CLOUD COMPUTING (ECO)SYSTEMS

SCIENCE, DESIGN, AND ENGINEERING

http://atlarge.science

Many thanks to our collaborators.
Many thanks to our international working groups:

LDBC The graph & RDF benchmark reference

Sponsored by:
NWO

VU VRIJE UNIVERSITEIT AMSTERDAM

bit.ly/VUCloudEcosystems

@Alosup

Prof. dr. ir. Alexandru Iosup

VU AMSTERDAM < SCHIPHOL < THE NETHERLANDS < EUROPE

Amsterdam
founded 10th century
pop: 850,000

VU
founded 1880
pop: 23,500

The Netherlands

pop: 16.5 M

Europe

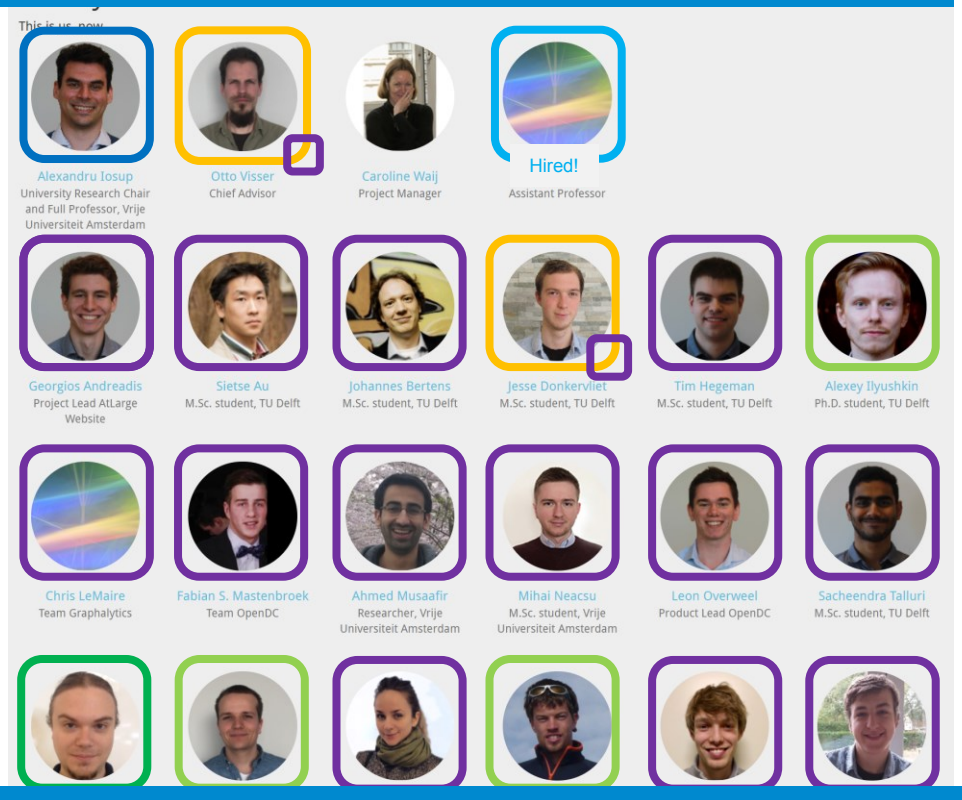
VU UNIVERSITY AMSTERDAM

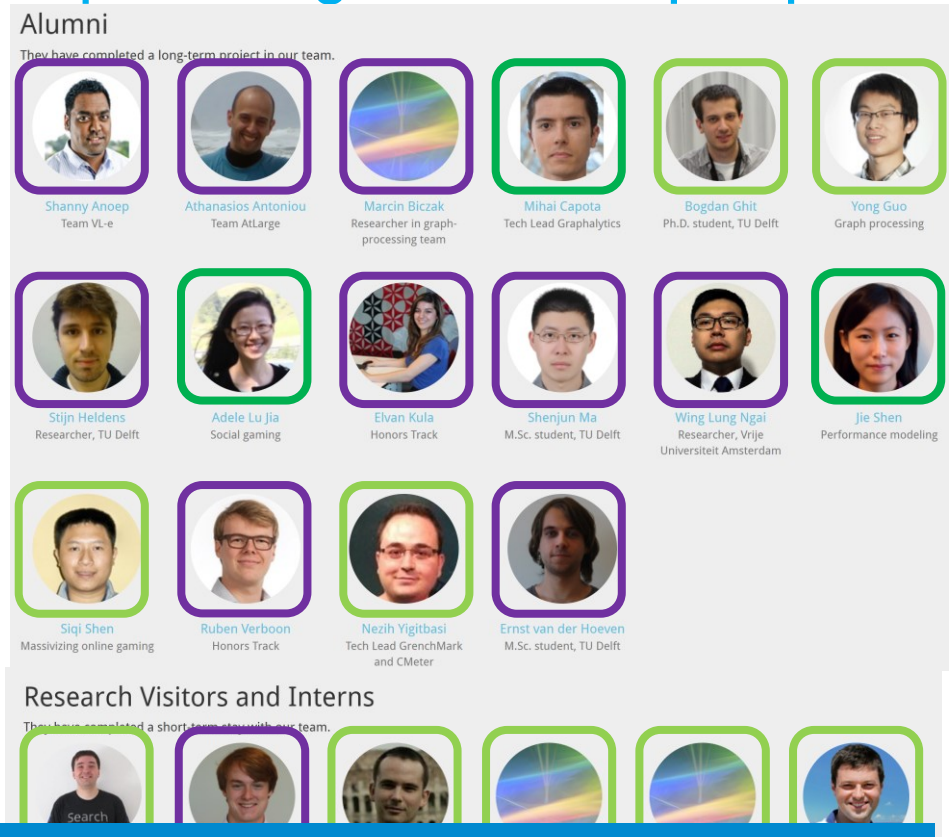
ATLARGE RESEARCH, OUR TEAM

VU VRIJE UNIVERSITEIT AMSTERDAM TU Delft

http://atlarge.science/people.html

- Professor
- Assistant Prof.
- Teacher
- Post-doc
- Ph.D. student
- Scientist





WE ARE A FRIENDLY, DIVERSE GROUP, OF DIFFERENT RACES AND ETHNICITIES, GENDERS AND SEXUAL PREFERENCES, VIEWS OF CULTURE , POLITICS, AND RELIGION. YOU ARE WELCOME TO JOIN!

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

- Education, my courses:
  - > Systems Architecture (BSc)
  - > Distributed Systems, Cloud Computing (MSc)
- Research, 15 years in DistribSys:
  - > Massivizing Computer Systems

- 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 Royal Young Academy of Arts & Sciences

VU

MASSIVIZING COMPUTER SYSTEMS: OUR MISSION

1. Improve the lives of millions through impactful research.

2. Educate the new generation of top-quality, socially responsible professionals.

3. Make innovation available to society and industry.

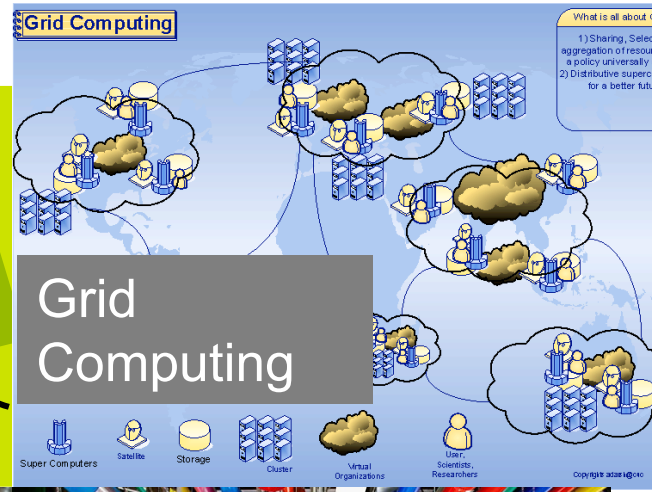
VU VRIJE UNIVERSITEIT AMSTERDAM

http://atlarge.science/about.html

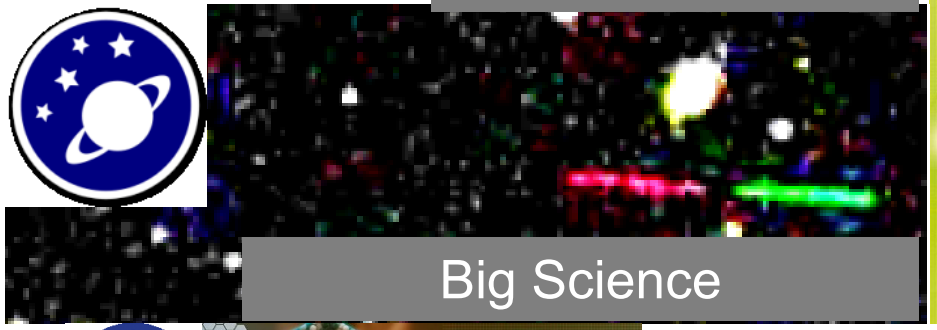
THIS IS THE GOLDEN AGE OF CLOUD SYSTEMS AND ECOSYSTEMS

Education for Everyone (Online)

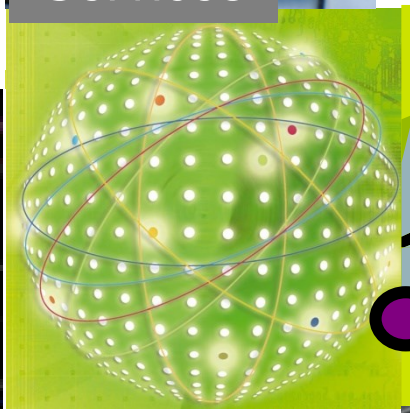
Business Services

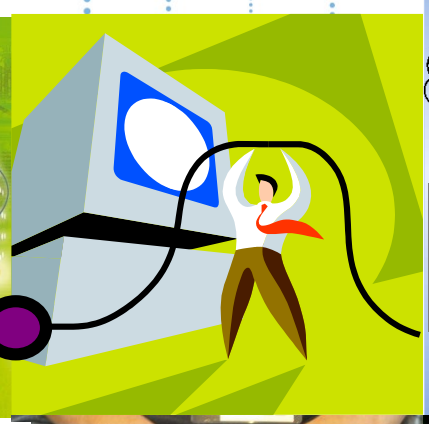


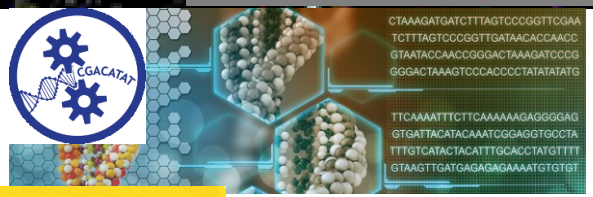
Grid Computing



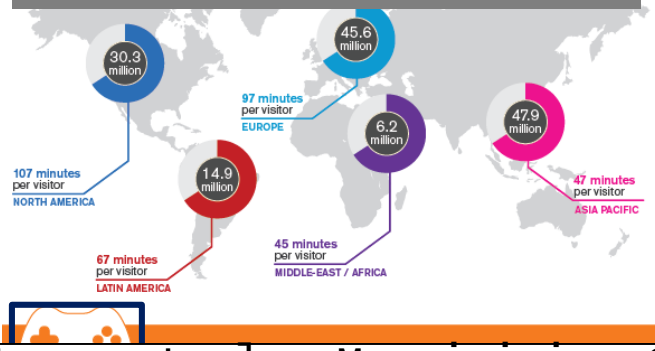
Big Science







Online Gaming



Datacenters

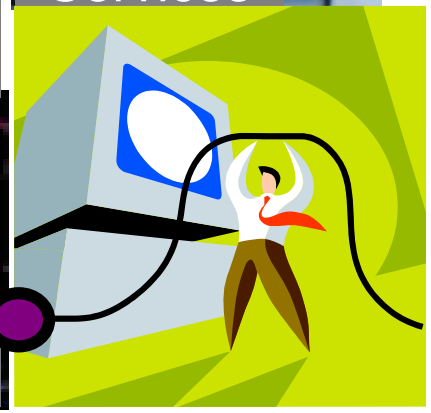
Daily Life

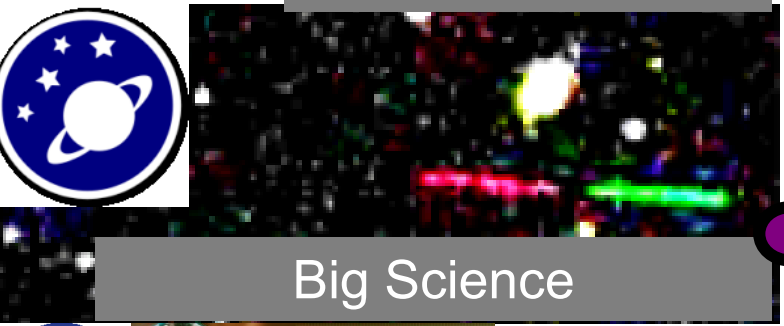
Iosup et al., Massivizing Computer Systems, ICDCS 2018. [Online]

