Making cars safer through technology innovation

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Introduction

Futurists have long dreamed of vehicles driving themselves. Remote control experiments date back nearly a century, and the 1939 New York World's Fair included automated highways in its "World of Tomorrow." But the reality of fully autonomous vehicles remained out of reach until recently, when new technologies suddenly turned the fantasies of the past into present-day realities.

The general public is aware that several large corporations and major automakers are developing self-driving technology. Less well known, however, is the extensive effort into assisted driving technologies and the semiconductor innovations enabling them. These technologies are rapidly changing car design, providing an evolution in automotive control that has put semi-autonomous vehicles on the roads now and fully autonomous options coming in just a few years.

Semi and fully autonomous automotive control, based on advanced electronic sensing and processing, are valuable for more than just the excitement that comes with a technological breakthrough. They deliver real benefits in fuel savings, mobility and convenience, travel time and the efficient use of roadways. Most important, however, are new forms of control that work actively to promote safety, not only for drivers and passengers, but other vulnerable road users as well.

Texas Instruments (TI) is at the forefront of automotive technology, driving innovation in analog and embedded-processing signal chains to shape the future of automotive electronics today.

Addressing the need for automotive safety

According to government agencies, approximately 40,000 people in the United States and about 1.25 million people worldwide died in traffic accidents last year. Traffic accidents remain the leading cause of death for young people in the U.S. and are high on the list of causes of death for the overall population. Above and beyond the fatalities are the even greater number of injuries and the high cost of repairs associated with accidents. Since traffic accidents are overwhelmingly caused by human error—as much as 90 percent, according to some estimates—assisting drivers so that they control their vehicles more safely is an obvious point of attack for reducing deaths and damages.

Vehicle control represents not only a remarkable opportunity to enhance road safety, but also a thriving market for those offering enabling electronic technology. Active safety systems represent the fastest growing portion of the ~$30 billion spent today on electronic components in automobiles worldwide. Leading-edge semiconductor solutions will help speed the introduction of these new capabilities, ushering in greater safety while sharing in this significant market.

Safety enhancements depend on advanced technology

Active safety depends on, among other things, advanced driver assistance systems (ADAS), a set of electronics-based technologies that are designed to aid in safe vehicle operation. ADAS innovations help prevent accidents by keeping cars at safe distances from each other, alerting drivers to dangerous conditions, protecting those in the car and on the street from bad driving habits, and performing other safety-related operations. ADAS also provides functions that will serve as important elements of computer-controlled autonomous operation in the future. If self-driving cars promise to free drivers so that they can use their time more effectively during commutes and longer trips, ADAS features will help minimize collision repairs, prevent injuries and save lives.

Automakers are racing to introduce more and more driver-assistance capabilities into new cars, with the market availability of many features increasing significantly every year. Automakers rely on leading semiconductor suppliers for a range of advanced integrated circuit (IC) technologies that can accurately and reliably support a variety of external sensors; communicate among the car's different systems and provide high-performance, heterogeneous processing for the computer vision and decision-making necessary for next-generation ADAS and automated driving systems.

Texas Instruments (TI) provides a wide portfolio of analog and digital products for ADAS and automated control and is innovating to provide solutions for future development.

The evolution of vehicle safety automation

Society of Automotive Engineers (SAE) International's J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems standard is a classification system designed to provide a common terminology for automated driving. **Figure 1** on the following page lists SAE International's Levels of Driving Automation for On-Road Vehicle.

Level 0 is no automation, and is already considered a thing of the past.

In the **Level 1** and **Level 2** stages, these systems can briefly take active control of the car to assist in parking, prevent backing over unseen objects and avoid collisions by braking or swerving. Sometimes the system actively controls an individual feature of the automobile, such as adapting front headlights automatically to upcoming curves and other changing conditions.

