ISIF

Perspectives

On Information Fusion

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ISIF Perspectives

Perspectives seeks bridging articles, expository papers and tutorials, classroom notes, and announcements on topics of general interest to the ISIF Fusion community. Fresh points of view on established topics are especially welcome, as are articles on topics of interest to the ISIF annual fusion conference. Papers containing new research should be directed to JAIF or other research journal. The standing Call for Papers (CfP) for ***Perspectives*** can be found at http://isif.org/sites/isif.org/files/CfP%20for%20Perspectives.pdf. The CfP for Fusion 2016 http://fusion2016.org/Call_For_Papers includes the topics (1) Theory and Representation, (2) Algorithms, (3) Modeling, simulation and evaluation, and (4) Applications.

Papers should be submitted online at http://isif.org/publications/isif-perspectives-information-fusion. The average length for submissions is approximately six (6) pages (in JAIF two-column format). All submissions will be reviewed for content and style, as well as suitability for ***Perspectives***. All papers accepted for publication will be written in a relaxed, colloquial style that facilitates understanding by a wide audience. Articles containing significant original research should be submitted to JAIF.

Cover: View of the Ngulia Rhino Sanctuary in Tsavo National Park, Kenya. The image is a mockup of a cliff-mounted ground radar return with a perfect 360° view of the entire sanctuary. The Kenyan Wildlife Service (KWS) rangers in the picture are inspecting an artificial watering hole while on a patrol to make rhino observations and report any signs of human intrusion. Fifty years ago, the valley was home for 10,000 black rhinos, but only 65 remain today.

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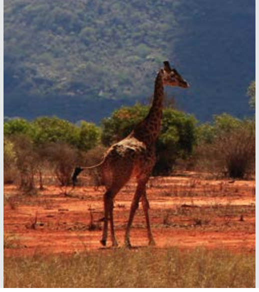
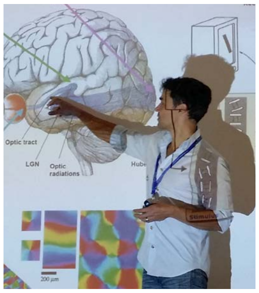



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ISIF

PERSPECTIVES MAGAZINE

The International Society of Information Fusion (ISIF) was founded to provide an active forum for the free and open discussion of ideas, applications, and methods for researchers and practitioners working in the new field of information fusion. The community is diverse by its very nature—it requires exploiting techniques that often span multiple technical disciplines and specialties. The ISIF community is also inherently international because the need for information fusion is felt, and felt deeply, in many countries across the globe. It is still a very young field and it is evolving quickly in both methods and scope of applications.

The ISIF community publishes JAIF, the *Journal of Advances in Information Fusion*. It is an established forum for the presentation of high-quality peer-reviewed archival scientific research papers. The community's needs are larger than this however. It has long been recognized that a new and more relaxed forum is needed, a forum in which members can discuss and share thoughts on many things that are important to the life of the community but fall outside the realm of peer-reviewed research. The new *ISIF Perspectives Magazine* is this forum.

The premier issue of *Perspectives* is in your hands. Welcome! It has two feature articles, one devoted to the truly noble cause of saving the rhinoceros in the wild and the other devoted to higher level fusion. We hope to have one or two such feature articles in every issue. In this issue we also have a book review. We plan to include a book review in every issue, with an emphasis on younger authors writing on focused topics and on books that are unlikely to be reviewed elsewhere. We will also include reports on ISIF activities. In this issue you will find reports on ISIF sponsored events, awards programs, and last year's Fusion Conference in Washington, DC. Future issues will welcome reports on student highlights and upcoming events. The history of the creation of ISIF almost 20 years ago is recounted here by one of its Founders. Much of this story was news to me. Selected obituaries will also be printed from those that are uploaded to the website at http://isif.org/member-obituaries. In every issue of *Perspectives* we endeavor to have something of interest to everyone working in information fusion. That is a lofty goal, one that we will always strive toward and hope to achieve.

Pulling together the first issue of a new publication is a demanding and time-consuming task. It happened only because many people, working separately and cooperatively, moved steadily toward a common goal. First and foremost I thank the authors and contributors themselves—without them there would be nothing to print. Every article no matter how small is reviewed (at an appropriate level) to ensure quality of content. For this, I thank the Associate Editors and anonymous reviewers who have contributed much time and effort to the task. I thank the ISIF Board for moving forward with the decision to add *Perspectives* as a forum for discourse. Finally, I thank the members of the ISIF community for their sustained commitment to the international cooperation needed for continued growth and development of the field of information fusion.

Roy Streit
Editor-in-Chief

Project Ngulia: Tracking Rangers, Rhinos, and Poachers

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Abstract—Poaching and wildlife trafficking is an escalating problem. The park rangers today are not only conservationists, they are also the guardians of critically endangered animals in the field. Many of them have been killed in recent years in the line of duty. The rangers in wildlife organisations have paramilitary training, but their equipment is very basic. Often the poachers are better trained and equipped than those seeking to protect national parks from intruders. Smart security technology—from communications tools to surveillance sensor technologies used for protection of critical infrastructure—is needed. In this paper we describe how innovative, cost-efficient technology can be used to assist wildlife organisations to combat poaching and wildlife trafficking. We use an ongoing pilot initiative, project Ngulia, led by the Kenya Wildlife Service aimed at protecting wildlife and other natural resources in Kenya.

INTRODUCTION

A WILDLIFE CRISIS—WITH GLOBAL SECURITY AND DEVELOPMENT IMPLICATIONS

On a bright day inside the Ngulia Rhino Sanctuary in Tsavo West National Park in Kenya, the guardians of the rhinos—the park rangers—can see as far as Mount Kilimanjaro. It emerges beyond a layer of other peaks that surround Ngulia, which stretches out over a 90 km^2 area. The area is called rhino valley because once upon a time 10,000 rhinos roamed here. Today, rhino valley is a shadow of its meaning. In the 1970s, Kenya was home to 20,000 rhinos. Today, there are only 650 left. The region's elephants have also seen significant reduction in recent years and this depressing story is all too common around the world. Between 2010–2015, almost 5,000 rhinos were slaughtered by poachers. Equally troubling, some of the world's worst terrorist organizations and transnational criminal syndicates are benefitting from this heinous activity and other environmental crimes. Indeed, the Islamic State, the Sudanese Janjaweed, Joseph Kony's Lord's Resistance Army, Boko Haram, and Al Shabaab are all directly or indirectly involved in raping mother earth of its wildlife and natural resources. For countries that rely on the tourist-popular animals, widespread poaching and other wildlife crimes are detrimental to their economic viability. The Kenyan tourism sector, for example, represents 15 percent of the country's gross domestic product (GDP). No animals to attract tourists with, means lost jobs and lost revenues. The problem is today well described in media, and for further reading on wildlife and environmental crime, we recommend [3], [4], [7], [9], [11], [15], [20], [25].

A GLOBAL RESPONSE EMERGES

As the national security and development implications from poaching and wildlife crime is becoming clearer, countries around the world are responding. In 2013, U.S. President Barack Obama and his former Secretary of State, Hillary Clinton, initiated a process that has led to a new U.S. national strategy to combat poaching and wildlife crime. Not only environmental agencies around the world are asked to up their efforts. Even the United States Department of Defence has been given marching orders to support the mission of safeguarding wildlife and other natural resources. The United Kingdom, Germany, the United Nations, the European Union, and a slew of other public and nongovernmental organizations are also spending more political capital and resources on the problem than at any other time in history.

PROJECT NGULIA: TECHNOLOGY AND INNOVATION ON EMERGING MARKETS

Project Ngulia is part of the global response to this wildlife crisis. Led by the Kenya Wildlife Service, the government authority charged with protecting Kenya's wildlife, a public-private sector consortium has come together to create a new gold standard for wildlife and natural resources protection. The project has the backing of some of the world's leading voices in the field, as well as the best technological competencies from both the academic and the private sector. We have a pilot project up and running in the Ngulia Rhino Sanctuary and we have a test site in Kolmården Zoo. The end result will be an impactful, cost-effective, and bottom-up technological platform that secures Ngulia, but that can also be scaled and replicated elsewhere. Our model has received international recognition by, for example, the Clinton Global Initiative and key members of the United States Congress.

BUSINESS OPPORTUNITIES

We want to save animals. We also know that no project is sustainable without the private sector seeing a commercial value in participating. Project Ngulia will do good, while at the same time present unprecedented opportunities for participating companies to break into new markets in emerging regions. Think for a second about what this and future applications of the project are trying to safeguard: wildlife, forests, and oceans. These are economic engines for countries in the same way that ports, energy infrastructure, and borders are. And all of these critical infrastructures need protection and the market for protection of critical infrastructure globally is vast. Project Ngulia is an unprecedented opportunity to prepare for this expanding market, reaching new costumers and finding new value for their products and service.

RESEARCH OPPORTUNITIES

No doubt, there are many positive effects and intentions of this pilot project. However, the purpose of this contribution is to highlight the connection to sensor fusion as a subject area in research. The research aspect of the project is two-fold: demonstrator opportunity and a test site to provide real data from a real application.

First, there is an increased demand from funding agencies and industry that research should benefit society, and that demonstrators are the first step to show relevance for real applications. In contrast to this bottom-up approach, funding agencies such as the European Union also define societal challenges from which research programs are defined. Both these trends aim at overcoming the "valley of death", commonly used to illustrate the gap between research at universities and development in industry. Project Ngulia provides ample opportunities to demonstrate research results, and perform long-term tests in real environments. Ultimately, sensor systems and platforms provided by industry together with fusion algorithms developed in this partnership can come quite close to complete products.

Second, researchers need real data for algorithm development, and the project will feature a test site at a zoo, where networks of heterogenous sensor systems will be deployed. Ground truth can be obtained by putting Global Position System (GPS) loggers on both humans and animals. All data will be accessible in real time from a cloud database, and algorithms can be illustrated for the general public through a web application programming interface (API).

It is the purpose of the remaining paper to explain these aspects in more detail.

> ## The Poaching Problem
>
> - 140,000 elephants and more than 3,600 rhinos have been slaughtered by poachers since 2010.
> - Over 1,000 park rangers have died in the past decade while defending the animals.
> - The illegal wildlife trade currently generates between \$7–23 billion a year—more than the illicit trafficking of small arms, diamonds, gold, or oil.
> - A rhino horn is worth more than \$65,000 per kilogram on the black market, which is more than gold or platinum.
> - Between 35,000–50,000 elephants are killed every year in poaching; three rhinos are poached every day.

TECHNOLOGY FOR WILDLIFE MONITORING

Using technology for wildlife monitoring is an old research area, and an early textbook on the subject is [27]. A recent survey of sensors for wildlife monitoring is provided in [6]. They use the taxonomy in [19], where a survey of different models for animal movement is presented. They divide the models and sensors according to whether they monitor trails of individual animals (called Lagrangian approach) or the presence of an animal at a specific place (called Eulerian approach):

- Tracking sensors: GPS, RFID, inertial sensors, radio transmitters.
- Surveillance sensors: radar, sonar, camera, thermometer, PIR, thermal camera, electronic noise, microphone, geophone.

An earlier state of the art survey of tracking technology is presented in [22], where the conclusion is that GPS is the most cost-effective tracking device, but that there are other radio-based options.

This section provides an overview of state of the art in research and technology initiatives. These initiatives are usually not described in the scientific literature, but more information is easily found by searching the Internet for the keywords we provide below. A common theme is that most initiatives are centered around a technical product or a single technical concept. A few of the initiatives selected below include several technology aspects. As we describe in the following sections, our approach differs significantly as being a bottom-up approach, where small technology and training steps are taken in a long-term holistic plan.

CAMERA SURVEILLANCE

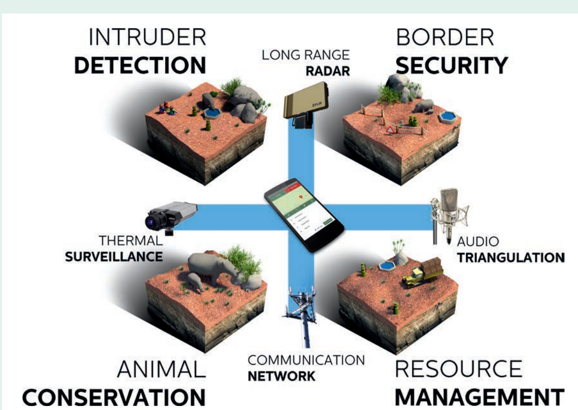
A common theme in many initiatives to detect poachers in the park at the same time as monitoring wildlife, is to put camera traps along the animal trails. The use of camera traps for wildlife monitoring is very old, and a good survey of the history is provided in the textbook [5]. With the advance of machine learning, these camera traps can be quite sophisticated. The traps can analyse the video stream in real time and save a still picture of large objects appearing in the scene. The built-in software can be more or less advanced in classifying images according to object and relevance [18]. Communication is as always a challenge, and both manual collection of memory cards (mostly for conservation purposes) and real-time transmission via cellular or satellite communication systems are used today. Among such initiatives we mention:

- The development of low-cost nano-satellites by NexGen Space LLC (US). The idea is to allow for large scale camera trap deployment, at a much lower cost compared to regular satellite communication. Surveillance sensors: radar, sonar, camera, thermometer, PIR, thermal camera, electronic noise, microphone, geophone.
- The smart camera traps Trail Guards by Wildland Security (US) include software for classifying humans. This meta information with pictures is transmitted by GSM or satellite to selected recipients.
- Instant Detect by Zoological Society of London is another camera trap initiative that has been running for some time. Its focus is wildlife monitoring, and they are using an app for crowd-sourcing manual classification of images.
- Binomial Solutions (India) is developing surveillance cameras, including thermal cameras, that include algorithms for learning animal movement pattern.

Ranger Duties and System Overview

The ranger duties include:

- Conservation: observations of individual rhinos and their condition.
- Border protection: patrolling the border by foot or by vehicle, looking for footprints or any other sign of intrusion.
- Intruder detection: poachers can rather easily pass the border, and the rangers are looking for footprints and cadavers.
- Resource management: the logistics include getting supplies out to the field and paper reports back to the headquarters, using one vehicle serving a vast area.



RADIO AND ACOUSTIC SURVEILLANCE

A survey on radio tracking methods for wildlife monitoring is provided in [14]. A particle filter based tracker is proposed in [13], where an airborne radio scanner measures received signal strength (RSS) from radio tags on the animals.

A similar approach was further tested in [21], but with a least squares approach to localisation. However, the purpose here was to find cell phones, for instance from missing people or poachers.

The field of acoustic monitoring of wildlife is surveyed in [8]. There is at least one initiative to develop microphone networks to monitor remote areas for gun shots, chain saws, motorcycles, etc. Technology Exploration Group (US) is using such a network to support unmanned aerial vehicle (UAV) missions. Further, MIT media lab has developed a ground sensor consisting of microphone and PIR motion sensor, which has been tested in Tsavo, Kenya.

AIRBORNE (DRONE) CAMERA SURVEILLANCE

The use of drones to monitor wildlife in vast areas is of course a very appealing approach, and there are many initiatives in demonstrating this approach also for antipoaching purposes. However, there are many hurdles to overcome, and large-scale sustainable deployments seem still far away. A general view of using robots to monitor wildlife in different environments is provided in [10], while below we mention a few initiatives in the field:

- The Air Shephard initiative is a collaboration between the University of Maryland, the Lindberg Foundation, and the Piece Parks. See also the Anti-Poaching Engine below.
- AidDrone uses infrared (IR) cameras to monitor the parks, and this combination has been evaluated in 52 parks in Kenya among other places.
- Wildeas has evaluated some 50 different drones for savannah monitoring. This company has also training and other sensor systems in their portfolio.

Also, manned aircraft are still used in some initiatives:

- ZAPwing is an initiative to use manned aircraft to monitor selected parks, which today covers at least 24 gaming reserves.
- Ichikowitz Family Foundation (IFF) donated a couple of helicopters to South Africa National Parks (SANparks), as a collaboration with defence industry through the Paramount group.

A machine learning algorithm is proposed in [18] for using a combination of airborne EO and IR cameras to automatically classify humans, rhinos, or other animals.

TRACKING DEVICES

The use of GPS tags is a convenient solution for tracking individual animals [17], and there are now lightweight units that can be used even on relatively small animals such as birds. For migrating birds where GPS cannot be used, light loggers is an alternative, and a tracking application based on the particle filter is presented in [26].

Energy constraints for using GPS, computations, and communication form a challenging design and optimisation problem as described in [12]. One promising solution is studied in [16]. The idea is to only use the GPS receiver for a few milliseconds every time a position is required, and let the server perform the computer-intensive and information-intensive computations. This reduces the receive time and computations several order of magnitudes, with a limited requirement on communication.

Many of the larger initiatives are also evaluating tracking devices on the animals. A spectacular trial has been performed by Piece Parks. With donations from the Dutch and Swedish post code lottery, Piece Parks has invested in a Rhino Protection Programme. In total, almost 50 million Euros have been donated to this programme, of which 15 million was during 2014. This is thus one of the largest programs in this field, and involves everything from night vision goggles to drones. The donation 2014 was used to a large extent for a sophisticated rhino horn marking project. The rhino horn is equipped with GPS trackers, color (to make the grinded horn less attractive), poison (that makes the end users sick but not dead), and radioactive isotopes (to detect rhino horn in the customs).

BACKEND DATABASE TOOLS

There are several software platforms for wildlife monitoring, such as SMART (Spatial Monitoring and Reporting Tool) [1] and Cybertracker [2]. These have been around for some time, and were originally developed by conservation practitioners.

Cybertracker is a field tool primarily aimed for reporting direct or indirect (tracks) animal observations. Today, Cybertracker is a combination of desktop and smartphone software that can be used by the rangers to report geo-tagged information about wildlife, and also human activity.

SMART was launched in 2013 as a tool to collect and analyse geo-tagged data offline, as a collaboration between multiple conservation agencies. SMART was originally developed as a desktop application for organising and visualising data from patrol reports as an off-line tool. Designing a database for wildlife reports can be challenging in itself, and [23] highlights the importance of unified data formats when handling biological data with GPS geotags. They suggest a modular software structure with a geospatial database as the core. They discuss the various requirements on the database management system that wildlife monitoring applications require.

During the 2015 Wildlife Crime Tech Challenge, there were several finalists that proposed software platforms for wildlife monitoring.

PROJECT NGULIA: TRACKING CHALLENGES

The poachers hunt the rhinos, the rangers hunt the poachers, and the rhinos are at risk. On top of this, the commanders are trying to coordinate the defence against the poachers, and the researchers are monitoring the health and conditions of the rhinos. Thus, the commanders and researchers are in great need for situational awareness, which ideally includes tracking of rhinos, rangers, and poachers. On the other hand, the poachers should under no circumstances get access to this information, or be able to use the same technology, for their heinous purposes.

Tracking these actors needs different information sources as described in this section, where also perspectives of this challenge are provided. Illustrations are in all cases results from our field tests in the local wildlife park Kolmården.

RANGERS

The ranger positions are most easily obtained with GPS. Our solution includes that each ranger has a personal smartphone that logs GPS coordinates and uploads these to a cloud database. All reports are also geo-tagged and time-stamped automatically.

