NAZARBAYEV UNIVERSITY
SCHOOL OF SCIENCE AND TECHNOLOGY

ROBT305 – Embedded Systems

Lecture 1 – Introduction & Course Overview

18 August 2015

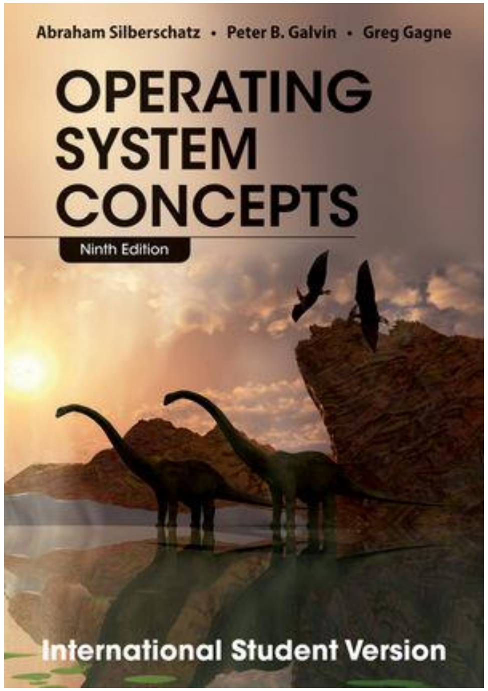
Course Prerequisites

- Background required (desired):
  - Microcontrollers (ROBT206)
  - Programming knowledge in C (CSSI)
  - Electric and electronic circuits (ROBT203, ROBT204)(desired)
  - Sensors (ROBT205) (desired)

- Teaching:
  - Lectures (small part of the course)
  - Practical exercises using BeagleBone Black boards and
  - embedded Linux
  - Project

Course Literature

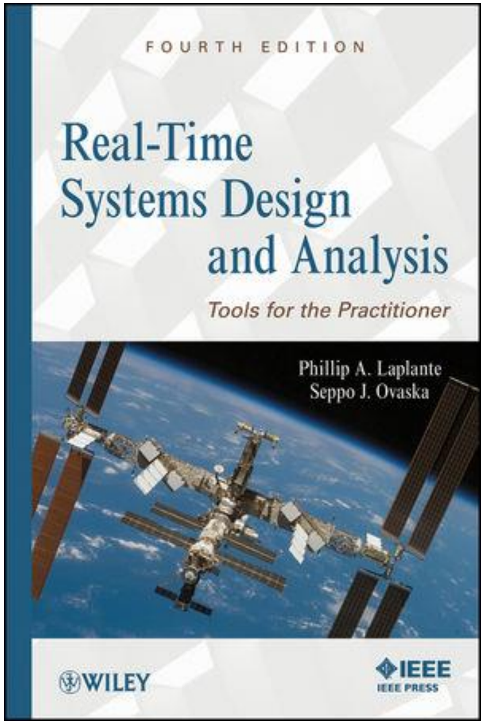
- **Operating System Concepts. Ninth Edition, International Student Edition**
  by A. Silberschatz, P. Baer Galvin and G. Gagne, 9th edition, 2012



- Grab a copy for yourself from the library
- Typically used by Computer Science students and provide basics of Operation Systems design like Windows, Linux, etc.
- Contain material related to our course and any practical programming assignments

Course Literature

- **Real-Time Systems Design and Analysis: Tools for the Practitioner** by P. A. Laplante & S. J. Ovaska, Forth edition, 2012



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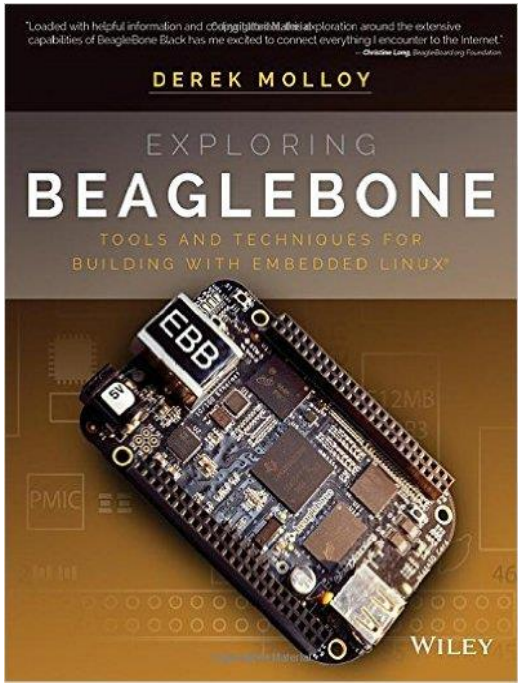
Course Literature

- **Exploring BeagleBone: Tools and Techniques for Building with Embedded Linux** by Derek Molloy, 2014



- ❑ Available in Moodle in electronic form
- ❑ Contain material related to practical BeagleBone Black boards

Course Oultine

- Hardware
- Operating Systems
- Linux
- Processes and threads
- POSIX
- RT definitions
- Scheduling and Synchronization
- BeagleBone Black assignments and projects

COURSE ASSESSMENT

Activity	Quantity	Weight
Quizzes	~5 (drop 1)	20%
Homework Assignments	~5	25%
Project	1	15%
Mid Semester Exam	1	15%
Final Exam	1	20%
Class Attendance and Participation		5%

Embedded Systems & Cyber-Physical Systems

“Dortmund“ Definition: [Peter Marwedel]

Embedded systems are information processing systems embedded into a larger product

Berkeley: [Edward A. Lee]:
Embedded software is software integrated with physical processes. The technical problem is managing time and concurrency in computational systems.

