Successes and Challenges in MBSE Education: from High-School to Post-Graduate

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Institute for Systems Research

Mission

ISR is home to cross disciplinary 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

The ISR is a permanent, interdisciplinary research unit in the Clark School of Engineering at the University of Maryland

- Successful NSF Engineering Research Center
  - One of first group of ERC's awarded (1985)
  - Graduated, fully self-sustaining
  - Permanent Institute status (1992), with base budget support
- Research leadership
  - Network security
  - Mobile and sensor networks
  - Hybrid communication networks
  - MEMS sensor and actuator design and fabrication
  - Nanotechnology
  - Manufacturing and product realization systems
  - Neuroscience and Neuromorphic engineering
  - Systems engineering methodologies
  - Signal processing and multimedia systems
  - Advanced control systems techniques
  - Supply chain management
  - Transportation systems such as air traffic management
- Cross-disciplinary, systems-focused education program
- Collaborations with Federal and State agencies, local and international corporations and universities worldwide.
- Commercial implementation of research results

The Next Frontier in Engineering Research and Education

- First quarter 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**

Economic, Market, Technology Drivers

- Rapid changes in technology
  - telecomm devices, the Internet, MEMS, biotechnology and bioengineering, microelectronics, DSP, software
- Fast to market most critical
  - moving niche markets; mass markets: winner-take all phenomena
- Increasing pressure to lower costs
  - standardization, open architectures, interoperable subsystems/components
- Increasingly higher performance requirements
  - communicate with multimedia to and from anyone, at any time, anywhere, data-driven mass-spectrometer, cellular networks with .9999999 availability
- Increasing complexity of systems/products
  - Lab on the Chip, cell telephone on the chip, materials with “on demand” physical properties, personal digital assistants, information networks, advanced aircraft, communication satellites
- Increasing presence of embedded information and automation systems
  - smart materials, smart spaces, wearable health monitors, electronically adjustable car suspensions, self-healing telecommunication networks, implantable precision drug delivery devices
- 70% of product/system failures due to bad or no SE effort

The Next Frontier in Engineering Research and Education (cont.)

- Encounter frequently ***system of systems***
- Complexity manifests itself through **heterogeneity of subsystems and components**
- The synthesis of complex engineered and other systems from components so as to meet specifications and the associated education **represent the next frontier in engineering research and education**
- It is the frontier that **will determine the next generation leaders among Universities and industry**

Complex Engineered Systems

- Critical characteristics
  - Many heterogeneous physical layer, hardware, software components
  - Multiple scales (time and structure)
  - IT and physical components are integrated for : learning and adaptation, higher performance, self-organization, self assembly
- They should be regarded as
  - distributed, asynchronous and hybrid dynamical systems
  - systems of subsystems that **sense, make decisions and execute actions**
  - closed loop systems with many loops
- These blocks are not co-located : fundamental limitations in performance and operation
- Knowledge foundation for most ISR faculty and students: control, communications and computer engineering

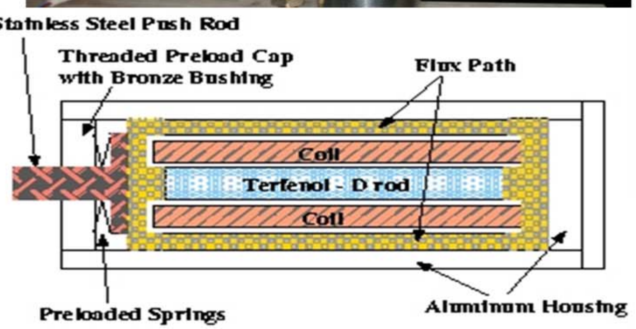
Complex Engineered Systems and IT

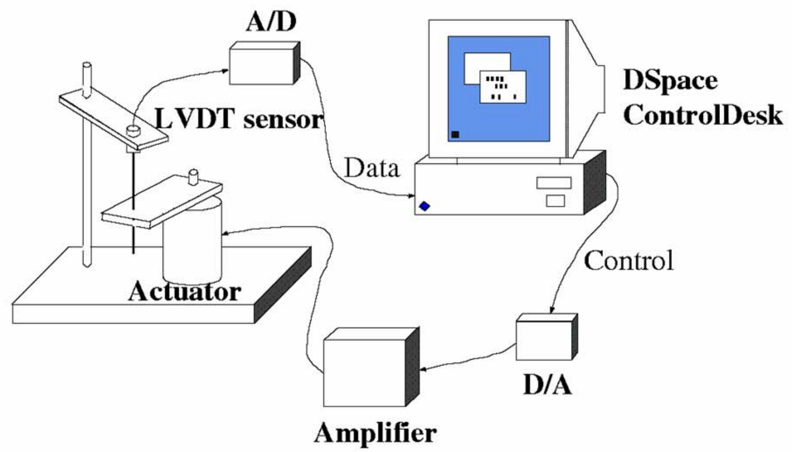
- As we embed an increasing number of IT components into complex engineering systems the nature of computation is also changing
  - different physical layers and platforms are used to execute these computations
- Now and in the future, we envision devices performing these computations and functions at scales not used before,
  - in physics-chemistry environments that are not just based in microelectronics
  - E.g. MEMS and microfluidics sensors and actuators, or nano sensors and actuators
- Increasingly these IT components are networked within the system
- Furthermore the behavior, safety and performance of complex engineered systems depend increasingly on the performance, design and safety of these IT components

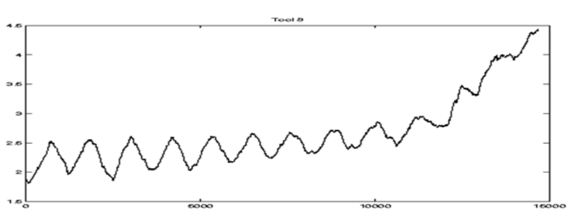
Sensing and Actuation via Micromagnetics Biologically Inspired Signal Processing

Control of a magnetostrictive actuator; micropositioning; challenge of hysteresis

- *Smart materials*
- *Shape memory alloys*
- *Micromagnetic control*
- *Magnetic wall motion*
- *Memory devices*
- *Cancelling waves*
- *Smart toolposts*
- *Micromagnetics with controlled characteristics*
- *Nanomagnetics*







Estimate the wear of a milling tool from information in the acoustic emissions via biologically inspired signal processing

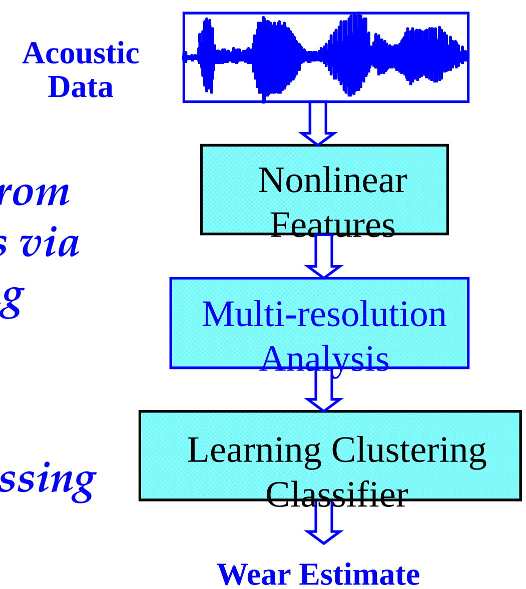
Vehicle acoustic identification

DOA estimation and acoustic ID

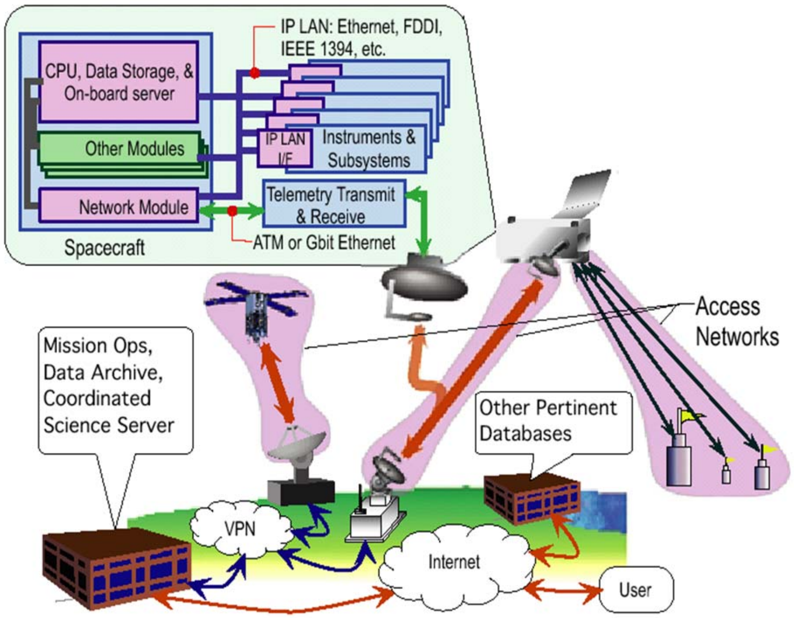
Stereausis and nonlinear sound processing

