LOCALIZATION

FINGERPRINTING LOCALIZATION

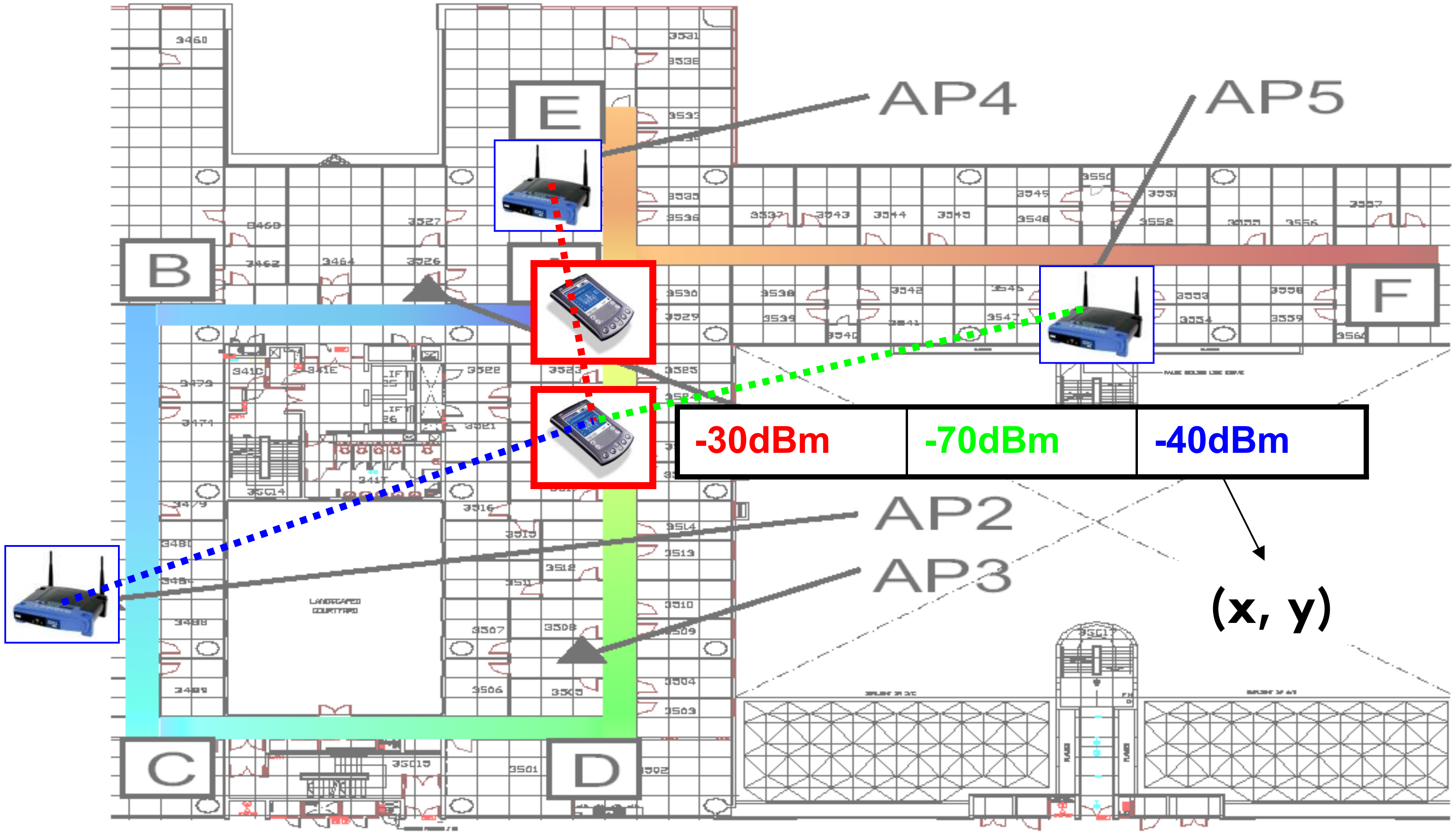
Fingerprinting

FINGERPRINTING LOCALIZATION

Localization using for example 802.11 in indoor applications

Dual use infrastructure: a huge advantage

SS BASED LOCALIZATION: FINGERPRINTING



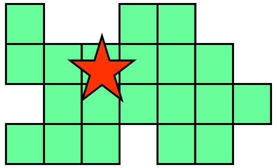
FINGERPRINTING

Output:
- A single location: the closest/best match (point based)
- Probabilistic approaches

[Bahl00, Ladd02, Roos02, Smailagic02, Youssef03, Krishnan04]

Output:

- area/volume likely to contain the localized object



Area is described by a set of tiles

Ability to describe uncertainty
- Set of highly possible locations

BACKGROUND: FINGERPRINTING LOCALIZATION

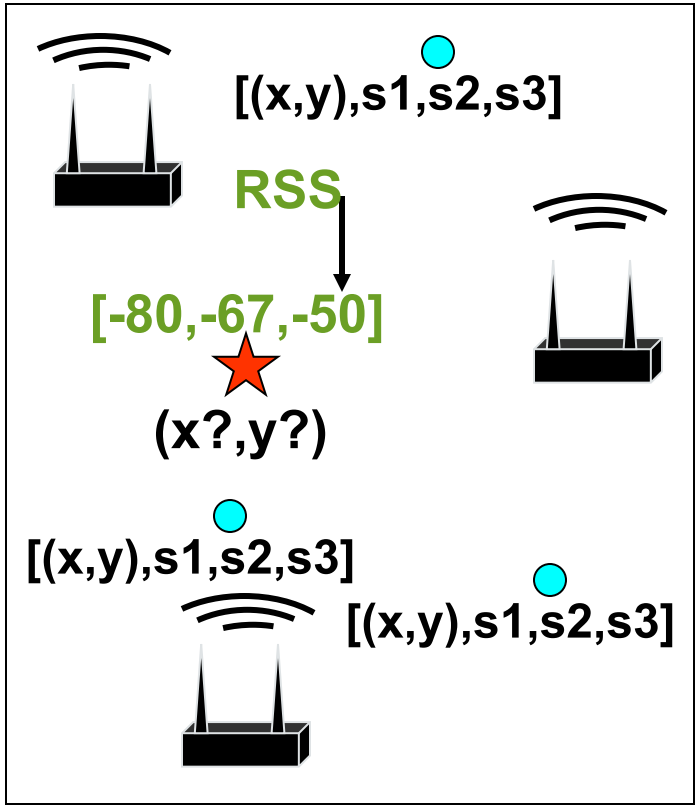
Classifiers/matching/learning approaches

