Present Developments in Control Applications

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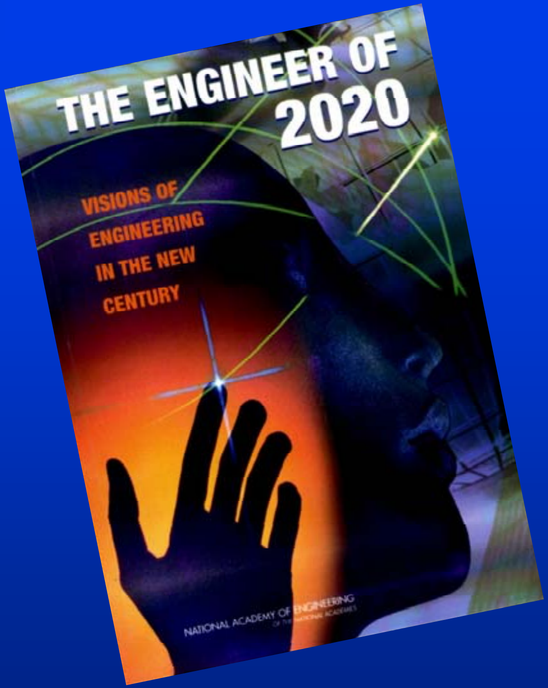
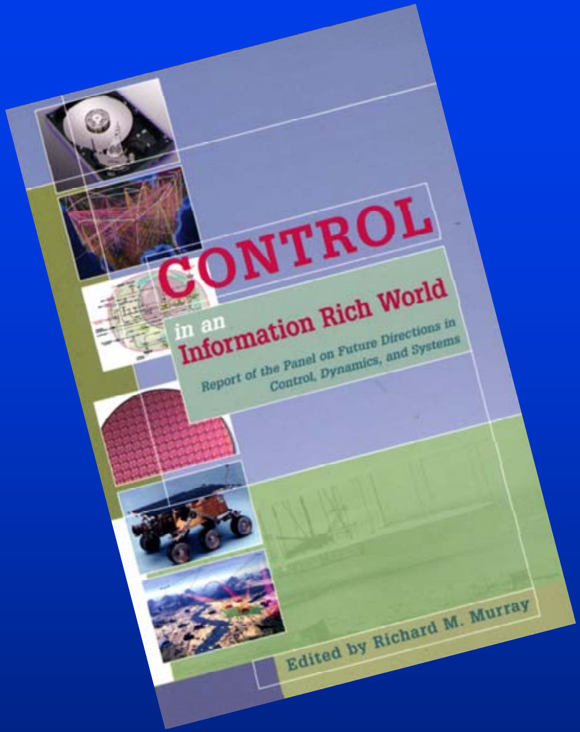
Sweden

Acknowledgements





Numerous friends and collegues in industry and academia

How Control Developed

- Early use
- The Field Emerges
- The Second Phase
- The Third Phase?

Control Emerges

- Drivers: gun control, radar ...
- Block diagrams, transfer functions
- Design tools: graphical
- Analog computing
- Holistic view of theory & applications

The Second Phase

- Drivers: space, computer control, mathematics
- Rapid growth of subspecialities
- Optimal, stochastic, nonlinear, ...
- Computational tools
- Impressive development of theory
- Holistic view was lost

The Third Phase?

- Drivers: embedded system, networks, biology, physics, ...
- Autonomy, distribution
- Exploding applications
- Hardware and software platforms
- Holistic view will be recovered?

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Breakthrough Technologies

Everything will, in some sense, be smart; that is, every product, every service, and every bit of infrastructure will be attuned to the needs of hte humans it serves and will adapt its behavior to those needs.

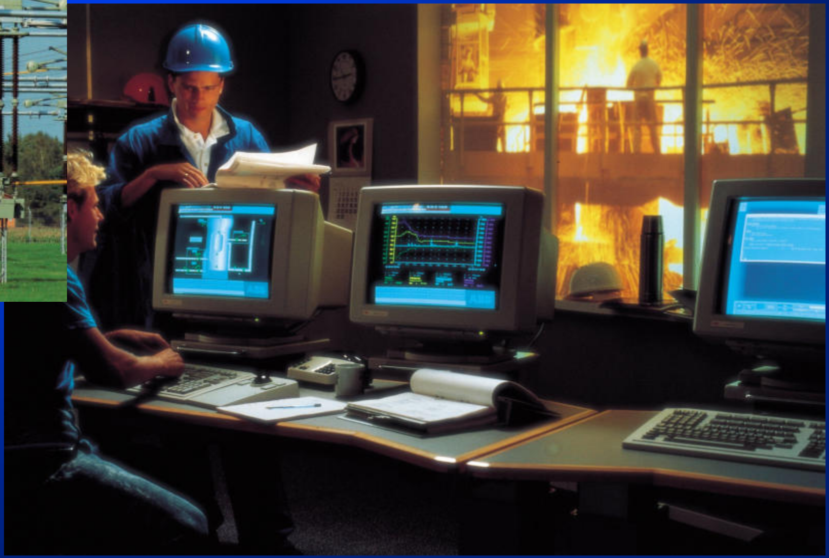
Sensing, actution, and control

NAE The Engineer of 2020

Control Everywhere

- Manufacturing
- Products
- Ideas
- Why?

