MASSIVIZING COMPUTER SYSTEMS – 21st CENTURY ICT INFRASTRUCTURE

VU ON SUSTAINABLE DISTRIBUTED COMPUTER ECOSYSTEMS

@Large Research
Massivizing Computer Systems

http://atlarge.science

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This work has received funding from the European Union's Horizon Research and Innovation Actions under Grant Agreement № 101093202 and from the NL 6G FNS Groeifonds-programma.

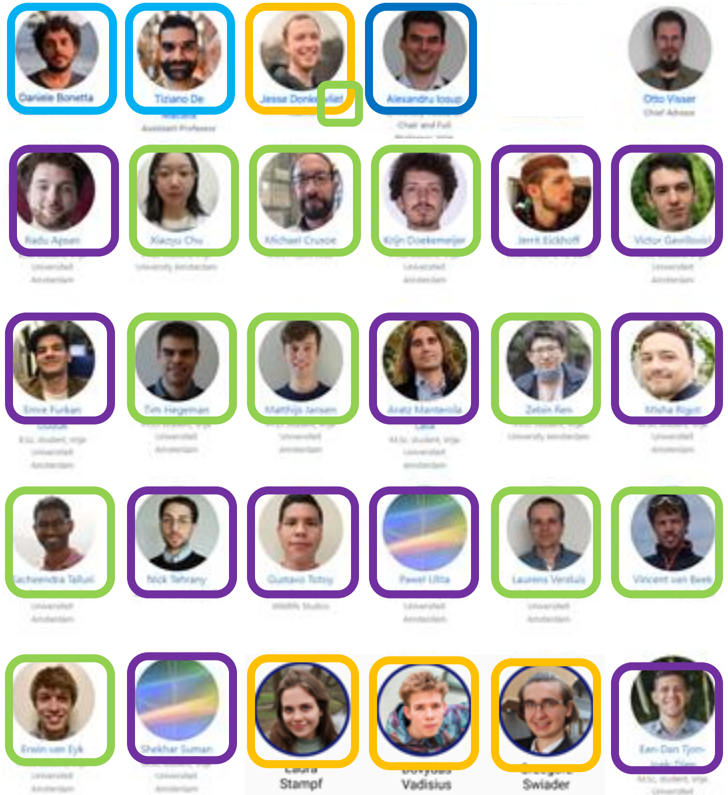
Lorentz Center, Oct'25

US IN 2 MINUTES

WE'RE MASSIVIZING COMPUTER SYSTEMS!

http://atlarge.science

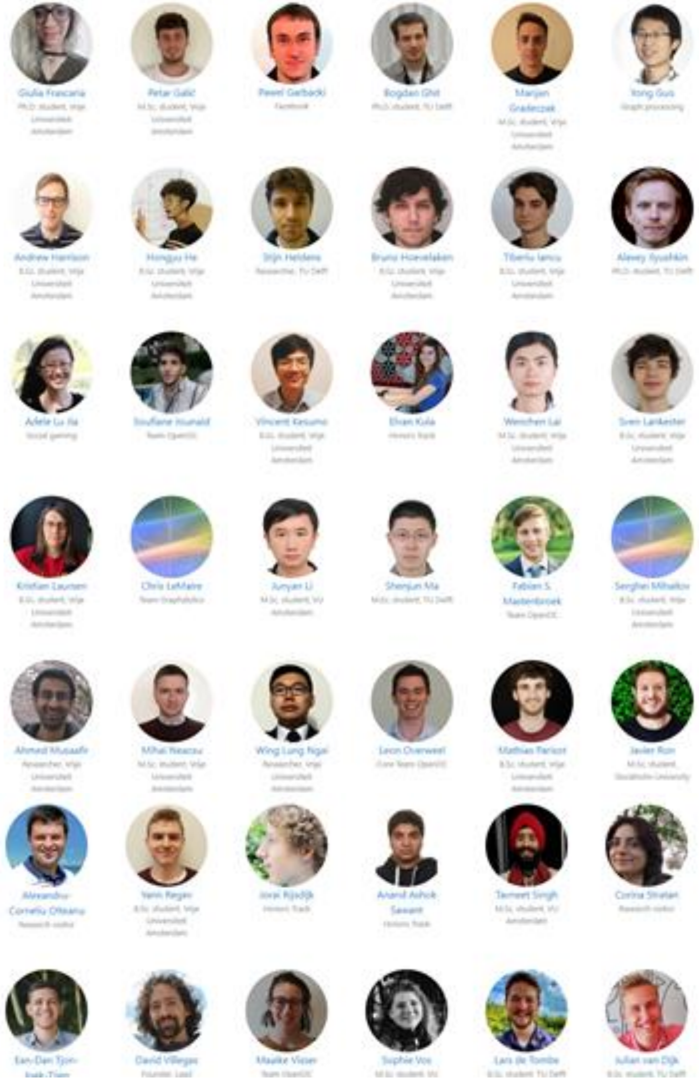
CURRENT TEAM



- Professor
- Assistant Prof.
- Teacher
- Visitor/P.-doc
- Ph.D. student
- Early Scientist MSc, BSc HP

ALUMNI

VISITORS



WE ARE A FRIENDLY, DIVERSE, LARGE GROUP, OF DIFFERENT VIEWS OF CULTURE, POLITICS, AND RELIGION. YOU ARE WELCOME TO JOIN!

WHO AM I?
PROF. DR. IR. CAV. ALEXANDRU IOSUP

- Education, my courses:
  > Honours Programme, Computer Org. (BSc)
  > Distributed Systems (MSc)

- Research, 15+ years in DistribSys:
  > Massivizing Computer Systems (ecosystems)
  > Chair NL IPN SIG Future Computer Systems and Networking
  > Chair SPEC RG Cloud Group

- About me:
  > I like to help… I train people in need
  > VU University Research Chair + Group Chair
  > NL ICT Researcher of the Year
  > NL Higher-Education Teacher of the Year
  > NL Young Royal Academy of Arts & Sciences
  > Knighted in 2020

VU

Massivizing Computer Systems

Research Group Bio

https://atlarge-research.com





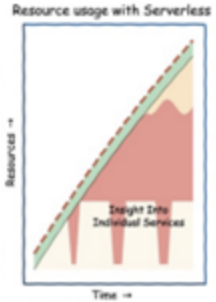
Alexandru IOSUP | Tiziano DE MATTEIS | Daniele BONETTA | Jesse DONKERVLIET | Matthijs JANSEN

Group Bio: CompSys | Massivizing Computer Systems group | National/EU projects, incl. NL Groeifondsprogramma 6G Future Network Services (€315M, 7 years), NL NWO OffSense, EU Horizon Graph-Massivizer (€5M), EU MCSA-RISE CLOUDSTARS

Serverless ± virtualized cloud environments: RM&S for workflow and serverless ops, back-end services, big data and graphs, aggregate and disaggregate resources, VM/contrainerization and JIT compiling, performance, availability, energy. Understand and experiment / analyze / benchmark ecosystems, design new parts, improve existing parts, share FAIR tools + Memex-like data.

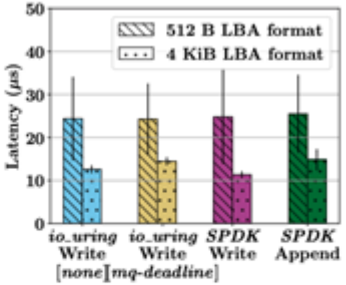
Digital Twin: ICT infrastructure/datacenter simulation, Operational Data Analytics, DC cockpit, VR/XR ops.

Relevant prior work (selection of tools and activities):

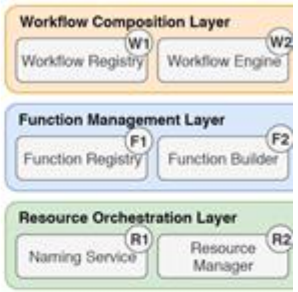


Serverless history + vision

OpenDC simulator



K8s/Storage benchmark



Continuum + Reference Archi

LDBC GRAPHALYTICS

Benchmark

spec Research

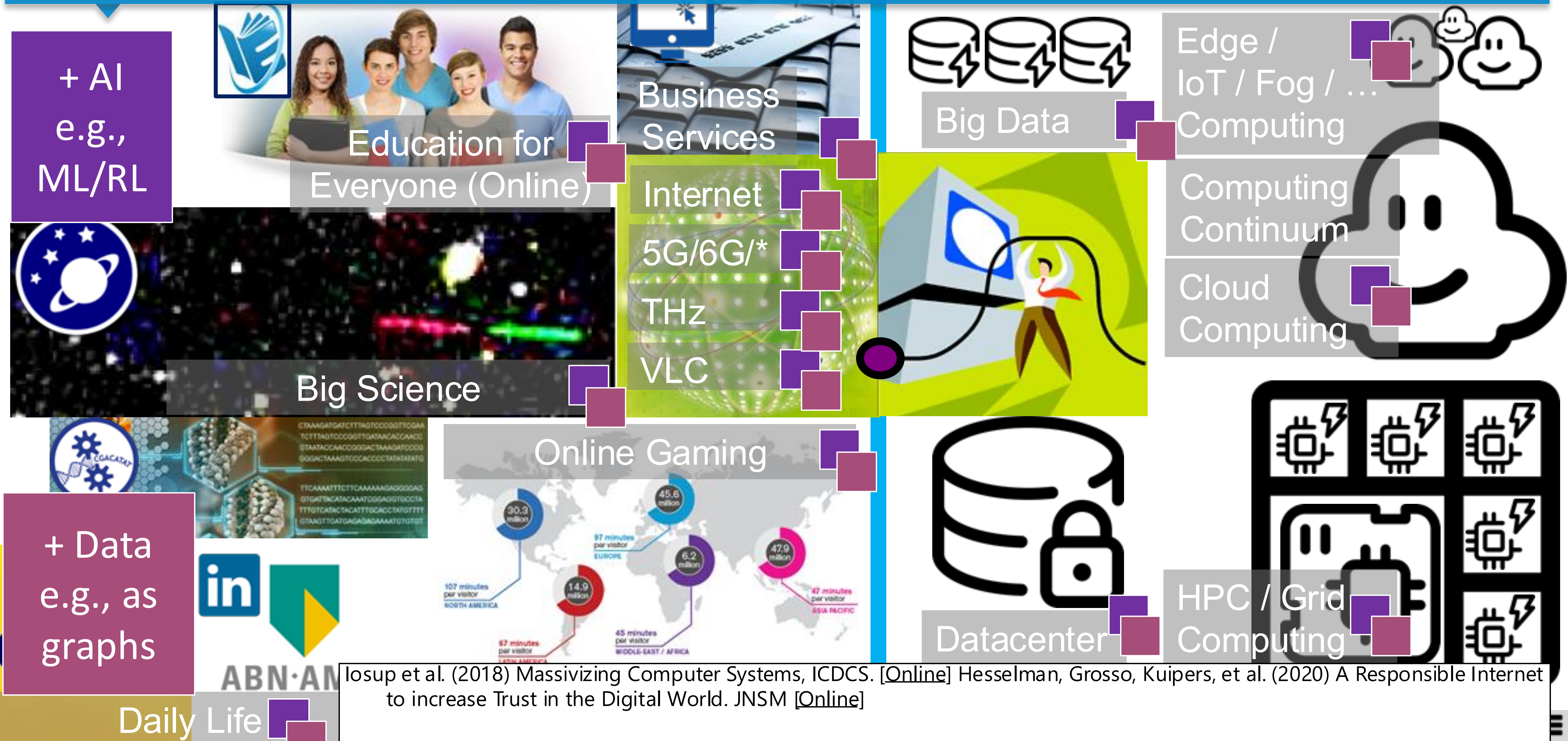
Cloud Group chair

Contact: info@atlarge-research.com

THIS IS THE GOLDEN AGE OF COMPUTER ECOSYSTEMS

1

GENERALITY OF MASSIVE COMPUTER ECOSYSTEMS



Iosup et al. (2018) Massivizing Computer Systems, ICDCS. [Online] Hesselman, Grosso, Kuipers, et al. (2020) A Responsible Internet to increase Trust in the Digital World. JNSM [Online]

Message 1

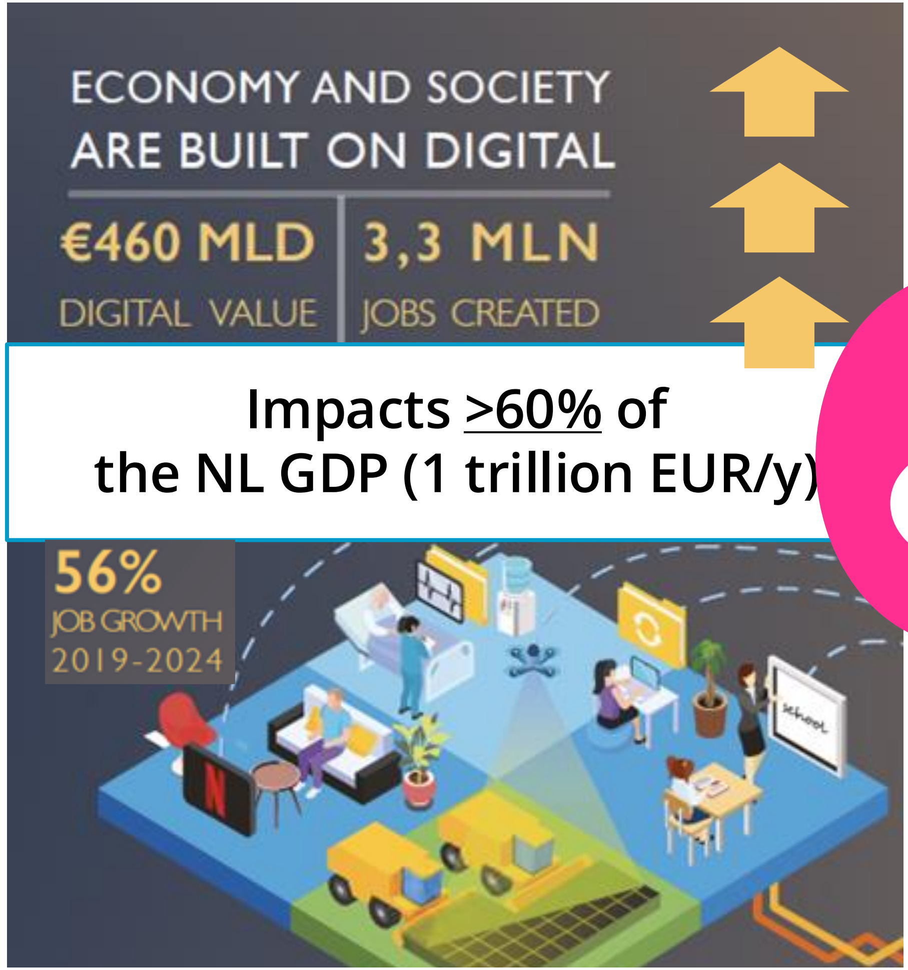
This is the Golden Age of Distributed Ecosystems

BUT WE CANNOT TAKE the SUSTAINABILITY of this TECHNOLOGY FOR GRANTED

2

(We need science to tackle the issues)

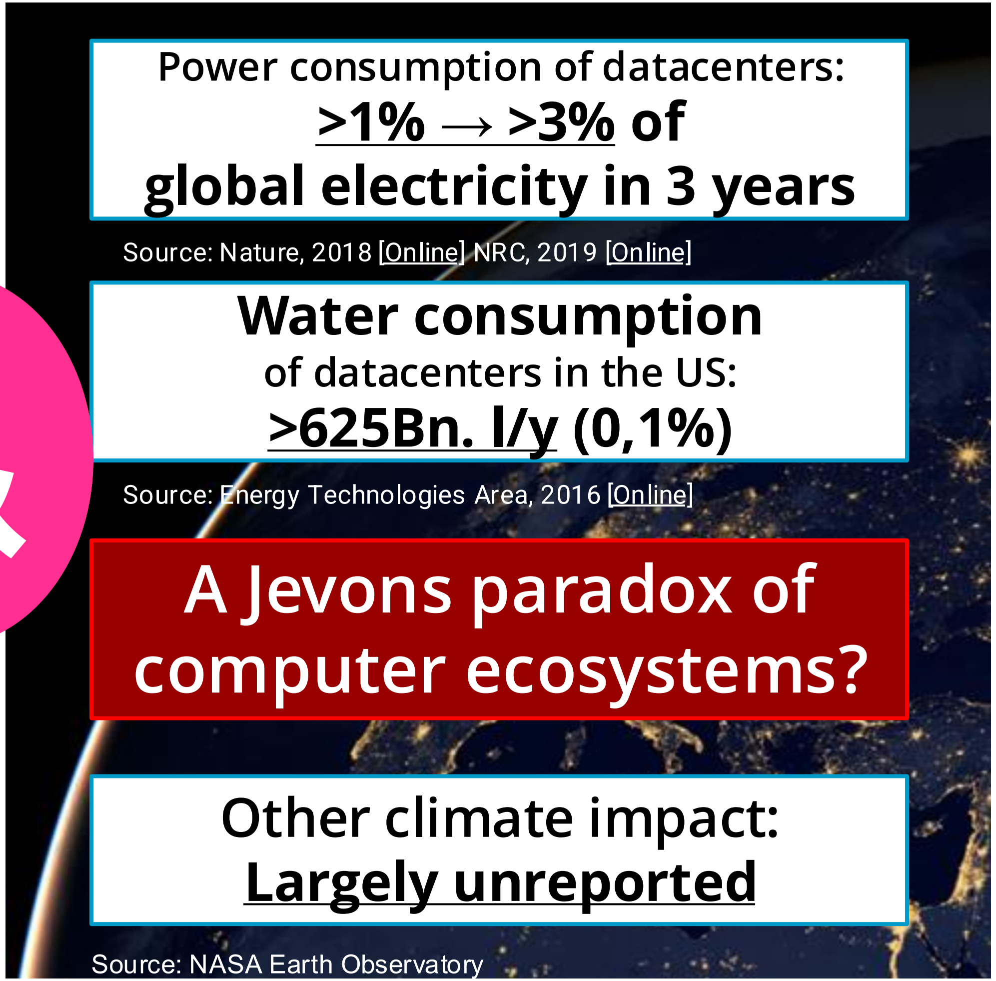
ECONOMIC AND CLIMATE SUSTAINABILITY OF MASSIVE COMPUTER ECOSYSTEMS



Impacts >60% of the NL GDP (1 trillion EUR/y)

Sources: Iosup et al., Massivizing Computer Systems, ICDCS 2018 [Online] / Dutch Data Center Association, 2020 [Online] / Growth: NL Gov't, Flexera, Binx 2020. Gartner 2019. IA 2017.

