TUTORIALS OUTLINE

1. Multisensor-Multitarget Tracker/Fusion Engine Development and Performance Evaluation for Realistic Scenarios

Thia Kirubarajan (McMaster University, Canada)

Abstract: While numerous tracking and fusion algorithms are available in the literature, their implementation and application on real-world problems are still challenging. Since new algorithms continue to emerge, rapidly prototyping them, developing for production and evaluating them on real-world (or realistic) problems efficiently are also essential. In addition to reviewing state-of-the-art tracking algorithms, this tutorial will focus on a number of realistic multisensor-multitarget tracking problems, simulation of large-scale tracking scenarios, rapid prototyping, development of high performance real-time tracking/fusion software, and performance evaluation on realistic scenarios. A unified tracker framework that can handle a number of state-of-the-art algorithms like the Multiple Hypothesis Tracking (MHT) algorithm, Multiframe Assignment (MFA) tracker and the Joint (Integrated) Probabilistic Data Association (J(I)PDA) tracker is presented. Modules for preprocessing (e.g., coordinate transformations, clutter estimation, thresholding, registration), data association (e.g., 2-D assignment, multiframe assignment, k-best assignment), filtering (e.g., Kalman filter, Interacting Multiple Model (IMM) Estimator, Unscented Kalman filter) and postprocessing (e.g., prediction, classification) are discussed. Fusion software with different architectures is also presented. Integration of sensors like radar, ESA, angle-only, PCL and AIS/ADS-B is demonstrated. Side-by-side performance evaluation of multiple algorithms using more than 30 metrics on realistic large-scale tracking scenarios is presented. A hands-on approach with ISR360, which is an end-to-end real-time software suite for Intelligence, Surveillance and Reconnaissance, will be the cornerstone of this tutorial.

The topics will include Review of Bayesian state estimation, Multitarget tracking system architecture, Implementation of J(I)PDA/MHT/MFA trackers, Implementation of a multisensor fusion engine, Implementation of realistic simulators, Implementation of a track analytics engine, Performance evaluation of trackers (MOP/MOE), and Real-world examples.

Eligibility: The proposed three-hour tutorial will be valuable to students, researchers and practicing engineers at universities, government research labs and companies who are interested in developing tracking and fusion solutions for real-world surveillance problems. This tutorial, which will be of high interest to a vast majority of participants, will complement (and follow-up on) the one typically presented by Prof Yaakov Bar-Shalom at Fusion conference where he focuses on theory.

Instructor's biography: Professor T. Kirubarajan (Kiruba) holds the title of Distinguished Engineering Professor and holds the General Dynamics Industrial Research Chair in Target Tracking and Information Fusion at McMaster University, Canada. He has published about 350 research articles, 11 book chapters, one standard textbook on target tracking and four edited volumes. In addition to conducting research, he has work extensively with government departments and companies to process real data and to transition his research to the real world through his company TrackGen. As part of this, he has led the development of a number of software programs, including MultiTrack for real-time large-scale multisensor-multitarget tracking, MultiFuse for distributed tracking, and ISR360 for visualization, performance analysis and situation awareness, which have been integrated into some real systems.

2. Multi Sensor and Data Fusion Approaches for Autonomous Driving: Concepts, Implementations and Evaluation

Bharanidhar Duraisamy, Tilo Schwarz and Martin Fritzsche (Daimler AG, Germany)
Michael Gabb (Robert Bosch GmbH, Germany)
Ting Yuan (Mercedes-Benz R&D, USA)

Abstract: This tutorial is focussed towards the stringent requirements, foundations, development and testing of sensor fusion algorithms meant for advanced driver assistance functions, self-driving car applications in automotive vehicle systems and vehicular infrastructure oriented sensor fusion applications. The audience would be provided with the presentation materials used in the tutorial. The complex sensor world of autonomous vehicles is discussed in detail and different aspects of sensor fusion problem related to this area is taken as one of the core subject of this tutorial. In addition a special discussion section on a sensor fusion system that is designed to work on the data obtained from environment perception sensors placed in an infrastructure such as a parking house is presented.

The audience can see the different representations of the surrounding environment as percepted by the heterogeneous environment perception sensors e.g. different kinds of radar (multi-mode radar, short range radar), stereo camera and lidar. The relevant state estimation algorithms, sensor fusion frameworks and the evaluation procedures with reference ground truth are presented in detail. The audience can get a first ever glimpse of the data set obtained from a sensor configuration that would be used in the future Mercedes Benz autonomous vehicles. Different target signatures obtained for various types of targets under different sensory conditions would be presented. An important tool for development, the simulation software that also helps in evaluating a concept or production software, verifying and validating different sensor models would be discussed in detail.

A section on urban automated driving application with support of infrastructure sensing, distributed computing, and Cellular radio is introduced. After a brief overview over the overall system and the individual components, the hybrid fusion design of the overall environmental perception for an automated vehicle comprising both onboard sensors and distributed environmental models delivered via cellular radio, is presented. Advantages and disadvantages of different fusion architectures for automated driving with support from infrastructure sensing are discussed and the influence of cellular radio and overall system latency on different approaches is presented. After a short discussion of possible approaches to incorporate a mixture of both geo-referenced and vehicle-fixed sensor data into a fusion system and the effect of ego localization errors on estimation uncertainty and this section with an introduction into behavior-generation for automated vehicles which are supported by environmental models received via cellular radio and the limits of behavior generation without the support of distributed environment perception.

Development of several simulation models based on real world sensor data and usage of these models in evaluating tracking and sensor fusion approaches and an additional aspect using simulation to create specialized dataset for Artificial Intelligence related applications. Real life sensor fusion systems requires stringent verification and validation procedures to ensure safe operations, a section of this tutorial covers this aspect.

The interesting part of the tutorial is covered on the different challenging and important real world implementation problems and practical aspects such as fusion with incomplete information, data association, sensor communication latency, real world testing, real-life like simulation etc. related to fusion and target tracking in automotive setting. Challenges in automated driving in highway and urban setting are discussed in detail during every section of this tutorial. Interesting research and application based discussion on centralized, decentralized and hybrid-distributed sensor fusion designs in particular to autonomous driving is discussed in depth using the results obtained using several real world data sets that contains various static and dynamic targets would be presented in this tutorial. Fusion and management of the different extended target and static object representations from heterogeneous information sources with different resolution is presented with examples.

Bharanidhar Duraisamy has been with Daimler's department of environment perception since his student years. He started his life with team sensor fusion as a research associate and continued on to write his doctoral work in the team. At present he is working in the area of Automotive Radar at Daimler, specializing in Radar signal processing, target tracking and information fusion. His work and interests are in the area of automotive multi-level sensor fusion with active and passive environment perception sensors, state estimation, signal processing, target tracking and specialized in Radar multi-mode target tracking designed for automotive intelligent vehicular applications, classification-fusion of relevant objects, multi-sensor data association, target tracking and detection. He has completed his master studies in computer science, robotics and automation from the Dortmund University of Technology, Germany and he is at present working towards his doctoral degree.

Dr. Ting Yuan is currently a Senior Research Scientist at Daimler Greater China Ltd, China and he used to work at Mercedes-Benz Research and Development North America, Inc., Sunnyvale, CA within the Autonomous Driving Department, where his fields of endeavour lie in detection, classification and tracking of moving/static objects using information from camera, Radar and Lidar systems, as well as data fusion for the multi-sensor systems. He received his Ph.D. degree from the Electrical and Computer Engineering Department at the University of Connecticut, Storrs, CT in 2013. He is an invited presenter on Automotive Radar System at 2016 IEEE Radar Conference, Philadelphia, PA. His research interests include target tracking, data fusion and multiple-model analysis.

