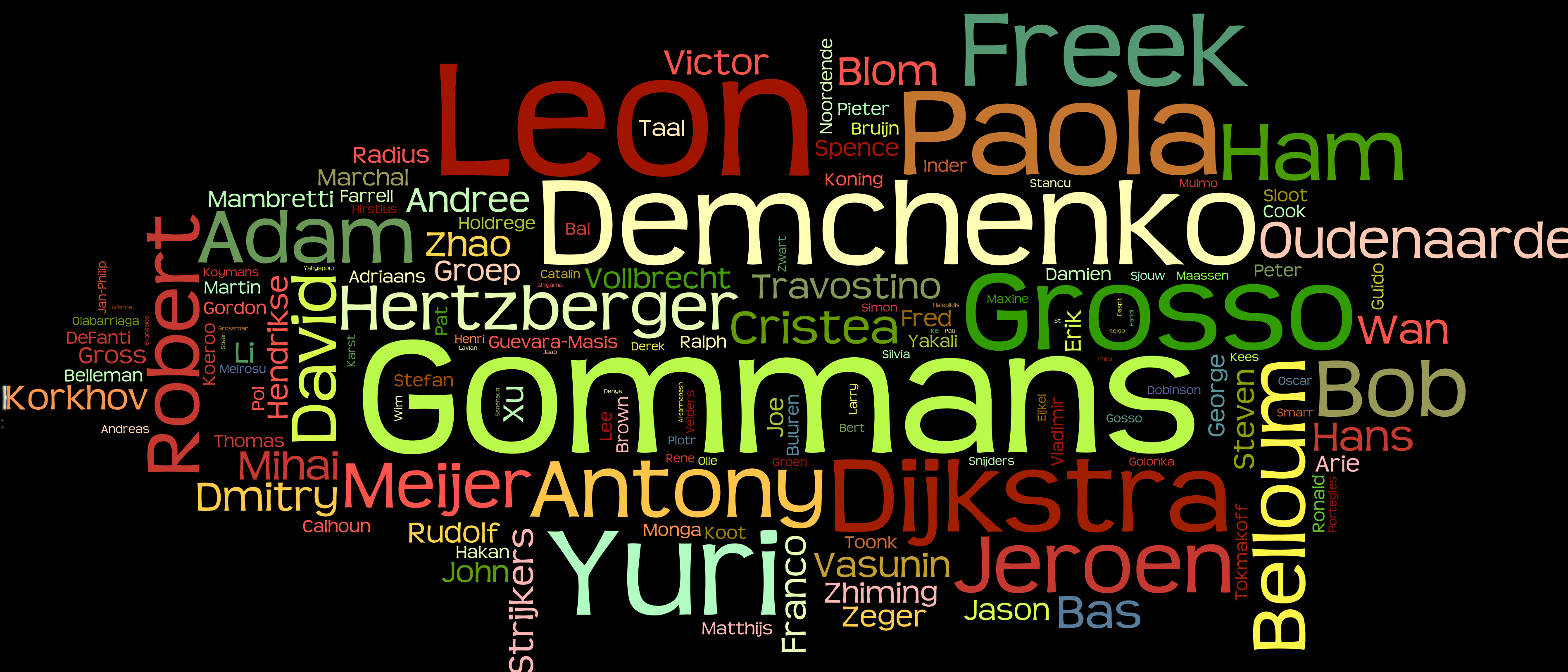
Smart Cyber Infrastructure for Big Data Processing

Cees de Laat & Paola Grosso & Zhiming Zhao



Science Faculty @ UvA

Informatics Institute

- AMLAB: Machine Learning (Prof. dr. M. Welling)
- FCN: Federated Collaborative Networks (Prof. dr. H. Afsarmanesh)
- ILPS: Information and Language Processing Systems (Prof. dr. M. de Rijke)
- ISIS: Intelligent Sensory Information Systems (Prof. dr. ir. A.W.M. Smeulders)
- CSL: Computational Science Laboratory (Prof. dr. P.M.A. Sloot)
- SNE: System and Network Engineering (Prof. dr. ir. C.T.A.M. de Laat)
- TCS: Theory of Computer Science (Prof. dr. J.A. Bergstra)

SNE - Mission

Can we create smart and safe data processing infrastructures that can be tailored to diverse application needs?

- *Capacity*
  - *Bandwidth on demand, QoS, architectures, photonics, performance*
- *Capability*
  - *Programmability, virtualization, complexity, semantics, workflows*
- *Security*
  - *Policy, Trust, Anonymity, Privacy, Integrity*
- *Sustainability*
  - *Greening infrastructure, Awareness*
- *Resilience*
  - *Failures, Disasters, Systems under attack*

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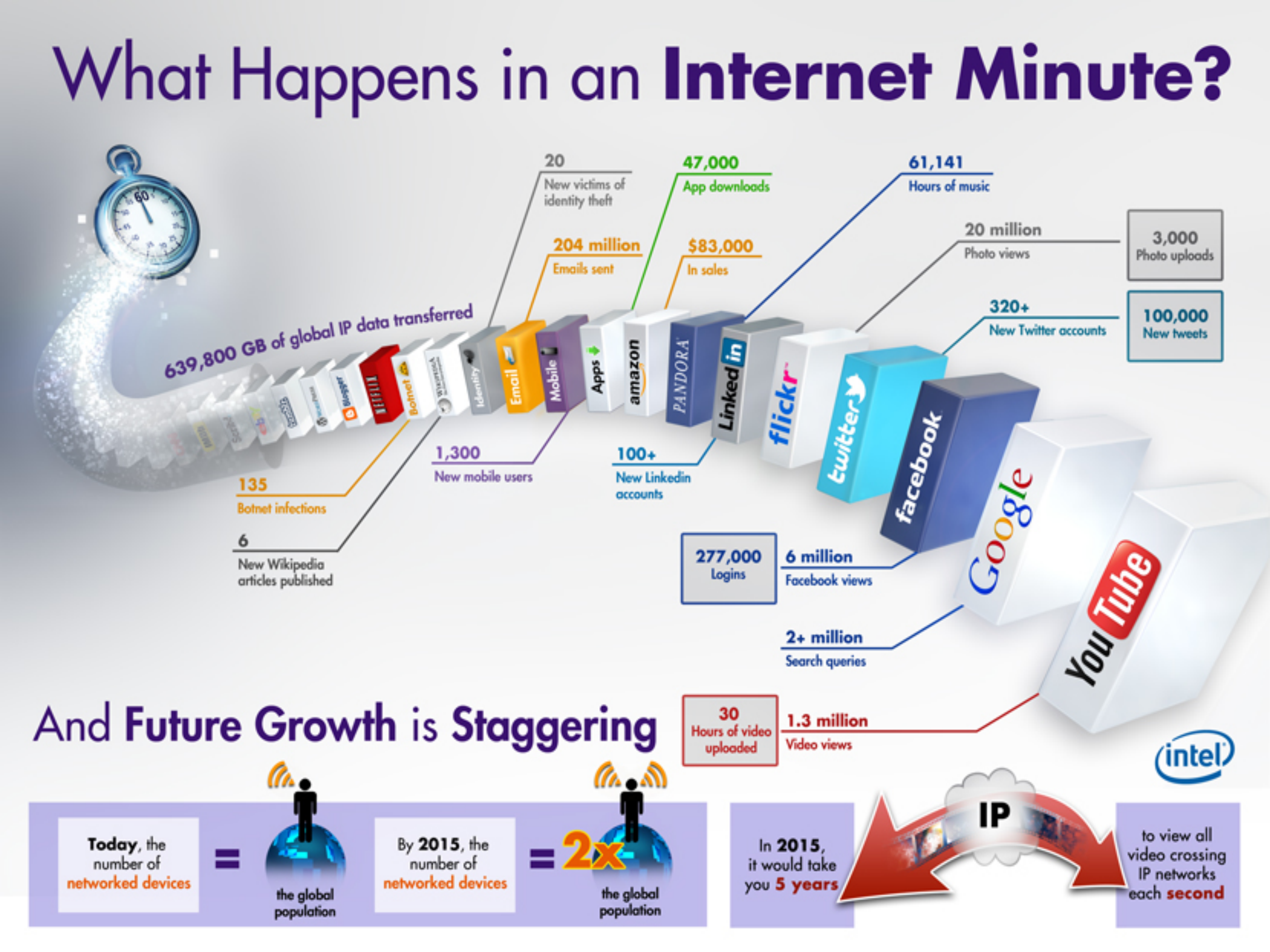
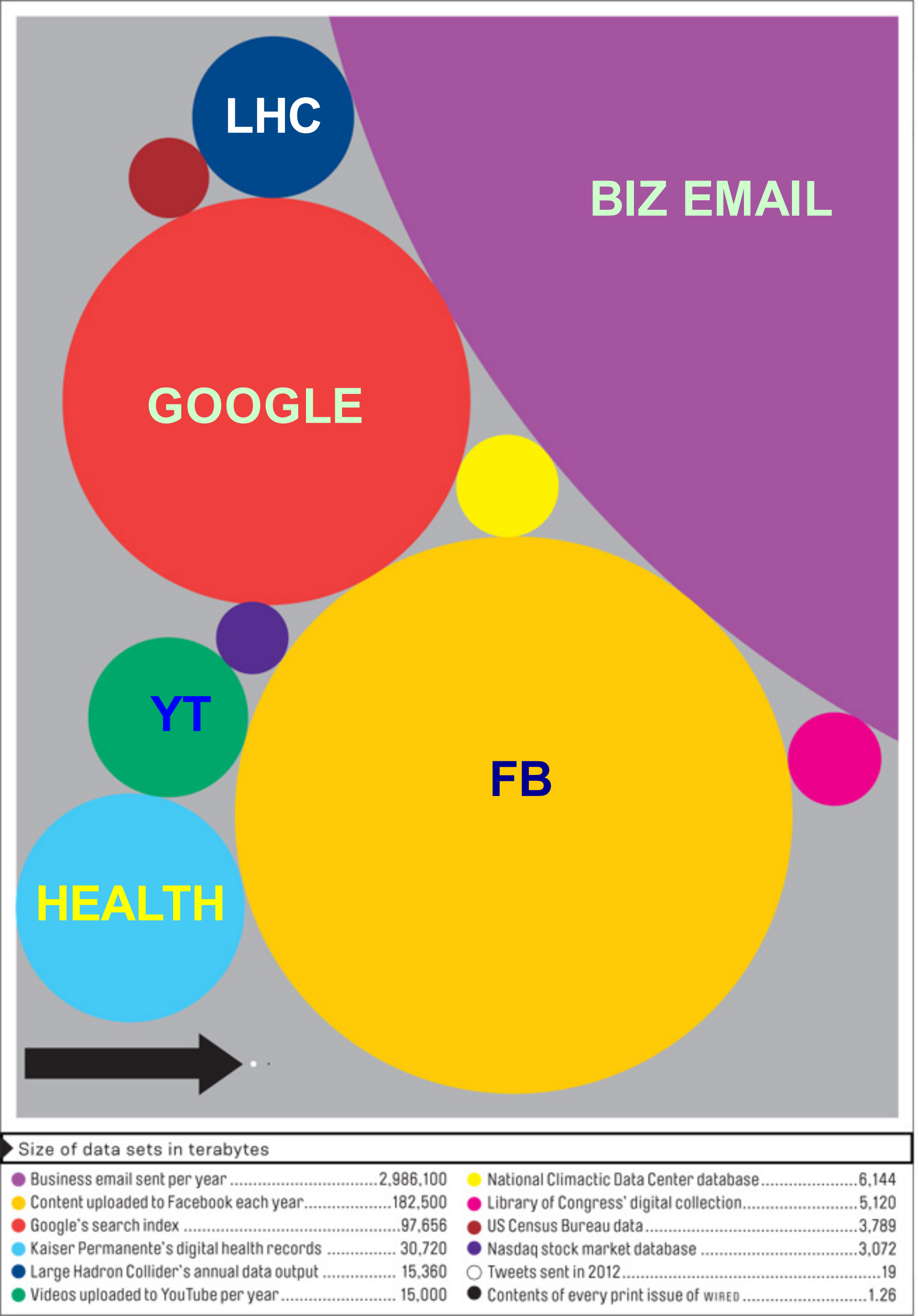
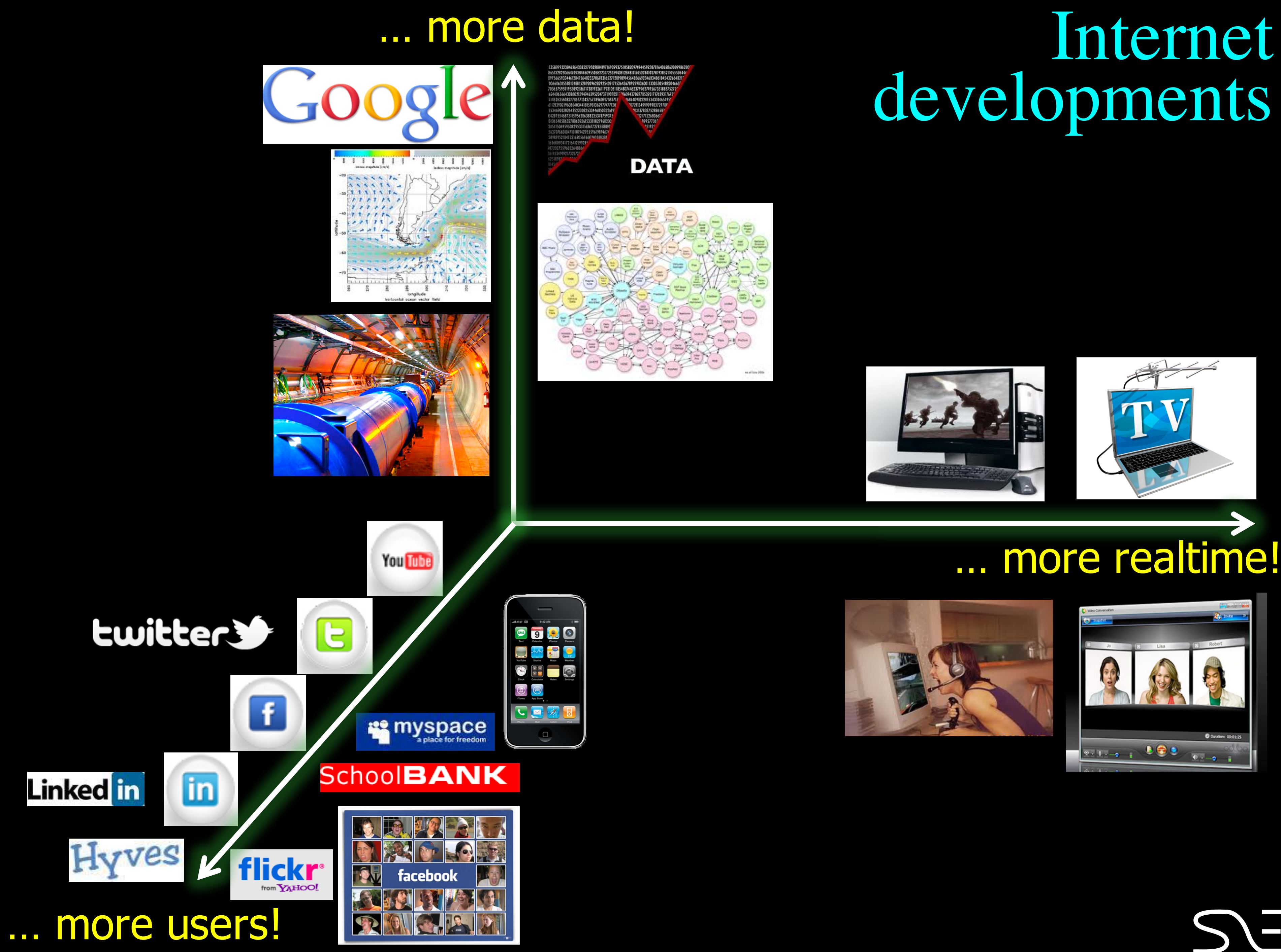


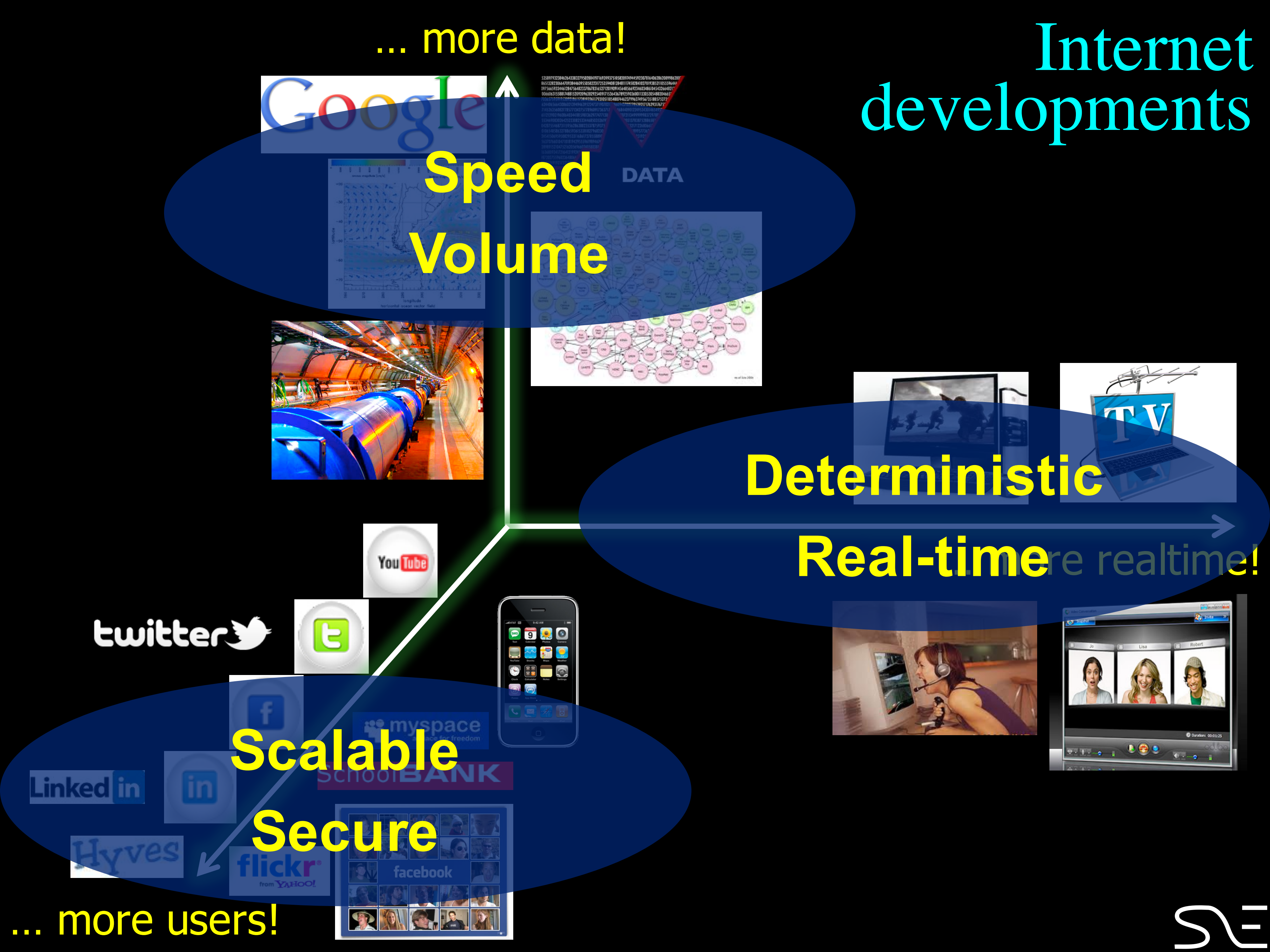
What Happens in an Internet Minute?
639,800 GB of global IP data transferred
20
New victims of identity theft
204 million
Emails sent
47,000
App downloads
$83,000
In sales
61,141
Hours of music
20 million
Photo views
3,000
Photo uploads
320+
New Twitter accounts
100,000
New tweets
135
Botnet infections
6
New Wikipedia articles published
1,300
New mobile users
100+
New Linkedin accounts
277,000
Logins
6 million
Facebook views
2+ million
Search queries
30
Hours of video uploaded
1.3 million
Video views
Botnet
Identity
Email
Mobile
Apps
amazon
PANDORA
Linkedin
flickr
twitter
facebook
Google
YouTube
And Future Growth is Staggering
Today, the number of networked devices
=
the global population
By 2015, the number of networked devices
=
2x
the global population
In 2015, it would take you 5 years
IP
to view all video crossing IP networks each second
intel



