MASSIVIZING COMPUTER SYSTEMS – THE ICT INFRASTRUCTURE MEMEX

VU ON THE DIGITAL COMPUTING CONTINUUM

@Large Research
Massivizing Computer Systems

http://atlarge.science

Continuum = infrastructure for the 21st century, different from what we had before

This project has received funding from the European Union's Horizon Research and Innovation Actions under Grant Agreement № 101093202.

VU VRIJE UNIVERSITEIT AMSTERDAM

Contributions from the MCS/AtLarge teams. Many thanks!
Many thanks to our collaborators, international working groups, authors of all images included here. Also thanks to
Radu Prodan, Martina Steinbacher, Dragi, Reza, and the KLU team.

GRAPH MASSIVIZER

CLOUD STARS

Rijksoverheid

NWO

@AIosup

Prof.dr.ir. Alexandru IOSUP

US IN 3 MINUTES

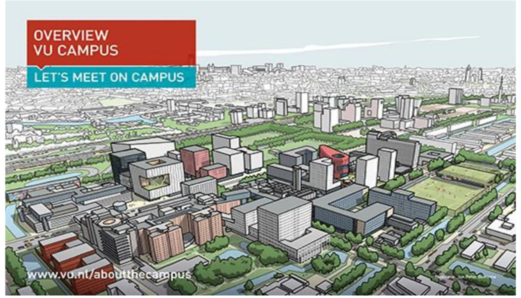
WE'RE MASSIVIZING COMPUTER SYSTEMS!

>

<

VU AMSTERDAM < SCHIPHOL < THE NETHERLANDS < EUROPE

Amsterdam
founded 10th century
pop: 850,000



VU
founded 1880
pop: >25,000
(~ 5,000 staff)

The Netherlands

pop: 16.5 M

Europe

VU UNIVERSITY AMSTERDAM

VU VRIJE UNIVERSITEIT AMSTERDAM

Massivizing Computer Systems

Research Group Bio

https://atlarge-research.com


Alexandru IOSUP


Animesh TRIVEDI


Tiziano DE MATTEIS


Daniele BONETTA


Jesse DONKERVLIET

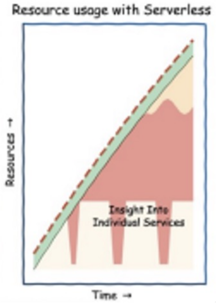

Matthijs JANSEN

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, aggregate and disaggregate resources, compute and IO, 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.

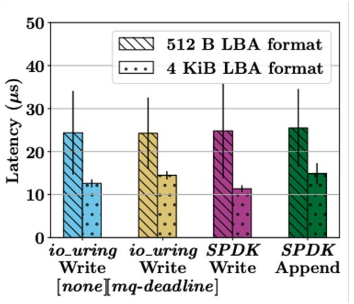
Digital Twin: ICT infrastructure/datacenter simulation, Operational Data Analytics, DC cockpit, VR/XR ops.

Relevant prior work (selection of tools and activities):

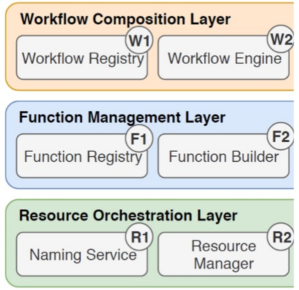


Serverless history + vision

OpenDC simulator



K8s/Storage benchmark



Continuum + Reference Archi

LDBC GRAPHALYTICS

Benchmark

spec Research

Cloud Group chair

Contact: info@atlarge-research.com

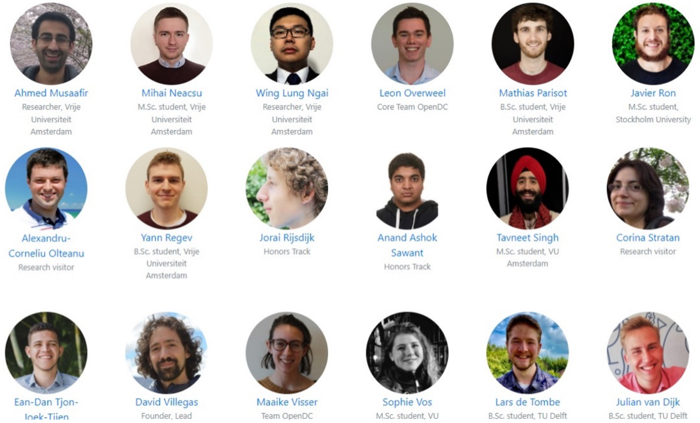
http://atlarge.science

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 RACES AND ETHNICITIES, GENDERS AND SEXUAL ORIENTATION, AND VIEWS OF CULTURE, POLITICS, AND RELIGION. YOU ARE WELCOME TO JOIN!

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

- Education, my courses:
  - Honours Programme, Computer Org. (BSc)
  - Distributed Systems, Cloud Computing (MSc)
- Research, 15 years in DistribSys:
  - Massivizing Computer Systems
  - About 30 young researchers in the team
- About me:
  - Worked in 7 countries, NL since 2004
  - 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



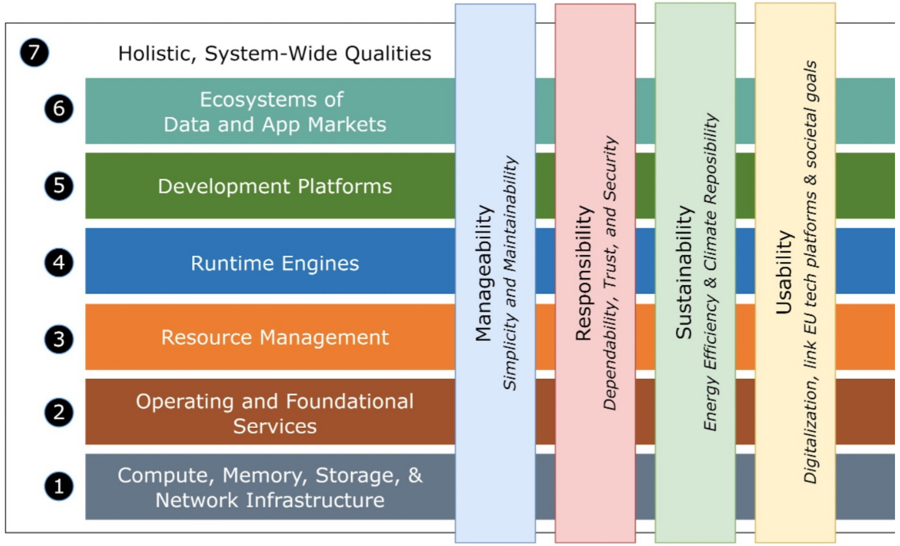

SINCE LAST YEAR – RE-BOOTED THE COMPSYS NL COMMUNITY…

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 CONFERENCE TO MENTION… https://2024.ccgrid-conference.org/

CCGRID 2024

Philadelphia, USA
May 5-9, 2024

The 24th IEEE/ACM international Symposium on Cluster, Cloud and Internet Computing

Program Chairs

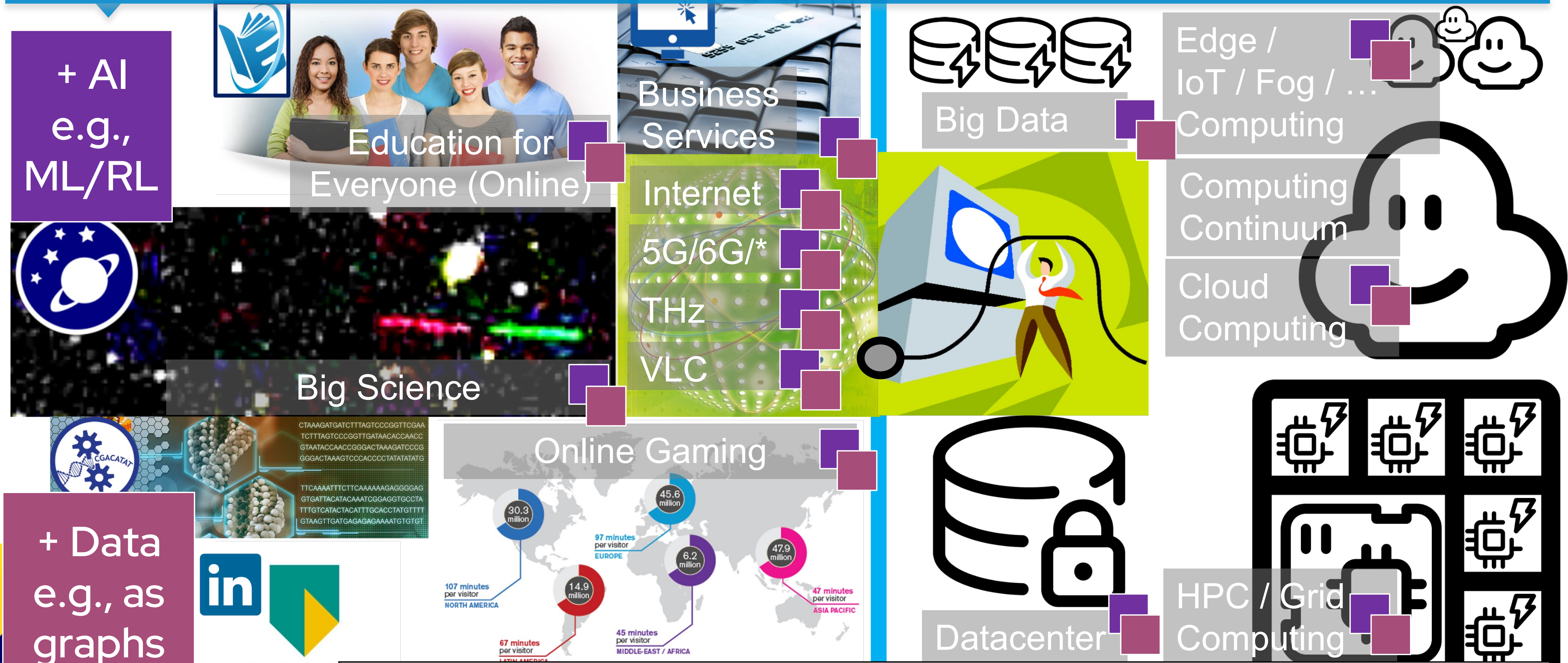
Alexandru Iosup, Vrije Universiteit Amsterdam, Netherlands
Xubin He, Temple University, USA
Beth Plale, Indiana University, USA

1. Hardware Systems and Networking
2. Software Systems and Platforms
3. Machine Learning (ML) for Systems and Systems for ML
4. Future Compute Continuum and Seamless Ecosystems
5. Applications and Workflows
6. Performance Monitoring, Modeling, Analysis, and Benchmarking
7. Distributed and Parallel Storage Systems
8. Education about Cluster, Cloud and Internet Computing

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]

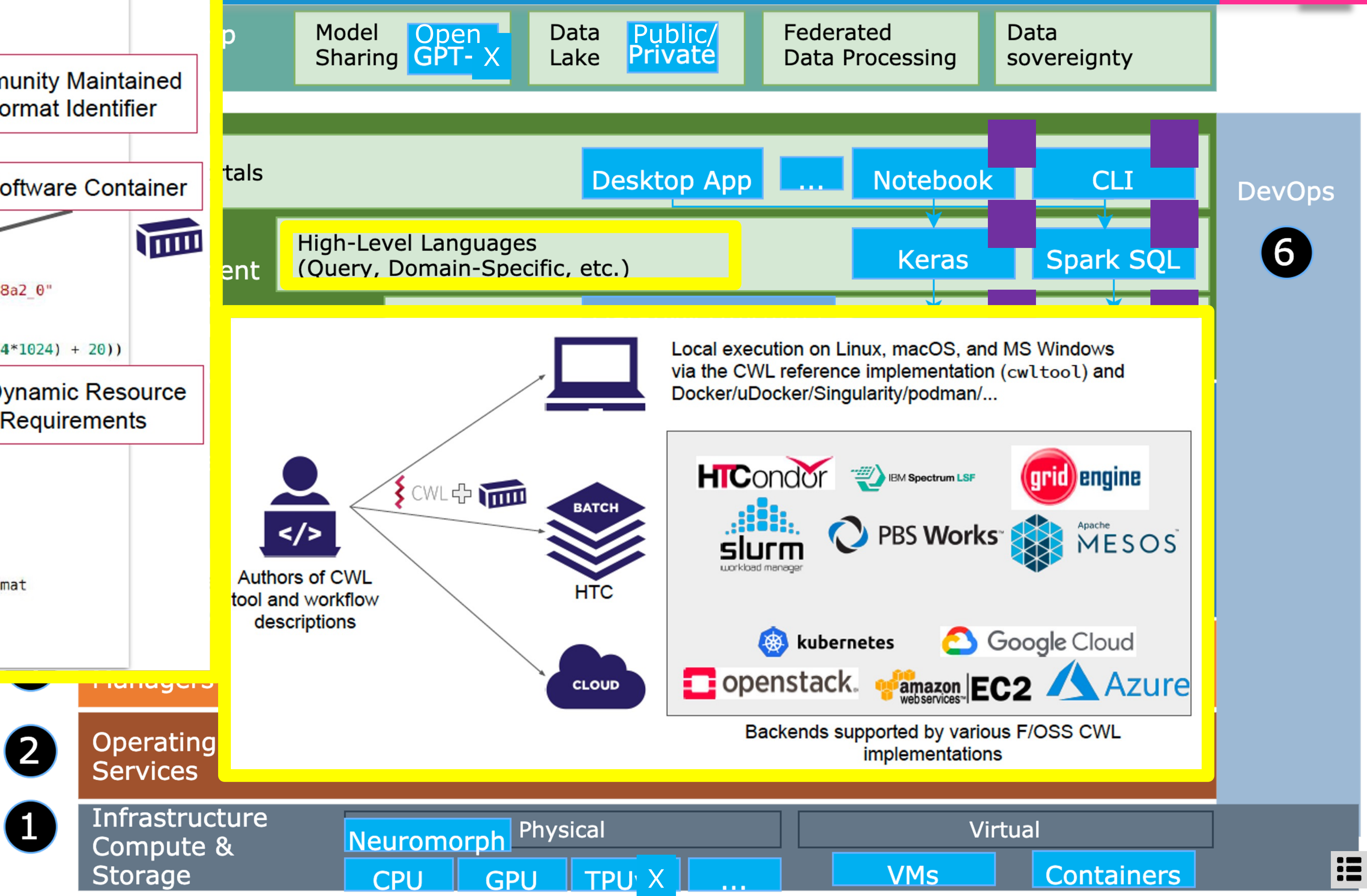
USING REPRODUCIBLE, COMPLEX WORKFLOWS …

```
cwlVersion: v1.0
class: CommandLineTool

doc: Spoa is a partial order aligment…

inputs:
  readsFA:
    type: File
    format: edam:format_1929
    doc: FASTA file containing a set of sequences.

requirements:
  InlineJavascriptRequirement: {}
hints:
  DockerRequirement:
    dockerPull: "quay.io/biocontainers/spoa:3.4.0--hc9558a2_0"
  ResourceRequirement:
    ramMin: $(15 * 1024)
    outdirMin: $(Math.ceil(inputs.readsFA.size/(1024*1024*1024) + 20))

baseCommand: spoa

arguments: [ $(inputs.readsFA), -G, -g, '-6' ]

stdout: $(inputs.readsFA.nameroot).g6.gfa

outputs:
  spoaGFA:
    type: stdout
    format: edam:format_3976
    doc: result in Graphical Fragment Assembly (GFA) format

$namespaces:
  edam: http://edamontology.org
```

