On the Definition and Scope of Information Fusion as a Field of Research

Abstract—A definition of information fusion (IF) as a field of research can benefit researchers within the field, who may use such a definition when motivating their own work and evaluating the contributions of others. Moreover, it can enable researchers and practitioners outside the field to more easily relate their own work to the field and more easily understand the scope of IF techniques and methods. Based on strengths and weaknesses of existing definitions, a definition is proposed that is argued to effectively fulfill the requirements that can be put on a definition of IF as a field of research. Although the proposed definition aims to be precise, it does not fully capture the richness and versatility of the IF field. To address that limitation, we highlight some topics to explore the scope of IF, covering the systems perspective of IF and its relation to machine learning, optimization, robot behavior, opinion aggregation, and databases.

Ronnie Johansson
Swedish Defence Research Agency
Stockholm, Sweden
ronnie.johansson@foi.se

Alexander Karlsson
Sten F. Andler
Marcus Brohede
Joeri van Laere
University of Skövde
Skövde, Sweden

Maria Klingegård (Nilsson)
Folksam and Integrated Transport Research Lab
Royal Institute of Technology
Stockholm, Sweden

Tom Ziemke
Linköping University
Linköping, Sweden

INTRODUCTION

In 2007, some 10 years after the inception of the International Society of Information Fusion (ISIF) information fusion (IF) conference, we set out to review the multitude of definitions for the subject that had been proposed until then and to craft a unifying definition. Our work was eventually presented in a technical report [1]. Over the years, other authors have cited the report repeatedly. The persistent interest in the report has prompted us to revisit the topic, now almost 15 years later; incorporate aspects of IF not explicitly covered by the proposed definition; and publish the work properly in this journal for future reference. Although we add a few definitions to our list, our proposed definition remains unchanged. Instead, we briefly explore some related topics that might be useful in a holistic perspective on IF systems.

Our aspiration is that the current paper will remain an attractive source of historical perspective on the emergence of the IF field, as well as an outlook on the scope of the field, to newcomers and seasoned practitioners alike.

The word "fusion"[1] is (colloquially and professionally) used in several contexts, perhaps predominantly in nuclear physics and enterprise mergers. By IF, we loosely mean, in a general and inclusive sense, exploitation of clues (e.g., signals, observations, evidence, and opinions) from (information) sources in the context of information processing to a decision-relevant state of interest. Therefore, a discussion of the interrelation and mutual dependencies of the concepts of IF, data fusion, and sensor fusion is an inhibitive distraction and outside the scope of this paper.

Also beyond this paper's scope is establishing differences in properties of source output, such as data, information, knowledge, evidence, and opinions. Furthermore, many different specialized subdomains have been defined, including image, feature, decision, and behavior fusion. In this study, we consider all of them to contribute to the characteristics of the IF field.

Although the proposed definition aims to restrict the limits of the field of IF, we simultaneously acknowledge a need to explore its scope to learn what can be expressed within the scope of IF and what concepts, solutions, and tools can be adopted from interacting technological and research fields (such as optimization and robotics). A potential benefit from such an endeavor is the invention of novel hybrid algorithms and more competent fusion systems.

The IF field builds on many different results that all can be applied to fuse data, including historical results from 18th- and 19th-century scholars such as Carl-Friedrich Gauss (mathematical statistics), Thomas Bayes (subjective probability and inference), and Nicolas de Condorcet (jury theorem [2]), current advances in machine learning [3], and the future potential of quantum computing [4].

The potential benefits of IF are quite domain agnostic, and hence unsurprisingly, applications exist in multiple domains, e.g., biometrics [5]; computer vision and image processing [6]; data mining [7]; machine learning [8], [9], [10]; information retrieval [10]; remote sensing [11]; robotics [12]; target tracking [13]; vehicle control [14]; and wireless sensor networks [15].

Three strategies for exploiting multiple sources have been presented [16]: complementary (sources providing separate, noninteracting data, such as surveillance cameras with nonoverlapping views); competitive (sources reporting on the same entity and providing redundant information that can be exploited to reduce uncertainty); and cooperative (sources providing

[1] Synonyms or related keywords encountered in the literature that also express the process of fusion: aggregate, amalgamate, blend, combine, integrate, merge, pool, and synthesize.

information that can be used to derive information not inferable by either source alone).[2] Hybrids of two or more of these strategies are possible [17].

