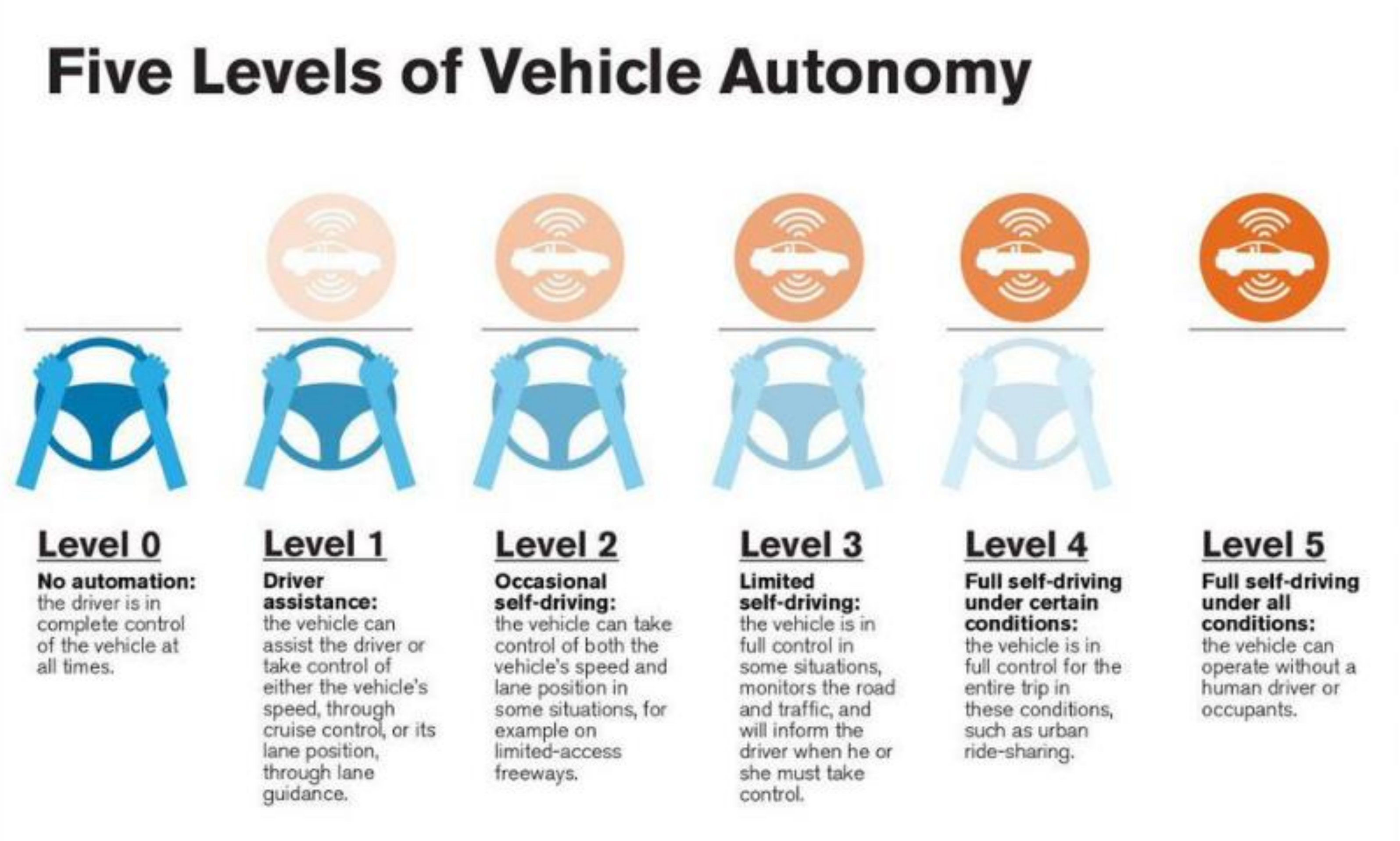
# Otonom Araçlar

Savaş Takan

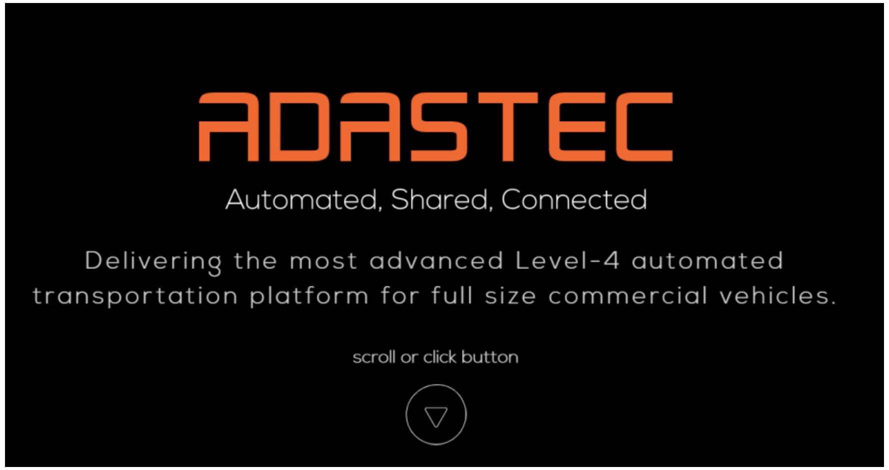
# Otonom Araçlar



# Karsan’ın Bursa’da ürettiği sürücüsüz otonom otobüs

Çalışan profili:

- Boğaziçi, Odtu, Bilkent
- Lisans, yüksek lisans





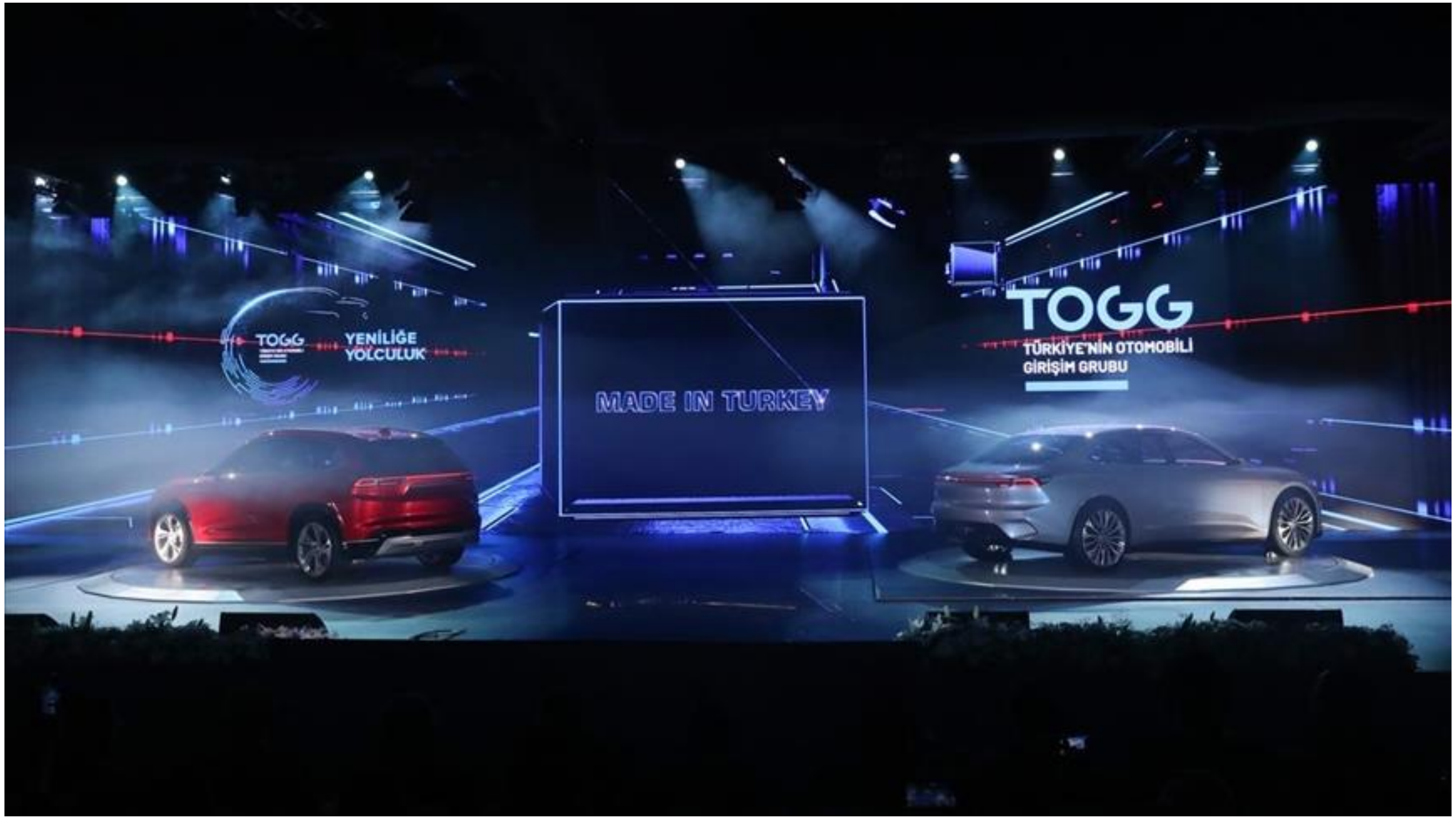
Kullandıkları teknolojiler: NVIDIA, ROS,  autoware, gezobo …

Üretim Yeri: Bursa

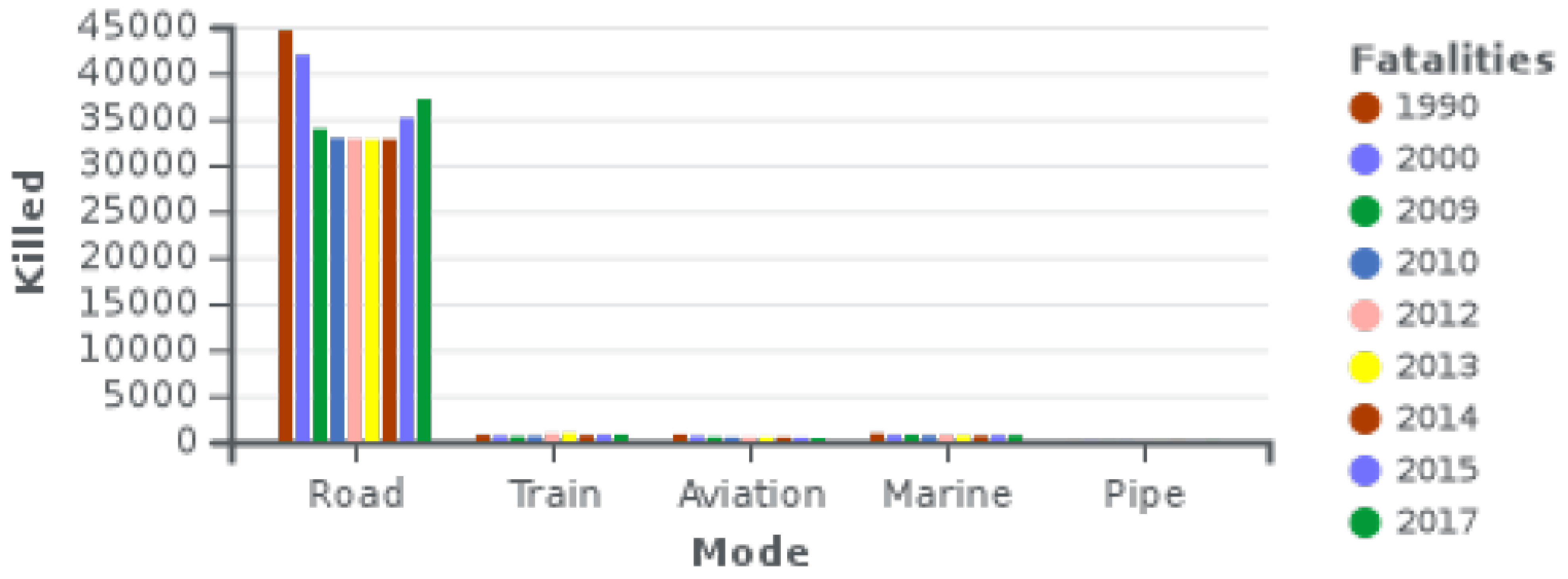
# Türkiye'nin Otomobili Girişim Grubu Sanayi ve Ticaret A.Ş.

