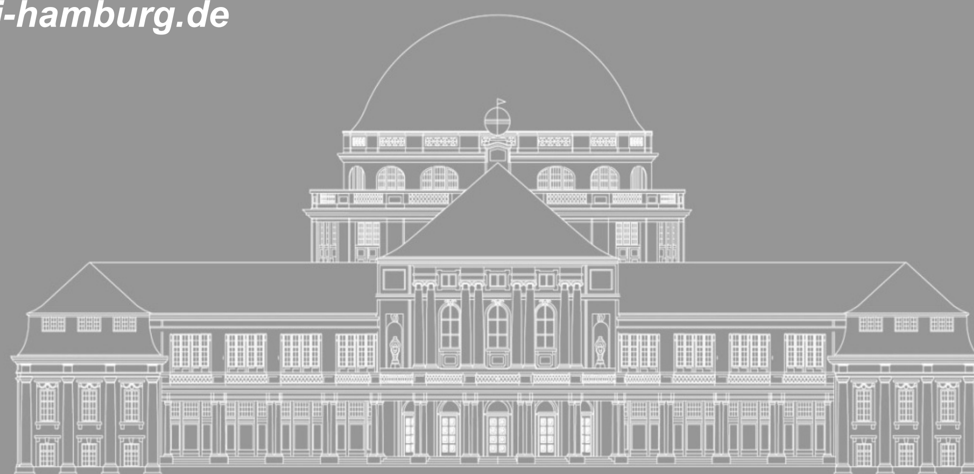
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Department of Informatics
Intelligent Robotics WS 2016/17

28.11.2016

Neural Models for Multi-Sensor Integration in Robotics

Josip Josifovski
4josifov@informatik.uni-hamburg.de

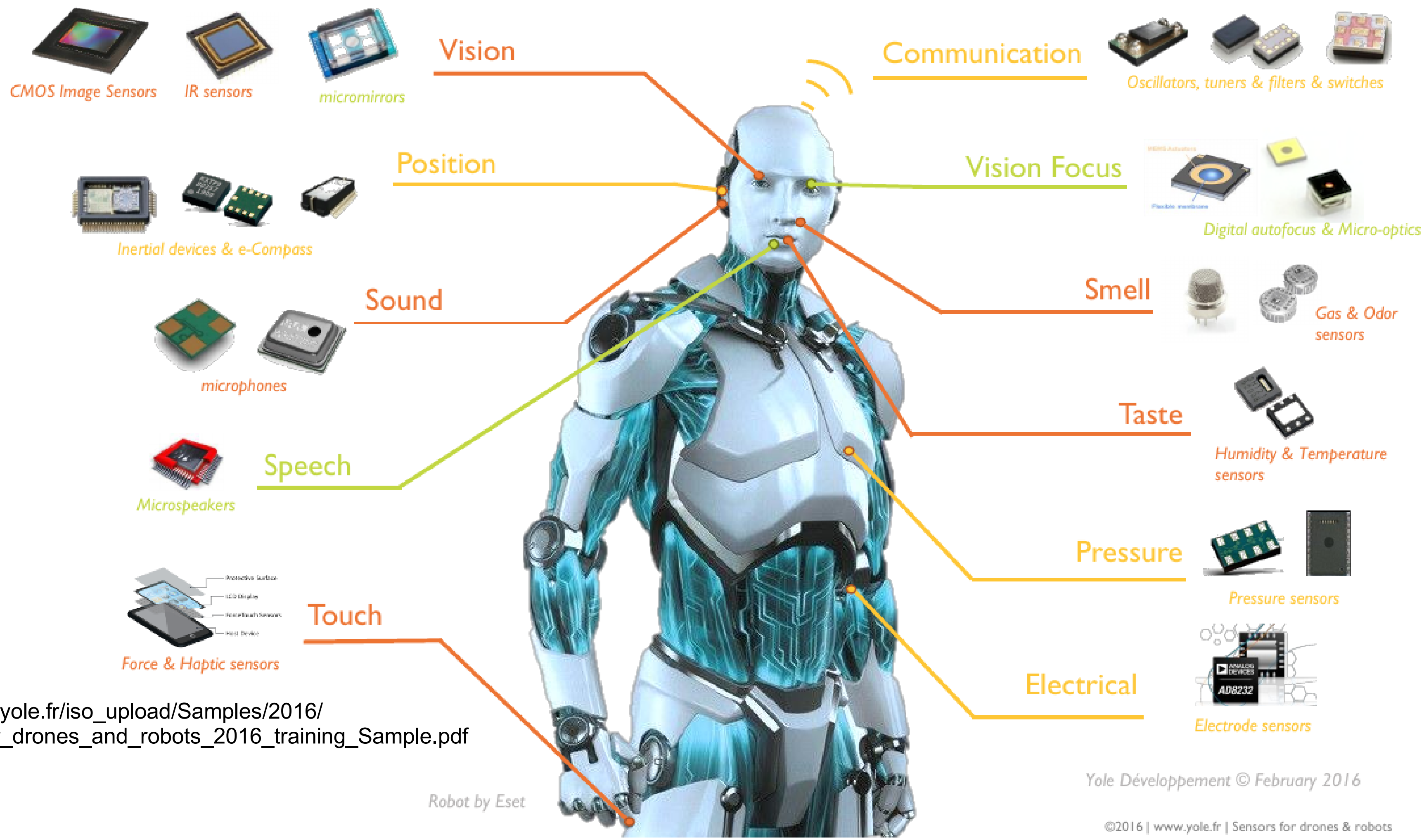


Outline

- **Multi-sensor Integration**:
  - Definitions, benefits, possible approaches
- **Neurally inspired sensor integration and fusion**
  - Ideas, benefits and drawbacks
- **Case: Robot control by Hierarchical Neural Network**
  - Robot and model description, results
- **Case: Sensor fusion for estimating robot heading**
  - Robot and model description, results
- **Current Research at our HRI Lab**
- **Summary**

