MASSIVIZING COMPUTER SYSTEMS

MASSIVIZING ONLINE GAMES: THE SCIENCE, DESIGN, AND ENGINEERING OF DISTRIBUTED ECOSYSTEMS (FOR ONLINE GAMING)

@Large Research
Massivizing Computer Systems

http://atlarge.science

bit.ly/MassivizingGames22

Massivizing Online Games = Rich challenge of computer systems, with societal impact!

Sponsored by:

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VU VRIJE UNIVERSITEIT AMSTERDAM

Contributions from the MCS team. Many thanks!
Many thanks to our collaborators, international working groups, authors of all images included here.
Also many thanks for the invitation, to all involved!

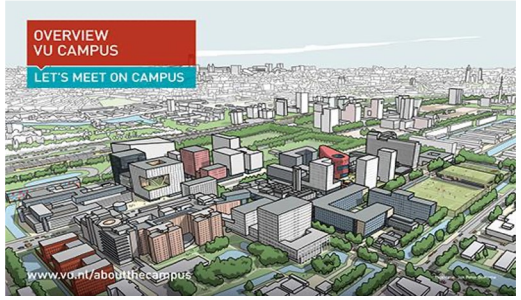
Prof.dr.ir. Alexandru IOSUP

US IN 1 MINUTE

WE'RE MASSIVIZING COMPUTER SYSTEMS!

VU AMSTERDAM < SCHIPHOL < THE NETHERLANDS < EUROPE

Amsterdam
founded 10th century
pop: 850,000



VU
founded 1880
pop: 23,500

The Netherlands

Europe

VU UNIVERSITY AMSTERDAM

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 Young Royal Academy of Arts & Sciences
  - > Knighted in 2020

VU

http://atlarge.science

VU VRIJE UNIVERSITEIT AMSTERDAM

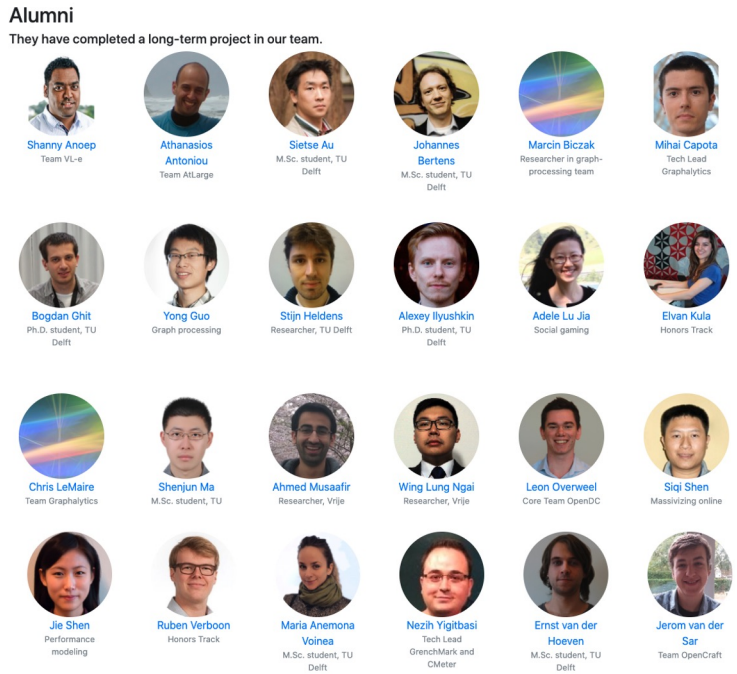
TU Delft

CURRENT TEAM

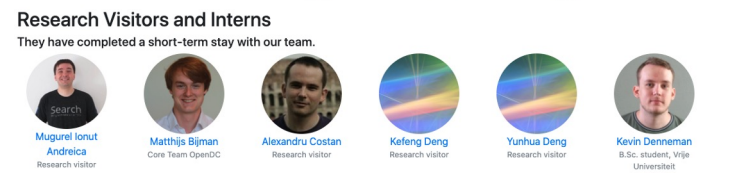
WE ARE HIRING
A NEW ASST. PROF.!

- Professor
- Assistant Prof.
- Teacher
- Visitor/P.-doc
- Ph.D. student
- Early Scientist

ALUMNI



VISITORS



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

MASSIVIZING COMPUTER SYSTEMS: OUR MISSION

http://atlarge.science/about.html

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

THIS IS THE GOLDEN AGE OF COMPUTER ECOSYSTEMS

1

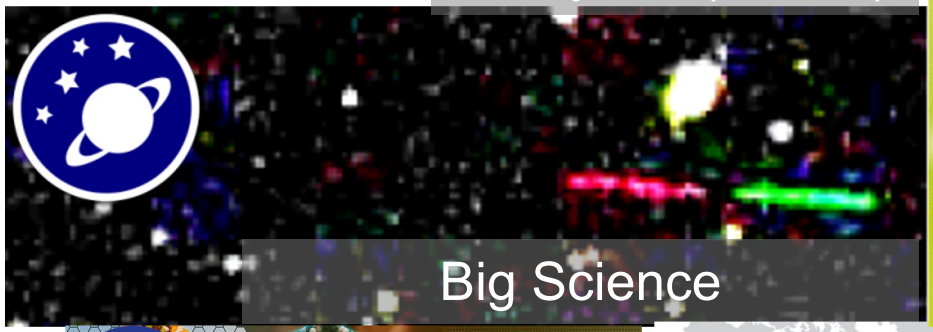
THIS IS THE GOLDEN AGE OF MASSIVE COMPUTER ECOSYSTEMS

Education for Everyone (Online)

Business Services

Big Data

Edge Computing



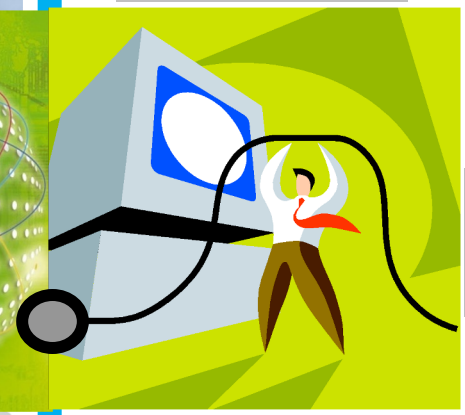
Big Science

Internet

5G/6G/*

THz

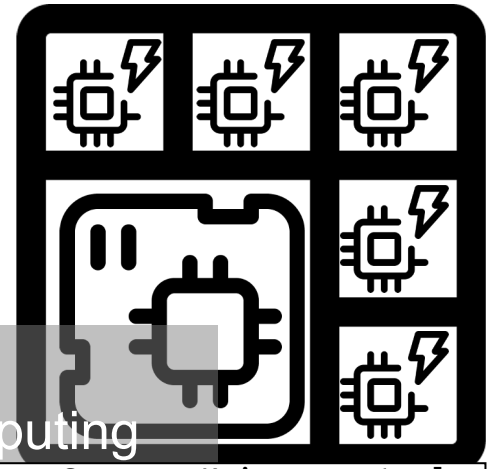
VLC



Cloud Computing

Online Gaming

Datacenter

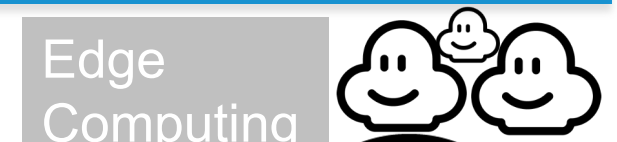


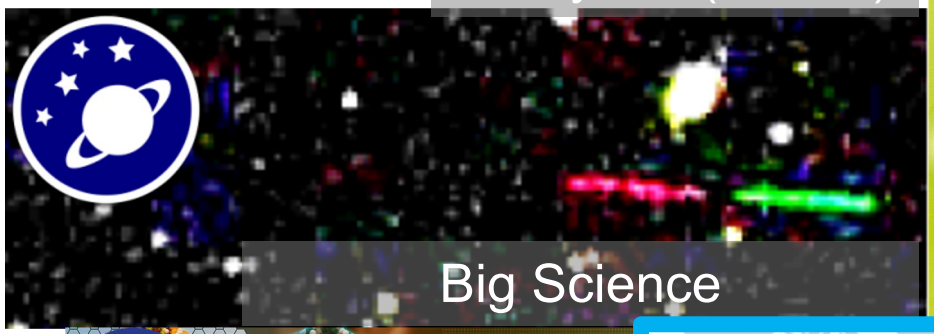
Grid Computing

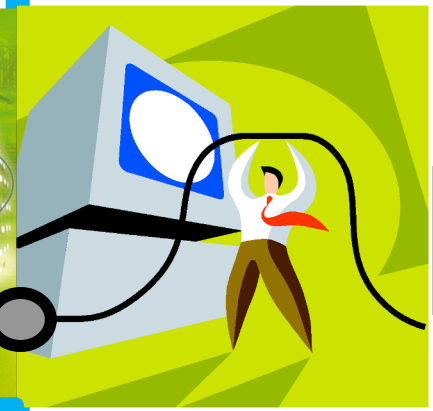
Daily Life

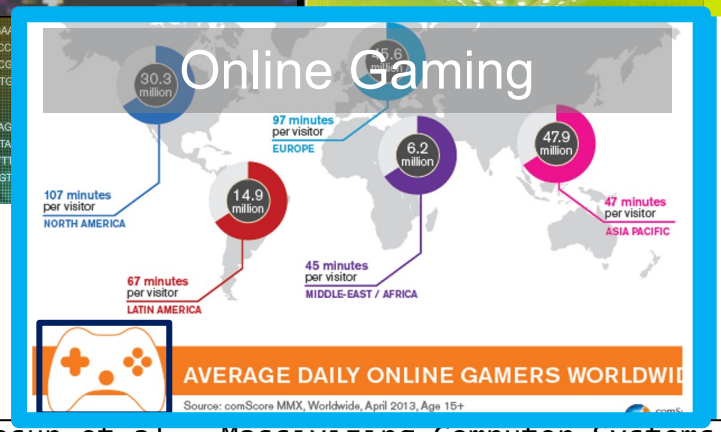
Iosup et al., Massivizing Computer Systems, ICDCS 2018. [Online] Hesselman, Grosso, Kuipers, et al. (2020) A Responsible Internet to increase Trust in the Digital World. JNSM [Online]

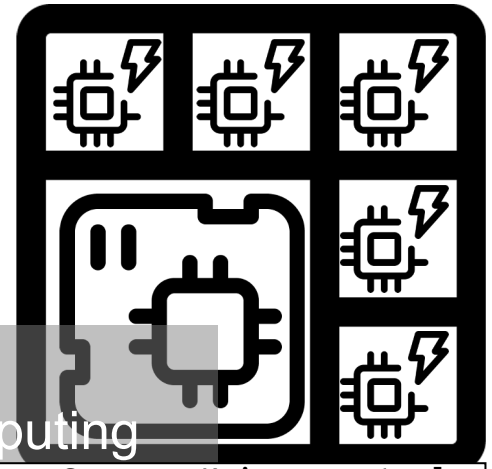
THIS IS THE GOLDEN AGE OF MASSIVE COMPUTER ECOSYSTEMS







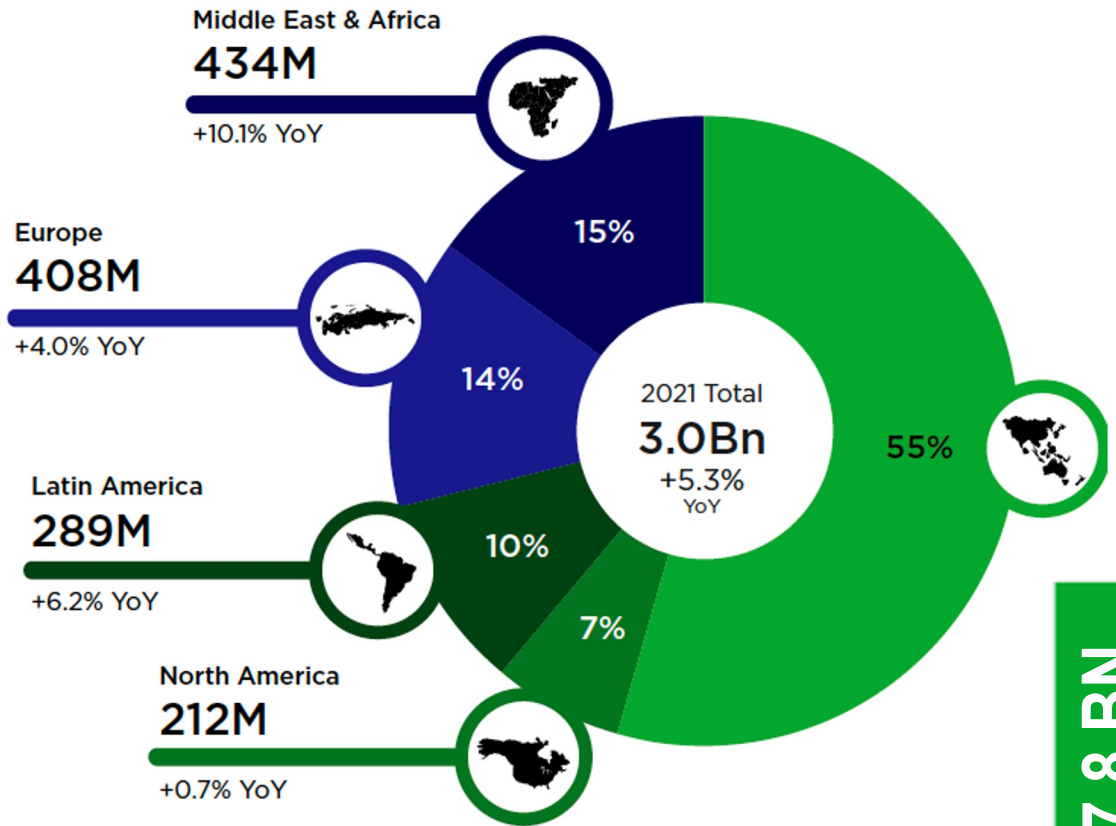




Daily Life

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

LOTS OF GAMERS, LOTS OF CULTURE, LOTS OF REVENUE



2021 Global Players. Source: Newzoo

2022 Essential Facts About the Video Game Industry. Source: The Entertainment Software Association.

$177.8 BN

2020

AVERAGE TIME SPENT PLAYING GAMES EACH WEEK: **13 HOURS**

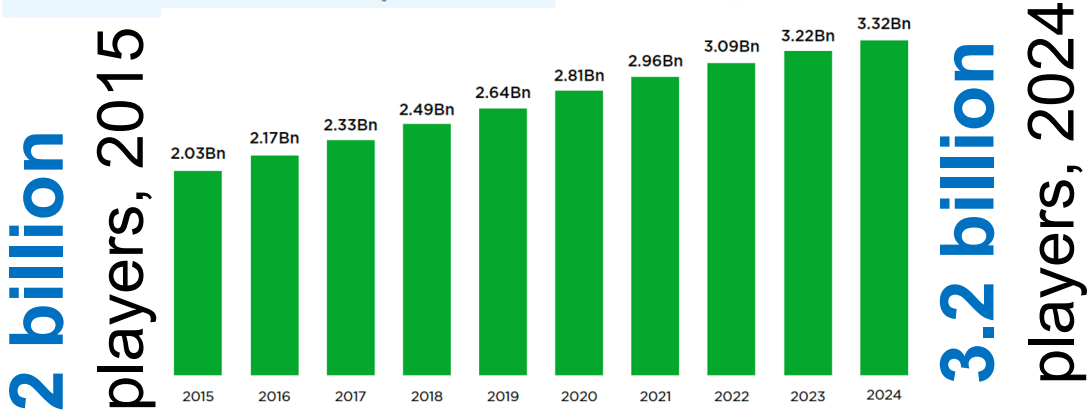
(UP 7% FROM 12 HOURS PER WEEK IN 2021)

48% identify as female

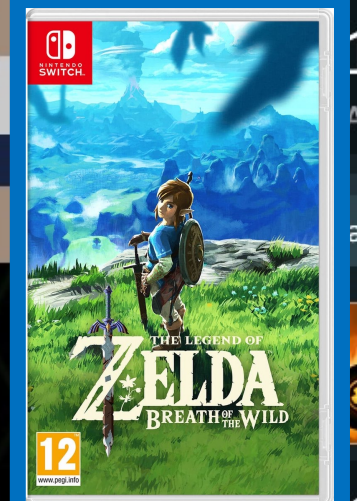
52% identify as male†

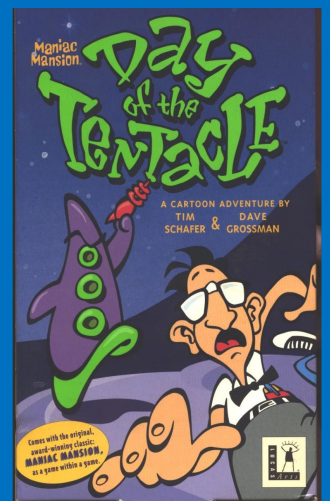
The average video game player is

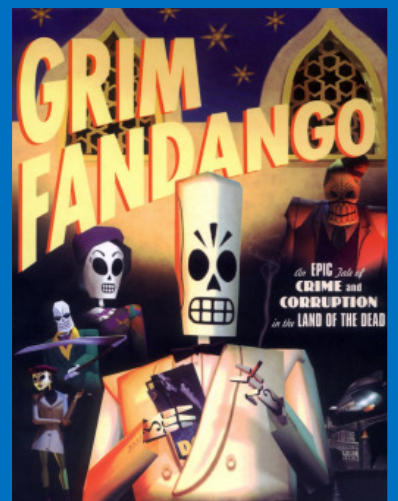
33 years old

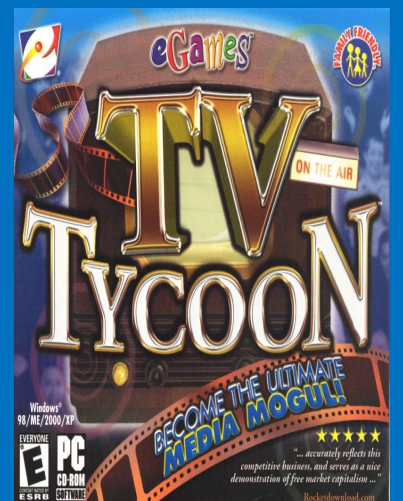


ME AS A GAMER: MULTI-PLATFORM/-GENRE + COMPLETIONIST









GAMES ARE INCREASINGLY MORE SOCIAL, BUILD COMMUNITIES

83%
of players say games introduce people to new friendships and relationships (up from 78%)

46%
of players have met a good friend, spouse, or significant other through video games (up from 42%)

61%
of players have met people through video games they otherwise would not have met (up from 54%)

61%
of players agree video games have helped them stay connected to friends/family (up from 53%)

55%
of players say video games have helped them develop deeper relationships with others

78%
of players agree video games promote social interaction

72%
of players see benefits of games for existing relationships

89%
of players see benefits of games for new relationships

67%
of parents agree video games helped their child connect with friends and family during the pandemic

2013 Game Masters museum exhibition. Personal collection.

2022 Essential Facts About the Video Game Industry.
Source: The Entertainment Software Association.

Games and Beyond

Take Minecraft

- Over **125 million people** play Minecraft every month
- **40,000+ mods**
- **100+ games "like M'craft."**

Generally Beneficial Features

- **Entertainment**
- Education
- Activism
- Social Interaction

YouTube

Minecraft: Connecting More Players Than Ever Before

by Helen Chiang, Studio Head, Mojang Studios • May 18, 2020 @ 6:00am

MINECRAFT

HISTORY BLOCKS

8-10 yrs old | 11-13 yrs old | 14-18 yrs old | 18+ yrs old | Geography | Reading and Writing | Service Learning & Social Good

The purpose of this activity is to guide teachers through an activity in which students reconstruct Unesco world heritage sites Minecraft.

How Greenpeace Used Minecraft to Stop Illegal Logging in Europe's Last Lowland Primeval Forest

Good game, everybody

By Angela Natividad | January 22, 2018

Pussy Riot, Idles to play Minecraft virtual festival 'Block by Blockwest'

It starts this Saturday

By Makena Kelly | @kellymakena | Apr 22, 2020, 1:33pm EDT

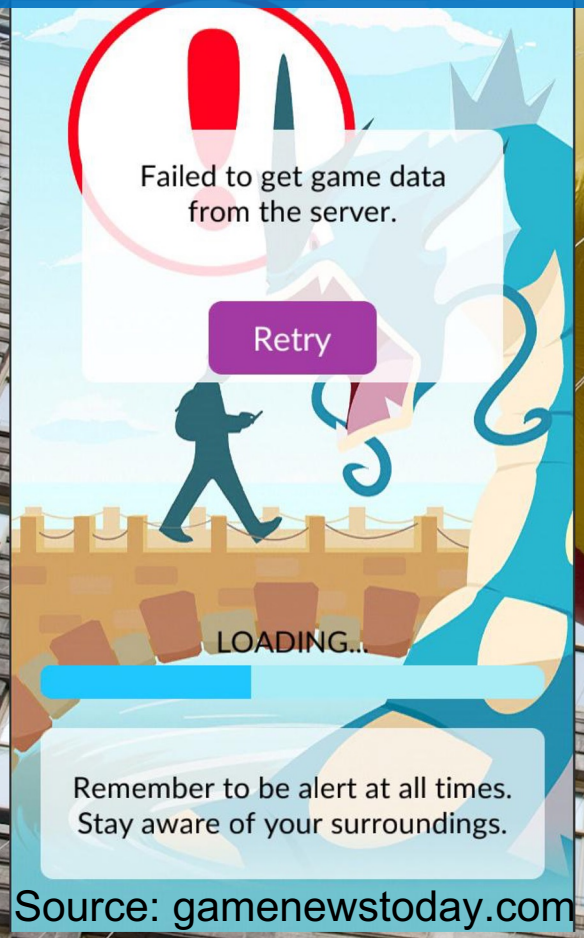
BUT WE CANNOT TAKE THIS TECHNOLOGY FOR GRANTED

2

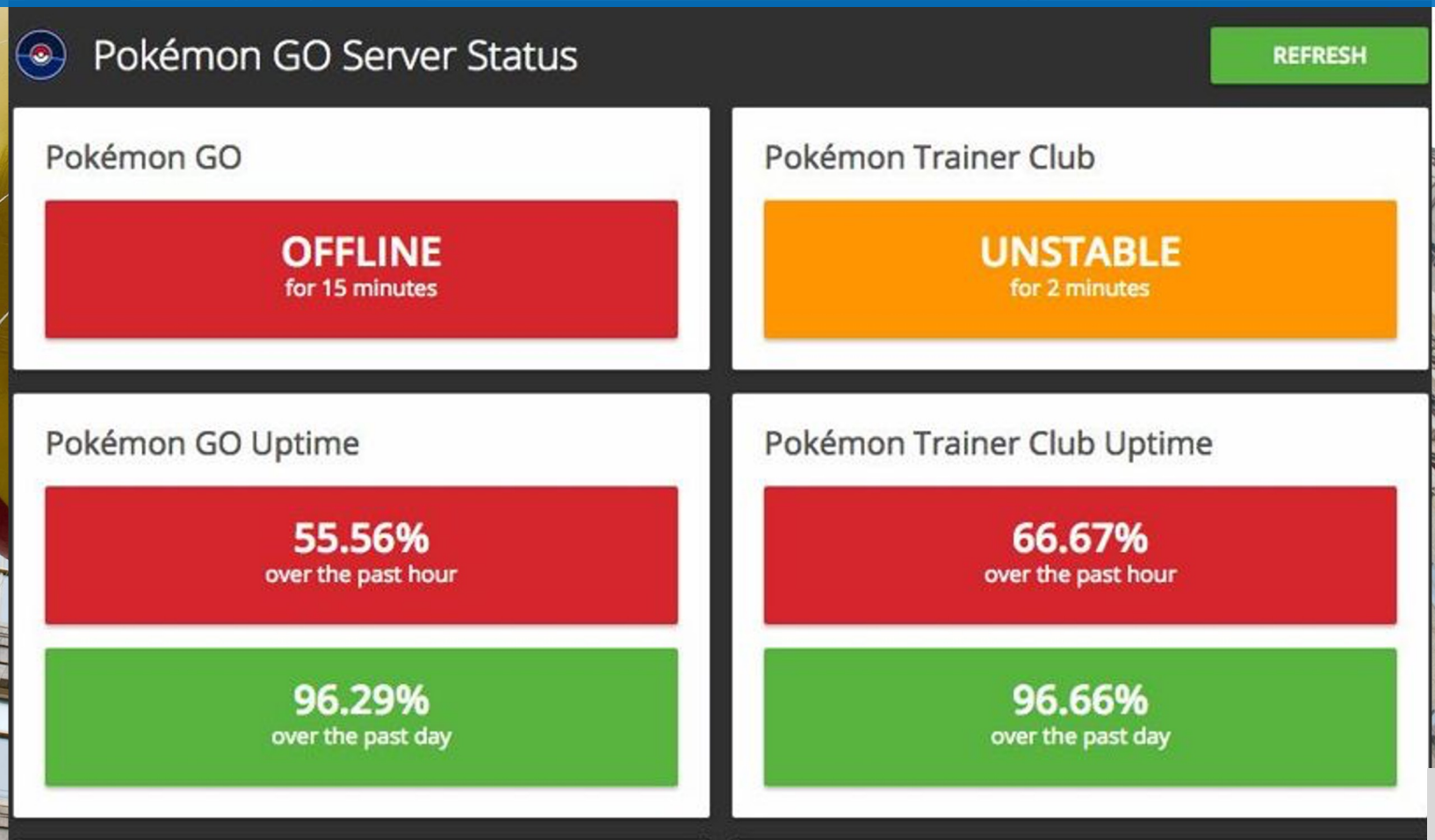
(So, this is why I am giving this talk)

PHENOMENON: UNAVAILABILITY OF GAMING SERVICES

UNCOVERING THE PRESENCE OF FAILURES



Source: gamenewstoday.com



PHENOMENON: PERFORMANCE DROPS IN GAMES

UNCOVERING THE PRESENCE OF PERFORMANCE ISSUES, EVEN LEADING TO CRASHES

Polygon

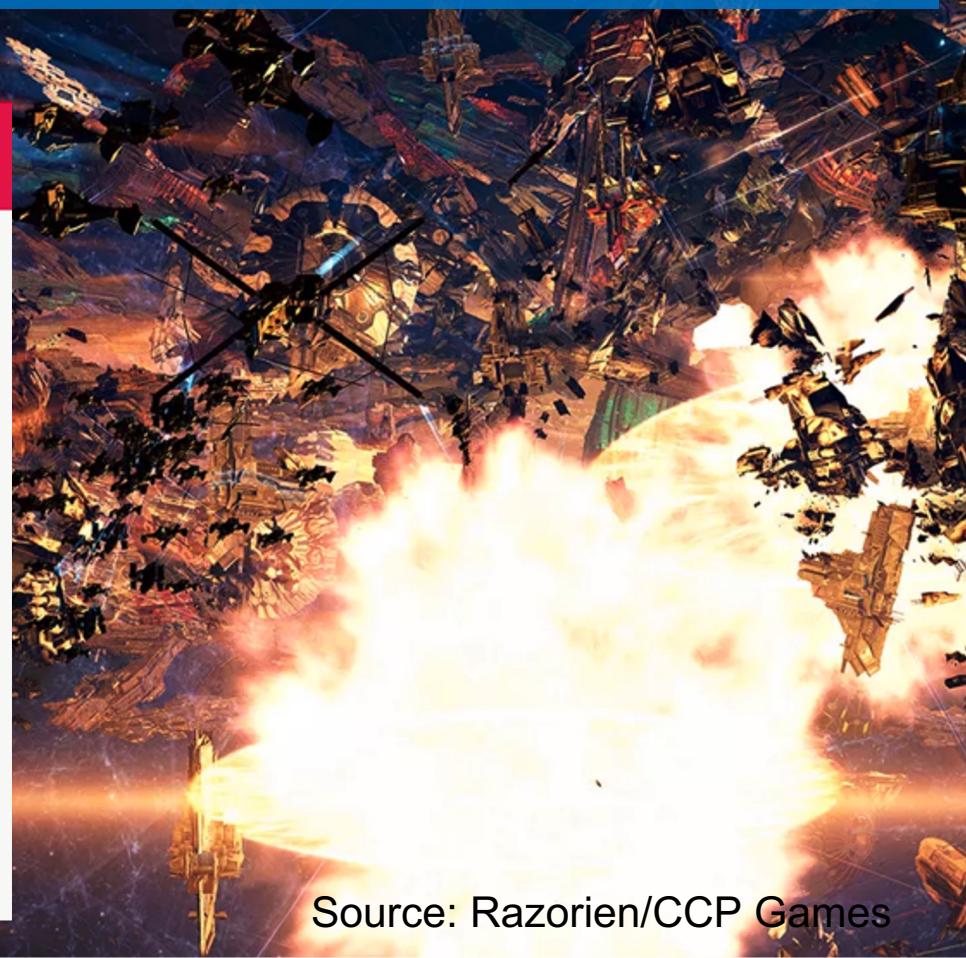
Source: http://bit.ly/EveOnline21Crash

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'

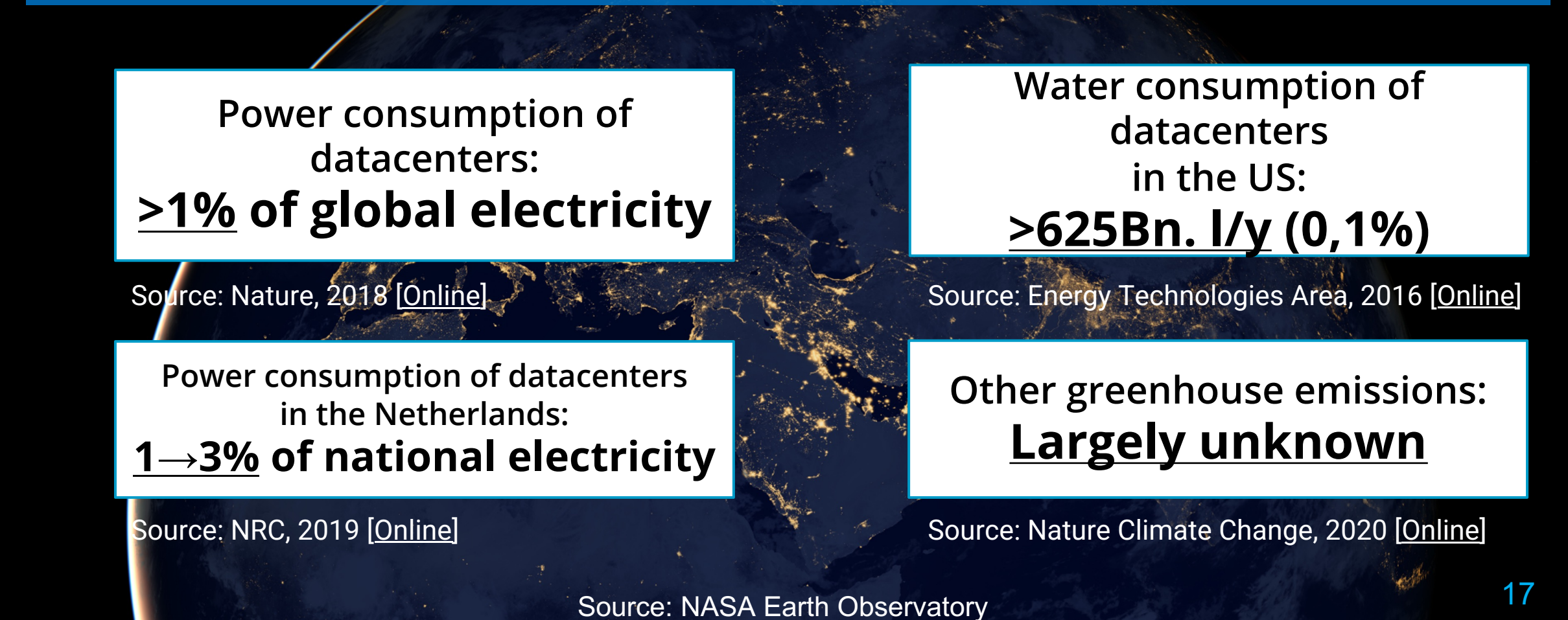
By Charlie Hall | @Charlie_L_Hall | Jan 5, 2021, 2:54pm EST



Source: Razorien/CCP Games

PHENOMENON: GAME SERVICE SUSTAINABILITY

UNCOVERING THE USE OF ENERGY AND WATER, THE IMPACT ON CLIMATE



Power consumption of datacenters:
>1% of global electricity

Source: Nature, 2018 [Online]

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

Source: Energy Technologies Area, 2016 [Online]

Power consumption of datacenters in the Netherlands:
1→3% of national electricity

Source: NRC, 2019 [Online]

Other greenhouse emissions:
Largely unknown

Source: Nature Climate Change, 2020 [Online]

Source: NASA Earth Observatory

PHENOMENON: CHEATING, OTHER TOXICITY IN GAMES

UNCOVERING THE PRESENCE OF TOXICITY AND FINDING WAYS TO ERADICATE IT

GAMING | ENTERTAINMENT | TECH

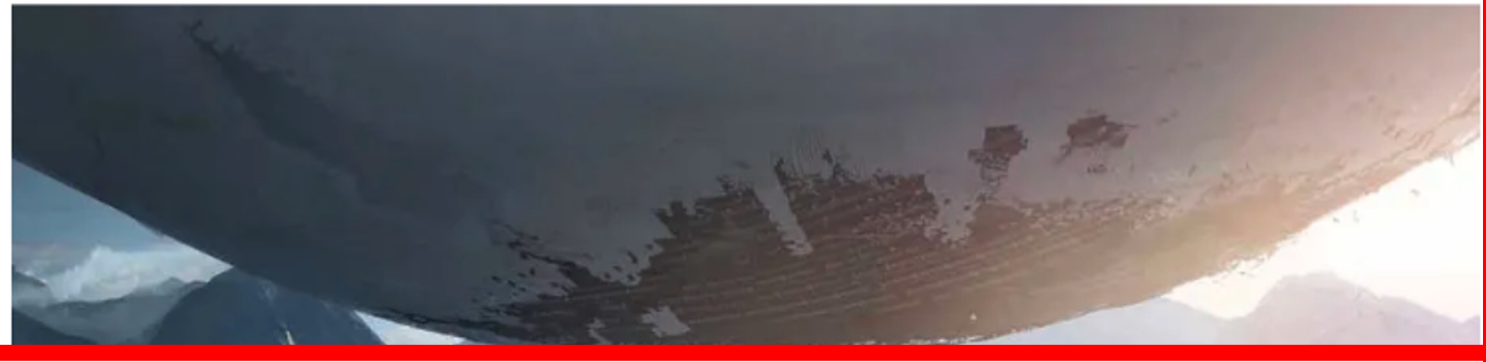
Source: The Verge.