There is always a bigger fish

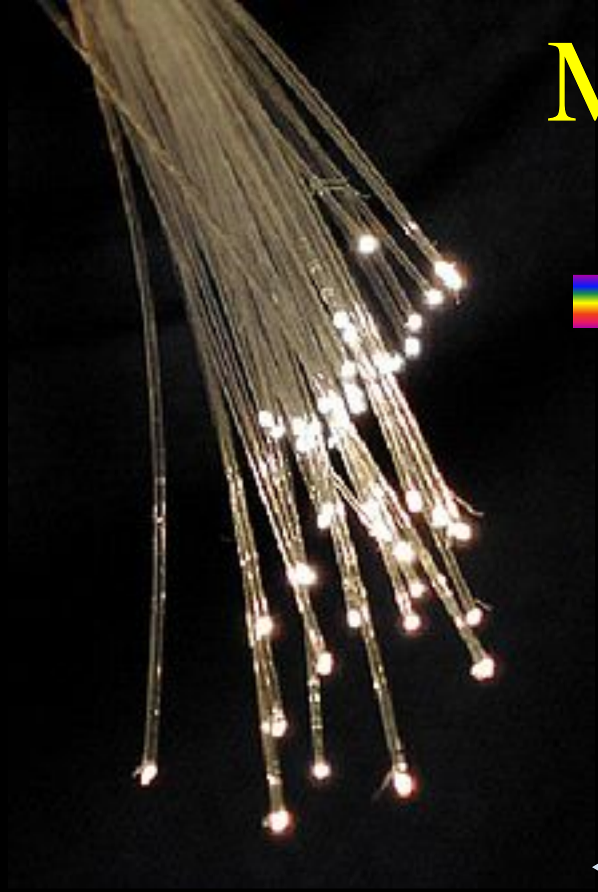
Internet developments

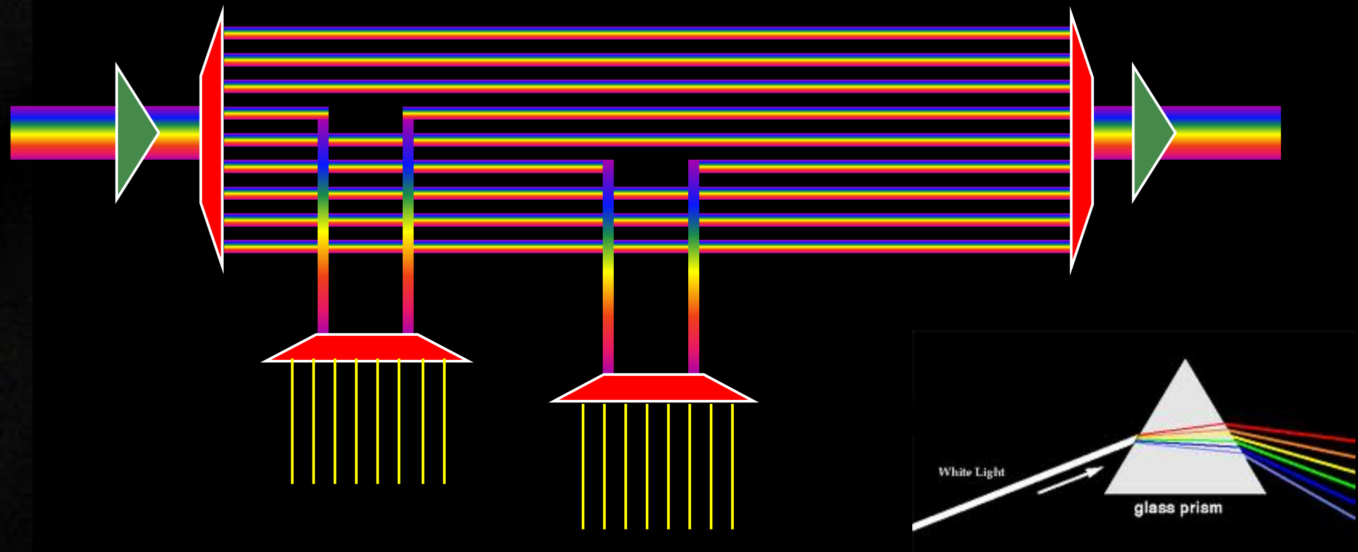


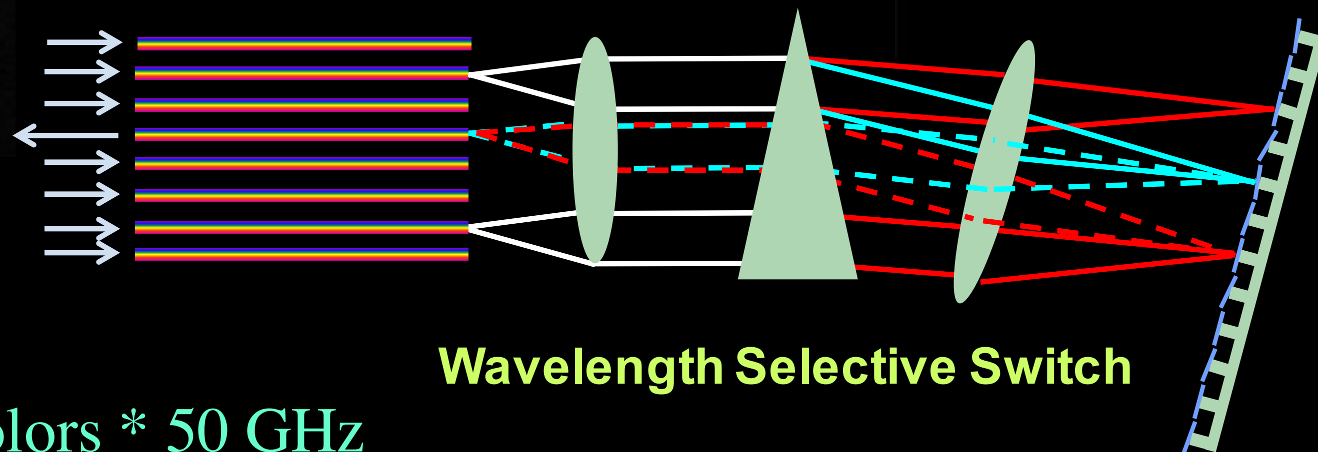


Internet developments
... more data!
Google
Speed
Volume
DATA
TV
Deterministic
Real-time
re realtime!
You Tube
twitter
myspace
Scalable
SchoolBANK
Linked in
Secure
Hyves
flickr
from YAHOO!
facebook
... more users!

Multiple colors / Fiber







Wavelength Selective Switch

Per fiber: ~ 80-100 colors * 50 GHz

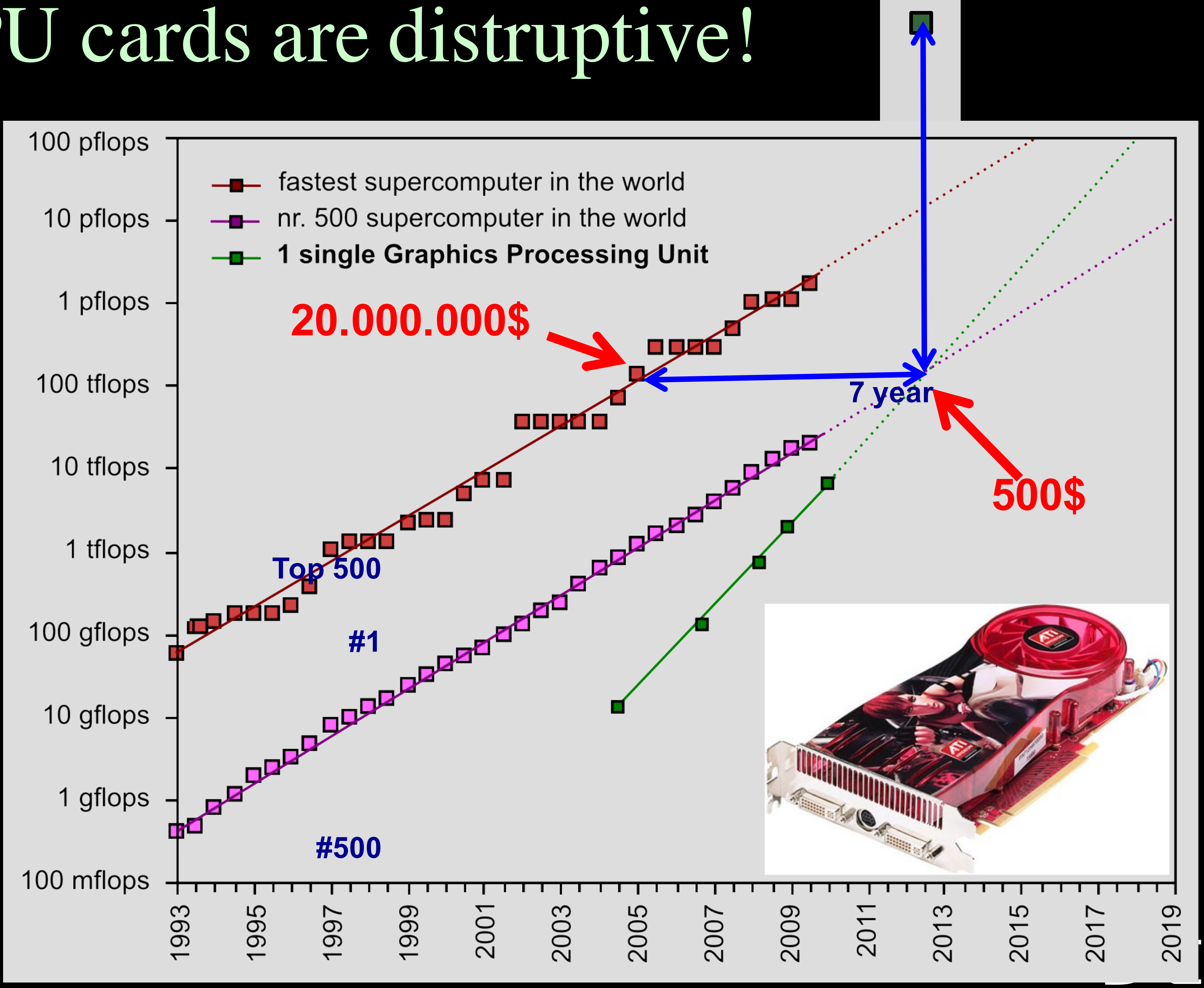
Per color: 10 – 40 – 100 Gbit/s

BW * Distance ~ $2*10^{17}$ bm/s

New: Hollow Fiber!

➔ less RTT!

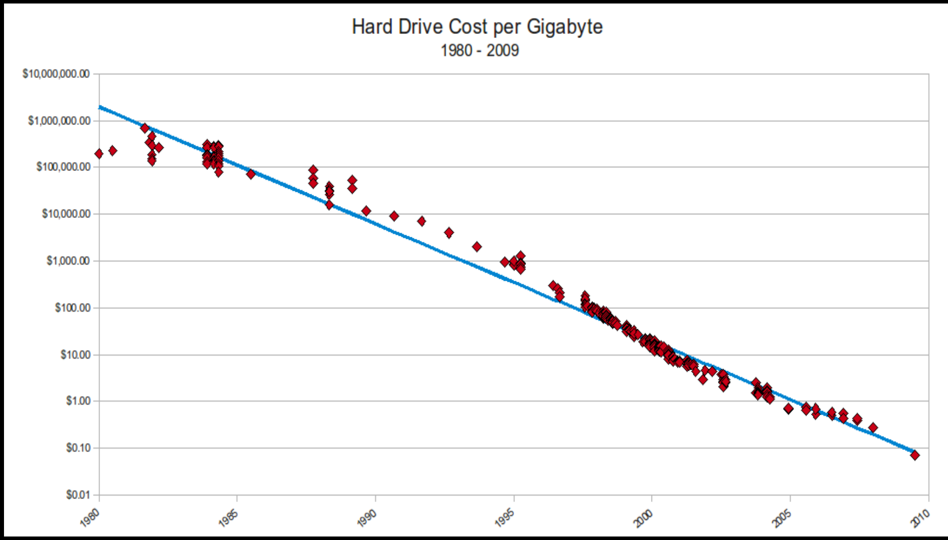
GPU cards are distruptive!



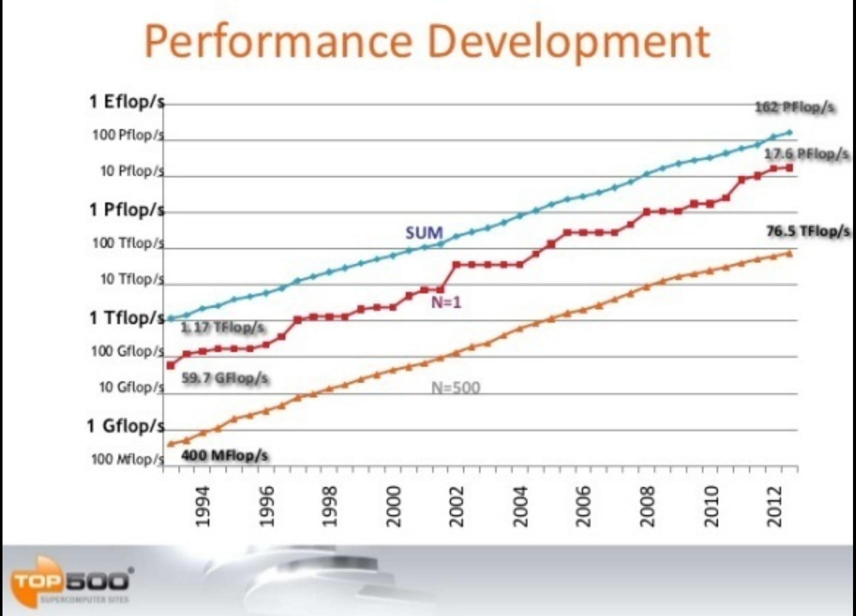
Reliable and Safe!

This omnipresence of IT makes us not only strong but also vulnerable.

- A virus, a hacker, or a system failure can instantly send digital shockwaves around the world.



The hardware and software that allow all our systems to operate is becoming bigger and more complex all the time, and the capacity of networks and data storage is increasing by leaps and bounds.

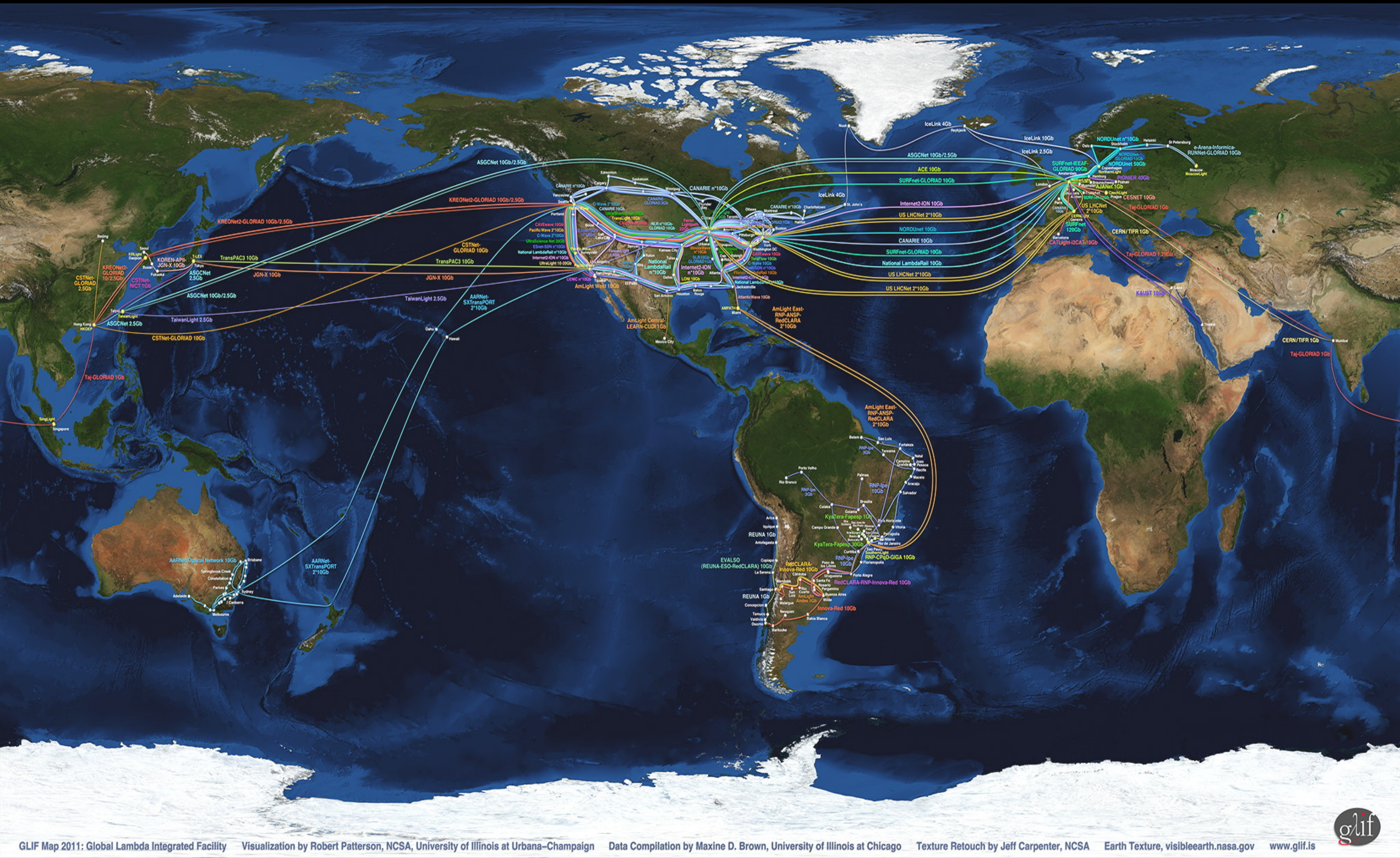


We will soon reach the limits of what is currently feasible and controllable.

https://www.knaw.nl/shared/resources/actueel/publicaties/pdf/20111029.pdf

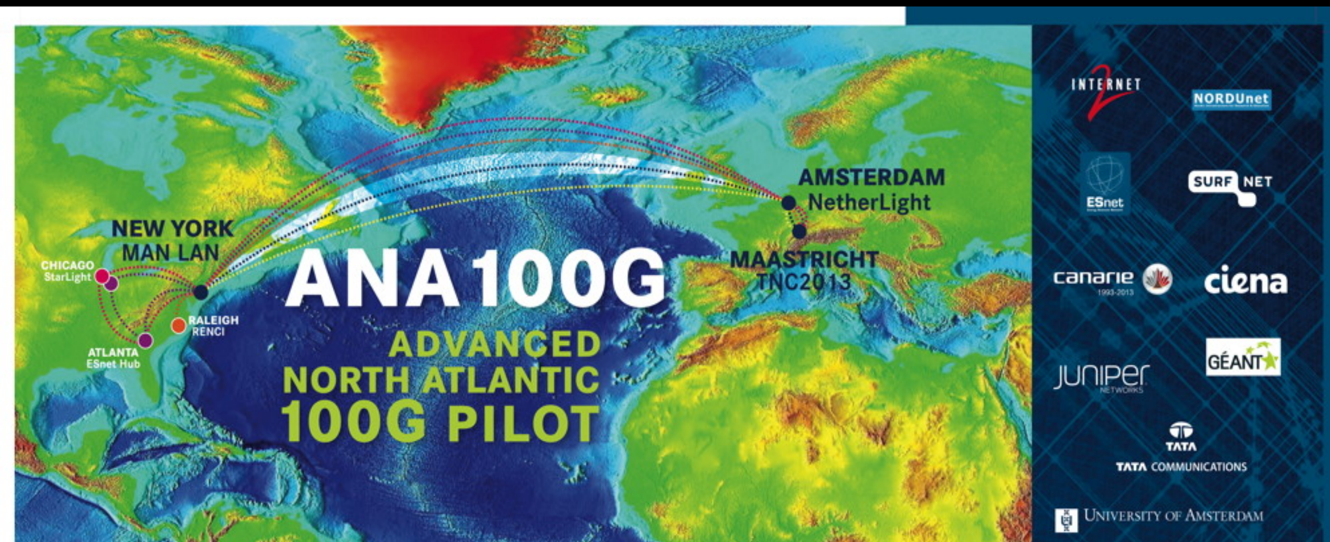
The GLIF – LightPaths around the World

F Dijkstra, J van der Ham, P Grosso, C de Laat, "A path finding implementation for multi-layer networks", Future Generation Computer Systems 25 (2), 142-146.