RHINOS

Also the rhino positions can be obtained with GPS, and there are special collars or foot rings developed for this purpose; see Figure 1 for one example of a product from one of our partner companies. Another partner is developing a device that is put in the thick skin of the rhino's neck, which also measures body

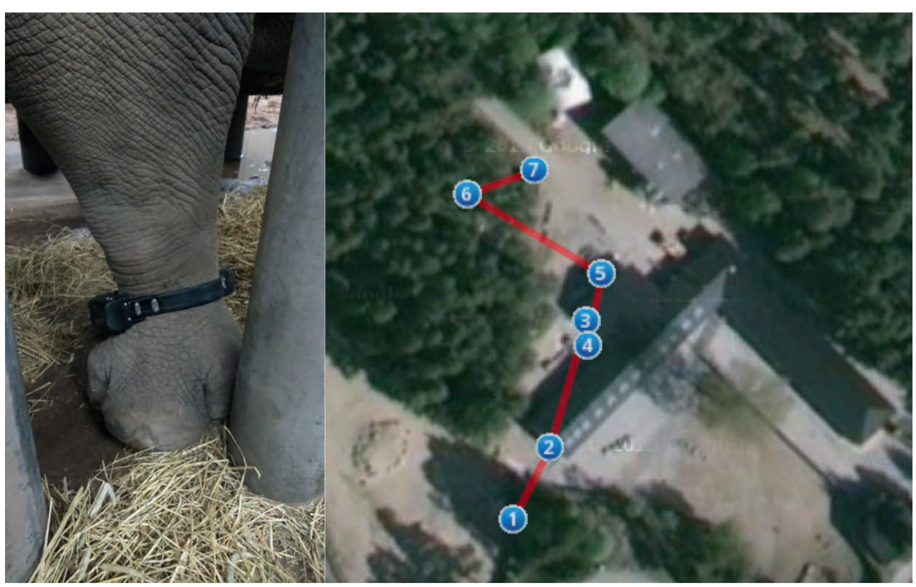


Figure 1
Example of a foot-mounted GPS tracker for rhinos. Position 6 is apparently a GPS outlier, so sensor fusion of step detections from accelerometer data to remove outliers is one research challenge. Pictures by Kolmården Zoo and FollowIT.

temperature and heart rate for health monitoring. It remains to be seen if any tracking devices will be on or inside the animals.

One drawback with having devices on the rhino is the powering. Batteries have a limited life-length, a couple of years for the products we are aware of. However, the rhinos cannot be tranquillised more than once during their life due to the stress it causes. Energy harvesting seems still not mature, and solar panels will suffer from dirt and wear.

Rhinos are also observed by the rangers. In fact, this is one of their main duties. This gives irregular observations over time, with rather good position accuracy. There are two kinds of reports they do.

- Direct sightings in the field or more commonly at the waterholes. The identity of the rhino can be determined by ear notch markings, but this requires observations of close distance where both ears are visible. Otherwise, incomplete id data are obtained, which implies an association challenge.
- Indirect sightings, for instance droppings, browsing traces, rest places, and foot prints. These have poor time resolution. Sometimes, droppings are sent for DNA identification, for the purpose of building up a database of DNAs, but which also provides the identity of the rhino (but with a long time-delay).

Sensors can also assist in rhino tracking. Thermal cameras, for instance placed at the waterholes or the trails that they often follow, can detect and classify rhinos, but without identification of individuals. A radar can probably also give an indication of possible rhino position and speed. Ground sensors and microphone arrays and networks are future possibilities.

Fusion of sensor data with manual reports is in fact a challenging research problem in itself. Sensor data includes a precise time stamp, while indirect sightings from tracks, droppings, browsing, and resting has a large time uncertainty, but no position errors. Some initial results are presented in [24].

POACHERS

One way to detect poachers before they reach the border is by using camera traps along the trails. A radar with a 5–10 km range can also give indication of approaching humans.

Once the poachers reach the border, there is a range of border protection systems available. Laser and microwave barriers are one solution. Other solutions include IR detectors and surveil-

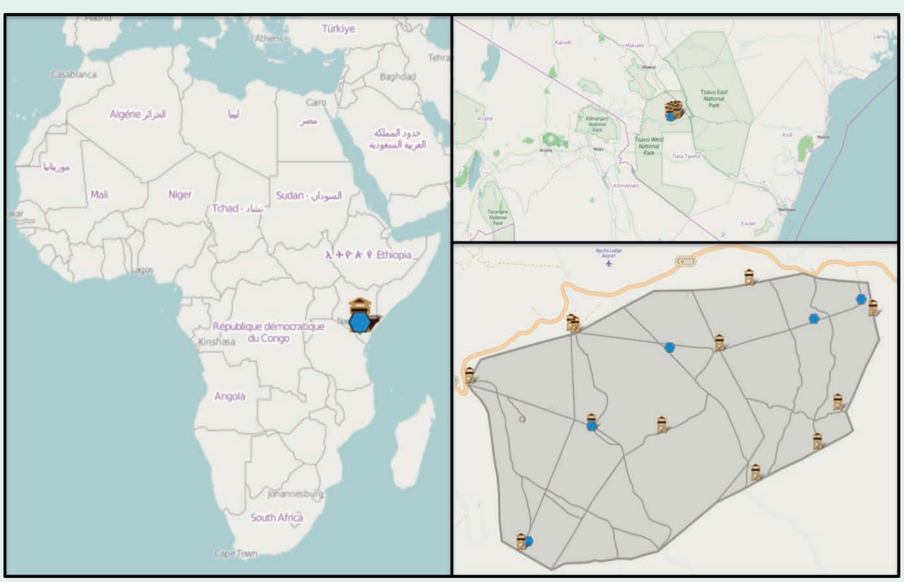
The Control, Command, and Communication System

A control, command, communication, and surveillance (C3S) system can include:

- A mobile platform (smartphone) for the rangers' digital reports.
- A mobile platform (tablet) for the commanders for situational awareness and command central.
- Additional infrastructure to secure robust wireless communication, perimeter protection, and wide area surveillance sensors.
- The C3S system is implemented as an app on smartphones. The first purpose of the app is to facilitate the daily work of the rangers to monitor wildlife, improve the logistics of resource management, and finally to protect the border and detect intruders. For safety reasons, among others, the ranger app is mainly an input device, where they send information to the cloud. No sensitive data are accessible from the app.

Ngulia

The rhino sanctuary Ngulia is situated in Tsavo West in the southeastern part of Kenya. Ngulia is about 90 km^2 large, and the border is 42 km long.



lance cameras. All these have a limited range and require line of sight. The Ngulia border consists of long straight parts, but still up to 100 surveillance cameras would be needed to cover the 42 km border. Geophones are an option to detect footsteps, but with an even shorter range.

There are a few emerging technologies with a longer range. A wire pair can be configured to be a metal detector using the change in induction. Such a system can reportedly detect as small things as a zip. Fiber loops can also be used to sense vibrations in the ground and detect footsteps and vehicles.

The rangers provide manual and indirect observations of poachers, when they patrol the border to look for footprints. The area on both sides of the fence is regularly raked, to make it easier to detect the footsteps.

In the case that the poachers successfully enter the sanctuary, tracking becomes even more important. Again, camera traps along the trails and surveillance EO and IR cameras at hotspots (water holes) can be used.

Finally, if they use their guns, the shot can be observed and reported by the rangers, and microphone networks can detect and localise the shot.

RADIO DETECTORS

A network of radio detection and bearing units can be a powerful tool to prevent radio communication for the poachers. The point is, even with only a few units, all GSM phones inside and outside the sanctuary can be detected and located. A larger frequency band can be scanned, to also find other communication devices.

A detected cell phone can easily be associated with an intruder. First, the ranger positions are known to the system, so these cell phones can be eliminated. Second, during

Outreach Activities

Selection of outreach activities:

- Demonstration of the app platform by Martin and Fredrik for the Swedish king in April 2015.
- Fredrik in discussions with the Kenyan ambassador to Sweden and the former minister of development in Sweden, at a workshop at Kolmården Wildlife Park November 2015.
- An article published in the *Washington Post* by Johan.
- Senator Chris Coons at a meeting at Stimson Center, talking about a Wildlife crime bill currently under consideration by the U.S. Congress.
- Johan presents the project at a Clinton Global Initiative luncheon 2015 with President Bill Clinton and Secretary Hillary Clinton.

Figure 2
Experiment with localization of a cell phone by measuring the RSS from a drone. The left picture shows a snapshot image from the drone, while the right picture shows the operator view, where the measurement positions are marked with yellow, and the estimated position after each measurement is illustrated with red. The true position is also marked here for reference. Picture from [21].

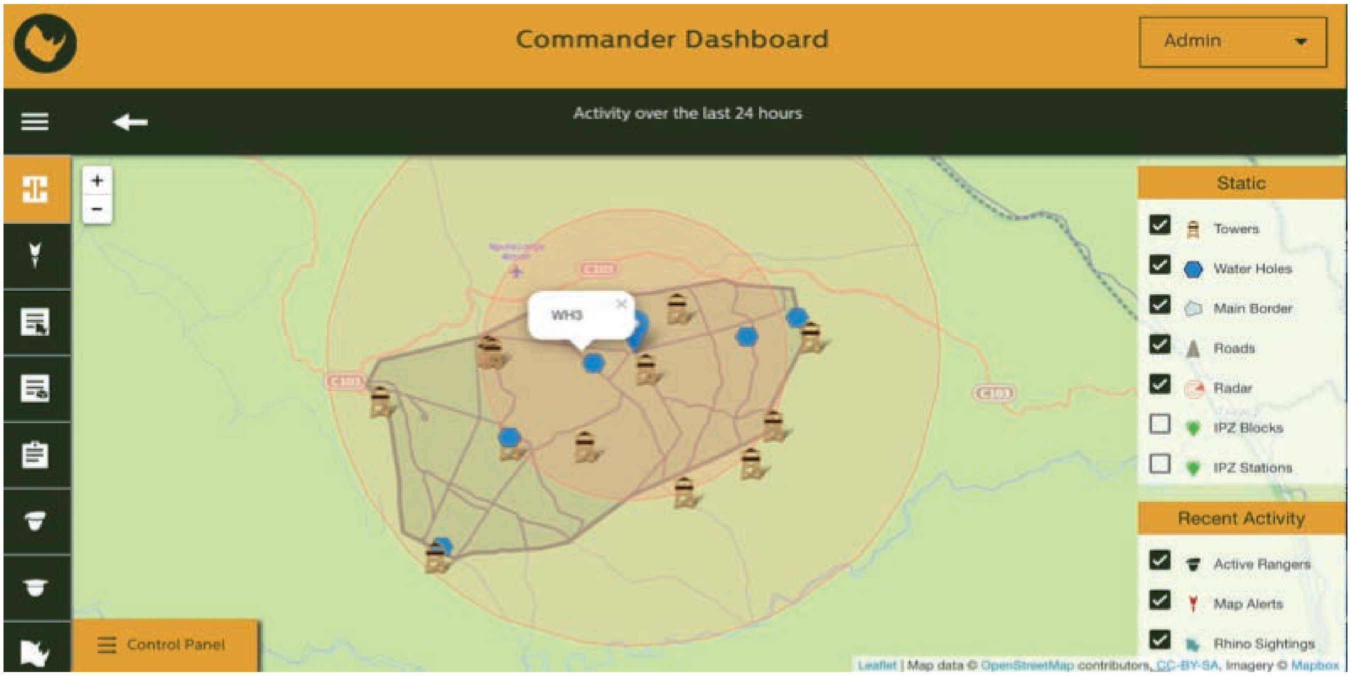


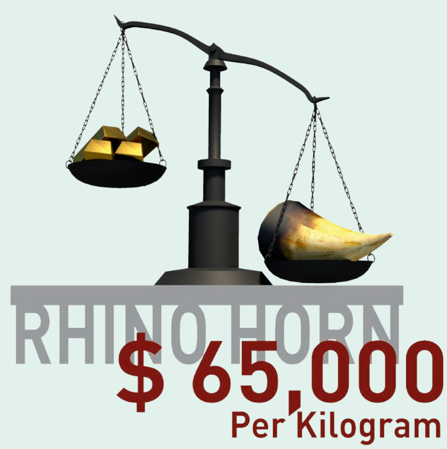
Figure 3
The commanders have an app with extended functionality, where they can access all data from the cloud. One of the map layers illustrates with circles the potential coverage for detecting humans and vehicles, respectively.

Figure 4
The top picture shows the operator view of a radar system, where the green dots mark the detections. The right view shows an image from a camera mounted on top of the radar. There is a rhino to the right and a human marked with yellow to the left. Top picture provided by Meteksan Savunma.

nighttime, the whole Tsavo park is closed for visitors. During daytime, visitors are only allowed in vehicles on the road network. Further, when visiting Ngulia 4–6 pm, they need to check in at the gate, and can after this be followed during their visit. All cell phone positions that do not correspond to any of the conditions above are thus very suspicious. Figure 2 illustrates a field test as reported in [21], where a radio receiver mounted on a drone is measuring RSS, and the location of the cell phone is iteratively improved.

High Demand

Rhino horn is valued higher per kilogram than gold and cocaine.



RADAR

A radar has the potential to be the backbone in the tracking system. A scanning ground radar has the ability to see moving objects at long distances. There are several commercial systems that claim detection of humans at 5 km distance and vehicles of ranges up to 10 km. If such a radar is placed centrally in Ngulia, it will cover a larger part of the park as illustrated with the two circles in the Dashboard view of Figure 3. For instance, all vehicles approaching the sanctuary can be detected to provide an early warning to the commanders.

Figure 4 shows a snapshot from one field test. The radar is put in scanning mode with a video camera attached to the top, and a human with GPS as ground truth is tracked, along with some savannah animals including rhinos.

Figure 5
Overlaying thresholded IR images on the EO images provide an efficient way to monitor the savannahs and assist the operator. Video, camera, and drone provided by Superfly.

Figure 6
A drone with EO and thermal cameras monitors an area where both a rhino and an intruder are trying to hide behind a tree. The thermal camera reveals the intruder, which is almost impossible to detect optically in the video stream. Video, camera, and drone provided by Superfly.

DRONES

Drones are a kind of ultimate platform for many of the sensors above, in particular EO and IR cameras, but also radio detectors as demonstrated in [21]. This obvious fact has led to many initiatives to bring drones to Africa. However, the acceptance by national authorities is not overwhelming, since still no sustainable solution based on drones has been demonstrated. In Kenya, a written agreement from the government is needed to use drones. This will likely change when the real benefits of drones as a supplement to other technologies can be demonstrated. The leap frog from no sensor surveillance to drone surveillance is simply not the right way to go.

However, the drone is a fantastic tool for wide area surveillance and border protection. An EO camera gives the commanders visual feedback, and the thermal camera can operate 24/7. Figures 5 and 6 provide illustrative examples.

With dedicated software it can automatically detect and classify humans, rhinos, and elephants. A positive side effect is that this would greatly simplify the important census challenges on the savannah.

Besides detection, tracking and classification in video streams, automatic route planning, and sensor management are research challenges for the future.

OBJECT CLASSIFICATION

The sensor information above suits a trained operator very well. However, training a large number of operators is not a sustainable solution. Support is needed for interpreting the sensor information, and calling the commanders attention only when anomalies are detected.

Figure 7 shows an example from [18] of classification from an airborne camera platform. Image learning is today a rather mature research area, and state of the art algorithms can be applied directly to training data from our field tests.

Figure 8 illustrates the micro-Doppler spectrum from a radar (the same as in Figure 4) in staring mode. In contrast to image classification, this is an emerging research area with few real data sets and experience from wildlife applications.

COMMUNICATION BACKBONE

In a country without cable infrastructure, both communication and powering are practical challenges. The sun provides energy today, both to the ranger stations and the radio towers. There are several operators with GSM network around Tsavo, but the coverage of each separate operator is poor. Inside Ngulia, connectivity was present about 30% of the time when the project started, while it is much better today after our operator has tuned the network. However, GSM offers only EDGE for data traffic, which is not what we consider to be broadband today. We have been investigating three ways to improve coverage and data capacity.

1. Radio repeaters are commonly used in distant villages, and so is our plan for the ranger stations. Figure 9 illustrates two ways the data can communicate between the devices and the cloud database. We have tested a BRCK unit, which is a locally developed kick-starter funded product. It includes a radio amplifier with external antenna, a router, a wifi hotspot, and a solar charged power station. This has the potential to improve local coverage, but not capacity.
2. Our telecom operator has partnered with a system manufacturer to boost the closest existing radio tower with a 3G base station. The introduction of H+ in Ngulia has improved data rates by several orders of magnitudes.
3. The ultimate goal of our operator is to put a radio tower inside Ngulia, to provide full coverage through the sanctuary.

Figure 7
Machine learning is used to train a classifier that is fed with EO and IR images. There are three classes: rhino (blue), humans (green), and other animals (red). Above, a zebra is found and below, a few seconds later, a rhino. Pictures from [18].

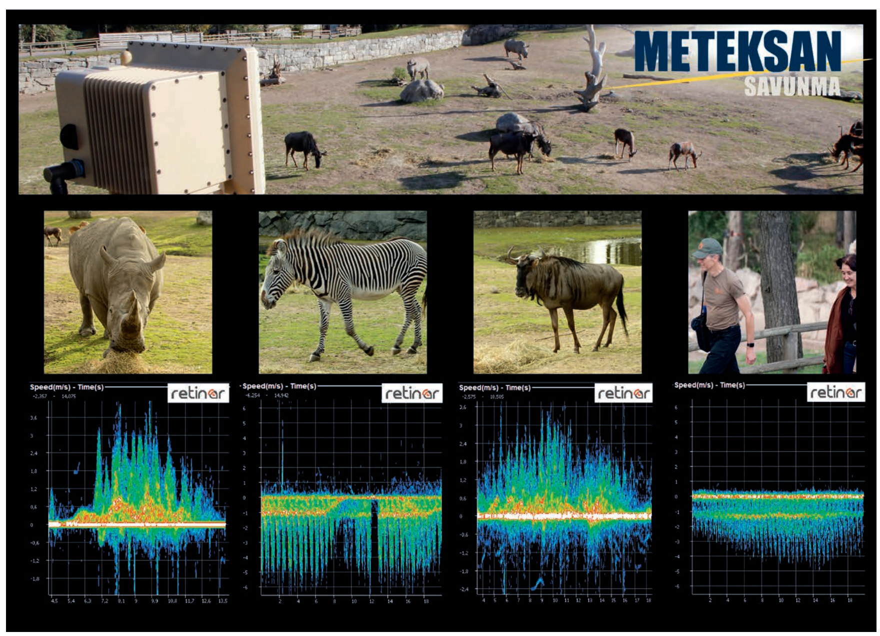


Figure 8
The micro-Doppler spectrum from a radar in staring mode reveals a particular pattern of the gait, caused by the speed variations of the limbs compared to the body. This can be used in the future for classification, also in far distances. Picture from wildlifesecurity.se.

PROJECT NGULIA: TIMELINE

This section provides a short overview of the different phases of the project, both what has already been done, and what the future plan is, as overviewed in Figure 10.

PHASE 1 (2010–2013)

The Stimson Center, in partnership with local nongovernmental organisations, conducts a comprehensive policy analysis of the current security and development environment in East Africa, particularly focusing on Kenya. Besides working with relevant Kenyan authorities, Stimson engages the broader donor community, including relevant offices in the United Nations and the governments of Australia, Finland, Sweden, and the United States. The outcome is an invitation by the Kenya Wildlife Service to conduct a pilot project focused on technology and innovation in Tsavo West National Park aiming to safeguard the remaining rhinoceros population there.

PHASE 2 (2014)

The year kicked off with a robust technical feasibility study at the Ngulia Rhino Sanctuary in Tsavo West National Park conducted in partnership by the Kenya Wildlife Service, Stimson, and the project's technology and innovation partner, Linköping

Figure 9
The C3 system exchanges information through a cloud based database, and the ranger device communicates with the cloud either directly over the cellular network, or via a wifi hotspot (BRCK) at their stations, which in turn is connected to the cellular network with external antennas and amplifiers. All data are encrypted and access relies on state of the art authentication procedures.

