

Institution: University of Stirling
Unit of Assessment: B11
<p>Section 1. Unit context and structure, research and impact strategy</p> <p>Context and structure</p> <p>The Division of Computing Science and Mathematics (CSM) in the Faculty of Natural Sciences combines cutting-edge, fundamental research in computational and mathematical techniques and technologies, together with their application to addressing societal challenges in environment, food, health, society and industry. Over the course of this REF period, CSM's research structure and staffing has met the aim set out in REF2014 "to push the boundaries of the levels of complexity that we are able to model and handle" in order to tackle and solve difficult practical problems. To achieve this, we refined our research group organisation (Figure 1) to promote the close working of the computing scientists and mathematicians across CSM on research challenges. Focussing collaborations with academics in other disciplines and close engagement with industry and the public sector further enhances this cooperative approach. Highlights of our achievements include:</p> <ul style="list-style-type: none"> • Appointment of 8 new lecturers to broaden and consolidate our research strengths; • Impact through optimisation of industrial scheduling and automated software bug fixing; • Impact on public policy through predictive modelling of environmental issues; • Significant research collaboration, with 80% of our REF-submitted outputs being with external collaborators, with 50% international across 14 countries; • New technical capacity, including high performance computing (HPC) for data science, an internet of things (IoT) base station, and specialised hardware for low-power vision and audition. <p>We are a Division with a diverse collaborative network across the University of Stirling (UoS) and globally. We have evolved to be the data-driven, computational engine at the heart of each of the UoS's three major research themes of <i>Cultures, Communities and Society</i>; <i>Global Security and Resilience</i>; and <i>Living Well</i>. Through our pro-active agenda we lead on 25% (3 of 12) of the university-wide research programmes underpinning these themes.</p> <p>Our UoA B11 submission consists of 18 FTE staff from CSM. So extensive is our mission-oriented collaborative approach that six CSM staff are submitted to four other UoAs where they have their most intense research collaborations (A3: Allied Health; A6: Agriculture, Food and Veterinary Sciences; C14: Environmental Studies; C20: Social Work and Social Policy).</p> <p>We organise our research under three broad research groups (Figure 1):</p> <ul style="list-style-type: none"> • BIological MODelling (BIOMOD) - predictive modelling of biological systems; • DAta science and Intelligent Systems (DAIS) - data-driven modelling and analytics for wider applications in decision-support, scheduling and cyber-security; and • COMputational Mathematics and Optimisation (COMMON) - the rigorous development of underpinning tools and techniques that are relevant to all application areas.

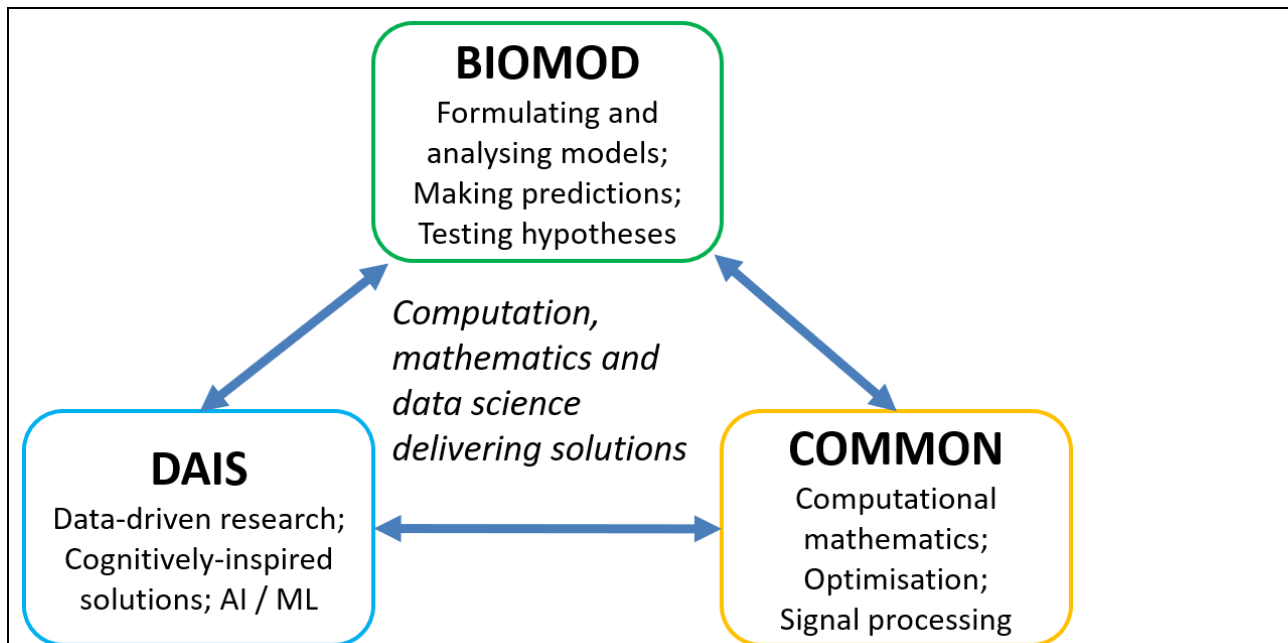


Figure1: CSM research groups; porous boundaries with joint PGRs, grants and publications.

All three groups contain computer scientists and mathematicians developing new techniques and their application. Collaboration between groups is encouraged, with a third of our grant applications including more than one research group.

Biological modelling (BIOMOD). B11 members: Cairns, Kirpichnikova, Norman, Shankland; . BIOMOD uses predictive modelling and optimisation techniques to describe, analyse and understand biological and socio-economic processes. Major application areas are (1) disease diagnosis, spread and control in human, animal and plant populations; and (2) global food security, particularly identifying vulnerabilities in the food chain. A fundamental focus is on the application of multiple approaches to single problems: for example, from population-based to individual (agent)-based models of disease spread, allowing mathematical analysis and computer simulations to provide complementary views on the same problem Underpinning this is the development of new, fundamental techniques for model generation, parameterisation and comparison. Antimicrobial resistance is a significant topic with cross-group collaboration with DAIS.

