Distributed embedded systems

- characteristics, examples, trends and challenges

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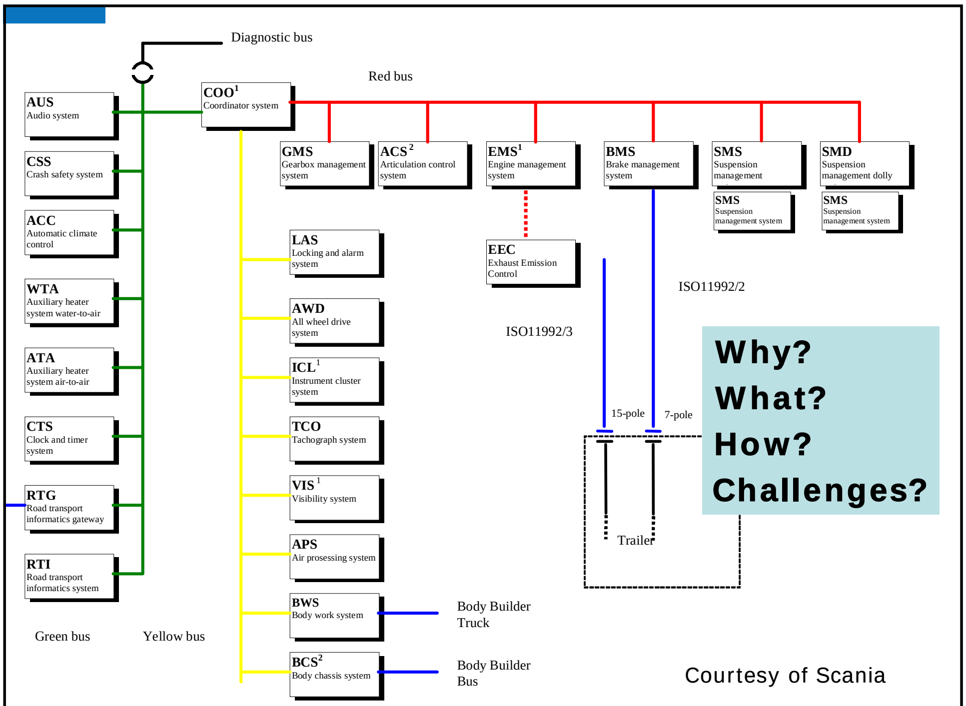
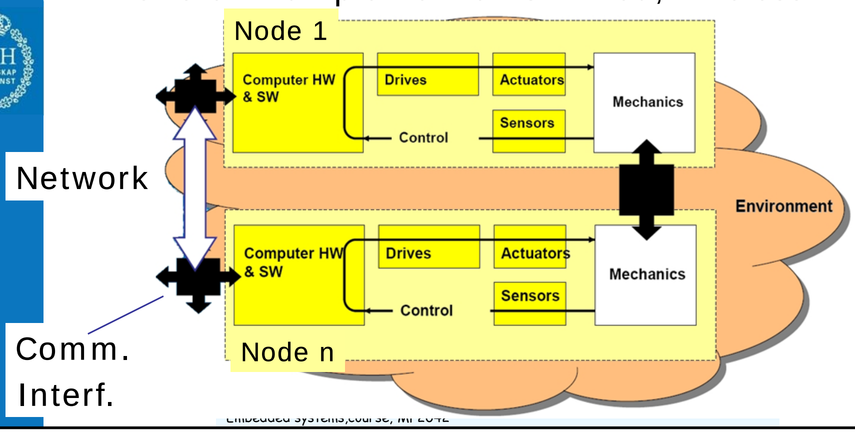
Outline

- Recap – why, what and how of distributed systems
  - Characteristics, Advantages, Problems
- Design issues for distributed embedded systems
  - Systems and application examples
  - Trends and research



What Is A Distributed System?

- A set of nodes connected by the network, cooperating to achieve a common goal
  - Node: a μC + I/O + communication interface
  - One or multiple networks: wired, wireless



Analogy

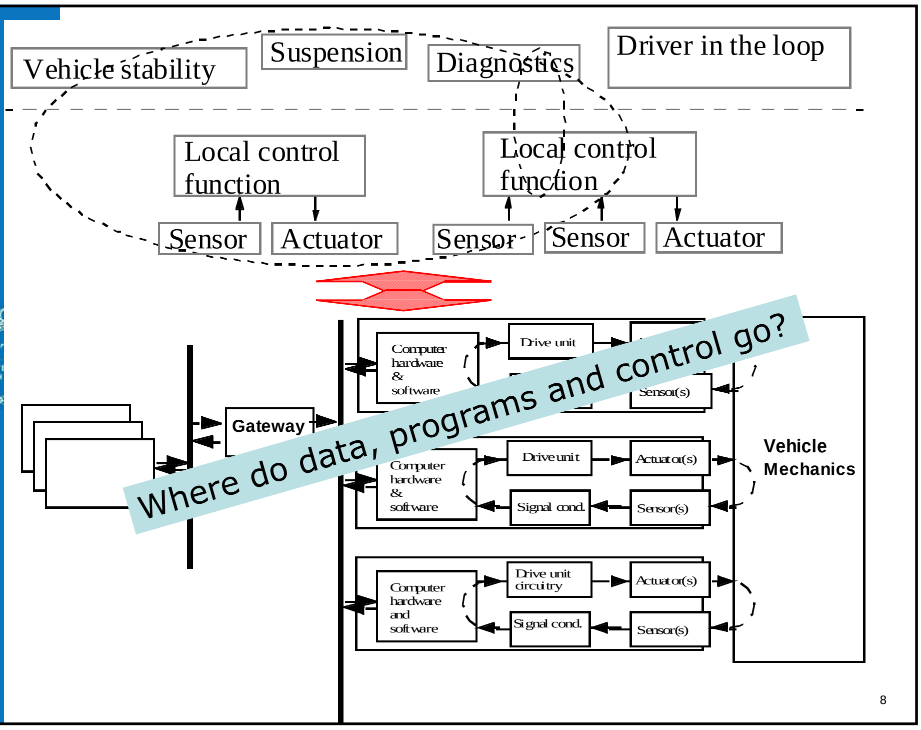
- Setup phase:
  - Communication model/pattern
  - Physical level; logical level; reliability
  - Broadcast vs. Point-to-point mode
- Design and implementation
  - Functions ~ the phrases
    - Allocated to hardware elements – ”nodes”
  - Timing and global clock
  - Access to the same com. network/scheduling
  - Application control logic - centralized