3. seviye **otonom** sürüş

Üretim Yeri: Bursa



# Otonom Araçlar



# Otonom Araçlar

# Otonom Araçlar

İletişim

Psikolojik

Etik

Hukuk

Sosyolojik

Toplumsal Kabul

# Otonom Araçlar

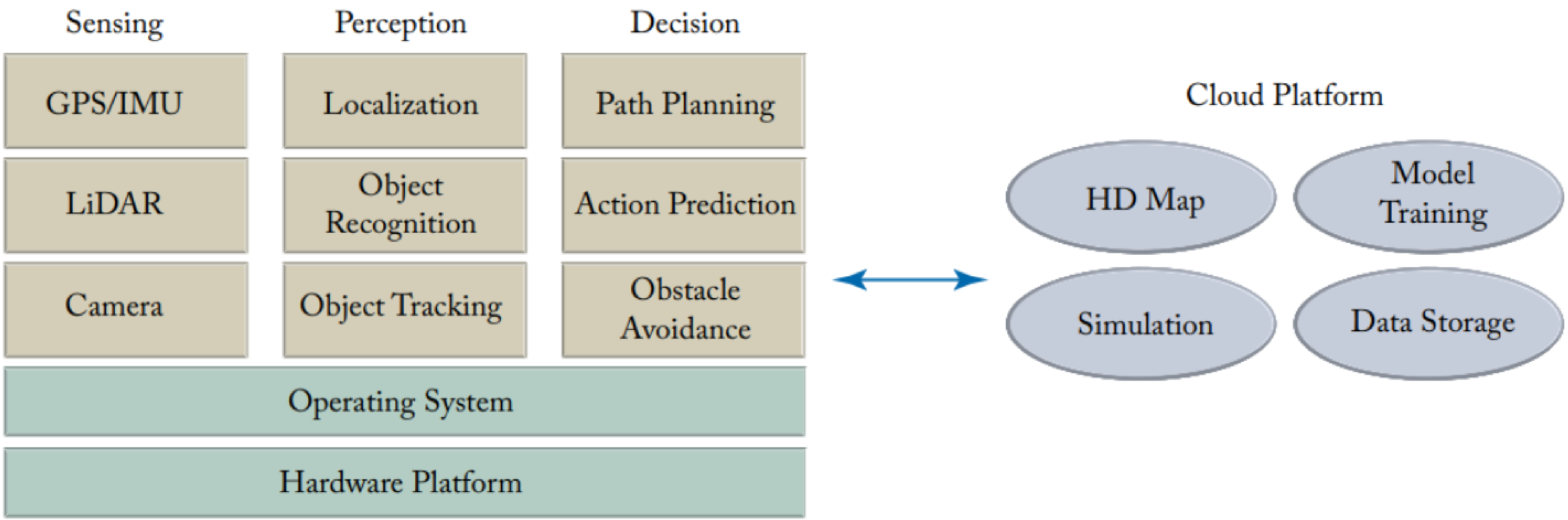
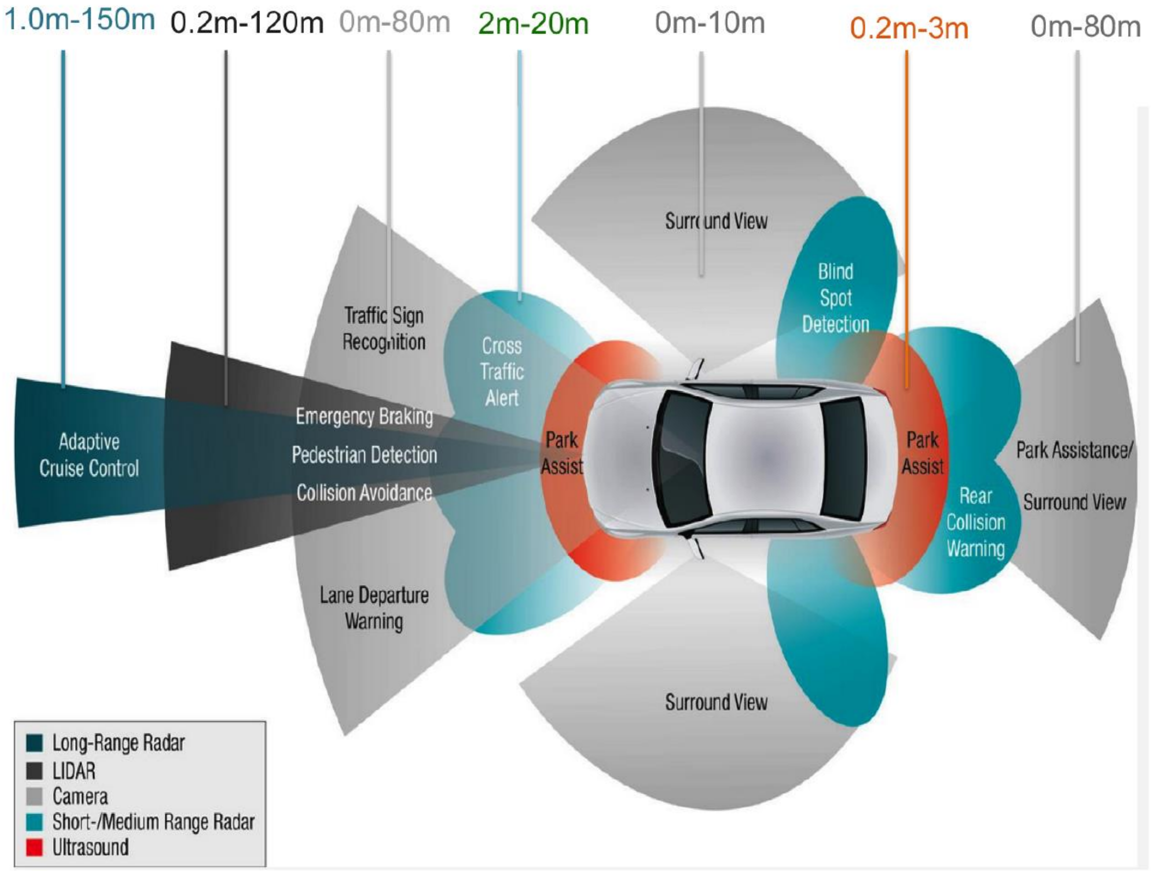
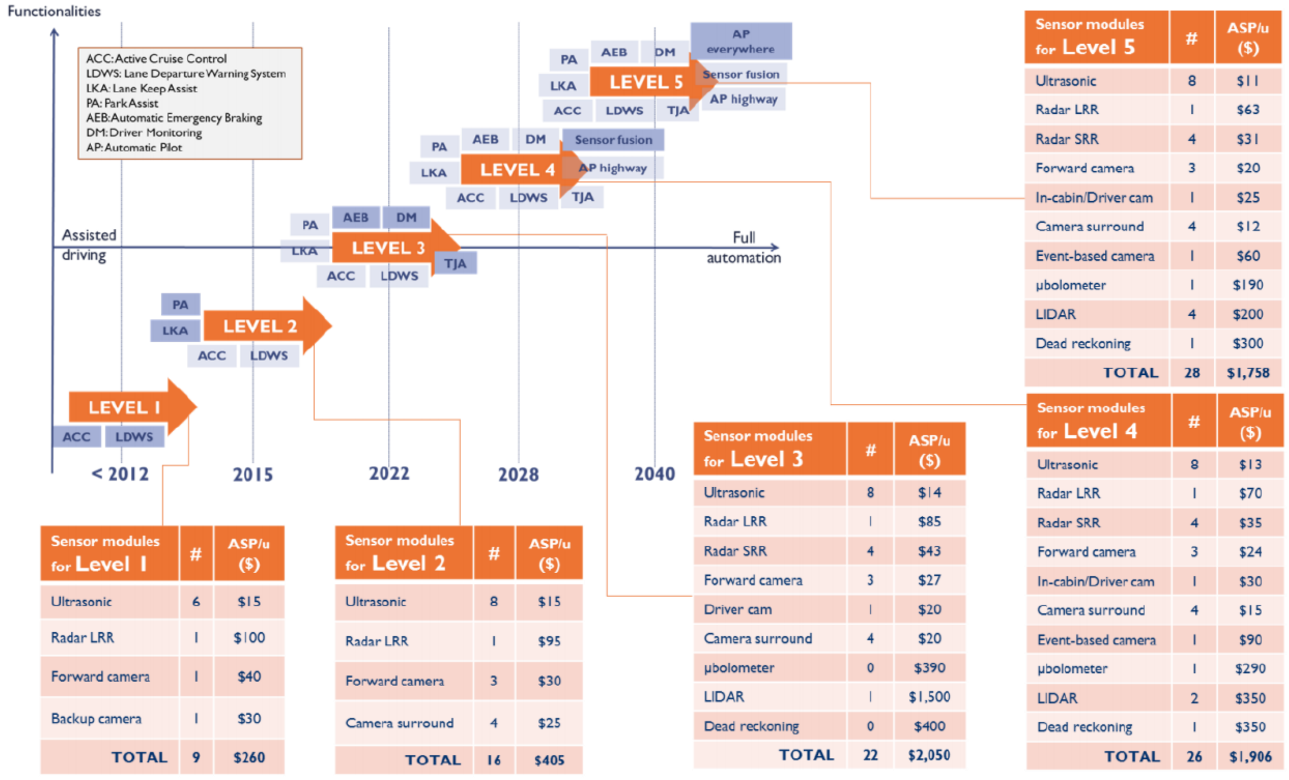



Figure 3.2: Autonomous driving system architecture overview from [140].

# Otonom Araçlar



# Otonom Araçlar




| Sensor modules for Level 1 | # | ASP/u ($) |
|---|---|---|
| Ultrasonic | 6 | $15 |
| Radar LRR | 1 | $100 |
| Forward camera | 1 | $40 |
| Backup camera | 1 | $30 |
| TOTAL | 9 | $260 |

| Sensor modules for Level 2 | # | ASP/u ($) |
|---|---|---|
| Ultrasonic | 8 | $15 |
| Radar LRR | 1 | $95 |
| Forward camera | 3 | $30 |
| Camera surround | 4 | $25 |
| TOTAL | 16 | $405 |

| Sensor modules for Level 3 | # | ASP/u ($) |
|---|---|---|
| Ultrasonic | 8 | $14 |
| Radar LRR | 1 | $85 |
| Radar SRR | 4 | $43 |
| Forward camera | 3 | $27 |
| Driver cam | 1 | $20 |
| Camera surround | 4 | $20 |
| µbolometer | 0 | $390 |
| LIDAR | 1 | $1,500 |
| Dead reckoning | 0 | $400 |
| TOTAL | 22 | $2,050 |

| Sensor modules for Level 4 | # | ASP/u ($) |
|---|---|---|
| Ultrasonic | 8 | $13 |
| Radar LRR | 1 | $70 |
| Radar SRR | 4 | $35 |
| Forward camera | 3 | $24 |
| In-cabin/Driver cam | 1 | $30 |
| Camera surround | 4 | $15 |
| Event-based camera | 1 | $90 |
| µbolometer | 1 | $290 |
| LIDAR | 2 | $350 |
| Dead reckoning | 1 | $350 |
| TOTAL | 26 | $1,906 |

| Sensor modules for Level 5 | # | ASP/u ($) |
|---|---|---|
| Ultrasonic | 8 | $11 |
| Radar LRR | 1 | $63 |
| Radar SRR | 4 | $31 |
| Forward camera | 3 | $20 |
| In-cabin/Driver cam | 1 | $25 |
| Camera surround | 4 | $12 |
| Event-based camera | 1 | $60 |
| µbolometer | 1 | $190 |
| LIDAR | 4 | $200 |
| Dead reckoning | 1 | $300 |
| TOTAL | 28 | $1,758 |

Figure 1.2: Sensor modules for each automation level from [251].

