

Event-Based Vision: Bringing More Performance and Efficiency to Improve Machine Vision Applications

Presented by: Prophesee

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ASSOCIATION FOR
ADVANCING AUTOMATION

Introducing Your Moderator

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A3: Association for Advancing Automation



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PROPHESÉE
METAVISION FOR MACHINES

Introducing Your Presenter



Gareth Powell
Product Marketing Director
Prophesee

Event-Based Vision Sensing

Bringing more performance and efficiency to improve machine vision applications

Gareth Powell
Director of Product Marketing

PROPHESÉE
META-VISION FOR MACHINES



AGENDA

- Brief introduction about Prophesee
- The Event Sensor (EVS) compared with the CMOS Image Sensor
- The Prophesee offer: sensors and software
- Industrial market application EVS use cases and benefits
- AI and Machine Learning with EVS
- The future: EVS markets and penetration
- Wrap up, Questions and Answers

A B O U T U S

PROPHESÉE

KEY FIGURES

130
PEOPLE



51
PATENTS
SENSOR
SYSTEM
ALGORITHMS
APPLICATIONS

70+

INTERNATIONAL
RECOGNITIONS



PRODUCTS

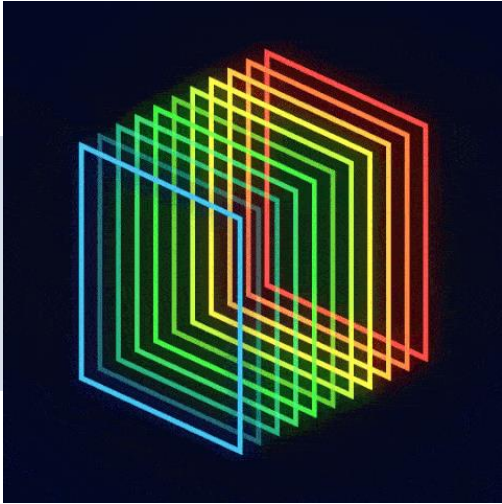
METAVISION®
SENSORS



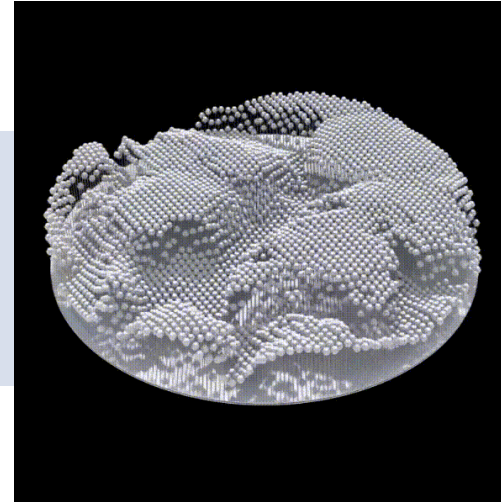
METAVISION®
INTELLIGENCE
SOFTWARE

DEVELOPMENT TOOLS

FRAMES VS EVENTS



FRAME-BASED



EVENT-BASED



1. Generates **sequential** static pictures
2. **Clock-driven** (pre-defined frame rate)
3. Needs **exposure times**
4. **Fix amounts** of data
5. Beautiful pictures for **human consumption** (High-resolution, color...)

1. Generates **continuous** events (asynchronous intelligent pixels)
2. **Scene-driven** ($1\mu\text{s}$ time resolution - 10,000 fps equivalent)
3. **No exposure time** (120dB HDR / 40mlux low light sensitivity)
4. Amounts of data **vary with scene dynamics** (10x to 1000x less)

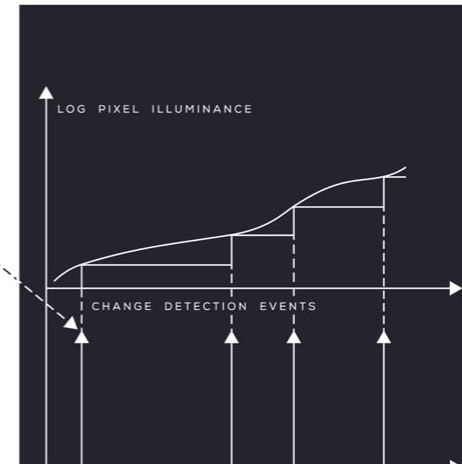
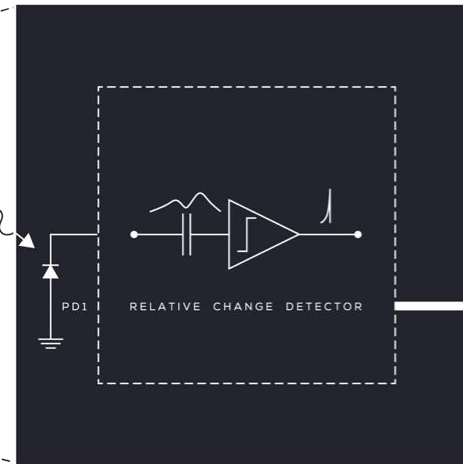
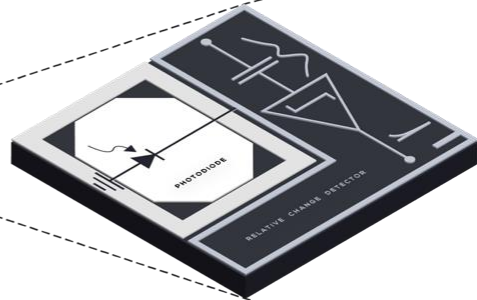
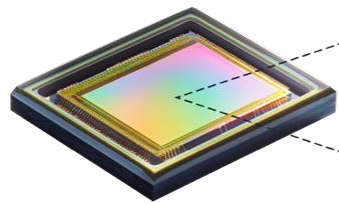
HOW DO (PROPHESÉE) EVENT SENSORS WORK..

Each pixel in the sensor operates asynchronously

Detects intelligently when there is a contrast change on any pixel

Contrast Detection Threshold is programmable

Pixels asynchronously output when contrast change occurs with low latency, in the form of XYT data



EMBEDDED FEATURES

- ④ Event Rate Control
- ④ High/Low/Bandpass filtering
- ④ Multiple ROI
- ④ Embedded micro/SRAM



GENERATES CONTINUOUS EVENTS
(ASYNCHRONOUS INTELLIGENT PIXELS)

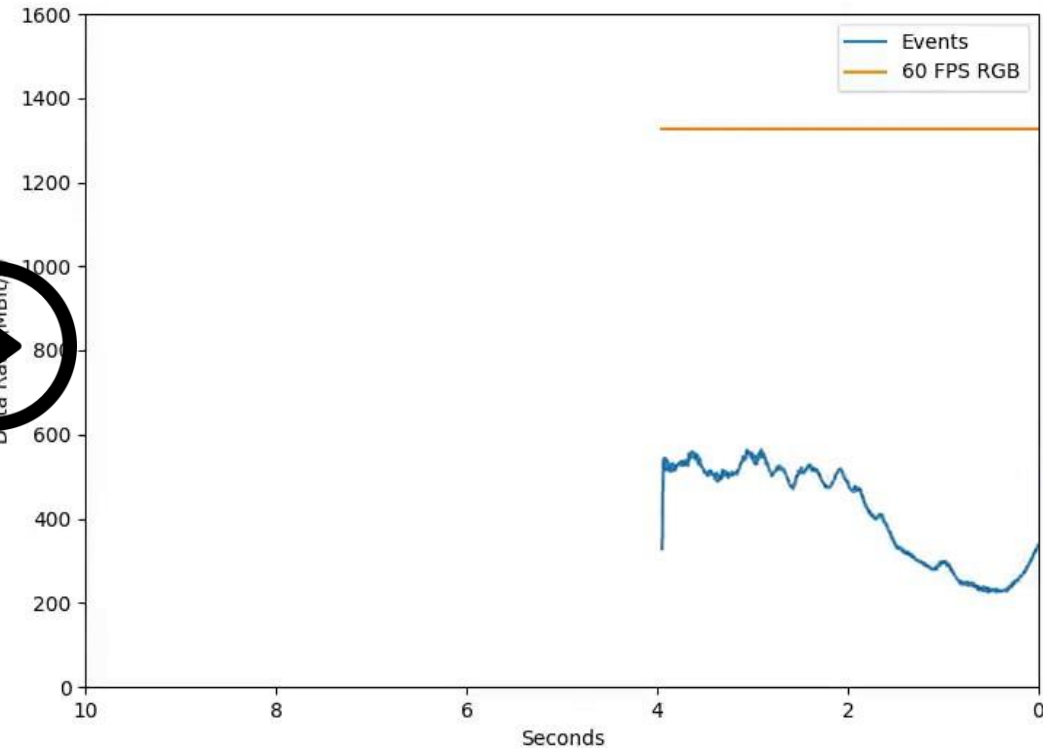


SCENE-DRIVEN
(1 μ S TIME RESOLUTION - 10,000 FPS EQUIVALENT)



