
HE IG VD

Intelligence Artificielle pour les systèmes autonomes (IAA)

Systèmes autonomes embarqués

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Février 2024

Basé sur le cours du Prof. A. Geiger

Hes·so
Haute Ecole Spécialisée de Suisse occidentale

Reconfigurable & embedded Digital Systems

Outline

Today's lesson

→ **Sensors**

→ The embedded systems equipped in cars

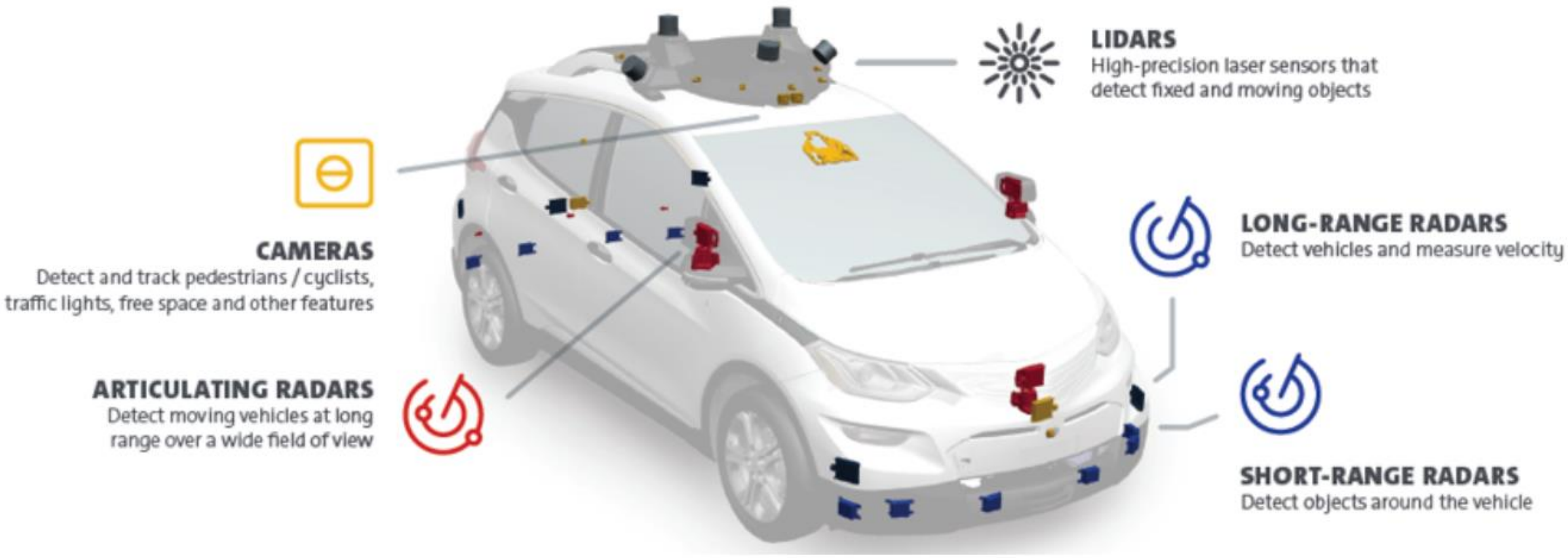
→ The crazyflie 2.1 hardware and software

Sensors equipped in an autonomous car

To enable 3D vision

→ Providing knowledge of the environment's geometry

→ Combining multiple different 3D sensor types



Enabling 3D Vision

Active and passive sensors

→ **Active**: emit sound/radio/light waves

- `Ultrasonic : short range (5 m)`
  `⇒ Parking, blind spot detection`
- `Radar : long range (300 m), low resolution`
  `⇒ Adaptive cruise control (ACC)`
- `Lidar : long range (100 m), mid resolution`
  `⇒ Self-driving vehicle prototypes (expensive)`

→ **Passive** : do not emit any waves

- `Stereo cameras: mid range (50 m)`
  `⇒ Cheap & high resolution, but require processing to obtain depth; accuracy depends on distance/texture`

Stereo cameras

Disparity Estimation to create 2.5D maps (not 3D yet)

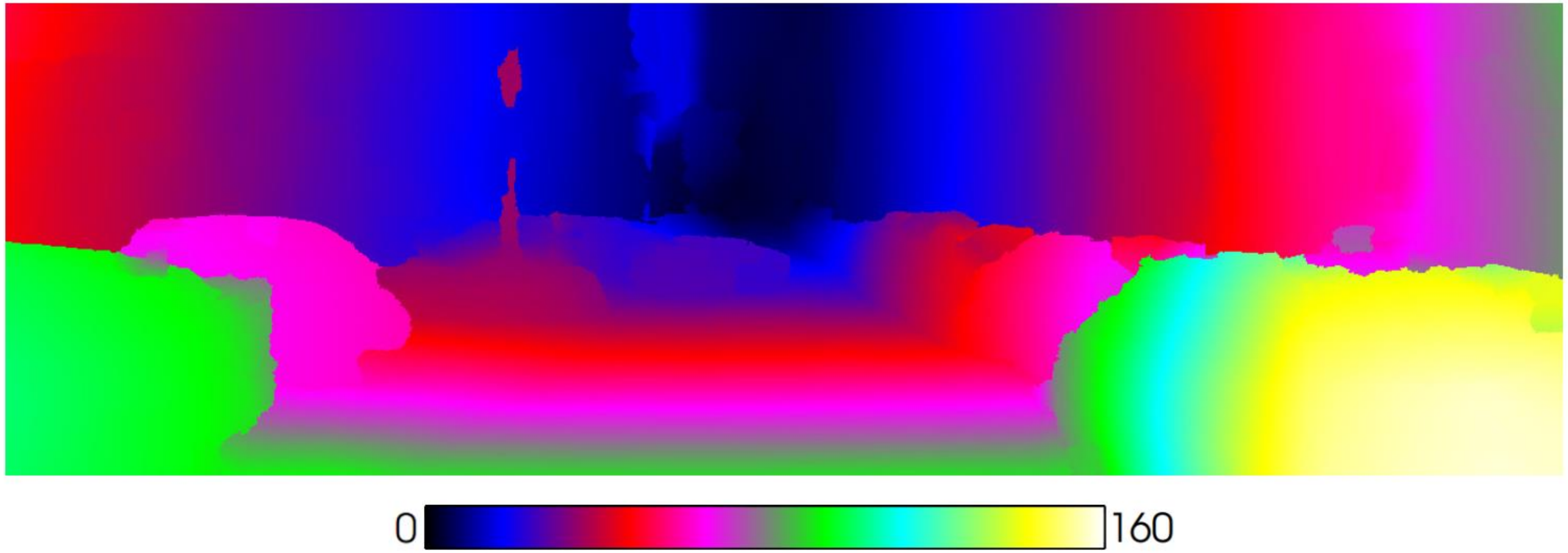
→ Input: Images of the 2 (laterally) displaced cameras (captured at the same time)

