Introduction to Grid Computing
May 2013

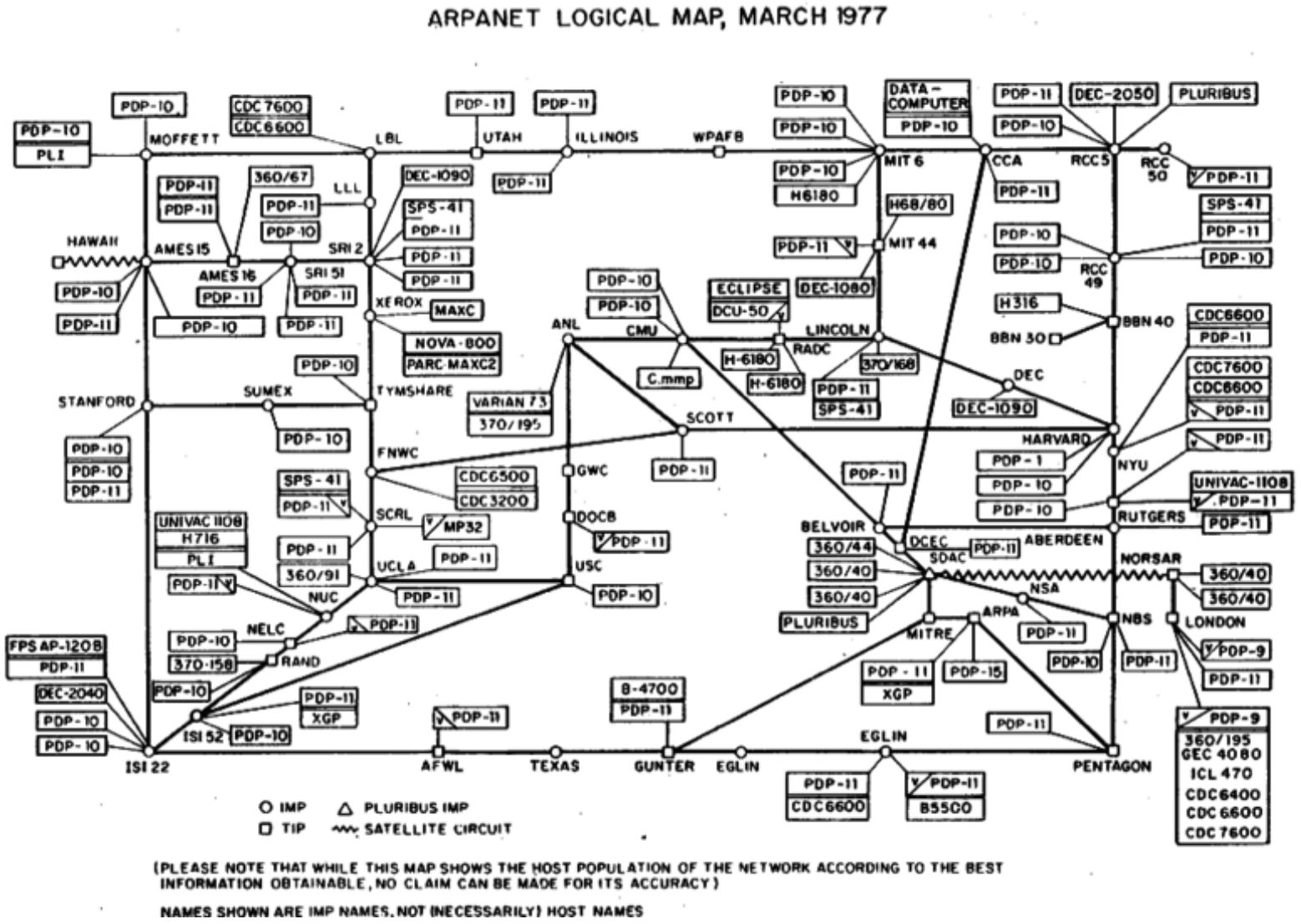
Marian Babik
CERN

Outline

- Networking
- Web
- Web 2.0
- Distributed systems
- Grid
- Cloud

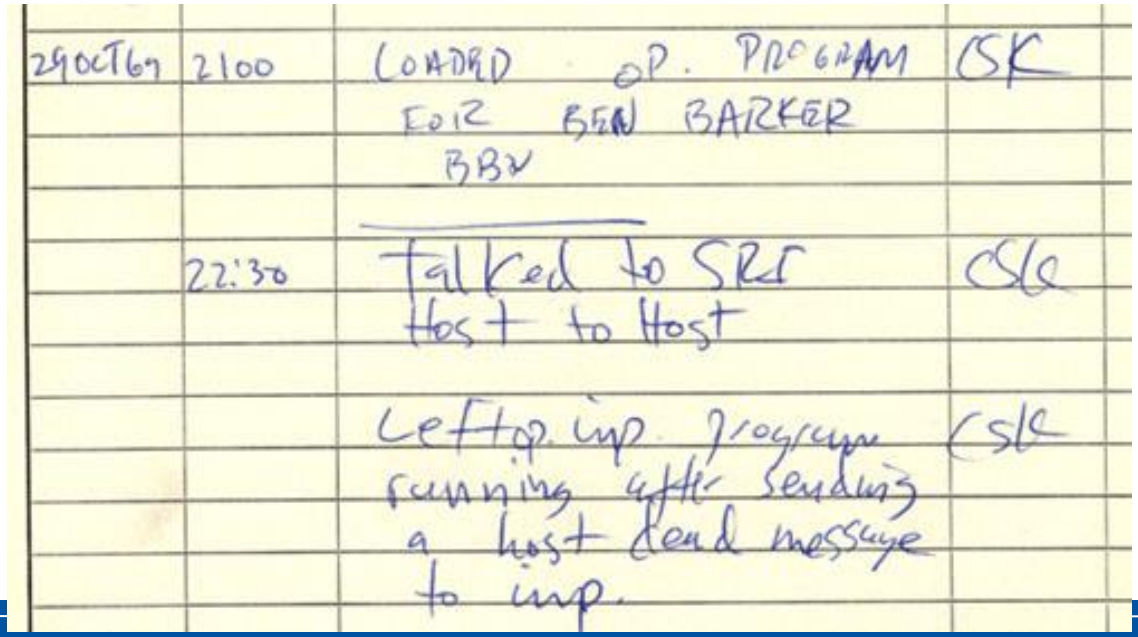
NETWORKING

Networking


ARPANET LOGICAL MAP, MARCH 1977
MOFFETT
LBL
UTAH
ILLINOIS
WPAFB
MIT 6
DATA-COMPUTER
CCA
RCC 5
RCC 50
PLURIBUS
DEC-2050
HAWAII
AMES 15
AMES 16
SRI 2
SRI 51
LLL
XEROX
MAXC
NOVA-800
PARC MAXC2
MIT 44
H68/80
H6180
ECLIPSE
DCU-50
DEC-1080
RCC 49
H316
BBN 50
BBN 40
CDC6600
CDC7600
ANL
CMU
C.mmp
LINCOLN
RADC
H-6180
370/168
DEC
DEC-1090
STANFORD
SUMEX
TYMSHARE
VARIAN 73
370/195
SCOTT
HARVARD
NYU
RUTGERS
UNIVAC-1108
FNWC
GWC
CDC6500
CDC3200
SCRL
MP32
DOCB
UNIVAC 1108
H716
360/91
UCLA
USC
NUC
BELVOIR
360/44
360/40
PLURIBUS
DCEC
SDAC
ABERDEEN
NORSAR
NSA
ARPA
MITRE
NBS
LONDON
NELC
RAND
FPSAP-120B
DEC-2040
ISI 22
ISI 52
XGP
AFWL
TEXAS
B-4700
GUNTER
EGLIN
PENTAGON
B5500
360/195
GEC 4080
ICL 470
CDC6400
CDC 6600
CDC 7600
IMP
TIP
PLURIBUS IMP
SATELLITE CIRCUIT
(PLEASE NOTE THAT WHILE THIS MAP SHOWS THE HOST POPULATION OF THE NETWORK ACCORDING TO THE BEST INFORMATION OBTAINABLE, NO CLAIM CAN BE MADE FOR ITS ACCURACY)
NAMES SHOWN ARE IMP NAMES, NOT (NECESSARILY) HOST NAMES

Networking

- ARPAnet (Advanced Research Projects Agency Network, 1962)
  - MIT, DARPA, US Dept. of Defense,
  - first operational packet switching network
  - data system could use one communications link to communicate with more than one machine by disassembling data into datagrams, then gather these as packets.

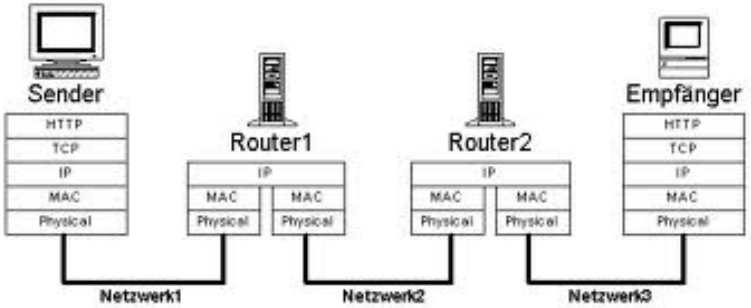


Networking

- + many others (UUCP, NPL, X.25, etc.)
- TCP/IP network stack
- IP(Internet protocol) – datagrams, packets, addressing
  - IP Address
    - 32bit (4 bytes) (e.g. 209.85.229.147)
    - 4,294,967,296 (2^32)
  - Domain Name System (DNS)
    - www.google.com -> 209.85.229.14
- TCP (Transmission Control Protocol)
  - provides the service of exchanging data reliably directly between two network hosts

Networking

- Routing
  - how to deliver packets from one host to another
    - Graph theory
    - Minimum spanning tree
    - Shortest path



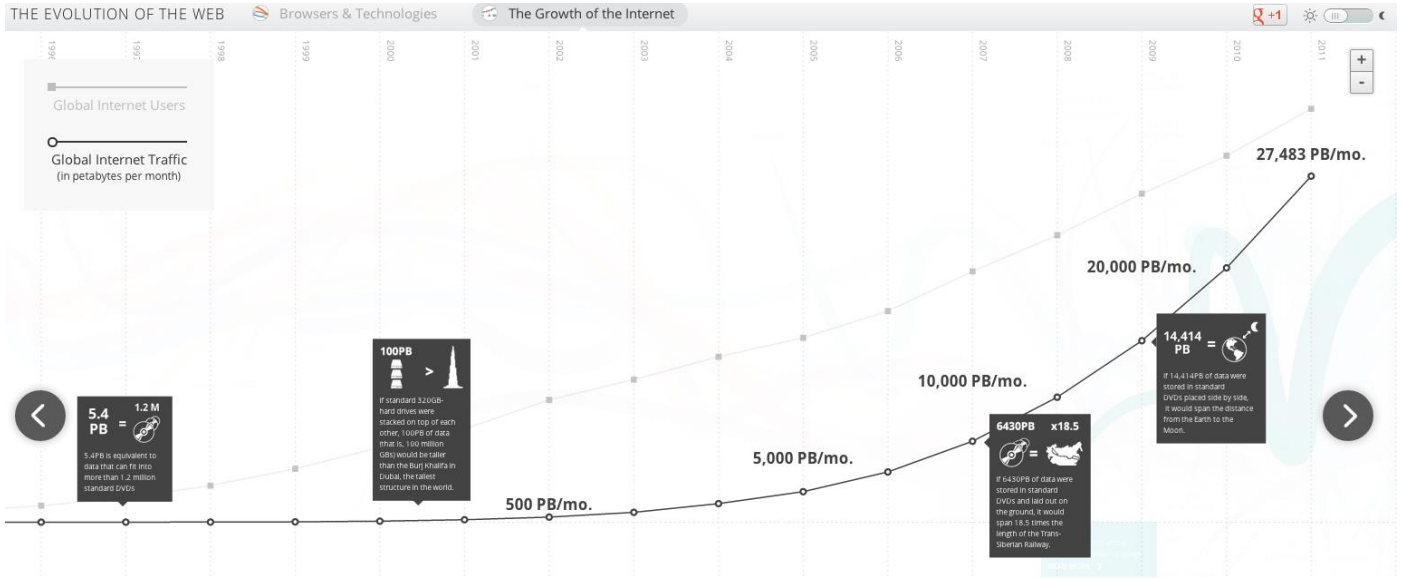
- Throughput/Latency
  - average rate of successful message delivery over a communication channel
    - 10Mbit/100Mbit/1Gbit
  - measure of time delay experienced in a system

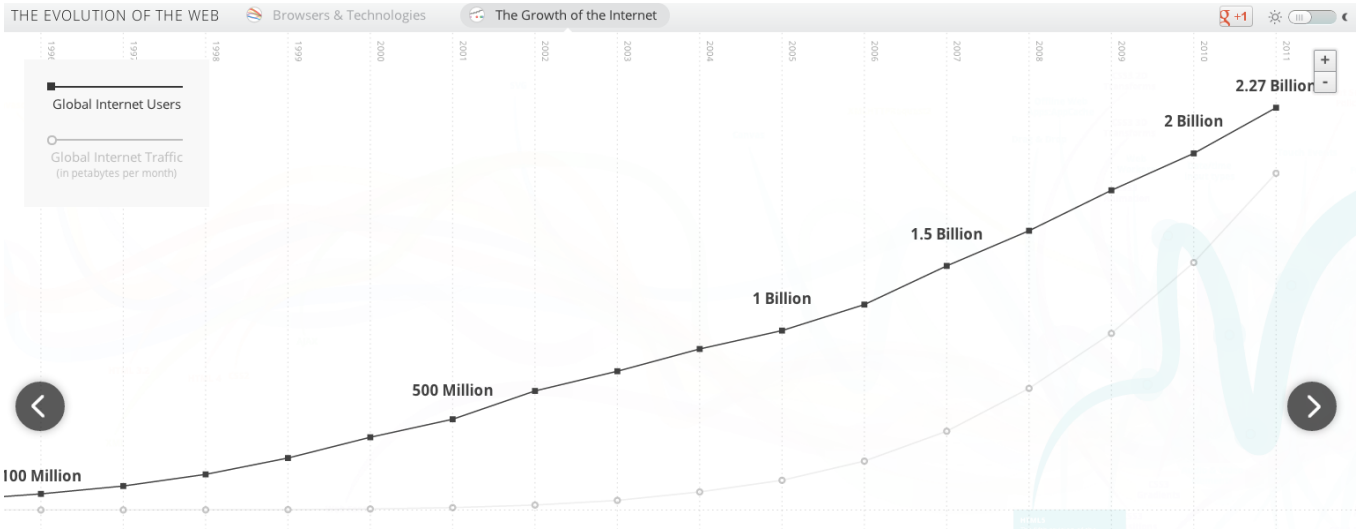
WEB

Web of Today!


Mittwoch, 10.9.2008
Schlagzeilen | TV-Programm | RSS | Newsletter | Mobil | Dienste | Startseite | Wetter | DER SPIEGEL
Le Matin Online
Le Matin Video | BleuBlog | Dossiers | Photos | Dessins | Concours | Jeux | Annonces
Accueil | Actu | Sports | People | Tendances | Multimédia | Loisirs | Dépêches | Femina | Bilan
Imiter le chef
Toutes les vidéos et les recettes sur le blog
Golfe du Mexique: l'ouragan Ike menace les USA
Edipresse: bénéfice en hausse de 10% au 1er semestre
Vidéo
COLLISIONNEUR DU CERN
Mise en route réussie du LHC: ce n'est pas la fin du monde!
Le CERN a procédé avec succès ce matin au démarrage du plus grand accélérateur de particules au monde, le Grand collisionneur de hadrons (LHC). A 09h33, le faisceau de protons était injecté dans l'anneau de 27 kilomètres et à 10h25, le tour complet était réalisé pour la première fois. Suivez l'expérience en direct sur le matin.ch | Suite
69 commentaires
Dossier
Le CERN et la fin du monde

Web of Today





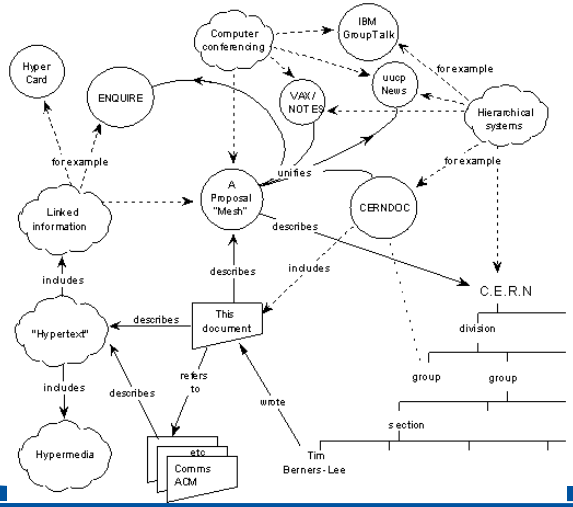
source: http://www.evolutionoftheweb.com/

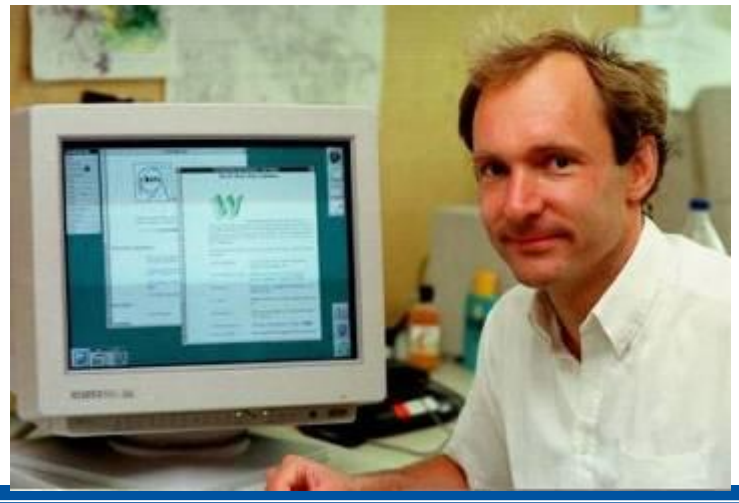
What is the Web ?

