Community Status Report and Proposed Revisions to the JDL Data Fusion Model

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Outline

- **Community Status - The Sensor/Data Fusion Working Group**
  - Origins
  - Status & Problems
  - Community Ideas and Feedback
- **The JDL Data Fusion Model -**
  - Taxonomy
  - Functional Model
  - Proposed Revisions

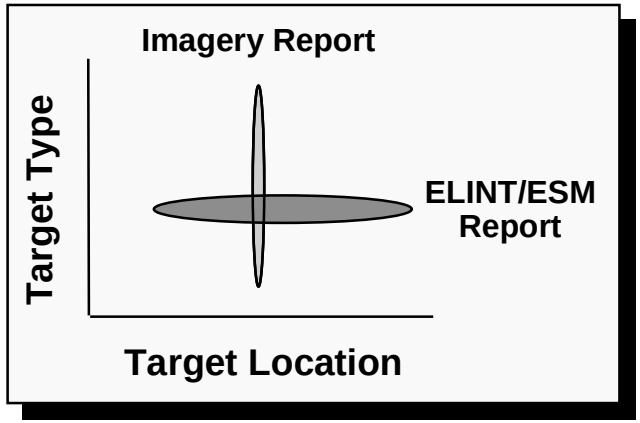
*Data Fusion is Essential to Interoperability and Information Utility**

- **Expect reduced expenditures for expensive sensor platforms:**
  - Reduced coverage
  - Fewer specialized missions
  - Less redundancy / Fewer alternatives
- **Therefore, increased emphasis will be placed on *processing,* to *do more with less***
- **Flow, access and use of information**
  - Communications bandwidth and connectivity
  - Data Correlation and Fusion
  - Collection Management & Battle Management

***** *Diane Roark, Senior Staff Member, House Permanent Select Committee on Intelligence; presented at SWC Combat Info/Intel Correlation Symp., Jan 96)*

Sensor Fusion Benefits

- **Combine Multi-Source/Multi-Discipline Information**
  - Target refinement: location/track, ID
  - Cross-domain imaging (e.g. E-O+SAR)
  - Force structure assessment
  - Own force vulnerability assessment
  - Supports Planning/Plan Execution/Re-planning
- **Maintain Track Continuity: Correlate Time-Separated Observations**
  - Intermittent sensor passes
  - Terrain masking and countermeasures
- **Cross-Sensor Cueing**
  - More efficient search
  - Enhanced detection
    (cued dwells; reduced threshold)
  - Reduced requirements on individual
    sensors (sensitivity, coverage, accuracy)
  - LO techniques (passive cueing of radar; bistatic sensing)



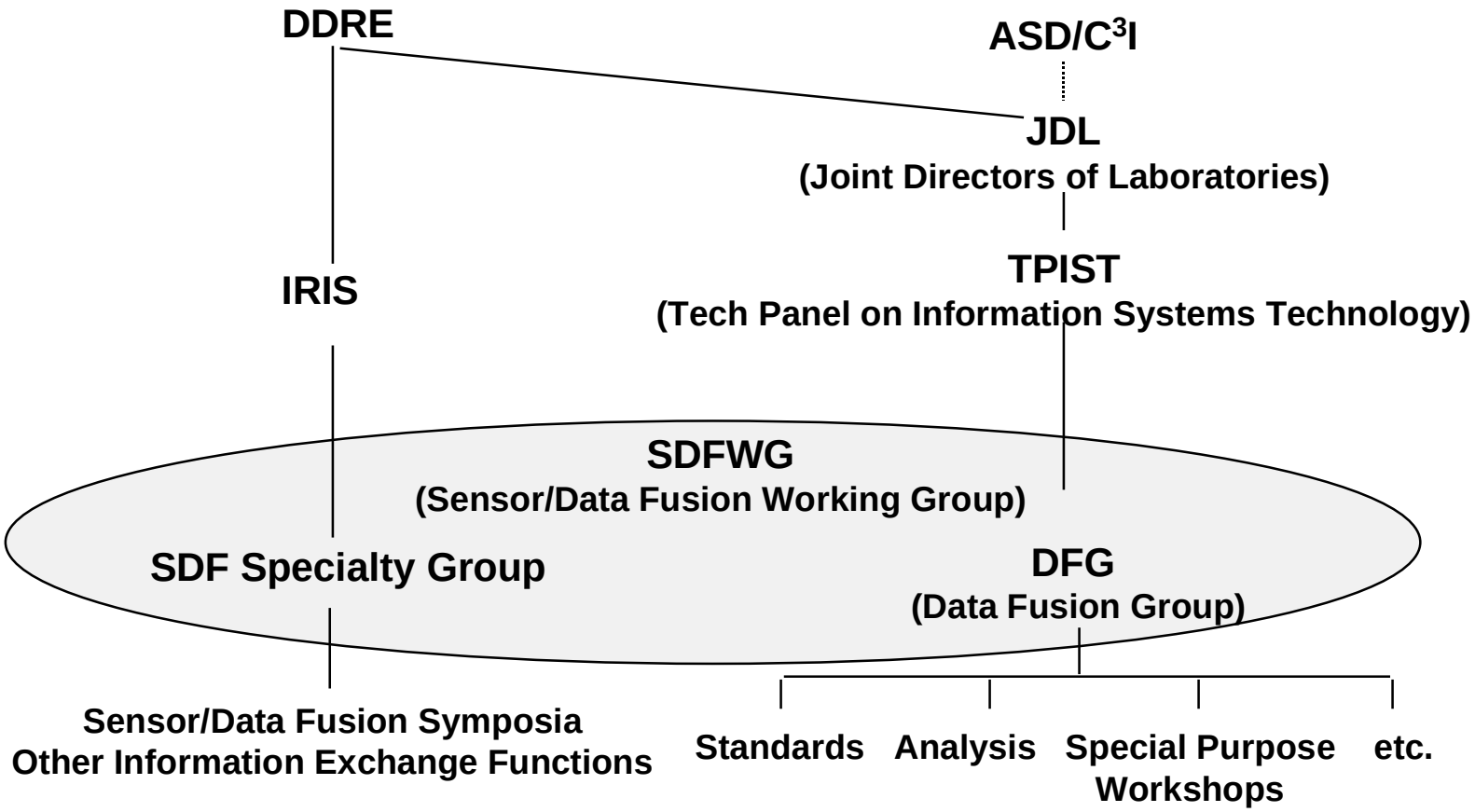
General Deficiencies in Data Fusion Systems

- **EFFECTIVENESS:**
  - **Performance:** *Lack of timely, accurate target & situation awareness*
  - **Focus:** *Information not tailored to decision-maker's needs*
  - **User Confidence:** *Can't assess information quality*
  - **Interoperability:** *Legacy systems can't talk to one another*
  - **Data Exploitation:** *Reported data doesn't include some types of useful data*
- **AFFORDABILITY:**
  - *Every new system is designed from scratch*

Problem Analysis

- **Failure to use available data and designs**
- **Lack of**
  - Standard methods for specifying data fusion problems
  - Objective performance metrics
  - Generally accepted comparative analyses of alternative techniques
  - Standard multi-spectral/multi-discipline target/collection models
- **Diverse data fusion systems can be represented under a common paradigm but it requires:**
  - Requirements & MOPs
  - Target/ Collection Models
  - Architectures & Functions
  - Data Sets
- **Use of such a paradigm would facilitate**
  - System Acquisition - Operation/ Interoperability
  - Adaptation/Re-use - Evaluation

Sensor/Data Fusion Working Group Family Tree



All-Pervasive Nature of Data Fusion Requires a Unified Organizational Approach

Sensor/Data Fusion Working Group

To develop a successful Fusion process (automated or manual) a good understanding of the following is required:

