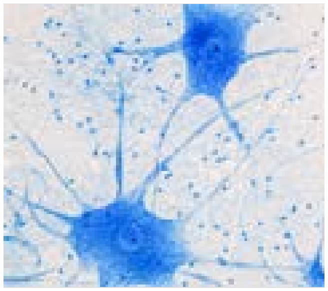
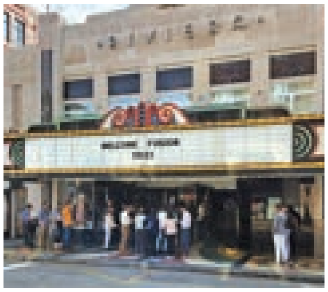
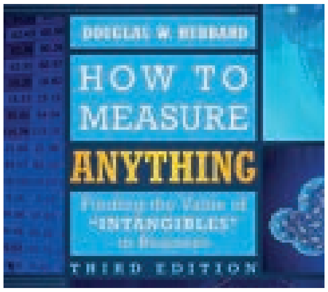
Table of Contents







OTHER EVENTS AND PROJECTS

INFORMATION FUSION HISTORY

BOOK REVIEW AND SUMMARY

INTRODUCTION TO THE ISSUE

PERSPECTIVES MAGAZINE

Benvenuti al settimo numero della rivista Perspectives![1] The 27th International Conference on Information Fusion returns to Italy, 18 years after its inaugural Italian edition in Florence. While your mind may wander through the canals of the magnificent city of Venice, you will surely appreciate projecting yourself toward the challenges that the information fusion community will face in the coming years.

This seventh issue provides such an opportunity by focusing on two stimulating areas that are "ethics" and "explainability." The first feature paper, by Wolfgang Koch from Fraunhofer FKIE (Germany), is an opinion piece entitled "Information Fusion for Defence—Discussion of Ethical Concerns" that sheds light on the intersection of artificially intelligent data and information fusion for enhancing security, from a modern German military perspective. It advocates soldierly dignity as a foundational element for the ethical design of information fusion systems, a point of view that may generate interesting discussions.

The second feature paper is by Ali K. Raz and Kuo-Chu Chang from George Mason University (USA), and Erik Blasch from MoveJ Analytics (USA), entitled "A Systems Engineering Perspective on AI Test and Evaluation: Explainability, and Counterfactuals." It advocates for the consideration of System Engineering principles into information fusion systems design, integrating Artificial Intelligence and Machine Learning through the whole life-cycle. They describe two methods, Explainable AI and Counterfactual Test and Evaluation, which should become standard practice for such an integration.

For the first time, this issue inaugurates a short "Anecdotes" section, by the pen of James Ferry from Metron (USA) who shares his "Close Encounter of the Third Kind with ChatGPT." It is our hope that others will find technically interesting vignettes they can tell in one page.

Building the future requires a solid foundation of the past. The information fusion history section presents two noteworthy pieces: Franklin E. White Jr., former chair of the JDL Data Fusion subpanel, offers a brief history of the Joint Directors of Laboratories (JDL) data fusion group, and the genesis of the now famous JDL data fusion model. An interview with Donald Reid by Chee-Yee Chong illuminates the author's seminal 1979 paper, which introduced Multiple Hypothesis Tracking (MHT).

The traditional Book Review section contains two articles. The first is a review by Larry Stone of Metron (USA) of the book *How to Measure Anything: Finding the Value of "Intangibles" in Business* by Douglas Hubbard. The other article is a concise overview by Lyudmila Mihaylova of *Deep Reinforcement Learning Hands-On* by Maxim Lapan. We hope the review and summary inspire readers to explore these books further.

As customary, this issue includes a comprehensive and beautifully illustrated report on the 26th FUSION conference, held in Charleston, South Carolina, USA, in 2023 by General chairs Terry Ogle (Georgia Tech Research Institute, USA) and Darin Dunham (Lockheed Martin, USA), with behind the scenes support from Jennifer Ogle (Clemson University, USA). You will also discover the 2024 ISIF awardees for Lifetime of Excellence and Young Investigator awards, recipients of the FUSION 2023 Best Paper and Best Student Paper awards, as well as updates from the two ISIF working groups: the Evaluation of Techniques for Uncertainty Representation (ETUR) and the Open-Source Tracking and Estimation (OSTE).

Without the invaluable contributions of all authors, the precious assistance of Darin Dunham, ISIF Vice President, Working Groups and Sponsorship, and the diligence of the *Perspectives* editorial team, this seventh issue would not have been possible. I extend a warm welcome to Chee-Yee Chong, who graciously agreed to join the team as Information Fusion History Associate Editor. I express my gratitude to the other Associate Editors Paulo Costa, Murat Efe, Jesus Garcia Herrero, Wolfgang Koch, Lyudmila Mihaylova, Emre Ozkan, Associate Editor-in-Chief Roy Streit, Administrative Editor David W. Krout and ISIF Vice President, Publications, Dale Blair for their unwavering support throughout the production of this issue. As always, Kristy Virostek, our Production Manager, ensured that everything proceeded smoothly. Our weekly meetings, spanning eleven time zones, have proven to be immensely productive!

A sincere thank you to everyone for your dedication, ideas, and energy.

Anne-Laure Jousselme
EiC *Perspectives* Magazine

[1] Welcome to the seventh issue of *Perspectives* magazine!

December 2023 Volume 18 Number 2 ISSN 1557-6418

JAIF 23

Journal of Advances in Information Fusion

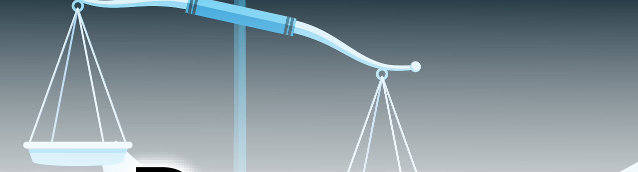
A semi-annual archival publication of the International Society of Information Fusion

Regular Papers **Page**

Guest Editorial:

Foreword to the Special Issue on Graph-Based Localization and Tracking

ISIF



Information Fusion for Defence: Discussion of Ethical Concerns

Wolfgang Koch
Chief Scientist
Fraunhofer FKIE
Wachtberg, Germany
w.koch@ieee.org

INTRODUCTION

As an opinion piece, meant to be somewhat provocative, this essay wishes to shed some light on artificially intelligent data and information fusion for securing security. It is the author's hope that it stimulates a discussion within the international information fusion community.

"All kinds of instruments are turned into weapons. […] We love the world of Kant but must prepare to live in the world of Hobbes. Whether you like it or not" [1]. This statement of Josep Borrell, High Representative of the European Union for Foreign Affairs and Security Policy, made in November 2021, marks the beginning of a new epoch. The information fusion community did wake up to its realities at the latest on February 24, 2022, when Russia attacked Ukraine. Evidently, the American political scientist Franzis Fukuyama was not right with his thesis of the "end of history" [2], which heralds its own end with comprehensive world peace. The opposite is the case.

Thirty years after the end of the Cold War, Western societies are being forced to learn again what truly sustainable and precious good security is to achieve all other individual, social, economic, cultural, political, or even ecological goods, i.e., the common good. Part of this new and austere reality are armament activities that are increasing around the globe, with the focus not only on the hopefully rather symbolic pursuit of nuclear weapons but also on the use of the latest technologies in artificial intelligence (AI), in combination with uncrewed platforms in all military domains. The focus here is on AI-assisted military systems.

ARTIFICIALLY INTELLIGENT DATA FUSION IN DEFENCE

Comprehensive data and information fusion from all available sensor and nonsensor sources, both model-based and data-driven—in short, AI in a rather broad view—already plays a key role for allied defence of humanity, freedom of nations, legal order, and world peace. Without this powerful technology, there are no effective armed forces, which depend on information superiority and decision dominance on land, at sea, in the air and space, or in cyberspace.

AI-driven multiple-source information fusion already transforms massive data streams from a vast variety of sources into comprehensive situation pictures, the basis for optimised management of sensors, communication links, and other resources, as well as command and control (C2) of weapon systems, including electronic warfare, on stationary or moving platforms. The resulting situational awareness and decision-making capabilities are enablers of improved interoperable effectiveness of allies cooperating with one another in combined multi-domain operations (MDOs).

In view of these considerations, artificially intelligent information fusion for defence poses a general question:

> *How should we decide "well" in terms of military action according to what is recognized as "true" in terms of reliable situation pictures and insight into their deficiencies in the "fog of war," i.e., their "known unknowns"?*

Turned into systems engineering, this leads to three fundamental tasks:

1. Design information fusion and decision support in a way that humans are not only mentally but also psychologically able to master each situation.
2. Identify technical design principles that facilitate the responsible use of artificially intelligent C2 and manned–unmanned teaming (MuM-T).
3. Guarantee that human decision makers in such support systems still have full superiority of information, decision-making, and execution of action.

"All thinking is art," observed the Prussian general and military philosopher Carl von Clausewitz (1770–1831). "Where the logician draws the line, where the pre-fixes end, there art begins" [3]. For this reason, applied ethics and a corresponding ethos and morality are essential soft skills, not only for commanders and staff but also for information fusion engineers, to be built up systematically in a spiral approach to operational and technical excellence.

Engineers do not need to execute military operations, just as soldiers will not program systems for situational awareness and for C2. However, both engineers and soldiers should be able to assess the strengths and weaknesses, risks, and opportunities of AI-enabled operations and technologies. The associated operational and technical competence, as well as the applied morality required, is teachable. It addresses key questions of soldierly dignity and responsible systems design, which are aggravated by using AI for defence and require special considerations, but are not fundamentally new ones.

In the age of digitalised military operations, loops to observe, orient, decide, and act, according to John Boyd (1976), and then to assess, so-called OODAA loops, are dramatically accelerating and thus to be executed "at machine speed" in a network-centric and collaborative way (Figure 1). Moreover, the pragmatic US definition of AI as "the ability of machines to perform tasks" that "normally require human intelligence" [4] also includes physical assistance systems such as AI-controlled exoskeletons or robots. For this reason, the immediate physical presence of humans in a potentially lethal environment is becoming increasingly dispensable.

> ***Without this powerful technology, there are no effective armed forces, which depend on information superiority and decision dominance on land, at sea, in the air and space, or in cyberspace.***

Quite in line with the US use of it, the term AI comprises not only, e.g., machine or deep learning but a whole "world" of data-driven and model-based algorithms, including approaches to Bayesian learning, game theory, and adaptive resources management, as shown by Koch [5], amongst many others. This "world of algorithms," realised by the art and craft of programming, enabled by qualitatively and quantitatively appropriate testing and training data, and running on distributed devices, drives a data processing cycle that starts from elementary signals, measurements, and observer reports collected from multiple and heterogeneous sources.

NEW ENGINES FOR ACCELERATING OODAA LOOPS

Interoperability in all military domains does not mean that it must be possible to directly access any means of a certain domain, such as air, sea, land, space, or cyber, from any domain. On the contrary, each domain must maintain its own competences and specific capabilities by developing them further in the sense of a common understanding of strategic, operational, and tactical planning. The German Army's concept of an AI-enabled MDO is an example of a domain-specific suboperation under the leadership of a domain leader. Sensors, effectors, and support services of different domains can achieve spatial and temporal superiority under a unified command focused on operational objectives. The essential prerequisite of the MDO is the end-to-end digitalisation of all levels and forces, which creates the preconditions for effect-oriented information superiority and decision dominance, the necessary basis for dominance in battle.

In future defence scenarios, crewed and uncrewed systems (UxSs) form a comprehensively networked system of systems. Cooperating multiple-sensor, multiple-effector UxSs protect soldiers or assets and execute reconnaissance or combat missions with electronic or kinetic impact, whereas satellites, early warning, refuelling, or transporting are integrated. The core infrastructure needed consists of so-called combat clouds, symbolically visualised for multiple domains in Figure 2, which fuse all required data, make mission-relevant information available in real time, and provide a means for adaptive resources management.

The US definition of AI explicitly includes "even decades-old AI," such as aircraft autopilot, missile guidance, and signal processing systems. Though many AI technologies are in a sense "old," there have been technological breakthroughs that have greatly increased the diversity of applications in defence where AI is practical, powerful, and useful.

Many recent achievements have been focused on machine learning, for example, a subfield of AI, and data-driven algorithms more generally. Such algorithms are closely related to mathematical statistics and encode knowledge that is automatically "learnt" from data in AI models. Due to the extremely large number of numerical values that characterises them, AI models are not accessible to direct human understanding; i.e., they are in a sense black boxes that may sometimes be turned into grey boxes using methods from explainable AI, perhaps exaggeratedly called so.

Figure 1
OODAA loops to be executed at ever-increasing speed by using a cloud of algorithms that perform tasks that normally require human intelligence. © Fraunhofer FKIE.

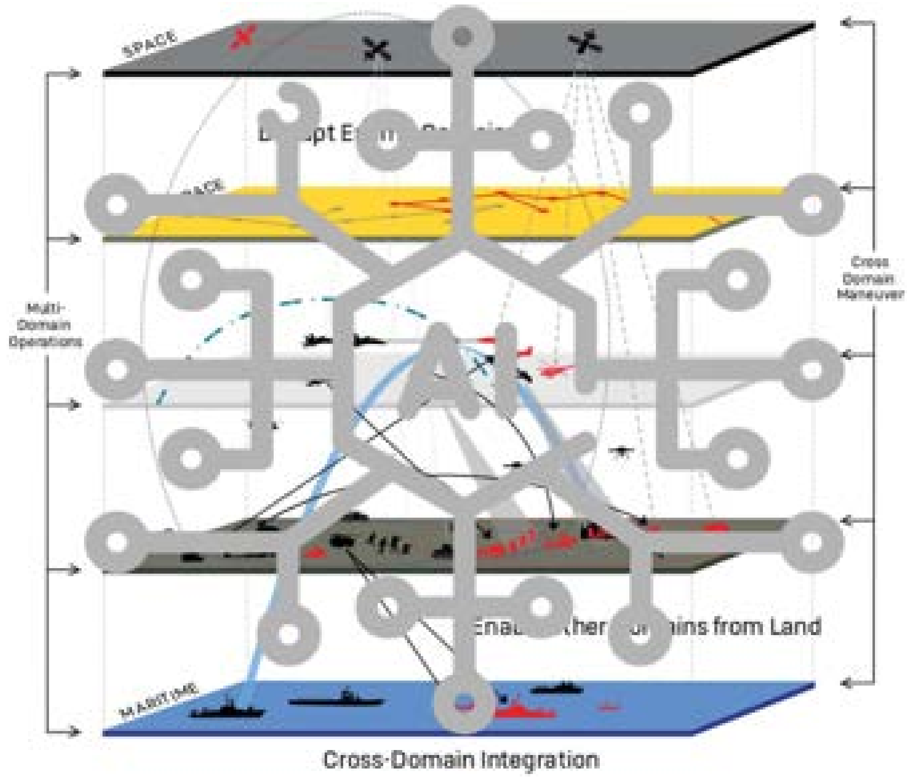


Figure 2
A multidomain combat cloud enables artificially intelligent automation in combat and reconnaissance missions. © Fraunhofer FKIE.

Algorithms for harvesting information from data and collecting data via adaptive resources management belong to the methodological core of cognitive and volitive engines for intelligence, surveillance, and reconnaissance; C2; and MuM-T that assist the intelligent minds and autonomous wills of commanders and staff. The concepts of mind and will to be assisted, and therefore of consciousness and autonomy, bring into view humans as people that are somebody and not something. Most interesting reflections on intentionality and its fundamental causal role in human behaviour have been presented by Kathryn Laskey [6].

Within this framework, new types of engines enhance and even augment the perceptive mind and the deliberate will of people, who alone are able to perceive intelligently and to act autonomously, in my view:

- ► *Cognitive engines,* in part already existing, fuse massive streams of sensor, observer, context, and mission data to produce comprehensive situation pictures, the basis for conscious human cognition to plan, perceive, act, and assess effects appropriately.
- ► *Volitive engines,* in part already existing, transform overall decisions of deliberate and responsible human volition into chains of automatically executed commands for data acquisition, subsystem control, and achieving effects on objects of interest.

The goal of cognitive and volitive assistance provided by such machines is to enable decision makers to remain capable of acting in complex situations with spatially distributed, moving assets and on short timescales. In a sense, certain processes that underlie conscious perception and causal action and that were previously reserved for humans are, so to speak, "excarnated," i.e., in contrast to "incarnation," no longer bound to a human body but transferred to machines on which they may be executed at enormously reduced processing time, scaled to enable massive processing at highly increased data rates. By this, they enable human performance enhancement far beyond the natural human levels.

Nevertheless, processes triggered by such engines are to be distinguished from natural intelligence and autonomy in the sense that they enhance the perceptive mind and the active will of people, who alone perceive intelligently and act autonomously and which is understood as a moral right, and the capability of a person to think for oneself and decide in a way that achieves a freely set effect, i.e., freely set by the chain of command. For this reason, and in accordance with the North Atlantic Treaty Organization's (NATO's) strategy on the use of military AI, to name an example, the responsibility of human decision makers is pivotal. It is always a human decision and within his or her responsibility to delegate subordinate decisions to a machine.

SOLDIERLY DIGNITY: A STARTING POINT FOR ETHICS

Perhaps surprisingly and rarely discussed so far, I base my considerations on a view of soldierly dignity. However, soldierly dignity cannot only include the dignity of the individual soldier and that of his or her comrades. The dignity of the opponent always plays a role. According to the first article of Germany's post-WWII constitution, for example, which drew lessons from the Nazi dictatorship, human dignity is the basic principle: "Human dignity shall be inviolable. To respect and protect it shall be the duty of all state authority" [7]. Its "inviolable" character is not limited to German citizens. It also includes hostile soldiers. Even during the Cold War and the confrontation with East German and Warsaw Pact soldiers standing on the inner-German border, the military documents spoke of "opponents" to be fought, not "enemies" to be destroyed. The ethical attitudes that are evident in current wars worry the observer.

Dwelling on this example, which is familiar to me, the founders of the post-WWII German Armed Forces, the Bundeswehr, that were shaped by their Christian faith and horrible experiences, saw it as their responsibility to start anew and anchor themselves in an ethical framework, which is characterised by human dignity and their Christian view of humanity. A prominent figure is General Wolf von Baudissin (1907–1993) [8]. In other countries, other religions may have led to similar conclusions. As a parliamentary army, exclusively acting on behalf of a mandate, the Bundeswehr is thus a deliberate antithesis of the German Wehrmacht, the regular armed forces of Nazi Germany. However, almost 80 years after the end of World War II (WWII), questions have arisen that need to be answered again today:

- What concrete values apply in today's societies and should therefore apply fundamentally to the armed forces as well?
- What exactly do our societies mean by "ethics" when we call for an ethical framework of values for soldiers and their use of military AI?
- What are concrete and societally acceptable criteria for "measuring" ethical and unethical actions, a major issue critical to any automation?
- Are legal standards to be equated with ethical standards? In addition, are they merely the "least common denominator"?
- How do modern societies define the relationship of ethics, virtues, values, norms, and the morality of armed forces?
- What is and must be unchangeably constant, and what is subject to a generally accepted "change in values"?
- How do AI-enabled situational awareness, options for intervention, and communication change the notion of ethically acceptable action in war?
- How can the Christian image of humanity, which the founders of the German Bundeswehr breathed, be assumed in the face of a force that is more than 50 percent nondenominational and hardly has any religious education or training?
- Are soldiers, despite all their training, sufficiently prepared for situations that demand ethical action in spatially boundless and accelerated battles?

Answers to these questions presuppose what societies also postulate as "ethical behaviour" in war. Is it defined by compliance with legal frameworks, such as international humanitarian law and the Geneva Additional Protocols, or the Christian principle of transforming the enemy into an opponent, which is based on the fundamental principle of love of neighbour? Opinions on this differ widely.