Level 3 involves semi-autonomous operation; the car takes over driving in certain circumstances, but the driver must be ready to resume control. Take for example highway driving. One semi-autonomous feature for highway driving is adaptive cruise control, which changes speeds automatically to keep pace with traffic. Another is lane-keep assistance, which uses a front or rear camera to keep the car centered in its lane and at a safe distance from other drivers.

Park assist takes full control during parking in crowded parking lots and garages, and in-cabin driver monitoring can detect an incapacitated driver and initiate a maneuver to pull the car over and stop it safely.

When cars move to fully autonomous operation in **Level 4** and **Level 5**, there may be no one in the driver's seat at all. The only occupant may be an elderly or handicapped person in the back seat,

SAE level	Name	Narrative definition	Execution of steering and acceleration/ deceleration	*Monitoring* of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)
Human driver **monitors the driving environment**						
0	No automation	The full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	N/A
1	Driver assistance	The *driving mode*-specific execution by a driver assistance system of either steering or acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial automation	The *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system **("system") monitors the driving environment**						
3	Conditional automation	The *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High automation	The *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full automation	The full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 1. *SAE International's levels of driving automation for on-road vehicle.*

or the car may be empty as it goes to pick up someone at school or the airport.

Each of these stages builds on the ones before it, fusing existing safety systems into new ones that are more complex. Today, most new cars appear with passive and even some active ADAS safety features, and availability is increasing rapidly. In fact, according to forecasts from the market research firm [IHS Market], the global ADAS market will surpass 302 million units annually in 2022 thanks in part to new technologies like driver-monitoring systems and side- and rear-mirror cameras. Features for advanced semi-autonomous operation are starting to appear in high-end vehicles today and moving down market while fully autonomous cars, still experimental today, are expected to follow in the 2020–2025 period.

As with almost all innovations, ADAS features tend to be introduced in high-end vehicles first, then migrate down to medium-priced and economy cars. In some cases, such as rear-view cameras, commercial vehicles have pioneered adoption because these features are especially valuable in the safe operation of large trucks.

The enabling IC technologies

Higher levels of automated- and assisted-driving capabilities and reliability requirements are generating a need for multi-modal systems with input from a variety of sensors, including ultrasound, RADAR, LIDAR and cameras (color, monochrome, stereo and infrared night vision) sensor technologies.

Satellite communications, as well as radio communications with nearby cars (vehicle-to-vehicle) and terrestrial installations (vehicle-to-infrastructure), are also necessary for positioning, localization, highway conditions and other information.

Figure 2 below shows typical Level 3 to Level 5 system architecture from a functional perspective. It is clear that to enable these systems a wide variety of functions working in real time are required.

Working in real time, as events occur, ADAS and automated driving systems will have to convert varied inputs into useful data forms and extract whatever information is necessary. These systems must merge information from different sources, decide the correct control action, and communicate appropriately to the driver or automatic control output. In addition to requiring high fidelity in the inputs themselves, the systems will rely on high-performance computations that can run a variety of algorithms concurrently.

For example, while low-level processing provides a steady stream of pre-filtered or pre-conditioned video images of a road, mid-level processing identifies important objects in sections of the images. High-level processing determines the type of object—other vehicles, people, animals, signs or lights—in addition to the speed at which the object is moving. A microcontroller (MCU) decides whether to proceed, stop or wait until (for example) the pedestrian moves, the light changes or a nearby car passes. Concurrently, data streams from other input sensors such as RADAR are being examined for information in case there are overriding conditions, such as poor visibility due to fog. Because any given sensor may face challenging external conditions, fusing inputs from different data streams greatly increases precision and reliability.