A precise definition of IF as a field of research may be important for practitioners whose interest in applying techniques developed in the field may increase with a better understanding of the types of problems addressed by these techniques. Furthermore, such a definition would allow researchers outside the area to more easily relate their own research to the field of IF and thereby allow a higher degree of cross-fertilization among different fields. Equally important to being able to conclude that something is a contribution to the field is being able to determine what is not a contribution—a too-loose definition would allow the inclusion of only vaguely related topics with minor relevance to the field as a whole. Hence, such a definition could also clearly play an important role for researchers already inside the field who have to motivate the relevance of their own work, as well as evaluate the contributions of others to the area.

However, such a definition only partially helps with exploring the scope of IF. To complement it, we continue to discuss some topics that relate to IF and seem to provide further insight regarding the content of its scope.

In the next section, we include a discussion (largely unaltered) of previous definitions of IF from our report [1]. Based on the limitations of these definitions, when it comes to defining the field of research, we suggest a novel definition that is more inclusive in some respects compared with several earlier definitions but can be used to more clearly conclude what is not considered a contribution to the field of research.

Although the proposed definition aims to be compact, we go on to highlight results that help to explore parts of the full scope of IF. We end with a discussion of the proposed definition. The full list of surveyed IF definitions is included in the appendix.

A PROPOSED DEFINITION OF THE RESEARCH FIELD

The basis for the following discussion is the definitions[3] of IF included in the appendix.[4]

DEFINITION CRITERIA

In the ideal case, several criteria should fulfill a definition of a research field. We consider the following three general criteria:

- Discipline, i.e., is it clear what the scientific fundaments of the research field are?
- Goal, i.e., does the definition clearly state what the goal of the research is, and is it obvious what can be considered progress toward this goal?
- Contribution, i.e., is it clear by what means the research field approaches the goal?

[2] A fourth strategy to consider could be coordinated (i.e., loosely coupled sources), covering one source queuing the other or providing context for data interpretation.

[3] We use the term "definition" loosely at this point, because IF sometimes is not explicitly defined but rather is outlined in passing.

[4] Other discussions of IF definitions can be found in [5, p. 13] and [33, p. 70].

DISCIPLINE

With only few exceptions, none of the definitions surveyed (see the appendix) explicitly positions the field as concerning the development of artifacts (i.e., an engineering science). In principle, the IF process as described in several of the definitions could equally refer to biological systems,[5] although most of them implicitly assume artificial systems. Only one definition mentions the scientific basis of the field: "As a technology, data fusion is actually the integration and application of many traditional disciplines and new areas of engineering to achieve the fusion of data" [18].

GOAL

Among the suggested goals one can find the following:

- "To achieve refined position and identity estimates" [19]
- "To refine state estimates and predictions" [20]
- To obtain "information of greater quality" [21]
- "To infer relevant situations and events related to the observed environment" [22]
- To maximize "the useful information content, for improved reliability or discriminant capability, while minimising the quantity of data ultimately retained" [23]
- "To perform inferences that may not be possible from a single sensor alone" [24]
- "To provide a better understanding of a given scene" [25]
- "The resulting decision or action is in some sense better (qualitatively and quantitatively, in terms of accuracy, robustness, etc.)" [26]
- To obtain "information that has greater benefit than what would have been derived from each of the contributing parts" [27]

Although some of these statements indicate how to measure progress toward the goal, e.g., by estimating the accuracy of predictions and estimates or the benefit for a decision maker, this is less clear in other cases either because of a vague target (e.g., greater quality) or because it is unclear why the entity by which progress is to be measured should be optimized (e.g., what is the purpose of performing inferences?).

Several aspects considered by some definitions would further restrict the focus of the research field:

- Sources, i.e., the definition could be restricted to certain types of data or information, e.g., from sensors
- Scenario, i.e., the definition could be restricted to certain types of applications or decision situations, e.g., time-critical decision making
- Type of process, i.e., the definition could be restricted to certain characteristics of the fusion process, e.g., continuous refinement

[5] Hall and McMullen, e.g., point out [36] that the use of "fusion" is hardly innovative, because animals have always used an integration of different senses to survive.