Offline phase:

- Collect training data (fingerprints)
- Fingerprint vectors: [(x,y),SS]

Online phase:

- Match RSS to existing fingerprints probabilistically or using a distance metric

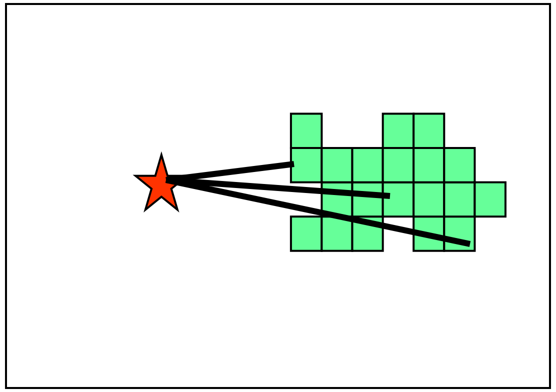


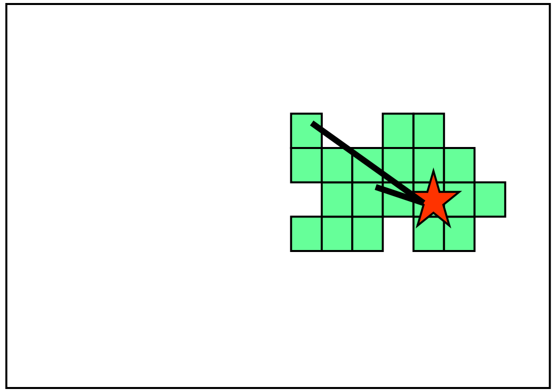
NEW METRICS: ACCURACY VS. PRECISION

Tile Accuracy % true tile is returned

Distance Accuracy distance between true tile and returned tiles (sort and use percentiles to capture distribution)

Precision size of returned area (e.g., sq.ft.) or % floor size



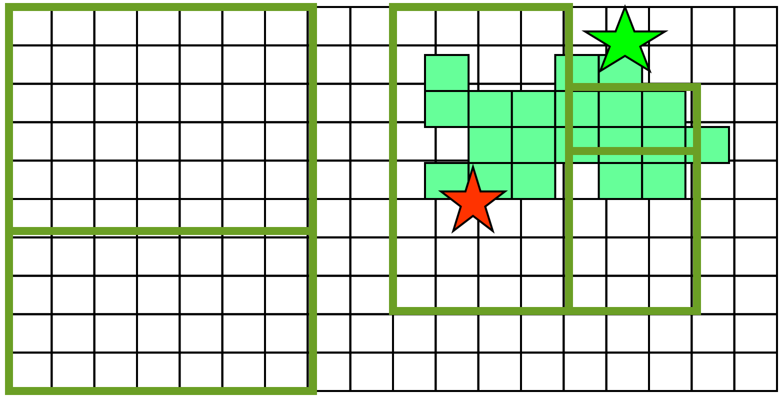


ROOM-LEVEL METRICS

Applications usually operate at the level of rooms

Mapping: divide floor into rooms and map tiles

- (Point –> Room): easy
- (Area –> Room): tricky



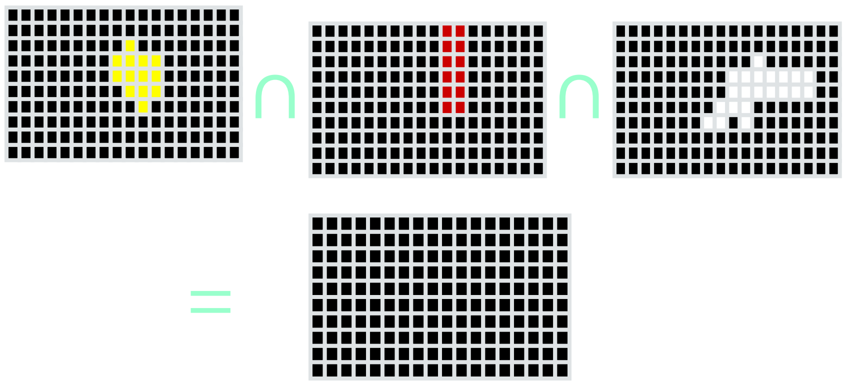
Metrics: accuracy-precision

<u>Room Accuracy</u> % true room is the returned room
<u>Top-n rooms Accuracy</u> % true room is among the returned rooms
<u>Room Precision</u> avg number of returned rooms

1. SIMPLE POINT MATCHING (SPM)

Build a regular grid of tiles, match expected fingerprints

Find all tiles which fall within a "threshold" of RSS



Eager: start from low threshold (s, 2s, 3s , …)

Threshold is picked based on the standard deviation of the received signal

Similar to Maximum Likelihood Estimation

2. Area-Based Probability (ABP-c)

Build a regular grid of tiles, tile ↔ expected fingerprint

Using "Bayes' rule" compute likelihood of an RSS matching the fingerprint for each tile

$$\boxed{p(Ti|RSS) \propto p(RSS|Ti) \cdot p(Ti)}$$

Return top tiles bounded by an overall probability that the object lies in the area (Confidence: user-defined)

Confidence ↑ → Area size ↑

INTERPOLATION: TO AVOID FINE POINT MEASUREMENTS

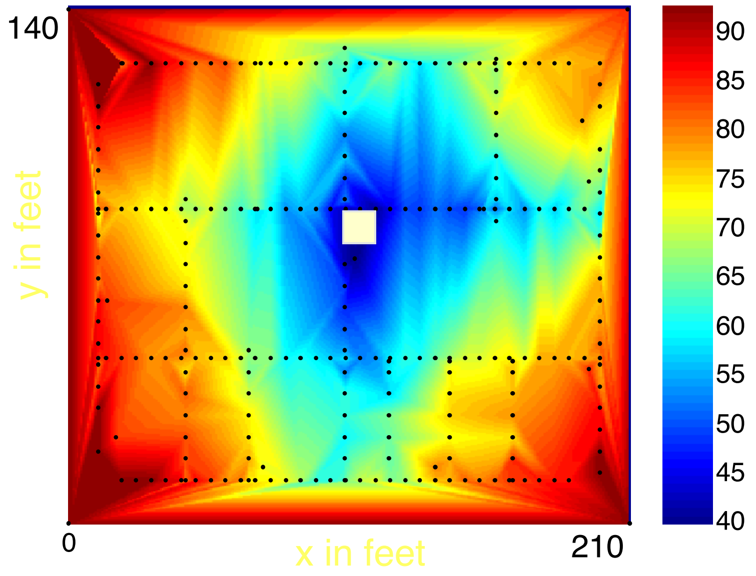
Interpolated Map Grid: (Surface Fitting)

Goal: Extends original training data to cover the entire floor by deriving an expected fingerprint in each tile

Triangle−based linear interpolation using "Delaunay Triangulation"

Advantages:

- Simple, fast, and efficient
- Insensitive to the tile size



SENSOR DATA FUSION

DATA/SENSOR FUSION

Wikipedia:
Sensor fusion is the combining of sensory data such that the resulting information is in some sense is better than what would be possible when these sources were used individually.

