Elec 4309 Senior Design

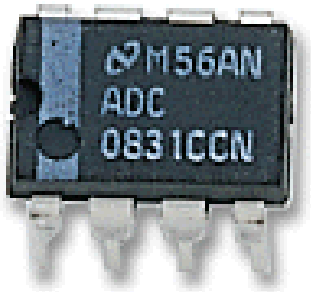
Wendell H Chun

Aug. 24, 2017

Semiconductor Revolution

- Led to the creation of integrated circuit (IC) technology.
- Effective, miniaturized, power electronics could amplify and deliver needed amount of power to actuators.
- Signal conditioning electronics could filter and encode sensory data in analog/digital format.
- Hard-wired, on-board, discrete analog/digital ICs provided rudimentary computational and decision-making circuits for control of mechanical devices.

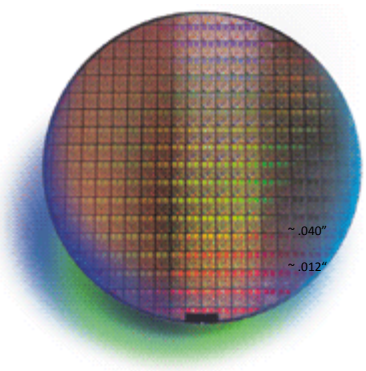
An Integrated Circuit



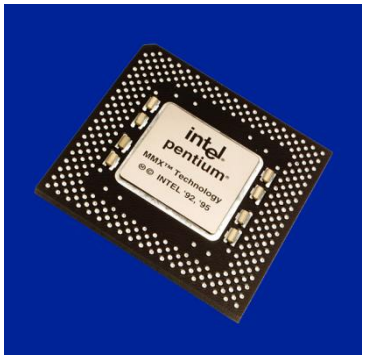
An A2D Converter

An Operational Amplifier

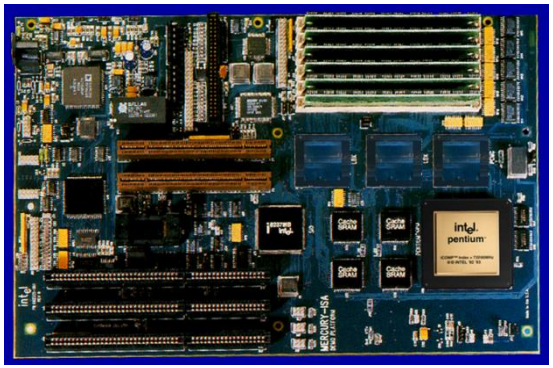
Overview of Packaging



Silicon Die



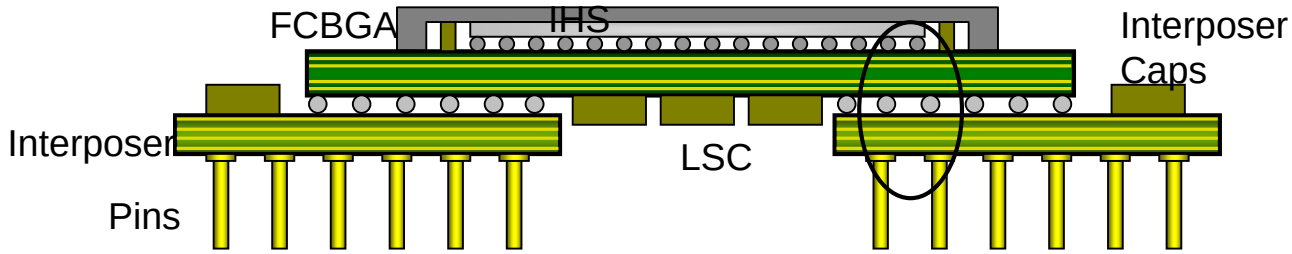
Package



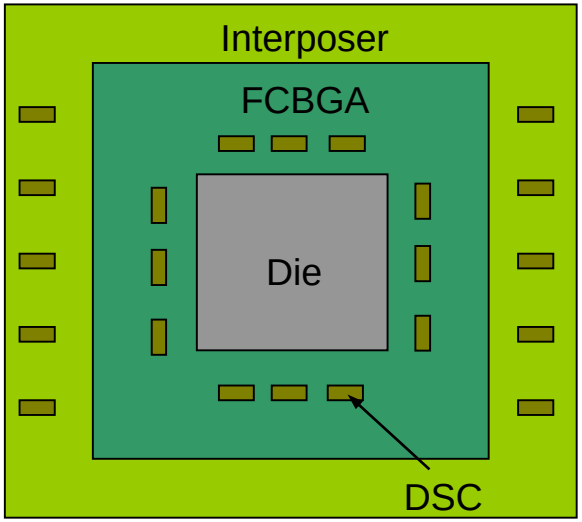
Motherboard

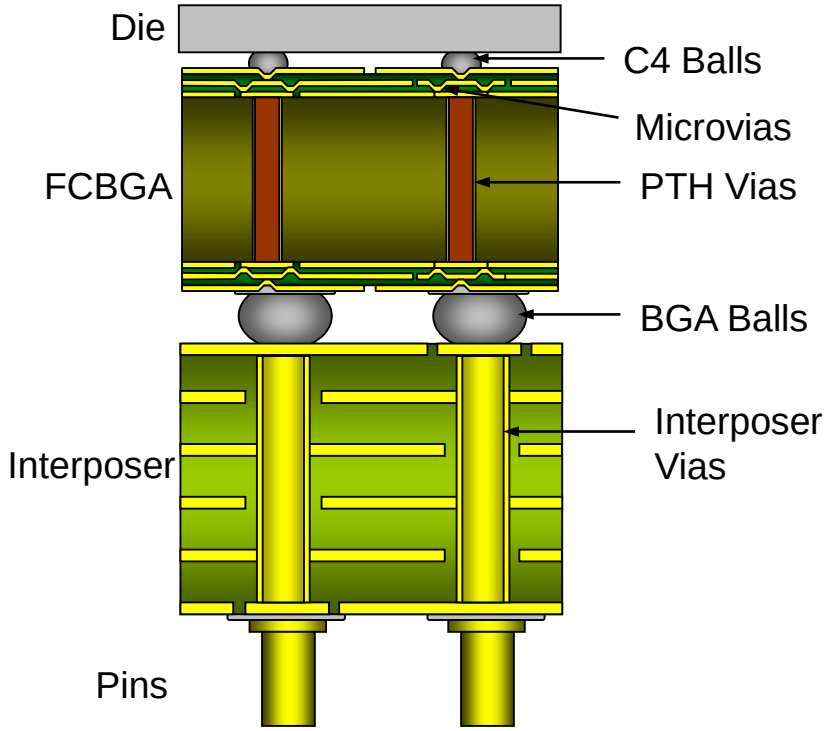
Courtesy of Intel Corp.