The relationship between soldier and society is of general interest. Some societies seem to consider their soldiers a "warrior class" apart from them. The concept of seeing soldiers as "citizens in uniform," which is realised in Germany, to mention an example, binds them to society, just as society is bound to its soldiers. Soldiers are therefore neither special in the sense of their citizenship nor standing outside of it or capable of being viewed negatively due to their profession. It is therefore just as unnecessary to pay special honour to soldiers as it was unacceptable to call them murderers in the NATO rearmament debate of the early 1980s. The profession of soldier is special because it requires the use of one's own life in an emergency. But this also applies to the police, bodyguards, and aid organisations in crisis areas. To German ears, it is impressive to hear uniform wearers in the United States being greeted on the street by schoolchildren with a "Thank you for your service." This would be inappropriate, as it seems, for a "citizen in uniform," as all citizens should be thanked more or less in this way.

Ethical action guarantees the dignity of the other person and one's own, the friendly fellow human and the military opponent. There are two options for discussing ethical issues in military AI that I do not follow here. The first sees only the military necessity and considers ethics in analogy to ergonomics: It is not really needed for the functionality of a weapon system, but if it does not imply any limitations, why not, if one feels better? The other option lists the dangers and risks of new technologies and, in view of these risks, proposes banning the use of AI in military systems regardless of what is happening in reality. I instead focus on humancentric design.

> *... the immediate physical presence of humans in a potentially lethal environment is becoming increasingly dispensable.*

HUMANCENTRIC DESIGN OF INFORMATION FUSION

The importance of automation for the German Armed Forces, to take an example, was recognised as early as in 1957, one year after the term AI was coined, when their conceptual architect wrote that because of automation, "human intelligence and manpower will once again be able to be deployed in the area that is appropriate for human beings" [8].

According to high-level documents of the German Ministry of Defence, to name an example, the importance of AI does not lie "in the choice between human or artificial intelligence, but in an effective and scalable combination of human and artificial intelligence to ensure the best possible performance" [9]. This statement comprises the ergonomic dimension, as well as the ethical and legal dimensions, of AI-based systems for defence; forms the basis for research questions concerning ethically aligned AI-based systems engineering; and aims at fulfilling a more fundamental military requirement.

Ethical criteria can only become "practicable" if it is possible to "translate" them into technical design principles to be considered in technology development from the outset, addressing three areas, as illustrated in Figure 3. First, care must be taken regarding what needs to be adhered to at any rate in a Kantian sense, i.e., international law or the rules of engagement. Second, we need to consider what is to be achieved, as mission success is also a moral good in a consequentialist sense. Finally, the soldierly virtues in an Aristotelian sense constitute the concept of the "citizen in uniform" and may comprehensively guarantee soldierly, and therefore human, dignity.

As the war in Eastern Europe or the attacks in the Gulf of Aden, with severe impact on the global economy, show, artificially intelligent drone technology may serve as an example of great significance for future conflicts.

Within this context, it must first be clarified whether the technical prerequisites for the responsible use of partially or fully automated reconnaissance and combat drones are feasible, i.e., compatibility with soldierly dignity. The spectrum ranges from remotely piloted air systems, in which the entire targeting cycle is completely under human control via partially automated individual drones and fully automated swarms of drones, to loitering ammunition, which can wait for hours for a target to be detected and then can be engaged.

So-called fire-and-forget weapons with sensory seeker heads have been around for a long time and are in use. It would therefore be perfectly legitimate to ask whether these weapons should or should not be replaced by artificially intelligent and ethically aligned weapon systems that can be used responsibly until the final weapon effect is released, thereby minimising collateral damage.

Figure 3
Intrapersonal tension of ethically acceptable action that typically leads to dilemmas. © Fraunhofer FKIE.

ON THE FUTURE COMBAT AIR SYSTEM ETHICAL AI DEMONSTRATOR PROJECT

In this spirit, and for the first time in Germany, an intellectual struggle over the technical implementation of ethical and legal principles accompanies a major air defence project from the outset. In the European Future Combat Air System (FCAS), manned jets of the latest generation are elements of a complex and comprehensively networked system of systems. Unmanned remote carriers protect the pilots as loyal wingmen and accompany them on reconnaissance and combat missions.

Based on exemplary scenarios discussed with the German Luftwaffe (German air force) and given rules of engagement, the FCAS ethical AI demonstrator identifies ethically relevant requirements for FCAS systems engineering. The focus is on the individual functions to be executed in the OODAA loop. So far, the observe and orient steps have been examined with regard to critically reflected situational awareness. The decide and act steps relate more directly to military action. The scenarios are intended to provoke ethical dilemma situations that are to be examined from a consequentialist and virtue ethics perspective. International humanitarian law, which can be astonishingly "cruel" for a naïve mind, is to be kept at any rate.

The central question is how ethically acceptable action under extreme time pressure and masses of data can be technically supported. I highlight several observations from ongoing discussions:

1. Ethically aligned system design must determine the situation picture, with its limitations, as reliably as possible. The use of artificially intelligent information fusion, which may be turned into a grey box, is indispensable. The request for full explainability seems to be an unfulfillable promise.

2. Which of the conceivable options for action are legally compliant must be checked automatically, i.e., instantaneously. If, for whatever reason, soldiers decide in a way that does not comply with the law or the rules of engagement, they must be informed of this in an appropriate manner.

3. Automated functions are to be provided that quickly calculate the probable consequences, along with uncertainties, of the respective decision alternatives, in the sense of a consequentialist evaluation of the act step, and present them in an ergonomically comprehensible manner. This aspect is related to the assess step.

4. Soldierly virtues are acquired as a trained habit, for example, in dealing with various forms of bias or grey boxes, and by confronting military personnel with ethical dilemma situations in a digital twin in the run-up to a mission.

5. The interplay between the consequentialist assess step and the exercise of soldierly virtue influences mission planning and personnel selection. The problem of self-protection would be at least partly eliminated by unmanned platforms. Dilemma situations between mission fulfilment and protection of noncombatants remain.

6. Under certain circumstances, combat decisions must be made automatically. The step to decide on the use of such a system in operations and on its technical design in advance must be consciously made by humans—beyond the operator in the cockpit—and they must take responsibility for them. The operator then represents the "human in the loop" by making a situation-dependent overruling decision.

7. Dilemmas remain even then. Consequentialist and virtue ethical considerations are made not during the operation but by parameterising the system in preparation for the operation. A situation-dependent "nevertheless" of an operator must remain possible.

My considerations lead to the thesis that the technical prerequisites for the responsible use of partially and fully automated drones within the framework on FCAS can be created. Moreover, this can be done in such a way that the risk to noncombatants and to soldiers deployed is minimised in accordance with the rules of engagement, or at least is considerably lower than, when using alternative weapon systems.

However, this does not mean that technological development will naturally lead to responsibly usable, artificially intelligent standoff weapon systems or that the quality of the decision-making basis for their use cannot be further improved. Even the development of ethically irresponsible AI-based drone technology is entirely possible and may be pursued.

This includes the conception of well-thought-out rules of engagement that address the risks of these AI-based technologies, which permeate all technical system components from their very design principles and comply with international humanitarian law, ethical values, and soldierly dignity. In accordance with the inherent nature of defence technology developments, the potential threat to own forces from hostile drone use needs to be countered. It is one of the tasks of the information fusion community to design solutions to counter this threat.

ETHICALLY ALIGNED INFORMATION FUSION IS ACHIEVABLE

Technically assisted information harvesting from uncertain observations and background knowledge in the "fog of war" always was, even more increasingly is, and will be key for military decision making and achieving intended effects. In the age of AI, military information fusion affects more than just the aspect of technical innovation, e.g., by "clever" fusion algorithms. It influences the entire way armed forces think and act. This leads to the following conclusions:

1. Appropriate applied ethics and corresponding morals are part of the human competencies that need to be developed and expanded to develop and deploy military information fusion systems responsibly.

2. In addition to the operational added value of artificially intelligent information fusion, ethical skills in dealing with information fusion technologies and ethical acceptance in the eyes of the conscience of individual soldiers, but also in the eyes of the research community, are essential characteristics of successful innovation.

3. In analogy to the oath of Hippocrates for physicians, the ceremonial oath of new recruits was considered indispensable when the German Bundeswehr was founded. It should be viewed with a fresh eye in the context of digitalisation in defence.

In the age of artificially intelligent uncrewed systems based on information fusion, direct contact between a system's own soldiers and their opponents is becoming rare. It seems almost impossible that troops will morph into an uncontrollable "mob of war." If soldierly dignity relies on remaining dignified themselves, then responsibly designed and professionally deployed drones will be helpful.

According to von Baudissin, the conceptual founder of the Adenauerian post-WWII armed forces in West Germany, a soldier is a soldier as a human. This means both that the dignity of soldiers, their own and of those to be fought, must be respected and that there is an obligation to develop their soldierly personality. The fact that soldiers are prepared for war, and thus for killing, does not contradict this. Rather, according to von Baudissin, "moral maturity can be achieved in the ethically challenging handling of lethal violence." He continues: "As human beings, soldiers are also required to respect the dignity of others" [8].

To let a modern soldier speak, General (ret.) Ansgar Rieks, Ph.D., Vice Chief of the German Air Force until 2023, soldierly dignity is generally preserved under seven conditions to which the information fusion community can contribute [10]:

1. Soldiers must be well equipped with technologies that provide situational awareness, trained in them, and prepared for their missions. In addition, they must derive pride from their military craft.

2. This includes the integration of information fusion technologies with well-adapted man–machine interfaces and an ethically aligned design from the outset.

3. The right of defence against a military aggressor remains a fundamental principle and is enabled by fusion-based decision support systems and automation.

4. Good leadership and mission tactics adapted to these technologies determine how the armed forces are treated.

5. The society as a whole supports its soldiers as citizens in uniform.

6. Soldiers are provided with operationalised ethical criteria that are oriented towards the new world of operations and technology.

7. Warfare observes fundamental ethical principles for action even “in war,” without giving up the ability “to win” through technological superiority.

REFERENCES

1. Gutschker, T. Europa ist in Gefahr [Europe is in danger]. *Frankfurter Allgemeine Zeitung* (Nov. 11, 2021).
2. Fukuyama, F. The end of history and the last man. *Free Press* (1992). https://pages.ucsd.edu/~bslantchev/courses/pdf/Fukuyama%20-%20End%20of%20History.pdf.
3. von Clausewitz, C. Vom Kriege *[On War]* (11th ed.). Hamburg, Germany: Nikol, 1832, II.3, p. 135.
4. Allen, G. Understanding AI technology. A concise, practical, and readable overview of artificial intelligence and machine learning technology designed for non-technical managers, officers, and executives. Joint Artificial Intelligence Center, Department of Defense, Washington, DC. Apr. 2022. [Online]. Available: https://apps.dtic.mil/sti/pdfs/AD1099286.pdf.
5. Koch, W. *Tracking and Sensor Data Fusion—Methodological Framework and Selected Applications.* Heidelberg: Springer, Mathematical Engineering Series, 2014.
6. Laskey, K. Agents with free will: a theory grounded in quantum physics. *ISIF Perspectives on Information Fusion*, Vol. 5, 1(2022),17–25.
7. Basic law for the Federal Republic of Germany, Art. 1. https://www.gesetze-im-internet.de/englisch_gg/englisch_gg.html#p0016.
8. von Baudissin, W. *Soldat für den Frieden. Entwürfe für eine zeitgemäße Bundeswehr [Soldier for Peace. Drafts for a Contemporary Bundeswehr].* München: Pieper, 1969.
9. Erster Bericht zur digitalen Transformation [First report on digital transformation]. Berlin, Germany: BMVg, Oct. 10, 2019. Online: https://www.bmvg.de/re-source/blob/143248/7add8013a0617d0c6a8f4ff969dc0184/20191029-download-erster-digitalbericht-data.pdf.
10. Rieks, A. et al. Drohnen und Ethik—kein Oxymoron! [Drones and ethics—no oxymoron]. In *Unbemannte Luftfahrzeugsysteme, [Uncrewed Aircraft Systems],* S. Nitschke Ed. Bad Neuenahr: Münch, 2024, p. 342.

Wolfgang Koch studied Physics and Mathematics at the RWTH Aachen, where he earned a Ph.D. degree in Theoretical Physics. At Bonn University, he holds a habilitation degree and teaches as a Professor for Computer Science. For many years, he has been head of “Sensor Data and Information Fusion” at Fraunhofer FKIE. His research comprises many aspects of defence digitalization. Within the areas of his scientific interests, he has published a monograph as well as numerous handbook chapters, journal articles, and conference papers.

Wolfgang Koch is a Member of the Board of Directors of the International Society of Information Fusion (ISIF). Being a Fellow, Distinguished Lecturer, Member of the Board of Governors, and head of the Germany Chapter of the IEEE Aerospace and Electronics Systems Society (AESS), he is active within the IEEE. Moreover, he is a member of the Sensors and Electronics Technology (SET) panel of the NATO Science and Technology Organization (STO) and contributes to many STO activities.

IEEE Advancing Technology for Humanity · AESS · ISIF · UNIVERSITÄT BONN · Fraunhofer FKIE

16th Symposium Sensor Data Fusion: Trends, Solutions, and Applications

Call for Papers

Motivation

To a degree never known before, human decision makers or decision making systems have access to a vast amount of data. Therefore, real-time data streams must not overwhelm the actors involved. On the contrary, the data are to be fused to high-quality information to provide a reliable decision support. Being a challenging exploitation technology at the common interface between sensors, command & control systems, data and information fusion has a large potential for future security and ISR systems in defence and civilian applications.

Scope

Sensor Data Fusion techniques provide higher-level information by spatio-temporal data integration, the exploitation of redundant and complementary information, and the available context. Important applications exist in logistics, advanced driver assistance systems, medical care, public security, defence, aerospace, robotics, industrial production, precision agriculture, traffic monitoring, sensor positioning, and resource management.

Plenary Talk

Daniel Cremers - *3D Computer Vision for Dynamic Scene Understanding*

Key Aspects

- Distributed sensor fusion in complex scenarios
- Fusion of heterogeneous sensor information
- State estimation
- Exploitation of non-sensor context knowledge
- Artificial Intelligence
- Autonomous systems
- Risk analysis
- Sensor and ressources management

Participants

The workshop addresses end users, software developers, research engineers, and scientists working in the area of sensor data fusion. They get insight into current research trends, innovative algorithms/system solutions, and new applications in a prospering evolving branch of applied informatics.

Fees

€ 199.-	Students
€ 399.-	ISIF or AESS Members
€ 449.-	IEEE Members
€ 499.-	Regular

- For the student registration a proof of the student status is required.
- One registration covers one paper only.

Contributions

Prospective authors are encouraged to submit high-quality full draft papers (6-8 pages, IEEE format). All submissions are subject to a peer-review process by the technical program committee. Accepted and presented papers will be submitted to IEEE for publication. At least one of the authors of each accepted contribution is expected to register for the Symposium, which will be held in Bonn, Germany, and to present the paper. Submissions can be uploaded to the CMT system at `https://cmt3.research.microsoft.com/SDF2024`. For more details contact `www.fkie.fraunhofer.de/sdf2024`.

Important Dates

12.08.2024	Submission of full draft papers
30.09.2024	Notification of acceptance
18.11.2024	Submission of the final version
25.11.2024	Start of SDF Symposium

A Systems Engineering Perspective on AI Test and Evaluation: Explainability and Counterfactuals

Ali K. Raz
George Mason University
Fairfax, VA, USA
araz@gmu.edu

Erik P. Blasch
MOVEJ Analytics
Fairborn, OH, USA
erik.blasch@gmail.com

Kuo-Chu Chang
George Mason University
Fairfax, VA, USA
kchang@gmu.edu

INTRODUCTION[1]

Artificial intelligence and machine learning (AI/ML) are becoming ubiquitous in modern systems, and the information fusion community has seen a recent surge in AI/ML-driven solutions for data fusion challenges. Advancements in AI/ML algorithms and technologies are quickly finding their way into software- and even hardware-based components of complex systems, often enabling unprecedented capabilities in performance and efficiency. Deep neural networks (DNNs) typically serve as the cornerstone for implementing modern AI/ML algorithms, encompassing supervised, unsupervised, and reinforcement learning (RL) paradigms. As DNNs and their underlying AI/ML implementations inevitably become integral components of complex systems, it is imperative to approach the design, development, integration, and testing of AI/ML from a holistic systems perspective. In this article, we advocate for the incorporation of systems engineering (SE) principles into the realm of AI/ML and discuss two emerging approaches—explainable AI (XAI) and counterfactual test and evaluation (cT&E)—to aid toward building a systems perspective of AI/ML implementation and deployment.

FROM AI/ML IMPLEMENTATION TO INTELLIGENT ENGINEERED SYSTEMS

An engineered system (ES) is essentially a collection of components that interact with each other and their operational environment to fulfill an intended purpose that cannot be achieved by the individual components alone. With the integration of AI/ML technology into these system components, the underlying ES transitions to a new class of intelligent engineered systems (IESs) with machine autonomy. The IESs present a unique set of challenges, stemming from the complexities inherent from traditional ES as well as those arising from the incorporation of AI/ML technologies. The AI/ML methods are broadly classified into ruled-based (e.g., expert systems), model-based (e.g., mathematical model), and data-driven, DNN-based methods [2]. The rule-based and model-based methods, which have been established for decades, are considered mature, well understood, and have been extensively studied for design, development, and integration into complex systems; the same cannot be said about the contextual and data-driven behavioral characteristics of DNNs.

The DNN implementation involves creating intricate mapping between inputs and outputs (I/O) through multiple hidden layers, using large datasets in supervised or unsupervised learning and environment/reward models in RL. The curated datasets are typically divided into training and validation sets, with roughly 80% of the data used for training the algorithm and the remaining 20% for validating the learning outcomes. Once trained, the DNN effectively operates as a black (i.e., invisible) box, lacking interpretable information regarding the decision-making processes within the hidden layers and the underlying I/O map (Figure 1 [1]). For example, once a DNN is trained for multimodal data fusion, it is difficult to know which sensor data input contributed more to the decision output; how much data are required to mitigate a future data imbalance situation; what the intended use or who the intended user is [3], and the extent to which information is labeled for data association [4].

Regarding IES, a DNN black box represents a component in a complex system that must effectively interact with other systems' components and the operational environment to meet the system's intended purpose. However, DNN development has primarily focused on algorithmic advancements and computational efficiencies, particularly within specific data and application domains such as image or face recognition; this presents a major limitation in AI/ML development, and challenges associated with integrating DNNs with other system components have often been neglected [5].

CHALLENGES OF AI/ML IMPLEMENTATION IN AN IES

Employing DNNs to integrate AI into IES poses several challenges because of their backbox nature. Relying solely on an 80-20 data split for training and validation, DNNs cannot be guaranteed to be fit for purpose to meet the overarching systems objectives. These objectives emphasize the necessity for systems to not only achieve their intended purposes but also to exhibit resilience to real-world operations, minimize unintended actions, address adverse effects, and acknowledge consequences. In complex systems, the behavior of a system emerges

[1] The ideas presented in this article are adapted from an earlier publication [1].

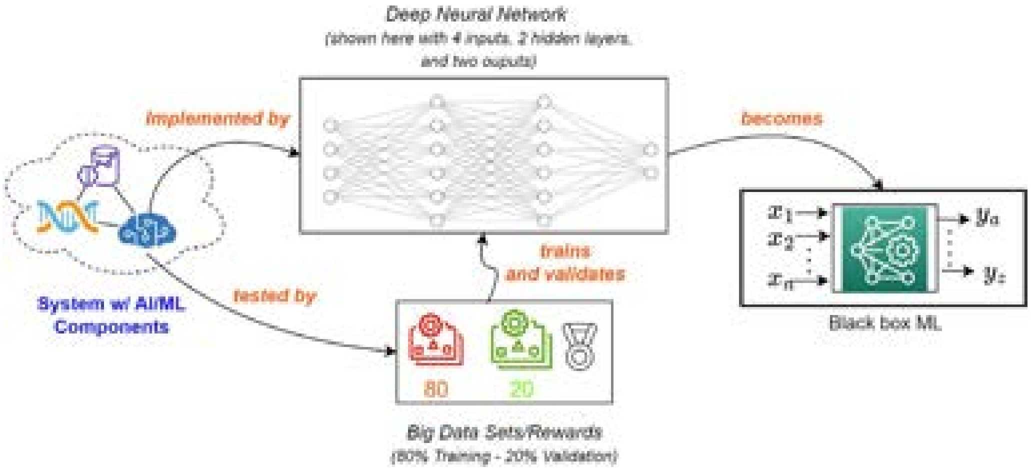


Figure 1
Black box nature of DNNs within an intelligent engineered system [1].

from the interactions between system components and their environment [6]. In this regard, the implementation and integration of opaque AI/ML must include broader IES considerations to ensure compatibility with the complex system dynamics and objectives.