CONTRIBUTION

Almost all definitions indicate that progress toward the goal is to be achieved by combining information from multiple sources. Some definitions try to characterize from where the benefit of combining information from multiple sources comes, as expressed in phrases such as "than would be possible, if these sources were used individually" [28] and "that has greater benefit than what would have been derived from each of the contributing parts" [27].

The problem with these definitions is that the alternative to combining information from multiple sources is unclear. One possible interpretation is that the alternative is to use only one of the sources. Hence, these definitions would state that the benefit of IF can be obtained by multiple sources rather than a single source, something that also seems to be implied by "than could be achieved by the use of single sensor alone" [29]. However, such statements are almost truisms, falsified only if the different sources provide redundant information. Another possible interpretation is that there is some straightforward way of combining the information from these sources, as opposed to the intended way that leads to a "greater benefit than the sum of the contributing parts" [30]. However, it is not clear what corresponds to this straightforward way (i.e., what constitutes "the sum of the contributing parts"); thus, the definitions provide no indication of how to measure progress. Furthermore, one could argue that the goal of the research field should be more compelling than just trying to outperform single-source solutions or straightforward ways of combining information from multiple sources.

THE PROPOSED DEFINITION

DEFINITION

"Information fusion is the study of efficient methods for automatically or semiautomatically transforming information from different sources and different points in time into a representation that provides effective support for human or automated decision making."

MOTIVATION

The definition states that the field is concerned with the synergistic transformation of information. This term is intended to cover all possible ways of combining and aggregating to infer, as well as to reduce, information. The transformation itself may require decisions supported by other transformations. We have chosen to emphasize that in addition to transforming information from different sources, we include transformation of information obtained from a single source at different points in time; e.g., a sensor often is conceived to persist over time. Sources can be of many kinds (e.g., sensors, databases, simulations, and humans). Similarly, information can be obtained from different types of data: text, numbers, graphs, etc.

The definition further stresses that the transformation is either automatic or semiautomatic, indicating that the field is restricted to artifacts, possibly acquired in cooperation with humans, and excluding purely biological systems from the scope of the definition. Hence, the field can be considered as belonging to the engineering sciences. This does not rule out that a great deal might be learned from the biological and cognitive sciences regarding how different senses are integrated in biological systems [31]. Furthermore, semiautomatic transformation could involve man-in-the-loop integration (e.g., human expert adjudicating fusion results or resolving conflicting results) or man-on-the-loop integration (e.g., human expert controlling the context of the fusion process, including altering the set of accessible dynamic models) while boosting trust for the IF system. An example of such human–machine data fusion is provided by Muesing et al. [32].

The definition points out that the transformation of information should be efficient and that it should result in effective support. This means that research contributions to this field should be evaluated based on the following:

1. Their effect on the decision-making process (human or automated) compared with alternative approaches
2. The cost of achieving that effect with respect to consumption of time and other resources compared with alternative solutions

DISCUSSION

An ideal definition should primarily provide guidance for researchers within the field on how to make progress. We believe that the proposed definition accomplishes this, since it quite clearly shows what is to be required from studies in the field.

A particular study within IF should, according to the definition, increase our understanding of what effect different methods of transforming information have on support in different decision situations and with different sources of information or how to achieve an effect in an efficient way. Such a study would then typically contribute to the field by providing new empirical evidence or theoretical arguments that certain methods of transforming information are superior to others for certain kinds of decision scenarios, evaluation criteria, and sources. Methods that support or facilitate the transformation are also relevant here, including methods for sensor management, process adaptation, data association and alignment, and infrastructure design. Studies may also contribute to the field by showing what requirements a particular decision situation puts on the methods for transforming the information.

The definition excludes work that brings no new knowledge regarding either the effectiveness or the efficiency of different ways of transforming information, since such studies will not contribute to the goal of understanding what results in the most efficient and effective support. We also believe that the proposed definition can be accepted by practitioners and researchers outside the field, since it—like most previous definitions—does not assume familiarity with field-specific terminology.

