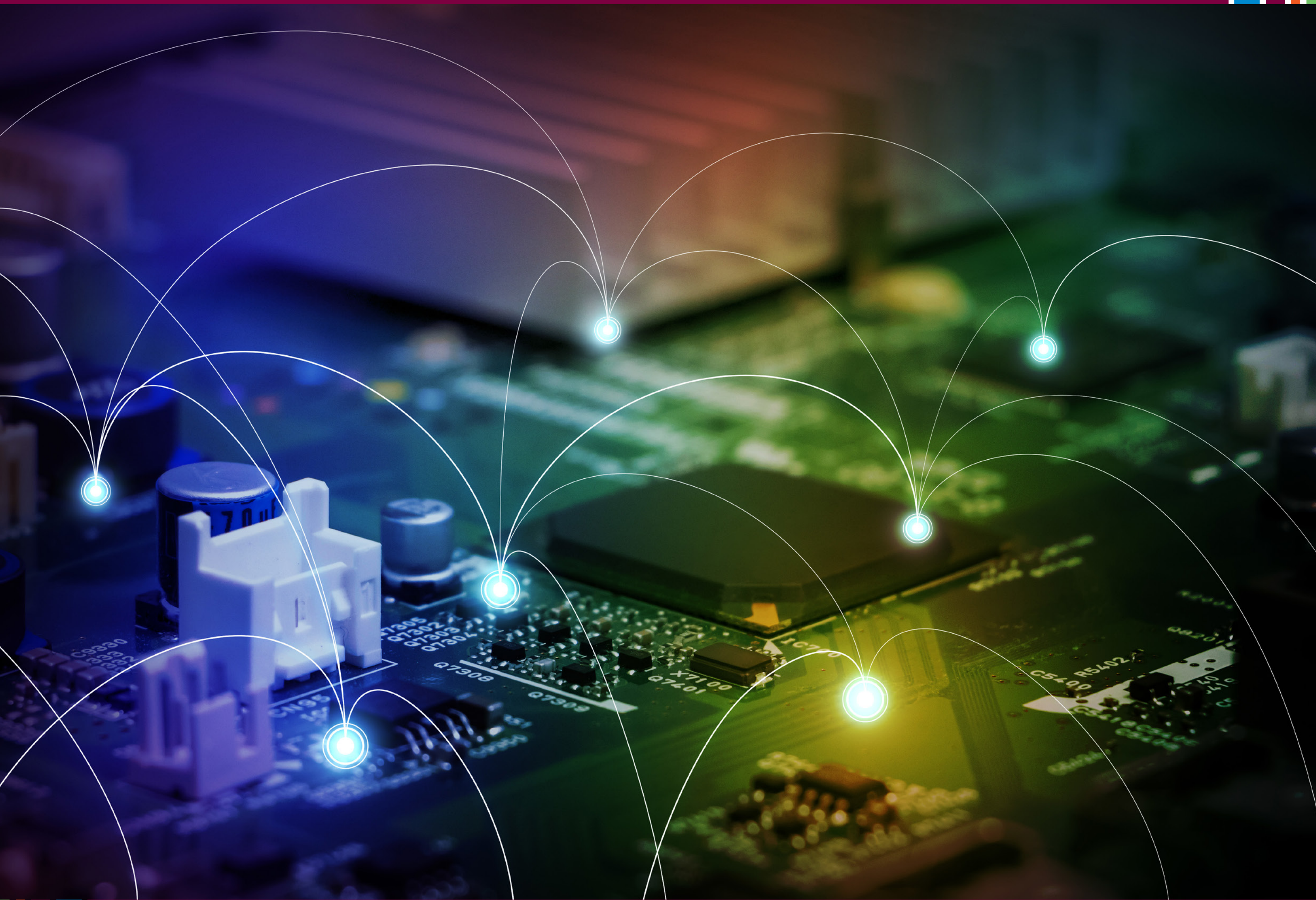
EPSRC
Investing in research for discovery and innovation

Engineering and Physical Sciences Research Council

New opportunities in signal processing



Report of an EPSRC workshop held on 7&8 February 2017 at the Mercure Holland House Hotel, Bristol

Summary

A number of challenges and opportunities were identified:

Challenges

- Beyond Big Data – linking data with context.
- Understanding and influencing human behaviour.
- Seeing round the corner.
- Systems signal processing.
- World sensing technology.
- Future living

Opportunities

- Linking mathematics, signal processing and applications.
- Privacy and security.
- Human-centric signal processing.
- Computational imaging.
- Sensing and communications challenges for signal processing.
- Novel technologies for signal processing.

In terms of outputs:

- There is a training need for this area, but it needs a holistic approach from acquisition to analysis.
- A call in the area is unlikely in the present climate.
- There is interest and value in setting up a network in the area.

Introduction

The pervasive nature of ICT presents challenges in communicating and transferring data between individuals, operators, machines and systems. Signal processing is at the heart of this revolution and the workshop was organised to explore some of the new and emerging opportunities and challenges. The two-day multidisciplinary workshop on New Opportunities in Signal Processing was organised by EPSRC's Information and Communications Technologies (ICT) theme brought together researchers in signal processing, the disciplines that feed into that research area and the application domains to which signal processing can be applied. The aim was to identify which new developments had the potential both to influence novel research in signal processing as well as in its applications.

The challenges

Over the period 2011 to 2016 EPSRC support for this research area had grown. However the focus of applications seemed to have narrowed. There is a well-coordinated activity in the defence sector resulting from the investment in 2013 in the £6 million University Defence Research Consortia. This means that whilst the priorities for defence-related research in this area have been the subject of scrutiny there has been no equivalent exploration of the opportunities outside of defence.

There seemed to be several areas in the non-defence sectors as well as societal challenges that offered opportunities and challenges. These include health, autonomous systems, robotics, and the creative industries. Outside of the ICT there need to be links with other academic domains and there are opportunities for researchers to exploit techniques emerging from areas such as mathematical sciences, machine learning and data science which could have an impact in signal processing.

The Workshop

The workshop brought together researchers in this area in order to identify

- the new opportunities in Digital Signal Processing arising from:
  - developments in other disciplines, such as mathematical sciences, that could be applied to DSP
  - development in technologies that open up new application domains but whose deployment depends on novel signal processing solutions; and
- the strategies and priorities for researchers addressing the civil aspects of DSP, including meeting development opportunities offered by the Global Challenge Research Fund.

