A Look at the Future of Systems Science and its Transformational Impact on Technology, Society, Work and Life

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THE NEXT FRONTIER IN ENGINEERING RESEARCH AND EDUCATION

- First 50 years of the 21st century will be **dominated** by advances in methods and tools for the **synthesis, implementation and operation of complex engineered systems to meet specifications in an adaptive, safe, (semi-) autonomous way**

- Evident from the areas emphasized by governments, industry and funding agencies world-wide:
  - **energy and smart grids**
  - **biotechnology**
  - **systems biology**
  - **nanotechnology**
  - **the new Internet and IoT**
  - **collaborative robotics**
  - **software critical systems**
  - **homeland security**
  - **custom materials design**
  - **systems healthcare**
  - **network science**
  - **smart enterprises**
  - **environment and sustainability**
  - **intelligent buildings and cars**
  - **precision health care**
  - **pharmaceutical manufacturing**
  - **broadband wireless networks – 5G**
  - **sensor networks**
  - **smart transportation systems**
  - **security-trust-privacy-authentication**
  - **cyber-physical systems**
  - **web-based social and economic networks**
  - **human - machine collaboration**
  - **neuromorphic AI**

Key Word: System

Σύν + τίθημι = Σύστημα

“The Nation that has the System Engineers has the Future”

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

The Institute for Systems Research

UNIVERSITY OF MARYLAND 1856

AKA

The Next Wonder – MBSE and MBE: from ideas to "making things and services"

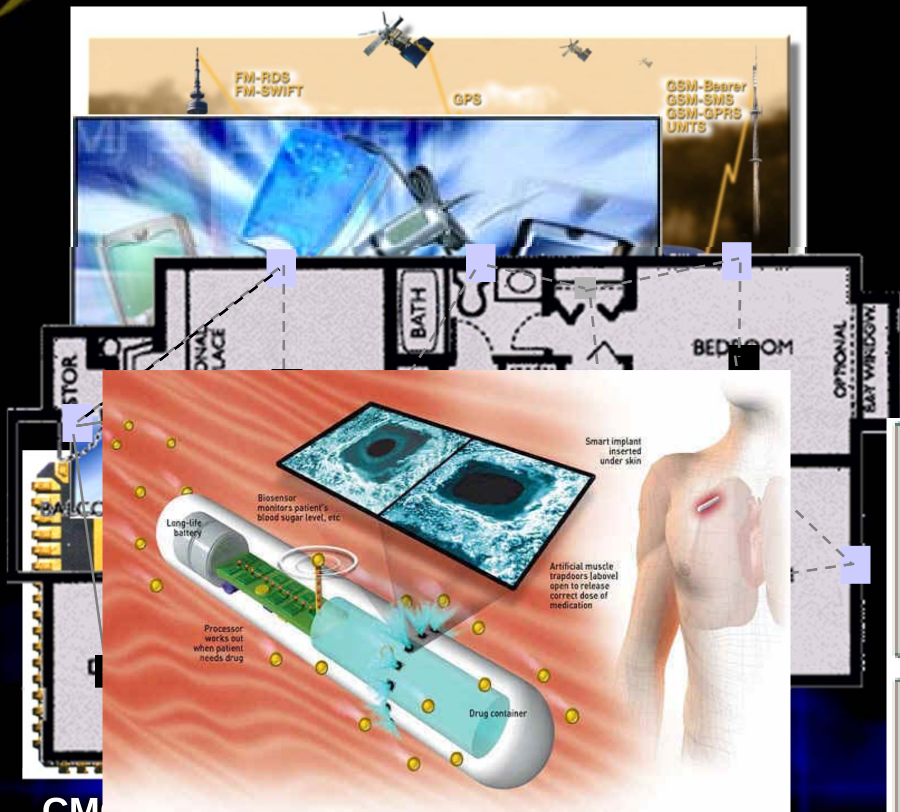
Outline

- The Vision and its development
- What happened since then?
- Key challenges -- Model-based Systems Engineering
- Example applications: Microgrids, modern-aircraft, sensor networks, energy efficient buildings, robotics and micro-robotics, collaborative robotics, wireless security, social networks over the Web, Health Care (ICU), democratizing manufacturing, personalized medicine
- Need for educational transformation

The Two Faces of Information Technology in Engineering

(*Baras -- 2003 White Symposium*)

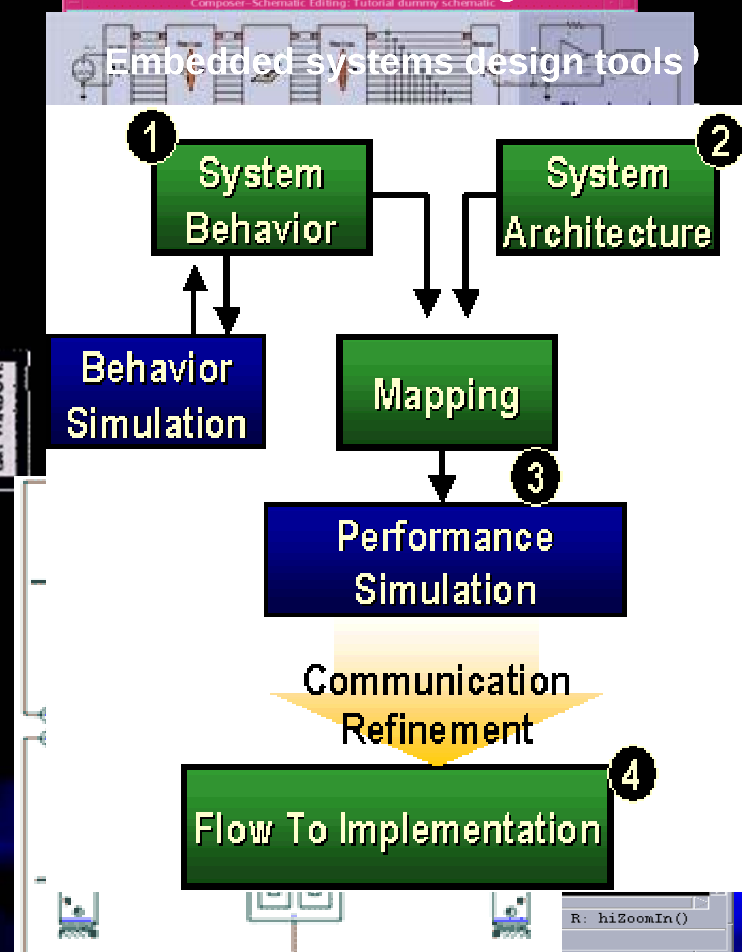
digital car



CMOS camera

smart pill-artificial muscle

Conventor MEMS design tools



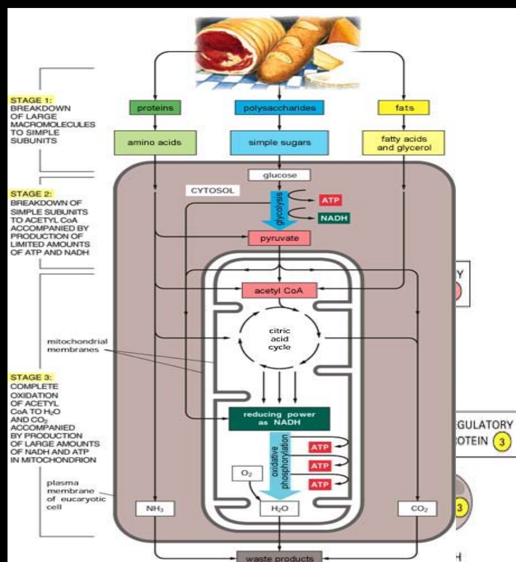
Ubiquitous presence of IT components as "building blocks"

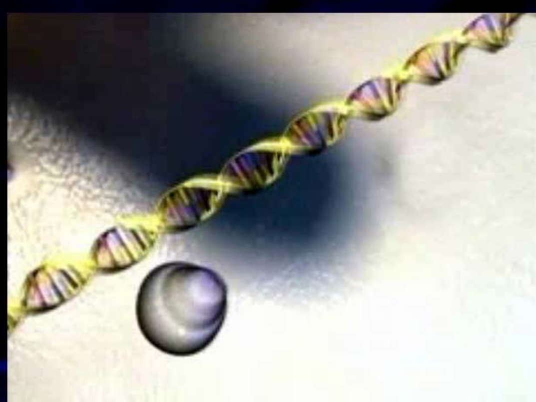
Increasing use of "system level" design and manufacturing CAD tools

From IT abstractions to “hardware”

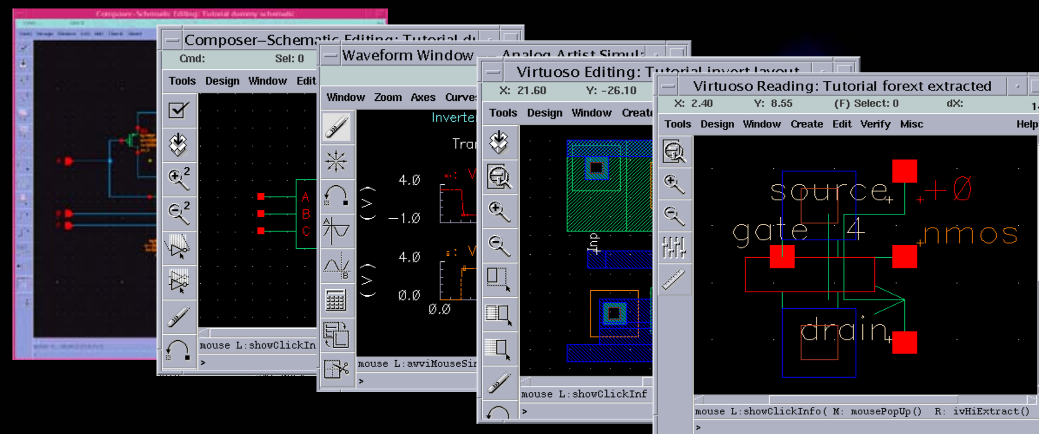
(*Baras -- 2003 White Symposium*)

From DNA ‘programs’ to living organisms



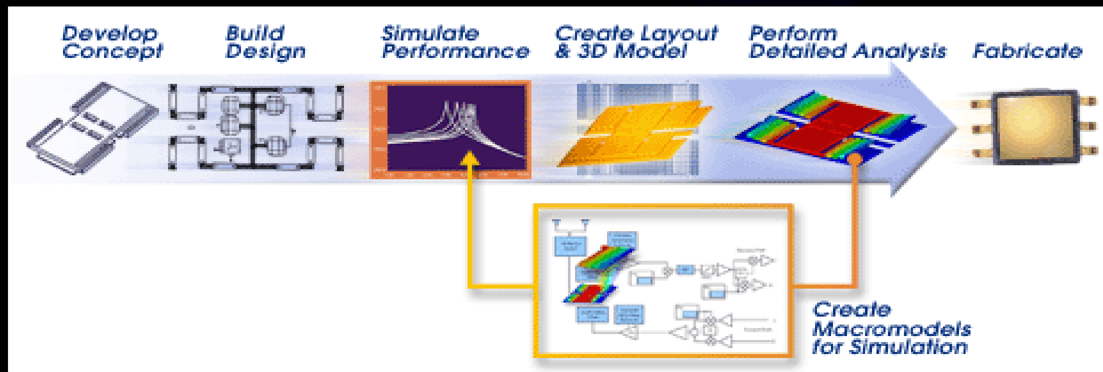


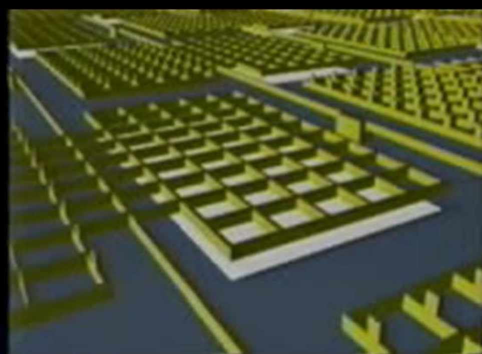
From CAD schematics to chips

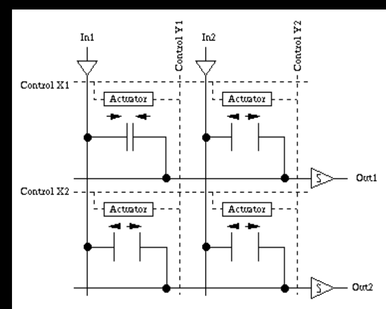


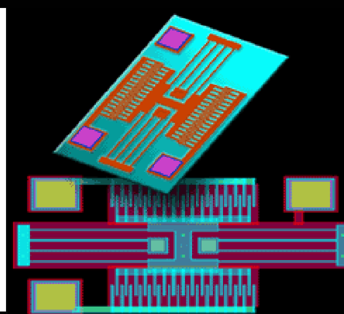
From IT abstractions to "hardware"

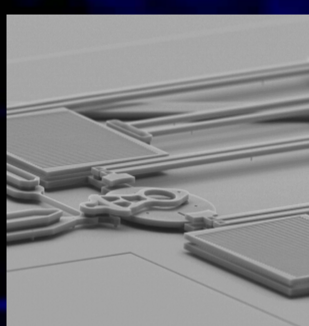
(*Baras -- 2003 White Symposium*)

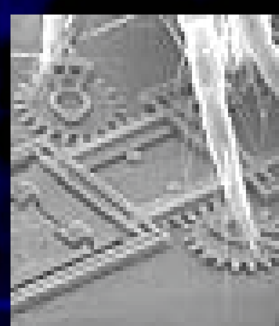


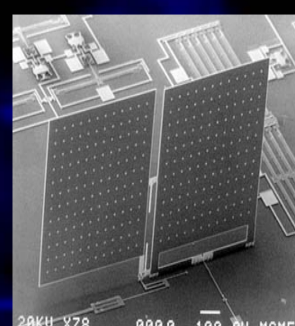


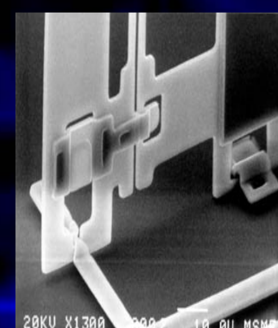


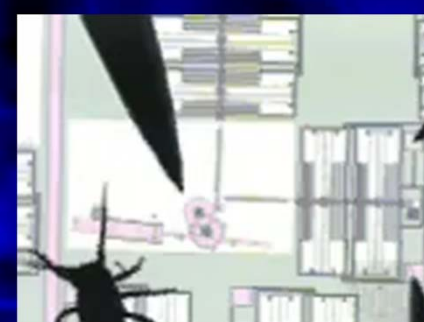








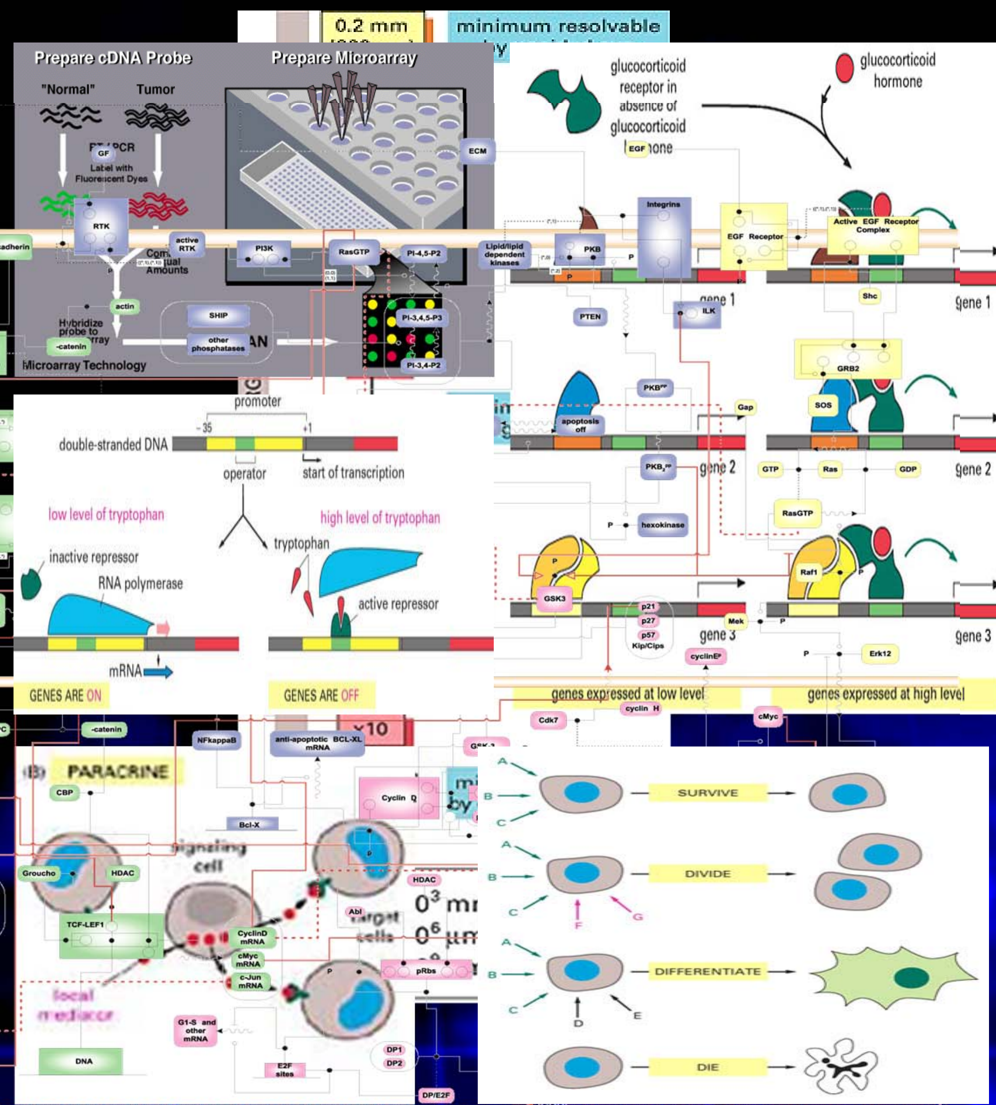




Why IT? Why the Two Faces?

(*Baras -- 2003 White Symposium*)

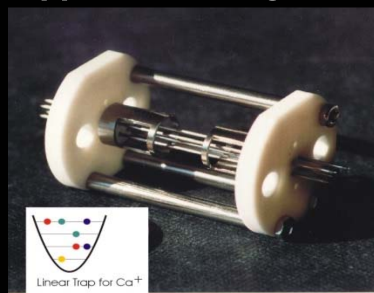
- A means for interfacing heterogeneous components and controlling complexity Embedded software and systems
- Micro-sensors, micromotors, MEMS
- Manufacturing 'ahead' of design; design verification Development and use of formal models and methods
- Microarrays, metabolic pathways, systems biology
- Signaling and communication
- Languages for hardware, cells, …. (XML, UML, DCL, SBML)
- Learning from biology (integration)

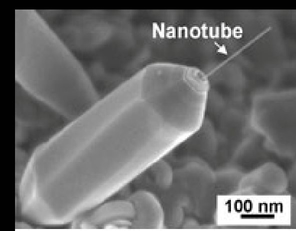


Challenges: A Glimpse into the Future (*Baras -- 2003 White Symposium*)

- Computing over new physical domains (quantum, organic, biological)

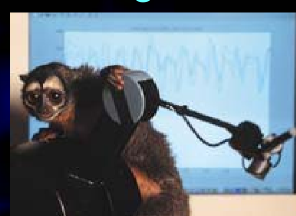
- from abacus to qubits
- entanglement
- nuclear spin, electron spin
- photon polarization, ion trap

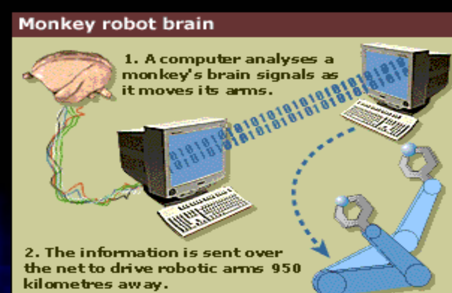




- Send a program over a network and at the other end receive hardware

- Communicating minds





- Swarm intelligence

RESEARCH

- At the interface of bio - nano - info
- Self - assembled systems

EDUCATION

- Teach holistic engineering

What has happened since then?

- **Design and manufacturing from Boeing 777 aircraft to Boeing 787 aircraft …**
- **Humans become integral part of systems -- *iPhone*, …**
- **Cyber-Physical Systems (CPS) …**
- **Social networks over the Web mushroomed …**
- **Economic networks over the Web mushroomed …**
- **Renewable energy, smart grid …**
- **Individual human genome generation becomes fast, inexpensive …**

What has happened more recently?

- Multisensory environmental monitoring spreads…
- Autonomous and connected cars designed and tested …
- Cloud Computing, “Big Data”, …
- Health information technology spreads …
- Internet of Things, Industrie 4.0, Industrial Internet
- First “printed” car …
- “Crowd sourcing” and manufacturing …

Boeing's Seventh Wonder

(*IEEE Spectrum, 1995 October*)

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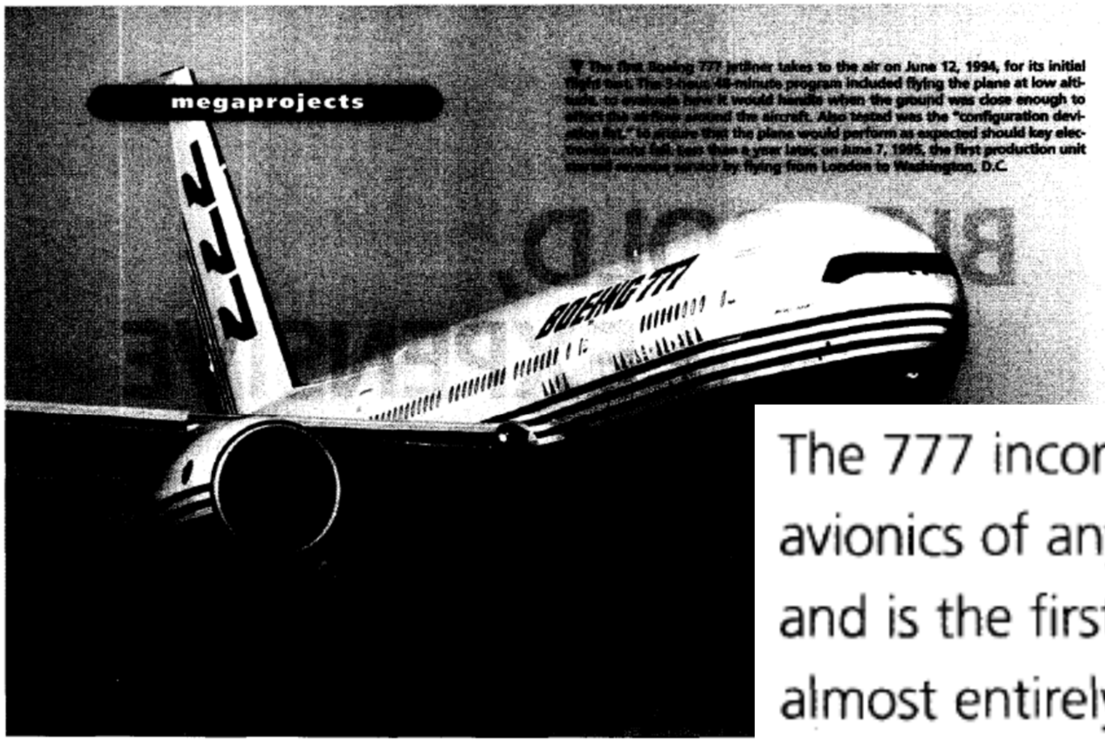


▼ The first Boeing 777 jetliner takes to the air on June 12, 1994, for its initial flight test. The 3-hour 48-minute program included flying the plane at low altitude, to evaluate how it would handle when the ground was close enough to affect the airflow around the aircraft. Also tested was the "configuration deviation list," to ensure that the plane would perform as expected should key electronic units fail. Less than a year later, on June 7, 1995, the first production unit started revenue service by flying from London to Washington, D.C.

The 777 incorporates the most advanced avionics of any commercial U.S. aircraft and is the first plane of any kind to be almost entirely computer-designed

BOEING'S SEVENTH WONDER

GUY
Cont
E.

Fresh start

The answers are in the new technology used in the 777 itself, and in the design-engineering revolution that stormed through Boeing, based in Everett, Wash., during the creation of its first all-new jetliner since the early 1980s. Advances in electronics and in computer-aided design, manufacture and simulation provided the foundation for the new technology. Using these tools and systems to an unprecedented extent, Boeing was able to start afresh with the 777, changing the way in which the company builds aircraft. The results have been so dramatic that practically every new Boeing flight product—from the new generation of the venerable 737 family and F-22 air superiority fighter to International Space Station and the proposed X-33 reusable launch vehicle—is adopting some part of the program pioneered by the 777.

