DISTRIBUTED SYSTEMS

Characterization of distributed systems

Dr Valerio Schiavoni and Prof Peter Kropf
University of Neuchâtel – Fall 2020

SUMMARY

CHARACTERIZATION OF DISTRIBUTED SYSTEMS

Introduction

Examples of distributed systems

Trends in distributed systems

Focus on resource sharing

Challenges

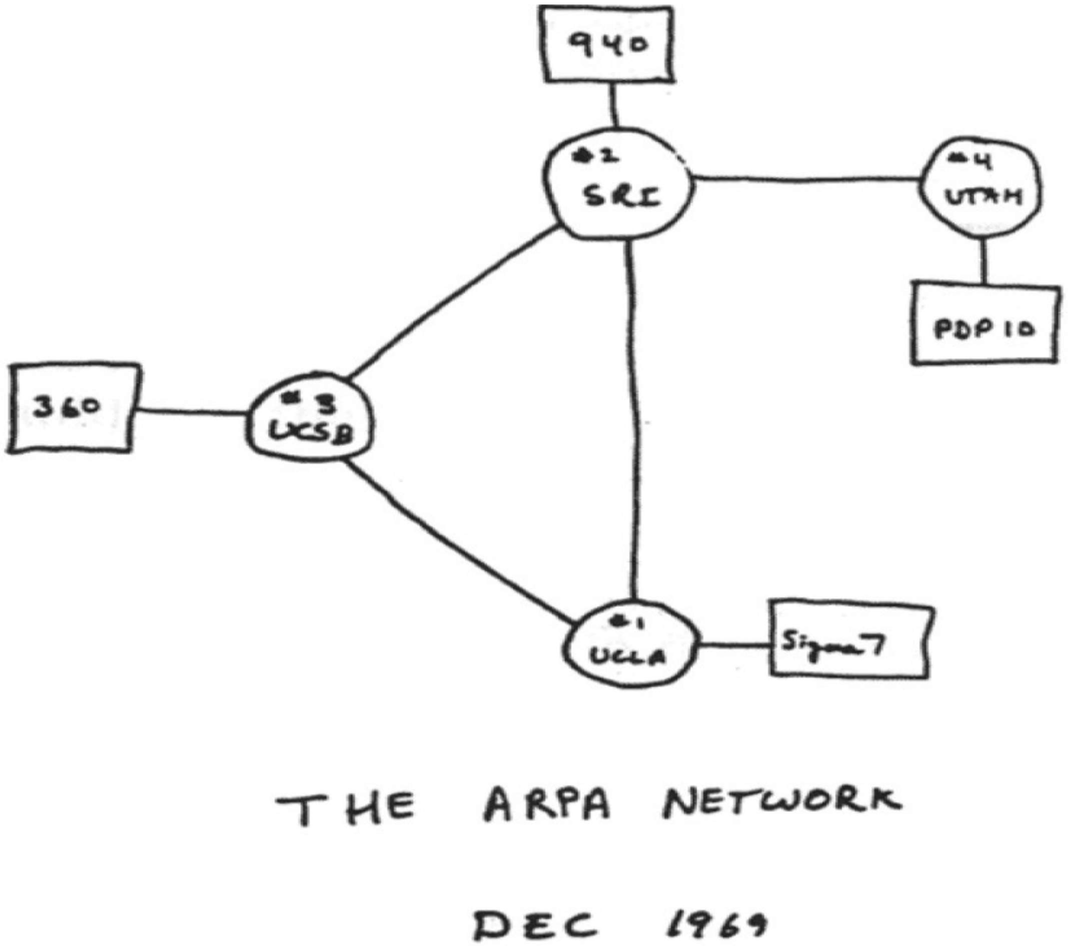
INTRODUCTION

- Distributed system
  - Hardware or software components
  - Located at networked computers
  - Communicate and coordinate their actions only by passing messages.
- Characteristics
  - Concurrency
  - No global clock
  - Independent failures
  - Share resources

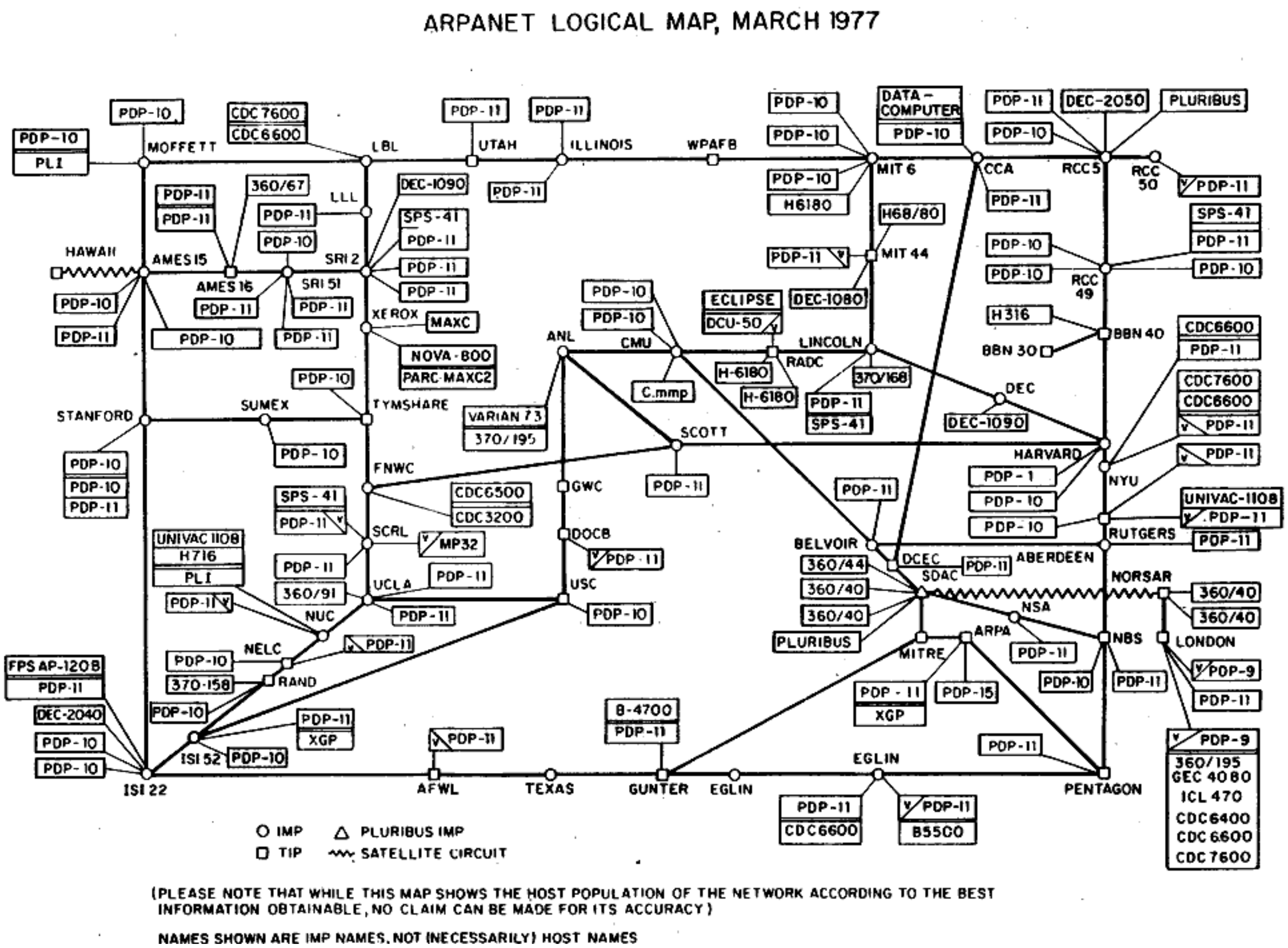
HISTORY: REVOLUTION – EVOLUTION ….