ONCE UPON A TIME … THE DAWN OF THE CLOUD

Education for Everyone (Online)

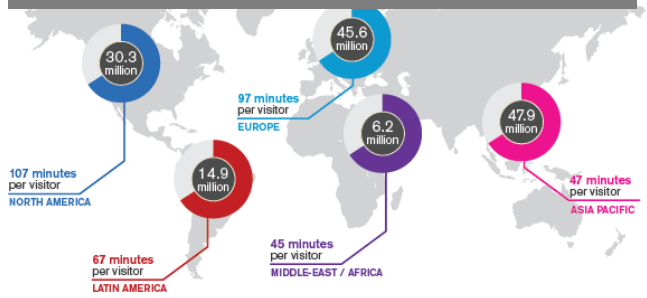
Business Services





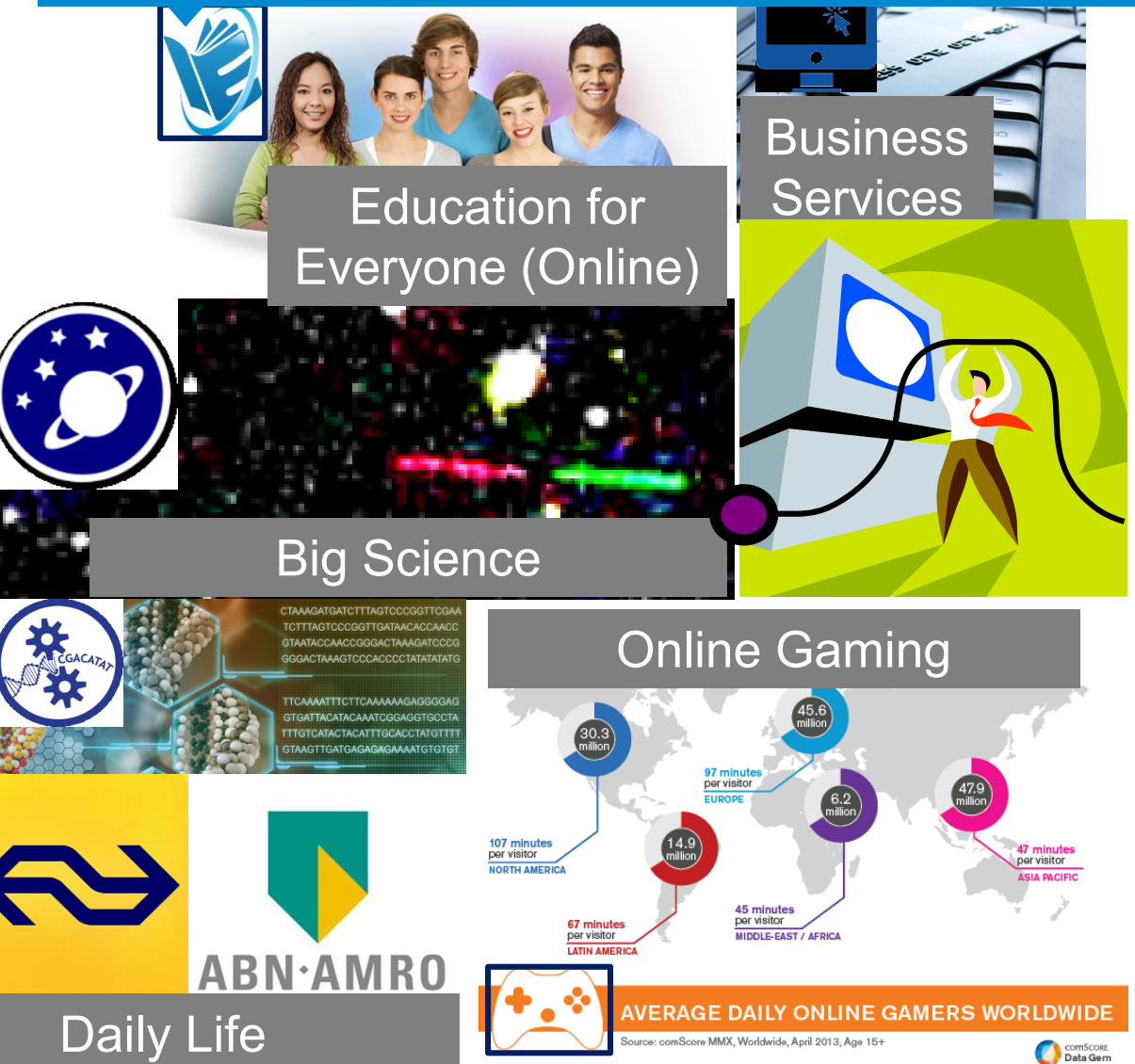
Big Science

Online Gaming



Daily Life

ONCE UPON A TIME … THE DAWN OF THE CLOUD (1960s)



MIT Prof. Martin Greenberger:

“ Computing services and establishments will begin to spread throughout every life-sector

[…] medical-information systems,

[…] centralized traffic control,

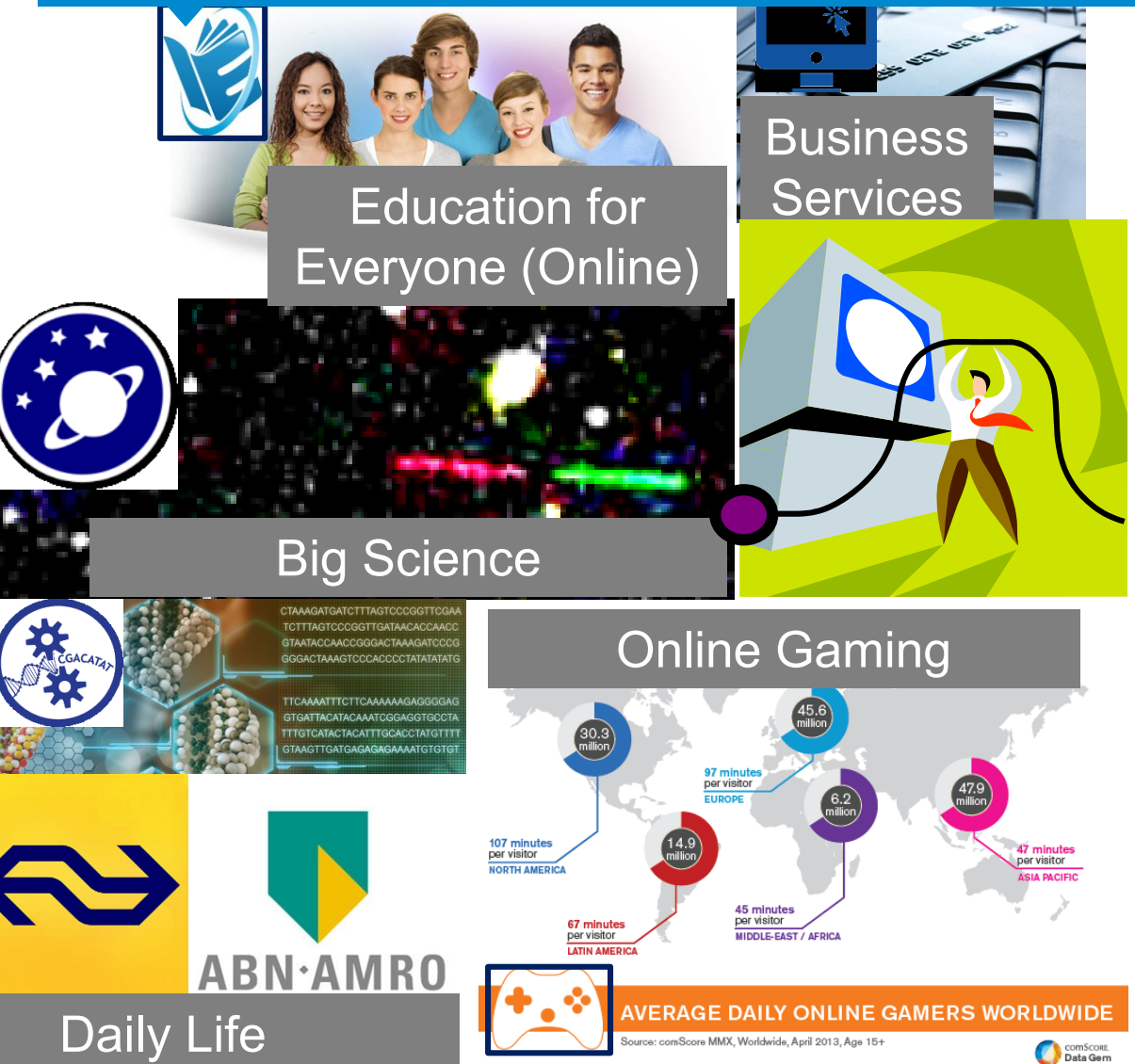
[…] catalogue shopping from […] home,

[…] integrated management-control systems for companies and factories

[…] ”

M. Greenberger (**1964**) The Computers of Tomorrow The Atlantic Monthly. Vol. 213(5), pp. 63-67, May.

ONCE UPON A TIME … THE DAWN OF THE CLOUD **(1960s)**



Data Processing ~ SaaS
IBM-Service Bureau Corp.(SBC)

Software/System Dev.~ PaaS
Computer Sciences Corp. (CSC)

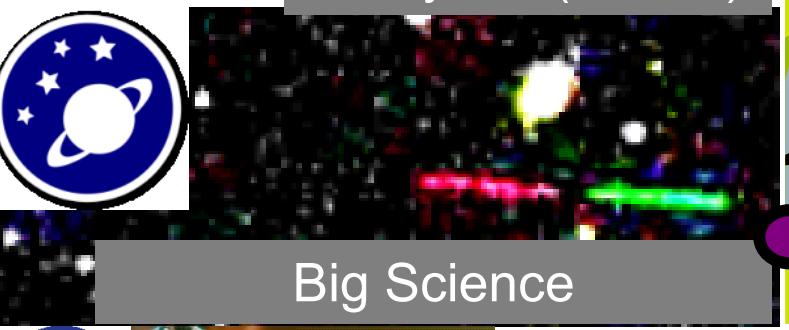
Time Sharing ~ IaaS
IBM-SBC, Tymshare, GE Inf.Serv. (GEIS)

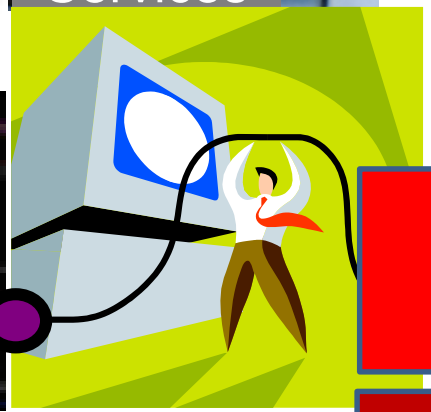
Facility management ~ IaaS
Electronic Data Systems (EDS)

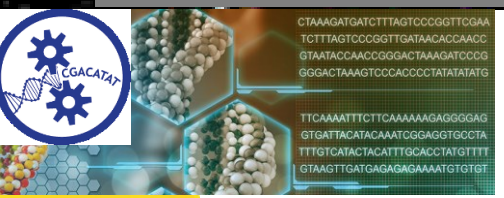
Other Services
IBM

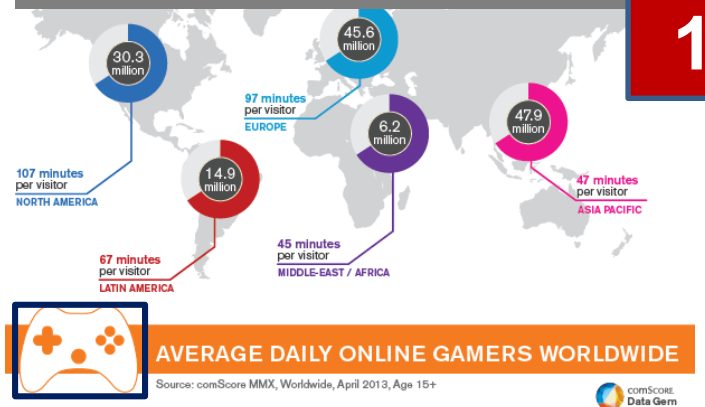
Source: J. R. Yost (2017) Making IT Work.