Multi-Sensor Integration - Definition

Multi-sensor integration - Sensor fusion - Modality - Multi-modal integration

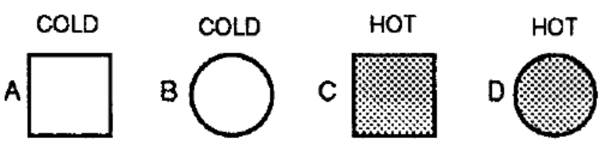


http://www.yole.fr/iso_upload/Samples/2016/Sensor_for_drones_and_robots_2016_training_Sample.pdf

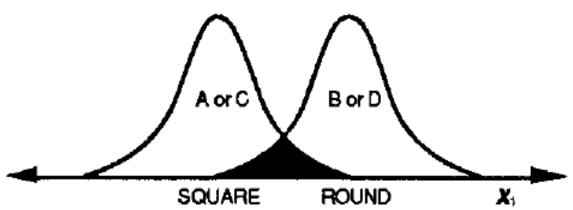
Multiple sensors – Benefits

The motivation behind usage of multiple sensors

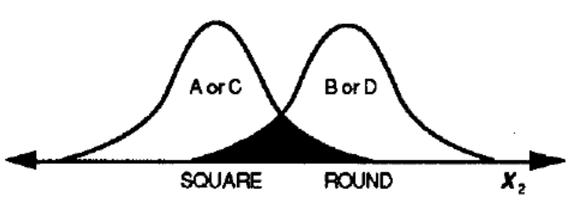
- Providing redundant information (increased reliability and availability)
- Providing complementary information (increasing dimensionality i.e. coverage)



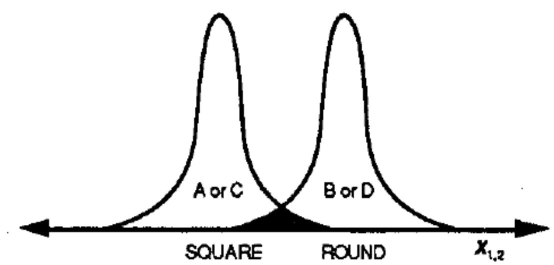
(a) Four objects.



(b) Sensor 1.



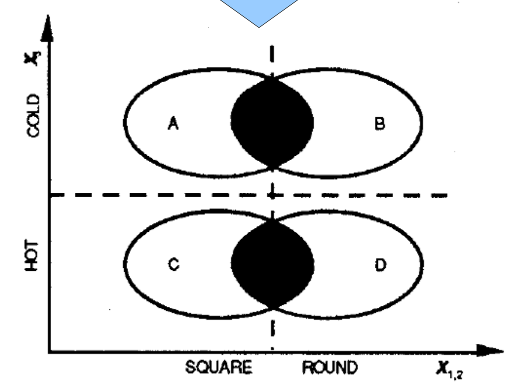
(c) Sensor 2.



(d) Sensors 1 and 2.

Redundant information of the two shape sensors improves precision in distinction of shape

Complementary information from additional heat sensor makes distinction possible



(e) Sensors 1, 2, and 3.

[1] Luo and Kay, 1990

Different approaches of MSI/Fusion

Estimation methods	Non-recursive: •Weighted Average •Least Squares Recursive: •Kalman Filtering •Extended Kalman Filtering
Classification methods	•Parametric Templates •Cluster Analysis •Learning Vector Quantization (LVQ) •K-means Clustering •Kohonen Feature Map •ART, ARTMAP, Fuzzy-ART Network
Inference methods	•Bayesian Inference •Dempster-Shafer Method •Generalized Evidence Processing
Artificial intelligence methods	•Expert System •Adaptive Neural Network •Fuzzy Logic

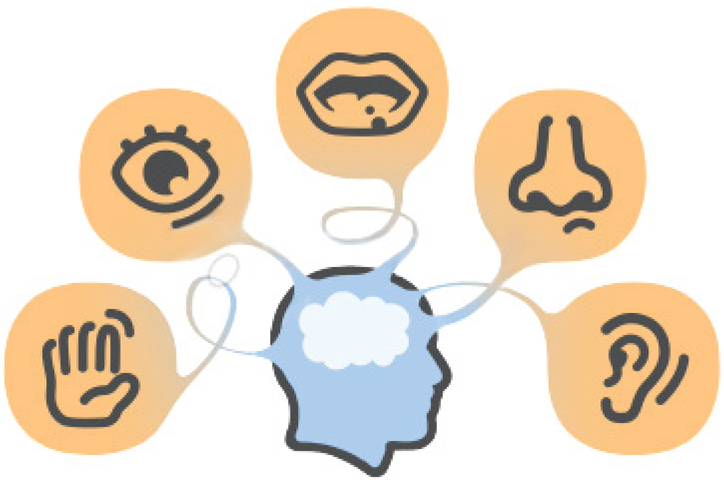
[2] Luo, Chih-Chen Yih and Kuo Lan Su, 2002

