CHAPTER 1
CHARACTERISATION OF DISTRIBUTED SYSTEMS

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SUMMARY

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CHARACTERIZATION OF DISTRIBUTED SYSTEMS

Introduction

Examples of distributed systems

Trends in distributed systems

Focus on resource sharing

Challenges

INTRODUCTION

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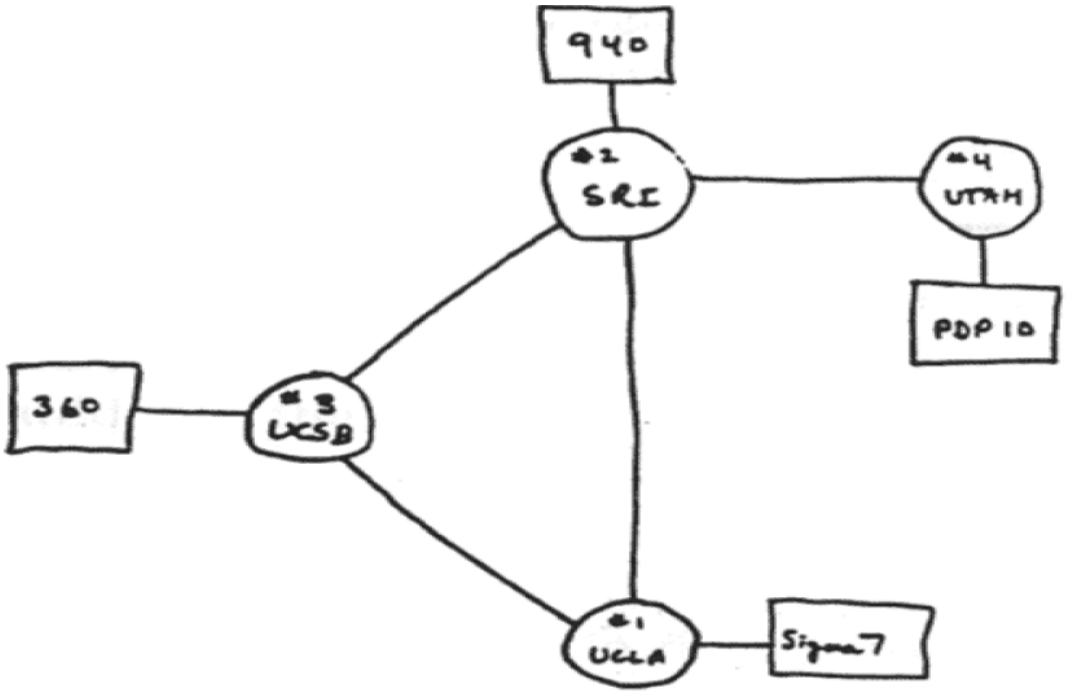
- Distributed system
  - Hardware or software components
  - Located at networked computers
  - Communicate and coordinate their actions only by passing messages.
- Characteristics
  - Concurrency
  - No global clock
  - Independent failures
  - Share resources