Destiny 2 cheat creators come to a $13.5 million settlement with Bungie

A traveler-sized sum

By Alice Newcome-Beill | Jun 17, 2022, 3:09pm EDT

SHARE



Valorant will start monitoring your voice chats starting July 13th

It's part of Riot's efforts to crack down on disruptive behavior

By Emma Roth | Jun 26, 2022, 5:05pm EDT

SHARE

THIS TALK, IN A NUTSHELL:

Massivizing Online Games =
Rich challenge of computer systems, with societal impact!

What to do?

Online Gaming used to be art,
is now also massive computing

New science

Online Gaming used to be networking, is now all of computing

Lots of work

Online Gaming used to be game worlds, is now all kinds of apps

>

Massivizing Online Games = Rich challenge of computer systems, with societal impact!

1. This is the Golden Age of massive computer ecosystems
2. But we cannot take this technology for granted
3. A new science to help massivizing computer ecosystems
4. Understand how things work: observe, synthesize, experiment
5. Design and build better systems:
   virtual worlds, analytics, content generation, meta-gaming
6. What's next? PLATO in the 21st century
7. Beyond games: Massivizing computer systems is a national priority in the NL!

Lots to do next!

A new science, of complex, smart computer ecosystems

3

(operational simplicity for the user)

DISTRIBUTED ECOSYSTEMS, 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 and providing services
    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

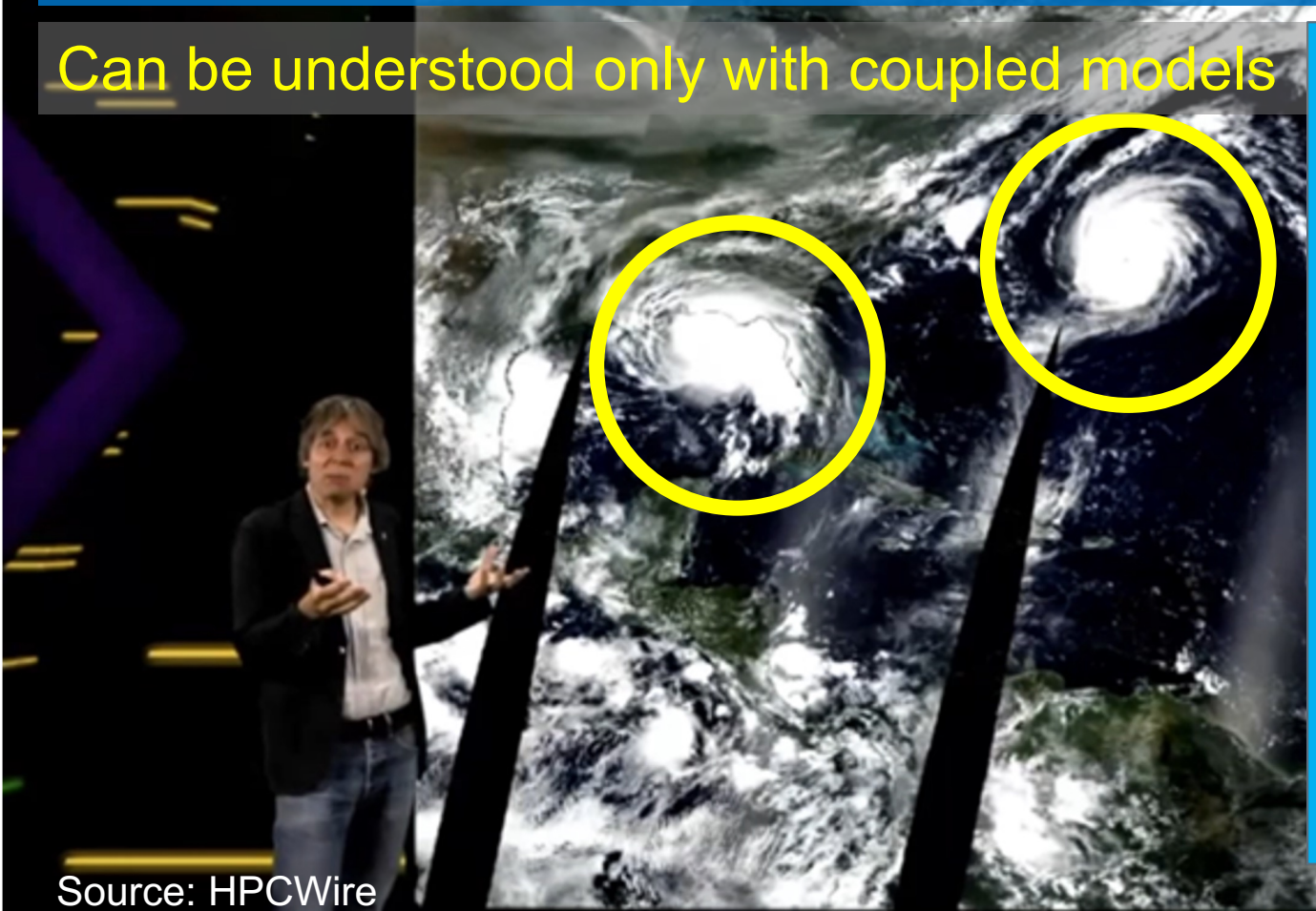
Iosup et al., Lecture Notes in Distributed Systems, Section 1.1.1

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

AN ANALOGY: MASSIVIZING CLIMATE SCIENCE

TAKE A HOLISTIC VIEW, BASED ON COUPLED NATURAL SYSTEMS

Can be understood only with coupled models



Source: HPCWire

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

(ONLINE) GAMES = MASSIVE COMPUTING ECOSYSTEMS

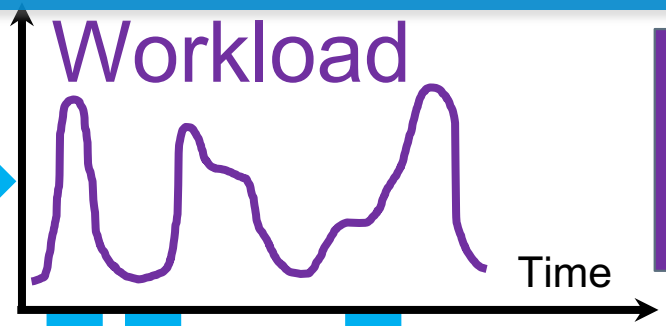
Do you recognize this App?

Here is how it operates…

ECOSYSTEM = SERVICES + COMPUTING + SMARTS + GOALS

Creators

Digital Services



100s of services … an ecosystem

Resource Manager and Scheduler

Computing Continuum

Extreme Automation, Performance, Dependability, Sustainability

THIS IS THE MODERN SCIENCE OF COMPUTER ECOSYSTEMS

IN A NUTSHELL

WHO?	 SCIENTISTS,  ENGINEERS,  DESIGNERS,  MANAGERS, ETC.
WHAT? MAIN GOAL	UNDERSTAND AND CONTROL DISTRIBUTED ECOSYSTEMS, TO TURN THEM INTO EFFICIENT, AUTOMATED UTILITIES
HOW? CENTRAL PARADIGM	ECOSYSTEM OPERATION AND CHARACTERISTICS DERIVE NON-TRIVIALLY FROM ITS SYSTEMS AND USERS (RECURSIVELY)
WHICH APPROACH?	MODERN DISTRIBUTED SYSTEMS AND PROBLEM-SOLVING

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

Massivizing Online Games = Rich challenge of computer systems, with societal impact!

1. This is the Golden Age of massive computer ecosystems
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7. Beyond games: Massivizing computer systems is a national priority in the NL!

Lots to do next!

LET'S UNDERSTAND HOW THINGS WORK!

4

> S01 S02 S03 S04E01 S04E02 S04E03 S04E04 S04E05 S05E01 S05E02 S05E03 S05E04 S05E05 S06 S07 S08

Message: 4_A Synthesize the ecosystem reference architecture

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

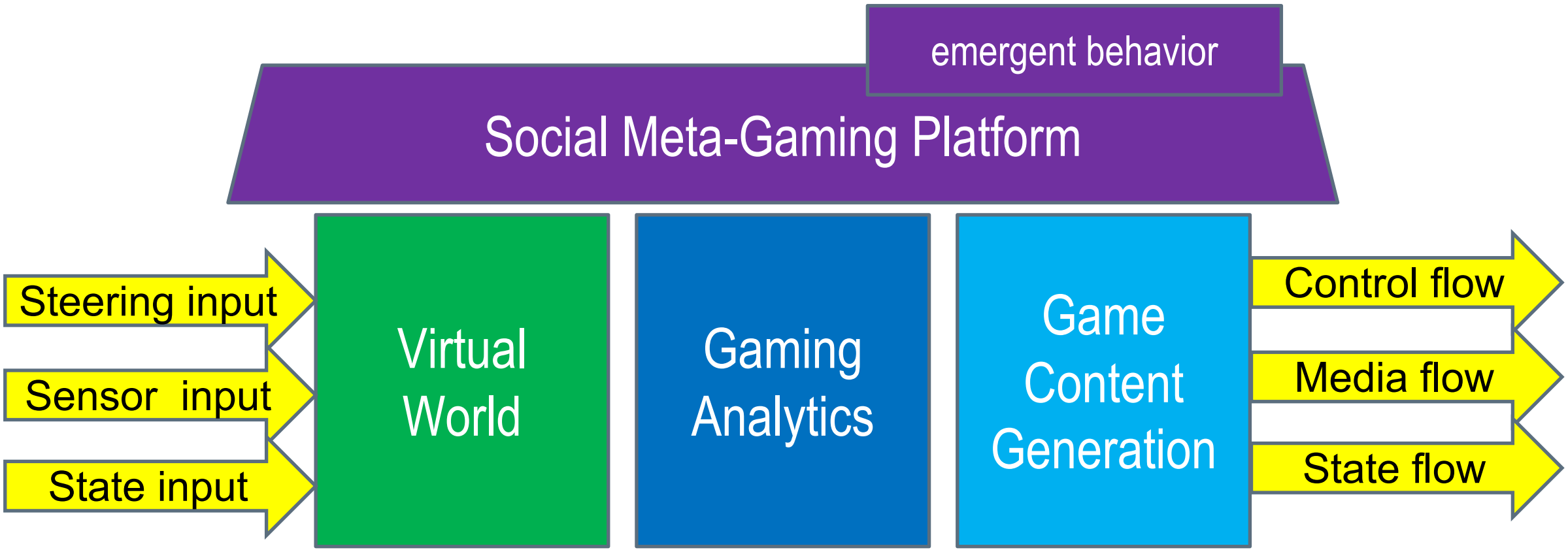
International Human Genome Sequencing Consortium, Initial sequencing and analysis of the human genome, Nature 409, Feb 2011. [Online]

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

ONLINE GAMING ECOSYSTEMS, HIGH-LEVEL VIEW

THE COMPLEXITY CHALLENGE

IOSUP ET AL. MASSIVIZING ONLINE GAMES



Iosup, Shen, Guo, Hugtenburg, Donkervliet, Prodan (2014) Massivizing online games using cloud computing: A vision. ICME Workshops [Online]

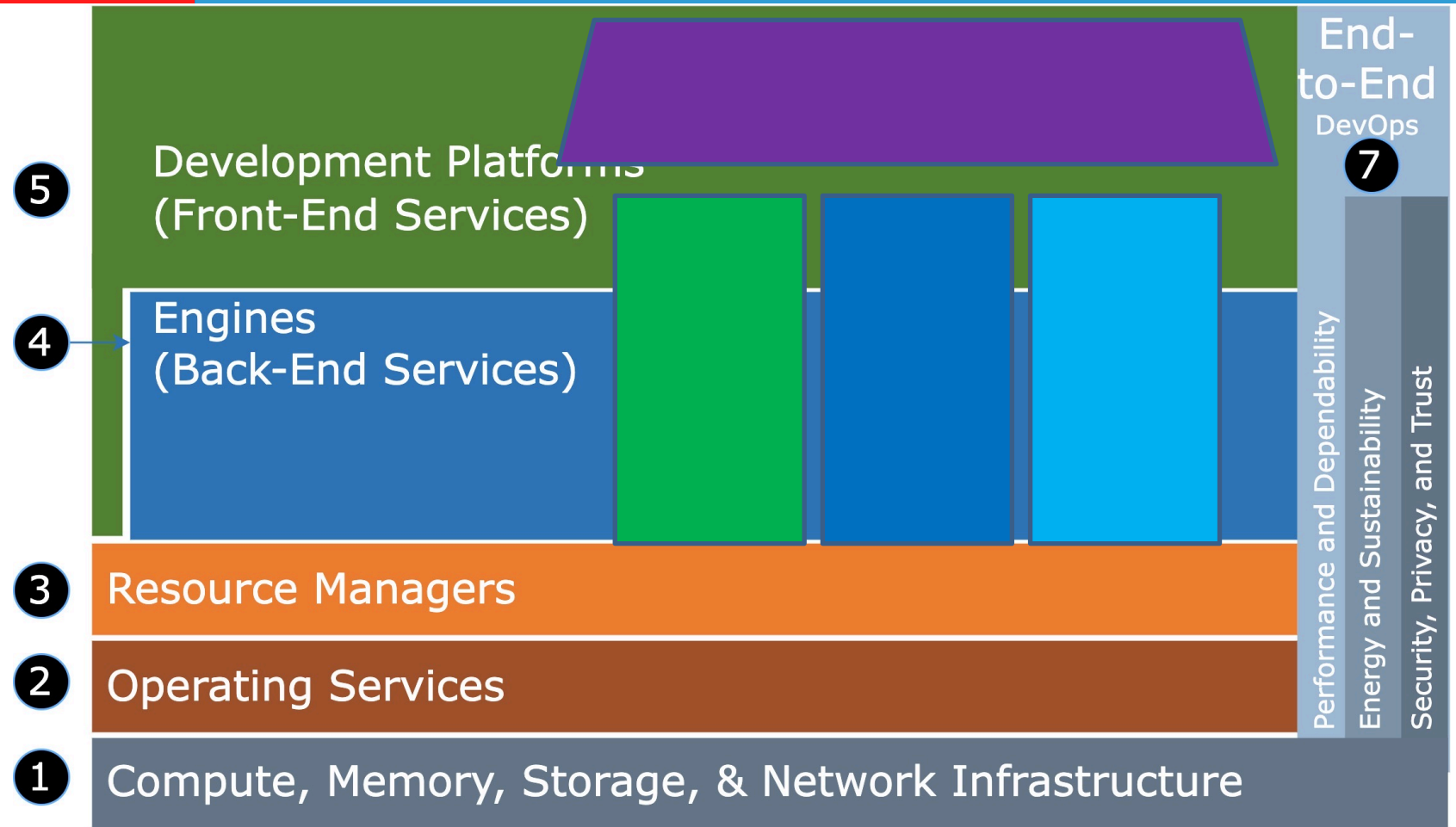
HOW TO MANAGE SYSTEM COMPLEXITY?

THE COMPLEXITY CHALLENGE

IOSUP ET AL. REFERENCE ARCHITECTURE FOR DCS, 2016

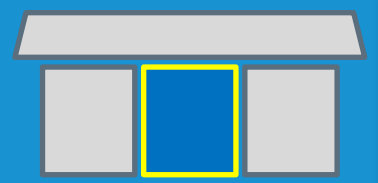
Focus on DevOps + Applications,
5 Core Layers:

5. Development (Front-end)
4. Runtime Engines (Back-end)
3. Resources
2. Operations Services
1. Infrastructure



[Iosup et al. ICDCS'18]

AI/ML/DL OPERATIONS FOR GAME SERVICES



ISSUES: COMPLEXITY, NON-TECHNICAL

IOSUP ET AL. 2021

Gaming Analytics

2

ML app = small part!

Adapted from:

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

7 Data & App Market: Model Sharing (GPT-3); Data Lake (Private); Federated Data Processing; Data sovereignty

5 Development Platforms (Front-End Services): Portals (Desktop App, ..., Notebook, CLI); High-Level Languages (Query, Domain-Specific, etc.) (Keras, Spark SQL); Programming Models (Data/NN structure / model / format / meta) (TensorFlow, Spark)

4 Engines (Back-End Services): Execution (ML Workflow: AirFlow; TensorFlow, Spark); Memory & Storage (Hops, HopsFS, HDFS); Network (Horovod, Globus)

3 Resource Managers: Kubernetes, Mesos, YARN

2 Operating Services: Zookeeper, Kafka

1 Infrastructure Compute & Storage: Physical (Neuromorph; CPU, GPU, TPUv4, ...); Virtual (VMs, Containers)

DevOps 6

Message: 4_B

Observe, measure ecosystem operation (mostly dynamics)

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

Radio Microwave Infrared Visible Ultraviolet X-Ray Gamma Ray

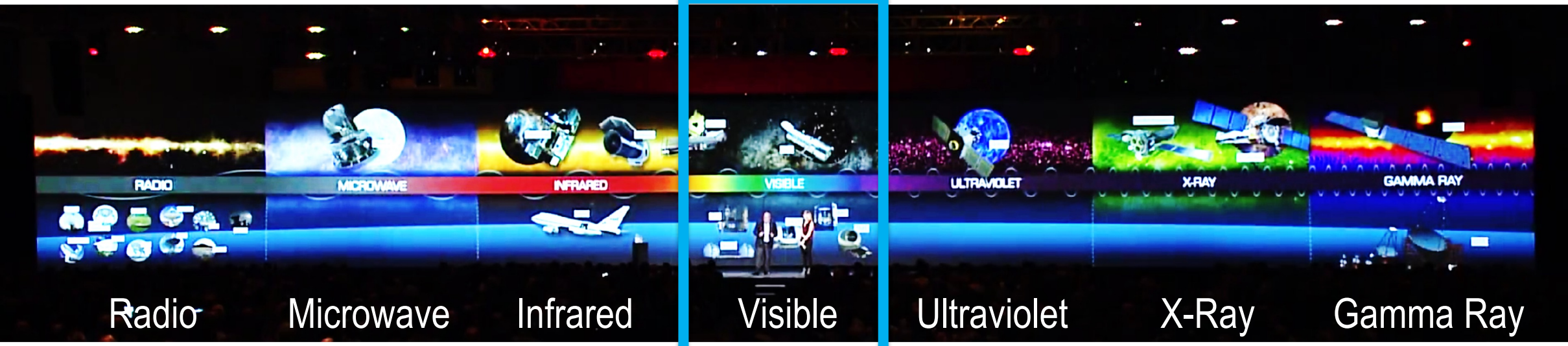
James Cordes, The Square Kilometer Array, Project Description, 2009 [Online]

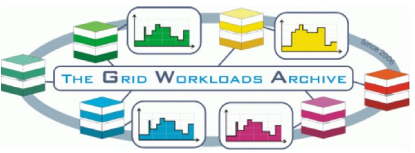
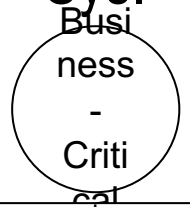
The Square Kilometer Array Factsheet, How much will it cost?, 2012 [Online]

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,
		[Versluis et al. TPDS'21]				
[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]

OUR VISION: THE DISTRIBUTED SYSTEMS MEMEX

Bush (1945) As we may think. The Atlantic, Jul 1945.

UNCOVERING THE MYSTERIES OF OUR UNIVERSE, PHYSICAL AND DIGITAL

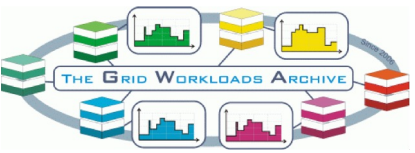
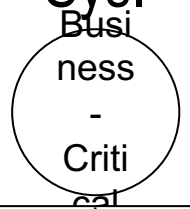
Find and eradicate performance issues

Quantitative evidence

Enable new designs and automation

Cultural and ethical concerns

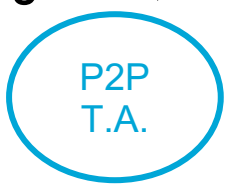
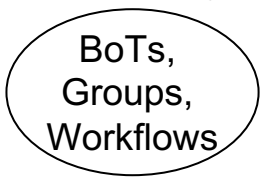
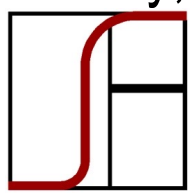
Understand how entire ecosystems behave and evolve

Cloud, Grid, Edge, Fog, etc.	One aspect: BigData, P2P	Sci.&Eng. Apps+Sys.	Consumer Apps+Sys.	Enterprise Sys.	Systems, Ecosystems	Performance, Availability,
						
[Iosup et al. EGCS'08]	[Zhang et al. CoNext'10]	[Versluis et al.'19] [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]

UNKNOWN PHENOMENA: INTER-, ADAPT-, EXAPTATION

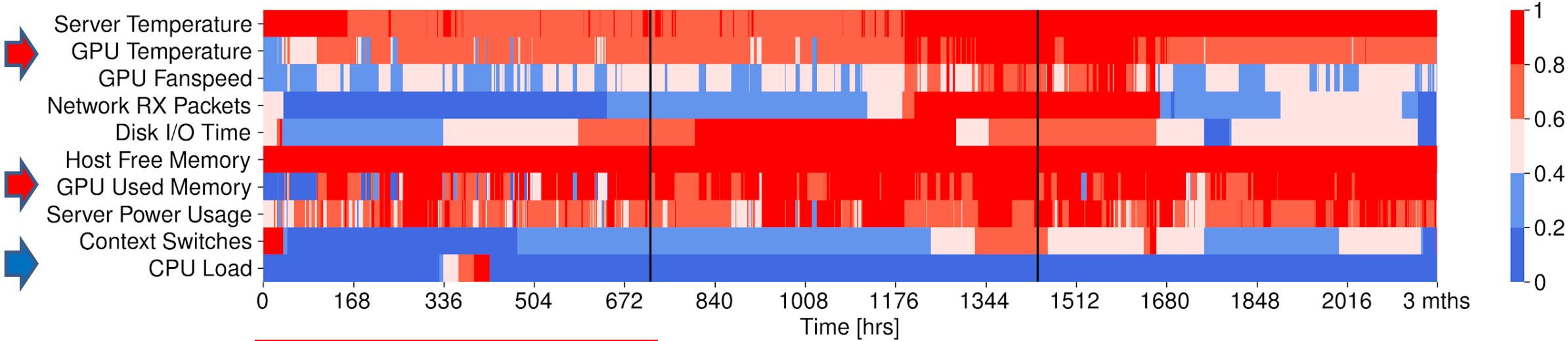
UNCOVERING THE MYSTERIES OF OUR UNIVERSE, PHYSICAL AND DIGITAL

SOME OF OUR DISCOVERIES

...	...	...	...	...
BOTS, NOT PARALLEL JOBS	GROUPS NOT RARE, DOMINANT	COMMUNITY DYNAMICS	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]

One Basic Result

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



Hot GPUs

Cold CPUs*

* when GPUs

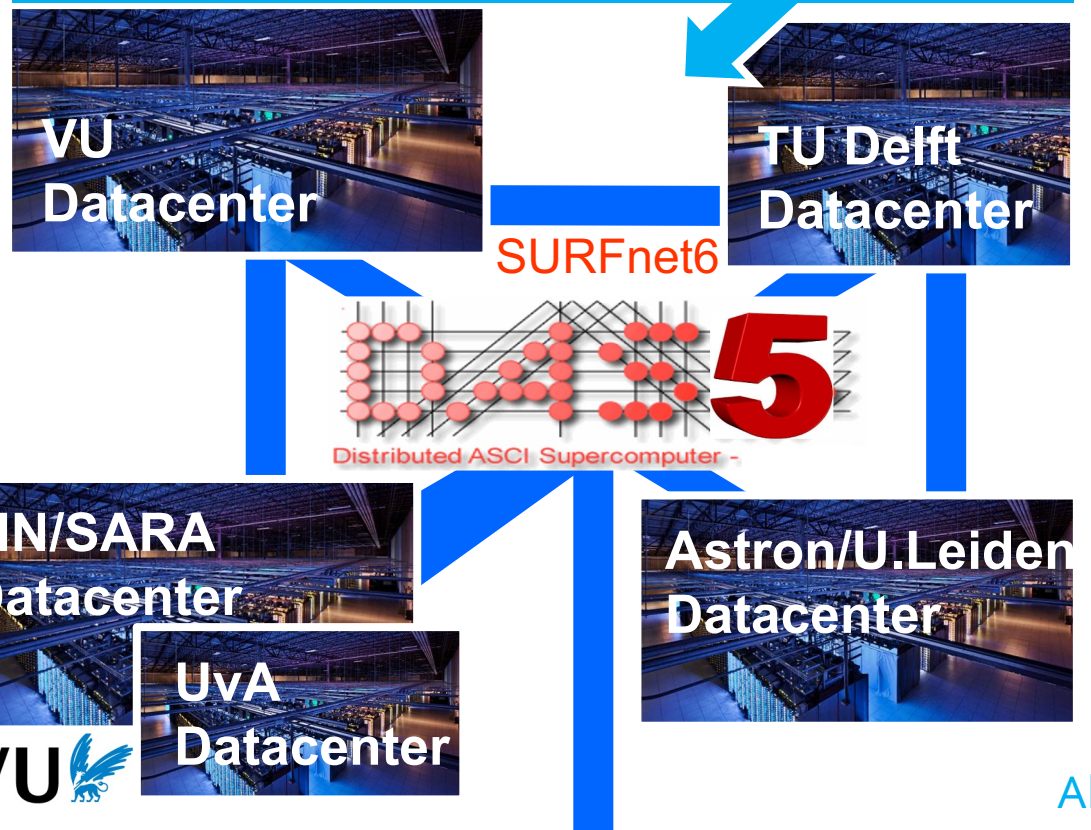
Could use less powerful, less expensive CPUs

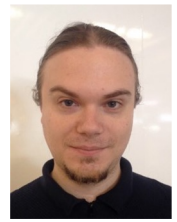
Message: 4_C Experiment with the ecosystem, real-world + simulation

EXPERIMENTAL METHODS OF DISCOVERY

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

Our Prototypes (*in phyisico/in vitro*)





Alex Uta

Georgios Andreadis

Fabian Mastebroek

acheendra

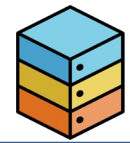
Maria

Laurens Versluis

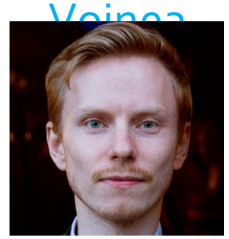
+

We also use clouds

+



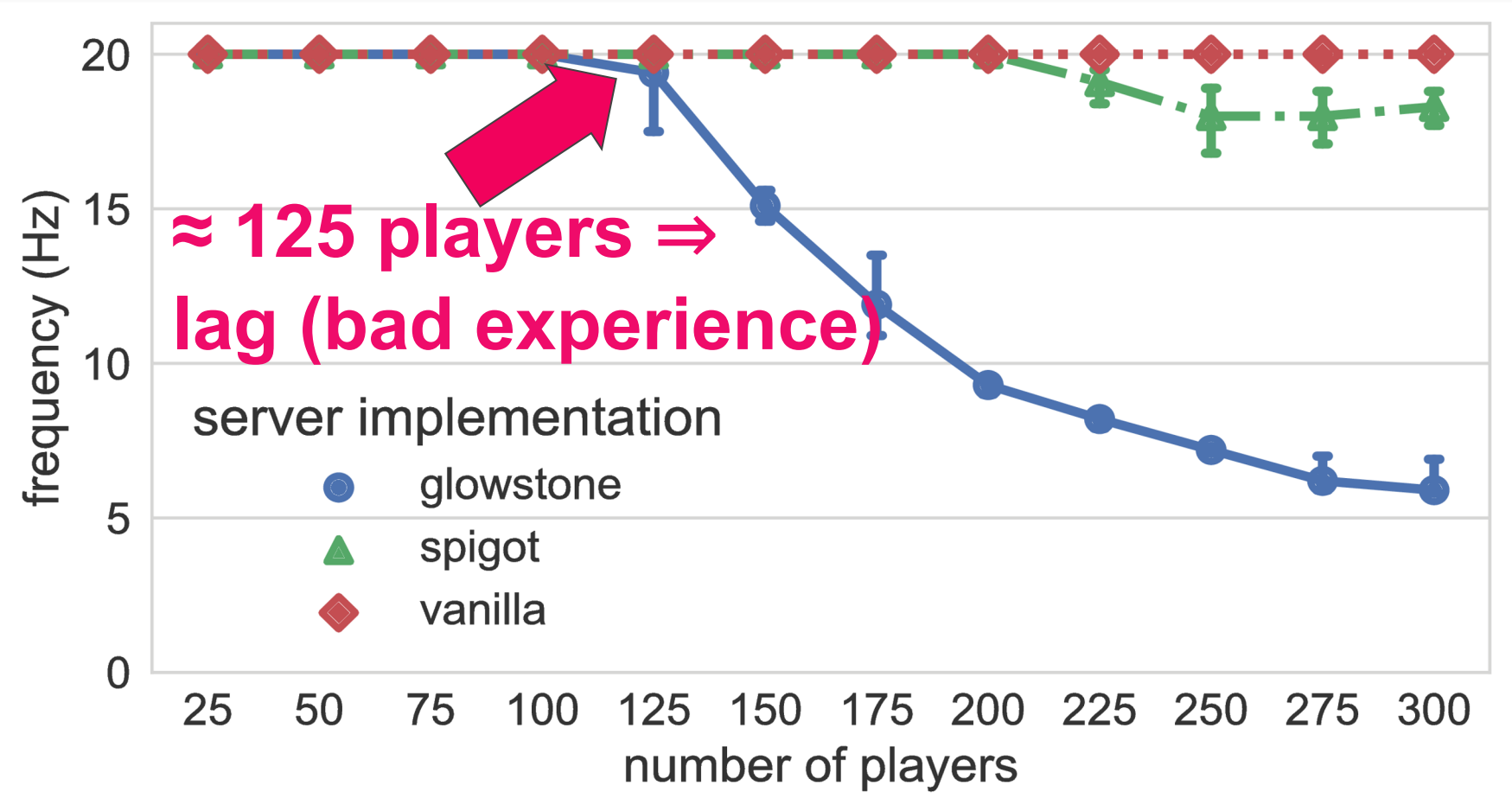
OpenDC



Alexey Ilyushkin

And simulators (*in silico*)

Minecraft only scales to hundreds of players



Jerom van der Sar, Jesse Donkervliet, Alexandru Iosup: Yardstick: A Benchmark for Minecraft-like Services. ICPE 2019

atlarge-research.com/opencraft/

… CAN WE AFFORD X? WHAT IF Y? A vs. B … vs. Z?

TOO COSTLY TO CONDUCT REAL-WORLD EXPERIMENTS, SO WE BUILT A SIMULATOR

OpenDC
simulator

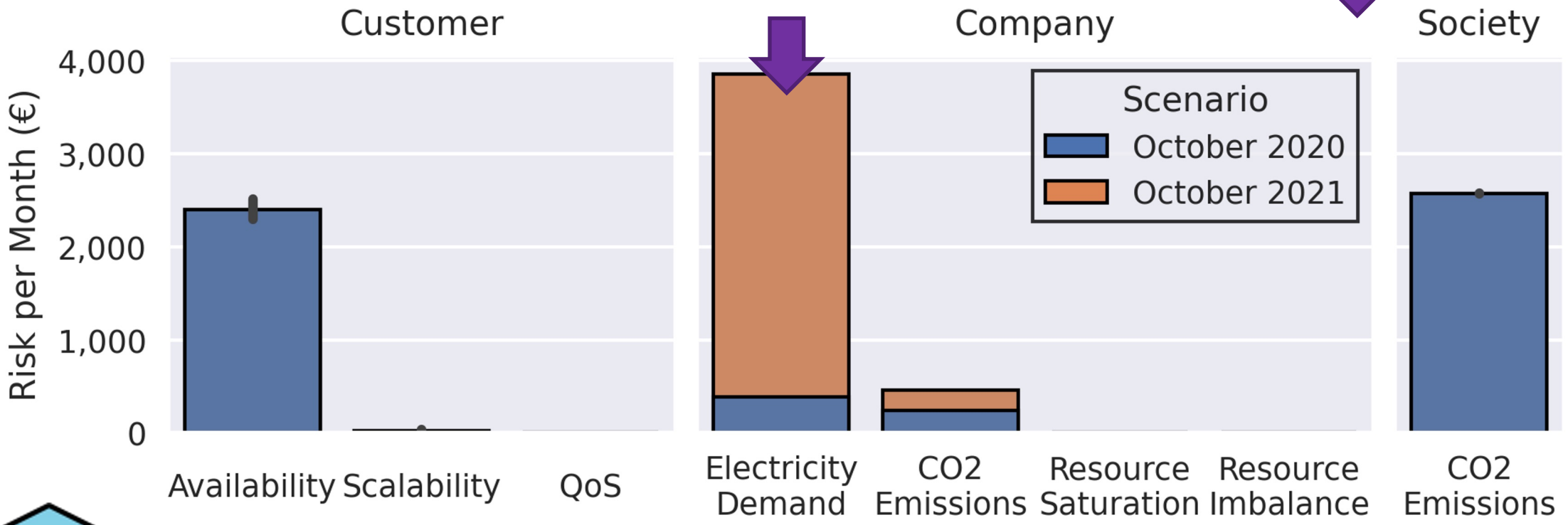
Learn more:
opendc.org

- Short-term resource management
- Long-term capacity planning
- Sophisticated model → many Qs, goals
- Supports many kinds of workloads
- Supports many kinds of resources
- Validated for various scenarios
- Work with major NL hoster
- Used in training, education, research

Fabian Mastenbroek

and more...

