SYSTEMS ENGINEERING
Research Center
A US DoD University Affiliated Research Center

Annual SERC Research Review

University of Maryland's Systems Engineering Research Capabilities

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The Institute for Systems Research
University of Maryland College Park

November 9-10, 2010
Hosts: University of Maryland and Fraunhofer Center
College Park, MD
www.SERCuarc.org

The Institute for Systems Research

http://www.isr.umd.edu

History

- An original NSF Engineering Research Center (founded 1985)
- Permanent Institute status within the Clark School of Engineering, University of Maryland (1992); with base budget support
- Graduated from the NSF program (1996); fully self-sustaining

Interdisciplinary research leadership

- Communication systems and networks
- Control systems and methodologies
- Neuroscience and biology-based technology
- Micro and nano devices and systems
- Design, operations and supply chain management
- Systems engineering methodologies
- Computing, speech, artificial intelligence, data mining

Mission

ISR is home to interdisciplinary research and education programs in systems engineering and sciences, and is committed to developing basic solution methodologies and tools for systems problems in a variety of application domains.

Distinctives

- Collaborations with federal and state agencies, local and international corporations and universities worldwide
- Commercial implementation of research results
- Interdisciplinary, systems-focused education program

ISR FACULTY, RESEARCHERS AND STUDENTS

40 joint appointment faculty, **25** affiliated faculty,
10 research faculty
in **5** colleges and **14** departments

42 Fellows of professional societies

20 NSF CAREER Awards

14 Young Investigator Awards

1 PECASE Award

1 National Academy of Engineering member

15 postdoctoral researchers leveraging research programs

170+ research graduate students

45 MS Systems Engineering/ENPM graduate students

20 undergraduate students in research programs

A. James Clark School of Engineering
- Aerospace Engineering
- Chemical and Biomolecular Engineering
- Civil and Environmental Engineering
- Electrical and Computer Engineering
- Fischell Department of Bioengineering
- Materials Science and Engineering
- Mechanical Engineering

College of Behavioral and Social Sciences
- Psychology

College of Computer, Mathematical & Physical Sciences
- Computer Science
- Institute for Advanced Computer Studies (UMIACS)
- Mathematics

Robert H. Smith School of Business
- Decision and Information Technologies
- Logistics, Business and Public Policy

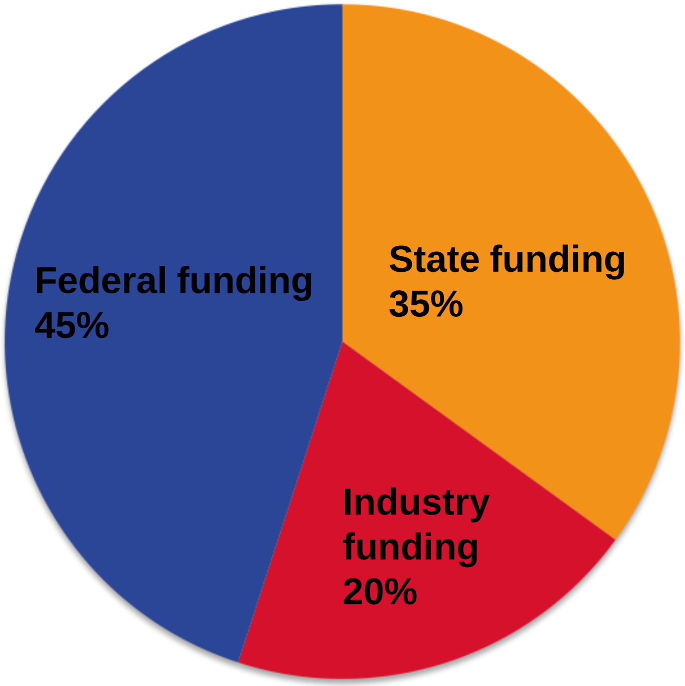
College of Chemical and Life Sciences
- Biology

ISR FUNDING PROFILE

Federal government, state government and industry funding

Federal funding sources include…

- National Science Foundation
- Department of Defense
  (Army, Navy, Air Force, DARPA)
- National Institutes of Health
- Federal Aviation Administration
- National Aeronautics and Space Administration
- Department of Energy
- National Institute of Standards and Technology



2009 research expenditures: $13 million

The Next Frontier in Engineering Research and Education

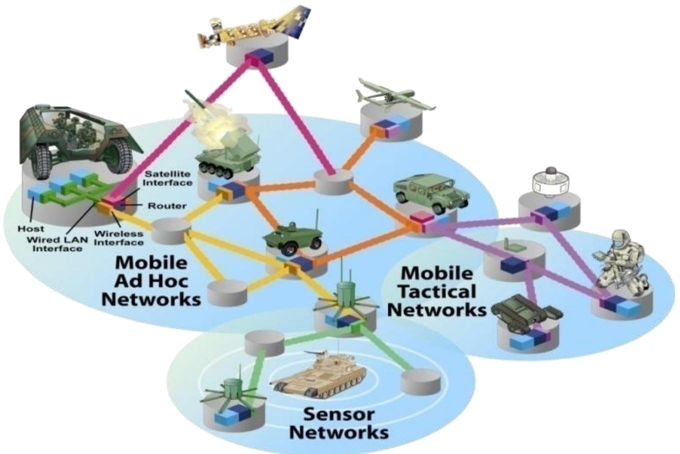
- First 25 years of the 21st century will be **dominated** by advances in methods and tools for the **synthesis of complex engineered systems to meet specifications in an adaptive manner**
- Evident from the areas emphasized by governments, industry and funding agencies world-wide:
  - **energy and smart grids**
  - **biotechnology**
  - **systems biology**
  - **nanotechnology**
  - **the new Internet**
  - **collaborative robotics**
  - **software critical systems**
  - **homeland security**
  - **materials design at sub-molecular level**
  - **network science**
  - **environment and sustainability**
  - **intelligent buildings and cars**
  - **customizable health care**
  - **pharmaceutical manufacturing innovation**
  - **broadband wireless networks**
  - **sensor networks**
  - **transportation systems**
  - **security-privacy-authentication in wireless networks**
  - **cyber-physical systems**
  - **web-based social and economic networks**

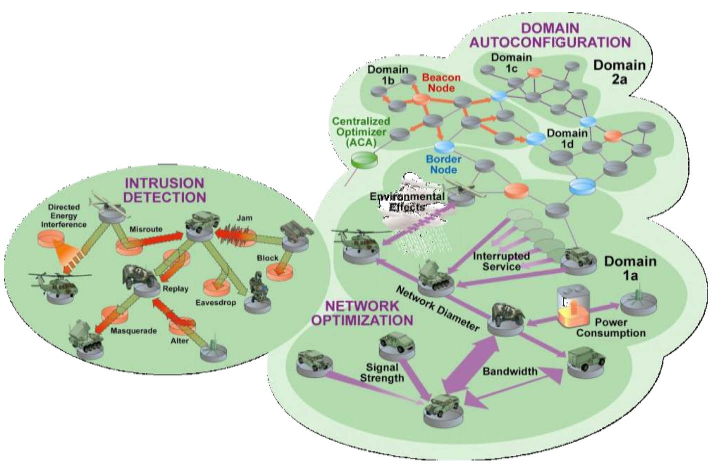
The Critical Role of IT

- Possible to undertake a successful research and education program to accomplish this vision is IT -- namely **networked embedded systems**
- Through embedded systems the heterogeneity of the various physical components is **translated into a common language** where design can be integrated
- Networked embedded systems have revolutionized cars, networks, energy, biology and many other fields; at scales from nano to macro
- Implied **programmability and re-programmability** has immense consequences
- In almost all ISR program areas we are interested in systems that are **"dynamic"**, that is they change in time

Example: Broadband Mobile Wireless Infrastructures (BMWI)

Hybrid MANET and WSN

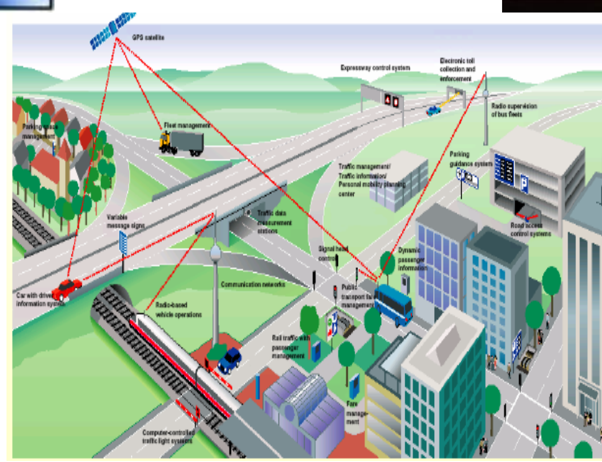


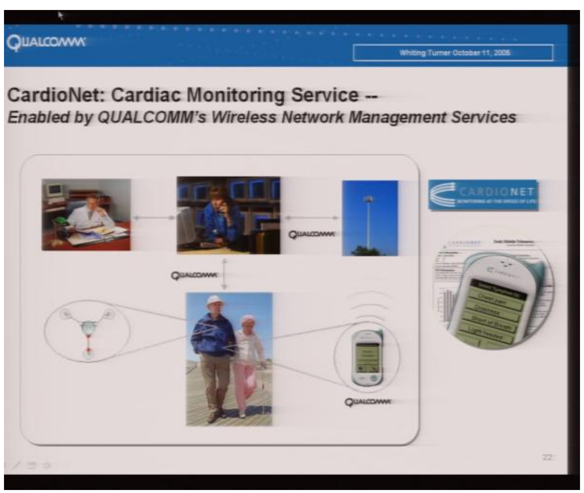


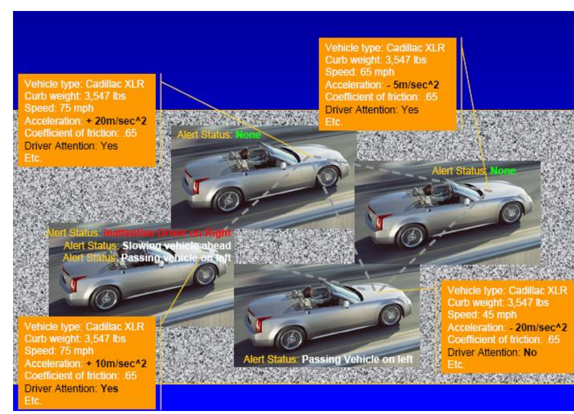
- System of Systems or Network of Networks
- Integrate: network management, security, routing, MAC, networks …
- Innovative services
- Net centricity

Component Based Networking

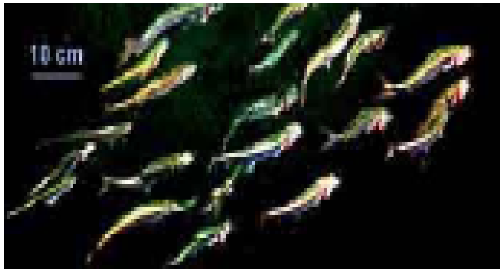
Broadband Wireless: Shaping Societies and Civilization





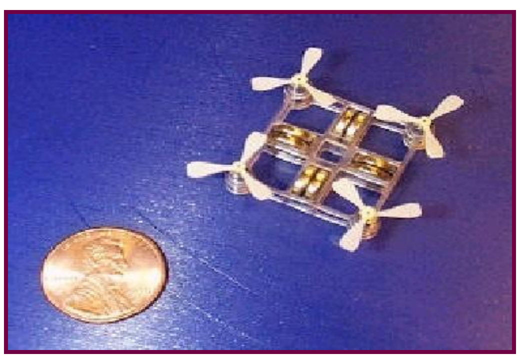


Example: Autonomous Swarms – Networked Control



- *Component-based Architectures*
- *Communication vs Performance Tradeoffs*
- *Distributed asynchronous*
- *Fundamental limits*

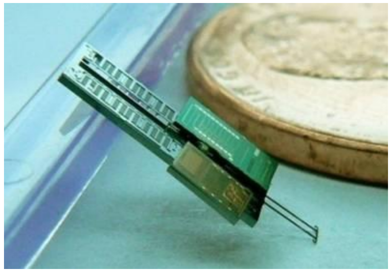
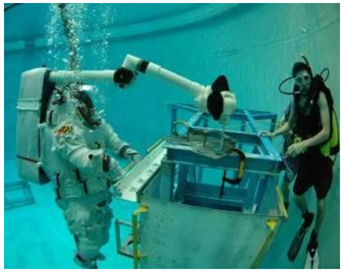
Collaborative Robotic Swarms



Maryland Robotics Center Research Focus

- Multi-disciplinary systems view of robotics
  - Sensors, Actuators, Structures, Control, Communication, and Autonomy
  - Equal emphasis on hardware and software
- Thrusts
  - Unmanned Vehicles
  - Robotics in Extreme Environments
  - Miniature Robots
  - Medical Robotics
  - Cooperative, Collaborative, Networked Robotics

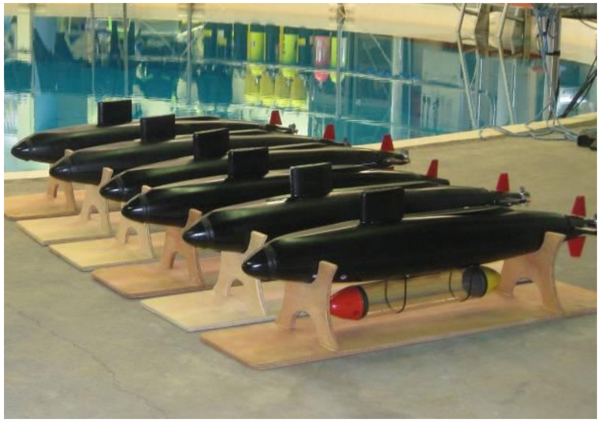



Maryland Robotics Center Applications

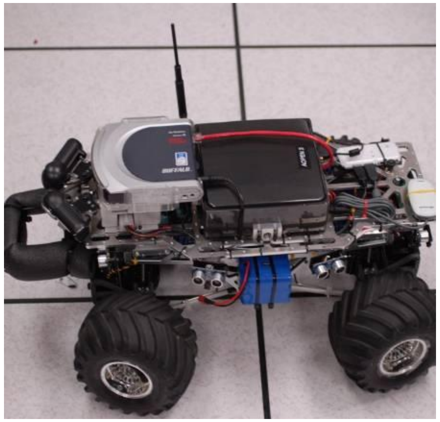
- Search, Rescue, Recovery
- Reconnaissance
- Space Exploration
- Underwater Exploration