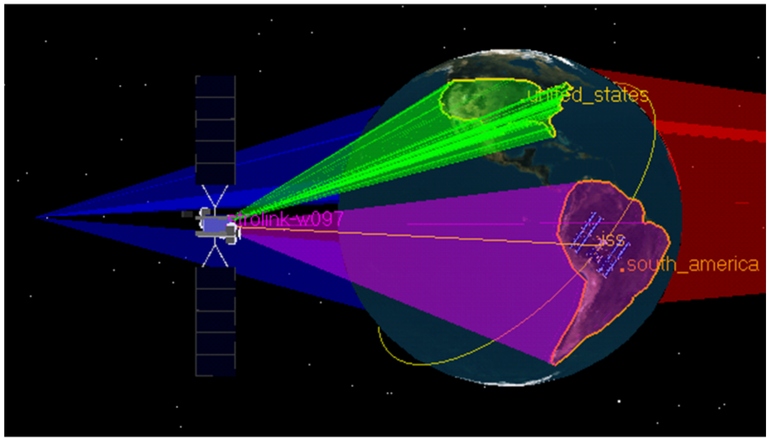
Speech recognition

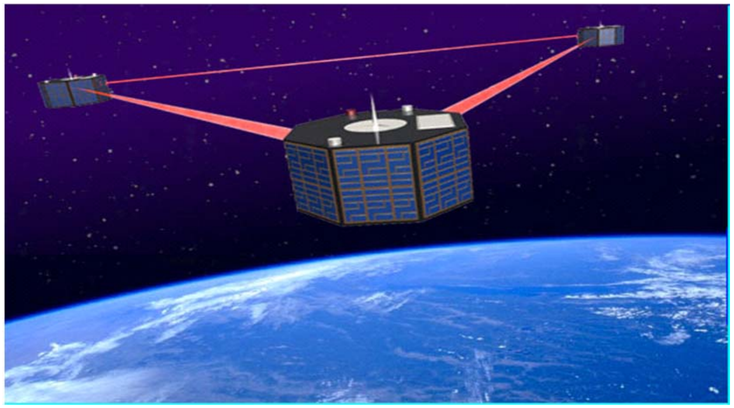
Speaker Identification

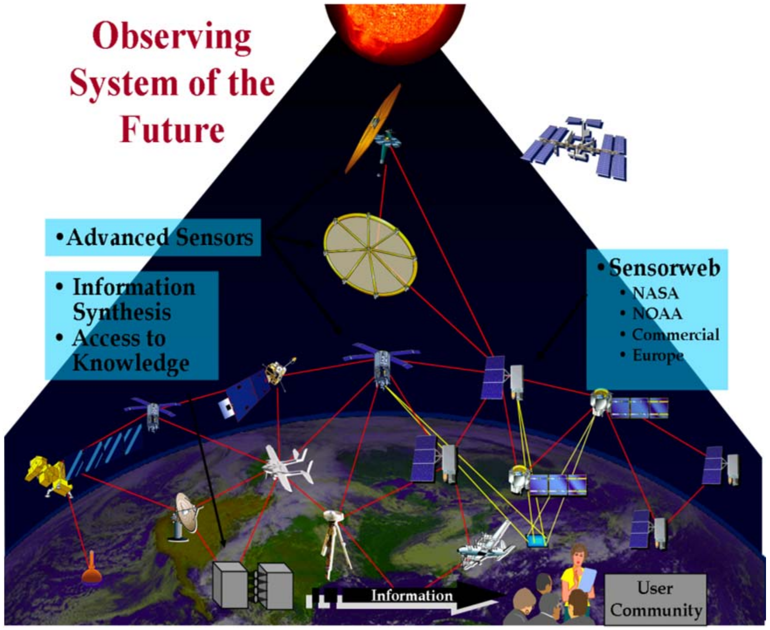


Hybrid Networks, SensorWebs, the ISS, Micro- and Nano-satellites



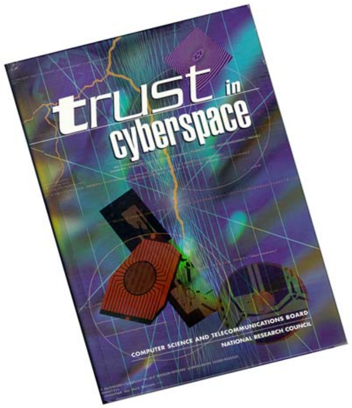


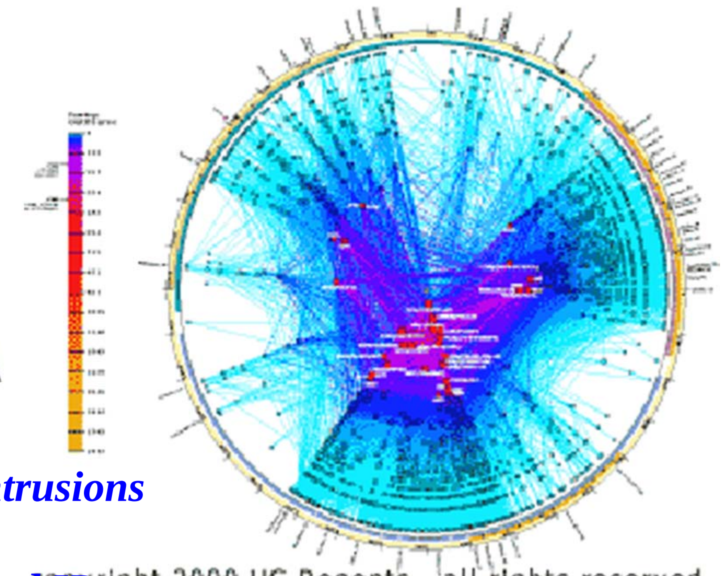




Systems Security

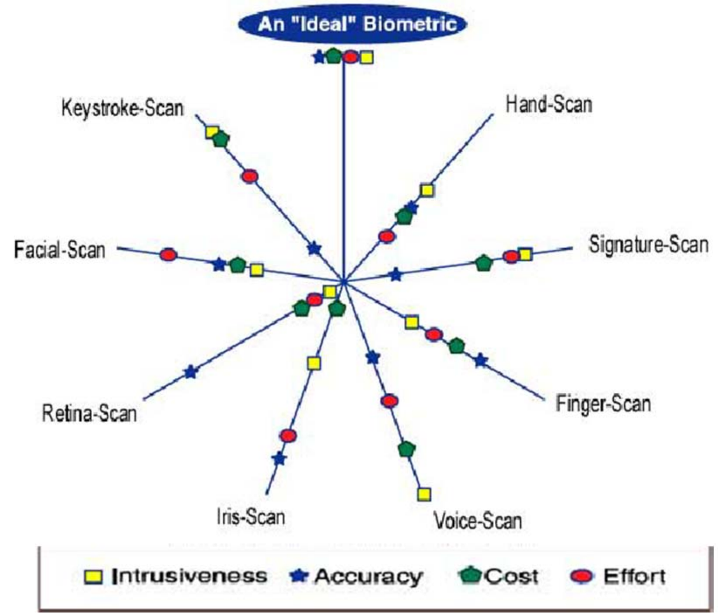
Network security and Information Assurance

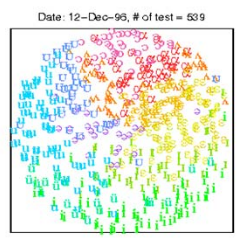


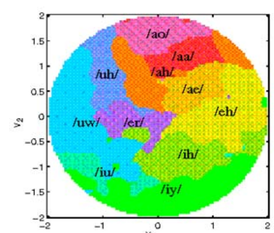


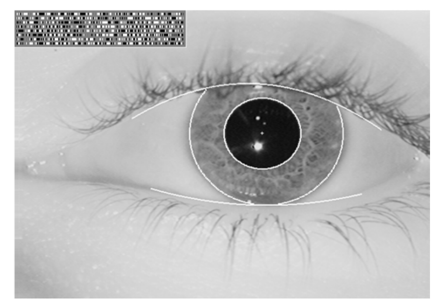
Formal models for intrusions
Attack Trees
Intrusion detection and ID
Learning attacks
Flow dynamics
Knowledge Management
Proactive control/response
Dynamic games
Distributed immune systems
Key management
Distributed trust establishment
Dynamic system problem
Dynamics on graphs