The AI/ML and the SE communities now recognize the limitations for the testing, evaluation, and integration of DNNs into IES. These limitations stem from the lack of robust systems methods, varying and inadequate evaluation methods, and limited approved standards. Considering the wider system operational considerations and their manifestation on DNN training and validating datasets, Barclay Brown's book, *Engineering Intelligent Systems,* postulates this problem as "the green school bus problem" [7]. This hypothetical problem posits that an AI system trained on a dataset primarily comprising military vehicles (typically green in color) may likely classify a green school or commercial bus as a military vehicle unless the dataset includes examples of green school buses (Figure 2). Although green school (and commercial) buses are rare in the United States, their existence is not impossible. A green bus scenario highlights the inherent biases and limitations within AI systems when they are not adequately trained on diverse and representative datasets [7].

Figure 2
Green bus (*from* https://commons.wikimedia.org/wiki/File:The_Green_Bus_school_bus_381_Volvo_Olympian_Northern_Counties_Palatine_II_R381_LGH_in_Birmingham_2_November_2008.jpg).

Judea Pearl, one of the leading researchers in AI/ML, has highlighted the lack of, and need for, cause and effect understanding of AI/ML methods [8], [9]. The absence of structured process models for designing, testing, and integrating AI/ML models has resulted in the lack of reproducibility of AI algorithms [10]. It is vital that these structured system life-cycle development models from SE (e.g., Vee Model [11]) become commonplace in AI/ML to ensure rigorous and replicable AI-development processes. Similarly, the technical debt of AI/ML algorithms, where the full cost and implications are not recognized until the integration stages, is gaining attention. This AI/ML oversight is often attributed to lack of operational considerations during the design and construction phases of DNN algorithms [12]. Furthermore, little consideration has been given for the operations, maintenance, and sustainment of models to evolve with changing situations.

In an IES, AI/ML may handle not only various decisions but also their interactions with other system components with and without AI/ML. These interactions can lead to emergent behaviors—positive and negative—that have significant implications for system performance and safety. The system engineers and designers must strive to establish and validate confidence toward testable, repeatable, and auditable actions, outputs, and decisions made by AI/ML systems. Additionally, it is critical to develop an understanding of failure mechanisms, modes, and consequences, along with effective failure mitigation techniques for certification and assurance. Furthermore, the AI/ML algorithms integrated into IES must function not only as intended within narrowly defined use cases, as dictated by the training and validation data set, but also must effectively operate within the broader operating envelop of the ES. Deployment requires careful consideration of system dynamics, potential interactions, and the robustness of AI/ML algorithms [13].

SE PERSPECTIVE FOR AI/ML CHALLENGES

The SE body of knowledge includes several system concepts and principles that facilitate stakeholder analysis, conceptual design, T&E, and verification and validation of ES. For illustration and discussion purposes, the underlying SE philosophy can be simplified by the Vee Model, which guides the development and evolution of a system from its inception of necessity to throughout its entire system lifecycle (Figure 3 [14]–[16]). The outer yellow boxes highlight modification to process model to include AI/ML components which consist for iterative refinement of SE artifacts with design and experimentation.

The SE approach has been identified as instrumental in expediting the integration of AI into practical systems [16]. Moreover, SE offers a framework for addressing notable challenges encountered by the AI community. Hendrycks et al. have recently delineated four pertinent unsolved challenges in AI/ML, mostly relating to the safety of ML algorithms [17]. These challenges include robustness, monitoring, alignment, and external safety, collectively indicating a lack of SE practices for AI/ML. Table 1 summarizes the AI/ML challenges and aligns them with common SE principles that directly address similar issues encountered in the development of a complex system [1], [11], [17], [18].

Integration of opaque AI/ML must include broader IES considerations to ensure compatibility with the complex system dynamics and objectives.

The major problem areas for AI/ML safety can typically be found in most introductory texts on SE as issues for most complex systems. Nevertheless, the current challenge for SE is to discover how to perform the SE activities and evaluation thereof (e.g., failure mode analysis, sensitivity analysis) with a lack of requirements and no knowledge of the AI/ML conceptual design or decision-making constructs. The SE goal is to provide testable, repeatable, and auditable actions, outputs, and decisions for AI/ML integration into IES.

Of particular interest here, these challenges compound when AI/ML is employed in the information fusion systems. The AI/ML challenges intersect with fusion challenges that involve inherent uncertainty and a multitude of heterogeneous sources, along with multitiered and interacting fusion processes in both low- and high-level fusion contexts.

In the following, two emerging approaches are discussed that, in the authors' views, should become part of standard SE practice for test, evaluation, and integration of AI/ML into IES. These approaches are particularly valuable for information fusion systems because they serve to concurrently address both AI/ML challenges and fusion system challenges from a systems perspective.

EXPLAINABLE AI

XAI transforms the opacity of AI/ML components and the underlying DNN to transparent models that are understandable and interpretable by humans [19]. XAI is an emerging area of research with many proposed approaches offering various forms of explanations; it can be used for understanding and interpreting

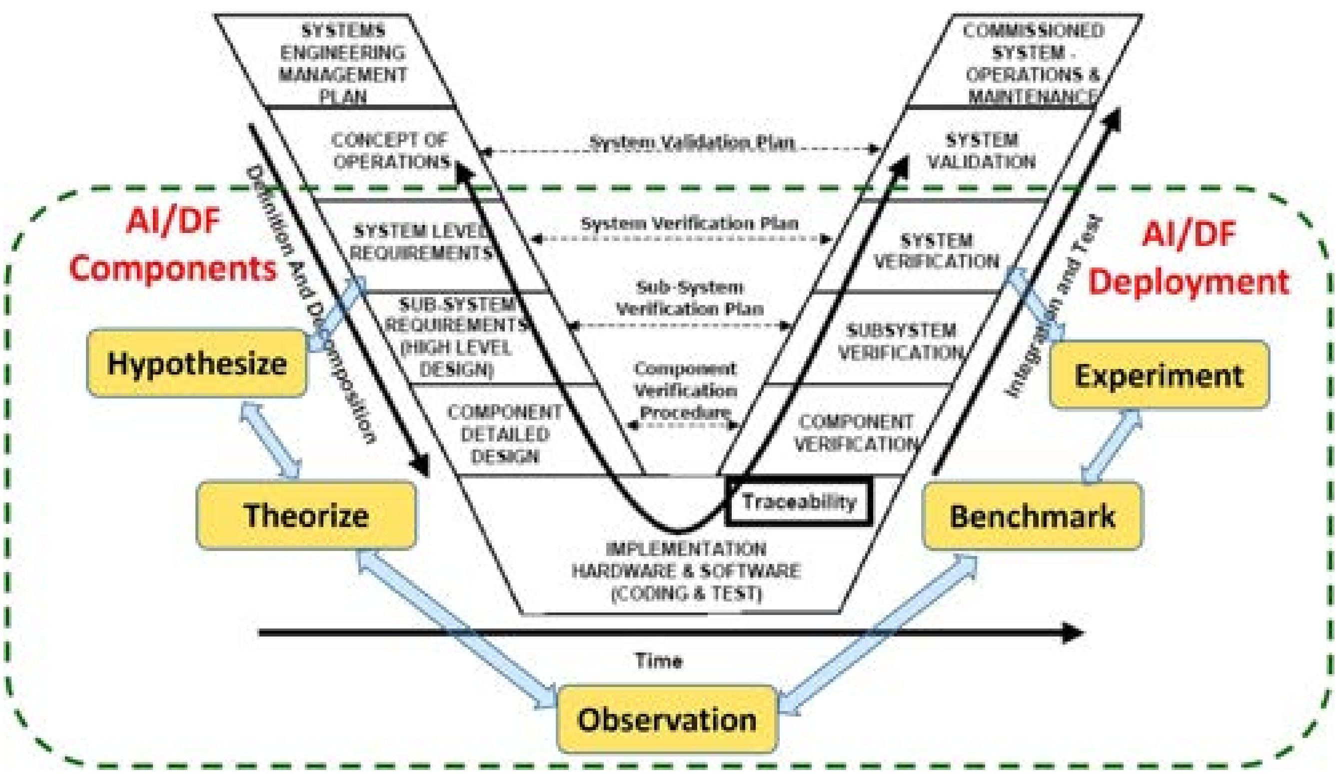


Figure 3
Systems engineering classical Vee Model in gray (adapted from references [14]–[16]).

Table 1

Unsolved Problems in ML and Proposed SE Solutions [1]	
ML Unsolved Problem [17]	**Systems Engineering Principles and Artifacts as Potential Solutions [11], [18]**
Robustness: resilience, black swan events, unusual events	System verification and validation, failure modes and effects analysis (right side of Vee Model)
Monitoring: unexpected model functionality, malicious use	Emergent behavior and interaction analysis, functional analysis (left side of Vee Model) Trade space exploration, design of experiments (both sides of Vee Model)
Alignment: "optimize with difficult to specify human values"	Stakeholder analysis, use case analysis, concept of operations (left side of Vee Model)
External safety: address risks, cyber attacks	External systems diagram, external interfaces, and context analysis (left side of Vee Model)

decision-making constructs of components embedded with AI/ML algorithms. These XAI approaches span from visualizing high-dimensional I/O data spaces and simplifying DNNs model with causality to identifying most the relevant features in the input space that influence the output of DNNs at any given time. Barredo et al. have provided a comprehensive overview of the XAI, while also highlighting its value and applications in the context of information fusion [19].

The absence of structured process models for designing, testing, and integrating AI/ML models has resulted in the lack of reproducibility of AI algorithms.

Employing XAI with the SE standard practice is key for addressing the opacity of the DNNs, establishing component behavior expectations, and assessing how a component with DNNs will interact with other components of the system with and without DNNs. Insights gained from XAI can help developers and testers examine AI system design and implementation issues; it can also help with sharing DNN outcomes and decision-making constructs with stakeholders and subject matter experts (SMEs), as well as support transparency and interpretability.

COUNTERFACTUAL TEST AND EVALUATION

cT&E is used for understanding DNN limitations and testing conformance to expected outcomes under hypothetical scenarios not typically included in training. It investigates the hypothetical "what-if" scenarios to find conditions in inputs, which provokes internal system faults and latent interactions, that could produce an imaginative desired or undesired result [20]. cT&E includes creatively designing metrics for evaluation, developing counterintuitive—and perhaps unlikely—use cases, and systematic design of experiments.

The development and training of DNNs does not include all conceivable input combinations; therefore, a full spectrum response of deployed DNN remains unknown. The unknown implies that regions of DNNs (within its hidden layers) may never be invoked in a traditional T&E sense. These unknowns are addressed through comprehensive cT&E by proposing hypothetical scenarios and subsequently analyzing the corresponding system behavior. By imaging and exploring different scenarios and examining DNN outcomes, stakeholders can identify bounds of pragmatic use and ensure that AI systems remain safe and adhere to expected outcomes, thereby mitigating risks and enhancing confidence in their deployment.

INFORMATION FUSION SYSTEM APPLICATION OF EXPLAINABILITY AND COUNTERFACTUALS

To illustrate XAI and cT&E for IES with information fusion, we briefly consider the following two applications.

First, a conceptual, high-level information fusion (HLIF) system designed to provide situational awareness based on inputs from heterogeneous sensors is considered. Recent advances in HLIF explore the integration of DNNs with promising results; however, a significant challenge lies in comprehending the decision-making processes within these underlying DNNs. For example, imagine a HLIF DNN tasked with fusing inputs from three sensors to determine the corresponding situation and produce an output (Figure 4[a]). Although traditional T&E approaches may focus on assessing the timeliness and performance of this HLIF DNN, the fusion engineers often lack insight into how sensor inputs are transformed into outputs.

The sensor fusion aggregation for the situational awareness challenge can be addressed by employing feature relevance explainability techniques, such as Shapley Additive Explanations (SHAP) [21]. When applied to the DNN illustrated in Figure 4(a), SHAP enables the derivation of an analytical expression, directly linking input values to the output (Figure 4[b]). By using this analytical expression, fusion SMEs can gain an understanding of whether the HLIF DNN aligns with the established knowledge base for its application.

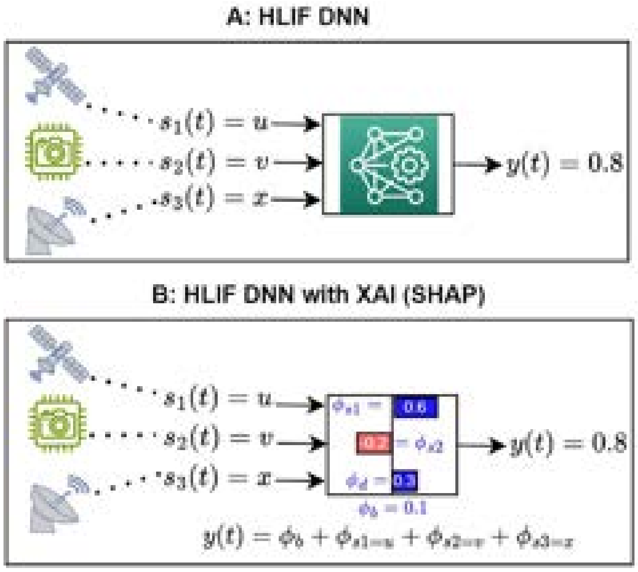


Figure 4
HLIF DNN with multisensory input: (a) black box HLIF DNN; (b) HLIF DNN with explainability.

In the second example, the causal Bayesian Network (BN) method is used to compare and prioritize counterfactual hypotheses for sensor allocation using an RL algorithm in a space situation awareness scenario [22], [23]. RL algorithms, implemented as multilayer DNN, use a model of the environment characterized by a state space, reward structure, and action space to train an RL agent. The agent is tasked with making decisions in dynamic and uncertain environments; however, once trained, the RL agents essentially operate as black boxes, lacking interpretability in their decision-making processes. In the proposed engineered explainable counterfactual evaluation Bayes Net (ExIcEBN) approach, we first construct a baseline "observational" BN model to evaluate the expected reward of an action based on the current environment state and the sensor allocation decision derived from the RL agent. Subsequently, we employ the twin networks model concept to predict the hypothetical world consequent of an event given a potential (counterfactual) antecedent [24].

XAI transforms the opacity of AI/ML components and the underlying DNN to transparent models that are understandable and interpretable by humans.

In twin networks model, a "factual world" twin represents what actually occurred in the event, whereas a "counterfactual world" indicates what could have happened to the "factual world" twin had the antecedent been different. The two worlds share a common set of domain-specific conditions. The evidence from the factual world is used to update past information on the shared contextual variables. The updated information is then used to predict the hypothetical outcome in the counterfactual world, considering both the updated contextual variables and the newly established antecedent [24], [25].

For example, consider a system event where a specific action (A = A1) was taken, and a high level of risk (R = high) was observed based on the estimated target uncertainty and activity. To assess the system under different potential circumstances, a counterfactual hypothesis might be proposed: "If the action had been different, the risk level could have been lower". The low-risk hypothesis aims to address the question, "Could the risk level have been lower if a different action had been taken?" (Figure 5).

To predict the hypothetical world outcome based on the updated information on the contextual variables and the newly established antecedent, we apply *do*-operator on the "control" variable [25]. The *do*-operator facilitates an intervention in the counterfactual world by enforcing a different value for the antecedent variable from the ones observed in the factual world and removes all incoming edges to the variable (Figure 5).

The counterfactual query process enables decision makers to compare the actual occurrences in the real world with what would have happened under a different scenario in a hypothetical world. The process can also assess whether the situation

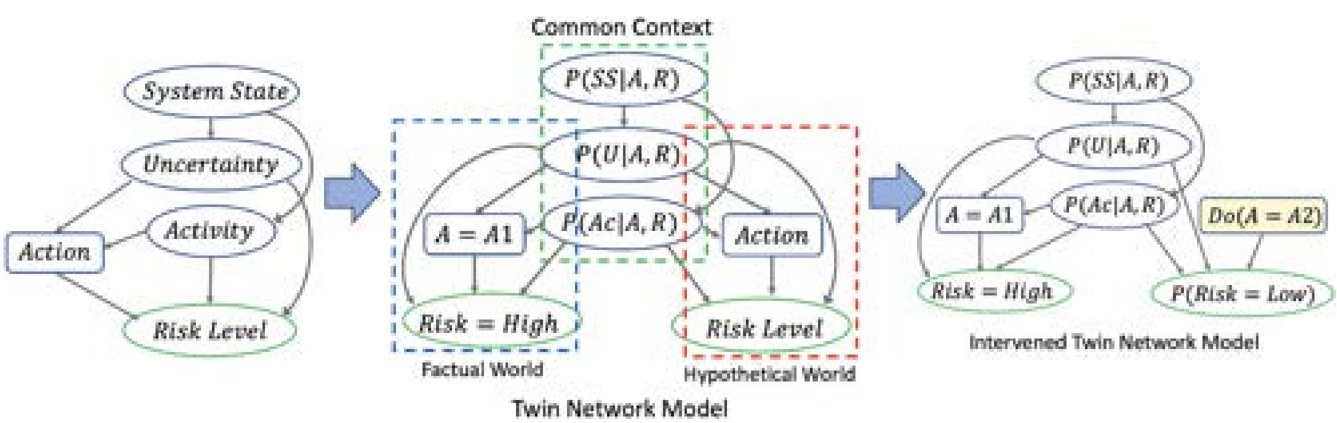


Figure 5
A twin network model example.

could have been managed more effectively if a different action had been taken or if additional information (e.g., target activity) had been known during the original assessment phase of the decision-making process.

CONCLUSIONS

Adopting AI/ML methods for IES and information fusion systems requires integrating these technologies into the system lifecycle from its inception to deployment. To appropriately understand and mitigate unintended outcomes and to ensure the development of safe and reliable systems, rigorous and thorough T&E and verification and validation processes are indispensable. This article highlights the need to employ explainable methods and counterfactual exemplars to better manage expectations, contextual use, and bound performance. Moreover, leveraging data fusion to reduce uncertainty in engineering information systems underscores the imperative to expand the SE Vee Model. The Vee Model expansion should include benchmarks for standardization, comparison, and certification, thereby providing a structured framework for evaluating the effectiveness and reliability of AI/ML integration within information fusion systems and future IES.