ONCE UPON A TIME … THE DAWN OF THE CLOUD (1970s)









Time Sharing ~ IaaS
GEIS invests in a large network
Tymshare invests in Tymnet
IBM invests in CALL 360

Technology **not ready**	Emergence of **the PC**
Slowdown: **1970 recession**	DoJ anti-trust **lawsuit vs. IBM**

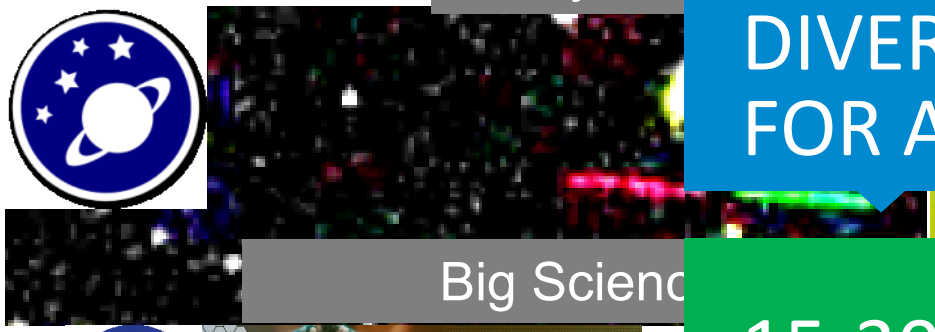
Source: J. R. Yost (2017) Making IT Work.

THIS IS THE GOLDEN AGE OF CLOUD COMPUTING (2010S)

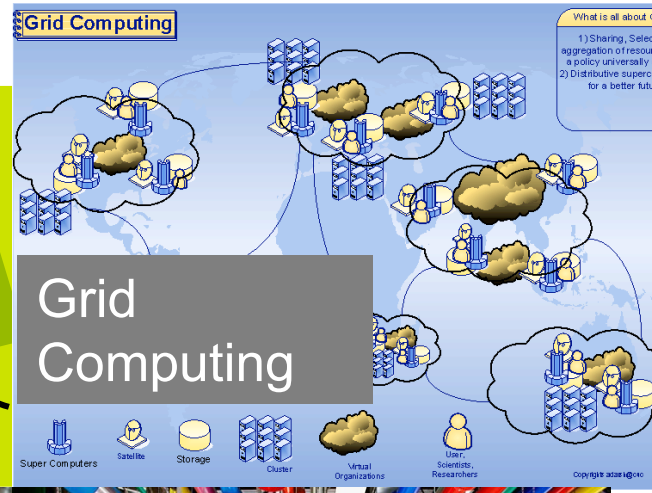
Education for Everyone (Online)

Business Services

DIVERSE CLOUD SERVICES FOR ALL

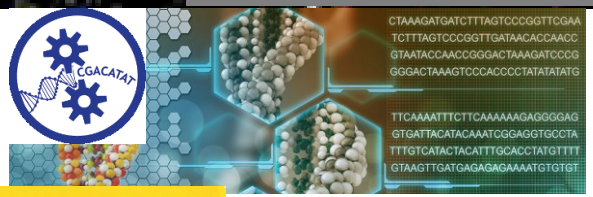


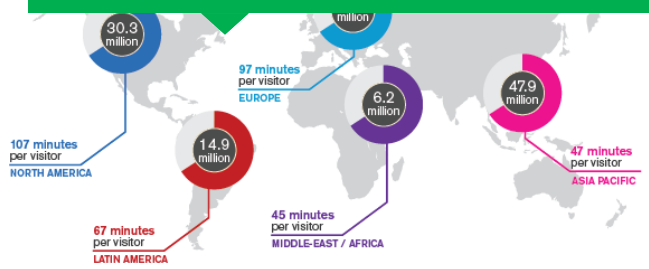
Big Scienc



Grid Computing

15-30% IT INDUSTRY





Datacenters

Daily Life

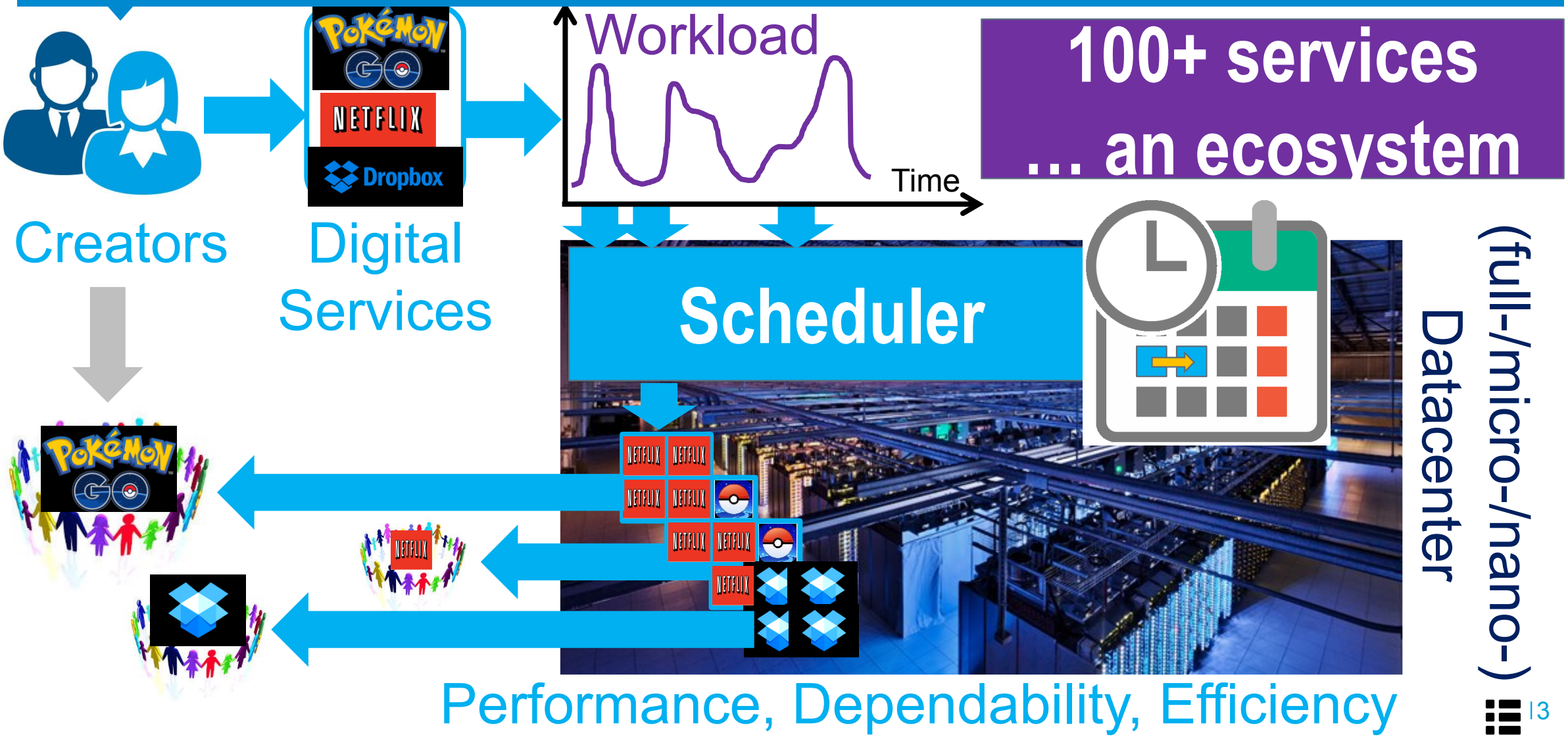
Iosup et al., Massivizing Computer Systems, ICDCS 2018. [Online]

THIS IS THE GOLDEN AGE OF CLOUD COMPUTING (2010S)

Do you recognize this App?

Here is how it operates…

THE CLOUD ECOSYSTEM: SERVICE, DATACENTER, SCHEDULER



DIVERSE CLOUD SERVICES FOR ALL… ARE WE THERE YET?

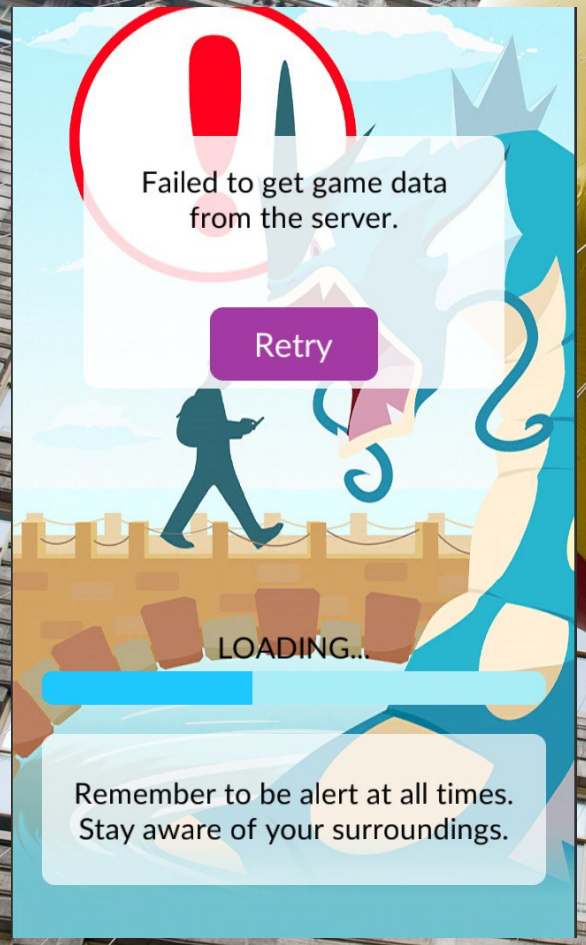
Technology
not ready

Emergence of
the mobile… 5G

Anti-trust
lawsuits vs. GAFAM

Not covered in this talk

Technology **not ready**



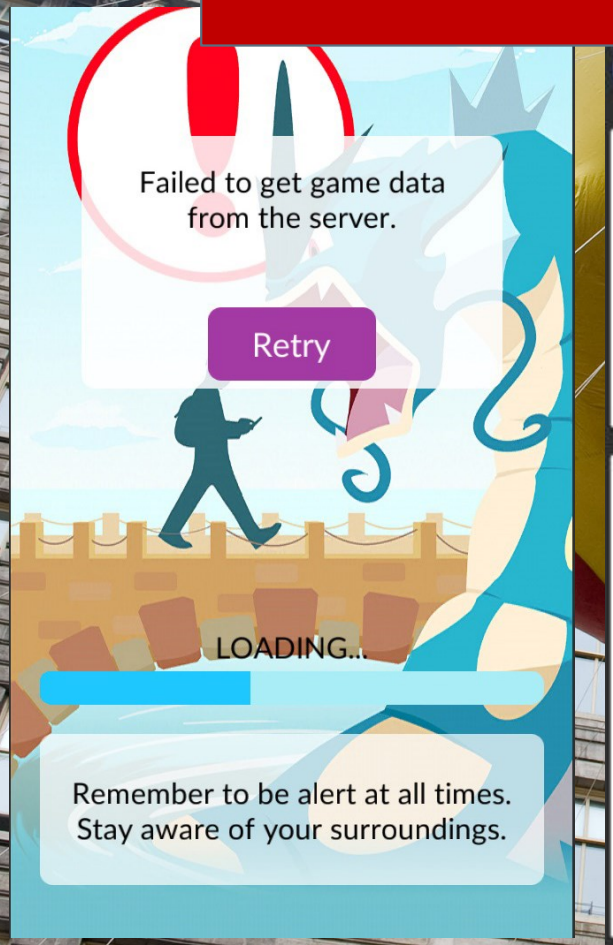
Pokémon GO Server Status

REFRESH

Pokémon GO	Pokémon Trainer Club
OFFLINE for 15 minutes	**UNSTABLE** for 2 minutes

Pokémon GO Uptime	Pokémon Trainer Club Uptime
55.56% over the past hour	**66.67%** over the past hour
96.29% over the past day	**96.66%** over the past day

Is 56% uptime good? 66%? 96%?