Dr. Tilo Schwarz has received his Diploma in Physics from the University of Stuttgart in 1995 and the Doctorate degree in Physics from the University of Kiel in 2000. He has worked from 1996-1999 as PhD student and from 2000 till today as a senior research scientist in the Environment Perception and Sensor Fusion departments of the Daimler Research and Advanced Engineering in Sunnyvale. His scientific interests are in the domains of computer vision, machine learning, signal processing and sensor fusion with primary applications in the field of machine vision and driver assistance systems.

Dr. Martin Fritzsche has received his diploma in Geophysics and his Doctoral degree in Electrical Engineering both from the University of Karlsruhe, Germany. He is with Daimler's research and development department for the past two decades. He has worked on several sensor fusion focussed active and passive safety oriented in-house and public funded projects related to intelligent vehicles. He has held lecture and keynote series in many conferences and events specific to intelligent vehicles, automotive safety research and applications. His core research interests are in the domains of pattern recognition, signal processing, state estimation, sensor fusion, target detection and tracking.

Michael Gabb is an Engineer with Bosch Research and Advanced Engineering for ADAS and Automated Driving in Stuttgart, where he works in the area of environmental perception, sensor fusion, and connected and distributed information processing for autonomous vehicles. Prior to joining Bosch, Michael worked for multiple years as research associate at Daimler Research in Ulm, where he worked in the area of sensor fusion and sensor signal processing. Michael holds a Diplom degree (equivalent to Master's degree) in Computer Science from University of Stuttgart he received in 2011.

3. Multisensor Data Fusion for Industry 4.0

Claudio M. Farias and Igor L Dos Santos (Universidade Federal do Rio de Janeiro, Brazil)
Manoel Saisse (National Institute of Technology, Brazil)

Abstract: The Internet of Things (IoT) is a novel paradigm that is grounded on Information and Communication Technologies (ICT). Recently, the use of IoT has been gaining attraction in areas such as logistics, manufacturing, retailing, and pharmaceutics, transforming the typical industrial spaces into Smart Spaces. This leads to a novel paradigm called Industry 4.0. Since IoT data is usually dynamic and heterogeneous, it becomes important
to investigate techniques for understanding and resolving issues about data fusion in Industry 4.0. Employment of Data fusion algorithms are useful to reveal trends in the sampled data, uncover new patterns of monitored variables, make predictions, thus improving decision making process, reducing decisions response times, and enabling more intelligent and immediate situation awareness. This tutorial aims to show the multisensory data fusion techniques used in the Industry 4.0 scenario as well as case studies.

Instructor's biography: The presenter of this tutorial will be Prof. Claudio Miceli
de Farias from Federal University of Rio de Janeiro. Claudio Miceli de Farias received a M.Sc. degree on Computer Science in 2010 and his doctorate degree in 2014 from the Federal University of Rio de Janeiro, Brazil. He is nowadays professor at the Tercio Pacitti Institute for Applications and Computational Research. Claudio coordinates undergrad activities in this institute and teaches Wireless Networks, Security, Internet of Things and Statistics. He is also reviewer of several Journals such as computer networks, IEEE sensors and computer communications. Claudio coordinates projects
in smart farms, Industry 4.0 and Autonomous Submarine vehicles. His research interests include smart cities, Industry 4.0, wireless sensor networks, network security, real time communications and video processing.

4. An Introduction to Track-to-Track Fusion and the Distributed Kalman Filter

Felix Govaers (Fraunhofer FKIE / University of Bonn, Germany)

Abstract: The increasing trend towards connected sensors ("internet of things" and "ubiquitous computing") derive a demand for powerful distributed estimation methodologies. In tracking applications, the "Distributed Kalman Filter" (DKF) provides an optimal solution under certain conditions. The optimal solution in terms of the estimation accuracy is also achieved by a centralized fusion algorithm which receives either all associated measurements or so-called "tracklets". However, this scheme needs the result of each update step for the optimal solution whereas the DKF works at arbitrary communication rates since the calculation is completely distributed. Two more recent methodologies are based on the "Accumulated State Densities" (ASD) which augment the states from

multiple time instants. In practical applications, tracklet fusion based on the equivalent measurement often achieves reliable results even if full communication is not available. The limitations and robustness of the tracklet fusion will be discussed.

At first, the tutorial will explain the origin of the challenges in distributed tracking. Then, possible solutions to them are derived and illuminated. In particular, algorithms will be provided for each presented solution. The list of topics includes: Short introduction to target tracking, Tracklet Fusion, Exact Fusion with cross-covariances, Naïve Fusion, Federated Fusion, Decentralized Fusion (Consensus Kalman Filter), Distributed Kalman Filter (DKF), Debiasing for the DKF, Distributed ASD Fusion, Augmented State Tracklet Fusion.

Eligibility: The intended audience are engineers, PhD students, or interested people who are working in the field of distributed sensor data fusion. The algorithmic and theoretical background of track-to-track fusion, tracklet fusion, and the distributed Kalman filter should be of interest for the audience. Problems, questions and specific interests are welcome for an open discussion.

Instructor's biography: Felix Govaers received his Diploma in Mathematics and his PHD with the title "Advanced data fusion in distributed sensor applications" in Computer Science, both at the University of Bonn, Germany. Since 2009 he works at Fraunhofer FKIE in the department for Sensor Data Fusion and Information Processing where he was leading the research group "Distributed Systems" for three years. Since 2017 he is the deputy head of the department "Sensor data and Information Fusion". The research of Felix Govaers is focused on data fusion for state estimation in sensor networks and non-linear filtering. This includes track-extraction, processing of delayed measurements as well as the Distributed Kalman filter and track-to-track fusion.

5. Information Quality in Human-Machine Integrated Environment

Galina Rogova, PhD
The State University of New York at Buffalo, USA

Abstract: Situation awareness in complex dynamic environment requires contextual understanding and interpretation of the events and behaviors of interest, which can be achieved by building a dynamic situational picture. The process of building such picture involves gathering and fusing a large amount of multimedia and multispectral information coming from geographically distributed sources to produce estimates of objects and their characteristics, and gain knowledge of the entire domain of interest. Information to be processed and made sense of includes but is not limited to data obtained from sensors surveillance reports, human intelligence reports, operational information, and information obtained from open sources (internet, radio, TV, etc.). Successful processing of this information may also demand information sharing and dissemination, and action cooperation of multiple stakeholders. Such complex environments call for an integrated fusion based human-machine system, in which some processes are best executed automatically while for others the judgment and guidance of human experts and end-users are critical.

The problem of building such integrated systems is complicated by the fact that data and information obtained from observations and reports as well as information produced by both human and automatic processes are of variable quality and may be uncertain, unreliable, of low fidelity, insufficient resolution, contradictory, and/or redundant. The success of decision making in complex fusion driven human-

machine environments depends on the success of being aware of, and compensating for, insufficient information quality at each step of information exchange. Thus quality considerations play an important role at each time when raw data (sensor reading, open source, database search results, and intelligence reports) enter the system as well as when information is transferred between automatic processes, between humans, and between automatic processes and humans.

The tutorial will discuss major challenges and some possible approaches addressing the problem of representing and incorporating information quality into fusion processes. In particular, it will present an ontology of quality of information and identify potential methods of representing and assessing the values of quality attributes and their combination. It will also examine the relation between information quality and context, and suggest possible approaches to quality control compensating for insufficient information and model quality.

Eligibility: This tutorial is intended for both researchers and practitioners from a wide variety of fields such as communication, intelligence, business processes, personal computing, health care, and databases, who are interested in understanding information quality problems in the complex human-machine integrated environment, and building methods for dealing with these problems.