Better: more accurate, more complete, and/or more dependable.

Multi-sensor information fusion (MUSSIF) encompasses the theory, methods, and tools conceived and used for exploiting synergy in information acquired from multiple sources (sensors, databases, information gathered by human senses, etc.).

WHAT SHOULD WE BE AWARE OF?

Sensors Measurements are uncertain

The most common sources of uncertainty

- little or no knowledge about measurement
- incomplete measurement (when data are approximated rather than waiting for complete data which may be time consuming and costly)
- limitations of the system

Sensors are not the same: design limitations, environmental sensitivity, observational considerations.

Thus, the performance of each sensor needs to be defined and quantified.

SENSOR LIMITATIONS

In general, a sensor measurement system tend to have one or more of the following limitations:

- Failure of a sensor or sensor channels, results in the loss of sensory data.

- Sensors individually designed to cover only a restricted region of the environment and provides measurement data about local events, aspects, or attributes.

- Many sensors require a finite time to perform some basic operations and transmit measurements for processing, thereby limiting the frequency of measurements.

- Measurements from sensors depend on the accuracy and precision of the basic sensing element used in the sensor and the data gathered would thus have limited accuracy.

- Uncertainty depends on the sensing environment; noisy environments present major challenges and often lead to noisy sensory data.

SENSORY DATA FUSION: WHAT CAN IT DO? BENEFITS

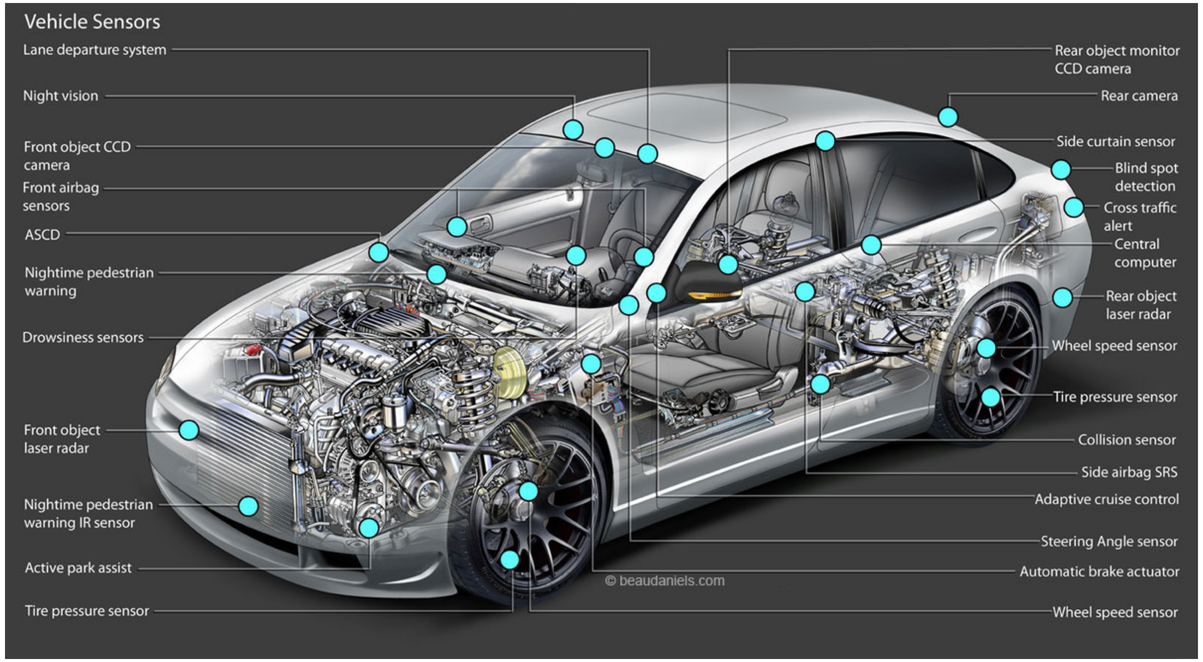
By the fusion of sensors' data we can expect one or more of the following potential advantages:

1. Multiple sensors would provide redundancy which, in turn, would enable the application to obtain information in case of partial failure, data loss from some sensors—i.e., fault tolerance capability, robust functional and operational performance.

2. One sensor can observe or sense where other sensors cannot observe or sense and hence can provide observations, to enhance spatial, phenomenon-geometrical coverage, and complementary information gathering.

3. Measurements obtained by one sensor can be verified/confirmed by the measurements of the other sensors, obtaining cooperative arrangement and enhancing the confidence—increased confidence in the inferred results.

4. Joint information would tend to reduce ambiguous interpretations and hence less uncertainty.



Uncertainty would arise if:

- some features were missing, such as obstacles in the path, eclipsing of radar cross section (RCS), Glint noise, or background clutter; the sensor cannot measure all relevant attributes and sensor limitations; or the observation is ambiguous or doubtful.

Hence, a single sensor cannot reduce uncertainty in its perception of the observed scene, and one of the effective solutions to many of the ongoing problems is multi-sensor data fusion.

SENSOR DATA FUSION: BENEFITS

5. Increased dimensionality of the measurement space, say measuring the desired quantity with optical sensors and ultrasonic sensors, the system is less vulnerable to interferences providing a sustained availability of the data.

6. Multiple independent measurements when fused would improve the resolution—enhanced spatial resolution.

7. Extended temporal coverage—the information is continually available.

8. Improved detection of the objects because of less uncertainty provided by the fusion process.

DATA FUSION: OBJECTIVES

In simple terms, the main objective of sensor DF is to collect measurements and sample observations from various similar or dissimilar sources and sensors, extract the required information, draw inferences, and make decisions.

These derived or assessed information and deductions can be combined and fused, with an intent of obtaining an enhanced status and identity of the perceived or observed object or phenomenon.