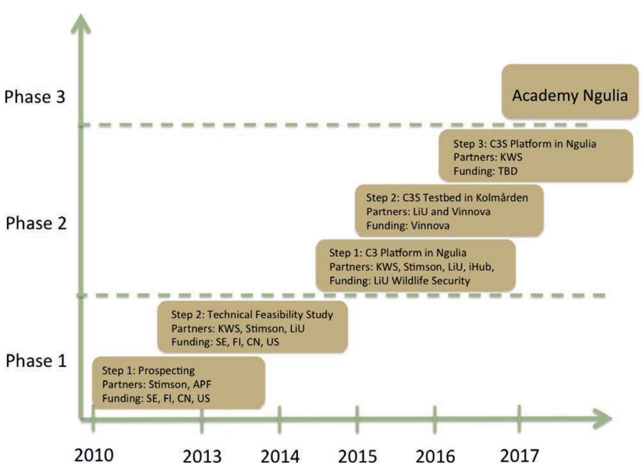


Figure 10
Overview of the development plan.

University. This exercise results in a multiyear technology and training plan. Partner organisations also negotiated and signed a Memorandum of Understanding in the fall of 2014 and began preparations to fully execute the plan in 2015.

PHASE 3 (2015–2016)

Because local ownership and investments are central tenants of our project, together with iHub, project partners design and develop a smartphone-based software for improved command, control, and communications (C3) in Ngulia. The platform is tested in the field and improved before being fully launched for use by park rangers, commanders, and research staff. The team spends a lot of time in the field for design and training; see Figure 11.

High Number of Fatalities

More than 1,000 rangers have been killed during the past ten years, and many more intruders.

A strategic partnership is developed with Kenyan telecommunications company Airtel that agrees to provide data packages and other necessities associated with the C3 system. Airtel also agrees to try to increase connectivity in the Ngulia sanctuary to ensure more advanced technology in subsequent phases of the project. Specifically, the C3 system's hardware consists of smartphones for the rangers, tablets for the commanders, and a cloud-based database hosting all information and communication. The ranger app is foremost an input device, where rangers note their observations regarding security and wildlife matters. Photo documentation is available as well as automatically geotagging. The app is also a navigation tool, where park rangers get their position overlaid on a map. The interface includes local landmarks such as waterholes, roads, trails, bunkers, borders, their patrol routes, and the like. There are also safety functions built into the app, such as the possibility to give haptic alarms in emergency situations, fall detections after accidents, as well as shot detection. The commander app includes the same functionality as the ranger app, but is foremost an administrative tool and platform for officers. The map interface shows the position and trajectories of all rangers and vehicles, security alerts, and rhino observations. The data can be accessed in real time or be analysed in retrospect. Commands are issued by broadcasting voice or text messages, and patrolling routes or ambush positions are defined for individual rangers.

PHASE 4 (2016–2017)

In this phase, sensor systems and radar for border and intruder detection, as well as area surveillance, will be added to the C3 platform. One or two radars will cover large objects moving inside and around the Ngulia border. Smart algorithms will be developed to distinguish humans from animals, and to monitor the rhino movements. The radar systems will have coverage of 5 km and 10 km radius, respectively. The radar stations are complemented with EO (standard) and thermal cameras with pan, tilt, and zoom. In this way, objects closer than a couple of kilometers detected by the radar can be zoomed in, further improving the classification of unidentified objects. Several other sensor systems will be investigated in parallel, such as microphone networks to detect shots, radio detection, and direction finding of communication equipment (cell phones) of possible intruders, border protection systems (unmanned ground sensors, fiber optics, microwave and laser barriers, surveillance cameras). At this stage, aerial surveillance could become relevant.

PHASE 5 (2018 ONWARD)

At this point, the park rangers, commanders, and research team are taking full advantage of the technological platform that makes their jobs easier, advances their mission, and cuts cost for the broader organisation. Following the successful deployment, other parks and organisations can scale and replicate the platform. This new gold standard for how technical systems can be used to tackle natural resource protection will assist governments, foundations, and the commercial sector worldwide.

The partner companies have complementary products and competences:

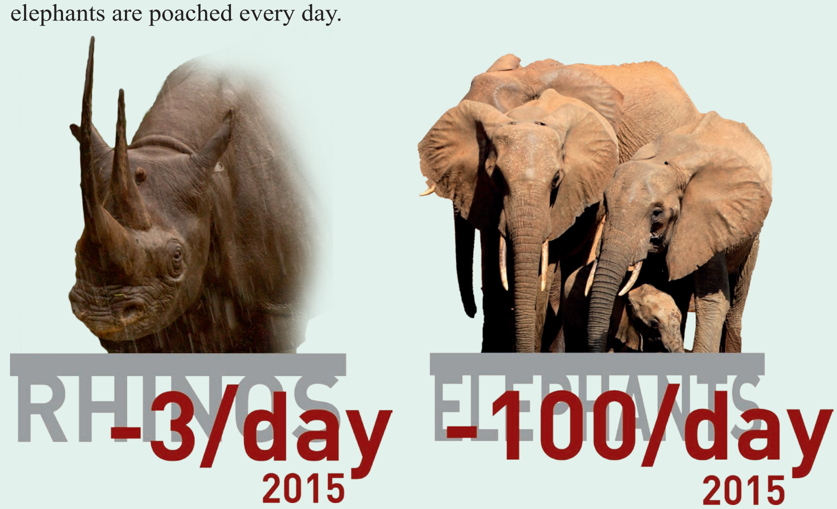
- There are sensor manufacturers (IP cameras, IR cameras, radar, tracking devices, drone manufacturers, etc).
- There are also system integrators and retailers of sensor systems.
- There are smaller highly nisched companies with deep knowledge in cyber-security and drone operation in Africa.
- There are also companies specialised in media production, such as one production company of TV films, one company for aerial video filming, and another one for aerial 3D modelling.

Finally, the Swedish wildlife park and zoo in Kolmården has a key role in the project, as a test site and providing expertise on conservation issues from the research frontier.

Figure 11
Project staff Angela, Mark, and Martin in a training session with rangers.

Poaching Statistics

Statistics from 2009–2014 show an alarming trend of increasing poaching. The trend seems to level out somewhat 2015–2016, but still 3 rhinos and over 100 elephants are poached every day.



CONCLUDING REMARKS

Wildlife security is an excellent opportunity to show what the fusion community can contribute to a societal challenge with three dimensions: conservation, economic development, and international security. The technical solutions to assist the rangers are focused around sensor and information fusion, where target tracking is the most concrete challenge: where are the rangers, rhinos, and poachers?

A further advantage of wildlife security as a demonstrator in information fusion is that it is an application on arm length's distance from military domains. The point with this is to appeal to students and the general public, to neutralize the common meaning of "drone" and "Command, Control and Communication System", and to avoid the immediate association of surveillance sensors with a threat to personal integrity.

We have a few lessons learned so far. First, the importance to think big from a research viewpoint. Many different competencies are needed, and a public/private partnership is a tool to get resources and publicity. Second, in such a large effort, researchers have to be patient, since it takes time to build up infrastructure before existing research can be demonstrated and before real data are available for new research. Finally, when working with end-users one should be careful to avoid technology leaps, and include training and continuous involvement in the development. Technology dumps must be avoided. Our approach takes many small steps, starting with a phone, ending with a drone.

REFERENCES

1. Smart (spatial monitoring and reporting tool) conservation software. URL http://www.smartconservationsoftware.org.
2. Cybertracker – towards a worldwide environmental monitoring network. URL http://www.cybertracker.org.
3. In cold blood: combatting organised wildlife crime, 2014. URL https://eia-international.org/report/in-cold-blood-combating-organised-wildlife-crime.
4. Wanted dead or alive: exposing the online wildlife trade, 2014. URL http://www.ifaw.org/sites/default/files/IFAW-Wanted-Dead-or-Alive-Exposing-Online-Wildlife-Trade-2014.pdf.
5. Nichols, J. D., and O'Connell, A. F. (Eds.). *Camera Traps in Animal Ecology: Methods and Analyses*. New York: Springer, 2011.
6. Baratchi, M., Meratnia, N., Havinga, P. J. M., Skidmore, A. K., and Toxopeus, B. A. G. Sensing solutions for collecting spatio-temporal data for wildlife monitoring applications: a review. *Sensors*, Vol. 13, 5 (2013). URL http://www.mdpi.com/1424-8220/13/5/6054/htm#b7-sensors-13-06054.
7. Bergenas, J., and Knight, A. Green terror: environmental crime and illicit financing. *SAIS Journal of International Affairs*, Vol. 35, 1 (2015). URL https://issuu.com/unpublications/docs/9788277011325.
8. Blumstein, D. T., Mennill, D. J., Clemins, P., Girod, L., Yao, K., Patricelli, G. et al. Acoustic monitoring in terrestrial environments using microphone arrays: applications, technological considerations and prospects. *Journal of Applied Ecology*, Vol. 48, 3 (2011), 758–767. ISSN 1365-2664. doi: 10.1111/j.1365-2664.2011.01993.x. URL http://dx.doi.org/10.1111/j.1365-2664.2011.01993.x.
9. de Greef, K., and Raemaekers, S. South Africa's illicit abalone trade: an updated overview and knowledge gap analysis. TRAFFIC International, Cambridge, UK, Tech Rep., 2014. URL http://static1.1.sqspcdn.com/static/f/157301/25583011/1414148973007/W-TRAPS-Abalonereport.pdf?token=J2JdwIqK8xi4GhZdtu6V7fHRAIw%3D.
10. Dunbabin, M., and Marques, L. Robots for environmental monitoring: significant advancements and applications. *IEEE Robotics & Automation Magazine*, Vol. 19, 1 (2012).
11. Gosling, J. The global response to transnational organized environmental crime. The Global Initative against Transnational Organized Crime, Tech Rep., 2014. URL http://www.globalinitiative.net/download/global-initiative/Gosling%20-%20Environmental%20Crime.pdf.
12. Juang, P., Oki, H., Wang, Y., Martonosi, M., Peh, L. S., and Rubenstein, D. Energy-efficient computing for wildlife tracking: design tradeoffs and early experiences with zebranet. *SIGARCH Computer Architecture News*, Vol. 30, 5 (2002), 96–107. doi: 10.1145/635506.605408. URL http://doi.acm.org/10.1145/635506.605408.
13. Körner, F., Speck, R., Göktogan, A. H., and Sukkarieh, S. Autonomous airborne wildlife tracking using radio signal strength. In *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS),* Oct. 2010, 107–112. doi: 10.1109/IROS.2010.5654385. URL http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5654385&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs all.jsp%3Farnumber%3D5654385.
14. MacCurdy, R. B., Gabrielson, R. M., and Cortopassi, K. A. *Automated Wildlife Radio Tracking*. New York: Wiley, 2011, pp. 1129–1167. ISBN 9781118104750. doi: 10.1002/9781118104750.ch33. URL http://dx.doi.org/10.1002/9781118104750.ch33.
15. Nellemann, C., Henriksen, R., Raxter, P., Ash, N., and Mrena, E. The environmental crime crisis: threats to sustainable development from illegal exploitation and trade in wildlife and forest resources. United Nations Environment Programme and GRID-Arendal, Nairobi, Kenya, Tech Rep., 2014. URL https://issuu.com/unpublications/docs/9788277011325.
16. Örn, D., Szilassy, M., Dil, B. J., and Gustafsson, F. A novel multi-step algorithm for low-energy positioning using GPS. Submitted to 19th International Conference on Information Fusion, 2016.
17. Recio, M. R., Mathieu, R., Denys, P., Sirguey, P., and Seddon, P. J. Lightweight GPS-tags, one giant leap for wildlife tracking? an assessment approach. *PLOS ONE*, Vol. 6, 12 (2011), doi:10.1371/journal.pone.0028225.
18. Schmidt, C. K. Rhino and human detection in overlapping RGB and LWIR images. Master's thesis, Linköping University, 2015. http://liu.divaportal.org/smash/record.jsf?pid=diva2.
19. Smouse, P. E., Focardi, S., Moorcroft, P. R., Kieand, J. G., Forester, J. D., and Morales, J. M. Stochastic modelling of animal movement. *Philosophical Transactions of the Royal Society B: Biological Sciences*, Vol. 365 (2010), 2201–2211.
20. Steiner, A. Putting a stop to environmental crime has become an imperative. *UN Chronicle: The Magazine of the United Nations*, Vol. LI, 2 (2014). URL http://unchronicle.un.org/article/putting-stop-global-environmental-crime-has-become-imperative/.
21. Sundqvist, J., Ekskog, J., Dil, B. J., Gustafsson, F., Tordenlid, J., and Petterstedt, M. Feasibility study on smartphone localization using mobile anchors in search and rescue operations. Submitted to 19th International Conference on Information Fusion, 2016.
22. Thomas, B., Holland, J. D., and Minot, E. O. Wildlife tracking technology options and cost considerations. *Wildlife Research*, Vol. 38 (2011). URL http://www.publish.csiro.au/?paper=WR10211. http://dx.doi.org/10.1071/WR10211.
23. Urbano, F., Cagnacci, F., Calenge, C., Dettki, H., Cameron, A., and Neteler, M. Wildlife tracking data management: a new vision. *Philosophical Transactions of the Royal Society B: Biological Sciences*, June 2010. doi: 10.1098/rstb.2010.0081.
24. Veibäck, V., Hendeby, G., and Gustafsson, F. On estimation with uncertain timestamps. Submitted to 19th International Conference on Information Fusion, 2016.
25. Vira, V., and Ewing, T. Ivory's curse: the militarization and professionalization of poaching in africa. C4ADS and Born Free, Tech Rep., 2014. URL http://www.allcreatures.org/articles/ar-Ivorys-Curse-2014.html.
26. Wahlström, N., Gustafsson, F., and Åkesson, S. A voyage to Africa by Mr. Swift. In *15th International Conference on Information Fusion*, 2012, 808–815.
27. White, G. C., and Garrott, R. A. *Analysis of Wildlife Radio-Tracking Data*. New York: Academic Press, 1990.

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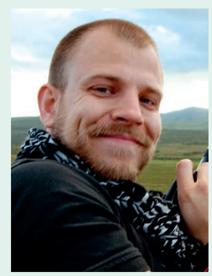
- He has a broad research project portfolio with quite a few industrial collaborations suitable for this project. The project provides a demonstrator arena for on-going research and challenging problems with field test data suitable for new research directions.
- With three successful spin-offs (www.niradynamics.se, www.softube.com, www.senionlab.com), he has experience in entrepreneurship that facilitates finding market opportunities for sensor fusion software in combination with complementing research and development.
- He is the director of Security Link (www.security-link.se), a national Swedish strategic research environment in the security area, with a focus on protection of critical infrastructure. This is beneficial for the security aspect of Project Ngulia.

Johan Bergenäs has his B.Sc. in political science and journalism from Iowa State University, Ames, and his M.Sc. in security studies from Georgetown University, Washington, DC. He is employed at the think tank Stimson Center, Washington, DC, and also serves as a senior advisor at Security Link, Linköping University. He is the initiator of project Ngulia (www.projectngulia.org).



Martin Stenmarck has an M.Sc. in electrical engineering and is employed by HiQ Ace AB as a software developer and project leader. He has previously been managing director for a web and graphical design firm. He contributes in the following roles.

- He is coordinating both software and hardware activities.
- He is the supervisory project leader of a team of 10 programmers at iHub in Nairobi.
- He is responsible for homepages and all graphical material to the project. He is also a good photographer and photoshop guru.

Situations and Contexts

Abstract—The semantics of context are examined, considering concepts of relevance, situations, and relationships. We define a situation as a set of relationships and a context as a situation that a) provides expectations for constituent entity states or b) is deemed relevant to the solution of an inference or response problem. The use of context variables in inferencing is examined. Predictive models as used in inferencing are construed as estimates of state distributions. The uses of context in inferencing can be differentiated into categories of target and information source characterization methods, appropriate to different assumptions concerning the quality of available prior models and observational data.

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CONTEXT

Human understanding is infused with a robust sensitivity to context. Our sense impressions are informed by a myriad of mitigating and extenuating circumstances that enrich our experience and deepen our understanding. Consciously or unconsciously we search for contextual clues and use them to resolve ambiguous or puzzling situations.

Many shortcomings in attempts at artificial intelligence—in machine vision, robotics, natural language, understanding, and information fusion—as well as in understanding human behavior artificial intelligence can be attributed to deficient appreciation of context. In this article we explore methods (a) to define and represent context, (b) to determine contexts as relevant to particular uses, and (c) to incorporate contextual information in reasoning and decision making.

A recent survey of context-related literature reveals a diversity of definitions of *context* [1]. In some usages, a context is considered to be a *situation* of some relevance (as "the bombing can be understood in the context of the Middle East Crisis"). In others, it is an *element* of such situations (as "the enhanced security measures make sense in the context of the recent bombing"). In yet other uses, a context is *information* about a situation or even a *source* of such information.

We have suggested the following definition as conducive to understanding and using contexts: A *context* is a *situation* that provides information that can be used either a) to condition expectations or b) to improve the understanding of a given inference or planning/control problem [2]. These two ways in which a situation can be used as context derive from a formulation by Gong [3], contrasting notions of *context-of* (C-O) and *context-for* (C-F). A situation can be C-O or C-F, depending on how it is used in reasoning. C-O-driven reasoning starts with a perceived situation to derive expectations about constituent entities, relationships, and activities. In contrast, C-F-driven reasoning starts with a particular problem—which might be an inferencing problem (what's happening?) or a control problem (what's to be done?)—and seeks to discover additional information that can resolve uncertainties in the problem solution [4], [5].

"A context is a situation that provides information that can be used either a) to condition expectations or b) to improve the understanding of a given inference or planning/control problem".

RELATIONS, RELATIONSHIPS, AND SITUATIONS

If contexts are situations that can be used in inferencing, we need to understand what situations are and how to reason about them. As in [6], [7], we follow Devlin [8] in defining situations in terms of relationships.

Let us differentiate the concepts of *relation* and *relationship*. We shall use "relation" to designate an abstraction, such as *marriage, ownership, hatred,* or *selling*. "Relationship", on the other hand, is used to designate an instantiation of a relation anchored within a situational context: Antony's marriage with Cleopatra, Othello's marriage with Desdemona, or Cleopatra's marriage with Othello. As the latter examples indicate, such contexts are not necessarily factual either in the real world or in a particular assumed fictional context.

Reasoning about attributes, relations, relationships and situations is facilitated if these concepts are "reified", i.e., treated as entities in the working ontology [8]. Explicitly defined, a *relation* is a mapping from *n*-tuples of entities ($n \geq 1$) to a relational state *r*:

$$R^{(n)} : X_1 \times \ldots \times X_n \rightarrow \mathcal{R}. \quad (1)$$

A *relationship* is an instantiation of a relation; i.e., an ordered $(n+1)$-tuple $\langle r^{(n)}, x_1, \ldots, x_n \rangle$ such that *r* applies to a sequence of arguments $\langle x_1, \ldots, x_n \rangle$. Attributes of individual entities are conveniently treated as unary relations, instantiations thereof as unary relationships.

The mapping from n + 1-tuples to relationships can be many-one, because the same entities $<x_1,\ldots,x_n>$ may be related multiply by the same relation: Two companies may simultaneously have two contracts with one another. The type of relationship may be the same, at some level of abstraction, e.g., land-use contract—but the relationships—the individual contracts—are distinct. Therefore, we will want to differentiate variables and their values from instantiations thereof [9].

By reifying relations and relationships, we allow higher-order variables: those that range over predicates of other variables. These can be employed using the cross-order predicate of *application*, which we represent by parentheses. Thus, an expression in the familiar form "$x(i)$" is read as "attribute x applies to the individual i", e.g., Isaac is blind. Similarly, "$x(i,j)$" says that relation x applies to the individuals i,j, e.g., that Isaac is the father of Jacob. We can also distinguish between predicative variables X and particular values x thereof: as in "Isaac's height is 180 cm": "$H(i) = h$, $h = 180$ cm". This allows us such expressions as "$g(H)$", as in "*height* is a unary relation (i.e., an attribute)" or "*taller than* is a binary, transitive, nonreflexive relation".

