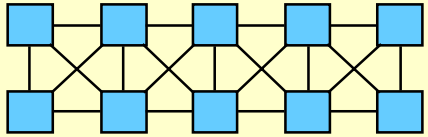


Analogic Computers Ltd

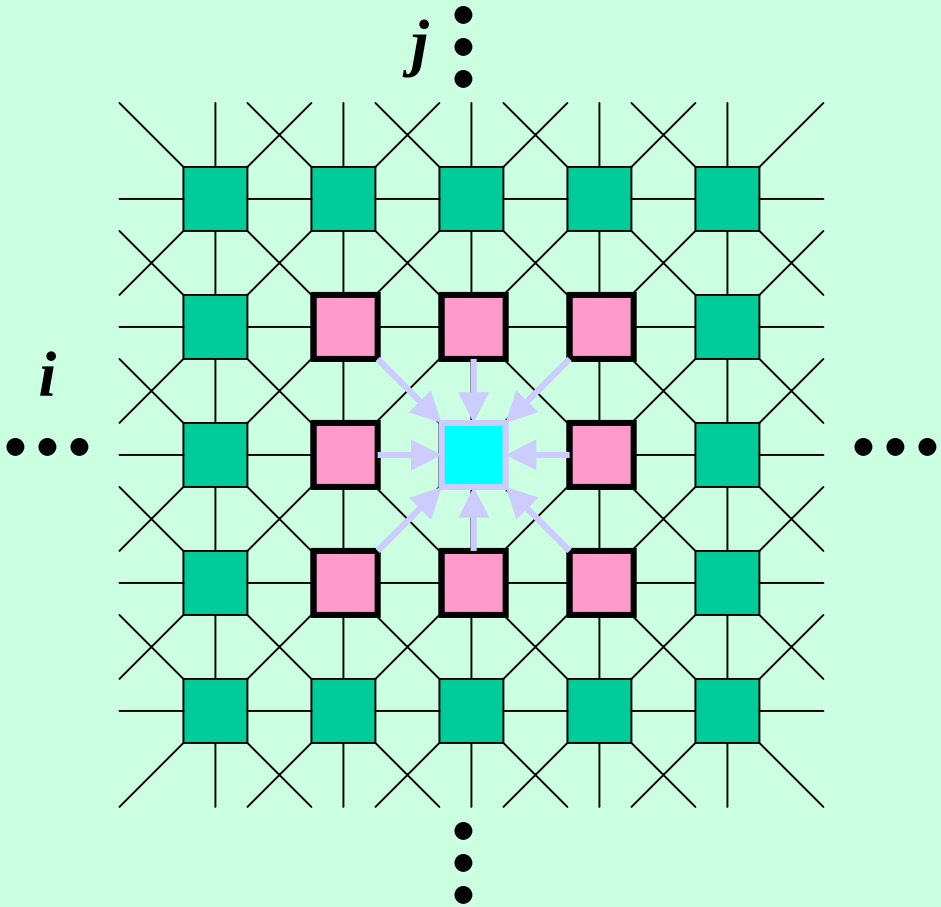
CNN Technology

- introduction, tools and application examples-

Outline

- **Introduction to CNN**
  - ***Array structure and the analog core cell***
  - ***CNN Universal Machine***
- **CNN implementations**
  - ***Analog mixed-signal VLSI***
  - ***Emulated digital VLSI***
  - ***Opto-electronic***
- **Tools and application examples**
  - ***Library of image processing primitives and subroutines***
  - ***Focal-plane and video-flow processing***
- **Summary**

CNN - Introduction



Cellular Neural/Nonlinear Network:

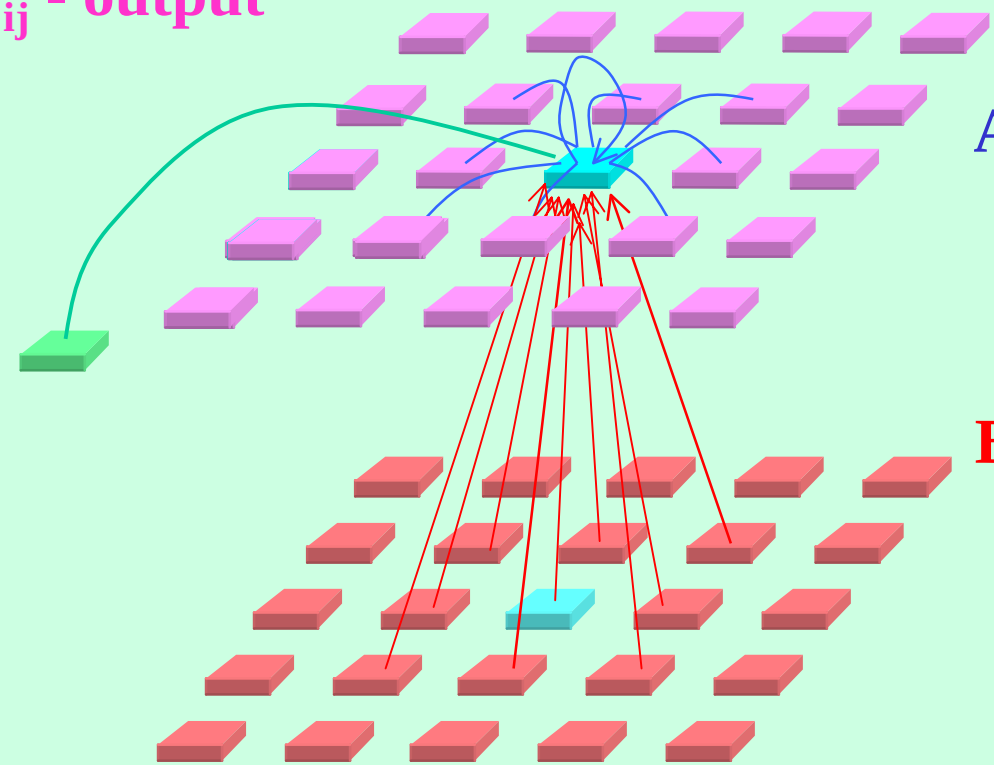
- **an analog processor array**
- **on a rectangular grid**
- **with space invariant**
- **local interactions.**