Multi-sensor data fusion (MSDF) would primarily involve:

- (1) hierarchical transformations between observed parameters to generate decisions regarding the location (kinematics and even dynamics), characteristics (features and structures), and the identity of an entity; and

- (2) inference and interpretation (decision fusion) based on a detailed analysis of the observed scene or entity in the context of a surrounding environment and relationships to other entities.

STRUCTURE OF DATA FUSION

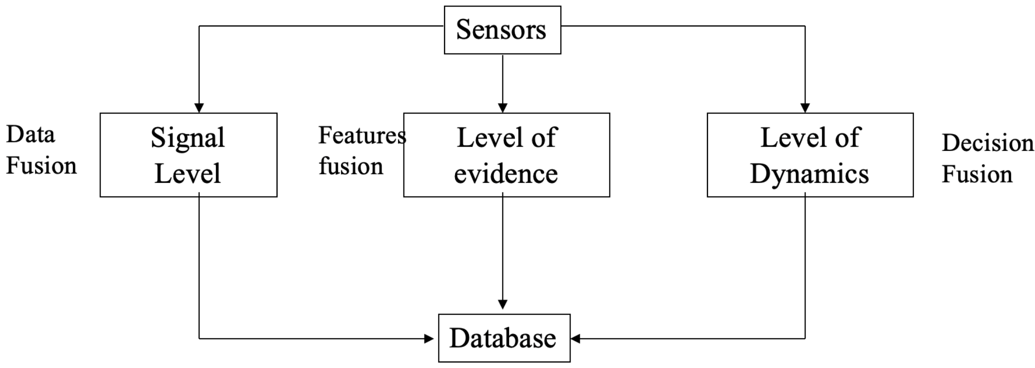
Fusion processes are often categorized in three levels of modes: low-, intermediate-, and high-level fusion, as follows:

1. Low-level fusion or raw-data fusion combines several sources of essentially the same type of raw preprocessed (RPP) data to produce a new raw data set that is expected to be more informative and useful than the inputs.

This can be expanded to include the fusion of estimated states of a system or object by using data from several, often dissimilar, sensors and is called state vector fusion. The entire process is called kinematic data fusion, which can include kinematic states as well as dynamic states, along with some fundamental concepts of data fusion.

2. Intermediate-level, mid-level fusion, or feature-level fusion combines various features. For example, in visual sensing, features may include edges, lines, corners, textures, or positions into a feature map. This map is used for segmentation of images, detection of objects, etc. This process of fusion is called pixel-, feature-, or image-level fusion.

3. High-level fusion, or decision fusion, combines decisions from several experts. Methods of decision fusion are voting, fuzzy logic, and statistical methods.



Level 0: Preliminary data processing – pixel or signal level data association and characterization.

Level 1: Data alignment, association, tracking and identification.

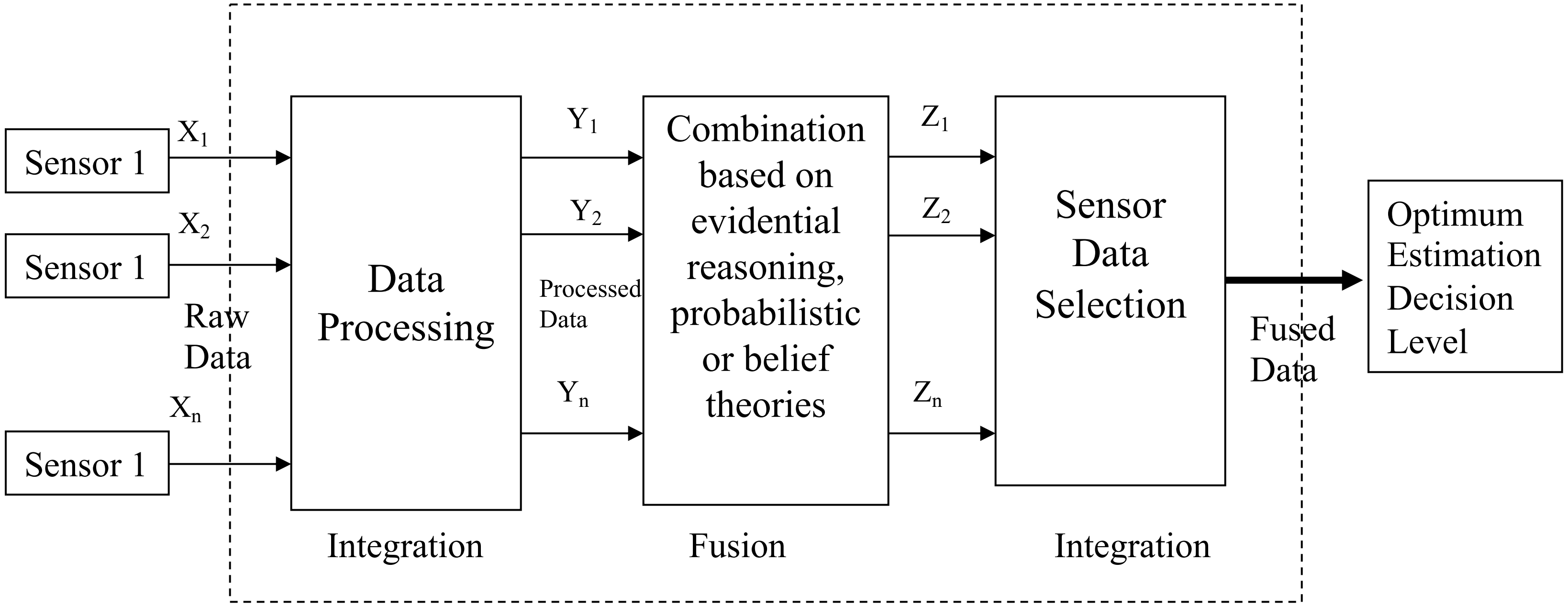
Level 2: Situation assessment.

Level 3: Threat assessment.

Level 4: Process Refinement includes adaptive processing through performance evaluation and decision or resource and mission management.

PROCESS CATEGORIZATION

Data fusion processes are often categorized as low, intermediate, or high, depending on the processing stage at which fusion takes place.