- Until 1985 large and expensive stand-alone computers
- Powerful microprocessors (price/performance increase of 10^{12} in 50 years)
- High-speed computer networks (LAN/WAN)
- Composition of computing systems of large numbers connected through high-speed networks – Clusters - Supercomputers
- Wireless - Mobile computing – Cloud Computing
- Integration at large to allow for ubiquitous access/use of infrastructures and devices

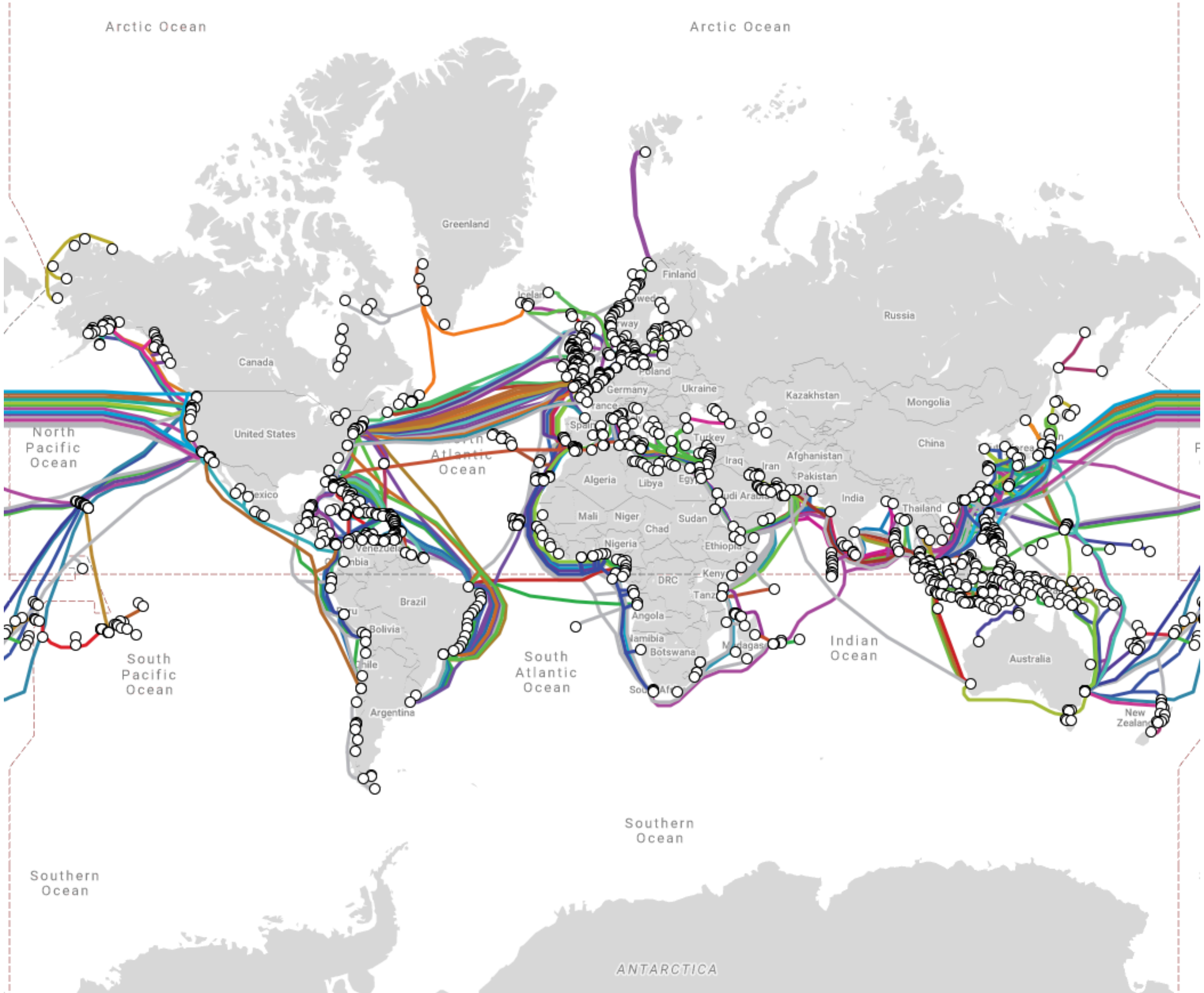
THE COMPLETE INTERNET IN 1969



THE COMPLETE INTERNET IN 1977



INTERNET GROWTH



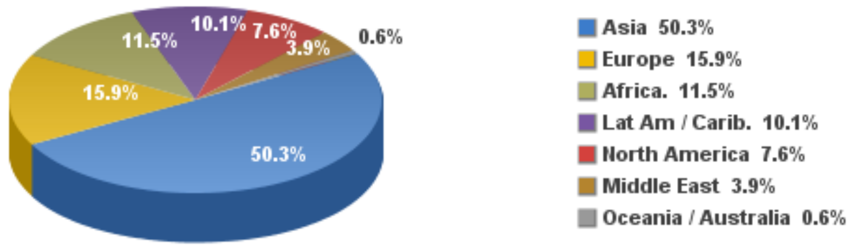
https://www.submarinecablemap.com/

INTERNET GROWTH

WORLD INTERNET USAGE AND POPULATION STATISTICS 2020 Year-Q2 Estimates						
World Regions	Population (2020 Est.)	Population % of World	Internet Users 30 June 2020	Penetration Rate (% Pop.)	Growth 2000-2020	Internet World %
Africa	1,340,598,447	17.2 %	566,138,772	42.2 %	12,441 %	11.7 %
Asia	4,294,516,659	55.1 %	2,525,033,874	58.8 %	2,109 %	52.2 %
Europe	834,995,197	10.7 %	727,848,547	87.2 %	592 %	15.1 %
Latin America / Caribbean	654,287,232	8.4 %	467,817,332	71.5 %	2,489 %	9.7 %
Middle East	260,991,690	3.3 %	184,856,813	70.8 %	5,527 %	3.8 %
North America	368,869,647	4.7 %	332,908,868	90.3 %	208 %	6.9 %
Oceania / Australia	42,690,838	0.5 %	28,917,600	67.7 %	279 %	0.6 %
WORLD TOTAL	7,796,949,710	100.0 %	4,833,521,806	62.0 %	1,239 %	100.0 %

NOTES: (1) Internet Usage and World Population Statistics estimates are for July 20, 2020. (2) CLICK on each world region name for detailed regional usage information. (3) Demographic (Population) numbers are based on data from the United Nations Population Division. (4) Internet usage information comes from data published by Nielsen Online, by the International Telecommunications Union, by GfK, by local ICT Regulators and other reliable sources. (5) For definitions, navigation help and disclaimers, please refer to the Website Surfing Guide. (6) The information from this website may be cited, giving the due credit and placing a link back to www.internetworldstats.com.

Internet Users Distribution in the World - 2020 Q1



Source: Internet World Stats - www.internetworldstats.com/stats.htm
Basis: 4,574,150,134 Internet users in March 3, 2020

https://internetworldstats.com/stats.htm

DISTRIBUTED SYSTEMS

- **Definitions**
  - *"A **system** in which **hardware** or **software** components located at **networked** computers communicate and coordinate their actions only by message passing."* [Coulouris]