REFERENCES

1. Raz, A. K., Miller, W., Chang, K.-C., Lin, Y., and Blasch, E. Explainable AI and counterfactuals for test and evaluation of intelligent engineered systems. *INCOSE International Symposium*, Vol. 33, 1, (2023), 1524–1539, doi:10.1002/iis2.13096
2. Majumder, U. K., Blasch, E. P., and Garren, D. A. *Deep Learning for Radar and Communications Automatic Target Recognition*. Norwood, MA: Artech House, 2020.
3. Blasch, E., Cruise, R., Aved, A., Majumder, U., and Rovito, T. Methods of AI for multimodal sensing and action for complex situations. *AI Magazine*, Vol. 40, 4 (2019), 50–65, doi:10.1609/aimag.v40i4.4813
4. Blasch, E., et al. Machine learning/artificial intelligence for sensor data fusion–opportunities and challenges," *IEEE Aerospace and Electronic Systems Magazine*, Vol. 36, 7 (July 2021), 80–93, doi:10.1109/MAES.2020.3049030
5. Freeman, L. Test and evaluation for artificial intelligence. *INSIGHT*, Vol. 23, 1 (2020), 27–30, doi:10.1002/inst.12281
6. Raz, A. K., Llinas, J., Mittu, R., and Lawless, W. F. Engineering for emergence in information fusion systems: a review of some challenges. In *Human-Machine Shared Contexts*, W. F. Lawless, R. Mittu, and D. A. Sofge, Eds. Cambridge, MA: Academic Press, 2020, pp. 241–255. doi:10.1016/B978-0-12-820543-3.00012-2
7. Brown, B. *Engineering Intelligent Systems*. Hoboken, NJ: Wiley, 2022, https://www.oreilly.com/library/view/engineering-intelligent-systems/9781119665595/, last access Dec. 13, 2022 [Online].
8. Pearl, J. Reasoning with cause and effect. *AI Magazine*, Vol. 23, 1 (Mar. 2002), doi:10.1609/aimag.v23i1.1612
9. Pearl, J., and Mackenzie, D. I. AI can't reason why. *Wall Street Journal*, May 18, 2018. https://www.wsj.com/articles/ai-cant-reason-why-1526657442, last access Apr. 27, 2020 [Online].
10. S. Higginbotham, Hey, data scientists: show your machine-learning work. *IEEE Spectrum*, 2020. https://spectrum.ieee.org/computing/software/hey-data-scientists-show-your-machinelearning-work, last access Apr. 27, 2020 [Online].
11. INCOSE. *INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities* (4th ed.). Hoboken, NJ: Wiley, 2015.
12. D. Sculley et al., Hidden technical debt in machine learning systems. In *Advances in Neural Information Processing Systems 28*, C. Cortes, N. D. Lawrence, D. D. Lee, M. Sugiyama, and R. Garnett, Eds. Curran Associates, Inc., 2015, 2503–2511, last access Apr. 29, 2020 [Online]. http://papers.nips.cc/paper/5656-hidden-technical-debt-in-machine-learning-systems.pdf
13. Blasch, E., Bin, J., and Liu, Z. Certifiable artificial intelligence through data fusion. arXiv, last access Nov. 2, 2021. doi:10.48550/arXiv.2111.02001
14. Kossiakoff, A., Biemer, S., Seymour, S., and Flanigan, D. *Systems Engineering Principles and Practice* (3rd ed.). Hoboken, NJ: Wiley, 2020.
15. Blasch, E., Raz, A. K., Sabatini, R., and Insaurralde, C. Information fusion as an autonomy enabler for UAV traffic management. In *AIAA Scitech 2021 Forum*, American Institute of Aeronautics and Astronautics, 2021. doi:10.2514/6.2021-0658
16. Raz, A. K., Blasch, E. P., Guariniello, C., and Mian, Z. T. an overview of systems engineering challenges for designing AI-enabled aerospace systems. In *AIAA Scitech 2021 Forum*, American Institute of Aeronautics and Astronautics, 2021. doi:10.2514/6.2021-0564
17. Hendrycks, D., Carlini, N., Schulman, J., and Steinhardt, J. Unsolved problems in ML safety. *ArXiv210913916 Cs*, Apr. 2022. Last access May 7, 2022 [Online]. http://arxiv.org/abs/2109.13916
18. Buede, D. M., and Miller, W. *The Engineering Design of Systems Models and Methods* (3rd ed.). Hoboken, NJ: John Wiley & Sons, 2016.
19. Barredo Arrieta, A., et al. Explainable artificial intelligence (XAI): Concepts, taxonomies, opportunities and challenges toward responsible AI. *Information Fusion*, Vol. 58 (Jun. 2020), 82–115. doi:10.1016/j.inffus.2019.12.012
20. Roese, N. J. Counterfactual thinking. *Psychological Bulletin.* Vol. 121, 1 (1997), 133–148. doi:10.1037/0033-2909.121.1.133
21. Lundberg, S. M., and Lee, S.-I. A unified approach to interpreting model predictions. In *Advances in Neural Information Processing Systems*, Curran Associates, Inc., 2017. Last access Dec. 13, 2022 [Online]. https://proceedings.neurips.cc/paper/2017/hash/8a20a8621978632d76c43dfd28b67767-Abstract.html
22. Fan, Z., Chang, K.-C., Raz, A. K., Harvey, A., and Chen, G. Sensor tasking for space situation awareness: Combining reinforcement learning and causality. In *2023 IEEE Aerospace Conference*, Big Sky, MT, IEEE, 2023, 1–9.
23. Fan, Z., Chang, K.-C., Chen, G., Khan, S., and Franco, M. Explainable deep reinforcement learning for space situational awareness: counterfactual explanation approach. In *2024 IEEE Aerospace Conference*, Big Sky, MT, IEEE, Mar. 2024.
24. Pearl, J. *CAUSALITY* (2nd ed.). Los Angeles, CA: Cambridge University Press, 2009. Last access Dec. 13, 2022 [Online]. http://bayes.cs.ucla.edu/BOOK-2K/
25. Pearl, J., and Mcckenzie, D. *The Book of Why: The New Science of Cause and Effect*. New York, NY: Basic Books, 2018.

Ali K. Raz, Ph.D. CSEP, is an assistant professor at George Mason University Systems Engineering and Operations Research department and an assistant director of Intelligent Systems and Integration at the C5I Center. His research and teaching interests are understanding collaborative autonomy and developing systems engineering methodologies for integrating autonomous systems with machine learning and information fusion. He holds a BSc. and MSc. in electrical engineering from Iowa State University and a Ph.D. in aeronautics and astronautics from Purdue University. He is a co-chair of INCOSE AI Working Group and a senior member of AIAA and IEEE.

Erik P. Blasch, Ph.D., is a program officer with the Air Force Research Laboratory. He received his B.S. in mechanical engineering from the Massachusetts Institute of Technology and his Ph.D. in electrical engineering from Wright State University in addition to Master's degrees in mechanical engineering, industrial engineering, electrical engineering, medicine, military studies, economics, and business. Additionally, his assignments include USAF Officer (retired)., adjunct associate professor, and president of professional societies. He is an experienced engineer with a demonstrated history of working in government administration, military operations, academic settings, and industrial innovation. His research includes information fusion, space-aware tracking, industrial avionics, and human factors designs, compiling 11 books, 62 patents, 170+ journal articles, and 500+ papers. He is a Fellow of AIAA (astronautics), IEEE (electrical), MSS (sensing), RAeS (aerospace), and SPIE (optical) societies.

Kuo-Chu Chang, Ph.D., is a professor of systems engineering and operations research department at George Mason University. He received his M.S. and Ph.D. degrees in electrical engineering from the University of Connecticut. His research interests include estimation theory, data fusion, Bayesian inference, machine learning, and financial engineering. He has more than 40 years of industrial and academic experience and has published more than 300 papers in the areas of multitarget tracking, distributed sensor fusion, Bayesian Networks technologies, and quantitative finance. He is an IEEE Fellow.

ISIF 25th Anniversary

2023 marks the 25th Anniversary of the International Society of information Fusion. As part of this celebration, we would like to honor and remember not only the technical achievements in our field, but also the people, places, events, and more. ISIF is collecting videos, photos, and short stories (250 words max.) from its members. Please find the form to make your contribution on: https://isif.org/isif-25th-anniversary-celebration-0

Disclaimer: This content may be used on our social media, website site, marketing materials, and more. Content must be owned by the submitter and cannot contain copyrighted material. By submitting photos, videos, and written content, you grant ISIF the right to use and distribute the submitted materials.

A Close Encounter of the First Kind* with ChatGPT

James Ferry
Metron, Inc.
Reston, Virginia, USA
ferry@metsci.com

How can Large Language Models (LLMs) like ChatGPT assist us with our technical work? True believers in Artificial Intelligence (AI) insist that those who leverage LLMs will displace those who don't during a chaotic transition period before AI makes human intelligence obsolete. Skeptics are unconvinced. They see ChatGPT as a souped-up search engine, rather than agent of societal upheaval. Whether harbinger of the AI singularity or mere shiny new toy, I didn't want to miss out. So, in early 2023, as LLMs were beginning to make headlines, I signed up for a paid subscription to OpenAI and looked for excuses to use it. Like many people, I found it helpful for generating snippets of code with the correct syntax. But could it do "real" math?

Shortly thereafter, I received the following late-night email from my colleague Roy Streit. "Jim, I encountered this problem today and thought of you. An orthogonal matrix Q is used to rotate an axis-aligned, origin-centered box in R^n. What is the smallest axis-aligned box that contains the rotated box? It seems like this ought to be easy, but it's late and I don't see a way to do it that doesn't require $O(2$^$n)$ calculations."

Hmm. Me neither. Perhaps the day has arrived when we handle such questions as offhandedly as using a calculator or performing a Google search. I pasted the question into ChatGPT 4, but left off the final sentence about efficiency. This rendered the question rather trivial. Would it be able to give a sensible mathematical answer to this easy version of the question?

Yes. ChatGPT noted that the box's "corners can be represented by points whose coordinates are all possible combinations of $\pm a_i$" where "a_i represents the half-length of the box along axis i." Apply Q to each of these corner points, find the maximum absolute value in each coordinate i, and then double the results to convert to side lengths. Very sensible.

But now came the real test. I responded, "Your algorithm is $O(2$^$n)$. Can you do this in polynomial time in n?"

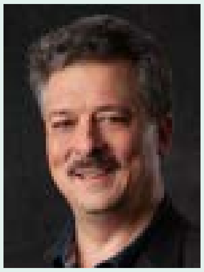
"Yes," ChatGPT responded without hesitation. Its response was long and thorough, so I'll summarize. It noted that the values of the i^{th} coordinate of the transformed box are the 2^n values $\pm Q_{i1}a_1 \pm Q_{i2}a_2 \pm \cdots \pm Q_{in}a_n$, where the Q_{ij} comprise the i^{th} row of Q. The maximum over these 2^n values is achieved when the signs are chosen to make each coefficient $\pm Q_{ij}$ non-negative. Therefore if we let $\vec{a}$ and $\vec{b}$ be the respective half-lengths (or, if you prefer, lengths) of (a) the original box and (b) the bounding box of its transformed version, then $\vec{b} = M\vec{a}$, where $M = \text{abs}(Q)$ is the matrix of entry-wise absolute values of Q.

Roy and I were delighted by the result. Neither of us had encountered, before now, the entry-wise absolute values of a matrix forming a useful operator. We were also curious about whether ChatGPT was truly reasoning, or leveraging a pre-existing solution from its training data, or something in-between. ChatGPT does not offer insights into how it generates its results. Microsoft Copilot does: it answered the original question, which did not ask for efficiency, with the efficient $O(n^2)$ solution, and when asked how it did this, it asserted that it reasoned it out for itself. I almost expected it to add, "and I'm offended that you would even ask."

LLMs are strange tools. They can pass for human in a sufficiently casual Turing test but are prone to outputting all-too-plausible nonsense. So far, I remain a casual user—I haven't tried to hone my prompt engineering skills, for example, or played with power tools like Auto-GPT. But I look forward enhancing my productivity by staying plugged into the technology as it evolves, whether it shepherds us into some brave new world or just the latest iteration of our current one.

* "Visual sightings of an unidentified flying object, seemingly less than 500 feet (150 m) away, that show an appreciable angular extension and considerable detail." https://en.wikipedia.org/wiki/Close_encounter

James Ferry, Ph.D., is a Principal Research Scientist at Metron, Inc. He specializes in applying Bayesian methods to solve Defense and Intelligence problems in a variety of domains, such as test and evaluation, tracking and data association, machine learning, and network science. He has 30+ publications in these and other areas. Prior to joining Metron in 2004, Dr. Ferry developed supercomputer simulations of multiphase fluid flows as a Research Scientist at the Center for Simulation of Advanced Rockets at the University of Illinois. He holds a Ph.D. in applied mathematics from Brown University and an S.B. in mathematics from MIT.



2024 ISIF Awards

W. Dale Blair
Georgia Tech Research Institute
Smyrna, GA, USA
dale.blair@grti.gatech.edu

2024 ISIF LIFETIME OF EXCELLENCE AWARD

The ISIF Board of Directors and the ISIF Awards Committee are pleased to announce that Prof. Peter Willett is the recipient of the highly prestigious 2024 *ISIF Yaakov Bar-Shalom Award for a Lifetime of Excellence in Information Fusion*. Prof. Willett's contributions to fusion of very low observable tracks, high-resolution measurement extraction, and leadership in formation and growth of ISIF are the basis for his nomination. The 2024 award will be presented at the 2024 FUSION conference in Venice, Italy in July 2024.

Prof. Peter Willett, 2024 recipient.

Prof. Willett received his BASc. in Engineering Science from the University of Toronto in 1982 and his Ph.D. from Princeton University in 1987. He has been a faculty member in the Electrical and Computer Engineering Department at the University of Connecticut since 1986. He was promoted to Professor in 1998. The IEEE elevated him to IEEE Fellow in 2003 for "contributions to detection, target tracking, and signal processing." His primary areas of research are statistical signal processing, detection, communications, data fusion, and tracking. Prof. Willett is very active in the organization of the *ISIF International Conference on Information Fusion* (FUSION). He served as Editor-in-Chief (EIC) of *IEEE Signal Processing Letters* from 2014-2016 and *IEEE Transactions on Aerospace and Electronic Systems* from 2006-2011. He served as Associate Editor and EIC for the *IEEE Aerospace and Electronic Systems Magazine* (2018-2022). He was Aerospace and Electronic Systems Society (AESS) Vice President for Publications, 2012-2014, and is Vice President for Finances, 2022-2024. From 1998-2005, he was an Area Associate Editor for three active journals: *IEEE Transactions on Aerospace and Electronic Systems* (for Data Fusion and Target Tracking) and *IEEE Transactions on Systems, Man, and Cybernetics* (parts A and B). He is a member of the IEEE AESS Board of Governors and of the *IEEE Signal Processing Society's Sensor-Array and Multichannel (SAM)* technical committee and was SAM-TC Chair (2014-2016).

The ISIF Lifetime of Excellence Award is the premier ISIF award given to a researcher or engineer in recognition of their outstanding contributions to the field of information fusion throughout their career. Contributions include technical advances, technical vision and leadership, education and mentoring, novel applications of information fusion and the associated engineering achievements, and service to ISIF. The initial award was given to Yaakov Bar-Shalom (2015), for whom the award was later named. Subsequent awardees were Chee-Yee Chong (2016), Pramod Varshney (2018), Ed Waltz (2021), and Roy Streit (2023).

2024 ISIF YOUNG INVESTIGATOR AWARD

The ISIF Board of Directors and the ISIF Awards Committee are pleased to announce that the recipient of the 2024 ISIF Young Investigator Award is Dr. Domenico Gaglione. The basis for Dr. Gaglione's award is his many contributions to the development of graph-based heterogeneous multi-sensor multi-target tracking algorithms to enhance maritime situational awareness. Dr. Paolo Braca nominated Dr. Gaglione for the 2024 award. It will be presented at the 2024 FUSION conference in Venice, Italy in July 2024.

Dr. Domenico Gaglione, 2024 recipient.

Dr. Gaglione received B.Sc. and M.Sc. in Telecommunications Engineering from University of Naples "Federico II" in 2011 and 2013, respectively. He received the Ph.D. in Signal Processing from University of Strathclyde in Glasgow, UK in 2017. Dr. Gaglione's research is centered on the advancement of techniques and algorithms within the domain of information fusion and signal processing with the primary objective of augmenting the maritime situational awareness. His main research focus regards the formulation of graph-based algorithms for various applications.

The ISIF Young Investigator Award is sponsored by the ISIF to acknowledge international recognition of outstanding contributions to the field of information fusion by an ISIF member under age 35. The goals of the ISIF in granting the award are to encourage individual effort and to foster increased participation by younger researchers and engineers. Past recipients are David Crouse (2016), Marcus Baum (2017), Karl Granström (2018), Florian Meyer (2021), and Florian Pfaff (2023).

FUSION 2023 Conference Awards

Zoran Sjanic
Saab AB, Sweden
Linköping University, Sweden
zoran.sjanic@liu.se

Samuel Shapero
Georgia Tech Research Institute, USA
samuel.shapero@gtri.gatech.edu

In 2023, Charleston, South Carolina welcomed the 26th International Conference on Information Fusion. This year, 153 papers were presented at the conference and published in the conference proceedings. All of these were nominally eligible for the Best Paper awards, in either the Student or Regular Paper categories.

The selection of the Best Student and Regular Paper and the runners-up was overseen by the Awards Committee, chaired by Samuel Shapero and Zoran Sjanic, that also included Yaakov Bar-Shalom, Chee-Yee Chong, and Jean Dezert. Downselection of the Best Papers occurred in multiple stages. Following peer review, the conference Technical Chairs ranked the papers by an average of the reviewers' scores and sent the top twelve papers in each category to the Awards Committee Chairs. To avoid a potential conflict of interest for the Best Student Paper award, Dr. Sjanic handled the regular papers, and Dr. Shapero handled the student papers.

Dr. Sjanic selected six regular papers, and Dr. Shapero selected eight student papers for the final ranking of the committee, based on their own close reading and more detailed metrics from the reviewers, while including the recommendation for awards and the reviewer's confidence in their assessment. The 14 finalists were sent to the remaining Awards Committee members, who independently reviewed and scored the finalists for rigor, technical excellence, and inspiration. The Awards Chairs used these scores to select the winner and two runners-up in each category.

The winners and runners-up were recognized at the Gala Dinner of the FUSION 2023 conference. On behalf of ISIF, we offer congratulations to all candidate papers with an obvious special mention to the winners!

2023 Jean-Pierre Le Cadre Best Paper award was presented to Marco Cominelli and Lance Kaplan by Sam Shapero and Zoran Sjanic.

JEAN-PIERRE LE CADRE BEST PAPER AWARD

- Best Paper: Marco Cominelli, Francesco Gringoli, Lance M. Kaplan, Mani B. Srivastava, and Federico Cerutti, "Accurate Passive Radar via an Uncertainty-Aware Fusion of Wi-Fi Sensing Data"
- First Runner-up: Anne-Laure Jousselme, Pieter de Villiers, Allan de Freitas, Erik Blasch, Valentina Dragos, Gregor Pavlin, Paulo C. Costa, Kathryn B. Laskey, Claire Laudy, "Uncertain about ChatGPT: enabling the uncertainty evaluation of large language models"
- Second Runner-up: Kisung You, Dennis Shung, "On the Spherical Laplace Distribution"

BEST PAPER (JEAN PIERRE LE CADRE AWARD)

Marco Cominelli, Francesco Gringoli, Lance M. Kaplan, Mani B. Srivastava, and Federico Cerutti, "Accurate Passive Radar via an Uncertainty-Aware Fusion of Wi-Fi Sensing Data"

Abstract—Wi-Fi devices can effectively be used as passive radar systems that sense what happens in the surroundings and can even discern human activity. We propose, for the first time, a principled architecture which employs Variational Auto-Encoders for estimating a latent distribution responsible for generating the data, and Evidential Deep Learning for its ability to sense out-of-distribution activities. We verify that the fused data processed by different antennas of the same Wi-Fi receiver results in increased accuracy of human activity recognition compared with the most recent benchmarks, while still being informative when facing out-of-distribution samples and enabling semantic interpretation of latent variables in terms of physical phenomena. The results of this paper are a first contribution toward the ultimate goal of providing a flexible, semantic characterization of black-swan events, i.e., events for which we have limited to no training data.

Erik Blasch, Anne-Laure Jousselme, Paulo Costa, Claire Laudy, Gregor Pavlin, and Valentina Dragos were awarded First Runner-up, pictured with Sam Shapero.

Frida Viset was awarded the 2023 Tammy L. Blair Best Student Paper award by Zoran Sjanic and Sam Shapero.

BEST STUDENT PAPER (TAMMY L. BLAIR AWARD)

Frida Viset, Rudy Helmons and Manon Kok, "Distributed Multi-Agent Magnetic Field Norm SLAM with Gaussian Processes"

Abstract—In indoor environments, accurate position estimation of multi-agent systems is challenging due to the lack of Global Navigation Satellite System (GNSS) signals. If the multiagent system relies upon noisy measurements of the change in position and orientation, the integrated position estimate can drift potentially unboundedly. Magnetic field simultaneous localization and mapping (SLAM) has previously been proposed as a way to compensate for position drift in a single agent. We propose two novel algorithms that allow multiple agents to apply magnetic field SLAM using their own and the other agents' measurements.