1. Community Maintained File Format Identifier

2. Software Container

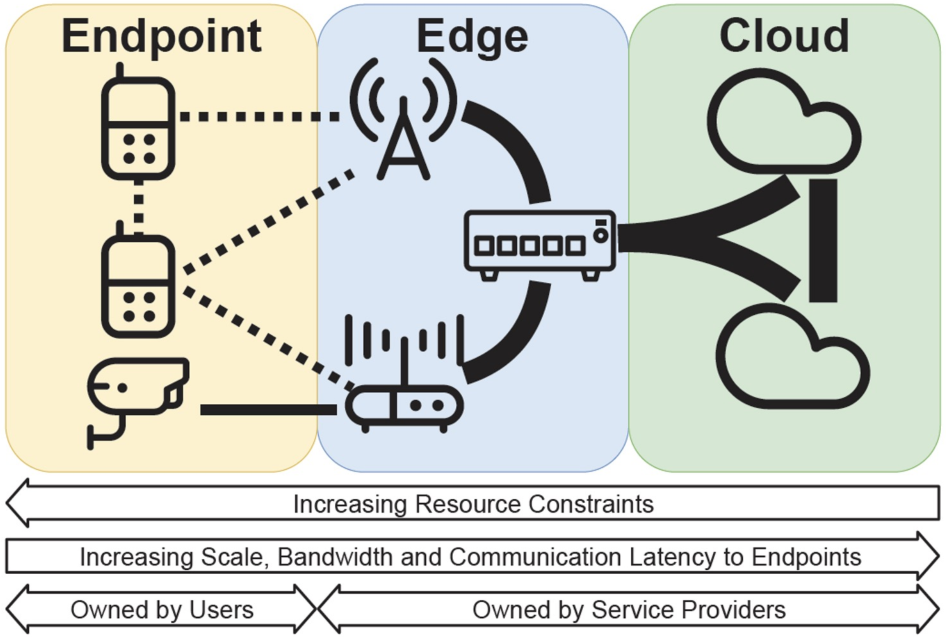
3. Dynamic Resource Requirements



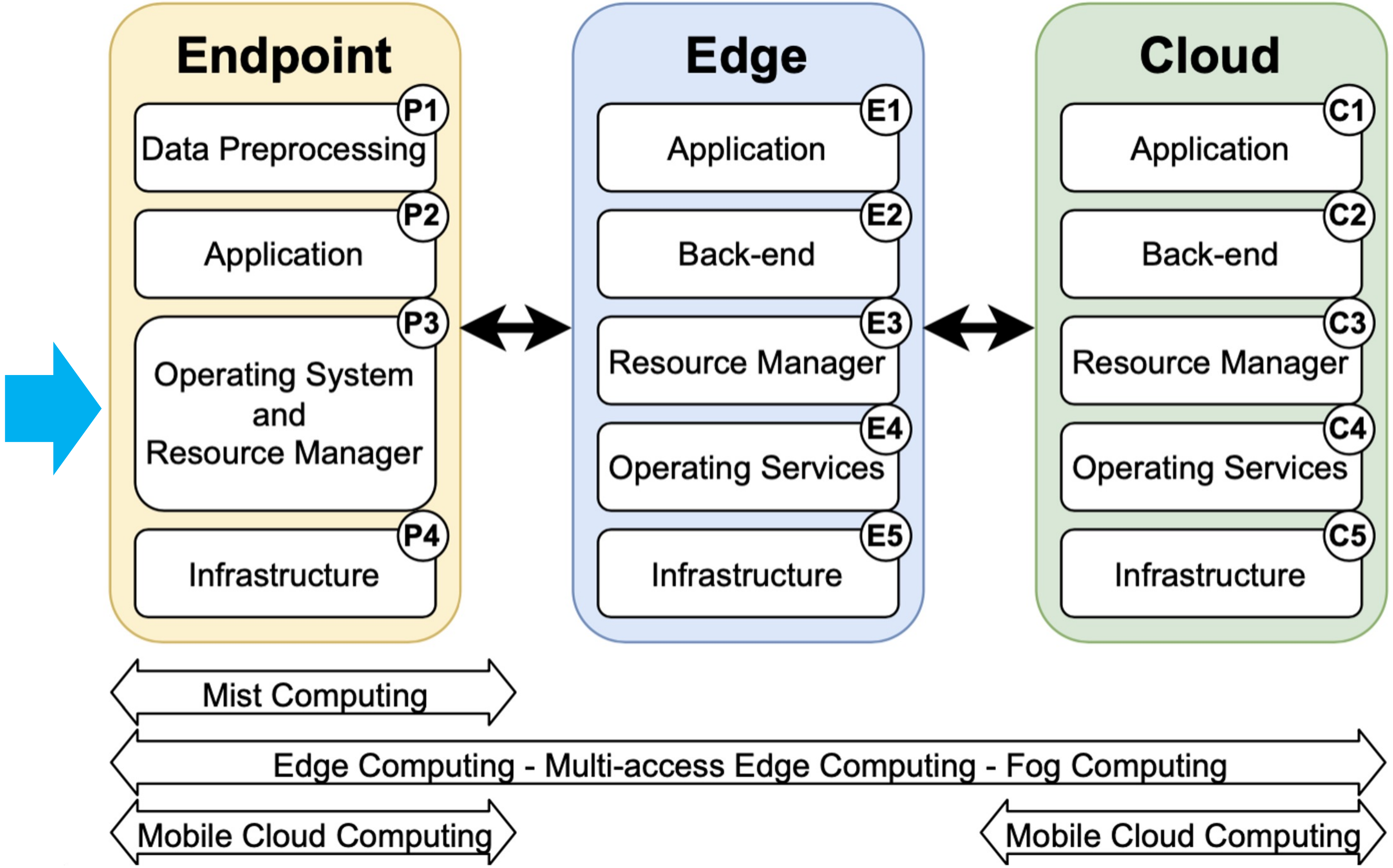
Crusoe et al. (2022) Methods Included: Standardizing Computational Reuse and Portability with the Common Workflow Language. CACM.

… RUNNING ON CONTINUUM RESOURCES & SERVICES

ISSUES: COMPLEXITY, NON-TECHNICAL



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

… IN A SMARTLY ORCHESTRATED ICT ECOSYSTEM …

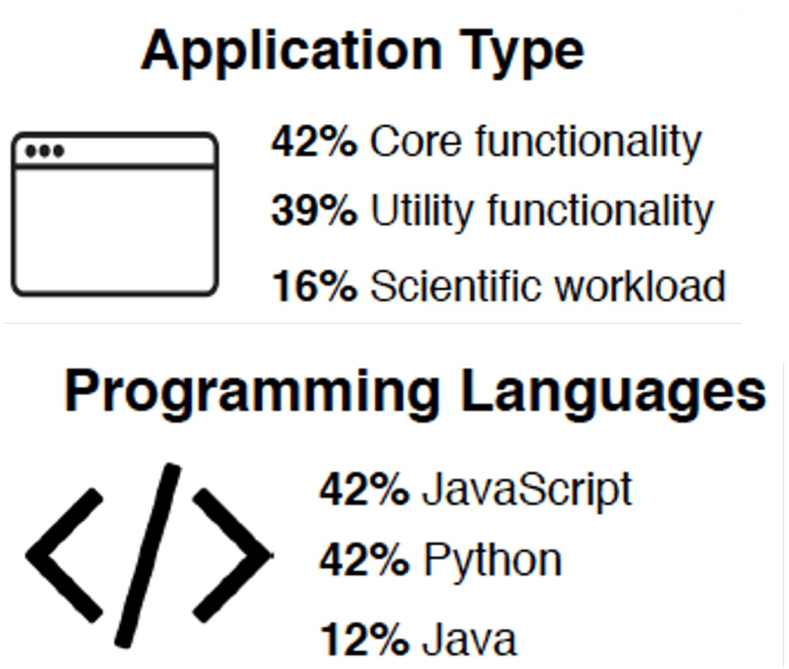
Extreme Automation, Performance, Dependability, Sustainability

…DELIVERING SERVERLESS COMPUTING PROPERTIES

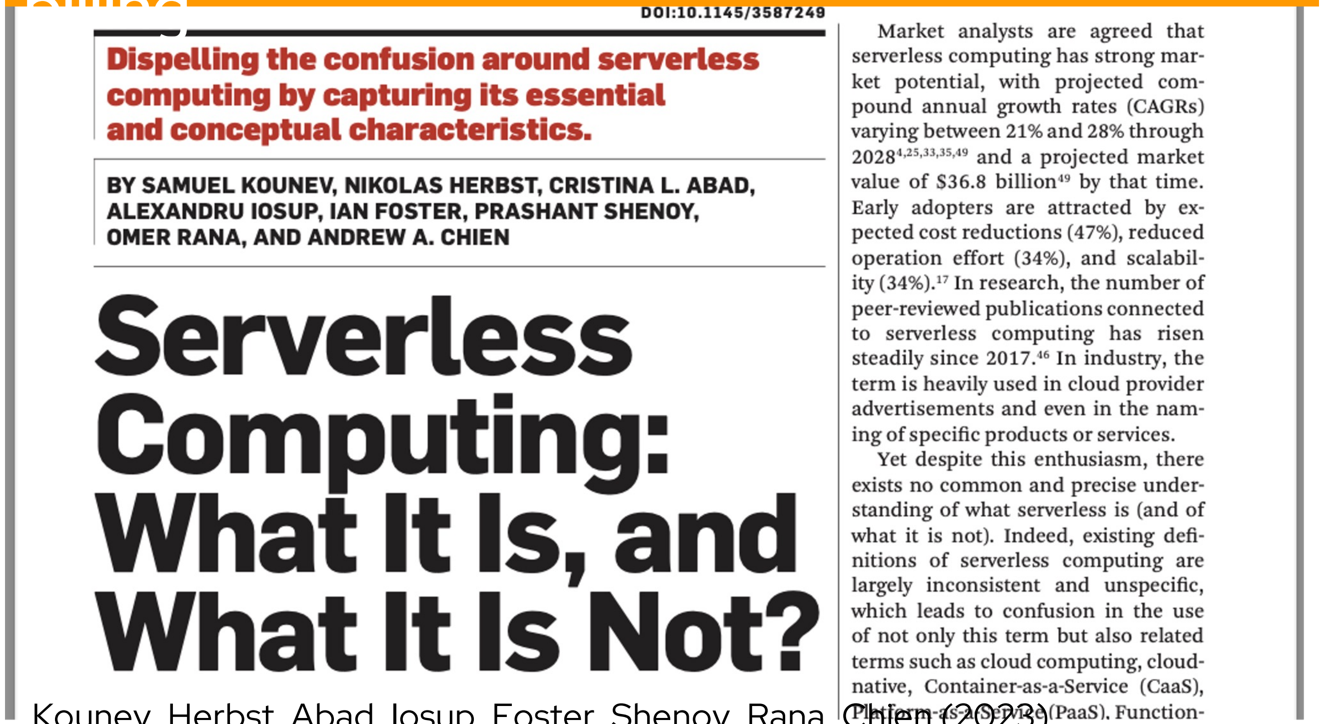
^

bit.ly/MassivizingServerless22

Serverless computing = extreme automation + fine-grained, utilization-based billing



Simon Eismann, Joel Scheuner, Erwin Van Eyk, Maximilian Schwinger, Johannes Grohmann, Nikolas Herbst, Cristina L. Abad, Alexandru Iosup (2022) The State of Serverless Applications: Collection, Characterization, and Community Consensus. IEEE Trans. Software Eng. 48(10)



DOI:10.1145/3587249

Dispelling the confusion around serverless computing by capturing its essential and conceptual characteristics.

BY SAMUEL KOUNEV, NIKOLAS HERBST, CRISTINA L. ABAD, ALEXANDRU IOSUP, IAN FOSTER, PRASHANT SHENOY, OMER RANA, AND ANDREW A. CHIEN

Serverless Computing: What It Is, and What It Is Not?

Market analysts are agreed that serverless computing has strong market potential, with projected compound annual growth rates (CAGRs) varying between 21% and 28% through 2028[4,25,33,35,49] and a projected market value of $36.8 billion[49] by that time. Early adopters are attracted by expected cost reductions (47%), reduced operation effort (34%), and scalability (34%).[17] In research, the number of peer-reviewed publications connected to serverless computing has risen steadily since 2017.[46] In industry, the term is heavily used in cloud provider advertisements and even in the naming of specific products or services.

Yet despite this enthusiasm, there exists no common and precise understanding of what serverless is (and of what it is not). Indeed, existing definitions of serverless computing are largely inconsistent and unspecific, which leads to confusion in the use of not only this term but also related terms such as cloud computing, cloud-native, Container-as-a-Service (CaaS), Platform-as-a-Service (PaaS), Function-

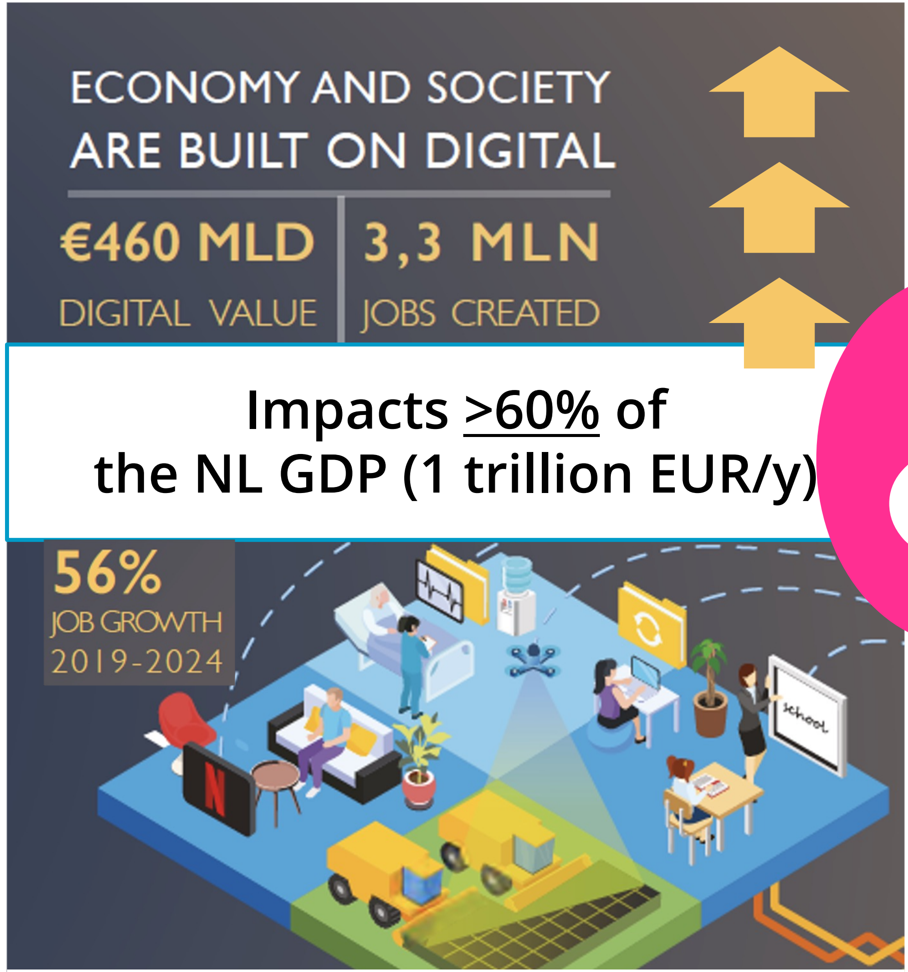
Kounev, Herbst, Abad, Iosup, Foster, Shenoy, Rana, Chien (2023) Serverless Computing: What It Is, and What It Is Not? CACM. Sep 2023 issue.

