A NOVEL VISION-SYSTEM-ON-CHIP FOR EMBEDDED IMAGE ACQUISITION AND PROCESSING

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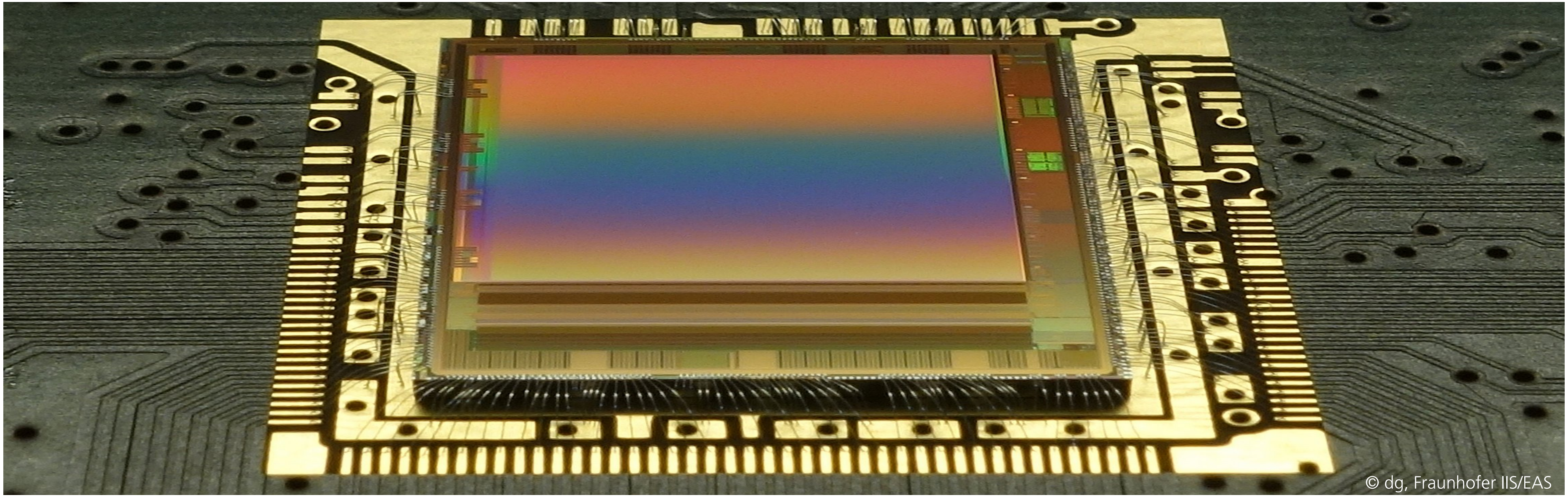

Outline

- Introduction
- Machine Vision Challenges
- Vision System-on-Chip
- Advanced Features
- Application Examples
- Conclusion

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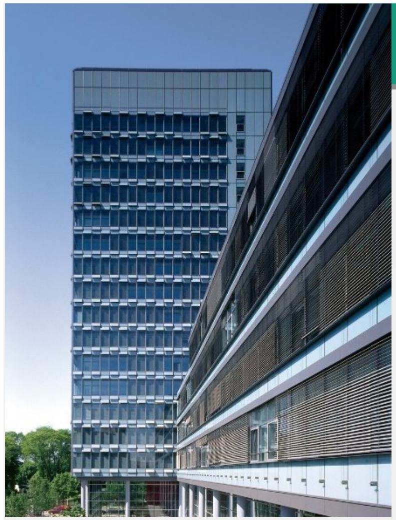
Introduction

Facts and Figures



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»Applied research of direct utility to private and public enterprises and of wide benefit to society«

- The largest organization dedicated to application-oriented research in Europe
- Important innovations, such as the music format mp3, white LEDs or high-resolution thermal imaging cameras

Fraunhofer Institute for Integrated Circuits

Founded	1985
Employees	more than 900
Budget	approx. 150 million €
Directors	Prof. Dr. Albert Heuberger Dr. Bernhard Grill

Division Engineering of Adaptive Systems

Founded	1992
Employees	approx. 110
Budget	approx. 13.1 million €
Director	Dr. Peter Schneider

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Introduction
Business Areas & Research Topics Division EAS

Challenges in the Development of Adaptive Systems

- complexity of the systems
- functional safety and reliability
- security and privacy
- variable application scenarios
- human-machine interaction

Design Methodology

- reliability and robustness of ICs
- functional safety

Efficient Electronics

- integrated sensor electronics
- system integration
- optical sensor technologies

Distributed Data Processing and Control

- industrial data analysis
- wireless-networked automation
- energy management

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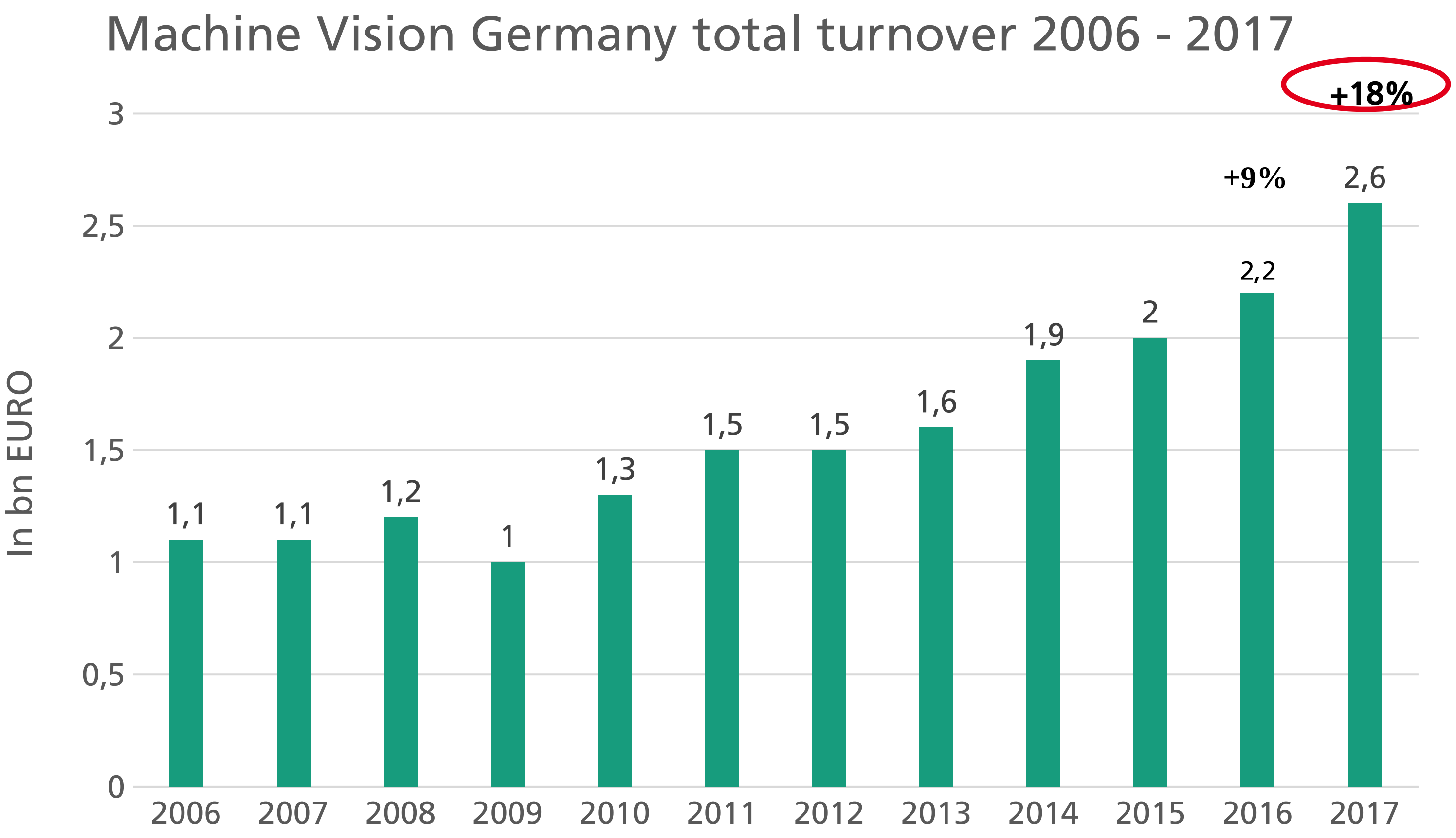
Machine Vision