Data Science and Intelligent Systems (DAIS). B11 members: Adair, Bhowmik, Graham, Haraldsson, Linson, Ochoa, Noguiera, Swingler; plus Hapca (C20). DAIS innovates brain-inspired computational techniques, evolutionary computation, signal processing, search and optimisation methodologies and applies them to a wide range of real-world, data-driven challenges. Application areas include assistive living, health and social care, cybersecurity, environmental systems and resource scheduling. Specialist areas include: analysis and visualisation of fitness landscapes; computational vision and image processing, including topics ranging from image watermarking for media security to low power vision and contextual image segmentation; automated software engineering and brain-inspired algorithms.

Computational Mathematics and Optimisation (COMMON). B11 members: Bracciali, Brownlee, Kolberg, Lee, Li, Maier; plus Farkas (A3). COMMON conducts research in computational and mathematical methods for solving complex dynamic problems, including symbolic computation and exponential analysis for signal processing; efficient parallel computation, metaheuristic and stochastic search methods (with cross-group collaborations with DAIS); and blockchain technologies. Leveraging this fundamental research, we apply new methods and techniques to solve difficult challenges in, for example, lung and skin cancer detection, remote sensing data processing, scheduling in the aviation, building and other

industries and power-efficient operation of computer and mobile networks (with cross-group collaborations with BIOMOD). COMMON is a new research group that was formed in early 2019 to combine existing strengths in differential equation modelling and optimisation with significant new expertise in important complementary domains, including signal processing and parallel computation.

Research strategy

Our overall research strategy is to identify, understand and address complex societal challenges using computational modelling and analysis. This is a core aim of each of the research groups. To address this over-arching aim, we assemble within- and cross-group clusters of researchers to develop solutions to challenges based on fundamental improvements in computational methods. These methods typically combine traditional computational and mathematical techniques with emerging data-driven approaches. The results are developed and deployed in close collaboration with specialists in other academic disciplines and the ultimate end-users in the public sector and industry. To fulfil this strategy, we work to satisfy the following two aims.

Aim 1: Develop new approaches to tackling complex societal challenges

Our research group structure and strategic staff appointments enables us to bring expertise in data science, mathematical modelling, signal processing and optimisation, plus software and hardware design for efficient computation to address complex challenges. Research groups embody a spirit of openness that encourages the sharing of ideas and collaborative working, both within and beyond individual RGs. This has led to joint publications and grant applications, plus shared supervision of PhD and MSc students. Recent examples of the synergies we are exploiting include:

- Multimodal data analysis for monitoring aquatic invasive weeds in India: Royal Academy of Engineering funded project (£300k) began in April 2020 involving DAIS and BIOMOD members, researchers from Biological and Environmental Sciences and Psychology at Stirling with external academic collaborators (U.K. and India) and other partners. Aquatic weeds cause major decline in food production, with 40% of available freshwater in India made unsuitable for fish production. This project uses computational modelling and image analysis to predict the extent of water hyacinth, which alone infests 20-25% of utilisable water in India. Serious gaming and other community engagement methods are used to assess damage caused by weed infestation to local communities and economies;
- Antimicrobial resistance is one of the top 10 threats to global health, as identified by the World Health Organization. Key to minimising this risk is optimising the use of antibiotics. Researchers from BIOMOD and DAIS, with collaborators in Stirling's Institute of Aquaculture, are using predictive modelling and multi-objective optimisation techniques applied to scheduling of treatment to minimise the impact of antimicrobial resistance. Their prediction of new, more efficient treatment regimes that reduce antibiotic usage is gaining media attention (BBC radio interview plus Sunday Times article, Feb 2020);
- An integrated approach across our three groups is combining start-of-the-art signal processing techniques in exponential analysis with data driven methods to improve sensing data analysis in diverse applications from antenna array design to malaria risk detection where the challenge is to identify small water bodies from remote sensing data. This research is carried out with collaborators in Biological and Environmental Sciences Stirling. This work will greatly expand due to an EU Horizon 2020-funded EXPOWER research and innovation staff exchange network, beginning in April 2021, enabling collaboration with researchers in Belgium, Germany, France, Netherlands, USA, Canada, South Africa and Taiwan.

Aim 2: Facilitate collaborative, interdisciplinary research

In addition to establishing a collegiate atmosphere that encourages collaboration within CSM, we develop and nurture collaborations with other academics and stakeholders to identify and understand complex challenges that can benefit from our approaches. Stirling's ethos and scope as an institution aids establishing close collaborative links across disciplines. We are highly proactive in leveraging Stirling's strengths in aquaculture, environmental sciences, health and sports sciences, social sciences, psychology, business and management, law and philosophy to add depth and range to our research. New contacts and collaborations have been formed through concerted efforts to create and exploit interaction through cross-disciplinary "away days", participating in the annual Stirling Festival of Research and leading on university-wide research programmes: *Being Connected*; *Global Food Security* and *Contextual learning and processing in humans and machines (CONTEXT)*

These mechanisms, and the programmes, have provided the means to bring a broad range of researchers together to discover the synergies that exist between disciplines, and what our data-centric, computational perspective can bring to many areas. This has led to the submission of larger, multidisciplinary grant applications. We have submitted 28% more applications but with a rise of 177% in the value of bids per year since 2017.