AMOUNT OF DATA VARY WITH SCENE DYNAMICS
(10X TO 1000X LESS)

DATA RATE EVENT CAMERA VS FRAMES



DATA RATE REDUCTION

- > No information loss
- > Less than 10 Mbits/s in average
- > 30x compared to frame-based camera

EVENTS ARE DISCRETE POINTS IN TIME

UNIFORM EXPOSURE SET ON THE SCENE
-> HIGH COMPARED TO SPEED = MOTION BLUR



FRAME-BASED

ASYNCHRONOUS PER-PIXEL EVENT WITH NO
EXPOSURE PERIOD



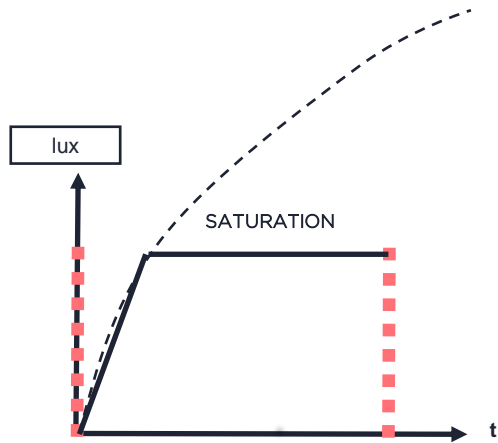
EVENT-BASED

BENEFITS OF EVS OVER CMOS SENSING:

- DOES NOT CREATE BLURRED EDGES ON MOVING OBJECTS
- NO PIXEL EXPOSURE MECHANISM OR FRAME CONCEPT ONLY FEW 10s OF μ S Latency

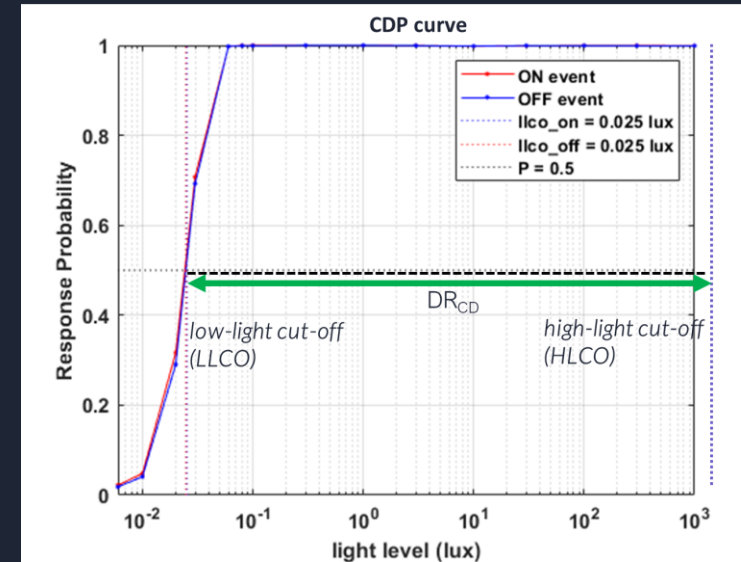
EVENT SENSORS ARE INHERENTLY HDR

UNIFORM PREDETERMINED EXPOSURE



FRAME-BASED

INDIVIDUAL PIXEL SAMPLING with LOG RESPONSE



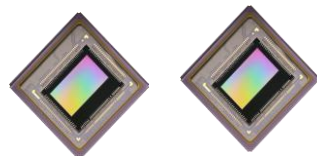
EVENT-BASED

BENEFITS OF EVS OVER CMOS SENSING

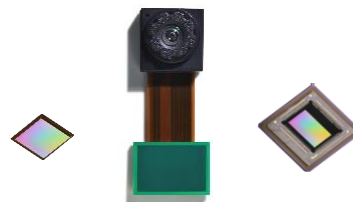
- 120 to 140dB HDR PERFORMANCE
- GOOD PERFORMANCE AT LOW-LIGHT (OPERATING BELOW 50mLux)

END-TO-END NEUROMORPHIC SOLUTIONS

SONY | PROPHESEE



IMX636/646 - HD IMX637/647 - VGA



GENX320

3D stacked (BSI) on CMOS wafer processing

SENSING

Evaluation tools
and reference
kits



10,000+
COMMUNITY MEMBERS

Metavision® Intelligence
and OpenEB users

PROCESSING



Metavision
® SDK

First
Commercial
Launch 2021



OpenEB

Open-Source
Offer to
Inventors
and
Researchers
Community



Metavision®
SDK

100+ Algorithms of Computer
Vision and AI, Datasets,
Application Examples

update releases

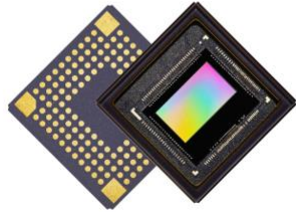


International Awards for
Metavision® Intelligence Suite



Event-Based Vision Sensor Jointly Developed

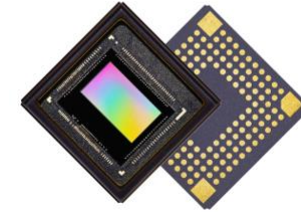
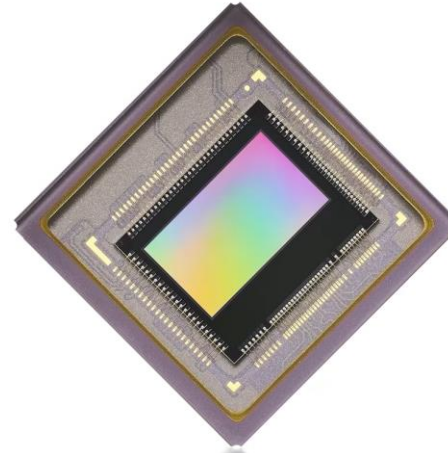
PROPHESÉE & **SONY**



IMX636 - HD

KEY FEATURES

- Resolution; 1280x720
- Optical format: 1/2.5"
- Ultra-High Speed: Latency: 220 μ s
- Dynamic Range >110dB
- Nominal contrast threshold: 25%
- Pixel size: 4.86 x 4.86 μ m
- Event Signal Processing embedded



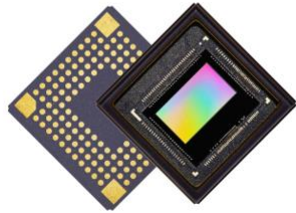
IMX637 - VGA

KEY FEATURES

- Resolution; 640x480
- Optical format: 1/4.5"
- Ultra-High Speed: Latency: 220 μ s
- Dynamic Range >110dB
- Nominal contrast threshold: 25%
- Pixel size: 4.86 x 4.86 μ m
- Event Signal Processing embedded

Event-Based Vision Sensor Jointly Developed

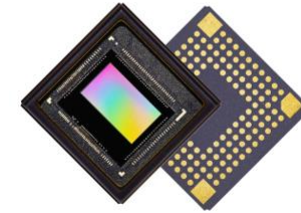
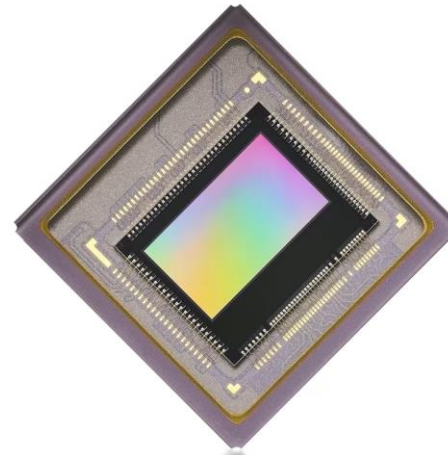
PROPHESÉE & **SONY**



IMX646 - HD

KEY FEATURES

- Resolution; 1280x720
- Optical format: 1/2.5"
- High Speed: Latency: 800µs
- Dynamic Range >120dB
- Nominal contrast threshold: 25%
- Pixel size: 4.86 x 4.86µm
- Event Signal Processing embedded



