



PARALLEL 9 / **COMPUTING**

Computing: Software WG

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Software in HEP

Predicting the software landscape across decades is very challenging.....

GitLab



GitLab Inc. 2011

PyTorch



Meta, 2016

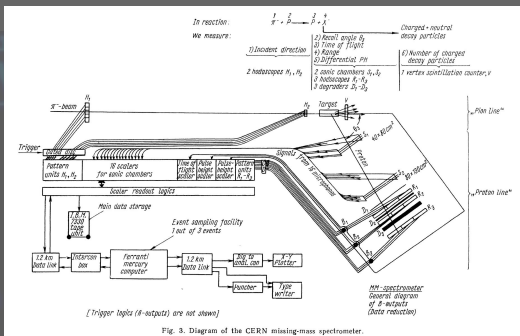
Conda-forge



Community, 2015

All broadly adopted by HEP community in the last 10 years...

Software in HEP

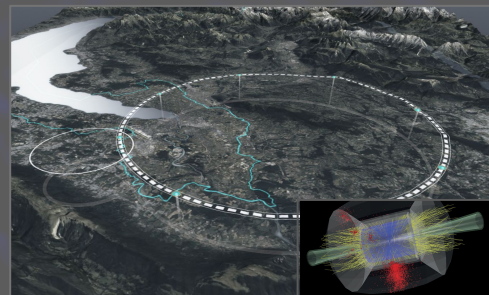
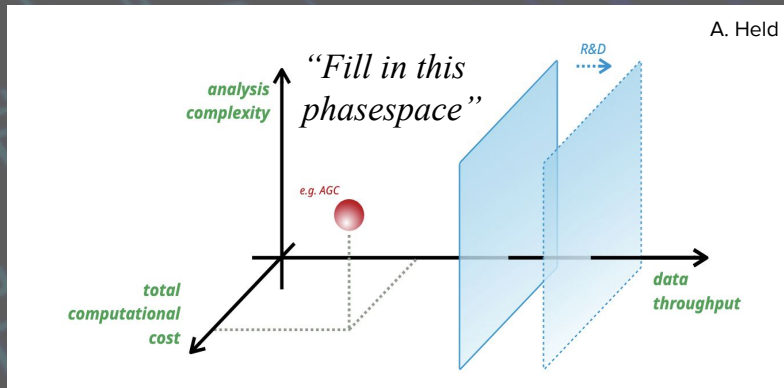


Missing-mass spectrometer, CERN, 1964

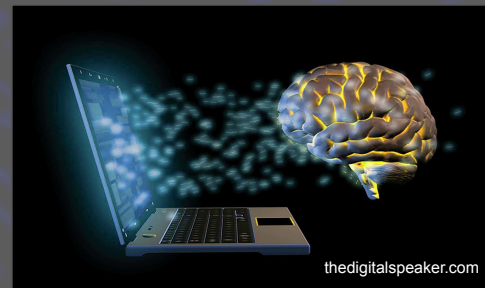


Ferranti Mercury, **first** CERN computer, connected online to the Missing Mass Spectrometer, 1958

Predicting analysis requirements across decades is *equally* challenging.....

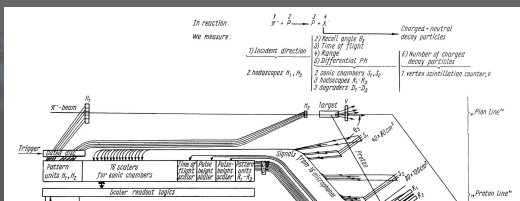


FCC ee(hh), Muon Collider... ?



Computer-human interface in 2070 (artist's impression)

Software in HEP



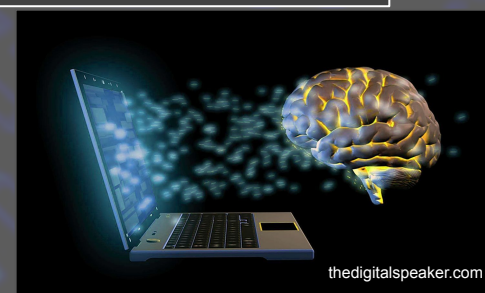
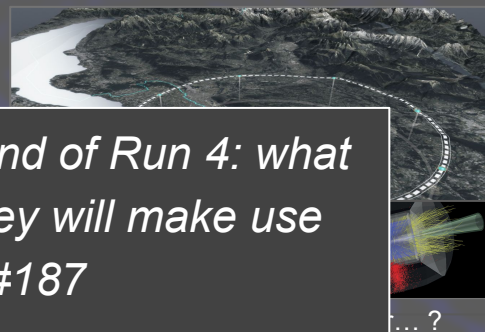
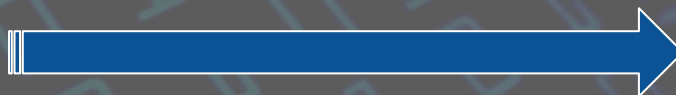
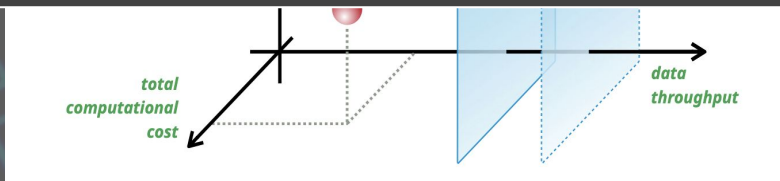
Predicting analysis requirements across decades is equally challenging.....