> **"The relevance of contextual information can be stated in terms of the contribution of such information in resolving values of problem variables…A context variable is a variable that an agent selects to evaluate or refine an estimate of one or more problem variables".**

We define a *situation* as a *set of relationships*. A *concrete situation s* is a set of fully anchored relationships $\{r|r$ obtains (i.e., holds true) in $s\}$. We should allow for imprecisely defined situations: The relationships that comprise a given situation may constitute a fuzzy set [6]. It will be convenient to conflate unit set and member to say that relationships are situations. What is more, because single-place relations are allowed, a single event (as in "the enhanced security measures are appropriate in the context of the recent bombing") is also a situation, consistent with our suggested definition of context.

Like relationships, a situation s may be real, or it might be conditional, hypothetical, fictitious, or otherwise counterfactual in some encompassing situation $t \supseteq s$ (t may be the universe at large). For example, the killing of Polonius is a situation that occurs in the context of Shakespeare's *Hamlet* but not in the world at large. The play *Hamlet* and various performances thereof, its plot, script, and various copies exist in the world at large. Its characters, situations, and events do not. The particular concerns of some agent (e.g., a person or an automated inference system) determine which situations are under consideration as contexts for those concerns.[1]

We can abbreviate $r \in s$, where r is a relationship and s is a situation as the conditional relationship $(r|s)$ read "r obtains in situation s". This is related to Devlin's use of the implicature notation $s \models \sigma$ for an infon σ [8].

THE USE OF CONTEXT IN INFERENCE

An inference problem q can be stated in terms of a utility function on the values of a problem-specific set of variables: $\omega_q : X \to \Omega^*$, where X is either a problem variable or a vector of problem variables. A *context for an inference problem* is a situation that is selected (by some agent) for use in understanding or solving the problem. We take this usage of context for an inference problem as an application of C-F, as used by Gong [3] and by us in [1], [2], [4], [5]: s is a context for resolving X, where X is a set of random variables. This can be contrasted with cases of C-O as in "in the context of today's economic news, it is likely that the Euro will strengthen". Such constructions have the form "in the context of S, $f(x)$", where P is a proposition (say, "the Euro will strengthen") and $f(.)$ is a modal expression, such as P is true or the probability that $P = p$ or it is likely that P or is impossible that P.

The relevance of contextual information can be stated in terms of the contribution of such information in resolving values of problem variables. We discuss this in the following. Let us consider how contexts can be used in evaluating problem variables to meet objectives. A general distinction can be drawn between *refinement* and *inference* of values of variables. In many data fusion problems, multiple measurements of a given variable are averaged or filtered to refine the estimate of that variable, exploiting independence in the measurement-to-measurement noise. Bayesian and Dempster-Shafer classifiers are examples of refinement (filtering) processes.

Often, however, the problem variables to be estimated are not themselves measured or are not measured with sufficient accuracy or confidence to meet users' needs. In such cases, the values of problem variables may be inferred totally or partially on the basis of other variables. Such inference assumes a model of the dependencies between measured variables and problem variables. Inference methods include, for example, structural equations, Bayesian belief networks, and neural networks.[2]

We may distinguish, then, between explicit problem variables and ancillary variables used in inference. We call the latter

[1] This we take to be the intent of Devlin's informal definition for situation as "a structured part of reality that is discriminated by some agent" [8, p. 31, paraphrased]. However, the agent should not be part of the definition: much like the noise of a tree falling in the forest, a situation can exist without being noticed or cared about. It is on this basis that we distinguish contexts from other situations.

[2] Kalman filters and related tracking filters are typically hybrid refinement or inference processes such that problem variables are those constituting a target's physical state (e.g., its kinematic state), but filtering occurs not in state space but in measurement space: received and predicted measurements are filtered to infer target states (by means of motion and measurement models), from which additional (e.g., future) measurements are predicted.

context variables. A context variable is a variable that an agent selects to evaluate or refine an estimate of one or more problem variables. Accordingly, we can define a *problem context* as a situation, comprising a set of entities and their relationships involving context variables and problem variables. Situations are selected as problem contexts for their presumed usefulness in solving the particular problem.

When a situation is used as a C-O, context variables are situational variables (ranging over relationships and sets of relationships); when used as a C-F, context variables are variables that are other than a given set of problem variables. By this definition, one problem variable can serve as a context variable for evaluating another problem variable. For example, an aircraft's observed speed may be used as a context for resolving its type, and, conversely, its estimated type can be used for resolving its speed (e.g., in bearings-only target tracking) [10].

"...it is preferable to distinguish inference problems on the basis of type of entity state variables rather than by type of entity. Depending on one's interests, many an entity can be considered alternatively as an individual (characterized in terms of level 1 variables) or as a relational structure (level 2 variables) or as a dynamic process (level 3). If it is a resource of the inference system itself, the same entity could be evaluated in terms of level 4 variables".

One way of defining relevance is statistical relevance as introduced by Salmon [11], whereby that the relevance of a value y of candidate context variable Y in determining a specific value x of problem variable X is

$$Rel(y,x) = \frac{p(x \mid y)}{p(x \mid \neg y)}. \tag{2}$$

Statistical relevance in a context s is, of course, given as

$$Rel(y,x \mid s) = \frac{p(x \mid s, y)}{p(x \mid s, \neg y)}. \tag{3}$$

The utility to a given inference problem q of evaluating a variable Y for the purpose of evaluating a problem variable X in the context of a situation s is

$$\omega_q(Y; X \mid s) = \omega_q(x \mid s) \int_X \int_Y Rel(y,x \mid s)\, dy\, dx. \tag{4}$$

For discrete-valued variables, integration can be replaced by summation. X or Y in this formulation can be an individual variable or a vector of variables. For example, the set of variables Y = {day of week, weather conditions, location} can provide a useful context for resolving joint states of interest in the set of problem variables X = {traffic conditions, location}.

CONTEXT-SENSITIVE STATE ESTIMATION

State estimation functions differ broadly according to the types of state variables to be estimated. It can be convenient to distinguish entity states of interest according to the "levels" described in various versions of the Joint Directors of Laboratories data fusion model. Levels of data fusion and resource management processes map into a categorization of entity state variables that a data fusion system is tasked to estimate or that a resource management system is tasked to control. Examples of such problem variables are given in Table 1. The third and fourth columns distinguish continuous-valued and discrete-valued variables at each level. The fifth and sixth columns, respectively, relate these to our particular rendition of data fusion and resource management levels [6], [7], [12].

As we argue in [2], [7], it is preferable to distinguish inference problems on the basis of type of entity state variables rather than by type of entity. Depending on one's interests, many an entity can be considered alternatively as an individual (characterized in terms of level 1 variables) or as a relational structure (level 2 variables) or as a dynamic process (level 3). If it is a resource of the inference system itself, the same entity could be evaluated in terms of level 4 variables.

Both C-O and C-F can play essential roles at any fusion level, but they are especially important in higher level fusion, in which variables of interest include relation, relationship, and situation variables that are not directly observable but must be inferred. Although a C-F is useful in evaluating specific attributive and relational states, a C-O provides a means for understanding expectations for and implications of such states. Generally, the larger context in which a problem is considered, the more fully will it be understood by being conditioned on a larger number of mutually independent context variables.

Level 1 fusion is concerned with *attributive* states; that is, with values of 1-place state variables, such as target location, type, or attributive parameters. In level 2 fusion, both attributive and *relational* states are pertinent, i.e., values of n-place state variables, $n \geq 1$. Belief networks can be used to propagate information among entities, relations, and the relationships in which they participate. Given our reification of relation and relationships, we can depict a level 2 hypothesis after the pattern of Figure 1. This figure is in the form of a factor graph, in which variables are represented as circles and functions on these variables are represented as squares [13]. Examples of such functions are causal conditions or conditional probabilities, but they can represent any relationship among variables. In our application, the functions are instantiations: individual entities, relationships, and situations, etc.

Likelihoods and state estimates can be propagated among the nodes of a level 2 hypothesis. Each node combines the ef-

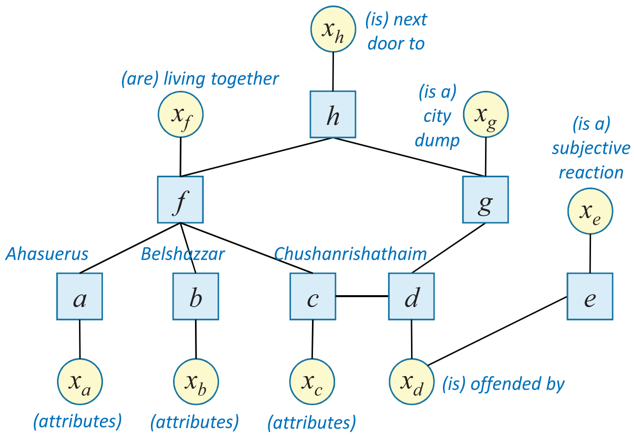

Figure 1
Factor graph representation of a level 2 hypothesis.

fects of evidence from its immediate neighbors and distributes its own evidence to them, ensuring, however, that information is not circulated back to an originating node. That is to say, a level 2 fusion process creates and updates nodes i in a level 2 hypothesis H, on the basis of data either

a) from an update to i based on associating one or more source reports with that node or

b) from an update to a node j that is an immediately neighbor to i in H.

In the former case, updating is attributive, analogous to updating a level 1 hypothesis. In the latter case, updating is relational, involving estimation of the relationships that occur between j and i in H and thereby refining the estimate of the state of i, x_i.

In the example shown in Figure 1, nodes *a, b,* and *c* postulate individual entities that participate in a relationship $f = <x_f, a, b, c>$ in which x_f is a relation. This relationship in turn, participates in another relationship $h = <x_h, f, g>$, in which g is yet another relationship. For example, x, y, and z could be the people Ahasuerus, Belshazzar, and Chushanrishathaim, and the relation x_f might be *living together* so that f is, roughly, a household or some subset thereof. Note that *living together* is an example of a relation of indefinite order, i.e., $x_f^{(n>1)}$. The relation x_h could be *next door to*; x_g the attribute (1-place relation) *city dump*; and x_d might be *is offended by*, applied to Chushanrishathaim in the relationship *d*. Additionally, x_e is a second-order attribute—perhaps *subjective reaction*—operating on the first-order relation x_d in the instantiation *e*.

The situation $s_1 = \{c, d, f, g, h\}$ might be the context for (C-F) evaluating Chushanrishathaim's attitude toward his present living situation. A different context could include his two housemates: $s_2 = s_1 \cup \{a, b\}$. Another might be the broader situation represented in the figure: $s_3 = s_2 \cup \{h, e\}$.

A belief propagation algorithm will determine the belief concerning the state of an entity (or, more precisely, of the vector of state variables associated with that entity) in terms of

Table 1

Entity State, Data Fusion, and Resource Management Levels[a]

Level	Entity Class	Example		Data Fusion (Inference) Level	Resource Management Level
		Continuous State Variables	Discrete State Variables		
0	Patterns, e.g., features or signals	Temporal/spatial/spectral extent, amplitude, and shape/modulations	Signal/feature class, type, attributes	Signal/feature assessment	Signal/feature management
1	Individuals, e.g., physical objects or events	Location, velocity, size, weight, event time	Object class, type, identity, activity, or attributes	Individual entity assessment	Individual resource management
2	Structures, e.g., relationships and situations	Distance, force/energy/ information transfer	Class, type, identity, or attributes of relations, slots, arguments, situations	Situation assessment	Resource relationship management (coordination)
3	Processes, e.g., courses of action, scenarios, and outcomes	State utility, duration, transition conditions	State transitions; class, type, identity, attributes of processes, scenarios, or impacts	Scenario/ outcome assessment	Mission objective management
4	System resources	All of the above, applied to system resources	All of the above, applied to system resources	System assessment	System management

[a] [2], [7].

- "local" evidence $\varphi_i(x_i)$, i.e., information about a particular state variable and
- evidence $\psi_{i,j}(x_i,x_j)$ concerning the entity from other situation elements used as context.

If beliefs are expressed as probabilities, the joint probability distribution of the set of state variables $\{x_1,...,x_N\}$ corresponding to the N nodes in such a graph is

$$p(\{x_1,...,x_N\}) = \frac{1}{N}\prod_{(ij)}\psi_{ij}(x_i,x_j)\prod_i \varphi_i(x_i). \tag{5}$$

The function $\psi_{i,j}(x_i,x_j)$ is an undirected compatibility function—say, Pearson product moment correlation—as a generalization from the directed conditional probability $p(x_i|x_j)$ [14].

Evidence is propagated as "messages" passed to node i from nodes j in its immediate neighborhood $N(i)$ in the graph of relationships in the relevant situation:

$$b_i(x_i) = k\varphi_i(x_i)\prod_{j\in N(i)} m_{ji}(x_i). \tag{6}$$

Messages are updated recursively through the graph as

$$m_{ij}(x_j) \leftarrow \sum_{x_i}\varphi_i(x_i)\psi_{ij}(x_i,x_j)\prod_{k\in N(i)\setminus j} m_{ki}(x_i). \tag{7}$$

The evaluation over $k \in N(i)\setminus j$ in the last term of (7) indicates that data is to be passed from all immediate neighbors of i other than j itself. It is shown in [14] that such restriction on message passing maintains consistency and convergence in any singly connected (i.e., nonlooping) graph.

We can expand (7) by marginalizing over instantiated relation variables:

$$m_{ij}(x_j) \leftarrow \sum_{x_i}\varphi_i(x_i)\sum_R p\left[x_i,x_j \mid R(x_i,x_j)\right]p\left[R(x_i,x_j)\right]\prod_{k\in N(i)\setminus j} m_{ki}(x_i). \tag{8}$$

This marginalization, of course, assumes discrete-valued relations. It is often practicable to partition continuous-valued attributes and relations into discrete bins for belief network propagation.

Because relations, attributes, and entities that are arguments of these can participate in multiple situations and relationships, the graph of a situation hypothesis can be multiply connected. Methods have been developed that provide exact or approximate joint probability distributions in a wide variety of graph topologies. These include Pearl's clustering algorithm [15], junction tree algorithms [16], the Shafer-Shenoy separator algorithm [17], and the generalized belief propagation formulation of Yedida et al. [14].

REASONING ACROSS FUSION LEVELS

As seen in Table 1, reasoning about relationships and situations has been considered the province of level 2 data fusion. Level 1 data fusion is concerned with estimation of states of entities considered as individuals. In contrast, fusion levels 2 and 3 are concerned with estimation of entities considered as aggregates: as relationships or situations and courses of action or scenarios, respectively [2], [7], [12], [18].

Situation assessment (level 2 data fusion)—whether implemented by people, automatic processes, or some combination thereof—involves inferences of the following types:

- inferring the presence and the states of entities on the basis of relationships in which they participate;
- inferring relationships on the basis of entity states and/or other relationships;
- recognizing and characterizing observed situations.

Whereas level 2 fusion concerns the estimation of observed states, level 3 fusion (concerns states that are projected; e.g., predicted future states [2], [7]. The temporal evolution of a situation, involving courses of action, interactions, and outcomes, constitutes a scenario [2], [18].

Level 2 and 3 inferences have direct analogy to those at level 1. Situation recognition is a problem akin to target recognition. Situation/scenario tracking is akin to target tracking [6], [18]. Characterizing situations is generally a matter of assessing the states of situation constituents and their interrelationships. The familiar Bayesian pattern for context-sensitive inferencing within fusion level 1 (L1 → L1) is given by

$$p\left[F(x) \mid G(x),s\right] = \frac{p\left[G(x) \mid F(x),s\right]p\left[F(x) \mid s\right]}{p\left[G(x) \mid s\right]},$$
$$p\left[G(x) \mid s\right] = \int_H p\left[G(x) \mid F(x),s\right]p\left[H(x) \mid s\right], \tag{9}$$

e.g., estimation of the probability of a single target state $F(x)$ from associated measurements $G(x)$ or prediction of state $F(x)$ from prior state $G(x)$ in situation s.

This can be generalized as

$$p\left[F^{(m)}(x_1,\ldots,x_m) \mid G^{(n)}(y_1,\ldots,y_n),s\right] = \frac{p\left[G^{(n)}(y_1,\ldots,y_n) | F^{(m)}(x_1,\ldots,x_m),s\right]p\left[F^{(m)}(x_1,\ldots,x_m) \mid s\right]}{p\left[G^{(n)}(y_1,\ldots,y_n) \mid s\right]}; \tag{10}$$

with application to various inference patterns within and between fusion levels by selection of relation orders m and n (Table 2).

The reification of relations and relationships allows us to relate one to another in or out of context. In this way, attributes of relations and relationships can be inherited; e.g., in an L2 → L2 inference (with some uncertainty) from *x is providing information to y* to *x is cooperating with y*. A situation state cannot only imply but can be implied by the states and relationships of constituent entities so that situational inferences can be given in the form of Boolean combinations of expressions, such as

$$\exists r \exists x_1,\ldots,\exists x_n \left[r = R^{(n)}\left(x_1,\ldots,x_n\right) \& F_1\left(x_1\right) \& \ldots \& F_n\left(x_n\right) \& \{r,x_1,\ldots,x_n\} \subseteq s\right] \Rightarrow G(s). \quad (11)$$

CONTEXT IN MODEL ASSESSMENT AND MANAGEMENT

Data fusion relies, in one way or another, on predictive models of information sources and of entities of interest (targets at all appropriate state estimation levels). In military applications, target models are generally expected to be provided by intelligence processes. Operational intelligence, in a process called intelligence preparation of the battlefield, provides values for context-sensitive prior probabilities $p(x|s)$. Technical intelligence provides target characterizations that combined with source characterizations allow evaluation of measurement likelihoods $p(Z|x, g)$ and probabilities of detection $p_D(x|s)$ for target states x, information source state g, and measurement sets Z. Fusion systems use information source measurement models that combine with target descriptions to provide values for $p(Z|x, g)$ and $p_D(x|g)$ and with contextual information, e.g., target densities, and background clutter levels, to provide values for false alarm rates $p_{FA}(g, s)$ for given contexts s.

In many, perhaps most, current information exploitation systems, source models are the responsibility of source developers. However, there are many applications where valuable information is available from sources whose design and operating characteristics are unknown to the information exploitation system or its developers [19]. The wealth of information available online and from traditional open-source media provides enormous opportunities for diverse information exploitation applications, as do novel sensors and sensor platforms (drones, crowdsourcing, etc.) but require some means for quality control, as discussed in [1], [19].

We have reported on the development of a prototype information exploitation system that assesses and modifies the target and source models it uses at various fusion and management levels as a means of exploiting nontraditional information sources [20].

Model assessment is a level 4 data fusion process, performing all the classical data fusion functions:

- *data preparation:* aligning in feature space, structure, and confidence the data used in inferring models;
- *data association*: establishing the range of phenomena to be used in determining and validating the model; and
- *state estimation*: estimating the distribution and dependencies of characteristics and behavior of modeled entities or entity classes.

Model assessment differs in one major respect from level 0–3 data fusion processes and, indeed, from other level 4 fusion processes. The business of these other data fusion processes is the estimation of states of particular entities in the world; i.e., of *instantiations* of entity classes. In contrast, model assessment is concerned with the inference of *possible* states or, more precisely, the inference of the *distribution* of states possible for a given entity or class of entities. Model assessment performs estimation and prediction just as in other types of level 0–4 data fusion but with the difference that now the estimation and prediction are of the characteristics and behaviors of *distributions* of level 0–4 entities or of classes of such entities.

"Model assessment performs estimation and prediction just as in other types of level 0–4 data fusion but with the difference that now the estimation and prediction are of the characteristics and behaviors of distributions of level 0–4 entities or of classes of such entities".

