LOCALIZATION

DATA FUSION MODELS

MSDF is a system-theoretic process (a synergy of sensing, signal and data processing, estimation, control, and decision making) that is very involved, and hence an overall model that interconnects the various aspects and tasks of the DF activities is very much needed. This would also lend a systems approach to the DF process.

Joint Directors of Laboratories Model

- A popular model, originating from the US Joint Directors of Laboratories (JDL), Department of Defense, is the JDL fusion model (DoD, USA, 1985/1992). The JDL model has five levels of data processing and a database.

- These levels are interconnected by a common bus and need not be processed in a sequential order; nevertheless, they can be executed concurrently.
- There are three main levels—levels 1, 2, and 3, as shown in Figure 2.3. There are many sublevels and auxiliary levels for processing data, combining the available information, and evaluating the performance of the DF system. Several such aspects are briefly reviewed here.
- Although the terms used here have been borrowed from defense applications, similar terms are quite appropriate for other nondefense civilian DF applications.

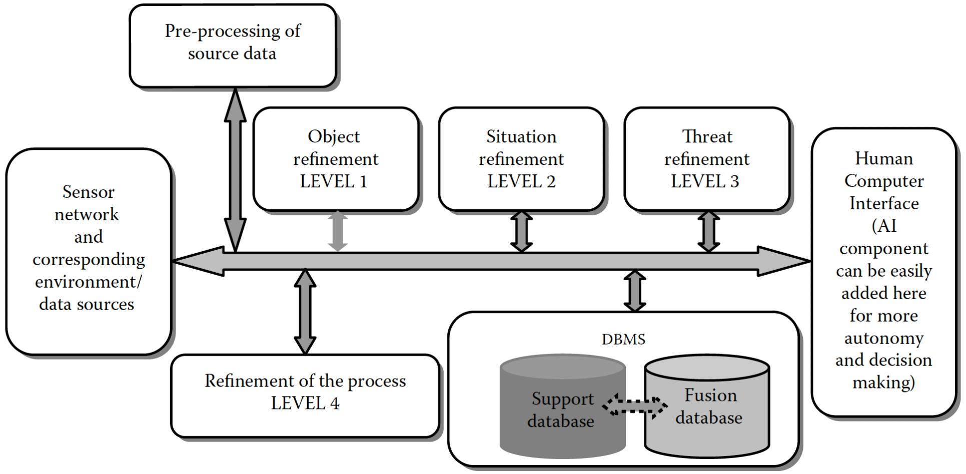


FIGURE 2.3
JDL data-fusion process models (USA): (a) top-level process model (adapted from Hall, D. L. 1992. Mathematical techniques in multi-sensor data fusion. Norwood, MA: Artech House. With permission);

JDL MODEL FOR CIVILIAN APPLICATIONS

For such civilian applications, some parts of the JDL model would be more appropriate, and interested users can determine the appropriate terms.

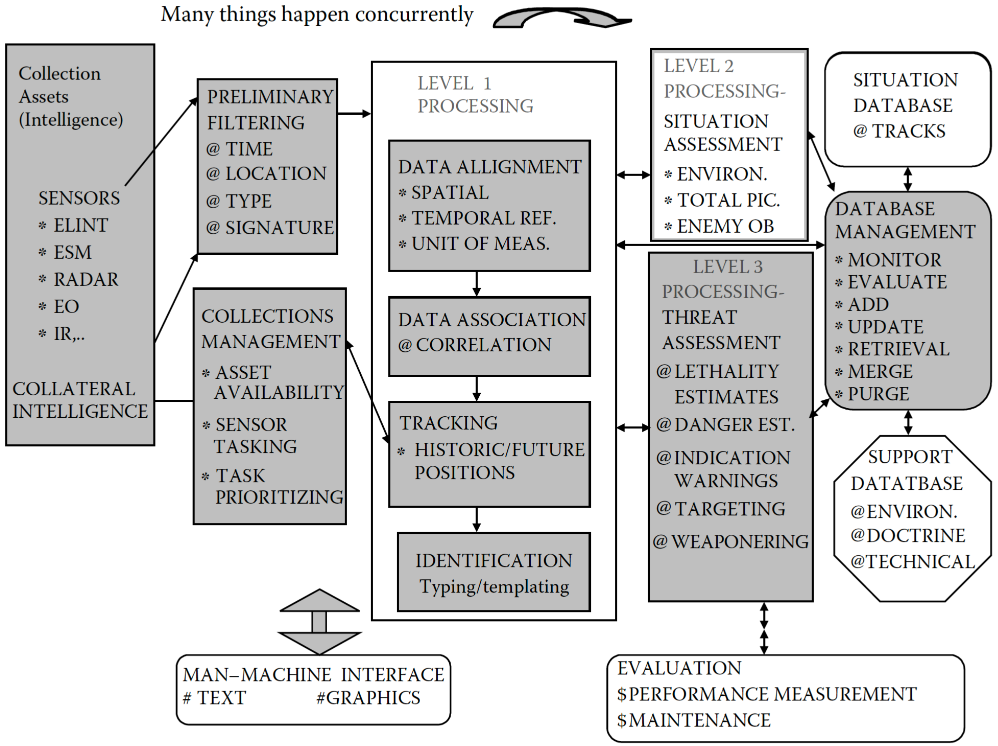
The JDL fusion–process model is a functionality–oriented DF model and is intended to be very general and useful across multiple application areas.