Cyber-Physical (cy-phy) Systems (CPS) are integrations of computation with physical processes [Edward Lee, 2006].

Cyber-physical system (CPS) =
Embedded System (ES) + *physical environment*

Embedded Systems

- *An **embedded system** is a computer system designed to perform one or a few dedicated functions, often with real-time computing constraints. It is usually embedded as part of a complete device including hardware and mechanical parts.*

- *Embedded systems span all aspects of modern life and there are many examples of their use: mobile phones, MP3 players, digital cameras, GPS receivers, household appliances, avionics system, medical systems, etc.*

- *Embedded processors can be microprocessors or microcontrollers.*

- *The program instructions written for embedded systems are referred to as firmware, and are stored in read-only memory or Flash memory chips. They run with limited computer hardware resources: little memory, small or non-existent keyboard and/or screen.*

Embedded Systems

Embedded systems (ES) = **information processing systems embedded into a larger product**

Examples:

Main reason for buying is **not** information processing

Application areas and examples

Graphics: © Alexandra Nolte, Gesine Marwedel, 2003

Application Area: Automotive Electronics

Functions by embedded processing:

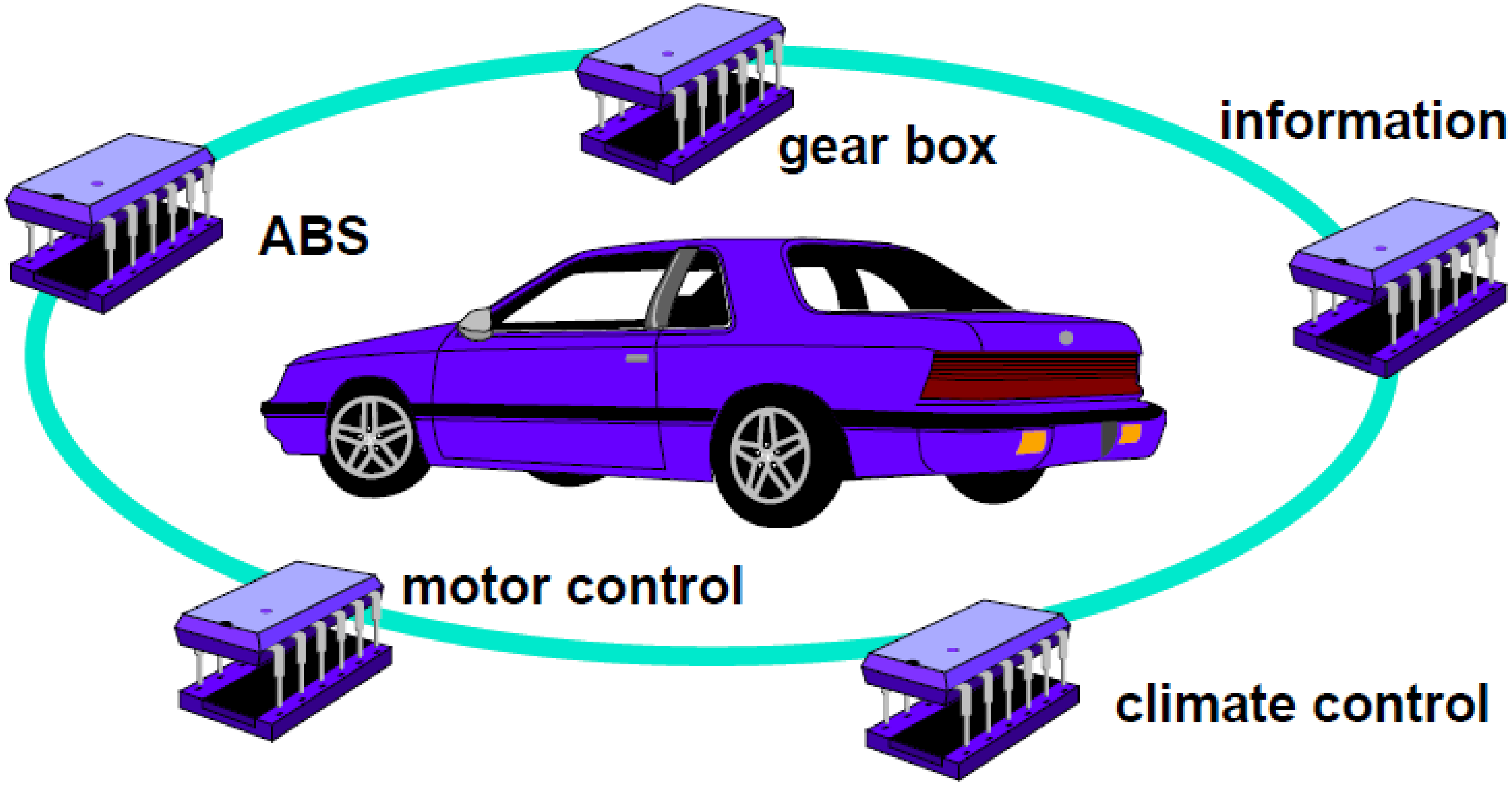
- ABS: Anti-lock braking systems
- ESP: Electronic stability control
- Airbags
- Efficient automatic gearboxes
- Theft prevention with smart keys
- Blind-angle alert systems
- ... etc ...

© P. Marwedel, 2011

- Multiple networks
- Multiple networked processors

Examples of Embedded Systems

Car as an integrated control-, communication and information system.