Communication models

OSI model oriented	RT model
General purpose	Dedicated
Little apriori knowledge	Often static
Point to point logical connection	Multicast
Sender & receiver addressing	Source addressing
Positive ack retransmission	Datagram
E.g. TCP/IP!	E.g. CAN!

Views of distributed systems

- Software allocation and roles of nodes
- Application program view
- Driver view
- Logical topology
- Physical layout
- Cables and wires
- Physical vs. Logical communication
  - Protocols



Application programmer view

```
msg[0]=0;
...
msg[6]=0;
msg[7]=50;

CANSendMsg( 0, 0x0cfe6cee, msg, 8, 0 );
delay_ms(1000);
dip204_clear_display();
...
```

Application program interface

Layered structure
- abstraction!

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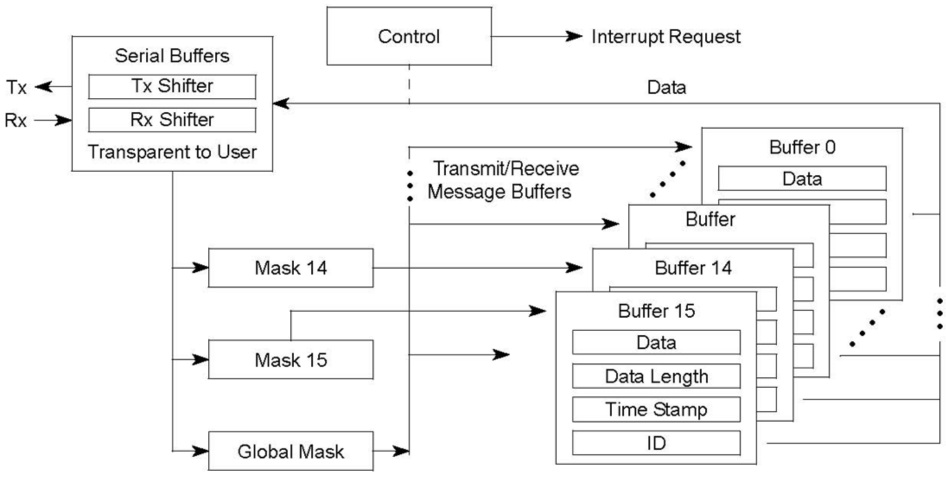
Driver view illustrated through Coldfire CAN



Courtesy of Freescale

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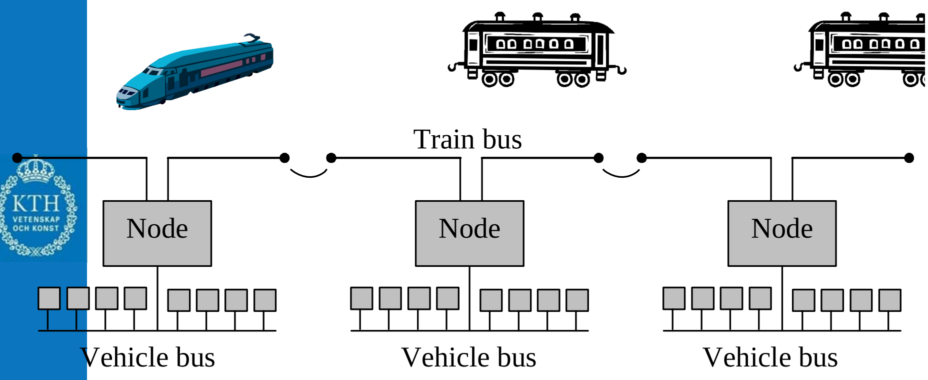
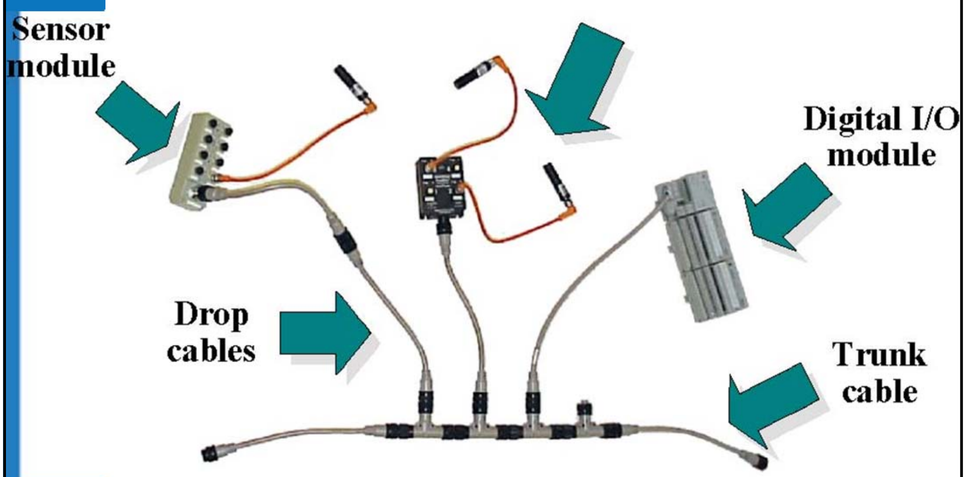
Logical hardware topology: trains