→ Output: Horizontal displacement (=disparity) per pixel (disparity map)

→ Disparity (per pixel) is anti-proportional to scene depth : we can create a 2.5D map

Stereo cameras

Disparity Estimation to create 2.5D maps (not 3D yet)



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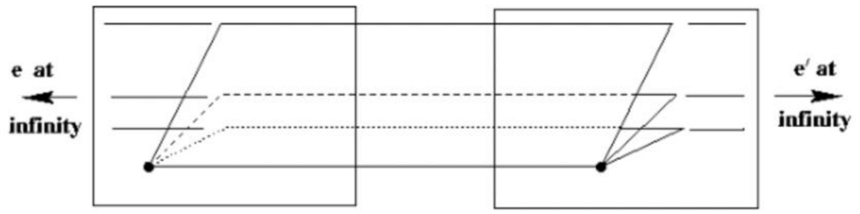
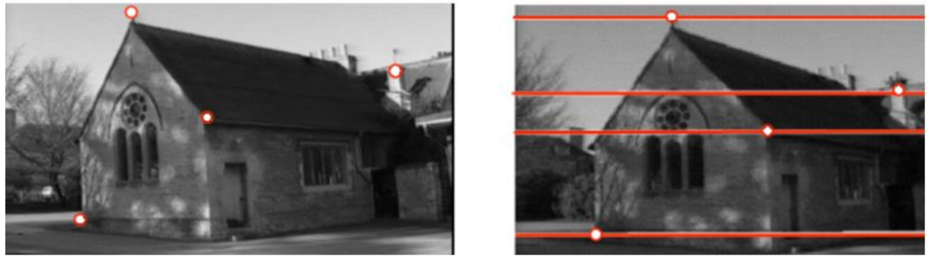
→ Disparity (per pixel) is anti-proportional to scene depth : we can create a 2.5D map

Constructing a dense 2.5D disparity map from 2 images

Pipeline

1. Calibrating cameras
2. Rectifying images
   - Compensating the fact that cameras are not perfecly aligned
3. Compute disparity map
4. Remove outliers
5. Obtain depth from disparity (triangulation)
6. Constructing 3D model (volumetric fusion)