IMX647 - VGA

KEY FEATURES

- Resolution; 640x480
- Optical format: 1/4.5"
- High Speed: Latency: 800µs
- Dynamic Range >120dB
- Nominal contrast threshold: 25%
- Pixel size: 4.86 x 4.86µm
- Event Signal Processing embedded

GENX320 NEW PRODUCT

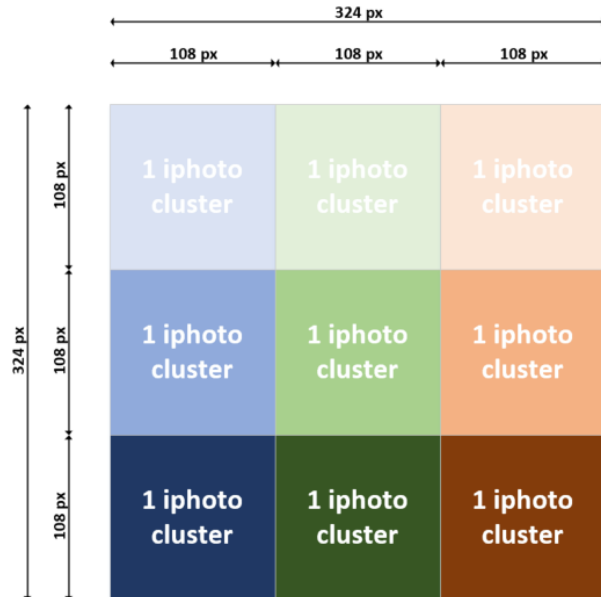
	Product
	GenX320MP bare die
	GenX320MP CM2 flex module
	CCAM5 GenX320MP COB module (no optics)
	CCAM5 GenX320MP CM2 flex module
	EVK3 with CCAM5 GenX320 COB module (with S-Mount optic)
	EVK3 with CCAM5 GenX320 CM2 module
	GenX320 COB module with interface to STM32F7 discovery kit

KEY FEATURES

- 320x320 array of 6.3 μ m contrast detection pixels (1/5" format)
- Event data output with row-level 1 μ s-precision time stamping
- 0.05 lux Low light cutoff
- High dynamic range >120dB
- Multiple power modes:
 - always-on ultra-low power mode
 - full-awareness low power mode
 - standard full performance mode
- Embedded Anti-flicker filtering (AFK), Event-rate Controller (ERC), and Spatio-temporal Contrast filter (STC).
- ML-friendly compressed and uncompressed event data streams
- 1-lane MIPI or configurable 8-bit parallel interface
- I²C and Four-wire serial peripheral interface.

GENX320 LOW POWER

MODE	ULP PASSIVE	LP	CPI STREAMING	CPI STREAMING	MIPI STREAMING
Sub-System		low activity	100KEPS CPI @ 10MHz	1MEPS CPI @ 10MHz	10MEPS MIPI @ 800MHz
pixel array	3x3 GCD	320 x 320 pixels	320 x 320 pixels	320 x 320 pixels	320 x 320 pixels
Digital ICN + CPU	Powered down	Powered, Clocked	Powered, Clocked	Powered, Clocked	Powered, Clocked
Digital readout	Powered down	Powered, Clocked	Powered, Clocked	Powered, Clocked	Powered, Clocked
Digital ESP + output I/F	Powered down	Powered, Gated	Powered, Clocked	Powered, Clocked	Powered, Clocked
	Total: 36μW	Total: 2.9mW	Total: 3mW	Total: 4.8mW	Total: 22.8mW



	MIPI	8b parallel
max. event rate	1 Gevt/s	250 Mevt/s
signaling standard	MIPI	CMOS logic
number of lanes	1	8
Max bit rate	max. 1.5Gb	200Mb @ 25MHz
modes / encoding	variable size + variable rate fixed size + variable rate fixed size + fixed rate	EVTx direct EVTx in JPEG container (STM32) serial 4bit word parallel AER

GENX320 PRINCIPAL MARKETS

AR/VR - WEARABLES

IOT/Edge AI/Smart-homes

Consumer TV/PC/Gaming

APPLICATION

- Short distance Tracking:
 - Eye,
 - Hands,
 - Gesture

- Edge Detection & classification
 - Smart doorbell
 - Fall Detection
 - Space awareness/SLAM
 - TinyML ecosystem

- Gesture recognition (no remote)
- Audience and statistics feedback on media content/publicity
- Multiple DOF (degrees of freedom) constellation tracking

EVS VALUE

- Speed & very limited data rate yielding low computational cost and much lower power consumption
- Eliminates thermal discomfort of users.

- Addresses privacy concerns versus CMOS image sensors
- Low power & smart wake-up
- Increased autonomy
- Activity detection & classification

- Addresses privacy concerns versus CMOS image sensors
 - Can work with no lens.
- Activity detection & classification
- EVS with frequency filtering to completely remove background and transmit spatial pose info of markers only



THE MOST COMPREHENSIVE EVENT BASED VISION SOFTWARE SUITE



95
algorithms

79
code samples

24
tutorials

6 EXTENSIVE MODULE FAMILIES

MACHINE
LEARNING

ANALYTICS

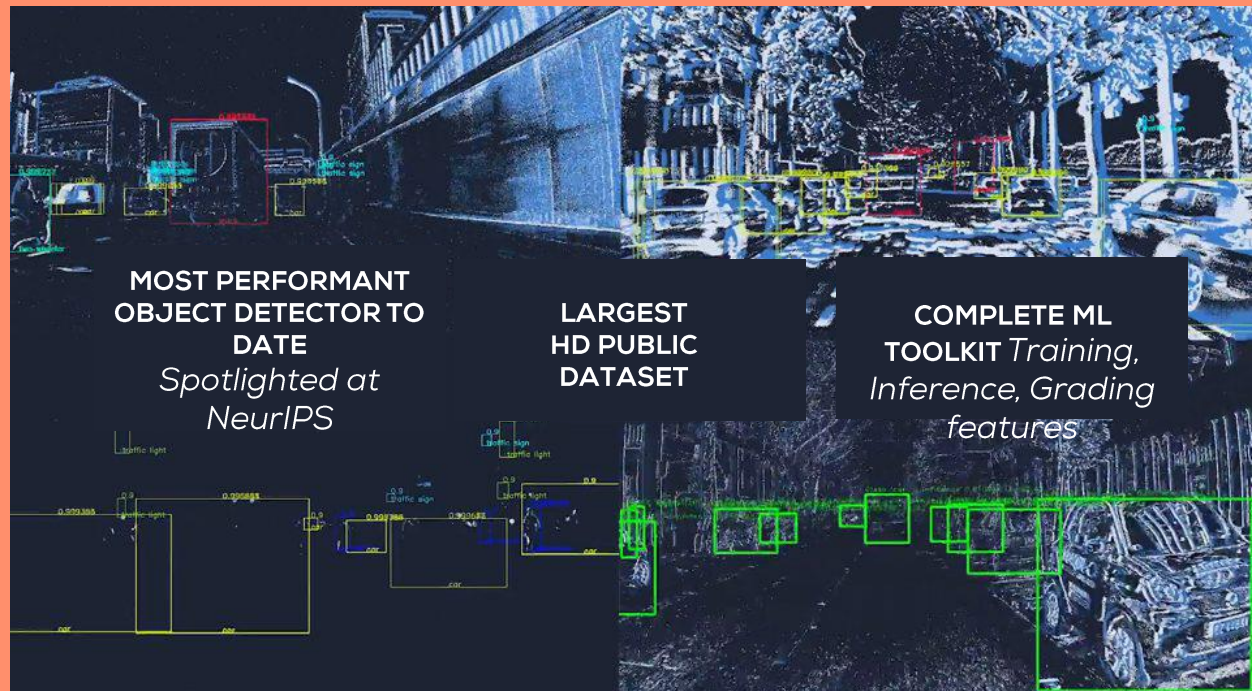
CALIBRATION

COMPUTER
VISION 3D

COMPUTER
VISION

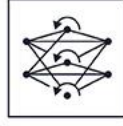
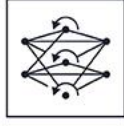
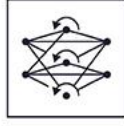
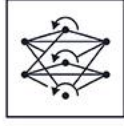
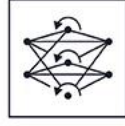
CORE