Participation was on the basis of expressions of interests. EPSRC was looking for expertise in a range a range of topics including:

- Communications signal processing in particular in relation to the Internet of Things, 5G and beyond
- Mathematics and statistics
- Data science (including formation and enhancement, representation and modelling, and, understanding from data)
- Machine learning
- Image processing and computer vision
- Visualisation and immersive technologies
- Psychoacoustic and visual perception
- Audio (music, speech, environmental)

Participants also had connections to application domains including:

- Healthcare (biostatistics, processing of medical data, data from sensors)
- Earth sciences and remote sensing
- Econometrics
- Robotics and autonomous systems

There was an opportunity for participants to showcase relevant research in a poster session.

The output will be a published report which will highlight the research opportunities to the broader community.

Setting the Agenda

Prior to the meeting participants were asked for their views on the challenges and the opportunities in signal processing. These were collected and grouped using the "Well Sorted" tool (**https://www.well-sorted.org**). The results set the agenda for discussions at the workshop.

What is Signal Processing?

The definition used was that adopted for the EPSRC Research Area of Digital Signal Processing (**https://www.epsrc.ac.uk/research/ourportfolio/researchareas/dsp/**):

Signal Processing is the theory, algorithms and architectures for processing data and signals and the information they carry (audio, video, image, speech, communication, sonar, radar, medical, sensor, graph signals, big data) for applications across science, technology and media. It includes the theory and techniques concerned with detection, estimation, coding, transmission, enhancement, analysis, representation, recording, reconstruction, transformation and interpretation of signals, data and information.

Keynote Talks

The meeting featured two scene-setting keynote talks. Rob Bowyer (McLaren Applied Technologies) outlined the challenges McLaren faced in developing and deploying technologies in a variety of application domains, not just automotive. Sofia Olhede (UCL) looked at the interface between mathematics and signal processing.

Rob Bowyer (McLaren Applied Technologies): "Signal processing: Challenges from our experiences in applying technologies that enhance our world"

- McLaren's vision: "To develop technology solutions that enhance our world"
- Approach: "To optimise people processes and complex systems" (to empower, not remove, the human in the loop).
- Five key themes for McLaren;
    - Motorsport (Teams and organisers, Drivers, Entertainment)
    - Automotive (Electrification, Autonomous, Connected)
    - Public Transport (Connected and Intelligent Train Platform)
    - Health (Digital Therapeutics, Human Performance, Adherence)
    - Strategic Partnerships (IoT, Industry 4.0)
- Particular signal processing challenges faced by McLaren;
    - Energy efficiency (Can we make DSP algorithms and architectures which require the least number of electrons to compute?), including;
        - Uptake in wearables and in future bioelectronics.
        - IoT and connected devices expected to scale massively.
        - Data centres expected to grow from current 3% of global electricity.
    - Robust Tracking (Can we create smart and robust tracking algorithms that use cheap sensors?), including;
        - Autonomous vehicles
        - Gait analysis (e.g for injury/illness detection)
        - Digital therapeutics
        - Mechanisms to manage sensor imperfections due to damage / manufacturing etc.
    - Low latency DSP (can we create a suite of 'sequential' algorithms appropriate for real time systems?), including;
        - Vibration health analysis/anomaly detection
        - Robotics
        - Ideally require recursive algorithms

- Anomaly detection (can we create robust signal processing algorithms to stitch together the ground truth?), including;
    - Data cleaning
    - Natural language processing
    - Feature extraction (speech/video processing)
    - Adaptation mechanisms
- Neural decoding (can we decode the nervous system?), including;
    - Treatment and diagnosis of organ and other diseases through neurostimulation and neurosensing in the central and peripheral nervous system.
    - Neurostimulation can upregulate or downregulate the immune system.
    - Tomography
    - Low signal to noise ratio.

Can it be done? Definitely!

Sofia Olhede (UCL): "Opportunities at the Interface of Signal Processing and Mathematics"

- Key opportunities at the interface of mathematics and signal processing include;
    - Networks/graphs
        - Networks are large and messy
        - Models do not always replicate real features
        - Algorithms for network models come with significant computational burden
        - Can we move beyond 'pretty pictures' and develop analysis methods which determine 'significance' or provable properties?
        - Handling temporal structure.
    - Functions on graphs
        - We often observe signals as functions on graphs e.g. fMRI/EEG.
        - Understanding must come from the topology of the graph.
        - Related to theory of spreading on graphs and theory of multiple time series.
    - Privacy preservation and anti-discrimination
        - Including concepts of privacy, fairness in classification (i.e. preventing discrimination) and transparency of algorithms (i.e. how can we 'break the black box' and rationally balance performance versus transparency).
    - Data governance
        - Current government interest e.g. from GOScience
        - Royal Society and British Academy project on data governance
        - IEEE project on Ethical Considerations in Artificial Intelligence and Autonomous Systems.
    - Tensor-valued observations
        - Networks in time can also be viewed as a tensor problem.
        - There is no unique tensor decomposition but sparsity can be used.
        - Processing and modelling becomes more challenging
    - Spatio-temporal processing
        - Because of spatial recording, spatial analysis remains a problem.
        - Multivariate analysis remains a problem especially when acquiring at different resolutions.
        - Going from very local analyses (pixel/voxel based understanding), computational tractability quickly becomes an issue.

- Causal inference
  - Classical approach is to use temporal correlation, but can have causation without correlation and vice versa.
  - Another approach to collect all models that show invariance in their predictive accuracy and find the causal model among them.
- Multimodal data
  - Medical imaging often yields many types of signals and we can need to combine images, sounds and categorical observations.
  - Having many types of observations is increasingly becoming the norm with the surveillance society/ubiquitous sensing, giving rise to many problems in data linkage.

Discussion covered the emerging importance of temporal structure and dynamics on graphs as well as how to improve awareness of ethical/privacy considerations e.g. through ethics case studies or dedicated workshops.

Breakouts: Challenges and Opportunities

Based on the inputs to the Well Sorted exercise participants addressed a number of Challenges and opportunities. For each, participants identified the unifying themes, what would be different If the challenge were met, the disciplines that needed to be involved, the application domains and the status of the relevant parts of the UK research community.