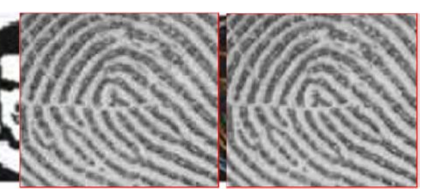
Biometrics



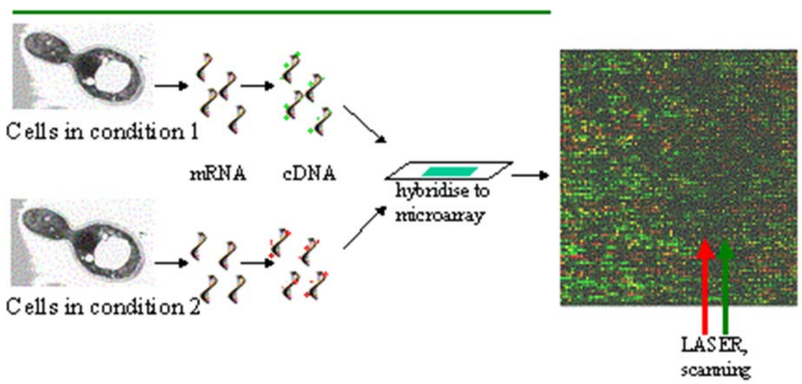


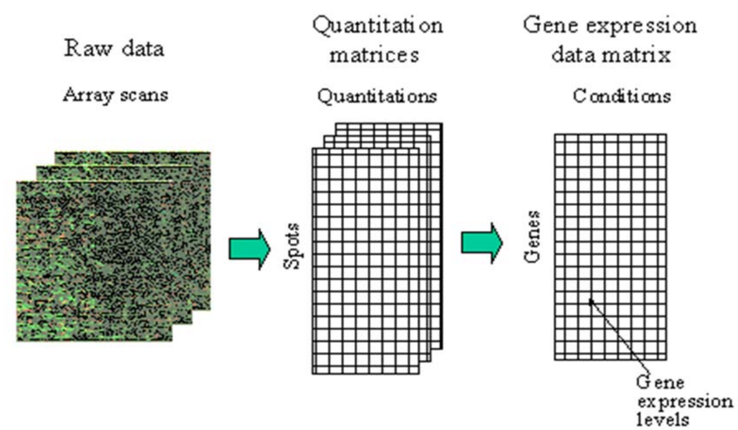




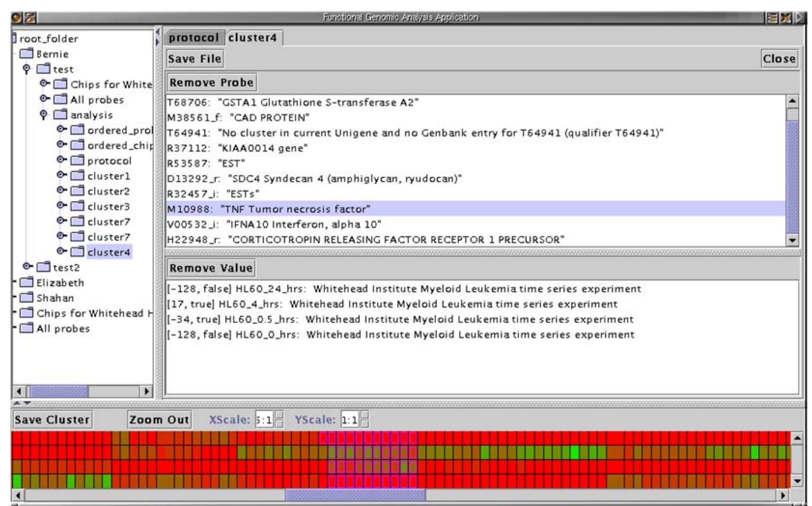


Systems Biology: Biotechnology

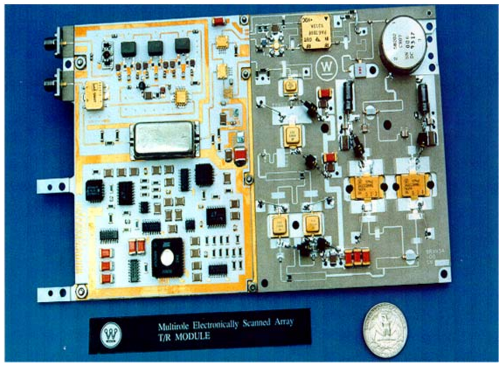




- *Gene Microarrays*
- *Expression analysis*
- *Target discovery*
- *Correlation with metabolic pathways*
- *Function discovery*
- *Proteomics*
- *In-silicon biology*
- *Cross-genome analysis*
- *Cell and Multi-cell dynamics, signaling, control*
- *DNA - computing*
- *Post-genome = systems biology*

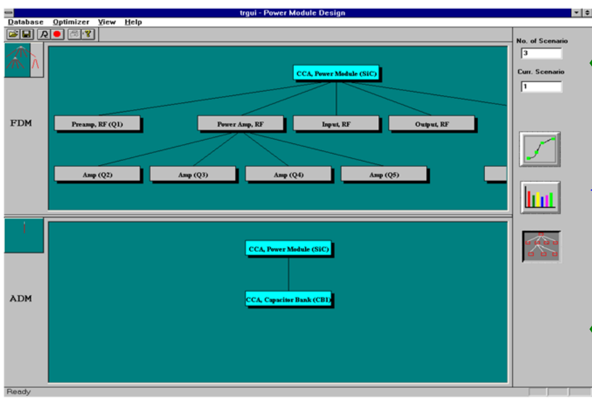


Integrated Product and Process Design



PROBLEM

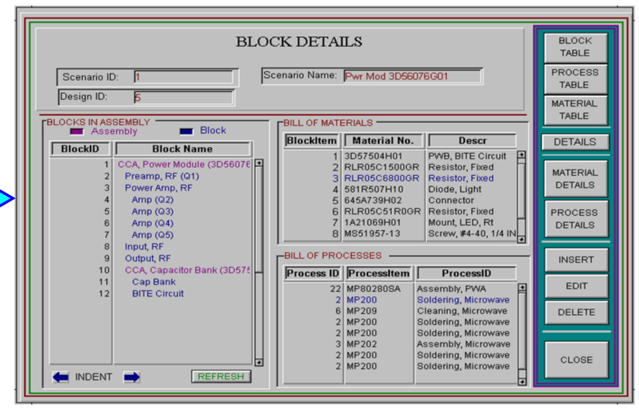
- **Integrate Electronic and Mechanical Design**
  - information interchange among tools used by designers
- **Identify alternative components**
  - integration with part catalogs, corporate databases
- **Help generate and evaluate alternative designs**
  - estimate cost, manufacturing time, reliability, 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

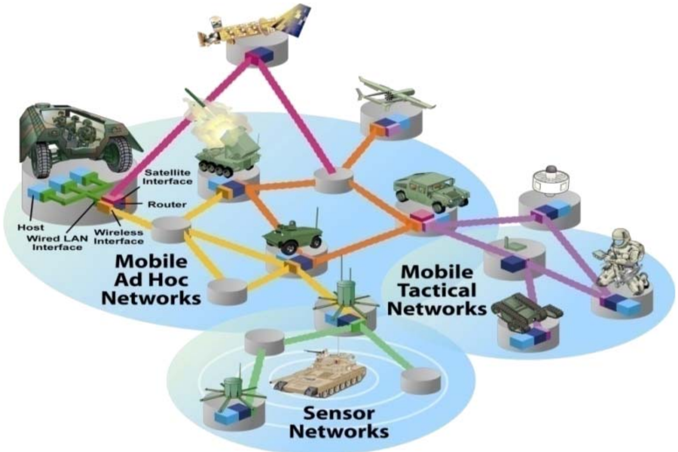


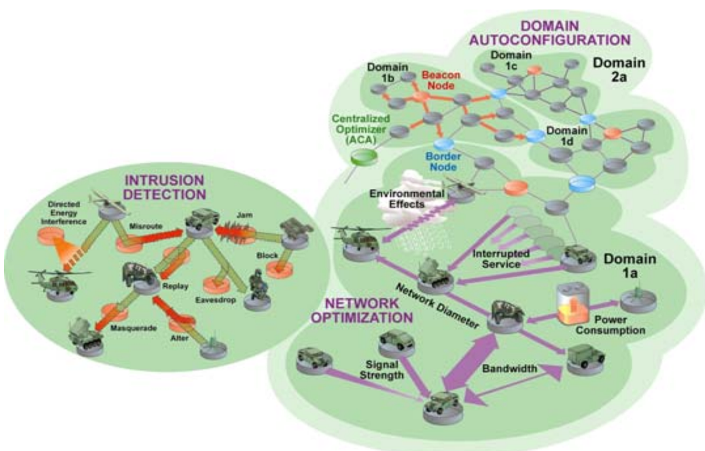
SOLUTION

- **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, ...**

Example: Broadband Mobile Wireless Infrastructures (BMWI)