While the need to support more and more multi-modal systems with multiple sensors per system is pushing the boundaries for silicon technology providers, at the same time automotive manufacturers face the challenge of how to integrate new sensors around the vehicle and their corresponding processing units without compromising vehicle design and internal occupant

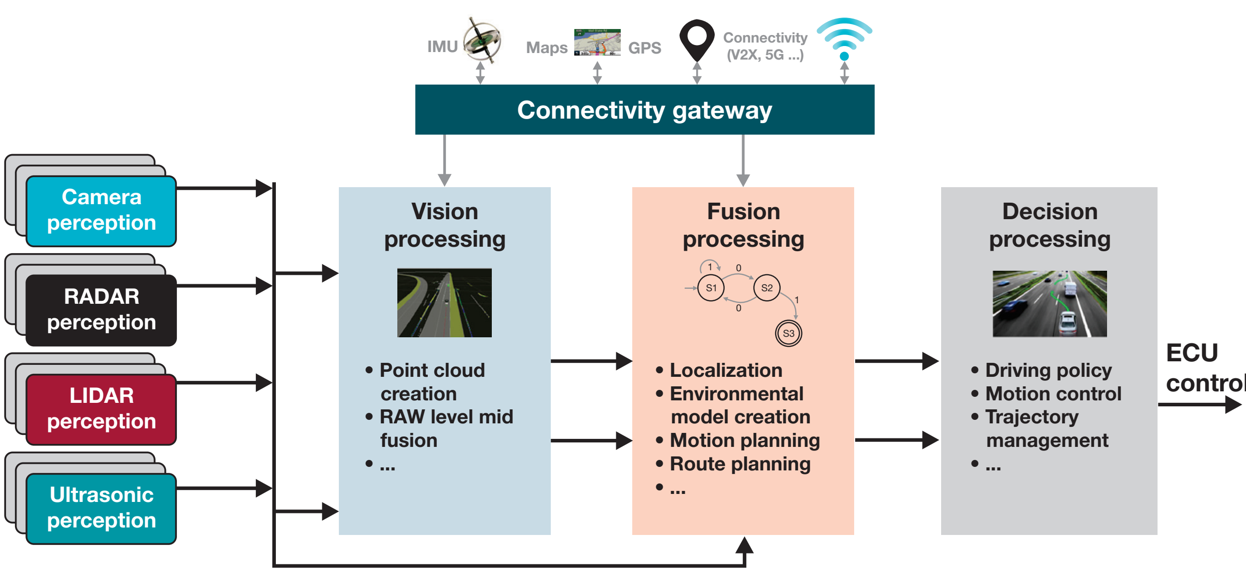

Figure 2*. Typical Level 3 to Level 5 system architecture.*

space. In addition, keeping system costs low enables mass reach for more and more feature-rich ADAS applications.

TI's system-on-chip (SoC) architecture enables highly efficient implementations capable of integrating multiple modality sensors while optimizing overall power, form factor and system costs. One key mechanism in which TI's SoC architecture can do more—while being more optimized—is by using a heterogeneous architecture approach.

What is heterogeneous architecture?

To understand the heterogeneous architecture concept better, let's briefly look at the automotive ADAS signal-processing chain. You can partition a high-level signal-processing chain into these segments:

- Low-level processing:
  - Concentrates on processing raw data from sensors such as a camera, RADAR, LIDAR, etc.
  - Low-level processing for a camera involves processing pixel data to create useful images for further processing. Low-level processing for RADAR sensor data involves performing correlation operations to detect objects and calculate velocity vectors.
- Mid-level processing:
  - Identifies objects of interest within images for use by high-level processing to recognize the objects, and a safety MCU deciding what the system should do.
  - In higher levels of assisted driving or automated driving, mid-level processing develops a complete understanding of a given scene based on one or more sensor modalities.
- High-level processing:
  - Scales from simply using the results of mid-level processing to perform actions such as braking, to functions such as route and driving-path planning for higher levels of autonomy.

Low-level processing tends to use relatively simple repetitive algorithms that operate in parallel to handle massive amounts of input data. Mid-level processing is between either extreme in both data size and algorithm complexity, and high-level processing has comparatively little data but complicated algorithms. While a general-purpose processor can code and execute these algorithms/functions, that is typically never the most efficient implementation. Each level is optimally performed by a different processing architecture, further analyzed in **Table 1**.

