

Sensor Fusion Concepts

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BE THE DIFFERENCE.

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What is **Sensor Fusion**?

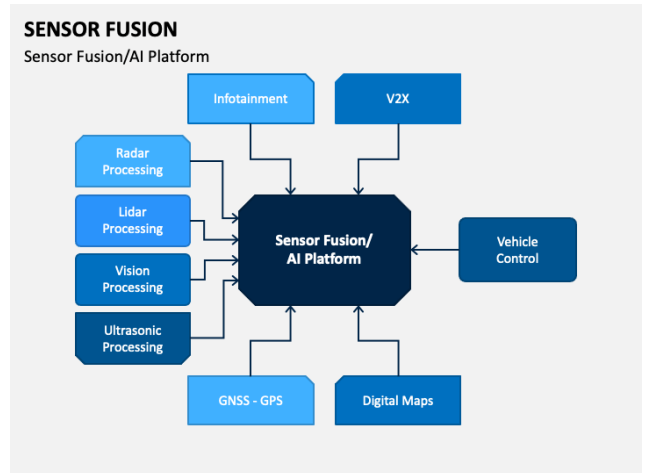
- Sensor fusion: process of combining inputs from two or more sensors to produce a more complete, accurate, and dependable “picture” of the **environment**, especially in dynamic settings.
- Goal of sensor fusion: provide improved results with the minimum number of sensors and minimum system complexity for the lowest cost.
- Known also as **multisensor integration** = how to combine data from different sources?

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Example: Autonomous Vehicles

- Sensor fusion is the ability to bring together inputs from multiple radars, lidars and cameras to form a single model or image of the environment around a vehicle.
- The resulting model is more accurate because it balances the strengths of the different sensors.



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Example: Mobile Robotics

- Data fusion:
 - Combine measurements from different sensors
 - Combine measurements from different positions
 - Combine measurements from different times
- Sensor integration techniques actively utilize diversity of information in overcoming the limitations of any one-sensor system



Source: <https://mro.oru.se/research/mobile-robot-olfaction/>

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Sensor Fusion Benefits

- Increased data quality
- Increased data reliability
- Estimation of unmeasured states
- Increased coverage areas

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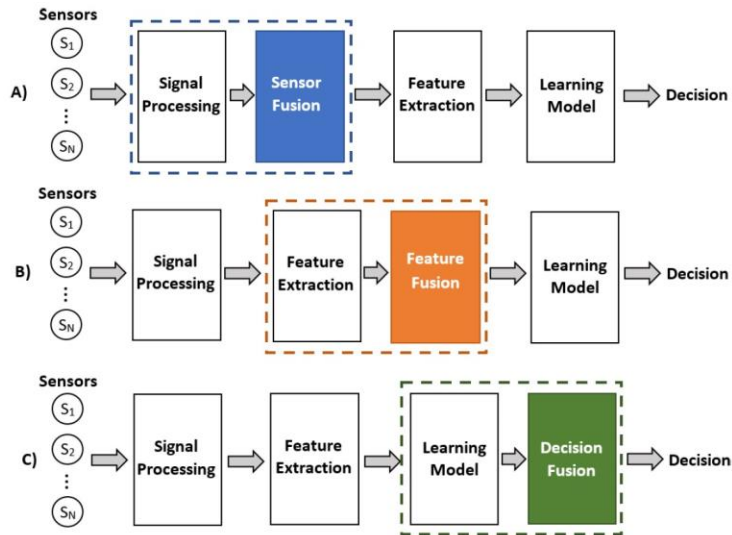
Sensor Fusion Levels

- With respect to the abstraction level of data processing, multi-sensor fusion has been classified into **three categories**:
 1. Fusion at the data-level
 2. Fusion at the feature-level
 3. Fusion at the decision-level

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Different fusion levels for sensor information



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Methodologies

1. Statistical:

- **Covariance**, cross variance

2. Probabilistic:

- **Kalman** filtering, maximum likelihood estimation, Bayesian networks

3. Knowledge-based and inference/reasoning:

- Artificial neural networks, fuzzy logic, **machine learning (ML)** algorithms

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1. Covariance Intersection

WIKIPEDIA The Free Encyclopedia

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Stone Soup

Examples / Multi-Sensor Fusion: Covariance Intersection Using Tracks as Measurements

