POST-DIGITAL - European Training Network on Post-Digital Computing [GA860360]

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Project Details

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EXECUTIVE SUMMARY

The Summer School "Novel Nonlinear Substrates for Neural Networks" was organised by the POST-DIGITAL beneficiaries Université de Franche-Comté, Thales and Université libre de Bruxelles and was held as a hybrid event from **15 to 17 September 2021 on the premises of FEMTO-ST in Besancon.**
The three-days Summer school consisted of several meetings and a training:
-an internal Tutorial on conceptors for POST-DIGITAL ESRs held by Prof Herbert Jaeger from University of Groningen with discussion
- talks of external speakers
- presentations from POST-DIGITAL ESRs on their research projects with discussion

We were especially pleased to be able to engage internationally renowned leading scientists and high-profile speakers to the Summer school including Prof Natalia Berloff (University of Cambridge), Prof Bhavin Shastri (Queen's University, Canada), Prof Alexander Khajetoorians (Radboud University Nijmegen, NL) and Prof Masaya Notomi (Tokyo Institute of Technology, Japan).

Publicised widely via a dedicated webpage on the POST-DIGITAL website and social media, the Summer school attracted more than 50 participants from different organisations. All 15 POST-DIGITAL ESRs took part in the event and we are happy that 11 POST-DIGITAL ESRs and representatives of 4 beneficiaries could take part in the event in person. After more than a year of online contacts and virtual events the Summer school in Besancon was a very special and positive experience for our ESRs and a crucial step in consolidating the student cohort and facilitating networking among the consortium.

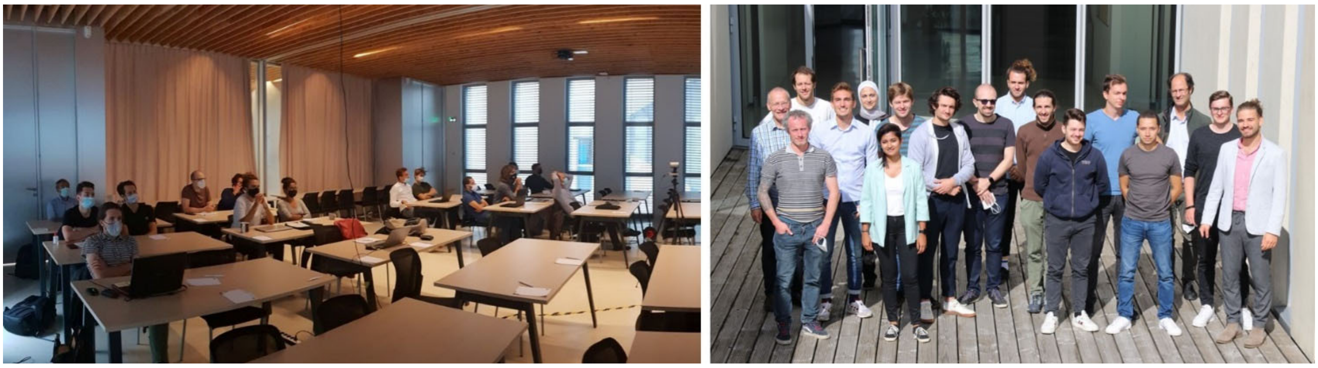

Figure 1 Participants of Summer school in FEMTO-ST, Besancon

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LIST OF ACRONYMS

EC	European Commission
ESR	Early Stage Researcher
ETN	European Training Network
POST-DIGITAL	Project 'POST-DIGITAL - European Training Network on Post-Digital Computing' EC GA 860360
ULB	Université libre de Bruxelles
UBFC	Université de Franche-Comté

1 SUMMER SCHOOL "NOVEL NONLINEAR SUBSTRATES FOR NEURAL NETWORKS"

The Summer School **"Novel Nonlinear Substrates for Neural Networks"** was held between **15 and 17 September** on the premises of **FEMTO-ST in Besancon, France**.