Impact strategy

Impact lies at the heart of our research and we have further intensified impact within our research culture through the Faculty Impact Strategy, which encompasses all researchers and research students in the Faculty of Natural Sciences. This Strategy has three objectives:

- to improve impact literacy through training and the sharing of best practice;
- to enable identification of a wide range of potential and ambitious impact objectives;
- to maintain an impact support structure; and, to recognise and track impact as it happens.

To achieve these, we have a CMS Impact Champion who coordinates with the Faculty's Associate Dean of Impact and the Faculty Impact Committee. Our impact case study authors act as 'impact ambassadors', sharing knowledge, skills, connections and insights gained during their journeys to successful impact creation. This collaborative approach allows us to proactively identify and respond to challenges/opportunities that arise from changes in circumstances. We share our best practice and learn from others across the institution through engagement with Impact Champions in other faculties and divisions and the institutional Impact Working Group. The importance of impactful research for CSM is recognised and rewarded within our appraisal and development process (Achieving Success), in our appointment criteria, and as a criterion for research leave.

An essential component of our impact strategy is continuing to widen our network of potential end-users, so that projects and associated grant applications are formulated with end-user outcomes built in from the outset. To support policy/societal impact we work with a range of collaborators from other disciplines who provide links to appropriate policy makers and stakeholders. To increase our industry contact base, we maintain an extensive Industrial Advisory Board, that currently has representatives from 40 local businesses; and we run targeted business engagement events, such as our "Computer Vision Showcase" at Stirling in March 2019 that was supported by the Scottish CENSIS Innovation Centre. We have embedded industrial links and research into our teaching through our Graduate Apprenticeship scheme, our MSc programmes in Big Data which have several students funded annually through the Scottish Data Lab who do their dissertations with Industry, and our Professional Doctorate. All these opportunities allow staff to interact with different types of industry and to develop relationships and research ideas with them. Interface, a Scottish Funding Council (SFC)-funded organisation, provides a "match-making" service with local businesses seeking academic partnerships. Potential partnerships from Interface are directed to relevant academics in CSM by our partner in the university's Research

Office, and partnerships resulting from these have led to several of the successful Innovation Vouchers listed below.

Impact is also being fostered through Stirling's active membership of the Scottish Informatics and Computer Science Alliance (SICSA) research pool, which coordinates interaction with industry through its business development executive and programmes. SICSA's annual DemoFest brings together researchers at an early stage with commerce and business leaders, where CSM researchers and PhD students regularly present their work.

The success of this integrated approach to impact awareness and generation is exemplified by our two impact case studies that involve the work of all three research groups:

The impact case study on the use of metaheuristics to improve software performance and process scheduling involves researchers from COMMON and DAIS and is a direct outcome of EPSRC funded research (DAASE project). It is a study led by two of our recent appointments to open ended positions who were employed as postdoctoral researchers on the DAASE project and who were both able to use their own links with industry and their leadership on the impact agenda to enhance their applications for the open-ended posts in a very competitive environment. They were supported by two more experienced staff members who, as well as their academic contribution, provided strong networks of industrial partners. The strength of this impact case study is the ability of these staff members to translate their cutting-edge research into results which are valued and used by the industrial partners.

Our impact case study on environmental sustainability has arisen from research in BIOMOD and through an Innovation Voucher enquiry as described above. The other impact described in the study comes from a large body of work and long-standing interdisciplinary collaboration with colleagues in the biological sciences including collaborators from the James Hutton Institute and the Centre for Environment Fisheries and Aquaculture Science who have both supported pathways to policy makers and have meant that the research has contributed to policy decisions by the Scottish Government.

Impactful research is pump-primed through a mixture of University and external resources:

- Match-funded PhD studentships, in part facilitated through the Scottish Data Lab and CENSIS Innovation Centres, with the university research programmes and match-funding rounds. Recent examples include match-funding from major companies (BT Research, ST Microelectronics), SMEs (Singapore-based FinTech company, Bambu) and publically-funded bodies (Scotland's Rural College: 3 studentships).
- Scottish Funding Council Innovation Voucher projects with local companies which aim to provide proof of concept for larger follow-on grants. New appointees since 2017 have been particularly successful here:
 - A £5k Innovation Voucher in 2020 with Falcon Foodservice Equipment, has now led to £60k follow-on project which began in November 2020;
 - A £5k SFC Innovation Voucher with Airspace Unlimited Scotland Ltd in 2020 has led to follow on £75k Innovate UK funded project which began in October 2020;
 - Four other Innovation vouchers have been awarded in the last two years and we are currently following up on that work.
- Other available small-grant mechanisms involving companies and organisations. Recent examples are:
 - A £48k grant from the EPSRC Internet of Food Things network for the pilot project "Use of sensors to improve pig productivity" in collaboration with the Scottish Pig Producers Association and the Agri-Epi centre in Edinburgh;

- A £27k proof-of-concept grant from Samordningsförbundet Centrala Östergötland, Sweden to work with Swedish and Icelandic (Janus Rehabilitation) collaborators on the “Rehabilitation Pathway Generator”, with the aim of this leading to longer term research and development and wider application e.g. in the NHS in the UK;
- A £24k Innovate UK grant with Digiland on the use of blockchain technologies for financial inclusion in Bangladesh;
- A £100k award from the Defence and Security Accelerator competition for the project, “Deep Learning for Depth-Based Image Segmentation”.
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- Scottish Funding Council Global Challenges Research funding administered by the University
 - £5k networking grant to support collaboration with India, which led to a £25k Royal Academy of Engineering networking grant and then the £300k project on invasive weeds in India described above
 - £25k and £33k grants looking at the use of Earth Observation to understand the extent and impact of floods and droughts in Bangladesh and the subsequent impact on food security and health, including covid-19.

The key to our impact strategy is to make awareness of impact a day-to-day activity in our research. The university’s research planning system, WorkTribe, provides facilities for recording impact from projects. Realising and recording long-term impact requires time and effort that is recognised as a legitimate research activity and resourced accordingly with dedicated staff time and administration support.