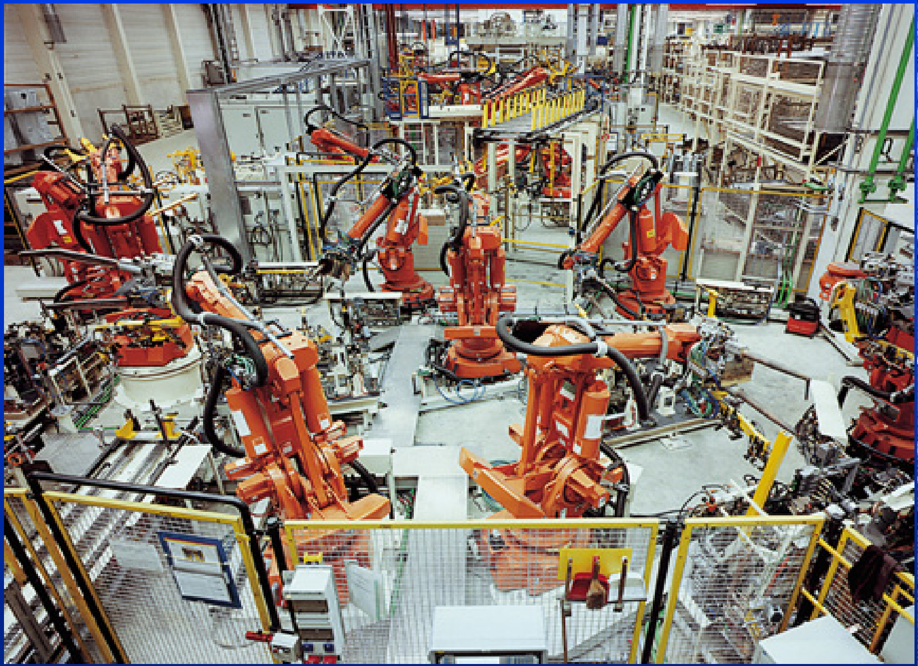
Power Generation and Distribution



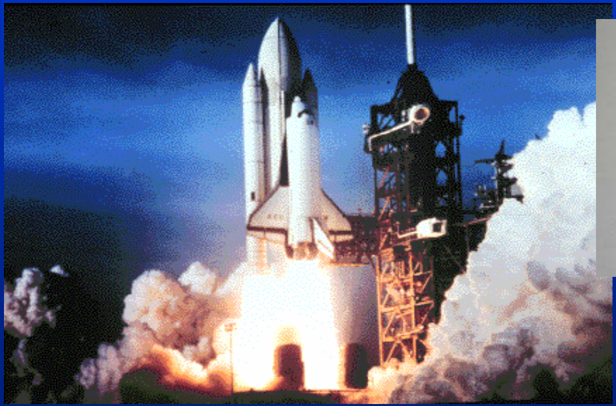
Process Control

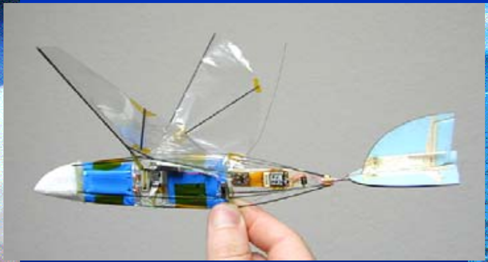


Discrete Manufacturing



Vehicles





Consumer Electronics

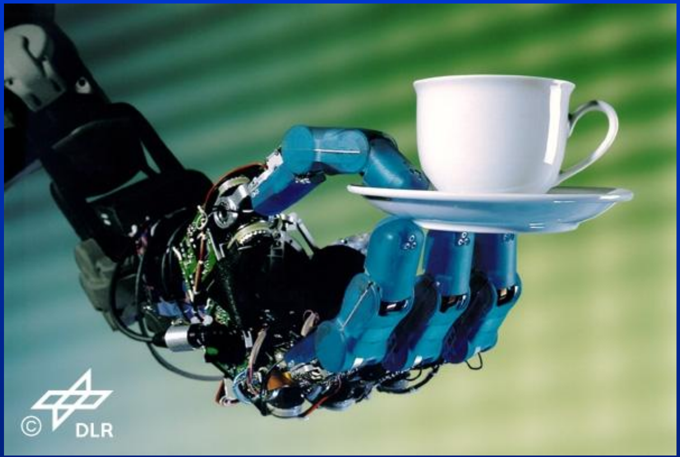
Biomedical

DLR Robots and Hands

LWR III: 7 joints weight/load =1.5

150 W, 3 cables

Hand II: 13 joints 3 kg finger force



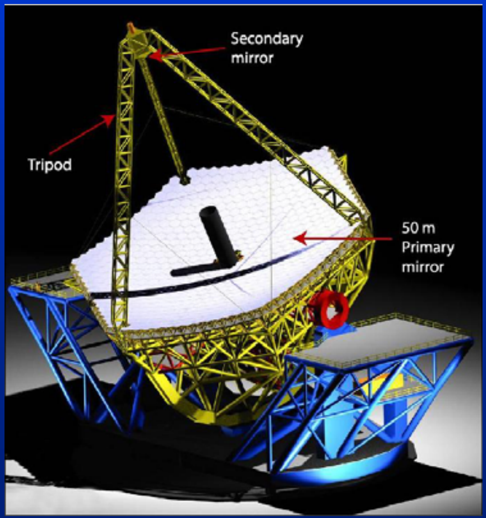
Gerd Hirzinger DLR

Science

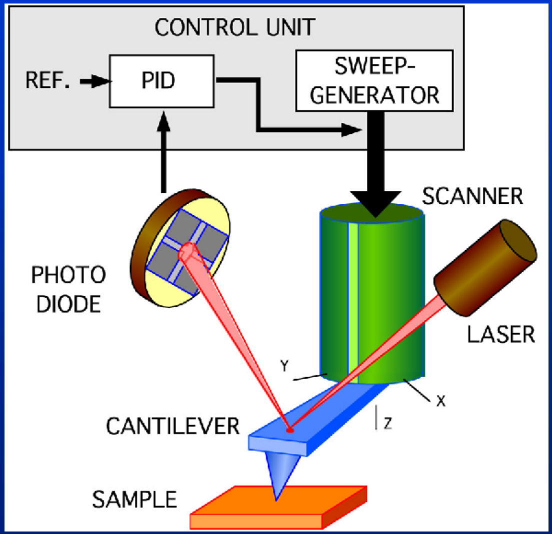
Ideas: Feedback and systems

Instruments: mega to nano

Adaptive Optics



Atomic Force Microscope



Biology

Feedback is a central feature of life. The process of feedback governs how we grow, respond to stress and challenge, and regulate factors such as body temperature, blood pressure, and cholesterol level. The mechanisms operate at every level, from the interaction of proteins in cells to the interaction of organisms in complex ecologies.

M. B Hoagland and B Dodson The Way Life Works Times Books 1995

Key Drivers

- Insight and understanding
- Knowledge and education
- Power of feedback and computing
- Tools
- Control a commodity?

The Power of Feedback

- Good systems from bad components
- Attenuate disturbances
- Stabilize unstable system
- Shape behavior
- Risk of instability

Control and Computing

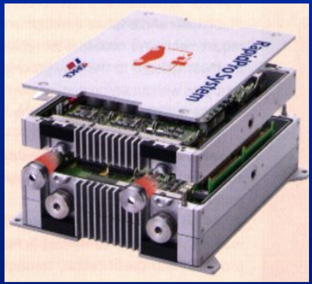
- Vannevar Bush 1927. Engineering can progress no faster than the mathematical analysis on which it is based. Formal mathematics is frequently inadequate for numerous problems, a mechanical solution offers the most promise.
- Herman Goldstine 1962. When things change by two orders of magnitude it is revolution not evolution.
- Gordon Moore 1965: The number of transistors per square inch on integrated circuits has doubled in approximately 18 months.

Tools

The MathWorks NATIONAL INSTRUMENTS dSPACE

- Sensors, actuators, process interfaces
- Computers ,signal processors, FPGA
- Tools for modeling, analysis, simulation and design
- Operating systems, automatic code generation





NASA's X43-A Scramjet Achieves Record-Breaking Mach 10 Speed Using MathWorks Tools for Model-Based Design

The Challenge

To design and automatically generate flight control software for a scramjet vehicle traveling at Mach 10 speed

The Solution

Use Simulink® to model and validate control systems, Real-Time Workshop® to automatically generate flight code, and MATLAB® to process and analyze post-flight data

The Results

Reduced development time by months

Accurately predicted separation clearance

Aided in achieving SEI CMM Level 5 process rating

The X43-A on its record-setting flight.

Our autopilot worked on the first try, which is amazing given that a vehicle like this had never been flown before. MathWorks tools helped us design and implement control systems that kept the vehicle stable throughout the flight."

Dave Bose,
Analytical Mechanics Associates

The MathWorks

Rapid Control

NI CompactRIO

Drivven: "We prototyped a full-authority engine control system … in just 3 man-months. In past projects, it took us at least 2 man-years and over $500,000 to develop similar ECU systems."

NATIONAL INSTRUMENTS™

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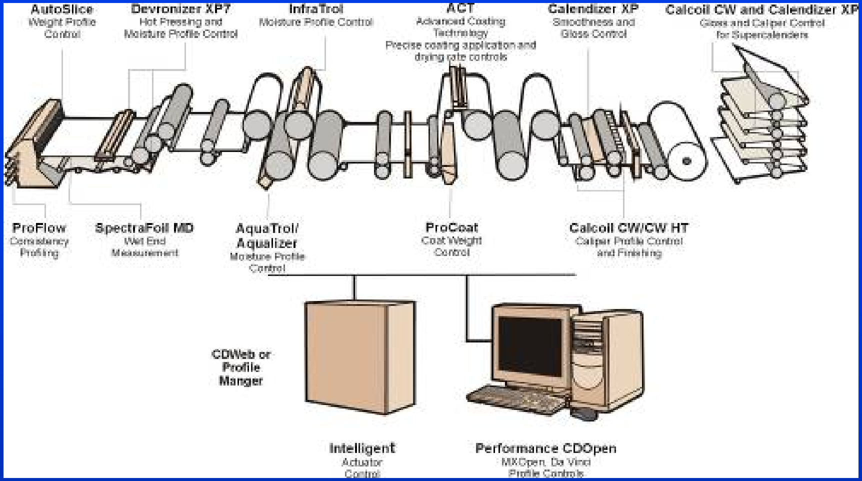
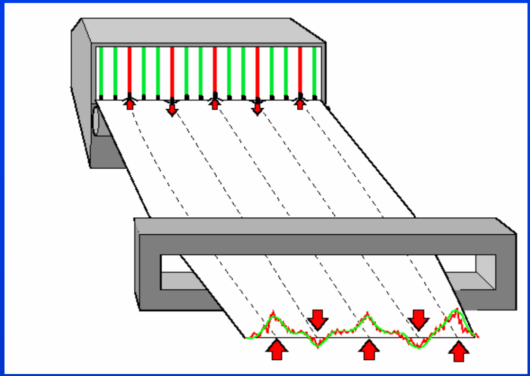
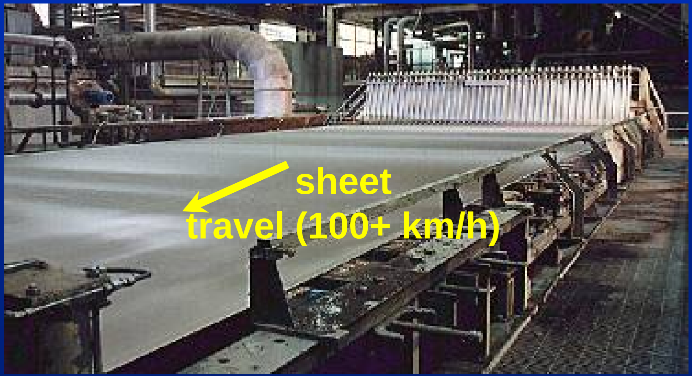
Cross Direction Control