Relevance

2017 – VDMA growth prognosis *(VDMA Fachabteilung Industrielle Bildverarbeitung)*

- German robotic and automation:
  +7 → +11 %
- industrial image processing:
  +9 → +18 % → 2.6 Mrd €



Source: VDMA Robotics + Automation

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Machine Vision

Challenges and Drivers

- **continuous growth** of image processing industry **– on passing lane**
- **automation** will drive the development
- **automation** is essential to remain competitive
- hunger for **process know-how** and **quality data** for digital production

… and how to **integrate vision** to meet this **needs**? → possible solution: **Vision Systems-on-Chip!**

https://www.computer-automation.de/feldebene/bildverarbeitung/artikel/150487/

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Vision System-on-Chip
Key Factors for Success

Vision-System-on-Chip must do

image acquisition as good* as and **image processing much better****

than a **traditional image sensor setup!**

*** as good...**

- **image quality** equal to high-speed image sensors for equivalent **application** → **compare** measurement **results**

**** much better...**

- speed → **continuous frame rate** including processing and
- latency → for real-time **processing** of captured images
- at lower **total power consumption** for equivalent tasks **including processing** and
- higher **flexibility** at lower **total development costs**.

→ This concept leads to a multi-purpose »Software-Defined Smart Camera«

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Vision System-on-Chip
Application Principles (1)

First and foremost: **Don't generate data you don't need!**

- focal plane pre-processing
- A/D conversion at a viable resolution
  - 1 bit binarization for high speed
  - 10 bit only where really necessary (image data)
- software-defined A/D converter
  - column-wise flexible programmable thresholds
  - reprogrammable algorithms (single slope, multiple slope, SAR)

Second: **What do we gain, if we give up a certain »correctness / precision / beauty«?** → **modeling and system simulations**

- slope converter → (very simple) SAR
  - much higher speed,
  - but missing codes under some circumstances
- compare measurement results, not intermediate images

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Vision System-on-Chip

Application Principles (2) – Additional Considerations

- optimizations if possible in software
  - calibration
  - error correction

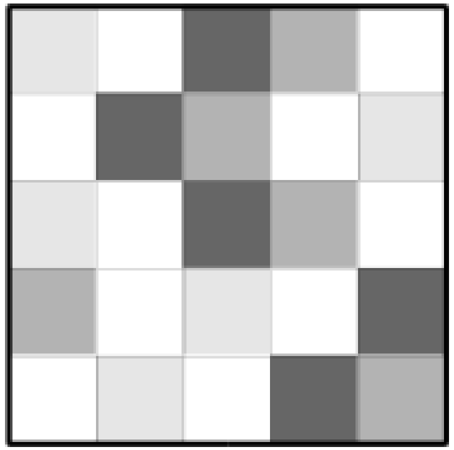
- VSoC-based solutions, if you definitely can't do them traditionally
  - speed
  - latency
  - flexibility

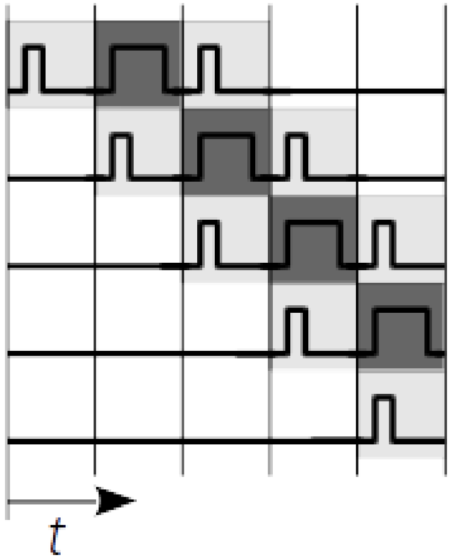
→ because **VSoC implementations** may be **challenging to implement**

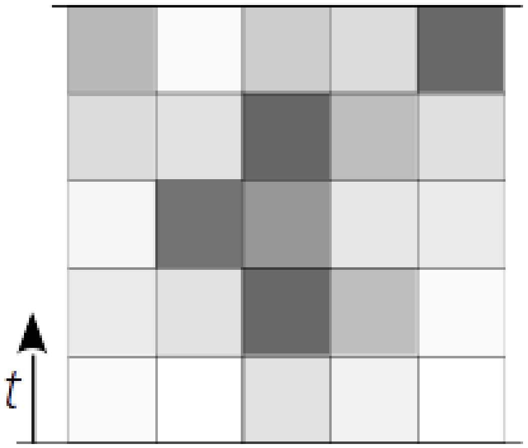
Vision System-on-Chip

Charge-Based Focal Plane Processing

- readout
  - line by line
  - windowing
- weighting
  - amplification
  - attenuation
  - local adaptation
- 1D convolution
  - low-pass filtering
  - contrast enhancement
  - edge detection