Because of the ongoing COVID-19 pandemic the Summer school was originally planned as an online event but due to the great interest of the POST-DIGITAL ESRs to meet the project team in person it was re-organised as a hybrid event which was possible thanks to the project beneficiary UBFC and the key organiser Dr Daniel Brunner. Although some of the POST-DIGITAL team members could meet during the Summer school in Trento in June 2021, the Summer school in Besancon was officially the first consortium meeting as 11 POST-DIGITAL ESRs and representatives from 4 project beneficiaries took part in it. We used this opportunity to co-locate several activities like a two-days module with talks from external speakers; presentations from the POST-DIGITAL ESRs on their individual projects followed by discussions; a training module on conceptors organised by Prof Herbert Jaeger from University of Groningen and social events for the project team in form of a daily common lunch of all participants and a workshop dinner. This event initiated some interesting research collaborations and it is pleasant to see how enthusiastic the POST-DIGITAL ESRs are to cooperate with other researchers within the POST-DIGITAL consortium and other organisations.
More about the tutorial in conceptors held by Prof Herbert Jaeger from University of Groningen in the framework of the Summer school in Besancon will be presented in the deliverable report M6.4.
In the following report we will focus on the first two days of the Summer school which included talks from external speakers and discussions on the POST-DIGITAL individual projects.

1.1 EXTERNAL SPEAKERS ON THE SUMMER SCHOOL "NOVEL NONLINEAR SUBSTRATES FOR NEURAL NETWORKS"

High calibre external speakers accepted invitations to present on the Summer school in Besancon: **Dr Alice Mizrahi** (Thales), **Prof. Natalia Berloff** (University of Cambridge), **Prof Bhavin Shastri** (Queen's University), **Prof Alexander Khajetoorians, (**Radboud University Nijmegen**), Prof Masaya Notomi,** NTT Basic Research Laboratories / Tokyo Institute of Technology and **Matteo Cucchi** (Technische Universitaet Dresden).

Dr Alice Mizrahi, Thales, France

Alice Mizrahi is a researcher at the joint CNRS/Thales lab within Thales Research and Technology. She received her PhD in Physics in 2017 from the "Université Paris Saclay". Her thesis, done partly at Unité Mixte de Physique CNRS/Thales and partly at the Center for Nanoscience and Nanotechnology, focused on the use of stochastic magnetic tunnel junctions as artificial neurons. She broadened her interest to swarm intelligence and memristors during her joint appointment as postdoctoral researcher at the National Institute of Standards and Technology and the University of Maryland, in the United States. Late 2018, she joined Thales Research and Technology to develop hardware for artificial intelligence.

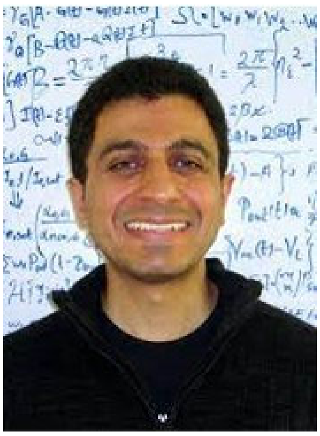
Prof Natalia Berloff, University of Cambridge, UK

Natalia Berloff is Professor of Applied Mathematics at the Department of Applied Mathematics and Theoretical Physics at University of Cambridge. She leads the Quantum Fluids Group with research interests in coherence in non-equilibrium quantum systems, superfluidity, quantum fluids, Bose-Einstein condensates, quantum simulators based on atomic and solid-state condensates. Natalia Berloff received her undergraduate degrees from the Lomonosov Moscow State University, Ph.D. from Florida State University, and held a faculty position at the University of California in Los Angeles before joining the University of Cambridge in 2002.

Prof Masaya Notomi, NTT Basic Research Laboratories / Tokyo Institute of Technology

Masaya Notomi received B.E., M.E., and Ph.D. degrees in applied physics from the University of Tokyo, Japan, in 1986, 1988, and 1997, respectively. In 1988, he joined NTT. Since then, his research interest has been to control the optical properties of materials/devices by artificial nanostructures (quantum wires/dots and photonic crystals). He is a Group Leader of Photonic Nanostructure Research Group and a Senior Distinguished Scientist with NTT Basic Research Laboratories. He is also a Guest Professor of Tokyo Institute of Technology. Prof. Notomi is a Member of the Japan Society of Applied Physics, American Physical Society, and Optical Society of America. He is serving as a Member of the National University Corporation Evaluation Committee in the Japanese government.

Prof Bhavin Shastri, Queen's University, Canada



Bhavin J. Shastri is an Assistant Professor of Engineering Physics at Queen's University, Canada. He earned the Honours B.Eng. (with distinction), M.Eng., and Ph.D. degrees in electrical engineering (photonics) from McGill University, Canada, in 2005, 2007, and 2012, respectively. He was an NSERC and Banting Postdoctoral Fellow (2012-2016) and an Associate Research Scholar (2016-2018) at Princeton University. With research interests in silicon photonics, photonic integrated circuits, neuromorphic computing, and machine learning, he has published more than 50 journal articles and 70 conference proceedings, 4 book chapters, and given over 35 invited talks and lectures including 2 Keynotes.

