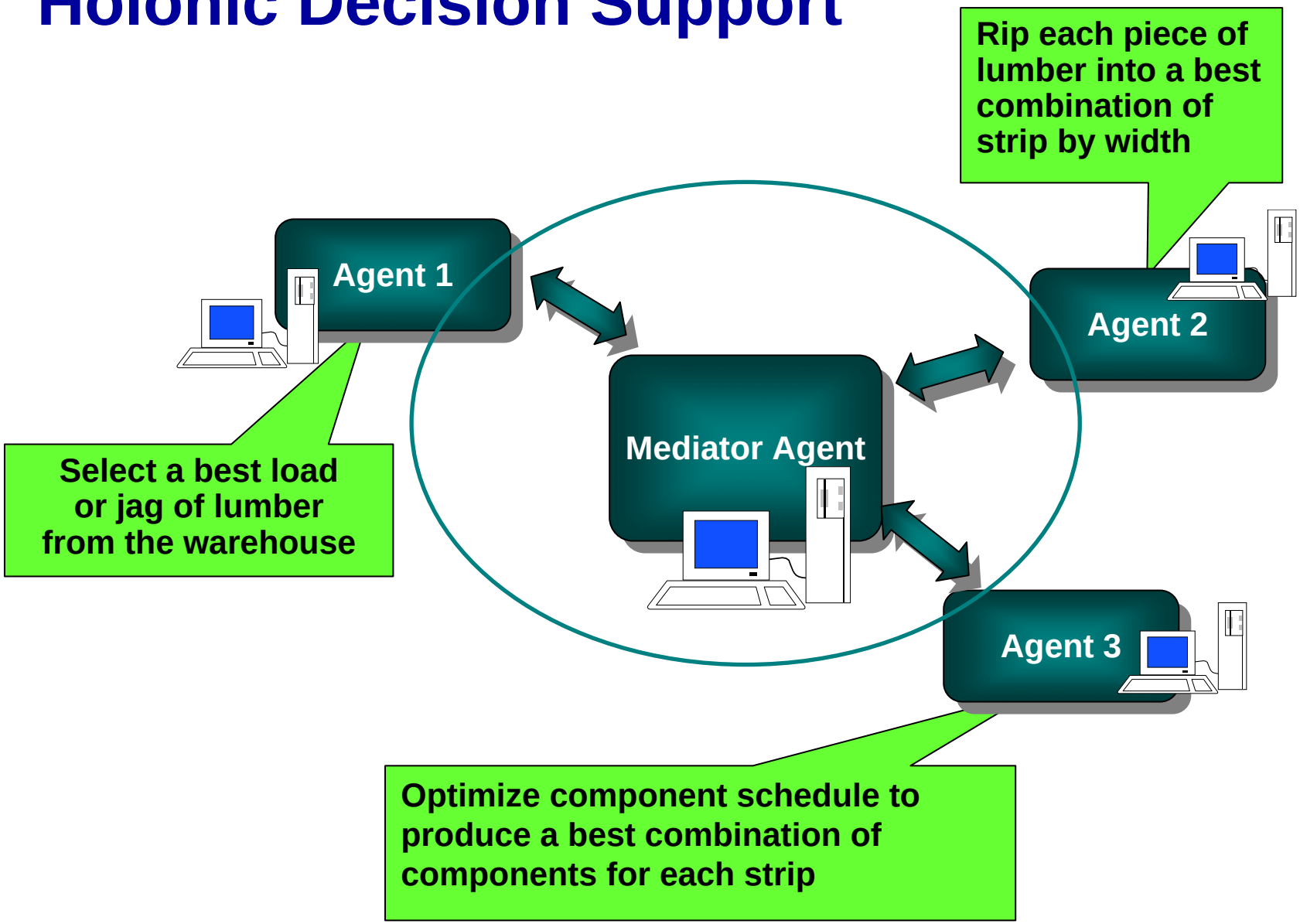
Universities

- Calgary, Connecticut, Hannover, Kagawa, Keele, Keio, Kobe, KU Leuven, Osaka Pref., Simon Fraser, Tokyo, Tsukuba, Vanderbilt