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over the past hour

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over the past day

Pokémon Trainer Club Uptime

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over the past hour

96.66%
over the past day

My Research: Massivizing Computer Systems

Technology **not ready**

Why does this* happen?

What to do about it*?

* In modern computer systems, several or all issues may be linked.
Thus, looking at any single issue in isolation is no longer sufficient.

MEANINGFUL DISCOVERY

science + engineering + design

[Iosup et al. ICDCS'18]

[Iosup et al. ICDCS'19]

REPRODUCIBILITY AND VALIDATION OF DISCOVERY

A PERENNIALLY TOUGH PROBLEM, IN COMPUTING BUT ALSO IN ALL OTHER SCIENCES

- METHODOLOGY
- OPEN SCIENCE
- REPORTING & DISSEMINATION
- REPRODUCIBILITY

* Conferences do not accept such material… except when they do…

Munafò et al., A manifesto for reproducible science, Nature Human Behaviour, Jan 2017. [Online]

REPRODUCIBILITY AND VALIDATION OF DISCOVERY

A PERENNIALLY TOUGH PROBLEM, IN COMPUTING BUT ALSO IN ALL OTHER SCIENCES

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- OPEN SCIENCE
- REPORTING & DISSEMINATION
- REPRODUCIBILITY

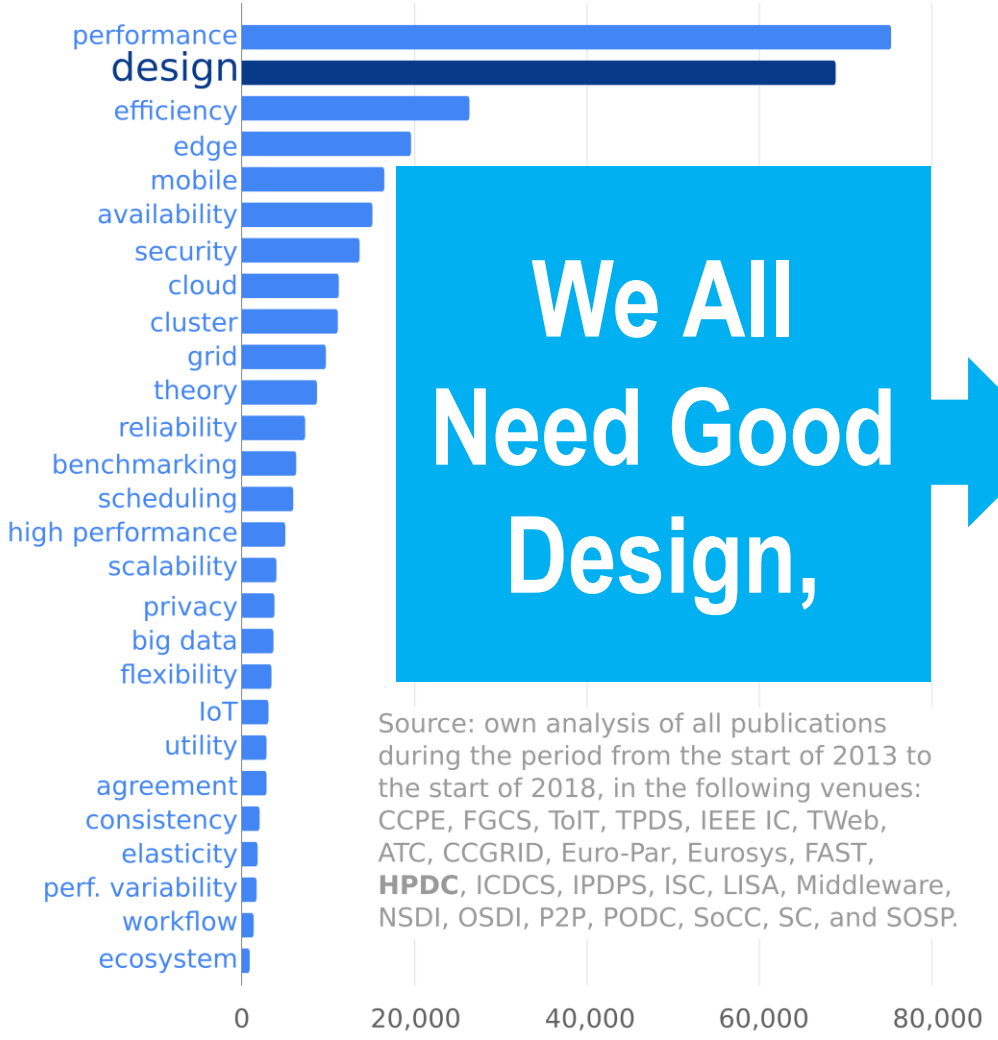
A. V. PAPADOPOULOS, L. VERSLUIS, A. BAUER, N. HERBST, J. VON KISTOWSKI, A. ALI-ELDIN, C. ABAD, J. N. AMARAL, P. TUMA, AND A. IOSUP (2019) METHODOLOGICAL PRINCIPLES FOR REPRODUCIBLE PERFORMANCE EVALUATION IN CLOUD COMPUTING.
IEEE TRANSACTIONS ON SOFTWARE ENGINEERING 2019 (IN PRINT)

SPEC RG CLOUD GROUP. TECHNICAL REPORT. APR 2019 [ONLINE]

* Conferences do not accept such material… except when they do…

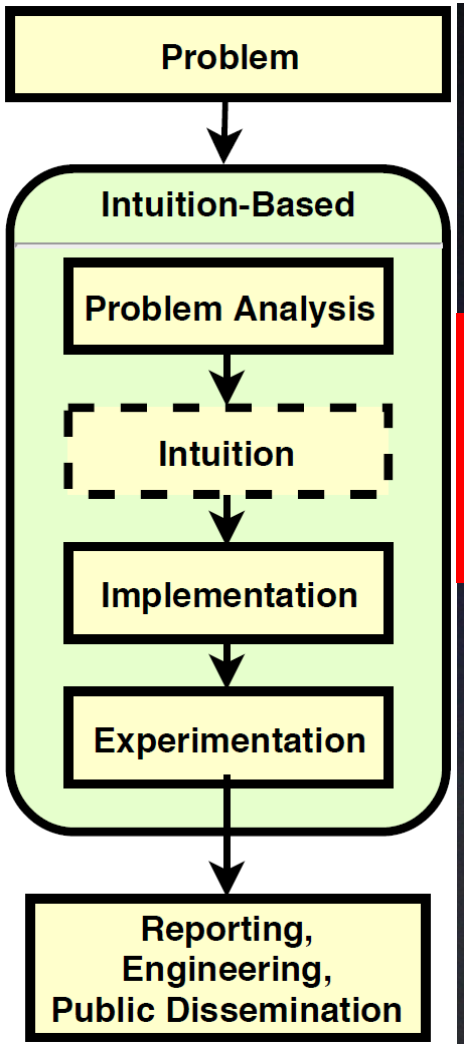
Munafò et al., A manifesto for reproducible science, Nature Human Behaviour, Jan 2017. [Online]

THE DESIGN OF DISTRIBUTED SYSTEMS AND ECOSYSTEMS

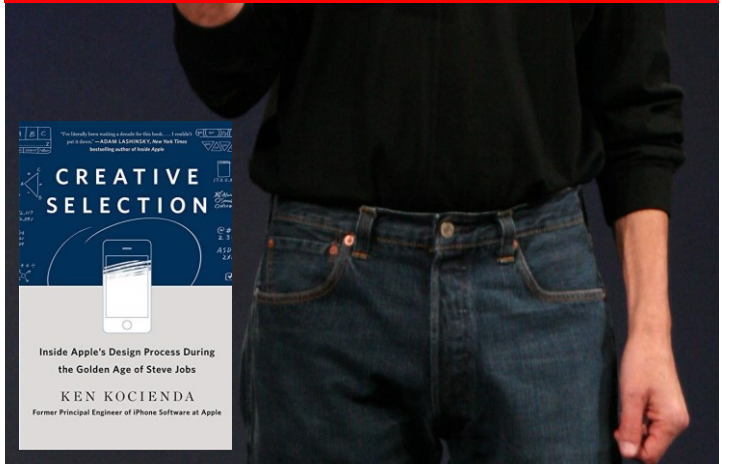


We All Need Good Design,

Source: own analysis of all publications during the period from the start of 2013 to the start of 2018, in the following venues: CCPE, FGCS, ToIT, TPDS, IEEE IC, TWeb, ATC, CCGRID, Euro-Par, Eurosys, FAST, **HPDC**, ICDCS, IPDPS, ISC, LISA, Middleware, NSDI, OSDI, P2P, PODC, SoCC, SC, and SOSP.