- Internet + Hypertext
- Hypertext ?
  - text displayed on a computer or other electronic device with references

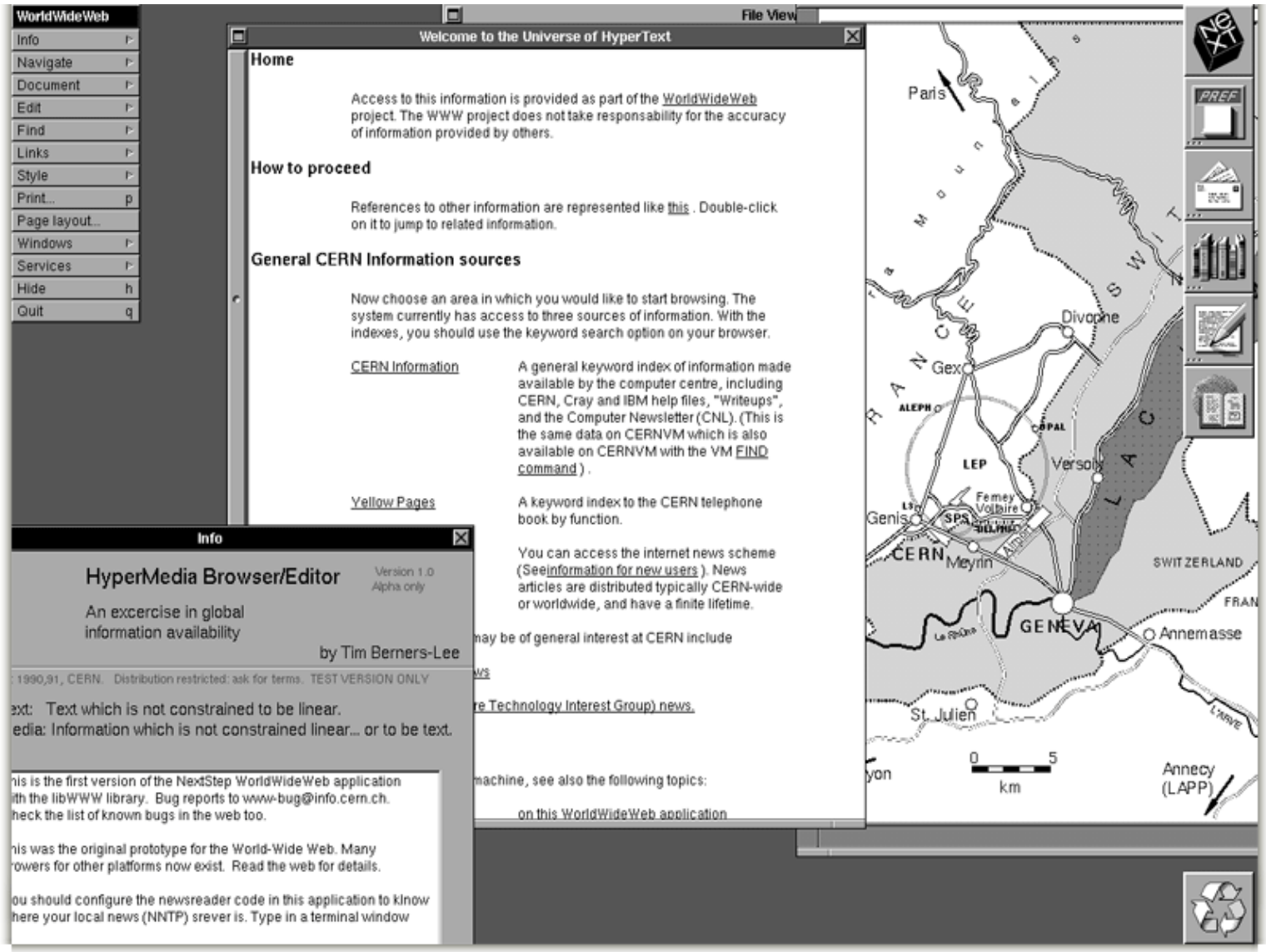
1991: Early **www system released** to HEP via the CERN program library. First web servers located in European physics laboratories.

1993: First Mosaic browser; web reaches 500 servers and 1% of Internet traffic; CERN places **WWW in the public domain**.





Web browser


WorldWideWeb
Info
Navigate
Document
Edit
Find
Links
Style
Print... p
Page layout...
Windows
Services
Hide h
Quit q
File View
Welcome to the Universe of HyperText
Home
Access to this information is provided as part of the WorldWideWeb project. The WWW project does not take responsability for the accuracy of information provided by others.
How to proceed
References to other information are represented like this . Double-click on it to jump to related information.
General CERN Information sources
Now choose an area in which you would like to start browsing. The system currently has access to three sources of information. With the indexes, you should use the keyword search option on your browser.
CERN Information
A general keyword index of information made available by the computer centre, including CERN, Cray and IBM help files, "Writeups", and the Computer Newsletter (CNL). (This is the same data on CERNVM which is also available on CERNVM with the VM FIND command) .
Yellow Pages
A keyword index to the CERN telephone book by function.
You can access the internet news scheme (Seeinformation for new users). News articles are distributed typically CERN-wide or worldwide, and have a finite lifetime.
Info
HyperMedia Browser/Editor
Version 1.0
Alpha only
An excercise in global information availability
by Tim Berners-Lee
Text which is not constrained to be linear.
Information which is not constrained linear... or to be text.
Paris
Divonne
Gex
ALEPH
LEP
Versoix
Genis
SPS
CERN
Meyrin
SWITZERLAND
GENEVA
Annemasse
St. Julien
Annecy (LAPP)
0 5
km

What happens when you visit a web page

- HTTP (HyperText Transfer Protocol) request

```
GET http://facebook.com/ HTTP/1.1
Accept: application/x-ms-application, image/jpeg, application/xaml+xml, [...]
User-Agent: Mozilla/4.0 (compatible; MSIE 8.0; Windows NT 6.1; WOW64; [...]
Accept-Encoding: gzip, deflate
Connection: Keep-Alive
Host: facebook.com
Cookie: datr=1265876274-[...]; locale=en_US; lsd=WW[...]; c_user=2101[...]
```

- DNS
  - facebook.com -> 66.220.156.25
- TCP/IP
  - Message -> packets -> datagrams
  - Routed to 66.220.156.25 port 80
- HTTP

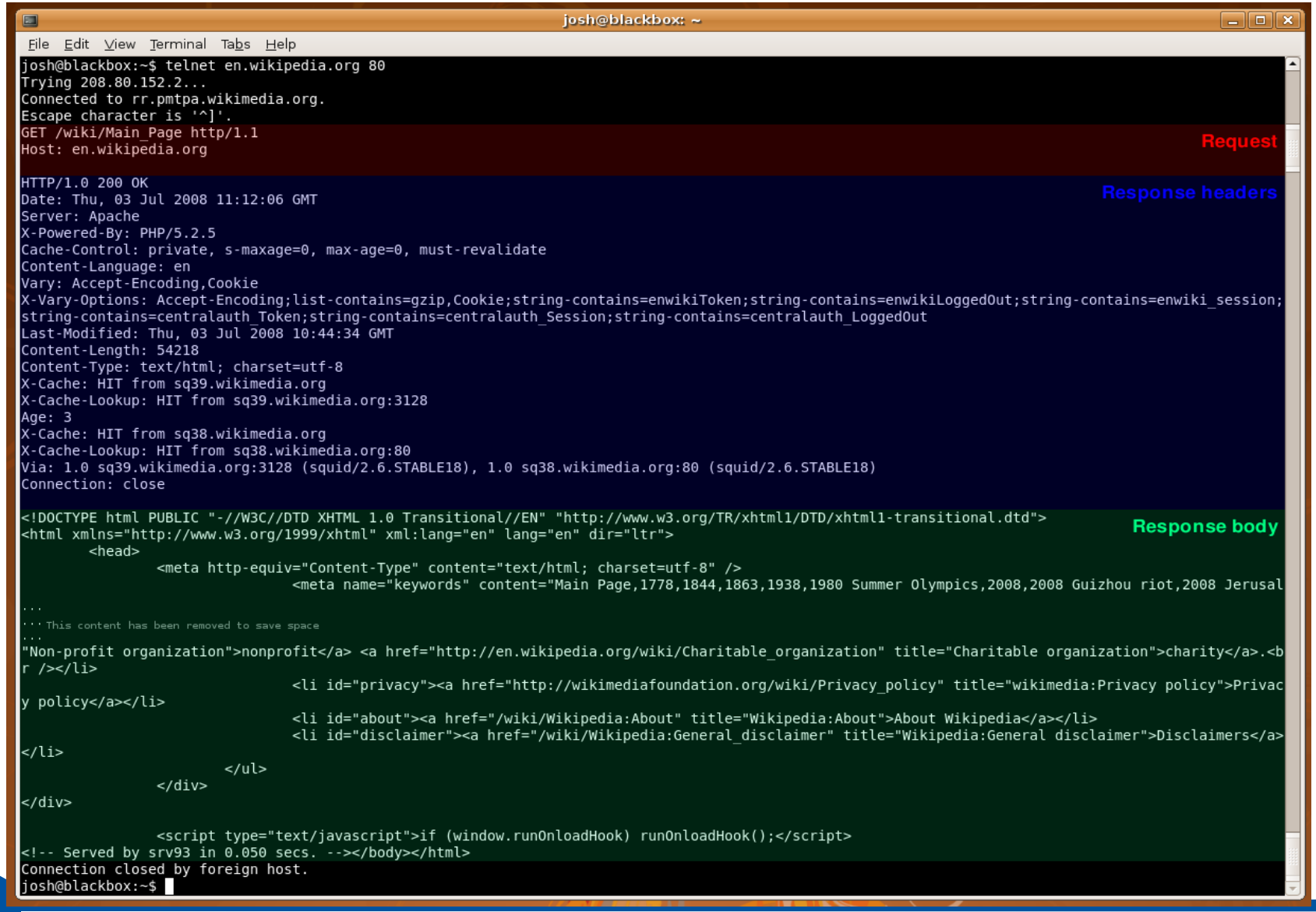
What happens when you visit a web page

- HTTP response
  - DNS, TCP/IP
  - HTML (HyperText Markup Language)

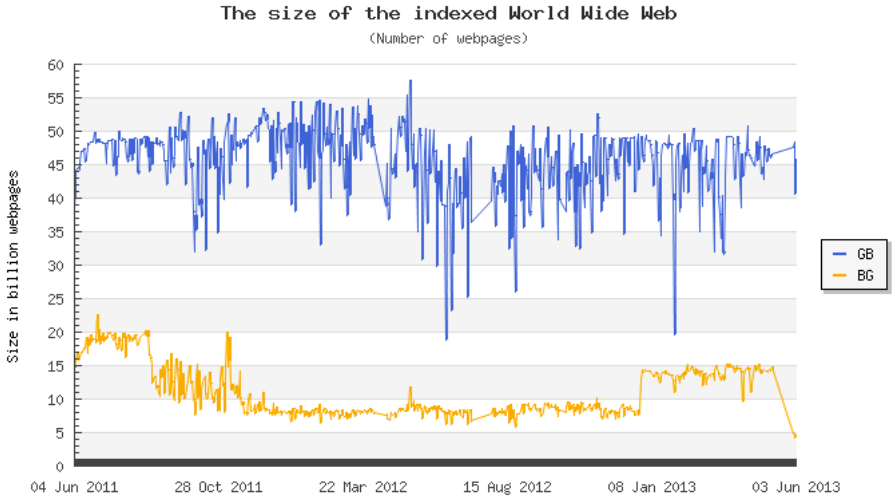

```
HTTP/1.1 200 OK
Cache-Control: private, no-store, no-cache, must-revalidate, post-check=0,
    pre-check=0
Expires: Sat, 01 Jan 2000 00:00:00 GMT
P3P: CP="DSP LAW"
Pragma: no-cache
Content-Encoding: gzip
Content-Type: text/html; charset=utf-8
X-Cnection: close
Transfer-Encoding: chunked
Date: Fri, 12 Feb 2010 09:05:55 GMT


<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Strict//EN"
      "http://www.w3.org/TR/xhtml1/DTD/xhtml1-strict.dtd">
<html xmlns="http://www.w3.org/1999/xhtml" xml:lang="en"
      lang="en" id="facebook" class=" no_js">
<head>
<meta http-equiv="Content-type" content="text/html; charset=utf-8" />
<meta http-equiv="Content-language" content="en" />
...
```

What happens when you visit a web page



Web



- Search
  - Pagerank – Sergey Brin, Larry Page (Google)
  - rank web pages that match a given search string
  - assumes that web pages linked from many important pages are themselves likely to be important
  - a recursive score for pages, based on the weighted sum of the PageRanks of the pages linking to them

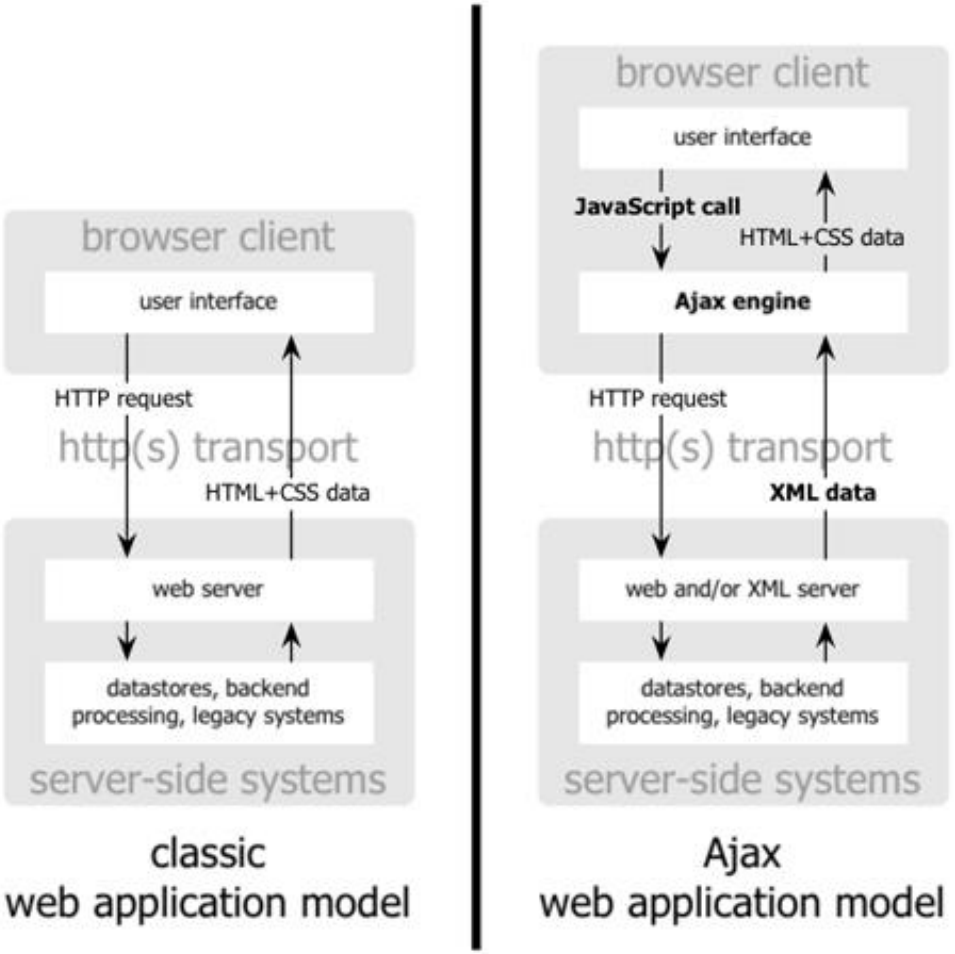
WEB 2.0

Web 2.0


Trumba
eskobo
Pageflakes
vimeo
kiko
skobsie
shadows
grovee
YouTube
Zimbra
smugmug
newsgator
Blogniscient
TiNFiNGER
shutterfly
PodDater
Feedster
favoor
ZAZZLE
Tailrank
TagWorld
nuvvo
dogear
yakalike
grouper
ODDPOST
iNeds
Lulu
blish
flagr
FireAnt
simplyhired
veoh
theadcloud
rbloc.com
gather
oyogi
cafépress
Renkoo
standpoint
meebo
lost-fm
Jotspot
Frappr!
jeteye
dabble
YEDDA
Writeboard
SHOUTWIRE
iKarma
AirSet
techmemeorandum
CalendarHub
Supr
pando
zigtag
Findory
backfence
clipmarks
wayfarer
gOFFICE
AllPeers
Rallypoint
Zoozio
blogbeat
Ziggs
vSocial
Boltfolio
wink
riya
Wordcast
Opinity
measuremap
bluepulse
STREAMLOAD
Ta-da Lists
FeedShy
jellyBarn.INC
nativetext
CONGOO
PODZINGER
RSS MAD
FeedTier
phanfare
Fruitcast
dPolls
flickr
Ning
Ookles
Strongspace
zoominfo
CASTPOST
yubnub
FeedBurner
Bloglines
FOTOLOG
ourmedia
Yub.com
Spot Runner
myspace
NewsAlloy
Alimydata.com
gabbroom
Gcast
openomy
ajchat
jambo
ROLLYO
ClipShack
chatsum
PANDORA
looklater
squishr
WebJay
PLAXO
Noodly
30 BETA
windir
diigo
box
Jots
Xdrive
vizu
digg
del.icio.us
AlmondRocks
Tagyu
writely
Simpy
Gtalkr
TRUVEO
egoSurf
Quimble
pegasus
remember the milk
SQUIDOO
picturecloud
newsvine
Clipfire
mozy
Basecamp
Netvibes
gOOway
Lexxe alpha
YOOKSTER
PXN8
facebook
43 Things
Technorati
Backpack
Gmail
yelp
kSmarkets
inform
filangy
magnolia
ShoZu
feedmarker
mercora
MusicSearch
Meet With Approval.com
HOMEPORTALS
Spin spy