ExoGeni @ OpenLab - UvA

Installed and up June 3th 2013



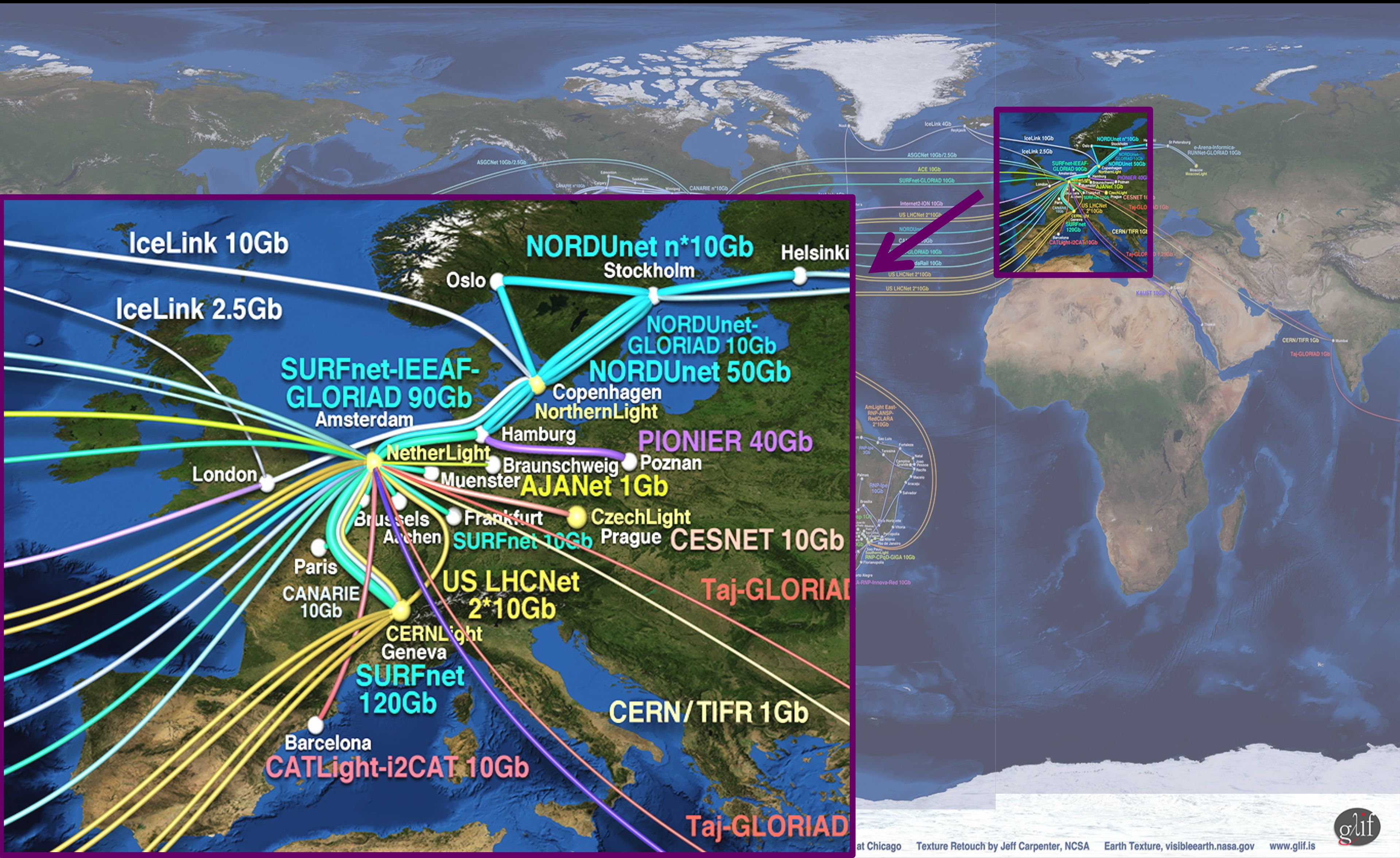
TNC2013 DEMOS JUNE, 2013

DEMO	TITLE	OWNER	AFFILIATION	E-MAIL	A-SIDE	Z-SIDE	PORTS(S) MAN LAN	PORTS(S) TNC2013	DETAILS
1	Big data transfers with multipathing, OpenFlow and MPTCP	Ronald van der Pol	SURFnet	ronald.vanderpol@surfnet.nl	TNC/MECC, Maastricht NL	Chicago, IL	Existing 100G link between internet2 and ESnet	2x40GE (Juniper)+ 2x10GE (OME6500)	In this demonstration we show how multipathing, OpenFlow and Multipath TCP (MPTCP) can help in large file transfers between data centres (Maastricht and Chicago). An OpenFlow application provisions multiple paths between the servers and MPTCP will be used on the servers to simultaneously send traffic across all those paths. This demo uses 2x40G on the transatlantic 100G link. ESnet provides 2x40G between MAN LAN and StarLight, ACE and USLHCnet provide additional 10GEs.
2	Visualize 100G traffic	Inder Monga	ESnet	imonga@es.net					Using an SNMP feed from the Juniper switch at TNC2013,and/or Brocade AL2S node in MANLAN, this demo would visualize the total traffic on the link, of all demos aggregated. The network diagram will show the transatlantic topology and some of the demo topologies.
3	How many modern servers can fill a 100Gbps Transatlantic Circuit?	Inder Monga	ESnet	imonga@es.net	Chicago, Ill	TNC showfloor	1x 100GE	8x 10GE	In this demonstration, we show that with the proper tuning and tool, only 2 hosts on each continent can generate almost 80Gbps of traffic. Each server has 4 10G NICS connected to a 40G virtual circuit, and has iperf3 running to generate traffic. ESnet's new "iperf3" throughput measurement tool, still in 'beta', combines the best features from other tools such as iperf, nuttcp, and netperf. See: https://my.es.net/demos/tnc2013/
4	First European ExoGENI at Work	Jeroen van der Ham	UvA	vdham@uva.nl	RENCI, NC	UvA, Amsterdam, NL	1x 10GE	1x 10GE	The ExoGENI racks at RENCI and UvA will be interconnected over a 10G pipe and be on continuously, showing GENI connectivity between Amsterdam and the rest of the GENI nodes in the USA.
5	Up and down North Atlantic @ 100G	Michael Enrico	DANTE	michael.enrico@dante.net	TNC showfloor	TNC showfloor	1x 100GE	1x 100GE	The DANTE 100GE test set will be placed at the TNC2013 showfloor and connected to the Juniper at 100G. When this demo is running a loop @ MAN LAN's Brocade switch will ensure that the traffic sent to MAN LAN returns to the showfloor. On display is the throughput and RTT (to show the traffic traveled the Atlantic twice)

Connected via the new 100 Gb/s transatlantic To US-GENI

Amsterdam is a major hub in The GLIF

F Dijkstra, J van der Ham, P Grosso, C de Laat, “A path finding implementation for multi-layer networks”, Future Generation Computer Systems 25 (2), 142-146.



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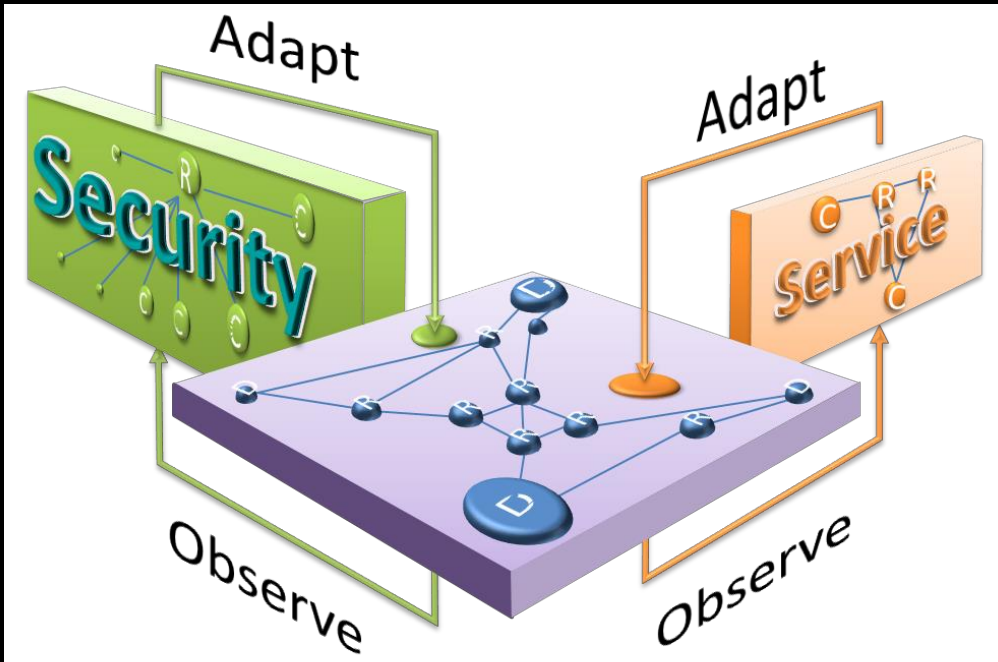
SARNET: Security Autonomous Response with programmable NETworks

Cees de Laat
Leon Gommans, Rodney Wilson, Rob Meijer
Tom van Engers, Marc Lyonais, Paola Grosso, Frans Franken,
Ameneh Deljoo, Ralph Koning, Ben de Graaff, Stojan Trajanovski

Cyber security program

- Research goal is to obtain the knowledge to create ICT systems that:
  - model their state (situation)
  - discover by observations and reasoning if and how an attack is developing and calculate the associated risks
  - have the knowledge to calculate the effect of counter measures on states and their risks
  - choose and execute one.

  In short, we research the concept of networked computer infrastructures exhibiting SAR: Security Autonomous Response.



SARNET

Security Autonomous Response with programmable NETworks

Cyber Security program

Pi: CdL

Co-Pi's: LG, RW, RM

Co-Sci: PG, TvE, FF, ML

400 + 285 + 300 kEuro

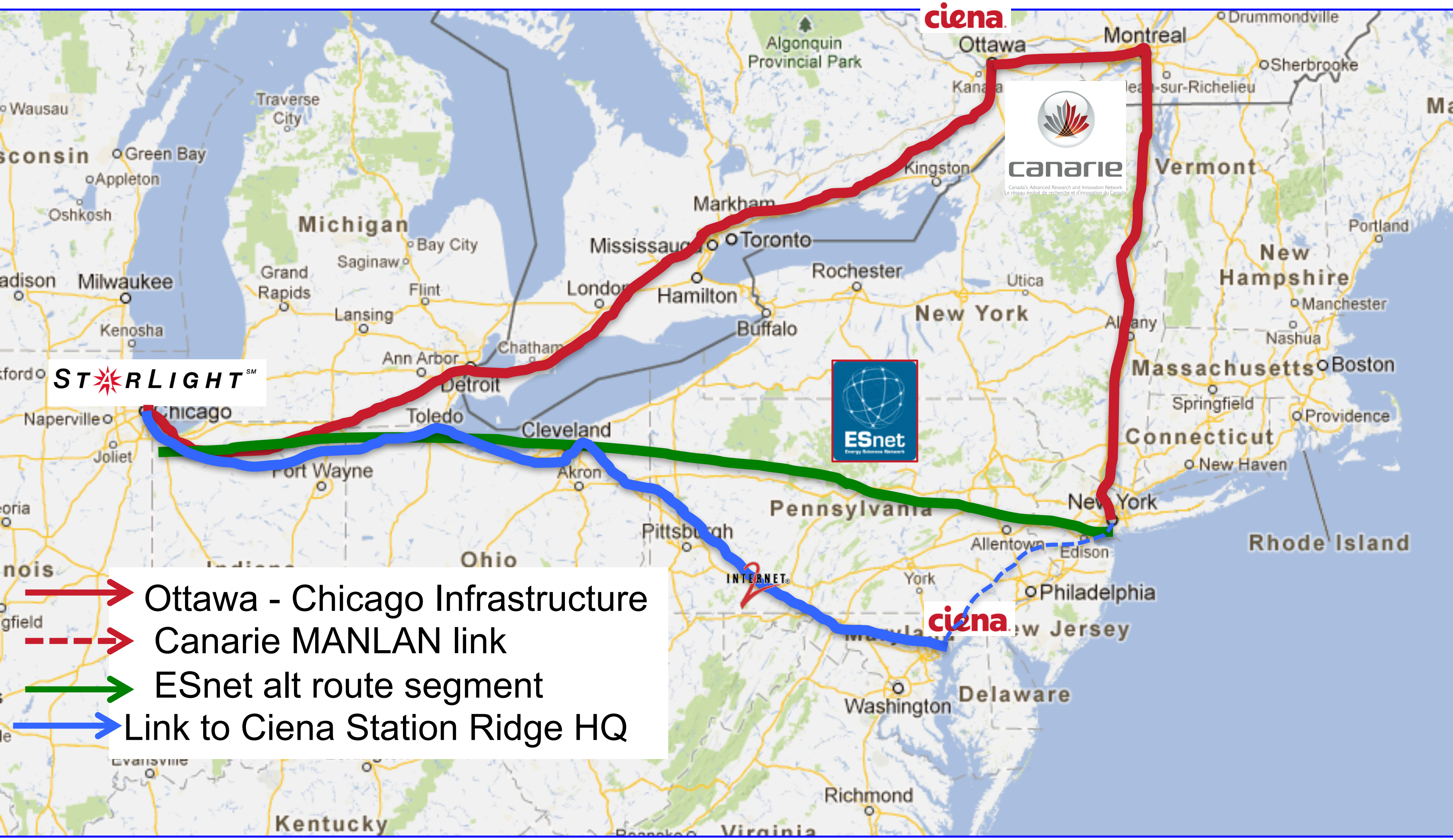
2 PhD's (AD, RK), 1 PD (ST)

Prog & Eng manpower (BG)

- Network virtualizations and SDN
- Reasoning
- Risk evaluation
- Trust groups
- Execute response & adaptation

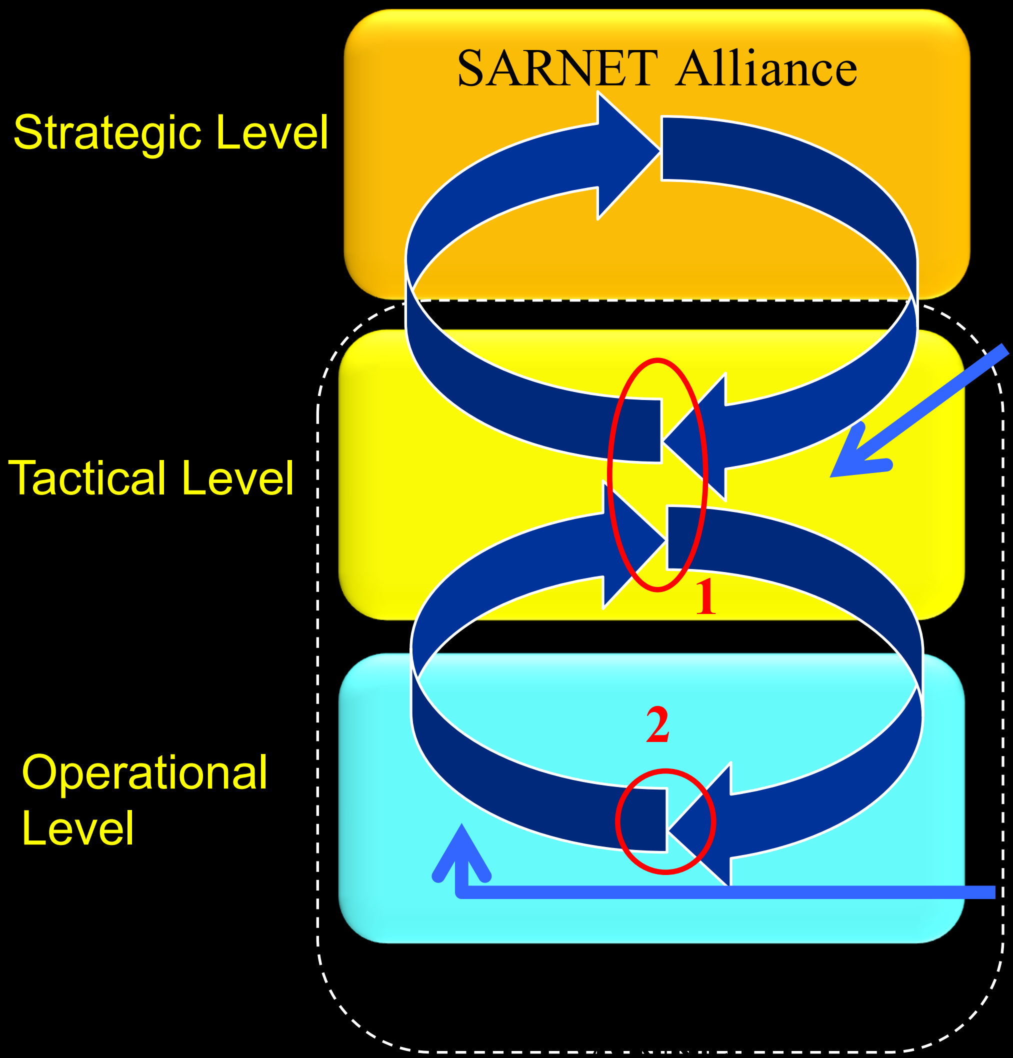
delaat.net/sarnet

Ciena's CENI topology



Context & Goal

Security Autonomous Response NETwork Research



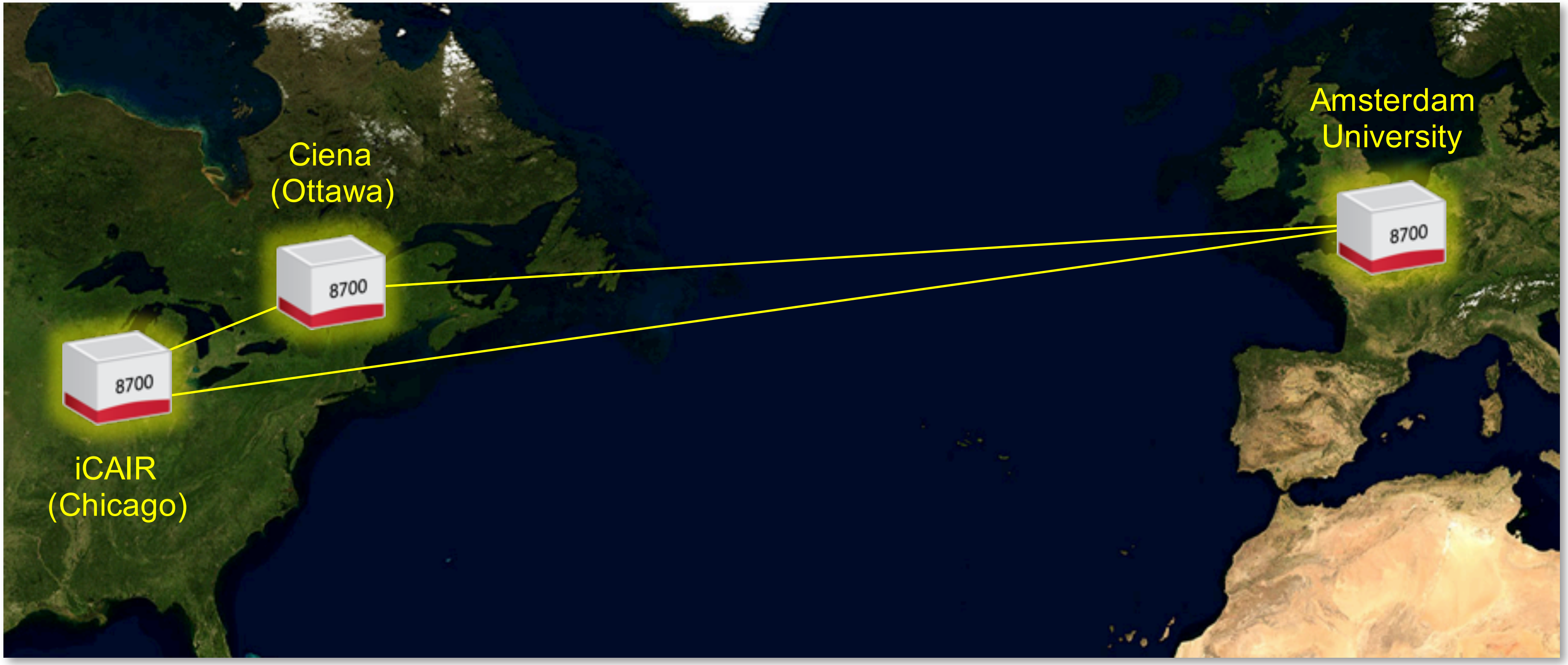
Ameneh Deljoo (PhD):
Why create SARNET Alliances? Model autonomous SARNET behaviors to identify risk and benefits for SARNET stakeholders

Stojan Trajanovski (PD):
Determine best defense scenario against cyberattacks deploying SARNET functions (1) based on security state and KPI information (2).

