

Institution: University of Plymouth
Unit of Assessment: UoA11 Computer Science and Informatics

1. Unit context and structure, research and impact strategy

Highlights

- We broadened research scope significantly with growing numbers of research applications in health technology, sustainability, agritech, and offshore renewable energy (ORE). These areas are central to the University of Plymouth's long-term strategy.
- Staff increased from 11.2 FTEs to 14.62; refreshed by seven new ECRs (section 2).
- Research income from UK, EU and international sources rose to £7.7M from £6.7M (section 3).
- A Cyber-SHIP lab was set up with over £3M of funding, a new and unique research facility designed to address key cyber security challenges facing the shipping industry (sections 3 and 4)
- A Big Data group was set up and interdisciplinary collaborations were invigorated through a new School structure (sections 3 and 4).

1 Overview

Research in Computer Science and Informatics at the University of Plymouth (UoP) is mainly carried out at two research centres, the **Centre for Robotics and Neural Systems (CRNS)** and the **Centre for Security, Communications and Networks (CSCAN)**. Both centres form part of the School of Engineering, Computing and Mathematics (SECaM) within the Faculty of Science and Engineering (FoSE). Several staff in UoA11 occupy leading roles in the Faculty (**Jones**, Executive Dean; **Ghita**, Associate Dean for International and Postgraduate; **Clarke**, Deputy Head of SECaM), which provides a strong position within the Faculty and University and enables impact on strategic decisions, including on research and postgraduate matters.

In REF2014 UoP submitted 12.4 category A staff to UoA11 in a submission that was focused on Cognitive Robotics and Neural Computation. The present REF2021 submission contains 17 category A (14.62 FTEs) and 7 category B staff representing 10% of the independent researchers in FOSE. The submission has a much wider scope than previously due to growth and major restructuring:

In 2019, the former School of Computing, Electronics and Mathematics (SoCEM) merged with the School of Engineering to form the School of Engineering, Computing and Mathematics. The School merger created a synergistic mix of academic disciplines, strengthening research through new interdisciplinary collaborations within the three core subject areas in the new School -- Engineering, Computing and Mathematics. This interdisciplinary environment aligns with Government and EPSRC priority areas of clean growth, digitalisation, autonomy, and health technology. It enhances sharing of good practice and alignment of processes and initiatives to maximise research and teaching benefits and effectiveness across the School. It also enables more effective interaction between research groups and training of researchers for industrial and research needs aligned to the future needs of the country, including the challenges of the fourth Industrial revolution and global

digital transformation. Therefore, CSCAN and CRNS sit together in a supportive environment and form a natural unit submission.

Furthermore, in 2016 **Cangelosi** and **Marocco** initiated the formation of a new BigData group. This responded to the enormous growth the field has seen in recent years reflected in UK Government strategy, especially Industry 4.0, which puts Computer Science, Data Science and AI at the core of developments across industries. In the reporting period, five lecturers were recruited to strengthen AI and Big Data in UoA11. Compared to REF2014, research now falls into four broad thematic areas: Robotics; Computational Neuroscience (REF2014); Big Data & Artificial Intelligence; Cyber Security & Networks (new).

SciVal data confirm that the majority of outputs cover core Computer Science topics (39.2%), Maths (including theoretical/data analyses, 11.3%) and Engineering (21.8 %). The remaining 27.7% cover a broad range of interdisciplinary topics, prominently in Neuroscience and Psychology (through research in Computational Neuroscience) and the Health/Medical area (Social robotics, HCI, and BigData). Given the interdisciplinary nature of research, UoA11 contributes strongly to the objectives of the University's three strategic research institutes (<https://www.plymouth.ac.uk/research/institutes>):

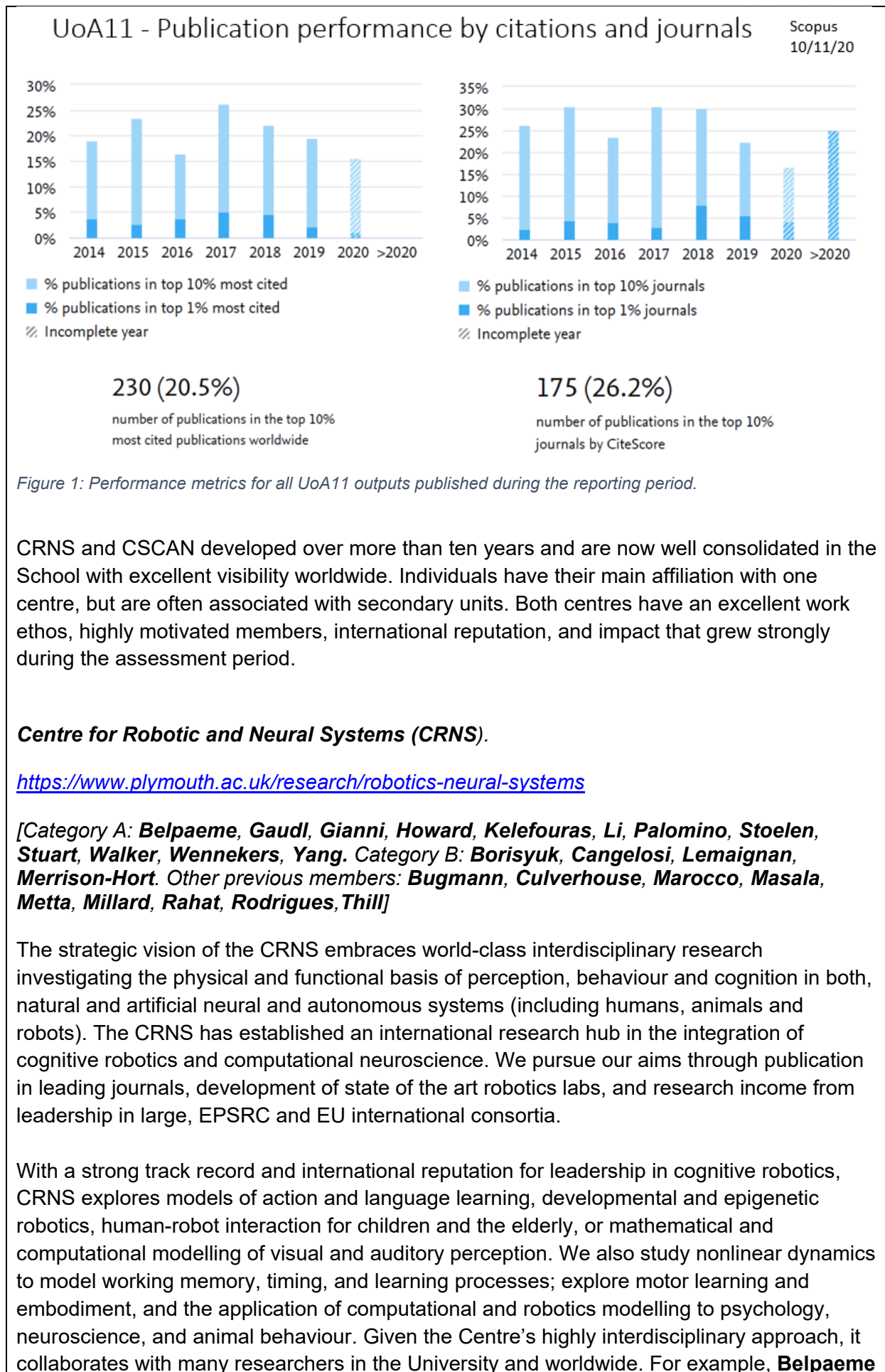
- **Marine** Institute via Marine Cyber Security; AI, Optimisation and Data Analysis; Autonomous Robotics.
- Plymouth Institute of **Health** and Care Research via Social and Healthcare Robotics (**impact case 1**); Computational Neuroscience; BigData for e-health.
- **Sustainable Earth** Institute via Agricultural robotics (**impact case 2**); Robotics and AI for Renewable Energy, especially offshore.