Model assessment processing can take the form of induction from instantiated states to the distribution of possible states. It also can involve explanation of observed phenomena by subsumption to higher-level models. As an example, a radar performance model will gain in predictive and explanatory power to the extent that it is subsumed to electromagnetic physics and to which the latter is subsumed to unified quantum and relativistic physics. Source model management can involve setting parameters to compensate for estimated sensor biases (sensor regis-

Table 2

Relation Orders for Intra- and Interlevel Inferencing

Inference Type	*m*	*n*	Application
L1 → L1	1	1	Inferring states of an individual from states of the same or another individual
L1 → L2/3	1	>1	Inferring relationships from individual states
L2/3 → L1	>1	1	Inferring individual states from relationships
L2/3 → L2/3	>1	>1	Inferring relationships from other relationships

tration and calibration) and adjusting sensor accuracy models to reflect estimated error statistics. Target model management can involve modifying predictive models of target and situation classes in response to updated estimates of the characteristics and behaviors of such entities.

CATEGORIES OF TARGET CHARACTERIZATION PROBLEMS

There are numerous applications in which we cannot count on having high-fidelity models of target attributes or behaviors. For example, an adept, agile adversary, such as encountered in nonconventional warfare will not provide us with large samples of regular patterns of behavior for use in training statistical models. Such a problem is very different than conventional target recognition or tracking problems that can be addressed by model-based methods.

Waltz [21] has proposed a categorization of inference problems. We adapt this scheme in [2], [7] to distinguish inference methods by the way they use observational data and predictive models, as summarized in Table 3:

CATEGORY 0 (MODEL-BASED RECOGNITION)

This category encompasses methods used in traditional target recognition systems, relying on high-confidence models of target characteristics and behaviors. Prediction can involve deductive and inductive methods, whereby target entities and activities are recognized by matching observations to those predicted by models, possibly conditioned by the context of such factors as information source characteristics, viewing geometry, observation media, and background.

CATEGORY 1 (ANOMALY-BASED DETECTION)

It can happen that background (or normal) activities are better characterized than target activity. By matching observations with prior models of background activities, anomalous phenomena are detected as an indication of possible activities of interest.

Both categories 0 and 1 assume the availability of observational data and of prior models that have been validated in one way or another: In category 0, these are models of target entities or activities; in category 1 these are models of normal or background activities. Recognition and prediction (deductive and inductive) methods can be used in processing model data to derive expected observations for use in the matching process.

In contrast, category 2 and 3 methods are used to overcome deficiencies in prior models or in observable data, respectively. In category 2, new models are composed adaptively to explain observed data. In category 3, activities of interest might not be observable, rather their prior feasibility is determined on the basis of contextual information.

"The uses of context in inferencing can be differentiated into categories of target and information source characterization methods, appropriate to different assumptions concerning the quality of available prior models and observational data".

CATEGORY 2 (HYPOTHESIS-BASED EXPLANATION)

The process in this category is one of abductive reasoning: building and testing models to best explain available data. Such a process is applicable to situations in which there is insufficient prior analytic understanding or training data to develop predictive models. An analyst or an automated process constructs a situation or scenario hypothesis in an attempt to account for observed data. As in the classical scientific method, the hypothesis is evaluated to predict further observables that could either confirm or refute the hypothesis. By acquiring such data as available, explanatory, predictive models of the observed situation or scenario are selected, refined, or rejected.

CATEGORY 3 (CONTEXT-BASED FEASIBILITY)

These methods do not rely on direct observational data, rather, contextual cues are used to determine the feasibility of broad classes of activities: domain constraints on adversary capability developments, strategic planning, etc. Such methods are the only ones available when activities of interest are unlikely to be detectable or discriminable at all.[3]

[3] It might be useful to add yet another category (category -1?) to encompass estimation refinement via filtering or smoothing in the absence of a model; e.g., without model-driven filter gains.

Table 3

Categories of Inference Problems and Methods

Category	Approach	Assumed Prior Models	Observational Data	Inference Method
0	Model-based recognition	Targets	Yes	Deduction and induction
1	Anomaly-based detection	Backgrounds	Yes	Deduction and induction
2	Hypothesis-based explanation	Situation context and components	Yes	Abduction
3	Context-based feasibility	Targets and backgrounds	No	Deduction and induction

We can further subdivide category 0 to distinguish cases in which target models are "given" from those in which target models are derived by statistical learning:

- **0a** in which the actual target state (at whatever state estimation level) is known absolutely, e.g., under controlled test conditions;
- **0b** in which predictive models of targets and their behaviors are obtained explicitly from design documentation or are derivable analytically from first principles;
- **0c** in which predictive models are estimated from training data. In this problem category, distinct from category 0b, models are estimated inductively, for which all the apparatus of data fusion is applicable.

CATEGORIES OF SOURCE CHARACTERIZATION PROBLEMS

Inferencing problems involve the exploitation of information from sources whose performance may be well or poorly characterized. Categories of source characterization problems can be defined in terms of the availability of predictive models of source performance. This categorization is analogous to that for target state inferencing, as both reflect methods for acquiring knowledge concerning problem variables: level 4 variables in the source characterization case; level 0–3 variables in the target characterization case. As with the categories of target characterization problems, the categories of source characterization problems differ in their dependence on contextual information:

- **S0a:** in which the actual source performance is known absolutely, e.g., undercontrolled test conditions;
- **S0b:** in which predictive models of source performance are obtained explicitly from design documentation or are derived analytically from available information concerning the source's feature space and inference methods. Pertinent information of this sort may be reported by the source in real time, or it might be obtainable from source design documentation or from more general models of the source class (e.g., an analytic receiver model);
- **S0c:** in which predictive models are developed from training data, using estimates of source, target and situation states, together with historical performance data referenced to ground truth, i.e., historical measures of reporting errors in known conditions. We can further distinguish subcategories of S0c, based on the quality of available ground truth, as defined in terms of the above target characterization categories:
  - **S0c/0a:** source performance is estimated on the basis of observed entity states that are known absolutely, as in ideal test conditions;
  - **S0c/0b:** source performance is estimated on the basis of observed entity states that are well modeled;
  - **S0c/0b:** source performance is estimated on the basis of observed entity states that are inferred statistically;
  - **S0c/1:** source performance is estimated on the basis of observed entity states that are inferred from contextual anomalies;
  - **S0c/2:** source performance is estimated on the basis of observed entity states that are inferred by explanation of observable data;
  - **S0c/3:** source performance is estimated on the basis of observed entity states that are inferred by explanation of contextual data.
- **S1:** in which the performance of the given source is derived by comparison of its product with that from other sources. This category may be further refined by distinguishing these other sources according to their source characterization categories and by distinguishing degrees of independence among the sources (e.g., whether they measure or report commensurate variables);
- **S2:** in which predictive models of source performance are constructed abductively to explain the observed behavior of the source. Such a method is used when no reliable information is available concerning the source, but source performance must be inferred from target state estimates as reported by the source and compared with available ground truth (e.g., in in a test environment). Examples of reported state estimates include expectation and covariance matrices for continuous state variables (such as location or kinematics) and probability vectors across discrete state variables (e.g., target class within an exhaustive disjoint taxonomy);
- **S3:** in which performance of an information source must be inferred on the basis of context, i.e., from circumstantial evidence. Such methods can be necessary when reporting from the given source is so sparse and variable that it is not feasible to develop a predictive model of the given source. This can occur with obscure Websites, graffiti, and such "unsourced" information. Useful contextual information might include features of the source reporting medium and style, the known or assumed reporting conditions, and correlated reporting from other available sources. In some cases, it might be feasible to stimulate the source to observe its differential behavior under known conditions.

SUMMARY

We have attempted a careful definition of terms pertinent to discussion of situations and contexts. A context is treated as a situation that provides expectations for constituent entity states (C-O) or that is deemed relevant to the solution of an inference or response problem (C-F). Context exploitation involves a) predicting the value of contextual information to meet information needs; b) selecting information types and sources expected to provide information useful in meeting those needs; c) determining the relevance and quality of acquired information; and d) applying selected information to a given problem. Predictive models as used in inferencing are construed as estimates of state distributions. The uses of context in inferencing can be differentiated into categories of target and information source characterization methods, appropriate to different assumptions concerning the quality of available prior models and observational data.

REFERENCES

1. Rogova, G. L., and Steinberg, A. N. Formalization of "context" for information fusion. In *Context-Enhanced Information Fusion*, L. Snidaro, J. Garcia, J. Llinas, E. Blasch, eds. Zurich, Switzerland: Springer, forthcoming.
2. Steinberg, A. N., and Rogova, G. L. System-level use of contextual information. In *Context-Enhanced Information Fusion*, L. Snidaro, J. Garcia, J. Llinas, E. Blasch, eds. Zurich, Switzerland: Springer, forthcoming.
3. Gong, L. Contextual modeling and applications. In *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics*, Waikoloa, HI, 2005.
4. Steinberg, A. N., and Rogova, G. L. Situation and context in data fusion and natural language understanding. In *Proceedings of the 11th International Conference on Information Fusion*, Cologne, Germany, 2008.
5. Steinberg, A. N. Context-sensitive data fusion using structural equation modeling. In *Proceedings of the 12th International Conference on Information Fusion*, Seattle, WA, 2009.
6. Steinberg, A. N. Foundations of situation and threat assessment. In *Handbook of Multisensor Data Fusion*, M. E. Liggins, D. L. Hall, and J. Llinas, eds. Boca Raton, FL: CRC Press, 2009, pp. 437–502.
7. Steinberg, A. N. and Snidaro, L. Levels? In *Proceedings of the 18th International Conference on Information Fusion*, Washington, DC, 2015.
8. Devlin, K. *Logic and Information*. Cambridge, United Kingdom: Cambridge University Press, 1991.
9. Shapiro, S. C., and Rapaport, W. J. The SNePS family. *Computers & Mathematics with Applications* Vol. 23, 2–5 (Jan.–Mar. 1992), 243–275.
10. Angelova, D., and Mihaylova, L. Sequential Monte Carlo algorithms for joint target tracking and classification using kinematic radar information. In *Proceedings of the 7th International Conference on Information Fusion,* Stockholm, Sweden, 2004.
11. Salmon, W. C. *Statistical Explanation and Statistical Relevance*. Univ. of Pittsburgh Press, 1971.
12. Steinberg, A. N., and Bowman, C. L. Revisions to the JDL data fusion model. In *Handbook of Multisensor Data Fusion*, M. E. Liggins, D. L. Hall, and J. Llinas, eds. Boca Raton, FL: CRC Press, 2009, pp. 45–68.
13. Kschischang, F. R., Frey, B. J., and Loeliger, H. A. Factor graphs and the sum-product algorithm. *IEEE Transactions on Information Theory*, Vol. *47*, (2001), 498–519.
14. Yedida, Y. S., Freeman, W. T., and Weiss, Y. Understanding belief propagation and its generalization. In *Exploring AI in the New Millennium*, G. Lakemeyer and B. Nevel, eds. San Francisco: Morgan Kaufmann Publishers, 2002, pp. 239–269.
15. Pearl, J. *Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference*. San Francisco: Morgan Kaufmann Publishers, 1988.
16. Cowell, R. Introduction to inference in Bayesian networks. In *Learning in Graphical Models*, M. Jordan and J. A. Thomas, Eds. Cambridge, MA: MIT Press, 1998, pp. 9–26.
17. Shafer, G. R., and Shenoy, P. P. Probability propagation. *Annals of Mathematics and Artificial Intelligence,* Vol. 2, (1990), 327–352.
18. Lambert, D. A. A unification of sensor and higher-level fusion. In *Proceedings of the 9th International Conference on Information Fusion*, Florence, Italy, 2006.
19. Bowman, C. L., and Steinberg, A. N. Affordable non-traditional source data mining for context assessment to improve distributed fusion system robustness. *Proceedings of SPIE,* Vol. 8756, (2013), 875603.
20. Steinberg, A. N., Bowman, C. L., Blasch, E. Morefield, C., Morefield, M., and Haith, G. Adaptive context assessment and context management. In *Proceedings of the 17th International Conference on Information Fusion*, Salamanca, Spain, 2014.
21. Waltz, E. *Knowledge Management in the Intelligence Enterprise*. Norwood, MA: Artech House, 2003.

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- He has presented numerous courses, seminars and workshops in the US, UK, Sweden, Norway, Germany, Bulgaria, Armenia, Estonia, Australia, Singapore, China, South Africa and Turkey.

Garfield Mellema

SUMMARY REPORTS

INTRODUCTION

The International Society of Information Fusion (ISIF) works to advance the field of information fusion by supporting a number of working groups and workshops. These activities, organized by groups or societies other than ISIF, play an important role in the advancement of the field. The supported workshops defy strict categorization, but they have a number of characteristics in common. Most importantly, they are scientific meetings with a single track for presentations and discussions, and the proceedings of the events are published for future reference. They often focus on a specific aspect of information fusion, and attendance is generally on the order of 50 participants, many of whom come from the local geographic region. They also have generally lower registration fees, which makes them attractive to potential end-users.

ISIF supports events by emailing announcements to ISIF members and adding links on the ISIF website. It also may provide financial support, typically structured to support students and new researchers. This may be a grant for student travel to the event or a best student paper award. ISIF is then recognized as an official sponsor in the event materials and event website.

If you are organizing a workshop, conference, or other scientific or technical event related to information fusion and would like to learn more about possible support from ISIF, contact the VP Working Groups or any other ISIF board member. Applications should be submitted six months before the event to allow time for the board to discuss and vote on your proposal.

This issue of *Perspectives* includes three event reports for events held in 2014. There are:

- IET Data Fusion and Target Tracking Conference 2014,
- CTFG Workshop 2014, and
- BELIEF 2014.

These reports are followed by a brief report on SDF 2014. Reports on ISIF-sponsored events in 2015 will appear in later issues of *Perspectives*.

IET DATA FUSION AND TARGET TRACKING CONFERENCE 2014: ALGORITHMS AND APPLICATIONS[1]

The Tenth IET Data Fusion and Target Tracking Conference was held April 30, 2014 at the University of Liverpool, United Kingdom. This conference series is a biennial event providing an opportunity for researchers, developers, and operators to discuss advances in and applications of data fusion technologies. Participation in this conference presented an opportunity for developers to hear from and speak directly with a broad spectrum of their end-users, and offered academics working in this field a platform from which to present their short- to near-term technology. With its dual focus on algorithms and applications, the conference was an opportunity to identify potential collaborations among researchers, users, and developers who are marketing products and tools employing data fusion.

The conference included two keynote speakers and 12 regular presentations in a single, oral track. There were 47 participants. Neil Gordon, head of the Tracking and Sensor Fusion Group at the Defence Science and Technology Organization, gave a keynote lecture titled "One, two, infinity… approximate Bayes for tracking and sensor fusion." In this talk, he contrasted the elegance of the Kalman filter with the nonlinear, non-Gaussian real world, which limits and frustrates those who wish to apply the Kalman framework. Many approximate methods have been developed in response, ranging from those attempting to retain the Kalman solution structure to those attempting to retain a more complete representation of the density function than just the first- and second-order moments. His talk focused on recent developments in Bayesian approximation methods and future requirements to help bridge the gap between low- and high-level fusion.

The second keynote speaker was Fred Daum, principal fellow at Raytheon, with a lecture titled "Particle flow for nonlinear filters, Bayesian decisions and transport." In this talk, he explained what particle filters are and why they are popular with engineers addressing real-world problems, despite their exponentially increasing cost to process. He then presented a new nonlinear filter theory that used particle flow to compute Bayes's rule. This filter theory was described as being many orders of magnitude faster than standard particle filters for the same accuracy, beating the extended Kalman filter by several orders of magnitude for nonlinear problems.

The rest of the day was filled with 12 shorter presentations. In addition to the many papers describing applications of particle filters, there were papers discussing belief functions, Bernoulli processes, Kalman filters, and probability hypothesis density (PHD) filters. The conference program and the presented papers are available on IEEE Xplore at http://ieeexplore.ieee.org. The papers are available in book form from Curran Associates at http://www.proceedings.com.

The best paper award of £300, sponsored by ISIF, was presented to Fredrik Gunnarsson of Ericsson Research and Linköping University and Fredrik Lindsten of Linköping University, Sweden for "Particle filtering for network-based posi-

[1] By Garfield Mellema, with material from the conference organizers.

tioning terrestrial radio networks." The paper described how the distance of a wireless mobile terminal from its base station and the signal direction of departure from that base station could be estimated from information already available in the network, as well as how particle filters and smoothers could be used to postprocess those measurements. An ISIF-sponsored travel grant was also awarded to cover the costs of a student's travel to the conference. The recipient, Shimin Feng of the University of Glasgow, presented the paper "Fusing kinect sensor and inertial sensors with multirate Kalman filter," which he cowrote with Roderick Murray-Smith, also of the University of Glasgow.

CTFG WORKSHOP 2014

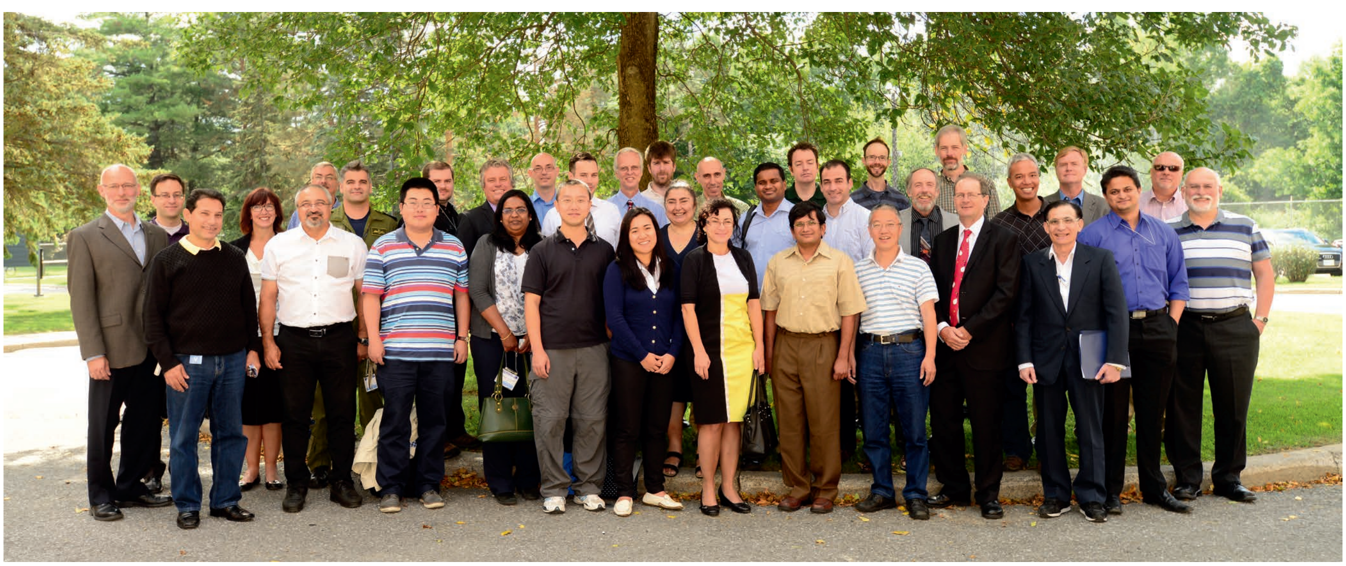
The Canadian Tracking and Fusion Group (CTFG) was established in 2010 with the objective of advancing awareness of information fusion and its use to address real-world problems, as well as to encourage collaboration among government, industry, and academia on problems of common interest related to information fusion. September 9–10, 2014 the CTFG held its fourth annual workshop, CTFG Workshop 2014, at the Communications Research Centre, Shirleys Bay, Ottawa, Canada. The workshop was well attended, with 55 participants from government, industry, and academia.

The format of the workshop was a single, oral track, with 14 authors presenting recent work of interest on topics such as source evaluation and performance, target tracking and filtering, detection and localization algorithms, and video processing and surveillance. In addition to these presentations, there was a talk by an invited speaker each day and a panel discussion at the end of the first day. A no-host dinner was held to encourage further discussion and collaboration.

The workshop was opened by Jocelyn Tremblay, who reflected on his early experiences as a defense scientist using Kalman filters for antisubmarine warfare late in the Cold War. In his current position as director general of science and technology center operations at Defence Research and Development Canada (DRDC), he has had the opportunity to view defense science on both broad and narrow scales, and he spoke of the importance of information fusion to defense science at all levels.

