Computing Infrastructures for Research & the Worldwide LHC Computing Grid

Building a global large-scale
ICT infrastructure
for research data processing

Maastricht University | Department of Advanced Computing Sciences

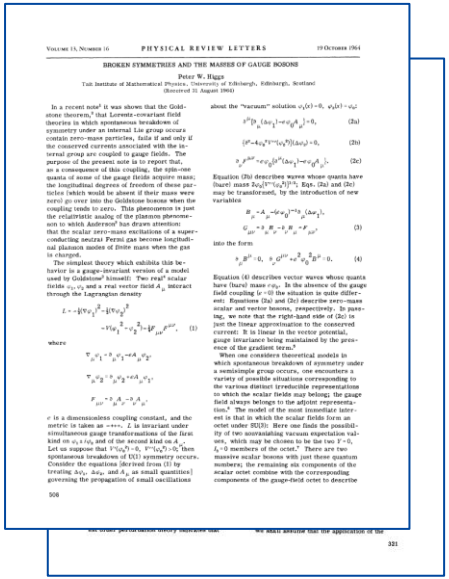
Nikhef

David Groep
DACS & Nikhef
4 November 2025
KEN3239/BCS3239 r1.2

Peter Higgs and Francois Englert at the 2013 Nobel prize press conference, Stockholm. Photo: Bengt Nyman, https://www.flickr.com/photos/97469566@N00

Exploding data? the Large Hadron Collider at CERN

1964



VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs

Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland

(Received 31 August 1964)

In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these particles (which would be absent if their mass were zero) go over into the Goldstone bosons when the coupling tends to zero. This phenomenon is just the relativistic analog of the plasma phenomenon to which Anderson[3] has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal plasmon modes of finite mass when the gas is charged.

The simplest theory which exhibits this behavior is a gauge-invariant version of a model used by Goldstone[2] himself: Two real[4] scalar fields φ_1, φ_2, and a real vector field A_μ interact through the Lagrangian density

$$\mathcal{L} = -\tfrac{1}{2}(\nabla\varphi_1)^2 - \tfrac{1}{2}(\nabla\varphi_2)^2 - V(\varphi_1^2+\varphi_2^2) - \tfrac{1}{4}F_{\mu\nu}F^{\mu\nu} + \tfrac{1}{2}e^2(\varphi_1^2+\varphi_2^2)A_\mu A^\mu + e(\partial_\mu\varphi_2)\varphi_1 A^\mu - e(\partial_\mu\varphi_1)\varphi_2 A^\mu, \quad (1)$$

where

$$\nabla_\mu\varphi_1 = \partial_\mu\varphi_1 + eA_\mu\varphi_2,$$

$$\nabla_\mu\varphi_2 = \partial_\mu\varphi_2 - eA_\mu\varphi_1,$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu.$$

e is a dimensionless coupling constant, and the metric is taken as $-+++$. $\mathcal{L}$ is invariant under simultaneous gauge transformations of the first kind on φ_1, φ_2, and of the second kind on A_μ. Let us suppose that $V'(\varphi_0^2) > 0$, $V'(\varphi_0^2) = 0$, then spontaneous breakdown of U(1) symmetry occurs. Consider the equations derived from (1) by treating $\Delta\varphi_1$, $\Delta\varphi_2$, and A_μ as small quantities] governing the propagation of small oscillations about the "vacuum" solution $\varphi_1(x) = 0$, $\varphi_2(x) = \varphi_0$:

$$\partial^2[\Box_1(\Delta\varphi_1) + e^2\varphi_0^2\Delta\varphi_1] = 0, \quad (2a)$$

$$(\partial^2 - 4e^2\varphi_0^2 V''(\varphi_0^2))(\Delta\varphi_2) = 0, \quad (2b)$$

$$\partial_\mu F^{\mu\nu} + e^2\varphi_0^2[\partial^2(\Delta A_\nu) - \partial_\nu\partial_\mu A_\mu] = 0. \quad (2c)$$

Equation (2b) describes waves whose quanta have (bare) mass $2\varphi_0[V''(\varphi_0^2)]^{1/2}$. Eqs. (2a) and (2c) may be transformed, by the introduction of new variables

$$B_\mu = A_\mu - (e\varphi_0)^{-1}\partial_\mu(\Delta\varphi_1),$$

$$G_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu = F_{\mu\nu}, \quad (3)$$

into the form

$$\partial_\mu B^\mu = 0, \quad \partial_\nu G^{\mu\nu} + e^2\varphi_0^2 B^\mu = 0. \quad (4)$$

Equation (4) describes vector waves whose quanta have (bare) mass $e\varphi_0$. In the absence of the gauge field coupling ($e = 0$) the situation is quite different: Equations (2a) and (2c) describe zero-mass scalar and vector bosons, respectively. In passing, we note that the right-hand side of (2c) is just the linear approximation to the conserved current: It is linear in the vector potential, gauge invariance being maintained by the presence of the gradient term.[5]

When one considers theoretical models in which spontaneous breakdown of symmetry under a semisimple group occurs, one encounters a variety of possible situations corresponding to the various distinct irreducible representations to which the scalar fields may belong; the gauge field always belongs to the adjoint representation.[6] The model of the most immediate interest is that in which the scalar fields form an octet under SU(3): Here one finds the possibility of two annihilating vacuum expectation values, which may be chosen to be the two $T=0$, $I_3=0$ members of the octet.[7] There are two massive scalar bosons with just these quantum numbers; the remaining six components of the scalar octet combine with the corresponding components of the gauge-field octet to describe

508

about the "vacuum" solution $\varphi_1(x) = 0$, $\varphi_2(x) = \varphi_0$:

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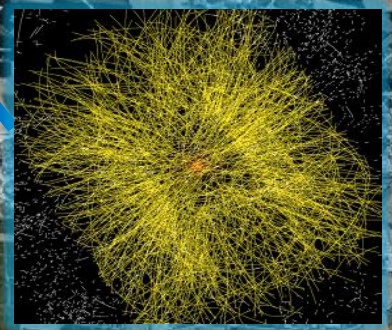
321

P. Higgs, Phys. Rev. Lett. 13, 508:

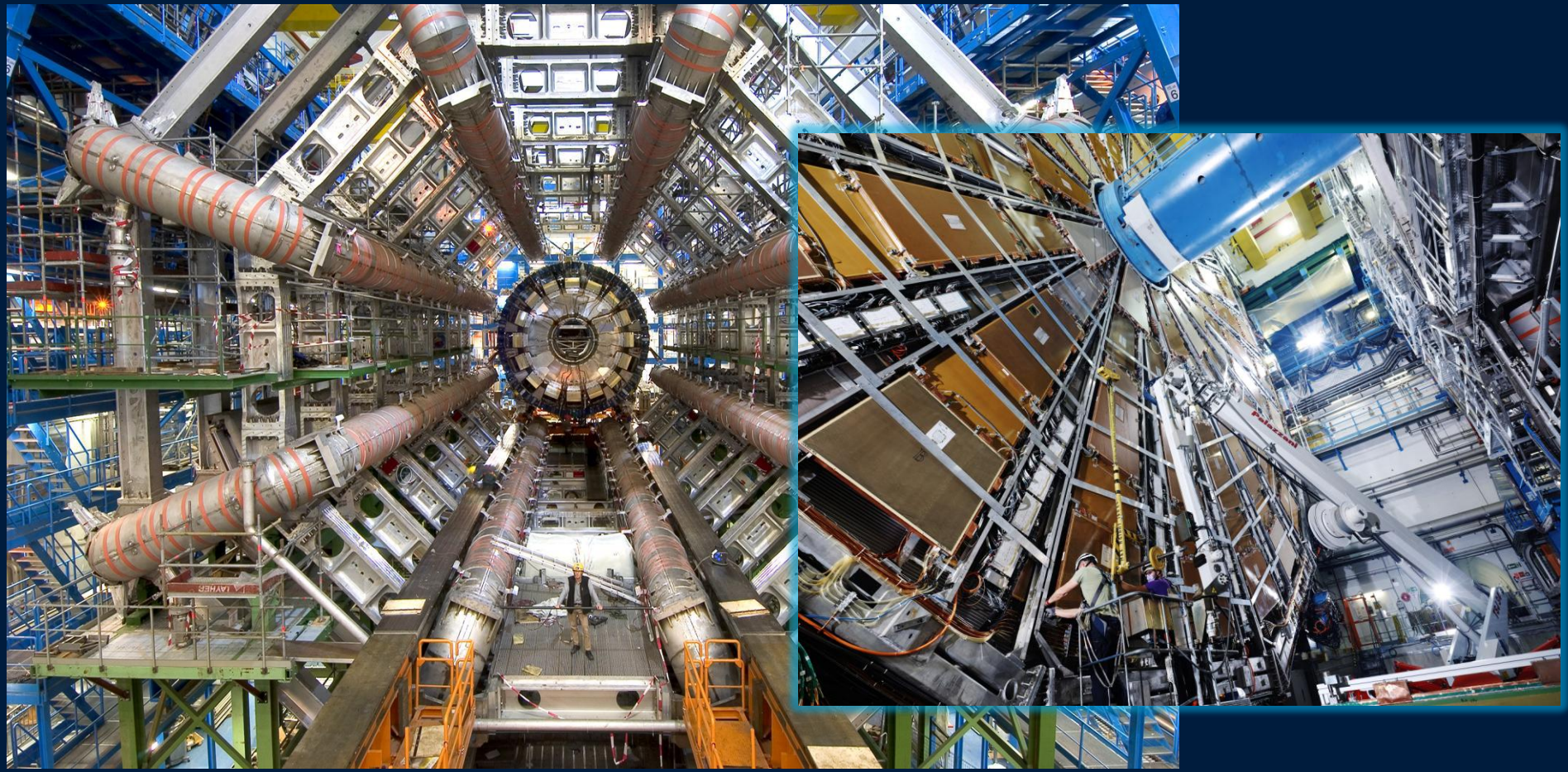
16823 characters, 165 kByte PDF

1998 - 2012 … 2030: HL-LHC … 2040+

~50 PiB/year primary data

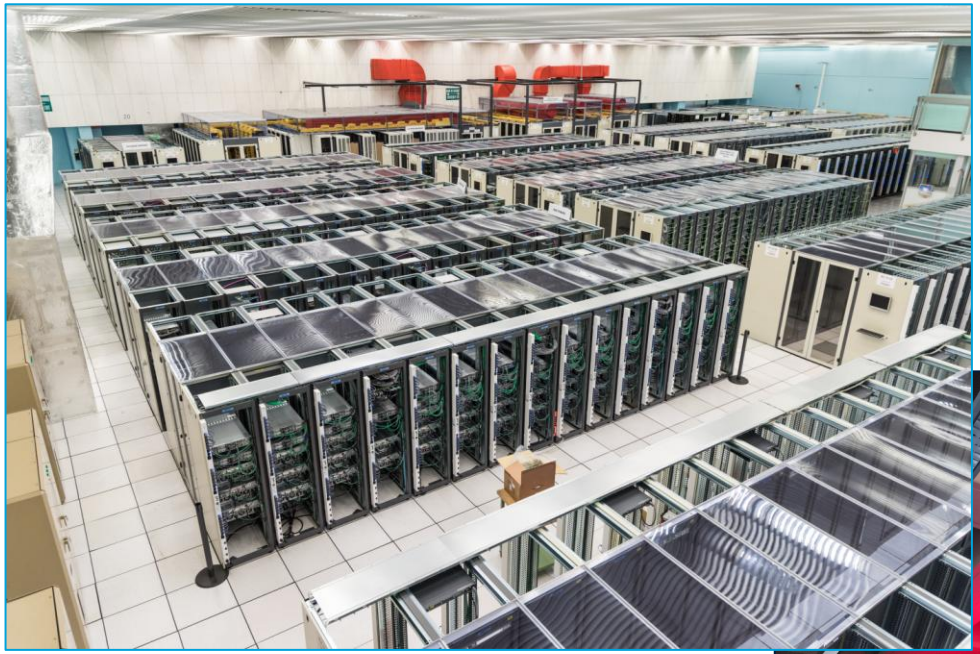


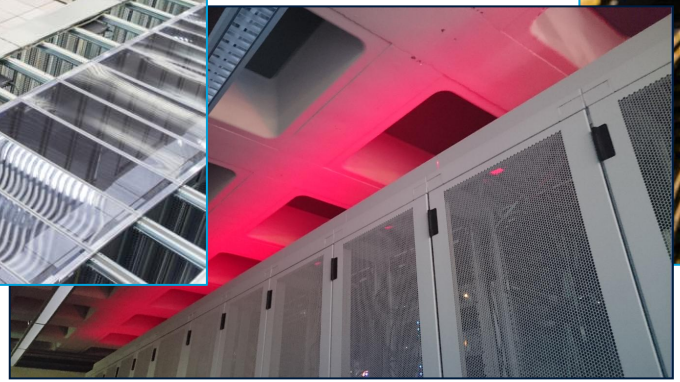
the LHC obviously looks for a lot more than just the Higgs mechanism. For example Alice looks at the Quark Gluon Plasma, LHCb for CP violation and the matter surplus (and lots more), and ATLAS and CMS look at almost anything. And all look at new BSM physics of course …



Images: ATLAS detector in the cavern at CERN. Source: CERN

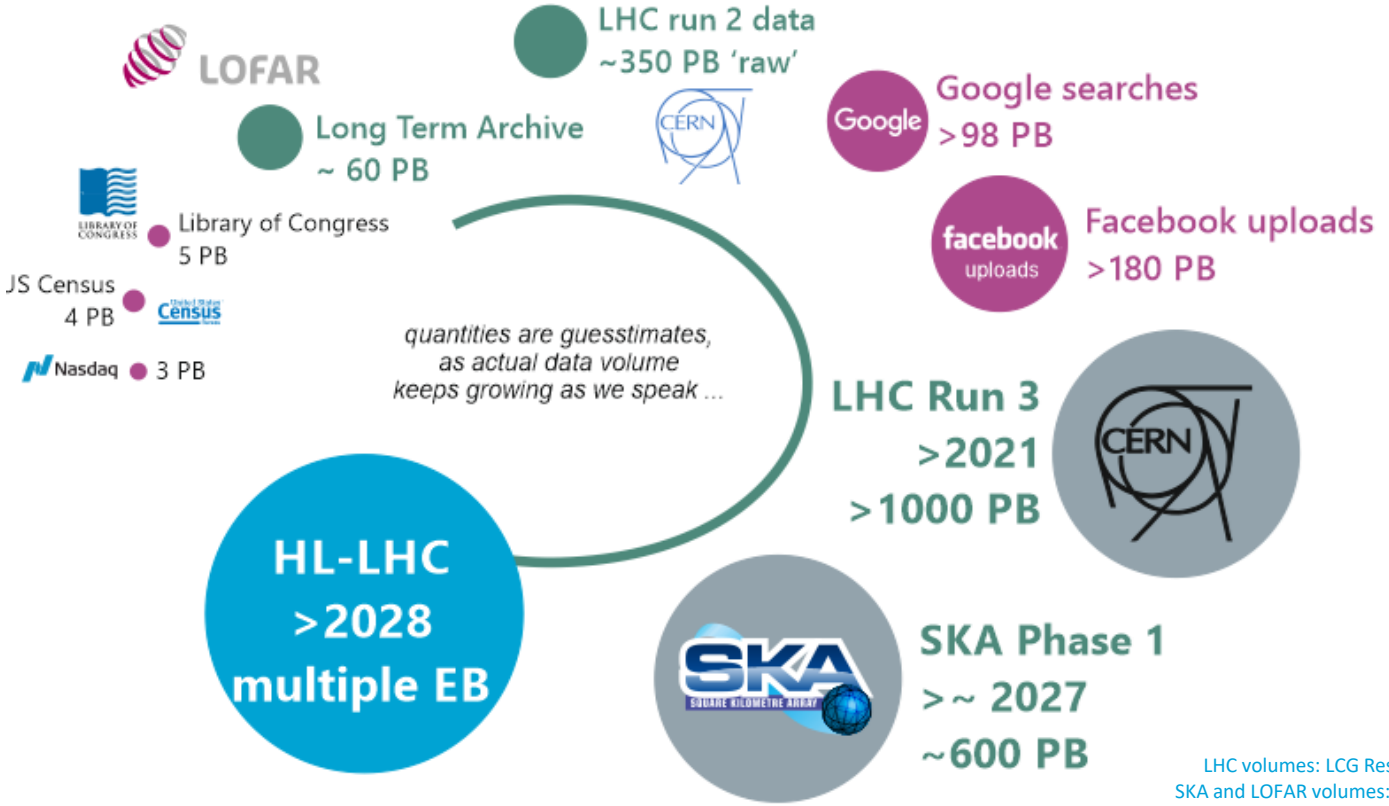
So ‘big science’ needs some computing …





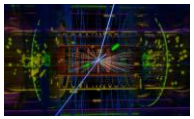
CERN Computing Centre B513, image: CERN, https://cds.cern.ch/record/2127440; tape library image CC-IN2P3 with LHC and LSST data; cabinets: Nikhef H234b

Processing at scale for data intensive science



Data from various sources, for public entities: data ca. 2018, indicative, within ~ factor 2
LHC volumes: LCG Resource Scrutiny Group & CERN; 2020
SKA and LOFAR volumes: ASTRON/Michiel van Haarlem, 2020

Volume versus complexity



ATLAS RAW single event
ROD File
1.60 MB

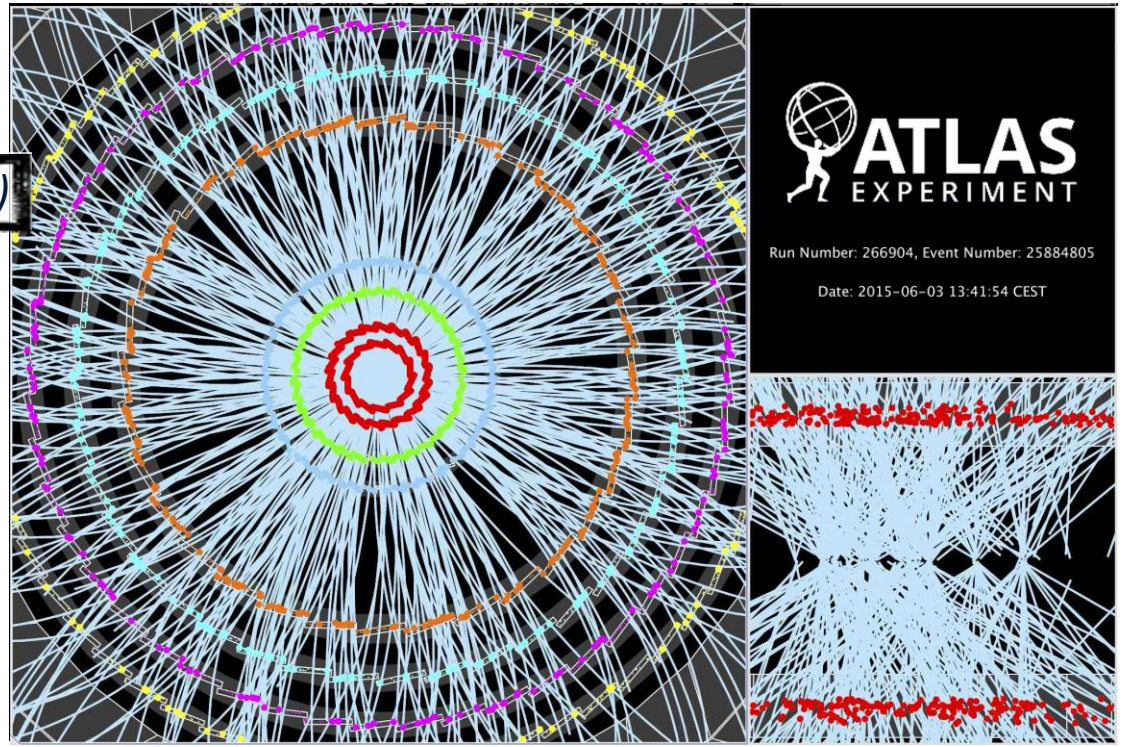
***~60 TByte/s** (compressed)*

Trigger system selects 600 Hz ~ 1 GB/s data

~ 10 seconds compute for a single event at ATLAS with 'jets' containing ~30 collisions

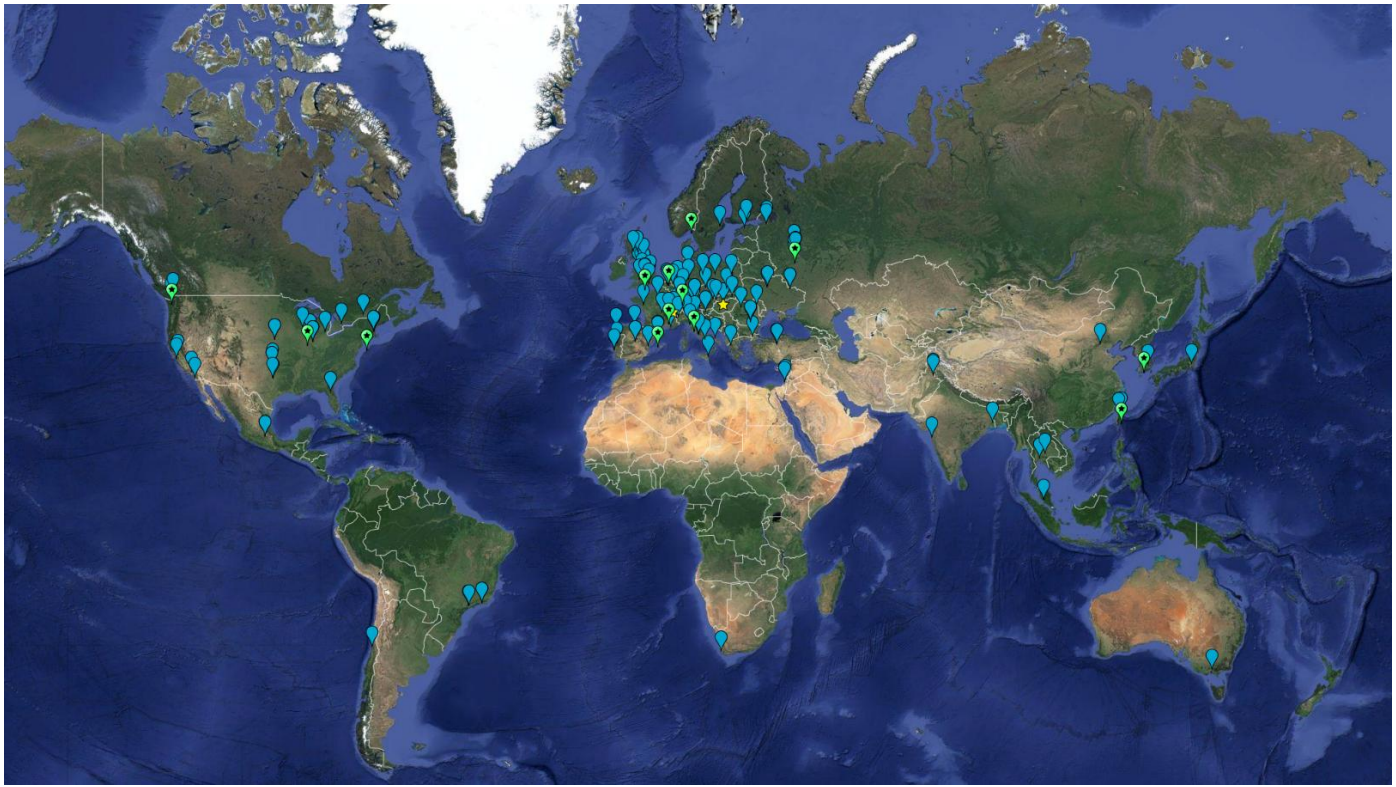
~10k researchers

CERN and ~170 institutes



Display of a proton-proton collision event recorded by ATLAS on 3 June 2015, with the first LHC stable beams at a collision energy of 13 TeV;
Event processing time: v19.0.1.1 as per Jovan Mitrevski and 2015 J. Phys.: Conf. Ser. 664 072034 (CHEP2015)

Not in one place: the worldwide LHC Computing Grid



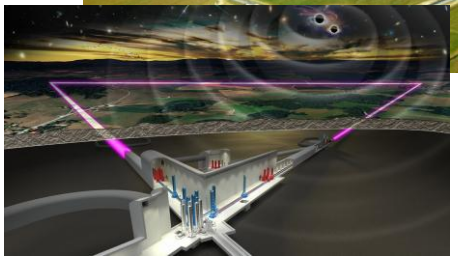
~ 1.4 million CPU cores
~ 1500 Petabyte
disk + archival

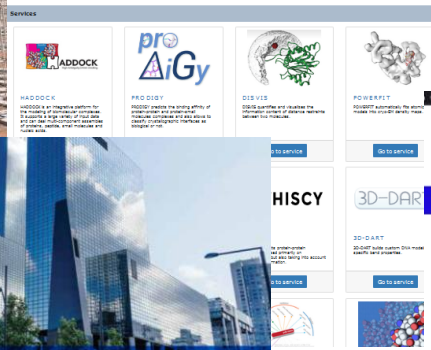
170+ institutes
40+ countries
13 'Tier-1 sites'
NL-T1:
SURF & Nikhef

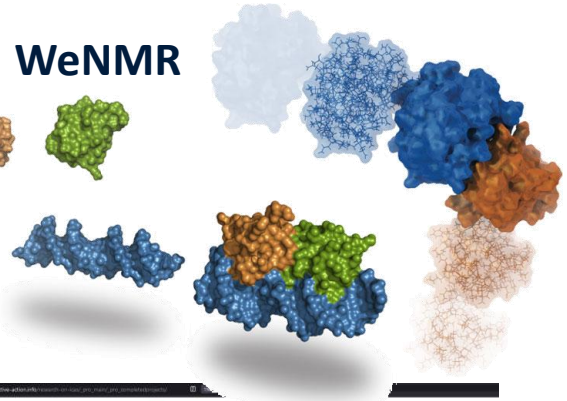
largely based on generic e-Infrastructures
EGI
EuroHPC
PRACE-RI
OpenScienceGrid
ACCESS-CI

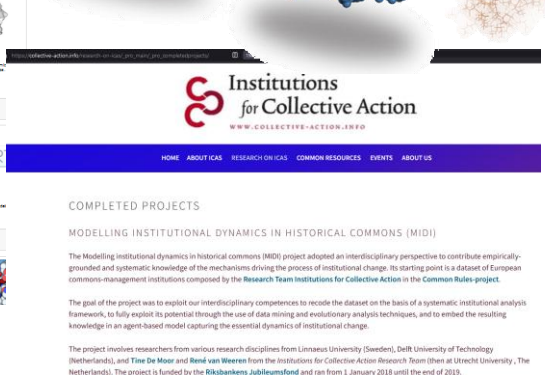
Earth background: Google Earth; Data and compute animation: STFC RAL for WLCG and EGI.eu; Data: https://home.cern/science/computing/grid
For the LHC Computing Grid: wlcg.web.cern.ch, for EGI: www.egi.eu; ACCESS (XSEDE): https://access-ci.org/, for the NL-T1 and FuSE: fuse-infra.nl, https://www.surf.nl/en/research-it

Scaling computing infrastructure – a common need









Sources: CERN https://wlcg.web.cern.ch/; HADDOCK, WeNMR, @Bonvinlab https://wenmr.science.uu.nl/; Virgo, Pisa, IT; SKAO: the SKA-Low observatory, Australia https://www.skatelescope.org/ - OpenMOLE simulation on EGI - https://cdn.egi.eu/app/uploads/2022/04/EGI_Use_Cases.pdf; agent-based modelling of ICAs: https://collective-action.info/research-on-icas/ Molood Dehkordi (TUDelft), Tine de Moor (EUR RSM)

This is a tour of {a,one} large-scale IT landscape

Today: a use case driven overview, looking at

- relationship of infrastructure and one application area: scientific computing
- scaling & interdependency of infrastructure components

  compute, storage, data, network, trust & identity, and security
  '*how to identify scalability bottlenecks*'
- no directly related questions or project tasks
  but don't fall asleep just yet

What you should be able to do by the end of today

“Build a
globally distributed data processing infrastructure
serving different customers and diverse workloads
at the Exascale”

or at least

- where to look for relevant standards and reference architectures
- know what scalability issues can affect globally distributed large-scale IT
- realise why this LsIT course is essential to making things actually work ☺

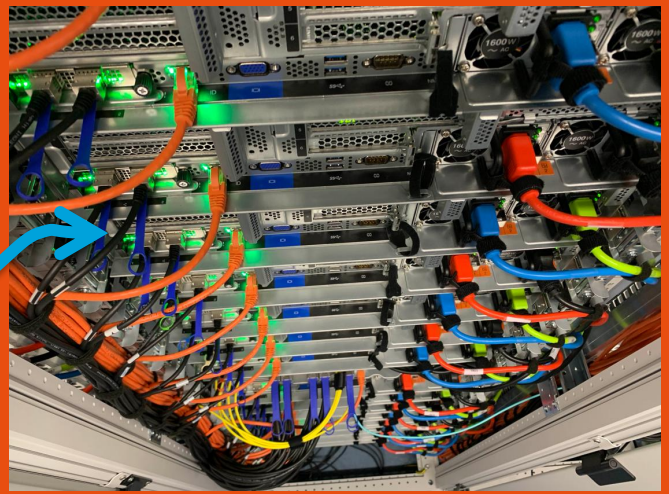
For a global large-scale IT system, we need to

1. **Build ‘sites’ that scales to lots of systems**
   - Datacentre
   - Power-efficient systems that can process lots of data
   - Orchestrate these systems to function *as a service*
   - sharing workload with brokering, data placement, and platforms
2. **Connect sites, services, and users together. Across the world**
   - with high speed networks, that can deal with latency and severance of links
   - for authenticated and authorised users
   - that collaborative gain access to services and data
   - and are secured and protected … also from themselves

and then getting actual users … is ‘just’ marketing and communications …

Start with …
a green field approach

from field to IT facility



From field to facility

Trekkersveld IV, Zeewolde. From Zeewolde Actueel, https://www.zeewolde-actueel.nl/nieuws/gemeente/254432/bestemmingsplan-trekkersveld-4-ligt-ter-inzage; Microsoft DC Middenmeer, from https://nos.nl/l/2512478,

You got the power!

Images: Anton Mors, David Groep, Nikhef

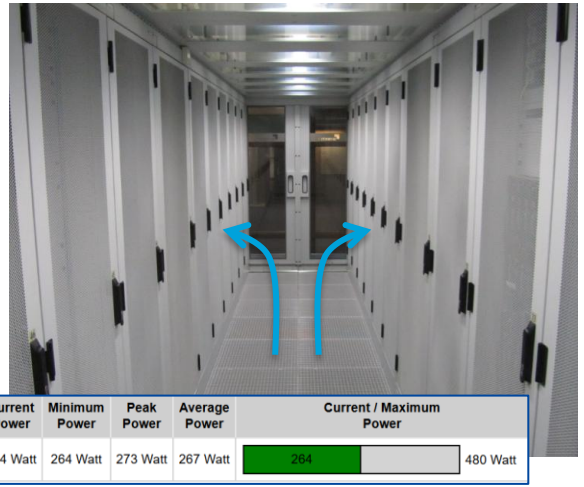
Converting electricity into … chilled air & heat

Left-side image: frame from a movie by Anton Mors, people replaced by … Adobe Firefly (“without people”?, oh well, this was its best result ☹)

NikhefHousing: a cold aisle

Data centres: where we put large-scale IT

- ‘tier-1’ … ‘tier-4’ datacenters - increasingly redundant
- systems are ‘lights out’: the DC may be miles away
- small or large, in terms of power and cooling capacity:
  - smallish: Nikhef Housing Amsterdam is ~2.5 MW,
  - Dutch AI Factory to be built in Groningen: ~10 MW
  - Microsoft Middenmeer Venster West: 285 MW
- data centre efficiency metric: $PUE = \frac{E_{total}}{E_{IT\_equipment}}$



Reducing cost and environmental impact:

- airflow engineering: prevent mixing of cold and hot air
- liquid cooling
- (free) cooling by changing inflow temperature
- Aquifer Thermal Energy Storage (ATES) to buffer heat (and re-use later for homes)

Typical PUEs vary from 1.03 (in Iceland) to 1.2 for ‘good’ datacenters in NL

Data centre tiering: Uptime Institute (Tunner, W.P.; Seader, J.H.; Brill, K.G. Tier Classifications Define Site Infrastructure Performance; White Paper)
Remote systems management: IPMI, Redfish and various vendor proprietary solutions – usually dedicated ‘out-of-band’ network connection, incl. remote KVM

Virtual and cloud services rely on this physical ‘stuff’

- HPC systems like the Dutch Snellius, a SuperMUC, LUMI, JUPITER, or Jules Verne,
- data-intensive computing like WLCG, radio astronomy, and so on
- your favourite (or not) typical hyperscalers like AWS, Azure, Google, OVH, Hetzner, …

and all those new AI systems and AI ‘factories’ that boost Nvidia stock nowadays …

DNI and NL-T1 capacity from 2023 DNI NWO, LOFAR, and WLCG; see https://www.surf.nl/onderzoek-ict/toegang-tot-rekendiensten-aanvragen ; fuse-infra.nl
SURF tape total: ~80 PByte by end 2022; image library at Schiphol Rijk from Sara Ramezani; NikhefHousing: https://www.nikhef.nl/housing/datacenter/floorplan/

Different types of large scale compute resources

- HPC and (computational) cluster computing:
  - modelling for weather/climate, fluid dynamics, but also e.g. QC-simulation

- HTC and data-intensive processing – horizontal scaling:
  - lots of data, as in High Energy Physics (HEP), *omics and protein docking, …
  - conveniently parallel,
    but (intensive) local I/O requirements on memory and scratch storage

- portals and many web applications:
  ‘horizontal’ scaling, often backed by cloud and virtualized resources
  - Cloud-native scaling and containers for ‘more of the same, different each time’
  - If it’s data at scale: object stores and ‘CDN’ web-scale caching

HPC: High Performance Computing; HTC: High Throughput Computing; K8S: Kubernetes; CDN: Content Delivery Network

Single CPU scaling stopped around 2004

- limitation is power, not circuit size
  - and clock frequency is most ‘power-hungry’
  - still some packages now @ TDP of 400W
- multiple cores on the same die helps:
  - AMD EPYC Genoa (Zen 4) has 96 cores/die
  - Intel Granite Rapids, Nvidia GraceHopper, …
  - but e.g. Intel Cascade Lake AP was less useful
- CPU design-level performance gains left
  - predictive and out-of-order execution
  - on-die parallelism (multi-core)
  - pre-fetching and multi-tier caching
  - execution unit sharing (‘SMT’)

  but at increased risk for security/integrity

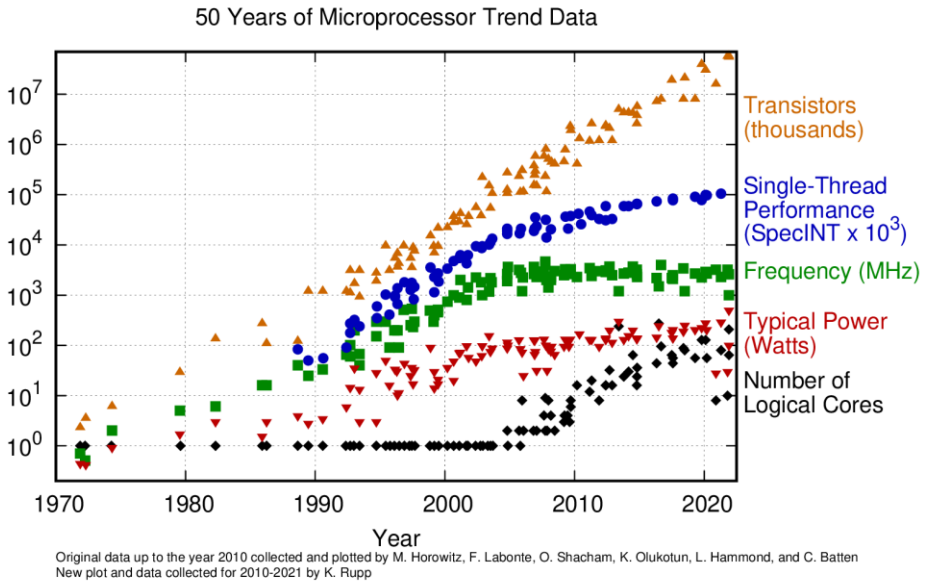
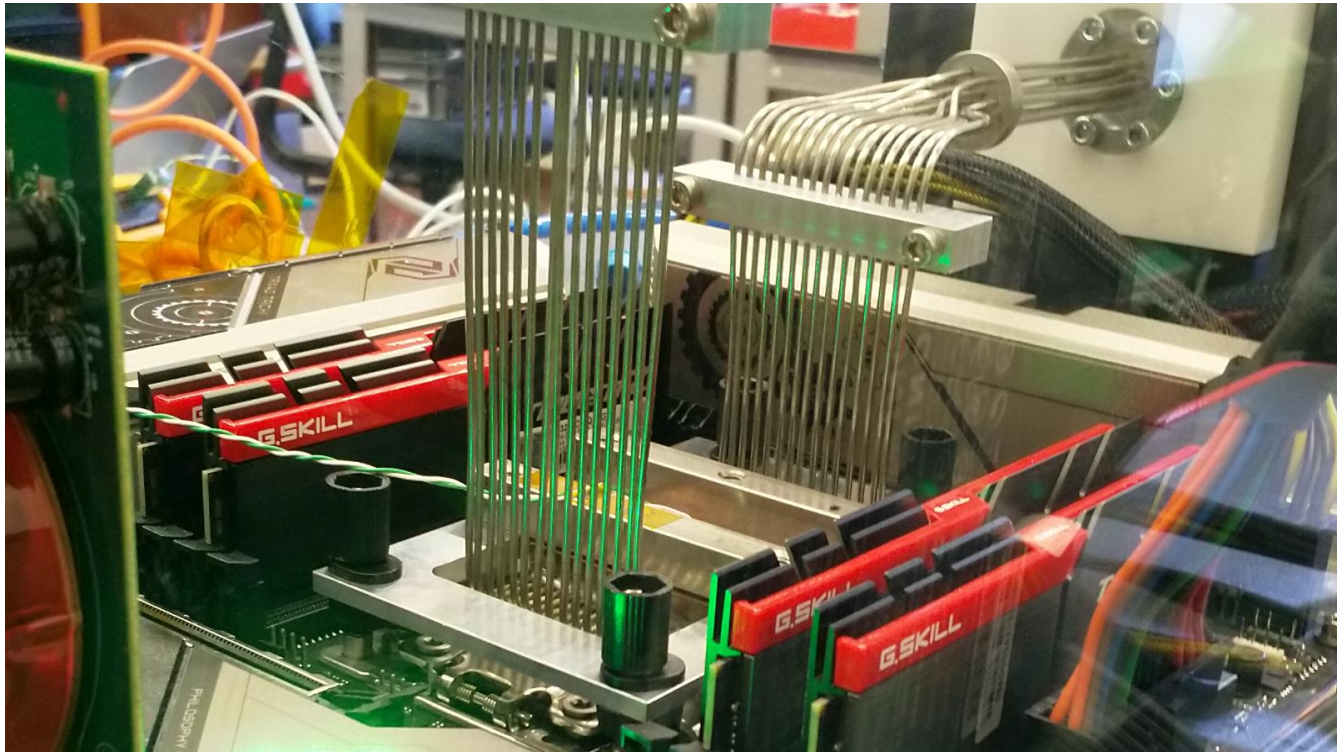


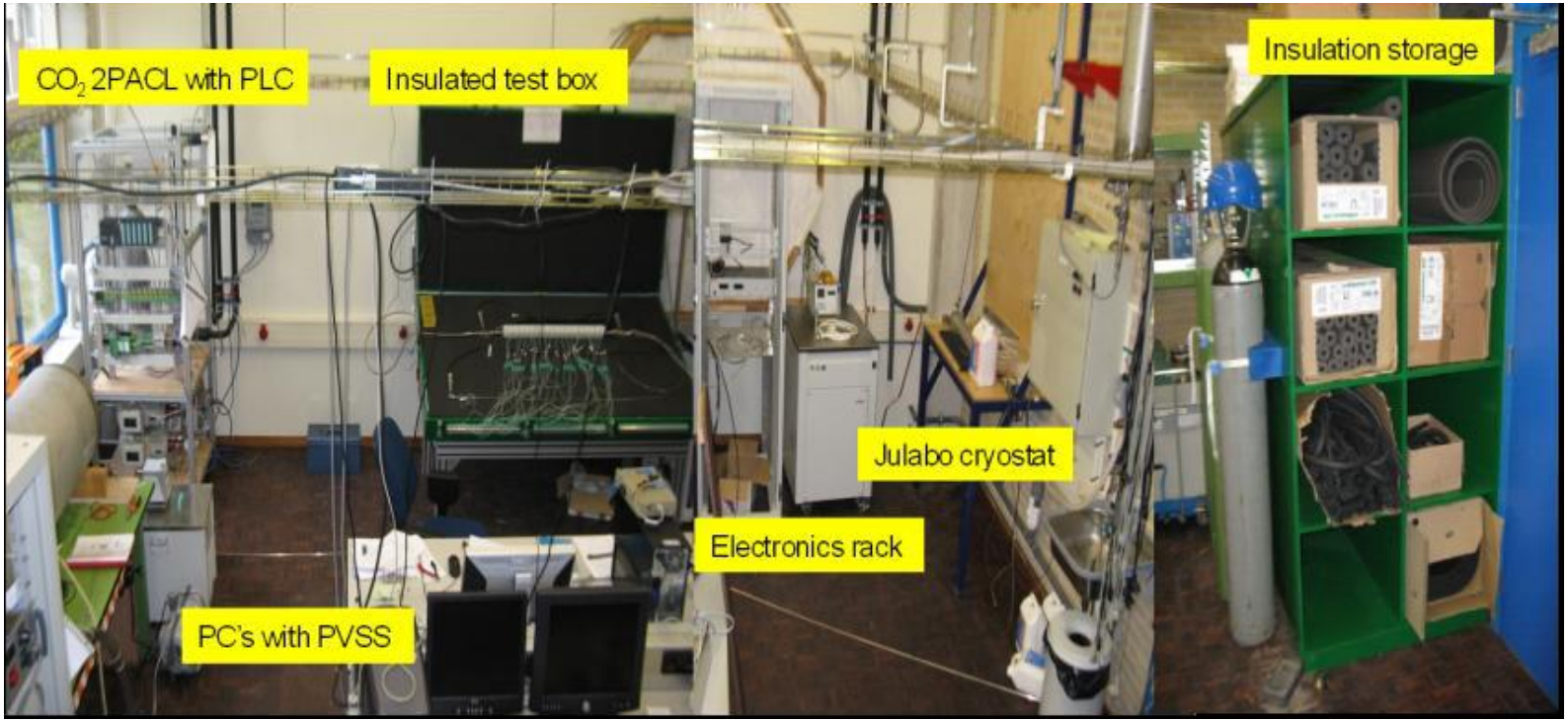
Image: K Rupp, https://github.com/karlrupp/microprocessor-trend-data

Fix the thing that didn’t scale well, CPU frequency??



LCO2 cooling of an AMD Ryzen Threadripper 3970X [56.38 °C] at 4600.1MHz processor (~1.25x nominal speed) sustained over all cores simultaneously, using the Nikhef LCO2 test bench system (https://hwbot.org/submission/4539341) - (Krista de Roo en Tristan Suerink)

… since you then need this around it …



Nikhef 2PA LCO2 cooling setup. Image from Bart Verlaat, Auke-Pieter Colijn *CO2 Cooling Developments for HEP Detectors* https://doi.org/10.22323/1.095.0031

Step one: scale *inside* one system

- multiple cores and SMT on a single die
- ‘trivial’ step-up is to do multiple sockets in one system
  2-socket, sometimes 4 socket on a motherboard
- to make it appear as a single shared memory system,
  cache coherency required between CPU cores and sockets
- useful for tightly coupled parallel applications
  (weather forecasting, fluid dynamics, climate), but
  not needed for ‘trivially parallel’ high throughput needs
- depending on architecture cache coherency may limit
  single-thread performance (although AMD did better here than Intel *lakes)

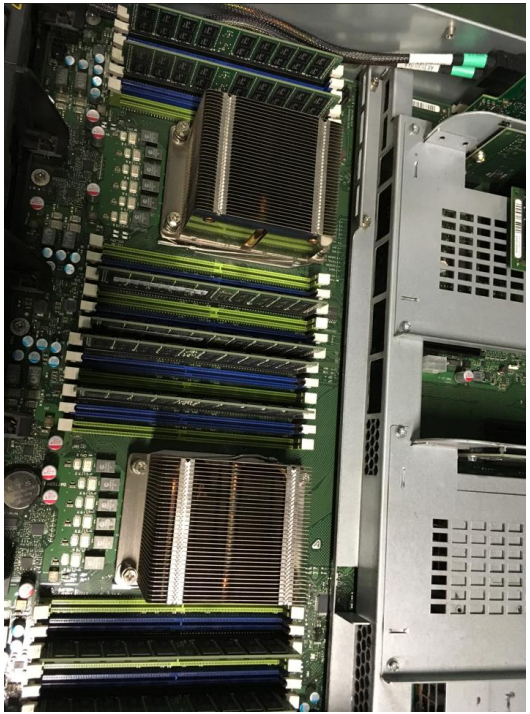


Image: dual-socket Fujitsu system at the Xenon experiment site, 2019. source: Tristan Suerink, Nikhef

CPU design changes may fit application, or not

AMD EPYC effective for applications like WLCG:

- Naples → Rome added shared memory die
- links all cores directly to memory

Rome-Milan improvement?

