The SMARTHEP European Training Network

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Abstract. **S**ynergies between **MA**chine learning, **R**eal-**T**ime analysis and **H**ybrid architectures for efficient **E**vent **P**rocessing and decision making (SMARTHEP) is a European Training Network with the aim of training a new generation of Early Stage Researchers to advance real-time decision-making, effectively leading to data-collection and analysis becoming synonymous.
SMARTHEP will bring together scientists from the four major LHC collaborations which have been driving the development of real-time analysis (RTA) and key specialists from computer science and industry. By solving concrete problems as a community, SMARTHEP will bring forward a more widespread use of RTA techniques, enabling future HEP discoveries and generating impact in industry. The students will contribute to European growth, leveraging their hands-on experience machine learning and accelerators towards concrete commercial deliverables in fields that can most profit from RTA, such as transport, manufacturing, and finance.
This contribution presents the training and outreach plan for the network, as well as some of its early results, and is intended as an opportunity for further collaboration and feedback from the CHEP community.

1 Introduction

The **S**ynergies between **MA**chine learning, **R**eal-**T**ime analysis and **H**ybrid architectures for efficient **E**vent **P**rocessing and decision making (SMARTHEP) European Training Network is a European Union Horizon-funded training network, with a focus on the real-time analysis techniques deployed in high energy physics (HEP) research and in industry. The network centres around 12 doctoral students across Europe employed as Early Stage Researchers (ESRs) within the Marie Skłodowska-Curie Actions (MSCA) framework. The network commenced in September 2021 and will conclude in September 2025, with each ESR position spanning the 3 years from September 2022 to September 2025.

This proceedings sets out the principles, approach and work of the SMARTHEP network, as presented on 9th May 2023 at CHEP2023.

2 SMARTHEP as a European Training Network

SMARTHEP is organised as a European Training Network, funded through the 2020 EU Horizon funding call. The primary aim of the network is to train 12 ESRs, whilst build-

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ing synergies between HEP and industry. The network takes a novel approach to building such synergies, structuring each ESR position (a 3 year period of doctoral study) around secondments in both HEP and industry. To achieve this, the network is formed of a series of partnerships between universities, research institutes and organisations in industry, as listed in Table 1.

Table 1. The 18 organisations which form the SMARTHEP network, listed by organisation type.

Category	Partners
Universities	Lund University, TU Dortmund
Research institutes	CERN, NIKHEF, CNRS
Industry partners	Ximantis, Verizon Connect
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The network is structured as 7 Work Packages (WPs) which are defined as follows:

- WP1, Management: overarching management of the network by the Project Manager, Project Coordinator, and Executive Board.
- WP2, Training: training and career development for network participants, provided by partners of the network, discussed further in Section 5.3.
- WP3, Machine learning & advanced data analysis: development of machine learning techniques for use in RTA contexts, as discussed in Section 3.2.1.
- WP4, Hybrid architectures: deployment of non-CPU architectures for acceleration of data processing, discussed in Section 3.2.2.
- WP5, Decision-making in research and industry: development of RTA-based decision-making technologies.
- WP6, Monitoring and discoveries: application of RTA approaches to data analysis.
- WP7, Dissemination and communication of results: publication and propagation of results from work completed by particpants.

WP1 and WP2 define the organisation of the network; WP3 and WP4 introduce the techniques and tools of real-time analysis to the network; WP5 and WP6 use said techniques and tools to produce results for HEP and industry; WP7 makes these results available and promotes their use.

2.1 Partnerships with universities and research institutes

Each ESR

The network has a particular focus on physics at the Large Hadron Collider (LHC). Each ESR is thus affiliated to one of the four major experiments based at the LHC: ALICE, ATLAS, CMS and LHCb. The network duration coincides with Run 3 of the LHC, 2022-2025. As such, ESR projects and outcomes have a focus on delivering required work for said experiments.

2.2 Partnerships with industry

A unique feature of the network is the extensive cooperation between HEP and industry across all ESR positions. RTA approaches have seen significant adoption in industry in recent years, with many organisations turning to RTA as a means to handle “big data”.

Figure 1. Trigger framework of the LHCb Experiment during Run 3 of the LHC. In Run 3, LHCb operates an entirely software-based trigger, processing events at the collision rate of 40MHz. Additionally, calibration of the detector is carried out in real time.

3 Real-time analysis

The issue of having to process large quantities of data in very short time periods is common to both HEP and industry, and remains a persistent problem in expansion of both areas. [1]

Real-time analysis is an umbrella term for a collection of techniques in data processing wherein data is processed in real-time, i.e. between recording and storage, often referred to as being "online".