Multi-sensor integration with NNs

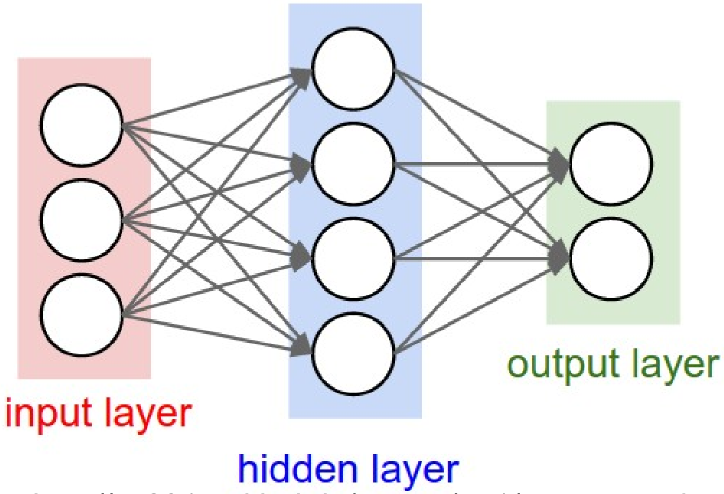
- Biologically inspired solution for MSI
- The brain as an integration model

- Benefits of using neural architectures:
  - Unified framework
  - Strong generalization abilities
  - Adaptability

- Drawbacks of using neural architectures:
  - Training procedure
  - Unclear causality