SAMURAI Deep Submergence Dexterous Manipulator

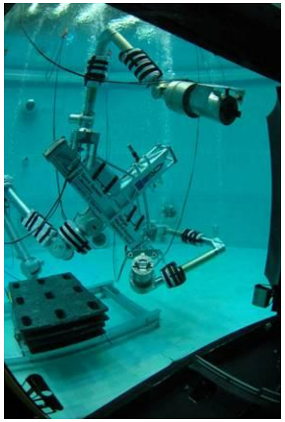


Underwater Robots

MINIR Surgical Robot



Ground Robot



Space Robot

Control *vs.* Communication

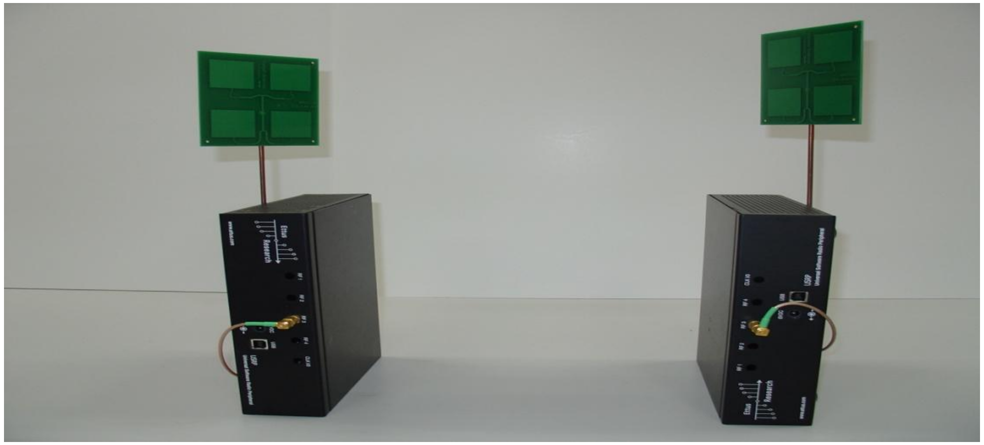
- Many graphs as **abstractions**
- **Collaboration graph** – or a model of what the system does (**behavior**)
- **Communication graph** – or a model of what the system consist of (**structure**)
- Nodes with **attributes** – multi-graphs – hypergraphs
- **Key question 1**: Given behavior, what structure (subject to constraints) gives best performance?
- **Key question 2**: Given structure (and constraints) how well behavior can be executed?

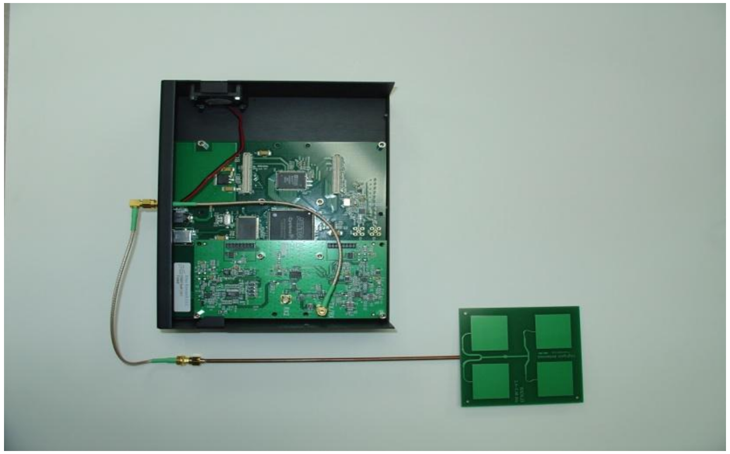
Example: Security, Authentication, Trust

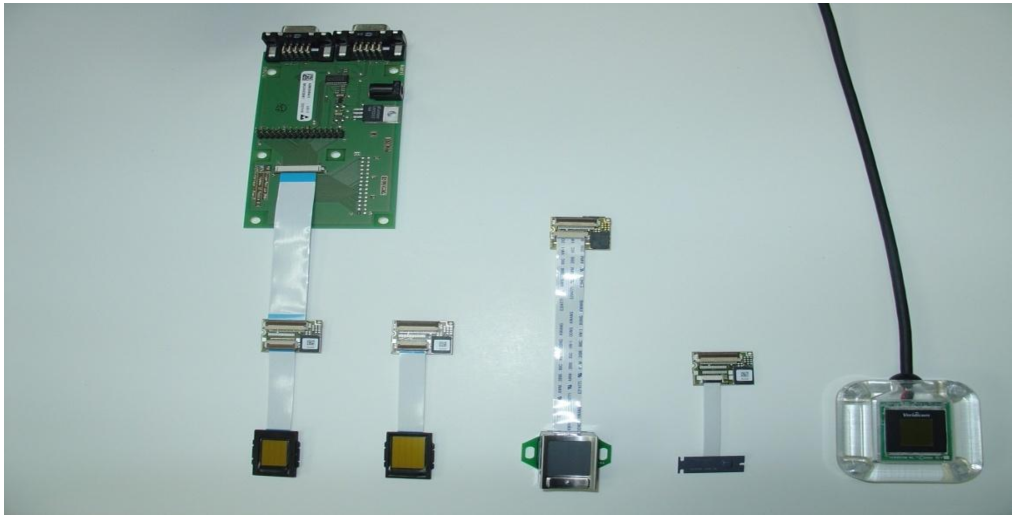
- **Universally Composable Security – when possible?**
- Software components and interfaces -- Design interfaces carefully and robustly – **major doors of attacks**
- Utilize to advantage the **physical layer** (vastly ignored todate)
  - Wave form, RF and hardware peculiarities $\Rightarrow$ lead to 'unshakeable' fingerprints
  - Authenticate the device to the network and then the user to the device $\Rightarrow$ reduces attack risk (**fewer times through the net**)
- Distribute assurance function across software and hardware (increases difficulty to attacker immensely)
  - Trusted platform module (TPM) – architecture modifications to allow multiple sources input (including biometrics) – open
  - TPM chip 'add on' to portable devices (TCG, TCN)
  - Chip authentication
- Distributed "communal" trust monitoring : 'Know thy neighbors well', but watch them – maintain assured neighborhood information

Experimental Validation

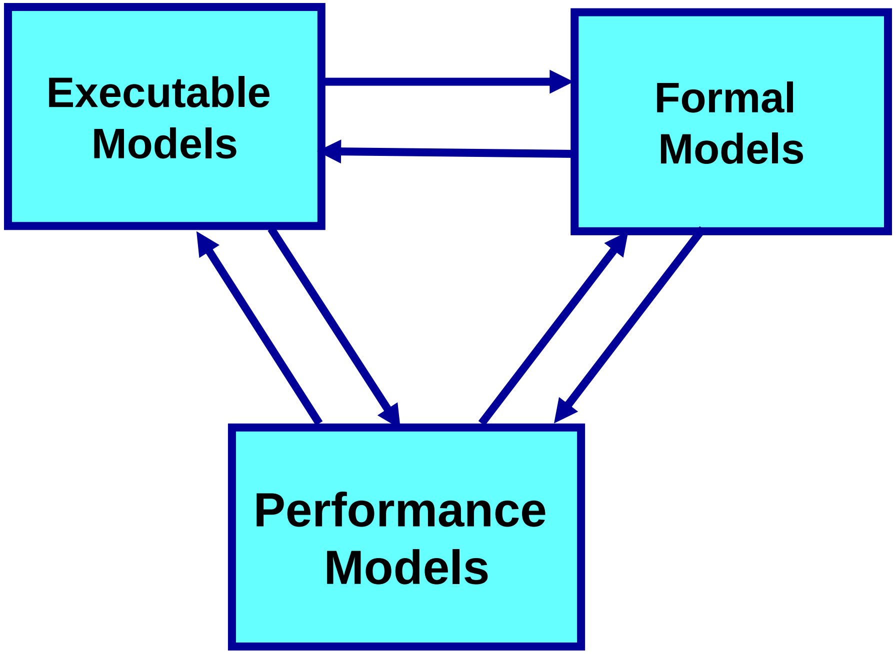
Demonstrated Very Low Power Authentication is Feasible







Universally Composable Security (UCS)



Studying compositionality is necessary!

Universally Composable Security of MANET Protocols:

- Network with many agents running autonomously.
- Agents execute in mostly asynchronous manner, concurrenty several protocols many times. Protocols may or may have not been jointly designed, may or not be all secure or secure to same degree.

Key question addressed :

- **Under what conditions can the composition of these protocols be provably secure?**
- **Investigate time and resource requirements for achieving this**

Universally Composable Security (UCS)

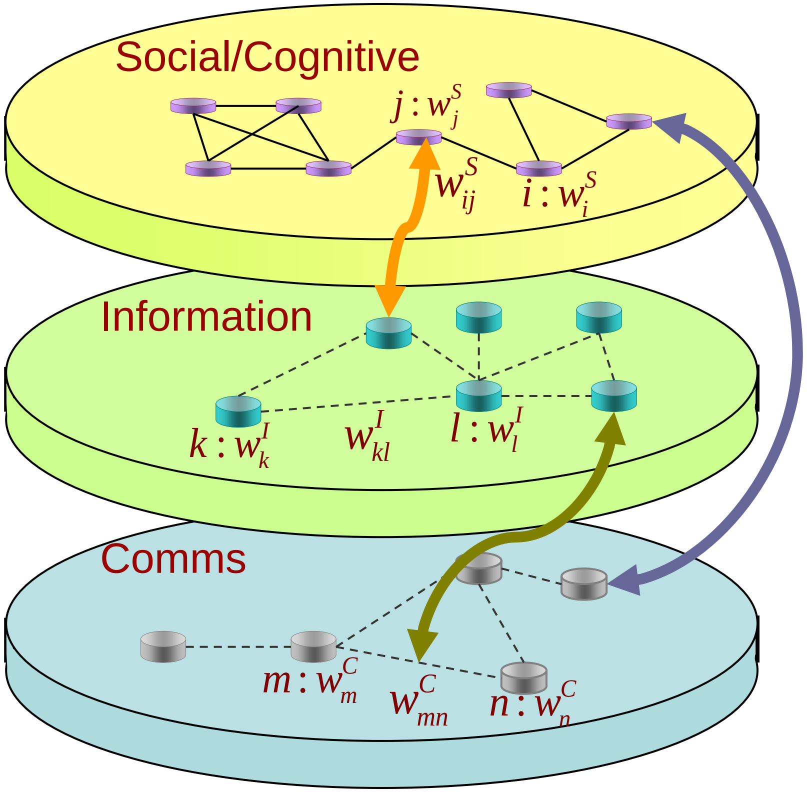
- When there is a clear majority of well behaving nodes (i.e.2/3) **almost any functionality is secure** under UCS
- When there is no clear majority then UCS is **impossible** to achieve unless there are pre-conditions – typically some short of trust mechanism
- Introducing **special structure in the network** (e.g. overlay structure, small subset of absolutely trusted nodes) helps substantially in establishing UCS, even without preconditions
- **Our current main applications:** military networks, health care networks, sensor networks, SCADA and energy cyber networks
- **Our main approach: Use "tamper proof hardware" (physical layer schemes, TPM etc.) even on a small subset of nodes to provably (validation) establish UCS**

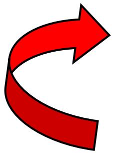
Security, Authentication, Trust (cont.)

- Cross-layer trust computation across the network
  - Distributed, self-checking, trust dynamics, topology effects
  - Include trust in routing via path metrics
- Distributed control around compromised neighborhoods – containment
- New **distributed hybrid systems** methods for IA and trust evaluation, combine logic and statistics
  - Combining distributed model checking and theorem proving techniques
  - Use natural randomness and other signatures for ID-based keying
- Design of distributed dynamic recommender and reputation systems
- Using TPM, TCN, to implement specification-based policies and testing of policies
  - Trusted platforms in social networks

Example: Dynamic Network Trust

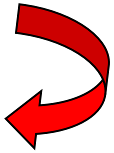
- Multiple Interacting Graphs
  - *Nodes*: agents, individuals, groups, organizations
  - Directed graphs
  - *Links*: ties, relationships
  - Weights on links : value (strength, significance) of tie
  - Weights on nodes : importance of node (agent)
- **Value directed graphs with weighted nodes**
- **Real-life problems: Dynamic, time varying graphs, relations, weights**





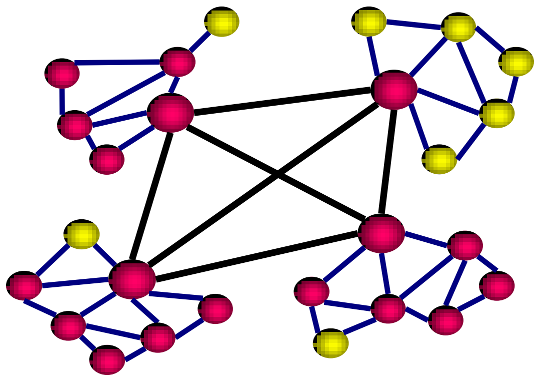
Organizational needs

Network architecture and operation



Example: Dynamic Network Trust (cont.)