Note: Go to the end to download the full example code or to run this example in your browser via Binder

Multi-Sensor Fusion: Covariance Intersection Using Tracks as Measurements

Background

The Covariance Intersection Algorithm from Julier and Uhlmann¹ is a popular algorithm for track-to-track fusion in target tracking systems. This approach is highly appealing due to its robustness, simple structure, and applicability to any tracking system that uses Gaussians as the basis for tracking. Generalisations to non-Gaussian systems have been proposed based on the exponential mixture density structure of the algorithm. The approach is based on a simple rule called the Chernoff Fusion Rule. However, due to the non-Bayesian formulation of the rule, it cannot be integrated straightforwardly into multi-target tracking algorithms which are based on Bayesian formulations.

A new Bayesian formulation for covariance intersection was recently proposed which allows for the integration of the approach into multi-target tracking algorithms.² The new formulation recasts the fusion rule as a Bayesian update rule that calculates a normalisation constant which enables integration into different multi-target tracking algorithms.

Formulation

Items of information a and b are known and are to be fused into information item c . We know a and b have mean/covariance \hat{a} , A and \hat{b} , B , but the cross-covariance is not known. The covariance intersection update gives mean and covariance for c as

$$C^{-1} = \omega A^{-1} + (1 - \omega) B^{-1},$$

$$\hat{c} = C(\omega A^{-1} \hat{a} + (1 - \omega) B^{-1} \hat{b}),$$

where ω is computed to minimize a selected norm, e.g. the trace, or the logarithm of the determinant. While it is necessary to solve an optimization problem for higher dimensions, closed-form solutions exist for lower dimensions.^[3]

Application

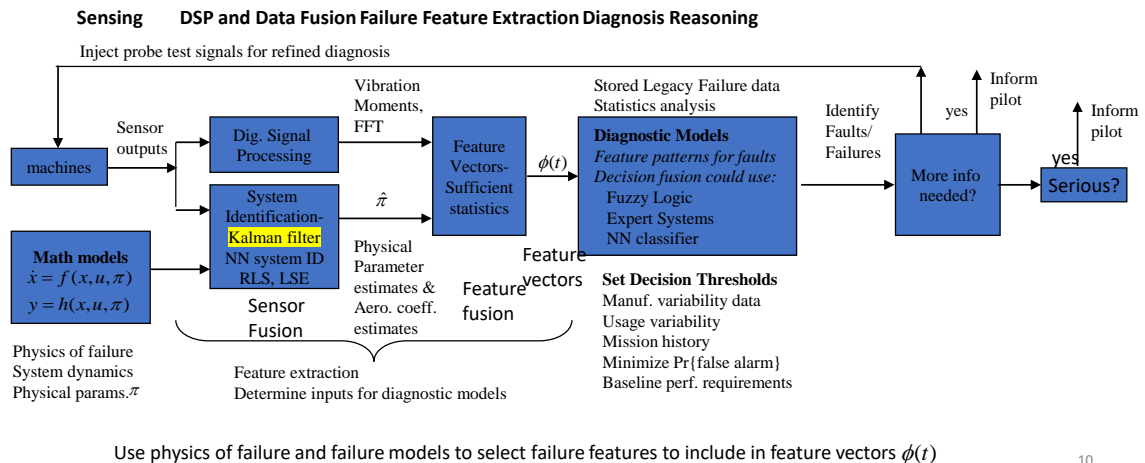
CI can be used in place of the conventional Kalman update equations to ensure that the resulting estimate is conservative, regardless of the correlation between the two estimates, with covariance strictly non-increasing according to the chosen measure. The use of a fixed measure is necessary for rigor to ensure that a sequence of updates does not cause the filtered covariance to increase.^{[1][9]}

Source: https://en.wikipedia.org/wiki/Covariance_intersection

Source: https://stonesoup.readthedocs.io/en/stable/auto_examples/Track2Track_Fusion_Example.html

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2. Kalman Filters Diagnostics



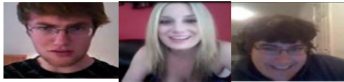
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3. Machine Learning

Multimodal Sentiment Analysis

MOSI dataset (Zadeh et al, 2016)