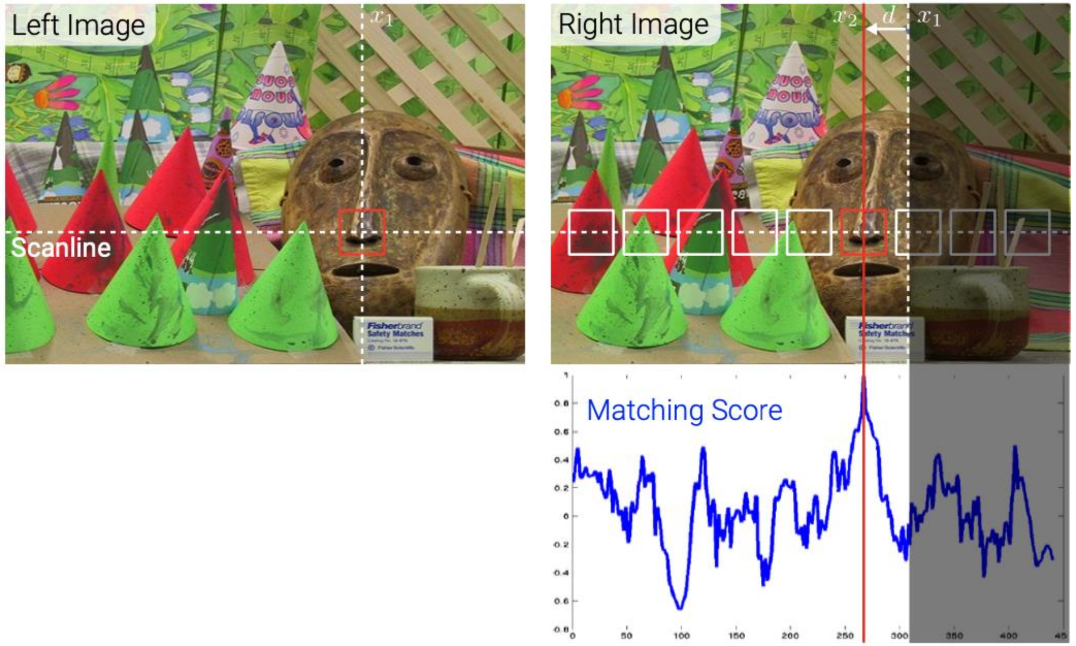


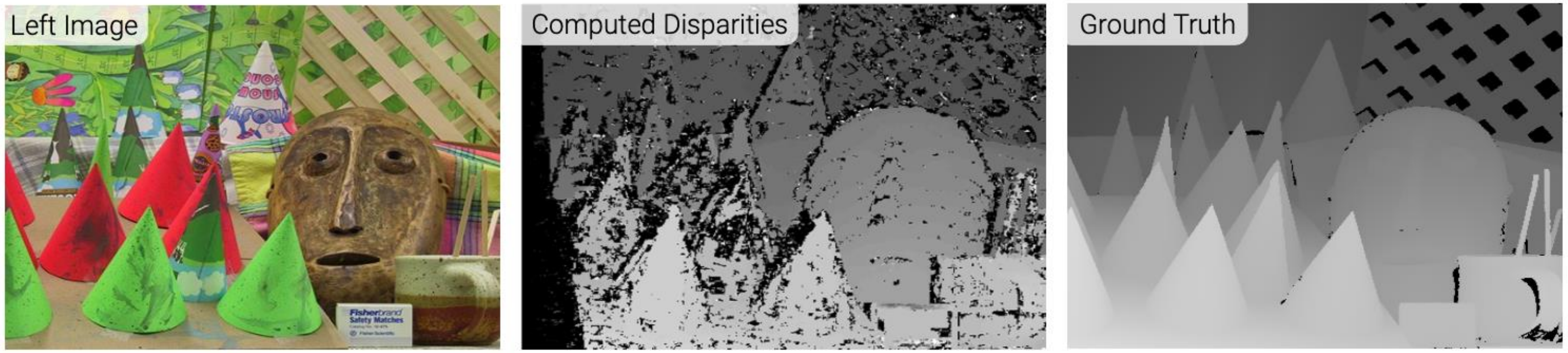


Constructing a dense 2.5D disparity map from 2 images

Pipeline

1. Calibrating cameras
2. Rectifying images
3. Compute disparity map
   - Stereo matching
4. Remove outliers
5. Obtain depth from disparity (triangulation)
6. Constructing 3D model (volumetric fusion)





Constructing a dense 2.5D disparity map from 2 images

Pipeline

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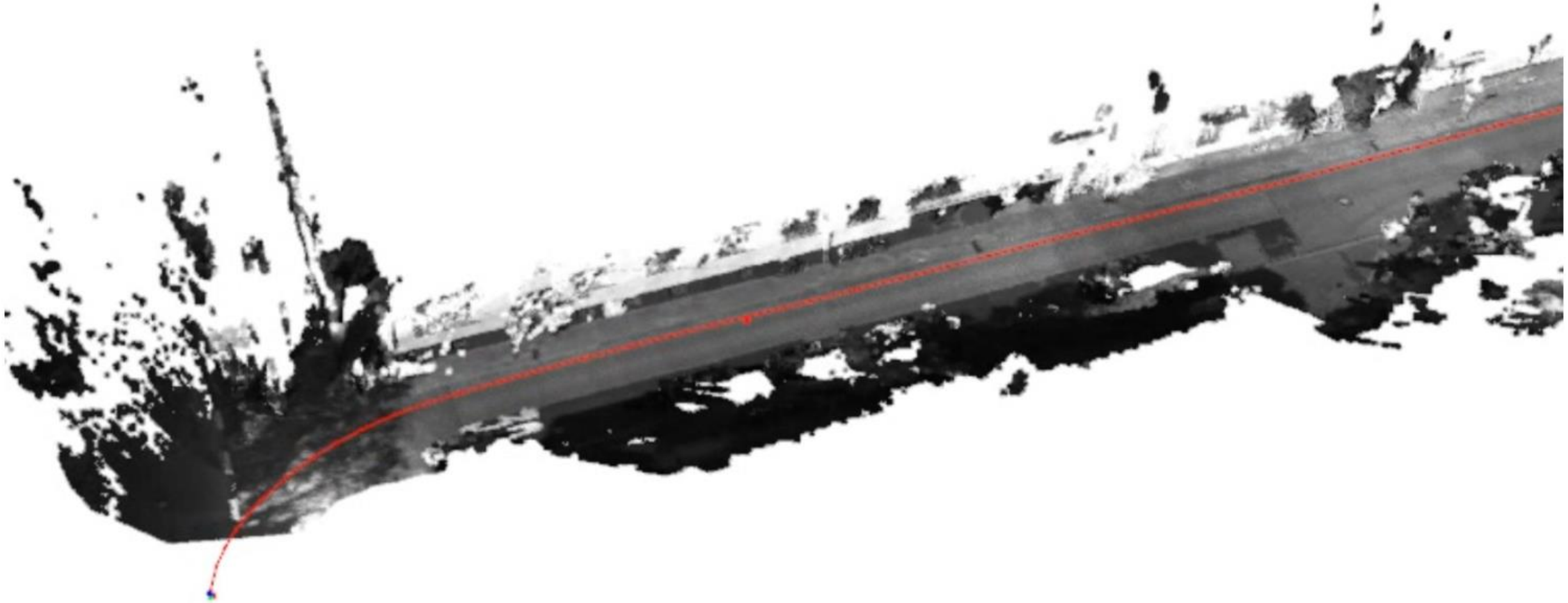
3D reconstruction using stereo cameras