&



Power consumption of datacenters:
>1% → >3% of global electricity in 3 years

Source: Nature, 2018 [Online] NRC, 2019 [Online]

Water consumption of datacenters in the US:
>625Bn. l/y (0,1%)

Source: Energy Technologies Area, 2016 [Online]

A Jevons paradox of computer ecosystems?

Other climate impact:
Largely unreported

Source: NASA Earth Observatory

SUSTAINABILITY MUST ADDRESS COMPLEXITY GROWTH

COMPLEX, DISTRIBUTED ECOSYSTEMS DO NOT ACT LIKE REGULAR COMPUTER SYSTEMS

Ecosystems don't have easily...

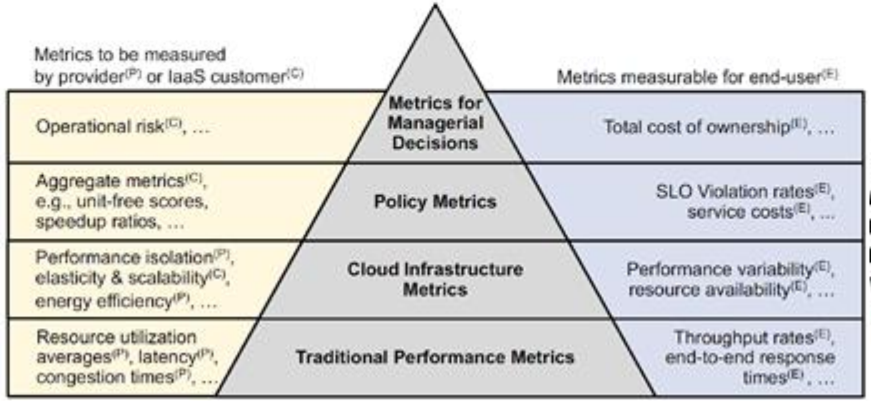
- Simplicity
- Maintainability
- Responsibility
- Sustainability
- Usability

which includes:

- Synchronization
- Consistency, consensus
- Performance
- Scalability, elasticity
- Availability, reliability
- Energy-efficiency

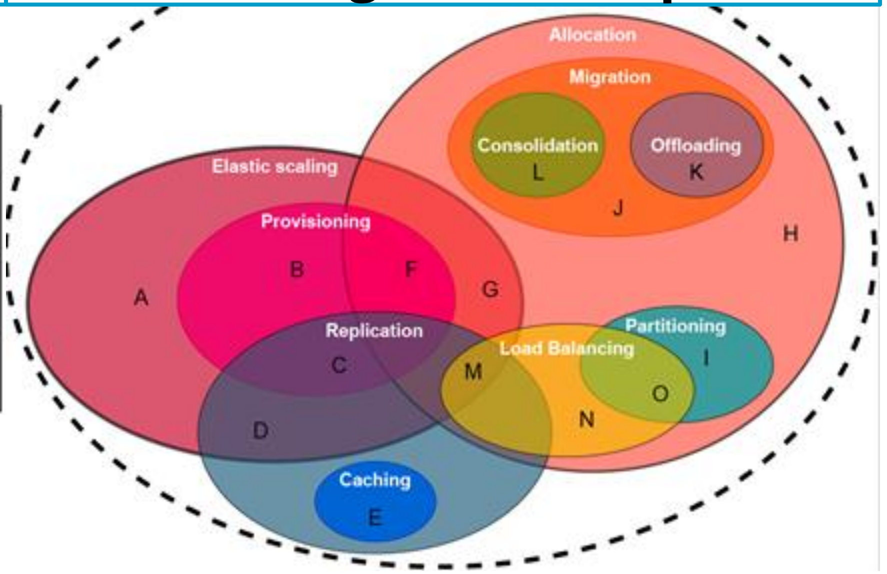
Iosup, Kuipers, Trivedi, et al. (2022) Future Computer Systems and Networking Research in the Netherlands: A Manifesto. CORR

Operational goals are becoming more complex



N. Herbst, E. Van Eyk, A. Iosup, et al. (2018) Quantifying Cloud Performance and Dependability: Taxonomy, Metric Design, and Emerging Challenges. TOMPECS 3(4).

Operational techniques are becoming more complex



Stijn Meijerink, Erwin van Eyk, Alexandru Iosup (2021) Multivocal Survey of Operational Techniques for Serverless Computing. White Paper.

SUSTAINABILITY vs. OPERATIONAL PHENOMENONA

PERFORMANCE, CONSISTENCY, & AVAILABILITY OF MASSIVE COMPUTER ECOSYSTEMS

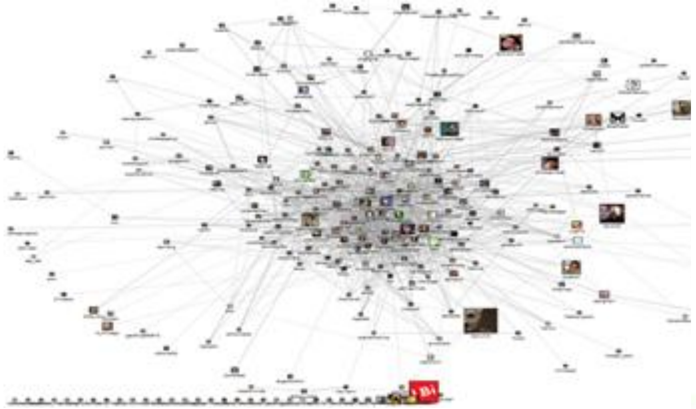
Nov 2024 (also monthly…)

Chu et al. (2025) An Empirical Characterization of Outages and Incidents in Public Services for Large Language Models. ICPE.

Talluri et al. (2021) Empirical Characterization of User Reports about Cloud Failures. ACSOS. Best Artifact Award.

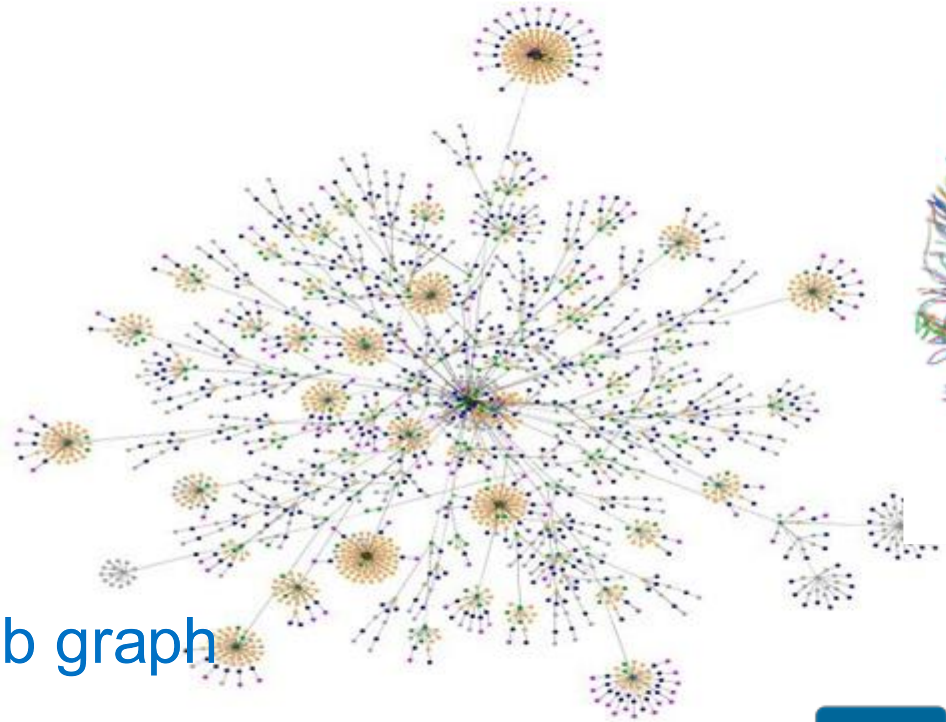
GRAPH DATA EVERYWHERE, UNPRECEDENTED SCALE

NEED TO MASSIVIZE GRAPH PROCESSING



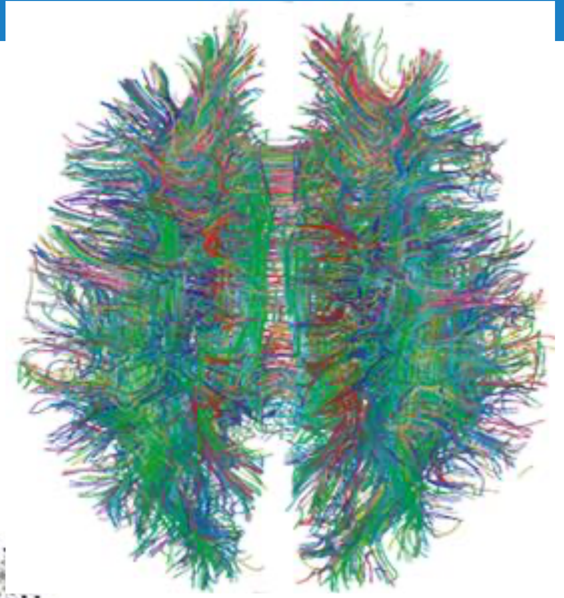
Social / gaming network

~1 billion vertices
~100 billion connections



Web graph

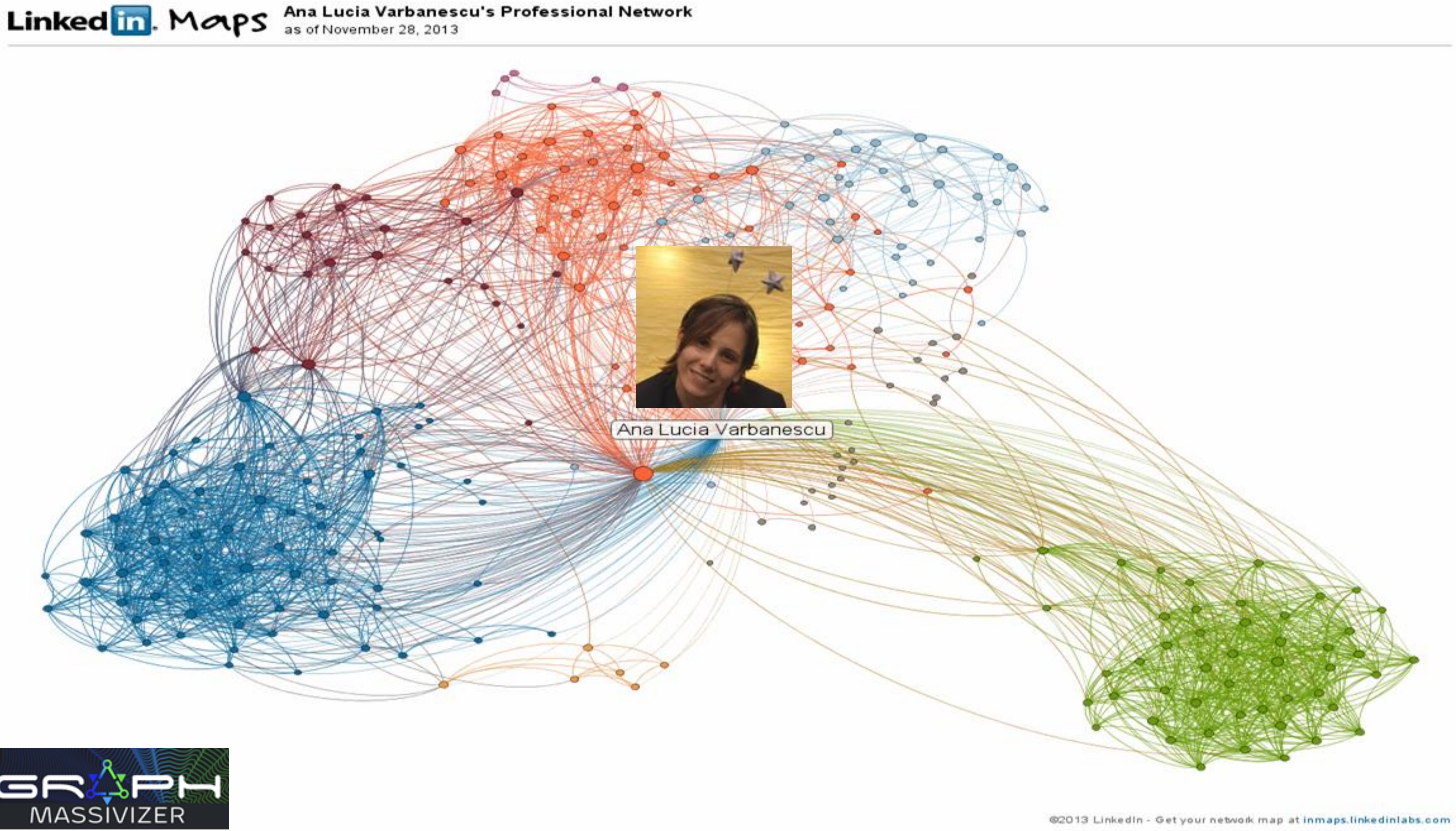
~50 billion pages
~1 trillion hyperlinks



Brain network

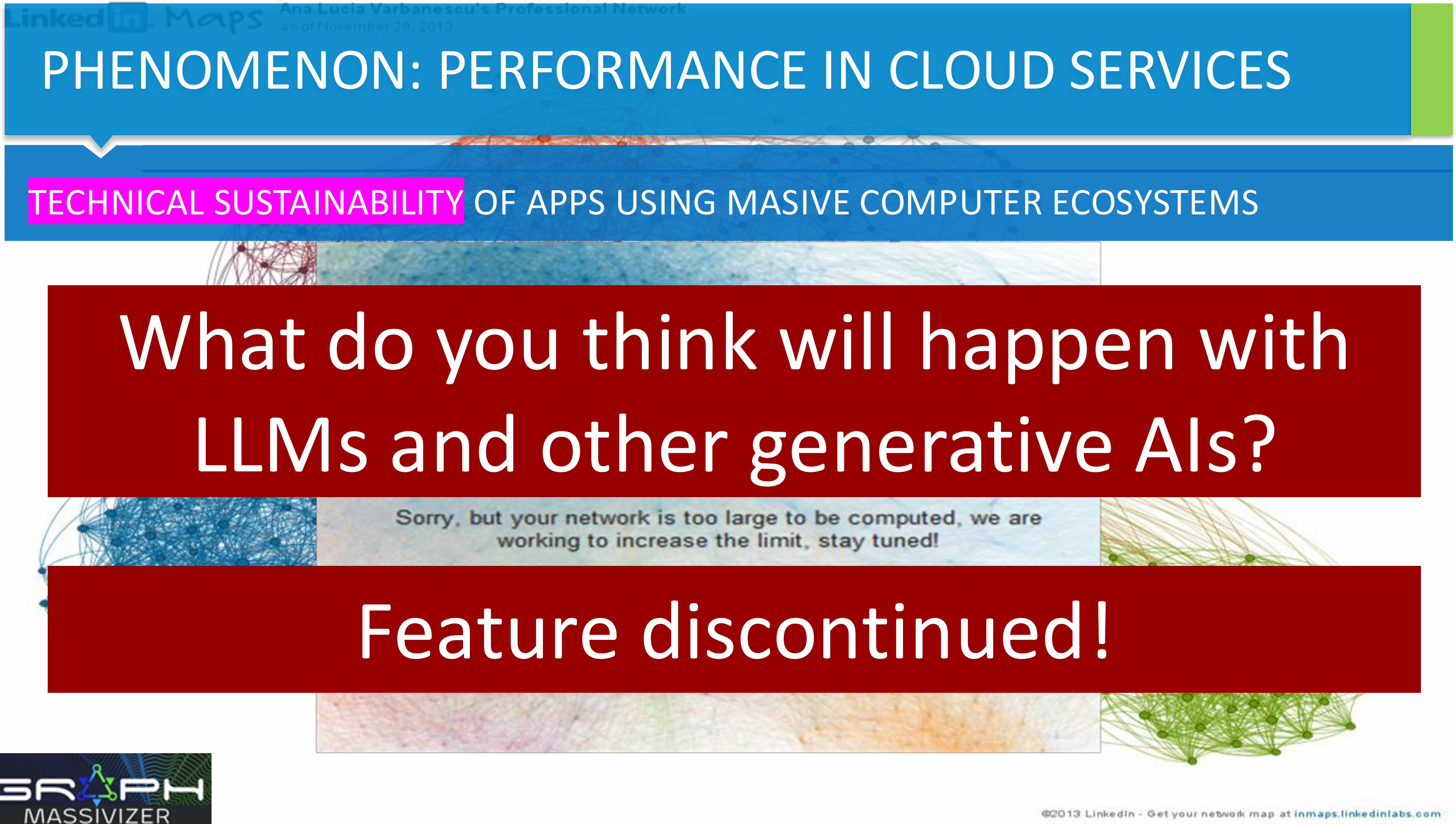
~100 billion neurons
~100 trillion connections

Sakr, Bonifati, Voigt, Iosup, et al. (2021) The Future Is Big Graphs! CACM.


