Results from Levels 2/3 Fusion Implementations: Issues, Challenges, Retrospectives and Perspectives for the Future – An Annotated View

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Abstract - This paper serves both as introduction to and motivation for the panel, and as a position paper to highlight retrospectives and perspectives on issues and challenges of Levels 2/3 fusion implementations by presenting an independent annotated point of view.

1 Introduction
This invited panel discussion was organized by the author, supported by John Salerno, in order to provide both a historical perspective of the evolution of the state-of-the-art (SOA) in higher-level “Levels 2/3” information fusion implementations by looking back over the past ten or more years, and based upon the lessons learned, to forecast where focus should be placed to further enhance and advance the SOA.

In order to promote exchange of ideas and to illuminate the historical, current and futuristic issues associated with Levels 2/3 implementations, leading experts were invited to present their respective views on various facets of this complex problem.

The panelists are, in alphabetical order:
- Dr. Joachim Biermann, FGAN-IKIE, Wachtberg, Germany,
- Dr. Eloi Bosse, RDDC, Val-Belair, Quebec, Canada,
- Dr. Subrata Das, Charles River Analytics, Cambridge, MA, USA,
- Dr. Paul Gonsalves, Charles River Analytics, Cambridge, MA, USA,
- Dr. Ivan Kadar, Interlink Systems Sciences, Lake Success, NY, USA,
- Dr. Dale Lambert, DSTO, Edinburgh, South Australia,
- Dr. Bradley Rhodes, BAE Systems, Burlington, MA, USA,
- Dr. Enrique Ruspini, SRI, Menlo Park, CA, USA, and
- Dr. John Salerno, AFRL, Rome Research Site, Rome, NY, USA.

It will be interesting to review the results of the panel and assess the degree of consensus vs. disagreement. A summary paper, capturing the essence of the panel discussion, is planned with contributions by all participants.

2 Modeling and Representation
Even though the Joint Director of Laboratories (JDL) definitions of the fusion levels were established in 1987, published 1991[1] and revised in 1999 [2], the meaning, effects, control and optimization of interactions among the fusion levels have not as yet been fully explored and understood [3], please refer to Figure 1 below (modified from [2]) and discussion in Section 3.

Levels 2/3 fusion, referred to as situation/threat assessment “SA/TA” or situation refinement/TA, depicted in Figure 1, has had several definitions over the years. Starting from the Revised JDL Fusion Model [2], SA is defined as “estimation and prediction of relations among entities, to include force structure and cross force relations, communications and perceptual influences, physical context, etc.”

DSTO [4] defined SA as “an iterative process of fusing the spatial and temporal relationships between entities to group them together and form an abstracted interpretation of the patterns in the order of battle data”. Issues with the above definitions, and some subsequent models based on these definitions are [3]: (1) not domain independent, (2) do not incorporate human thought processes, human perceptual reasoning and essence of response time, (3) imply use of limited a-priori information, and (4) only imply potential for new knowledge capture.

That is, one needs the ability to control Levels 1-4 [2, 5] processes for knowledge capture in SA, and used in TA. In addition, SA/TA is to establish relationships (not necessarily hierarchical) and associations among entities, it should anticipate with a-priori knowledge in order to rapidly assess, interpret and predict what these relationships might be; it should plan/pre-plan, predict, anticipate again with updated knowledge, adaptively learn, and control the fusion processes for optimum knowledge capture and decision making. These features are similar to the characteristics of human perceptual reasoning. Therefore, it is conjectured that the “optimum” SA/TA system should emulate human thinking as much as possible, e.g., the perceptual reasoning machine paradigm framework [5]. These constructs have been previously presented by the author [5, 6] and reiterated herein for their relevance. Related knowledge representation and reasoning (KRR) implementation methods and issues are discussed in Section 3.
Furthermore, the fusion model itself is undergoing a revision to incorporate a “user-level”, and to partition the Level 4 “feedback” into separate components [7].

Other related issues yet to be addressed, for example at the “user-level” are the human machine interface, the interactions among multiple communities of users, and interfaces to the information fusion system.

3 Interactions of Levels 2/3 with other fusion levels

It is implied from the foregoing and depicted in Figure 1, that fusion levels are loosely coupled because each level has different non-commensurate objective function to optimize.

Issues: Level 1 processing has effects on Levels 2/3 and vice-versa [2, 3]:

Level 1 processes under RM control may optimize kinematic and ID states of entities, but do not necessarily optimize performance at Levels 2 and 3. Thus individual “Level” or joint optimization is needed at each iteration step.

Level 2 performs "situation (refinement) assessment" (SA), by estimation and prediction of relations among entities, with objectives to include force structure and cross force relations, communications and perceptual relations, physical context etc., as noted before.

Level 3 performs "threat (refinement) assessment" (TA), by estimation and prediction of effects on situations of planned or estimated/predicted actions by the participants with objectives to include interactions between action plans of multiple players (e.g. assessing susceptibilities and vulnerabilities to estimated/predicted threat actions given one’s own planned actions).