Processing architecture	Purpose	Example blocks	Low-level raw processing	High-level control processing
Hardware accelerator (HWA)	Low-level processing (pixel, raw sensor data)	Image signal processor (ISP), RADAR, LIDAR	High	NA
Single instruction multiple data (SIMD)	Low-level processing	Embedded vision engine (EVE), deep learning		Low
Multiple instruction multiple data (MIMD)	Low-level/mid-level processing	EVE, digital signal processor (DSP), deep learning		
Very long instruction word (VLIW)	Mid-level processing	DSP		
Reduced instruction set computing (RISC)	High-/control-level processing	MCU, ARM® processor	Low	High

Table 1. *Heterogeneous architecture mapping.*

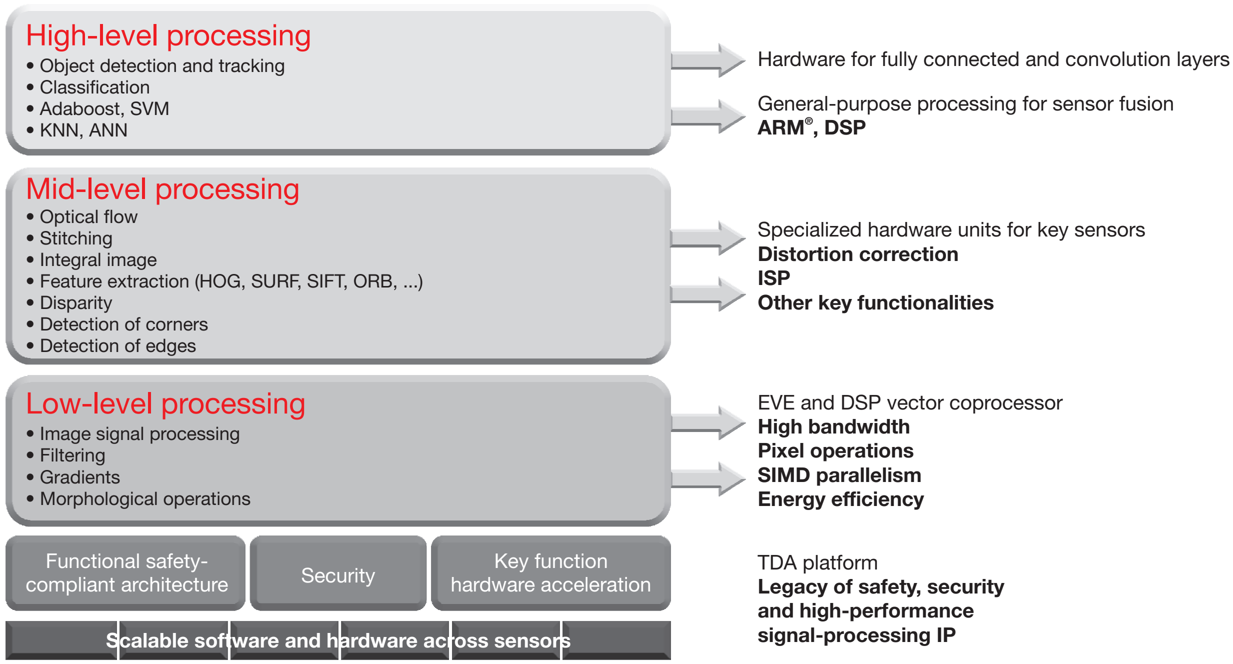

Figure 3*. Mapping functions to the right processing architecture.*

The most efficient way to map any ADAS function is to map each segment of the signal-chain processing to the most efficient processing architecture, as shown in **Figure 3**.

ADAS data flows also require real-time processing. Mapping low-level processing to dedicated accelerators or an SIMD pipeline reduces overall software overhead while maintaining and meeting real-time processing goals.