  - *"A system that consists of a collection of two or more independent computers which coordinate their processing through the exchange of synchronous or asynchronous **message passing**."*
  - *"A distributed system is a collection of **independent computers** that appear to the users of the system as **a single computer**."* [Tanenbaum]
  - *"A distributed system is a collection of **autonomous computers** linked by a **network** with software designed to produce an integrated computing facility."*
  - *"A distributed system is one in which the **failure** of a machine you have never heard of can cause your own machine to become **unusable**".* [Lamport]
  - They have in common:
    - Distributed hardware and/or
    - Distributed data and/or
    - Distributed control
    - Computers connected through some network

DISTRIBUTED SYSTEMS

- **Computer Networks vs. Distributed Systems vs. Parallel computers**
  - Computer Networks: the autonomous computers are explicitly visible and must be specifically addressed
  - ***Distributed systems***: the multiple autonomous computers and components are transparent to the user
  - Parallel computers: single system view without physical separation

  - Many problems are however in common:
    - Scheduling
    - Load balancing
    - Resource and data sharing/distribution
    - Reliability, security, availability

  - Networks are in some sense also distributed systems (e.g. name services) and every distributed system relies on services provided by a network
  - Distributed systems may serve the same purpose as parallel computers: *high performance*

EXAMPLES OF DISTRIBUTED SYSTEMS

Key application sectors using distributed systems technology

- Finance and commerce
- The information society
- Creative industries and entertainment
- Healthcare
- Education
- Transport and logistics
- Science
- Environmental management

WEB SEARCH

Current leader in web search technology

- Owns (now) the largest and most complex distributed system in the history of computing
- Underlying physical infrastructure
  - Very large numbers of networked computers
  - Located at data centers all around the world
- Distributed file system
  - Very large files
  - Heavily optimized for search
- Distributed storage system
  - Fast access to very large datasets
- Coordination service
- Programming model
- Large parallel and distributed computations

MASSIVELY MULTIPLAYER ONLINE GAMES

Large numbers of users interact through the Internet with a persistent virtual world.