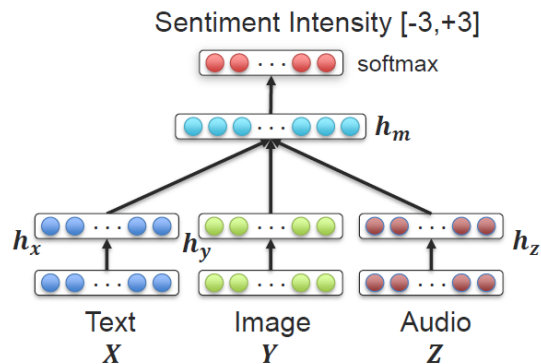


- 2199 subjective video segments
- Sentiment intensity annotations
- 3 modalities: text, video, audio

Multimodal joint representation:

$$h_m = f(W \cdot [h_x, h_y, h_z])$$

Source: MultiComp Lab, CMU



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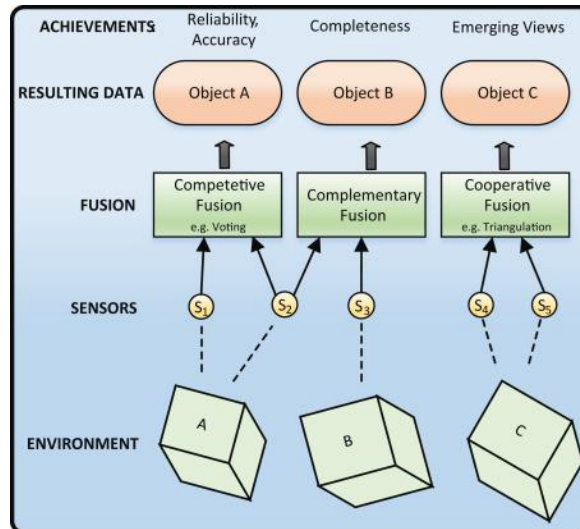
Sensor Source Classifications

- **Redundant or competitive sensors** - used to provide information about the same target, and their outputs are combined to increase the reliability or confidence of the output.
- **Complementary sensors** - provide information that represents different aspects of the environment and can be combined to produce more complete global information.
- **Cooperative sensor fusion** - combines the inputs from multiple sensor modalities, such as audio and visual, to produce more complex information than the individual inputs.

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Competitive, complementary, and cooperative sensor fusion



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Joint Directors of Laboratories (JDL) model – Five levels for fusion methodologies

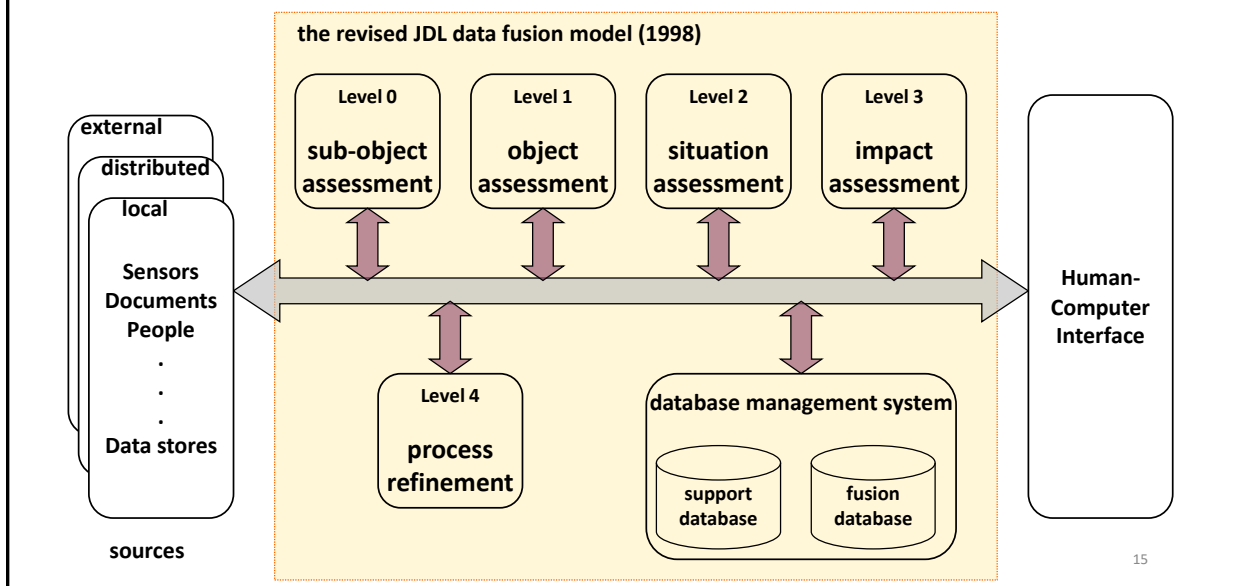
- **Level 0** — source preprocessing is the lowest level of data fusion. It includes signal conditioning and fusion at the signal level.
- **Level 1** — object refinement uses the preprocessed data from the previous level to perform spatio-temporal alignment, correlations, association, clustering or grouping techniques, state estimation, etc.
- **Level 2** — situation assessment establishes relationships between the classified and identified objects.
- **Level 3** — impact assessment evaluates the relative impacts of the detected activities in level 2 to support a situation analysis.
- **Level 4** — process refinement is used to improve Levels 0 to 3 and to support sensor and general resource management.