BUT WE CANNOT TAKE THIS TECHNOLOGY FOR GRANTED

2

(We need science to tackle the issues)

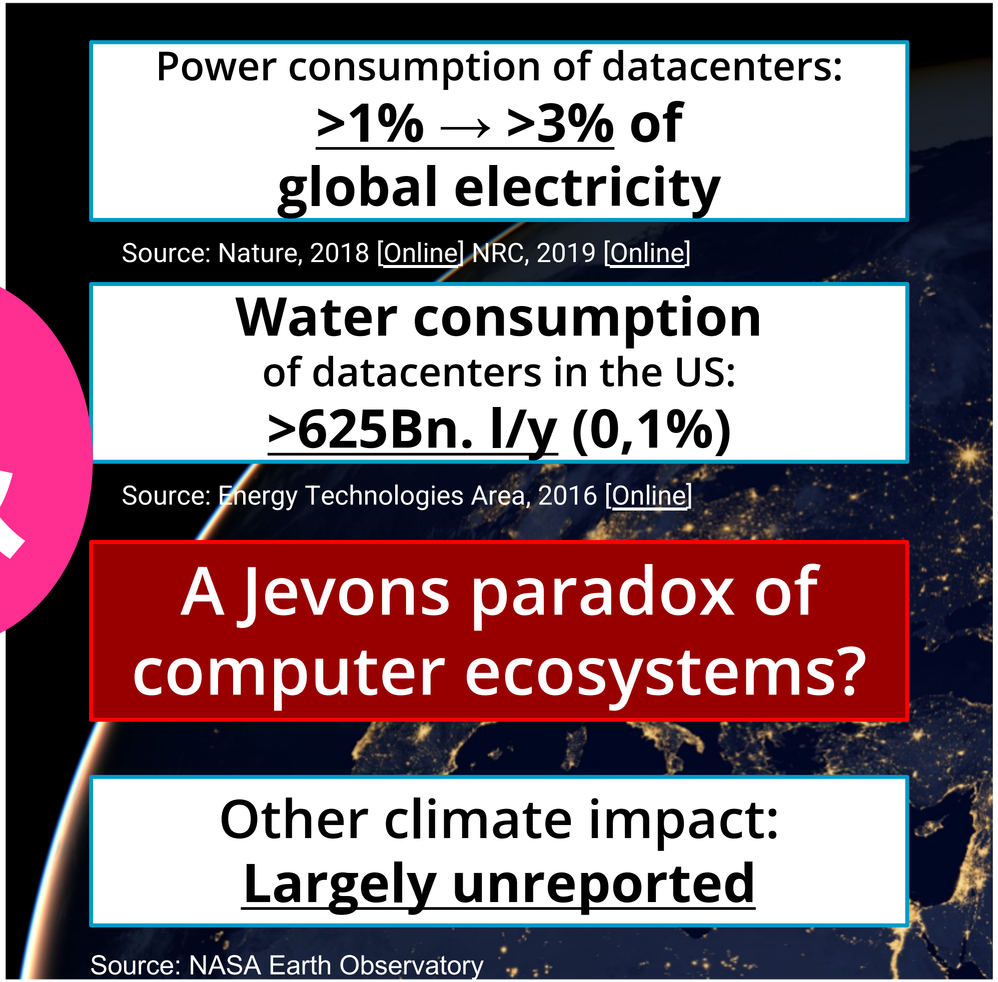
RESPONSIBILITY OF MASSIVE COMPUTER ECOSYSTEMS



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

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]

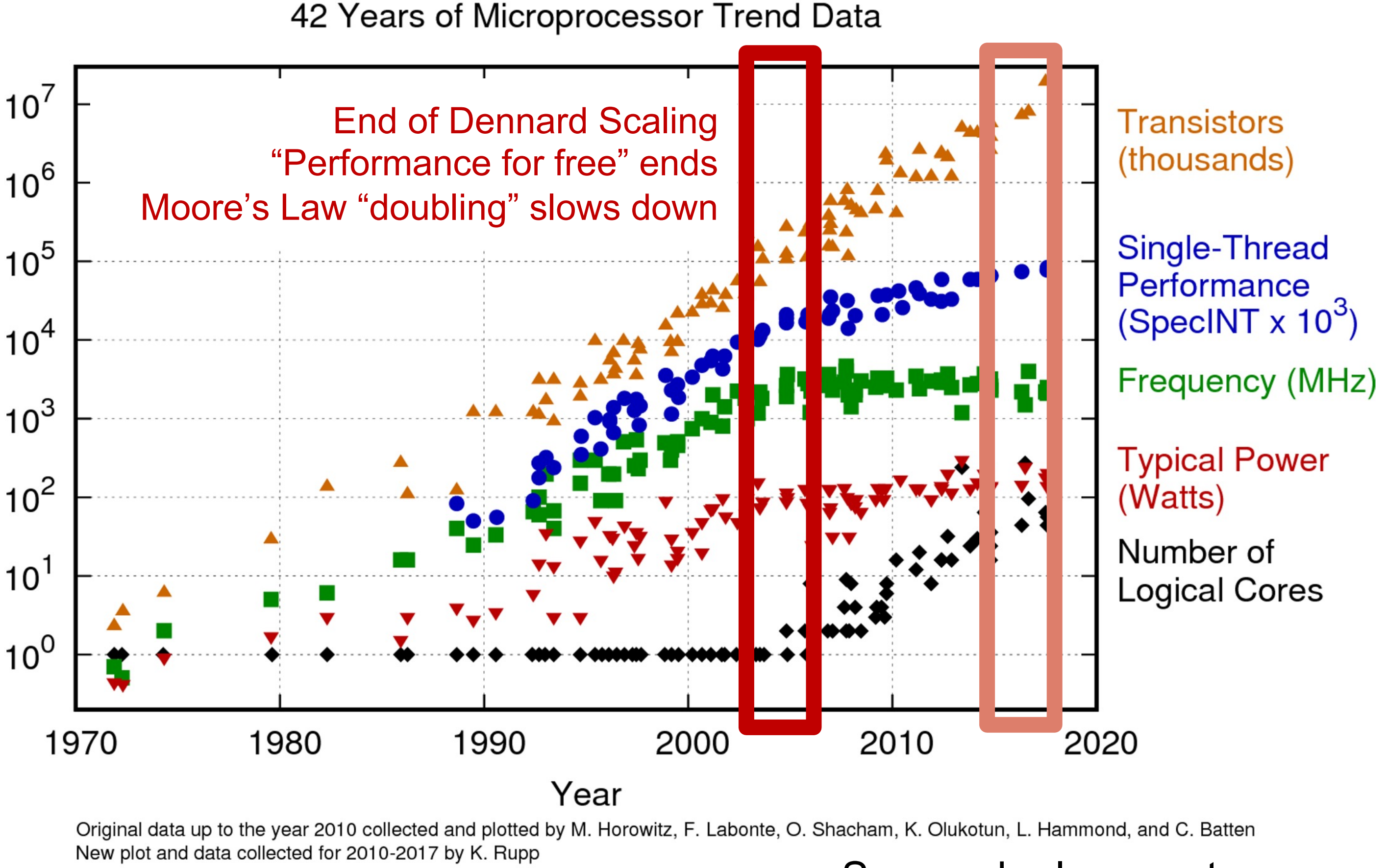
A Jevons paradox of computer ecosystems?

Other climate impact: **Largely unreported**

Source: NASA Earth Observatory

TECHNOLOGY EVOLUTION

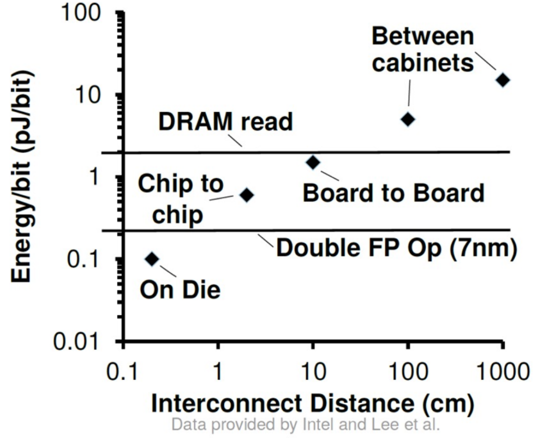
END OF MOORE'S LAW/DENNARD SCALING → COMPLEX, DISTRIBUTED ECOSYSTEMS



Source: karlrupp.net

Need for parallelism and distribution

Cost of energy for data movement still high



COMPLEXITY GROWS

COMPLEX, DISTRIBUTED ECOSYSTEMS DO NOT ACT LIKE REGULAR COMPUTER SYSTEMS

Ecosystems don't have easily…

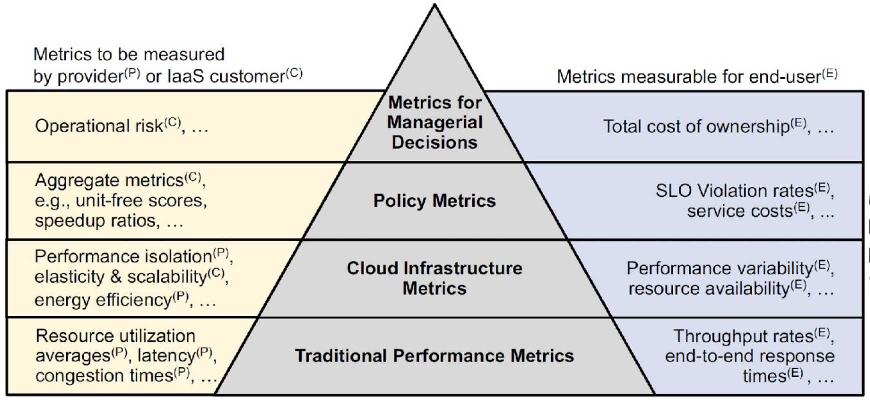
- Simplicity
- Maintainability
- Responsibility
- Sustainability
- Usability

which includes:

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

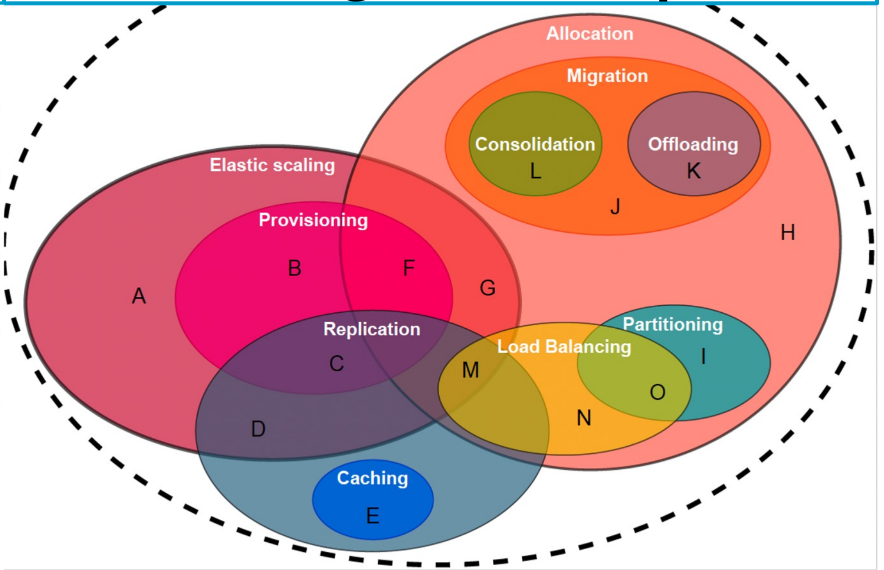
Iosup, Kuipers, Trivedi, et al. (2022) Future Computer Systems and Networking Research in the Netherlands: A Manifesto. CORR

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).

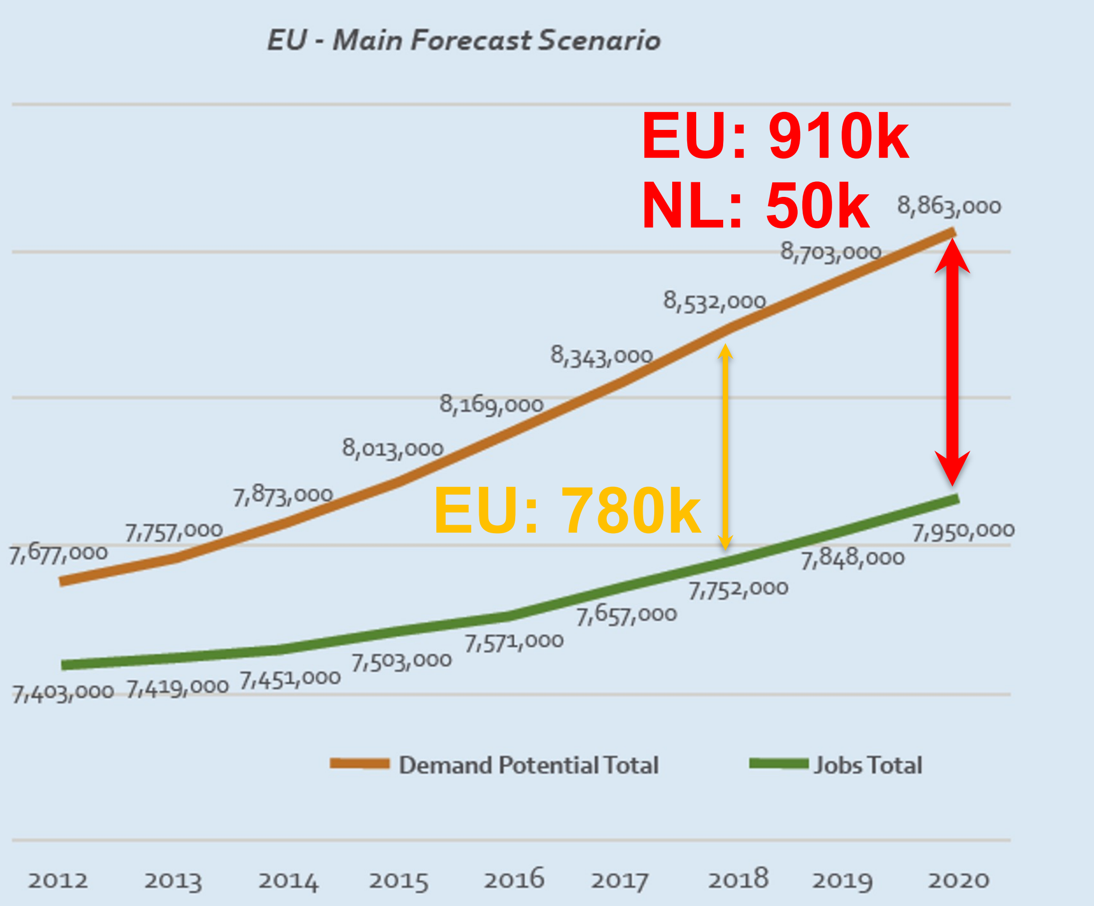
Operational techniques are becoming more complex



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

FEW CAN OPERATE COMPLEX IT ECOSYSTEMS

THE WORKFORCE GAP, IN THE NETHERLANDS & IN EUROPE



Does not start at 0!