"It is not yet clear how most analyses will be done even at the end of Run 4: what computing hardware they will require, what software libraries they will make use of, or even the language in which they will primarily be written" #187

Miss



Ferranti Mercury, **first** CERN computer, connected online to the Missing Mass Spectrometer, 1958



Computer-human interface in 2070 (artist's impression)

Software in HEP

Luckily, we had some help...

~30 ESPPU inputs
for software!

The Critical Importance of Software for HEP

Prepared by the HEP Software Foundation, with inputs from the HEP community.

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This document has been endorsed by the following experiments and
INFN, EPIC, LHCb, MCnet, WLCG

Key4hep: A Software Framework for Future Colliders

Juan Miguel Carceller¹, Mateusz Fila¹, Thomas Madlener², Leonhard Reichenbach^{1,3},
André Sailer¹, and Swathi Sasikumar¹

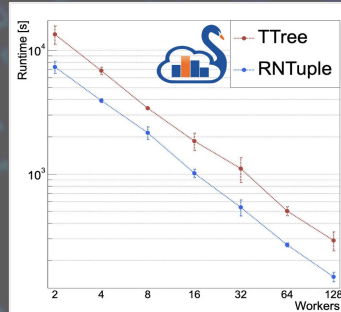
On behalf of Key4hep

¹CERN, Geneva, Switzerland

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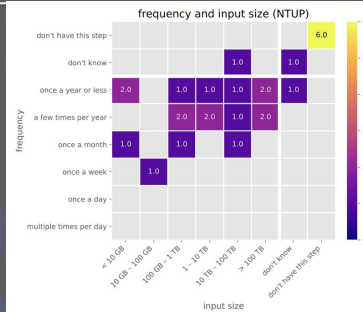
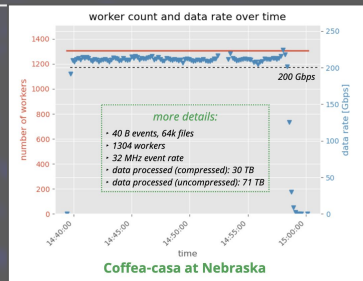
³University of Bonn, Germany

Along with ongoing
benchmarking of
where we are
now...



Analysis Grand
Challenge

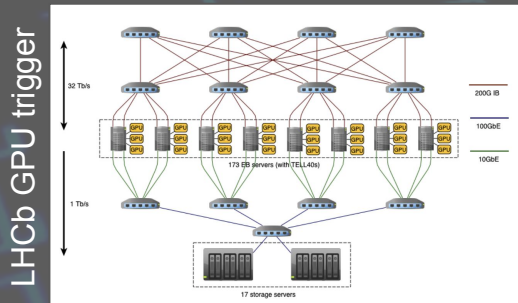
Analyst survey



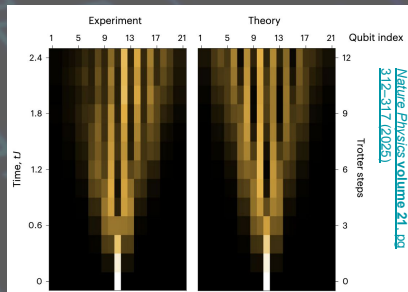
What will our software do?

Software will be required to do more and more of it...

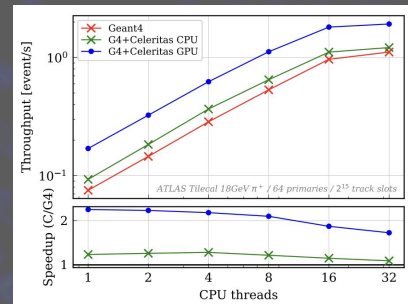
“Software and computing are an integral part of experimental design, trigger and data acquisition, simulation, reconstruction, and analysis, as well as related theoretical predictions” #67



“...future online data acquisition software in HEP and NP trends towards operating triggerless or streaming readouts” #67



“theoretical physics community must continue to develop numerical strategies and codes to keep pace with technological development of new architectures” #73



“implement (parts of) the simulation workflow on GPUs, in particular to speed up processes such as optical photons and EM showers” #127

How will our software look?