Future strategic directions

Through our research and staffing strategy, we have established several major areas of multi-disciplinary strength providing a focus for new and early career staff to flourish and ensure their progression to senior researchers

Research in computational techniques will emphasise:

- **Optimisation:** techniques (particularly meta-heuristic) and applications to model parameter fitting, automated software engineering, scheduling problems. This builds on existing strengths, continuing the type of work underpinning our impact case study on application of optimisation. All three research groups are involved in development and use of optimisation;
- **Data-driven predictive modelling:** melding traditional mathematical modelling with computational and data analytic approaches. This will build particularly on the focus of the BIOMOD group but also draw on expertise from DAIS and COMMON. The aim is to be able to build better predictive models by creating techniques that automate model development, drawing upon machine learning and formal computational methods. This broadly includes most of the researchers in CSM;
- **Vision and image processing:** new methods for extracting useful information from imaging data obtained from a range of devices including digital cameras and remote sensing in different frequency bands. Work with Biological and Environmental Sciences BES is creating new techniques in contextual image processing and signal extraction from sparse data to maximise the information that can be obtained from very large-scale remote sensing data. Collaboration with psychologists is bringing a biological perspective to improve computational vision.

Fitting with the university’s research themes and building on our recent work, new computational techniques will be co-developed to solve challenges particularly in two broad application areas in which we are making advances:

- **Food security:** all three foci of our computational techniques are being brought to bear on issues that affect the security of our food chains. Building and optimising models of components of the food chain to enable identification of key risk points and make predictions of interventions to manage risks are the major aims;
- **Improving health and well-being:** All the computational techniques are applied to generate increased understanding of societal health risks and to help provide solutions. This ranges from predicting disease spread, to diagnosing disease from medical images, to enhanced assistive devices to improve quality of life.

Within these application areas we will place a strong emphasis not just on technological solutions to problems, but the entire deployment lifecycle: impact, sustainability, socio-economic effects, legal issues. We will do this through our ongoing approach of creating multi and inter-disciplinary teams to work on projects, combining technology with sociology, law, management and other disciplines.

Section 2. People

Staffing strategy and staff development

Our strategic emphasis is on recruiting and developing staff to strengthen existing areas and to add complementary new skills. University investment in our success has allowed us to make eight new appointments at lecturer level since 2017. These appointments have strengthened our existing research expertise and expanded our range. Expansion includes posts in cybersecurity (Bhowmik, Brownlee), plus appointments in computational and mathematical methods for signal processing and parallel computation (Lee, Maier), data analytics and machine learning (Adair, Nogueira). Continuing strengths in optimisation (Haraldsson) and predictive modelling (Kirpichnikova) have been boosted.

We have a strong record in nurturing staff from an early career stage through to professorships. Of the current cohort of four professors, three are due to promotions within this REF period, all having started initially as lecturers in CSM. For the first time the professorships in CSM (and B11) are now held by a majority of women (Norman, Ochoa, Shankland). In the face of strong, world-wide competition, three CSM PDRAs were appointed on merit to the new lectureships (Adair, Brownlee, Haraldsson), highlighting the quality of the training they have received in CSM and their desire to pursue careers in the academic environment that CSM provides.

The strength of our research culture and nurturing environment was recognised at a university level in April 2019 with the appointment of Norman (BIOMOD) as Institutional Dean of Research Engagement and Performance to promote a positive and collaborative research environment which helps everyone to reach their potential.

The CSM management structure ensures that all divisional needs, including research activity, are suitably planned and resourced. The Executive group oversees all divisional activities and comprises the Head of Division, Director of Learning and Teaching, Director of Research, and Director of Research Postgraduates. This group meets fortnightly to ensure the demands of research, teaching and administration are effectively met. Adjoining these planning meetings, open divisional meetings are held in the informal environment of the divisional coffee room, at which all staff can come to raise and discuss any issues with the Executive.

The Research Committee comprises the Director of Research, Research Group leaders, Director of Research Postgraduates, REF coordinators (including Impact), early career researchers and research postgraduate representatives, and others on invitation or request. The Committee meets monthly to oversee research-related matters, such as resource allocation and planning, and PGR progression.

This management structure supports efficient and effective planning, with clear lines of communication for all members of CSM. Decision-making is open to scrutiny and anyone can raise matters of concern and agenda items for the Executive or Research Committee. The Divisional Research Strategy is maintained as a live document and is further shaped by open discussions during annual research away days and during the regular Research Group meetings.

In addition to sharing of ideas and active research, the three research groups provide a fostering environment particularly for early career researchers, including:

- Grant proposal formulation and early-stage review;
- Paper writing early-stage review;
- Sandpits to generate new research initiatives;
- Mix of skills: grant writing, paper writing, technical, outreach, impact;
- Exposure of PDRAs to wider perspectives on managing research;
- Celebration of success and sharing of progress in a supportive team environment.