1. **Physics of the Sensor/Collector AND the Phenomena (NSSF)**
2. **Data Fusion Processes (DFG)**
3. **Warfare Mission Area**
4. **Customer/User**

- **In the current Era of C4ISR and emphasis and need for integration, it is past time that we, as a community, started working on these issues.**

Key Data Fusion Problems [18,20]

- **"Easy" Problems:** Solutions Known → *Coordination, Funding, Engineering*

– Stovepipes	C3 Architecture
– Interoperability & Data Latency	C3 Arch, Interfaces & Processing
– Spatio-Temporal Alignment	C3, Registration, Calibration
– Integration with Collection Management	C3 Arch, Process Control
– Confidence Normalization	Source Modeling, Reporting
– High Density, Dynamic Environments	Hyp Generation, Hyp Selection

- **Difficult Problems:** Fundamental Research Needed → *Science*

– Predictable Performance	Modeling & Simulation
– Highly Ambiguous, Noise-Like Indicators	Context Sensitive HG, HITL
– "Subtly-Related" Indicators	Adaptive Fusion Trees, HITL
– Low Confidence Models	Hyp Generation, Hyp Selection, Dynamic Databases, HITL

HITL = Human-in-the-Loop

Current and Potential Future Activities

CURRENT	FUTURE
• **Community Information Exchange -** Government/Industry/Academia	
– National Symposium (with IRIS) – Workshops	– International Symposium – Professional Journal – Education Programs
• **Standards -** Acquisition, Test and Evaluation	
– Functional Model and Taxonomy – Engineering Guidelines	– Algorithm/Software Library – Test Sets – Interfaces – Performance Metrics

Evolve toward an Information Analysis Center (IAC)

Develop Strategy to Coordinate Roles and Responsibilities

- **Define Functional Needs**
  - **Standards for Acquisition, System Engineering, T&E**
    - Data exchange and commonality
  - **Technology Development**
  - **Information Exchange**
    - Symposia, Workshops, Education, Publication
  - **Data Bases and Models**
    - Algorithms, Multi-Source Test Sets and Models
- **Coordinate with**
  - **DUSD A&T**
  - **ASD/C^3I**
  - **DDR&E**
  - **CMS**
  - **Joint Staff (JCS)**
  - **DISA (DII/COE)**
  - **DARPA**
  - **Labs**
  - **Intel Agencies**
  - **Services**
- **Work Toward a Prototype IAC**

Burgeoning Symposia - Need Coordination?

- **IEEE - Fusion 98 (International - Open)**
- **National Correlation Working Group (NCWG)**
- **ISCAS - Special Session**
- **Exploitation Technology Symposium (ETS)**
- **SPIE - Fusion Sessions**
- **Others?**

Outline

- **The Sensor/Data Fusion Working Group - FE White**
  - Origins
  - Status & Problems
  - Community Ideas and Feedback
- **The JDL Data Fusion Model - AN Steinberg**
  - Functional Model
  - Taxonomies
  - Proposed Revisions
  - Example Applications
  - Summary Assessment and Key Problems

Definitions[19]

A process dealing with the association, correlation, and combination of data and information from single and multiple sources to achieve refined position and identity estimates, and complete and timely assessments of situation and threats, and their significance.

The process is characterized by continuous refinements of its estimates and assessments, and by evaluation of of the process itself, to achieve improved results.

Sensor Fusion = Data Fusion from Multiple Sensors (same or different sensor types)

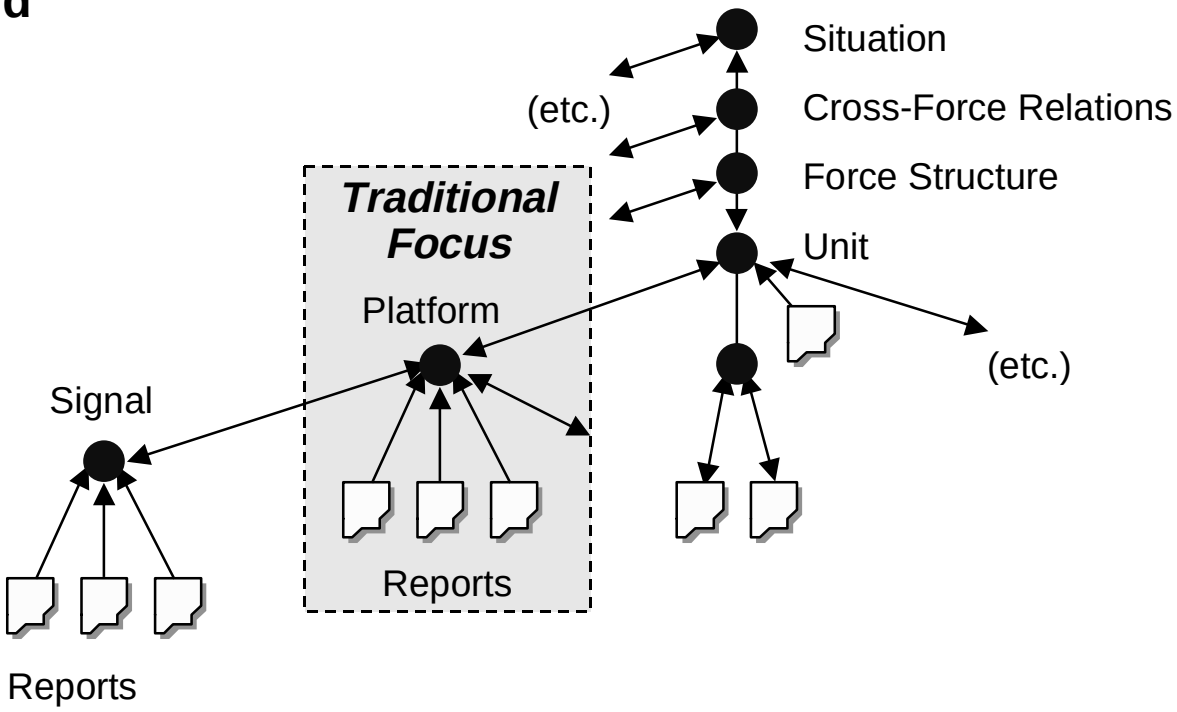
- **Data Fusion = Combining information to estimate or predict the state of some aspect of the world**
- **Data Fusion Functions:**
  - **Data Alignment**