Prof Alexander Khajetoorians, Radboud University Nijmegen, The Netherlands:

Alexander Khajetoorians is Professor of Scanning Probe Microscopy within the Institute for Molecules and Materials at the Radboud since 2014. He studied Physics and Applied Mathematics at the University of California, Berkeley. Here he worked as a research and teaching assistant. From 2006 to 2008 Khajetoorians worked as a trainee with a fellowship from the National Science Foundation in the Department of Physics at the University of Texas, Austin. In 2008 he obtained his PhD on research focusing on Alkali adsorbates on quantum thin metal films.

After his PhD, Alexander Khajetoorians went to the University of Hamburg to work at the Institute of Applied Physics. He has been awarded numerous prizes including the Gerhard Ertl Young Investigator Award in 2012 and the Nicholas Kurti Prize in 2014. Since 2013, he was awarded an Emmy Noether Research group by the DFG, and is internationally renowned for his work on single spin detection and manipulation of atomic magnetic structure.

Matteo Cucchi, Technical University Dresden, Germany:

Matteo Cucchi is working in Dresden Integrated Center for Applied Physics and Photonic Materials (IAPP) in the group of Prof. Karl Leo.

Matteo obtained his Bachelor degree in Material Science from the University of Rome in 2015 and his Master’s degree in Organic and Molecular Electronics from the Technische Universitaet Dresden in 2018.

1.2 Topics and Abstracts

- Spin-torque oscillators for neuromorphic computing, **Dr Alice Mizrahi, Thales**

Spintronic devices exhibit a wide range of functionalities that are promising for neuromorphic computing. In particular, spin torque oscillators can act as artificial neurons due to their non-linear dynamics. In this talk Alice provided several paths to leverage the non-linear dynamics of spin torque oscillators for computing, as well as describe the challenges that need to be addressed. She focused on a particular architecture pushed by her research group, a neural network where the spin torque neurons and synapses are connected through radiofrequency signals.

- Optoelectronic Accelerators based on Integrated Nanophotonics, **Prof Masaya Notomi,** Tokyo Institute of Technology

Optical computing has reappeared on the stage of research and is expected to break the limitation of CMOS processors, especially for analog computations. To fully utilize the merit of optics in computing, however, it is essentially important to combine optic and electronic circuits very efficiently. Here we show that integrated nanophotonics enables extremely-efficient optical-to-electrical and digital-to-analogue conversion. We also show how to implement them in optoelectronic accelerators enabling ultralow-latency computations.

- What can we 'learn' from atoms? Going beyond neuromorphics **Prof Alexander Khajetoorians,** Radboud University Nijmegen

The quest to implement machine learning algorithms in hardware has focused on combining various materials, each mimicking a computational primitive, to create device functionality. These endeavors have led to the beautiful development of dedicated hardware that, working in combination with software, can perform pattern recognition tasks. Ultimately, these piecewise approaches limit functionality and efficiency, while complicating scaling and on-chip learning, necessitating new approaches linking physical phenomena to machine learning models. Likewise, this raises the question if there are new machine learning algorithms to be discovered, utilizing the particular properties of quantum properties of matter where there are no obvious links to established models. In his talk Prof Khajetoorians discussed the first steps toward a new paradigm in computing, routed in fundamentals studies based on the idea of letting the physics do the work. He introduced the concept of an atomic orbital memory and how coupling leads to tunable multi-modal landscapes. He discussed how the ensuing stochastic dynamics mimics the Boltzmann machine, scaled to just seven atoms. In this discussion, Prof Khajetoorians reviewed the emergence of multiple and separable time scales, an adaption of long-term potentiation in biological matter, which serves the basis for self-adaption and on-chip learning. He concluded with an outlook on concepts that go beyond the current neuromorphic paradigm, combining concepts related to quantum coherent and quantum technologies.