SUPPLEMENTARY PERSPECTIVES

A fair proportion of the research literature in the IF field concerns issues such as improved filtering techniques and combination rules. That part of the literature is well covered elsewhere. Here, we briefly discuss some topics that may provide the IF field with supplementary perspectives that can be useful for exploring the scope of IF and developing more comprehensive and versatile IF systems.

ALGORITHMIC AND SYSTEMS PERSPECTIVES

It is often helpful to study IF from both an algorithmic perspective and a systems perspective (SP). The former emphasizes the foundations of IF algorithms, their applicability, and their performance. The SP was entered into the widely acknowledged Joint Directors of Laboratories (JDL) model in the early 1990s [33, p. 75], covering control of the fusion process, centralized versus distributed architecture, knowledge bases, and varying mission and decision-maker objectives.

The SP encompasses multisensor integration [12], which concerns all kinds of synergistic uses of information sources, including the strategy labeled as coordination (described in the introduction). Since the SP does not require directly collaborating sources, additional quality metrics such as the system's spatial and temporal coverage, robustness to failure, decision maker's utility, and level of achieved autonomy emerge. The latter item also illuminates IF as part of the perception capabilities of an intelligent agent.

DATA MINING AND MACHINE LEARNING

Making a clear distinction between data mining and machine learning (DMML) is challenging—as is distinguishing IF from DMML, because both focus on exploiting data for improved insight and decision making. Roughly, IF can be considered to have the qualities of being online, sequential, and deductive, whereas DMML is offline, batch driven, and inductive. In practice, there are abundant exceptions, and the division is not clear-cut.

In the literature, examples (1) of DMML supporting IF, (2) of IF supporting DMML, and (3) with IF and DMML are indistinguishable. An example of option 1 was provided in 1998 by Waltz [34], in which observations were simultaneously fed to a DMML and an IF module. The former learns the parameters of dynamic models that are used by the latter for improved state estimation. Some examples of option 2 were provided by Torra [7] and Marcos and Azcarraga [35], including preprocessing data (data cleansing by reducing uncertainties) and fusing classifier output [8]. Finally, for option 3, a trained ANN can be seen as a fusion operator [36].

OPTIMIZATION PERSPECTIVE

IF can be seen as an explicit optimization problem, i.e., finding the world state that is most consistent with observed world data. By taking this approach, optimization tools may be leveraged for IF. A few examples of this interpretation exist [37] that approach the Kalman filter from an optimization perspective. IF might also benefit from using other optimization techniques, such as linear programming [38], distributed optimization [39] (e.g., fusing preprocessing opinions), and bilevel optimization [40].

ROBOTIC BEHAVIOR AND COMMAND FUSION

Research on autonomy in mobile robotics has explored the idea of fusing commands rather than information. Independent modules representing different kinds of competing robot behaviors (e.g., collision avoidance) jointly produce output action. In IF, uncertainty in information is usually treated explicitly, but in command fusion, each behavior module evaluates the current world state and proposes a preferred command; these are then fused into a final selected action. A few methods applying voting and fuzzy logic approaches for command fusion have been surveyed [41].

AGGREGATION OF OPINIONS

Far from all imaginable fusion rules are akin to Bayesian inference. Subfields concern the joint decisions of committees of "expert" agents whose aggregation[6] rules seek consensus, rather than reinforcement of Bayesian posteriors. One example is social choice theory in multiagent systems [42], which encourages an axiomatic analysis of aggregation rules. Other types of aggregation rules have been presented [43]. In wireless sensor networks, aggregation is a common topic, but it usually focuses on reduction of energy usage and data transmission [15], [44].

DATABASE INTEGRATION

The need for fusion also occurs when multiple databases or knowledge bases, with semantically overlapping content, are in use. Typically, the involved databases are immutable to the fusion process, which is performed on the fly when a query is issued. The process is called data integration and aims to provide a unified view of the collection of data sets while resolving inconsistencies, in part, using fusion methods. In [45], the authors resolve inconsistencies in relational data on three levels—schema, tuple, and value—employing various strategies to resolve inconsistent values, such as maximum value, voting, or letting the user decide.