Overview of Packaging



Courtesy of Intel Corp.





Overview of Packaging

- "Packaging engineers today must solve complex, coupled problems that require fundamental understanding of electrical, thermal, mechanical, material science, and manufacturing principles."
  - Dr. Nasser Grayeli, Intel Corporation

Electrical Functions of the Package

- **Power Delivery**
  - Supply a clean power and reference voltage to active devices on the die.
- **Signal Input/Output**
  - Transmit signals from the die to the motherboard faithfully and in minimum time.
- **EMI/EMC**
  - Minimize radiation of electromagnetic energy into the environment, and the impact of ambient electromagnetic energy on circuit performance.

Foundations of Electrical Engineering

- Electrophysics.
- Information (Communications) Theory.
- Digital Logic.

Foundations of Electrical Engineering

- ***Electrophysics***:
  - Fundamental theories of physics and important special cases.
  - Phenomenological/behavioral models for situations where the rigorous physical theories are too difficult to apply.

Hypothesis, Model, and Theory

- A ***hypothesis*** is an idea or suggestion that has been put forward to explain a set of observations. It may be expressed in terms of a mathematical ***model***. The *model* makes a number of predictions that can be tested in experiments. After many tests have been made, if the *model* can be refined to correctly describe the outcome of all experiments, it begins to have a greater status than a mere suggestion.
- A ***theory*** is a well-tested and well-established understanding of an underlying mechanism or process.

Hypothesis, Model, and Theory

- Maxwell's equations are '*just a theory*' and yet my cell phone works!
- At one time, a theory would have been referred to as a 'law'.
  - Newton's laws
  - Boyle's law
- But remember no theory is a complete description of all reality; all theories are incomplete.
- Electrical engineers make use of a number of theories – some of which are special cases of others.

Four Fundamental Forces of Physics

- Gravitational Force
  - Associated particle is graviton (hypothesized)
  - Always attractive
  - Varies inversely as the square of the distance
- Electromagnetic Force
  - Associated particle is photon
  - 10^{42} times stronger than gravity
  - Force can be attractive or repulsive
  - Varies inversely as the square of the distance
- Strong Interaction
  - Associated particle is gluon
  - About 100X stronger than electromagnetic force but only acts over distances the size of an atomic nucleus
  - Responsible for holding the protons and neutrons together
- Weak Interaction
  - Associated particles are the weak gauge bosons (Z and W particles)
  - Acts only over distances the size of an atomic nucleus
  - Responsible for certain types of radioactive decay

The Standard Model

- Physicists call the theoretical framework that describes the interactions between elementary building blocks (quarks and leptons) and the force carriers (bosons) the Standard Model.
- Most of the standard model is a *theory*; some of it is still *hypothesis*.
- Physicists use the Standard Model to explain and calculate a vast variety of particle interactions and quantum phenomena. High-precision experiments have repeatedly verified subtle effects predicted by the Standard Model.

The Standard Model

- The biggest success of the Standard Model is the unification of the electromagnetic and the weak forces into the so-called *electroweak force*.
- Many physicists think it is possible to eventually describe all forces with a Grand Unified Theory or a so-called ***Theory of Everything*** (ToE).
  - M-theory (a generalization of superstring theory) is the current embodiment of the ToE.

Information Theory

- Originally developed by Claude Shannon of Bell Labs in the 1940s.
- ***Information*** is defined as a symbol that is uncertain at the receiver.
- The fundamental quantity in information theory is ***channel capacity*** – the maximum rate that information can be exchanged between a transmitter and a receiver.

Information Theory

- Defines relationships between elements of a communications system. For example,
  - Power at the signal source
  - Bandwidth of the system
  - Noise
  - Interference
- Mathematically describes the principals of data compression.

Information Revolution

- Development of VLSI technology led to the introduction of microprocessor, microcomputer, and microcontroller.
- Now computing hardware is ubiquitous, cheap, and small.
- As computing hardware can be effortlessly interfaced with real world electromechanical systems, it is now routinely embedded in engineered products/processes for decision-making.
  - Microcontrollers are replacing precision mechanical components, e.g., precision-machined camshaft that in many applications functions as a timing device.
  - Programmability of microcontrollers is providing a versatile and flexible alternative to the hard-wired analog/digital computational hardware.
  - Integrated computer-electrical-mechanical devices are now capable of converting, transmitting, and processing both the *physical energy* and the *virtual energy* (information).
- Result: Highly efficient products and processes are now being developed by judicious selection and integration of sensors, actuators, signal conditioning, power electronics, decision and control algorithms, and computer hardware and software.

Digital Logic

- Digital logic signals are really analog signals, and digital circuits are ultimately designed using circuit theory.
- However, in many situations the function of a digital circuit is more easily synthesized using the principles of digital logic.

Digital Logic

- Based on logic gates, truth tables, and combinational and sequential logic circuit design
- Uses Boolean algebra and Karnaugh maps to develop minimized logic circuits.