BOEING 787: CLEANER, QUIETER, MORE EFFICIENT

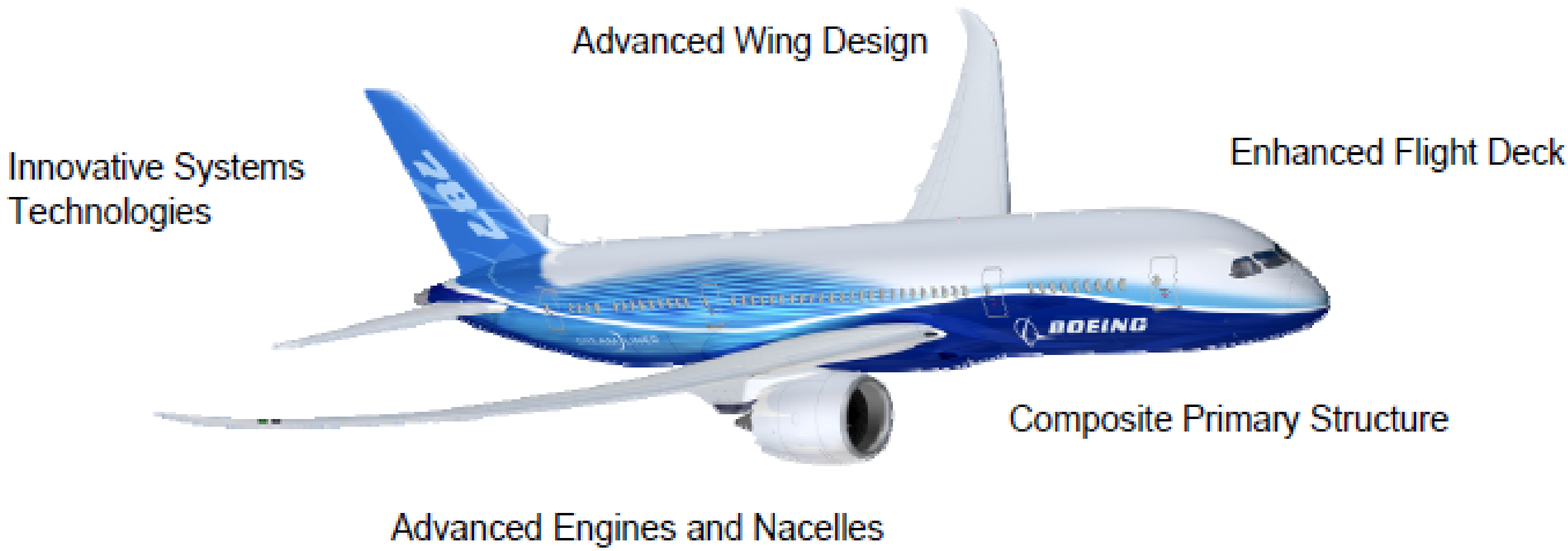
The 787 Dreamliner delivers:

*Relative to the 767

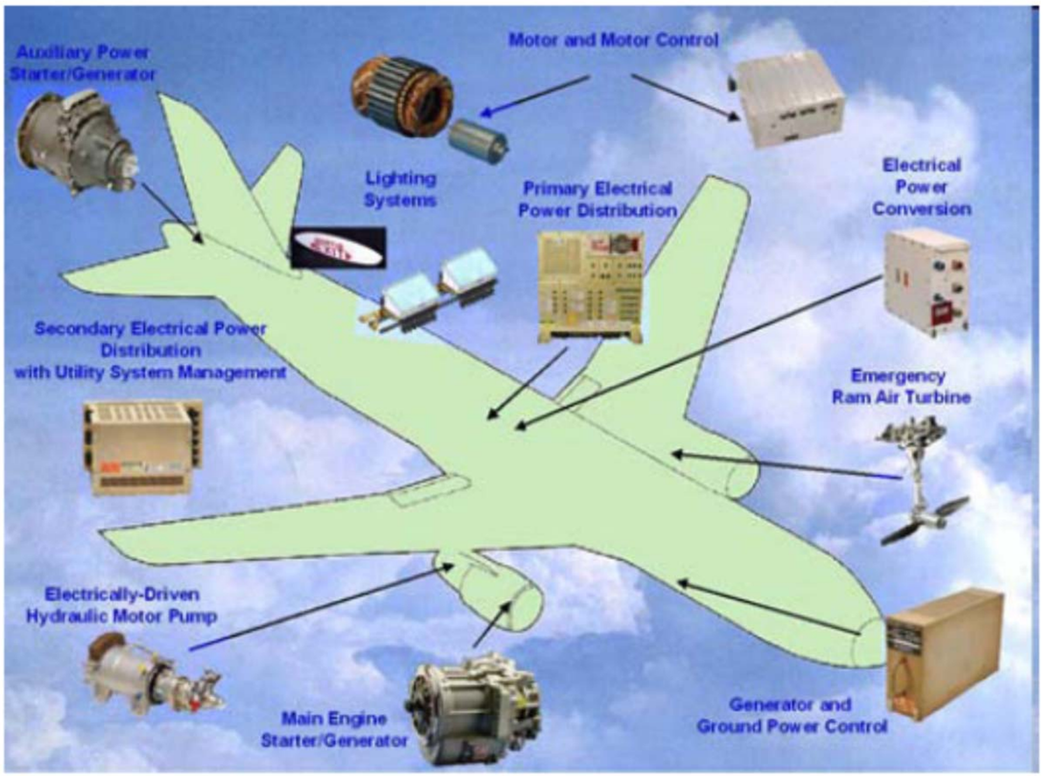
20%* reduction in fuel and CO_2

28% below 2008 industry limits for NOx

60%* smaller noise foot print



MBSE for Fault Tolerant Vehicle Management Systems (Electrical, Hydraulic, etc.)



[Image: hamiltonsunstrand.com]

Goal: Synthesize logic to switch between generators and loads on-demand and to handle faults so as to stay within safe operating envelope

Joint with UTRC

iPhone -- Smartphone

A remarkably innovative systems integration

Attention to the user

The device that can do "everything"

Mobile wallet gains currency

- September 14, 2011 5:56 pm

He not usually avoids carrying to fail by his wallet and reason adult a line, though a drumming also automatically adds faithfulness points to his Walgreens' faithfulness card, also stored in his phone, and can assistance him redeem any banking he competence have downloaded from a Internet.

Soon, he will be means to do a same for his favorite sandwich during Subway. McLaughlin, arch rising payments officer during Mastercard, has been one of a initial to try out a Google Wallet mobile compensate complement introduced by a Internet hulk in May in partnership with Citigroup and Mastercard Worldwide.

http://wn.com/Google_Wallet

Google Wallet

BBC NEWS

TECHNOLOGY

19 May 2011 Last updated at 20:47 ET

Mobile wallet offered to UK shoppers

GOOGLE, CITI, MASTERCARD, FIRST DATA AND SPRINT TEAM UP TO MAKE YOUR PHONE YOUR WALLET

Google Wallet will enable consumers to tap, pay and save with their phones

NEW YORK, May 26, 2011 /CNW/ – At an event today, Google, Citi, MasterCard, First Data and Sprint announced and demonstrated Google Wallet, an app that will make your phone your wallet so you can tap, pay and save money and time while you shop. For businesses, Google Wallet is an opportunity to strengthen customer relationships by offering a faster, easier shopping experience with relevant deals, promotions and loyalty rewards.

Mobile Wallets: Security and Privacy Questions Raised By New Google App

First Posted: 9/20/11 07:32 PM ET Updated: 9/20/11 07:32 PM ET

React

It is billed as the future of commerce: swiping a smartphone at the checkout counter instead of a credit card.

On Monday, Google made its foray into the budding market of mobile payment systems by launching Google Wallet, an app that stores users' credit card information on their phones, allowing them to purchase goods by swiping their phones at stores.

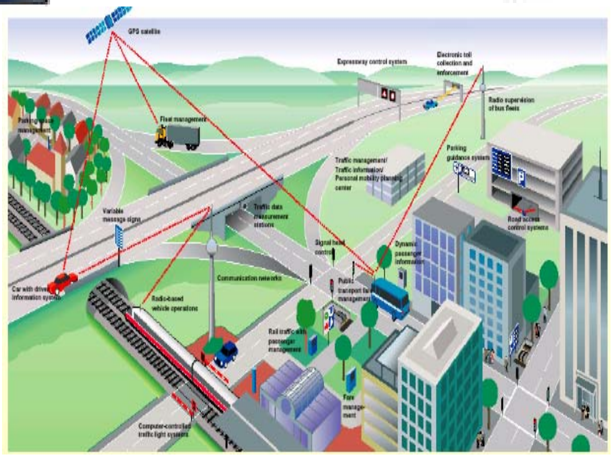
Future "Smart" Homes and Cities

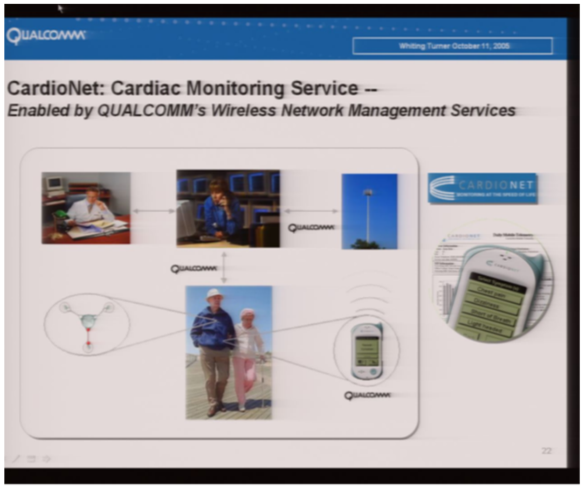
- UI for "Everything"
  - Devices with Computing Capabilities & Interfaces
- Network Communication
  - Devices Connected to Home Network

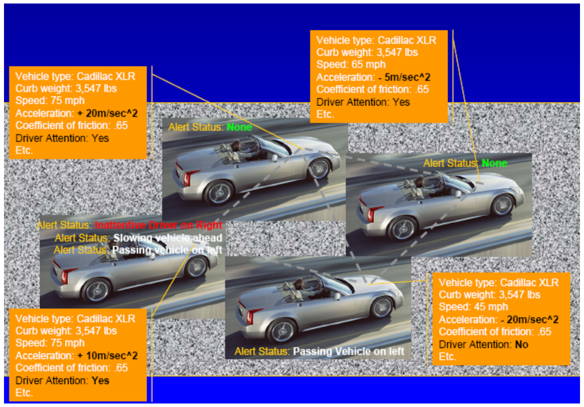
- Media: Physical to Digital
  - MP3, Netflix, Kindle eBooks, Flickr Photos
- Smart Phones
  - Universal Controller in a Smart Home

- Smart Meters & Grids
  - Demand/Response System for "Power Grid"
- Wireless Medical Devices
  - Portable & Wireless for Real-Time Monitoring

Wireless and Networked Embedded Systems: Ubiquitous Presence







Fundamental Challenges

Our research identified the following fundamental challenges for the modeling, design, synthesis and manufacturing of CPS:

- Framework for developing cross-domain **integrated modeling hubs** for CPS;
- Framework for linking these integrated modeling hubs with tradeoff analysis methods and tools for **design space exploration**;
- Framework of linking these integrated synthesis environments with **databases of modular component and process** (manufacturing) models, backwards compatible with legacy systems;
- Framework for translating textual requirements to mathematical representations as constraints, rules, metrics involving both logical and numerical variables, **allocation of specifications** to components, to enable automatic **traceability** and **verification**.

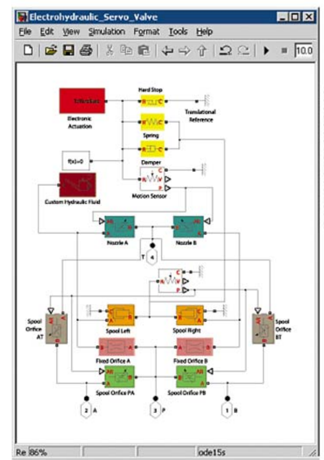
Virtual Engineering Everywhere
Multi-Physics models

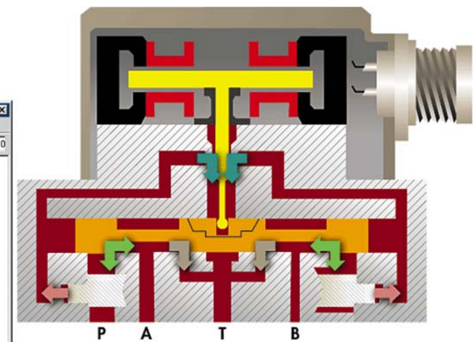
Helping over 30 different teams and skills in the company work together

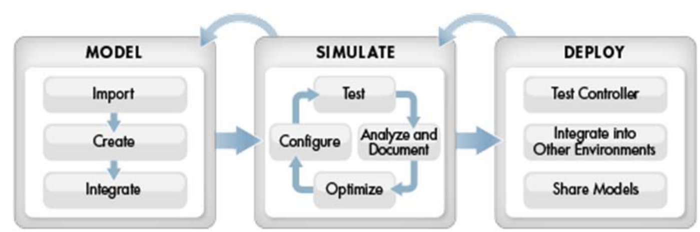
Linking over 40 different EE design representations throughout the entire development process

Ensuring that the EE design flow is integrated at the same level of quality and performance as the 3D CAD system

Model based design and executable specification in the OEM/supplier chain







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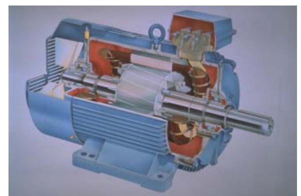
Model Integration Challenge: Physics

Heterogeneity of Physics



Electrical Domain	Mechanical Domain	Hydraulic Domain	Thermal Domain	• • •
Theories, Dynamics, Tools	Theories, Dynamics, Tools	Theories, Dynamics, Tools	Theories, Dynamics, Tools	

Physical components are involved in multiple physical interactions (multi-physics)
Challenge: How to compose multi-models for heterogeneous physical components

MODEL BASED SYSTEMS ENGINEERING (MBSE)

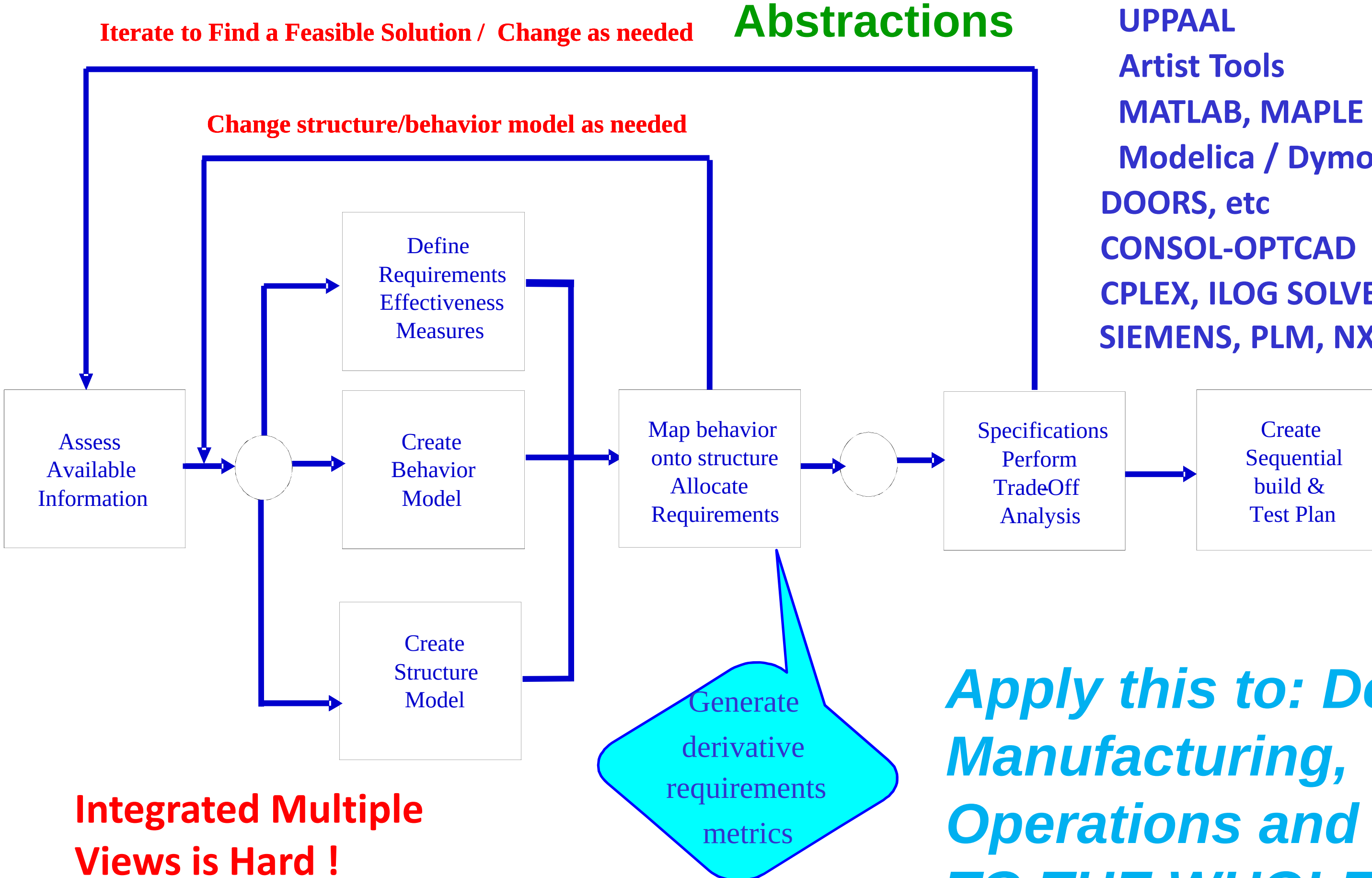
The Institute for Systems Research

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

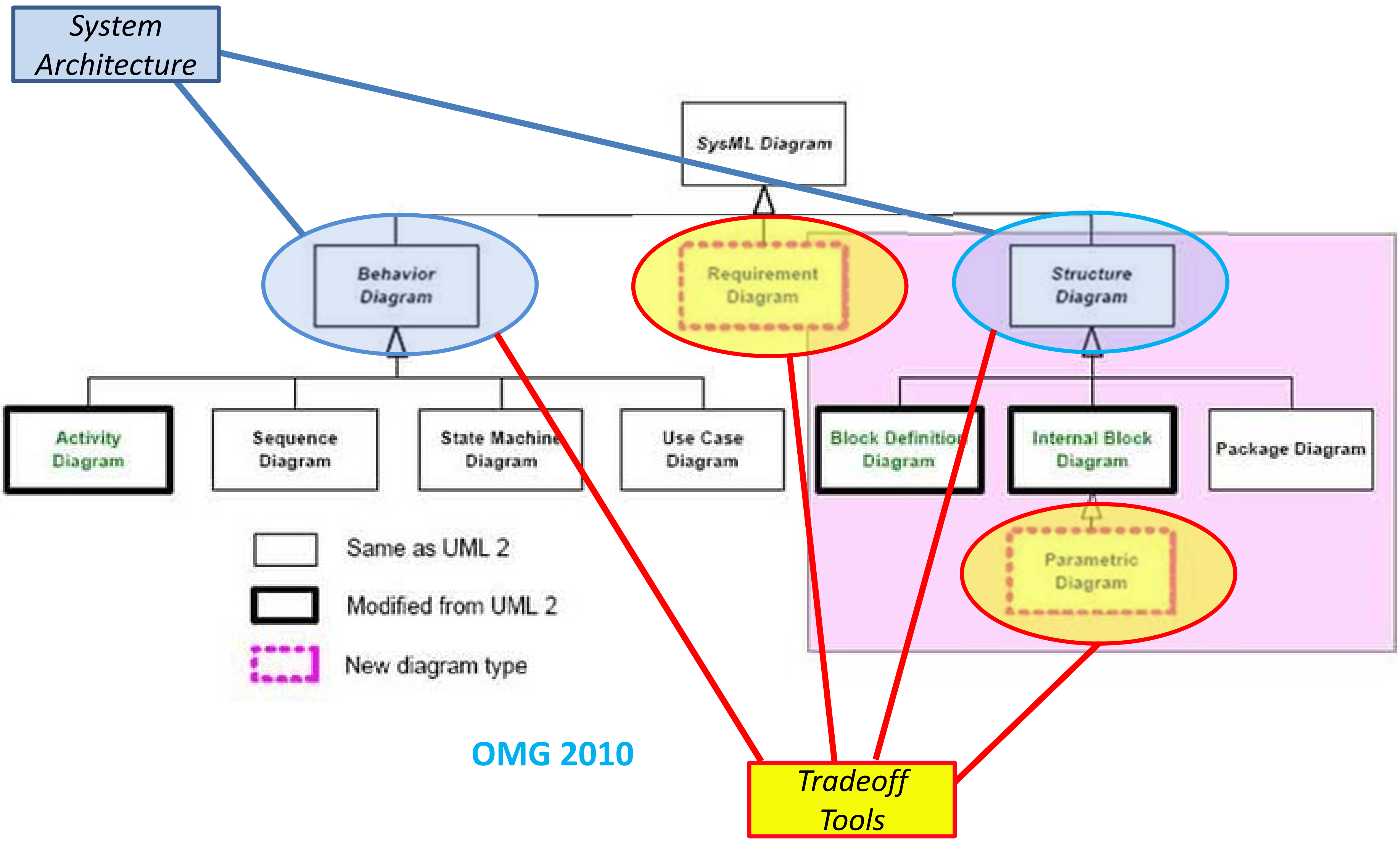
DOORS, etc
CONSOL-OPTCAD
CPLEX, ILOG SOLVER,
SIEMENS, PLM, NX, TEAM CENTER



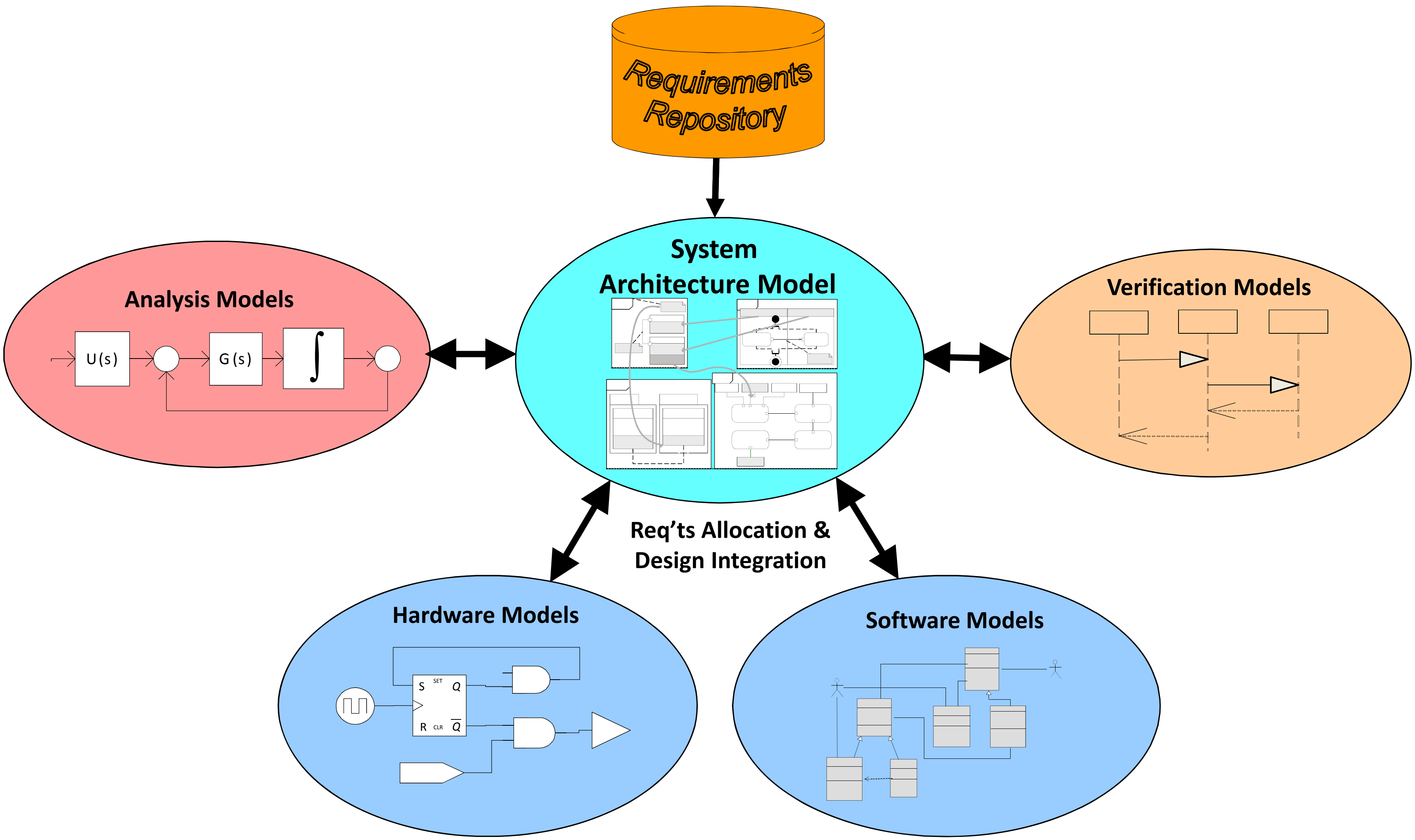
Integrated Multiple Views is Hard !