# Otonom Araçlar

| Performance aspect | Human | AV | | | CV | CAV |
|---|---|---|---|---|---|---|
| | | *Radar* | *Lidar* | *Camera* | *DSRC* | *CV+AV* |
| Object detection | Good | Good | Good | Fair | n/a | Good |
| Object classification | Good | Poor | Fair | Good | n/a | Good |
| Distance estimation | Fair | Good | Good | Fair | Good | Good |
| Edge detection | Good | Poor | Good | Good | n/a | Good |
| Lane tracking | Good | Poor | Poor | Good | n/a | Good |
| Visibility range | Good | Good | Fair | Fair | Good | Good |
| Poor weather performance | Fair | Good | Fair | Poor | Good | Good |
| Dark or low illumination performance | Poor | Good | Good | Fair | n/a | Good |
| Ability to communicate with other traffic and infrastructure | Poor | n/a | n/a | n/a | Good | Good |

**Dedicated short-range communications** (DSRC)

# Otonom Araçlar

| CAR AUTOMATION SENSORS & DATA VOLUMES | | |
|---|---|---|
| **Sensor type** | **Quantity** | **Data generated** |
| Radar | 4–6 | 0.1–15 Mbit/s |
| LIDAR | 1–5 | 20–100 Mbit/s |
| Camera | 6–12 | 500–3,500 Mbit/s |
| Ultrasonic | 8–16 | <0.01 Mbit/s |
| Vehicle motion, GNSS, IMU | - | <0.1 Mbit/s |
| **TOTAL ESTIMATED BANDWIDTH** | | |
| **3 Gbit/s (~1.4TB/h) to 40 Gbit/s (~19 TB/h)** | | |

# Dataset

Table 3.2: Driving datasets from [254].

| Dataset | Image | LIDAR | 2D annotation | 3D annotation | ego signals | Naturalistic | POV | Multi trip | all weathers | day & night |
|---|---|---|---|---|---|---|---|---|---|---|
| Cityscapes [45] | ✓ | | ✓ | | | | Vehicle | | | |
| Berkley DeepDrive [252] | ✓ | | ✓ | | | | Vehicle | | ✓ | ✓ |
| Mapillary [166] | ✓ | | ✓ | | | | Vehicle | | ✓ | ✓ |
| Oxford RobotCar [148] | ✓ | ✓ | | | | | Vehicle | ✓ | ✓ | ✓ |
| KITTI [67] | ✓ | ✓ | ✓ | ✓ | | | Vehicle | | | |
| H3D [177] | ✓ | ✓ | | ✓ | | | Vehicle | | | |
| ApolloScape [95] | ✓ | ✓ | ✓ | ✓ | | | Vehicle | | | |
| nuScenes [28] | ✓ | ✓ | ✓ | ✓ | | | Vehicle | | ✓ | ✓ |
| Udacity [219] | ✓ | ✓ | ✓ | ✓ | | | Vehicle | | | |
| DDD17 [21] | ✓ | | ✓ | | ✓ | | Vehicle | | ✓ | ✓ |
| Comma2k19 [199] | ✓ | | | | ✓ | | Vehicle | | | ✓ |
| LiVi-Set [39] | ✓ | ✓ | | | ✓ | | Vehicle | | | |
| NU-drive [213] | ✓ | | | | ✓ | Semi | Vehicle | ✓ | | |
| SHRP2 [218] | ✓ | | | | ✓ | ✓ | Vehicle | | | |
| 100-Car [119] | ✓ | | | | ✓ | ✓ | Vehicle | | ✓ | ✓ |
| euroFOT [20] | ✓ | | | | ✓ | ✓ | Vehicle | | | |
| TorontoCity [231] | ✓ | ✓ | ✓ | ✓ | | | Vehicle, Aerial, Panorama | | | |
| KAIST multi-spectral [41] | ✓ | ✓ | ✓ | | | | Vehicle | | | ✓ |

# Autonomous Driving

- Stanley (Level 5 SAE ADS) – (Stanford University)
- DAVE2 – (NVIDIA)
- Waymo – (Google)

# OS

- Real-time operating systems (RTOS)
- General-purpose operating systems (GPOS)

American Megatrends

## RTOS and GPOS Differences

### RTOS

*Real-Time Operating System*

- Deterministic: no random execution pattern
- Predictable Response Times
- Time Bound
- Preemptive Kernel

**Examples:**
Contiki source code, FreeRTOS™, Zephyr™ Project

**Use Case:**
Embedded Computing

### GPOS

*General-Purpose Operating System*

- Dynamic memory mapping
- Random Execution Pattern
- Response Times not Guaranteed

**Examples:**
Microsoft® Windows® operating system, Apple® macOS® operating system, Red Hat® Enterprise Linux® operating system

**Use Case:**
Desktop, Laptop, Tablet computers

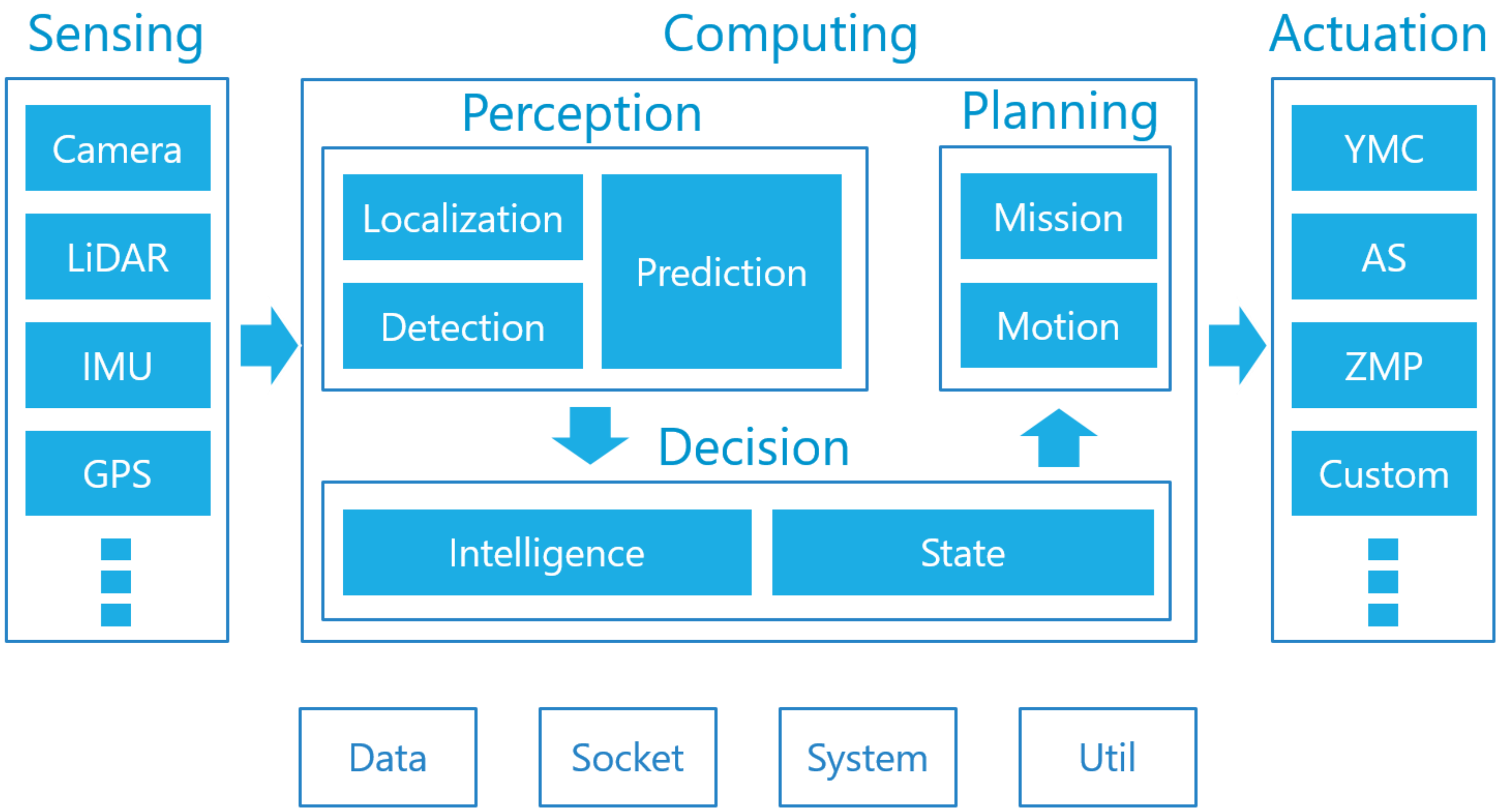
# OS

- QNX Neutrino (BlackBerry)
  - Ford, Acura, VW, BMW, and Audi
- WindRiver VxWorks
  - Toshiba, Bosch, BMW, Ford, VW
- Green Hills INTEGRITY
- NVIDIA DRIVE™ OS
  - Tesla, VW, Mercedes-Benz, Audi, Veoneer, and Bosch
- Mentor Nucleus® OS

# OS

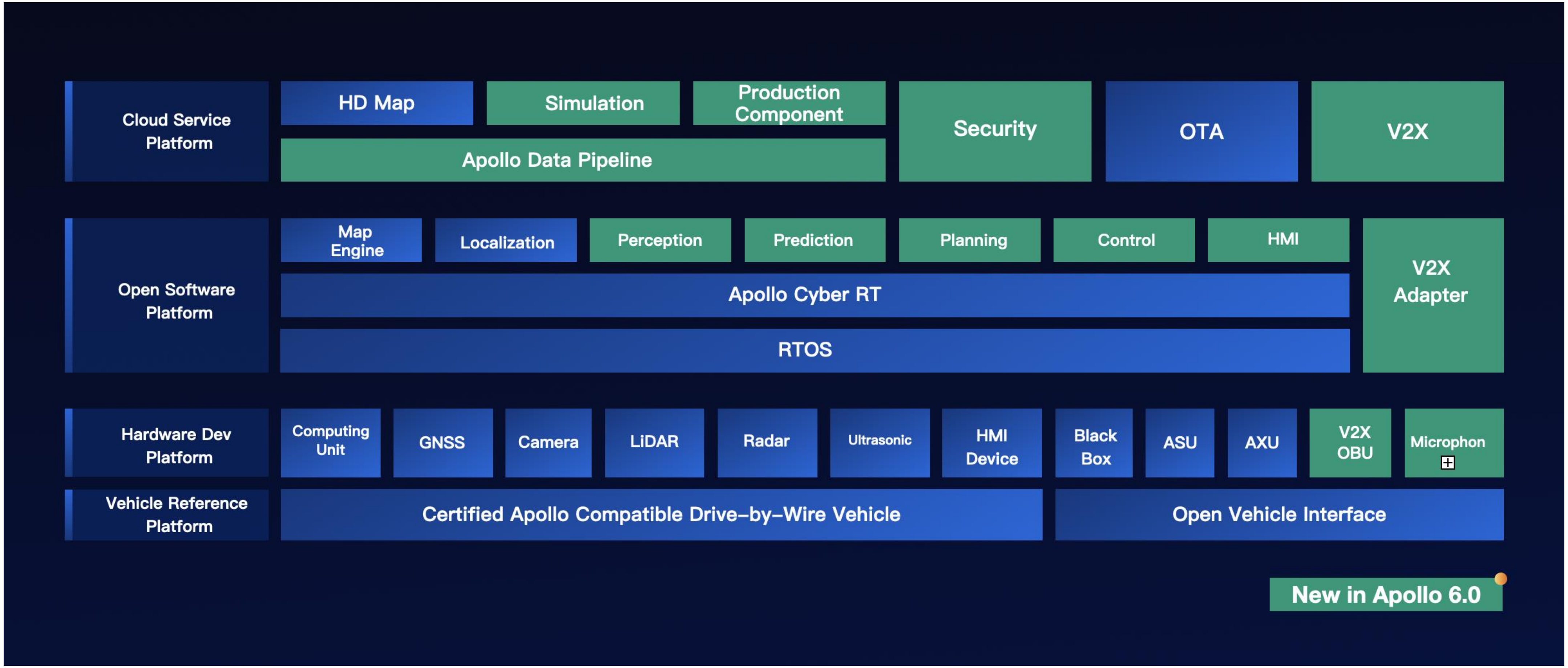
- **Automotivelinux**
  - BMW, GM, VW, Toyota, Chevrolet, Honda, Mercedes, Tesla, Lyft, Baidu
- Android Automotive OS
  - Renault, Nissan, Mitsubishi
- Apple CarPlay
  - Audi, BMW, Toyota, Nissan, Ford, Honda, Mazda, and Mercedes-Benz.
- **ROS (Robotic Operating System)**
  - General Motors, BMW, Ford, Bosch, Karsan
- Microsoft