Source: e-Skills for Jobs in Europe, 2014

PHENOMENON: PERFORMANCE IN CLOUD SERVICES

UNCOVERING THE PRESENCE OF PERFORMANCE ISSUES, EVEN LEADING TO CRASHES

Polygon

Source: http://bit.ly/EveOnline21Crash

NEWS

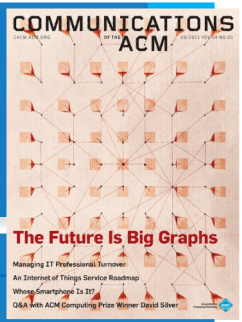
Players in Eve Online broke a world record — and then the game itself

Developers said they're not 'able to predict the server performance in these kinds of situations'

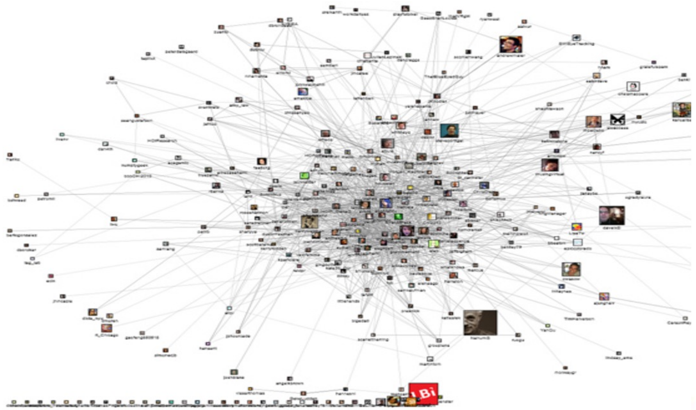
By Charlie Hall | @Charlie_L_Hall | Jan 5, 2021, 2:54pm EST

Source: Razorien/CCP Games

GRAPH DATA EVERYWHERE, UNPRECEDENTED SCALE

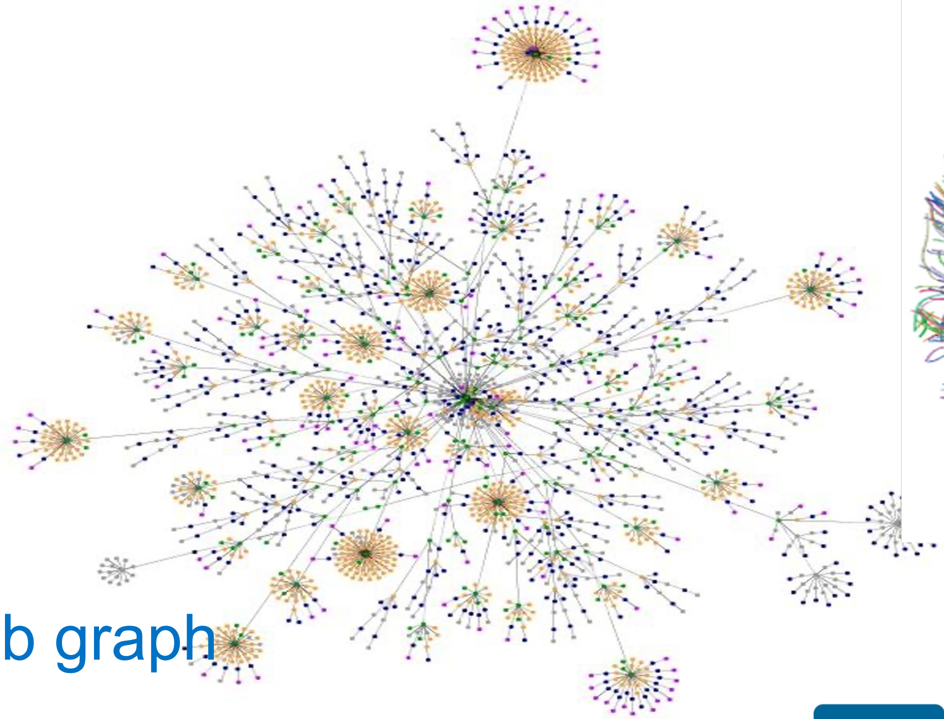


NEED TO MASSIVIZE GRAPH PROCESSING



Social / gaming network

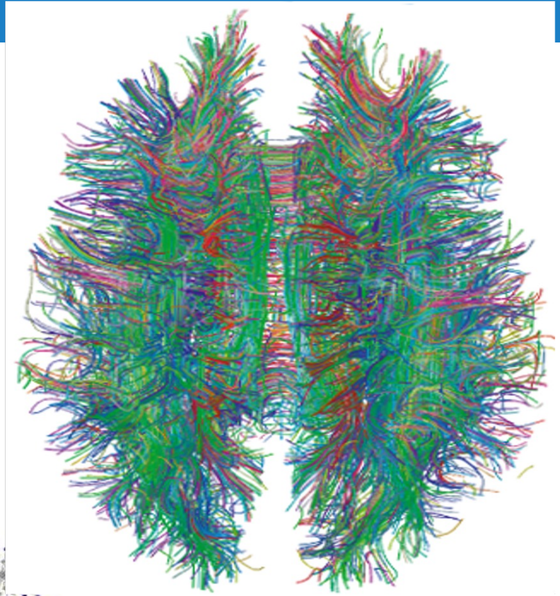
~1 billion vertices
~100 billion connections



Web graph

~50 billion pages
~1 trillion hyperlinks

LinkedIn

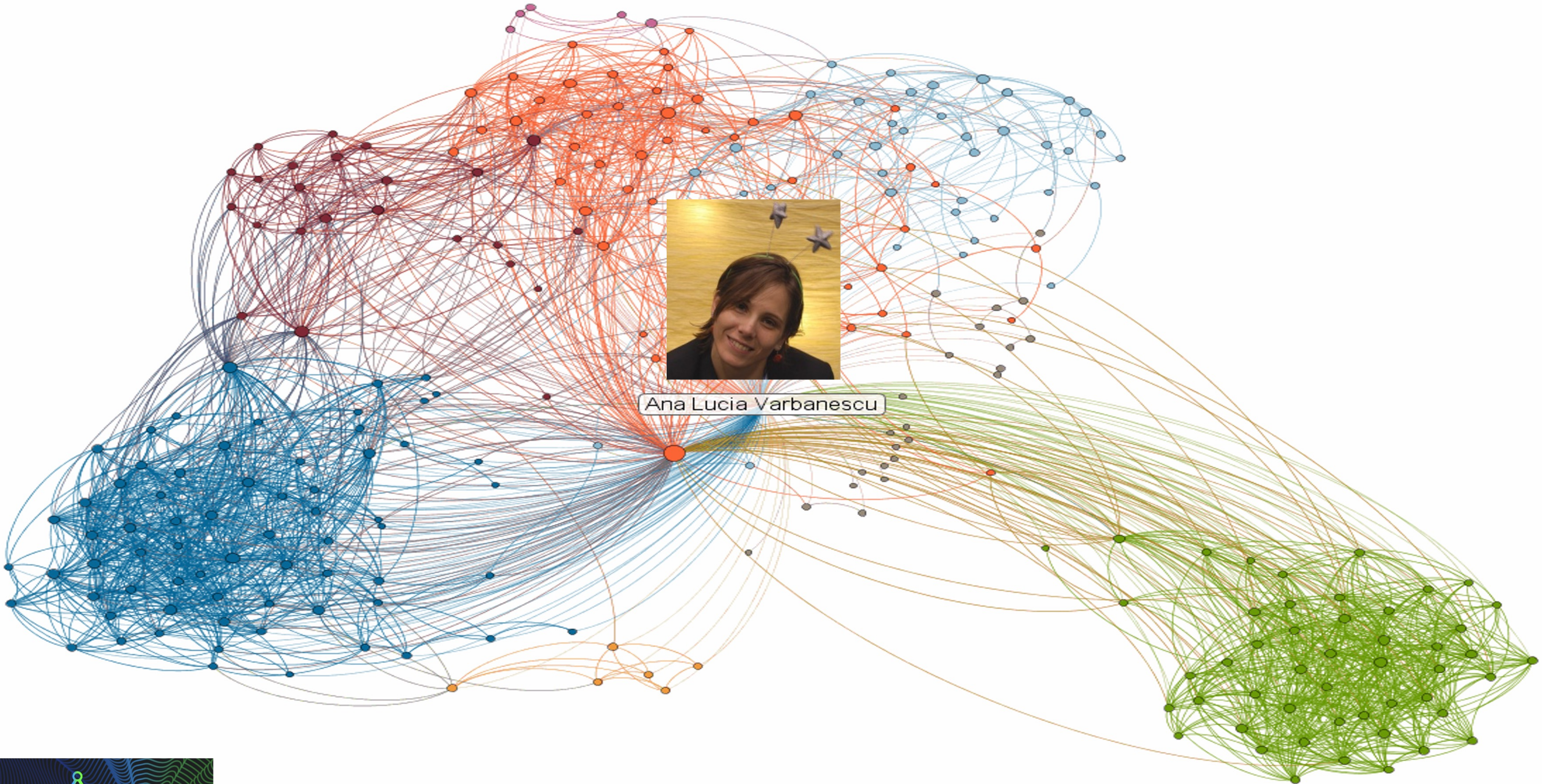


Brain network

~100 billion neurons
~100 trillion connections

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

Linked in. Maps Ana Lucia Varbanescu's Professional Network
as of November 28, 2013



PHENOMENON: PERFORMANCE IN CLOUD SERVICES

UNCOVERING THE PRESENCE OF PERFORMANCE ISSUES, EVEN LEADING TO CRASHES

Feature discontinued!

GRAPH MASSIVIZER

IN THIS TALK: INTRO TO THE DIGITAL / COMPUTING / EDGE-CLOUD CONTINUUM

(What do we need in CompSys infrastructure for the 21st century)

3

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

DOI:10.1145/3434642

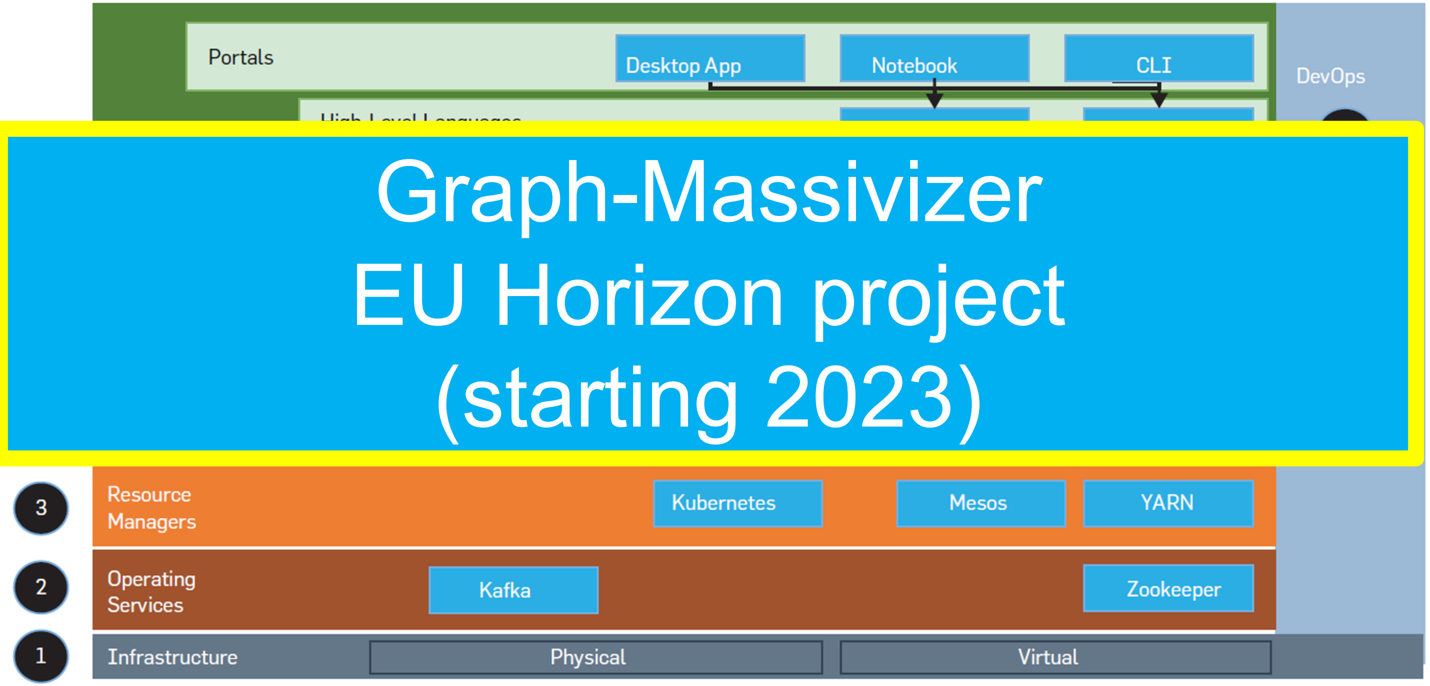
Ensuring the success of big graph processing for the next decade and beyond.

BY SHERIF SAKR, ANGELA BONIFATI, HANNES VOIGT, AND ALEXANDRU IOSUP

The Future Is Big Graphs: A Community View on Graph Processing Systems

GRAPHS ARE, BY nature, 'unifying abstractions' that can leverage interconnectedness to represent, explore, predict, and explain real- and digital-world phenomena. Although real users and consumers of graph instances and graph workloads understand these abstractions, future problems will require new abstractions and systems. What needs to happen in the next decade for big graph processing to continue to succeed?

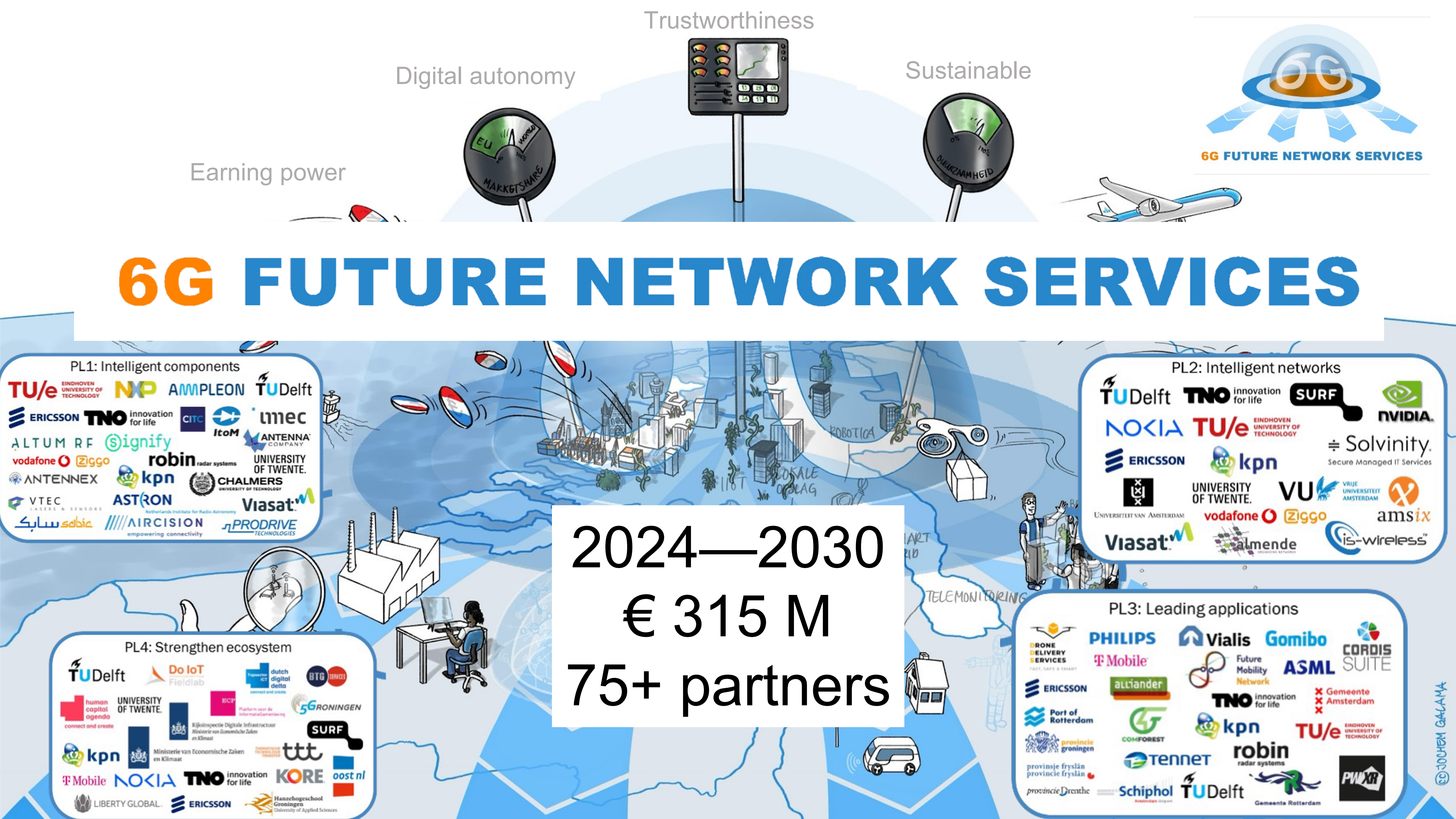
CACM Cover/Featured article, Sep 2021



Graph-Massivizer
EU Horizon project
(starting 2023)

(*) Digital twin for datacenters, with partners CINECA, UniBo, etc.

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


Trustworthiness
Digital autonomy
Sustainable
Earning power
6G FUTURE NETWORK SERVICES
EU
MARKTSHARE
DUURZAAMHEID
6G FUTURE NETWORK SERVICES
PL1: Intelligent components
PL2: Intelligent networks
2024—2030
€ 315 M
75+ partners
PL4: Strengthen ecosystem
PL3: Leading applications
ROBOTICA
LOKALE OPSLAG
TELEMONITORING

Objectives AND kEY TECHNOLOGIES FOR A 6g DevOps PLATFORM & DIGITAL TWIN

Phase 1: 2024–mid-2026

Reduce complexity for app providers and network operators through a comprehensive DevOps platform, including a 6G Digital Twin.