Strategic Aims

Our mission is to promote innovative research in core and applied Computer Science domains that reaches the widest national and international recognition and highest impact.

Figure 1 displays performance metrics of all UoA11 research outputs over the REF period. The figure shows that 20.5% of outputs perform in the top 10% worldwide and 2 to 5 % in the top 1%. More than a quarter of outputs appeared in the top 10% of journals and 2 to 7% in the top 1% (as measured by 'CiteScore', the average citation count per document in a journal). The plots confirm consistency of this outstanding performance over time.

Based on this data and wider achievements outlined in the subsequent sections, we have met all strategic aims identified in the REF2014 submission (see especially the highlights at the top of this section).



cooperates with Luc Steeles (Universidad Pompeu Fabra) on the Evolution of Language or Bram Vanderborght (Vrije Universiteit Brussel) on Human Computer Interaction; **Cangelosi** works with Giorgio Metta (Scientific Director of the Istituto Italiano di Tecnologia) on Cognitive Robotics or Steve Furber (Uni Manchester) on neuro-inspired hardware for robots. **Borisyuk** develops models of tremor with Nada Yousif at Imperial and tadpole spinal cord models with Alan Roberts from UWE Bristol; **Howard** published on limb control with Dan Wolpert (Columbia) and Konrad Koerding (Upenn); **Wennekers** develops models of brain-function with Palm (Universitaet Ulm) and language with Pulvermueller (Freie Universitaet Berlin).

Strong research strands evidenced by our **selected outputs** include:

[Robotic Control; Sensors and Actuators:] **Stoelen** and **Howard** lead **Impact case 1** on **agricultural robotics**, where low-cost public domain harvesting robots are deployed in real environments. **Chen** works on robot controllers for a wide range of applications. His publications have attracted an immense level of scientific attention in terms of citations.

[Social and cognitive robotics:] **Impact case 2** by **Belpaeme, Cangelosi & Gaudi** considers robot applications in **social, educational and health contexts**. Their work on robot-supported child learning has set new scientific agendas and attracted a wide press attention including front page coverage by Science Robotics and Scientific American.

[Computational Neuroscience:] **Borisyuk, Wennekers & Howard** have a long-standing publication record and international visibility in CNS topics such as dynamical modeling of neural systems (Borisyuk), brain-inspired language and cognition models (Wennekers) or movement control (Howard).

During the evaluation period additional staff were recruited to counteract staff turnover. Three early career lecturers complement and extend our core competences in Robotics: **Gianni** is an internationally recognised expert in search and rescue robotics and multi-robot systems. He also has responsibility for our Nvidia Lab. **Gaudi's** research is focused on AI, games, animal behaviour and low-cost robotics, especially in the health sector. **Li** is an expert in Machine Learning, Control Theory, Smart Materials and Soft Robotics. All three are highly promising researchers with a quickly increasing international visibility evidenced by their research outputs. **Gianni** and **Gaudi** secured grant income soon after hired. **Gianni** started two projects about aerial robot swarms for offshore wind turbine inspection and decommissioning nuclear submarines (with Babcock, UK); **Gaudi** has a significant role in EPIC2, where robotic systems are explored in health care environments. This is a major project headed at the University's new strategic Centre for Health Technology (<https://www.plymouth.ac.uk/research/epic>).

As an important element of growth, the research scope of the unit has been significantly broadened and extended beyond Robotics and Neural Computation into wider Artificial Intelligence technologies. This new initiative focuses on statistical learning, machine learning and big data as well as optimisation methods in various contexts. It responds to strong trends in Computer Science research and Industry requirements, and is well aligned with UK research strategies: For instance, the EPSRC intends to grow its "Artificial Intelligence" theme, and the UK Government's Industrial Strategy published in 2017 includes AI as one of four grand challenges. Three ECRs joined since 2017, covering a variety of complementary topics in these areas (**Walker**: AI and optimisation, **Kelefouras**: optimised computing hardware; **Palomino**: sentiment analysis).

The scope of this initiative is even wider: members of the Centre (**Cangelosi, Masala**) initiated the implementation of a Big Data research group, which recruits members from across the School (Computing, Maths, Engineering) and serves as a platform for projects within SECaM as well as with other units (**Palomino, Gianni** and **Kelefouras** work with the Centre for Health Technology; **Wennekers and Howard** with the School of Psychology).

Centre for Security, Communications and Networks (CSCAN).

<https://www.plymouth.ac.uk/research/centre-for-security-communications-and-network-research>

[Category A: **Clarke, Ghita, Jones, Papadaki, Sun, Tam**. Category B: **Furnell, Other: Shiaeles, Stengel**]

CSCAN dates back to the 1980s, with a proven long-term research pedigree, including both, collaborative work with industry and participation in European research initiatives.

Work at the Centre focuses on **Digital Forensics, Human Aspects of Cyber Security, Networking and Communications**, and **Marine and Maritime Cyber Security**. Some highlights (see submitted outputs) are early studies for user authentication using bio-metrics and behaviour profiles (**Clarke, Furnell, Papadaki**), information security compliance modelling in organisations (**Furnell**), content-based video quality prediction (**Sun**), internet traffic classification (**Ghita**), or **Tam's** highly recognised work about Android malware behaviour reconstruction.

CSCAN has recently set-up a new Maritime Cyber Threats research group (**Jones, Tam**) which aligns with the University's focus upon the marine sector. The group brings together leading-edge multidisciplinary research and practical expertise from across the University and beyond. It is uniquely placed to make significant contributions in maritime cyber-security. The group is supported by grants from H2020 (CYBER-MAR) and Research England (CYBER-SHIP, £3M). An ECR, **Tam**, has significantly contributed to setting up the Lab; she has been appointed to a lecturer post in 2019. A second ECR (Asad, UoA12) was appointed lecturer in 12/2019.