# All in One: autoware.ai (ROS 1), autoware.auto (ROS 2)



# All in One: Apollo (Baidu)

# All in One: Apollo (Baidu)



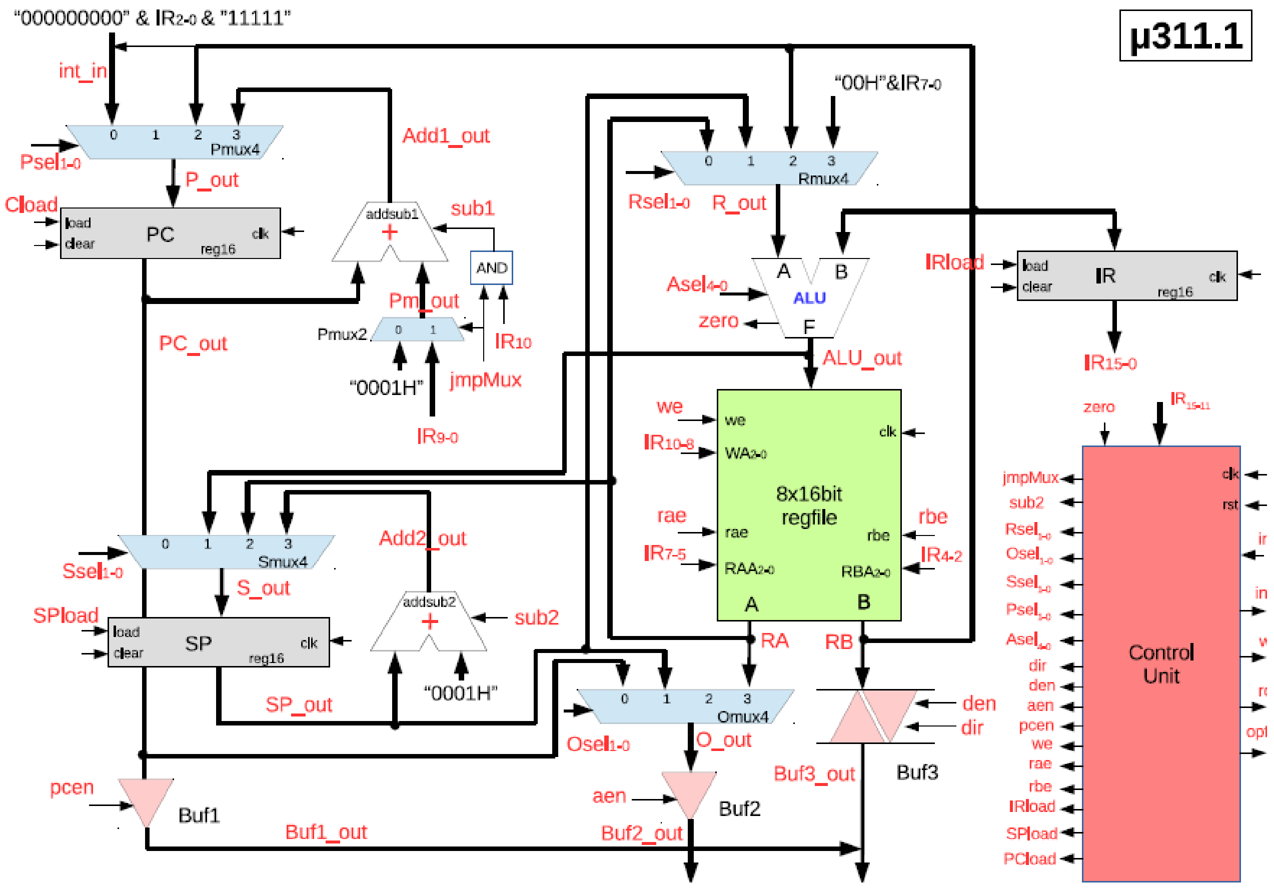
# Simülatörler

| | | Documentation | | | | | Environment | | | | Sensors | | | | | Output Training Labels | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | For Driving | | Actors | | Cameras | | | Others | | | | |
| | Licence | Installation | Environments | Sensor config | Output labels | Engine | Urban | Off-road | Humans | Cars | RGB | Depth | Thermal / IR | Lidar | Radar | Semantic Segmentation | 2D bbox | 3D bbox |
| CARLA | MIT | + | + | + | + | UE | T | - | + | + | + | + | - | + | - | + | + | + |
| AirSim | MIT | + | + | + | + | UE | T C | F M G | - | + | + | + | + | + | - | + | -* | -* |
| Deepdrive | MIT | + | - | + | - | UE | R | - | - | + | + | + | - | - | - | -* | -* | + |
| LGSVL | Propr | + | + | + | + | Unity | C | - | + | + | + | + | - | + | + | + | + | + |
| Sim4CV | Propr | + | - | - | - | UE | T | D G | + | + | + | + | - | - | - | + | + | + |
| SynCity | Propr | NA[45] | NA | NA | NA | Unity | T C H | D F G U M | + | + | + | + | + | + | + | + | + | + |
| Unikie | Propr | NA | NA | NA | NA | NA | C | U H | + | + | + | - | - | + | - | NA | NA | NA[46] |
| rFpro | Propr | NA | NA | NA | NA | NA | T C R | - | + | + | + | + | NA | + | + | + | NA | NA |
| Cognata | Propr | NA | NA | NA | NA | Custo | C | - | + | + | + | NA | NA | + | + | + | NA | NA |
| SCANeR Studio | Propr | NA | NA | NA | NA | NA | C R | - | NA | + | + | NA | NA | + | + | + | NA | NA |
| Highwai | Propr | NA | NA | NA | NA | Unity | C | - | + | + | + | + | + | + | NA | NA[47] | + | + |
| NVIDIA Drive | Propr | NA | NA | NA | NA | UE | C H | - | NA | NA | + | NA | NA | + | + | + | + | NA |

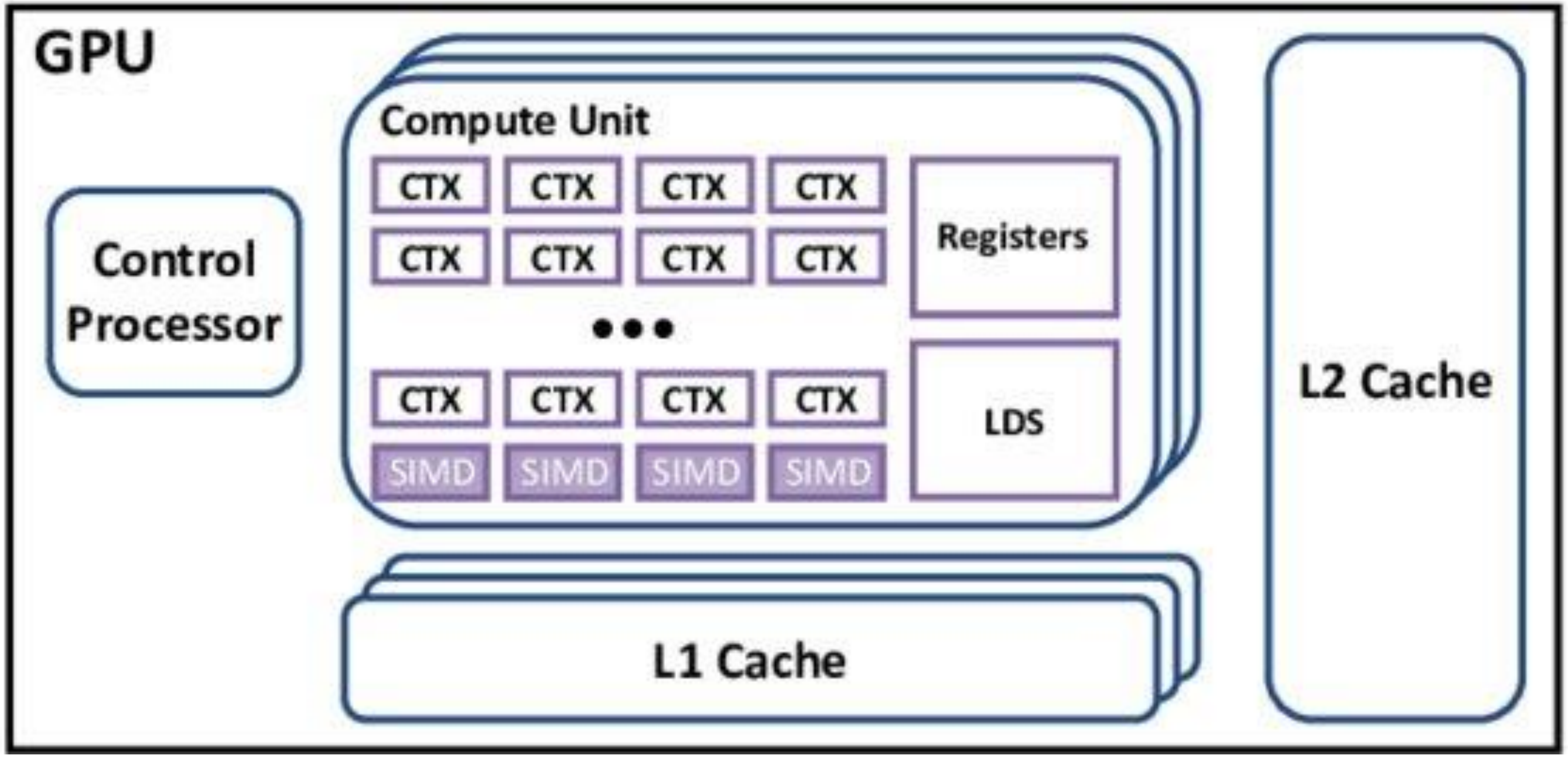
# Donanım: heterogeneous computing

- «Mikrokontroller»
- CPU
- GPU
- FPGA

# Donanım: CPU ve «Mikrokontroller»

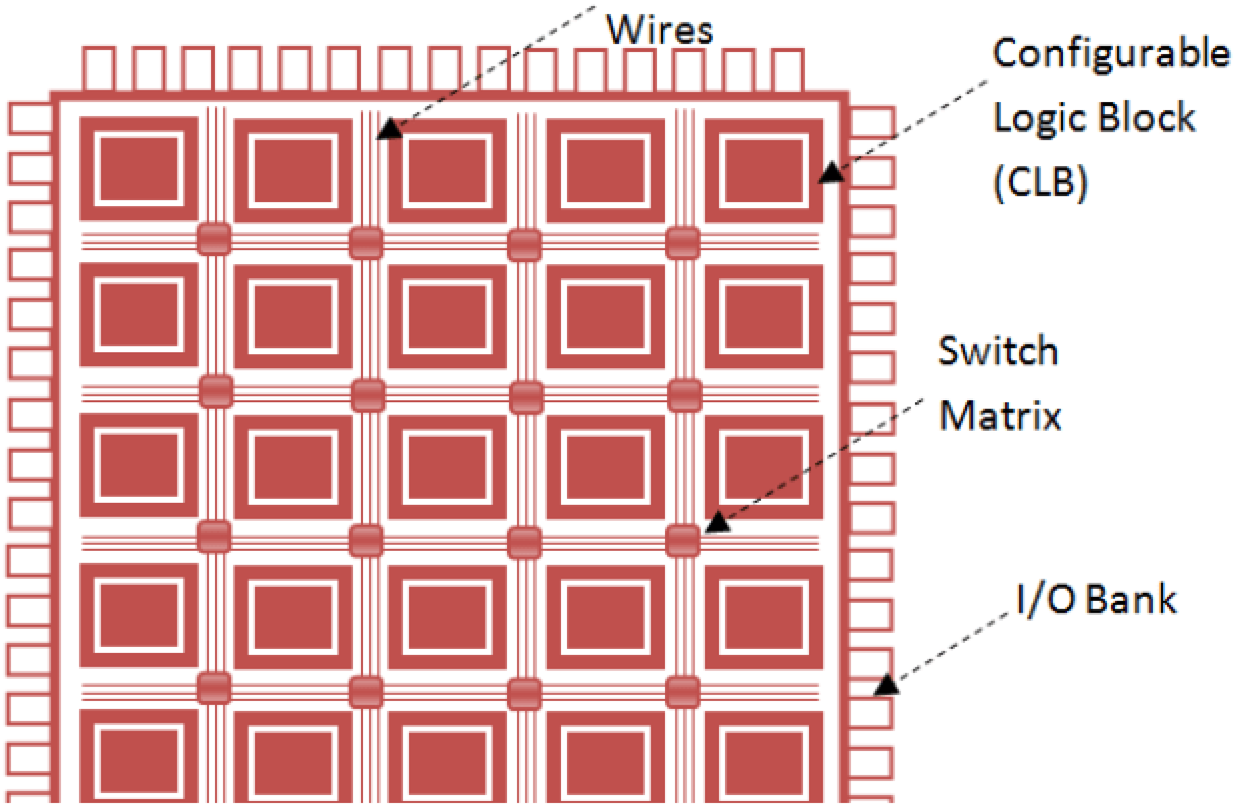


# Donanım: GPU

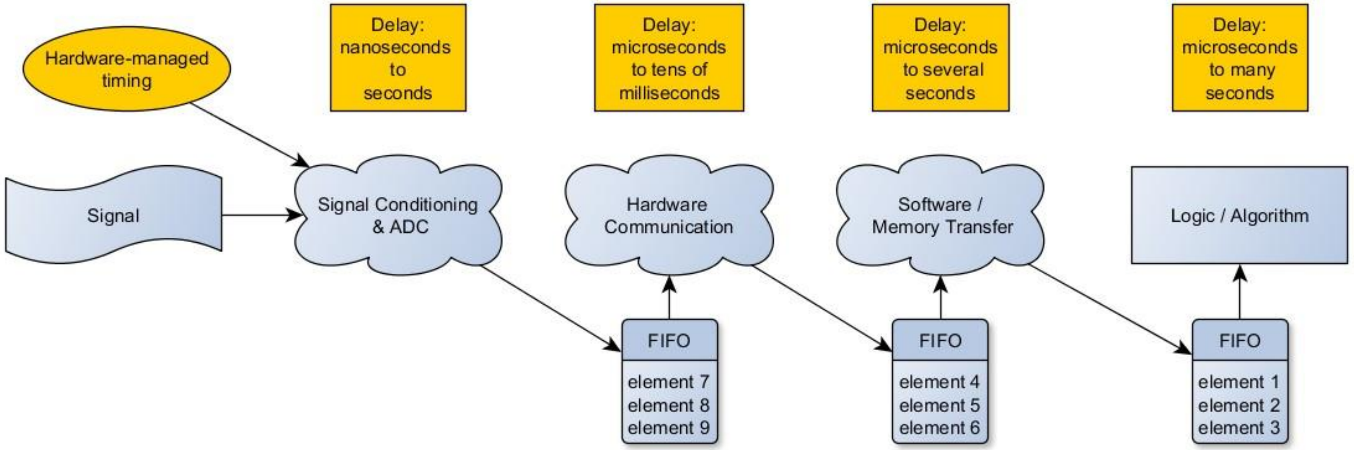

GPU
Compute Unit
CTX
CTX
CTX
CTX
CTX
CTX
CTX
CTX
CTX
CTX
CTX
CTX
SIMD
SIMD
SIMD
SIMD
Registers
LDS
Control Processor
L1 Cache
L2 Cache