Multiple 2.5D maps fused into a 3D reconstruction



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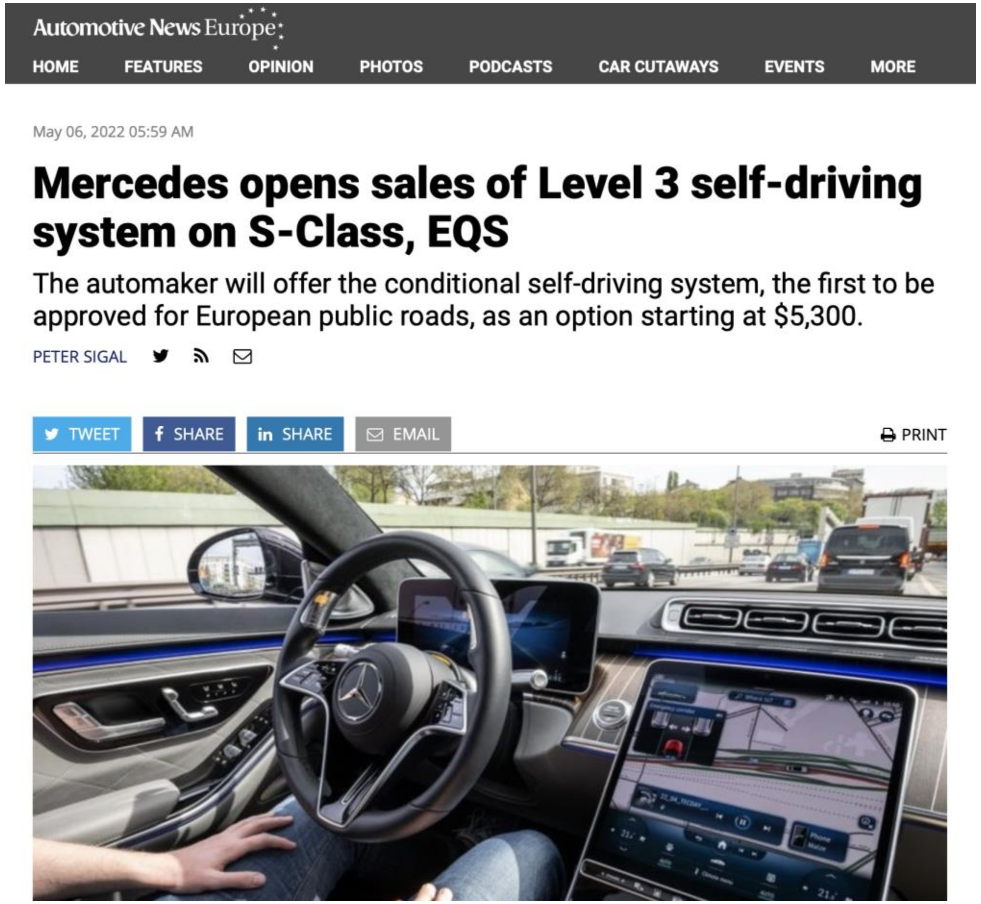
Companies providing Level2+ (and Level 3)

And companies providing HW/SW to those companies

→ Tesla:
- “The first ones”
- Providing Level 2 (certified)
- And claiming higher levels (Level 5) being tested in shadow mode.

→ Mercedes (S-class and EQS)
- First ones providing (2022) Level 3 certified car in Europe
- Openly announced partnership with NVIDIA



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Mercedes opens sales of Level 3 self-driving system on S-Class, EQS

The automaker will offer the conditional self-driving system, the first to be approved for European public roads, as an option starting at $5,300.

PETER SIGAL

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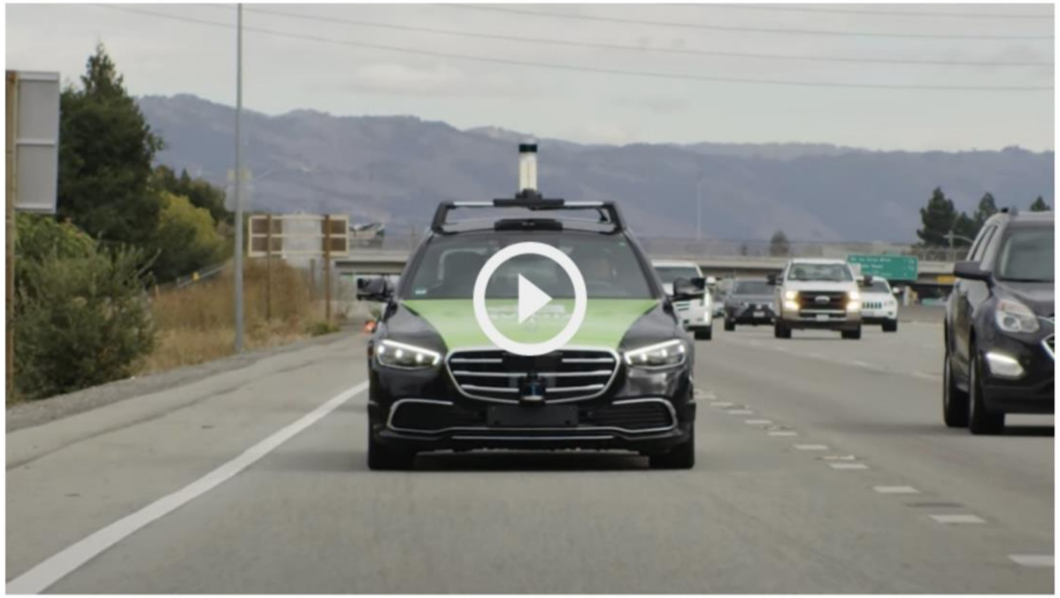
https://www.forbes.com/sites/bradtempleton/2019/04/29/teslas-shadow-testing-offers-a-useful-advantage-on-the-biggest-problem-in-robocars/?sh=798773cf3c06
https://europe.autonews.com/automakers/mercedes-opens-sales-level-3-self-driving-system-s-class-eqs

