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A. Automotive Systems

Automobiles are one large application area for fault tolerant, advanced embedded systems

In the following, we want to look at:

- Application areas
- Technological and market reasons
- Fault tolerance requirements and designs

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Advanced embedded systems used in cars:

- Trip computer (fuel cons.,etc.)
- Electronic ignition
- Airbag
- Immobilizer, keyless entry
- ABS
- ESP
- ...
- *All networked (CAN bus) !*

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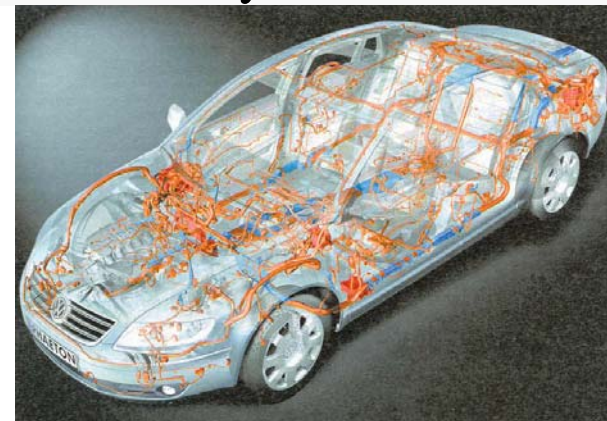
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2002: Opel Vectra has over 40 sensors (25 types)

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2003 VW Phaeton: 3.9km cables weighing 64kg
 2003 Mercedes S-Class: 3.0km cables weighing 39 kg

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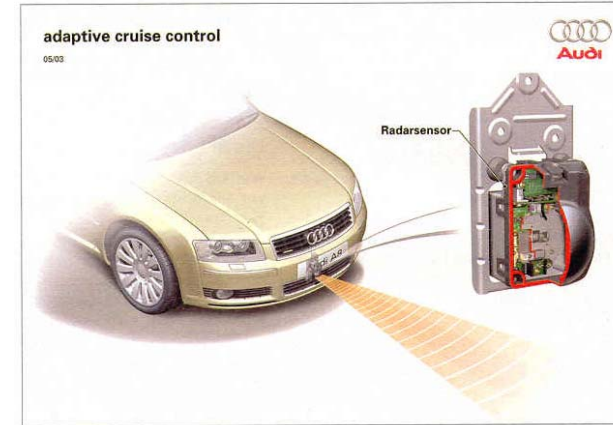
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Distrionic: 2001 only for Mercedes-Benz, BMW, Jaguar
Bräunl 2004 2003 many other car manufacturers

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Statistics (source: Philips/c't, 14/2003)

Cost of car electronics relative to total price:

in 2003: 8% on average (30-40% for top class)

until 2010: 20-40%

BMW 7series (2001) has 80 embedded controllers
on board

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Reliability

- Breakdown statistics for Germany, 2001
- 10-40 breakdowns per year for 1000 vehicles (1-4%) (range depending on manufacturer!)
- About **50%** of all breakdowns are due to electronics faults

• *So why put even more electronics in cars?*

• **Reliability ≠ Safety**

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Reasons for having electronics in cars

1. Safety
2. Economy
3. Comfort

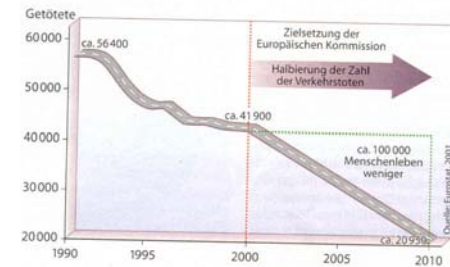
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1. Safety

- Statistics: 42,000 people died in road accidents in Europe in the year 2000
- EU wants to reduce road fatalities by half until 2010



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2. Economy

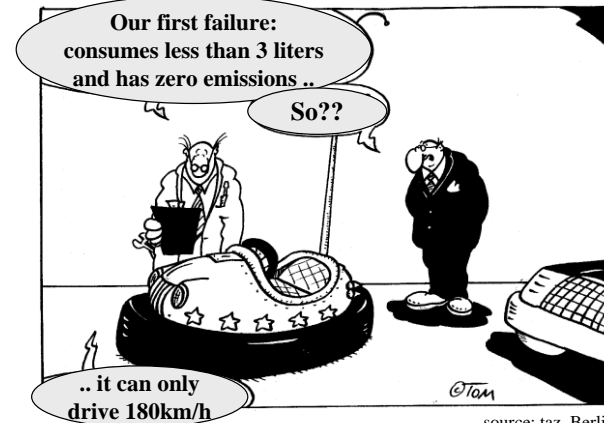
- New emission laws coming up, e.g. California
- Production cars use as low as 3 liter fuel per 100km
 - 1999: Volkswagen Lupo Diesel 2.99 l / 100 km, powered by 1.2 Liter Turbo-Diesel (TDI) motor with 45 KW, weight-reduced chassis
- How to further reduce fuel consumption?
 - hydrogen engine
 - improvements on petrol/diesel engines
 - improvements on chassis

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The three liter car



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How to further reduce fuel consumption?