LEADING ML TOOLKIT



OPEN SOURCE ARCHITECTURE

MACHINE LEARNING



DETECTION INFERENCE

DETECTION TRAINING

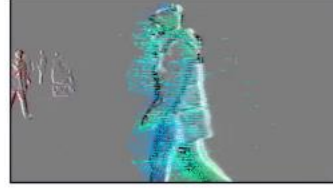
DETECTION KPI

OPTICAL FLOW INFERENCE

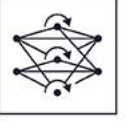
OPTICAL FLOW TRAINING

GESTURE CLASSIFICATION INFERENCE

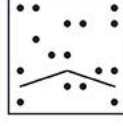
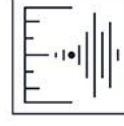
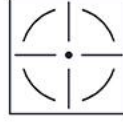
GESTURE CLASSIFICATION TRAINING



MACHINE LEARNING



ANALYTICS



VIDEO TO EVENT

EVENT TO VIDEO

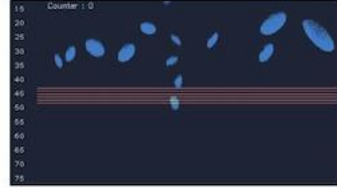
PARTICLE SIZE MONITORING

OBJECT TRACKING

VIBRATION MONITORING

SPATTER MONITORING

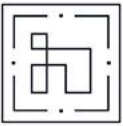
HIGH-SPEED COUNTING



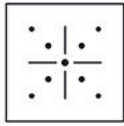
CALIBRATION



COMPUTER VISION 3D



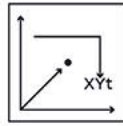
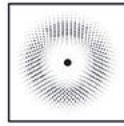
NEW



COMPUTER VISION



CORE



CALIBRATION

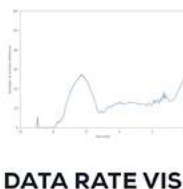
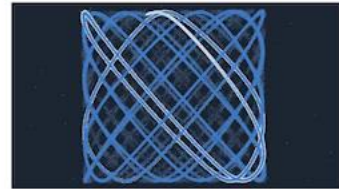
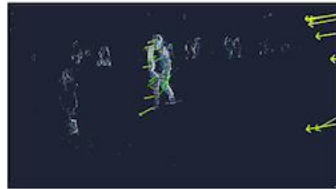
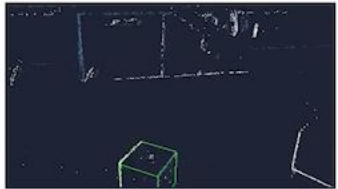
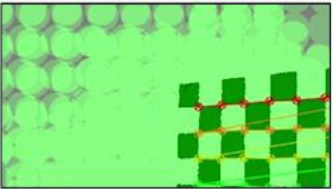
EDGELET TRACKING

ACTIVE MARKER

OPTICAL FLOW

ULTRA SLOW MOTION

XYT VISUALIZATION



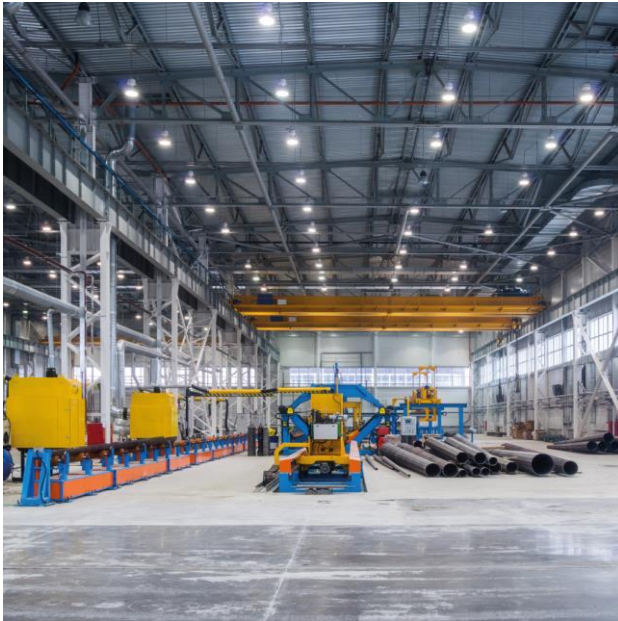
DATA RATE VISUALIZATION

Use cases

- MV market needs
- EVS Use case examples and unique benefits



INDUSTRIAL MV CUSTOMERS NEEDS



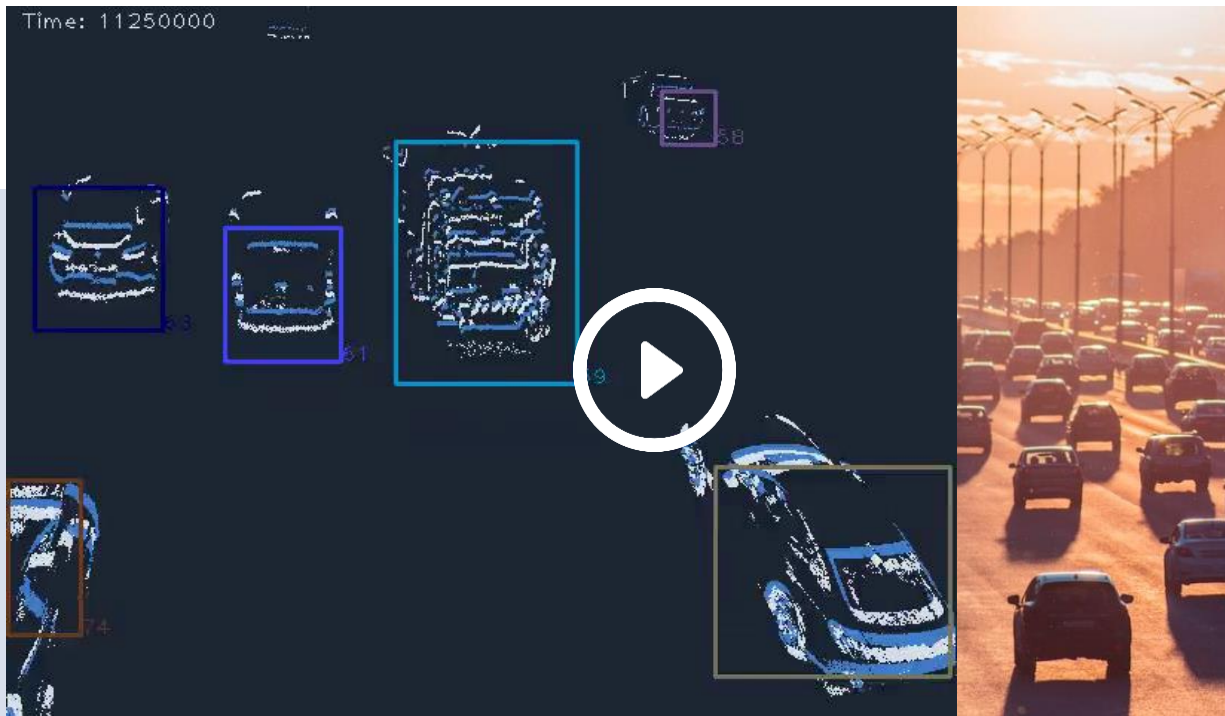
- Increased productivity
- Differentiation in a crowded market where everyone uses the same CMOS sensors
- Reduce system level costs to retain competitiveness
- More intelligence/autonomy at the edge to reduce cloud storage/processing time
- Future-proof solutions to enable increased throughput with adoption of AI/ML technology
- Reduce the illumination power and cost
- Need to reduce carbon footprint (Ind 4.0)



OBJECT TRACKING

Typical applications: Traffic Monitoring, AMR/Robot navigation (2D/3D), Industrial safety

OBJECT TRACKING



Track moving objects in the field of view. Leverage the **low data-rate and sparse information** provided by event-based sensors to track objects with **low compute power**.