The first invited speaker was Col. Gregory D. Burt, commander of the Canadian Forces Intelligence Group, with a talk titled "Information related challenges: a CFINTCOM perspective." His view of information fusion was from the perspective of the end user, where the value of a system is determined by its end result and the value of information is determined by its effectiveness in achieving that result. In the context of defense intelligence, and from the perspective of the operator, Burt raised the question of how information fusion could provide more effective tools to shift the balance of human activities from searching to analyzing. The requirements of the analyst are improved collation, analysis, collaboration, information management (IM), and advanced tools. To achieve this will require more than just automation; it will require an improved methodology, taking into account modern and future information technology, IM, and knowledge management, always keeping the end purpose in mind.

The second invited speaker was Capt. (Ret'd) Kurt Salchert of Beyond the Border Consulting. A veteran of 30 years in the Royal Canadian Navy with a long list of leadership positions, including his final years as commander of the North American Aerospace Defense Command, Kurt Salchert provided unique insight into the end user's view of information fusion in the context of naval surveillance and security. A key challenge he cited is to provide the right information at the right points along a response-threat timeline. Information that is too early or too detailed is wasteful, as is information that is too late or insufficient. He also reinforced the need for international collaboration and information exchange to support maritime security. A grant from ISIF was used to pay the travel expenses of Kurt Salchert.



CTFG Workshop 2014 participants. (Photo by Janice Lang, DRDC)

Elisa Shahbazian of OODA Technologies opens the panel discussion at CTFG Workshop 2014 with a presentation on the roles and challenges of high- and low-level data fusion. (Photo by Janice Lang, DRDC)

At the end of the first day, there was a panel discussion on the theme "From low-level to high-level fusion: challenges in C4ISR applications." The panel members were Kurt Salchert, Elisa Shahbazian of OODA Technologies, and Dan Brookes, defense scientist on the DRDC Northern Watch Technology Demonstration Project. The discussion began with a short presentation by Shahbazian that introduced the roles and challenges of high- and low-level data fusion. With increasing interest in the Canadian Arctic and the recent announcement of a proposed fiber-optic link to that region, it was no surprise that much of the discussion centered on the problem of arctic surveillance, in particular maritime surveillance. Subtopics of interest included the utility of information transfer between low and high levels and the differences in how performance is evaluated at the different levels.

The rest of the talks presented during the workshop were grouped into four sessions. The Source Evaluation and Performance session included three presentations dealing with information at a relatively high level of refinement and another on the very low, numerical measurement level. The Target Tracking and Filtering session included three presentations on the detection and tracking of targets at the sensor measurement level. The Detection and Localization Algorithms session continued on this theme but focused on the localization of a single target. Higher-level information fusion returned to the agenda in the final Video Processing and Surveillance session, in which the speakers addressed issues related to site surveillance using diverse sensors, including some preprocessed higher-level information streams.

An abridged copy of the workshop presentations was distributed to participants. More information about CTFG Workshop 2014 can be found on the CTFG website at http://www.ctfg.ca.

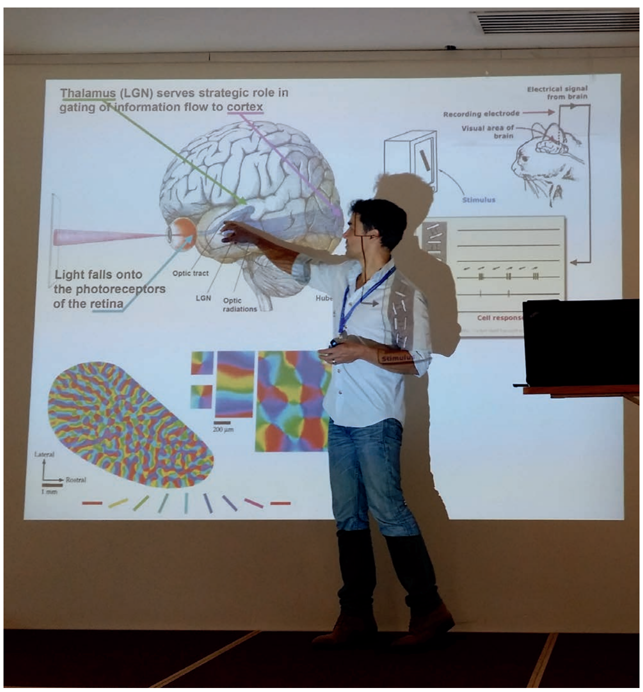
BELIEF 2014[2]

The theory of belief functions, also referred to as evidence theory or Dempster-Shafer theory, was first introduced by Arthur P. Dempster in the context of statistical inference and was later developed by Glenn Shafer as a general framework for modeling epistemic uncertainty. These early contributions have been the starting points of many important developments, including the transferable belief model, the theory of hints, and the Dezert-Smarandache theory. The theory of belief functions is now well established as a general framework for reasoning with uncertainty, and it has well understood connections to other frameworks, such as probability, possibility, and imprecise probability theories.

The Belief Functions and Applications Society (BFAS) was created to promote teaching, research, application, and creation of knowledge in the domain of belief functions; their extensions; and the links they can share with other theories and techniques. Under that mandate, the BFAS organized a series of biennial conferences on belief functions to provide opportunities to exchange ideas and present new results on the theory of belief functions and related areas, such as random sets, imprecise probability, and possibility theory. BELIEF 2014 was held September 26–28, 2014 at St. Hugh's College, Oxford, United Kingdom.

[2] By Garfield Mellema and Fabio Cuzzolin, with material from the BELIEF 2014 organizers.

About fifty participants attended Belief 2014.



The invited speaker Prof. Nando de Freitas from Oxford University's Computer Science department, during his talk about novel deep learning approaches.

The conference included two invited speakers and 47 regular presentations in a single, oral track. There were 58 registered participants. The conference began with an invited talk by Professor Nando de Freitas of the Computer Science Department of Oxford University, titled "Deep beliefs." He spoke at length about novel deep-learning approaches and the impact they are having in artificial intelligence and machine learning. Following a break for refreshments, there were sessions of regular presentations on belief combination, machine learning, and applications. The day concluded with a general meeting of the BFAS.

The second day opened with an invited talk by Professor Thomas Lukasiewicz, also of the Computer Science Department of Oxford University. In this presentation, titled "Uncertainty in the semantic web," he spoke about his work on uncertainty, noting that the logic-based approaches used in the field could find a natural generalization with the framework of belief functions logic. The day continued with sessions of regular presentations on theory, applications, and networks. In the evening, there was a conference banquet and award ceremony.

The final day of the conference featured a panel discussion, an open discussion session titled "The future of belief functions in the context of uncertainty theory." The question was raised of how to maximize the impact and visibility of work in this field. A tentative action list was proposed, including the launch of a series of methodological challenges to bring more focus to the work, advances toward completing the missing elements of belief theory, and improved means of communication among the scientists interested in belief functions. Regular presentations included sessions on theory, data association, information fusion, and geometry.

Two awards were presented. The Best Paper Award went to Thomas Reineking and Kerstin Schill of the University of Bremen, Germany, for their paper "Evidential object recognition based on information gain maximization." The paper, which proposed an active object recognition framework based on belief function inference and information gain maximization, was signaled by the board to be an example of novelty and significant methodological contribution likely to spur further research.

The Best Student Paper Award, sponsored by ISIF, went to Ph.D. student Philippe Xu and his advisors, Franck Davoine and Thierry Denœux, from the Université de Technologie de Compiègne, France, for the paper "Evidential logistic regression for SVM classifier calibration." The paper proposes an interesting calibration method to transform the output of a classifier into a belief function, a significant methodological contribution. Thanks to the ISIF grant, Philippe Xu attended the Fusion 2015 conference in Washington, DC, and presented a paper titled "Evidential multinomial logistic regression for multiclass classifier calibration," follow-up work of his BELIEF 2014 paper.

More information about BELIEF 2014, including the invited talks, can be found at the conference website at http://cms.brookes.ac.uk/staff/FabioCuzzolin/BELIEF2014/. The proceedings of BELIEF 2014 were published in book format by Springer's Lecture Notes in Artificial Intelligence/LNCS series, Volume 8764, and are available online at http://www.springer.com/computer/ai/book/978-3-319-11190-2. More information about the BFAS, including conferences and schools, can be found on the society website at http://bfas.iutlan.univ-rennes1.fr/.

SDF 2014

The ninth annual workshop on "Sensor Data Fusion – Trends, Solutions, Applications" (SDF 2014) was held October 8–10, 2014 at the University of Bonn, Germany. By design, the SDF workshops are not just about theories, equations, and data. They are also opportunities for workers in the field to meet one another, discuss areas of common interest, and explore potential collaborations. Designed to appeal to both newcomers to the field and experienced workers, SDF 2014 included a tutorial by Wolfgang Koch and a plenary lecture on maximum-likelihood methods by Peter Willett. There were 22 papers presented on a variety of topics related to information fusion at and near the sensor level. Sessions ranged from localization, tracking, navigation, and multisensor fusion to advances in pattern recognition, context fusion, and estimation theory. The Best Student Paper Award was sponsored by ISIF, and it was presented to Antonio Zea, a student of Uwe Hanebeck at the Karlsruhe Institute of Technology, Karlsruhe, Germany. Papers from the event are available on IEEE Xplore.

More information about SDF 2014, as well as photos of the event, can be found in the February 2015 review by Koch in the *IEEE Aerospace and Electronic Systems Magazine* at http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7063665&tag=1.

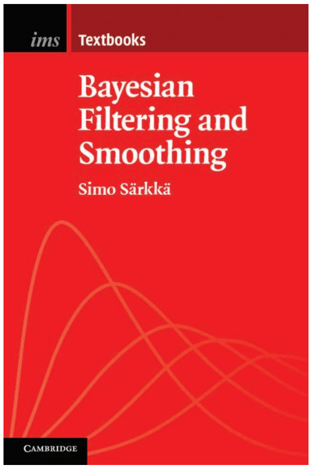
Book Review

Bayesian Filtering and Smoothing

Simo Särkkä

Cambridge University Press, Cambridge, UK
ISBN: 978-1-107-61928-9, Paperback, 2013, 252 pages

Reviewed by Lennart Svensson



Bayesian Filtering and Smoothing by Professor Simo Särkkä is an excellent contribution to the filtering and smoothing literature. It is very well written, accurate, and it covers essentially all the key techniques in the field in an elegant and pedagogical manner. Apart from being an outstanding book, another advantage is that a soft copy (a PDF version) is freely available online from the homepage of the author.

The filtering and smoothing area is important, thanks to its wide applicability ranging from positioning, navigation, and control to brain imaging and audio signal processing. The field was long dominated by the Kalman filter and the extended Kalman filter, but has received many important contributions over the past 20 years, most of which are nicely explained in this book. Different types of sigma point techniques, such as unscented, Gauss-Hermite, and cubature filters, take up a central position. The book also covers particle filtering solutions as well as an introduction to Bayesian inference in general. However, considering that the book is relatively short it is only natural that it cannot cover everything and readers who are primarily interested in multiple model filtering methods or solutions to the data association problems for target tracking should look for a different book.

An excellent feature of this book is how clearly it explains the relations between the many filtering and smoothing solutions, by first outlining a general solution and later indicating how well-known filtering and smoothing algorithms try to approximate that. Doing so helps the reader to view many of the existing algorithms as instantiations of a single general solution, which is an essential perspective in order to understand and get a manageable overview of the field.

The chapters that deal with sigma point techniques for filtering and smoothing are my favorite parts of this book, where the author clarifies both the motivations and the technical details behind existing algorithms. Presenting a clear summary of the sigma point techniques may sound like a small achievement, but considering that some early papers gave rise to significant misunderstanding of the theory, see, e.g., [1], [2], it is refreshing to read a text that does not leave any room for misconceptions. The chapters are further enhanced by the fact that the same arguments and exposition are used first in the development of Gaussian filtering methods and later reused to obtain the corresponding smoothing algorithms. A technical remark is that the author emphasizes the moment matching perspective on Gaussian filtering, whereas the statistical linear regression motivation, see, e.g., [3], [4], is not mentioned.

Another important tool for nonlinear filtering is the family of particle filters, also known as sequential Monte Carlo or sequential importance resampling methods [5]. The book dedicates one chapter to particle filtering and another chapter to particle smoothing, in which the background theory and motivations are nicely presented along with many of the key algorithms. These chapters are sufficiently detailed in order to enable the reader to use particle filters and smoothers to solve a wide range of problems, but they are less complete than the corresponding chapters on Gaussian methods and do not attempt to cover all existing algorithms. For instance, even though the book covers algorithms such as the Rao-Blackwellised particle filters, the reader is instead referred to the literature in order to understand the details regarding the auxiliary particle filter.

Perhaps one of the most obvious proofs that I really like this book is that I have selected it to be the main literature in a Masters course named "Sensor fusion and nonlinear filtering" that I teach. The course is still fairly new and I have not yet received much feedback on the literature, though many students were grateful that they could download a soft copy for free.

Reading the book requires basic knowledge in statistics, calculus, and linear algebra and I would recommend the book to Master students, PhD students and to most people working in the field. Anyone who has been using extended Kalman filters in the past and is curious to investigate more modern alternatives should find this book a rich source of inspiration, in particular thanks to its brilliant overview on Gaussian filters. Some may find the text a bit too brief, but succinct descriptions certainly also have their advantages and I personally find its style very appealing; especially since it is still complete in all its arguments and details.

When reviewing a book on such a mature field as nonlinear filtering it is inevitable to compare it with existing literature. Some of my favorite books on filtering are [6], [7], and [8] that all have their pros and cons. All of these three books are actually in some ways more suitable for a practitioner than the *Bayesian Filtering and Smoothing* book; [7] contains many chapters that are dedicated to various applications, whereas both [6] and [8] provide detailed descriptions regarding, e.g., how to tune filters and check their consistency. Perhaps my main reservation regarding Professor Särkkä's new book is that it lacks a chapter on motion and measurement models, which are essential components in most filters and nicely covered in both [6] and [8]. On the other hand, the topics that are covered in the *Bayesian Filtering and Smoothing* book are covered very nicely and I regard the chapters that deal with Gaussian filtering and smoothing as the most complete and accessible summary of those techniques that I have seen.

It is clear to me that most people who work with nonlinear filtering would benefit from reading this book and should have it in their bookshelf (or on a hard drive) for future references. I will personally continue using it in my courses on this topic, simply because I think it contains a brilliantly elegant and illuminating description of the field.

REFERENCES

1. Julier, S., and Uhlmann, J. Unscented filtering and nonlinear estimation. *Proceedings of the IEEE*, Vol. 92, 3 (2004), 401–422.
2. Gustafsson, F., and Hendeby, G. Some relations between extended and unscented Kalman filters. *IEEE Transactions on Signal Processing*, Vol. 60, 2 (2012), 545–555.
3. Arasaratnam, I., and Haykin, S. Cubature Kalman filters. *IEEE Transactions on Automatic Control*, Vol. 54, 6 (June 2009), 1254–1269.
4. García-Fernández, A. F., Svensson, L., and Morelande, M. Iterated statistical linear regression for Bayesian updates. In *Proceedings of the 17th International Conference on Information Fusion (FUSION)*, Salamanca, Spain, July 2014.
5. Doucet, A., Godsill, S. J., and Andrieu, C. On sequential Monte Carlo sampling methods for Bayesian filtering. *Statistics and Computing*, Vol. 10, 3 (2000), 197–208.
6. Bar-Shalom, Y., Li, X. R., and Kirubarajan, T. *Estimation with Applications to Tracking and Navigation: Theory, Algorithms, and Software*. New York: Wiley, 2001.
7. Ristic, B., Arulampalam, S., and Gordon, N. *Beyond the Kalman Filter: Particle Filters for Tracking Applications*. Norwood, MA: Artech House, 2004.
8. Gustafsson, F. *Statistical Sensor Fusion*. Lund, Sweden: Studentlitteratur, 2010.

W. Dale Blair

ISIF AWARD PROGRAM

To encourage excellence and advancements in the research community for information fusion, ISIF sponsors awards for significant achievements in the field of information fusion. This field is diverse and comprises target tracking, detection, estimation, sensor fusion, applications of information fusion, image fusion, information fusion systems architectures, classification, learning, Bayesian and reasoning methods, and data mining. The ISIF Awards Committee for 2016 includes Shozo Mori, Lawrence Stone, Yaakov Bar-Shalom, Elisa Shahbazian, Paulo Costa, and myself as Chair.

ISIF proudly sponsors three society awards and two conference awards. These are

- ISIF Lifetime of Excellence in Information Fusion,
- ISIF Young Investigator Award For Contributions in Information Fusion,
- ISIF Exceptional Service Award,
- ISIF FUSION Conference Best Paper Award, and
- ISIF FUSION Conference Best Student Paper Awards.

All of the awards are presented annually during the award banquet at the FUSION Conference. This article shares additional details of these awards. Additional details of the award and selection processes are available at www.isif.org.

The Premier award is the ISIF Lifetime of Excellence in Information Fusion. This award is given for a lifetime of contributions to information fusion. It was first given in 2015 and subsequently named in 2016 for the first recipient, Yaakov Bar-Shalom, whose career began in the pre-internet days of punched cards. The ISIF Yaakov Bar-Shalom Award for a Lifetime of Excellence in Information Fusion recognizes a researcher or engineer for 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 award consists of a commemorative recognition plaque and a travel grant to receive the award. This award may be given annually, if outstanding candidates are nominated, but it is expected to be given at least once every 3 years because individuals with the anticipated level of contributions to information fusion throughout a career will be rare. The selection process is managed by the ISIF Awards Committee. Nominations are solicited from the ISIF membership and nominees must have been a member of ISIF for a total of at least 10 years. Anyone qualified to appraise the candidate's contributions may formally nominate the candidate. Nominations are due by the 31st day of January in the year of the award and the award is presented at the annual FUSION conference. Dr. Chee Chong is the 2016 recipient of the ISIF Yaakov Bar-Shalom Award.

Yaakov Bar-Shalom at FUSION 2000 in Paris

Chee Chong, 2016 Recipient of the Yaakov Bar-Shalom Award

The ISIF Young Investigator Award is sponsored by the ISIF to grant international recognition for outstanding contributions to the art of information fusion by a young ISIF member. The goals of the ISIF in granting this award are to encourage individual effort and to foster increased participation by younger researchers and engineers. This ISIF award consists of a commemorative recognition plaque and travel grant to receive the award. An eligible candidate must be no more than 35 years of age on the first day of January for the year in which they will be honored, and she/he must also be a member of ISIF with at least three years of ISIF membership. Nominations will be solicited from the ISIF membership and the selection process is managed by the ISIF Awards Committee. Anyone qualified to appraise the candidate's contributions to the art of information fusion may formally nominate the candidate. A full nomination package that includes an exhaustive curriculum vita and at least three endorsement letters is required by the 31st day of January in the year of the award. The ISIF Young Investigator Award is presented at the annual FUSION conference. This year is the first year of the ISIF Young Investigator Award and Dr. David Crouse is the first recipient.

David Crouse, 2016 Recipient of the ISIF Young Investigator Award

This year, ISIF introduces the ISIF Robert Lynch Award for Exceptional Service to recognize an individual who has provided great service to the society. The award was established in memory of Robert (Bob) Lynch who contributed regularly over many years to the organization of the annual FUSION conference and tirelessly to the founding and production of the *Journal for Advances in Information Fusion* (JAIF), the founding

Robert (Bob) Lynch

of *ISIF Perspectives on Information Fusion*, and the maintenance of the ISIF web site. The award consists of a commemorative recognition plaque and an honorarium. Good candidates for the service award would have numerous contributions that might include active and prolonged participation in the annual FUSION conferences, exceptional leadership in the organization of FUSION over many years, service to the ISIF Board of Directors in either elected or appointed positions, publications in JAIF, leadership and contributions to the JAIF editorial board and its production, support of the ISIF website and working groups, and other activities that promote ISIF and the area of information fusion. This award may be given annually, if outstanding candidates are nominated, but it is expected to be given once every three years because individuals with the anticipated level of contributions to ISIF will be rare. The nominee shall have made a series of major contributions to ISIF and the information fusion community over multiple years. Nominees must have 10 years of membership in ISIF. Anyone qualified to appraise the candidate's contribution[s] may formally nominate the candidate. A full nomination package that includes an exhaustive curriculum vita is provided to the chair of the ISIF Awards Committee prior to the 31st day of January in the year of the award.