Instructor's biography: Dr. Rogova is a research professor at the State University at Buffalo as well as an independent consultant (DBA Encompass Consulting). She is a recognized expert in information fusion, information quality, and decision making, and lectured internationally on this topic. Her other research expertise includes reasoning under uncertainty, machine learning, and image understanding. She has worked on a wide range of defense and non-defense problems such as situation and threat assessment, information quality in information fusion, computer-aided diagnosis, and understanding of volcanic eruption patters, among others. Her research was funded by multiple government agencies as well as commercial companies. She published numerous papers and co-edited 7 books including a Springer book entitled "Information Quality in Information Fusion and Decision Making." She served as a committee member, session chair and organizer, and tutorial lecturer for numerous International Conferences on Information Fusion. Dr. Rogova was a member of organizing committees of multiple NATO ASI and NATO ARWs on information fusion and decision support.

6. Analytic Combinatorics for Multi-Object Tracking and Higher Level Fusion

Murat Efe (Ankara University, Turkey); Roy Streit (Metron Inc., USA)

Abstract: This tutorial is designed to facilitate understanding of the classical theory of Analytic Combinatorics (AC) and how to apply it to problems in multi-object tracking and higher level data fusion. AC is an economical technique for encoding combinatorial problems—without information loss—into the derivatives of a generating function (GF). Exact Bayesian filters derived from the GF avoid the heavy accounting burden required by traditional enumeration methods. Although AC is an established mathematical field, it is not widely known in either the academic engineering community or the practicing data fusion/tracking community. This tutorial lays the groundwork for understanding the methods of AC, starting with the GF for the classical Bayes-Markov filter. From this cornerstone, we derive many established filters (e.g., PDA, JPDA, JIPDA, PHD, CPHD, Multi Bernoulli, MHT) with simplicity, economy, and insight. We also show how to use the saddle point method (method of stationary phase) to find low complexity approximations of probability distributions and summary statistics.

Eligibility: The intended audience is any engineer, Ph.D. student, and interested person working in multi-object tracking and data fusion. The development should be of special interest to individuals working in what is often called random finite sets (or finite point processes), and those working on large problems requiring principled approximations. Open discussion of problems and specific interests are welcome.

Roy Streit Senior Scientist, Metron, Reston, Virginia, and Professor (Adjunct) of Electrical and Computer Engineering, University of Massachusetts–Dartmouth. IEEE Fellow. IEEE AESS Board of Governors, 2016-18. President, ISIF, 2012. Research interests include multi-target tracking, multi-sensor data fusion, medical imaging, signal processing, pharmacovigilance, and business analytics. Author, *Poisson Point Processes,* Springer, 2010 (Chinese translation, Science Press, 2013). Co-author, *Bayesian Multiple Target Tracking*, 2nd Edition, Artech, 2014. Seven US patents.

Murat Efe Professor and Head of the Electrical and Electronics Engineering Department at Ankara University. Numerous papers in refereed journals, conferences, and seminars on target tracking/data fusion. Local coordinator of the NATO Lecture Series on Multisensor Fusion in 2012. Technical consultant to a number of defense companies on tracking and fusion related projects. On the executive board of the Electrical, Electronics and Informatics Research Group of the Scientific and Technological Research Council of Turkey. Board of Directors of ISIF for the term 2014-2016 and again for the term 2017-2019.

7. Extended Object Tracking: Theory and Applications

Karl Granström (Chalmers University of Technology, Sweden)
Marcus Baum (University of Goettingen, Germany); Jens Honer (Valeo, Germany)

Abstract: Autonomous systems are an active area of research and technological development. These systems require intelligence and decision making, including intelligent sensing, data collection and processing, collision avoidance and control. Autonomous systems, especially autonomous cars need to be able to detect, recognise, classify and track objects of interest, including their location and size. In the light of autonomous systems this tutorial will focus on tracking of extended objects, i.e., object tracking using modern high resolution sensors that give multiple detections per object. State of the art theory will be introduced, and relevant real world applications will be shown where different object types, e.g., pedestrians, bicyclists, and cars, are tracked using different sensors such as lidar, radar, and camera.

The multiple object tracking problem is defined as keeping track of an unknown number of moving objects, and historically it has been focused on so called point objects which give at most one detection per time step. However, modern sensors have increasingly higher resolution, meaning that it is common to see multiple detections per object. For example, this is the case when automotive radar or lidar sensors are used. In order to be able to use point object algorithms for these sensors, heuristic clustering algorithms are applied to the raw measurements to obtain object hypotheses. In challenging scenarios, the hard decisions of the clustering algorithms affect the performance of the tracking algorithm due to the associated loss of information.

Consequently, so called extended object tracking algorithms which are capable of handling several measurements per object are required. With multiple detections it also becomes possible to estimate the objects' shapes and sizes, in addition to the objects' locations and dynamical properties such as

velocity and turn-rate. For an autonomous vehicle operating in a crowded urban area it is paramount to be able to know if an object is a car, a bicyclist, a pedestrian, or belongs to some other category since this knowledge directly affects the driving behavior. The estimates of the shape and size are very important as they can be utilised in the process of distinguishing between different object types.

The aim of this tutorial is to introduce the audience to extended object tracking, with a focus on both the underlying theory and relevant real world applications. The object tracking problem will be defined and several modern multi-object tracking algorithms for point objects will be introduced. Several examples from multiple object tracking in urban environments will be given, and the difficulties involved with the use of the point object assumption are illustrated. Afterwards, the modelling of object shapes and measurements in extended object tracking algorithms are introduced in detail and the integration in multiobject tracking algorithms is outlined. Finally, several applications of the presented extended object algorithms in automotive applications are shown.

The following topics will be included in the tutorial:

Theory:

- Brief review of state estimation: Kalman filter (KF), particle _lter (PF), Bayesian conjugate priors.
- Shape parametrization: from simple geometric shapes to complex arbitrary shapes
- Measurement modeling: number of detections per object and type of measurement spread. Poisson Point Process spatial model. Modelling based on reflection points located on a rigid body.
- Tracking multiple extended objects: Probability Hypothesis Density (PHD) filter, Cardinalized PHD filter, Labelled Multi-Bernoulli filters, Poisson Multi-Bernoulli filters.
- Multiple extended object data association: clustering based methods, and sampling based methods.

Applications:

- Tracking of different object types: pedestrians, bicycles, and cars
- Different sensor modalities: lidar, camera, and radar
- Occlusion modeling in dense urban environments

Eligibility: The intended audience is academics and professionals with an interest in multiple extended object estimation. Recommended prerequisite knowledge is linear algebra, probability theory and state estimation. Knowledge of Random Finite Set (RFS) based algorithms for point target tracking is helpful, but not necessary.

Karl Granstrom is a postdoctoral research fellow at the Department of Signals and Systems, Chalmers University of Technology, Gothenburg, Sweden. He received the MSc degree in Applied Physics and Electrical Engineering in May 2008, and the PhD degree in Automatic Control in November 2012, both from Linkoping University, Sweden. He previously held postdoctoral positions at the Department of Electrical and Computer Engineering at University of Connecticut, USA, from September 2014 to August 2015, and at the Department of Electrical Engineering of Linkoping University from December 2012 to August 2014. His research interests include estimation theory, multiple model estimation, sensor fusion and target tracking, especially for extended targets. He has received paper awards at the Fusion 2011 and Fusion 2012 conferences. In 2018, Karl Granstrom received the ISIF Young Investigator Award for outstanding contributions to the art of information fusion sponsored by the International Society of Information Fusion (ISIF).

