SEVENTH FRAMEWORK PROGRAMME

Sensor Fusion

Efi Vitzrabin, Yael Edan

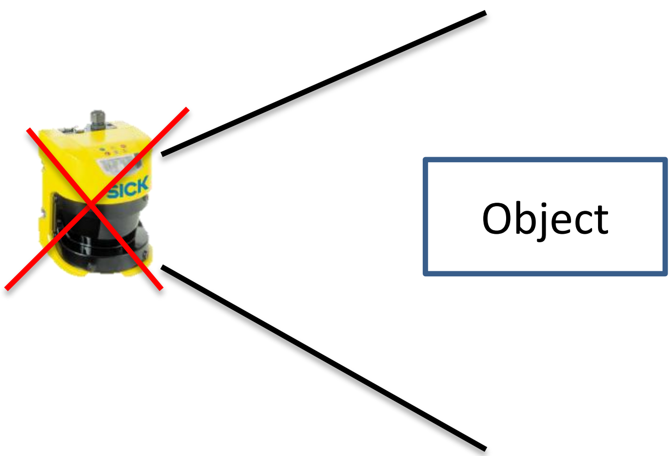
Ben-Gurion University of the Negev

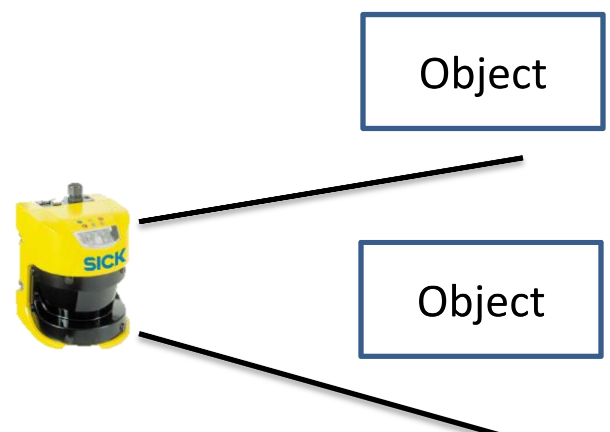
CROPS

"Clever Robots for Crops"

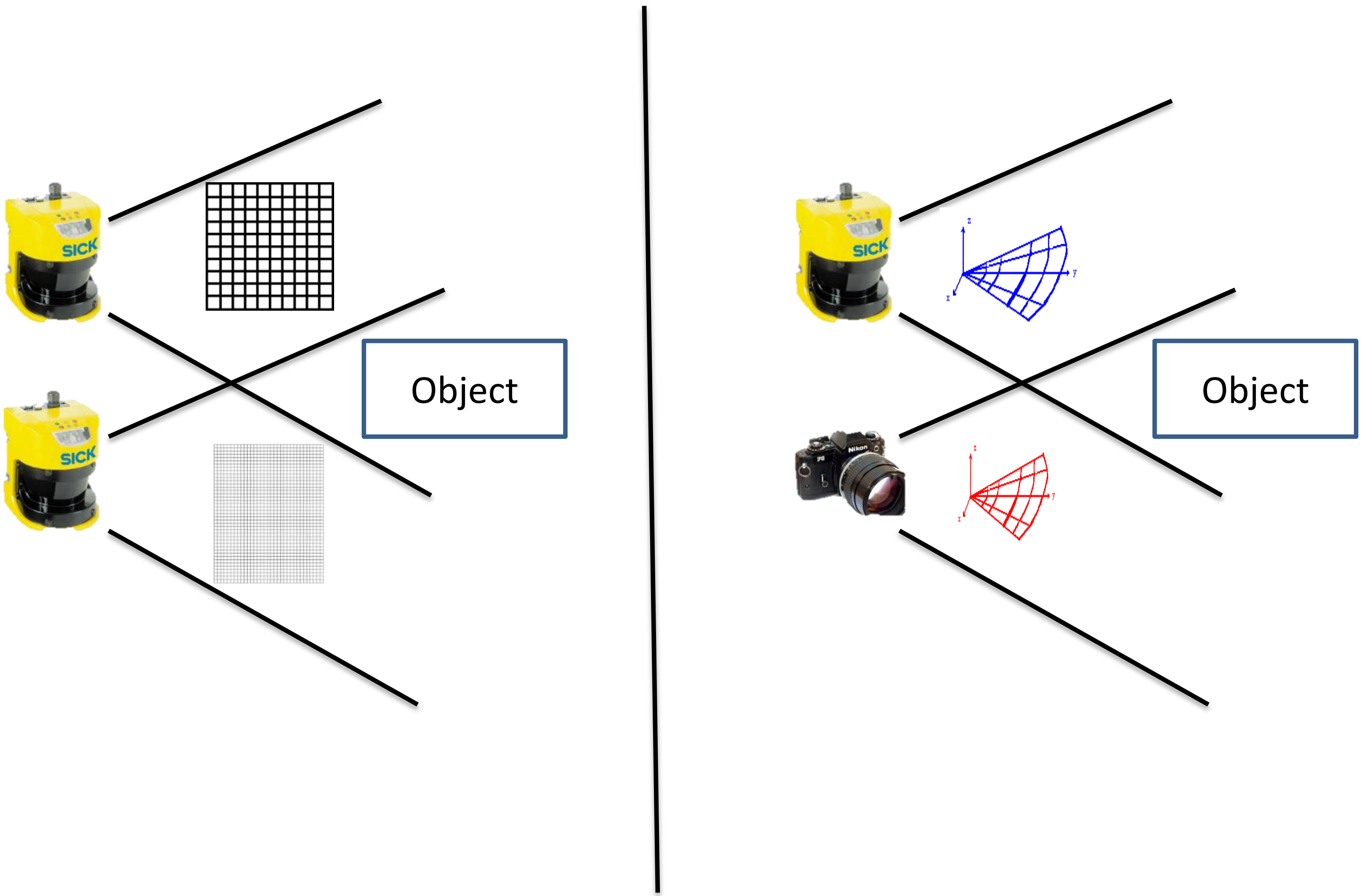
Background

Why do we need multiple sensors?



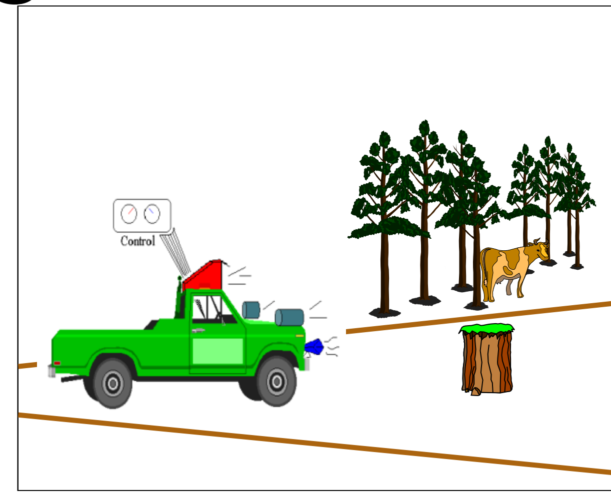


Background

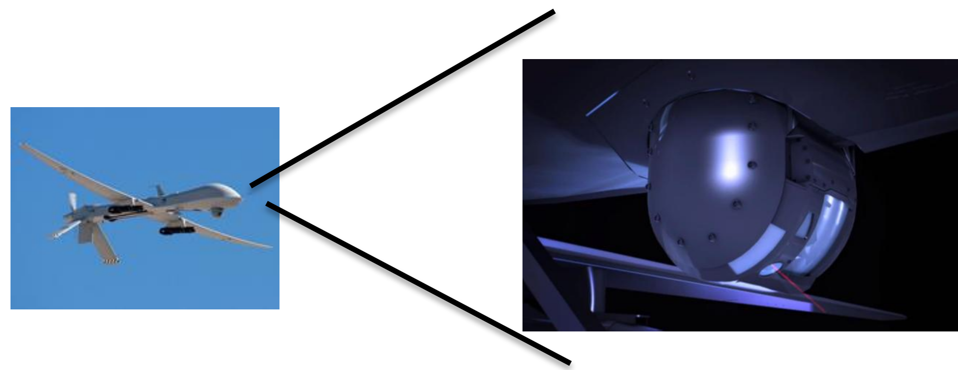


Applications

- Mapping for mobile robots



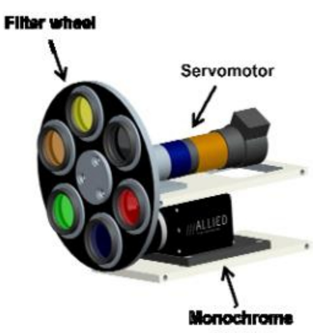
- Target detection



- Localization (GPS+INS)