LinkedIn Maps
Ana Lucia Varbanescu's Professional Network
as of November 28, 2013
Ana Lucia Varbanescu
©2013 LinkedIn - Get your network map at inmaps.linkedinlabs.com

PHENOMENON: PERFORMANCE IN CLOUD SERVICES

TECHNICAL SUSTAINABILITY OF APPS USING MASIVE COMPUTER ECOSYSTEMS



What do you think will happen with LLMs and other generative AIs?

Feature discontinued!

Message 2

Much to discover and do until technology ready

OVER-ARCHING GOAL:

WE'RE BUILDING 21st CENTURY ICT INFRASTRUCTURE

3




IN 2022, WE RESTARTED THE COMPSYS COMMUNITY… JOIN US!

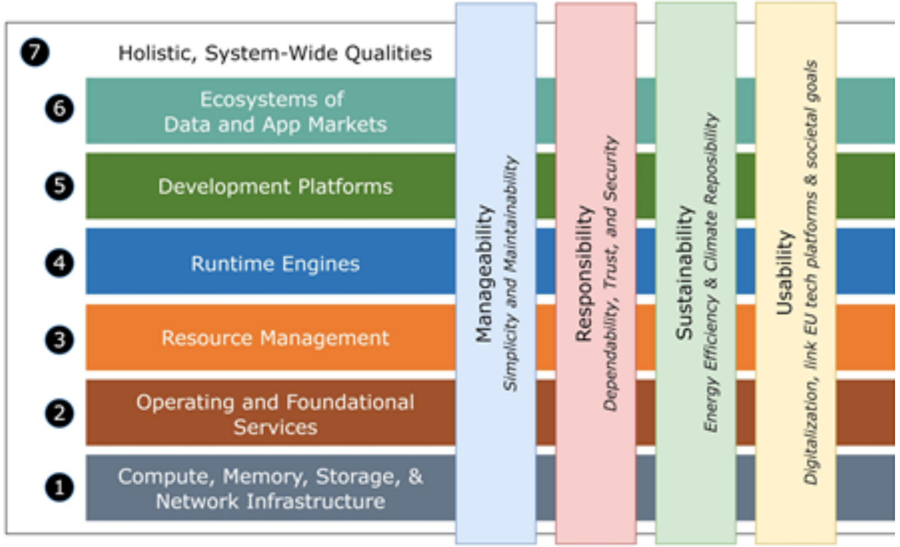
ICT-RESEARCH PLATFORM NETHERLANDS

SIG FCSN + Manifesto on Computer Systems and Networking Research

Clear vision for the field in the NL, 2021-2035

Signed

50 PIs / Leads
07 universities
05 relevant societal stakeholders



Available

Full version https://arxiv.org/pdf/2206.03259
Who’s Who in CompSysNL? https://bit.ly/CompSysNLWhosWho

VU VRIJE UNIVERSITEIT AMSTERDAM

ONE PROJECT TO MENTION…

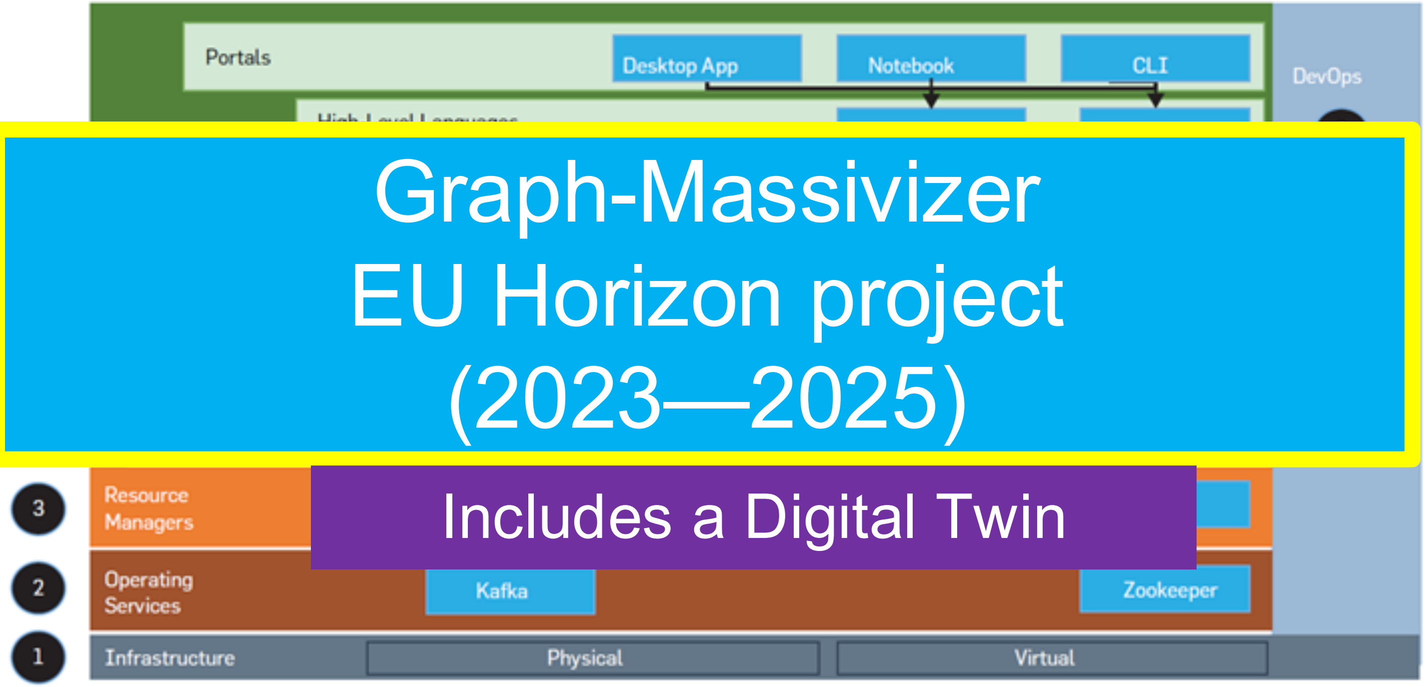
GRAPH MASSIVIZER

Big Graph Processing: Used in AI/ML, FinTech, ICT Infra., Industry 4.0, Energy Mgmt.*, etc.

Vision: Massivizing computer systems approaches are key to enable big graph ecosystems

contributed articles

CACM Cover/Featured article, Sep 2021



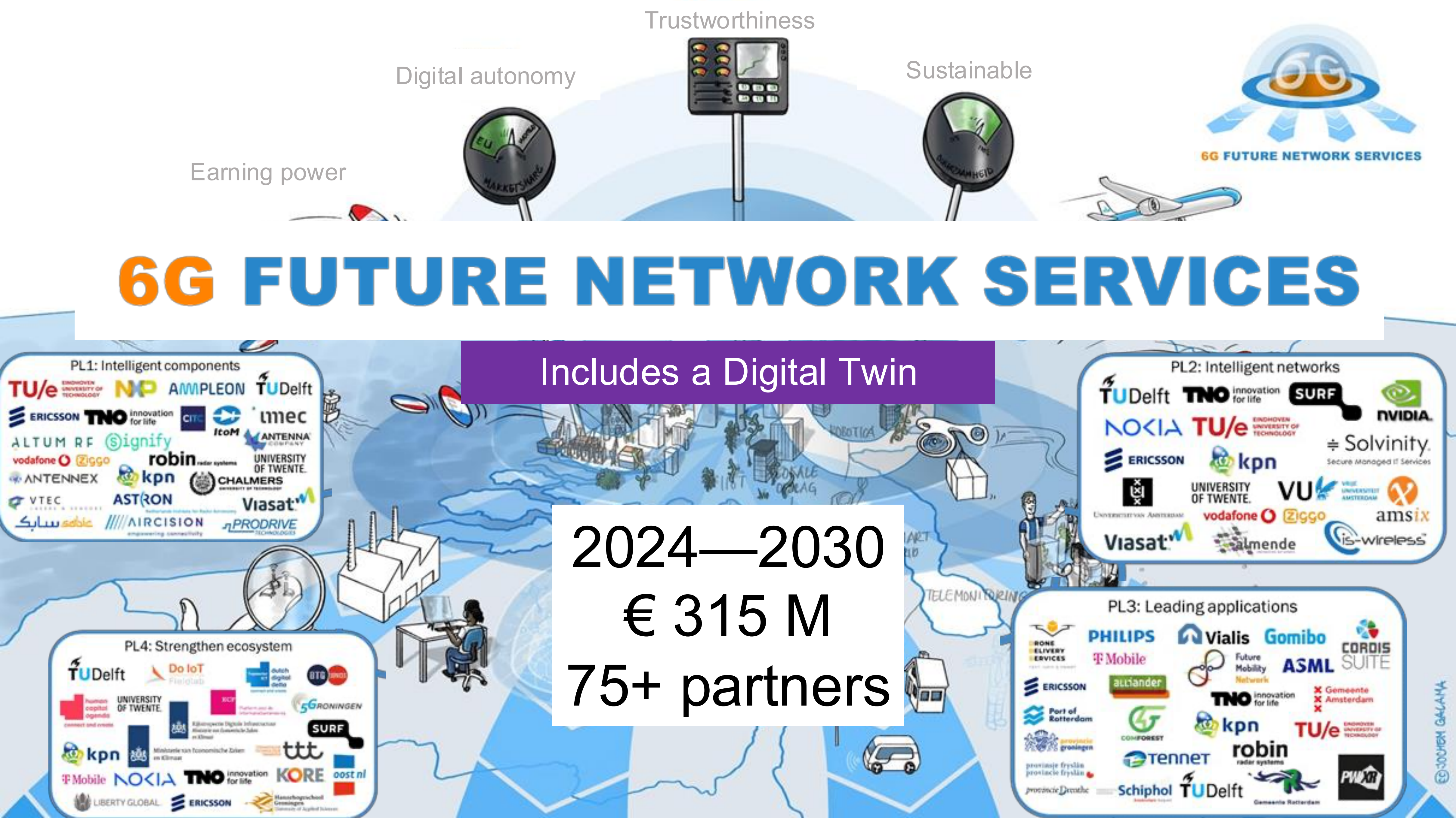
Graph-Massivizer
EU Horizon project
(2023—2025)

Includes a Digital Twin

(*) Digital twin for datacenters, with partners including CINECA

Sakr, Bonifati, Voigt, Iosup, et al. (2021) The Future Is Big Graphs! CACM.

https://graph-massivizer.eu/

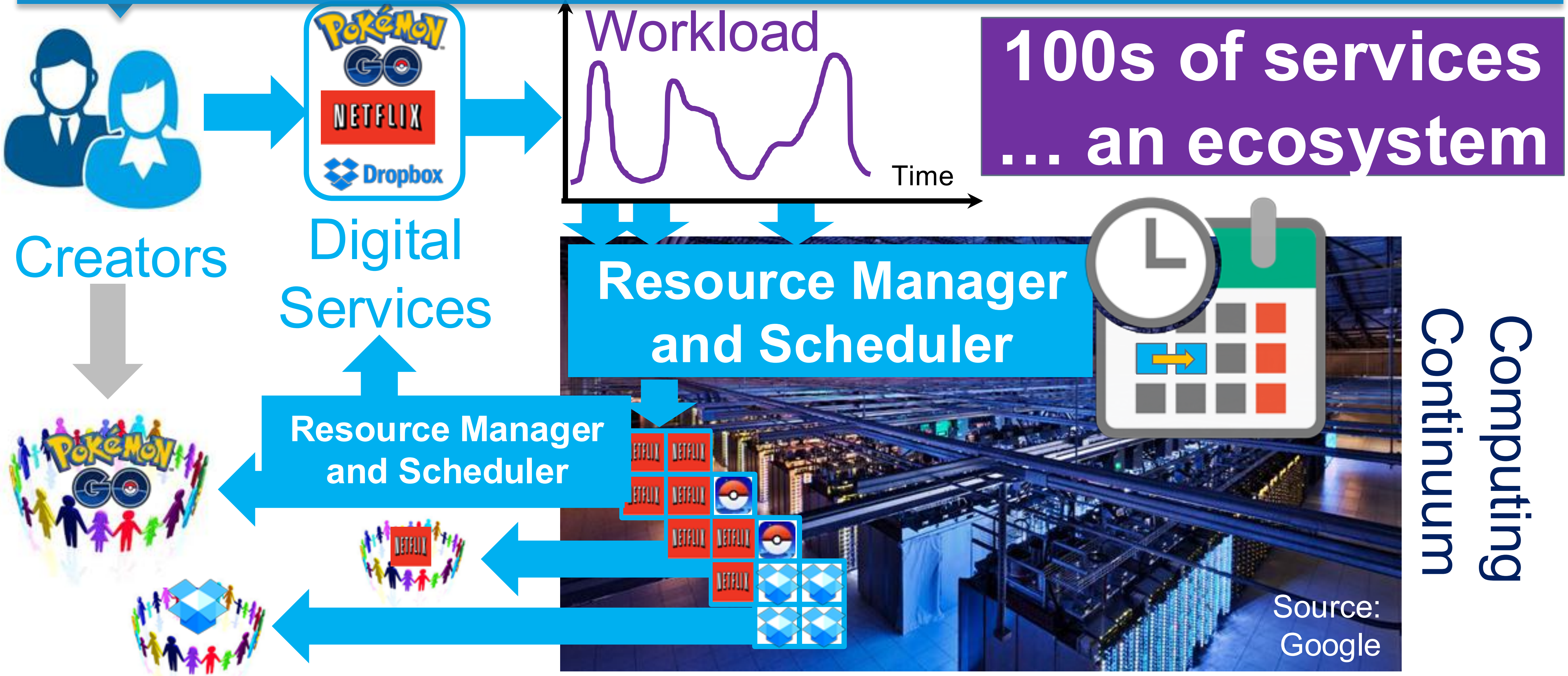

Trustworthiness
Digital autonomy
Sustainable
Earning power
6G FUTURE NETWORK SERVICES
6G FUTURE NETWORK SERVICES
Includes a Digital Twin
2024—2030
€ 315 M
75+ partners
PL1: Intelligent components
TU/e
NXP
AMPLEON
TU Delft
ERICSSON
TNO innovation for life
imec
ALTUM RF
Signify
ANTENNA COMPANY
vodafone
Ziggo
robin
UNIVERSITY OF TWENTE.
ANTENNEX
kpn
CHALMERS
VTEC
ASTRON
Viasat
sabic
AIRCISION
PRODRIVE
PL2: Intelligent networks
TU Delft
TNO innovation for life
SURF
NVIDIA
NOKIA
TU/e
Solvinity
ERICSSON
kpn
UNIVERSITY OF TWENTE.
VU
vodafone
Ziggo
amsix
Viasat
almende
is-wireless
PL3: Leading applications
PHILIPS
Vialis
Gomibo
CORDIS SUITE
T Mobile
ASML
ERICSSON
alliander
TNO innovation for life
Gemeente Amsterdam
Port of Rotterdam
kpn
TU/e
TenneT
robin
Schiphol
TU Delft
PL4: Strengthen ecosystem
TU Delft
Do IoT
UNIVERSITY OF TWENTE.
5Groningen
SURF
kpn
T Mobile
NOKIA
TNO innovation for life
KORE
oost nl
LIBERTY GLOBAL
ERICSSON

A new science, of complex, smart computer ecosystems, ensuring operational simplicity for the user.

4

(From here on, it's all details.)

ECOSYSTEM = SERVICES + COMPUTING + SMARTS + GOALS



Extreme Automation, Performance, Dependability, Sustainability

AN ANALOGY: MASSIVIZING CLIMATE SCIENCE

TAKE A HOLISTIC VIEW, BASED ON COUPLED NATURAL SYSTEMS

Can be understood only with coupled models

Climatologist Bjorn Stevens. Source: HPCWire

* In climate science, issues are often linked.
The same occurs in massive computer (eco)systems.