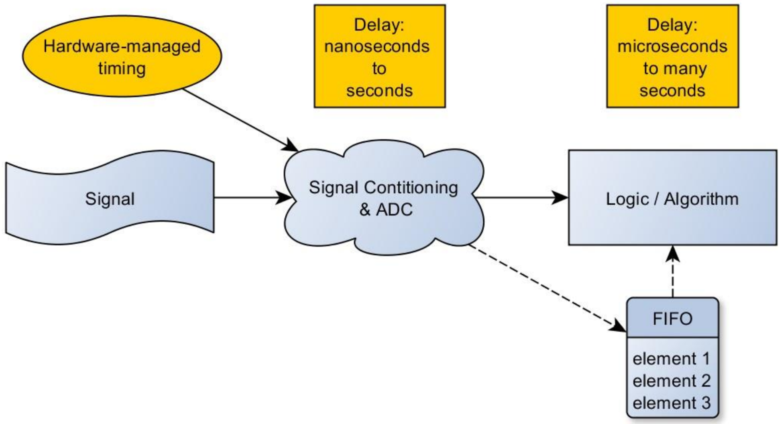
# Donanım:FPGA

A = 2
B = 3
C = A + B
D = C + A
A = A + 2

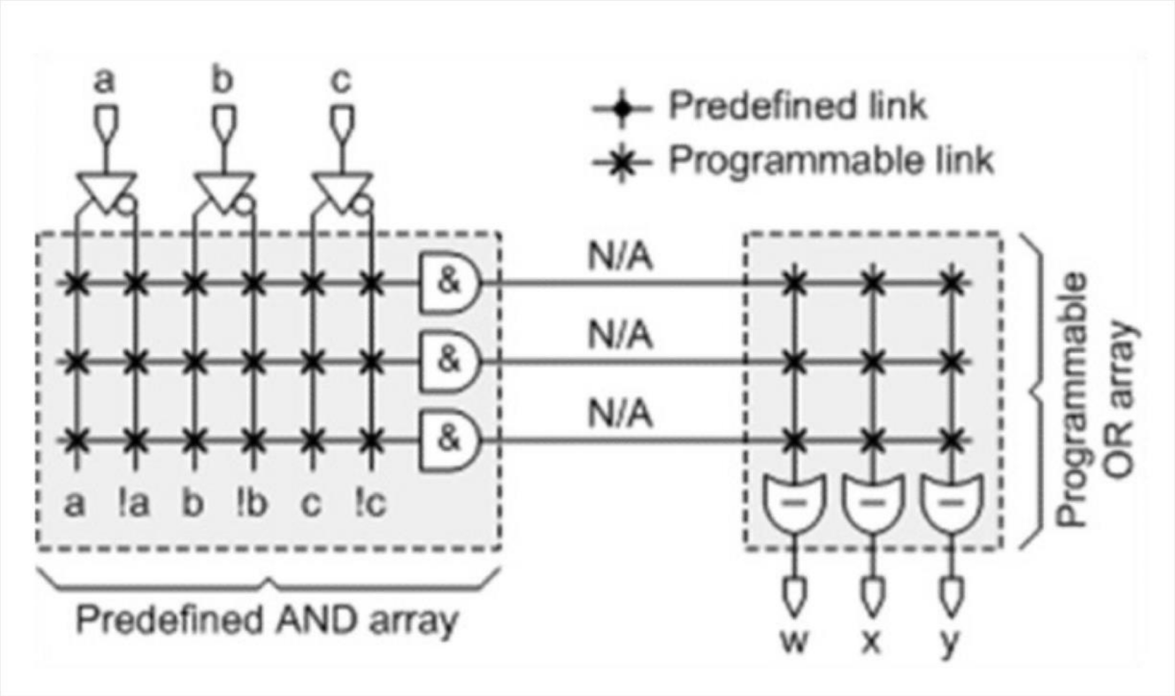


# Donanım:FPGA

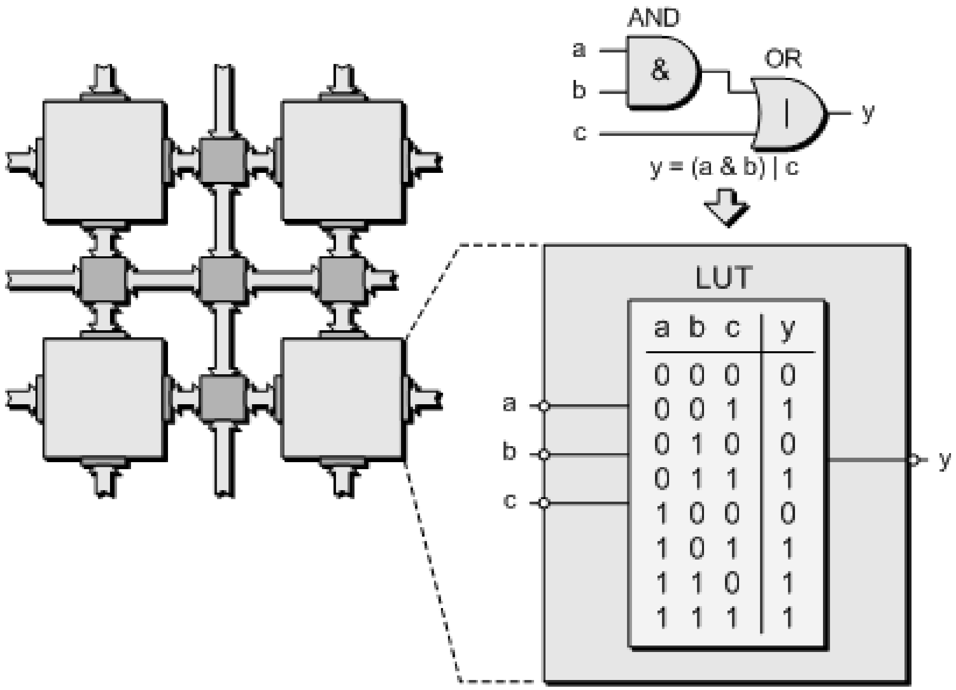


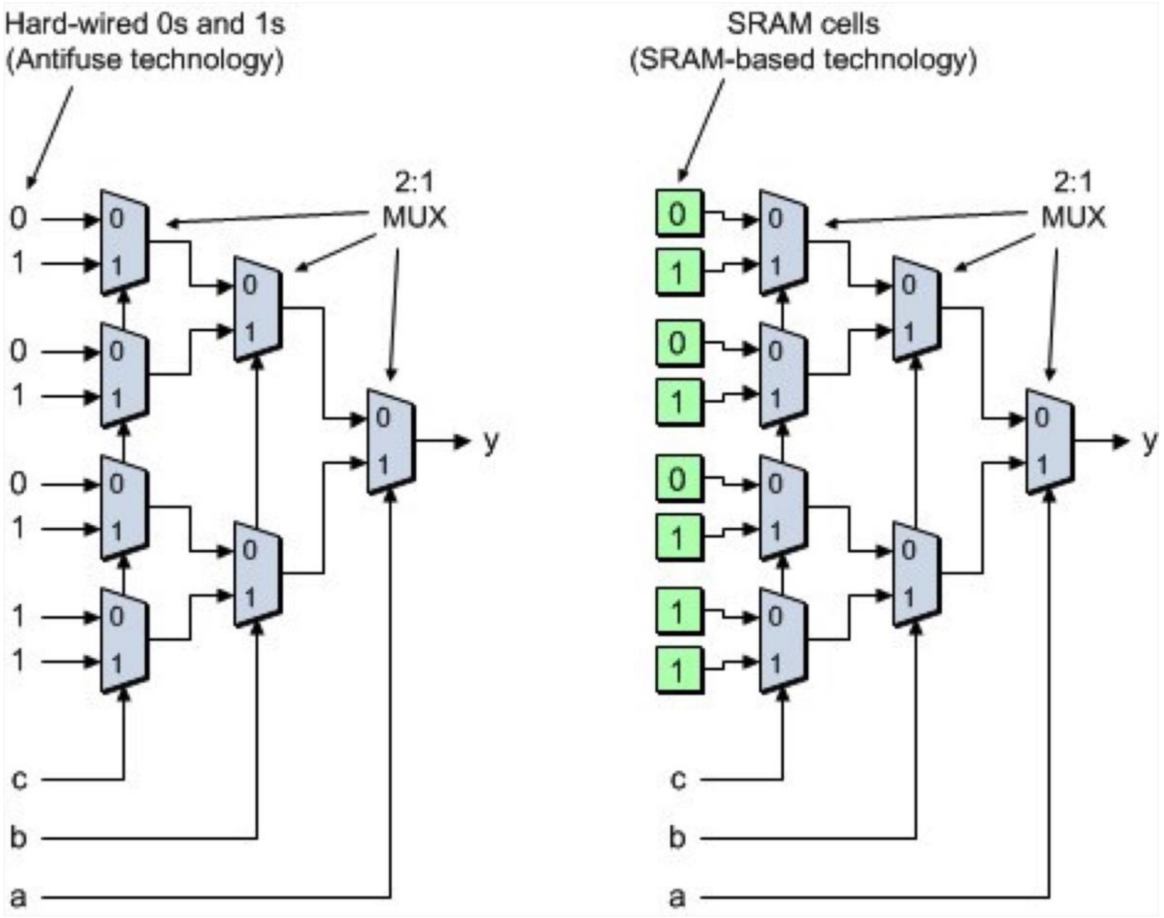
# Donanım:FPGA

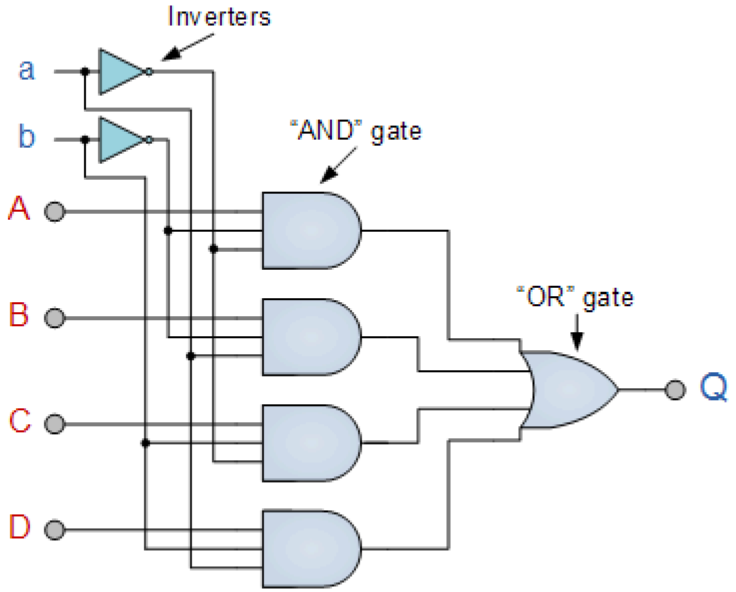



Programmable Logic
Arrays



# Donanım:FPGA



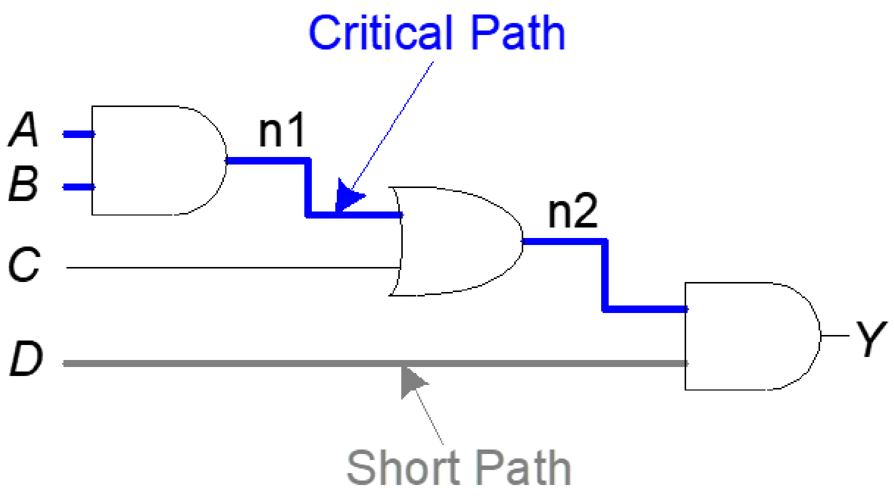



# Donanım:FPGA

| Row number | $x_1$ | $x_2$ | $x_3$ | Minterm | Maxterm |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | $m_0 = \bar{x}_1\bar{x}_2\bar{x}_3$ | $M_0 = x_1 + x_2 + x_3$ |
| 1 | 0 | 0 | 1 | $m_1 = \bar{x}_1\bar{x}_2x_3$ | $M_1 = x_1 + x_2 + \bar{x}_3$ |
| 2 | 0 | 1 | 0 | $m_2 = \bar{x}_1x_2\bar{x}_3$ | $M_2 = x_1 + \bar{x}_2 + x_3$ |
| 3 | 0 | 1 | 1 | $m_3 = \bar{x}_1x_2x_3$ | $M_3 = x_1 + \bar{x}_2 + \bar{x}_3$ |