Web 2.0

- Javascript
- AJAX



Semantic Web

- group of methods and technologies to allow machines to understand the meaning - or "semantics" - of information on the Web
- Based on
  - Logic models
  - Information retrieval
  - Machine learning
- e.g. Wolfram Alpha (http://www.wolframalpha.com/)

DISTRIBUTED SYSTEMS

Distributed systems

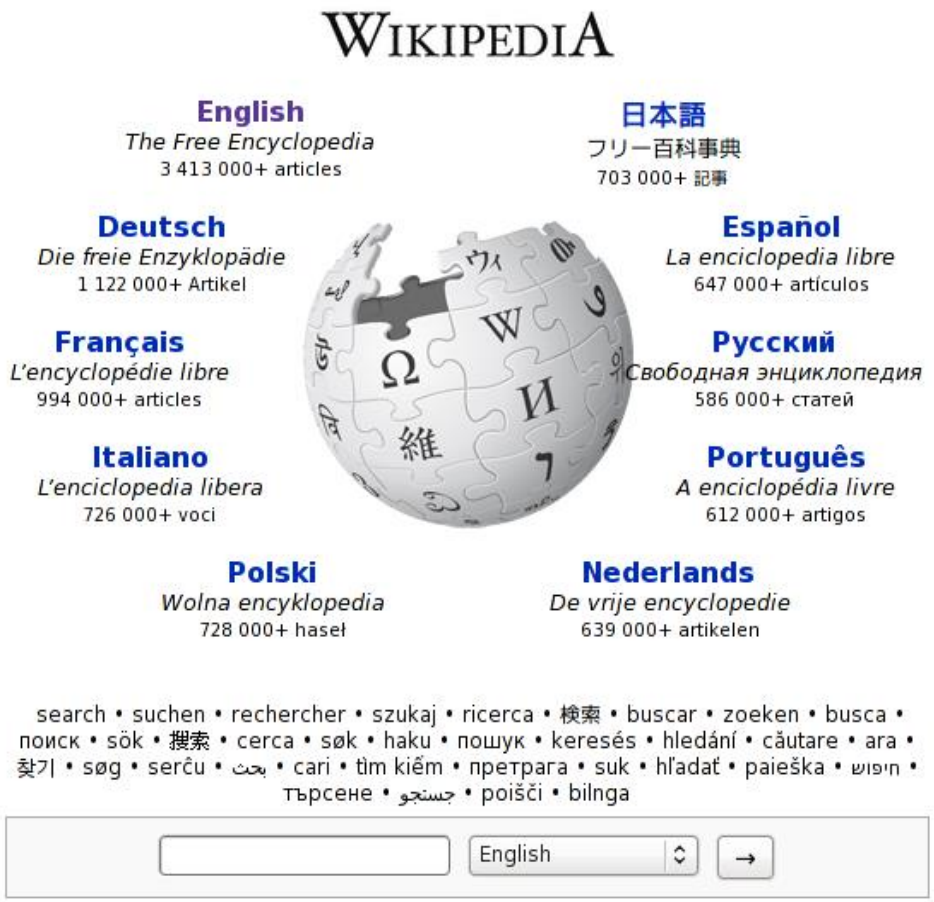
- Distributed system
  - Web (WIKIPEDIA)
  - Torrent
  - Distributed computing system:
    - Data intensive (Hadoop, map-reduce)
    - CPU intensive (Condor)

Distributed systems

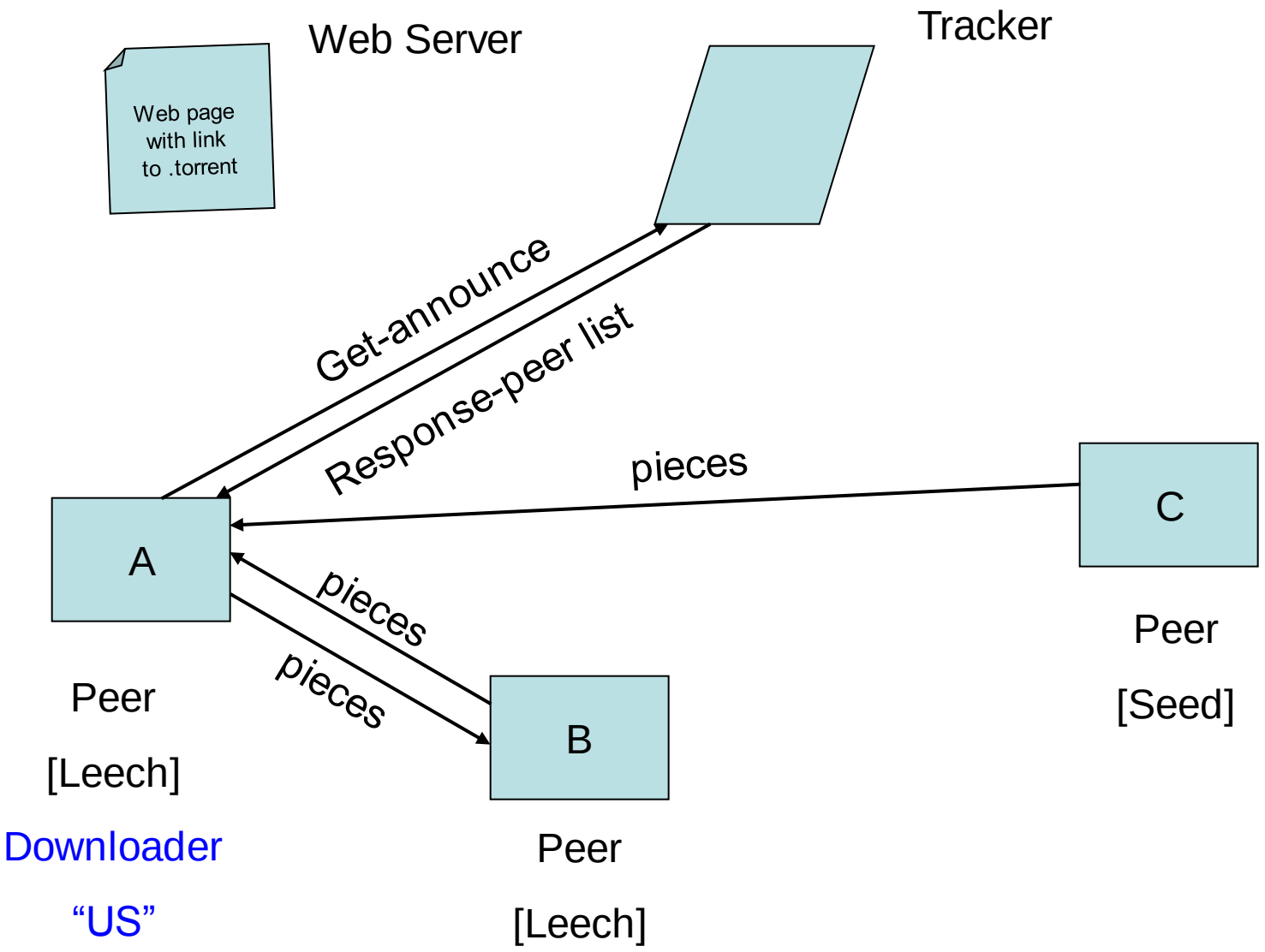
- Common properties
  - Fault tolerance
    - When one or some nodes fails, the whole system can still work fine except performance.
    - Need to check the status of each node
    - Each node play partial role
    - Each computer has only a limited, incomplete view of the system. Each computer may know only one part of the input.
  - Resource sharing
    - Each user can share the computing power and storage resource in the system with other users
  - Load Sharing
    - Dispatching several tasks to each nodes can help share loading to the whole system.
  - Easy to expand
    - We expect to use few time when adding nodes. Hope to spend no time if possible.

Wikipedia

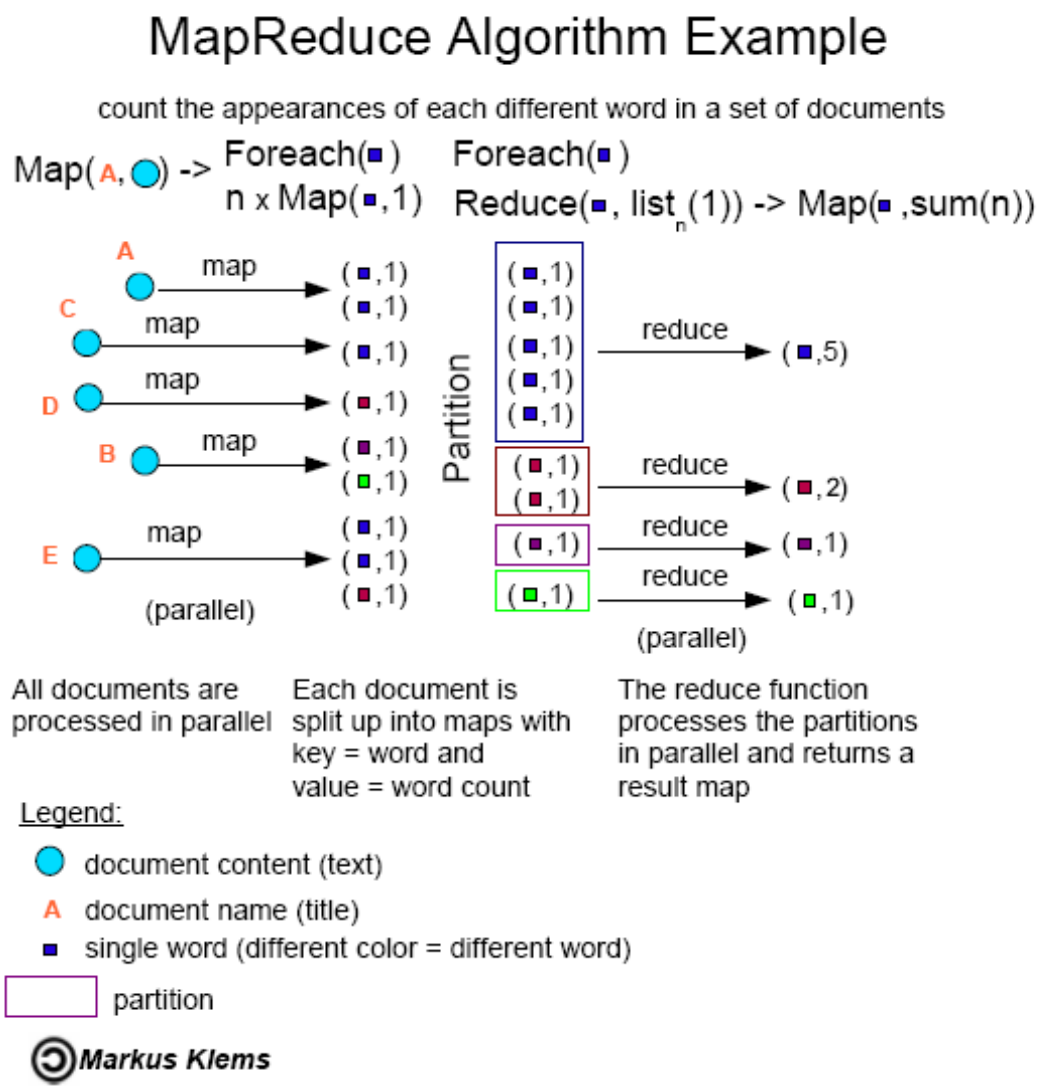
- Web



Torrent


Web Server
Web page with link to .torrent
Tracker
Get-announce
Response-peer list
pieces
A
C
pieces
pieces
Peer
[Leech]
Downloader
"US"
B
Peer
[Leech]
Peer
[Seed]

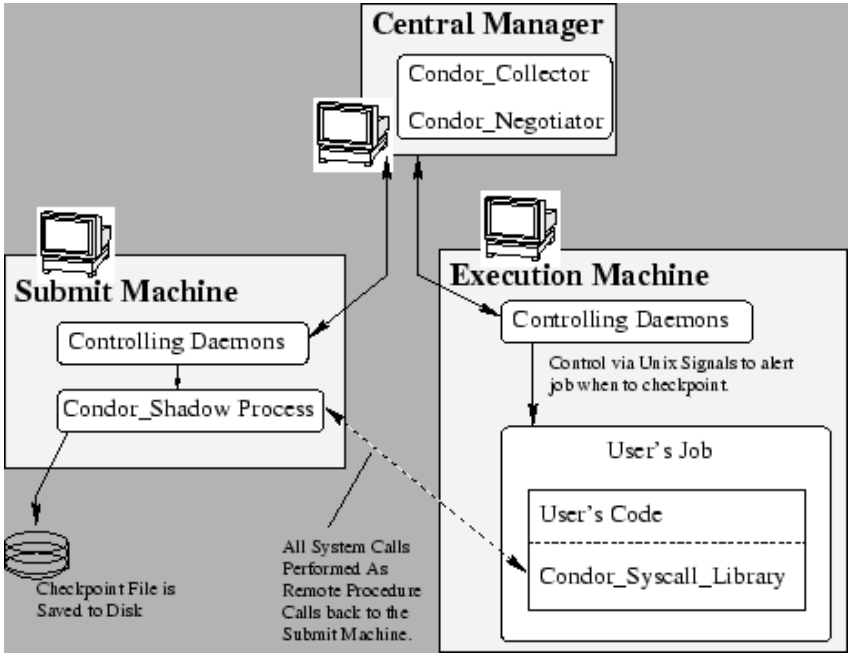
Hadoop (MapReduce)



Condor

- Distributed computing (clusters, farms)

Condor



- 1992
- Queuing policy
  - Match task and computing nodes
- Resource Classification
  - Each resource can advertise its attributes and master can classify according to this
- 2010 (680k LOC)
  - Apache Web Server: ~60,000 LOC
  - Linux TCP/IP network stack: ~80,000 LOC
  - Windows XP (complete) : ~40 million LOC

GRID

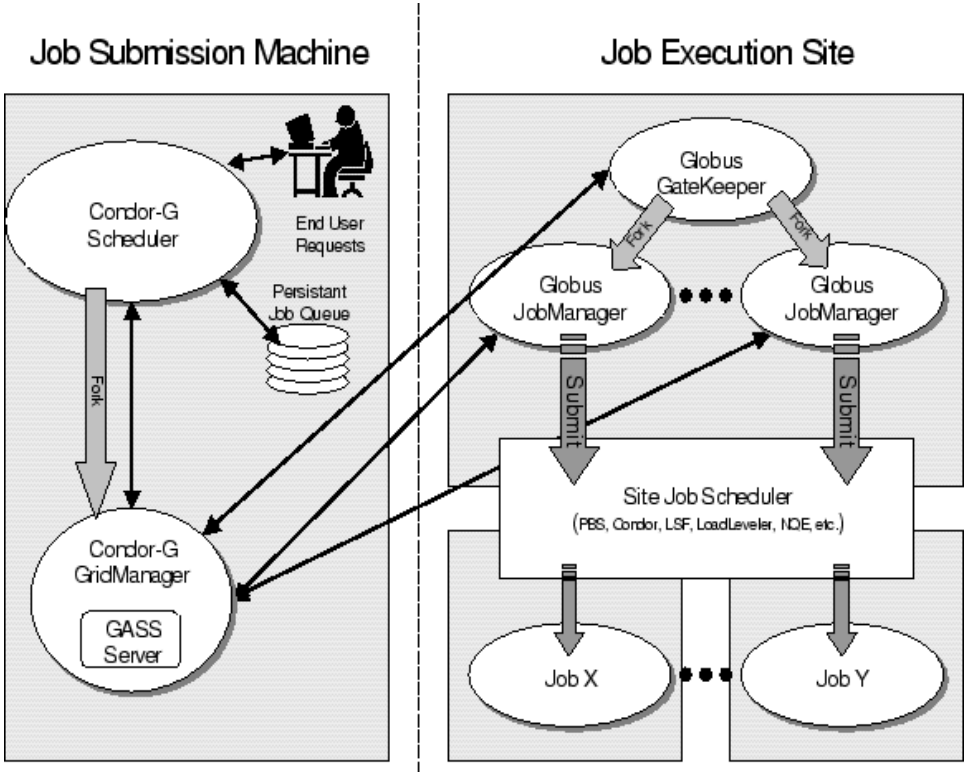
What is the Grid?

The **World Wide Web** provides seamless access to information that is stored in many millions of different geographical locations

The **Grid** is an infrastructure that provides seamless access to computing power and data storage capacity distributed over the globe

What is the Grid?

- Distributed computing + Web ;-)
- Request/response
  - Data resource (dataset)
  - Computational job



Grid history

- Name “Grid” chosen by analogy with electric power grid (Foster and Kesselman 1997)
- Vision: plug-in computer for processing power just like plugging in toaster for electricity.
- Concept has been around for decades (distributed computing, metacomputing)
- Key difference with the Grid is to realise the vision on a global scale.

How does the Grid work?

- It relies on advanced software, called **middleware**.
- Middleware automatically finds the **data** the scientist needs, and the **computing power** to analyse it.
- Middleware balances the load on different resources. It also handles **security, accounting, monitoring** and much more.