Electricity Expenses become High Risk



Electricity expenses become **primary risk** in datacenters

Experiments are also Expensive!
An Environmental Perspective

112

Core-hours

2.1

kWh

Delft →  → Rotterdam

In Simulation

8,600,000,000

Core-hours

116,000,000,000

kWh

 **x 55 billion!**

In Reality

Exact numbers confidential, depend on topology

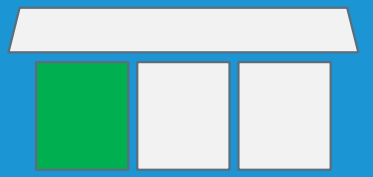
Massivizing Online Games = Rich challenge of computer systems, with societal impact!

1. This is the Golden Age of massive computer ecosystems
2. But we cannot take this technology for granted
3. A new science to help massivizing computer ecosystems
4. Understand how things work: observe, synthesize, experiment
5. Design and build better systems:
   virtual worlds, analytics, content generation, meta-gaming
6. What's next? PLATO in the 21st century
7. Beyond games: Massivizing computer systems is a national priority in the NL!

Lots to do next!

LET'S DESIGN & BUILD IN DISTRIBUTED 5 ECOSYSTEMS!

Message: 5A

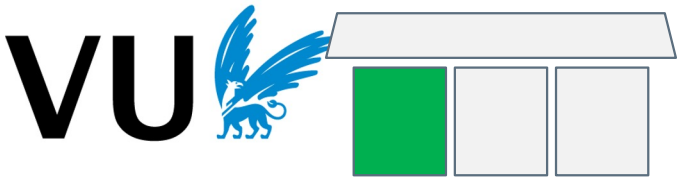


Scaling ~ creative palette of techniques, design and use wisely

5a SCALING IN AND OUT THE VIRTUAL WORLD OF A GAME

Goal: Build an efficient platform for massive scalability

1. Close to players
2. No upfront costs, no maintenance, pay for what is actually used
3. Compute platforms: multi-cores, GPUs, clusters, all-in-one!
4. Auto-scaling mechanisms and policies
5. Performance guarantees
6. Hybrid deployment model
7. Geo-distributed scheduling
8. Code for various compute platforms—platform profiling
9. Load prediction miscalculation costs real money
10. What are the services?
11. Vendor lock-in?
12. *My* data



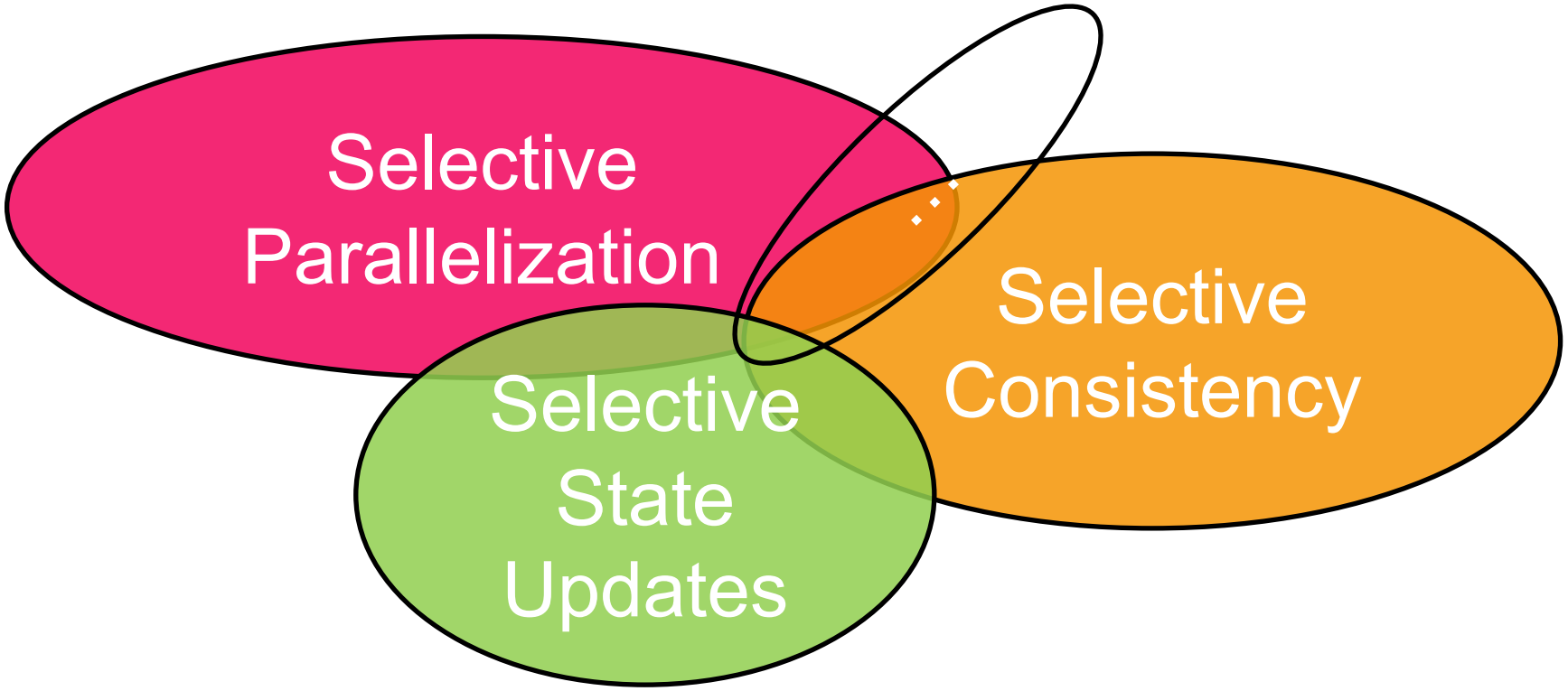
Done

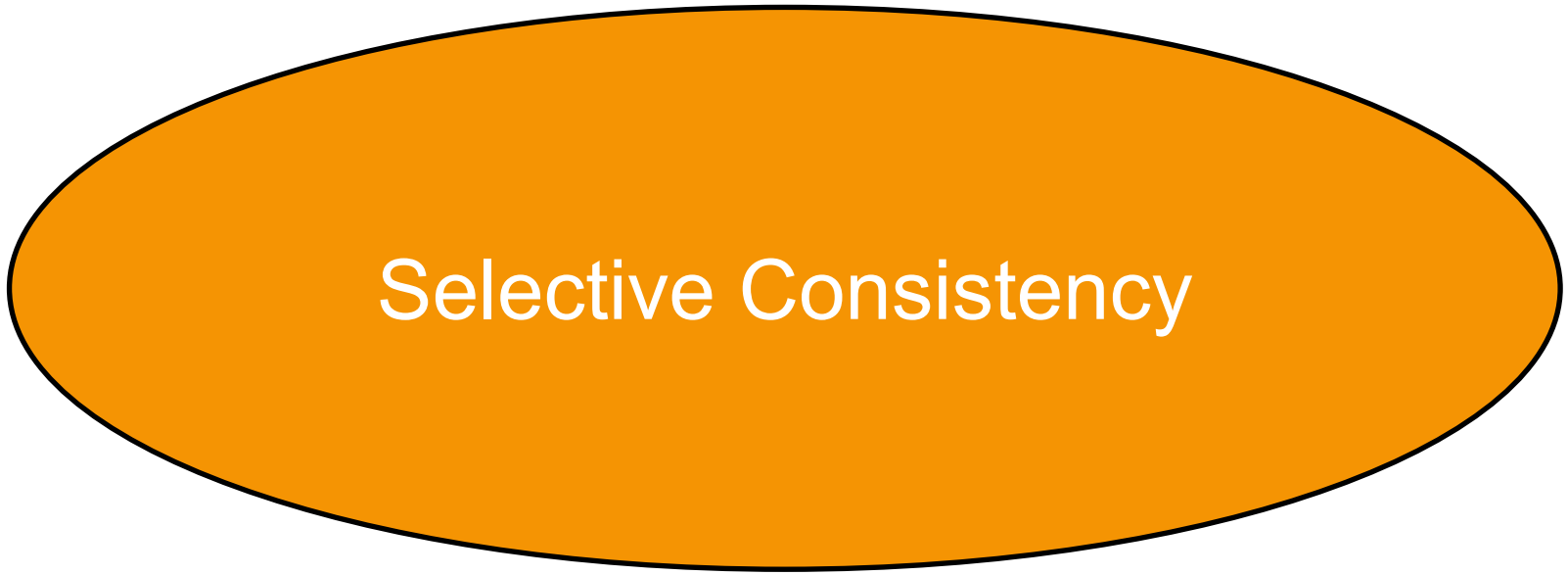
Open challenge

HOW TO SCALE GAMES ACROSS THE ECOSYSTEM? 5A1

IT'S SCALING TECHNIQUES!

REFERENCE VIEW ON OPERATIONAL TECHNIQUES



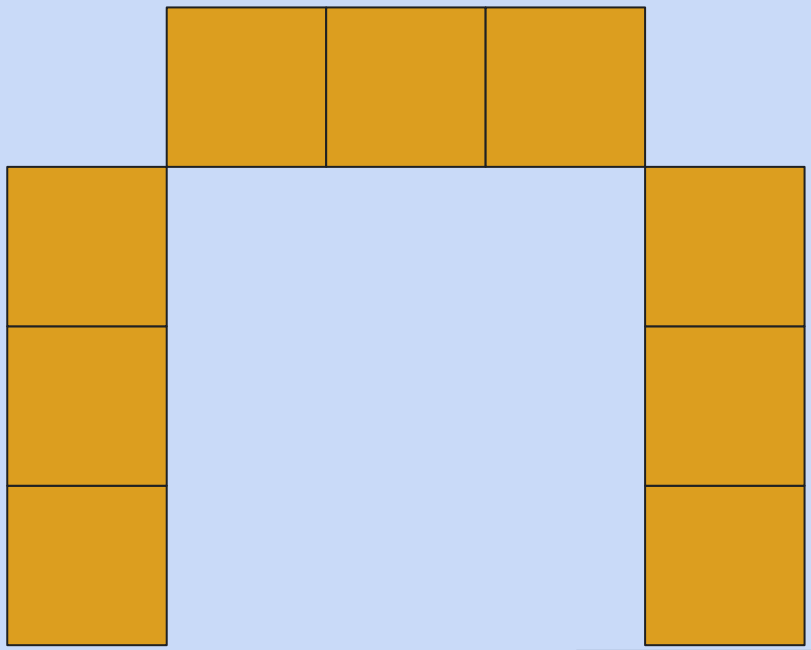

Selective Consistency

CHALLENGE: CONSISTENCY IN HIGH-STAKES APPS

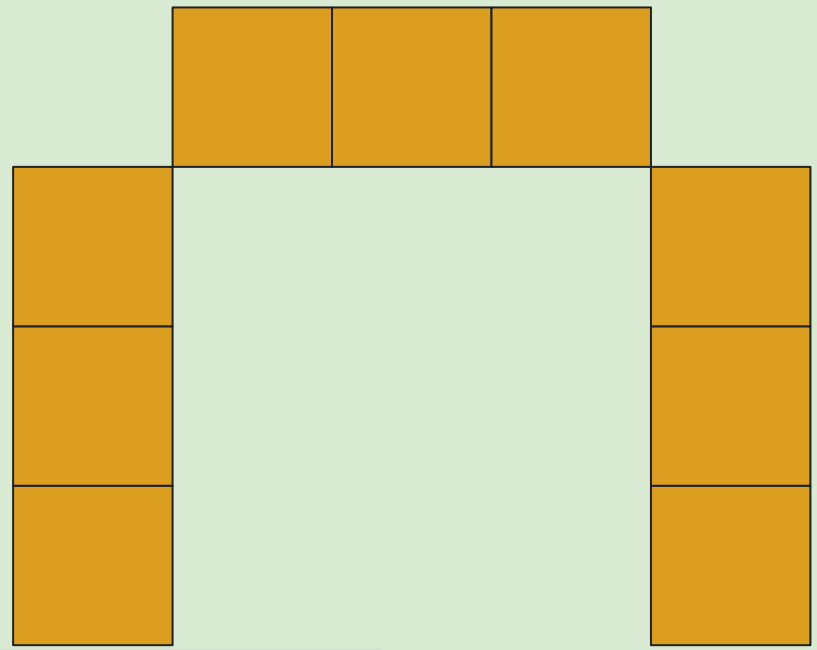
Consistency Example: Current Approach

Tick: 1

Server



Client



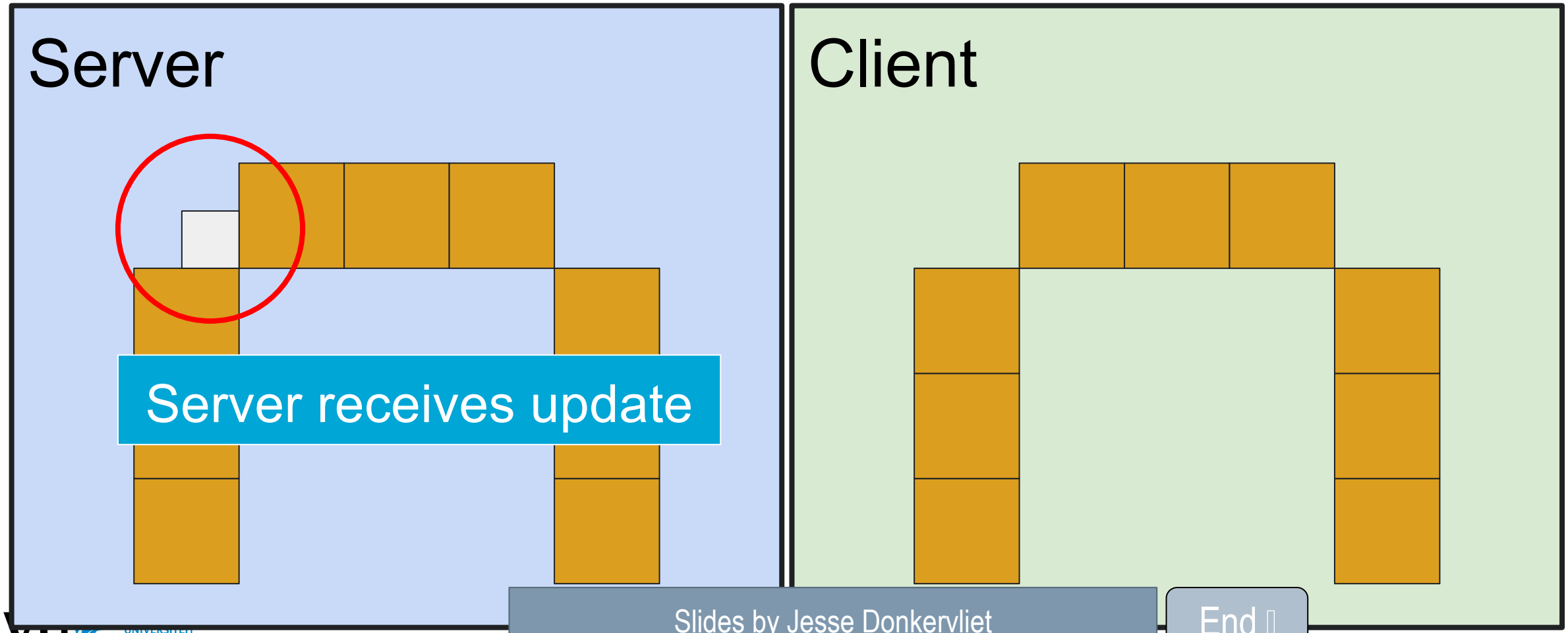
Slides by Jesse Donkervliet

End

CHALLENGE: CONSISTENCY IN HIGH-STAKES APPS

Consistency Example: Current Approach

Tick: 2



Slides by Jesse Donkervliet

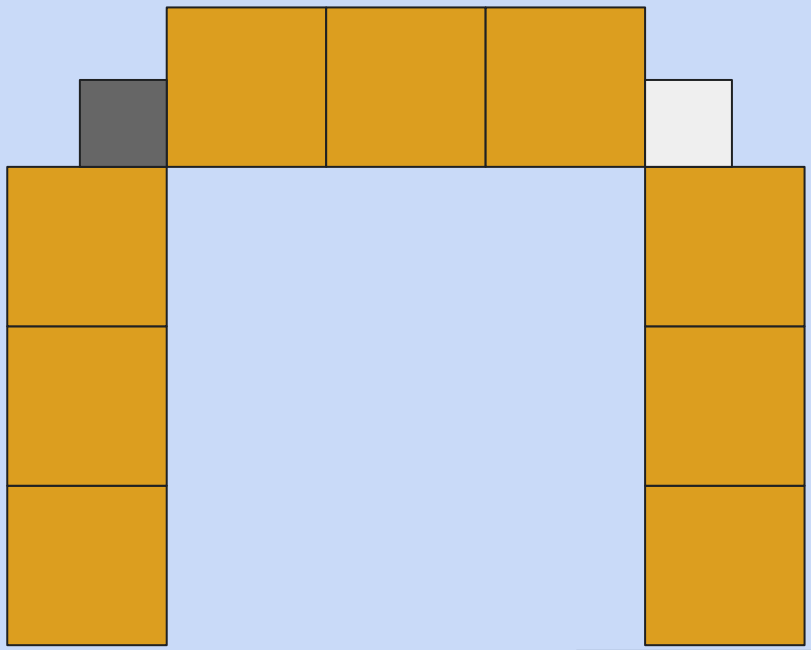
End

CHALLENGE: CONSISTENCY IN HIGH-STAKES APPS

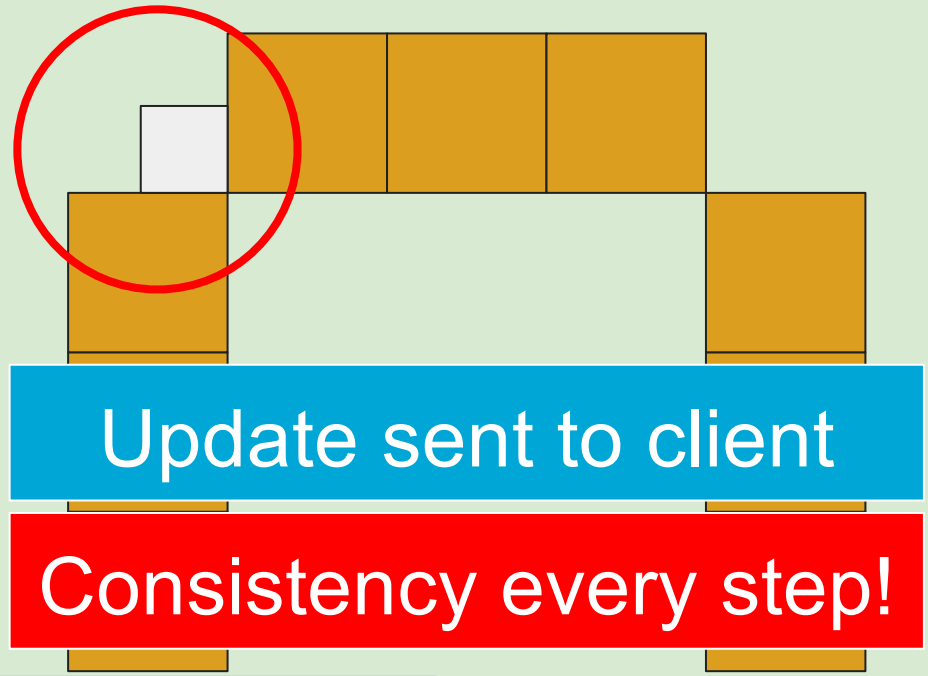
Consistency Example: Current Approach

Tick: 3

Server



Client



Update sent to client

Consistency every step!

Slides by Jesse Donkervliet

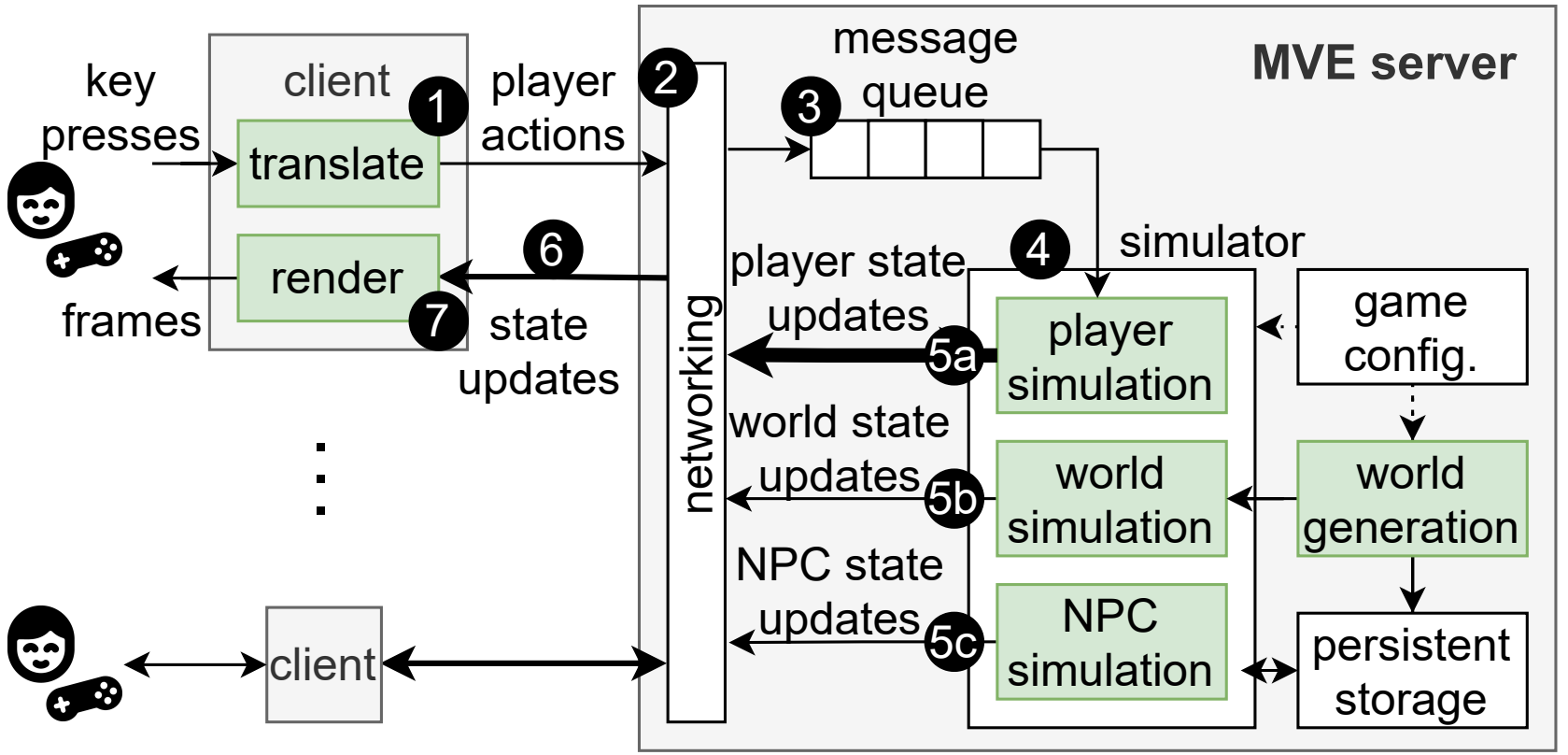
End

Dyconits: Scaling Minecraft-like Services through Dynamically Managed Inconsistency

Jesse Donkervliet, Jim Cuijpers, Alexandru Iosup

jesse.donkervliet@vu.nl
@jdonkervliet
https://atlarge-research.com/opencraft/

MVE System Model

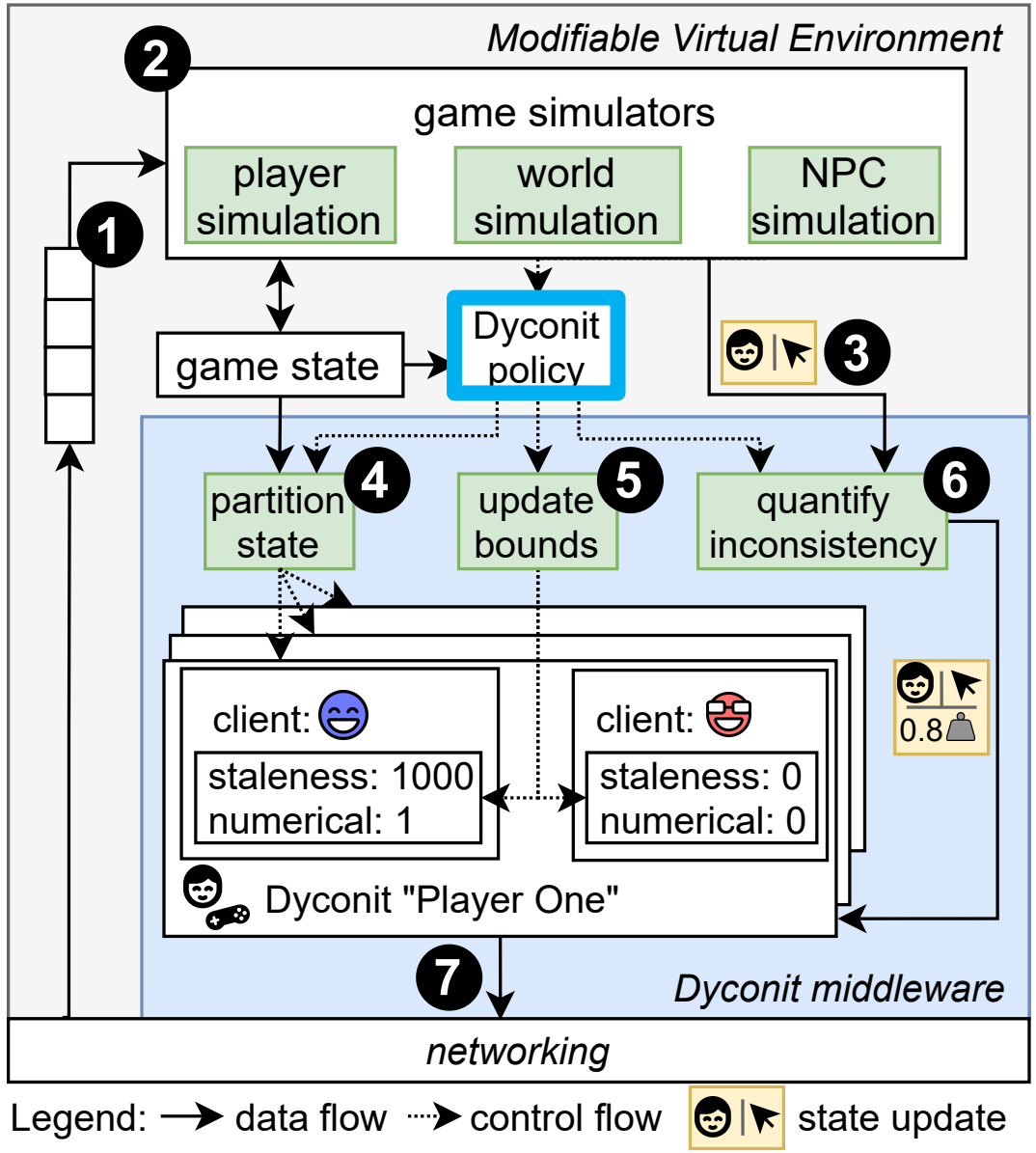


Design of the Dyconit Middleware

1. Fundamental DS concept
   Conits

2. Mechanism to deliver function/SLA
   Dyconits

3. Technique for short-term dynamics
   Adaptive dyconit management, with policies



Dyconits: Using the conit consistency model

Quantify inconsistency in the system using three metrics

1. Staleness (how old is this update?)

2. Numerical error
   (how large is the impact of this update?)

3. Order error
   (how does this update relate to other updates?)

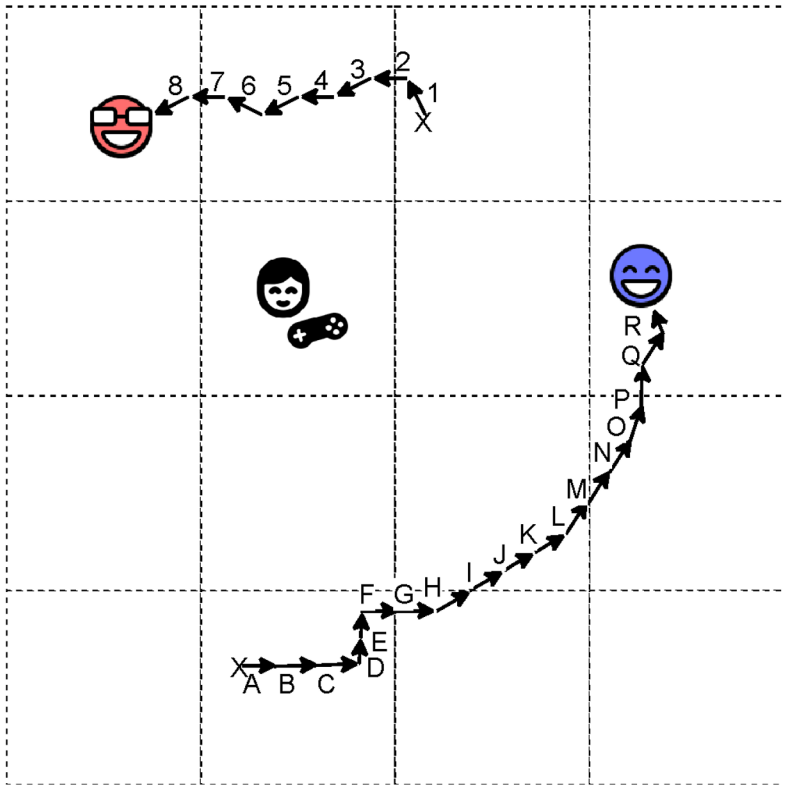
+ DyConit = conit + dynamic conit management
  (change bounds at runtime, based on actual gameplay)

Slides by Jesse Donkervliet

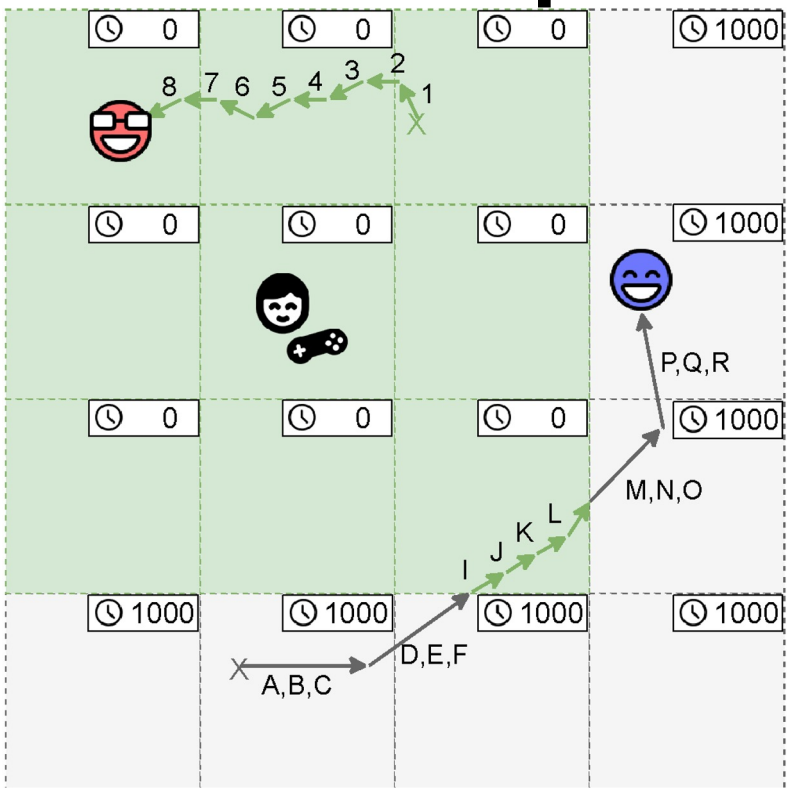
End →

Dyconit Policies Here be algorithms!