The work at CSCAN has led to many successful postgraduate projects and associated publications. About half of UoA11's PhD completions were located in CSCAN. In addition to an active base of postgraduate and postdoctoral research, CSCAN's research also underpins MSc and MRes programmes at UoP.

The CSCAN Network of European Universities (established in 2004) continues to flourish and facilitates research co-operation with academic institutions across Europe: the University of Applied Sciences, Darmstadt, Furtwangen University of Applied Sciences and, since February 2015, the Frankfurt University of Applied Sciences. This has created a community of 17 doctoral students throughout the reporting period.

Future Strategy

The launch of SECaM in 2019 and the new UoP institutes - Marine, Health, and Sustainability - provided an opportunity to revisit research and impact strategy for the next 5 years. We installed a new research group on BigData and AI in CRNS, which now contains Robotics,

Computational Neuroscience (REF2014), Big Data and AI. We embrace new opportunities in digitalisation, artificial intelligence and robotics emerging in the 4th Industrial Revolution and identified in the UK Industrial Strategy. Our objectives are

- Grow the staff base in Computing in the School to extend the range of competences and operational power. Four new lecturers/senior lecturers have already been hired *after* the staff cut-off date for this REF; a full professor post in AI has been advertised to further strengthen leadership.
- Prioritize excellent, impact-yielding research, aligned to UKRI strategies and supported by enhanced international collaborations, increasing the number of world-leading publications and grant income, and maintaining an outward focus that informs international facilities and national policies.
- Maximize sustainable research impact, by taking full advantage of our new School and its state-of-the-art infrastructure, of growing SME networks and multidisciplinary industrial projects.
- Strengthen our CPD provision, and continue to expand our research-informed, educational and public engagement programmes to increase awareness of the importance of Computer Science in pupils and the public.
- Sustain and consolidate our outstanding team of postdoctoral researchers, and increase our complement of PGR students.

Open Access Policy

The UoA complies fully with REF Open Access policies and the School encourages researchers to use this option. The University published its Research Data Management policy in 2018 to ensure data integrity, discoverability and reuse throughout the lifecycle of research projects. Publications are made available publicly online (<https://pearl.plymouth.ac.uk/>), usually under OA licenses funded by grants. Members of UoA11 contribute to OpenAccess software, notably YARP, a widely used robotics platform developed under supervision of **Metta**, who held a 20% contract at UoP for 5 years during the assessment period (<https://en.wikipedia.org/wiki/YARP>). Parts of YARP were developed and tested in robotics projects in Plymouth (ITALK, Poeticon). Members of UoA11 edit for Open Access journals: **Wennekers** (PLOS one, Frontiers in Computational Neuroscience, Frontiers in Neuroinformatics, Digital), **Belpaeme** (Frontiers in Robotics and AI), **Cangelosi** (Frontiers in Neurorobotics).

Covid 19

In response to the pandemic, staff were encouraged to work from home, but can access research labs on demand where necessary, consistent with government regulations. Strict hygienic and behavioural procedures are in place throughout University buildings. Online meetings take place at increased frequency, with weekly subject group meetings, bi-weekly School meetings and monthly research planning meetings of the Centres. A SECaM research planning day took place online in 12/2020 and UoP conducted a survey of the impact of Covid19 on staff work and wellbeing.

2. People

Table 1 provides staffing data. All staff are on permanent contracts, ensuring strategic continuity and job security. Three are on part-time contracts holding second appointments abroad (**Stoelen, Belpaeme**) or for a focus on research (**Papadaki**). Three researchers are professors, 6 associate professors, 7 grade 8 lecturers and one grade 7. This profile reflects the recent refreshment of our staff base, also visible in the high numbers of younger staff. Four colleagues are female (24%) and 13 male, slightly better than UK averages for females in professional Computing jobs (ca 20%, various sources) or female students in Computer Science (18%, <https://www.stemwomen.co.uk/>). Twelve of 17 staff have a non-British background, 8 originate from EU countries, and 4 from Asia and Southern America; 3 are from a non-Caucasian background. These numbers are indicative of a highly international and inclusive workforce; on average only 13.8% of the UK population is from an ethnic minority background. It is a stated strategic aim of SECaM to become a beacon for EDI in the university <https://www.plymouth.ac.uk/about-us/university-structure/service-areas/equality-diversity-and-inclusion>.

Table 1: Staffing profiles within UoA11 (% per headcount; n=17 category A researchers)

Grade	% (#)	Age group	%	Employment Basis	%
Professor	18 (3)	25-34	17.6	Full-Time	82.4
Ass. Professor	35 (6)	35-44	29.4	Part-Time	17.6
Lecturer	47 (8)	45-54	29.4	Employment Terms	%
		55-64	23.5	Permanent	100
		65+	0	Fixed-term	0

Ethnicity	%	Gender	%	Disability	%
BME	23.5	m	76.5	No	82.4
Not known	5.9	f	23.5	Not known	11.8
White	70.6			Yes	5.9

i. Staffing strategy and staff development

Our staffing strategy aims to grow excellence at all levels and to attract the best researchers in line with our objectives and needs. The international reputation of CRNS and CSCAN helps with attracting high-quality applications from around the world.

Aligned with the University's internationalisation strategy we advertise and hire internationally and expect staff to collaborate at an international level.

We attempt to position the unit ideally for Industry 4.0 by interdisciplinary and international collaboration and growth of research, especially through new investments into AI and robotics. Four new lecturer/senior lecturer and one professor post have been allocated to the unit focusing on AI, robotics and cyber security.

Research within the unit aligns with the University's three strategic institute themes: Marine, Health and Sustainability. Collaborations in these areas are actively encouraged and growing. Impact is reached by working with end users and industry (Honda, Babcock, Bosch, Derriford National Trust, and others). Potential for research impact is a key element of the recruitment criteria for new staff.

All submitted staff are on balanced contracts. UoP aims at a workload giving equal weight (40%) to research and teaching, and 20% to administrative responsibilities.

The unit saw a large throughput of researchers in the reporting period. The majority of outward moves were due to career progression: seven junior lecturers / ECRs took offers for permanent academic posts elsewhere (**Yang, Rodrigues, Lemaignan, Masala, Rahat, Shiaeles, Millard**), one entered industry (**Merrison-Hort**). This demonstrates excellent opportunities for career development at the unit. Furthermore, three senior staff took new academic posts elsewhere (**Borisyuk, Cangelosi, Furnell**) and two retired (**Bugmann, Culverhouse**) although they are still affiliated with the unit as visiting researchers.