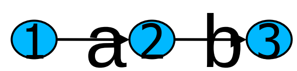
- Trust evaluation, trust and mistrust dynamics
  - Spin glasses (from **statistical physics**), phase transitions



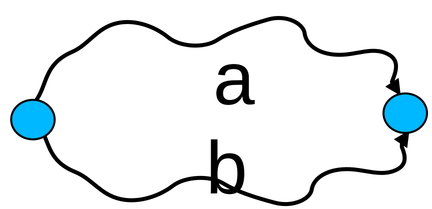
$$s_i(k+1) = f\left(\hat{J}_{ji}, s_j(k) \mid j \in N_i\right)$$

- **Indirect** trust; reputations, profiles; Trust computation via 'linear' **iterations in ordered semirings**

$$a \otimes b \leq a, b$$



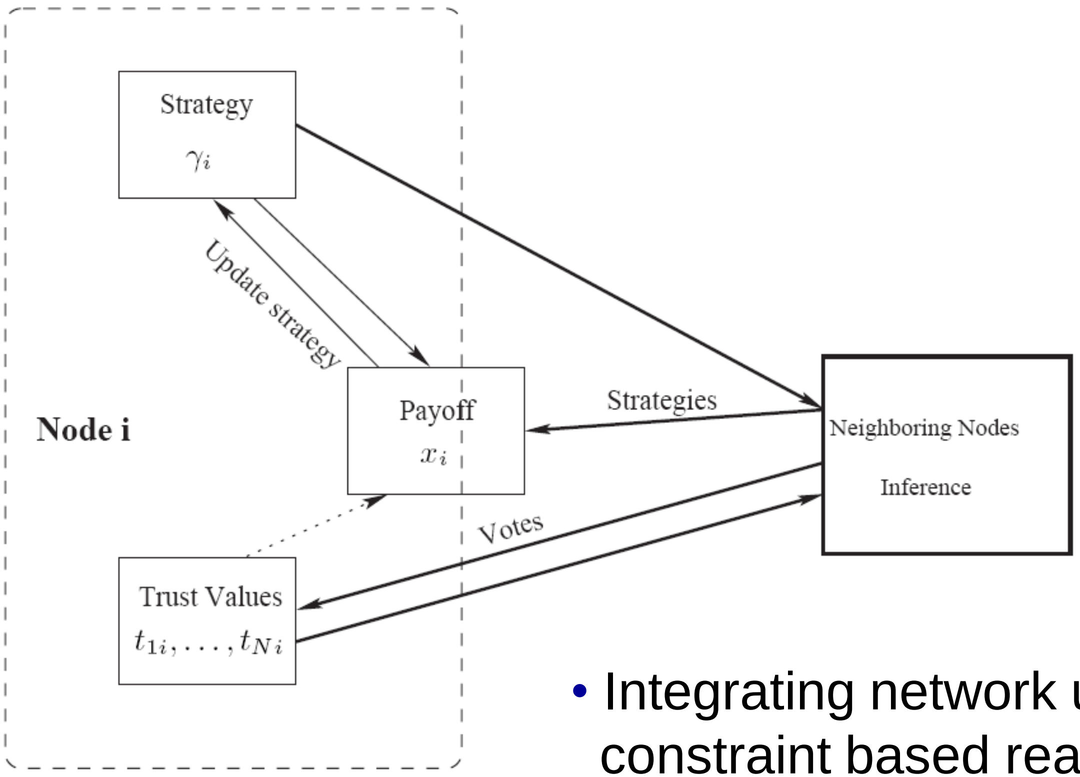
$$a \oplus b \geq a, b$$



2007 IEEE Leonard Abraham prize
New Book Draft

- **Direct trust: Iterated pairwise games on graphs** with players of many types

Example: Trust and Collaboration



Two linked dynamics

- **Trust / Reputation propagation and Game evolution**

$$\gamma_i(t+1) = f^i(x_i(t), \gamma_i(t), \gamma_j(t), t_{ij}(t))$$
$$t_{ik}(t) = g^i(t_{ij}(t), v_{jk}(t)) \quad \forall k \in N$$
$$x_i(t) = h^i(\gamma_i(t), \gamma_j(t))$$
$$v_{ij}(t) = p^i(\gamma_j(t), t_{ji}(t))$$

- Integrating network utility maximization (NUM) with constraint based reasoning and coalitional games

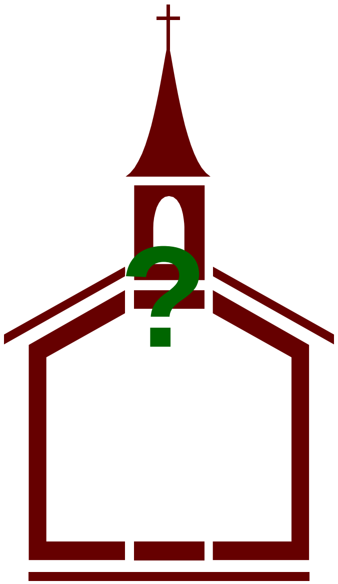
- Beyond linear algebra and weights, semirings of constraints, constraint programming, soft constraints semirings, policies, agents
- Learning on graphs and network dynamic games: behavior, adversaries
- Adversarial models, attacks, constrained shortest paths, …

Example: Future Automotive Control Systems

- The new trend is
  - Break the "one-subsystem one-ECU" paradigm
  - Distribute functionalities over several nodes to optimize number and cost of ECUs
- Advantages
  - flexibility, cost reduction, redundancy (fault-tolerance)
  - more sophisticated control enabled by more powerful hardware

AUTOSAR

Smart Cars – Smart Buildings



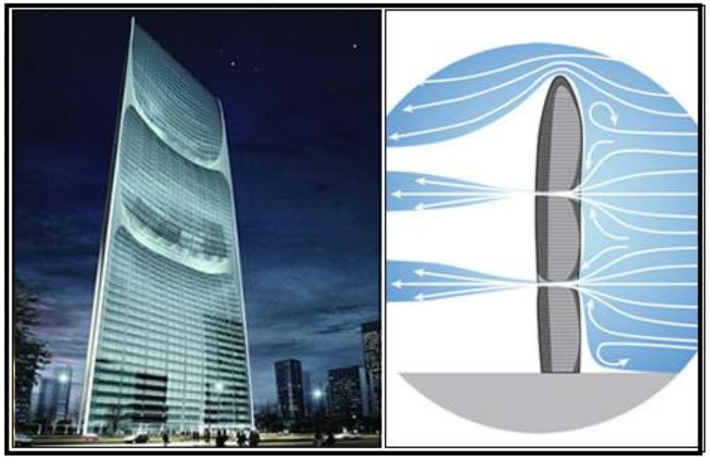
Smart Car
- light & compact
- low-drag design
- fuel efficient
- low emission
- 95% recyclable
- efficient accessories
- friendly factory

Smart & Green Building
- energy efficient
- use renewable energy
- green building materials
- low environmental impact
- responsive to climate/site
- responsive to user needs
- healthy environment

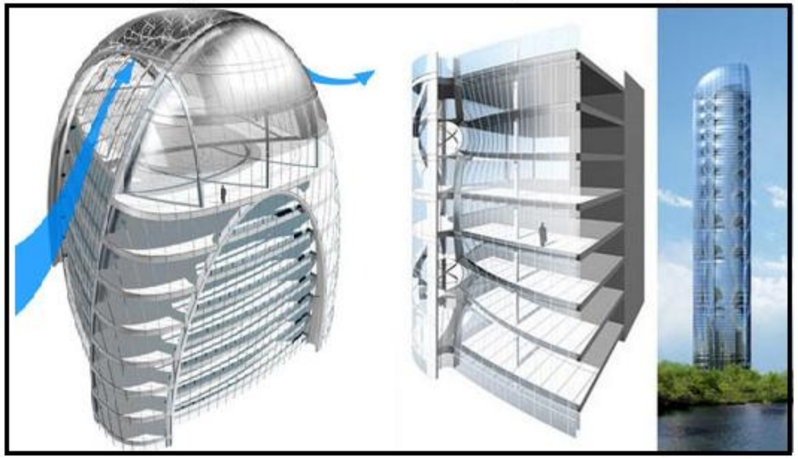
Example: Cyber-Physical Building Systems

- Research focus: Platform-Based Design for Building-Integrated Energy Systems.

Pearl River Tower Complex

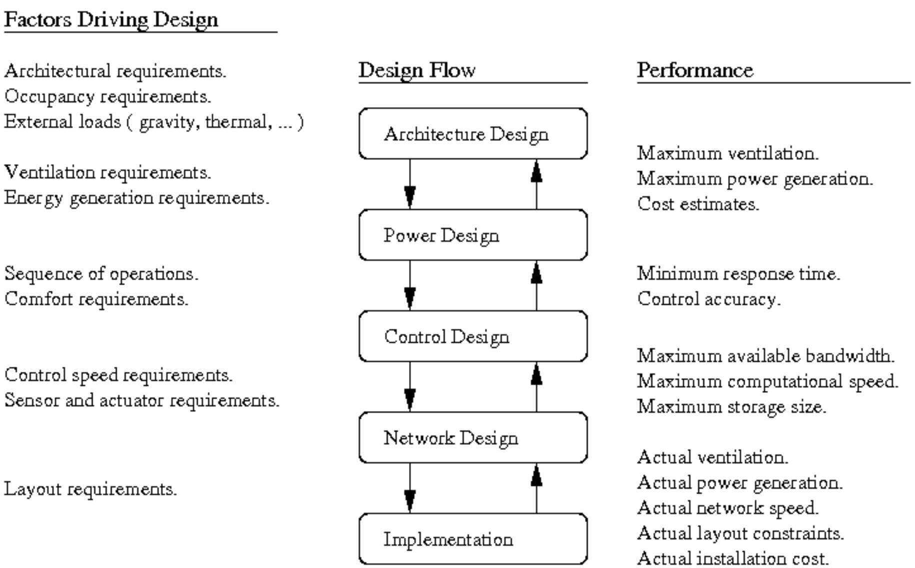


Green Technology Tower –– Architectural Proposal for Chicago

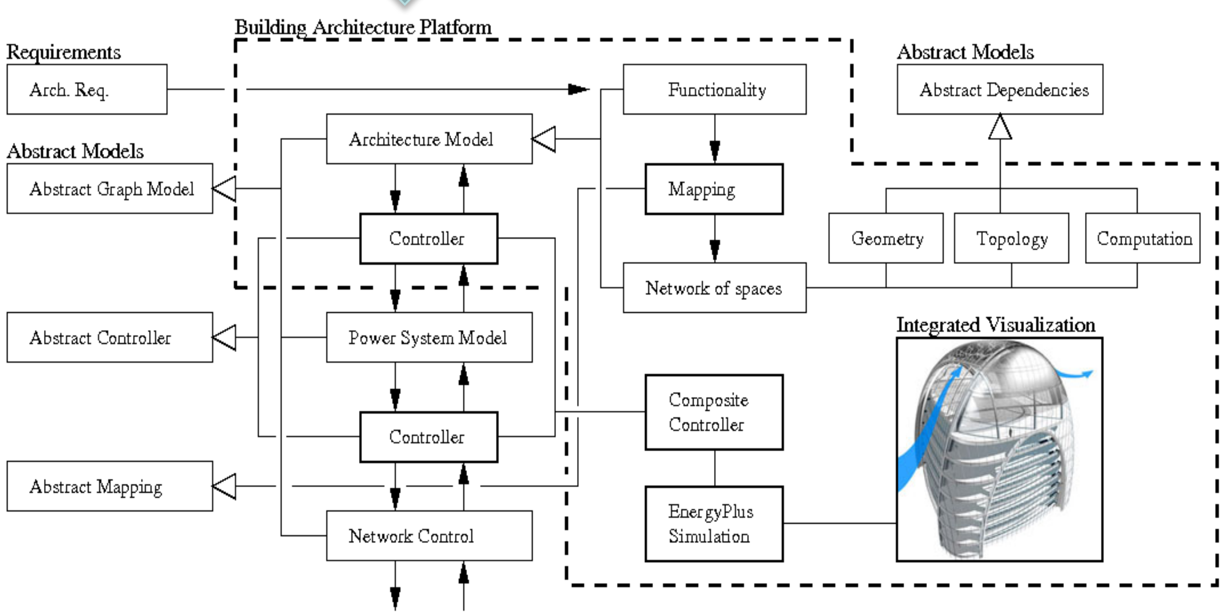


Cyber-Physical Building Systems Design

- Design Platform Stack

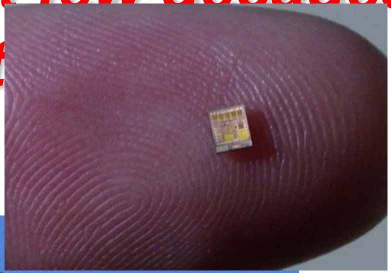


Research: Design of a scalable and extensible platform infrastructure



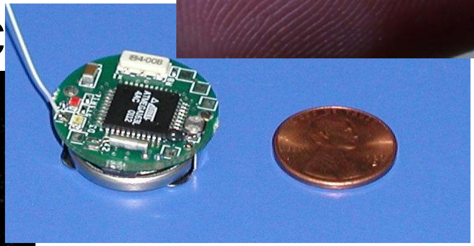
Example: Wireless Sensor Networks (WSN)

"While the last 50 years have been dominated by a march to ever more complex computers, the next few decades will see the rise of simple sensors -- by t



Business Week

- Sensor and Sensor networks are bec



- Embed numerous dis

  interact w

- Exploit s , in situ, sensing

  these devices so that they coordinate to perform higher-level identification and tasks.
- Distributed & large-scale like the Internet - but, physical instead of virtual, resource constrained, and with real-time constraints

Wireless Sensor Network Challenges

Design

What h/w and s/w platform to use?
How to organize the application?
What are good programming abstractions?