    (spatio-temporal,

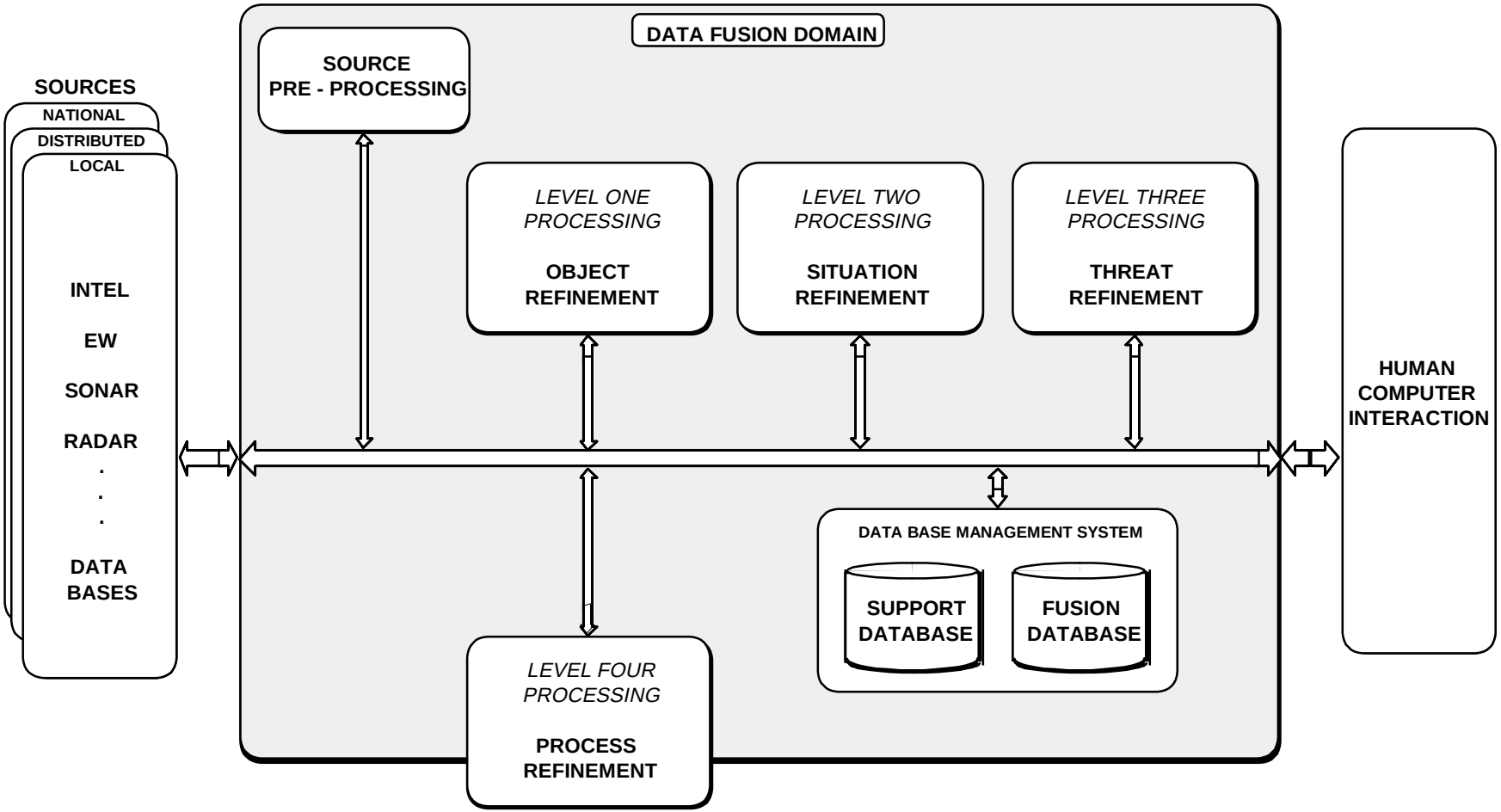
    data normalization,

    evidence conditioning)
  - **Data Association**

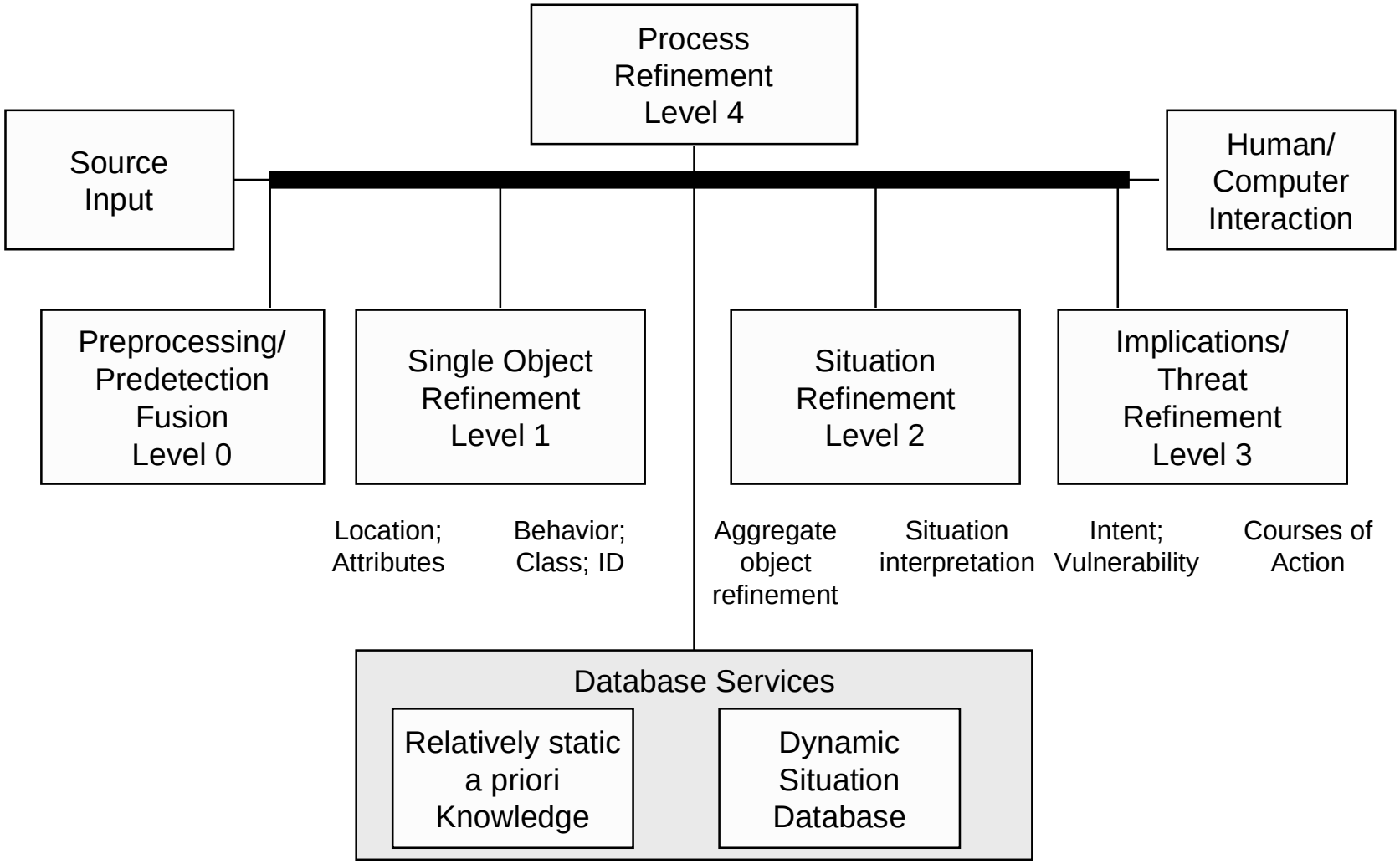
    (hypothesize entities)
  - **State Estimation & Prediction**



Data Fusion Model
(Revised 1992)



JDL Data Fusion Functional Model
(Revised 1997)



Definition of Component Functions

ALIGNMENT:	Transforming data to common formats and frames of reference (spatio-temporal, measurement and attributive) and confidence.
CORRELATION:	Computing the “similarity” in data
ASSOCIATION:	Determining likelihood that data could have been caused by the same entity
TRACKING:	Creating and updating entity state estimates by associating sensor measurements over time using a predictive model of entity dynamics
CLASSIFICATION	Determining that a perceived entity is of a generic or specific type
IDENTIFICATION	Recognizing a perceived entity as particular individual
SITUATION ASSESSMENT	Inferring relations among entities , to include force structure and cross force relations, communications, physical context, etc.
IMPACT ASSESSMENT:	Estimating the significance (i.e cost/benefit) of perceived or predicted situations and impact on planned actions
THREAT ASSESSMENT:	Significance assessment regarding detected or predicted hostile situations, to include force susceptibilities and vulnerabilities to enemy postures, intentions and courses of action