Staff turnover allowed us to build a refreshed staff base with a wider range of skills than in the 2014 submission. This applies specifically to new topics in AI, BigData, and Marine & Cyber Security where we hired a significant number of new staff at lecturer level during the assessment period. Key appointments were in the field of AI and Optimisation (**Walker, Kelefouras**), Big Data (**Palomino**), Robotics (**Gianni, Gaudi**), and Cyber Security (**Tam**, internally promoted). These researchers have strong records of accomplishment and clear potential to generate research excellence and impact (cf. their submitted outputs; **Walker and Gaudi** have attracted competitive UoA internal studentships; **Gaudi, Gianni and Tam** brought in several research grants).

Career development

We have a strong commitment to developing scholars to provide leadership and sustainability, endorsing the University's commitment to the Concordat to Support the Career Development of Researchers. The University has successfully retained the Excellence Award (see Institutional environment statement).

Principles of career development apply across staff at all levels from research fellows to senior staff, with additional measures in place for new and early career researchers. All academic staff develop research plans and take part in a formal personal development scheme (PDR) to gauge performance and set objectives. Staff are evaluated annually against the previous year's objectives, their job descriptions and individual requirements. Results are propagated upwards to the HoS and Dean for School and Faculty level oversight and planning. The PDR is also a measure to communicate Faculty and School strategy downwards. New staff are allocated a mentor for one year who advises on academic issues.

A wide range of training sessions is available for UoP researchers catering for people at all career stages. This extends from REF strategy, impact and Open Access issues to research and presentation skills. Sessions are delivered internally or by external trainers, in collaboration with the Doctoral College and relevant UoP units. Compulsory online courses must be undertaken and refreshed at prescribed intervals: Equality and Unconscious Bias, Mental Health Awareness, Diversity in the workplace, GDPR and Information Security. Training also takes place at School away days where identified topics are covered (eg funding opportunities and procedures; REF; research strategy). Training is monitored as part of the PDR process. The School further encourages the achievement of professional academic accreditations.

UoP operates an annual promotion scheme with associated workshops to clarify processes. Promotions are awarded according to merit in accordance with defined criteria. Since 2014 one person was promoted to professor (**Clarke**; m), one to associate professor (**Papadaki**; f) and four to lecturer level (**Stoelen, Tam, Lemaignan and Merrison-Hort**; 3m, 1f). **Clarke**,

Papadaki, Stoelen, Lemaignan and Merrison-Hort had been with the University since their PhD studies at the time of promotion, demonstrating ongoing long-time support of staff. **Tam** (f) entered the University as a research fellow in 2017, secured a lecturer appointment 2019 and continues to contribute to the Cyber-SHIP lab.

The School also runs a scheme for semester-long sabbaticals (eg **Dahl, Marroco**).

New Researchers and Early Career Researchers

The School has a strong commitment to support young researchers and their career development. At the census date, we had seven ECRs (**Tam, Gianni, Gaudi, Kelefouras, Walker, Palomino, Stoelen**). Seven ECRs secured permanent academic posts elsewhere during the reporting period (**Lemaignan & Yang**, UWE Bristol; **Masala**, Manchester Metropolitan; **Millard**, University Lincoln; **Rahat**, Swansea University; **Rodrigues**, BCAM, Spain; **Shiaeles**, Portsmouth).

We support research assistants and ECRs through:

- *Mentoring*. New members of staff are allocated a research-active mentor for specific guidance on research, career development, and grant writing.
- *Performance Development Review (PDR)*. Senior members of the School who review all staff and give advice and support for development needs.
- *ECR Research Forum*: This is a school-wide group of ECRs who self-organise to provide mutual support, with regular meetings, reading club, grant writing support, etc.
- *Workload adjustments*. New researchers have a reduced teaching load of 20% (instead of typically 40%) and no major administrative responsibilities.
- *Postgraduate Teaching Certificate*. Primarily a teaching course, but includes procedures and regulations relevant to research, eg PGR student supervision and Doctoral College (DC) support.
- *Internal courses*: delivered through the DC covering a wide spectrum of skills including project management, IPR, research and presentation skills, grant writing etc.
- *PhD Studentships and Small Grant Competitions*. In the past, more than 50% of internally funded PhD studentships and small grants were priority-allocated to ECRs to kick-start their research productivity and supervisory experience.
- *External visitors*: The research centres run seminar series supported by the School with internal and external speakers, providing opportunities for junior staff to develop presentation skills and foster networking.

Equality and Diversity

As one of its strategic objectives SECaM is committed to the advancement of equality, diversity and inclusion in employment and career development. The University, the School of Computing, Electronics and Mathematics, and the School of Engineering attained Athena SWAN bronze awards in recognition of a commitment to improving gender equality in October 2018. In November 2020 the new School, SECaM, also received an Athena SWAN bronze award. <https://www.plymouth.ac.uk/about-us/university-structure/service-areas/equality-diversity-and-inclusion/athena-swan>

EDI issues in relation to recruitment, promotion, and research are monitored through the yearly PDR process and by research centre leads for reporting to the Faculty Research Committee. The School carefully formulates recruitment and marketing documents not to exclude under-represented groups, and aims to be able to shortlist at least one female

candidate for each externally advertised post. It is HR policy for recruitment panel members to receive training in equality and diversity issues. All members of staff complete compulsory online training on equality and diversity, and unconscious bias.

Output selection for this REF submission followed peer rankings of up to five best outputs of each researcher by internal and external reviewers. The single best output for each researcher was chosen and the remaining outputs selected according to the rankings. There were no ambiguities of choice in the process that could have disadvantaged minorities. Several of the best papers are from active female members of the unit. The UoA submits ~24% females, slightly more than females among Computing students or in professional Computer Science jobs. In December 2020 the School has offered two new posts in AI and Cyber Security to females. In a wider context, the University provides wellbeing and counselling services, access to on-campus nurseries for staff, and it supports maternity/paternity leaves.

ii. Research Students

Postgraduate research students are key to our research environment. **104 PhD students completed during the reporting period**, roughly 15 completions per year or 1 per FTE per year. The number of completions is stable over time. 20% of completions in the School were by females; 48% had a BAME background. Recruitment was by a variety of sources, such as four Marie Curie training networks (APRIL, SECURE, DCOMM, COGNOVO), the CSCAN Network of European Universities, a range of EU grants and additional internal studentships distributed within the School in a competitive process (~3 per year). The School secured an EPSRC DTP with a focus on Offshore Renewable Energy (ORE) and provides further PhD studentships in Health & Medical Technologies for which members of UoA11 have successfully applied (**Walker, Gianni**). CSCAN also attracts self-funded students from Kuwait and Saudi-Arabia (> 20 students).