CNN - Introduction

x_{ij} - state/ y_{ij} - output

z - bias

u_{ij} - input



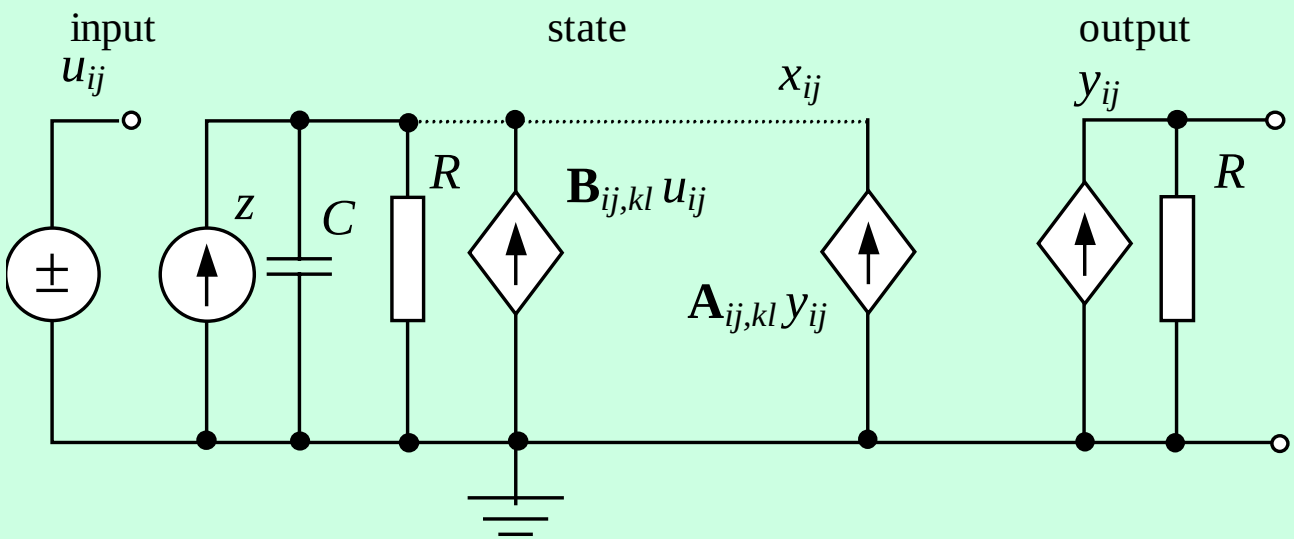
$$\mathbf{A} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 2 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

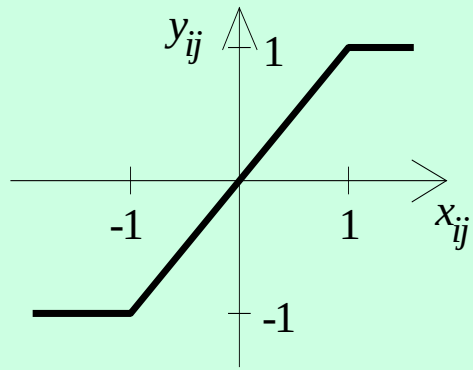
$$\mathbf{B} = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