MODELS OF THE DATA FUSION PROCESS AND ARCHITECTURES

Sensor-fusion networks (NWs) are organized topologies that have specified architectures and are categorized according to the type of sensor configuration (see also Figure 2.2):

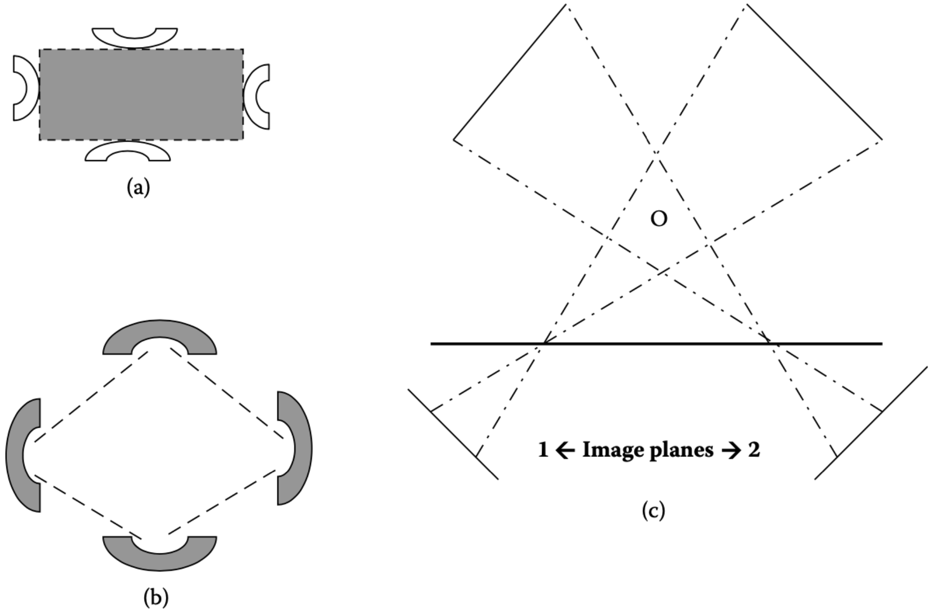
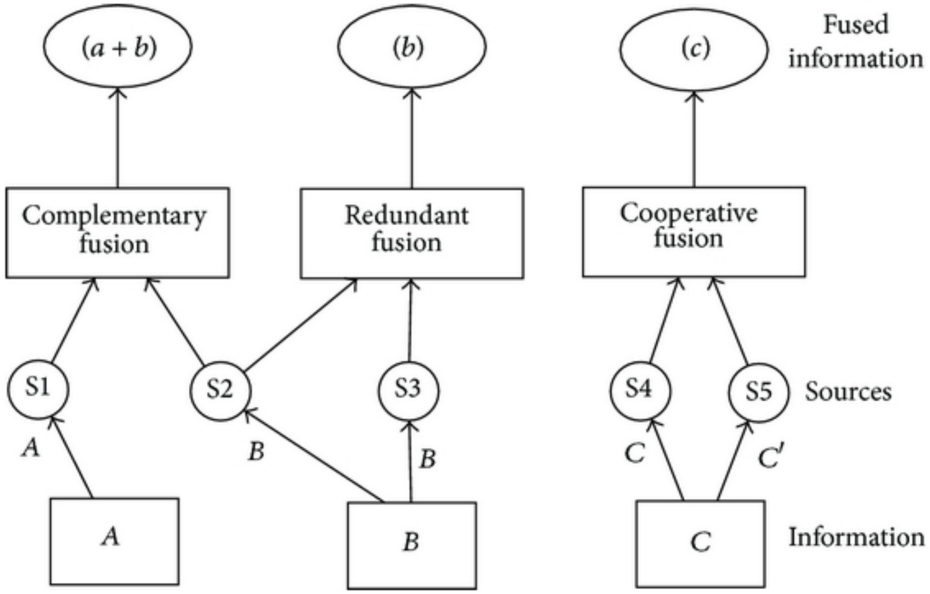


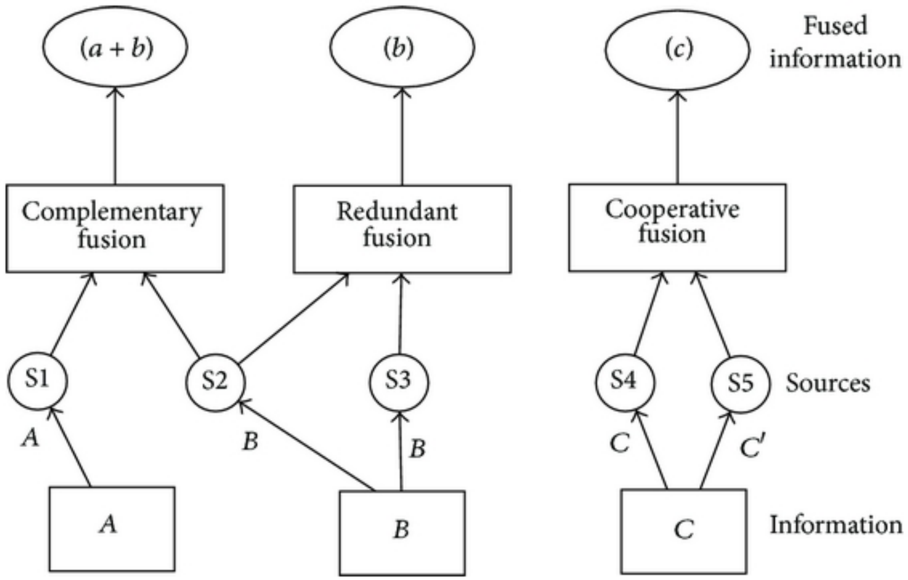
FIGURE 2.2
Data-fusion sensor networks: (a) Complementary sensor network: viewing different regions. (b) Competitive sensor network: viewing the same area. (c) Cooperative sensor network: two vision cameras producing a single 3D image of "O."

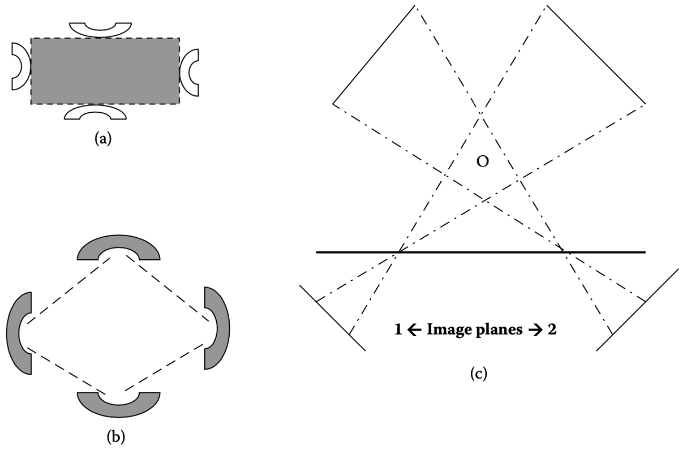


COMPLEMENTARY SDF

In this type of sensor configuration, the sensors do not depend on each other directly. One sensor views one part of the region, and another views a different part of the region, thereby giving a complete picture of the entire region.