Toolchains for app providers → D2.2.2 6G DevOps Platform → Demonstrator

- T2.2.1 6G-ready app development
  Developing front- and back-end services for event-driven serverless and data-streaming workflow apps
- T2.2.2 Declarative app deployment and operation
  Developing software components and pipelines for declarative app deployment and operation
- T2.2.3 App testing and life-cycle management
  Defining, benchmarking, and facilitating apps, and providing concrete evidence of operational performance

Toolchains for network operators → D2.2.1 6G Digital Twin → Demonstrator

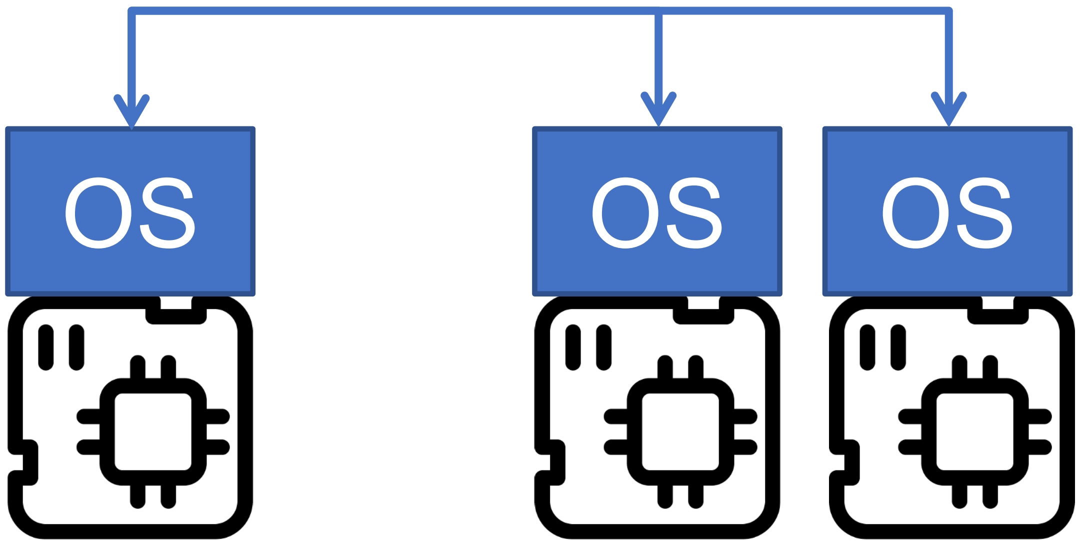
- *T2.2.4 Models & simulation for a 6G Digital Twin*
  Digital twinning of full-stack 6G networks, linked to telemetry from WP2.3
- *T2.2.5 Intent-based networking & explainability*
  Leveraging Intent-Based Networking to instruct and interact with AI-driven network
- *T2.2.6 Resilient & secure network evolution*
  Managing and evolving resources to respond to long-term needs, recover from disasters, etc.

Message 4

A new way of thinking about continuum systems

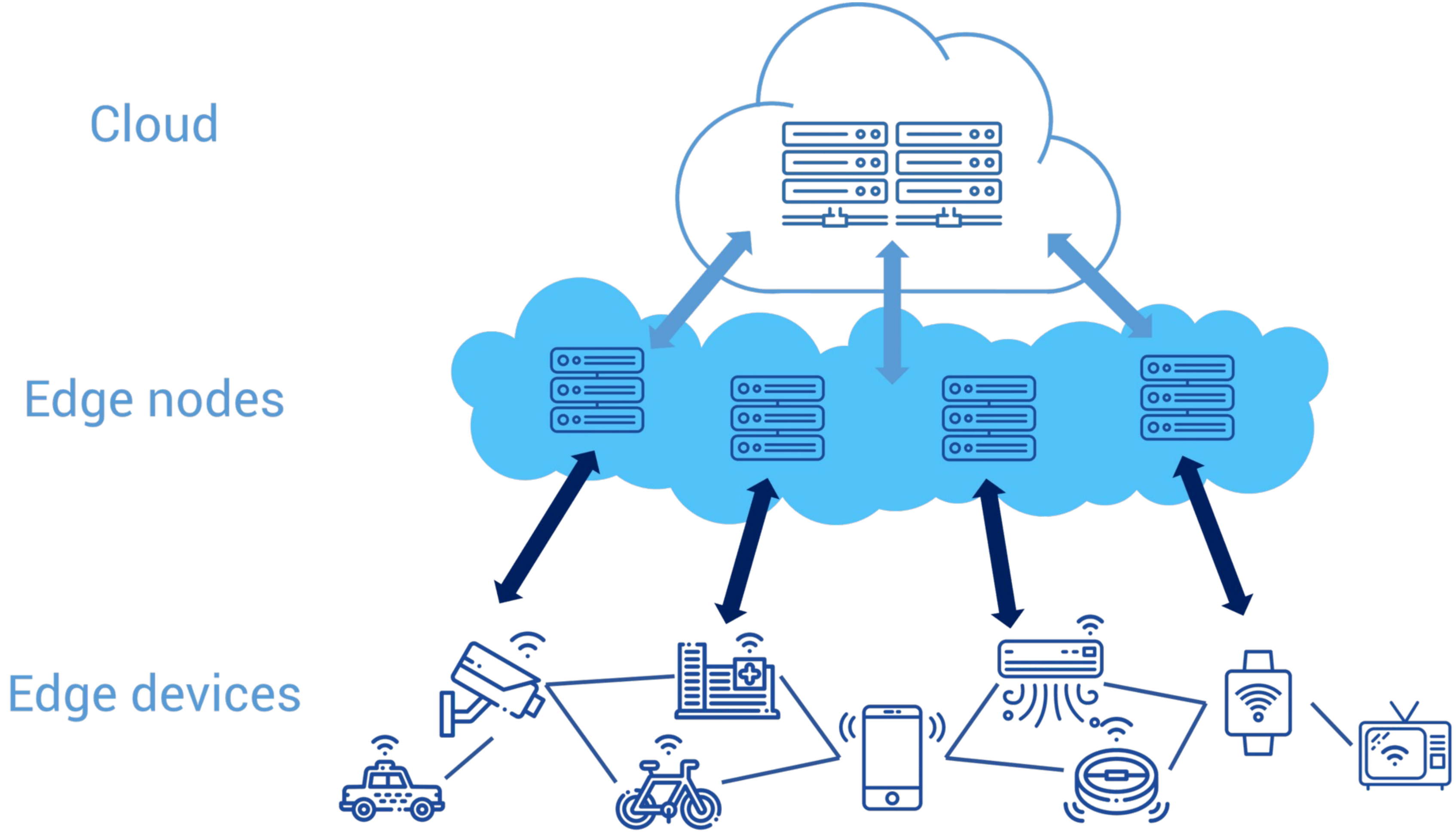
Traditional system models in computing

- System and the systems view
- **Computer network**
- Operating system
- **Computer system**
  (from CO course)



How well do previous system models match this?

Computing continuum (over)view

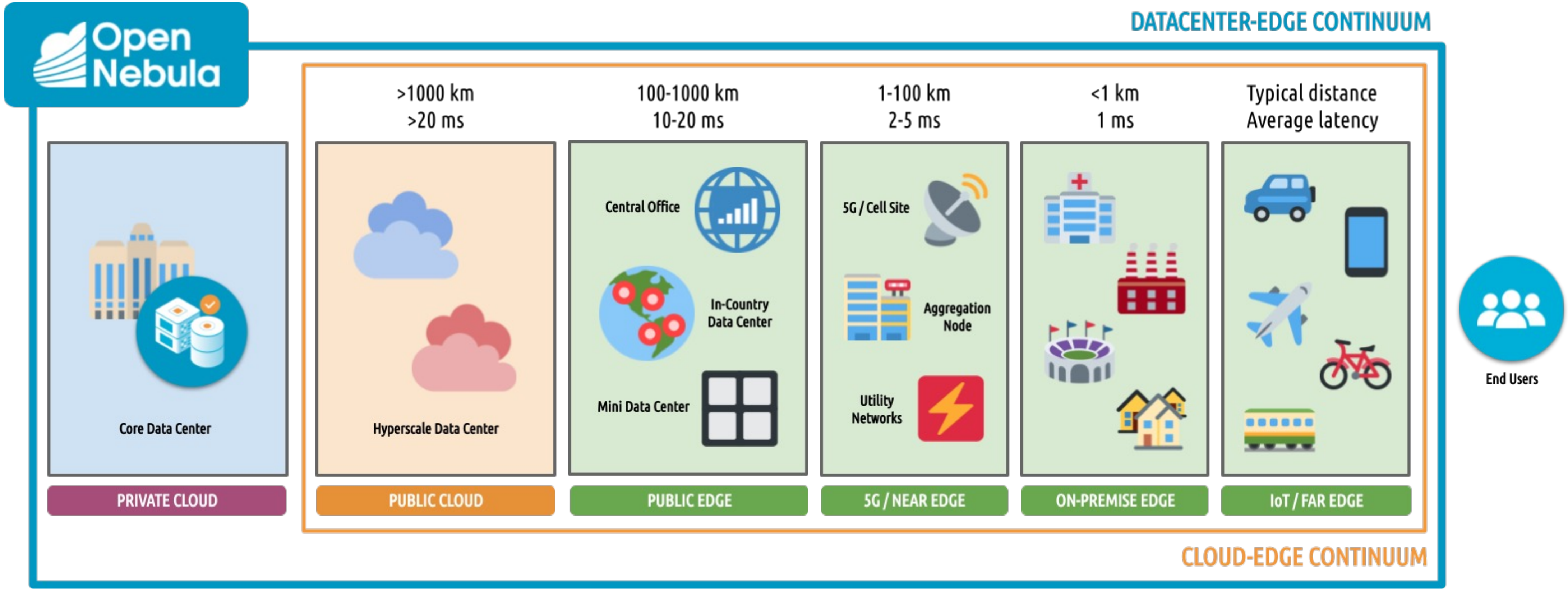


Slide by Ana-Lucia Varbanescu

https://futuresoftech.com/edge-computing-101/

How well do previous system models match this?

Computing continuum (over)view



Slide by Ana-Lucia Varbanescu

https://opennebula.io/blog/experiences/building-an-open-source-edge-computing-platform/

Distributed Systems

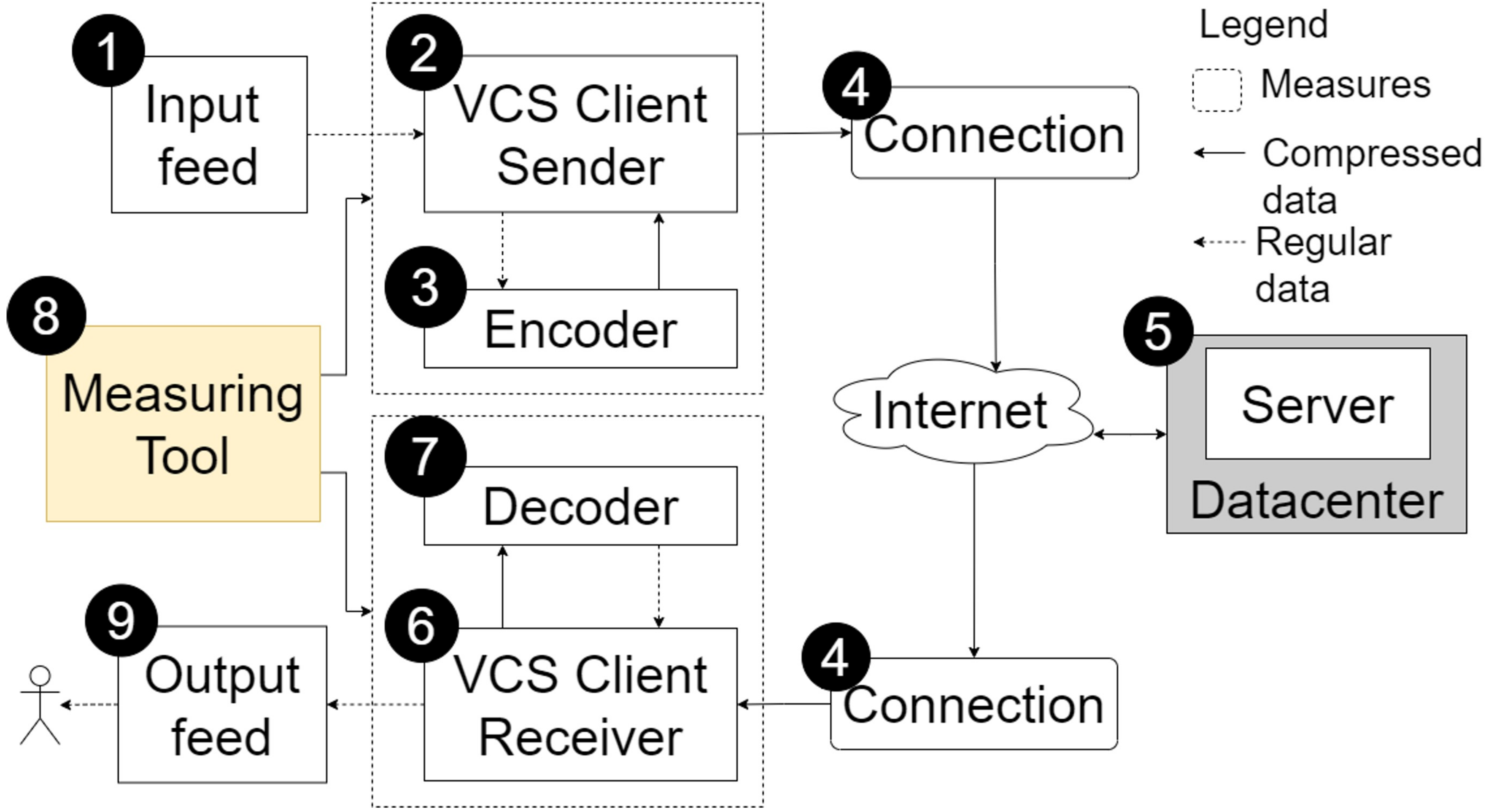
4.1

What is a Distributed System? Our definition

1. Group of 2+ constituents, often homogeneous
2. Physically distributed → network to communicate
3. Constituents orchestrate their actions, may be autonomous
4. System structure and organization ensure responsibility
    1. Completing functions or services
    2. Providing desirable non-functional properties
    3. Possibly subject to Service Level Agreements / Objectives
5. Long and short-term dynamics occur in the system

Continuum matched by distributed system models?

