Presentation

TriCore: an Hybrid DSP/Microcontroller Approach with Applications to the Automotive Industry

Fabrice Azevedo

Introduction

- Architecture Evolution

- New Applications (Automotive)
  - •Regulations regarding reduced emissions
  - •Regulations regarding improved safety
  - •Consumer demand for personal conveniences
  - • ITS initiative

→

  - • Efficient Electric Cars
  - • Smarter Cars (navigation systems, voice activated controls)
  - • Safer Cars (Adaptive Cruise Control, Electronic brakes, Electronic Steering)
  - •Connected Cars (GPS, instant local weather and transit info, Internet)

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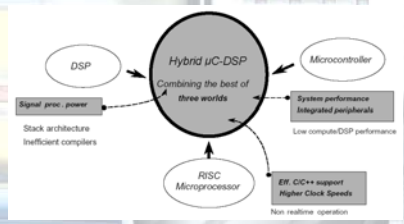
Introduction

- Convergence of Architectures
  - RISC
    - •HLL support, efficient compilers, high performance ↗
    - •No real-time capabilities ↘
  - DSP
    - •Number crunching capabilities ↗
    - •Poor interrupt response, inefficient compilers ↘
  - µC
    - •Multi-tasking, fast interrupt response, code efficiency ↗
    - •reduced DSP capabilities ↘



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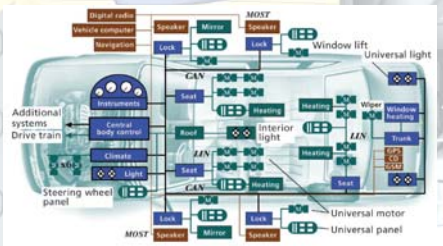
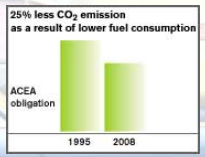
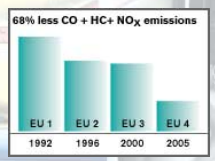
Introduction

- Engine Control Evolution
  - Enhanced Features



  - Environmental Constraints





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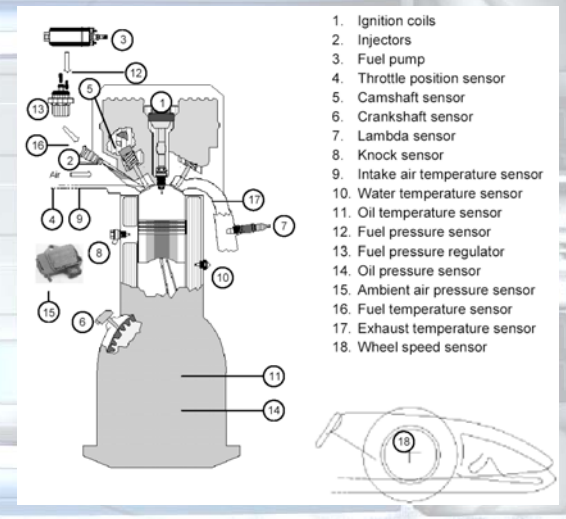
Engine Control

- Engine (SI) Overview



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Engine Control

- Engine Control
  - Sensors
    - •Rotational motion (camshaft and crankshaft)
    - •Pressure (manifold, turbo)
    - •Angular and linear position (transmission gear, pedal)
    - •Temperature (water cooling, ambient air)
    - •Others (mass air flow, exhaust gas, knock sensor, linear acceleration, fuel level)
  - Algorithm
    - •Static model, using lookup tables (lookup tables: input vs. output values relationship, obtained on a engine simulator for general engine operational modes)
    - •Dynamic model
  - Actuators
    - •Fuel injection (timing, quantity, mixture)
    - •Intake Air (temperature, density)
    - •Fuel ignition (spark timing)