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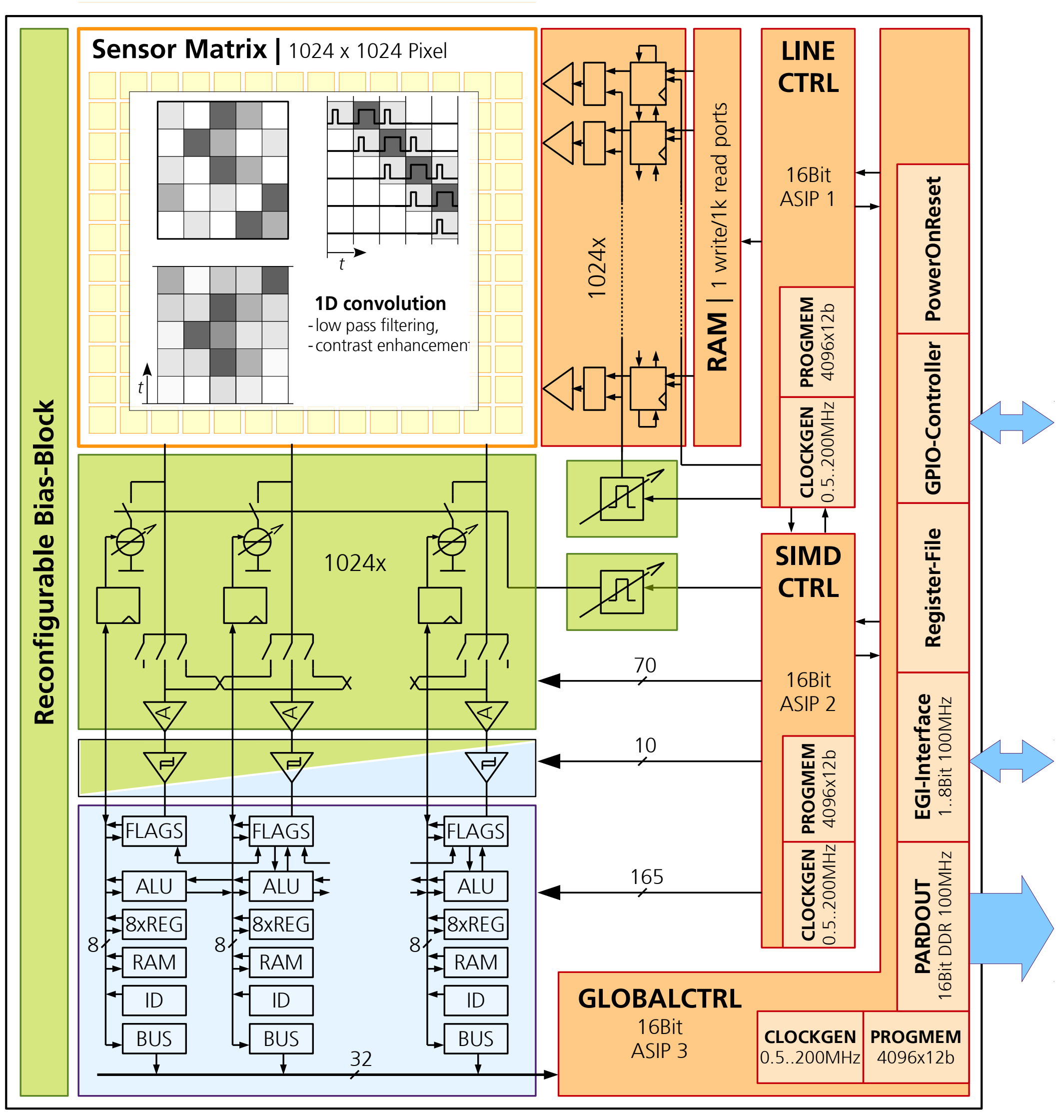
Vision System-on-Chip

Basic Architecture and Features

- sensor matrix with 1024 x 1024 pixels
  - 8.75µm pixel pitch
  - linear / logarithmic (HDR) characteristics (with FET pixels)
- LINECTRL
  - pixel control
  - charge-based readout and processing
- SIMDCTRL
  - column-parallel analog frontend
  - column-parallel digital (SIMD) processing elements
- GLOBALCTRL
  - I/O – operation with various digital interfaces (Parallel, SPI and GP-I/O)
- infrastructure - reconfigurable bias block
- software and processing libraries
  - snapshot, rolling shutter, multi-RoI access
  - column-parallel analog filtering
  - column-parallel A/D-conversion (1...10 Bit)
  - digital feature extraction (corners, HoG, LBP)



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Vision System-on-Chip

Software Programming based on Python with Inline Assembler

```python
# Demo 4: Threshold Image
# apply a digital threshold value

# python setup
from chrispy.chrisp2.cores import simd
from chrispy.macro import CConstInt
from libcam2 import Cam21Platform as         \
Cam2Platform
from libch2dev import skeletons
from libch2dev.image_lpl8 import ImageLPL8
from libch2dev.vsoc_chrisp2 import           \
VSoCChRISP2

import cv2
# skeleton setup
skel = skeletons.SkelCam2GlobalShutterTime()
skel.add_roi(8, 32, 32, 960, 960)

# VSoC setup
platform =                                   \
Cam2Platfo                2.168.1.100")

vsoc = VSoCChRISP2(platform)

skel.configure_regfile(vsoc)

vsoc.set_clock("simd", 100)
vsoc.set_clock("lctrl", 100)
vsoc.set_clock("glb", 35)
```

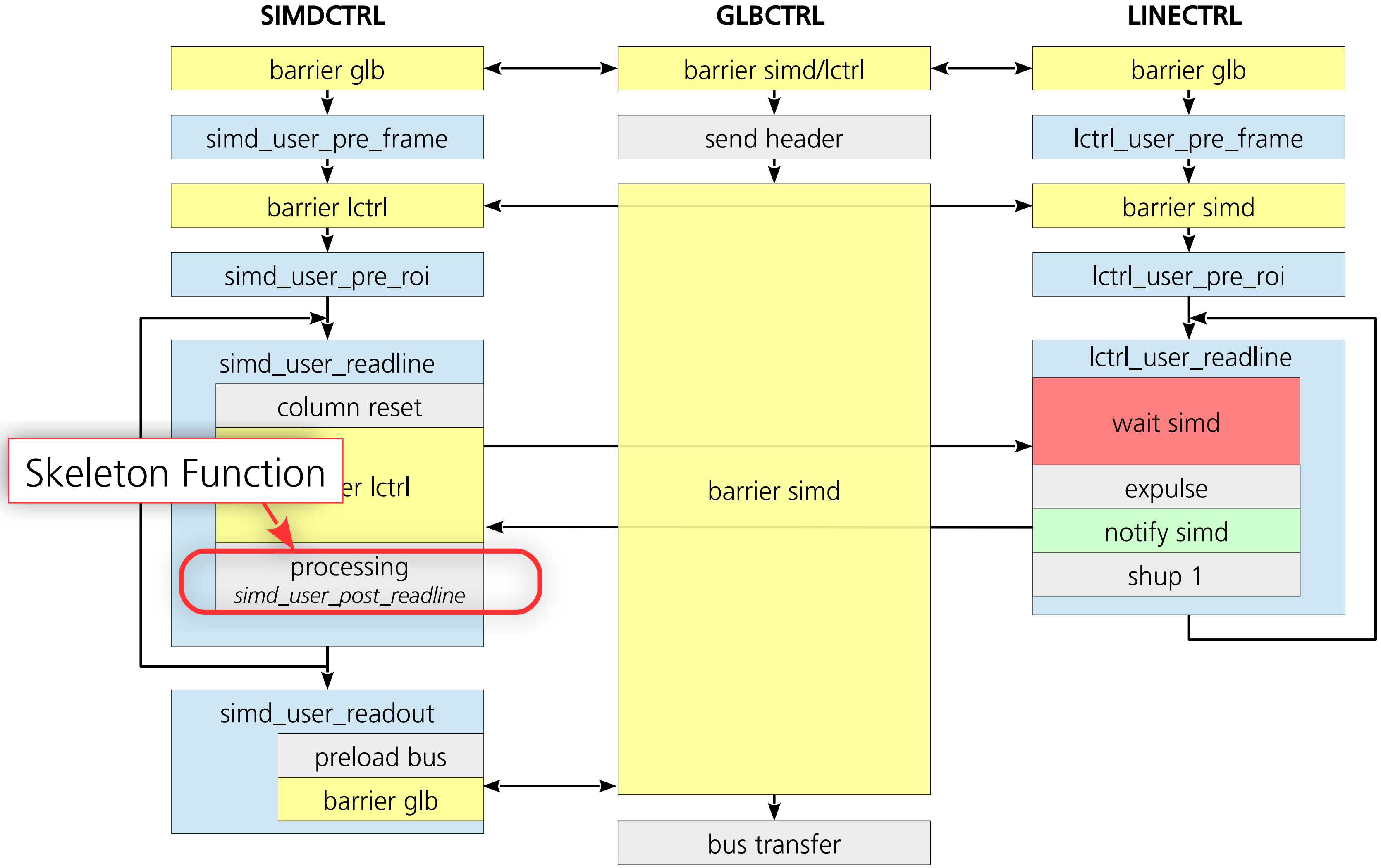
Skeleton

```python
# VSoC code: threshold algorithm
@simd.macro()
def simd_demo(roi_idx : CConstInt, roi_cnt : \
CConstInt):
    simd.api.inline_asm(["simd_mov r_0, r_1",
                         "ld 20",
                         "simd_cp_tos r_0",
                         "simd_movf flg_m0, flg_c",
                         "simd_xnor r_0, r_0",
                         "simd_selact ACT0",
                         "simd_xor r_0, r_0",
                         "simd_selact ACTIVE",
                         "simd_mov r_1, r_0"])
skel.reg_slot("simd_user_post_readline", simd_demo)

# program initialization
skel.compile_and_start(vsoc)

# host code: setup and main loop
platform.acq.mode.set_exposure_time(30000)
platform.acq.mode.set_frame_period(1e6/10)
while True:
    try:
        desc = platform.b_get_image()
        header, img = ImageLPL8(desc).get_roi(0)
        cv2.imshow("disp", img)
        cv2.waitKey(1)
    except:
        continue
```