Marcus Baum is Professor of Computer Science at the University of Gottingen, Germany, and Visiting Professor at the University of Passau, Germany. He received the Diploma degree in Computer Science from the University of Karlsruhe (TH), Germany, in 2007, and graduated as Dr.-Ing. (Doctor of Engineering) at the Karlsruhe Institute of Technology (KIT), Germany, in 2013. From 2013 to 2014, he was Postdoc and Assistant Research Professor at the University of Connecticut, CT, USA. His research interests are in the field of data fusion, estimation, and tracking. Marcus Baum is a Associate Administrative Editor of the Journal of Advances in Information Fusion (JAIF) and Associate Editor of Letters of the IEEE Transactions on Aerospace and Electronic Systems. In 2017, Marcus Baum received the ISIF Young Investigator Award for outstanding contributions to the art of information fusion sponsored by the International Society of Information Fusion (ISIF).

Jens Honer studied physics at the University of Stuttgart and finished his PhD in theoretical physics (quantum optics) in 2013. In 2013 he joined Valeo CDA (Comfort and Driving Assistance Systems) to design the first data fusion systems based on Radar, Lidar and cameras in the Systems and Functions department. Since 2016 he is appointed Valeo Expert for Sensor Fusion and Environment Perception and leads the algorithm design for the next generation environment perception system in Valeo CDA DSF (Driving Systems and Functions) since 2017. His fields of interests include localization, machine learning, environment perception, extended and multi-target tracking. He has co-organized a tutorial about multiple extended object tracking and sensor fusion the 2018 International Conference on Information Fusion (FUSION).

8. Machine and Deep Learning for Data Fusion

Subrata Das (Machine Analytics, Inc., USA)

Abstract: In this tutorial, I will present some techniques for fusion and analytics to process big centralized warehouse data, inherently distributed data, and data residing on the cloud. The broad range of artificial intelligence and machine and deep learning techniques to be discussed will handle both structured transactional and sensor data as well as unstructured textual data such as human intelligence, emails, blogs, surveys, etc., and image data. Specifically, the tutorial will explore Deep FusionÒ to solve multi-sensor big data fusion problems applying deep learning and artificial intelligence technologies.

As a background, this tutorial is intended to provide an account of both the cutting-edge and the most commonly used approaches to high-level data fusion and predictive and text analytics. The demos to be presented are in the areas of distributed search and situation assessment, information extraction and classification, and sentiment analyses.

Some of the tutorial materials are based on the following two books by the speaker: 1) Subrata Das. (2008). “High-Level Data Fusion,” Artech House, Norwell, MA; and 2) Subrata Das. (2014). “Computational Business Analytics,” Chapman & Hall/CRC Press.

Tutorial Topics include the following: High-Level Fusion, Traditional Machine Learning Algorithms, Popular Deep Learning Algorithms (e.g. Convolutional & Recursive Neural Networks, Deep Belief Networks and Restricted Boltzmann Machine, Stacked Autoencoder), Bagging and Boosting, Descriptive and Predictive Analytics, Text Analytics, Decision Support and Prescriptive Analytics, Cloud Computing, Distributed Fusion, Hadoop and MapReduce, Natural Language Query, Graphical Probabilistic Models, Bayesian Belief Networks, Text Classification, Supervised and Unsupervised Classification, Information Extraction, Natural Language Processing, Demos in R and Python.

The intended audience include designers and developers of analytics systems for any vertical (e.g., defense, healthcare, finance and accounting, human resources, customer support, transportation) who work within business organizations around the world. They will find the tutorial useful as a vehicle for moving towards a new generation of big data fusion and analytics approaches.

Dr. Subrata Das is the founder of Machine Analytics, a company in the Boston area providing business analytics and data fusion consultancy services and developing customized solutions for clients in government and industry. Subrata is the consulting Chief Data Scientist at Alphaserve Technologies in NY. Subrata served as a technology consultant at MIT Lincoln Lab. Subrata's technical expertise includes mathematical logics, probabilistic reasoning, and a broad range of computational artificial intelligence and machine and deep learning techniques. Subrata is also an adjunct faculty at Northeastern University and at Villanova School of Business.

Subrata spent two years in Grenoble, France, as the manager of over forty researchers in the document content laboratory at the Xerox European Research Centre. In the past, Subrata led many projects funded by DARAP, NASA, US Air Force, Army and Navy, ONR and AFRL. In the past, Subrata held research positions at Imperial College, London, received a PhD in Computer Science from Heriot-Watt University in Scotland, and masters from University of Kolkata and Indian Statistical Institute. Subrata has published many journal and conference articles. He is the author of five books including Computational Business Analytics, published by CRC Press/Chapman and Hall, and High-Level Data Fusion, published by the Artech House.

Subrata has published many conference and journal articles, edited a journal special issue, and regularly gives seminars and training courses based on his books. Subrata served as a member of the editorial board of the Information Fusion journal, published by Elsevier Science.

9. Information Fusion Systems Engineering and Testing

Ali Raz (Purdue University, USA); James Llinas (University at Buffalo, USA)
Dan DeLaurentis (Purdue University, USA)

Abstract: Information fusion (IF) systems find their application in multiple domains from defense applications to self-driving cars, and autonomous systems. Irrespective of the application domain, an IF system's objective is to produce optimal state/situation estimates from various sources that are supportive of typically mixed-initiative decision-making which leads to an action. These three processes of fusion, sensemaking, and decision-making have critical interdependencies that are often overlooked in IF system design. Engineering the IF system capability requires a holistic, systemic perspective that includes evaluation of a multitude of interacting design variables which span the fusion, sensemaking and decision-making aspects; this tutorial will address this systems engineering approach and evaluation methodology.

In this tutorial, first the interdependencies between fusion, sensemaking, and decision-making are introduced, followed by a development of a domain-agnostic framework which provides holistic design and performance evaluation of an IF system. Various process interdependencies are discussed, and an IF system development framework is presented that leverages Systems Engineering principles and Model-based Systems Engineering techniques for practical system development. On the evaluation side, this tutorial pairs the Systems Engineering approach with statistical methods and will provide theoretical foundations for performing design and analysis of experiments, followed by a hands-on IF system application example. A refresher on Monte-Carlo simulations and hypothesis testing will also be provided. At the conclusion of the tutorial, the participants will be able to:

1) Identify and discuss the nature of interdependencies in fusion, sensemaking, and decision-making processes and derive the implications for IF system design
2) Appreciate the value of Systems Engineering to provide a systemic methodology for IF system and decompose the IF system into a set of inter-dependent design variables
3) Formulate an 'experimental design' for the IF system design and performance evaluation
4) Employ hypothesis testing for comparing uncertain data and perform analysis of variance (ANOVA) to establish statistical significance of design variables and interactions
5) Perform multiple comparison statistical range tests to quantify the impact of variation and obtain sensitivity analysis amidst interacting design variables

Eligibility: Graduate students, industry practitioner, and fusion researchers who are faced with evaluating fusion system performance, comparing different design options and/or algorithms.

Dr. Ali K. Raz is a Visiting Assistant Professor at Purdue University School of Aeronautics and Astronautics. His research interests are in Complex Systems, System-of-Systems Engineering, and Information Fusion System, particularly applying statistical methods for information fusion performance evaluation. He has worked at the John Hopkins University Applied Physics Laboratory and a DoD agency in the area of fusion performance evaluation. He was the recipient of Alexander Kossiakoff fellowship awarded jointly by the John Hopkins University and the International Council on Systems Engineering (INCOSE) for developing performance evaluation methods for large-scale system-of-systems in defense applications. Prior to joining Purdue University, he was a systems engineer at Honeywell Aerospace in Phoenix, AZ. He holds a Bachelors and Masters of Science in Electrical Engineering from Iowa State University, Ames, IA, USA, and a Ph.D. in Aeronautics and Astronautics from Purdue University, West Lafayette, IN, USA. He is a certified systems engineering professional (CSEP) from the International Council on Systems Engineering (INCOSE).