Because they are complementary, they can be combined to establish a more complete picture of the phenomenon being observed and hence the sensor datasets would be complete. For example, the use of multiple cameras, each observing different parts of a room, can provide a complete view of the room. The four radars around a geographical region would provide a complete picture of the area surrounding the region (Figure 2.2a). Fusion of complementary data is relatively easy because the data from independent sensors can be appended to each other.





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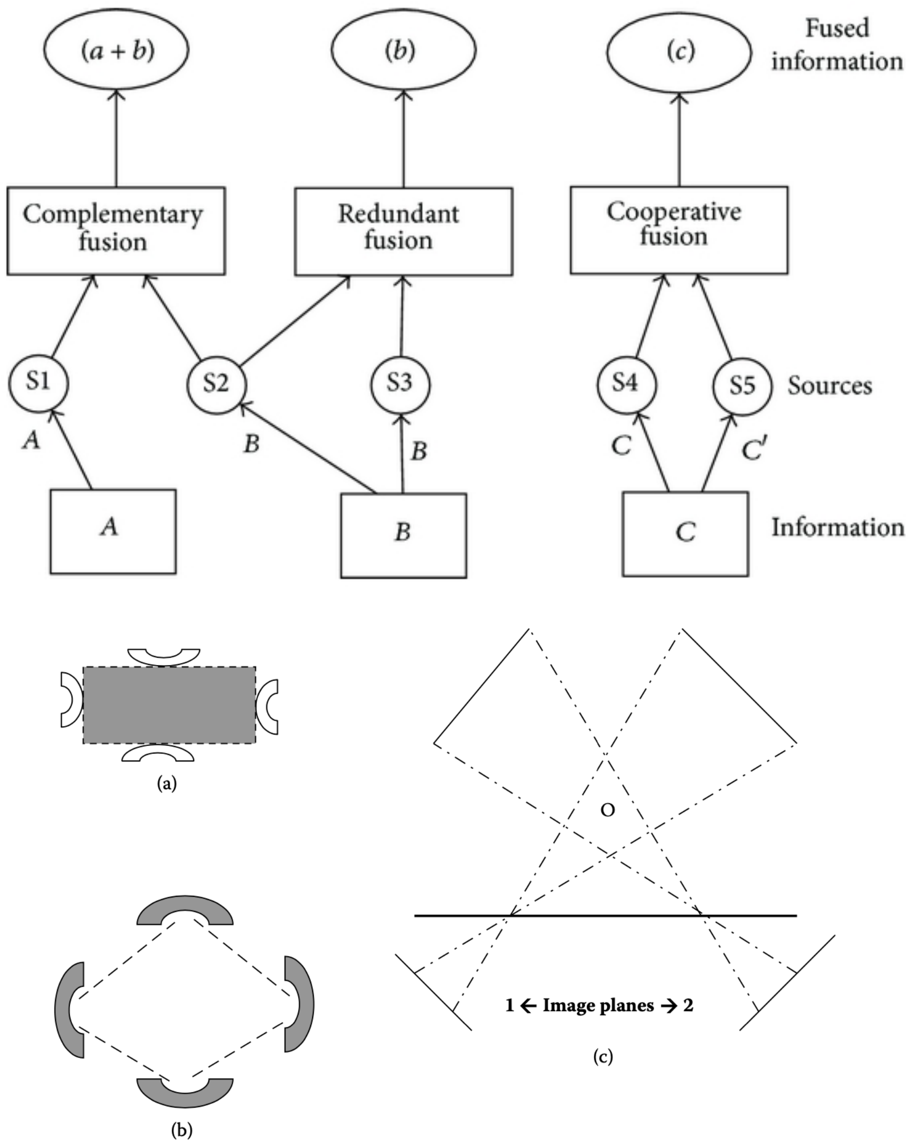
COMPETITIVE SDF

In this type of configuration (Figure 2.2b), each sensor delivers independent measurements of the same attribute or feature.

Fusion of the same type of data from different sensors or the fusion of measurements from a single sensor obtained at different instants is possible.

This configuration would provide robustness and fault-tolerance because comparison with another competitive sensor can be used to detect faults.

Such robust systems can provide a degraded level of service in the presence of faults; moreover, the competing sensors in this system do not necessarily have to be identical.



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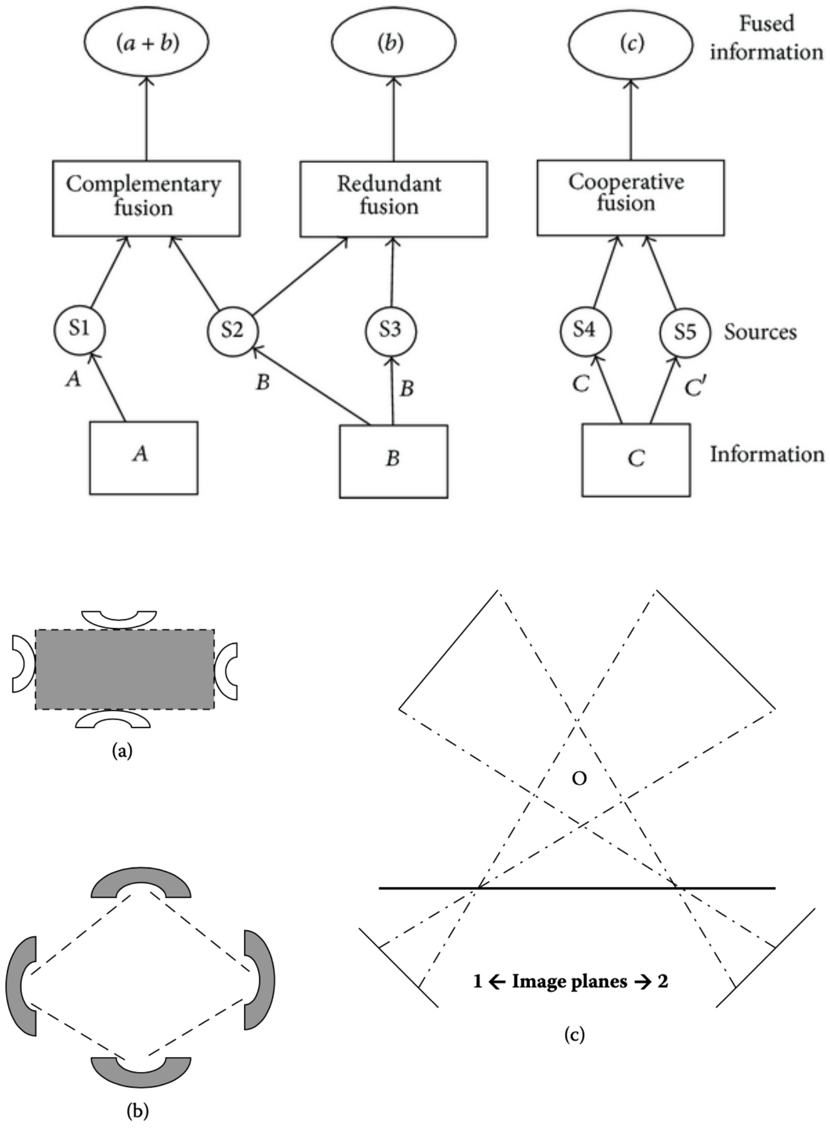
COOPERATIVE SDF