Skeleton Function

Vision System-on-Chip

Vision Processing Library based on Skeletons



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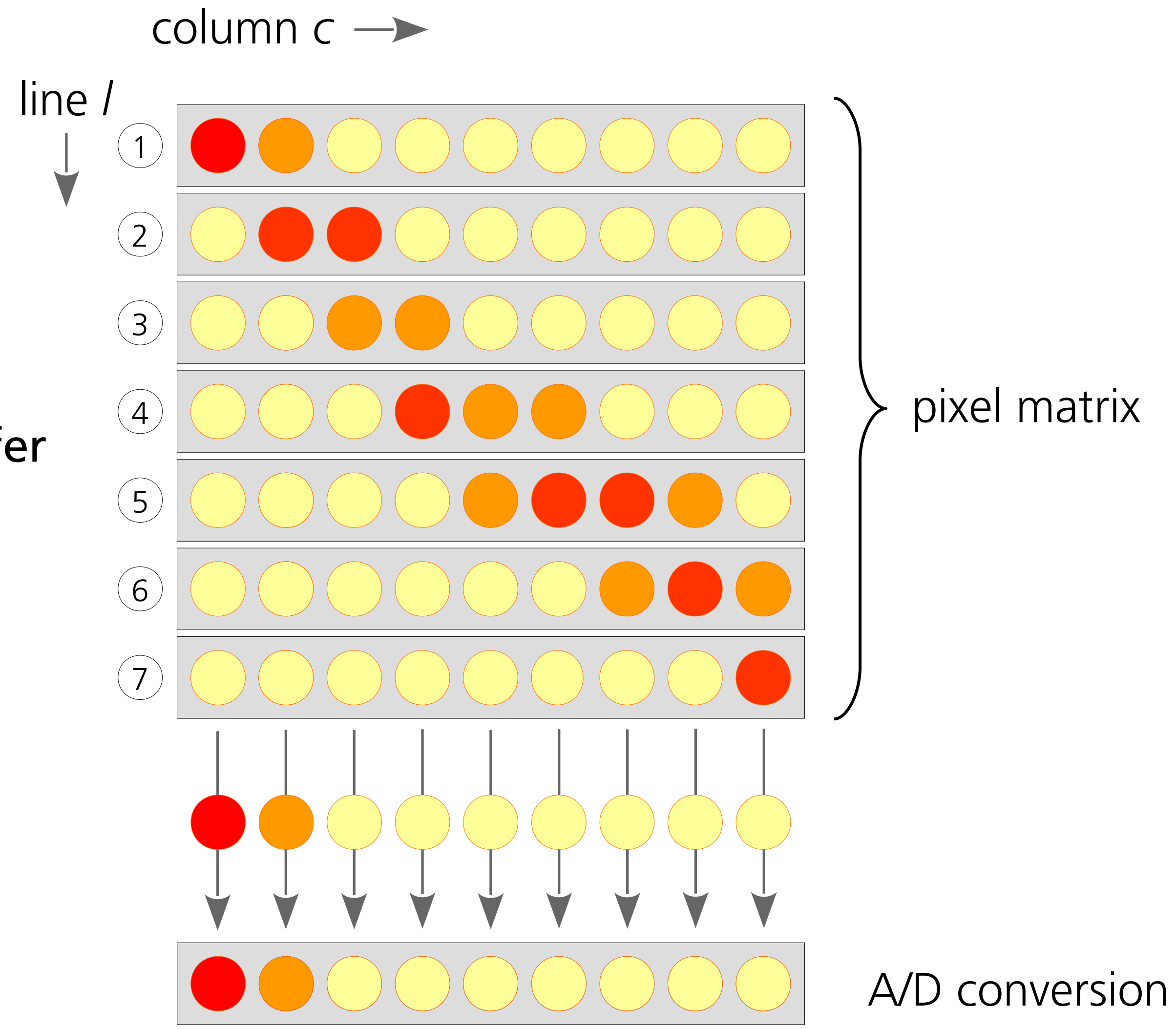
Advanced Features

Scenario 1: Sparse Pixel Data

- pixel matrix with **sparse data in *L* lines**
  - pixel values above threshold
- example
  - laser line with orthogonal intensity profile
- sequential transfer of pixel values to readout buffer
  - transfer time: T_T
- sequential A/D conversion of each line
  - conversion time: T_C
- all operations for each pixel line
  - total readout time: $T_{tot} = L\ (T_T + T_C)$
  - total conversion power consumption für C columns: $P_{tot} = L\ P_C$



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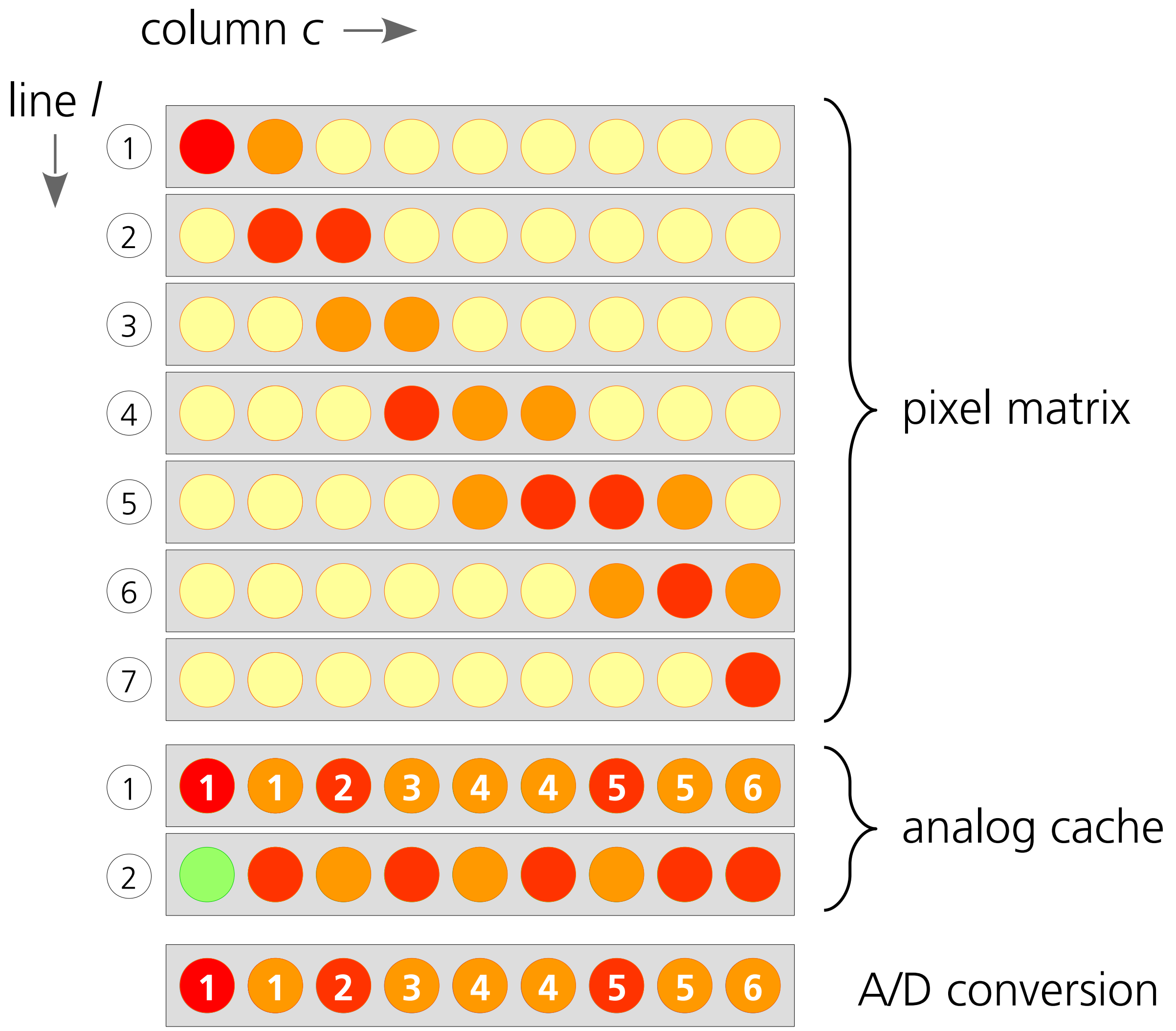
Advanced Features