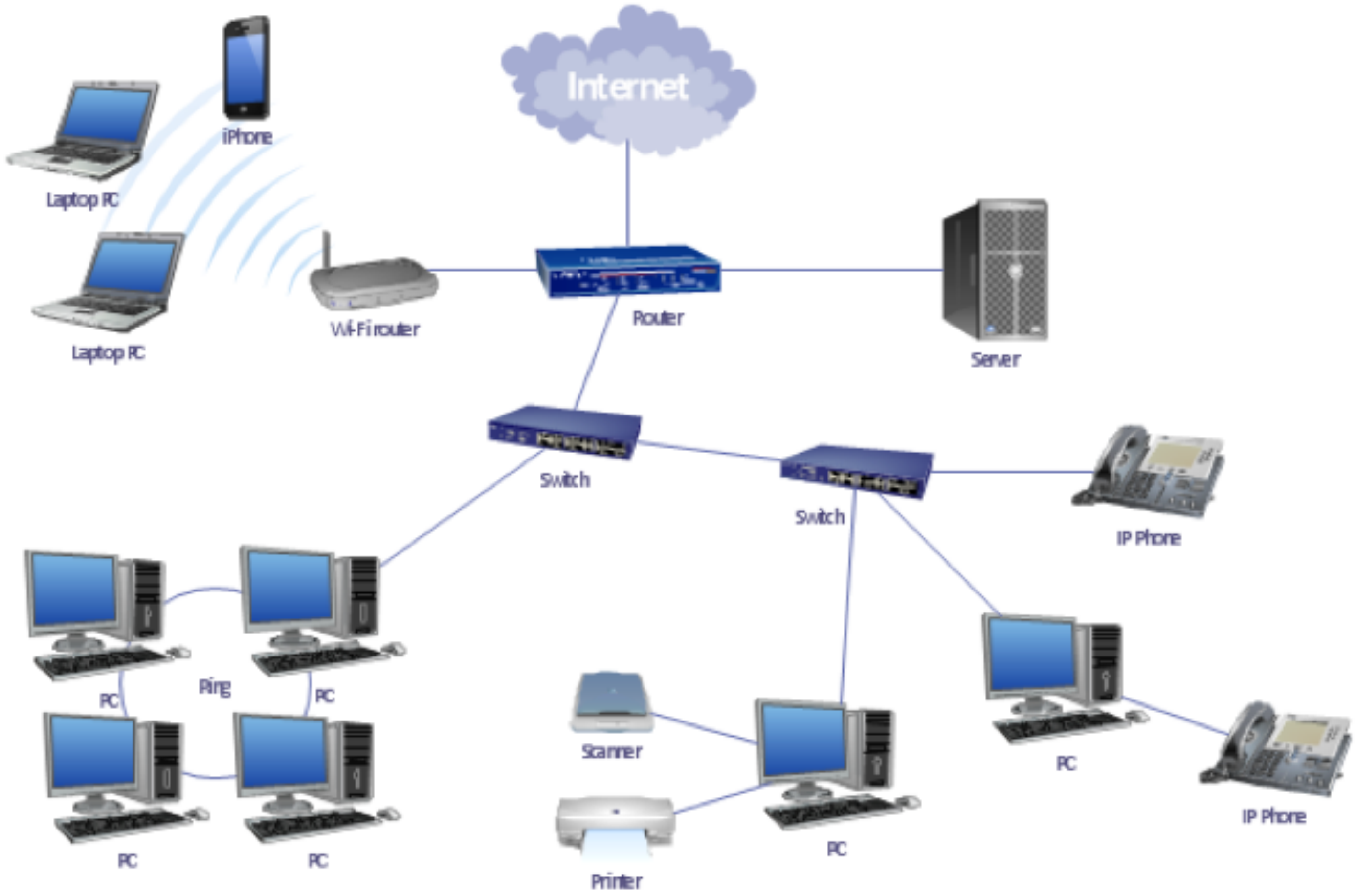
- Largest online games
  - Client-server architecture with a single centralised copy of the state of the world
  - Optimized network protocols and ensure a rapid response
  - Load is partitioned in a clusters
- Other MMOGs
  - The universe is partitioned
  - Users are dynamically allocated a server
    - Usage patterns, network delays
- Nice new ideas
  - Completely decentralized approaches
  - Peer-to-peer technology

TRENDS IN DISTRIBUTED SYSTEMS

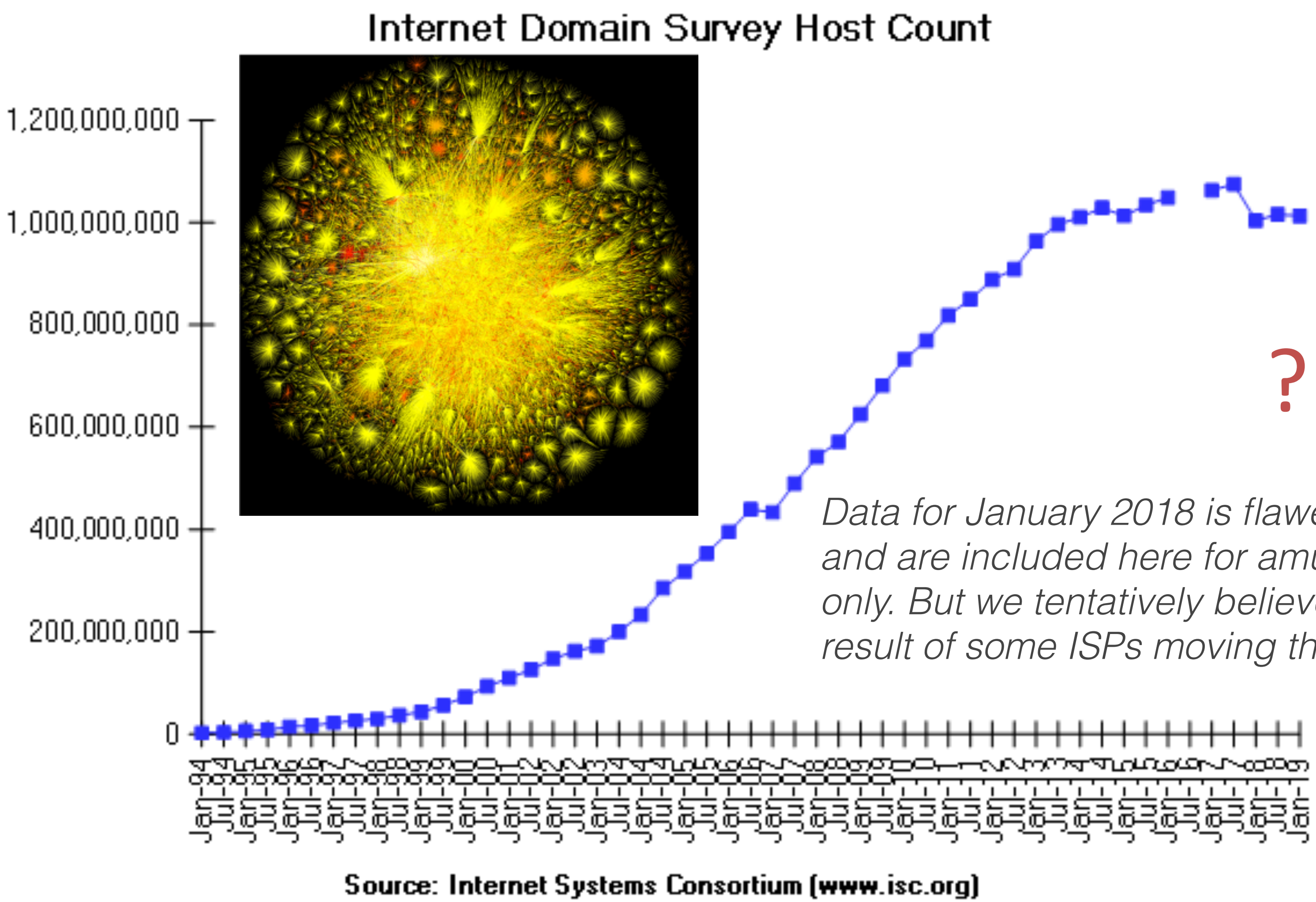
Distributed systems' influential trends of change

- Pervasive networking technology
- Ubiquitous computing
  - Desire to support the user
- Mobility
- Demand for multimedia services
- Distributed systems as a utility

PERVASIVE NETWORKING AND THE MODERN INTERNET



INTERNET GROWTH



Data for January 2018 is flawed….
and are included here for amusement purposes only. But we tentatively believe that it is the result of some ISPs moving their customers to IPv6.