The University considers educating the next generation of academics and researchers central to its mission. It coordinates postgraduate studies through the University's Doctoral College (DC), such that all students receive excellent and extensive support at the same high level of quality.

Recruitment follows strict procedures to guarantee equality, inclusivity and fairness, as well as wide and international advertisements of posts. A trained recruitment team reviews applications and interviews shortlisted candidates according to procedures very similar to those for standard academic posts. Students are provided with dedicated office accommodation and all necessary lab access and computing infrastructure. Depending on the funding source, special-purpose equipment, travel or other resources are provided. Where possible, students are collocated to support a lively student environment.

Training and Support

The DC offers a range of training courses in research and transferrable skills, such as project management, networking, career management, presentation skills, etc. Students evaluate with their supervisors which courses to take. Student members of Marie Curie training networks did benefit from additional training as part of the network, eg sessions in science communication, entrepreneurship, or the opportunity to organise a student-led conference.

Supervisory teams consist of a Director of Study and a second supervisor, but can have more members if an interdisciplinary research topic requires this. A further independent UoP

academic ('expert commentator') reviews progress at several junctures (initial proposal, transfer report, final thesis, viva). All supervisors are trained as required by the DC. Less experienced supervisors are paired with an experienced colleague.

Students are fully integrated into their Centres and the School's research environment. They partake in regular lab meetings, internal and external seminars, and the general international research culture. They benefit from interaction with national and international visitors to the School and have a representative on the School's research committee.

Progress Monitoring

Comprehensive monitoring procedures are in place overseen by the DC. Frequent informal meetings are complemented by formal three-monthly meetings, annual progress reports, and crucial milestones recorded in an online monitoring system (gradbook). The expert commentator provides critical scrutiny and guidance independent of the supervisory team. As progress permits, students transfer after 12 months from an MPhil to a PhD route.

3. Income, infrastructure and facilities

Our research environment is supported by state-of-the-art **Infrastructure and facilities**. Most researchers and all PGR students have generous office space in a modern building erected in 2002/03 that also features some of the Computing labs, lecture halls, large community areas and a cafeteria. Robotics and additional Networking and Security Labs are in buildings close-by (less than 5 minutes). The University is investing £50M into a new building that will host major parts of the School of Engineering, Computing and Mathematics from the start of the 2023/24 academic year. This will contain shared lab-spaces, teaching space, IT services and other facilities, notably a high-tech virtual engineering suite to which all research groups will have access. Our existing spaces in other buildings have been re-developed, with generous new space for Computer Gaming and an AR/VR laboratory.

CRNS labs are supported by three technicians. Equipment has been purchased through a combination of University infrastructure investments and project budgets. The Cognitive Robotics and Human-Robot Interaction Lab hosts an iCub humanoid baby robot, one of the most advanced platforms for research on cognitive robotics. **Metta**, who developed the iCub platform and is now director of the Italian Institute of Technology, held a 20% Professor post at UoP for 5 years in order to collaborate on joint projects (POETICON++, SECURE, BABEL). We also have five Nao Aldebaran humanoid robots used in HRI experiments (**Cangelosi, Belpaeme**), a MetraLab Scitos mobile platform for research on robot companions for the elderly (**Belpaeme, Gaudi**, link to UoP's Health and Care Research Institute), two manipulandum set-ups for motor neuroscience research (**Howard**), autonomous un-manned aerial and terrestrial vehicles for search and rescue (**Gianni**, linked to UoP's Marine Institute), and custom made low-cost robots for research into swarm robotics (**Millard, Gaudi**). CRNS runs an Nvidia lab of powerful workstations with in total 54 Tesla GPUs (**Gianni**) and in collaboration with Mathematics we have access to the School's 1024 core HPC Computer cluster for extensive simulations in Robot Learning (**Cangelosi, Wennekers**), Computational Neuroscience (**Borisjuk, Wennekers**) and BigData applications (**Walker, Palomino**). CRNS hosts other specialised equipment such as a Plankton Image Analyser system (**Culverhouse**) and an Information Visualisation Lab (**Stuart**).

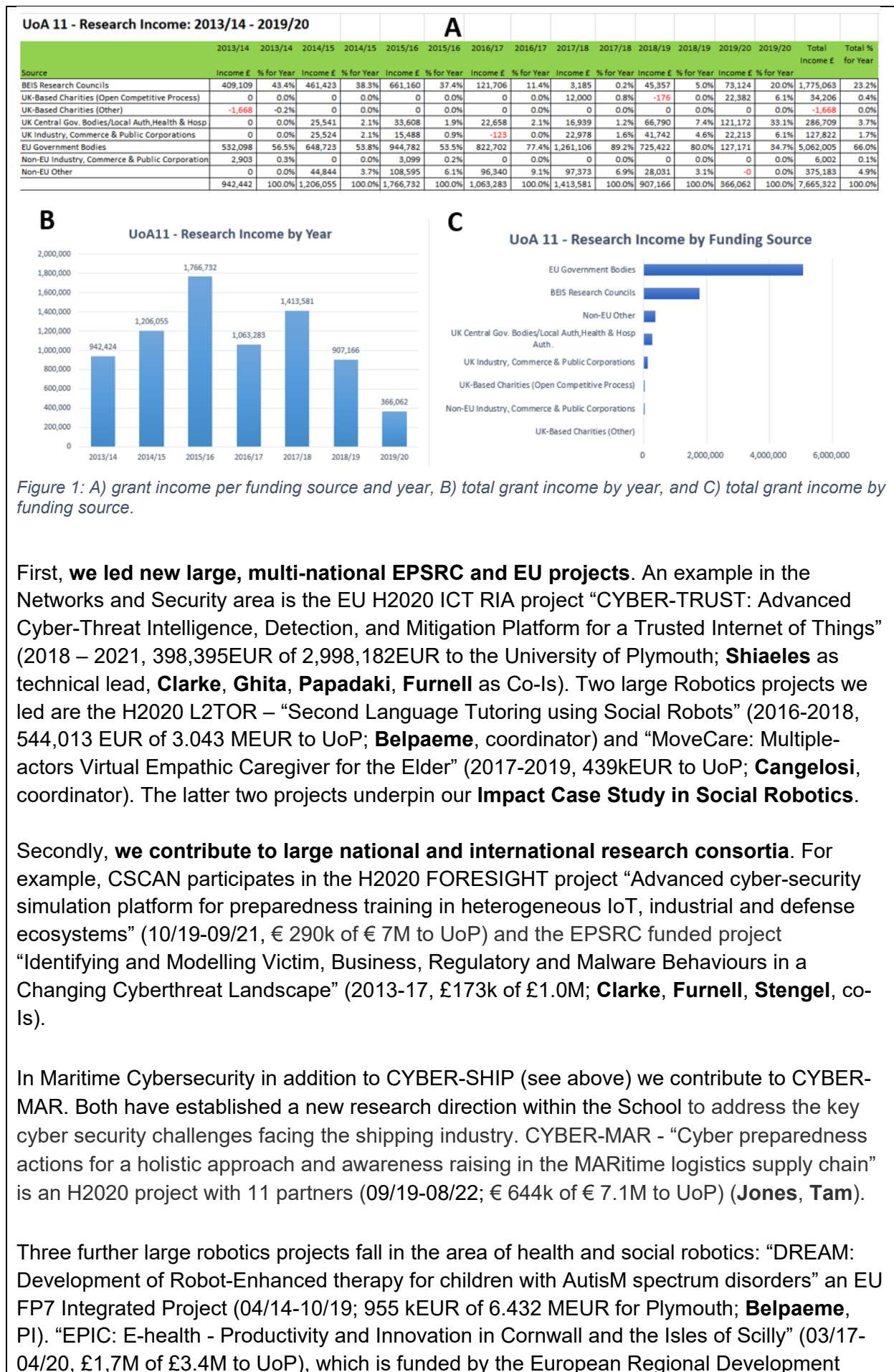
CSCAN also has an excellent modern technology infrastructure with several related computing facilities. The Cyber Security lab (**Clarke, Furnell, Papadaki**) is a 42-seat Security and Forensics laboratory, a custom-designed facility dedicated to activities relating to security research, related undergraduate and postgraduate teaching, and Capture-the-Flag activities. This facility represented an investment of over £200K when launched in October 2011; with additional investments of £40K in 2015 and £50K in 2019 to upgrade the computers and servers to a higher specification. All activities in the room are closely monitored utilising CCTV, traffic monitoring, firewalling, and extensive logging. Desktop PCs are controlled and audited with access to security toolkits provisioned through virtualisation (examples include hacking toolkits like Kali Linux, Social Engineering Toolset, and forensics tools as FTK). In addition, the School supports a separate Networks laboratory, which is used by the Cybersecurity students for their network technology modules. This facility has 40 seats, is equipped with £250K of Cisco and F5 networking and security equipment, and allows for a wide range of networking topologies to be deployed (covering LAN, wireless, ISP-customer-to-datacentre) as well as a lab cloud and datacentre infrastructure.