Our first algorithm is a centralized algorithm that uses all measurements collected by all agents in a single extended Kalman filter. The algorithm simultaneously estimates the agent's position and orientation and the magnetic field norm in a central unit that can communicate with all agents at all times. In other applications, there is no central unit available, and there are communication drop-outs between agents. Our second algorithm is therefore a distributed algorithm for multiagent magnetic field SLAM, that can be employed even when there is no central unit, and when there are communication failures between agents.

TAMMY L. BLAIR AWARD

- Best Student Paper: Frida Viset, Rudy Helmons and Manon Kok, "Distributed Multi-Agent Magnetic Field Norm SLAM with Gaussian Processes"
- Best Student Paper Runner-up (tie): Anton Kullberg, Isaac Skog and Gustaf Hendeby, "Iterated Filters for Nonlinear Transition Models"
- Best Student Paper Runner-up (tie): Joseph Johnson, Yaman Kindap and Simon Godsill, "Inference for Variance-Gamma Driven Stochastic Systems"

Anton Kullberg and Joseph Johnson were recognized as runners-up (tie) for Best Student Paper, pictured with Zoran Sjanic.

ISIF Working Groups Report

Darin Dunham
Lockheed Martin
Huntsville, Alabama, USA
dunhamdt@gmail.com

UPDATES ON WORKING GROUPS

International Society of Information Fusion (ISIF) sponsors working groups by providing recognition, status, and support. The support includes a meeting place during the FUSION Conference and related website links. It can also include support for virtual meetings. The working groups bring together researchers who share a common interest. For more information, or to submit a proposal for a new working group, please see the ISIF website: https://isif.org/about/working-groups/isif-working-groups or contact Darin Dunham, Vice President Working Groups. Currently, there are currently two working groups that ISIF supports. Here is a quick summary of their focus areas and activities.

ETUR WORKING GROUP ACTIVITIES BY PAULO COSTA (GMU) AND ANNE-LAURE JOUSSELME (CS GROUP)

The Evaluation of Techniques for Uncertainty Representation Working Group (ETURWG) was discussed at FUSION 2010 in Edinburgh and charted by the ISIF BoD in July 2011. Since its inception, the group organizes special sessions at the FUSION conference every year, edited a JAIF special issue (vol. 13, issue 2, Dec. 2018), organized a tutorial at FUSION 2020, and holds bi-weekly meetings (142 so far) gathering 78 members including roughly 15 core members. ETURWG provides a forum for collectively evaluating techniques for assessing, managing, and reducing uncertainty. Activities include establishing features required for any quantitative uncertainty representation to support the exchange of soft and hard information in a net-centric environment, developing a set of use cases involving information exchange and fusion requiring reasoning and inference under uncertainty, and defining evaluation criteria supporting unbiased comparison among different approaches applied to the use cases. The ETURWG encourages a community experience within the areas of focus.

Recent progress includes:

- A methodology to enable formal analysis of Large Language Models (LLMs) uncertainty handling, supported by the Uncertainty Representation and Reasoning Framework (URREF) ontology. The experimental setup proved its efficiency in capturing aspects of ChatGPT uncertainty handling. This piece of work was recognized as the first runner-up paper at FUSION 2023 (see page 22).
- Identified possible modifications to the URREF ontology that will be discussed and eventually implemented in URREF ontology Version 4.0 under development.
- An analysis of the machine learning problem complexity utilizing Qualitative Models of Data Generating Processes (QM-DGP). The approach: (i) informs the design of the models, such that the relevant information can be absorbed through machine learning; and (ii) enables determination of the quantities of training data required for learning of good quality models.
- The first challenge for high-level information fusion, submitted at the FUSION 2024 conference. Participants to this challenge should propose AI solutions to increase pilots' situational awareness by fusing flight-related information disseminated via "Notice to Airmen" (NOTAMs) https://hlif-challenge.s3g-labs.fr/.

The group will focus in 2024 on advancing the design of an URREF-driven workflow for heterogeneous data fusion as well as the analysis of the framework's strengths and limitations.

STONE SOUP BY PAUL THOMAS (DSTL)

The other working group supported by ISIF is the Open-Source Tracking and Estimation Working Group (OSTEWG), also known as the Stone Soup project. It exists to provide the tracking and state estimation community with a framework for the development and testing of algorithms. The working group has formed a community focused on development of a software architecture which allows code components to be plugged-in in a modular fashion, such as algorithms, sensor models and simulators. The idea is to provide a flexible and unified software platform for researchers to develop, test, and benchmark a variety of existing multi-sensor and multi-object estimation algorithms. It also aims to allow rapid prototyping of new algorithms in Python by providing a set of libraries that implement the necessary functions for tracking and state estimation, together with metrics for their evaluation.

- OSTEWG currently has 48 members.
- The working group meets every year at the FUSION conference.
- The meeting comprises 'development-level' briefings and discussions (i.e., less mature and more collaborative than full FUSION papers).
- Competitive awards ("The Mini-Stronies") are presented at the FUSION conference for: (i) best Stone Soup contribution; (ii) most improved class; (iii) small code contribution; and (iv) best documentation.
- OSTEWG will hold a special session at FUSION 2024.

FUSION 2023 REPORT

Terry Ogle and Darin Dunham
General Chairs of Fusion 2023

The 26th International Conference of Information Fusion, FUSION 2023, was held in Charleston, South Carolina, USA from June 27-30, 2023. Despite significant flight delays and cancellations along the East Coast caused by severe summer storms, holiday travel, and a shortage of air traffic controllers in the Northeast, most attendees made it to Charleston to enjoy FUSION 2023. The last U.S.-based ISIF conference was held in Washington, DC, FUSION 2015. In 2019, we proposed Charleston for its meticulously preserved history, walkability, charm, and hospitality. Since 2013, Charleston has been named the No. 1 city in the United States by Travel + Leisure! It has also had one of the fastest-growing airports in the nation for several years.

Charleston, South Carolina, has a documented history of over three centuries and is one of America's most culturally rich and historically significant cities. Founded in 1670 by English colonists, Charleston served as a trade and commerce hub in the colonial era becoming a vital port city as it is today. Charleston had a varied history with a role in the transatlantic slave trade and roles in the American Revolutionary War and Civil War. The city has numerous architectural sites such as antebellum mansions, stately churches, and colorful row houses (i.e., Rainbow Row) that reflect its diverse history. Charleston is known for its cultural heritage from the Gullah Geechee people, African descendants in the South Carolina Lowcountry. Charleston provides a window into the past with its historic sites, museums, and vibrant neighborhoods that tell a story over the centuries.

The Charleston Place Hotel, located in the heart of downtown overlooking the historic City Market, was home to FUSION 2023. Our conference attendees enjoyed over 40,000 square feet of onsite meeting space and four-star accommodations with easy access to world-renowned restaurants, numerous historic sites, the City Market, upscale shopping, and great views along the Charleston Harbor.

Opening Plenary Session with Henrik Christensen

Here are a few comments from the post-event participant survey:

- "The conference felt very relaxed. I had plenty of time to chat with colleagues and explore Charleston. I also loved the 5k. Photos were great."
- "It was well organized. The activities were right next to the hotel such that you could do both the conference and the sightseeing. Probably attended the most events of a Fusion conference."
- "Charleston was a great city to have the conference in."

- "Hard to choose. I got so much new and interesting research input and made many new professional connections. In spectacular surroundings!"
- "Beautiful venue, supportive staff, plenty of food."
- "Apart from the program, rich in content, the social events were really good and helped a lot to break the ice between people."

In total, Fusion 2023 had 273 attendees and 24 guests from 23 unique countries. There were 191 paper submissions from 699 contributing authors. Multi-sensor & multi-target tracking, defense & security, and nonlinear filtering & Monte Carlo methods were the top three topic areas for submissions. The program committee consisted of 225 reviewers who submitted 717 paper reviews. Each paper had at least 3 reviews with 3.75 reviews on average. Ultimately, the technical committee, Peter Willett, Marcus Baum, Florian Meyer, Anne-Laure Jousselme, and Gustaf Hendeby, did a fantastic job and accepted 155 papers for a 0.81 acceptance rate. The program chairs, Stefano Coraluppi and Ondřej Straka, meticulously arranged 154 conference papers and 3 journal paper presentations into 12 sessions. There were also 9 special sessions included, selected by Murat Efe and Terence van Zyl. Our publication chairs, Felix Govaers and Paolo Braca, ensured that the papers presented were published on IEEE Xplore.

Erik Blasch giving Introduction to Information Fusion at Fusion Boot Camp

Fusion 2023 had 84 student attendees, nearly one-third of the conference attendees. This infusion of new talent and interest speaks volumes about the future of ISIF and information fusion. In organizing this conference, we focused on student engagement and introduced 'student' name badge tags to ensure sponsors and industry partners could readily identify students to welcome them to our organization. On the day before the conference, 35 students and professionals participated in the inaugural Fusion Boot Camp, a full day of introduction to information fusion courses. Sessions included introductions to information fusion by Erik Blasch, estimation techniques led by Dale Blair, and discussions on data association facilitated by Stefano Coraluppi. Following lunch, the afternoon encompassed distributed target tracking with Felix Govaers, fusion and association with attributes/classification with Yaakov Bar-Shalom, distributed inference and information fusion with Pramod Varshney, and high-level fusion presented by Lauro Snidaro and Erik Blasch. A warm shout-out to each speaker for volunteering their time for this amazing event. Following the boot camp, everyone was invited to socialize and network at the IEEE Young Professionals Reception in the Grand Hall.

Student attendees enjoying the Icebreaker after Tutorials

On Tuesday, we hosted 10 tutorials in two sessions, morning and afternoon. The morning session consisted of:

- High-Level Information Fusion Theory meets AIM by Eric Blasch,
- An Introduction to Track-to-Track Fusion and the Distributed Kalman Filter by Felix Govaers,
- Multitarget Tracking and Multisensor Information Fusion: Recently Developed Advanced Algorithms by Yaakov BarShalom,
- Graph-Based Localization, Tracking, and Mapping by Erik Leitinger,
- Estimation and Tracking of Graph Signals by Tirza Routtenberg, and
- Systematic Filter Design for Tracking Maneuvering Targets: Getting Guaranteed Performance Out of Your Sensors by Dale Blair.

Following lunch, the afternoon session included:

- Deep Learning for Multispectral, Multiresolution, and Multisensor Data Fusion by Fahimeh Farahnakian,
- The Basics of Belief Functions and More by Dan Harris,

- Algorithms for Estimation of Noise Parameters in State Space Models by Ondrej Straka, and
- Quantum Computing and Quantum Physics Inspired algorithms: Introduction and Data Fusion Examples by Martin Ulmke.

There were 137 tutorial registrations, with graph-based localization, estimation of noise parameters, and belief functions being the most popular subjects for Fusion 2023. In all, there were 93 tutorial attendees with 44 students taking both morning and afternoon tutorials. Paul Miceli, David Crouse, and Ali Raz were tutorial chairs for Fusion 2023 and did an outstanding job organizing our tutorials.

Kellyn Rein presented on HUMINT - Context, Meaning, and the Mythical 'Meat Sensor'

Roy Streit, Fusion 2023 Plenary Chair, arranged for three plenary sessions at Fusion 2023. Henrik Christensen, the Qualcomm Chancellor's chair on robot system and a distinguished professor of computer science and engineering at UC San Diego presented 'Multi-Sensory Fusion for Micro-Mobility', a discussion of sensor mixtures used in autonomous vehicles for campus mail delivery. Kellyn Rein, retired from the Research Institute for Communication, Information Processing Ergonomics (FKIE) at Fraunhofer Gesellschaft, presented 'HUMINT – Context, Meaning and the Mythical "Meat Sensor"', a discussion about data collection and processing from human sources. Victoria Rubin presented 'Artificial and Human Intelligence Solutions to Combat Mis- and Disinformation: Examples, Methodologies, Limits', a talk on the spread of disinformation and its effect on decision-making.

Making connections and making memories at the Fusion photobooth

Social interactions were also a focus in planning Fusion 2023. A photo booth was set up in the Grand Hall during the conference which provided a fun opportunity for engagement and a mechanism for social media posts.

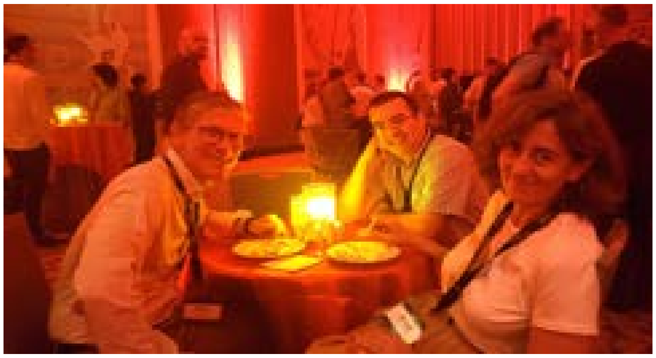
The Icebreaker was held outdoors in the Market Street Circle in front of the Charleson Place with live music provided by Garrett Arwood & the Centennials from Nashville, TN. Dale Blair showed off his moves on the dance floor getting everyone excited to attend dance lessons throughout the weeklong conference. During the Icebreaker, attendees had the opportunity to take guided carriage rides through historic downtown Charleston.

Icebreaker participants leaving on a carriage ride around Charleston

Dale Blair giving dance lesson attendees a taste of what's to come at the Icebreaker!

The welcome reception for Fusion 2023 was held at the historic Riviera Theatre directly across King Street from the conference venue. The Riviera is a revitalized Art Deco masterpiece from the 1930's where everything boasted luxury and extravagance. Fusion 2023 participants were transported back in time to a prohibition era speak-easy disguised as a movie theatre with food and drinks, live music, and dancing. The band was led by Nathan Byers who also developed the Fusion 2023 conference website!

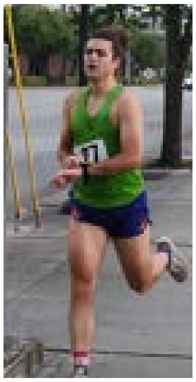
What appears to be the Riviera Theater on the outside was turned into a speakeasy on the inside

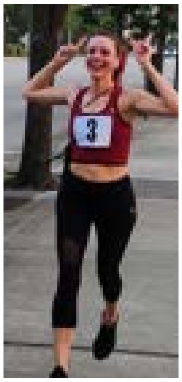


Good times at the speakeasy!

This year we had two athletic events – a 5K run and a golf tournament. You may not know that Charleston built America's first golf course, Harleston Green, and organized the first club, the South Carolina Golf Club, in 1786. Today, Charleston boasts several first-class golf courses, including the Wild Dunes Harbor Course, designed by Tom Fazio, where we held the tournament. The Harbor Golf Course is known for its challenging design and beautiful views, and most of all, water. The inaugural golf tournament was a success, and Paul Miceli took first place.

The FUSION 2023 5K Run challenged our 27 competitors to a grueling climb in the first half. The run took them to the peak of the Cooper River Bridge (a gain of 250 feet with a max grade of 4.8%) and back to the historic Cigar Factory building for breakfast. The run was modeled after the Annual Cooper River Bridge 10k which is the third largest 10K and the fifth largest road race in the United States. Despite the early morning humidity, a beautiful sunrise and fantastic views of the Charleston Harbor created a memorable experience for all. Ryan Beeson (time:18:33 min) and Paul Miceli (time: 19:12 min) finished first and second for the men's category, and Clara Menzen (time: 27:40 min) and Samantha LeGrand (time: 28:18 min) finished first and second for the women – and 2023 marks the first time the women's finish has been recognized.





27 Runners participated in the 5K Fusion Run over Cooper River Bridge

1st Place Male - Ryan Beeson
1st Place Female - Clara Menzen

The Fusion 2023 gala dinner was held in the Grand Ballroom of The Charleston Place. Lawrence Stone of Metron opened the event with a presentation on 'Finding Lost Gold Cities in Ecuador'. Larry's presentation was a perfect complement for this conference, as finding and preserving lost shipwrecks off the coast of Charleston is near and dear to the heart of the local residents.

Lawrence Stone presented the "Lost City of Gold"

The Golden Gala Dinner - Featuring the Emerald Empire Band and 25 Years of Fusion Presentation

The décor for Fusion 2023 was that of antiqued gold artwork and decorations with a celebration of the 25 years of ISIF conferences. The handmade table centerpieces for the banquet were each an example of fusion in gilded gold art – representing the Charleston pineapple fountain, the ISIF logo, and the state flag of South Carolina. During dinner, Dale Blair and Yaakov Bar Shalom presented the ISIF society awards, and Sjanic Zoran and Sam Shapero, presented the Fusion 2023 conference awards.

At Fusion 2023, attendees were presented with a diverse array of excursion options to enrich their conference experience. One such adventure allowed participants to delve into naval history with a visit to the USS Yorktown, a storied aircraft carrier with a rich legacy dating back to World War II. On a captain's guided tour, attendees gained exclusive access to areas typically off-limits to the public, exploring the original captain's quarters, the anchor room, and even climbing aboard a B-25 bomber. This excursion provided a captivating glimpse into the daily life of sailors at sea, spanning pivotal moments in history from World War II to the recovery of the Apollo 8 space capsule. Along with a scenic water taxi ride, the excursion also offered great views of the harbor, dolphins, and a harborside lunch.

Alternatively, participants seeking a journey through the annals of Southern heritage embarked on an excursion to the Boone Hall Plantation, a historic estate steeped in centuries of tradition. Founded in 1681, the plantation's majestic live oak-lined entrance served as a picturesque backdrop for guided tours of the grounds, including the plantation house, slave quarters, garden, and butterfly pavilion. Afterward, attendees savored a Southern family-style lunch.

The final excursion for Fusion 2023 was a historic walk-through downtown Charleston. Starting at the historic Cigar Factory on East Bay Street, home to the Clemson Design Center in Charleston (CDC.C) - a unique collection of design and preservation programs. We learned about Clemson's preservation programs with Charleston's foremost experts in architectural conservation, architectural history, landscape preservation, and urban/preservation planning. Then we visited the Aiken-Rhett House – the city's most intact antebellum urban complex with slave quarters and a work yard. After a southern farm-to-table style brunch, we walked to some amazing places hidden around downtown Charleston. We wrapped up our day at the Preservation Society of Charleston store on King Street to pick up some unique treasures of Charleston to share on our return home!

On the flight deck of the USS Yorktown

Architectural history at the Aiken-Rhett House

Sponsorship is an important part of any conference and Fusion 2023 was no exception. In total, we raised $32,500 in sponsorships for Fusion 2023. To show our appreciation, we put a lot of emphasis on sponsor and student engagement during the conference. Sponsors were strongly encouraged to set up exhibits and engage students and professionals. Lockheed Martin graciously donated as a Gold level sponsor of Fusion 2023, Mitsubishi Electric as a Bronze level sponsor, Metron as Silver level, and finally, Information Fusion Technologies (IFT), MathWorks, Systems & Technology Research (STR), and Clemson University each as Exhibitor level sponsors. Fusion 2023 would not have been as successful without our sponsors!

The Grand Hall was constantly buzzing with coffee and participants visiting sponsor booths

As we close out Fusion 2023, our treasurer, Phil West, will no doubt be responding to tax and audit questions, but in the end, we managed to make a small profit. Thank you to everyone for coming and making Fusion 2023 a great success! We would also like to thank the ISIF Board of Director's for the opportunity to host Fusion 2023 in Charleston, SC. A special thank you to everyone on the organizing committee - this would not have been possible without you. And last, but not least, a note of gratitude to Clemson University for all the help in pulling off this amazing event off! Finally, it isn't a party until something gets broken – Peter Lovassy, we hope you have fully repaired.

We will leave you with some pictures of the committee... See you next year in Italy for Fusion 2024!

