Tradeoffs in the Design of Higher-Level Fusion Systems

Dr. Dale A. Lambert
DSTO Fusion for Situation Awareness Initiative
Command Control Communications and Intelligence Division
Edinburgh South Australia 5111.
dale.lambert@dsto.defence.gov.au

Abstract – When designing a higher-level fusion system the designer must choose between options, and in doing so confronts a number of tradeoffs. This paper outlines some of those options and the tradeoffs that those options involve.

Keywords: higher-level fusion, situation awareness, object assessment, situation assessment, impact assessment, data fusion.

1 Introduction
While there are various definitions of data fusion, the author prefers “... the process of utilising one or more data sources over time to assemble a representation of aspects of interest in an environment” ([1]). A fusion system is a capability assembled to perform data fusion, while a higher-level fusion system is a fusion system that can assess relationships between objects and/or assesses the consequences of those relationships. When designing a fusion system to satisfy a particular fusion task, the designer must make choices, many of which involve tradeoffs. This paper explores the various tradeoffs that confront designers of higher-level fusion systems.

2 The Automation Tradeoff
Higher-level fusion systems typically involve a mix of activities performed by both people and machines. This engenders the automation tradeoff, which considers whether certain activities should be performed by people alone, by machines alone, or through some combination of people and machines. Endsley and Kabar ([2]) highlight this tradeoff by identifying 10 levels of automation ranging from Manual Control (human performs human generated and selected actions) through to Full Automation (machine performs machine selected actions generated by machine without human intervention). There are well understood contexts in which people will reliably make perception, comprehension and projection errors ([3]) and there are well understood contexts in which machines struggle to produce correct timely solutions ([4], [5]). The challenge is to draw on the complementary capabilities of people and machines to provide effective solutions efficiently where possible.

3 The Integration Tradeoff
Fusion systems involving more than one component require a means of integrating the disparate components. This raises machine-machine integration (MMI) issues, human-human integration (HHI) issues and human-machine integration (HMI) issues in general. For each of these, design decisions are required concerning both communication and command and control (C²) policy. These decisions are further refined by fusion problems generally and aspects of the particular fusion problem under consideration.

3.1 Communication
Communication concerns what is to be communicated, who it is to be communicated between, when it is to be communicated, how it is to be communicated, and why it is to be communicated. For MMI this involves tradeoffs concerning communication protocols (e.g. {RS232, WiFi}, {HTTP, SMTP, FTP}), communication topology (e.g. {star, bus, tree}), communication roles (e.g. {client-server, peer-to-peer}, {one-to-many, many-to-many}), communication bandwidth, et cetera. For HHI it raises tradeoffs concerning the form of communication (e.g. speech, text, image, gesture) and the content of communication (speaker’s intent, theories of meaning, indeterminacy of translation thesis). For HMI there are tradeoffs regarding interaction modalities (e.g. {keyboard, mouse, speech, hand gesture}, {projectors, speakers, computer screen} and interaction modes (e.g. desktop, windows, virtual advisers).

3.2 C² Policy
Communication policy is required in addition to communication capability to provide governance for determining who can communicate with whom. This warrants a choice of governance protocol (e.g. CNP, ECNP, PAP ([6])) for machine-machine networks that support less restrictive MMI. HHI tends to be determined by command and control constructs that trade off ideals like authority, competency and responsibility ([6]).
4 The Fusion Model Tradeoff

4.1 General Fusion Model

A general higher-level fusion system requires the application of a fusion model to the human, machine, MMI, HMI and HHI aspects to conceptualize a solution for a specific fusion problem. A number of fusion models have been developed (e.g. [8], [9], [10]), with variants of the JDL model ([9]) being the most prominent. Among JDL models, the revised JDL model ([9]), the Blasch and Plano model ([11]) and the deconstructed JDL model ([1]) represent a sequence of JDL models with a decreasing emphasis on machine fusion and an increasing emphasis on the role of the human in fusion systems. For general higher-level fusion systems, the author favours the deconstructed variant of the JDL model ([1]) comprising: stored representations of objects (level 1); stored representations of relations between objects (level 2); and stored representations of effects of relations between objects (level 3).