$z = -0.5$

Template - the program of the network: **[A B z]**

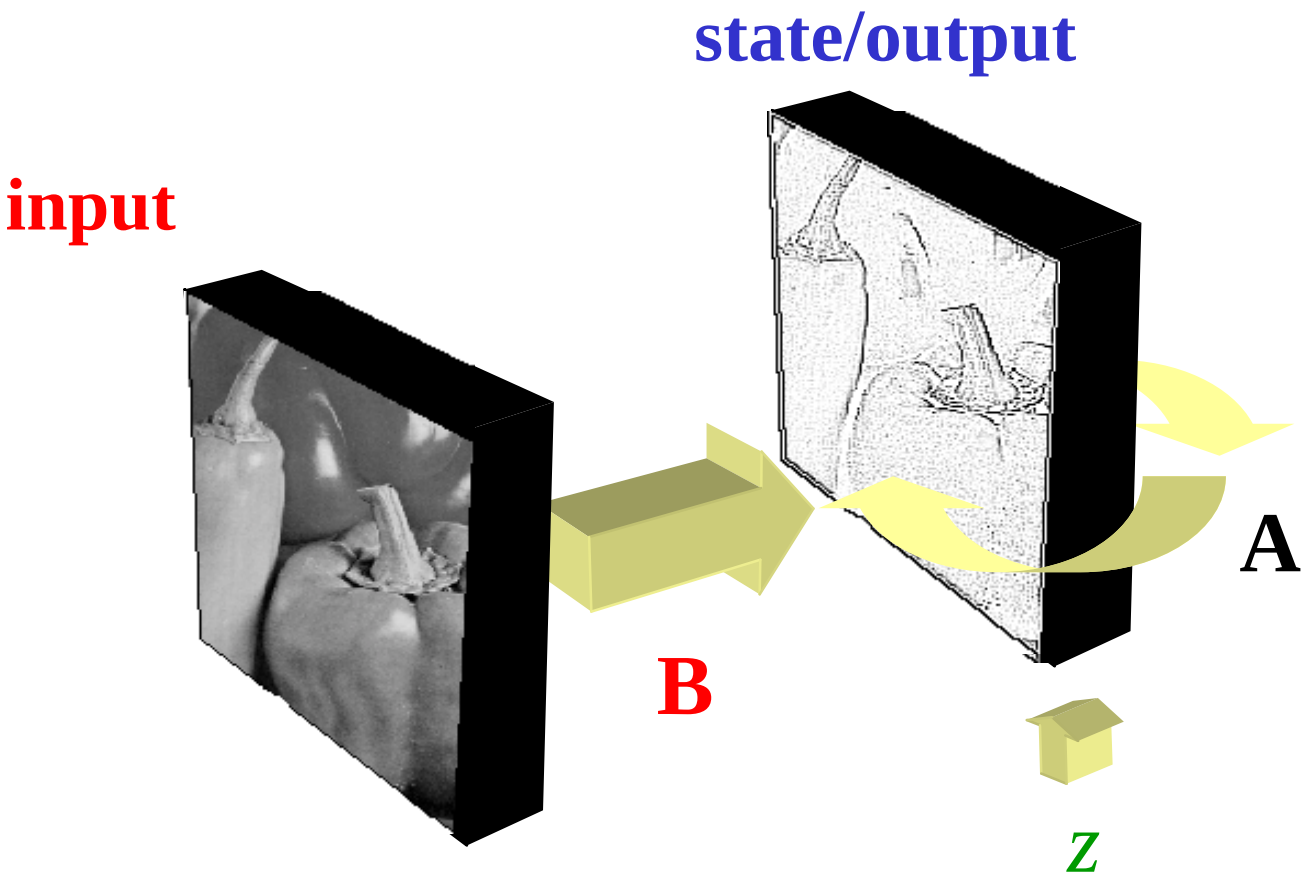
CNN core cell



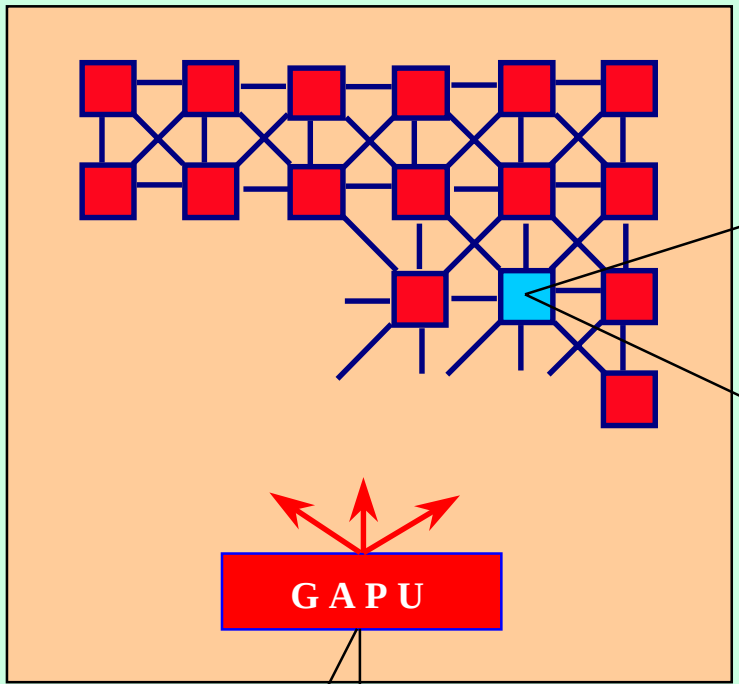


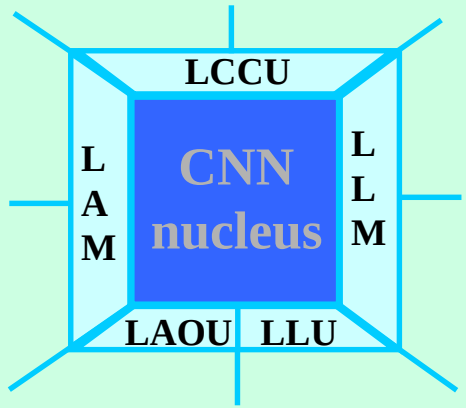
$$C\,\frac{dx_{ij}}{dt}(t) = -\frac{1}{R}\,x_{ij}(t) + \sum_{C(kl)\in N_r(i,j)} \mathbf{A}_{ij,kl}\,y_{kl}(t) + \sum_{C(kl)\in N_r(i,j)} \mathbf{B}_{ij,kl}\,u_{ij} + z$$

Parallel CNN array computation



CNN Universal Machine (CNN-UM)





LAM: Local Analogue Memory
LLM: Local Logic Memory
LCCU: Local Communication and Control Unit
LAOU: Local Analogue Output Unit
LLU: Local Logic Unit

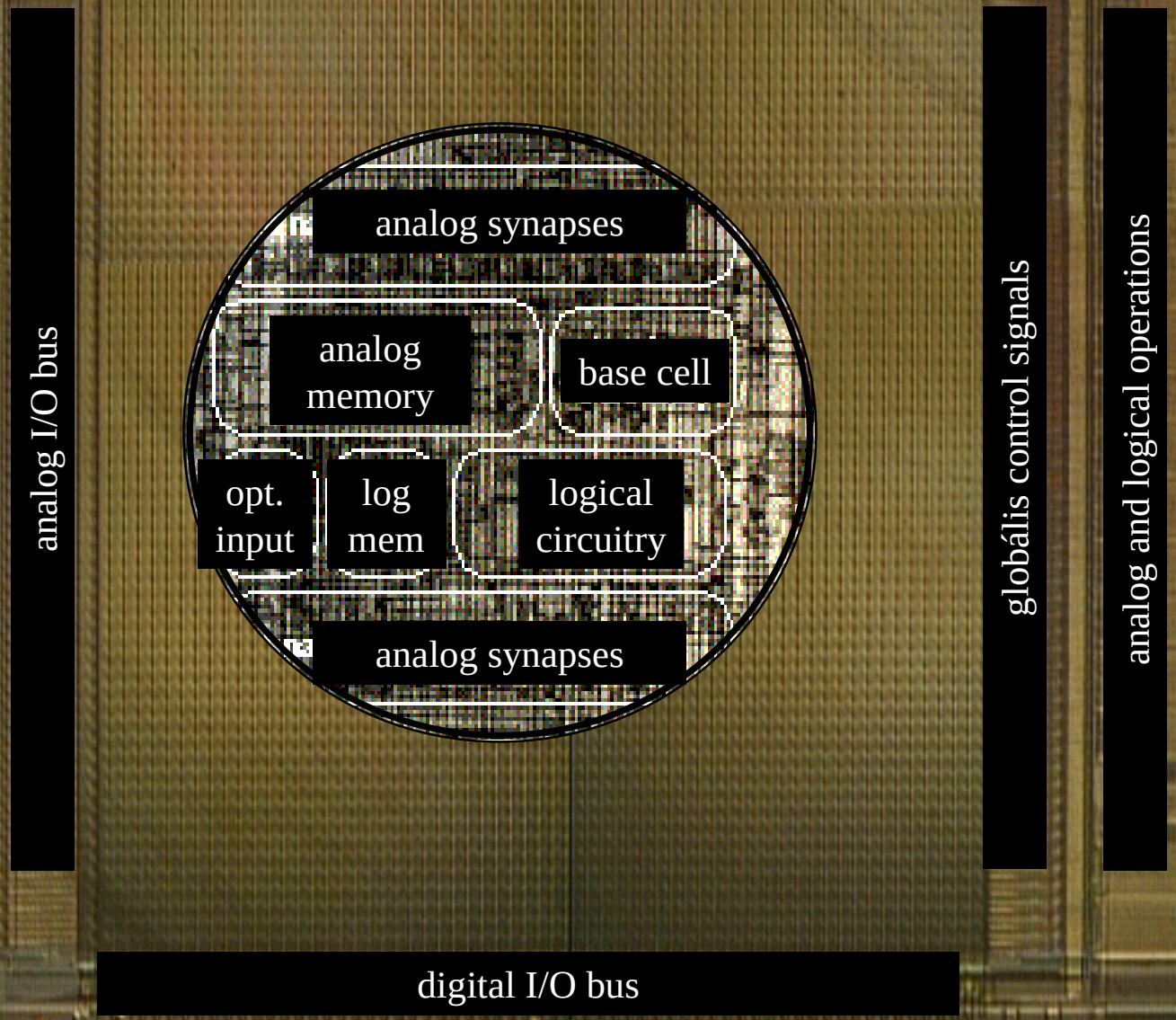
GAPU: Global Analogic Programming Unit

APR: Analog Instruction Register
LPR: Logic Program Register
SCR: Switch Configuration Register
GACU: Global Analogic Control Unit