Aims

Acquisition, processing, and combination of information generated by multiple knowledge sources



Aims

Provide improved information for **detection**, **estimation**, and **decision-making.**

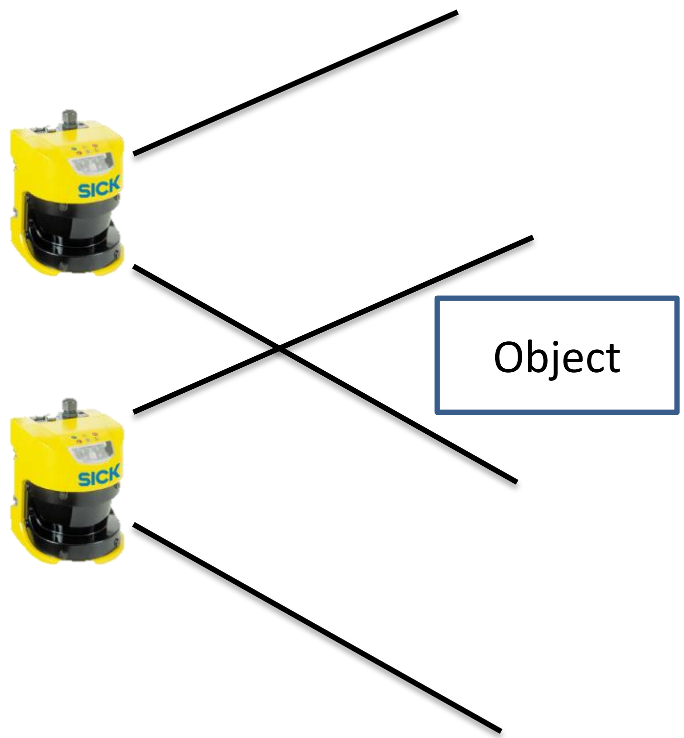
1+1 >> 2

Agenda

- Interaction modes
- Representation levels
- Virtual sensors
- Taxonomy
- JDL Model
- Performance measures
- Application examples
- Dirty secrets in sensor fusion