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

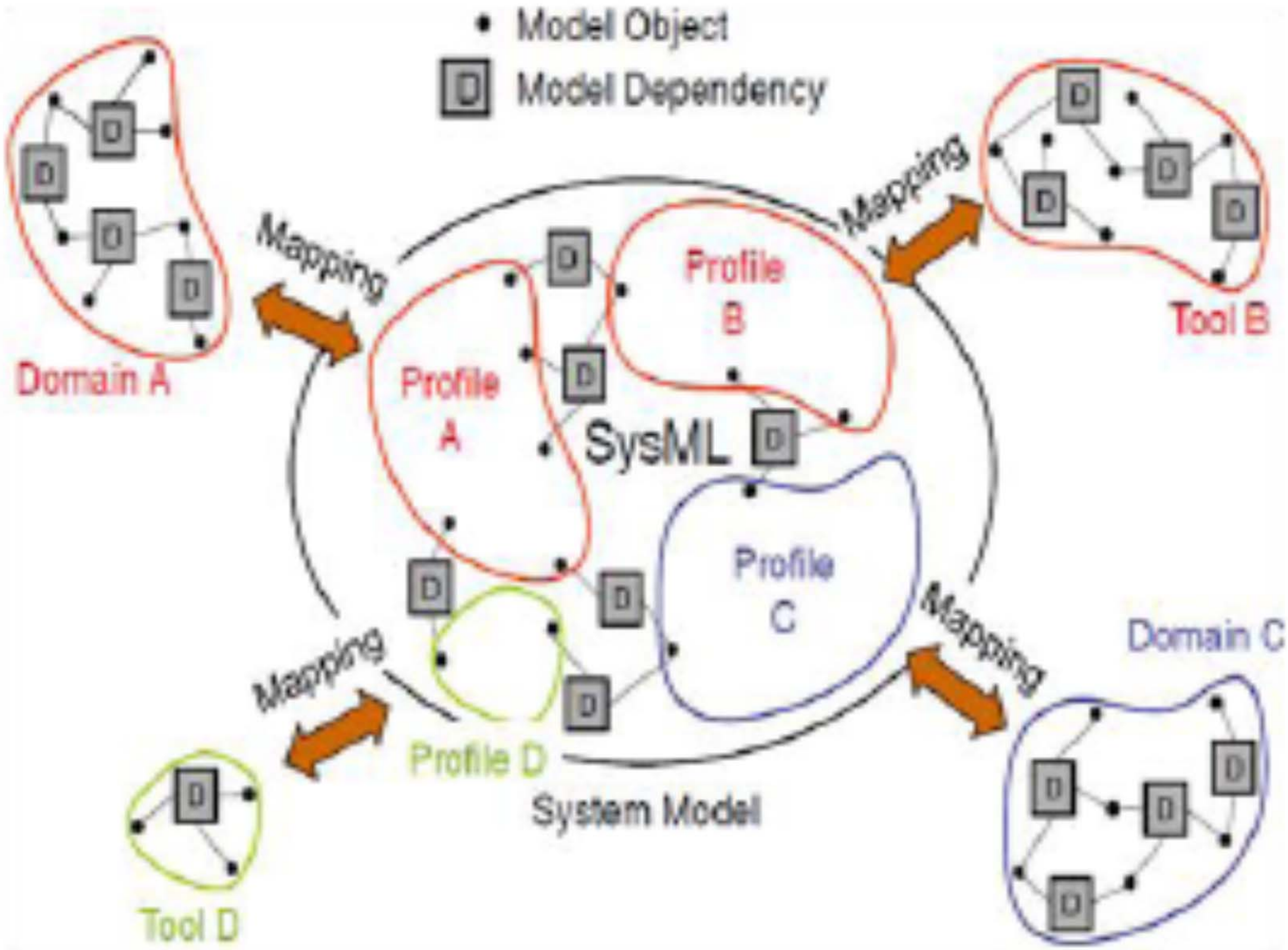
SysML Taxonomy



Using *System Architecture Model* as an Integration Framework



System Modeling Transformations-- Metamodeling (Models of Models)



A Rigorous Framework for Model-based Systems Engineering

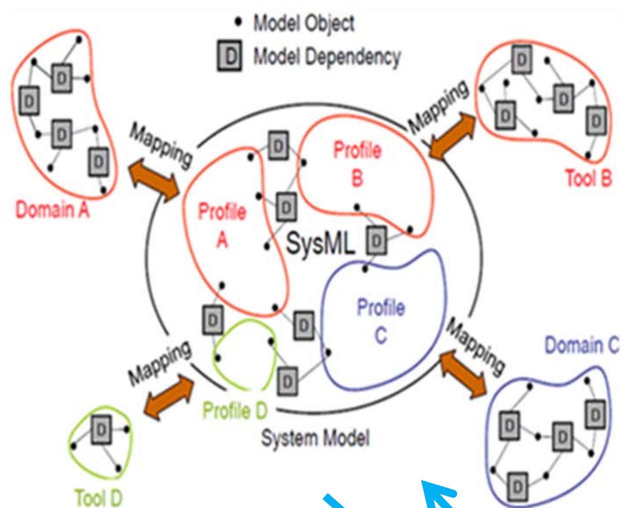
The Institute for Systems Research

The Challenge & Need:

Develop scalable holistic methods, models and tools for enterprise level system engineering

Multi-domain Model Integration via System Architecture Model (SysML)

System Modeling Transformations



“ Master System Model”

Update System Model

ILOG SOLVER, CPLEX, CONSOL-OPTCAD

Tradeoff parameters

ADD & INTEGRATE

Multiple domain modeling tools

- **Tradeoff Tools (MCO & CP)**
- **Validation / Verification Tools**
- **Databases and Libraries of annotated component models from all disciplines**

DB of system components and models

BENEFITS

- **Broader Exploration of the design space**
- **Modularity, re-use**
- **Increased flexibility, adaptability, agility**
- **Engineering tools allowing conceptual design, leading to full product models and easy modifications**
- **Automated validation/verification**

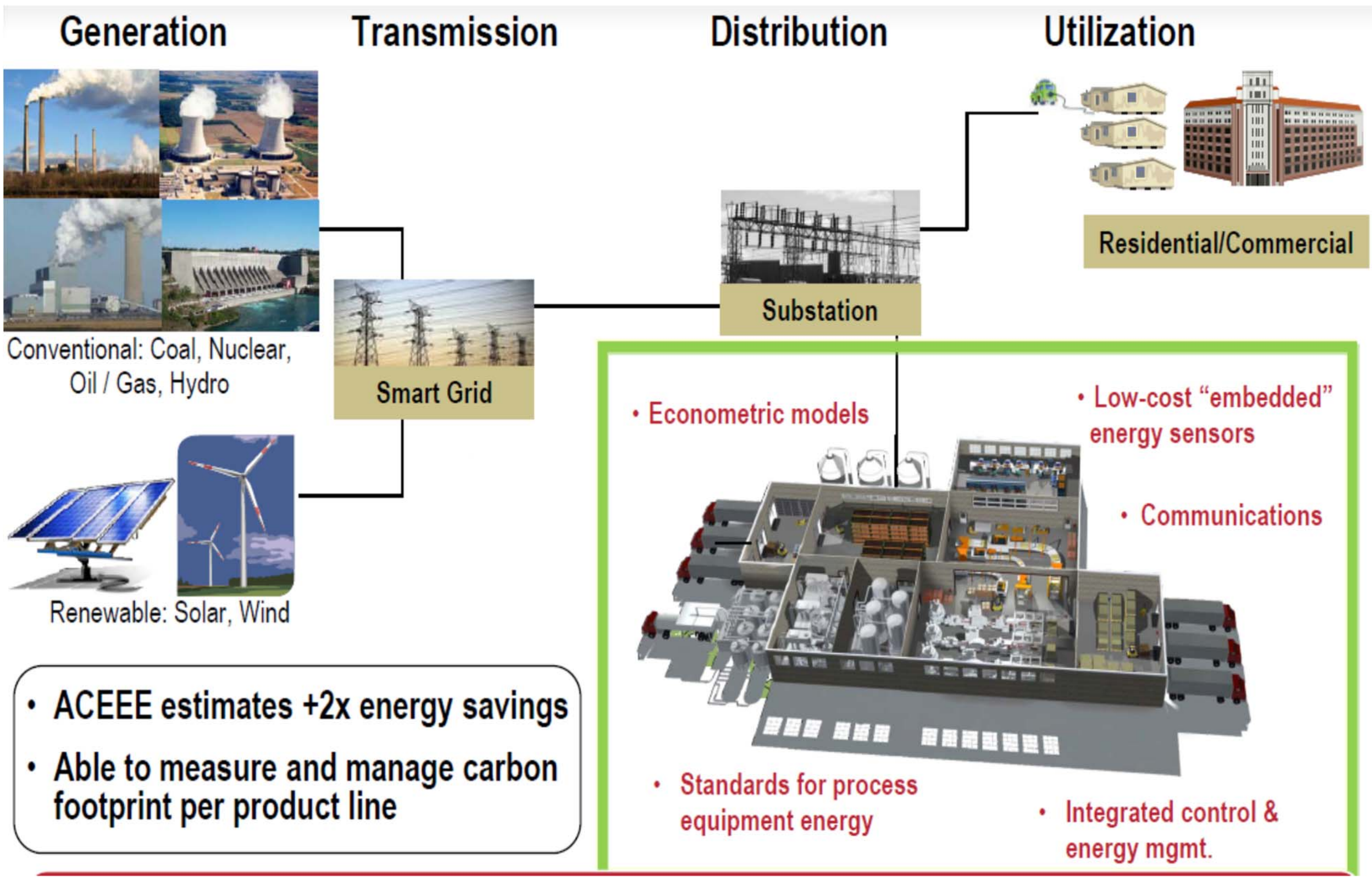
APPLICATIONS

- **Avionics**
- **Automotive**
- **Robotics**
- **Smart Buildings**
- **Power Grid**
- **Health care**
- **Telecomm and WSN**
- **Smart PDAs**
- **Smart Manufacturing**

Requirements Engineering

- **How to represent requirements?**
  - Automata, Timed-Automata, Timed Petri-Nets
  - Dependence-Influence graphs for traceability
  - Set-valued systems, reachability, … for the continuous parts
- **How to automatically allocate requirements to components?**
- **How to automatically check requirements?**
  - **Approach**: Integrate contract-based design, model-checking, automatic theorem proving
- **How to integrate automatic and experimental verification?**
- **How to do V&V at various granularities and progressively as the design proceeds – not at the end?**
- **The front-end challenge: Make it easy to the broad engineering user?**

Smart Grids in a Network Immersed World



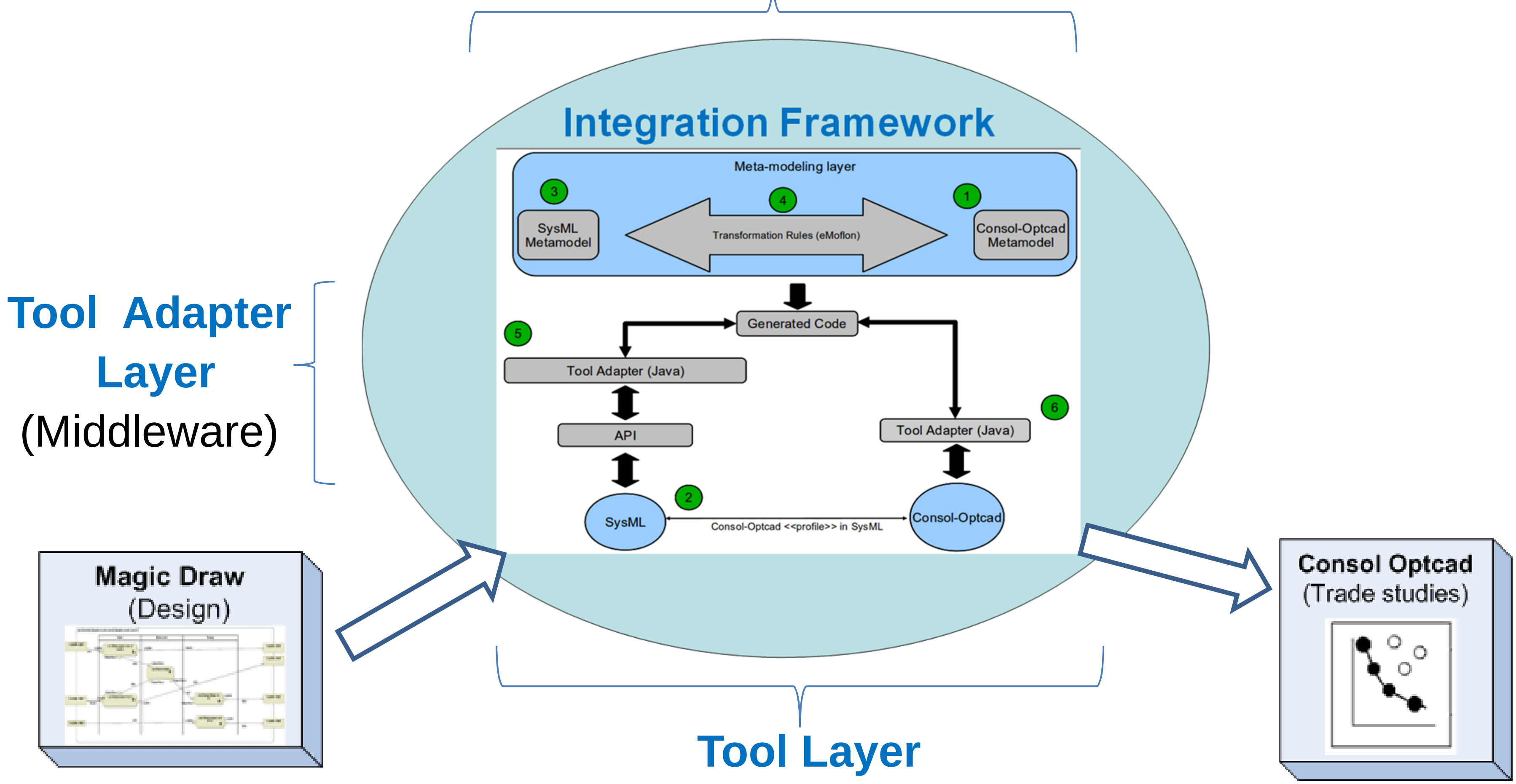
Courtesy: Rockwell

SysML and Consol-Optcad Integration

Overview

Meta-modeling Layer

(Enterprise Architect + eMoflon, Eclipse development environment)



Tool Layer

(Magic Draw, Consol Optcad)

Microgrid Problem Formulation

Objectives

Minimize Operational Cost: $OM(\$) = \sum_{i=1}^{N} K_{OM_i} P_i t_{i_{operation}}$

Minimize Fuel Cost: $FC(\$) = \sum_{i=1}^{N} C_i \frac{P_i t_{i_{operation}}}{n_i}$

Minimize Emissions: $EC(\$) = \sum_{i=1}^{N} \sum_{i=1}^{M} a_k (EF_{ik} P_i t_{i_{operation}} / 1000)$

P_i : power output of each generating unit

t_i : time of operation during the day for the unit i

n_i : efficiency of the generating unit i

N : number of generating units

M : number of elements considered in emissions objective

$K_{OM_i}, C_i, a_k, EF_{ik}$: constants defined from existing tables

Microgrid Problem Formulation

Constraints

- Meet electricity demand : $P_i \geq Demand(kW) = 50 \cdot (0.6\sin(\frac{\pi t}{12}) + 1.2)$

  Functional constraint and shall be met for all values of the free parameter *t*
- Each power source should turn on and off only 2 times during the day

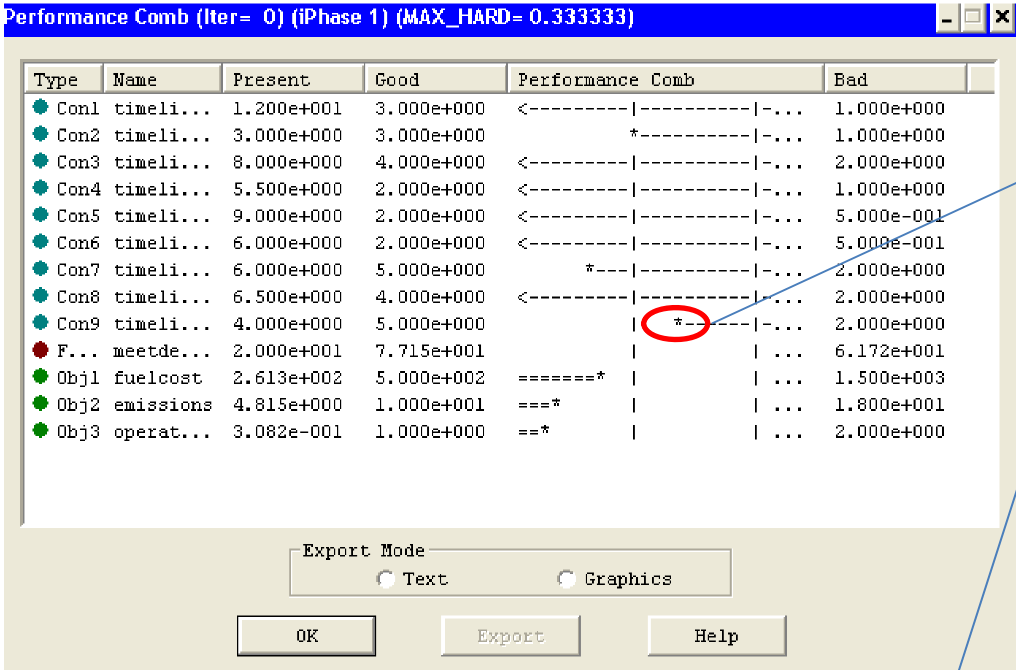
Constraints for correct operation of the generation unit

- Each generating unit should remain open for at least a period x_i defined by the specifications: $t_{i\_off\,1} - t_{i\_on1} \geq x_i$ and $t_{i\_off\,2} - t_{i\_on2} \geq x_i, \quad i = 1,2,\ldots N$

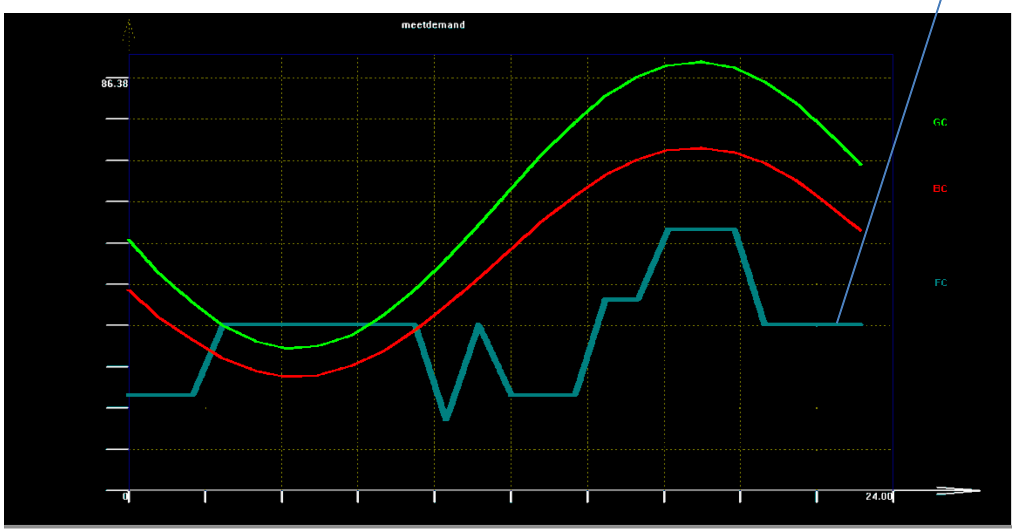
- Each generating unit should remain turned off for at least a period y_i defined by the specifications: $t_{i\_on2} - t_{i\_off1} \geq y_i, \quad i = 1,2,\ldots N$

The problem has a total of *15 design variables, 10 constraints and 3 objective functions*

Tradeoff Study in Consol-Optcad



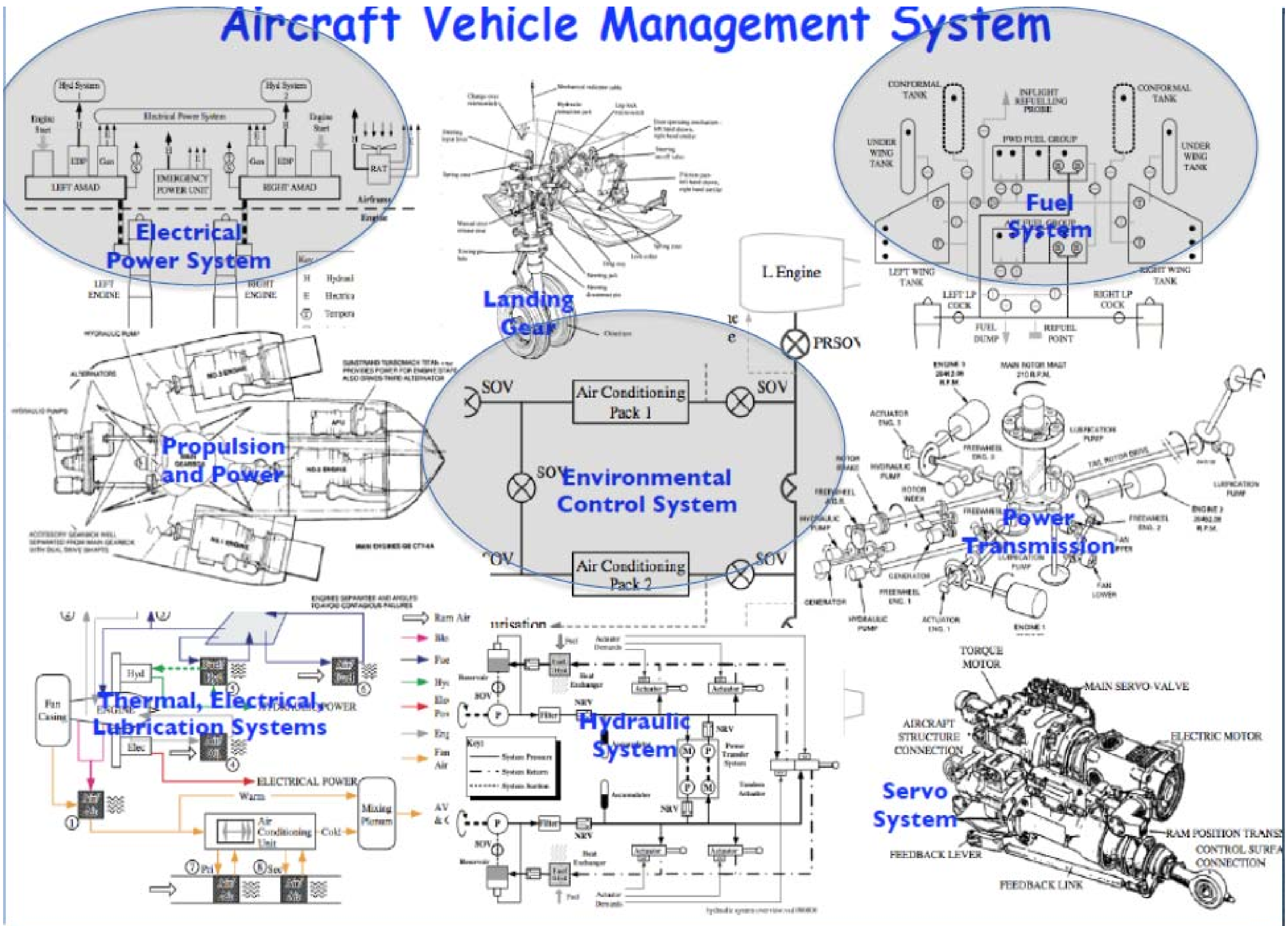
Type	Name	Present	Good	Performance Comb	Bad
Con1	timeli...	1.200e+001	3.000e+000	<----------|----------|-...	1.000e+000
Con2	timeli...	3.000e+000	3.000e+000	*----------|-...	1.000e+000
Con3	timeli...	8.000e+000	4.000e+000	<----------|----------|-...	2.000e+000
Con4	timeli...	5.500e+000	2.000e+000	<----------|----------|-...	1.000e+000
Con5	timeli...	9.000e+000	2.000e+000	<----------|----------|-...	5.000e-001
Con6	timeli...	6.000e+000	2.000e+000	<----------|----------|-...	5.000e-001
Con7	timeli...	6.000e+000	5.000e+000	*---|----------|-...	2.000e+000
Con8	timeli...	6.500e+000	4.000e+000	<----------|----------|-...	2.000e+000
Con9	timeli...	4.000e+000	5.000e+000	| *-----|-...	2.000e+000
F...	meetde...	2.000e+001	7.715e+001	| | ...	6.172e+001
Obj1	fuelcost	2.613e+002	5.000e+002	=======* | | ...	1.500e+003
Obj2	emissions	4.815e+000	1.000e+001	===* | | ...	1.800e+001
Obj3	operat...	3.082e-001	1.000e+000	==* | | ...	2.000e+000



Iteration 1 (Initial Stage)

- ✓Hard constraint not satisfied
- ✓ Functional Constraint below the bad curve
- ✓ All other hard constraints and objectives meet their good values
- ✓ Usually the user does not interact with the optimization process **until all hard constraints are satisfied**

Aircraft Vehicle Management System



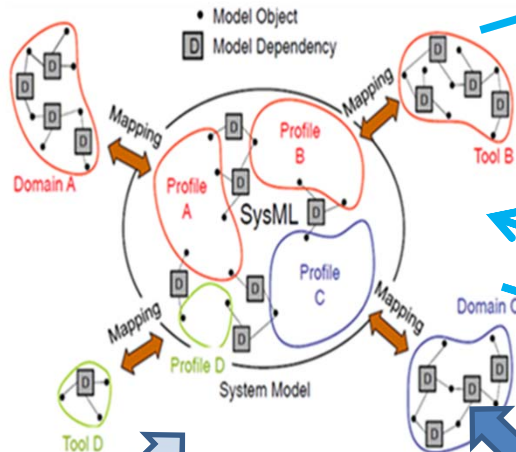
Latest Vision and Collaborations

MBSE Challenge & Need:
Develop scalable holistic methods, models and tools for future grids
Real-time distributed dispatch
Distributed sensing and control
Architecture design and evaluation

UMD: Integrated Modeling Hub
Power grids, Smart grids

Multi-domain Model Integration via System Architecture Model (SysML)

