KIT
Karlsruher Institut für Technologie

SCC
Scientific Computing Center

GridKa

ETP
Institut für Experimentelle Teilchenphysik

CERN

Unraveling Grid Computing:

From Basics to WLCG

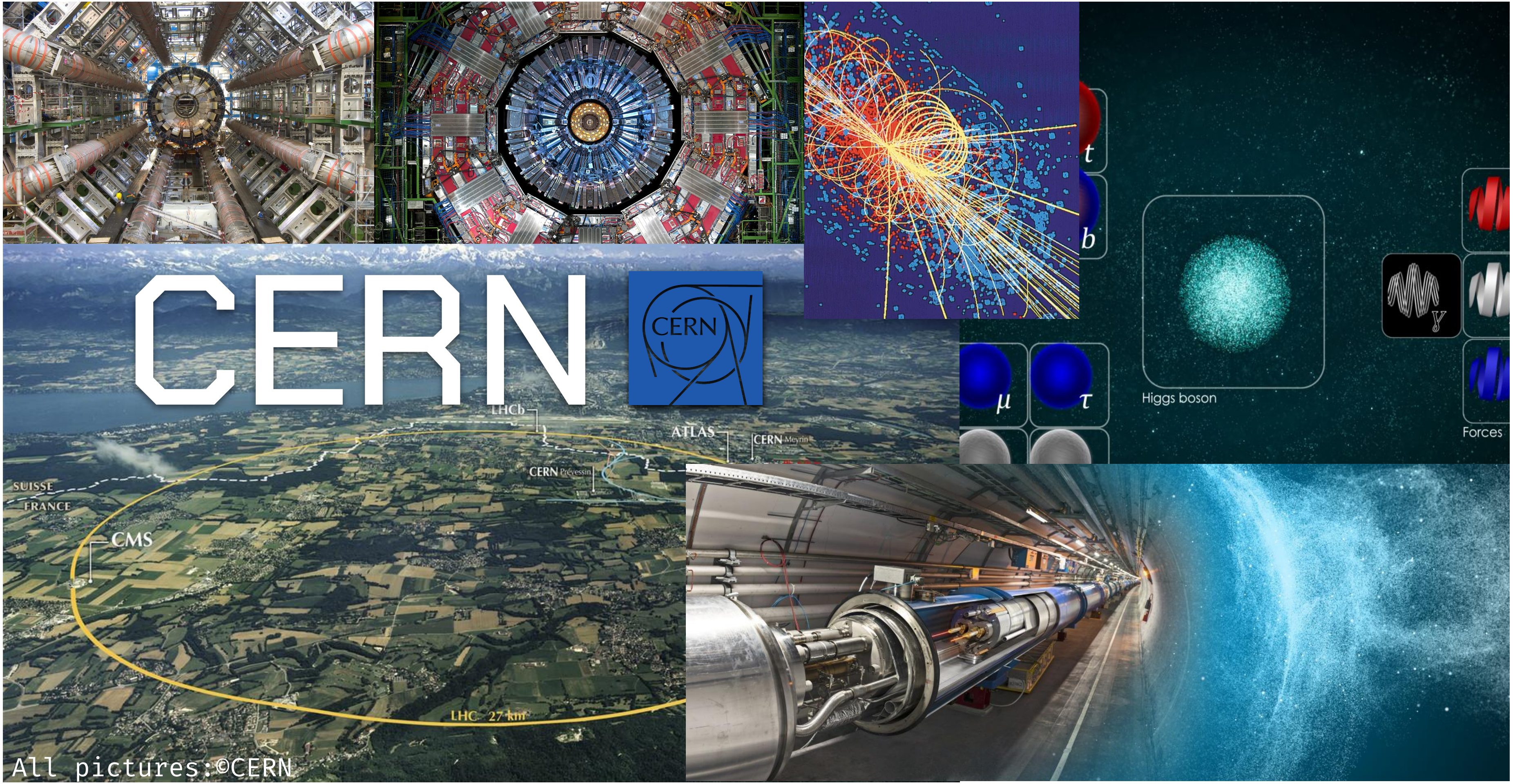
“A complex, chaotic scene depicting a globe with numerous computing resources such as servers, data centers, and computers distributed unevenly around it. These resources are interconnected by a tangled, knotted thread, symbolizing a complicated and disorganized network.” (DALL-E)

By Robin Hofsaess (Robin.Hofsaess@cern.ch)

Hi there!
I am Robin Hofsaess,

a PhD student in Physics at KIT, Germany. Currently, I am working on efficiency and workflow optimizations for HEP jobs on Opportunistic Resources, like HPC centers, integrated in GridKa, the German T1 center. My main interests are computers, music (guitar), biking, gaming, and also a little bit of physics :D

CERN



All pictures:©CERN

WHERE THE
WEB
WAS BORN

In the offices of this corridor, all the fundamental technologies of the World Wide Web were developed.

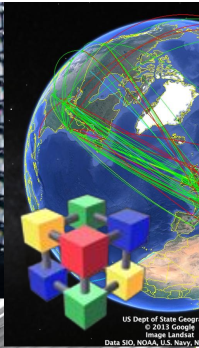
Started in 1990 from a proposal made by Tim Berners-Lee in 1989, the effort was first divided between an office in building 31 of the Computing and Networking Division (CN) and one in building 2 of the Electronics and Computing for Physics Division (ECP).

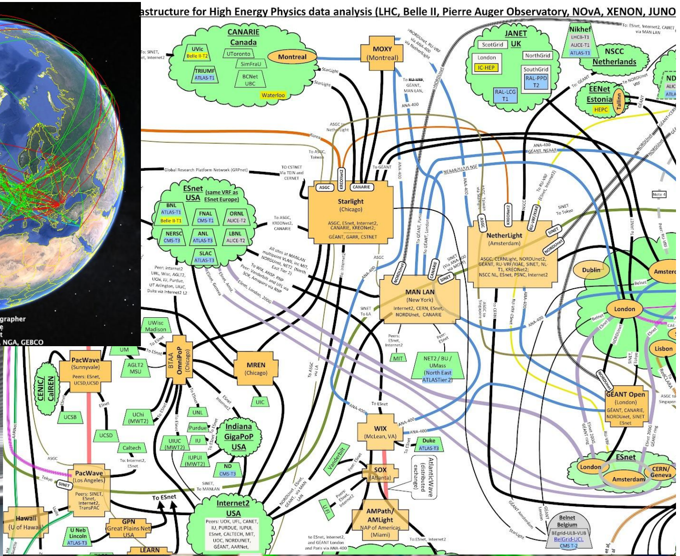
In 1991 the team came together in these offices, then belonging to ECP. It was composed of two CERN staff members, Tim Berners-Lee (GB) and Robert Cailliau (BE), aided by a number of Fellows, Technical Students, a Coopérant and Summer Students.

At the end of 1994 Tim Berners-Lee left CERN to direct the WWW Consortium (W3C), a world-wide organization devoted to leading the Web to its full potential. The W3C was founded with the help of CERN, the European Commission, the Massachusetts Institute of Technology (MIT), the Institut National pour la Recherche en Informatique et en Automatique (INRIA), and the Advanced Research Projects Agency (ARPA).