Virtual Organization

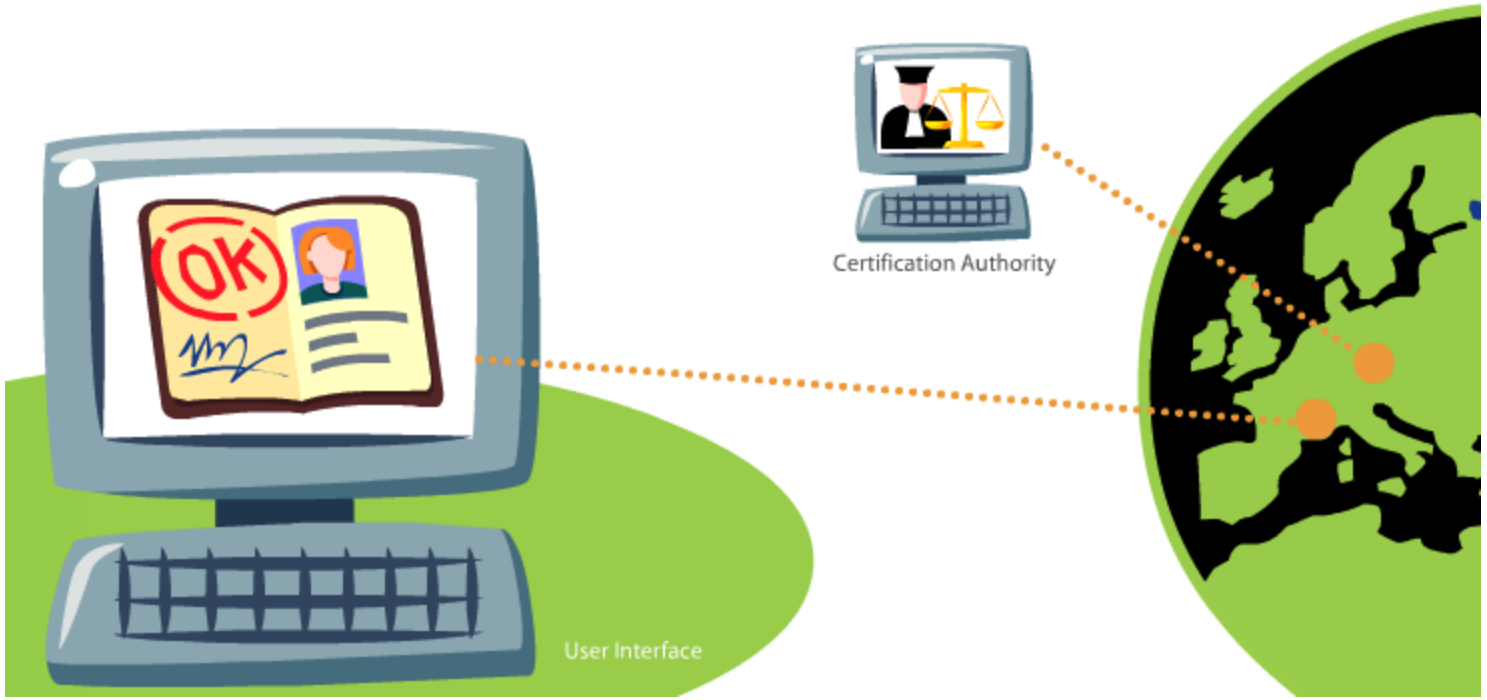
High Energy Physics, Earth Observation and Biology are examples of communities made up of several institutions and individuals sharing the same interests and the same scientific goals. They greatly benefit from putting together their computing resources, data and scientific instruments.

Such distributed communities are called ***Virtual Organisations***.

Step 1: Join Virtual Organization

To have access to the Grid facility, you need to join a *Virtual Organisation*.

Step 3: Get a permission



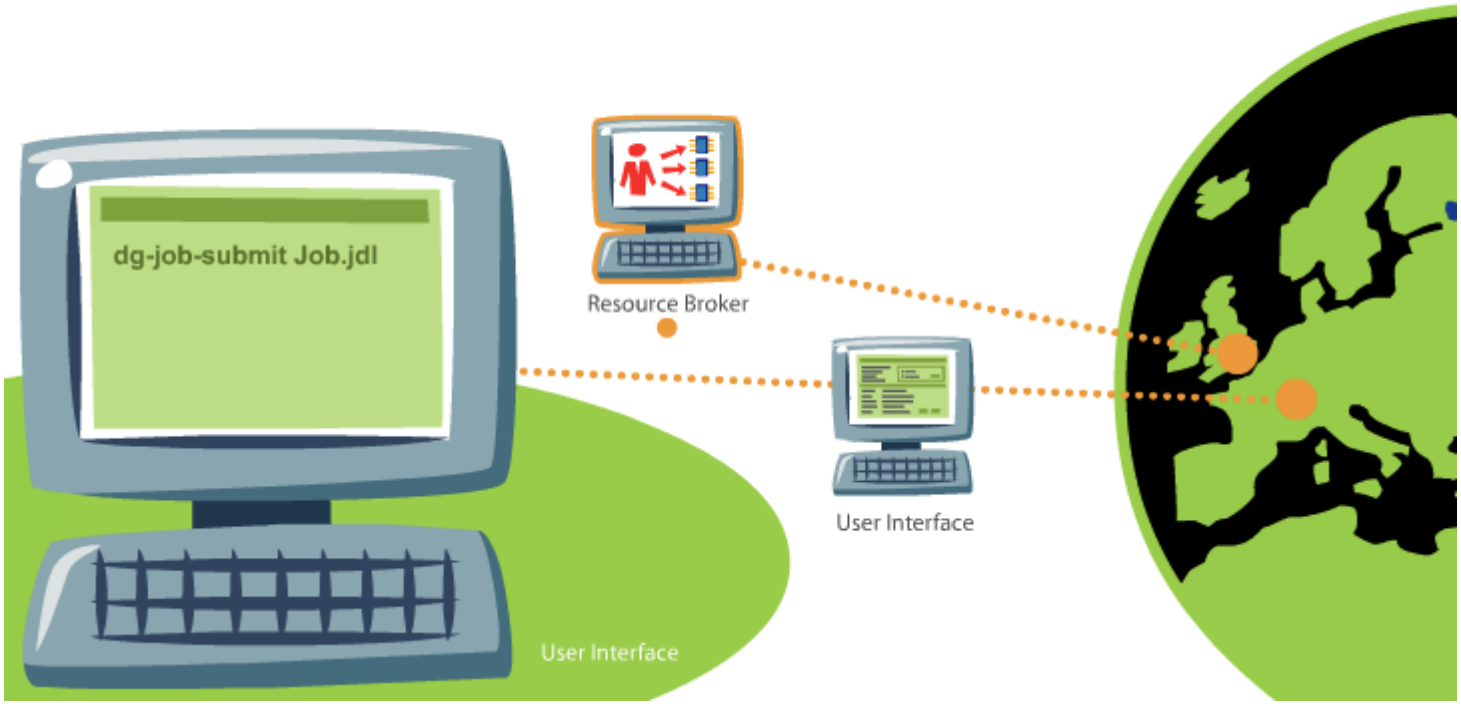
Step 4: Write a file describing your job

To run a job on the LCG/EGEE Grid Facility, you have to describe it in the ***Job Description Language*** (***JDL***).

JDL specifies job characteristics such as the application to use, the input data, the required resources, etc.

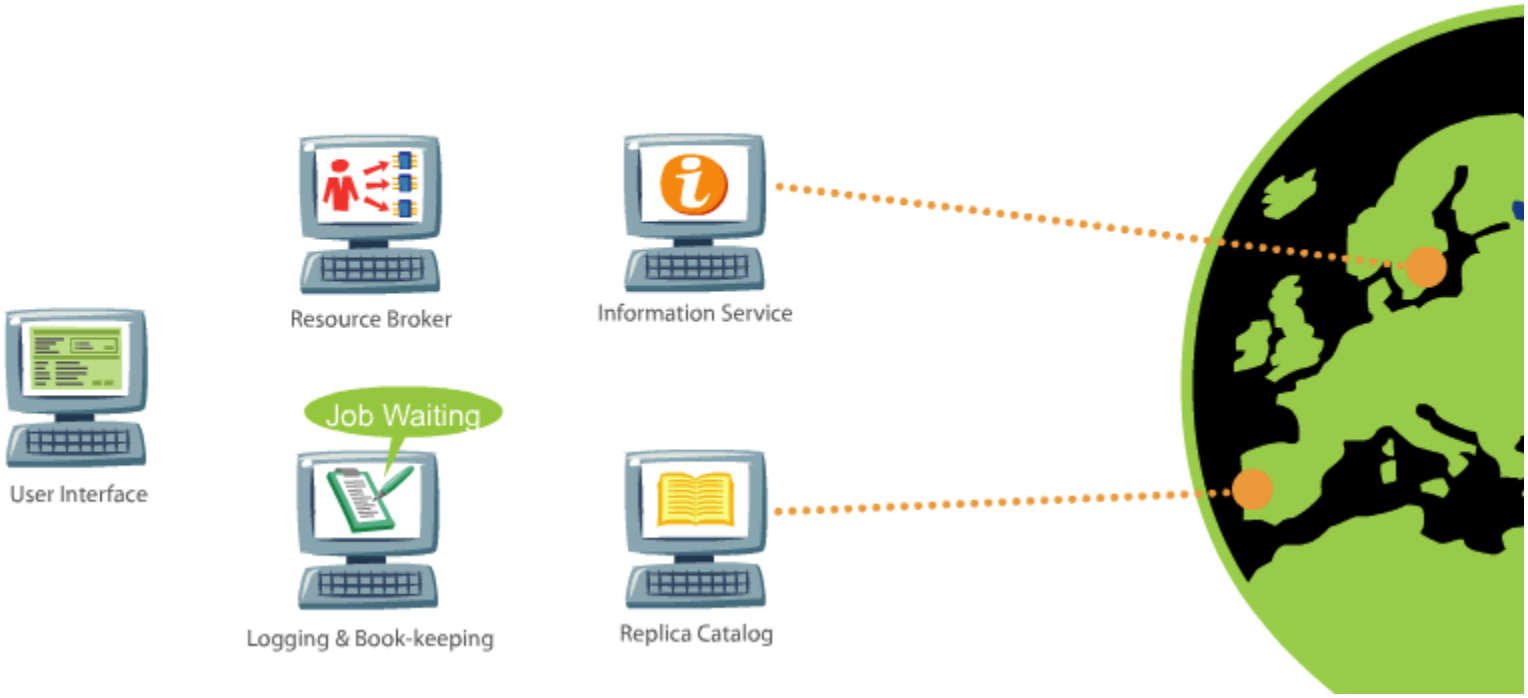
Step 5: Submit your job to the resource broker

Once you have the jdl file for your job, you can submit it to the ***Resource Broker***.



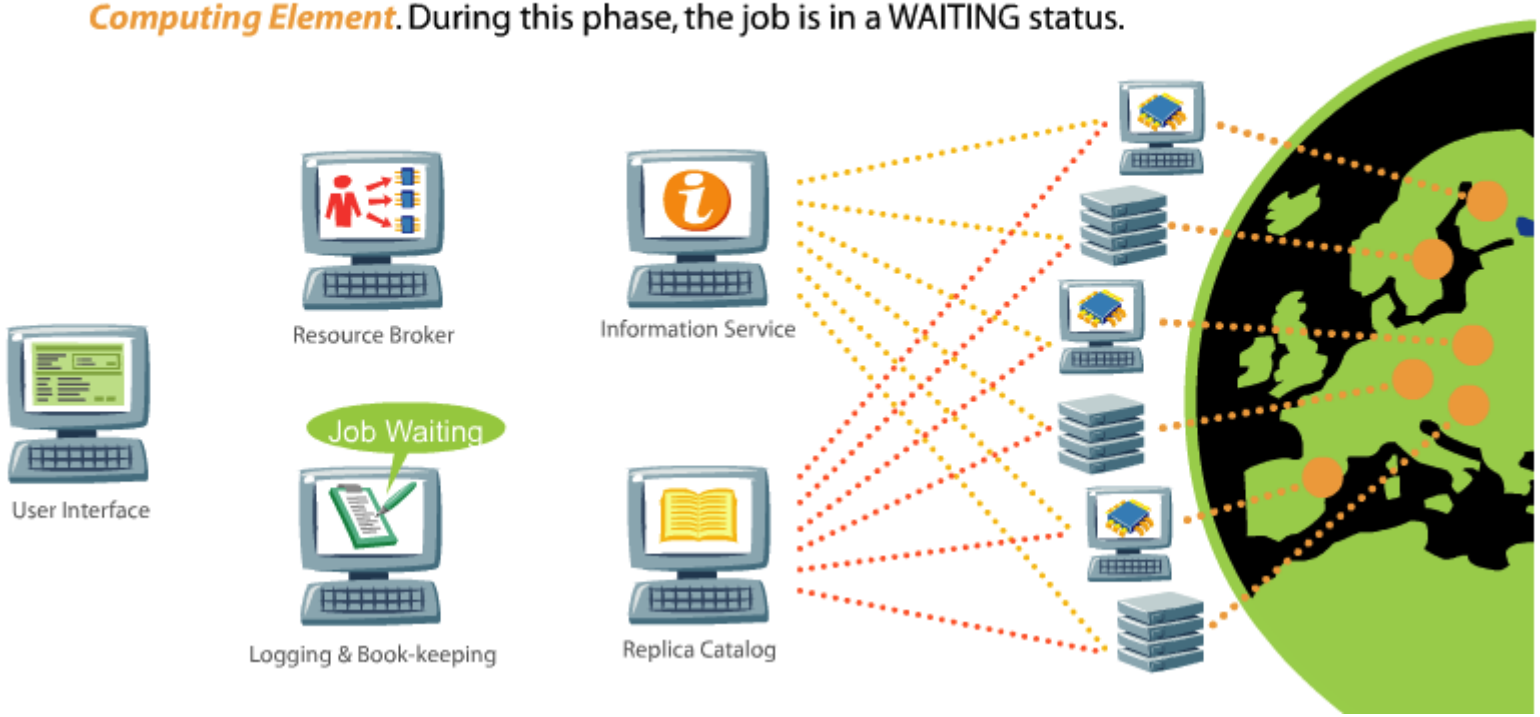
Step 5: Submit your job to the resource broker

Based on the information given in the JDL file, the *Resource Broker* queries the *Information Service* and the *Replica Catalog* to check resources.



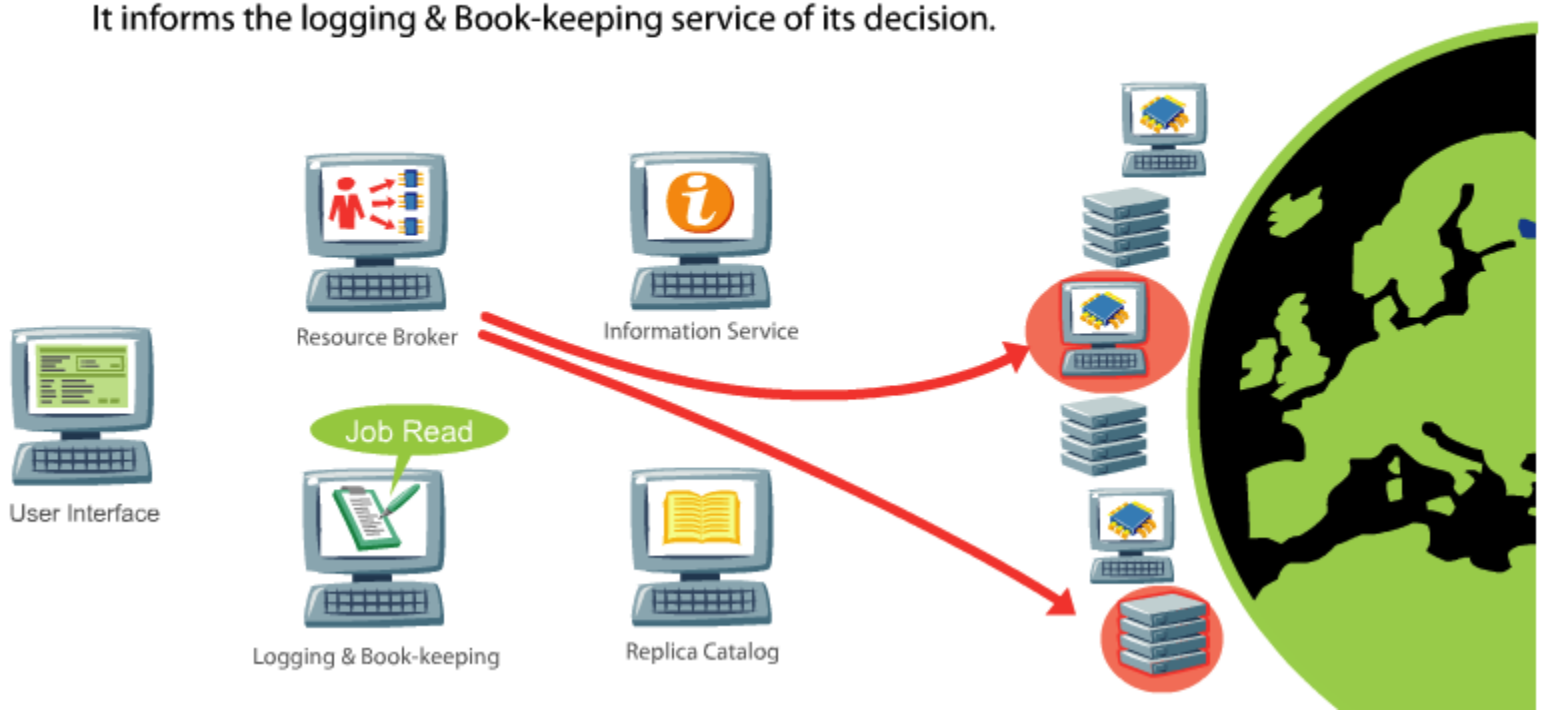
Step 5: Submit your job to the resource broker

The *Replica Catalog* and the *Information Service* hold information on the current status of all the sites. The Resource Broker uses this info to match the job to a suitable *Computing Element*. During this phase, the job is in a WAITING status.



Step 5: Submit your job to the resource broker

The Resource Broker ***makes its choice***. It has found a suitable Computing Element and the Storage Element with the necessary data.
It informs the logging & Book-keeping service of its decision.