Model for Video Conferencing Systems



Cuijpers, Elsendoorn, Tjon-Joek-Tjien, Iesari, Casenove, Donkervliet, Iosup (2021) An Empirical Evaluation of Video Conferencing Systems Used in Industry, Academia, and Entertainment. ICPEW 2021

Distributed Ecosystems (in the Continuum)

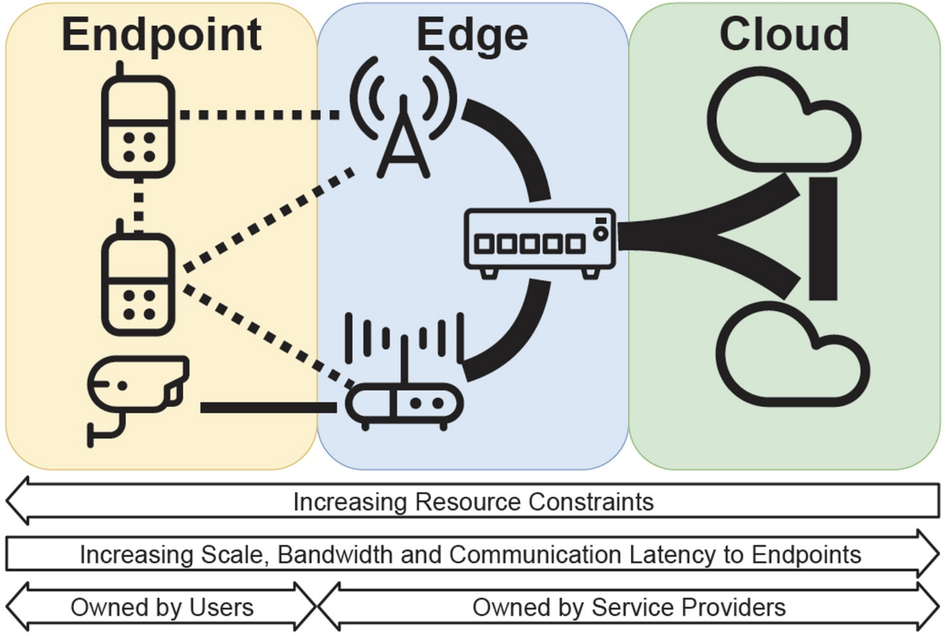
4.2

What is a Distributed Ecosystem? Our definition

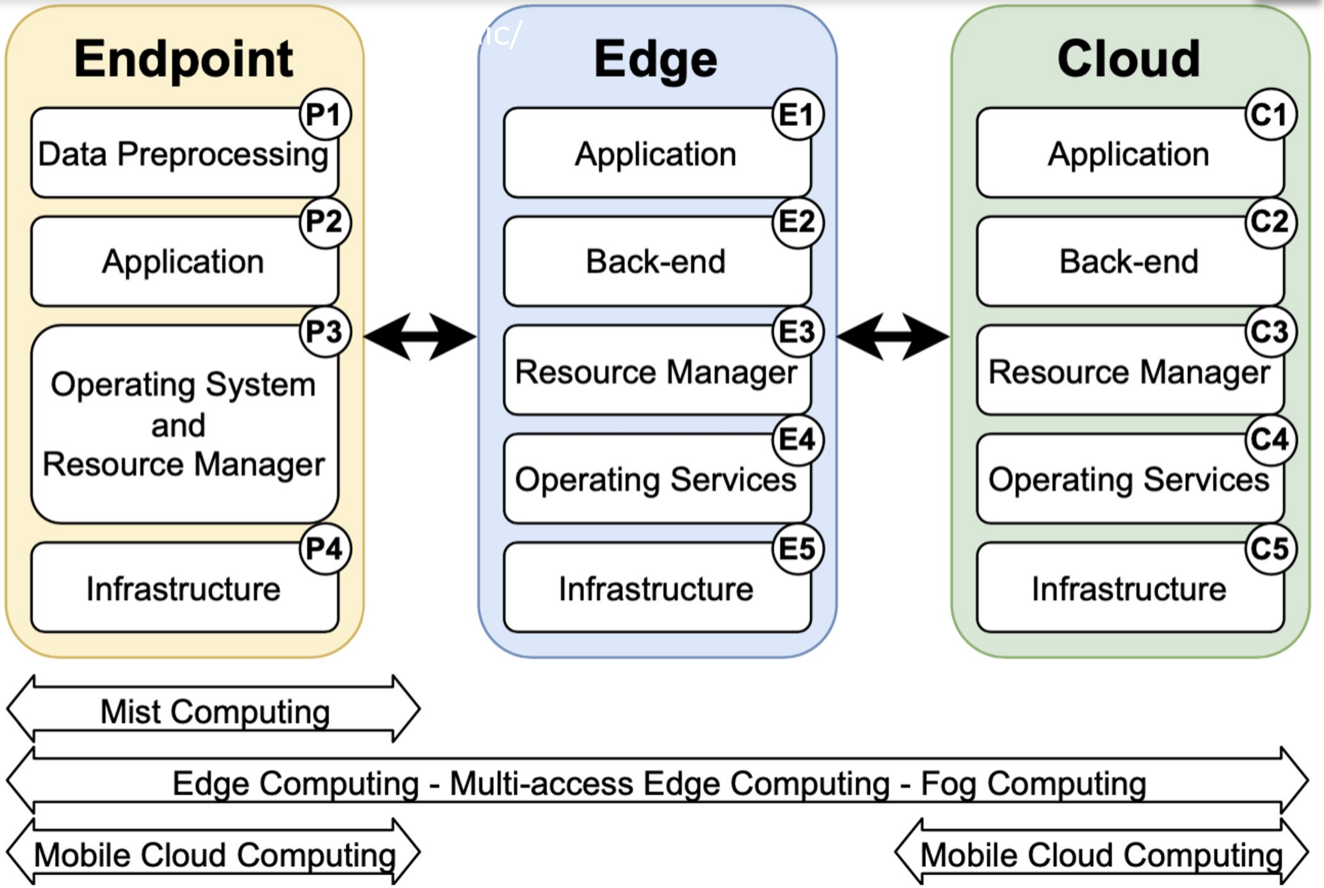
1. Set of 2+ constituents, often heterogeneous
2. Each constituent is a system or an ecosystem (recursively)
3. Constituents are autonomous, cooperative or in competition
4. Ecosystem structure and organization ensure responsibility
    1. Completing functions
    2. Providing desirable non-functional properties
    3. Fulfill agreements with both operators and clients, clients in the loop
5. Long and short-term dynamics occur in the ecosystem

Iosup et al., Massivizing Computer Systems, ICDCS 2018. [Online]

CONTINUUM RESOURCES & SERVICES



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



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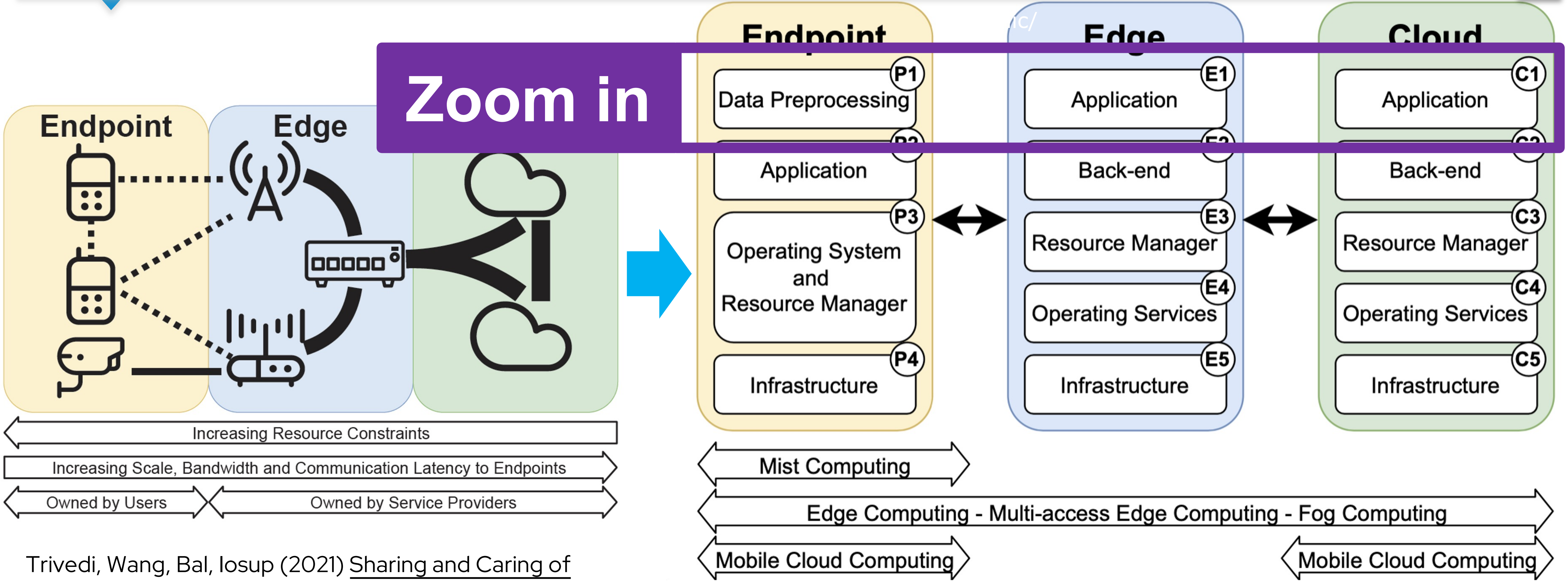
CONTINUUM RESOURCES & SERVICES



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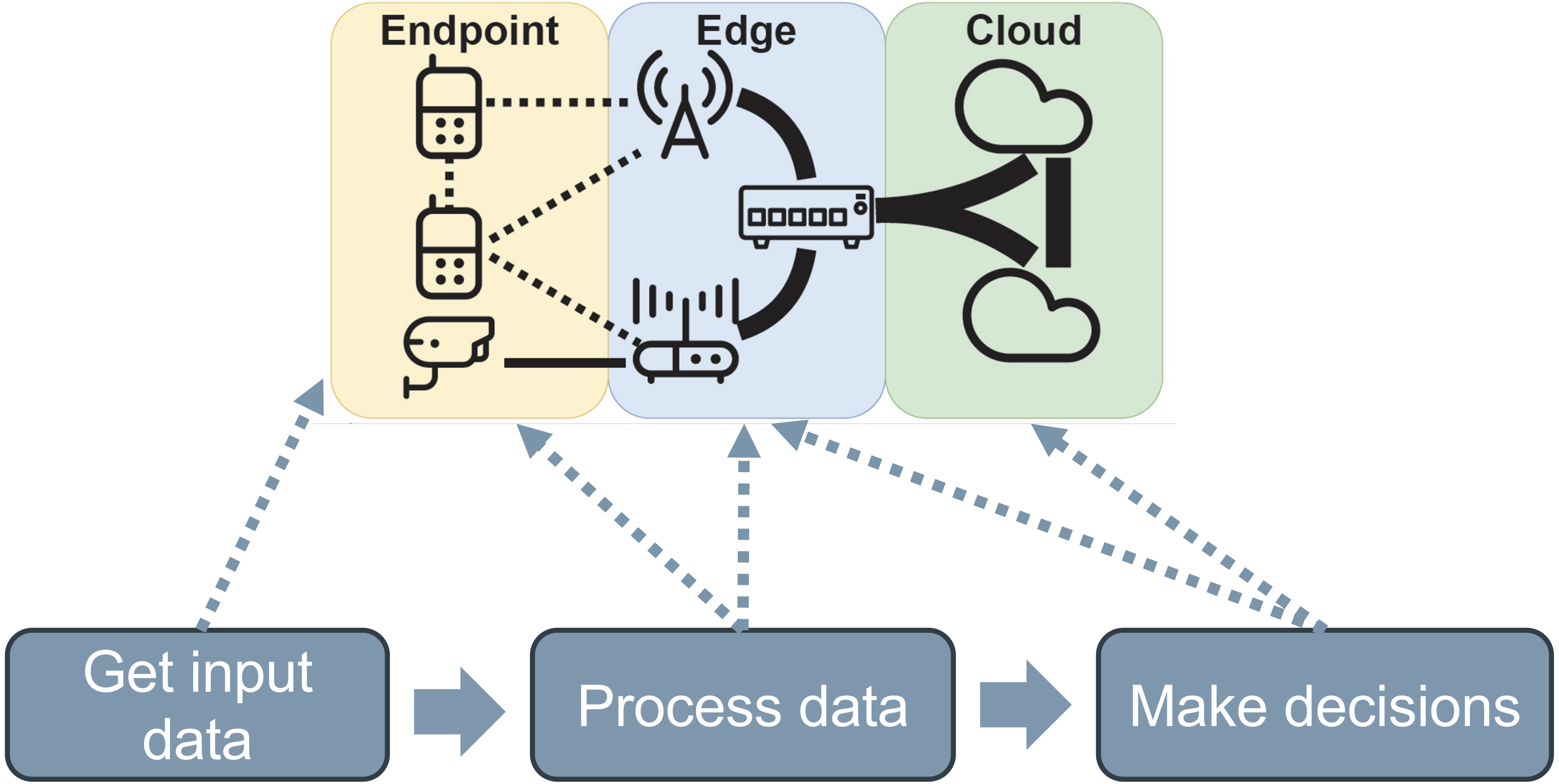
APPLICATIONS IN THE CONTINUUM

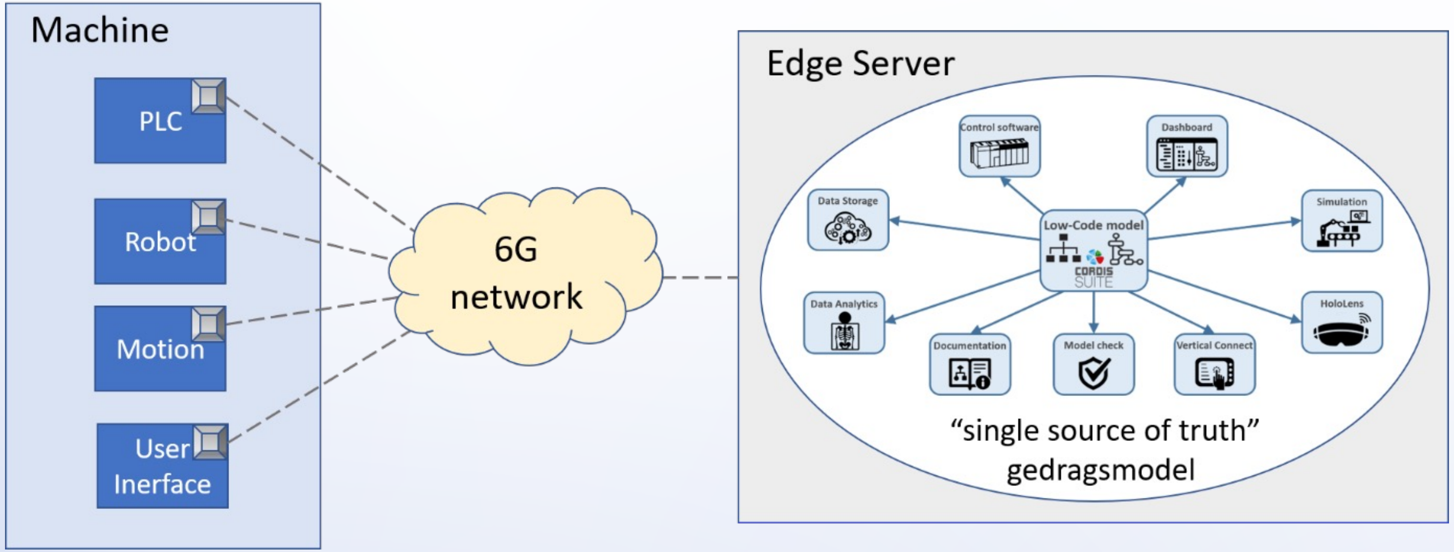


Slide by Ana-Lucia Varbanescu

6G wireless factory: wire & connector removal within machine

Source: TNO/PL3

6G “eSIM capable embedded module”



6G Requirements

- < 1 ms for motion control
- Sensor fusion & actuator control on edge
  TR 22.804 & 3GPP SA1 S1-212056r6
- Raw data > 20 Gbps
- Deterministic network
- Flexible coverage (extension)

Benefit usecases

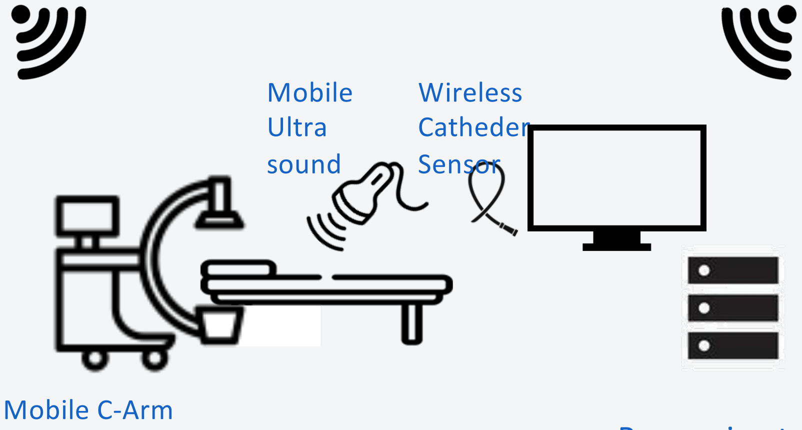
- Realtime firmware update to achieve new efficiencies
- RAW data to identify new efficiencies with AI
- XR visualization for maintenance

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY
HIGH TECH SOFTWARE CLUSTER
CORDIS SUITE
kpn
ASML
FNS 6G

Image-guided therapy:

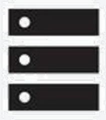
Source: TNO/PL3

Operating theater



Processing to at least guarantee safe termination of procedure

Stringent network latency budget, as budget is dedicated to image quality (for productivity & operating safety)



Full fledged Applications
3D rendering
Supporting software tools
(Integration of applications in different clouds)

6G Requirement

- Bound latency budget 1 ms
- Packet loss / jitter is predictable
- Support advanced 3D video rendering in the edge
- Peakrate > 20 gbps raw data (for studio setup allowing more realtime / AI manipulation)

Benefits

- Support for specialized medical centers (no IT staff)
- Advanced tooling over the lifecycle to improve productivity
- Less on prem. Upgrades during the lifecycle

