*EECE-4710 "IoT and TinyML"*

# Sensor Fusion Concepts

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BE THE DIFFERENCE.

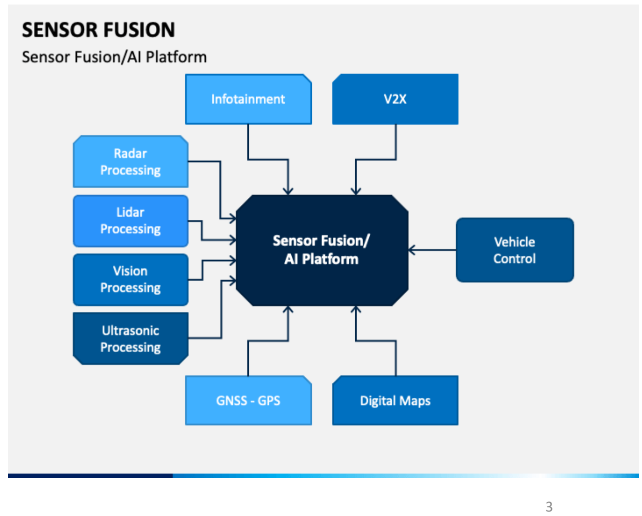


## What is Sensor Fusion?

- 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?

# 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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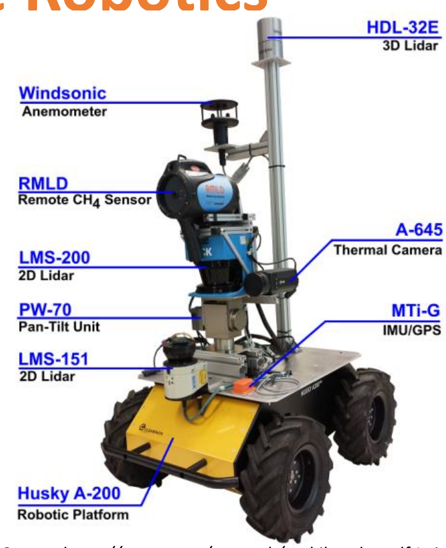
# Example: Mobile Robotics

- 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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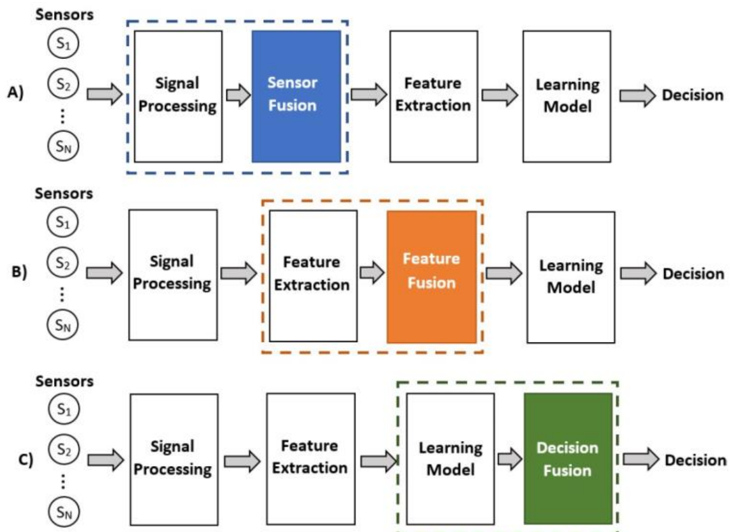
# Different fusion levels for sensor information