System Modeling Transformations

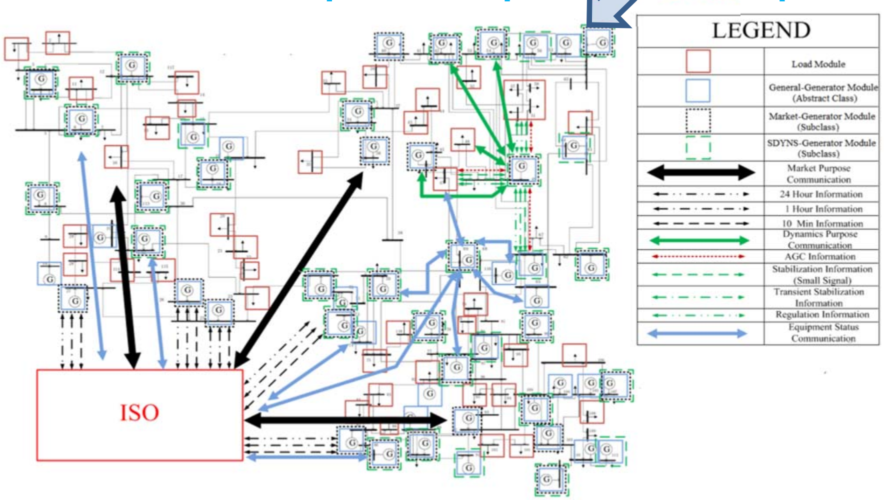


ILOG SOLVER, CPLEX, CONSOL-OPTCAD

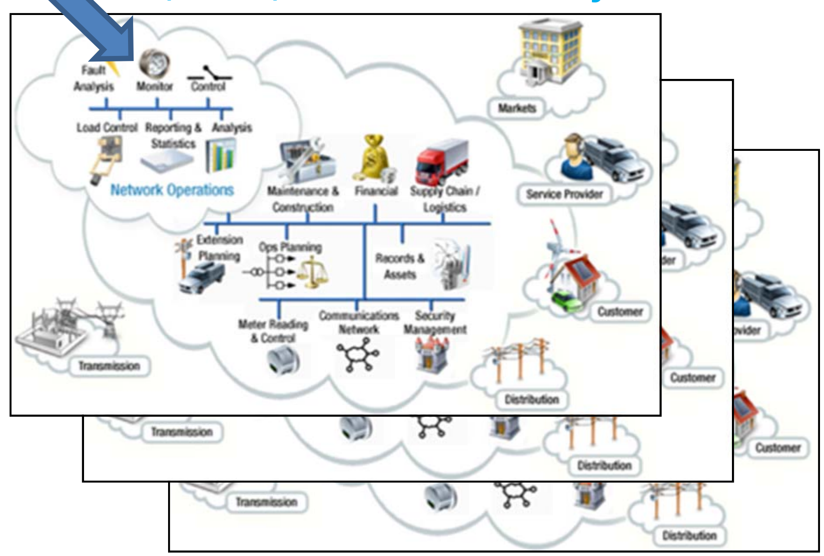
Databases Libraries of system components and models

- Multi-metric tradeoffs
- Design/Operation space Exploration
- System model updates
- Architecture exploration
- Real-time user interaction

CMU: DyMonDS based Smart Grid in a Room Simulator
End-to-End Stable Optimal Dispatch Concepts

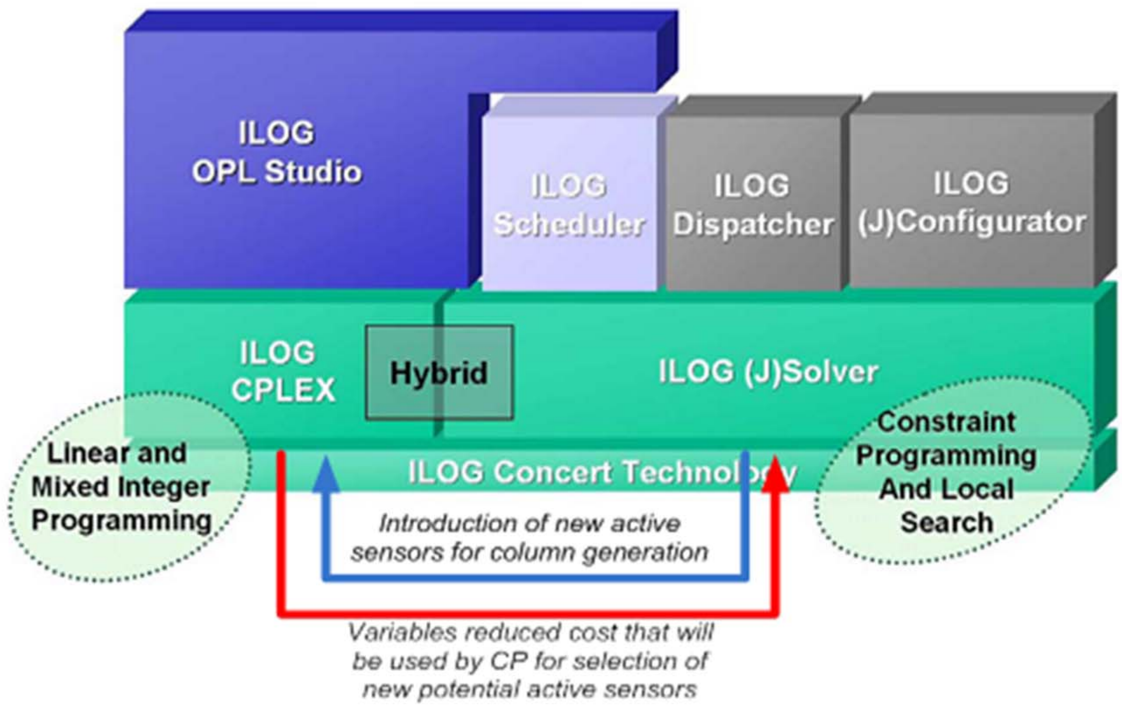


HU, UMD, NIST and Industry Testbeds



INTEGRATION OF CONSTRAINT-BASED REASONING AND OPTIMIZATION FOR TRADEOFF ANALYSIS AND SYNTHESIS

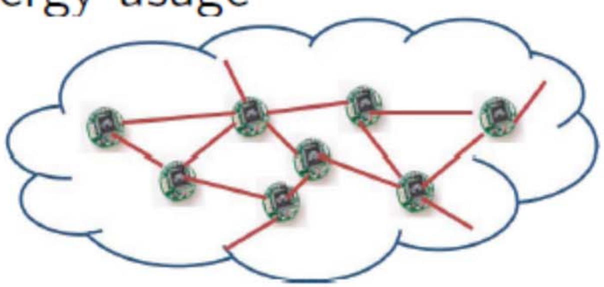
To enable rich design space exploration across various physical domains and scales, as well as cyber domains and scales



Wireless Sensor Networks Everywhere

Wireless Sensor Networks (WSN) for infrastructure monitoring

- Environmental systems
- Structural health
- Construction projects
- Energy usage



MBSE for Wireless Sensor Networks

- **Model libraries**
  - Application Model Library
  - Service Model Library
  - Network Model Library
  - Physical System Model Library
  - Environment Model Library
- **Development Principles**
  - Event-triggered: Statecharts in SysML
  - Continuous-time: Simulink or Modelica

MBSE Approach to Energy Efficient Buildings

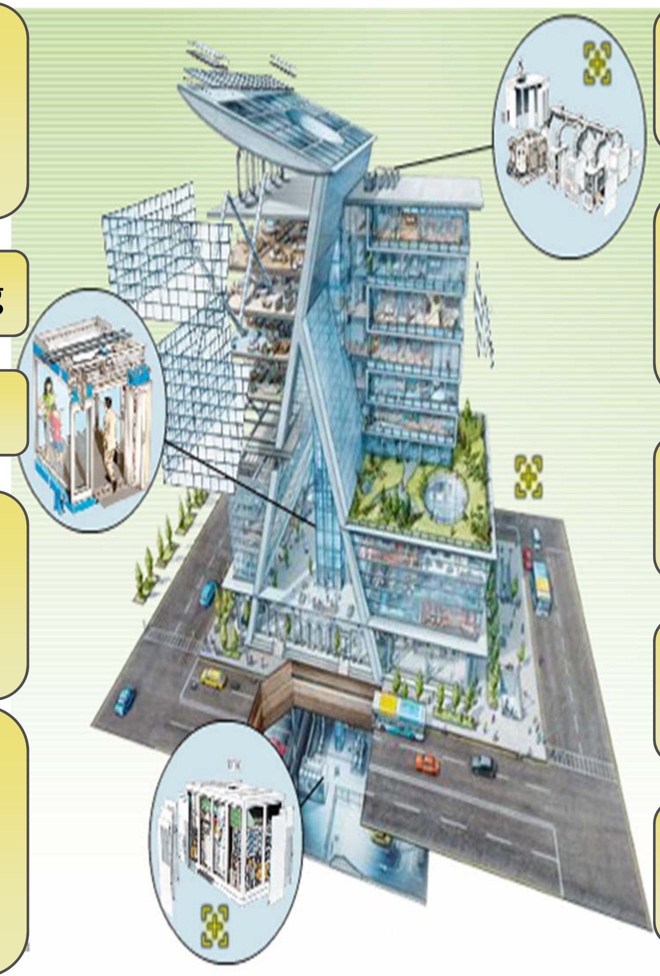
Buildings Design Energy and Economic Analysis

Windows and Lighting

HVAC

Domestic/International Policies, Regulation, Standards, Markets

Demonstrations, Benchmarking, Operations and Maintenance



Natural Ventilation, Indoor Environment

Networks, Communications, Performance Database

Sensors, Controls, Performance Metrics

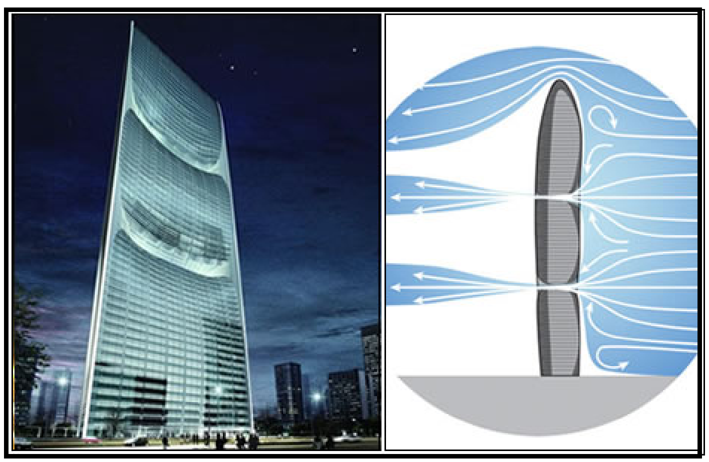
Power Delivery and Demand Response

Building Materials, Misc. Equipment

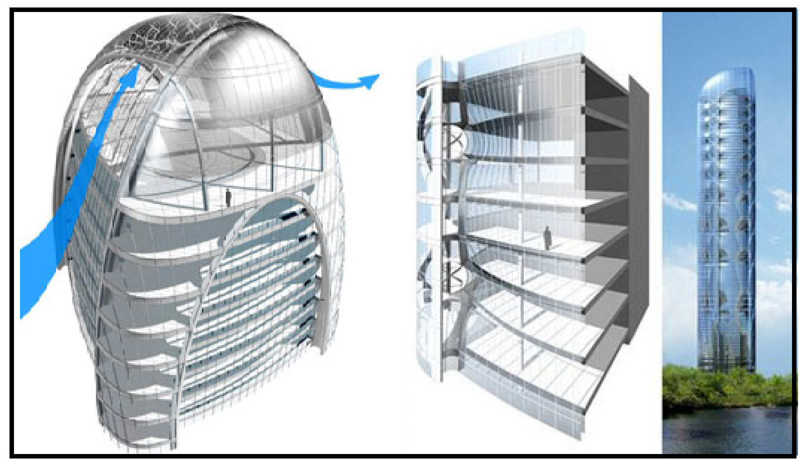
Buildings as Cyber-Physical Systems

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

Pearl River Tower Complex



Green Technology Tower –– Architectural Proposal for Chicago



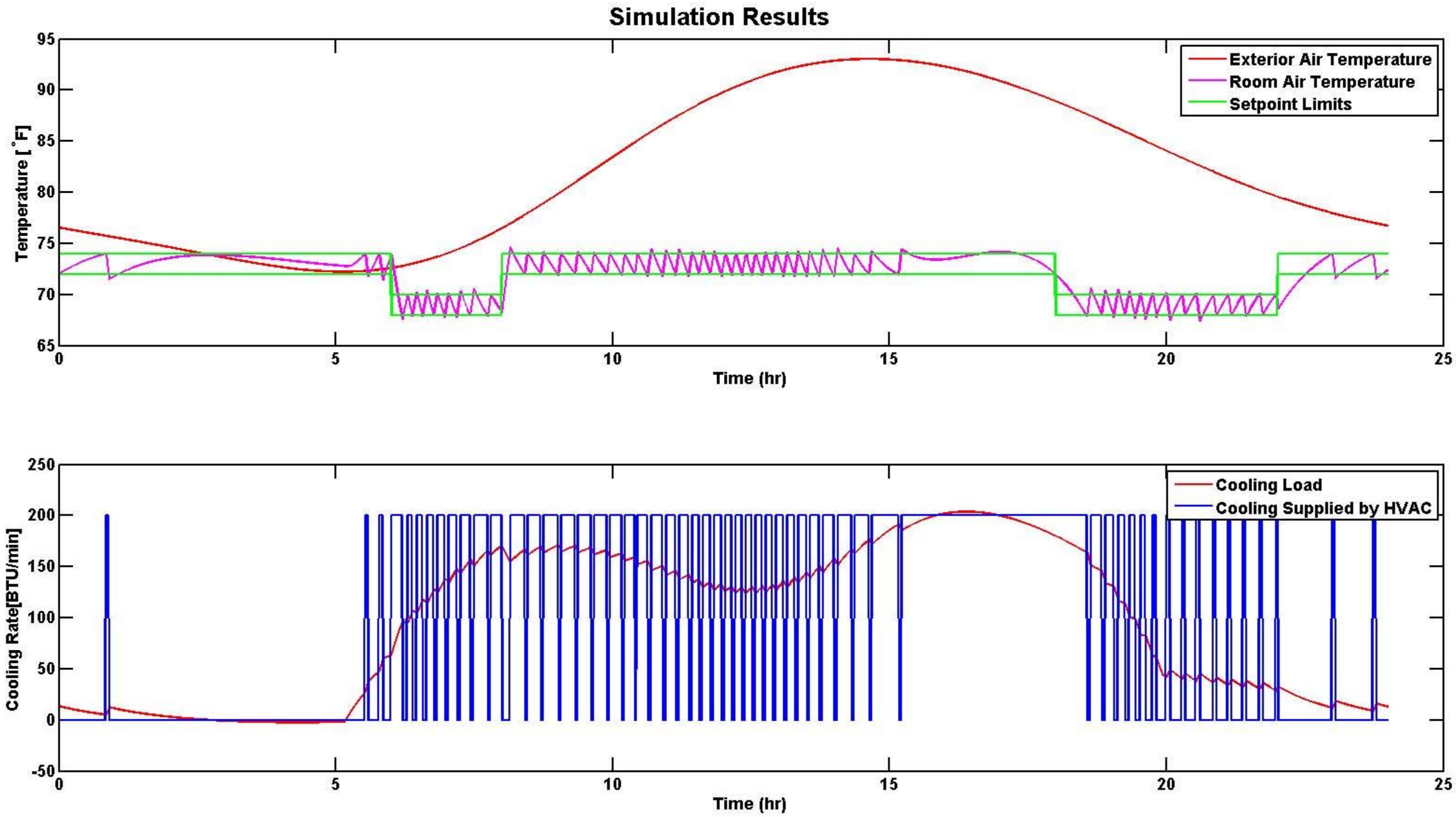
NET-zero Energy Building

NIST Net Zero Energy Residential Test Facility

Courtesy J. Kneifel (2012)

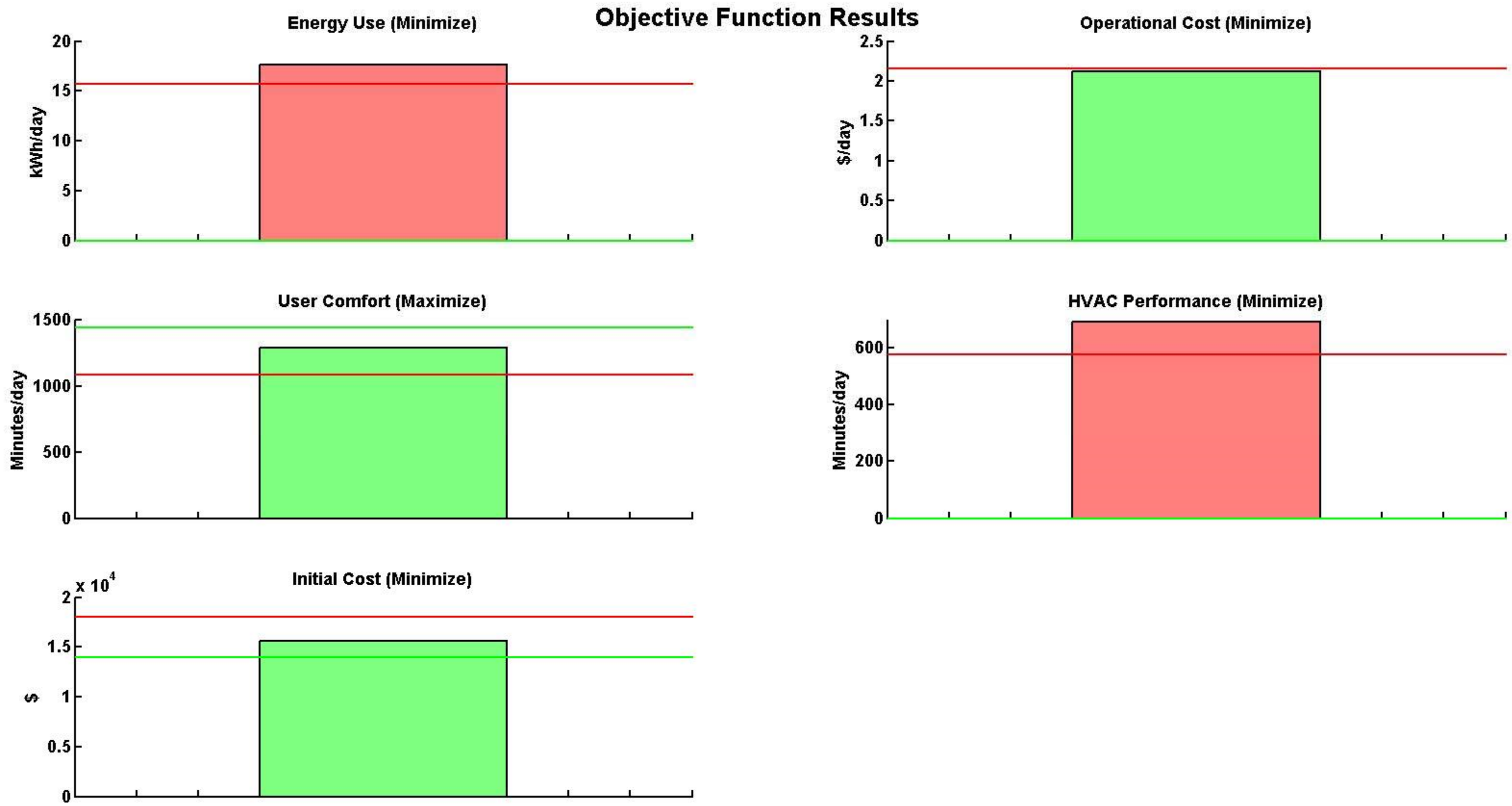
MULTI-OBJECTIVE OPTIMIZATION

Simulation



MULTI-OBJECTIVE OPTIMIZATION

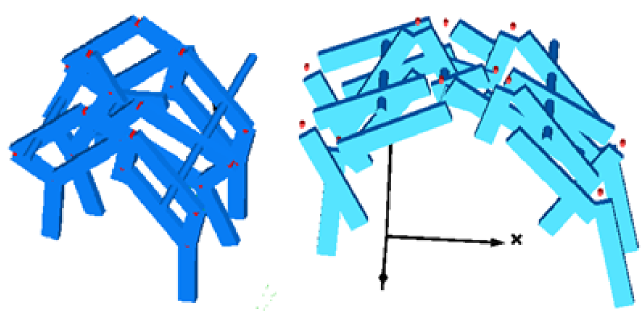
Simulation



MBSE for Robotic Arms and Grippers

- Transcend areas of application: from space to micro robotics
- Include material selection in design
- Include energy sources, resilience, reliability, cost
- Include validation-verification and testing
- Use integrated SysML and Modelica environment
- Link it to tradeoff tools CPLEX and ILOG Solver
- Demonstrate reuse, traceability, change impact and management

Application to Microrobotics

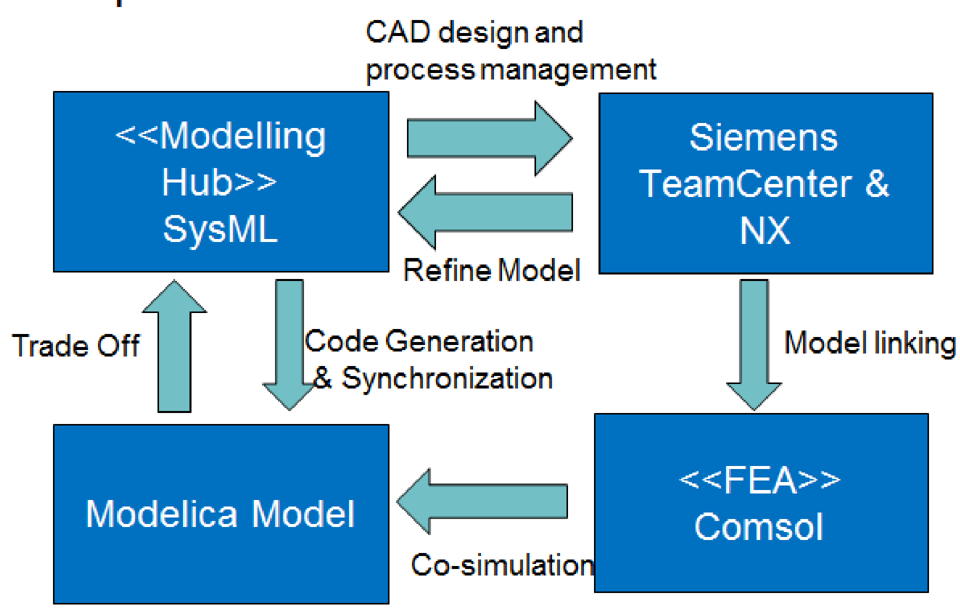


(a) (b)

- Micro-robots design and manufacturing require control algorithm and physical layer (material and geometry) co-design.
- This insect-like robot is modeled in Modelica language using Differential Algebraic Equation.
- We are working on a Model-Based Systems Engineering approach to perform analysis, modeling and tradeoff for robotics and its material and control parameters.

Siemens Tools Utilization

- Design and analysis CAD model at the design phase
- Guide requirement to implementation from CAD design to physical simulation



Virtual Engineering Everywhere

(Automotive manufacturing, AUTOSAR,…)

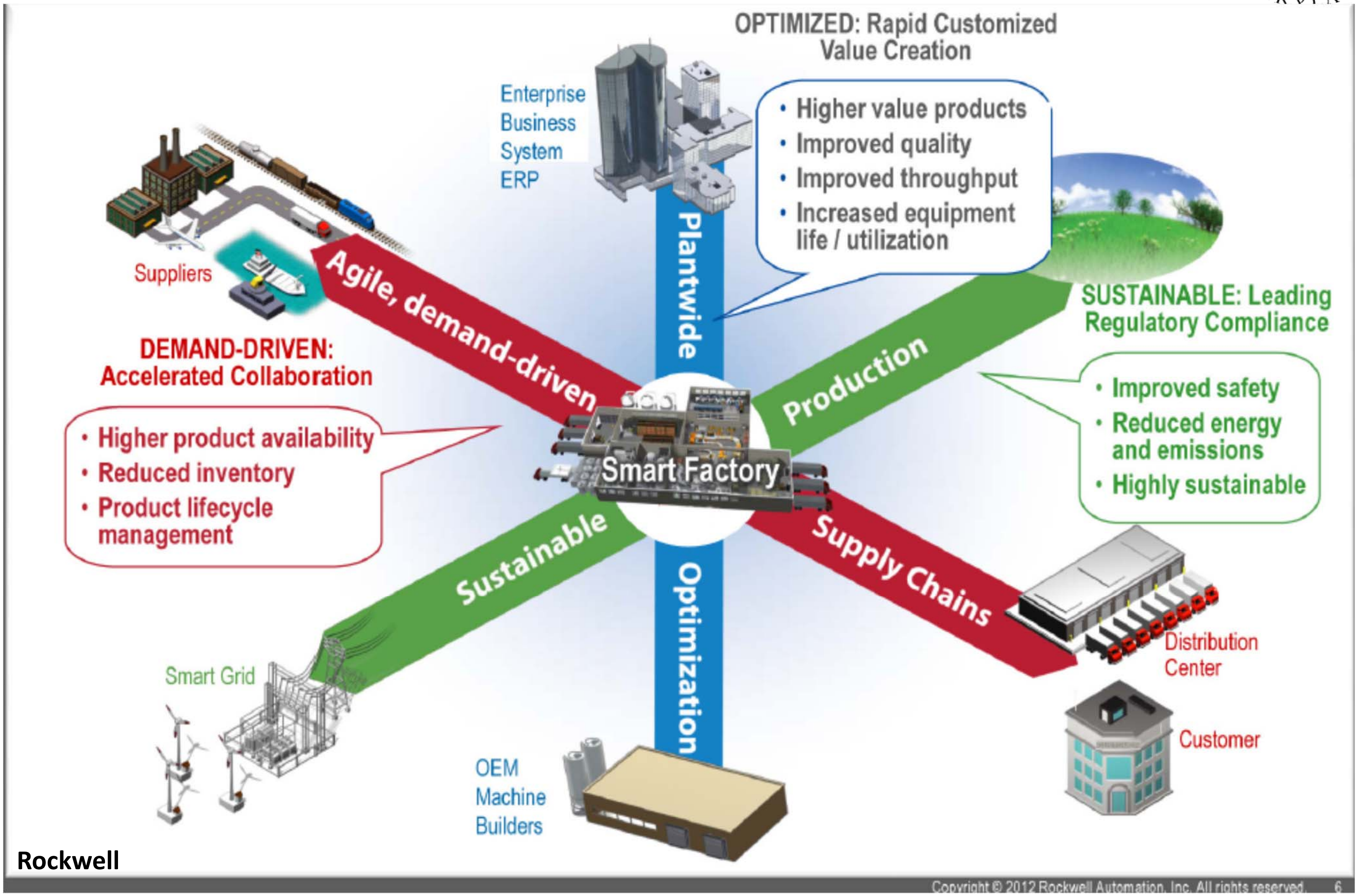
Helping over 30 different teams and skills in the company work together