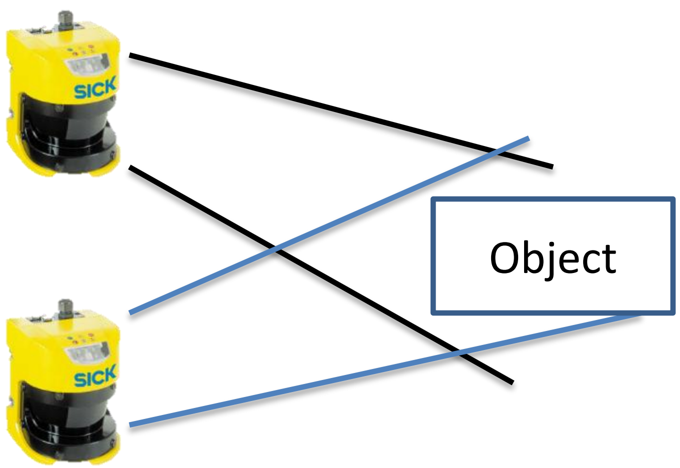
Interaction models

Complementary



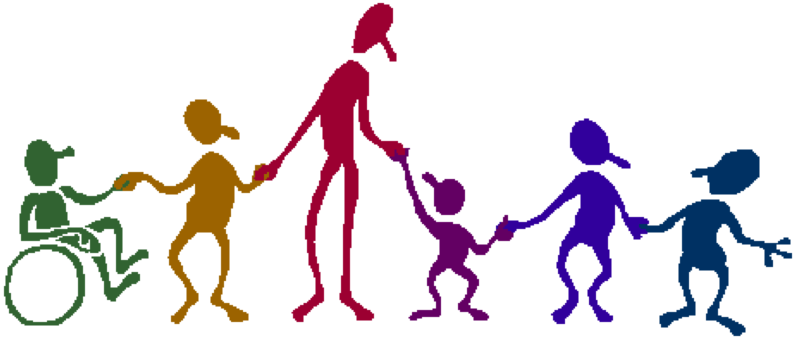
Interaction models

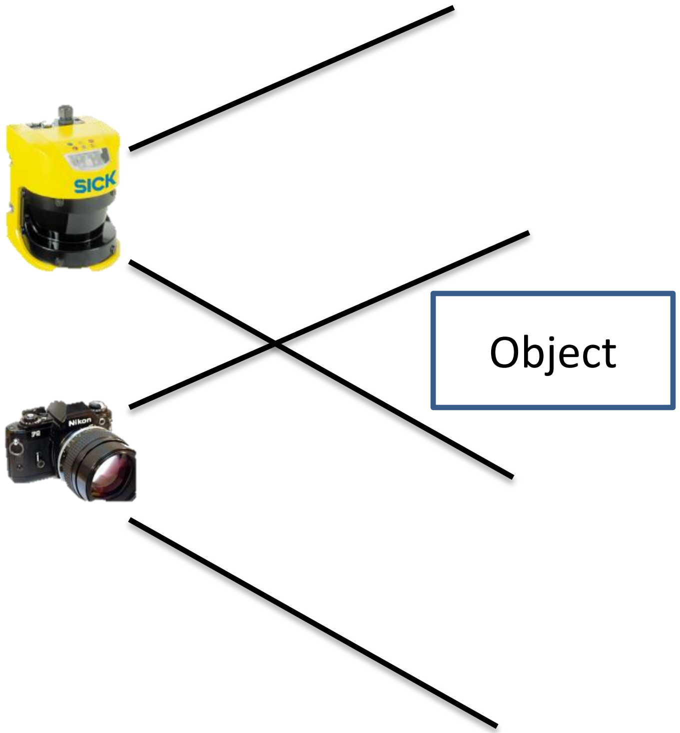
Competitive



Interaction models

Cooperative

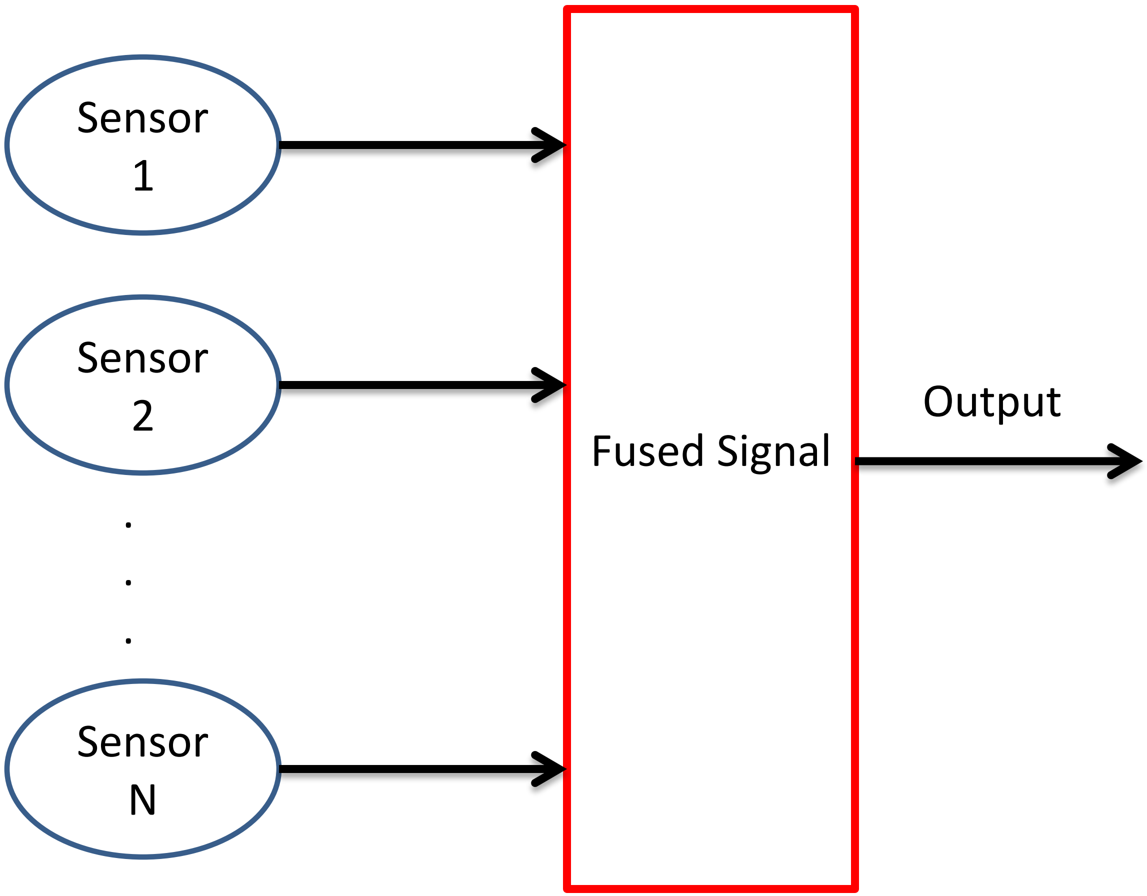




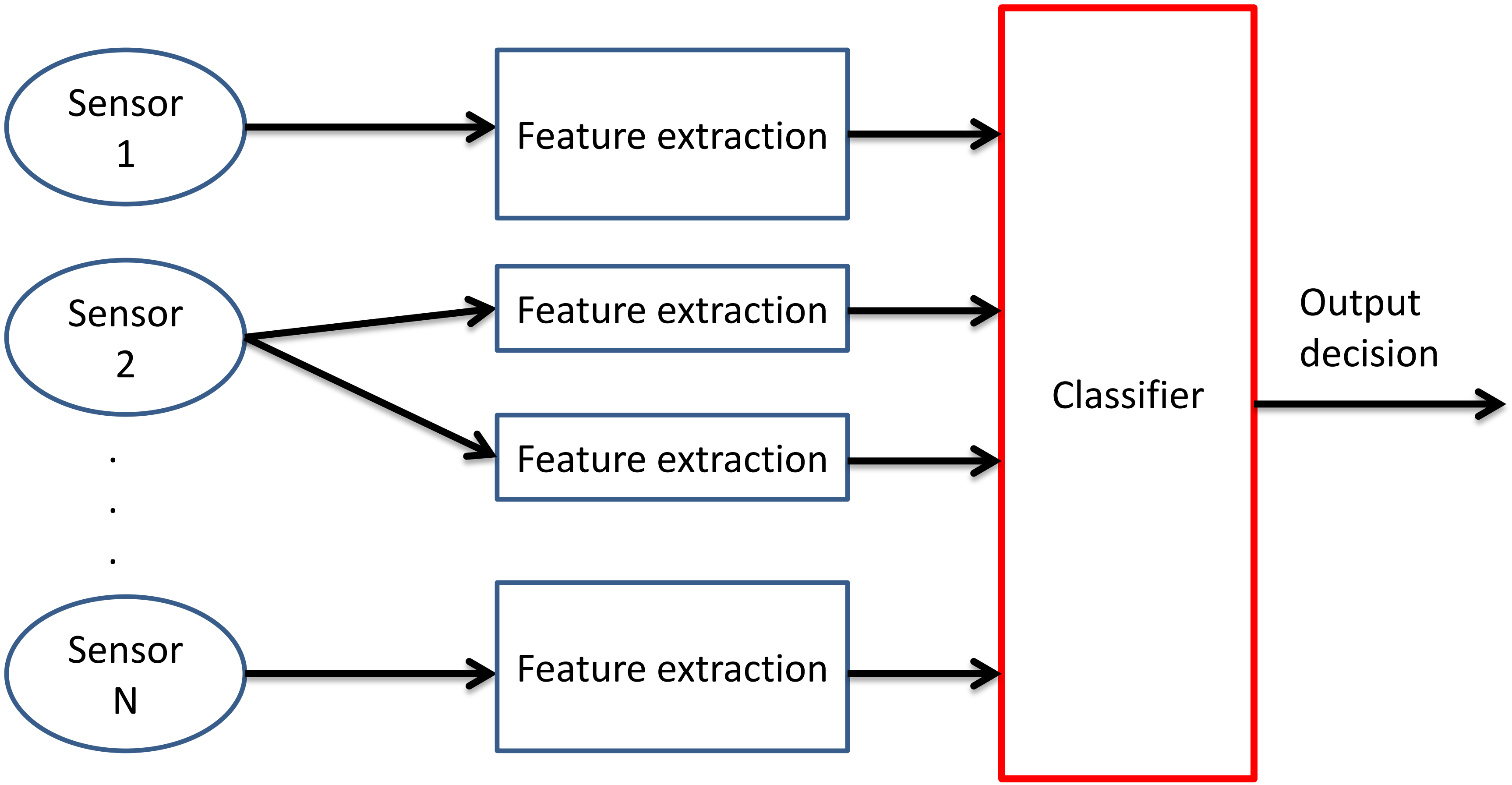
Representation levels

- Signal level (pixel level)
- Feature level
- Decision level (symbol/object level)