Today: Five Ideas, Building toward a Program where Sustainability Is a First-Class Citizen

1. How to model the system? A: Reference architectures
2. How to automate improvement processes? A: Digital Twins
3. Which requirements? A: A pyramid of metrics
4. How to manage? A: RM&S frameworks
5. How to improve observability? A: ODA + Memex

–

All toward: An R&D&I program, with 8 pillars, on massivizing computer systems that enables sustainability

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Massivizing in 8* "easy" steps…

(*) Computer scientists often use 8 as their "round" number

Supported by a science that provides foundational models, operational laws, reference designs, experiments, analysis, longitudinal data

1. Applications: From single app to workflows, from workflows to development and operation of long-term, interacting pipelines; new techniques and devices to control operation, including VR devices and Metaverses
2. Automated deployment and execution for complex applications and services, leveraging resources including accelerators and multi-party services to ensure functional and non-functional properties as needed
3. Resource management and scheduling as first-class citizens, able to smartly combine diverse techniques across all operational layers and to improve (optimize) operation across user and operator goals
4. In-flight service management, smartly providing desirable operational properties including consistency and provenance, according to dynamic, adjustable, application-driven needs with serverless principles
5. Digital Twin on the side, smartly providing clear insights for on-going operations, and trusted and comparative analysis leading to superior short- and long-term decisions
6. From mere monitoring to Operational Data Analytics, and from logs to an ICT Infrastructure Memex
7. Toward highly desirable (sustainable, performant, scalable, available, efficient, flexible, secure, etc.) combination of ecosystems in the digital continuum – and reproducible and comparable
8. A coherent view on apps, services, and resources where everything is dynamic, interacting, autonomous, and viable long-term – from everything discardable to guarantees, attribution, and sovereignty for the entire 21st century

Focus on sustainability of many kinds

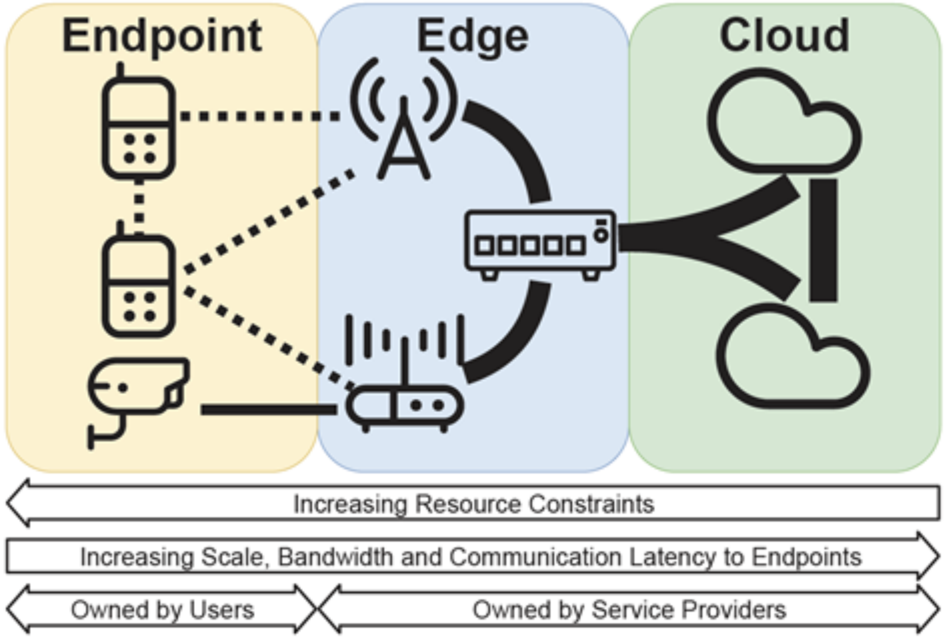
Idea:
Model the world through reference architectures

4.1

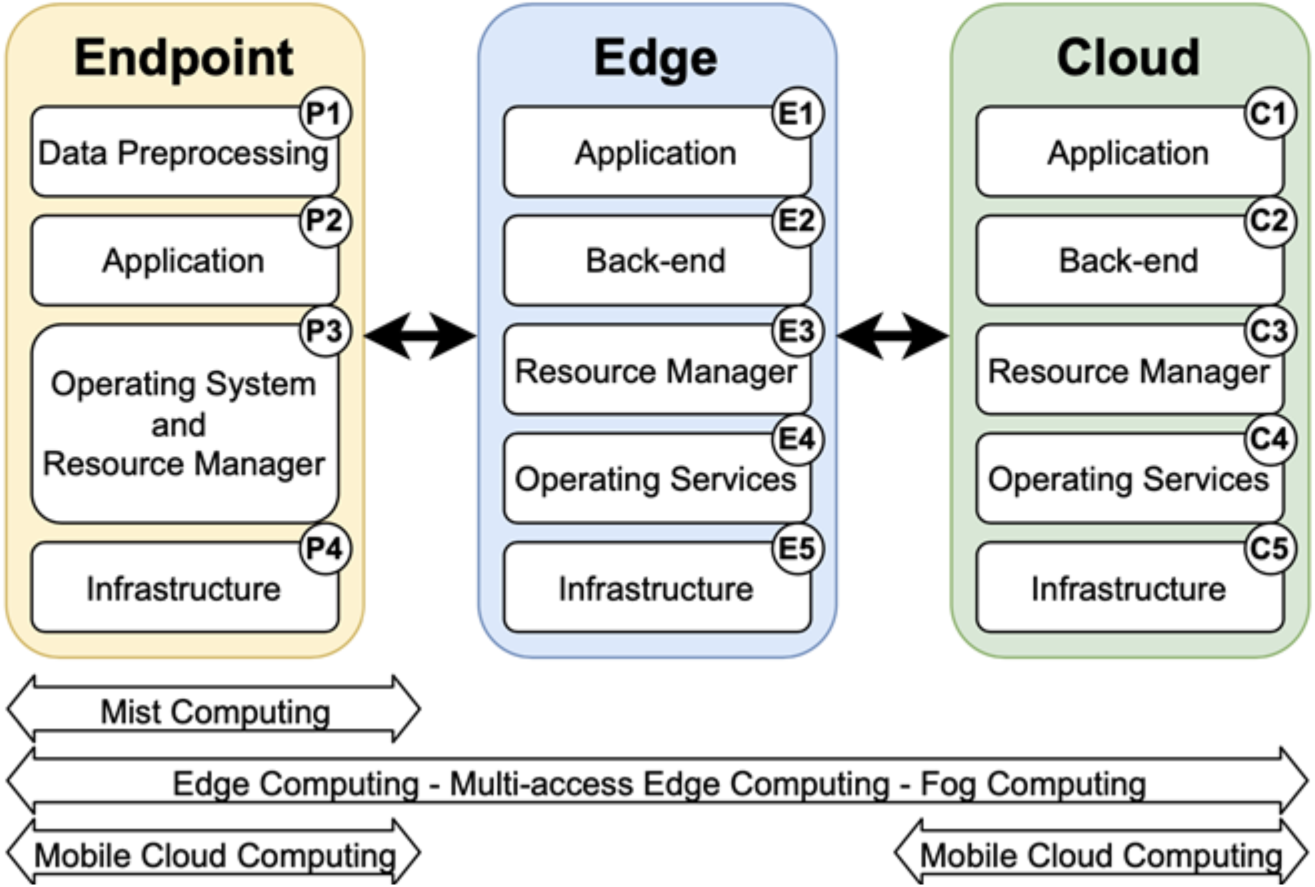
ALL RUNNING ON CONTINUUM RESOURCES & SERVICES

ISSUES: COMPLEXITY, NON-TECHNICAL

Consider sustainability across the continuum, not only a single element



Trivedi, Wang, Bal, Iosup (2021) Sharing and Caring of Data at the Edge. HotEdge.



Jansen, Al-Dulaimy, Papadopoulos, Trivedi, Iosup (2023) The SPEC-RG Reference Architecture for the Edge Continuum. CCGRID. Open access: https://doi.org/10.48550/ARXIV.2207.04159

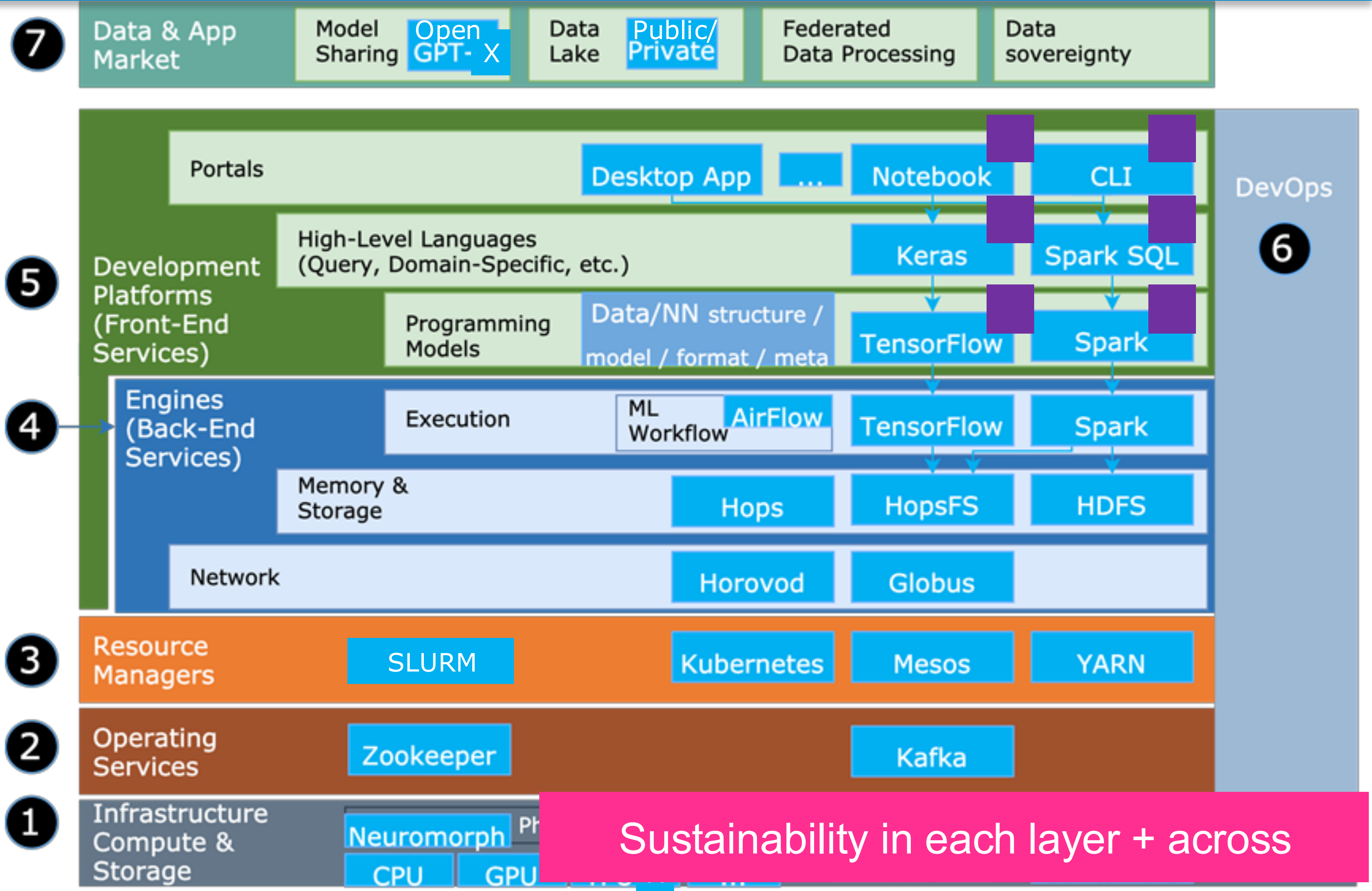
REFERENCE ARCHITECTURE: FITS AI/ML, BIG DATA, SCIENTIFIC, ENGINEERING, BUSINESS CRITICAL, ONLINE GAMING, OTHER APPS

ML app is a small part, but now we can do complex workflows

Rest is systems, HW+SW, including HPC

Adapted from:

Sakr, Bonifati, Voigt, Iosup, et al. (2021) The Future Is Big Graphs! CACM.



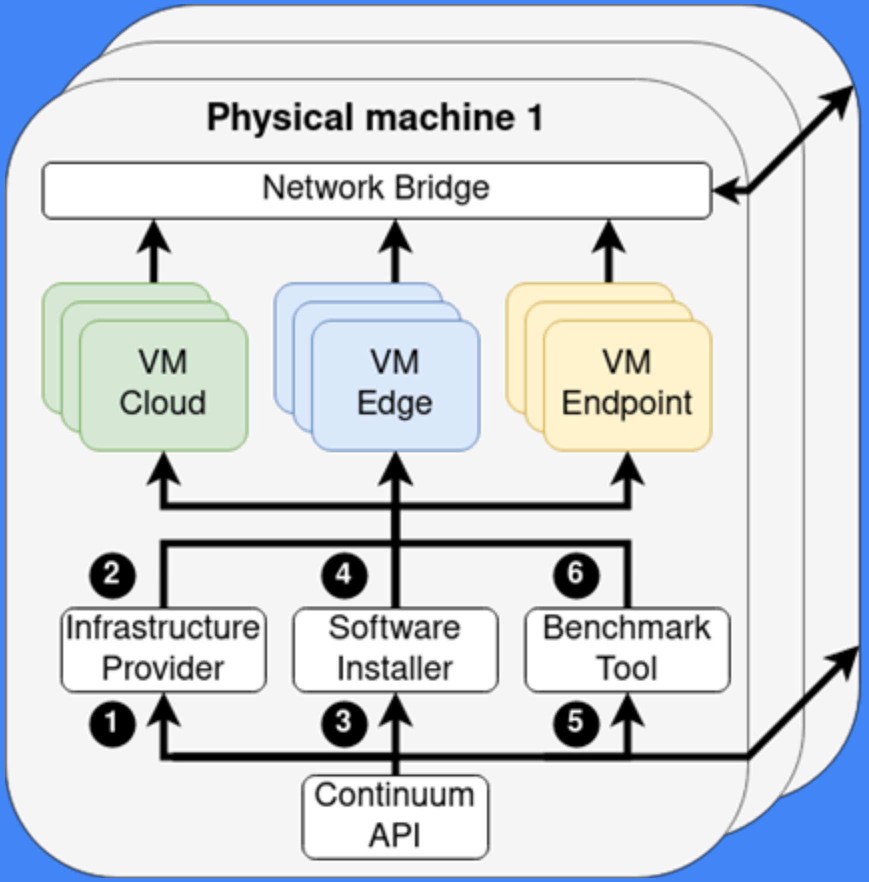
Sustainability in each layer + across

Continuum

Automate cloud-edge infrastructure deployment and benchmarking in the compute continuum

https://github.com/atlarge-research/continuum

Can be used to conduct sustainability experiments in each layer + across, and across the continuum



Matthijs Jansen, Linus Wagner, Animesh Trivedi, and Alexandru Iosup (2023) Continuum: Automate Infrastructure Deployment and Benchmarking in the Compute Continuum. ACM/SPEC ICPE Companion.

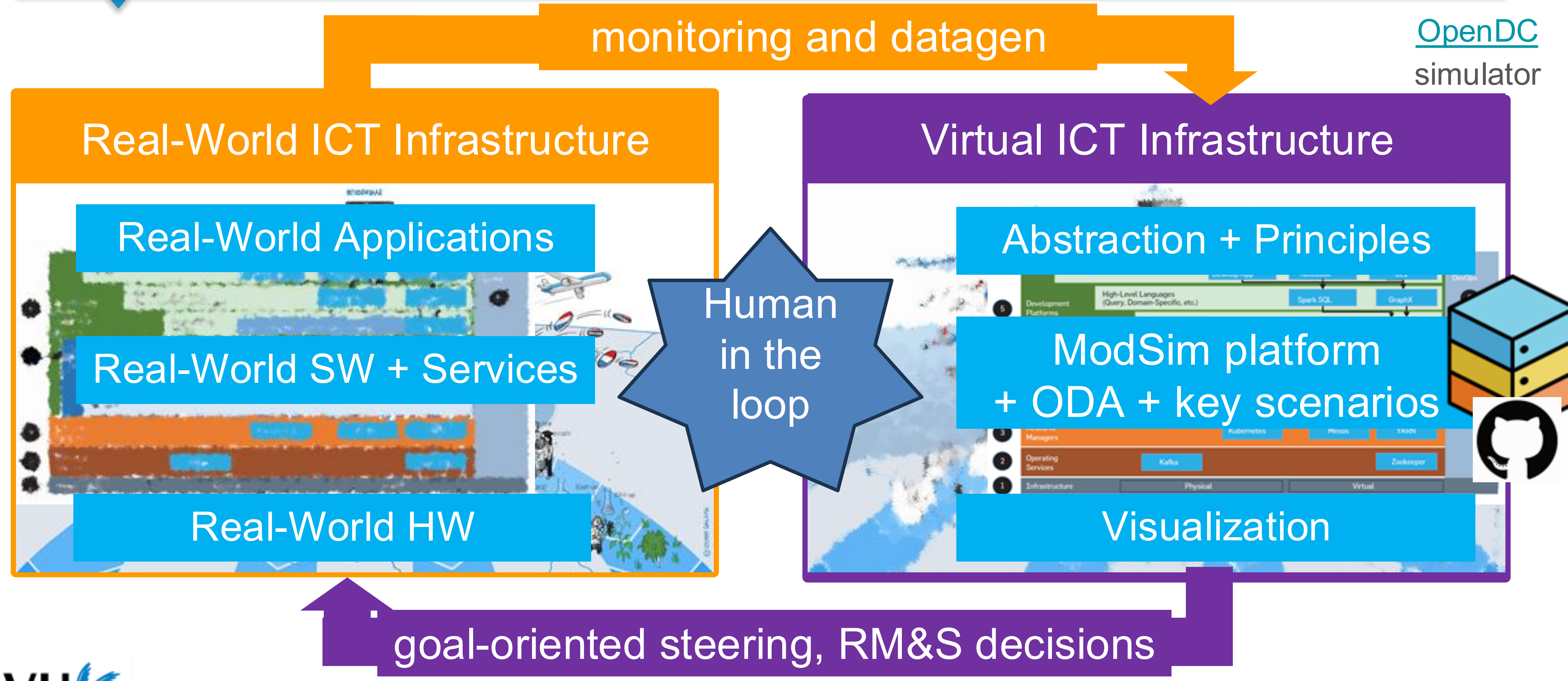
Matthijs Jansen, Auday Al-Dulaimy, Alessandro V. Papadopoulos, Animesh Trivedi, and Alexandru Iosup (2023) The SPEC-RG Reference Architecture for the Compute Continuum. IEEE/ACM CCGRID.