TNO PHILIPS ERICSSON FNS 6G

Active E-Sports

Source: TNO/PL3

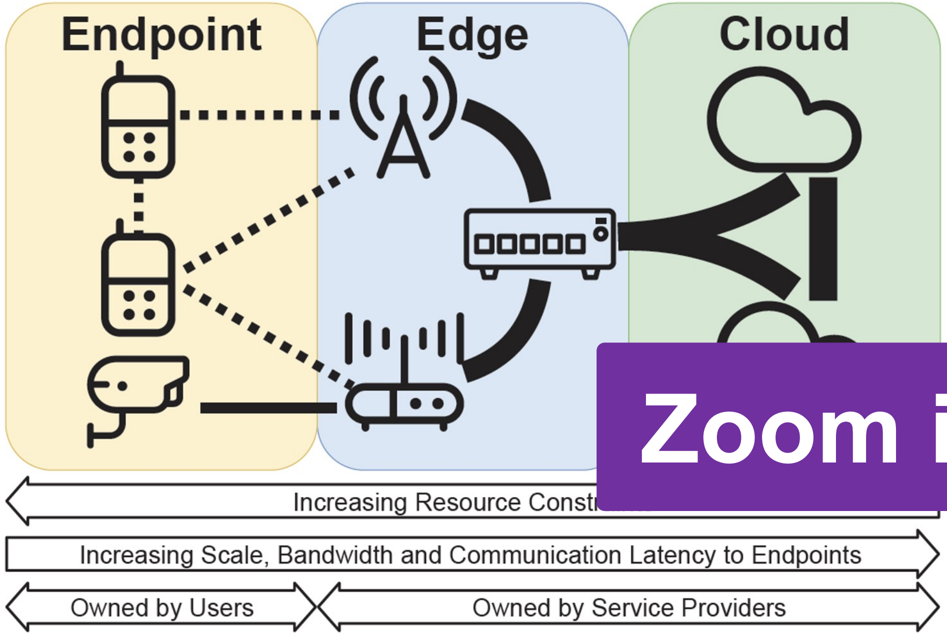
6G Requirement

- Density low latency capacity - 12 Camera's – 1 GBps
- Processing in the (edge) cloud for multi-geo-player
- Peakrate > 20 gbps raw data (for studio setup allowing more realtime / AI manipulation)

Benefits

- Low & fast setup costs ad hoc e-sports allowing entry mass market (as a service)
- Low setup costs advanced studio setup

CONTINUUM RESOURCES & SERVICES



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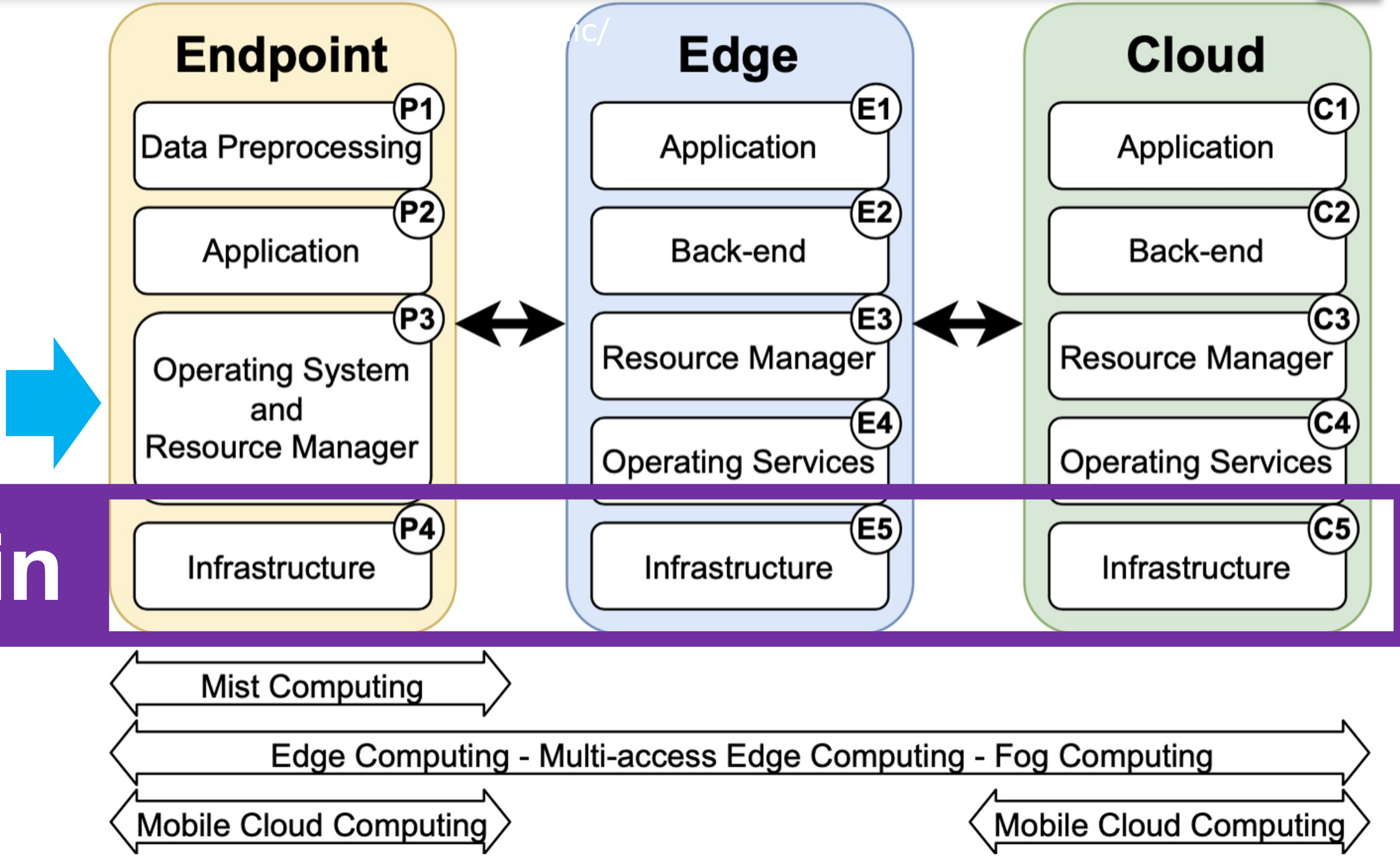
Zoom in



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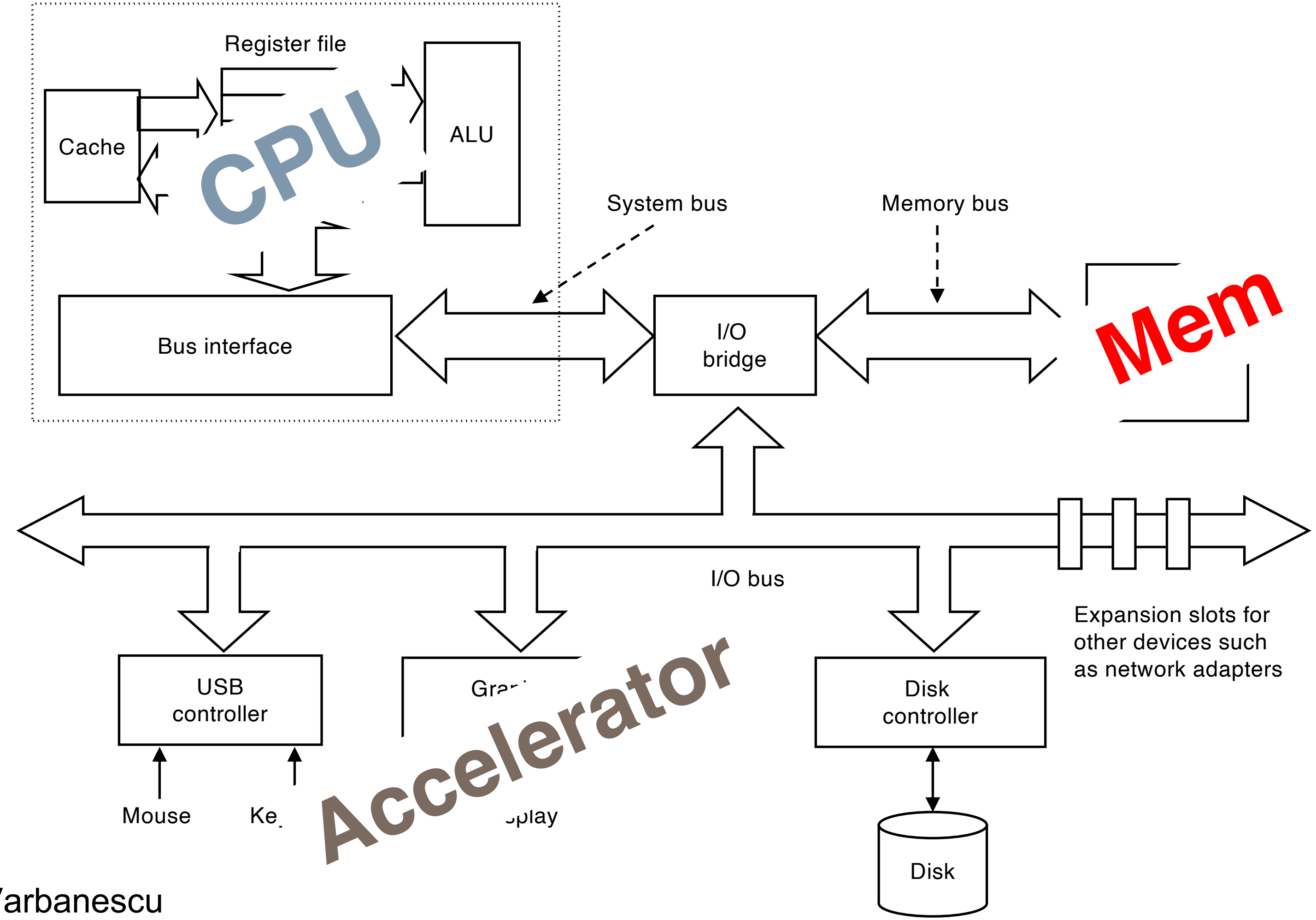
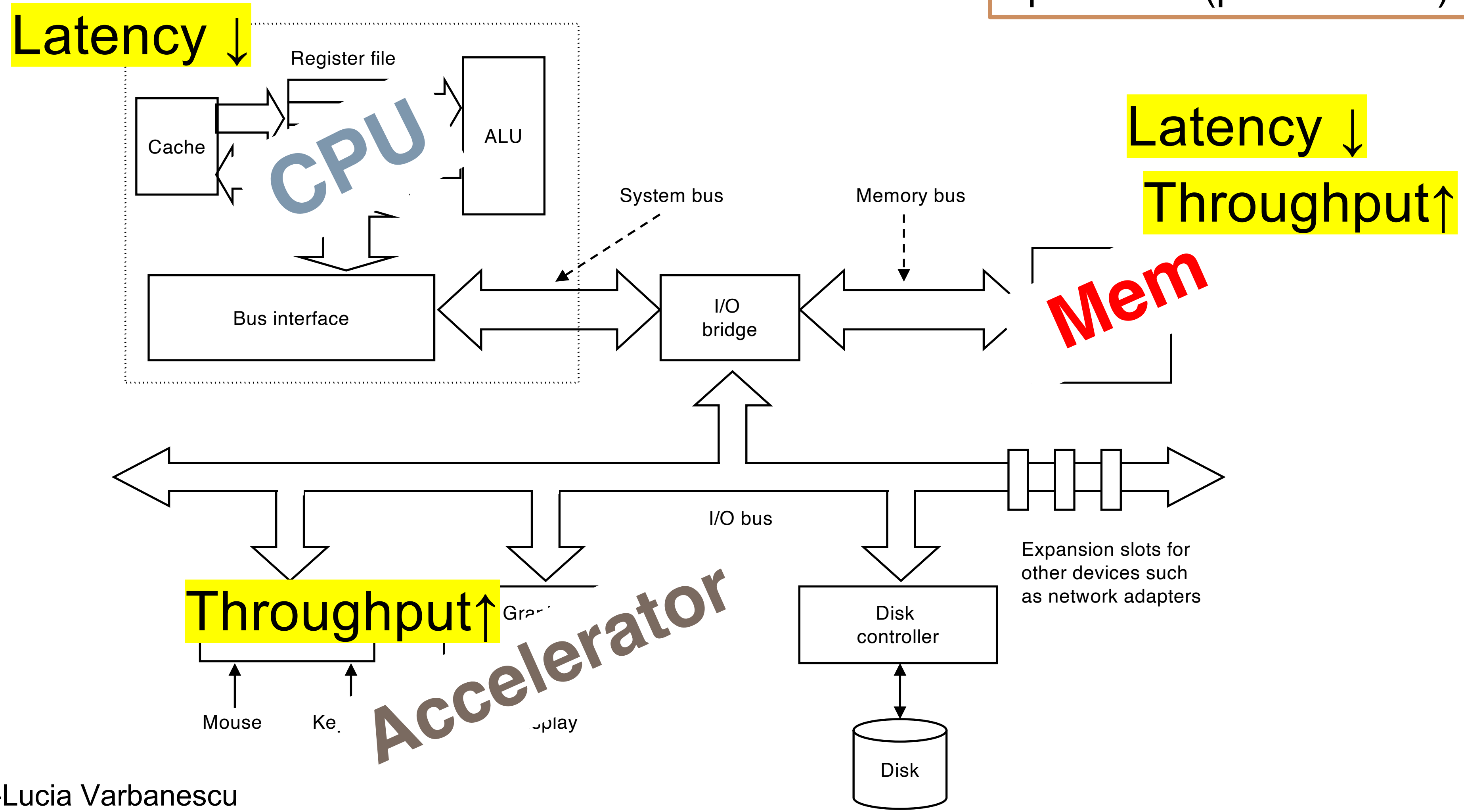
Basic computing system



Slide by Ana-Lucia Varbanescu

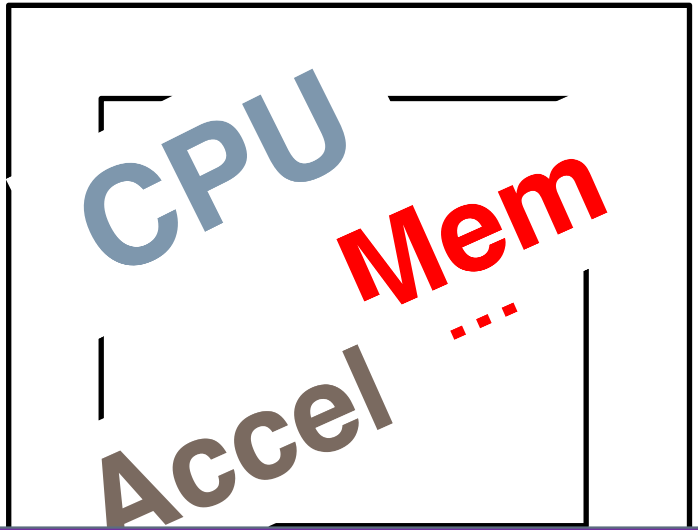
Basic computing system

Latency – time per operation
Throughput – volume of operations (per time unit)

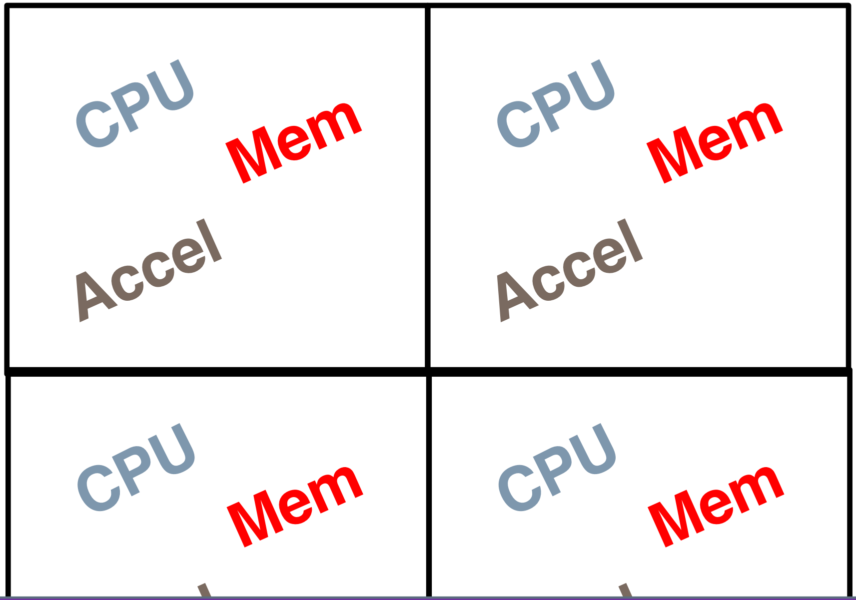


Slide by Ana-Lucia Varbanescu

Bigger & more computers …



vs.



