

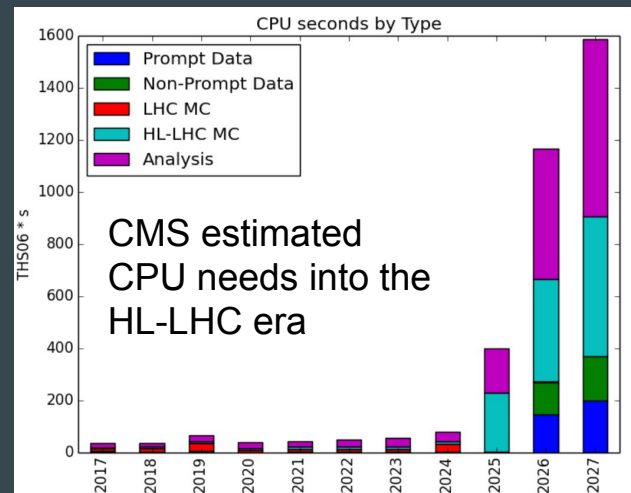
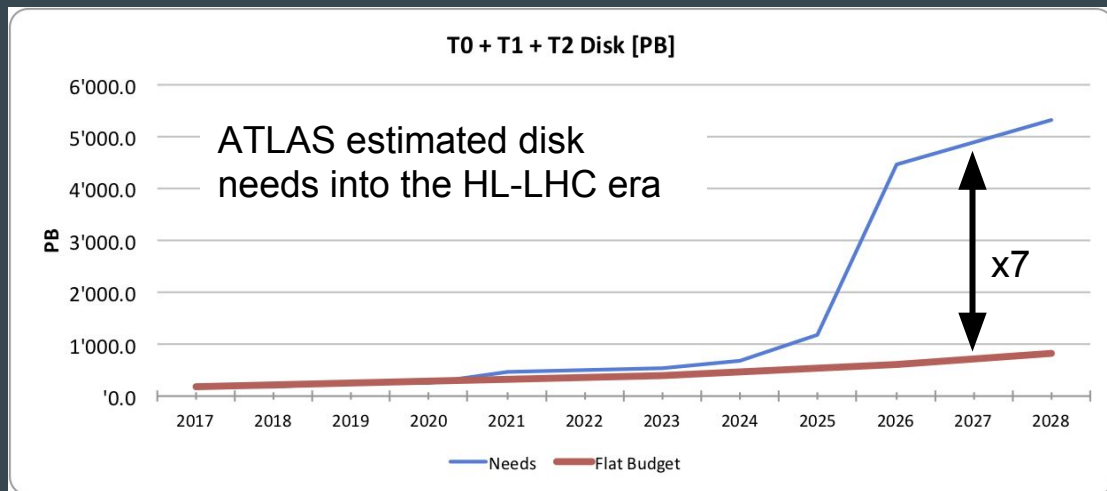


HEP Software Foundation Community White Paper

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Challenges for the next decade

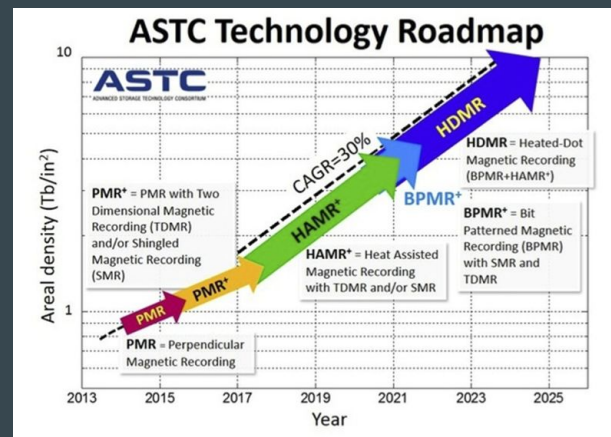
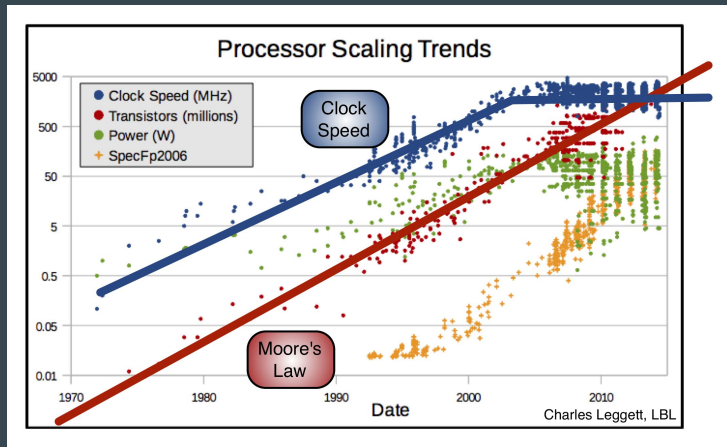
- HL-LHC, expected in 2026, brings a huge challenge to software and computing
 - Both rate and complexity rise