CONCLUDING REMARKS

We have summarily reviewed a large number of definitions for sensor, data, and IF and discussed them in terms of whether they clearly state the goal for the research field, the scientific fundaments, and in what way the field is supposed to approach the goal. Based on limitations or restrictions of earlier definitions, we have presented a novel definition that clearly points out a goal for the research field, how the field approaches the goal, and implicitly that the field can be considered an engineering science. Furthermore, we have argued that the definition can be used for clearly distinguishing what should—and what should not—be considered a contribution to the field. We also believe that researchers and practitioners outside the field can relate to the definition, which allows cross-fertilization, as well as the promotion of interests, in applying tools and techniques developed in the field.

[6] In that domain, the term "aggregation" is preferred.

To obtain a more complete understanding of the implications of the definition—including the relevance of the field for other fields and areas of application—the terms in the definition require further exploration and clarification. This includes providing more exact characterizations of the following:

1. The methods used for transforming information
2. The eligible sources of information
3. The technical infrastructures to automate IF
4. The effects of IF in different decision-making situations
5. The potential decision-making situations for using IF systems

This list is by no means complete, which means that it will continue to evolve as the research field advances.

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APPENDIX. DEFINITIONS OF FUSION

In this appendix, we present several definitions of IF (or subdomains) put forward over the years. In many cases, the definitions are aged, possibly reflecting that the need to invent definitions was more imperative in the vibrant early days. More recently, authors seem to be largely content with referring to the old definitions. One perspective on fusion that has emerged in recent years but is not covered by these definitions is that of contextual information [46].

Only a few of the definitions covered try to define a field of research. Most of them define these terms as processes. These are nevertheless included here since they, with only a little modification, in principle could serve as definitions for the research field (e.g., "Information fusion is a research field concerned with the study of processes for…").

Definitions that have been added since our previous report [1] are marked with an asterisk. The definitions are tagged with superscript letters representing the supposed domain of origin.[7]

JDL (1987)[t]

Data fusion is "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 situations and threats, and their significance. The process is characterized by continuous refinements of its estimates and assessments, and the evaluation of the need for additional sources, or modification of the process itself, to achieve improved results." [19]

DURRANT-WHYTE (1988)[r]

"The basic problem in multi-sensor systems is to integrate a sequence of observations from a number of different sensors into a single best-estimate of the state of the environment." [47]

LLINAS (1988)[t]

"Fusion can be defined as a process of integrating information from multiple sources to produce the most specific and comprehensive unified data about an entity, activity or event. This definition has some key operative words: specific, comprehensive, and entity. From an information–theoretic point of view, fusion, to be effective as an information processing function, must (at least ideally) increase the specificity and comprehensiveness of the understanding we have about a battlefield entity or else there would be no purpose in performing the function." [48]

RICHARDSON AND MARSH (1988)[r]

"Data fusion is the process by which data from a multitude of sensors is used to yield an optimal estimate of a specified state vector pertaining to the observed system." [18]

MCKENDALL AND MINTZ (1988)[r]

"The problem of sensor fusion is the problem of combining multiple measurements from sensors into a single measurement of the sensed object or attribute, called the parameter." [49]

WALTZ AND LLINAS (1990)[t]

"This field of technology has been appropriately termed data fusion because the objective of its processes is to combine elements of raw data from different sources into a single set of meaningful information that is of greater benefit than the sum of the contributing parts.

As a technology, data fusion is actually the integration and application of many traditional disciplines and new areas of engineering to achieve the fusion of data." [30]

LUO AND KAY (1992)[r]

"Multisensor fusion … refers to any stage in an integration process where there is an actual combination (or fusion) of different sources of sensory information into one representational format." [12]

ABIDI AND GONZALEZ (1992)[r]

"Data fusion deals with the synergistic combination of information made available by various knowledge sources such as sensors, in order to provide a better understanding of a given scene." [25, p. xi]

[7] Symbols: d (database), i (image), r (robotics), s (remote sensing), t (target tracking), w (wireless sensor networks), or left out if generic or unknown.