Ralph Koning (PhD)
Ben de Graaff (SP):
1. Design functionalities needed to operate a SARNET using SDN/NFV
2: deliver security state and KPI information (e.g cost)

CENI, International extension to University of Amsterdam

Research Triangle Project. Operation Spring of 2015



National Science Foundations ExoGENI racks, installed at UvA (Amsterdam), Northwestern University (Chicago) and Ciena's labs (Ottawa), are connected via a high performance 100G research network and trans-Atlantic network facilities using the Ciena 8700 Packetwave platform. This equipment configuration is used to create a computational and storage test bed used in collaborative demonstrations.

Position of demo @ SC15

Objective

- To get a better understanding for cyber attack complexity by visually defend a network suffering from basic volumetric attacks.
- To find a way to visualize future research in automated response.

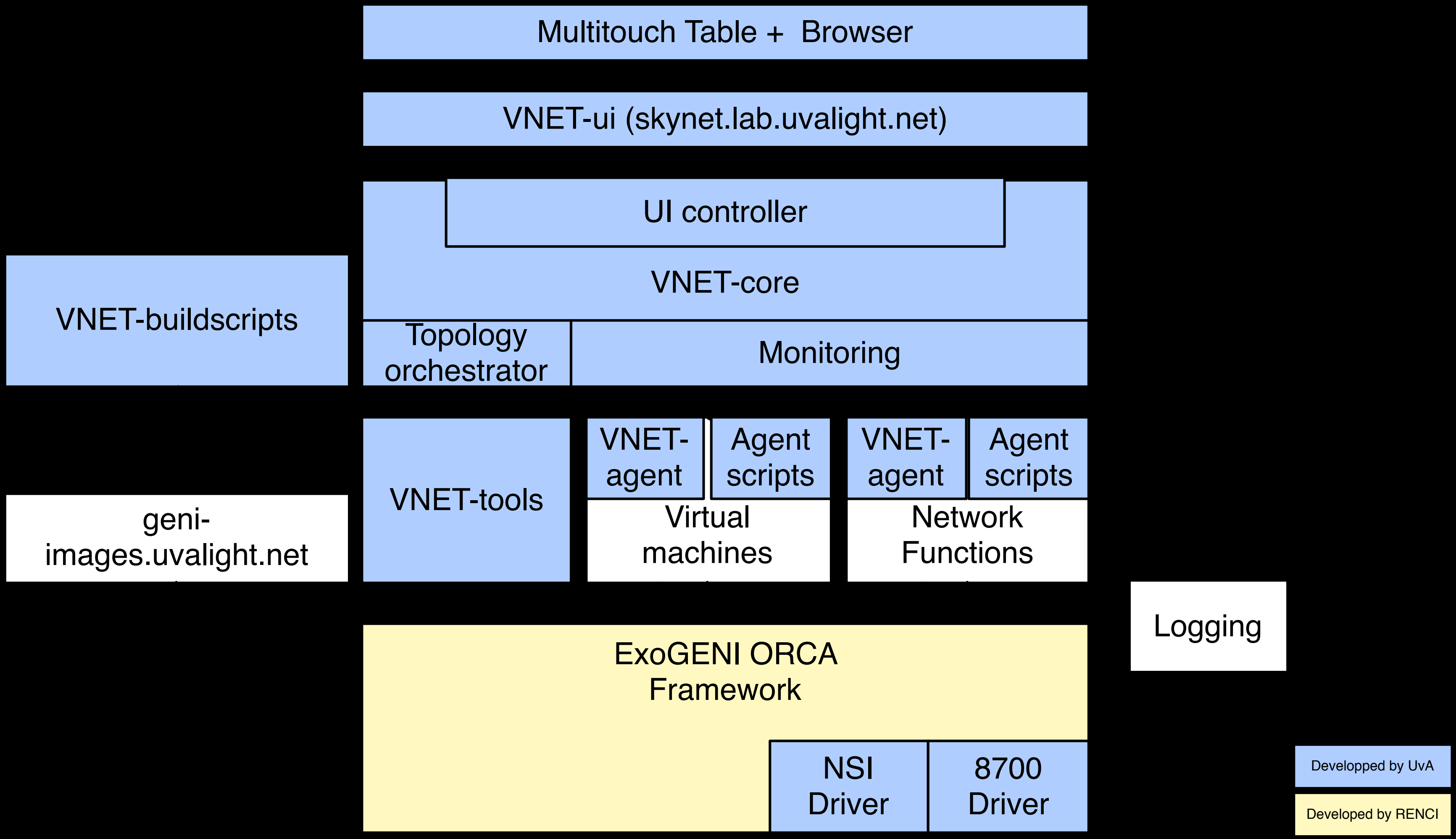
Demo highlights

- Pre-programmed attack scenarios that are able to show defense functions.
- Virtual sales + income from web services
- Defense cost

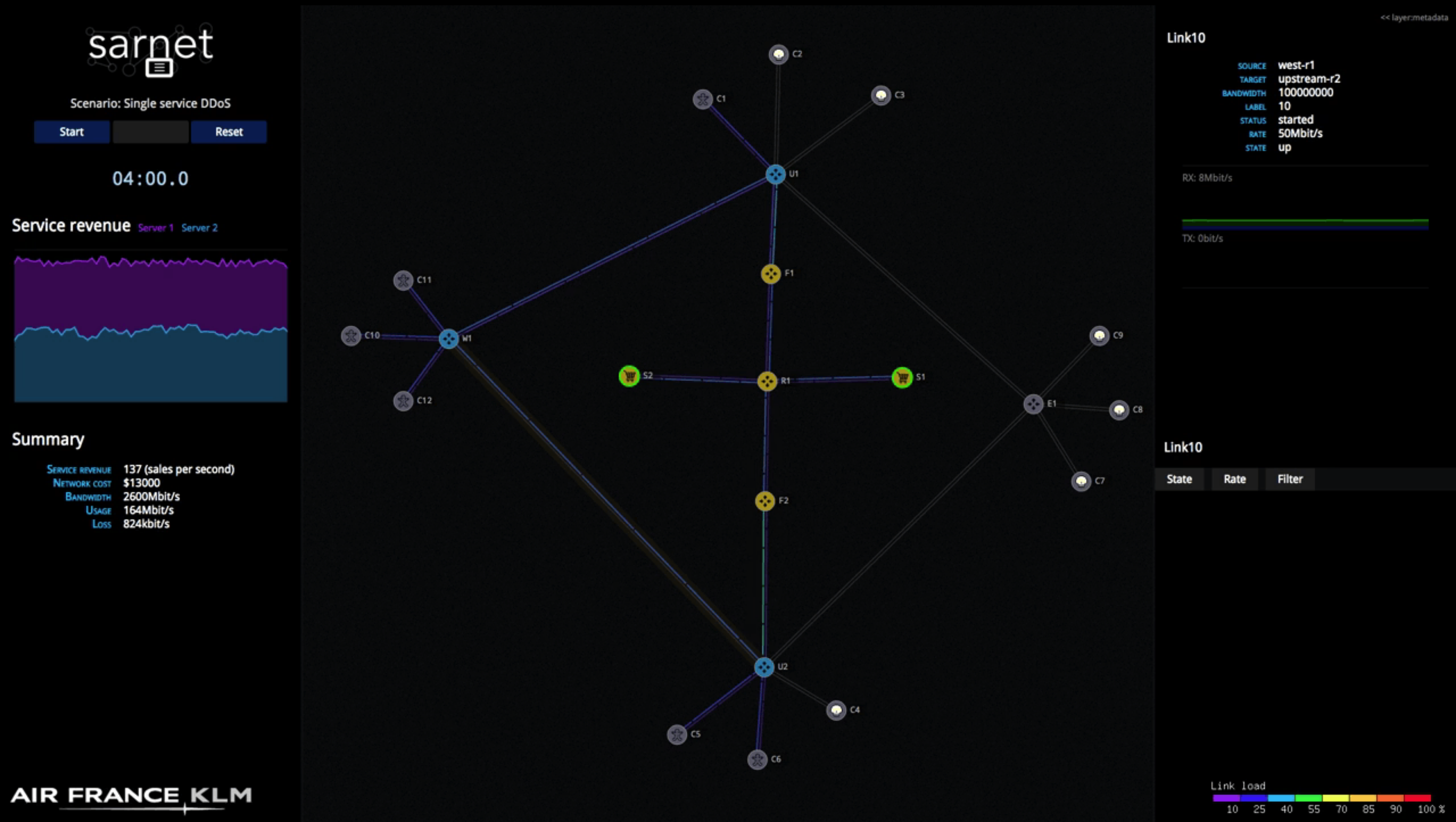
DDoS Defence functions.

- Filtering
- Blocking
- Resource Scaling

Demo stack


Multitouch Table + Browser
VNET-ui (skynet.lab.uvalight.net)
UI controller
VNET-core
VNET-buildscripts
Topology orchestrator
Monitoring
VNET-tools
VNET-agent
Agent scripts
Virtual machines
VNET-agent
Agent scripts
Network Functions
geni-images.uvalight.net
Logging
ExoGENI ORCA Framework
NSI Driver
8700 Driver
Developped by UvA
Developed by RENCI

Demo


sarnet
Scenario: Single service DDoS
Start
Reset
04:00.0
Service revenue
Server 1
Server 2
Summary
Service revenue 137 (sales per second)
Network cost $13000
Bandwidth 2600Mbit/s
Usage 164Mbit/s
Loss 824kbit/s
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
U1
U2
W1
E1
F1
F2
R1
S1
S2
<< layer:metadata
Link10
source west-r1
target upstream-r2
bandwidth 100000000
label 10
status started
rate 50Mbit/s
state up
RX: 8Mbit/s
TX: 0bit/s
Link10
State
Rate
Filter
Link load
10 25 40 55 70 85 90 100 %

Service Provider Group framework

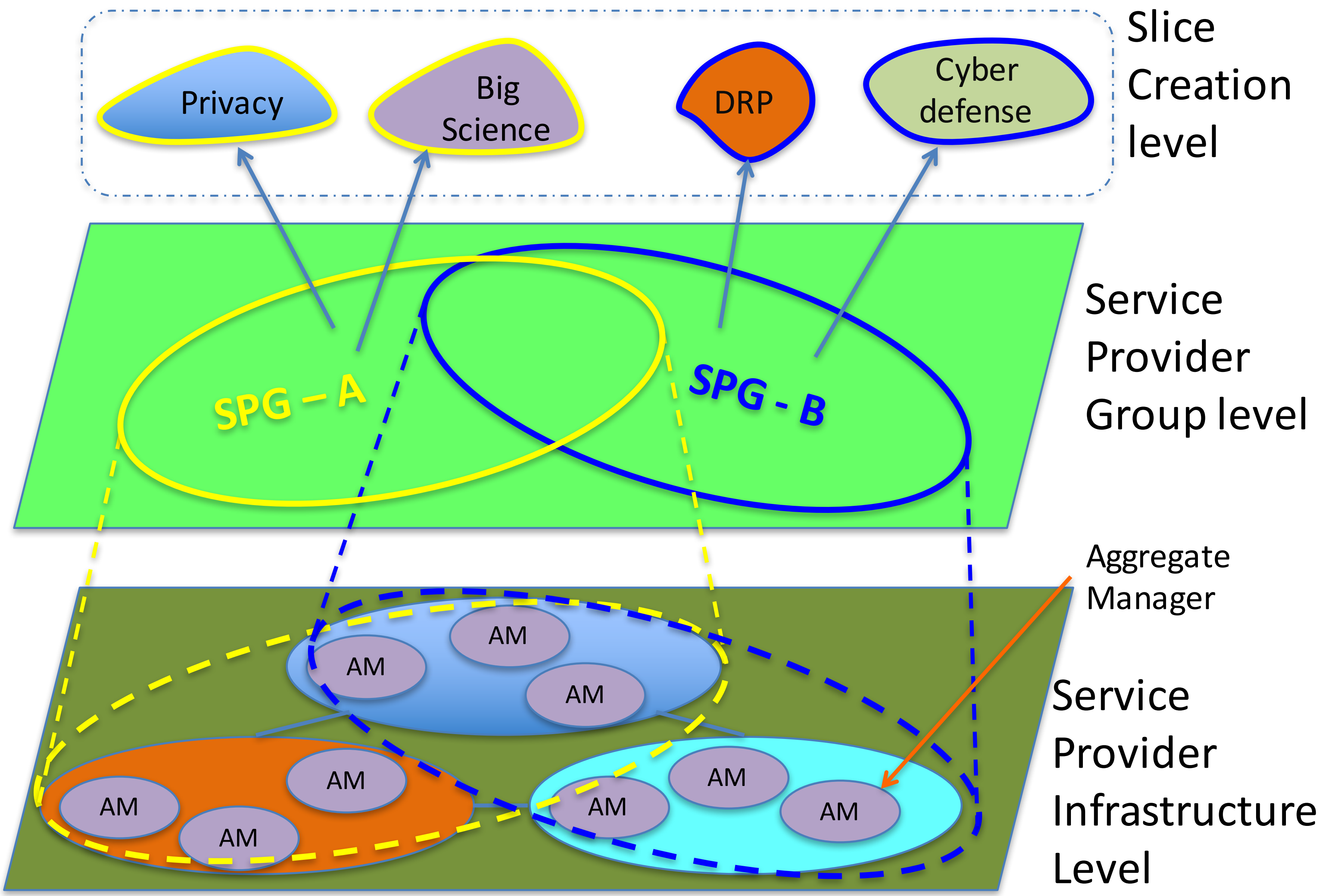
A Service Provider Group (SPG) is an organisation structure providing a defined service only available if its members collaborate.

Examples:

Service Provider Group Characteristics

- Autonomous members acting together on a decision to provide a service none could provide on its own
- Appears as a single provider to a customer
- Appears as a collaborative group to members with standards, rules and policies that are defined, administered, enforced and judged by the group.
- Autonomy in the group: every member signs an agreement declaring compliance with common rules, unless local law determines otherwise.
- Membership rules organizes trust amongst members and manage group reputation and viability.

Envisioned role of the SPG: define slice archetypes?



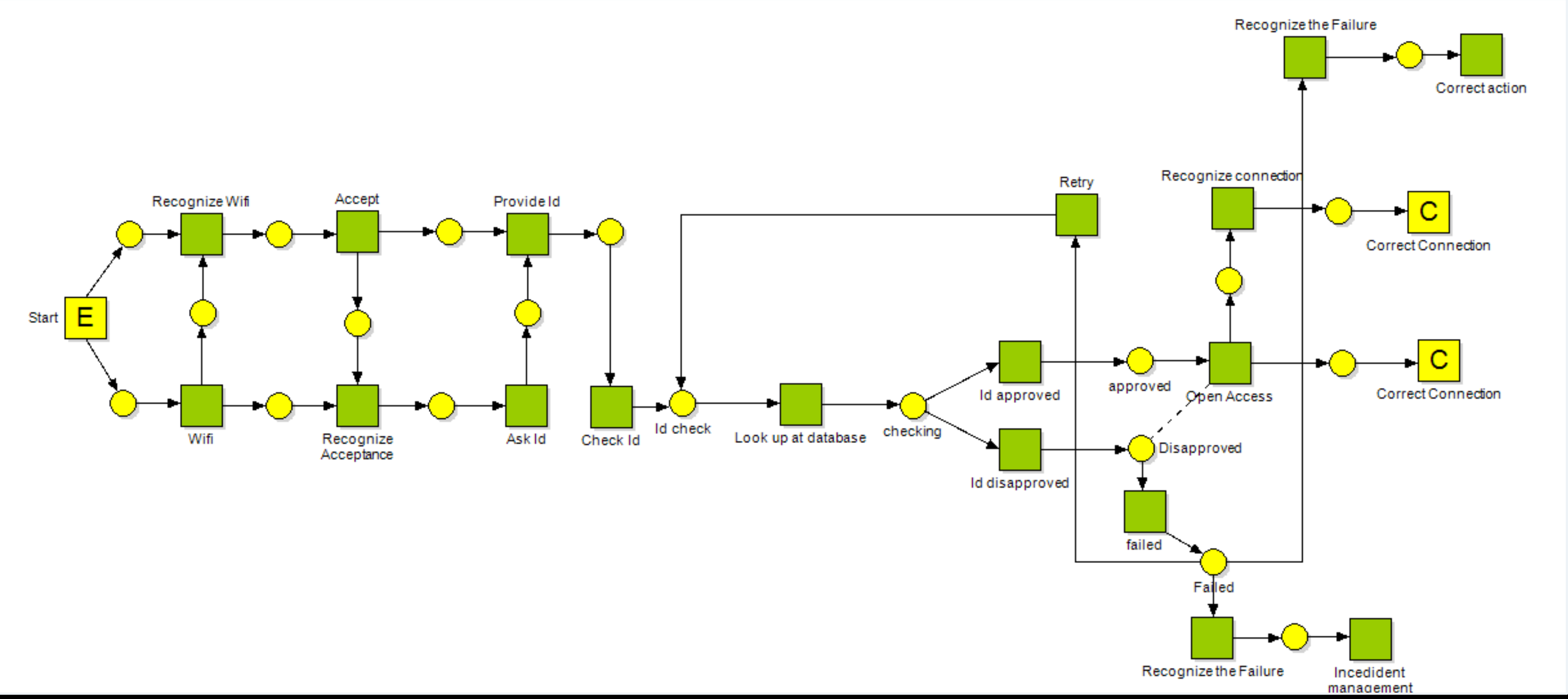
Agent Based Modelling Framework

	Main component
Signal layer	Message / Act
Action layer	Action / Activity
Intentional layer	Intention
Motivational layer	Motive

In our model, we refer to four layers of components:

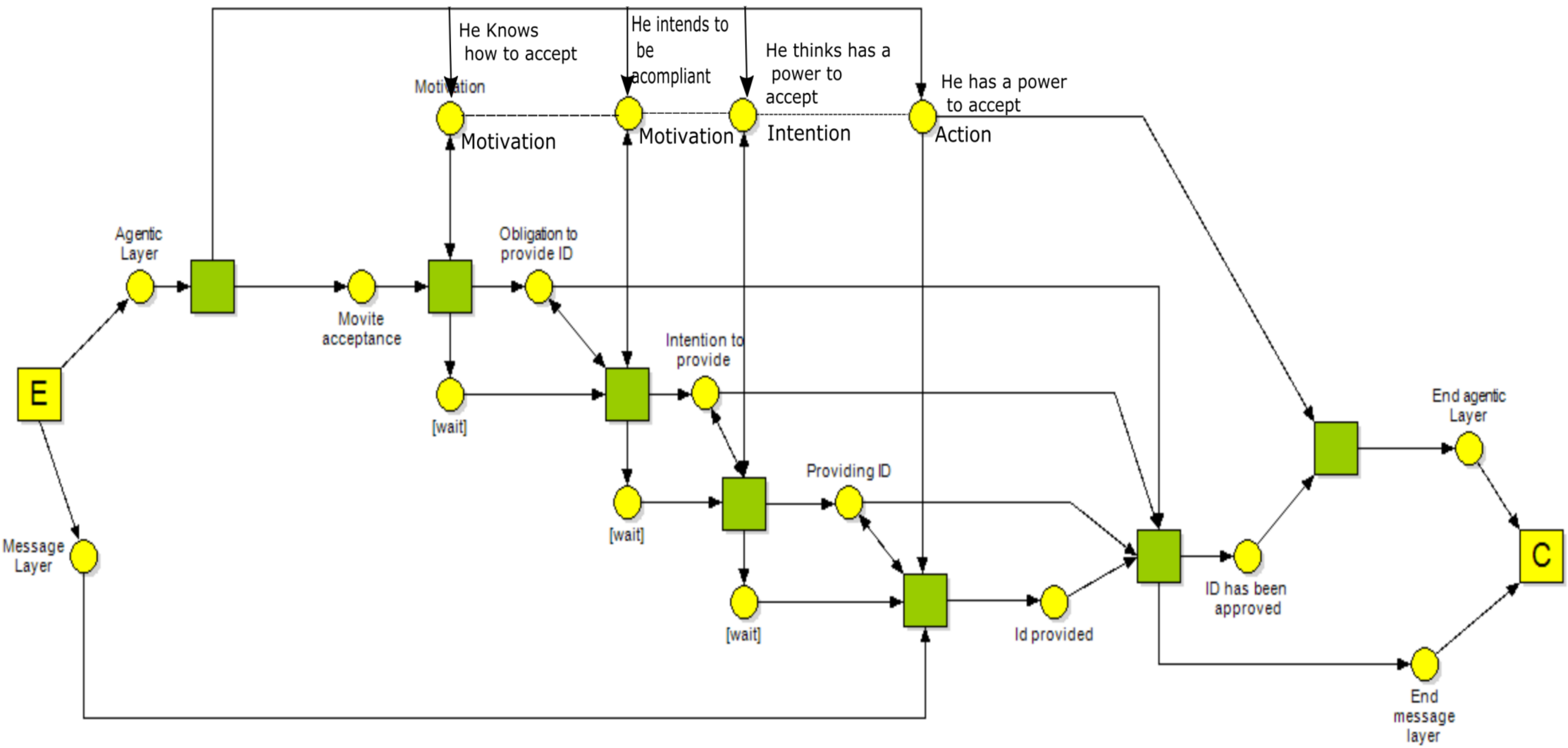
- the signal layer— describes acts, side-effects and failures showing outcomes of actions in a topology.
- the action layer—actions: performances that bring a certain result,
- the intentional layer—intentions: commitments to actions, or to build up intentions,
- the motivational layer—motives: events triggering the creation of intentions.