Idea:
Automate process-improvement through Digital Twins

4.2

HELPED BY A DIGITAL TWIN FOR ICT INFRASTRUCTURE

[OpenDC](#) simulator



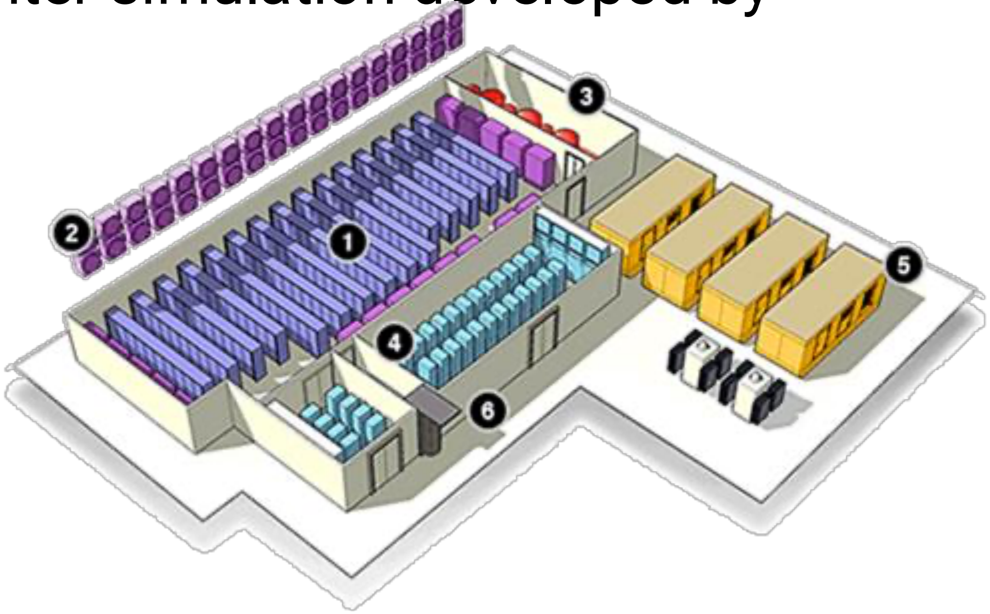
OpenDC

Datacenter Simulation

OpenDC: SIMULATION PLATFORM FOR ICT INFRASTRUCTURE

… SHORT-TERM: X or Y? WHERE TO PUT Z? LONG-TERM: CAN WE AFFORD A? WHAT IF B HAPPENS?

OpenDC[1] is an open source platform for datacenter simulation developed by AtLarge Research[2]



Goals:

Teach about sustainability!

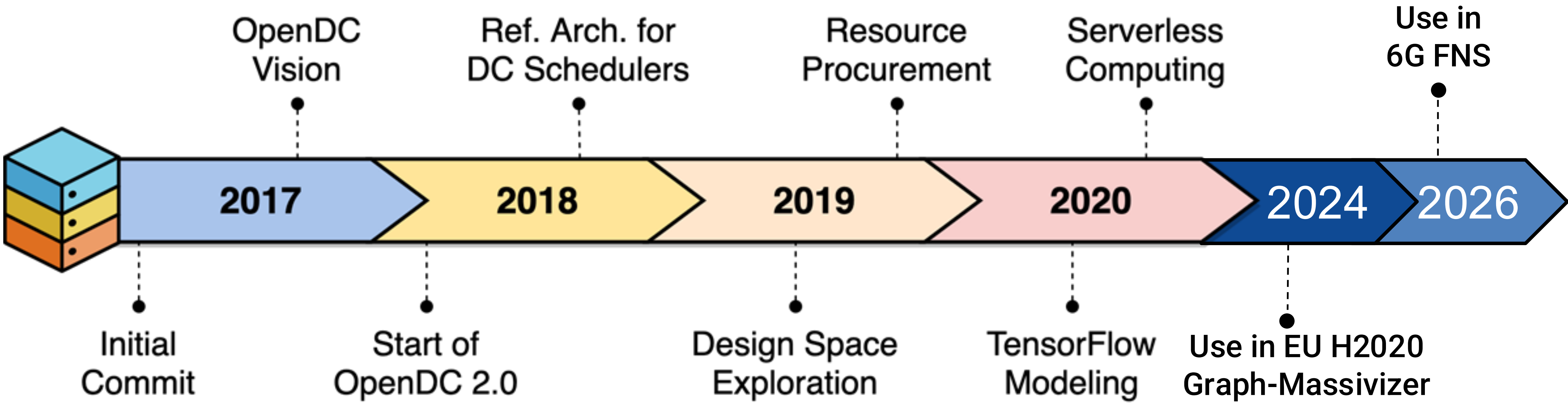
a. Enable Cloud computing education

b. Support research into datacenters

Sustainability studies!

The development of OpenDC

From humble beginnings to large scale projects



https://github.com/atlarge-research/opendc

Learn more: opendc.org

Fabian Mastenbroek, Georgios Andreadis, Soufiane Jounaid, Wenchen Lai, Jacob Burley, Jaro Bosch, Erwin Van Eyk, Laurens Versluis, Vincent van Beek, Alexandru Iosup (2021) OpenDC 2.0: Convenient Modeling and Simulation of Emerging Technologies in Cloud Datacenters. CCGRID 2021: 455-464. [Online]

OpenDC Projects

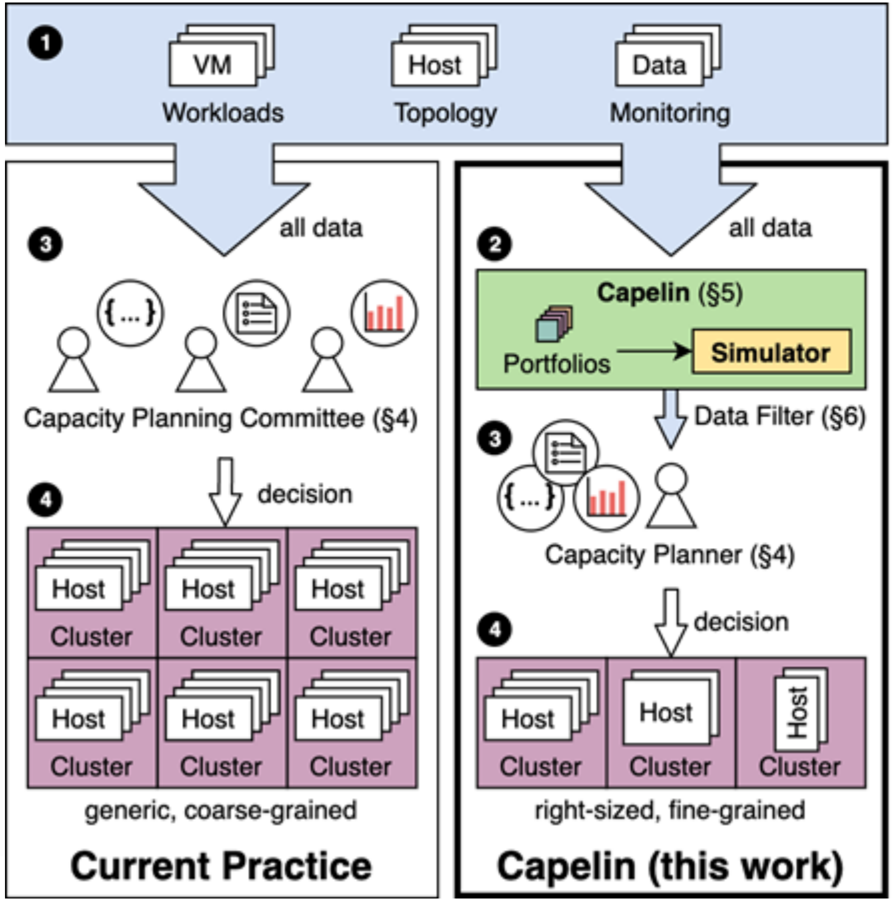
CAPELIN: FAST DATA-DRIVEN DC CAPACITY PLANING

WE SURVEYED AND ANALYZED 89 USE-CASES

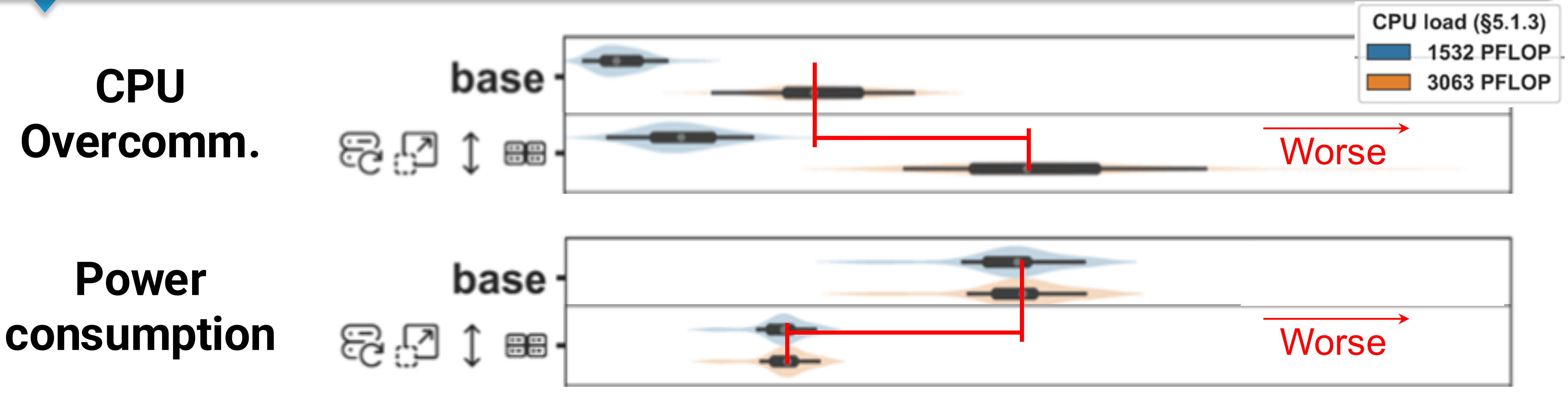
- High-impact problem
- Long-term effects
- Difficult to predict

Our work: Capelin + OpenDC

- Sophisticated approach
- Based on validated simulator
- Work with major NL hoster



Example: Horizontal vs. Vertical Scaling



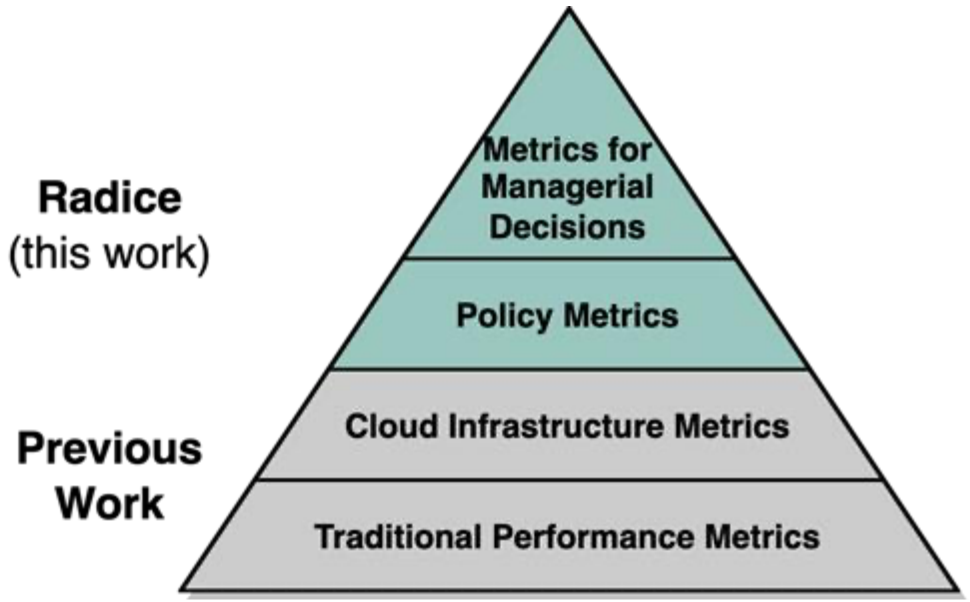
Capelin enables complex **trade-off exploration**, e.g., **power** vs. **performance**

Slides by Georgios Andreadis, with input from Alexandru Iosup et al.

Fabian Mastenbroek, Georgios Andreadis, Soufiane Jounaid, Wenchen Lai, Jacob Burley, Jaro Bosch, Erwin Van Eyk, Laurens Versluis, Vincent van Beek, Alexandru Iosup (2021) OpenDC 2.0: Convenient Modeling and Simulation of Emerging Technologies in Cloud Datacenters. CCGRID 2021: 455-464. [Online]

Radice: Data-driven Risk Analysis of Sustainable Cloud Infrastructure using Simulation

- Utilize metrics collected in datacenters
- Risk represented as a **portfolio of risk factors**
- Risk factors composed of:
  - SLO (Service Level Objective)
  - Compliance Period
  - Cost function
- Three categories: **customer-facing** risks, **company-facing** risks, **society-facing** risks
- Cost expressed as financial impact (e.g., euros)



Slides by Fabian Mastenbroek,
with input from Alexandru Iosup et al.

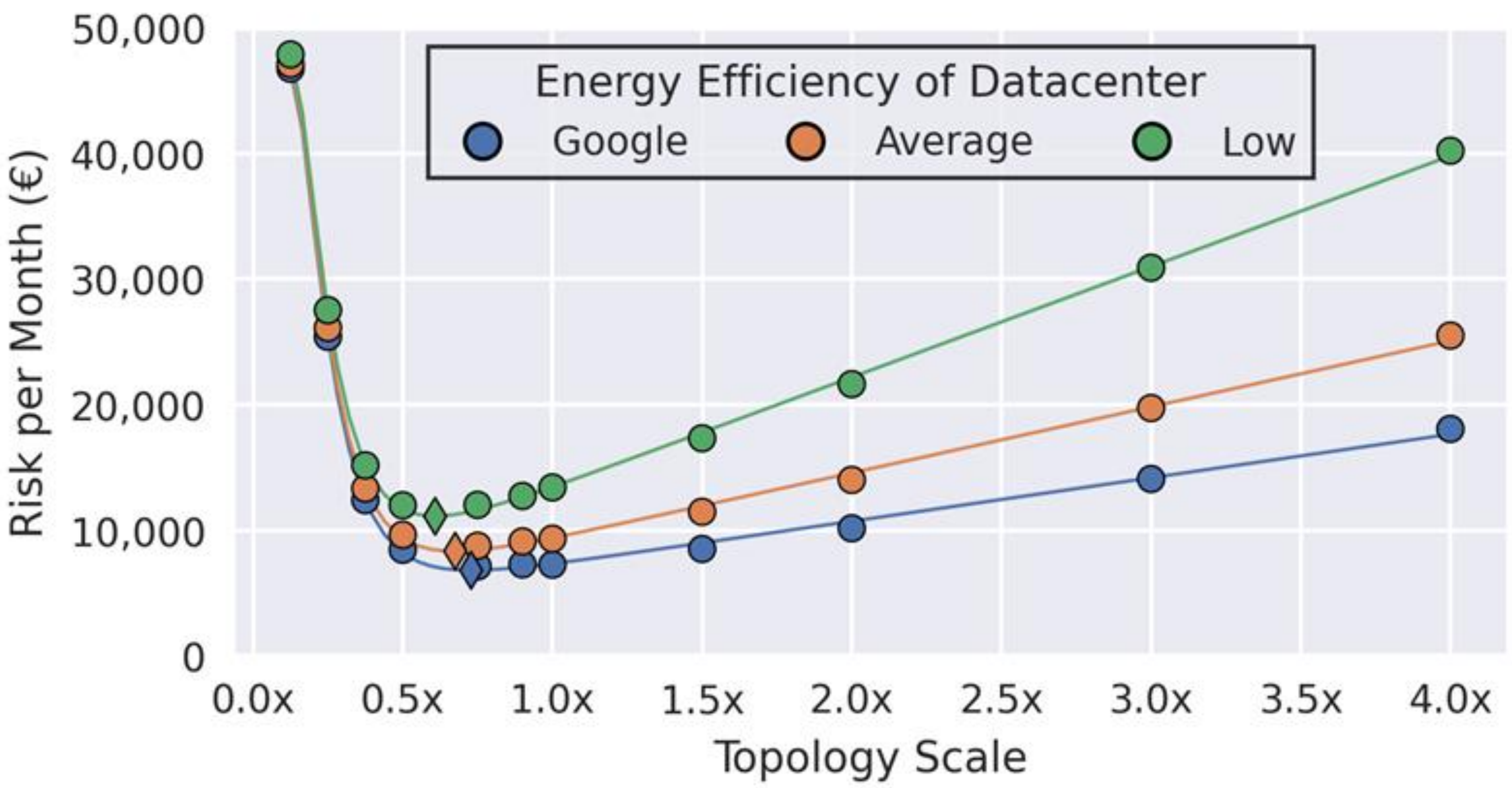
Fabian Mastenbroek, Tiziano De Matteis, Vincent van Beek, Alexandru Iosup (2025)
RADiCe: A Risk Analysis Framework for DataCenters. FGCS.
Editor's Choice, nominated for 2025 Best Paper Award.