| 4 | 1 | 0 | 0 | $m_4 = x_1\bar{x}_2\bar{x}_3$ | $M_4 = \bar{x}_1 + x_2 + x_3$ |
| 5 | 1 | 0 | 1 | $m_5 = x_1\bar{x}_2x_3$ | $M_5 = \bar{x}_1 + x_2 + \bar{x}_3$ |
| 6 | 1 | 1 | 0 | $m_6 = x_1x_2\bar{x}_3$ | $M_6 = \bar{x}_1 + \bar{x}_2 + x_3$ |
| 7 | 1 | 1 | 1 | $m_7 = x_1x_2x_3$ | $M_7 = \bar{x}_1 + \bar{x}_2 + \bar{x}_3$ |

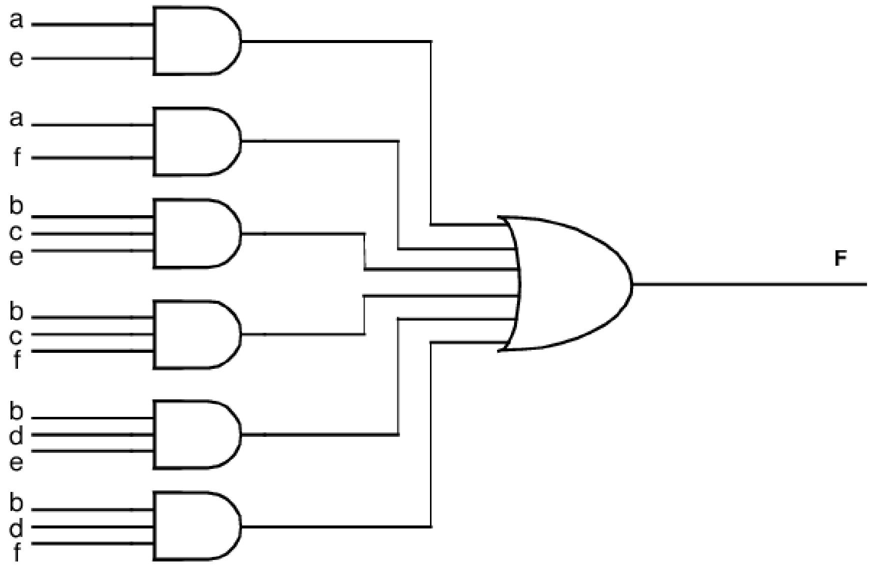
M0 x M1 x M2 x M3

# Donanım:FPGA

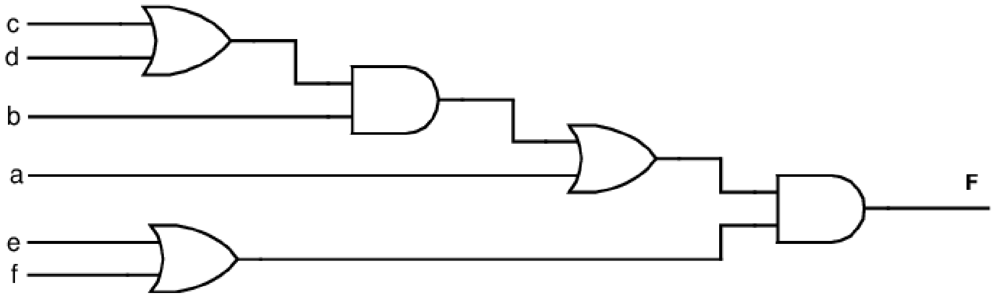



**Critical (Long) Path:** $t_{pd} = 2t_{pd\_AND} + t_{pd\_OR}$

**Short Path:** $t_{cd} = t_{cd\_AND}$

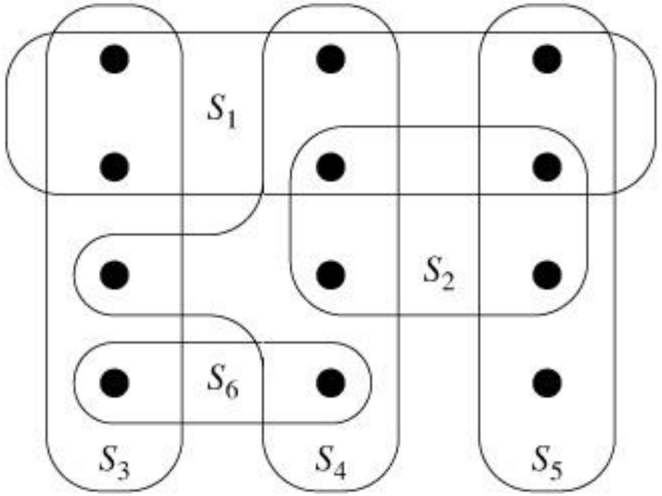


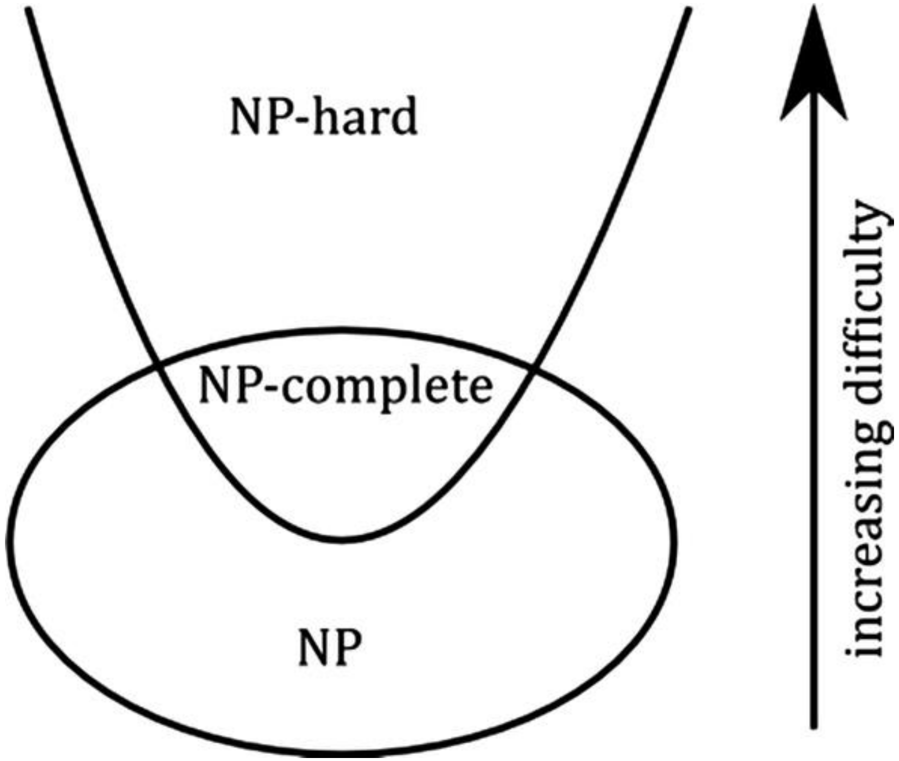

(a)



# Donanım:FPGA

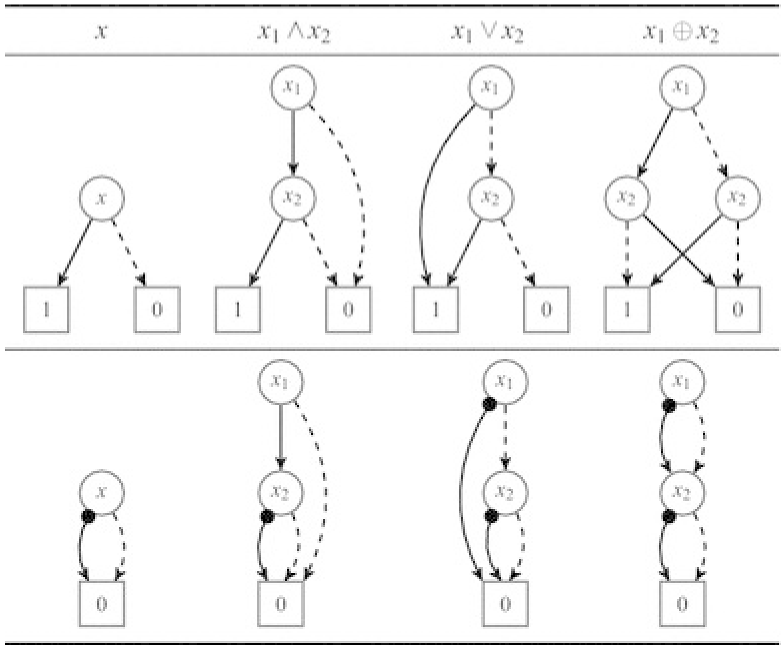
- Boolean satisfiability problem
- Set Cover Problem
- Quine-McCluskey method