Dr. James Llinas is a Research Professor Emeritus and Founder, Director of the Center for Multisource Information Fusion at the State University of New York at Buffalo, New York in the United States. He is an internationally recognized expert in sensor, data, and information fusion, co-authored the first integrated book on Multi-sensor Data Fusion, and have taught and lectured internationally for over 20 years on this topic. He also co-edited and co-authored the Handbook of Data Fusion, the text on Distributed Fusion for Net-centric Operations, and most recently the book on Context Enhanced Information Fusion.

Dr. Daniel A. DeLaurentis is a Professor in Purdue University's School of Aeronautics and Astronautics. He is the Director for Purdue's Institute for Global Security and Defense Innovation and leads Purdue's Center for Integrated Systems in Aerospace (CISA), which is home to 20 faculty affiliates, six professional research staff, and numerous dedicated graduate students. He also leads the Center's largest recent project with the Missile Defense Agency's Enhanced C2BMC program developing agent-based modeling and simulation for the development of advanced battle management architectures. His research is conducted under grants from NASA, FAA, Navy, the DoD Systems Engineering Research Center UARC, and the Missile Defense Agency. He teaches undergraduate and graduate courses in system design and system-of-systems engineering. Dr. DeLaurentis is an Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA), and senior member of the IEEE. He is also AIAA Deputy Strategic Technologies Coordinator since 2011. He is also Co-Chair of the System-of-Systems Technical Committee in the IEEE Systems, Man, and Cybernetics (SMC) community and is an Associate Editor of the IEEE Systems Journal.

10. Estimation of Noise Parameters in State Space Models: Overview, Algorithms, and Comparison

Ondrej Straka (University of West Bohemia, Czech Republic)
Jindřich Duník (University of West Bohemia & Honeywell International, Czech Republic)
Jindrich Havlik (University of West Bohemia & NTIS, Czech Republic)

Abstract: Knowledge of a system model is a key prerequisite for many state estimation, signal processing, fault detection, and optimal control problems. The model is often designed to be consistent with random behavior of the system quantities and properties of the measurements. While the deterministic part of the model often arises from mathematical modeling based on physical, chemical, or biological laws governing the behavior of the system, the statistics of the stochastic part are often difficult to find by the modeling and have to be identified using the measured data. Incorrect description of the noise statistics may result in a significant worsening of estimation, signal processing, detection, or control quality or even in a failure of the underlying algorithms. The tutorial introduces a more than six decades-long history as well as recent advances and the state-of-the-art of the methods for estimation of the properties of the stochastic part of the model. In particular, the estimation of state-space model noise means, covariance matrices, and other parameters is treated. The tutorial covers all major groups of the noise statistics estimation methods, including the correlation methods, maximum likelihood methods, covariance matching methods, and Bayesian methods. The methods are introduced in the unified framework highlighting their basic ideas, key properties, and assumptions. Algorithms of individual methods will be described and analyzed to provide a basic understanding of their nature and similarities. Performance of the methods will also be compared using a numerical illustration.

Eligibility: The tutorial is intended for researchers, engineers, and graduate students interested in the state estimation, target tracking and navigation, decision making, and system identification.

Ondrej Straka received his M.Sc. and Ph.D. degrees in cybernetics from the University of West Bohemia, Pilsen, Czech Republic, in 1998 and 2004, respectively. Since 2015, he has been an Associate Professor with the Department of Cybernetics, University of West Bohemia. He has fifteen years of the teaching experience at the UWB. Currently, he is a lecturer for graduate and post-graduate courses on estimation theory, stochastic systems and processes and mathematical control theory. He has published over 75 journal and conference papers and was involved in development of several software frameworks for nonlinear state estimation and system identification. He has participated in a number of projects of fundamental research and in several project of applied research (e.g., GNSS-based safe train localization and attitude and heading reference system). His current research interests include local and global nonlinear state estimation methods, system identification, noise covariance matrix estimation in state-space models, performance evaluation, and fault detection in navigation systems. Dr. Straka was a recipient of Werner von Siemens Excellence Award in 2014 for the most important result in the basic research.

Jindrich Dunik is a scientist at the Department of Cybernetics, University of West Bohemia (UWB), Czech Republic and at the Aerospace Advanced Technology Europe, Honeywell International. He received his Ing. (M.Sc.) and Ph.D. degrees in Automatic Control in 2003 and 2008, respectively, both from the UWB. Until 2010, he was with the UWB. From 2010 he is with Honeywell and from 2013 again with the UWB working in the areas of state estimation and navigation system design and integration. He is the author or co-author of more than 50 technical papers (both journal and conference) and granted patents. He has 8 years of the teaching experience at the UWB and, currently, he is teaching graduate courses on "System Identification and Filtering" and "Adaptive Systems". Dr. Dunik was a recipient of Werner von Siemens Excellence Award in 2014 for the most important result in the basic research.

Jindrich Havlik received his M.Sc. degree in automatic control in 2014 and he began the PhD. study programme the same year, both at the Department of Cybernetics, at the University of West Bohemia, Czech Republic. Since 2012, he has participated in several research projects at the Department dealing with navigation and state estimation. He is co-author of toolboxes for system identification and nonlinear state estimation and author or co-author of 8 journal or conference papers in the field of nonlinear filtering and system identification. His current research interests include local nonlinear state estimation and measures of nonlinearity/nongaussianity.

11. Trust Fusion and Belief Reasoning with Subjective Logic

Audun Jøsang (University of Oslo, Norway)

Abstract: This tutorial provides background theory and demonstrates practical application subjective logic in the areas of reasoning under uncertainty, computational trust and trust fusion. The tutorial is given by the author who started developing subjective logic in 1997, with a book published in 2016.

1. Representation and interpretation of subjective opinions
a. Formal representation of binomial, multinomial and hyper opinions
b. Correspondence between subjective opinions and other relevant representations of trust such as binary logic propositions, probabilities, Dempster-Shafer belief functions,
c. Expressing opinions as PDFs (probability density functions) and qualitative measures

2. Algebraic operators of subjective logic
a. Operators for binomial opinions: transitivity, fusion, product, coproduct
b. Operators for multinomial opinions: conditional deduction and abduction, trust transitivity and fusion

3. Applications of subjective logic
a. Trust networks modelling and analysis
b. Subjective Bayesian reasoning modelling and analysis
c. Subjective networks based, on a combination of subjective Bayesian and trust networks

Eligibility: This tutorial is targeted at researchers, system designers and developers working in industry and academia in the following areas: Information fusion in general, Computational trust, AI in general, Decision support tools, Bayesian networks.

Dr. Audun Jøsang, Professor at the at the University of Oslo, and Adjunct Professor at Queensland University of Technology, Australia Prof. Jøsang is the main author behind subjective logic which is widely applied by researchers and practitioners in the areas of uncertainty representation, belief fusion, Bayesian reasoning, computational trust and reputation systems.

Before joining Oslo University in 2008, Prof. Jøsang worked as Associate Professor at QUT and research leader for cybersecurity at DSTC in Australia, system design engineer at Alcatel Telecom in Belgium and research scientist at Telenor in Norway. Prof. Jøsang has a Master's in Information Security from Royal Holloway College, University of London, and a PhD from NTNU in Norway.

12. Overview of High-Level Information Fusion Theory, Models, and Representations

Erik Blasch (Air Force Research Lab, USA)

Abstract: Over the past decade, the ISIF community has put together special sessions, panel discussions, and concept papers to capture the methodologies, directions, needs, and grand challenges of high-level information fusion (HLIF) in practical system designs. This tutorial brings together the contemporary concepts, models, and definitions to give the attendee a summary of the state-of-the-art in HLIF. Analogies from low-level information fusion (LLIF) of object tracking and identification are extended to the HLIF concepts of situation/impact assessment and process/user refinement. HLIF theories (operational, functional, formal, cognitive) are mapped to representations (semantics, ontologies, axiomatics, and agents) with contemporary issues of modelling, testbeds, evaluation, and human-machine interfaces. Discussions with examples of search and rescue, cyber analysis, and battlefield awareness are presented. The attendee will gain an appreciation of HLIF through the topic organization from the perspectives of numerous authors, practitioners, and developers of information fusion systems. The tutorial is organized as per the recent text:

E. P. Blasch, E. Bosse, and D. A. Lambert, *High-Level Information Fusion Management and Systems Design*, Artech House, April 2012.