$[A_1\ B_1\ z_1], [A_2\ B_2\ z_2], \ldots$

"Analogic (analog+logic) algorithm"

CNN Universal Machine (CNN-UM)



ACE4K CNN-UM chip

- **Resolution: 64x64 = 4096 analog processors**
- **Power consumption: 1W**
- **Total silicon area: $1cm^2$**
- **Speed: 1,7 Tera (10^{12}) equivalent digital operations/sec**
- **Designed in 98-99 at IMSE CNM (Seville) in cooperation with ANCL MTA-SZTAKI (Budapest)**

Instruction set of the CNN Visual Microprocessor

- **Spatio-temporal nonlinear PDEs**
  - ***binary and gray-scale***
- **Mathematical morphology operations**
  - ***binary and gray-scale***
- **Local logic operations**
  - ***pixel-by-pixel logic operations on two black-and-white images***
- **Global logic operations**
  - ***pixel-wise logic OR, AND for a whole black-and-white image***
- **Internal image transfer**
- **External image and template transfer**
- **Direct optical input**

CNN-UM









Aladdin: a CNN chip prototyping and development system

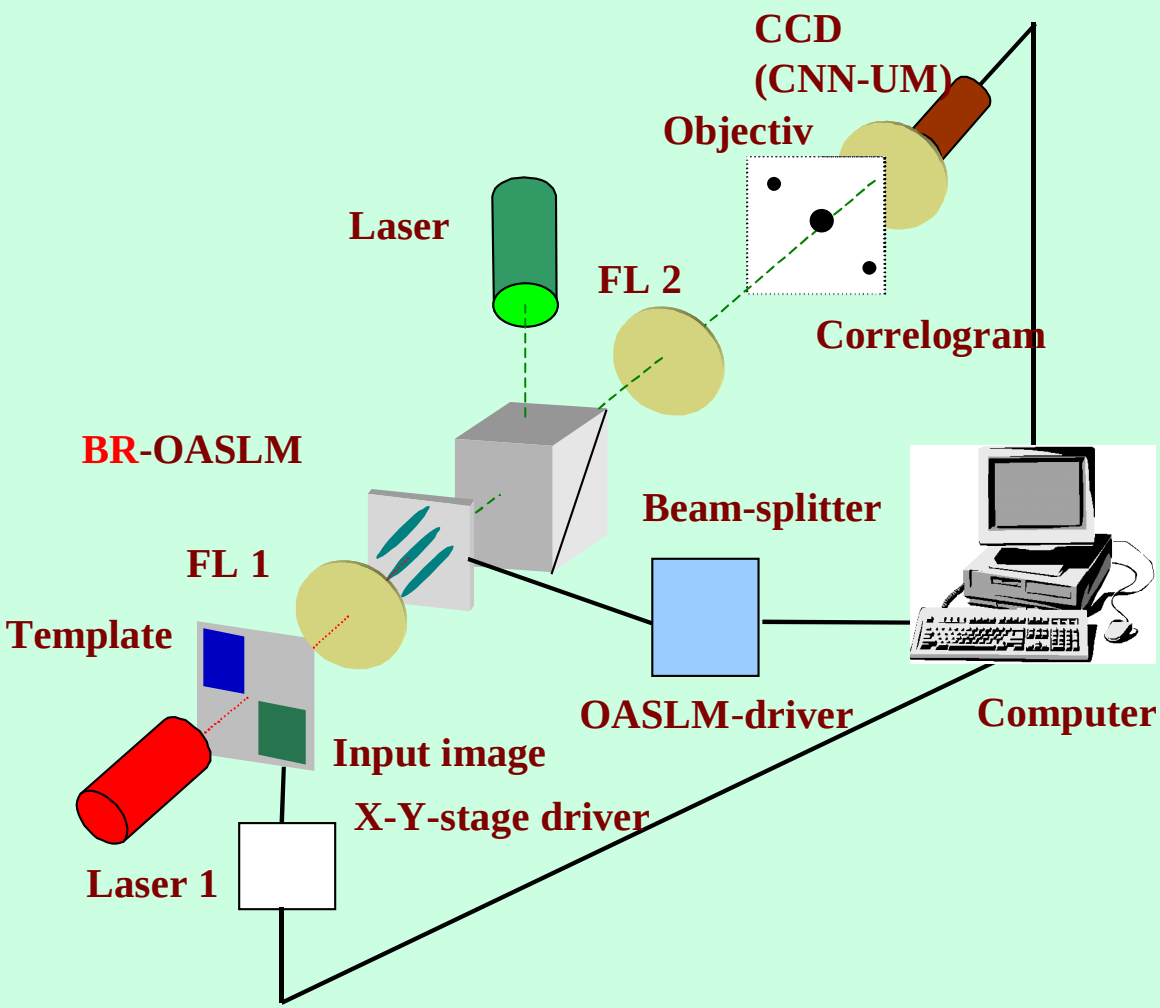
Emulated digital CNN-UM implementation

- **CASTLE project**
  - **emulated digital CNN implementation**
  - **24 digital processors integrated on a single chip**
  - **12, 6, 1 bit resolution processing**
  - **Speed: 3x3 convolution (12 bit) takes 1ns (20 GOPs)**
  - **Area: 1cm^2**
  - **Technology: 0.25 μ**
  - **Application: real-time video processing**