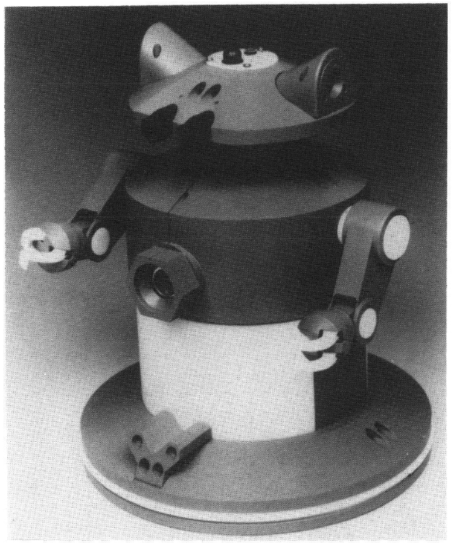
http://www.autismmind.com/

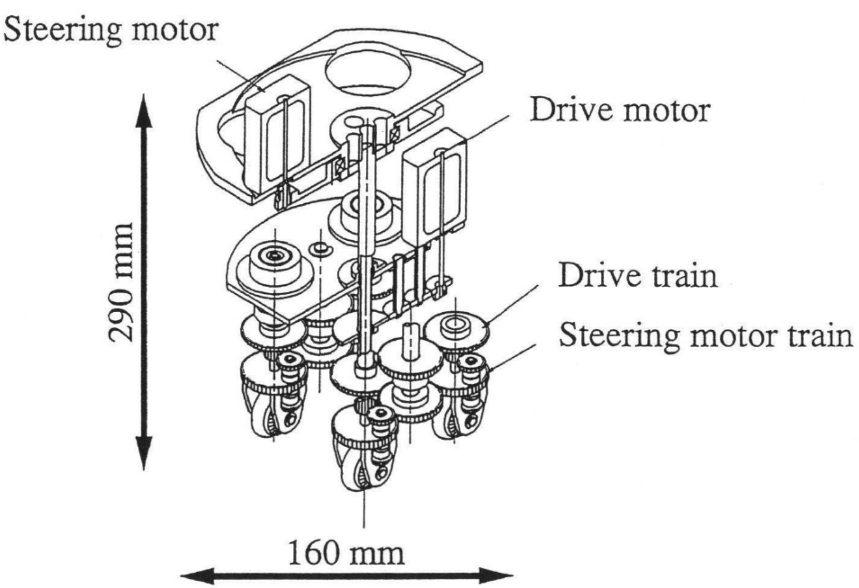


http://cs231n.github.io/assets/nn1/neural_net.jpeg

Robot control by Hierarchical NN

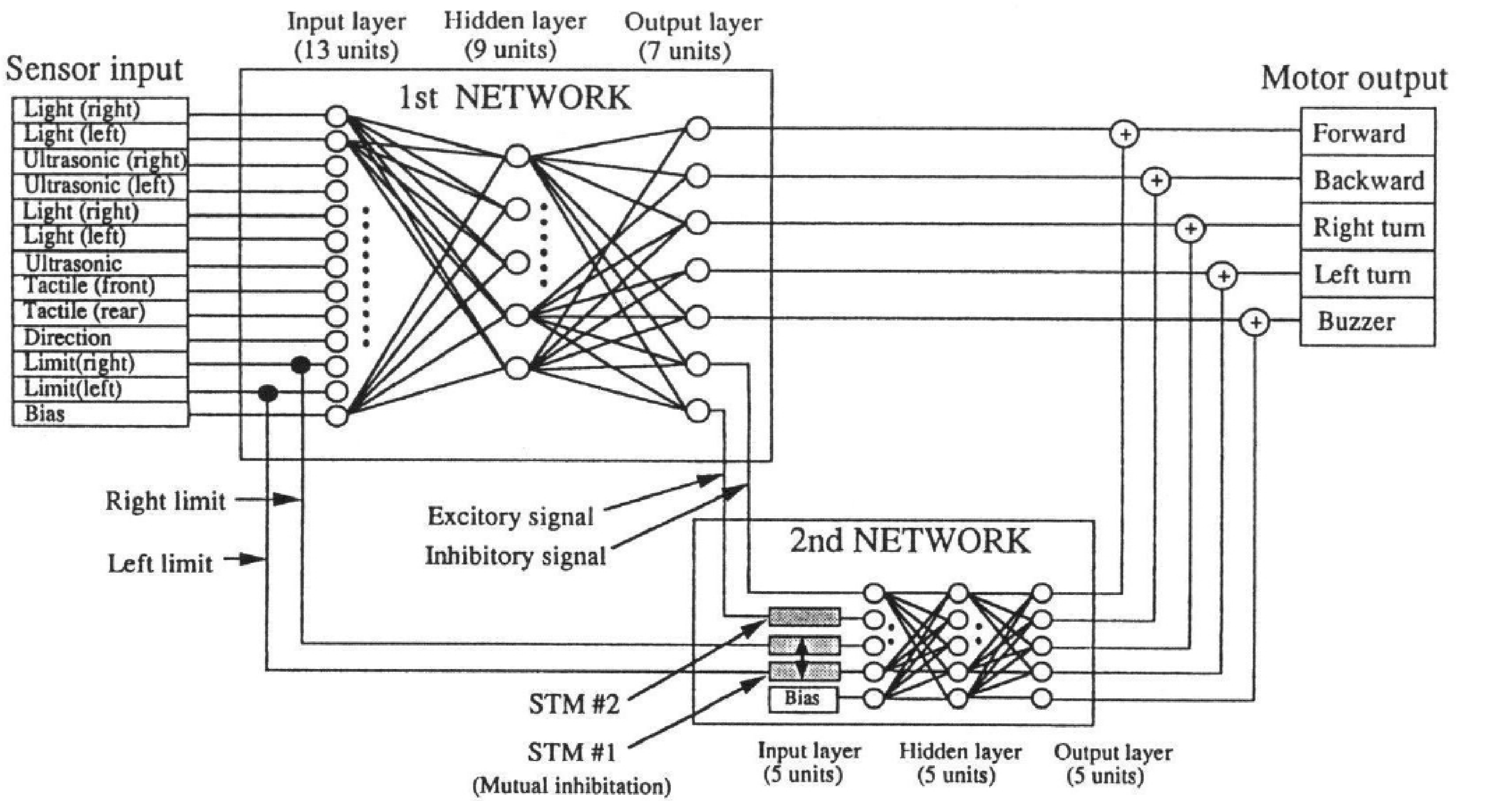
- Autonomous mobile robot equipped with 12 sensors of different types: **ultrasonic** sensors, **infrared** sensors, **tactile** sensors, **limit** sensors
- Locomotion:
  - 4 wheels aligned in same direction
  - Steering motor for heading
  - Drive motor for moving