The Cyber-SHIP lab, linked with UoP's Marine Institute, is a new and unique national research facility designed to address key cyber security challenges facing the shipping industry (**Jones, Tam**) established in November 2019 through £3million funding from Research England and industry. Dedicated space in the Marine Building has been repurposed for the lab in close proximity to the full bridge navigation simulator. The lab brings together a host of connected maritime systems currently found on an actual ship's bridge, featuring cutting edge maritime technology including radar equipment, a voyage data recorder (VDR), an Electronic Chart Display and Information System (ECDIS), an automatic identification system (AIS) and communications devices. Experts in cyber security and information systems can now assess them for weaknesses, and identify the human and technological changes needed to make them secure for the future. The setup is unique world-wide, it engages 18 commercial UK partners and sees strong interest from overseas. <https://www.plymouth.ac.uk/research/cyber-ship-lab>

The University supports research through its administrative structures: The Research and Innovation team supports the preparation of grant applications and manages grants; the IP/commercialisation committee supports exploitation of IP rights up to part-funding start-up companies (eg **Stoelen's** spin-out company Fieldwork Robotics Ltd; <https://fieldworkrobotics.github.io/>); a new R&D fund is designed to stimulate industrial collaboration and knowledge transfer.

Research Income

During this REF period, the Unit has received significant **income** through new RCUK, EU and international grants. Figure 4 details funds received per academic year by funding source (A). Part B displays year totals and demonstrates a steady income of around £1.1M per year. The data for the 19/20 financial year ends in June.



Fund (ERDF) (**Cangelosi, Dahl, Belpaeme**) and EPIC 2, a follow-up of the EPIC project also funded by the ERDF (5/20-4/23, **Gaudi, Palomino, Clarke**, £4.1M to UoP).

Thirdly, we complement our income from large collaborative projects and postgraduate training networks (see below), by **standard grants** from EPSRC, BBSRC and other sources. Examples are the EPSRC BABEL project to study brain-inspired cognitive systems (to **Cangelosi** and **Wennekers**; £1.2M to UoP); the THRIVE robotics project funded by the *US Air Force Office of Science and Research (AFSOR-EOARD)*, to **Cangelosi** \$555k); or various projects from the Newton Trust (UK) and the European Regional Development Fund to **Stoelen** to develop agricultural robots (£338k). (The latter partly underpin our **Impact Case in Agricultural Robotics**.)

Fourthly, **we received significant funding for postgraduate training networks:**

2016-19 *EU H2020 Marie Skłodowska-Curie EID European Industrial Doctorate*, €1,345,614 (€819,863 to UoP) “APRIL: Applications of Personal Robotics for Interaction and Learning”. (Cangelosi as Coordinator/PI; **Belpaeme, Dahl** co-Is).

2016-19 *EU H2020 Marie Skłodowska-Curie ETN*, €546,573 “DCOMM: Deictic Communication”. **Cangelosi** PI, With K Coventry (U. East Anglia) as ETN coordinator, and 8 other partners.)

2015-18 *EU H2020 Marie Skłodowska-Curie ETN*, €546,573 “SECURE: Safety Enables Cooperation in Uncertain Robotic Environments”. (**Cangelosi, Metta** (UoP & IIT)).

2013-17 *EU FP7 Marie Curie Innovative Doctoral Program*, €4,077,315 (all to UoP) “COGNOVO: Cognitive Innovation” (PI S. **Denham**, with Co-Is **Cangelosi, Belpaeme, Borisyuk, Wennekers** et al.).

2015-18 *EU H2020 Marie Skłodowska-Curie ETN*, €547K “QoE-NE: innovative Quality Of Experience management in Emerging mulTimedia services” (**Sun**, co-I).

We further received several **prestigious European postgraduate Fellowships**.

2016-18 *EU FP7 Marie Curie Intra European Fellowship*, €183k “CAREER-AID: Controlled Autonomous Robot for Early diagnosis and Rehabilitation of Autism and Intellectual Disability”. **Cangelosi** PI, Daniela Conti as Fellow (grant awarded but transferred to Sheffield Hallam University).

2015-17 *EU FP7 Marie Curie Intra European Fellowship*, €195k “DOROTHY: Donating Robots a Theory of Mind”. **Belpaeme** PI, **Lamaignan** as Fellow.

2014-16 *EU FP7 Marie Curie Intra European Fellowship*, €231k “DeCoRo: Developmental Contextdriven Robot learning”. **Cangelosi** PI, **Stoelen** as Fellow.