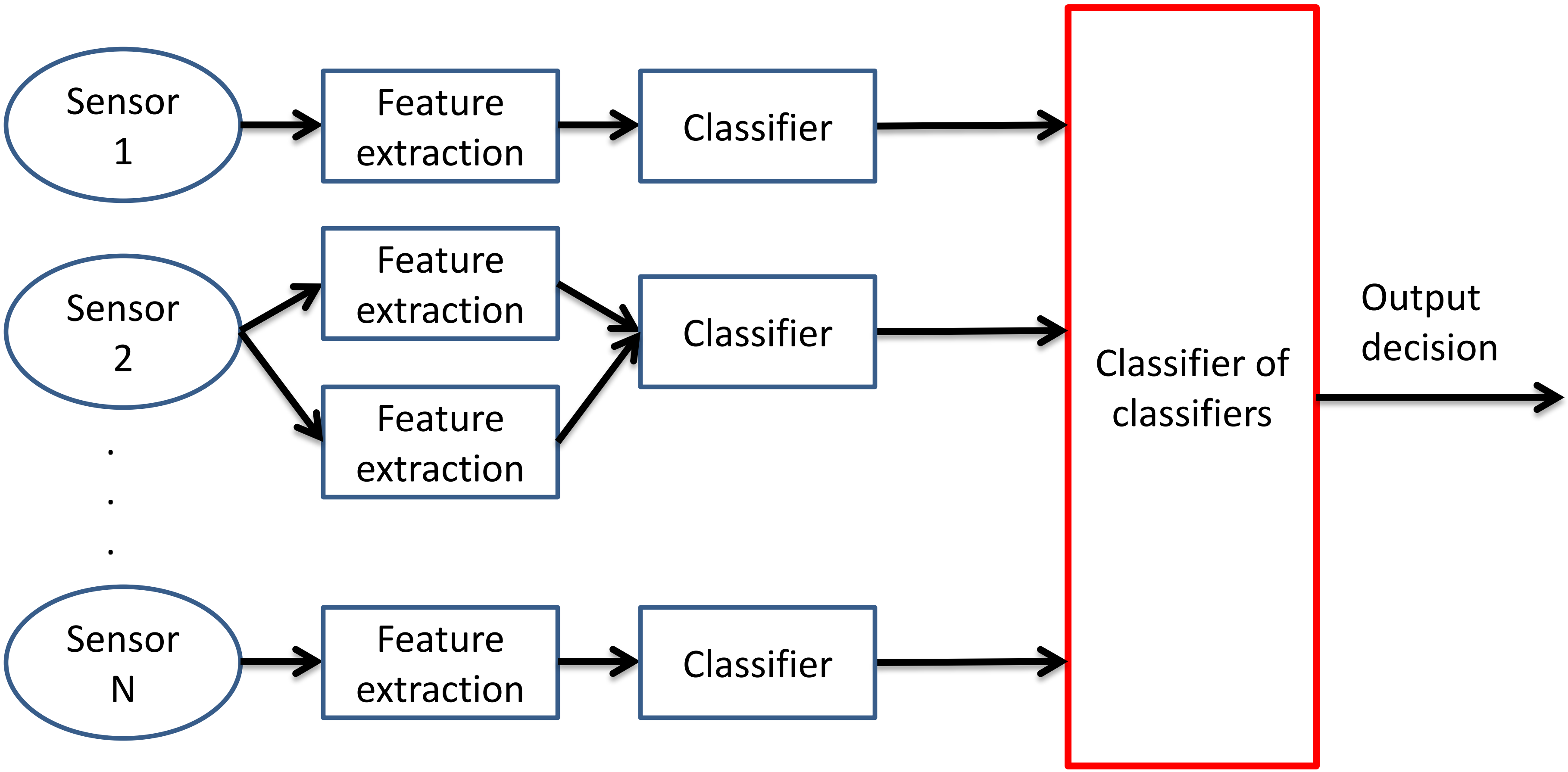
Signal level representation



Feature level representation

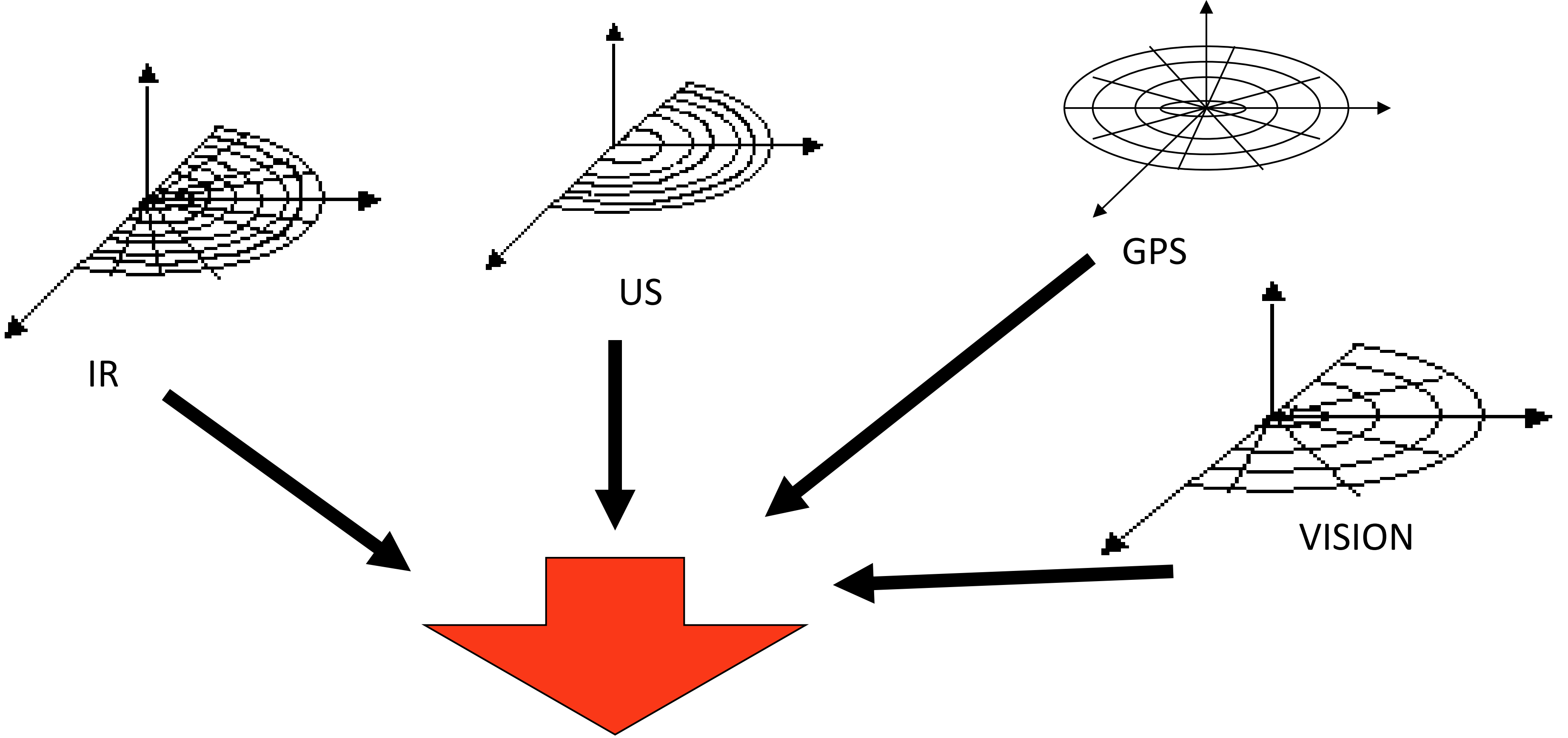


Decision level representation

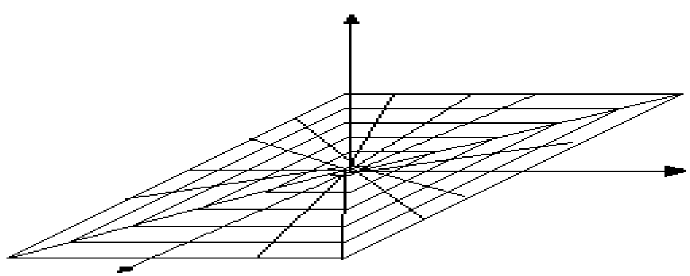


Virtual sensors

Instead of using only real sensors, virtual sensors (i.e. combination of algorithms) can be used as sensors.

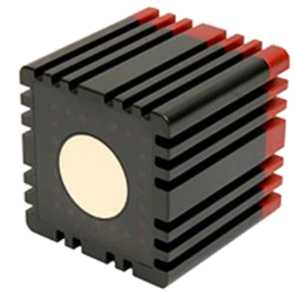


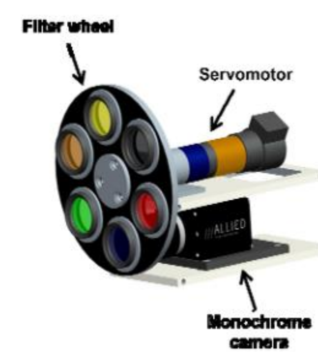
Virtual Sensor (VS)



Taxonomy

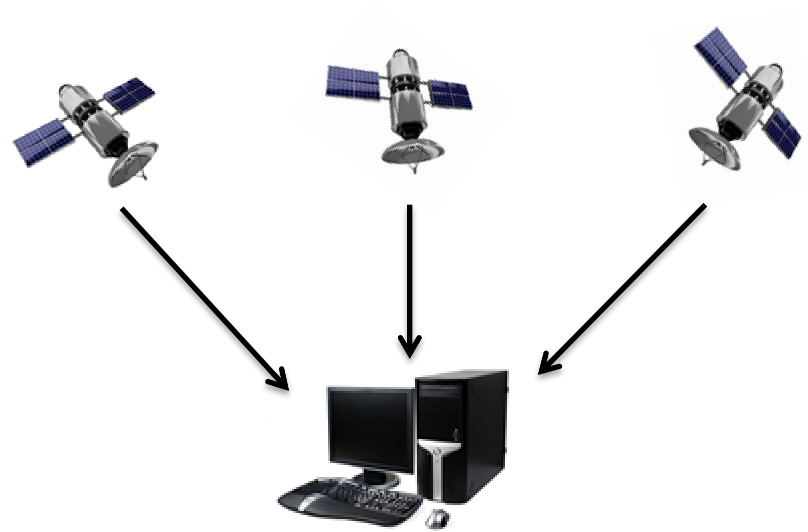
- Architecture
- Update method
- Dynamic/Static
- Feedback and memory
- Algorithms
- Optimization