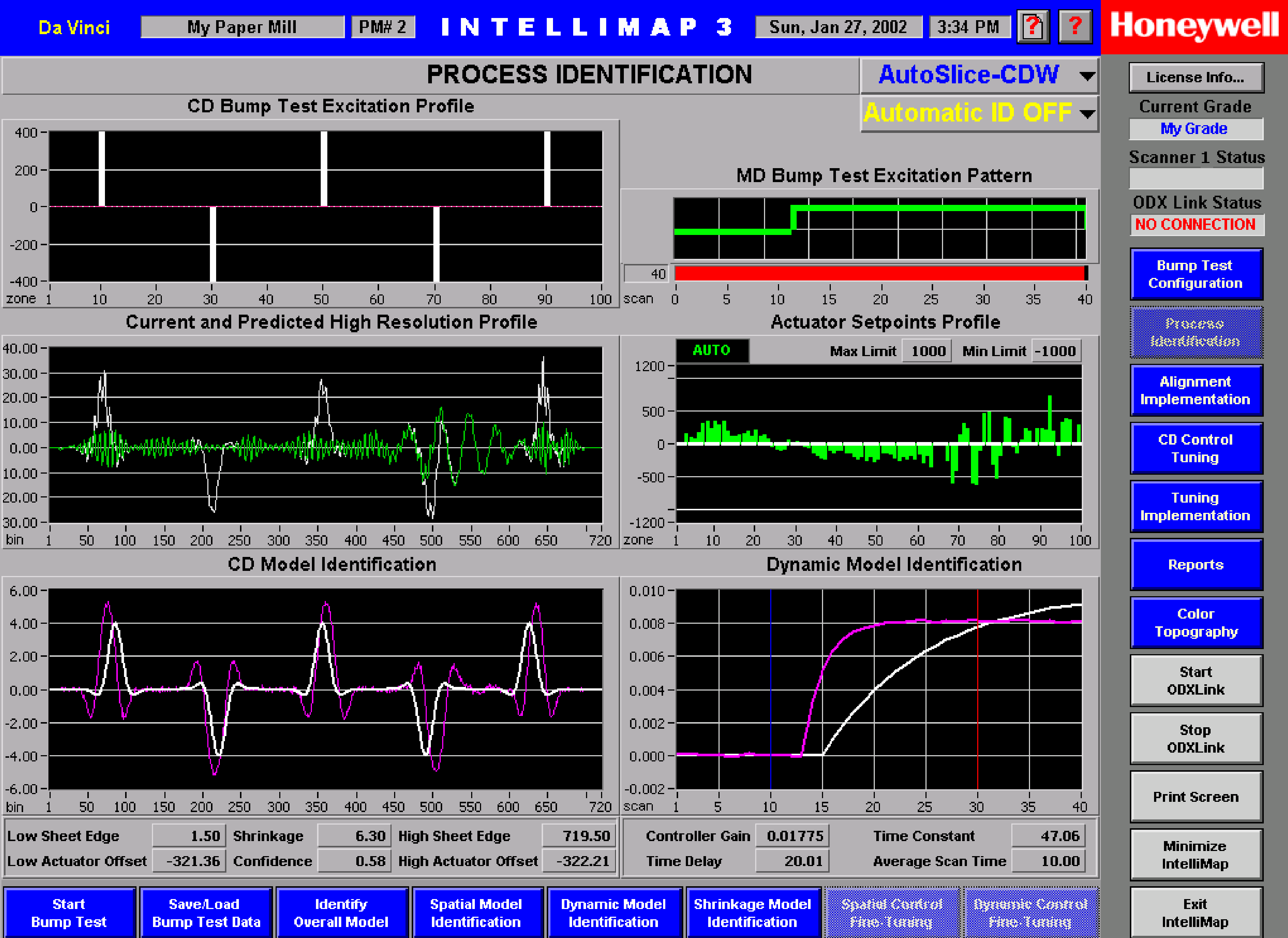




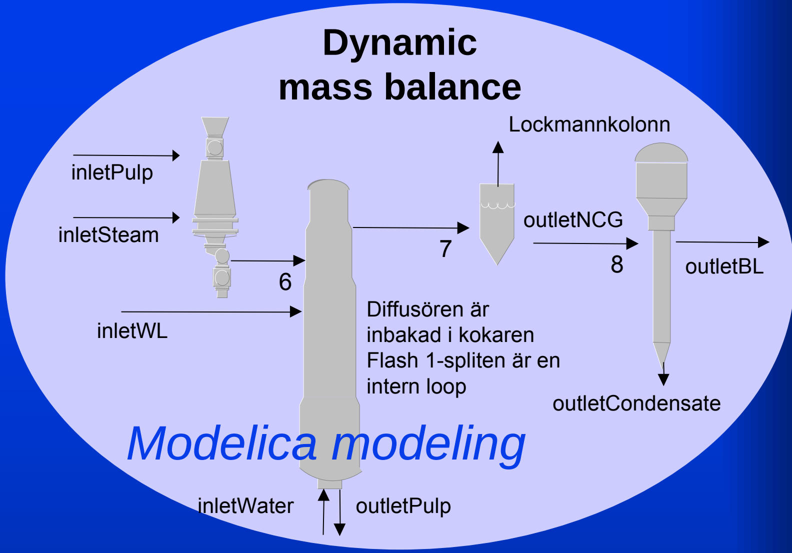


Several hundred sensors and actuators, millisecond operation, controlling paper thickness to within microns!

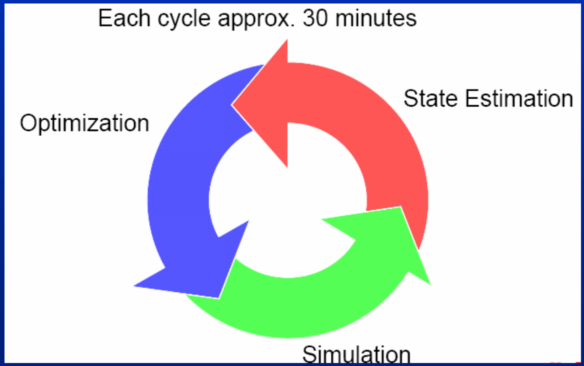
Honeywell Laboratories


Da Vinci
My Paper Mill
PM# 2
INTELLIMAP 3
Sun, Jan 27, 2002
3:34 PM
Honeywell
PROCESS IDENTIFICATION
AutoSlice-CDW
Automatic ID OFF
License Info...
Current Grade
My Grade
Scanner 1 Status
ODX Link Status
NO CONNECTION
CD Bump Test Excitation Profile
MD Bump Test Excitation Pattern
Current and Predicted High Resolution Profile
Actuator Setpoints Profile
AUTO
Max Limit 1000
Min Limit -1000
CD Model Identification
Dynamic Model Identification
Low Sheet Edge 1.50
Shrinkage 6.30
High Sheet Edge 719.50
Low Actuator Offset -321.36
Confidence 0.58
High Actuator Offset -322.21
Controller Gain 0.01775
Time Constant 47.06
Time Delay 20.01
Average Scan Time 10.00
Bump Test Configuration
Process Identification
Alignment Implementation
CD Control Tuning
Tuning Implementation
Reports
Color Topography
Start ODXLink
Stop ODXLink
Print Screen
Minimize IntelliMap
Exit IntelliMap
Start Bump Test
Save/Load Bump Test Data
Identify Overall Model
Spatial Model Identification
Dynamic Model Identification
Shrinkage Model Identification
Spatial Control Fine Tuning
Dynamic Control Fine Tuning