MOBILE AND UBIQUITOUS COMPUTING

Mobile computing

- Computing while on the move
  - Unusual environment
- Still provided with access to home resources
  - Continue to access the Internet
- Access to local resources
  - Location-aware or context-aware computing
- Challenges
  - deal with variable connectivity and disconnection
  - maintain operation in the face of device mobility

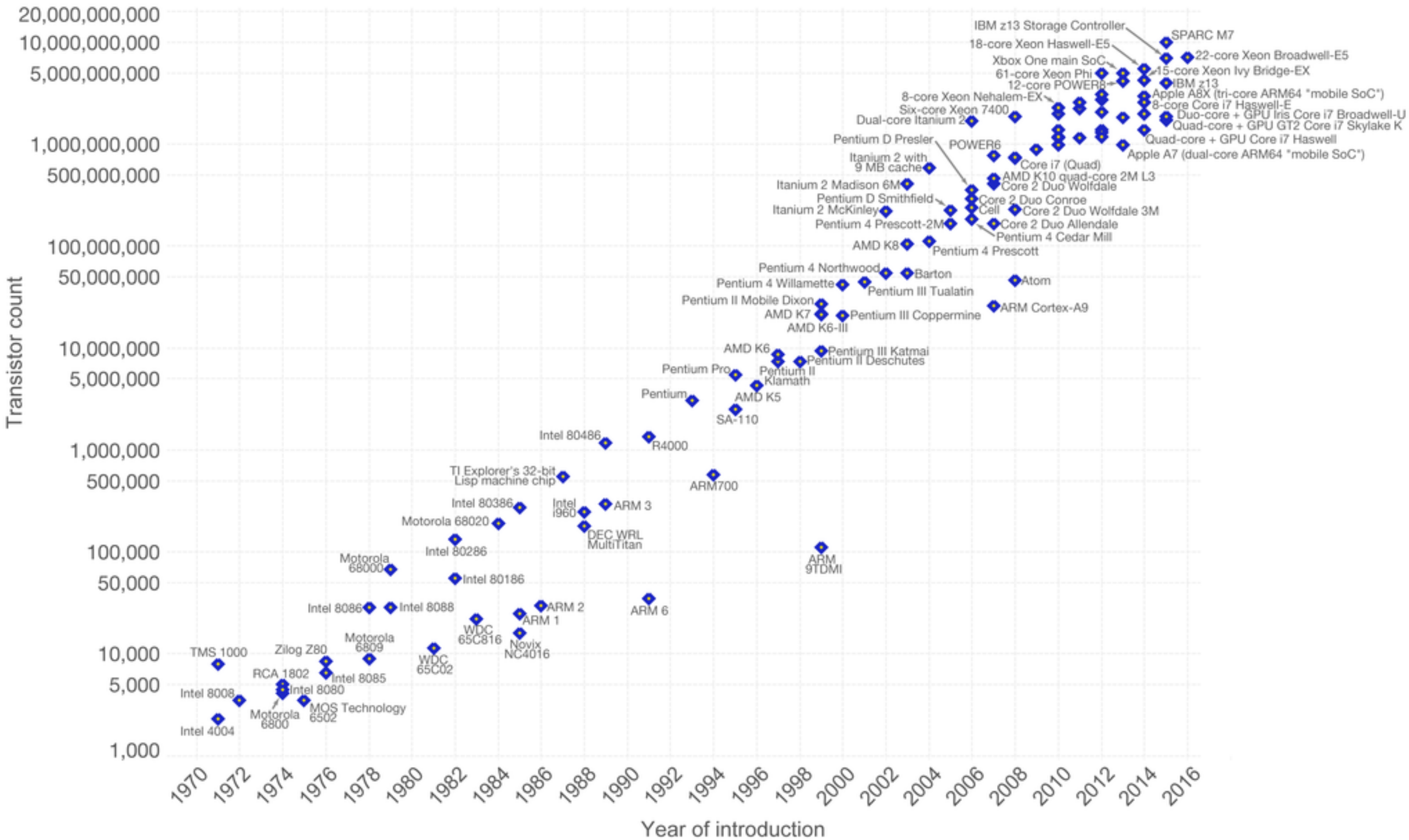
UBIQUITOUS COMPUTING

- Harnessing of many small, cheap computational devices
- Present in users' physical environments
  - Eventually become so pervasive: won't be noticed anymore
- Behaviour is transparently and intimately tied to a physical function
- Only useful if they can communicate with one another

- Ubiquitous and mobile computing overlap

Moore's Law – The number of transistors on integrated circuit chips (1971-2016)

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are strongly linked to Moore's law.



Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

DISTRIBUTED COMPUTING AS UTILITY

- Resources
  - Physical resources as storage and processing
  - Software services
- Available to networked computers
- Across the global Internet
- **Cloud computing**
- Implemented on cluster computers
  - Provide the necessary scalability

FOCUS ON RESOURCE SHARING

- Resource sharing
  - Users share hardware to reduce costs
  - Share more elaborated resources to collaborate

- Sharing patterns vary widely
  - No cooperation - search engine
  - Computer-supported cooperative work (CSCW)

SERVICE

- Distinct part of a computer system
- Manages a collection of related resources
- Offers functionality to users and applications
  - Ex. data storage, printing, electronic payment
- Accessed via a defined set of operations

- Resources are inside computers
  - Only accessed from others through communication
  - Each resource is managed by a program
    - Communication interface enables access and update
      - Reliably and consistently

CLIENT-SERVER COMPUTING

- Server: a running program (a process)
  - On a networked computer
- Accepts requests
  - From programs running on other computers
- Performs a service
  - Responds appropriately

- Client: the requesting processes

REMOTE INVOCATION

- Requests are sent in messages
  - From client to server
- Replies are sent in messages
  - From the server to clients