Deployment & Configuration

How many nodes?
Where should the nodes be placed?
How to discover address, location, clock etc.?

Runtime: Inside the network

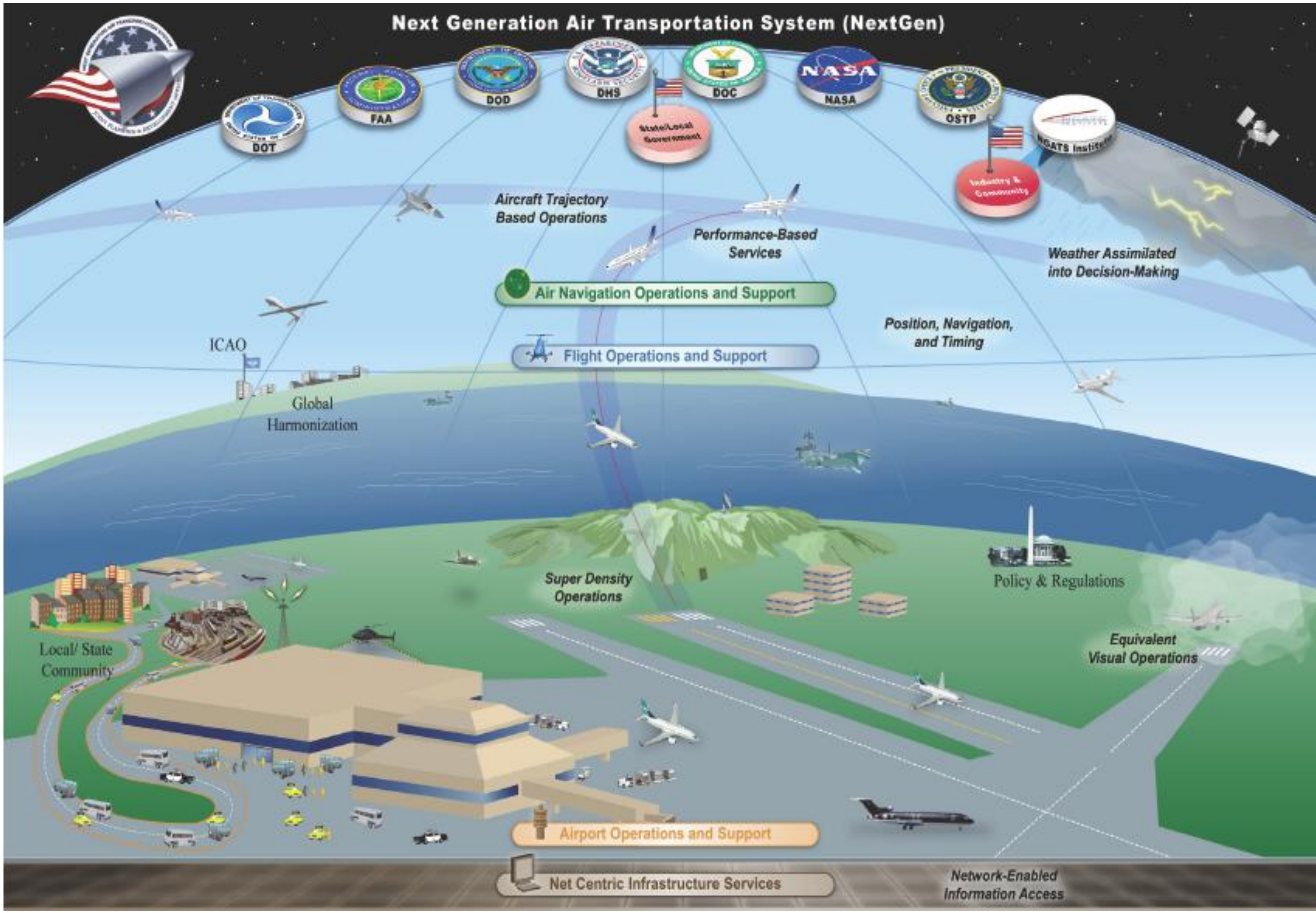
How to route queries to the nodes?
How to estimate and exfiltrate the answers?
How to maintain location, time, calibration etc.?
How to operate in an energy-aware manner?
How to manage the network?

Runtime: At the back-end

How to manage the network?
How to visualize and manage the data from the sensor network?
How to interface with the applications/users?

Large-scale
Distributed
Real-time (control, events)
Physically-coupled
Unattended
Resource-constrained
Wireless
Collaborative computation
…

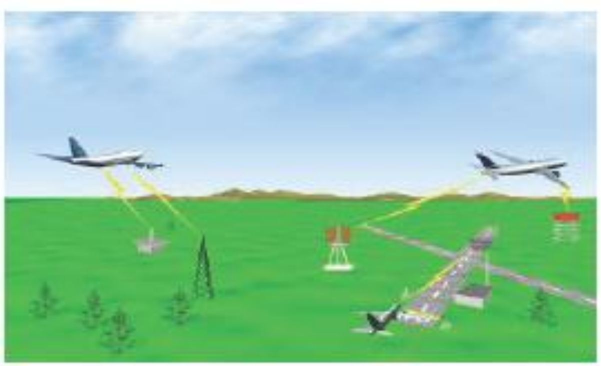
Example: FAA NextGen

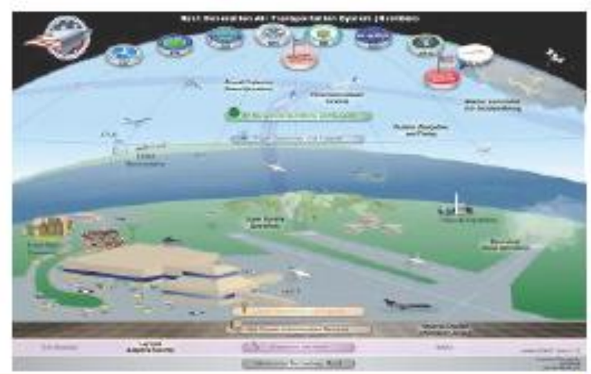


FAA NextGen (cont.)

NextGen: Improving Efficiency & Capacity

Today's NAS		NextGen
Ground-based Navigation and Surveillance	→	Satellite-based Navigation and Surveillance
Air Traffic Control Communications By Voice	→	Routine Information Sent Digitally
Disconnected Information Systems	→	Information More Readily Accessible
Air Traffic "Control"	→	Air Traffic "Management"
Fragmented Weather Forecasting	→	Forecasts Embedded into Decisions
Airport Operations Limited By Visibility Conditions	→	Operations Continue Into Lower Visibility Conditions
Forensic Safety Systems	→	Prognostic Safety Systems

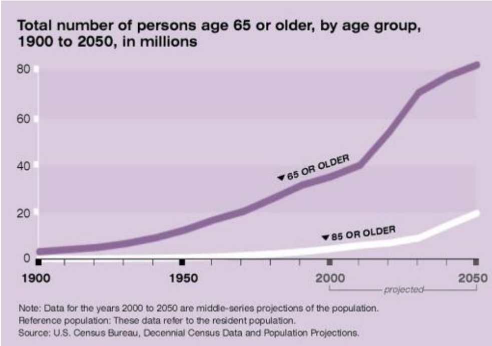


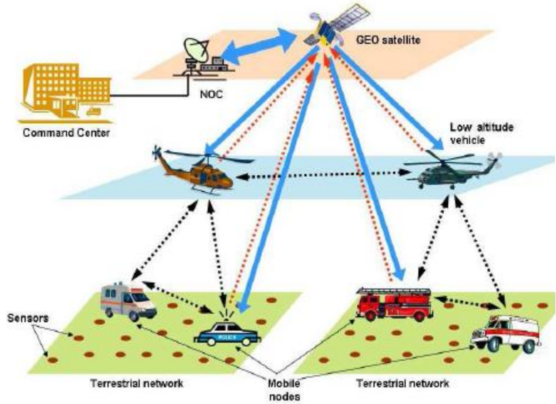


Example: HEALTH IT Components

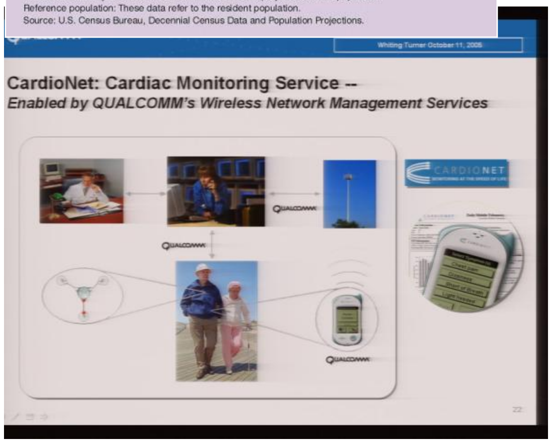
- **Broadband Hybrid Communication Networks with widely available access**
- **Universal patient records and dissemination**
- **Universal logistics support (insurance, databases, accounting, case management)**
- **Web-based services**
- **Mini-clinics and inexpensive tests and consultations**
- **Social, behavioral aspects**
- **Hospital information and management systems**
- **Multimedia systems, robotics, tele-surgery, new operating rooms**
- **Health care management systems**
- **Security, trust, authentication and privacy**

"I would like more Systems Engineering principles for Health Care"
Harvey V. Fineberg, President of the Institute of Medicine
"Innovation in Medical Technology", Whiting-Turner Lecture – 2009

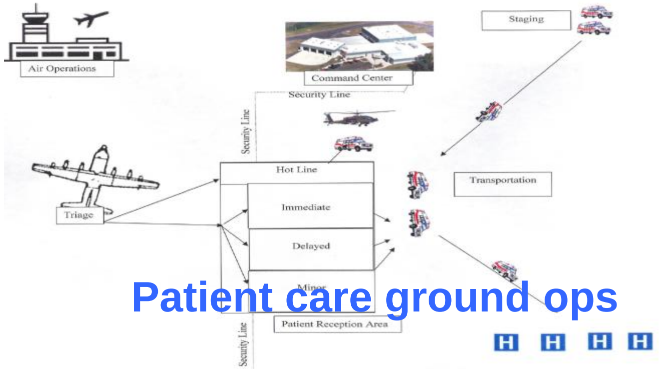




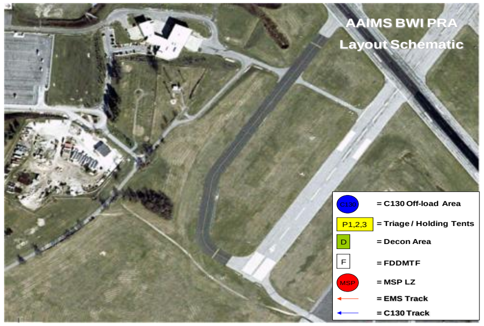
Everyday health through everyday devices



Wireless Information Networks: Innovation for better Quality of Life and Work



Patient care ground ops



Disaster relief and health care delivery and management

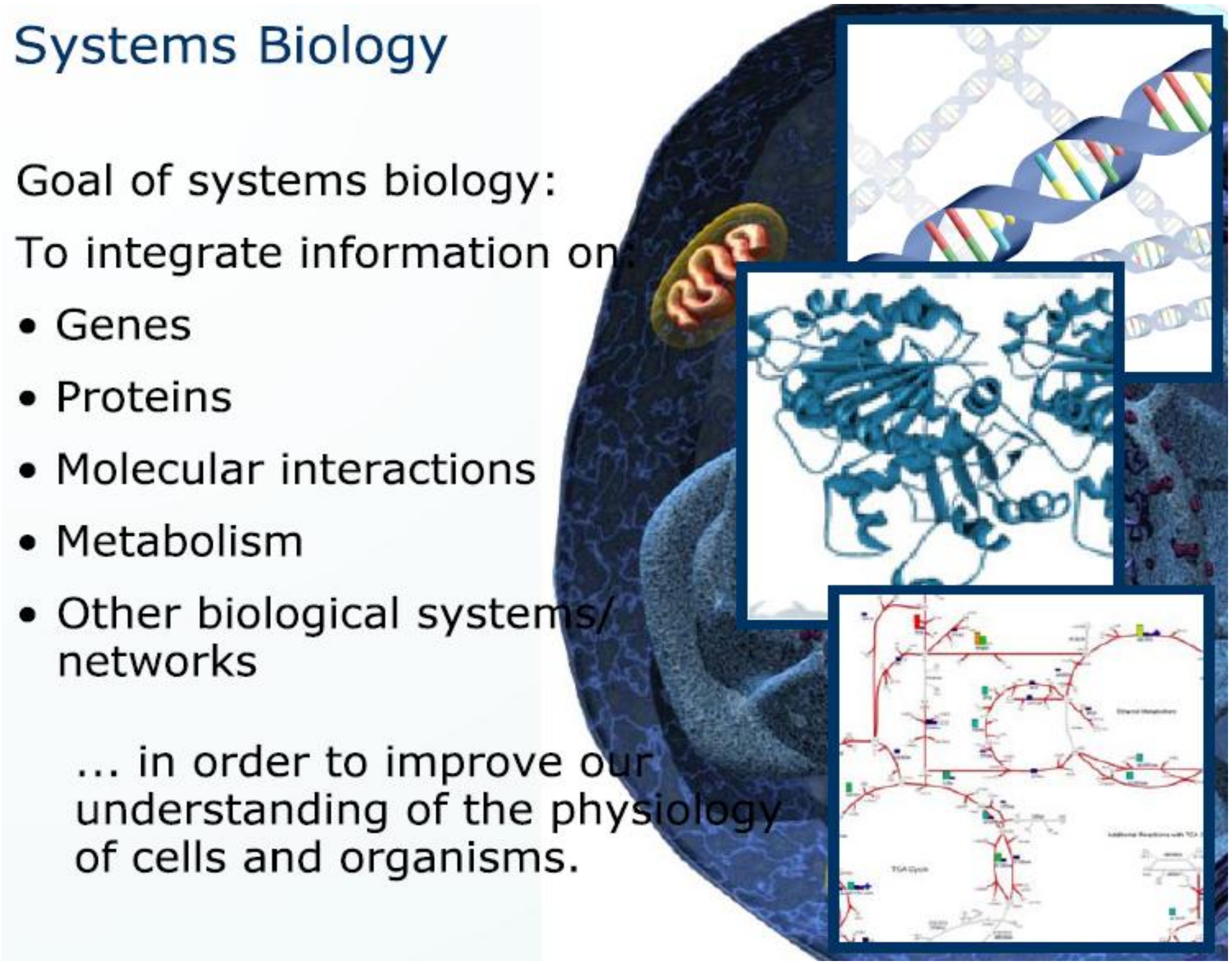
High quality low cost health care for rural and underdeveloped areas