Linking over 40 different EE design representations throughout the entire development process

Ensuring that the EE design flow is integrated at the same level of quality and performance as the 3D CAD system

Model based design and executable specification in the OEM/supplier chain

Smart Manufacturing

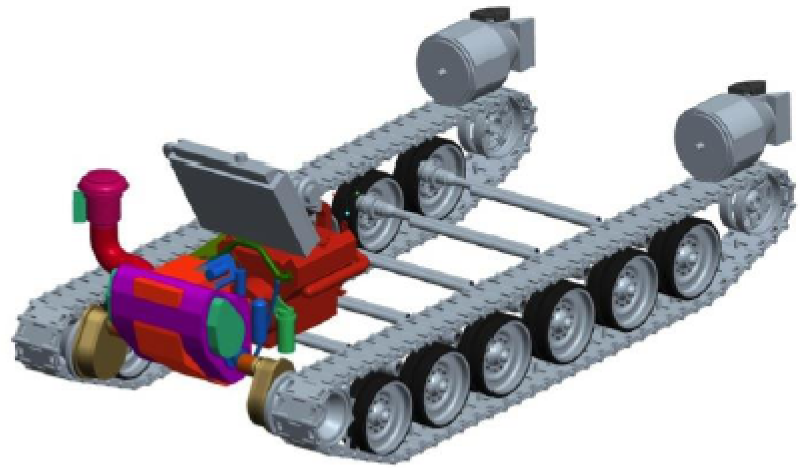


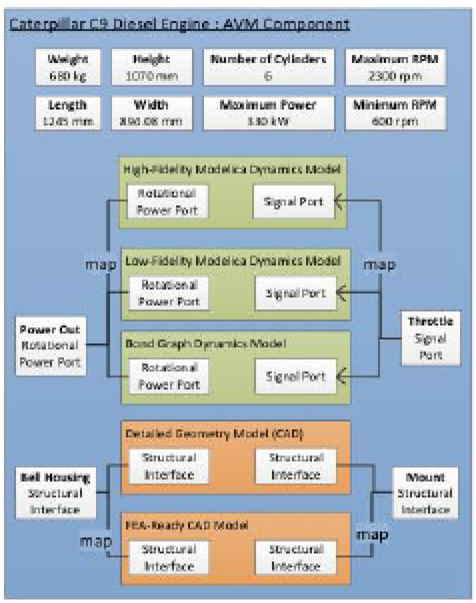
Rockwell

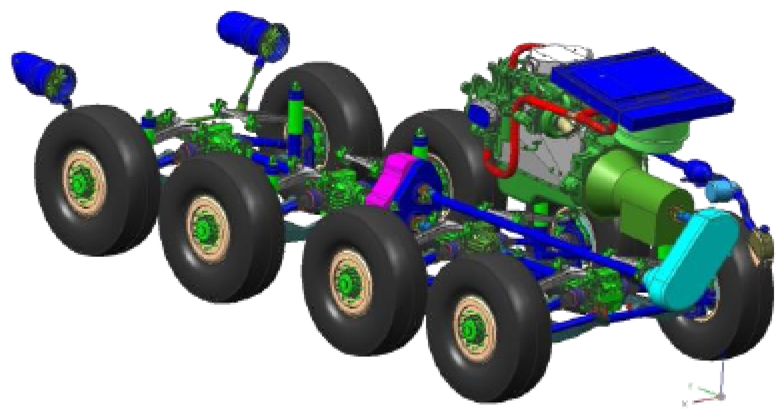
META – iFAB – AVM: Component Models

As of today:

- 131 component classes
- 469 component instances
- 43 parametric components
- 112 ITAR protected models
- 357 non-ITAR protected models







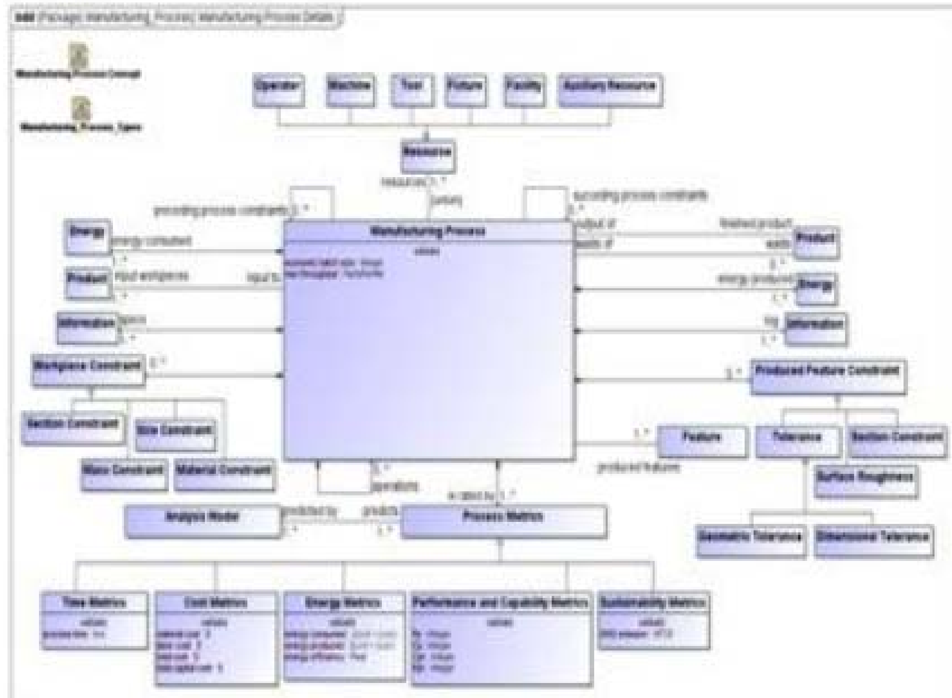
Source: Ricardo PLC

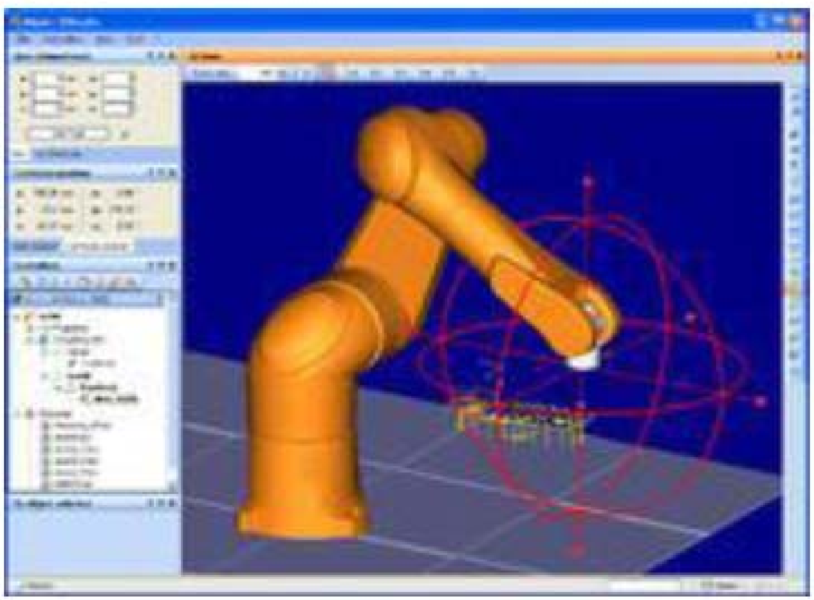
META – iFAB – AVM: Manufacturing Process Models Semantics Across Domains

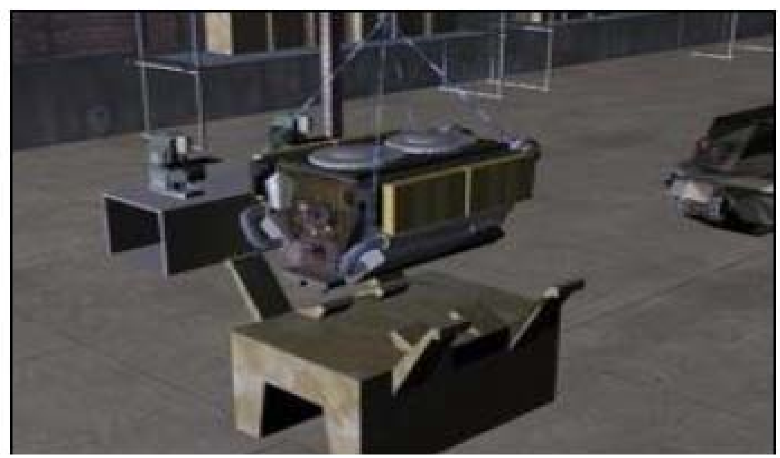
The Institute for Systems Research

As of today:

- 7 material shaping processes
- 19 general processes
- 231 machine instantiations
- 64 manual labor units
- 3,212 tools



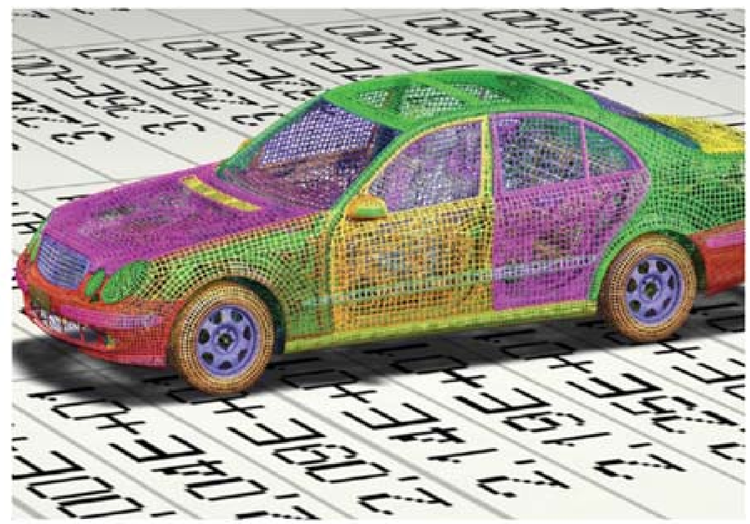


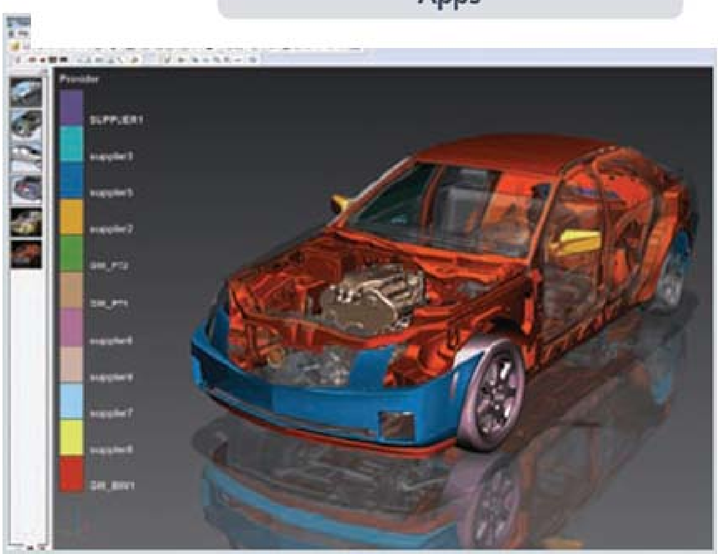


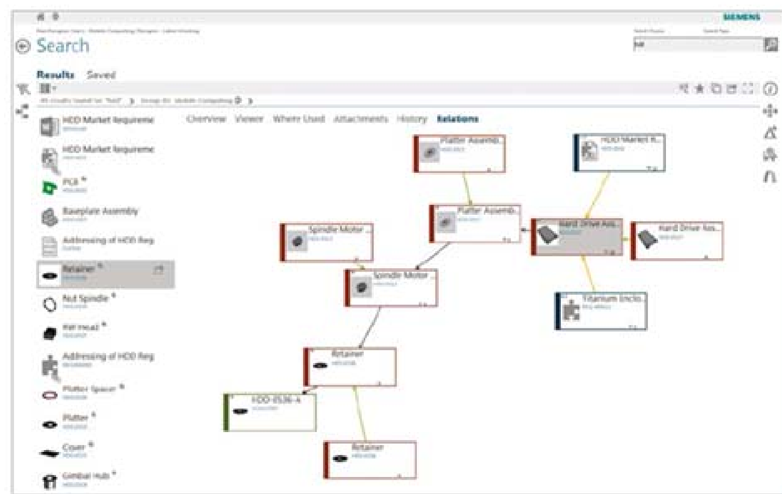
Sources: Penn State ARL; GM Research

The Institute for Systems Research

Integrating in Hubs
Siemens PLM Tools: Automotive

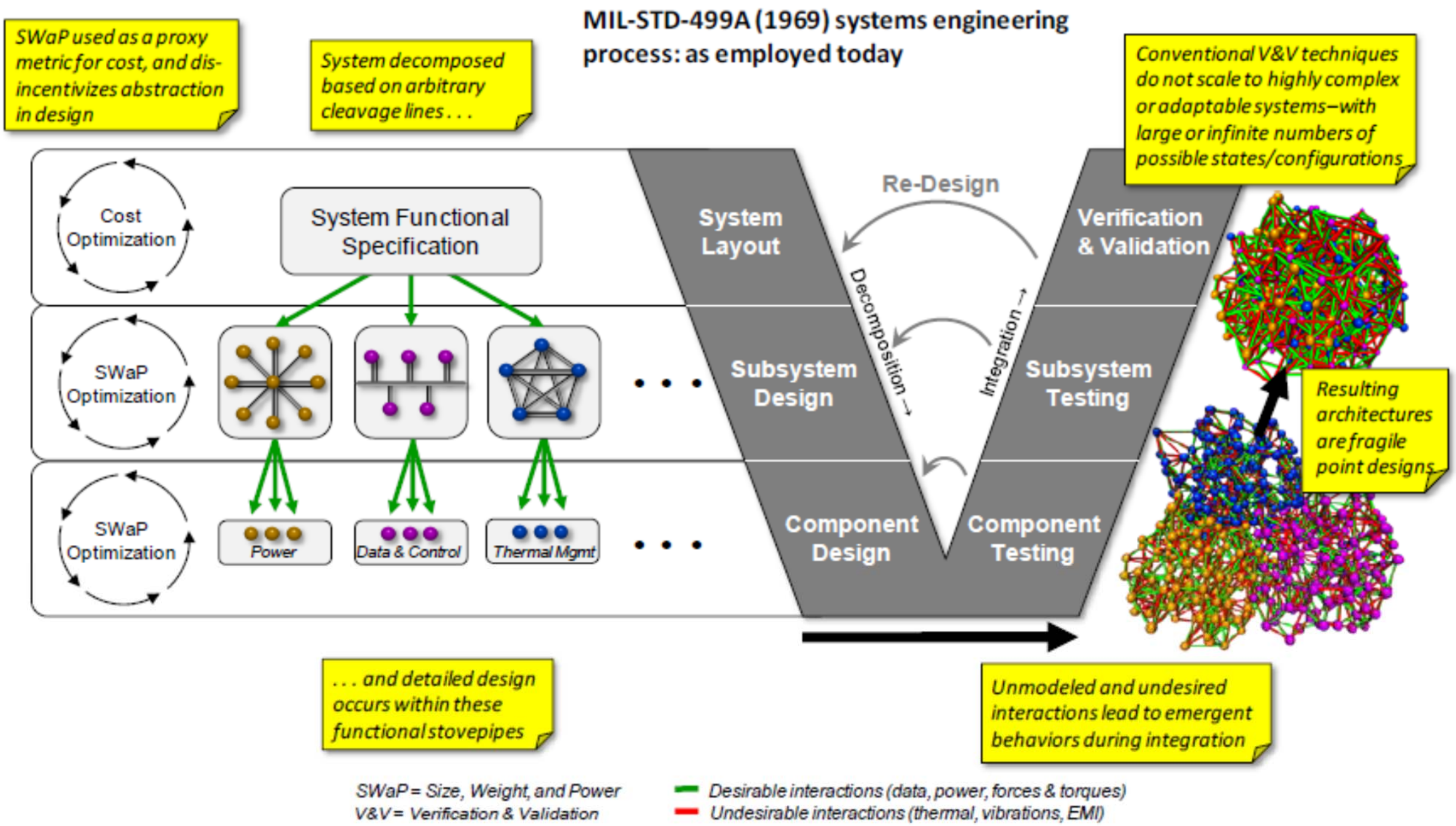






SIEMENS

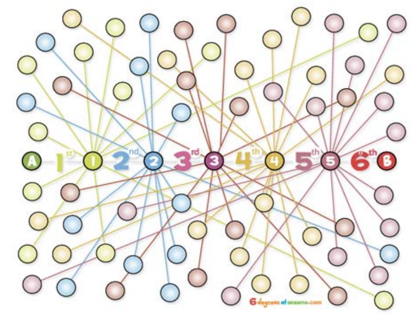
Need to Improve Systems Engineering Methods and Tools Dramatically



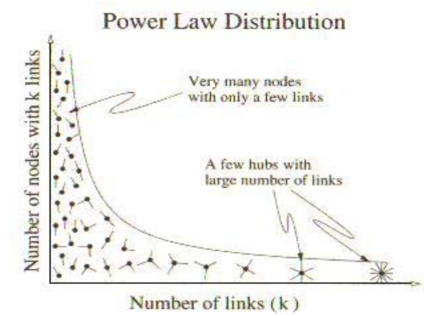
Source: Paul Eremenko, DARPA/TTO

Social Networks -- Challenges

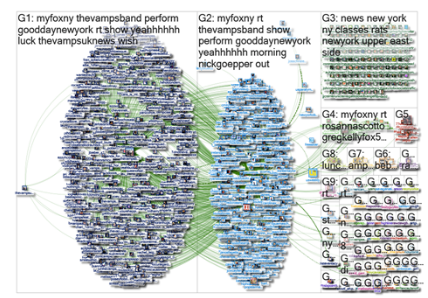
- We are much more "social" than ever before
  - Online social networks (SNS) permeate our lives
  - Such new Life style gives birth to new markets
- Monetize the value of social network
- Major characteristics of social networks
  - The small-world effect (6 degree of separation)
  - Scale-free degree distribution (power-law)
  - Community structure (clustering)
- Statistical models
  - Random Graph (Poisson, exponential)
  - Small-World
  - Preferential Attachment
- SNS applications (e.g. advertising) should consider these properties



Small-world effect



Scale-free distribution



Community structure

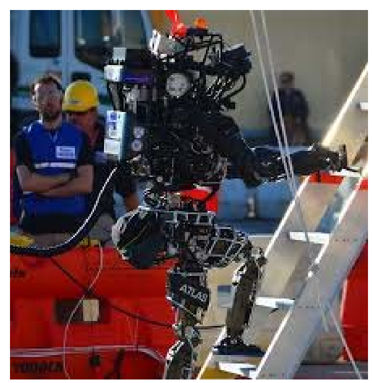
Social and Cognitive Robotics: Collaborative Autonomy





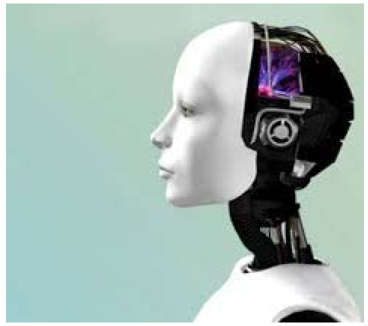




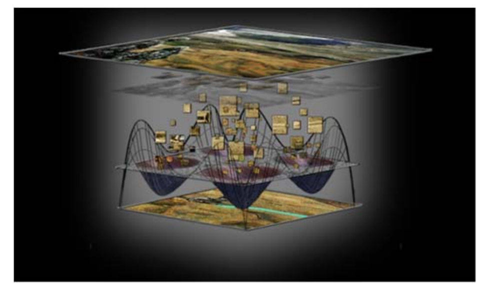


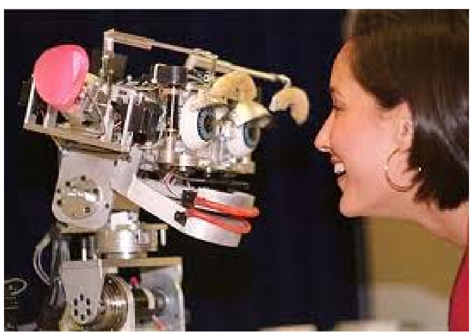

The Institute for Systems Research

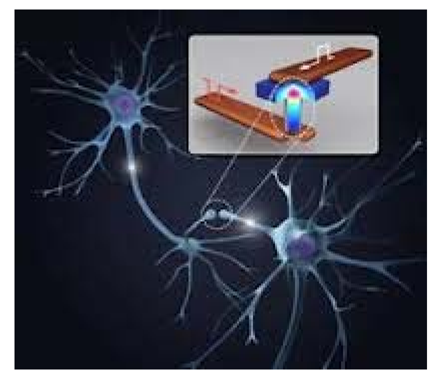
Perception-Cognition and Co-Robots



The pressure of P on C
The return of analog computation?
Non-von Neumann Architectures?
Physics of computation?
Beyond Turing?







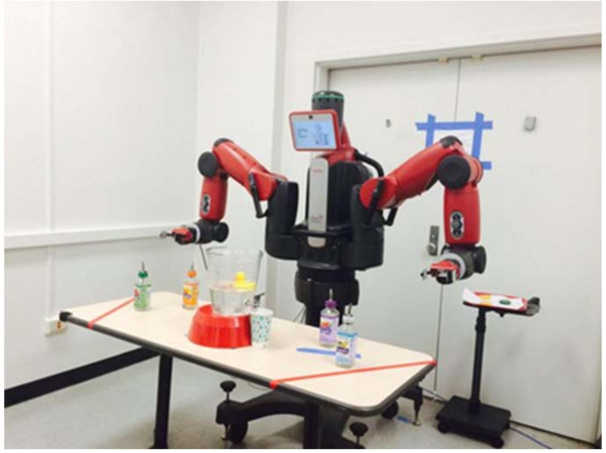
Cognition and knowledge generation from sensory perception – communicating with humans – collaboration
Not just obeying commands – the inverse problem

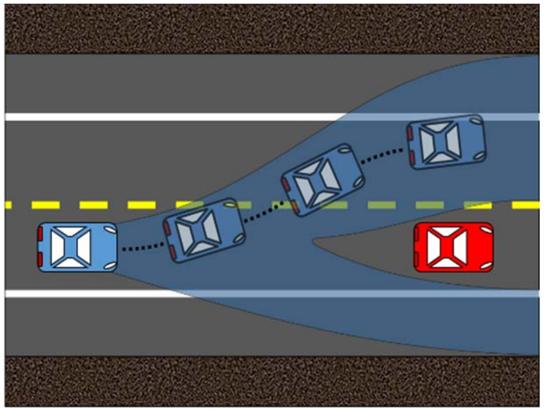
Learning Tasks, Changing Environments

- Teach through demonstrations
  - Easy training, hard to generalize to new constraints
- Program planning techniques
  - Generalize to constraints, manually design objectives

Temporal Logic, Robots, Human-Robot Teams

- Finite time logical constraints arise due to:
  - ✓Task description
  - ✓Decision making process
  - ✓Inherent inter–system interactions
  - ✓Other (a)causal dependencies



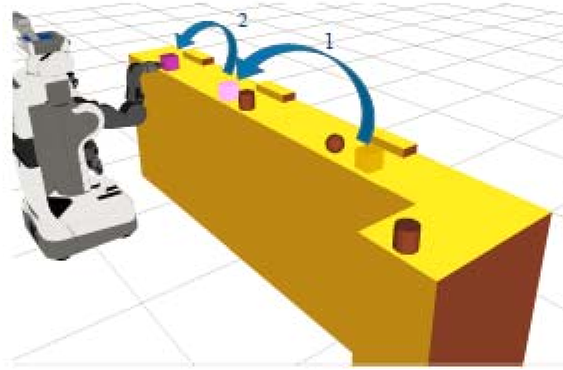


Constraints:

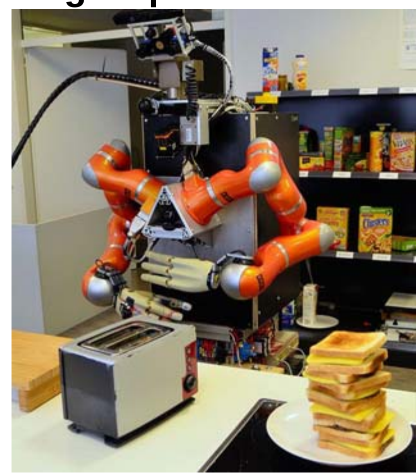
- Safety
- Human involvement
- Physical limitation

A Robotic Motion Planning Example

- Manipulation task planning[2]
  - First, take food to customers and bring the empty plates back to the preparation area. Next, show the tip jar to the ones whom have already finished eating.
- The question is how fast to take the food to the customers, or what is a good time to ask for the tips from the customers. So timing aspects are important.
- Many robotic tasks require finite time constraints.
- LTL is unable to address finite time constraints and hence we need MITL.