Huge range of tools available makes interoperability across software ecosystems crucial

"Many analyses have integrated a variety of ML tools, often including industry-standard software libraries" #187

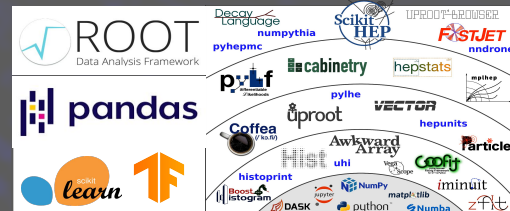
"Establishing common tools and frameworks could reduce the time wasted on duplicative efforts, streamline interoperability..., and accelerate scientific advancement." #124

New languages are also on the horizon

"... recent addition to the community is a small but growing group of analysts employing Julia. ...significant performance benefits against Python and usability benefits against C++ make Julia an appealing" #67

Collaboration with external software projects is key

"work is ongoing to integrate both the AdePT prototype and the Celeritas code within the Gaussino framework... a fruitful synergy between external and LHCb R&D projects" #127



Where will our software run?

The resources that run our software will change as funding agencies favor interdisciplinary infrastructures

“HPC centers are crucial partners... offering either pledged resources or for providing additional opportunistic resources” #12

Meaning our code must adapt...

“HEP codebases, traditionally optimized for x86_64 CPUs, require modernization to run efficiently on different architectures ... increasingly used at HPC sites” #12

Portability libraries will help...

*“The gap between current **JENA** domain workflows and accelerated hardware in HPC centers should be addressed through high-level frameworks such as Kokkos, Alpaka, SYCL, and C++ extensions” #124*

We should see this as an opportunity...

“It will require modernisation and refactoring of millions of lines of software and it will be an opportunity to streamline the code and possibly improve its performance” #9



How will we get there?

We do not know what software we will use at the next machine, but we know what we will use to build that machine ...

- HEP community has agreed on one common software stack to develop the next big collider

"members of the ILC, CLIC, FCC, CEPC and the Muon Collider communities ... decided to pool their resources to develop a common and shared software stack ... Key4hep project which has become the de facto standard for studying detector concepts in any currently foreseen future collider"
#240

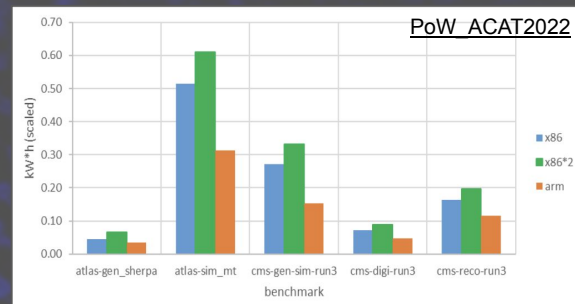
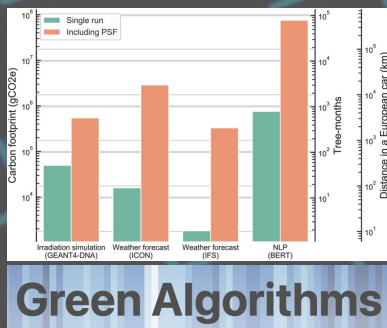


Sustainability

Increased focus on environmental impact of computing

WLCG strategy: *“Reduce the cost, energy consumption, and carbon footprint of computing by being able to use a wide range of resources including Grid, public or private clouds, HPCs, and by expanding the architecture” #9*

This is a general effort across science particularly with increasing use of ML



As well as making HEP analyses FAIR

“[preservation] comprises keeping the data alive, accessible and usable, across the ever changing IT infrastructure and technologies, including data and software quality procedures” #138



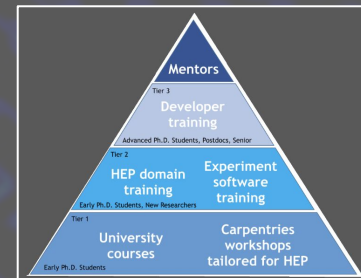
Careers and Training

As software evolves, and with the high-turnover in HEP, we must have quality training programmes and incentivise those who produce/deliver them

“Dedicated training is crucial to maintain a pool of experts with the necessary skills and knowledge” #127

And maybe the most important point stressed by ~ all inputs...

“We must ... provide a career path for those involved in software and computing, including in training, by creating job opportunities at labs and universities on par with those involved in detector construction” #67



3000+ users trained so far! #67

Summary

- Huge amount of input from experiments (current and future), facilities, theory community... on the future of software in HEP
 - Thank you to all!
 - We will do this input justice in the ESPP 2026 update
- Now have focused talks on “HEP software: past, status and prospects” and “Key4HEP and Future collider software”

"When I came to CERN, my job was not only to find problems and solve them, but also to try and convince the physicists that computers were something useful."

Paolo Zanella (Head of CERN Data Handling Division 1976-1989)