Data Fusion Functional Model *[17,19]*

The JDL model (1987-91) and the draft revised model (1998)

- **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 — Impact Assessment ~~Threat Refinement: intent estimation, event prediction~~, consequence prediction, susceptibility and vulnerability assessment**
- **Level 4: Process Refinement: adaptive data acquisition and processing (an element of Resource Management)**

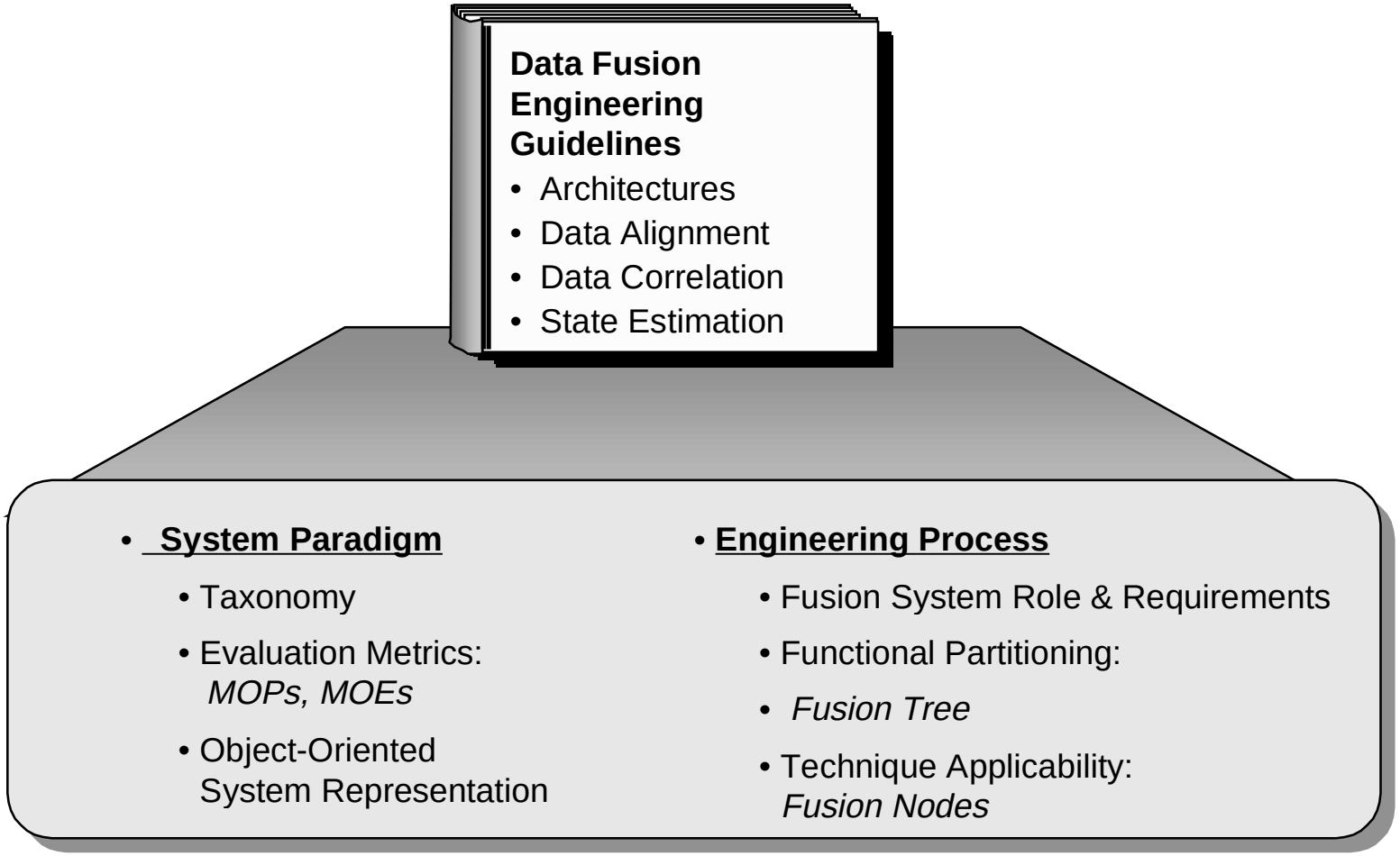
Additional and Revised Taxonomies

- **Physical Object**
  - Object, Entity, Target
- **System Representation of Physical Object**
  - Track, Perceived Entity, (Target) Hypothesis
- **Object State Dimensionality**
  - Attributive/Kinematic, Discrete/Continuous
- **Concrete Physical Object**
  - Object, Target, Platform
- **Aggregations**
  - Clusters, Aggregate Objects, Ensembles
- **Data Alignment**
  - Common Referencing, Data Pre-Processing

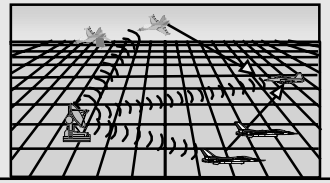
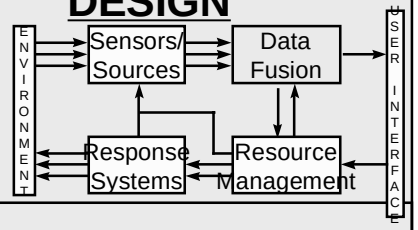
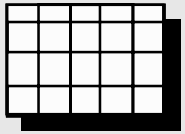
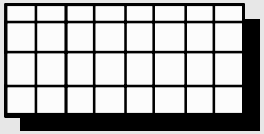
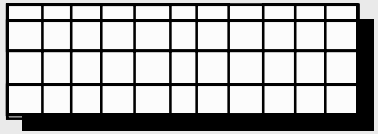
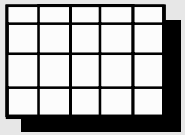
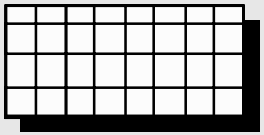
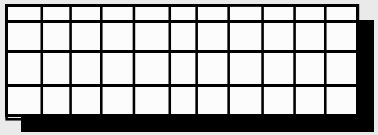
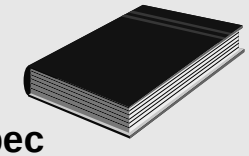
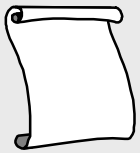
Data Fusion Levels: Alternative Schemes

Data Fusion "Level"	Type of Data Exploited	Type of Process		Type of Entity Characterized
		Association	Estimation	
0	Measurements • Pixels • Predetected Signals	• Detection • Segmentation • Feature Extraction • Sorting	• Feature State Est. • Signal State Est. • State Prediction	• Region • Feature • (Detected) Signal
1	• Regions/ Features • Signals • Tracks	• Report/Track • Track/Track	• Object State Est. • Object State Prediction	• Physical Object (Platform, Target, Equipment)
2	Relationships • Subordination • Coordination • Conflict	Relational • Bayesian Nets • Clustering • Templating	• Aggregate State Est. • State Prediction	• Aggregation (Unit, Force Structure, Comm Net, etc.) • Situation
3	• Track State/Prediction • Relationship to Own Assets • Cost Model	• Filtering • Relational Analysis	• State Prediction • Cost/ Significance Est.	• Threat State (Event, Time, Relationship) • Event Prediction • Significance
4	• Object/Situation State • Event Prediction/ Significance • Response Plan Uncertainty State	• Operations Research • Optimal Control	Planning & Control • Of Fusion Process • Of Information Acquisition Process	Plan & Controls • Data Fusion • Collection Mgmt • Part of Resource Mgmt