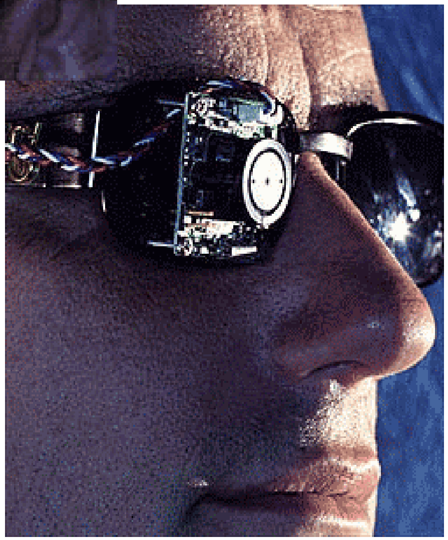
Application Area: Avionics

- Flight control systems,
- anti-collision systems,
- pilot information systems,
- power supply system,
- flap control system,
- entertainment system,
- …

- Dependability is of outmost importance.

Medical Systems

- For example:
  - Artificial eye: several approaches, e.g.:
    - Camera attached to glasses; computer worn at belt; output directly connected to the brain, "pioneering work by William Dobelle". Previously at [www.dobelle.com]



- Translation into sound; claiming much better resolution. [http://www.seeingwithsound.com/etumble.htm]

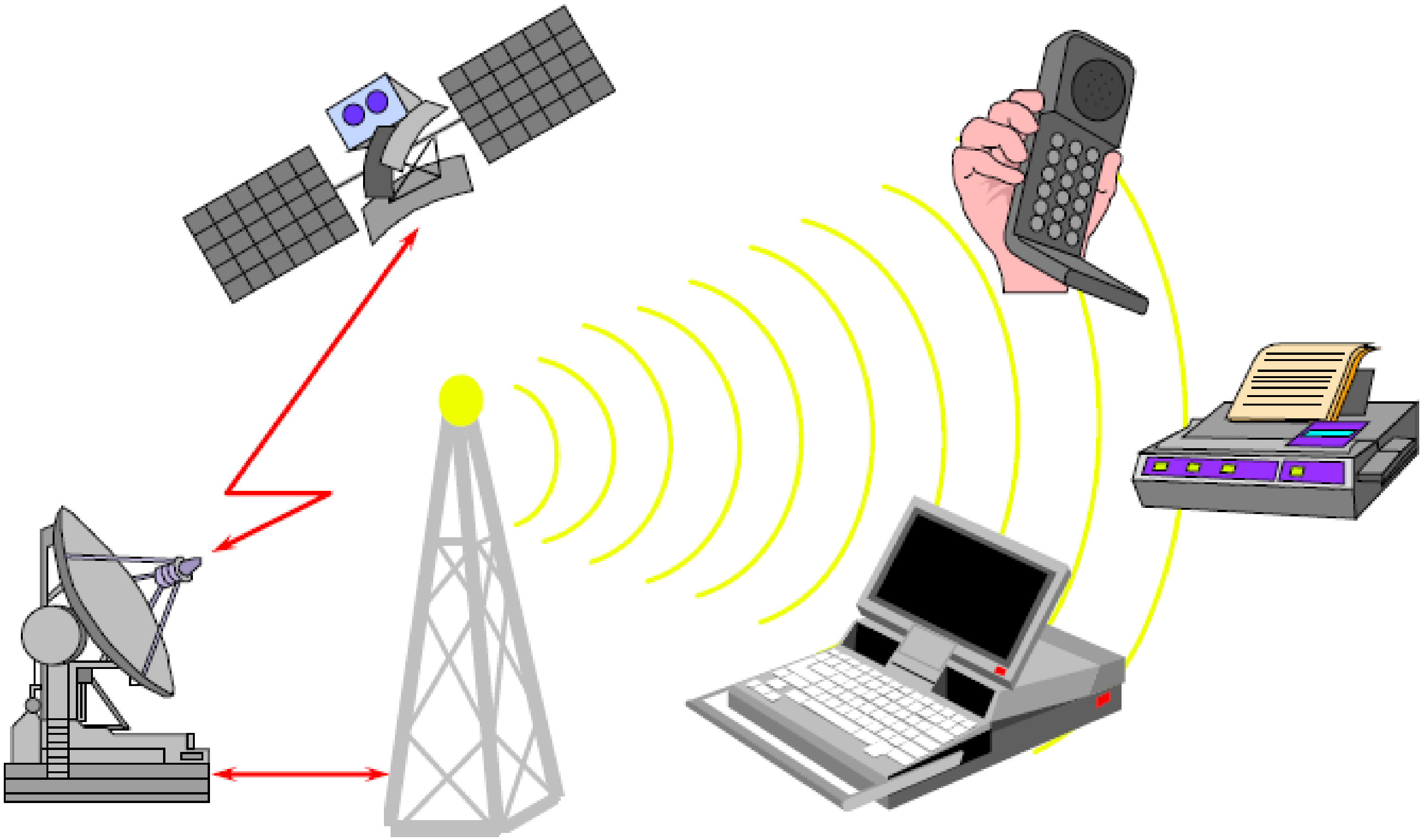
Robotics and Machinery

Logistics & Communication

- Applications of embedded/cyber-physical system technology to logistics:
  - Radio frequency identification (RFID) technology provides easy identification of each and every object, worldwide.
  - Mobile communication allows unprecedented interaction.
  - The need of meeting real-time constraints and scheduling are linking embedded systems and logistics.
  - The same is true of energy minimization issues