[3] Nagata et al. 1990

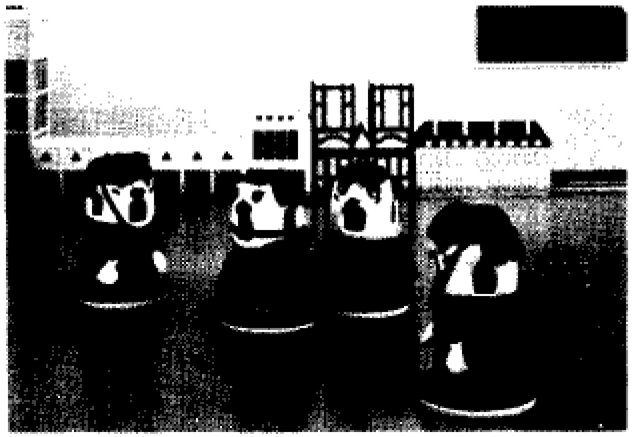
The network model for robot control



[3] Nagata et al. 1990

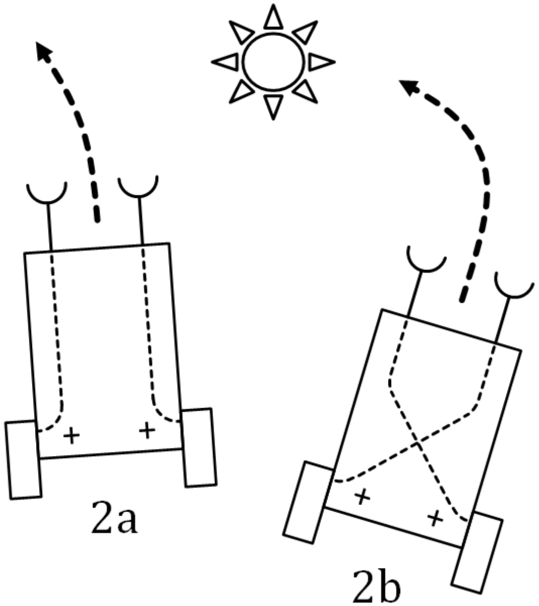
Emergent behavior of the robot

- **Training algorithm:** modified version of the backpropagation algorithm (pseudo-impedance control)
- **Training patterns:** obtained from running a simulation, only a subset of all possible 4096 patterns is needed
- **Behavior:** depending on the training patterns used, two different behaviors of the robots emerge (cops and robbers)



[3] Nagata et al. 1990

Comparison with Braitenberg vehicles

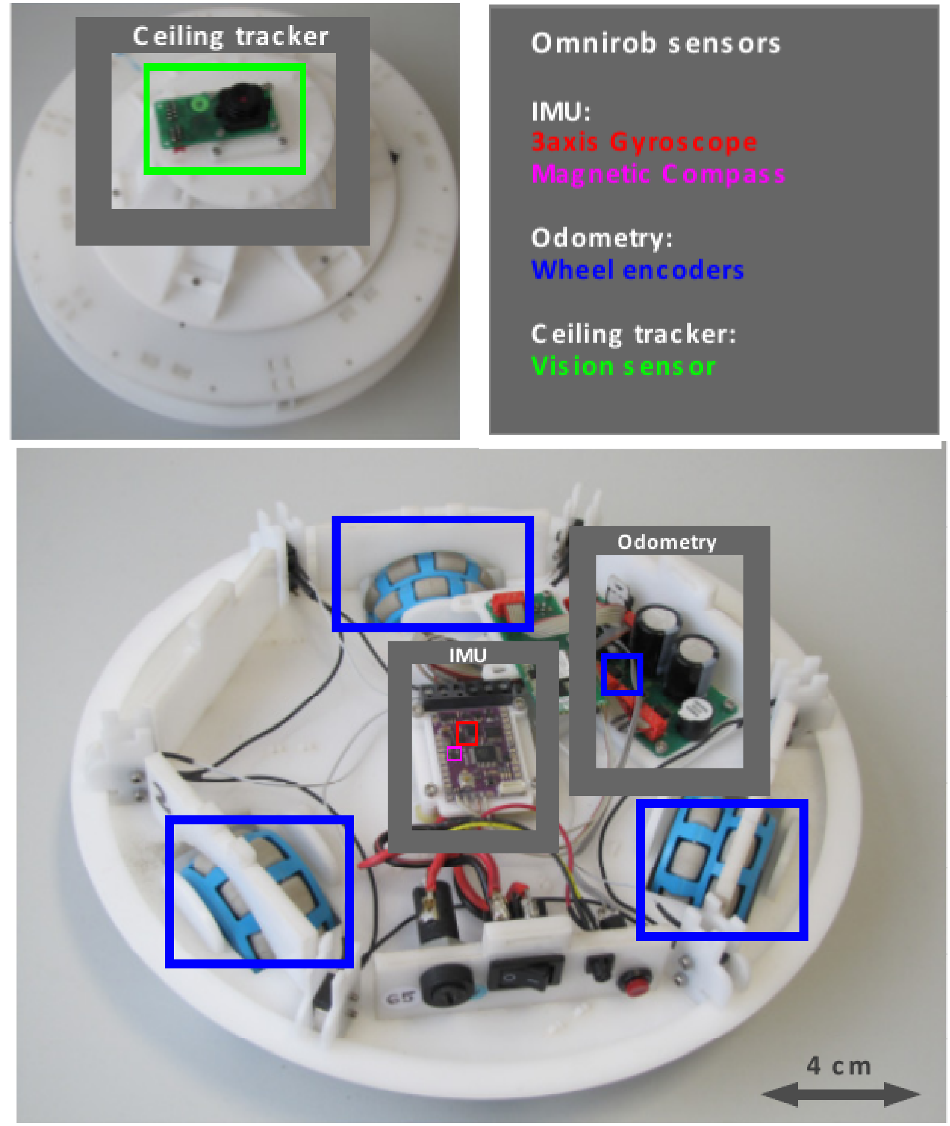


Thomas Schoch – www.retas.de

Sensor fusion for estimating robot heading

- Robot equipped with 4 different sensors for estimating direction: **gyroscope**, **compas**, **wheel encoder** and **camera**
- **Biologicaly inspired** sensor fusion model
- Based on the principles of **cortical** procesing such as **localization**, **distributed processing** and **recurrency**