Which one is best?

Scale-up (vertical scaling)
Bigger machine

Scale-out (horizontal scaling)
More machines

Slide by Ana-Lucia Varbanescu

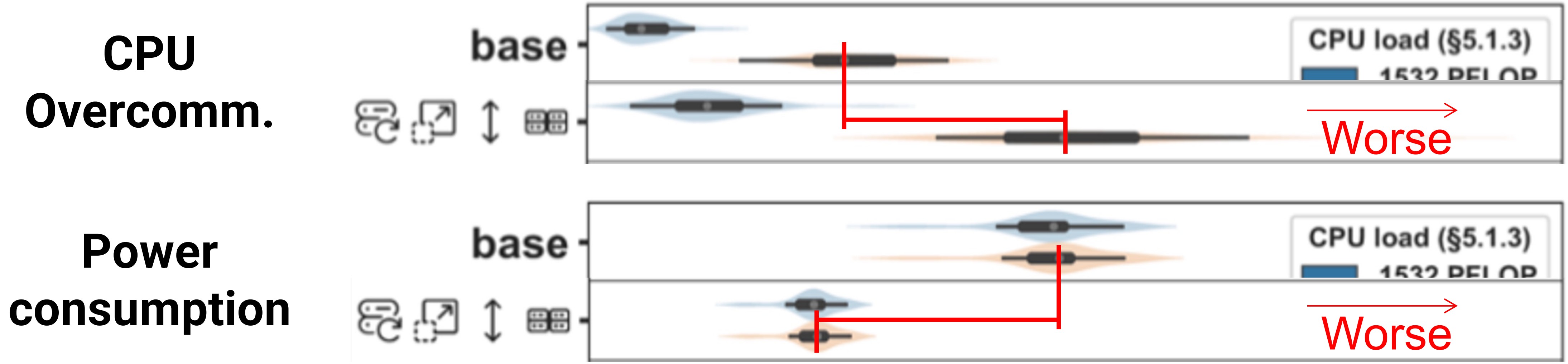
A Multi-Metric View of Datacenter Operations

Requested CPU cycles	Failed VM time slices	Total submitted VMs
Granted CPU cycles	Mean CPU usage	Max. num. queued VMs
Overcommitted CPU cycles (throughput metric)	Mean CPU demand	Total finished VMs
Interfered CPU cycles	Mean num. VM per host	Total failed VMs
Power consumption (responsibility/cost metric)	Max. num. VM. per host	

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

Andreadis et al. (2022) Capelin: Data-Driven Capacity Procurement for Cloud Datacenters using Portfolios of Scenarios. IEEE TPDS 33(1).

Example: Horizontal vs. Vertical Scaling
Multi-objective optimization, no overall best



1. Capelin enables complex **trade-off exploration**
2. Vertical scaling: **power** vs. **performance**

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

From large to small …

1. HPC clusters = supercomputers
2. Servers/Clusters = data-centers
3. Many-core = Accelerators = GPUs and alikes
4. Multi-core = CPUs
5. Co-processors = heterogeneous CPUs
6. Single-core = ILP, SIMD
7. Mix-and-match of the above = FPGA
8. Dedicated HW = ASIC

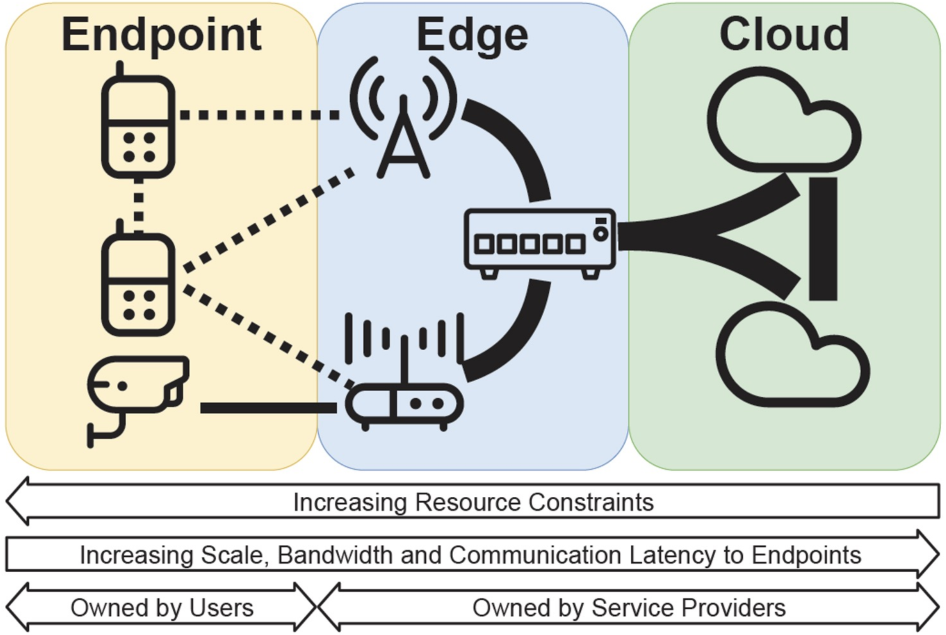
Cloud/Data-center

Edge

End-point

CONTINUUM RESOURCES & SERVICES

Zoom in



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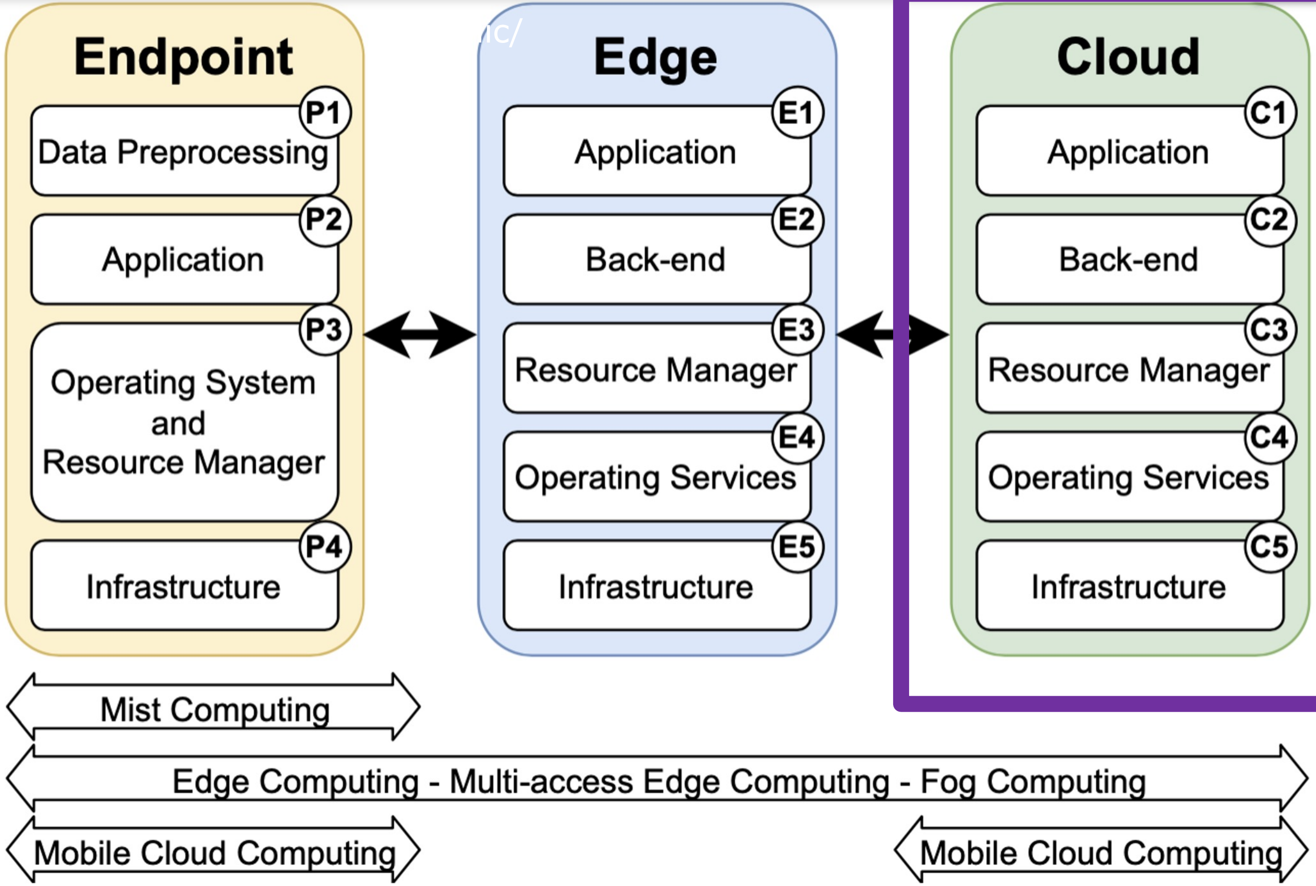

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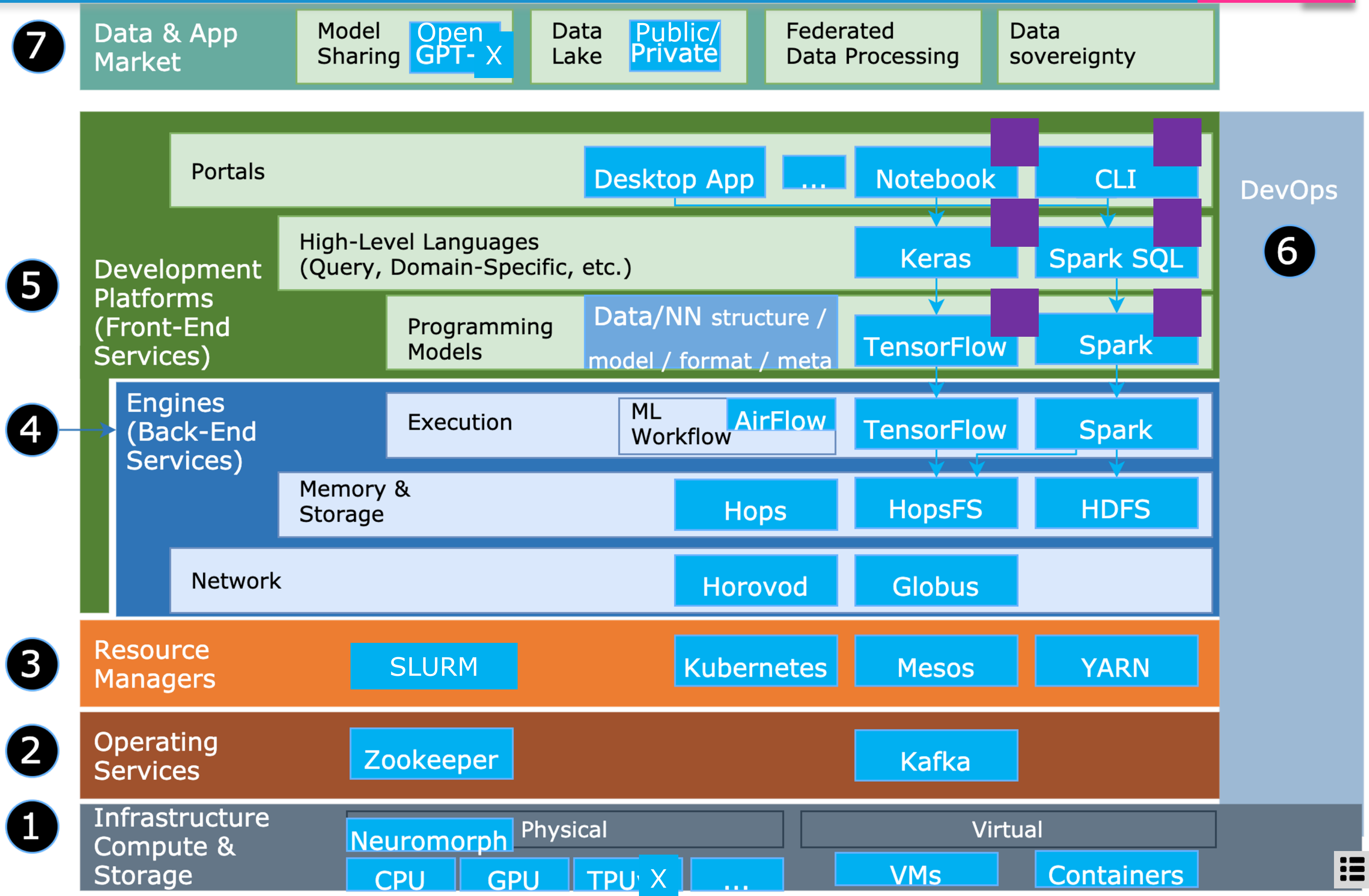
ONE SYSTEM MODEL: FITS AI/ML, BIG DATA, SCIENTIFIC, ENGINEERING, BUSINESS CRITICAL, ONLINE GAMING, OTHER APPS

^

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.

TAKE-HOME

We're building the ICT infrastructure for the the 21st century. We have many (developing) theories and practical results, and large ongoing projects. To discuss:

- Theory: What are the core components of the digital continuum? How do they relate - what is a good reference architecture for the continuum?
- Theory: Are performance and availability just parts of a conceptual continuum?
- Theory: We say: Just touch it with your lower lip, briefly, and move away if too hot. How to reason about energy use, both short- and long-term?
- Practice: How to build continuum components? How to assemble them well? How to deploy and later orchestrate them well?
- Theory/Practice: How to understand the continuum?
- Ethics: If a tree falls in front of you, do you have to see it? From plausible deniability to responsibility in ICT infrastructure management

- Etc. (Propose your own)

WANT TO READ MORE ON THE TOPIC?

MASSIVIZING COMPUTER SYSTEMS

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.
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3. Jansen et al. (2023) The SPEC-RG Reference Architecture for The Compute Continuum. CCGRID.
4. Versluis et al. (2023) Less is not more: We need rich datasets to explore. FGCS 142.
5. Crusoe et al. (2022) Methods included: standardizing computational reuse and portability with the Common Workflow Language. CACM 65(6).
6. Andreadis et al. (2022) Capelin: Data-Driven Capacity Procurement for Cloud Datacenters using Portfolios of Scenarios. IEEE TPDS 33(1).
7. Eismann et al. (2022) The State of Serverless Applications: Collection, Characterization, and Community Consensus. IEEE Trans. Software Eng. 48(10).
8. Sakr, Bonifati, Voigt, Iosup, et al. (2021) The future is big graphs: a community view on graph processing systems. Commun. ACM 64(9).
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11. Papadopoulos et al. (2021) Methodological Principles for Reproducible Performance Evaluation in Cloud Computing. IEEE Trans. Software Eng. 47(8).
12. Versluis et al. (2020) The Workflow Trace Archive: Open-Access Data From Public and Private Computing Infrastructures. IEEE TPDS 31(9).
13. 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.
14. Erwin Van Eyk, Lucian Toader, Sacheendra Talluri, Laurens Versluis, Alexandru Uta, Alexandru Iosup (2018) Serverless is More: From PaaS to Present Cloud Computing. IEEE Internet Comput. 22(5).
15. Alexandru Iosup, Tim Hegeman, Wing Lung Ngai, Stijn Heldens, Arnau Prat-Pérez, Thomas Manhardt, Hassan Chafi, Mihai Capota, Narayanan Sundaram, Michael J. Anderson, Ilie Gabriel Tanase, Yinglong Xia, Lifeng Nai, Peter A. Boncz (2016) LDBC Graphalytics: A Benchmark for Large-Scale Graph Analysis on Parallel and Distributed Platforms. Proc. VLDB Endow. 9(13).