Simplified Eduroam case at signalling layer



Petri net of EduRoam Case
(first step)

Describing Intentions, Motivations and Actions



Petri net of EduRoam Case

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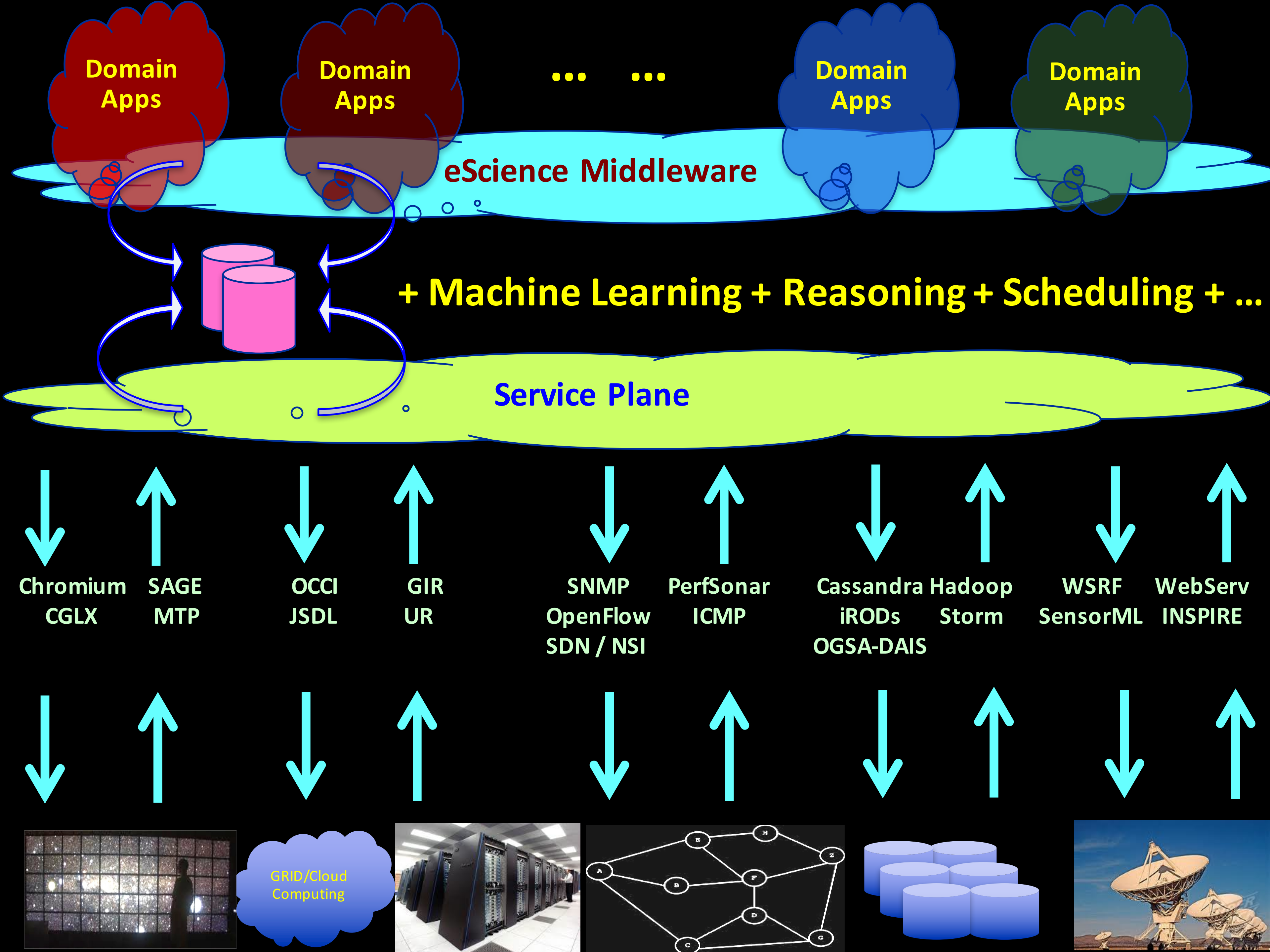
I want to

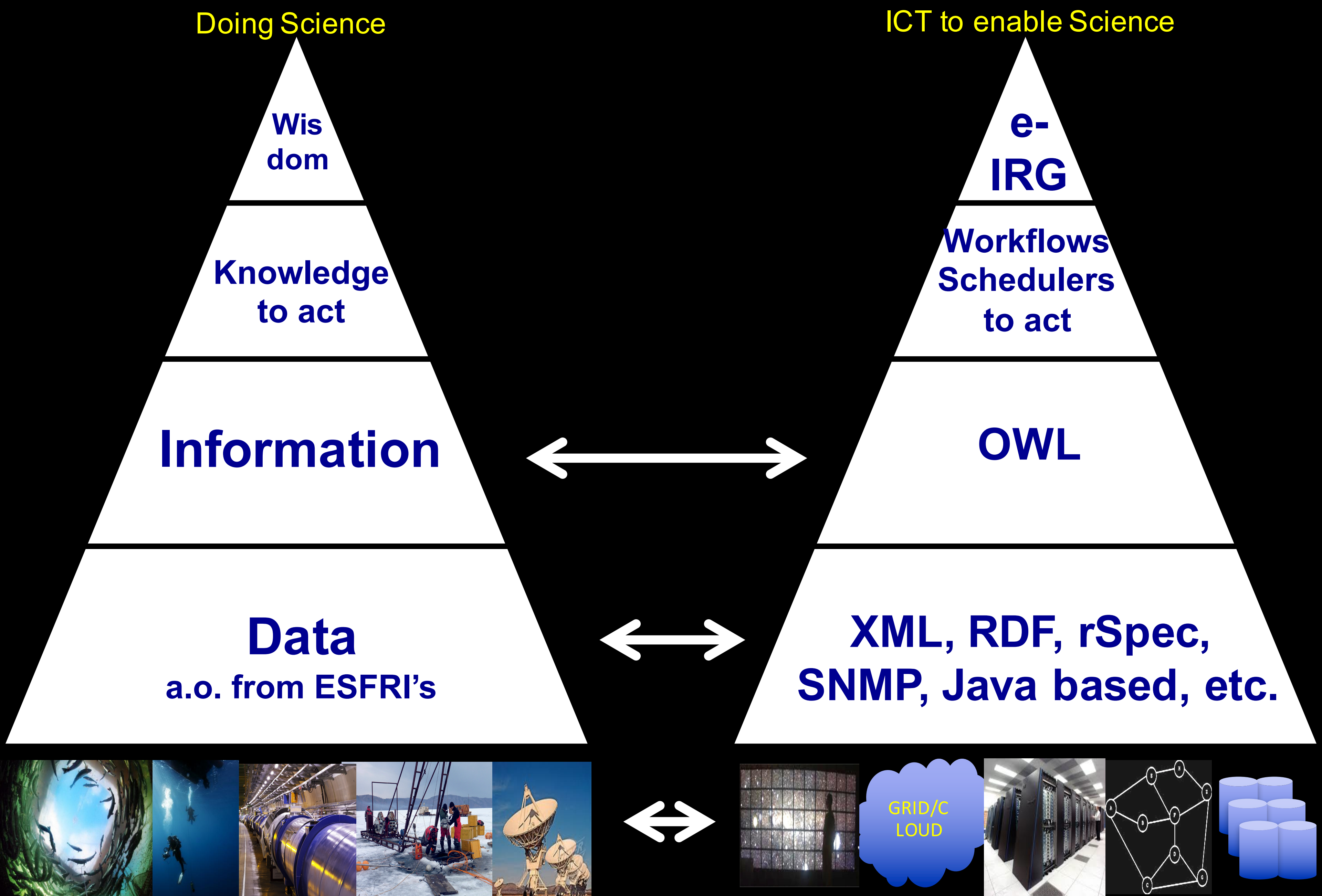
"Show Big Bug Bunny in 4K on my Tiled Display using green Infrastructure"

- Big Bugs Bunny can be on multiple servers on the Internet.
- Movie may need processing / recoding to get to 4K for Tiled Display.
- Needs deterministic Green infrastructure for Quality of Experience.
- Consumer / Scientist does not want to know the underlying details.

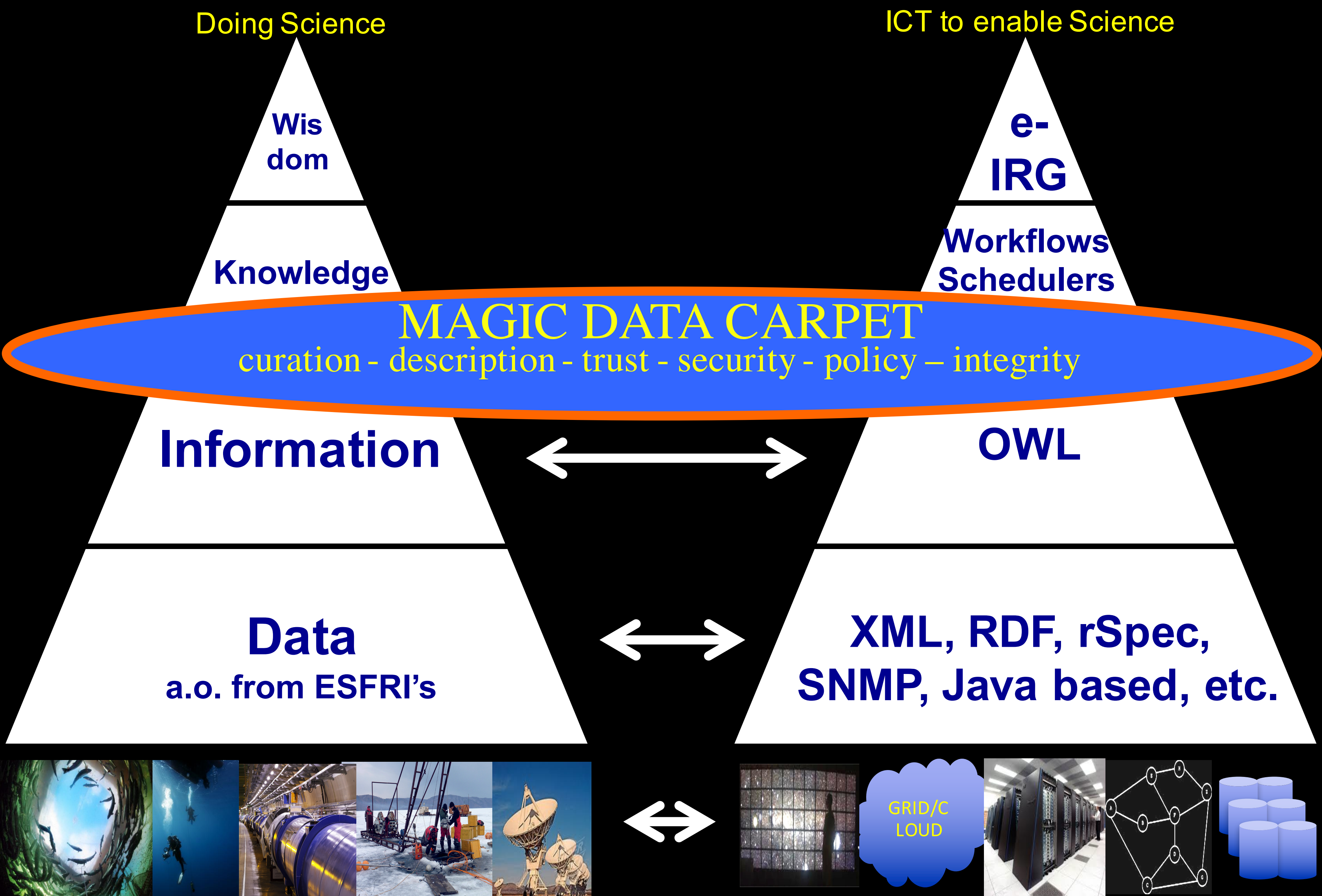
➔ His refrigerator also just works!


Domain Apps
Domain Apps
... ...
Domain Apps
Domain Apps
eScience Middleware
+ Machine Learning + Reasoning + Scheduling + ...
Service Plane
Chromium
CGLX
SAGE
MTP
OCCI
JSDL
GIR
UR
SNMP
OpenFlow
SDN / NSI
PerfSonar
ICMP
Cassandra
iRODs
OGSA-DAIS
Hadoop
Storm
WSRF
SensorML
WebServ
INSPIRE
GRID/Cloud Computing

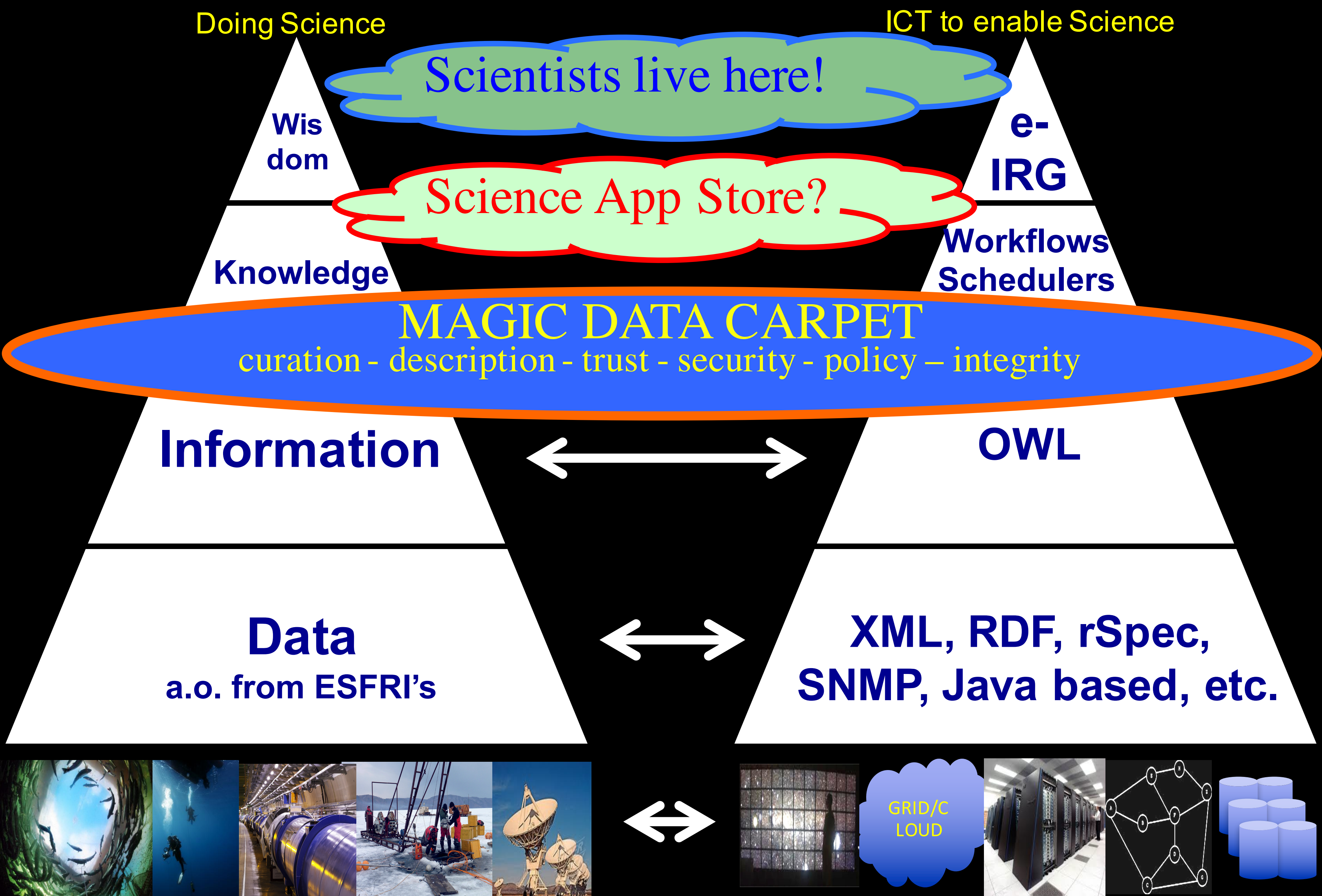
The Big Data Challenge



The Big Data Challenge



The Big Data Challenge



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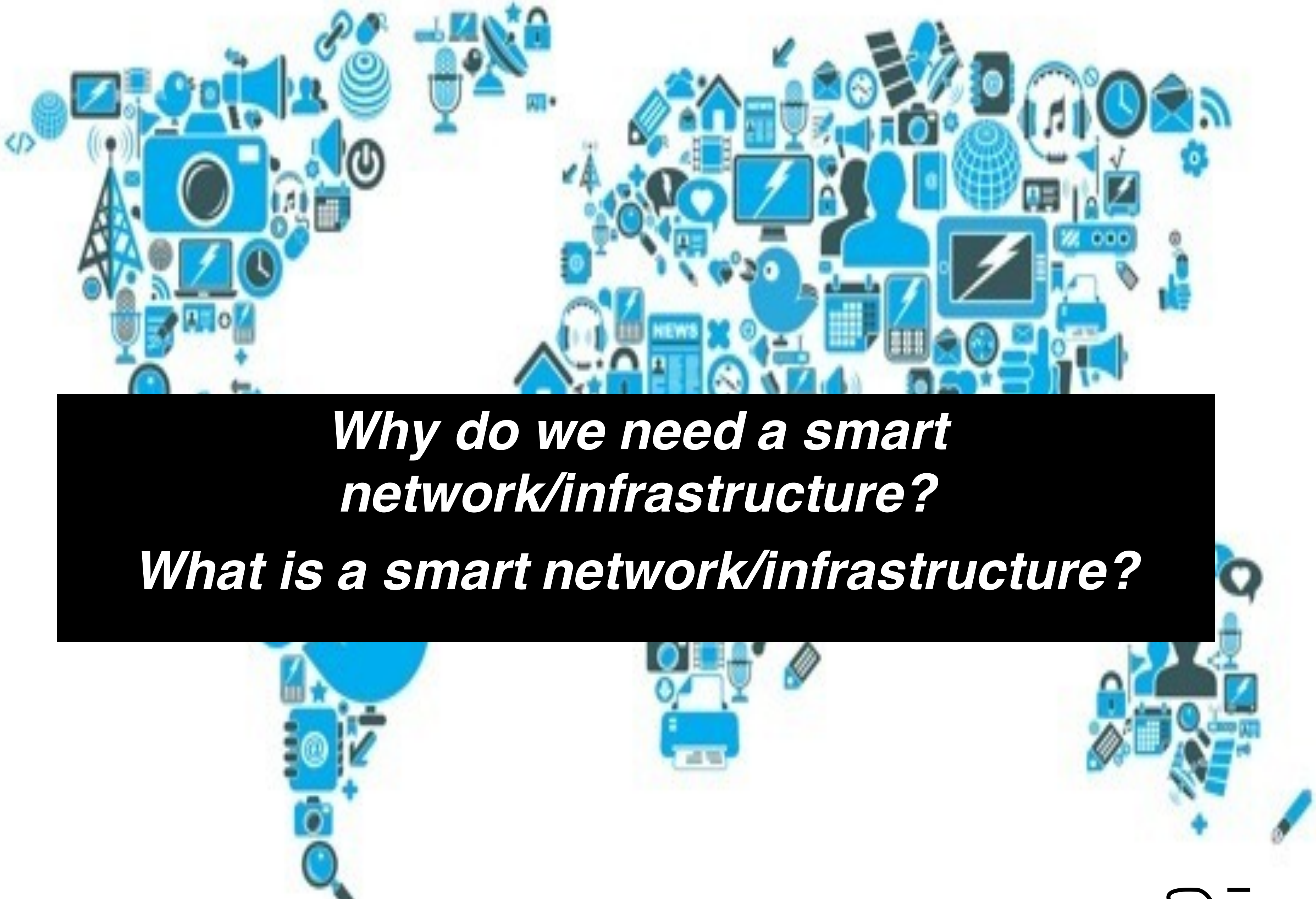
The smart network, the smart infrastructure

Dr. Paola Grosso
System and Network Engineering (SNE) research group
UvA
Email: p.grosso@uva.nl

Universiteit van Amsterdam

System and Network Engineering



Why do we need a smart network/infrastructure?