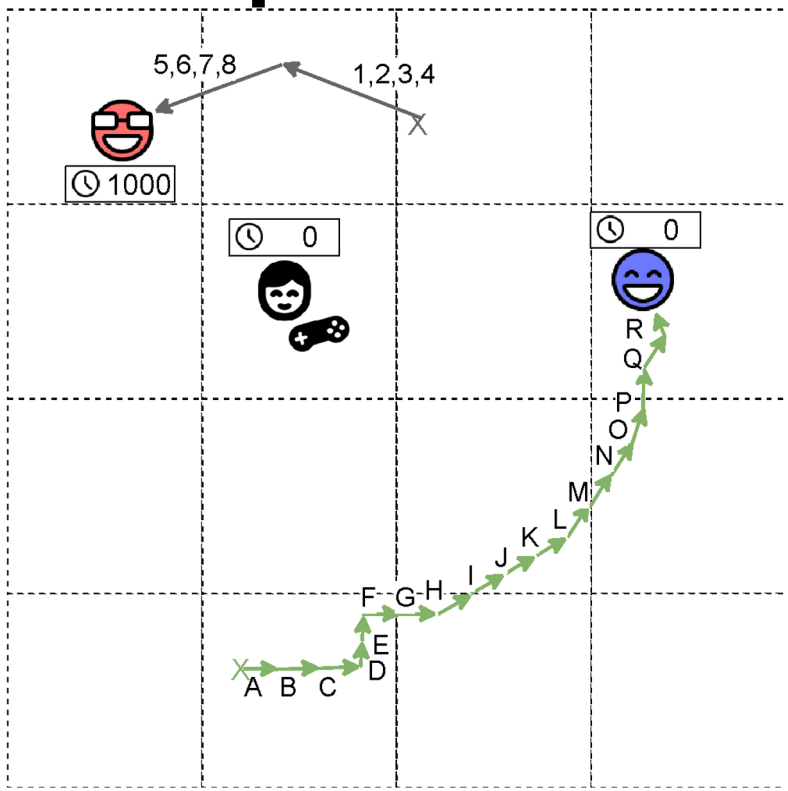
Use Feedback to Improve Operation



(a) No Dyconits

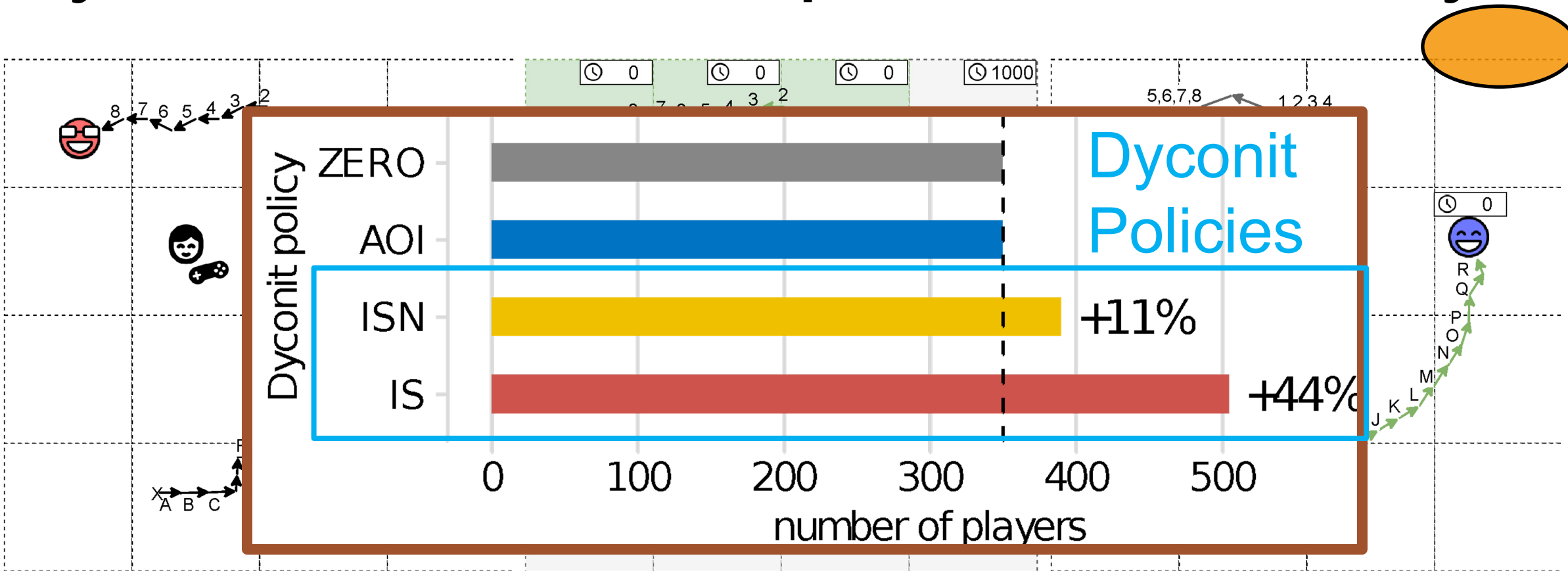


(b) Area Of Interest policy



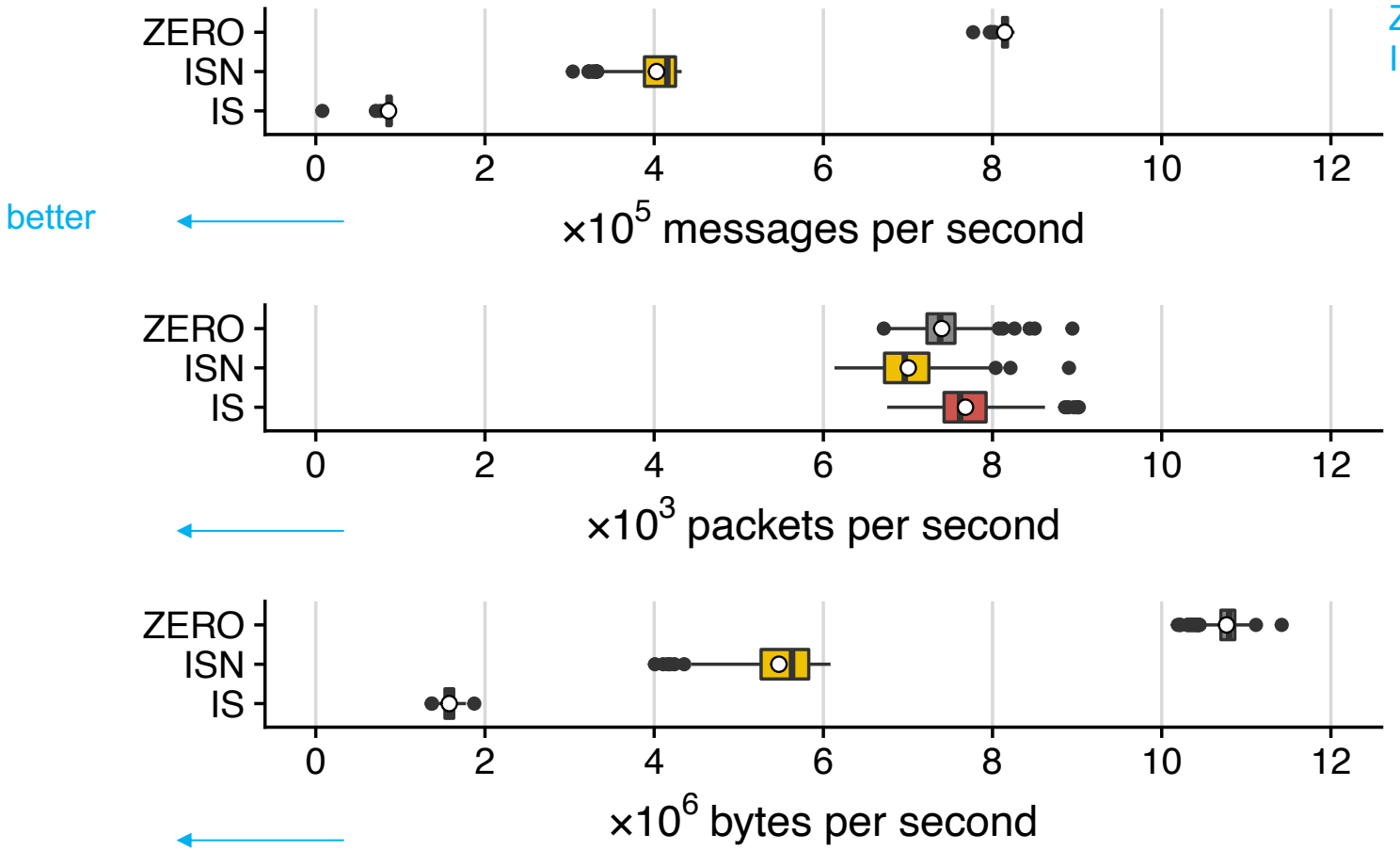
(b) Interest Set policy

Dyconit Policies Improve Scalability



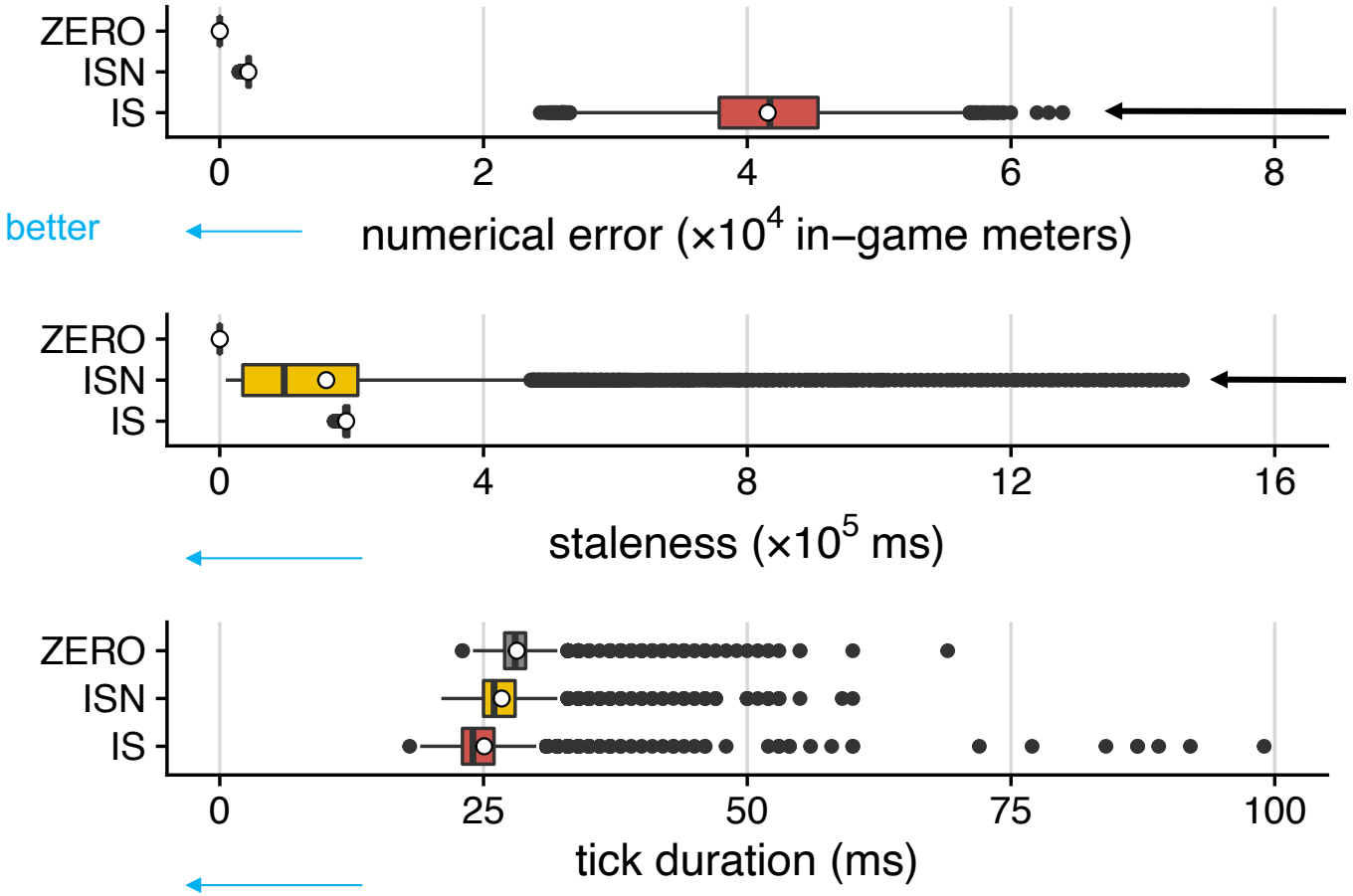
(a) No Dyconits (b) Area Of Interest policy (b) Interest Set policy

Dyconits Reduce Bandwidth Usage



ZERO = common game
ISN, IS = our dyconits

Dyconits Bound Inconsistency

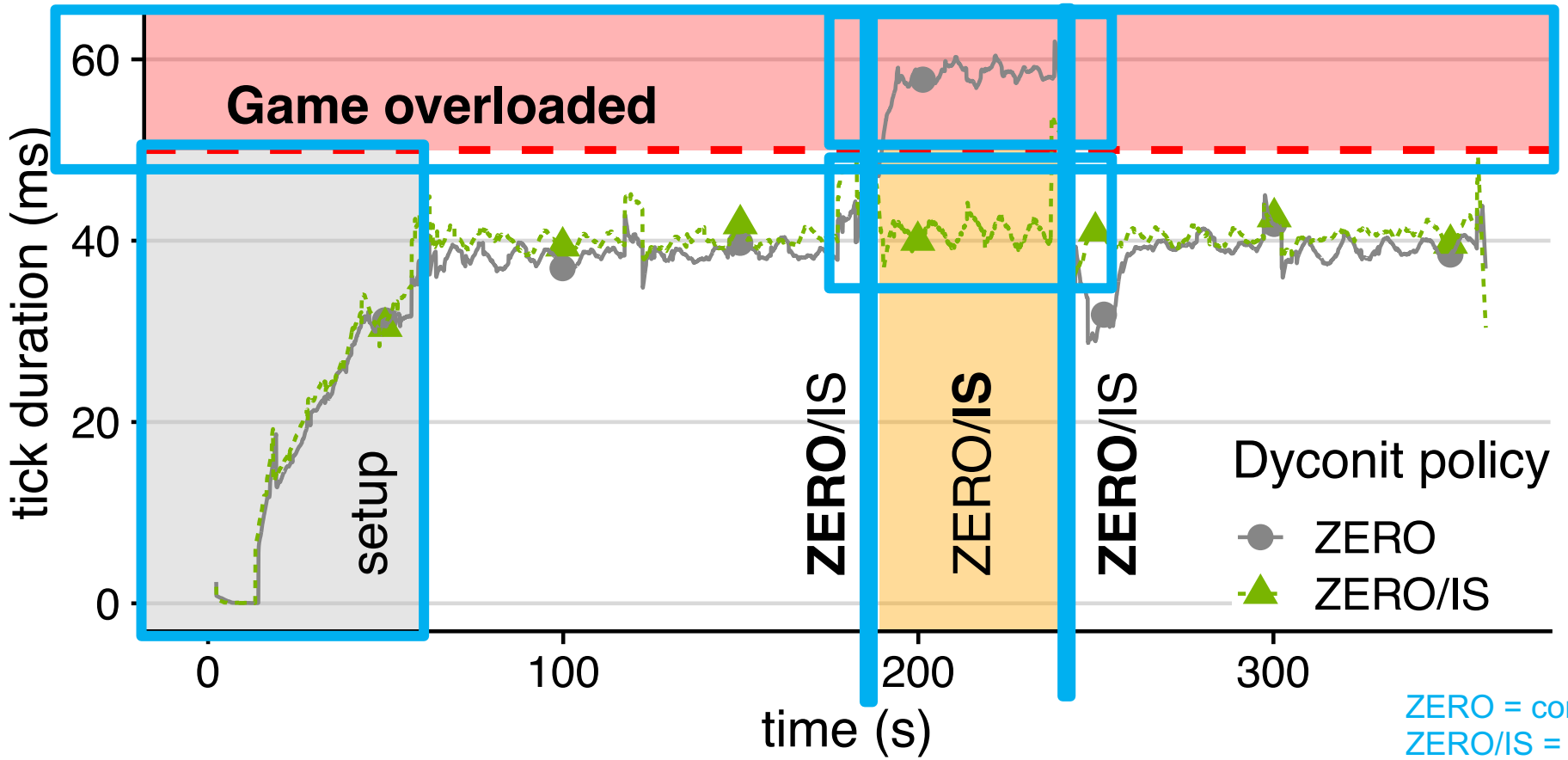


≈0.55 to 1.5 meters error per player per avatar

Up to 7.5 seconds error per player

ZERO = common game
ISN, IS = our dyconits

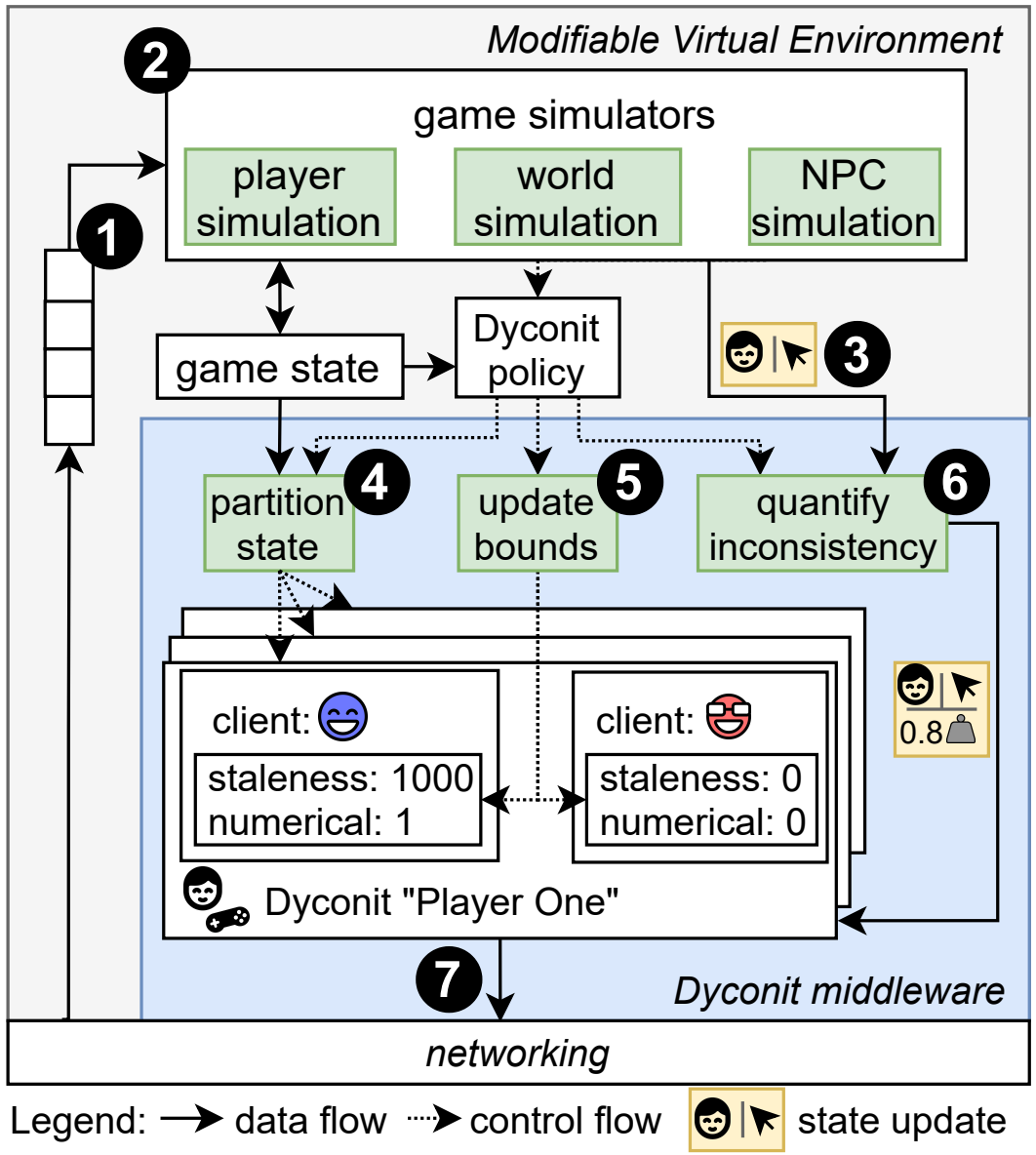
Dyconits Can Dynamically Trade-off Consistency for Performance



ZERO = common game
ZERO/IS = our dynamic approach

Main Contribution

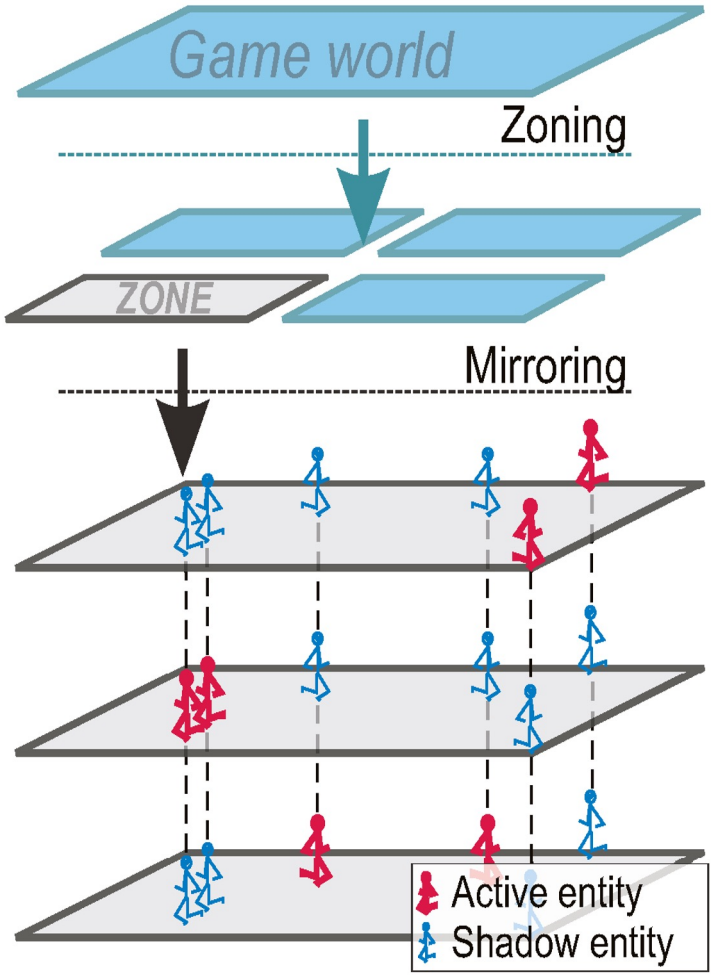
1. Design of *Dyconits* to address scalability issues
2. Realization of a Minecraft-like game using Dyconits; Game and Dyconits code publicly available
3. Real-world experiments to evaluate scalability



Opencraft: https://github.com/atlarge-research/opencraft
Dyconits: https://github.com/atlarge-research/opencraft-dyconits


Selective Parallelization

Game parallelization models

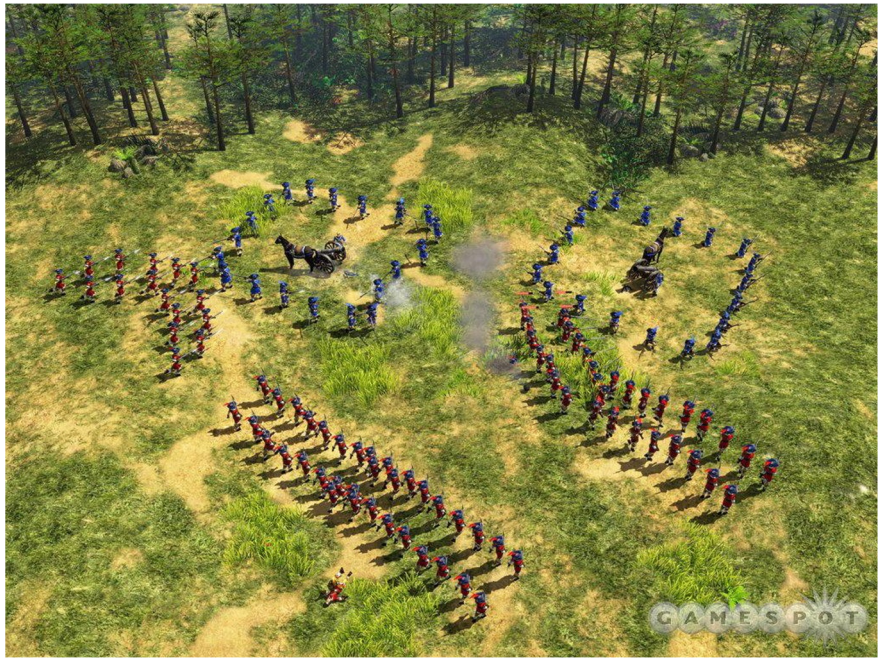


- Zoning: huge game-world division into geographical sub-zones – each zone is handled by different machines
- Mirroring: the same game-world handled by different machines, each one handling a subset of all entities
- **Instancing/sharding**: multiple instances of the same zone with independent states


Selective State Updates

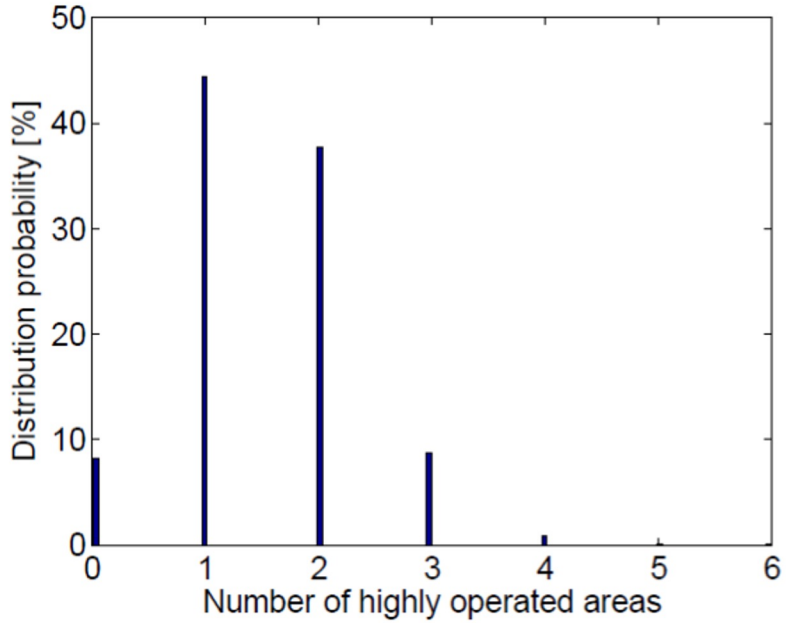
Remember RTS Games?

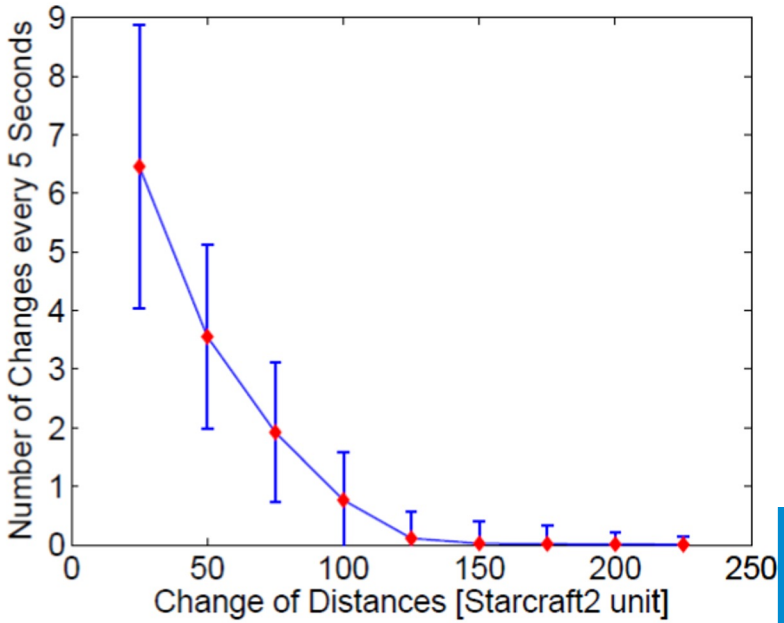
- Players control tens up to hundreds of units.
- Players need to take decisions in real-time.



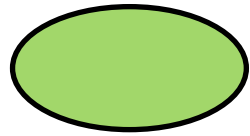
Traditional AoI does not work

- Area of Interest (AoI) = traditional mechanism for RPG: only receive information around avatar, but…
- …In RTS, each player has tens of units under control, so much more data to be transferred
- … In RTS, players change focus (interest) more often than in RPG and FPS, so higher management overhead





Core Idea



- Partition the game into multiple areas (rectangular)
- Each player pays attention to different areas + attention level
- Depending on attention level and machine performance, player receives different types of information (**commands** or **state**) about game world
- Each player can have multiple Areas of Simulation (AoS) and Areas of Update (AoU), and also multiple No-Update Areas (NUA)

Experimental results

- Simulator and prototype RTS game
- Evaluate in two Cloud platforms: EC2 and Azure
- Prototype about 20k lines of C++ code
  - Based on an open source game (~6k lines)
- Up to 200 players and **10,000 battle units**
  - **State-of-the-art unplayable at 1-2,000**
  - **Crashes not uncommon due to CPU and Network bottlenecks**
- Using our AoS-based method can lead to

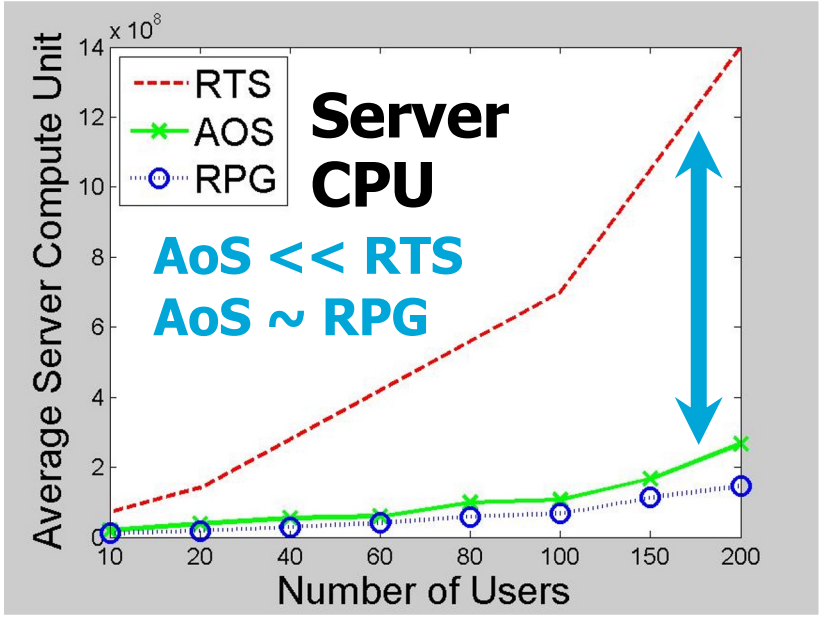
  lower CPU consumption than pure event-based method (RTS) and

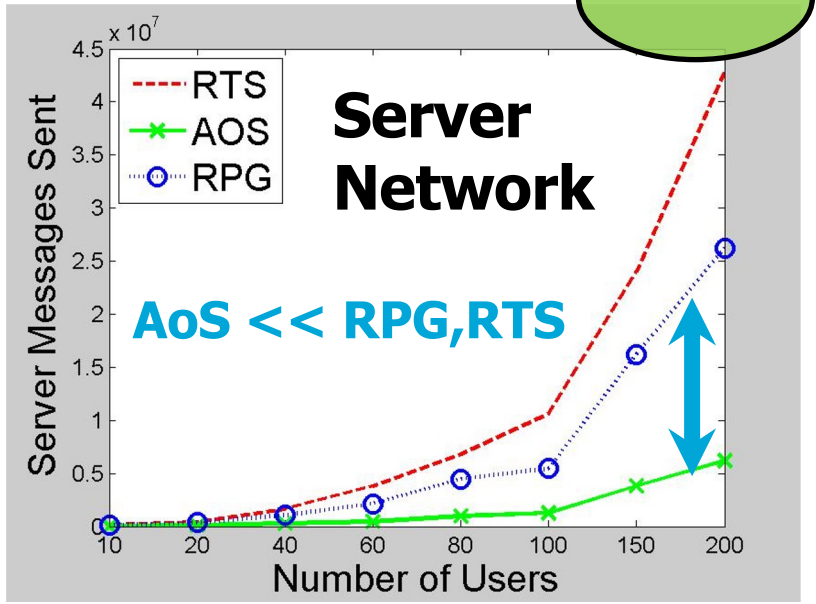
  lower network consumption than pure update-based method (RPG)

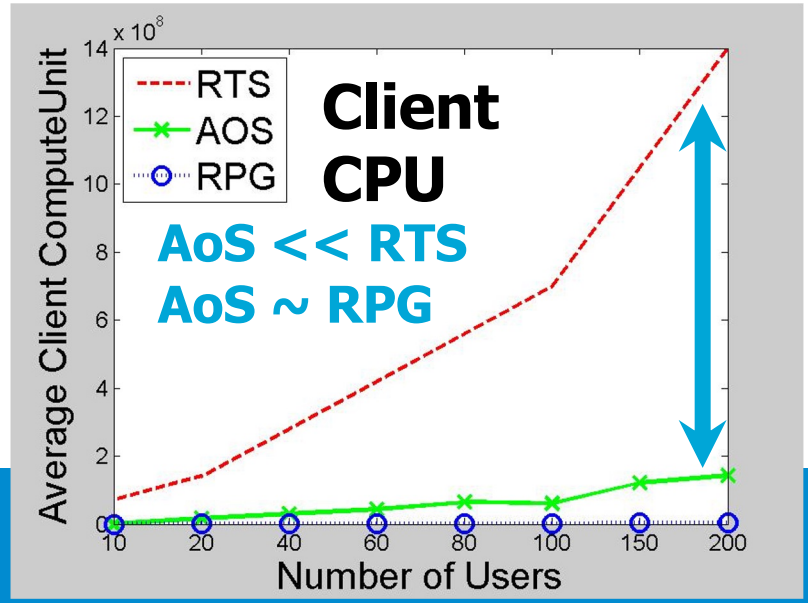
Experimental results

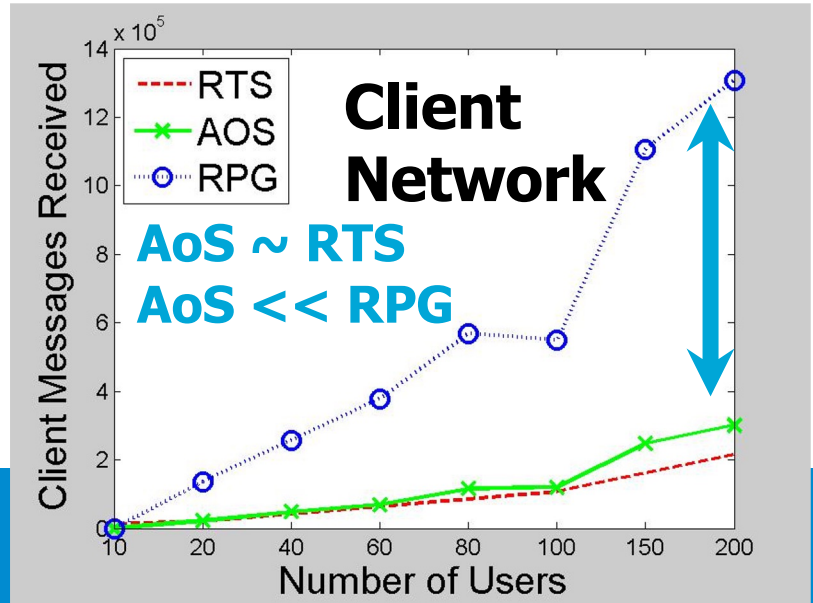
AoS can lead to lower resource use per player

Allows **better scalability** than current RTS and RPG games





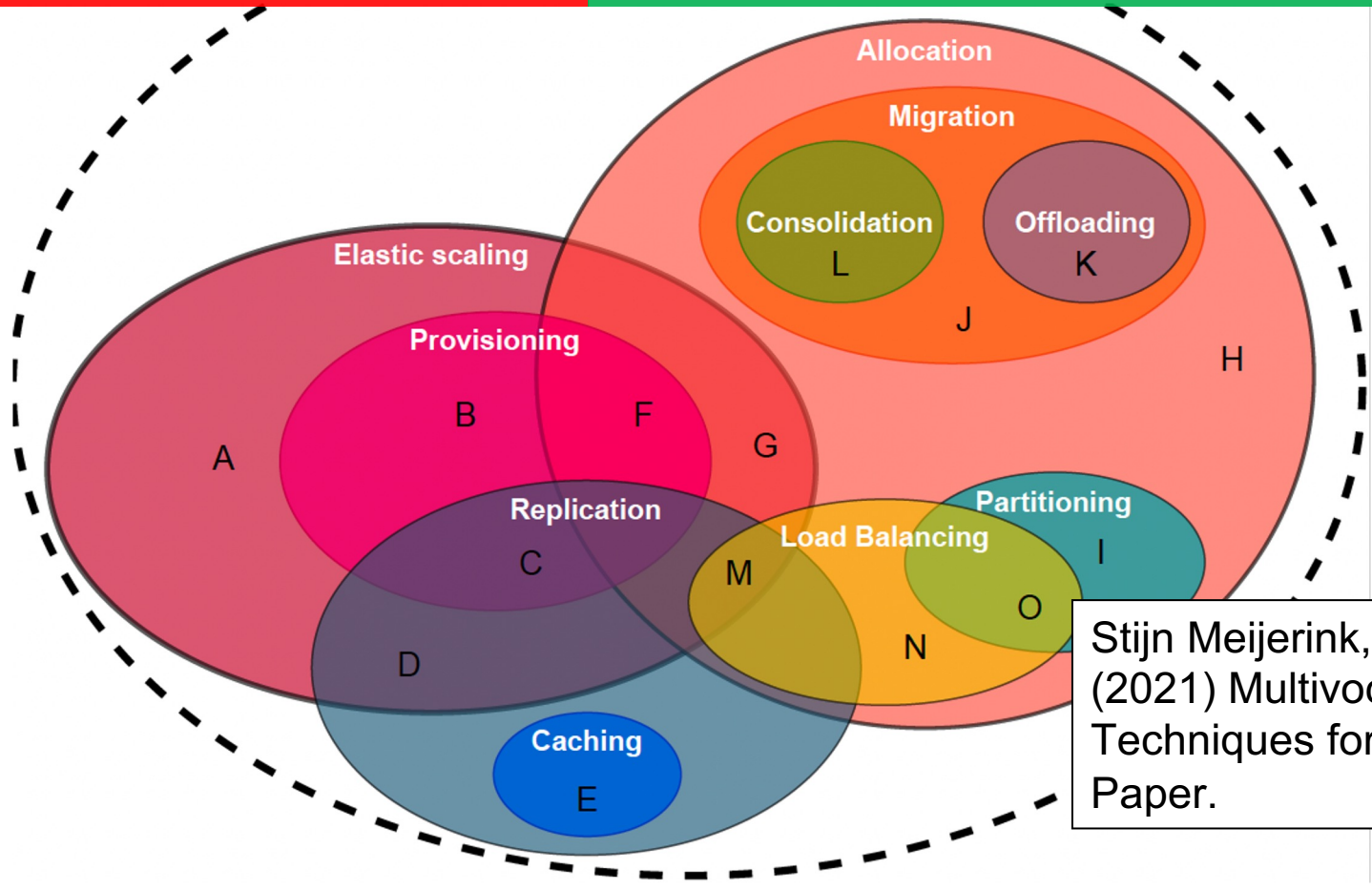




HOW TO AUTOMATE X ACROSS THE ECOSYSTEM?