Power Systems

- Generation of electrical energy
- Storage of electrical energy
- Distribution of electrical energy
- Rotating machinery-generators, motors

Electromagnetics

- Propagation of electromagnetic energy
- Antennas
- Very high frequency signals
- Fiber optics

Solid State

- Devices
  - Transistors
  - Diodes (LED's, Laser diodes)
  - Photodetectors
- Miniaturization of electrical devices
- Integration of many devices on a single chip

Communications/Signal Processing

- Transmission of information electrically and optically
- Modification of signals
  - enhancement
  - compression
  - noise reduction
  - filtering

Controls

- Changing system inputs to obtain desired outputs
- Feedback
- Stability

Digital Design

- Digital (ones and zeros) signals and hardware
- Computer architectures
- Embedded computer systems
  - Microprocessors
  - Microcontrollers
  - DSP chips
  - Programmable logic devices (PLDs)

Microprocessors for Embedded Systems

- Computing systems are everywhere
- Most of us think of “desktop” computers
  - PC’s 
  - Laptops 
  - Mainframes
  - Servers
- But there’s another type of computing system
  - Far more common...

Embedded Systems

- Embedded computing systems:
  - Computing systems embedded within electronic devices
  - Hard to define. Nearly any computing system other than a desktop computer
  - Billions of units produced yearly, versus millions of desktop units
  - Perhaps 50 per household and per automobile

“Short List” of Embedded Systems

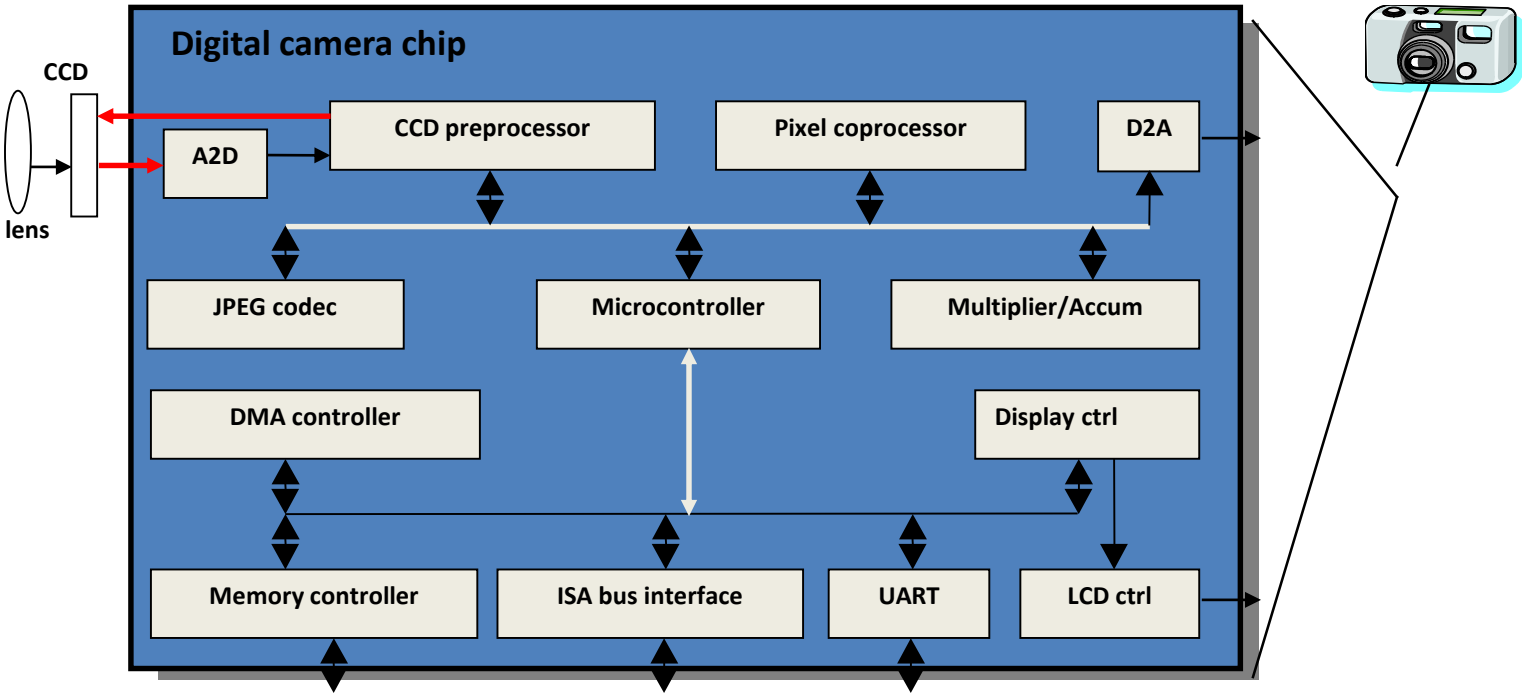
Anti-lock brakes
Auto-focus cameras
Automatic teller machines
Automatic toll systems
Automatic transmission
Avionic systems
Battery chargers
Camcorders
Cell phones
Cell-phone base stations
Cordless phones
Cruise control
Curbside check-in systems
Digital cameras
Disk drives
Electronic card readers
Electronic instruments
Electronic toys/games
Factory control
Fax machines
Fingerprint identifiers
Home security systems
Life-support systems
Medical testing systems
Modems
MPEG decoders
Network cards
Network switches/routers
On-board navigation
Pagers
Photocopiers
Point-of-sale systems
Portable video games
Printers
Satellite phones
Scanners
Smart ovens/dishwashers
Speech recognizers
Stereo systems
Teleconferencing systems
Televisions
Temperature controllers
Theft tracking systems
TV set-top boxes
VCR’s, DVD players
Video game consoles
Video phones
Washers and dryers