- Better aerodynamics
1982: **Audi** 100 [3rd generation], drag coefficient $c_w = 0.3$
- Aluminium body (weight reduction)
1993: **Audi** introduces full aluminium body at IAA Frankfurt
100kg less weight reduces fuel consumption by 0.3–0.5 l / 100km
- Continuously variable transmission
2000: **Audi** introduces step-less gearbox, more efficient
- Electrical valves (weight reduction)
- Advanced engine control unit (embedded system, software)



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Audi multitronic, 2000



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3. Comfort

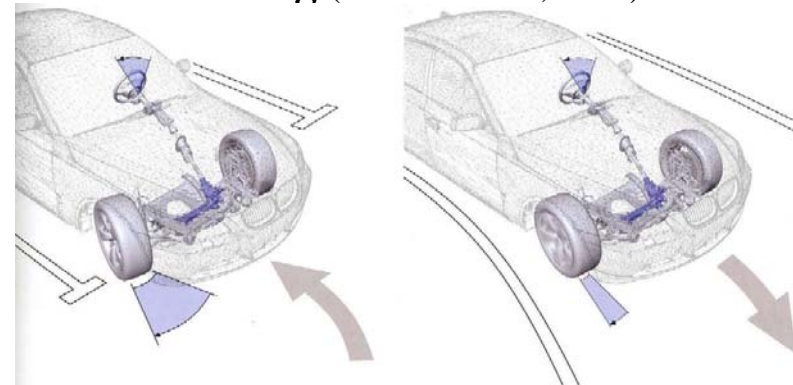
- Cars with advanced electronics features are more attractive to customers
- 90% of real innovations happen in electronics (BMW 2003)
- 35% of added value for high-end models is in electronics (BMW 2003)
- Example: “Distronic” 2001 (radar-based active cruise control) originally by Mercedes-Benz, BMW, Jaguar
- Example: BMW 5series 2003
 - active steering
 - head-up display
 - active curve light
 - active suspension



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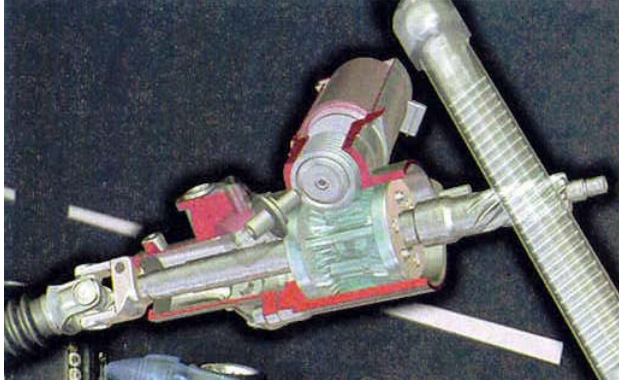
Active Steering (BMW 5series, 2003)



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Active Steering (BMW 5series, 2003)



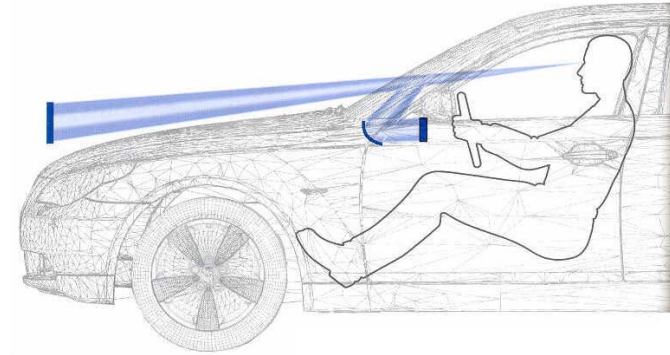
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Head-Up Display (BMW 5series, 2003)