In this type of configuration, data provided by two independent sensors are used to derive information that would not be available from a single sensor (see Figure 2.2c), as in a stereoscopic vision system.

By combining the two−dimensional (2D) images from two cameras located at slightly different angles of incidence (viewed from two image planes), a three− dimensional (3D) image of the observed scene, marked "O," is determined.

Cooperative sensor fusion is difficult to design, and the resulting data will be sensitive to the inaccuracies in all the individual sensors.

In terms of usage, the three categories of sensor configurations are not mutually exclusive, because more than one of the three types of configurations can be used in most cases. In a hybrid configuration, multiple cameras that monitor a specific area can be used. In certain regions monitored by two or more cameras, the sensor configuration could be either competitive or cooperative.



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Data-fusion sensor networks: (a) Complementary sensor network: viewing different regions. (b) Competitive sensor network: viewing the same area. (c) Cooperative sensor network: two vision cameras producing a single 3D image of "O."

INPUT/OUTPUT DATA TYPES BASED CLASSIFICATION

Composed of the following five categories:

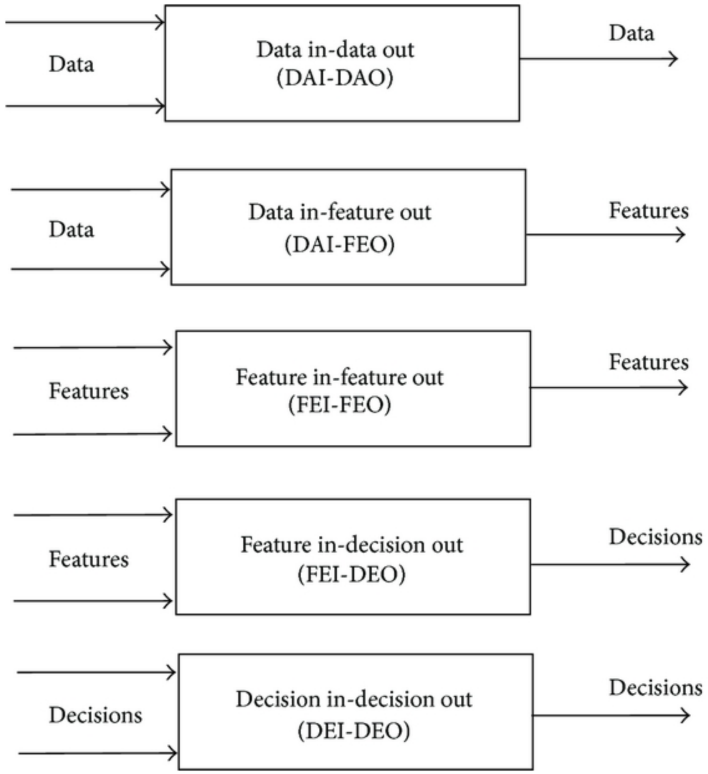
(1) Data in-Data out (DAI-DAO): this type is the most basic or elementary data fusion method that is considered in classification. This type of data fusion process inputs and outputs raw data; the results are typically more reliable or accurate. Data fusion at this level is conducted immediately after the data are gathered from the sensors. The algorithms employed at this level are based on signal and image processing algorithms;

(2) Data in-Feature out (DAI-FEO): at this level, the data fusion process employs raw data from the sources to extract features or characteristics that describe an entity in the environment;

(3) Feature in-Feature out (FEI-FEO): at this level, both the input and output of the data fusion process are features. Thus, the data fusion process addresses a set of features with to improve, refine or obtain new features. This process is also known as feature fusion, symbolic fusion, information fusion or intermediate-level fusion;

(4) Feature in-Decision out (FEI-DEO): this level obtains a set of features as input and provides a set of decisions as output. Most of the classification systems that perform a decision based on a sensor's inputs fall into this category of classification;

(5) Decision In-Decision Out (DEI-DEO): This type of classification is also known as decision fusion. It fuses input decisions to obtain better or new decisions.