- Not just a simple extrapolation of Run 2
- Resources needed will exceed those from technology evolution alone

The evolving technology landscape

- Increase in single-core CPU throughput stalled
- Many/multi core systems are the norm
 - Serial or multi-process processing is under severe memory pressure
- Co-processors now commonplace
 - GPGPUs, FPGAs - greater throughput, far more challenging programming model
- Wide vector registers (up to 512 bit)
- Power a dominant factor
- Storage capacity climbing
 - 100TB disks possible by HL-LHC, but little I/O improvement expected
- Network capacity keeps growing



Software challenges for HL-LHC

- Pile-up of $\sim 200 \Rightarrow 100 \times$ CPU of today
 - Moore's law over 10 years : only a $\times 10$
- With a flat budget, Moore's law is the real maximum we can expect on the HW side
- HEP software typically executes one instruction at a time (per thread)
 - Since ~ 2013 CPU (core) performance increase is due to more internal parallelism
 - $\times 10$ with the same HW only achievable if using the full potential of processors
 - major SW re-engineering required (but rewriting everything is not an option)
 - Co-processors like GPUs are of little use until the problem has been solved
- Increased amount of data requires to revise/evolve our computing and data management approaches
 - We must be able to feed our applications with data efficiently
- « HL-LHC salvation » will come from software improvements, not from hardware

HEP Software Foundation (HSF)



- The LHC experiments, Belle II and DUNE face the same challenges
 - HEP software must evolve to meet these challenges
 - Need to exploit all the expertise available inside and outside our community for parallelisation
 - Many problems are intrinsically sequential. Need to work on reconstruction algorithms too.
- Cannot afford any more duplicated efforts
 - Each experiment has its own solution for almost everything (framework, reconstruction algorithms...)
- **The goal of the HSF is to facilitate coordination and common efforts in software and computing across HEP in general**

Community white paper inception

- From Spring 2016 discussions, idea started to crystallise at the May 2016 HSF Meeting at LAL
 - describe a *global vision for software and computing* for the HL-LHC era and HEP in the 2020s
- Formal charge from the WLCG in July 2016
 - Anticipate a "software upgrade" in preparation for HL-LHC
 - Identify and prioritize the software research and development investments
 - i. to achieve improvements in software efficiency, scalability and performance and to make use of the advances in CPU, storage and network technologies
 - ii. to enable new approaches to computing and software that could radically extend the physics reach of the detectors
 - iii. to ensure the long term sustainability of the software through the lifetime of the HL-LHC

Starting the process

- Started to organise into different working groups at the end of 2016
- Kick-off workshop 23-26 January 2017, San Diego
 - 110 participants, mainly US + CERN
 - 2.5 days of topical working group meetings
 - Extensive notebooks of initial discussions
- Groups held workshops and meetings in the subsequent months
 - Broadening the range of participation
 - Some invited non-HEP experts to participate



Concluding the process



- Workshop in Annecy 26-30 June started to draw the process to a close
 - 90 Participants: 48 US, 42 Europe (of which 20 from CERN)
- 13 working groups presented their status and plans
- Substantial progress on many Community White Paper chapters
 - WGs used the workshop to make further progress on writing
- There was a fair amount of optimism about writing the final Roadmap in August

Editorial board and roadmap document draft

- Real progress started after the summer
- Set more realistic goals
 - Individual WG chapters by end of September
 - Overall draft roadmap paper by end of October
- 14 working group chapters available for community review*
- Editorial Board was set up, with the aim of encompassing the breadth of our community
- First draft released 20 October
- Second draft of the text was prepared by a small team within the Editorial Board
 - Released 17 November
- Predrag Buncic (CERN) - Alice contact
- Simone Campana (CERN) - ATLAS contact
- Peter Elmer (Princeton)
- John Harvey (CERN)
- Benedikt Hegner (CERN)
- Frank Gaede (DESY) - Linear Collider contact
- Maria Girone (CERN Openlab)
- Roger Jones (Lancaster University) - UK contact
- Michel Jouvin (LAL Orsay)
- Rob Kutschke (FNAL) - FNAL experiments contact
- David Lange (Princeton)
- Dario Menasce (INFN-Milano) - INFN contact
- Mark Neubauer (U.Illinois Urbana-Champaign)
- Eduardo Rodrigues (U. Cincinnati)
- Stefan Roiser (CERN) - LHCb contact
- Liz Sexton-Kennedy (FNAL) - CMS contact
- Mike Sokoloff (U.Cincinnati)
- Graeme Stewart (CERN, HSF)
- Jean-Roch Vlimant (Caltech)