A variety of mechanisms are used to facilitate staff development and enable staff to set and achieve personal goals, in keeping with university and divisional aims and strategy:

- Careful time management through workload modelling is aimed at ensuring that all staff have appropriate dedicated research time, ranging from 100% for PDRAs to at least 40% for individuals on Research and Teaching contracts, at all stages of career progression. Research time is further prioritised for new / early career staff and those with significant grant income, altering the balance in favour of research time;
- The annual “Achieving Success” process is used to support staff in all aspects of their academic endeavours, including planning for and achieving their best possible career trajectory. A personal plan for the coming year (with thought to longer term goals) is developed in consultation with their line manager (Head of Division). The emphasis is on ensuring that staff have clearly defined goals, and that any barriers to achieving these goals are identified and can be minimised through planning and resource allocation at the individual and divisional / faculty level;
- Training and refresher sessions for new and experienced staff in effective PhD supervision is encouraged, particularly through training sessions organised by the university’s Institute of Advanced Studies, which oversees all aspects of PGR training;
- Senior and progressing staff are facilitated to undergo management training programmes. For example, four staff have gone through the award winning, institutional specific ILM level 5 leadership and management training. Two of our staff regularly contribute to the Aurora programme, which is Advance HE’s leadership development initiative for women, as role models, mentors and presenters. Several staff have also undertaken that programme;
- All staff, but particularly early career staff are encouraged to take part in the locally run Stirling crucible which provides training and network opportunities;
- All research-active staff are encouraged to apply for research leave to enable generation of new grant proposals, research outputs and impact. Applications can be made every seventh semester and are only successful if the research plan has clear, achievable goals. Plans are carefully reviewed by the Research Committee, in consultation with the Executive, to ensure divisional needs are met, before presentation to the Dean of Faculty for approval;
- Early career and all new staff have a mentor within the Division. All staff may have a mentor, on request. Such mentors may come from outside the Division, allowing staff to gain wider views of academic life;
- Strong support is given for individual fellowship applications, particularly for early career staff and postdoctoral fellows on fixed-term contracts: we work closely with the university’s Research and Innovation Services to ensure appropriate schemes are targeted and key expectations of funders are met. Robust peer review is carried out for all applications. Excellent proposals attract extra university support, as needed, including potential for on-going appointments beyond the end of fellowships, and PhD studentships being attached to the fellowship. For example, Norman secured teaching-buyout during the period of 1 Sept 2019 to 31 Aug 2021, via a Leverhulme Research Fellowship.

Research students

We provide a collegiate atmosphere in which PhD students are fully integrated in research activity through CSM research group and PhD cohort activities. The Director of Postgraduate Research maintains oversight and direction of PhD recruitment, supervision and training activities.

University-wide postgraduate research (PGR) community development and training are facilitated through the university's Institute of Advanced Studies.

All students have a principal and second supervisor. Supervisory meetings are recorded by the student on the web-based Research Compass system. Each year, students produce an annual report detailing progress to date and plans for completion. This report is then the subject of a viva, conducted by two academics who are not members of the supervisory committee. This viva is attended by supervisors, who monitor proceedings and may be consulted separately by the examiners.

PGR students gain wider experience and participation in CSM through the following activities:

- Postgraduates are represented on CSM research and teaching committees;
- Students participate in research group activities, including seminars, discussion groups, peer review sessions. They are encouraged to try out conference presentations in these groups and to obtain peer review of outputs before submission;
- Students run their own research and social meeting group, PGTips, which provides mutual support, an informal discussion forum, and opportunity for initial peer review;
- Students in the unit run an annual PhD day, which is a mix of poster and oral presentation of their work to CSM;
- A Computing Science and Mathematics Skills (COSMoS) forum, was initiated by the students, who identified the need for exposure to new skills and technologies particular to our discipline. Sessions presented by students and staff have ranged from using Latex for document preparation, to Bayesian statistical methods, to time management for research;
- Further training, including thesis writing and career development, is available through workshops run by the university's Institute of Advances Studies;
- Students compete in the Institute of Advanced Studies annual "Three-minute thesis" competition, which hones skills in conveying complex research topics to a diverse audience and in a concise manner;
- Students also participate in Scottish Informatics and Computer Science Alliance (SICSA) events, including the annual PhD conference and the DemoFest outreach event. In 2019, Stirling students and staff organised and hosted the SICSA PhD conference.

We take advantage of match-funding for PGR recruitment through opportunities provided by the university and external bodies such as the Scottish Data Lab Innovation Centre, with 25% of the current cohort on match-funded studentships. Such studentships are a priority for developing first-stage research with impact and in training the next wave of researchers in how to conduct a research project in close collaboration with end-users. Students gain significant experience in the different cultures and expectations of industry and business.

In addition, we established a Professional Doctorate in Big Data Science that has admitted its first students in 2020. This has a taught component in the first year, for which funded places are available through the Scottish Data Lab. The programme is strongly focussed on research projects in direct collaboration with business and industry.

Equality and diversity

We have an academic appointed as the Equality and Diversity Officer for CSM, and they are responsible for ensuring staff are aware of training and support possibilities in this area that the university and external organisations may offer. They are proactive in ascertaining issues that arise within CSM, and this is a standing agenda item at Divisional meetings.

The University's commitment to gender equality was recognised in the institutional Athena SWAN Bronze award in 2016. CSM is further committed to achieving Departmental Athena Swan recognition, and we are working towards applying for this in November 2021.

We have improved awareness of the conscious and unconscious biases that affect all stages of recruitment and advancement in research with training for staff on these panels. In addition, our approach to recruitment recognises alternative career paths to becoming a researcher in computing science, and all panel members are made aware of the potential bias towards non-standard routes to academic research, and of the equivalent value of administrative and pastoral care duties that may have disproportionately impacted women. Our selection criteria also recognise the value of candidates who have made progress in their academic and research careers whilst balancing family and caring commitments, or health and other restrictions.

We have established a diverse cohort of researchers, with staff from Scotland, England, Ireland, India, Italy, Russia, Taiwan, Australia, West Indies, USA, Venezuela, Germany, China, Romania, Brazil. A third of CSM permanent staff are female, including 3 of 4 professors (8/24).

The mental health of our staff and students is paramount and underpins planning of work arrangements. Senior CSM staff run informal sessions presenting their own experiences and inviting discussion, promoting the realisation that mental health issues can affect anyone. The Achieving Success process enables staff to raise and discuss barriers to success, including achieving a suitable work/life balance and coping with the stresses of their careers. This has been vital during the 2020/1 Covid-19 pandemic, and staff have been able to review and revise their goals set during Achieving Success in 2019 to reflect the changes in work practices and day-to-day living that have been necessary.