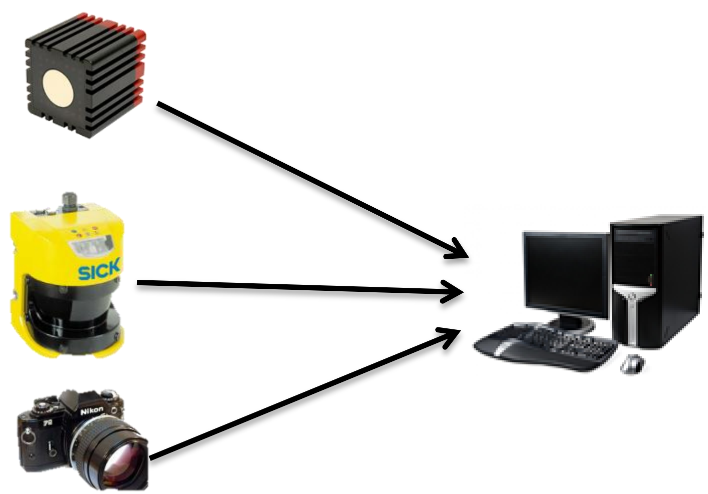


Architectures

- **Distributed**



- **Centralized**



Update method

- **Synchronous**

- **Asynchronous**

Dynamic/Static update

- **Static**

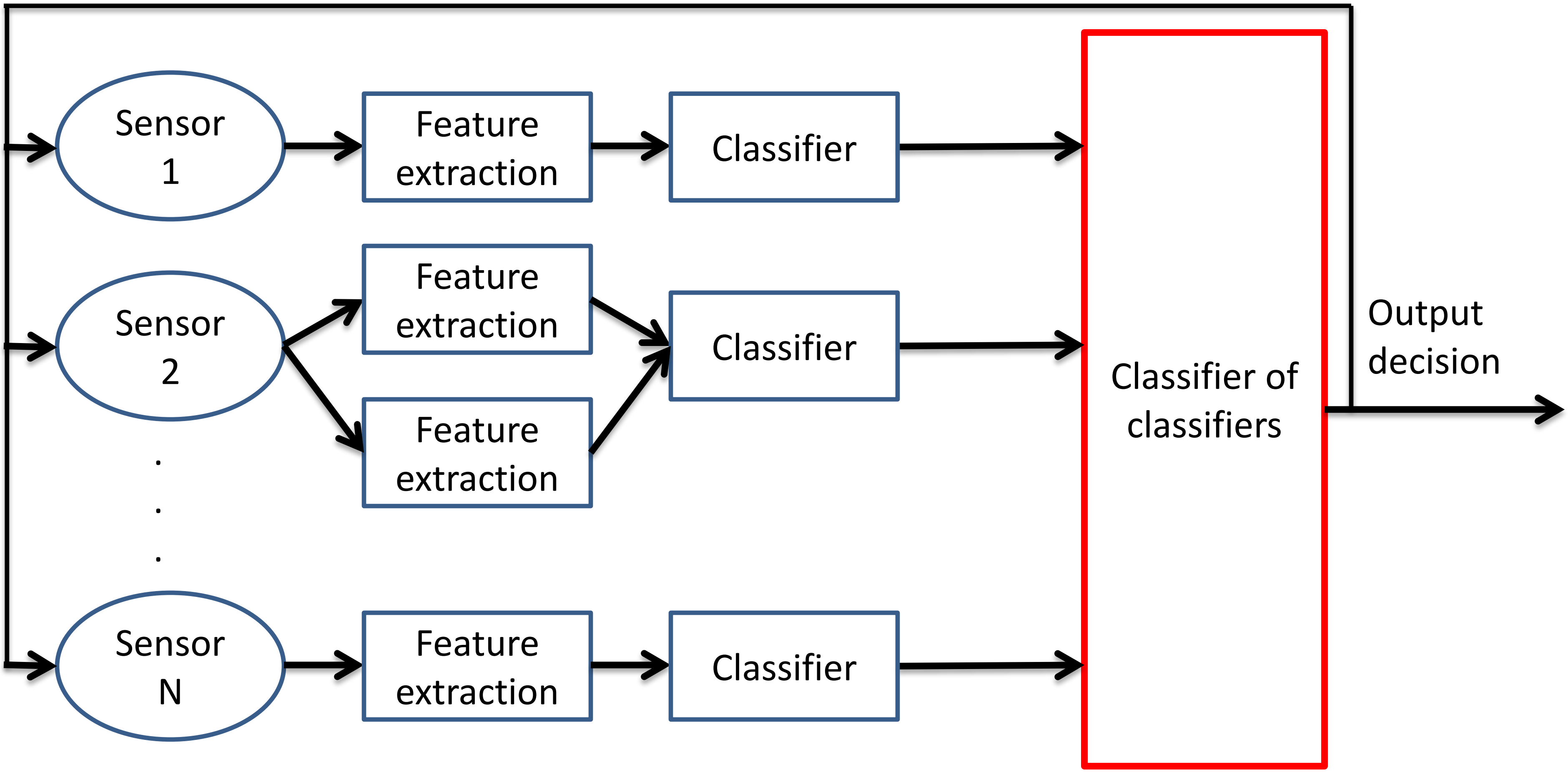
- **Dynamic**

Feedback and memory

- **Feedback** –incorporated in the fusion system from the last sensory output.

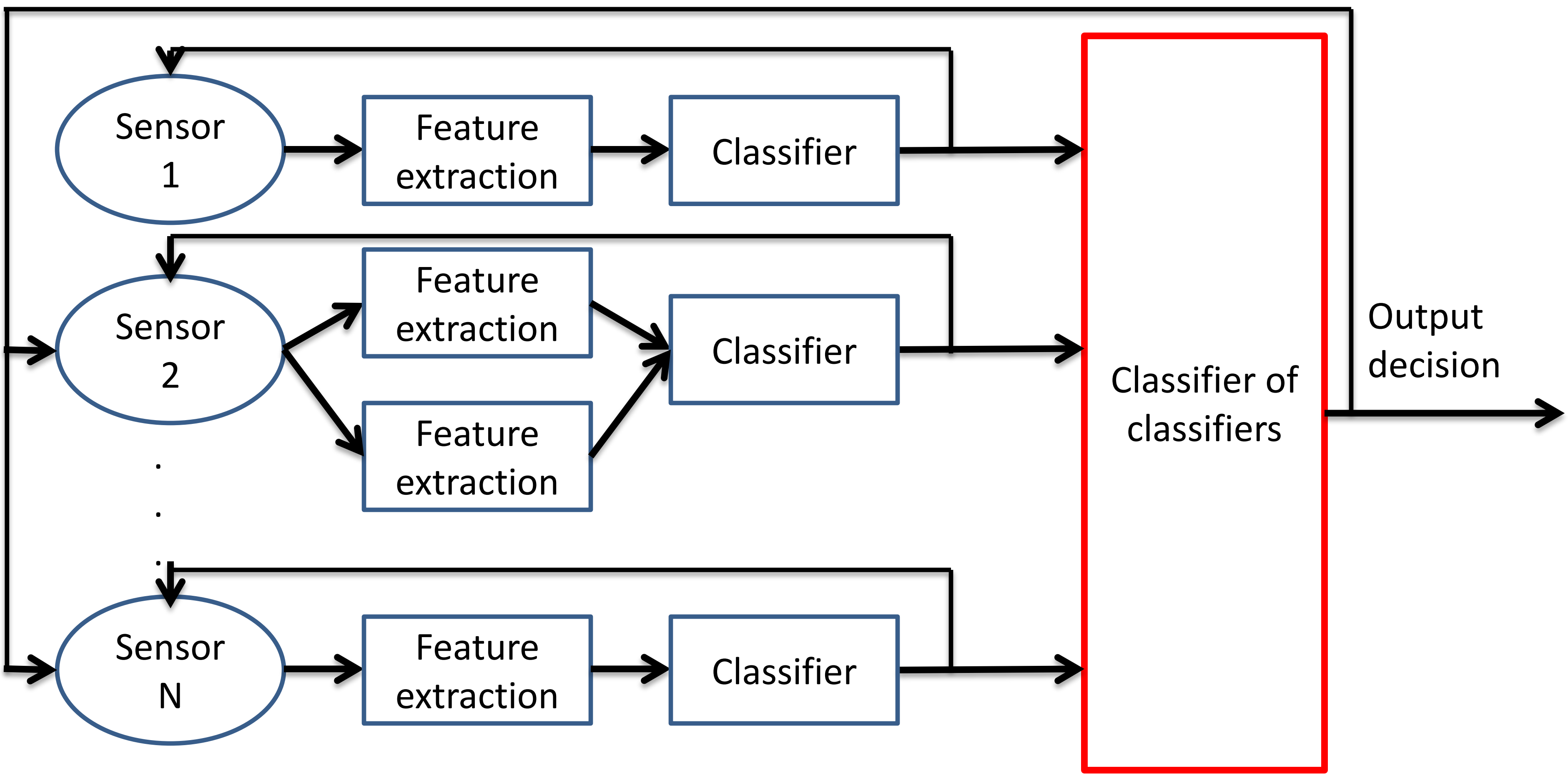
- **Memory** – each sensor can also store in memory the last action it decided.