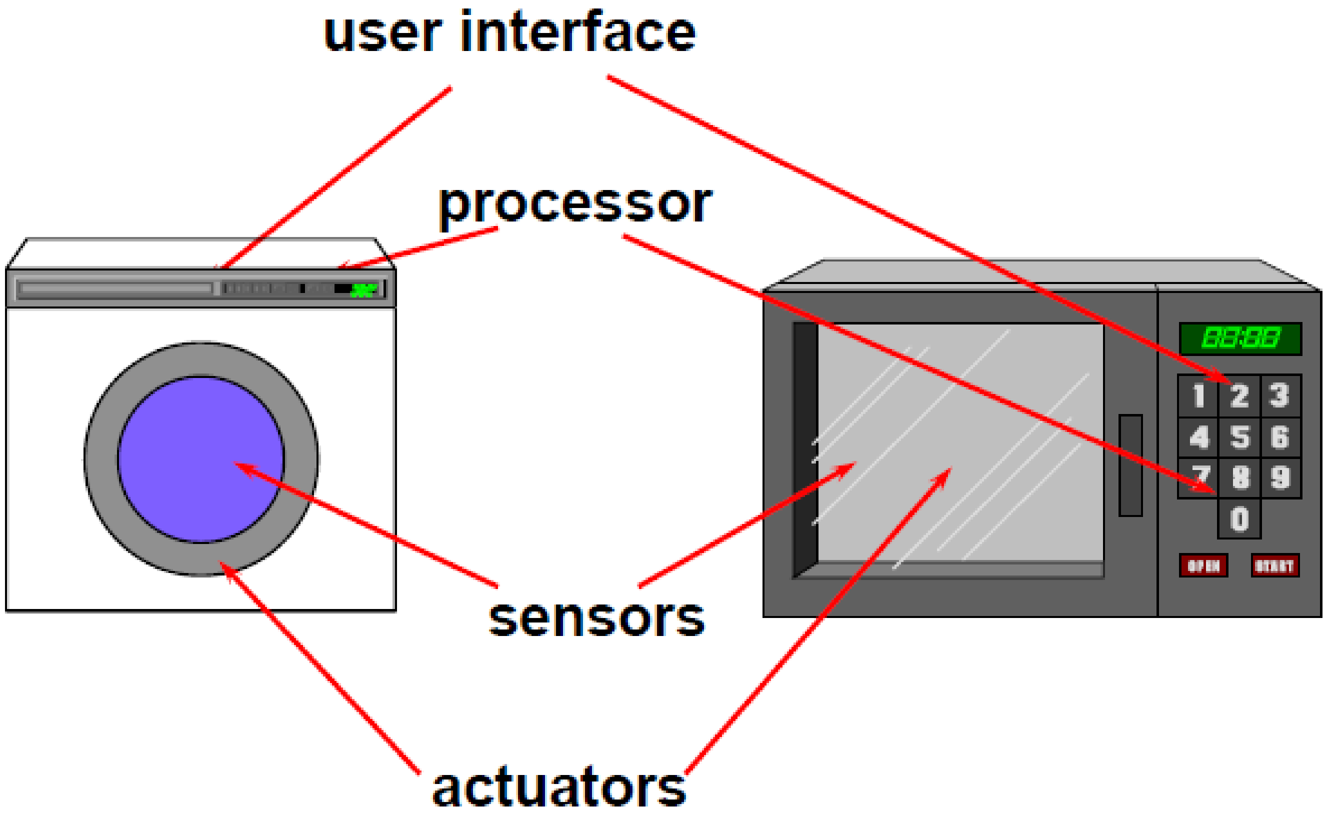
Communication

Information systems, for example wireless communication (mobile phone, Wireless LAN, …), end-user equipment, router, …



Home Appliances

Consumer electronics, for example MP3 Audio, digital camera, home electronics, … .