Hybrid MANET and WSN

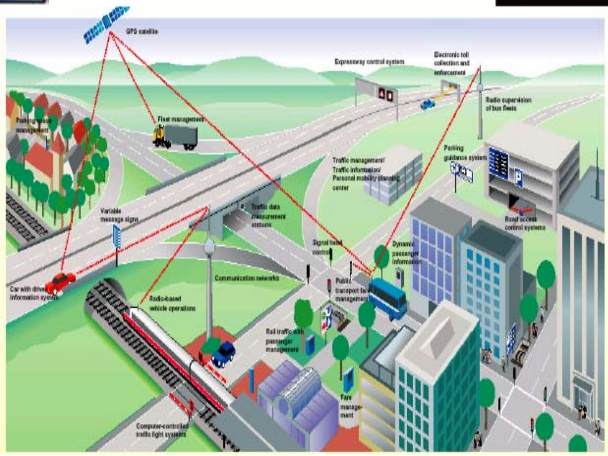


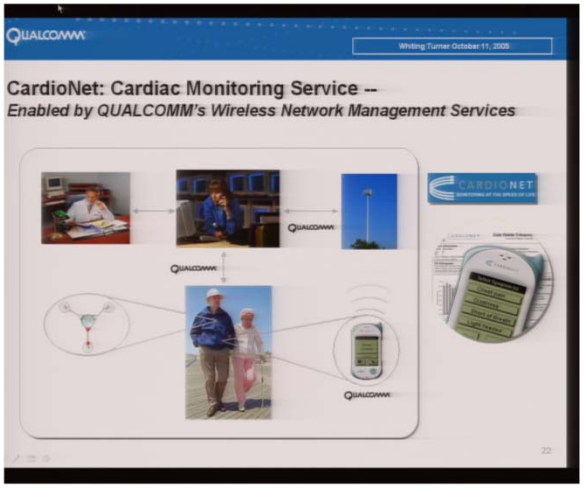


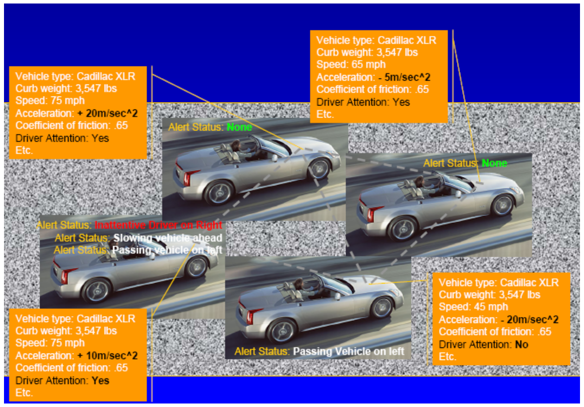
- **System of Systems or Network of Networks**
- **Integrate: network management, security, routing, MAC, networks …**
- **Innovative services**
- **Net centricity**

Component Based Networking

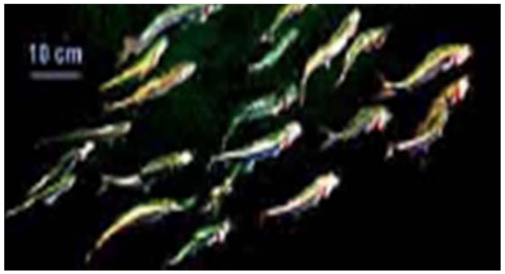
Broadband Wireless: Shaping Societies and Civilization





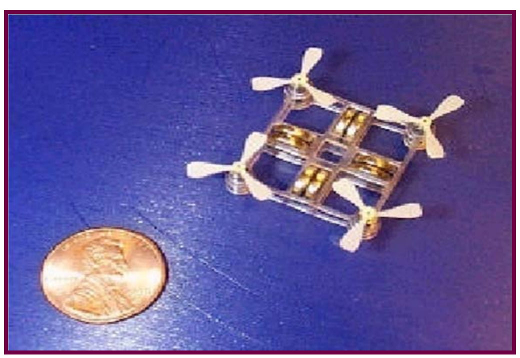


Example: Autonomous Swarms – Networked Control



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

Collaborative Robotic Swarms



Transforming Engineering Education – Incorporate Systems 'Thinking'

- Develop systematic ways to engineer component-based architectures for synthesis and manufacturing of complex systems from heterogeneous components and supply chains
- Address directly the need for the two fundamental shifts in engineering design
  - **moving forward from the 'design to manufacture and assemble' to 'integration and product-life cycle mangement' of heterogeneous components. Thus we do not need to insist anymore on 'orthogonality of concerns' for the components. They can overlap or be 'quasi-orthogonal'.**
  - **the ubiquitous embedded IT components allow better integration and most importantly via programmability allow for new functionalities to be created and for easier insertion of new technologies in a system during its life-cycle.**
- What is happening in aerospace and automotive industry is a good example.
- These trends are becoming pervasive in all engineered systems.

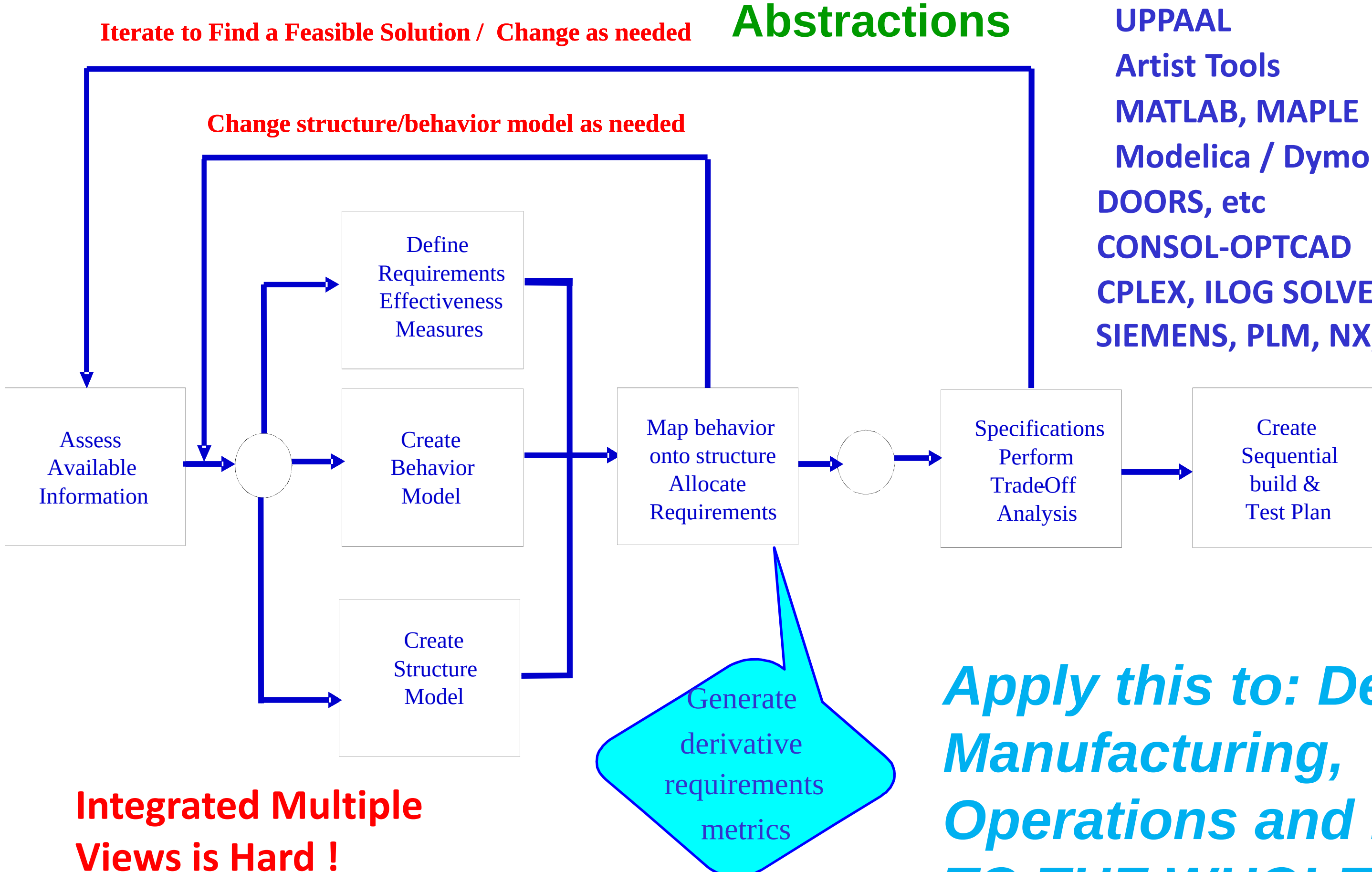
MODEL BASED SYSTEMS ENGINEERING

Integrated System Synthesis Tools & Environments missing

Model - Based Information – Centric Abstractions

Model- - based
- UML - SysML - GME - eMFLON
- Rapsody
- UPPAAL
- Artist Tools
- MATLAB, MAPLE
- Modelica / Dymola