- shared L3 cache benefits tightly coupled HPC, but not HTC, limited by ‘off-die memory’

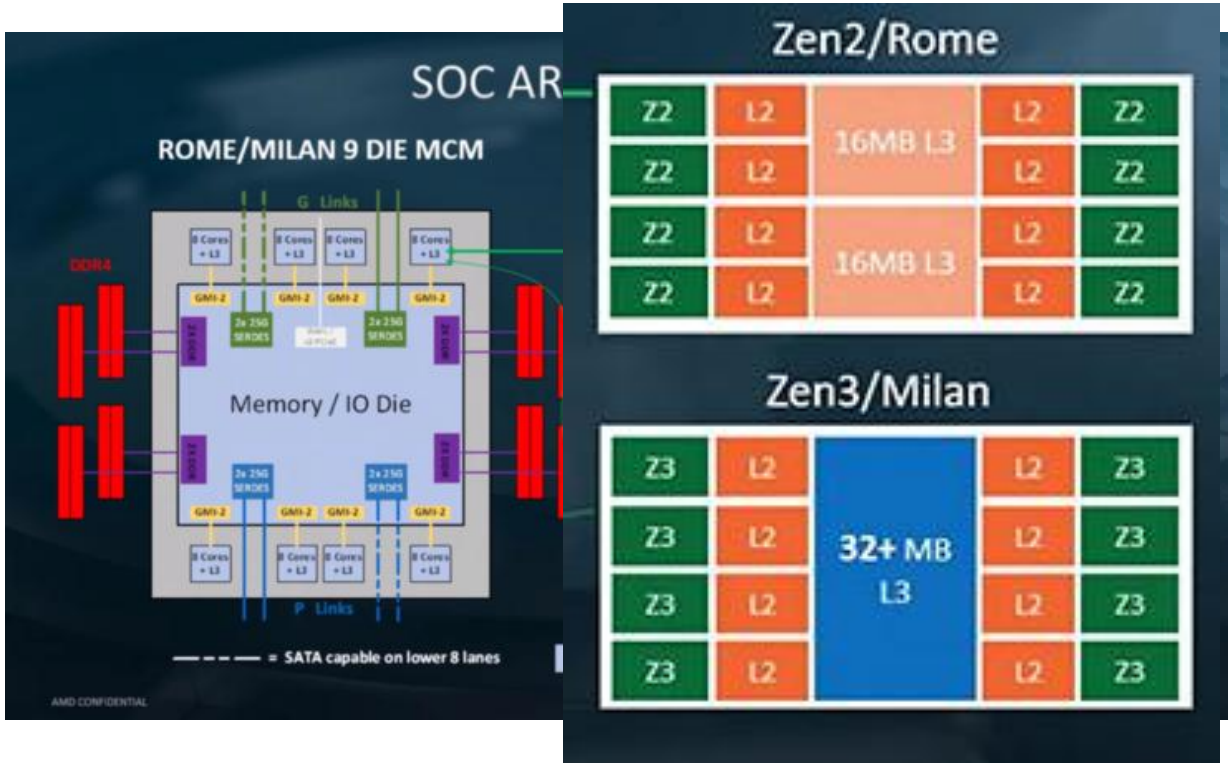
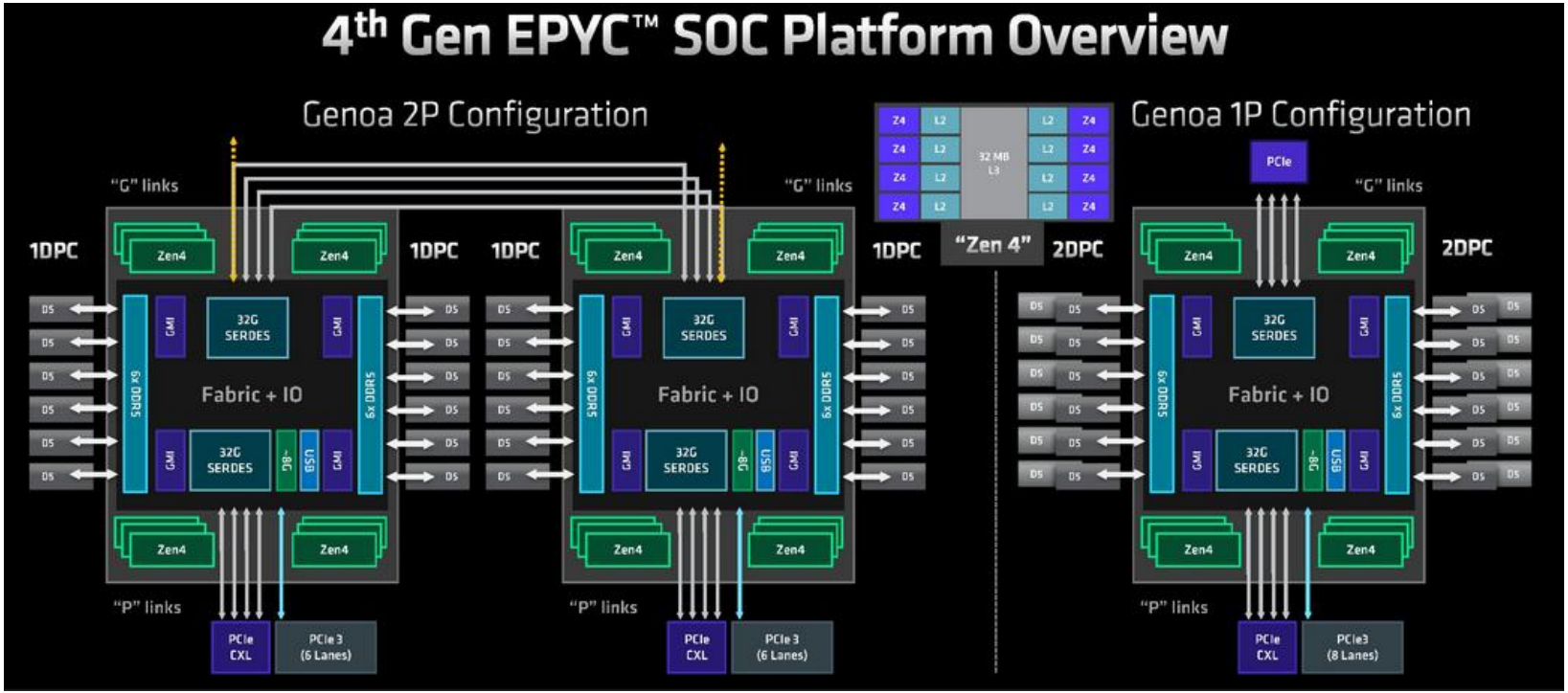


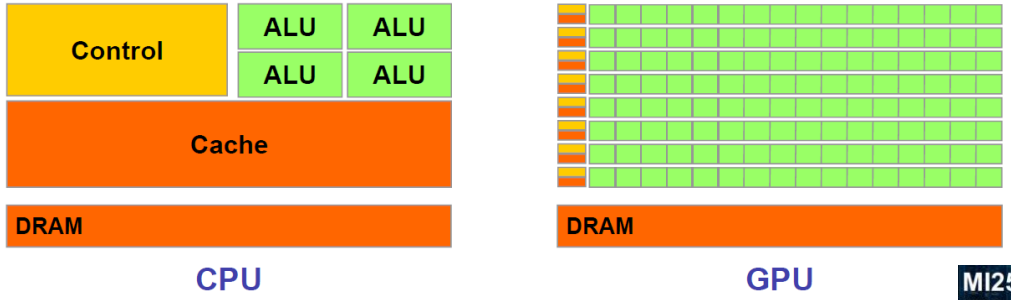
Image source: AMD, retrieved from https://m.hexus.net/tech/news/cpu/135479-amd-shares-details-zen-3-zen-4-architectures/

Scaling up, more examples



AMD EPYC Genoa platform, image from https://www.semianalysis.com/p/amd-genoa-detailed-architecture-makes

Accelerators – general purpose GPUs



leaving FPGAs out for a moment – but those are particularly useful in guaranteed-latency scenarios!

- but co-processing comes at a cost of moving data to and from the GPU
- often faster to keep computing and do selection & conditionals later
- computation speed heavily depends on precision (even 4-bit precision is used)
- quite power hungry!

Image: 'Massively Parallel Computing with CUDA', Antonino Tumeo Politecnico di Milano, https://www.ogf.org/OGF25/materials/1605/CUDA_Programming.pdf
Floorplan image of die: AMD MI250 GPU, slide source: AMD

GPU enhanced system, with 4 ‘partitionable’ GPUs (L40)

DACS FSE CSLab

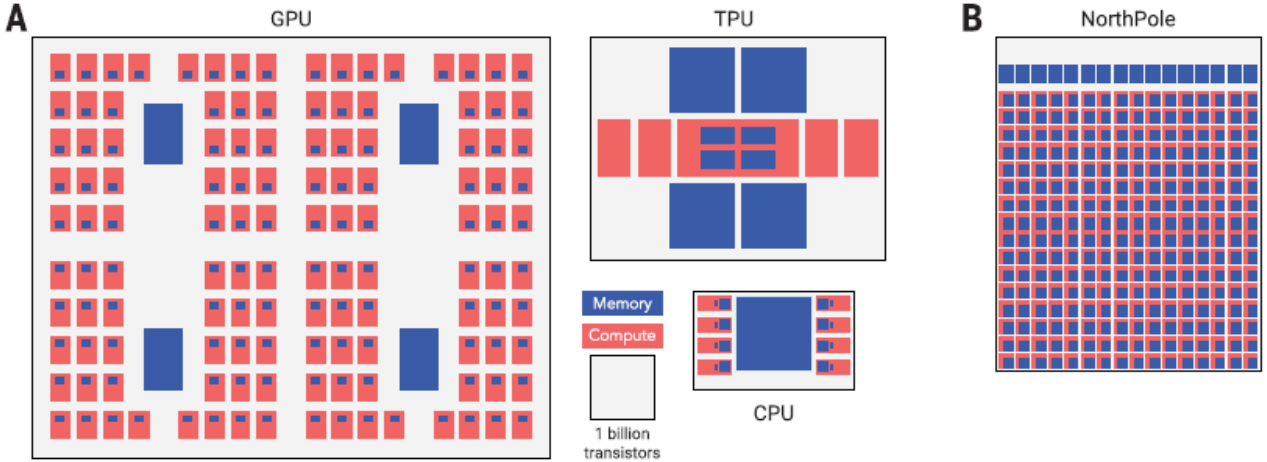
DACSGPU003,
at Debeyeplein 1

info@fse-cslab.nl

Aiming to remove the data access bottleneck

Separating memory from processing introduces the memory misses that slow down CPU processing as well GPUs due to need for (RDMA) main memory access

Some very recent designs aim to eliminate this by temporal co-location of program and memory (IBM NorthPole AI, Oct ‘23) with data-flow driven compute

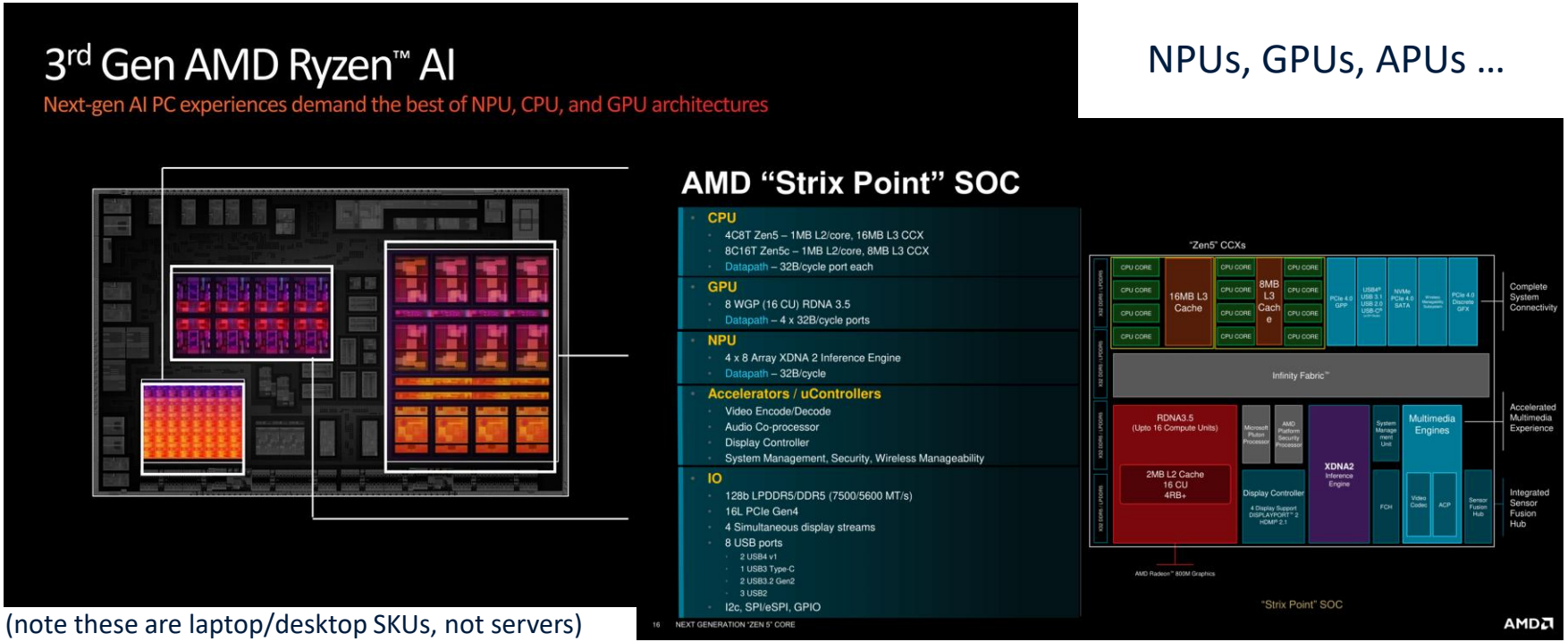


Physical organization of on-chip memory (blue) and compute (red) are diagrammed for representative processors, scaled to constant transistors per unit area. From Modha’s paper Modha et al., *Science* **382**, 329–335 (2023)

Modha *et al.* https://doi.org/10.1126/science.adh1174 or read https://research.ibm.com/blog/northpole-ibm-ai-chip
PCIe card photo from https://www.ibm.com/blogs/solutions/jp-ja/northpole-ibm-ai-chip/

Hybrid SOCs and heterogeneous architectures

NPUs, GPUs, APUs …



(note these are laptop/desktop SKUs, not servers)

Images: AMD Ryzen 9 HX 370 AI, Strix SOC – compare also Intel Lunar Lake architecture

but there *is* also a serious issue here …

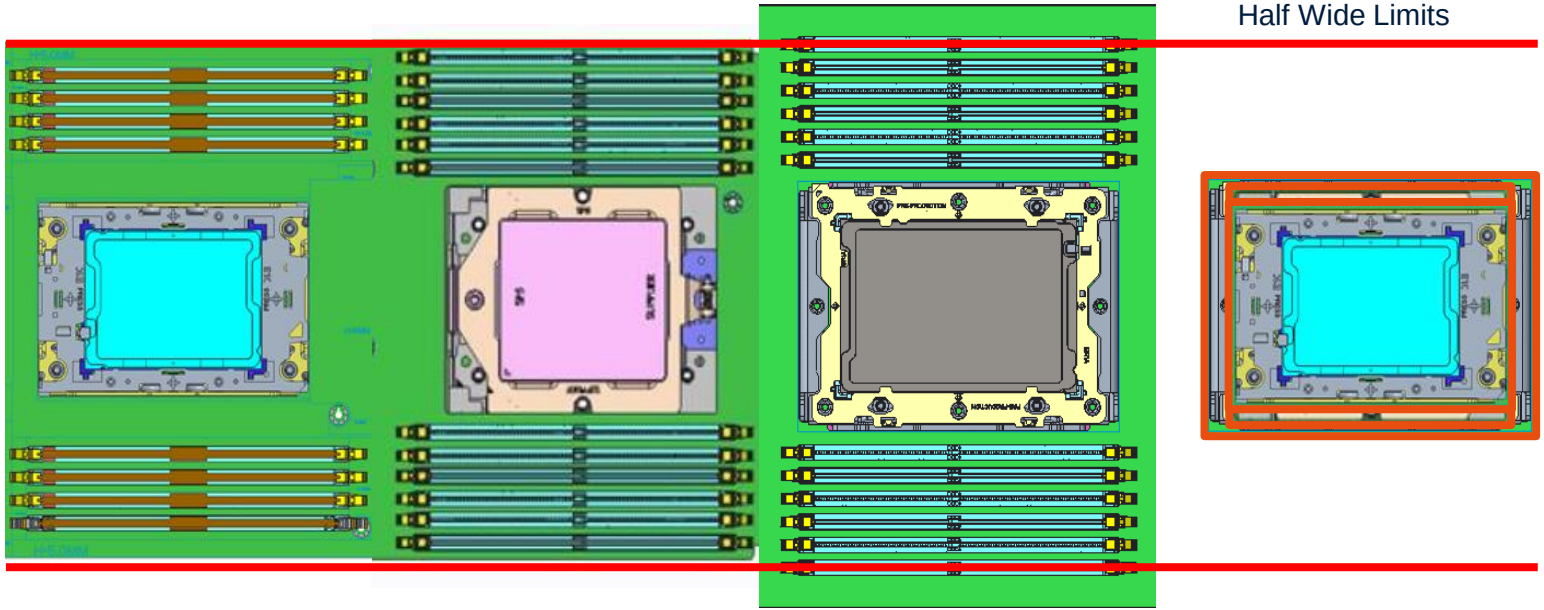
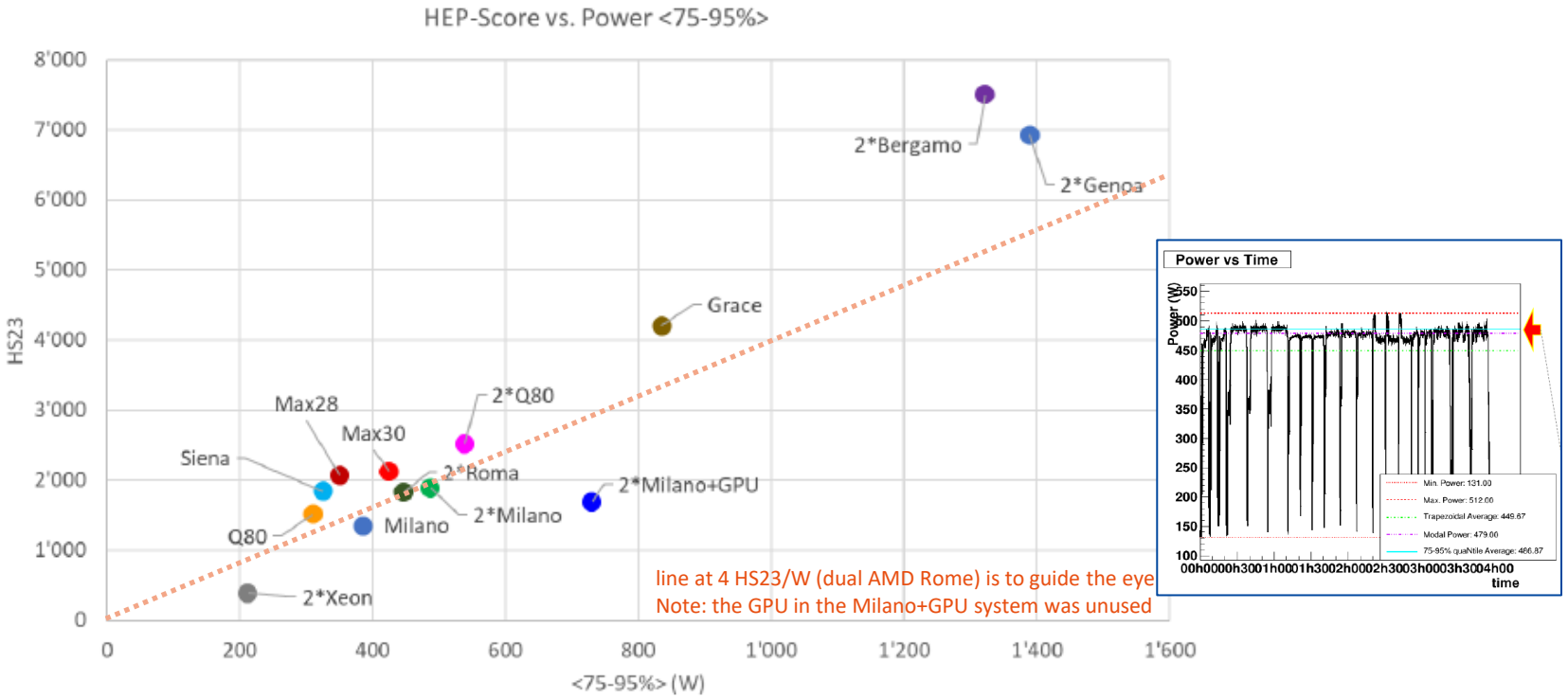


Image thanks go to Rick Koopman – Lenovo at the HTCondor Workshop 2024 https://indico.cern.ch/event/1386170/

The energy bottleneck: architecture figure of merit

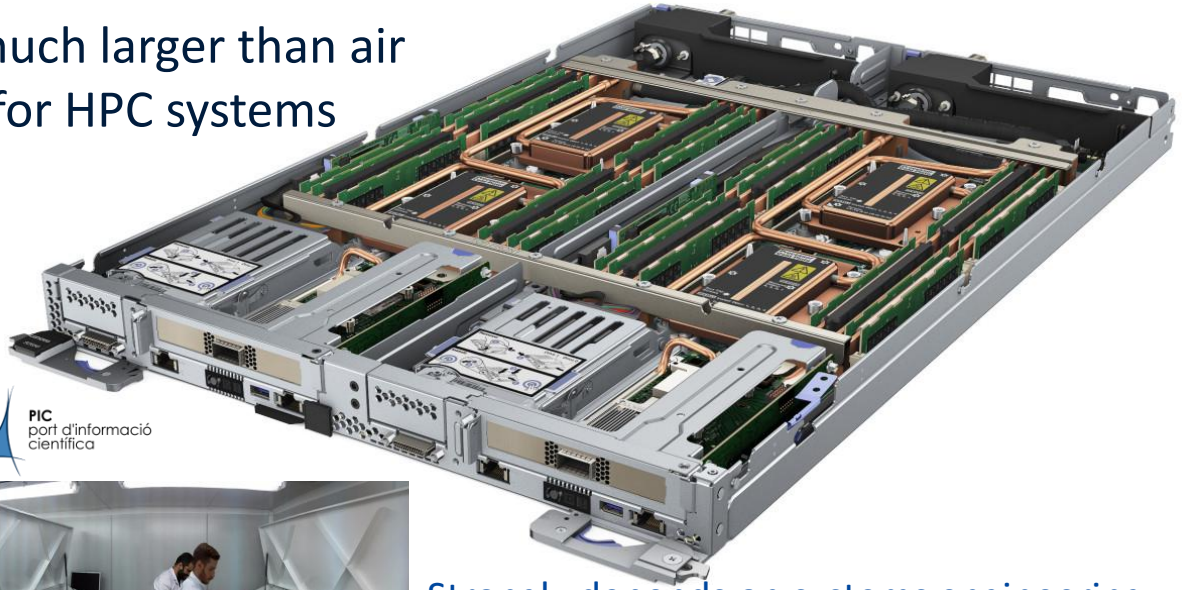


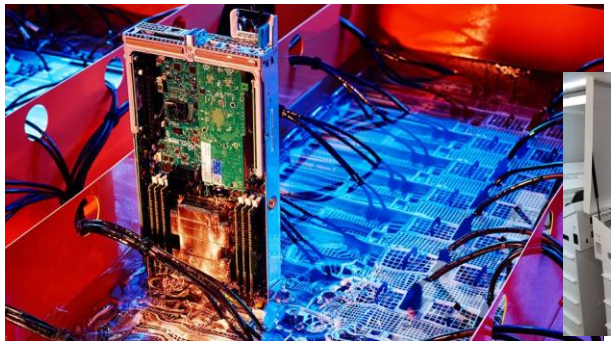
Data and graphs: Emanuele Simili, Glasgow University, at CHEP2024 (https://indico.cern.ch/event/1338689/contributions/6011562/)
HEPSPEC23 benchmark: https://gitlab.cern.ch/hep-benchmarks/hep-benchmark-suite ('memory-intensive' high throughput processing application benchmark)

How to get this heat out … in liquid form, maybe?

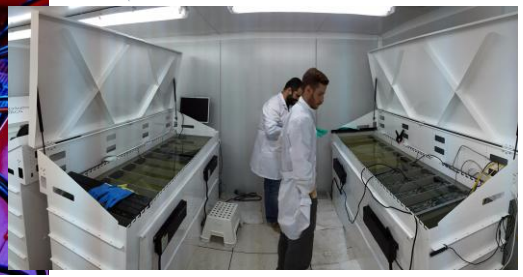
- Heat capacity of liquid is much larger than air
- by now (almost) standard for HPC systems

- immersive systems look cool, but are ‘a bit hard’ on maintenance





PIC
port d'informació
científica



Strongly depends on systems engineering: when water inlet temperature can be >40 degC, you have almost always free cooling

Image source dual-board system: Lenovo, ThinkSystem SD650
immersive cooling image https://hypertec.com/blog/sustainable-emerging-tech-liquid-immersion-cooling/, PIC T1 centre, Barcelona, ES

And if large-scale IT does not quite fit … ahum …

Image source: https://lambdalabs.com/products/blade

SuperMicro (branded as ‘Lambda Blade’)
4U chassis, supporting 10 consumer-grade GPUs …
… with a bump

Scaling up – beyond one lone motherboard

Several scalable computing models

- a-priori manual definition of scale: {podman,docker}-compose, cloud VM dashboards
- ‘cloud-native’ dynamic scaling - ‘horizontal’ or ‘vertical’ -
  works well for services that lend themselves to load balancing
  (used by kubernetes, docker swarm, many cloud APIs)
- ‘infrastructure-as-a-service’ tools to meta-manage these, like Hashicorp’s Terraform
- Parameter sweeping and throughput computing management: batch systems
- Application-driven scaling: parallel computing (MPI) and distributed underlays (like parallel tasks in matlab or jupyter python notebooks)

← take the parallel computing course ☺

compute farms: ‘milking’ computer clusters

But workloads usually need more than *just* compute

- **balanced features** for node throughput CPU, storage, memory bandwidth & latency, NIC & network speed

For example for WLCG:

- **single-socket** multicore systems are fine, today typically 64-128 cores per system
- **network**: 2x25Gbps (matching #cores)
- **memory**: say ~ 8 GiB/core
- **local disk**: 8-16 TB NVME (~100GB/core)

\+ space (physical + power) to add **GPUs**

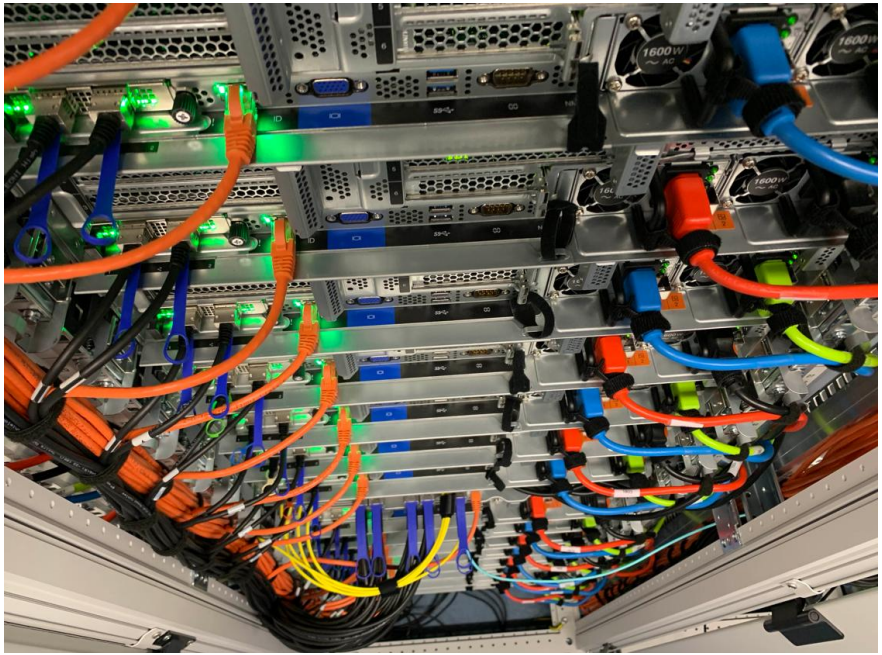
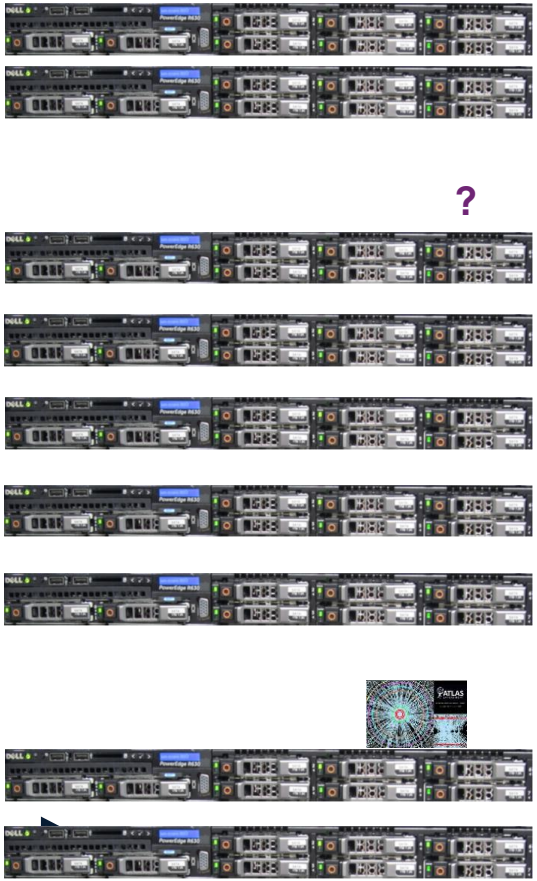
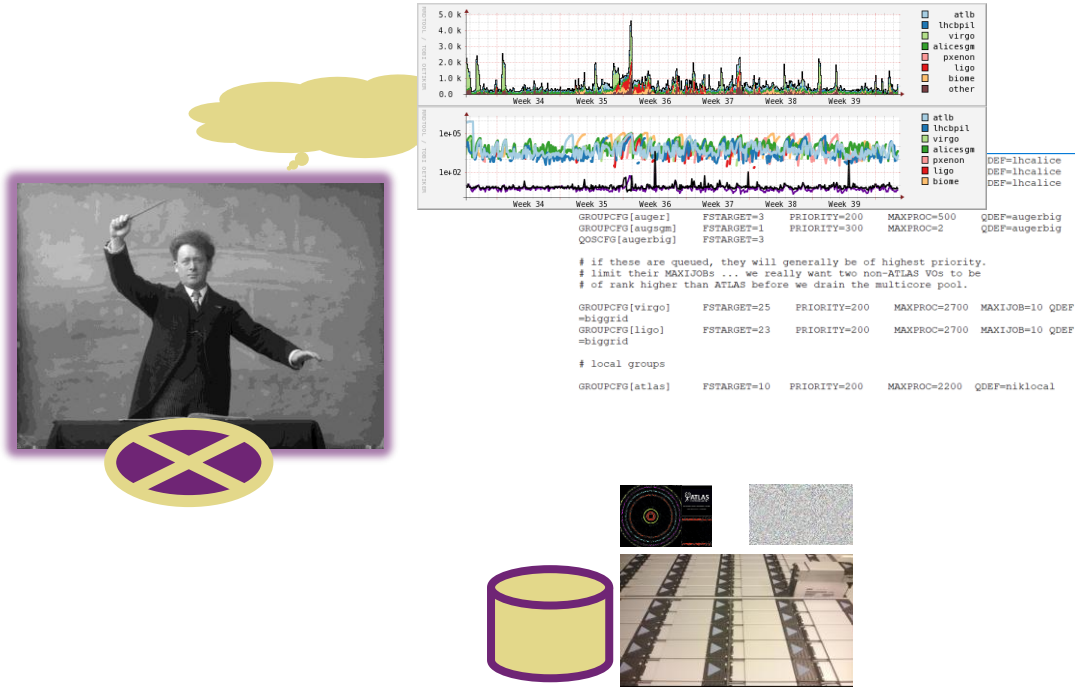


Image: Cluster ‘Lotenfeest’ at the Nikhef NDPF, acquired March 2020. Lenovo SR655 with AMD EPYC 7702P 64-Core single-socket. Some with 4 L40s Nvidia GPUs

Cluster computing and ‘conveniently parallel’ HTC



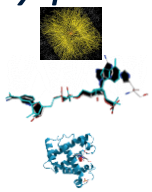


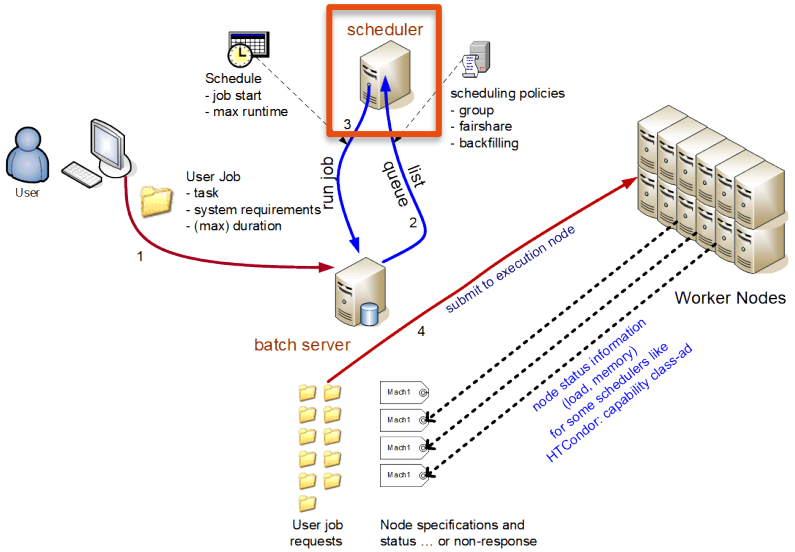
- ‘like milking cows’ (if you feed them lots of power first)
- parallel access to data comes at a cost of high IOPS

Batch system platform

Many things in life are *conveniently parallel*

- HEP events & simulation
- ligand matching & drug discovery
- structural biochemistry
- …





challenge not in parallelism itself

- we have had HPC systems for ages

but

- large numbers of (single-core) jobs
- heterogeneous workloads
  sharing the same set of worker nodes
- computing with concurrent data access

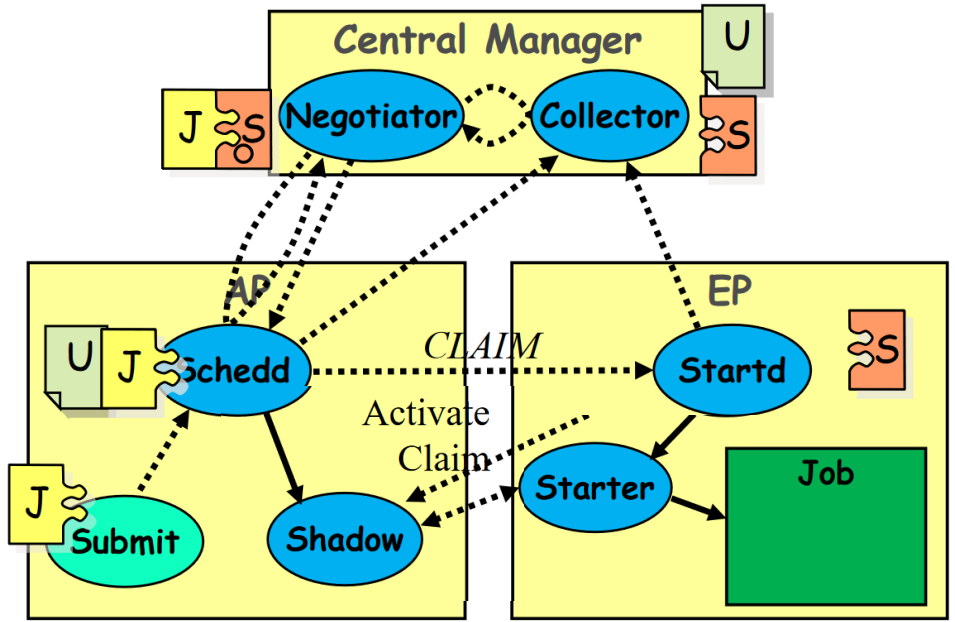
```
korf.nikhef.nl:

                                                            Req'd    Req'd       Elap
Job ID                  Username    Queue    NDS   TSK    Memory   Time    S   Time
----------------------- ----------- -------- ----- ------ ------ --------- - ---------
33134895.korf.nikhef.n  lhcbpi08    lhcb         1      1  5120m  41:59:57 R  37:46:21   wn-choc-023
33134901.korf.nikhef.n  lhcbpi08    lhcb         1      1  5120m  41:59:57 R  40:04:09   wn-smrt-128
33134908.korf.nikhef.n  lhcbpi08    lhcb         1      1  5120m  41:59:57 R  37:14:29   wn-choc-030
33134917.korf.nikhef.n  lhcbpi08    lhcb         1      1  5120m  41:59:57 R  14:23:42   wn-smrt-072
33135197.korf.nikhef.n  atlb019     atlasmc      1      4  16040 208:00:00 R 183:02:04   wn-mars-018+
wn-mars-018+wn-mars-018+wn-mars-018
33135883.korf.nikhef.n  atlb019     atlasmc      1      4  16040 208:00:00 R 166:44:22   wn-mars-018+
wn-mars-018+wn-mars-018+wn-mars-018
33142633.korf.nikhef.n  lhcbpi08    lhcb         1      1  5120m  41:59:57 R  37:30:47   wn-mars-043
33149106.korf.nikhef.n  lhcbpi08    lhcb         1      1  5120m  41:59:57 R  10:23:30   wn-car-027
33149132.korf.nikhef.n  lhcbpi08    lhcb         1      1  5120m  41:59:57 R  32:36:49   wn-mars-057
33149220.korf.nikhef.n  lhcbpi08    lhcb         1      1  5120m  41:59:57 R  32:50:19   wn-choc-044
33151669.korf.nikhef.n  lhcbpi08    lhcb         1      1  5120m  41:59:57 R  09:49:53   wn-choc-009
33152704.korf.nikhef.n  atlb019     atlasmc      1      4  16040 208:00:00 R 128:39:13   wn-mars-018+
wn-mars-018+wn-mars-018+wn-mars-018
```

Scalable submission: HTCondor

Matchmaking based on ‘ClassAds’

- both jobs and machines advertise their requirements and capabilities in ‘classified advertisements’
- *matchmaking* done by a negotiator
  execution nodes are autonomous (mostly)

helps for scalability and resilience



HTCondor, Miron Livny *et al.*; Compiled from Todd Tannenbaum (2024 HTCondor Workshop) https://indico.cern.ch/event/1386170/contributions/6127903/

Estimated Response Time (and predicting it?)

- ‘Fair share’ – distributing load over time in a ‘continuous job supply’ system

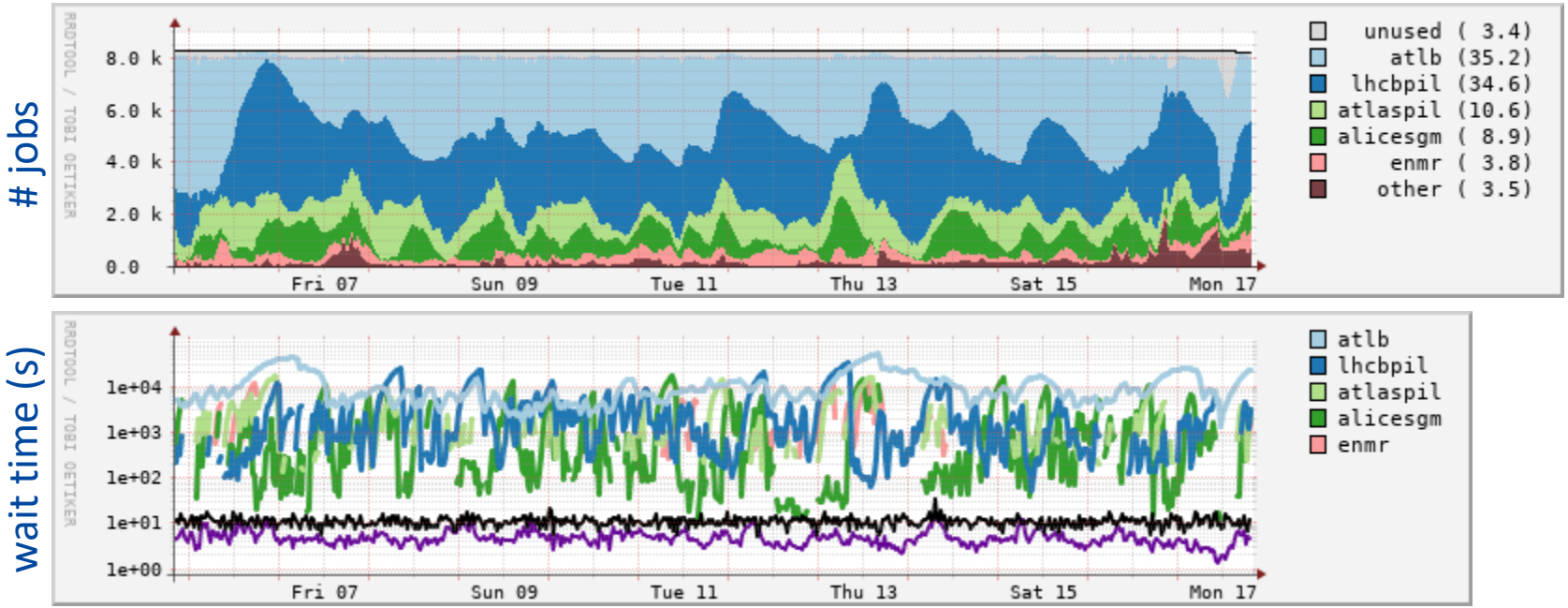


Image: Nikhef NDPF DNI “Grid” cluster. Period: October 6-17, 2022; top-5 communities; GRISview images: Jeff Templon

For work on run time prediction in high-occupancy clusters , see Hui Li *Workload characterization, modeling, and prediction …* https://hdl.handle.net/1887/12574

Occupancy: service level differs per intended target audience

For organized ‘production’ computing (planned months in advance in WLCG)

- ***predictable* scheduling** is more important (steady flow of results)
- **maximizing efficiency**: resource cost is the limiting factor in (physics) results
- co-scheduling with data (pre-placement) is required
- community-authorization based access to data sources only

For ‘local’ users, e.g. students whose progress tomorrow depends on results *today*

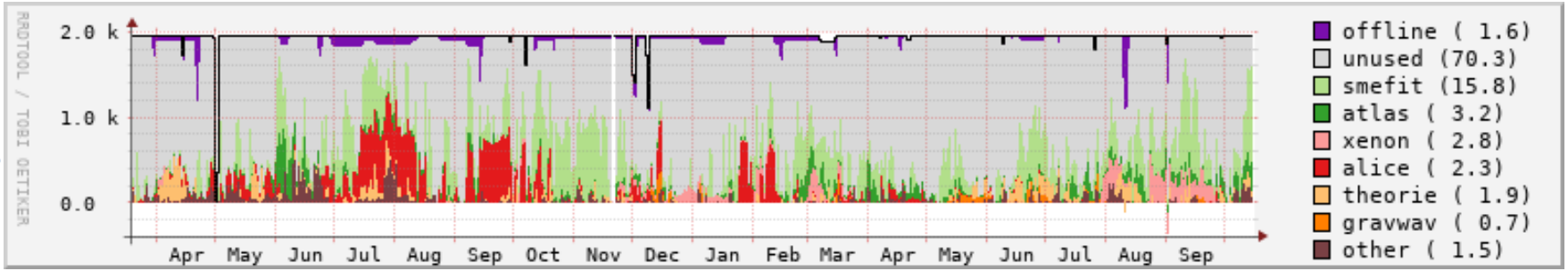
- ***response time*** is more important than efficiency
- fast turn-around/short waiting times by heterogeneous (‘competing’) user base
- data access must be parallelism-ready, but is ‘always’ local on-site
- local storage credentials and sharing with desktop and Jupyter environments

so offering two distinct classes of services is (in this case) intentional

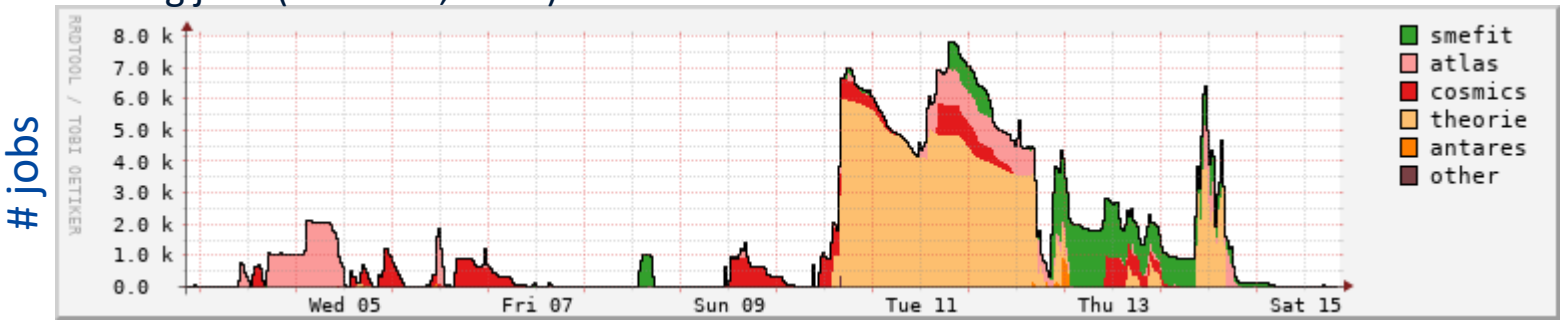
Local analysis clusters ‘Tier-3 / Tier-2 computing’

period: March 2021 .. October 2022

Running jobs:

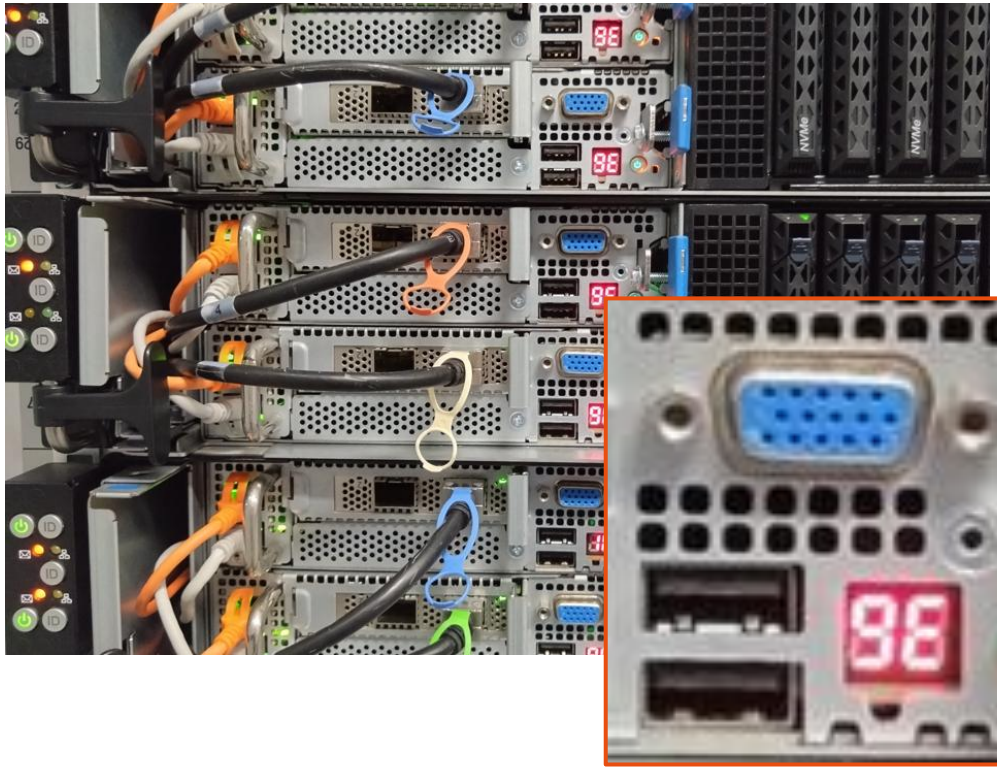


Waiting jobs (Week 40, 2022):



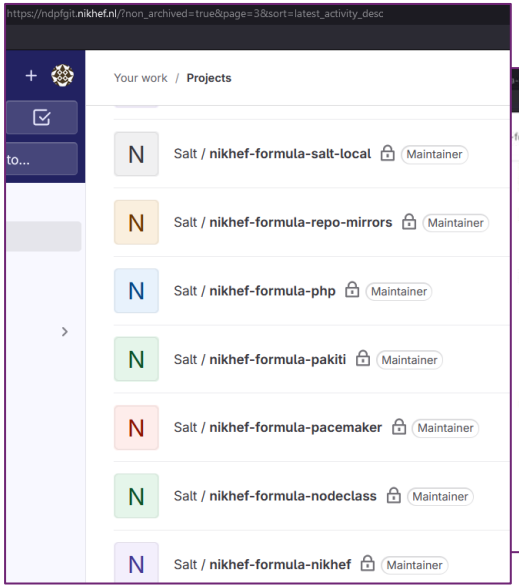
Source: NDPF Statistics overview, https://www.nikhef.nl/pdp/doc/stats/ - GRISview images: Jeff Templon for NDPF and STBC

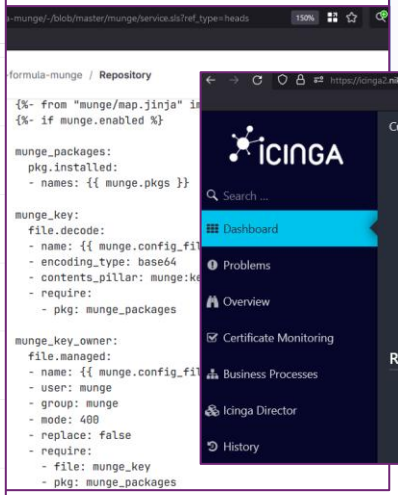
But … fancy an interactive (console) install?