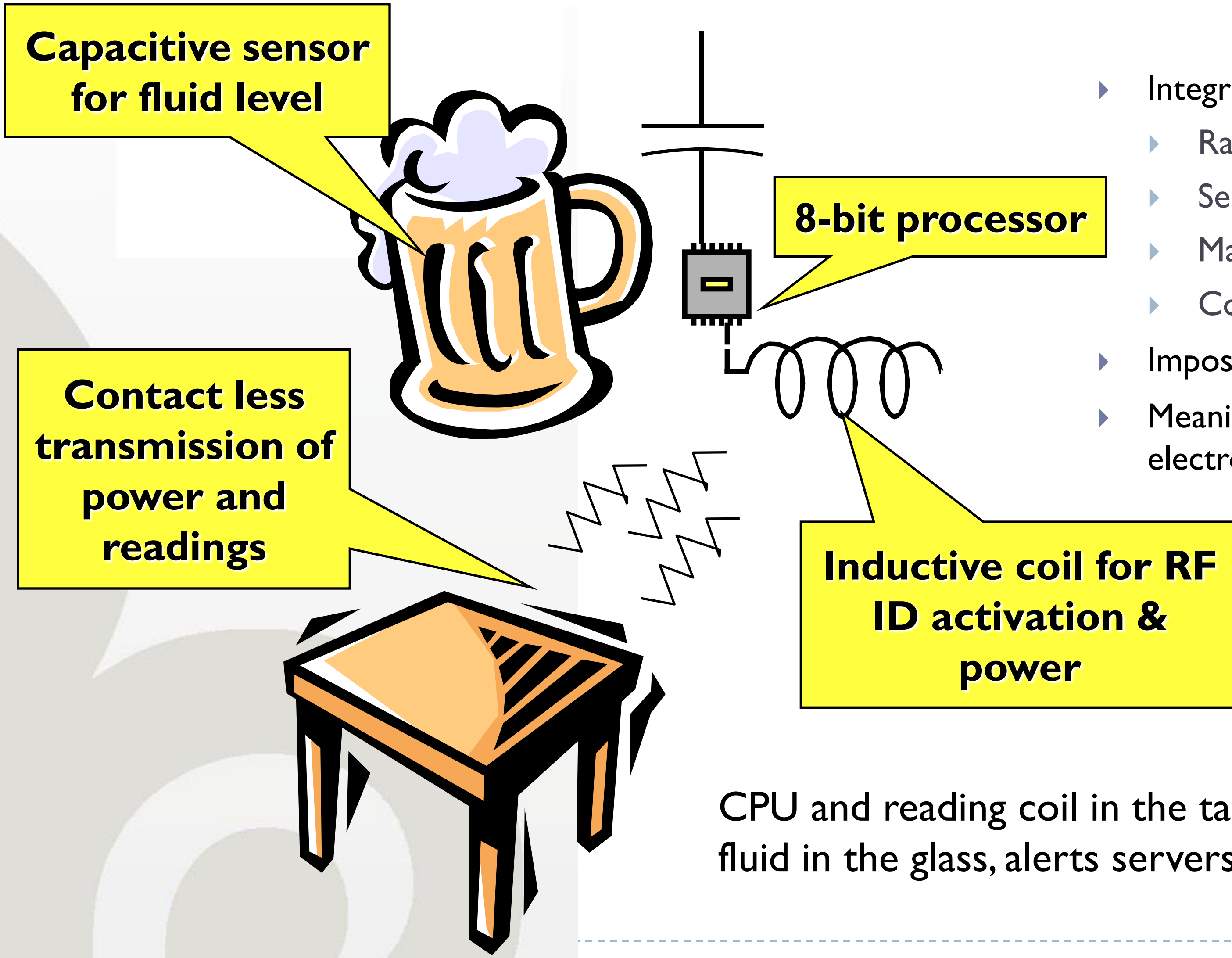
Embedded products are found in:

- Robotics
- Industry
- Automotive
- Aerospace
- Medical systems
- Mobile systems
- Communication
- Networking
- Household products (dishwasher, etc)
- Media products – broadcasting
- Cameras
- ---- in other words, everythere ----

Practical Embedded Systems

- Aerospace
  - Flight control
  - Navigation
  - Pilot interface
- Automotive
  - Airbag deployment
  - Antilock braking
  - Fuel injection
- Household
  - Microwave oven
  - Rice cooker
  - Washing machine
- Industrial
  - Crane
  - Paper machine
  - Welding robot
- Multimedia
  - Console game
  - Home theater
  - Simulator
- Medical
  - Intensive care monitor
  - Magnetic resonance imaging
  - Remote surgery

Smart Beer Glass

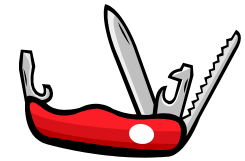


- Integrates several technologies:
  - Radio transmissions
  - Sensor technology
  - Magnetic inductance for power
  - Computer used for calibration
- Impossible without the computer
- Meaningless without the electronics

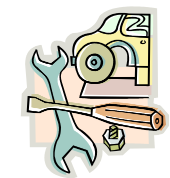
CPU and reading coil in the table. Reports the level of fluid in the glass, alerts servers when close to empty

Common characteristics

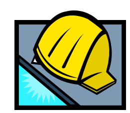
Dependability



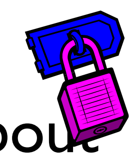
- CPS/ES must be **dependable (reliable)**,
  - **Reliability *R(t)* =** probability of system working correctly provided that is was working at t=0



  - **Maintainability *M(d)* =** probability of system working correctly d time units after error occurred.
  - **Availability $A(t)$**: probability of system working at time t
  - **Safety**: no harm to be caused