JDL model is expected to facilitate a higher–level interpretation of certain entities within the context of the intended application environment.

The JDL–data fusion process (DFP) model is a conceptual model that identifies the processes, functions, categories of techniques, and specific techniques applicable for DF.

DFP is defined and conceptualized by sources of information, human–computer interaction, preprocessing at the source, DF levels, and finally, the data management system, including performance evaluation.

The JDL model is an information–centered, abstract model, with specific characteristics.



(b)

FIGURE 2.3
JDL data-fusion process models (USA): (b) the detailed process model (adapted from Waltz, E. and J. L. Llinas. 1990. Multi-sensor data fusion. Boston: Artech House. With permission.)

LEVEL 1

Level 1 performs the following four functions:

- Transforms data into a consistent set of units and coordinates;
- Refines and extends to a future time the estimates of an object's position, kinematics, dynamics or attributes;
- Assigns data to the objects to allow the application of statistical estimation techniques; and
- Refines the estimation of an object's identity or classification.

Level-1 fusion can be categorically divided into two parts:

- kinematic fusion, which involves fusion of local information to determine the position, velocity, and acceleration of moving objects, such as missile, aircraft, ships, people, and ground vehicles; and
- Identity fusion, which involves fusion of parametric data to determine the identity of an observed object, e.g., deciding whether a moving object is a missile or an aircraft. Identity estimation can be augmented by rule-based expert systems, wherein various types of factual or procedural information can be exploited to aid the identity estimation.

LEVEL 2

Situation refinement: In this level, an attempt is made to find a contextual description of the relationship between the objects and observed events.

After processing the data at level 1, the situation is ascertained and further analysis is carried out to refi ne the situation, if needed.

The main goal is to obtain a total picture of the enemy's objective for purposes such as defense application.

This is a very complex process.

LEVEL 3

Threat refinement (level 3): On the basis of the a priori knowledge and predictions about the future situation, inferences about vulnerabilities and opportunities for operation are constructed. During threat assessment, several aspects are considered, such as

(1) estimation of danger,

(2) indication of warning, and

(3) targeting. The ultimate aim is to obtain a refined assessment of the threat (and its perception), on which important decisions and actions can be based.

LEVEL 4

Process refinement, is a metaprocess that monitors the system performance, e.g., real-time constraints, and reallocates sensors and sources to achieve particular goals or mission objectives.

At this level, we are not concerned with the data (processing). However, sensor management is an appropriate aspect to study and employ at this level for optimal use of sensor suites.

Some DF theorists and practitioners also include the cognitive-refinement level [4] as level 5, which is between level 3 and the HCI, thereby introducing the concept of AI at this stage in a limited manner.

MODIFIED WATERFALL FUSION MODEL

The waterfall fusion process (WFFP) model emphasizes the processing functions of the lower levels, as depicted in Figure 2.4

The processing stages of the waterfall model have some similarities with the JDL model. They are as follows:

(1) Sensing and signal processing relating to source preprocessing (level 0 of JDL model);

(2) feature extraction and pattern processing corresponding to object refinement (level 1 of JDL model);

(3) situation assessment (SA) relating to situation refinement (level 2 of JDL model); and

(4) decision making relating to threat refinement (level 3 of JDL model). The WFFP model is similar in some aspects to the JDL model; however, the WFFP model is simple to apply.