IT'S OPERATIONS!

REFERENCE VIEW ON OPERATIONAL TECHNIQUES

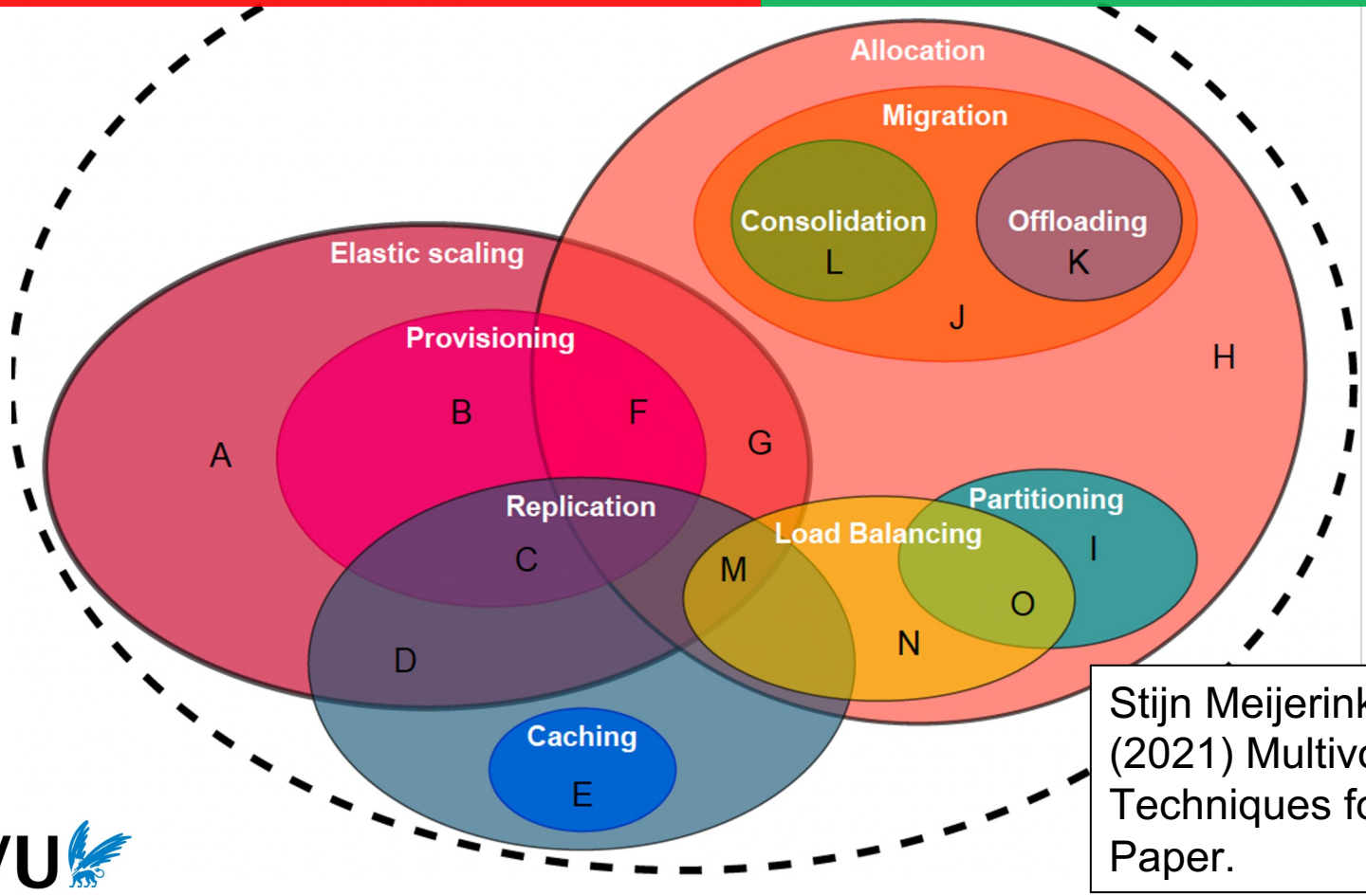


Stijn Meijerink, Erwin van Eyk, Alexandru Iosup (2021) Multivocal Survey of Operational Techniques for Serverless Computing. White Paper.

HOW TO AUTOMATE OPS ACROSS THE ECOSYSTEM 5A2

IT'S OPERATIONS!

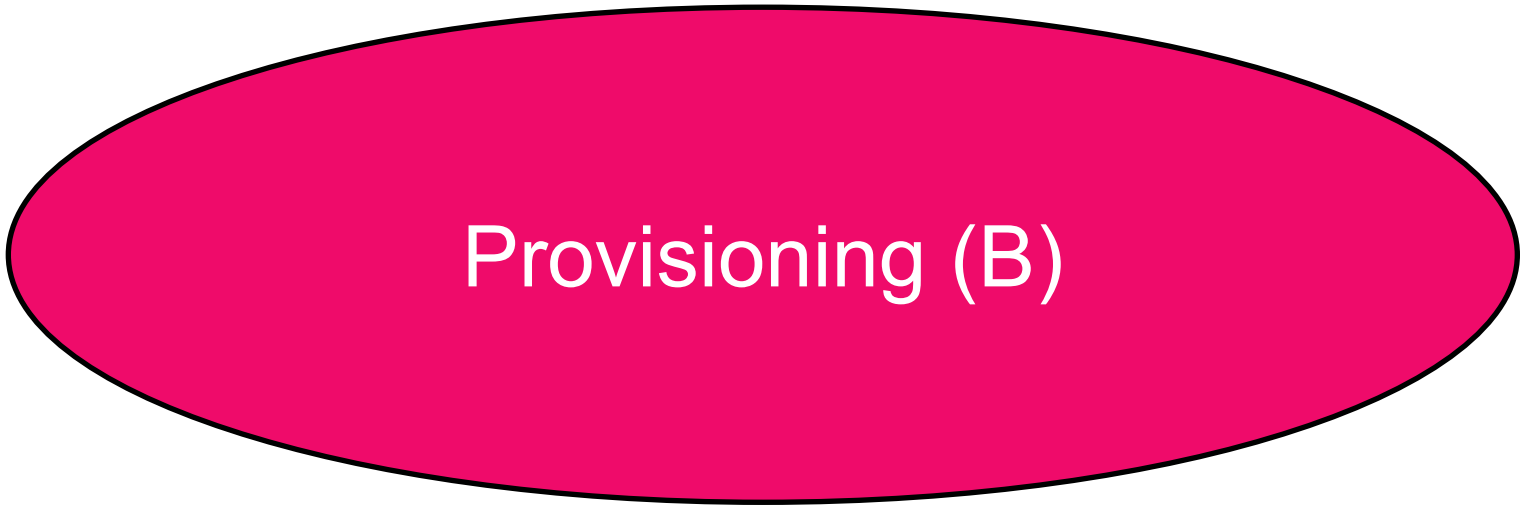
REFERENCE VIEW ON OPERATIONAL TECHNIQUES



Provisioning (B)

Offloading (K)

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


Provisioning (B)

World of Warcraft, a Traditional HPC User?!

(since 2003)

- 10 data centers
- 13,250 server blades, 75,000+ cores
- 1.3PB storage
- 68 sysadmins (1/1,000 cores)

http://www.datacenterknowledge.com/archives/2009/11/25/wows-back-end-10-data-centers-75000-cores/

Cloud-based hosting model

- Using data centers for dynamic resource allocation

- Main advantages:
  1. Significantly lower over-provisioning
  2. Efficient coverage of the world is possible

Inter-operable

Scalability

photon UNITY NETWORKING

PubNub

unity

UNREAL ENGINE

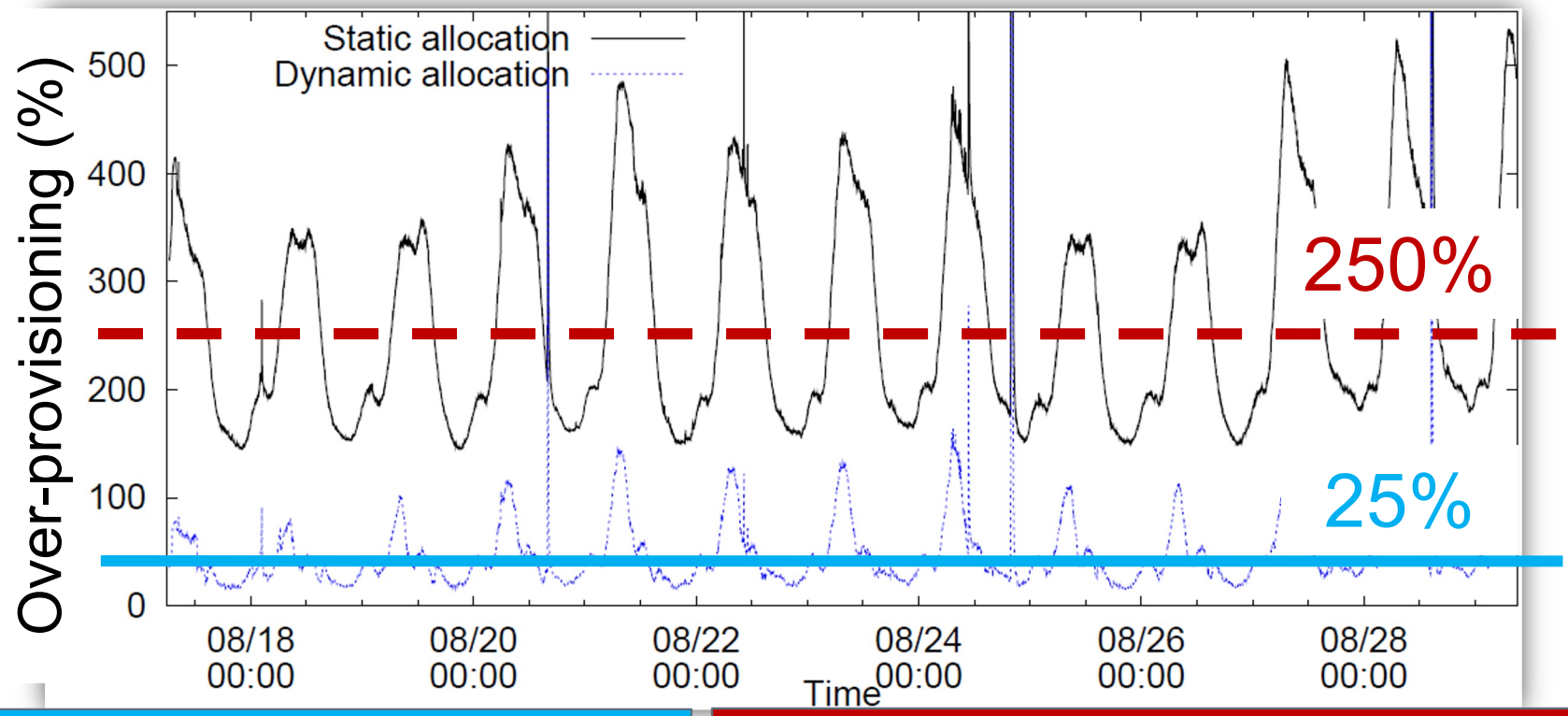
Autonomous

Reusable

[Source: Nae, Iosup, and Prodan, ACM SC 2008]

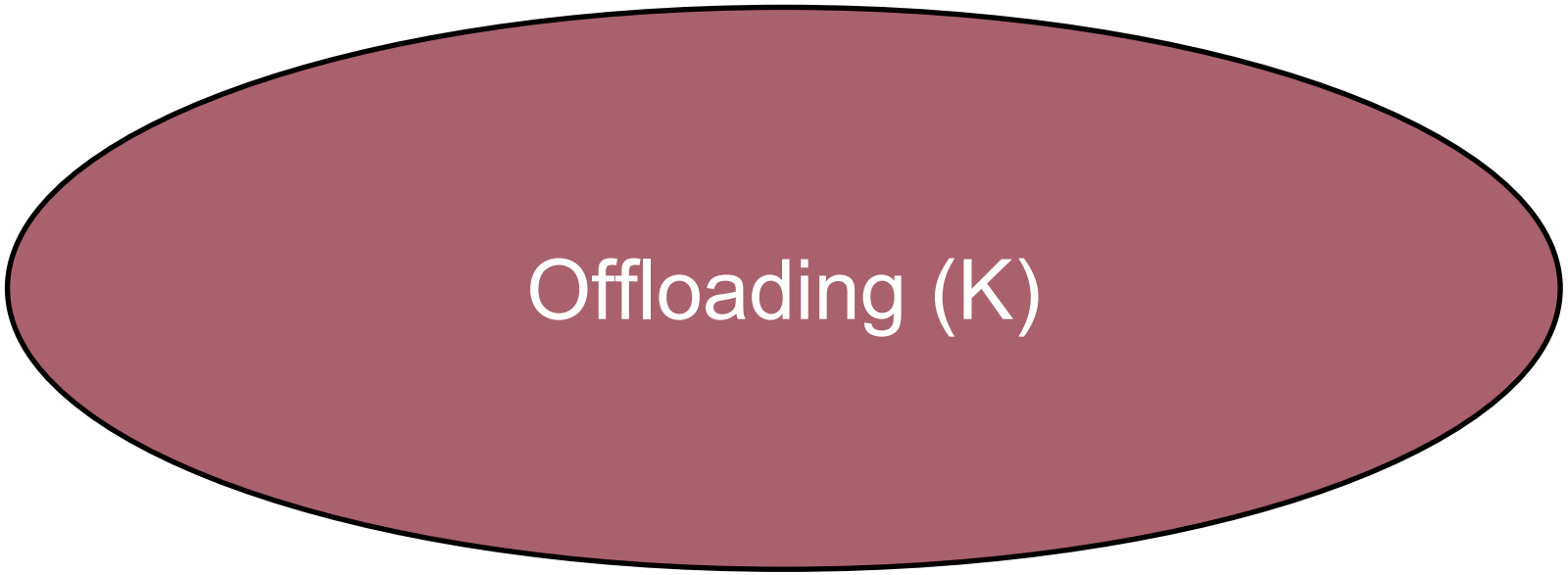
Resource Provisioning and Allocation
Static vs. Dynamic Provisioning

[Source: Nae, Iosup, and Prodan, ACM SC 2008 / TPDS 2011]



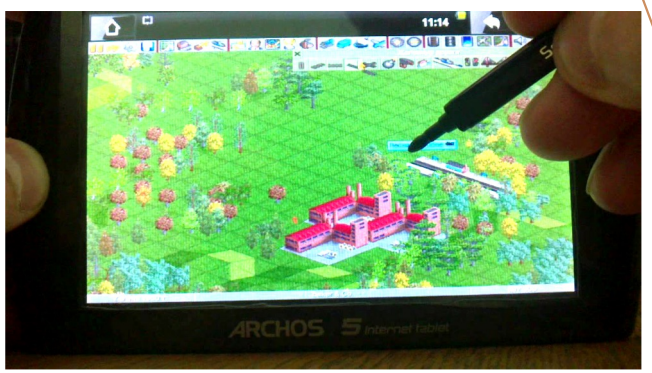
Consolidation is important!

… but need to rethink metrics, prediction, sched., OS, etc.

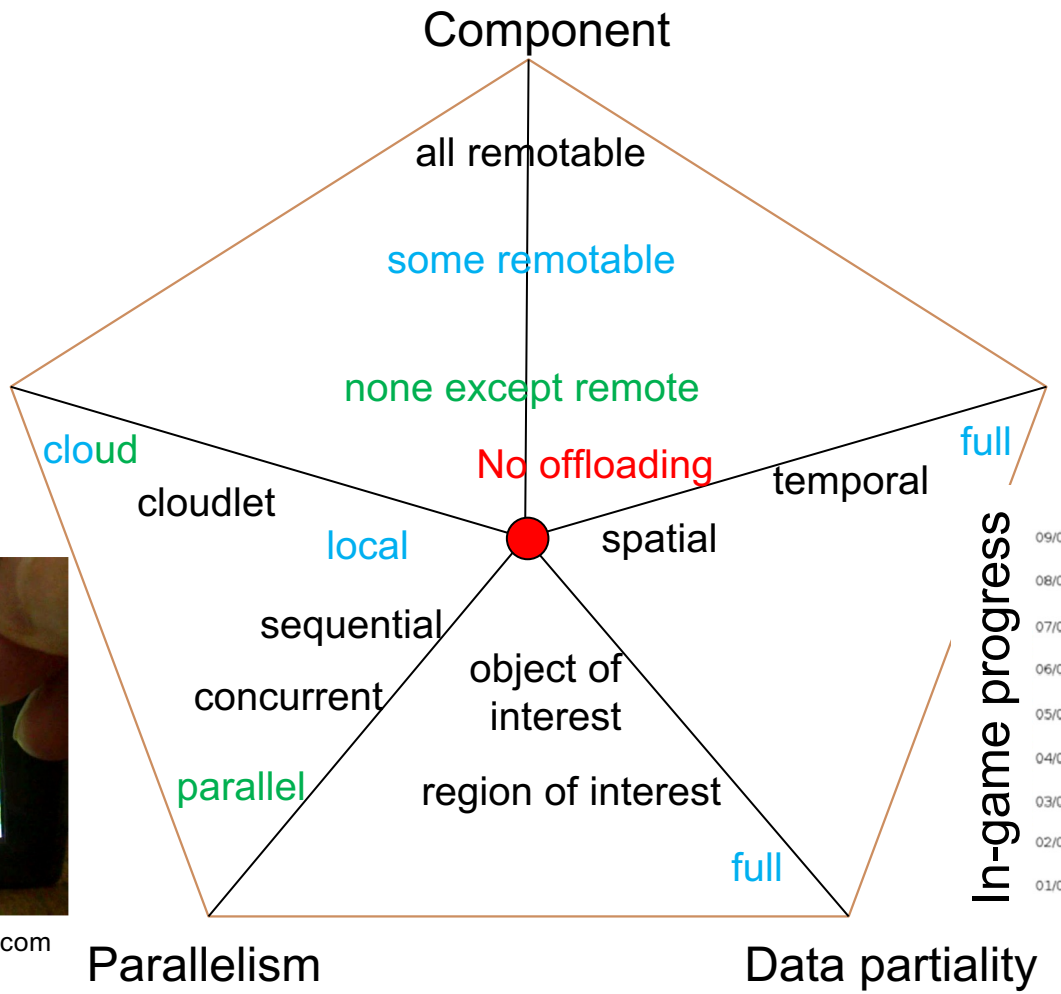

Offloading (K)

Exploratory Space for Offloading

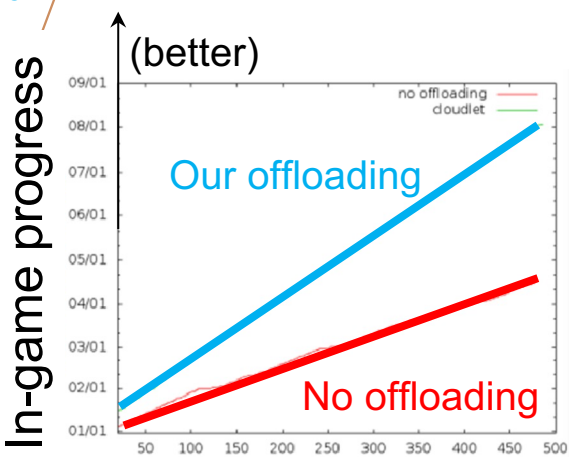
Scalability



source: youtube.com



Cloud gaming / SuperServer:
OnLive,
Gaikai,
Sony Online,
Microsoft Live,
etc.

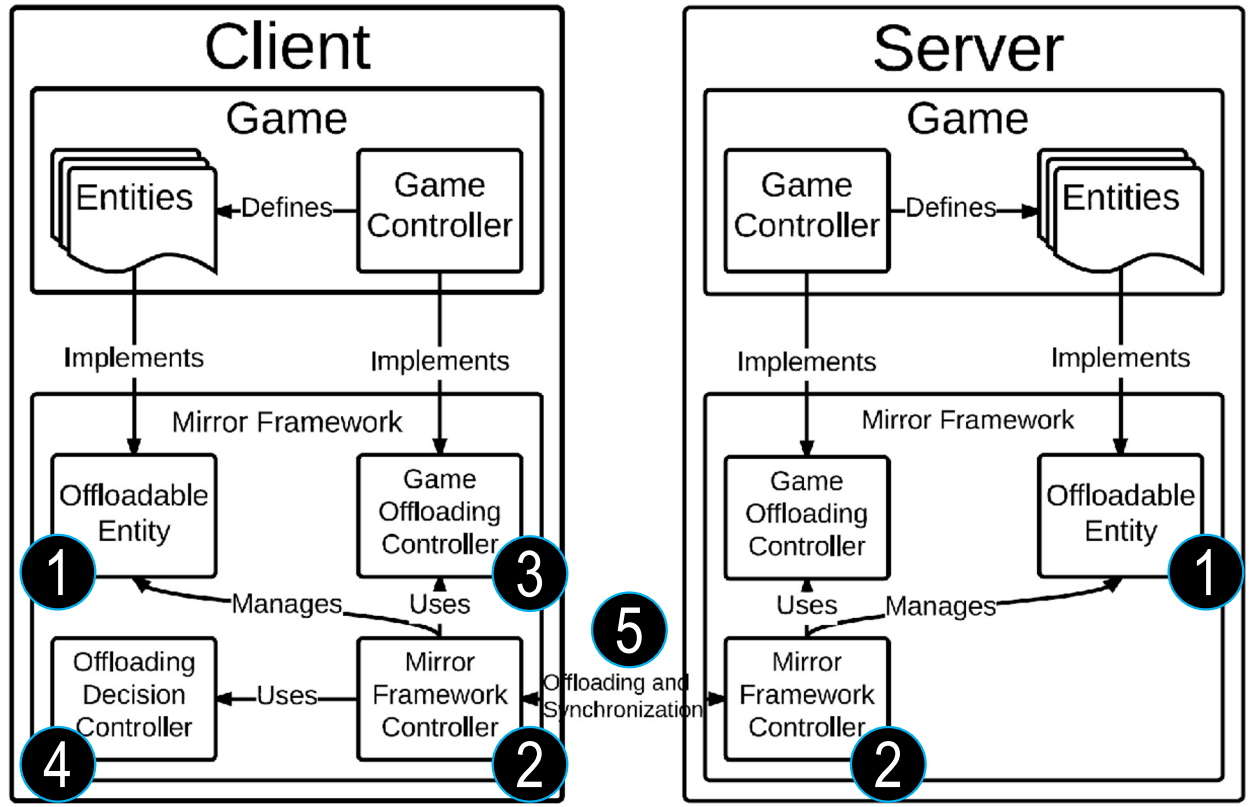


A.-C. Olteanu, N. Tapus, A. Iosup: Extending the Capabilities of Mobile Devices for Online Social Applications through Cloud Offloading. CCGRID 2013: 160-163.

The Mirror Architecture for Game Offloading

Scalability

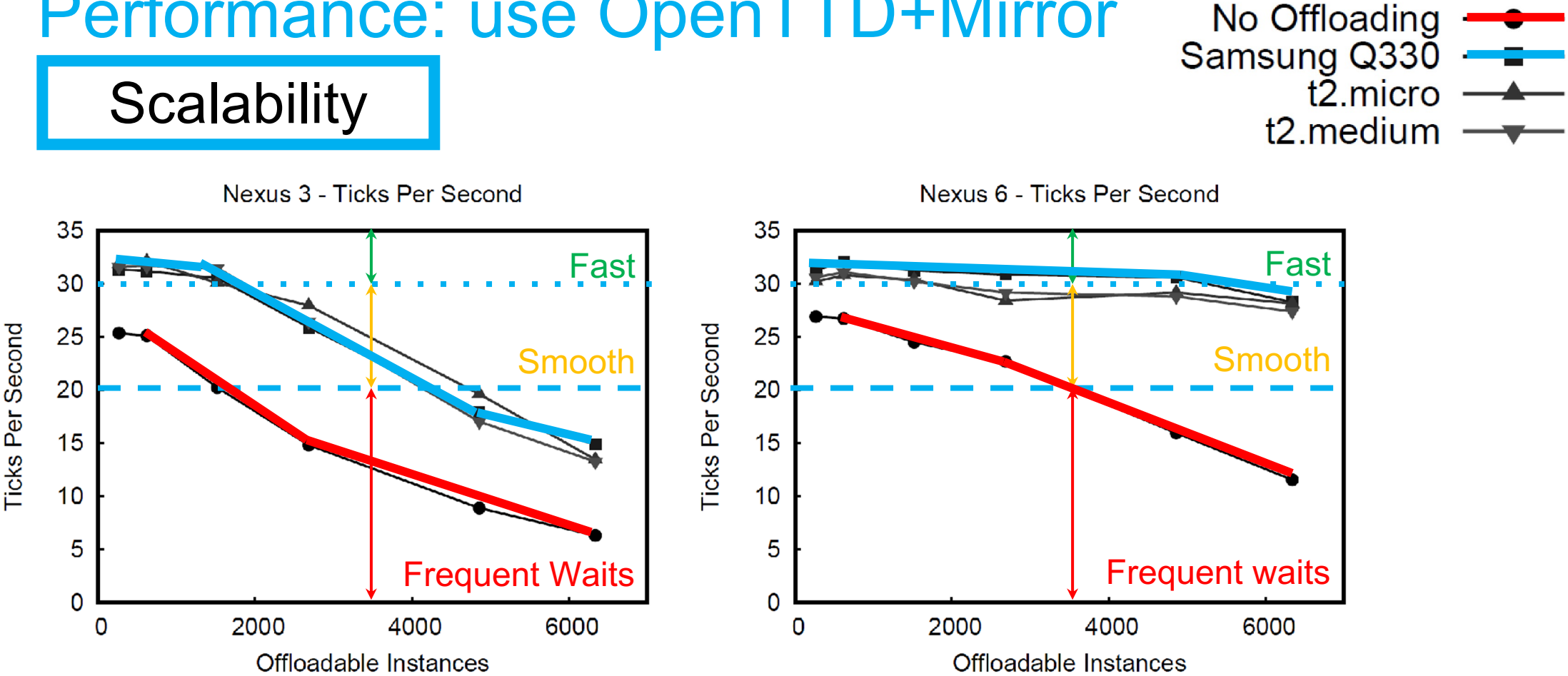
1. Offloadable Entity
   - (A part of) a game-object class
   - Mirrored on client and server
2. Mirror Framework Controller
   - Manages offloading sessions, all
3. Game Offloading Controller
   - Exposes main game-loop as API
4. Offloading Decision Controller
   - Only on client
5. Offloading + Synchronization Protocols



M. H. Jiang, O. W. Visser, I. S. W. B. Prasetya, Alexandru Iosup:
Mirror: A computation-offloading framework for sophisticated mobile games. CCPE 2018.

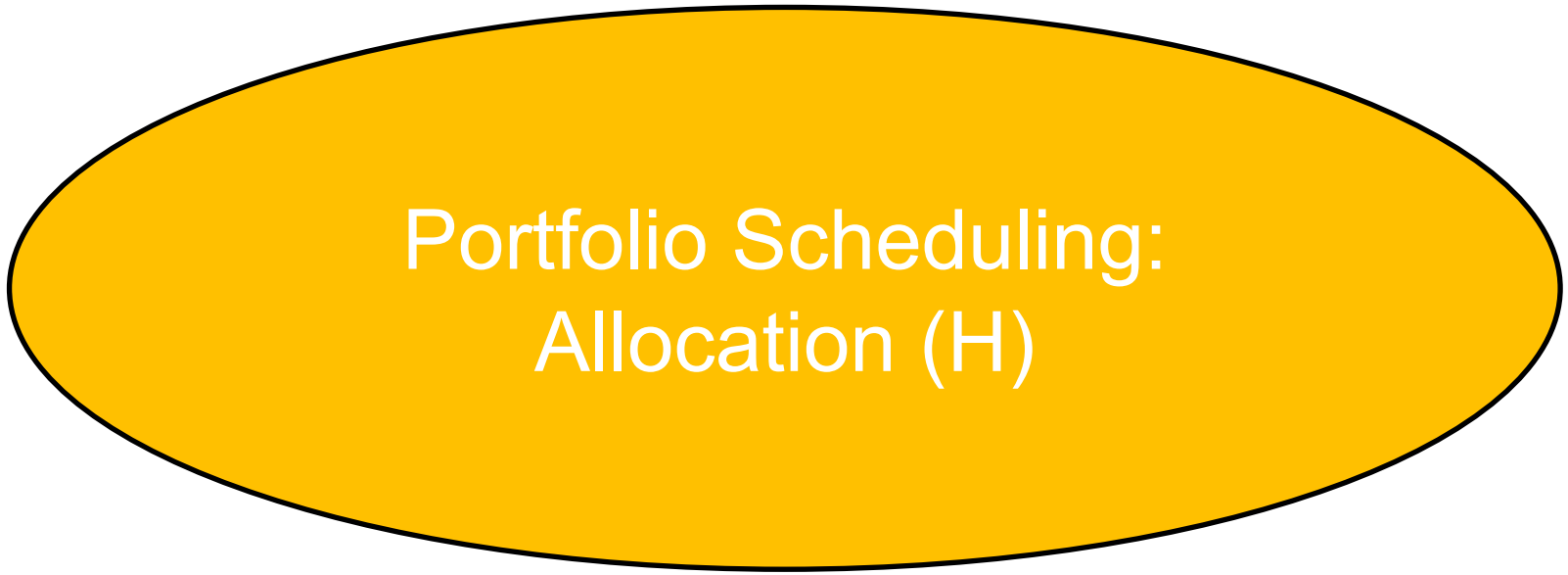
Performance: use OpenTTD+Mirror

Scalability



OpenTTD+Mirror+Offload All delivers significantly better performance than OpenTTD without offloading

M. H. Jiang, O. W. Visser, I. S. W. B. Prasetya, Alexandru Iosup: Mirror: A computation-offloading framework for sophisticated mobile games. CCPE 2018.