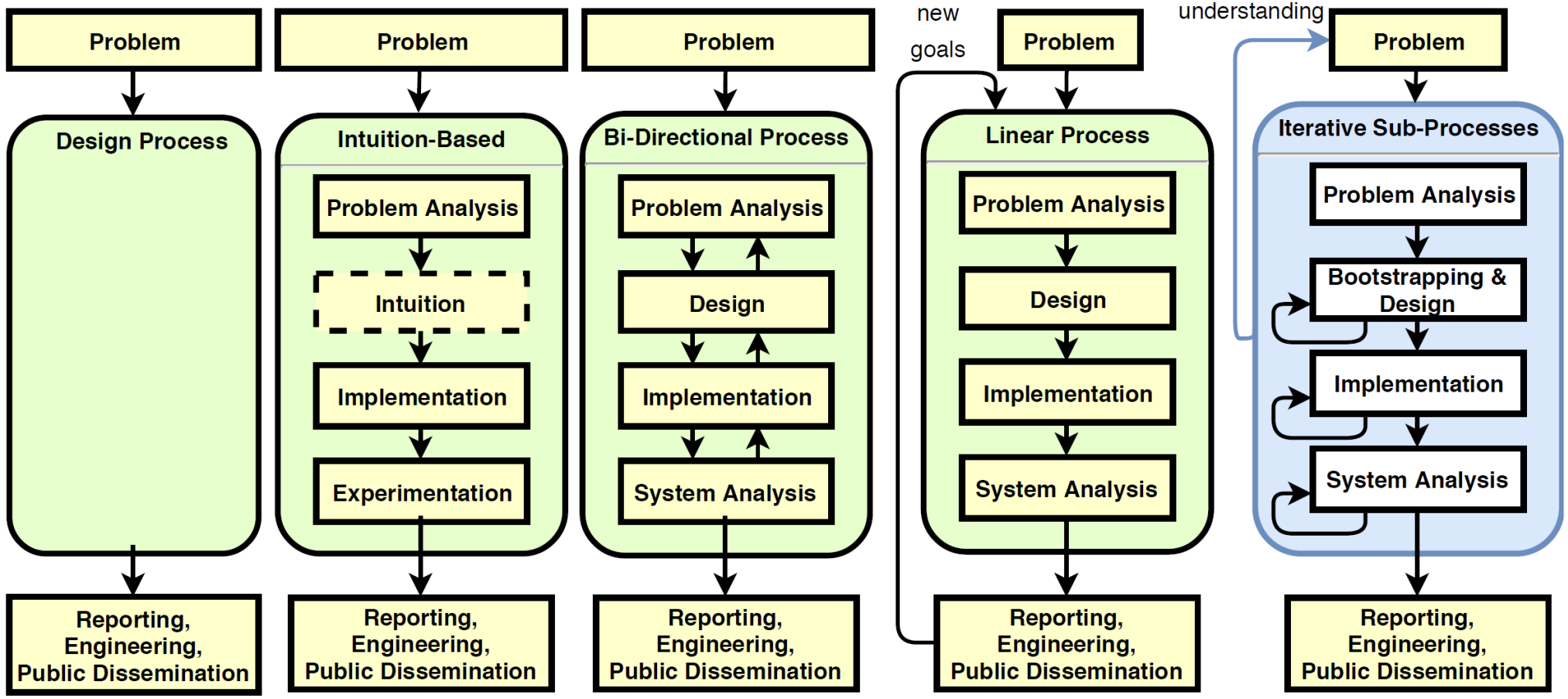


But We Are Not All Steve Jobs



THE ATLARGE DESIGN PROCESS FOR DISTRIBUTED SYSTEMS AND ECOSYSTEMS

bit.ly/AtLargeDesign1Talk

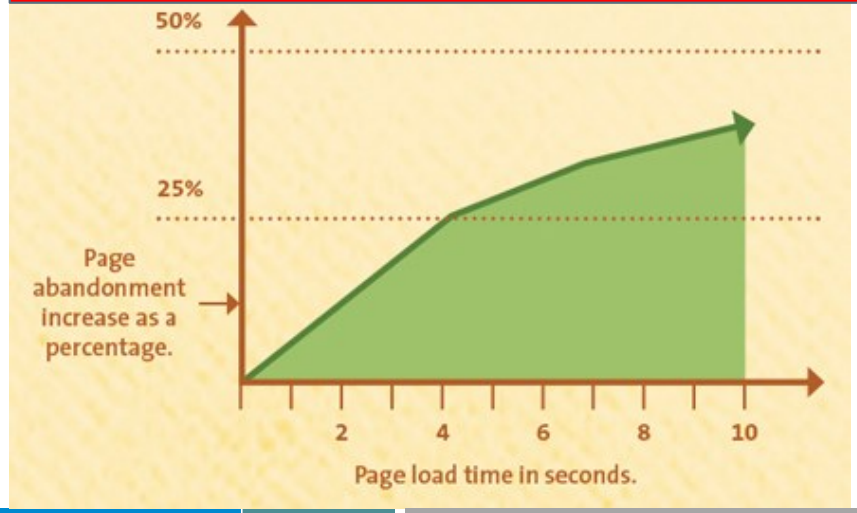


[Iosup et al. The AtLarge Vision on the Design of Distributed Systems and Ecosystems. ICDCS'19] Online version: http://arxiv.org/pdf/1902.05416

CHALLENGE: MEET SERVICE LEVEL AGREEMENTS

PERFORMANCE, DEPENDABILITY, AND OTHER NON-FUNCTIONAL CHALLENGES

We Cannot Maintain the Ecosystems we Have Built (and Thought We've Tested, and Validated)



Sources: https://www.fastcompany.com/1825005/how-one-second-could-cost-amazon-16-billion-sales

Goog
world
System

Cloudflare and Google dealt with issues that affected countless sites and users on Tuesday.

By David Yaff

July 2, 2019

When a website won't load, many internet users turn to DownDetector, a site that keeps track of online disruptions, providing frequent updates
infrastructure.

Sources:https://www.nytimes.com/2019/07/02/business/cloudflare-google-internet-problems.html

MEANINGFUL DISCOVERY

UNCOVERING THE MYSTERIES OF OUR UNIVERSE

GALILEO GALILEI, 1608-9, 3-8X TELESCOPE

MERELY AN INSTRUMENT?

FUNDAMENTAL SCIENCE?

Garney. The Inquisition's Semicolon: Punctuation, Translation, and Science in the 1616 Condemnation of the Copernican System, ArXiv document 1402.6168. [Online]

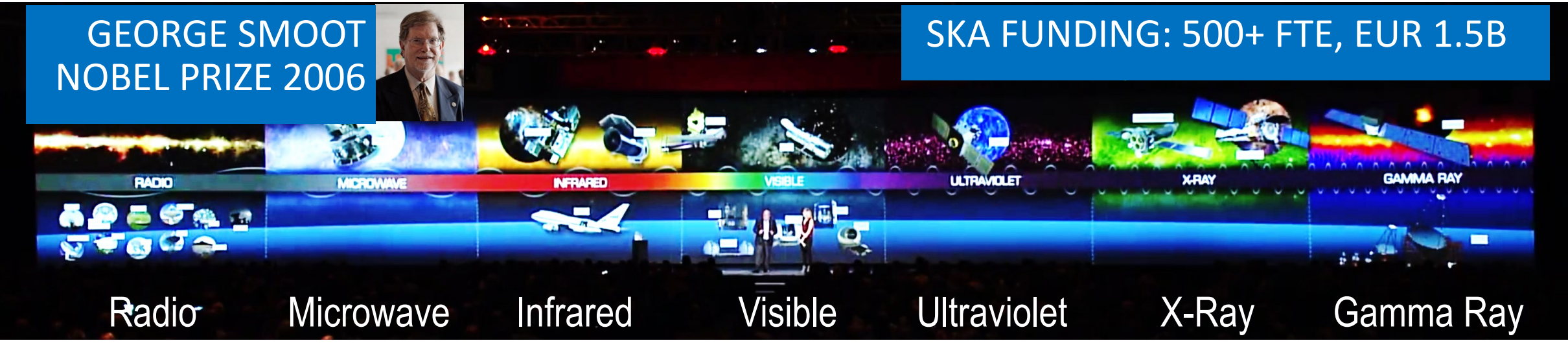
Phil Diamond and Rosie Bolton, Life, the Universe & Computing: The story of the SKA Telescope, SC17 Keynote. [Online]

DISCOVERY = LARGE-SCALE, LONG-TERM STUDY

UNCOVERING THE MYSTERIES OF OUR PHYSICAL UNIVERSE

GEORGE SMOOT
NOBEL PRIZE 2006

SKA FUNDING: 500+ FTE, EUR 1.5B



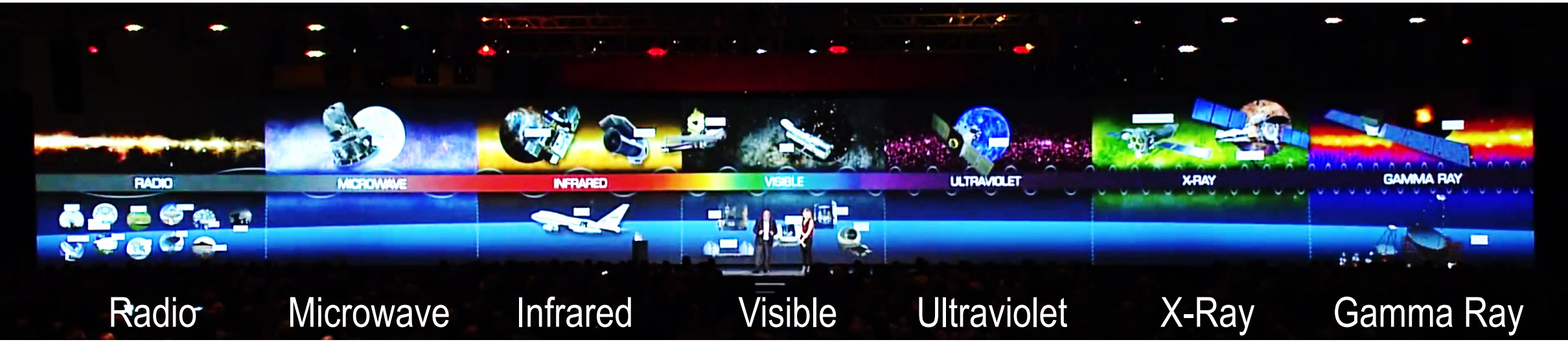
James Cordes, The Square Kilometer Array, Project Description, 2009 [Online]

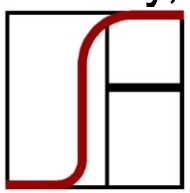
The Square Kilometer Array Factsheet, How much will it cost?, 2012 [Online]

Phil Diamond and Rosie Bolton, Life, the Universe & Computing: The story of the SKA Telescope, SC17 Keynote. [Online]

DISCOVERY = LARGE-SCALE, LONG-TERM STUDY

UNCOVERING THE MYSTERIES OF OUR UNIVERSE, PHYSICAL AND DIGITAL



Radio	Microwave	Infrared	Visible	Ultraviolet	X-Ray	Gamma Ray
Cloud, Grid, Edge, Fog, etc.	One aspect: BigData, P2P	Sci.&Eng. Apps+Sys.	Consumer Apps+Sys.	Enterprise Sys.	Systems, Ecosystems	Performance, Availability, etc.
The Grid Workloads Archive	P2P T.A.	BoTs, Groups, Workflows	Game Trace Archive	Business -Critical		
[Iosup et al. FGCS'08]	[Zhang et al. CoNext'10]	[Iosup et al. IEEE IC'11]	[Guo et al. NETGAMES'12]	[Shen et al. CCGRID'15]	[Ghit et al. CCGRID'14]	[Iosup et al. CCGRID'10]

THE WORKFLOW TRACE ARCHIVE

96 traces

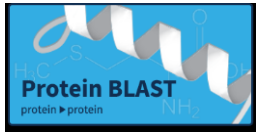
Laurens Versluis

METADATA AND TRACES FOR YOUR WORKFLOW SYSTEMS

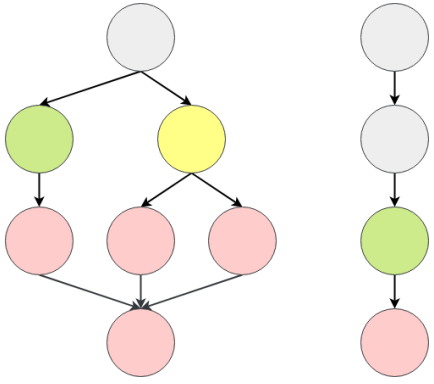
WORKFLOWS ARE COMMON IN MANY DOMAINS

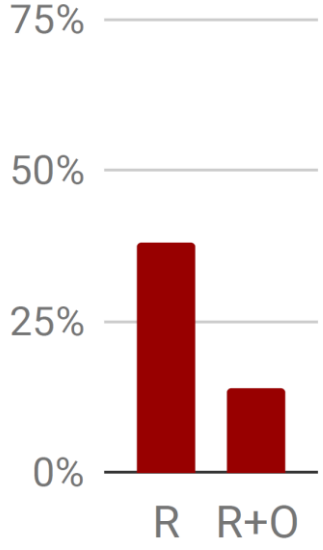
EXCEPT IN SCI., DESIGN, & ENG.