What is a smart network/infrastructure?

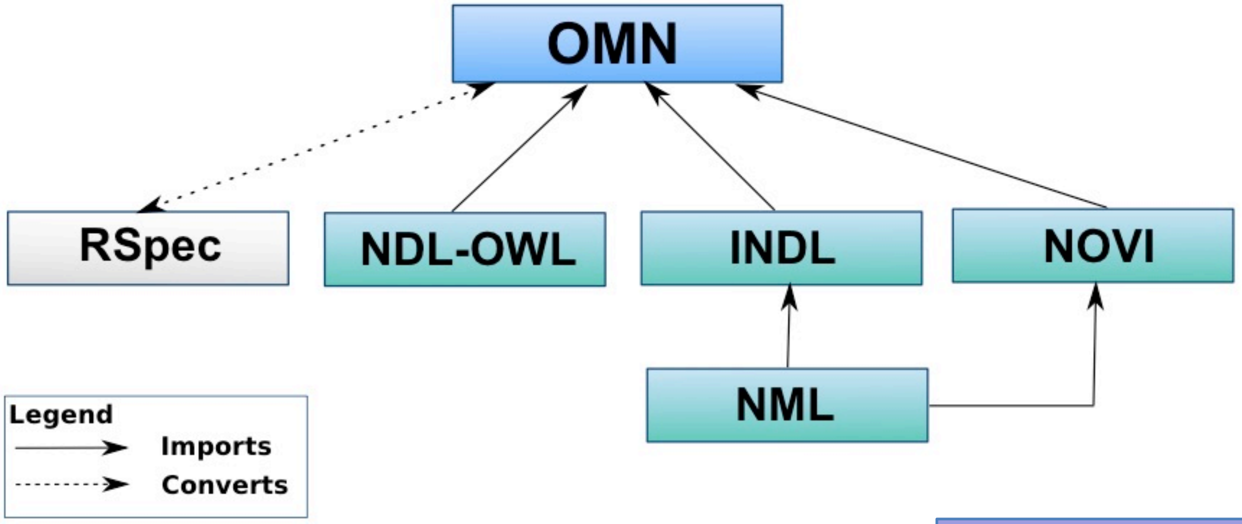
We exploit **richer network and infrastructure descriptions** to *deliver federated network and clouds services.*

We leverage the **SDN paradigm** to *align network behavior closer and applications needs*.

We get:

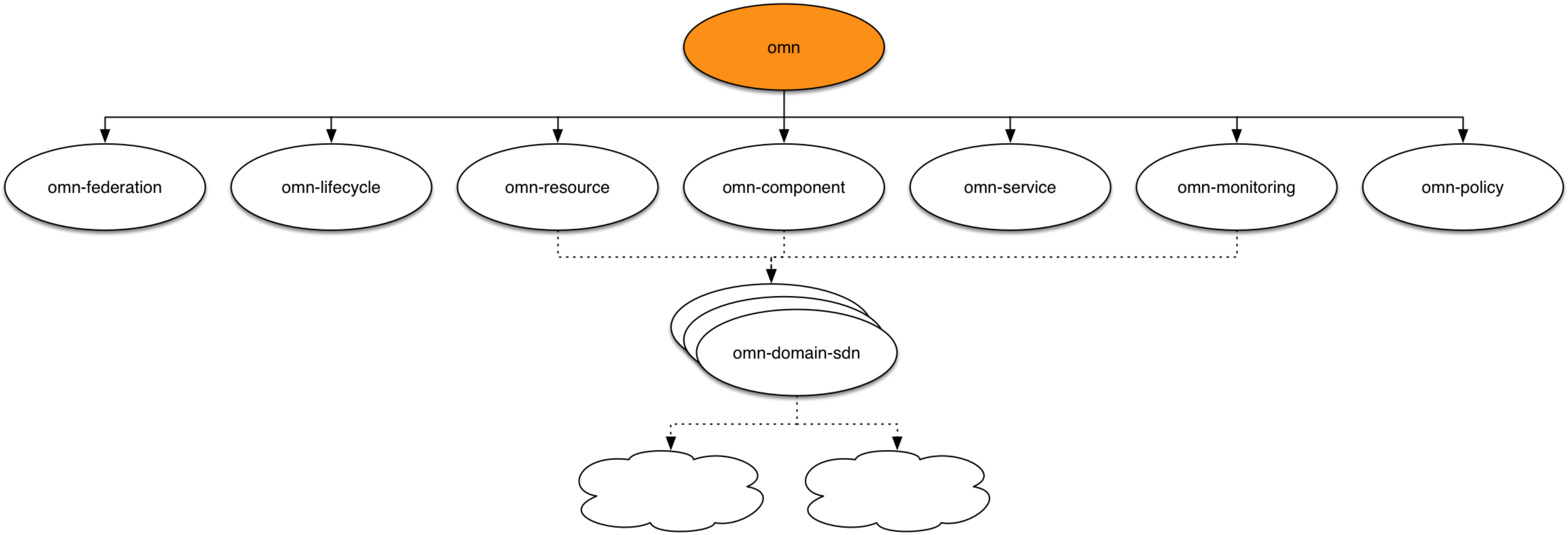
- more energy-efficient,
- more secure,
- more adaptable networks

Ontology families



M. Ghijsen, , J. v/d Ham, P. Grosso, C. Dumitru, H. Zhu, Z. Zhao, C. De Laat
"A Semantic-Web Approach for Modeling Computing Infrastructures," Computers and Electrical Engineering, vol. 39 (8), pp. 2553–2565, 2013

OMN – Open Multinet



https://github.com/open-multinet
https://github.com/open-multinet/playground-rspecs-ontology/tree/master/omnlib/ontologies

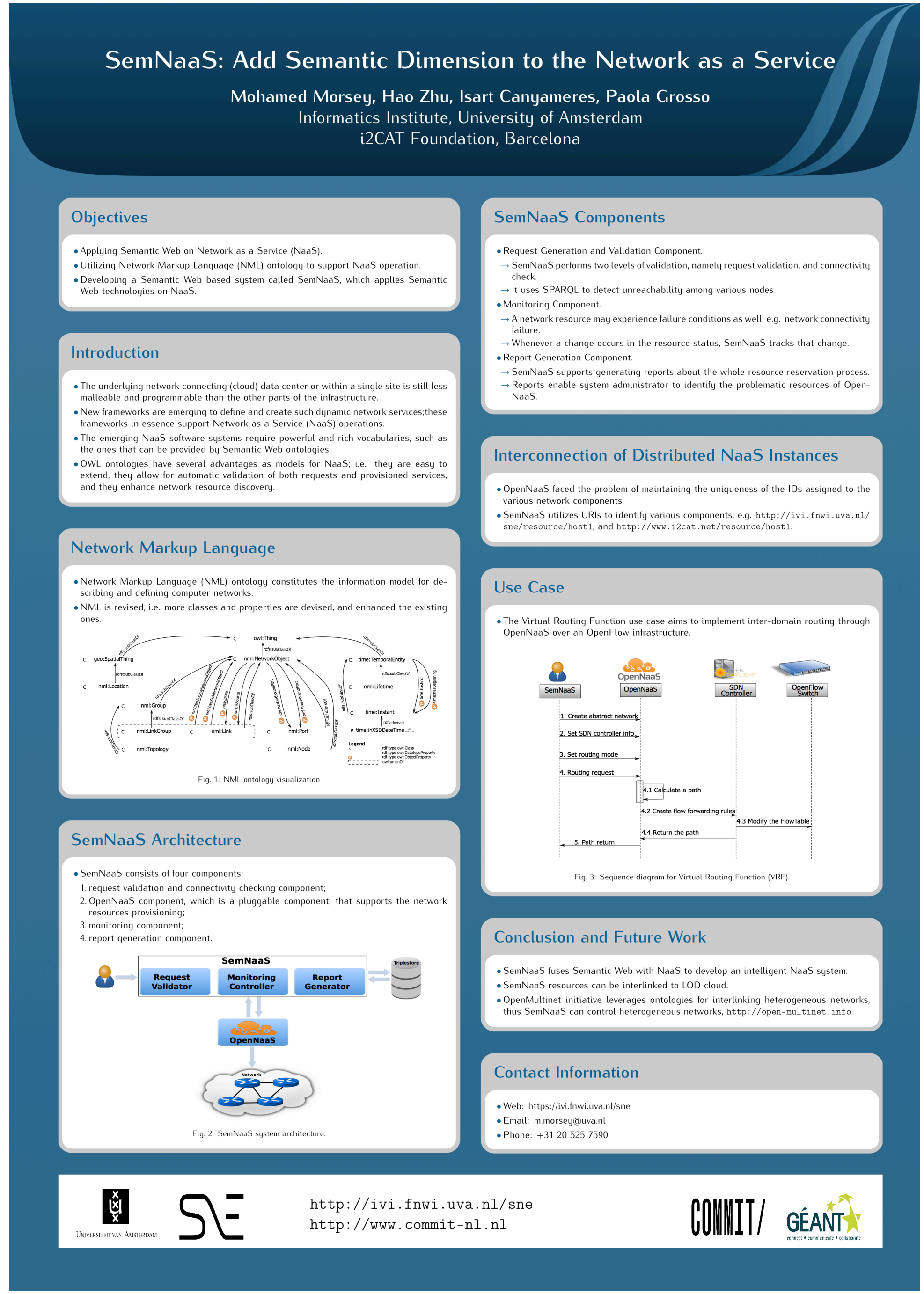
A. Willner, C. Papagianni, M. Giatili, P. Grosso, M. Morsey, Al-Hazmi Y., I. Baldin
The Open-Multinet Upper Ontology - Towards the Semantic-based Management of Federated Infrastructures
The 10th International Conference on Testbeds and Research Infrastructures for the Development of Networks & Communities (TRIDENTCOM 2015)

Transitioning from OpenNaas to SemNaaS

Developed a semantic enabled Network-as-a-Service (NaaS) system

Applied NML2/OMN on that system.

M Morsey, H Zhu, I Canyameres, P Grosso
SemNaaS: Add Semantic Dimension to the Network as a Service
The Semantic Web: ESWC 2015 conference



UNIVERSITEIT VAN AMSTERDAM

SWSDI 2016 Workshop

The First International Workshop on Semantic Web for Federated Software Defined Infrastructures (SWSDI2016)
Co-located with ESWC 2016, Anissaras, Crete, Greece. May, 2016

Contents [hide]

Workshop Objectives

The main objective of SWSDI 2016 is to study the applicability and maturity of Semantic Web based methodologies for modelling the newly emerging software-defined (computing and networking) infrastructures, particularly federated infrastructures and federated Clouds. Furthermore, SWSDI 2016 aims to identify how the Semantic Web surpasses other approaches, such as the exchange of simple XML or JSON serialized tree data structures.

Workshop organizers
Jorge Cardoso, University of Coimbra, Portugal
Paola Grosso, University of Amsterdam, The Netherlands
Mohamed Morsey, University of Amsterdam, The Netherlands
Alexander Willner, TU Berlin, Germany

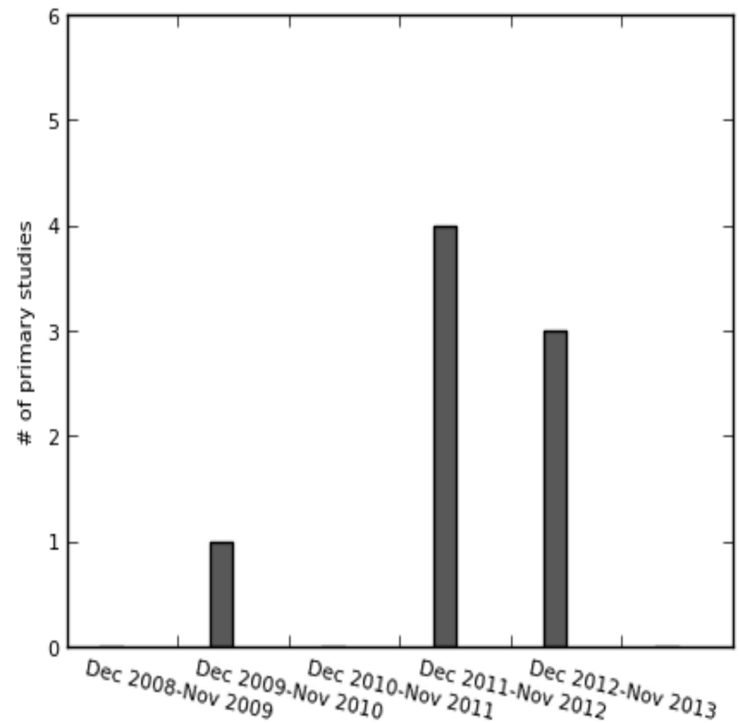
Deadlines
Paper submission : Friday March 4th, 2016.
Notification of acceptance: Friday April 1st, 2016.

UNIVERSITEIT VAN AMSTERDAM

System and Network Engineering

Emerging interest in SDN for energy efficiency

- Emerging studies improve on the energy consumption of servers by the VM migration.
- Some change the OpenFlow protocol to be energy-aware.
- All of them are implemented in intra-data center scale.
- All have a fixed initial traffic matrix.

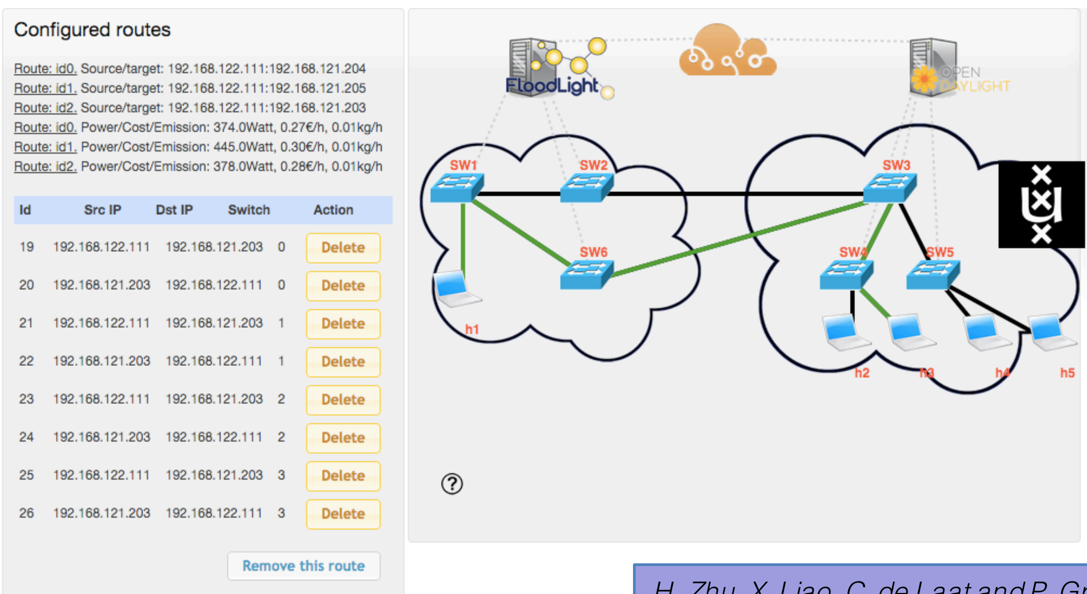


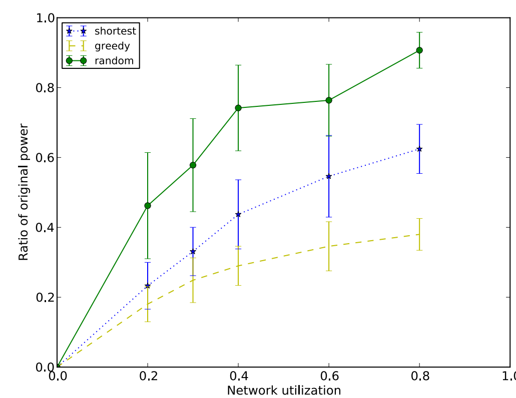
Yearly distribution of the OpenFlow technique adoption by decision frameworks from December 2008 to November 2013

Moghaddam, F. A., Lago, P., & Grosso, P.
Energy-Efficient Networking Solutions in Cloud-Based Environments: A Systematic Literature Review.
ACM Computing Surveys (CSUR), 47(4), 64. (2015)

Green routing with SDN

Make a routing decision to aggregate traffic over a subset of links and devices in over-provision networks and switch off unused network components





H. Zhu. X. Liao, C. de Laat and P. Grosso. (2015)
Joint flow routing-scheduling for energy efficient software defined data center networks
(to appear in Elsevier Journal of Network and Computer Applications)

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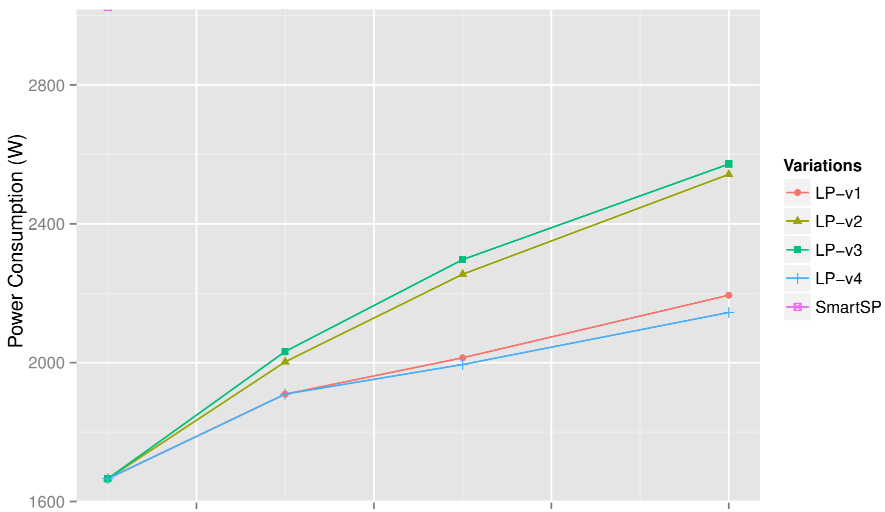
System and Network Engineering

How much savings?