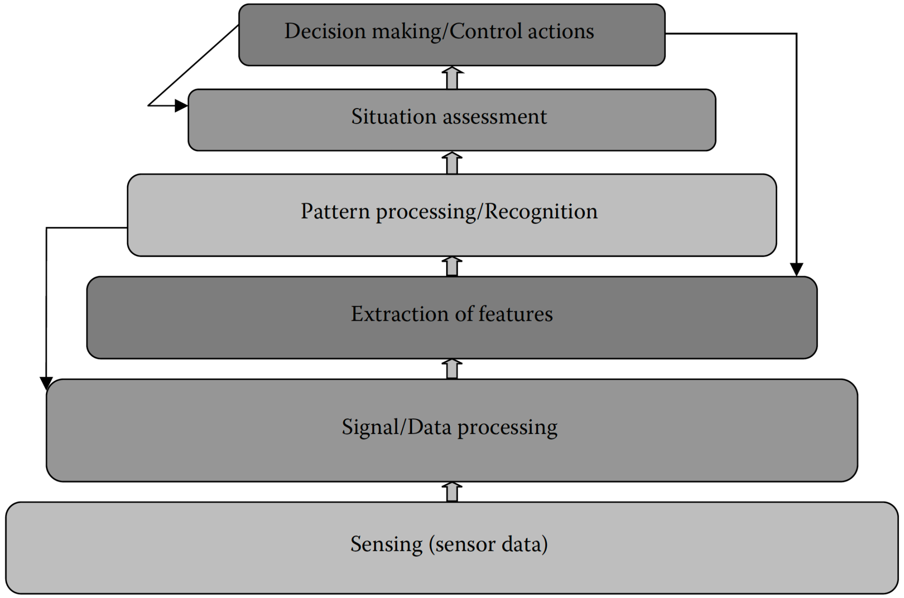


FIGURE 2.4
Modified waterfall fusion–process model: The shadings indicate the increasing task complexity in each three–stage processing; it includes at least one open–loop control action.

INTELLIGENCE CYCLE–BASED MODEL

Because the DF process has some inherent cyclic processing behavior that is not captured in the JDL model, the intelligence cycle–based (IC) model tries to capture these cyclic characteristics, comprised of the following five stages:

1. In the planning and direction stage, the intelligence requirements are determined.

2. In the collection stage, the appropriate information is gathered.

3. In the collation stage, the collected information is streamlined.

4. In the evaluation stage, the available information is used and the actual fusion is carried out.

5. In the dissemination stage, the fused intelligence and inferences are distributed.

This model is a macrolevel data-processing DF model and looks more like a top-level model than the WFFP model. The sublevel actions and processing tasks are not defined or indicated in the IC model, although these tasks can be implicitly presumed to be present. It would be appropriate to regard the IC model as a superset model, and it appears to be more abstract than the JDL and the modified WFFP models.

BOYD MODEL

The Boyd control cyclic (or observe, orient, decide, and act [OODA]) loop (BCL) model, shown in Figure 2.5, represents the classic decision support mechanism in military–information operations and has been widely used for sensor fusion; it has a feedback loop. It uses the OODA cycle, described below:

(1) the observation stage is mainly comparable to the source preprocessing step of the JDL model and as a part of the collection phase of the IC model;

(2) the orientation phase contains, perhaps implicitly, the functions of levels 1, 2, and 3 of the JDL model, whereas in the IC model, this stage corresponds to the structured elements of the collection and the collation phases;

(3) the decision stage compares with level 4 of the JDL model and the process refinement and dissemination phases of the IC model; and

(4) the action phase is a comparable to the dissemination phase in the IC model, and in the JDL model, there is no apparent closed loop.