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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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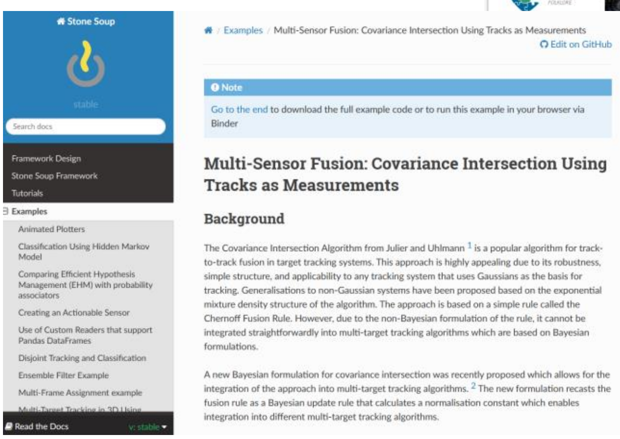
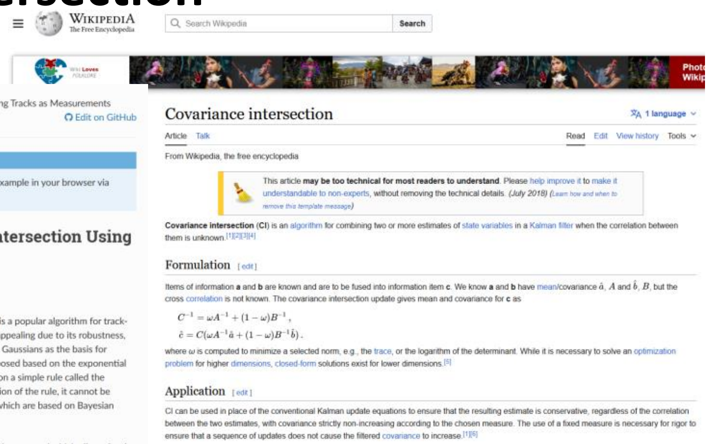
# 1. Covariance Intersection




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




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

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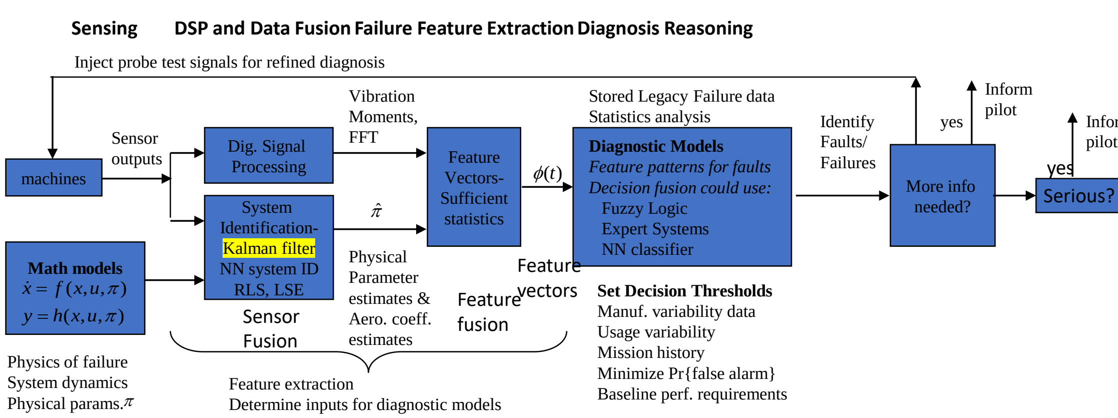
# 2. Kalman Filters Diagnostics




Use physics of failure and failure models to select failure features to include in feature vectors $\phi(t)$

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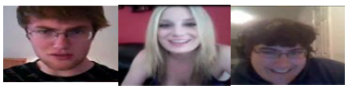
# 3. Machine Learning

## Multimodal Sentiment Analysis

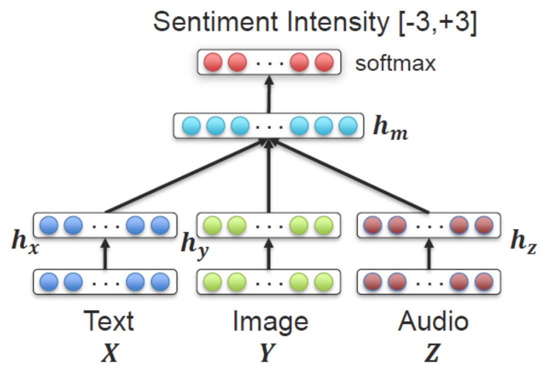
**MOSI dataset (Zadeh et al, 2016)**



- 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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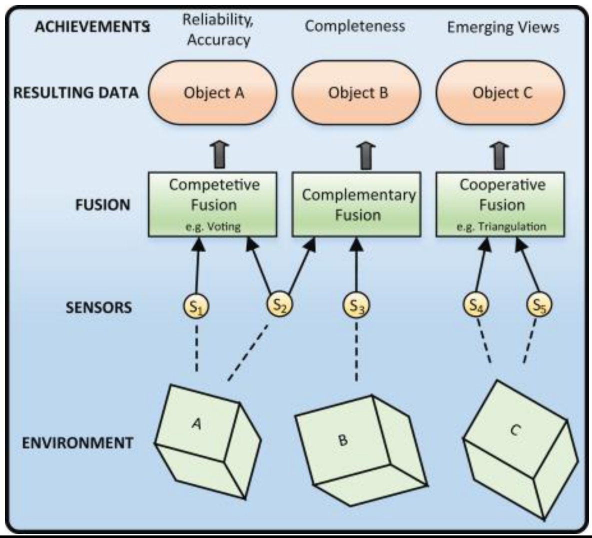
## Competitive, complementary, and cooperative sensor fusion