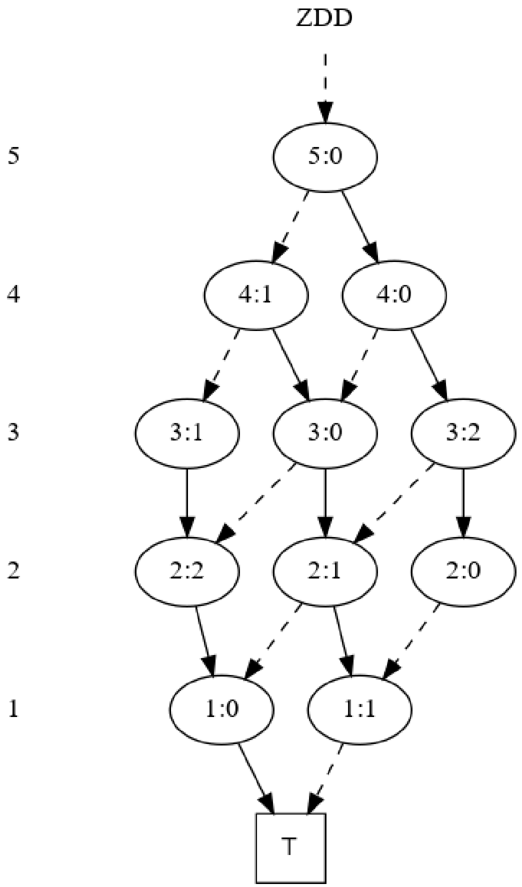


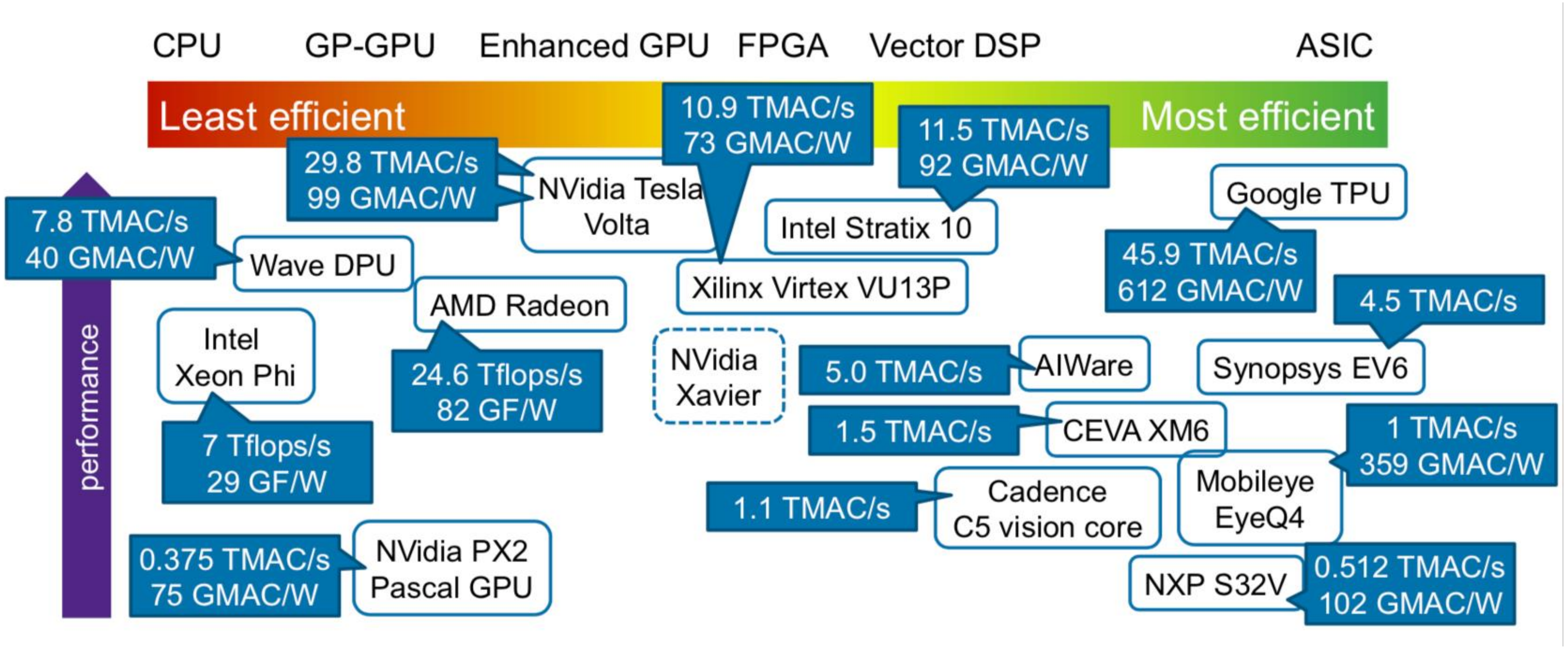
# Unate and Binate functions

- BDDs
- ZDDs



# Otonom Araçlar



# Otonom Araçlar

| **Test cases** | **Intensiveness** | **Best case FPGA** | | **Best case GPU** | | **Time ratio** | **Energy ratio** |
|---|---|---|---|---|---|---|---|
| | | **Time** | **Energy** | **Time** | **Energy** | | |
| KNN Algorithm 1 | Memory-access | 4.24ms | 0.43mJ | 3.04ms | 1.2mJ | 1.4 | 0.36 |
| KNN Algorithm 2 | | **1.23ms** | **0.003J** | 0.93s | 84J | 0.0013 | 3.57E-05 |
| Black Scholes Model European Option | Floating-point computation | **0.0788ns** | **1.67nJ** | 0.164ns | 14.76nJ | 0.48 | 0.11 |
| Black Scholes Model Asian Option | | **0.0815ns** | **1.96nJ** | 0.168ns | 15.12nJ | 0.45 | 0.13 |
| Heston Model European Option | | **0.157ns** | **3.33nJ** | 0.604ns | 48.32nJ | 0.26 | 0.069 |
| Heston Model European Barrier Option | | 0.158ns | 4.917nJ | 0.813ns | 65.04nJ | 0.19 | 0.076 |
| Bitonic Sort without HLS Optimizations | Memory-access | 152ms | 760mJ | 16ms | 480mJ | 9.5 | 1.58 |
| Bitonic Sort with Optimizations | | 17ms | **272mJ** | **16ms** | 480mJ | 1.06 | 0.57 |

# Otonom Araçlar

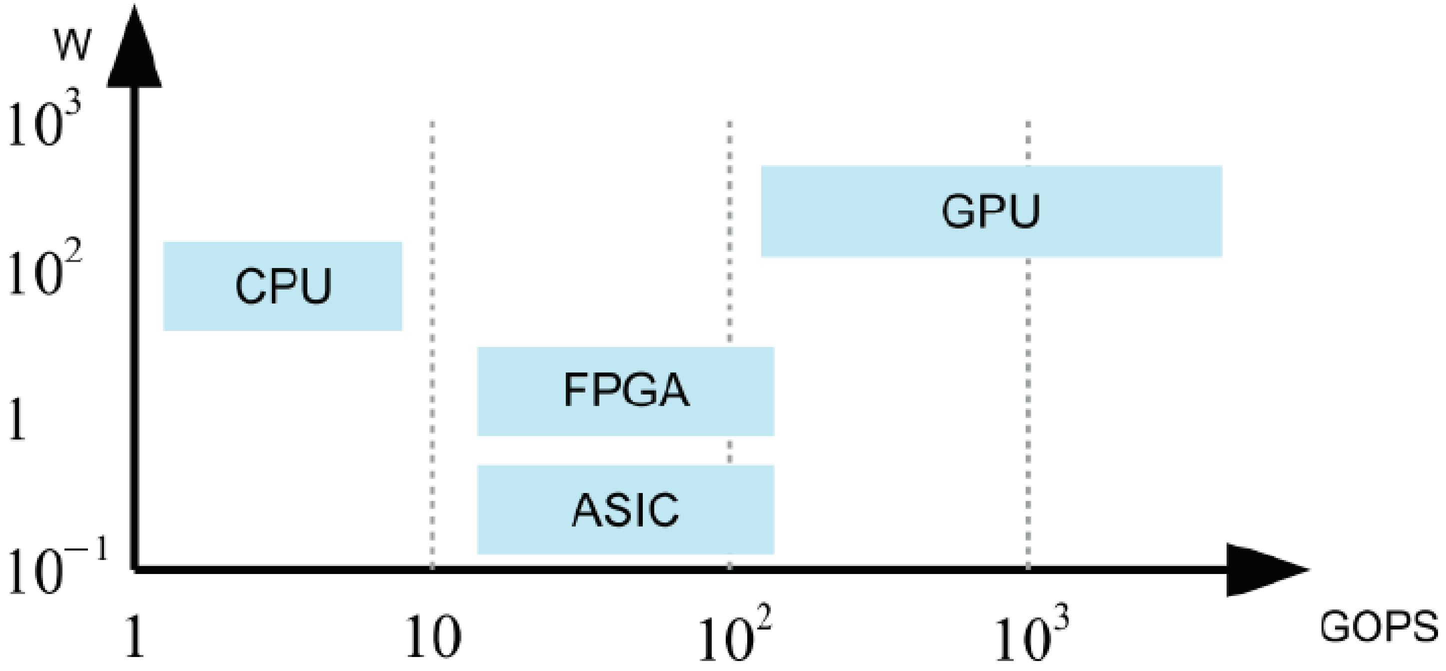
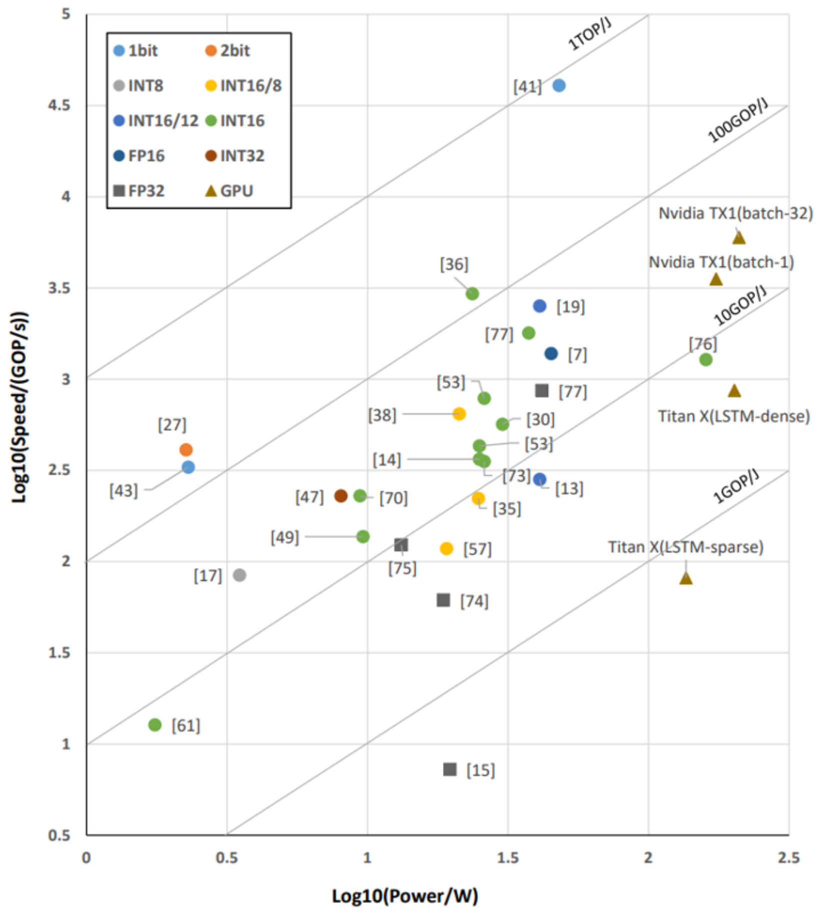



Figure 3.8: Comparison between different platforms.