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

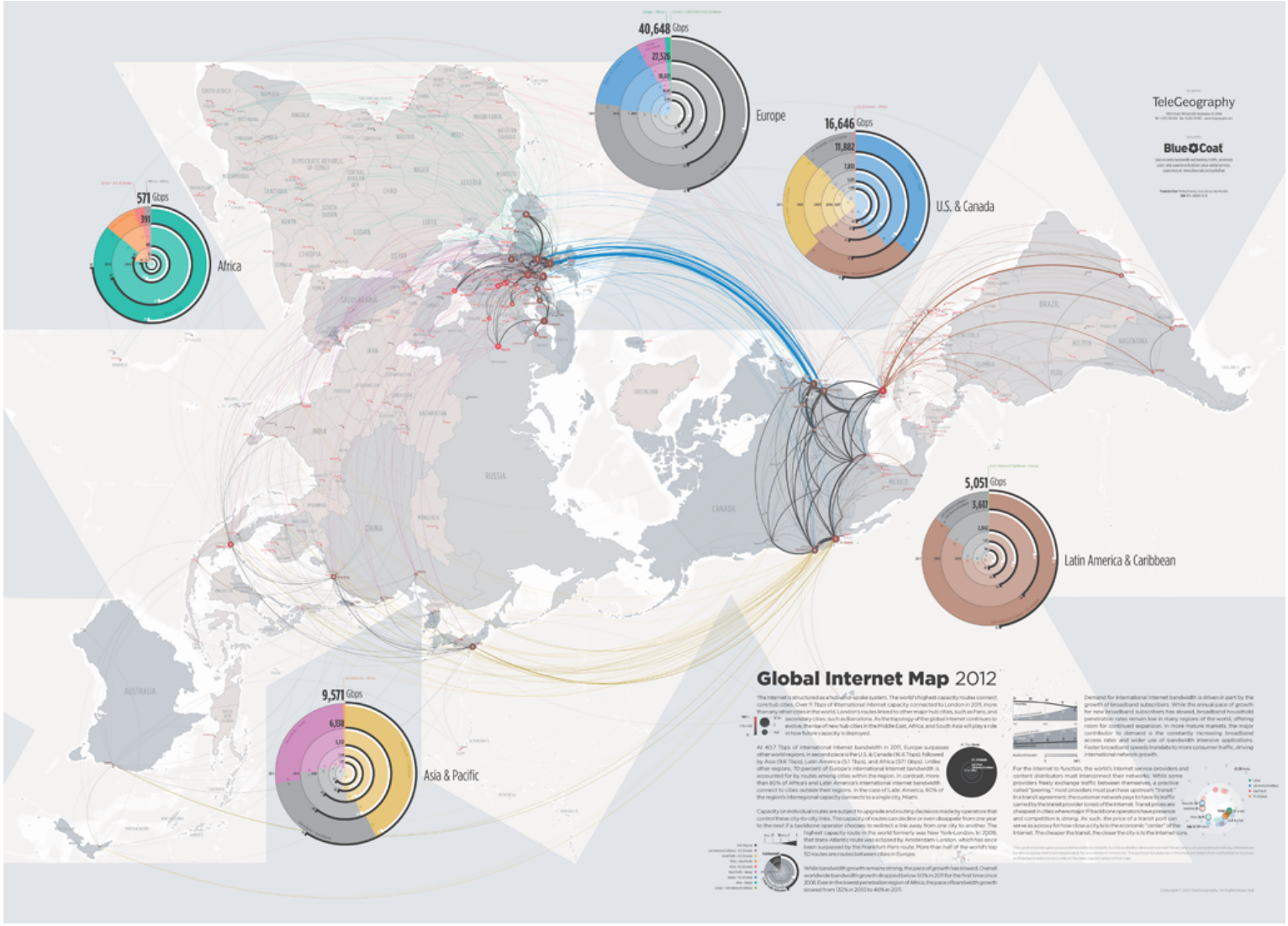
THE COMPLETE INTERNET IN 1969



THE ARPA NETWORK

DEC 1969

INTERNET GROWTH



INTERNET GROWTH

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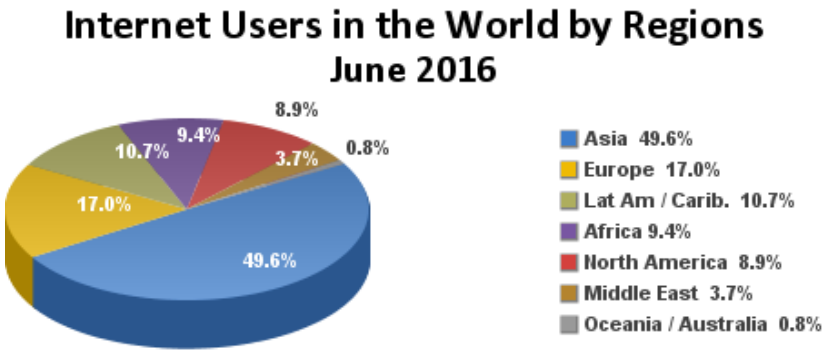
WORLD INTERNET USAGE AND POPULATION STATISTICS JUNE 30, 2016 - Update						
World Regions	Population (2016 Est.)	Population % of World	Internet Users 30 June 2016	Penetration (% Population)	Growth 2000-2016	Users % of Table
Africa	1,185,529,578	16.2 %	339,283,342	28.6 %	7,415.6%	9.4 %
Asia	4,052,652,889	55.2 %	1,792,163,654	44.2 %	1,467.9%	49.6 %
Europe	832,073,224	11.3 %	614,979,903	73.9 %	485.2%	17.0 %
Latin America / Caribbean	626,054,392	8.5 %	384,751,302	61.5 %	2,029.4%	10.7 %
Middle East	246,700,900	3.4 %	132,589,765	53.7 %	3,936.5%	3.7 %
North America	359,492,293	4.9 %	320,067,193	89.0 %	196.1%	8.9 %
Oceania / Australia	37,590,704	0.5 %	27,540,654	73.3 %	261.4%	0.8 %
WORLD TOTAL	7,340,093,980	100.0 %	3,611,375,813	49.2 %	900.4%	100.0 %