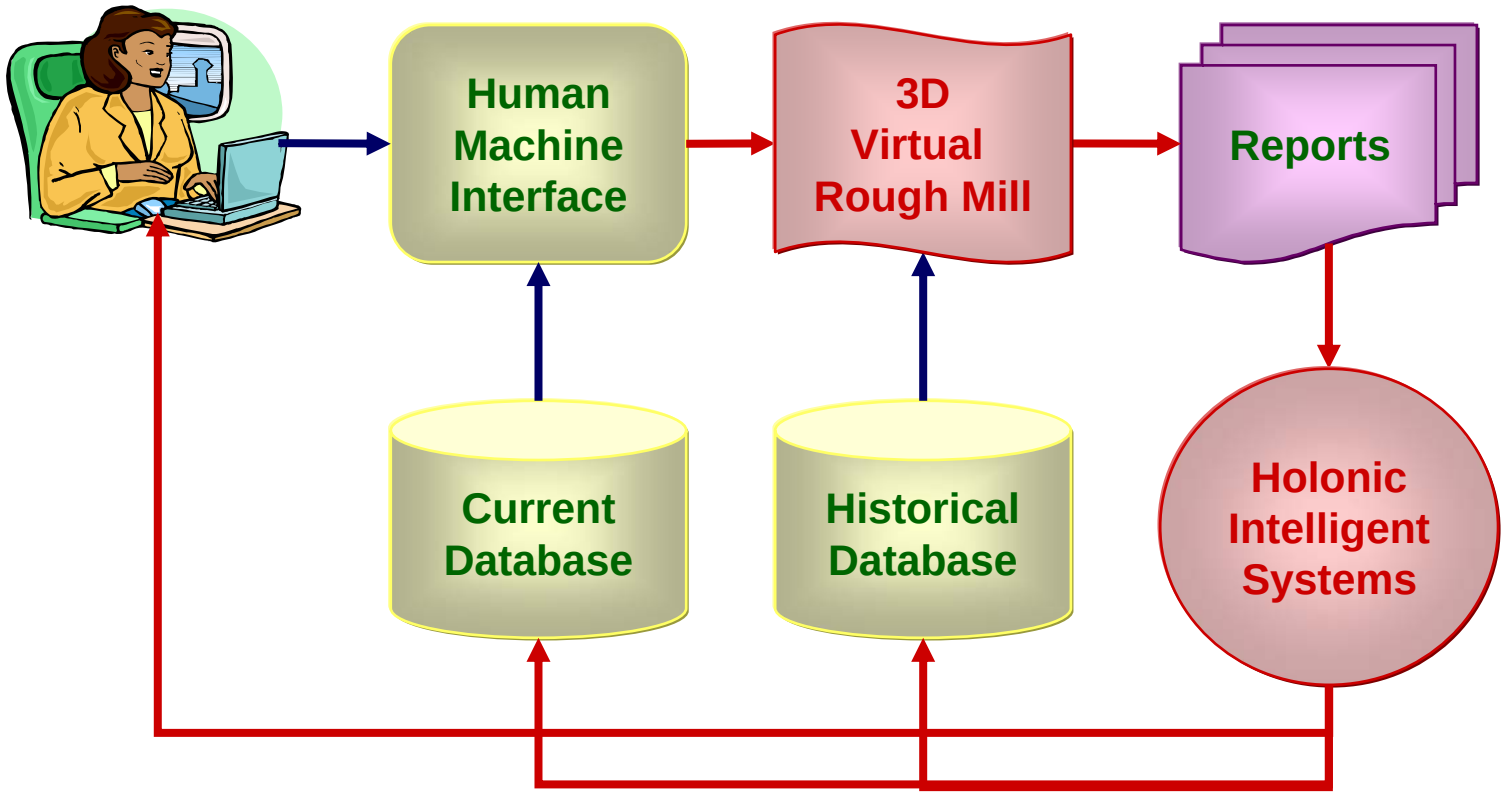
Defect Sensitive Manufacturing



Holonic Decision Support



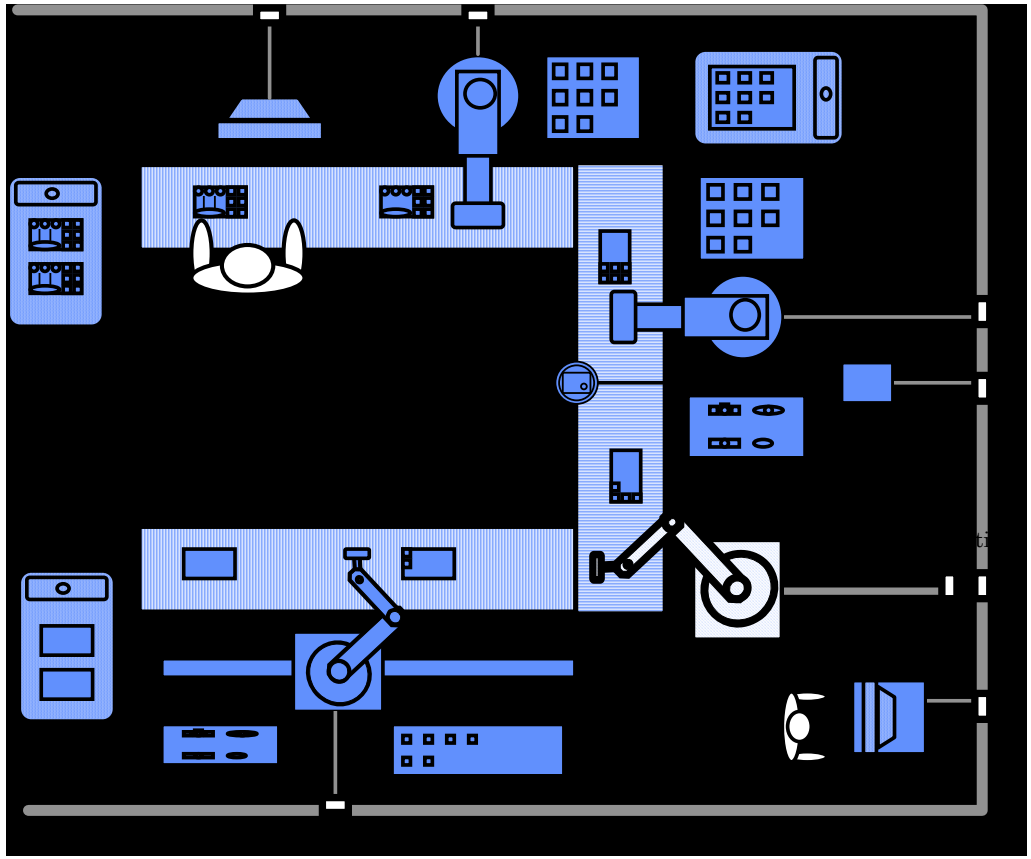
Rough Mill Decision Support System



E. Elghoneimy, O. Uncu, W. A. Gruver, and D. B. Kotak, "Simulation and Decision Support Models for Rough Mills: A Multi-Agent Perspective," *Proceedings of the 2005 IEEE International Conference on Systems, Man, and Cybernetics*, Hawaii, USA, October 2005