Second synthesis draft

- 74 page document
- 12 sections summarising R&D in a variety of areas for HEP Software and Computing
- **Almost all major domains of HEP Software and Computing are covered**
- Incorporated lots of community feedback on the first draft
- Time for your feedback on second (and last) draft **until December 1st**
- Please sign the paper [here](#)

HSF-CWP-2017-01

A Roadmap for HEP Software and Computing R&D for the 2020s

The HEP Software Foundation

v0.2 Released 2017-11-17

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Detector simulation

- **Simulating our detectors consumes huge resources today**
 - Remains a vital area for HL-LHC and intensity frontier experiments in particular
- **Main R&D topics**
 - **Improved physics models** for higher precision at higher energies (HL-LHC and then FCC)
 - Hadronic physics in LAr TPCs needs to be redeveloped
 - Adapting to **new computing architectures**
 - Can a vectorised transport engine be demonstrated to work in a realistic prototype?
 - **Fast simulation** - develop a common toolkit for tuning and validation
 - Can we use Machine Learning profitably here?
 - **Geometry modeling**
 - Easier modelling of complex detectors, targeting new computing architectures

Software trigger and event reconstruction

- **Move to software triggers is already a key part of the program for LHCb and ALICE already in Run 3**
 - ‘Real time analysis’ increases signal rates and can make computing much more efficient (storage and CPU)
- **Main R&D topics**
 - Controlling charged **particle tracking resource consumption** and maintaining performance
 - Do current algorithms’ physics output hold up at pile-up of 200 (or 1000)
 - Can tracking maintain low p_T sensitivity within budget?
 - Improved use of **new computing architectures**
 - Multi-threaded and vectorised CPU code
 - Extending use of GPGPUs and possibly FPGAs
 - Robust **validation** techniques when information will be discarded
 - Using modern continuous integration, tackling multiple architectures with reasonable turnaround times

Data analysis and interpretation

- **Today we are dominated by many cycles of data reduction**
 - Aim is to reduce the input to an analysis down to a manageable quantity that can be cycled over quickly on ~laptop scale resources
 - Key metric is ‘time to insight’
- **Main R&D topics**
 - How to **use the latest techniques** in data analysis that come from outside HEP?
 - Particularly from the Machine Learning and Data Science domains
 - Need ways to seamlessly interoperate between their data formats and ROOT
 - Python is emerging as the *lingua franca* here, thus guaranteeing PyROOT is critical
 - New Analysis Facilities
 - Skimming/slimming cycles consume large resources and can be inefficient
 - Can **interactive data analysis clusters** be set up?
 - **Data and analysis preservation** is important

Data management and organisation

- **Data storage costs are a major driver for LHC physics today**
 - HL-LHC will bring a step change in the quantity of data being acquired by ATLAS and CMS
- **Main R&D topics**
 - Adapt to new needs driven by changing algorithms and data processing needs, e.g.,
 - The need for **fast access to training datasets** for Machine Learning
 - Supporting **high granularity access** to event data
 - Needed to effectively exploit backfill or opportunistic resources
 - **Rapid high throughput** access for a future analysis facility
 - Processing sites with **small** amounts of **cache storage**
 - Do this profiting from the advances in industry standards and implementations, such as Apache Spark-like clusters (area of **continued rapid evolution**)
 - **Consolidate** storage access interfaces and protocols
 - Support **efficient hierarchical access** to data, from high latency tape and medium latency network

Facilities and distributed computing

- **Storage and computing today are provided overwhelmingly from WLCG resources**
 - Expected to continue for HL-LHC, but to be strongly influenced by developments in commodity infrastructure as a service (IaaS, commercially this is usually Cloud Computing)
- **Main R&D topics**
 - Understand far better the **effective costs** involved in delivering computing for HEP
 - This needs to be sensitive to **regional variations in funding** and **direct and indirect costs**
 - e.g. smaller sites frequently contribute 'beyond the pledge' resources, power costs and human resources
 - Full model is unfeasible, but providing a reasonable gradient analysis for future investment should be possible
 - Should we invest in better network connectivity or in more storage?
 - How to take better advantage of **new network and storage technologies** (software defined networks, object stores or content addressable networks)
 - Strengthen **links to other big data sciences** (SKA) and computing science; how to share network resources