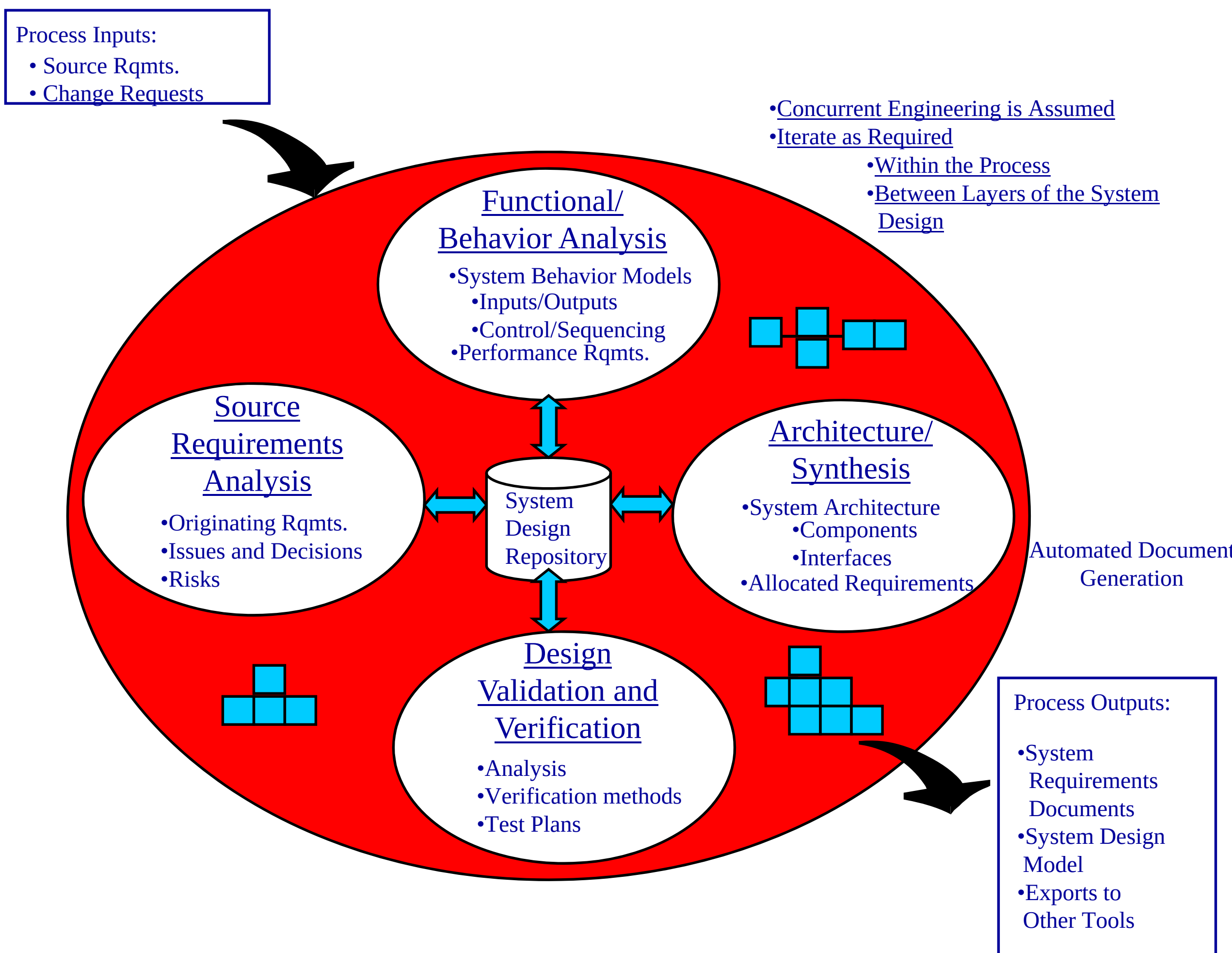
DOORS, etc
CONSOL-OPTCAD
CPLEX, ILOG SOLVER,
SIEMENS, PLM, NX, TEAM CENTER



Integrated Multiple Views is Hard !

Apply this to: Design, Manufacturing, Operations and Management TO THE WHOLE LIFE-CYCLE

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

The Challenge and the Opportunity

From a synthesis perspective

- Architecture
- Requirements and their Management
- Formalization of the constraints imposed by the physical layer (physics and chemistry at the appropriate scale)

  Physical - cyber interface and boundary

Grand Challenge :

Compositional Approach to Complex Engineered Systems Design / Synthesis, Manufacturing and Life-Cycle Management

What is really needed is a Transformation in Engineering:
in R&D and in Education

Software Engineering *vs.* Systems Engineering

- Software Engineering with Object Orientation, UML, metrics, etc. has made a lot of progress towards this process
- Similar efforts are under way for Systems Engineering
  - Most lack serious foundations
  - All ignore the **Physics Question**
- **Systems Engineering is much harder than Software Engineering**, precisely because the **design rules predicated by the physics of implementation (electrical, chemical, mechanical, hybrid, etc.) must be satisfied**
- **Physics of implementation must be also selected**: Multi-physics models and design
- Only then we can repeat the VLSI "miracle" in system synthesis
- Can it be done? **YES**

  See the design of Boeing 777

“Physics” Matters

- **System Synthesis** requires the following steps (at least)
  - **Collection of Requirements**
  - **Construct System Structure (what the system consists of)**
  - **Construct System Behavior (what the system does)**
  - **Map Behavior onto Structure and vice a versa (what components will perform a specific part of behavior)**
  - **Allocate requirements to Structure and Behavior**
  - **Trade-Off Analysis**
  - **Validation and Verification (i.e. Test Plan)**
- In this process **implementation technology** must be specified at some point (c.f. silicon, dimension, MEMS, ?)
- **Physics is central** to the latter but influences all others
- **Reducing Design** (read Synthesis) **to compilation** requires understanding and characterization of design rules and their incorporation in the synthesis process
- But physics selection **must be done late** in the synthesis process

Educational Needs / Background

- Need to "see the bigger picture" earlier
- Current undergraduates are different from past and heterogeneous
  - Heterogeneity will increase; especially among the very best; the candidate "creators" of future engineering breakthroughs
- Basic calculus, physics and chemistry already done at a very good level among the best high schools; AP courses; College bypass
- Computers as indispensable communication-modeling-experimentation tools
- Programming replaces calculus; a "representation" symbology
- The Internet; access to knowledge that is easily searchable; multimedia depositories of experiments
- Virtual 3-D Labs
- Easier to collaborate