Portfolio Scheduling:
Allocation (H)

The Technical Version

General

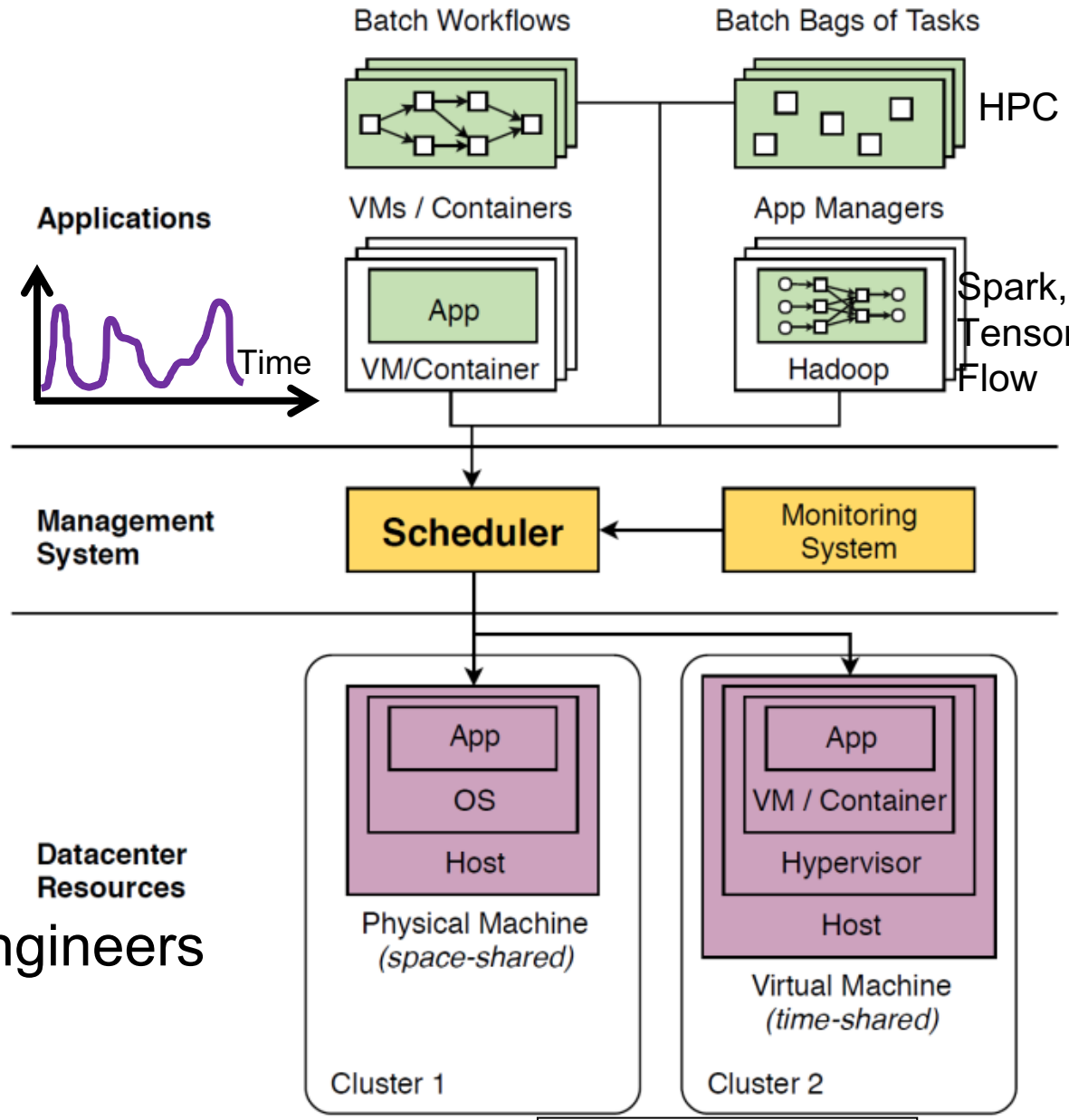
DS-specific

Scheduler needs to

- Make and take decisions
- (classic theory helps here)

but also to

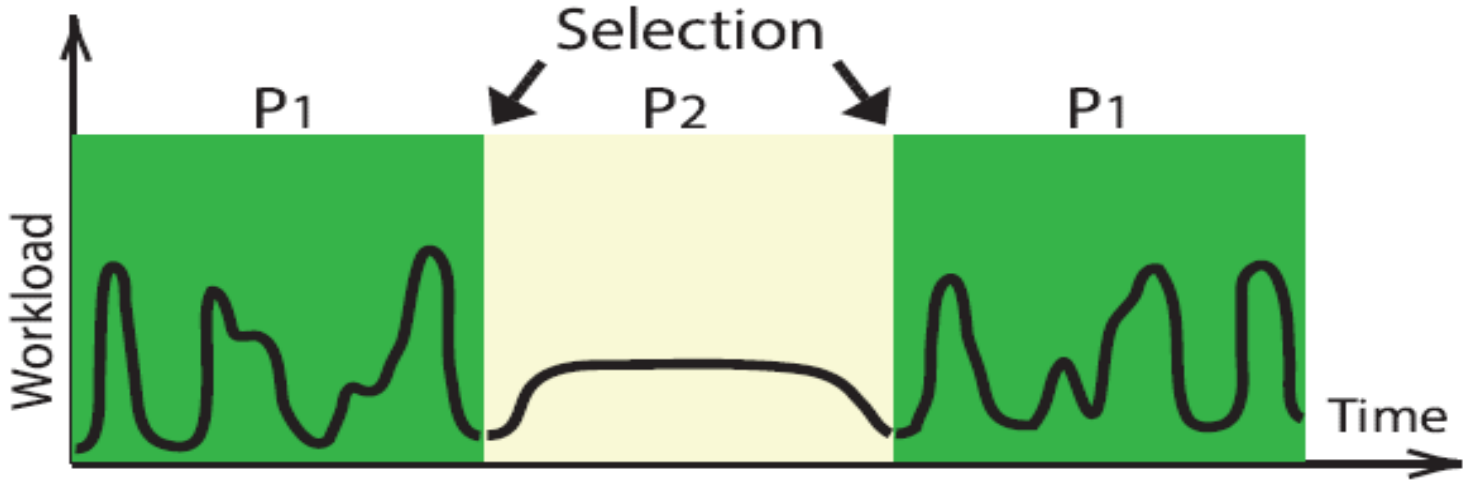
- Use system feedback (Monitoring, possibly also eng.)
- Address workload and resource heterogeneity, dynamicity, structure / topology, etc.
- (2010s+) Explain decisions to engineers



Andreadis et al. SC 2018. [Online]

Portfolio Scheduling, In A Nutsh

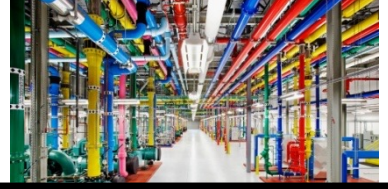
- Datacenters cannot work without one or even several schedulers
- Instead of ephemeral, risky schedulers, we propose to



1. Create a set of schedulers (resource provisioning and allocation policies)
2. Select active scheduler online, apply for the next period, analyze results

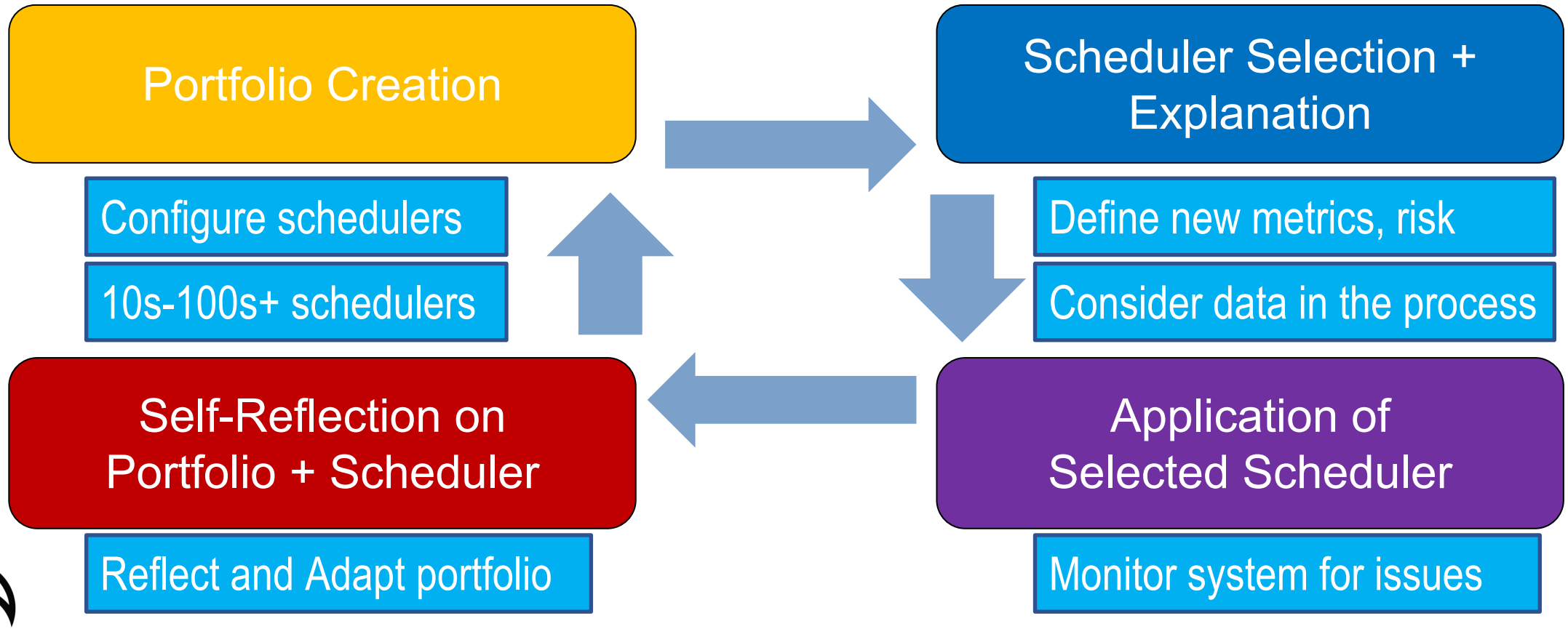
(Repeat)

K. Deng et al. Exploring portfolio scheduling for long-term execution of scientific workloads in IaaS clouds. SC|13

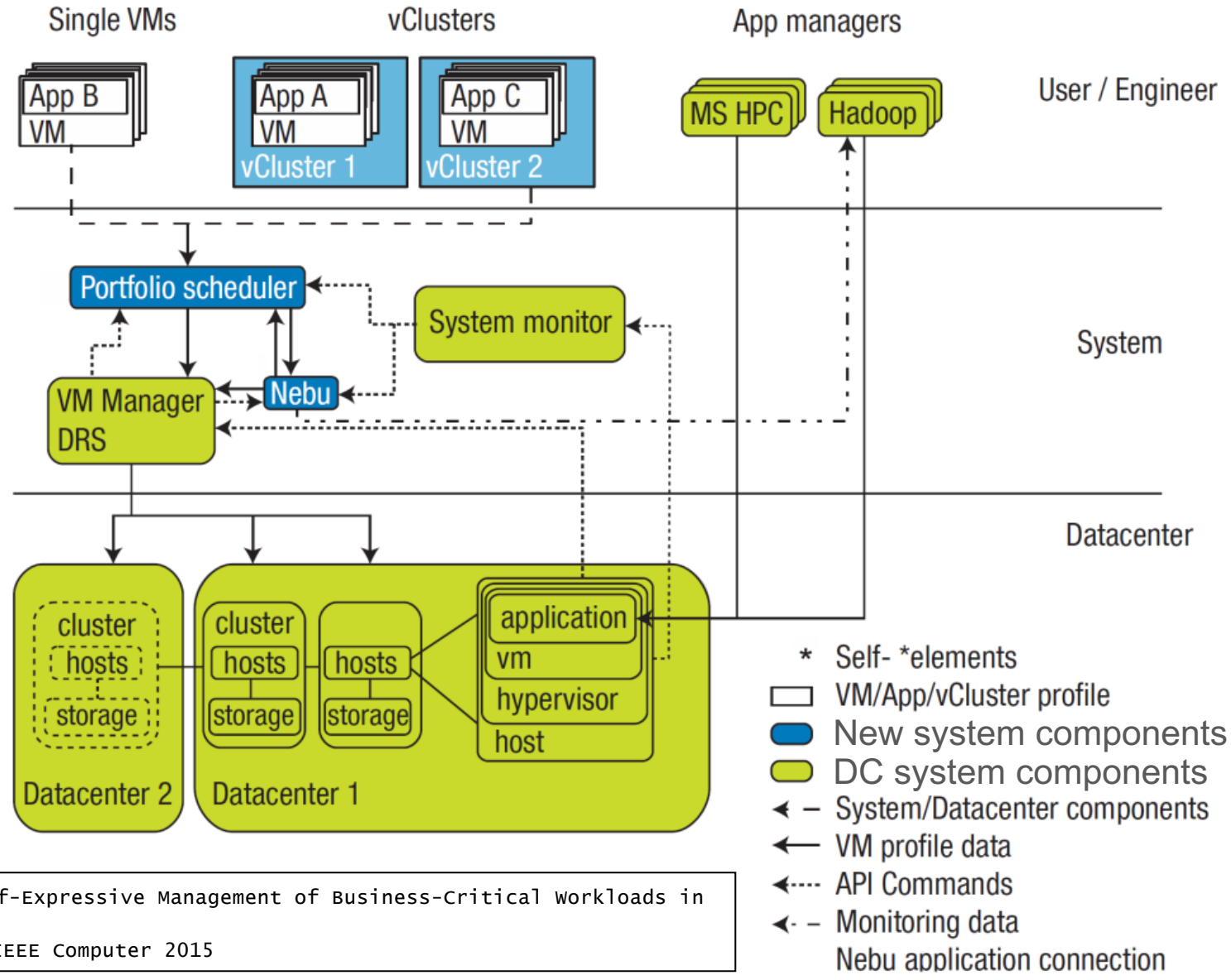


Portfolio Scheduling

Generalized Portfolio Scheduling for Computer Systems

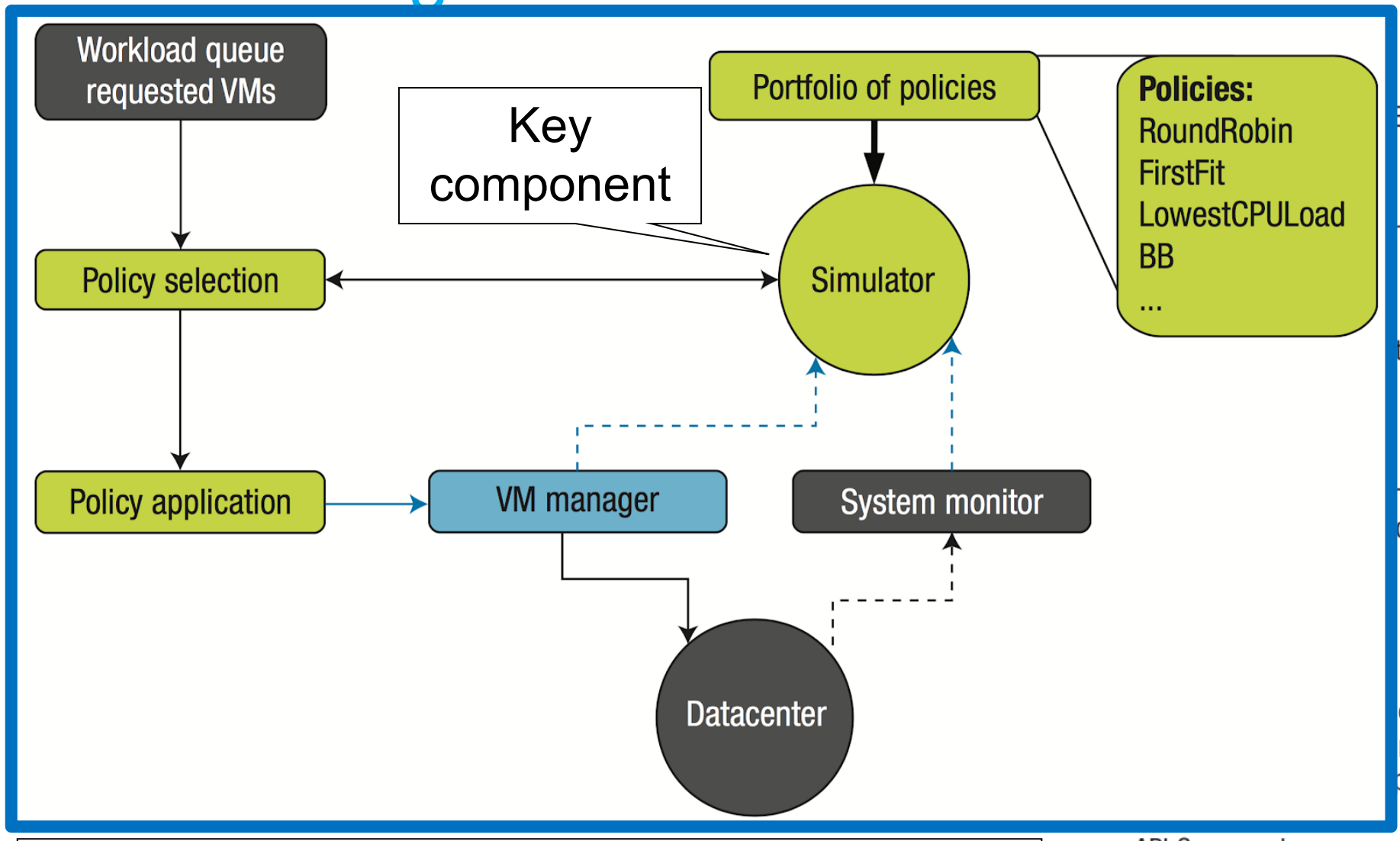


Portfolio Scheduling in Datacenters



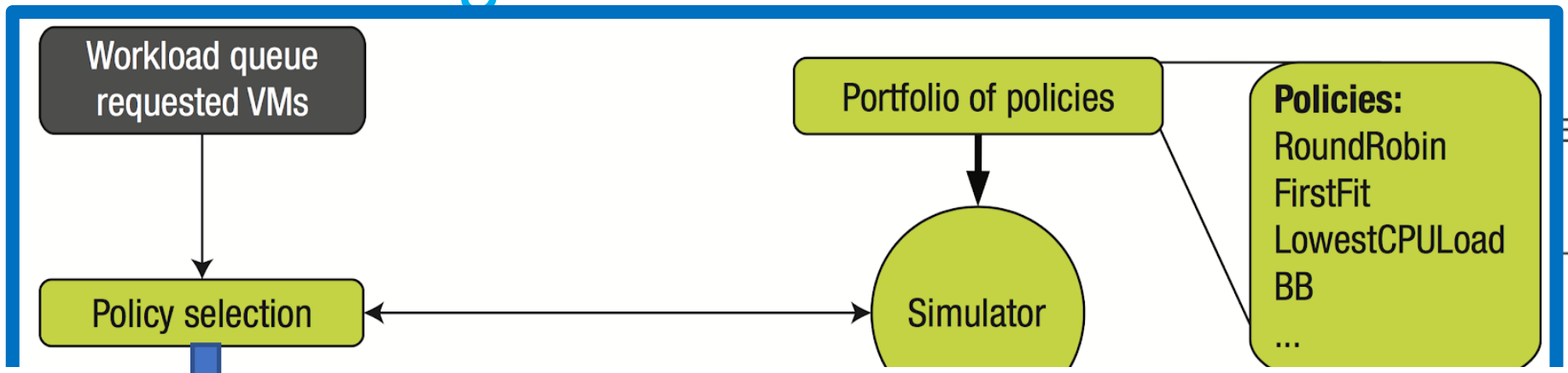
V. van Beek et al. Mnemos: Self-Expressive Management of Business-Critical Workloads in Virtualized Datacenters. IEEE Computer 2015

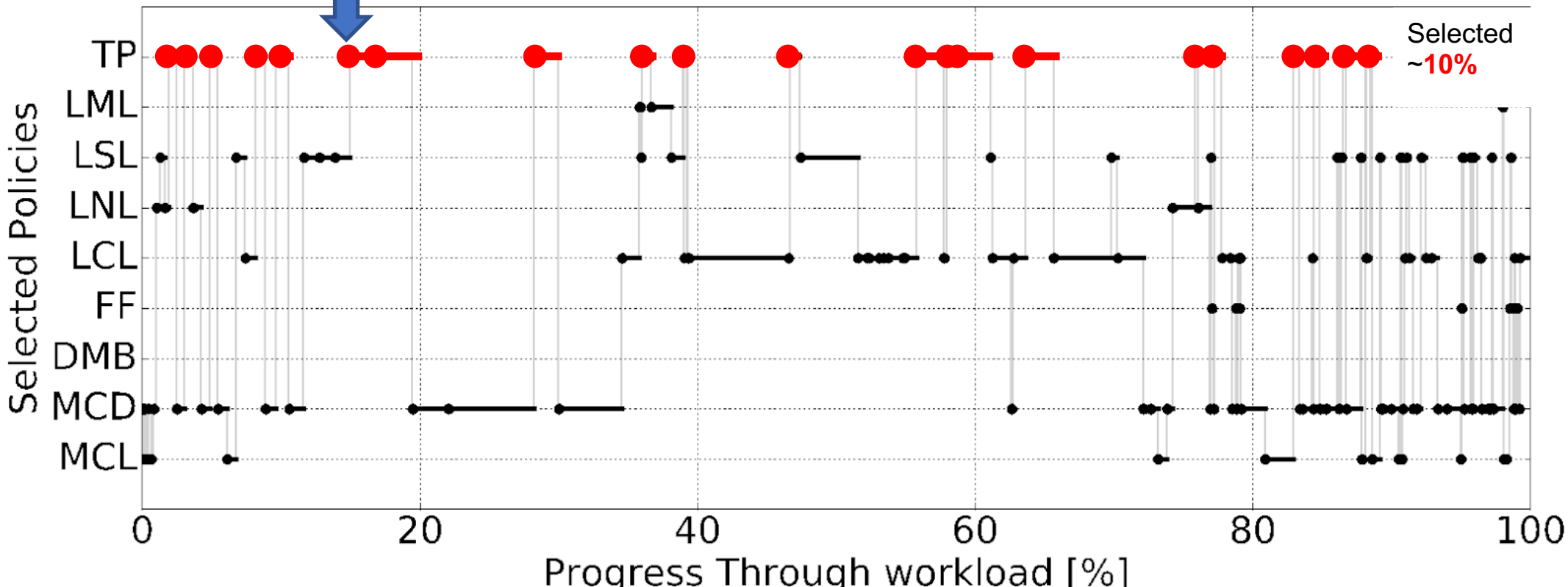
Portfolio Scheduling in Datacenters



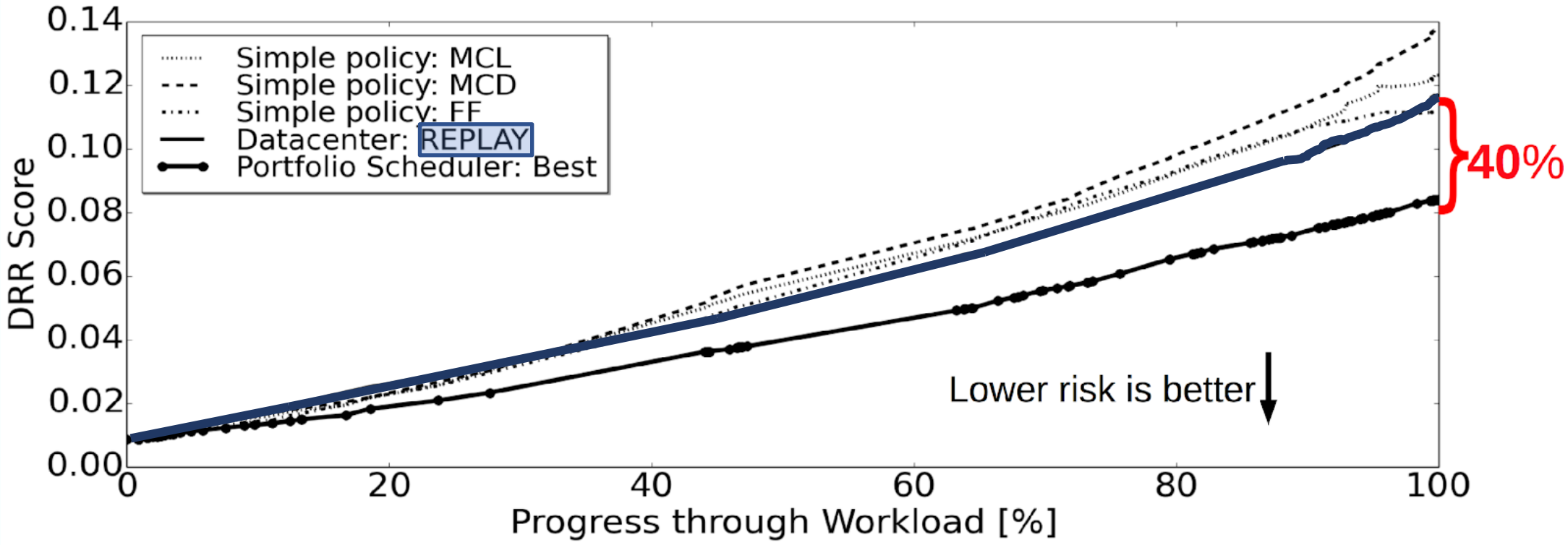
V. van Beek et al. Mnemos: Self-Expressive Management of Business-Critical Workloads in Virtualized Datacenters. IEEE Computer 2015

Portfolio Scheduling in Datacenters



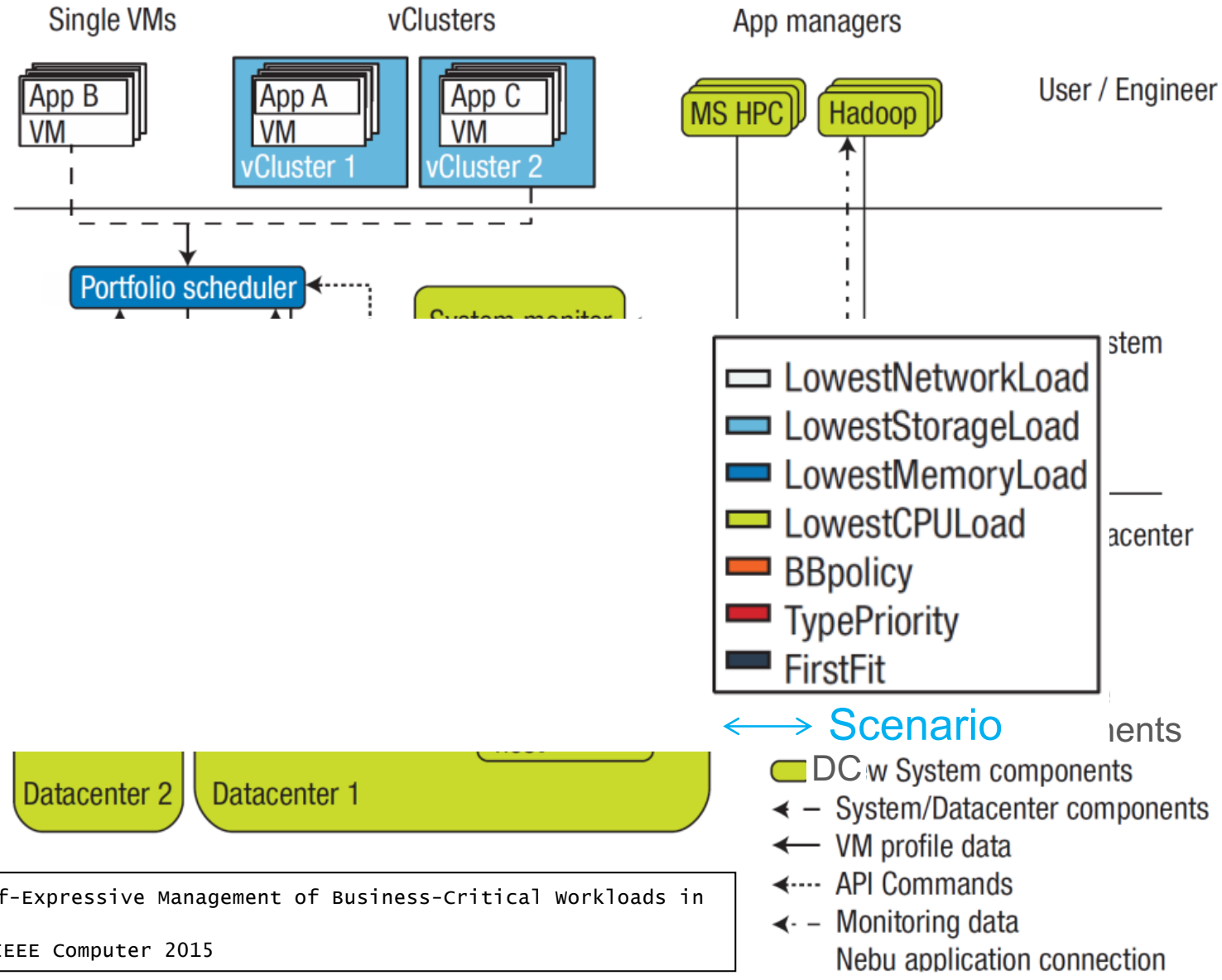


Portfolio Scheduling in Datacenters

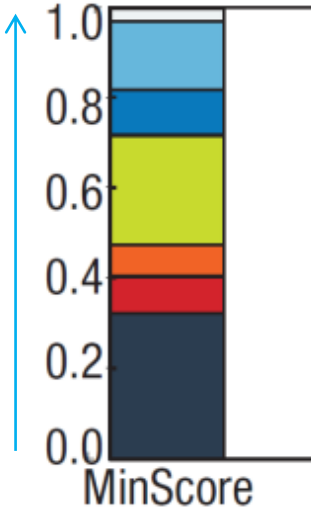


1. Portfolio scheduler achieves the lowest risk of all scenarios.
2. Portfolio scheduler achieves at least **35%** lower DRR compared to individual policies.
3. **40%** lower DRR than commercial production system (REPLAY).

Portfolio Scheduling in Practice: Risk Management

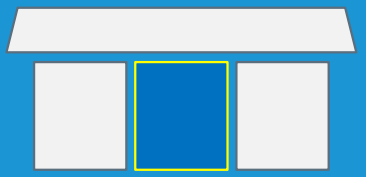


Policy selected, fraction of decisions



V. van Beek et al. Mnemos: Self-Expressive Management of Business-Critical Workloads in Virtualized Datacenters. IEEE Computer 2015

Message: 5B



Analytics ~ Only beginning to scratch the surface

GAMING ANALYTICS: SOCIAL EVERYTHING!

- **Social Network**=undirected graph, **relationship**=edge
- **Community**=sub-graph, density of edges between its nodes higher than density of edges outside sub-graph

Goal: Improve gaming experience

1. Ranking / Rating
2. Matchmaking / Recommendations
3. Detect and combat toxicity
4. Exporting data
5. Play Style/Tutoring

Done

Open challenge

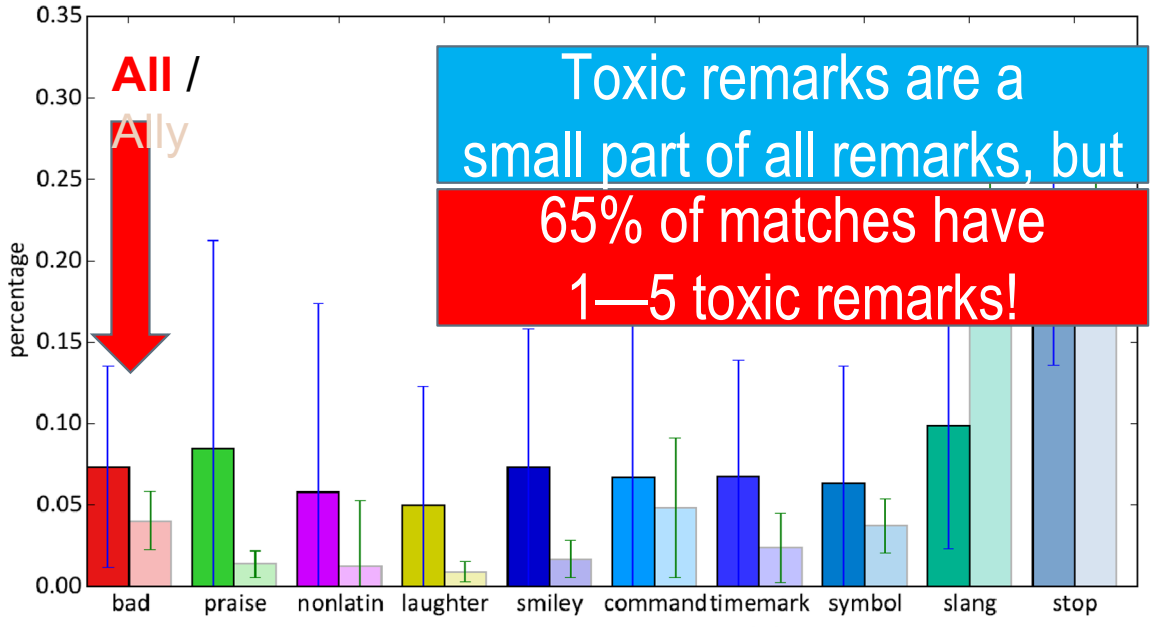
Blizzard: World of Warcraft's Quest for Big Data

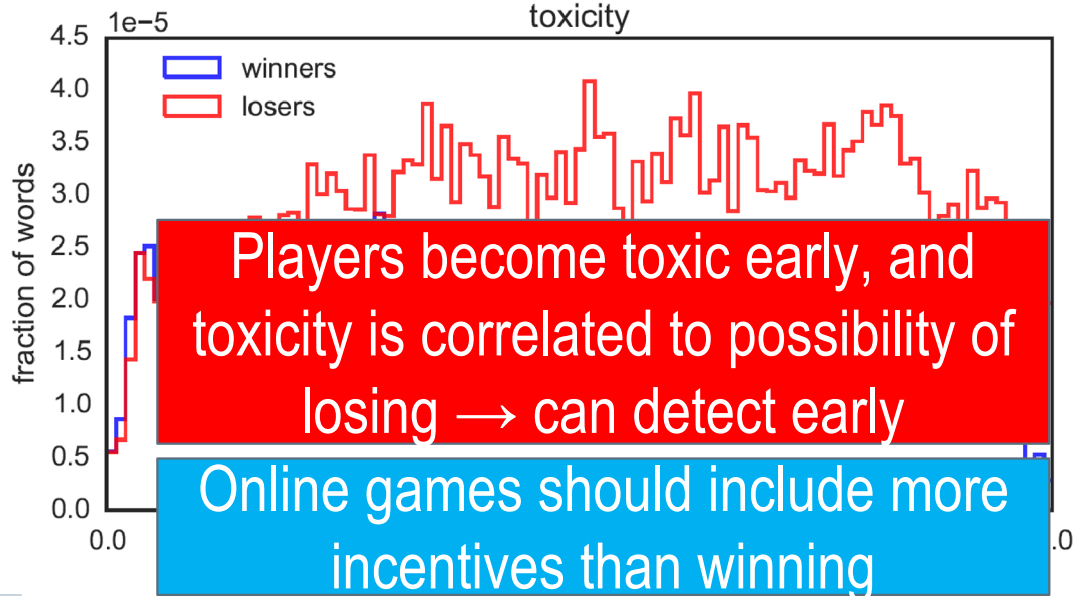
Source: Amanda Gerdes, talk at Terradata Partners Conference, NL, Dec 2016.