Compacting Pixel Readout

- column-specific **analog cache memory**
  - storage of *M* intermediate results
- fast pixel scan mode
  - readout of pixel values or convolution results
  - with hidden copy to cache memory
  - **high-speed data analysis** (e.g. compare)
  - **write access control based on results**
- high-precision readout mode
  - readout of cache memory
  - A/D conversion with 1…10 Bit
  - **high-precision data analysis**
- A/D conversion only for cache content
  - $T_{tot} = L\ T_T + M\ T_C$ & $P_{tot} = M\ P_C$



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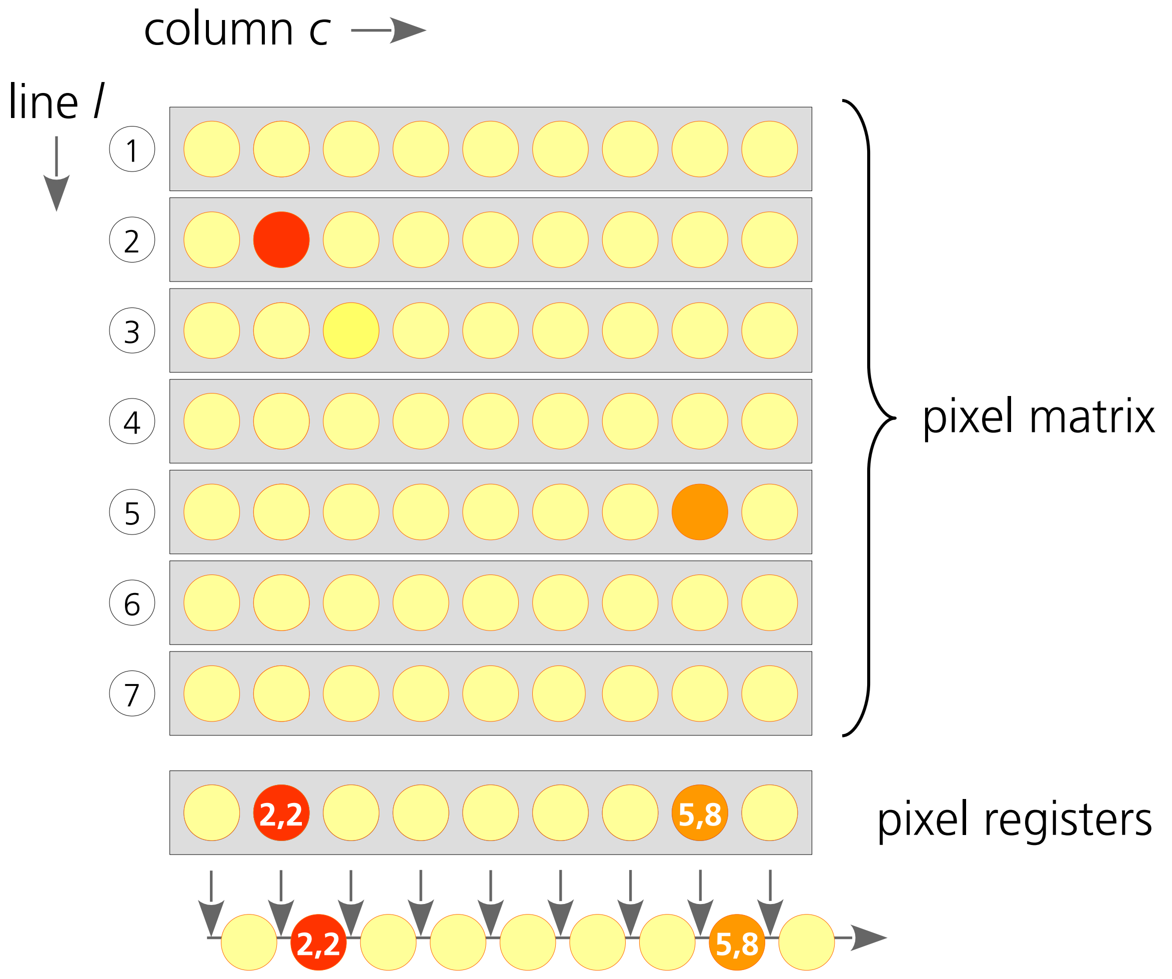
Advanced Features

Scenario 2: Sparse Column Data

- pixel matrix with **sparse data in *N* pixels**
  - discrete »active« pixels
- Examples
  - interference modulation of image stack
  - pixel-based triangulation (e.g. vibrometry)
- sequential readout of pixel values
  - transfer time per data set: T_R
- total readout time: $T_{R,\,tot} = C\ T_R$