BFTA 2023 Report

BRIEF REPORT ON THE BELIEF FUNCTIONS AND THEIR APPLICATIONS SCHOOL 2023

Van-Nam Huynh
Japan Advanced Institute of Science and Technology
Ishikawa, Japan
huynh@jaist.ac.jp

Thierry Denoeux
University of Technology of Compiègne
Compiègne, France
thierry.denoeux@utc.fr

Anne-Laure Jousselme
CS Group Research Lab, France
anne-laure.jousselme@csgroup.eu

Frédéric Pichon
David Mercier
Université d'Artois, France
frederic.pichon@univ-artois.fr
david.mercier@univ-artois.fr

The Belief Functions and Their Applications (BFTA) school is a biennial event organized by the Belief Functions and Applications Society (BFAS), offering a unique opportunity for students and researchers to learn about fundamental and advanced aspects of the theory of belief functions (also referred to as Dempster-Shafer theory, or evidence theory), a formalism for reasoning with uncertainty. BFTA 2023, the sixth edition of the school, was held in a hybrid mode at the Japan Advanced Institute of Science and Technology (JAIST) in Ishikawa, Japan, from October 27–31, 2023.[1]

Student poster session.

The school gathered 40 attendees who were lecturers, students, and senior researchers from 17 universities, research institutes, or companies from nine countries. The success of this event was greatly due to the ISIF, which covered some of the lecturer travel fees, as well as to BFAS, who awarded grants covering registration fees for four students from Singapore, China, Vietnam and France.

Twelve lectures and other activities were organized over four days. On 28 October, the school started with the lecture by Thierry Denoeux (University of Technology of Compiègne, France) on "Introduction to the Theory of Belief Functions," which presented fundamental concepts and issues in the theory. The second lecture by Prakash Shenoy (School of Business, University of Kansas, USA) presented "Graphical Belief Function

Participants and lecturers of the BFTA 2023 school.

[1] https://bfasociety.org/BFTA2023/

Models: Theory, Computation and Applications," introducing Dempster-Shafer theory (DST) of belief functions from the perspective of the so-called Valuation-based Systems, an abstract framework for several uncertainty calculi including belief function theory, probability theory, possibility theory, propositional calculus, with its local computational mechanism and applications. In his lecture on "Information Fusion in the Theory of Evidence," Frédéric Pichon (University of Artois, France) comprehensively explored the problem of combining multiple pieces of evidence represented by belief functions, with an in-depth discussion of Dempster's rule of combination and a jungle of alternative combination rules, as well as the issue of combination rule selection when reliability and/or independence of the evidence sources are not guaranteed. At the end of the day, a poster session was arranged to provide an opportunity for student participants to present their work and exchange with other school participants and lecturers.

The second day, 29 October, began with Thierry Denoeux lecturing on "Evidential Clustering," which addressed the issue of quantifying clustering uncertainty using DST and discussed several evidential clustering algorithms recently developed. Anne-Laure Jousselme (CS Group Research Lab, France) lectured on "Measuring Inconsistency in Evidence Theory," providing a survey on internal and external measures of inconsistency including entropy, specificity, conflict and distance measures and their applications. The afternoon was a break time for visiting local sights and the city of Kanazawa.

The third day, 30 October, started with the lecture by Chunlai Zhou (Renmin University of China) on "Differential Privacy for Belief Functions," which for the first time introduced new definitions of differential privacy corresponding to Shafer's semantics as randomly encoded messages and Walley's interpretation as imprecise-probabilities for belief functions and provided a hypothesis-testing framework for these definitions. Then from Raleigh, North Carolina, Ryan Martin (North Carolina State University, USA) remotely lectured on "Old and New Developments in (Consonant) Belief Functions for Statistical Inference," providing a general imprecise-probabilistic framework for statistical inference. Hieu-Chi Dam (JAIST) presented "Applications of Belief Functions for Exploring Novel Materials" to introduce a novel application of the Dempster-Shafer theory to materials science in materials modeling and discovery. From the city of Xi'an, China, Zhunga Liu (Northwestern Polytechnical University) closed the day by remotely presenting his lecture on "Pattern Classification with Belief Functions" that thoroughly discussed evidential models for pattern classification with multi-source and heterogeneous data.

On the last day, 31 October, Thierry Denoeux presented his third lecture "Epistemic Random Fuzzy Sets: Theory and Application to Machine Learning," introducing a more general theoretical framework unifying DST and fuzzy set theory for modeling uncertainty and demonstrating its application to machine learning. Van-Nam Huynh (JAIST) presented "Application of Dempster-Shafer Theory to Ensemble Classification and User Preferences," examining how DST could be applied in ensemble classification, recommendation and user preference modeling.

The afternoon began with a BFAS information meeting. During this meeting, Thierry Denoeux presented the society to new members and announced the next BELIEF conference to be held in Belfast, UK September 4-6, 2024.[2] Masahiro Inuiguchi (Osaka University, Japan) concluded the school with his lecture on "Application of Possibility Theory to Optimization and Decision Making." In the end of the day a live Q&A session and open discussion was organized, allowing the students to receive guidance from the lecturers about their research topics.

Videos of some of the lectures are available on the BFAS YouTube channel at https://www.youtube.com/@bfas_channel.

Lecture by Prof. Chunlai Zhou, Renmin University of China.

Tour of Kanazawa for the social event.

[2] https://bfasociety.org/Belief2024/

LAFUSION 2023 Report

LAFUSION 2023: A FIRST WORKSHOP IN INFORMATION FUSION IN LATIN AMERICA

Claudio Miceli de Farias
Federal University of Rio de Janeiro, Brazil
cmicelifarias@cos.ufrj.br

The culmination of months of meticulous planning and anticipation, the LAFUSION 2023 workshop, hosted by the Federal University of Rio de Janeiro, unfolded as a testament to the power of international collaboration in the realm of technology.[1] Last November 23rd in Rio, there was the first event of its kind. In this report, we delve into the multifaceted dimensions of the event, exploring its diverse participation, cutting-edge presentations, interactive panels, and the overarching impact it has had on the global technological landscape.

The LAFUSION workshop attracted participants from over 10 different countries of Latin America, underscoring its status as a truly international gathering of minds. Representatives from academic institutions, industry sectors, and research organizations converged at the event, bringing with them a rich tapestry of perspectives and experiences that served as the cornerstone of insightful discourse throughout the workshop. It was a hybrid conference with 80 attendees, with 50 in-person and 30 virtual participants. The workshop was streamed on YouTube which had nearly 400 views. The audience was vibrant and interactive.

Audience attending the first keynote.

Livestream presentation since LAFUSION was a hybrid workshop.

A cornerstone of the LAFUSION workshop was its lineup of presentations, which served as a platform for researchers and experts to showcase the latest advancements in various fields of Information Fusion. There were 20 papers presented, ranging from artificial intelligence and machine learning to environmental protection. Attendees were treated to a plethora of talks that elucidated groundbreaking research findings, emerging trends, and innovative methodologies driving the forefront of technological innovation.

Complementing the presentations were two panels, designed to provide attendees with practical, hands-on experience in cutting-edge technologies. Participants immersed themselves in intensive sessions, ranging from deep learning boot camps to blockchain hackathons, where they gained invaluable insights, honed their skills, and explored the potential applications of emerging technologies in real-world scenarios.

Dr. José Brancalion presented Embraer's research in the area of Information Fusion as well as several case studies. Those case studies gave the audience a view of the company's

[1] https://lafusion.cos.ufrj.br/

Prof. Eduardo Bezerra From CEFET-RJ presents a new Precipitation nowcasting method.

direction and research, and it was very interesting to see how research efforts outside academia can lead to remarkable results.

The second panel was given by Prof. Claudio Miceli and it intended to showcase approaches to prepare papers for the FUSION Conference. One of the goals of the workshop was to form and prepare an Information Fusion community to interact with the FUSION community worldwide. In this talk, Prof. Miceli showcased the most common mistakes and potential solutions in the papers submitted to the workshop.

Integral to the fabric of the LAFUSION 2023 workshop were the networking opportunities it afforded, serving as fertile ground for the cultivation of professional relationships and the exchange of ideas beyond the confines of formal sessions. Attendees engaged in vibrant discussions, forged meaningful connections, and laid the groundwork for future collaborations that promise to transcend borders and propel the Latin American Information Fusion community forward.

Three papers were awarded, and there was a tie for the Best Paper award. The papers "A Heterogeneous Data Integration for Vessel Activity Monitoring in Territorial Waters" and "ESS Technologies Evaluated by a Swarm Evolutionary Metaheuristic: An Information Fusion Concepts Application

Leonardo V. Acioly Filho was awarded the Best Paper.

in Smart Grids" both received the Best Paper award and authors received a 100% waive on FUSION 2024 registration. The paper "Enhancing Semantic Understanding in Command and Control: An Ontological Approach for Message Enrichment" received a Runner-up award. A special thanks go to the FUSION 2024 organizers and ISIF for their support.

In retrospect, the LAFUSION 2023 workshop stands as a testament to the transformative power of international collaboration in driving innovation. Through its diverse participation, cutting-edge presentations, interactive panels, and networking opportunities, the event not only facilitated the exchange of knowledge and ideas but also served as a catalyst for forging lasting partnerships.

As a direct result of LAFUSION 2023, an LAFUSION special session will be held at FUSION 2024 in Venice. We expect to see not only the extended versions of the papers presented in the LAFUSION 2023 workshop but also some new faces! Finally, LAFUSION 2024 is already in the making! Hope to see you all July in Venice and November in Rio.

FUSION 2025

For the first time FUSION is
coming to South America! Welcome to Rio!
FUSION 2025 welcomes full paper submissions (5 -8 pages).
All papers must be original (i.e., not previously published) and not currently under review by any other conference or journal.

Topics of Interest
include, but are not limited to:

Theory and Representation:
Probability theory, Bayesian inference, statistical-relational learning, representation learning, graph-based fusion models, argumentation, Dempster-Shafer theory, possibility and fuzzy set theory, rough sets, knowledge representation and reasoning, ontologies/semantics, logic-based representations, decision theory, random sets, finite point processes and others.

Algorithms:
Multi-modal information fusion, ML, AI and tinyml, soft fusion/MLP and LLMs, cognitive methods, sequential inference, data mining, behavioral analysis, signal processing, recognition, classification, nonlinear filtering, data association, tracking, prediction, situation assessment, fusion architectures, resource management , contextual adaptation, anomaly detection.

System Applications and Systemic Issues:
Soft-hard fusion, autonomous systems, distributed systems, cloud/edge computing/fusion, defense/security, robotics, intelligent transportation, mining/manufacturing, environmental observation/satellite/climate monitoring, disaster response, economics, e-health, bioinformatics, condition monitoring, video streaming, and other emerging applications.

Human in the Loop Applications:
User refinement/human-in-the-loop fusion (incorporating human input and feedback into the fusion process) and intelligent user interfaces for fusion systems, decision support.

Test and Evaluation:
Trust in fusion systems, explainability and uncertainty of fusion processes, computational methods, formal methods for fusion performance, benchmarks/testbeds.

Important Dates

Paper Submissions due: March 1, 2025
Acceptance Notification: May 1, 2025
Camera Ready due: June 1, 2025

ISIF International Society of Information Fusion
AESS IEEE Aerospace and Electronic Systems Society
IEEE

SDF–MFI 2023 Report

Felix Govaers
Wolfgang Koch
Fraunhofer FKIE, Germany
felix.govaers@fkie.fraunhofer.de

Florian Pfaff
University of Stuttgart, Germany

Uwe D. Hanebeck
Karlsruhe Institute of Technology, Germany

IMPRESSIONS OF THE IEEE SYMPOSIUM SENSOR DATA FUSION AND INTERNATIONAL CONFERENCE ON MULTISENSOR FUSION AND INTEGRATION (SDF–MFI 2023)

In November 2023, the highly anticipated conferences MFI and SDF Symposium took place together in Bonn, Germany, marking a significant event in the field of conferences with a focus on applications in target tracking, state estimation, and data fusion for automation and robotic systems. The event saw a robust participation of 99 attendees hailing from 16 different countries, including the United States and various nations across Asia, underscoring its international significance. Spanning three days, the conference was structured to facilitate not only the dissemination of cutting-edge research but also to foster networking and collaborative opportunities among participants.

DAY 1: TUTORIALS AND ICEBREAKER EVENT

The conference commenced with an engaging series of five tutorials grouped in morning and afternoon sessions, which aimed at providing attendees with in-depth knowledge on various aspects of sensor data fusion. These sessions were designed to cater to both newcomers and seasoned experts in the field, ensuring a comprehensive understanding of the subject matter.

The highlight of the evening was the icebreaker event held at a former brewery, where attendees enjoyed a joint dinner. This casual and welcoming setting provided an excellent opportunity for participants to network, discuss their work informally, and build connections that would last beyond the conference.

DAYS 2 AND 3: TECHNICAL PRESENTATIONS AND KEYNOTES

Over the course of the conference, 37 technical presentations were delivered across 12 sessions in two parallel tracks. The SDF Symposium format, with 30-minute time slots for each presentation, was highly effective in allowing speakers to delve deeply into their topics. This format also facilitated detailed discussions, enabling a thorough exploration of the ideas presented. The sessions focused on advances in methodology for estimation theory, intelligent systems, and navigation, but also provided insights into applications of camera processing for tracking and automotive driver assistance.

The heart of the conference was undoubtedly the keynote presentations delivered on the second and third days. Henk Blom, the founder of the Interacting Multiple Model scheme, captivated the audience with his insights on the application of AI in air transportation, highlighting the potential of artificial

Uwe Hanebeck opening the SDF Symposium and providing information on important parts of a conference.


Henk Blom starting his keynote on AI in air transportation.

intelligence to influence this critical sector. Following suit, Jörg Stückler presented on the following day, delving into visual SLAM methods and their implications for navigation and mapping technologies. These keynotes were not only informative but also inspirational.

The Gala Dinner served as a formal celebration of the conference's successes and achievements. During this event, the Best Paper awards (students and non-students) were announced, recognizing the exceptional contributions of researchers to the field of sensor data fusion. The evening was further enhanced by a stunning piano recital from Julia Rinderle[1], featuring pieces from

Martin Ulmke, Head of Distributed Sensor Systems at Fraunhofer FKIE, celebrates Markus Walker, recipient of the Best Paper award.

Pianist Julia Rinderle giving a wonderful recital and framing the gala dinner.

[1] https://juliarinderle.de/

ORGANIZATION AND AWARDS

Executive Chairs:

- Wolfgang Koch, Fraunhofer FKIE and University of Bonn
- Uwe D. Hanebeck, Karlsruhe Institute of Technology

Technical Chairs:

- Florian Pfaff, University of Stuttgart
- Felix Govaers, Fraunhofer FKIE

Program Chair:

- Manon Kok, Delft University of Technology

Tutorial Chair:

- Isabel Schlangen, Fraunhofer FKIE

Best Paper Award:

- Markus Walker, Marcel Reith-Braun, Peter Schichtel, Mirko Knaak, Uwe Hanebeck: *Identifying Trust Regions of Bayesian Neural Networks*

Best Paper Award Runner-up:

- Conor Rosato, Alessandro Varsi, Joshua Murphy, Simon Maskell: *An O(*$\log_2 N$*) SMC2 Algorithm on Distributed Memory with an Approx. Optimal L-Kernel*

Best Paper Award 2nd Runner-up:

- Kolja Thormann, Marcus Baum: *Single-Frame Radar Odometry Incorporating Bearing Uncertainty*

Best Student Paper Award:

- Jannik Springer, Marc Oispuu, Wolfgang Koch, Peter Knott: *Joint Emitter Localization and Calibration for Moving Array Sensors*

Best Student Paper Award Runner-up:

- Daniel Frisch, Uwe Hanebeck: *Deterministic Von Mises–Fisher Sampling on the Sphere Using Fibonacci Lattices*

Best Student Paper Award 2nd Runner-up:

- Alexander Scheible, Thomas Griebel, Martin Herrmann, Charlotte Hermann, Michael Buchholz: *Track Classification for Random Finite Set Based Multi-Sensor Multi-Object Tracking*

Chopin, Brahms, and Beethoven—a fitting tribute to the city of Bonn's most famous son.

The combined SDF-MFI 2023 conference was unequivocally a great success, marked by high-quality presentations, impactful keynotes, and fruitful networking opportunities. The careful organization of the event ensured that attendees had a rich and rewarding experience. As participants returned to their home countries, they carried with them not only new knowledge and insights but also valuable connections and memories from the conference.

All publications of SDF–MFI 2023 may be found in IEEE *Xplore.*[2] SDF 2024 will be held again in Bonn, Germany, November 25-27, separate from MFI 2024, which will take place September 2-4 in Pilsen, Czechia.

[2] https://ieeexplore.ieee.org/xpl/conhome/10361261/proceeding Organization and Awards

IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems

September 4-6, 2024, Pilsen, Czechia

www.mfi2024.org

Theory:
Probability theory, Bayesian inference, nonlinear estimation, Dempster-Shafer, fuzzy sets, logic, machine learning, neural networks, distributed architectures

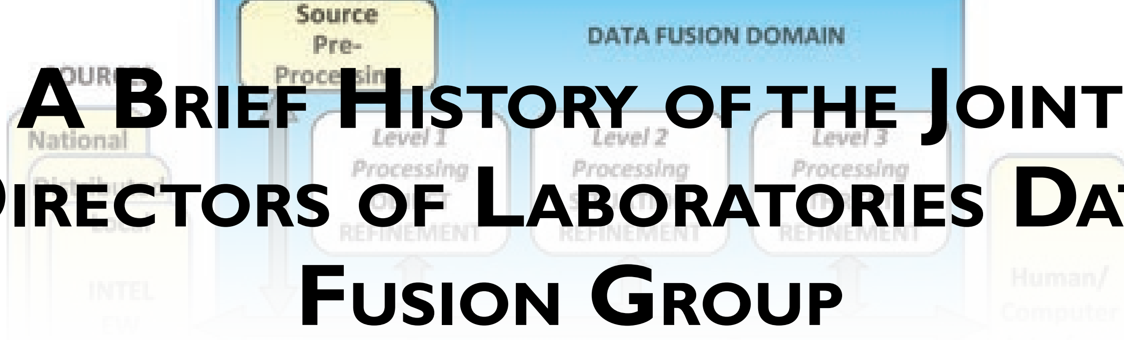
Sensors:
RGB and depth cameras, radar and sonar, laser scanner, infrared sensors, IMU

Algorithms:
Tracking and localization, SLAM, perception, AI in robotics, cognitive systems, sensor registration, big data, sensor management, distributed sensor systems, recognition, visual servoing, learning by demonstration

Applications:
Sensor networks, multi-robot systems, distributed and cloud robotics, bio-inspired systems, service robots, automation, biomedical applications, autonomous vehicles (land, sea, air), navigation, Internet-of-Things, smart cities, cyber-physical systems, Industry 4.0, search/rescue/audition, field and swarm robotics, force and tactile sensing

Registration type	Price
Full non-member	500€
RAS/IES/AESS member	400€
Student non-member	300€
Student RAS/IES/AESS member	200€

University of West Bohemia · IEEE · IEEE Robotics & Automation Society · IEEE Industrial Electronics Society · ies · AESS



A Brief History of the Joint Directors of Laboratories Data Fusion Group

Franklin E. White, Jr.
Former Chair of the JDL Data Fusion Subpanel
FEWsionworks
San Diego, CA, USA
fewsionworks@icloud.com

Over the course of 40 years, the origins and evolution of the U.S. National and International fusion communities have become obscured for contemporary audiences. This paper briefly sheds light on the development of the fusion communities. More detail on the challenges, successes, and setbacks experienced by the community founders and community development can be found in a more extensive document, which is available online. Central to establishing fusion communities was the Joint Directors of Laboratories (JDL) Data Fusion Subpanel (DFS)/Group (DFG) and their evolving fusion model, taxonomy, and lexicon.[1] Collectively, along with the outreach efforts of the DFS, the model and accompanying documents provided a frame of reference for recognizing and defining research and development of fusion processes across a broad spectrum of disparate activities from defense to medicine. As one of the original members, I would like to document some of the history of the JDL and fusion community, offering both an historical essay and a personal memoir. Because of the loss of documents and reliance on memory, notes, and unpublished reports, some details may be uncertain, and any errors or opinions expressed are my own and do not represent any official position.