SWC Project Correlation Engineering Guidelines

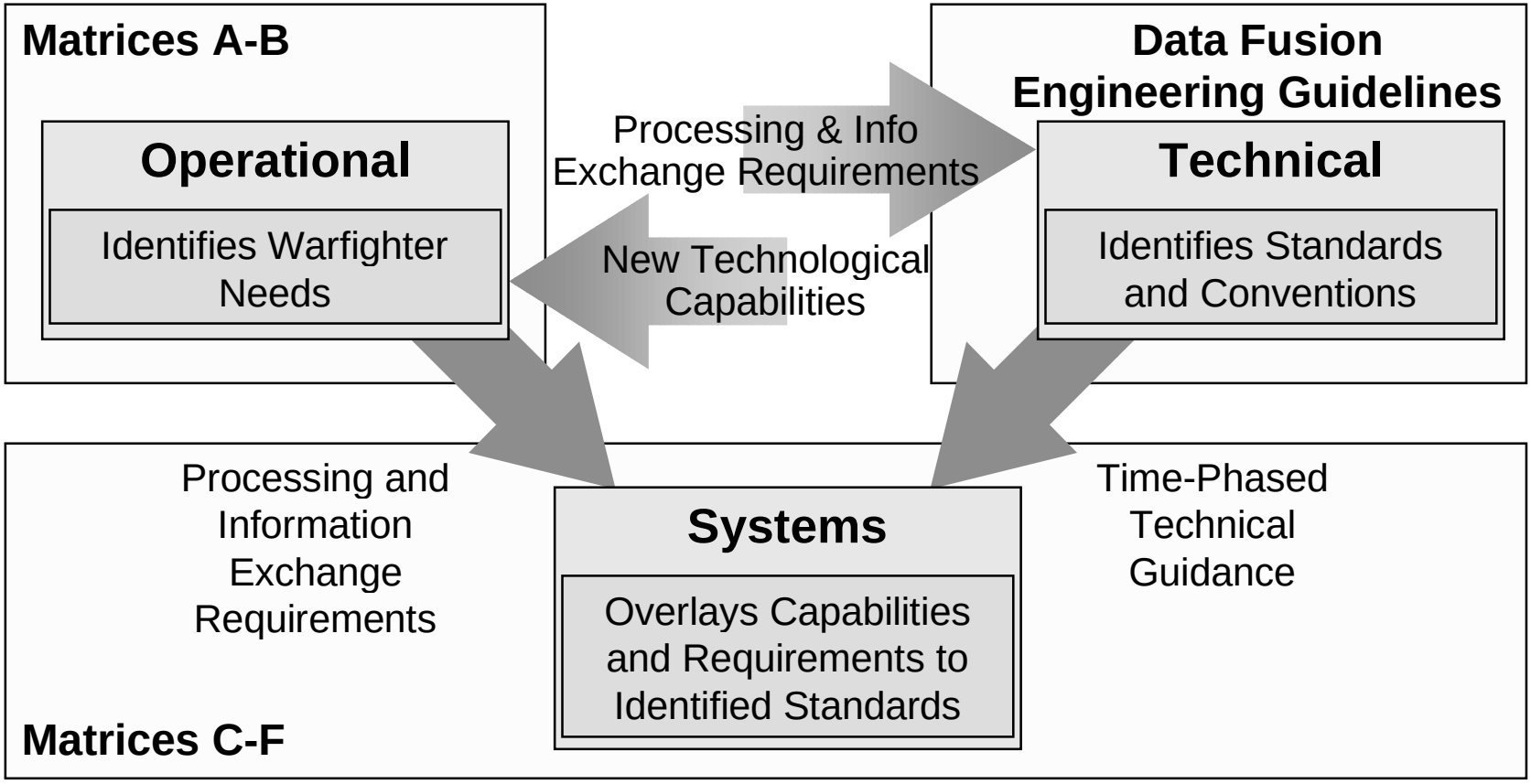


Data Fusion System Engineering Phases & Products *[17,18,19]*

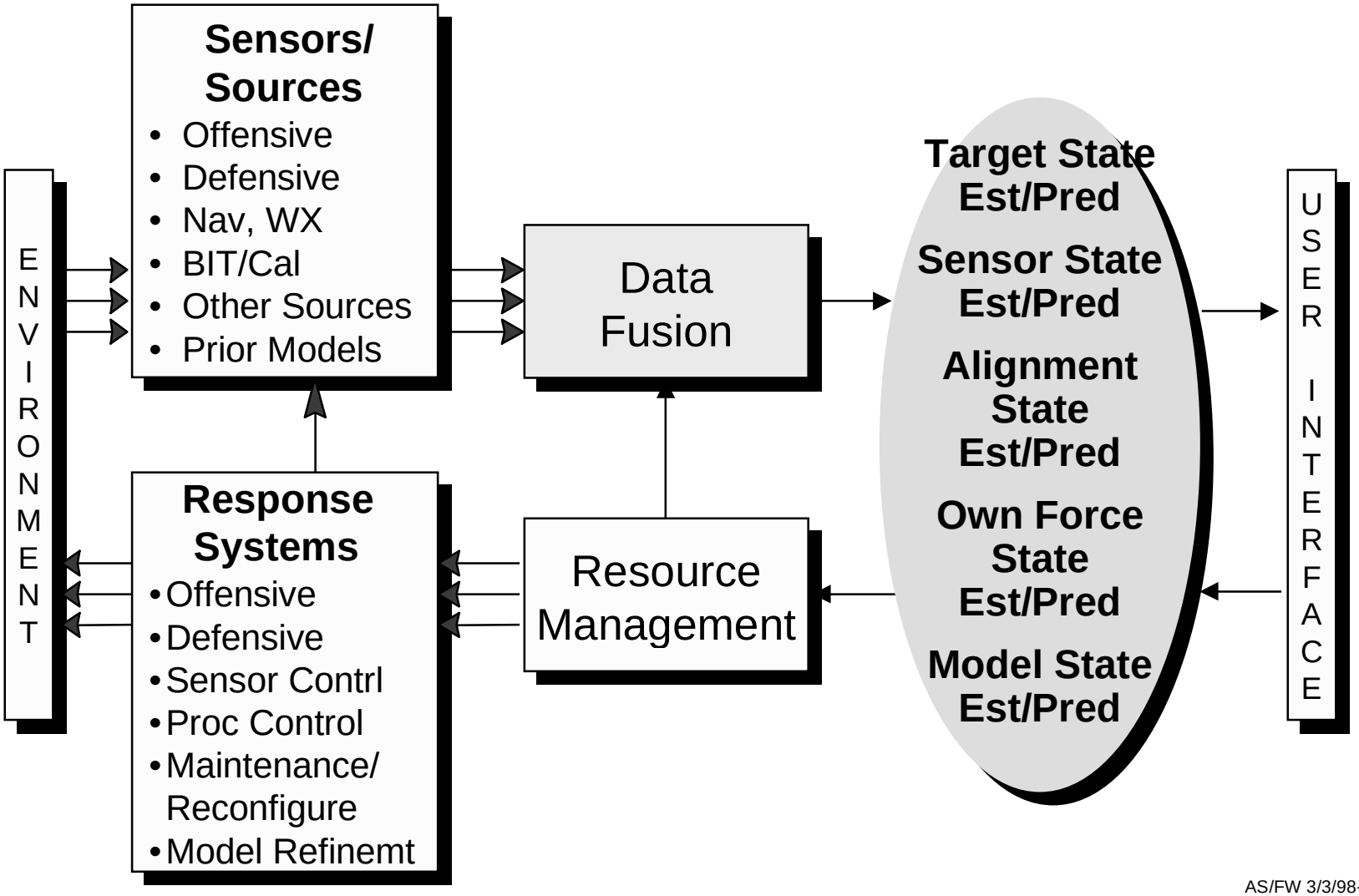
DESIGN PHASE	**REQUIREMENTS REFINEMENT**	**DESIGN**
1. Operational Architecture Design: *Fusion Role*	**CONOPS** 	**Black Box Spec** 
2. System Architecture Design: *Fusion Tree*	**MATRIX A SYSTEM INPUTS** Q A T; Source 1 2 3  **MATRIX B SYSTEM OUTPUTS/RQMTS** Q A T Implement; User 4 5 6 	**MATRIX C FUSION TREE CHARACTERIZATION** Tree Specs Node Specs; Level 0 1 2 
3. Component Function Design: *Fusion Node Processing*	**MATRIX D NODE INPUTS** Q A T; Source a b c  **MATRIX E NODE OUTPUTS/RQMTS** Q A T Implement; Source d e g 	**MATRIX F FUSION NODE CHARACTERIZATION** Data Align Assoc State Est.; Node a b c 
4. Detailed Design/ Development: *Pattern Application*	**Module Spec** 	**Code** 