Issues: Level 2 fuses the spatial and temporal relationships between entities to group them together and form an abstracted interpretation of the patterns in the order of battle data; Level 3 fuses the combined activity and capability of enemy forces to infer their intentions and assess the threat that they pose, with interrelated but not necessarily commensurate objectives.

Therefore, it would appear that in order to achieve “optimal results at all levels”, each component needs to locally optimize its own actions while interacting with each other under global resource management (RM) control. However, in most fusion systems input to RM is derived from Levels 2 and/or 3 and the RM objective function is strictly based on maximizing Level 1 objectives as discussed above. Furthermore, the input at each fusion level changes as RM objective function is optimized. Therefore, it is possible that the local utility functions at Levels 2 and 3 are no longer optimal, and in general, may conflict with Level 1 objectives.

These observations usher in a host of issues relating to selection of commensurate objective functions as we seek to optimize the performance at each level while satisfying the global composite objective (utility function) of RM with respect to mission goals, subject to decision making under uncertainty [3] or alternatively jointly optimize Levels 1-3. Some of these issues, and associated challenges, were discussed in detail by the author at FUSION-06 [3] and listed in summary form below:

- Most research in this area has focused on sensor and platform management at Level 1 to optimize kinematic and ID objective functions based on commensurate utility and/or information measures.
- Many RM systems operate in open loop (e.g., cross cueing sensors at Level 1) to improve kinematic and ID MOMs. The resultant interaction with Levels 2 and 3 do not necessarily yield improved measures-of-moments (MOMs) at those levels.
- There has been minimal research directly managing Levels 2 and 3, and selecting SA and TA specific objective-functions.
• Possible approaches could be based upon fuzzy-sets based models, mapping fuzzy outcomes to probabilities to compute commensurate entropy-based objective functions providing common framework for-interactions-among-levels.
  
  Issues include model representation fidelity and mapping accuracy. In addition, more research is needed in the area of joint optimization with low computational complexity, and on how to formulate joint-objective-functions.
  
  Potential solutions include game theoretic approaches with multiple players with or without knowing individual players’ objective functions. Research in these areas needs to be extended to incorporate response time dependence.

• A related general issue with optimizing at each level separately is the possibility of conflicting objectives and not achieving a global optimum with respect to fusion system mission objectives.

4 Evolving tools for Levels 2/3

Early approaches to higher-level fusion evolved from mainstream use of early expert system tools (e.g., Knowledge Engineering Environment, “KEE”, Automatic Reasoning Tool, “ART”) built in ZETA-LISP, both rule-based providing forward and backwards chaining, while ART provided hypotheses generation capability and prediction), other tools were based on: strings oriented symbolic (objects-oriented) language (SNOBOL-4) for pattern matching, common-LISP, logic (PROLOG), logical templates, procedural-LISP-based, such as Procedural Reasoning System “PRS”, case-based languages, blackboard (BB) representations, associative memory, schema-based languages and neural networks (NN) for knowledge elicitation/acquisition, with the basic methodologies remaining a part of current approaches.

Current, and potential future trends, are primarily based on agent-based models of interactions, including BBs, NN behavioral learning systems for knowledge acquisition, ontology representations (extending schemas), probability (Bayes-nets and Dempster-Shafer calculi) and possibility (fuzzy-sets)-based methods, graph theory oriented relational representations, game theoretic methods of optimization, some coupled with influence diagram formulations [8], but not excluding rule-based expert system tools, such as CLIPS built using C and JAVA [9], with the above representing a non-exhaustive representative list. The author is not aware of any comprehensive studies to compare the efficacy of the “historical main stream” and “current-main stream” trends.

In addition, related methods of knowledge elicitation/acquisition, representation and reasoning (KRR) have not appeared to have made significant strides over the past few years in spite of several conferences devoted to KRR [10], illustrating the difficulty associated with this topical area. The following list highlights potential KRR issues and challenges [5, 6]:

• Adequacy of KRR (logic, semantics, ontology, probabilistic, fuzzy sets, neural networks, associative memory, blackboard, simulations, rules, computation) how to quantify and measure?

• Expressiveness of models vs. tractability of inference
  - Measures of richness of model vs. knowledge that inference is decidable and will produce and answer efficiently

• Managing Complexity
  - Limits about tractability - how to bound the problem with incomplete knowledge

• Data Information
  - How to manage heterogeneous and uncertain Knowledge Sources, and detect duplicate or incomplete concepts

• Presentation of knowledge to different users/experts with different levels of expertise

5 Conclusions

The purpose of this paper was to serve both as introduction to and motivation for the panel, and as a position paper to highlight retrospectives and perspectives on issues and challenges of Levels 2/3 fusion implementations by presenting an independent point of view. There are many other possible additional implementation issues and challenges remain, for example, in: model refinement, computational and processing methods, optimization, automation and decision making, human-machine interface and integration, distributed systems, knowledge elicitation and representation, and potentially many more issues and challenges that hopefully will be either addressed by the panel, or addressed as part of future research in this area.

References