Mill Wide Control



25	Production units
38	Buffer tanks
250	Streams
250	Measurements
2500	Variables



Slide from Alf Isaksson

ABB

Global Enterprise Control

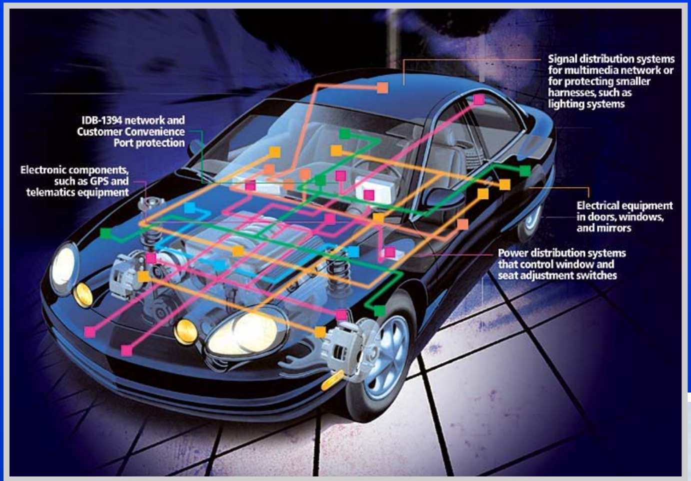
Strategic, Enterprise system, global, 1-10 years

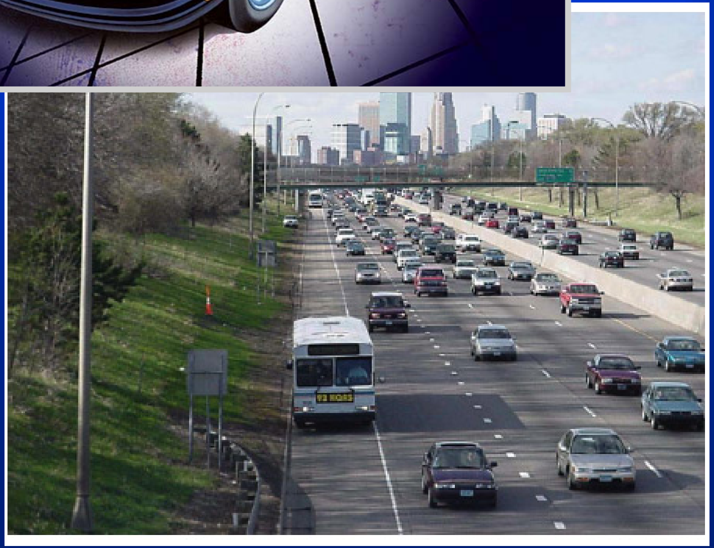
Tactical, Manufacturing system, 10 km, year, shift,

Operational, Process Control, 1 km, shift, ms

Automotive

- Engine control
- Power trains
- Cruise control
- Adaptive cruise control
- Traction control
- Lane guidance assistance
- Platooning

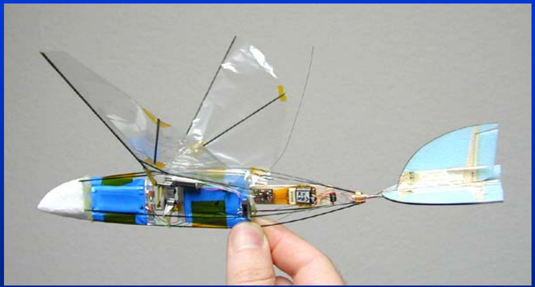




Automotive

- Strongly enhanced performance
- Strong technology driver
- Large numbers (microcontroller)
- Low costs
- Safe design and operation of networked embedded systems