[4] Axenie and Conradt, 2013

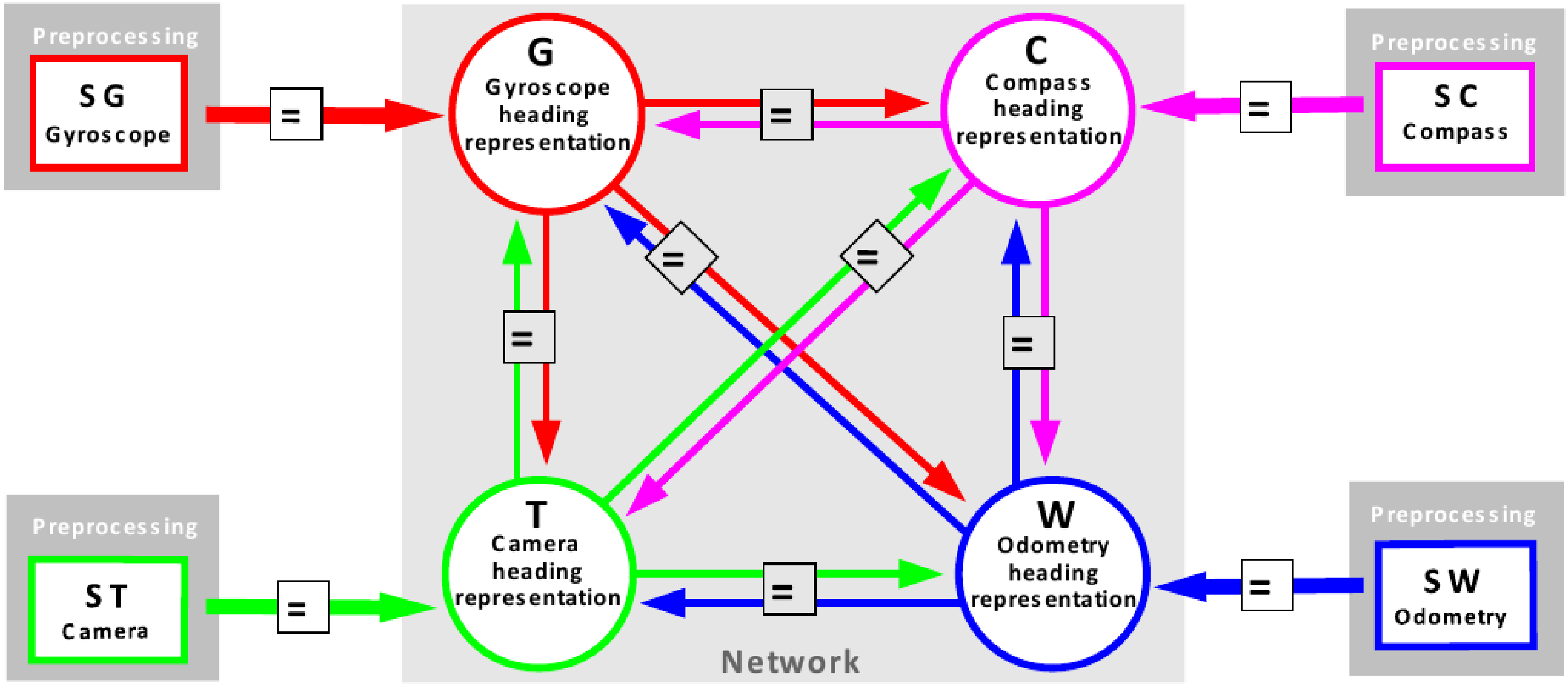


Recurrent graph network for sensor fusion

Network of four **fully connected nodes** which **mutually influence** each other

Information in nodes is encoded by **neural population code**

The network **pushes** all representations **towards an equilibrium** state



[4] Axenie and Conradt, 2013

The network dynamics

η(t) – update rate at time t
E – mismatch between node m_i and m_j

[4] Axenie and Conradt, 2013

Generic update rule:

$$m_i(t+1) = m_i(t) - \eta(t) \cdot E_{m_i,m_j}(t), \quad E_{m_i,m_j}(t) = m_i(t) - f_{m_i,m_j}(t) \quad (1)$$

$$\eta_{i,j}(t+1) = \eta_{i,j}(0) \cdot \frac{\sum_{k=1}^{N-\{i\}} E_{m_i,m_k}(t)}{N \cdot E_{m_i,m_j}(t)} \quad (2)$$

network's belief (numerator)

Example update rules for the Gyroscope (G) node:

$$G(t+1) = (1 - \eta_{G,C}(t)) \cdot G(t) + \eta_{G,C}(t) \cdot C(t), \quad (3)$$

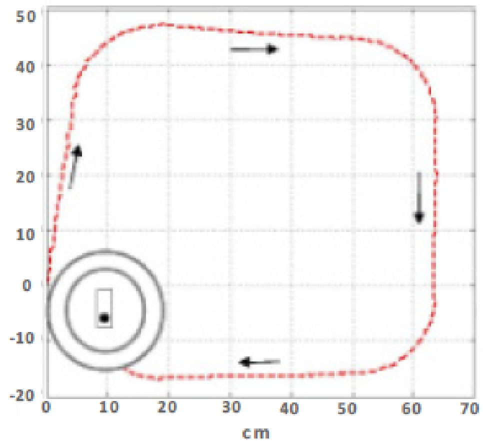
$$G(t+1) = (1 - \eta_{G,W}(t)) \cdot G(t) + \eta_{G,W}(t) \cdot W(t), \quad (4)$$

$$G(t+1) = (1 - \eta_{G,T}(t)) \cdot G(t) + \eta_{G,T}(t) \cdot T(t), \quad (5)$$