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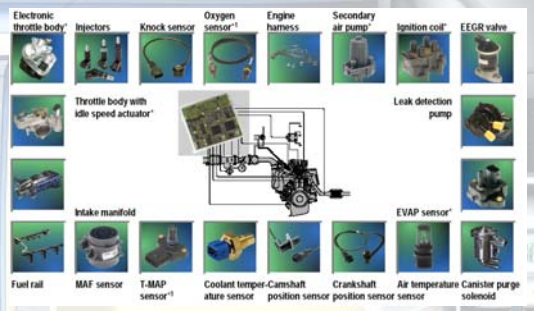
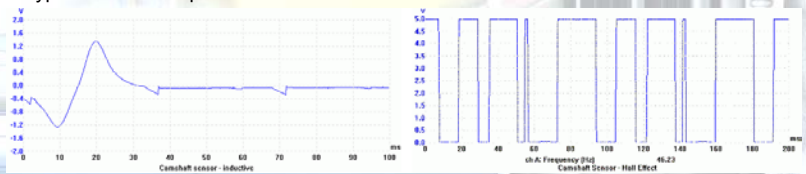
Engine Control

- Engine sensors/actuators



•Typical sensor output



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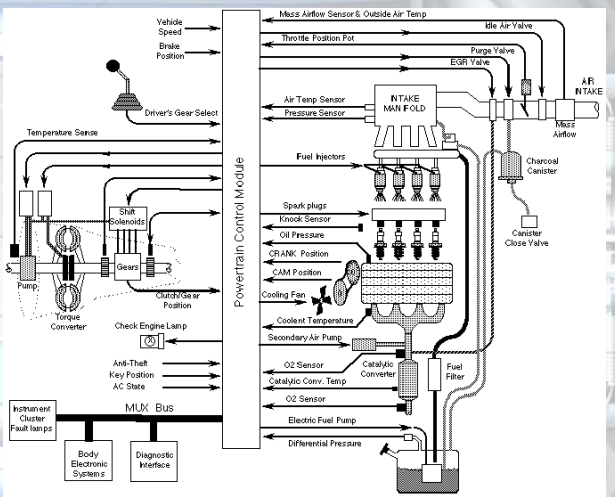
Engine Control

- Control Architecture Overview



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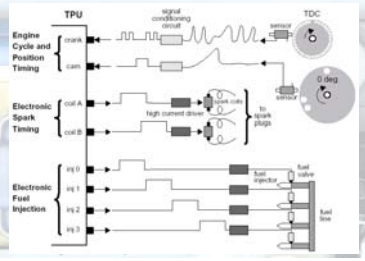
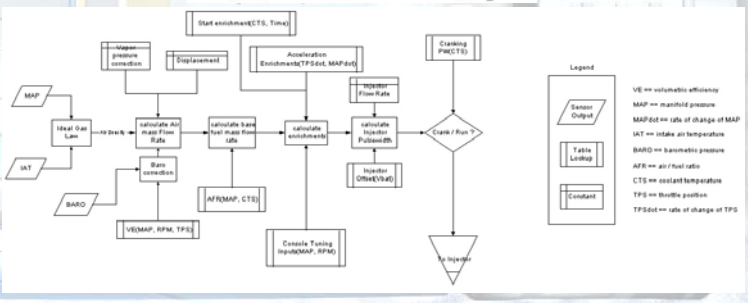
Engine Control

- Algorithm Overview





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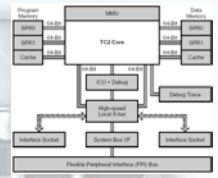
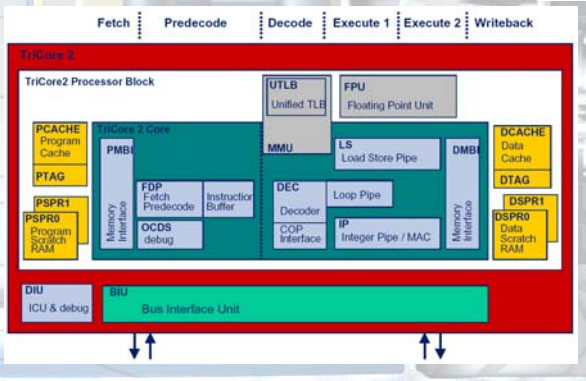
TriCore Architecture