Driving with NVIDIA’s self-driving car

Mercedes S Class models (Level2+) powered by NVIDIA



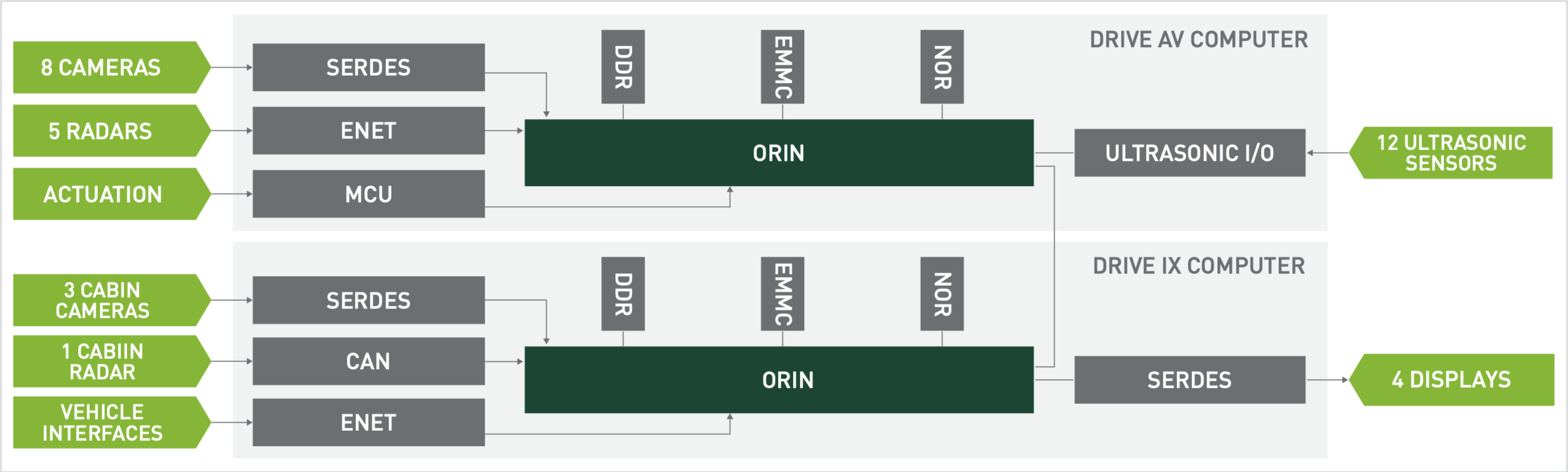
Ride with NVIDIA’s Self-Driving Car

https://blogs.nvidia.com/blog/2020/09/02/mercedes-benz-s-class-ai-cockpit-powered-nvidia/
https://www.nvidia.com/en-us/self-driving-cars/drive-chauffeur/

”Embedded processing” in autonomous cars

NVIDIA Drive : for Level 2+ autonomous driving

→ Working on NVIDIA Drive Orin SoC

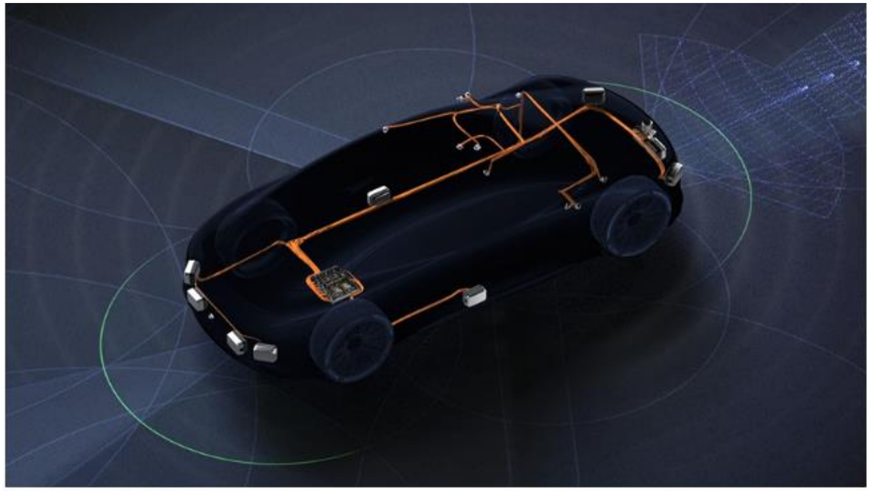


https://www.nvidia.com/content/dam/en-zz/Solutions/self-driving-cars/drive-platform/auto-print-drive-product-brief-final.pdf

Hardware capabilities

Drive AGX Orin DevKit

Component	Description	Details
One Orin SoC	12 Cortex-A78A CPU	
	Deep Learning Accelerators (DLA)	87 TOPS (INT8)
	NVIDIA Ampere architecture-class integrated GPU	167 TOPS (INT8) | 5.2 TOPS (FP32)
	Programmable Vision Accelerators (PVA)	2048 GMACS (INT8) | 512 GMACS (INT16)
	Image Signal Processor (ISP)	1.85Gigapixels/s
	Video encoder	Up to 1.0GPix/s (H.265)
	Video decoder	Up to 1.9GPix/s
	Memory bandwidth (256-Bit LPDDR5)	~200GB/s
DRIVE AGX System I/O	Camera	90Gb/s over 16x GMSL(R) ports
	LIDAR/Radar	~30Gb/s over Ethernet
	Vehicle IO	6 CAN interfaces
Included Accessories	Network Interface Adapter	Converts 1GbE Rugged Auto HMT-D IO to Standard Ethernet RJ45 IO
	Other cables	Connects the DRIVE AGX system to a host development computer