THE WORKFLOW TRACE ARCHIVE CORRECTS THIS



Shell





universität innsbruck

Alibaba.com® Global trade starts here.™

WorkflowHub

Shell

2σ TWO SIGMA

Los Alamos NATIONAL LABORATORY

Google

TU Delft Delft University of Technology

Pegasus

VU UNIVERSITY AMSTERDAM

spec Research

[Versluis et al. The Workflow Trace Archive]
Tech.rep.: http://arxiv.org/pdf/1906.07471

http:// wta.atlarge.science

MEANINGFUL DISCOVERY IN DISTRIBUTED ECOSYSTEMS

UNCOVERING THE MYSTERIES OF OUR UNIVERSE, PHYSICAL AND DIGITAL

BUT … WHY WOULD YOU NEED TO UNCOVER AN ARTIFICIAL UNIVERSE?! YOU BUILT IT!

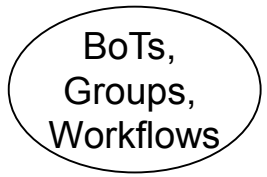
Cloud, Grid, Edge, Fog, etc.

[Iosup et al. FGCS'08]

One aspect: BigData, P2P

[Zhang et al. CoNext'10]

Sci.&Eng. Apps+Sys.



[Iosup et al. IEEE IC'11]

Consumer Apps+Sys.

[Guo et al. NETGAMES'12]

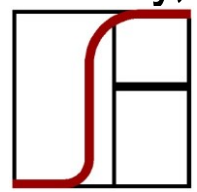
Enterprise Sys.

[Shen et al. CCGRID'15]

Systems, Ecosystems

[Ghit et al. CCGRID'14]

Performance, Availability, etc.

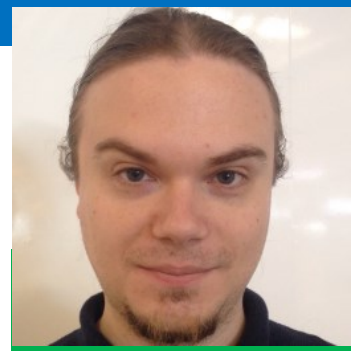


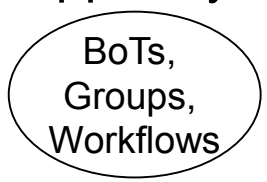
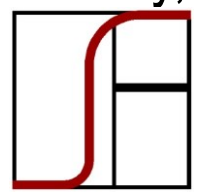
[Iosup et al. CCGRID'10]

UNKNOWN PHENOMENA: INTER-, ADAPT-, EXAPTATION

UNCOVERING THE MYSTERIES OF OUR UNIVERSE, PHYSICAL AND DIGITAL

Toward a Distributed Systems Memex

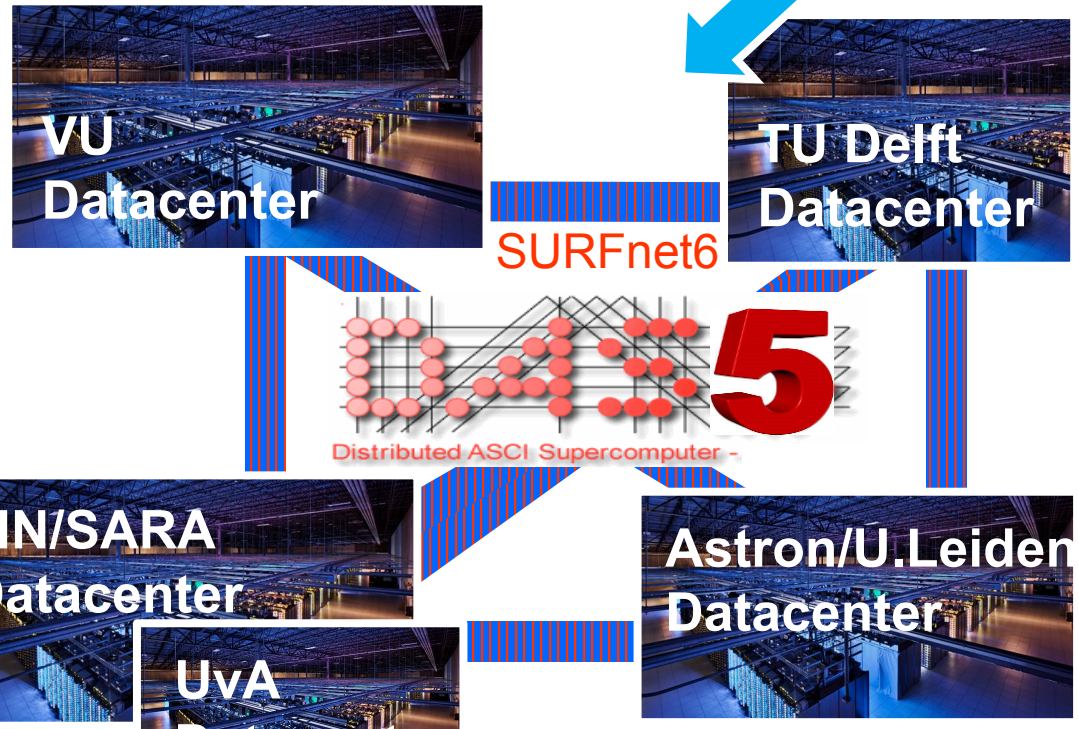


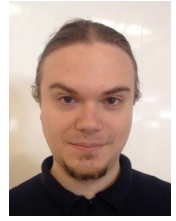
...	...	...		...
BOTS, NOT PARALLEL JOBS	GROUPS NOT RARE, DOMINANT	COMMUNITY FORMATION	SYSTEMIC VARIABILITY	CORRELATED, NOT IID FAILURES
Cloud, Grid, Edge, Fog, etc.	One aspect: BigData, P2P	Sci.&Eng. Apps+Sys.	Consumer Apps+Sys.	Enterprise Sys.	Systems, Ecosystems	Performance, Availability, etc.
						
[Iosup et al. FGCS'08]	[Zhang et al. CoNext'10]	[Iosup et al. IEEE IC'11]	[Guo et al. NETGAMES'12]	[Shen et al. CCGRID'15]	[Ghit et al. CCGRID'14]	[Iosup et al. CCGRID'10]

EXPERIMENTAL METHODS OF DISCOVERY

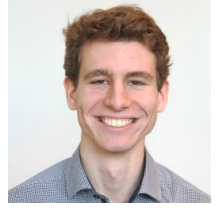
UNIQUE OPPORTUNITY: WE DRINK OUR OWN CHAMPAGNE (*IN VIVO*)!

Our Prototypes (*in phyisico/in vitro*)





Alex Uta



Georgios Andreadis

Fab Mastel

Maria Voinea

Laurens Versluis

Alexey Ilyushkin

\+

We also use clouds

\+

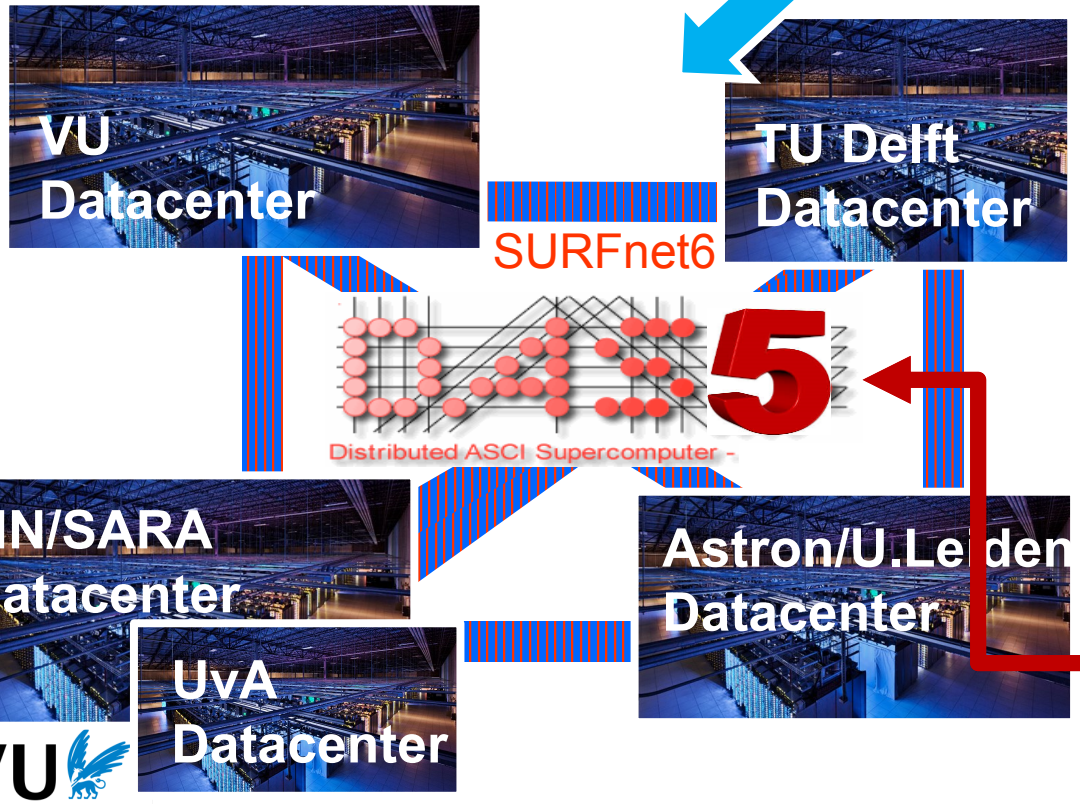
OpenDC

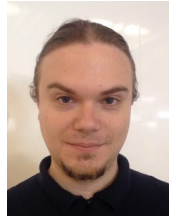
And simulators (*in silico*)

EXPERIMENTAL METHODS OF DISCOVERY

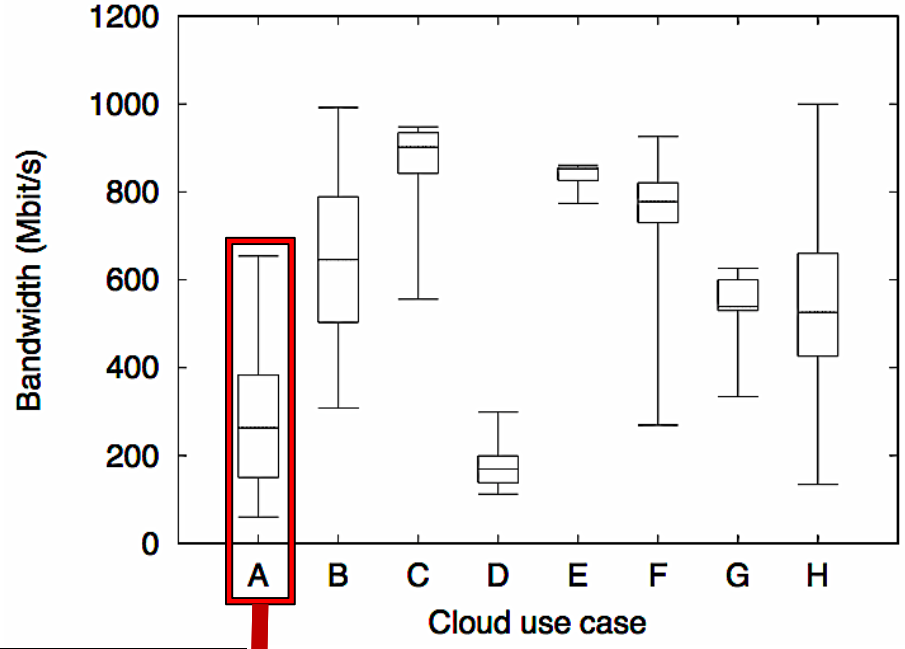
UNDERSTANDING THE PHENOMENON OF PERFORMANCE VARIABILITY

Our Prototypes (*in phyisico/in vitro*)