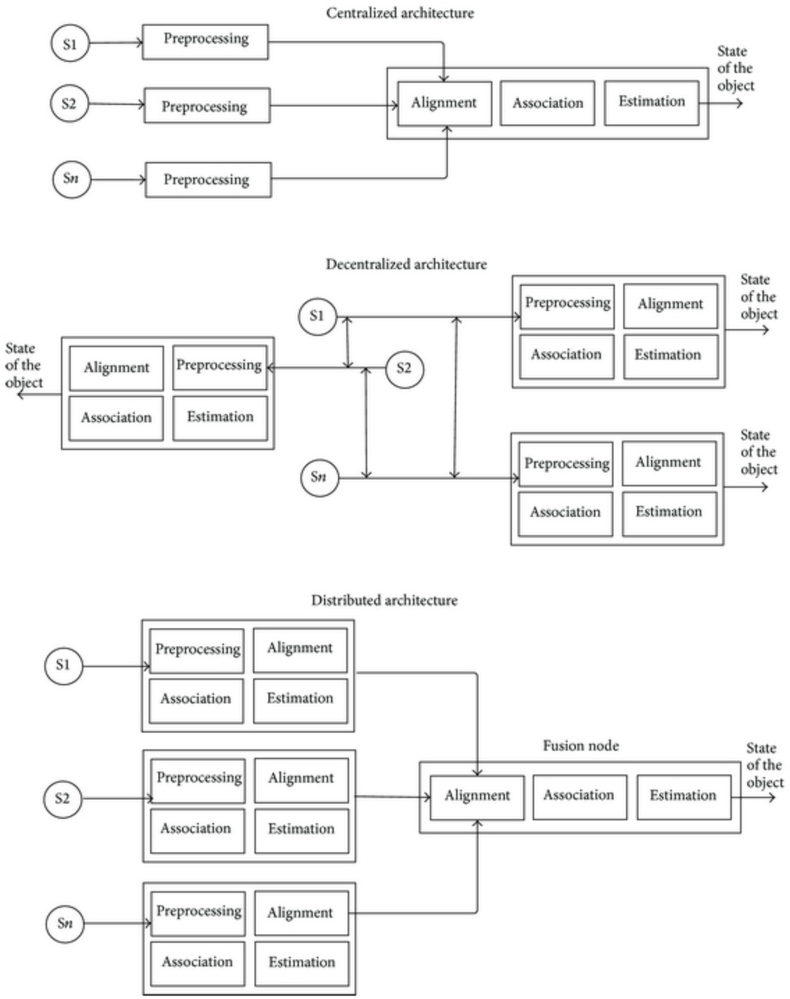


CLASSIFICATION BASED ON THE TYPE OF ARCHITECTURE

1. Centralized: the fusion node resides in the central processor that receives the information from all of the input sources. All the fusion processes are executed in a central processor that uses the provided raw measurements from the sources. The sources obtain only the observations measurements and transmit them to a central processor to perform data fusion.

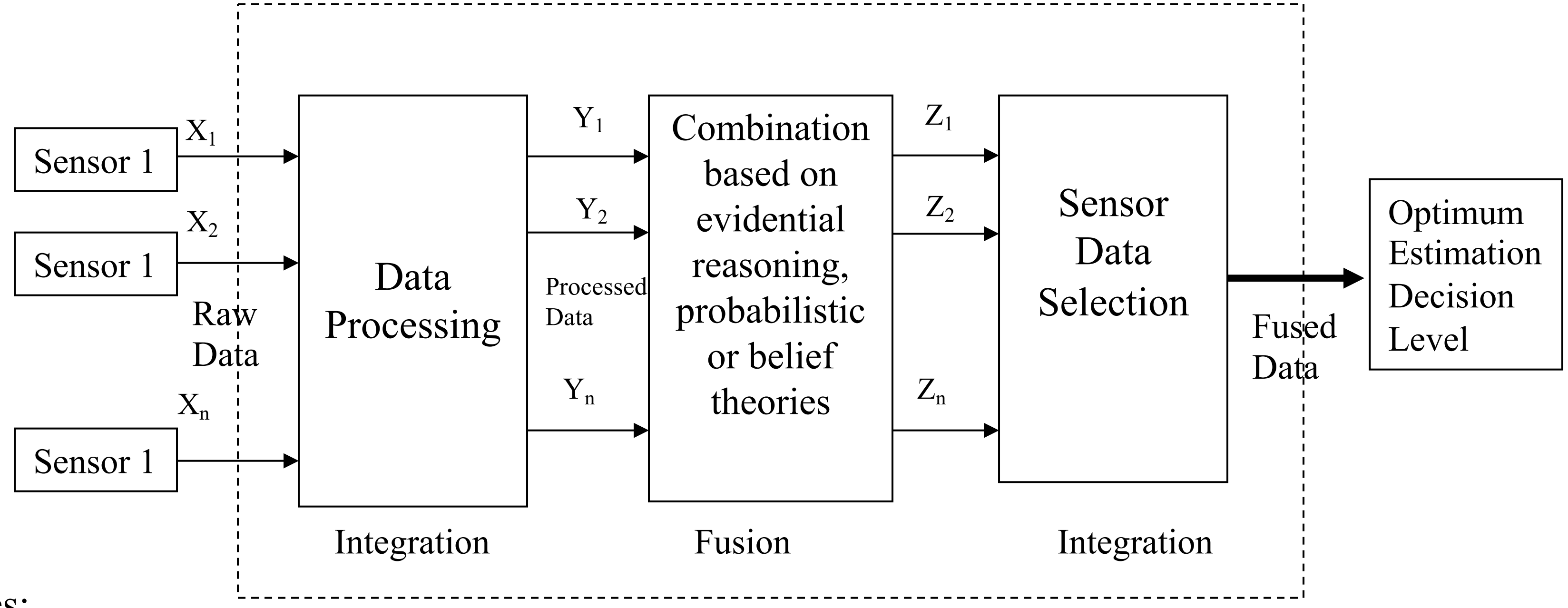
2. Decentralized: a network of nodes in which each node has its own processing capabilities and there is no single point of data fusion. Therefore, each node fuses its local information with the information that is received from its peers. Data fusion is performed autonomously, with each node accounting for its local information and the information received from its peers.

3. Distributed: measurements from each source node are processed independently before the information is sent to the fusion node (can be more than one).



DATA FUSION SOURCE SELECTION AND PROCESSES

- Data processing
- Data/information/decision combination
- Data selection



DF involves the study of several allied disciplines:

- (1) signal processing;
- (2) computational and numerical techniques and algorithms;
- (3) information theoretical, statistical, and probabilistic methods;
- (4) sensor modeling, sensor management, control, and optimization;
- (5) neural networks, approximate reasoning, fuzzy logic systems, and genetic algorithms;
- (6) system identification and state-parameter estimation (least square methods including Kalman filtering); and
- (7) Computational data base management. Several principles and techniques from these fields strengthen the analytical treatment and performance evaluation of DF fusion systems.

DESIGN ASPECTS

When building an MSDF system, the following aspects pertaining to an actual application are of great importance:

- Use of optimal techniques and numerically stable and reliable algorithms for estimation, prediction, and image processing;
- Choice of data fusion architectures such as sensor nodes and the decision-making unit's connectivity and data transmission aspects;
- Defining the accuracy that can be realistically achieved by the data fusion process or system and conditions under which data fusion provides improved performance; and
- Keeping track of the data collection environment in a database management system. The main point here is the goal to make synergistic utilization of the data from multiple sensors to extract the greatest amount of information possible about the sensed object, scene, or environment.
- Conversion of data to a representation that is conducive to fusion (from images, sounds, smell, shapes, textures,

etc.), conversion of data into contextually meaningful perceptions and features involving or leading to a large number of distinctly intelligent decision processes.