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Information Fusion – Basics on IF

Combination Techniques for Uncertain Information in Measurement and Signal Processing

Information Fusion Prof. Dr.-Ing. Volker Lohweg

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Lectures – Contents

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2.1 Basics

- In this chapter we will familiarise the concept of information fusion based on sensory units.

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2.1 Basics

- The lack of information which is supplied by sensors should be completed by information fusion.
- Let us assume that S_1 and S_2 are two sensory information sources with different active principles (e.g. pressure and sound), then symbolically, we can describe the union of information as follows:

$$Perf(S_1 \cup S_2) > Perf(S_1) + Perf(S_2).$$

- The *Performance Perf* of a system should be higher than the performance of the two mono-sensory systems, or at least, we should have

$$Perf(S_1 \cup S_2) > \max\{Perf(S_1), Perf(S_2)\}.$$

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2.1 Basics

- A general phrase is as follows:

> "Information fusion expresses the means and the tools for the alliance of data origination from different sources; it aims to obtain information of greater quality, the exact definition of "**greater quality**" will depend on the **application**."
>
> (L. Wald; Some terms of reference in data fusion, *IEEE Transactions on Geoscience and Remote Sensing*, No. 37(3): pp. 1190-1193, 1999)

- The fusion process incorporates *performance*, *effectiveness* and *benefit*.
- With fusion of different sources the *perceptual capacity and plausibility* of a combined result should be increased.

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2.1 Basics

- The main problem in information fusion

- Too much data
- Poor models
- Bad features / too many features
- Applications not analysed properly

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- Data reduction mechanisms
- Complex, but effective models

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2.1 Basics

- Today's world: Mono-sensor systems
  - Difficulties with Mono-sensor systems
    - Raw data noise:
      - Sensors, illumination, mounting, external noise sources, …
    - Intraclass variations:
      - Aging of sensors, maintenance, etc.
    - Interclass variations:
      - Different production states over a period of time, similarities in the feature space of multiple application flaws.
    - Nonuniversality:
      - Non-stable data or features from a subset of data.

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2.1 Basics

- Challenges in Multi-sensor systems
  - Robust sensors
    - Sensor performance
  - Coupling of Image and non-image fusion
    - Creation of time series of data
  - Calculus of fused data and data uncertainty
    - Methods, which are the best?
  - Complexity of methods
    - Bayes Framework
    - Dempster-Shafer's Method
    - Fuzzy Set Methods, etc.
  - Human Interface to multi-sensor systems
    - Integration of human knowledge
    - Interaction with a system

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2.1 Basics

- Multi-sensor systems
  A generic multi-sensor system consists of four important units:
  - the sensor unit which captures raw data from different measurement modules resp. sensors;
  - the feature extraction unit which extracts an appropriate feature set as a representation for the machine to be checked;
  - the classification unit which compares the actual data with the corresponding machine data stored in a database;
  - the decision unit which uses the classification results to determine whether the obtained results represent a good or valid result.

2.1 Basics

- Dirty secrets in information fusion (up to 2000, after David L. Hall, Penn State University)
  - There is no substitute for a good sensor.
  - 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.
  - It is difficult to quantify the value of data fusion.
  - Fusion is not a static process.

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2.1 Basics

- Dirty secrets in information fusion (2005, after David L. Hall, Penn State University)
  - There is *still* no substitute for a good sensor (and a qualified human to interpret the results).
  - Downstream processing *still* cannot absolve upstream sins.
  - Not only may the fused result be worse than the best sensor – but failure to address pedigree, information overload, and uncertainty may show a worst result.
  - Still no magic algorithms (even agents, ontology, D-S nets, etc.).
  - Never enough data (but we can help by hybrid methods).
  - It's not the data!!!
  - …