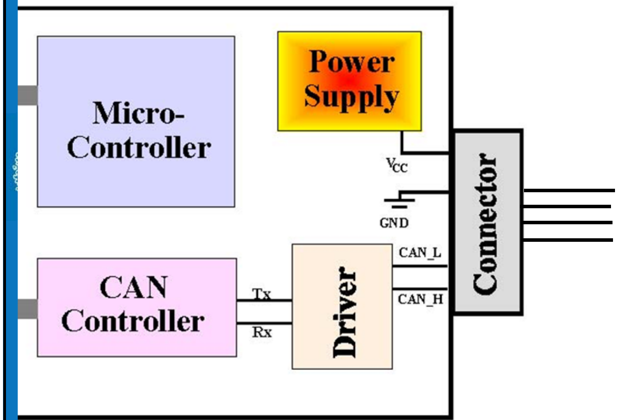
Courtesy of Bombardier

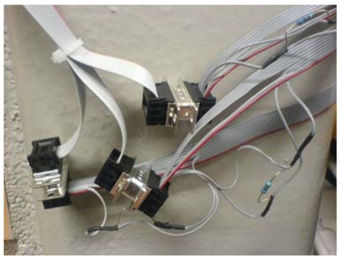
Physical layout



Courtesy of Kvaser

Signal and cabling view





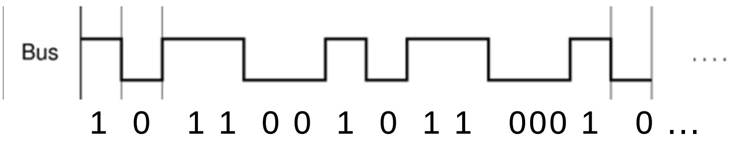
Data transmission over CAN:

Application, datalink and physical level views

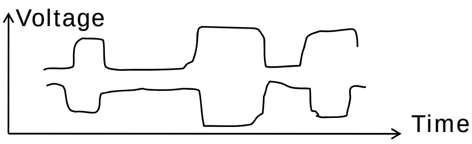
CANSendMsg(0, 0x0cfe6cee, msg, 8, 0);

And levels inbetween!

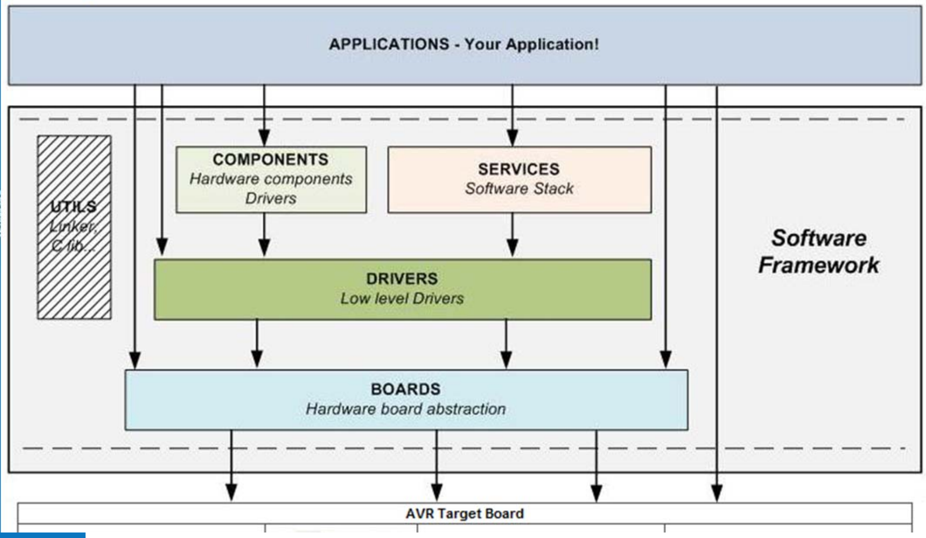
- Driver software



Diff.
Transmission
(Rs422)



Layering



Views of distributed systems

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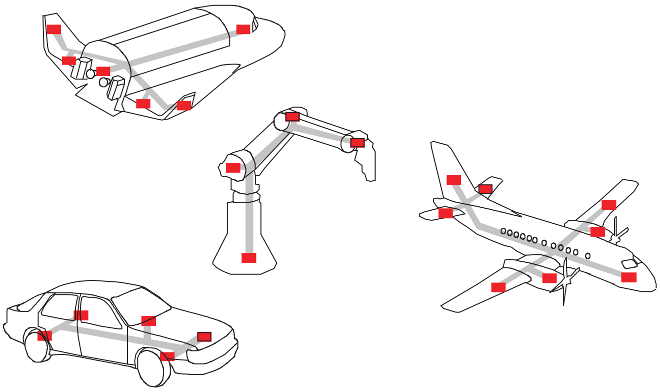
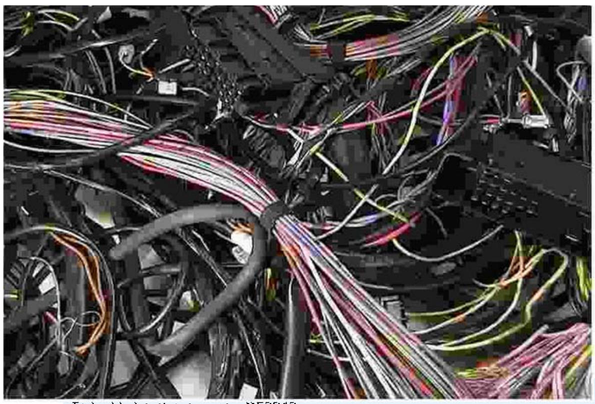
Why distributed systems?



