Multicore on Wheels
Craig Stephens
A Brief History of Automotive Controls
Emissions Requirements

[Diagram showing NOx (g/mi) vs. NMHC (g/mi) for different years: 1968, 1970, 1973, 1977, 1980, 1994, 2004]
Emissions Requirements

NOx - NMOG/NMHC

SULEV30 (PZEV)
Stage V/VI (Petrol)
T2B4
T2B5
ULEV II

0 20 40 60 80 100 120
NMOG/NMHC (mg/mi)

0 20 40 60 80 100 120
NOx (mg/mi)

Stage V/VI (Petrol)

1970
1968

1973
1977
1980
2004

0 1 2 3 4 5 6
NMHC (g/mi)
Fuel Economy Requirements

US MPG Regulatory Landscape

Average Annual CO₂ Improvement Required by Global Regulations (2015-2020)

<table>
<thead>
<tr>
<th>Country</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>4.7%</td>
</tr>
<tr>
<td>CAN</td>
<td>4.7%</td>
</tr>
<tr>
<td>EU</td>
<td>5.1%</td>
</tr>
<tr>
<td>Brazil</td>
<td>3.4%</td>
</tr>
<tr>
<td>China</td>
<td>5.5%</td>
</tr>
</tbody>
</table>
Impact of Increasing Gears on Shift Complexity
Impact of Increasing Gears on Shift Complexity

Shift and Apply Element Complexity by Transmission Gear Number
Impact of Increasing Gears on Memory

Automatic Transmission Code/CAL Growth

ROM (BYTES)

0 200000 400000 600000 800000 1000000 1200000

- Code
- Cal

Fuel Economy & CO₂

Processor Calculations

4 speed 6 speed 10 speed
<table>
<thead>
<tr>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Park Assist</td>
</tr>
<tr>
<td>Adaptive Cruise Control</td>
</tr>
<tr>
<td>Active City Stop</td>
</tr>
<tr>
<td>Pedestrian Detection</td>
</tr>
</tbody>
</table>

**Driver Assistance and Active Safety**
Transition to Autonomous Driving

**Top-Down Workstream**
- Building on more than a decade of experience of research into Autonomous vehicles create a state-of-the-art Autonomous Driving platform.
- Full Autonomy emerges along with non-traditional business models based on Mobility solutions.
- Advance alternate approaches to semi-autonomous features.
- Driver may be taken out of the loop.

**Bottom-Up Workstream**
- Increasingly capable semi-autonomous operation driven by Active Safety regulations and revenue opportunities for Driver Assistance technologies.
- Enhancing sensors, algorithms and actuator technology to create new, increasingly-capable automated driving features.
- Driver remains in the loop.
- Capability may plateau over time.
Sensing the Surroundings

GPS

IMU
Vehicles comprise a small segment within the Internet of Things, but are an extremely impactful one now and in the future.
Evolution of Automotive Control

Current State

Traditional Automotive Control
- Domain specific controls (PT, Chassis, EE, etc)
- PID and look-up tables.
- Driver in the loop.
- Functional organisation specific business models.

Drivers for Change
- Emissions and Fuel Economy
- Driver Assistance and Active Safety
- Autonomous Vehicles
- Connectivity
- Substantial increase in system interactions & complexity.
- Progress in AI methods & tools

Future State

Advanced Automotive Control:
- New computational platforms
- Driver increasingly out of the loop
- Smart use of MPC, adaptive, & optimal control
- Expanding control incl. AI & robotic tools & techniques
- Increasing role of preview & cloud based control,
- Cyber-security, & Functional Safety
- Flexible functional and S/W architectures
- Upgradable control S/W

Drivers for Change
- Emissions and Fuel Economy
- Driver Assistance and Active Safety
- Autonomous Vehicles
- Connectivity
- Substantial increase in system interactions & complexity.
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Foundation
Implications
Component Delivered Value to Systems and Systems of Systems

- Single ECUs
- Systems
- Complex, Networked Systems

EXAMPLE: FRONT LIGHTING

Simple Lights (1995)

Adaptive Front Lighting (2005)

Glare Free High Beam System (2015)
Complexity

Today's In-Vehicle Networked Control System

Automotive Embedded Software Lines of Code

Notes: Numbers of Lines of Code represent a single specific vehicle-series variant configuration...

Vehicle Control Signal Interaction

Source: Ford R&A Vehicle and Battery Controls
TRENDS...On Board Value is Shifting

<table>
<thead>
<tr>
<th>Year</th>
<th>Value Contribution</th>
<th>Mechanics</th>
<th>Electronics</th>
<th>Software</th>
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<tbody>
<tr>
<td>1995</td>
<td></td>
<td>22%</td>
<td>76%</td>
<td>2%</td>
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<tr>
<td>2005</td>
<td></td>
<td>10%</td>
<td>61%</td>
<td>29%</td>
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<tr>
<td>2015</td>
<td></td>
<td>18%</td>
<td>50%</td>
<td>32%</td>
</tr>
</tbody>
</table>

Lines of Code:
- 1995: 10K
- 2005: 10M
- 2015: >100M

Number of ECUs:
- 1995: 10
- 2005: 40
- 2015: 70

Value Contribution:
- Mechanics
- Electronics
- Software
MultiCore: The Logical Next Step
How Did we Approach MultiCore

Experimentation in Research and Advanced Engineering.

• Early Evaluation Boards.
• Build the SW environment.
• Simple experiments with partitioning.
• Working with Tier 1’s and MultiCore Manufacturers (progress and fast feedback)

What did we learn:

• Obvious physical partitioning is pretty easy.
• Control needs (cohesion and coupling) tend to work against each other and degrade the ability to gain the same advantage that MultiCore provided in the PC world.
• MultiCore was mature and stable – not so for the tools, processes and implementation.
• Choices had to be made on what SW can run on the different cores (especially true of initial MultiCore designs where core 2 did not have a checker core).
• Lessons learned on checker cores, memory performance influenced future hardware generations
Controls:
• Online adaptation and optimisation.
• Advanced control methods (MPC, AI/ML)

Automotive Technology Trends
• Ever increasing functionality.
• Ubiquitous data.
• Always connected.
• SW Updates.
• Functional Safety.
• Security & privacy.

Business
• New suppliers, new partners and new competitors.
• Consumer electronics.
Future Outlook

- MultiCore was a big step but the steps that are coming are much bigger.
- A revolution in automotive computing.
- Massive on-board and off-board computational resources.
- Heterogeneous on board computing platforms; MultiCore, GPU’s, FPGA’s, SoC’s.

The next steps need a lot more upfront work on process, tools and methods.