2013-15 *EU FP7 Marie Curie Intra European Fellowship*, €221k “ORATOR: Integrating Object Recognition and ActiOn for action sentence production and comprehension in a developmental humanoid Robot”. **Cangelosi** PI, Beata Grzyb as Fellow.

These fellowships were all highly successful: **Stoelen** and **Lamaignan** received lecturer posts at UoP afterwards. **Stoelen** now shares his post in Plymouth with an Associate Professor post in Norway. **Lamaignan**, Conti and Grzyb are currently research associates at Bristol University, Sheffield Hallam University and UCL, respectively.

Finally, we use **enterprise-focused grants** for research development and proof-of-concept innovative projects. These can be third-stream projects that generate applied research funded by external, non-academic partners of the University of Plymouth Enterprise Limited. Examples are a *Honda European Graduate Network* funded by Honda (Offenburg, Germany) for £93,176, 2017-20, a UoP grant to set-up Fieldwork Robotics Ltd, 2017 a spin-out company led by **Stoelen** (£50k), and proof-of-concept funding to **Stoelen** and **Howard**.

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

Our research strategy puts strong emphasis on national and international collaborations to maximise impact. We contribute extensively to our research communities through the full spectrum of available measures like conference organisation and chairing, editorial and reviewing activity, or membership of learned societies and outreach activities.

Co-authorship is a direct measure of our intensive collaborations and their impact on visibility. Table 2 shows that almost all our publications (98.1%) present collaborative work of which almost two thirds (62%) are with international co-authors. The vast majority (96.5%) are outputs from academic collaborations. With a field-weighted citation index (FCWI) of 1.71 they are cited more than 70% more frequently than an average paper in our field.

Table 2: Collaboration data derived from all publications of the unit (1121 publications)

Collaboration type	%	Scholarly	Citations	FCWI
Data from Scopus (up to 10 Nov 20)	outputs	outputs		
International collaboration	61.6	691	8207	1.91
National collaboration only	15.4	173	1064	1.34
Institutional collaboration only	21	236	2155	1.67
Single authorship (no collaboration)	1.9	21	30	0.32
Academic-corporate collaboration	3.5	39	324	2.25
No academic-corporate collaboration	96.5	1082	11132	1.73

International Collaboration

As the previous section details we have **led major collaborative and agenda-setting programmes** in all our target areas of research. **Cangelosi** and **Belpaeme** attracted many large international grants in robotics (APRIL, MoveCare, CAREER-AID, SECURE, THRIVE, among others) that firmly established our world-leading role in humanoid cognitive robotics and social and health-care robotics. **Belpaeme** and **Gaudi** will develop this line of research in the future in collaboration with the Centre for Health Technology (**Jones**; EPIC, EPIC2 projects) (<https://www.plymouth.ac.uk/research/centre-for-health-technology>).

Members of CSCAN (**Shiaeles**, **Furnell**, **Clarke**, and **Stengel**) collaborated with national experts on the EPSRC project "Identifying and Modelling Victim, Business, Regulatory and Malware Behaviours in a Changing Cyberthreat Landscape" and also, internationally, on the H2020 FORESIGHT project: "Advanced cyber-security simulation platform for preparedness training in heterogeneous IoT, industrial and defense ecosystems". These projects aim at tackling the ever growing Cybercrime threat in the UK and worldwide.

The CYBER-Ship lab is a national capability that engages researchers from throughout the University (**Jones** and **Tam** from the Maritime Cyberthreat Research group, members of CSCAN, Psychology, Maritime Law and Economics, Navigation and Maritime Science) as

well as 18 commercial partners. It is accessible by national and international experts and is actively seeking further collaborations with academic and industry partners. Few locations worldwide bring together a similarly broad infrastructure and expertise to explore maritime cyber-security. We therefore expect this new group to flourish and gain extensive visibility and strong impact quickly.

Much of **our research is interdisciplinary**, especially, in Computational Neuroscience (**Wennekers, Borisyuk, Howard, Merrison-Hort**) or the growing fields of Health and Social Robotics see EPIC/EPIC2 (**Gaudi, Belpaeme**); ORE (**Walker, Gianni**) as well as autonomous systems (collaborations with Mechanical Engineering). Here we benefit from the university's institute structure: marine (ORE), health (health and social robotics) and sustainability (agritech). **Howard** recently contributed to highly influential research on Morality and Creativity with colleagues in the School of Psychology. These studies would not have been possible without his expert input on haptic and 3D visualisation technologies, and his expertise in human Psychophysics. **Borisyuk** further led high impact interdisciplinary research on central pattern generators in collaboration with Roberts and Soffe (UWE Bristol). This work is important for future bio-inspired embodied robots with small (tadpole) brains and featured on the front page of the Journal of Neuroscience. **Wennekers** collaborated on large-scale human-like neural models with **Cangelosi** (then UoP), **Pulvermueller** (Freie Universitaet Berlin), **Garagnani** (Goldsmiths) and **Furber** (University of Manchester) to understand language learning in humans. This work aimed at neural language models for humanoid robots that make use of the SpiNNaker architecture to reach real-time performance. This led to new spiking neuron algorithms and implementations on iCub, iCub simulator and SpiNNaker boards. **Belpaeme** and **Gaudi** further collaborated locally with the eHealth research group on robots in health care (EPIC and EPIC2 grants). This collaboration is central to one of our impact cases.

A focus of high-impact activity are the Marie Curie **international training networks** we run or contributed to: APRIL, DCOMM, SECURE and COGNVO. These allowed us to dive into research topics at the frontier of science and steer the respective research agendas. Many of our postgraduate students and fellows on these projects have chosen a career in science, where they can contribute to their fields further. In particular, COGNVO (<https://cognovo.eu/>) was a highly interdisciplinary, extremely successful EU Innovative Training Network established at UoP that aimed at exploring Creativity and Behavioural Change from the widest variety of perspectives. 13 EU fellows and 12 PhD students (additionally funded by UoP) collectively engaged on this endeavour. Members from UoA11 (**Borisyuk, Wennekers, Cangelosi, Wennekers, Howard, Bugmann**) supervised 6 students on Robotics and Computational Neuroscience topics, and were on the supervisory teams of 8 others. The ITN finished in 2017 and was exceptionally successful. Several of the fellows have permanent academic posts already.

We have also developed strong interdisciplinary collaborations with colleagues in the Marine and Health Institutes. **Howard, Borisyuk, Wennekers, Cangelosi** and **Belpaeme** work and publish frequently with members of the School of Psychology. **Belpaeme, Gaudi, Clarke** and **Palomino** cooperate closely with the research group for eHealth. **Culverhouse, Jones** and **Tam** have strong links to the Marine Institute, and members of the Autonomous Marine Systems Group (which are submitted to UoA12) are associated members of the CRNS. The interdisciplinary nature of our research is visible in many of our submitted outputs.