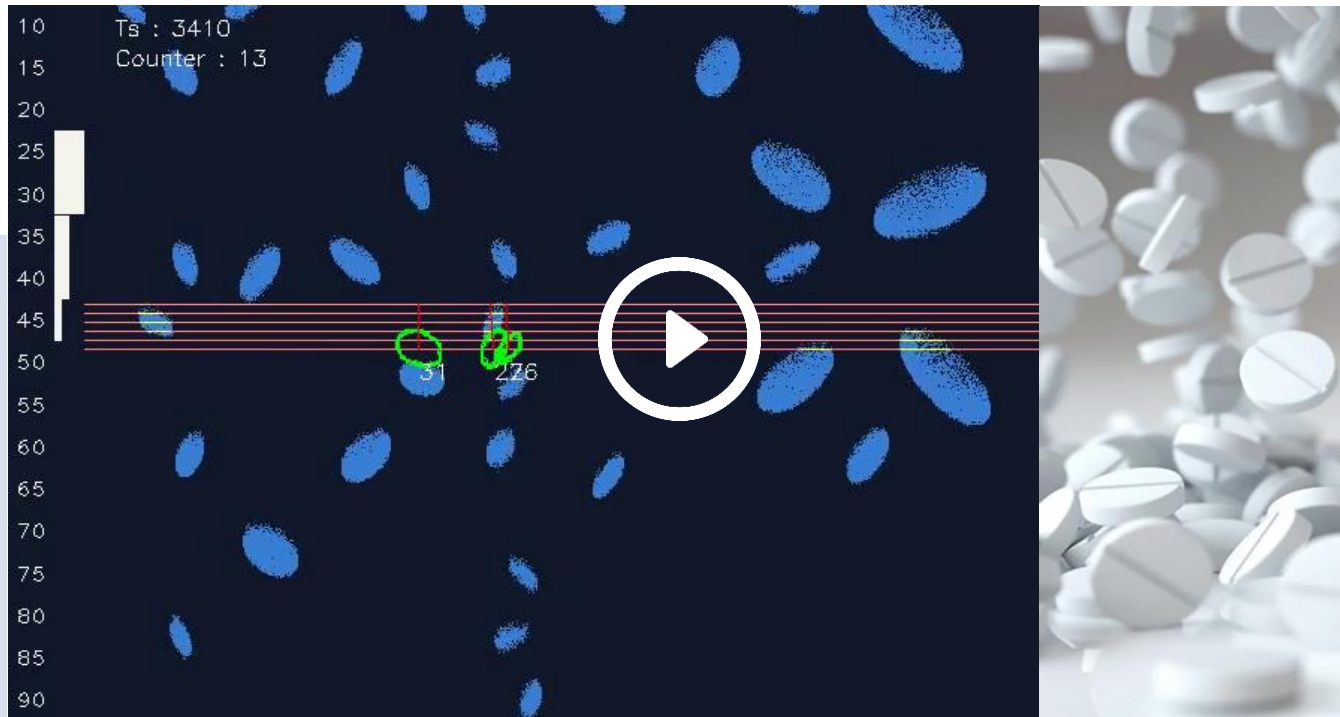
Continuous tracking in time: no more "blind spots" between frame acquisitions
Native segmentation: analyze only motion, ignore the static background



PARTICLE SIZE MONITORING

Typical applications: High speed counting/sorting, Batch homogeneity & Gauging

PARTICLE/OBJECT SIZE MONITORING



Control, count and measure the size of objects moving at very high speed in a channel or a conveyor.

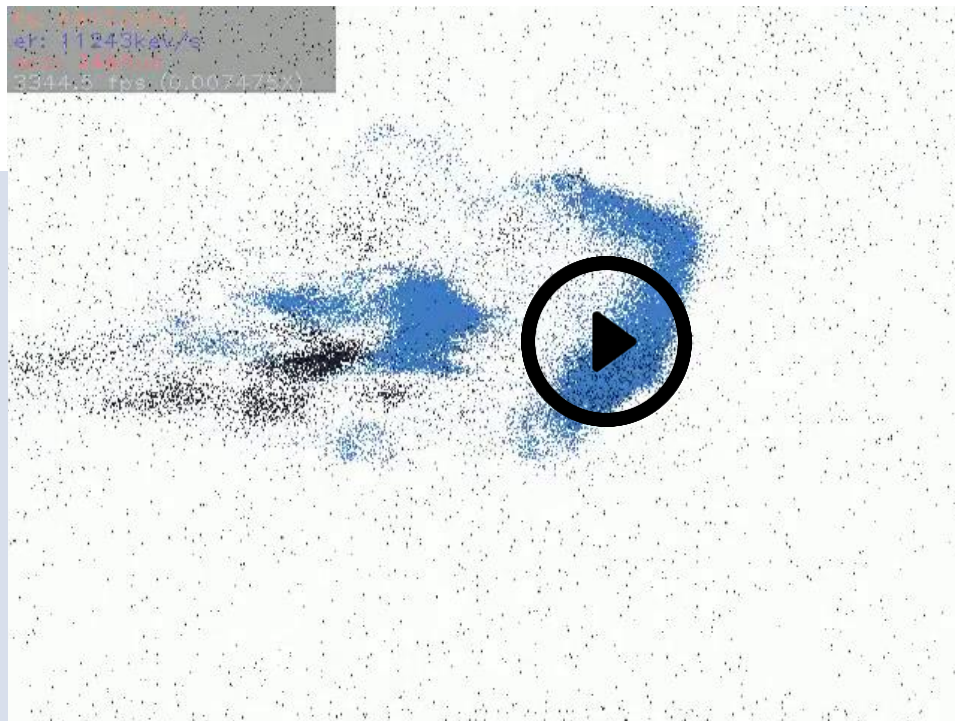
Up to 500 000 pix/s speed
>99% counting precision



PLUME MONITORING

Typical applications: Dispensing uniformity & Coverage control, Quality & efficiency of dispersion, Fluid dynamics analysis for inline process monitoring, Agriculture

HIGH-SPEED PLUME MONITORING (Aerosols-Spray)



Real time analysis and monitoring of spray dispensing of fluids.

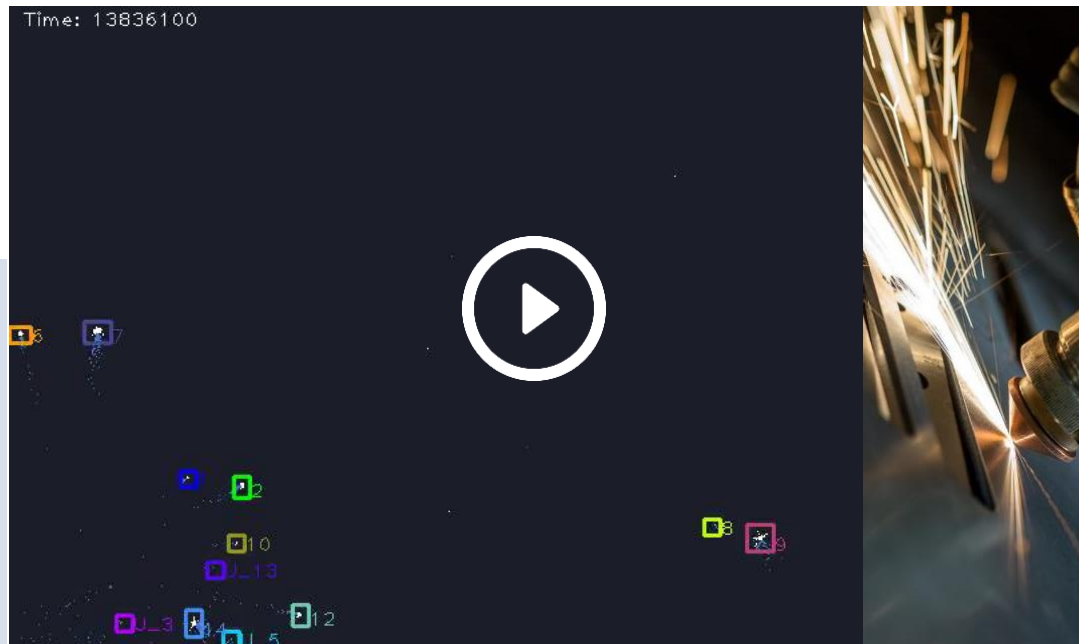
Ultra slow-motion view (200.000 equiv. fps) for homogeneity and optical flow for direction and velocity of plume & PIV.



SPATTER MONITORING

*Typical applications: Traditional milling, laser & process monitoring,
Quality prediction*

SPATTER MONITORING



The **high temporal resolution** and **dynamic range** of the Event-Based Vision sensor allows small particles to be tracked in the most demanding environment.