Broadband Wireless Benefits to Society

Health Care

- Much higher quality health care at lower cost and much wider availability
- Essential for preventive maintenance based healthcare
- Essential for health care in rural and underdeveloped areas (almost 95% of the current earth's population and locations)
- Patient education and awareness
- Physician, nurse and hospital training

Example: Systems Biology -- The Ultimate Systems Challenge



SYSTEMS BIOLOGY

Integrative approach in which scientists study pathways and networks

will touch all areas of biology, including drug discovery

Requires

- ***Quantitative models of properties of components and their interactions***
- ***Computational methods to manage complexity***

Trends for Future of Medicine

(from Siemens)

- ➔ From reactive to proactive, predictive, preventive
- ➔ Combination of in-vitro and in-vivo diagnostics
- ➔ Completion of diagnostics towards therapy and progress tracking

Molecular Medicine

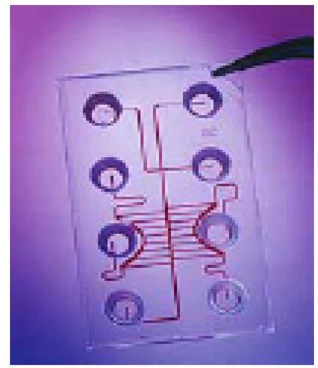
- *Bio-, Nano-, Info- Technologies*
  - *Bio-Medical Knowledge Fusion*
  - *Molecular Diagnostics*
  - *Personalized Medicine*
- *Theranostics*
  - *Computer-aided Diagnosis & Treatment*
  - *Molecular Imaging*
  - *Imaging for Drug Effectiveness*

Hybrid Loc -- Biochips

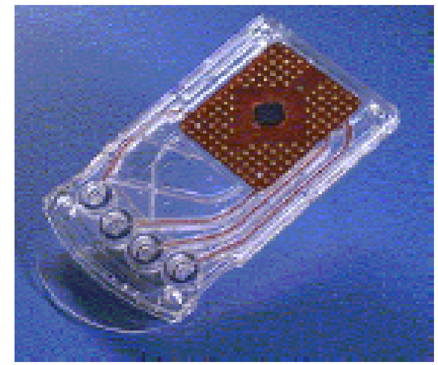
Biochips are currently emerging with different form factors and technologies for applications in research, pharma and healthcare

All biochip concepts are disposables

DNA µArray



µfluidic chip



µfluidic chip
+
DNA µArray

Applications:

- Basic research
- Pharma R&D / Drug development } "Red Biotech"
- Healthcare
- Agriculture and environment — "Green Biotech"
- Industrial and process control — "Grey Biotech"

2

Revolutionizing Drug Testing

- Rapidly approaching untenable situation in human health -- Blockbuster drugs, which cure major diseases afflicting huge populations, are being pulled from the shelves (e.g., Vioxx) for unforeseen side-effects. They are being replaced by drugs that have smaller market potential and more localized impact (subpopulations, e.g., FluMist).
- The current cost of developing a drug and getting it to market exceeds $1B and the process takes over ten years.
- These competing forces cannot be resolved without truly transformational changes in the way drugs are discovered, developed, and approved.
- This need is exacerbated by the emergence of personalized medicine – a natural outcome of high throughput sequencing technologies.

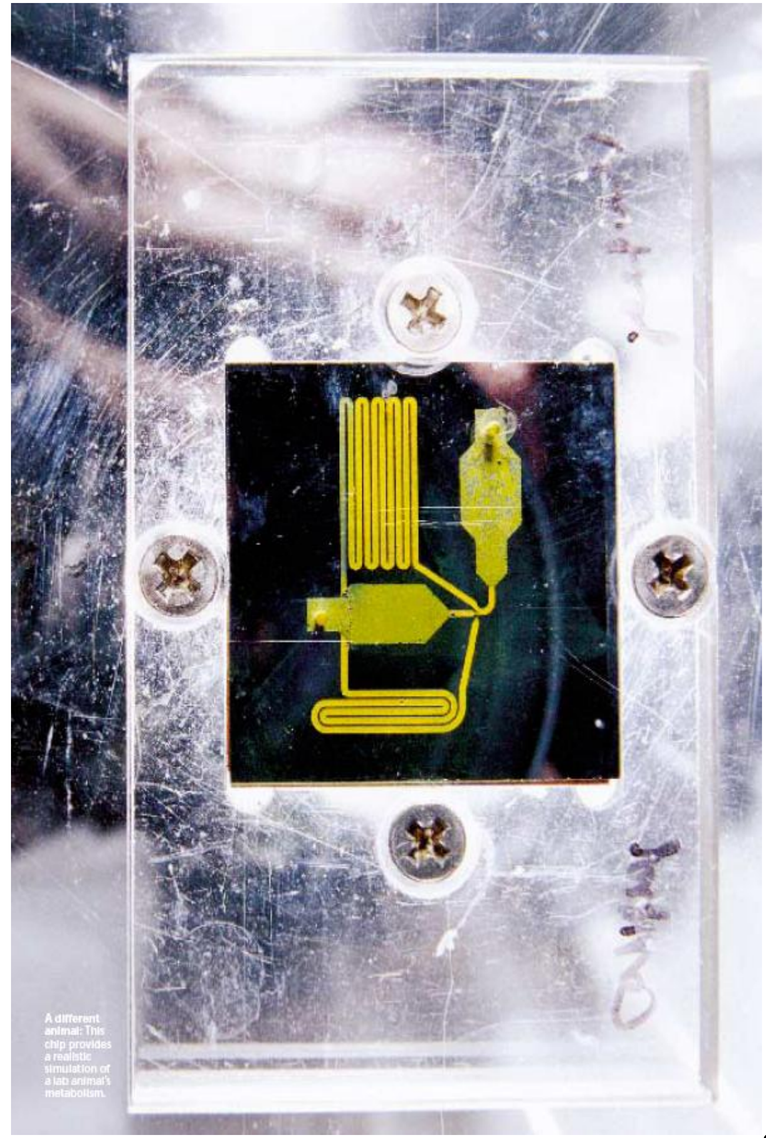
Lab-on-a-chip for Drug Testing

(from Michael Shuler)

the silicon guinea pig

Pharmaceutical companies anxious to see if experimental drugs have toxic side effects may soon turn to a thumbnail-sized silicon chip, packed with live cells, that mimics the metabolism of a lab animal. Such "animal on a chip" devices could help to quickly and cheaply spot toxic compounds, sparing companies years and millions of dollars in the drug discovery process.

BY DAVID H. FREEDMAN | PHOTOGRAPHS BY DAVID BARRY



A different animal: This chip provides a realistic simulation of a lab animal's metabolism.

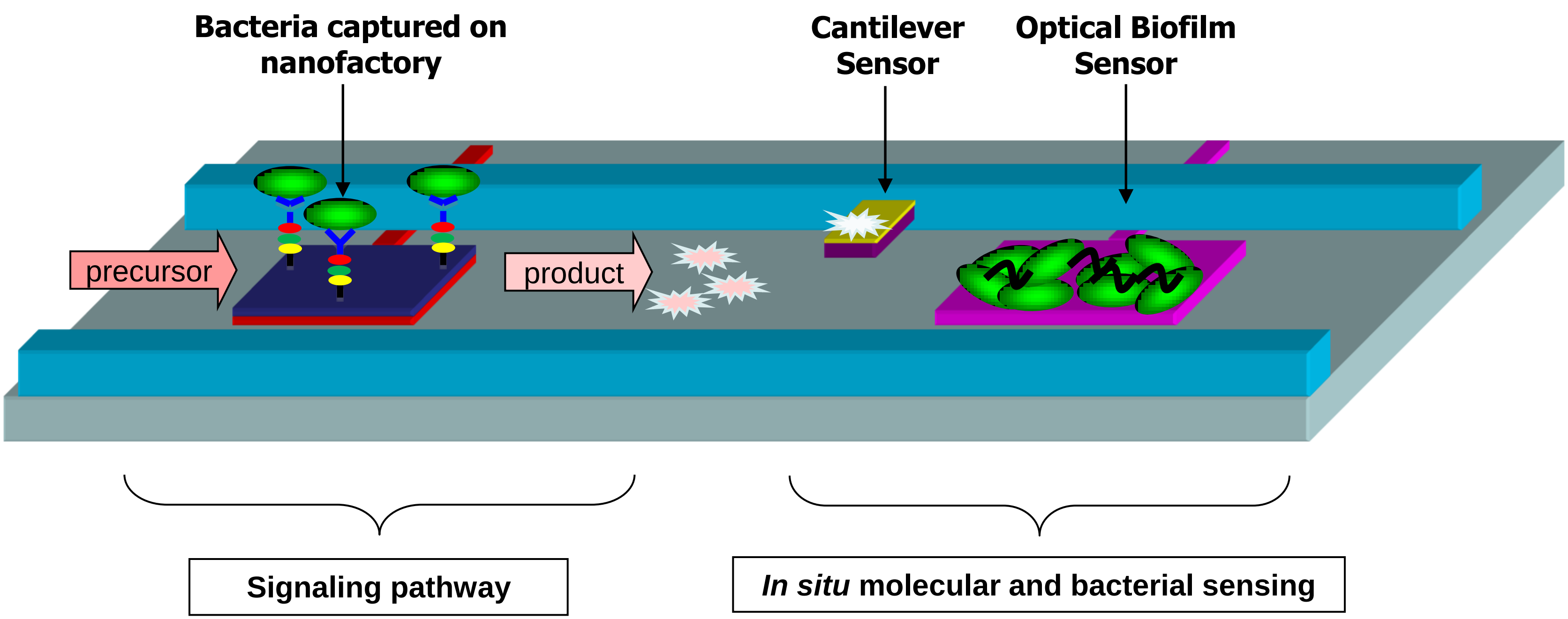
Compositional Synthesis of Heterogeneous LOC

Challenges

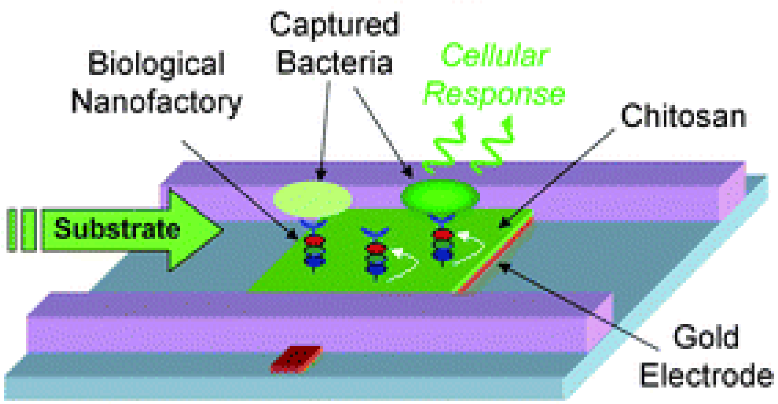
- While both biological and microfabricated systems are capable of receiving and transmitting signals, their communication is often incompatible – **they communicate using different languages**. The challenge is to **engineer a new interface between biological and microfabricated systems**.
- At the present time, **there are no general design tools allowing users to design a LOC for a specific application**. Each LOC device and every component in the LOC must be custom designed from sketches developed by experts in university research labs. Designs by different designers are different, and typically are not inter-operable.
- It is highly desirable to have a general, user-friendly automated design/control tool for LOC development, so that scientists in application areas can design microfluidic biodevices customized for their applications.