- Overview





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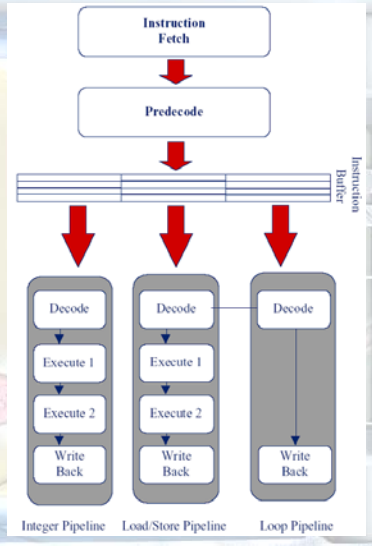
TriCore Architecture

- Pipeline



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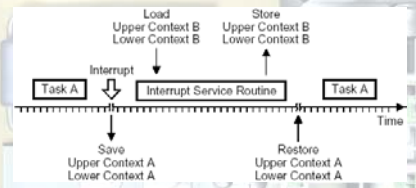
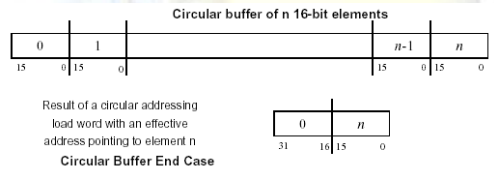
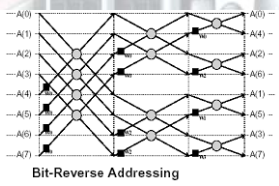
Analysis

- Mixed 16/32 Bit Instruction Set
- Special Instructions
- Task Switching



- Addressing Modes





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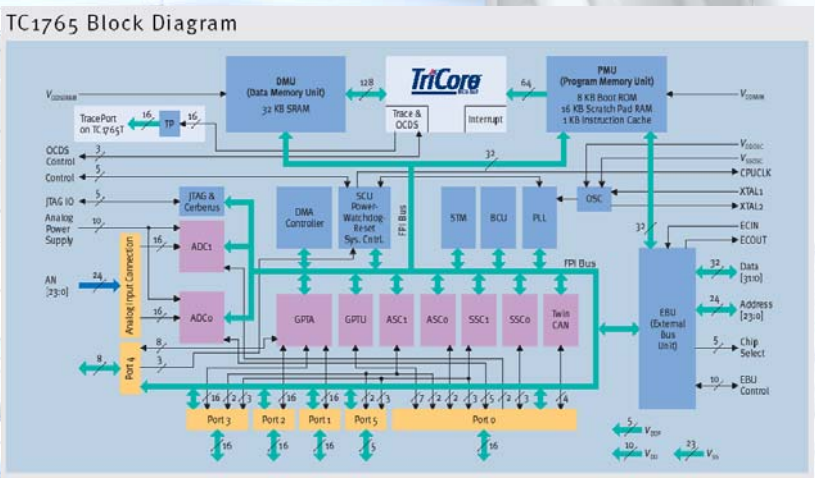
Further Analysis...

- One implementation of TriCore: T1765, customized for engine control



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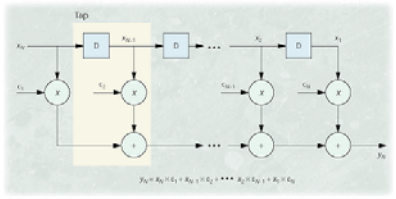
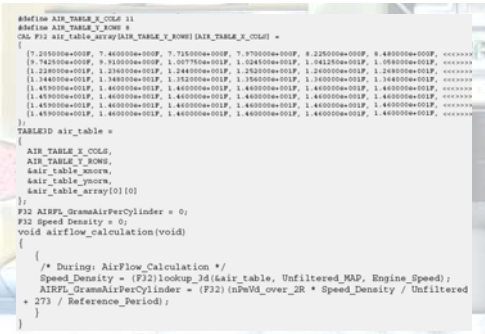
Further Analysis...