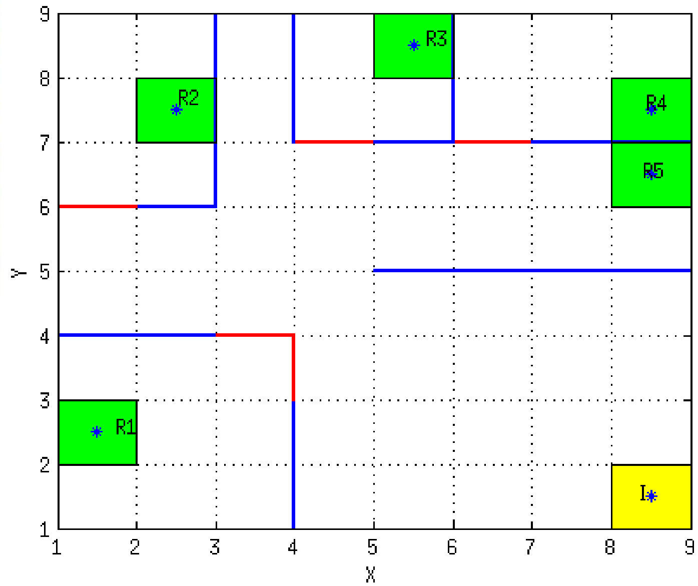


Towards manipulation planning with temporal logic specifications[2]



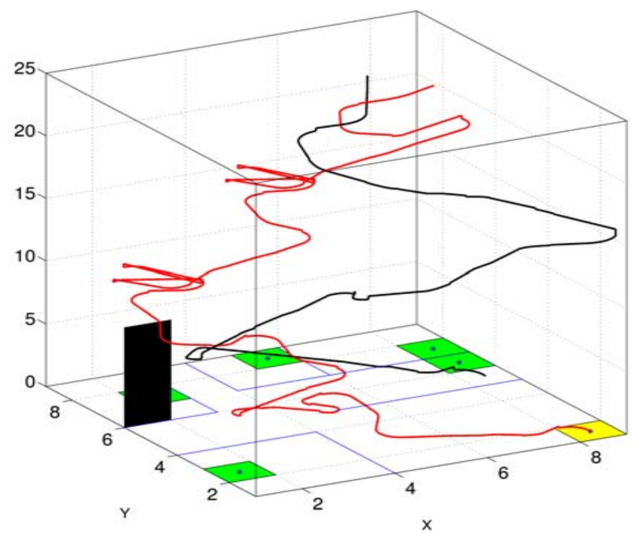
2. K. He, M. Lahijanian, L. E. Kavraki, and M. Y. Vardi, “Towards manipulation planning with temporal logic specifications,” in *Robotics and Automation (ICRA), 2015 IEEE International Conference on*, 2015,

Collaborative Planning and Re-planning with Finite-Time Task Constraints



Starting from I, visit R3 within the time Interval I1, visit R4 within time interval I2; before visiting R3 or R4, robot must Visit R2 . Eventually visit R1 and R5, and Complete the whole task in least time.

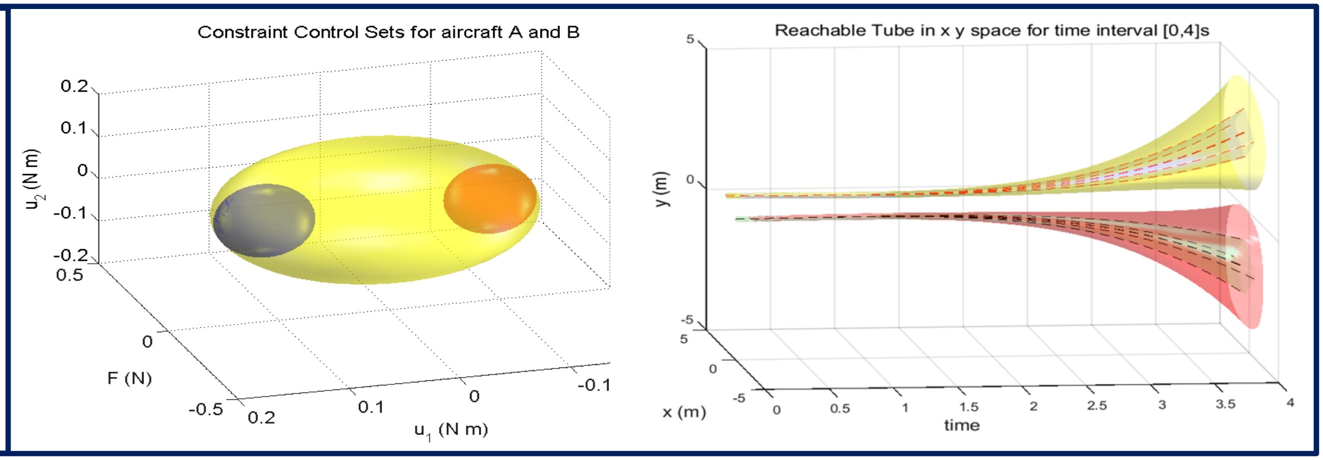
Multiple fires, diverse conditions
Need to assess and plan/allocate

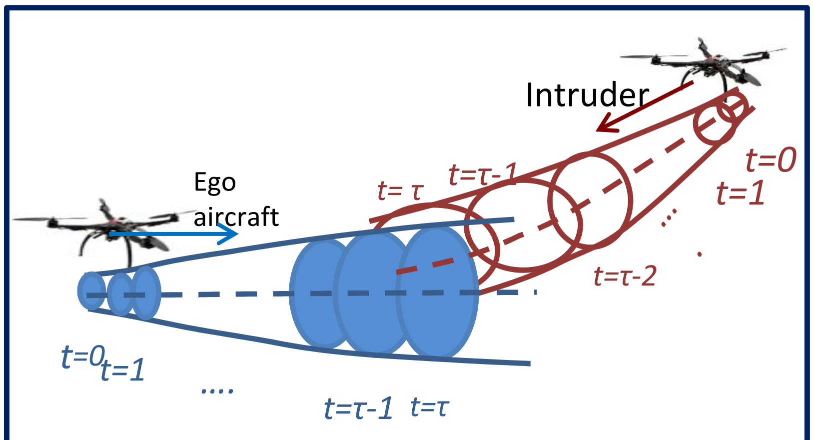


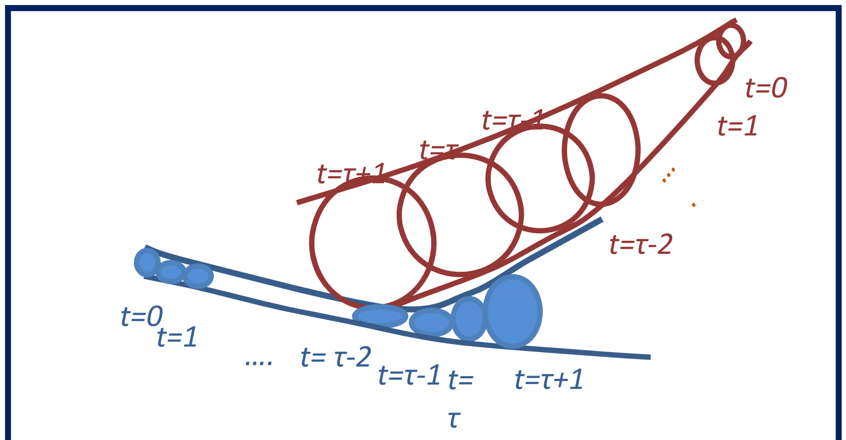
Resulting Continuous path In 3D space and time

Safety Guarantees via Reachability Analysis

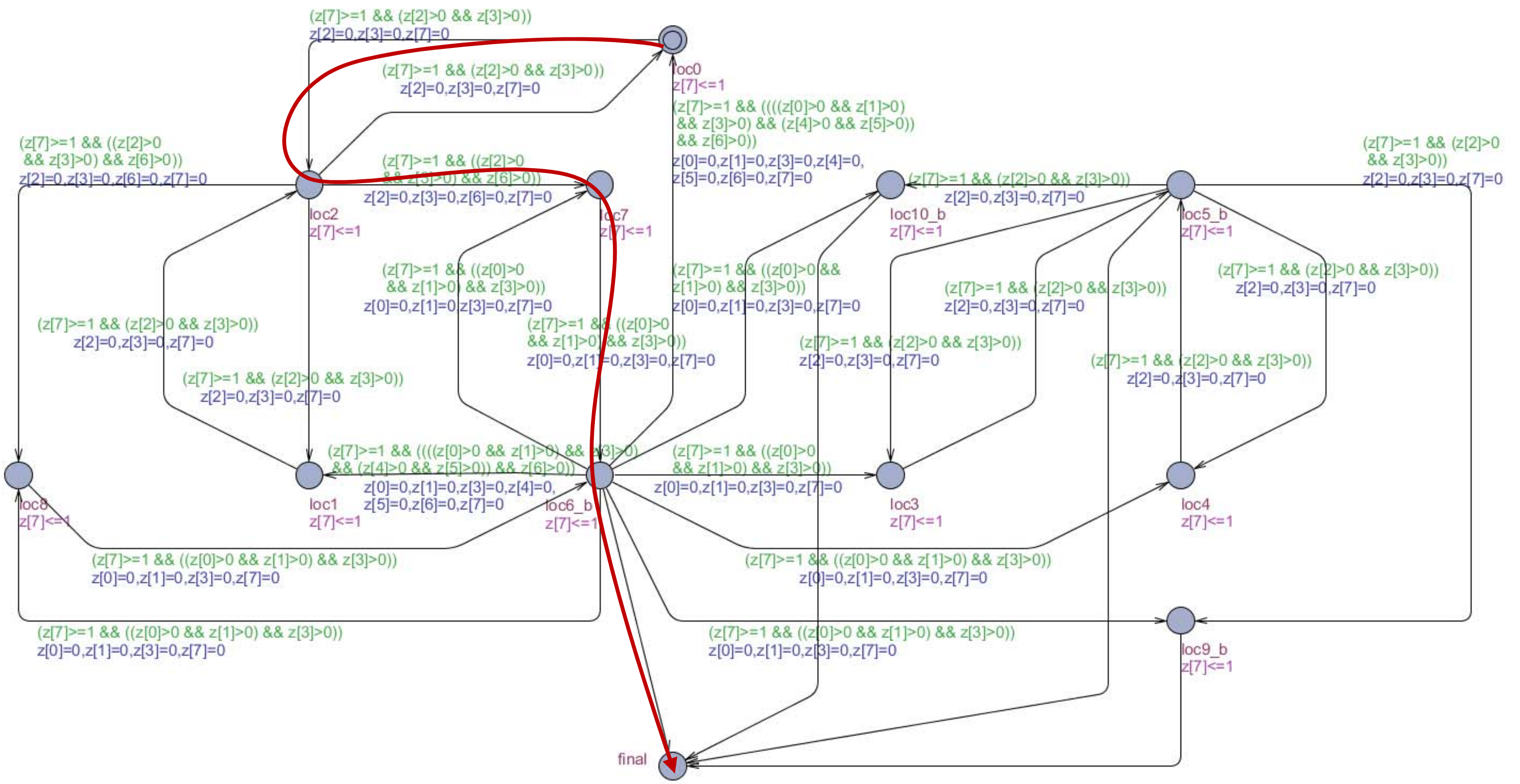
$$\dot{\xi} = v$$
$$\dot{v} = -g\mathbf{e_3} + \frac{F}{m}R\mathbf{e_3}$$
$$\dot{R} = R\hat{\Omega}$$
$$\dot{\Omega} = J^{-1}(-\Omega \times J\Omega + M)$$







Path on the Automaton



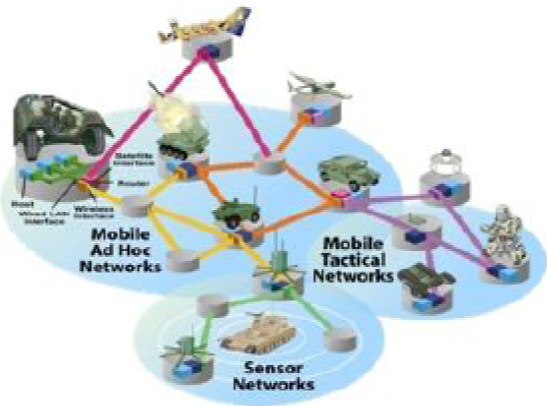
Generated timed automata and the fastest path using UPPAAL[4]

4. G. Behrmann, A. David, K. G. Larsen, J. Hakansson, P. Petterson, W. Yi, and M. Hendriks, “UPPAAL 4.0,” in *Third International Conference on Quantitative Evaluation of Systems, 2006. QEST 2006.*, 2006, pp. 125–126.

Component Based Networking: Network MBSE for MANET

The Challenge & Need:

Design DoD and Commercial MANET Adaptive to Dynamic Mission Requirements



Dynamic Interconnection and Interoperability

- Broadband wireless nets capable for multiple dynamic interface points
- Any node can serve as interface/gateway

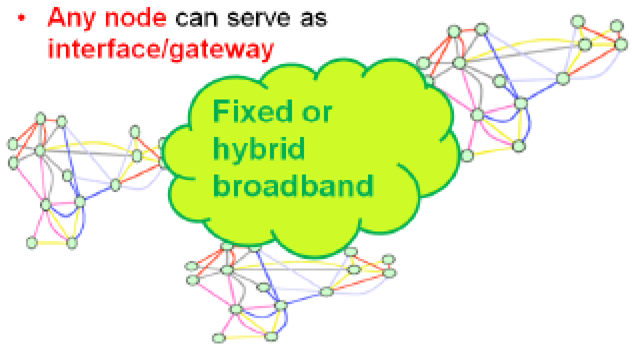
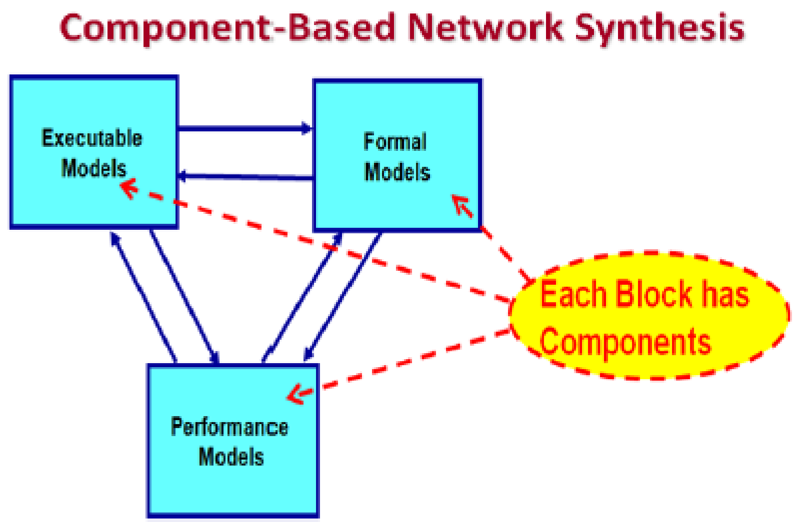


Fig.1: Intelligent Wireless Multi-Nets

Fig.2: Component Based Networking



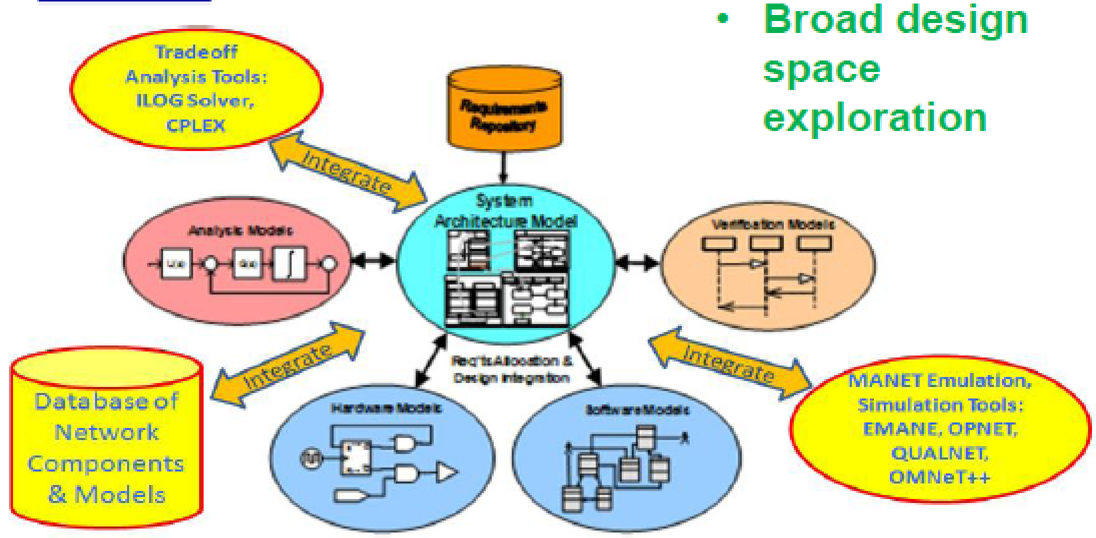


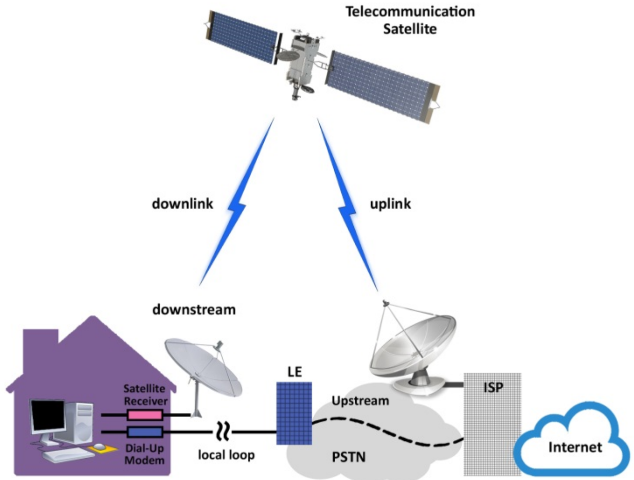
Fig. 3: Network MBSE Toolset : integrating **SysML** Architecture Model with DB of network models, emulation-simulation models, tradeoff tools

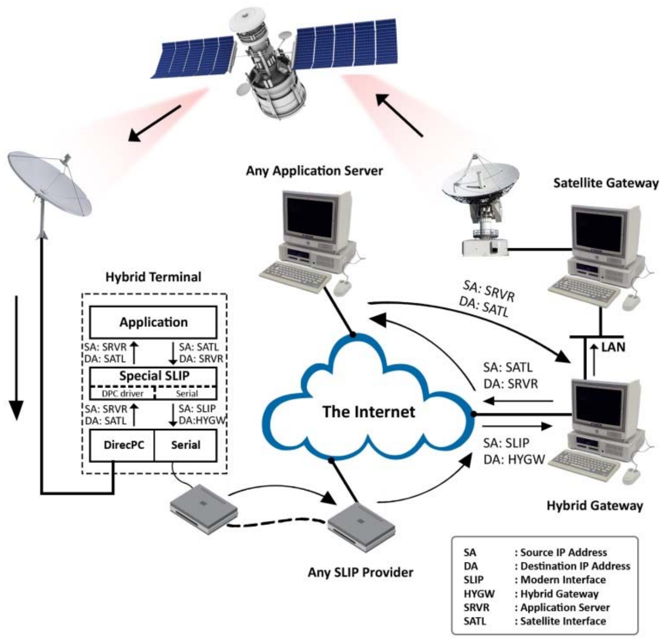
BENEFITS

- Reduced MANET cost and fielding time
- Modularity and re-use
- Increased agility in designing, modifying and fielding new MANET
- Broad design space exploration

Internet over Satellite

- Internet explosion over all types of networks
- Satellites viable Internet "nodes"





1995--DirecPC Turbo Internet™

- *5 times faster*
- *Asymmetry – usability issues*

- 1994 -- Initial Internet over satellite protocol, involved: splitting the connection, address spoofing, selective acknowledgment.
- They informed TCP that delay in ACKs was due to physical path delay and not to congestion (as TCP is designed to assume).

Collaboration with HNS







Continuous cost/performance improvement

1995 DirecPC · ***1999 DirecDu*** · ***2001 DiREC AY***

DW4000
- PC-hosted, consumer terminal

DW4020
- Satellite IP router
- DHCP
- NAT
- Self-hosted
- Enterprise focus

DW6000
- Single module unit
- Integrated dial backup

DW7000
- 3 x throughput increase
- High-speed inroutes to 1.6 Mbps
- Dual LAN subnets
- Integrated serial-to-IP conversion
- Multiband Support
- RIPv2

HN7000S
- DVB-S2 with ACM
- AIS Adaptive Inroute
- Closed-loop timing
- VRRP / PBR
- Integrated VoIP (HN7740S)

INTRODUCED **Multimedia Appliance** (2002)

INTRODUCED **Voice Appliance** (2003)

INTRODUCED **Serial Appliance** (2004)

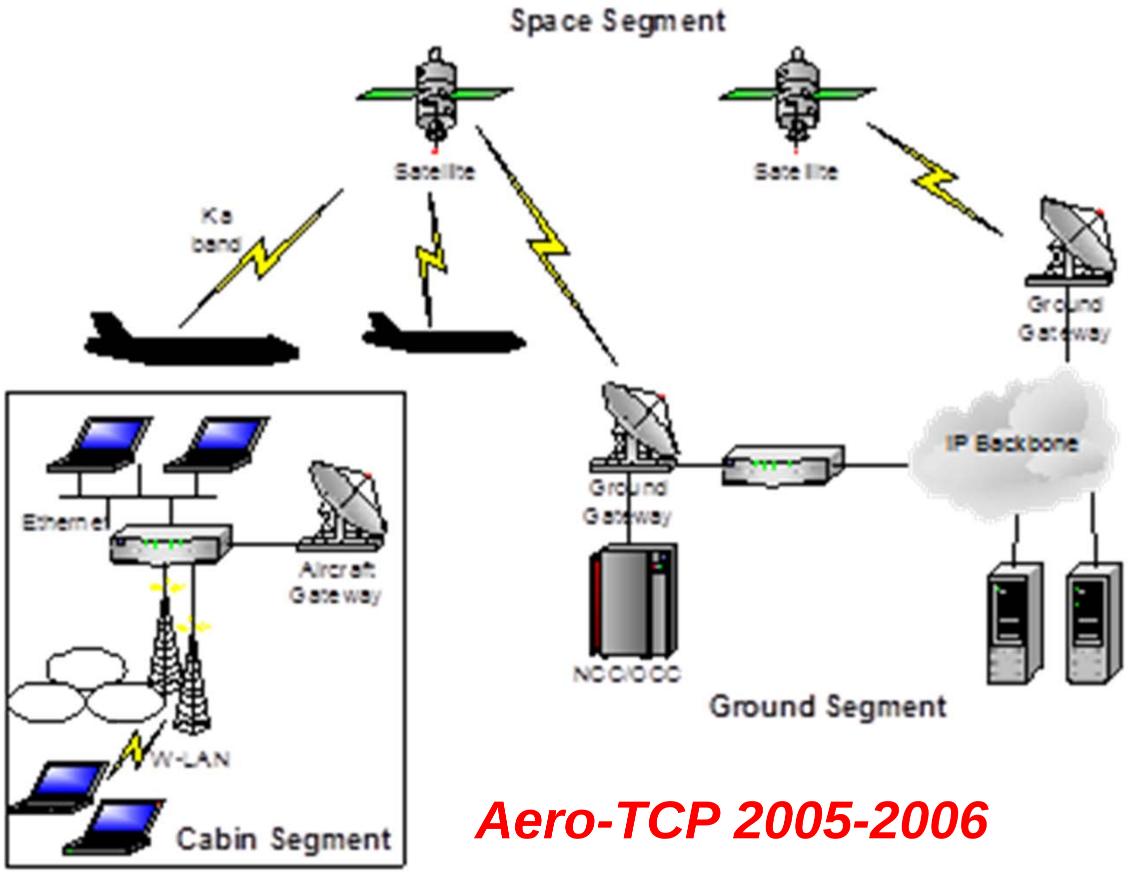
IPoS™

TIA, ETSI, ITU Open Standard Platform

2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007

Aero-TCP

Boeing Connexion 2001-2006



Aero-TCP 2005-2006

Since 2011 satellite-based ***broadband Internet to planes*** has received much attention from airlines and the FCC, with deployment of in-flight satellite-based Internet service

Satellite Constellations

- More than 50% of the world's population without Internet access; 3 ... occupies less than
- Mobile w ... story
- Can brin ... places
- More dev ... ters, sensors, ...
- Need con

- OneWeb (Qualcom ... son), Airbus, Arianespace): one ... es at 1,200km), great coverage, Internet ... nderserved areas
- Integrates with terr ... d 3G, 4G LTE and Wi-Fi services

- Creates huge opportunities for economic growth world-wide

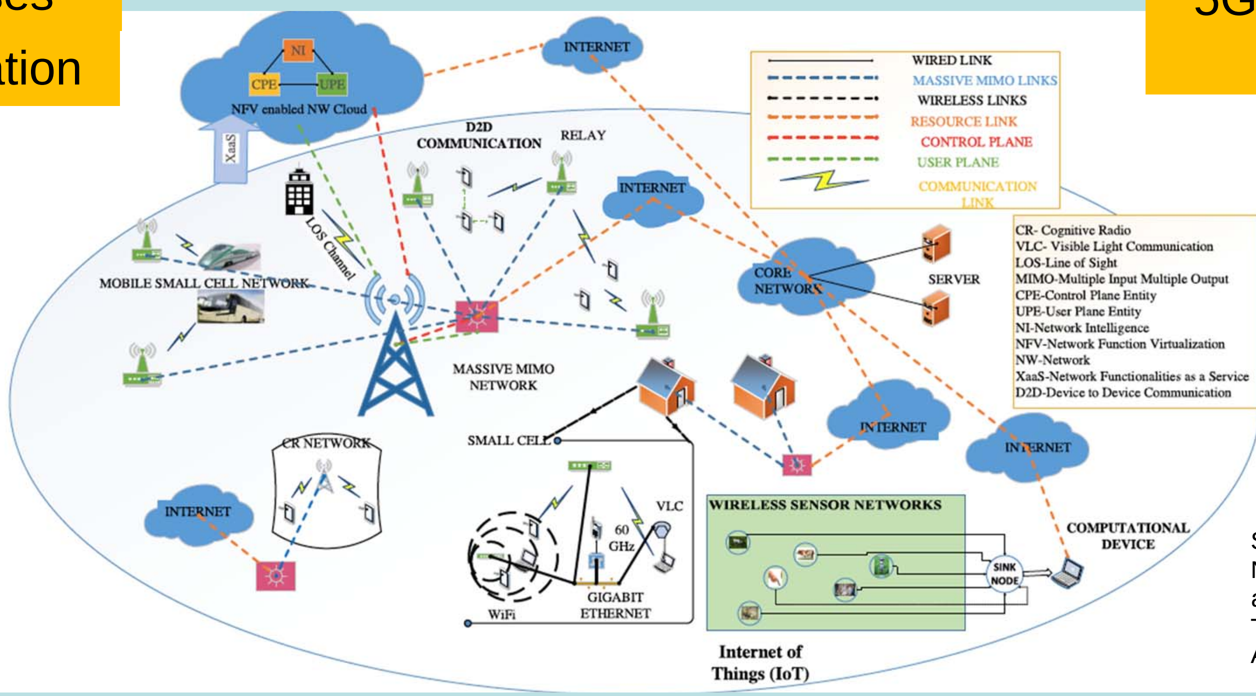
5G Vision

End-to-end ecosystem to enable a fully mobile and connected society
Value creation towards customers and partners, with existing and emerging use cases
Delivered with consistent experience
Enabled by sustainable business models