https://developer.nvidia.com/drive/hyperion

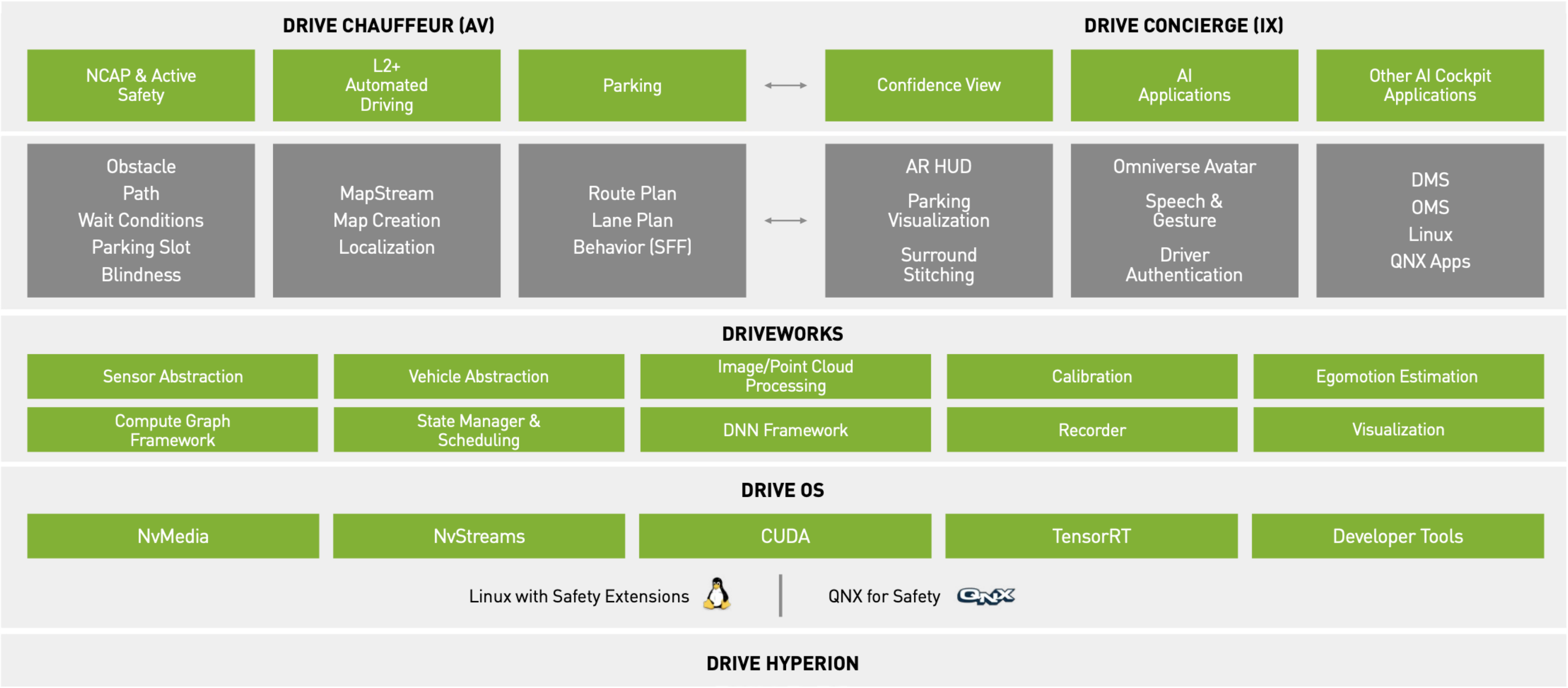
Supported software features

All supported features in a Mercedes Level2+ car today

Active Safety	Highway Driving	Urban Driving and Parking	Cockpit
> Automatic Emergency Braking > Automatic Emergency Steering > Lane Departure Warning > Lane Keeping Assist > Blind Spot Monitoring > Traffic Sign Assist > Stop Sign and Traffic Light Assist	> Adaptive Cruise Control > Lane Centering > Driver-Initiated Lane Change > Automatic Lane Change > Lane Fork to Follow Route (Highway Interchange) > Lane Merge > Speed Adaptations for Curves and Speed Limit Changes	> Traffic Light Stop at Intersection > Protected Intersection Turn > Unprotected Intersection Turn > Roundabout > Yield to Pedestrian Crossing > Parking Assist > Remote Parking	> Confidence View > Augmented Reality > AR HUD > Parking Visualization > Fused Awareness > Conversational AI > Driver/Occupant Monitoring > Activity Monitoring

NVIDIA Drive SDK

For NVIDIA Drive Orin SoC



Sommaire

Cours d’aujourd’hui

→ Sensors

→ The embedded systems equipped in cars

→ **The crazyflie 2.1 hardware and software**

Crazyflie 2.1 – The drone itself

Main HW characteristics

→ Crazyflie 2.1 nanodrone
- Main processor: ARM Cortex-M4 @168MHz, 192kb SRAM, 1Mb
- Radio: ARM Cortex-M0, 32Mhz, 16kb SRAM, 128kb flash
  - 2.4GHz ISM band radio
- Micro-USB connector

→ IMU specification
- 3 axis accelerometer / gyroscope (BMI088)
- High precision pressure sensor (BMP388)

→ Flying time of 7 minutes (charging time 40min)
- Maximum payload of 15g (the drone’s weight is 27g)
- Labs: careful! Keep your done charged!

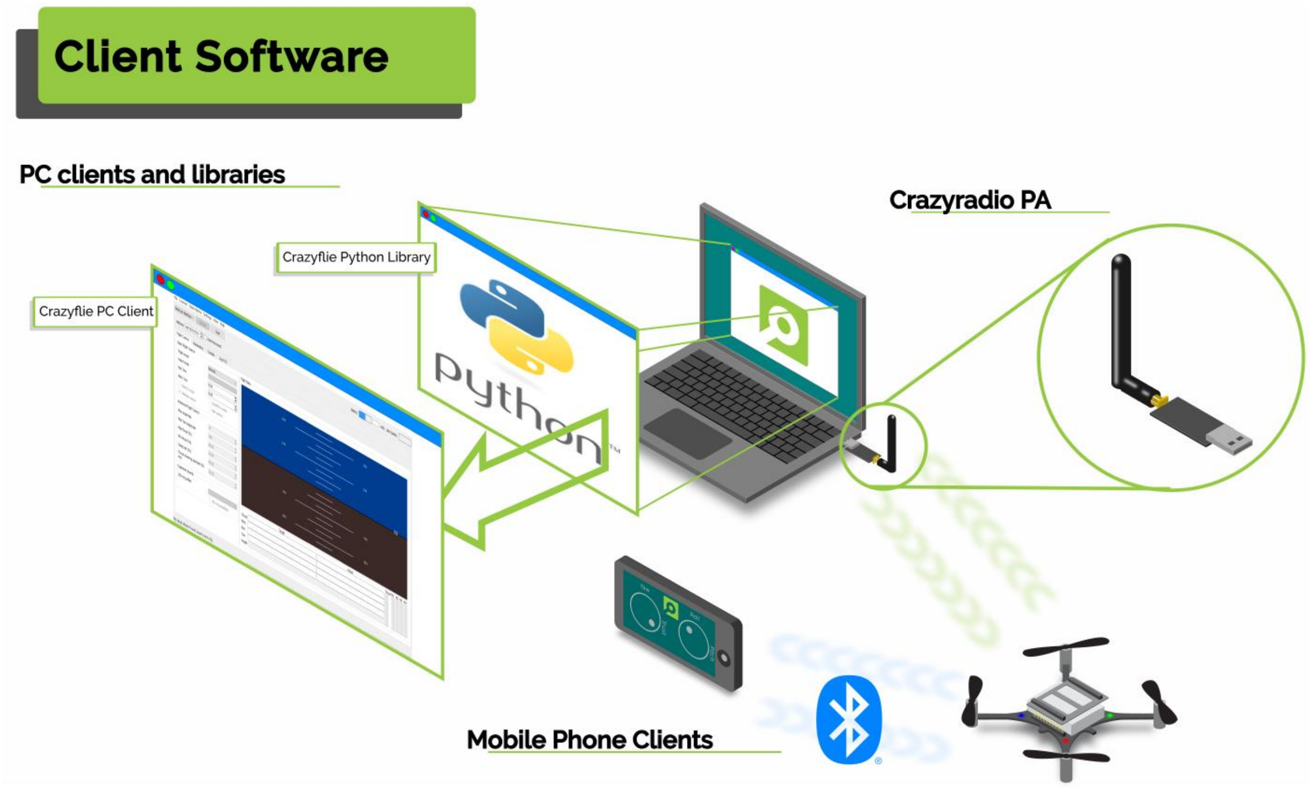
→ Open-source !