HALL (1992)[t]
"Multisensor data fusion seeks to combine data from multiple sensors to perform inferences that may not be possible from a single sensor alone." [24]

DEFENCE SCIENCE AND TECHNOLOGY ORGANIZATION (1994)[t]
Data fusion is "a multilevel, multifaceted process dealing with the automatic detection, association, correlation, estimation, and combination of data and information from single and multiple sources." [50]

MALHOTRA (1995)[t]
"The process of sensor fusion involves gathering sensory data, refining and interpreting it, and making new sensor allocation decisions." [51]

ANTONY (1995)[t]*
"Data fusion is the process of combining evidence to support intelligence generation." [52]

HALL AND LLINAS (1997)[t]
"Data fusion techniques combine data from multiple sensors, and related information from associated databases, to achieve improved accuracy and more specific inferences than could be achieved by the use of single sensor alone." [29]

GOODMAN ET AL. (1997)[t]
Data fusion is to "locate and identify many unknown objects of many different types on the basis of different kinds of evidence. This evidence is collected on an ongoing basis by many possibly allocatable sensors having varying capabilities" and to "analyze the results in such a way as to supply local and over-all assessments of the significance of a scenario and to determine proper responses based on those assessments." [53]

PARADIS ET AL. (1997)[t]
"Data fusion is fundamentally a process designed to manage (i.e., organize, combine and interpret) data and information, obtained from a variety of sources, that may be required at any time by operators or commanders for decision making.... Data fusion is an adaptive information process that continuously transforms available data and information into richer information, through continuous refinement of hypotheses or inferences about real-world events, to achieve a refined (potentially optimal) kinematics and identity estimates of individual objects, and complete and timely assessments of current and potential future situations and threats (i.e., contextual reasoning), and their significance in the context of operational settings." [54]

STARR AND DESFORGES (1998)
"Data fusion is a process that combines data and knowledge from different sources with the aim of maximising the useful information content, for improved reliability or discriminant capability, while minimising the quantity of data ultimately retained." [23]

WALD (1998)[s]
"Data fusion is a formal framework in which are expressed means and tools for the alliance of data of the same scene originating from different sources. It aims at obtaining information of greater quality; the exact definition of greater quality will depend upon the application." [21]

EVANS (1998)
Data fusion is "the combining of data from different complementary sources (usually geodemographic and lifestyle or market research and lifestyle) to 'build a picture of someone's life'." [55]

WALD (1999)[s]
"Data fusion is a formal framework in which are expressed the means and tools for the alliance of data originating from different sources." [56]

STEINBERG ET AL. (1999)[t]
"Data fusion is the process of combining data to refine state estimates and predictions." [20]

GONSALVES ET AL. (2000)[t]
"The overall goal of data fusion is to combine data from multiple sources into information that has greater benefit than what would have been derived from each of the contributing parts." [27]

HANNAH ET AL. (2000)
"Fusion is defined materially as a process of blending, usually with the application of heat to melt constituents together (OED), but in data processing the more abstract form of union or blending together is meant. The 'heat' is applied with a series of algorithms which, depending on the technique used, give a more or less abstract relationship between the constituents and the finished output." [57]

HALL AND LLINAS (2001)[t]
"Information fusion is an Information Process dealing with the association, correlation, and combination of data and information from single and multiple sensors or sources to achieve refined estimates of parameters, characteristics, events, and behaviors for observed entities in an observed field of view. It is sometimes implemented as a Fully Automatic process or as a Human-Aiding process for Analysis and/or Decision Support." [58]

DASARATHY (2001)
"Information fusion encompasses the theory, techniques, and tools conceived and employed for exploiting the synergy in the information acquired from multiple sources (sensor, databases, information gathered by humans etc.) such that the resulting decision or action is in some sense better (qualitatively and quantitatively, in terms of accuracy, robustness and etc.) than would be possible, if these sources were used individually without such synergy exploitation." [26]

APPRIOU ET AL. (2001)

"Fusion consists in conjoining or merging information that stems from several sources and exploiting that conjoined or merged information in various tasks such as answering questions, making decisions, numerical estimation, etc." [59]

MCGIRR (2001)

"The process of bringing large amounts of dissimilar information together into a more comprehensive and easily manageable form is known as data fusion." [60]

LAMBERT (2001)[t*]

"Data fusion is the process of utilizing one or more data sources over time to assemble a representation of aspects of interest in an environment." [61]

DURRANT-WHYTE (2001)[r*]