The JDL originated from a need for coordination in research and technology among the Navy, Army, and Air Force, highlighted in a 1982 Defense Science Board study (the Hermann Report) executed for the Assistant Secretary of Defense for Command, Control, Communications, and Intelligence (ASDC3I). The Hermann Report emphasized that lack of coordination led to inefficiencies and duplication, particularly in Command Control and Communications (C3) research and further suggested combining the services' C3 laboratories into one Joint C3 laboratory. In response to the potential loss of their in-house laboratories, the services established the JDL, comprising the Four-Star Service Acquisition Chiefs, in late 1982 to ensure communication and coordination across service laboratories. The JDL set up several technology panels (TP), of which the Technical Panel for C3 (TPC3) was most relevant to the findings of the Hermann Report. The JDL TPC3 members were the technical directors of the three service C3 laboratories: Navy, the Naval Ocean Systems Center (NOSC), Bob Hillyer; Air Force, the Rome Air Development Center (RADC), Fred Diamond; and Army, the Communications-Electronics Command (CECOM), Ted Pfeiffer. These laboratories still exist in some form and are still C3 laboratories.

In a bold move, the TPC3 created a program of technology leveraging and demonstration, as well as a program of basic research in C3. It was funded by the services and the ASDC3I. Consequently, the TPC3 was unique among all the JDL technology panels because it had an approximately $5 million annual budget and an ASDC3I charter to perform work to advance the cause of Joint C3. With approvals and funding lined up and, significantly, the backing of the ASDC3I, the TPC3 implemented a program comprising a Basic Research Group, a Technology Applications and Demonstration group and four subpanels focused on the driving issues in Joint C3: ELINT Correlation, Networks and Distributed Processing, Decision Aids, and Dynamic Spectrum Management. Although the JDL, the TPC3, and the program structure evolved, the program had remarkable success through the early 1990s.

The DFS was born as the ELINT Correlation Subpanel in the original program plan created by the JDL TPC3 in 1984. The original members were Jim Tremlett of Rome Labs, Marty Wolff of CECOM, and Frank White of NOSC. The subpanel held its first meeting in late 1984 in conjunction with a TPC3 meeting at Rome Labs in Rome, New York. When we briefed the JDL TPC3, our plan was accepted with a significant caveat. Fred Diamond asserted that ELINT Correlation was only a small subset of a much larger problem, specifically, the fusion of data from all kinds of sensors and sources into information that could be actionable for decision makers at all echelons. He declared our title and focus was too narrow and by direction of the JDL TPC3, we would be known as the "Data Fusion Subpanel." The three of us were stunned, having spent time over some months and two intense days in Rome Labs, preparing our plan. But the TPC3, while complimentary, were unanimous that the focus was too limited and that we should build on our plan but expand the scope to reflect the true nature of the problem.

The directed change and the implications of addressing all of data fusion was intimidating; however, for me, it was an eye opener. Because of my Navy background in underwater acoustics, Naval Intelligence, and research at NOSC, it occurred to me that I had been a fusion practitioner for more than 15 years, had used some of the earliest available algorithms and tools for automating fusion, and was now developing new tools. Although I had missed the breadth of fusion in my own experience, Fred Diamond's concept resonated and excited me. Jim was primarily

[1] Steinberg, A. N., Bowman, C. L., White, F. E., Blasch, E. P., and Llinas, J. Evolution of the JDL model. *ISIF Perspectives on Information Fusion*, Vol. 6, 1 (2023), 36–40.

interested in COMINT signals and, to some level, ELINT but not in the broader scope. Marty Wolfe was an early artificial intelligence researcher and, although he could see that AI would play a role in fusion, he was concerned that the demands of a broadened scope would divert him from his primary focus. Over the next few meetings, it also became clear that being on the DFS would be a time consuming, potentially diverting collateral duty that would involve traveling for quarterly meetings at least and probably a lot more. As a result, Jim and Marty nominated me as Chair and elected to be replaced on the panel. A panel of one was going nowhere, but fortunately, Len Converse from Rome labs and Army representatives Larry Cook, and later Richard Anthony from the Army laboratory at Vint Hill, VA, stepped up. All of us were strongly attracted by the expanded fusion charter, and the DFS was formally established in 1985 (Figure 1).

As the DFS hashed out a way forward, it became evident that three individuals were inadequate to address the subject and the subpanel would have to contact the broader community—not only government agencies but industry and academia as well. On a personal note, the idea of expanding the subpanel was facilitated by some serendipitous events. First, Jim Llinas, in San Diego on other business in 1985, stopped by NOSC to visit his old friend, Vic Monteleon, who happened to be the JDL TPC3 program manager. In their discussions, Jim expressed his interest in data fusion and was promptly dragged into my office. Jim at the time was at HRB Singer, and, as we discussed fusion, we realized how much we had in common, centered around a passion for data fusion. About the same time in 1985, my Navy sponsor from the Navy Electronics Systems Command (NAVELEX) informed me that NAVELEX had sponsored a fusion conference in early 1984, chaired by Otto Kessler at Naval Air Development Center in Warminster, PA. He directed that no funding for travel or other contributions to the DFS would be available unless

Figure 1
Some members of the JDL Data Fusion Subpanel circa 1994. Back row (left to right): Otto Kessler (NADC), Kim Langdon (Army), Pete Buckley (AFCEA), Representative (USMC), Sam Fisher (DIA), Frank White (NOSC). Foreground (left to right): Jim Llinas (Calspan), Dick Napolitano (NSA), Dick Baer (IC Staff), and Bill Doig (DFS Secretary).

Otto was included. I called Otto and invited him to our next meeting, where we discovered a common thread in the passion for fusion; both Jim and Otto joined the DFS. Jim, along with Ed Waltz and Dave Hall, became the technical conscience and Otto the tireless fundraiser and advocate. All became lifelong friends.

The creation of the DFS acted as a seed crystal dropped into a supersaturated solution. A surprising number of individuals from across the services, agencies, academia, and industry had been working on fusion problems for years, often in relative isolation. Many of these researchers were attracted to the DFS as it gathered information. Despite initial challenges, the DFS added members from the Navy (Otto Kessler, later Mark Owen), Air Force (Mike Hinman, Joe Antonik, Phil Hanselman, Eric Blasch), and Army (Kim Langdon, Joe Karakowski, Bennett Hart, Larry Cook, later Ray Freeman, Dale Walsh). The DFS also grew with official representation from NSA (Fred McHugh, Dick Napolitano, David Lange); DIA (Sam Fisher); CIA, the Intelligence Community Staff (Richard Baer, LtGen. Norm Wood [USAF retired]), and the Office of the Assistant Secretary of Defense for Intelligence (OASDI, Richard Baer). Members from industry and academia continued to be added. Dave Hall, Ed Waltz, David Noble, Alan Steinberg, Chee Chong, and Chris Bowman were early active members who made major contributions. The TPC3 program also provided funding for a subpanel secretary, essential to documenting discussions and decisions, a role ably filled by Clancy Hatleberg first, and then for most of the time the DFS was active under the TPC3 with Bill Doig. If I have forgotten anyone—and I am sure that I have—I apologize and welcome a memory jog.

The DFS began to appreciate the scope of the fusion domain and the number of fusion research projects and programs that were being conducted across multiple communities. These efforts were trying to solve some aspect of sensor or information fusion. Much of this effort was happening without understanding what anyone else might be doing or what aspect of the fusion problem was being addressed. As the expanded DFS wrestled with ways to approach addressing data fusion, the group decided that the DFS would not take on a project of building fusion systems, tools, or even algorithms but rather focus on developing a Data Fusion Community. This decision had profound effects because, although it limited our resources, it provided a specific focus and made the DFS a safe place to exchange ideas. The DFS developed a charter, received permission to expand membership, and began the community building efforts, many of which continue to present. To facilitate a more complete understanding of data fusion, the DFS developed a functional data fusion model, a definition of fusion, a lexicon to define terms, and a taxonomy of fusion techniques. These endeavors provided a common framework for understanding and discussing data fusion across different domains.

The subpanel wrestled with these tasks over the early years of their existence. The most significant of their endeavors was the development of what has become the JDL Data Fusion model (interestingly the JDL is known today, almost exclusively in conjunction with the model). This was not a straightforward process; numerous illustrative models were proposed and discussed from 1985–1987, with the first consensus model published in 1987/1988. Feedback from the published model and continuing discussion led to what has been called the original JDL model, published in 1991. This functional model has been durable and is widely known across many communities. Although the fundamental design of functional levels of fusion has proven resilient, the evolution of the model continues with revisions and feedback debated and published by the community. The process of evolving the Data Fusion Model was instructive and central to the panel's work for years, providing a framework for understanding data fusion needs, the role of data fusion, and organizing the data fusion environment. This process should continue but needs to be formalized, more robust, and more rigorous.

To expand outreach and interchange, a community forum was essential, and the establishment of the Tri-Service Data Fusion Symposium was one the most critical community endeavors undertaken by the DFS. The first Data Fusion Symposium was held in June 1987 and, despite funding struggles annually since, continuing today as the National Symposium on Sensor and Data Fusion (NSSDF). The DFS also encouraged the development of academic courses and the generation of defining documents and textbooks to formalize the discipline of data fusion across varied applications. Today numerous texts and important fusion classes are available at universities and service schools, such as the Naval Postgraduate School. In the mid 1990s, through NATO and information agreements with allies, interest in an international community was emergent, culminating in 1999 when members of the DFG, particularly Jim Llinas and Chee Chong, established the International Society of Information Fusion (ISIF).

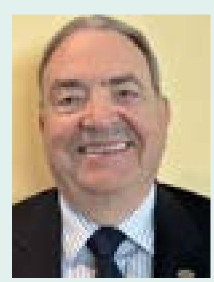
Despite these successes, the DFS faced challenges in sustaining community-building efforts because of limited funding and organizational changes within the JDL structure. As the DFS evolved into the DFG and integrated into larger Department of Defense organizations emphasizing oversight and redundancy elimination, maintaining its original community-focused objectives became increasingly difficult. The data fusion model, lexicon, and taxonomy were in widespread use. Feedback from the growing community was pouring in with suggestions (e.g., evolving the model, changing definitions), and the DFG had no way of resolving them.

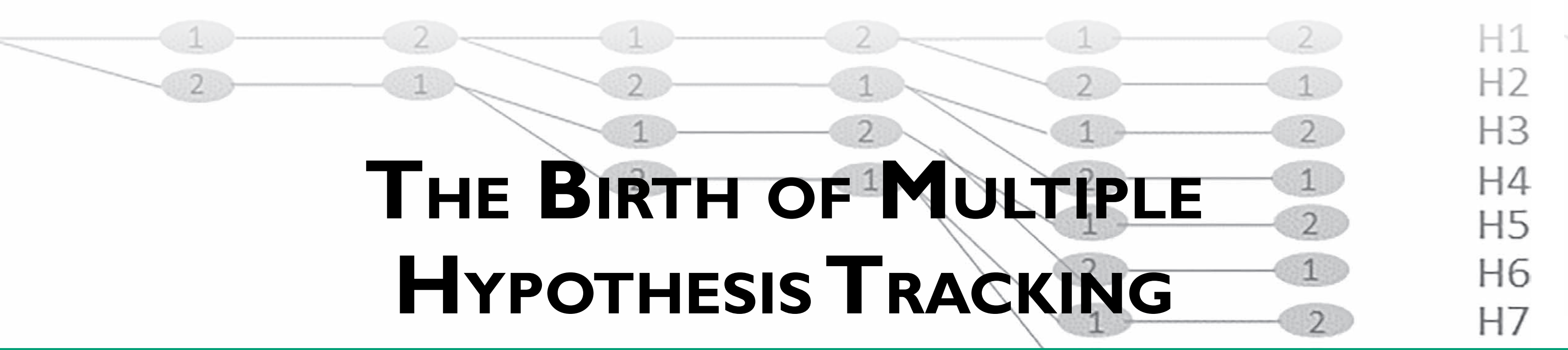
Fortunately, the DFG had continued to expand, and several members came from other coordinating groups that were directly or peripherally involved in data fusion. One group, focused on sensors and sensor fusion, were already associated with a Defense Technical Information Center (DTIC) Information Analysis Center (IAC), specifically the Infrared Information Analysis (IRIA) Center. To expand the community and unify the organizational approach, Alan Steinberg (a member of both groups) spearheaded the effort to combine elements of the group's efforts, creating in 1996 a new organization and a single symposium, leveraging benefits of the IAC structure and funding. This unified symposium became the NSSDF.

The DTIC moved IRIA and other Sensor IACs into a new IAC called SENSIAC, which now runs the Military Sensing Symposia (MSS), one of which is the NSSDF. This series of Symposia has been successful, and, although the SENSIAC charter calls out sensors, sensor processing, and sensor and data fusion, many of the objectives of the DFG, inter alia, Fusion Community management policy, technology leveraging, and code/algorithm libraries have not been implemented. The NSSDF has been partially successful only as a forum for continuing dialogue and decision-making regarding the evolution of the JDL model and other community products and issues. Although community and fusion model issues are often presented at the NSSDF, constraints of classification level, which excludes some essential participants, and time constraints, which do not allow the thoughtful dialogue and interchange of ideas needed for the resolution of community issues, hinder the process. This is not to fault MSS or the NSSDF, but it leaves open the question of how to address pressing issues in a community that is now international in scope.

This is a very brief history of the JDL DFS/DFG. We should look to the history to guide the future, the missteps, and failings along with the successes. A few of those who participated in the development of the fusion community are gone (notably Otto Kessler, Dave Hall, and Chris Bowman), and the rest of us are aging. None of us knew what we were getting into when we started, nor that it would become a lifetime's effort. The work is not over, much is left to be done, but it is good work! Fusion for many of us has been about supporting our military, ensuring their safety and success. But fusion now is recognizably critical in medicine, transportation, air traffic control, rail safety and more—and it's of global importance. Of course, the importance has always been there, we are just continually discovering how vital fusion is across the board. It is up to new generations to carry the work forward, and I believe that the future is bright.

Franklin E. White spent 36 years with the U.S. Navy as an officer and scientist, researching sensors, command control, and fusion, in ASW and intelligence systems. He was chair of the JDL, DFG, from 1984–2005. He has always participated in international cooperation in fusion research under Defense Exchange Agreements and The Technology Cooperation Program C4I group's Action Group and TP on data and information fusion. He was elected a Fellow of the MSS in 2023 and continues to serve (part time) as a scientist for the MITRE Corporation.





The Birth of Multiple Hypothesis Tracking

Chee-Yee Chong
Independent Researcher
Los Altos, CA, USA
cychong@ieee.org

Donald Reid
Retired
San Jose, CA, USA
donreid63@yahoo.com

DONALD REID, INTERVIEWED BY CHEE-YEE CHONG, MARCH 2024

Reid's 1979 seminal paper "An algorithm for tracking multiple targets"[1] presents multiple hypothesis tracking (MHT), which has become a significantly popular tracking approach implemented in many systems. Since he left the tracking community shortly after publishing the paper, very few people know about the inventor of this valuable algorithm. This interview provides some missing information.

CC: *You joined the U.S. Air Force after graduating from the U.S. Military Academy at West Point, NY, in 1963. West Point trains mostly future Army officers. How did you end up in the Air Force?*

DR: Way back when I graduated, 1/8 of the class could go into another service. So, I decided to join the Air Force.

CC: *You must have done very well at West Point. How did you get to go to Stanford to get a master's degree as your first assignment?*

DR: I have no idea; those decisions were beyond my pay grade. I was in the top 5% of my class in my junior year, and I was sent to Stanford to get my master's degree in aero- and astronautics. That was during the Vietnam War. I was lucky because some of my West Point classmates were sent to Vietnam and died in action. After graduation I was first assigned to Vandenburg Air Force Base (VFAB), CA, to work on the then classified KH-8/Gambit program, which launched spy satellites that took images of the Earth using film.

CC: *Can you say what you did on the program?*

DR: First some background. On previous camera spy satellite programs, the contractor (Lockheed Missiles and Space Company) was paid more for meeting the schedule than on how well the satellite was tested to meet performance. So, the satellite was shipped to VAFB before it was completely tested, and then technicians at VAFB (who were not as experienced as those at the factory) would have to retest and fix any technical problems. The new head of the National Reconnaissance Office thought this was a bad idea and decided that the satellites should be completely tested at the factory and then sent directly to the launch pad and mated on top of the booster (a Titan III Rocket). However, just to make sure, he wanted those of us at the base to monitor testing of the satellites at Lockheed before they were shipped to the base. I had the good fortune to be one of those.

CC: *Why did you decide to return to Stanford in 1969?*

DR: One reason I left the Air Force was my boss's boss. For some reason he didn't like me. I didn't know why. Perhaps it was because I was an Academy graduate. My boss was great and gave me a good performance report, but his boss—the endorsing official—put me right in the middle. Right in the middle means I would never get beyond the grade Major if I had stayed in the Air Force. That's when I decided it was time to go back to Stanford and get my PhD.

CC: *You received your PhD in aeronautic and astronautic engineering from Professor Art Bryson in 1972, when the aerospace industry in California was doing very well. Why did you go to the Institute for Defense Analysis (IDA) in the Washington D.C. area and not join Lockheed, Northrop, or other small R&D companies in the San Francisco Bay are,a such as Systems Control?*

DR: Stanford University is very good about inviting potential employers of its new graduates to come to the campus and recruit. I interviewed several companies, and IDA was one of them. I grew up in northern Virginia not far from IDA, and I thought it would be a good time to go back to my roots, but now with a wife and two children. We arrived in the early morning during the middle of a hurricane and got inside our "new" home, which my dad still owned at that time. The home had no furniture or anything. My wife broke down and started crying.

CC: *What did you do at IDA?*

DR: I was in the division of IDA that supported the Weapon Systems Evaluation Group; it was across Shirly Highway from the Pentagon, which was headed by a (three stars) lieutenant general. My job involved lots of travel around different military bases evaluating the status of the weapons, how they were employed, and their sensors. One interesting study was something called target engagement. You started with the sensors on one end and the weapons on the other end, with processing in between.

CC: *Why did you move back to Lockheed Palo Alto Research Lab in 1976?*

DR: I was getting a bit bored with studies. At a conference in San Diego, Herb Rauch (co-inventor of the Rauch, Tung, Strebel smoother) suggested I join him at Lockheed. I decided it's time for us to go back to California. My wife and two little kids left first to find a house. I wanted to live in Palo Alto, near Stanford University. The house that we could have bought for $30,000 when we left in 1972 was now $120,000. I could afford one for only $60,000, so we ended up in San Jose, CA.

[1] Reid, D. B. An algorithm for tracking multiple targets. *IEEE Trans. Auto. Control*, Vol. 24, 6 (1979), 843–854.

CC: *Housing prices have increased a lot since the 1970s. The same house in Palo Alto today will be worth $2 million because of the growth of Silicon Valley companies such as Apple, Oracle, Google, Facebook, etc. What did you work on at Lockheed Palo Alto Research Lab?*

DR: I was expecting when I got there that they would have a job for me. Well, their job for me was to create new jobs for other people in the lab. Specifically, I had to start writing proposals for the internal research and development (IRAD) program, which was funded by the overhead that we charged the government on contracts.

CC: *How did you get into target tracking? What about MHT?*

DR: My boss wanted me to create proposals that we could present to the government for the IRAD program. I had attended conferences that had target tracking and that sounded like an interesting area for me. In fact, I had discussions with Yaakov Bar-Shalom, who worked for a small company (Systems Control) that was about half a mile from where I worked in Palo Alto. This was before he went to the University of Connecticut. I told him about my ideas on delaying association decisions by maintaining multiple hypotheses. He said it was a reasonable idea.

CC: *Bar-Shalom called it "time depth" with revision of probabilistic associations as new data are received. Your 1979 paper had some simulation results. Did you write the program to generate those results?*

DR: The programming language I used was FORTRAN 4. There was an IBM computer card for each line of code. Each computer card was created by me on a key punch machine. In theory, I could have printed the code neatly by hand for a secretary to punch up the cards, but that would have taken two or three times longer than just punching them myself. Also back then, you would draw a long, black line diagonally across the box of cards so that if by some accident you dropped the deck, you could easily get them back in the right order. At this point I should confess that I didn't have a complete target tracking program, but only enough code to create the figures in the paper.