In 1995 Tim Berners-Lee and Robert Cailliau received the ACM Software System Award for the World Wide Web. In 2004, Tim Berners-Lee was awarded the first Millenium Technology Prize by the Finnish Technology Award Foundation.

The CERN Library
June 2004


US Dept of State Geographer
© 2013 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO


astructure for High Energy Physics data analysis (LHC, Belle II, Pierre Auger Observatory, NOvA, XENON, JUNO

All pictures:©CERN

2023!

~200.000.000

GB of physics data

>1.710.000.000

GB transferred via FTS

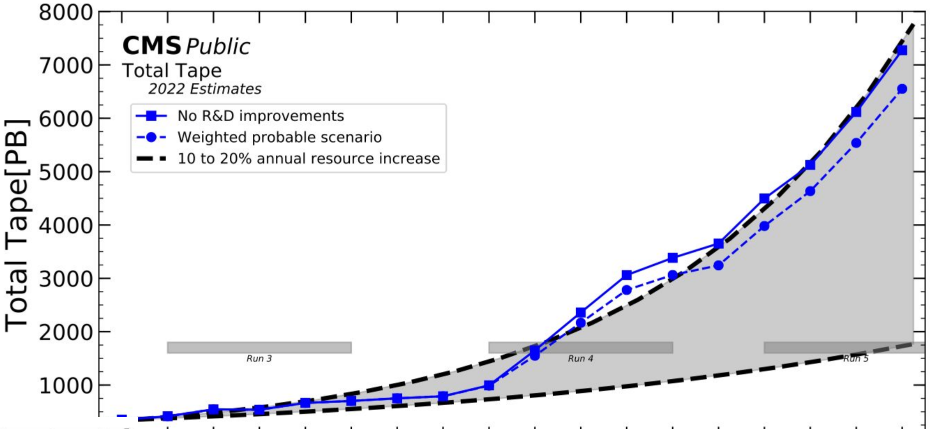
367,176,289

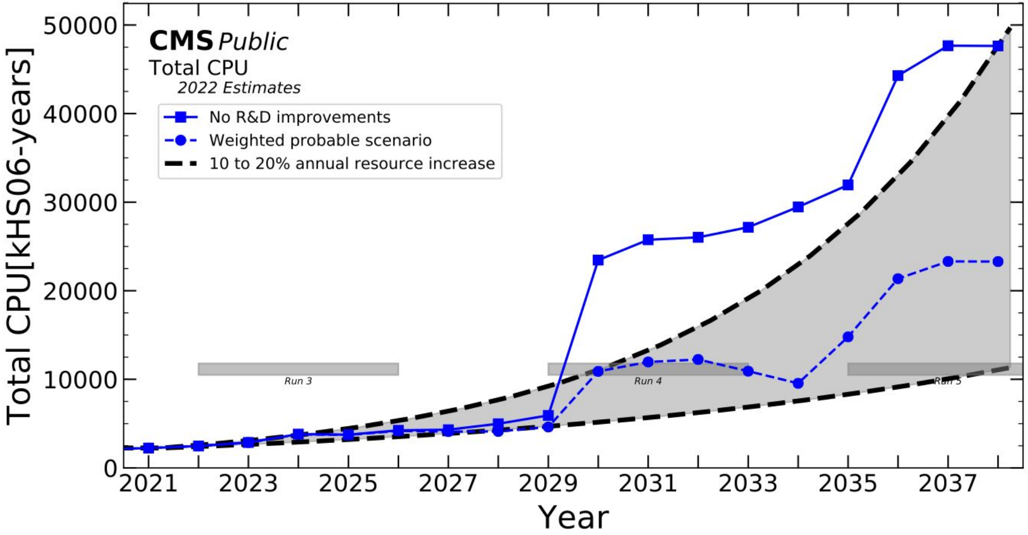
Number of compute jobs

The EGI Accounting Portal is an EGI service provided by CESGA

CMS

Resource projections





- The data rates of the HL-LHC will expectedly increase the resource demand drastically
- With constant research and development (and funding), we expect to stay within the projections
- Source

The (20 years old) solution:

Grid Computing

01 What is Grid Computing?

A historical overview: from basics to grid computing

02 How Does a Computing Grid Look Like?

Learning the concepts behind a modern computing grid

03 The Worldwide LHC Computing Grid (WLCG)

Let’s have a look at one of world’s biggest grids!

Computing

is the process of utilizing computer technology to complete tasks or solve problems through the execution of algorithms and manipulation of data.

Physical Computing

Personal Computing

Utility Computing

Edge Computing

High Performance Computing

Distributed Computing

Green Computing

Cluster Computing

Cloud Computing

Parallel Computing

Quantum Computing

Grid Computing

Scientific Computing

Social Computing

Evolutionary Computing

Soft Computing

Mobile Computing

Creative Computing

Enthusiast Computing

Wearable Computing

Automotive Computing

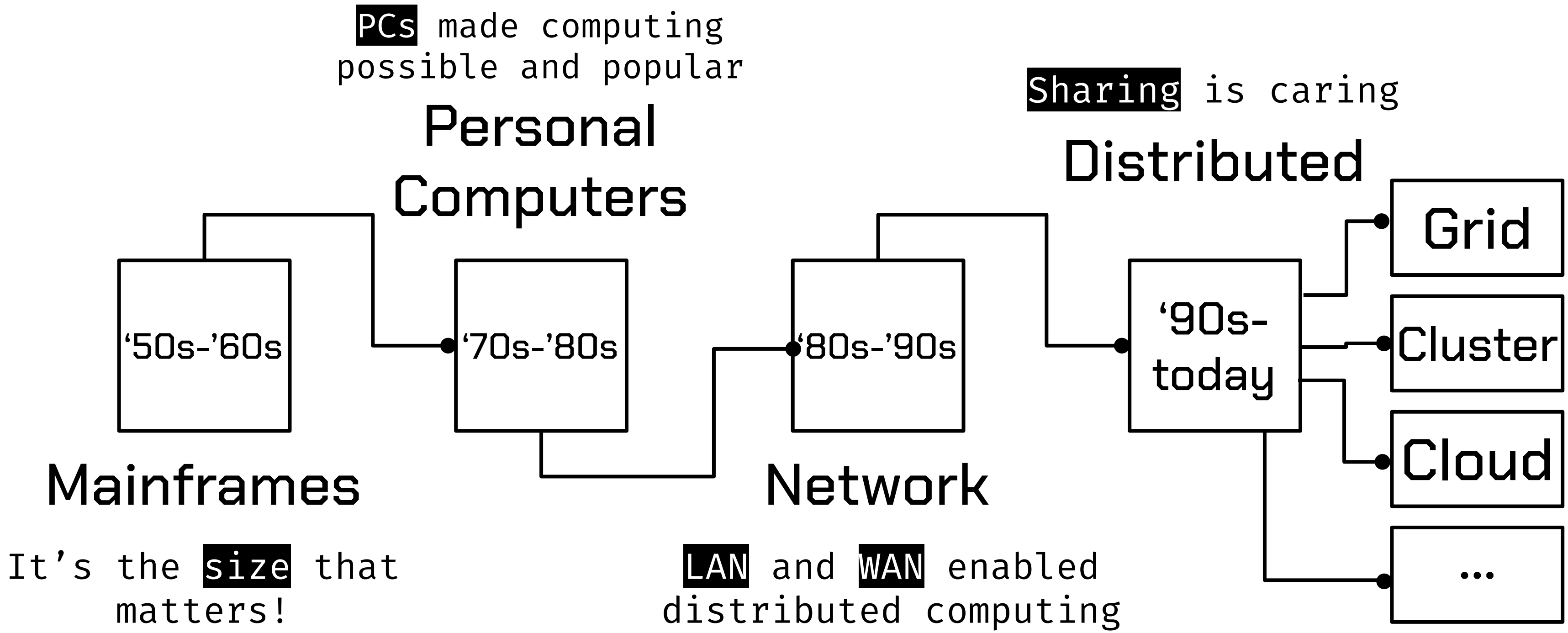
01

What is Grid Computing?