Up to **200k fps rendering** (5 μ s time resolution)
Simultaneous XYT tracking of all particles with up to **140dB dynamic range**

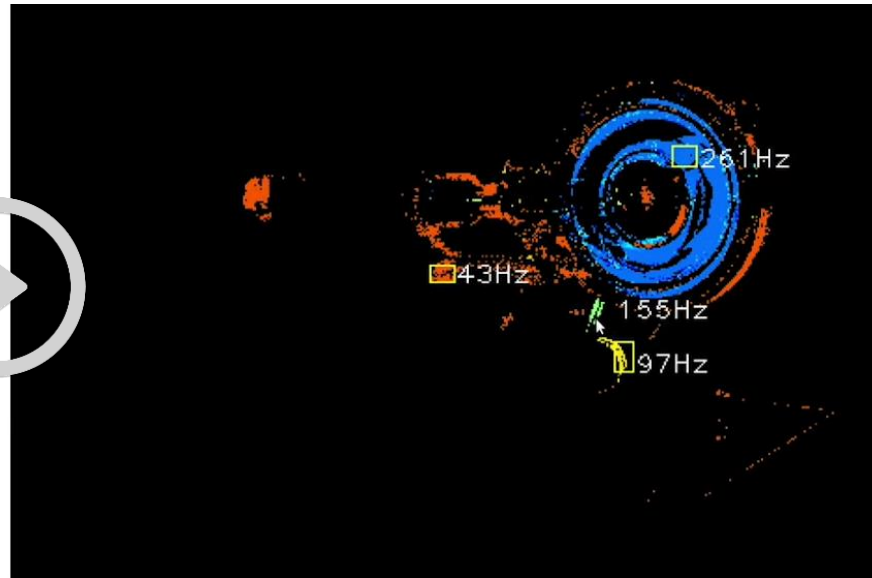
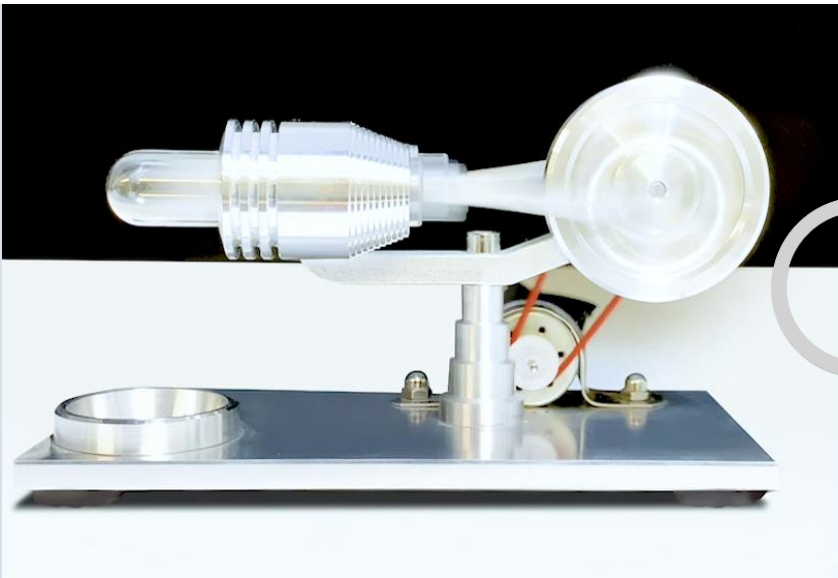


ANALYTICS

VIBRATION & FREQUENCY MONITORING

*Typical applications: Motion monitoring, Vibration monitoring,
Frequency analysis for predictive maintenance*

VIBRATION & FREQUENCY MONITORING



From 1Hz to kHz range

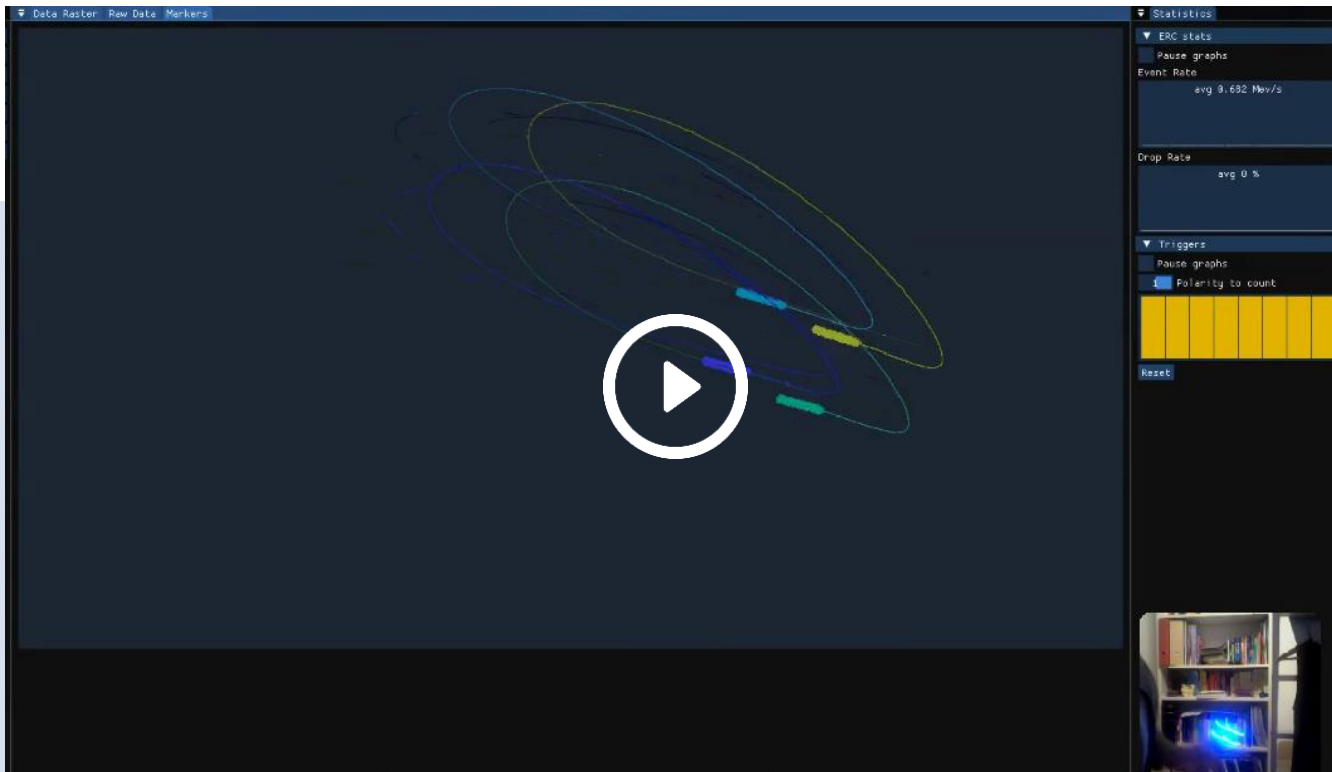
<0.1Hz Accuracy of measurements

1 Pixel Spatial accuracy

Non-intrusive, Non-contact, Easy to setup

ACTIVE-MARKERS APPLICATION

Typical applications: Motion monitoring, 3D pose estimation, remote controls, safety systems