- New Stakeholders
  - Game Development Team
  - Engagement Manager + Team
  - Data Scientists
  - External Partners + crowdsourcing
- New Requirements
  - Balanced decentralized data warehouse
  - 90% of decision-making done by algorithms
  - From transactional to data-driven and model-driven behavioral data
- New Applications
  - Matchmaking
  - Event prediction
  - Recommendations
  - Fraud detection and classification
  - Micro-segmentation for campaigns
  - Third-party / crowdsourced analysis

TOXICITY DETECTION IN ONLINE GAMES

- Data collection and cleansing
  - Representative MOBA game
  - DotAlicious ~13k games, Feb 2012
  - Identified ~10k games w/ victory/loss
- Analysis
  - Used chat logs, both ally-chat and **all-chat**
  - Natural Language Processing limited topics
  - Analyzed vocabulary using toxicity-detection rules

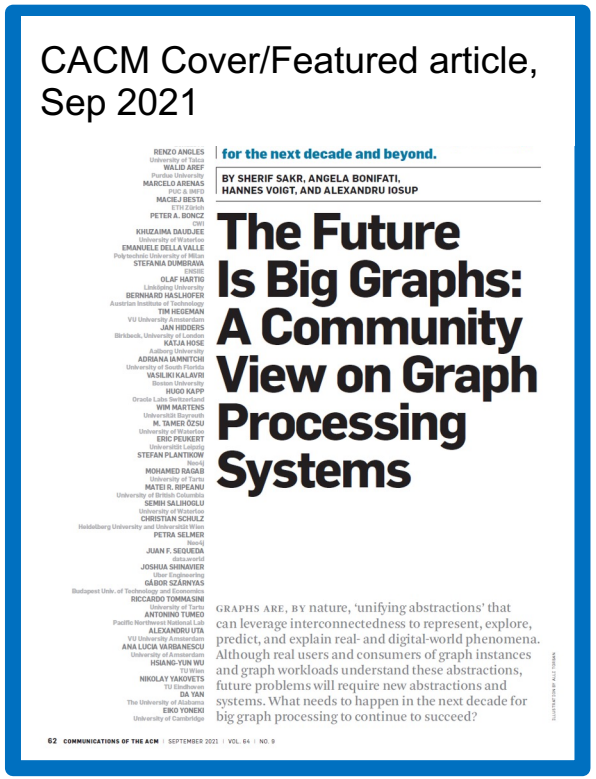




Maertens, Shen, Iosup, Kuipers. Toxicity detection in multiplayer online games. NETGAMES 2015: 1-6 (Best Paper Award)

GRAPH PROCESSING FOR GAME SERVICES

CACM Cover/Featured article, Sep 2021



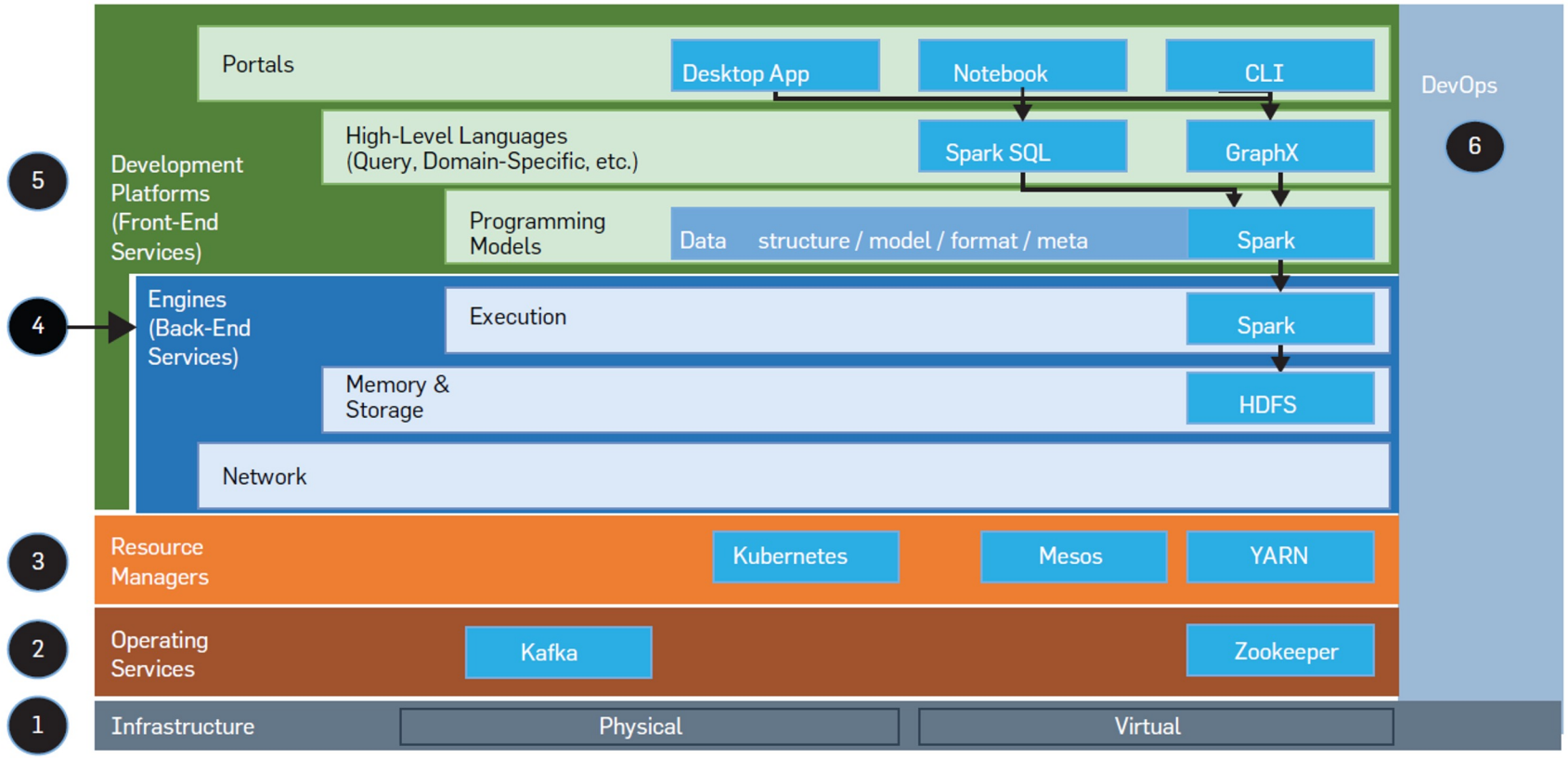
for the next decade and beyond.

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?

62 COMMUNICATIONS OF THE ACM | SEPTEMBER 2021 | VOL. 64 | NO. 9



VU VRIJE UNIVERSITEIT

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

INTERACTION GRAPHS: FROM GAME INSTANCES TO SOCIAL TIES

- How to map the relationships in matches to graphs?
  - Players are mapped to nodes
  - Relationships between players are mapped to edges

- We use six different mappings and various thresholds:
  - **SM:** two players occur more than n times in the same match
  - **SS:** two players occur more than n times on the same side
  - **OS:** two players occur more than n times on opposing sides
  - **ML:** two players have lost more than n matches together
  - **MW:** two players have won more than n matches together
  - **PP:** a directed version of the mappings above. Link if percent matches played together.

VU

L. Jia, S. Shen, R van de Bovenkamp, A. Iosup, F.A. Kuipers, D.H.J. Epema. Socializing by Gaming: Revealing Social Relationships in Multiplayer Online Games, ACM Trans. Knowl. Disc. Data. 2015.

FROM PLAYERS TO GRAPH CLUSTERS AND BACK (TO MATCHMAKING)

- Players→Graph→Clusters (thresholding)
- Bonding score—enjoyment increases when playing together
  - +1/player if clustered players in same game

Matchmaking based on interaction graphs much better than random

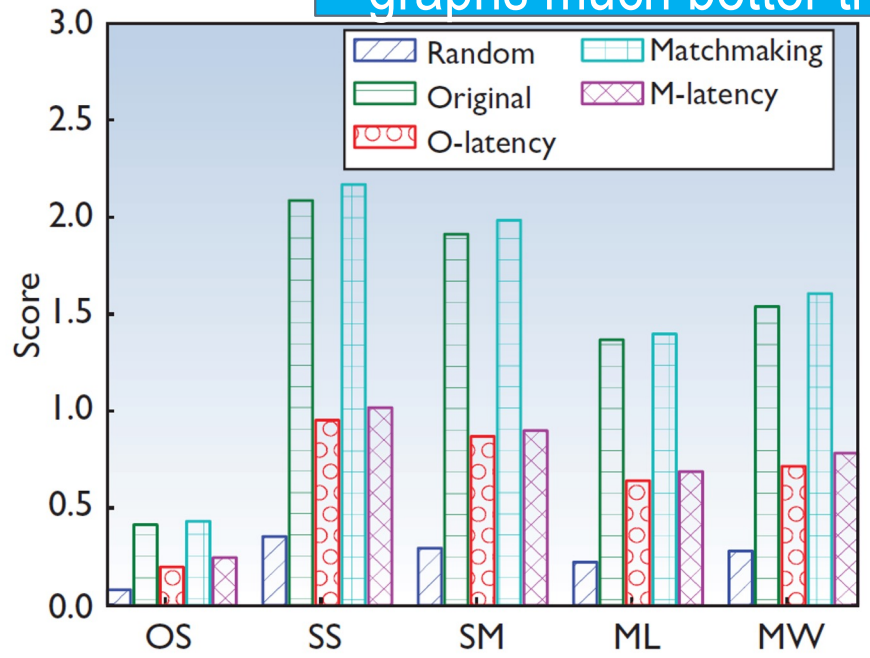
Team 1

Player	Cluster
A	1
B	2
C	1
D	3
E	4

Team 2

Player	Cluster
F	2
G	5
H	3
I	6
J	3

Bonding score: 0 3 5 7



L. Jia, S. Shen, R van de Bovenkamp, A. Iosup, F.A. Kuipers, D.H.J. Epema. Socializing by Gaming: Revealing Social Relationships in Multiplayer Online Games, ACM Trans. Knowl. Disc. Data. 2015.

Message: 5c

Content ~ Computational power → emerging creativity, freshness

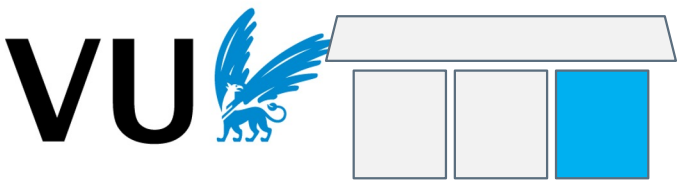
CONTENT, CONTENT, CONTENT!

Goal: Produce and distribute content for 1BN players

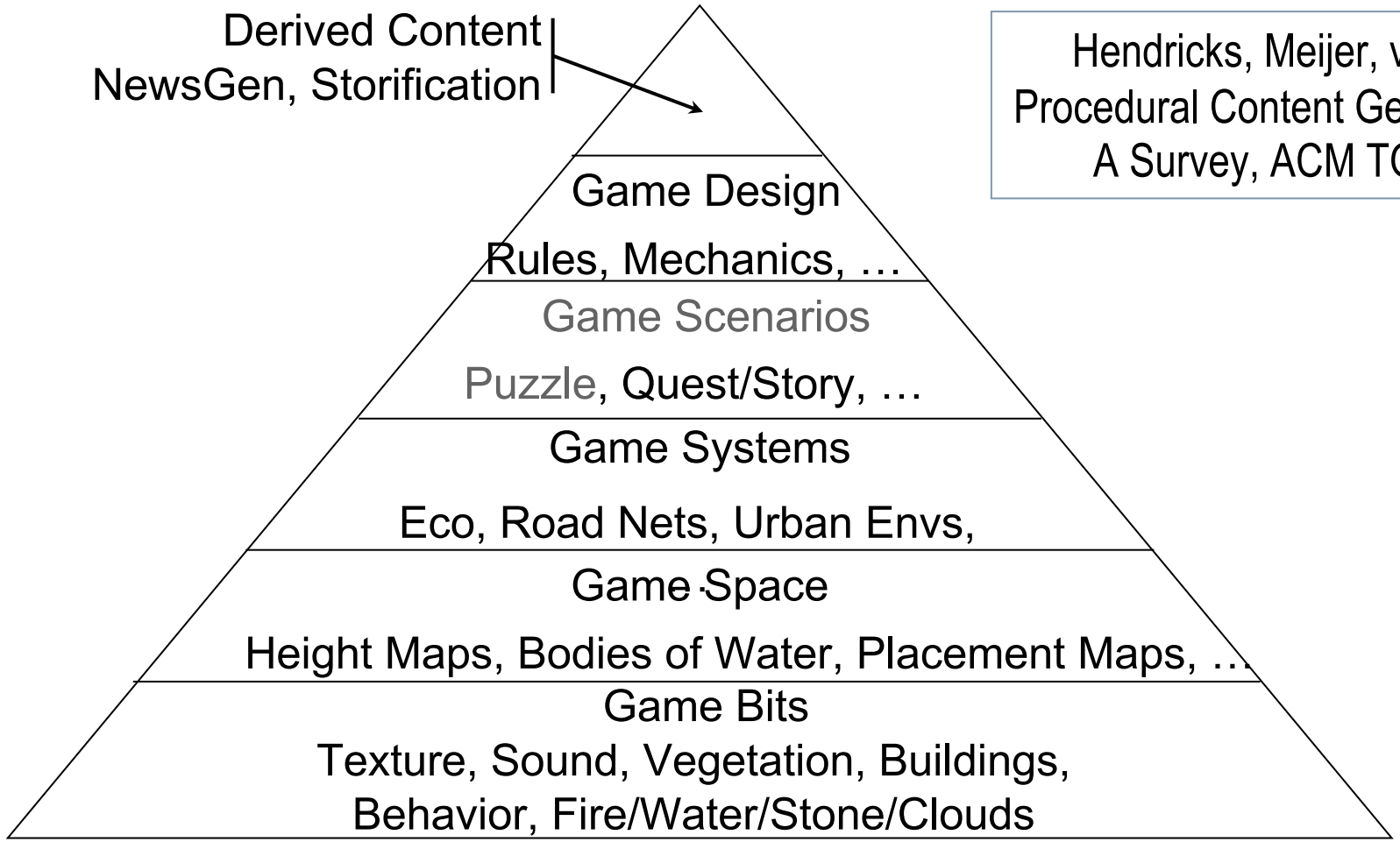
1. Game Analytics → Game statistics
2. Content distribution/ Streaming content
3. Crowdsourcing
4. Storification
5. Auto- / user-generated game content
6. Adaptive game content at scale
7. Make procedural content as appealing as designer content


Source: America's Army 3rd party heat map

Source: newsmap research team



(Procedural) Game Content (Generation)

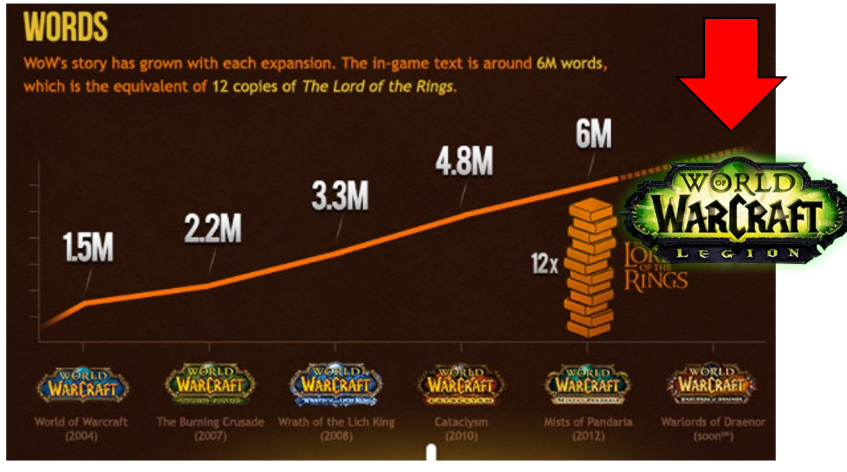


Hendricks, Meijer, vd Velden, Iosup, Procedural Content Generation for Games: A Survey, ACM TOMCCAP, 2012

STRATEGIES FOR CONTENT GENERATION

- **Clone**
  - Budget: $
  - Zero recognition from game designers
  - Amazing career in sales, does not work on Steam, players are unhappy

- **Franchise and 18-/24-month DLC**
  - Budget: $$$, upfront + $-$$ / update
  - Little recognition from game designers
  - Works fine for sales, works on Steam, players unhappy



- **Frequent updates, fast-pace DLC**
  - Budget: $, upfront + $ / update
  - Breaks industry models: often based on technology, etc.
  - Players are happy

CITIES SKYLINES

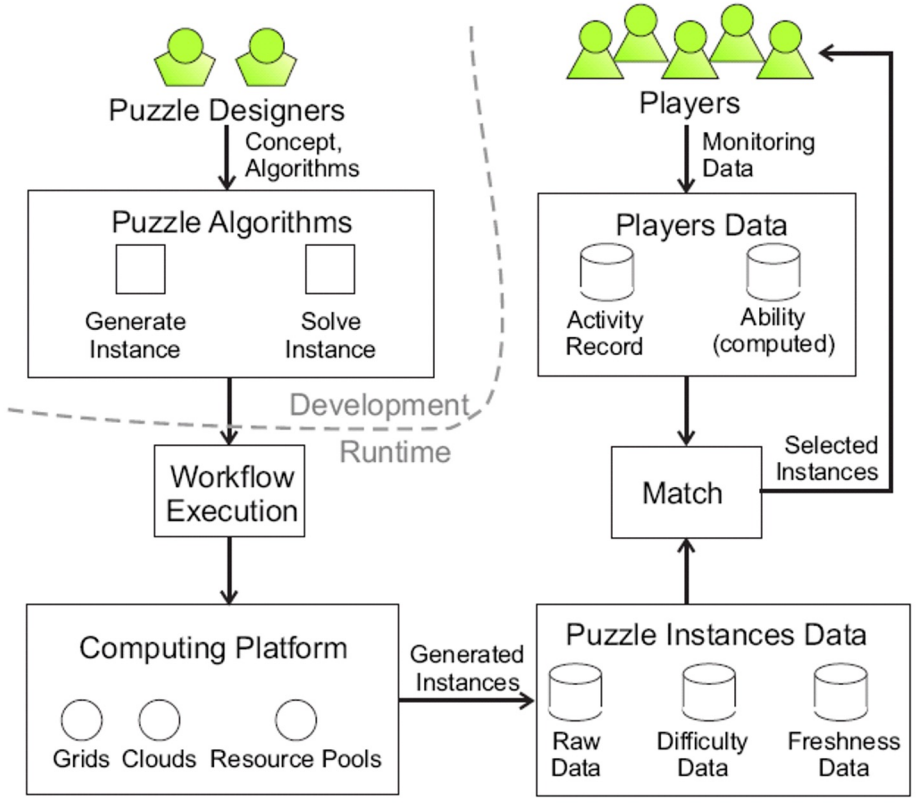
RUNESCAPE

Source: Sergey Galyonkin, SteamSpy: Some things you should know about Steam, Jun 2015.

The POGGI Content Generation Framework

Scalability

INPUT:
Only the puzzle concept, and the instance generation and solving algorithms, are produced at development time



Smart system to recommend instances to players

Elastic system to generate instances on-demand, reliably, efficiently, and with performance guarantees

A. Iosup, POGGI: Puzzle-Based Online Games on Grid Infrastructures, EuroPar 2009 (Best Paper Award)

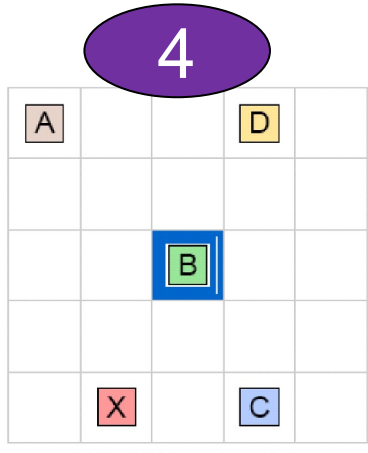
Puzzle-Specific Considerations

Generating Player-Customized Content

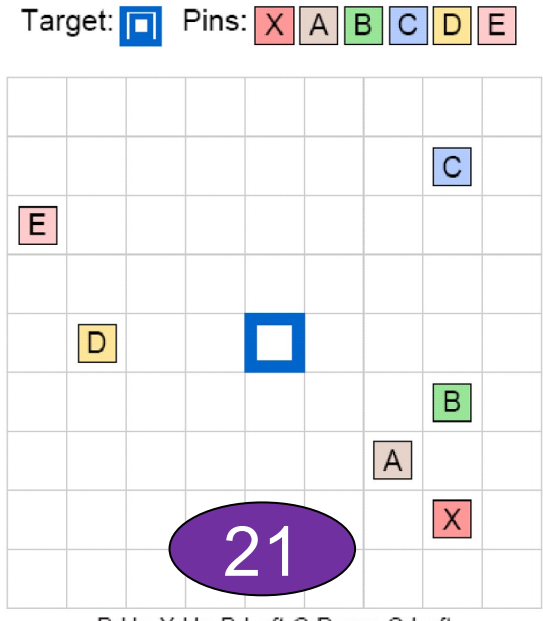
Scalability (of content)

Puzzle difficulty

- **Solution size**
- Solution alternatives
- Variation of moves
- Skill moves



X:Right A:Right B:Up X:Up
(Best solution: 4 moves)



B:Up X:Up B:Left C:Down C:Left
B:Down B:Right B:Down E:Right E:Down
E:Right B:Up A:Up B:Left C:Down
C:Right E:Down X:Left E:Left X:Down
X:Left
(Best solution: 21 moves)

Player ability

- Keep population statistics and generate enough content for most likely cases
- Match player ability with puzzle difficulty
- Take into account puzzle freshness

Message: 5D

Meta-gaming ~ Community techniques emerging

META-GAMING: BEYOND THE DESIGNED INTERACTION

Meta-gaming="When you play a number of games, not as ends unto themselves but as parts of a larger game, you are participating in a metagame." (Dr. Richard Garfield)

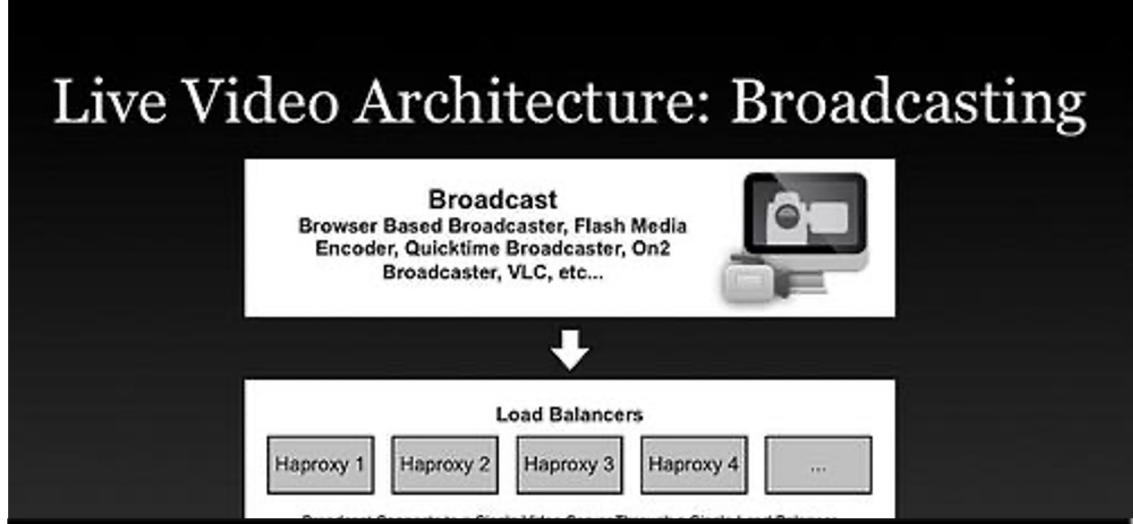
Goal: Self-Organizing Gaming Communities of Millions of Players

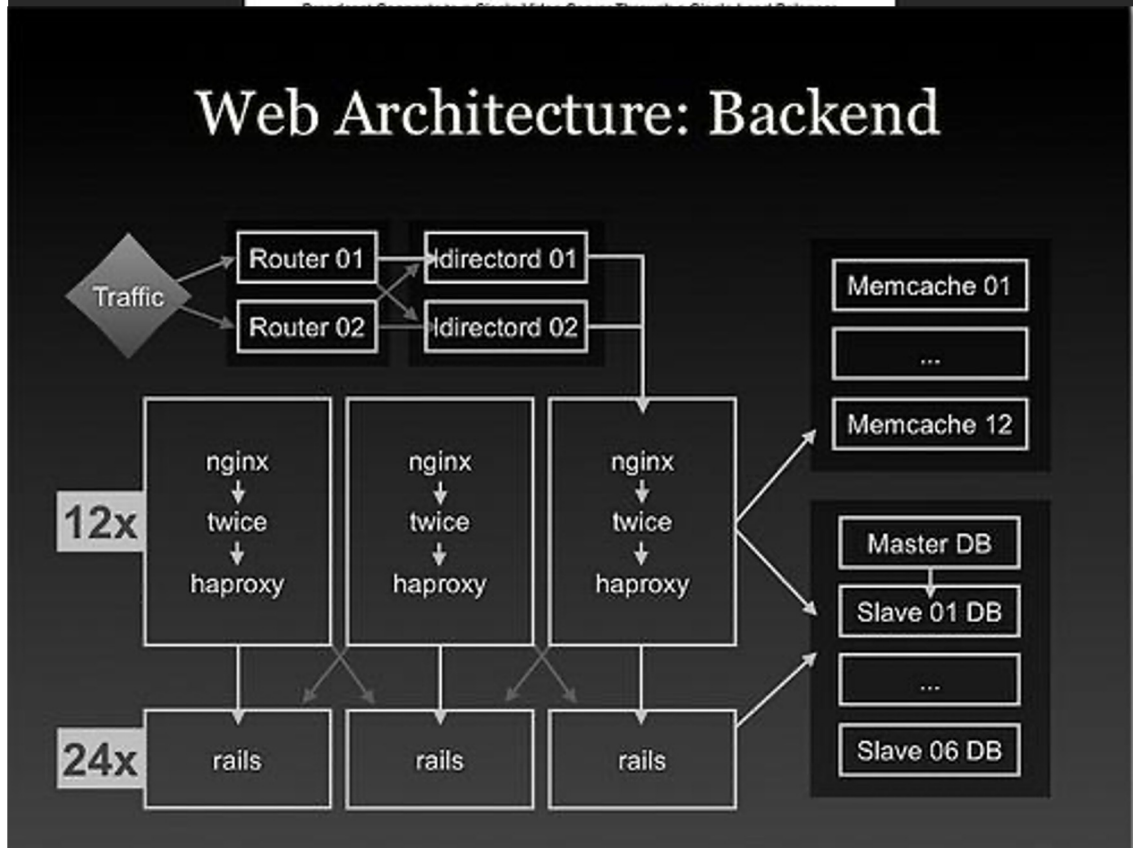
1. Recording player behavior
2. Understanding player behavior
3. Ranking / Rating
4. Play style analysis — Done
5. Exporting data — Open challenge

R. Garfield. Metagames. Horsemen of the Apocalypse: Essays on Roleplaying, 2000. Reproduced as Lost in the Shuffle: Games Within Games, http://www.wizards.com/Magic/magazine/Article.aspx?x=mtg/daily/feature/96

TWITCH.TV (JUSTIN.TV)

- Functionality
  - Video streaming: concurrent streams avg. 30k / max. 2m
  - Chat: 10b messages/day
  - API-based access to functionality + data: avg. 50k reqs./s
  - Data science infrastructure
  - DevOps: distributed everything
- Main lesson:
  - Distributed ecosystem





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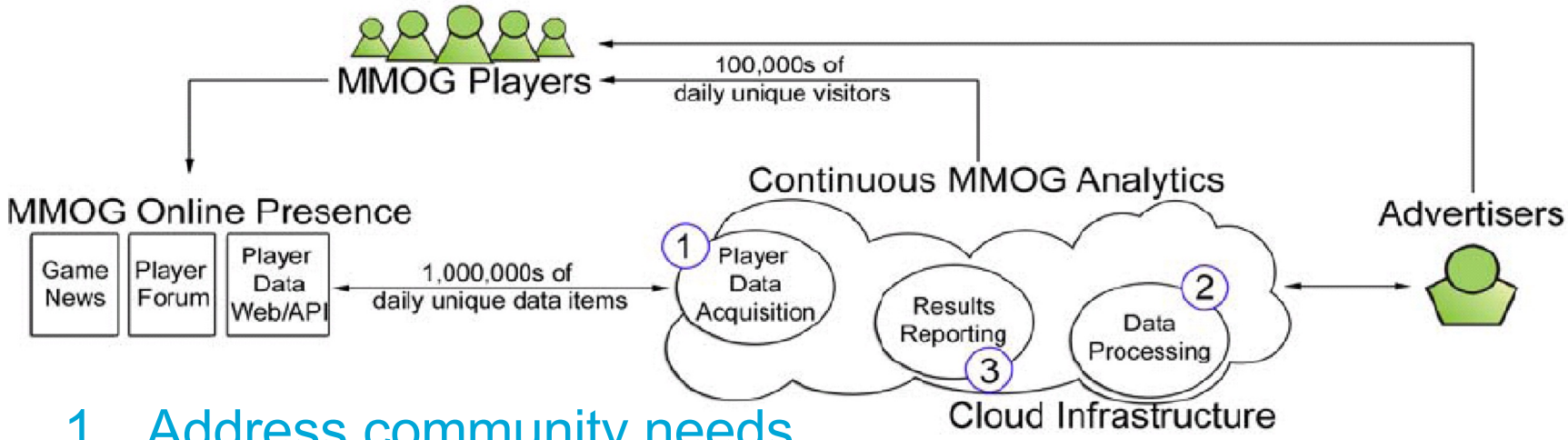
https://blog.twitch.tv/twitch-engineering-an-introduction-and-overview-a23917b71a25
http://highscalability.com/blog/2010/3/16/justintvs-live-video-broadcasting-architecture.html

THE CAMEO FRAMEWORK



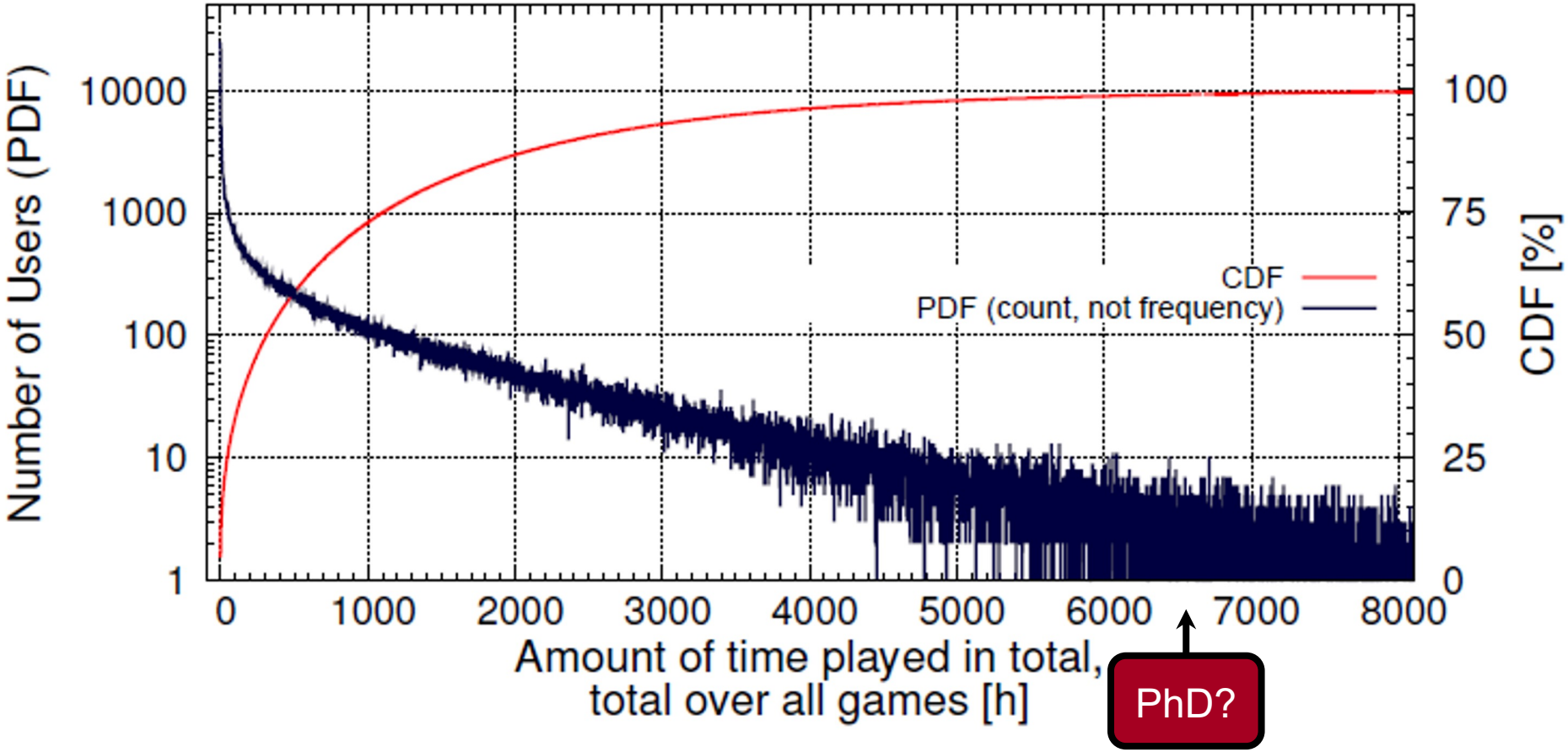
1. Address community needs
   - Can analyze skill level, experience points, rank
   - Can assess community size dynamically
2. Using on-demand technology: Cloud Computing
   - Dynamic cloud resource allocation, Elastic IP
3. Data management and storage: Cloud Computing
   - Crawl + Store data in the cloud (best performance)
4. Performance, scalability, robustness: Cloud Computing

A. Iosup, CAMEO: Continuous Analytics for Massively Multiplayer Online Games on Cloud Resources. ROIA, Euro-Par 2009 Workshops, LNCS 6043, (2010)

@large: Sample Analytics Results

Analysis of Meta-Gaming Network

Observed XFire: 2008—2011 (3+ years), 500K of 20M players



S. Shen, and A. Iosup, The XFire Online Meta-Gaming Network: Observation and High-Level Analysis, MMVE 2011

Massivizing Online Games = Rich challenge of computer systems, with societal impact!