A small (historical) overview and definition

> “ A computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities.”
>
> —Ian Foster and Carl Kesselman (The Grid: Blueprint for a New Computing Infrastructure, 1998)

The Journey to Grid Computing



Mainframes

‘50s-’60s

It’s the size that matters!

Personal Computers

‘70s-’80s

PCs made computing possible and popular

Network

‘80s-’90s

LAN and WAN enabled distributed computing

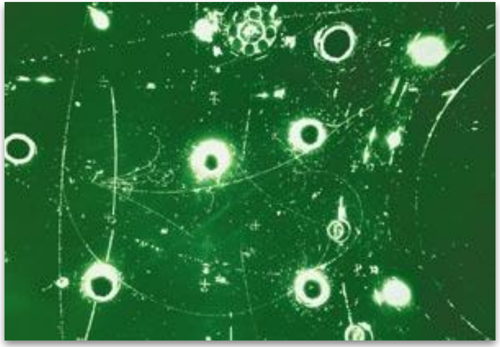
Distributed

‘90s-today

Sharing is caring

- Grid
- Cluster
- Cloud
- …

The Journey to Grid Computing



1950s-1960s: Mainframe Computing

- Computing dominated by centralized, large mainframe computers
- Very rare and expensive
- Terminal access for multiple users on site
- 1958: CERN's first computer

In this era, computing was very exclusive. Particle physics typically wasn't that Privileged… Analysis was mainly done by hand!

https://cerncourier.com/a/in-the-tracks-of-the-bubble-chamber/

The Journey to Grid Computing

1960s: Mainframe Computing

- 1960: IBM 709 as second Computer

"With Mercury and the 709 operating together, CERN had its first experience of compatibility problems. This was a continuing source of difficulty as various different computers came into operation at CERN."

⇒ **The first heterogeneous IT infrastructure at CERN!**
(Already with its merits and pitfalls…)

- With the 709: Introduction of FORTRAN

The Journey to Grid Computing

1970s-1980s: Personal Computing

- PCs made computing power broader accessible
- Shift to decentralized computing
- Computer Science strongly gained in popularity

Businesses, laboratories, and even individuals could own and operate their own computing resources.

Source

The Journey to Grid Computing

1980s-1990s: Network Computing

- LAN and Internet enabled communication between computers
- Resource (and data) sharing over the network became possible!
- First client-server architectures:
  - multiple clients could request services from centralized servers
- First computing clusters (multiple computers interconnected)
- Beginning of the *Internet* at CERN

The Journey to Grid Computing

Also 1990s: Parallel and Distributed Computing

- Start of parallel usage of multiple (distributed) computers for the same problems (not necessarily at the same place!)
- Many new concepts in software development (and collaboration)
  - E.g. breaking down tasks into smaller sub-tasks that could be processed concurrently across different processors or computers
- First public distributed volunteer computing projects:

GIMPS SETI@home distributed.net

2^P-1
Great
Internet
Mersenne
Prime
Search
Finding World Record Primes Since 1996

SETI@HOME

distributed.net

Folding@home was the first exa-scale computing system during Covid in 2020!

The Journey to Grid Computing

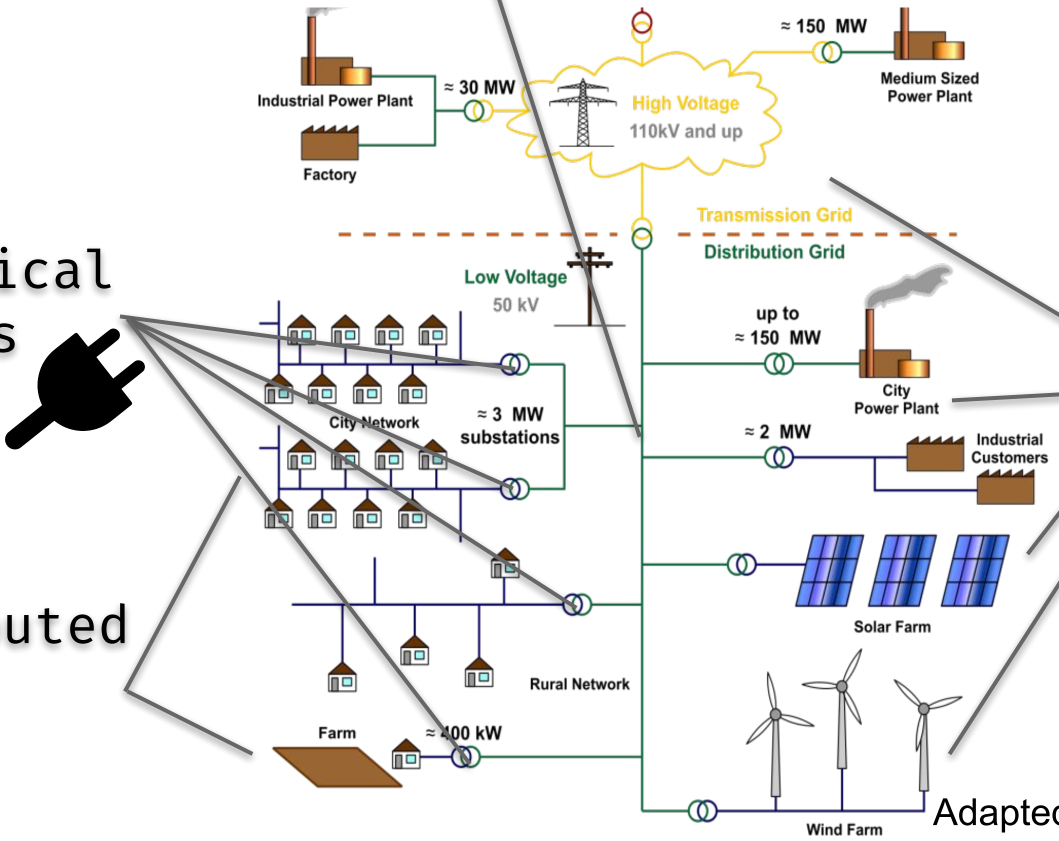
2000s: Grid Computing

- Grid computing built upon the earlier stages by focusing on connecting computers across multiple organizations
- 2001: The European DataGrid project was introduced to develop a production quality computing grid to pave the way for the LHC Computing Grid (LCG)
- 2003: First prototype with 25 sites worldwide (LCG-Phase 1)
- Today: widely established concept in science and industry

What is Grid Computing?