plus 3 more based on automation systems → exercise

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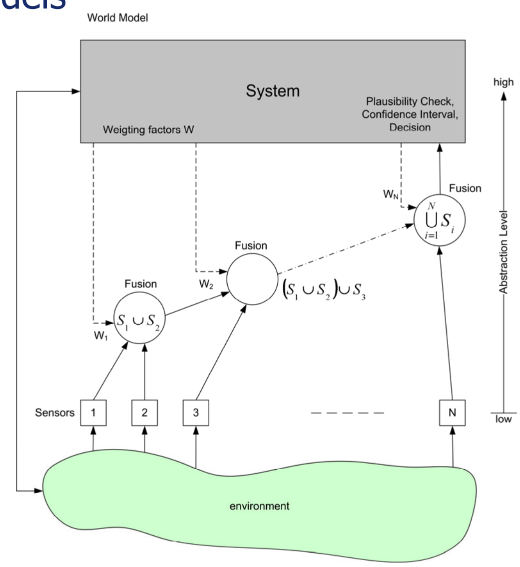
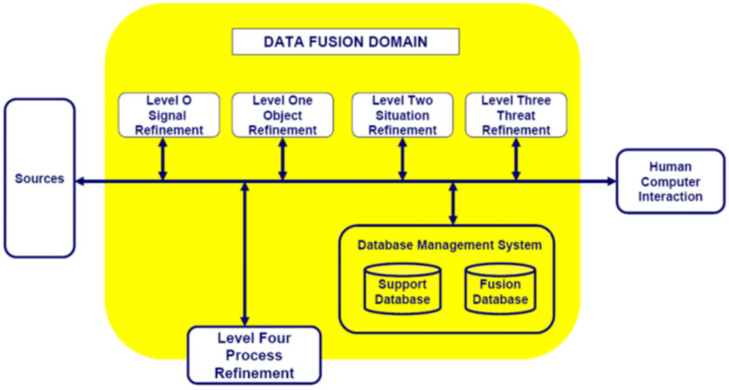
2.2 Concepts – Fusion Models

- World Model
  - Scheme of a general Multi-Sensory system which reacts on environmental behaviour.
  - Sensor models
  - Declarations regarding statistical behaviour about sensor data.
  - General question: How can sensors be connected?



2.2 Concepts – Fusion Models

- JDL Model (1993 - 1997)*



*) named after the Data Fusion Subpanel of the **J**oint **D**irectors of the **L**aboratories of the US Department of Defence.

2.2 Concepts – Fusion Models

- JDL Model (1993 - 1997)
  - **Level 0**—Sub-Object Data Association and Estimation: pixel/signal level data association and characterization
  - **Level 1**—Object Refinement: observation-to-track association, continuous state estimation (e.g. kinematics) and discrete state estimation (e.g. target type and ID) and prediction
  - **Level 2**—Situation Refinement: object clustering and relational analysis, to include force structure and cross force relations, communications, physical context, etc.
  - **Level 3**—Significance Estimation [Threat Refinement]: threat intent estimation, [event prediction], consequence prediction, susceptibility and vulnerability assessment
  - **Level 4**—Process Refinement: adaptive search and processing (an element of resource management)

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2.2 Concepts – Fusion Models

- JDL Model (1993 - 1997)
  - Problems with the JDL model
    - The Model is frequently cited. However, the model does not deliver a useful approach of data fusion.
    - Furthermore, it is difficult to recognise the levels 2 and 3 in non-military scenarios.
  - Conclusion: In our scenarios we should reflect on other models.

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2.2 Concepts – Fusion Models

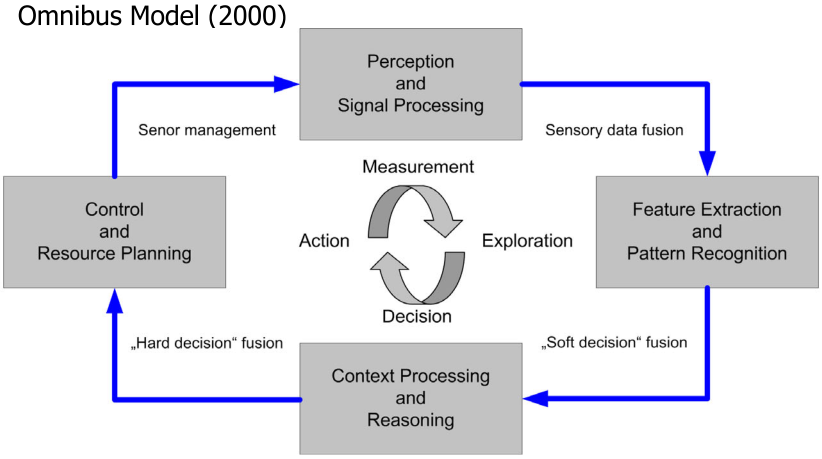
- Omnibus Model (2000)*
  - The omnibus model defines the fusion process as an *active measurement* process in a *control loop*.
  - The model is based on four parts:

    1. Measurement (perception and signal processing)
    2. Exploration (feature extraction and pattern recognition)
    3. Decision (context processing and reasoning)
    4. Action (control and resource planning)

*) Bedworth, M.; O'Brien, J.; Jemity, M.; *The Omnibus model: a new model of data fusion?*, Aerospace and Electronic Systems, Magazine, IEEE, Volume: 15, Issue: 4, page(s): 30-36, Apr 2000.