Why not Analog Cabling?

- Traditional method: a μC is connected to distributed sensors and actuators by dedicated analog cables
- An example: 1900 wires, 2.2km long

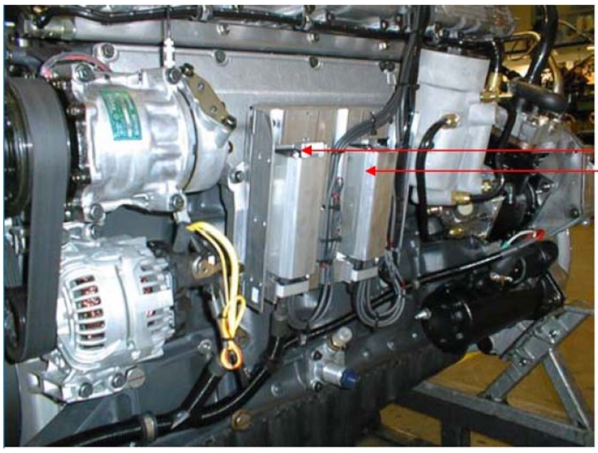


Reducing Cables with Network

- Digital signals – robustness against noise
  - Increase data integrity
- Reduce the cost of cables, connectors
- Increase system reliability (fewer connectors)
- Shared resources and information:
  - Sensors, actuators, computations, …
- Modularity
- Performance
- Local intelligence

A Mechatronic Module

- Scania diesel engine and controller



ECU connectors on top of the ECU

Interfaces:
- Mechanical Connections
- CAN

Many advantages!!! What are the problems???

- (partial) failures
- Delays
- Consistency
- Organizational challenges
- How to deal with distributed functions?
- How to verify?

Distributed systems – failure modes

Nodes

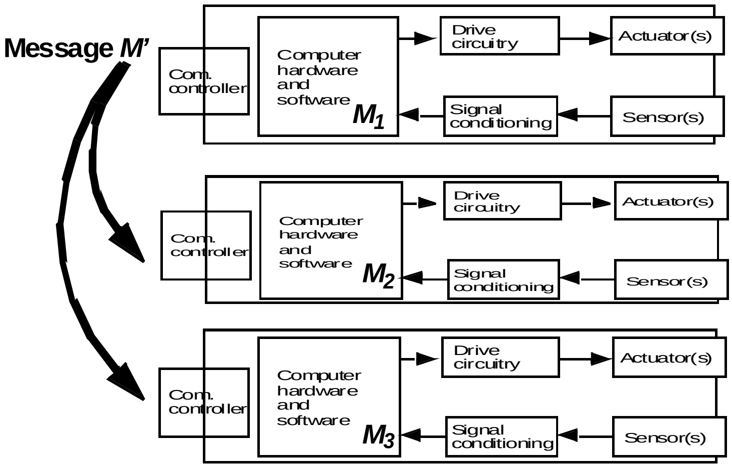
- Omission
  - Fail-silent
  - Signalled failure
- Value
  - Wrong data sent
- Timing
  - E.g. too early, too late
- Interference
  - "Babbling idiot"
- Commission
  - Unintended message

Network

- Omission
  - Transient or permanent
  - Permanent failure – special case: Network becomes partitioned!
- Value
  - Alteration of value
- Timing
  - Network failure causes delay/different delays
- Interference
- Commission

Attributes: Duration, Detectability, Symmetry

Distributed state variables, {M1, M2, M3} => the system state; is it consistent?



When is the state required to be consistent?
Consistency in the precense of faults?
Trade-offs --> compare voice vs. file transfer!

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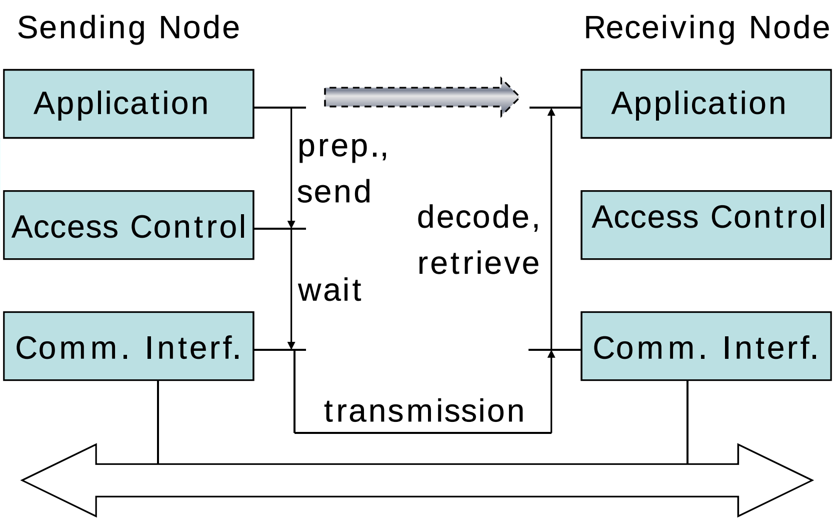
Time delays in distributed systems