Note: Q A T = Data Quality, Availability, Timeliness

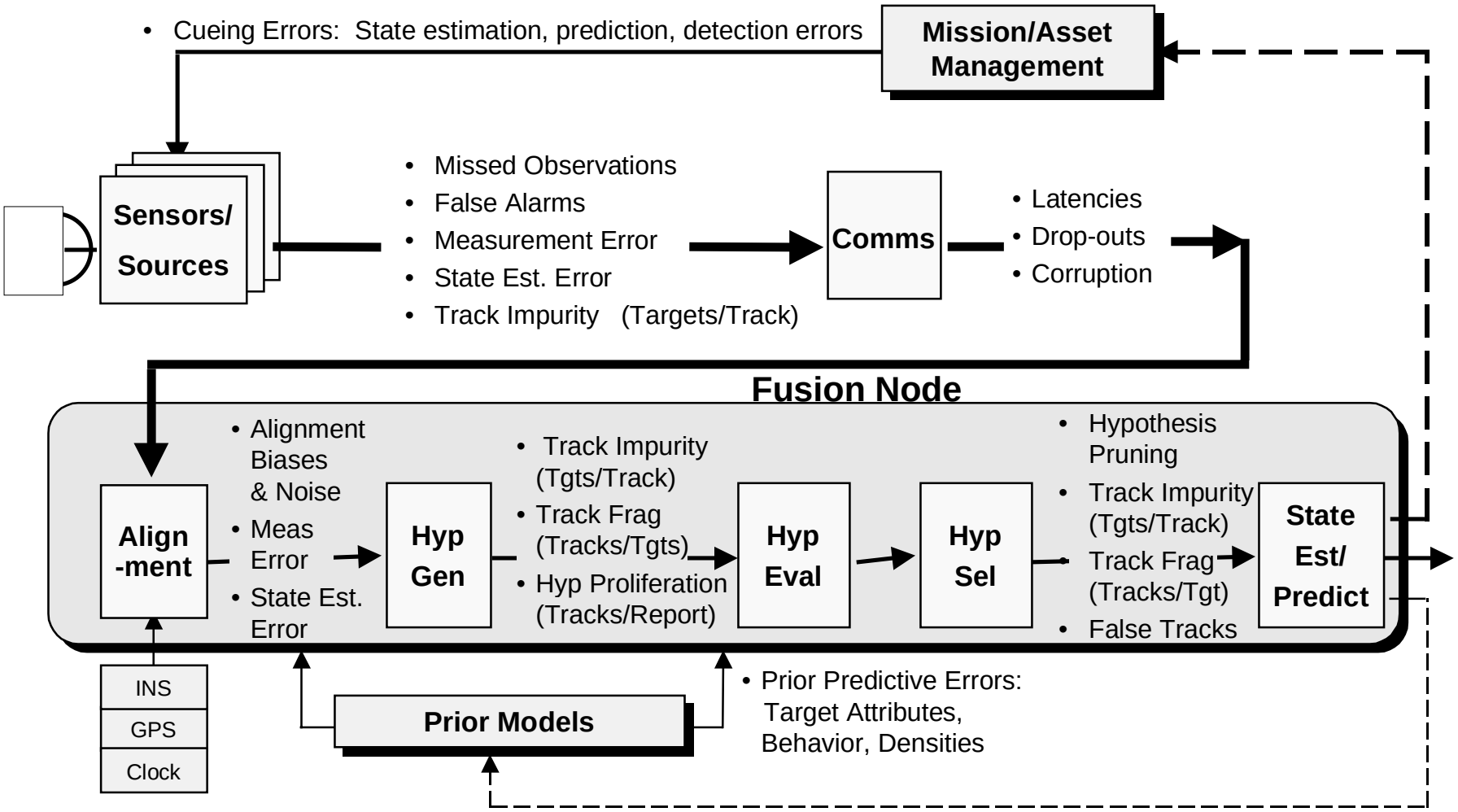
Data Fusion Design in C4ISR Architecture Frameworks



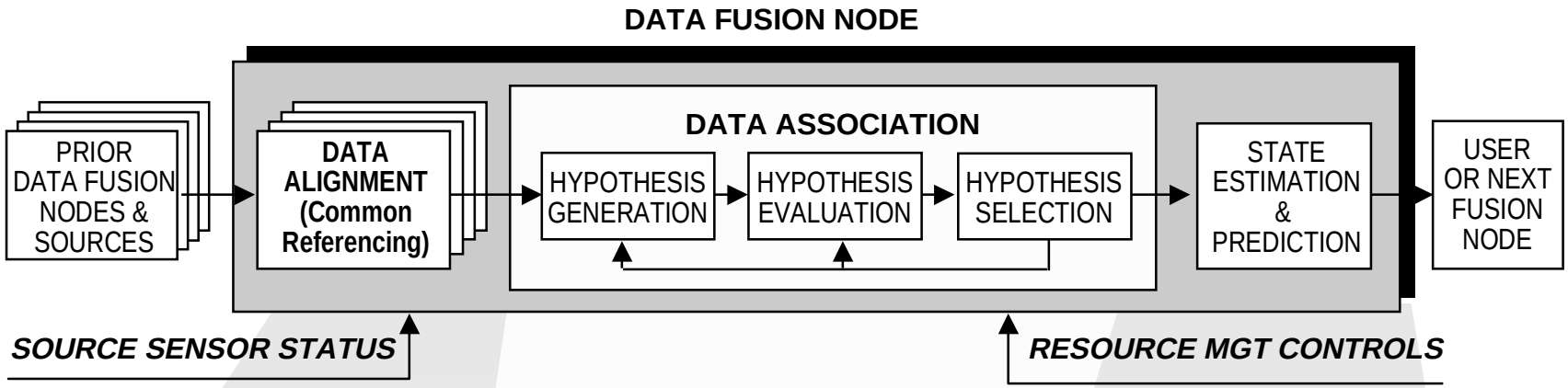
Role of Data Fusion in an Integrated Information Processing System