Challenges

1. Beyond Big data: Does fidelity make you smarter? Context matters

Unifying

- data and context have equal contribution to make - not solely data driven
- context: prior/human knowledge/physical modelling/intent
- more data or good summary statistics not necessarily sufficient (avoids experiential need for data)

Different

- deals with data starved areas or cases where training data are not economic
- better environmental modelling
- underwater fibres – use to monitor shipping around harbours
- don't want speech synthesis to be too perfect – need to know it's a machine
- more efficient identification of road incidents (distributed acoustic sensing)
- Cost savings (distributed acoustic sensing)

Disciplines

- Phenomenologists
- sensor technology
- acoustics
- physics
- physical modelling
- culture, anthropology, sociology, business/economics
- psychology
- need to understand different measures of success
- need to bring in humanities and social sciences at the outset

Application

- speech modelling for less popular languages (lacking training data)
- transport
- environment
- music/art – improved creativity
- music tech: better classification systems eg moving into cultural appreciation

Status

- Very good in music tech
- Art investigation – limited activity in the UK
- Speech synthesis – internationally leading
- distributed contiguous sensing and underwater sensing

2. Understanding and Influencing Human Behaviour

Unifying

- inferring human behaviour
- human behaviour analysis
- enabling validation of SP through relevant datasets (currently limited or unavailable)

Different

- uplift in precision medicine eg better monitoring of progression of neurological conditions
- enable treatment at home – reducing strain on health care systems
- continuous passive monitoring with relevant feedback
- economic benefit – enabling more people to work
- improved rehabilitation
- develop pattern of life models for use in various contexts
- key challenge: human behaviour and fundamental issue across vast range of areas

Disciplines

Need to consider what signals need to looked at

Interaction between disciplines is important

Issues around privacy

- Medical sciences: physiotherapy, rehabilitation, neurology, psychology
- Sociology: behaviour of multiple individuals, common patterns, interactions, cultural acceptance
- sensors, signal processing, machine learning, video processing
- sensor fusion and multimodality of sensors
- vision/audio expert
- domain experts (eg sport, health) for access to real world data
- sports science, biomechanics, dance and music
- development of new sensors (low cost, wearable, non-intrusive

Applications

This kind of technology will be at the centre of everything we do with machines

- smart homes, cities, workplaces, factories
- healthcare, assisted living
- robotic
- security, crowd behaviour, crowd safety
- education

Status

Uk strong in creative industries, world leading in biomechanics.

Less strong on linking to applications

Analytics (sensors lagging behind) Wearables assisted living

still a challenge of taking into the wild

3. Seeing round the corner

Unifying

- imaging modalities
- computational methods
- healthcare
- neuroimaging
- multi dimensional and multitemporal sensing and imaging
- higher throughput for imaging and processing

Different

- scalable complexity ie dimension independent convergence
- exploiting uncertainty to aid implementation solutions
- view imaging devices

Disciplines

- optics, photonics (systems and sensors) + parallel computing and informatics (big image data)
- medicine (applications on clinical diagnostics

Application

- Environmental sensing
- medical and neuroimaging

Status not answered

4. Systems Signal Processing

Unifying

- cross coupling between different aspects of complexity
- the communication of data: storage is communication from the past to the future
- sensor to data storage to implementation: distributed complexity, co-dependent complexity.

Processing of physically separate datasets in parallel gives enormous data sets. How do we cope? don't have a strong enough set of design principles to tackle this problem efficiently. Data/comms/storage is a resource and the resources are distributed. The challenge is this is proliferating because of 5G and IoT. Need reconfigurability and security

Different

- Engineering signal processing systems with high performance and lower cost (energy, monitoring)
- Understanding of the trade-offs between storage, communications, computation, size, weight and power
- Ability to decouple energy – optimal design for specific points in the process.

Disciplines

- Data structures, storage, algorithms, processing architectures - different people so need to bring together
- Education of DSP system engineers

- Apply MODAF or other framework
- Computer/description language experts
- domain expertise
- comms expertise
- operational research
- security issues (esp of reconfiguring)
- data protection and ethics

Application

- Broad – anything to do with processing

Status

UK well placed as anywhere. This is global problem and there is no one leader – so potential to take the lead and influence standards if this is joined up.

ICAS 2019 in Brighton is opportunity to do something.

5. World sensing technology

Unifying

- sensing of physical systems and inference
- massive scale sensing
- inference, interpolation, prediction
- multimodal sensing
- sparse sensing
- uncertainty quantification
- multitemporal
- sensing through uncertainty
- good enough processing – no ground truth

Different

- Better understood environmental processes
- security of supply
- more efficient agriculture (water, fertiliser, planting) and more robust and efficient food production
- large scale/multi scale inference
- improved climate predictions

Disciplines

- exploiting domain knowledge of experts
- biology
- physics (photonic systems)
- chemistry (spectroscopy)
- geoscience, geophysics, earth sciences
- electronics (sensor design)
- environmentalists
- engineering
- maths, statistics

Application

- forest canopy modelling
- ice cap/flood/tsunami modelling

- animal population monitoring
- agriculture
- geohazards (earthquake, landslide, flooding)
- fluorescence microscopy,
- environmental sensing (hyperspectral)
- multi-spectral imaging

Status

Internationally string but needs consolidation/rationalisation

6. Future Living

Unifying

- signals for/from people
- sensors and networks in the wild
- human in the loop
- smart environments
- security and privacy
- heterogenous data and big data

Different

- Research needs to be ahead of public demand on security
- energy efficient and low cost eg energy harvesting
- balance between smart and secure (latency and reliability)
- verification and validation
- transfer of skills – extension of control as well as sensing
- Interoperability between IoT and internet of humans
- smooth handover of autonomy between system and machine
- systems that have human control
- flexible adaptable self learning technology
- voice controllable
- individual specific models
- robust to anomalies at multiple levels: graceful degradation

Discipline

- social sciences, psychology and design
- game designers (gamification?)
- more realistic test beds
- healthcare and community support professionals
- law, ethics, policy
- business management
- signal processing and machine learning
- optimisation and modelling

Application

- personalised preventative healthcare
- ambient assisted living (AAL)
- efficient energy use (home/city), smart grids
- transportation

- education, eg special needs

Status

- connected network – strong on provision but not scale
- Machine Learning (ML) – very strong
- future living in general – far behind
- Asian countries have easier access to data
- behind in large scale system integration
- behind in commercialisation
- pockets of excellence but not harmonised

Opportunities

1. Linking maths to signal processing and applications

Unifying

- synergy between graph theory and signal processing
- multimodal interactions: quantification of uncertainties
- distributed sensing, processing, fog computing
- non-stationary/time evolution
- data fusion

Different

- ability to deploy more and smaller sensors (fog computing)
- opportunity to understand why a well thought out solution doesn't beat a brute force one
- ask smarter questions (data-based, needs domain experts)

Disciplines

Maths, stats, physics

2. Privacy and security

Unifying

- privacy aware sensing (opportunity for SP)
- tied to anomaly detection/ integrating
- fairness, trust
- unique challenges in multiple streams of data

Different

- Algorithms impact on privacy in unexpected ways
- processing in encrypted domains
- building security into DSP
- embedding security into the physical layer
- interfering/meddling with sensor outputs

Disciplines

- Comms (physical layer security)
- statistics
- encryption
- groups working on privacy
- sensors

Application

- IoT
- Healthcare, assisted living
- smart homes, cities, transport (connected cars)
- Defence
- RAS
- autonomous vehicle
- aerospace (air traffic)
- energy, smart grids
- industry and manufacturing

Status

Unknown because of secrecy, but GCHQ strong. Not leading on signal processing and privacy. US lead on physical layer security for comms.