And the list goes on and on

Some Common Characteristics of Embedded Systems

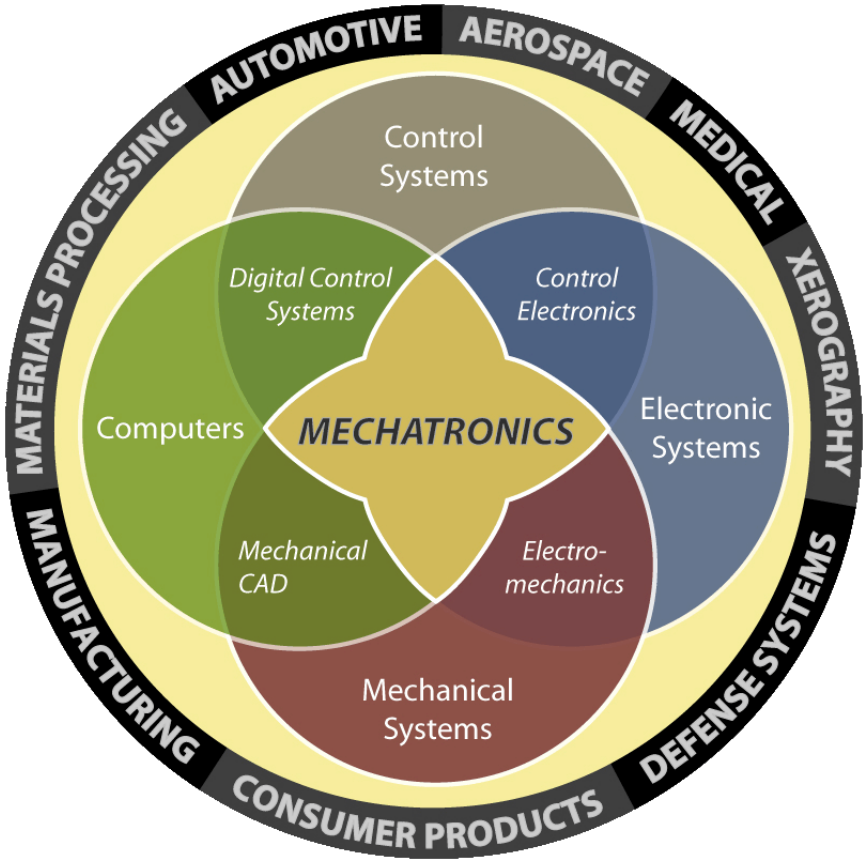
- Single-functioned
  - Executes a single program, repeatedly
- Tightly-constrained
  - Low cost, low power, small, fast, etc.
- Reactive and real-time
  - Continually reacts to changes in the system's environment
  - Must compute certain results in real-time without delay

Embedded System Example: Digital Camera



- Single-functioned -- always a digital camera
- Tightly-constrained -- Low cost, low power, small, fast
- Reactive and real-time -- only to a small extent

Mechatronics



The synergistic combination of mechanical, electrical, and computer engineering

- Emphasis on integrated design for products
- Optimal combination of appropriate technologies