Feedback and memory



Sensor fusion system with feedback without memory

Feedback and memory



Sensor fusion system with feedback and memory

Sensor fusion algorithms

Fuzzy Logic

Logical AND

Logical XOR

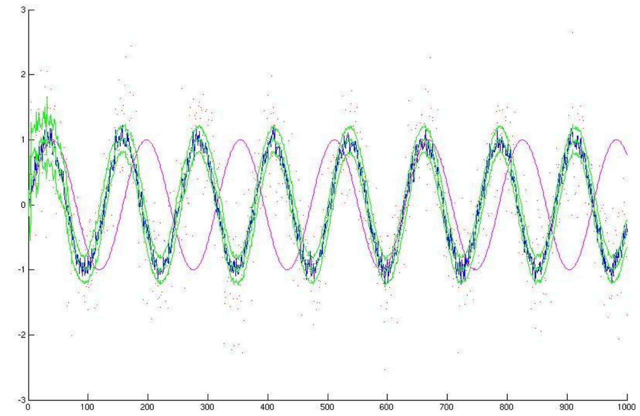
Logical OR

Kalman Filter

Certainty Factor

Pixel/Signal level algorithms

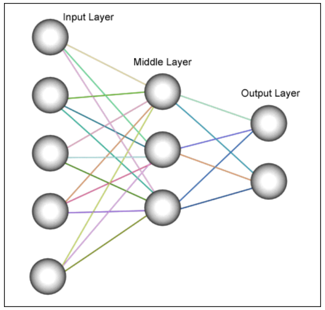
- Kalman Filtering



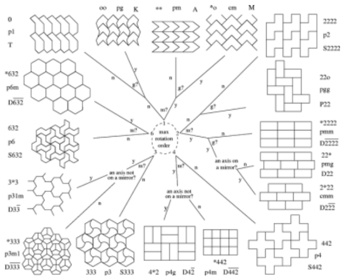
- Estimation methods

Feature level SF algorithms

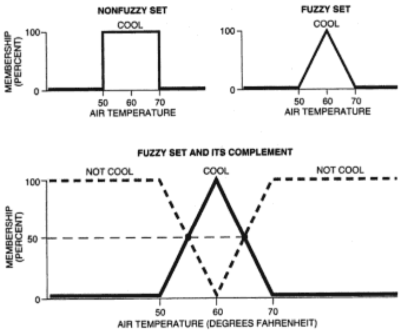
- Neural networks



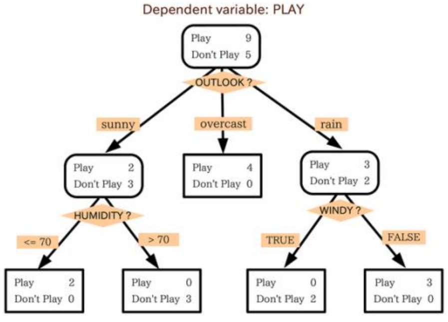
- Pattern recognition



- Fuzzy logic



- Decision trees



Decision level SF algorithms

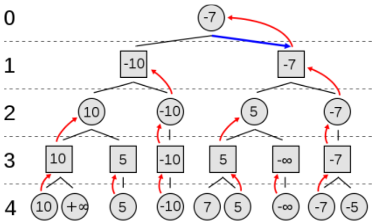
- Bayesian inference

$$
\begin{aligned}
P(D^+|T^+) &= \frac{P(T^+|D^+)P(D^+)}{P(T^+)} \\
&= \frac{P(T^+|D^+)P(D^+)}{P(T^+|D^+)P(D^+) + P(T^-|D^-)P(D^-)}
\end{aligned}
$$