3. Human Centric Signal processing

Unifying themes

- human centric
- biomedical signals
- signals that aren't traditionally used for communication
- information fusion/uncertainty
- multiple sensors
- how signal is presented and used by human
- network behaviour (social)
- affective computing
- need real time, low latency
- all raise ethics/privacy concerns
- great commercial potential and economic benefit

What would be different

- personal healthcare
- improved outpatient monitoring
- biomechanical science applications
- improved preventative care (health)
- improved human-human communication through technology and human/machine interaction
- improved insights into motor control
- improved immersive systems
- improved indoor localisation technologies and opportunities (smart homes)
- geolocation aware sensors
- would arise ethical/privacy questions

Disciplines

- Sports science
- neuroscience
- psychology
- speckle computing/fog/IoT (tiny sensors that can communicate) – information/computer science
- ethnography
- health economics

Applications
- Robotics
- biomechanical sciences and link to neuro diseases
- sports science
- prosthetics
- rehabilitation

UK status
- heavily industry driven currently
- uni research focussed on systems
- some activity on printed sensors (on skin)
- need to link diverse range of disciplines and build capacity - UK probably has coverage in many aspects, but not adequately linked
- availability of data an issue (privacy issues and industry often won't share)
- product development difficult eg because people issues such as making the item non-intrusive.

4. Computational imaging

Unifying
- Acquisition, processing of images from different modalities
- broad view of image eg including seismic fields
- smarter data acquisition and impact on methodology - processing

What would be different
- disruptive – eg acquire whole light field in a camera and process afterwards – will change the way cameras are built
- seismic sensors/tomography
- Safer Autonomous vehicles – LIDAR – advances in sensors could enable imaging of scenes in real time
- Hybrid modalities – waves and fields – different experiments – technology producing images of diagnostic significance. hyperspectral – Would have application in other areas
- Microscopy – optimising with computational tools. Bringing together fluorescent microscopy researchers and low photon technologies to produce better microscopes
- Need to look at the system – holistic approach

Disciplines
- Optics, photonics, wave specialists to link to signal processing
- biologists (application domain)
- Need to link to communities who develop the technologies with the computational/SP community – working together, not in silos
- computer vision
- Too much driven by experiment with computation as an after thought

Application
- microscopy
- creative industries (eg sp for special effects)
- autonomous vehicles
- tomography

UK status
UK has strong, world-leading groups in this space in science, creative industries and computer vision. US is better at integration

5. Sensing and Communication challenges for signal processing

Unifying

- About system which acquire the signals
- sensor technologies that require methodology development
- communications aspects
- multi-level signal processing: individual devices to networks

Different

- ability to use data from an increasing range of sources whilst maintaining privacy
- less intrusive sensing
- more personalised sensing
- improved signal acquisition technology is implicit in these

Disciplines

- sensor physics
- electronic engineering
- battery tech/energy efficiency
- business schools/economics (avoid designing uneconomic infrastructure; consider commercial issues
- operational research/optimisation

Application

- Connects to implementation/deployment
- wireless sensing
- smart homes and assisted living – reducing complexities

UK status

Mixed picture – less strong on IoT sensors, strong in quantum, strong in processing

6. Untitled

Unifying

- machine learning
- big data: velocity, volume, variety (SP opportunities)
- Coupling SP with machine/deep learning
- understanding what is going on in ML algorithms

Different

- a single coherent framework integrating SP and ML
- a better understanding and theory of deep learning
- physical interpretability from ML algorithms
- compressed sensing to mitigate data storage issues
- data sets – opportunity or limitation
- computationally efficient representations
- inspiration from the types of representation in DL to advance SP
- curated datasets for challenges

Disciplines

- machine learning
- signal processing
- maths/stats
- subject experts producing the data

Application

- geophysics inc satellite arrays (remote sensing)
- earth sciences
- bioimaging datasets – going beyond manual
- geohazards (earthquakes, landslides, floods)
- medical generally – where 'understanding' of data is key (not rule-based)
- precision agriculture/farming

Status - not completed

7. Novel methodologies for signal processing

Unifying

- a focus on methodological developments inc maths, stats and machine learning
- Subsets:
- big data
- deep learning
- multi modal
- machine learning
- system characterisation
- a connection is trying to process more data
- sampling storage and compression aspects
- acquisition process – improvement

Different

- be able to solve more realistic problems
- more insight, better efficiency
- very broad set of methodological developments with wide range of potential impacts
- theoretical underpinning of big data – application to large datasets
- improved development time – quicker to implement algorithms
- easier adaptation of methodologies to applications
- tailor design of system to method of acquisition
- shorter timescale to insights, understanding
- moving beyond big data

Disciplines

- signal processing and machine learning
- information theory
- stats, maths
- learning theory, statistical machine learning
- electronic engineering, sensor design
- physics

Applications

- autonomous systems: multi modal sensors and a need to work in real time
- data acquisition – IoT

Status

UK very strong across these areas

Final Discussion

Plenary discussion focussed on summarising the key points from the meeting and what messages emerged for the wider community and EPSRC.

Q: What is the position of CDTs in this area?

- A: Not clear that there are any specific to the area but several in the areas of ICT and Mathematical Sciences are likely to have relevance.

Q (NB): Is one of the messages that there is a training need in the area?

- A: Yes, across signal processing and machine learning but also bringing in ethical and privacy considerations.
- A: Need broad engagement with related communities including, for example, data acquisition.
- A: Need a holistic approach which includes whole pipeline from acquisition to analysis.
- A: Mentioned CDTs not just from the training perspective but also because they provide critical mass.
- A: Perhaps a need for networking opportunities, bringing in sensor communities.
- A: Need to bring in all people in the pipeline.
- NB: Sounds like a network would be helpful so we would encourage people to self-organise to prepare an application through standard mode.