2.2 Concepts – Fusion Models

- Omnibus Model (2000)



2.2 Concepts – Fusion Models

- Model Variations and details
  - Generally three fusion types, depending on the abstraction level, are possible.
  - The higher the abstraction level, the more efficient is the fusion.
  - However, the high abstraction level fusion is not necessarily more effective due to the fact that data reduction methods must be used. Therefore, information loss will occur.

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2.2 Concepts – Fusion Models

- Model variations and details
  - *Signal level fusion – Sensor Association Principle*
    - At signal level all sensor signals are combined. It is necessary that the signals are comparable in a sense of
      - Data amount / sampling rate (adaption),
      - Registration,
      - Synchronisation.

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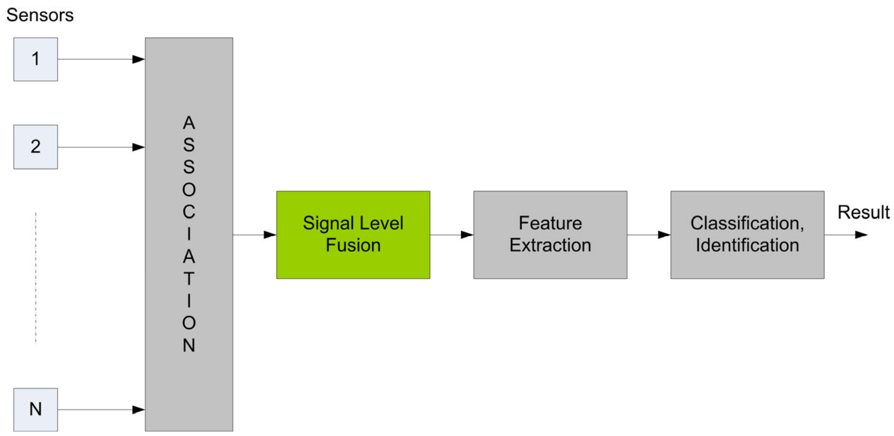
2.2 Concepts – Fusion Models

- Model Variations and Details
  - Sensor Association Principle



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2.2 Concepts – Fusion Models

- Model variations and details
  - *Feature level fusion – Feature Association Principle*
    - At feature level all signal descriptors (features) are combined. This is necessary if the signals are not comparable or complementary in a sense of
      - Data amount / sampling rate (adaption),
      - Registration,
      - Synchronisation.
    - Usually this is the case if images and 1D sensors are in use. There is no spatio-temporal coherence between the sensor signal.

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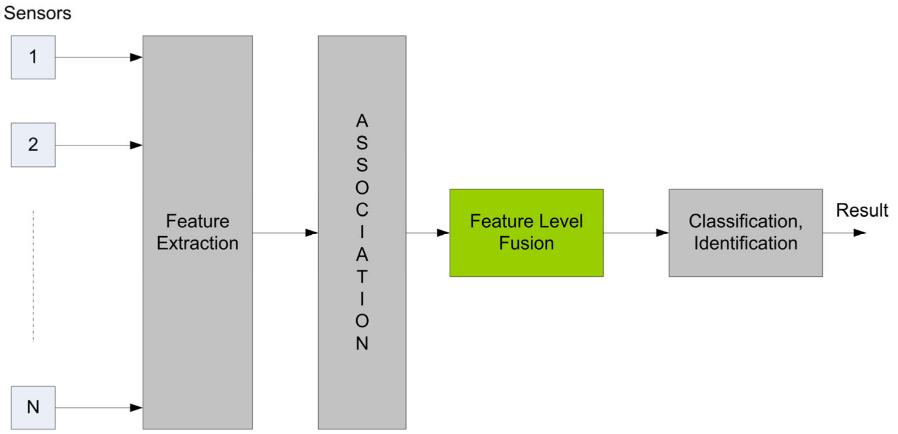
2.2 Concepts – Fusion Models

- Model Variations and Details
  - Feature Association Principle



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2.2 Concepts – Fusion Models

- Model variations and details
  - *Symbol level fusion – Symbol Association Principle*
    - At symbol level all classification results are combined. In this case the reasoning (the decision) is based on probability or fuzzy membership functions (possibility functions). This is necessary if the signals are not comparable or complementary in a sense of
      - Data amount / sampling rate (adaption),
      - Registration,
      - Synchronisation and
      - *Expert's know-how* has to be considered.