- FIR Filter



Clock	Integer Unit	Load/Store Unit	Loop Unit
clock 1	-	Load C_0, C_1, C_2, C_3	-
clock 2	-	Load X_0, X_1, X_2, X_3	-
clock 3	MAC C_0X_0, MAC C_1X_1	Load C_4, C_5, C_6, C_7	Loop Start
clock 4	MAC C_2X_2 , MAC C_3X_3	Load X_4, X_5, X_6, X_7	-
clock 5	MAC C_4X_4, MAC C_5X_5	Load C_8, C_9, C_{10}, C_{11}	-
clock 6	MAC C_6X_6, MAC C_7X_7	Load X_8, X_9, X_{10}, X_{11}	Loop
...	...	...	-
clock 130	MAC $C_{254}X_{254}$, MAC $C_{255}X_{255}$	-	-
clock 131	-	Store Result	-

- Lookup Tables



```
#define AIR_TABLE_X_COLS 11
#define AIR_TABLE_Y_ROWS 9
CAL_F32 air_table_array[AIR_TABLE_Y_ROWS][AIR_TABLE_X_COLS] =
{
  {7.205000e+000F, 7.460000e+000F, 7.715000e+001F, 7.970000e+001F, 8.225000e+001F, 8.480000e+001F, <<<<<<<
  {9.742500e+000F, 9.910000e+000F, 1.007750e+001F, 1.024500e+001F, 1.041250e+001F, 1.058000e+001F, <<<<<<<
  {1.228000e+001F, 1.236000e+001F, 1.244000e+001F, 1.252000e+001F, 1.260000e+001F, 1.268000e+001F, <<<<<<<
  {1.344000e+001F, 1.348000e+001F, 1.352000e+001F, 1.356000e+001F, 1.360000e+001F, 1.364000e+001F, <<<<<<<
  {1.459000e+001F, 1.460000e+001F, 1.460000e+001F, 1.460000e+001F, 1.460000e+001F, 1.460000e+001F, <<<<<<<
  {1.459000e+001F, 1.460000e+001F, 1.460000e+001F, 1.460000e+001F, 1.460000e+001F, 1.460000e+001F, <<<<<<<
  {1.459000e+001F, 1.460000e+001F, 1.460000e+001F, 1.460000e+001F, 1.460000e+001F, 1.460000e+001F, <<<<<<<
  {1.459000e+001F, 1.460000e+001F, 1.460000e+001F, 1.460000e+001F, 1.460000e+001F, 1.460000e+001F, <<<<<<<
};
TABLE3D air_table =
{
  AIR_TABLE_X_COLS,
  AIR_TABLE_Y_ROWS,
  &air_table_xnorm,
  &air_table_ynorm,
  &air_table_array[0][0]
};
F32 AIRFL_GramsAirPerCylinder = 0;
F32 Speed_Density = 0;
void airflow_calculation(void)
{
  {
    /* During: AirFlow_Calculation */
    Speed_Density = (F32)lookup_3d(&air_table, Unfiltered_MAP, Engine_Speed);
    AIRFL_GramsAirPerCylinder = (F32)(nPmVd_over_2R * Speed_Density / Unfiltered
+ 273 / Reference_Period);
  }
}
```

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Conclusions

- Architecture Evolution
  - TriCore is well equipped for engine control
  - Specialized architecture, to solve software issues at hardware level
  - Integration of hardware function into the processor
  - Evolution towards software-based solutions
  - Interesting strategy from the chipmaker (re-usable, licensable core)
  - Hybrid architecture as the first step towards total merging/integration
- Engine Control
  - Pending on sensors development
  - New challenges as hybrid or electrical vehicles
  - Environmental and efficiency issues

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