The Jean-Pierre Le Cadre Award recognizes excellence among researchers and scientists in information fusion. Jean-Pierre Le Cadre's career was highly motivated by his pursuit of excellence in his research. Beginning in 2010, the Jean-Pierre Le Cadre Award is for the best paper of the FUSION conference and includes a certificate and an honorarium. The Jean-Pierre Le Cadre Award is managed by the organizing committee for the FUSION conference for that year. The 2015 recipients of the award were Shozo Mori, Kuochu Chang, Hajime Takahashi, and Chee-Yee Chong for coauthoring "An Application of Interacting Multiple Model Tracking Method to Financial Modeling and Asset Allocation."

Jean-Pierre Le Cadre lecturing at FUSION 2000 in Paris

Students are the lifeblood of ISIF and the future of information fusion. Tammy Blair played a key role in the organizing committee for multiple FUSION conferences and was passionate about involving students. Tammy died in San Diego, California during the week following the 2009 FUSION conference, where she contracted the Swine Flu. The ISIF Tammy Blair Best Student Paper Award encourages the involvement of young researchers and scientists in information fusion. It honors Tammy Blair's commitment to ISIF and her efforts to involve students in the annual FUSION conference. In addition to the best student paper, as judged by the FUSION organizing committee, two runners-up are recognized annually. All awardees receive certificates and honorariums. Student authors of finalist papers are required to attend the FUSION conference. The 2015 recipient of the award was Muhammad Altarnash Khan for the paper entitled "Improvements in the Implementation of Log-Homotopy Based Particle Flow Filters" that was coauthored with Martin Ulmke.

Tammy Blair at the 2006 FUSION in Florence, Italy

The ISIF Board of Directors is committed to promoting excellence and achievement in the area of information fusion, and a strong ISIF awards program is considered to be a critical piece of that vision.

ISIF Conference Report

Paulo Costa and Kathryn Laskey

Fusion 2015
Washington, D.C.
July 6-9, 2015

18th FUSION IN WASHINGTON, DC

ISIF organized its 18th annual flagship conference last July in the capital of the United States of America. George Mason University's C4I and Cyber Center and IEEE's Aerospace and Electronic Systems Society co-organized the conference. In keeping with the international goals and purpose of ISIF, more than half of FUSION 2015's 389 attendees arrived in Washington, DC, from countries other than its host nation. This diversity highlights the broad appeal of the conference and the international community supporting it. The FUSION community has been experiencing steady growth throughout its already substantial history. One of the most impressive statistics in FUSION 2015 was the technical richness observed in its 12 tutorials, 282 presentations, and 3 keynote addresses, with a wide range of approaches, applications, and novel ideas covering all aspects of the information fusion spectrum.

Unbeknownst to the vast majority of its attendees are the hurdles and challenges involved in organizing such complex events, which range from tricky logistics to new government travel regulations to the high expectations created by the history of exquisitely organized FUSION conferences. We briefly address a few of these in this article.

Dr. Moshe Khan's plenary talk – The Impact of Sensor and Data Fusion Thought on Engineering Practice and Engineering Education.

TECHNICAL PROGRAM

All the conference activities occurred on a dedicated floor at the Grand Hyatt, which provided the focus and convenience to leverage the richness of the technical program. Activities started with twelve tutorials held on Monday, September 6, a day before the main conference, which lasted through Thursday. Coordinating four days of intense activities was a huge undertaking. In numbers, the FUSION 2015 technical program committee comprised 259 members, providing at least two expert reviews of each of the 357 submitted papers; many papers had more than two reviews. The result was a vibrant set of regular and special sessions, which were convened in the eight break-out rooms. A complete list of all 22 special sessions can be found on the conference website at fusion2015.org.

The conference proceedings were distributed to all attendees on site. They also have been published in IEEE Xplore, and are posted on the ISIF website for FUSION 2016 attendees. Further details of the conference, including a photo gallery of the events, can be found at fusion2015.org.

We are especially grateful to our plenary speakers whose keynote address on the mornings of the conference brought to conference attendees a rare mix of technical competence, experience, and passion for information fusion, and taking perspectives ranging from academia to industry to government. This year's speakers were:

- Moshe Kam, "The impact of Sensor and Data Fusion thought on Engineering Practice and Engineering Education, 1975–2015",
- Colleen Keller, "Bayesian Search for Missing Aircraft", and
- Edward Cope, "Integrative GEOINT Foresight: Fusion of Transdisciplinary Expertise via Visual Analytics, Models, and Collaborative Computing".

We thank them for sharing their unique spark of excitement to our technical program at the start of each day.

> *"The Fusion Conference series always provide a terrific value for us in industry as a means of keeping up-to-date with the latest and the greatest research in the field. Fusion 2015 excelled in that regard! The technical program was outstanding in both content and depth, covering an amazing spectrum of different areas of information fusion with valuable tutorials, vibrant keynote speeches, and an amazing array of regular and special sessions that left no stone unturned. I am a regular attendee and arrived in D.C. with pretty high expectations for Fusion 2015, but the technical program managed to surpass all of them."*
>
> *José Brancalion – Embraer S.A.*

Mahendra Mallick, Jean Dezert (President of ISIF for 2016), and Shozo Mori at the FUSION 2015 reception.

Snapshot of the Gala Banquet. Standing: Sten F. Andler, Anne-Laure Jousselme, Valentina Dragos. Seated: Paulo C.N. Costa, Paulo C.G. Costa, Kathryn Laskey, and Max Krüger.

SOCIAL ACTIVITIES

Washington, DC is consistently cited as one of the most expensive cities in the US and in the world (e.g. http://www.expatistan.com/cost-of-living/index). One of the major challenges in the organization of FUSION 2015 was to design a social program that brings a sense of the finest DC has to offer, while avoiding the high costs of many of the most popular attractions. We were fortunate enough to secure attractions that met these criteria. The reception was housed at the Mansion on O Street, a unique blend of music museum, executive lodging, restaurant, retreat venue, B&B, tourist attraction, and treasure hunt locale. The building consists of a series of five interconnected townhouses and includes over 100 rooms with over 70 secret doors. It has been featured in the National Geographic Traveler and on the Travel Channel as an ever changing environment that "combines history, art and architecture to craft an exhilarating entertainment experience found nowhere else on earth". Anecdotal feedback from attendees was consistent with this description.

> *"I live in the Washington, DC area for a long time, but the Fusion 2015 reception venue was an awesome surprise to me. A unique place with a cozy yet sophisticated atmosphere. What a wonderful event…."*
>
> *KC Chang, Professor – George Mason University*

Beyond the highly positive atmosphere of the reception, the most anticipated social event of the program was the Gala dinner, held at the National Portrait Gallery near the White House. Dinner was served in the Robert and Arlene Kogod Courtyard, an enclosed courtyard with an elegant glass canopy offering a uniquely sophisticated atmosphere. Before dinner was served, an awards ceremony recognized some of ISIF's greatest contributors. Awards included the Pierre Le Cadre Award for the Best Paper of the conference, and the Tammy Blair Award for the Best Student Paper. A high note this year was the establishment of the new ISIF Lifetime Achievement Award. This award was presented to Dr. Yaakov Bar-Shalom. The awards ceremony was followed by a delicious dinner. The night's main attraction was a 17-musician jazz band performing a range of numbers that covered various periods of American music.

> *"It is not every day one can enjoy great food and company within a reserved courtyard in a Smithsonian museum at the center of the US capital, including a live jazz band, a grand piano, and an exquisitely decorated setup. The Fusion 2015 gala dinner was indeed a memorable event."*
>
> *Sten F. Andler, Professor of Computer Science – University of Skövde, Sweden*

ORGANIZATION

The decision to host Fusion 2015 was made in the Spring of 2013. Although this might sound like plenty of time to plan the conference, the reality is that an event as large and complex as Fusion in any major (and expensive) city needs considerable lead time to line up the best selection of venues and secure favorable pricing. Most of the major FUSION 2015 contracts were either finalized or arranged in 2013. These included the venue (Grand Hyatt) and the gala dinner venue (Smithsonian National Portrait Gallery), although negotiations on details continued right up to the very day of the event. Fusion conferences now have a cycle of three years between approval and the event.

FUTURE

The driving force behind the FUSION conferences is the information fusion community. Not only have the members of our all-volunteer organizing committee played important roles in past FUSION conferences, but we have also relied on help from past organizers, ISIF Board of Directors members, and others with a genuine desire to see a successful conference. For good reason, the FUSION conferences have developed a hard-earned reputation for their combination of technical excellence, networking opportunities, and vibrant social programs. We learned from our "first-person perspective" in organizing this event that the commitment of the fusion community is deep and plays a vital role in the conference's success. We are grateful to everyone for their contributions to a successful FUSION 2015.

> *"The Fusion 2015 organizing team did an exceptional job of handling all aspects of the conference. Their hard work and dedication paid huge dividends with a conference that came off without a hitch. This year's conference maintained the high standards that our community expects and looks forward to each year. All of the sessions contained high quality presentations; the venue was perfect; and the social events provided the perfect atmospheres for networking, enjoyment, and relaxation."*
>
> *Darin Dunham – ISIF President*

Early History of International Society of Information Fusion

Chee-Yee Chong
Independent Researcher
Los Altos, CA, USA

Abstract—The International Society of Information Fusion (ISIF) was formed in 1998 to address the needs of the information fusion community. Several communities were involved in information fusion around that time but there was not a single technical society with focus on information fusion. FUSION'98 provided an opportunity for people with interests in fusion to get together. ISIF was formed to be a sponsor for FUSION'99 and future fusion conferences. Several individuals played key roles in the early history of ISIF.

The International Society of Information Fusion (ISIF) was formed in 1998. Its main activity is sponsorship of the annual Fusion conferences. Conference attendees automatically become members because the registration fee includes the ISIF membership dues. Thus most people know ISIF through its conferences, but know little else about ISIF itself and its history.

This paper will discuss the early history of ISIF with emphasis on how it was formed. It will reveal interesting tidbits such as Fusion 1998 was not sponsored by ISIF, and a key player in its formation was not from the fusion community.

FUSION COMMUNITIES AROUND 1998

It is hard to pinpoint when sensor fusion, data fusion, or information fusion was established as a separate research area. However, fusion-related activities were performed as soon as multiple sensors or sources became available, initially by human operators, and then in autonomous systems such as robots. Several communities with fusion activity are discussed here.

DEFENSE AND AEROSPACE COMMUNITY

As in many fields, early research was funded mostly by government for defense and aerospace applications because there was a need to utilize the data available from multiple sources. By around the 1980s, there was a defense research community working on detection, tracking, target recognition, and identification with data from radar and other sensors.

Many researchers in the radar community had backgrounds in signal processing and control systems. Thus, papers on information fusion appeared in signal processing and control/estimation conferences and journals. These papers included the probabilistic data association filter (PDAF) [1] and multiple hypothesis tracking (MHT) [2], [3]. Because of its focus on aerospace and defense, the IEEE Aerospace and Electronic Systems Society gradually replaced the Control Society as the home for fusion researchers, with more papers appearing in the *IEEE Transactions on Aerospace and Electronic Systems*.

Within the US defense community, the MIT/ONR Workshop on Distributed Information and Decision Systems Motivated by Command-Control-Communications (C3) Problems (1978 to mid-1980s) brought together researchers in academia, industry, and government. In 1987, two conferences dedicated to information fusion were started: the Tri-Service Data Fusion Symposium (1987–1995) and the National Symposium on Sensor Fusion (1987–1996). These two conferences restricted their attendance to researchers for the US government, and in 1997 merged into the National Symposium on Sensor and Data Fusion.

Even though there were meetings dedicated to fusion, there was no single group focused on data fusion. Around 1983, the Joint Directors of Laboratories (JDL) Technical Panel for C3 formed the Data Fusion Sub-Panel, chaired by Franklin White from Naval Ocean Systems Center (NOSC). This panel, later known as the Data Fusion Group (DFG), conducted surveys of the fusion research community to assess the state of the art and developed the well-known JDL data fusion model [4].

Data fusion in Europe had a late start when compared with the United States. However, the fusion community grew rapidly in the United Kingdom and continental Europe. Papers on fusion were published mostly in the Institution of Electrical Engineer (IEE) journals. The Eurofusion conference was held in the United Kingdom in 1998 and 1999.

In Australia, the Defense Science and Technology Organization (DSTO) was active in information fusion, including the development of data fusion lexicons [5]. The First Australian Data Fusion Symposium was held in Adelaide in 1996. While it was a successful conference, the second symposium was not held until 1999, when it became part of the Information, Decision and Control (IDC) Conference.

ROBOTICS, AUTOMATION, AND INTELLIGENT SYSTEMS COMMUNITY

Fusion of data from multiple sensors is needed to control robots and support automation [6]. The IEEE International Conference on Multisensor Fusion and Integration (MFI) for Intelligent Systems was started in 1994 to focus on problems and solutions of particular interest to this community. Sponsors of this conference include the IEEE Robotics and Automation Society (RAS) and the IEEE Industrial Electronics Society (IES). This community involves more academic researchers than the defense and aerospace fusion community with many conferences held in Europe.

ARTIFICIAL INTELLIGENCE AND COMPUTER VISION COMMUNITY

Information fusion is a natural application for artificial intelligence (AI) because humans are expert fusers that combine information from sight and sound. In response to the Japanese Fifth Generation Computer project, the US government started the Strategic Computing Initiative to advance the state of the art in computing and machine intelligence, and fusion was one of the application areas [7]. Thus fusion papers started to appear in American Association of Artificial Intelligence (AAAI) conferences and International Joint Conference on Artificial Intelligence (IJCAI).

The AI community recognized very early that reasoning under and management of uncertainty is an important component in intelligent systems [8]. The first Uncertainty in AI Conference was held in 1985 with the Association for Uncertainty in AI (AUAI) as its sponsor. The AUAI community consisted mostly of researchers in probabilistic reasoning, but there were also conferences for evidential reasoning, possibility theory, and other approaches.

Computer vision is an important area in machine intelligence, and fusion in computer vision is an active area of research [9]. Papers are presented in Computer Vision and Pattern Recognition (CVPR) conferences and published in journals such as the *IEEE Transactions on Pattern Analysis and Machine Intelligence*.

OTHER INFORMATION FUSION COMMUNITIES

The International Society for Optical Engineering (SPIE) sponsors conferences on many popular topics. Conferences on fusion started to appear in the early 1990s. Examples include Signal Processing, Sensor Fusion, and Target Recognition since 1992 [10], and Sensor Fusion and Aerospace Application since 1993 [11].

The remote sensing and Earth science communities have the task of combining satellite data and other image data [12], [13]. They have their own society in IEEE, the Geoscience and Remote Sensing Society, which holds conferences and has its own journal. Although image fusion is an important problem in defense and security, there is little interaction between the two communities.

FUSION'98

By around 1997, information fusion was an active area of research with international involvement. There were several conferences on different aspects of fusion, but there was not a single international conference or a professional community dedicated to information fusion.

HOW FUSION'98 WAS STARTED

In January 1997, *Proceedings of the IEEE* published a special issue on data fusion with an introduction on multisensor fusion [14]. This issue is probably the first time that papers on diverse fusion applications such as defense, robotics, and remote sensing appear in the same publication. The time was ripe for an international conference on information fusion.

Professor Hamid Arabnia of the University of Georgia is the founder and chair of the annual International Conference on Parallel and Distributed Processing Techniques and Applications (PDPTA), which was started in 1995. From 1995 to 1997, the conference received between 10 and 30 submissions each year on fusion of multisource and multisensor data, but was unable to accept all the papers because they were only marginally relevant to the PDPTA conference. At PDPTA in June 1997, it was decided to have a new conference in 1998 to accommodate the papers related to fusion. During an open panel discussion, Dr. Dongping (Daniel) Zhu from a small company called Zaptron, Inc., suggested to call the conference "Fusion". He offered to be, and in fact became, the General Co-Chair of the 1998 International Conference on Multisource-Multisensor Information Fusion (FUSION'98).

Daniel Zhu received his Ph.D. from Virginia Polytechnic Institute and State University in 1993 with a thesis on "A feasibility study of using CT image analysis for hardwood log inspection". According to his company website [15], his research experience includes image fusion in machine vision, satellite mobile telecom systems, sensor fusion in GPS navigation, hyper-space data mining in informatics, chemometrics, pharmacokinetics, econometrics, industrial process optimization, knowledge fusion in diagnostic expert systems, and neurofuzzy information fusion for financial forecasting and risk management. He worked for several companies and in 1997 founded Zaptron Systems, Inc. in Silicon Valley to focus on data mining and intelligent controls, with applications in search engines, network management, and controls. According to the company website, the company moved to Beijing, China, in 2004 and has products in business analytics and text mining for the financial industry.

Daniel saw the potential of information fusion but as a newcomer to the fusion community, he needed help in attracting papers and attendance. He started by searching the internet for fusion experts to serve on the organizing committee. The first call for papers (CFP) in Fall 1997 listed Belur Dasarathy, who had a website on information fusion, as publicity chair, but the rest of the team did not have enough members from the traditional fusion community. Daniel Zhu contacted Professor X. Rong Li (University of New Orleans), who was well known for his many publications in tracking, and asked him to chair a steering committee. After some initial hesitation because Daniel was not known to the fusion community, Rong decided that the fusion conference was a good idea and formed the steering committee in January 1998. Members included about 25 well-known researchers from academia, industry, and government. Several other committees were set up to involve as many people as possible. The advisory committee was smaller with 11 members. The international program committee had over 50 members. However, many members were not active and some names were included without contacting the individuals.

The CFP in spring 1998 listed Professor Lotfi Zadeh (UC Berkeley) as Honorary Chairman, Daniel Zhu and Dr. Rabiner Madan (ONR) as General Co-Chairs. In addition to serving as General Co-Chair, Madan also arranged a grant from ONR to support student attendance. Other sponsors included the National Science Foundation, US Army Research Office, and the US Army Night Vision and Electronic Sensors Directorate. The list of keynote speakers included Professor Yaakov Bar-Shalom (University of Connecticut), Dr. Enrique Ruspini (SRII), and Colin Johnson, editor of *Electrical Engineering Times*. The inclusion of Colin Johnson was intended to promote the conference beyond the traditional fusion communities, and reflected Daniel Zhu's ambitions about the fusion conference.

Rabiner Madan (left) chairing a FUSION'98 session.

Yaakov Bar-Shalom giving the keynote at FUSION'98.

PAPERS AND ATTENDANCE

Since FUSION'98 was a new conference with no prior history and a very general CFP, it attracted papers in diverse areas such as defense and security, remote sensing, image fusion, air traffic control, robotics, industrial automation, finance, medical, etc. Papers in defense and security have become the mainstay for the fusion conferences, while industrial automation, finance, medical, are seldom found in later conferences. There were also more papers on fuzzy sets and neural networks in FUSION'98 than later conferences due to the composition of the committees. The conference proceedings had 136 papers in 29 sessions.

FUSION'98 was held at the Monte Carlo Hotel in Las Vegas from July 6 to July 9, 1998, with attendance of about 160 from North America, Europe, and Asia. Some participants attended this conference out of curiosity and stopped attending when they found out that the conference did not cover their research areas. Other attendees found the conference useful and continued their attendance of future conferences. There are probably a handful of people who have attended all conferences.