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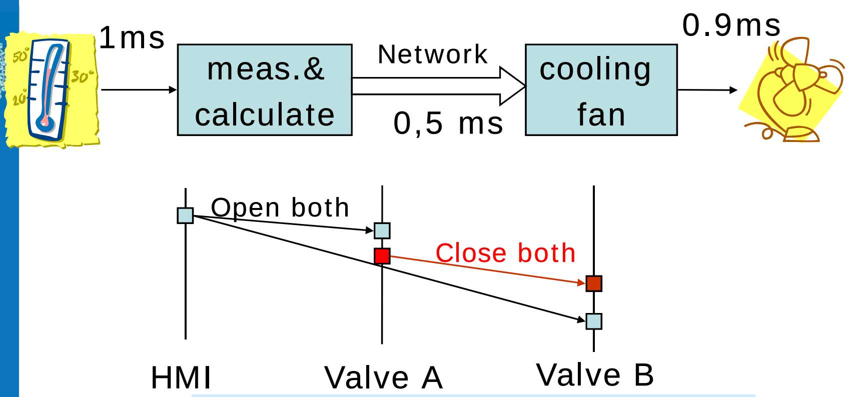
Delays and event ordering

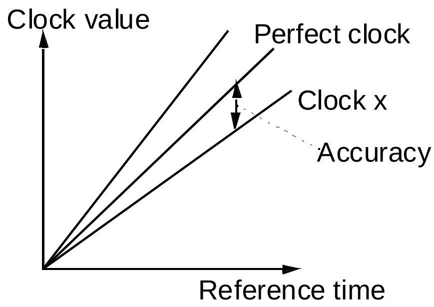
- Incorrect event order possible



Clock synchronization

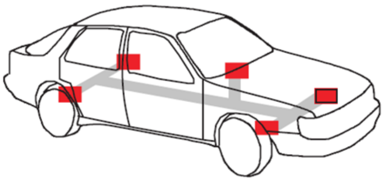
Local unsynchronized clocks:
- Granularity
- Drift rate, e.g. 10^{-7}s/s
- Clock drift rate ~ temp. & voltage applied to the crystal resonator

Free running clocks will drift apart



Clock synchronization
-Establishing an approximate global time within a system
-Internal clock synchronization -> precision of the global clock
→ Master/slave vs. distributed clock synchronization
- Synchronization to an external time reference

Why are there so many types of networks, technologies and protocols??

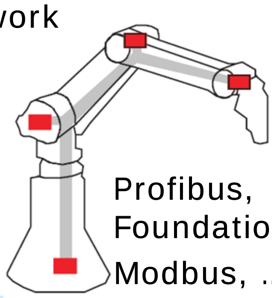


Controller area network

CanOpen, Volcano, J1939, …

LIN, Most, Flexray

Train Communication Network



Ethernet, TCP/IP

MIL1553B

Profibus, Foundation Fieldbus, Modbus, …

Wireless, short range

Cellular

BACnet, Lonworks

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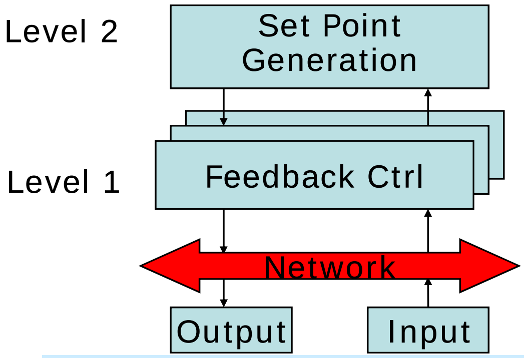
Design issues

- Centralized or distributed system?
- Which type of distributed system?
  - Logical topology and physical layout
  - Decentralization of data, programs & control
  - Which communication protocol
- How to design and dimension them?
  - The importance of the system architecture!
    ➔ Cost vs. Reliability vs. Performance vs. ...
  - Delays, synchronization and failures
  - Verification?
  - Who does what?

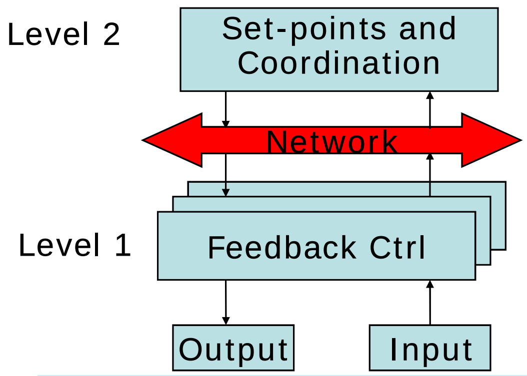
Distributed I/O

- Common in process control
- Additional time-delay in control loop
- Care has to be taken to synchronize sensor inputs and multiple outputs