Q: Are there multi-centre CDTs – these would suit an area such as this?

- A: Yes, but can present management challenges especially when more than two institutions involved.
- Comment: If we're going to set up a network, ICASSP 2019 will be in Brighton. May be an important opportunity.

Q: Is a targeted call out of the question?

- NB: Couldn't do a call this year as already committed and in the current financial climate would be difficult to fund. In view of the increased emphasis on community led research, the need and scope for a call would ideally be identified by the network.

Q: What are the next steps for EPSRC?

- NB: Write up outputs and circulate to attendees in the first instance and then publish these and invite input from the wider community. See the output as more of a consultation than a report.

Q: How many people would be interested in establishing a network?

- A: [Show of hands] almost everyone.

Q: Is anyone involved in EUSIPCO? Could there be opportunities for satellite meetings?

- A: Yes.

Annexe 1: Well Sorted Reports

The following are the Challenges and Opportunities identified by participants prior to the meeting and which formed the basis of the discussions.

1. Challenges

Colour	#	Title	Description
	1	Smart homes/cities	Emerging applications for smart homes and smart cities include sound recognition for security, urban planning, acoustic ecology and ambient assisted living. Challenges include data collection/privacy issues, context adaptation, and overlapping sources.
	2	Smart Home/Assisted Living	As well as home assistant devices e.g. Amazon Echo/Alexa, there is potential for intelligent monitoring and assistance devices based on signal processing from visual, audio and other time-sequence data around the home.
	3	Internet of Things	Enabling devices to collect an exchange data and to calibrate autonomously will require new signal processing methods where calibration and data estimation is done jointly.
	4	Security	With more and more sensing devices being attached to IoT platforms, the potential for security breaches has never been higher.
	5	Analysis of social media data	The social sciences has been heavily involved in the development of network analysis; the ubiquity of social media and the new availability of such (large/complex) data provide challenges in terms of extracting information from them.
	6	Social Media Analysis	Social media can be processed just like any sensor. Improving detection performance is important, as is minimizing the generation of false alarms and extracting as much information as possible. Doing so without large amounts of computation is challenging.
	7	Big data time- varying/ unstructured/social analysis	Generating big data analytics in different frameworks, dealing with time varying, unstructured or social data, e.g., audio/visual, social, IoT, and using them to make predictions or understand trends greatly depends on advanced efficient SP/ML approaches.
	8	Mobile phone app data	The social sciences has been heavily involved in the development of network analysis; the ubiquity of social media and the new availability of such (large/complex) data provide challenges in terms of extracting information from them.

Colour	#	Title	Description
	9	Agri-Science	"Agricultural science is a broad multidisciplinary field of biology that encompasses the parts of exact, natural, economic and social sciences that are used in the practice and understanding of agriculture." – Monitoring
	10	Environmental Sensing	Lidar is an acknowledged tool for extracting spatial structures from 3D) scenes coupled with passive multispectral and hyperspectral images extract spectral information about the scene which can provide info on the health of the canopy
	11	Drone data	Drones seem to be becoming more popular. There is a potential that data challenges could present themselves in terms of amalgamation of spatio-temporal data from different sources with different degrees of granularity.
	12	Defence Sector and Remote Sensing	Multiple data modalities are also of interest in the defence sector, particularly in remote sensing applications where emerging problems involve fusing visible images, hyperspectral images, and LIDAR. These also calls for new signal processing approaches.
	13	Knowing about implementations	Experts in signal processing may have little knowledge of implementation issues. Parallel and other computing models are ubiquitous (GPUs, Apache Spark), but when devising signal processing, we rarely consider these models.
	14	Fog computing	Increasingly more and more analytics are being moved from the cloud closer to the source. This will inevitably mean more processing on low end devices, possibly limiting the types of processing that can be done.
	15	Data storage	A typical smart city may have tens of thousands of sensors, producing many Tbs of data. What needs to be stored? How should it be?
	16	New abstractions	To tame the increasing complexity of signal processing, we may devise new approaches to exploit graphical representations (UML analogy for processes) of problems as well as (re)using and standardazing signal processing modules.
	17	New data structures	Presently, signal processing algorithms have been developed for numbers organized in matrices (vectors, sequences). Working with more complex (and heterogeneous) data structures (tensors, graphs) with corresponding math apparatus would be useful.

Colour	#	Title	Description
	18	Trends vs. outliers	Large datasets with high transmission rates mean it is essential to quickly detect significant trends but also recognise outliers of interest. How can signal processing identify them fast enough to cope with data rates?
	19	Low Complexity Sensing	The growth in devices and systems in the IoT with a myriad of applications ranging across home, health and systems monitoring offers an opportunity for the design of low-complexity sensing algorithms to enable on-board processing
	20	Rapid integration of data from distributed sensors	Distributed sensors and swarms of autonomous instruments need to communicate but are slowed down by channel bandwidth. Can innovative processing approaches reduce signals to their most relevant characteristics, without sacrificing too much quality?
	21	Modelling from sparse measurements	Sensors cannot measure physical processes at all locations, and sparse data needs integrating into local and regional models, without excessive computation loads. How can multidimensional processing address this?
	22	Music technology	The large amounts of music data available (audio, video, scores and images) require signal processing technologies able to combine these different modalities and extract high-level semantic information (benefiting both the economy and society).
	23	Audio Wave Field & Light Field Coding	For fully immersive media experience, sound and visual sources should be accurately recreated from any user position in the scene. Audio Wave Field and Light Field Coding are complementary tools to achieve next-generation Cinematic VR experience.
	24	Speech synthesis	The arrival of wavenet, that takes as input the raw speech signal has introduced a new era where the importance of feature extraction is challenged. Such end-to-end systems have emerged also for emotion classification or music information retrieval.
	25	Distributed Acoustic Sensing	A disused fibre can become 5000 microphones running at 2KHz. We need to extract the information present from this new kind of sensor. If we can do so, then the world's fibre optic backbone will become its nervous system.