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7. Beyond games: Massivizing computer systems is a national priority in the NL!

Lots to do next!

Message: 6

What's next?

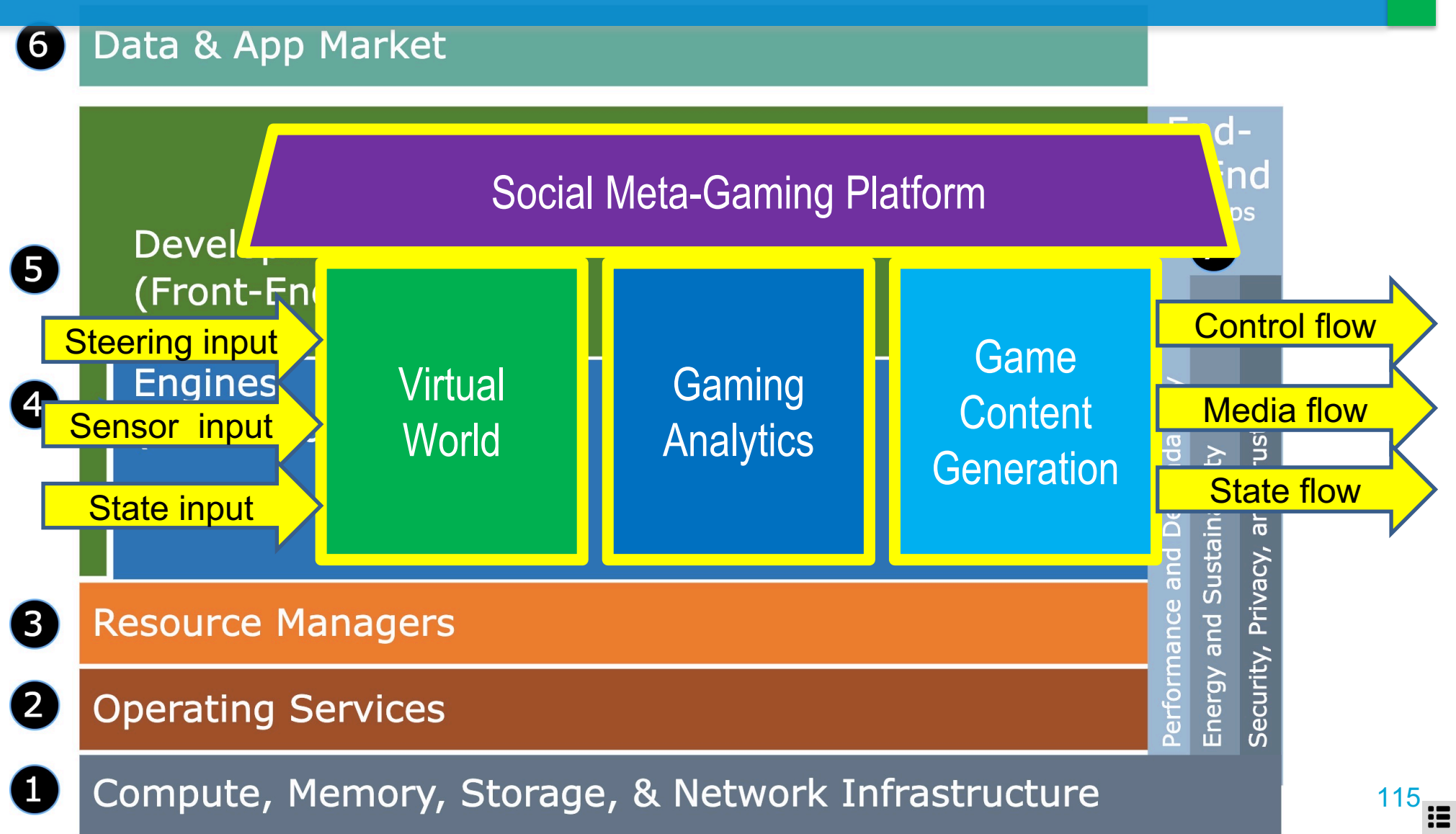
--OR--

PLATO in the 21st century

PLATO: Early Games, Early Social Apps (1970s)

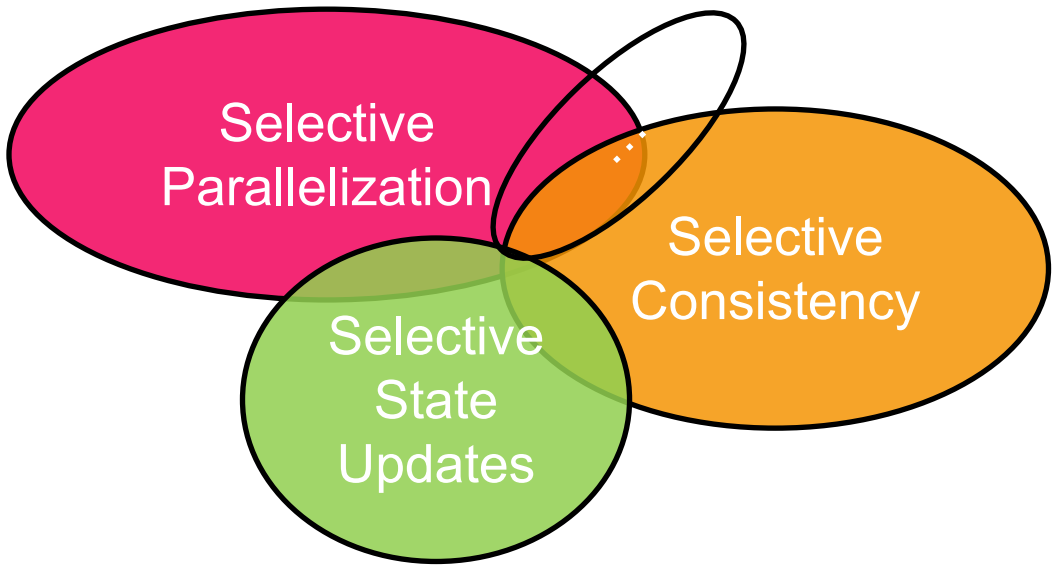
- PLATO
  - Early learning management system
  - Distributed, thousands of deployments
  - Basics of messaging, communication
  - Basics of many online game genres
  - Basics of social networking

HOW TO MANAGE SYSTEM COMPLEXITY?

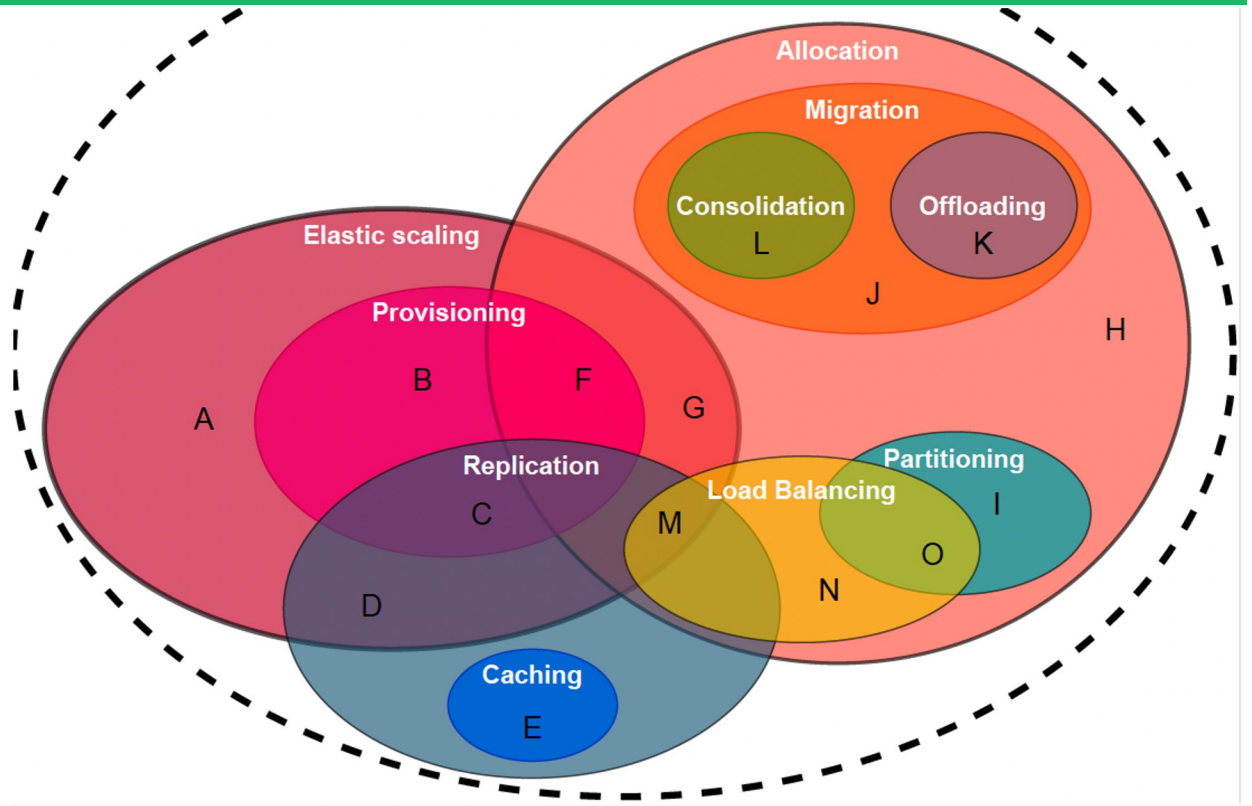


HOW TO EXPLORE SYSTEMATICALLY…

EXTREME SCALING TECHNIQUES



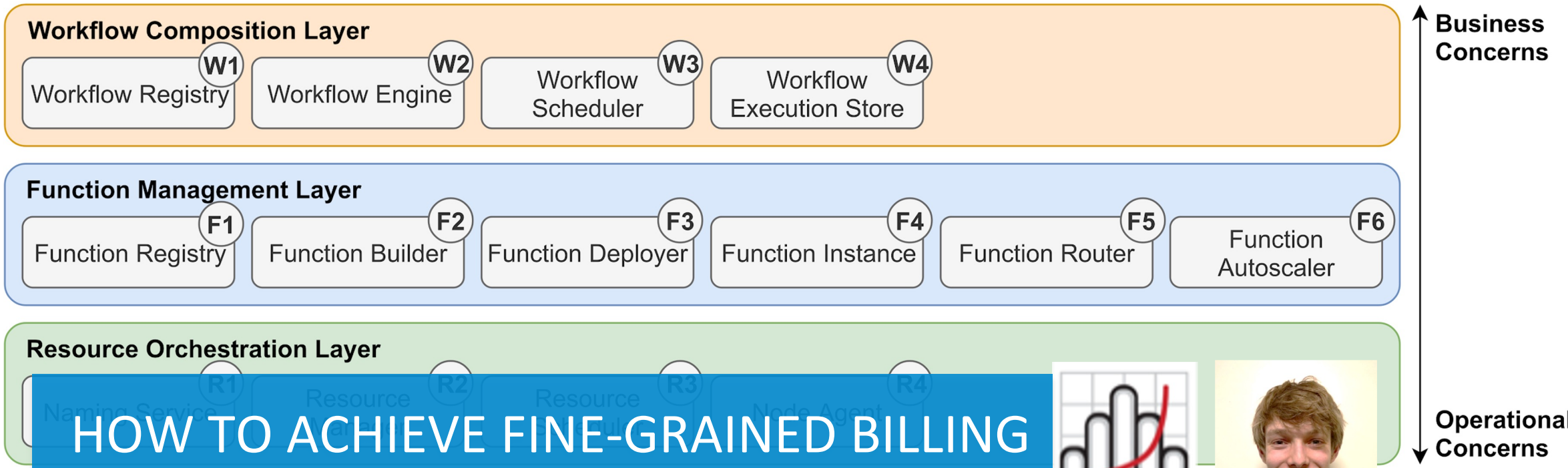
OTHER OPERATIONAL TECHNIQUES



HOW TO MANAGE SERVERLESS OPERATIONS?

EXTREME AUTOMATION

REFERENCE ARCHITECTURE OF FAAS PLATFORMS



HOW TO ACHIEVE FINE-GRAINED BILLING AND UTILIZATION-BASED BILLING?

Erwin van Eyk

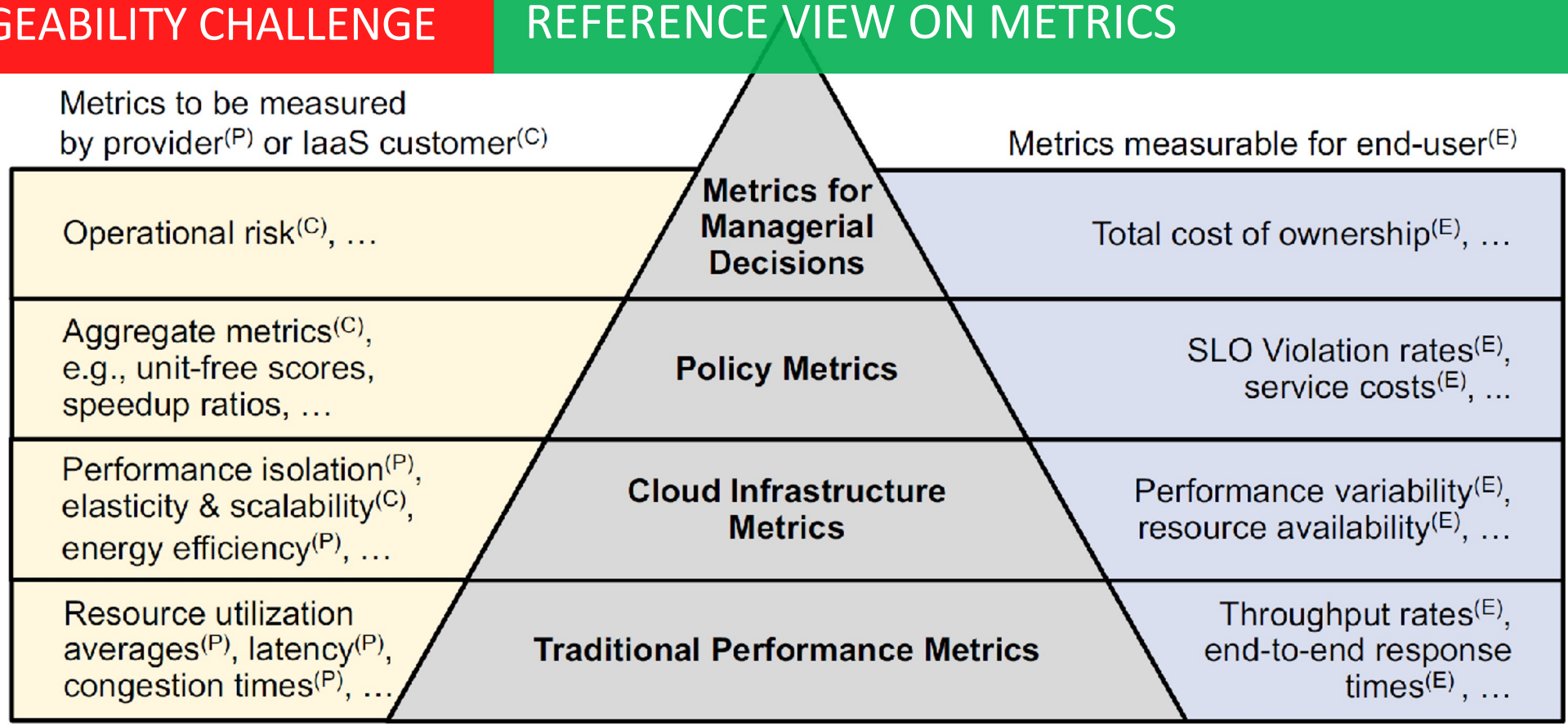
[van Eyk et al. (2019) Serverless is More: From PaaS to Present Cloud Computing, IEEE Internet Computing] [Online]

WHAT TO MEASURE? HOW TO INFER/PREDICT?

spec Research Serverless

MANAGEABILITY CHALLENGE

REFERENCE VIEW ON METRICS



N. Herbst, E. Van Eyk, C. L. Abad, A. Iosup, et al. (2018) Quantifying Cloud Performance and Dependability: Taxonomy, Metric Design, and Emerging Challenges. TOMPECS 3(4): 19:1-19:36

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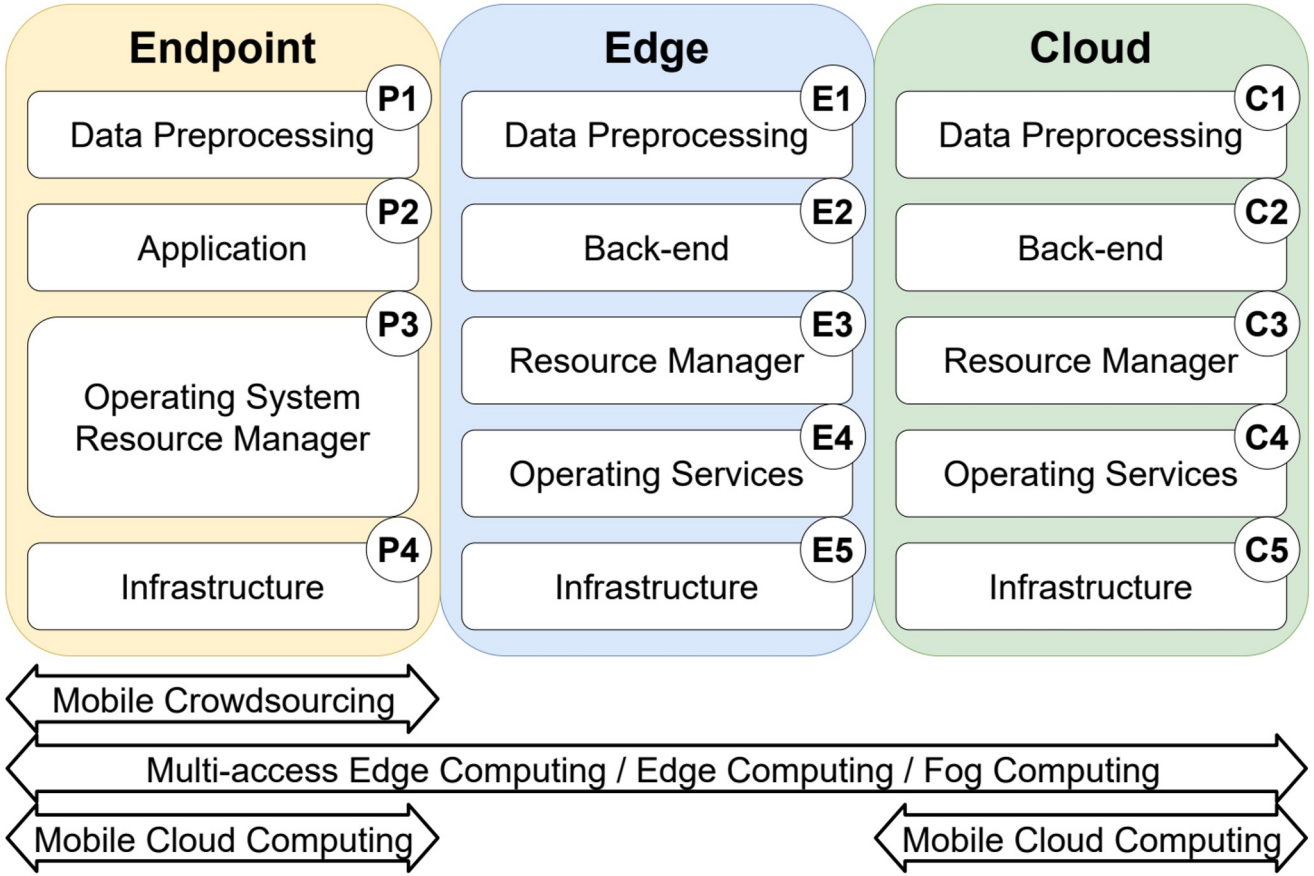
HOW TO USE THE COMPUTING CONTINUUM

THE COMPLEXITY CHALLENGE

REFERENCE ARCHITECTURE ACROSS PLATFORMS

HOW TO CONTAINERIZE EVERYTHING?



[Jansen, Trivedi, Iosup, et al. (2022) Ongoing Work

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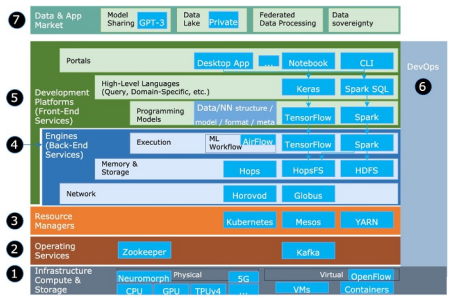
Lots to do next!

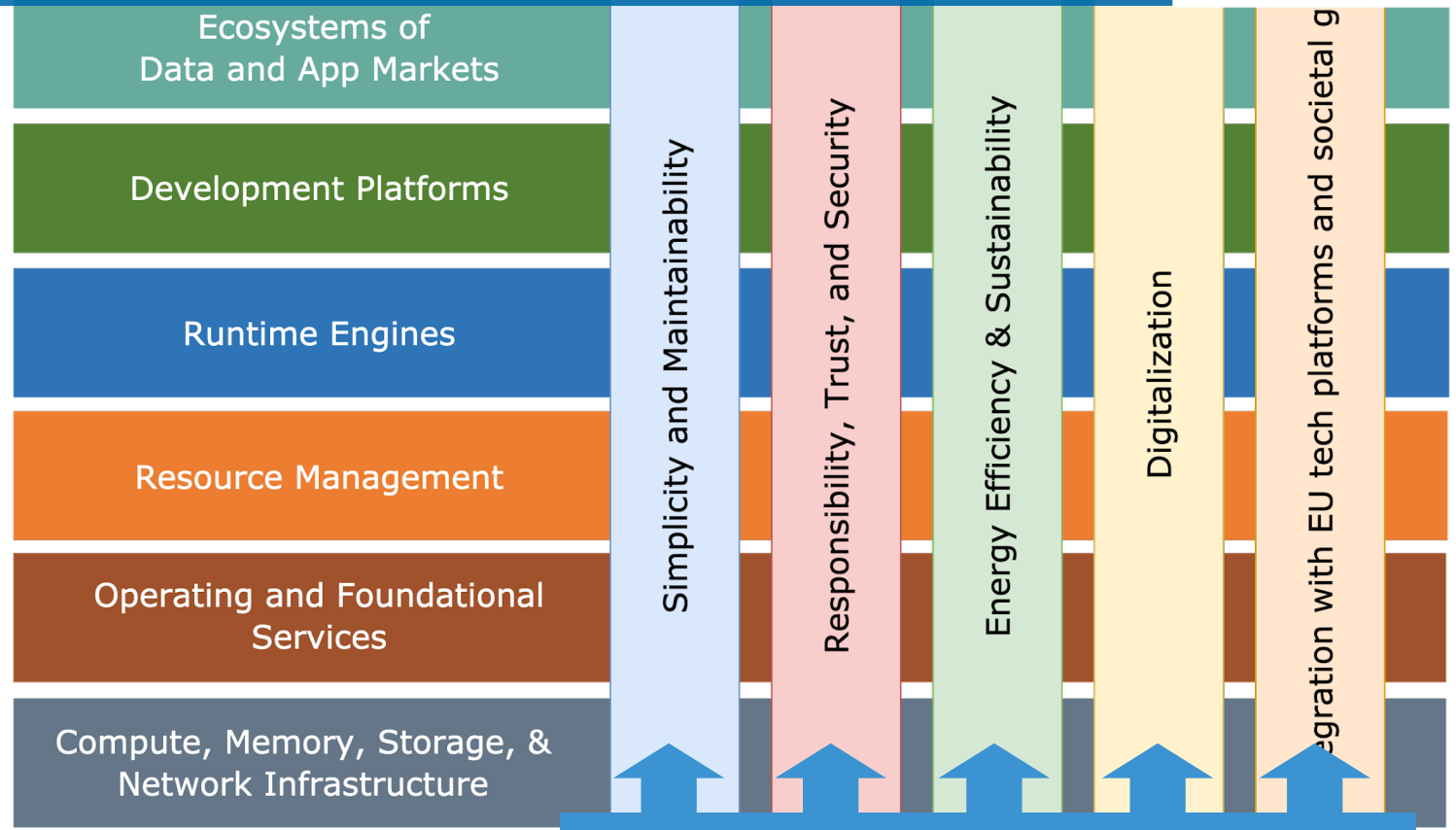
Message: 7

Beyond games: Massivizing computer systems = NL priority!

https://bit.ly/ManifestoCompSysNL
https://arxiv.org/abs/2206.03259

A LARGER VISION OF HOW COMPUTING WILL HELP OUR SOCIETY





A.Iosup@vu.nl
http://atlarge.science

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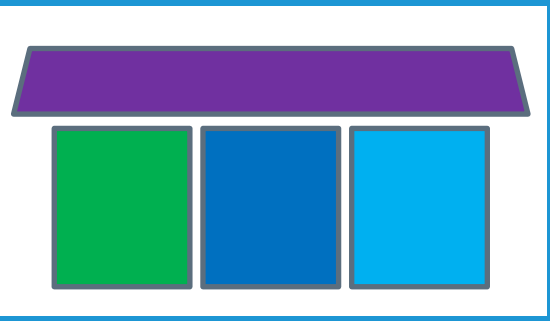
Take-Home Message >

Lots to do next!

TAKE-HOME MESSAGE:

Massivizing Online Games =
Rich challenge of computer systems, with societal impact!

Understand how things work:
observe, synthesize, experiment



Design and build better systems:
virtual world, analytics, content generation, and meta-gaming techniques, individual and all put together into gaming ecosystem

Lots to do next!

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Lots to do next!

WANT TO READ MORE ON THE TOPIC?

MASSIVIZING COMPUTER SYSTEMS

FURTHER READING

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

1. Crusoe et al. (2022) Methods Included: Standardizing Computational Reuse and Portability with the Common Workflow Language. CACM. (accepted, in print)
2. Andreadis et al. (2022) Capelin: Data-Driven Capacity Procurement for Cloud Datacenters using Portfolios of Scenarios. TPDS.
3. Sakr, Bonifati, Voigt, Iosup, et al. (2021) The Future Is Big Graphs! CACM.
4. Eismann et al. (2021) A Review of Serverless Use Cases and their Characteristics. TSE.
5. Eismann et al. (2021) Serverless Applications: Why, When, and How? IEEE Softw. 38(1): 32-39 (2021)
6. Mastenbroek et al. (2021) OpenDC 2.0: Convenient Modeling and Simulation of Emerging Technologies in Cloud Datacenters. CCGRID.
7. Versluis and Iosup (2021) A survey of domains in workflow scheduling in computing infrastructures: Community and keyword analysis, emerging trends, and taxonomies. FGCS.
8. Uta et al. (2020) Is Big Data Performance Reproducible In Modern Cloud Networks? NSDI.
9. Donkevliet et al. (2021) Dyconits: Scaling Minecraft-like Services through Dynamically Managed Inconsistency. ICDCS.
10. Versluis et al. (2020) The Workflow Trace Archive. TPDS.
11. Hegeman et al. (2021) GradeML. HotCloudPerf.
12. Uta et al. (2020) Beneath the SURFace: An MRI-like View into the Life of a 21st-Century Datacenter. login USENIX
13. Iosup, Hegeman, et al. (2020) The LDBC Graphalytics Benchmark. CoRR.
14. Abad, Iosup, et al. An Analysis of Distributed Systems Syllabi With a Focus on Performance-Related Topics.

MASSIVIZING COMPUTER SYSTEMS

FURTHER READING

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

1. Iosup et al. The AtLarge Vision on the Design of Distributed Systems and Ecosystems. ICDCS 2019 ← Start here
2. Uta et al. Is big data performance reproducible in modern cloud networks? NSDI 2020
3. Van Eyk et al. The SPEC-RG Reference Architecture for FaaS: From Microservices and Containers to Serverless Platforms, IEEE IC 2019
4. Papdopoulos et al. Methodological Principles for Reproducible Performance Evaluation in Cloud Computing. TSE 2019 and (journal-first) ICSE 2020
5. van Beek et al. Portfolio Scheduling for Managing Operational and Disaster-Recovery Risks in Virtualized Datacenters Hosting Business-Critical Workloads. ISPDC 2019
6. van Beek et al. A CPU Contention Predictor for Business-Critical Workloads in Cloud Datacenters. HotCloudPerf19

\+ Iyushkin et al. Performance-Feedback Autoscaling with Budget Constraints for Cloud-based Workloads of Workflows. Under submission

Etc.

MASSIVIZING COMPUTER SYSTEMS

FURTHER READING

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1. Iosup et al. Massivizing Computer Systems. ICDCS 2018 ← start here
2. Andreadis et al. A Reference Architecture for Datacenter Scheduling, SC18
3. Van Eyk et al. Serverless is More: From PaaS to Present Cloud Computing, IEEE IC Sep/Oct 2018
4. Uta et al. Exploring HPC and Big Data Convergence: A Graph Processing Study on Intel Knights Landing, IEEE Cluster 2018

5. Talluri et al. Big Data Storage Workload in the Cloud. ACM/SPEC ICPE 2019.
6. Toader et al. Graphless. IEEE ISPDC'19.
7. Jiang et al. Mirror. CCPE 2018.
8. Ilyushkin et al. Autoscalers. TOMPECS 2018.
9. Versluis et al. Autoscaling Workflows. CCGRID'18.
10. Uta et al. Elasticity in Graph Analytics? IEEE Cluster 2018.

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. Iosup et al. Self-Aware Computing Systems book.
15. Iosup et al. LDBC Graphalytics. PVLDB 2016.

Etc.

MASSIVIZING COMPUTER SYSTEMS

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1. Jerom van der Sar, Jesse Donkervliet, Alexandru Iosup. Yardstick. ICPE (2019)
2. M. H. Jiang, Otto W. Visser, I. S. W. B. Prasetya, Alexandru Iosup: A mirroring architecture for sophisticated mobile games using computation-offloading. Concurrency and Computation: Practice and Experience 30(17) (2018)
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4. Marcus Märtens, Siqi Shen, Alexandru Iosup, Fernando A. Kuipers: Toxicity detection in multiplayer online games. NETGAMES 2015: 1-6
5. Adele Lu Jia et al. (2015) Socializing by Gaming: Revealing Social Relationships in Multiplayer Online Games. TKDD 10(2): 11:1-29.
6. Iosup et al. (2014) : Analyzing Implicit Social Networks in Multiplayer Online Games. IEEE Internet Computing 18(3): 36-44 (2014).
7. Alexandru Iosup: POGGI: generating puzzle instances for online games on grid infrastructures. Concurrency and Computation: Practice and Experience 23(2): 158-171 (2011)
8. Siqi Shen, Otto W. Visser, Alexandru Iosup: RTSenv: An experimental environment for real-time strategy games. NETGAMES 2011: 1-6
9. Alexandru Iosup, Adrian Lascateu, Nicolae Tapus: CAMEO: Enabling social networks for Massively Multiplayer Online Games through Continuous Analytics and cloud computing. NETGAMES 2010: 1-6
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11. Vlad Nae, Alexandru Iosup, Radu Prodan: Dynamic Resource Provisioning in Massively Multiplayer Online Games. IEEE Trans. Parallel Distrib. Syst. 22(3): 380-395 (2011)
12. Vlad Nae, Radu Prodan, Alexandru Iosup, Thomas Fahringer: A new business model for massively multiplayer online games. ICPE 2011: 271-282