2.2 Concepts – Fusion Models

- Model Variations and Details
  - Table 2.2-1 Abstraction levels in fusion

Fusion Level	*Signal Level*	*Feature Level*	*Symbol Level*
Type of fusion	Signals, Measurement Data	Signal Descriptors, Numerical Features	Symbols, Objects, Classes, Decisions
Objectives	Signal and Parameter Estimation	Feature Estimation, Descriptor Estimation	Classification, Pattern Recognition
Abstraction Level	low	middle	high
Applicable Data Models	Random Variables, Random Processes	Feature Vectors, Random Variable Vectors	Probability Distributions, Membership functions
Fusion conditions (spatio-temporal)	Registration / Synchronisation (*alignment*)	Feature Allocation (*association*)	Symbol Allocation (*association*)
Complexity	high	middle	low

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2.3 Strategies

- The information gain is usually based on two facts. The information assignment of each sensor depends on
  - *redundant* information fusion or
  - *complementary* information fusion.

By means of **redundant information** the uncertainty of information, the signal-to-noise ratio (SNR) and the evidence plausibility can be increased. The reliability of data can be improved.

Complementary information is created by means of heterogeneous sensors. Incomplete information from a single sensor can be supplemented by another type of sensor.

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2.3 Strategies

- Integration concepts of single sensors in a multi-sensor system strongly depend on the place of installation and the types of data.
- Different strategies are available:
  - *Competitive integration* – Fusion of similar sensor data with equivalent effective information. The goal is the reduction of signal uncertainty.
    - Prominent example: Mean value generation for SNR improvement.
  - *Complementary integration* – Fusion of different sensor data with the goal to close information gaps. In this case signal averaging is destructive.
  - *Cooperative integration* – In this case the information is distributed (e.g. spatio-temporal). Only after interpretation of all sensory data the fusion result can be established.

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2.3 Strategies

- The method of resolution for a fusion strategy can be divided in *three basic patterns*.
  - *M*-of-*N*-decision for *M* of *N* available information sources. Which sources are the best?
  - Allocation and integration of all sources depending on the reliability (plausibility, certitude, etc.) of each source.
  - 1-of-*N*-decision for *1* of *N* available information sources. The best adequate sensor for a certain task must be used. The sensors are used in a serial manner.

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2.3 Strategies

- Error as Source of Uncertainty
  - While collecting evidence, missing, ambiguous/varying, and noisy (*in the data transformation sense*) facts can cause uncertain (*more than one possible*) conclusions.
  - Error sources:
    - **False Positive** ("It's true!")
    - When a test incorrectly gives a positive result (Type I error or α-error).
    - **False Negative** ("It's false!")
    - When a test incorrectly gives a negative result (Type II error or β-error).

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2.3 Strategies

- Apart from the raw data, other circumstantial information is *also* taken into account in order to extract those environmental data objects.
- Examples of such circumstantial information includes:
  - **Experience with the methods** and technical devices that are used for data capture.
  - **Knowledge about the applications** and products has to be involved.
  - **Information about the circumstances** of the situation is needed (image, sound, temperature, date, time, etc.).

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2.3 Strategies

- **Human experts** always take such information into account when evaluating a sample.
  - Any attempt to automate this process without including such information is doomed to failure.
- A promising strategy is to form a **working hypothesis**, and to support or challenge this hypothesis based on the information available.

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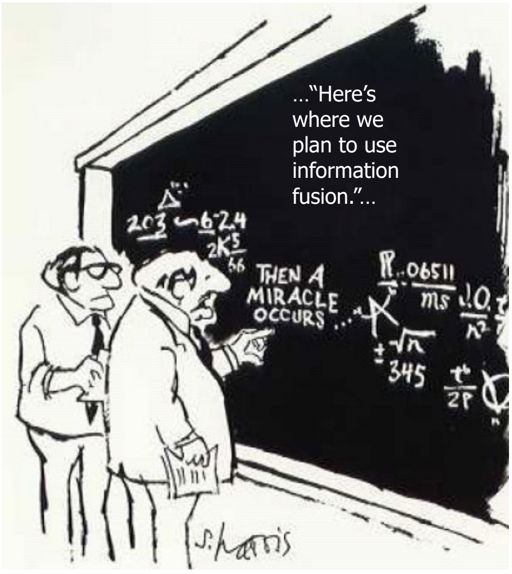
2.3 Strategies

- … in the end



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