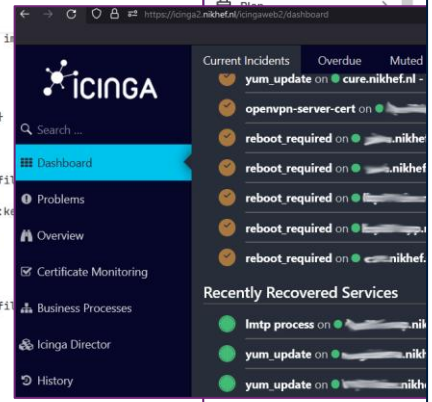


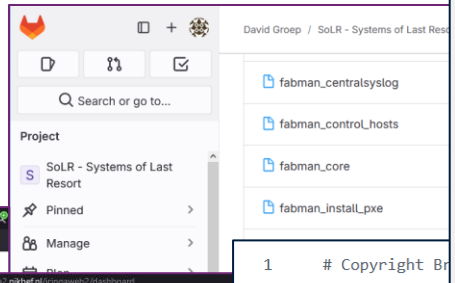
Images: Nikhef Housing H234b NDPF science processing data centre

On the way to ‘Software Defined Infrastructure’ …










```
[root@protosaurus ~]# cat docker-compose-clean.yml
version: '3'
services:
  database:
    image: postgres:13.4-alpine
    environment:
      - POSTGRES_USER=hedgedoc
      - POSTGRES_PASSWORD=SECRET
      - POSTGRES_DB=hedgedoc
    volumes:
      - database:/var/lib/postgresql/data
    restart: always
    deploy:
      resources:
        limits:
          memory: 1G
    healthcheck:
      disable: true
  app:
    # Make sure to use the latest release from https://hedgedoc.org/latest-release
    image: quay.io/hedgedoc/hedgedoc:1.9.9
    environment:
      - CMD_DB_URL=postgres://hedgedoc:SECRET@database:5432/hedgedoc
      - CMD_URL_ADDPORT=true
      - CMD_DOMAIN=sharemd.nikhef.nl
      - CMD_USECDN=false
      - CMD_URL_ADDPORT=false
      - CMD_PROTOCOL_USESSL=true
      - CMD_ALLOW_ORIGIN=[ 'localhost', 'sharemd.nikhef.nl', 'nikhef.nl' ]
      - CMD_HSTS_ENABLE=false
      - CMD_CSP_ENABLE=false
```

```
1   # Copyright Br
2   # SPDX-License
3
4   annotations:
5     category: CMS
6     licenses: Apache-2.0
7     images: |
8       - name: apache-exporter
9         image: docker.io/bitnami/apache-exporter:1.0.9-debian-12-r2
10      - name: os-shell
11        image: docker.io/bitnami/os-shell:12-debian-12-r32
12      - name: wordpress
13        image: docker.io/bitnami/wordpress:6.6.2-debian-12-r15
14  apiVersion: v2
15  appVersion: 6.6.2
16  dependencies:
17  - condition: memcached.enabled
18    name: memcached
19    repository: oci://registry-1.docker.io/bitnamicharts
20    version: 7.x.x
21  - condition: mariadb.enabled
22    name: mariadb
23    repository: oci://registry-1.docker.io/bitnamicharts
```

Nikhef NDPF Salt & Reclass (Dennis van Dok, Andrew Pickford, Mary Hester); SoLR Ansible; Docker Compose for sharemd.nikhef.nl ; example Helm chart from https://github.com/bitnami/charts/blob/main/bitnami/wordpress/

Scaling things '… as a service'

Systems or storage today are usually not physical

- 'predefined' virtualization
  of systems, network and (block) storage
- can be
  single site, distributed, outsourced, or federated

- IaaS: Infrastructure as a Service
  ('EC2-like' VM hosting, VPS, S3 storage)
- PaaS: Platform as a Service
  (container hosting, batch systems, database platforms like DynamoDB …)
- SaaS: Software as a Service
  (science application portals, ERP systems, …)

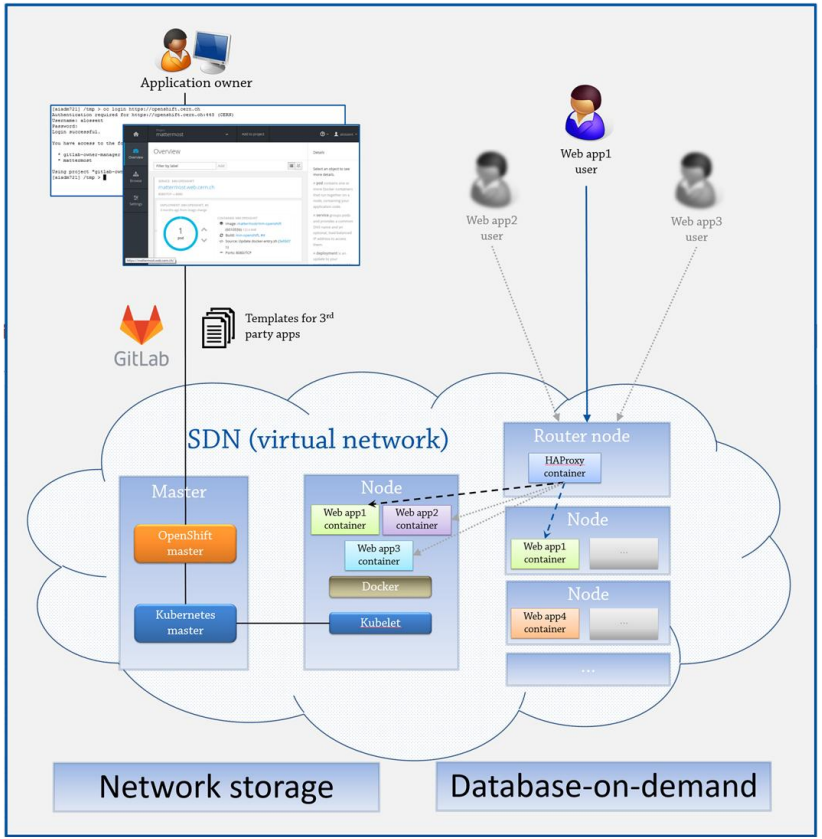
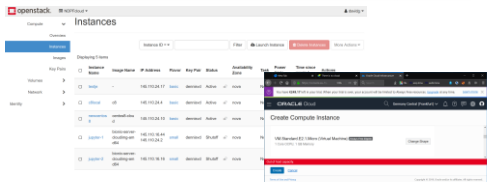
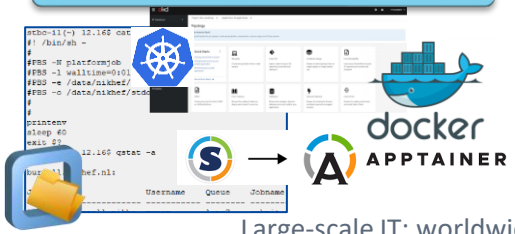


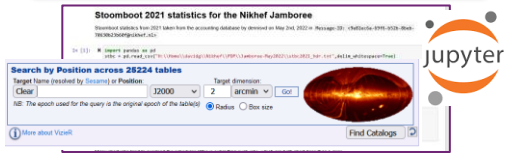
Image from CERN's OpenShift, A Lossent *et al* 2017 *J. Phys.: Conf. Ser.* **898** 082037 https://doi.org/10.1088/1742-6596/898/8/082037

Moving the management boundary

	Infrastructure-as-a-Service	Platform-as-a-Service	Software-as-a-Service
Guest	Application	Application	Application
	Data	Data	Data
	Runtime environment	Runtime environment	Runtime environment
	Middleware	Middleware	Middleware
Hyper visor	Operating system	Operating system	Operating system
	Virtualisation layer	Virtualisation layer	Virtualisation layer
Host	Physical server	Physical server	Physical server
	Storage devices	Storage devices	Storage devices
	Network	Network	Network



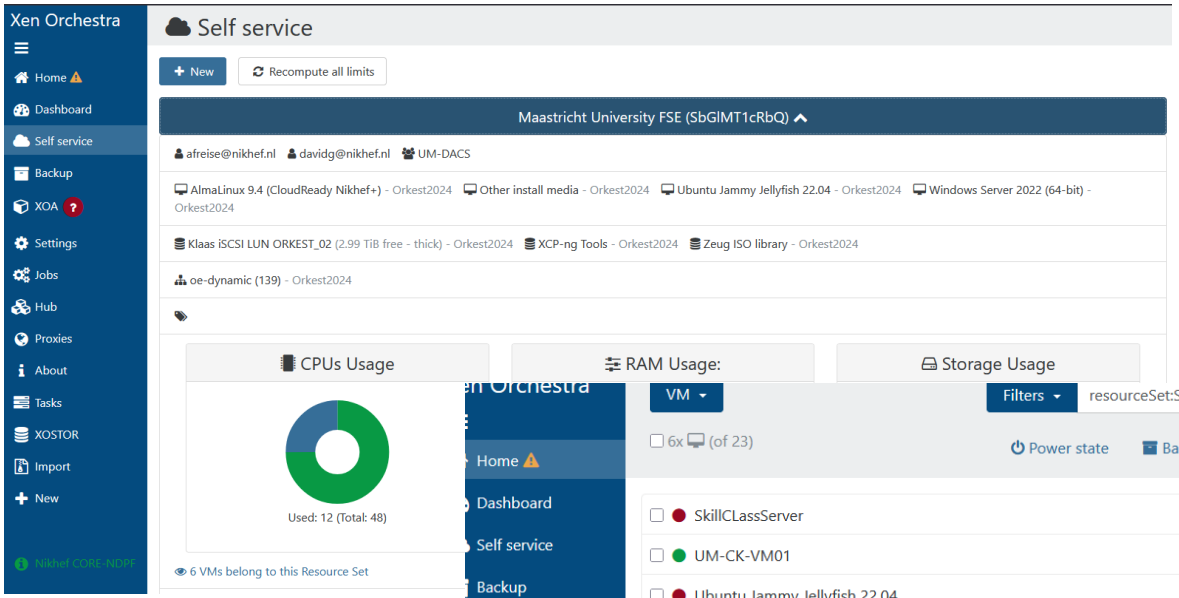


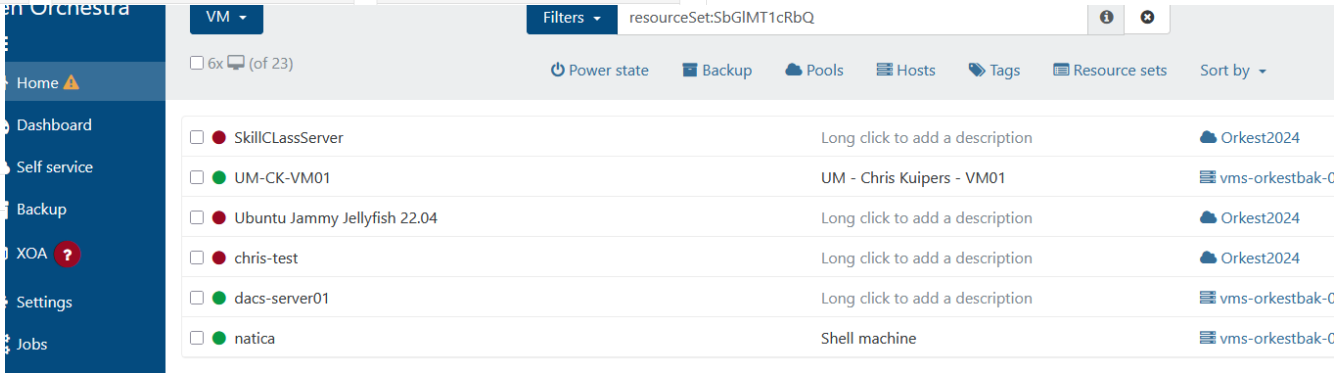


Astronomy catalogue: https://vizier.cds.unistra.fr/

IaaS: openstack.com, Oracle OCI; PaaS: dsri.maastrichtuniversity.nl, apptainer.org, cvmfs.readthedocs.io, kubernetes.io, slurm.schedmd.com; SaaS: Jupyter.org

Infrastructure as a Service example: DACS FSE CSLab





virtual machines as a service with interactive web and API

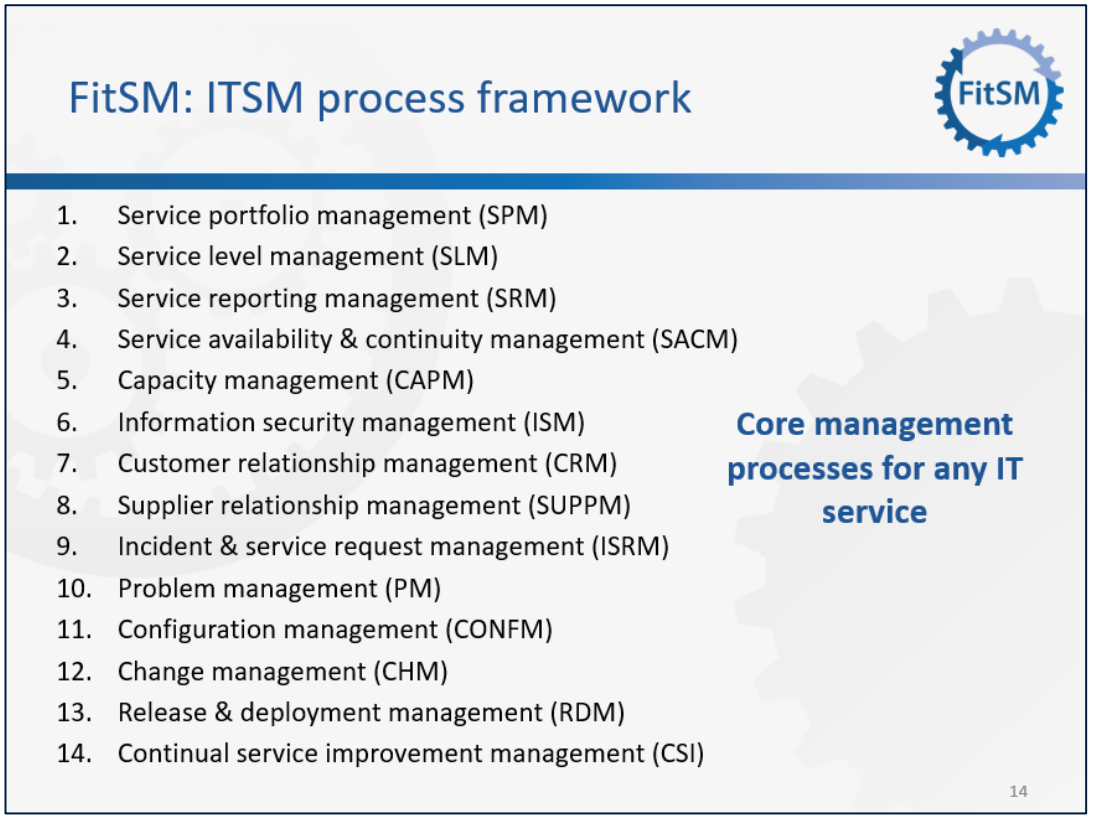
XenOrchesta
DACS FSE CSLab

What is a ‘service’: on Service Management Systems

Structuring service management

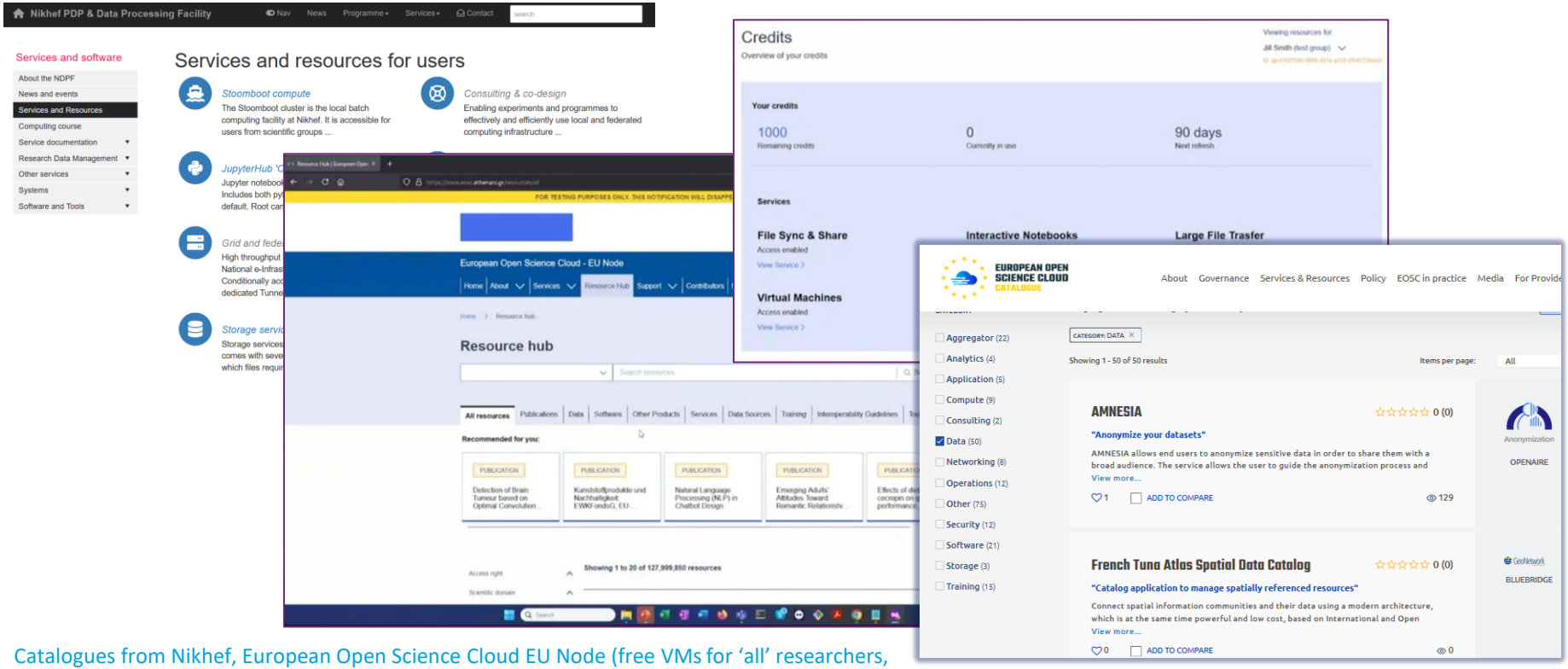
- ISO 20000 standard
- ITIL (now at ITIL v3)
- https://www.fitsm.eu/

and a whole bunch of others, like COBIT, AgileSM, …



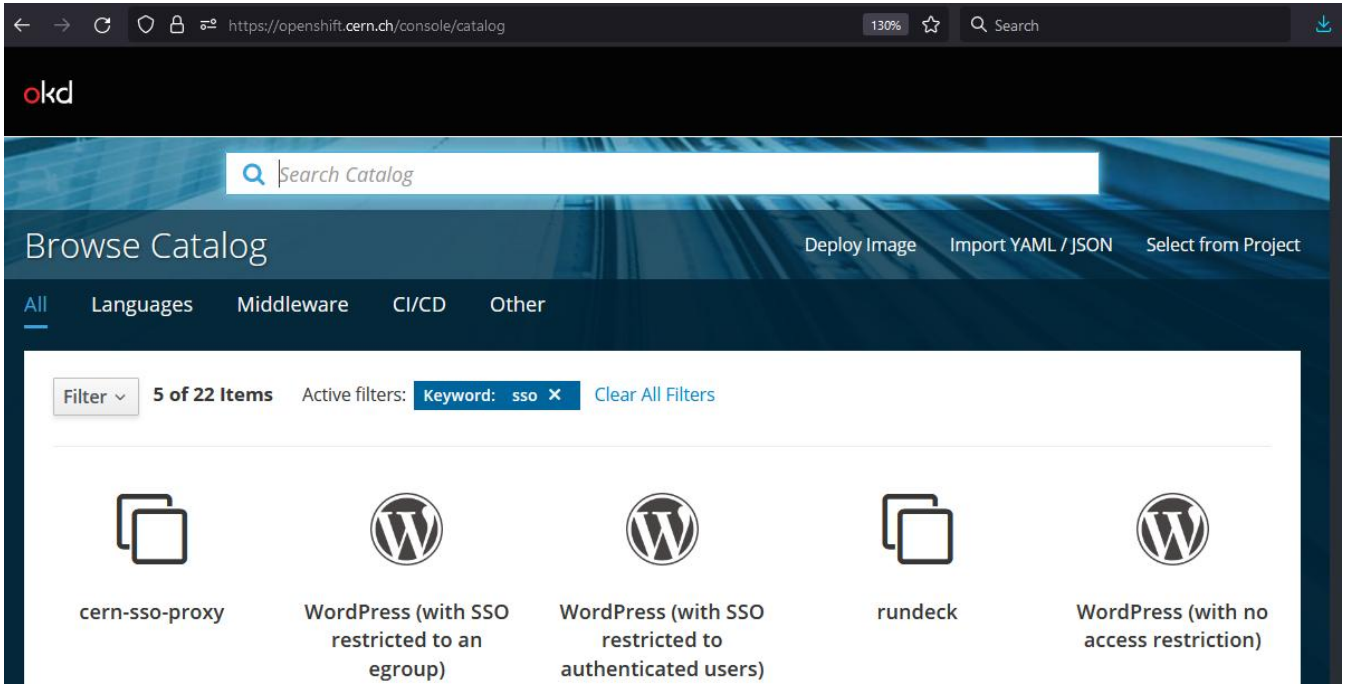
Slide with PR list from https://www.fitsm.eu/

Service portfolios – what do you offer, and to whom



Catalogues from Nikhef, European Open Science Cloud EU Node (free VMs for 'all' researchers, subject to https://open-science-cloud.ec.europa.eu/system/files?file=2024-10/EOSC-EU-Node-User-Access-Policy-v1.0.pdf)

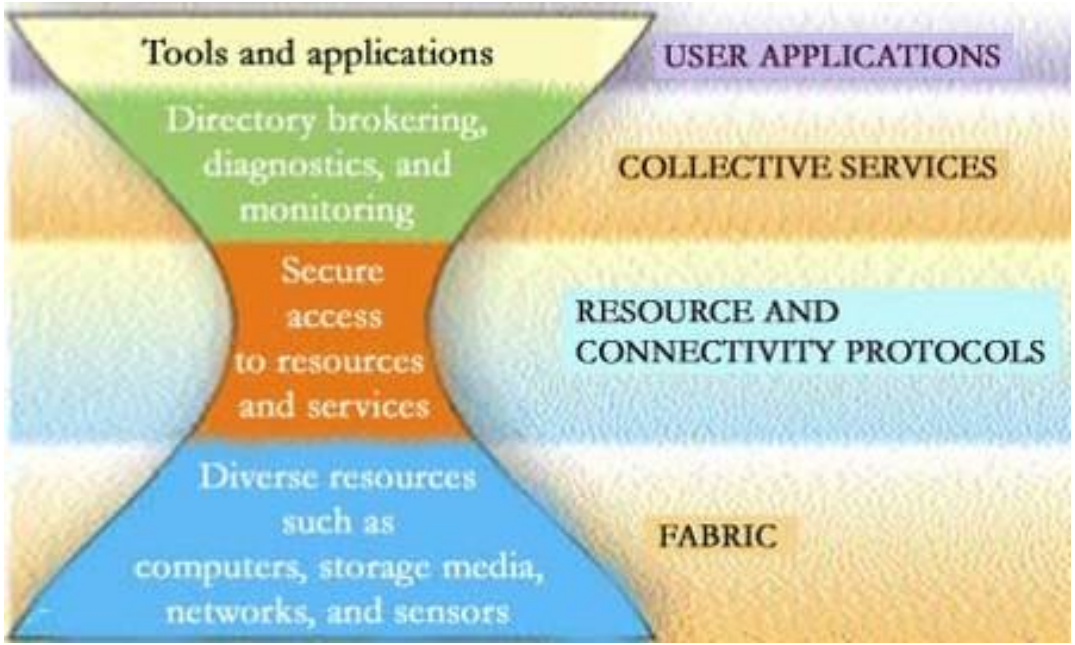
A service catalog is still built on systems & networks



OpenShift (OKD) system at CERN (accessible for CERN users only) – at Maastricht use the DSRI infrastructure: https://dsri.maastrichtuniversity.nl/

Common interfaces to the different clouds?

‘protocol hourglass’



hourglass image: Alessio Merlo in The Condor on the Grid: state of art and open issues,

Standard interfaces for compute and data?

hourglass model ‘kind-of’ worked for IP and web with http as common standard

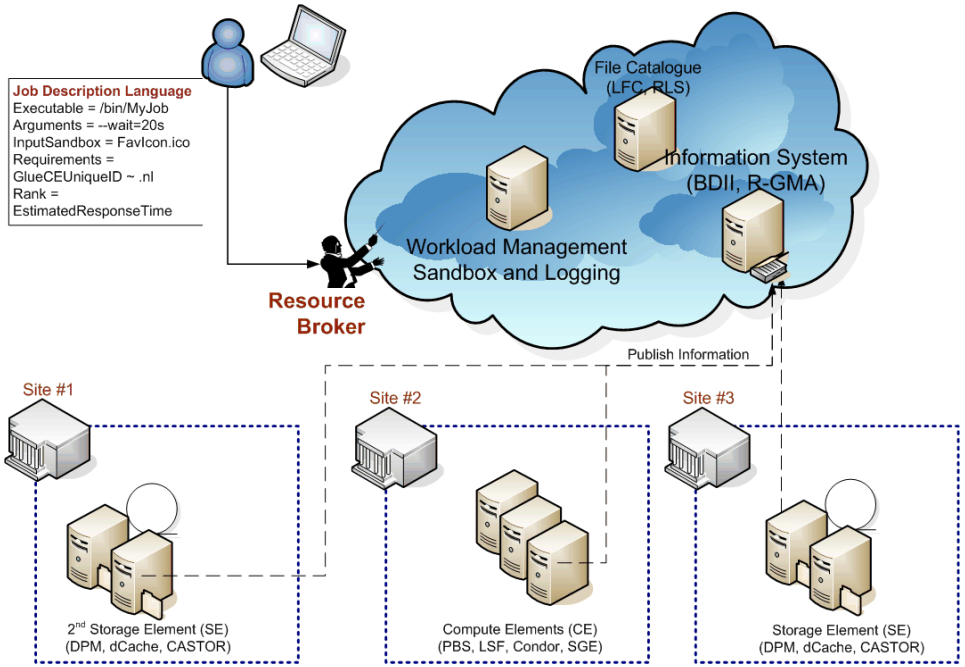
- a very simple stateless interface

protocols for higher-level services never quite reached this level of global interop

- requirements too complex and stateful
- use cases were usually scoped

slowly changing now but only for similarly simple things, like on-line object storage

Is distributed computing too bespoke …?



Interoperable cloud? Compare OGF’s OCCI WG GFD.221 (https://www.ogf.org/documents/GFD.221.pdf) with e.g. Amazon S3 API or the OwnCloud CS3 interfaces

DIRAC: spanning heterogeneous resource models

Add a scheduling layer!

‘any (IT) problem can be solved by adding an extra level of indirection’

DIRAC is just one example

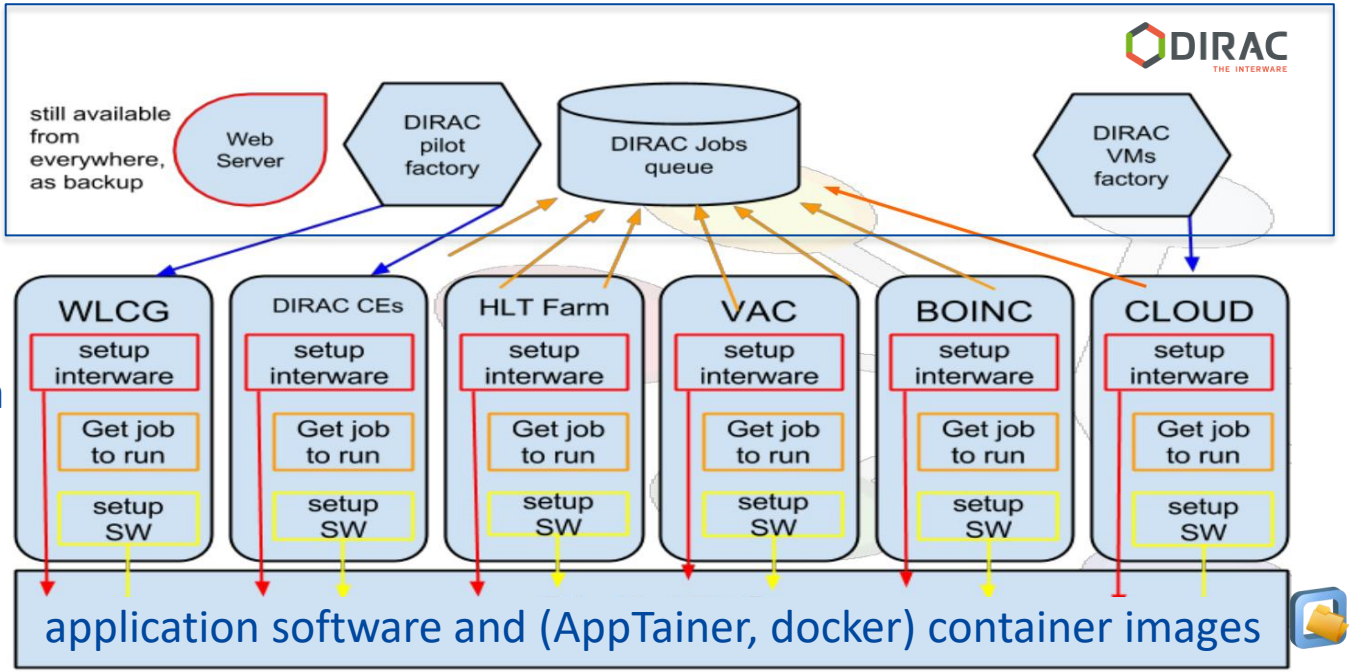
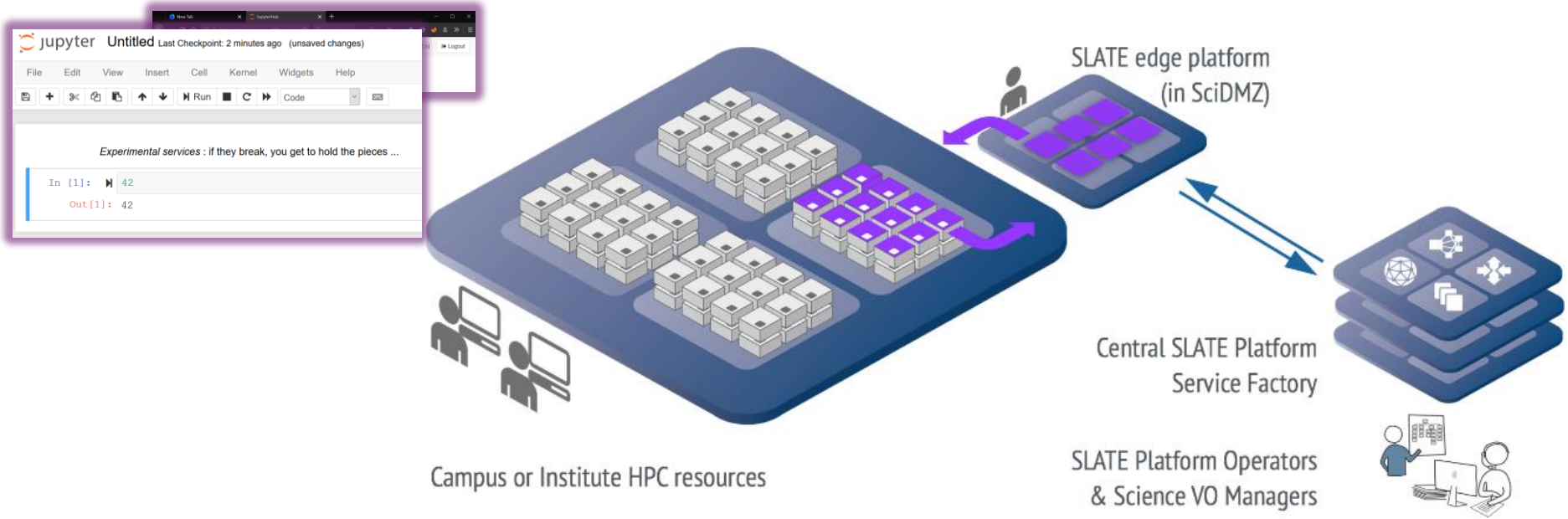


Image: DIRAC project, A. Tsaregorodtsev *et al.* CPPM Marseille, from https://dirac.readthedocs.io/ ; CVMFS (CERN VM File System) is a common software distribution platform using distributed signed data objects in a cached hierarchy using CDN techniques, see https://cernvm.cern.ch/fs/

An overlay network of containers

Nobody wants a cloud per-se … what folk want is a solution …

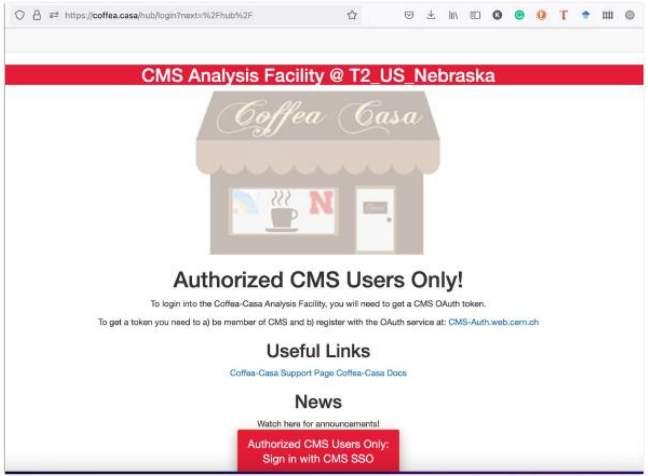


‘alien containers’ HPC integration - container computing, using curated application images

Image sources: NDPF JupyterHub service “Callysto”; SLATE: Service Layer At The Edge – Rob Gartner (UChicago), Shawn KcMee (UMich) *et al.* – slateci.io

Containerised workloads: between ‘PaaS’ and ‘SaaS’

CMS Coffea-Casa Analysis Facility: https://coffea.casa



Powered by CMS IAM instance

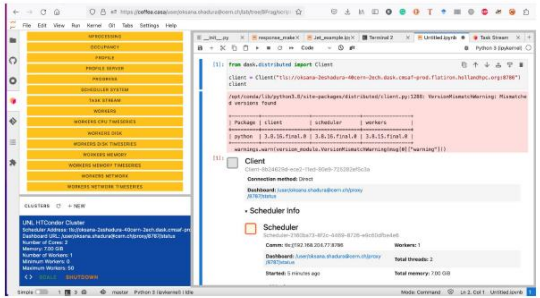
15

lding blocks: easy integration with scalable computing ources

provides a task-management computational ork in Python (based on the manager-worker gm)

tegrates with HPC clusters, running a variety of hedulers including SLURM, LSF, SGE and TCondor via ***“dask-jobqueue”***

is allows us to create a user-level teractive system via queueing up in the tch system

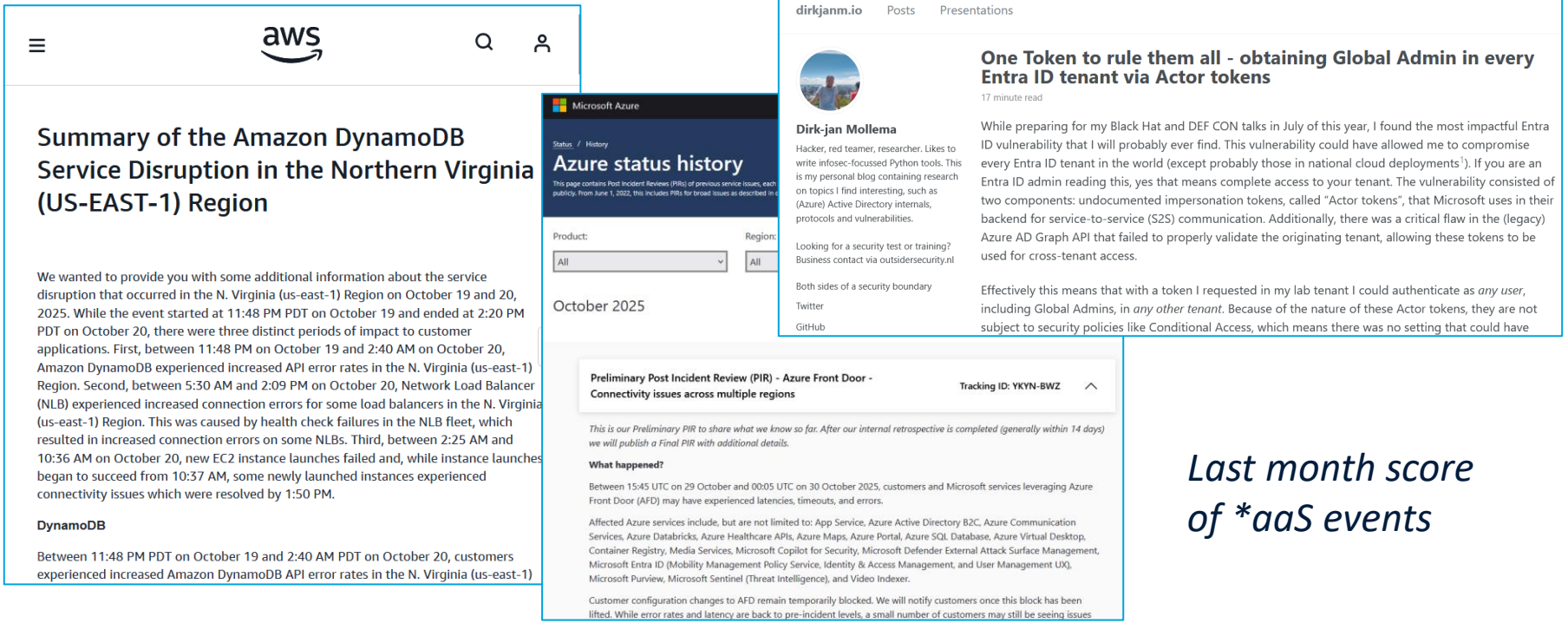


k can be used inside Jupyter or you can simply nch it through Jupyter and connect directly from r laptop

14

Images: Oksana Shadura et al (UNebraska Lincoln), Brian Bockelman (Morgridge Institute) at CHEP2023 https://indico.jlab.org/event/459/contributions/11610/

On leaky abstractions and circular dependencies



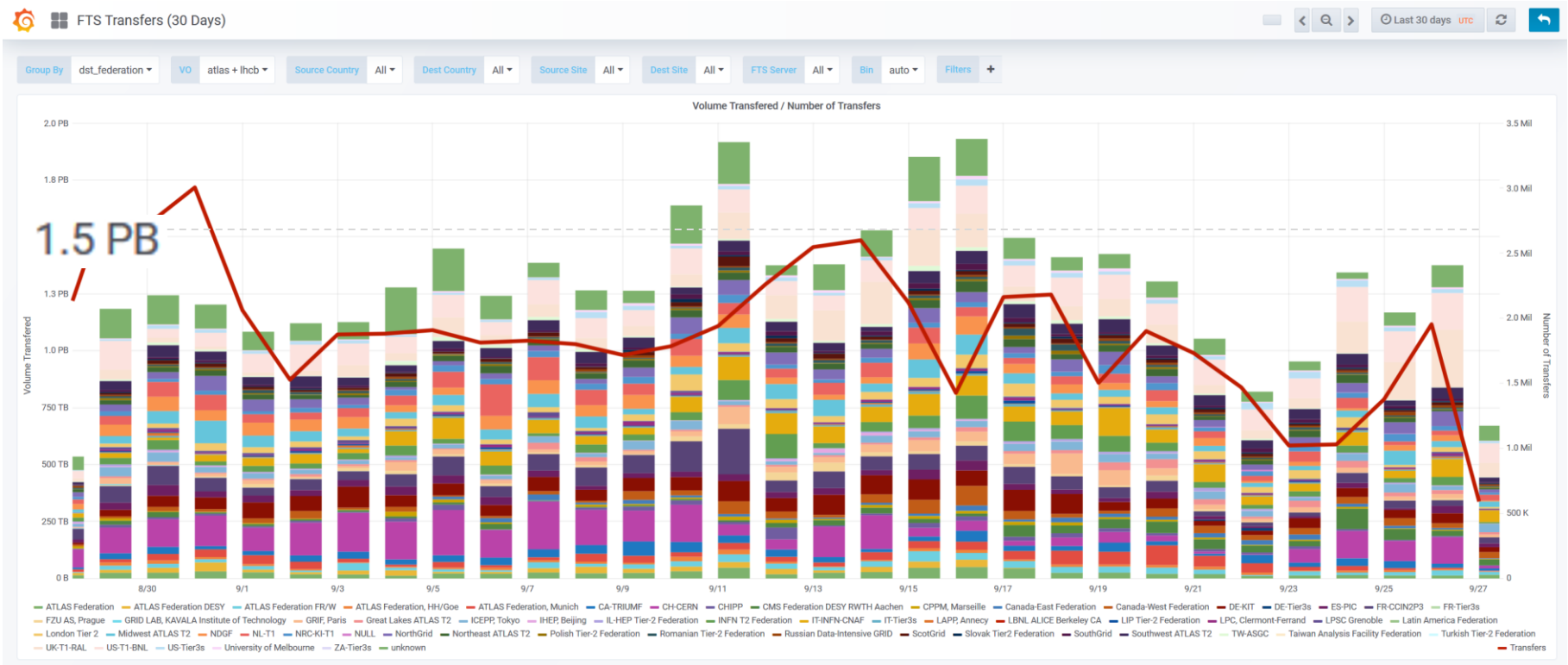
*Last month score of *aaS events*

https://aws.amazon.com/message/101925/, https://azure.status.microsoft/en-us/status/history/, https://dirkjanm.io/obtaining-global-admin-in-every-entra-id-tenant-with-actor-tokens/

Putting more than one together

The Internet Is Not Enough!
More than one user …
Perspectives on global federated access

High *throughput* computing is in the end about data



source: https://monit-grafana.cern.ch/d/000000420/fts-transfers-30-day ; data: November 2020 ; CERN FTS instance WLCG: daily transfer volume ATLAS+LHCb

‘Elephant streams in a packet-switched internet’

‘You may have plenty of shovels,
but where to leave the sand?’

- wheelbarrow works fine in your garden
- want to send it to different places?
  Use waggons on a train,
  or ships with containers
- always from A-to-B?
  A conveyer belt will do much better!