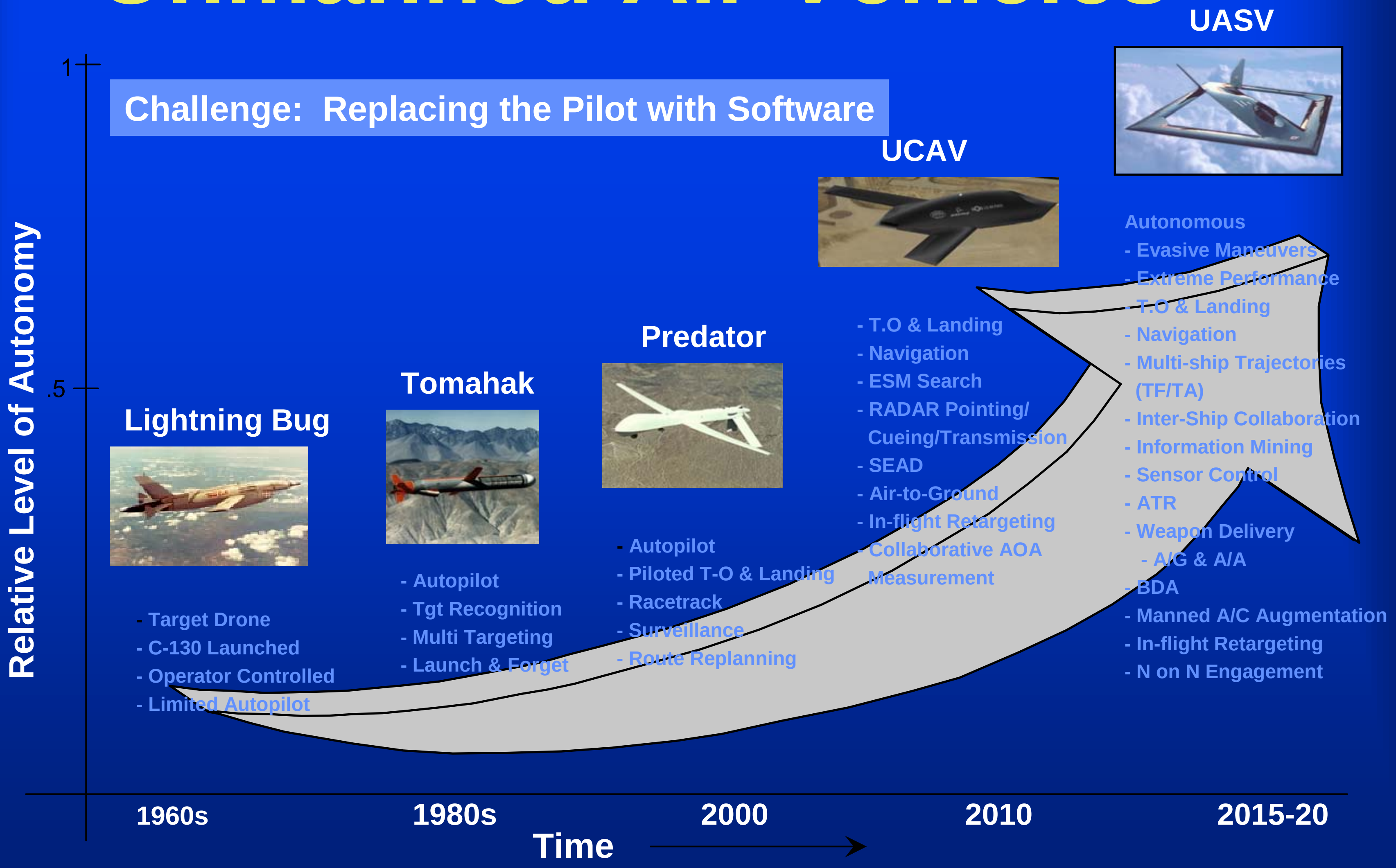
Aerospace



Boeing 777 1995

Pilot crew 1280 networked processors

Unmanned Air Vehicles



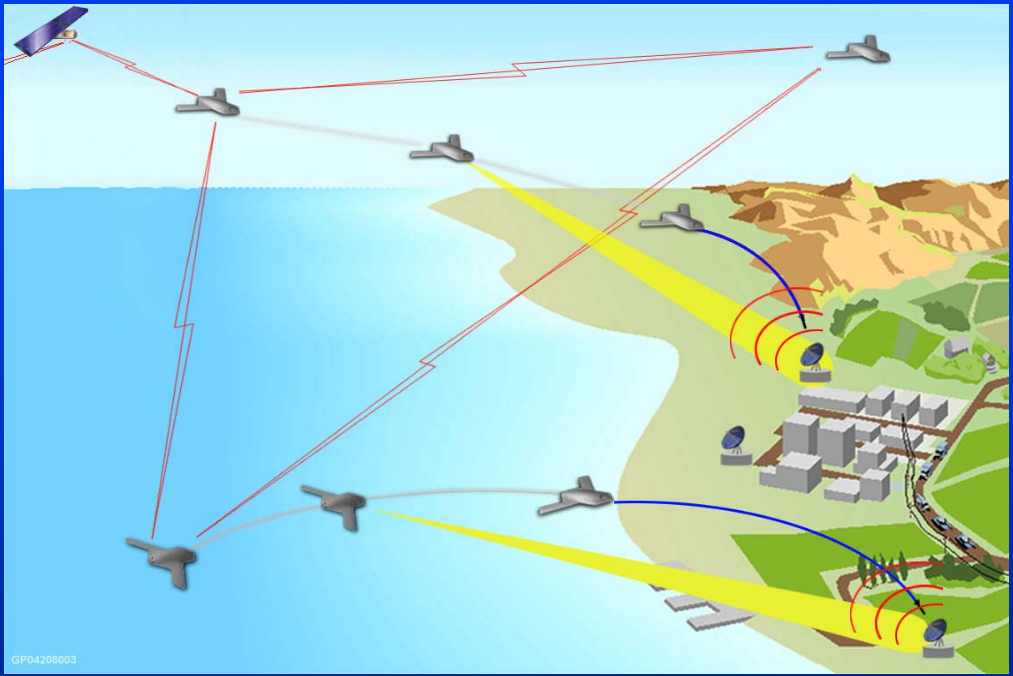
Siva Banda U.S. Air Force Research Lab

Cooperative Control is Hard

Coupling
- Precedence constraints
- Joint tasks
- On-line computation

Uncertainty
- Target locations
- Threat environment
- Enemy actions
- Engagement outcomes

Communication Constraints
- Asynchronous COMM
- Limited throughput
- Delays and outages



Siva Banda AFRL

Scientific Instruments

- Scientists (physics, biology)
- Revolutionary properties
- Control is mission critical
- Control is performance critical

Atomic Force Microscope

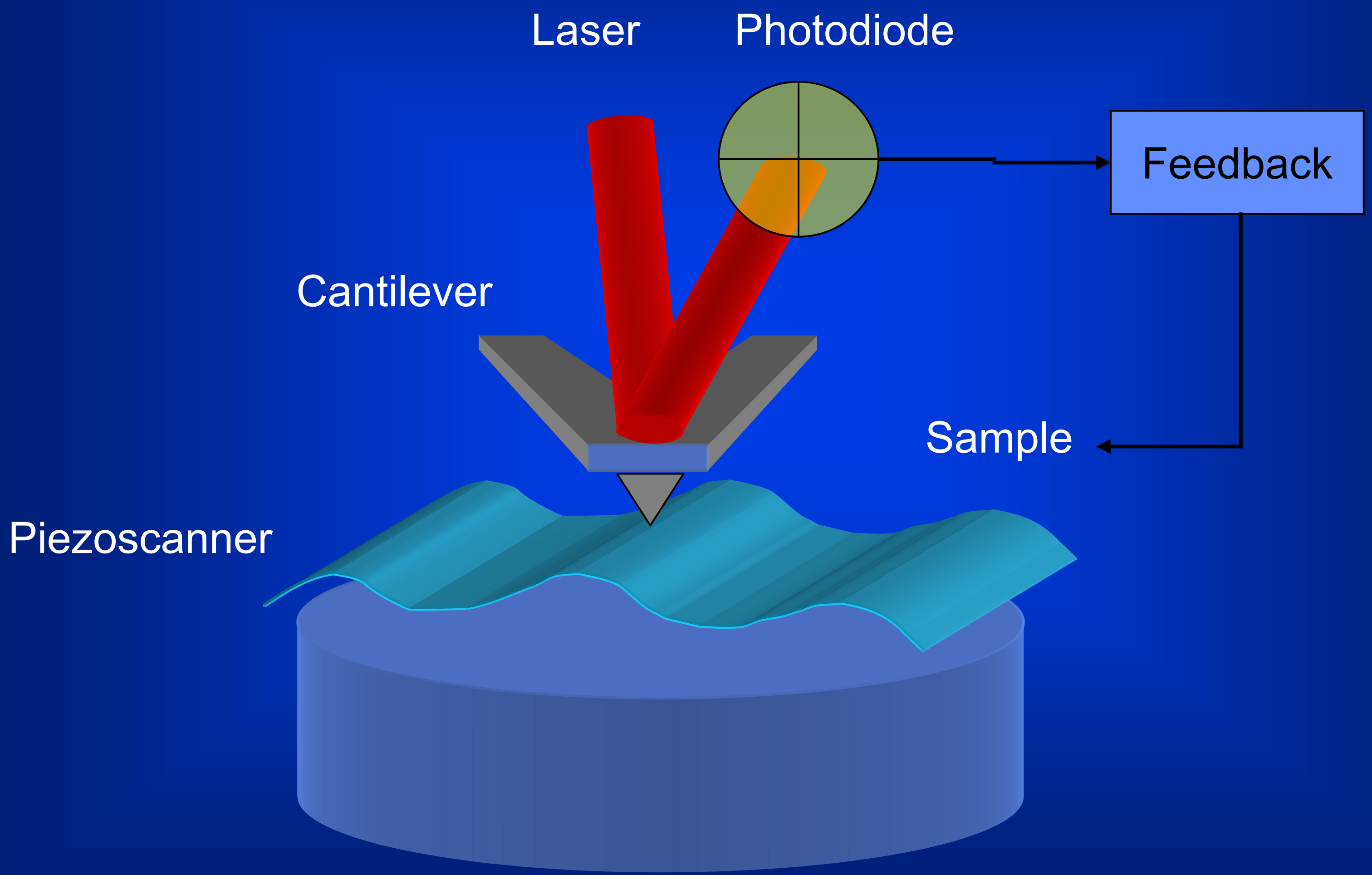
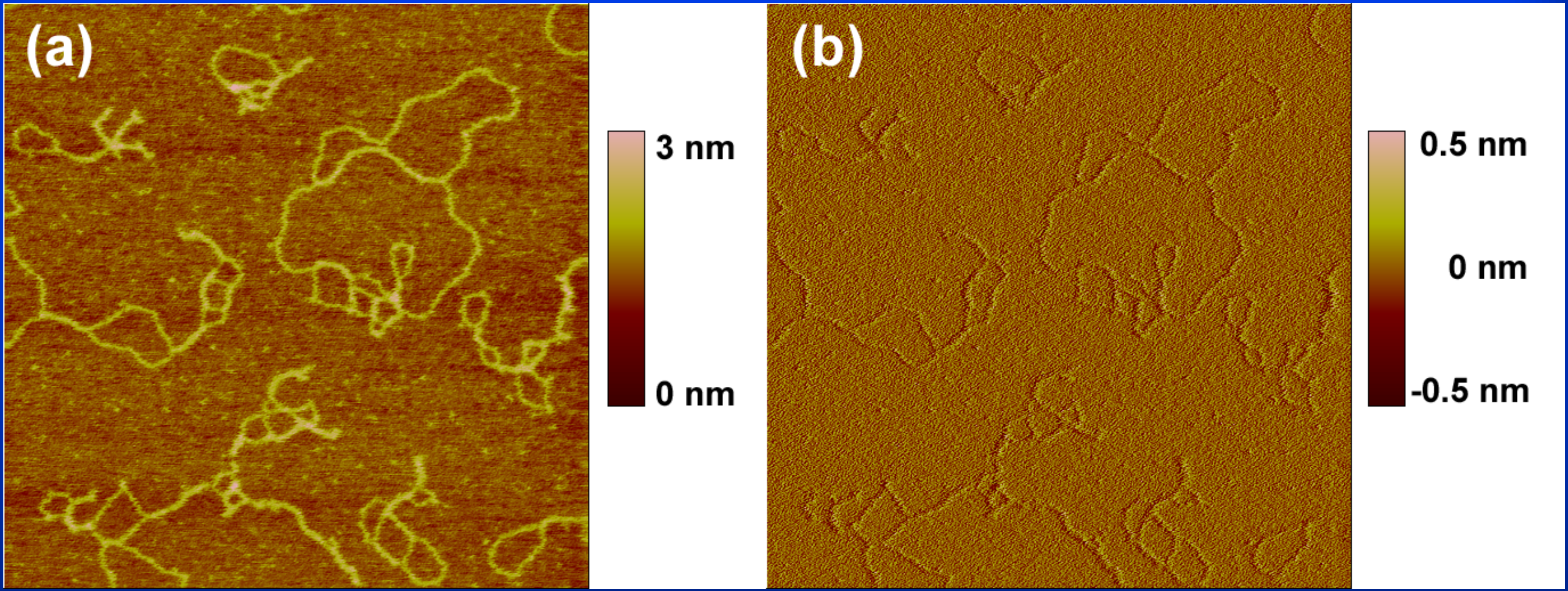