3.1 Principles of RTA

In HEP, this is commonly seen in trigger systems, for example the LHCb trigger shown diagrammatically in Figure 1. Since it is not possible to record the detector output and carry out event reconstruction at the LHC collision rate of 40MHz, a trigger must be devised to select only those events which are relevant to the physics goals of a given experiment. Such a trigger conventionally consists of a hardware trigger acting directly on parts of the detector output, and a staged software trigger, applying gradually more fine-tuned selections with increasing amounts of reconstructed event detail.

In industry, the limitations of the scale of "big data" looms over many applications of computing. However,

It is therefore ... Figure 2

Figure 2. Diagram demonstrating the real-time analysis approach to data processing.

3.2 Tools of RTA

Online processing of data has been enabled by advances in computing over the past two decades, particularly in the areas of machine learning and hybrid architectures.

3.2.1 Machine learning

Central to the RTA approach is rapid decision making on complex data. Often such decision making is challenging to implement using classical selection cuts [2].

Machine learning techniques can also be applied to pattern recognition and anomaly detection—tasks which cannot be realistically carried out on the scales of data presently being analysed.

3.2.2 Hybrid architectures

Typical computational resources consist of Central Processing Units (CPUs), processors which are designed for general purpose computation, with large on-board memory and often multiple processing cores. Alternative architectures, such as those shown in Figure 3, can be applied in conjunction or in place of CPU architectures to accelerate processing where the

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Field-programmable gate arrays (FPGAs) [3]. FPGAs are thus well-suited to bespoke, computationally light but highly parallelisable tasks, such as low-level trigger decisions.

Graphical Processing Units (GPUs) can also be employed to . [4]

Figure 3. Comparison of computing architectures.

4 Early stage researchers

The 12 ESRs form the core of the network, with the training and partnerships providing a scaffold for the completion of their respective outcomes. These ESRs work with HEP and industry partners throughout the 3 years of their doctoral study.

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Shortly after the commencement of the ESR positions, each ESR supervisor completed a Personal Career Development Plan with their ESR. This document details the

4.1 Structure of ESR positions

Each ESR is enrolled as a doctoral student at a partner university for 3 years. This university is typically also the primary institution of the ESR, though the industry-centred ESR projects 2 and 10 (discussed in Section 2) are carried out with industry partners near to the university of enrollment. Where partner universities require a longer period of study or typically provide extensions to a 3 year study programme, commitments to further enrollment are provided by each partner university where necessary. At the end of the period of doctoral study, each ESR will receive a doctorate in particle physics from their university of enrollment.

ESRs

Each ESR will undertake a secondment in HEP during their studies, either at another partner university or a partner research institute. This is generally organised to last for 6 months, though this varies from project to project.

In addition to their time working in HEP, each ESR will also spend time working in industry, typically as a secondment of 3-4 months (though this is again flexible to the specific programme of each ESR position).

4.2 Examples of ESR positions

The ESR positions of the network are summarised in Table 2. Particular examples are also listed below. a

Table 2. Please write your table caption here

Early-stage researcher	Primary affiliation	HEP secondment	Industry
ESR#: Name	University	CERN	Ximant
ESR2: Laura Boggia	IBM France (enrolled at Université Sorbonne)	CERN	Ximant
ESR7: Jamie Gooding	TU Dortmund on LHCb	CERN	Ximant
ESR9: Carlos Cocha	University	CERN	Ximant
ESR10: Joachim Hansen	University	CERN	Ximant
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5 Network outcomes

As an obligation to the European Union, intended network outcomes were laid out as a set of deliverables. These deliverables act to a guide the progression of the network and its participants. Key outcomes of the network are discussed in the following sections.

5.1 Goals of HEP and industry

The core outcomes of the network are a set of goals, which are completed on behalf of the network partners by the network participants. These goals vary, with the majority associated to a specific ESR position, for example, the goal of "calibration of ALICE TPC for heavy-ion physics" associated to ESR10, Joachim Hansen.

5.2 RTA whitepapers

As a deliverable of the network, the participants will write a series of whitepapers reviewing the current RTA state-of-the-art. The four whitepaper topics are listed in the following subsections and an overview is given for each. At time of writing, these whitepapers are expected to be submmited for publication by the end of 2023.