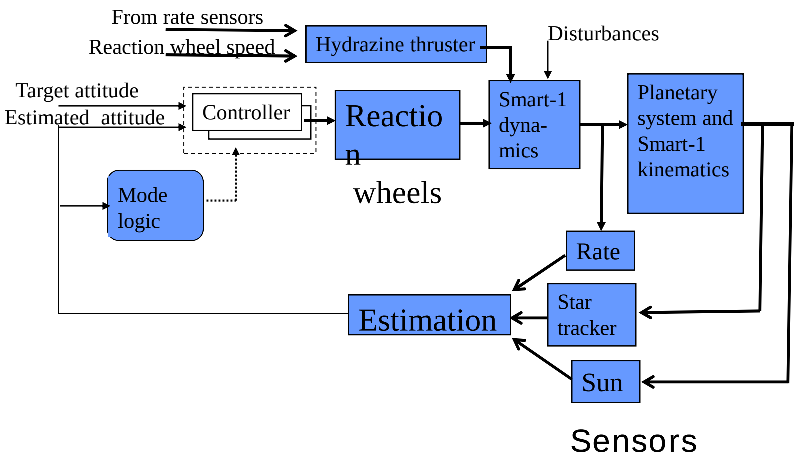


Decentralized local control

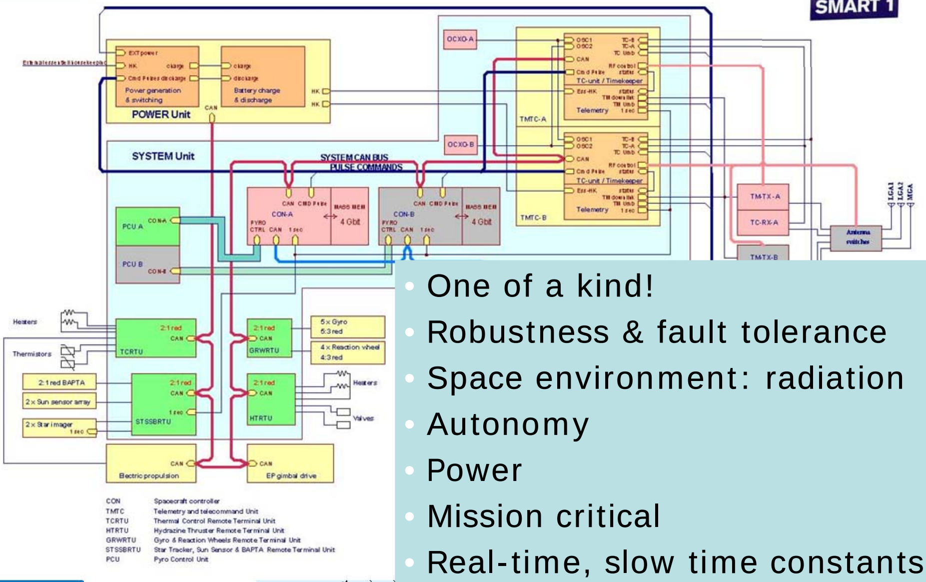
- Common in machine control and automotive
- Need for synchronization of level 1 loops with coordinator



Attitude control system in the science mode of operation



Smart-1 block diagram



- One of a kind!
- Robustness & fault tolerance
- Space environment: radiation
- Autonomy
- Power
- Mission critical
- Real-time, slow time constants

Main on-board computer

TCS695E single chip ERC32 processor, 20 MHz clock

EEPROM 2 Mbyte EDAC protected

SRAM 3 Mbytes EDAC protected, needs SW scrubbing cycle < 1 minute,

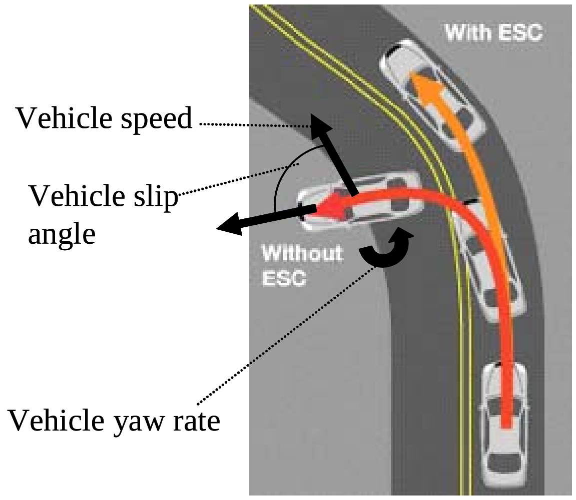
MassMemory 512 Mbyte, EDAC protected, HW scrubbing

CAN controllers, 2 kBytes FIFO in reception path
→ Purchased VHDL code; radiation tolerant FPGA

Watchdog, 2 s timeout, can be disabled per pulse telecommand

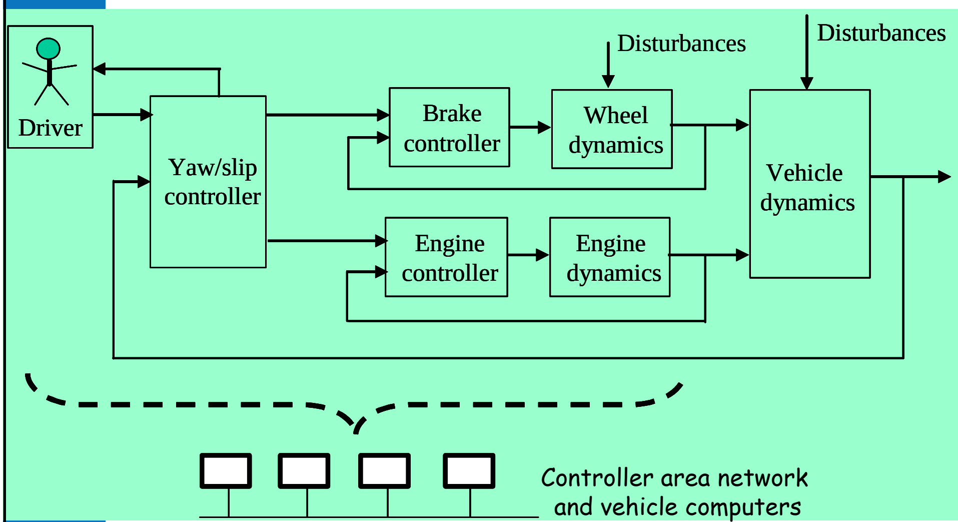
JTAG I/F for EEPROM software upload and board HW checkout