Electric Motor Assembly

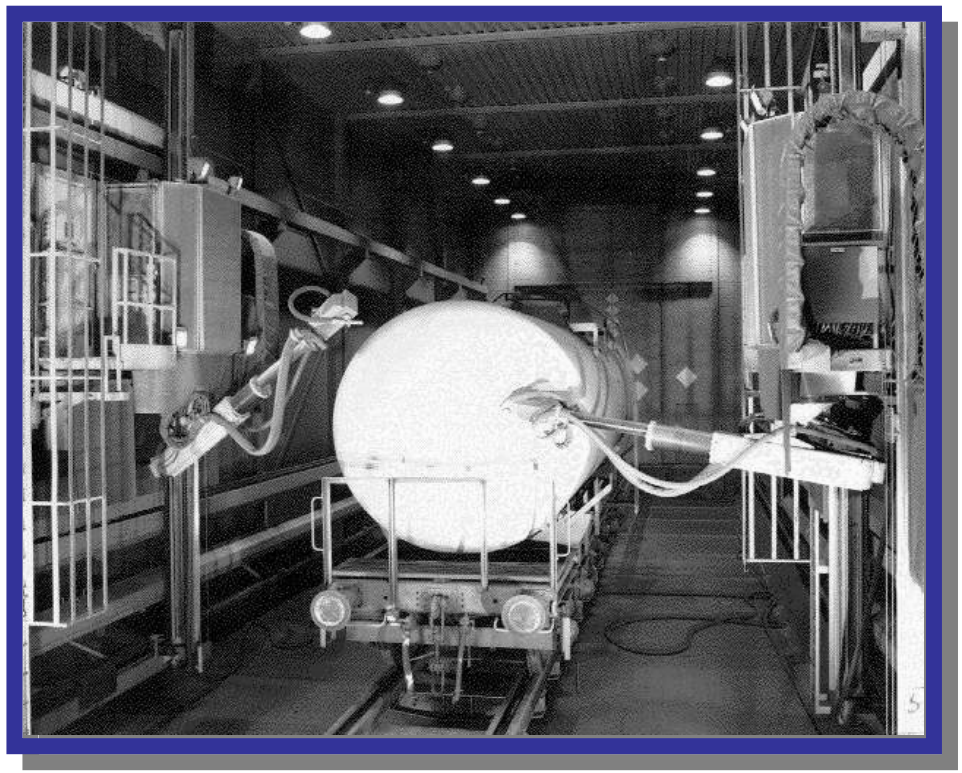
- Highly variable, small volume production
- Effective interaction between humans and industrial robots
- Human workers are essential
- Controlled as a holonic system



Yaskawa Electric Company, HMS Consortium, 2004

Automated Shot Blasting

- Increases efficiency of automated surface treatment
- Accommodates wide variety and large sizes of workpieces
- Four gantry robots
- 24 simultaneous axes
- Controlled as a holonic system