https://en.wikipedia.org/wiki/Data_fusion

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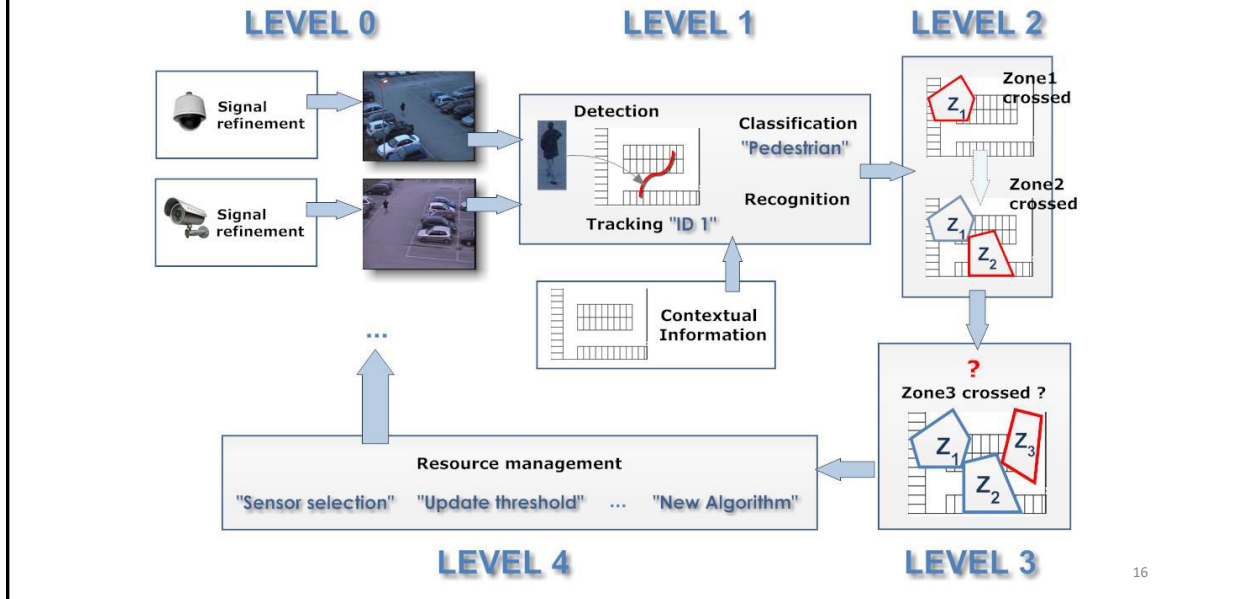
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Sensor Fusion Model



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Example



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Credits

- Jeff Shepard, Sensor fusion levels and architectures, 2021
 - <https://www.sensortips.com/featured/sensor-fusion-levels-and-architectures-faq/>
- <http://www-2.cs.cmu.edu/~sensing-sensors/>
- [A Review of Data Fusion Techniques](#), Hindawi
- [A Survey of Internet-of-Things: Future Vision, Architecture, Challenges and Services](#), IEEE
- [An Overview of IoT Sensor Data Processing, Fusion, and Analysis Techniques](#), MDPI
- [Data Fusion and IoT for Smart Ubiquitous Environments](#), IEEE
- [Multi-Modal Fusion for Objective Assessment of Cognitive Workload](#), IEEE
- [Sensors and Data Acquisition](#), Science Direct