The PGR Director has identified mental health as a key issue for our PGR students and is working with them to create a supportive community that prevents students becoming isolated and unable to deal with the pressures of their studies. This has been particularly important during 2020, with students not able to meet in person. Weekly on-line meetings are used to provide a sense of community and ensure students do not feel socially isolated from their peers.

Flexible working is encouraged through largely informal arrangements, but also by timetabling meetings in core hours (10am to 4pm) to allow staff to fulfil family commitments, such as child/adult care. University infrastructure facilitates remote working through a comprehensive web portal, including secure file sharing. By agreement we restrict expectations to responding to emails to basic working hours (9am to 6pm).

Section 3. Income, infrastructure and facilities

Income

Income is principally from UKRI (EPSRC, BBSRC), Academies (Royal Academy of Engineering, Academy of Medical Sciences) and charitable trusts (Carnegie, Leverhulme). Large grant applications target GCRF/ODA funding (CSM members are both PIs and CIs on recent bids) and EU Horizon 2020. Most grants are collaborative in nature, involving external academic investigators and end-user stakeholders. Highlights of major funding led by CSM during the REF period:

EPSRC Programme grant (2012 - 2019, £2.4M Stirling), "DAASE: Dynamic Adaptive Automated Software Engineering" involved a consortium of universities including UCL, Birmingham and York. It also engaged with a range of stakeholders including ABB Group, Berner and Mattner, BT Laboratories, Ericsson, GCHQ, Honda, IBM, Microsoft Research, Motorola and Northrop Grumman Air Park Systems and Air France/KLM.

- CSM contributed world-leading research in meta-heuristic optimisation techniques to this project, which forms the basis of our "optimisation" impact case study. Ochoa was promoted from lecturer to professor during the lifetime of the grant, and key researchers Brownlee and Haraldsson are new lecturer appointments, ensuring the sustainability of this research in CSM beyond the duration of this project.

Royal Academy of Engineering funded project (2020 - 2023, Stirling £300k), “Multimodal data analysis for monitoring aquatic invasive weeds in India” includes collaborators in Psychology and Biological Sciences with external collaborators and partners in both the U.K. and India.

- Direct result of workshop funded by an Academy of Medical Sciences Networking grant. Brings together expertise in earth observation and computational modelling.

EPSRC AV-CogHear project grant (2015 - 2019, Stirling £300k), “Towards Visually-driven Speech Enhancement For Cognitively-inspired Multi-modal Hearing-aid Devices” in collaboration with University of Sheffield, MRC Institute of Hearing Research and Phonak Hearing Systems.

- Established a focus on multi-modal machine learning in CSM and this is now a well-established theme within the DAIS research group.

BBSRC project grant (2013-2016, Stirling £240k), “Balancing resource and energy usage for optimal performance in a neural system” in collaboration with Universities of Leicester and Edinburgh.

- Crossed the boundaries of the DAIS and BIOMOD research groups to consider an aspect of nervous systems that is relevant to building efficient artificial neural networks.

EPSRC project grant (2016-2019, Stirling £150k), “TRANSIT: Towards A Robust Airport Decision Support System for Intelligent Taxiing” in collaboration with Queen Mary (lead) and Lincoln University and external stakeholders.

- Complemented DAASE with work on optimisation for complex scheduling.

Leverhulme research grant (2016-2018, Stirling £100k), “The Cartography of Computational Search Spaces”

- Fundamental theoretical work underpinning optimisation research in DAASE project and DAIS and COMMON research groups.

Leverhulme Research Fellowship (2019-2021, £55k): “Developing a theoretical understanding of non-linearities in the food system and practical ideas to take advantage of them”

- Will identify risks in the current food system and what action is needed to avoid them. The non-linearities include trade-offs, feedback loops and tipping points.

To complement large grant bids and diversify our funding base, we encourage bids to smaller grant mechanisms, such as Carnegie Research Incentive grants and industrial-based contracts through e.g. Innovate UK, Scottish Funding Council (SFC) Innovation Vouchers and focussed grant calls. This is particularly helping new members of staff to establish their research programmes, such as the examples given in Section 1 under “Impact strategy”, plus:

- A £15k Carnegie Research Incentive Grant (2021 to 2022) to consolidate work on exponential analysis;
- A £10k Carnegie Research Incentive Grant (2019 to 2020) to consolidate work on genetic improvement of software (impact case study).

Infrastructure and Facilities

Specialist research infrastructure centres around high-performance computing facilities for computationally intensive model simulation and data analytics, plus related hardware for data collection and processing of visual, auditory and remote sensor signals:

In 2019, CSM became home to an Internet-of-Things (IoT) base-station, provided courtesy of IoT Scotland. Boston networks provides the infrastructure which is being rolled out across Scotland. This gateway enables acquiring sensor signals within a 20-mile radius. This is facilitating interdisciplinary collaboration with researchers collecting “in-the-field” sensor data, in Aquaculture and Biological and Environmental Sciences with CSM providing data processing resources, including state-of-the-art data analytics via machine learning and optimisation techniques.

This facility will play a significant role in the new Scottish International Environment Centre which is receiving investment of £22m through the Stirling and Clackmannanshire City Region Growth Deal. Through the Environment Centre, the IoT base-station will be complemented by the new Forth Valley 5G Innovation Hub, launched in September 2020. These facilities will support the Forth Environmental Resilience Array (Forth-ERA) project which will involve the capture, processing and sharing of data from across Forth Valley using EE’s 5G network. Sensors, satellite data and artificial intelligence will be used to provide vital information on water quality and other factors to inform decisions that could provide major economic and sustainability benefits to the area. This innovative, cross-disciplinary and cross sectoral approach – bringing together science, research, business and regulation – will be a global exemplar of green recovery, which is easily scaled and could be replicated worldwide. Forth-ERA will work alongside several regional stakeholders, including: the Scottish Environment Protection Agency (SEPA), Scottish Water, Diageo, NatureScot, Forth Estuary Forum and Forth Valley Chamber of Commerce.