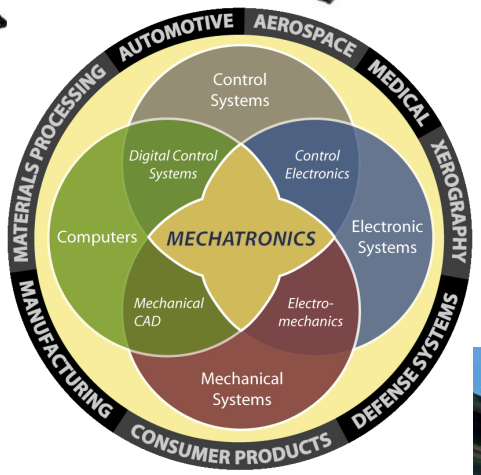
Mechatronic Systems

Tools

Computers

Cars

Consumer Electronics



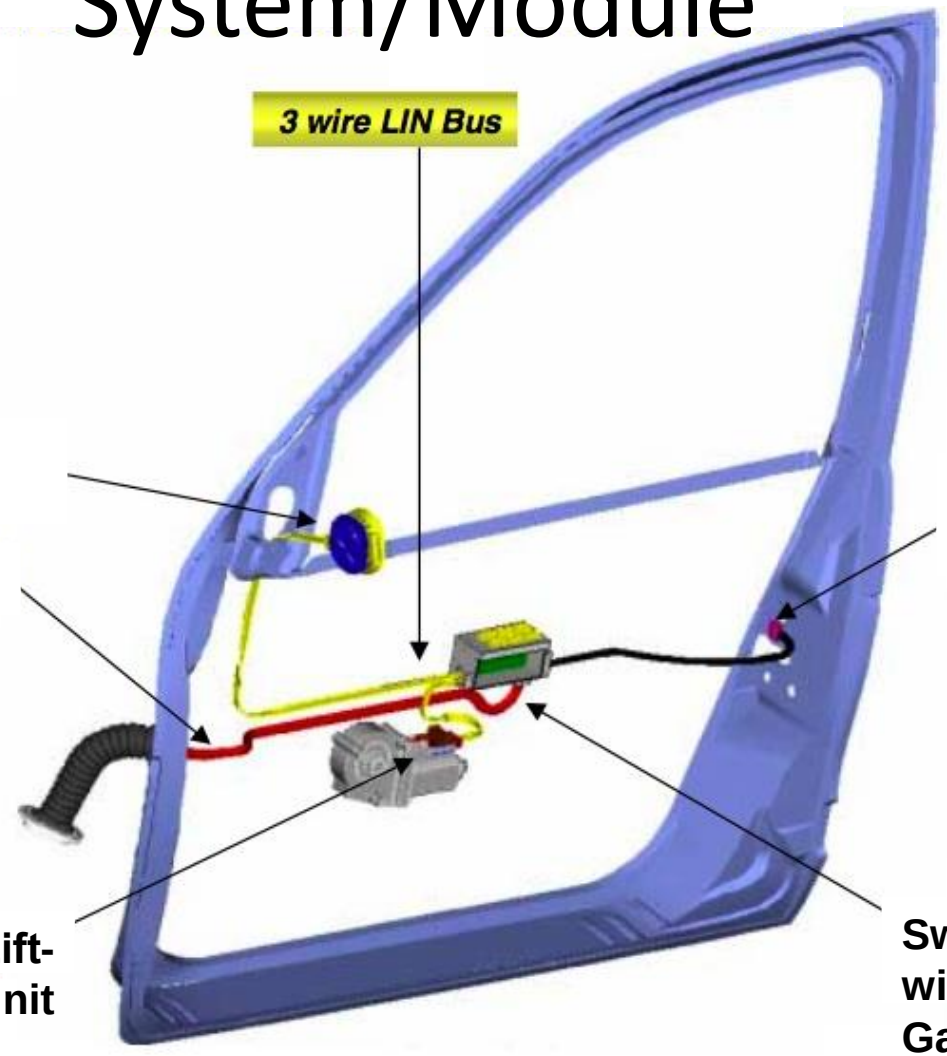
Stealth Bomber

MEMS

Micro to Macro Applications

High Speed Trains

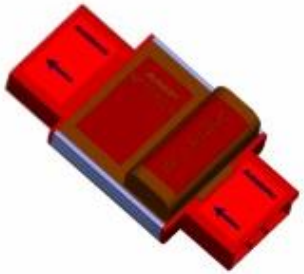
Mechatronic Systems: Door System/Module



"Smart" Mirror motor-unit pin-header

CAN Bus

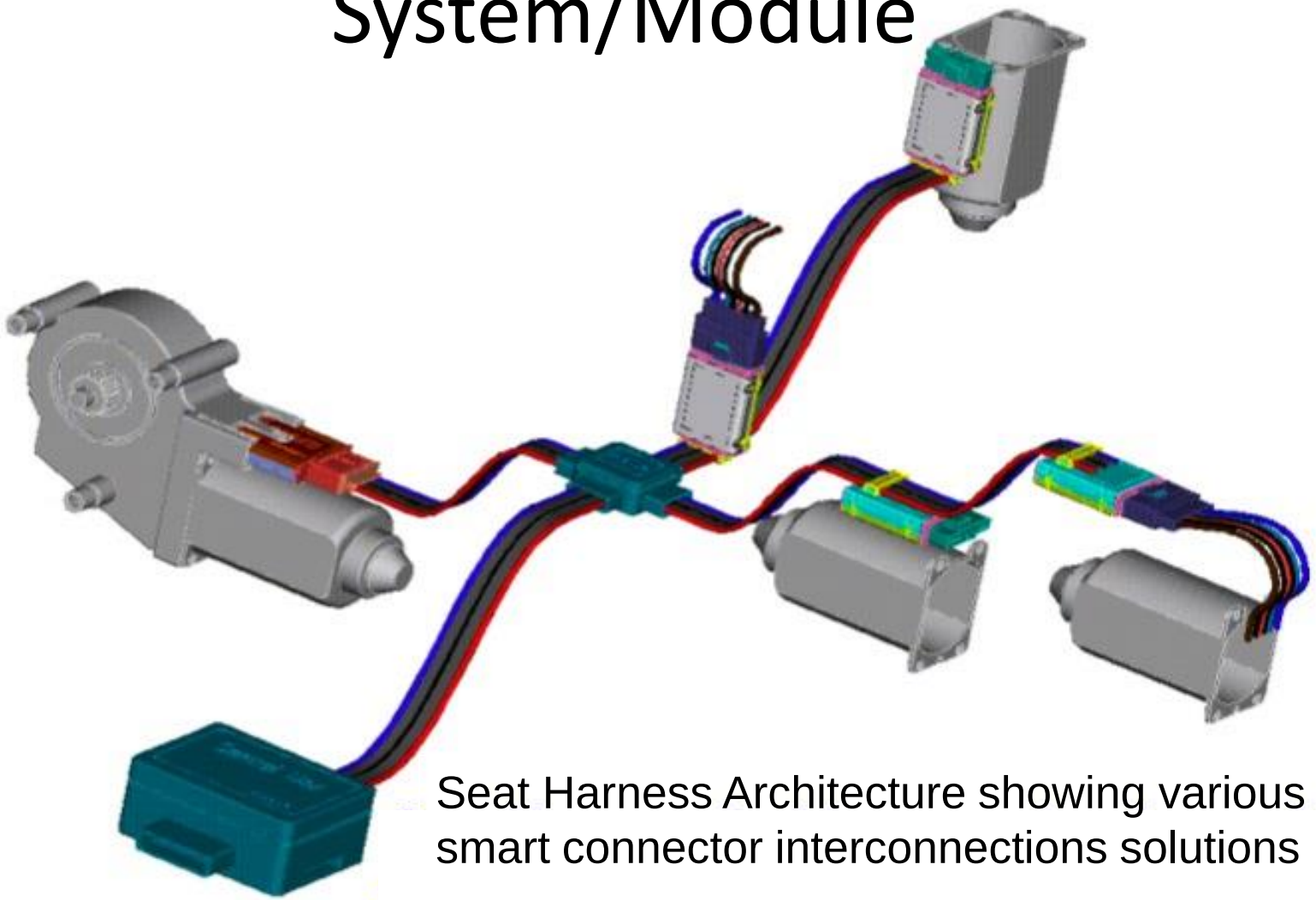
"Smart" Doorlock



"Smart" Window Lift-unit

Switchboard with CAN Bus Gateway

Mechatronic Systems: Seat System/Module



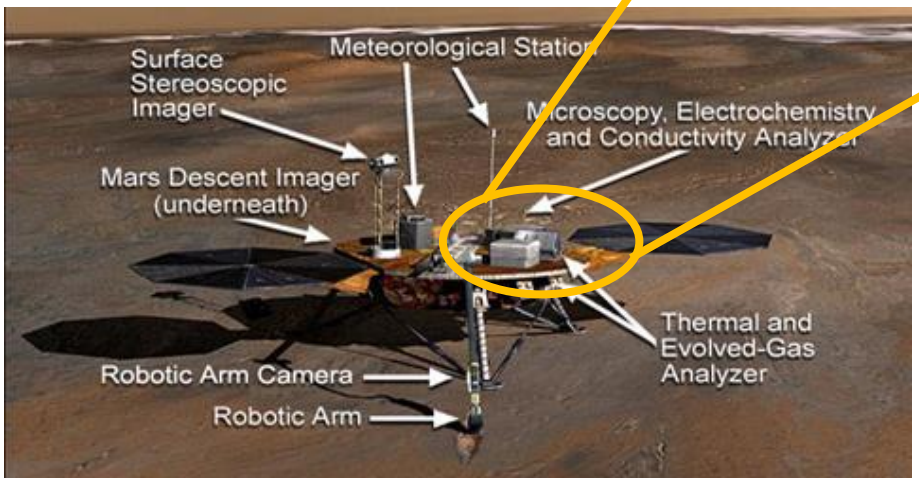
Seat Harness Architecture showing various smart connector interconnections solutions

Mechatronic Systems: Space Exploration Applications

Phoenix Mars Lander's

System Can

- Collect specimens
- Has automated onboard lab for testing specimens



Advantages

- Robot that can travel to other planets and **take measurements automatically**.