MICROSYSTEMS - UMD BIOCHIP COLLABORATIVE

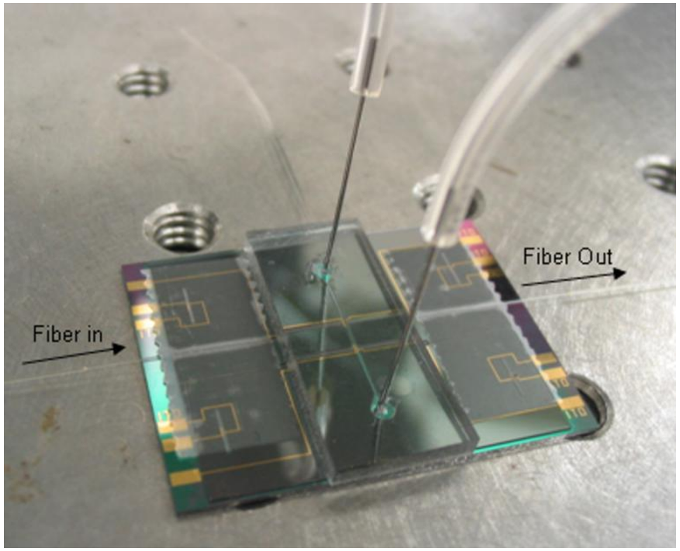
- Utilize molecular bioengineering in translating communication between biological and microfabricated systems
- Focus on manipulating bacterial communication and observing effects on-chip
- Work lays foundation for development of targeted in-vivo devices



MICROSYSTEMS - LAB ON A CHIP ACTIVITIES



R. Fernandes *et al*. Lab on a Chip, 2010



P. Dykstra *et al*. Sensors and Actuators B, 2009

- Aminopolysaccharide chitosan allows for spatially controlled deposition and biological functionality
- Various enzymes are immobilized in microfluidic channels
- Optical, mechanical and electrical detection mechanisms are employed

Example: Network Science

Taxonomy of Networked Systems

Infrastructure / Communication Networks

Internet / WWW
MANET
Sensor Nets
Robotic Nets
Hybrid Nets: Comm, Sensor, Robotic and Human Nets

Social / Economic Networtks

Social Interactions
Collaboration
Social Filtering
Economic Alliances
Web-based social systems

Biological Networks

Community
Epiddemic
Cellular and Sub-cellular
Neural
Insects
Animal Flocks

The Fundamental Trade-off

- The nodes **gain** from collaborating
- But collaboration has **costs** (e.g. **communications)**
- **Trade-off: gain from collaboration *vs* cost of collaboration**

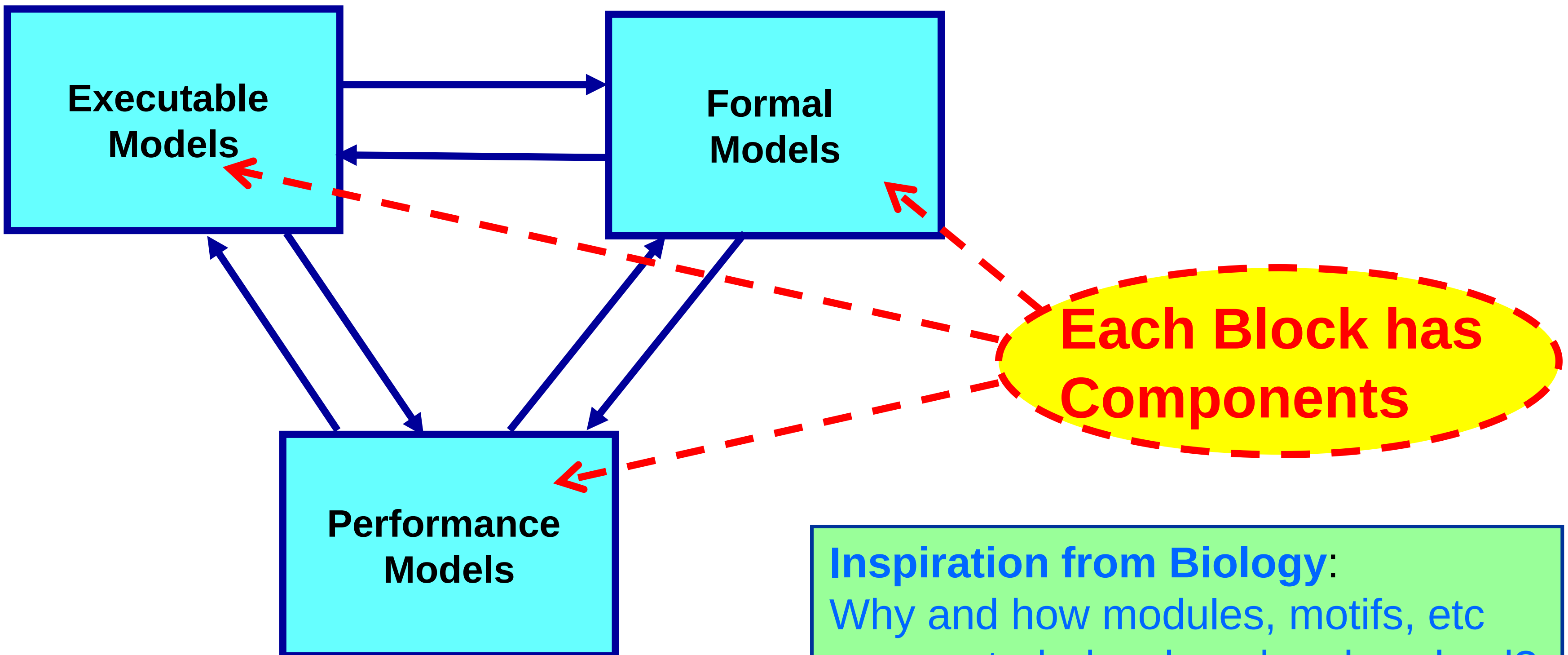
Vector metrics involved typically

➡ **Constrained Coalitional Games**

- **Example 1**: **Network Formation** -- Effects on Topology
- **Example 2**: **Collaborative robotics, communications**
- **Example 3**: **Web-based social networks and services**
- **Example 4**: **Groups of cancer tumor or virus cells**

• • •

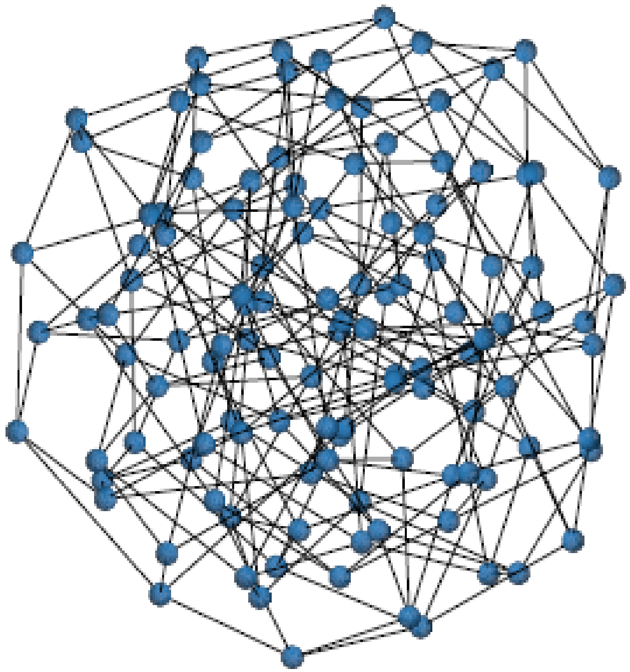
Component-Based Heterogeneous Network Synthesis …

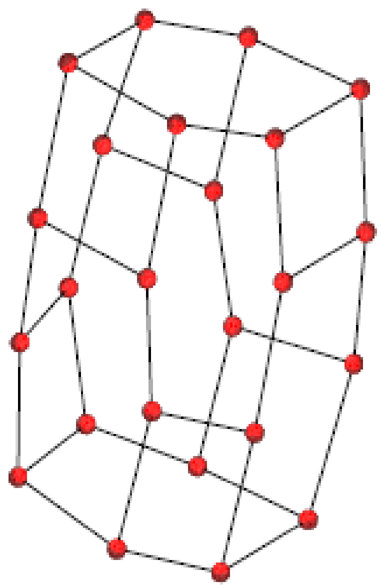


Inspiration from Biology:
Why and how modules, motifs, etc are created, developed and evolved?

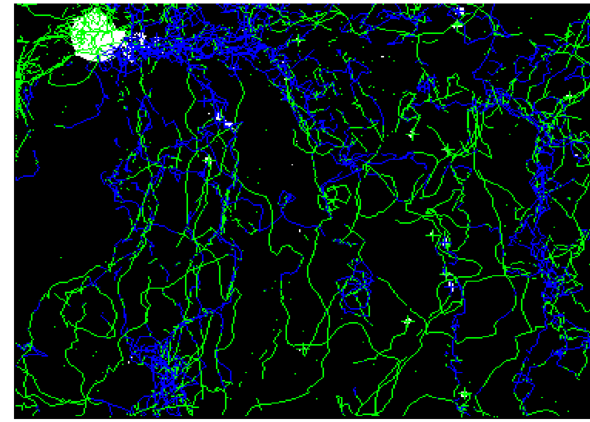
Grand challenge: Develop this framework for distributed, partially asynchronous systems, with heterogeneous components and time semantics

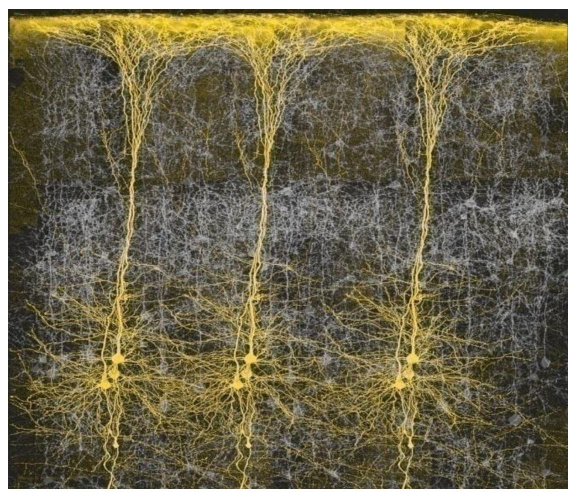
Expander Graphs – Ramanujan Graphs

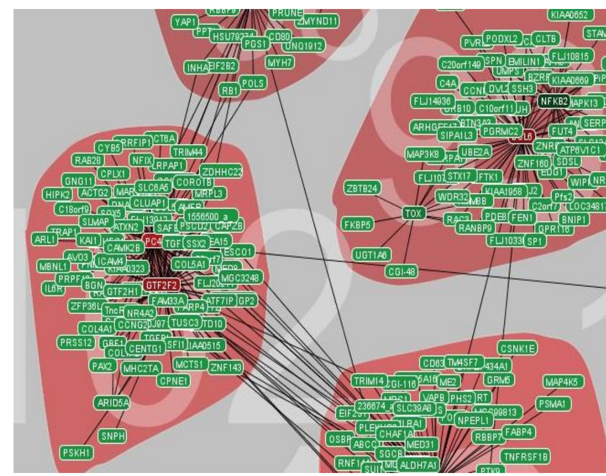




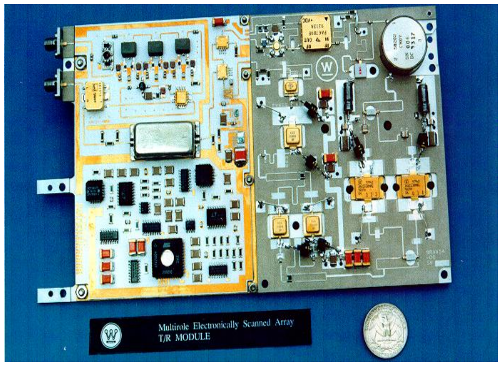
Biological Networks



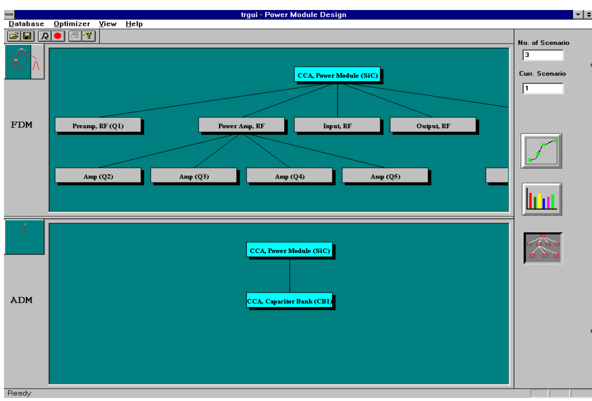




Integrated Product and Process Design of T/R Modules



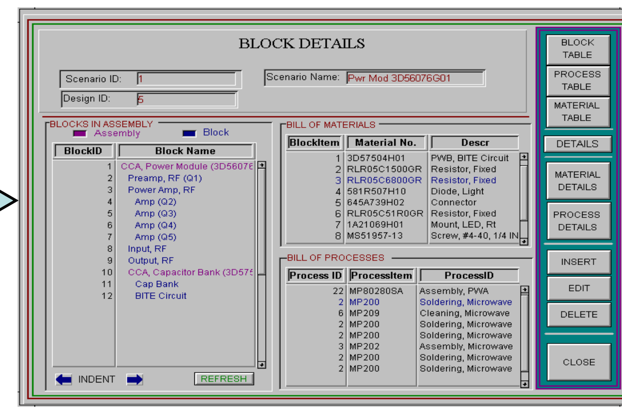
PROBLEM **Integrate Electronic and Mechanical Design**
information interchange among tools used by designers
Identify alternative components
integration with part catalogs, corporate databases
Help generate and evaluate alternative designs
estimate cost, manufacturing time, reliability, etc.evaluate tradeoffs
Help generate process plans
process parameters, time estimates, etc.