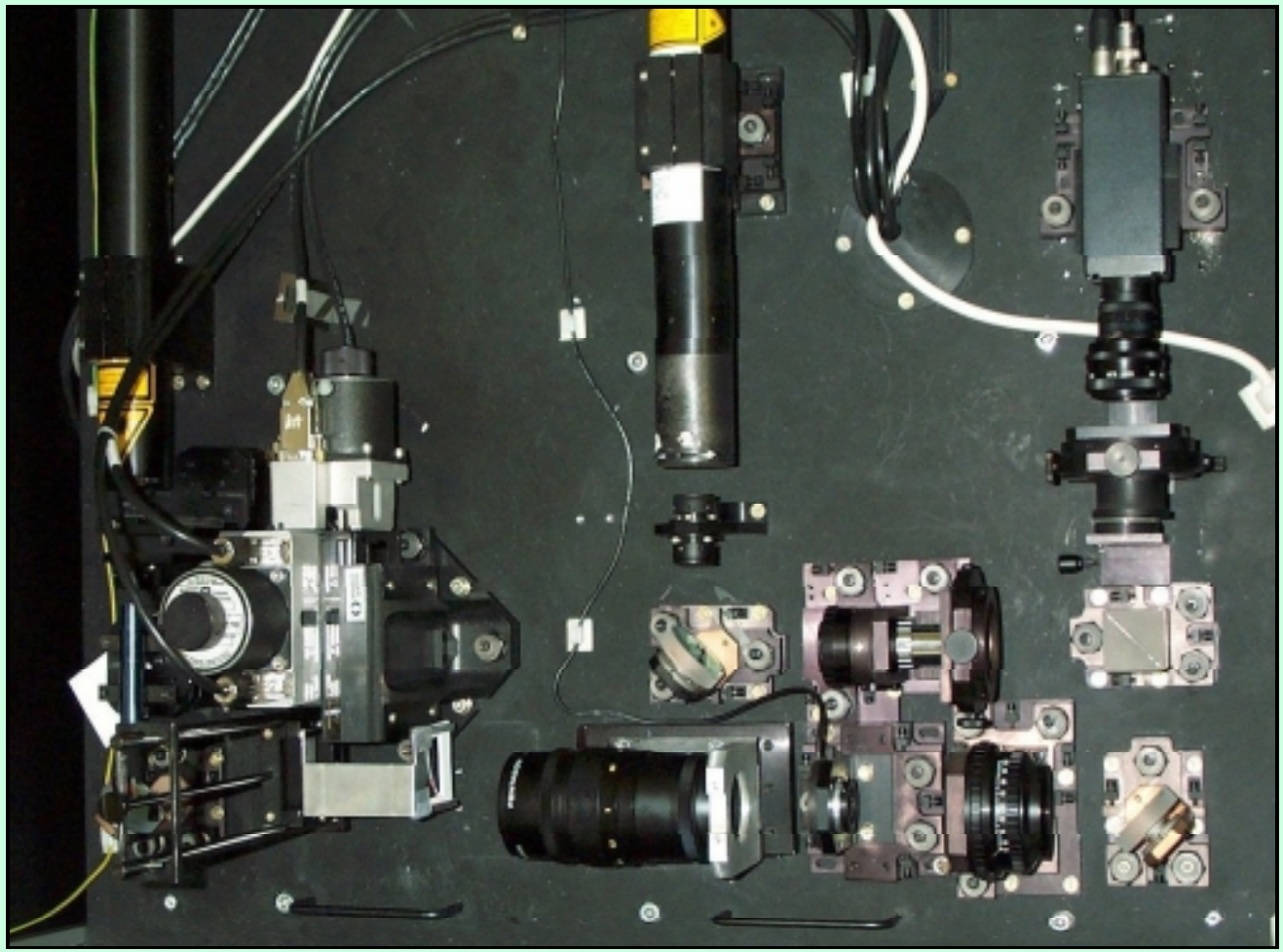
Opto-electronic CNN-UM implementation

- **Recent advances in optical computing:**
  - **electrically addressable spatial light modulators (SLMs);**
  - **optically addressable spatial light modulators (OSLMs);**
  - **mirror arrays**
  - **programmable semitransparent mirrors**
- **Opto-electronic CNN-UM:**
  - **combines optics and analog VLSI**
  - **a programmable optical computer**

Opto-electronic CNN-UM implementation



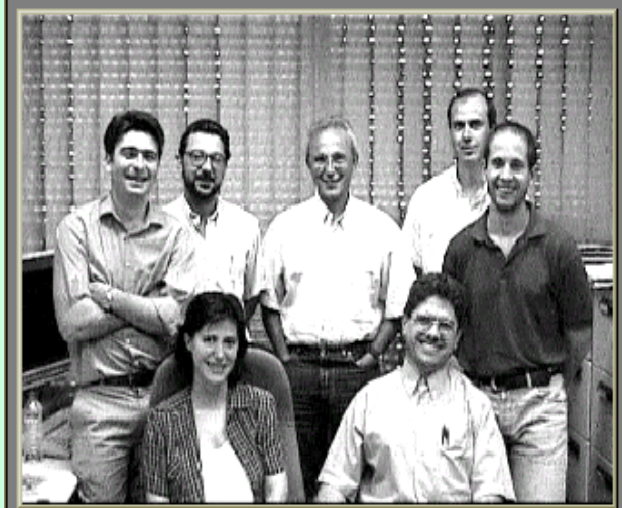
Opto-electronic CNN-UM implementation



Tools and application examples

- **Standard image processing functions**
  - **a library of image processing primitives and subroutines**
- **Real-time focal-plane image processing:**
  - **Over 10,000 frames/sec image acquisition and classification**
- **On-line video-flow processing:**
  - **Bubble-debris separation**
  - **Multi-modal image fusion**

Thresholded gradient as edge detection

Input image	Simulated	Done by the chip
		

Halftoning of gray-scale image

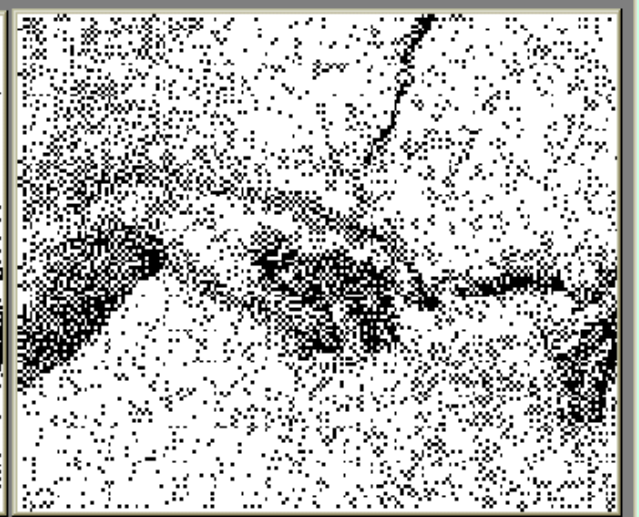
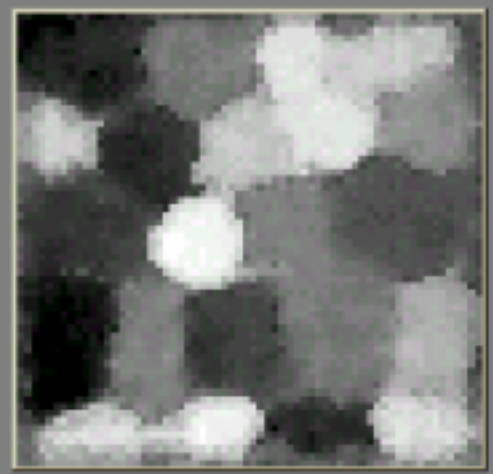
Input image	Simulated	Done by the chip
		