Example application: stability control

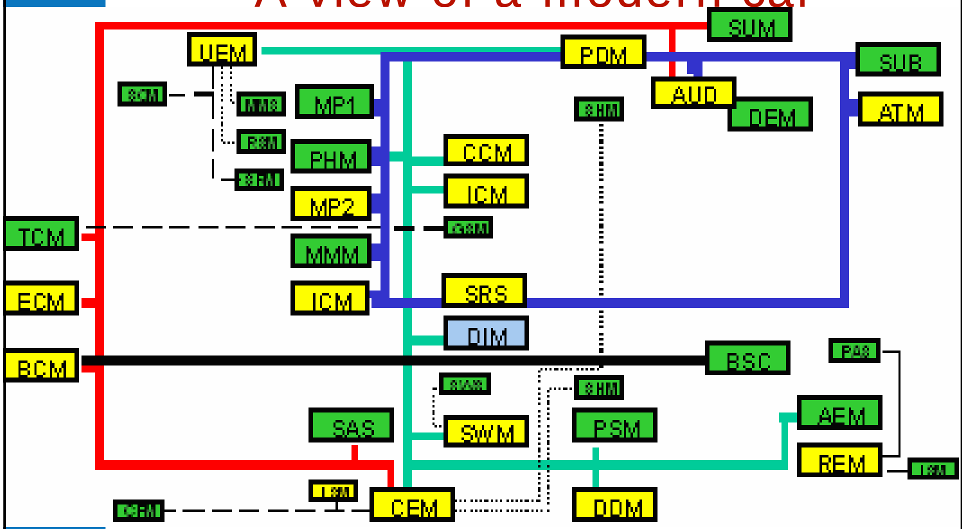


Source: ESC education - www.esceducation.org

Example application: vehicle stability control



A view of a modern car



Which nodes are involved in vehicle stability control?

Distributed systems perspective

- 70's – Distributed control in process automation
- 80's – Avionics
- 90's – Automotive
- External connectivity and wireless

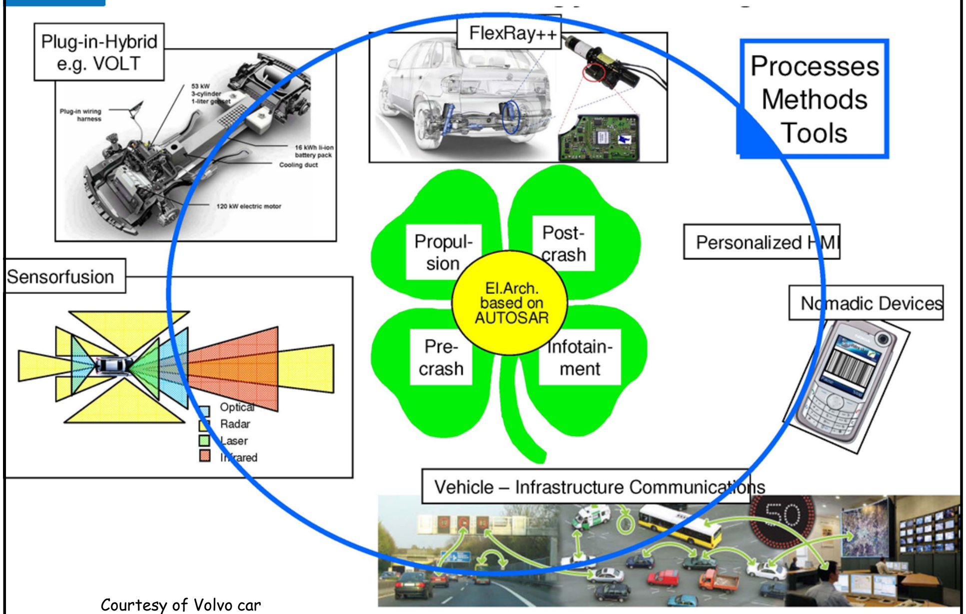
Telecom; cellular telephony

Computer communication; Internet; TCP/IP, wireless

Short range wireless communication; Bluetooth, Zigbee, ...

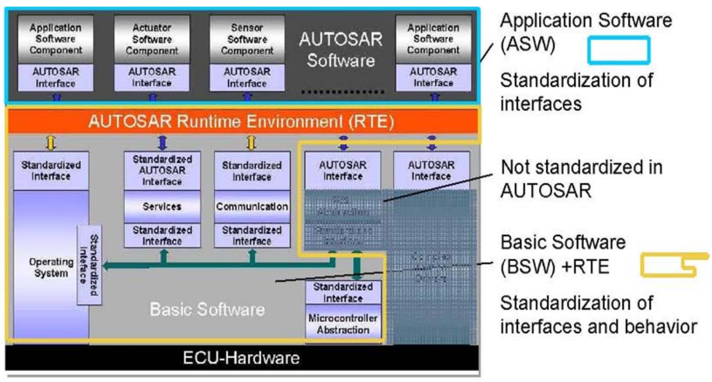
Trends

- Connectivity
- New (distributed) functions
- Convergence
- Standardized platforms
  - Middleware – for example Autosar
  - Protocols
- Product lines and model-based development
  - Reuse of SW and HW components
- Evolving electronics; multicore



Courtesy of Volvo car

Autosar – Automotive SW architecture

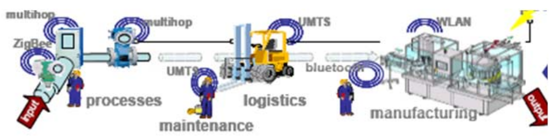


Autosar also defines information exchange

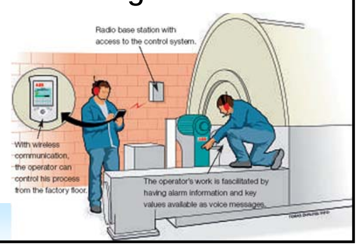
Objectives: Basic SW: Decoupling of Hardware and Application Software
Application SW: Relocation / Reuse of SW-Components between ECUs

Benefits of wireless networking in industrial control

- Cost (wiring and installation)