Source: Internet World Stats - www.internetworldstats.com/stats.htm
Basis: 3,611,375,813 Internet users on June 30, 2016

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- **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

- **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
  - 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 the largest and most complex distributed system in the history of computing
- Underlying physical infrastructure
  - Very large numbers of networked computers
  - Located at data centres 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

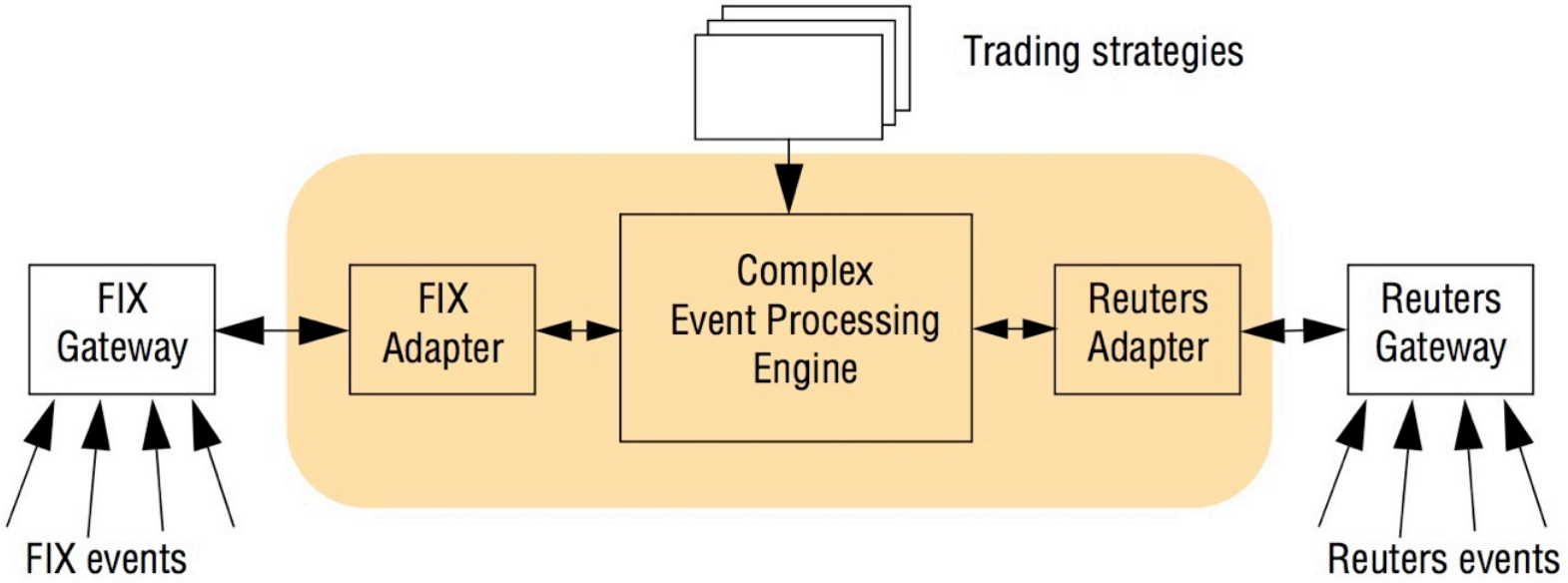
MASSIVELY MULTIPLAYER ONLINE GAMES

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

- Largest online game
  - 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

FINANCIAL TRADING

- Distributed event-based systems
- Complex Event Processing



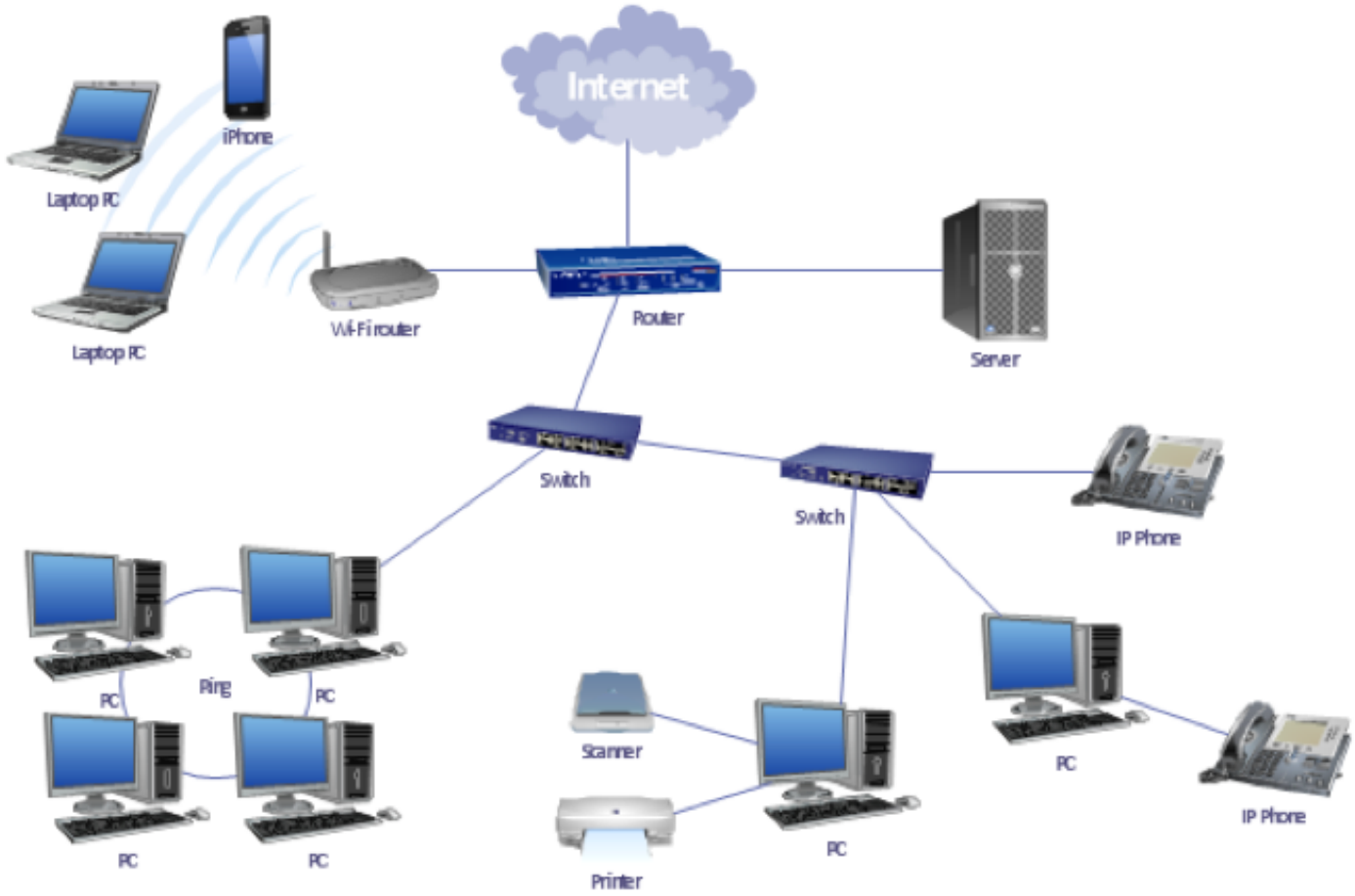
Instructor's Guide for Coulouris, Dollimore, Kindberg and Blair, Distributed Systems: Concepts and Design Edn. 5