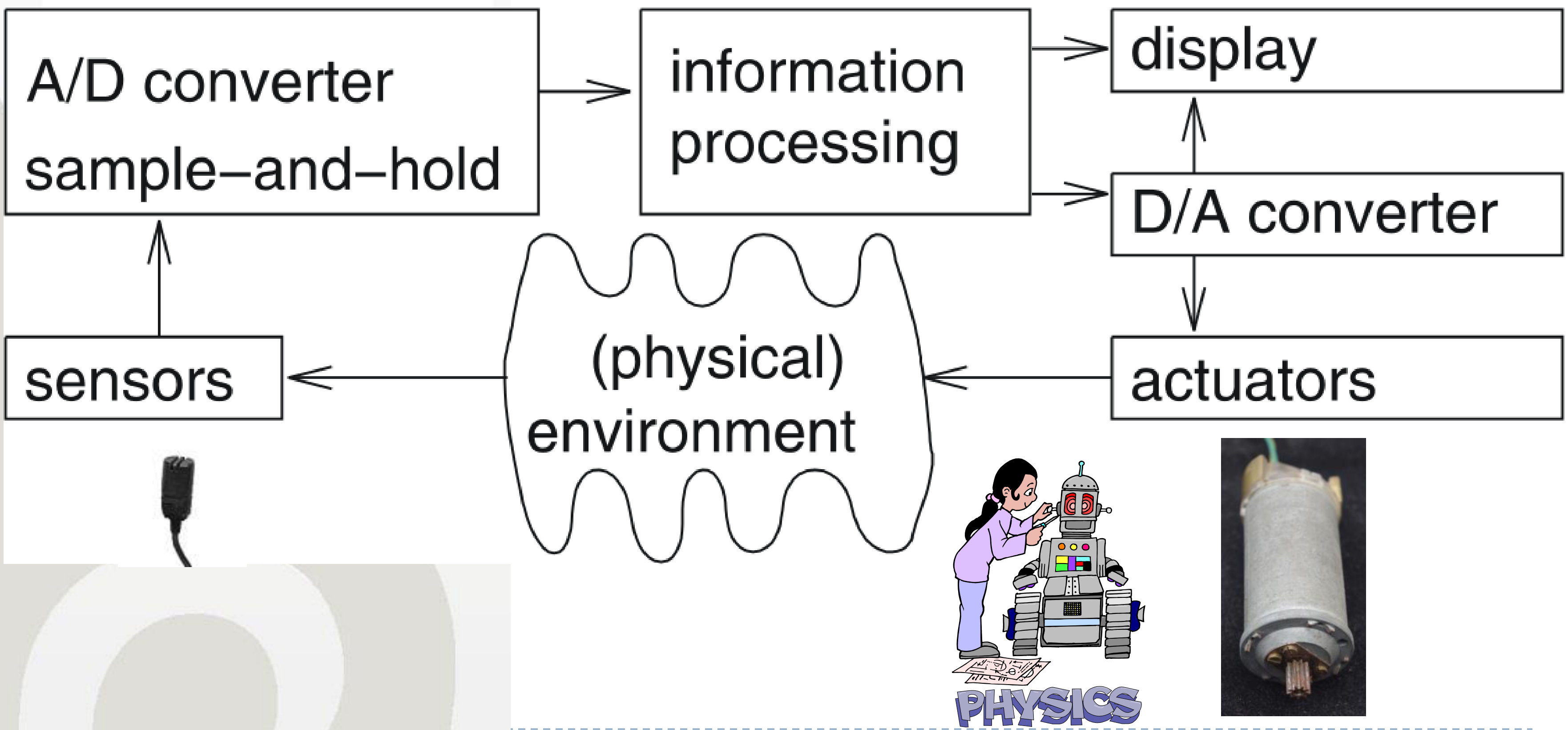
  - **Security**: confidential and authentic communication



Even perfectly designed systems can fail if the assumptions about the workload and possible errors turn out to be wrong.
Making the system dependable must not be an after-thought, it must be considered from the very beginning

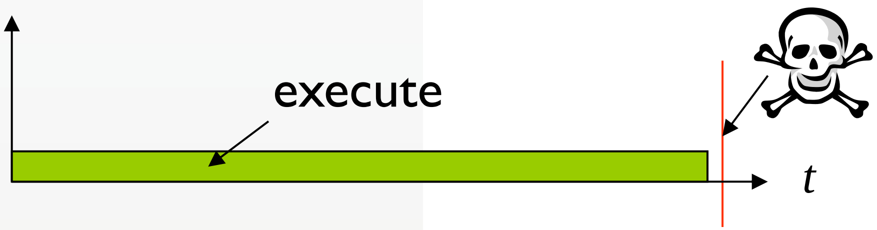
ES Hardware

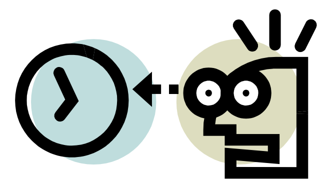
- ES hardware is frequently used in a loop (“***hardware in a loop***“):



Real-time constraints

- CPS must meet **real-time constraints**
  - A real-time system must react to stimuli from the controlled object (or the operator) within the time interval **dictated** by the environment.