Colour	#	Title	Description
	26	Art Investigation, Restoration and Preservation	There is currently interest in the use of multiple imaging modalities to support the non-invasive and non-destructive technical study, restoration and preservation of art-work. This calls for new multi-modal signal analysis and processing approaches.
	27	Low-Photon and Quantum Imaging	Imaging based on acquiring information with single individual photons or particles has application in medical (non-invasive imaging), underwater (for UAVs) and environmental applications (hyperspectral).
	28	New Sig Proc Methods for Hyperspectral Image Data	New applications in hyperspectral imaging, combined with cheap devices, lead to high volume and complexity of data. This requires new signal processing tools to extract and process the key features in real time.
	29	Brain connectivity	Brain imaging systems (fMRI, MEG) generate data sets with large number of channels. Need signal processing tools to characterise these signals and interactions between signals.
	30	Mesoscopic scale neuroimaging	Mesoscopic two photon microscopy - recent imaging of functional signals at sub cellular resolution, simultaneously across nearly the entire surface a mouse cortex, using a mesolens. This necessitates new scalable signal processing approaches.
	31	Miicroscopy for large-scale 3D neural recording	Understanding the functioning of the brain requires instruments capable of recording many neurons simultaneously and at high speed. This can be achieved only by combining hardware design with image processing methods and methods for data inference.
	32	Precision medicine	Precision medicine is to arrive at the optimal clinical decisions based on the data from disparate sources. This is particularly important for the elderly who usually have multiple complications.
	33	Personalised Healthcare	Use of personal/smart devices for monitoring an individual's activity and health related signals. Data sets can be long, unconstrained, irregularly sampled, with different characteristic time scales. Need for new techniques to quantify this data.
	34	Healthcare Sector and Medical Imaging	Multiple imaging modalities such as MRI and PET of extreme interest in the healthcare sector, most notably in medical imaging applications. This calls for new joint signal acquisition, analysis and processing algorithms to support these applications.

Colour	#	Title	Description
	35	Prediction and disgnosis of Alzheimer's	While neuroimaging has been applied to study Alzheimer's (AD), no single modality can depict the full picture of AD, since each one has its own advantages and limitations. The challenge here is to find the underline associations between them.
	36	Segmentation from medical images	Accurate delineation of boundaries remains crucial for image-guided surgery/therapy/drug administration. However, because multi-factors are at play, each algorithm presents both proc and cons. Deep learning led approaches appear to be promising.
	37	Medical image/environmental/ clinical data analysis	Adaptive SP/machine learning methods can fuse different data modalities (imaging, environmental, clinical) and domain knowledge, producing effective personalized diagnosis/assessment, e.g., of neurodegenerative diseases, or of patient/elderly health.
	38	Tomography	Tomography is to this day restricted to produce a quantitative image without any diagnostics on the credibility of the image apart from the data fit error. Statistical methods can remedy this through producing a UQ map, alas they are cumbersome in HD.
	39	Panomics	We need to process biological data in a way that is both rigorous but which also scales up to be able to consider enormous datasets. Current solutions only offer one or the other o these. We need a fast alternative to MCMC that loses none of its accuracy.
	40	Augmented feedback for skill learning	Learning new motor skills can benefit from providing perceptual information about motion signals to learners, but it is still a challenge to identify the optimal mapping structure between motion signals and perceptual displays.
	41	Recovering qualities of human movement	Although humans can perceive a great deal of information from the movements of others (gender, emotion, intentions, etc.), reliably extracting this information automatically from motion sensor signals is still a substantial challenge.
	42	Behaviour analysis and human machine interaction	Multimodal adaptive signal processing, based on DNNs, transfer learning and knowledge, can analyze user behaviors in various contexts or in-the-wild, assess the quality of HCI systems & improve effectiveness in recommender/financial/ advertising systems.

Colour	#	Title	Description
	1	Developments in Machine Learning	There is much research being done in machine learning, developing pragmatic practical algorithms for computationally difficult tasks. Signal processing in general could benefit from more synergy between the two disciplines
	2	Integrating Machine Learning and Signal Processing	A typical pipeline is to perform some signal processing to create "features", and then use your favourite machine learning algorithm. However both of these can be cast as probabilistic models, and could be combined into a single framework.
	3	Convergence of machine learning and sig proc	Increasing amounts of signal processing involve machine learning methods, most recently deep learning. How can we ensure that the best machine learning research is combined with the best signal processing research?
	4	Deep Learning	This topic has already made a big impact in many areas, such as speech recognition and face recognition but there are still many areas in signal processing where is could be applied in the future.
	5	Machine Learning	Autonomous or remote systems need to sift through large amounts of data and complex signals. Can machine learning be used to highlight the most important parts, or decide which should be stored/ transmitted?
	6	Deep Learning	Deep learning (DL) neural networks have shown potentials in processing signals, in particular, images, overtaking the other machines learning approaches.
	7	Machine Learning	Recent advances in machine learning and AI have created a methodological shift in signal processing research: examples include feature learning, deep architectures and recent probabilistic machine learning approaches.
	8	Machine Learning	Machine learning can be used either in sequence or in parallel with signal processing. An example of the first case is extracting features and then doing classification on them. An example of the second case is feature learning using neural networks.
	9	Deep neural architectures and transfer learning	Deep neural architectures are the state-of-the-art in extracting rich features from big data & following time varying data. Transfer learning is the main method to apply trained networks in new cases, which is of great significance for signal processing.

Colour	#	Title	Description
	10	Data driven and knowledge based signal analysis	The major drawback of (deep) neural networks is that it is not easy to explain how they derive their decisions. Interweaving DNNs with knowledge representation/ ontologies, or extracting rules from them is of great significance for achieving this in SP.
	11	Optimal sensing for machine learning	In many cases, decisions are made on sampling rates and other parameters based on practical reasons. However it might be that if the end goal, these could be optimised for better classification accuracy (or other metric), and in fact could be adaptive.
	12	Bayesian Dictionary Learning	The goal is to decompose signals into simpler basis functions and the reconstruction coefficients, learning both. Current approaches require noise levels to be determined via heuristic methods, and are generally fail in the cases of corrupted/missing data.
	13	Big Data	This is the first choice without any doubts. We are only going to produce more data in future, and will need a lot of expertise to understand how to use it well.?
	14	Big Data	Extracting useful information from huge amounts of heterogeneous data presents a serious problem for signal processing.
	15	Signal Processing for Big Data	Given the growth we experience on data, discuss the models and SP-related tools and their promise for significant impact on many traditional but also in various emerging large-scale applications
	16	Beyond Data Science	Adding rigor to the hype: Big Data and Data "Science" are currently doing well targeting the low-hanging fruit. There will (hopefully!) be a time to move in from the sidelines and get actively involved in setting an agenda that involves more innovation.
	17	Transients in extremely large datasets	Large datasets are generated in many fields (e.g. deep-sky astrophysics, nuclear physics, marine acoustics). Some events (e.g. Gamma-Ray Bursts, acoustic emissions) will be extremely short in fluctuating backgrounds. How can they be detected accurately?
	18	Better verification/validation	A key advantage of having lots of data is that real-world methods can be more systematically verified with robust one time out-of-sample tests. The are opportunities in creating new test methodologies and concisely reporting multi-dimensional performance.