"Data fusion is the process of combing information from a number of different sources to provide a robust and complete description of an environment or process of interest. Data fusion is of special significance in any application where a large amounts of data must be combined, fused and distilled to obtain information of appropriate quality and integrity on which decisions can be made." [62, p. 4]

BELL ET AL. (2002)

"Sophisticated information fusion capabilities are required in order to transform what the agents gather from a raw form to an integrated, consistent and complete form. Information fusion can occur at multiple levels of abstraction." [63]

LI ET AL. (2003)[t*]

"Estimation fusion, or data fusion for estimation, is the problem of how to best utilize useful information contained in multiple sets of data for the purpose of estimating an unknown quantity—a parameter or process (at a time). These data sets are usually obtained from multiple sources (e.g., multiple sensors)." [64]

SHARMA AND APURVA (2003)*

"The task of sensor data fusion involves integration of numerous data streams, originating from separate sensors, into a consistent model that represents the pertinent high-level features of the tactical environment and then to present an assessment of their significance." [65]

CHALLA ET AL. (2005)[w]

Multisensor data fusion "is a core component of all networked sensing systems, which is used either to:

- join/combine complementary information produced by sensor to obtain a more complete picture or
- reduce/manage uncertainty by using sensor information from multiple sources." [66]

JALOBEANU AND GUTIÉRREZ (2006)

"The data fusion problem can be stated as the computation of the posterior pdf [probability distribution function] of the unknown single object given all observations." [67]

SINHA ET AL. (2006)[w*]

"The estimation fusion problem can be categorized as a class of problems in which estimates of a continuous parameter/state vector obtained by different sources are to be combined to obtain an overall estimate which in general has better accuracy." [68]

MASTROGIOVANNI ET AL. (2007)[w]

"The aim of a data fusion process is to maximize the useful information content acquired by heterogeneous sources in order to infer relevant situations and events related to the observed environment." [22]

WIKIPEDIA (2007)[d,t]

"Information Integration is a field of study known by various terms: Information Fusion, Deduplication, Referential Integrity and so on. It refers to the field of study of techniques attempting to merge information from disparate sources despite differing conceptual, contextual and typographical representations. This is used in data mining and consolidation of data from semi- or unstructured resources." [69]

"Sensor fusion is the combining of sensory data or data derived from sensory data from disparate sources such that the resulting information is in some sense better than would be possible when these sources were used individually. The term better in that case can mean more accurate, more complete, or more dependable, or refer to the result of an emerging view, such as stereoscopic vision (calculation of depth information by combining two-dimensional images from two cameras at slightly different viewpoints).

The data sources for a fusion process are not specified to originate from identical sensors. One can distinguish direct fusion, indirect fusion and fusion of the outputs of the former two. Direct fusion is the fusion of sensor data from a set of heterogeneous or homogeneous sensors, soft sensors, and history values of sensor data, while indirect fusion uses information sources like a priori knowledge about the environment and human input.

Sensor fusion is also known as (multi-sensor) data fusion and is a subset of information fusion." [28]

MSN ENCARTA (2007)[d]

"Data integration: the integration of data and knowledge collected from disparate sources by different methods into a consistent, accurate, and useful whole." [70]

ARDESHIR GOSHTASBY AND NIKOLOV (2007)[i*]

"Image fusion is the process of combining information from two or more images of a scene into a single fused image that is more informative and more suitable for visual perception or computer processing" [71]

DAS (2008)*

"High-level data fusion … is the study of relationships among objects and events of interest within a dynamic environment. The study is supported by analyses of data produced by the sensors placed within the environment. By dynamic we mean the state of the environment, and hence relationships among its objects and events, changes due to both natural/internal events and external events by players (also called actions) within the environment." [72]

RAOL (2010)[t*]

"Data fusion means combining information from several sources, in a sensible way, in order to estimate or predict some aspect of an observed scene, leading to the building of a world model of the environment […] The term information fusion (IF) is used for the fusion of any kind of data and data sources […] and is also applicable in the context of data mining and database integration. This term covers all aspects of the fusion field, except nuclear fusion or fusion of different types of music, which may be discordant." [73, p. 4]