Lesson 1: Introduction – What is HLIF
- DFIG Levels 1 – 5 going from LLIF (Assessment) to HLIF (Awareness)
- HLIF Models
- HLIF Grand Challenges
- Comparisons of theories, representations, and implementations

Lesson 2: Situation Awareness (SAW) Models
- Process, interpreted, and State Transition models
- SAW projection/prediction

Lesson 3: Information Management Management of Information as an architecture
- Testbed Approaches
- User Issues (models, displays, interaction)

Lesson 4: Fusion System Design/Evaluation

Scenario based design
HLIF Evaluation (metrics)

Eligibility: This tutorial will be valuable for researchers, developers, and practitioners, while primarily intended for:
Researchers in basic science exploring high-level information fusion theory and applied applications towards demonstrations in laboratory simulations and operational field studies for situation awareness.
System engineers and developers of information fusion and command and control systems who are required to specify, develop, integrate, test, and evaluate high-level information fusion capabilities.
Technical managers who oversee data and command and control developments; for these managers the tutorial will serve as a valuable technical discussion on the terminology, concepts, and implementation challenges of high-level information fusion.
Graduate level students studying advanced information fusion theory, representations, techniques, and technologies.

Erik Blasch is a founding member of the International Society of Information Fusion (ISIF) in 1998. He was on the ISIF Board of Governors from 2000-2010 and the 2007 President. He was recognized with the 2014 *Joseph Mignogna Data Fusion Award* from the U.S. Department of Defence Joint Directors of Laboratories Data Fusion Group. Dr. Blasch served on the IEEE Aerospace and Electronics Systems Society (AESS) Board of Governors (2011-2016) and is currently a Disnguished Lecturer.
He has focused on information fusion, target tracking, pattern recognition, and robitcs research compiling 700+ scientific papers and book chapters. He holds 19 patents, presented over 30 tutorials, and is an associate editor of three academic journals. His books include *High-Level Information Fusion Management and Systems Design* (Artech House, 2012) and *Context-Enhanced Information Fusion* (Spriner, 2016), and *Multispectral Image Fusion and Colorization* (SPIE, 2018).

From 2000-2010, Dr. Blasch was the information fusion evaluation tech lead for the Air Force Research Laboratory (AFRL) Sensors Directorate—COMprehensive Performance Assessment of Sensor Exploitation (COMPASE) Center, adjunct professor with Wright State University, and a reserve Air Force officer. From 2010-2012. Dr. Blasch was an exchange scientist to Defence R&D Canada at Valcartier, Quebec in the Future Command and Control (C2) Concepts group. Form 2012-2017, he was with the AFRL Information Directorate and currently is a Program Officer at the Air Force Office of Scientific Research.

Dr. Blasch received his B.S. in Mechanical Engineering from the Massachusetts Institute of Technology in 1992 and Master's Degrees in Mechanical ('94), Health Science ('95), and Industrial Engineering (Human Factors) ('95) from Georgia Tech and attended the University of Wisconsin for a MD/PhD in Neurosciences/Mech. Eng until being called to military service in 1996 to the United States Air Force. He completed an MBA ('98), MSEE ('98), MS Econ('99), and a PhD ('99) in Electrical Engineering from Wright State University and is a graduate of Air War College ('08).
He is the recipeint of the IEEE Bio-Engineering Award (Russ-2008), IEEE AESS Magazine Best Paper Award (Mimno-2012), Military Sensing Symposium Ledaership in Data Fusion Award (Mignogna-2014). He is a Fellow of SPIE, Associate Fellow of AIAA, and a Fellow of IEEE.

13. Multitarget Tracking and Multisensor Information Fusion

Yaakov Bar-Shalom (University of Connecticut, USA)

Abstract: This tutorial will provide to the participants the latest state-of-the art techniques to estimate the states of multiple targets with multisensor information fusion. Tools for algorithm selection, design and evaluation will be presented. These form the basis of automated decision systems for advanced surveillance and targeting. The various information processing configurations for fusion are described, including the recently solved track-to-track fusion from heterogeneous sensors.

Eligibility: Engineers/scientists with prior knowledge of basic probability and state estimation (see, e.g., [2]). This is an intensive course in order to cover several important recent advances and applications.

Introduction (Overview)

Review of the Basic Techniques for Tracking

[vhb1.4.1{1.4.4] Parameter estimation vs. state estimation. The Kalman, the Alpha-Beta(-Gamma) and the Extended Kalman filters: their capabilities and limitations.

Tracking Targets with Multiple Behavior Modes

[vhb1.4.6] The Interacting Multiple Model (IMM) estimation algorithm | a real-time implementable, self-adjusting variable-bandwidth, tracking filter.

[379v] A Multiple IMM Approach with Unbiased Mixing for Thrusting Projectiles

Reference: IEEE Trans. Aerosp. Electronic Systems, 48(4):3250-3267, Oct. 2012.

Multisensor Data Fusion

[vhb8.3] Information processing configurations in multisensor tracking.

Type I: Single sensor or reporting responsibility.

Type II: Single sensor tracking followed by track-to-track fusion. The dependence of local tracking errors at independent sensors.

Type III: Measurement-to-measurement association followed by central dynamic association and tracking.

Type IV: Centralized tracking/fusion.

Information Matrix Fusion

[vhb8.4] A special centralized tracking/fusion configuration. Algorithms for synchronous and asynchronous sensors.

Heterogeneous Track-to-Track Fusion

[383v] T2TF from an active and a passive sensor. Why T2TF can be superior to centralized fusion.

Reference: J. of Advances in Information Fusion, 6(2):131-149, Dec. 2011.

Bias Estimation for Passive Sensors

[416v] Bias estimation for optical sensor measurements with targets of opportunity. The minimum number of sensors and targets needed.

Reference: Journal of Advances in Information Fusion, 9(2):59-74, Dec. 2014.

Measurement-to-Measurement Fusion from Passive Sensors

[388v] Statistical efficiency of composite position measurements from fusing LOS (line of sight angle) measurements. The only obtainable covariance | from the CRLB (Cramer-Rao Lower Bound) | is shown to be the actual covariance.

Reference: IEEE Trans. Aerosp. Electronic Systems, 49(4):2799-2806, Oct. 2013.

14. Object Tracking Sensor Fusion and Situational Awareness for Assisted- And Self-Driving Vehicles Problems, Solutions and Directions

Thia Kirubarajan (McMaster University, Canada)

Abstract: The automotive industry has been undergoing a major revolution in the last few years. Rapid advances have been made in assisted- and self-driving vehicles. As a result, vehicles have become more efficient and more automated. A number of automotive as well as technology companies are in the process of developing smart cars that can drive themselves. While totally self-driving cars are still in their infancy, some features like self-parking, proximity detection and lane identification have already made it into production in high-end vehicles. In spite of these recent developments, significantly more research is needed in order to perfect these nascent technologies and to make them ready for mass production. This provides the motivation for this tutorial.

In this tutorial, we aim to discuss a number of problems related to assisted- and self-driving vehicles, potential solutions and directions for research & development. The issues discussed in this tutorial will span multitarget tracking, multisensor fusion and situational awareness within the context of smart cars. We will also present some of the algorithms that are available in the open literature as well as those we have developed recently. In addition, we will also discuss related computational issues and sensor technologies. Finally, we will present some results on real data.