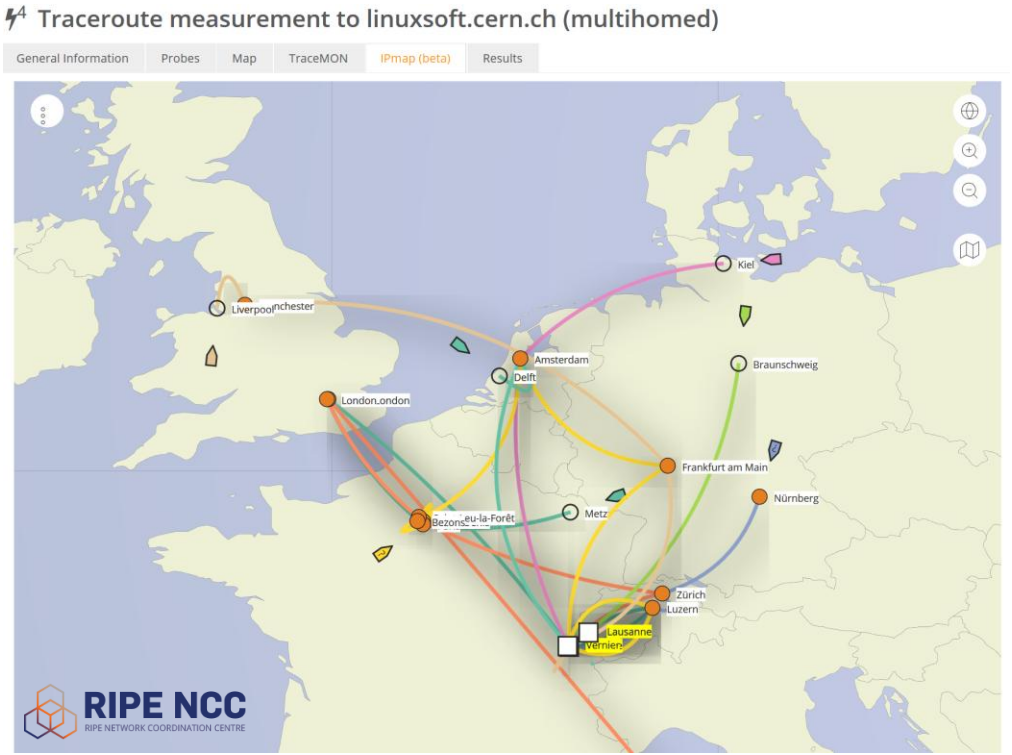
… although you still need
a hole to dump it in …

Image conveyor belt tunnel near Bluntisham, Cambridgeshire by Hugh Venables, CC-BY-SA-4.0 from https://www.geograph.org.uk/photo/4344525

A quick look at internet routing …

network paths
from various places
in Western Europe

towards an IP address at CERN



Data: RIPE NCC Atlas project, TraceMON IPmap, atlas.ripe.net, measurement 9249079

Many paths to Rome … i.e. to your server

- From a home connected to Freedom Internet to *spiegel.nikhef.nl*

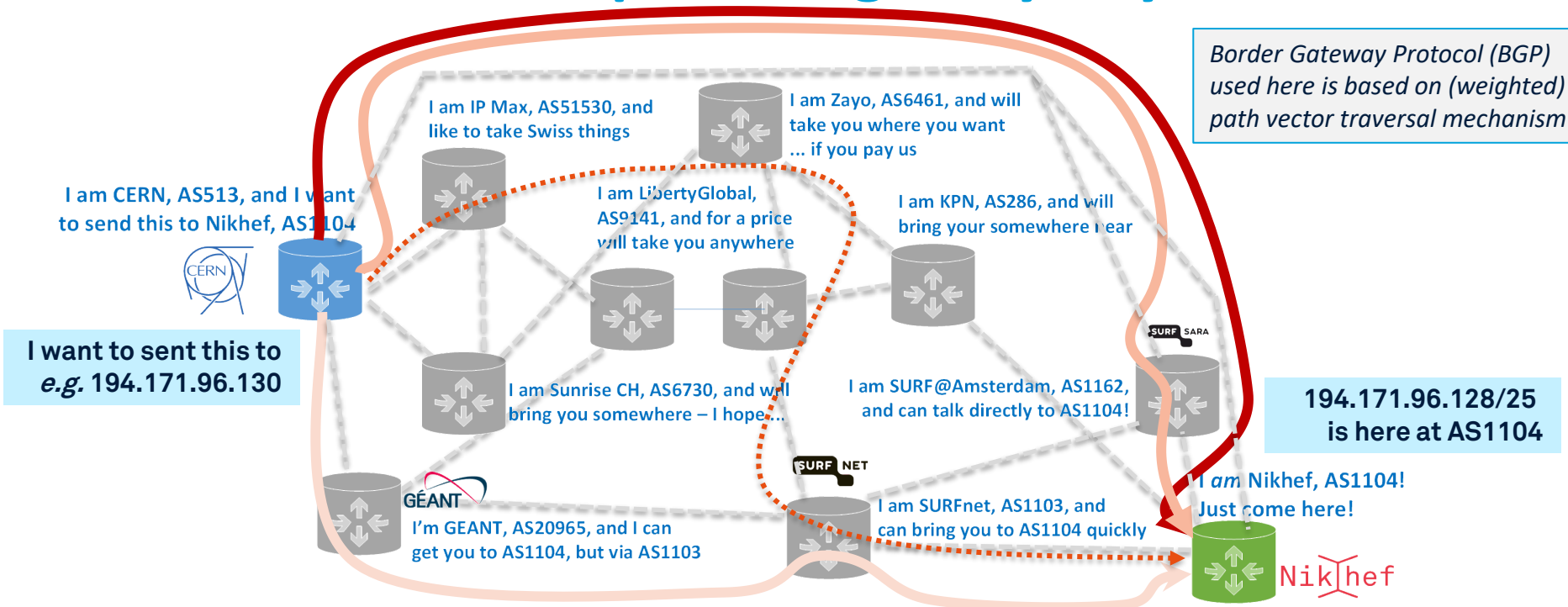
```
[root@kwark ~]# traceroute -6 -A -T gierput.nikhef.nl
traceroute to gierput.nikhef.nl (2a07:8500:120:e010::46), 30 hops max, 80 byte packets
 1  2a10-3781-17b6.connected.by.freedominter.net (2a10:3781:17b6:1:de39:6fff:fe6b:4558) [AS206238]  0.810 ms  1.052 ms  1.330 ms
 2  2a10:3780::234 (2a10:3780::234) [AS206238]  7.460 ms  7.655 ms  7.705 ms
 3  2a10:3780:1::21 (2a10:3780:1::21) [AS206238]  8.868 ms  9.054 ms  9.103 ms
 4  et-0-0-1-1002.core1.fi001.nl.freedomnet.nl (2a10:3780:1::2d) [AS206238]  10.017 ms  9.934 ms  10.263 ms
 5  as1104.frys-ix.net (2001:7f8:10f::450:66) [*]  10.898 ms  11.744 ms  11.797 ms
 6  gierput.nikhef.nl (2a07:8500:120:e010::46) [AS1104]  11.502 ms  7.800 ms  7.357 ms
```

- but from Interparts in Lisse, NH:

```
[root@muis ~]# traceroute -6 -A -I gierput.nikhef.nl
traceroute to gierput.nikhef.nl (2a07:8500:120:e010::46), 30 hops max, 80 byte packets
 1  2a03:e0c0:1002:6601::2 (2a03:e0c0:1002:6601::2) [AS41960]  1.380 ms  1.371 ms  1.369 ms
 2  2a02:690:0:1::b (2a02:690:0:1::b) [AS41960]  1.305 ms  1.312 ms  1.312 ms
 3  et-6-1-0-0.asd002a-jnx-01.surf.net (2001:7f8:1::a500:1103:2) [AS1200]  1.957 ms  2.000 ms  2.052 ms
 4  ae47.asd001b-jnx-01.surf.net (2001:610:e00:2::49c) [AS1103]  2.443 ms  2.505 ms  2.507 ms
 5  irb-4.asd002a-jnx-06.surf.net (2001:610:f00:1120::121) [AS1103]  2.041 ms  2.138 ms  2.138 ms
 6  nikhef-router.customer.surf.net (2001:610:f01:9124::126) [AS1103]  8.977 ms  7.957 ms  7.951 ms
 7  gierput.nikhef.nl (2a07:8500:120:e010::46) [AS1104]  7.922 ms  8.093 ms  8.081 ms
```

AS41960: Interparts; AS1200: AMS-IX route reflector; AS1103: SURFnet; AS1104: Nikhef; AS206238: Freedom Internet – on the FrysIX there is direct L2 peering

Where do internet packets go anyway?



grey-dash lines for illustration only: may not correspond to actual peerings or transit agreements; red lines: the three existing LHCOPN and R&E fall-back routes; yellow: public internet fall-back (least preferred option)

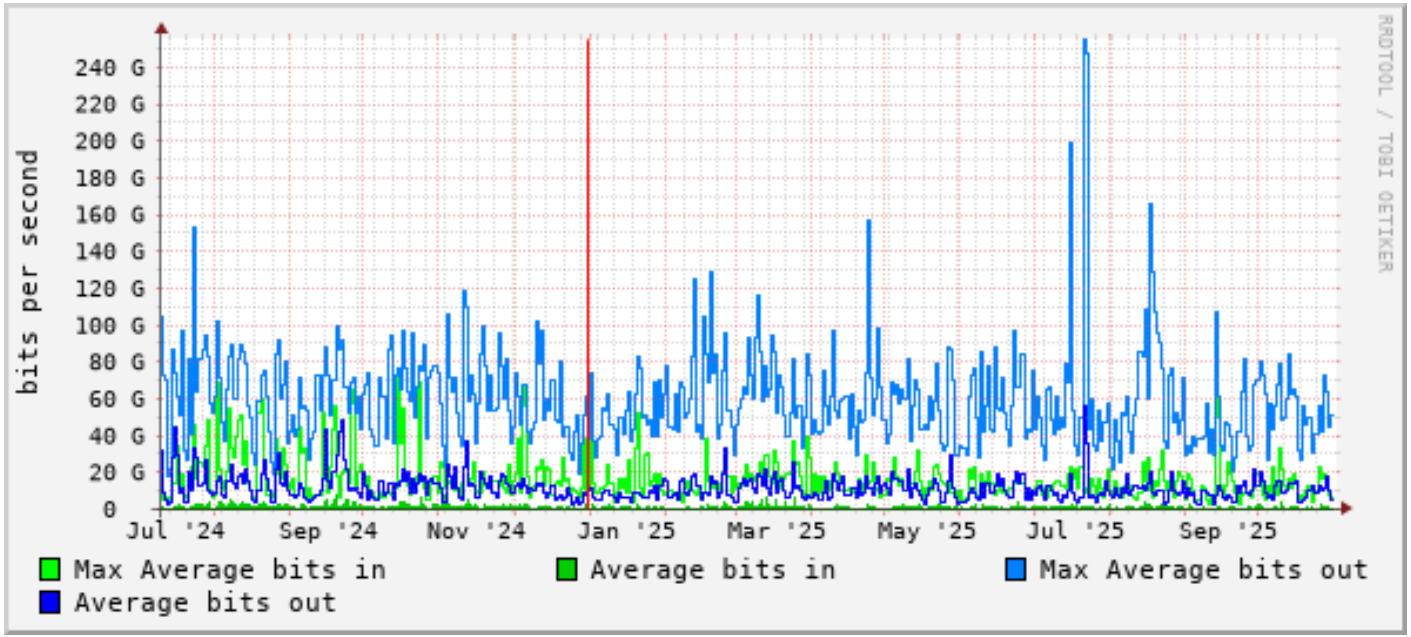
Announcing routes: the Border Gateway Protocol

```
davidg@deelqfx-re0> show route receive-protocol bgp 192.16.166.21 table LHCOPN

LHCOPN.inet.0: 316 destinations, 344 routes (316 active, 0 holddown, 0 hidden)
  Prefix                  Nexthop              MED     Lclpref    AS path
* 109.105.124.0/22        192.16.166.21        10                 513 39590 I
* 117.103.96.0/20         192.16.166.21        10                 513 24167 I
* 128.142.0.0/16          192.16.166.21        10                 513 I
* 130.199.48.0/23         192.16.166.21        10                 513 43 ?
* 130.199.185.0/24        192.16.166.21        10                 513 43 ?
* 130.246.176.0/22        192.16.166.21        10                 513 43475 I
```

```
davidg@deelqfx-re0> show route advertising-protocol bgp 192.16.166.21 table LHCOPN

LHCOPN.inet.0: 316 destinations, 344 routes (316 active, 0 holddown, 0 hidden)
  Prefix                  Nexthop              MED     Lclpref    AS path
* 192.16.186.160/30       Self                                    I
* 194.171.96.128/25       Self                                    I
* 194.171.98.112/29       Self                                    I
```

IPv4 routes advertised from AS513/CERN (for all sites on LHCOPN) to AS1104/Nikhef (top), and the routes announced by AS1104/Nikhef to CERN, on 5 Nov 2022

Typical data traffic to and from the processing cluster



Source: Nikhef cricket graph for compute clusters only on deelqfx – https://cricket.nikhef.nl/

Network is more than just what it says on the tin

More network bandwidth does not mean your *data* gets there faster

- memory requirements (since TCP needs a capability to re-transmit)

- tcp ‘slow start’
- congestion control algorithms

TCP throughput calculator

Theoretical network limit

rough estimation: rate < (MSS/RTT)*(C/sqrt(Loss)) [C=1] (based on the Mathis et.al. formula)

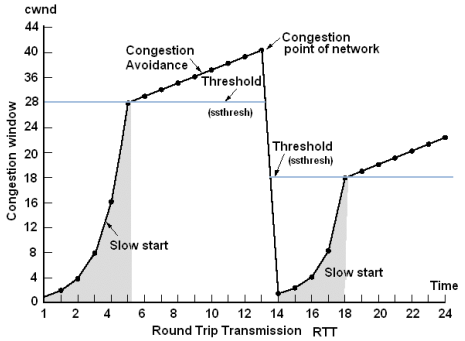
network limit (MSS 9000 byte, RTT: 150.0 ms, Loss: $2.304*10^{-11}$ ($2*10^{-09}$%)) : **100000.00 Mbit/sec.**

Bandwidth-delay Product and buffer size

BDP (100000 Mbit/sec, 150.0 ms) = **1875.00 MByte**

required tcp buffer to reach 100000 Mbps with RTT of 150.0 ms >= **1831054.7 KByte**

maximum throughput with a TCP window of 1831054 KByte and RTT of 150.0 ms <= **100000.00 Mbit/sec.**



Useful sources: https://www.switch.ch/network/tools/tcp_throughput/, https://fasterdata.es.net/

tcp slow-start graphic from Abed et al, *Improvement of TCP Congestion Window over LTE- Advanced Networks* IJoARiC&CE 2012

The cat video that destroyed it all …

latency AMS-GVA 17 ms
congestion event @20ms:
2 ms of UDP traffic to GVA

- TCP protocol sensitive to packet loss
  - 3 lost packets is enough to trigger this
- different congestion avoidance algorithms exists (~20 by now)
- loss severely impacts links w/large ‘bandwidth-delay-product’ (BDP)
- NL: ~3 ms, US East: 150ms

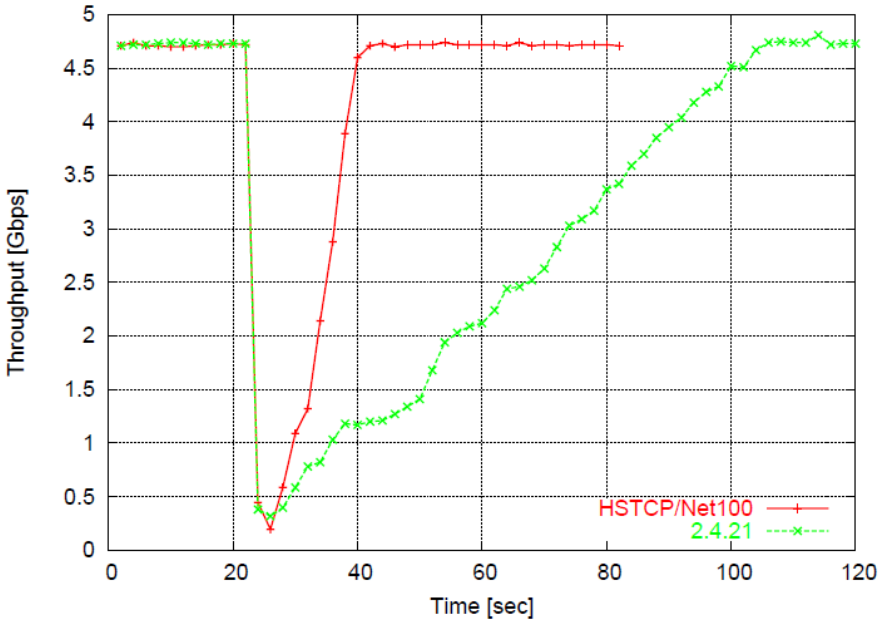


Figure 10: HSTCP versus stock TCP recovery time

source: Catalin Meirosu et al. *Native 10 Gigabit Ethernet experiments over long distances* in FGCS, doi:10.1016/j.future.2004.10.003 – aka. ATL-D-TN-0001

LHCOPN – distributing raw data

LHCOPN

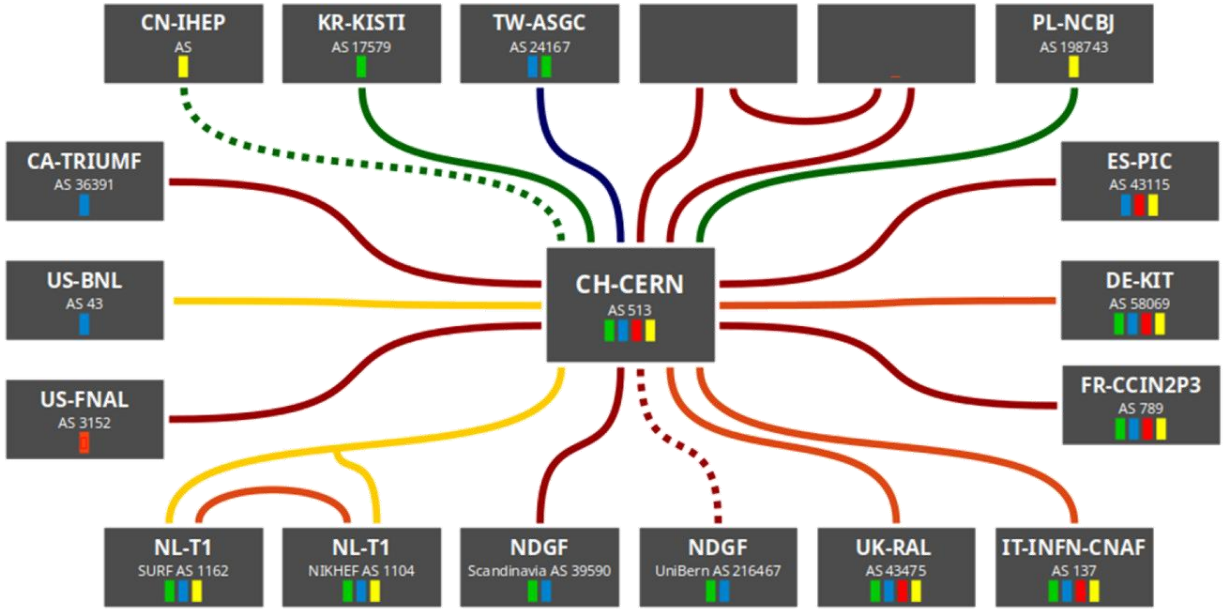
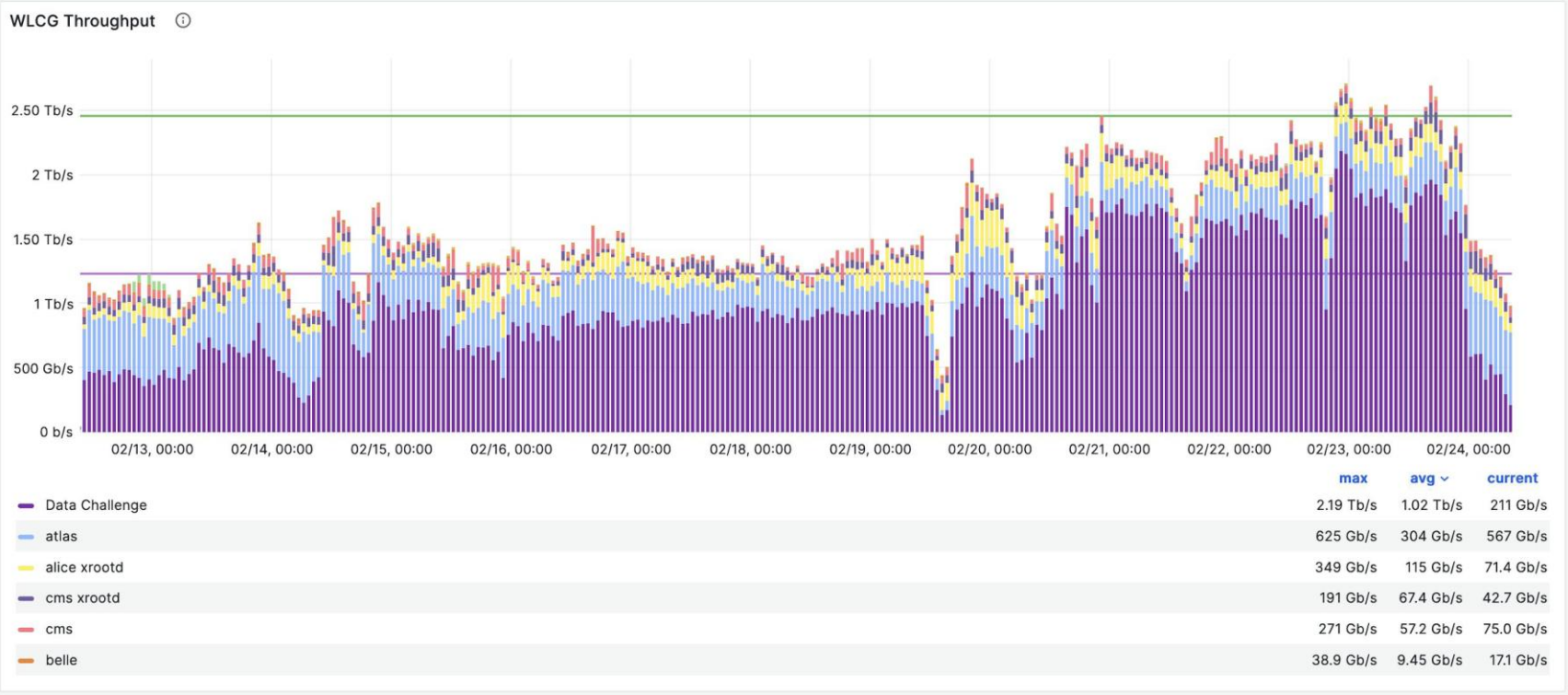


Image source: Edoardo Martelli, CERN, https://lhcopn.web.cern.ch/

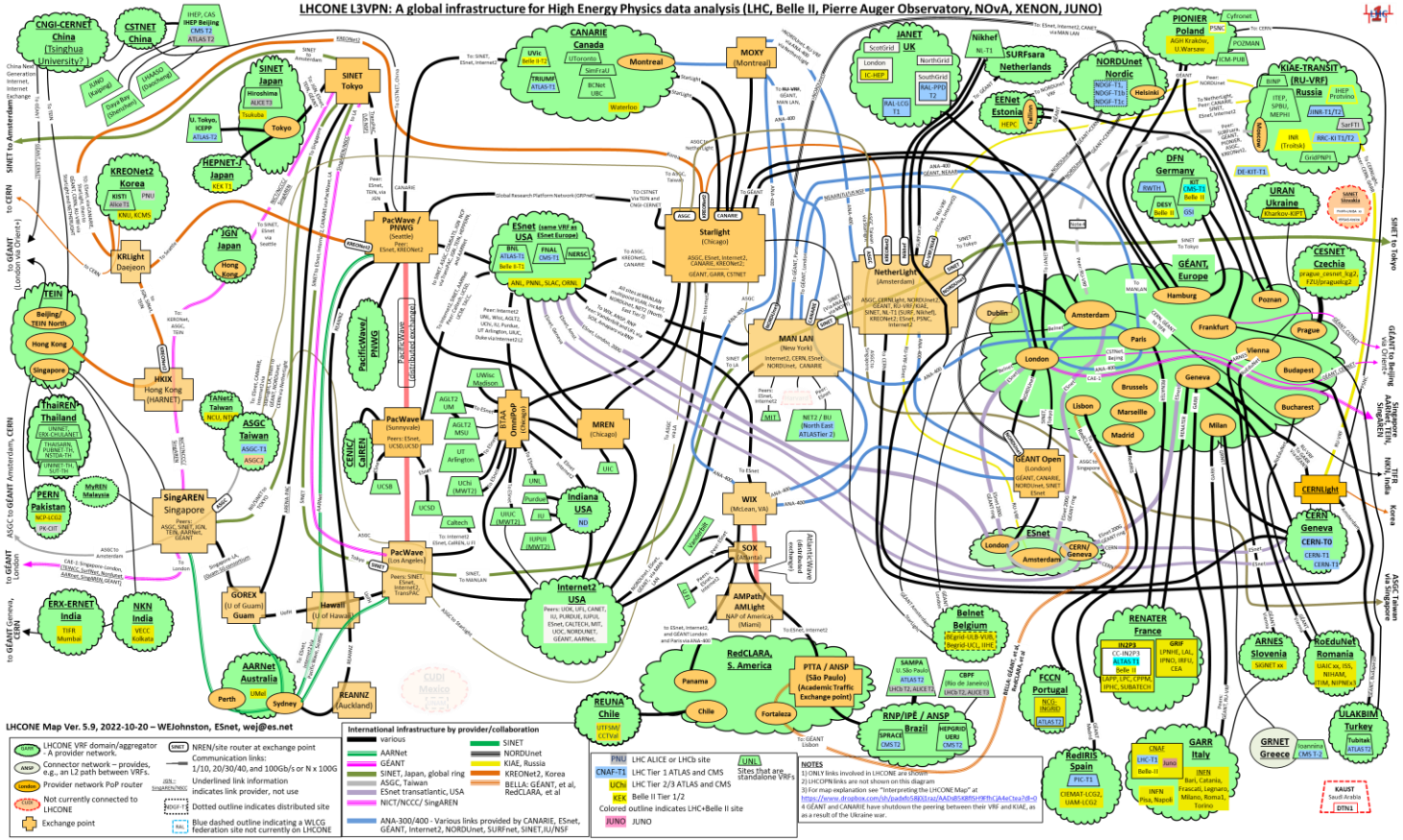
LHCOPN – traffic levels for data transfer (DC24)



	max	avg	current
Data Challenge	2.19 Tb/s	1.02 Tb/s	211 Gb/s
atlas	625 Gb/s	304 Gb/s	567 Gb/s
alice xrootd	349 Gb/s	115 Gb/s	71.4 Gb/s
cms xrootd	191 Gb/s	67.4 Gb/s	42.7 Gb/s
cms	271 Gb/s	57.2 Gb/s	75.0 Gb/s
belle	38.9 Gb/s	9.45 Gb/s	17.1 Gb/s

From Lassnig, M., & Wissing, C. et al. (2024). WLCG/DOMA Data Challenge 2024: Final Report. Zenodo. https://doi.org/10.5281/zenodo.11444180

LHCone



LHCone ("LHC Open Network Environment") – visualization by Bill Johnston, ESnet version: October 2022 – updated with new AS1104 links

‘ScienceDMZ’

Predicable performance and data access for research

‘where research services, data, and researchers meet’

- latency hiding through caching
- **security zoning/segmentation** protects specific data sets
- **outside any enterprise perimeter**

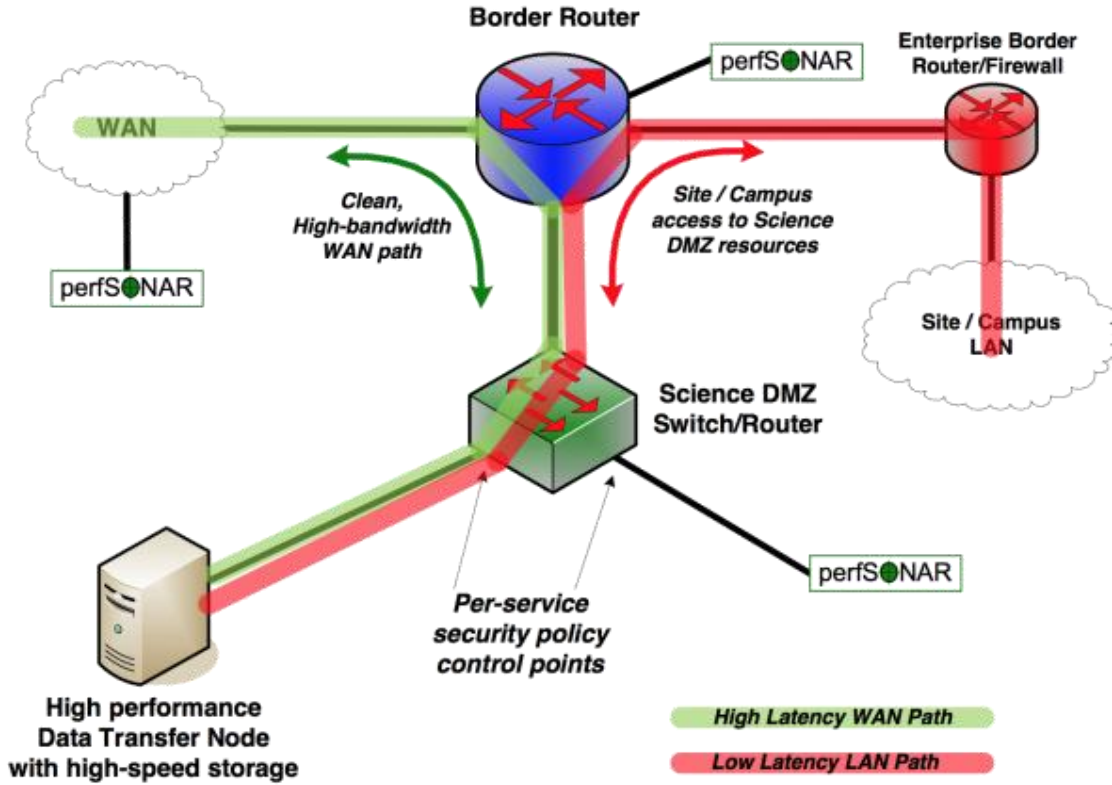
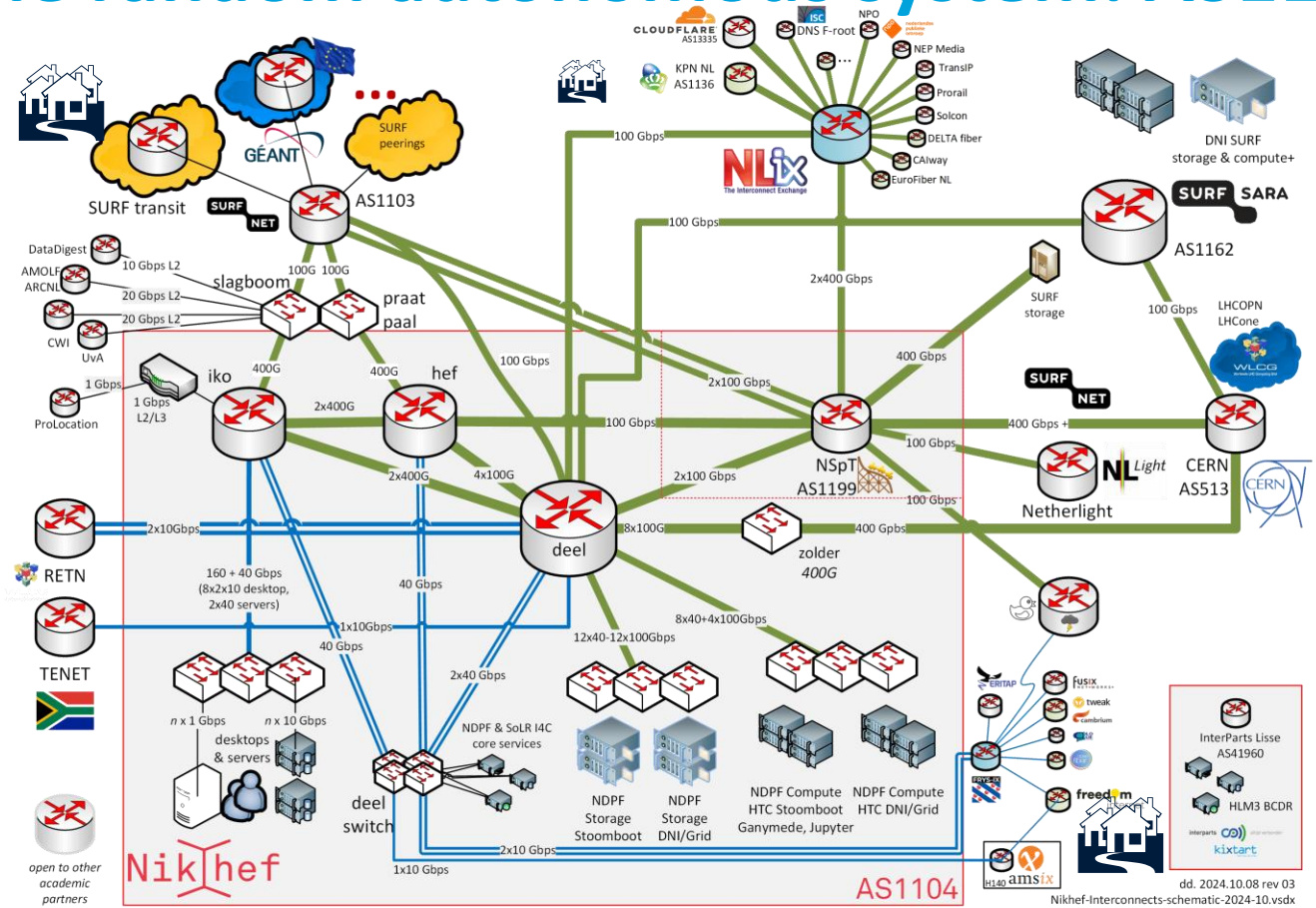


Image and ‘ScienceDMZ’ concept promulgated by ESnet (see fasterdata.es.net)

Just one random autonomous system: AS1104



AS1104
state as of Oct 2024

Exercising the network – sensor data and events

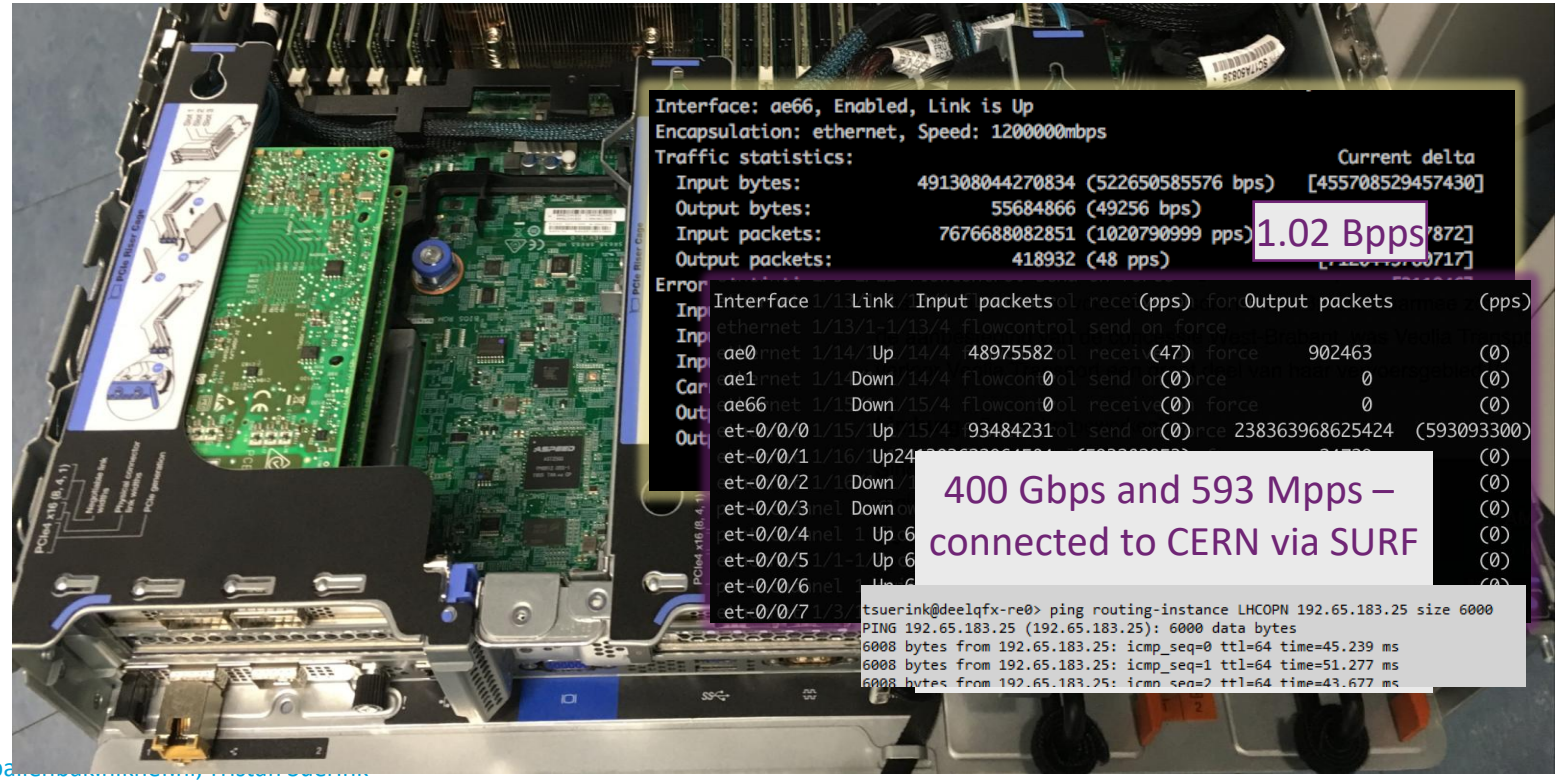
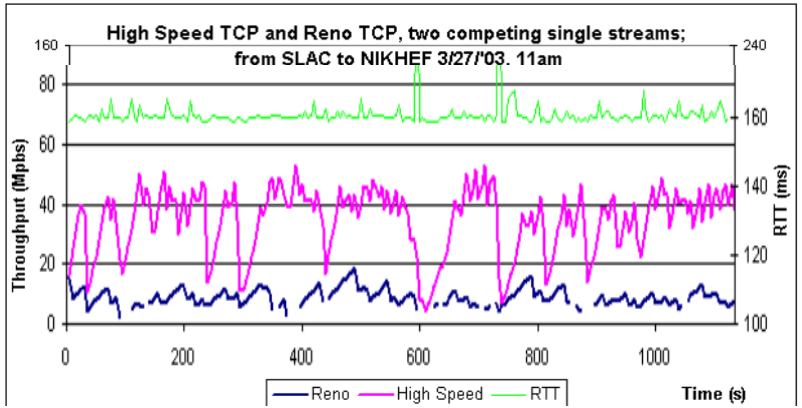


Image: ba

Scaling data access: ‘system-aware design’ at application layer

Reading data ‘scattered’ in a file - simply using POSIX-like IO - when done over the network severely exposes latency

and TCP slow-start makes that even worse



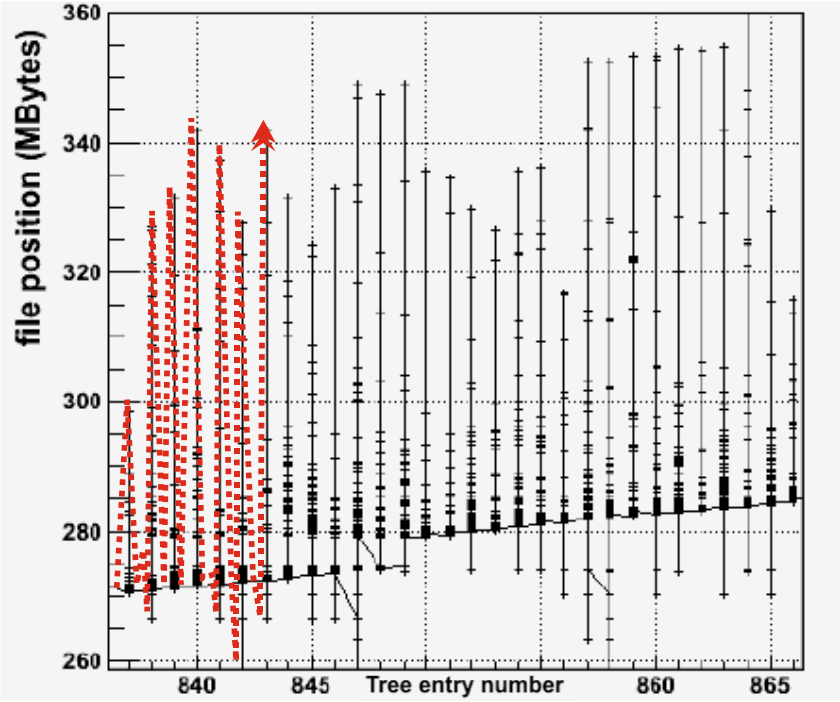
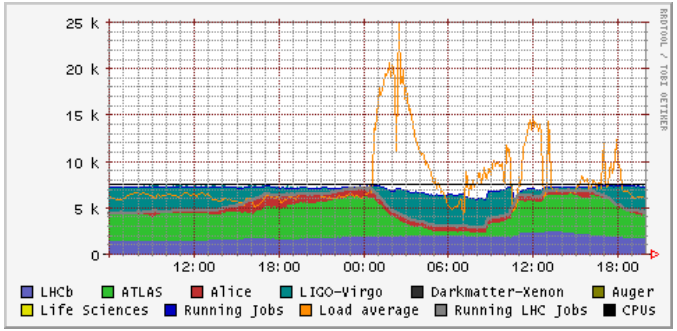


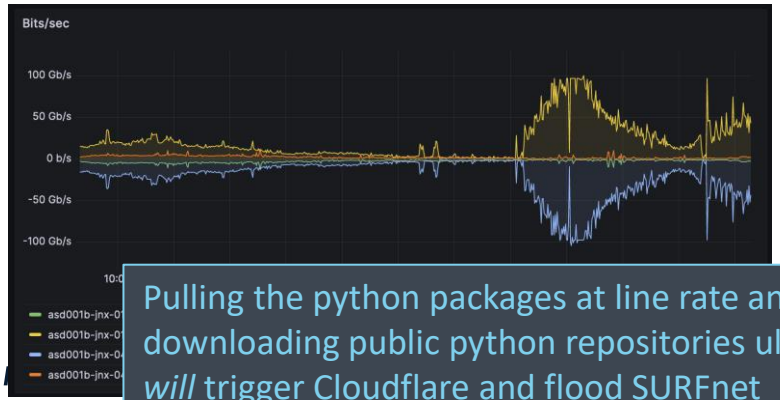
Image of TCP slow-start and packet loss impact (in Mpps): Antony Antony et al., Nikhef, for DataTAG, 2003(!)
Right: base graphic: Philippe Canal “Root I/O: the fast and the furious”, CHEP2010 Access pattern reflects Root versions < 5.28, before Ttree caching and ‘baskets’

And some traffic is triggered by researchers scaling up ‘accidentally’ from a laptop to a cluster without too much thought

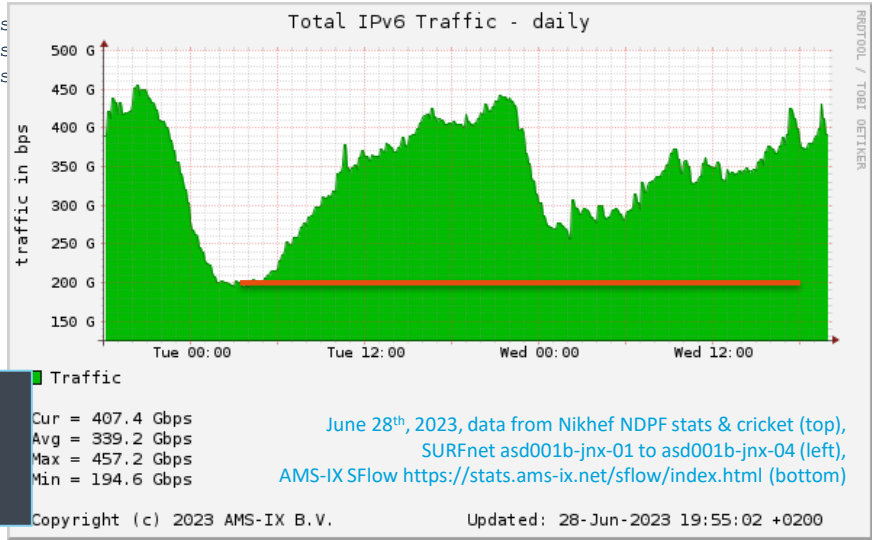
A researcher doing mass creation of containers, rebuilding their python ‘virtual env’ for each job, running on >> 4000 cores

```
[root@wn-pep-002 ~]# top
top - 09:40:47 up 71 days, 12:17,  2 users,  load average: 110.38, 101.43, 106.3
Tasks: 700 total,   7 running, 666 sleeping,   0 stopped,  27 zombie
%Cpu(s): 17.0 us,  2.0 sy,  0.0 ni, 81.0 id,  0.0 wa,  0.0 hi,  0.0 si,  0.0 st
KiB Mem : 39462902+total, 23514457+free, 10406320 used, 14907812+buff/cache
KiB Swap: 67108860 total, 66841340 free,   267520 used. 37964784+avail Mem

   PID USER      PR  NI    VIRT    RES    SHR S  %CPU %MEM     TIME+ COMMAND
 82661 ligo000   20   0 5618756 396356    924 R 360.0  0.1   5:14.43 mksquashfs
 72615 ligo000   20   0 5626336 248516    816 R  90.0  0.1   5:44.11 mksquashfs
 83257 ligo000   20   0 5611608 219300    852 S  90.0  0.1   1:17.66 mksquashfs
 ...
```





Pulling the python packages at line rate and downloading public python repositories ultimately *will* trigger Cloudflare and flood SURFnet



June 28th, 2023, data from Nikhef NDPF stats & cricket (top), SURFnet asd001b-jnx-01 to asd001b-jnx-04 (left), AMS-IX SFlow https://stats.ams-ix.net/sflow/index.html (bottom)

For example for HL-LHC, or SKA, more is needed > 2028 …

- ‘Typical’ network is now mixed 400G-100G
- Push experiments to 800Gbps in metro area, and a local (AMS) loop has been demonstrated
- next: 800 → 1600G AMS-GVA ☺

Web screenshot: btg.org,
Images Nokia 7750-SR1x in Nikhef AMS H234b: Tristan Suerink

Research data traffic looks like … a DDoS to others ☺

Belastingdienst

Home Menu Zoeken

Home > Actueel > ICT en informatievoorziening > De systemen testen dankzij een unieke samenwerking

Lees voor

De systemen testen dankzij een unieke samenwerking

Op dez

Een goe
Examen
Wat geb
Vragen
Terug n

Het begon in 2018. Een bijzondere samenwerking tussen overheden, internetproviders- en exchanges, academische instanties, non-
pr
du
sin
n plat
vapen
alitie.

Dinsdag 14 maart 2023 | Het laatste nieuws het eerst op NU.nl

Door Rutger Otto

12 feb 2023 om 05:02
Update: een maand geleden

202 reacties

Een goed begin

De voorbereidingen van de avond beginnen ver voordat de oefening gepland staat. Elke organisatie bepaalt welke systemen ze willen aanvallen en hoe de aanval uitgevoerd wordt. Het 'red team' is verantwoordelijk voor de aanvallen, het 'blue team' voor de verdediging. Eén van de partijen die avond is Nikhef. Tristan, IT architect bij Nikhef, geeft aan dat zij dit belangeloos doen, gedreven door een maatschappelijke motivatie.

Nikhef is het Nationaal instituut voor subatomaire fysica in Nederland. Het beschikt over een gigantische bandbreedte, wat noodzakelijk is voor een dergelijke oefening waarbij zeer veel data wordt verstuurd. Zij zijn onderdeel van de aanvallende teams en

Betastingsdienst

Home

Home > Aanslagen > Ik heb een DDoS aanslag ontvangen - wat nu?

Ik heb een DDoS aanslag op mijn netwerk ontvangen - wat nu?

U ontvangt een DDoS aanslag op uw netwerk, bijvoorbeeld omdat u vergeten bent werkende tegenmaatregelen te nemen. Er staat dan een geschat aantal pakketten per seconde op uw monitoring.

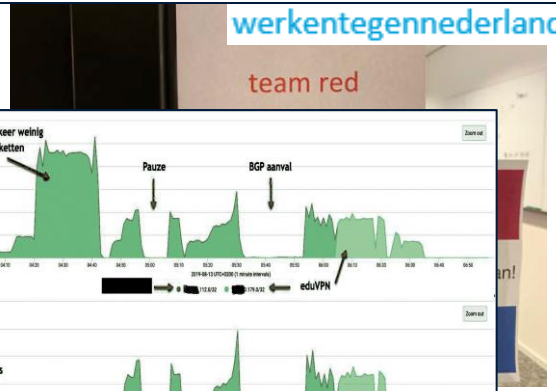
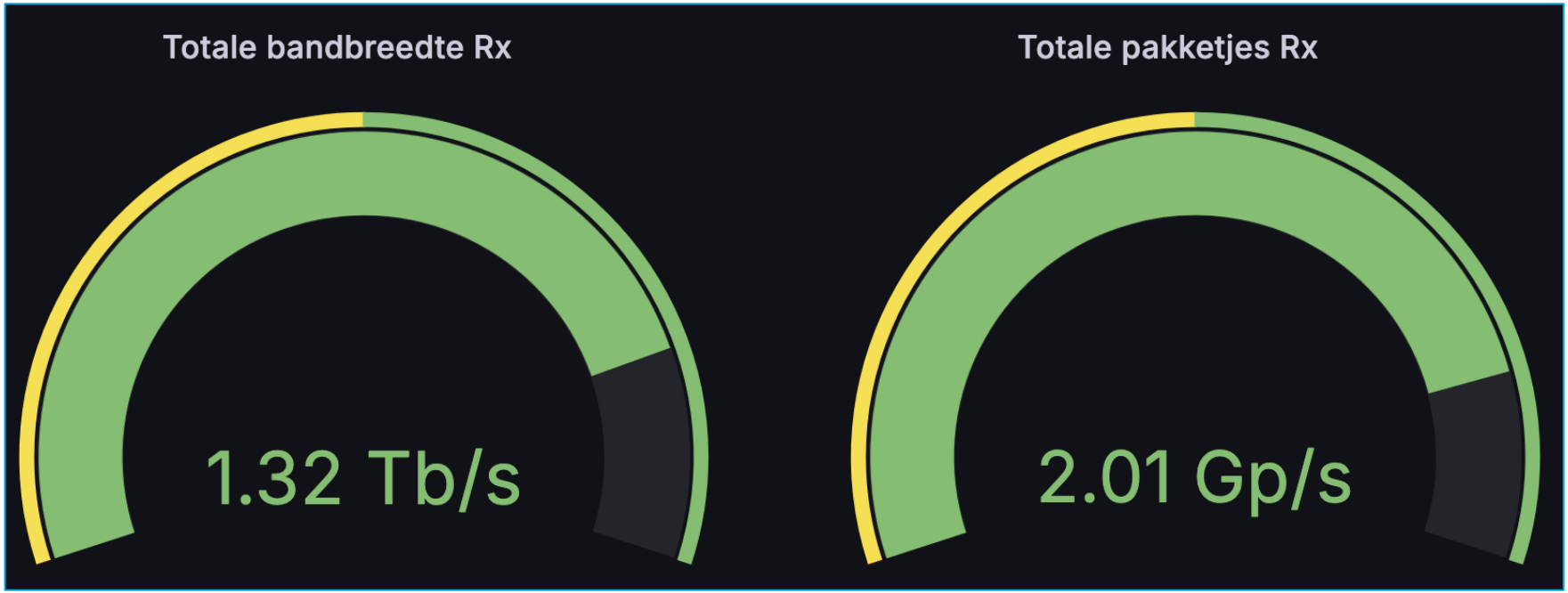


Image sources: belastingdienst.nl, rws.nl, nu.nl

with packets being more destructive than bandwidth …



https://wiki.nikhef.nl/grid/2Bpps_Machine - in preparation for the 2025 Resilience Exercise -

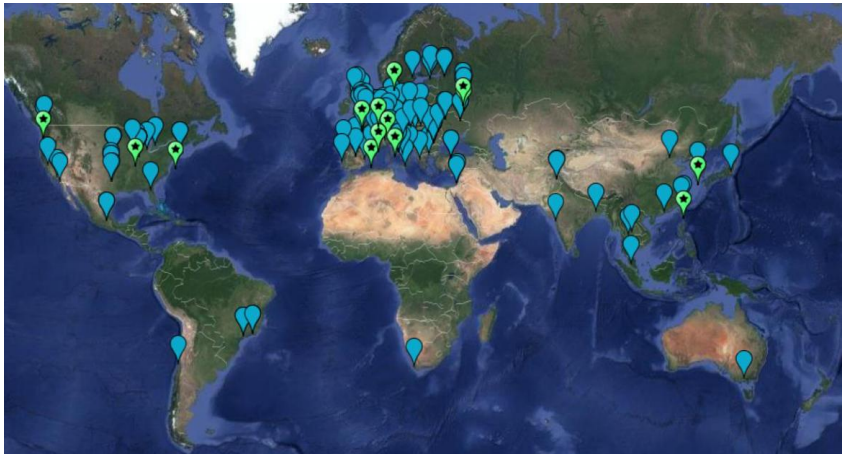
Access: Trust & Identity

More than one user, *from*
more than one organization, *in*
more than one country

WLCG: when we met a global trust scaling issue

- 170 sites
- ~50 countries & regions
- ~12000 users

so … just *how* many interactions ??



people photo: a small part of the CMS collaboration in 2017, Credit: CMS-PHO-PUBLIC-2017-004-3; site map: WLCG sites from Maarten Litmaath (CERN) 2021

Scaling issues – credentials at each site does not work

state of Grid and the LHC computing in 2000

NIKHEF
NATIONAAL INSTITUUT VOOR KERNFYSICA EN HOGE-ENERGIEFYSICA

Guest / students form (pleas

1. This form is completed in connection with:

☐ work experien
☐ otherwise, vis

CERN/User Registration

CERN COMPUTER CENTRE - US

http://cern.ch/it/documents/ComputerUsage/CompA

To be returned to the User Registration box at the en
completed by a user who requires a computer accou
Department, and is not yet registered in another grou

To be completed by the User :

It is **MANDATORY** to provide the following inform
treated confidentially and only be used for ensuring
Supply name as registered by the Users' Off

FAMILY NAME(S): ……
FIRST NAME(S) : ……
SEX [M] [F] BIRTHDATE: Day …..… Month …… Year ……
HOME INSTITUTE/FIRM: ……
NATIONALITY: ……...*CERN SUPERVISOR……
*CERN DEPARTMENT: . . . . . *CERN ID NUMBER (as on CERN card)……..