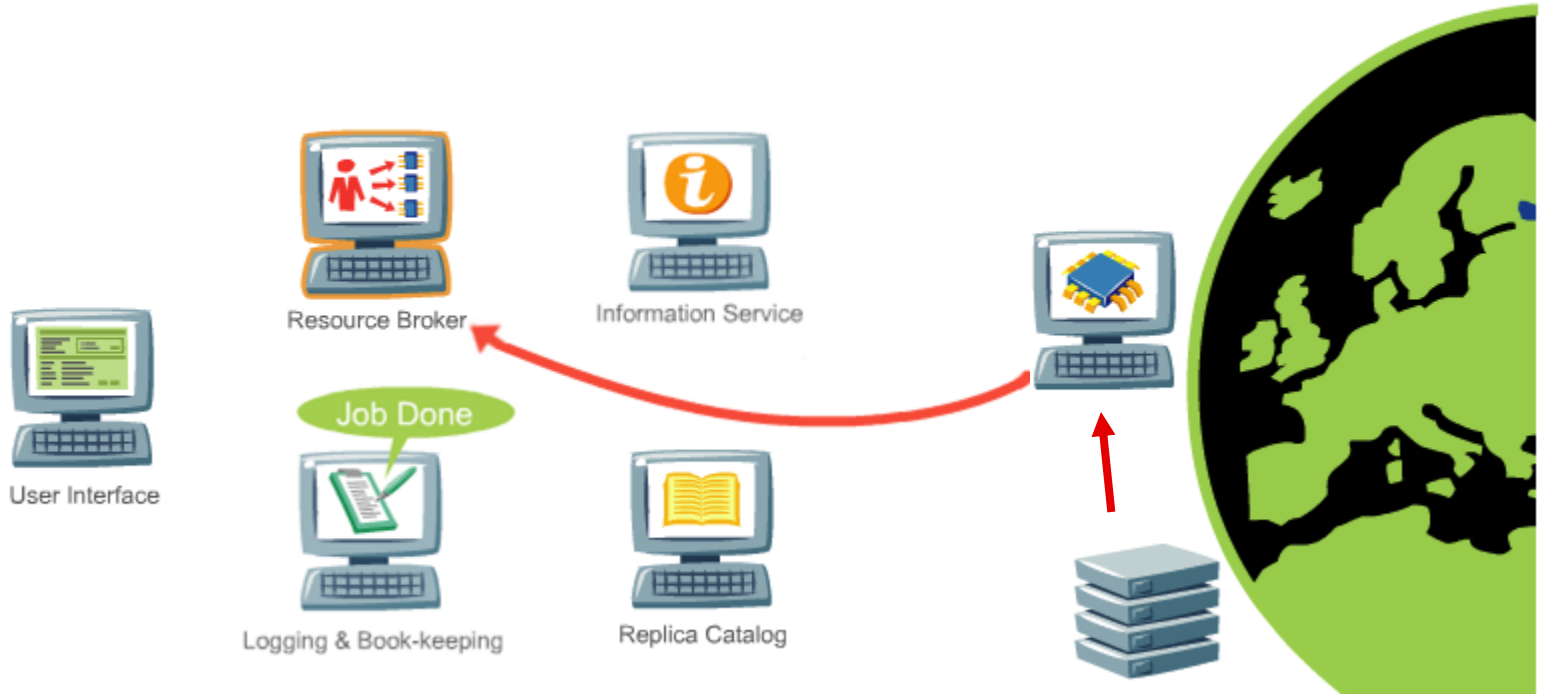


Step 6: Check the status of your job

During all this process, you can check the status of your job by contacting the ***Logging & Book-keeping Service***.

Step 6: Check the status of your job

The execution of the job has completed on the Computing Element.
The *Computing Element transfers the output to the Resurce Broker*.

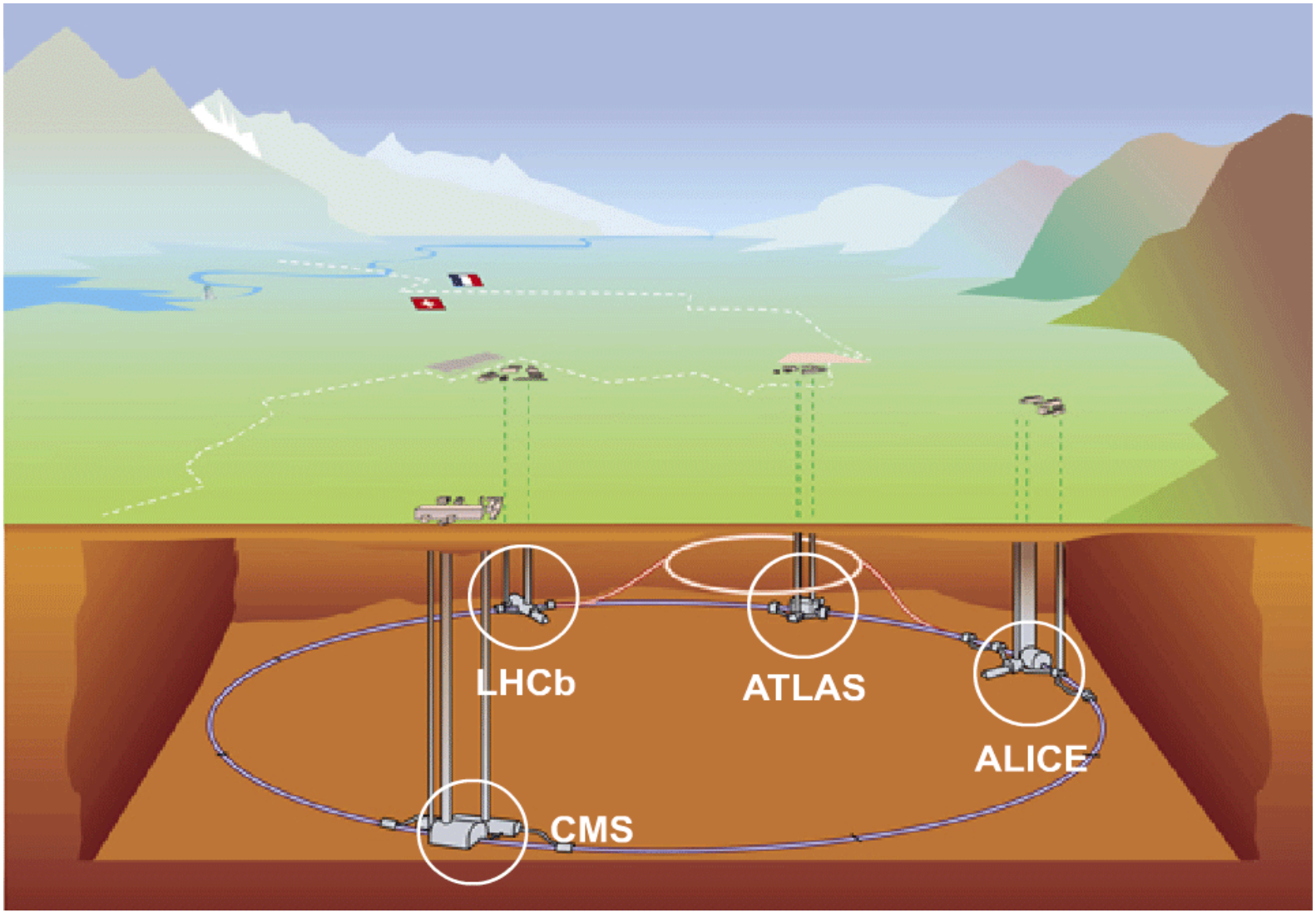


Step 7: Get the results

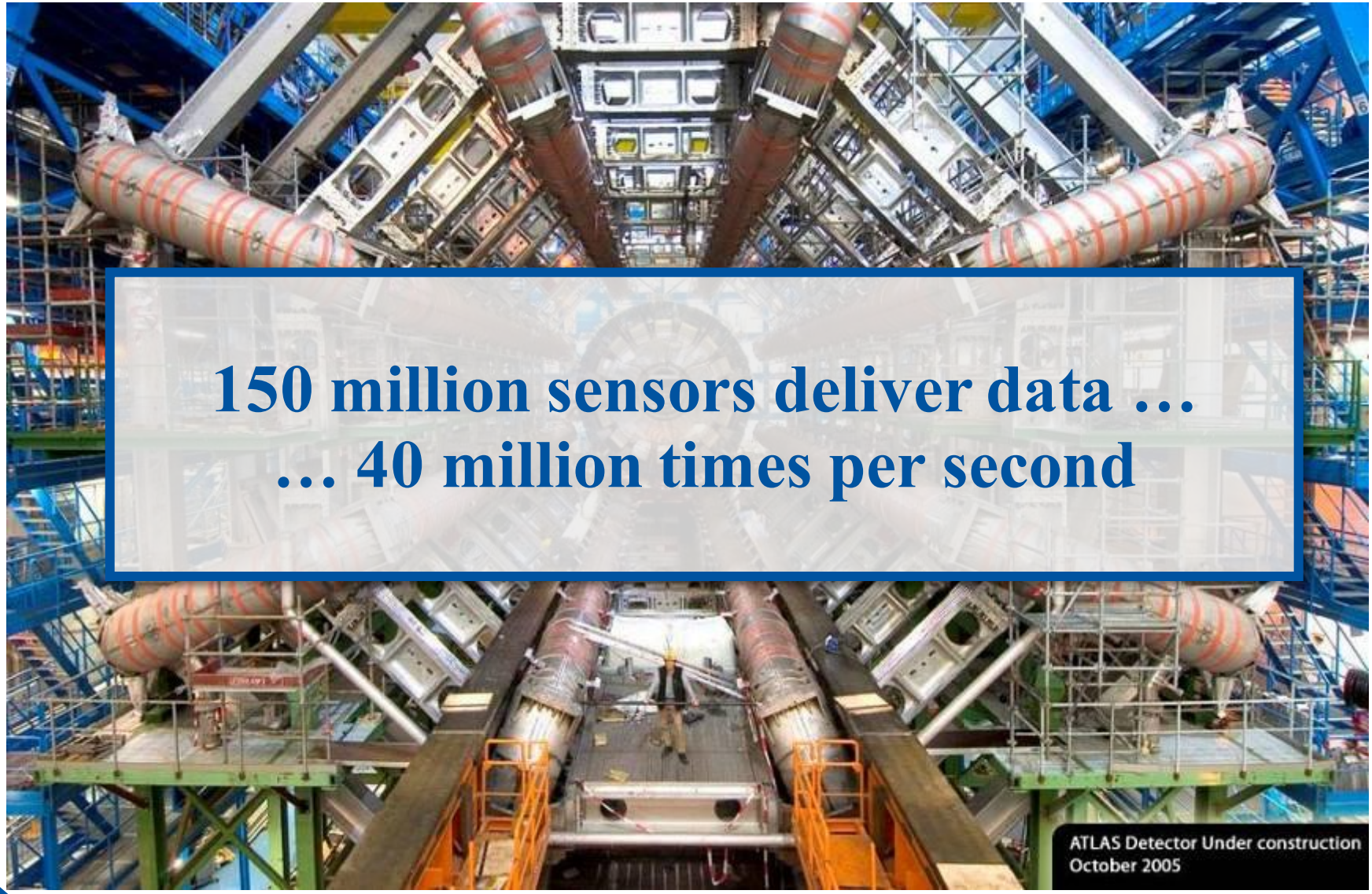
You can now retrieve your Output from the Resource Broker.
When finished, book-keeping ***information is purged***.

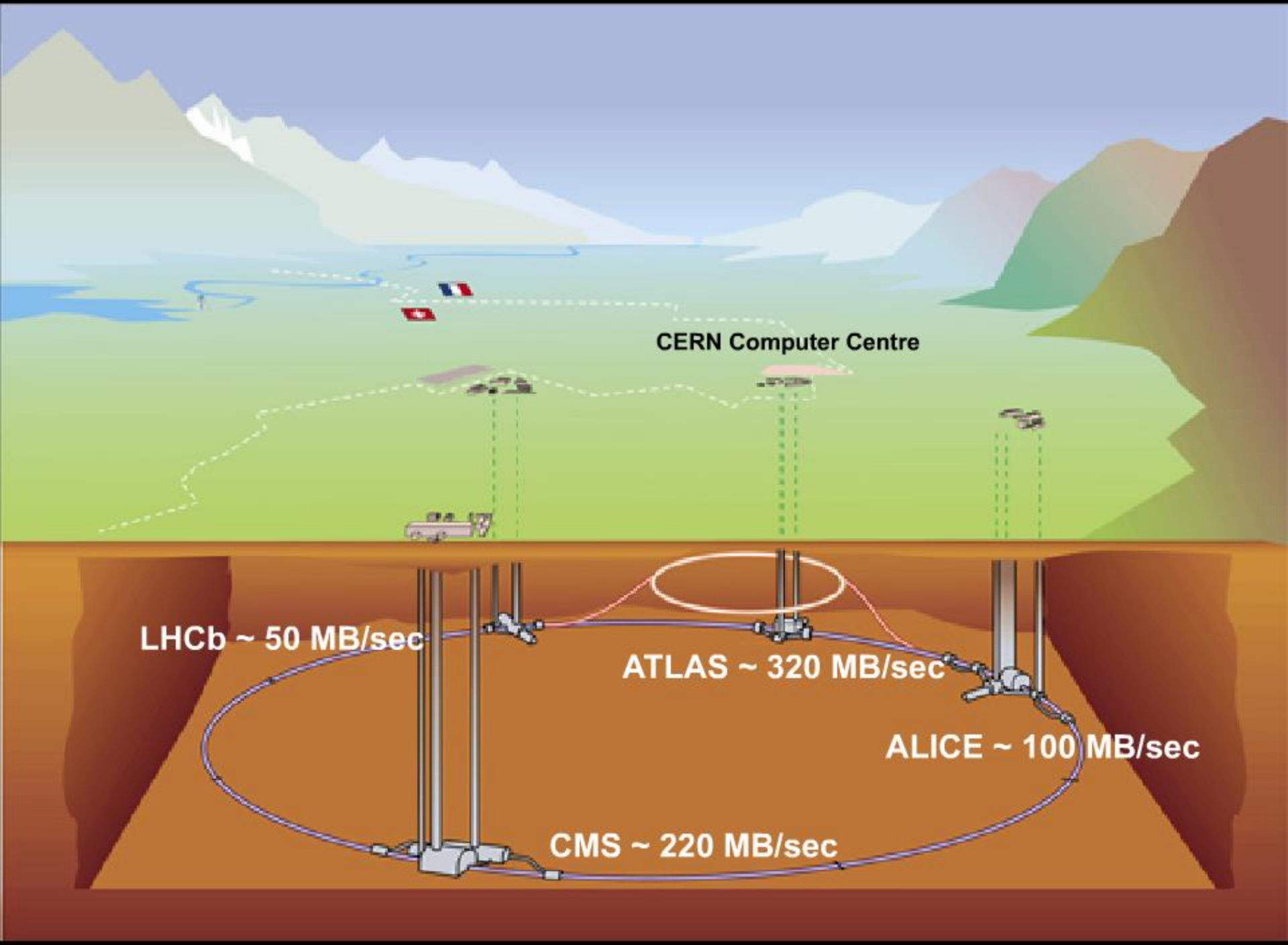
Why the Grid at CERN?