Eligibility: The proposed three-hour tutorial will be valuable to students, researchers and practicing engineers at universities, government research labs and companies who are interested in developing tracking and fusion solutions for automotive applications.

Professor T. Kirubarajan (Kiruba) holds the title of Distinguished Engineering Professor and holds the General Dynamics Industrial Research Chair in Target Tracking and Information Fusion at McMaster University, Canada. He has published about 350 research articles, 11 book chapters, one standard textbook on target tracking and four edited volumes. In addition to conducting research, he has work extensively with government departments and companies to process real data and to transition his research to the real world through his company TrackGen. As part of this, he has led the development of a number of software programs, including MultiTrack for real-time large-scale multisensor-multitarget tracking, MultiFuse for distributed tracking, and ISR360 for visualization, performance analysis and situation awareness, which have been integrated into some real systems. Currently, he is working with a major auto manufacturer on developing tracking, fusion and situational awareness algorithms for assisted- and self-driving vehicles.

15. Sensor Fusion and Tracking - a Hands-on MATLAB Workshop

Rick Gentile (MathWorks, Inc., USA)
Elad Kivelevitch (MathWorks, USA)

Abstract: We propose a 4 hour, hands-on workshop that is described below. The attendees would get access to all software and exercises that we cover in the tutorial.

Sensor Fusion and Tracking – a Hands-on MATLAB Workshop

Perception is at the core of research and development efforts for autonomous systems. Sensor fusion and multi-object tracking are critical components of perception systems. In this workshop, we introduce a set of tools to design, simulate, and analyze systems that fuse data from multiple sensors to maintain position, orientation, and situational awareness for surveillance systems and autonomous systems.

In this hands-on workshop, you will write code and use MATLAB to:
1. Define trajectories and generate detections from simulated sensors (e.g. radar, EO/IR, and RWR sensor models)
2. Explore multi-object trackers, fusion and localization algorithms
3. Quickly compare state estimation filters, motion models, and multi-objects trackers
4. Perform "what-if" analysis with different multi-object trackers
5. Evaluate system accuracy and assignment performance

We will also review advanced topics including:
- Tracking extended objects
- Tracking with sensors that produce range or angle-only detections
- Tracking large numbers of objects (e.g. flocks, etc.)
- Generating code to speed up simulation and to deploy algorithms

Eligibility: Modeling and simulation tools for sensor fusion and tracking can increase productivity in the development of multi-object trackers. We will describe modeling techniques that we believe will help the attendees with tracking basics by demonstrating configurable building blocks for state estimation filters, motion models, and multi-objects trackers. In addition, we have architected our algorithms in way that could help attendees provide a common "sandbox" to share and collaborate in the future.

Dr. Elad Kivelevitch is a Principal Software Engineer at MathWorks, Inc. He is responsible for developing sensor fusion and tracking tools for autonomous systems. Dr. Kivelevitch received his Ph.D. in Aerospace Engineering from the University of Cincinnati in 2012, and his M.Sc. (2005) and B.Sc. (1997) in Aerospace Engineering from the Technion - Israel Institute of Technology.
Dr. Kivelevitch has 20 years of experience working on autonomous vehicles and sensor fusion in academia, government, and the private sector. He is the elected-chair of the AIAA Intelligent Systems Technical Committee (ISTC).

Rick Gentile focuses on Phased Array, Signal Processing, and Sensor Fusion applications at MathWorks. Prior to joining MathWorks, Rick was a Radar Systems Engineer at MITRE and MIT Lincoln Laboratory, where he worked on the development of many large radar systems. Rick also was a DSP Applications Engineer at Analog Devices where he led embedded processor and system level architecture definitions for high performance signal processing systems, including automotive driver assist systems. Rick co-authored the text "Embedded Media Processing". He received a B.S. in Electrical and Computer Engineering from the University of Massachusetts, Amherst and an M.S. in Electrical and Computer Engineering from Northeastern University, where his focus areas of study included Microwave Engineering, Communications and Signal Processing.

16. Data Fusion Performance Metrics

Mark E Silbert (AM Pierce & Assoc, USA)
Craig Agate (Toyon Research, USA)
Charles Rea (NAVAIR & NAWC-AD, USA)

Abstract: The purpose of this tutorial is to give the attendees an understanding of what data fusion performance metrics are and what they provide. The tutorial will present many of the key performance metrics including how they are computed and the limitations of those metrics. The truth-to-track assignment problem will also be explained and its impact on the metrics.

The purpose of this data fusion (DF) metrics tutorial is to give the attendees an understanding of what data fusion performance metrics are and what they provide. Data fusion systems are used to track and identify objects in a dynamic environment using one or more sensors. Tracking and identifying objects is a complex process that is difficult to do well. There have been many approaches over the years each offering different strengths and weaknesses. It is important to realize that no single DF system is optimal for all scenarios and domains. All DF systems rely on the quality and quantity of the sensors and sources providing data. If the input data is suspect, then the DF system output will also be (classic garbage in, garbage out problem). Ideally, the DF system provides an accurate and timely operating picture to give the operator good situational awareness to make informed decisions. Unfortunately, due to the potential complexity and variety of tasks that a DF system must support, it is nearly impossible to presume that it will provide the most accurate information in all situations. The tutorial will help the attendees understand this point and explain how data fusion systems must be evaluated for the particular situations the system is expected to encounter.

With this understanding, the tutorial will explain various key quantitative metrics such as accuracy, redundancy, completeness. It will also explain qualitative metrics such as track purity heat maps. The tutorial will introduce the SIAP metrics, which was the first attempt by the DoD to standardize DF performance metrics. Before most metrics can be applied, it is necessary to determine which track should be assigned to which object. Assigning tracks to objects is called the truth-to-track assignment problem. The tutorial will explain the purpose for this assignment along with the methods and difficulties of this assignment process.

By the end of the tutorial, the attendees will have a better understanding of the following questions:
Why should we care about performance metrics?
What are the SIAP performance metrics? How are they computed?
What is the truth-to-track assignment problem? Why is it relevant to performance metrics? How is the assignment problem addressed?

Dr. Mark Silbert is a data fusion engineer and subject matter expert at AM Pierce. Prior to working at AM Pierce, he worked at NAVAIR with 37 years of experience and was recognized as a NAVAIR Fellow for Data Fusion. Dr. Silbert has worked 20 years supporting ASW efforts at NAVAIR. While at NAVAIR, Dr. Silbert had been involved in numerous research and development efforts focused on information/data fusion, decision-aiding, and artificial intelligence. He was directly involved in developing the data fusion system on nearly every intelligence, surveillance, and reconnaissance (ISR) Navy platform. He has also authored and co-authored several technical publications related to this work. In addition to supporting many acquisition programs, Dr. Silbert is currently supporting the DARPA CODE program. In addition, Dr.

Silbert has taught undergraduate and graduate courses in artificial intelligence, computer science, mathematics, and statistics.

Dr. Craig Agate received his B.S. and M.S. degrees in electrical engineering from the California State University, Northridge, CA, and a Ph.D. in Electrical Engineering from the University of California at Santa Barbara where his dissertation focused on Bayesian estimation methods. Currently the Fusion and Tracking Lead at Toyon Research Corporation, he works on problems in the area of estimation (nonlinear filtering, particle filtering, track-to-track association and fusion, Bayesian networks, etc.). Besides algorithm development, he has helped develop a Metrics Toolbox at Toyon Research that is used to evaluate tracking and fusion systems.