To be completed by the Group Administrator:

Fermilab

For Office Use Only

ID:	Action:	ID Exp:	
Insurance:	Medical:	Safety:	
Computer:	Stkrm:	Family:	
NON-473:	Sensitive:	Verifier:	Date:

Name:

Last	First	Middle
SWIETZER	JOHN	JAMES

University or Institution Name: Telephone:

FLORIDA STATE UNIVERSITY	850-644-XXXX

Experiment/Department:

Exp. / Dept.	Spokesperson	Home Institution Contact	Contact Telephone
D0	WOMERSLEY/WEERTS	SHARON HAGOPIAN	850-644-4777

Authentication – proving *who* are you

Authenticating to a *single service* is relatively simple

- per-service identity (username) and secrets (e.g. password or TOTP token)
- server-side: list of valid users and (hashed and hopefully salted) secrets

```
[root@kwark ~]# cat /etc/passwd
root:x:0:0:root:/root:/bin/bash
bin:x:1:1:bin:/bin:/sbin/nologin
daemon:x:2:2:daemon:/sbin:/sbin/nologin
adm:x:3:4:adm:/var/adm:/sbin/nologin
lp:x:4:7:lp:/var/spool/lpd:/sbin/nologin
sync:x:5:0:sync:/sbin:/bin/sync
shutdown:x:6:0:shutdown:/sbin:/sbin/shutdown
halt:x:7:0:halt:/sbin:/sbin/halt
```

```
root:$6$s8ciAG5gLuv2bPQS$6EcskgtKvQ.rHbif
davidg:$6$nDYcIez2Uaufbtlg$R1hS/Qjn0qYQZk
marianne:$6$p3CeevG6jfNDqZj1$HKHqUTnt2fEqQfkA/m5J3oAOA0zSvgLCKOSQhPS
```

Passport image: cropped from original by Jon Tyson on Unsplash https://unsplash.com/photos/Hid-yhommOg

Authorization – what you are allowed to do

soon needs specifying **access rights** to resources, based on an access **policy**

- might be implicit or ad-hoc
- be in formal policy language like XACML (*example: Argus PDP)*
- or be service-specific *example: Linux sssd config*

```
resource "http://cern.ch/authz/ce1" {
   action "http://cern.ch/authz/actions/ce-submit" {
      rule permit {
         vo="atlas"
         pilot-job="true"
      }
      rule deny {
         pilot-job="true"
      }
   }
}
```

simplified Argus policy language – can map directly to XACML

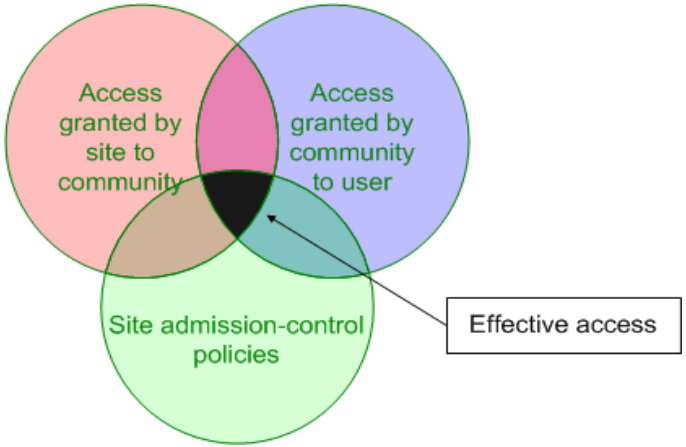
```
ldap_access_order = filter,authorized_service
ldap_access_filter = (|(memberOf=cn=gridSrvAdministrators,ou=DirectoryGroups,dc=farmnet,
dc=nikhef,dc=nl)(memberOf=cn=gridMWSecurityGroup,ou=DirectoryGroups,dc=farmnet,dc=nikhef
,dc=nl)(memberOf=cn=nDPFPrivilegedUsers,ou=DirectoryGroups,dc=farmnet,dc=nikhef,dc=nl))
```

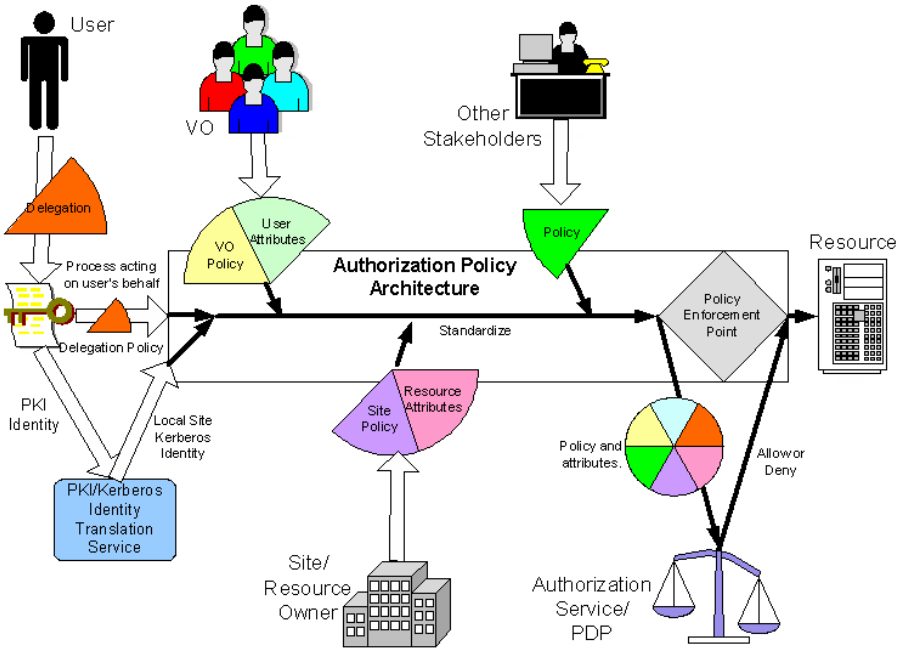
Policy example: Argus system, https://argus-documentation.readthedocs.io/en/stable/misc/examples.html; service-specific: sssd.conf ldap auth_provider

Authorization and access control

Access control is ultimately enforced by the service provider

(unless data-level encryption is used, where the data owner retains some control)





policy overlap diagram by Olle Mulmo, KTH for EGEE-I JRA3, policy pie: Open Grid Forum OGSA working group and Globus Alliance

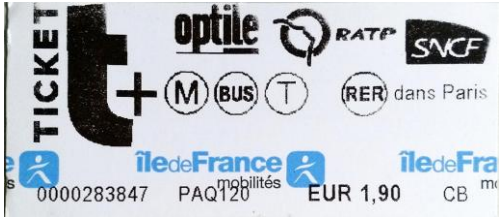
Authorization policy subjects

AuthZ policies need subject attributes (‘claims’)

- **bound to an verifiable identity** statement
  - e.g. visa are strongly linked to a specific entity, and asserted by a trusted party (by the service)
- be a **bearer token**
  - scoped to a relying party, a service, or an action
- **self-asserted**
  - quite useless unless backed by verifiable evidence, like in self-sovereign identity schemes

Transport mechanisms (see also RFC2903)

- pushed alongside the service access,
- pulled from the source as needed, or
- pushed by the attribute source as an agent



USA visa image source: https://2009-2017.state.gov/m/ds/rls/rpt/79785.htm ; RATP bearer token, issued for the Paris public transport system

Scaling credentials: per service per user

Many start with *credentials* dedicated to each service where you need access

- Number of to-be-protected credentials:

$$\mathcal{O}(n_{services}) * \mathcal{O}(n_{users})$$

- usually creates a strong link to authorization:

  different accounts for different roles, multiplying the number of credentials per user

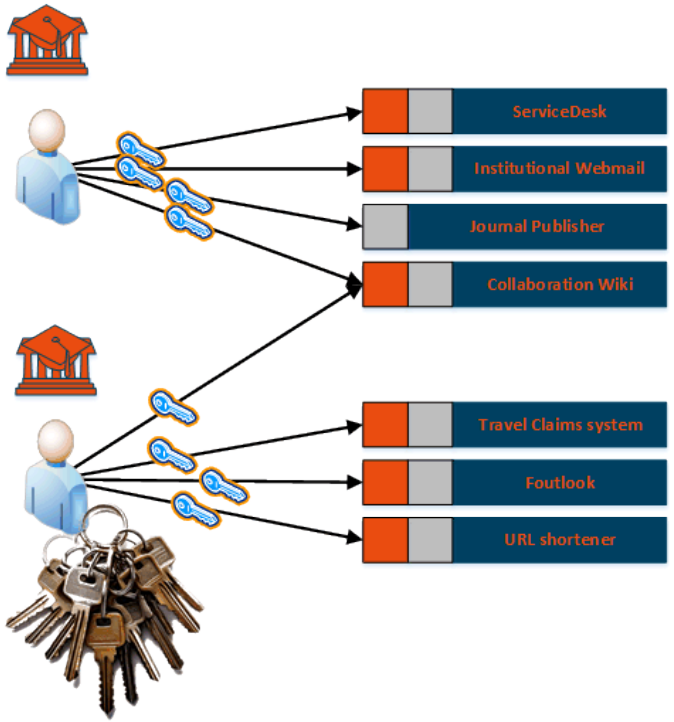


Image imspired by AARC NA2 training module “Authentication and Authorisation 101” – keychain image created by generative AI

bilateral SSO: per service single identity source per ‘home’ organisation

#credentials required ↓

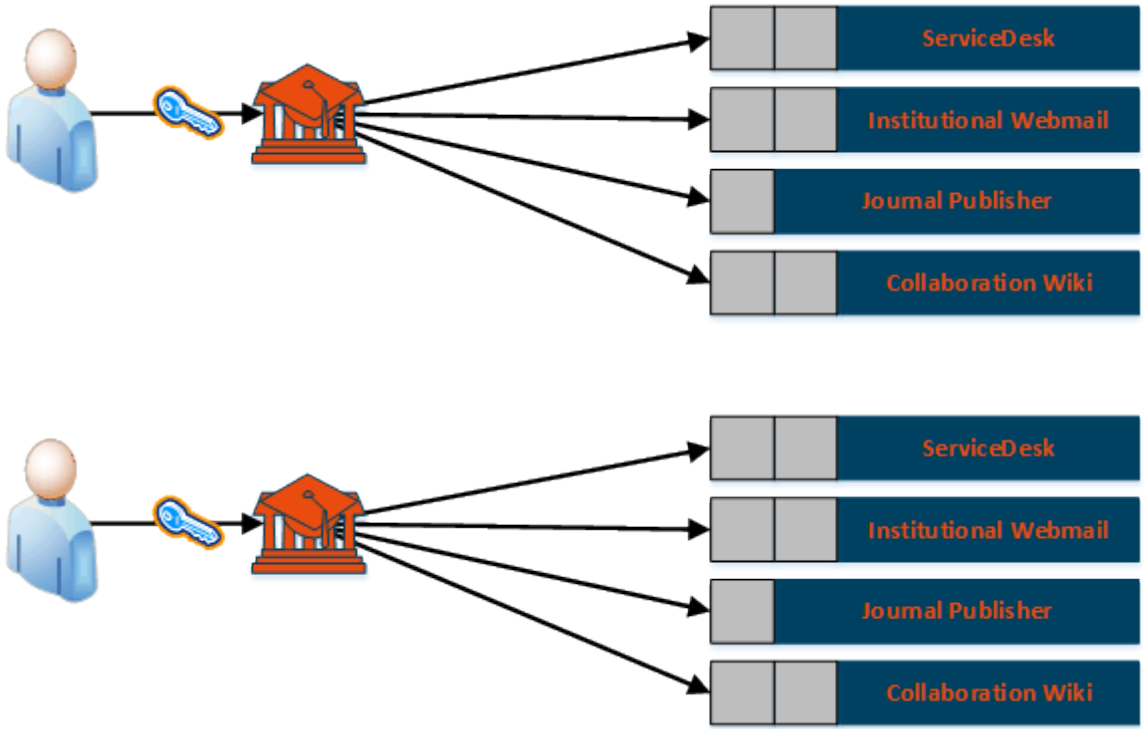
from previously

$\mathcal{O}(n_{services}) * \mathcal{O}(n_{users})$

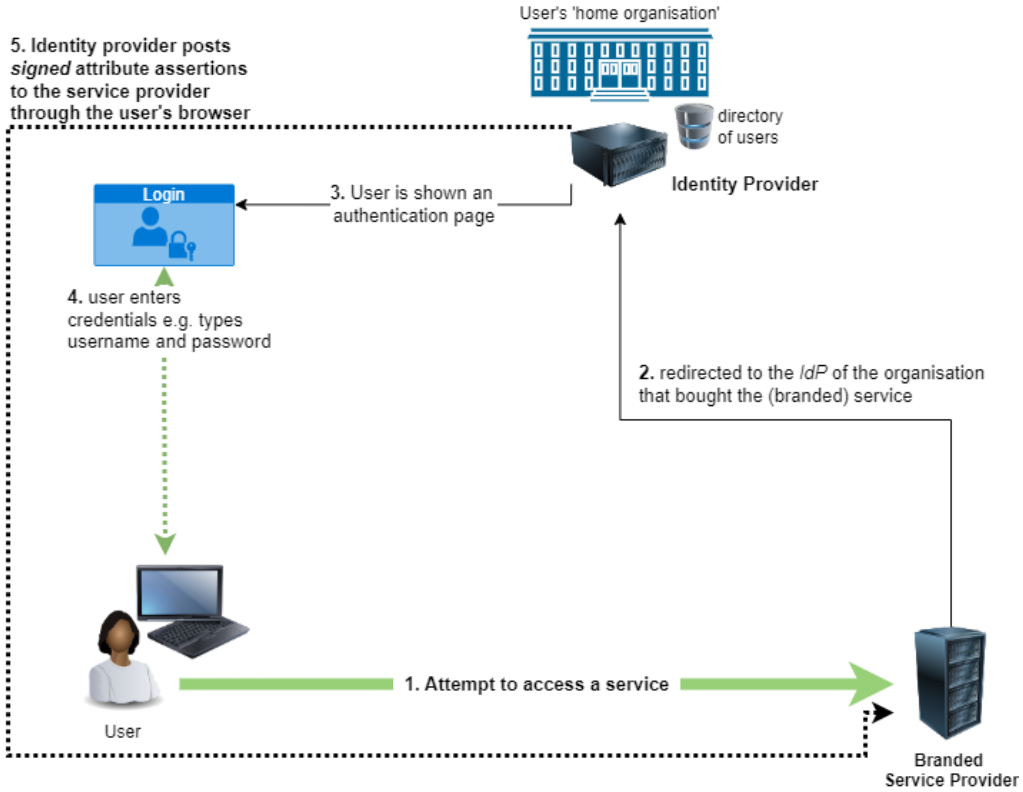
to

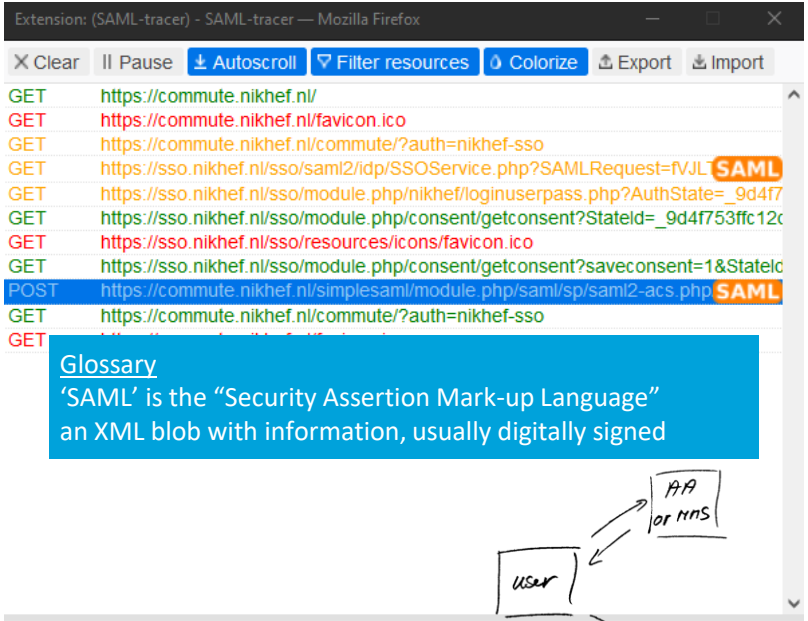
$\mathbf{\mathcal{O}(n_{users})}$
$+ \mathcal{O}(n_{services} * n_{home\text{-}orgs})$

in first order at least



Enterprise (SAML) Single sign-on: browser redirect as login flow





SAML-tracer plugin by Tim van Dijen (SSC-ICT) *et al.*
https://github.com/simplesamlphp/SAML-tracer

Under the hood, sends a (signed) XML document

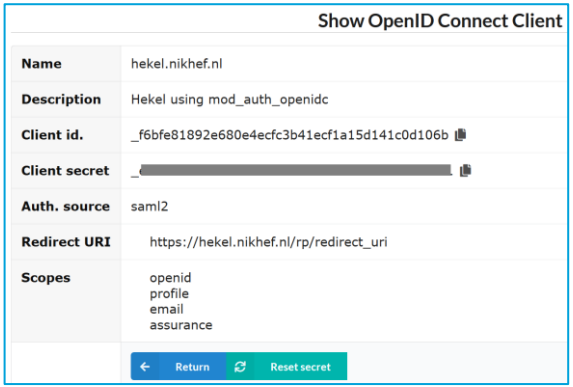
```
<saml:Subject>
     <saml:NameID Format="urn:oasis:names:tc:SAML:2.0:nameid-format:persistent">xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx</saml:NameID>
     <saml:SubjectConfirmation Method="urn:oasis:names:tc:SAML:2.0:cm:bearer">
       <saml:SubjectConfirmationData NotOnOrAfter="2022-10-21T18:16:40Z"
         Recipient="https://attribute-viewer.aai.switch.ch/Shibboleth.sso/SAML2/POST"
         InResponseTo="_64c10a60c382bdaeb328653d9d25951c" /></saml:SubjectConfirmation>
   </saml:Subject>
   <saml:Conditions NotBefore="2022-10-21T18:11:39Z"
                    NotOnOrAfter="2022-10-21T18:16:40Z">
     <saml:AudienceRestriction>
       <saml:Audience>https://attribute-viewer.aai.switch.ch/shibboleth</saml:Audience>
     </saml:AudienceRestriction>
   </saml:Conditions>
   <saml:AuthnStatement AuthnInstant="2022-10-21T17:33:29
                        SessionNotOnOrAfter="2022-10-22T0
                        SessionIndex="_90f745f18f712b6a56
    <saml:AuthnContext>
        <saml:AuthnContextClassRef>urn:oasis:names:tc:SAM
        <saml:AuthenticatingAuthority>https://sso.nikhef.
    </saml:AuthnContext>
   </saml:AuthnStatement>
```

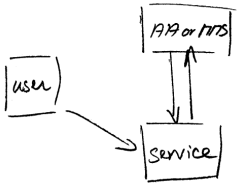
```
<saml:AttributeStatement>
     <saml:Attribute Name="urn:mace:dir:attribute-def:cn"
                     NameFormat="urn:oasis:names:tc:SAML:2.0:attrname-format:uri">
       <saml:AttributeValue xsi:type="xs:string">David Groep</saml:AttributeValue>
     </saml:Attribute>
     <saml:Attribute Name="urn:oid:2.5.4.3"
                     NameFormat="urn:oasis:names:tc:SAML:2.0:attrname-format:uri">
       <saml:AttributeValue xsi:type="xs:string">David Groep</saml:AttributeValue>
     </saml:Attribute>
     <saml:Attribute Name="urn:mace:dir:attribute-def:eduPersonAffiliation"
                     NameFormat="urn:oasis:names:tc:SAML:2.0:attrname-format:uri">
       <saml:AttributeValue xsi:type="xs:string">employee</saml:AttributeValue>
       <saml:AttributeValue xsi:type="xs:string">member</saml:AttributeValue>
       <saml:AttributeValue xsi:type="xs:string">faculty</saml:AttributeValue>
     </saml:Attribute>
     <saml:Attribute Name="urn:oid:1.3.6.1.4.1.5923.1.1.1.1"
     ...
```

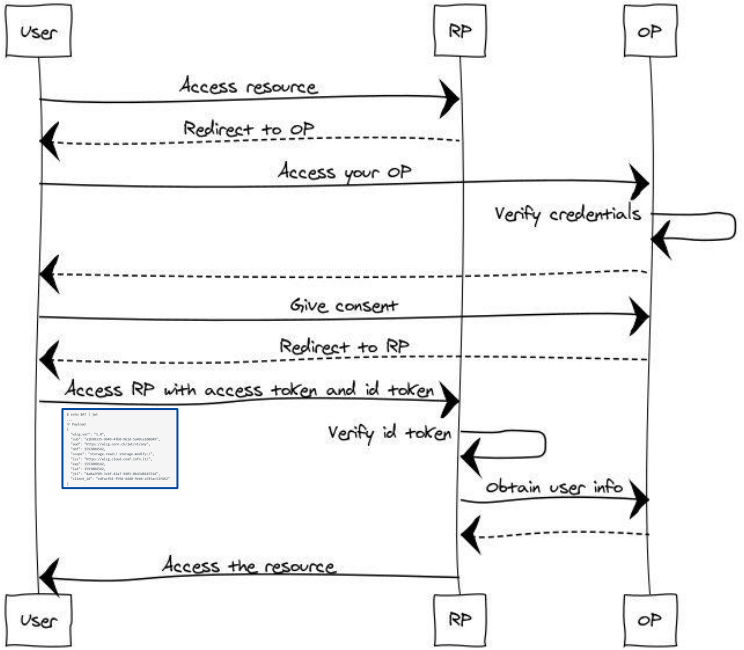
OpenID Connect and OAuth2: the ‘modern’ way

- Quite .well-known
  (used by lots modern ‘non-enterprise’ SSO)

- shows signs of its initial design objective:
  one source of identity (Openid Provider, ‘OP’),
  and *many* services (Relaying Parties, ‘RP’)



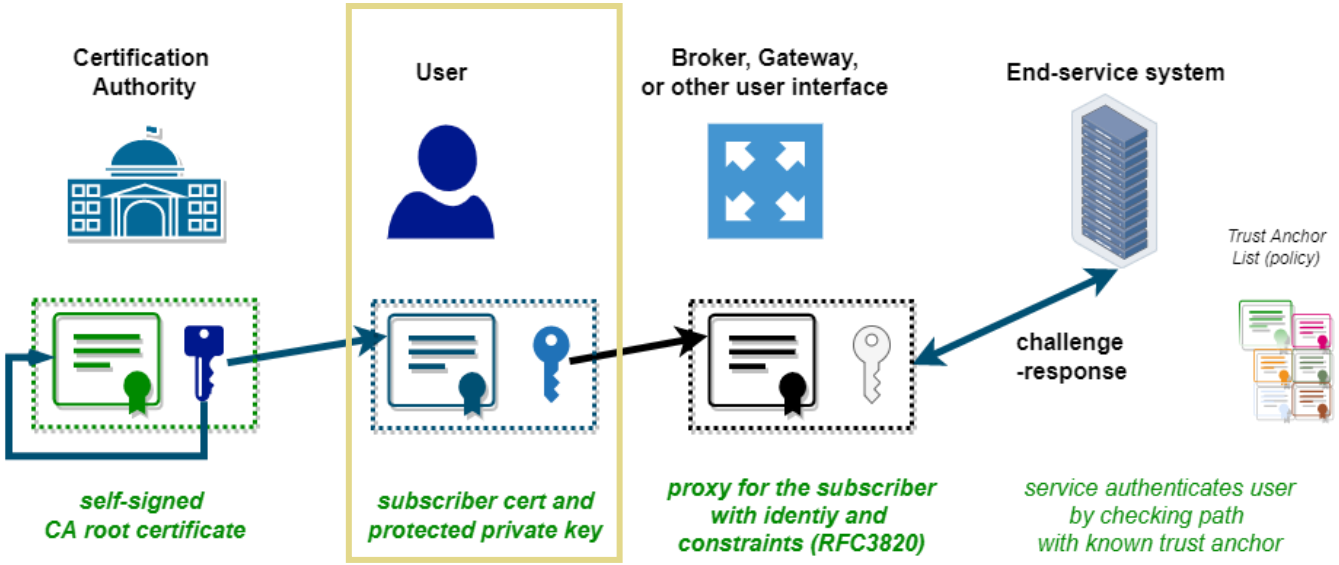




Shown is the ‘implicit flow’, other flows possible. Image source: AARC NA2 training on AAI 101
See https://openid.net/ for protocols and standardization work

PKI client certificates – user* *client held* credentials

You have seen *https*, but the same PKI Certificates can be used for clients, not servers …



RFC3820 'proxy' certificates extend identity-certificate concept with (policy-restricted) delegation

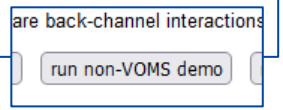
```
Version: 3 (0x2)
Serial Number:
    34:f3:e3:5f:c0:53:0b:a6:ef:2b:4a:79:01:b5:50:3b
Signature Algorithm: sha384WithRSAEncryption
Issuer: C = NL, O = GEANT Vereniging, CN = GEANT eScience Personal CA 4
Validity
    Not Before: Apr  2 00:00:00 2022 GMT
    Not After : May  2 23:59:59 2023 GMT
Subject: DC = org, DC = terena, DC = tcs, C = NL, O = Nikhef, CN = David
Groep davidg@nikhef.nl
Subject Public Key Info:
    Public Key Algorithm: rsaEncryption
        RSA Public-Key: (4096 bit)
        Modulus:
            00:f0:0d:c0:ff:ee:f0:0d:f0:0d:c0:ff:ee:f0:0d:
            ...
            ff:50:6d
        Exponent: 65537 (0x10001)
X509v3 extensions:
    X509v3 Key Usage: critical
        Digital Signature
                                                    Authentication
        Certificate Policies:
        Policy: 1.2.840.113612.5.2.2.5
```

* think we found everyone in the world who could deal with certificates: about (100 000) people …

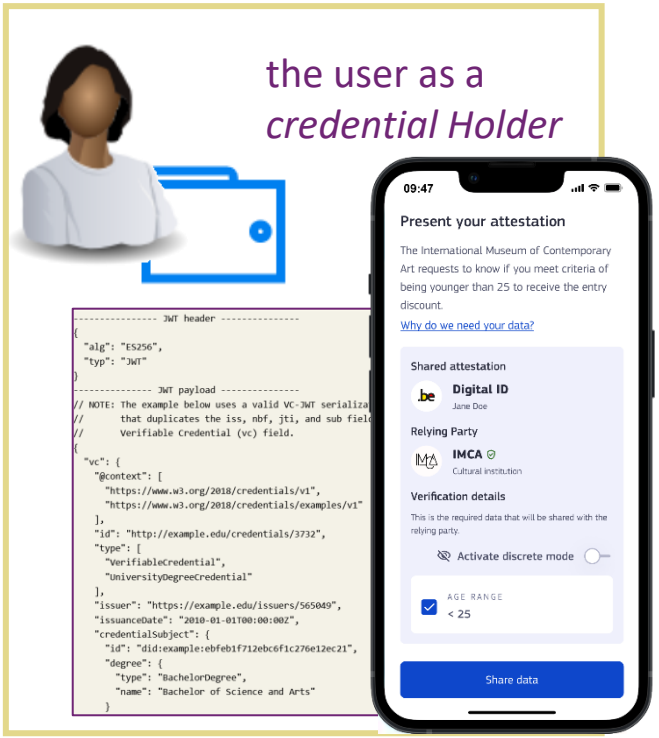
Different tech also an AAA push concept: X.509 and a trust PKI

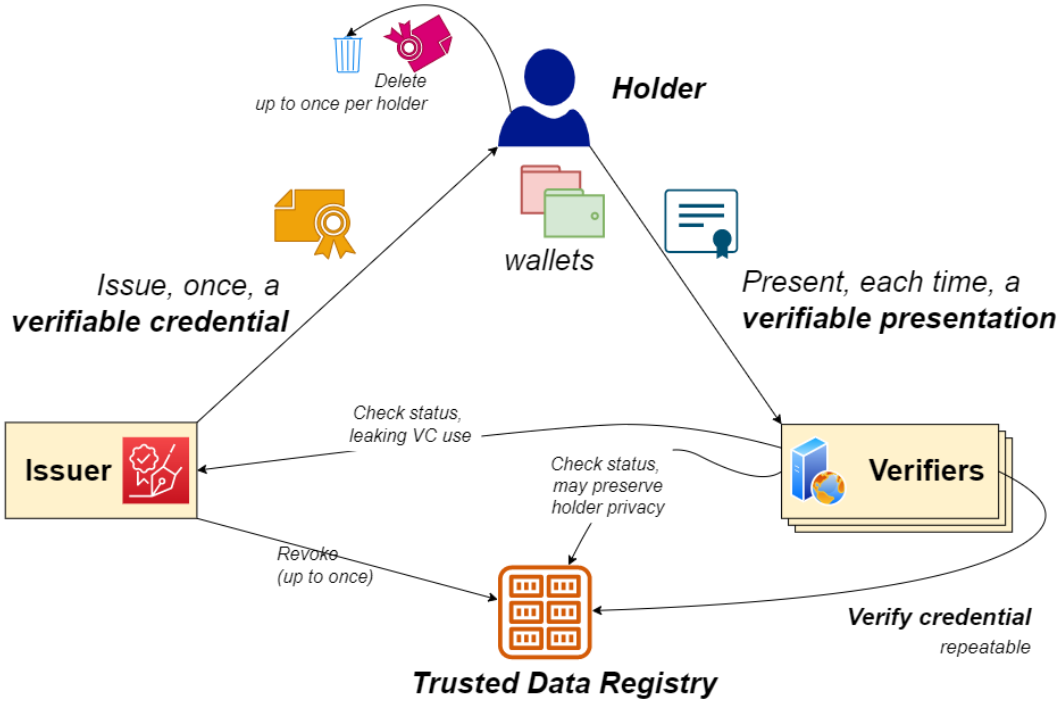
```
Version: 3 (0x2)
Serial Number:
    34:f3:e3:5f:c0:53:0b:a6:ef:2b:4a:79:01:b5:50:3b
Signature Algorithm: sha384WithRSAEncryption
Issuer: C = NL, O = GEANT Vereniging, CN = GEANT eScience Personal CA 4
Validity
    Not Before: Apr  2 00:00:00 2022 GMT
    Not After : May  2 23:59:59 2023 GMT
Subject: DC = org, DC = terena, DC = tcs, C = NL, O = Nikhef, CN = David Groep davidg@nikhef.nl
Subject Public Key Info:
    Public Key Algorithm: rsaEncryption
        RSA Public-Key: (4096 bit)
        Modulus:
            00:f0:0d:c0:ff:ee:f0:0d:f0:0d:c0:ff:ee:f0:0d:
            ...
            ff:50:6d
        Exponent: 65537 (0x10001)
X509v3 extensions:
    X509v3 Key Usage: critical
        Digital Signature, Key Encipherment
    X509v3 Basic Constraints: critical
        CA:FALSE
    X509v3 Extended Key Usage:
        E-mail Protection, TLS Web Client Authentication
    X509v3 Certificate Policies:
        Policy: 1.2.840.113612.5.2.2.5
```

You should be able to get an 'IGTF-DOGWOOD' assurance certificate from RCauth.eu.
Go to https://rcdemo.nikhef.nl/ and select the 'Basic demo' and use 'run non-VOMS' to get and view your short-lived certificate



Identity wallets with VCs held by the user, are another





Flow diagram inspired by: Lifecycle Details (5.1), Verifiable Credentials Data Model v1.1, W3C Recommendation 03 March 2022, https://www.w3.org/TR/vc-data-model/
EU eID Wallet from https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-digital-identity_en
Appimage: European Commission, at https://ec.europa.eu/digital-building-blocks/sites/display/EUDIGITALIDENTITYWALLET/Security+and+Privacy

Interoperable wallet federation example: life-long learning

time to think less institution-centric?

EBSI Wave 2 (15 MS, 20 HEIs, 2 EUA)

Study

01 A student gets a diploma with a list of course units validated from Erasmus (Transcript of Records Credential) (ES/BE/IT)

02 A student applies for a PhD with a Bachelor / Master degree from a foreign country (Bachelor/Master Diploma Credential) (RO/GR/FR)

03 A student gets access to local discounts using student credential (European Student IDentity) (BE/ES)

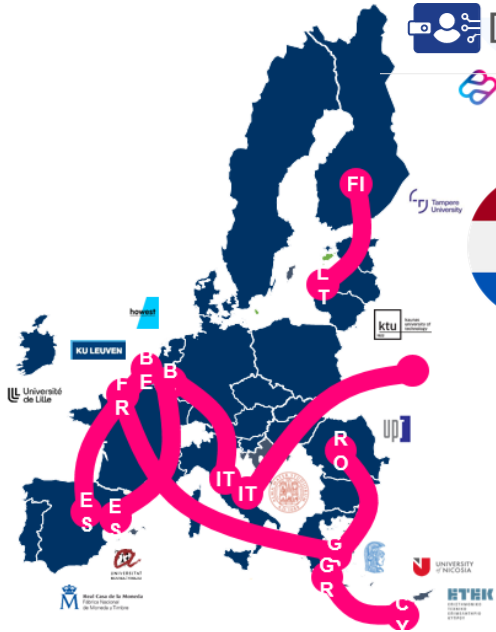
04 A refugee presents an EQPR to a European Italian University to apply for a Master (EQPR - CoE Refugee Passport) (IT/DE)

Work

05 A graduated citizen applies for a job with a Degree from a foreign country (License to Practice Credential) (GR/CY)

Grow

06 A PhD student applies for specific courses in a foreign country (Cross-border Micro-credentials) (FI/LT)



DC4EU

ebsi

HOME PROJECT

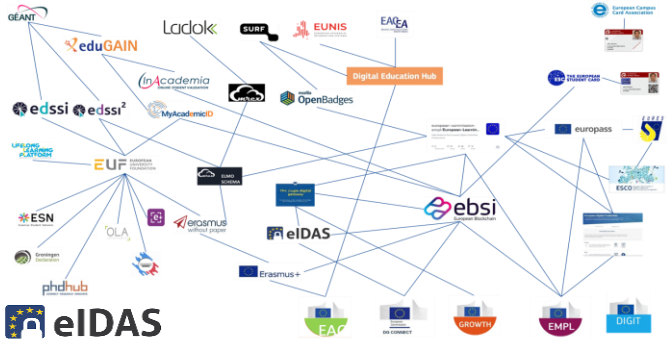
GEANT Association

Stichting Internet Domeinregistratie Nederland

SURF BV

Vezcozo BV

Dienst Uitvoering Onderwijs – Dutch Education Ministry



Images from Lluís Ariño, for the DC4EU project. See e.g. https://www.dc4eu.eu/consortium/#netherlands

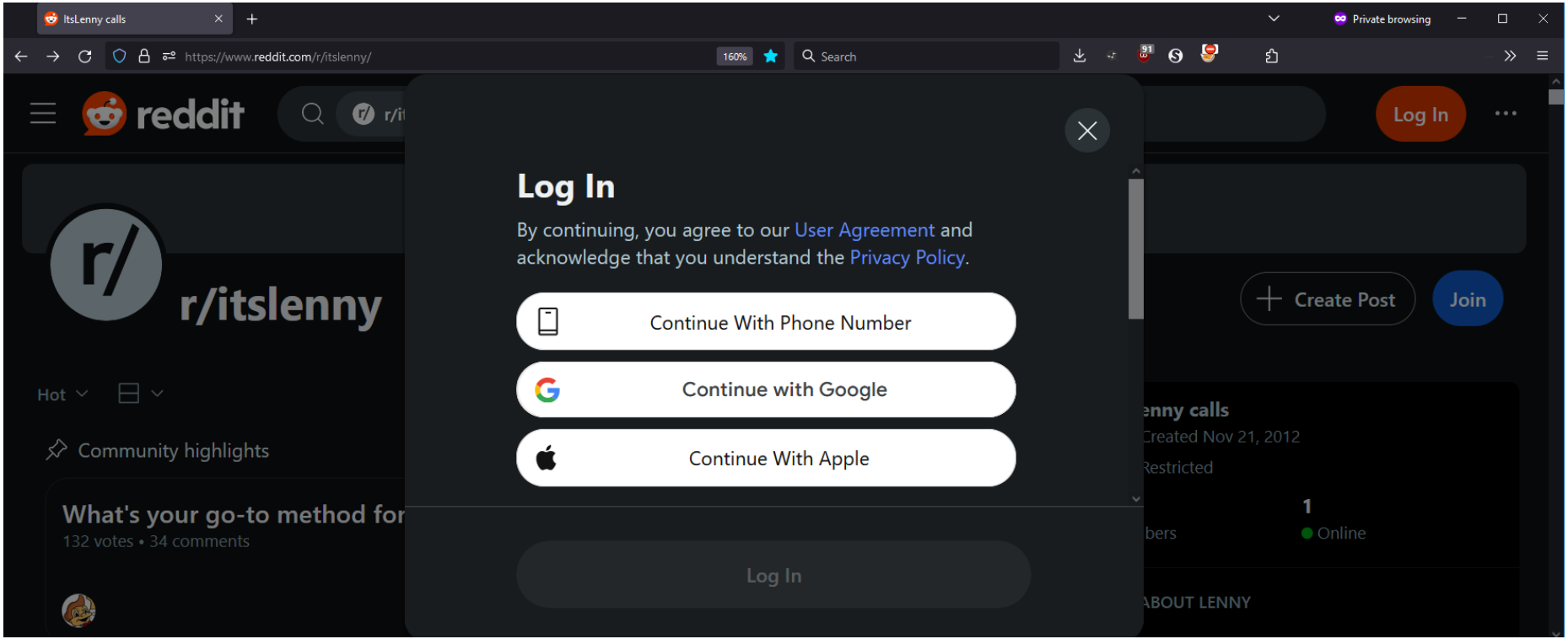
eIDAS

Can we scale better with a ‘federated’ Authentication and Authorisation Infrastructure (‘AAI’)

with one service provided to
several organisations (universities)

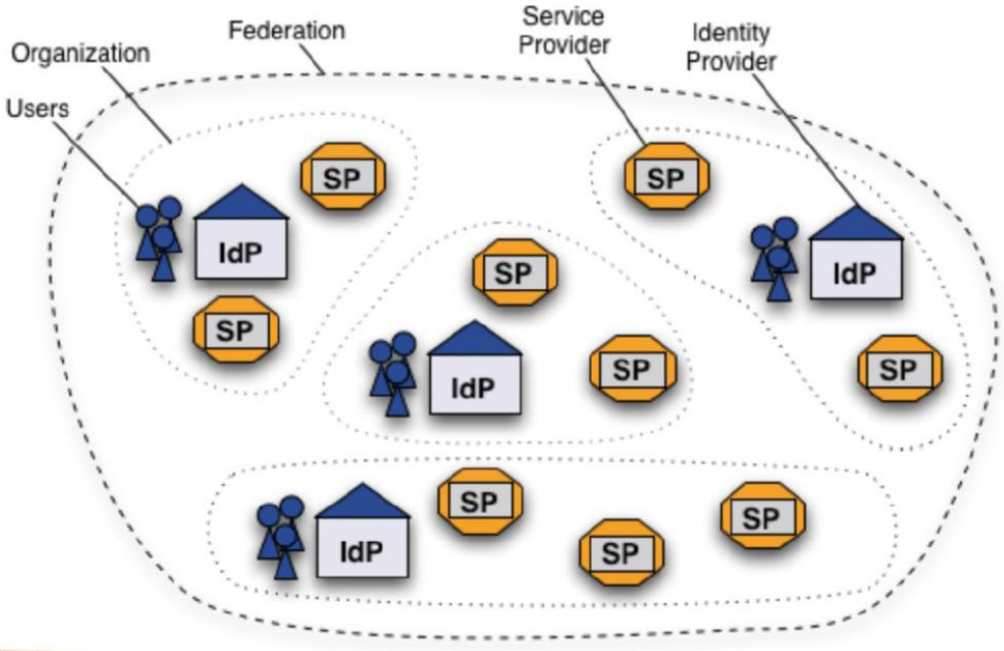
Looking at authentication first …

Where are you from??



Federation

portability of identity information across otherwise autonomous administrative domains

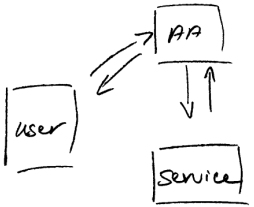


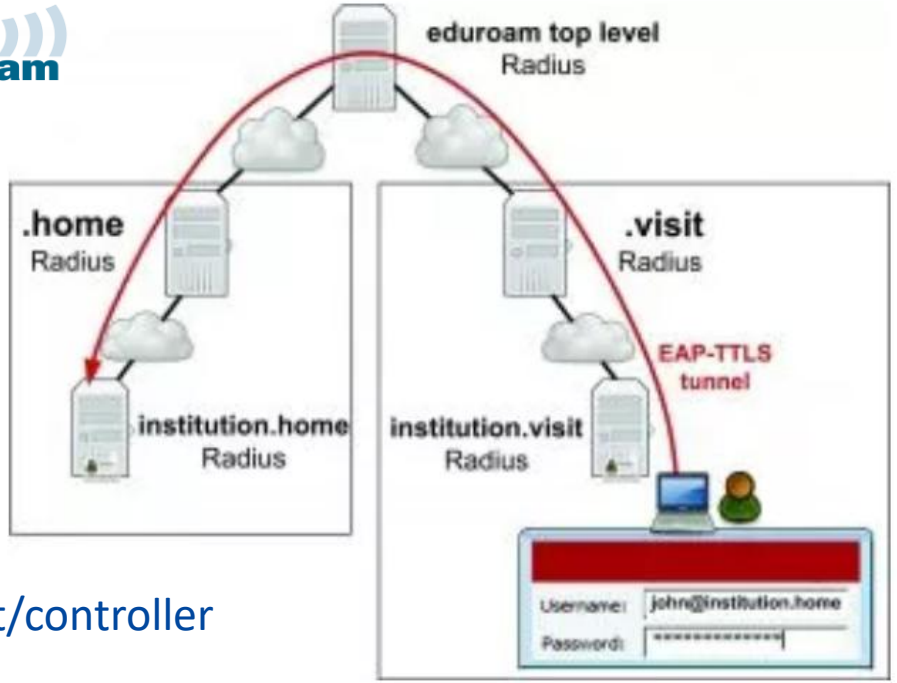
Shibboleth IdP image and SAML2 auth flow by SWITCH (CH) – see also https://refeds.org/ on federation structure and (assurance and security) guidelines

One simple federation you know: eduroam

service-specific trust
between organisations
globally

hierarchical RADIUS servers based
an 802.1x secure exchange
over TLS or EAP-TTLS
tunneling your credentials
back to your home institution

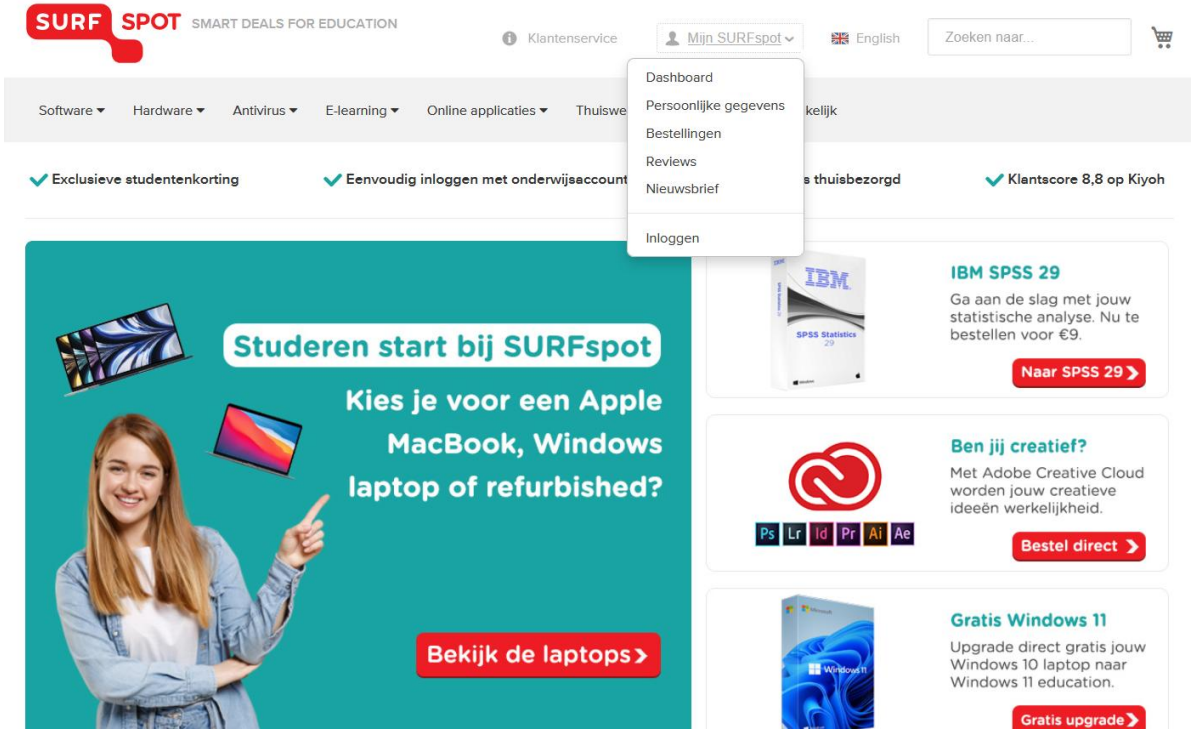




RADIUS server then instructs WiFi access point/controller

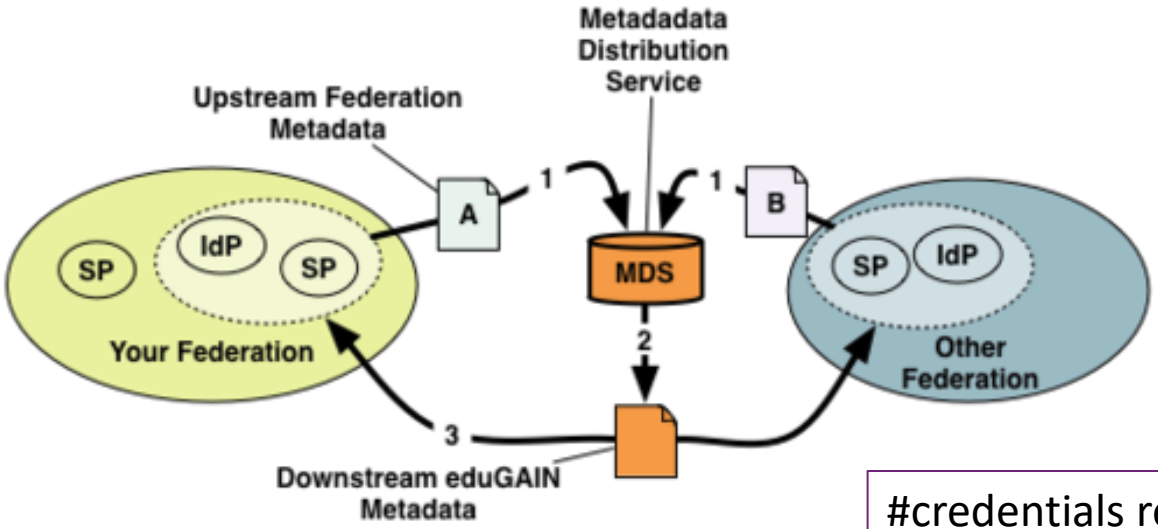
eduroam: Klaas Wieringa et al., image from https://eduroam.org/how/, GEANT ; RADIUS: RC2865 https://www.rfc-editor.org/rfc/rfc2865; see also freeradius.org

Your favourite federated service?



https://surfspot.nl/

Multilateral federation and entity meta-data



Listing of all entities (1572), 42 federations

1	IdP 29 Mayis University Entity ID: https://kimlik.29mayis.edu.tr/simplesaml/saml2/idp/metadata.php Entity categories: Data Protection Code of Conduct v1; REFEDS Research and Scholarship Registrar: YETKİM Org: Istanbul 29 Mayis University	ECCS Entity details
2	IdP A*STAR - Agency for Science, Technology and Research Entity ID: https://a-star.singaren.net.sg/simplesaml/saml2/idp/metadata.php Entity categories: REFEDS Research and Scholarship Registrar: Singapore Access Federation - SGAF Org: A*STAR - Agency for Science, Technology and Research	ECCS Entity details
3	IdP AAF Virtual Home Entity ID: https://vho.aaf.edu.au/idp/shibboleth Entity categories: REFEDS Research and Scholarship SIRTFI: asserted Registrar: AAF Org: AAF Virtual Home	ECCS Entity details
4	IdP AARNet Entity ID: https://shibboleth.aarnet.edu.au/idp/shibboleth Entity categories: REFEDS Research and Scholarship SIRTFI: asserted Registrar: AAF Org: Australian Academic and Research Network (AARNet)	ECCS Entity details
5	IdP ACCESS CI Entity ID: https://access-ci.org/idp Entity categories: REFEDS Research and Scholarship; http://id.incommon.org/category/registered-by-incommon SIRTFI: asserted Registrar: InCommon Org: National Center for Supercomputing Applications	ECCS Entity details
6	IdP ACOnet staff Entity ID: https://idp.aco.net/idp/shibboleth Entity categories: Data Protection Code of Conduct v1; REFEDS Research and Scholarship Registrar: ACOnet Identity Federation Org: ACOnet staff	ECCS Entity details
	IdP AIRCentre Entity ID: https://idp.aircentre.org/idp/shibboleth	ECCS

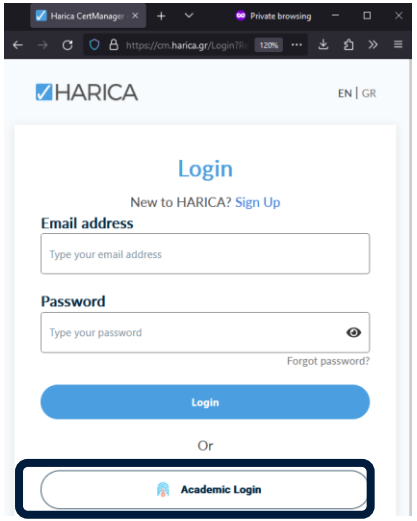
#credentials required?