Other specialist facilities in CSM include a Computational Intelligence lab that houses hardware for low-power vision (cameras and FPGA) and audition (silicon cochlea), with a sound-proof recording studio. Projects looking at real-time visual object detection and sound-source localisation are being undertaken with this hardware.

Research-specific high-performance computing in CSM includes two large servers that address different computational needs. Firstly, a new server has been funded by the Faculty of Natural Sciences, Stirling, in 2018 specifically for very large memory requirement and GPU-compatible data analysis and provides 768 GB of RAM, 32 CPU cores and 32 TB of data storage. It is equipped with 4 Nvidia 1080Ti graphics cards to train and apply Deep Learning Neural Network methods. While used heavily within CSM, it is available to any Stirling researcher who needs such computational specifications. It is facilitating collaborative work between CSM and other researchers at Stirling, such as from Biological and Environmental Sciences. The other HPC facility is a cluster with 120 CPU cores, used extensively for parameter searching and optimisation tasks involving GAs/EAs. This was originally funded by an EPSRC project grant but has been maintained for all to use. We have two full-time computing staff to run and maintain these facilities. In addition, Stirling is a partner in, and user of, the ARCHIE-WeSt supercomputer facility housed at Strathclyde University.

Open access is a priority for all research outputs, with the University paying publication fees for journal papers to enable this. All outputs are placed in a Stirling’s On-line Research Repository (STORRE). In addition, it is strongly encouraged that research data and other research outputs, such as computer code, are made freely available through depositing in the University’s data store (DataSTORRE) and by distribution on publicly accessible forums, such as GitHub (for computer code).

Section 4. Collaboration and contribution to the research base, economy and society

Collaboration

CSM research is highly collaborative and we generate and work with collaborative groupings over a range of domains: within the University and both nationally and internationally with other academic institutions and with a range of industry, policy and public stakeholders.

Most of our research is undertaken in collaboration with internal and external academic and stakeholder partners. Academic collaborators include UCL, Sheffield, York, Queen Mary, Lincoln,

Edinburgh, Glasgow, Strathclyde, Birmingham and others, principally in Europe and North America. We regularly host research visits from international academics, including visitors from Canada, USA, France, Belgium, India, South Africa, Switzerland, Spain, Mexico, Finland, Brazil, Algeria, Germany, Lithuania, Denmark.

Scotland-wide interactions are significantly facilitated by our membership of SICSA. New contacts are made, and research activity generated through the SICSA research themes and associated workshops. Bhowmik is a SICSA Cybersecurity research theme leader. Shankland led the SICSA modelling, and abstraction research theme (2012-2016) and Smith (now retired) was a SICSA Artificial Intelligence research theme leader. We have run SICSA-supported workshops on:

- Real-world transport optimisation (January 2015);
- Artificial intelligence (May 2016).

Funded stake-holder interactions include BT, KLM-Air France, Janus Rehabilitation (Iceland), ST Microelectronics, Falcon Foodservice Equipment, DEFRA, DASA, Forestry Commission, Phonak AG, Fera Science Ltd, Bambu (Singapore), Scottish Rural College (SRUC), Unitech Ltd, UCare Foundation, Marine Science Support and others. These interactions have funded PhD studentships and produced high-quality academic outputs and technologies that are being deployed by the stakeholders (as evidenced in our impact case studies).

To widen our links, particularly internationally, CSM researchers have been involved in setting up and running funded research networks. These researchers:

- have used an Academy of Medical Sciences GCRF Networking £24k grant, in collaboration with the National Institute of Plant Health Management, Hyderabad, India, to run a workshop in India in April 2019 on “Protecting Food Security in SE Asian Countries by Developing Early-Warning and Ready-Response Systems for Invasive Weed Incursions”. This has now led to a £300k grant from the Royal Academy of Engineering to carry out a substantive project (see Section 3);
- chair HPC-enabled Modelling for Life Sciences, in the EU Horizon 2020 cHiPSet Cost Action on High-Performance Modelling and Simulation for Big Data Applications, involving 30+ countries (<http://chipset-cost.eu/>);
- are PI on the EPSRC-funded “Predictive Modelling for Healthcare Technologies through Maths (POEMS)” network, with Manchester and Sheffield. This network fostered links between academics, clinicians and industrialists to generate new applications for mathematical modelling approaches to problems in medicine and healthcare.

Contributions to the research base

We are involved in the training of the next generation of scientists through the organisation of specialist conferences and workshops, running focussed tutorials at international venues and teaching on summer schools:

- Bracciali, Organising Chair: Computational Intelligence methods for Bioinformatics and Biostatistics. 13th International Meeting, CIBB, Stirling Sept 1-3, 2016;
- Bhowmik, Organising Chair: Special session on Multimedia Signal Processing for Cybersecurity and Privacy. IEEE International Conference on Digital Signal Processing 2017;
- Lee, Coordinator: Dagstuhl Seminar 15251 “Sparse modelling and multi-exponential analysis”, Schloss Dagstuhl – Leibniz Center for Informatics, Germany, 14-19 June 2015;
- Lee, General Chair: Milestones in Computer Algebra (MICA 2016), University of Waterloo, Waterloo, Ontario, Canada, 16-18 July 2016;
- Lee, Tutorial chair: International Symposium on Symbolic and Algebraic Computation 2020 (ISSAC 2020), Kalamata, Messinia, Greece, 20-23 July 2020;