Colour	#	Title	Description
	19	Multivariate time series analysis	Functional interactions typically use bivariate methods. Many data (neurophysiology, neuroimaging) have 100s of channels, need new tools to capture interactions. Partial correlation offers one approach but needs to be scaled up and alternatives considered.
	20	Non-stationary analysis	More realistic experiments can generate non-stationary data. Wavelets becoming more commonly used, but often in bespoke manner, needs further developmental work and consideration of alternative methods e.g. from field of synchronization, others...?
	21	Non-linear time series analysis	Much of the time series repertoire assumes linearity, there is a need to develop non linear analysis for more complex data sets. Higher order moments offer one approach, but extensive applications are lacking, and other approaches need to be looked at.
	22	Multi-resolution statistics	High sampling rates and long periods of operation mean large datasets can contain several levels of information, which pertinence is governed by the scale of measurement. How robust are they? Can parallel fields offer similar approaches?
	23	Uncertainty quantification	UQ in large-scale Bayesian inference problems and development of simulation algorithms with dimension independent convergence rates. Examples in inverse problems, tomography.
	24	Synergising Stats, Engineering and Comp Sci	There is only one world and yet different communities currently see it through such different glasses that they can't communicate. The mutual disrespect is denied by many while "interdisciplinary" is used as a passport to winning grants. We can do better.
	25	Optimal experimental design	Optimal experimental design in the context of estimation problems has been mostly addressed in the context of compressed sensing. Opportunities arise in collecting optimal data sets by utilising statistical a priori available information.
	26	Graph and Network Theory	Data stored and shared in real-world complex systems can be modelled as signals residing on the vertices of graphs. In order to extract information from data residing on graphs it is important to combine graph theory with signal processing methods.

Colour	#	Title	Description
	27	Randomised algorithms in asynchronous processing	The availability of large data sets in inference and parameter estimation problems poses several challenges for "all-at-once" optimisation schemes. Randomised algebra could provide effective alternatives be replacing calculations with estimations.
	28	Mathematics and Multi-Modal Data Processing	The field of mathematics can contribute with insights about how to construct novel mathematical representations for multi-modal data – including Euclidean and non-Euclidean ones – that can underpin the development of new signal processing algorithms.
	29	Information Theory and Multi-Modal Data Processing	The field of information theory can lead to new ideas about how to quantify the information content of multi-modal data that can be used as a proxy to develop nearly-optimal multi-modal data sensing, analysis and processing algorithms.
	30	Statistics and Multi-Modal Signal Processing	The fields of statistics – plus the fields of machine learning and learning theory – can also contribute with insights about how to learn multi-modal data representations from data to underpin the development of new signal processing algorithms.
	31	Signal processing for multi-modal perception	There are many under-explored opportunities to research ways of processing multiple signals for multi-modal perception (e.g. audio-visual-haptic displays) in human-machine interaction. Different signals may be best perceived by different senses.
	32	Audio-visual and multimodal signal processing	New machine learning methods (e.g. deep learning) mean that there are parallel challenges in different modalities, e.g. vision or audio, that tended to be the focus of different groups. How can we work together across these modalities?
	33	Algorithmic Complexity and System/Sensor Design	Need more systematic perspective on algorithm complexity currently it is at the level of an art), resulting in potentially dangerous gap between "real" signal processing as implemented industry. Need to integrate SP algorithms design in the system design.
	34	Distributed Sensing and Processing	Distributed sensing and processing (i.e. sensor networks) e.g. where mobile platforms are increasingly able to gather large volumes of data and process some of it onboard with limited communication bandwidth to communicate with other sensor nodes.

Colour	#	Title	Description
	35	Autonomous systems	Automation will be high on the agenda in coming years. The autonomous systems are only as good as their design which, due its inevitable failure to reflect all aspects and scenarios, may have many undesirable side effects.
	36	Acoustics	Signal processing and acoustics often address similar problems, however there is limited interaction between the two. Relevant topics in acoustics for signal processing include acoustical measurement, instrumentation, and physical modelling.
	37	Distributed Acoustic Sensors	Hardware exists to turn a 50km long disused fibre into a distributed array of 5000 microphones each running at 2KHz. We could, for example, monitor roads using such sensors, if only we could extract all the information present from the data.
	38	Intelligence for the Internet of Things	Internet of Things devices are very power constrained. New sparse and adaptive sampling can overcome this; as can on-board processing reducing communication overheads. There are opportunities for increasing the range of functions possible 'on-board'.
	39	Internet of Things	"The interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data." Major challenges to signal processing - dimensionality, distributed processing, security.
	40	IoT sensor/biosensor network	IoT technology will soon integrate different sensing/ communication techniques (such as visible light communications). New signal processing techniques will be sought after for solving energy efficiency problems in such networks.
	41	Tactile Internet	"This brand new technology demonstrated is based on the one-millisecond latency capability of 5G, which is a critical network performance index to materialize Tactile Internet." – Major challenges – handling new modalities and latency.
	42	Computer chip architecture/ GPU technologies	GPUs etc allow processing to be done using simple mathematical computations in parallel, which could provide efficiency in online signal processing applications.

Colour	#	Title	Description
	43	Quantum information and sensing protocols	Aspects of quantum mechanics are finding application in various technologies. For instance the strong correlations present in entangled photons has use in high-performance imaging systems. What future signal processing challenges or opportunities exist?
	44	Energy analytics	The deluge of energy (electricity and gas) data from the smart grid at high resolutions offers a massive opportunity in disaggregation, improving appliance efficiency, human behaviour, assistive living (activity recognition).
	45	Earthquake monitoring caused by human intervention	Understanding the side-effects of human activities or industrial processes such as mining, geothermal operations or underground gas storage is growing in importance especially with the possibility of monitoring resulting small scale earthquakes signals.
	46	Emerging commercial opportunties	Many opportunities are emerging that rely heavily on signal processing and efficient pipelines. How do the size and cost and speed of such systems influence the future of signal processing?
	47	Privacy and security	As the systems are getting more complex and smarter, embedded signal (and data) processing algorithms will impact these aspects at many different levels.
	48	Privacy and security in signal processing	Signals can contain much private information about people, e.g. home security cameras, medical or fitness monitors. How can we preserve personal privacy and security of access to these signals while still allowing signal processing?
	49	Signal processing for cybersecurity	Identify signal processing approaches to protect information in both communications networks as well as distributed systems.
	50	Signal Processing for optical communications	Maximising the nonlinear channel capacity and delivering ultra-high speed optical communication systems.
	51	Computational imaging systems	A variety of novel imaging systems are emerging from research and into applications. How do these systems make use of signal processing and what impact does it have on next generation imaging technology?