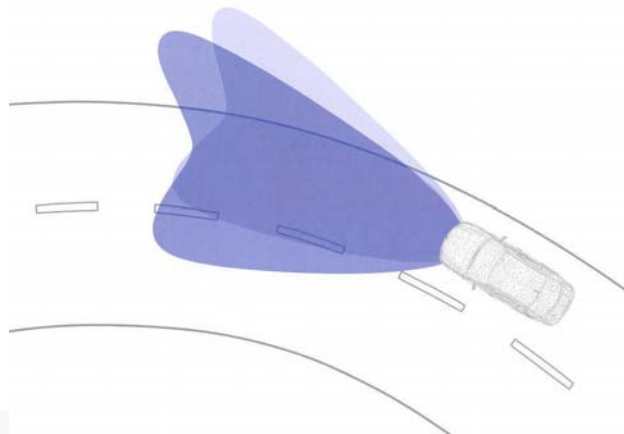
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Curve Light (BMW 5series, 2003)



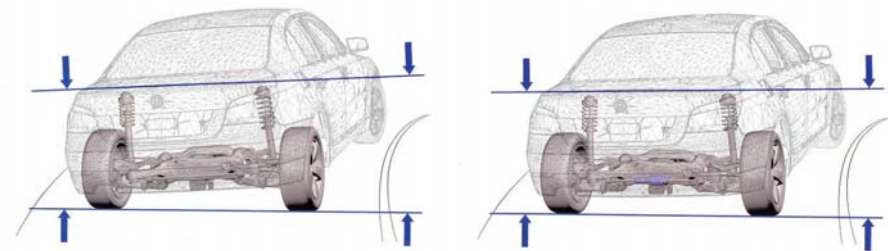
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Active Suspension (BMW 5series, 2003)



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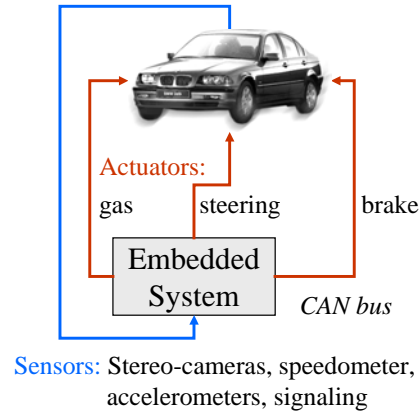
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The Future: Autonomous Cars

- Electronic gas
- Electronic brake
- Electronic steering



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Fault tolerance

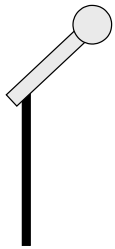
- Controllers must be fault tolerant
cannot tell driver to “reboot”, i.e. switch engine off/on
→ danger of “PC feeling”
- Fail-Safe principle (here: fail silent)
e.g. ABS must not suddenly brake hard
- Car x-by-wire systems often have hydraulic or mechanical fall-backs. These will disappear over time (currently required by law).
- DIN study for steer-by-wire, 1994/1995 (see diagram)
hardest remaining problem, gas- and brake-by-wire in use

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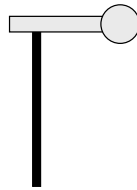
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Fail-Safe

- Example: train signal



go!



stop! *or power failure in signal!*

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Redundancy

- **Train:** double redundancy
if two controllers have different result: stop the train
- **Car steering:** triple redundancy
steering must remain working, e.g. majority vote out of 3

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Brake-by-wire

- Currently uses electric/hydraulic hybrid system (legal requirement)
- Fault tolerance:
 - Traditional hydraulic brake
 - ABS/ESP electrical brake
 - Parking brake
 - Gear shift down
- Pure brake-by-wire requires
 - Fault tolerant in-car power supply
 - Change from 12V to 42V power supply ($P = I \cdot U$, more power, less current, thinner cables)

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Why Drive-by-wire ?

- Reduce weight
- Improve car handling (change steering in steep curves to keep car on road, similar to ESP)
- More flexible car design since no steering column
- Fully autonomous driving
- Some issues can already be achieved by BMW's active steering, incl. "wake-up rattle" for driver using "lane departure warner"

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Fault Tolerance for Drive-by-wire

- Triple redundancy in steering wheel angle sensor
- Triple redundancy for steering controller
- Double redundancy for steering motor (actuator)
- Double redundancy in steering wheel and steering column torque sensor
- No redundancy (single motor) for steering wheel force-feedback
- Double redundancy for force-feedback controller
- Double redundant power supply plus additional battery
- Double redundant driver warning system for system failure

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Steer-by-wire