Image of DNA String



Georg Schitter UCSB

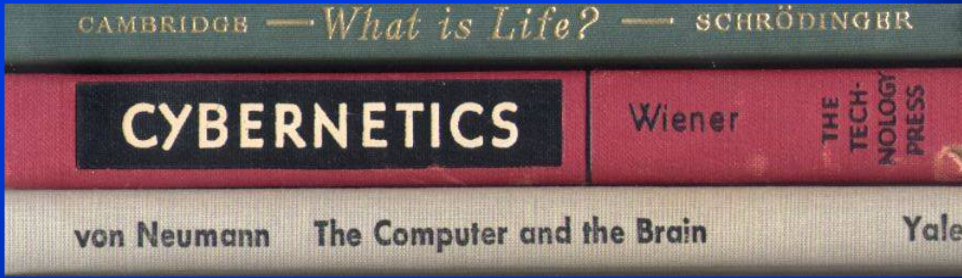
Impact of Control

- Enabling technology
- Increased scan rate
- Improved image quality
- Integrated process and control design
- Tuning tools for easy use

Biology

A long tradition

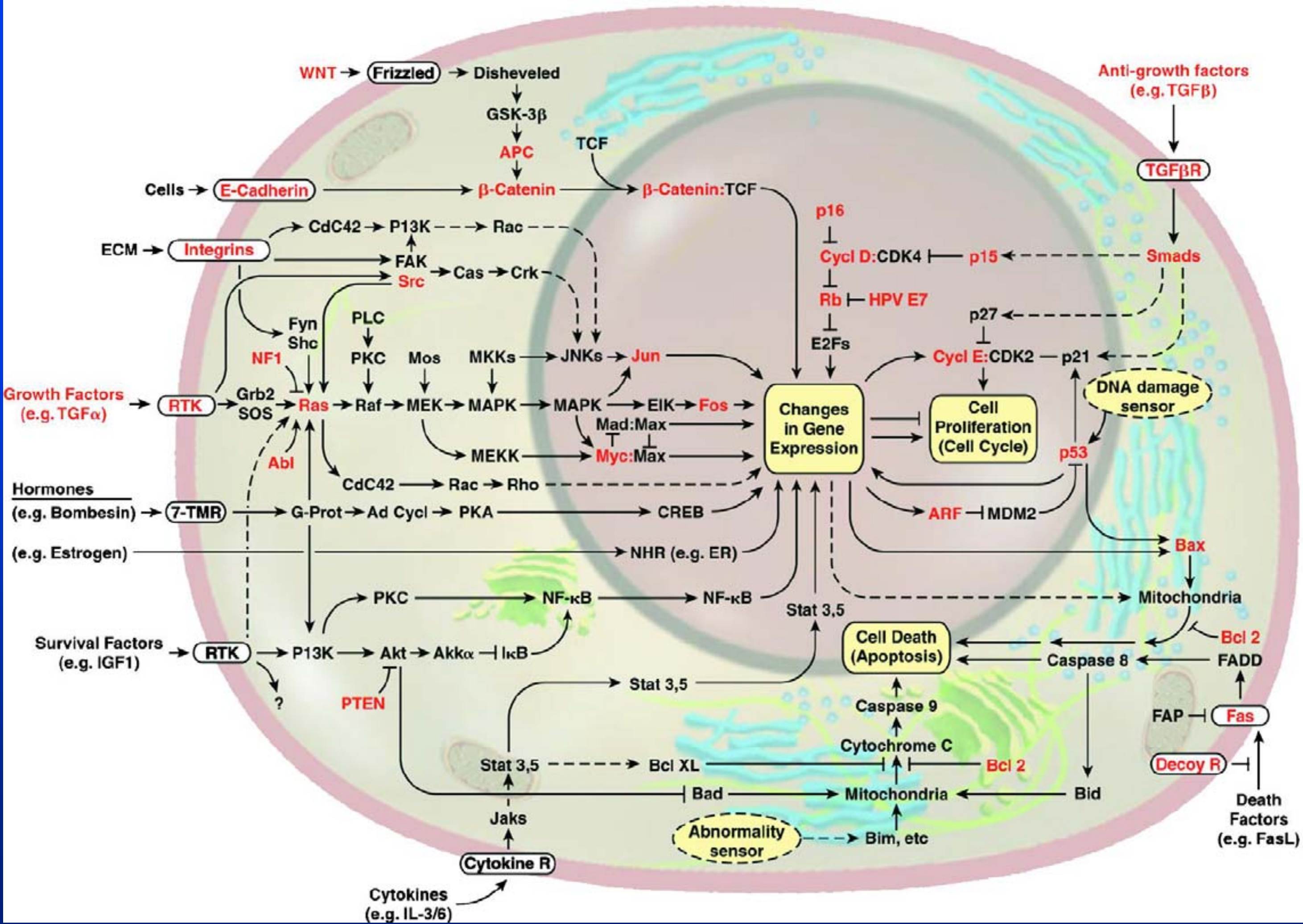
- Schrödinger 1944
- Wiener 1948
- von Neumann 1958
- Bellman Mathematical Biosciences
- Understanding dynamics and control crucial
- What is new?



Systems Biology

Leading biologists have recognized that new systems-level knowledge is urgently required in order to conceptualize an organize the revolutionary developments taking place in the biological sciences, and new academic departments and educational programs are being established at major universities, particularly in Europe and in the United States

Signaling Circuit in Mammalian Cell



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The Systems Perspective

In the past steady increases in knowledge has spawned new microdisciplines within engineering. However, contemporary challenges – from biomedical devices to complex manufacturing designs to large systems of networked devices – increasingly require a systems perspective

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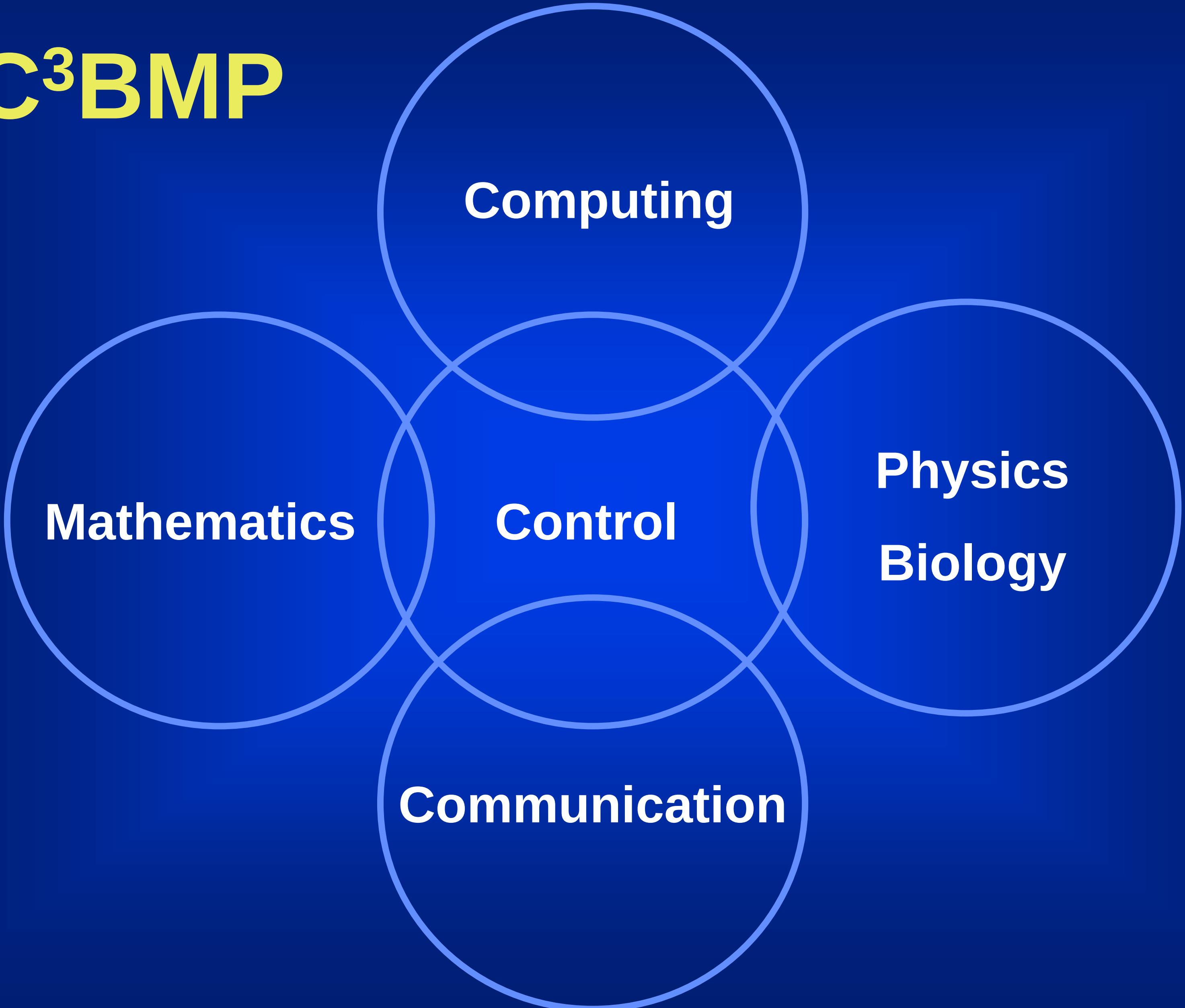
C^{3}BMP