- Lee, Tutorials at 19th International Conference on Computer Algebra in Scientific Computing (CASC 2017), Chinese Academy of Sciences, Beijing, China, 18-22 September 2017;
- Ochoa gives regular tutorials at major international conferences, including:
 - Recent Advances on Fitness Landscape Analysis Genetic and Evolutionary Computation Conference (GECCO), Prague, Czech Republic, July 2019;
 - LON-Maps: The Cartography of Computational Search Spaces, Parallel Problem Solving From Nature (PPSN), Coimbra, Portugal, September 2018;
 - Search-Maps: Visualising and Exploiting the Global Structure of Computational Search Spaces, Genetic and Evolutionary Computation Conference (GECCO), Kyoto, Japan, July 2018.
- Graham has been an invited lecturer on the Baltic-Nordic Neuroinformatics Summer School each year since its inception in 2013 (held in Lithuania, Finland, Estonia, Latvia, Poland and Germany so far).

Our research dissemination includes staff giving keynotes and invited talks at international events, for example:

- Norman: Invited speaker ECMTB (European conference on Mathematical and Theoretical Biology) July 2018;
- Lee: Plenary talk at 20th Conference on Applications of Computer Algebra (ACA 2015), Fordham University, New York City, New York, USA, 9-12 July 2015;
- Ochoa: Keynote Speaker at the Visualisation Methods in Genetic and Evolutionary Computation (VizGEC 2019) Workshop, held in conjunction with the Genetic and Evolutionary Computation Conference, GECCO 2019, Prague July 2019;
- Ochoa: Keynote Speaker at the 13th Artificial Evolution Conference, EA 2017, October 25-27, 2017, Paris, France (Ochoa).

Our conference submissions include several Best Paper Awards:

- Ochoa has 4 best paper awards: EvoCOP (2016, 2017, 2019) and GECCO (2018);
- Ochoa received the Evo* Award for Outstanding Contribution to Evolutionary Computation in Europe 2020 (April);
- Swingler won Best paper prize at IJCCI, 2016.

Staff contribute to the wider academic process through acting as editors and paper reviewers for journals and conferences, and by participating in grant reviewing and grant panel meetings for a variety of funding bodies. Staff are members of the EPSRC College, BBSRC Pool of Experts and Carnegie Trust Research Incentives schemes and so sit on grant panels and regularly review grant proposals. Staff have also been on grant panels for EU H2020 and NSF (USA).

Journal editorial boards: Elsevier journal of Data in Brief (Bhowmik), Special issue on Advances in Multimedia Signal Processing for Cybersecurity, Elsevier Journal of Information Security and Applications (Bhowmik, Lead guest Editor), Journal of Biological Dynamics (Graham), Journal of Animal Ecology (Norman), Consumer Communications and Networking Series for IEEE Communications Magazine (Kolberg, Editor), Complex and Intelligent Systems (Brownlee), Peer-to-Peer Networking and Applications Journal (Kolberg), Wireless Communications and Mobile Computing (Kolberg), ACM Communications in Computer Algebra (Lee, Editor), Journal of Symbolic Computation: special issue on Milestone of Computer Algebra (Lee, Guest Editor), Evolutionary Computation Journal (Ochoa), IEEE Transactions on Evolutionary Computation (Ochoa), ACM Transactions on Evolutionary Learning and Optimisation (Ochoa, Associate Editor), Genetic Programming and Evolvable Machines (Ochoa), Frontiers in Neuroinformatics (Graham).

Wider contributions to the research base, economy and society

Through promoting women in computing on the UK stage, Shankland acts as a role model and plays a major role in promoting science in the wider academic and public domains:

- Chair of BCS Women in Computing Research (2015-);
- Durham Lovelace lecture invited speaker 2016;
- Keynote speaker at
 - Aurora 2016, 2017, 2018, 2019 (AdvanceHE leadership training)
 - International Women's Day Conference, Aberdeen 2017
 - LSE Power (London School of Economics annual conference for professional services), June 2019
- Award: Suffrage Science Computer Science and Mathematics 2016
- Award: Scottish Woman of the Year (Services to Science and Technology) 2017.

Beyond standard academic outlets, staff contribute their expertise more widely through participation on a variety of advisory boards:

- Bhowmik: Chair (2018), Ad-hoc-group on Media Blockchain, International JPEG standardisation committee (ISO/IEC JTC1/SC29/WG1 (ITU-T SG16));
- Bhowmik: Committee member: IST/37 - Coding of picture, audio, multimedia and hypermedia information, British Standards Institution (Bhowmik);
- Kolberg: ScotlandIS Digital Skills Partnership Advisory Board;
- Ochoa: Member of ACM SIGEVO Executive Board (ACM Special Interest Group for Genetic and Evolutionary Computation), since 2015;
- Swingler: Currently advising Edinburgh City Council and Edinburgh Trams on the specification of a driver monitoring system.

CSM also regularly hosts a series of public lectures at Stirling, entitled "A random walk through mathematics and computing science", during the Spring of each year, to which many staff contribute. These attract a diverse audience of around 50 people over a wide age-range from the local community. They are a prime mechanism for instilling enthusiasm in computing science and mathematics as subjects to study for school-age children, and to stimulate interest in undergraduates in the research possibilities in these fields.

Conclusion

CSM continues to foster a dynamic and sustainable research environment in which computer scientists and mathematicians work together on solving complex challenges facing today's societies, in food and health, the environment, business and social organisation. Predictive modelling and data science include many valuable computational approaches to help tackle these challenges in our data-rich world. We are building our capacity in developing and exploiting such techniques and to further strengthen our interdisciplinary and stakeholder links so that our work continues to have significant scientific and practical impact over the long term.