"Data fusion [is] the process of combining or integrating measured or preprocessed data or information originating from different active or passive sensors or sources to produce a more specific, comprehensive, and unified dataset or world model about an entity or event of interest that has been observed." [73, p. 11]

CHANG ET AL. (2014)[i*]

"Image fusion is a process of combining images obtained by sensors of different wavelengths simultaneously in a view of the same scene to form a composite image. The fused image is produced to improve image content and to make it easier for the user to detect, analyze, recognize, and discover targets and increase his or her situational awareness." [74]

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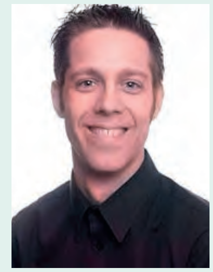
Ronnie Johansson is a senior researcher at the Swedish Defence Research Agency, employed since 2010 and conducting research primarily on the intersection of decision support systems, the internet of things, machine learning, fusion, and information acquisition. Between 2006 and 2014, he was employed at the University of Skövde (part time from 2010), where he taught, advised students, conducted research, and co-organized the Skövde workshop on IF topics. He has served on the program committees of both the IF and the multisensor fusion and integration conferences, and he has acted as reviewer for several journals. In 2018, he was on the organizing committee of the International Joint Conference on Artificial Intelligence.

Alexander Karlsson is an associate professor of informatics within the Skövde Artificial Intelligence Lab at the University of Skövde, Sweden. He has a research background in information and data analysis for the purpose of decision making. A particular focus of his research within IF has been on how to model and combine uncertainties using different types of uncertainty representations. His current research focus involves combining data-driven approaches within artificial intelligence/data science, together with modeling of domain knowledge for the purpose of knowledge extraction, exploratory data analysis, and decision making. Recent interest involves probabilistic programming for building customized models in a fast, iterative manner as a way of learning and exploring data.

Sten F. Andler is a professor of computer science at the University of Skövde, Sweden, and a member of the Distributed Real-Time Systems research group, as well as the Privacy, Information Security, and CyberSecurity collaboration platform. He was program director of Infofusion at Skövde for 10 years, funded by the Swedish Knowledge Foundation and industry/university. Andler served three terms on the ISIF board of directors and was vice president of working groups. He was previously a research staff member at the IBM Almaden Research Center for 13 years. He received his Ph.D. in computer science in 1979 from Carnegie Mellon University and Chalmers University of Technology, Göteborg. Andler is a member of the Association for Computing Machinery and the Institute of Electrical and Electronics Engineers Computer Society and is on the editorial board for *Innovations in Systems and Software Engineering*.



Marcus Brohede has been a lecturer at University of Skövde since 2000. He was part of the Infofusion research program, both as a researcher and as administrator.

Joeri van Laere is an assistant professor at the University of Skövde, Sweden. He holds a Ph.D. in information systems from the Delft University of Technology, the Netherlands. van Laere performs research at the interface of organization science, communication science, and information systems. His research interests include business intelligence, crisis management, situation awareness, gaming simulation, organizational change, and distributed work. He has published at several international conferences, such as the International Conference on Information Fusion, European Conference on Information Systems, Hawaii International Conference on System Sciences, and Information Systems for Crisis Response and Management, and in journals including *Information Fusion, European Journal of Information Systems, Information Systems Management,* and the *Journal of Decision Systems*.

Maria Klingegård (formerly Nilsson) has been a traffic safety researcher at Folksam since 2020, associated with the Integrated Transport Research Lab, KTH, Sweden. During her Ph.D. studies, Klingegård developed capturing semiautomated decision making, capturing the interaction between humans and IF-based decision support. Her specialty includes the intersection between human and technology with a focus on distributed, embodied, and situated cognition. Maria holds a Ph.D. in information technology from Örebro University (Sweden) and an M.Sc. in human computer interaction with ergonomics from University College London (United Kingdom). Her competence ranges from real-world field tests, test tracks, and experiments to demonstration projects and workshops.

Tom Ziemke is professor of cognitive systems in the computer science department at Linköping University, Sweden, where he leads the Cognition & Interaction Lab. His main research interests are in situated and embodied cognition, with a focus on people's interaction with autonomous technologies, such as social robots and automated vehicles.