The LHC accelerator and the 4 experiments



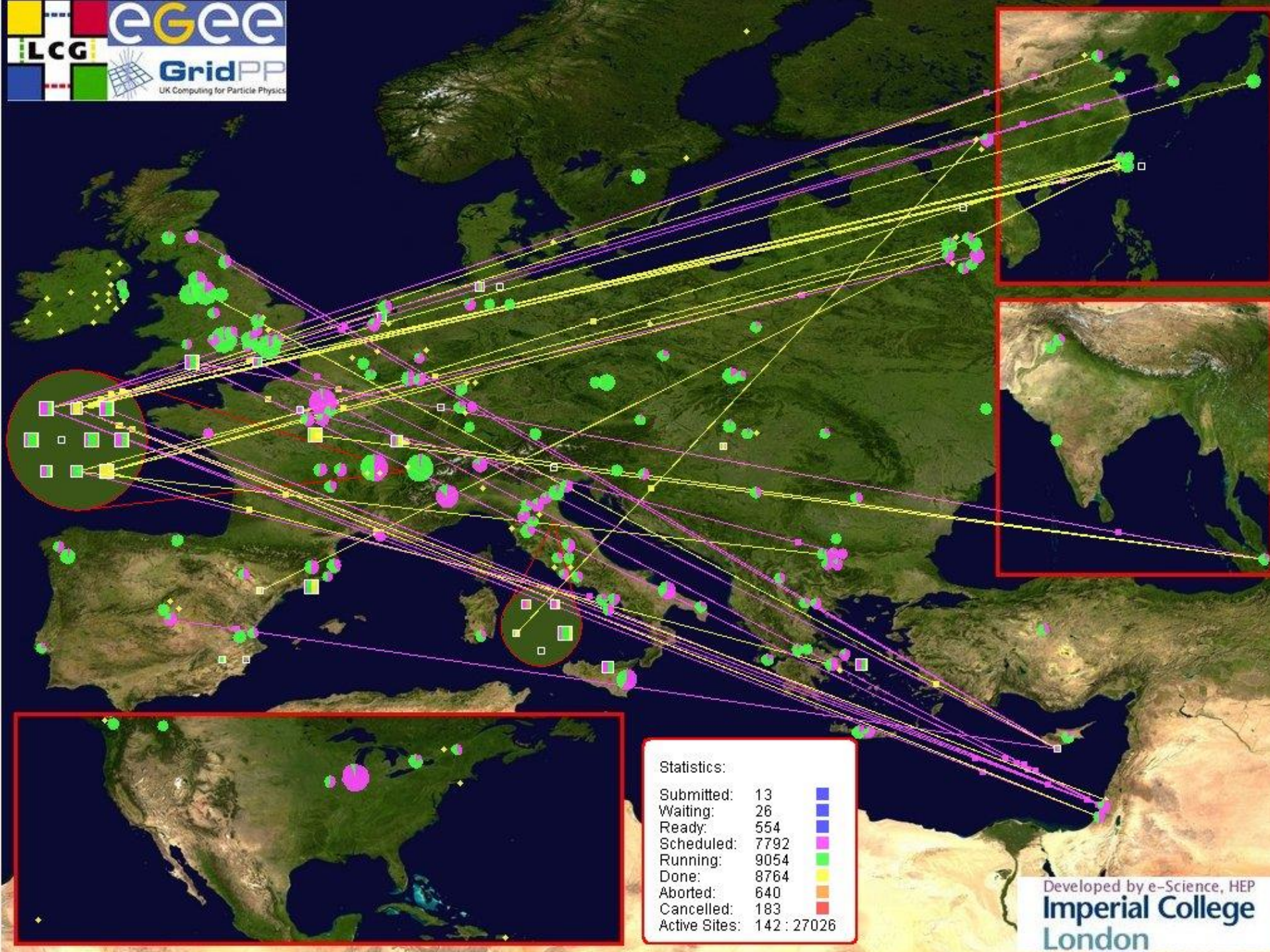
View of the ATLAS detector



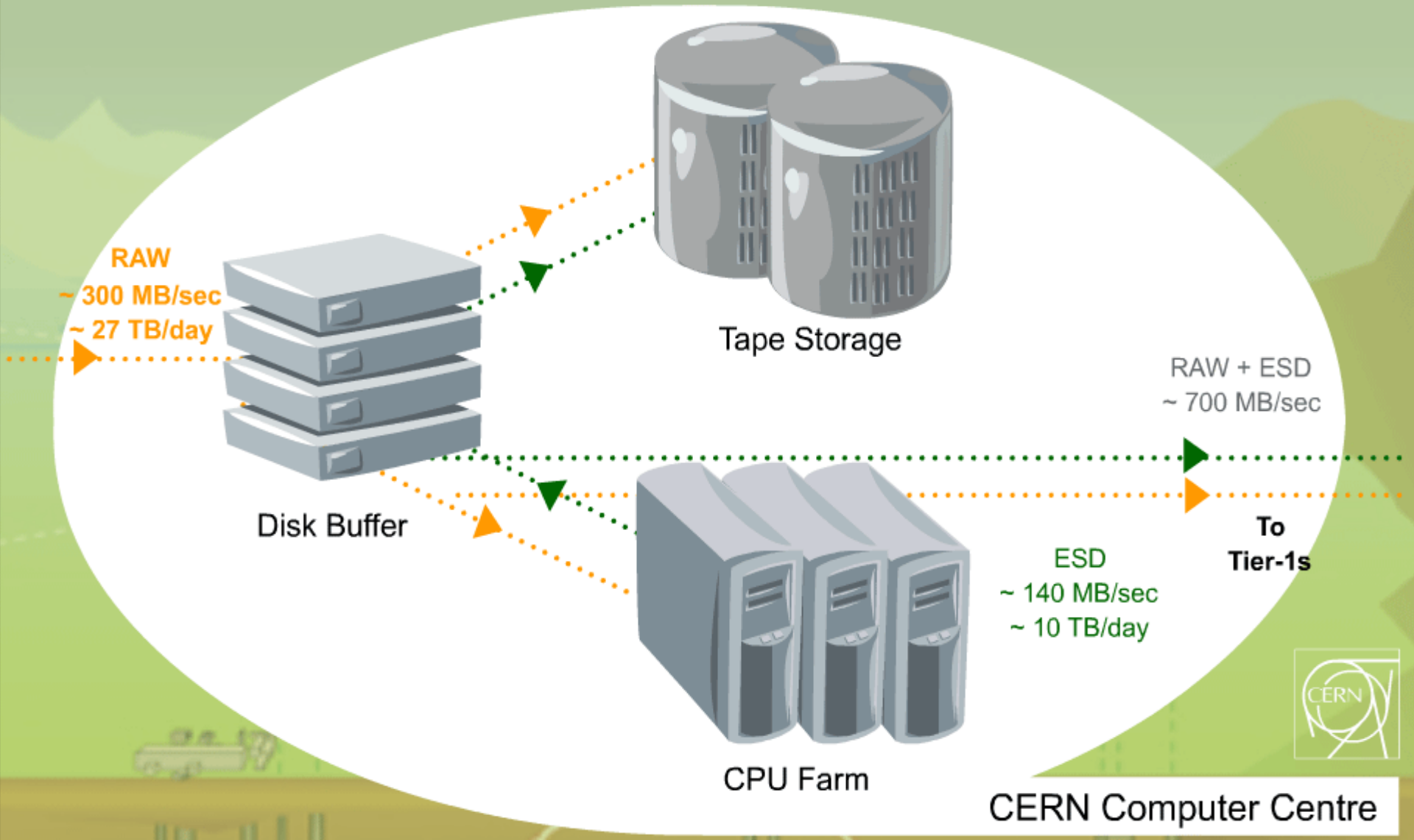

CERN Computer Centre
LHCb ~ 50 MB/sec
ATLAS ~ 320 MB/sec
ALICE ~ 100 MB/sec
CMS ~ 220 MB/sec

The LHC Data Challenge

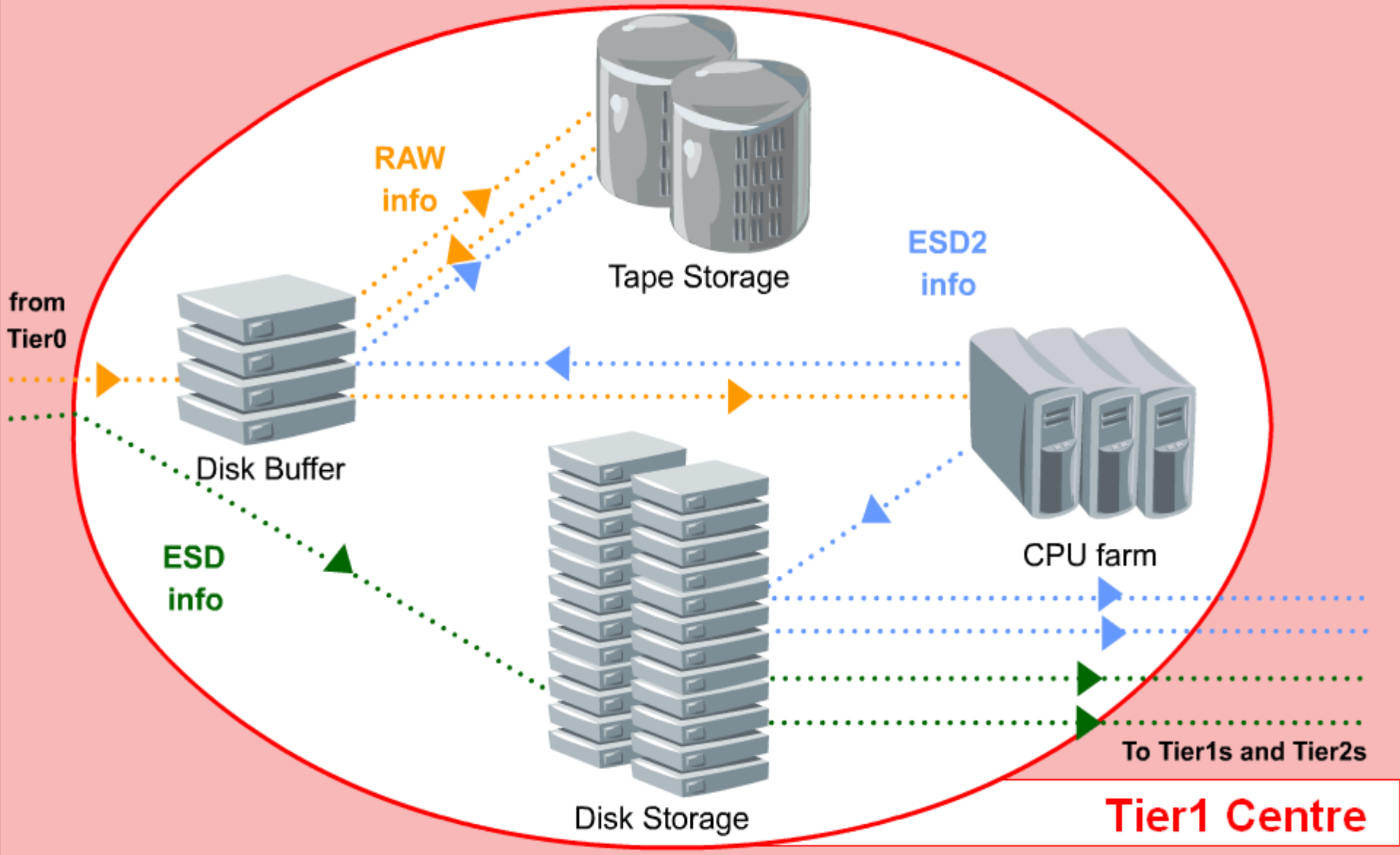
- The accelerator will run for 10-15 years
- Experiments will produce about **15 Million Gigabytes** of data each year (about 20 million CDs!)
- LHC data analysis requires a computing power equivalent to **~100,000 of today's fastest PC processors**
- Requires many cooperating computer centres, as CERN can only provide ~20% of the capacity


LCG
eGee
GridPP
UK Computing for Particle Physics
Statistics:
Submitted: 13
Waiting: 26
Ready: 554
Scheduled: 7792
Running: 9054
Done: 8764
Aborted: 640
Cancelled: 183
Active Sites: 142 : 27026
Developed by e-Science, HEP
Imperial College
London

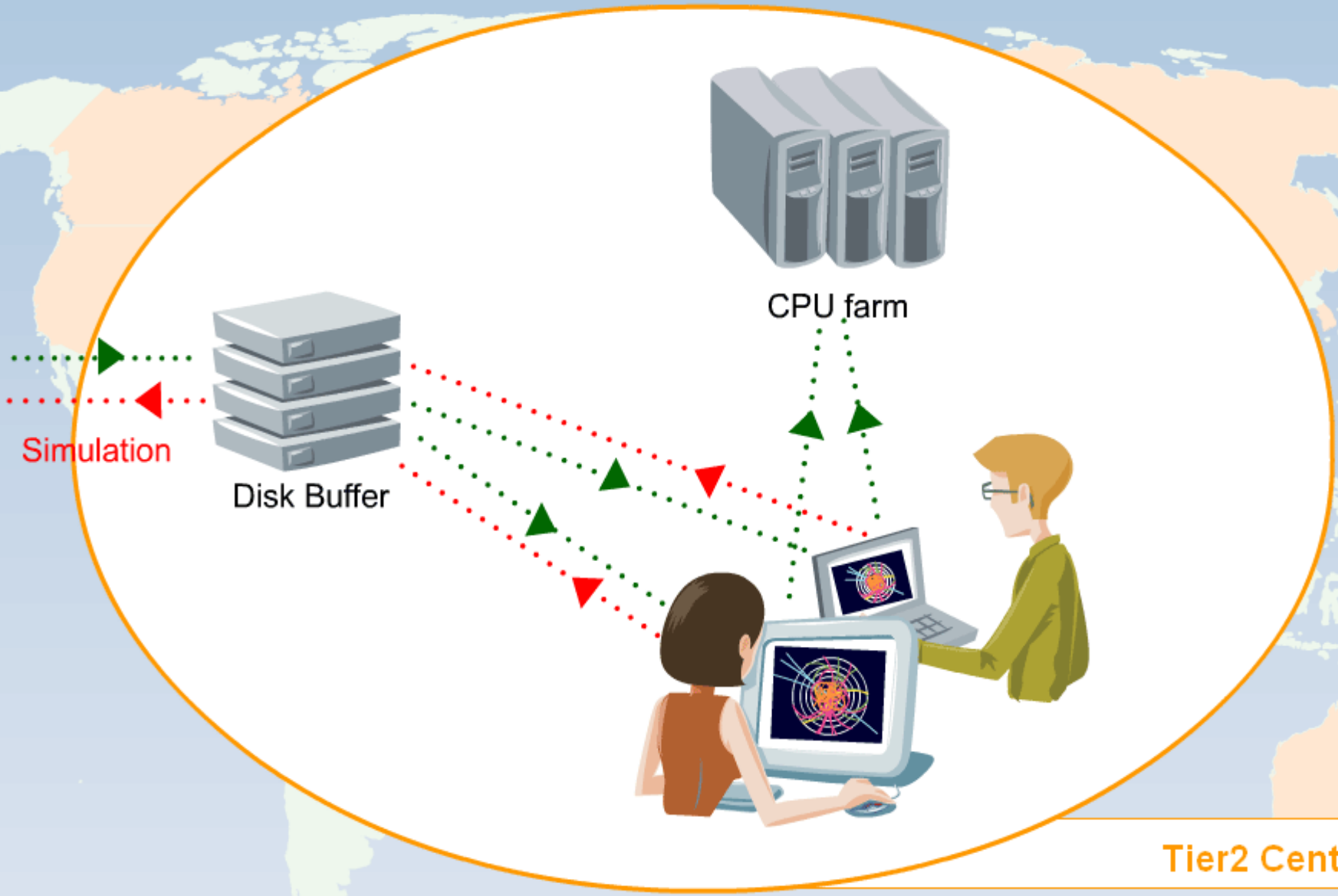
One Tier0 Centre (CERN)



Eleven Tier1 Centres

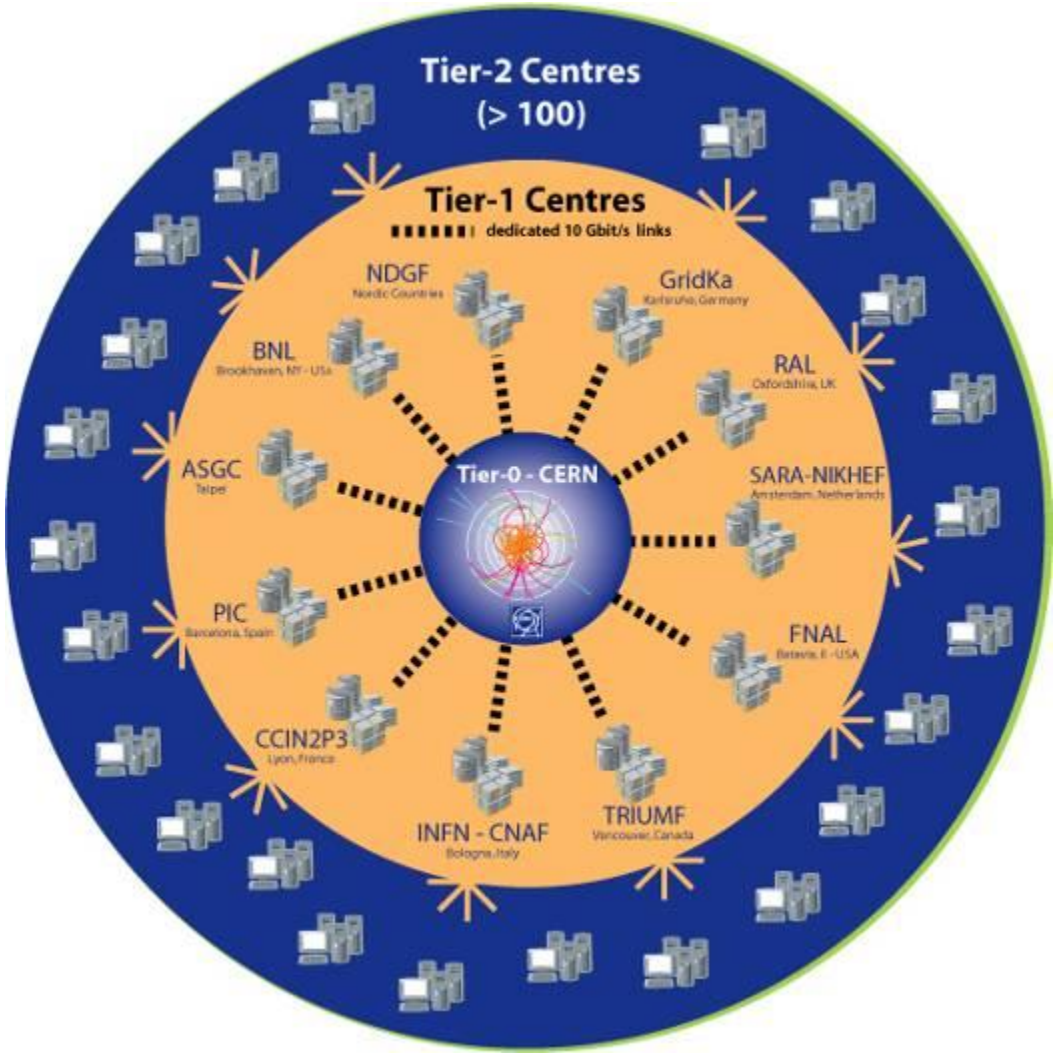


>100 Tier2 Centres



LHC Computing Grid project (LCG)

- More than 170 computing centres
- 12 large centres for primary data management: CERN (Tier-0) and eleven Tier-1s
- 38 federations of smaller Tier-2 centres
- 35 countries involved



WLCG: Worldwide LHC Computing Grid

- Project to build and maintain data storage and computing infrastructure for LHC
- Uses infrastructure of several Grid organizations where 2 the biggest ones are
  - EGI (founded by EC)
  - OSG (founded by US)