Programming and controlling the Crazyflie 2.1

Additional HW (Crazyradio PA) and SW needed to program the drone

→ To program and control the crazyflie you need:
- Crazyradio PA (USB dongle) connected to your PC
- Initially you can control the crazyflie with a phone (or remote control)

→ The drone uses a ROS-based operating system



Adding new shields (decks) to enable autonomous flying

The AI-deck and the Flow deck

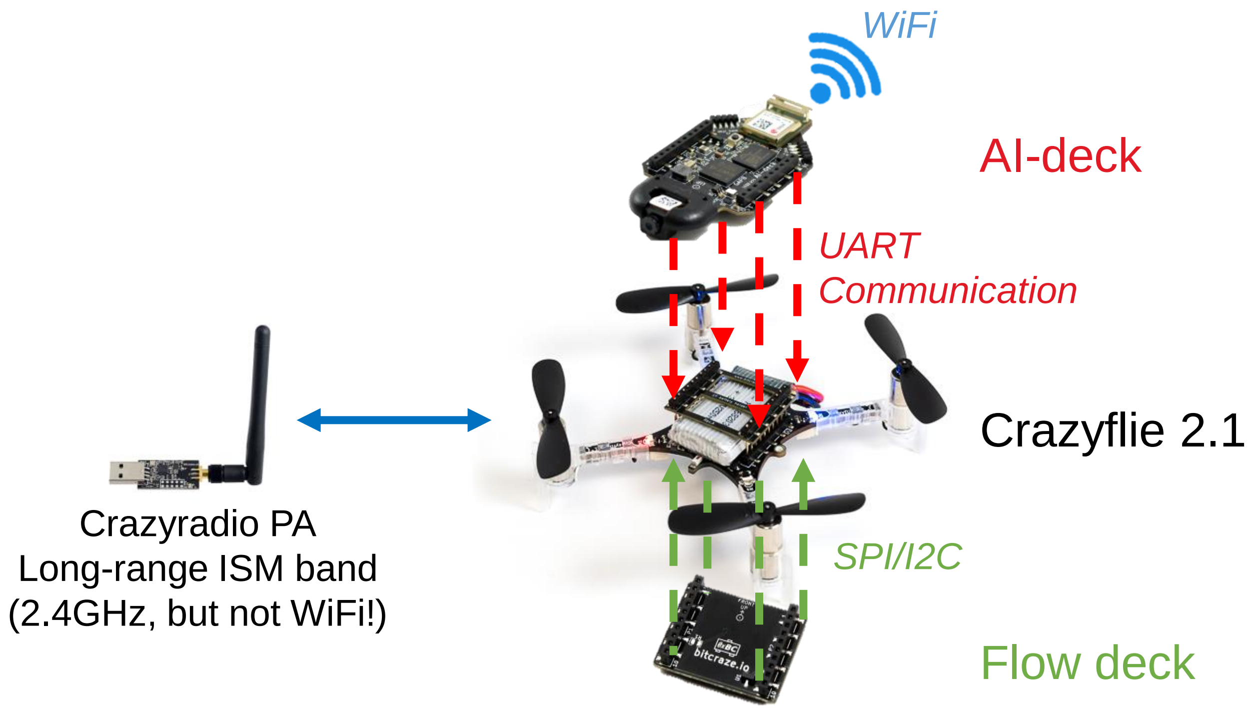
→ AI-deck:

- Camera, WiFi and AI accelerator
- Attached on top of the Crazyflie 2.1

→ Crazyflie 2.1

→ Flow deck v2

- Height control for more stable flying
- Attached to the bottom of the drone, sensor looking down