- Unconventional computing with liquid light, **Prof Natalia Berloff,** University of Cambridge

The recent advances in developing physical platforms for solving combinatorial optimisation problems reveal the future of high-performance computing for quantum and classical devices. Unconventional computing architectures were proposed for numerous optical systems, including parametric oscillators, memristors, lasers and nanolasers, optoelectronic systems, photonic simulators, trapped ions, polariton and photon condensates. A promising approach to achieve computational supremacy over the classical von Neumann architecture explores classical and quantum hardware as Ising and XY machines. Gain-dissipative platforms such as the networks of optical parametric oscillators, coupled lasers and non-equilibrium Bose-Einstein condensates such as exciton-polariton or photon condensates use an approach to finding the global minimum of spin Hamiltonians which is different from quantum annealers or quantum computers. In her talk, Prof Berloff discussed the principles of the operation of the devices based on such systems, the challenges they present, and the question of comparing different platforms' performance.

- Silicon photonics for neuromorphic computing and artificial intelligence,**Prof Bhavin Shastri,** Queen's University, Canada:

Artificial intelligence enabled by neural networks has enabled applications in many fields (e.g. medicine, finance, autonomous vehicles). Software implementations of neural networks on conventional computers are limited in speed and energy efficiency. Neuromorphic engineering aims to build processors in which hardware mimic neurons and synapses in brain for distributed and parallel processing. Neuromorphic engineering enabled by silicon photonics can offer sub nanosecond latencies, and can extend the domain of artificial intelligence and neuromorphic computing applications to machine learning acceleration (vector-matrix multiplications, inference and ultrafast training), nonlinear programming (nonlinear optimization problem and differential equation solving) and intelligent signal processing (wideband RF and fiber-optic communications). In his talk Prof Shastri discussed current progress and challenges of neuromorphic photonics to scale to practical system.

- Dendritic organic electrochemical networks for implantable bioelectronics and reservoir computing **Matteo Cucchi,** Technical University Dresden

Early detection of malign patterns in patients' biological signals can save millions of lives. Despite the steady improvement of AI-based techniques, the practical clinical application of these methods is mostly constrained to an offline evaluation of the patients' data. Previous studies have identified organic electrochemical devices as ideal candidates for biosignal monitoring. However, their use for pattern recognition in real-time was never demonstrated. I will present the production, characterization, and use of brain-inspired networks composed of organic electrochemical transistors for time-series predictions and classification tasks using the reservoir computing approach.

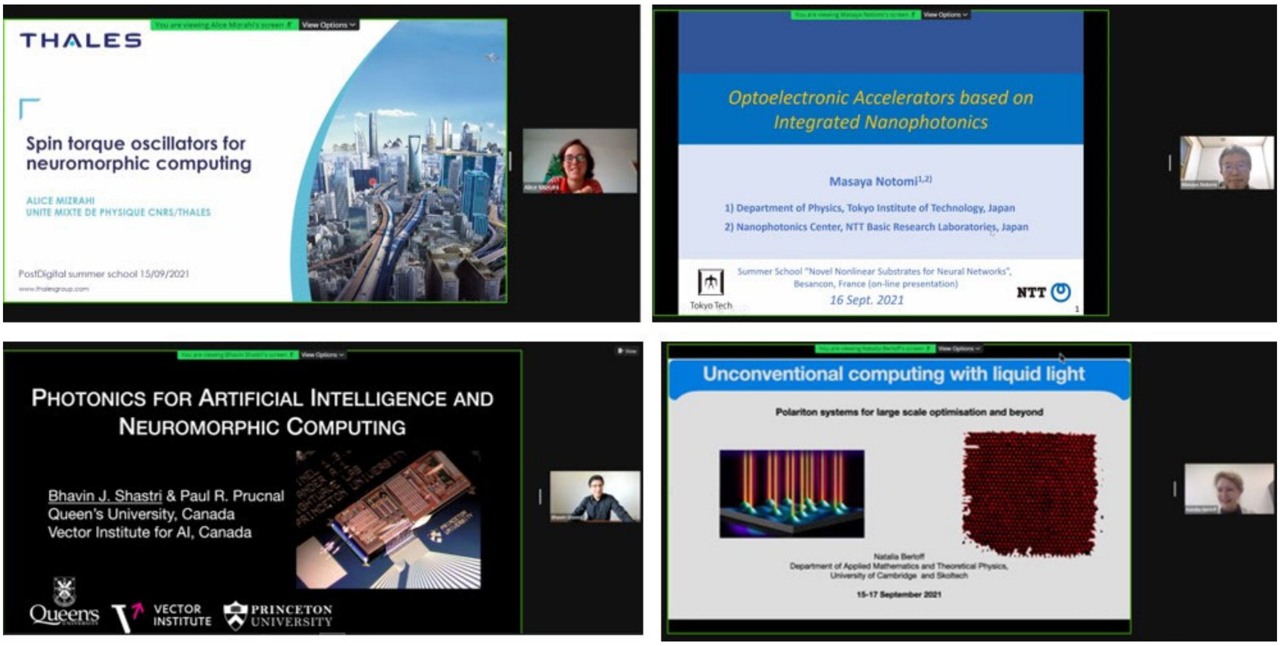


Figure 2 Presentations on the Summer School "Novel Nonlinear Substrates for Neural Networks"