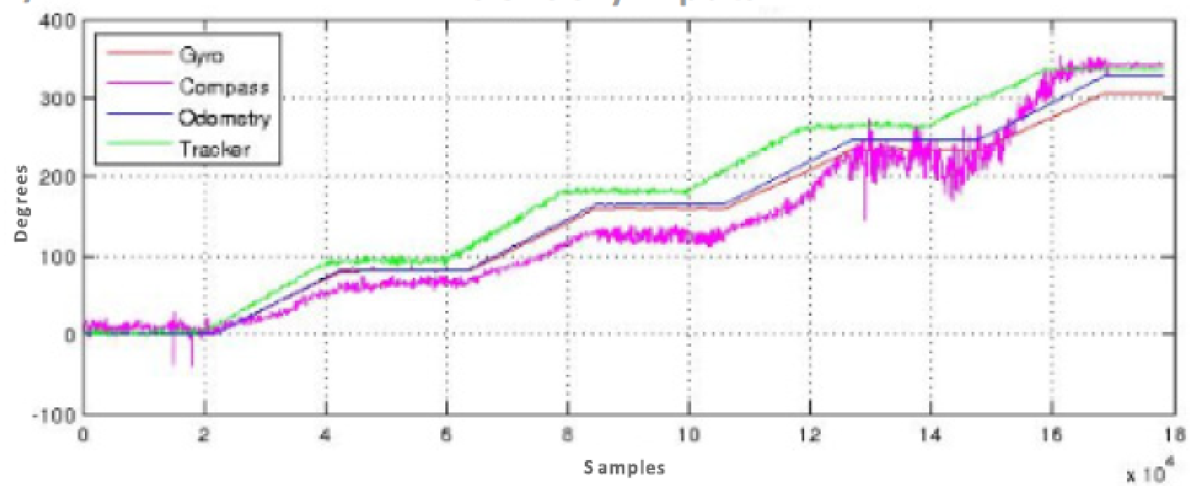
$$G(t+1) = (1 - \eta_{G,SG}(t)) \cdot G(t) + \eta_{G,SG}(t) \cdot SG(t), \quad (6)$$