TRENDS IN DISTRIBUTED SYSTEMS

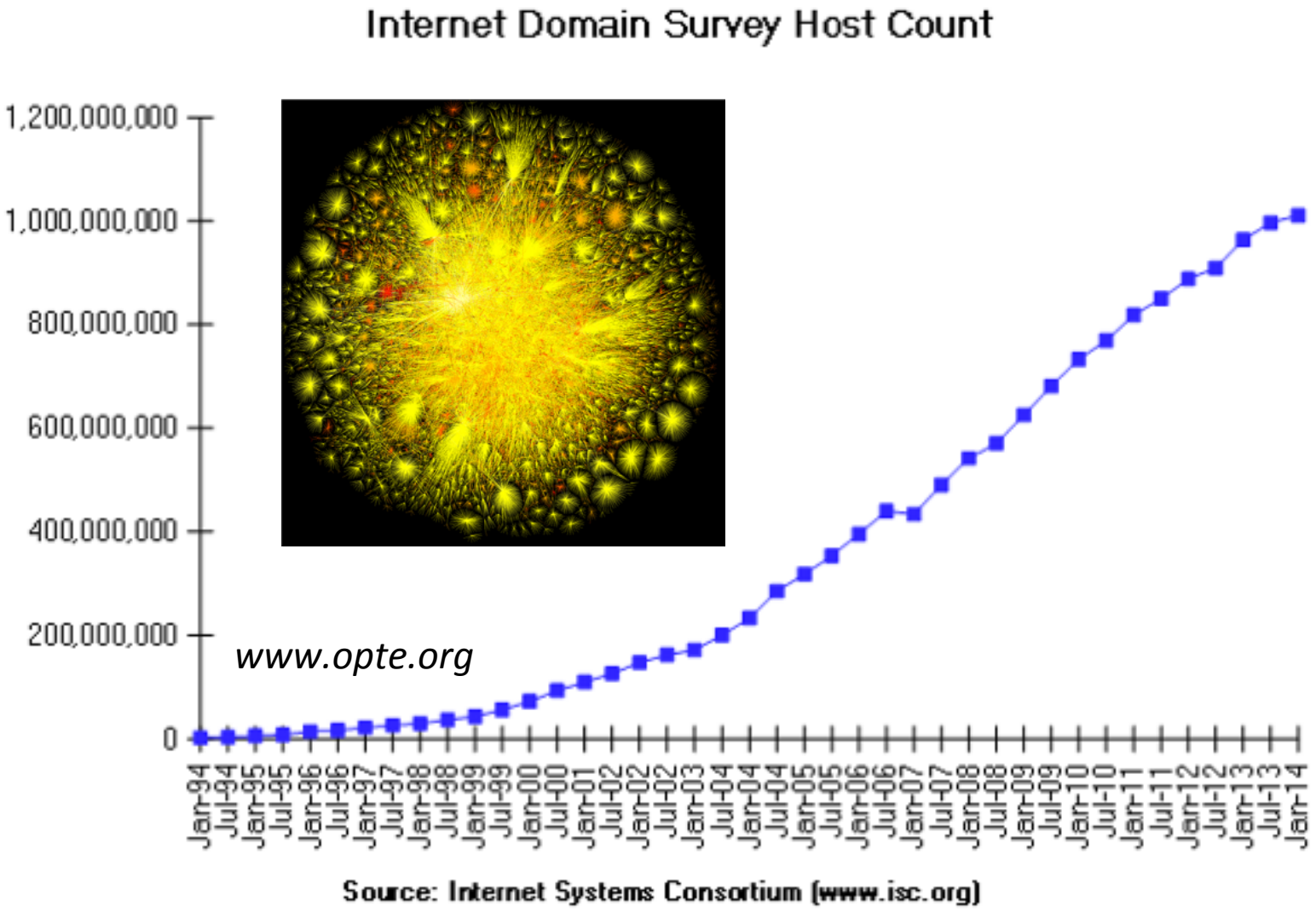
Distributed systems' influential trends of change

- 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



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

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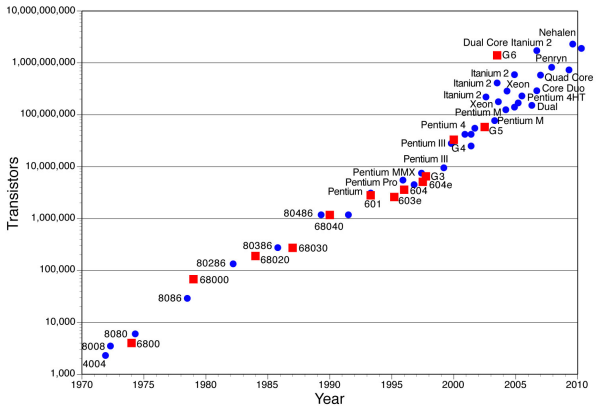
- Harnessing of many small, cheap computational devices
- Present in users' physical environments
  - Eventually become so pervasive: won't be noticed anymore
- Behaviour is transparently and intimately tied to a physical function
- Only useful if they can communicate with one another