We adopt linear programming to determine how to program flows in the network.

We show that in FatTree networks, where switches can save up to 60% of power in sleeping mode, we can achieve 15% minimum improvement assuming a one-to-one traffic scenario.
Two of our algorithm variations privilege performance over power saving and still provide around 45% of the maximum achievable savings.

F. A.. Moghaddam and P. Grosso. (2016)
Linear Programming Approaches for Power Savings in Software-defined Networks
(Under review at the NetSoft conference 2016)

Universiteit van Amsterdam

System and Network Engineering

4th International Conference on ICT for Sustainability (ICT4S)

Aug 30 - Sep 2, 2016 - Amsterdam, The Netherlands

Home Calls & Dates Program Team ict4s.org Venue Search

General chair
Anwar Osseyran, SURFsara & University of Amsterdam, The Netherlands

Program chairs
Paola Grosso, University of Amsterdam, The Netherlands
Patricia Lago, VU University Amsterdam, The Netherlands

Deadlines
Paper submission : Monday April 11th, 2016.
Notification of acceptance: Tuesday May 31st, 2016.

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System and Network Engineering

SARNET

SARNET
Secure Autonomous Response Networks

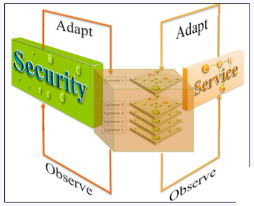
Ralph Koning (UvA), Ameneh Deljoo (UvA), Robert Meijer (TNO), Leon Gommans (KLM),
Tom van Engers (UvA), Rodney Wilson (Ciena), Cees de Laat (UvA)

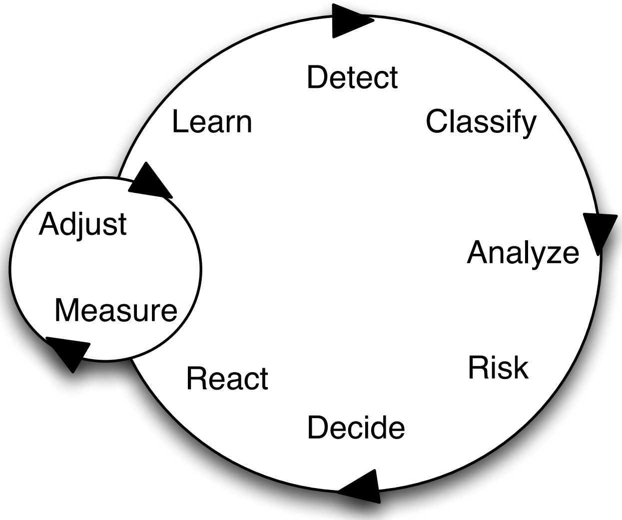
SARNET

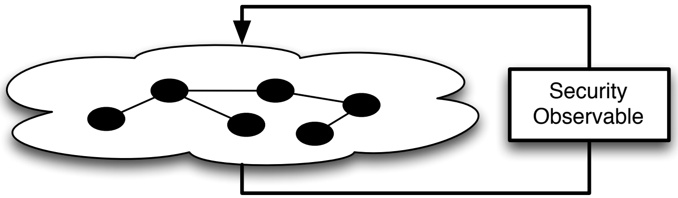
SARNET, Secure Autonomous Response NETworks, is a project funded by the Dutch Research Foundation. The University of Amsterdam, TNO, KLM, and Ciena conduct research on **automated methods against attacks** on computer **network infrastructure**.

The research goal of SARNET is to obtain the knowledge to create ICT systems that

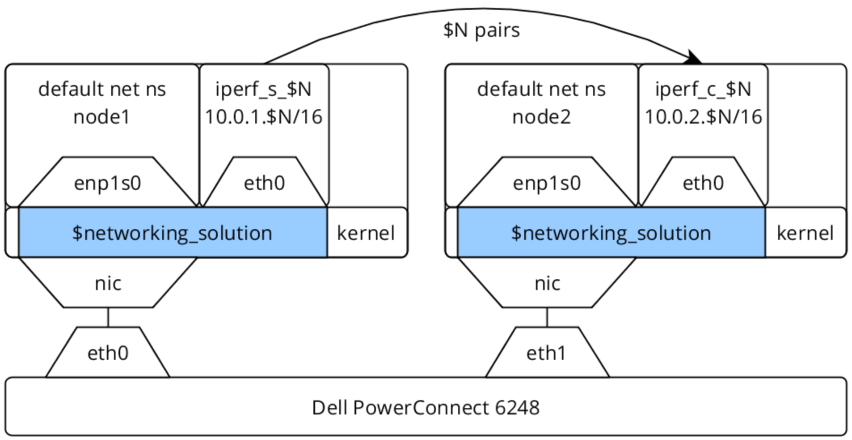
- **model** the system's state based on the emerging behaviour of its components,
- discover by observations and **reasoning** if and how an attack is developing and calculate the associated risks,
- have the **knowledge** to calculate the effect of countermeasures on states and their risks, and
- choose and **execute** the most effective **countermeasure**.

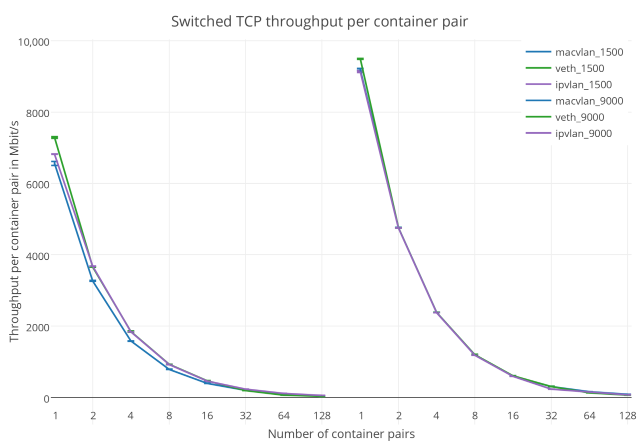






Container networking





We benchmarked three kernel modules: **veth**, **macvlan** and **ipvlan**, to quantify their respective raw TCP and UDP performance and scalability.

Our results show that the macvlan kernel module outperforms all other solutions in raw performance. All kernel modules seem to provide sufficient scalability to be deployed effectively in multi- containers environments.

J. Claassen, R. Koning and P. Grosso. (2016)
Linux containers networking: performance and scalability of kernel modules
Accepted at NOMS 2016

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Open research directions

- Can we create Semantic NaaS in federated environments?
- How can software services exploit SDN for energy efficiency of the applications?
- Are containers and (SDN) overlays the solution for secure networks?

Dr. Zhiming Zhao

Senior Researcher
System and Network Engineering
University of Amsterdam

EU H2020 SWITCH (**Scientific Coordinator**)
EU H2020 ENVRI^{PLUS} (**Theme Leader**)
EU H2020 VRE4EIC (**Task Leader**)

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Web: *http://staff.fnwi.uva.nl/z.zhao/*

Modeling, Developing and Controlling *Quality Critical Distributed Systems* on Programmable Infrastructures.

SWITCH

plus ENVRI
Environmental Research Infrastructures Providing Shared Solutions for Science and Society

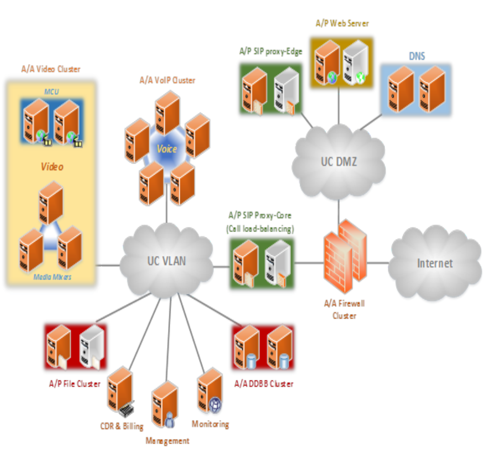
VRE 4 EIC

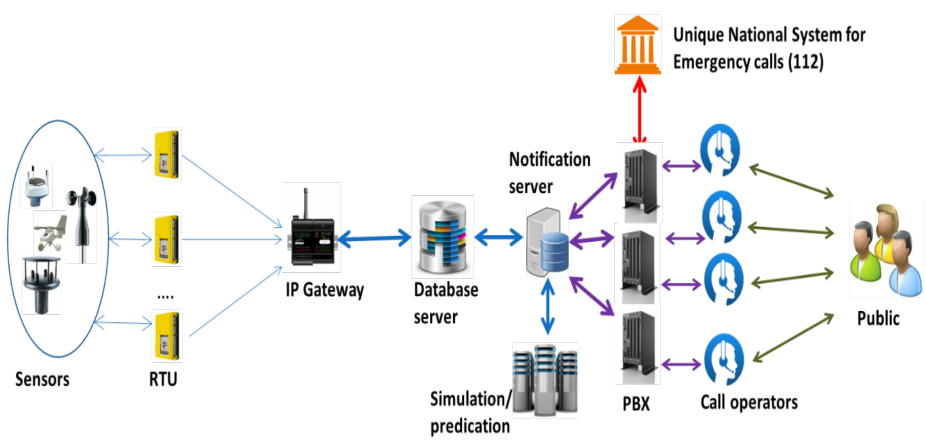
Research topics

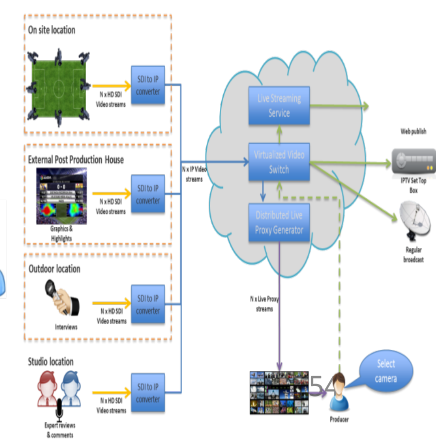
- Programming, provisioning and controlling models for time critical applications on programmable infrastructure
- Interoperable research infrastructures for system level of big data sciences
- Virtual research environments for large scale research communities

Time critical applications

- have **very high** business potential or social impacts, e.g.,
  - live event broadcasting,
  - disaster early warning, and
  - real-time business collaboration;
- have **very critical** quality requirements for services, e.g.,
  - video quality, system interaction, or data delivery;
- But are **very expensive in** implementation and operation.

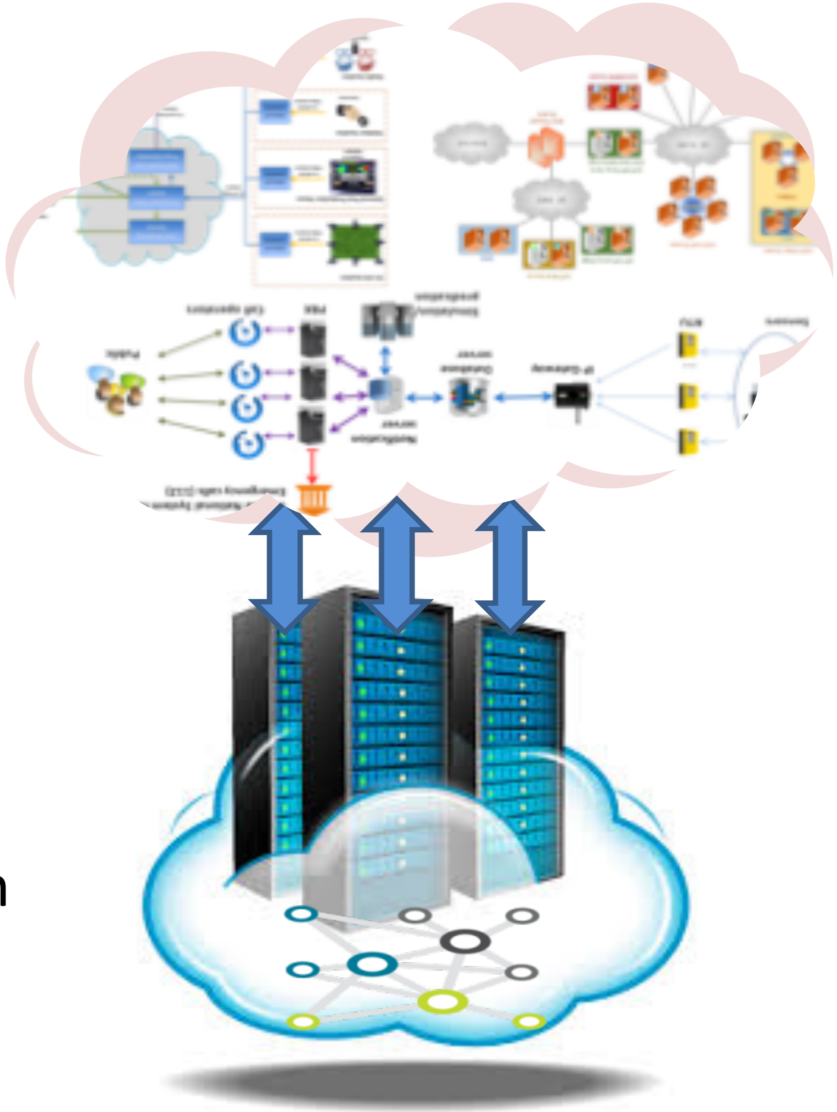






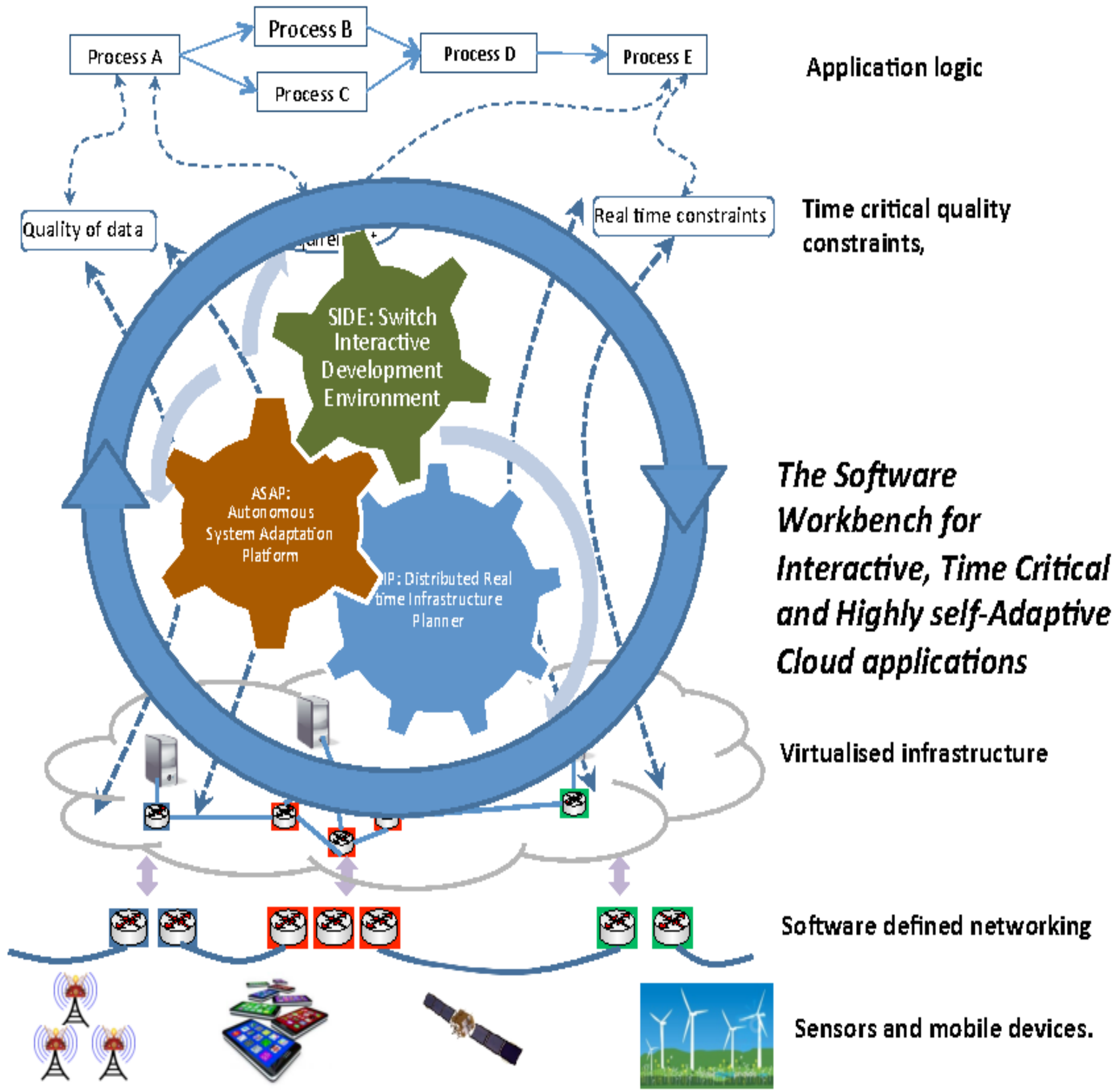
Challenges and difficulties

- Development challenges
  - QoS/QoE between different levels
  - Verification
  - Optimization
- Provisioning challenges
  - Infrastructure customization
  - Fast provisioning
- Operation challenges
  - Run-time monitoring adaptation
  - Autonomous/human-in-the-loop control



About SWITCH

SWITCH addresses the **entire life-cycle** of time-critical, self-adaptive Cloud applications by developing **new middleware and front-end tools** to enable users to **specify** their time-critical requirements for an application interactively using a direct manipulation user interface, **deploy** their applications and **adapt** the infrastructure to changing requirements **at runtime** either automatically (using the specified requirements) or by human intervention if desired.