Experimental results of the model

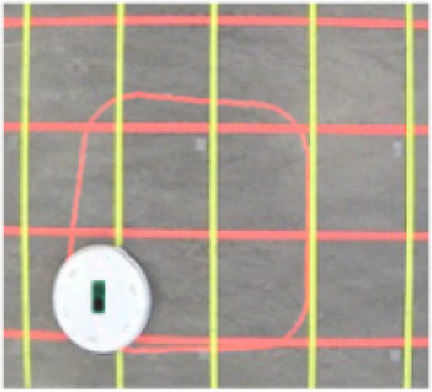
Robot reference trajectory



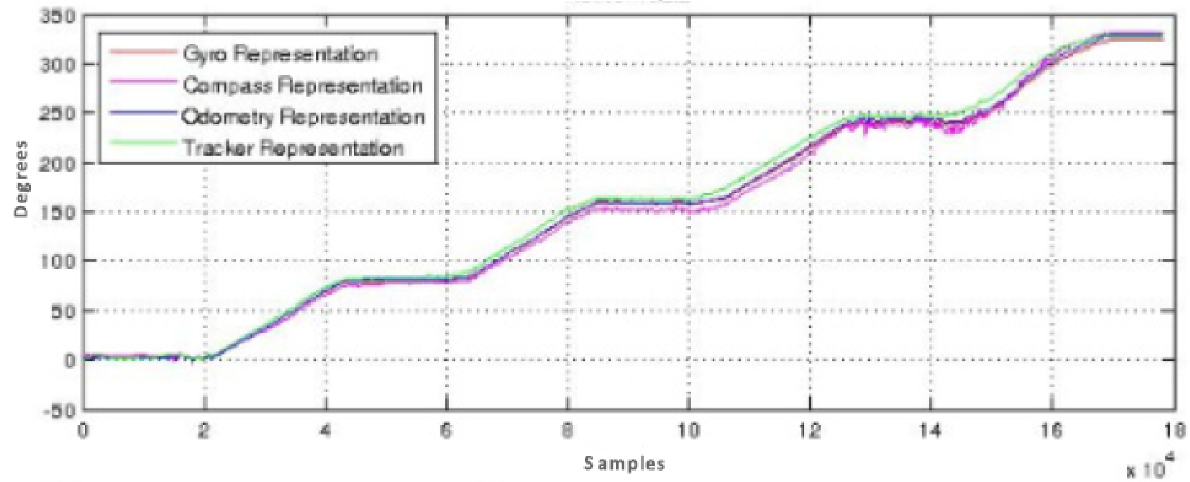
Sensory inputs



Robot real trajectory



Network internal representations



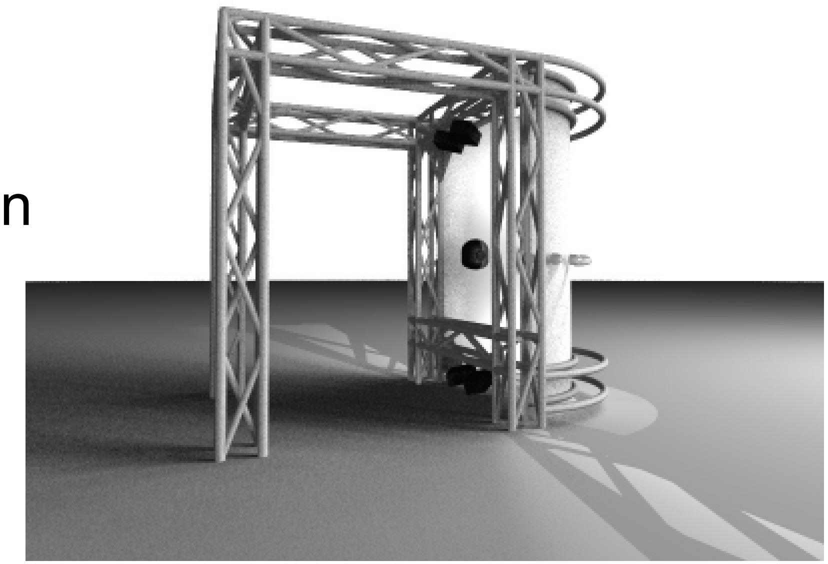
[4] Axenie and Conradt, 2013

Experiments in the HRI Lab at WTM

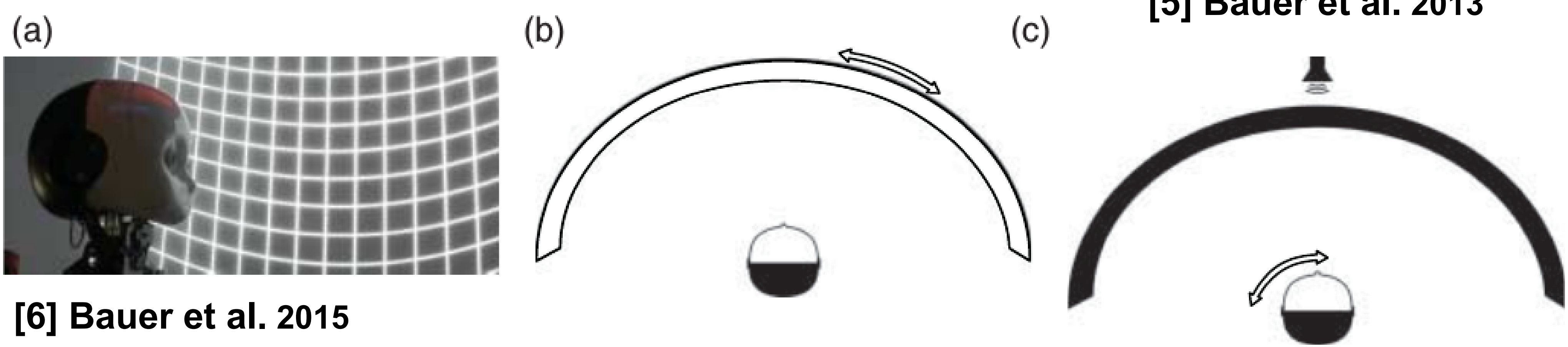
The HRI Lab at Knowledge Technology Department

- Allows for experiments with models for multi-modal (**audio-visual**) sensory integration

- **Compromise** between the advantages of **real world** and **simulation**



[5] Bauer et al. 2013



[6] Bauer et al. 2015

Experiments in the HRI Lab at WTM

Video of the HRI Lab

Neuaral models for MSI – Summary

Conclusions:

- Neurally inspired models have **strong generalization** abilities. Their **adaptability** allows for dealing with **unknown** and **changing environments**

- Their advantages come with the price of **training** and **complexity** of the sensor-actuator relationship, bringing **causality** which is sometimes **hard to interpret** and **not predictable**

Questions?

Thank you for the attention

Literature

1) Luo, Ren C., and Michael G. Kay. "A tutorial on multisensor integration and fusion." Industrial Electronics Society, 1990. IECON'90., 16th Annual Conference of IEEE. IEEE, 1990.

2) Luo, Ren C., Chih-Chen Yih, and Kuo Lan Su. "Multisensor fusion and integration: approaches, applications, and future research directions." IEEE Sensors journal 2.2 (2002): 107-119.

3) Nagata, Shigemi, Minoru Sekiguchi, and Kazuo Asakawa. "Mobile robot control by a structured hierarchical neural network." IEEE Control Systems Magazine 10.3 (1990): 69-76.

4) Axenie, Cristian, and Jörg Conradt. "Cortically inspired sensor fusion network for mobile robot heading estimation." International Conference on Artificial Neural Networks. Springer Berlin Heidelberg, 2013.

5) Bauer, Johannes, and Stefan Wermter. "Learning multi-sensory integration with self-organization and statistics." Ninth international workshop on neural-symbolic learning and reasoning NeSy. Vol. 13. 2013.

6) Bauer, Johannes, Jorge Dávila-Chacón, and Stefan Wermter. "Modeling development of natural multi-sensory integration using neural self-organization and probabilistic population codes." Connection Science 27.4 (2015): 358-376.