Sensor Fusion Performance is Affected by System Context



Fusion Node Paradigm

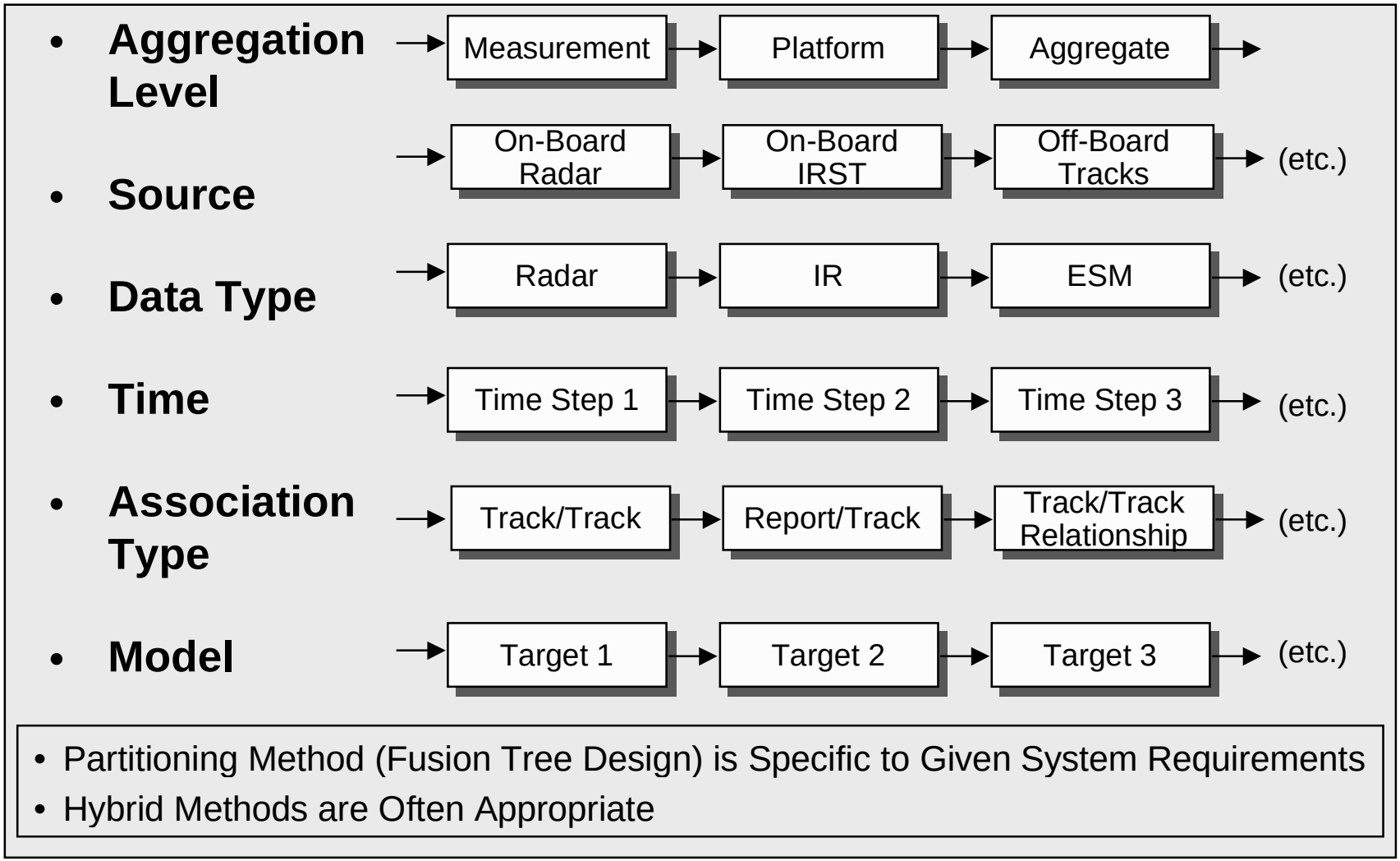


- **DETECT AND RESOLVE DATA CONFLICTS**
- **CONVERT DATA TO COMMON TIME AND COORDINATE FRAME**
- **COMPENSATE FOR SOURCE MISALIGNMENT**

- **GENERATE FEASIBLE & CONFIRMED ASSOCIATION HYPOTHESES**
- **SCORE HYPOTHESIZED DATA ASSOCIATIONS**
- **SELECT, DELETE, OR FEEDBACK DATA ASSOCIATIONS**

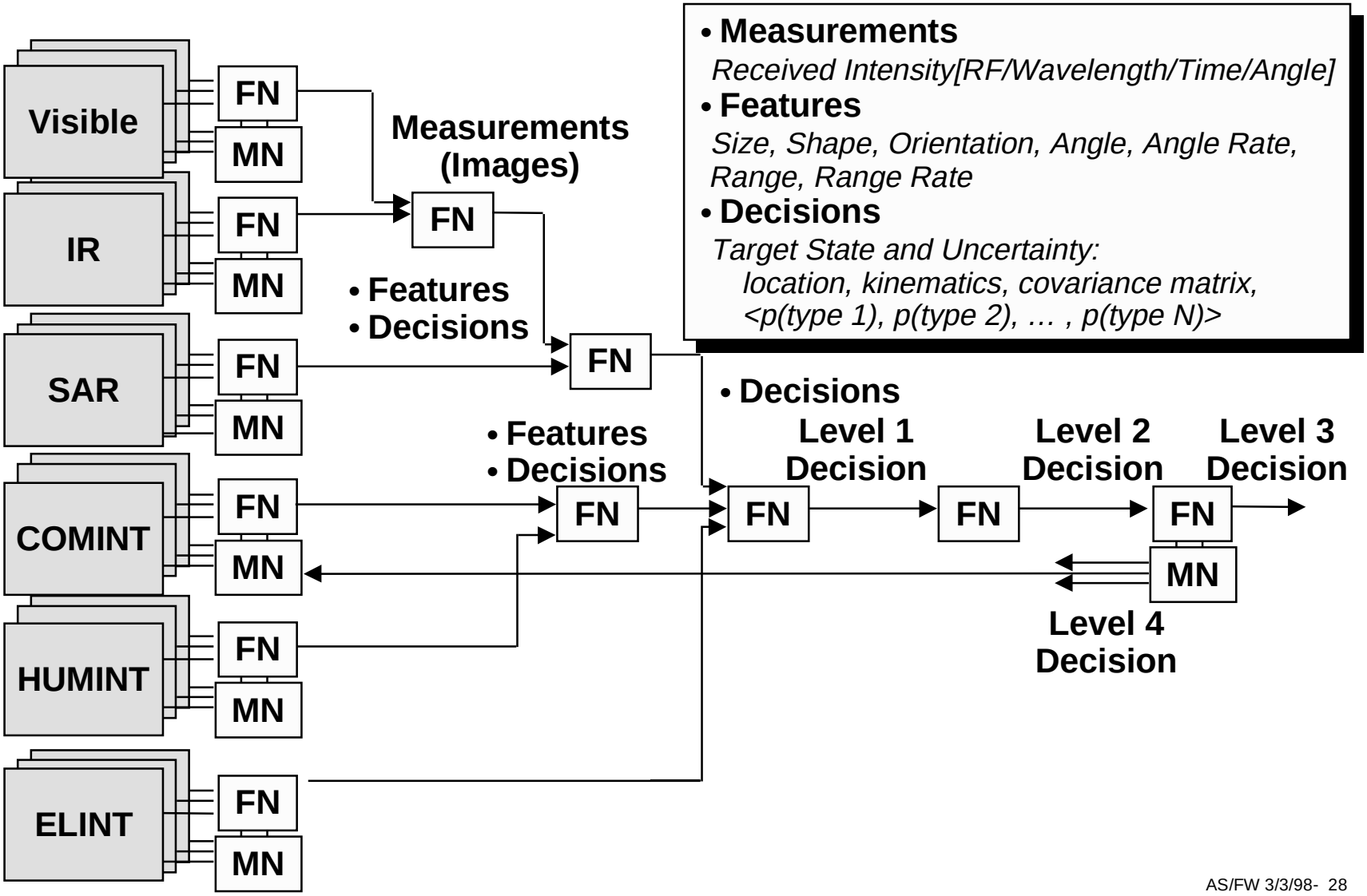
- **ESTIMATE/PREDICT ENTITY STATES**
  - KINEMATICS, ATTRIBUTES, ID, RELATIONAL STATES
- **ESTIMATE SENSOR/SOURCE MISALIGNMENTS**
- **FEED FORWARD SOURCE/ SENSOR STATUS**