Donald Reid (center) with Yaakov Bar-Shalom (left) and Chee-Yee Chong (right) at FUSION 2018 in Cambridge, UK.

CC: *Getting company approval to publish a paper is quite difficult these days, especially on research supported by an IRAD program. How did you get approval to publish your paper?*

DR: Approval was easy in those days. After completing the Lockheed report that documented the algorithm, I asked my friend Herb Rauch whether he thought it was good enough to publish. He said yes, and I presented the paper at the 1978 IEEE Conference on Decision and Control. The Transactions on Automatic Control version of the paper was published in 1979.

CC: *I have the Lockheed report. The external distribution list includes researchers in other companies that were potential competitors. This type of technical exchange is quite rare today. Your paper has a very simple title but got everyone's attention right away. Why did you leave the tracking field?*

DR: I've often been asked why I didn't continue in the field. The short explanation is a short story. I was in charge of a small group working on an IRAD project that included my brother, Malcolm, and an older gentleman named Robert (Bob) Bryson (no relation to Art Bryson, my PhD advisor at Stanford). These IRAD projects had to be justified every year to Lockheed management. In 1980 I did so to Lockheed's chief scientist from Sunnyvale. In the course of the presentation, I proposed development of a Fusion Center. I had previously worked at IDA on a target engagement task force. In this study, we examined the three areas of reconnaissance, weapons, and command and control, so, I knew that the current buzzword for integrating sensor data was called fusion. Therefore, in my presentation to said chief scientist, I proposed that we work on a Fusion Center. His background, however, was in nuclear engineering, and he objected to my use of the word fusion.

A few weeks later a friend of mine from my Stanford days, Dave Klinger, was in Palo Alto looking for engineers to work for him at Lockheed Missiles and Space in Sunnyvale. Considering the previous information, I told him, "Now might be a good time". I also asked for a raise, which he was able to get for me. I then went to my boss in Palo Alto, told him of Dave's offer, and asked him whether he would give me a raise. He said, "I never stop someone from improving themselves".

CC: *Can you say what you worked on?*

DR: Over the years, I've worked on a number of different satellite programs for Lockheed (and later Lockheed Martin). These usually included work on the attitude determination and attitude control systems, but also included satellite operations. In addition, I've had the pleasure of working in West Germany on two separate 3-year periods in the 1980s and later in England in the 2000s, also on two separate 3-year periods.

CC: *Did you ever regret not continuing on MHT? You could have joined companies such as ORINCON or ALPHATECH, which developed MHT used in real systems, and made a lot of money when they were sold.*

DR: Not until now. Until this moment I didn't think you could make money doing research on MHT.

Book Review

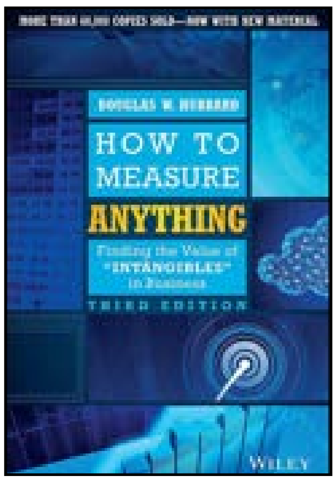
Lawrence D. Stone
Metron, Inc.
Reston, Virginia, USA
stone@metsci.com

How to Measure Anything: Finding the Value of "Intangibles" in Business

Douglas W. Hubbard
3rd Edition, Wiley, 2014
ISBN: 978-1-118-53927-9, $52.00 USD, Hardcover: 432 Pages

INTRODUCTION

The provocative title of this book caught my eye since I was embarking on a new project that involved measuring the operational utility of a system. How do you measure that? I hoped this book would help me answer that question. As one can see from the title, the book is directed toward business problems, but the methods Hubbard proposes can be applied to any problem where one is using subjective or expert opinion to estimate inputs to a problem.



The author does an excellent job of drawing the reader into his book which involves much more than just measurement. First, he explains what he means by "measure." He means make an estimate. He points out that all measurements are estimates, even ones made with highly accurate and precise instruments. They all have measurement errors or uncertainties. In fact, we know from the Heisenberg uncertainty principle that it is theoretically impossible to measure some quantities, such as position and momentum, with no error. Hubbard points out that the goal of measurement is to reduce the uncertainty in the quantity being measured, that is, to improve the estimate of the quantity. The author is serious about his claim of being able to measure anything. He gives some examples to back-up his claim. In one situation, the Cleveland Orchestra wanted to measure whether its performances were improving. How did they do this? By counting the number of standing ovations for its performances. If this number increased, the orchestra felt that their performances must be improving.

He then asks, "Why do you want to make the measurement?" Usually, the reason is to help make a decision in the presence of uncertainty. This can be a business decision, such as whether to upgrade an information technology system or launch a new product, but this can be true for almost any difficult decision. More generally, the author considers the situation where there is a decision to make, and there is a model that predicts the outcomes of the possible decisions. However, the outcomes and associated risks are uncertain, typically because some of the inputs to the model are uncertain. To make a good decision, one must reduce these uncertainties.

As the book progresses, the reader realizes that the author has led him from the provocative claim of being able to measure anything to a Bayesian decision theory approach to making decisions.

The book is intended for industry, government, or civic organizations that want to make better decisions. It is not aimed at the data fusion community which is already well-aware of Bayesian decision theoretic methods. Even so, I found the book had useful nuggets for the data fusion community. In terms of estimating "unknown" parameters, the author claims that the following are almost always true, even if the problem is "unique and unlike any other problem ever encountered," which is a claim often made by decision makers.

- It has been measured before.
- You have far more data than you think.
- You need far less data than you think.
- Useful, new observations are more accessible than you think.

The author gives examples for each of these claims. For the first claim, he suggests searching the internet for references to papers or documents that present results for measuring the item in question or perhaps something closely related. He provides suggestions for how to form queries to get specific rather general information. As researchers, most of us are familiar with this approach when it comes to writing a paper. We use a search engine and references in papers to find prior publications related to our work. Following the author's lead, I performed a search on "operational utility" and got measurements designed for utilities such as electric or gas ones. I then refined my search to "measuring military operational effectiveness" and obtained a much more useful set of references.

To support the claim that you need far less data than you think, he first observes that in most cases, many of the inputs have very little effect on the estimated results of a model, or they are known with enough certainty that they are not driving the risk in the decision. It is common that one or two very uncertain inputs are producing the uncertainty in the results. He then points out that a small number of measurements of these inputs can reduce their uncertainty dramatically. To support this claim, he provides the following rule of five: *There is a* 93.75% *chance that the median of a population is between the smallest and largest values* ***in any random sample of five*** [emphasis added] *from the population.*

Of course, there are some caveats, e.g., the samples must be random with each sample being an independent draw from the population. However, this is a remarkable result showing how

"...managers are reluctant to measure inputs that are important to decisions, believing in many cases that it would be too expensive or too hard to make the measurements that would reduce the uncertainty in a decision."

a small amount of data can produce a large amount of information (reduction in uncertainty) when your initial uncertainty is large. If the initial uncertainty is small, the reduction will be much smaller, but you may not need more information about an input with small uncertainty.

The author gives another striking example called the "Urn of Mystery." This example is an idealization of the situation where you wish to estimate the percentage of a population that has a certain characteristic, like the percentage of employees of a large company that take public transportation to work. The mystery is described as follows: *Suppose I have a warehouse full of large urns. Each urn is filled with marbles and each marble is either green or red. The percentage of marbles that are green in a single urn can be anything from 0 to 100% and all percentages are equally likely. The rest of the marbles are red. Assume the marbles are thoroughly and randomly mixed in each urn. Suppose I draw one urn at random, draw one marble from that urn, and observe its color. What is the probability of that color being the majority color over all the urns in the warehouse? The answer is 75%.* (This is correct, I checked the math myself.) Here we have obtained a remarkable amount of information about that population from only one sample!

These are interesting examples, but why are they important? The author has helped many companies make important decisions. In many of these cases, he observed that managers are reluctant to measure inputs that are important to decisions, believing in many cases that it would be too expensive or too hard to make the measurements that would reduce the uncertainty in a decision. The point of the examples is to show that when uncertainty is the largest, you obtain the most benefit from a few measurements. This reluctance to measure is not limited to business people. It also occurs among decision analysts. Hubbard wrote an article titled "Modeling without Measurements" for the October 2009 edition of *ORMS Today* [1]. He noted that: *A detailed analysis of 60 major decision analysis projects, a survey of Monte Carlo users, and a review of related literature showed…*

1. *Inputs for models are rarely calibrated. Models that depend heavily on subjective estimates [rarely employ] methods to adjust for errors [in these estimates].*

2. *Modelers rarely improve the initial model [by performing] empirical measurements of uncertain values….*

3. *Even organizations steeped in performance metrics rarely measure the performance of [the] models themselves.*

I don't know about you, but I winced when I read 1–3 above. It is too true, even of my own work. For example, some of my current projects rely on subjective estimates from experts. Being good Bayesians, my coworkers and I are developing methods for these experts to express their estimates and their uncertainty in those estimates. However, until I read Hubbard's book, I had not thought of how to calibrate and improve those estimates. Here he provides a real nugget for Bayesians and modelers in general.

Hubbard quotes Daniel Kahneman and Amos Tversky, who performed many studies testing people's probabilistic intuition, as saying: *Our thesis is that people have strong intuitions about random sampling; that these intuitions are wrong in fundamental respects; that these intuitions are shared by naïve subjects and by trained scientists; and that they are applied with unfortunate consequences in the course of scientific inquiry.*

For example, in [2], Kahneman and Tversky showed that people will routinely overestimate the probability of extreme sample results. These results emphasize the need to calibrate experts' probability judgements.

CALIBRATING EXPERTS

Chapter 5 provides a method for calibrating the uncertainty estimates of experts. Hubbard begins this chapter with the following discussion: *How many hours per week do employees spend addressing customer complaints? How much would sales increase with a new advertising campaign? Even if you don't know the exact values to [answer] questions like these, you still know something. You know that some values would be impossible or at least highly unlikely. Knowing what you know now about something actually has an important and often surprising impact on how you should measure it or even whether you should measure it. In fact, quantifying our current level of uncertainty is a key part of the statistical methods we are using…*

The author's calibration method involves asking the experts to make estimates in terms of 90% containment intervals of items such as:

- In what year did Isaac Newton publish the universal laws of gravitation?
- How many inches long is a typical business card?

The experts are provided with the answers so they can compare their estimates to the actual values to see whether their intervals are typically too large or too small. This process and the subsequent feedback to the experts was repeated a number of times to allow the experts to improve their uncertainty estimates. Does this improve the experts' ability to express their uncertainty for an unrelated question such as one that is important for a business decision? Hubbard performed the following study to find out.

Hubbard reported the results from 927 subjects (see pp. 112 and 113 of the book) that he put through a half day of calibration tests of the type described above. The initial test contained 10 questions. On this initial test, only 50% of the 90% containment intervals contained the correct answer. At the end of the half day, he gave a final 20 question calibration test. For this test, over 80% of the intervals contained the correct answer. Clearly a big improvement. The tests were given to different subjects over several years, and the test questions varied from year to year. The results quoted above are aggregated over all the subjects that finished the half day of calibration. Impressive results, but they required a half day of calibration. If the decision is important, this effort should be worth it. The book's Appendix provides a set of calibration questions and answers that may be used to calibrate experts.

> **"Often only a few measurements will produce a dramatic reduction in uncertainty and thus risk."**

MEASURING THE PERFORMANCE OF MODELS

In my experience, this does happen occasionally but not as often as it should. My work has been predominately with the US Navy, so my examples are drawn from that experience. The Navy does test some detection and tracking systems in the following way. Developers are given some real (at sea) data to test and develop their system. This provides a way for the developers to adjust the inputs to their systems to improve their performance. The software implementing the systems is given to a third party to test and grade their performance on a hidden data set. If the highest performing system performs significantly better than the existing system, the existing system is replaced by the new one.

This is not quite the same as a test during a real operation, but such tests are often hard (if not impossible) to perform. I have also developed a Bayesian search and rescue planning system for the US Coast Guard. The system is called SAROPS which is presently in use by the Coast Guard and is highly regarded by them. However, we have never performed a test of SAROPS vs the Coast Guard's manual planning method. It is hard to imagine how you would do this. You could contemplate flipping a fair coin before a search to decide whether the search should be planned with SAROPS or the manual method and then compare results. Of course, for ethical reasons, you would never perform this experiment. However, Hubbard cites a number of studies [3],[4], showing that even rough statistical models greatly outperform seat of the pants decision making. That is encouraging.

I do know of one case where it was possible to compare a Bayesian search planning methodology to manual planning by experts. In the 1970s, the Navy routinely flew aircraft to drop sonobuoys to detect adversarial submarines whose rough location was provided by a surveillance system. My colleagues and I at Daniel H. Wagner Associates developed a Bayesian search planning program for use in planning where to drop the buoys. Once the system was developed, it was used experimentally on some searches while others were planned using the existing manual methods. At the end of this test period, we compared the results from the two methods. The Bayesian computer method increased detection probability by a factor of 2 even though the computer method was used on the harder, more complicated problems, while the manual method tended to be used on the simpler, easier problems. When people ask me whether Bayesian search planning actually works (improves the results), I usually give them this example. However, test results like these are rare for military systems for obvious reasons.

LIST OF CHAPTERS

From the list of chapters (text box), one can obtain an outline of the author's method of convincing business managers to use statistical decision tools when making hard decisions. As you can see, the theme of the book is measurement and how to measure almost anything. However, in Part III, he introduces the concept of decision models by using them to express the risk (and reward) of making a decision. The topic of risk leads naturally to the concept of reducing uncertainty to reduce risk and to allow a manager to make a better decision. One of the best ways to reduce uncertainty is to make some measurements. As the author notes, often only a few measurements will produce a dramatic reduction in uncertainty and thus risk.

This book is long, roughly 400 pages, because the author provides lots of discussion, anecdotes, and examples from his long experience helping managers make difficult and important decisions. This is the right approach for managers. He builds the case for statistical decision making slowly using many examples and lots of discussion. He leads the manager slowly from wanting to measure something to statistical decision analysis. In the end, this is a full-blown discussion of statistical decision analysis for managers with practical instructions for performing and using these analyses. Quite a performance. All with a minimum of mathematics. Very impressive and an interesting read.

NUGGETS

I gleaned three nuggets from this book which I think are useful for data fusion analysts as well as decision analysts:

1. If you are using subjective inputs provided by experts, calibrate them. This may be difficult or time consuming to do, but if the decision or the system relying on these inputs is important, it is probably worth doing this or at least trying to do it.

2. If some inputs or parameters are driving the uncertainty and, therefore, the risk in a model, try to devise some method of obtaining measurements of these inputs to reduce their uncertainty. As the author points out, if the uncertainty in a value is large then a few measurements can greatly reduce it.

3. Try to test the effectiveness of your model or decision system. If you can't do this in an operational situation, perhaps you can use recorded data to test your system. Of course, withhold some data to perform a blind test of the system after you have tuned it on the rest of the data.

As well as being an interesting book to read, I learned some interesting facts about small samples and found several items of good advice for my own work. Now let's see if I can follow that advice.

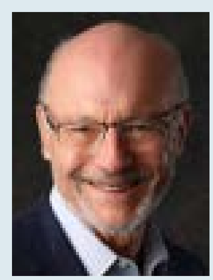
REFERENCES

1. Hubbard, D. How the Decision Analysis Culture's Lack of Empiricism Reduces its Effectiveness. *Modeling Without Measurements*. (2009). https://doi.org/10.1287/orms.2009.05.12
2. Kahneman, D., and Tversky, A. Subjective Probability: A Judgement of Representativeness. *Cognitive Psychology*, Vol. 3, (1972), 430–454.
3. Grove, W.M. and Meehl, P.E. Comparative Efficiency of Informal (Subjective, Impressionistic) and Formal (Mechanical, Algorithmic) Prediction Procedures: The Clinical Statistical Controversy. *Psychology, Public Policy, and Law*, Vol. 2, (1996), 293–323.
4. Grove, W.M., Zald, D.H., Lebow, B. S., Snitz, B. E., and Nelson, C. Clinical versus Mechanical Prediction: A Meta-Analysis. *Psychological Assessment*, Vol. 12, No. 1, (2000), 199–30.

Lawrence Stone is Chief Scientist at Metron Inc. He is a member of the National Academy of Engineering and a fellow of the Institute for Operations Research and Management Science (INFORMS). He is a recipient of the Jacinto Steinhardt Award from the Military Applications Section of INFORMS in recognition of his applications of Operations Research to military problems.

In 1975, the Operations Research Society of America awarded the Lanchester Prize to his text *Theory of Optimal Search*. In 1986, he produced the probability maps used to locate the *S.S. Central America* which sank in 1857, taking millions of dollars of gold coins and bars to the ocean bottom one-and-one-half miles below. In 2010, he led the team that produced the probability distribution that guided the French to the location of the underwater wreckage of Air France Flight AF447. Recently, he used search theory methods to help guide the Canadian exploration company, Aurania, to the location of one of the lost Spanish gold cities in Ecuador.

He coauthored the 2016 book *Optimal Search for Moving Targets*. He was one of the primary developers of the Search and Rescue Optimal Planning System (SAROPS) used by the U.S. Coast Guard since 2007 to plan searches for people missing at sea. He continues to work on a number of detection and tracking systems for the U.S. Navy. He is a coauthor of the 2014 book *Bayesian Multiple Target Tracking, Second Edition* as well as the 2023 book *Introduction to Bayesian Tracking and Particle Filters*.



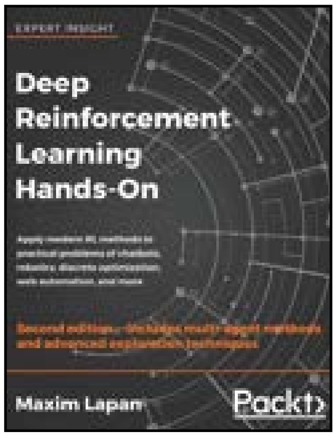
Book Summary

Deep Reinforcement Learning Hands-On: Apply modern RL methods to practical problems of chatbots, robotics, discrete optimization, web automation, and more

Maxim Lapan
Packt Publishing, 2020
ISBN-13: 978-1-83882-699-4, $49.99 USD, 826 pages

Lyudmila Mihaylova
The University of Sheffield
Sheffield, United Kingdom
l.s.mihaylova@sheffield.ac.uk

This excellent book on recently developed deep Reinforcement Learning methods consists of 25 chapters and covers both fundamentals of Reinforcement Learning and new topics such as chatbots training with reinforcement learning, trust region policy methods and AlphaGo Zero methods.



The book first summarises the main ideas behind Markov decision processes, the cross-entropy method and the Bellman equation of optimality. Next, it goes at the level of deep Q-networks, including their extensions such as duelling and categorical deep Q-networks. The actor-critic methods have been given special attention. Trust region policy optimisation and proximal policy optimisation (PPO) are also considered in detail, with many examples.

The book is a very useful and practical guide towards understanding and hands on experience of the Reinforcement Learning domain. The book also gives knowledge on deep learning with Pytorch—starting gradually with tensors, gradients, and neural network building blocks with different loss functions, and then moving to numerous examples with different Reinforcement Learning methods. The book is accompanied by a Github link with the related Python code[1] which stimulates reproducible research.

The presented methods are aimed at generating control strategies and have a broad range of applicability—in robotics (for path planning) and in intelligent transport systems, including for autonomous vehicles and others. The Reinforcement Learning control algorithms presented in this book can be implemented with different types of sensor data and can leverage advancements in multi-sensor data fusion.

"…the new architecture, called imagination-augmented agent (I2A), is to allow the agent to imagine future trajectories using the current observations…"

[1] https://github.com/PacktPublishing/Deep-Reinforcement-Learning-Hands-On?tab=readme-ov-file

The digital versions of each of the published volumes are available at https://isif.org/publication/perspectives/issues.