Image size: QCIF 176x144

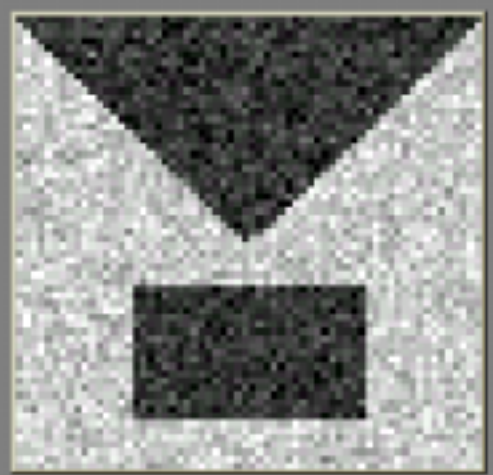
Nonlinear diffusion

Input 'A'

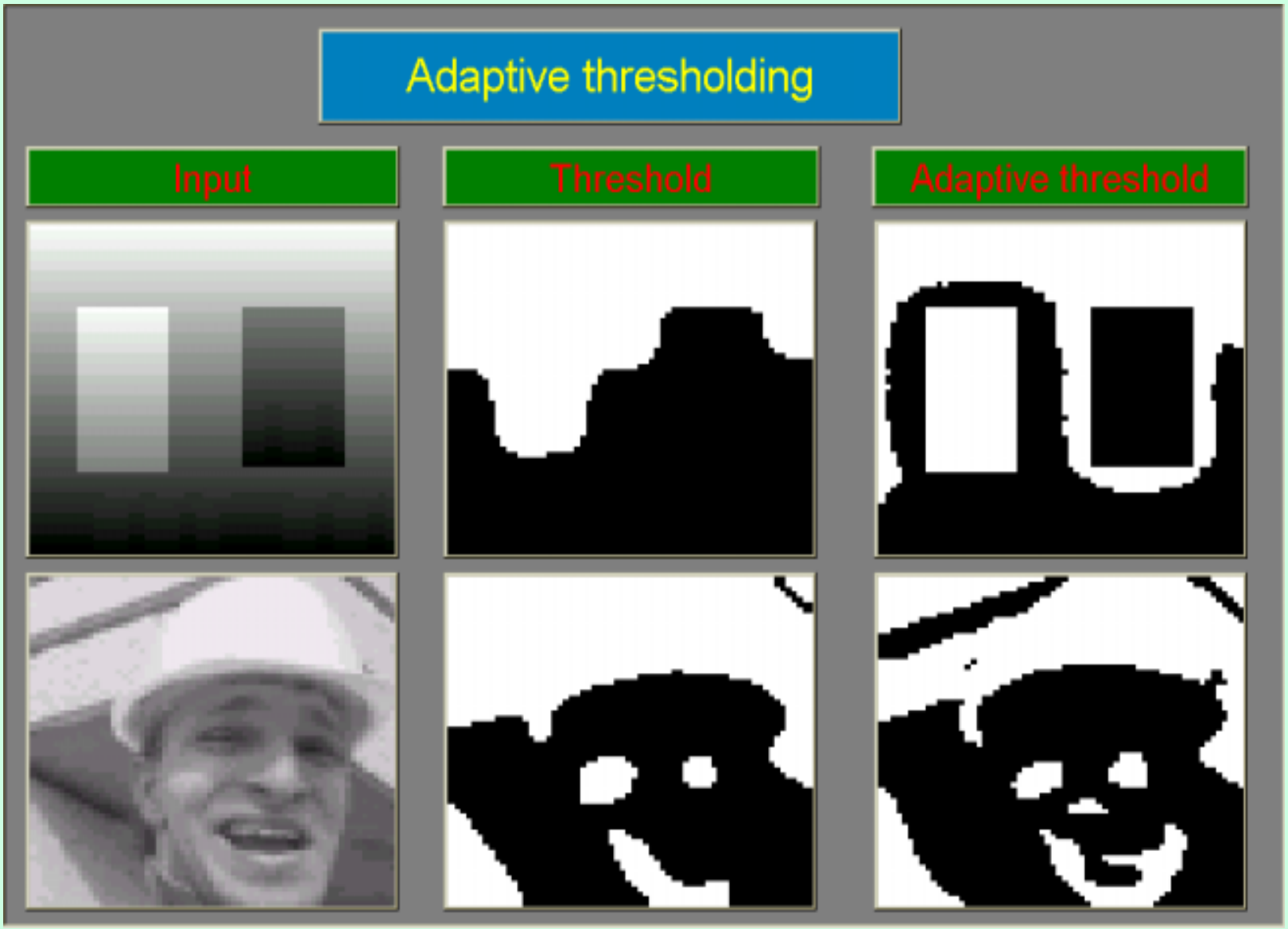
Output 'A'



Input 'B'



Output 'B'


Adaptive thresholding
Input
Threshold
Adaptive threshold

Impulse noise removal by changing the local maxima, minima to local average

Input image

Filtered image

Motion Detection

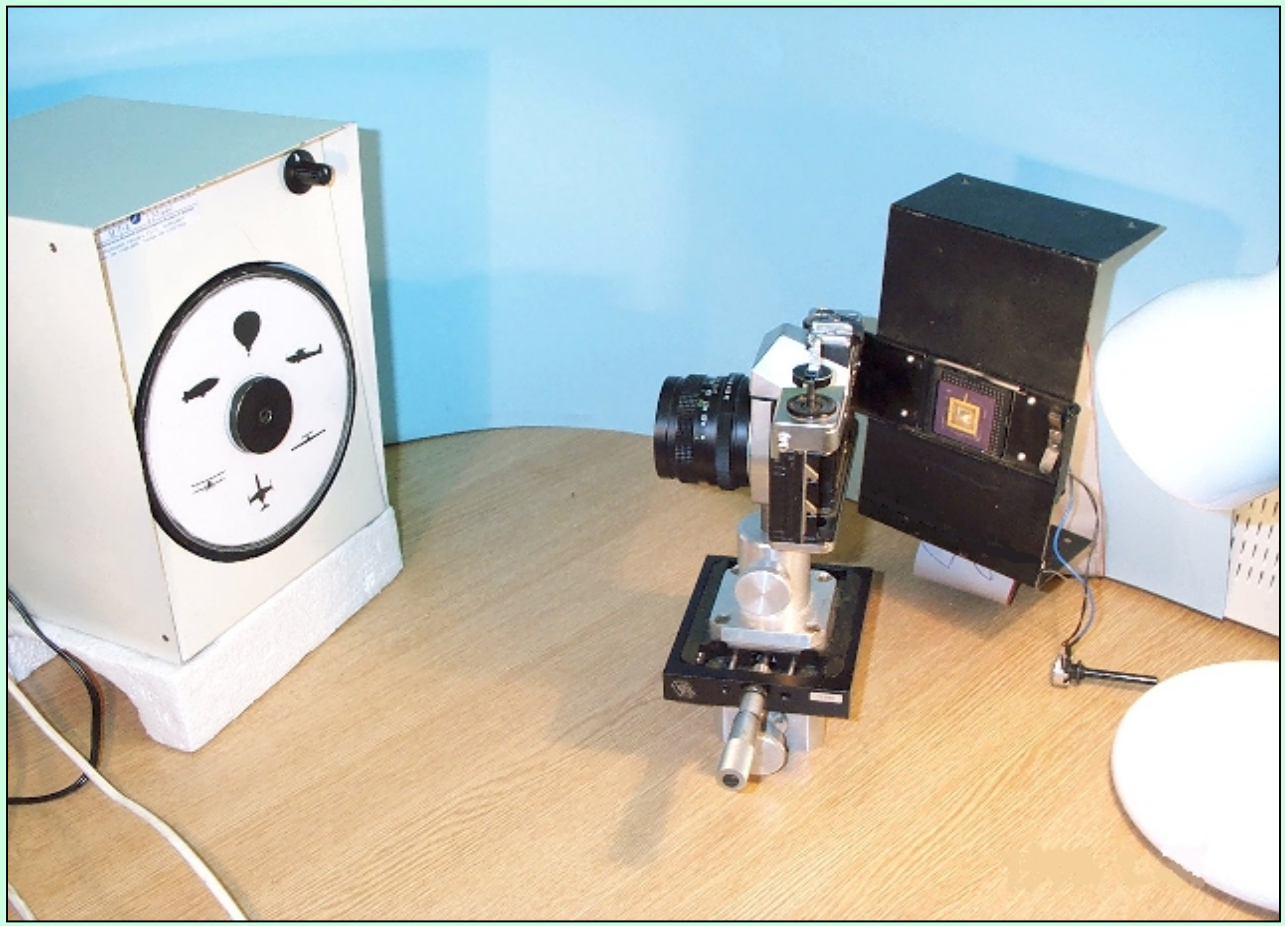
Separation of the stationary and moving parts