Charles Rea is Naval Air Systems Command's (NAVAIR) lead data fusion engineer, senior subject matter expert (SME), and the Sensor Fusion Branch Manager, AIR 4.5.5.3. Mr. Rea has 14 years of experience in data fusion technology. His work is split between NAVAIR acquisition support and research and development (R&D). He is currently the data fusion lead for most of the Navy's intelligence, surveillance, and reconnaissance (ISR) or Command & Control aviation platforms. In addition, he supports various program executive offices as the senior data fusion technical advisor. Mr. Rea's R&D efforts have focused on data fusion algorithms, decision-aiding tools, and data fusion system performance evaluation techniques. He has authored several technical publications related to this work.

17. Social Data Analysis for Intelligence

Valentina Dragos (ONERA, France)

Abstract: This tutorial investigates several issues of social data analysis for intelligence. Social data is understood as information collected from social media including various networks and platforms that show what online users publish on those platforms but also how they share, view or engage with content or other users. The tutorial does not break down how to make sense of social media data, but raises questions to be addressed before exploring social media as a resource for intelligence analysis. The tutorial will be organized into seven chapters. The first chapter introduces intelligence analysis as the application of cognitive methods to weigh data and test hypotheses within a specific socio-cultural context.

The second chapter explores some of the unique features of cyberspace that shape how people behave in this new social realm. The chapter also analyses how the virtual domain of cyberspace is unlike the environmental domains of air, land, maritime and space and how it challenges traditional understanding of concepts such as temporality, conflict, information, border, community, identity or governance.

The next chapter investigates the notions of trust and reliability for artefacts in the cyberspace, ranging from information items to sources to more sophisticated structures such as virtual communities. The chapter shows that trust may be diminished is spite of the tremendous volume of information and that the cyberspace is prone to phenomena causing harm to data completeness and credibility. Several such phenomena will be considered: opacity and information filtering (echo chambers, bubble filters), disinformation campaigns (fake news, propaganda, hoaxes, site spoofing), misleading intentions (data leaks), biased interactions (social boots, smoke screening).

Chapter 4 investigates the nature of social data content, asking the question of whether social data conveys factual and useful pieces or information or rather subjective content in the form of personal opinions, beliefs and impressions. The discussion is based on two illustrations of social data analysis. The first one tackles fake news propagation in the aftermath of terrorist attacks; the second one addresses the subjective assessment of concepts conveying extreme ideologies online.

Chapter 5 identifies pitfalls in exploring the cyberspace both in isolation and considering its interconnectedness with the real world. First, the cyberspace comes with its own riddles and pairs of opposite concepts having blurred frontiers: free speech and actions vs. online hate or cyberbullying; online privacy and personal data vs. fake profiles and identities; transparency vs. anonymity by design. Second, additional pitfalls occur when social data is analyzed in the light of events in the real life. Specific phenomena induced by white data and real-life bias induced by silent communities will be discussed.

Chapter 6 addresses the question of how gathering, processing and analyzing social data impacts the intelligence analysts, given the characteristics of those data.

The last chapter concludes the tutorial by illustrating the state of art on tools and techniques for cyberspace exploration along with several ongoing research projects, NATO research tracks and initiatives addressing the many facets of social data analysis. While showing that, from a practical standpoint, solutions are still at *afterthe- fact forensics* level, the chapter will highlight several initiatives adopted by various instances to counter illegal content and online hate and finally to make the Internet a safer place.

Eligibility: This tutorial is intended for students, researchers and practitioners who are interested in cyberspace exploration and social data analysis. Thanks to illustrations based on realistic use-cases, the participants will learn major challenges of gathering, analyzing and interpreting data from social media and will discover major initiatives undertaken to offer solutions to some of those challenges and to make the cyberspace a more resilient environment.

Dr. Valentina Dragos is a research scientist, member of the Department of Information Modeling and Systems at ONERA, The French Aerospace Lab in Palaiseau, France. Valentina received Master and PhD degrees in Computer Science from Paris V University and her research interests include artificial intelligence, with emphasis on natural language processing, semantics technologies and automated reasoning. Since joining ONERA in 2010, Valentina contributed to several academic and industrial security-oriented projects, addressing topics such as: semantic interoperability for command and control systems, heterogeneous information fusion, and exploitation of semantic data (HUMINT, OSINT) for situation assessment. In January 2018 Valentina has been appointed by the French Ministry of Defence to integrate the NATO Research Track IST 159 "Exploration of Cyberspace for Intelligence".

18. Introduction to Sensor Management

Ken Hintz (George Mason University, USA)

Abstract: The student will have an understanding of the need for sensor management, the terminology associated with it, and the impact of sensor management on situation assessment. The student

will also be introduced to information based sensor management and the underlying need for maximizing the expected information value rate as an optimizing criterion. Essential to information fusion is the control of the sensors that make the observations and collect the data to be fused into information that changes our knowledge of the situation. Sensor management has progressed from the scheduling of single sensor pointing to single sensor agile functionality to the current need for multiple heterogeneous sensor management. Along with this progression of sensor diversity and complexity, there has been an attempt to deal with this profusion of data with this "big data" presenting its own class of problems. Sensor management is a methodology for reducing the total size of the data collected in an environment in order to focusing on relevant, important, valued, data and its timely collection utilizing the "best" sensor or combination of sensors.

Recently, the field of sensor management has expanded to include the fusion of hard (measurements of a physical process) and soft (human derived, e.g., social media) data. The brief tutorial will review some of the key concepts in sensor management and devote approximately 1/3 of the time to presenting the unifying concept of information based sensor management (IBSM) and the 6 partitioned components which comprise it. The tutorial is a subset of the instructor's book manuscript in preparation and under contract to Artech House scheduled for publication in 2020, Sensor Management in ISR.

This tutorial will be valuable for researchers, developers, and practitioners, while primarily intended for:

- Researchers in sensor management and the use of sensors to effectively assess a situation.
- System engineers and developers of heterogeneous sensor systems, particularly those involved in extracting the maximum valued information from an environment for creating actionable intelligence.
- Technical managers who oversee data/information/knowledge acquisition and the users of command and control; for these managers and users the tutorial will serve as a valuable technical discussion on the terminology, concepts, and implementation challenges of sensor management and particularly information based sensor management.
- Graduate level students studying advanced sensors and sensor integration methodologies.

Dr. Ken Hintz has been an Associate Professor in the Department of Electrical and Computer Engineering at George Mason University since 1987. He designed and established the Bachelor and Masters in Computer Engineering Degree Programs at GMU and teaches courses in sensor engineering, image processing, and computer engineering.

Dr. Hintz' current research interest is in Orchestrated Resource Management (ORM) and Information Based Sensor Management (IBSM) supported by the Naval Postgraduate School. He also developed a new method for pre-shot detection of barrelled weapons based on his discovery of cavity induced modulation (CIM), developed methods for the automatic detection of landmines utilizing ground penetrating radars, and designed and implemented technical means for INF treaty verification utilizing image processing of large X-ray images for the U. S. Arms Control and Disarmament Agency.

Before joining GMU, Dr. Hintz was with the Naval Surface Warfare Center, Dahlgren, VA, working in electronic warfare and radar signal processing where he designed and built the original AN/ULQ-16 pulse analyzer. Prior to working at NSWC, Dr. Hintz was with the U. S. Navy as a designated Naval Aviator stationed for 3 years in Rota, Spain flying Electronic Warfare Reconnaissance with Fleet Air Reconnaissance Squadron Two (VQ-2). During that time he became designated Electronic Warfare Aircraft Commander (EWAC) in both the EC-121 and EP-3E aircraft.

Dr. Hintz holds 25 patents, 8 patents pending, is a Fellow of SPIE, a Senior Life Member of IEEE, and lead author on a book on Microcontrollers. He received his B.S. degree in Electrical Engineering from Purdue University, West Lafayette, Indiana in 1967 and his M.S. and Ph.D. degrees in Electrical Engineering from the University of Virginia in 1979 and 1981 respectively.