- Ubiquitous and mobile computing overlap

... MEANS:

- The **disappearing computer**: from fixed to mobile to wearable
- It is about the Computer in the World and NOT the World in the Computer : bridging the gap between virtual and real world
- Context- and location-aware, diverse and numerous, human-centric
- Smart devices with spontaneous network capabilities that have access to any information or provide access to any service “on the net”
- Vision: everyday objects become smart and interconnected; they communicate and cooperate
- Much technology driven: *Moore’s law*



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DISTRIBUTED COMPUTING AS A 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

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- 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

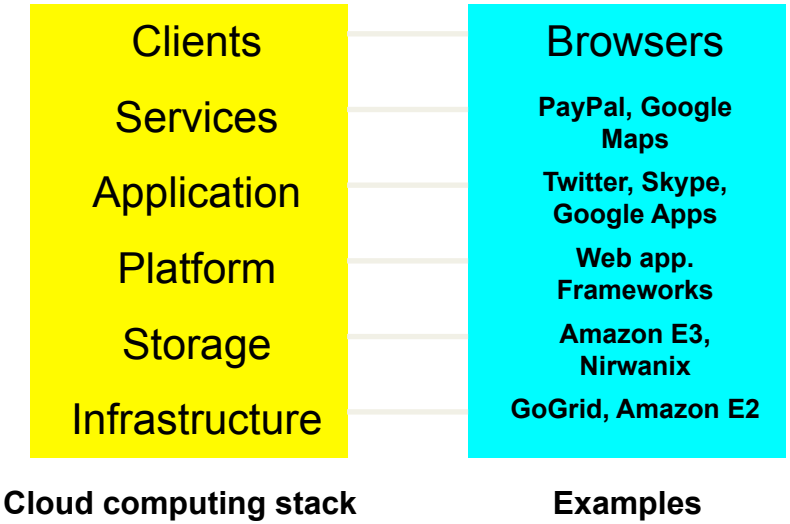
- Remote invocation
  - Complete operation
    - Request and reply

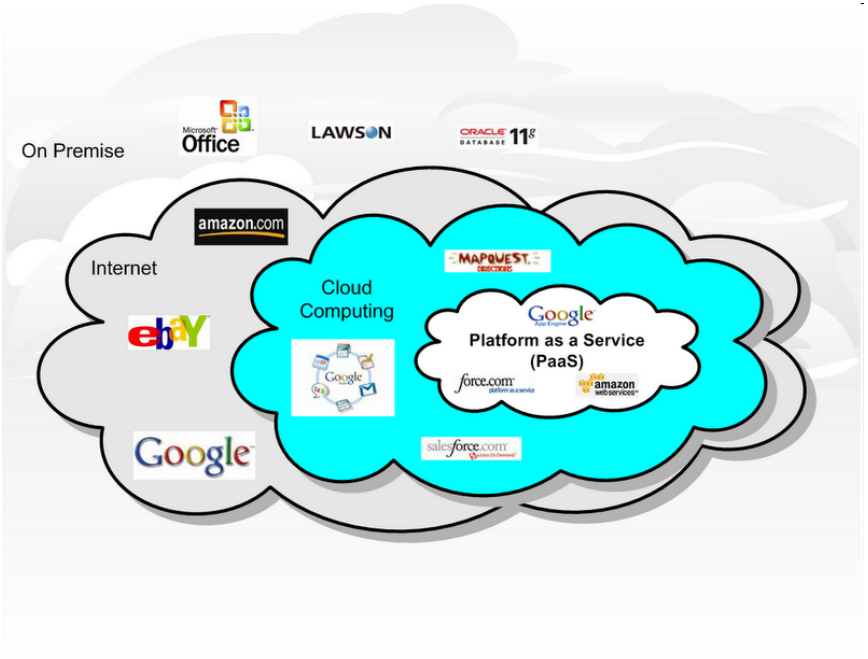
CLIENT AND SERVER ROLES

- 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





CHALLENGES

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

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

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- 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
  - Ex. semaphores (operating systems)

TRANSPARENCY

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- **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