- Invoke an operation
  - Client sends a request

- Remote invocation
  - Complete operation
    - Request and reply

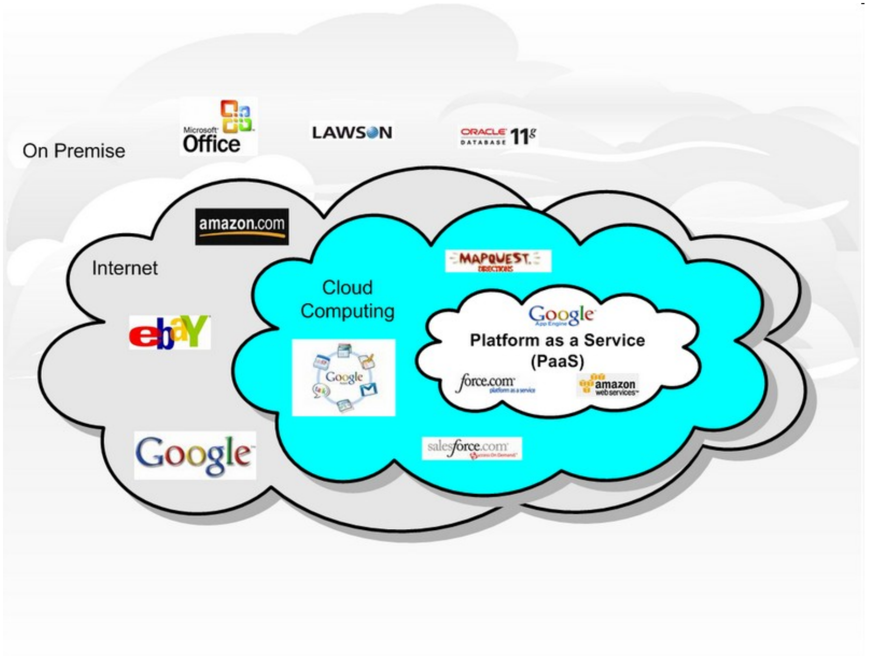
CLIENT AND SERVER ROLES

- Clients are active
  - Make requests
  - Last as long as their applications
- Servers are passive
  - Run continuously
  - Wake up when they receive requests
- Same process may be both a client and a server
  - Servers sometimes invoke operations on other servers
- Terms ‘client’ and ‘server’ apply only to the roles played in a single request

CLOUD COMPUTING

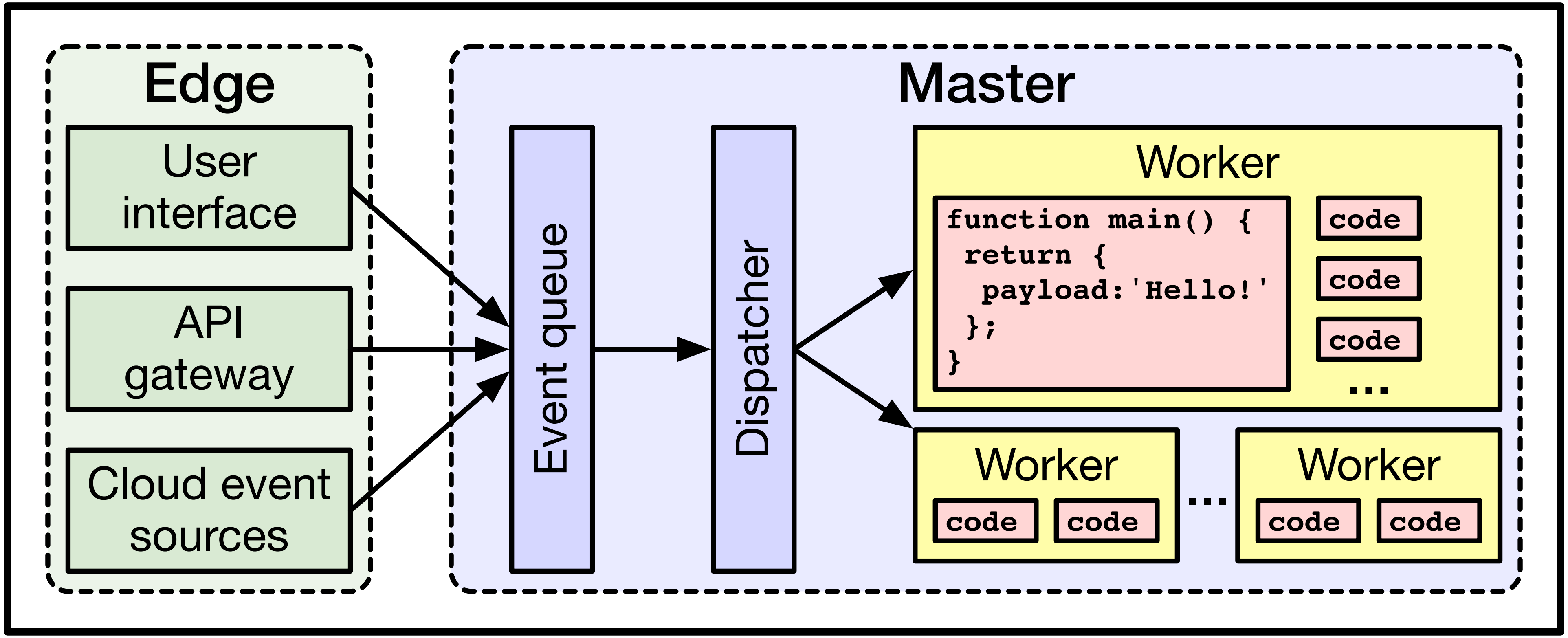
- “**Cloud computing** is a paradigm of computing in which dynamically scalable and often virtualized resources are provided as a service over the Internet. “ (W)
  - IaaS : Infrastructure as a Service
  - PaaS : Platform as a Service
  - SaaS: Software as a Service
  - MaaS: Metal as a Service
  - FaaS: Function as a Service

Cloud computing stack	Examples
Clients	Browsers
Services	PayPal, Google Maps
Application	Twitter, Skype, Google Apps
Platform	Web app. Frameworks
Storage	Amazon E3, Nirwanix
Infrastructure	GoGrid, Amazon E2