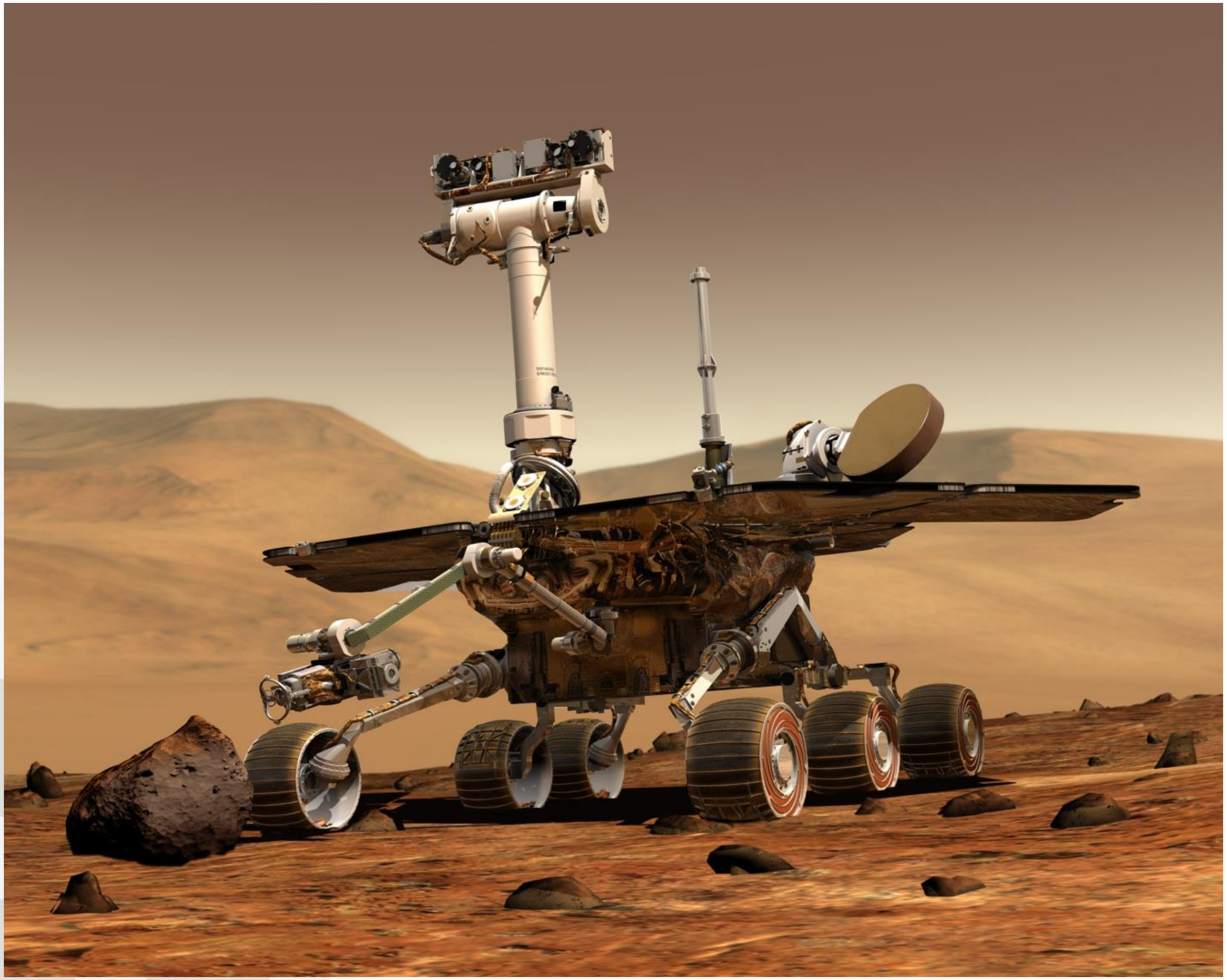


- **“A real-time constraint is called hard, if not meeting that constraint could result in a catastrophe“**
- All other time-constraints are called **soft**.
- A guaranteed system response has to be explained without statistical arguments

Real-Time Systems & CPS

- CPS, ES and Real-Time Systems synonymous?
  - For some embedded systems, real-time behavior is less important (smart phones)
  - For CPS, real-time behavior is essential, hence RTS $\cong$ CPS
  - CPS models also include a model of the physical system

Mars Exploration Rover of NASA



Mission Aims

There is 4 main aims of the mission:

- Clarify whether there was life on Mars
- Acquire detailed Mars climate data
- Acquire detailed Mars geological data
- Prepare human landing to Mars

Curiosity Mars Rover

Dimensions

- Length 2,9 m
- Height - 2,2 m with elevated camera
- Width - 2,7 m
- Wheel diameter is about 51 cm
- Weight – 174 kg

Power Supply

- nuclear battery (thermoelectric generator)

Instruments

Mast Camera (MastCam)

Chemistry and Camera complex (ChemCam)

Rover Environmental Monitoring Station (REMS)

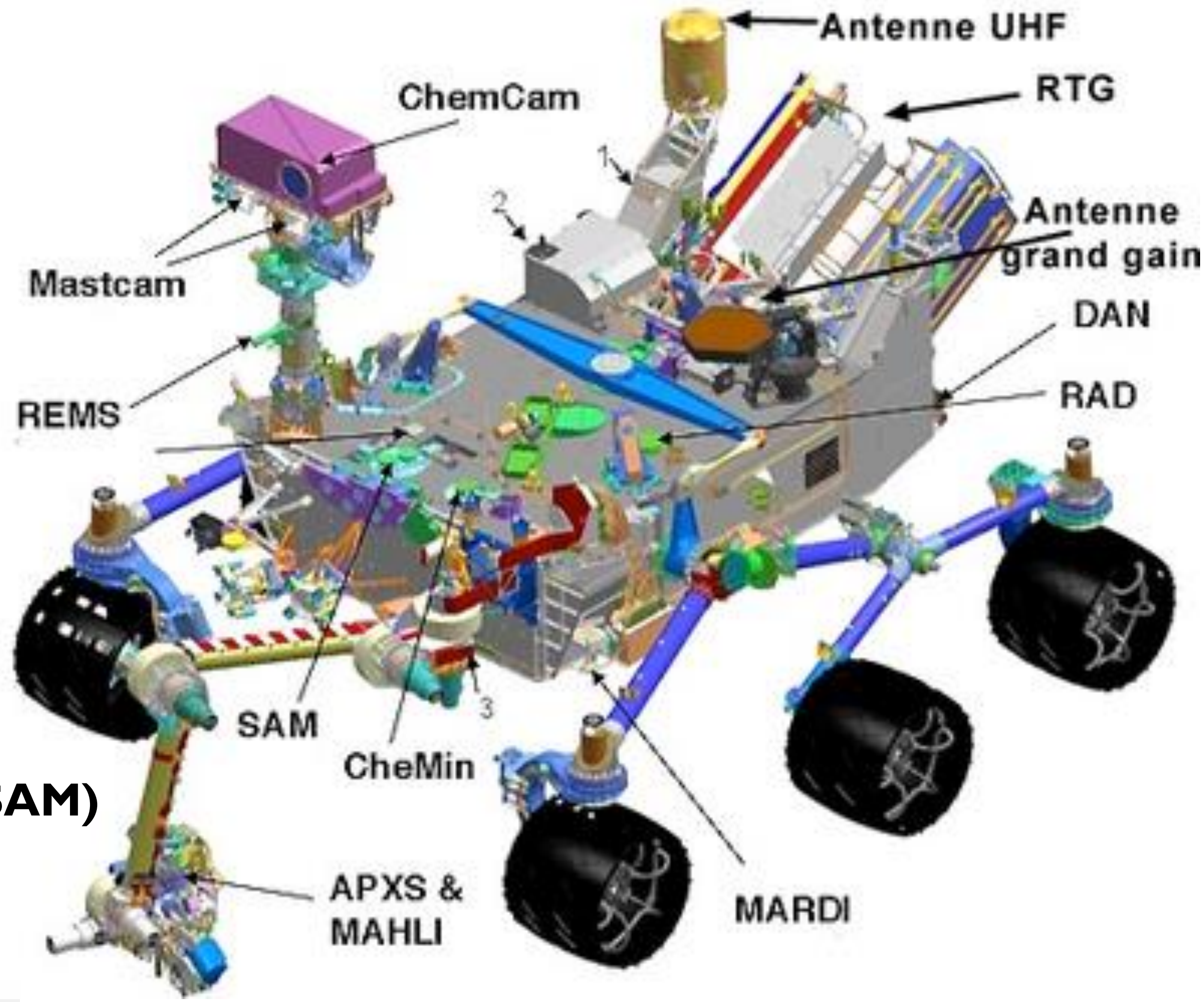
Mars Hand Lens Imager (MAHLI)