GridPP
UK Computing for Particle Physics

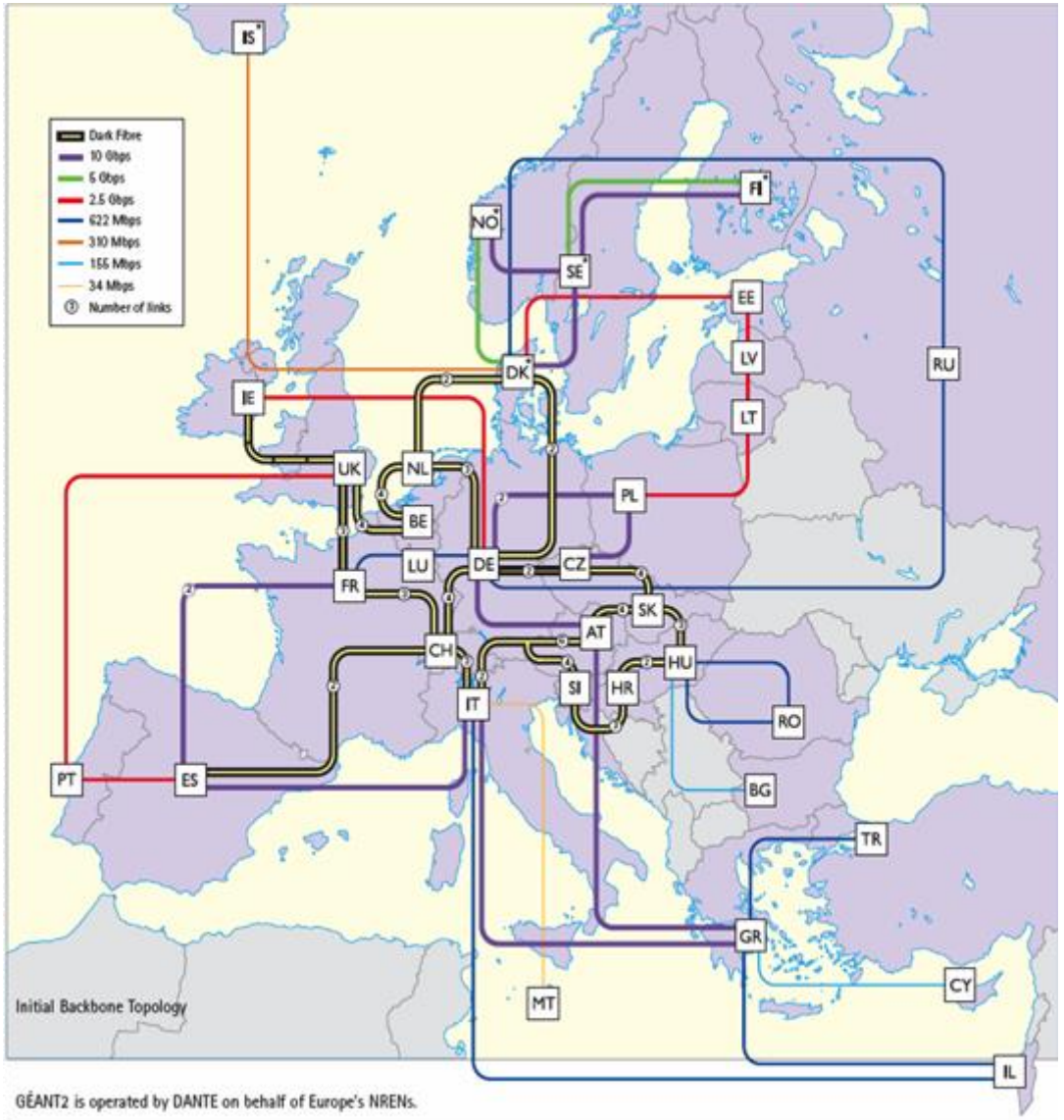
NORDUGRID
Grid Solution for Wide Area Computing and Data Handling

Resources needed for the LHC computing

Name	Sites	CPUs			Online Storage Space (GB)		Nearline Storage Space (GB)		Grid Jobs		
		Physical	Logical	SI2000	TotalSize	UsedSize	TotalSize	UsedSize	Total	Running	Waiting
AEGIS	6	312	1,056	2,305,920	27,761	35%	0	0%	576	54%	0%
ArmGRID	4	36	144	345,600	2,179	13%	0	0%	12	2%	75%
BALTICGRID	3	56	92	102,684	0	0%	0	0%	11	10%	9%
BIGGRID	14	4,017	17,152	41,226,064	4,204,350	50%	1,265,011	90%	13,973	65%	19%
Consorzio Cometa	6	684	1,368	2,243,288	115,679	34%	0	0%	763	0%	98%
D-Grid	11	5,518	21,802	47,901,980	10,631,901	38%	0	0%	68,635	250%	20%
DE-KIT	1	108	216	491,712	167,405	33%	0	0%	16	6%	12%
DECH	1	112	448	879,424	86,995	0%	0	0%	174	38%	1%
EELA	7	115	317	515,295	7,144	10%	0	0%	81	17%	18107008%
EELA2	1	152	344	1,037,504	35,641	0%	0	0%	0	0%	0%
EGEE	248	56,492	167,714	373,956,582	60,176,251	54%	60,083,689	65%	274,805	124%	45315%
EGEE IBERGRID	1	128	512	1,143,296	73	12%	0	0%	3	0%	0%
EGI	59	13,711	48,770	106,364,766	13,836,881	41%	40,000	43%	81,129	121%	19200%
EUFORIA	1	152	344	1,037,504	35,641	0%	0	0%	0	0%	0%
EUMED	2	227	668	1,224,960	0	0%	0	0%	2	0%	399999650%
GILDA	3	86	120	137,616	545	19%	0	0%	78	1%	97%
GRID-CSIC	1	0	0	0	322	100%	0	0%	0	0%	0%
GRIDPP	15	3,569	11,309	23,138,493	4,037,221	57%	0	0%	15,078	69%	353763%
GRISU	8	755	1,894	2,978,876	120,491	32%	0	0%	1,174	20%	66%
http://www.euasiagrid.org	1	12	48	790,176	131	8%	0	0%	1	2%	0%
I2G	2	451	1,780	3,489,248	539,422	48%	0	0%	960	53%	0%
IBERGRID	7	987	3,438	6,864,770	556,196	45%	0	0%	1,028	29%	648508%
INGRID	2	317	1,258	2,153,914	281,304	45%	0	0%	844	66%	0%
LCG	1	1	2	762	72	30%	0	0%	0	0%	0%
LITGRID	2	44	44	16,764	0	0%	0	0%	1	0%	100%
Total	**599**	**158,633**	**473,428**	**1,053,365,254**	**179,214,559**	**92,301,318**	**132,426,147**	**85,373,578**	**817,785**	**612,548**	**354,444,881**

The Géant Research Network

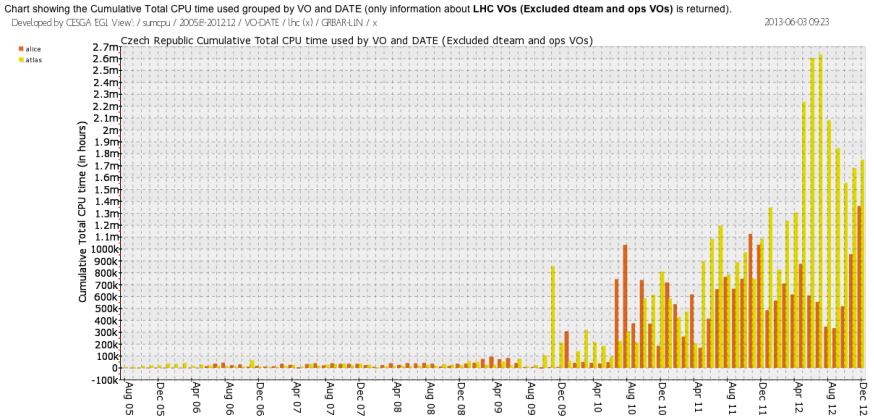
- General purpose network connecting national research and education nets (NREN)
- For LHC in addition: Optical Private Network with 10Gb/s links over dark fibres



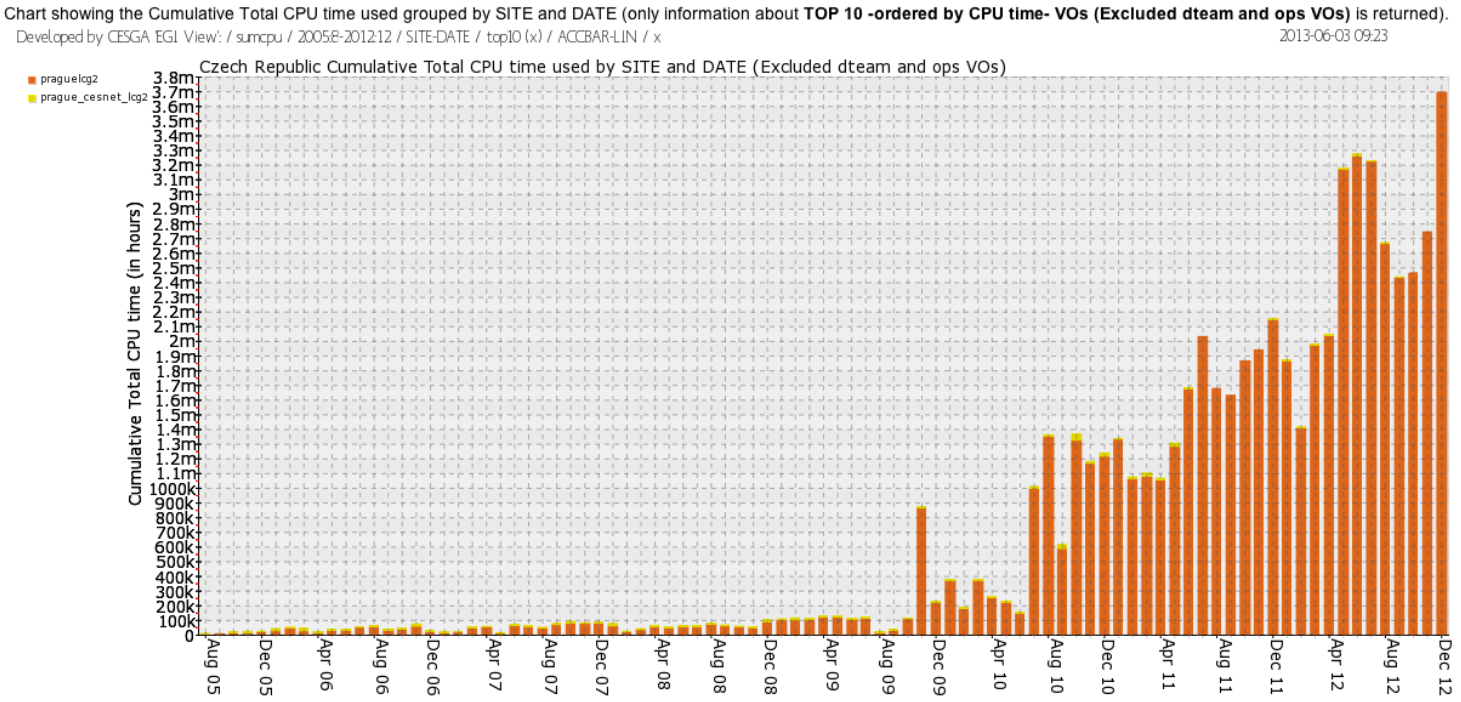
MetaCentrum – Czech Grid Initiative

- Activity of CESNET association
- http://www.metacentrum.cz/
- Supporting ALICE, ATLAS, Auger, VOCE, EUAsiaVO, etc.
- Tier 2 Sites:
  - PragueLCG2
  - Prague_CESNET_LCG2
- Participating institutes:
  - CESNET
  - Masaryk University Brno
  - Charles University
  - West Bohemian University in Pilsen
  - Brno University of Technology
  - South Bohemian University in Ceske Budejovice

Czech Grid Initiative Activity



- Czech Grid ran ~ 5.7M jobs in 2012 – workload has continued to increase

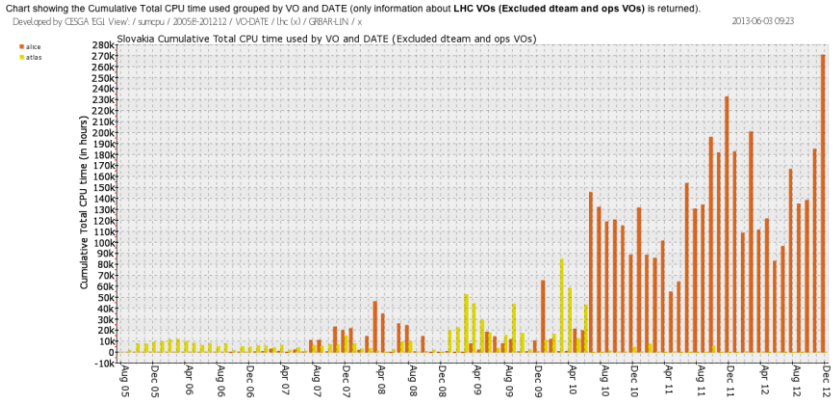


Slovak Grid Infrastructure

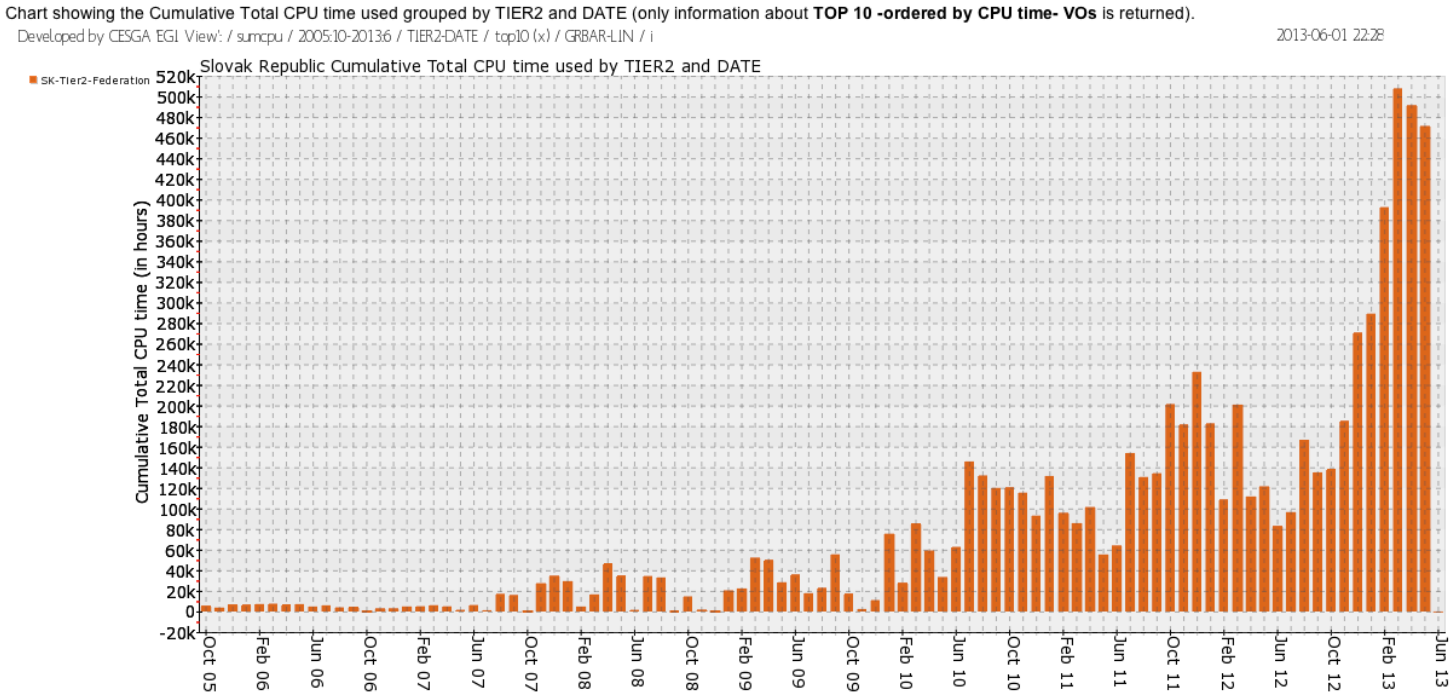
- Slovakia is a federated Tier-2/3 HEP community
- Slovak Grid Initiative / www.slovakgrid.sk

- Tier 2 sites:
  - FMPHi-UNIBA – ATLAS, ALICE
  - IEPSAS-Kosice – ATLAS, ALICE, CDF, H1
- TU-Kosice – VOCE, BIOMED
- IISAS-Bratislava – ESR, VOCE, BIOMED

Slovak Grid activity

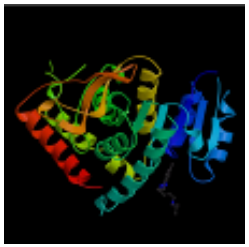


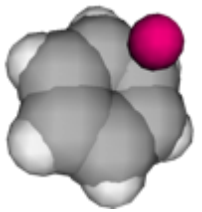
- Slovak Grid ran ~ 927k jobs in 2012 – workload has continued to increase
- Distribution of work across Tier 2/Tier3 really illustrates the importance of the grid system

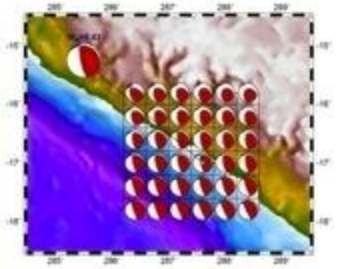


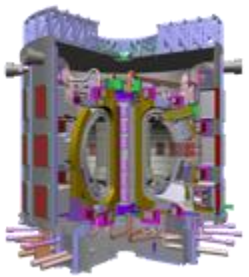
EGEE: Scientific disciplines

- Growth and diversification of applications.
- Reported apps. only ⇒ *underestimate!*







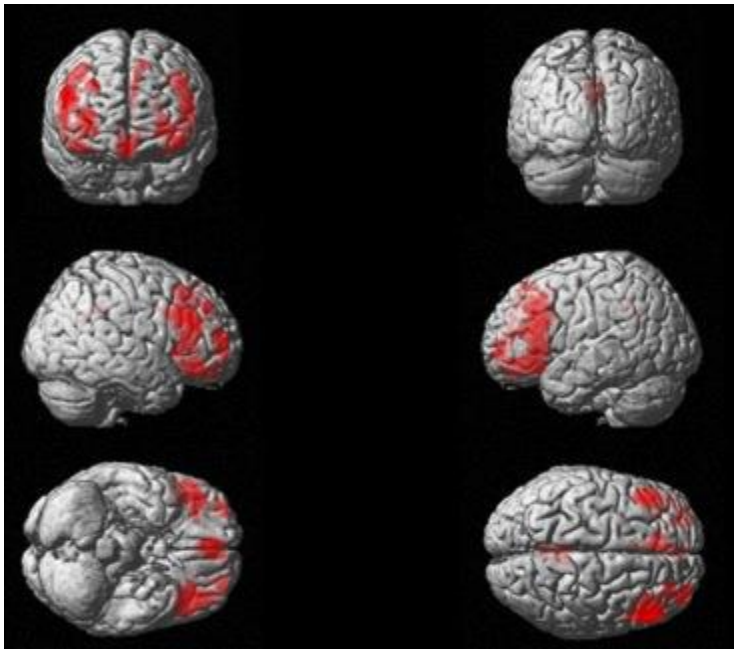


	6/2006	2/2007	1/2008
Astron. & Astrophysics	2	8	9
Computational Chemistry	6	27	21
Earth Science	16	16	18
Fusion	2	3	4
High-Energy Physics	9	11	7
Life Sciences	23	39	37
Others	4	14	21
Total	62	118	117