- Distributed computing paradigm with:
  - Shared heterogeneous computational resources across multiple (geographic disperse) administrative domains loosely coupled over network and controlled centrally (but not managed!)
  - Distributed users of Virtual Organizations (VO) with a common access interface
  - Goal: Collaboration on complex (compute) projects across different geographic and institutional boundaries to solve a common large-scale problem
- The naming “Grid” is inspired by the power grid

The grid



Identical access

Distributed users

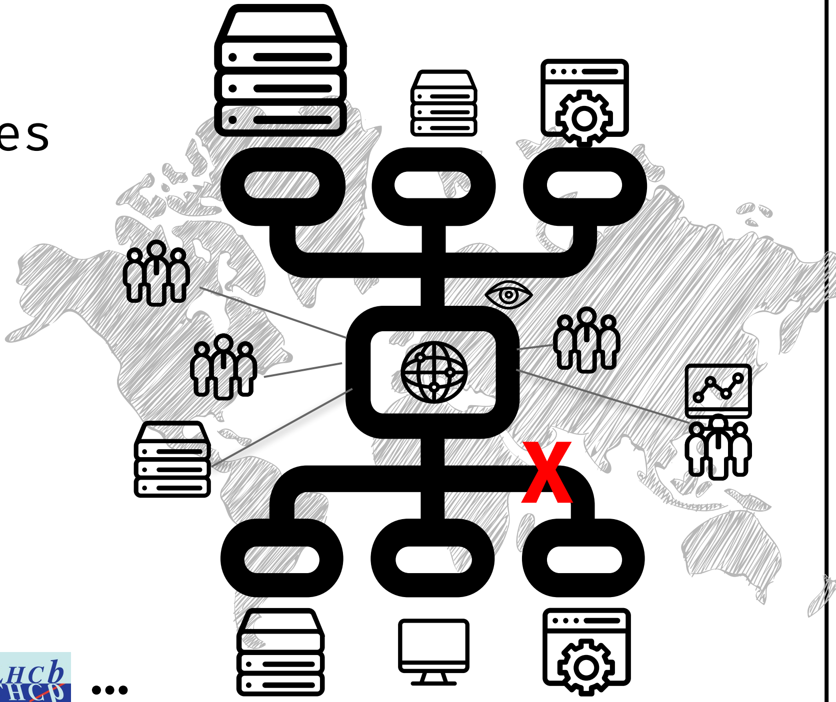
Distributed, heterogeneous resources

Adapted from: Source (CC BY 3.0)

What is Grid Computing?

- Key aspects:
    - Coordinated hetero. Resources
    - Standardized software
    - Scalability and flexibility
    - Reliability and redundancy
    - Cost efficiency
    - Collaboration and shared contributions

CMS ATLAS EXPERIMENT ALICE LHCb …



> “Grid Computing is a distributed computing paradigm that involves a coordinated sharing of heterogeneous, flexible, loosely coupled resources across dynamic and geographically dispersed organizations with the goal to create a "virtual supercomputer" that is able to solve complex, large-scale problems.”
>
> — own definition

Further Reading

- https://web.archive.org/web/20141122035905/http://dlib.cs.odu.edu/WhatIsTheGrid.pdf
- The History of the Grid
- Grid History and Standards

02

How Does a Computing Grid Look Like?

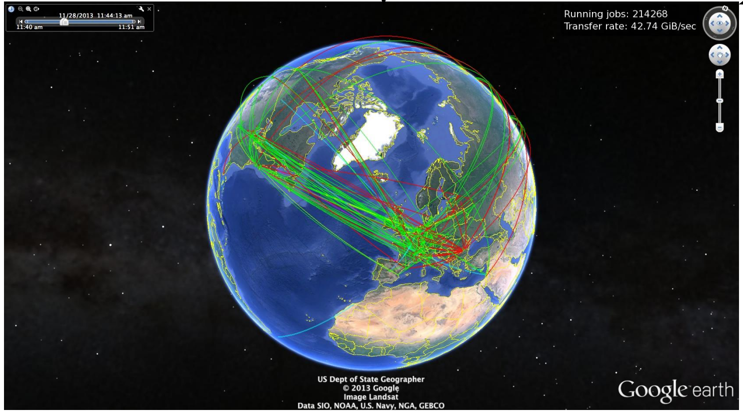
Let’s have a more detailed look at the key concepts and core components of a modern computing grid

Key Components of a Grid

Hardware

Software and Tools

Organizational

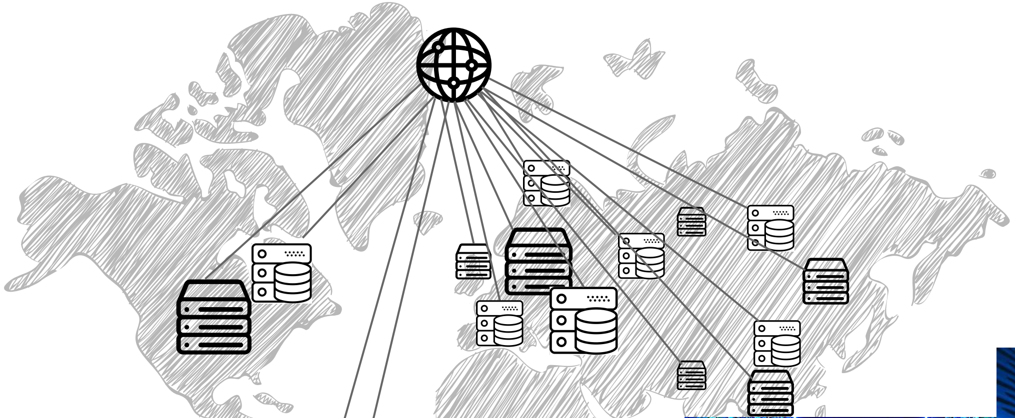


Source

Key Components of a Grid

Servers:
- Compute
- Databases
- Monitoring
- …

Hardware



Network:
- Switches
- Routers
- Firewalls
- …

Storage:
- Tape
- Disk

Key Components of a Grid

ARC gLite (outdated)

Grid middleware:

- Resource management
- Security
- User interfaces
- Backend for further services
- Interoperability

Compute Element:

- E.G. HTCondor or ARC

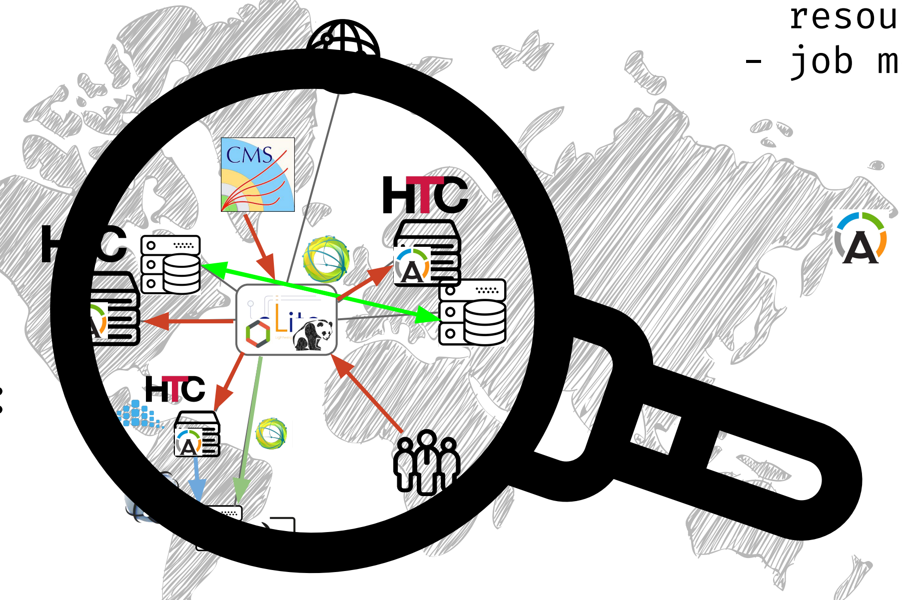
Data management:

- data placement
- data transfers and replication
- data access

Software and Tools

Workflow management:

- defining workflows
- job submission and resource allocation
- job monitoring



Virtualization:

- mostly containers

Monitoring:

- grid status
- metadata
- jobs

Frontend: e.g. CRAB + CMSSW

Key Components of a Grid

Organizational

Grid Initiatives:
- R&D
- Support
- Security
- Standardization
- Accounting

Administration:
- Governance
- VOs
- Collaborators
- Policies

Institutions:
- Contribute resources and manpower

Pledges:

Politics:
- e.g. dCMS

Further Reading

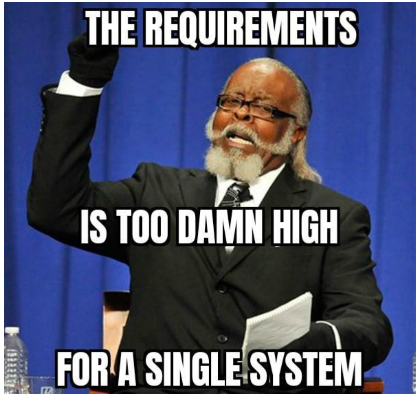
- A “classic” grid middleware: https://en.wikipedia.org/wiki/GLite
- What is Grid Computing (AWS)
- https://www.egi.eu/

03

The Worldwide LHC Computing Grid (WLCG)

World’s ~~biggest~~ most sophisticated open source, scientific computing grid!
(Unfortunately, it’s not the biggest — we probably cannot challenge AWS EC2 …)

WLCG: The Beginning



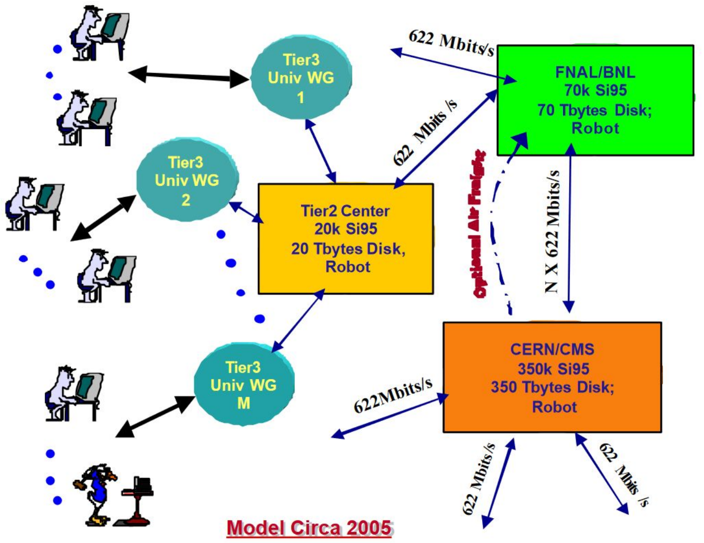
- End 1994: LHC was approved

Requirements on the IT infrastructure:

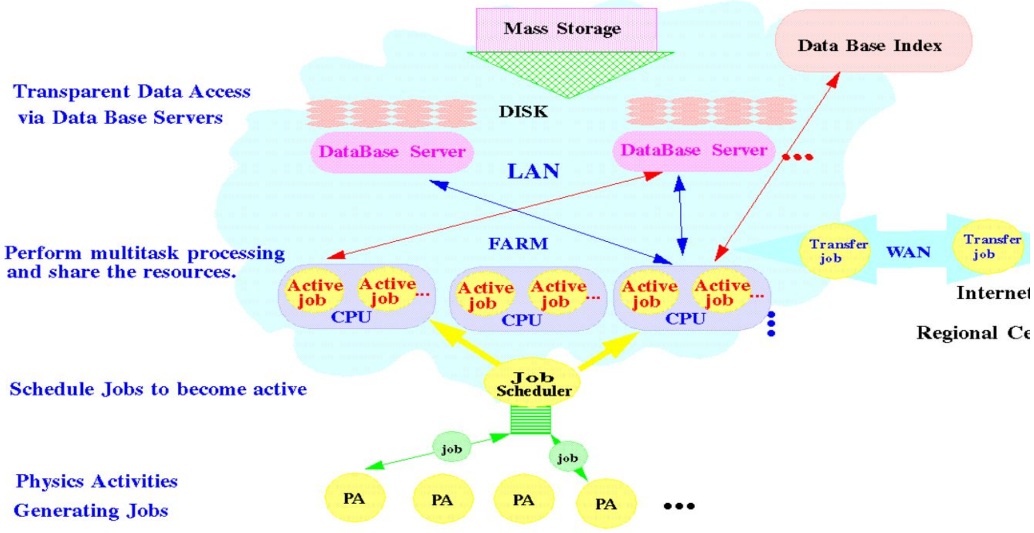
  - The storage and efficient processing of PBs of data
  - Distribution of users and copies of the data around the world
  - Collaboration and shared contributions
  - Reliability, redundancy (of services), and sustainability
  - Scalability and cost effectiveness
  - National interests (e.g. of funding agencies)

- 1998: The Models of Networked Analysis at Regional Centers for LHC (MONARC) project was initiated to find a feasible architectural model for the LCG

WLCG: MONARC Simulations



mputing for an LHC Experiment Based on a Hierarchy of Computing Centers. Capacities