FORMATION OF ISIF

The idea of a fusion society first appeared in the FUSION'98 email to committee members from Daniel Zhu and Rong Li. The Las Vegas meeting provided an opportunity for people who shared common interests in information fusion to get together. Many attendees saw the need to continue the conference and to form a professional society for its sponsorship. Furthermore, the society had to be created as soon as possible because FUSION'99 needed a sponsor to sign the legal agreements with a hotel or conference center and publication house.

Activities shifted to a high gear from August 1998 to the end of 1998. Daniel was not too busy at the time with his business and wanted to move ahead as quickly as possible.

Rong Li (right) chairing a session.

(From left) Rong Li, Jean Dezert, Vincent Nimier, and Alain Apriou.

(From left) Pramod Varshney, Rabiner Madan, and Nageswara Rao.

(From left) Shozo Mori, Chee-Yee Chong, and Jim Llinas.

(From left) Daniel Zhu, Yaakov Bar-Shalom, and Rong Li.

He immediately set up the website www.inforfusion.org to publicize the fusion society and FUSION'99. As a professor, Rong Li wanted to follow standard procedures and solicit inputs before moving ahead. He had already set up a website www.infofusion.org for general fusion information and used this website to solicit inputs on a fusion society, FUSION'99, and a fusion journal. For a while, there were two websites on information fusion but the isif.org domain was not available until several years later.

Daniel started working on the incorporation of the International Society of Information Fusion (ISIF) after he returned to California from the conference. He asked an attorney in San Jose to file the necessary papers for incorporation and apply for non-profit status in the United States. He paid from his own pocket all the upfront expenses, which were not repaid until after FUSION'99. ISIF was officially incorporated in September 1998 and received tax exempt status in April 2000.

The newly formed ISIF needed a board of directors and officers to manage its business. Since ISIF did not have any members to elect to the board, Rong Li suggested the formation of an organizing committee to propose an initial board and officers. Rong invited many people to join, resulting in an organizing committee well represented by fusion experts in academia, industry, and government, and from North America, Europe, Asia, and Australia.

Erik Blasch and Jean Dezert held the first ISIF Board election in December 1998. The officers elected were Jim Llinas (USA) as president, Chee-Yee Chong (USA) as treasurer, and Daniel Zhu (USA) as secretary. Other board members were Mark Bedworth (UK), Yaakov Bar-Shalom (USA), Belur V. Dasarathy (USA), Alfonso Farina (Italy), X. Rong Li (USA), Daniel McMichael (Australia), Jane O'Brien (UK), and Pramod K. Varshney (USA). The predominantly aerospace and defense background of the initial board basically set the future direction of ISIF and the fusion conferences.

Another task of the organizing committee was to draft the constitution and bylaws for the management of the society. A subcommittee including Erik Blasch, Chee-Yee Chong, and others solicited inputs from many people. The task took longer than expected, and the final version was not approved until spring of 2000. One important decision was to include the membership fee in the conference registration fee because organizations usually pay for conference registration but not professional society membership. However, this has created some problems in recent years because moving the conference from continent to continent prevents some people from attending the conference every year, resulting in a lapse in their membership. There is now a way to join ISIF without attending the Fusion conference.

FUSION'99

FUSION'99 was the first fusion conference officially sponsored by ISIF. Daniel Zhu proposed FUSION'99 during FUSION'98 in Las Vegas. Again, Daniel wanted to move quickly and proposed himself as General Chair and Sunnyvale, California as

(From left) Jim Llinas, Mrs. Llinas, Ivan Kadar, and Galina Rogova.

the location. Rong wanted to solicit more inputs, but eventually agreed to serve as General Vice Chair and invited Pramod Varshney to be program chair. Since FUSION'99 was no longer related to Hamid Arabnia, who managed the logistics for FUSION'98, Daniel handled all the logistics of the conference and was compensated for his services. With the help of Rong Li, the conference had many co-sponsors, including several IEEE societies, the Army Research Office, and NASA Ames Research Center. In addition to a general chair, the conference also had an honorary chair, steering committee chair, and advisory committee chair to involve as many people as possible.

The conference was a great success with 203 attendees (up from 161 of FUSION'98) and 187 papers. More importantly, the conference provided the initial members for ISIF and the funds to support fusion activities such as conferences and the journal.

The plenary speakers were Professor Ren Luo (National Chung Cheng University, Taiwan), Dr. Ken Ford and Dr. Peter Norvig, NASA Ames Research Center, USA, and Dr. Franklin White, SPAWAR, USA. A meeting was held with Professor Luo to discuss cooperation with the IEEE International Conference on Multisensor Fusion and Integration (MFI), but no concrete actions resulted from the meeting.

JOURNAL OF ADVANCES IN INFORMATION FUSION

During FUSION'98, some attendees discussed the possibility of starting a journal on information fusion. Belur Dasarathy surprised everyone by announcing that he was starting a new journal called *Multi-Sensor Information Fusion* with Elsevier Science, with him as the editor in chief. After the conference, Belur submitted a proposal to ISIF to adopt *Information Fusion* as the official journal. The benefit to ISIF would be a discounted subscription that would be added to the membership dues. However, ISIF wanted to retain some editorial control. These difficulties were not resolved, and Elsevier's *Information Fusion* journal remains separate from ISIF, which in time started the *Journal of Advances in Information Fusion* (JAIF).

Oliver Drummond (2nd from left), and Shozo Mori (between Rong Li and Daniel Zhu).

ISIF AFTER FUSION'99

With the members from the attendees of FUSION'99, the first election of the board of directors was held in fall 1999. The board for 2000 consisted of Yaakov Bar-Shalom, Pramod Varshney, Mark Bedworth, James Llinas, Erik Blasch, Chee-Yee Chong, Belur Dasarathy, Alfonso Farina, and Dongping (Daniel) Zhu. The officers were Yaakov Bar-Shalom as president, Chee-Yee Chong as secretary, and Erik Blasch as treasurer.

Daniel Zhu had hoped that ISIF and the fusion conferences would help him grow his business. Since the direction of ISIF no longer aligned with his business area, he lost interest in ISIF and did not attend Fusion 2000 in Paris. He completely cut his tie with ISIF in 2001.

Except for Belur Dasarathy, several other initial board members continued to be active in ISIF. Pramod Varshney was president in 2001, Yaakov Bar-Shalom again in 2002, X. Rong Li in 2003, and Chee-Yee Chong in 2004.

EPILOG

ISIF evolved naturally over the ensuing years, gaining new members with each FUSION conference and naturally new leadership as well. It is almost 20 years since the founding of ISIF, and its early years are not well known to the current membership. The challenges faced by those who recognized the need for an information Fusion community and founded ISIF in response to that need are outlined in this short note.

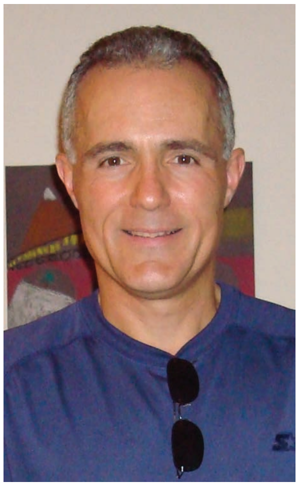
REFERENCES

1. Bar-Shalom, Y., and Tse, E. Tracking in a cluttered environment with probabilistic data association. *Automatica*, Vol. 11, 5 (Sept. 1975), 451–460.
2. Morefield, C. L. Application of 0-1 integer programming to multitarget tracking problems. *IEEE Transactions on Automatic Control*, Vol. AC-22, 3 (June 1977), 302–312.
3. Reid, D. An algorithm for tracking multiple targets. *IEEE Transactions on Automatic Control*, Vol. AC-24, 6 (Dec. 1979), 843–854.
4. White, F. E., Jr. A model for data fusion. In *Proceedings of the 1st National Symposium Sensor Fusion*, Vol. 2, 1988.
5. DSTO (Defence Science and Technology Organization) Data Fusion Special Interest Group, Data fusion lexicon. Department of Defence, Australia, Sept. 1994.
6. Luo, R. C., Lin, M. H., and Scherp, R. S. Dynamic multi-sensor data fusion system for intelligent robots. *IEEE Journal on Robotics and Automation*, Vol. 4, 4 (Aug. 1988), 386–396.

7. Nii, H. P., Feigenbaum, E. A., Anton, J. J., and Rockmore, A. J. Signal-to-symbol transformation: HASP/SIAP case study. *AI Magazine*, Vol. 3, 2 (1982).
8. Ng, K.-C., and Abramson, B. Uncertainty management in expert systems. *IEEE Expert*, Vol. 5, 2 (Apr. 1990), 29–48.
9. Aggarwal, J. K. *Multisensor Fusion for Computer Vision - Proceedings of the NATO Advanced Research Workshop on Multisensor Fusion for Computer Vision,* Grenoble, France, June 26–30, 1989*,* NATO ASI Subseries F, 1993.
10. Libby, V., and Kadar, I. (Eds.). *Proceedings of SPIE Signal Processing, Sensor Fusion, and Target Recognition,* Vol. 1699, 1992.
11. Aggarwal, J. K., and Nandhakumar, N. (Eds.). *Proceedings of SPIE Sensor Fusion and Aerospace Applications Conference,* Vol. 1956, 1993.
12. Wald, L. An overview of concepts in fusion of earth data. In *Proceedings of the EARSeL General Assembly*, Lyngby, Denmark, June 1997.
13. Pohl, C., and Van Genderen, J. L. Multisensor image fusion in remote sensing: concepts, methods and applications. *International Journal of Remote Sensing*, Vol. 19, 5 (1998), 823–854.
14. Hall, D. L., and Llinas, J. An introduction to multisensor data fusion. *Proceedings of the IEEE*, Vol. 85, 1 (Jan. 1997), 6–23.
15. Daniel Zhu biography. Available: http://www.zaptron.com/china/members/zhu/

BOB LYNCH, 1960–2015

We bring some sad news for the ISIF community: On August 14th at about 2:30AM we lost a great friend, Bob Lynch.



Bob in a relaxed moment with his family.

For those who don't know, Bob was diagnosed with cancer in 2010. Bob's positive attitude, his enthusiasm, his good humor and optimism: these were how he was a great researcher, mentor, teacher and coach. And these were also how he approached his disease; he let all of us believe that each piece of news about his health was a positive one. So even for those of us who did know of Bob's battle with that horrible disease, his passing was a true shock. We admire him ever more as we learn more about his fight.

Bob was born in Albany NY, and brought up by his mother and grandmother. College was not the local norm, but Bob's determination nonetheless brought him to prestigious Union College in Schenectady NY, where he earned his BS and MS in electrical engineering. A fresh engineer, he opened his career at IBM in 1984, and six years later moved to the Naval Undersea Systems Center in New London CT. NUSC became NUWC, and Bob stayed, for more than 21 years, working on many signal processing applications: sonar, pattern matching, ATR, data fusion, image processing and even electronic watermarking. Bob left NUWC in 2013 and has since been growing his consultancy business.

Bob got his doctorate in 1999 after some clever and principled work about Bayesian machine learning and feature reduction. Bob cared very deeply about the field: he continued writing papers (64 are recorded on scopus) that developed his ideas ever more thoroughly. He patented his algorithms and worked passionately with interested colleagues in a number of sites: Pennsylvania, Montana and New Mexico. Bob wanted his ideas applied and used; and they were, they worked quite nicely.

One of the tightest applications for Bob's ideas was data fusion: Bob had come up with an extremely effective way to *fuse* opinions from different sources even when their levels of expertise and overlap were unknown. So, naturally, Bob entered the FUSION community, which probably had no idea what was coming.

Bob was a tireless contributor to our Fusion society: session chair, ISIF Fusion 2009 General Co-Chair (Seattle, with Chee-Yee Chong), ISIF Webmaster, ISIF VP of Communications, ISIF Board Member, Managing Editor of ISIF's JAIF. Bob played a key role in ISIF's flourishing. For example: Bob single-handedly pushed – and pushed hard enough – with Elsevier to get JAIF "indexed" on Scopus, meaning that JAIF now is recognized in the academic tenure process. JAIF is growing, and Bob is part of the reason that is happening.

Bob at FUSION 2009 (he was General Chair) sharing a moment with Roy Streit.

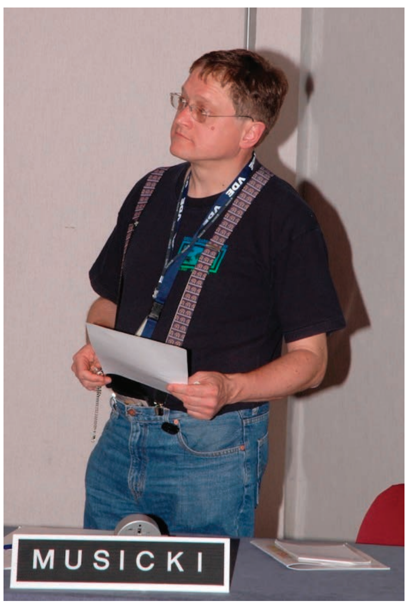
Bob loved to contribute. He loved to teach. He was delighted to encourage students and junior co-workers – and the athletic teams he coached.

He leaves behind his wife Cheryl and two sons Bobby Jr. and Ryan. And he leaves behind many of us who miss him very much.

DARKO MUŠICKI, 1957–2014

Quite unexpectedly for most of us, the information fusion community lost Darko Mušicki, one of its pioneering personalities, on June 8, 2014, in Ansan City, Korea. Mušicki, born on April 2, 1957, in Belgrade, Serbia, not only was pushing the frontiers of research in our rapidly evolving branch of applied science but also generously shared his knowledge with a new generation as an academic teacher, most recently at Hanyang University, Korea. Many of us have lost a warm-hearted, humble, inspiring colleague and friend who enthusiastically shared his ideas and immensely loved lively discussions.

Mušicki's posthumous papers had to be presented by others. This clearly shows how rapidly Mušicki was snatched from the middle of his life as a passionate researcher. His last paper, "Generating Function Derivation of the IPDA Filter," written by himself, Taek Lyul Song, and Roy Streit, deals with a hot topic in our community. This paper builds on Mušicki's careful analysis and evaluation of the integrated probabilistic data association (IPDA) filter and its multitarget variants as he was beginning his exploration of point process and random set methods for tracking filter design. The paper was presented by his personal friend Roy Streit at the ISIF/IEEE Workshop on Sensor Data Fusion in Bonn on October 9, 2014. Mušicki had been looking forward to coming back to this workshop in Germany, this "little sister" of the grand Fusion conferences, since he stayed in Germany for an extended research visit at Fraunhofer Institute for Communication, Information Processing and Ergonomics in 2007.

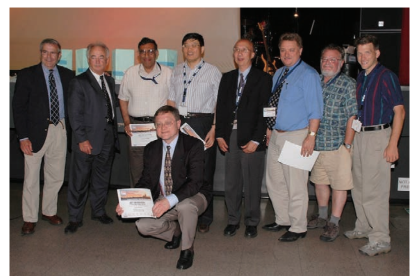


Mušicki as he was known to most of us—presenting at Fusion 2008 in Cologne, Germany.

Mušicki's work with his German colleagues is an example that highlights his attitude as a researcher who combined mathematical skills with proven sense for practical engineering solutions to solve problems in emitter location, a research area to which he contributed many papers in his career. By properly approximating complicated probability density functions, he effectively fused measurements of time and frequency differences of arrival for mobile intermittent emitter geolocation and tracking. Mušicki's work laid a sound theoretical foundation for the development of practical state-of-the-art algorithms in these applications.

Mušicki received his B.A. (1979) and M.S. (1985) degrees in electrical engineering from the University of Belgrad, Serbia. A university document calls him "the best student of his generation" and "the first student in the history of the Department to graduate one year before target date." This exceptional young engineer proved his pioneering personality while taking the opportunity to immigrate to Australia when the Iron Curtain was lifted. There he received his Ph.D. degree in 1994 from the University of Newcastle. Mušicki was a principal research fellow at the University of Melbourne, Australia, before he joined Hanyang University in 2010 as a full professor. Research and teaching were for him two sides of the same coin—he loved his students, and his students loved him.

Mušicki's research interest were in the core of our community, covering topics such as multiple-target tracking, classification, nonlinear estimation, emitter geolocation, fusion in distributed wireless sensor networks, resource allocation, and applications for radar and sonar. He wrote many articles in archival journals such as *IEEE Transactions on Aerospace and Electronic Systems, IEEE Transactions on Automatic Control,* and *IEEE Transactions on Signal Processing; IET Radar, Sonar and Navigation;* and *Automatica.* In 2011, he cowrote the well-established textbook *Fundamentals of Object Tracking,* published by Cambridge University Press.



Mušicki as ISIF president at Fusion 2008 in Cologne, Fusion's 10th anniversary, with former ISIF presidents (left to right): James Llinas, Yaakov Bar-Shalom, Pramod Varshney, X. Rong Li, Chee Chong, Dale Blair, Pierre Valin, and Erik Blasch.

As a member of the board of directors of International Society for Information Fusion (ISIF) since 2005, Mušicki shaped the profile of our community, especially when he served as ISIF president in 2008, when our young society celebrated its 10th anniversary at Fusion 2008 in Cologne, Germany.

Mušicki was a Christian. May all of us remember in our thoughts and prayers Darko Mušicki, his wife Dragana, his daughter Korana, and his son Luka.

Wolfgang Koch

ISIF VISION STATEMENT

The International Society of Information Fusion (ISIF) is the premier professional society and global information resource for multidisciplinary approaches for theoretical and applied INFORMATION FUSION technologies. Technical areas of interest include target tracking, detection theory, applications for information fusion methods, image fusion, fusion systems architectures and management issues, classification, learning, data mining, Bayesian and reasoning methods.

ISIF Journal of Advances in Information Fusion (JAIF)

The Journal of Advances in Information Fusion (JAIF) is the flagship journal of ISIF. JAIF is an open-access, peer-reviewed, semi-annual, archival journal published electronically and distributed via the internet. JAIF was founded in July 2006. The journal is indexed at SCOPUS, free for authors, and freely available for readers at http://www.isif.org/journal. Authors are invited to submit both regular papers as well as short correspondences describing advances, applications, and new ideas in information fusion, both theory and application. Authors of papers presented at our annual International Conference on Information Fusion are strongly encouraged to consider submitting expanded versions of their papers to JAIF. Manuscripts can be submitted at http://jaif.msubmit.net.

The International Conference on Information Fusion Reaches Its 20th Anniversary

X. Rong Li and Roy Streit

General Co-Chairs of FUSION 2017

The 20th International Conference on Information Fusion (FUSION 2017) will be held on July 10-13, 2017 in Xi'an, China. Sponsored by the International Society of Information Fusion, FUSION 2017 aims to introduce the latest information fusion related technical developments and academic research results. It will provide a platform for researchers and practitioners all over the world to network and discuss the most recent progress in information fusion related fields. All papers presented at the conference will be peer reviewed and all accepted papers will be included in the conference proceedings and IEEE Xplore, indexed by EI Compendex. Special awards and forums will also be provided to celebrate the 20th anniversary of the International Conference on Information Fusion.

Xi'an is one of the oldest cities of China, with more than 3,100 years of history. Since the 11th century BC, Xi'an had been the Capital of China for more than 1,100 years under 11 dynasties. As a famous symbol for the Chinese culture, Xi'an is the eastern terminus of the ancient Silk Road and home to the world-famous, more than 2,200-years-old Terracotta Warriors and Horses. Other historical sites include the more than 1,300-years-old Big Wild Goose Pagoda and the 14 km-long ancient city walls, etc., leaving you with unforgettable memories of Xi'an.

General Co-Chairs: X. Rong Li (USA), Roy Streit (USA)

Technical Co-Chairs: Brian La Cour (USA), Vesselin Jilkov (USA), Mieczyslaw Kokar (USA), David Salmond (UK)

Submission Deadlines: February 15, 2017 (special session and tutorial proposals), March 1, 2017 (regular papers)

Website: www.fusion2017.org