Assembly Data Model
Process Designer View

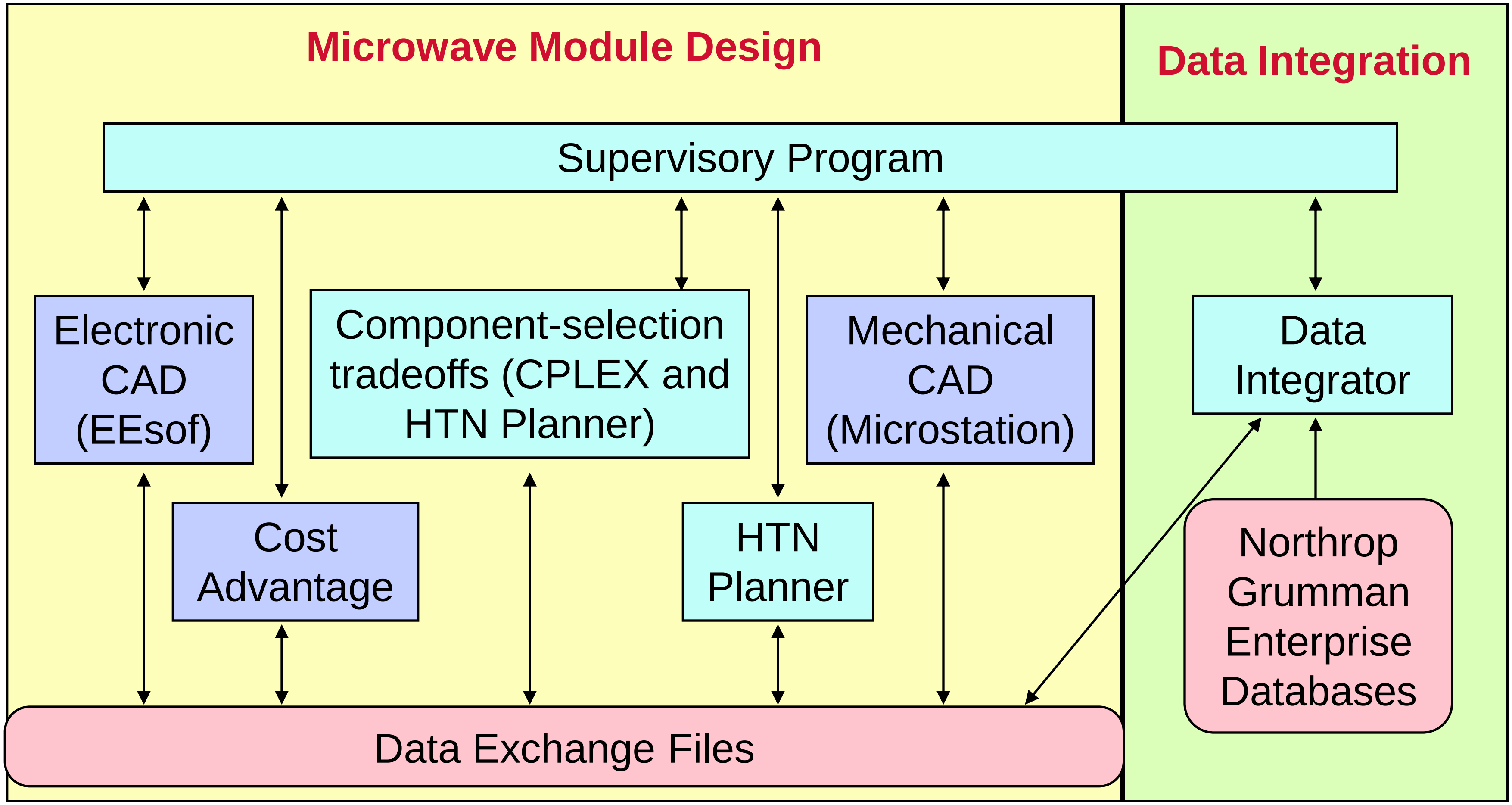
Entity-Relation Diagrams

Functional Data Model
Product Designer View

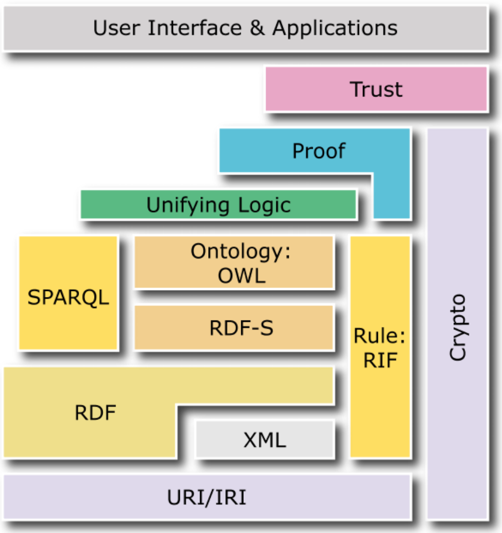


SOLUTION **Object-Relational Databases and Middleware to integrate heterogeneous distributed data sources:**
multi-vendor DB, text, data, CAD drawings, flat, relational, object DBs
Entity-Relation Diagrams to provide multiple expert views of the data and integrate product and process design phases into a single system environment
Hierarchical Task Network planning to explore alternate options at each level of the product: parts and material, processes, functions assemblies
Multicriteria Optimization for trade-offs: cost, quality, manufacturability, ...

IPPD System Architecture



Ontology-Enabled Traceability Mechanisms



Research Objective

Explore benefits of ontology-enabled traceability mechanisms for team-based design and management of SoS.

Observation

The Internet and "project development problems" are both chaotic systems of systems.

Our research approach:

Compare the needs of a requirements engineering system to the Internet and look for solutions along parallel lines of thought.

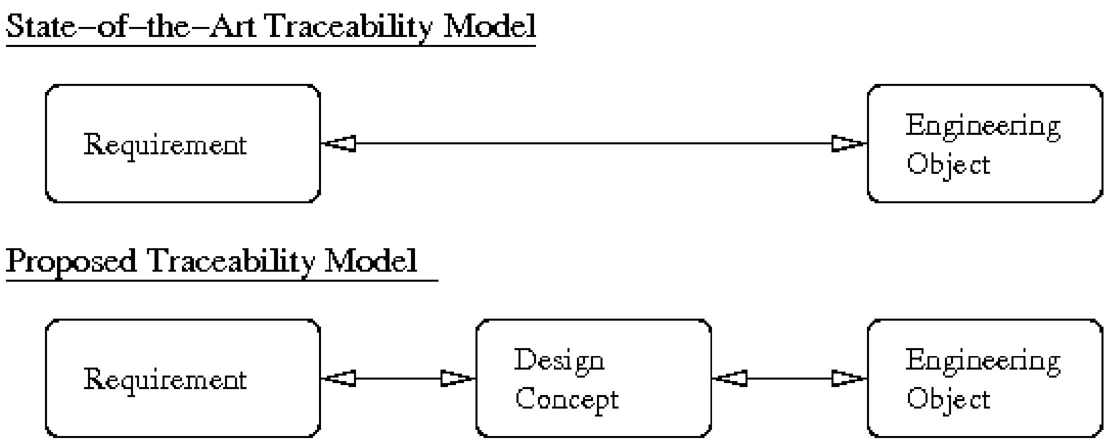
Goals of the Semantic Web:

...give information a well-defined meaning, thereby creating a pathway for machine-to-machine communication and automated services based on descriptions of semantics.

Note: Requirements and UML/SysML diagrams can be encoded in XML and RDF.

Traceability Mechanisms for MBSE

New idea: Ontology-enabled Traceability Mechanisms.

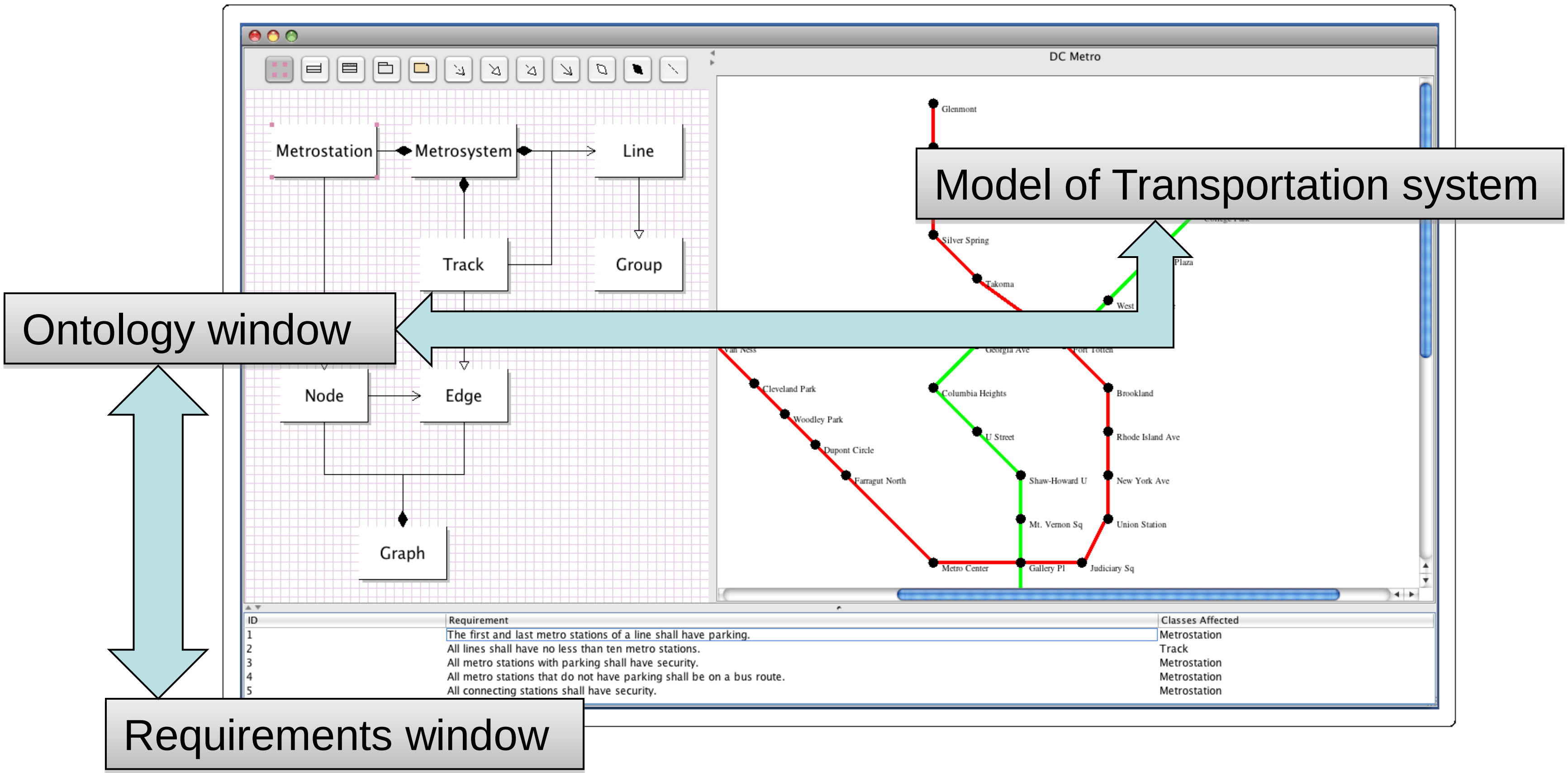


Approach: **Requirements are satisfied through implementation of design concepts**. Now traceability pathways are threaded through design concepts.

Key Benefit: Rule checking can be attached to "design concepts" – therefore, we have a pathway for **early validation**.

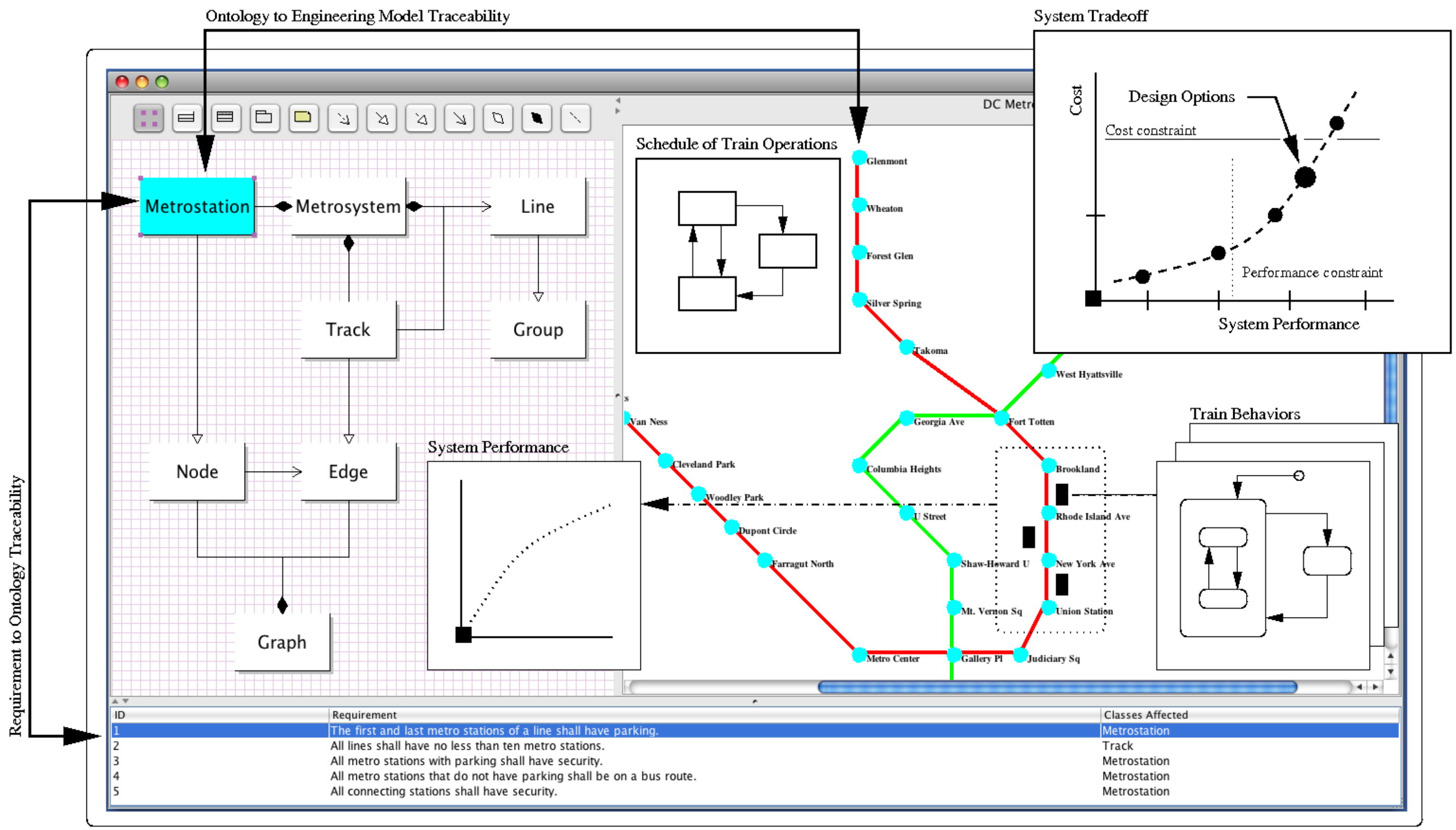
Prototype Implementation: Ontology-Enabled Traceability for Washington D.C. Metro System.