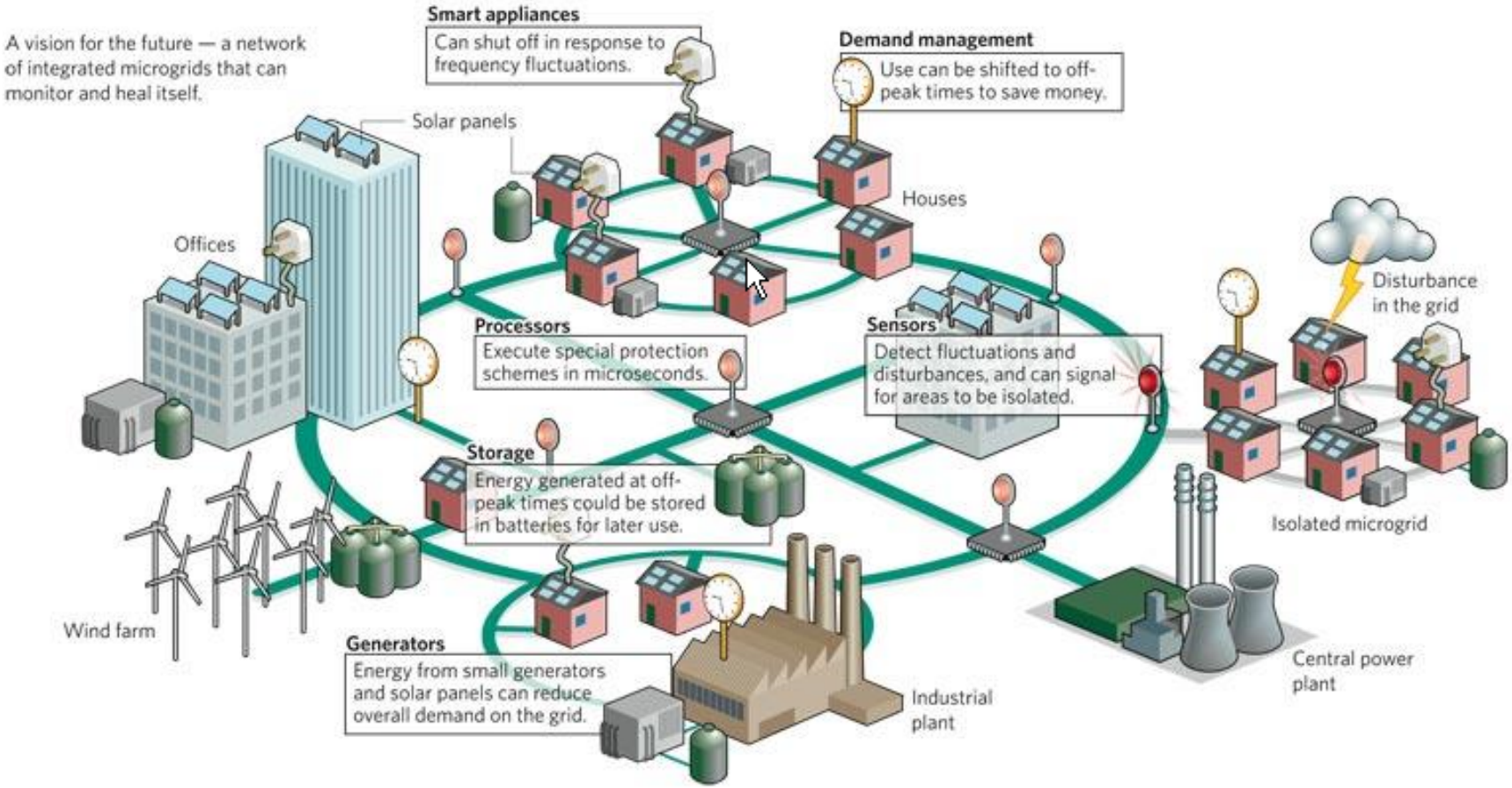
VTT Automation and Blastman Robotics Ltd, HMS Consortium, 1995-2004

Automotive Engine Assembly

- DaimlerChrysler plant in Stuttgart, Germany
- V6 and V8 engines
- USA / Europe / Asia (90 variations)
- Assembly of large, heavy engines