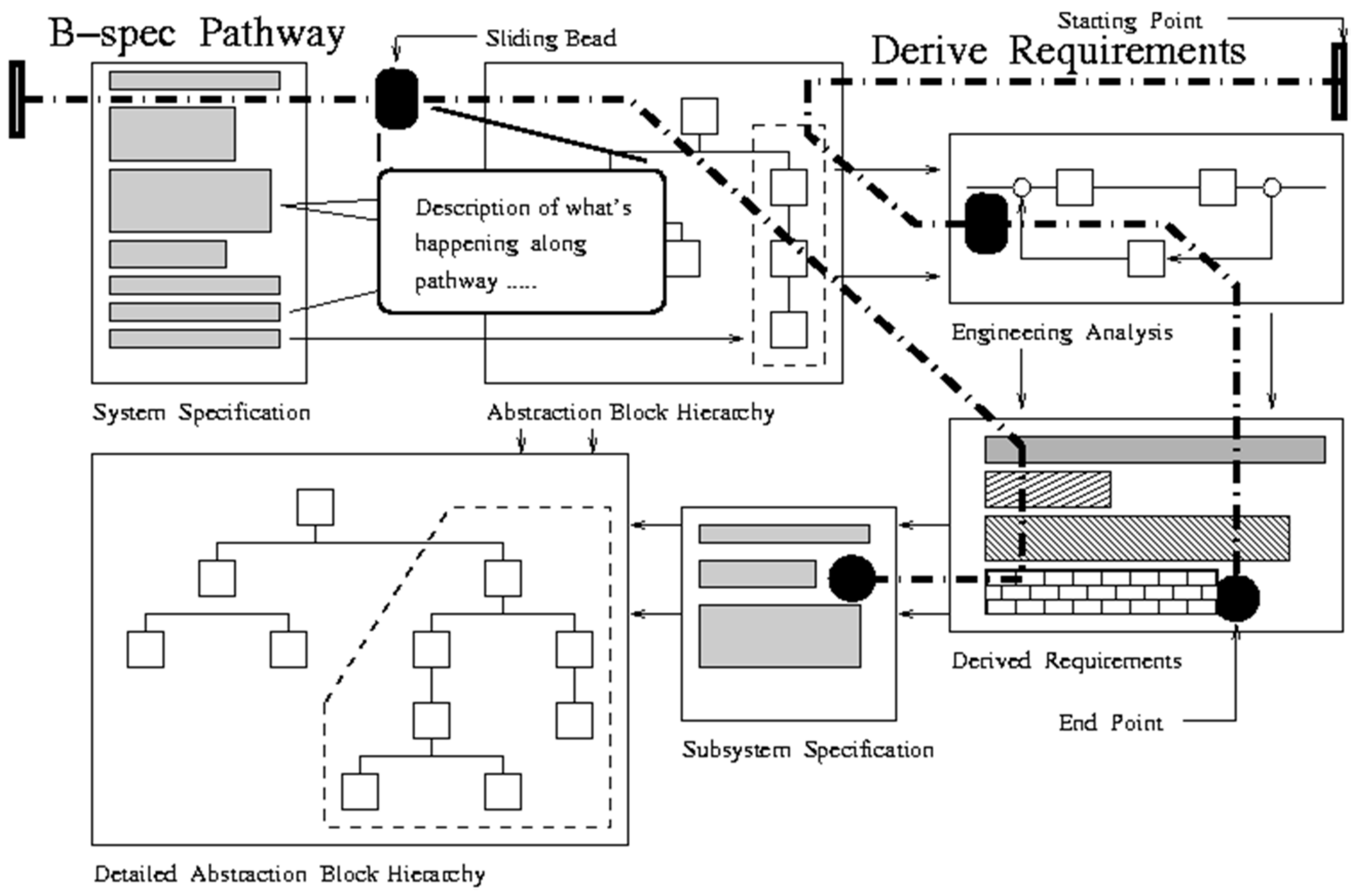
Our Strategy and Approach

- Promote “information technology-centric” design, operation and management of systems/products
- Do everything using computers and information abstractions: from conception, to design, to parts selection, to manufacturing, to operations
- Hardware/software implementations and specific technology selections near the very end; once and it must work flawlessly
  - Paradigm: “Boeing’s seventh wonder” IEEE Spectrum, 1995 (c.f. 777)
- Abstract multiple disciplines to properly annotated information representations
  - allows communication between disciplines: multiple contextual views
  - much better management of the overall process
- Develop sophisticated algorithmic, mathematical and quantitative methods implementable in modern software environments
- Work simultaneously on top-down (methodological) and bottom-up (specific applications) research and advances
- Promote Behavior-Structure Co-Design and “Orthogonalization” of Design Concerns

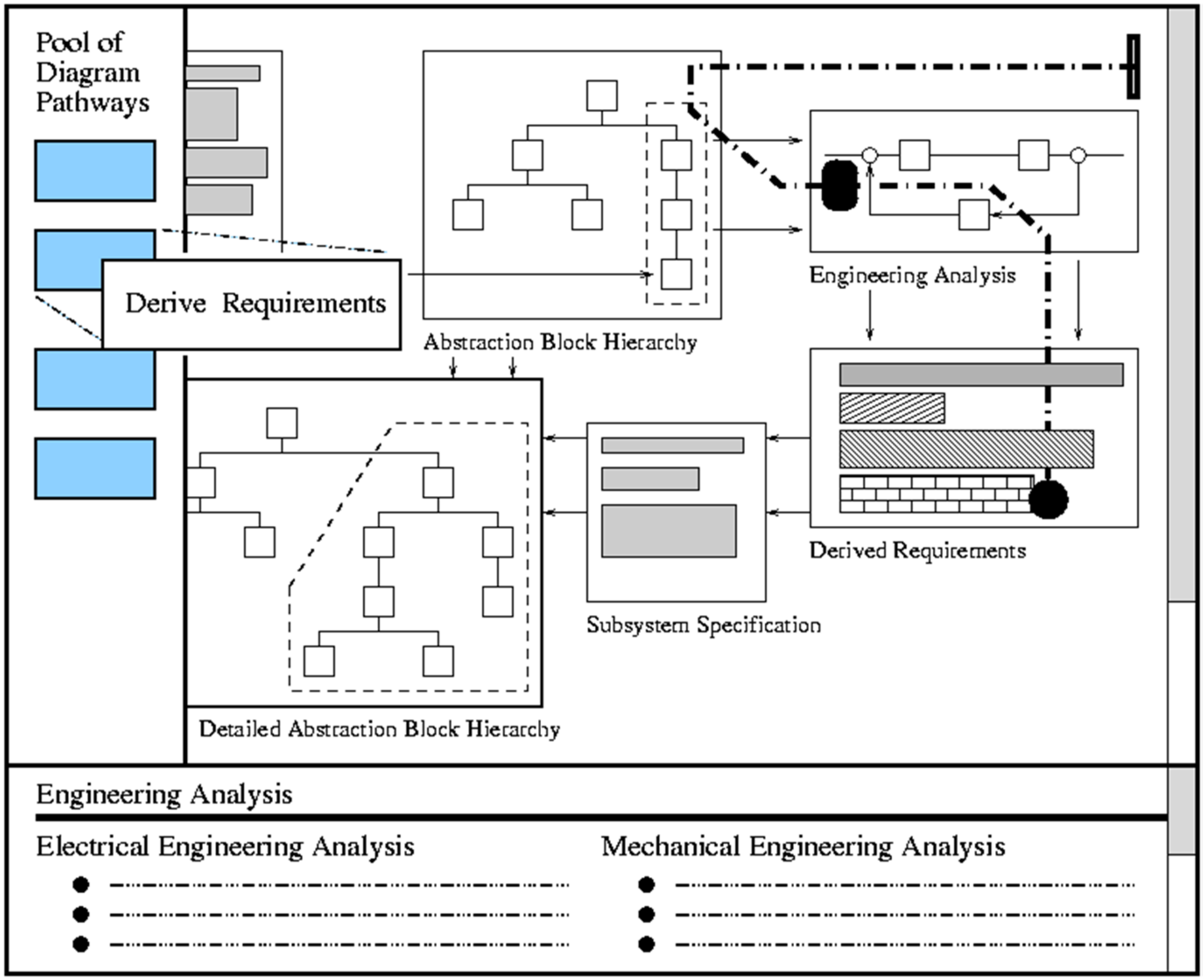
Annotating Diagrams with Use Case Pathways

- Use Case Pathway : a wiggly line that enables a student to visualize scenarios threading through a system, without the scenarios being specified in great detail

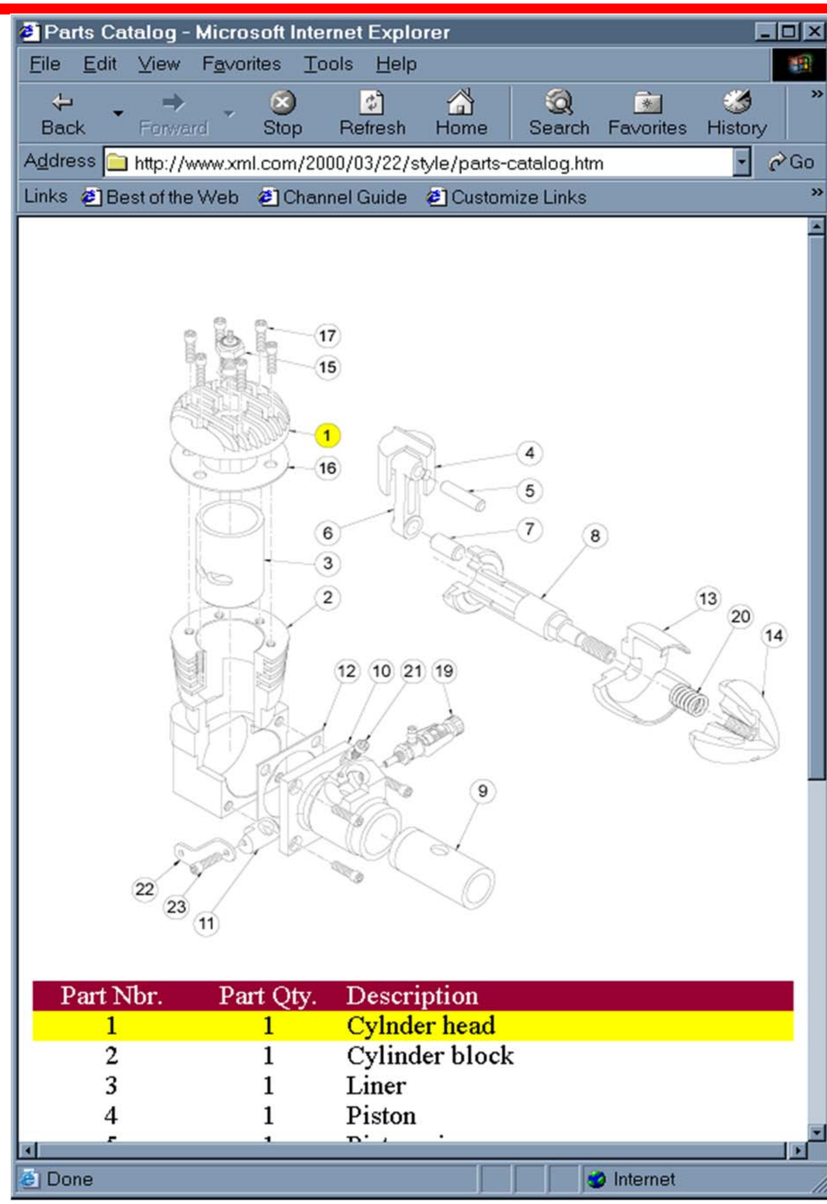
- Pathways will help students answer questions like: Where did I come from? Show me what to do now? What should I do next?