Downscaling to save electricity?

1. **Downscaling** results in lower risk amid soaring electricity prices

   but

2. Datacenter operators must **compromise** between lower **topology scale** and higher **SLA compliance**

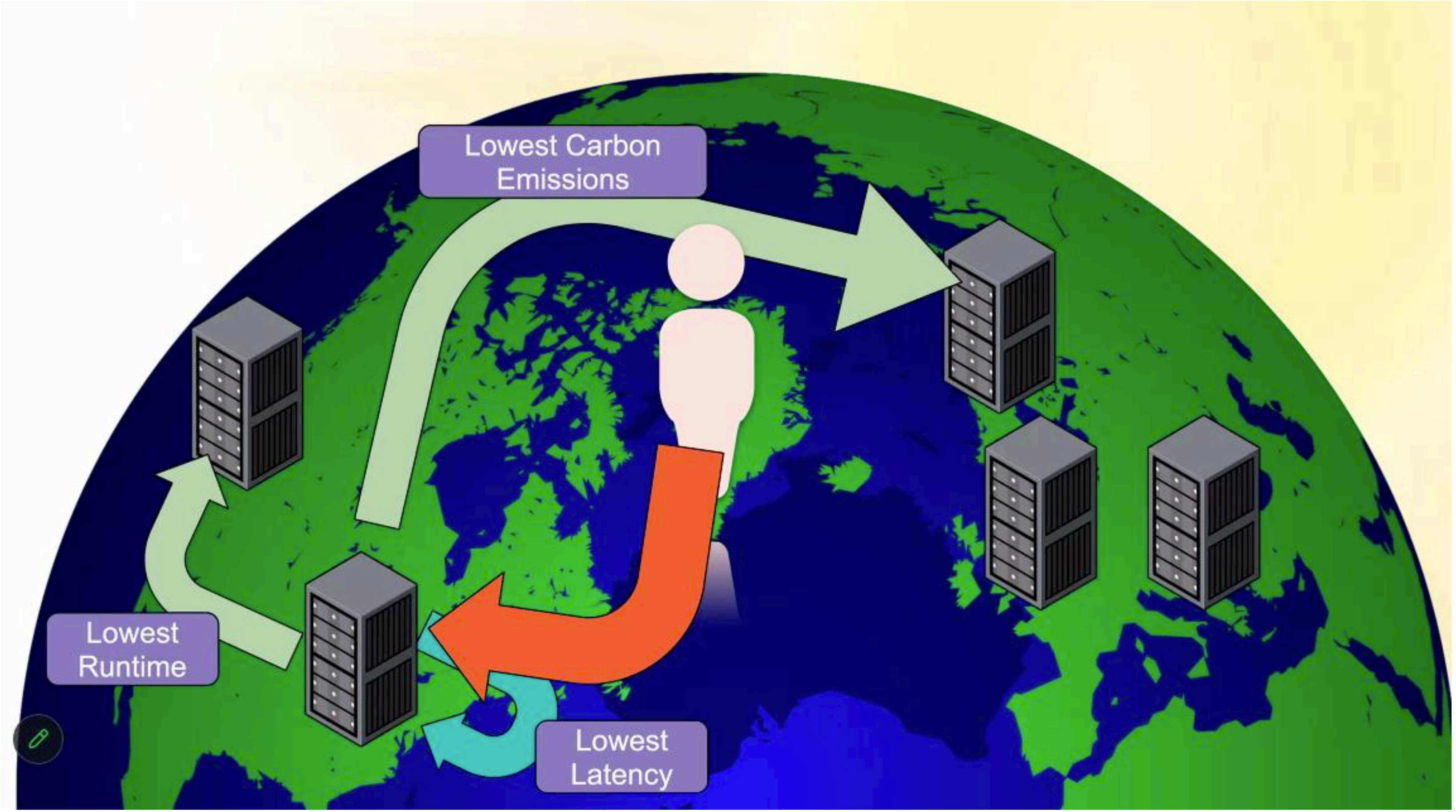


Slides by Fabian Mastenbroek,
with input from Alexandru Iosup et al.

Idea: Understand requirements through a pyramid of metrics (or: beyond traditional metrics)

4.3

Different Performance Goals for Different Stakeholders Practical Example



Robert Cordingly, Jasleen Kaur, Divyansh Dwivedi, Wes Lloyd (2023) Towards Serverless Sky Computing: An Investigation on Global Workload Distribution to Mitigate Carbon Intensity, Network Latency, and Cost. IC2E 2023: 59-69

Slide by Robert Cordingly, presented to SPEC RG Cloud on Oct 31, 2023

FOOTPRINTER

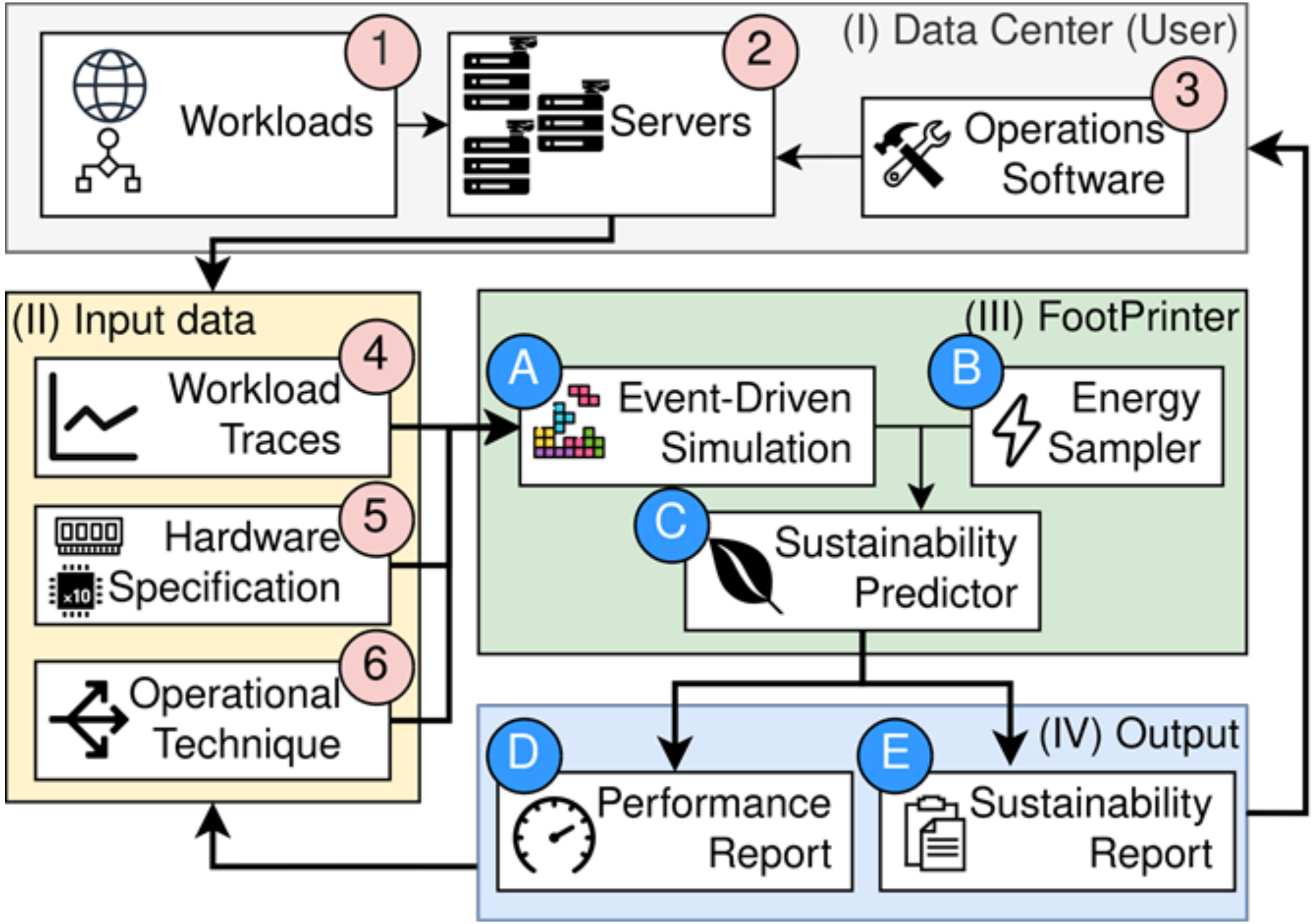
FootPrinter: Quantifying the Carbon Footprint

(I) Gather data

(II) Convert to input data

(III) Run FootPrinter

(IV) Analyze performance and sustainability reports & act



Dante Niewenhuis, Sacheendra Talluri, Alexandru Iosup, Tiziano De Matteis (2024) FootPrinter: Quantifying Data Center Carbon Footprint. HotCloudPerf.

Use Case 1: Evaluate carbon footprint

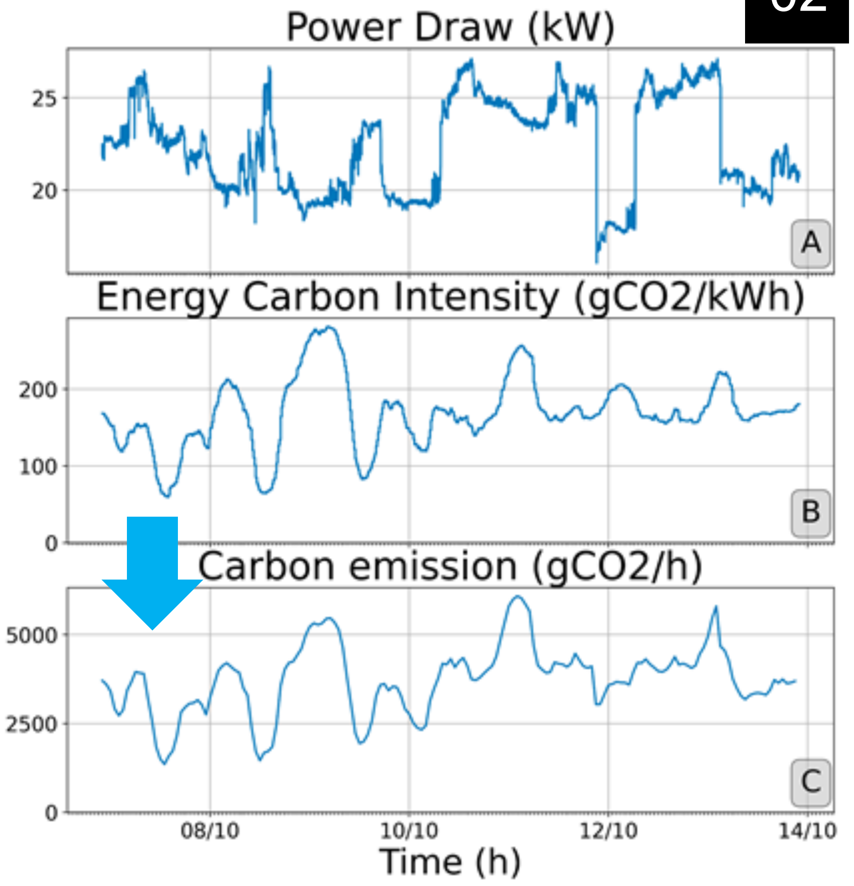
The carbon footprint is determined:

A. Determine power draw

B. Collect the carbon intensity (e.g., ENTSO-E)

C. Calculate carbon emissions

Carbon emission is primarily influenced by carbon intensity



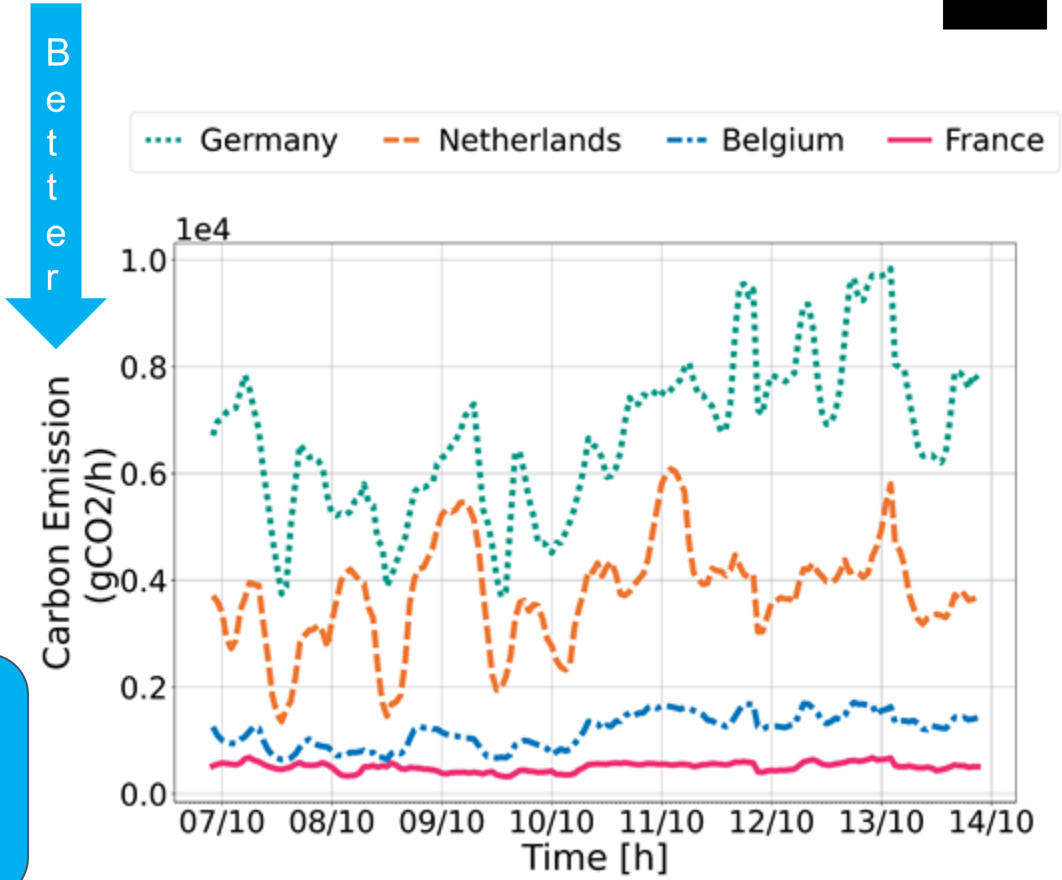
The Carbon emissions of a data center for a specific workload and RM&S policy

Dante Niewenhuis, Sacheendra Talluri, Alexandru Iosup, Tiziano De Matteis (2024) FootPrinter: Quantifying Data Center Carbon Footprint. HotCloudPerf.

Use Case 2: Compare location

- Run the same workload
- Change data center location
- Compare carbon footprint

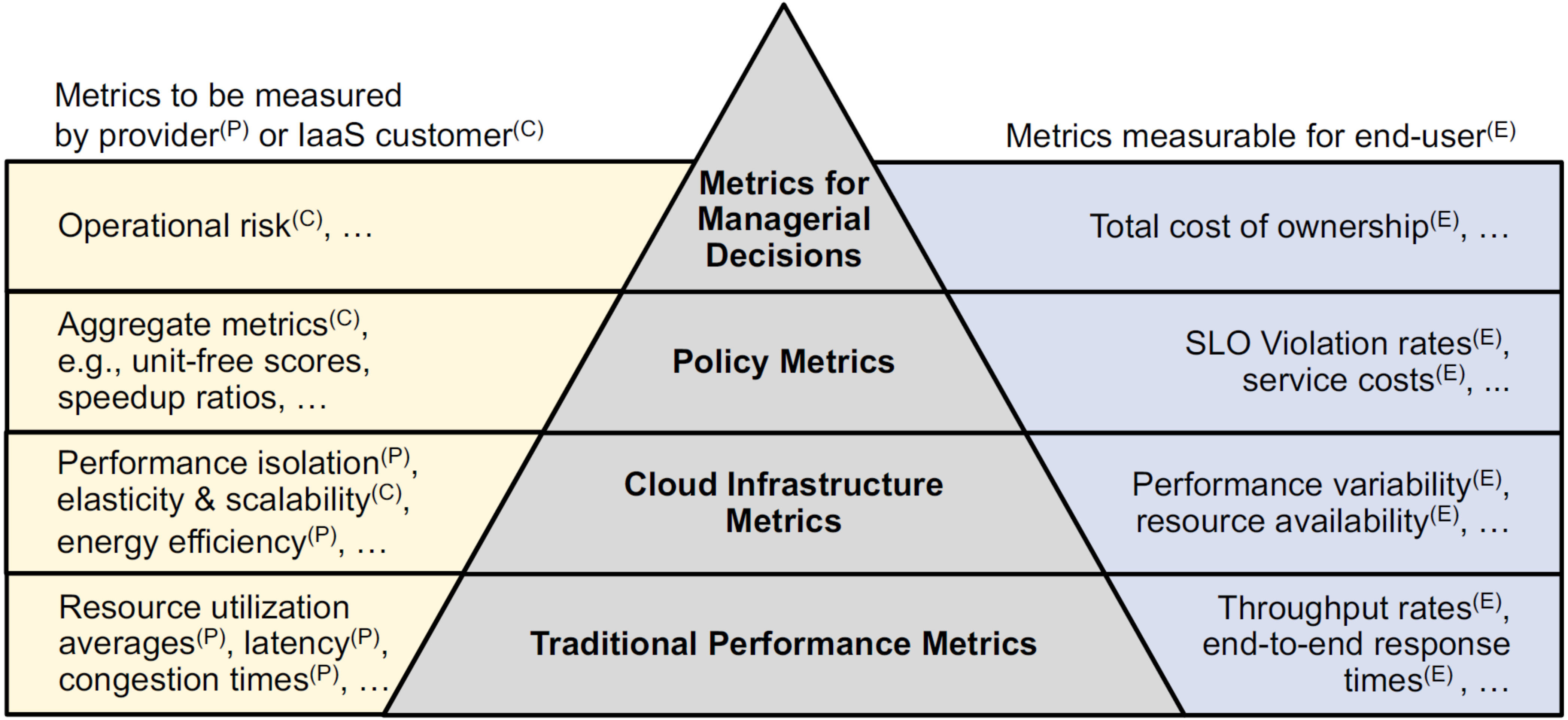
The location of a data center has significant effect on its carbon footprint