Alternative Fusion Tree Partitioning Schemes[17,18,19]

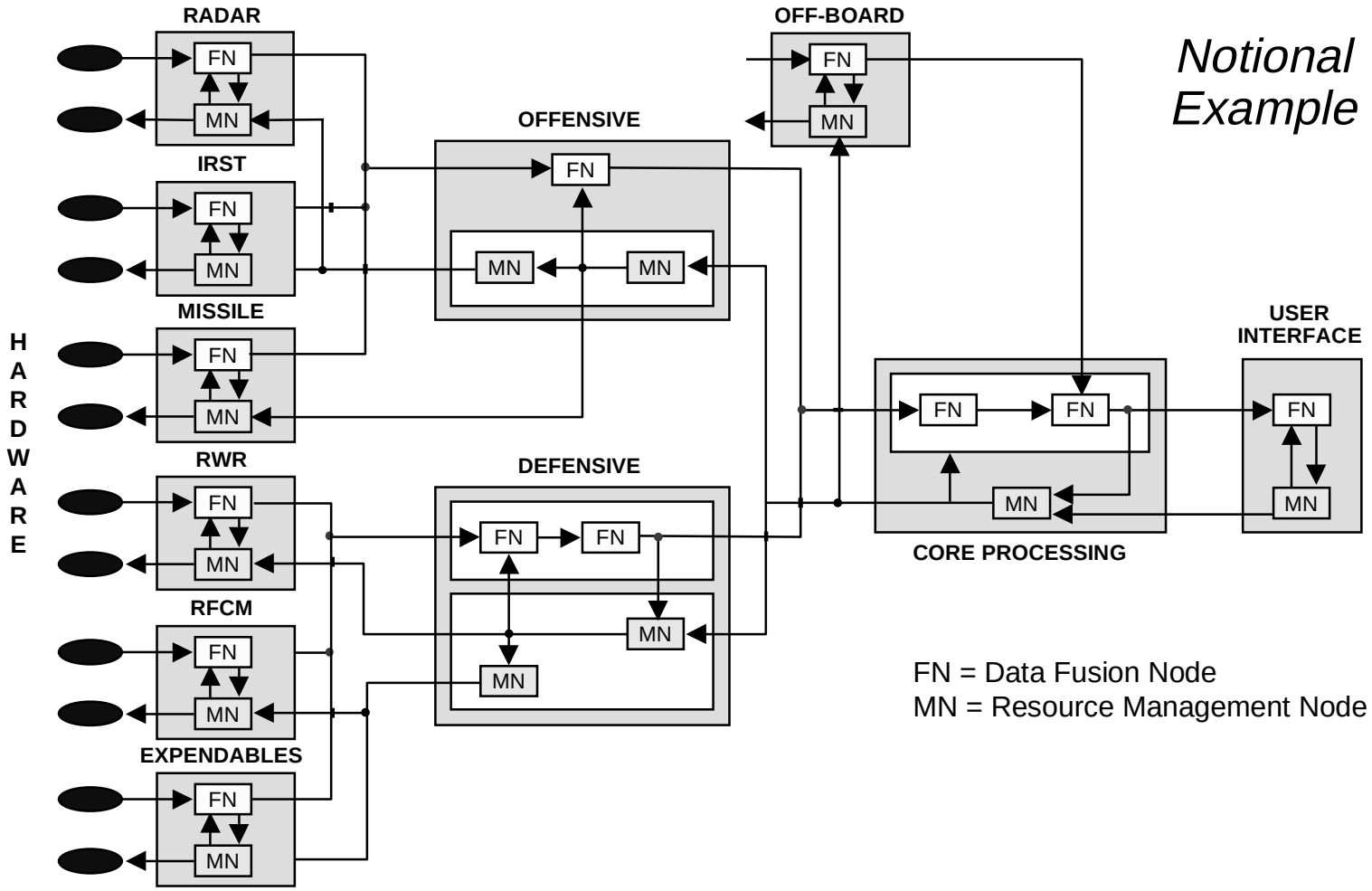


- Partitioning Method (Fusion Tree Design) is Specific to Given System Requirements
- Hybrid Methods are Often Appropriate

Battlefield Situation Awareness Example



Hybrid Architecture Example:
Data Fusion and Resource Management Trees[4]



Summary Data Fusion Technology Assessment (1 of 2)[4]

DATA FUSION LEVEL	SUMMARY OF THE STATE OF THE ART	CURRENT LIMITATIONS	DESIRED NEAR TERM CAPABILITIES
Level 1: Positional, Kinematic, Attribute Estimation	• Relatively mature - numerous techniques for tracking - current research in MHT, JPDA trackers • Object I/D fusion dominated by feature & decision methods - current R&D in ANS and syntactic methods	• Difficulty tracking targets in dense target environment, low SNR, maneuvering targets • Selection of attributes for classification • Selection/use of multiple techniques in concert	• Off-the-shelf software package for robust estimation • Multi-technique approach for object I/D • Methodology & guidelines for algorithm selection • Standard test beds, data sets
Levels 2 and 3: Situation and Significance	• Relatively immature - heuristic techniques include templating, expert systems - numerous experimental prototypes	• Doctrinal Basis not well-defined • Limited understanding of decision makers needs • Evolving threat environment • Limited cognitive models	• Robust techniques to solve subset of situation/threat refinement • Basis for cognitive models
Level 4: Process Refinement	• Mixed maturity - well founded technology for single sensor - immature for multi-sensors - MOPs defined - prototype expert systems	• MOE not well-defined • Disconnect between mission management and fusion management • Hybrid architectures challenging	• MOE/MOP Consensus • Metrics baseline • Generic architecture and techniques for multi-sensor control

Summary Data Fusion Technology Assessment (2 of 2)[4]

DATA FUSION FUNCTIONAL AREA	SUMMARY OF THE STATE OF THE ART	CURRENT LIMITATIONS	DESIRED NEAR TERM CAPABILITIES
Human-Computer interface (HCI)	• Numerous tools for rapid prototyping • Current research in display design, crew position layout, workload aspects • Ergonomic *vice* cognitive focus	• Limited HCI research specific to data fusion • Limited cognitive models for focus of attention, stress management, alternative decision styles	• Integrated exploitation of advanced technology (e.g., HDTV, virtual reality, multi-media) • Intelligent Groupware • Multi-person HCI
Data Base Management	• Numerous commercial tools (relational models) • Fourth-generation query languages • Trend toward object-oriented DBMS	• Simultaneous optimization of storage and retrieval • Distributed concurrency • Multi-level security	• Natural language interfaces • S/W based solution to multi-level security • COTS DBMS to handle diverse data (image, text, data, KBS)
Development Environment	• Robust development standards and procedures for conventional systems • Widespread development of application specific prototypes • Single *vs.* multi-sensor models	• Lack of Standard MOPs and test sets • Disjoint test beds and simulation tools • Limited tools/MOE for Level 2,3 fusion	• Robust test-bed for Test and Evaluation • Metrics for MOP/MOE • Fusion Software Library and Clearinghouse • Data Fusion System Engineering methodology

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Community Update - Summary

- **Pervasiveness of Data Fusion Is a Double-edged Sword:**
  - Belongs to Everybody but Nobody
- **Infrastructure is Needed to Reduce Acquisition, Development and Operational Costs**
  - Architecture Standards
  - Coordination
    - DOD, Other Government, Industry, Academia, Internationa
- **Community Needs Activism**
  - Next Generation of Leaders