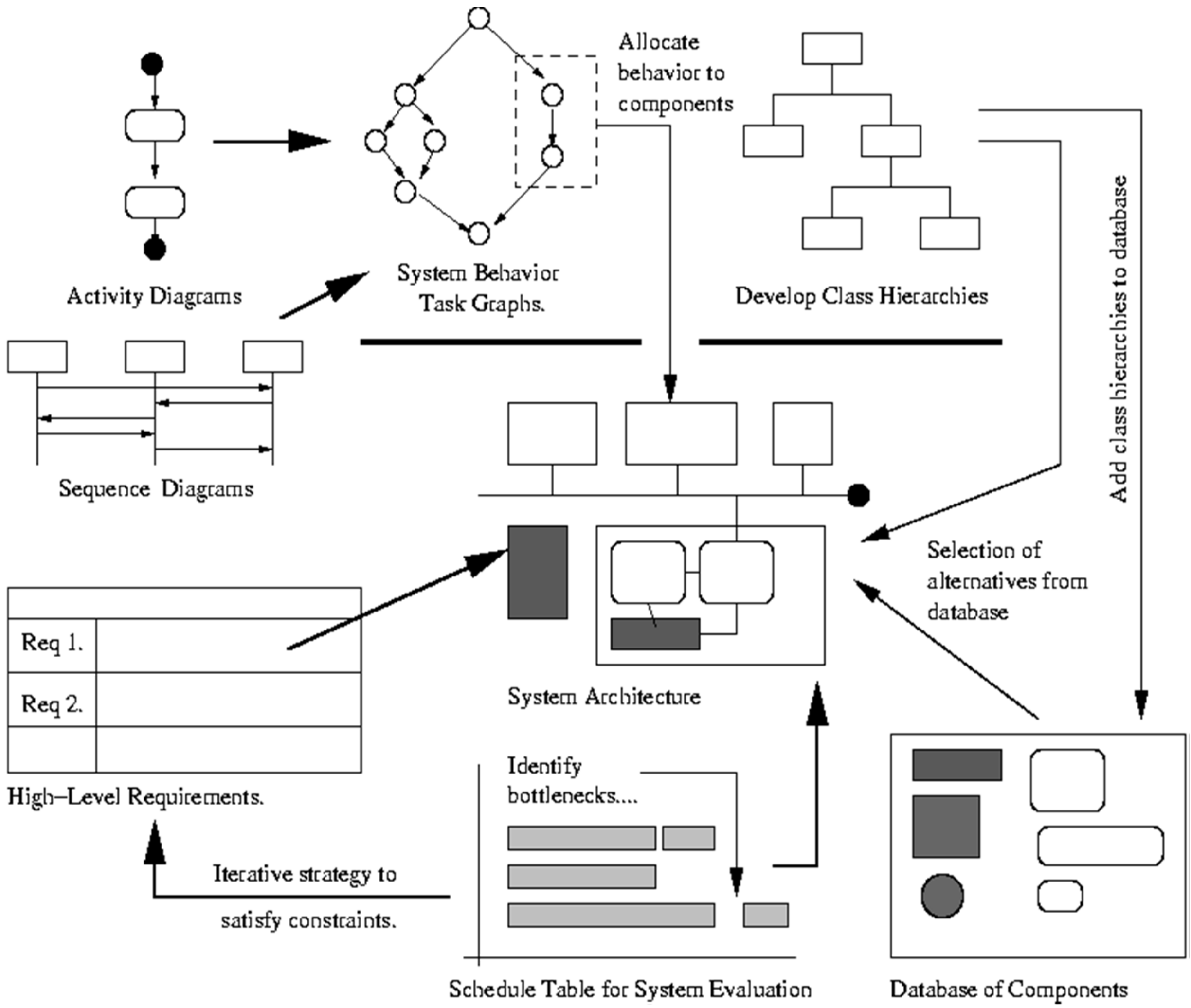
Annotating for Multiple Disciplines



Example: Traceability of Requirements to System Parts



The "big" picture



Looking Ahead

- Engineers will be able to identify attributes of each component, and the fragments of functionality that each will perform. The identification process is linked back to the high-level requirements.
- They will formulate multi-objective trade-off analysis problems. Specifications are written as design constraints. Typical design objectives are cost, performance, throughput and reliability.
  Most of the constraints for trade-off analysis will come from the requirements-specifications.
- Deposition and recovery of the developed annotated (by requirements) model chunks of system behavior and system structure to and from an object-relational database is facilitated.

MS in Systems Engineering

TWO DEGREE OPTIONS

MASTER OF SCIENCE SYSTEMS ENGINEERING (MSSE)

The broadly-based, cross-disciplinary MSSE program is offered by the Institute for Systems Research. Students benefit both academically and professionally by:

- Being exposed to a wide range of systems engineering principles, including software tools for modeling and optimization, decision and risk analysis, stochastic analysis, and human factors engineering;
- Becoming familiar with the financial and management issues associated with complex engineering systems; and
- Acquiring a deep understanding of one particular application area.

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. Students specialize in computer and software, information, control, manufacturing or process systems; communications and networking; signal processing; or operations research. Drawing on the engineering, computer science, and management experience of University of Maryland faculty, the program makes optimum use of the university's advanced facilities, including symbolic capabilities, engineering workstations, and computer communication networks.

MASTER OF ENGINEERING SYSTEMS ENGINEERING (ENPM)

The Professional Master of Engineering Program (ENPM), Systems Engineering, is offered through the A. James Clark School of Engineering's Office of Advanced Engineering Education. The ENPM is a practice oriented, part-time graduate program designed to assist engineers in the development of their professional careers and to provide the technical expertise needed in the business, government, and industrial environments. Late afternoon and evening classes are taught by the College Park faculty and experienced adjunct faculty at the College Park campus, designated learning centers in Maryland, and online.

The Programs in Brief

MSSE

DEGREE REQUIREMENTS

The following courses are required:

Systems Engineering Core

ENSE 621 Systems Engineering Principles
ENSE 622 System Modeling and Analysis
ENSE 623 Systems Engineering Design Project
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 four electives. Those choosing the non-thesis option take an additional six electives.

Both Supplemented by Technical Electives form many Technical Areas

ENPM-SE

DEGREE REQUIREMENTS

The ENPM Systems Option requires four courses from the systems engineering core, three courses 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

Selected Topics from Project Management Component

Project Management

ENCE 620 Risk Analysis in Engineering

ENCE 423 Project Planning, Scheduling and Control

ENCE 662 Introduction to Project Management

ENCE 665 Management of Project Teams

ENCE 667 Project Performance Measurement

ENCE 624 Managing Projects in a Dynamic Environment

ENCE 627 Decision and Risk Analysis for Project Management

Three Core Courses in the ISR MSSE Program

- **ENSE 621 Systems Concepts, Issues and Processes** (3)
  This course (along with ENSE 622/ENPM 642) is an introduction to the professional and academic aspects of systems engineering. Topics include models of system lifecycle development, synthesis and design of engineering systems, abstract system representations, visual modeling and unified modeling language (UML), introduction to requirements engineering, systems performance assessment, issues in synthesis and design, design for system lifecycle, approaches to system redesign in response to changes in requirements, reliability, trade-off analysis, and optimization-based design.
- **ENSE 622 Systems Requirements, Design and Trade-Off Analysis** (3)
  This course builds on material covered in ENSE 621/ENPM 641, emphasizing the topics of requirements engineering and design and trade-off analysis. The pair of courses serves as an introduction to the professional and academic aspects of systems engineering. Liberal use will be made of concepts from the first course, ENSE 621/ENPM641, including models of system lifecycle development, synthesis and design of engineering systems, visual modeling and unified modeling language (UML), requirements engineering, systems performance assessment, issues in synthesis and design, design for system lifecycle, approaches to system redesign in response to changes in requirements, reliability, trade-off analysis, and optimization-based design.
- **ENSE 623 Systems Projects, Validation and Verification** (3)
  This course builds on material covered in ENSE 621/ENPM 641 and ENSE 622/ENPM 642. Students will work in teams on semester-long projects in systems engineering design, using the modeling framework developed in the preceding two courses in the sequence to explore system designs that are subjected to various forms of testing. Students will be using all of the concepts from prior courses, as well as topics introduced in this class including validation and verification, model checking, testing, and integration.