Mechatronic Systems: Sanitation Operations

Systems Uses

- Motion sensors
- Control circuitry
- Electromechanical actuators
- Independent power source

Soap Dispenser

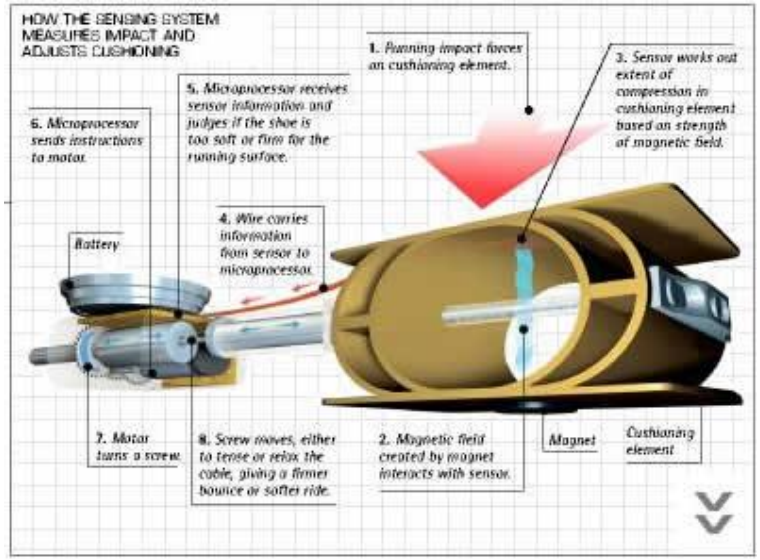
Paper Towel Dispenser

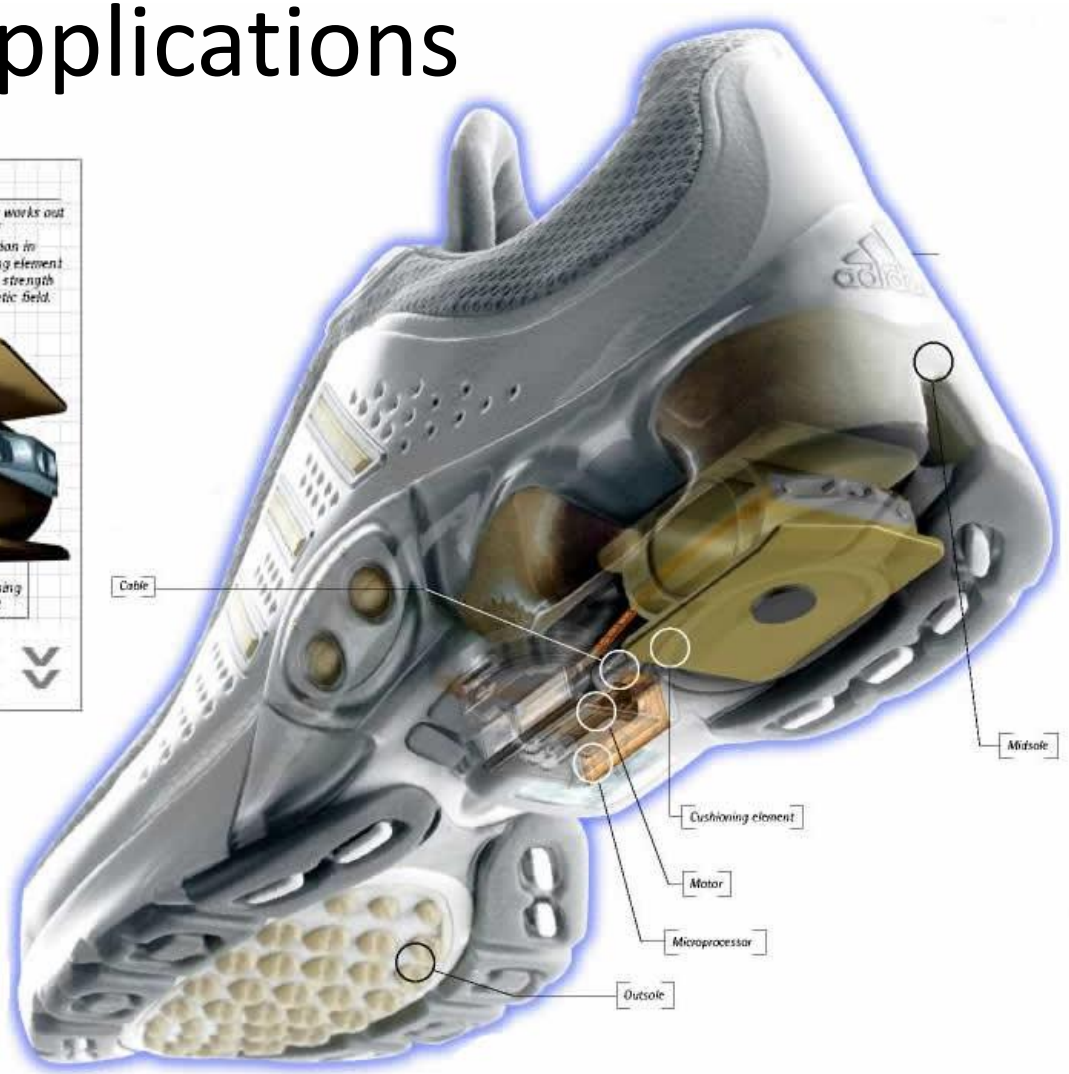
Advantages

- **Reduces spread of germs** by making device hands free
- **Reduces wasted materials** by controlling how much is dispensed