Daimler, Fraunhofer IPA, HMS Consortium, 2000-04

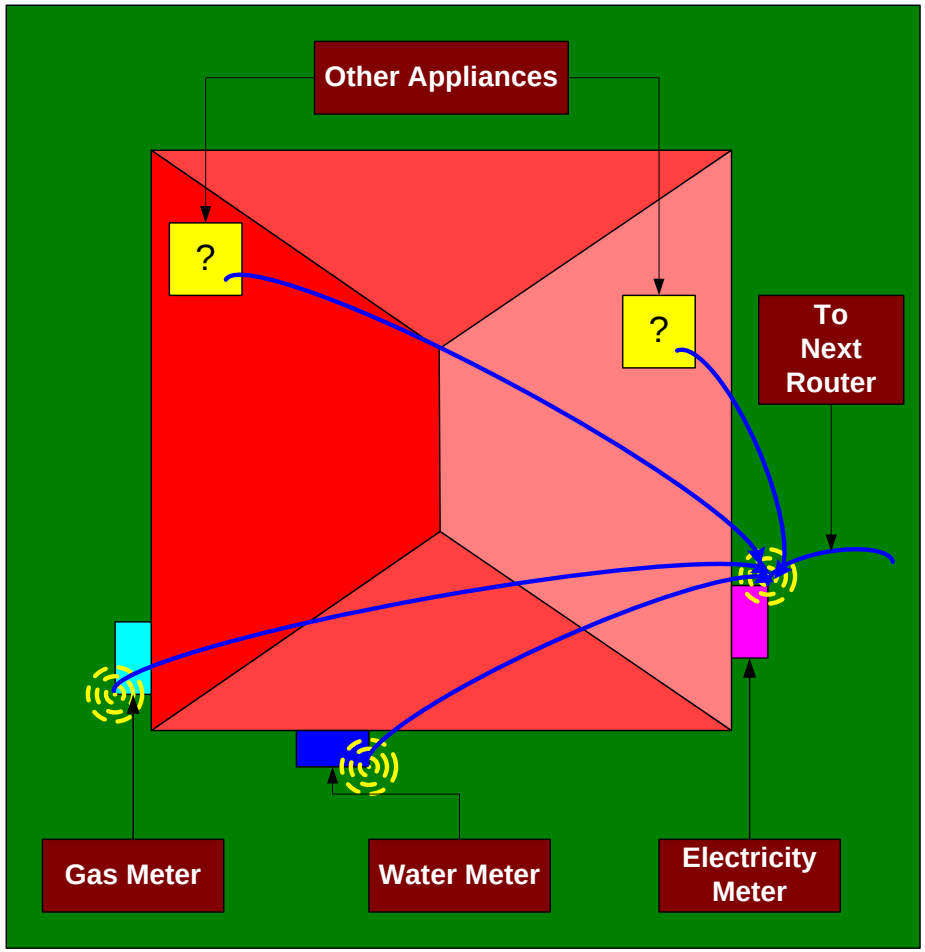
Smart Grid