Original image parts

Moving parts

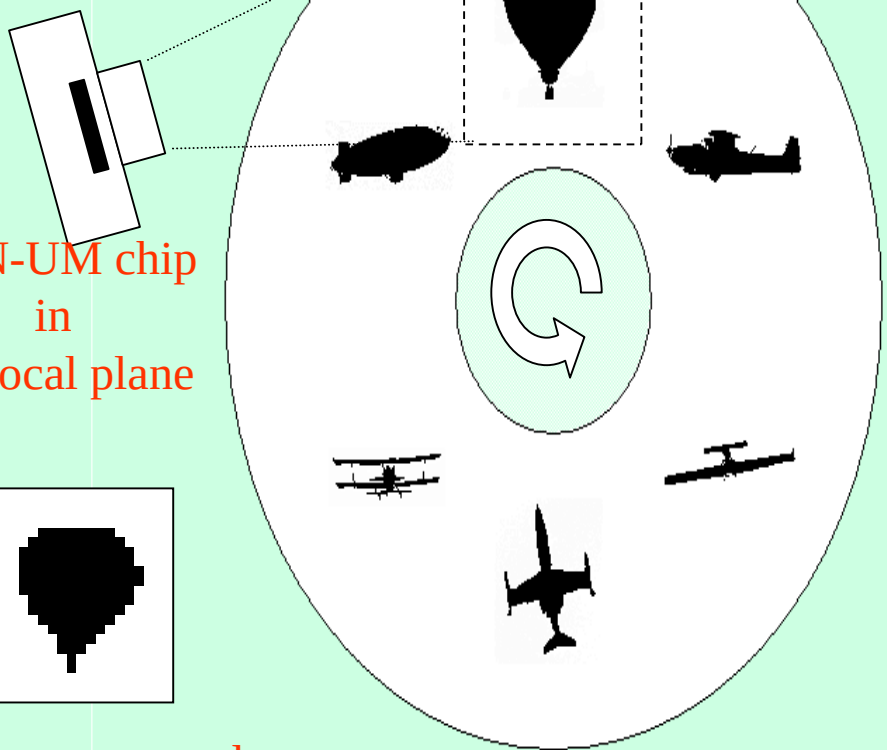
Stationary

Focal-plane Image Processing:
Ultra High frame-rate image classification



Ultra High frame-rate image classification

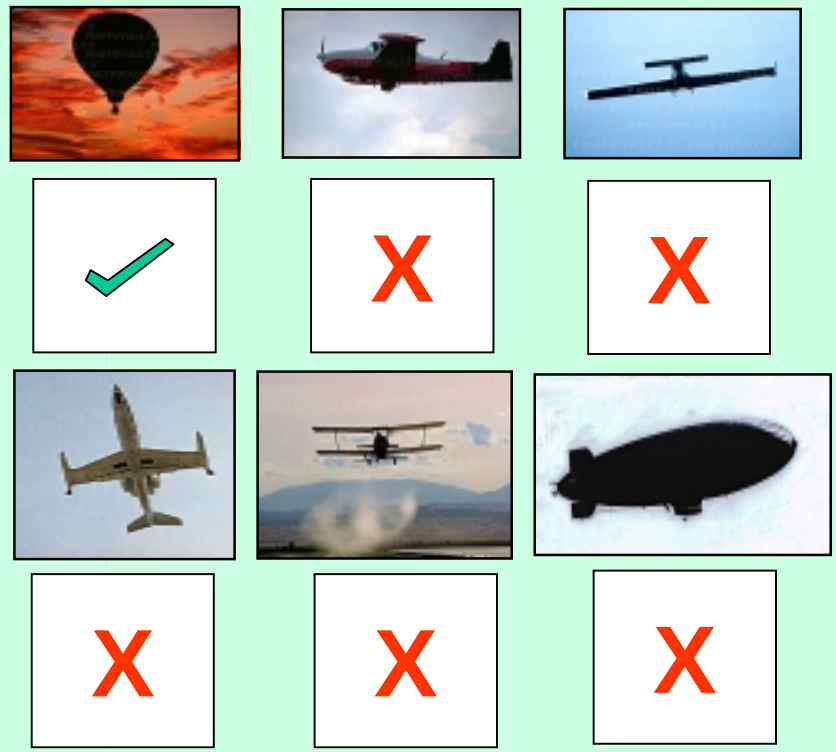
Viewable area



CNN-UM chip
in
the focal plane

Image, captured
by the chip

Classification result

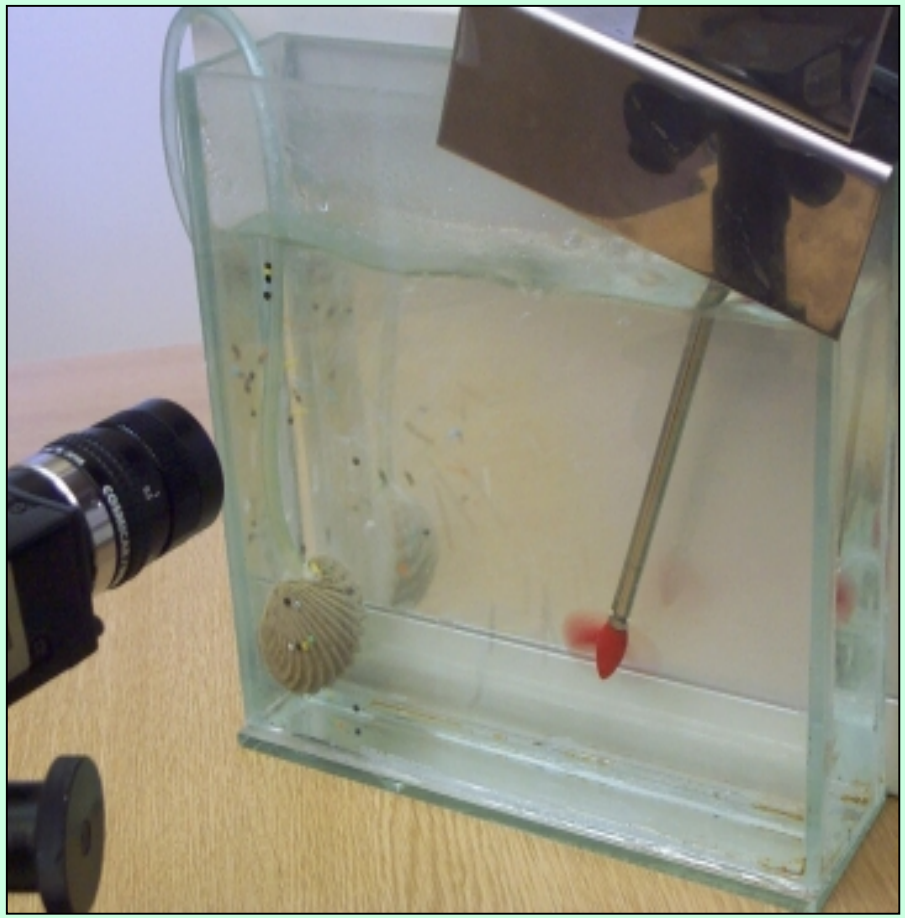


Object not in center: X

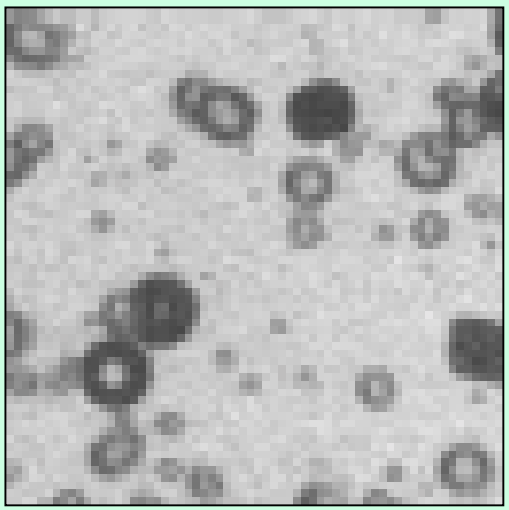
Main features of the experimental setup

- **Maximum frame-rate with the current setup: 10,000 fps**
- **Maximum frame-rate with an optimized setup: 50,000 fps (stroboscopic illumination, faster electronic environment)**
- **Maximum speed of the disk: 3,000 r/min (~10m/s) adjustable**

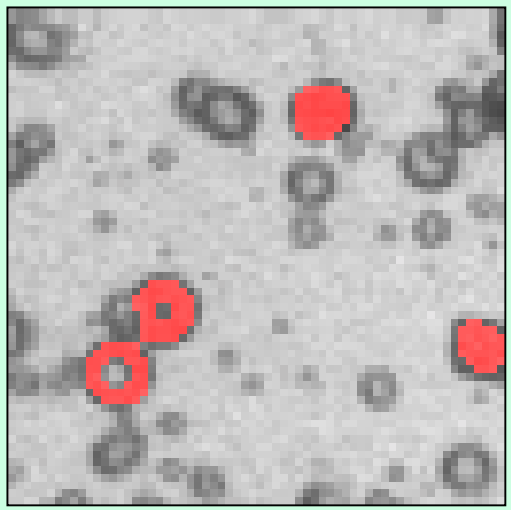
On-line video-flow processing: Bubble-debris separation