Software **W**orkbench for **I**nteractive, **T**ime **C**ritical and **H**ighly self-adaptive Cloud applications

- EU H2020 ICT RIA project
- Funding 3M, 6 partners
- Coordinator: University of Amsterdam (**Zhiming Zhao**, **Cees de Laat**)
- Duration: 3 years


Zhiming Zhao


Carlos Rodrigo Rubia Marcos

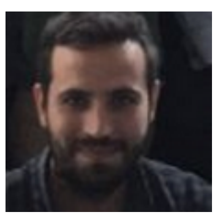

Andrew Jo


Vlado Stankovski


George Surciu


Pedro Ferreira


Cees de Laat

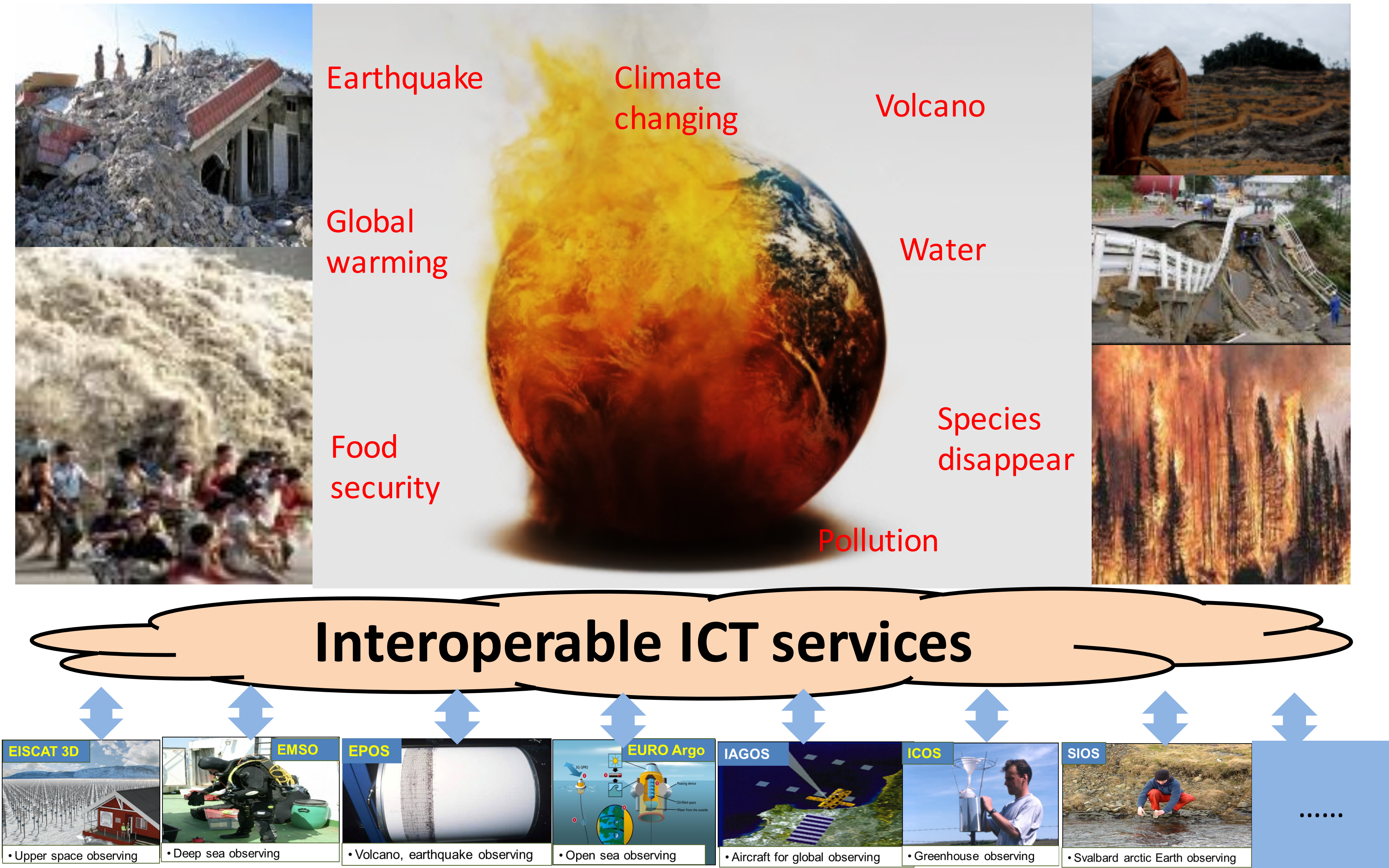

Francisco Jesus Hidalgo


Ian Taylor

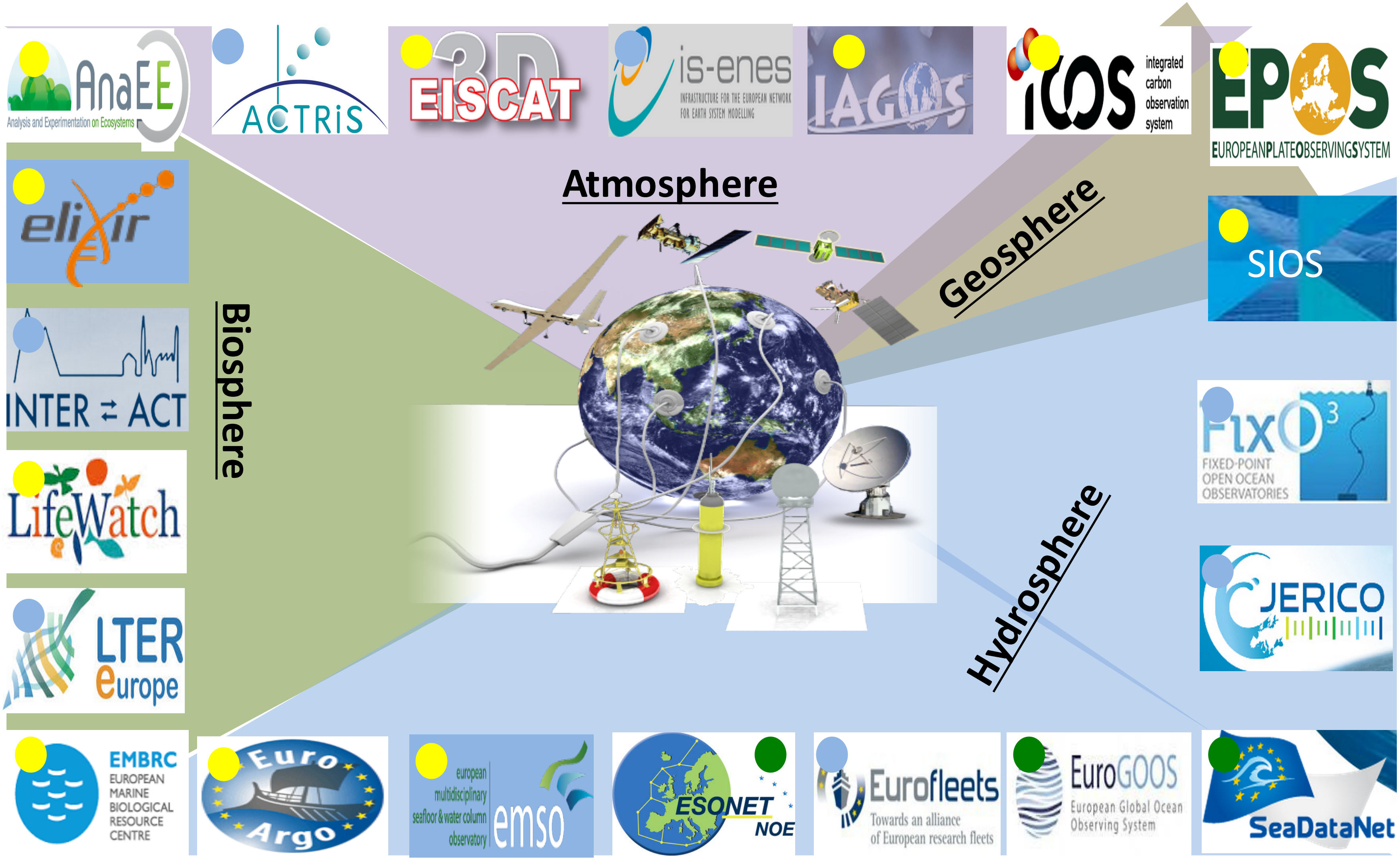

Alexandre Vlisses

Universiteit van Amsterda Wellness Telecom CARDIFF UNIVERSITY Univerza v Ljubljani Beia CONSULT INTERNATIONAL mog

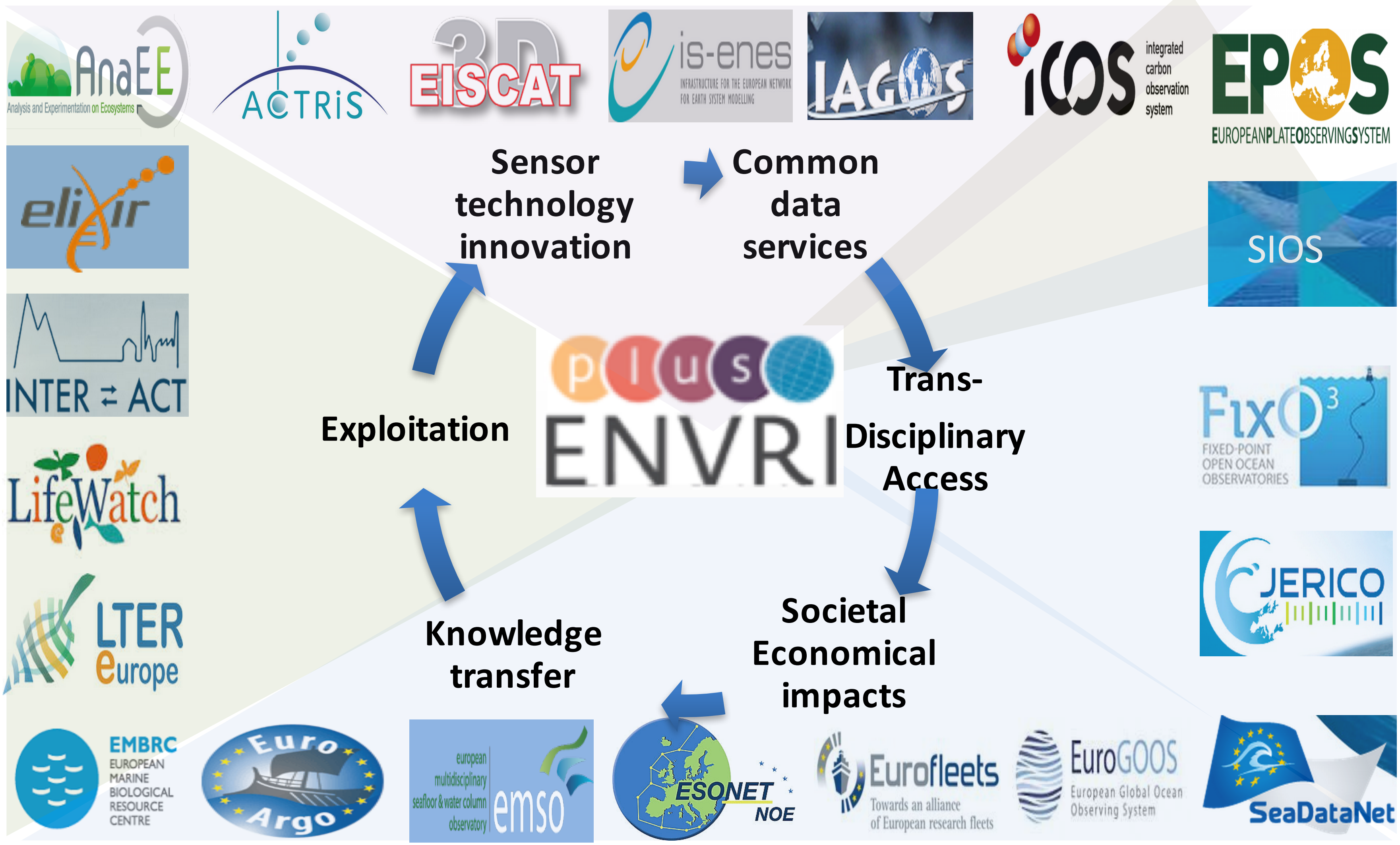
Motivation: societal challenges- system level of environmental sciences



Interoperable infrastructures for environmental sciences



Research Infrastructures, I3, and ESFRIs in environmental Sciences



ENVRI plus

Environmental Research Infrastructures Providing Shared Solutions for Science and Society

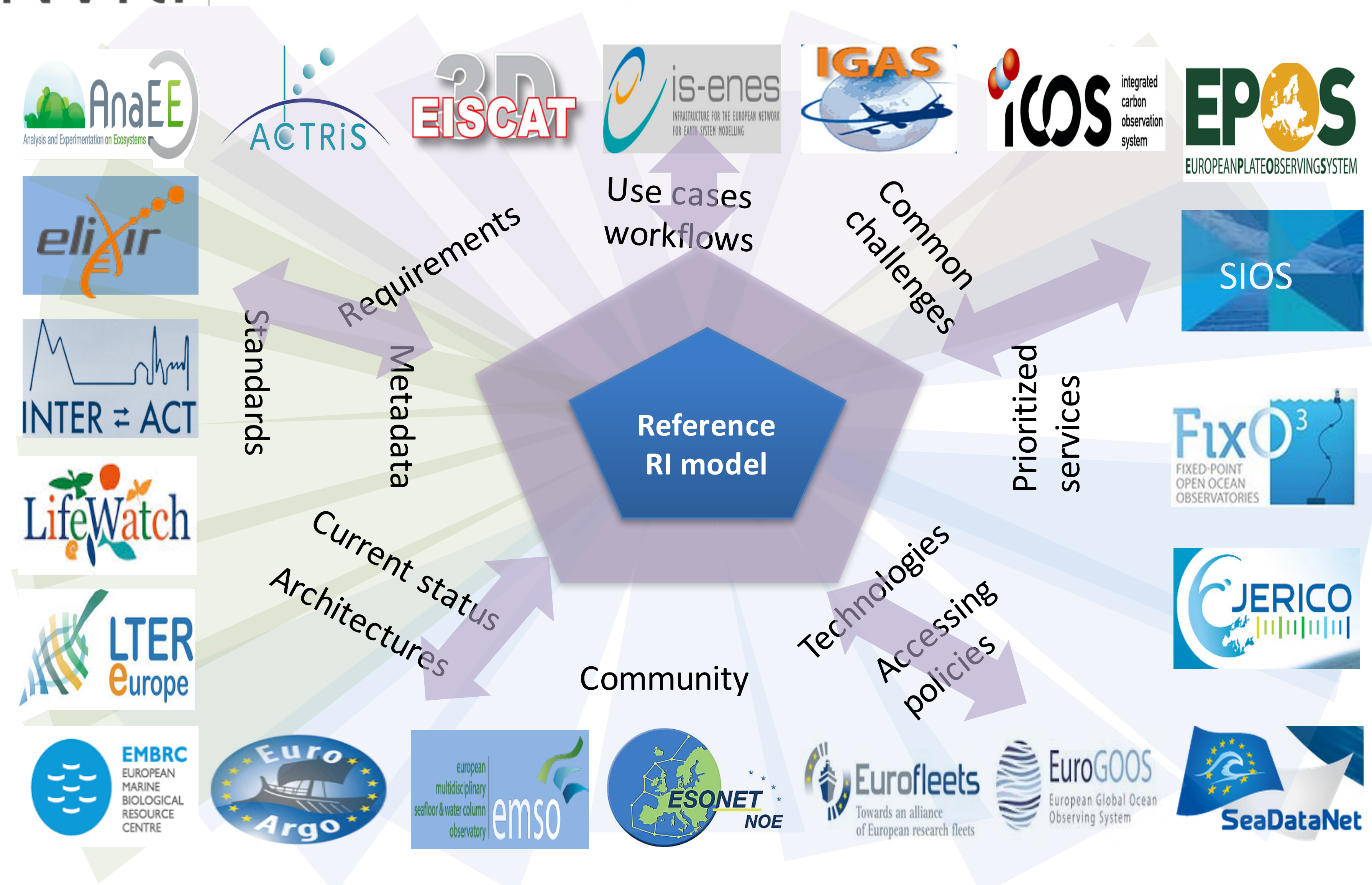
Common data services

- Curation
- Identification Citation
- Cataloguing
- Processing
- Optimization
- Provenance

ENVRI plus

Environmental Research
Infrastructures Providing Shared
Solutions for Science and Society

Ontological framework



Environmental Research Infrastructures Providing Shared Solutions for Science and Society

ENVRI^{PLUS}

- ENVRI^{PLUS}: www.envriplus.eu, 15M Euro, 4 years
- The data for science theme: 5M Euro
- Partners: 37
- Theme leader: University of Amsterdam (**Zhiming Zhao**)
- Key members in the *Data for Science* theme

Zhiming Zhao (UvA)

Paola Grosso (UvA)

Alex Vermeulen (LU/ICOS)

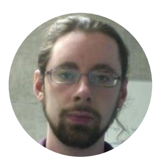
Leonardo Candela (CNR)

Keith Jeffery (EPOS)

Yannick Legre (EGI)

Malcolm Atkinson (UEDIN)

Alex Hardisty (CU)



Paul Martin (UvA)

Daniele Bailo (INGV/EPOS)

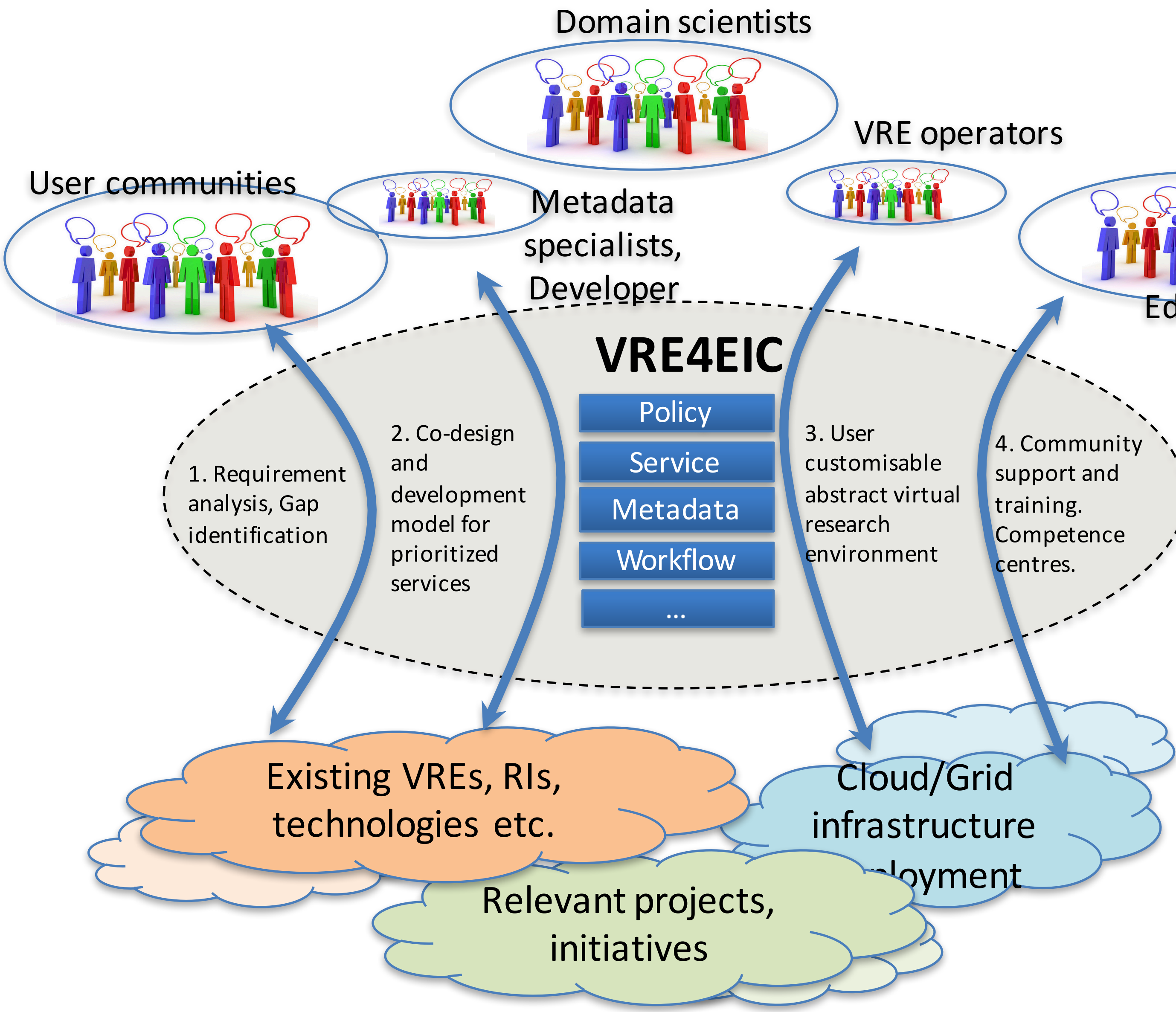
Thomas Loubrieu (INFERMERE/EMSO)

Barbara Magagna (EEA/LTER)

VRE4EIC

- EU H2020: VRE4EIC project
- Virtual Research Environment (VRE)
- Our contribution: lead the task of research sustainability, exploitation of VRE development to the ENVRI^{PLUS} community.

The basic idea of VRE4EIC



VRE to **E**mpower multi-disciplinary research communities and accelerate **I**nnovation and **C**ollaboration

Summary

- Exchange of research experiences, ideas etc.
  - Time critical cloud computing
  - Environmental sciences and big data infrastructures
  - Virtual research environments
- Joint proposals
  - EU-China
  - NWO-NSFC

Questions?

http://delaat.net

http://delaat.net/sarnet

Leon Gommans, "Multi-Domain Authorization for e-Infrastructures", UvA, Dec 2014.

http://delaat.net/pubs/2014-t-3.pdf

Rudolf Strijkers, "Internet Factories", UvA, Nov 2014.

http://delaat.net/pubs/2014-t-2.pdf

Contact us:

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z.zhao@uva.nl