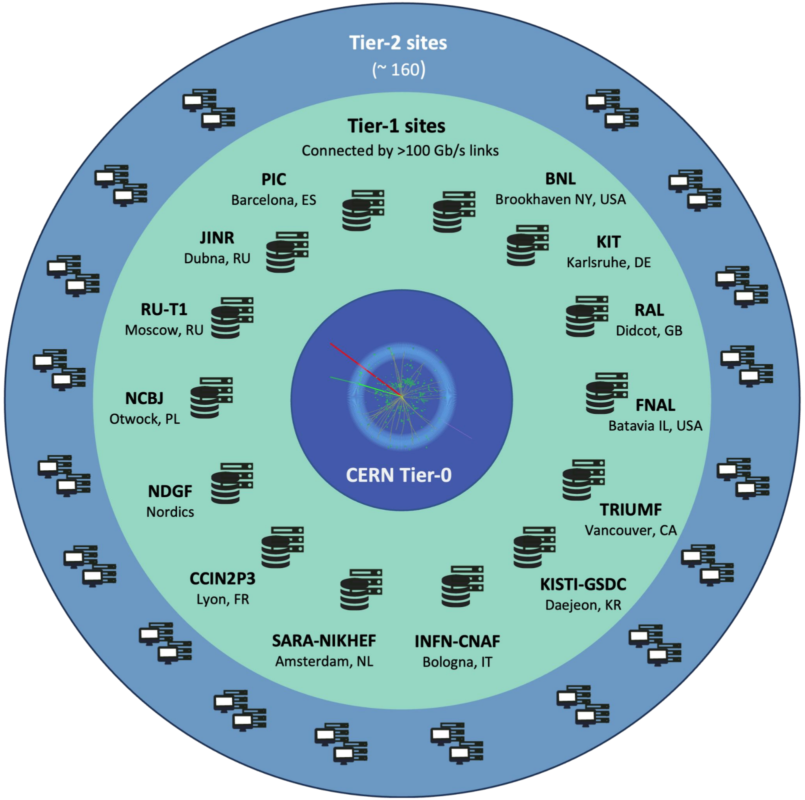
Source

Fig. 2-3 Schematic view of a regional Centre Model.

Instead of a giant computing center, we seek a distribution of our compute and storage resources.

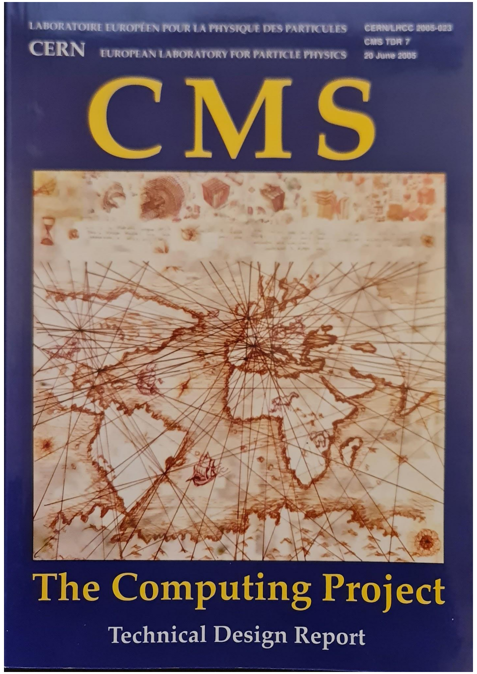
WLCG: Hierarchical Structure

- “Tiers” of the WLCG:
  - T0:
    - data centre at CERN
    - 20% of total compute
    - first copy of data
  - T1:
    - backup share of data
    - dist. of data to T2s
  - T2:
    - provide significant compute power
  - T3: local analysis groups



WLCG: The Beginning

- End 1994: LHC was approved
- 1998: The MONARC project was initiated to find a feasible architectural model for the LCG
- 2002: The success led to the LCG proposal
- 2005: The LCG Technical Design Report was published
- 2008: Beginning of the LHC and LCG operations



LABORATOIRE EUROPÉEN POUR LA PHYSIQUE DES PARTICULES
CERN EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CERN/LHCC 2005-023
CMS TDR 7
20 June 2005