5G Use Cases

5G Value Creation

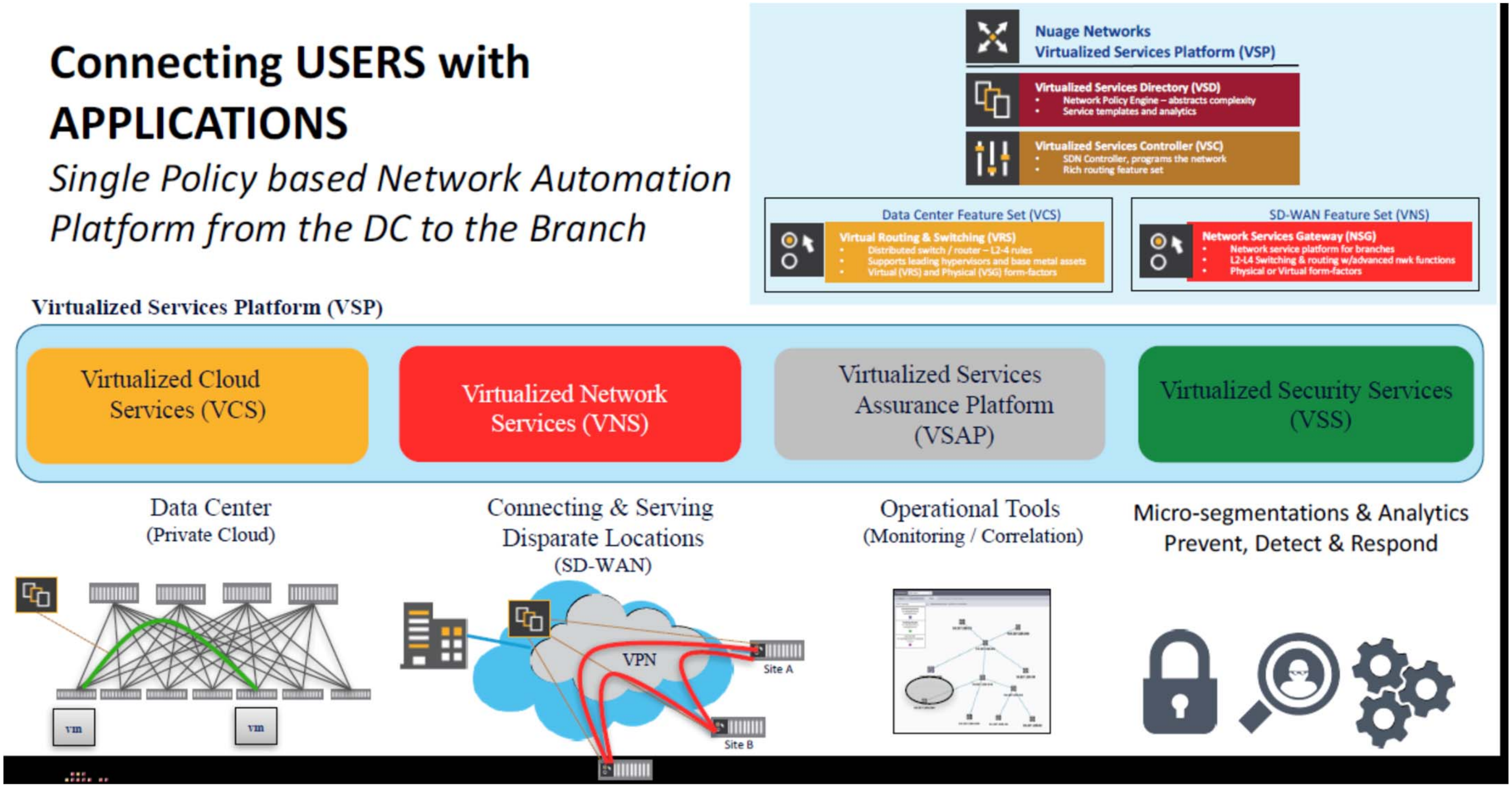
5G Business Models



SRC: A Survey of 5G Network: Architecture and Emerging Technologies, IEEE Access, 2015

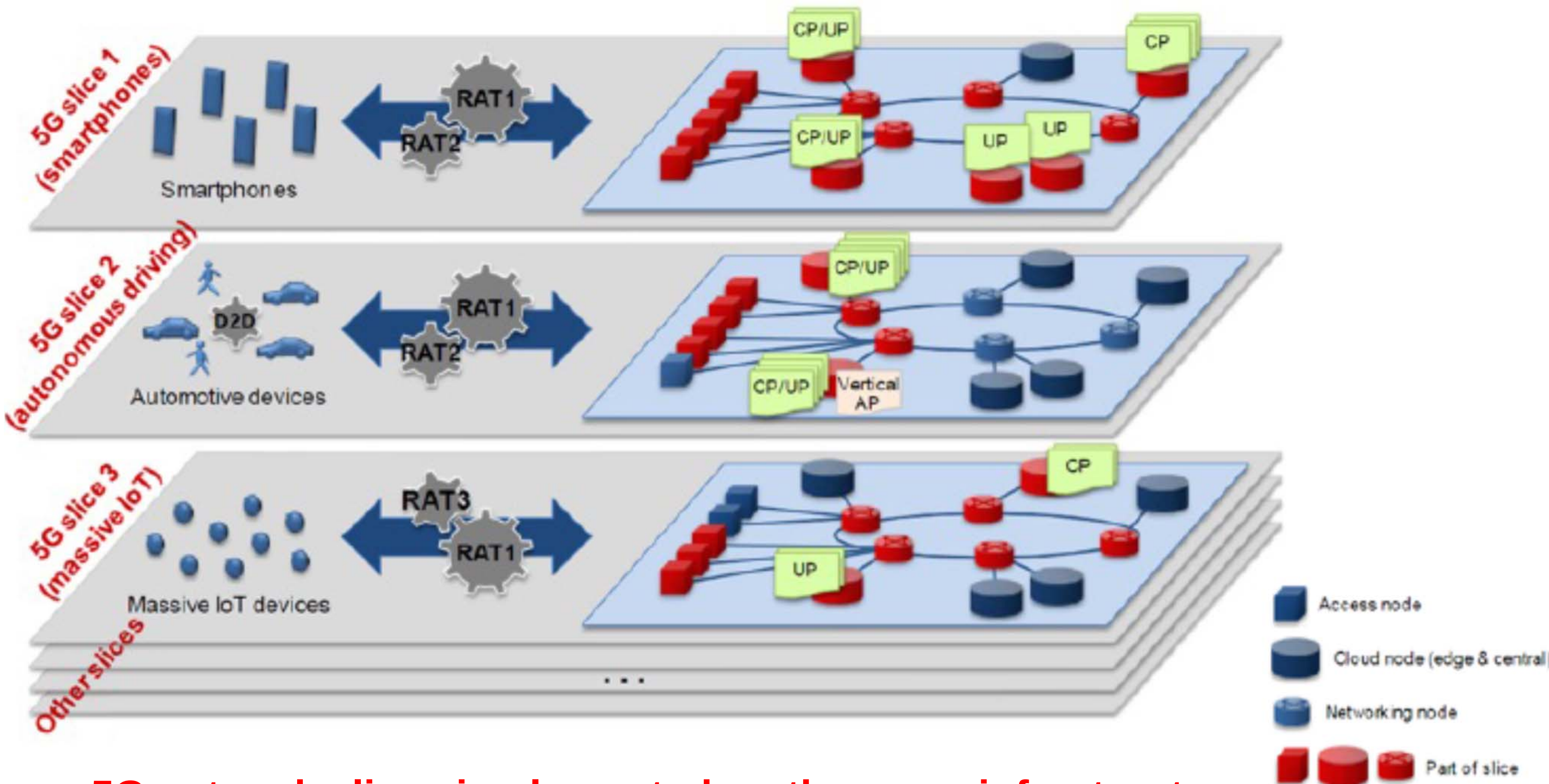
Network of networks,'' i.e., a heterogeneous system comprising a variety of air interfaces, protocols, frequency bands, access node classes, and network types

Virtualizing the Network – Network as a Service (NaaS)?



Ericsson

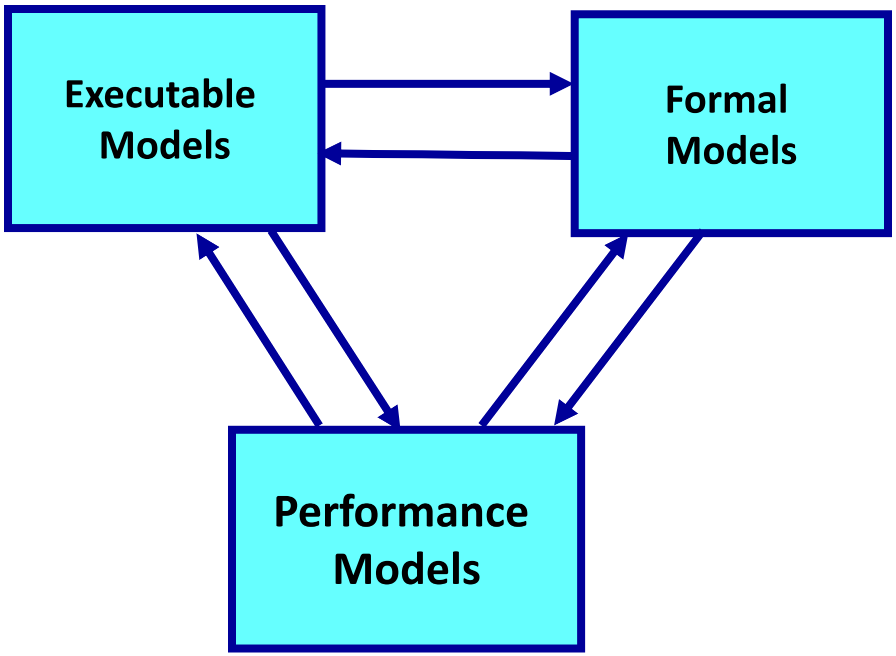
Network Slicing



5G network slices implemented on the same infrastructure

SRC: NGMN

Component-based Networks and Composable Security



Studying compositionality is necessary!

Universally Composable Security of Network 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)

- **Results todate (Canetti, Lindell, …)** :
  - 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
- **Many applications:** military networks, health care networks, sensor networks, SCADA and energy cyber networks
- **The challenge and the hope: Use "tamper proof hardware" (physical layer schemes, TPM etc.) even on a small subset of nodes to provably (validation) establish UCS – role of fingerprints and physical layer techniques.**
- **Establish it and demonstrate it?**

Cars are Heavily Computerized: Electronics in Cars and Vulnerabilities

UW/UCSD Work:

Kosher et al., IEEE Symposium on Security and Privacy, '10

- Reach CAN bus through diagnostic port

Checkoway et. al., USENIX Security, '11

- Remote attacks
- Insert virus into computer system in mechanic shop
- Bluetooth
- Telematics unit
- CD player

Hardware-Software Integrated Security: Key Ideas and Challenges

- **Exploit characteristics (a.k.a. FINGERPRINTS) of physical layer**
  - Waveform, RF and hardware peculiarities
  - Embed artificial and stealthy ‘fingerprints’
- **Distribute assurance/trust function across software and hardware (increases difficulty to attacker significantly)**
- **Trusted Platform Modules (TPM) and derivative technologies**
- **Secure Biometrics and Sensor Fingerprints**
- **Challenges:**

  (a) How to use informative time varying pieces of the biometric?

  (b) Develop anti-spoofing techniques using the sensor signature?

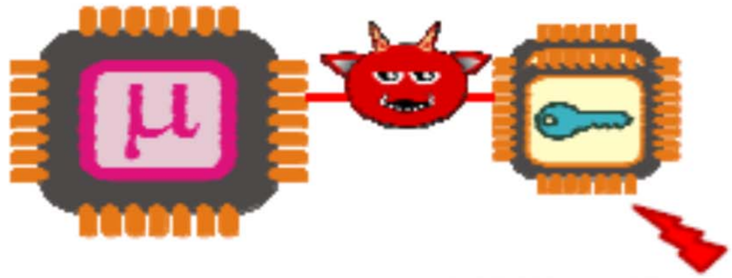
  (c) System integration and validation of the various physical layer techniques

  (d) Proof methods that security is improved – Information theoretic methods
- **Transformational concept: Authenticate the device to the network and then the user to the device** $\Rightarrow$ reduces attack risk
- **“Push” security defense to the boundary**

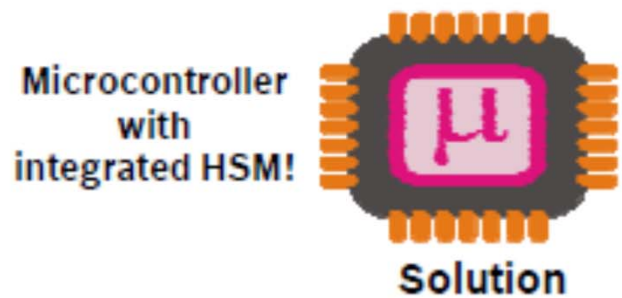
New Ideas: Hardware-Based Security

Using an external TPM?

- Initial idea: Use an existing component-of-the-shelf like a TPM or SmartCard as root-of-trust
  - But…

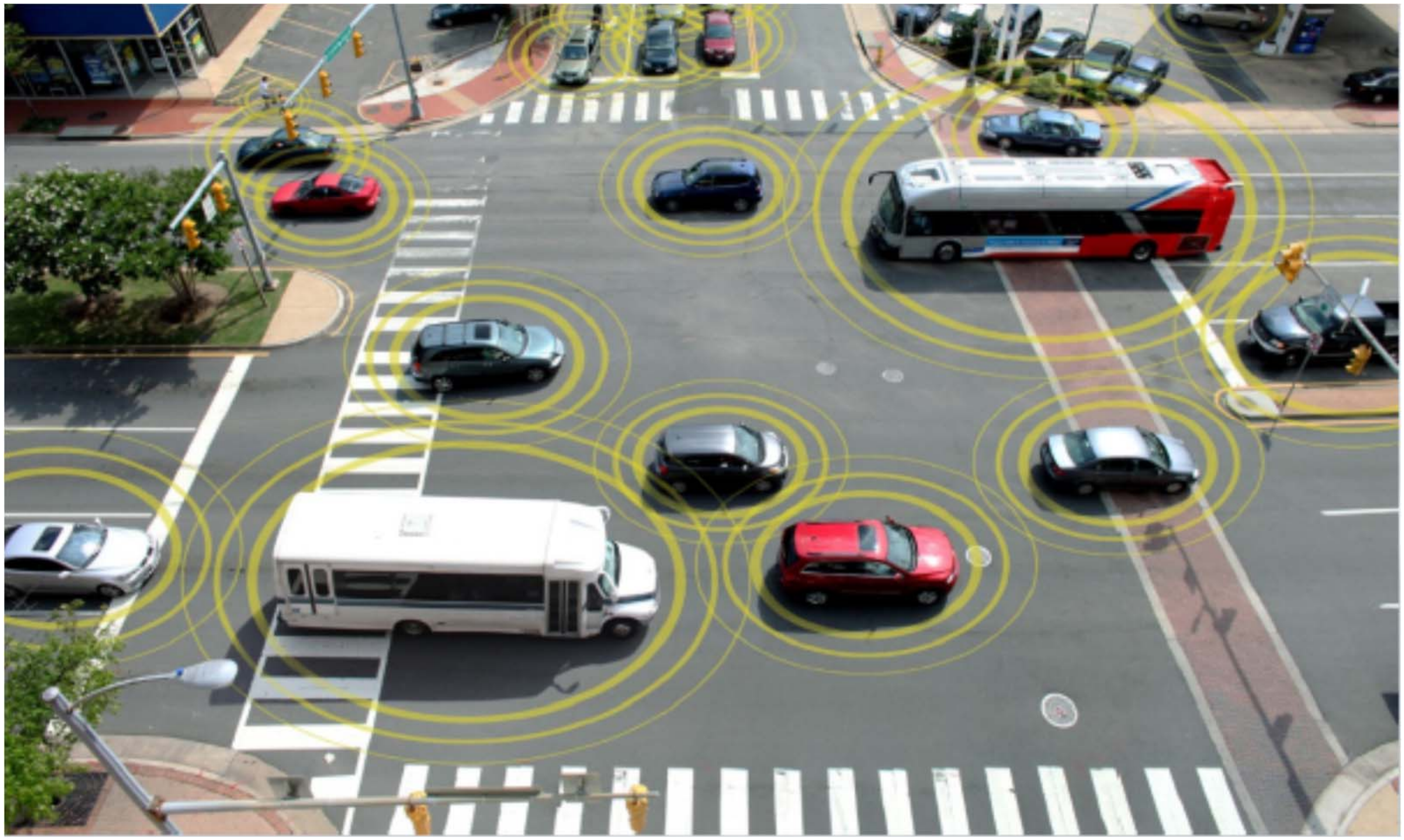


- Cost, PCB area,
- Quality requirements, availability of suitable components (e.g. temperature range) and

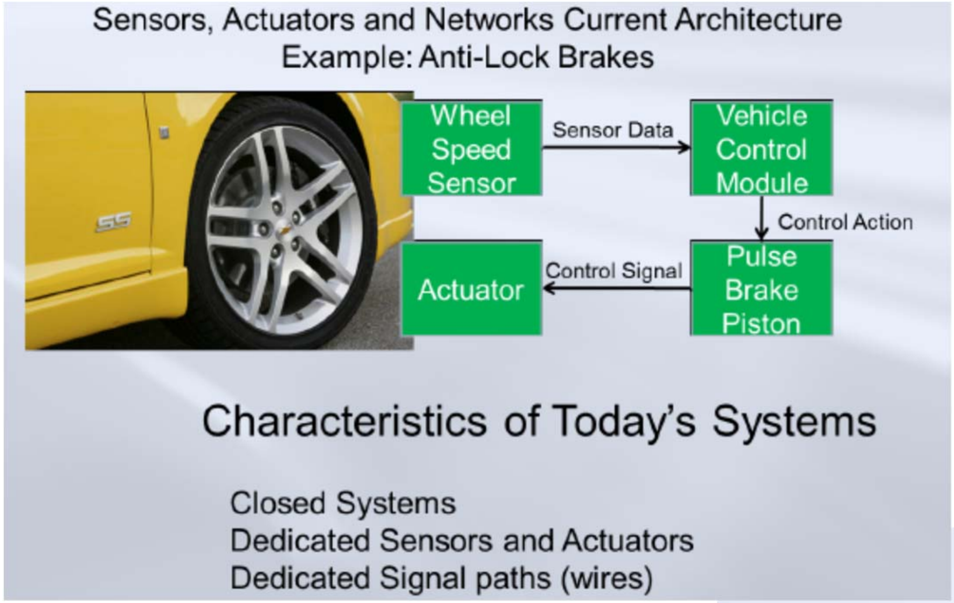


- Sensitivity to valid attacks
  - Reset attack (TPM is reset, manipulated µC continues operation)
  - Data exchange between µC and TPM not protected

Connected Cars: External

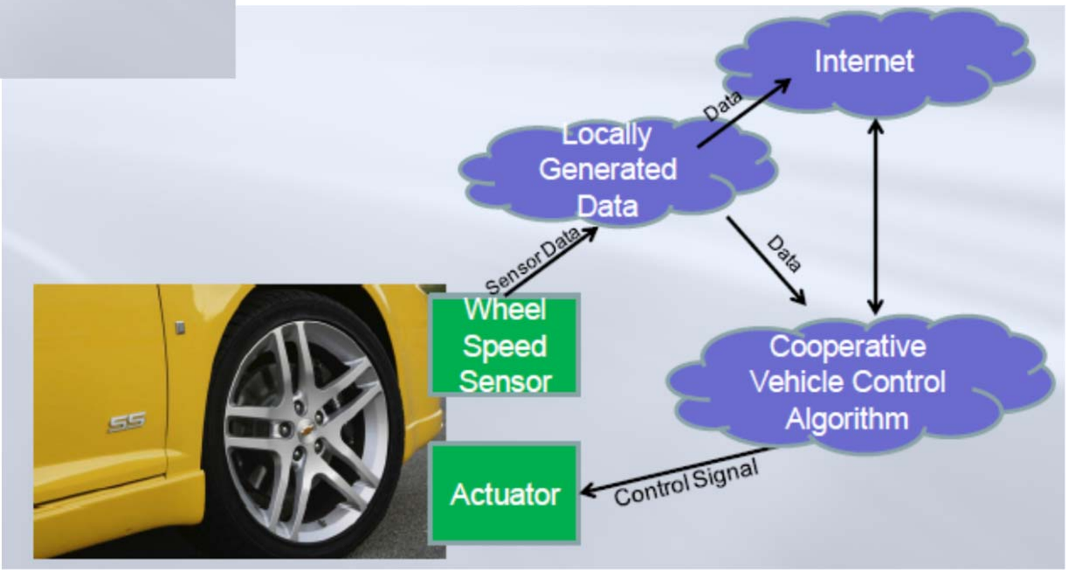


Connected Cars: Cognitive and Collaborative

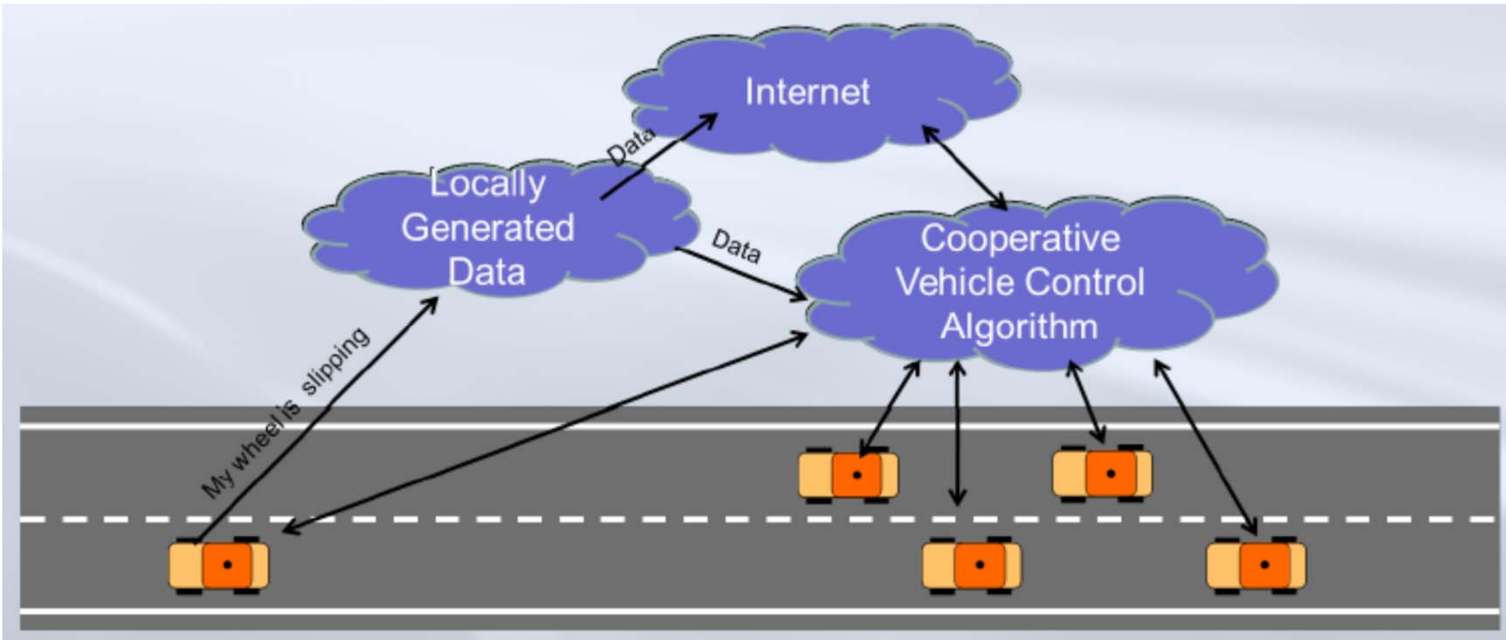


Current

Future



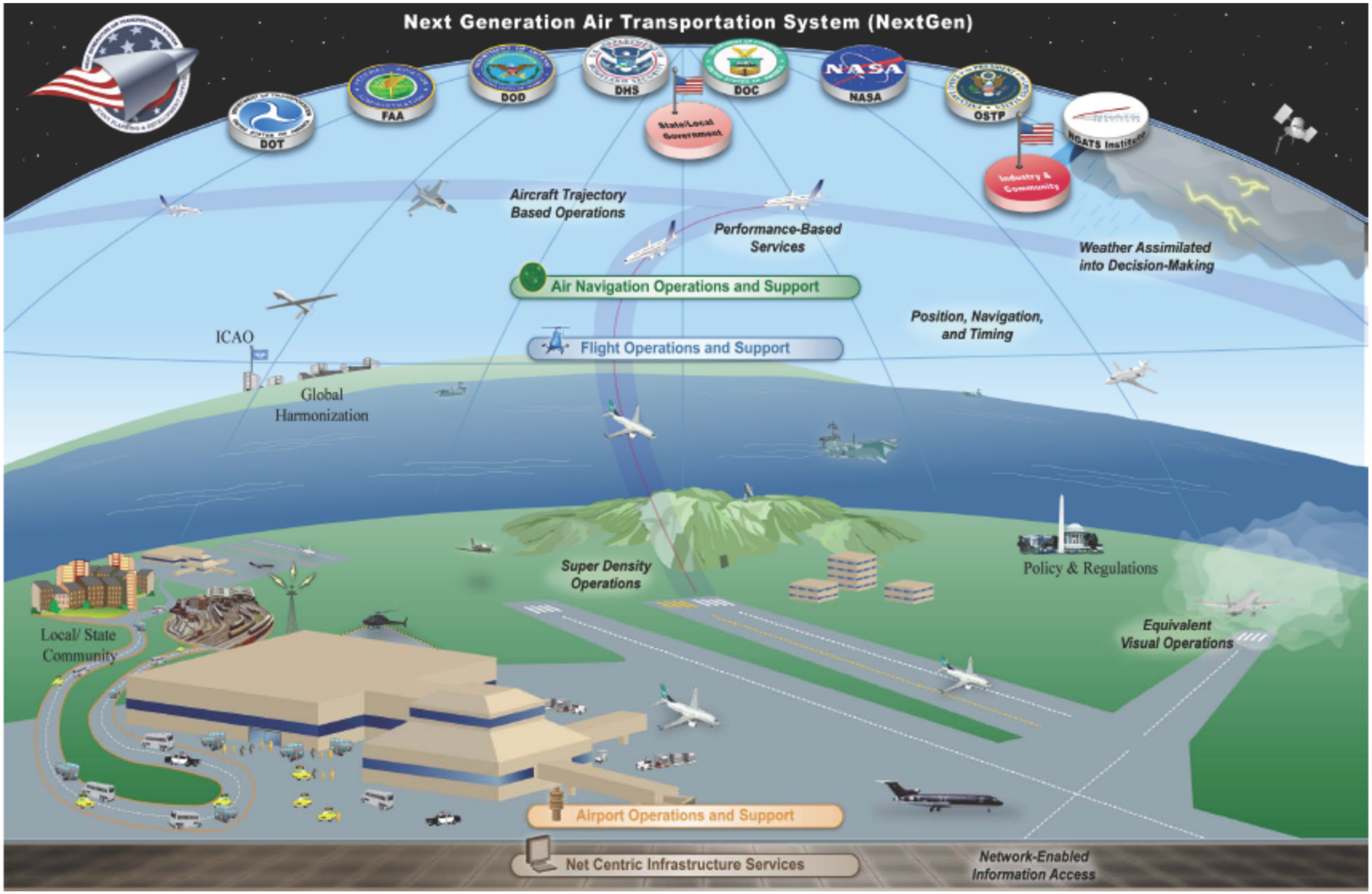
Connected Cars: Cognitive and Collaborative