The Carbon emissions during the same workload on different locations

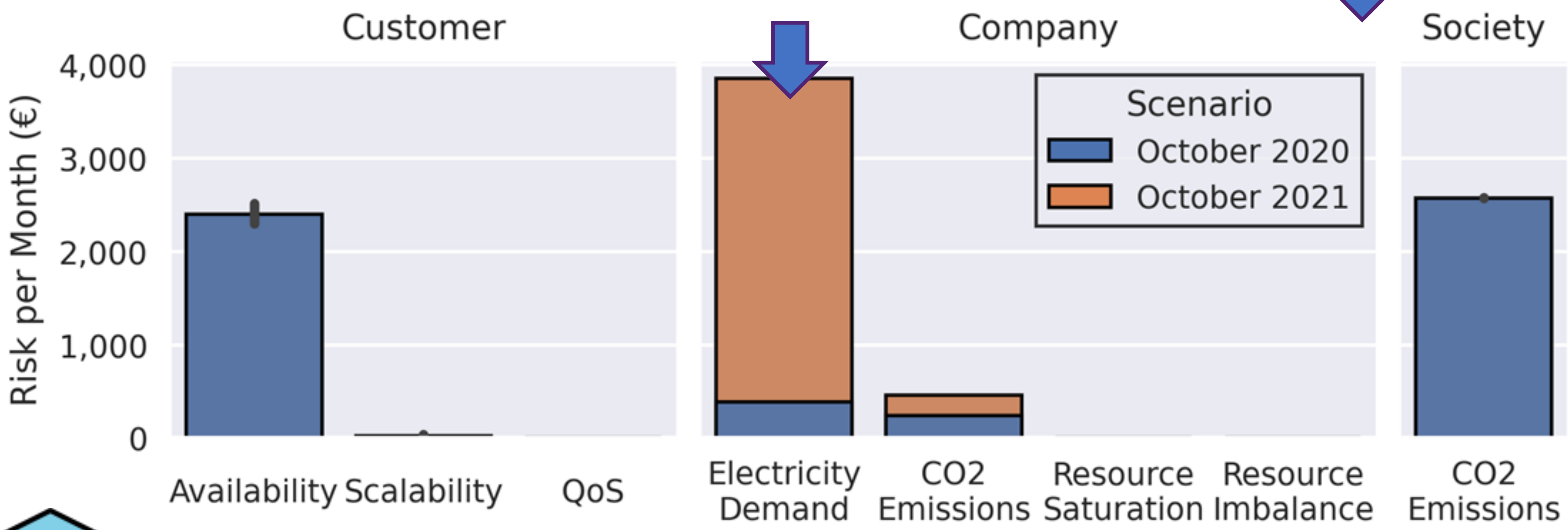
Dante Niewenhuis, Sacheendra Talluri, Alexandru Iosup, Tiziano De Matteis (2024) FootPrinter: Quantifying Data Center Carbon Footprint. HotCloudPerf.

Different Performance Goals for Different Stakeholders
A Framework for (New) Operational Metrics



N. Herbst, A. Bauer, S. Kounev, G. Oikonomou, E. Van Eyk, G. Kousiouris, A. Evangelinou, R. Krebs, T. Brecht, C. L. Abad, A. Iosup: Quantifying Cloud Performance and Dependability: Taxonomy, Metric Design, and Emerging Challenges. TOMPECS 3(4): 19:1-19:36 (2018)

Example: Evolution of Electricity Expenses



Electricity expenses become **primary risk** in datacenters

Fabian Mastenbroek, Tiziano De Matteis, Vincent van Beek, Alexandru Iosup (2025)
RADiCe: A Risk Analysis Framework for DataCenters. FGCS.
Editor's Choice, nominated for 2025 Best Paper Award.

An unusual metric: The cost of *making* decisions
Real-world experiments are very expensive!
An Environmental Perspective

In Simulation	In Reality
112 Core-hours	**8,600,000,000** Core-hours
2.1 kWh	**116,000,000,000** kWh

Delft →  → Rotterdam

 **x 55 billion!**

In Simulation

In Reality

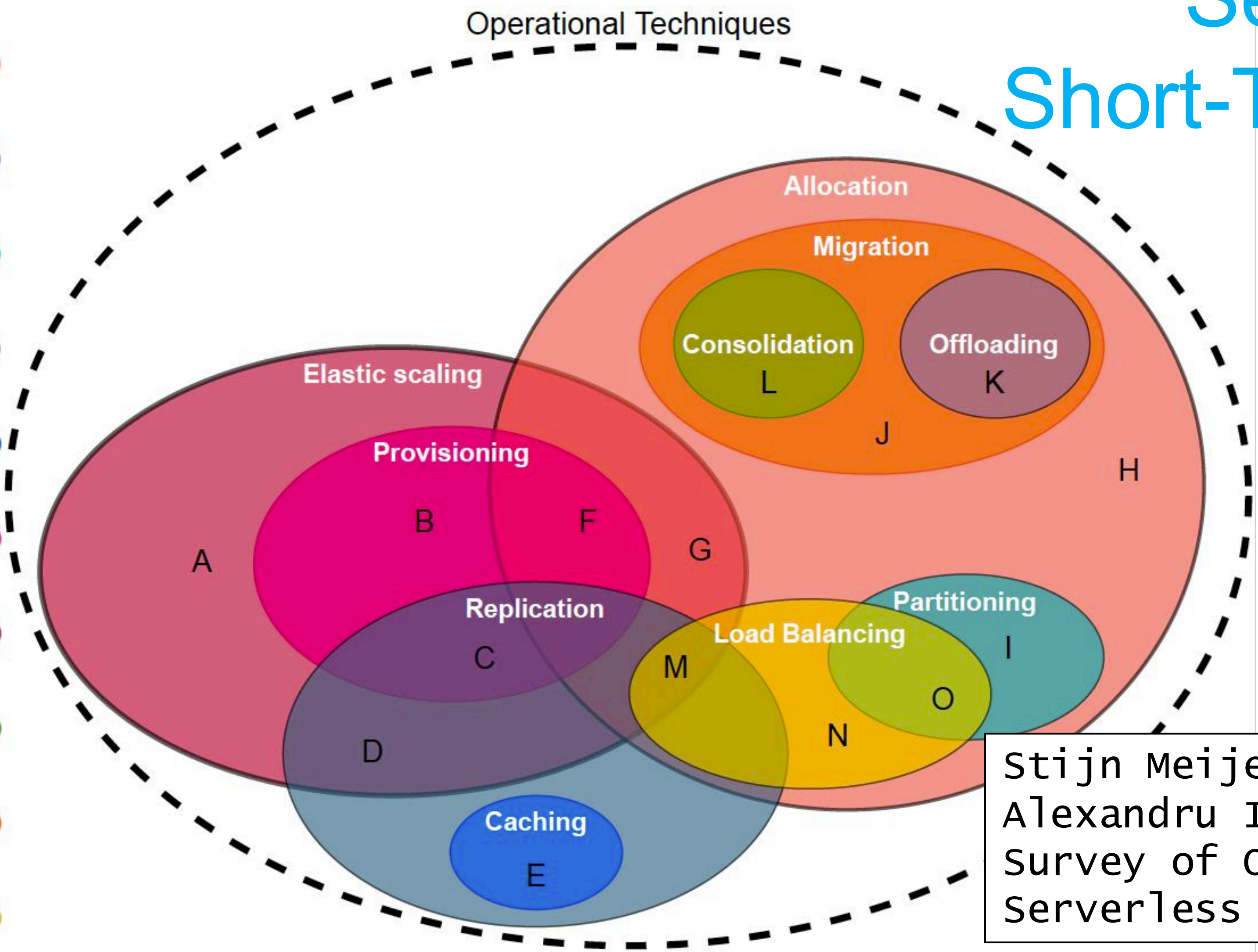
Exact numbers confidential, depend on topology

4.4

Idea:
Manage resources and workloads effectively through RM&S frameworks (or: beyond intuitive best-effort)

Selected Dynamic, Short-Term Techniques

- Allocation
- Replication
- Partitioning
- Offloading
- Caching
- Provisioning
- Elastic scaling
- Consolidation
- Migration
- Load Balancing



Stijn Meijerink, Erwin van Eyk, Alexandru Iosup (2021) Multivocal Survey of Operational Techniques for Serverless Computing. White Paper.

Recap →

Idea:
Improve observability through Operational Data Analytics and the computing continuum
Memex

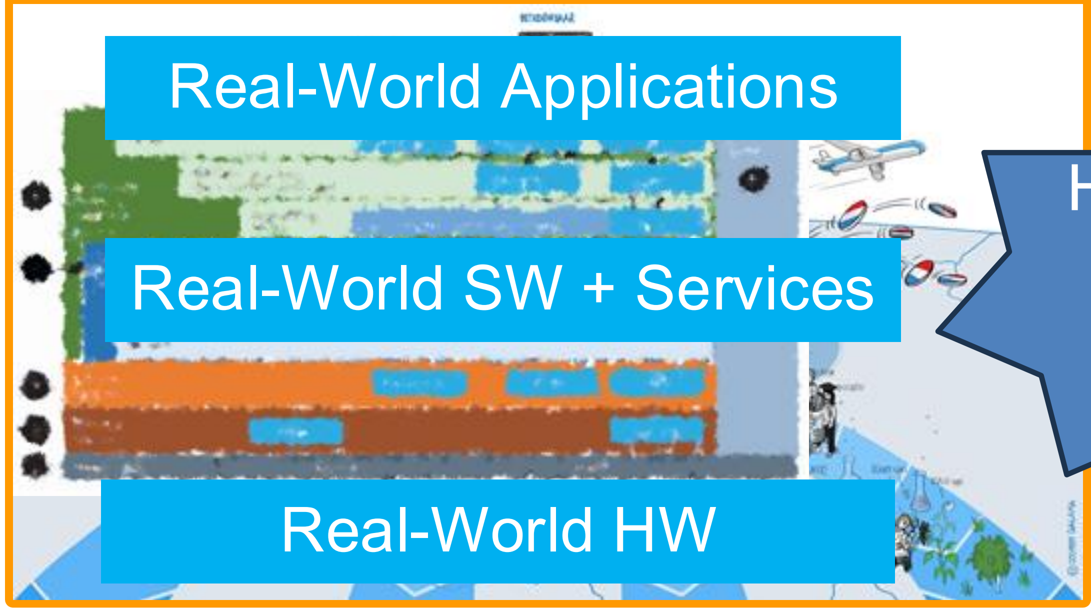
4.5

OPERATIONAL DATA ANALYTICS

monitoring and datagen

Shekhar Suman, X. Chu, A. Iosup (2024) ODA framework for large-scale infrastructure. WiP.

Real-World ICT Infrastructure

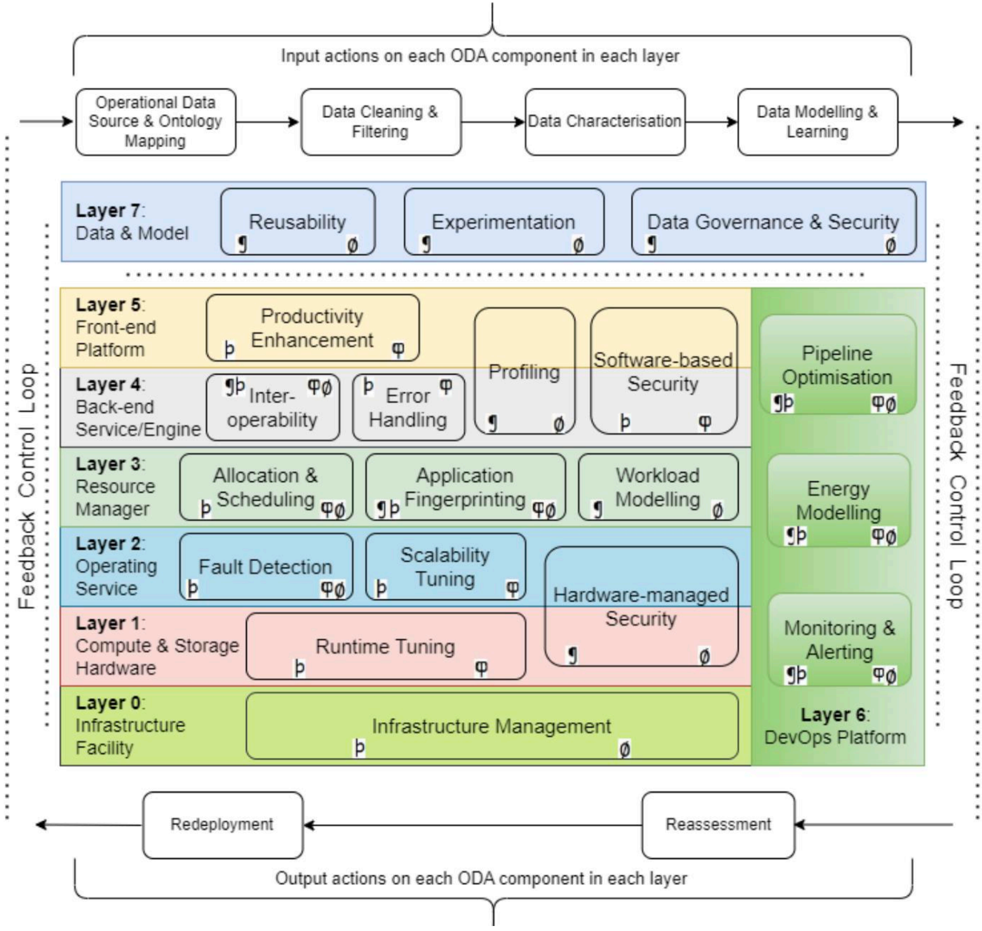


Real-World Applications

Real-World SW + Services

Real-World HW

Human in the loop



Legend

Data Sources:

¶: On-demand
þ: Online

ODA mode of operation:

φ: In-band
Ø: Out-of-band

OPERATIONAL DATA ANALYTICS

monitoring and datagen

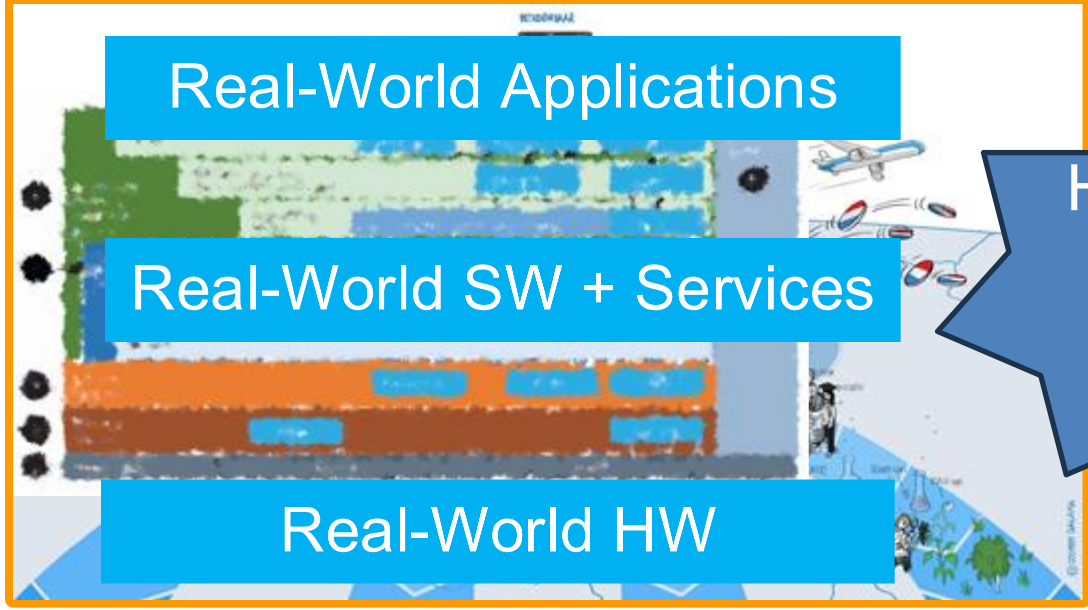
Shekhar Suman, X. Chu, A. Iosup (2024) ODA framework for large-scale infrastructure. WiP.