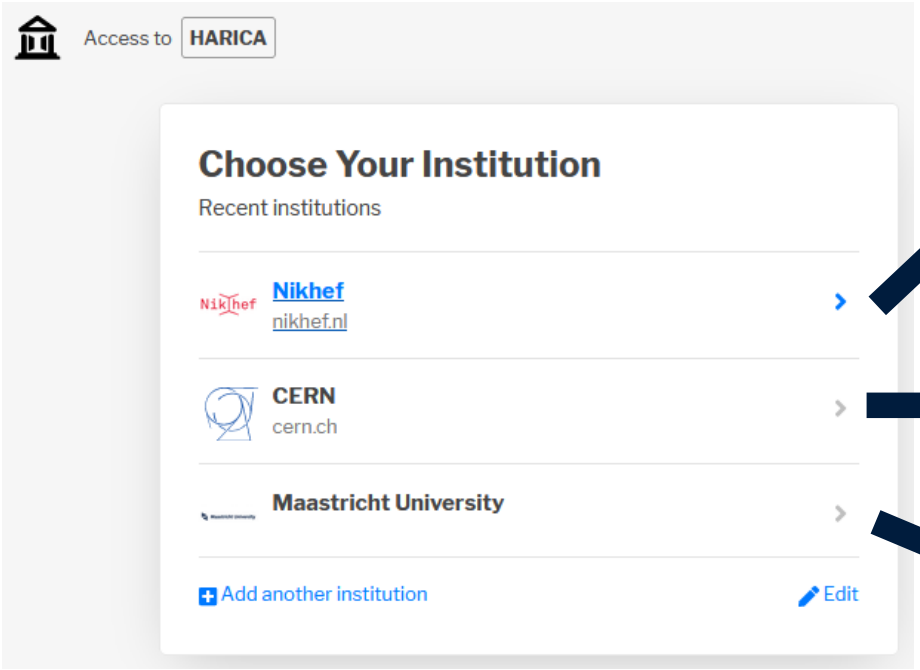
from $\mathcal{O}(n_{users}) + \mathcal{O}(n_{services} * n_{home\text{-}orgs})$

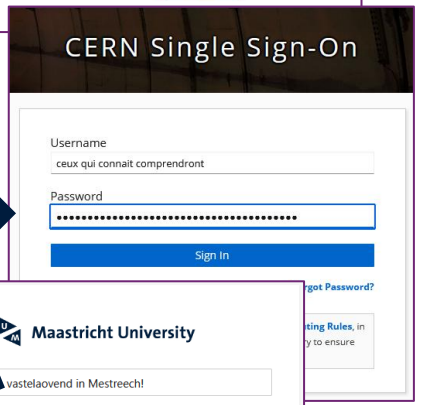
to ~ $\mathcal{O}(n_{users}) + \mathcal{O}(n_{home\text{-}orgs}) + \mathcal{O}(n_{services})$

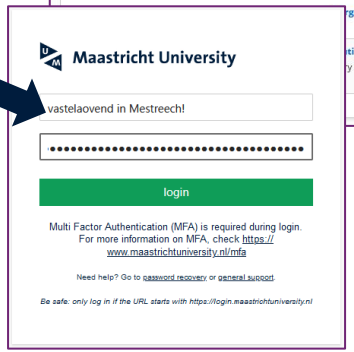
MDS meta-data flow: https://wiki.geant.org/display/eduGAIN/Metadata+Flow+in+eduGAIN
eduGAIN meta-data https://mds.edugain.org/edugain-v2.xml ; table excerpt from https://technical.edugain.org/entities showing only R&S IdPs, i.e. those supporting research …

Federation and discovery can be different aspects





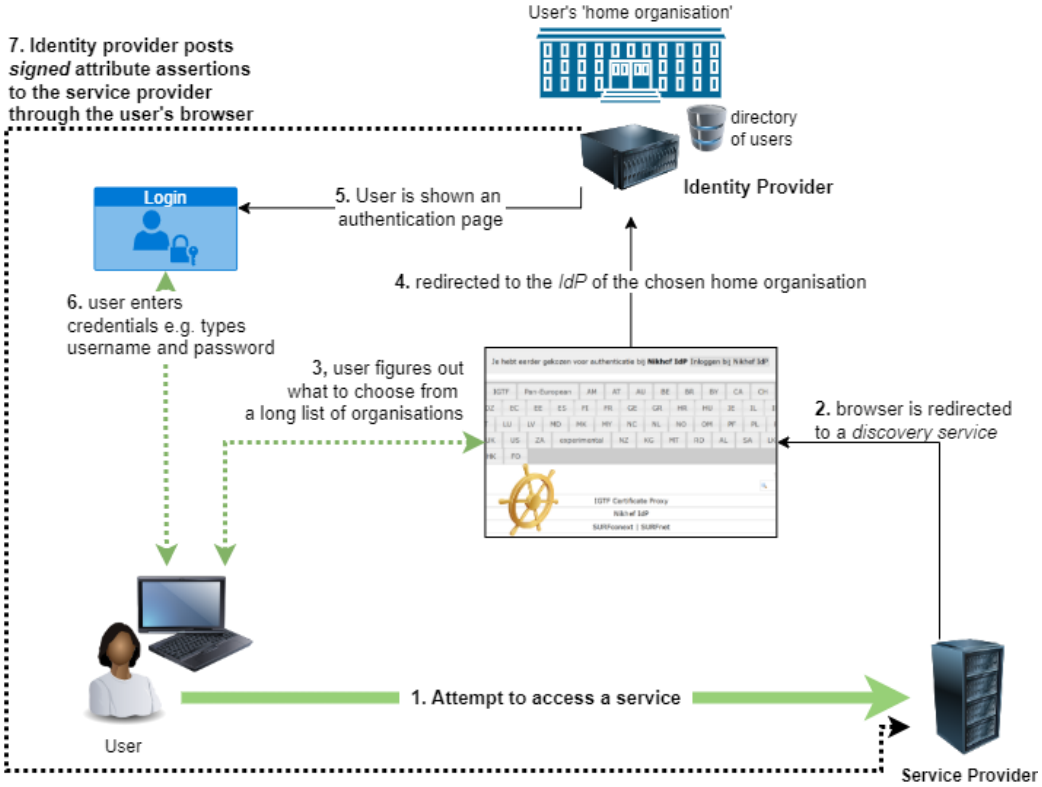


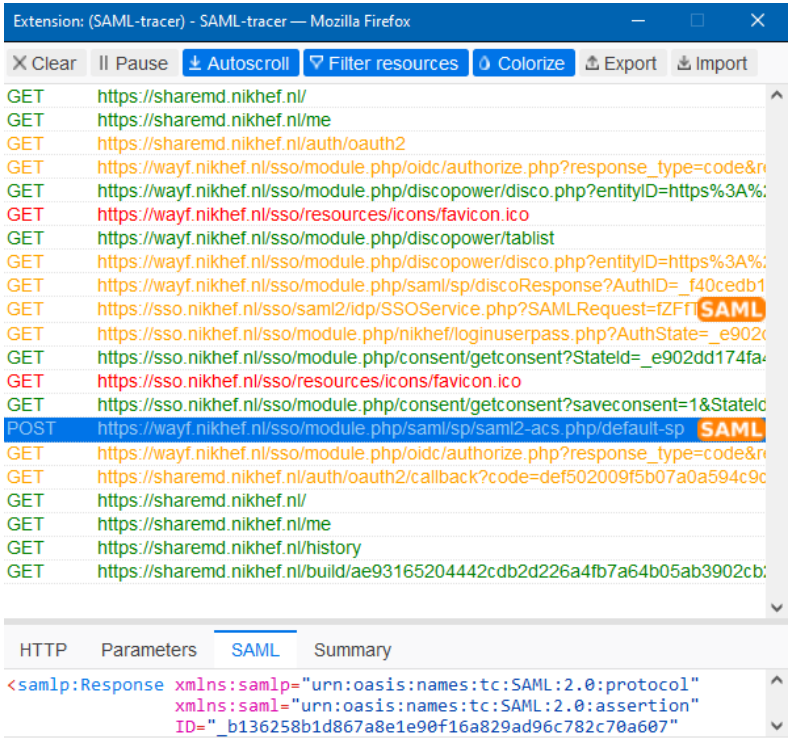


"to proxy or not to proxy, that's the question"

An example cross-institutional service by HARICA, the GEANT TCS G5 provider, presenting a SeamlessAccess.org discovery page

Full mesh or hub-n-spoke, with SAML meta-data





Access to the ShareMD service through token translation service SAML->OIDC with the simpleSAMLphp suite – simplesamlphp.org, sharemd.nikhef.nl

AAI: different technologies, same federation idea

SAML - Security Assertion Markup Language WebSSO ('SAML2Int' federation)

- XML-formatted 'attribute statements' over web transport (usually POST)
- **SAML-Metadata**: list of entities with description of bindings with entityAttributes

PKI - Public Key Infrastructure

- trusted third party (a *certification authority* a.k.a. *CA*)
  signs X.509 formatted certificates with name, issuer, serial number, and extensions
- CAs can sign end-entities as well as other CAs (hierarchically or by cross-signing)
- *bridge CAs* render a technical implementation of a shared policy (assurance)
- *policy-bridges* don't sign anything, but curate *distribution*
  (like browsers and operating systems based on CA/BF requirements, IGTF for research infras)

OpenID Federation – Federating OpenID Connect parties

- federate end-points for OIDC Providers and Relying Parties (or OAuth2), with similar models

note: federation based on 'ultimate trust' domains (e.g. cross-realm Kerberos) also exists …

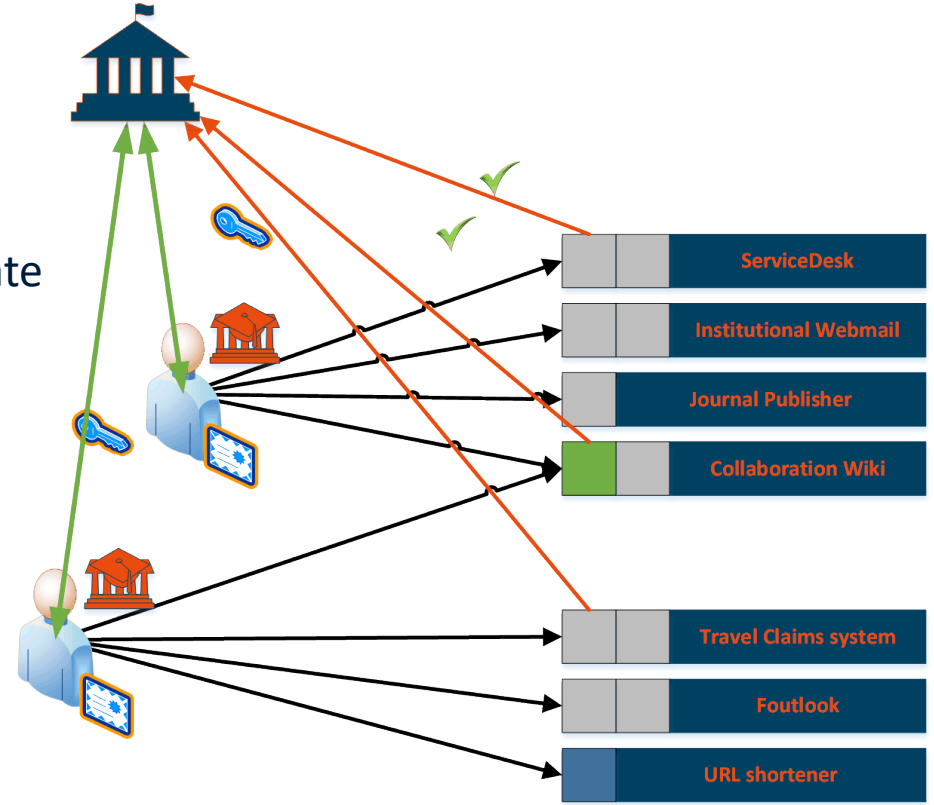
See www.oasis.org for SAML; RFC5280 (tech) & RFC3247 (policy) for PKIX, https://igtf.net/ and https://cabforum.org;
OpenID Connect Federation: https://openid.net/specs/openid-connect-federation-1_0.html

Federation with user-centric AAI

A trusted authority giving the user
a ‘self-managed’ credential, like a passport

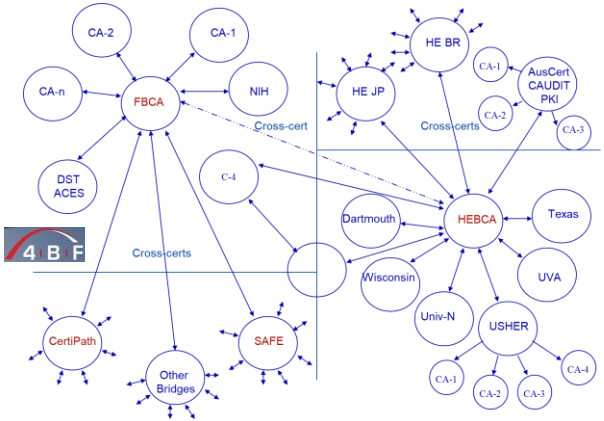
- a personal authentication digital certificate
- a verifiable credential in a wallet
- …

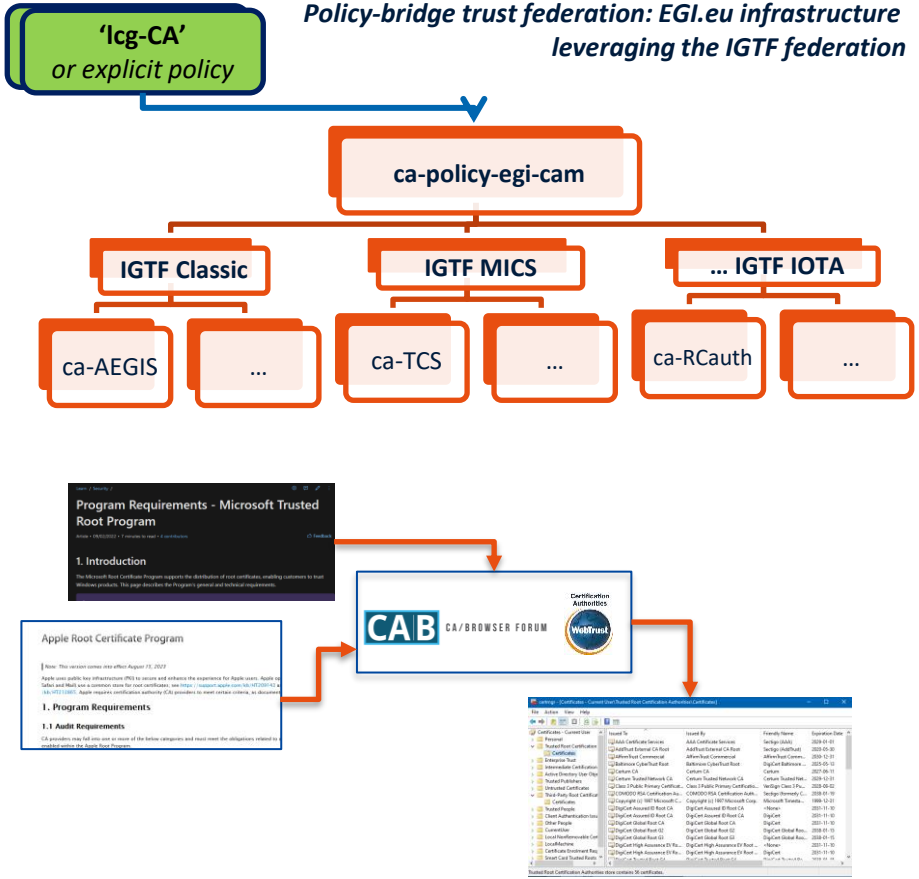
verified (on-line and also offline)
at the original trusted issuer
or at an independent trusted verifier



Federation: technological …
… or policy bridge

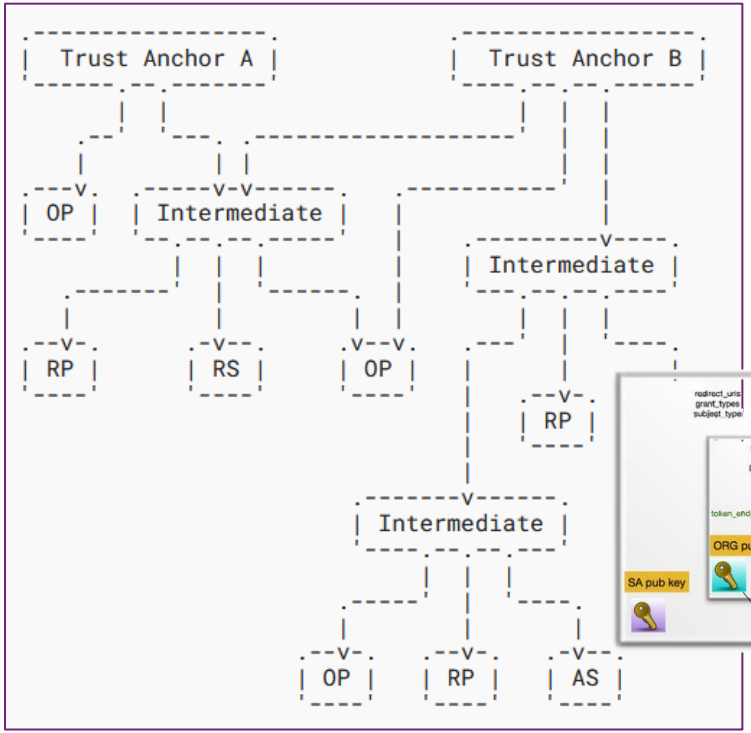
trust remains with the relying party
can be *bridged* by either cross-signing (left)
or by policy agreements (right)





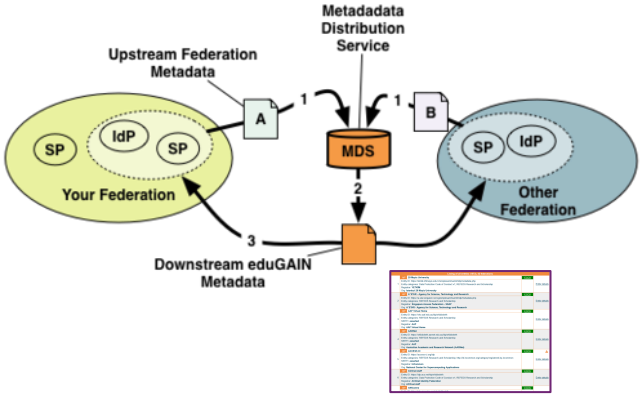
Left-hand image: 4 Bridges Forum, source: Scott Rea (then: Dartmouth University)
Images: cabforum.org, WebTrust logo: from DigiCert.com; image MS root store, https://learn.microsoft.com/en-us/security/trusted-root/program-requirements

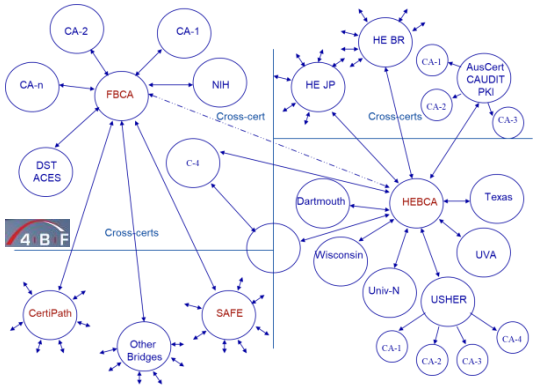
Federation concept is technology agnostic



Here showing

- ***OpenID Federation***
- ***SAML federation***
- ***BridgePKI***
  (‘ReallyOld™’)



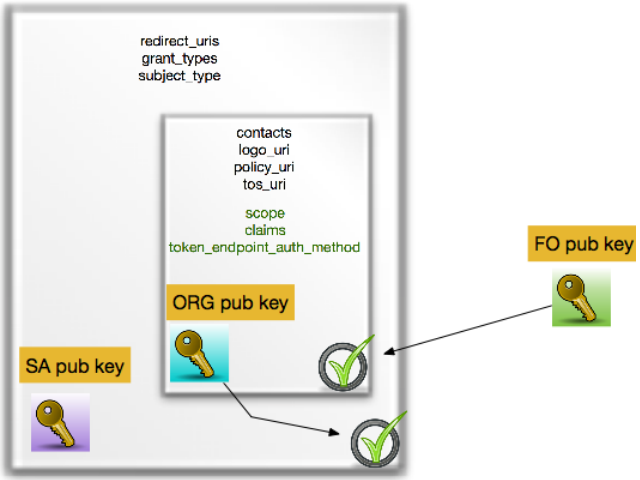


OpenID Federation signing image by Roland Hedberg; text diagram from OpenID Federation spec https://openid.net/specs/openid-federation-1_0.html
MDS meta-data flow: https://wiki.geant.org/display/eduGAIN/Metadata+Flow+in+eduGAIN

OpenID Federation

OIDC endpoints + trust policy data for registration can be federated in a meta-data feed

- makes OIDC ‘federatable’ (plain oidc is single OP)
- as for PKIX, can be technical or policy bridge
- delegated metadata makes ‘OIDC-fed’ scale in webscale scenarios



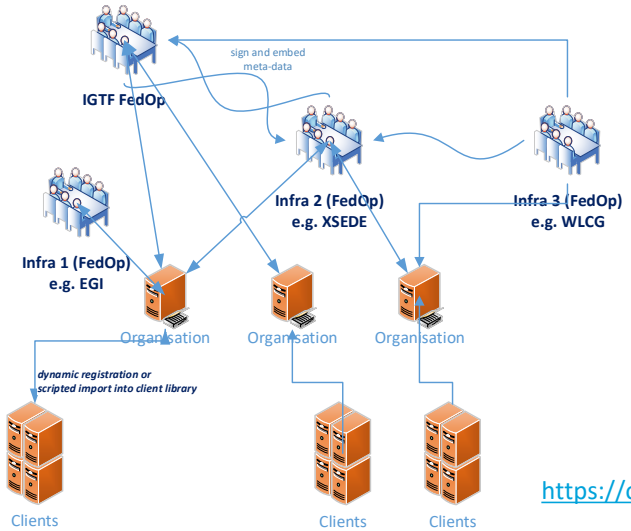
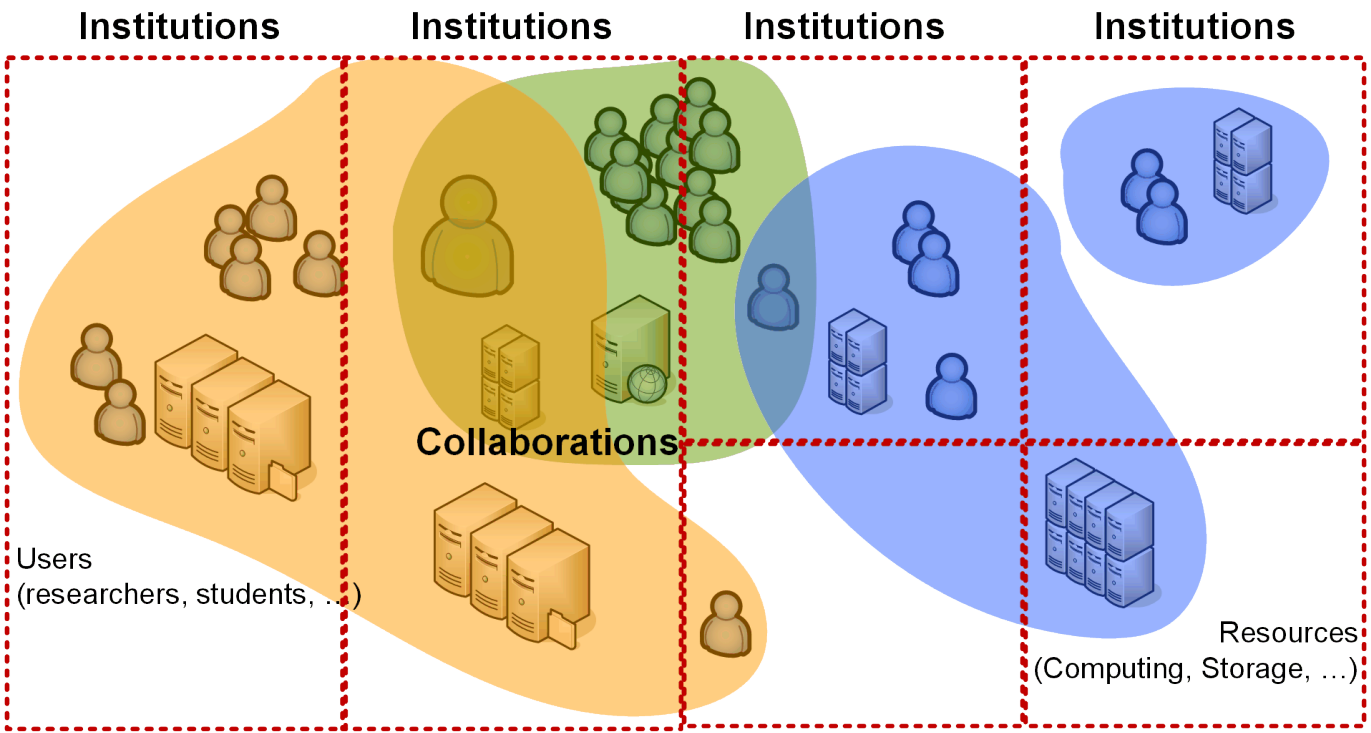


Image: Roland Hedberg, University of Umeå
OpenID Connect Fedrration:
https://openid.net/specs/openid-connect-federation-1_0.html

‘Orthogonal’ sources of Authority



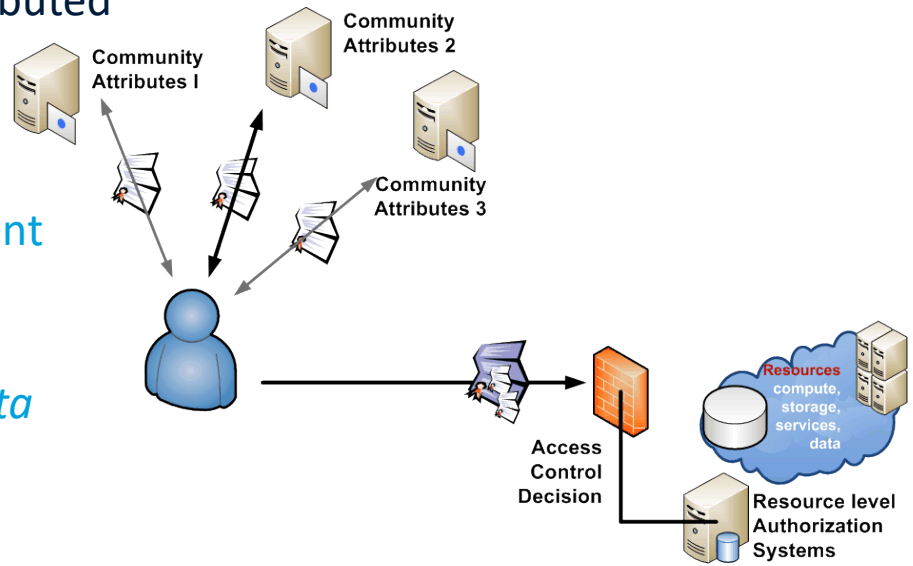
Multiple sources of authority: the community

- authorization assertion providers (attribute authorities) use the identifier(s) from authentication in their membership services

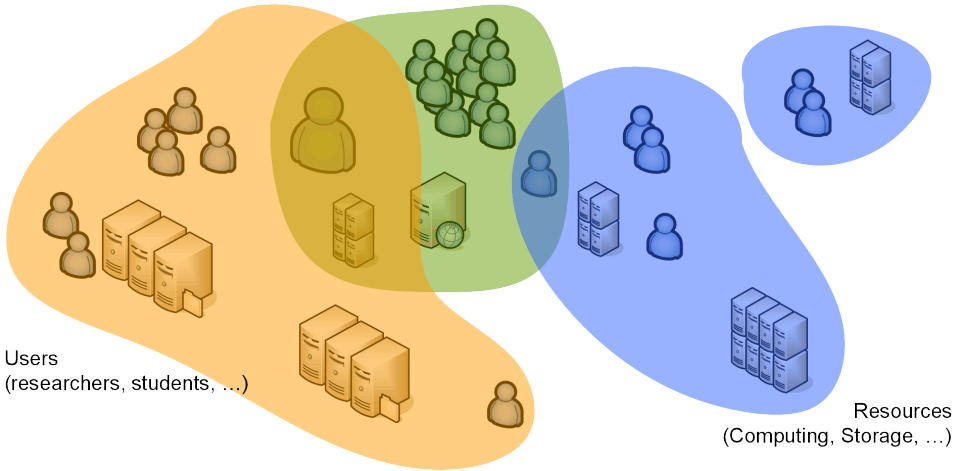
- *source of authority* for attributes is distributed

for example:
- community membership from an experiment
- affiliation status from home organisation

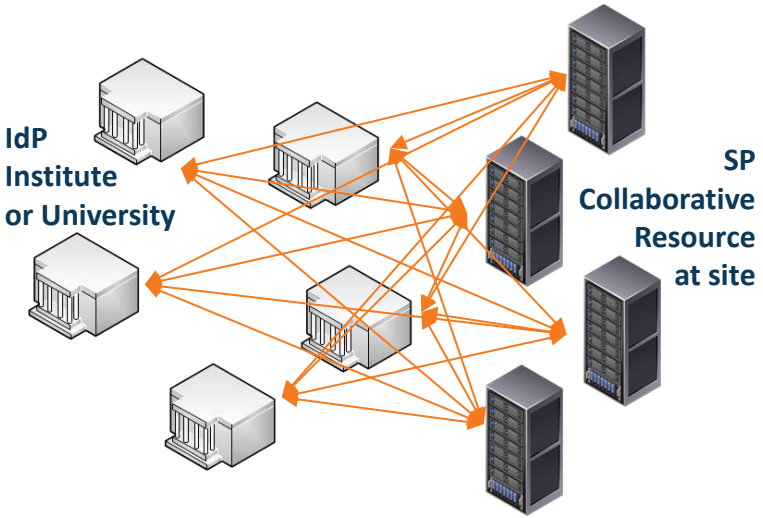
may be jointly needed to access sensitive data that is subject to medical-ethical clearance



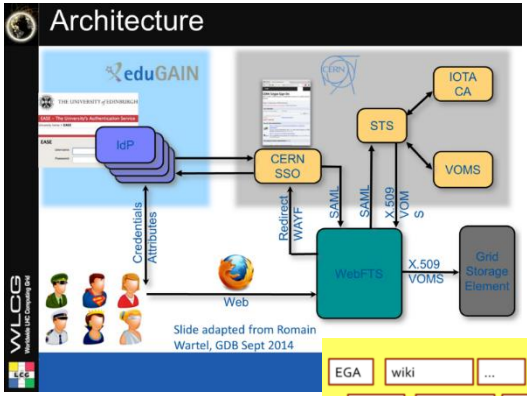
A fundamental scaling issue remained unique to research (and to joint venture business …)



for identity and user data
‘n x m’ agreements remain(ed)

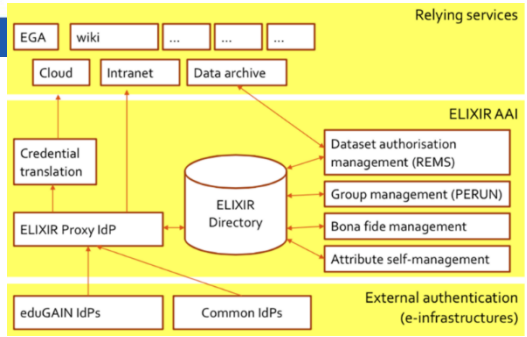


Managing complexities of federation & identity

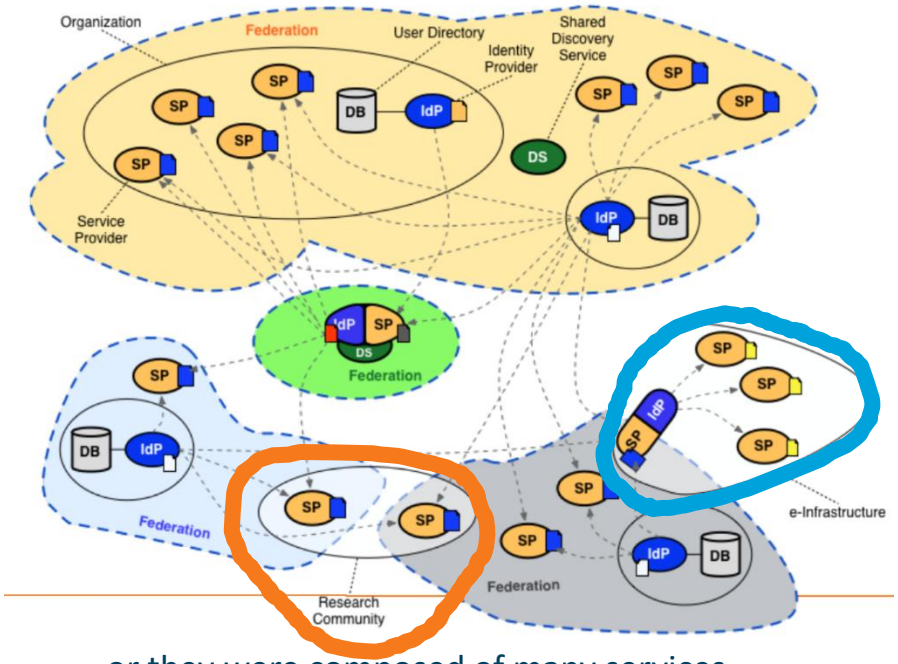


WebFTS prototype 'FIM4R' in wLCG Romain Wartel et al.

ELIXIR reference architecture 2016 Mikael Linden et al.



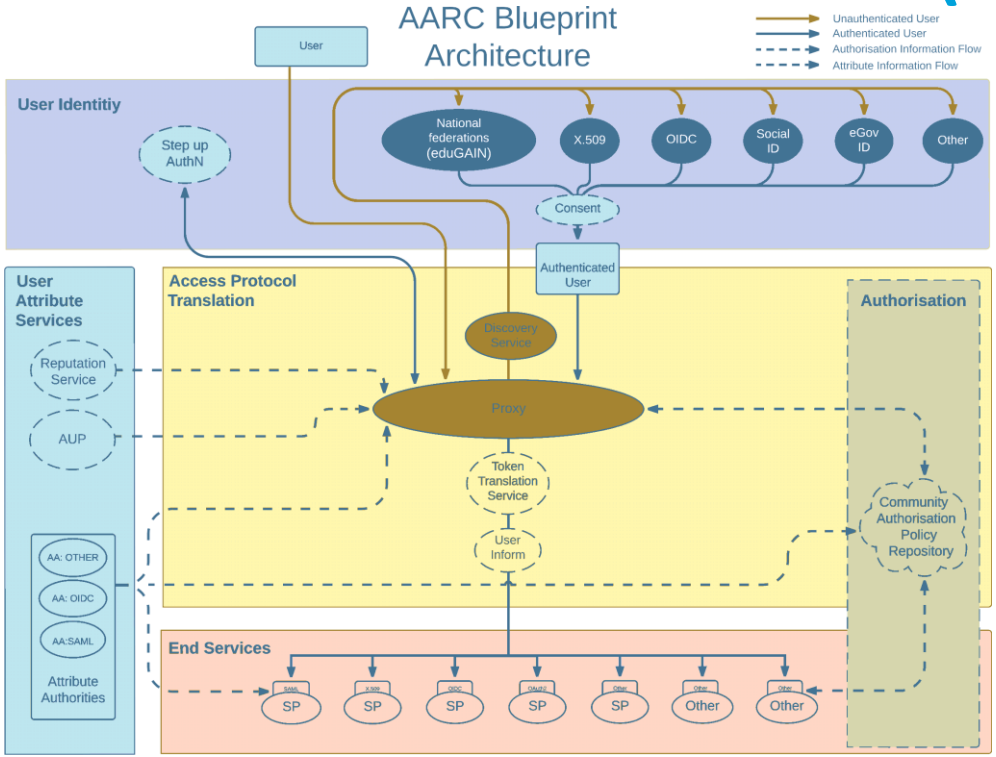
communities had either invented
their own 'proxy' model to abstract complexity

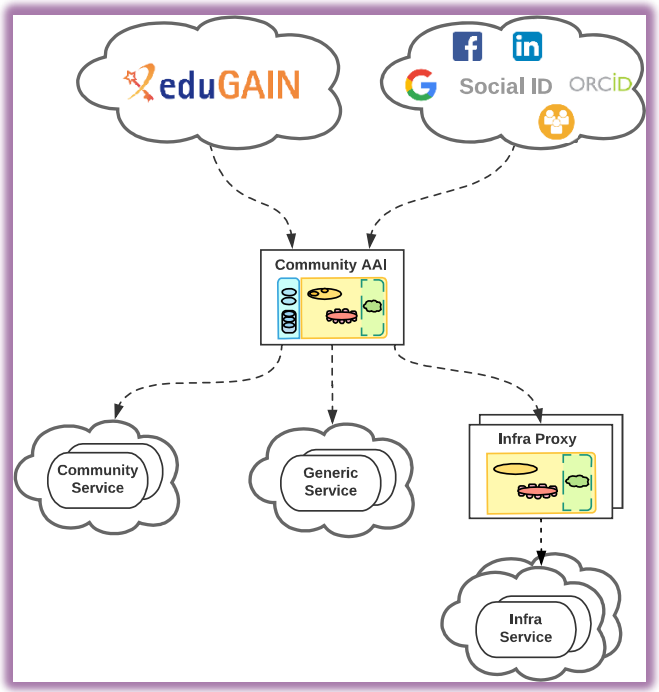


or they were composed of many services
each of which had to manage federation complexity

Community images: Romain Wartel, CERN; Mikael Linden, CSC; Lukas Hammerle, SWITCH

Most trust flows from the (research) community



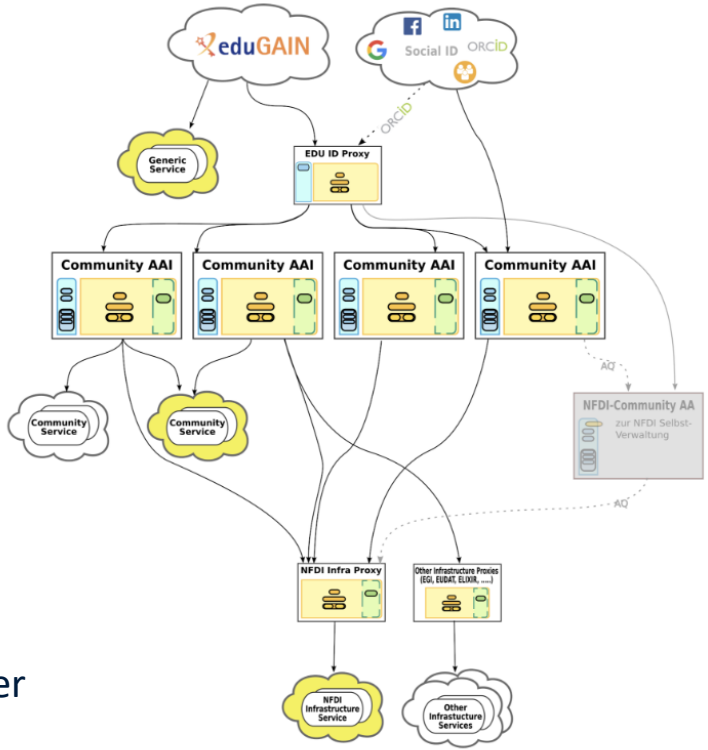


AARC Blueprint Architecture (2019) AARC-G045 https://aarc-community.org/guidelines/aarc-g045/; stacked proxies: EOSC AAI Architecture
EOSC Authentication and Authorization Infrastructure (AAI), ISBN 978-92-76-28113-9, http://doi.org/10.2777/8702

Composite AAIs: proxies beyond just the research infrastructures

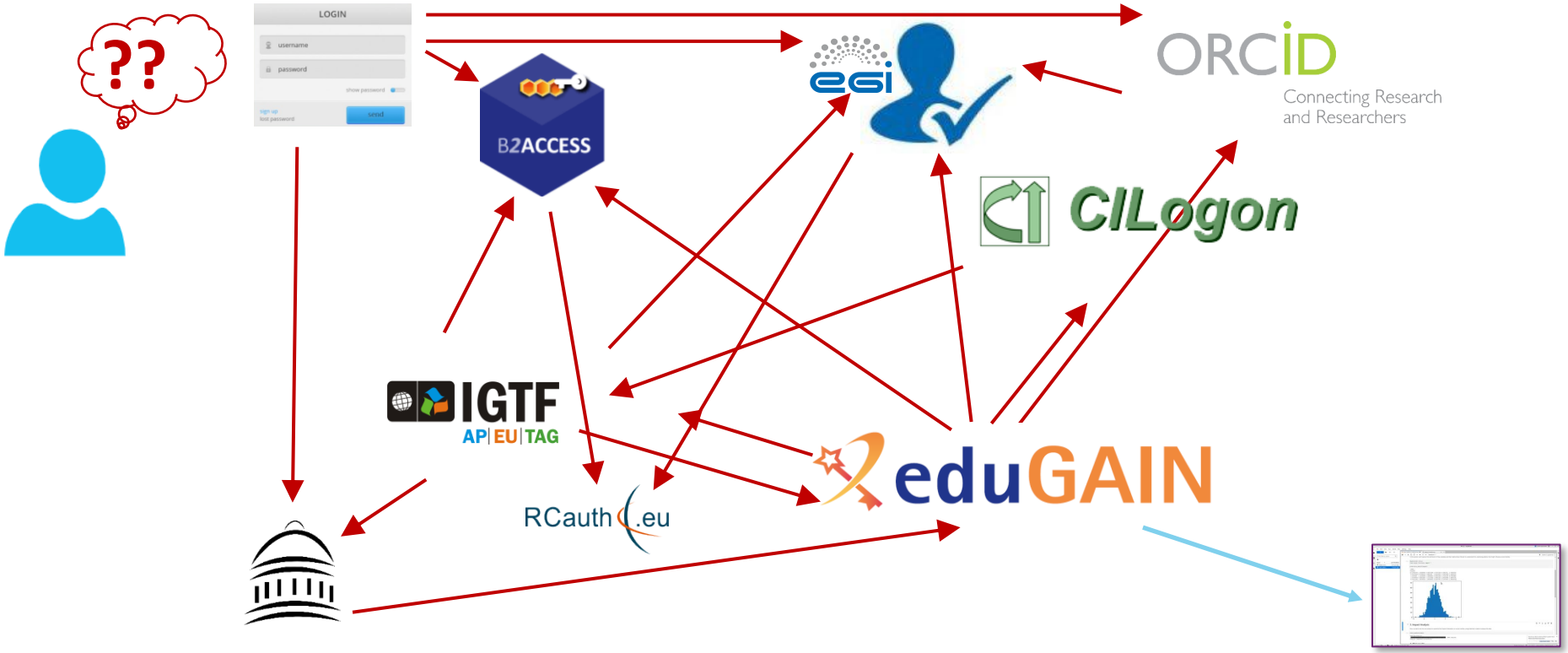
Proxy model harmonizes IdPs from many sources

- **eduID**-style identifiers
  - ‘life-long learning’ identifiers
  - independent student identifier (the ESI) for mobility & Erasmus-without-papers
  - eduGAIN-alignment, but also a ‘provider of last resort’
- **eIDAS** and government eID (e.g. DigID)
  - identity assurance step-up
- **ORCID** provides identifier portability through linking
  - provides name linking and persistent attribution
  - since it persists, also very useful to allow access *independent of home organisation* throughout a career



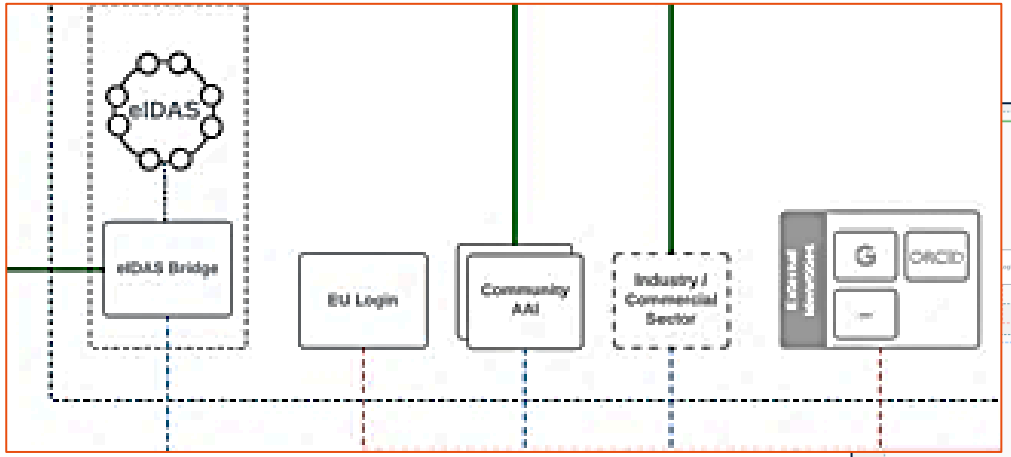
Composite AAI image source: Christos Kanellopoulos (GEANT), Marcus Hardt (KIT)