Alex Uta

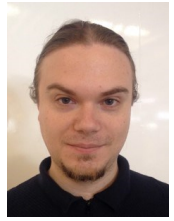


EXPERIMENTAL METHODS OF DISCOVERY

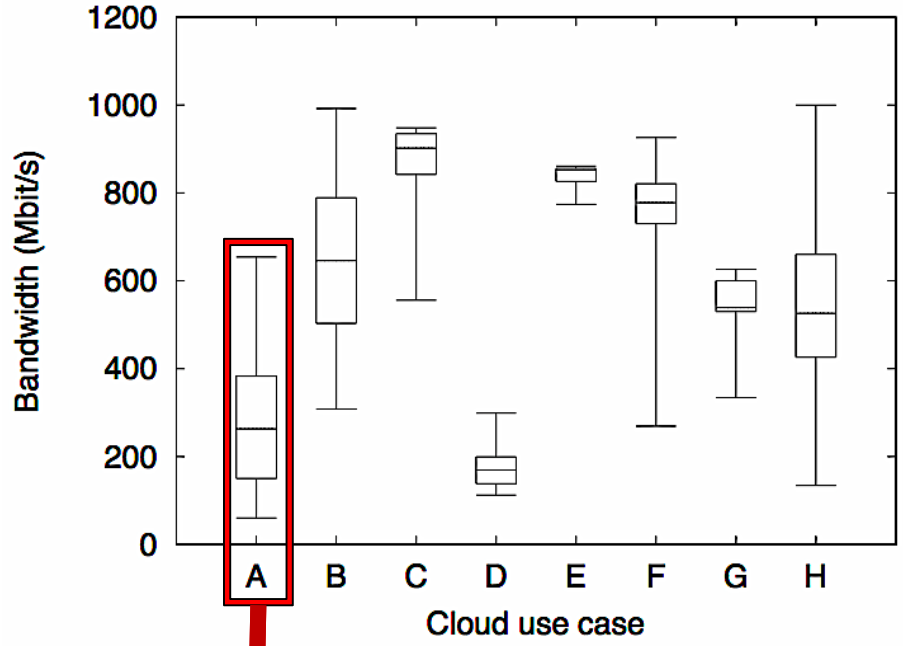
NETWORK VARIABILITY AFFECTS BIG DATA PERFORMANCE → NEW DESIGNS NEEDED

Our Prototypes (*in phyisico/in vitro*)

Application	Maximum Slowdown	Bandwidth Distribution
Wordcount	1.61	A
Sort	1.51	D
Terasort	1.79	A
K-Means	1.48	D
Bayes	1.14	A
Pagerank	1.07	A



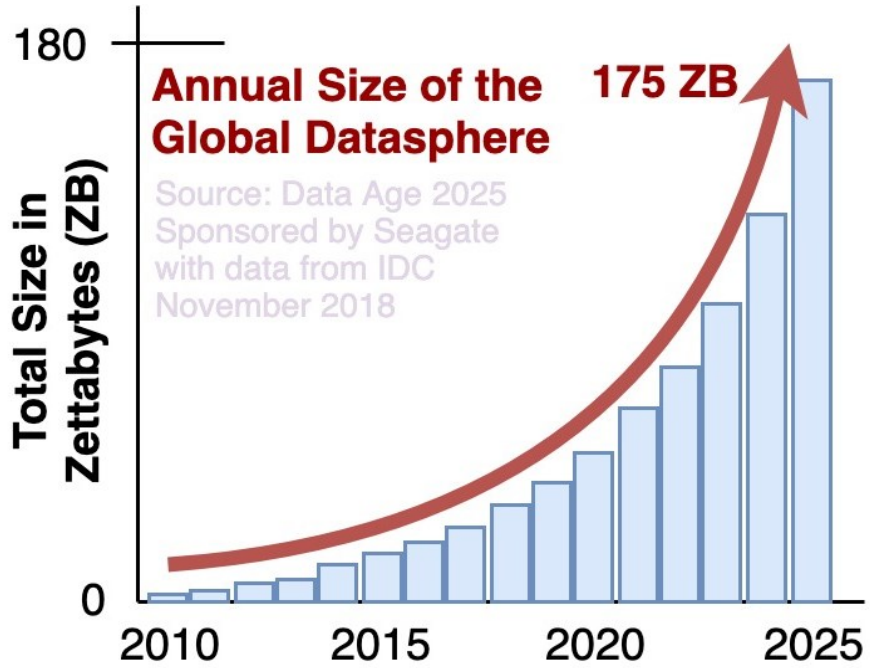
Alex Uta



CHALLENGE: SYSTEMATIC DESIGN & DESIGN-SPACE EXPLORATION

THE COMPLEXITY CHALLENGE

We Build and Test
Isolated Computer Systems, Yet
Everything Works in Stacks and Ecosystems
... Need to Reason About Them!



<<1% OF BIG DATA BY MATT TURK (2017)
"SW. IS EATING THE WORLD"

UNKNOWN PHENOMENA: INTER-, ADAPT-, EXAPTATION

UNCOVERING THE MYSTERIES OF OUR UNIVERSE, PHYSICAL AND DIGITAL

BUT … HOW CAN DESIGNERS MANAGE COMPLEXITY, WITH SO MANY PHENOMENA?

…

BOTS, NOT PARALLEL JOBS

Cloud, Grid, Edge, Fog, etc.

[Iosup et al. FGCS'08]

…

GROUPS NOT RARE, DOMINANT

One aspect: BigData, P2P

P2P T.A.

[Zhang et al. CoNext'10]

…

COMMUNITY FORMATION

Sci.&Eng. Apps+Sys.

BoTs, Groups, Workflows

[Iosup et al. IEEE IC'11]

…

SYSTEMIC VARIABILITY

Consumer Apps+Sys.

Game Trace Archive

[Guo et al. NETGAMES'12]

…

CORRELATED, NOT IID FAILURES

Enterprise Sys.

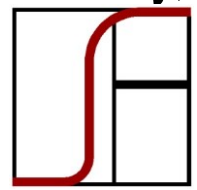
Business -Critical

[Shen et al. CCGRID'15]

Systems, Ecosystems

[Ghit et al. CCGRID'14]

Performance, Availability, etc.



[Iosup et al. CCGRID'10]

MEANINGFUL DISCOVERY

BUT … IS THERE A SYSTEMATIC WAY TO APPROACH THESE PHENOMENA?

FUNDING: > 3B USD

- The Human Genome Project:
  - > Physical map covering >90% human genome
  - > Sequence data made available open-access
- Big Science:
  - > Took >10 years to complete
  - > Led by US, work by 20 groups in CN, DE, FR, JP, UK, US
- Big impact:
  - > Decrease cost of sequencing
  - > Facilitate biomedical research

International Human Genome Sequencing Consortium, Initial sequencing and analysis of the human genome, Nature 409, Feb 2011. [Online]

Julie Gould, The Impact of the Human Genome Project, Naturejobs blog, 2015. [Online]

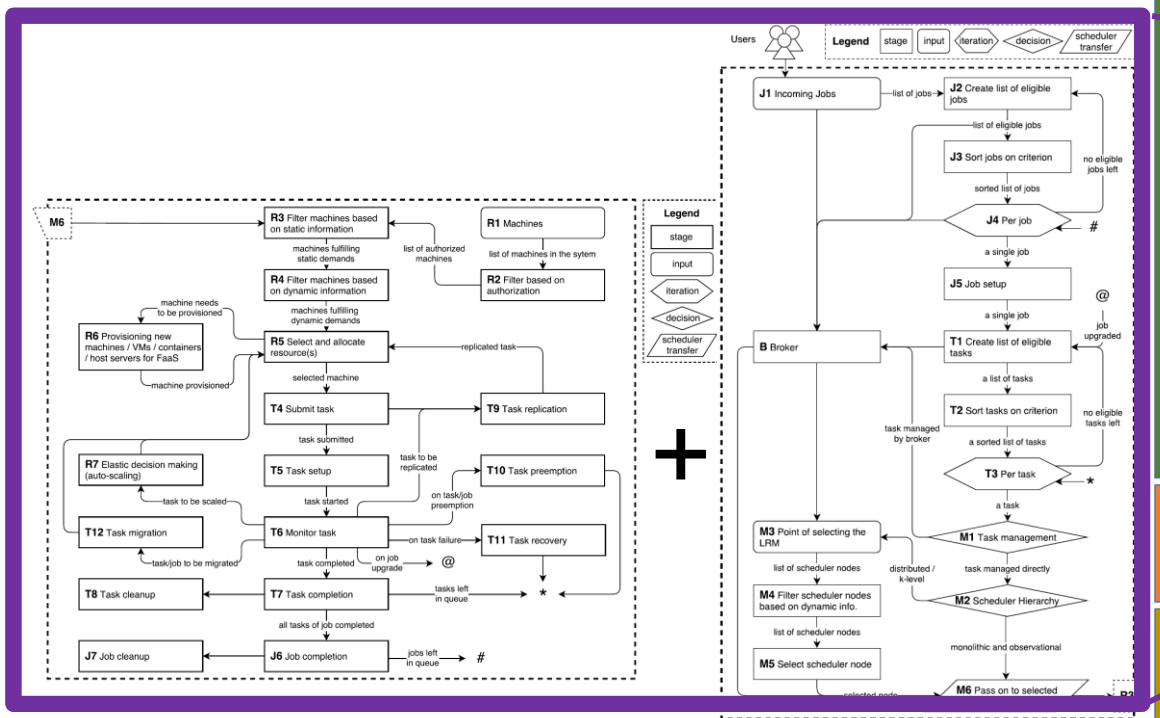
HOW TO MANAGE SYSTEM COMPLEXITY?