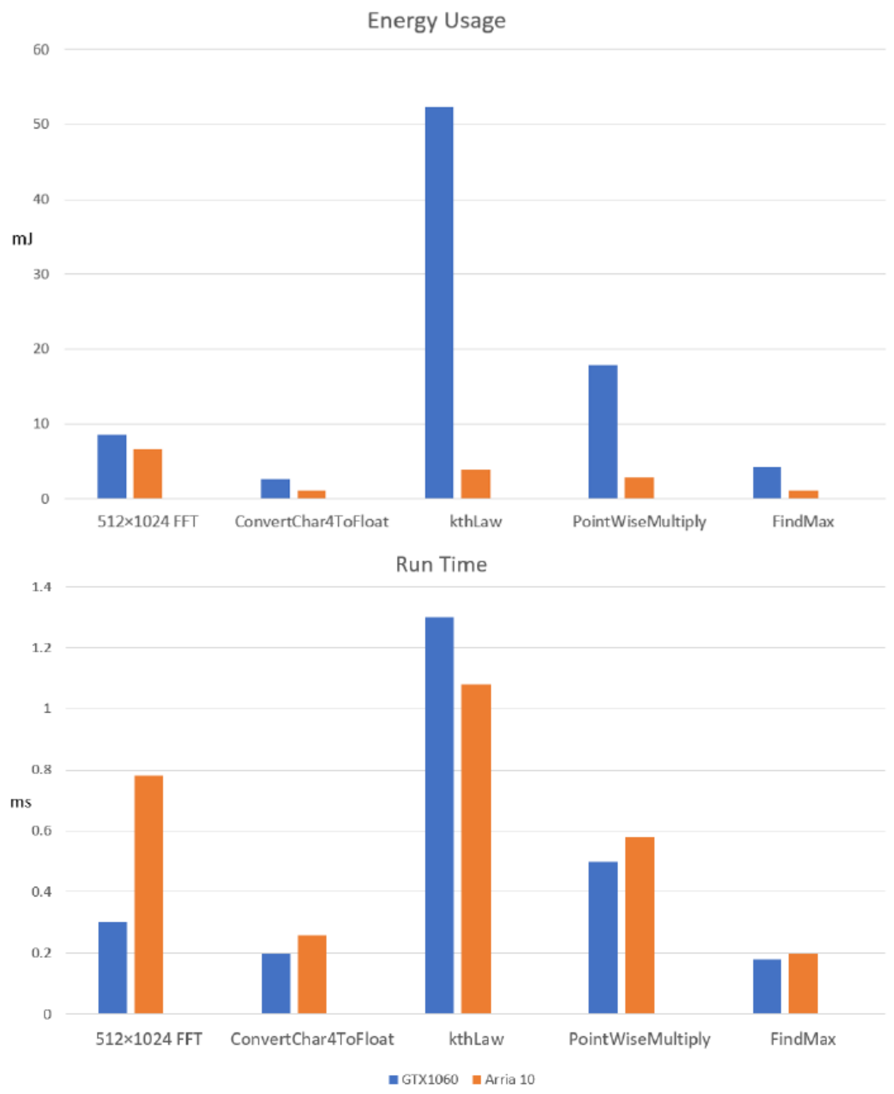
# Otonom Araçlar




| | Data Format | Speed (GOP/s) | Power (W) | Eff. (GOP/J) | Resource(%) DSP | logic | BRAM | FPGA chip |
|---|---|---|---|---|---|---|---|---|
| [43] | 1bit | 329.47 | 2.3 | 143.2 | 1 | 34 | 11 | Zynq XC7Z020 |
| [41] | 1bit | 40770 | 48 | 849.38 | - | - | - | GX1155 |
| [27] | 2bit | 410.22 | 2.26 | 181.51 | 41 | 83 | 38 | Zynq XC7Z020 |
| [17] | INT8 | 84.3 | 3.5 | 24.1 | 87 | 84 | 89 | XC7Z020 |
| [57] | INT16/8 | 117.8 | 19.1 | 6.2 | 13 | 22 | 65 | 5SGSD8 |
| [35] | INT16/8 | 222.1 | 24.8 | 8.96 | 40 | 27 | 40 | XC7VX690T |
| [38] | INT16/8 | 645.25 | 21.2 | 30.43 | 100 | 38 | 70 | GX1150 |
| [19] | INT16/12 | 2520 | 41 | 61.5 | 54 | 89 | 88 | XCKU060 |
| [61] | INT16 | 12.73 | 1.75 | 7.27 | 95 | 67 | 6 | XC7Z020 |
| [49] | INT16 | 136.97 | 9.63 | 14.22 | 89 | 84 | 87 | XC7Z045 |
| [70] | INT16 | 229.5 | 9.4 | 24.42 | 92 | 71 | 83 | XC7Z045 |
| [73] | INT16 | 354 | 26 | 13.6 | 78 | 81 | 42 | XC7VX690T |
| [14] | INT16 | 364.4 | 25 | 14.6 | 65 | 25 | 46 | 5SGSMD5 |
| [30] | INT16 | 565.94 | 30.2 | 22.15 | 60 | 63 | 65 | XC7VX690T |
| [53] | INT16 | 431 | 25 | 17.1 | 42 | 56 | 52 | XC7VX690T |
| | | 785 | 26 | 30.2 | 53 | 8.3 | 30 | XCVU440 |
| [76] | INT16 | 1280.3 | 160 | 8 | - | - | - | XC7Z020+ XC7VX690T×6 |
| [77] | INT16 | 1790 | 37.46 | 47.8 | 91 | 43 | 53 | GX1150 |
| [36] | INT16 | 2940.7 | 23.6 | 124.6 | - | - | - | ZCU102 |
| [7] | FP16 | 1382 | 45 | 30.7 | 97 | 58 | 92 | GX1150 |
| [47] | INT32 | 229 | 8.04 | 28.5 | 100 | 84 | 18 | Stratix V |
| [15] | FP32 | 7.26 | 19.63 | 0.37 | 42 | 65 | 52 | XC7VX485T |
| [74] | FP32 | 61.62 | 18.61 | 3.3 | 80 | 61 | 50 | XC7VX485T |
| [75] | FP32 | 123.5 | 13.18 | 9.37 | 88 | 85 | 64 | Stratix V |
| [77] | FP32 | 866 | 41.73 | 20.75 | 87 | - | 46 | GX1150 |

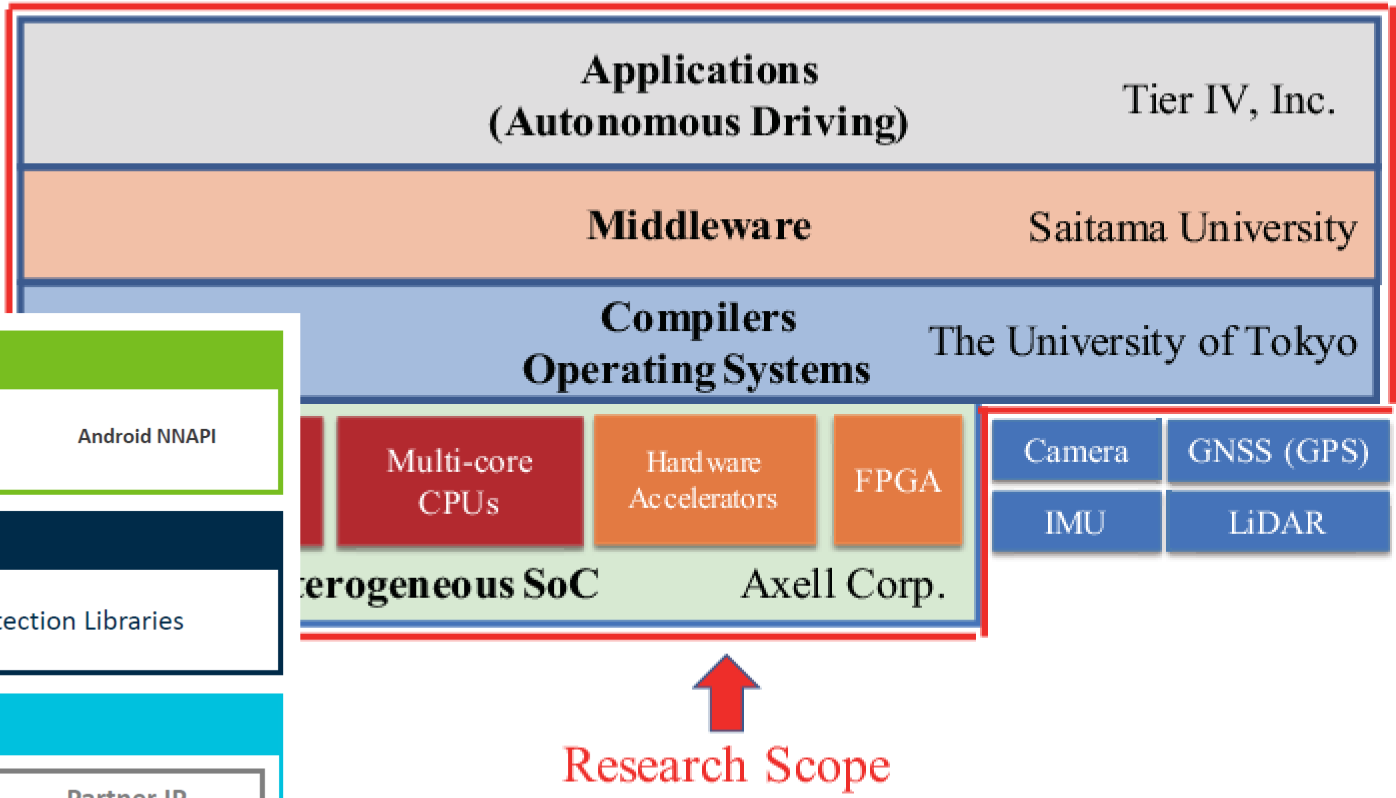
# Donanım:FPGA vs GPU vs CPU

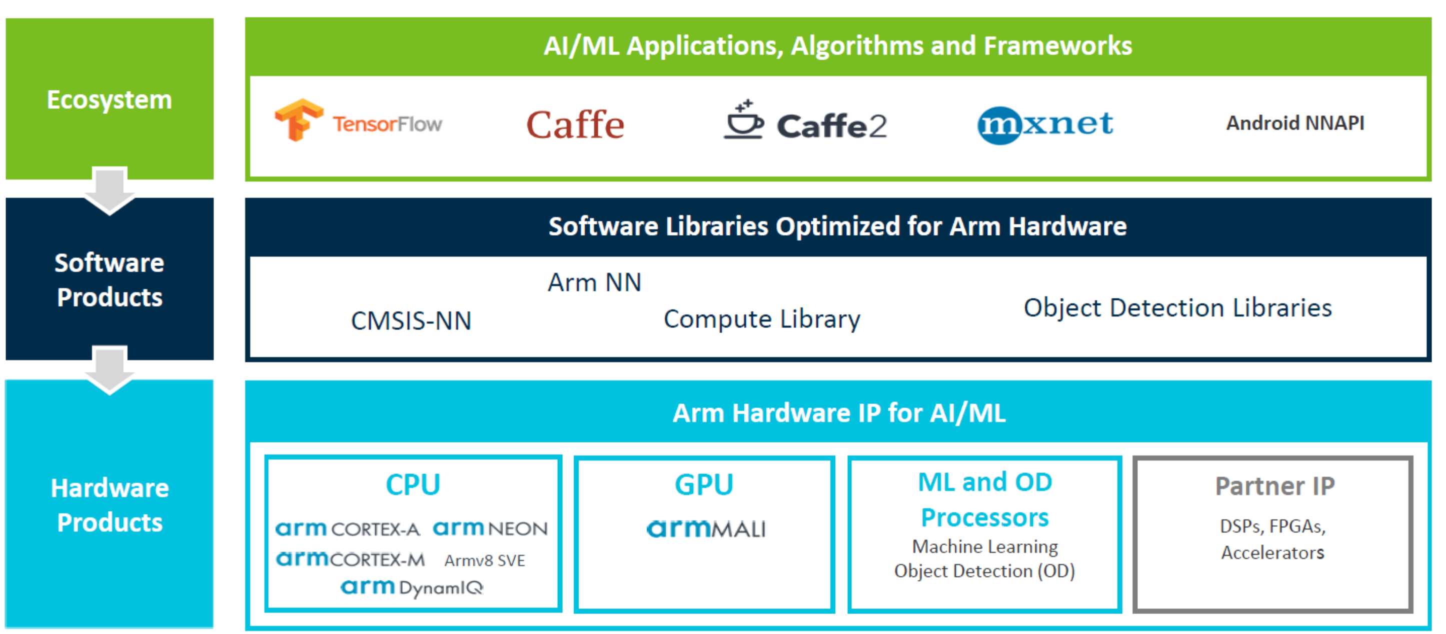
- FPGA
  - Domain specific hardware
  - high performance-per-watt
  - high-throughput
  - real-time processing
  - flexibility
  - low latency
  - Custom I/O
- GPU
  - Kolay öğrenim
  - Yazılım desteği
  - Geniş kullanım alanı
  - Daha ucuz
- CPU ve Mikrokontroller
  - En kolay öğrenim
  - Yazılım desteği
  - Geniş kullanım alanı
  - En ucuz



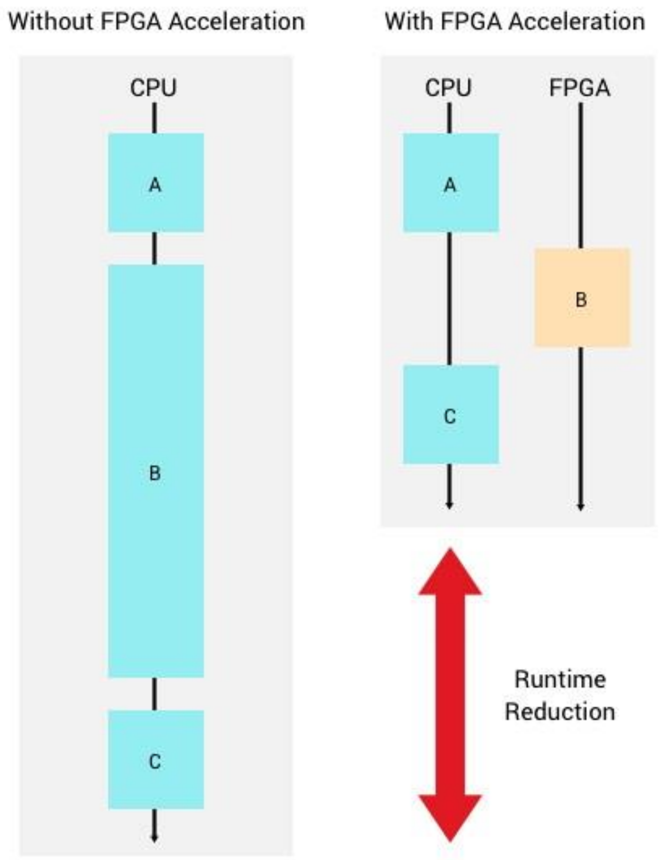
# Heterogeneous computing

# Heterogeneous computing



# Heterogeneous computing



# Teşekkürler