Computing
Mathematics
Control
Physics
Biology
Communication

Modeling and Simulation

There will be growth in areas of simulation and modeling around the creation of new engineering "structures". Computer-based design-build engineering ... will become the norm for most product designs, accelerating the creation of complex structures for which multiple subsystems combine to form a final product.

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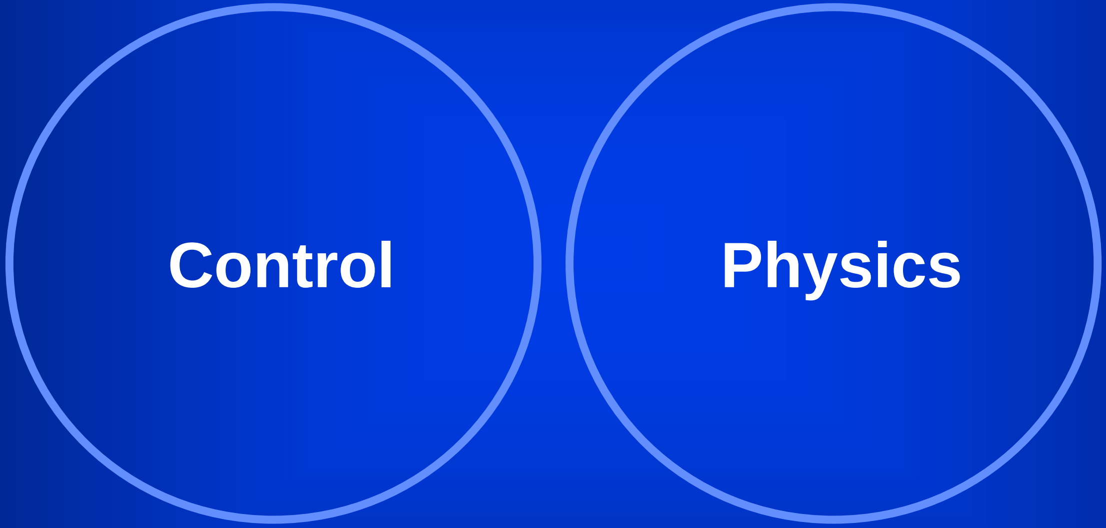
The Modeling Barrier



Blockdiagrams ODEs

Mass, energy, momentum

Block diagrams unsuitable for serious physical modeling

Modelica (www.modelica.org)

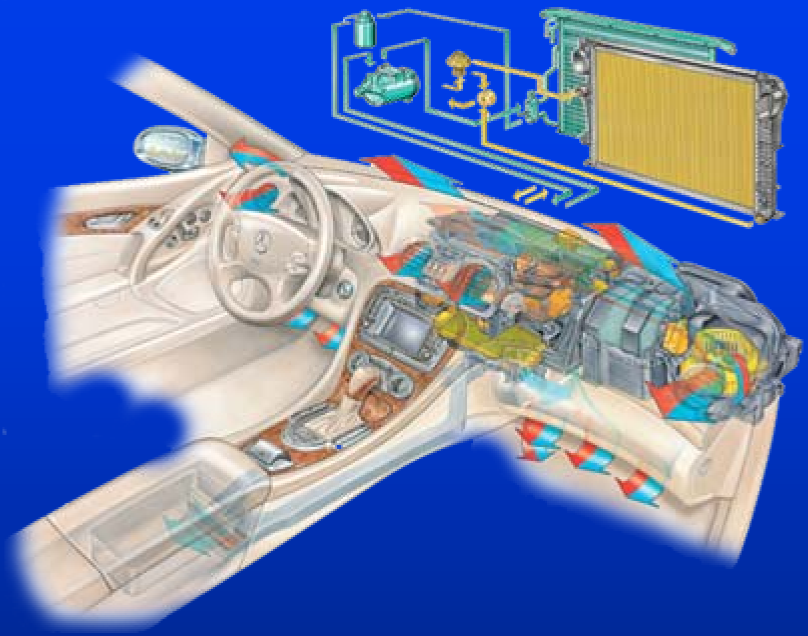
- Block diagrams and ODEs not suited for physical modeling – the control/physics barrier
- Behavior based (declarative) modeling is a good alternative
- European activity based on industry/university collaboration
- Groups with broad competence and experience

Modelica (www.modelica.org)

- Mimics how an engineer builds a real system
- Object oriented, component-based, multi-domain
- Efficient engineering through reuse
- Model libraries (free and commercial)
- Simulator Dymola (Dynasim)
- Extensive symbolic manipulation, automatic inversion, ...
- Efficient real-time code
- Syntax and semantics formally defined

Dynasim

Automotive Climate Control

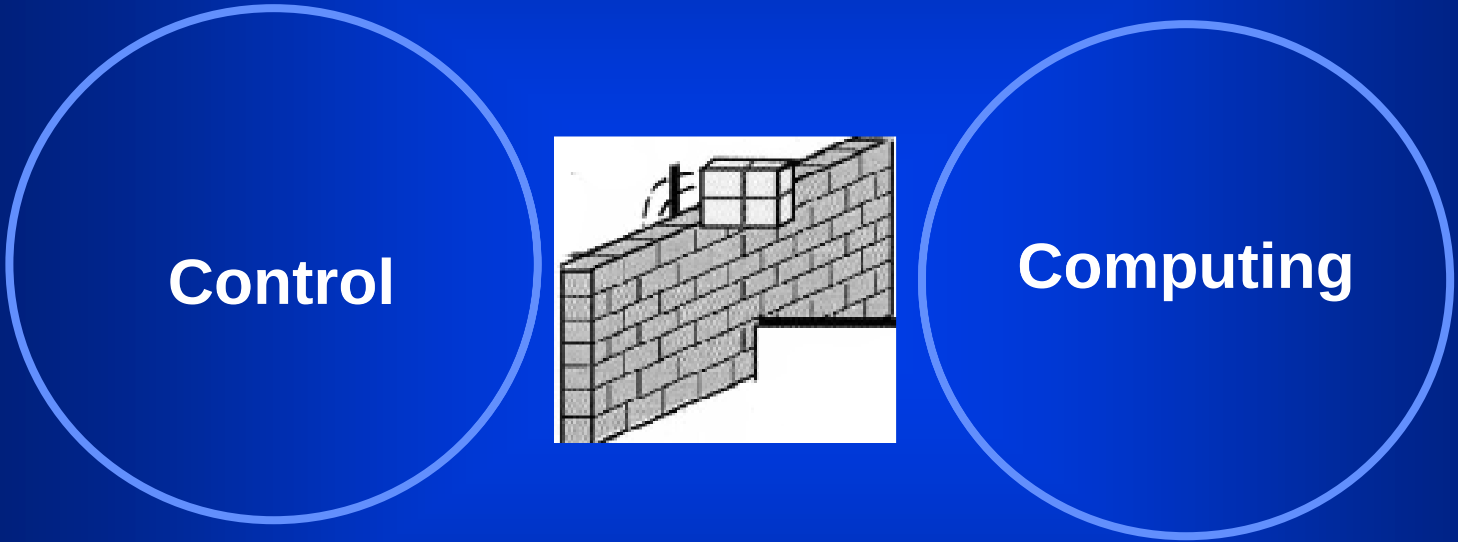


- Audi, BMW, DaimlerCrysler, Volkswagen and their suppliers have standardized on Modelica
- Suppliers provide components and validated Modelica models based on the AirConditioning library from Modelon
- Car manufacturers evaluate complete system by simulation
- IP protected by extensive encryption

Picture courtesy of Behr GmbH & Co.