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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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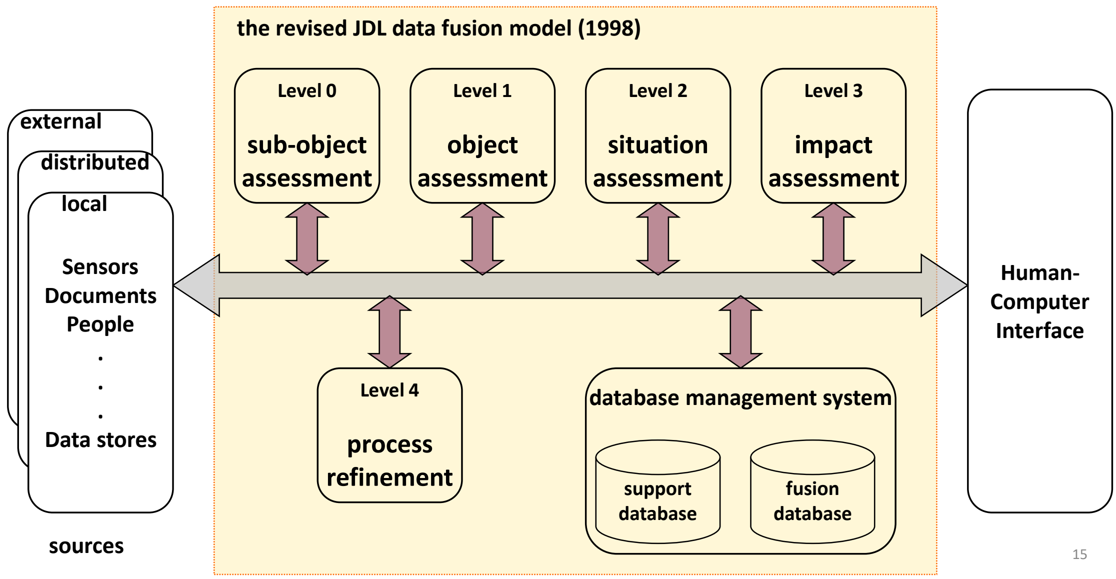
# Sensor Fusion Model

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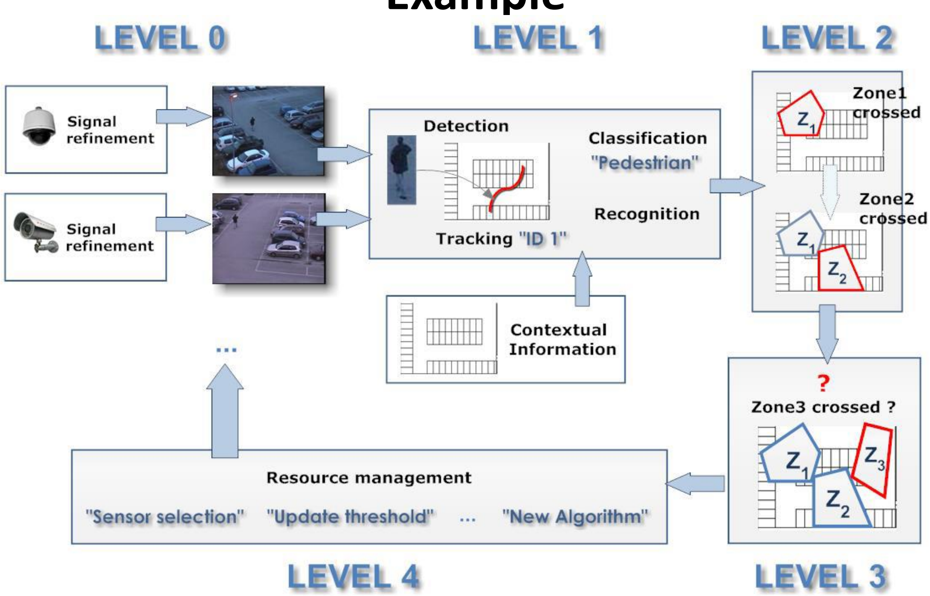
# Example

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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


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