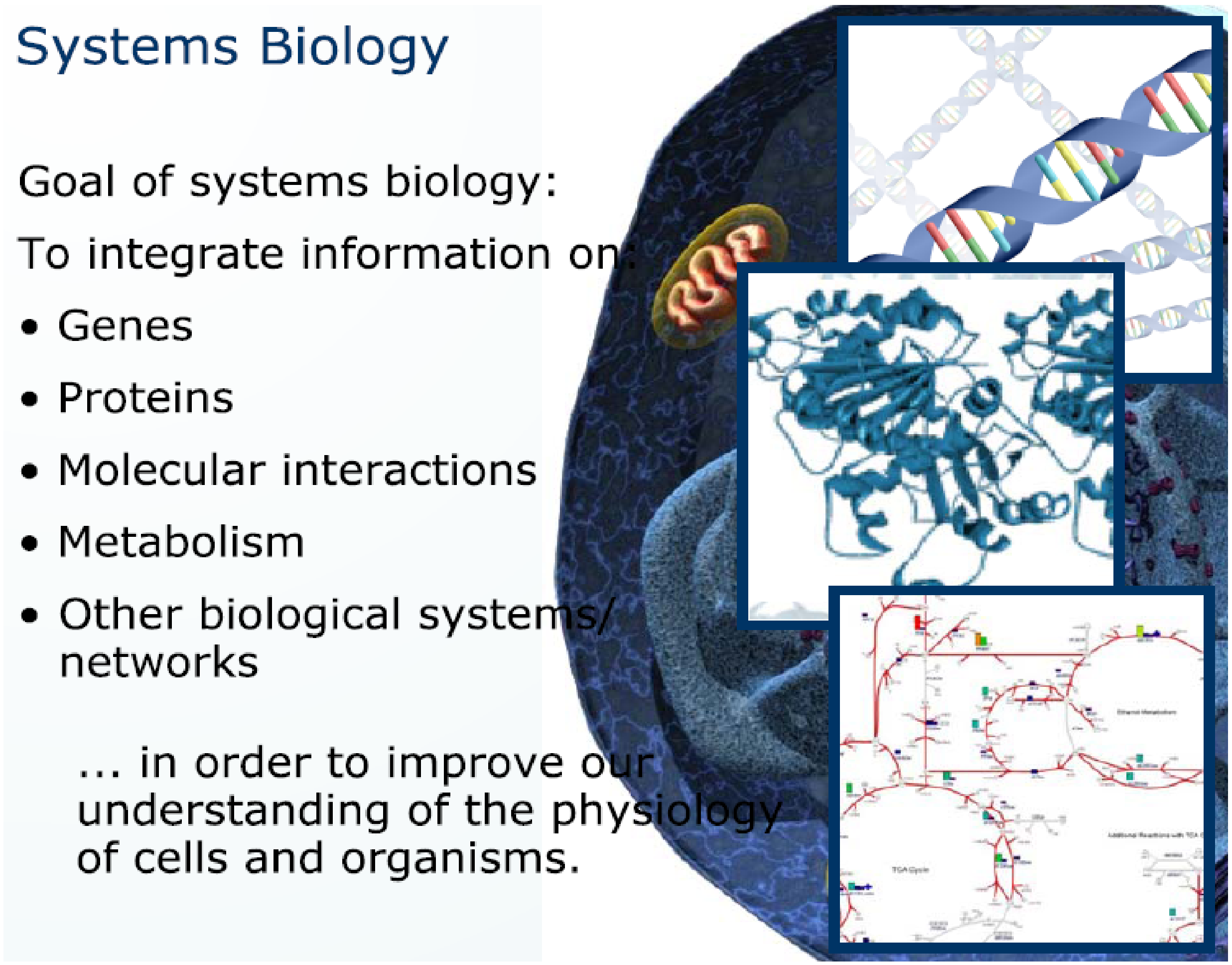
Key Challenge: **Humans**

We are developing novel frameworks to include humans in this collaborative networked CPS environment

FAA NEXTGEN


Next Generation Air Transportation System (NextGen)
DOT
FAA
DOD
DHS
DOC
NASA
OSTP
State/Local Government
Industry & Community
NGATS Institute
Aircraft Trajectory Based Operations
Performance-Based Services
Weather Assimilated into Decision-Making
Air Navigation Operations and Support
Flight Operations and Support
Position, Navigation, and Timing
ICAO
Global Harmonization
Super Density Operations
Policy & Regulations
Local/ State Community
Equivalent Visual Operations
Airport Operations and Support
Net Centric Infrastructure Services
Network-Enabled Information Access

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*

A Systems Biology Model for Alzheimer's Disease

- **Study the roles of cholesterol, LRP, ApoE and inflammation in disease pathogenesis**
- Studied effect of simvastatin treatment on LRP and ApoE levels, in addition to changes in Aβ
- Developed a mathematical model that integrates energy & lipid metabolism, the inflammatory response & expression of key proteins
- Model results were verified using results from experiments
- **No previously developed model has used systems biology nor multi-level networks to study AD**

Forefront of AD research:

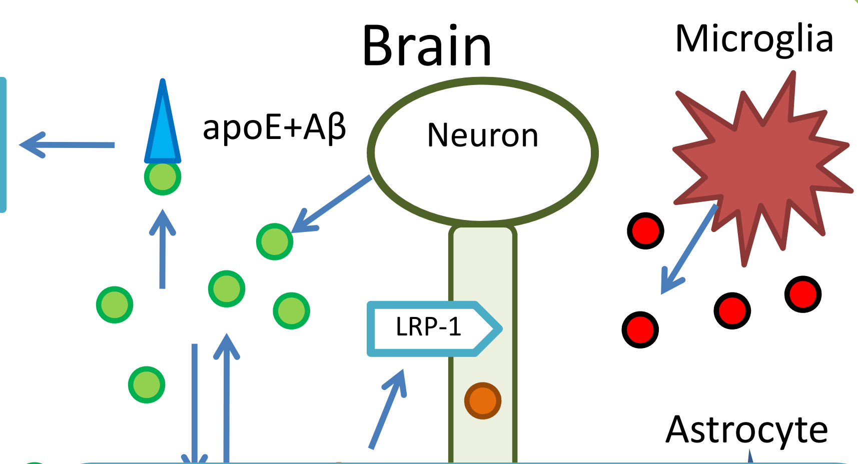
Interplay between lipid metabolism & inflammation

apoE:
- Coordinates re-distribution of cholesterol during growth, repair &

IL-1:
- Pro-inflammatory cytokine
- Expressed by microglia in response to:
  - Stress
  - ↑ Aβ
  - ↑ Glutamate
- Functions:
  - ↑ neurotransmitter turnover rate
  - ↓ activation threshold for HPA axis
  - Causes hypoglycemia
  - ↑ Acetylcholinesterase activity → ↓ ACh

- Synapse formation
- Co-localizes w/ Aβ plaques

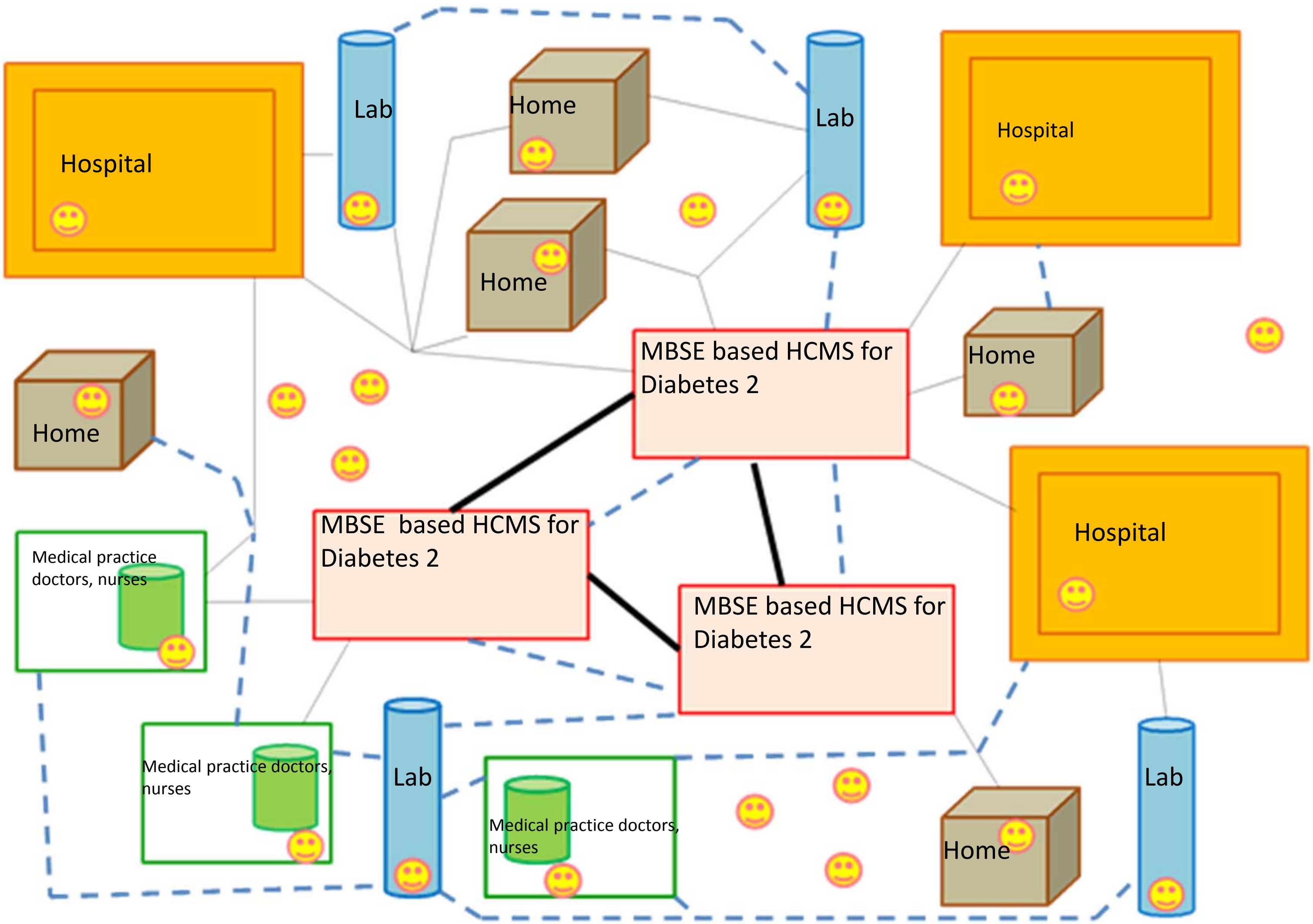
ion



LRP-1:
- Transport of Aβ to blood
- Transfer of cholesterol to neurons & other CNS cells via apoE carrier binding

Aβ Cholesterol ApoE

MBSE based HCMS for Diabetes II and its functional connectivity



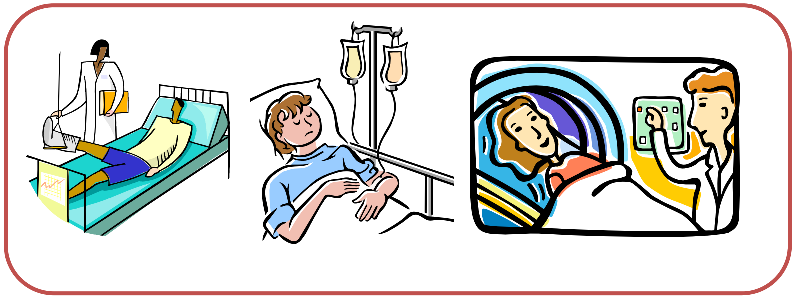
Reasoning Engine: Decision Making & Analytics Capabilities

Can provide answers to many practical questions, queries, problems, from health care management perspective

- Evaluate patient risk behavior impact on health care quality
- Evaluate “best” health care achievable
- Can learn from new data, treatment results, improve models
- Evaluate “value” of new proposed tests and interventions
- Provide aggregate statistics for insurance policies calibration
- Find best tests and interventions for patient type, disease state
- Evaluate effects of incentives and rewards for health “maintenance”
- Evaluate sequences of tests and treatments for reversing disease

Model-Based Systems Engineering for ITU Management

The Institute for Systems Research

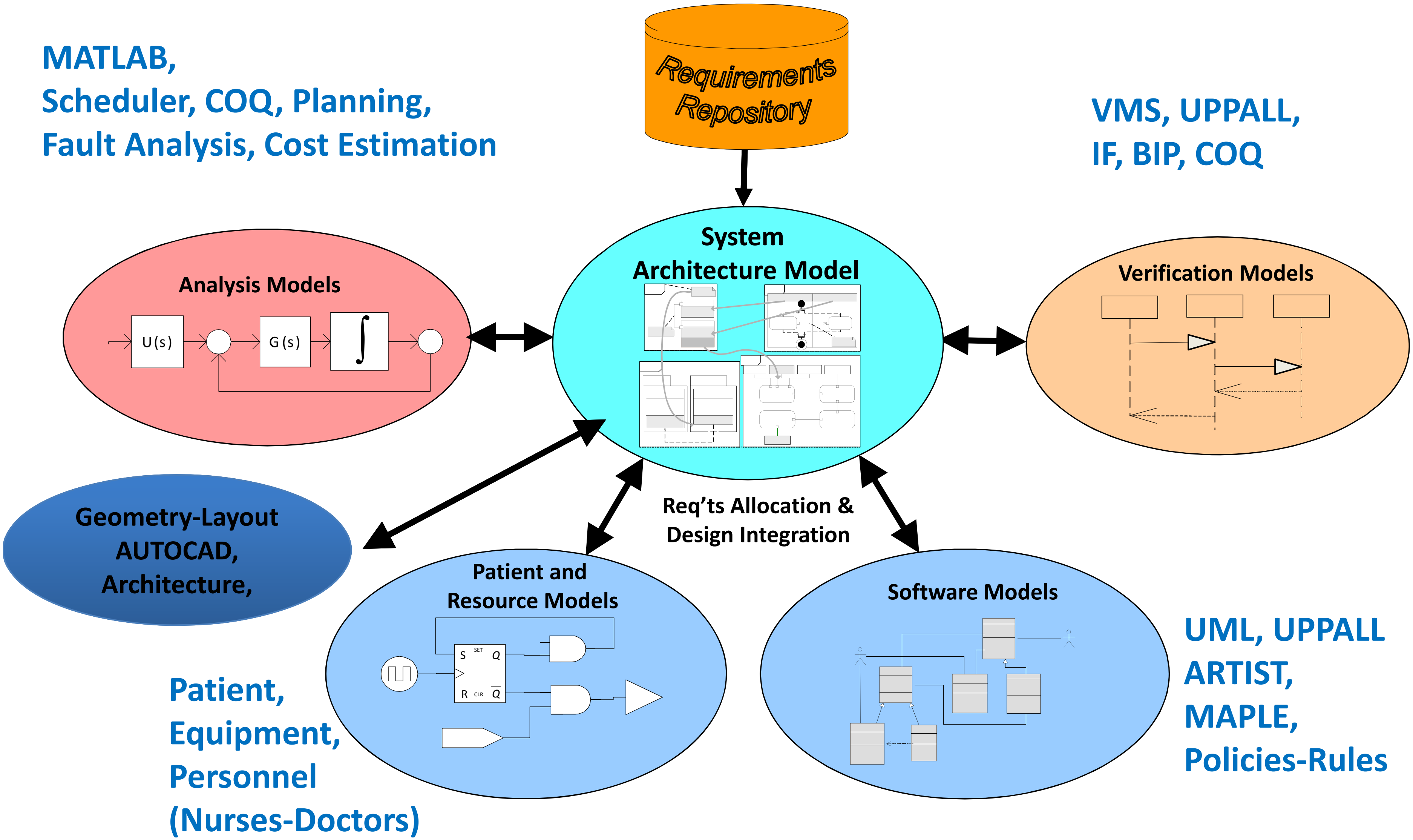


Healthcare operations

Monitor performance,
generate ideas,
implement changes

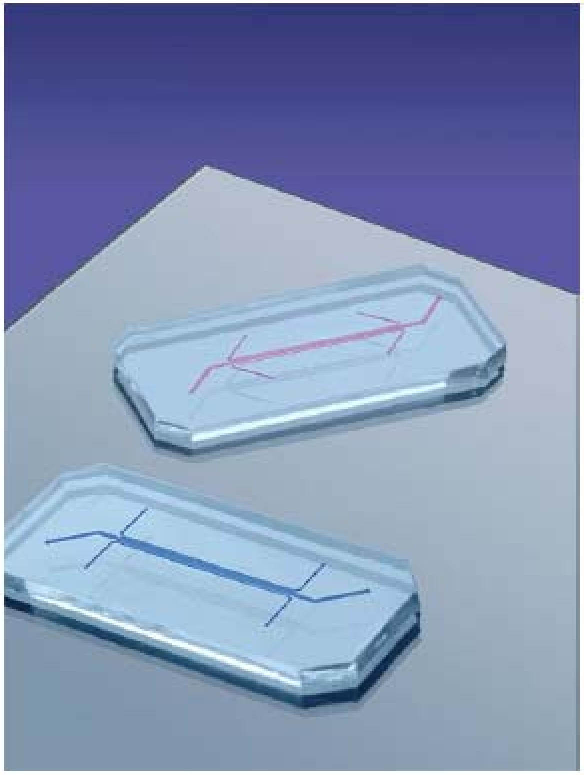
Build models,
analyze operations,
predict changes

Using *System Architecture Model* as a MODEL Integration Framework

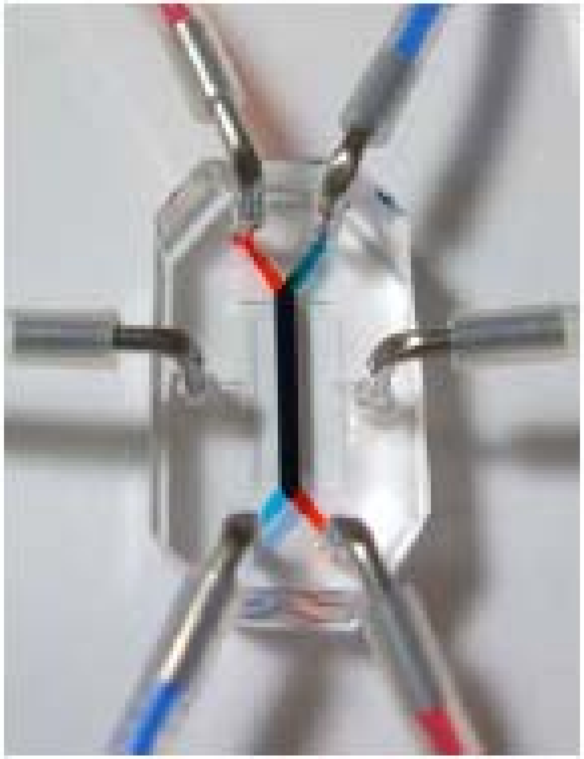


Revolutionizing Drug Manufacturing: Organ-on-a Chip -- Biochips

Wyss-Lung on a chip -- 2010



Wyss-Gut on a chip -- 2012



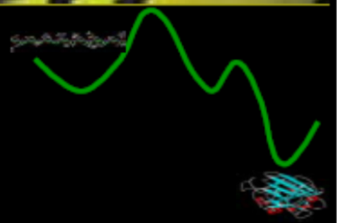
Revolutionizing Drug Testing

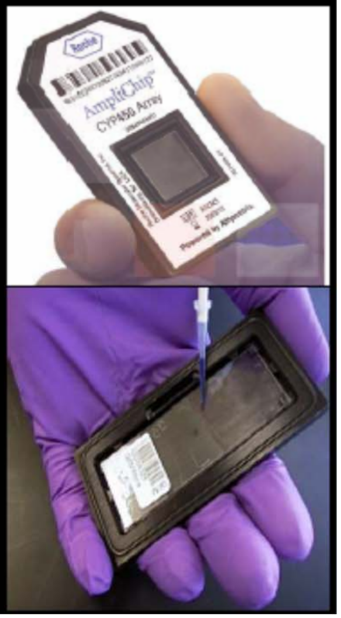
- Rapidly approaching untenable situation in human health -- Blockbuster drugs, which cure major diseases afflicting huge populations, are being pulled from the shelves (e.g., Vioxx) for unforeseen side-effects.
- They are being replaced by drugs that have smaller market potential and more localized impact (subpopulations, e.g., FluMist).
- Current cost of developing a drug and getting it to market exceeds $1B and 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.

Personalized Medicine

Personalized Medicine

Use of genetic and non-genetic molecular information to individualize prevention, diagnosis, treatment and prognosis for each person with greater precision.

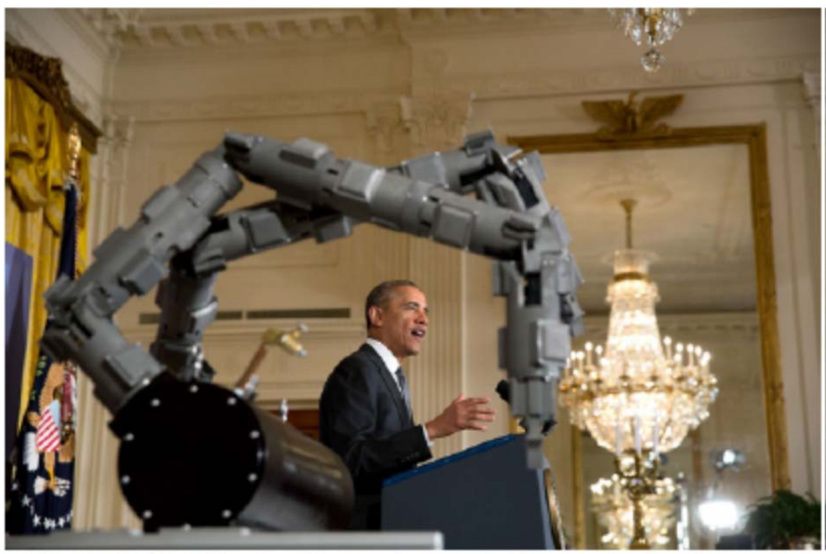




The paradigm of personalized medicine, PMC
personalizedmedicinecoalition.org

Digital Manufacturing Design Innovation Institute (DMDII)

- Announced February 25, 2014, 2014 by President Obama
  http://www.whitehouse.gov/the-press-office/2014/02/25/president-obama-announces-two-new-public-private-manufacturing-innovatio



President Barack Obama delivers remarks announcing two new public-private Manufacturing Innovation Institutes, and launches the first of four new Manufacturing Innovation Institute Competitions, in the East Room of the White House, Feb. 25, 2014. (Official White House Photo by Lawrence Jackson)

- Headquartered in Chicago, Illinois
- Academic-Industry-Government "Mega Project" $320M co-funding, 5 years
- **Goal**: Revitalize manufacturing along the lines described in this lecture

- "Infinite number of virtual factories and an open-source manufacturing platform"

"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

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***

Need to Transform 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**

- ***Compositional synthesis, manufacturing and life-cycle management*** of complex engineered systems

- This compositional synthesis advances engineering to the next frontier, **way beyond 'plug and play synthesis'**

THE ISR SE 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.

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

Both Supplemented by Technical Electives form many Technical Areas

A Bold Experiment

Starting early in the education chain

Undergraduates working with industry and government mentors on SE projects

Comparative Impact on Transforming Life-Work-Society

- Typography
- Microelectronic chips
- The PC
- The Internet
- MBSE

Thank you!

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Questions?