1.3 POST-DIGITAL ESRS' PRESENTATIONS, NETWORKING

Although the Summer School "Novel Nonlinear Substrates for Neural Networks" was an open event, an important goal was to give the POST-DIGITAL consortium the opportunity to meet in person and thus to facilitate the close exchange between our researchers. It was especially pleasing to see that the POST-DIGITAL ESRs are very interested in meeting face to face and initiated the organisation of a hybrid event. All 15 POST-DIGITAL ESRs took part in the Summer School, (11 joined it in person, 4 ESRs took part online).

11 POST-DIGITAL ERSs joined the Mini-Symposium on the premises of FEMTO-ST:

Steven Abreu (Groningen)
Anas Skalli (UBFC)- assistant organiser
Mirko Goldman (CSIC)
Daniel Hesslow (LigntOn)
Tigers Jonuzi (VLC Photonics)
Lucas Talandier (CSIC)
Guillaume Pourcel (Groningen)
Enrico Picco (ULB)
Ivan Boikov (Thales)
Sarah Masaad (IMEC)
Alessandro Lupo (ULB)

4 POST-DIGITALL ESRs joined the event online:

Diego Arguello Ron (Aston)

Long Hoang Nguyen (Aston)

Benedikt Vettelschoss (IMEC)

Elger Vlieg (IBM)

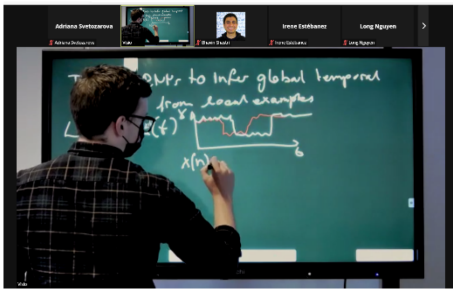


Figure 3. Mirko Goldmann (CSIC) presenting his project topic

Several POST-DIGITAL ESRs have presented different problems from their project subjects and initiated very constructive discussions and brainstorming which resulted in some very promising collaborations like the collaboration between Alessandro Lupo, ULB and Tigers Jonuzi, VLC Photonics on implementation of frequency multiplexed reservoir computers in InP photonic integrated circuits.

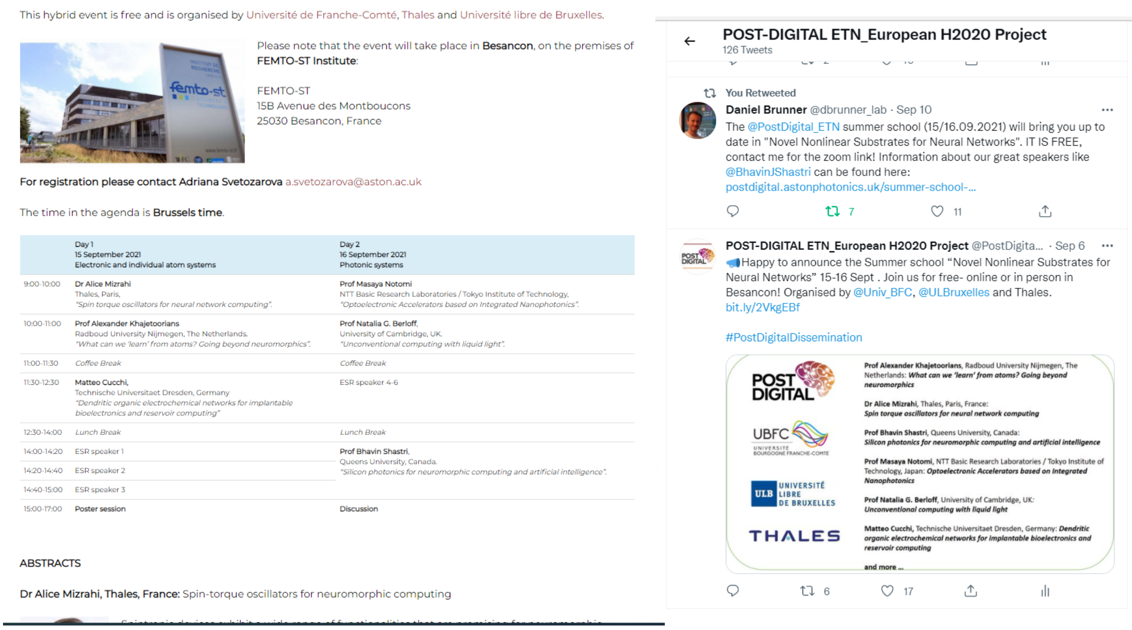
The following POST-DIGITAL ESRS initiated brainstorming on different topics:

Alessandro Lupo (ULB)
Daniel Hesslow (LightOn)
Guillaume Pourcel (Groningen)
Mirko Goldmann (CSIC)
Tigers Jonuzi (CSIC)
Anas Skalli (UBFC)
Enrico Picco (ULB)
Ivan Boikov (Thales)
Steve Abreu (Groningen)

Figure 4 Steven Abreu (Groningen) presenting his project topic on the Summer school in Besancon

1.4 WEBSITES AND SOCIAL MEDIA

The Summer School “Novel Nonlinear Substrates for Neural Networks” was presented on the website of the project POST-DIGITAL, providing information about the programme and the speakers on the event. In addition, the invitation to the Summer school was widely advertised through personal contacts, mailing lists and social media, such as Twitter. This resulted in more than 50 participants on the Summer school (more than 30 online participants and more than 20 participants on the premises of FEMTO-ST in Besancon).



This hybrid event is free and is organised by Université de Franche-Comté, Thales and Université libre de Bruxelles.

Please note that the event will take place in **Besancon**, on the premises of **FEMTO-ST Institute**:

FEMTO-ST
15B Avenue des Montboucons
25030 Besancon, France

For registration please contact Adriana Svetozarova a.svetozarova@aston.ac.uk

The time in the agenda is **Brussels time**.

	Day 1 15 September 2021 Electronic and individual atom systems	Day 2 16 September 2021 Photonic systems
9:00-10:00	**Dr Alice Mizrahi** Thales, Paris, *“Spin torque oscillators for neural network computing”.*	**Prof Masaya Notomi** NTT Basic Research Laboratories / Tokyo Institute of Technology, *“Optoelectronic Accelerators based on Integrated Nanophotonics”.*
10:00-11:00	**Prof Alexander Khajetoorians** Radboud University Nijmegen, The Netherlands. *“What can we ‘learn’ from atoms? Going beyond neuromorphics”.*	**Prof Natalia G. Berloff,** University of Cambridge, UK. *“Unconventional computing with liquid light”.*
11:00-11:30	*Coffee Break*	*Coffee Break*
11:30-12:30	**Matteo Cucchi,** Technische Universitaet Dresden, Germany *“Dendritic organic electrochemical networks for implantable bioelectronics and reservoir computing”*	ESR speaker 4-6
12:30-14:00	*Lunch Break*	*Lunch Break*
14:00-14:20	ESR speaker 1	**Prof Bhavin Shastri,** Queens University, Canada. *“Silicon photonics for neuromorphic computing and artificial intelligence”.*
14:20-14:40	ESR speaker 2	
14:40-15:00	ESR speaker 3	
15:00-17:00	**Poster session**	**Discussion**

ABSTRACTS

Dr Alice Mizrahi, Thales, France: Spin-torque oscillators for neuromorphic computing

POST-DIGITAL ETN_European H2020 Project
126 Tweets

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Daniel Brunner @dbrunner_lab · Sep 10
The @PostDigital_ETN summer school (15/16.09.2021) will bring you up to date in "Novel Nonlinear Substrates for Neural Networks". IT IS FREE, contact me for the zoom link! Information about our great speakers like @BhavinJShastri can be found here: postdigital.astonphotonics.uk/summer-school-...
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POST-DIGITAL ETN_European H2020 Project @PostDigita... · Sep 6
Happy to announce the Summer school “Novel Nonlinear Substrates for Neural Networks” 15-16 Sept . Join us for free- online or in person in Besancon! Organised by @Univ_BFC, @ULBruxelles and Thales.
bit.ly/2VkgEBf

#PostDigitalDissemination

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Figure 5 Summer School “Novel Nonlinear Substrates for Neural Networks” on the POST-DIGITAL website and on Twitter