A Bold Experiment

Starting early in the education chain

Undergraduates working with industry and government mentors on SE projects

Capstone Course

- Systems Thinking up front
- Groups of 3-5 students on projects – hands-on
- Industry as customers, co-workers, judges
- Learn the concepts and methods and tools on the job
- 7/24 open lab to work on projects

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

The Challenge and a Proposal

- What is the "highest payoff" common denominator in basic education for all Engineering undergraduates
- What should replace "calculus"?
- What are the key needs for New Engineering?
- What is the proper use of computers and networks?
- How to best recognize the different student background (computers, Internet)?

- Three courses in:

  Object Oriented Modeling linked to Physical Modeling, Control and Trade-offs, Signal Representation and Processing
- Leading to a Collaborative Design Project course

Fundamental Observations/Facts

(i) Disciplines and components in engineering should be taught with reference to a larger system where the component will lie or where a specific discipline will interact with other disciplines.

(ii) The analytical side of engineering teaching should be enlarged so as to encompass calculus and logic-computation in a more balanced manner.

(iii) Laboratory and design work emphasizing systems aspects should start as early as possible and be included in as many courses as possible.

The Proposal

As a first step towards accomplishing the required change we are proposing:

the development of three undergraduate courses that will be taught across all engineering disciplines

at the sophomore-junior level

and will be supported by Laboratory design and experimentation work in teams

Course 1: Systems Modeling

- **Modular modeling of heterogeneous systems using elements and extensions of software and systems engineering formal modeling languages (UML, SYSML, etc), differential and difference equations, extended finite machines and logic models**
- **Precursors of these ideas exist in block diagrams of systems, finite state machine charts, functional flow block diagrams,box diagrams**
- **Allows abstraction of models for continuous time, discrete time, and hybrid systems in an intuitive way that is the same for all disciplines. It keeps the specifics of the physical layer for much later in the modeling process. It has been used successfully by all engineering disciplines, by computer scientists, by biologists and chemists.**
- **This "information-centric" environment must be coupled with discipline specific modules at the physical layer to provide a powerful modeling environment for systems, as well as logic modeling**
  - For instance this could be done by linking UML models to the modeling language system *Modelica* ; or Simulink; or …
  - This will also allow specifications and requirements to be embedded in the model right from the beginning (this comes from the UML framework)

Course 2: Optimization, Requirements and Trade-Offs, Feedback

- Design should be treated as a multi-criteria problem and right from the start will show how to handle trade-offs
- Introduction of a unified view of optimization and logic (or constrained) programming; View the design of controls within this framework and include design of analog, digital and hybrid systems
- Examples should vary according to specific disciplines but can include (already existing) examples from aerospace, computer engineering, telephone networks, signal processing, chemical engineering, biology, cross-disciplinary
- The emphasis is on the proper "abstractions" of feedback, robustness, stability, regulation, and not on the specifics of a particular discipline
- Elements and concepts of testing and validation for a system and its controls should be introduced

Course 3: Measurements and Signals Semantics and Processing

- Take an integrated view of signals as strings of values of numerical, digital or logical variables
- Treat analog, digital, hybrid signals in the unified language of strings and functions and operations on them (which are really systems); capitalizes on the fact that current and future generation engineering students are very familiar with computing concepts
- It addresses the fact that most systems and their controls will involve a mixture of system modalities
- Include representations of signals for control and signal generation modules as well as mappings to specific disciplinary hardware (physical layer)
- Include examples of sensors and sensing signals, their representations and their impact on monitoring and control
- Include a discussion of signals and actuators: a rich set of examples from different disciplines

Our Challenge

The principal objective of the proposal is to introduce in the foundational core for engineering education the key concepts of system models, controls and signals in a way that integrates computer related ideas and constructs into these foundations from the start

It addresses the often emphasized need for a new integrative approach to engineering (holistic rather than in parts) which addresses the needs for modular design, systems thinking and team work

It is a major CHALLENGE AND OPPORTUNITY for our field "Systems and Control Engineering"

ISR Education Programs

The Institute for Systems Research

University of Maryland 18 56

Primary/Secondary

Young Scholars Program

High School Program for Women

Upward Bound (planned for 1999)

Undergraduate

Gemstone Program

Research Experience for Undergraduates (REU)

Systems Undergraduate Research Fellowships (SURF)

Outreach

Office of Graduate Minority Affairs

College of Engineering Honors Program and Center for Minorities in Science and Engineering

Graduate

M.S. Degree Program in Systems Engineering (MSSE)

Master of Engineering Program (ENPM)

Graduate Fellowships

Research Assistantships

Internships

Certificate Program in Systems Engineering (under development)

Outreach

Foreign Student Exchange Program

Life-Long Learning

Visitors Program, including practicing engineers

Post-Doctoral Research Fellowships

Sabbaticals

Outreach

Short Courses

Workshops

Seminars, Colloquia and Lectures

Accelerated M.S. Program (Modeled after Institute EureCom)

- 1 year program
- 100 graduates per year; top quality
  - National and international recruitment
- 1 semester: regular (semester long courses), 5 to 6
- 1 semester: groups of short courses (intensive) on applications, tools, software, hardware
- 3 months (summer) project with industry
  - Industry advisor and faculty advisor
  - Plan project during second semester
- Course selection and delivery
  - Partners to help in structure (need)
  - Fast implementation

Suggestions for Executive Education in Systems Engineering

Ideas/Suggestions

- 1- 4 short courses
  - Duration (from 1 day to a week to 4 weeks, but flexible)
  - On site, at UMD or via Web
- Two paths possible
  - Technical Management Path
  - Acquisition and Project Management Path
- Teach how to develop a SEP
- Test by few hands-on examples
- Link SEP and Project Management
  - Build in early warning indicators and tracking

Development and Execution Phases

- Course material development (approx. 3 months)
- First test and evaluation offering
- Feedback and adjustments

Crowdsourcing Manufacturing

- ***Google's Project ARA***: Smartphones are composed of modules (of the owner's choice) assembled into metal frames

- ***Ubundu Edge Project***: crowdsourcing the most radical smartphone yet "Why not look for the best upcoming tech and throw it together to stay ahead of the competition?"
- ***Crowdsourcing*** the development and manufacturing of ***small unmanned aerial vehicles***

"Democratizing" Manufacturing

- **Goal**: Transforming more ordinary people to "makers" of products and services
- Helping small and medium size companies to manufacture products and services – **bridge the "gap"** from innovation, prototyping, to manufacturing

- General Electric (GE) opens manufacturing fab lab to spark ideas and participation in manufacturing through making
- Several companies have also opened up similar "open" labs: Ford etc.
- Several regional manufacturing centers (industry-university-government) are being established in various regions of USA
- "Industrial Internet" (USA) and "Industrie 4.0" (GE-EU) arrive

The "Hottest" Job Market Currently

"The Nation that has the System Engineers has the Future"

John S. Baras, *Systems and Signals*, Vol. 4.2, May 1990

Our Students! – The Joy of "Creation"

- Students (young in particular) come to engineering because they really want to make artifacts!
- Let's keep their enthusiasm! They like to make gadgets!
- To have a chance to become a Systems Engineer one MUST be first a GOOD Engineer in one of the engineering disciplines
- Help them: Create Libraries of Sharable Modules and Models and Case Studies (like in Vision and Robotics)
- Value -- Industry input/view :
  - It takes them (industry) 5-7 years of internal courses and job rotations to educate-train a person to be a Systems Engineer
  - If we (through University education) reduce this time by 2-3 years this represents, ACCORDING TO THEM (industry) real and huge VALUE!

Conclusions – Recommendations - Questions

- Develop MS programs with more hands-on and direct industry links
- Follow MBA paradigm? After 2-3 years work in industry?
- Develop something like the MIT Lean Manufacturing and Leaders in Manufacturing curriculum
- Follow the example of Physicists (Ed Redish, UMD, "Teaching Physics with the Physics Suite" http://www2.physics.umd.edu/~redish/Book/) and develop a hyper-text navigable MBE and MBSE curriculum for self-learners and several levels of education and self-testing
- Certificates add-ons to current programs
- We need to educate two levels of engineers (Technion Report of 2001) : the "creators" of the methods and tools and the "users"
- 3 basic courses in all undergraduate curricula
- Co-Teaching as a rule?
- KTH-TUM-NTUA effort on high-school apprenticeships on "systems thinking and IT tools" towards the "Society of Makers"
- PHD programs?
- Need Text books including e-books and linked software and Labs

Thank you!

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Questions?