- Dempster–Shafer

- Weighted decision methods

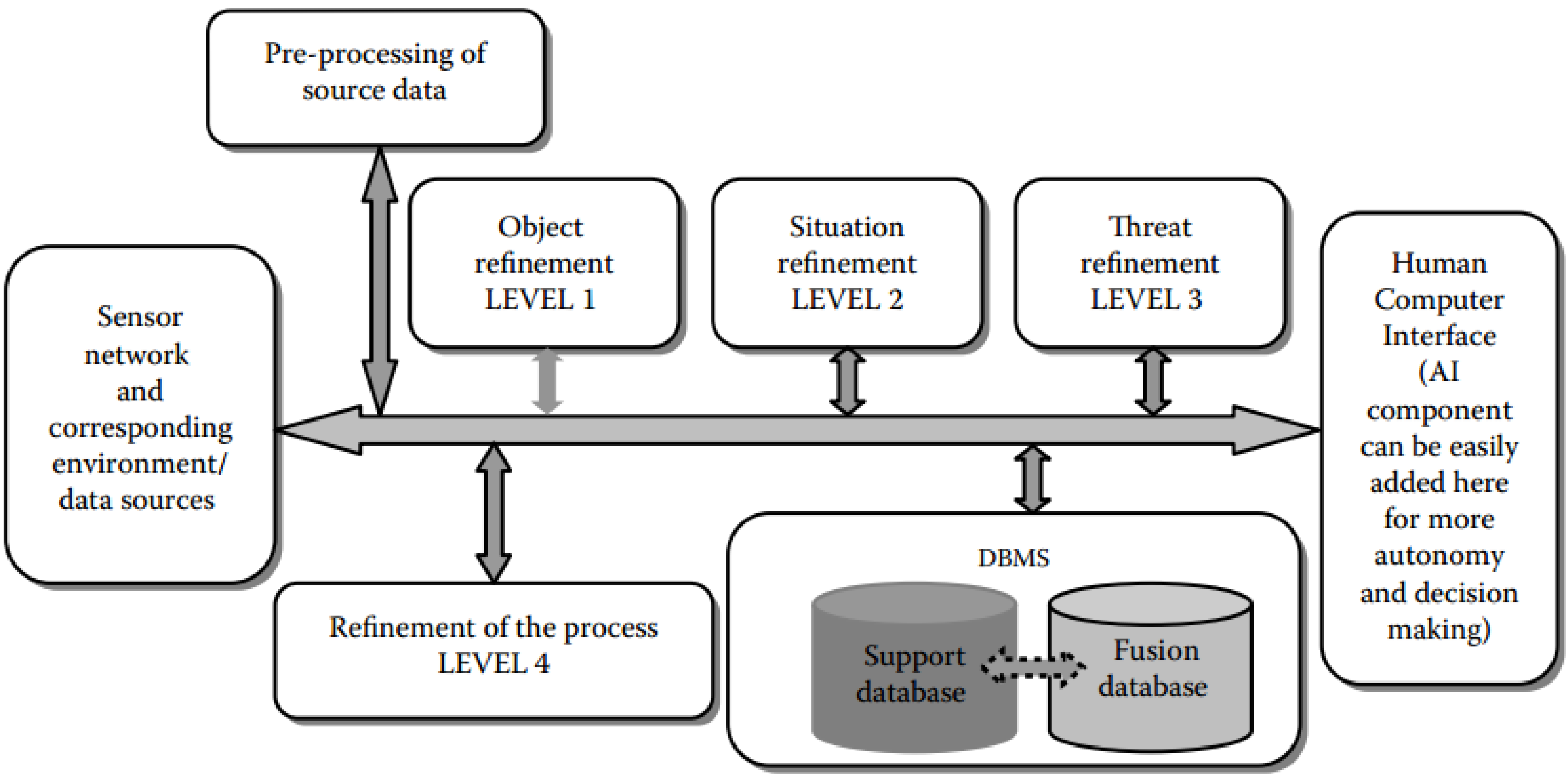
- Minimax



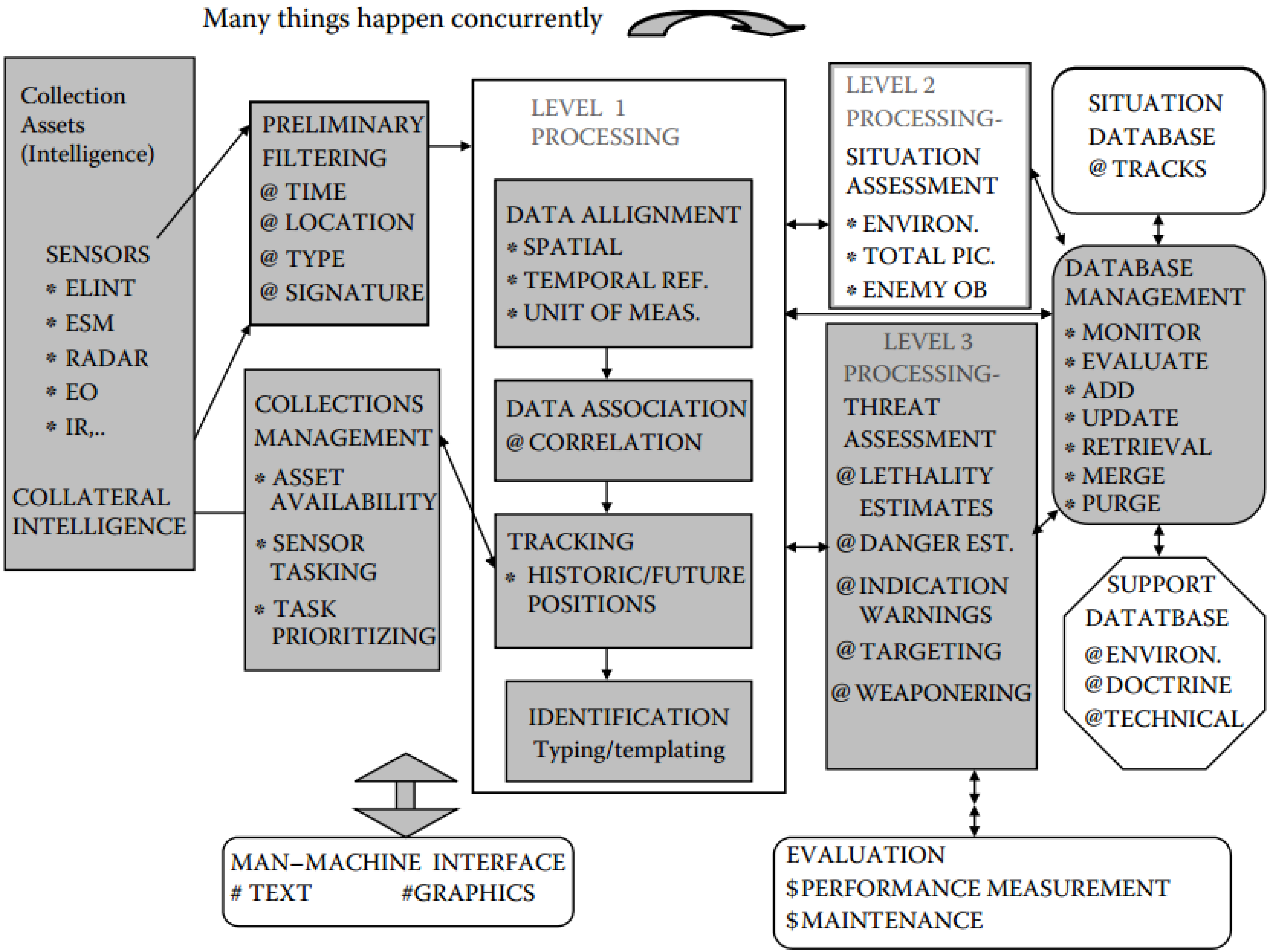
Taxonomy - Optimization

Optimization criterion	Description
Least squares	Minimize the sum of residuals
Weighted least squares	Minimize the sum of the weighted squares of the residuals
Mean square error	Minimize the accepted value of the squared error
Bayesian weighted least squares	Minimize the sum of the weighted squares of the residuals constrained by a-priori knowledge of the value
Maximum likelihood estimate	Maximize the multivariate probability distribution function

JDL Model



(Handbook of Multisensor Data Fusion: Theory and Practice 2009)

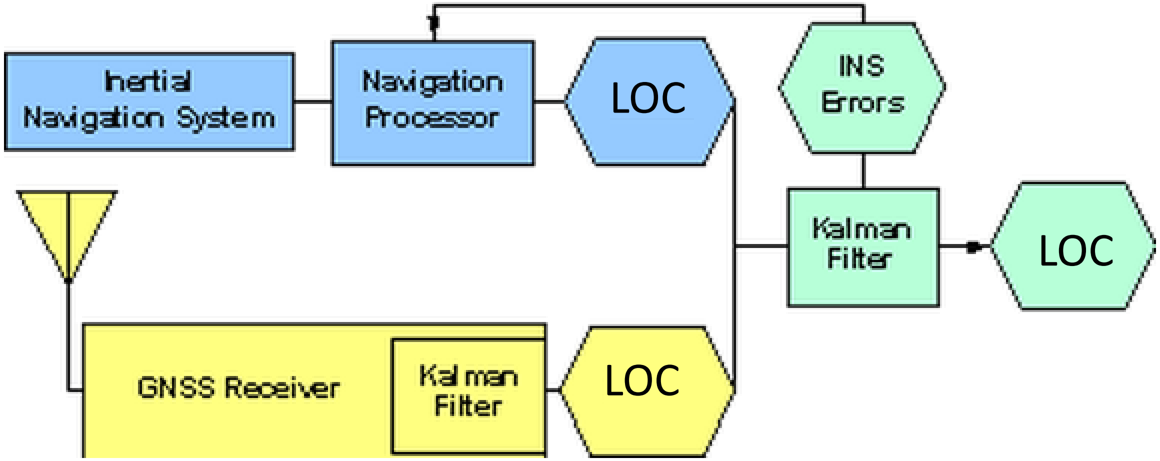


(Handbook of Multisensor Data Fusion: Theory and Practice 2009)

Performance measures

- Object detection
- Misclassified objects
- Error in distance of classified objects
- Rate of detections
- False positive detections
- …

Example 1



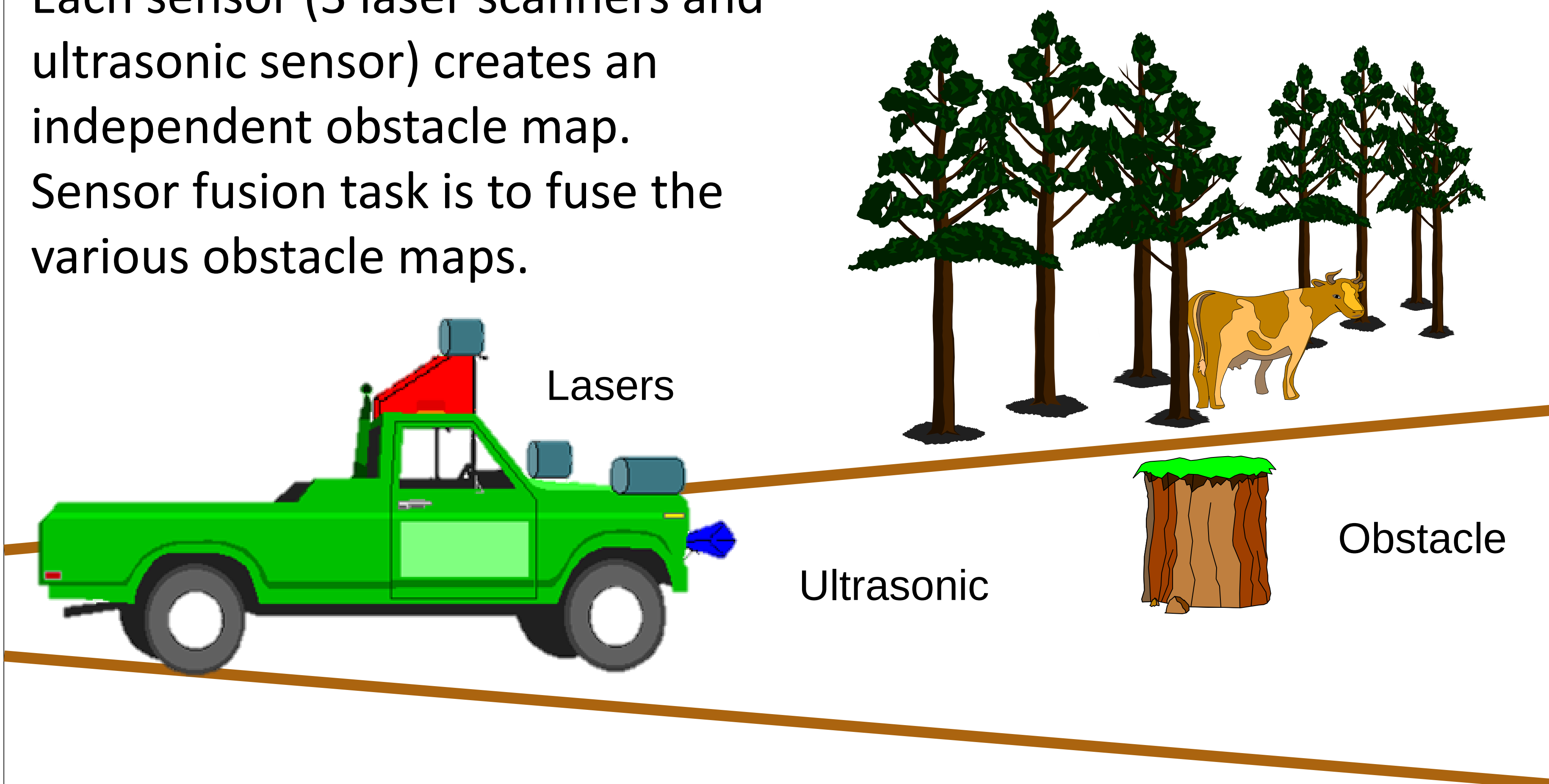
GPS, INS (Inertial Navigation System) integration – **Signal level**
Both the GPS and INS provide the same data (location). Each sensor has its own characteristics:
GPS – long time stability, large noise; INS – short time stability

The fusion system is: **distributed, asynchronous , dynamic, feedback, no memory.**
This type of GPS, INS fusion is called loose coupled