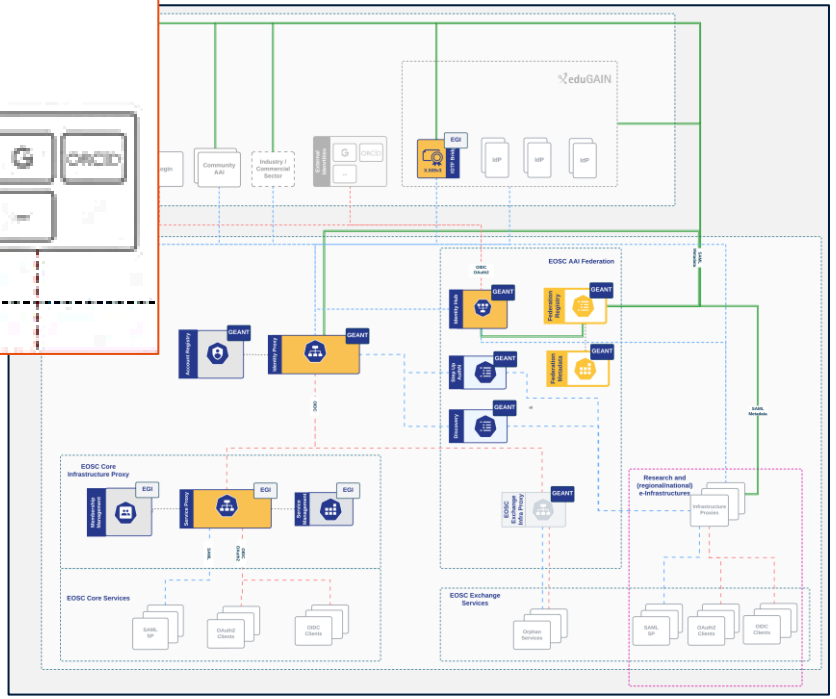
But institutional identity sources may make loops ☹



European Open Science Cloud (EOSC) AAI Federation

***Identity assurance** brings the true value:*
authenticators are aplenty, and 'MFA'
far less interesting than vetted identities.
But HEI home IdPs seem reluctant to provide it …





user identity comes 'with the user' from outside,
mediated by the research community, ORCID,
or from the home member state involved

Image: EOSC AAI for the EOSC Core and Exchange Federation for the EOSC European Node by Christos Kanellopoulos, Nicolas Liampotis, David Groep (June 2023)

EOSC – it's a federation yet again

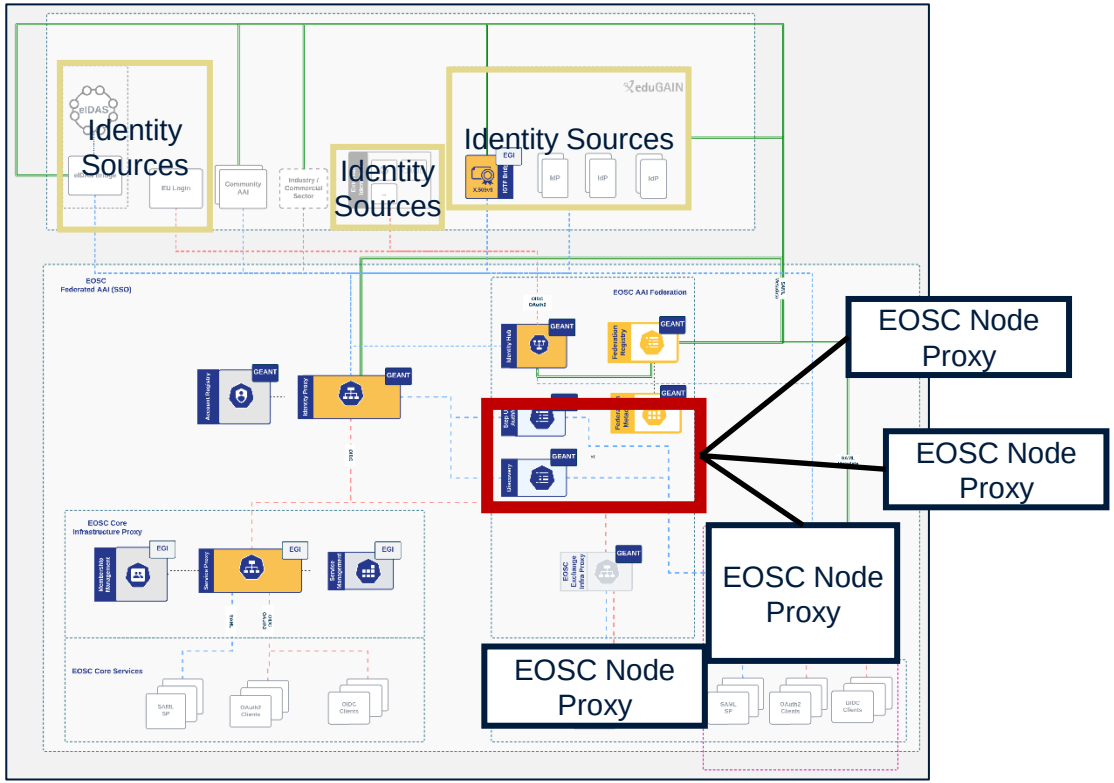
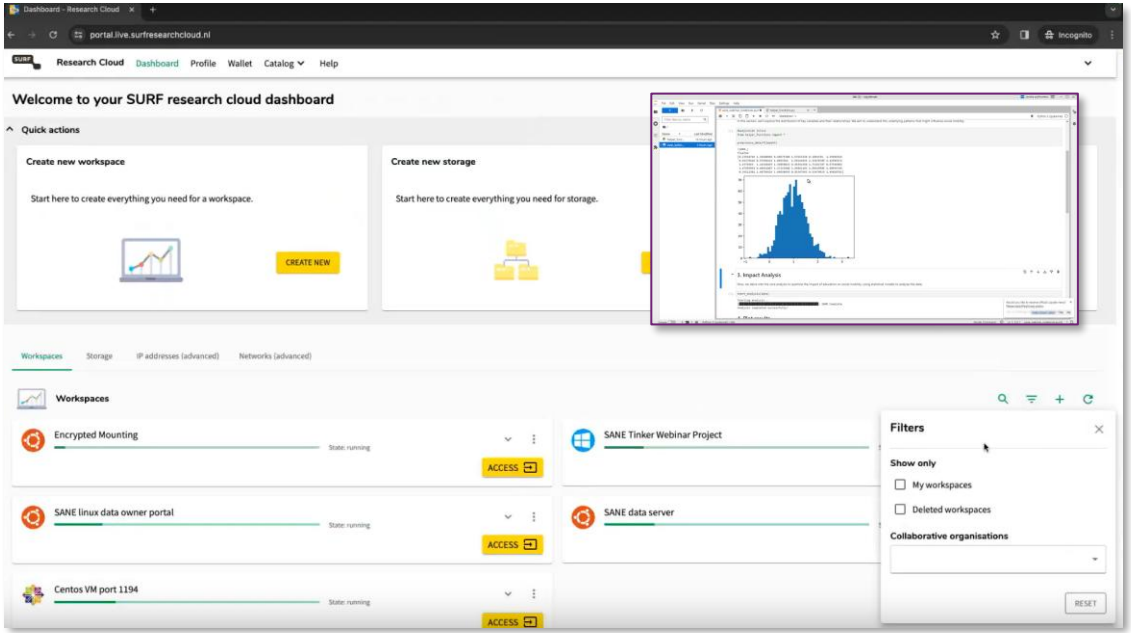
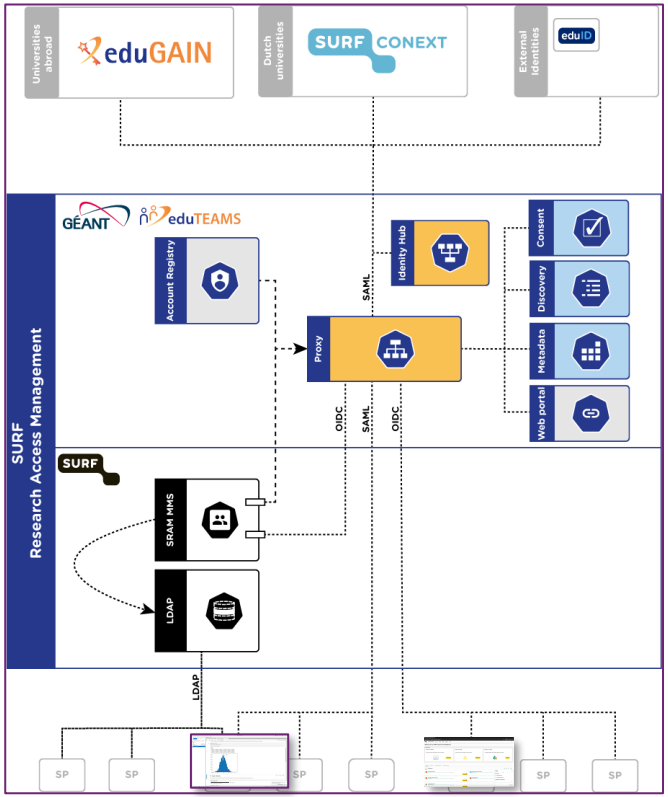


Image: EOSC AAI for the
EOSC Core and Exchange Federation
for the EOSC European Node
Christos Kanellopoulos, Nicolas Liampotis, David Groep (June 2023)

Example: SURF Research Cloud Secure Supercomputing





SURF SRAM architecture, Raoul Teeuwen *et al.* from
https://servicedesk.surf.nl/wiki/display/IAM/Dienstbeschrijving+SURF+Research+Access+Management
SURF Research Cloud capture: from Introduction to SANE (Secure ANalysis Environment)
webinar February 2024, by Martin Brandt et al., SURF
https://www.surf.nl/themas/onderzoeksinfrastructuur/sane-veilige-omgeving-voor-analyse-van-gevoelige-data

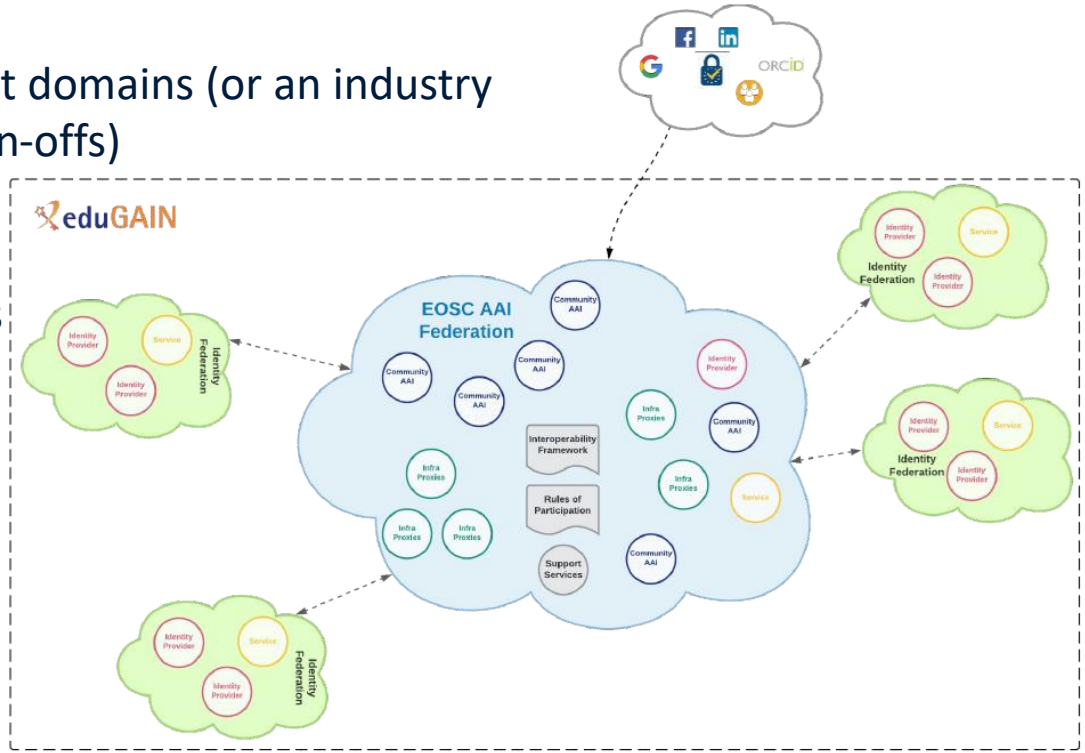
When many proxies from different groups come together

When collaborations cross different domains (or an industry sector with lots of mergers and spin-offs)

- proxies with each group
- inter-federate SP/IdP interfaces
- each federation can add own policy and entity filtering

Example

European Open Science Cloud (EOSC) AAI based on federations and proxies

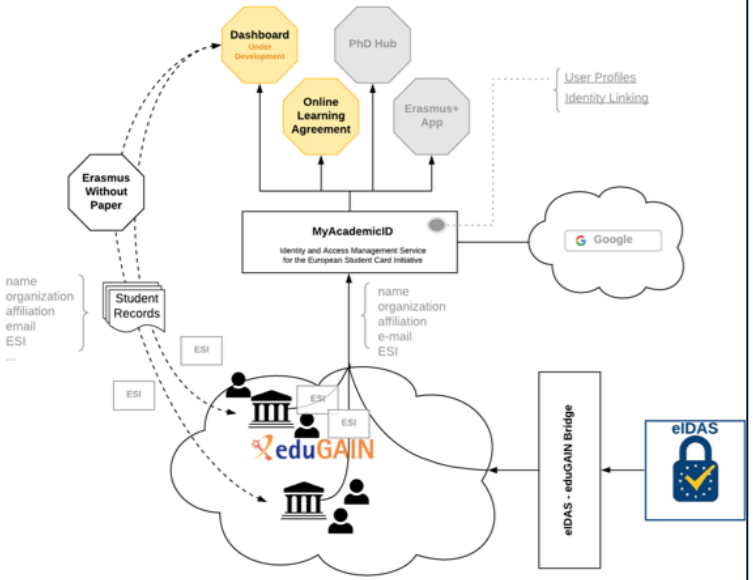


Christos Kanellopoulos (GEANT) for the EOSC AAI Federation in "The EOSC Core", https://eoscfuture.eu/wp-content/uploads/2022/04/EOSC-Core.pdf

Also building blocks for your student identity, Erasmus+, and EWP

MyAID Architecture

- Provides an Authentication Proxy for the core Erasmus+ services (Online Learning Agreement, Dashboard, PhD Hub and the Erasmus+ App).
- Supports authentication via eduGAIN, eIDAS and Google



The AARC Blueprint – a very digestible architecture … so

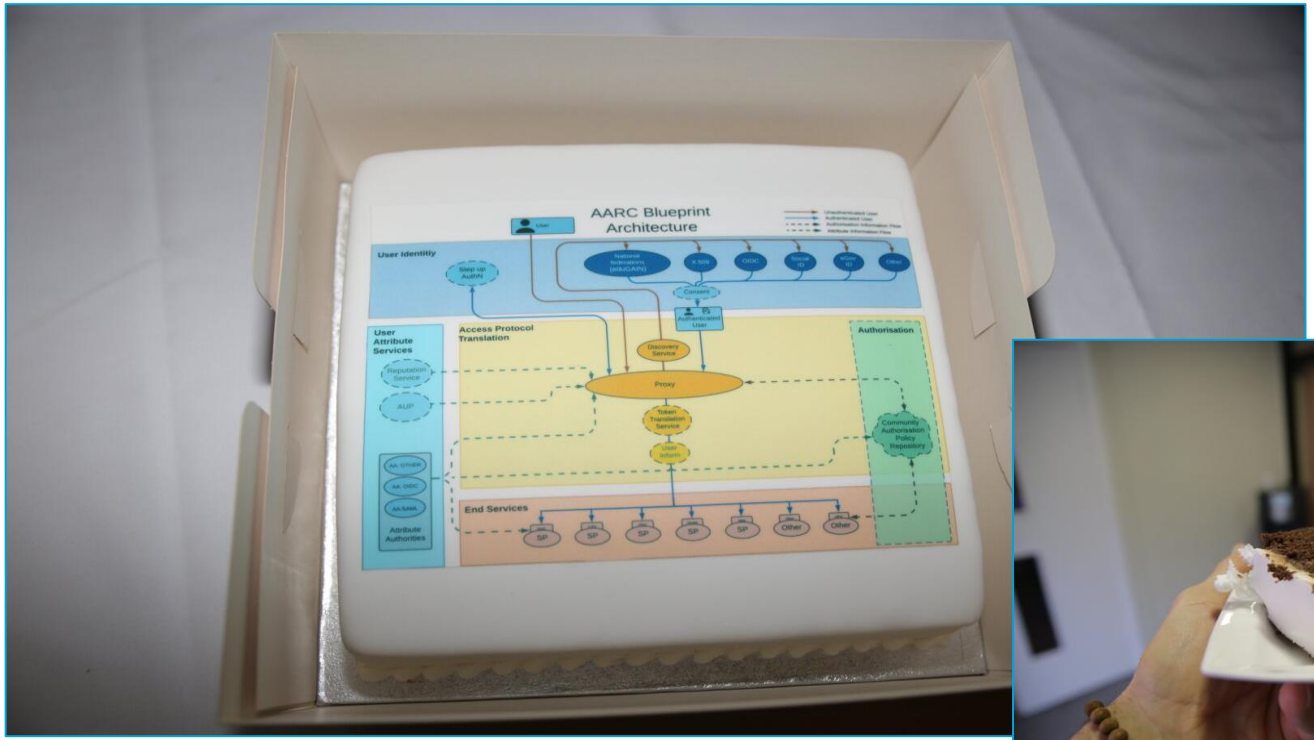


Photo credit: Marcus Hardt

Putting it back together again

Common patterns in scalability

Make and treat computing as the research instrument it is today – institutionally and globally

Institutional:
e.g. FSE CSLab, DSRI,

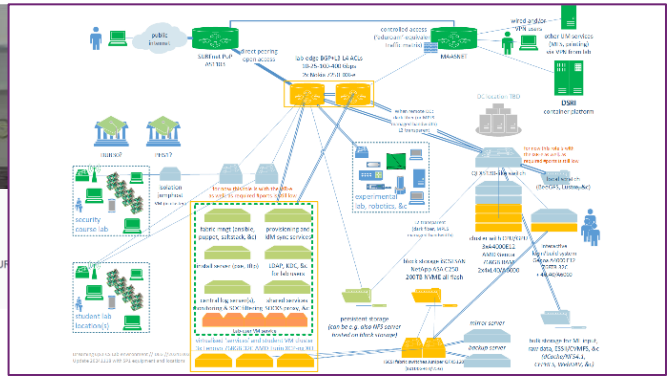
National Infrastructure
SURF Snellius HPC

as well as JP's HPCI,
US's AccessCI, &c of course!

There are today as much part of science as detectors are to physics
and: users should move seamlessly between tiers

Photos: Nikhef NDPF, DelftBlue/TUDelft, SURF Data Repository, Snellius, SURF @ DigitalRealty; EuroHPC images: EuroHPC, LUMI Consortium, Jules Verne consortium

Education labs are much like ad-hoc research as well



SRAM API 1.0

/swagger_api/apispec.json

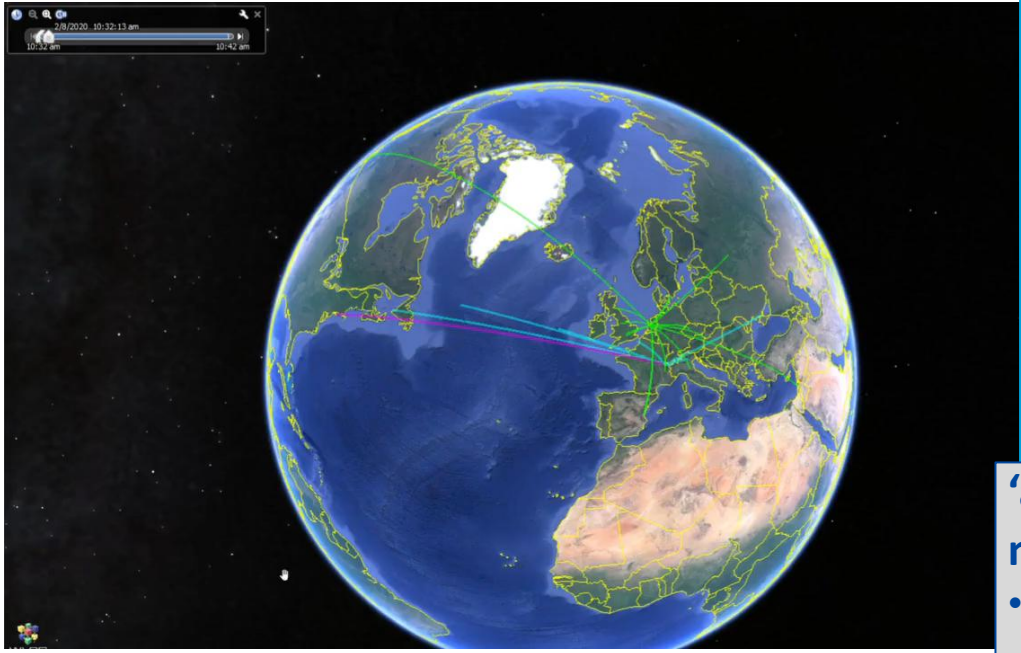
Documentation for the public APIs of SUF

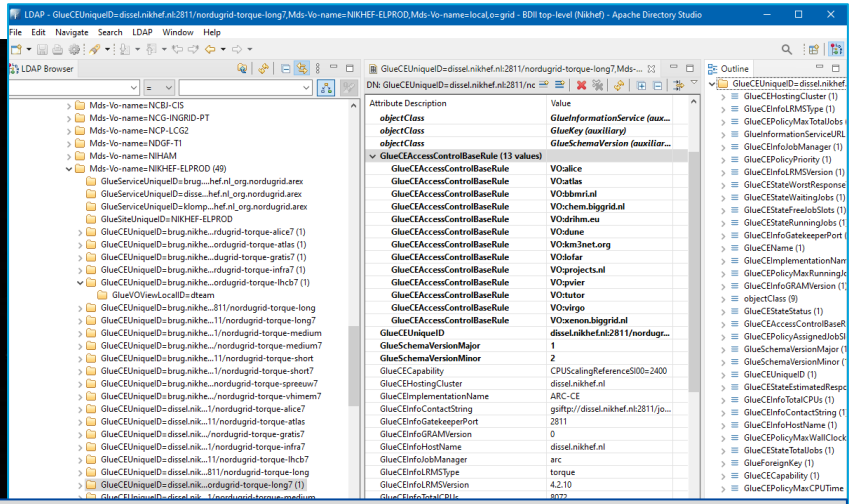
Organisation All endpoints for organisations using an organisation API token

POST	/api/collaborations/v1 Post a new collaboration.		post_api_collaborations_v1
DELETE	/api/collaborations/v1/{co_identifier}	Delete collaboration.	delete_api_collaborations_v1__co_identifier_
PUT	/api/collaborations/v1/{co_identifier}/members	Update collaboration membership.	put_api_collaborations_v1__co_identifier__members
DELETE	/api/collaborations/v1/{co_identifier}/members/{user_uid}	Delete collaboration membership.	delete_api_collaborations_v1__co_identifier__members__user_uid_
PUT	/api/collaborations/v1/{co_identifier}/units	Update collaboration units.	put_api_collaborations_v1__co_identifier__units
PUT	/api/collaborations_services/v1/connect_collaboration_service	Connect service to collaboration.	put_api_collaborations_services_v1_connect_collaboration_service
PUT	/api/collaborations_services/v1/disconnect_collaboration_service	Disconnect service from collaboration.	put_api_collaborations_services_v1_disconnect_collaboration_service

Photo by sunrise University on Unsplash; network diagram: FSE CSLab, Maastricht University; SRAM API: https://sram.surf.nl/apidocs/

A global infrastructure





'an infrastructure with components matched to application need'

- systems architecture: compute (HTC clusters), networking, storage, and application structure
- in a balanced and {energy,cost}-efficient setup

BerkeleyDB Information System for EGI, from top-level BDII at ldap://bdii03.nikhef.nl:2170/o=grid; Earth visualization: https://dashb-earth.cern.ch/, Google Earth

So: did we solve this inherently-cross-domain issue … ?

Both Yes and No

Even WLCG alone today comprises
over 900 000 CPU cores,
2.9 Exabyte of near-line storage,
1330 Petabye of disk storage,
12 200 users, 110 nationalities,
170 institutes in over 70 countries
which is some definition of 'works'

Authentication and authorization 'AAI' infrastructures enable research every day

But building an *interoperable* system enabling multi-domain distributed computing remains a challenge … even for a single company

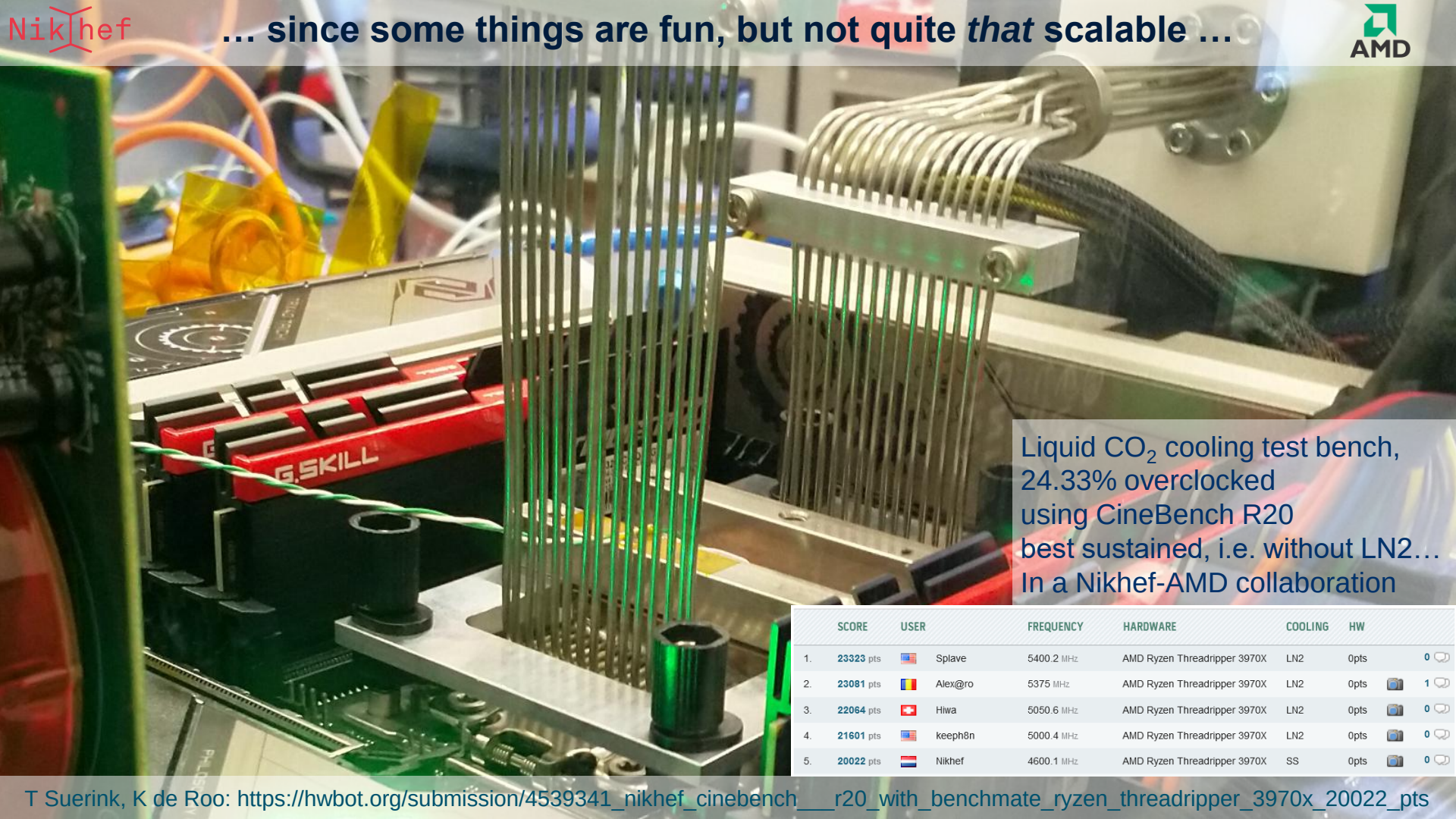
site map: WLCG, visualization: CERN IT https://wlcg-public.web.cern.ch/about and https://wlcg.web.cern.ch/using-wlcg/monitoring-visualisation/monthly-stats

Look for the common pattern …

- It's all about *balanced* systems
  - systems are like congested highways: no use solving just *one* bottleneck
  - and the bottlenecks may be inside the system as well as in interconnects
- Horizontal scaling, and be as stateless as possible
  - although persistent storage obviously has to retain some state ☺
  - edge scales horizontally, and scaling from 2+ is much easier than from 1→ 2
- Scaling *collaboration and trust* federation is as complex as scaling systems
  - composing services across administrative domains is ubiquitous
  - but beyond a certain size, $\mathcal{O}(100)$, you will find need for some policy and review

And: you can move problems around, but it's hard to actually *solve* them!

… since some things are fun, but not quite *that* scalable …



Liquid CO_2 cooling test bench,
24.33% overclocked
using CineBench R20
best sustained, i.e. without LN2…
In a Nikhef-AMD collaboration

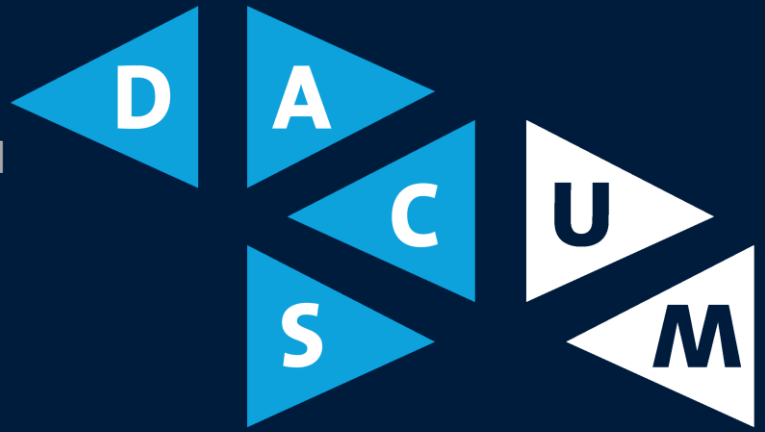
	SCORE	USER	FREQUENCY	HARDWARE	COOLING	HW	
1.	23323 pts	Splave	5400.2 MHz	AMD Ryzen Threadripper 3970X	LN2	0pts	0
2.	23081 pts	Alex@ro	5375 MHz	AMD Ryzen Threadripper 3970X	LN2	0pts	1
3.	22064 pts	Hiwa	5050.6 MHz	AMD Ryzen Threadripper 3970X	LN2	0pts	0
4.	21601 pts	keeph8n	5000.4 MHz	AMD Ryzen Threadripper 3970X	LN2	0pts	0
5.	20022 pts	Nikhef	4600.1 MHz	AMD Ryzen Threadripper 3970X	SS	0pts	0

T Suerink, K de Roo: https://hwbot.org/submission/4539341_nikhef_cinebench___r20_with_benchmate_ryzen_threadripper_3970x_20022_pts

Q&A

or enjoy the remained of today …

David Groep, david.groep@maastrichtuniversity.nl
https://www.nikhef.nl/~davidg/presentations/
https://orcid.org/0000-0003-1026-6606

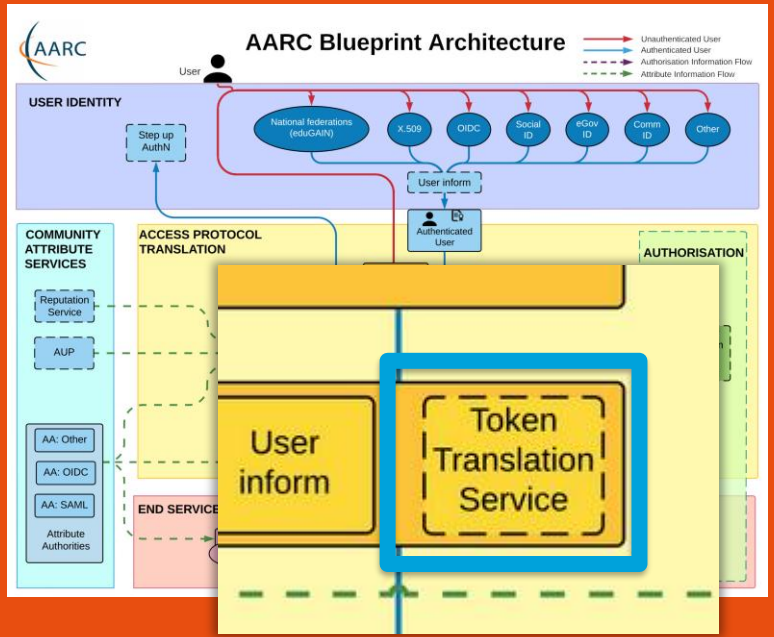


Nikhef

Maastricht University | Department of Advanced Computing Sciences

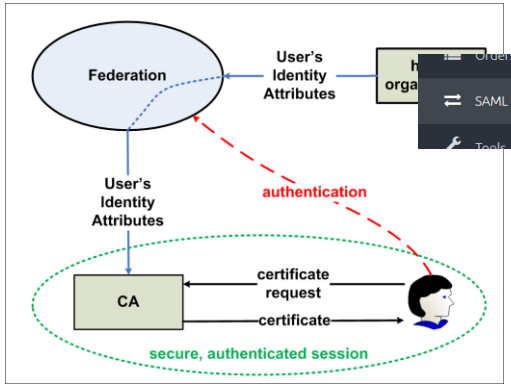
Distributed collaborative services
a more technical example with RCauth.eu

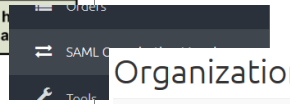
Credential translation in the AARC BPA
… building RCauth.eu
Leveraging federation and collaboration
for ubiquitous research credentials



Bridges and Token Translation Services

TCS - for users that manage to grasp the idea



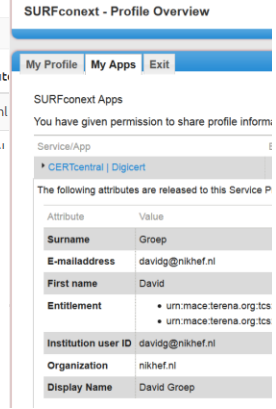


Organization Mapping

+ New Mapping

Organization	Attribut
Nikhef	nikhef.nl

SURF GÉANT



SURFconext - Profile Overview

My Profile | My Apps | Exit

SURFconext Apps

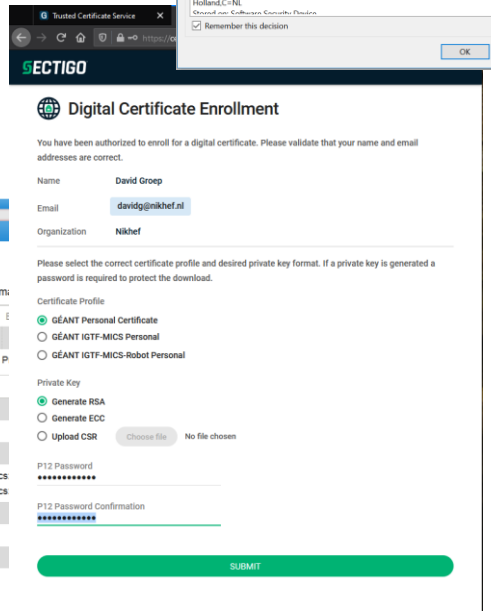
You have given permission to share profile informa

Service/App

CERTcentral | Digicert

The following attributes are released to this Service P

Attribute	Value
Surname	Groep
E-mailaddress	davidg@nikhef.nl
First name	David
Entitlement	• urn:mace:terena.org:tcs • urn:mace:terena.org:tcs
Institution user ID	davidg@nikhef.nl
Organization	nikhef.nl
Display Name	David Groep



SECTIGO

Digital Certificate Enrollment

You have been authorized to enroll for a digital certificate. Please validate that your name and email addresses are correct.

Name David Groep

Email davidg@nikhef.nl

Organization Nikhef

Please select the correct certificate profile and desired private key format. If a private key is generated a password is required to protect the download.

Certificate Profile

- GÉANT Personal Certificate
- GÉANT IGTF-MICS Personal
- GÉANT IGTF-MICS-Robot Personal

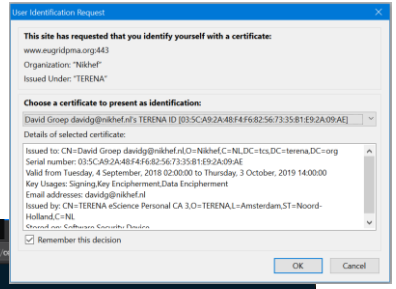
Private Key

- Generate RSA
- Generate ECC
- Upload CSR — Choose file — No file chosen

P12 Password

P12 Password Confirmation

SUBMIT



User Identification Request

This site has requested that you identify yourself with a certificate:

www.eugridpma.org:443

Organization: "Nikhef"

Issued Under: "TERENA"

Choose a certificate to present as identification:

David Groep davidg@nikhef.nl's TERENA ID [03:5C:A9:2A:48:F4:F6:82:56:73:35:81:E9:2A:09:AE]

Details of selected certificate:

Issued to: CN=David Groep davidg@nikhef.nl,O=Nikhef,C=NL,DC=tcs,DC=terena,DC=org
Serial number: 03:5C:A9:2A:48:F4:F6:82:56:73:35:81:E9:2A:09:AE
Valid from Tuesday, 4 September, 2018 02:00:00 to Thursday, 3 October, 2019 14:00:00
Key Usages: Signing,Key Encipherment,Data Encipherment
Email addresses: davidg@nikhef.nl
Issued by: CN=TERENA eScience Personal CA 3,O=TERENA,L=Amsterdam,ST=Noord-Holland,C=NL

Remember this decision

OK Cancel

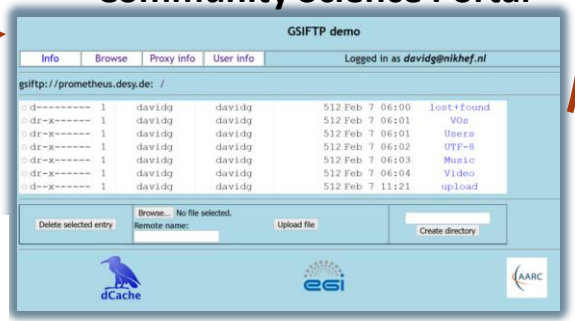
TCS is a SAML Service Provider (today by Sectigo)
to eduGAIN: where eligible authenticated users obtain client certificates for access to many research services
A globally recognized identity for all employees & students (they are automatically eligible!).

GEANT Trusted Certificate Service - https://ca.dutchgrid.nl/tcs/,
https://cert-manager.com/customer/surfnet/idp/clientgeant, https://www.geant.org/Services/Trust_identity_and_security/Pages/TCS.aspx

Seamless in-line token translation services from ‘SAML’ to PKIX

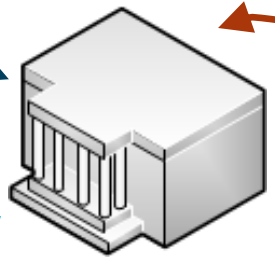
user facing | hidden back-end

Community Science Portal

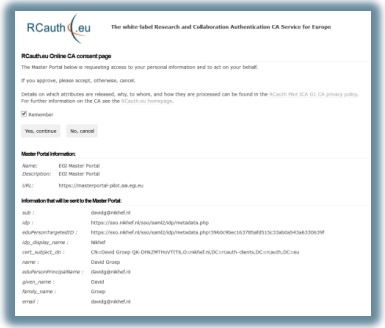


User Home Org
or Infrastructure IdP

see also https://rcdemo.nikhef.nl/

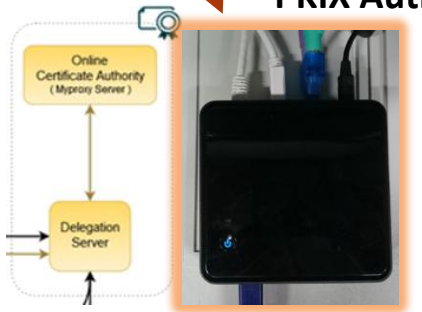


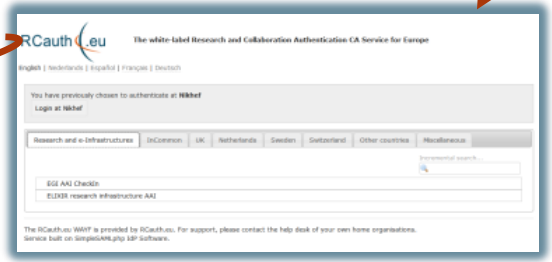
REFEDS R&S
Sirtfi Trust



Infrastructure Master Portal Credential Store

IGTF accredited PKIX Authority





Policy Filtering WAYF to eduGAIN

Unique certificated from FIM via eduPerson and REFEDS R&S

Sources of naming and uniqueness, that work *today*

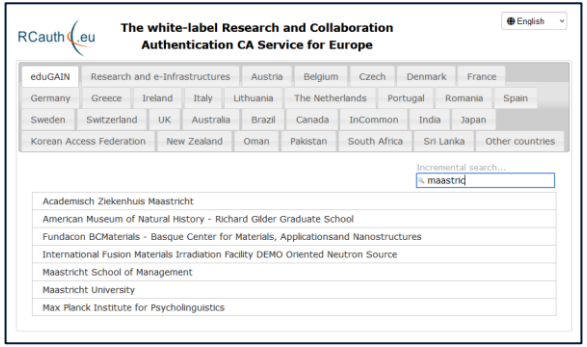
- **eduPersonPrincipalName** – scoped point-in-time unique identifier, which could be, but usually is not, privacy preserving: “davidg@nikhef.nl”, “P70081609@maastrichtuniversity.nl”
- **eduPersonTargetedID** – scoped transient non-reassigned identifier, like urn:geant:nikhef.nl:nikidm:idp:sso!*27c8d63ed42c84af2875e2984*
- **subject-id** - a scoped persistent non-reassigned identifier, which should be privacy-preserving: 44f7751265a6e8b228f9@nikhef.nl

Plus the (domain-name based) schacHomeOrganisation and a ‘**representation of the real name**’

/DC=eu/DC=rcauth/DC=rcauth-clients/O=*orgdisplayname*/CN=*commonName +uniqeness*

uniqueness will added to commonName via hashing of *ePPN, ePTID, subject-id*, so that an enquiry via the issuer allows unique identification of the vetted entity”

The ‘back side’ of a typical RCauth portal data flow



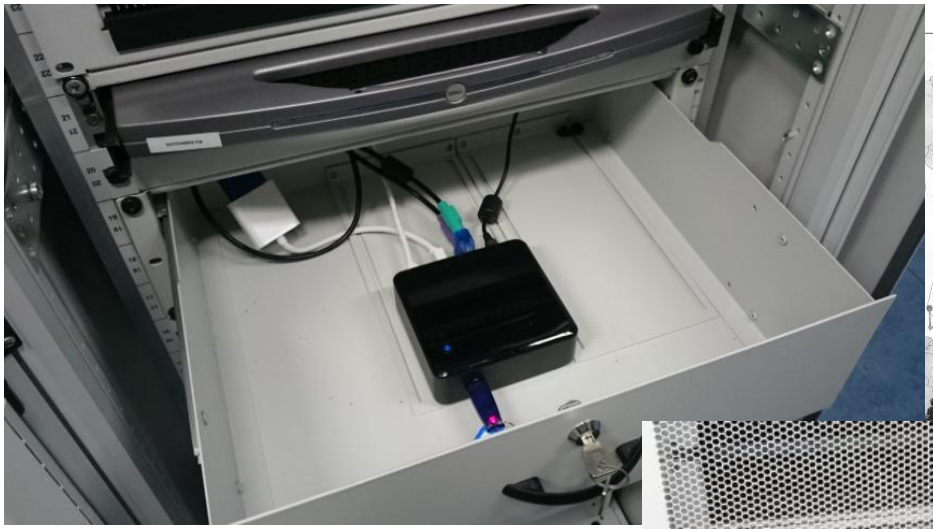
Parsed ID Token:

```
stdClass Object
(
    [typ] => JWT
    [kid] => E01796EA0367564935B0981731B9B116
    [alg] => RS256
)
stdClass Object
(
    [sub] => P70081609@unimaas.nl
    [idp] => http://login.maastrichtuniversity.nl/adfs/services/trust
    [eduPersonTargetedID] => http://login.maastrichtuniversity.nl/adfs
    [idp_display_name] => Maastricht University
    [cert_subject_dn] => CN=Groep\, David (DACS) KWwWAnhI4psmiGTw 1,O=
    [name] => Groep, David (DACS)
    [eduPersonPrincipalName] => P70081609@unimaas.nl
    [given_name] => David
    [family_name] => Groep
    [email] => david.groep@maastrichtuniversity.nl
    [iss] => https://aai.egi.eu/mp-oa2-server
```

Proxy information:

```
subject   : /DC=eu/DC=rcauth/DC=rcauth-clients/O=maastrichtuniversity.nl/CN=Groep, David (DACS) KWwWAnhI4psmiGTw 1/CN=208760481/CN=466908503
issuer    : /DC=eu/DC=rcauth/DC=rcauth-clients/O=maastrichtuniversity.nl/CN=Groep, David (DACS) KWwWAnhI4psmiGTw 1/CN=208760481
identity  : /DC=eu/DC=rcauth/DC=rcauth-clients/O=maastrichtuniversity.nl/CN=Groep, David (DACS) KWwWAnhI4psmiGTw 1/CN=208760481
type      : RFC compliant proxy
strength  : 2048 bits
path      : /tmp/x509up_uiI4TkF
```

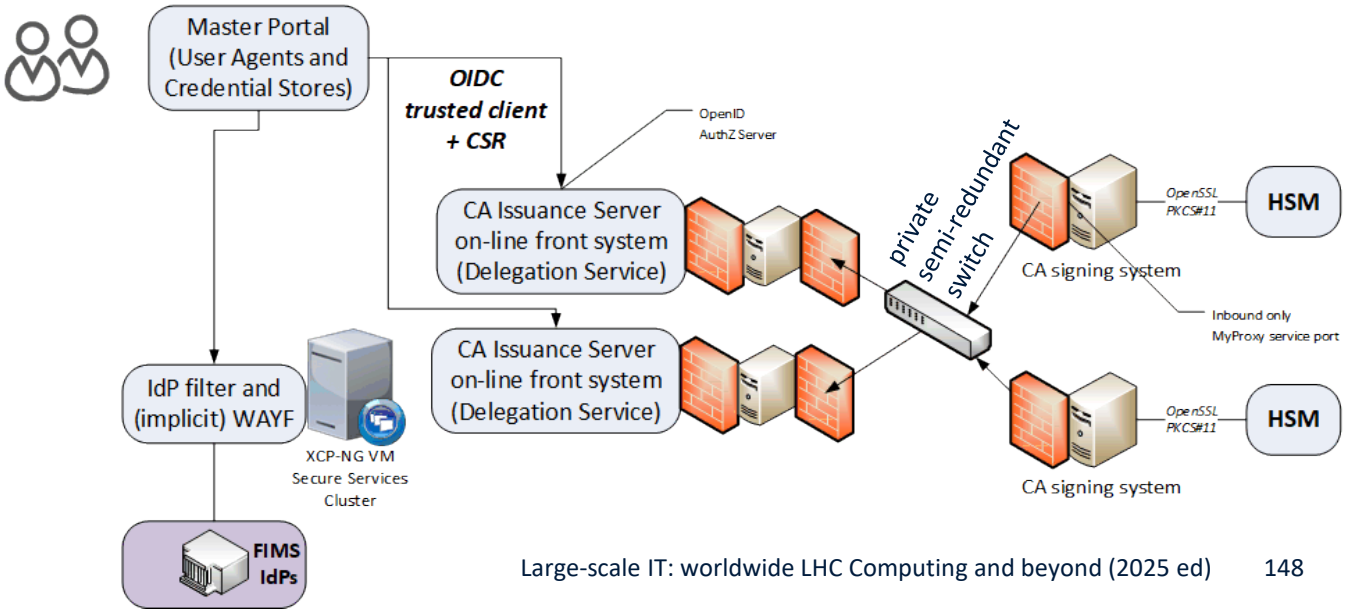
With a single, yet fully compliant, ‘Heath Robinson’ CA