Mechatronic Systems: Sports Applications

Running Shoes

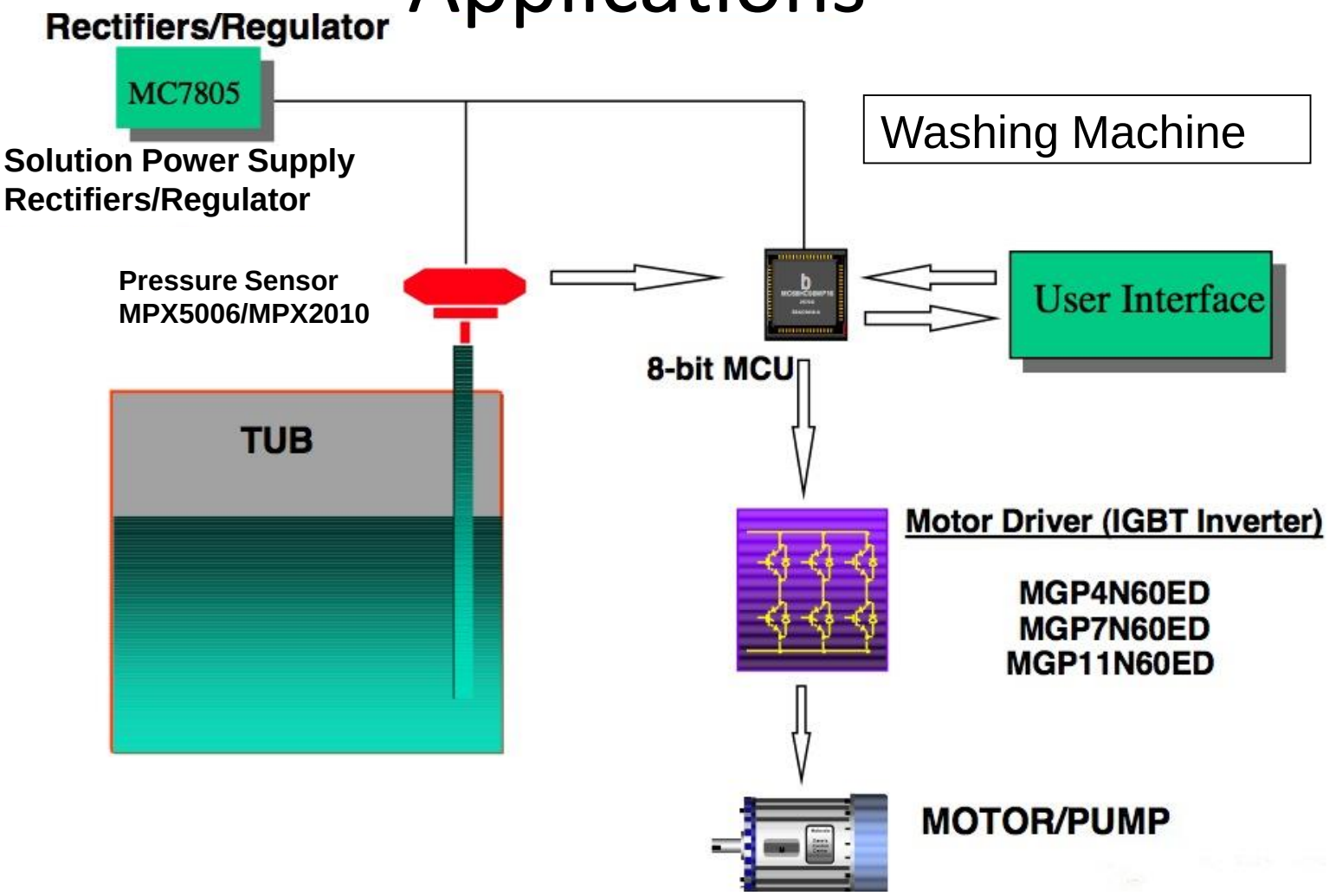




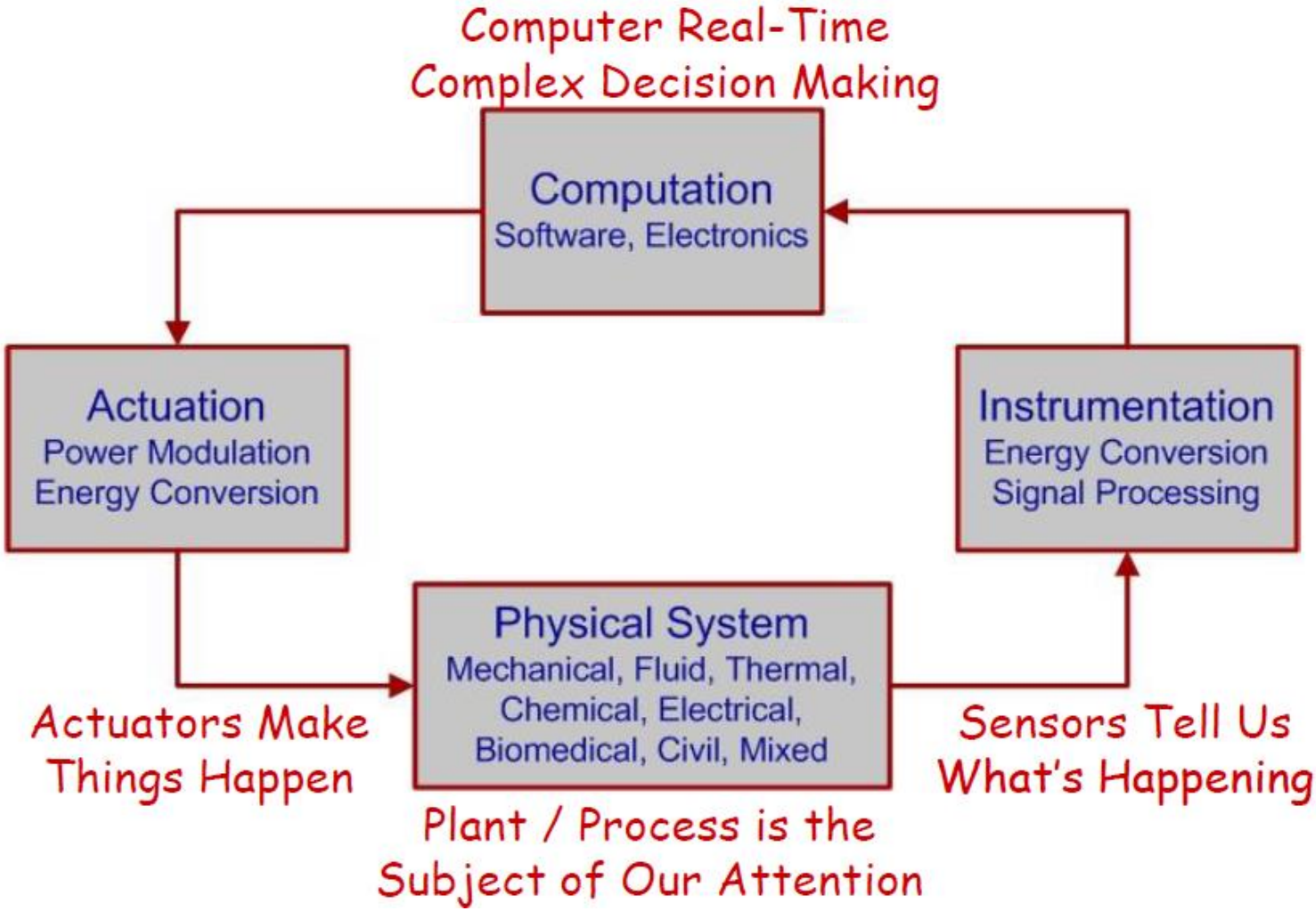
Advantages

- **Automatically changes cushioning** in shoe for different running styles and conditions for improved comfort

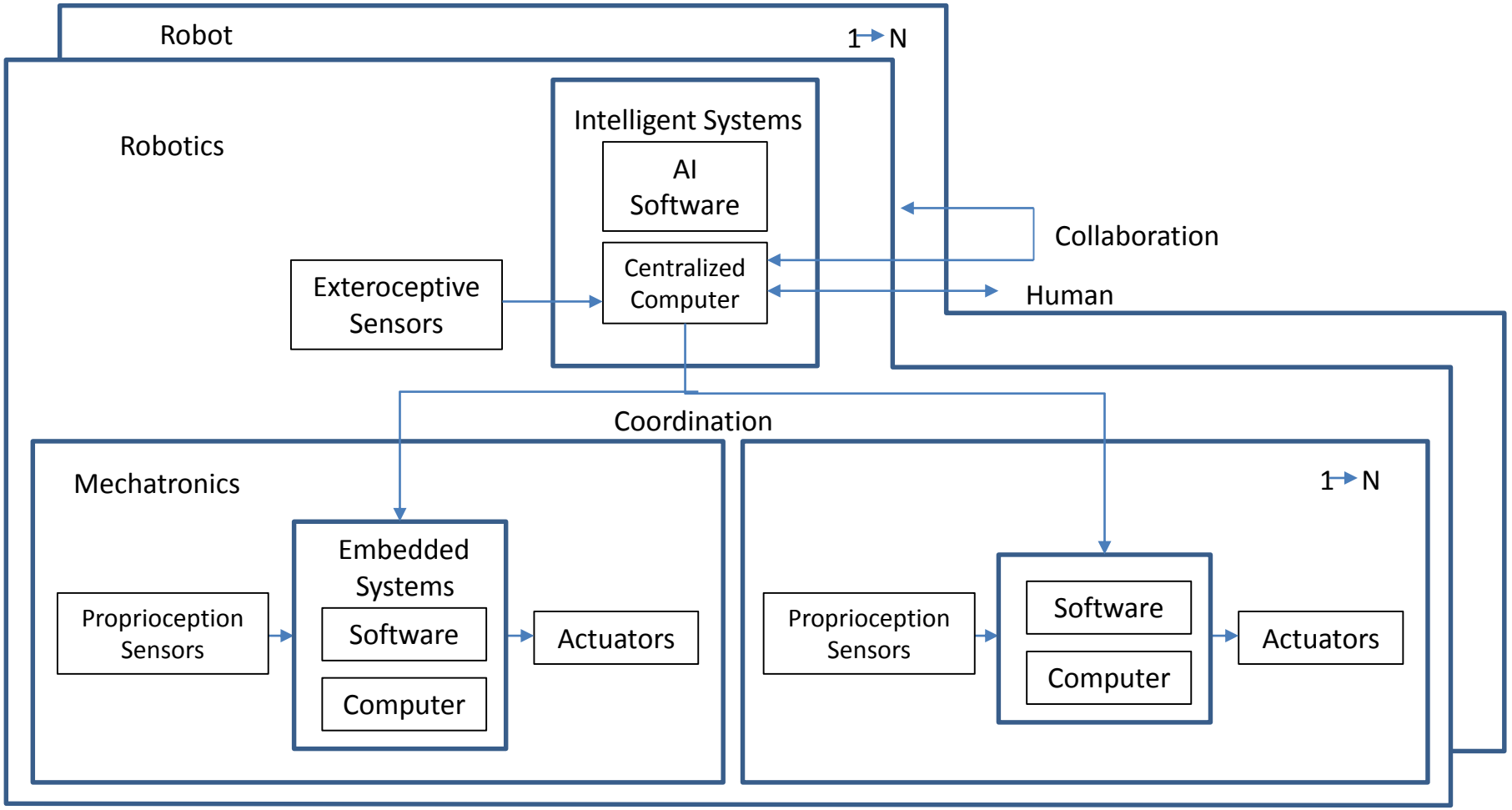
Mechatronic Systems: Smart Home Applications



General Mechatronic Model



A Model for Robotics



Summary

- Types of Projects:
  - Power
  - Electronics
  - RF/Communications/Signal Processing
  - Controls
  - Embedded Systems
  - Mechatronics (Mechanical/Electrical Integration)
  - Hardware/Software Integration