Examples 2

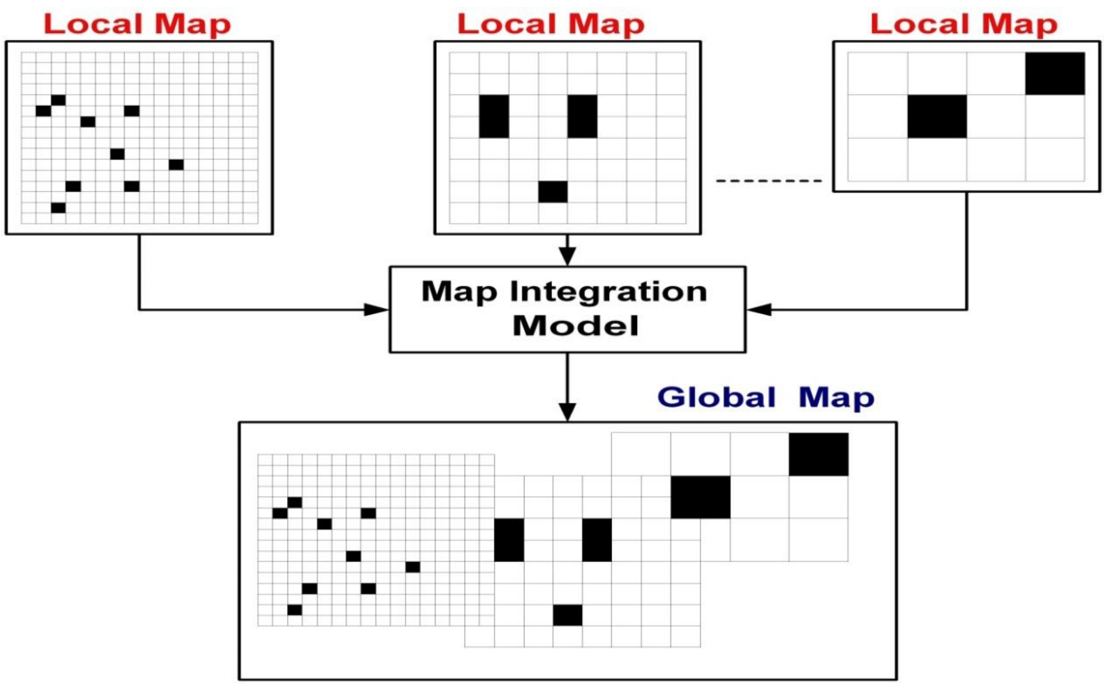
Autonomous vehicle must drive and detect obstacles.

Each sensor (3 laser scanners and ultrasonic sensor) creates an independent obstacle map. Sensor fusion task is to fuse the various obstacle maps.



Examples 2

The fusion level is at the **decision level**
The fusion system is: **centralized**, **asynchronous** - each sensor can work in different frequency, **dynamic** – the vehicle moves, **memory** – the last map remains in the memory, new obstacles are added to it.
Each obstacle map can have a different resolution and is updated as soon as sensory information is available.

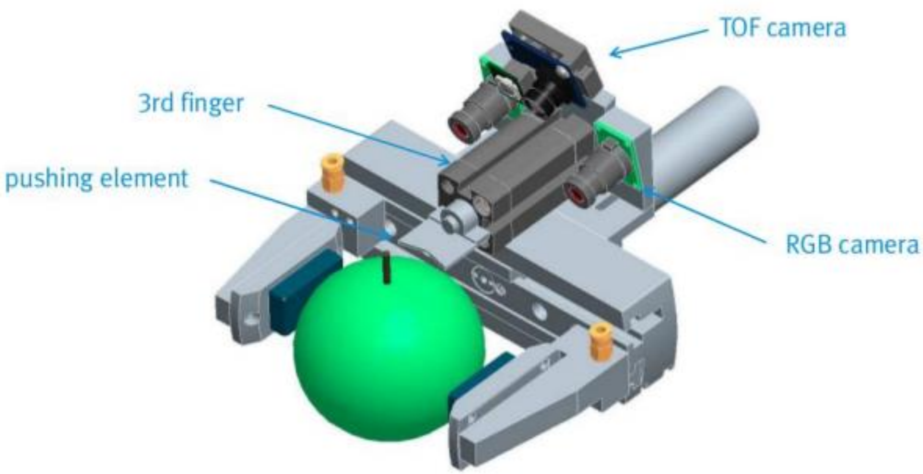


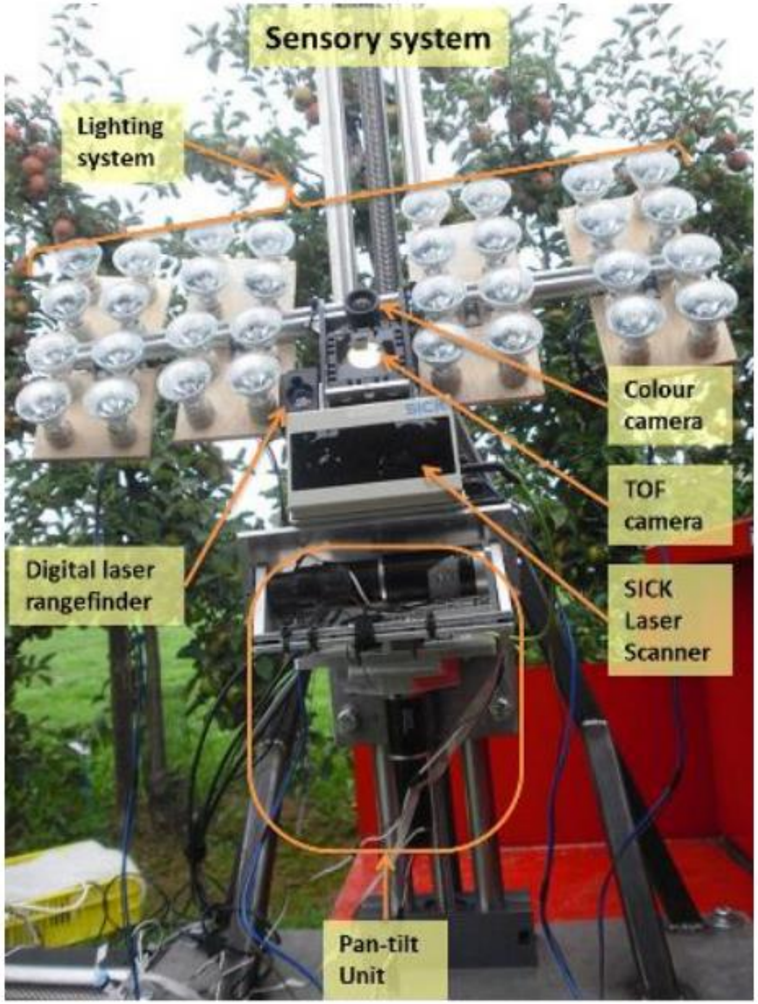
Example 2 – other alternatives

If the sensors send their raw data, then:
The fusion level is at the **feature level.**
The fusion system is: **centralized**, **asynchronous** - each sensor can work in different frequency, **dynamic** – the vehicle moves, **memory** – the last map remains in the memory, new obstacles are added to it.

Advantages	Disadvantages
Can have more precise results	Depended on all sensors
More sophisticated algorithm is needed	Hard to predict behavior In complex environment

cRops Sensor Fusion





crops sensor fusion

- Decision level
- Centralized
- Asynchronous
- Dynamic
- Feedback
- Adaptive weighted decision methods

cRops sensor fusion

The accuracy of each virtual sensor:

$$a_i = \sum_{t=1}^{m} (c_i(t) \equiv y(t)) / m$$

a – accuracy of each virtual sensor

c – classifier result

m – number of training data

The final classification result is the weighted sum:

$$C(j) = \sum_{i=1}^{n} w_i c_i(j)$$

When:

$$w_i = \frac{a_i}{\sum_{k=1}^{n} a_i}$$

cRops sensor fusion

Weights adapt to changes in sensory performances by changing the accuracy of each sensor depending on feedback:

$$a_i(t) = \sum_{j=t-k+1}^{t-1} (c_i(j) \equiv C(j)) / k$$

Dirty secrets in sensor fusion

(Handbook of Multisensor Data Fusion: Theory and Practice 2009)

- There is no substitute for a good sensor.
- There is no substitute for good data.
- All sensors have limitations.
- Downstream processing cannot absolve the sins of upstream processing.
- The fused answer may be worse than the best sensor.
- There are no magic algorithms.
- **There will never be enough training data.**

Thank you!
Questions?

Efi Vitzrabin
efivi@post.bgu.ac.il