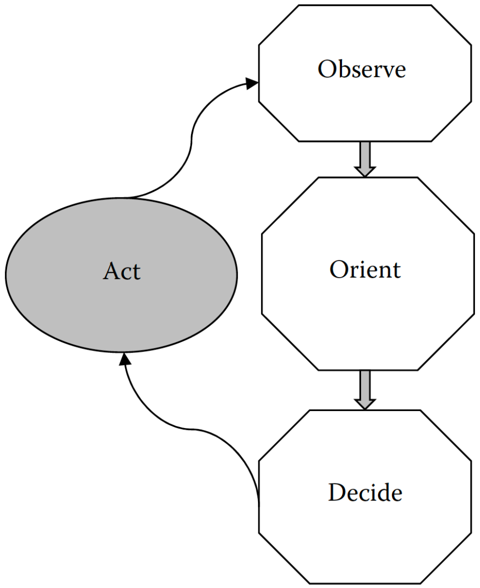


FIGURE 2.5
The Boyd observe, orient, decide, and act cyclic-loop model.

OMNIBUS MODEL

The OB model integrates most of the beneficial features of other approaches, as shown in Figure 2.6.
The OB model defines the order of the processes involved to make the cyclic nature more explicit and additionally, it uses a general terminology.
Its cyclic nature is comparable to the BCL model. It provides reasonably detailed processing levels compared to the BCL model. The various levels are as follows:

(1) The sensing and signal processing steps are conducted by the observation phase of the BCL model;

(2) the feature extraction and pattern processing comprise the orientation phase;

(3) the context processing and decision making are included in the decision phase; and

(4) The control and resource tasking are conducted by the action phase. The sensor DF is the route from the observation to the orientation phases. The path from orientation to decision is through soft-decision fusion. The route from decision to action is through hard-decision fusion, and from action back to observation involves the sensor- management process.

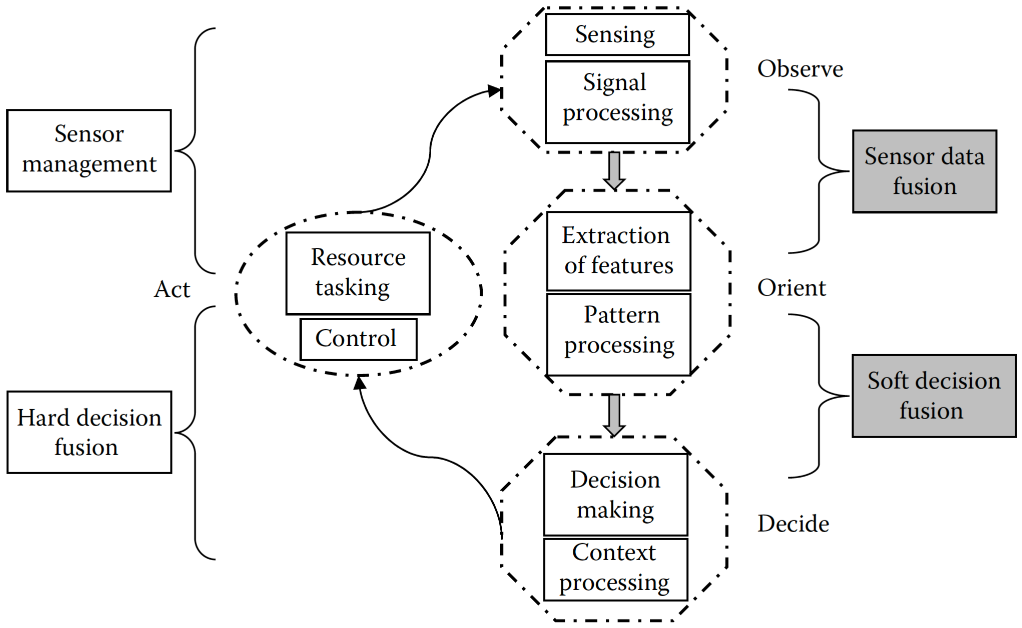


FIGURE 2.6
The omnibus cyclic data-fusion model: The rectangles define the omnibus model in more detail compared to the Boyd observe, orient, decide, and act model (BCL in dotted lines).

OMNIBUS MODEL

Some aspects of the WFFP model are also found in the OB model.

- The OB fusion–process model is more complete than the WFFP (and modified WFFP), IC, and BCL fusion models because it encompasses many important features and functional aspects of these models.

- The OB model is simple and easy to apply and follow for many non–defense DF applications.
- In addition, the OB model is more generalized than the previous three models and has a cyclic and closed–loop action element, making it more attractive than the JDL fusion model.
- Thus, the OB model can be regarded as the standard fusion–process model for nondefense DF processing and applications.