Modelon

The Implementation Barrier



Feedback,Stability, ODE, PDE
Moderate complexity
Robustness

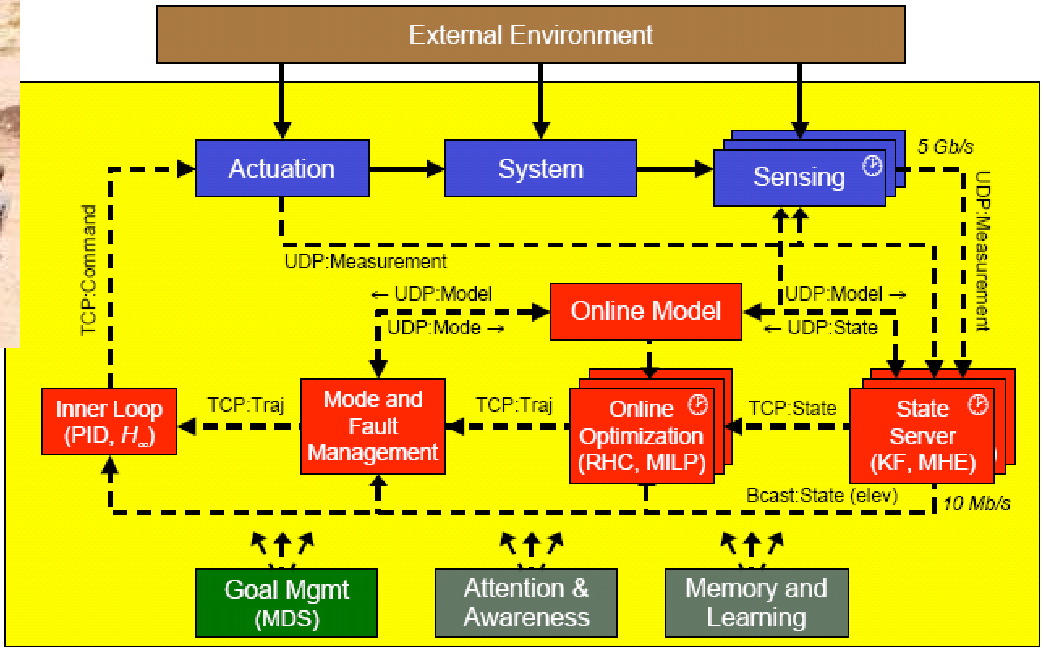
Logic, languages, DES,FSM
High complexity
Abstraction

Networked embedded systems

Safe Design

- Much more than automatic code generation
- Formal specification, design, verification and validation
- System architecture
- Integration of subsystems
- Modification, upgrade

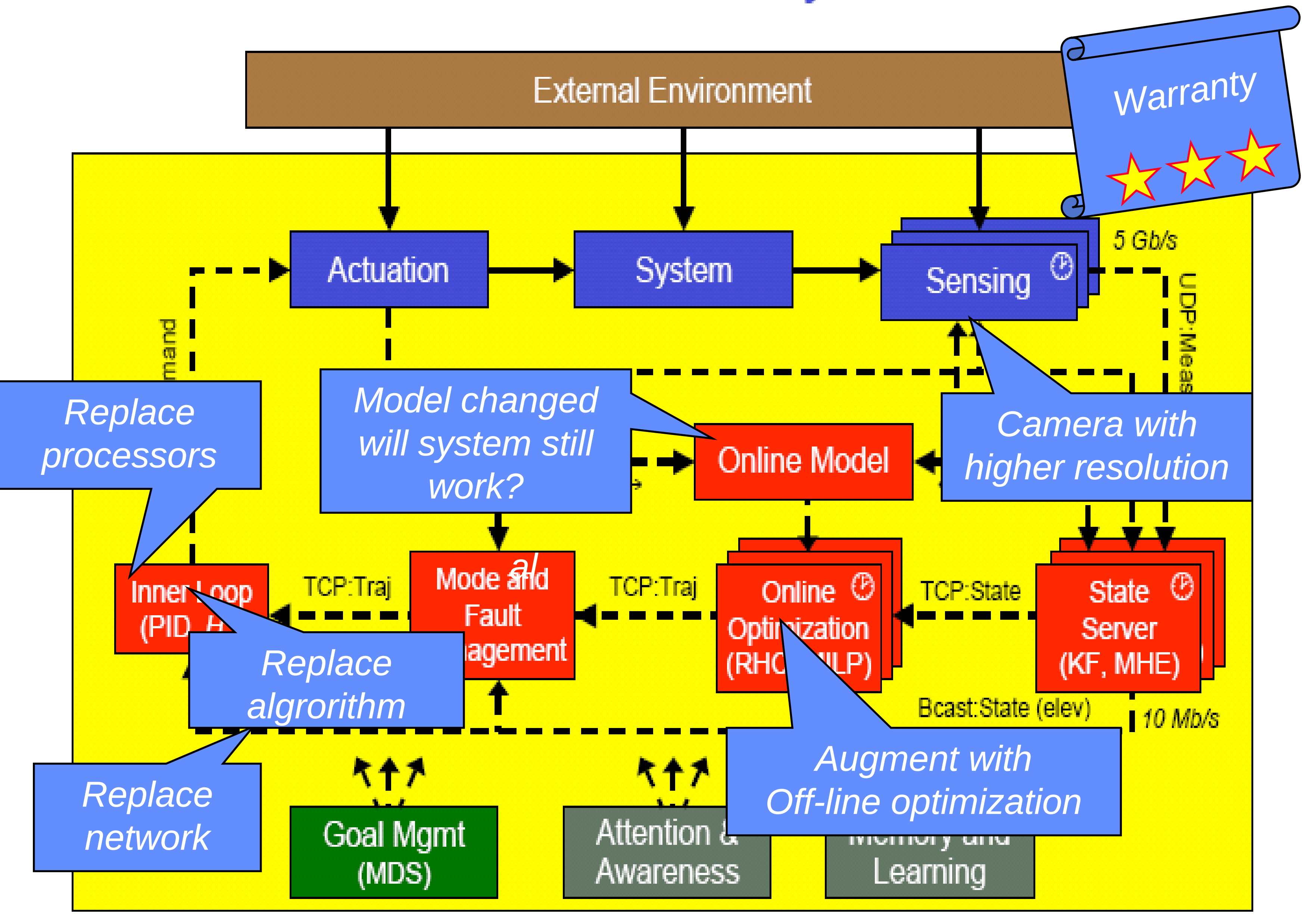
An Example



DARPA Grand Challenge

Caltech Alice

Slide from R Murray Caltech


External Environment
Warranty
Actuation
System
Sensing
5 Gb/s
UDP:Meas
Model changed will system still work?
Online Model
Camera with higher resolution
Replace processors
Inner Loop (PID, A
TCP:Traj
Mode and Fault Management
TCP:Traj
Online Optimization (RHC, MILP)
TCP:State
State Server (KF, MHE)
Replace algrorithm
Augment with Off-line optimization
Bcast:State (elev)
10 Mb/s
Replace network
Goal Mgmt (MDS)
Attention & Awareness
Learning

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Conclusions

- Tremendous advances
- Control everywhere
- Massive computations
- The systems challenge
- Like 1956 but at a higher level
- A role for IFAC?