AI-deck specifications

Adding a camera, WiFi and acceleration for AI tasks

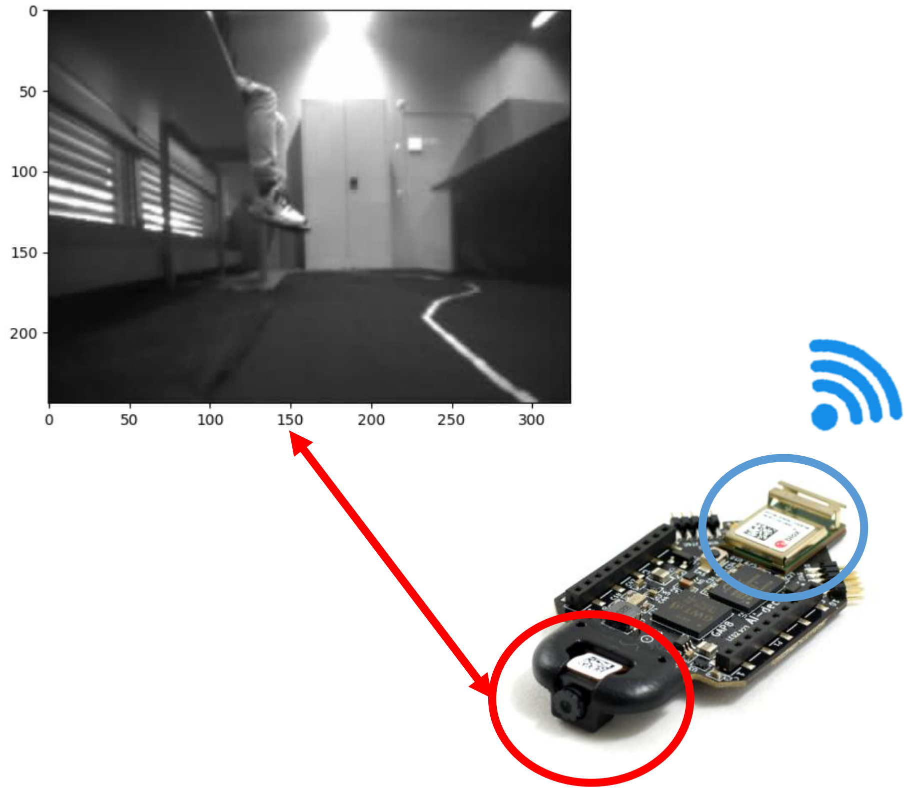
→ The GAP8 chip: a RISC-V based accelerator
- GAP8 – Ultra low power 8+1 core RISC-V
- 250MHz internal clock (max)
- ~8Gflops at tens of mW
- A Convolutional Neural Network accelerator (HWCE)

→ Himax HM01B0 – Ultra low power 320×320 monochrome camera.

→ WiFi Connection (for streaming camera images)
- 512 Mbit HyperFlash and 64 Mbit HyperRAM
  ESP32 for WiFi

→ UART connection to the Crazyflie

→ Based on the PULP cores from ETHZ



https://www.bitcraze.io/documentation/hardware/ai_deck_1_1/ai_deck_1_1-datasheet.pdf
https://greenwaves-technologies.com/wp-content/uploads/2021/04/Product-Brief-GAP8-V1_9.pdf

The “brain” inside the AI-deck

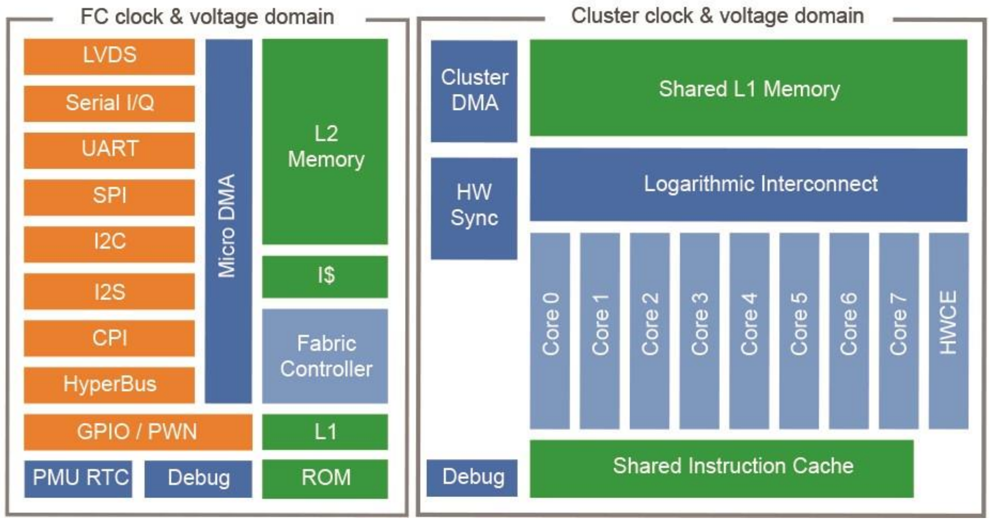
GAP8 hardware and software architecture

→ Software

- PULP OS
- Or FreeRTOS (used in this course, better support)

→ Hardware

- GAP8 is based on the PULP RI5CY core
  - 4-stage in-order 32-bit RISC-V cores
  - 8 cores for acceleration + 1 core for control
  - No FP unit !



- HWCE (hardware convolution engine) : for running CNNs
  - Input and output pixels and weights must be 16-bit, 8-bit or 4-bit fixed-point numbers

https://gwt-website-files.s3.amazonaws.com/gap8_datasheet.pdf
https://pulp-platform.org/docs/ri5cy_user_manual.pdf

Improving Crazyflie’s positioning

Optical navigation

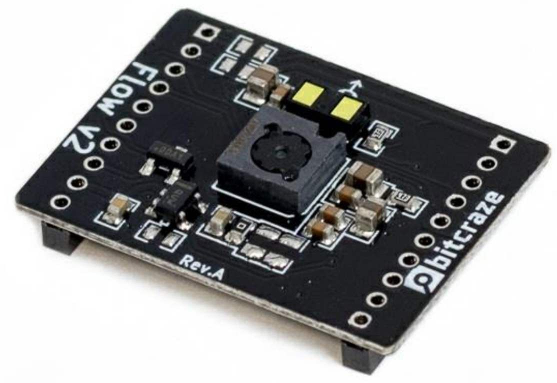
→ VL53L1x ToF sensor to measure distance to the ground:

- up to 4 meters within a few millimeters

→ PMW3901 optical flow sensor measures movements on the ground

→ Goal: create a flying 3D robot that can be pre-programmed to fly distances in any direction

- Very stable flying platform



TODOs for today

Exercises

1. Analysis of the NVIDIA Drive solution in detail
    - https://www.nvidia.com/content/dam/en-zz/Solutions/self-driving-cars/drive-platform/auto-print-drive-product-brief-final.pdf
    - Hardware, software and simulation solutions

2. Analysis of the Crazyflie
    - All components and shield
    - RI5CY cores and GAP8

Lab material

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