A single-site locally-highly-available RCauth at Nikhef Amsterdam

- Most ‘fault-prone’ components are
  - Intel NUC (single power supply)
  - HSM (can lock itself down, and the USB connection is prone to oxidation)
  - DS front-end servers (physical hardware, albeit with redundant disks and powersupplies)

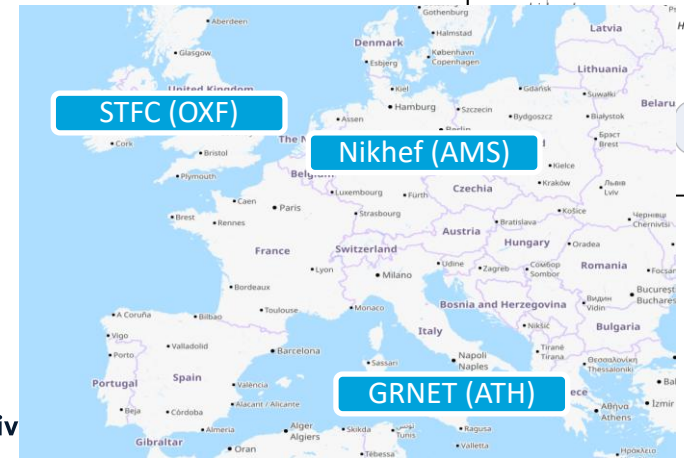
Eliminated SPOFs first using ‘local HA’

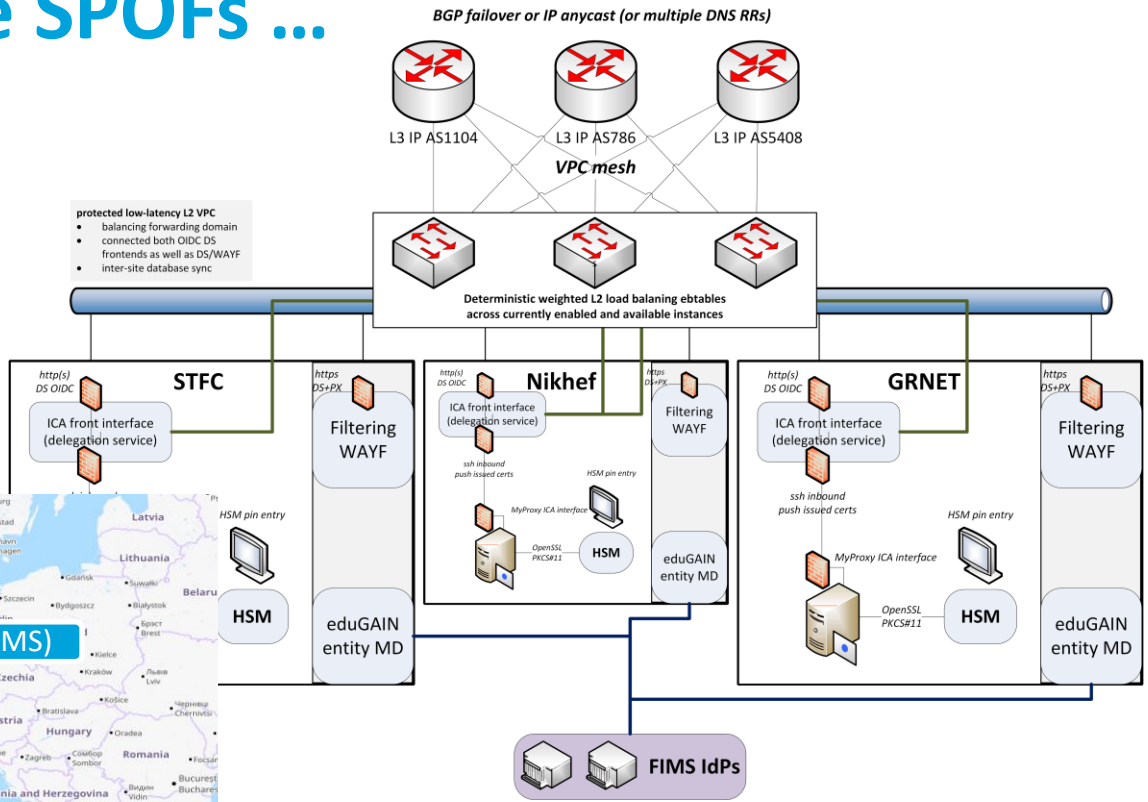


Since we do not like SPOFs …

Distributed High Availability setup

- across the 3 sites
- design for minimal effort
- readily-available techniques
  - L3 VPN (OpenVPN) or L2 VPC
  - Linux HAProxy



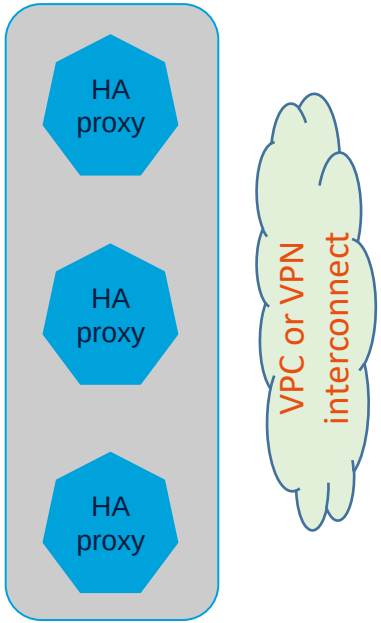


work supported by the EOSC Hub and EOSC Future Horizon Europe projects

A *transparent* multi-site setup is needed for the user

User

- connects to HA proxy at **{wayf,pilot-ica-g1}.rcauth.eu**
- HA proxy sends users to **“closest”** working service
- primarily **forward to its own DS** when available



If a HA loses its backend DS, can still route to another DS over VPC/VPN backend

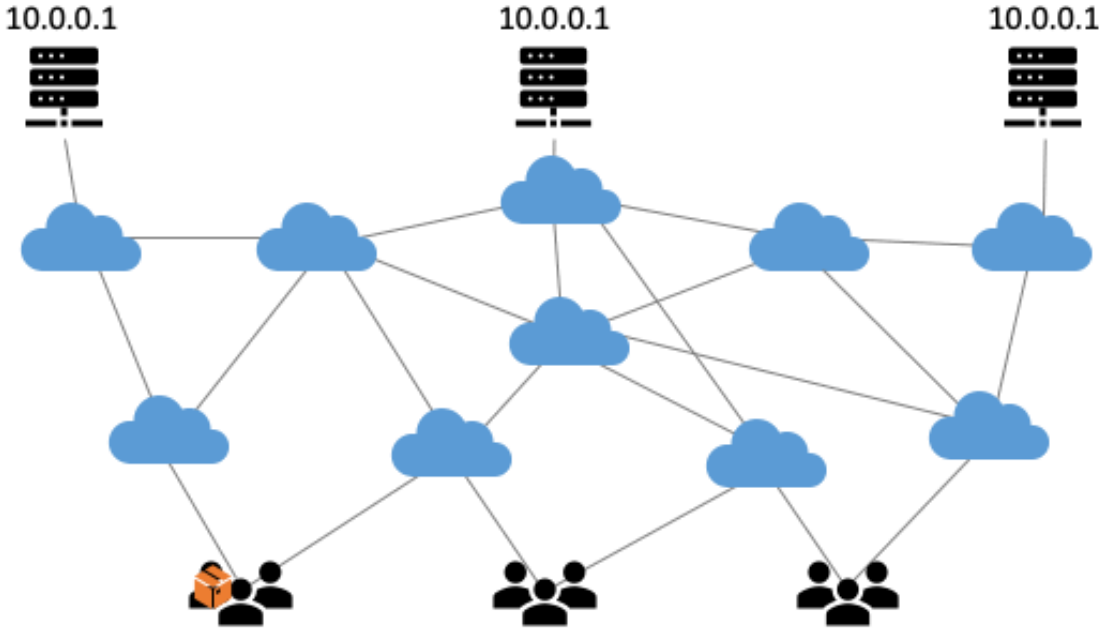
Straightforward proven solution is IP anycast

wherever the user is, the service is at

- **2a07:8504:01a0::1**
- or for legacy IP users at 145.116.216.1

selected imagery: Mischa Sallé, Jens Jensen, Nicolas Liampotis

Anycast: when the same place exists many times



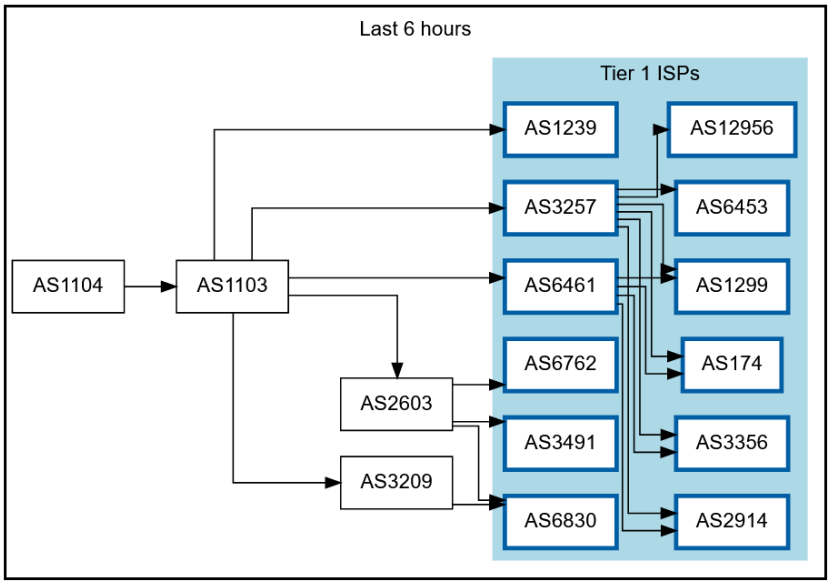
So we used

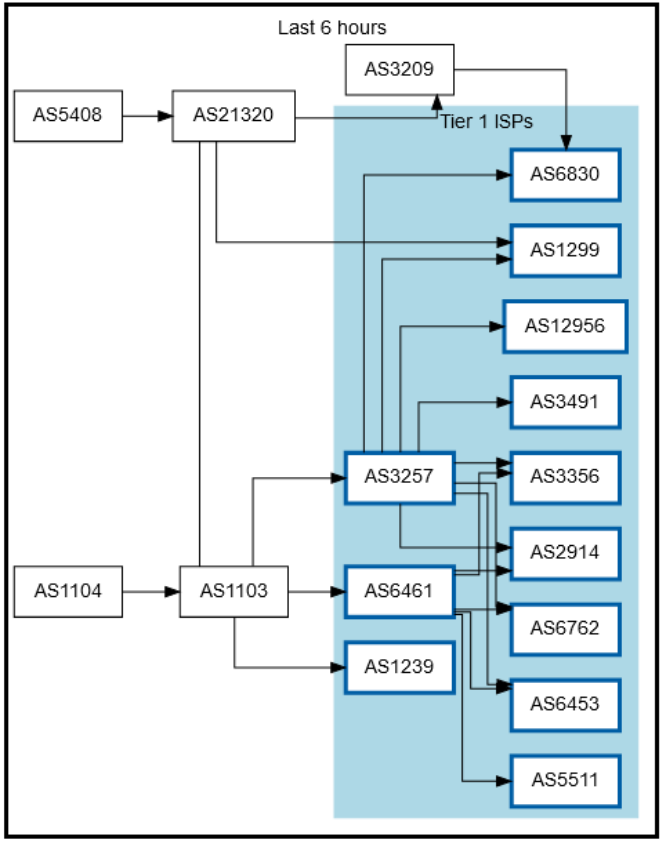
- 3 (for now: 2) sites
- one VM at each site exposing 2a07:8504:01a0::1
- smallest v6 subnet (/48)
- bird + a service probe
- each site's own ASN
- some IRR DB editing
- IPv4 is similar, with a /24

and some monitoring

routing image: SIDNlabs - https://www.sidnlabs.nl/en/news-and-blogs/the-bgp-tuner-intuitive-management-applied-to-dns-anycast-infrastructure

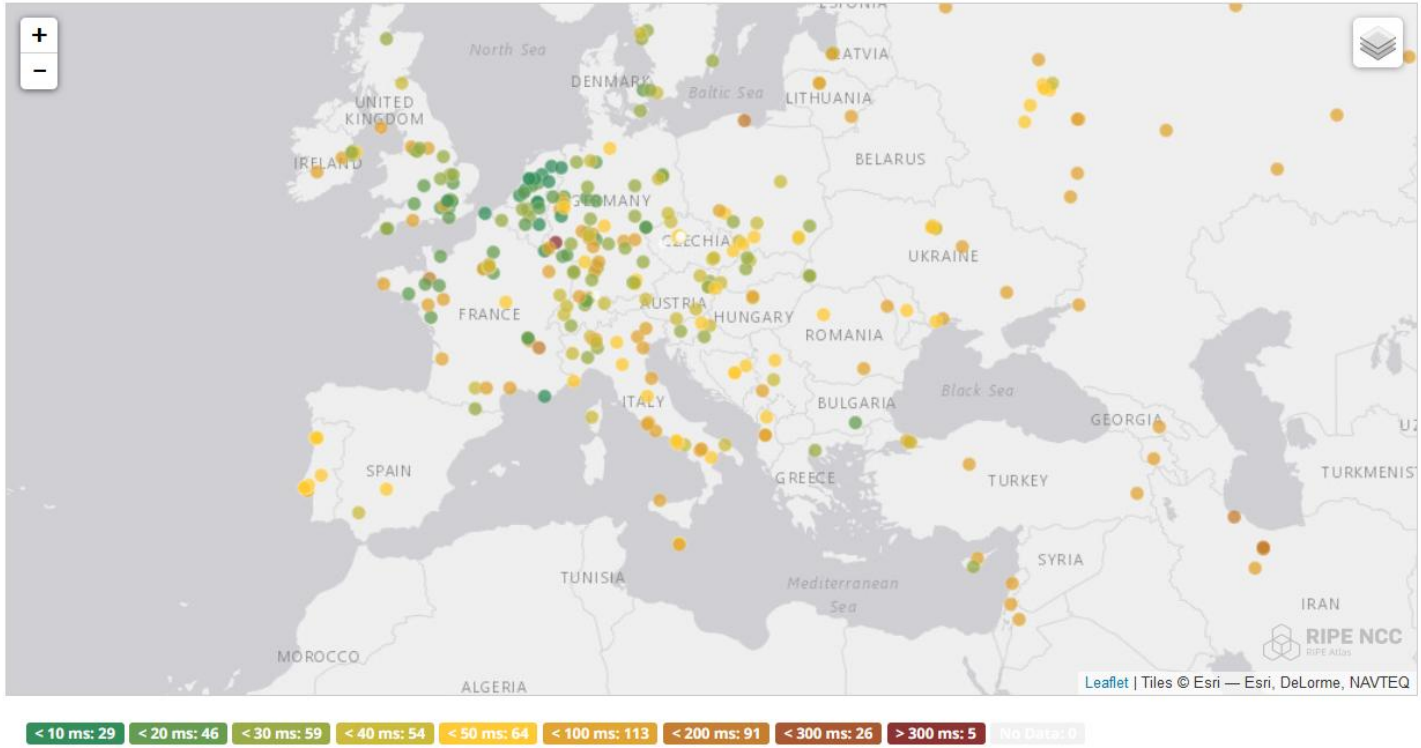
Getting 2a07:8504:1a0::/48 out there





route maps: bgp.tools for 2a07:8504:1a0::/48 – IPv4 for 145.116.216.0/24 is similar – imagery from November 2022

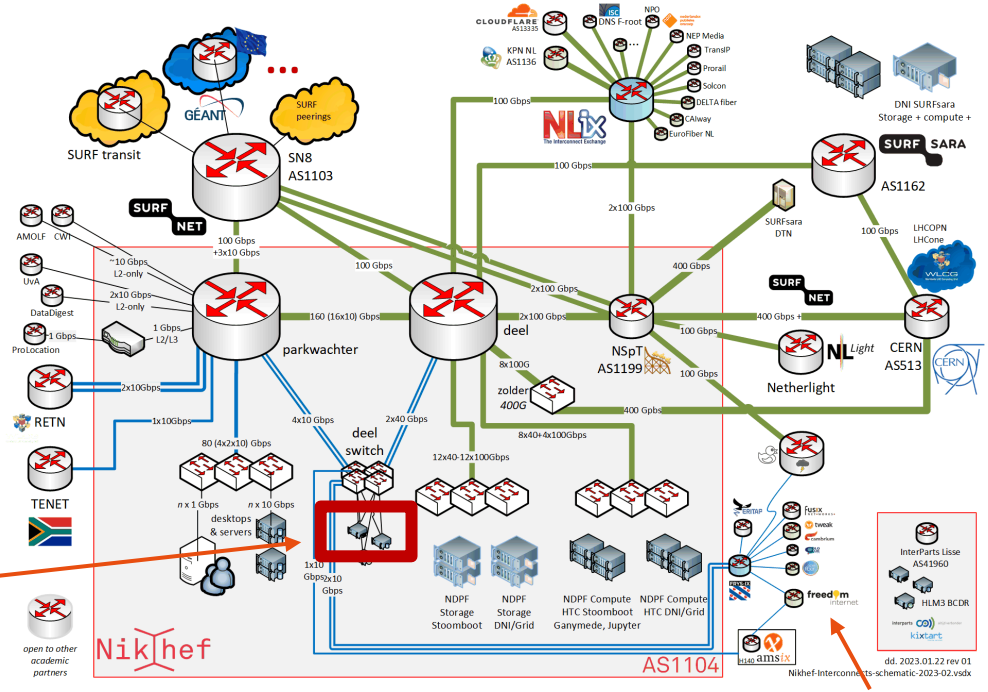
And you get reasonable load balancing in Europe for free



map: RIPE NCC RIPE Atlas - 500 probes, distributed across Europe (https://atlas.ripe.net/measurements/50949024/)

Shortest path, also when mixing with the default-free zone

```
[root@kwark ~]# traceroute -IA 145.116.216.1
traceroute to 145.116.216.1 (145.116.216.1), 30 hops max, 60 byte packets
 1  cmbr.connected.by.freedominter.net
      (185.93.175.234) [AS206238]
 2  connected.by.freedom.nl
      (185.93.175.240) [AS206238]
 3  et-0-0-0-1002.core1.fi001.nl.freedomnet.nl
      (185.93.175.208) [AS206238]
 4  as1104.frys-ix.net (185.1.203.66) [*]
 5  parkwachter.nikhef.nl
      (192.16.186.141) [AS1104]
 6  gw-anyc-01.rcauth.eu
      (145.116.216.1) [AS786/AS5408/AS1104]
```



rcauth.eu HA proxy

Route from home to RCauth.eu, from my home Freedom Internet ISP

me, at home

RCauth demonstrator

RCauth is an AARC BPA token translation service that forges X.509 end-user certificates that are managed in a central portal for you (the portal is ‘elevator.nikhef.nl’)

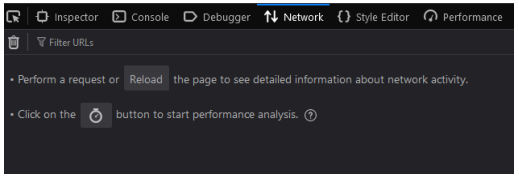
Qualified users are all those in eduGAIN with basic assurance (Sirtfi version 1 + Research & Scholarship entity categories), and everyone in a Dutch SURF ‘Annex IX’ institution – such as UM

Your end-entity certificate is globally IGTF trusted under the ‘Identifier Only Trust Assurance’ (IOTA) profile

RCauth do-it-yourself demo

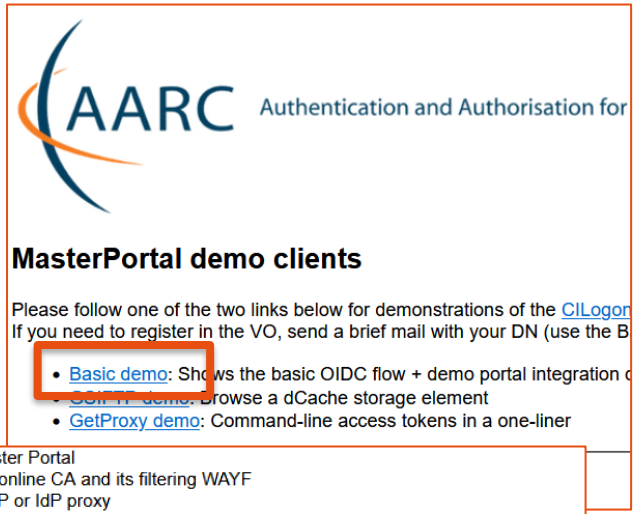
- Go to https://rcdemo.nikhef.nl/
- select “Basic Demo”

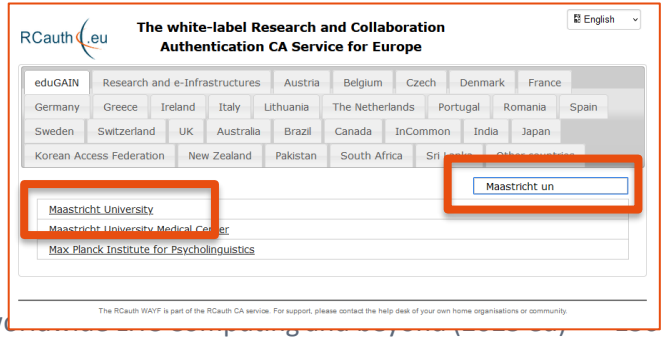
- Enable browser Inspector (F12) on the network tab, (and start the SAML tracer extension if you have it)



- Run the “non-VOMS demo”

- From eduGAIN, select “Maastricht University”



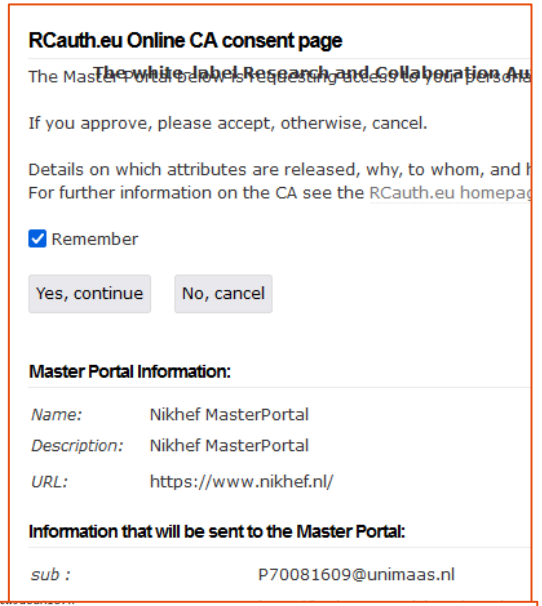


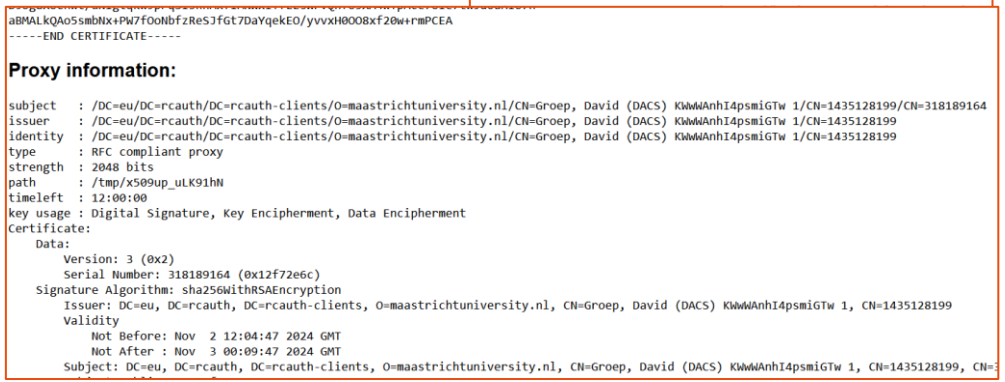
RCauth: SAML to UM, but OIDC for your credential management service

- Approve transfer in OIDC flow & see your PKI X.509 user cert!

- Review the network interactions with
  - engine.surfconext.nl
  - login.maastrichtuniversity.nl
  - pilot-ca1.rcauth.eu
  - elevator.nikhef.nl (this is the credential management service where your long-term private key is)

- What is the difference in the POSTs?
- Can you see the difference in the SAML and the OIDC flow?





RSA Crypto

Just in case … you cannot factor ‘55’

Establishing trust at a distance

Remote trust needs cryptography in some way

Client authentication

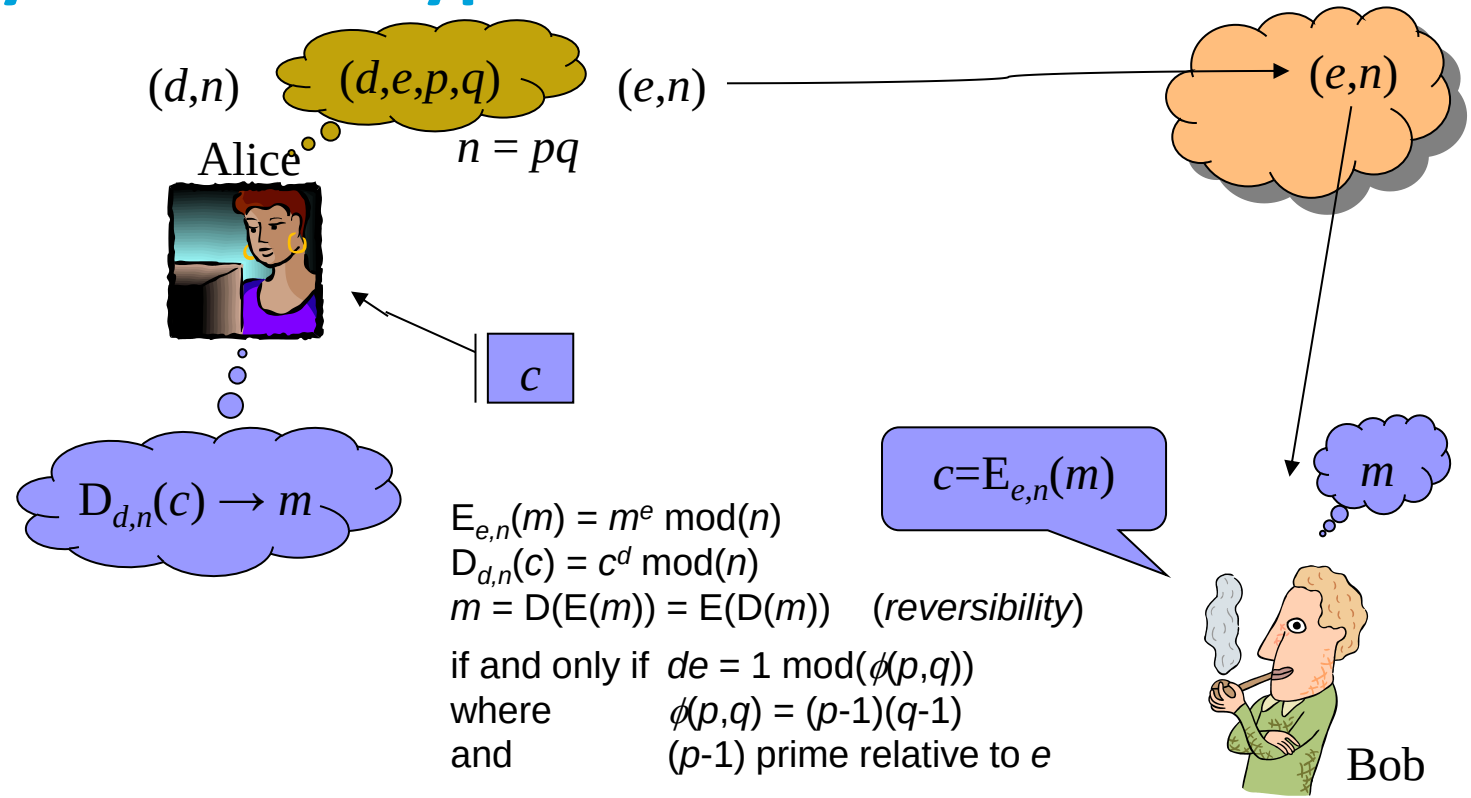
- pre-shared secrets, may be salted hashed on service side
- required: secure one-way hash function
- need a **protected channel** between identifiable end-points

Mutual authentication

- eithers need a lot of shared keys, a trusted third party (TTP), or mesh validation (WoT)
- with the TTP and multiple services comes the need for crypto
- across administrative domains, *key distribution* is the larger challenge

The cryptography used can be either *symmetric* or *asymmetric*, ‘public key’

Asymmetric crypto: RSA interlude needed?



$E_{e,n}(m) = m^e \bmod(n)$
$D_{d,n}(c) = c^d \bmod(n)$
$m = D(E(m)) = E(D(m))$ (*reversibility*)

if and only if $de = 1 \bmod(\phi(p,q))$
where $\phi(p,q) = (p-1)(q-1)$
and $(p-1)$ prime relative to e

Rivest, Shamir and Adleman, Communications of the ACM 21 (2), 120-126

6-bit RSA (note: this might be broken quickly …)

- Take a (small) value e = **3**
- Generate a set of primes (p,q), each with a length of k/2 bits, with (p-1) prime relative to e.
  (p,q) = **(11,5)**
- $\phi(p,q)$ = (11-1)(5-1) = **40**; n=pq=**55**
- find d, in this case **27** [3*27 = 81 = 1 mod(40)]

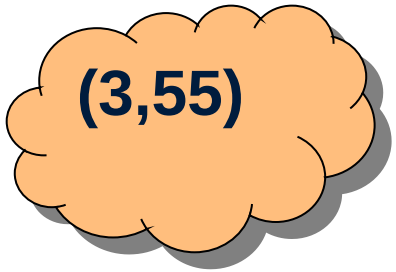
- Public Key: **(3,55)**
- Private Key: **(27,55)**

$E_{e,n}(m) = m^e \bmod(n)$
$D_{d,n}(c) = c^d \bmod(n)$
$m = D(E(m)) = E(D(m))$
if a.o. if $de = 1 \bmod(\phi(p,q))$
where $\phi(p,q) = (p-1)(q-1)$

Message exchange

Encryption:

- Bob thinks of a plaintext $m(<n)$ = **18**
- Encrypt with Alice's public key **(3,55)**
- $c=E_{\mathbf{3;55}}(18)=18^3 \bmod(55) = 5832 \bmod(55) = \mathbf{2}$
- send message **"2"**



Decryption:

- Alice gets **"2"**
- she knows private key **(27,55)**
- $E_{\mathbf{27;55}}(2) = 2^{27} \bmod(55) = \mathbf{18}$!

$E_{e,n}(m) = m^e \bmod(n)$
$D_{d,n}(c) = c^d \bmod(n)$
$m = D(E(m)) = E(D(m))$
if a.o. if $de = 1 \bmod(\phi(p,q))$
where $\phi(p,q) = (p-1)(q-1)$

If you just have (3,55), it's hard to get the 27…

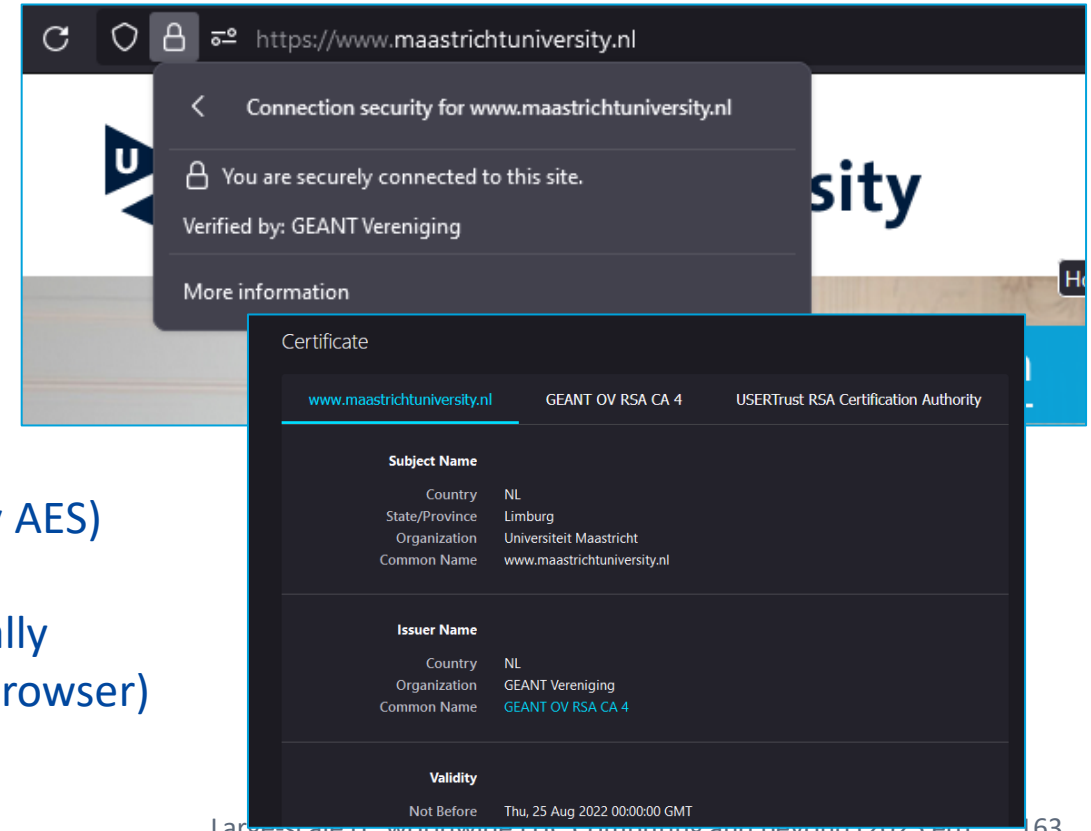
but also: the maximum plaintext is limited by the modulus length

The most used asymmetric crypto application

Asymmetric crypto underpins the transport layer security of all of the web today

- ASN.1 syntax data with X.509 (RFC5280) structure
- mostly RSA or Elliptic Curves (EC)
- used to negotiate a (symmetric) bulk cipher (typically AES)

then used to protect channel to usually *unauthenticated* client application (browser)



Other ancillary materials

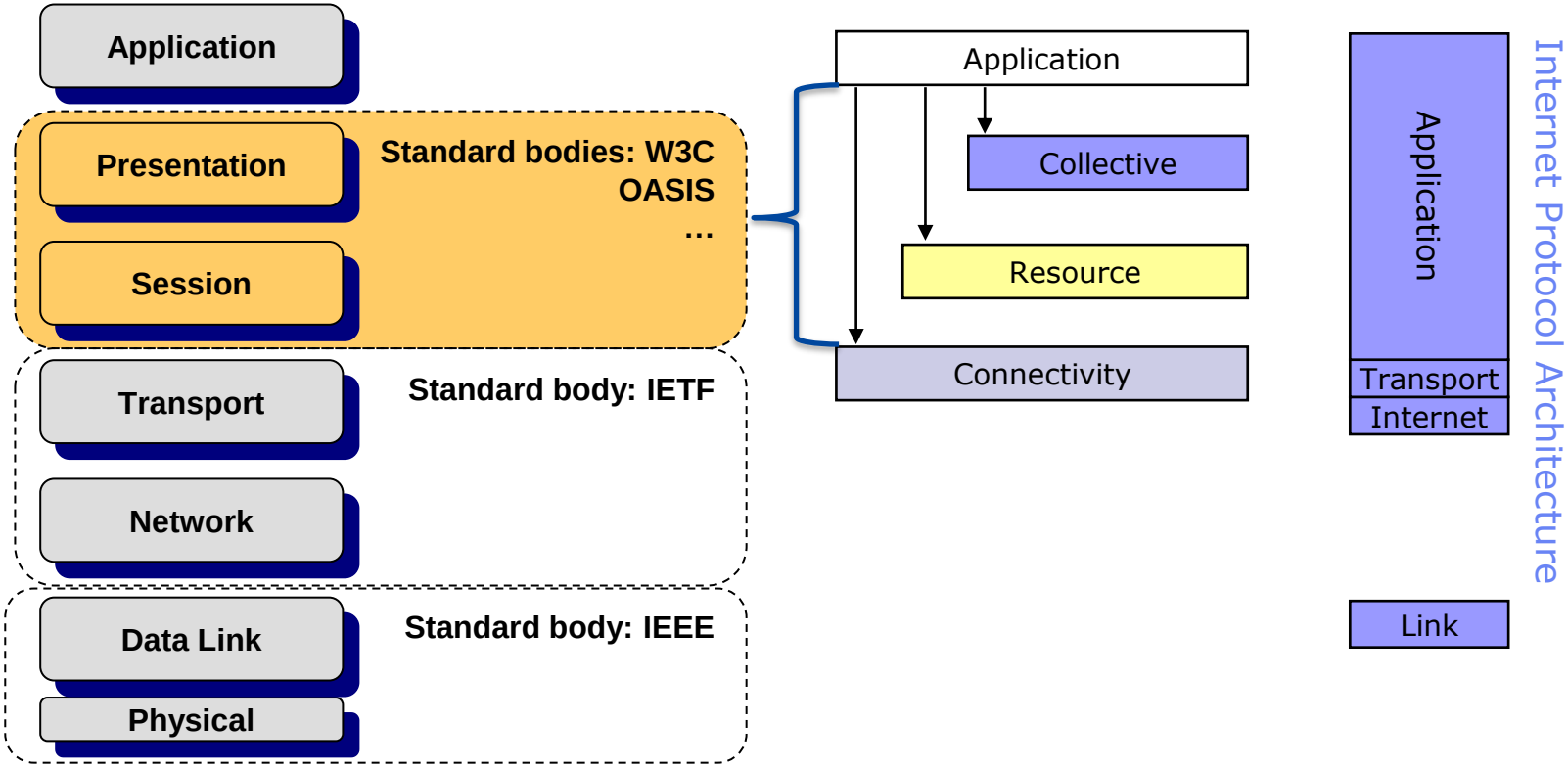
Following slides are provided here
merely as generic background

Open Systems Interconnection model (OSI model)

Layer			Function
Host layers	7	Application	High-level protocols (resource sharing, remote file access)
	6	Presentation	Translation of data between a networking service and an application
	5	Session	Managing communication sessions, i.e., continuous exchange of information in the form of multiple back-and-forth transmissions between two nodes
	4	Transport	Reliable transmission of data segments between points on a network
Media layers	3	Network	Addressing, routing and traffic control
	2	Data link	Transmission of data frames between two nodes connected by a physical layer
	1	Physical	Transmission and reception of raw bit streams over a physical medium

OSI X.200 layering model, ITU-T (CCITT), https://www.itu.int/rec/T-REC-X.200; image adapted from https://en.wikipedia.org/wiki/OSI_model

OSI vs Internet Protocol Architecture model



Private (direct) peerings to distribute traffic load

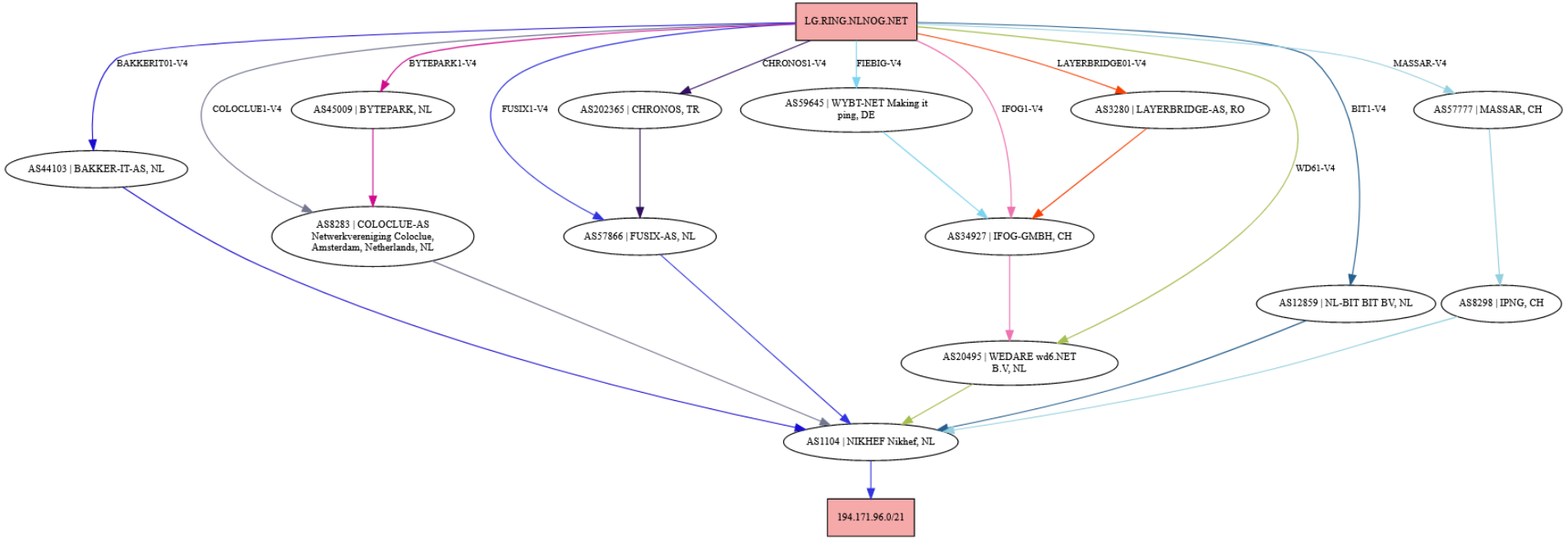
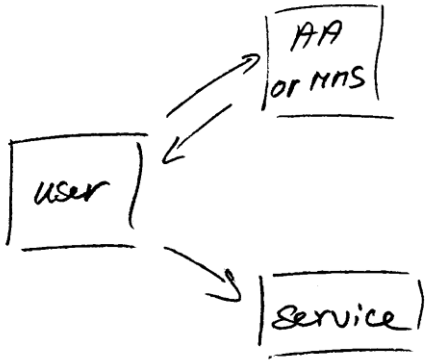
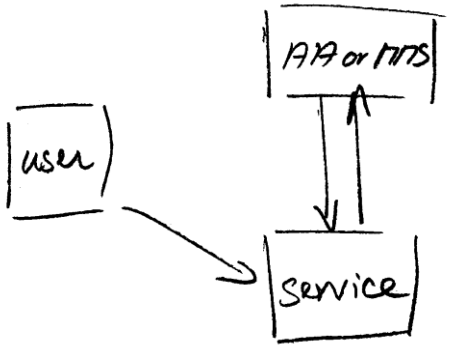


Image sources: NLNOG RING map https://lg.ring.nlnog.net/

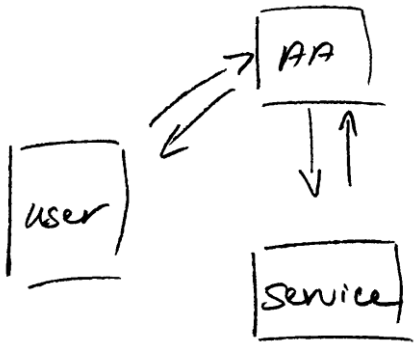
RFC2904 authorization models: three AuthZ flows



‘push’



‘pull’



‘agent’

Authorization models: AAA Authorization Framework, RFC2904, Vollbrecht et al.

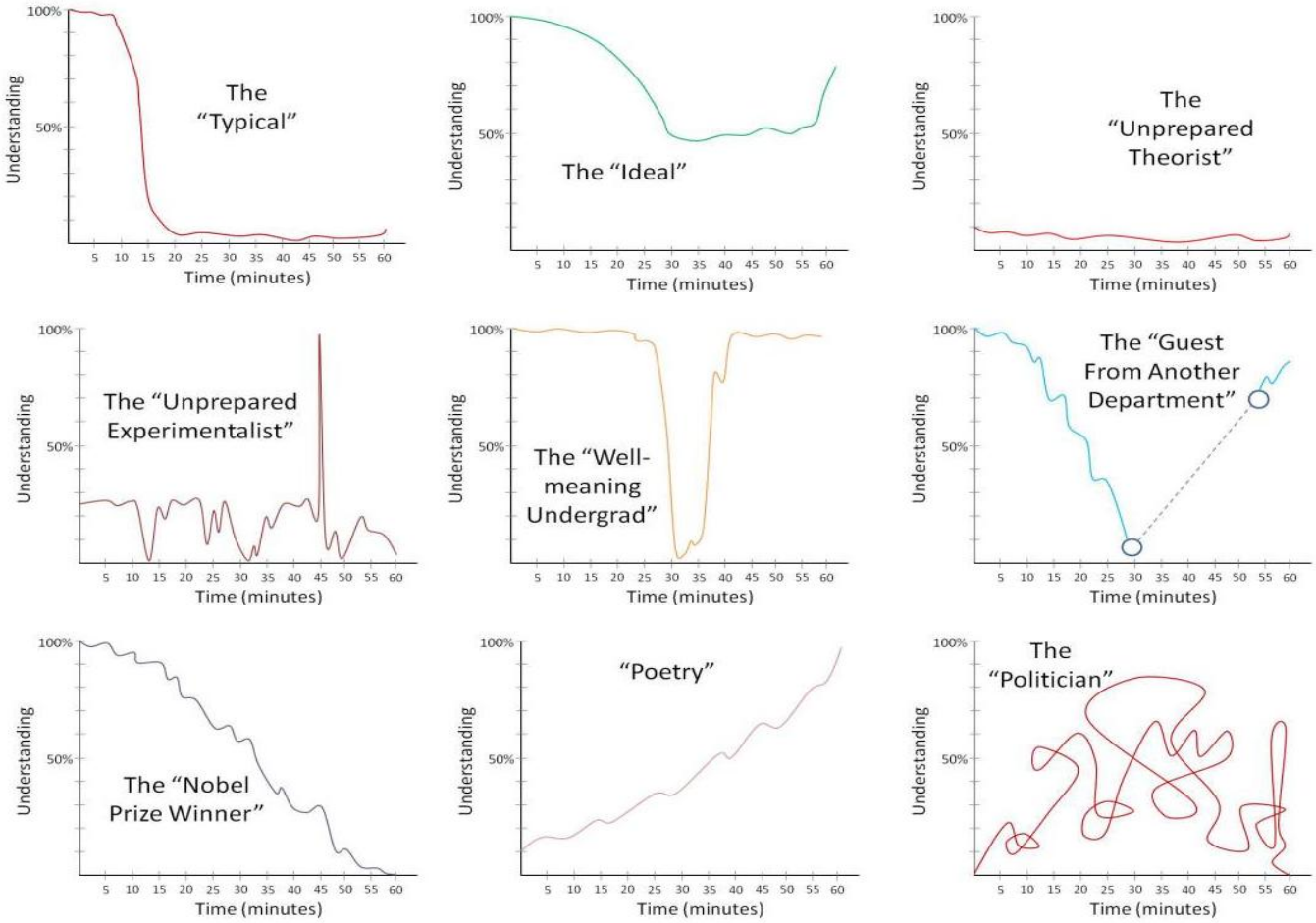
OAuth2 & JWTs: assertions can be quite detailed

```
$ echo $AT | jwt
...
* Payload
{
  "wlcg.ver": "1.0",
  "sub": "a1b98335-9649-4fb0-961d-5a49ce108d49",
  "aud": "https://wlcg.cern.ch/jwt/v1/any",
  "nbf": 1593004542,
  "scope": "storage.read:/ storage.modify:/",
  "iss": "https://wlcg.cloud.cnaf.infn.it/",
  "exp": 1593008142,
  "iat": 1593004542,
  "jti": "da0a2f89-3cbf-42a7-9403-0b43d814551d",
  "client_id": "edfacfb1-f59d-44d0-9eb6-a745ac52f462"
}
```

OAuth2 Access Token following the WLCG AuthZ WG Profile, from: https://wlcg-authz-wg.github.io/wlcg-authz-docs/token-based-authorization/

Example flow in the European Open Science Cloud

EOSC Portal & Marketplace Amnesia service by the OpenAIRE e-infrastructure, EOSC Helpdesk: Zammad hosted by KIT https://eosc-helpdesk.eosc-portal.eu



http://manyworldstheory.com/2013/10/03/the-9-kinds-of-physics-seminar/

Nulla folia post hoc sunt

Thanks for watching!

“En daarmee, geachte luisteraars, laat ik u over aan
de verpozing die uw babbelklant u gemeenlijk pleegt te bieden.”