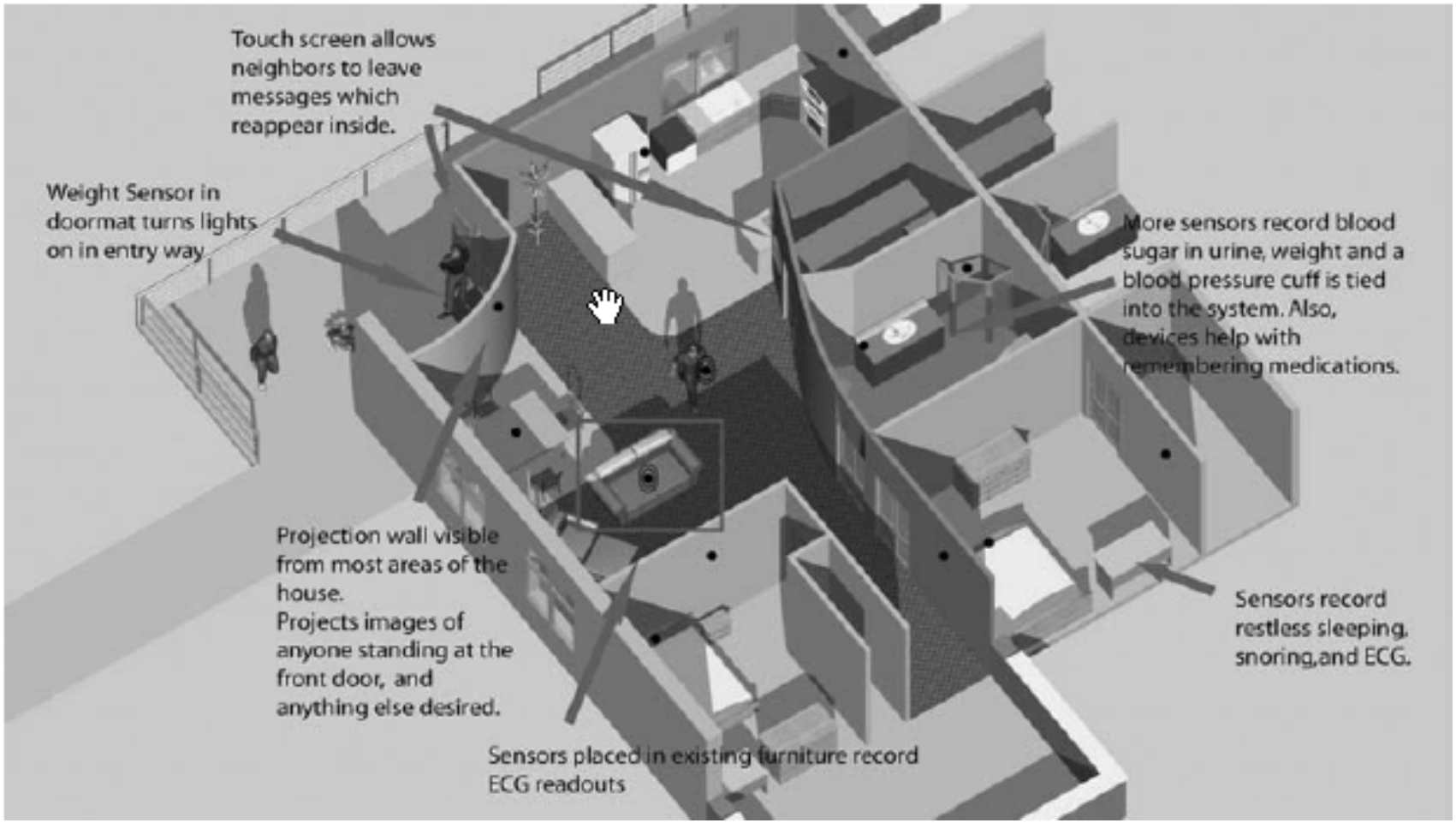
Source: “You think you’re so smart grid,” VTS Enviro Group, May 19, 2009