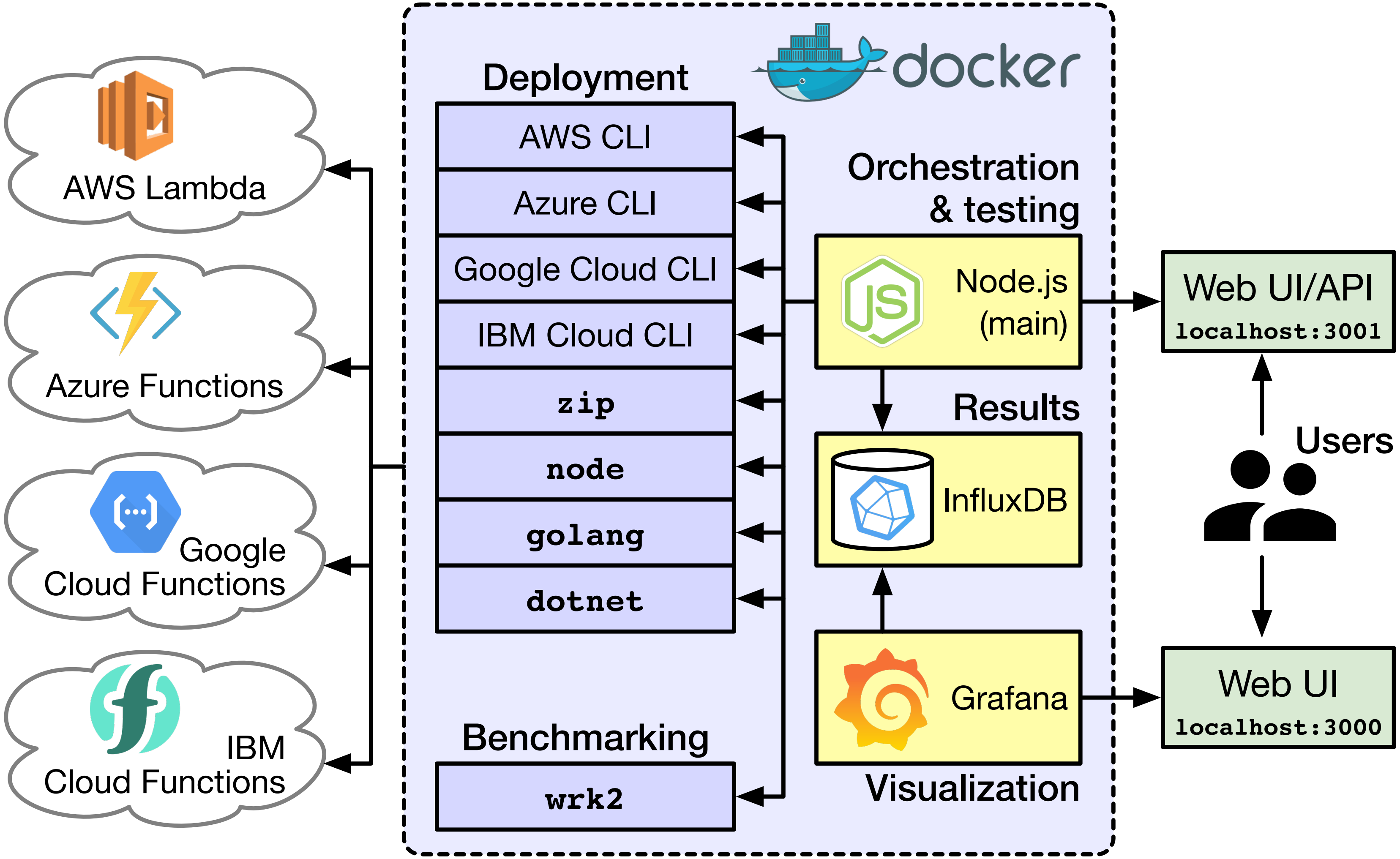
FaaS

High-level serverless FAAS platform architecture



Pascal Maissen, Pascal Felber, Peter Kropf, Valerio Schiavoni, FaaSdom: A Benchmark Suite for Serverless Computing, ACM DEBS'20
https://arxiv.org/abs/2006.03271

ARCHITECTURE OVERVIEW



CHALLENGES

- Heterogeneity
- Openness
- Security
- Scalability
- Failure handling
- Concurrency
- Transparency
- Quality of service

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HETEROGENEITY

- Variety, difference
  - In hardware and in software

- Middleware: a software layer
  - Provides a programming abstraction
  - Masks underlying heterogeneity
  - Implemented over the Internet protocols
  - Provides a uniform computational model
    - Used by the programmers of servers and distributed applications
  - Example:
    - Library to invoke a method of an object in a remote computer
    - Hiding the fact that messages are passed over a network

OPENNESS

- Open systems
  - Their key interfaces are published
  - A uniform communication mechanism is provided
  - Constructed from heterogeneous hardware and software, possibly from different vendors.

  - To work correctly
    - Careful test the conformance of each component

SECURITY

- Shared resources often have a high intrinsic value
  - Security is of considerable importance
- Three principle components:
  - Confidentiality
  - Integrity
  - Availability
- Including :
  - User authentication
  - Access control
  - Secure communication
  - Data integrity
  - Resource usage control
  - Availability
  - Privacy

SCALABILITY

- Scalability: system remains effective with
  - Significant increase in the number of resources
  - Significant increase in the number of users

- Challenges:
  - Controlling the cost of physical resources
  - Controlling the performance loss
  - Preventing software resources running out
  - Avoiding performance bottlenecks

FAILURE HANDLING

- Techniques for dealing with failures
  - Detecting failures
  - Masking failures
  - Tolerating failures
  - Recovery from failures
  - Redundancy

- Distributed systems provide a high degree of availability
  - Proportion of time that it is available

CONCURRENCY

- In a concurrent environment
  - Any object that represents a shared resource
  - Must ensure that it still operates correctly
- Implementation not intended for use in a distributed system usually need modification
  - Operations must be synchronized, so its data remains consistent
  - Consistent scheduling of concurrent activities (preservation of dependencies)
  - Avoidance of deadlock and livelock problems
  - Standard techniques
  - Semaphores (operating systems)

TRANSPARENCY

- **Transparency**
  - *Access*
    hide differences in data representation and how a resource is accessed
  - *Location*
    hide where a resource is located
  - *Migration*
    hide that a resource may move to another location
  - *Relocation*
    hide that a resource may be moved to another location while in use
  - *Replication*
    hide that a resource is replicated
  - *Concurrency*
    hide that a resource may be shared by several competitive users
  - *Failure*
    hide failure about the recovery of a resource
  - *Persistence*
    hide whether a (software) resource is in memory or on disk