Staff in UoA11 are actively engaged in **Conference Organisation and Chairing**.

Wennekers organised and chaired MSBDy17 (with Achermann, Zurich, and Olbrich, Leipzig) “Brain dynamics on multiple scales, their dynamics, and integrated approaches (June 2017, sponsored with 18kEUR by the Max Planck Institute for Complex Systems. **Cangelosi** and **Belpaeme** acted as general and co-Chair of the IEEE ICDL-EPIROB conferences 2017 in Lisbon and 2018 in Tokyo. They also co-directed the “APRIL Summer School”, 10-13 July 2016, Cefalù, Italy. **Belpaeme** was further co-director (with Bram Vanderborght, Vrije Universiteit Brussel) and **Thill** (University of Plymouth / Radboud University, Netherlands) of the 2nd and 3rd International Summer Schools on Social Human-Robot Interaction, 2017, in Portugal and 2015, in Finland. **Furnell** has co-chaired five instances of the *International Conference on Information Systems Security and Privacy (ICISSP)* and **Sun** was symposium co-chair for Communication Software, Services and Multimedia Applications (CSSMA) at IEEE ICC 2019, Shanghai, China and at IEEE ICC 2014, Sidney, Australia. **Walker** has chaired the annual *Visualisation in Genetic and Evolutionary Computation* workshop (held at ACM’s GECCO) since 2012. In addition, staff were co-organising Chairs / PC chairs of over 20 other conferences and workshops and served on the programme committees of another 60+ workshops and conferences within the reporting period.

Members of the unit gave 10+ **keynote lectures** at international conferences. Examples include **Furnell**: “Cybersecurity Illiteracy”, 18th Annual Security Conference, Las Vegas, USA, 30 April 2019. **Clarke**: “Is Digital Forensics a Necessity for Organisations?”, University of Nevada (Reno), May 2019. **Belpaeme**: Keynote at Joint IEEE International Conference on Development and Learning and on Epigenetic Robotics 2018, Tokyo, Japan. **Cangelosi**: Intrinsically Motivated Open-ended Learning Workshop. Rome, 2017. This is in addition to more than 30 other **invited presentations** at conferences and 100+ further invited academic talks.

Journal editorships: CRNS staff contribute as editors-in-chief and associate editors to more than 20 journals, including major IEEE and open access journals. A selection of these are Editor-in-Chief of “Interaction Studies” (**Cangelosi**) and “IEEE Transactions in Autonomous Mental Development” (**Cangelosi**), “Information and Computer Security” (**Furnell**), associate editorship of “Neural Networks” (**Borisjuk**), “PLOS one” (**Wennekers**), “Ecological Informatics” (**Culverhouse**), “Frontiers Neuroinformatics” (**Wennekers**), Frontiers Computational Neuroscience (**Wennekers**), Entertainment Computing (**Belpaeme**), International Journal of Advanced Robotic Systems (**Belpaeme**), Computers and Security (**Clarke, Furnell**), The Computer Journal (Oxford)(**Furnell**). All staff engage in regular peer-review of journal articles.

Our staff serve their communities by taking multiple roles in **disciplinary associations and learned societies**: **Jones** serves as chair of UKCRC Membership Committee and BCS Appeals Committee. He is also member of UKCRC Exec and the BCS Academy Board. **Furnell** is member of the annual Wilkes Award Committee for The Computer Journal. He was lead contributor to the design of academic degree certification programmes for the National Cyber Security Centre, as well as a contributor to the international Cybersecurity Curricula Guidelines from the ACM/IEEE Joint Task Force. As an Associate of the Oxford Martin School, University of Oxford, **Furnell** contributed to two working groups (*Building Cyber Skills and Leadership* and *Controlling Risks Through Technology and Processes*) within the Global Cyber Security Capacity Centre. **Sun** served as Vice-Chair for the IEEE Communications Society, Multimedia Communications Technical Committee; **Walker** on the IEEE Task force on Many Objective Optimization; and **Gaudi** as general committee member and editor for the Society for the Study of Artificial Intelligence and Simulation of Behaviour (AISB).

Several colleagues are IEEE Senior or Regular Members (**Jones, Belpaeme, Clarke, Cangelosi, Stoelen, Sun**); Members of the ACM (**Furnell, Jones, Stoelen**); Fellows of the British Computing Society (**Jones, Clarke, Furnell, Cangelosi**); a Fellow of the Institution of Engineering and Technology (**Jones**) or members of more than ten other recognised organisations. Four are members of the EPSRC peer review college (**Jones, Belpaeme, Cangelosi, Borisjuk**), three review for the BBSRC (**Howard, Borisjuk, Wennekers**) and all staff act as regular referees of other national, EU and overseas projects by international funding agencies. Senior members served extensively as external PhD examiners (**Belpaeme, Borisjuk, Cangelosi, Clarke, Furnell, Sun, Wennekers**). **Wennekers** was external reviewer for the foundation of an MSc in Computational Cognitive Neuroscience at Goldsmiths.

Community and Outreach

Examples of **wider contributions** to the economy and society includes **Furnell's** contribution to the development of the Chartered Institute of Information Security new skills framework for information security professionals. The framework led to a change in work-based practice in the public and private sector (eg BT, AXA, GSK). The National Technical Authority at GCHQ has used it to underpin its Certified Cyber Professional Scheme.

Stoelen is collaborating closely with local groups in Devon and Cornwall to develop agri-robotic harvesting systems. On a wider scale he provides open access to his low-cost Gummi Arm technology (<https://mstoelen.github.io/GummiArm/>).

Stuart pushed forward a project with University hospitals Plymouth NHS Trust on data visualisation in the clinical environment, and **Wennekers** worked with the Westcountry River Trust to implement a data collection and visualisation system for their extended sensor networks.

Members of the unit are active in outreach, with school visits and several activities brought regularly to events such as open days, showcases and science festivals. For example, **Belpaeme, Cangelosi** and **Gaudi** use nao-robots for social robotics and health-care demonstrations and **Gaudi** evolved gaming, VR and multi-media applications to feature at public events.

The School hosts the **Computing at Schools Regional Centre** for the South West, which aims at establishing Computing firmly in all primary and secondary schools (<https://www.plymouth.ac.uk/about-us/university-structure/faculties/science-engineering/cas-regional-centre-south-west>)

We are also actively engaged in the **British Computer Science Society** where **Palomino** chairs the South West branch (<https://www.bcs.org/membership/member-communities/south-west-branch/south-west-branch-committee/>)

Finally, various research projects attracted a large amount of press interest, notably our impact cases about social robotics and agritech (**Stoelen & Howard; Cangelosi, Belpaeme & Gaudi**).