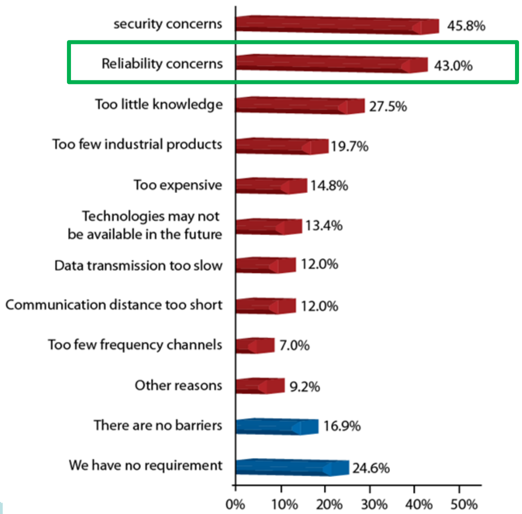


- Flexibility
  - Less physical design limitations
  - More mobile equipment
  - Faster commissioning and reconfiguration
- Reliability
  - No cable wear and tear
  - No connector failure



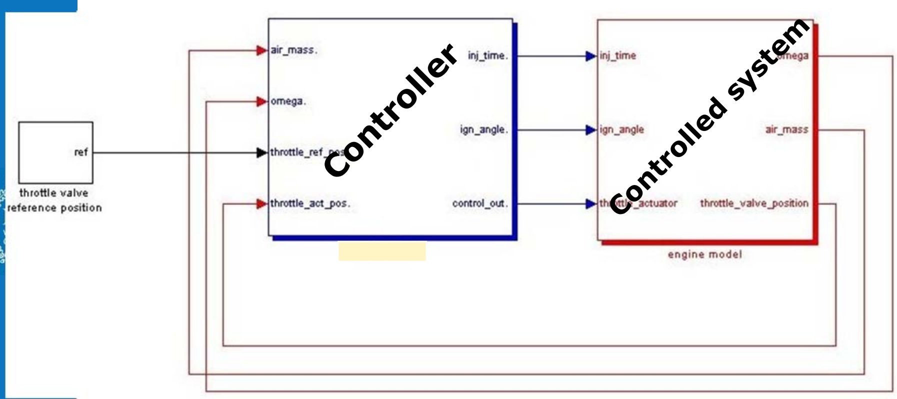
Courtesy of Karl-Henrik Johansson

Barriers against wireless networking in industrial control

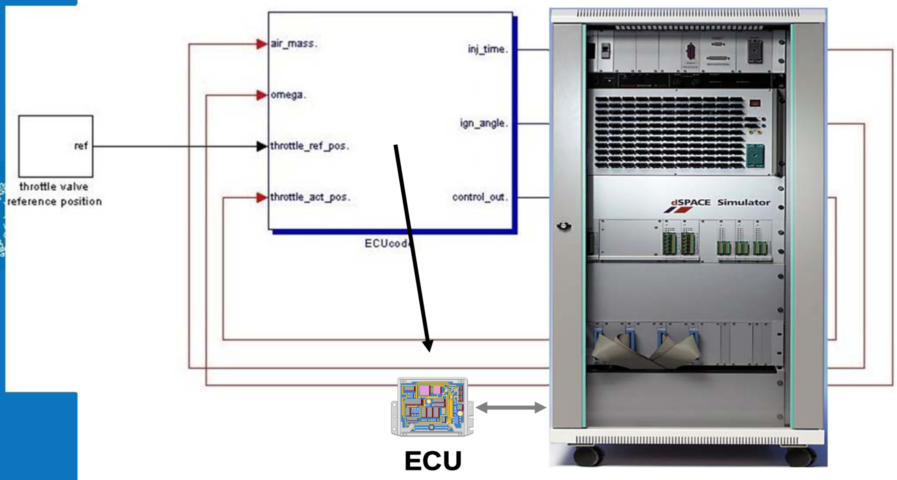


”Market pulse: Wireless in industrial systems: cautious enthusiasm”, Industrial Embedded Systems, Winter 2006

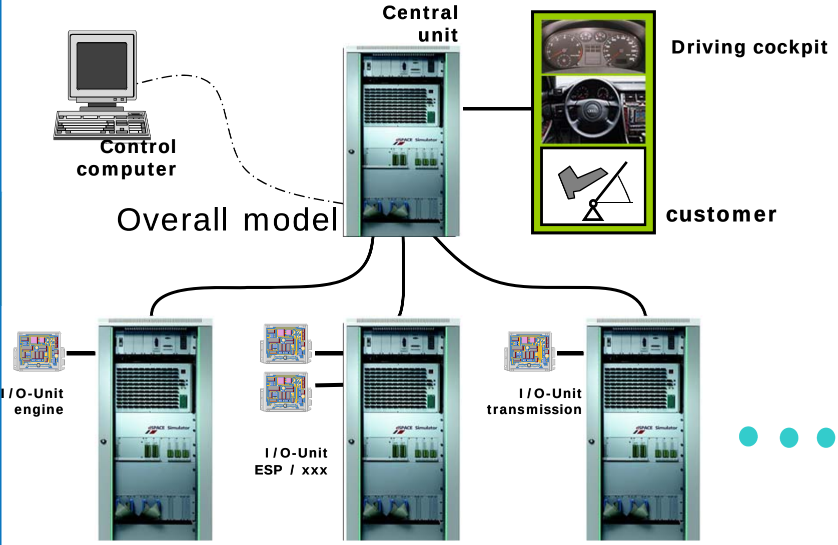
Prototyping and different hardware



Hardware in the loop simulation



Concept – for a network test



I/O - program

Summary

- Why, what & how of distributed systems
  - Remember the exercise!

- Design issues for distributed embedded systems
  - Architecture and verification
    - Dealing with complexity
  - Trends:
    - Increasing connectivity and convergence
    - Standardization