PITFALLS OF DISTRIBUTED COMPUTING

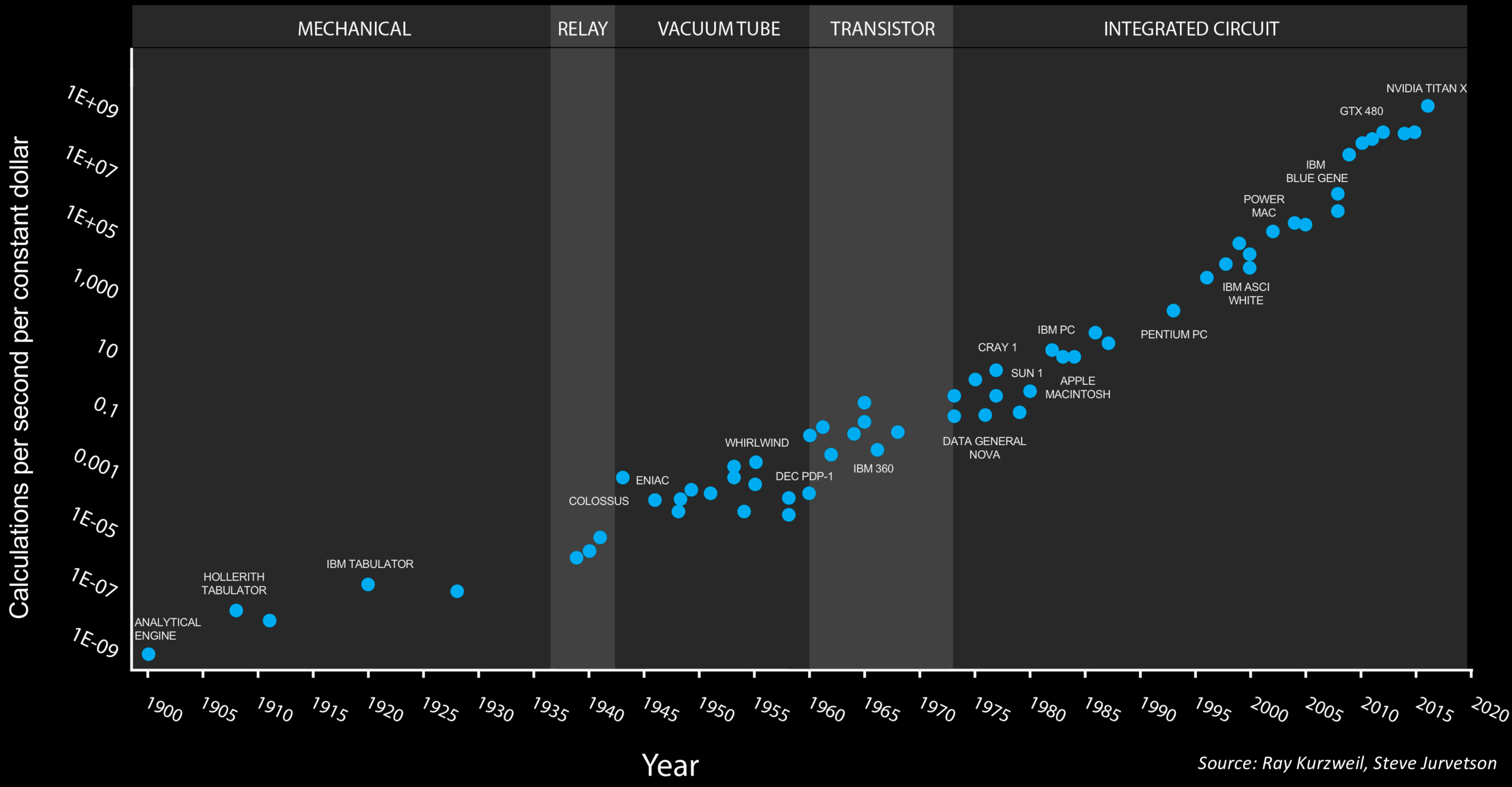
- The network is reliable
- Latency is zero
- Bandwidth is infinite
- The network is secure
- Topology doesn't change
- There is one administrator
- Transport cost is zero
- The network is homogeneous

TOP500.ORG

June 2020

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Supercomputer Fugaku** - Supercomputer Fugaku, A64FX 48C 2.2GHz, Tofu interconnect D, Fujitsu RIKEN Center for Computational Science Japan	7,299,072	415,530.0	513,854.7	28,335
2	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband, IBM DOE/SC/Oak Ridge National Laboratory United States	2,414,592	148,600.0	200,794.9	10,096
3	**Sierra** - IBM Power System AC922, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband, IBM / NVIDIA / Mellanox DOE/NNSA/LLNL United States	1,572,480	94,640.0	125,712.0	7,438
4	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway, NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
5	**Tianhe-2A** - TH-IVB-FEP Cluster, Intel Xeon E5-2692v2 12C 2.2GHz, TH Express-2, Matrix-2000, NUDT National Super Computer Center in Guangzhou China	4,981,760	61,444.5	100,678.7	18,482
6	**HPC5** - PowerEdge C4140, Xeon Gold 6252 24C 2.1GHz, NVIDIA Tesla V100, Mellanox HDR Infiniband, Dell EMC Eni S.p.A. Italy	669,760	35,450.0	51,720.8	2,252
7	**Selene** - DGX A100 SuperPOD, AMD EPYC 7742 64C 2.25GHz, NVIDIA A100, Mellanox HDR Infiniband, Nvidia NVIDIA Corporation United States	272,800	27,580.0	34,568.6	1,344
8	**Frontera** - Dell C6420, Xeon Platinum 8280 28C 2.7GHz, Mellanox InfiniBand HDR, Dell EMC Texas Advanced Computing Center/Univ. of Texas United States	448,448	23,516.4	38,745.9	
9	**Marconi-100** - IBM Power System AC922, IBM POWER9 16C 3GHz, Nvidia Volta V100, Dual-rail Mellanox EDR Infiniband, IBM CINECA Italy	347,776	21,640.0	29,354.0	1,476
10	**Piz Daint** - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100, Cray/HPE Swiss National Supercomputing Centre (CSCS) Switzerland	387,872	21,230.0	27,154.3	2,384

FUTURE VENTURES — 120 Years of Moore's Law



Source: Ray Kurzweil, Steve Jurvetson