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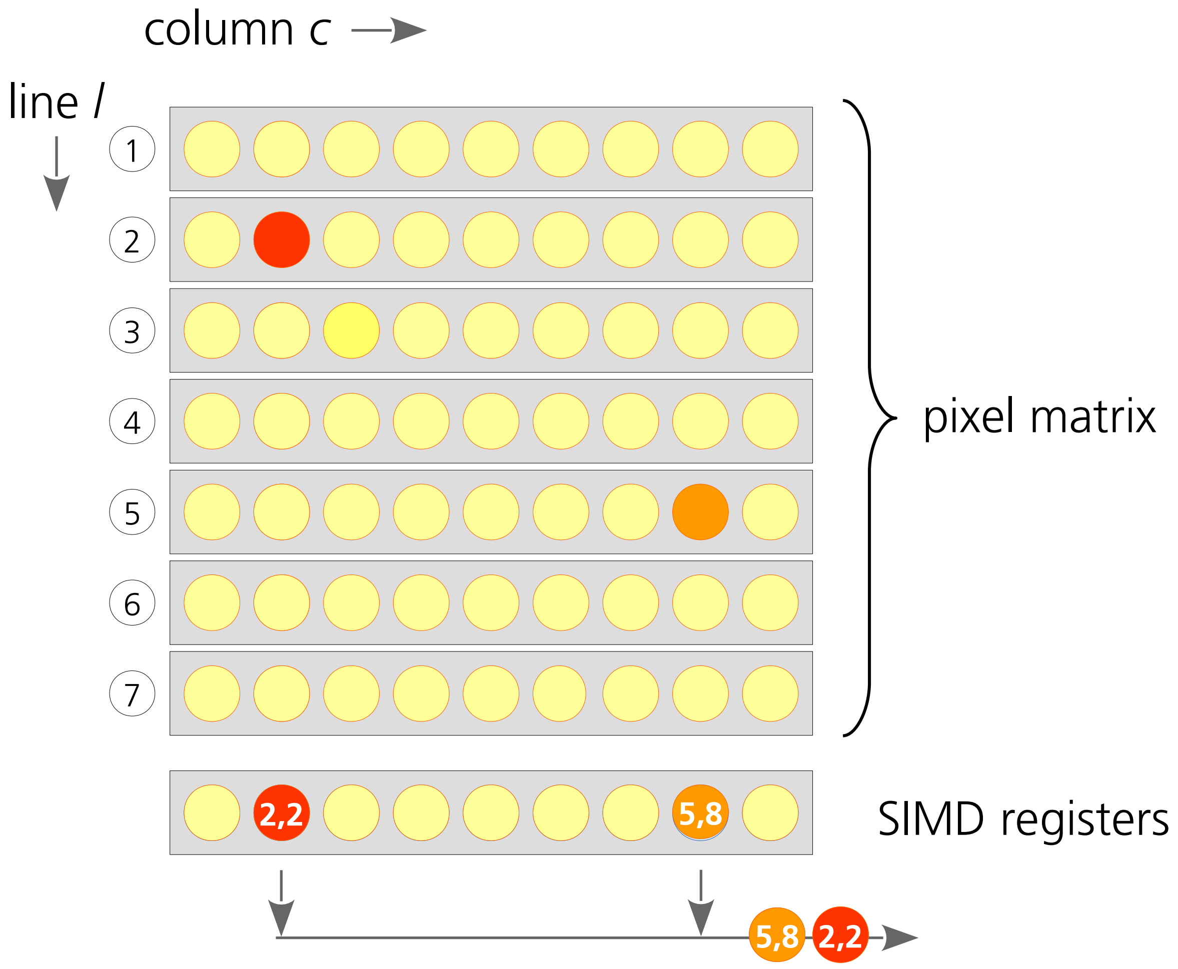
Advanced Features

Compacting Asynchronous SIMD Readout

- **asynchronous readout of active elements**
  - activity controlled by each SIMD-element
  - compacting factor depending on number of active elements
- total readout time: $T_{R,\,tot} = C\ T_R$



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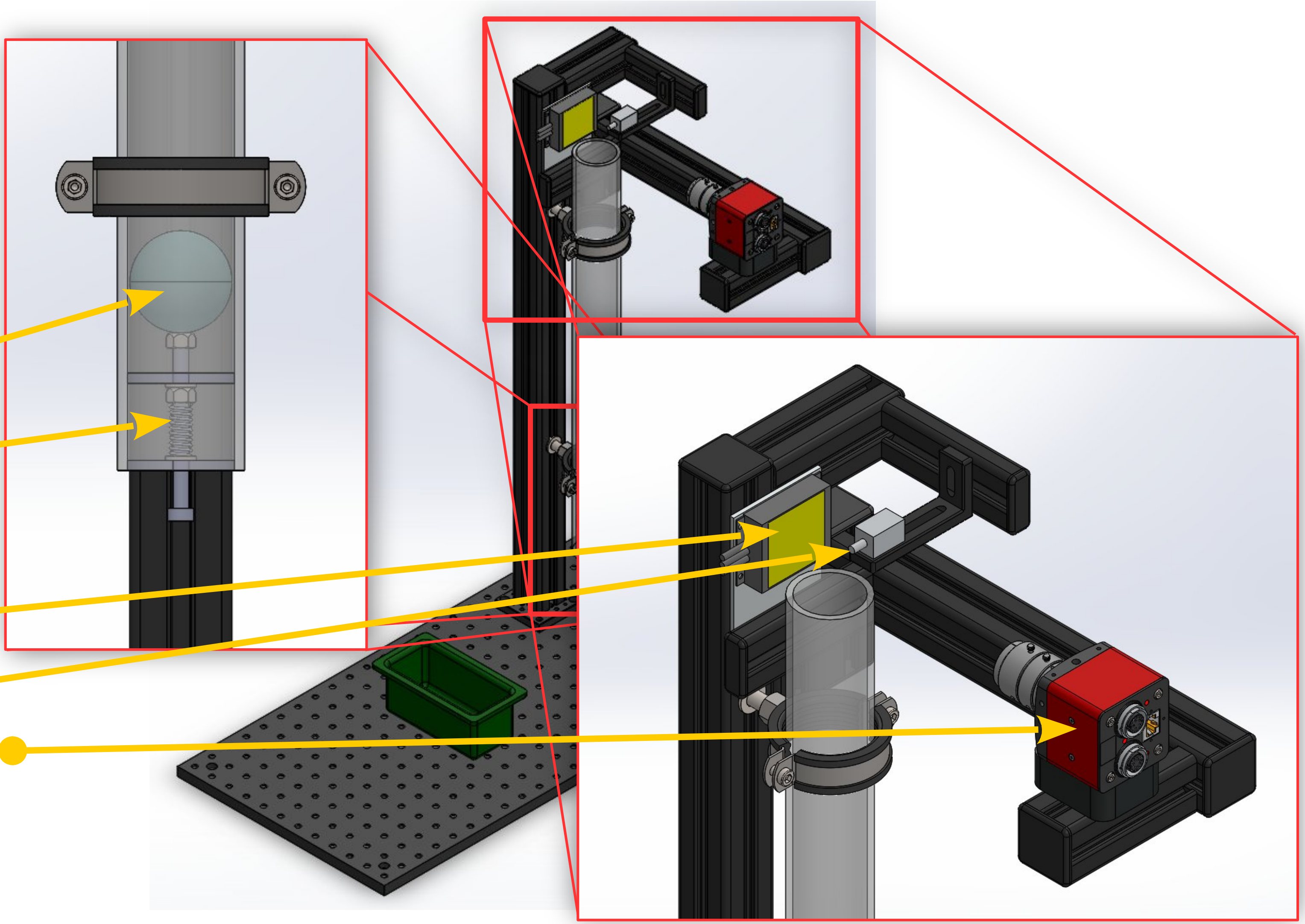
Application Examples (1)

Low-Latency Processing Cycle

»Hit a freely **flying ball**
with the right **impulse**
at the right **moment**
so that it falls **into a vessel**«

- mechanical setup with
  - a ball in a pipe with
  - a spring-loaded plunger at the bottom
- sensor-actuator setup with
  - an area light,
  - a solenoid at the pipe exit and
  - a VSoC Camera for control