Enabling easier software development and scalability

While a heterogeneous architecture is super-efficient in mapping a signal chain—and thus enables cost- and power-efficient system development—programming many different types of processing cores is admittedly a more involved task at times, especially when coupled with the pressures of developing new systems under intense market competition. The software used will have to be abstracted, refined and reused in later systems as active safety capabilities evolve.

The TI SoC architecture also integrates hooks such as inter-processing core (IPC) and cache coherency to enable a very efficient ADAS software framework. The purpose of the software framework is to enable open compute as much as possible, thereby relieving developers from the complexity of a heterogeneous architecture while providing all of the benefits.

For instance, in addition to its own software frameworks, TI is a key contributor to the Khronos OpenVX standard for computer vision acceleration. OpenVX addresses the abstraction of a heterogeneous architecture while having minimal overhead and complete user flexibility.

OpenVX's advantages are highlighted below. **Figure 4** on the following page shows a high-level view of OpenVX implementation on TI SoCs. The result is full entitlement of performance on TI SoCs through portable OpenVX interface.

- Portable, power-efficient vision processing.
- Accelerated, distributed, parallel computing on DSPs, EVEs, HWAs and ARM processors.

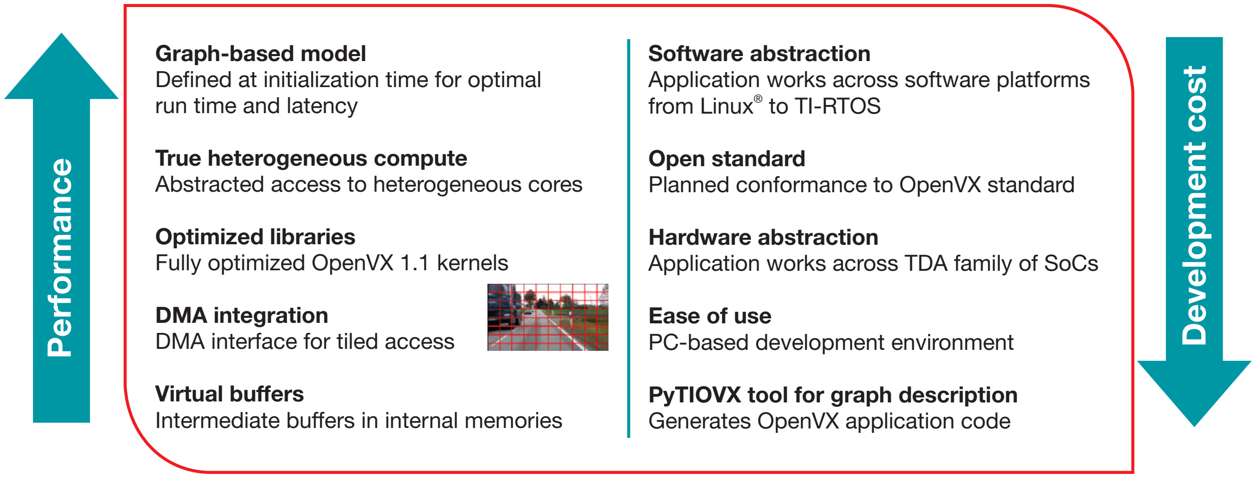

***Figure 4**. OpenVX implementation on TI SoC.*

- Scalability across TI's TDA2x, TDA2Ex, TDA3x and TDA-Next driver-assistance SoC family.
- TI-real-time operating system (TI-RTOS) and Linux® OS support.
- PC (Windows®) emulation for application and kernel prototyping.
- Automated application and kernel-wrapper code generation.
- Compliance with the OpenVX 1.1 specification.

TI's deep learning development

In addition to simplifying the overall software development using Open frameworks like OpenVX, TI is also revolutionizing deep learning development to TI SoCs, by enabling out-of-the-box simplified development flows. TI deep learning flow enables learning and development on PC or Cloud environment where power and cost constraints can be relaxed to maximize performance and reduced development time, but enables easy deployment at low power on automotive production TDA devices.