Very simple. UML representation for one ontology. All traceability relationships are hard-coded. Visualization cuts across stages of system development.



Current Work

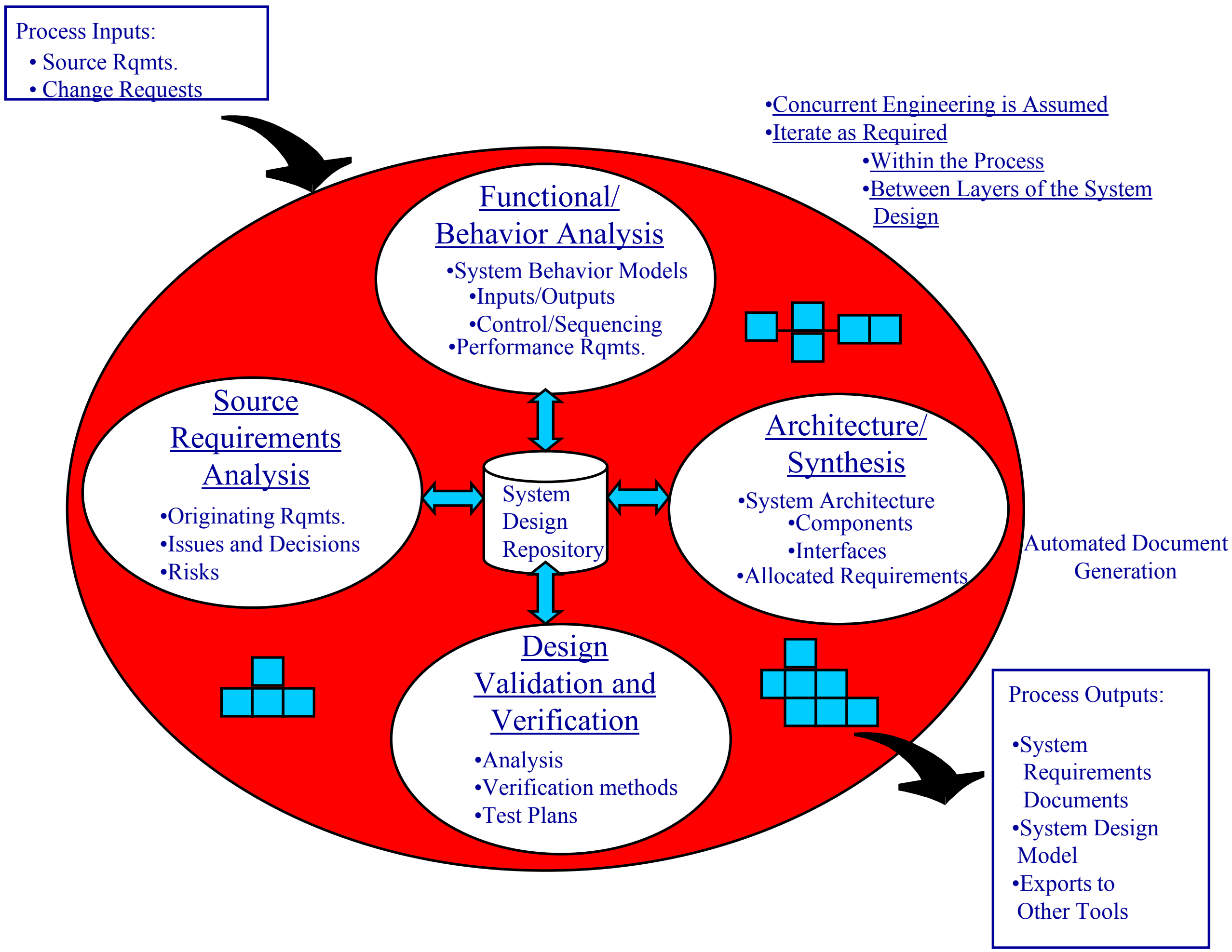
Re-design implementation to maximize use of software design patterns. Add train behaviors. Traceability to states and transitions in behavior. Extend ontology-enabled traceability mechanisms to multiple viewpoint design. Explore use of SysML and Semantic Web Technologies.



Transforming Engineering

- Move from a ***reductionist*** scientific approach to an ***integrative*** scientific approach
- **The challenge is to synthesize engineering systems so as to be able to generate predictable system behavior and performance by integrating behaviors and performance of system components**
- We call this ***compositional synthesis*** of complex engineered systems.
- This compositional synthesis advances engineering to the next frontier, **way beyond 'plug and play synthesis'**

Advanced Methods and Environments for Systems Engineering



CORE SYSTEMS ENGINEERING TOPICS

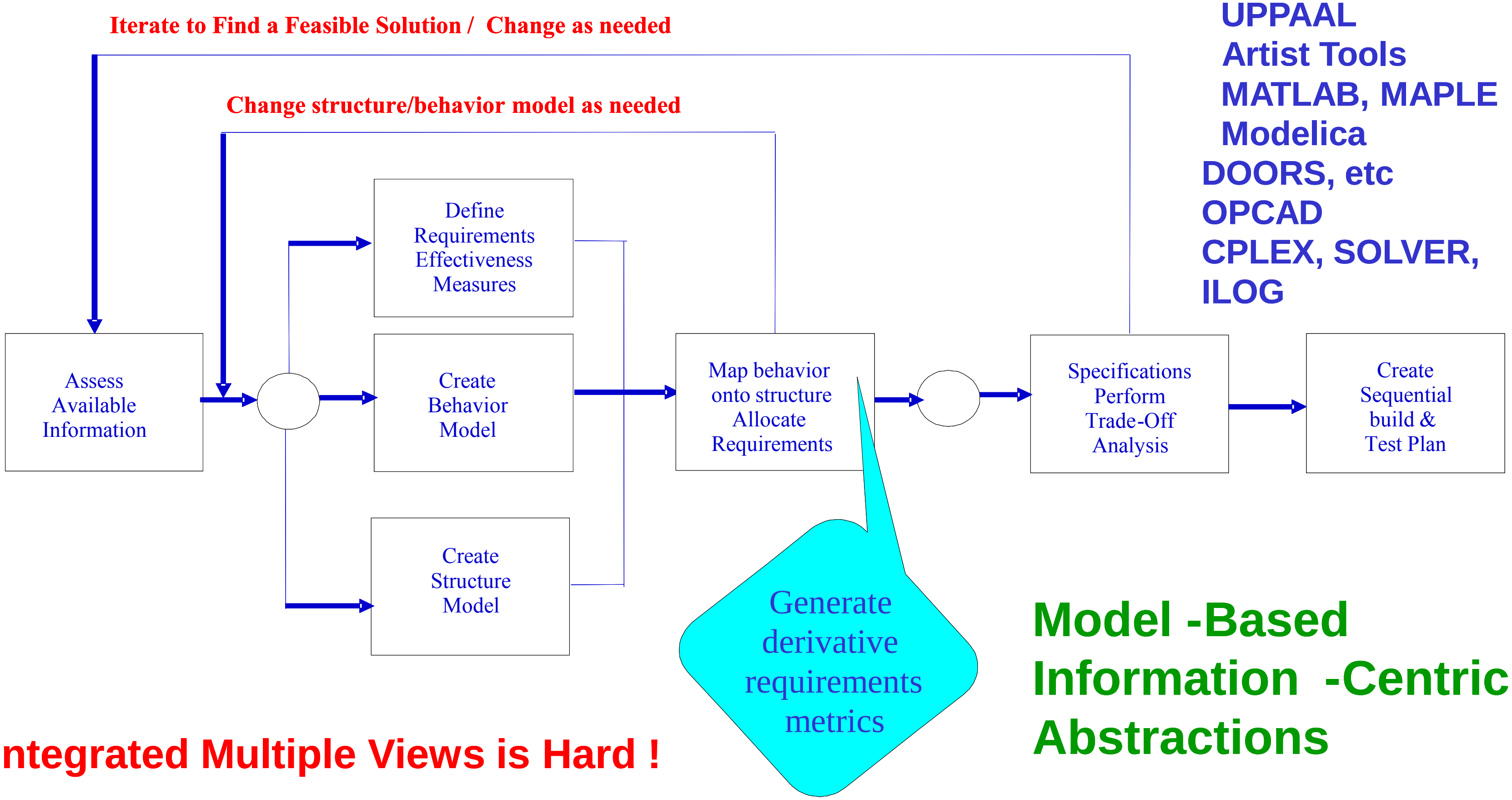
- Object Oriented modeling and beyond
- Automata, languages, design rules
- Trade-off analysis and multi-objective optimization
- Testing, validation, behaviors
- Logic programming and optimization
- Performance over time, hybrid systems
- Simulation and performance analysis

Component-Based System Design and Synthesis Process

Integrated System Synthesis Tools - Environments missing …

Model-based
- **Beyond UML -- SysML**
- **Rapsody**
- **UPPAAL**
- **Artist Tools**
- **MATLAB, MAPLE**
- **Modelica**

DOORS, etc
OPCAD
CPLEX, SOLVER, ILOG



Model -Based Information -Centric Abstractions

Integrated Multiple Views is Hard !

MASTERS PROGRAMS IN SYSTEMS ENGINEERING

Master of Science, Systems Engineering (MSSE)

A broadly-based, cross-disciplinary degree offered by ISR. Designed with substantial industry input, the MSSE program covers a range of topics, from systems definition, requirements, and specifications, to systems design, implementation, and operation, in addition to the technical management of systems projects.

Professional Master of Engineering, Systems Engineering (ENPM)

A practice-oriented, part-time graduate program that helps engineers develop their professional careers and provides technical expertise needed in business, government, and industrial environments. Offered by the A. James Clark School of Engineering.

MASTER OF SCIENCE, SYSTEMS ENGINEERING

The MSSE degree offers both thesis and non-thesis options.
The following courses are required:

Systems Engineering Core

ENSE 621 Systems Concepts, Issues and Processes

ENSE 622 System Requirements, Design and Tradeoff Analysis

ENSE 623 Systems Projects, Validation and Verification

ENSE 624 Human Factors in Systems Engineering

Management Core

ENSE 626 Systems Life Cycle Cost Estimation

ENSE 627 Quality Management in Systems

Those choosing the thesis option also take ENSE 799 Master's Thesis (for six credits) as well as an additional two electives. Those choosing the non-thesis option take an additional four electives.

PROFESSIONAL MASTER OF ENGINEERING, SYSTEMS ENGINEERING

Designed for working engineers. Late afternoon and evening classes are taught by faculty and experienced adjunct faculty at College Park, learning centers in Maryland, and online. There are 30 credits of course work and no research component.

Degree Requirements

The ENPM Systems Option requires four courses from the systems engineering core, three from the management core, and four electives. The courses are identical to the MSSE curriculum.

Systems Engineering Core

ENPM 641 Systems Engineering Principles

ENPM 642 System Modeling and Analysis

ENPM 643 Systems Engineering Design Project

ENPM 644 Human Factors in Systems Engineering

Management Core

ENPM 646 Systems Life Cycle Cost Estimation

ENPM 647 Quality Management in Systems

Technical Electives

Project management, information systems, software engineering, computer and software systems, control systems, process systems, manufacturing systems, signal processing systems, communication and networking systems, and operations research. Courses come from the ENPM program as well as from regular departmental offerings.

Key Questions for Undergraduate Engineering Education

How to implement the best changes to prepare students for system level design and compositional synthesis?

A change of culture is required!

- **What are the common elements?**
- **How to best prepare Engineering students?**
- **How early to introduce what?**

Undergraduate Engineering Education

- Educational Challenge: undergraduate courses with system level thinking
- My three favorite topics:
  - System Models for Synthesis (calculus, logic, physics)
  - Signals and Measurements Representation and Processing
  - Optimization, Trade-off analysis, Feedback
- To be taught in all Engineering Departments, supported by appropriate hands-on applications (a la Medical School)
- Will help create communication between disciplines via the appropriate IT abstractions
- Currently offering “ENES 489P: Hands-on Systems Engineering Projects” – Capstone Pilot

NEW FOR FALL 2010

ENES 489P

SPECIAL TOPICS IN ENGINEERING

HANDS-ON SYSTEMS ENGINEERING PROJECTS

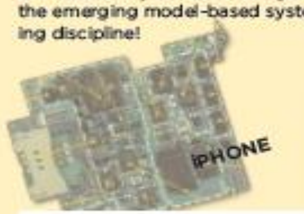
WOULD YOU LIKE TO UNDERSTAND:

- How to master system complexity?
- How to build systems to meet time and budget requirements?
- How to build systems that can be easily verified and validated?
- How to control risk?
- How to design safe systems?

This course will be a great opportunity for senior-level undergraduates and graduate students in all engineering disciplines. You'll get the chance to work in teams on hands-on, complex systems design in collaboration with industry and government experts.

Be among 10 select groups in the country to be introduced to the new area of systems engineering. Systems engineering is rapidly developing as a much-sought-after career path for engineers of all kinds and is proven to be a critical factor for U.S. competitiveness.

Get ahead of your class and get introduced to the emerging model-based systems engineering discipline!



INSTRUCTORS Professor Mark A. Austin and Professor John S. Baras
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3 CREDITS

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www.isr.umd.edu/~austin/enes489p.html

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Questions?