5.2.1 ML for RTA

The first network whitepaper provides a review of current ML applications to HEP in RTA contexts and corresponding best practices. Examples of such applications range from data-taking, e.g. in particle identification at the ALICE experiment, to offline analysis, e.g. anomaly detection for diject resonance searches at the ATLAS experiment. [5, 6]

5.2.2 Hybrid architectures at the LHC

The use of hybrid architectures by LHC experiments is reviewed in the second SMARTHEP whitepaper. Acceleration of tasks such as selection and reconstruction by hybrid archetictures was developed significantly during Run 2 of the LHC (2015-2018). Run 3 deployments of hybird architectures capitalise on this progress, e.g. in the use of FPGAs in the ALICE Central Trigger System and the use of GPUs in the ATLAS High Level Trigger farm. [7, 8]

5.2.3 Trigger and data acquisition systems of the LHC

In the third whitepaper, the trigger and data acquisition (TDAQ) systems of LHC experiments are reviewed, with a focus upon best practices for both TDAQ hardware and software. As such, this whitepaper reviews topics ranging from upgrades to the ATLAS TDAQ system, to the Allen framework of the LHCb experiment enabling software trigger operation at a 30 MHz readout rate. [9, 10]

5.2.4 RTA techniques at LHC experiments

The final whitepaper focuses on the use of RTA techniques at LHC experiments, in particular in the context of RTA-enabled searches and anomaly detection. For example, in dark photons searches carried out by the CMS and LHCb experiments, which require access to signals previously excluded by prior non-RTA frameworks. [11, 12] To avoid overlap with the whitepaper discussed in Section 5.2.3, this whitepaper does not cover the use of RTA approaches in trigger systems. An exception is made for cases wherein the trigger system forms an inherent part of a process, e.g. RTA-enabled searches where trigger systems provide offline-quality data for direct analysis use.

5.3 Training of ESRs

Funding is allocated within the network for participants to attend relevant training activities. In the case of ESRs, training and career devlopment is discussed in writing their respective PCDP, providing a clear overview of their intended and requested training activities. Examples of such activities include attendance of specialist industrial training sessions and academic schools. Training is also provided within the network, between participants, for example in the First SMARTHEP School on Collider Physics and Machine Learning discussed in Section 6.2.

5.4 Software and digital assets

The work of the ESRs will generate a number of digital assets (e.g. software packages, data processing tools), with many being applicable beyond narrow academic/industrial applications.

The network is committed to producing making any produced digital assets **F**indable, **A**ccessible, **I**nteroperable, and **R**eusable (FAIR). [13] Under these guiding principles

Additionally, our assets and results should be open and accessible to the wider community. To implement these commitments, a project on GitHub has been created to host such assets, https://github.com/SMARTHEP. Other assets and resources will be made available on the network website, https://smarthep.org.

6 Network events

Network events form a backbone of the SMARTHEP network, giving participants unique opportunities to meet, exchange ideas and develop. Whilst the events of the network are focused on an ESR audience, SMARTHEP has made many events available to additional interested early career scientists working/studying at SMARTHEP institutes.

6.1 SMARTHEP Kick-off Meeting

To mark the commencement of the ESR positions, a kick-off meeting was held at the University of Manchester from 21st to 25th November 2022. This meeting formally introduced ESRs to the network, discussing the objectives and organisation of the network, in addition to introducing the topics-of-work of each ESR. The meeting also served as an opportunity for participants from all sides of SMARTHEP to meet in person, network and discuss ideas. To facilitate this, a visit to the Jodrell Bank Centre for Astrophysics was held. A review paper-writing course was organised by academic writing consultancy group Scriptoria, to train ESRs ahead of the writing of the 4 whitepapers discussed in Section 5.2.

6.2 First SMARTHEP School on Collider Physics and Machine Learning

The First SMARTHEP School on Collider Physics and Machine Learning was hosted by Université de Genève between 10st to 13th November 2022. The school delved into many aspects directly relevant to the network, through a varied programme including:

- Lectures on experimental physics at collider experiments by Anna Sfyrla.
- Lectures on theoretical physics and Monte Carlo event generators by Torbjörn Sjöstrand.
- Hands-on lessons in machine learning by Maurizio Pierini.
- Evening seminars on multimessenger astronomy by Teresa Montaruli and the CERN experimental programme by Jamie Boyd.

The school also directly succeeded the mid-term meeting of the network with the EU Project Officer, a key stage in the lifecycle of the network, wherein the progress and trajectory of the network was evaluated by the European Union.

6.3 Upcoming events

At time of writing, the network still has two years ahead of it, in which further network events are planned. These will guide the governance of the network, develop ESR expertise and deepen collaborations with industry.

The network assembly sits as a cornerstone of network policy and governance.

Accelerator bootcamps in specific aspects of RTA . These are likely to take place in the summer of 2024.

An industry applications school will round off the collaboration with industry. It is intended that most ESRs will have completed their industry secondments by this time.

7 Conclusion

The network will provide valuable contributions in HEP, particularly to the commisioning and operation of LHC experiments throughout Run 3 of the LHC. Additionally, the network serves to further the adoption of RTA approaches in industry and do demonstrate the value of collaboration between HEP and industry.

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