Data processing frameworks

- **Experiment software frameworks provide the scaffolding for algorithmic code**
 - Currently there are many implementations of frameworks, with some sharing between experiments (e.g., ATLAS and LHCb share Gaudi, Intensity Frontier experiments use art)
 - All of these frameworks are evolving to support concurrency
- **Main R&D topics**
 - **Adaption to new hardware**, optimising efficiency and throughput
 - We need the best libraries for this and these will change over time
 - Incorporation of external **(co)processing resources**, such as GPGPUs
 - **Interface with workload management system** to deal with the inhomogeneity of processing resources
 - From volunteer computing to HPC job slots with 1000s of nodes
 - **Which components can actually be shared and how is that evolution achieved?**

Machine learning

- Neural networks and Boosted Decision Trees have been used in HEP for a long time
 - E.g. particle identification algorithms
- More recently the field has been significantly enhanced by new techniques (Deep Neural Networks) and enhanced training methods
 - Very good at dealing with noisy data and huge parameter spaces
 - A lot of interest from our community in these new techniques, in multiple fields
- Main R&D topics
 - **Speeding up** computationally intensive pieces of our workflows (fast simulation, tracking)
 - **Enhancing physics reach** by classifying better than our current techniques
 - Improving **data compression** by learning and retaining only salient features
 - **Anomaly detection** for detector and computing operations
- Significant efforts will be required to make effective use of these techniques
 - **Good links with** the broader Machine Learning and Data **Science communities** required

Other technical areas of work

Conditions Data

- Growth of alignment and calibration data is usually linear in time
 - Per se, this does not represent a major problem for the HL-LHC
- Opportunities to use modern distributed techniques to solve this problem efficiently and scalably
 - Cacheable blobs accessed via REST
 - CVMFS + Files
 - Git

Visualisation

- Many software products developed for event visualisation
 - Part of the framework, with full access to event and geometry data
 - Standalone as a lightweight solution
- New technologies for rendering displays exist, e.g., WebGL from within a browser

- **These areas are both examples of where we can refocus current effort towards common software solutions**
- **This should improve quality, economise overall effort and help us to adapt to new circumstances**

Data, software and analysis preservation

- We seem to be doing well compared to other fields
- Challenge is both to physically preserve bits and to preserve knowledge
 - DPHEP has looked into both
- Knowledge preservation is very challenging
 - Experiment production workflows vary in significant details
 - Variety of different steps are undertaken at the analysis stage, even within experiments
- Need a workflow that can capture this complexity
 - Technology developments that can help are, e.g., containers
- CERN Analysis Preservation Portal forms a good basis for further work
 - Needs to have a low barrier for entry for analysts
 - Can provide an immediate benefit in knowledge transmission within an experiment

Software development, training and careers

- **Experiments have modernised their software development models a lot recently**
 - Moving to git and CMake as standard components
 - Using social coding sites (gitlab, github) coupled to Continuous Integration
- **Additional tools would benefit the community**
 - Static analysis of code, refactoring code, performance measures
- **Using new tools requires investing in training for the community**
 - The more commonality in the tools and techniques, the more training we can share
 - This provides preservation and propagation of knowledge
- **Our environment is becoming more complex; we require input from physicists *whose concerns are not primarily in software***
 - **Sustainability** of these contributions is extremely important
- **Recognition of the contribution of our specialists in their careers is extremely important**

Community white paper - moving forwards



- Community White Paper process has been a success
 - Engaged more than 250 people and produced more than 300 pages of detailed description in many areas
- Summary roadmap lays out a path forward and identifies the main areas we need to invest in for the future
 - Supporting the HL-LHC Computing TDRs and NSF S2I2 strategic plan
- Current draft will undergo a final process of refinement and conclude in a month
- HEP Software Foundation has proved its worth in delivering this CWP Roadmap
 - Achieving a *useful* community consensus is not an easy process
- We now need to marshal the R&D efforts in the community, refocusing our current effort and helping to attract new investment in critical areas
 - The challenges are formidable, working together will be the most efficacious way to succeed
 - HSF will play a vital role in **spreading knowledge** of new initiatives, **encouraging collaboration** and **monitoring progress**
 - Workshops planned for next year (with WLCG) and at sessions before CHEP