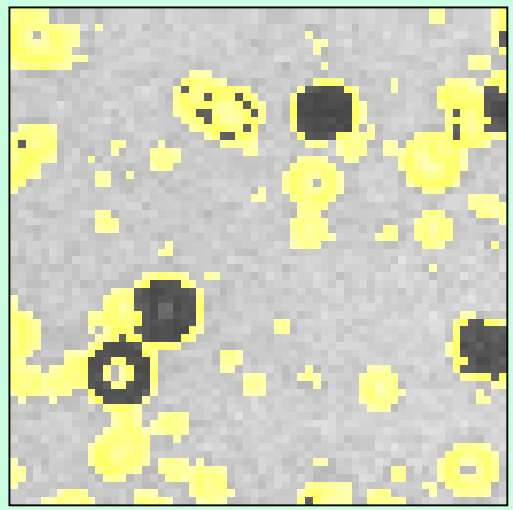
Measurement results



Captured image sequence



Marbles (debris)



Bubbles

Image fusion and object tracking

Daylight camera image

Long wave IR camera image

Image fusion and object tracking

Daylight camera image

Long wave IR camera image

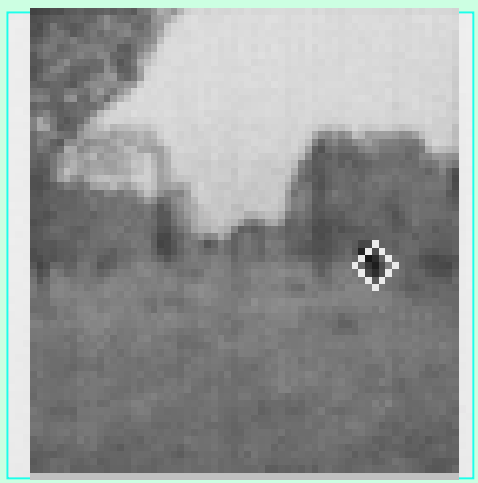
Fused image sequence

Fusion Combined with Tracking

IR camera input

Daylight camera input

Tracking and fusion output



Summary

- **An analogic CNN visual microprocessor architecture (CNN-UM) and computational infrastructure has been developed**

- **Potential application areas: real-time focal plane image processing (e.g. trigger event detection and object tracking); on-line video-flow processing (e.g. quality control, maintenance, security and surveillance)**