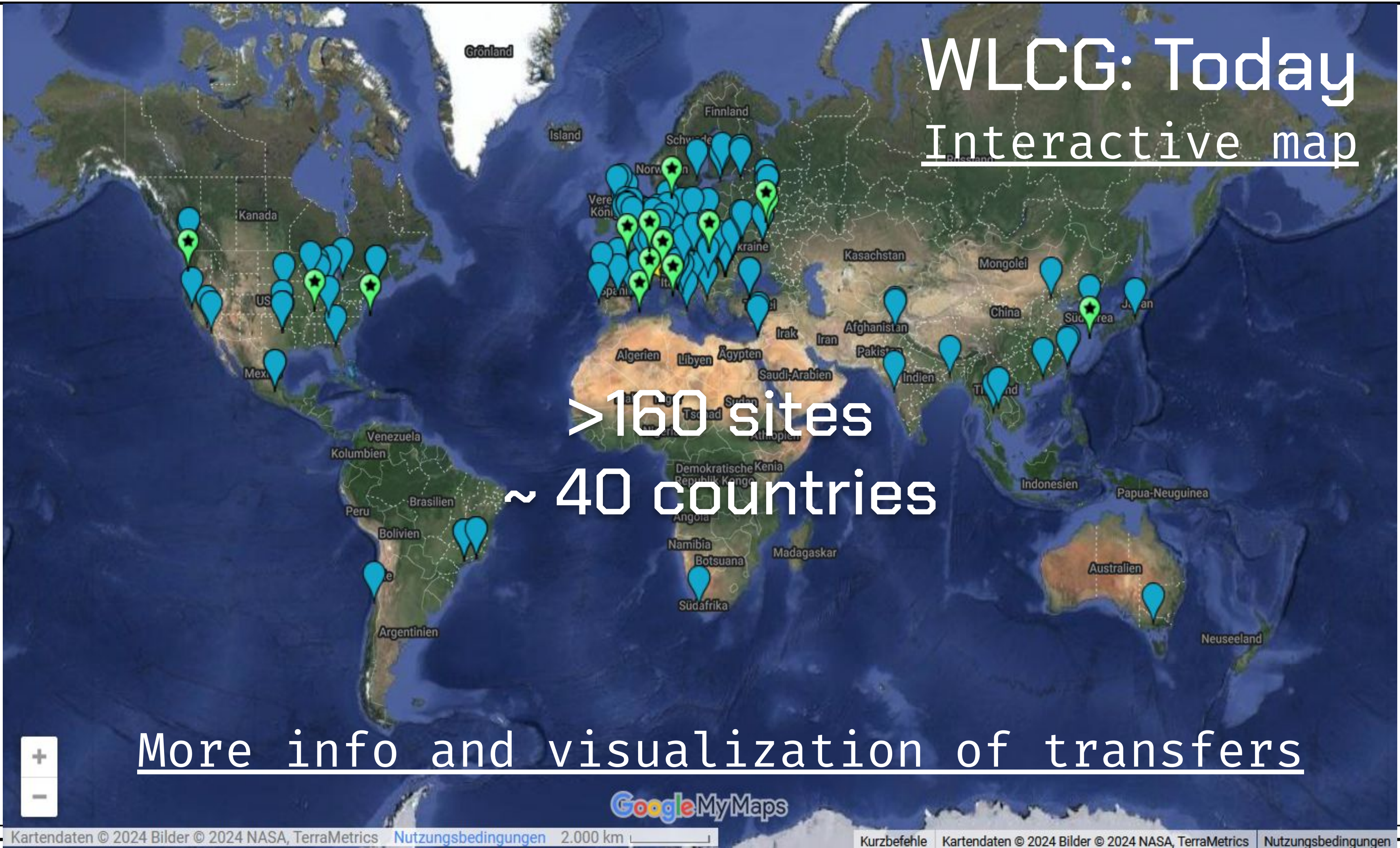
CMS

The Computing Project

Technical Design Report

WLCG: Today

Interactive map



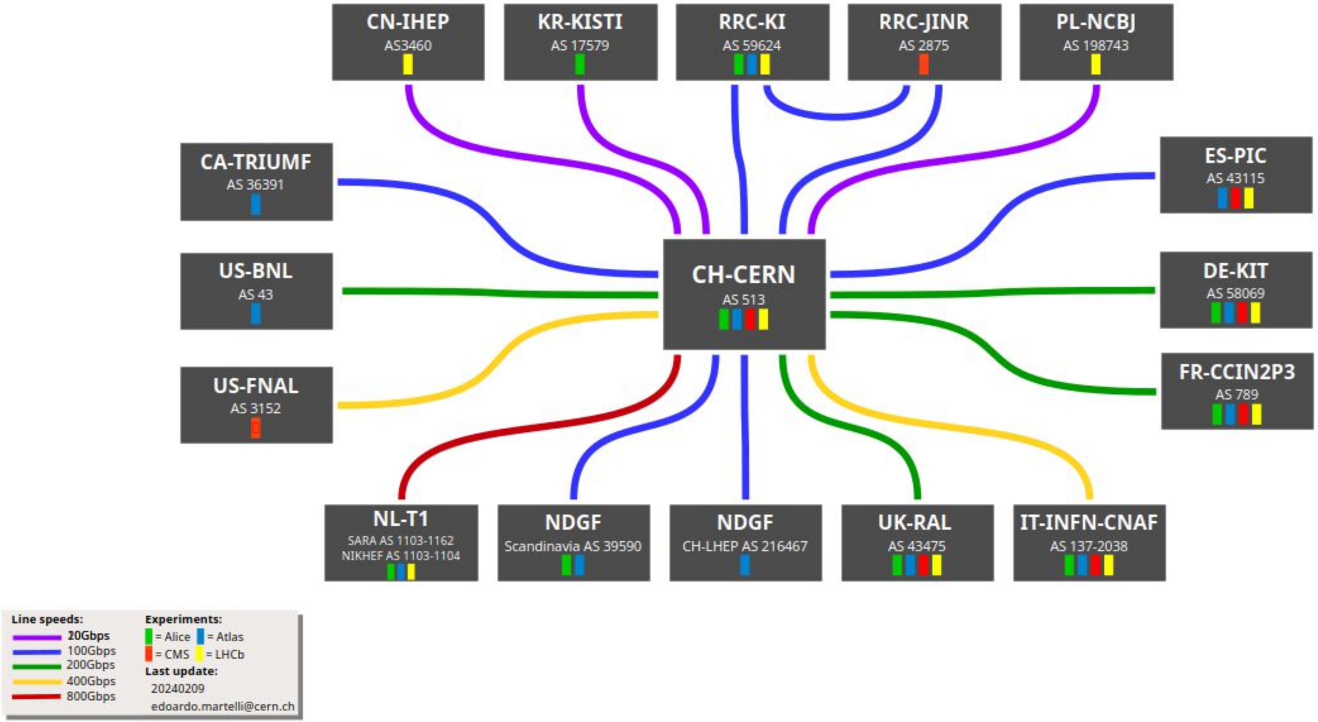
>160 sites

~ 40 countries

More info and visualization of transfers

WLCG: Network

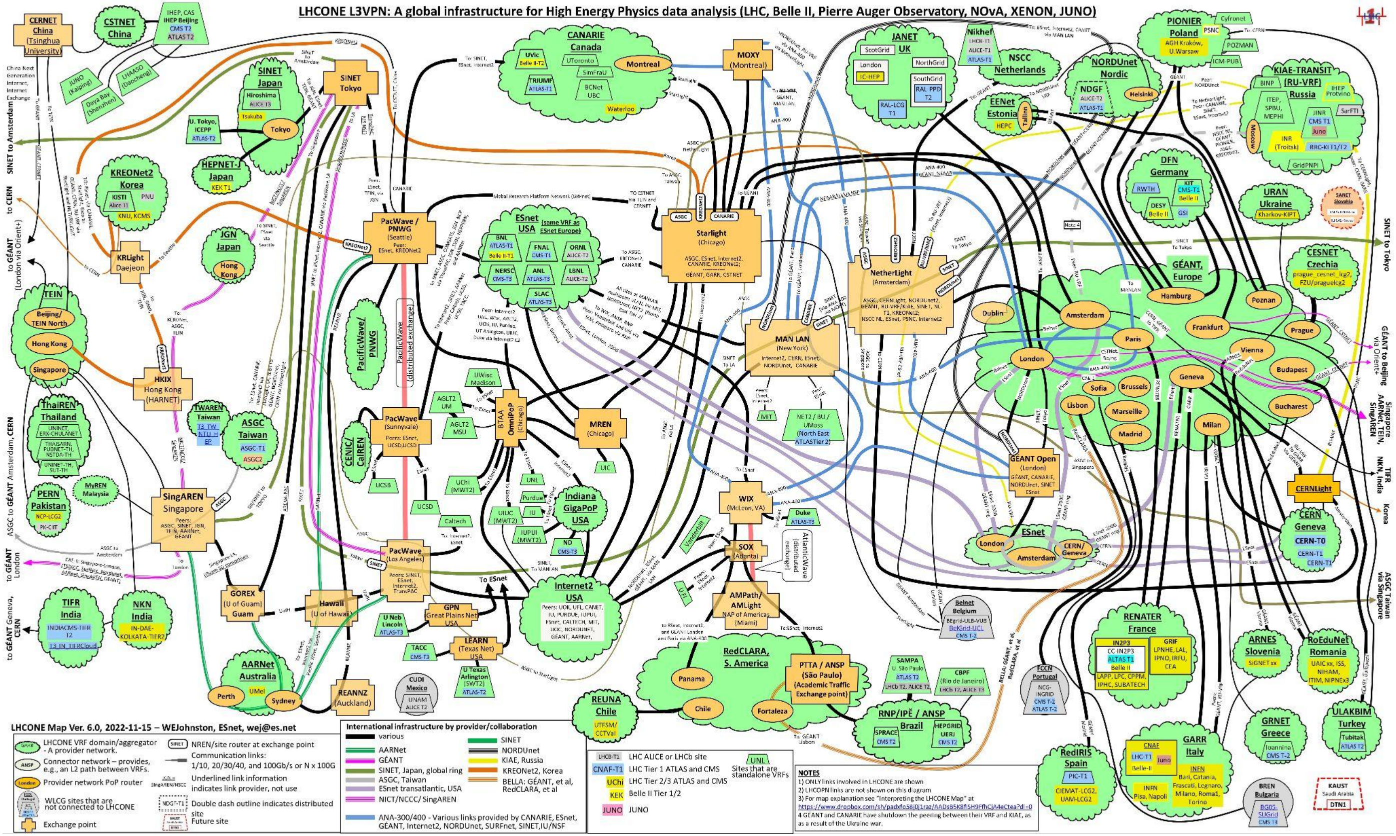
LHCOPN



E.g. monitoring for KIT:

- I
- II
- III

WLCG: Network



Monitoring

Total traffic:
- LINK 1
- LINK 2

WLCG: Overview

~1.400.000

CPU cores within WLCG

1.500.000

TB tape storage space

> 800.000

TB disk storage space

112.596

Concurrently running jobs

>260

GB/s global transfer rate

Source

WLCG: Benefits and Challenges

Benefits

- Massive data handling
- Enables worldwide research
- Collaboration and sharing
- Eff. resource utilization
- Cost efficient
- Easy to contribute
- Reliable and flexible

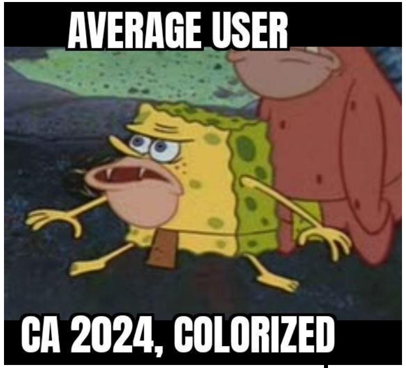
Challenges

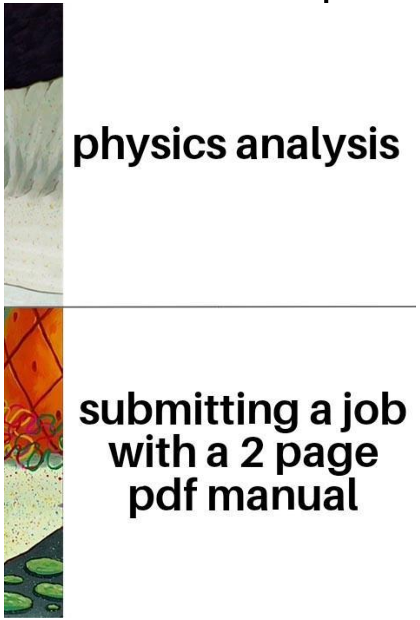
- Data management and access
- Security concerns
- Interoperability
- Network and latency
- Policies
- Complexity (management and usage)
- Default user …

WL


WLCG with
of co
'i prefere running on
laptop, that's more ea


WHAT GIVES PEOPLE FEELINGS OF POWER
MONEY
STATUS
10000 RUNNING JOBS
@iamnotanartist_


AVERAGE USER
CA 2024, COLORIZED

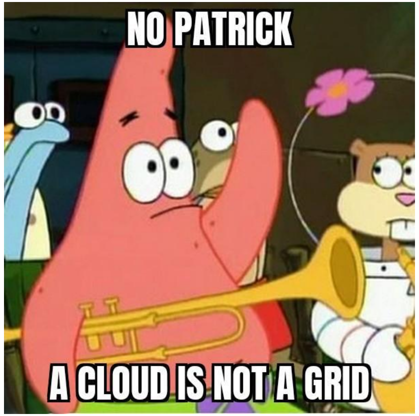

physics analysis
submitting a job with a 2 page pdf manual

Further Reading

- MONARC report
- Good overview: https://wlcg-public.web.cern.ch/structure
- WLCG public side: https://wlcg-public.web.cern.ch/
- https://wlcg-public.web.cern.ch/tiers

Bonus: How about Cloud Computing?

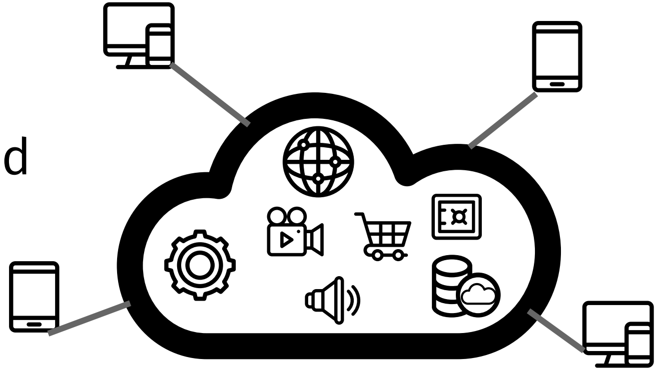
Is a Cloud a Grid?



> “A Cloud is a model for enabling reliable, convenient, on-demand network access to a shared pool of configurable computing resources (networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.”
>
> — own definition

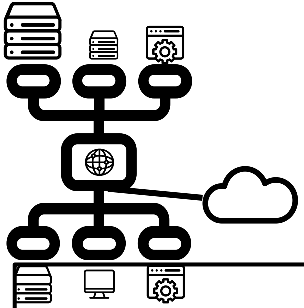
What is Cloud Computing?

- Cloud Computing is also a form of distributed computing that provides on-demand access to a shared pool of resources over the internet
- Fixed definition by NIST
- Different types:
  public, hybrid, private cloud
- Different models:
  IaaS, PaaS, SaaS
- Underlying infrastructure not specified
- It offers scalable and elastic services with a pay-as-you-go pricing model, mainly focusing on business and consumer applications.

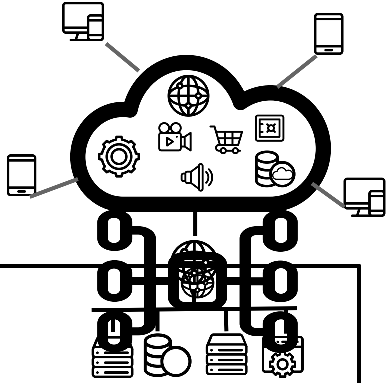


Comparison

	Cloud	Grid
Distributed computing	✓	✓
Scalable, flexible	✓	✓
Cost efficient	✓	✓
Reliability and redundancy	✓	✓
Enable large scale data analysis	✓	✓



Grid vs. Cloud Computing



Grid

- Decentralized heterogeneous resources from many organizations
- Centrally controlled
- More complex access mechanisms
- Purpose: common goal (e.g. large scale research applications)
- One task per job

Cloud

- Centrally managed homo. resources belonging to one organization
- User controlled
- Easy access over the web
- Purpose: elastic provisioning of non-related ready-to-use services
- Complex services (like CDNs)

⇒ A cloud can be deployed on a grid, a cloud can be a part of a grid, but a grid is not a cloud!

Example: The Tier-0 at CERN

“[…] Over 90% of the resources for computing in the Data Centre are provided through a private cloud based on OpenStack, an open-source project to deliver a massively scalable cloud operating system.”
Source Monitoring

Bonus: How about Cloud Computing?

Could we replace the Grid by a (Commercial) Cloud?

Bonus: How about Cloud Computing?

Sure, Why not?

Well…

Well ...

Example: AWS

(very rough estimate for 2023)

Storage: (Speed=???, prob. too low)

- 900PB disk: 18.900.000 USD
- 1.5EB tape: 6.000.000 USD

Compute: (with 100G WAN)
1.280.000 cores: 693.786.744 USD

Transfers:(tape only: ~50GB/s avg)
1.577.000.000GB: 94.600.000 USD

Does not include:
- Other transfers
- Databases
- Monitoring
- Person power
- ...

Very rough estimate:
1.000.000.000 USD per year

\+ Vendor lock-in ...

Thanks!