4.2 Machine-Based Fusion Model

The deconstructed JDL model deliberately parameterizes the JDL model so that the three identified levels can be applied to machines, people and integrations involving the two. The tradeoff with the deconstructed JDL model is a diluted model for machine-based model fusion. In response the author has recommended a supplementary machine-based STDF fusion model ([12]) which is more detailed than the JDL model while seeking to highlight a unified approach across levels 1, 2 and 3.

5 The Situation Awareness Tradeoff

In [1] the author observes that the application of the deconstructed JDL model to people results in situation awareness as defined by Endsley ([13]). Situation awareness is the product of human-based fusion. The situation awareness tradeoffs for a specific fusion problem include the perception, comprehension and projection requirements for both individuals and collectives within the fusion system. The generic human limitations noted in section 2 apply, but the approach taken for a specific fusion problem will also vary with the individual differences of the personnel concerned, such as skill sets and culture. Human dialog provides the basis for the problem specific HHI transfer of situation awareness. It employs various visual, audio and haptic modalities together with problem specific language, percepts and concepts.

6 The Fusion C² Policy Tradeoff

There are a variety of C² tradeoffs to consider in a higher-level fusion system. Spatially distributed systems offer greater robustness against localized failure, but usually at a greater communication and product distribution cost. Systems that trade unity of command for decentralised intent offer greater robustness against impaired or misguided will, but require agreement mechanisms to secure unity and can suffer from increased...
communication costs and degraded awareness. Systems with mixed initiative strategies between people and machines allow both people and machines to inject intent into the system, but doing so without people wanting to turn off the machine is a subtle exercise. In [14] and [15] the author promotes a ubiquitous command and control (UC²) framework in which people and machines are considered uniformly as agents that can contract capability from one another in a laissez-faire, distributed and decentralised manner. [16] illustrates its application as a fusion C² strategy. Any desirable C² policy can be understood as a UC² system with additional constraints imposed.

7 The Representation Tradeoff

An important aspect of higher-level fusion systems is the ability for the machine to represent aspects of interest in the problem environment. This introduces tradeoffs relating to expressivity and the extent to which the machine understands the meaning of its representations through embedded formal logics ([17]). Both issues have associated tradeoffs with computational efficiency and computational effectiveness.

8 The Information Processing Tradeoff

The manner in which machines process information also introduces tradeoffs. The choice of models about the environment always involves tradeoffs through the assumptions made about those models, whether they be statistical models in lower-level fusion or symbolic theories with uncertainty in higher-level fusion. The probability p(X) of event X is always really p(X|C) relative to some assumed context C. Tradeoffs also arise between analytic and heuristic solutions ([18]), particularly when closed form analytic solutions are not possible, analytic solutions are not computationally efficient, or an analytic approach is unintelligible to an end user.

9 The Machine Integration Tradeoff

The manner in which machines integrate fusion specific information with people and other machines is fairly well developed for lower-level machine based assessments, with tactical digital information link (TADIL) data communications and “dots on maps” interfaces as archetype examples. The same cannot be said for higher-level machine integration, which currently relies upon non-fusion specific MMI technologies like SMTP and JPEG and non-fusion specific HMI technologies like powerpoint and web pages. Future refinements of higher level conceptualizations will see the introduction of higher-level fusion specific data communications technologies. The author has been involved in the development of some higher-level fusion technologies for HMI ([19]).

10 Conclusion

The appropriate higher-level fusion system for a specific domain will vary with that domain, but will address a collection of issues that are common to all higher-level fusion systems. This paper provides a brief catalogue of some of the design choices confronting designers of higher-level fusion systems and identifies some of the key tradeoffs associated with those choices.

References