Automated Meter Reading

- Remotely monitor usage of electricity, water, and gas
- Send data on demand to utility company for monitoring and billing
- Enable different prices to be billed for energy consumption depending on time of day

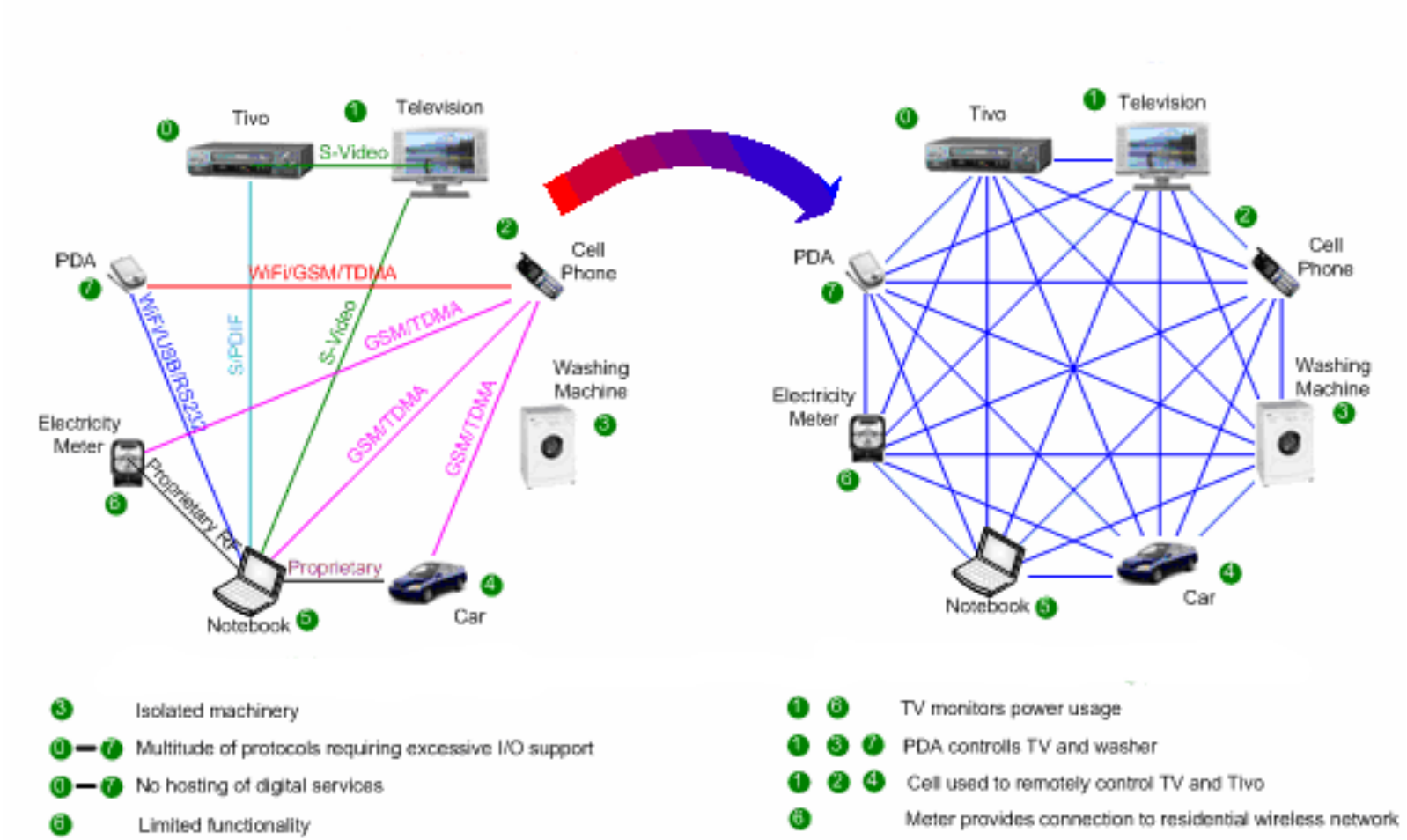


Smart Home



Source: S. Ahson and M. Ilyas, RFID Handbook, CRC Press, 2008

Integrated Digital Services



Weak Integration

Strong Integration

Conclusions

- Holonic intelligence has broad applications to
  - manufacturing and supply chains
  - energy management
  - aerospace and defense systems
  - smart homes
- Holonic intelligent systems provide
  - improved flexibility
  - reduced setup time
  - higher robustness
  - improved scalability
  - integration of human intelligence

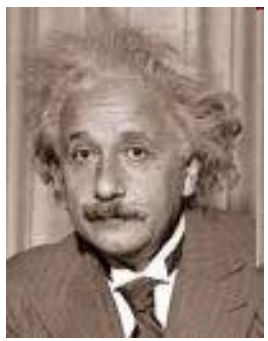
Conclusions

- Holonic intelligent systems have demonstrated capabilities to control physical equipment
- Holonic intelligent systems offer a migration path from centralized legacy systems to fully distributed systems
- International standards are being developed for holonic intelligent systems

Paradigm Change

"The formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science."

A. Einstein and L. Infeld



Acknowledgements

Intelligent Robotics Corporation
North Vancouver, Canada

Intelligent / Distributed Enterprise Automation Laboratory
Simon Fraser University, Burnaby, Canada

Holonic Manufacturing Systems Consortium
Intelligent Manufacturing Systems Program

Distributed Intelligent Systems Technical Committee
IEEE Systems, Man, and Cybernetics Society

For further information …

Intelligent Robotics Corporation
www.iroboticscorp.com

Intelligent/Distributed Enterprise Automation Laboratory
www.ensc.sfu.ca/idea – select “Publications”

Holonic Manufacturing Consortium
www.ims.org – and select “Completed Projects”

IEEE Technical Committee on Distributed Intelligent Systems
www.ieeesmc.org - select “Technical Committees”