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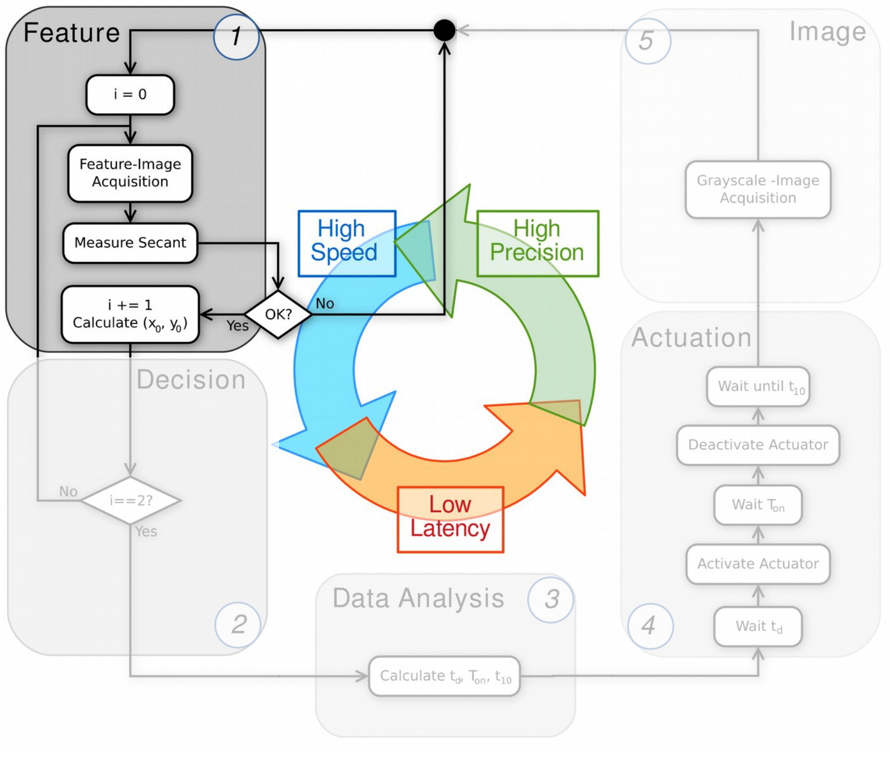
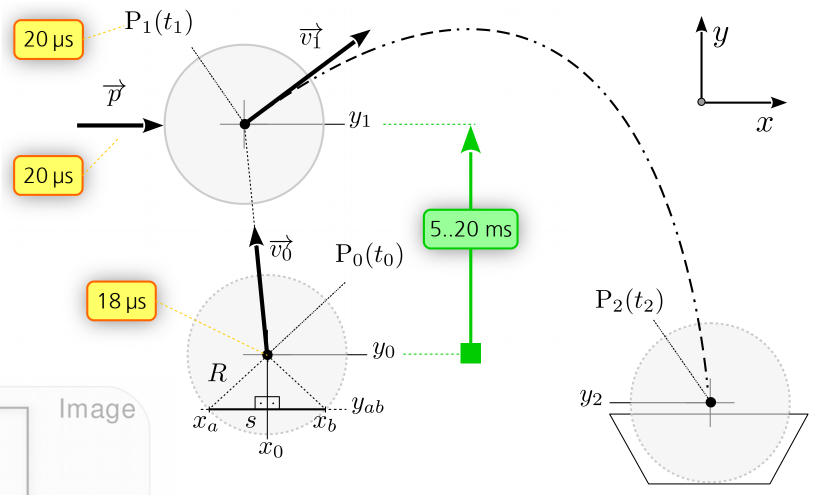
Application Examples (1)

Generic Processing Cycle

- high-speed feature extraction (5 kHz) (1)
  - object edge detection
  - position calculation
- low-latency analysis and decision making
  - trigger on data validity (2)
  - object trajectory prediction (3)
  - actuator control (4)
- high-precision measurement data acquisition
  - image acquisition at flyby (5)
  - data acquisition for process analysis
  - object position & speed
  - actuator position and speed





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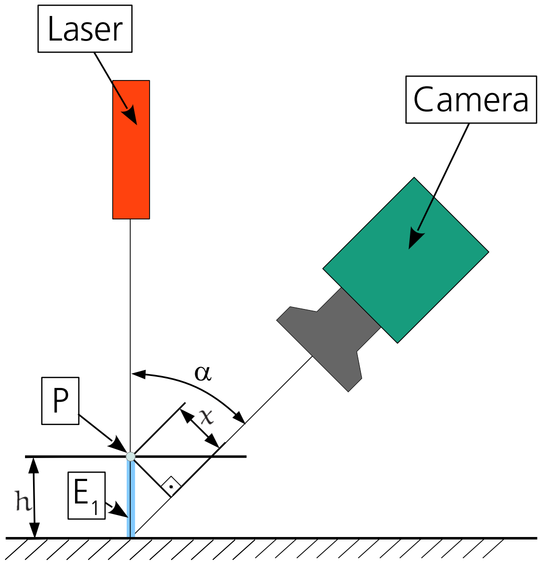
Application Examples (2)
Sheet of Light

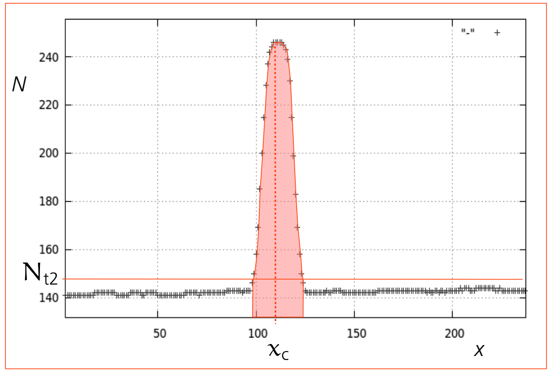
First and most important: **don't generate data you don't need**

- 1D filtering before A/D conversion
  - size of convolution kernel depending on laser line
  - ADC resolution depending on speed (in software)
  - only output laser line position



Second: **what do we gain, if we give up a certain »correctness / precision / beauty«?**

- no need to convert all speckles if we can filter beforehand
- much higher speed
- lin / log processing for non-cooperative surfaces → not a real CoG possible



→ very high flexibility for profile post-processing / closed-loop control

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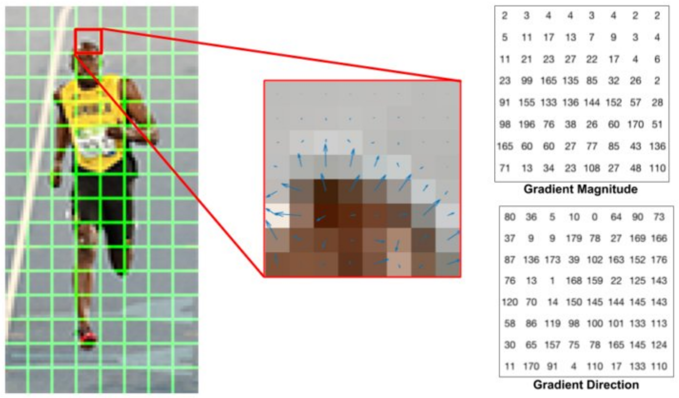
Application Examples (3)

Histogram of Oriented Gradients (HoG)