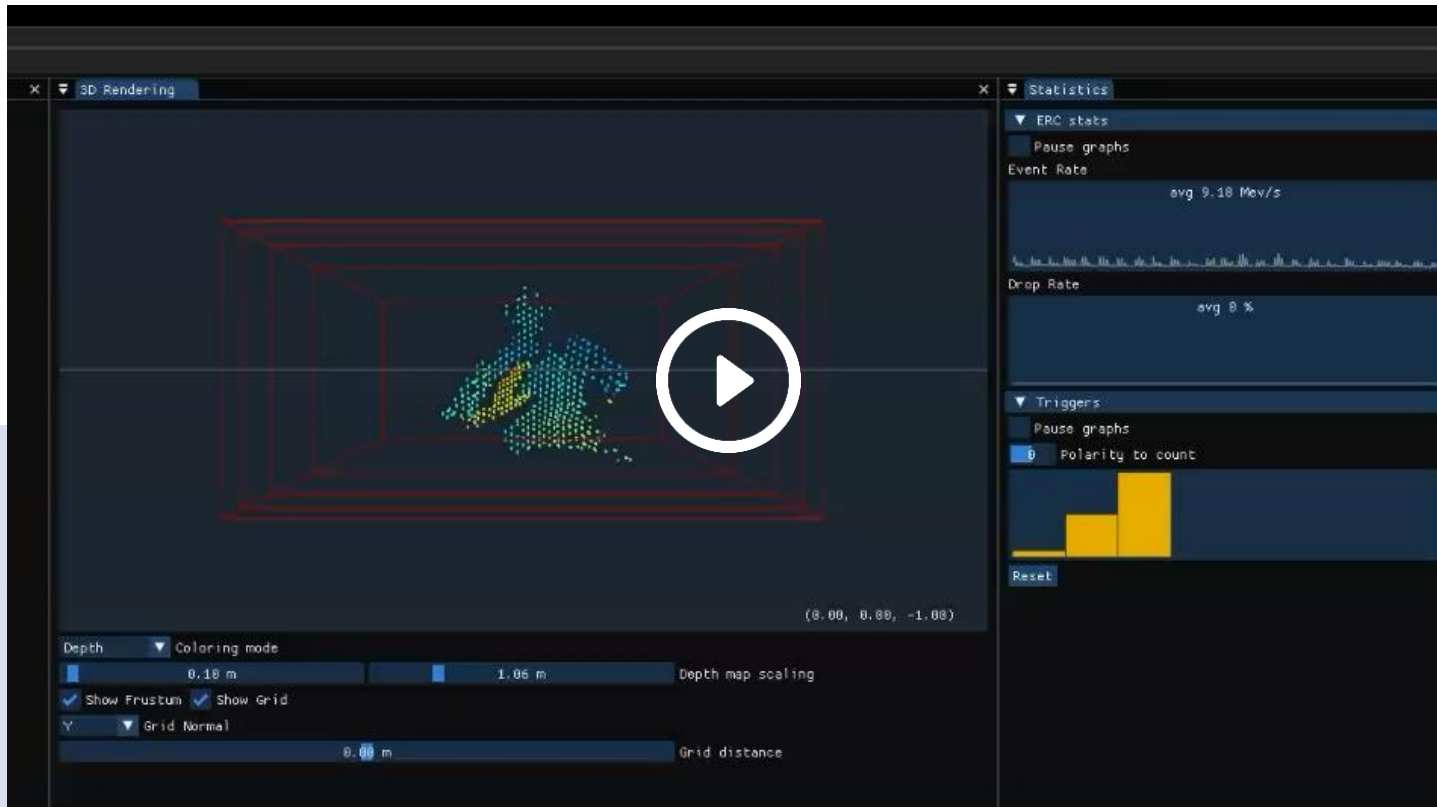


- Detect very accurately light pulses
- Total background extraction
- Encodes values in pulse intervals
- Can provide 3D info

- Active markers with multiple DoF
- Each marker has a different ID

EVS 3D STRUCTURED LIGHT

3D Structured light with IMX636 Event-Based Metavision[®] sensor



- Up to 600Hz Point cloud generation
- <1.5% RMSE error @600Hz
- 3x baselines for short, medium and long ranges

3D TECHNOLOGIES COMPARISON

	Stereo (passive)	Structured light (CMOS Imager)	Laser triangulation	Time of Flight	PROPHESEE Structured light
Distance & range	Medium to far (depending on the baseline)	Short to medium	Short & limited	Far & scalable	Short to medium
Resolution	GOOD	GOOD	GOOD	FAIR	GOOD
Depth accuracy	FAIR	GOOD	VERY GOOD	FAIR	GOOD
Software complexity	BAD	FAIR	FAIR	GOOD	GOOD
Real-time capability	BAD	BAD	BAD	GOOD	VERY GOOD
Low light	BAD	GOOD	GOOD	GOOD	GOOD
Outdoor	GOOD	BAD	BAD	BAD to FAIR	GOOD
Compactness	FAIR	FAIR	FAIR	GOOD	FAIR
Energy per single 3D scan	GOOD	BAD	BAD	BAD	GOOD to FAIR

Best overall performance

MAIN BENEFITS FOR PROCESSING EVENTS WITH ML MODELS

1. ULTRA-LOW LATENCY

- High temporal resolution allows lower latency detection
- Inference at any rate is virtually possible
- Only limited by computation time

2. REDUCED COMPUTATION

- Learn simpler patterns and features
- No need to learn invariance to background (for static camera)

3. EASIER GENERALIZATION

- Light invariance allows for easier generalization
- E.g. models trained at day light perform with night scenes

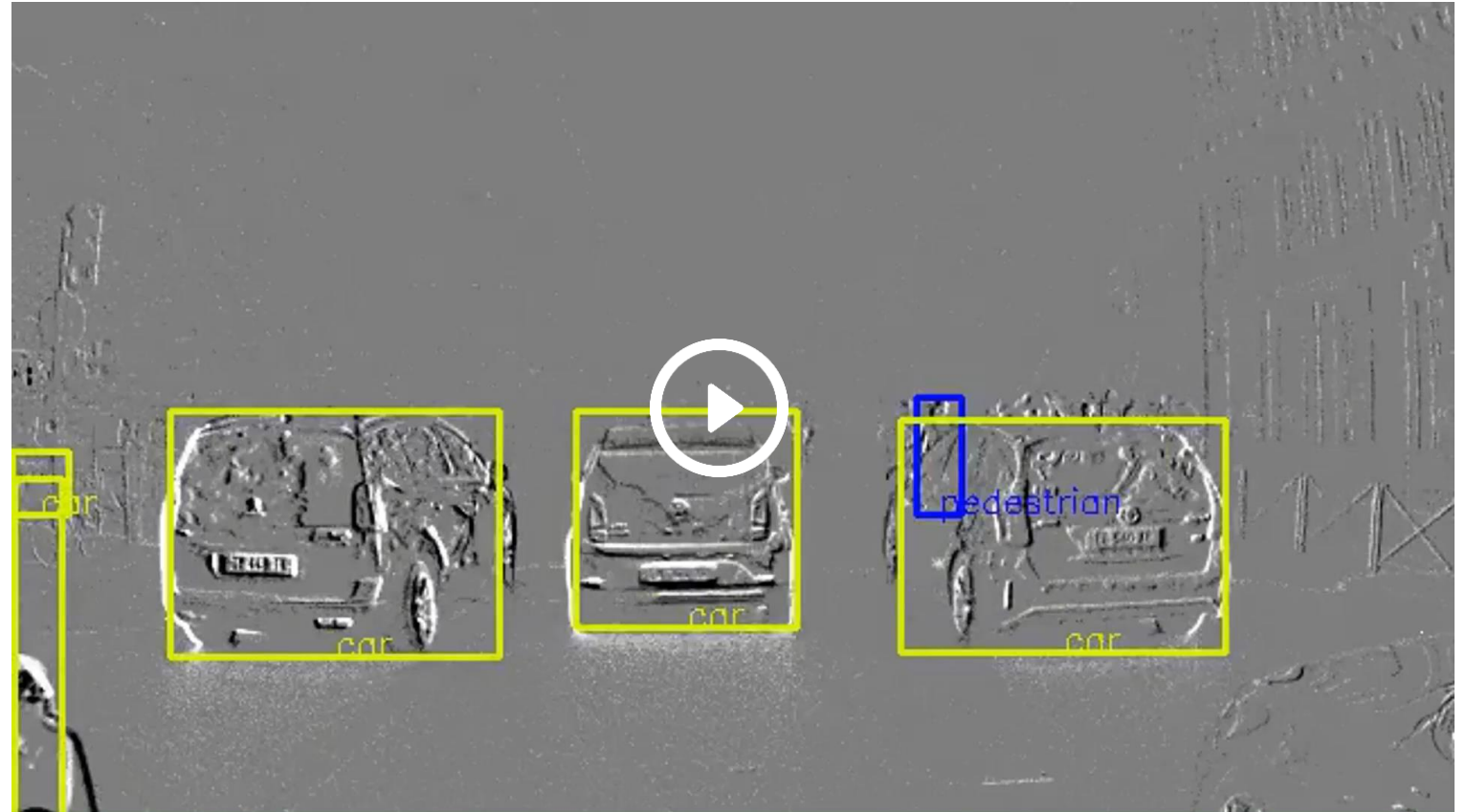
ULTRA-LOW LATENCY

Event-based benefit 1: Temporal Resolution

- Low-latency detection
- Continuous data nothing missed between frames
- Inference at high rates

Event-Based automotive dataset:

- 7 classes (Car, truck, van, pedestrian, two-wheeler, ...)
- 25M boxes for object detection and tracking
- HD 1280x720 event camera resolution



50Hz inference VGA sensor on mobile processor (cfr. Frame-based Mobilenet-v2 13Hz)