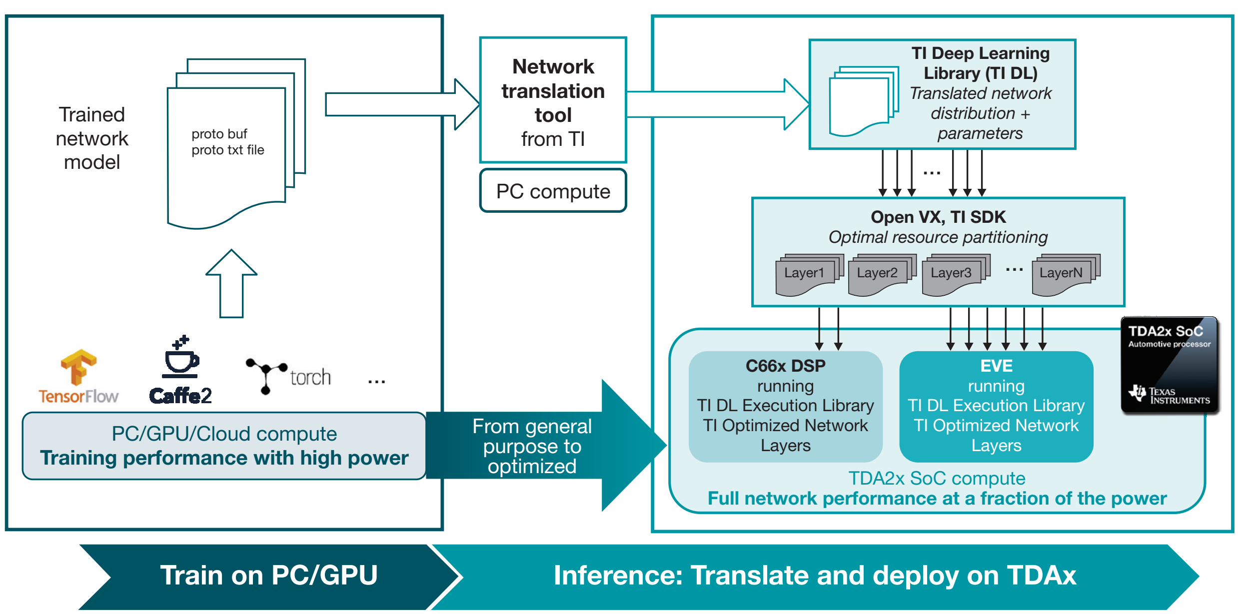

***Figure 5**. TI deep learning flow on TDA SoCs.*

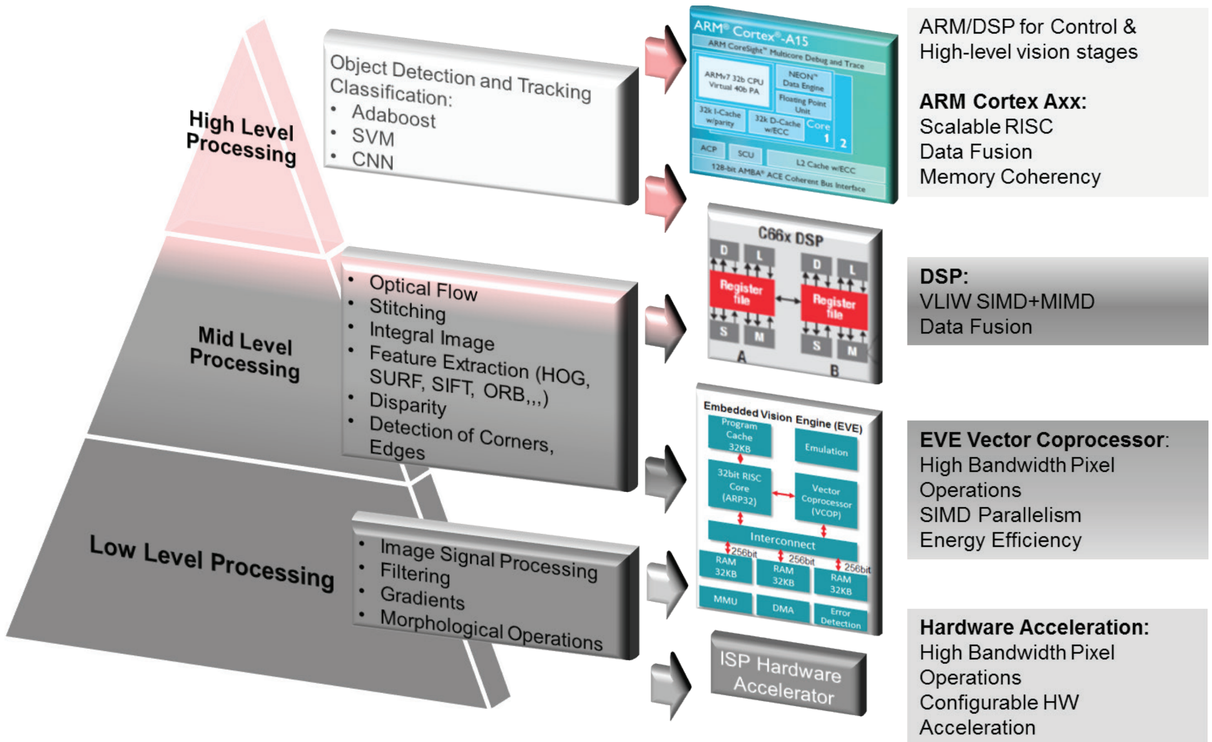

***Figure 6**. TDA2x SoC heterogeneous architecture.*

TDA SoCs—paving the way

TI's TDA2x ADAS SoC technology has a programmable vision accelerator containing one or more specialized EVEs to handle massive amounts of video system data, ISPs for camera pre-processing, a DSP for more general signal processing and RISC options that include several ARM microprocessors.

Automotive expertise for building safety systems

TI's SoC portfolio includes MCUs, multicore DSPs and heterogeneous vision processors. When developing ADAS and automated driving features, automakers look for technology and logistics strength when choosing a semiconductor vendor. To meet these requirements, TI became an early supplier of active safety semiconductor systems. The company's role in supplying active safety technology builds on a decades-long relationship with automakers, dating back to development of the earliest anti-lock brakes.

Supply logistics can be a barrier to new entrants in the automotive industry, since they lack in-depth compliance experience with relevant automotive safety standards such as International Organization for Standardization (ISO)/Technical Specification (TS) 16949 for quality management and ISO 26262 for functional safety. Hundreds of millions of safety MCUs shipped to date testify to TI's safety expertise, which extends through all stages of analog and digital design and manufacture. Automotive customers can also rely on the company's worldwide design support and manufacturing footprint to help speed system development and ramp to volume production. Multi-source global fabrication assures customers of a reliable, long-term product supply.

With these capabilities, TI can deliver innovative technology solutions for active safety development and manufacturing, from the simplest driver assistance to the fully autonomous vehicles of the future.

Technology for future safety, appearing today

Fully autonomous cars will not appear in significant numbers on the roads for a decade or so, and more time will pass before virtually all new vehicles are capable of driving themselves. But in the meantime, a steadily increasing number of vehicles will offer increasing levels of assisted driving to help make them safer while reducing fuel consumption and adding operator convenience. Enabling active safety features depends on innovative advanced electronics, including sensing advancements for external input; high-performance processing to evaluate driving conditions and aid decision making; and a variety of analog components for signal conditioning, communications and system power control.

Automakers need reliable supplies of IC devices from semiconductor vendors, as well as strong design support and the expertise required to advance technology in the years ahead.

What the world will be like with self-driving cars is sometimes difficult to imagine, but one thing is certain: TI's advanced IC technology and culture of innovation will play a significant role in bringing it about.

For more information

To learn more about how TI is innovating to ensure safety and security, see www.ti.com/innovation-safety.

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