Source: *http://www.learnopencv.com/histogram-of-oriented-gradients/*

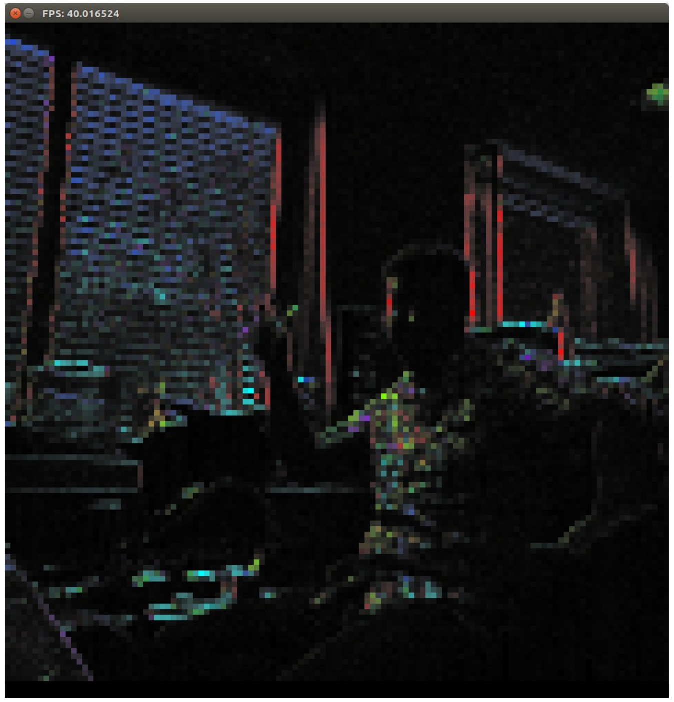
General Description

- paper by N. Dalal und P. Triggs (2005)
- gradient → absolute value + angle → histogram
- post-processing with SVM or other methods

Application Details

- example with 1 MPix / 8x8 pixel per region
  - OpenCV on Intel Core I7: ≈ *7 Hz / 150W*
  - skeleton on VSoC: approx. *40 Hz / 200mW*
- detection and localization of people

→ **highly flexible feature extraction / privacy by design**



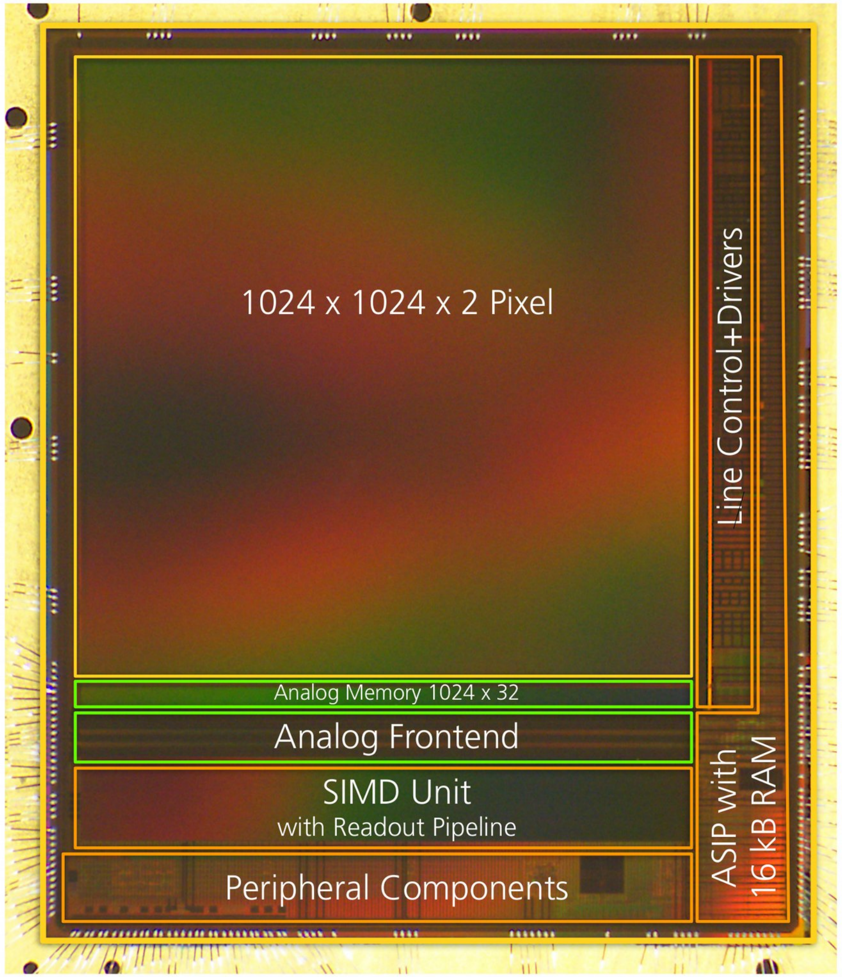
Conclusion

Our **Vision System-on-Chip** architecture

- has been developed based on essential customer needs,
- has unique features regarding low latency and dynamic range
- is extremely flexible for a large variety of special applications

now its time

- to **realize applications** that benefit from our VSoC approach and
- to **enable our customers** to bring this **leading edge technology** to **their markets.**



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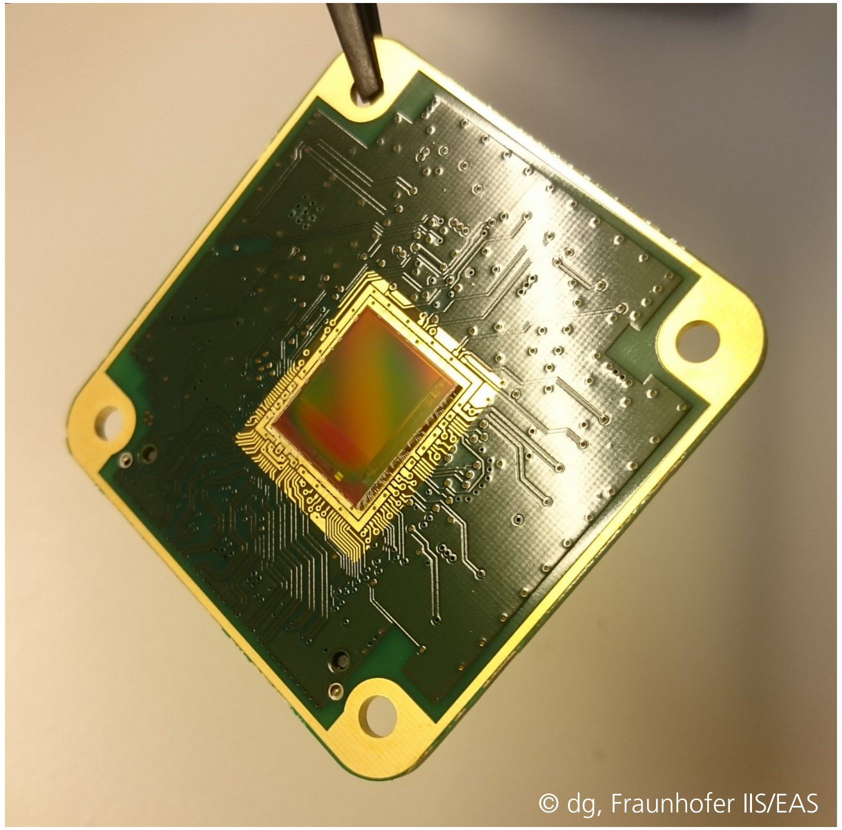
Your Benefits

- planning and realization of ambitious **optical measurement, testing** and **control tasks** for
  - **quality assurance** via **automated full testing** and
  - **quality improvement** through **optical process control**

- **customer-specific software-defined smart camera systems** for
  - the **flexible and efficient** implementation of
  - image acquisition and processing methods

- **sensor module** based on advanced **Vision-System-on-Chip**

- optimization of **total system costs** and **product life cycle**



See you on Hall 1 / boot G42

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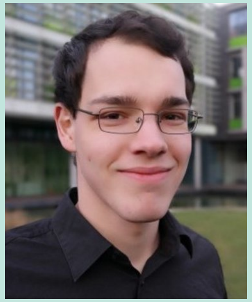

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