Colour	#	Title	Description
	52	Computational Imaging	In computational imaging, computation (signal processing) plays an integral role in the image formation process. In the context of microscopy, higher image quality can only be achieved by combining tools from optical design and image processing.
	53	Computational imaging systems	A variety of novel imaging systems are emerging from research and into applications. How do these systems make use of signal processing and what impact does it have on next generation imaging technology?
	54	Computational Imaging and Sensing	Advances in sensors offers challenges in applications in defence, medicine etc e.g. in low-photon count/quantum imaging; it is a combined question of sensing and reconstruction and often high-dimensional with opportunities for codesign of systems.
	55	Image processing and computer vision	For human behavior understanding and intelligent system.
	56	Smart techniques for reducing image throughput	There is a grand challenge in biomedical image data brought by rapid advances in image sensors, microelectronics and imaging techniques. Smart imaging processing techniques would reduce the data throughput and acquisition, bringing significant impact.
	57	High frame rate 3D ranging	Recent advances in image sensors have enabled rapid developements of camera systems for 3D ranging, especially for security applications. With smart imaging techniques, such imaging systems are more likely to be widely adopted due to reduced cost.
	58	Human Activity Recognition in Video	The field of human activity recognition grew significantly in the last ten years, but the state of art in action and activity recognition is still significantly below the accuracy required for real world applications.
	59	Multimodality Neuroimaging	Finding biomarkers from multi-modality neuro-images (PET, MR, CT, PET-CT) plays an important role in diagnostics of Alzheimer's disease (AD) since no single imagine can reveal the diseased status of AD in full. Novel approaches should be in place.

Colour	#	Title	Description
	60	4D echocardiography	While high-dimensional ultrasonic scanners can reveal more detailed information about human organs, e.g. the moving heart, they suffer from bottleneck effect due to their sheer volume size, such as blurred visualization, slower motion, and partial segment.
	61	Electromyography Signal Processing	It can be used for assessing and recording the electrical activity produced by skeletal muscles which are required for Motion Analysis, gesture recognition, joint biometrics and robot control.
	62	Wearable sensor and DSP	Monitoring and assessing body movements and behaviour.
	63	Data quality from sensors in healthcare	Data driven preventative healthcare using wearables and similar is increasingly important. However data is often poor quality with many artifacts. There are significant opportunities in motion artifact removal and robust information extraction.
	64	Healthcare and psychology	Offers tremendous opportunities from signals arising from ECG, EEG, eye tracking and human motion sensors to improve quality of care, within hospital and self-management after discharge but also assess human perception and response to images and video.
	65	Life sciences	In the past genetic and in general evolutionary algorithms have managed to push the boundaries for several signal processing problems. In the future, maybe more mature nature-inspired methods can lead to even more efficient systems.
	66	Perceptualizing biological information	Many human activities (e.g. skill learning, rehabilitation) benefit from providing users with information about their biological states. Signal Processing has opportunities to optimize the communication of such information to enhance performance outcomes.
	67	Interpersonal interaction signals	Detecting relevant non-verbal signals and processing these to facilitate communication between two or more individuals in real-time for coordinated activity is an opportunity to enhance many future interpersonal interactions.

Colour	#	Title	Description
	68	Personalised and human centered signal processing	Having trained a system in a human related problem, this needs to adapt next to the characteristics of each specific subject. Designing systems able to detect their performance deterioration & adapt to new subjects/environments can be important for SP.
	69	Cognitive Science	Several topics in the field of cognitive science can influence signal processing research towards modelling human perception and the creation of "human-like" computing systems. Examples include auditory cognition, neuroscience and visual perception.
	70	Psychology	If we want to have human in the centre (aka human-like computing), then it may be beneficial to take the psychology principles into mind, when for example developing methods for affective signal processing or social signal processing.

Annexe 2: Attendance

Emmanouil Benetos	Queen Mary, University of London
Nigel Birch	EPSRC
Philippe Blondel	University of Bath
Rob Bowyer	McLaren Applied Technologies
Alex Casson	The University of Manchester
Jonathan Chambers	University of Newcastle
Daniel Coca	University of Sheffield
Zoran Cvetkovic	King's College London
Tom Diethe	University of Bristol
Pier Luigi Dragotti	Imperial College London
Xiaohong Gao (Sharon)	Middlesex University
Simon Godsill	University of Cambridge
Deniz Gunduz	Imperial College London
David Halliday	University of York
Yulia Hicks	Cardiff University
Adrian Hilton	University of Surrey
James Hopgood	University of Edinburgh
Stefanos Kollias	University of Lincoln
Margarita Kotti	Toshiba Research Cambridge
David Li	University of Strathclyde
Baihua Li	Loughborough University
Zhenhong Li	Newcastle University
Pavel Loskot	Swansea University
Simon Maskell	University of Liverpool
John McAllister	Queen's University Belfast
Stephen McLaughlin	Heriot-Watt University

Majid Mirmehdi	University of Bristol
Matthew Nunes	Lancaster University
Timothy O'Farrell	University of Sheffield
Sofia Olhede	University College London
Dolly Parkinson	EPSRC
Mark Plumbley	University of Surrey
Nick Polydorides	University of Edinburgh
Matthew Rodger	Queen's University Belfast
Miguel Rodrigues	University College London
Mark Sandler	Queen Mary, University of London
Seb Savory	University of Cambridge
Simon Schultz	Imperial College London
Matthew Scott	EPSRC
Dimitra Simeonidou	University of Bristol
Lina Stankovic	University of Strathclyde
Michael Ward	EPSRC

EPSRC
Investing in research for
discovery and innovation

Engineering and Physical Sciences Research Council
Polaris House
North Star Avenue
Swindon
SN2 1ET

epsrc.ukri.org

EPSRC is part of UK Research and Innovation

Produced by UKRI's internal service provider