Real-World ICT Infrastructure

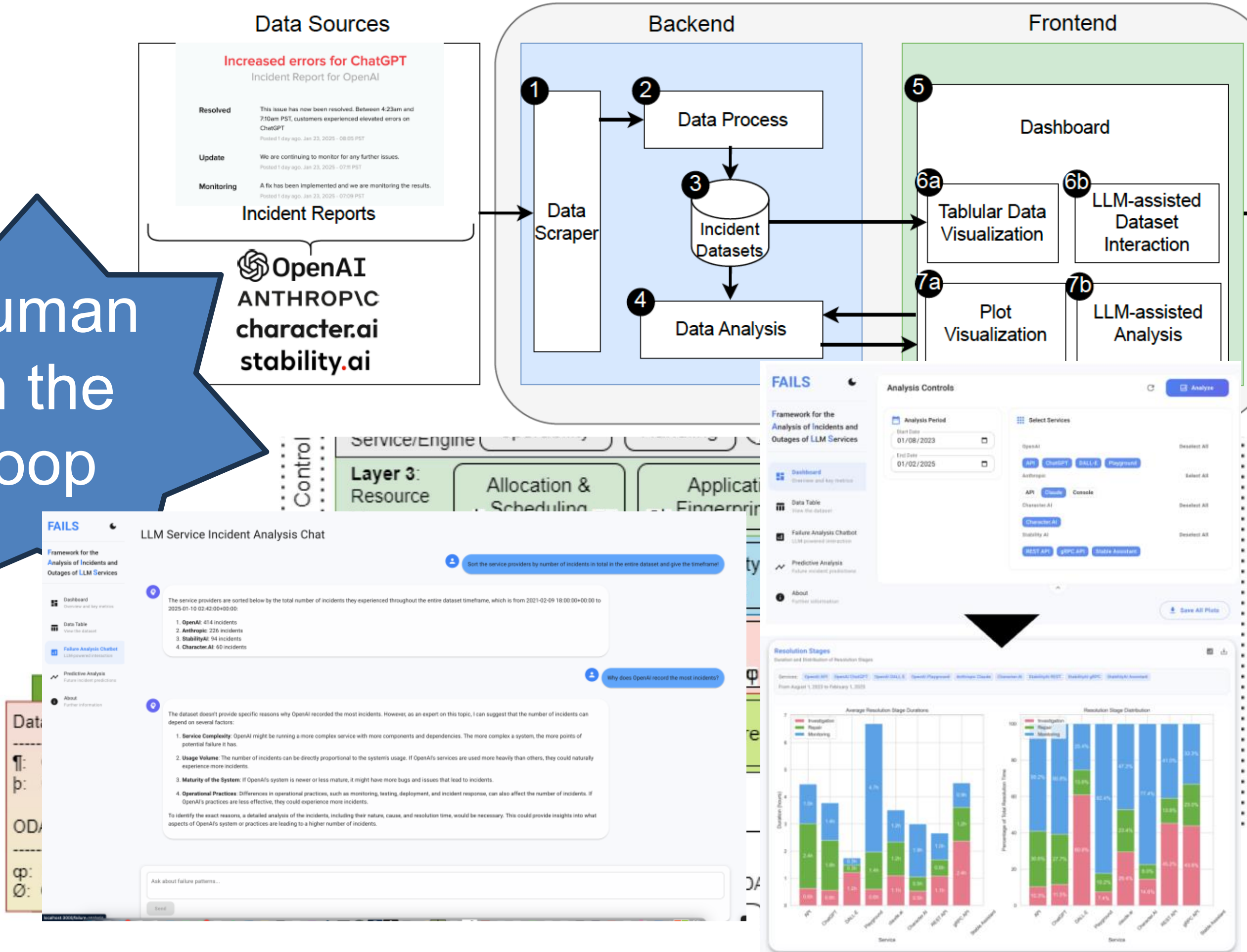
Real-World Applications

Real-World SW + Services

Real-World HW



Human in the loop



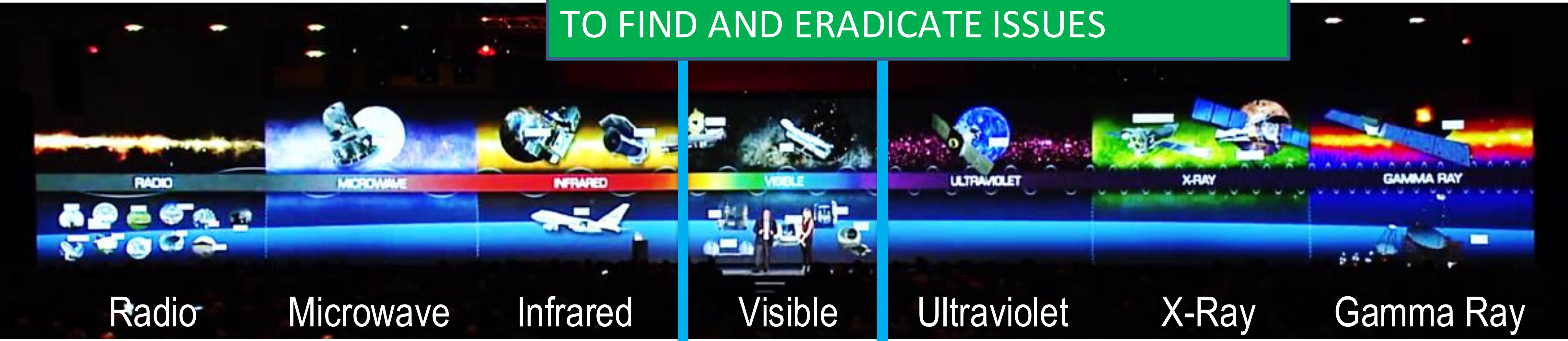
Sándor Battaglini-Fischer, Nishanthi Srinivasan, Bálint László Szarvas, Xiaoyu Chu, Alexandru Iosup (2025) [FAILS: A Framework for Automated Collection and Analysis of LLM Service Incidents](). ICPE.

THE CONTINUUM MEMEX = LARGE-SCALE, LONG-TERM STUDY

UNCOVERING THE MYSTERIES OF OUR UNIVERSE, PHYSICAL AND DIGITAL

+

TO FIND AND ERADICATE ISSUES



Radio | Microwave | Infrared | Visible | Ultraviolet | X-Ray | Gamma Ray

Radio: Cloud, Grid, Edge, Fog, etc.

[Iosup et al. FGCS'08]

Microwave: One aspect: BigData, P2P

P2P T.A.

[Zhang et al. CoNext'10]

Infrared: Sci.&Eng. Apps+Sys.

[Versluis et al. TPDS'21]

Groups, Workflows

[Iosup et al. IEEE IC'11]

Visible: Consumer Apps+Sys.

Game Trace Archive

[Guo et al. NETGAMES'12]

Ultraviolet: Enterprise Sys.

Business-Critical

[Shen et al. CCGRID'15]

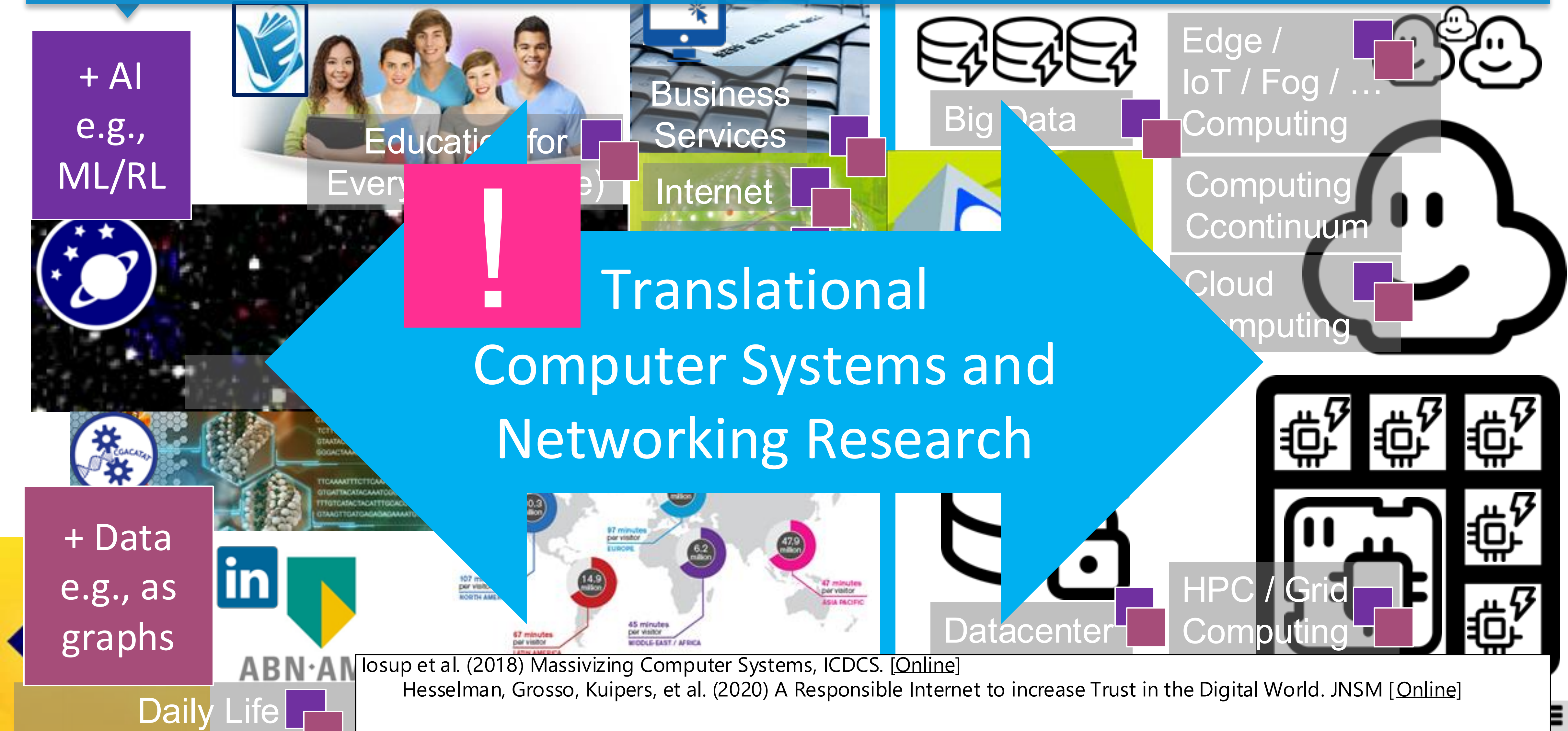
X-Ray: Systems, Ecosystems

[Ghiț et al. CCGRID'14]

Gamma Ray: Performance, Availability,

[Iosup et al. CCGRID'10]

NEW PROCESS – APPLICATION DOMAINS AND COMPUTER ECOSYSTEMS SCIENCE ARE MUTUALLY REINFORCING



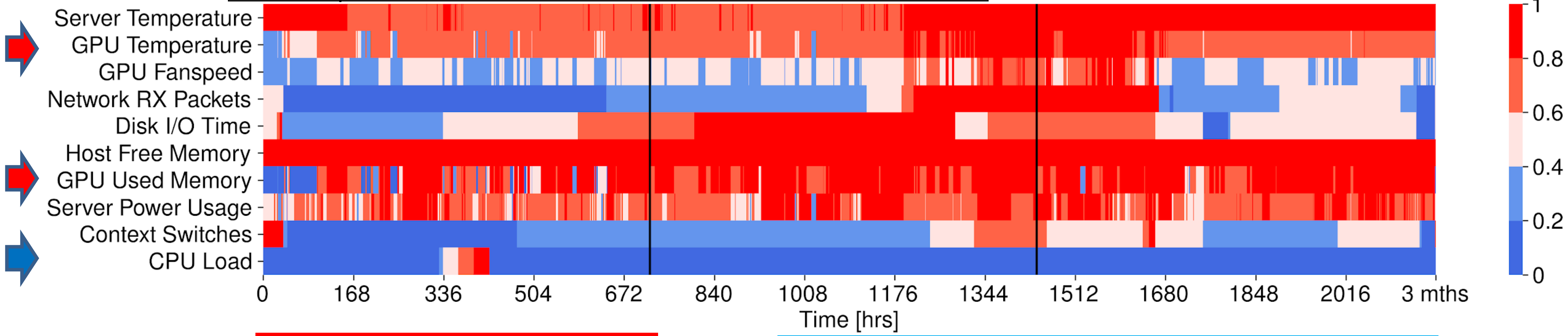
Iosup et al. (2018) Massivizing Computer Systems, ICDCS. [Online]
Hesselman, Grosso, Kuipers, et al. (2020) A Responsible Internet to increase Trust in the Digital World. JNSM [Online]

APPROACH: COMBINE MANY METRICS FOR HOLISTIC INSIGHT

One Basic Result in DC design

Uta et al., Beneath the SURFace (2020) An MRI-like View into the Life of a 21st-Century Datacenter. USENIX; login.

Versluis et al. (2023) Less is not more: We need rich datasets to explore. FGCS 142.



Hot GPUs

Cold CPUs*

* when GPUs

Could use less powerful, less expensive CPUs

5

An R&D&I program on massivizing computer systems that enables sustainability, with 8 pillars

Massivizing in 8* “easy” steps…

(*) Computer scientists often use 8 as their “round” number

Supported by a science that provides foundational models, operational laws, reference designs, experiments, analysis, longitudinal data

1. Applications: From single app to workflows, from workflows to development and operation of long-term, interacting pipelines; new techniques and devices to control operation, including VR devices and Metaverses
2. Automated deployment and execution for complex applications and services, leveraging resources including accelerators and multi-party services to ensure functional and non-functional properties as needed
3. Resource management and scheduling as first-class citizens, able to smartly combine diverse techniques across all operational layers and to improve (optimize) operation across user and operator goals
4. In-flight service management, smartly providing desirable operational properties including consistency and provenance, according to dynamic, adjustable, application-driven needs with serverless principles
5. Digital Twin on the side, smartly providing clear insights for on-going operations, and trusted and comparative analysis leading to superior short- and long-term decisions
6. From mere monitoring to Operational Data Analytics, and from logs to an ICT Infrastructure Memex
7. Toward highly desirable (sustainable, performant, scalable, available, efficient, flexible, secure, etc.) combination of ecosystems in the digital continuum – and reproducible and comparable
8. A coherent view on apps, services, and resources where everything is dynamic, interacting, autonomous, and viable long-term – from everything discardable to guarantees, attribution, and sovereignty for the entire 21st century

Focus on sustainability of many kinds

WANT TO READ FURTHER?

FURTHER READING

https://atlarge-research.com/publications.html

1. (*) Alexandru Iosup, Fernando Kuipers, Ana Lucia Varbanescu, Paola Grosso, Animesh Trivedi, Jan S. Rellermeyer, Lin Wang, Alexandru Uta, Francesco Regazzoni (2022) Future Computer Systems and Networking Research in the Netherlands: A Manifesto. CoRR abs/2206.03259.
2. (+) Fabian Mastenbroek, Tiziano De Matteis, Vincent van Beek, Alexandru Iosup (2025) RADiCe: A Risk Analysis Framework for DataCenters. FGCS. Editor's Choice, nominated for 2025 Best Paper Award.
3. [+] Sacheendra Talluri, Nikolas Herbst, Cristina L. Abad, Tiziano De Matteis, Alexandru Iosup (2024) ExDe: Design space exploration of scheduler architectures and mechanisms for serverless data-processing. Future Gener. Comput. Syst. 153: 84-96.
4. [+] De Matteis, Gianinazzi, de Fine Licht, Hoefler (2023) Streaming Task Graph Scheduling for Dataflow Architectures. HPDC.
5. (*) Kounev, Herbst, Abad, Iosup, et al. (2023) Serverless Computing: What It Is, and What It Is Not? CACM 66(9).
6. [+] Jesse Donkervliet, Javier Ron, Junyan Li, Tiberiu Iancu, Cristina L. Abad, Alexandru Iosup (2023) Servo: Increasing the Scalability of Modifiable Virtual Environments Using Serverless Computing. ICDCS.
7. (*)[+] Jansen et al. (2023) The SPEC-RG Reference Architecture for The Compute Continuum. CCGRID.
8. [+] Versluis et al. (2023) Less is not more: We need rich datasets to explore. Future Gener. Comput. Syst. 142: 117-130.
9. (*)[+] Crusoe et al. (2022) Methods included: standardizing computational reuse and portability with the Common Workflow Language. CACM 65(6).
10. [+] Andreadis et al. (2022) Capelin: Data-Driven Capacity Procurement for Cloud Datacenters using Portfolios of Scenarios. IEEE TPDS 33(1).
11. (*) Eismann et al. (2022) The State of Serverless Applications: Collection, Characterization, and Community Consensus. IEEE Trans. Software Eng. 48(10).
12. (*)[+] Sakr, Bonifati, Voigt, Iosup, et al. (2021) The future is big graphs: a community view on graph processing systems. Commun. ACM 64(9).
13. (*)[+] Mastenbroek et al. (2021) OpenDC 2.0: Convenient Modeling and Simulation of Emerging Technologies in Cloud Datacenters. CCGRID.
14. (*) Papadopoulos et al. (2021) Methodological Principles for Reproducible Performance Evaluation in Cloud Computing. IEEE Trans. Software Eng. 47(8).
15. (*)[+] Versluis et al. (2020) The Workflow Trace Archive: Open-Access Data From Public and Private Computing Infrastructures. IEEE TPDS 31(9).
16. (*) Alexandru Uta, Alexandru Custura, Dmitry Duplyakin, Ivo Jimenez, Jan S. Rellermeyer, Carlos Maltzahn, Robert Ricci, Alexandru Iosup (2020) Is Big Data Performance Reproducible in Modern Cloud Networks? NSDI.

Legend: (*) High impact in the field [+] FAIR data or software