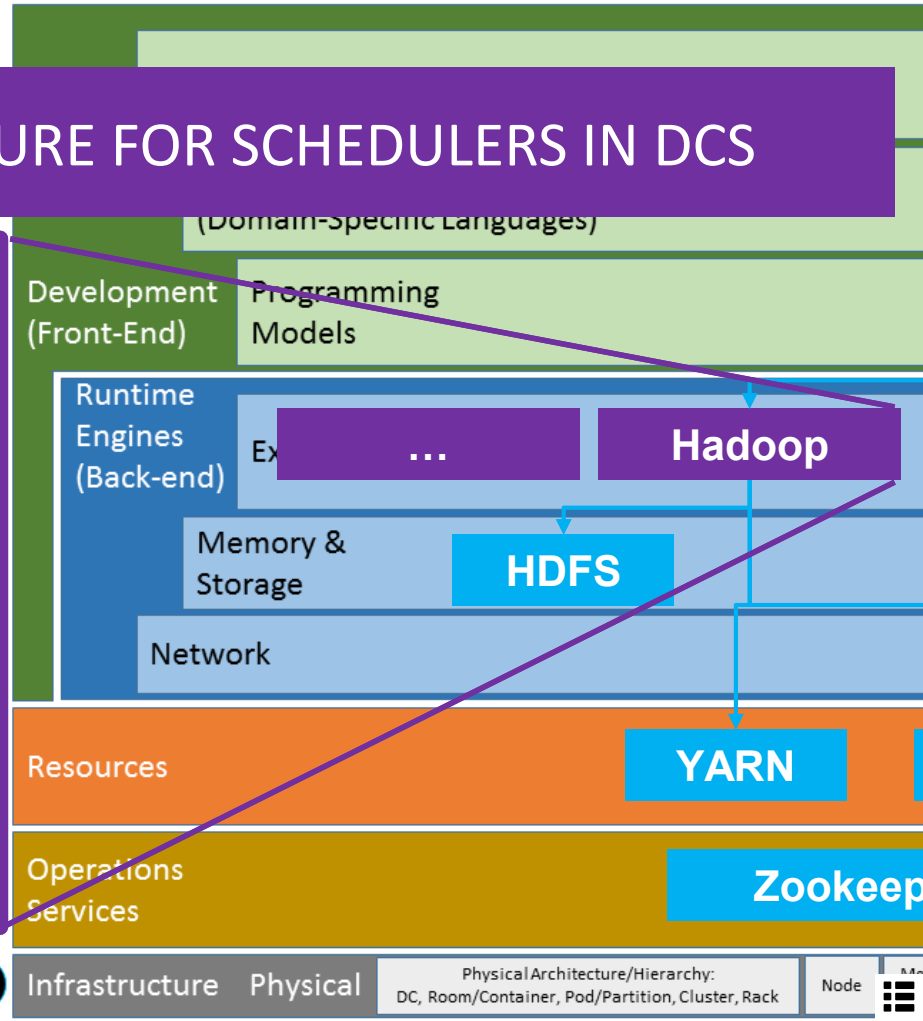
THE COMPLEXITY CHALLENGE

IOSUP ET AL. REFERENCE ARCHITECTURE FOR DCS

Georgios Andreadis

ANDREADIS ET AL. REFERENCE ARCHITECTURE FOR SCHEDULERS IN DCS



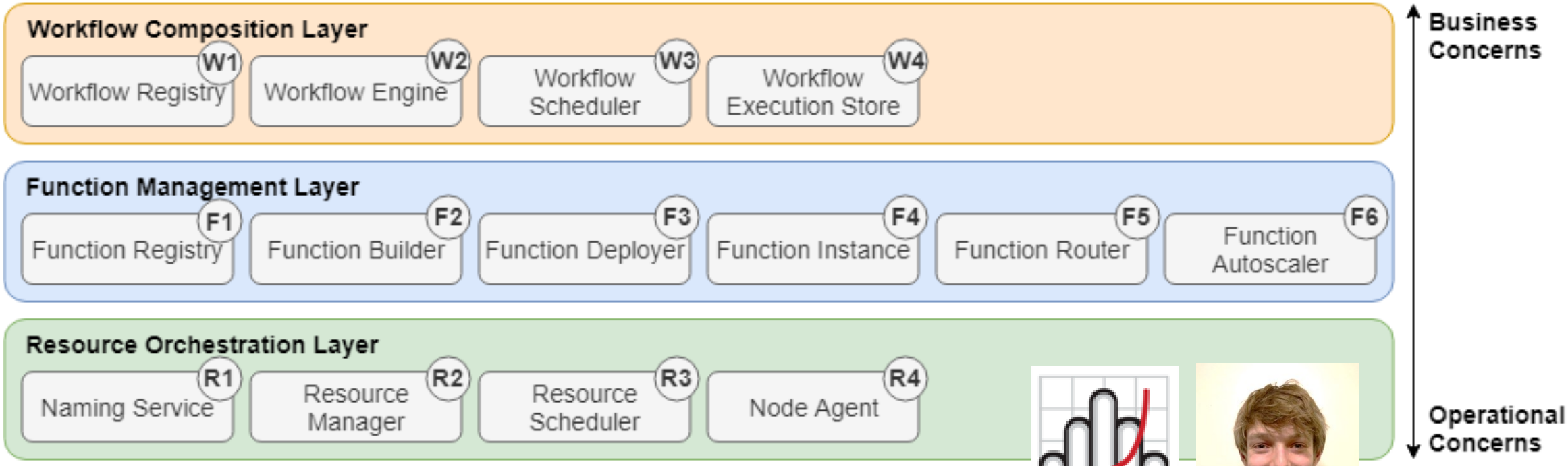


[Andreadis et al. SC'18]

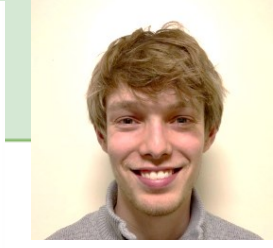
HOW TO MANAGE SYSTEM COMPLEXITY?

THE COMPLEXITY CHALLENGE

WIP REFERENCE ARCHITECTURE OF FAAS PLATFORMS



[van Eyk et al. (2018) Serverless is More: From PaaS to Present Cloud Computing, IEEE Internet Computing] [Online]



Erwin van Eyk

CHALLENGE: EFFICIENCY, SUSTAINABILITY, RESPONSIBILITY!

THE RESOURCE MANAGEMENT CHALLENGE

Based on Jay Walker's recent TED talk.

Need To Be Much More Efficient,

Need to Also Be Ethical, and to Educate Our Clients

PSY Gangnam consumed ~500GWh

= more than entire countries* in a year (*41 countries),
= over 50MW of 24/7/365 diesel, 135M liters of oil,
= 100,000 cars running for a year, ...

Source: Ian Bitterlin and Jon Summers, UoL, UK, Jul 2013.
Note: Psy has >3.5 billion views (last update, May 2018).

Erwin
van Eyk

Alexandru
Iosup

Serverless / FaaS Execution

Vision and Architecture for Serverless Execution in Cloud Environments

van Eyk, Toader, Talluri, Versluis, Uta, Iosup: Serverless is More: From PaaS to Present Cloud Computing. IEEE Internet Computing Sep/Oct 2018. [Online]

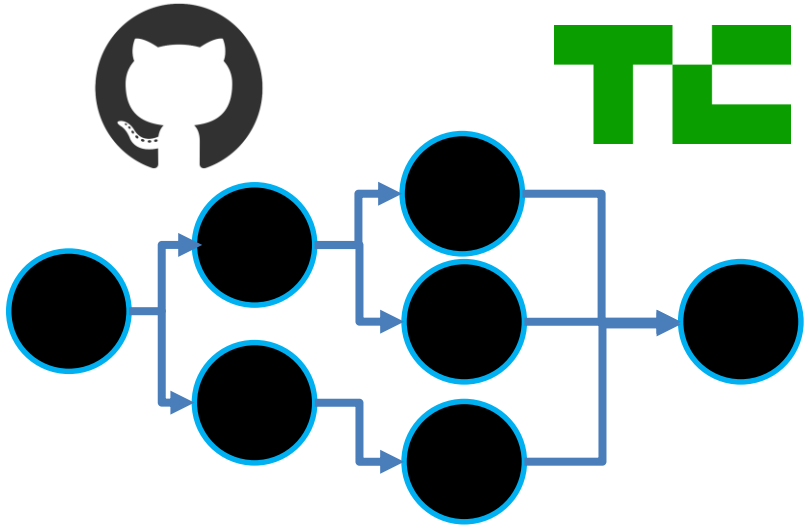
Erwin Van Eyk, Alexandru Iosup, Cristina L. Abad, Johannes Grohmann, Simon Eismann: A SPEC RG Cloud Group's Vision on the Performance Challenges of FaaS Cloud Architectures. ICPE 2018. [Online]

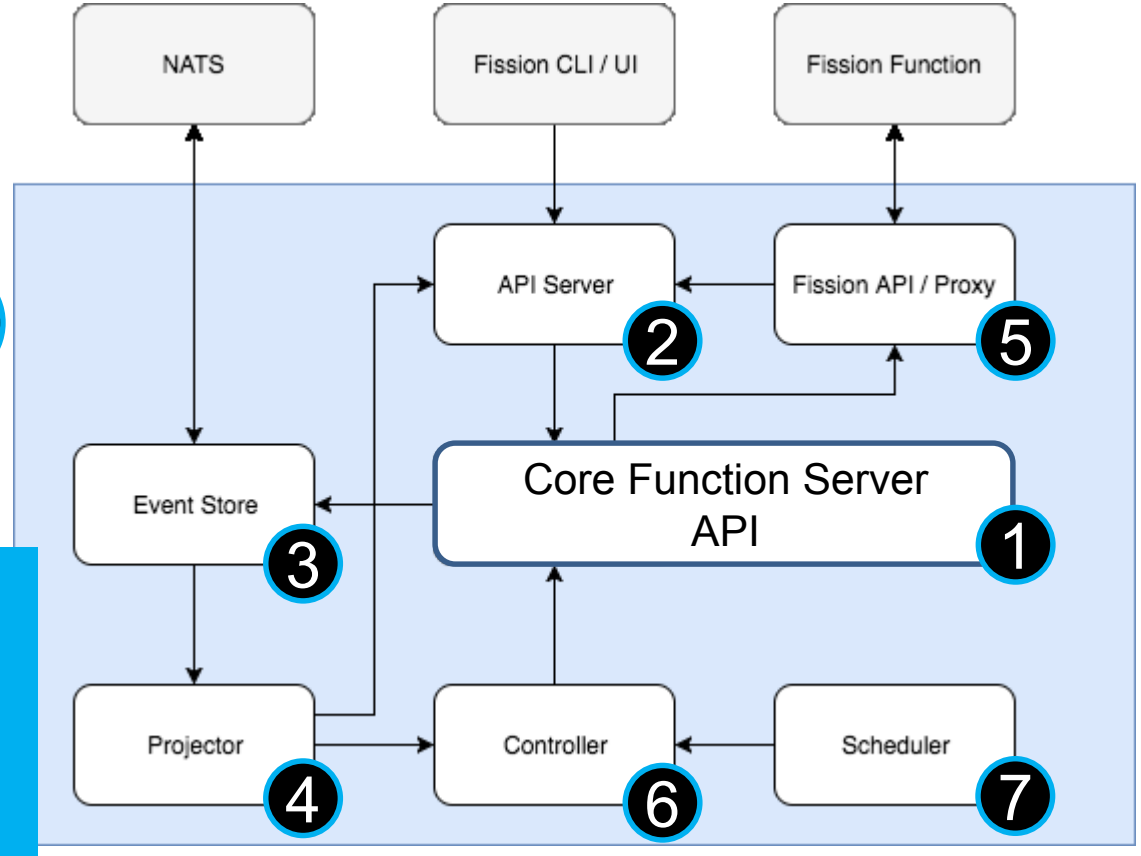
Erwin van Eyk, Simon Seif (SAP), Markus Thoemmes (IBM Germany), Alexandru Iosup. The SPEC Cloud Group's Research Vision on FaaS and Serverless Architectures. Workshop on Serverless Computing (WoSC'17), held in conjunction with Middleware'17. [Online]

SERVERLESS STREAMING WORKFLOWS

DESIGNING SERVERLESS ARCHITECTURES, APIS, AND SCHEDULERS

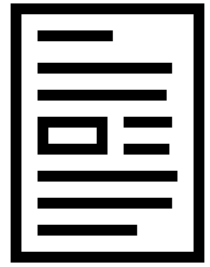
Erwin
van Eyk





The first serverless workflow management engine, now part of the Serverless ecosystem at Fission.io

MASSIVIZING COMPUTER SYSTEMS



FURTHER READING

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

1. Iosup et al. Massivizing Computer Systems. ICDCS 2018 ← start here
2. Iosup et al. The AtLarge Vision on the Design of Distributed Systems and Ecosystems. ICDCS 2019
3. Papdopoulos et al. Methodological Principles for Reproducible Performance Evaluation in Cloud Computing. IEEE Trans. on Sw. Eng. 2019
4. Van Eyk et al. Serverless is More: From PaaS to Present Cloud Computing, IEEE IC Sep/Oct 2018

5. Andreadis et al. A Reference Architecture for Datacenter Scheduling, SC18
6. Talluri et al. Characterization of a Big Data Storage Workload in the Cloud. ACM/SPEC ICPE 2019.
7. Ilyushkin et al. Autoscalers. TOMPECS 2018.
8. Uta et al. Exploring HPC and Big Data Convergence.
9. Uta et al. Elasticity in Graph Analytics? IEEE Cluster 2018.

10. Toader et al. Graphless. IEEE ISPDC'19.
11. Herbst et al. Ready for rain? TOMPECS 2018.
12. Guo et al. Streaming Graph-partitioning. JPDC'18.
13. Iosup et al. The OpenDC Vision. ISPDC'17.
14. van Beek et al. Managing Operational and Disaster-Recovery Risks in Virtualized DCs. ISPDC'19.
15. Iosup et al. LDBC Graphalytics. PVLDB 2016.

CLOUD SYSTEMS AND ECOSYSTEMS

PART OF THE LARGER VISION OF MASSIVIZING COMPUTER SYSTEMS

Many thanks to 200+ collaborators

- Golden Age of Cloud Ecosystems ... Yet many challenges

1. Reproducibility
2. Design Process
3. Trace Archives
4. Phenomena: performance variability, etc.
5. Reference Architecture
6. Serverless engine
7. Benchmarking (*)
8. Simulation for (datacenter) operation (*)

(*) extra slides

- Much left to do ... Time to engage with the SPEC RG Cloud Group!

VU

NWO

http://atlarge.science