Alpha Particle X-ray Spectrometer (APXS)

Sample analysis at Mars (SAM)

Mars Descent Imager (MARDI)

Navigation cameras (navcams)

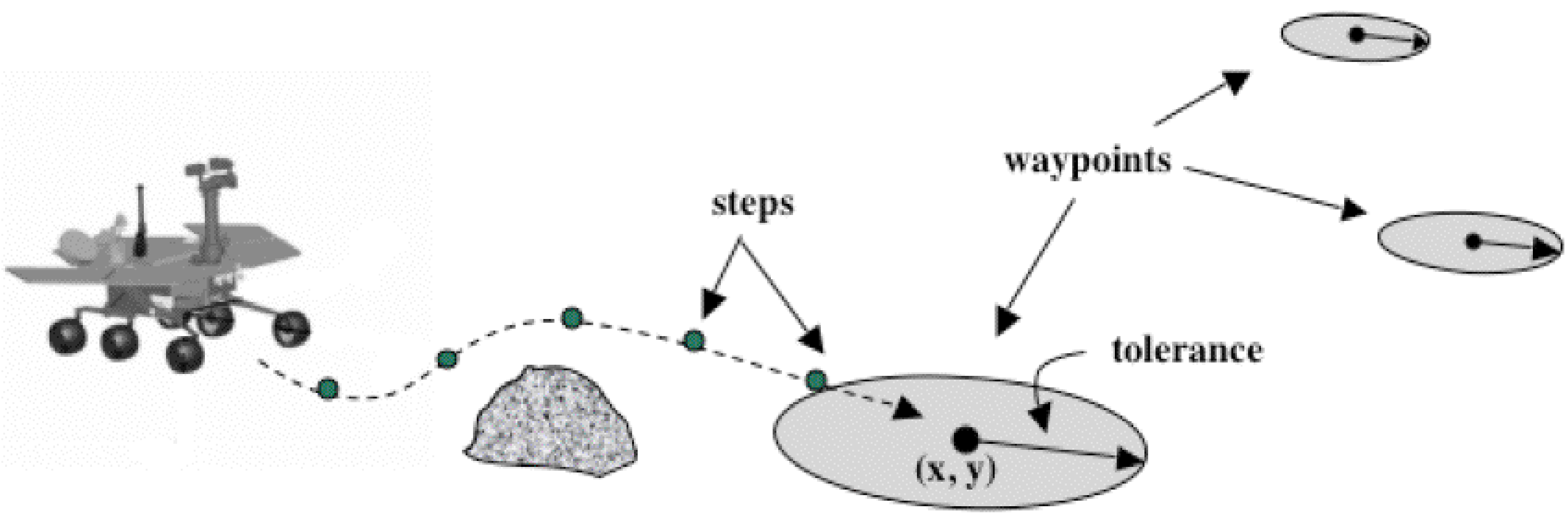


Dynamic Albedo of Neutrons (DAN)

Radiation assessment detector (RAD)

Navigation Subsystem

- The Mars atmosphere prevent using ultrasonic sensors with high precision
- Autonomous navigation system was based on stereo vision system
- Maximum speed is restricted due to limited performance of the onboard computer



High Level Control

- ❑ rover daily action program consists of a sequence of high level commands:
- ❑ Move on 2.3 m forward
- ❑ Turn to 0.5 rad to right on a spot
- ❑ Move to point (X,Y)
- ❑ Take a color photo in the location X,Y,Z

Movement Control

❖ Movement control system has three levels:

➢ Low level commands;

➢ Arc movement with given parameters;

➢ Autonomous movement to target location.

❖ Low level commands allow direct control of wheel rotation and turning.

❖ Used for system testing and direct remote control in nonstandard operation

Arc Movement

- Arc movement is the base movement for all other types of movements
- Direct movement and turn on a spot are special cases of arc movement
- Path to target points is constructed from arc segments for obstacle avoidance
- Present location of the robot is estimated using an inertial navigation system including 3-D accelerometers, gyroscopes, wheel encoders.

Onboard Software

- Commercial real-time operating system VxWorks.
- This is a preemptive multitasking system widely used in aerospace, defense, industry and other areas
- 9 Mb of memory out of which 1.4 Mb is the movement control module


Mars
Science
Laboratory

Any Questions?