Condensed Matter Physics
Comp. Fluid Dynamics
Computer Science/Tools
Civil Protection
Finance

SPM: Alzheimer's disease evaluation

- Statistical Parametric Mapping (SPM) – powerful but difficult to use
  - Need of huge amount of data –> sharing instead of building own repositories
  - Computational power needed to achieve results fast enough

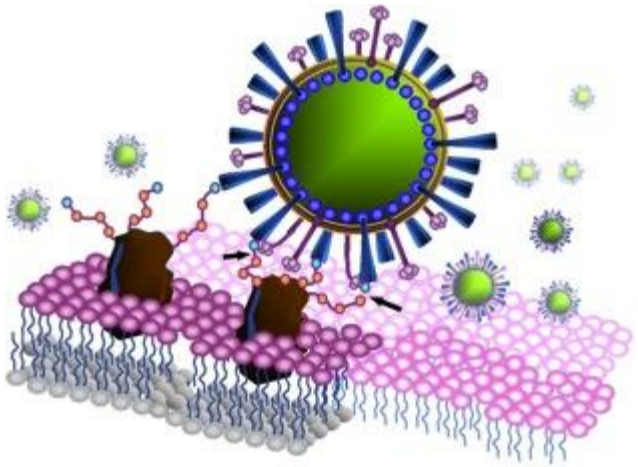


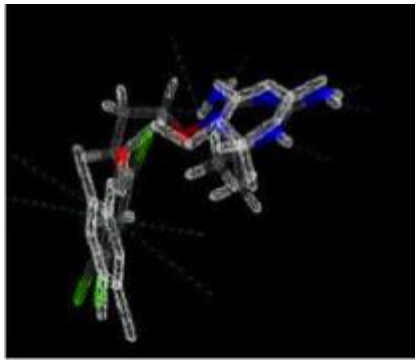
WISDOM: In silico drug discovery

April 2006, Asian and European labs analysed 300K possible drug components against the H5N1 virus using EGEE infrastructure

- 2000 computers for 4 weeks
- (equivalent of 100 years on a single computer)

Preparation for the second run are ongoing





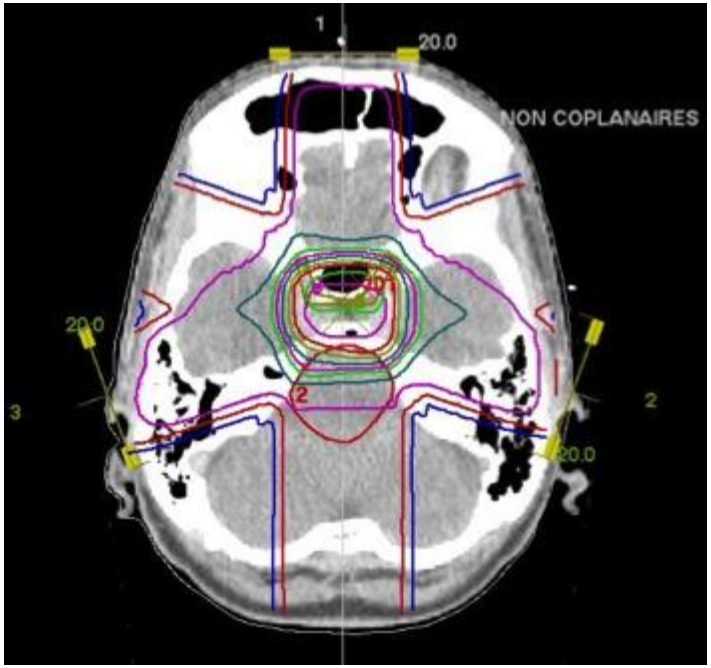
October 2006 – January 2007, the same analysis for malaria resulted in 140 million dockings (80 000 per hour)

- 5000 computers for 2.5 month (equivalent of 420 years on a single computer)

WISDOM
Initiative for grid-enabled drug discovery against neglected and emergent diseases

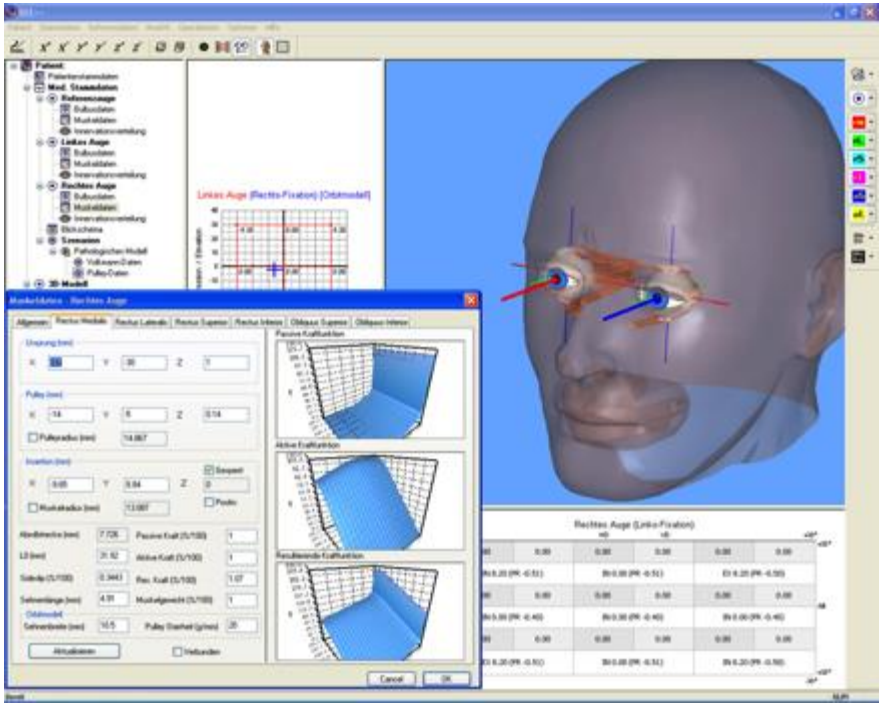
GATE: radiotherapy planning

- Goal is to improve accuracy of the treatment of cancer by ionizing radiations of the tumours
- Therapy planning is computed from the MR (Magnetic Resonance) scans
  - Tumours are accurately located in 3D
  - Radiation doses needed to be applied are computed
- Due to the Monte Carlo approach – very easy to divide in the parallel



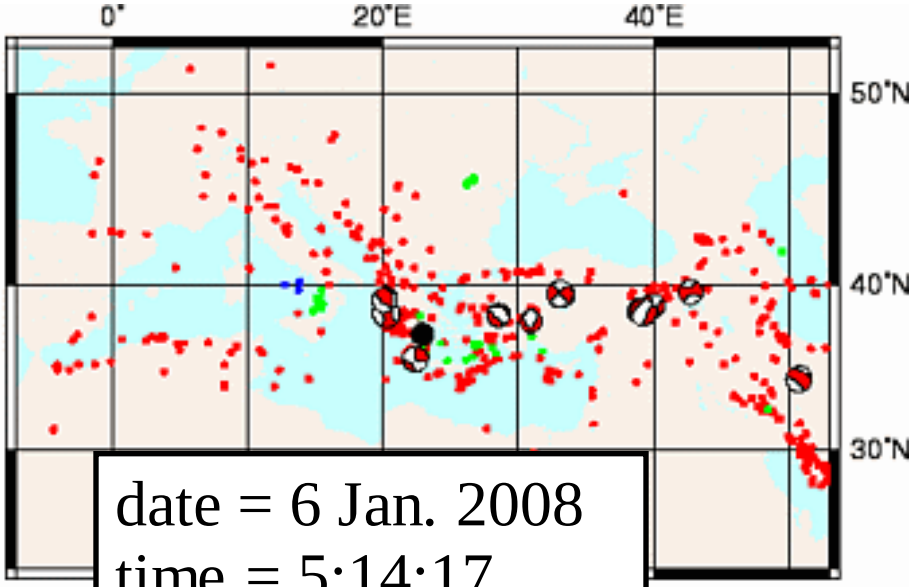
SEE++: Virtual Eye Surgery

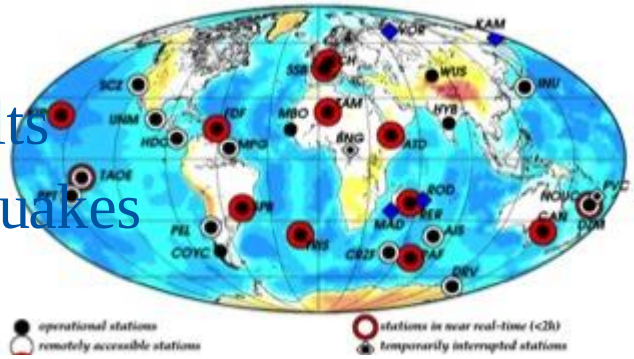
- Simulation system that aims at the forecast of clinical operation results
- Used to simulate pathologies and evaluate possible treatments
- User presentation on the client -> computation in the Grid

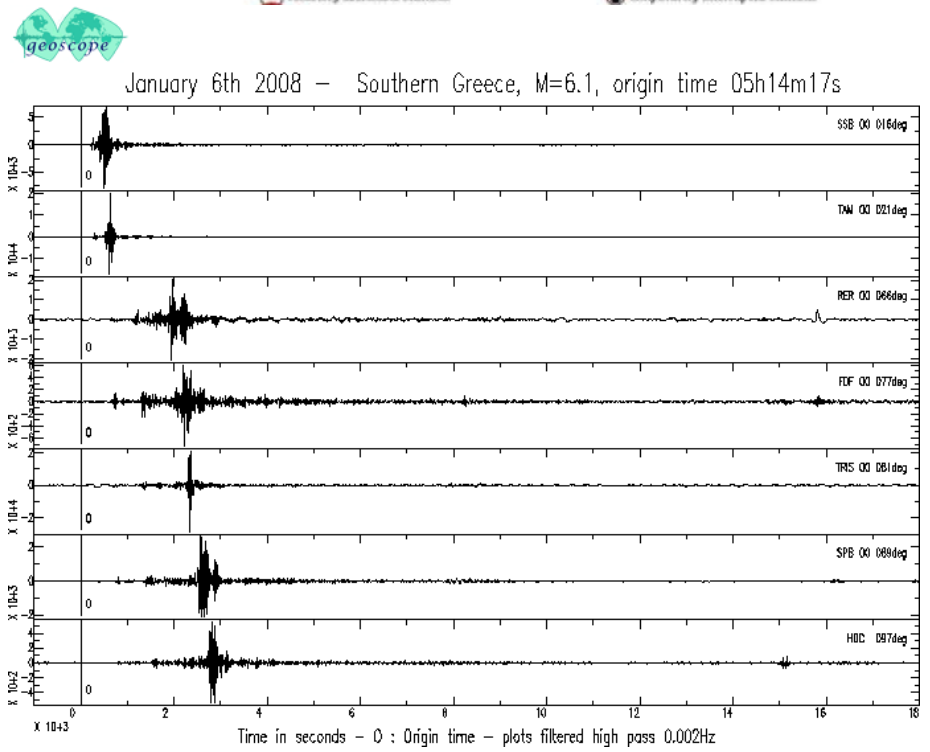


GEOSCOPE: determine the earthquake source

- Localization of earthquakes
- Determination of rupture modes of the faults
- Results within a few hours of major earthquakes







date = 6 Jan. 2008
time = 5:14:17
depth = 50.9 km
magnitude = 6.1
latitude = 37.150°
longitude = 22.934°

The Grid = SETI@HOME ???

- The GRID
  - Reliable computer centres
  - Hardware and software
    - Dedicated,
    - Static,
    - Fully controlled
  - costs
- SETI@HOME
  - Home PCs
  - Hardware and software
    - Heterogeneous
    - Shared
    - Dynamic
  - “for free”

CLOUD

Cloud

- Web-based computing, whereby shared resources, software and/or information are provided to computers and other devices on-demand.
- Providers
  - Amazon EC2 Cloud
  - Google Compute Engine
  - Azure
- Service models
    - Computer (PaaS)
    - Web/Database (SaaS)
    - Cluster (IaaS)
    - Network (NaaS)

References

- Wikipedia (www.wikipedia.org)
- Web
  - Semantic Web
  - Linked Data (linkeddata.org)
  - Wolfram alpha (www.wolframalpha.com)
- Grid
  - EGEE (www.eu-egee.org)/ EGI
  - SlovakGrid (www.slovakgrid.sk)
  - WLCG(lcg.web.cern.ch)
- Cloud
  - Amazon EC2 service, Google Web Apps

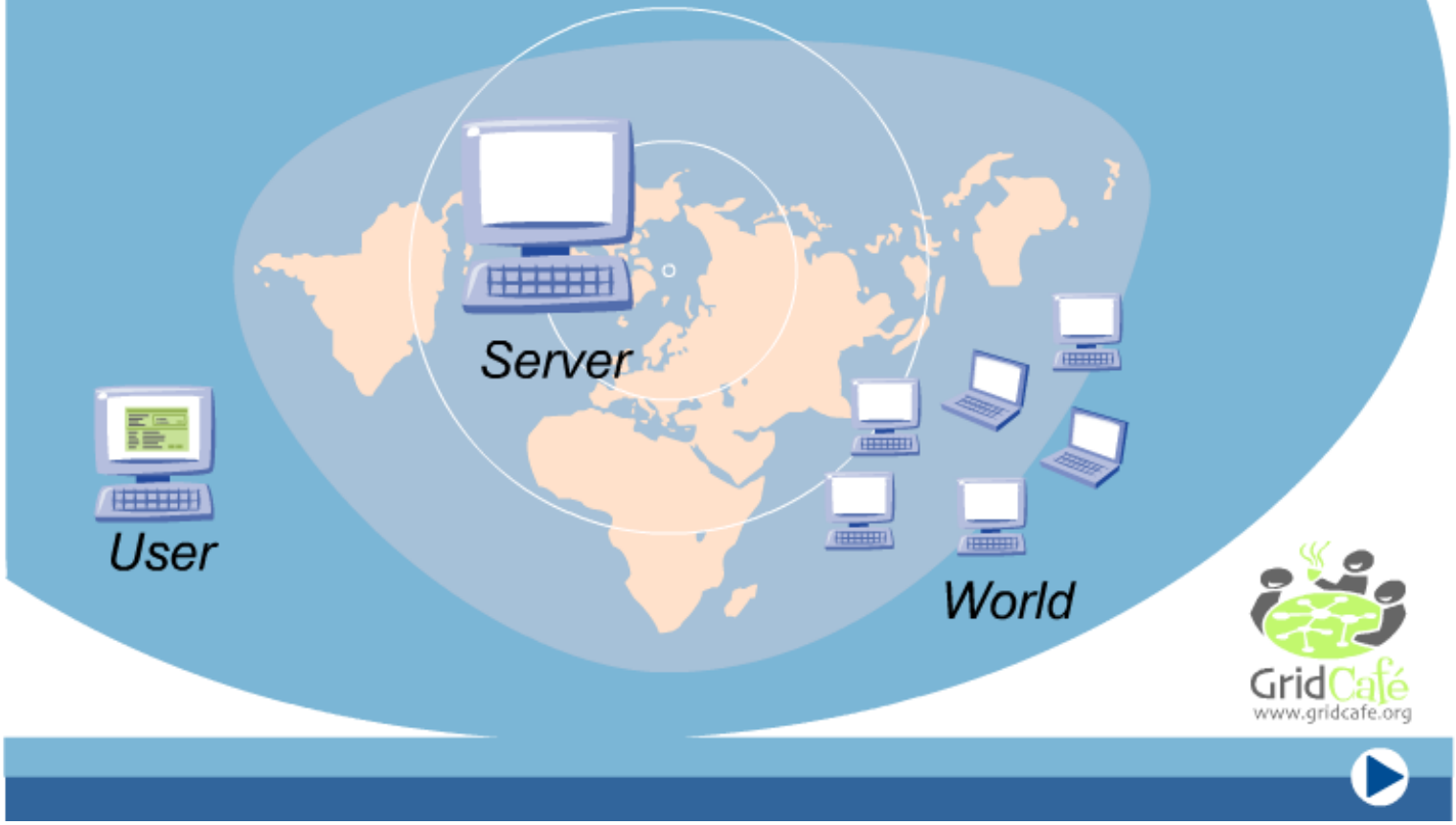
Summary

- World Wide Web – born at CERN - elaborate set of interlinked documents accessible over the Internet
- Grid computing
  - Infrastructure that provides seamless access to computing power and data storage
  - Suitable for problems that need huge/shared data, can run in parallel or need to be run frequently
- EGI – largest existing European Grid infrastructure (academic)
- Slovak Grid Initiative
- Many existing applications besides high energy physics

Commercial Software

- Gaussian
  - http://www.gaussian.com/
  - Predicts the energies, vibrational freq., … of molecular systems.
  - VO-based licensing model, actually in use in gaussian VO.
- MathWorks
  - http://www.mathworks.com/
  - Integrate MATLAB & Distributed Computing Engine with EGEE.
  - Both client and server are licensed in this model.
- Interactive Supercomputing
  - http://www.interactivesupercomputing.com/
  - Similar to DCE; used from multiple clients (MATLAB, Python, R)
  - Server licensed, some clients licensed

What is the Web?



Why was the Web invented at CERN?

- Science depends on free **access to information** and exchange of ideas. CERN is the hub of a worldwide community of **6500 scientists** in **80 countries.**
- CERN has a long history of being at the forefront of **scientific computing** and **networking** (first lab on Internet outside the US).
- During the preparation of the previous large project LEP, the need to share documents in a global way became vital.

How did it start?

- 1989: **Tim Berners-Lee** circulates "Information Management: A proposal" to help with future Large Hadron Collider project.
- 1991: Early **www system released** to high energy physics via the CERN program library. First web servers located in European physics laboratories.
- 1993: First Mosaic browser; web reaches 500 servers and 1% of Internet traffic; CERN places **WWW in the public domain**.