DATA SPARSITY

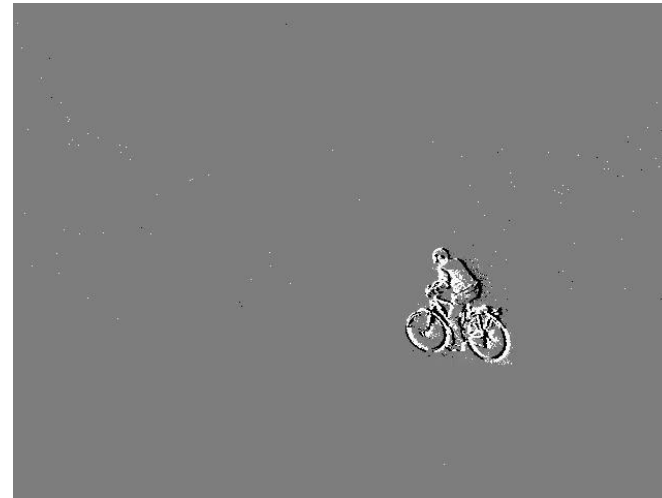
Event-based benefits 2:

Sparsity

- Sparse input allows for **reduced computation**
- Learn simpler patterns
- No need to learn invariance to background



Frames: Complex Background
Complex Texture



Events: Only relevant contrast
features

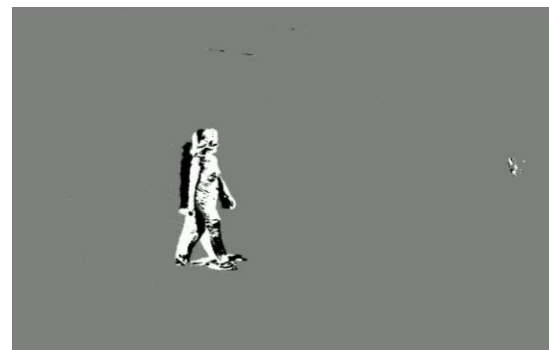
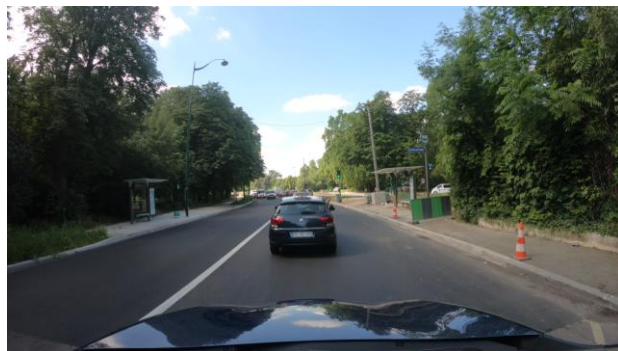
LIGHT INVARIANCE

Event-based benefit 3:

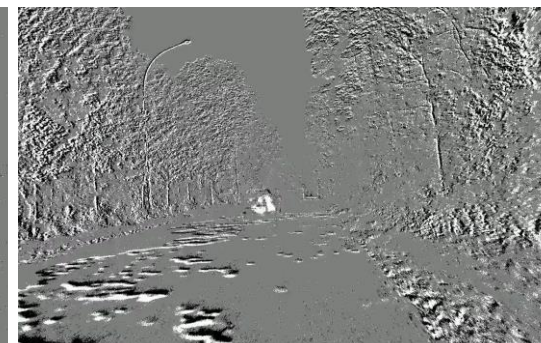
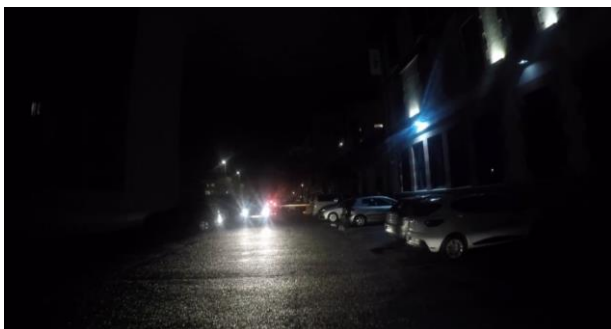
Light invariance

- Event sensors react to **relative changes**, independently of **absolute light levels**
- Light invariance allows for **easier generalization** of ML models

Day



Night



OBJECT DETECTION NIGHT

Light invariance

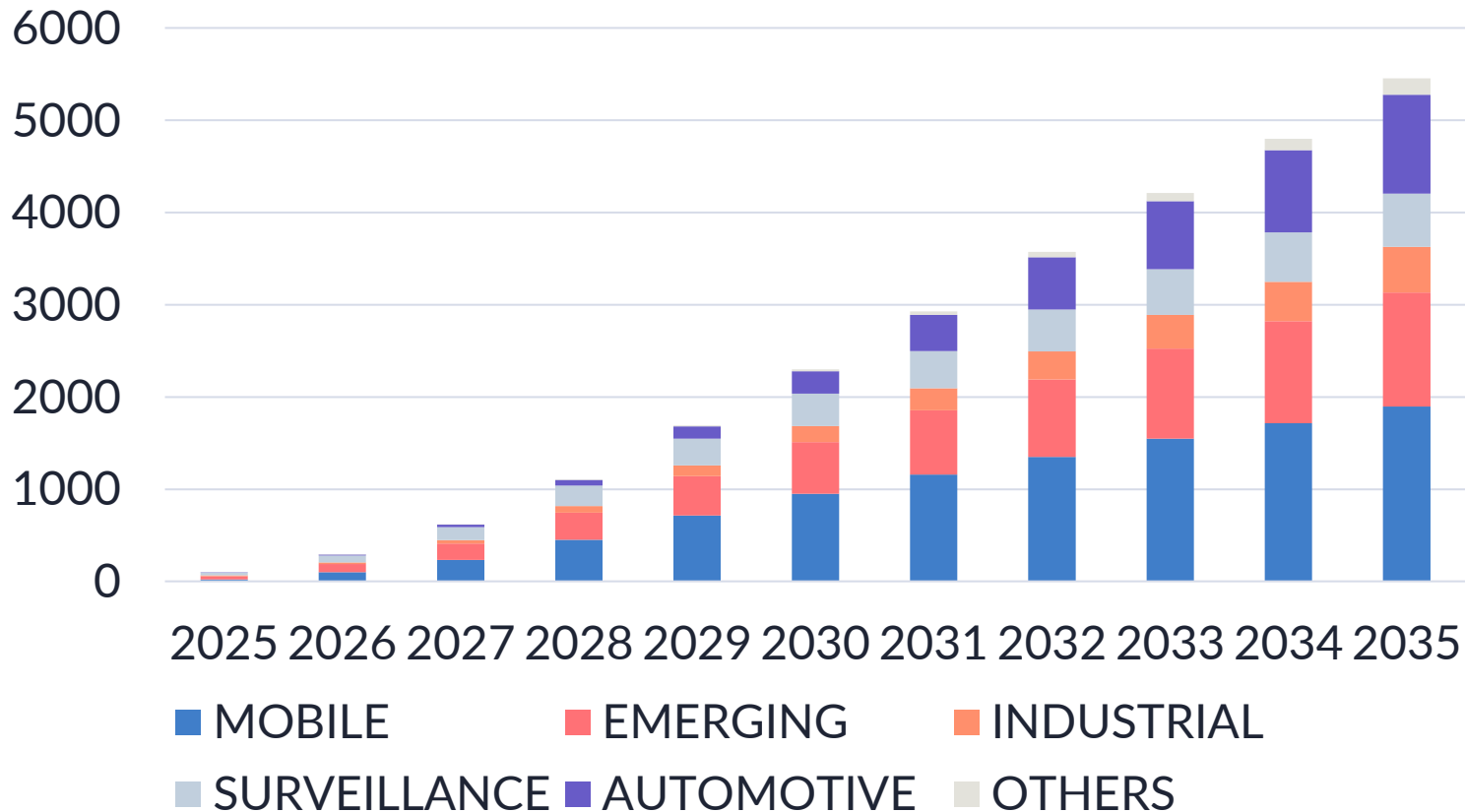
Inference on night data with network trained only with day data



Wrap Up

- Event sensing has come-of-age thanks to modern stacked BSI wafer technology
- EVS is ideal for **machine vision** (pre-sorted at pixel level, fast, high robustness to challenging lighting conditions), motion-understanding capabilities by design.
- 2024 will see the release of several major EVS based MV cameras from major players
- Future-proof AI/ML with perfect match to growing SNN techniques that offer lowest latency and power for complex tasks

NEUROMORPHIC SENSING WILL PENETRATE 10% OF THE TOTAL CIS MARKET BY 2030



EB Sensor Market will reach 2B by 2030:

- **MOBILE** (40%),
- **EMERGING** applications in **CONSUMER** (AR/VR, Gaming, Robotics, Smart Home/Building) and **AUTOMOTIVE** (DMS, ADAS) (35%)
- **INDUSTRIAL** (8%)
- **OTHERS** (17%)

THANK YOU



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