Glossary

A

Access Control List (ACL) list of pairs (subject, value) defining the set of access rights to an object; for example, read, write, and execute permissions for a file.

Advanced Configuration and Power Interface (ACPI) open standard for device configuration and power management by the operating system. It defines four Global "Gx" states and six Sleep "Sx" states. For example, "S3" is referred to as Standby, Sleep, or Suspend to RAM.

Advanced Microcontroller Bus Architecture (AMBA) open standard, on-chip interconnect specification for the connection and management of a large number of controllers and peripherals.

Amazon Machine Image (AMI) a unit of deployment, an environment including all information necessary to set up and boot an instance including: (1) a template for the root volume for the instance, e.g., an operating system, an application server, and applications; (2) launch permissions controlling all AWS accounts that can use the AMI to launch instances; and (3) a block device mapping specifying the volumes to be attached to the instance when launched.

Amdahl's law formula used to predict the theoretical maximum speedup for a program using multiple processors/cores. Informally, it states that the portion of the computation that cannot be parallelized determines the overall speedup.

Anti-entropy a process, often using Merkle trees, for comparing the data of all replicas and updating each replica to the newest version.

App Engine (AE) an ensemble of computer, storage, search, and networking services for building web and mobile applications and running them on Google servers.

Application Binary Interface (ABI) the projection of the computer system seen by a process or thread in execution. ABI allows the ensemble consisting of the application and the library modules to access the hardware. ABI does not include privileged system instructions; instead, it invokes system calls.

Application Program Interface (API) defines the set of instructions the hardware was designed to execute and gives the application access to the Instruction Set Architecture layer. It includes High Level Language (HLL) library calls that often invoke system calls. The API is the projection of the system from the perspective of the HLL program.

Application layer deployed software applications, targeted towards end-user software clients or other programs, and made available via the cloud.

Auction a sale where items are sold to the highest bidder.

Auditor party conducting independent assessments of cloud services, information system operations, the performance, and the security of the cloud implementation.

Audit systematic evaluation of a cloud system by measuring how well it conforms to a set of established criteria, e.g., security audit if the criteria is security, privacy-impact audit if the criteria is privacy assurance, and performance audit if the criteria is performance.

Authentication credential something that an entity is, has, or knows that allows that entity to prove its own identity to a system.

Auto Scaling AWS service providing automatic scaling of EC2 instances through grouping of instances, monitoring of the instances in a group, and defining *triggers*, pairs of CloudWatch alarms, and policies that allow the size of the group to be scaled up or down.

AWK utility utility for text processing based on a scripting language.

B

Bandwidth the number of operations per unit of time; for example, the bandwidth of a processor is expressed in Mips or Mflops, while the memory and I/O bandwidth are expressed in Mbps.

Basic Core Equivalent (BCE) quantity describing how resources of a multicore processor are allocated to the individual cores. For example, a symmetric core processor can be configured as sixteen 1-BCE cores, eight 2-BCE cores, four 4-BCE cores, two 6-BCE cores, or one 16-BCE cores. An asymmetric core processor may have ten 1-BCE cores and one 6-BCE core.

Basic input/output system (BIOS) system component invoked after a computer system is powered on to load the operating system and later to manage the data flow between the OS and devices, such as keyboard, mouse, disk, video adapter, and printer.

Bigquery fully managed enterprise data warehouse for large-scale data analytics on the Google cloud platform.

BigTable distributed storage system developed by Google to store massive amounts of data and to scale up to thousands of storage servers.

Bisection bandwidth the sum of the bandwidths of the minimal number of links that are cut when splitting the system into two parts.

Bit-level parallelism parallel computing based on increasing processor word size, thus lowering the number of instructions required to process larger size operands.

BitTorrent peer-to-peer communications protocol for file sharing.

Border Gateway Protocol (BGP) path-vector reachability protocol. It maintains a table of IP networks that designate network reachability among autonomous systems and makes the core routing decisions for the Internet based on path, network policies, and/or rule sets.

Borg management software for clusters consisting of tens of thousands of servers co-located and interconnected by a data center-scale network fabric.

Boundary value problem problem with conditions specified at the extremes of the independent variable(s).

Bounded input data defining property of batch processing. The computing engine has as input a dataset of known contents and size, as opposed to processing a continuous stream of incoming data.

Broker entity that manages the use, performance, and delivery of cloud services and negotiates relationships between cloud service providers and cloud users.

Buffer overflow anomaly in which a program, while writing data to a buffer, overruns the buffer's boundary and overwrites adjacent memory locations.

BusyBox software providing several stripped-down Unix tools in a single executable file and running in environments such as Linux, Android, FreeBSD, or Debian.

Bus.Device.Function (BDF) data used to describe PCI devices.

Byte-range tokens used to specify the range of read and write operations to data files.

Byzantine failure a fault presenting different symptoms to different observers. In a distributed system a Byzantine failure could be: an *omission failure*, e.g., a crash failure, failure to receive a request or to send a response; it could also be a *commission failure*, e.g., process a request incorrectly, corrupt the local state, and/or send an incorrect or inconsistent response to a request.

C

Callback executable code passed as an argument to other code; the callee is expected to execute the argument either immediately or at a later time for synchronous and, respectively, asynchronous callbacks.

Callstack data structure storing information about the active subprograms invoked during the execution of a program. Also called execution stack, program stack, control stack, or run-time stack.

Carrier a networking organization that provides connectivity and transports data between communicating entities. Also, a carrier signal is a transmitted electromagnetic pulse or wave at a steady base frequency on which information can be imposed by modulation.

Causal delivery extension of the First-In-First-Out (FIFO) delivery to the case in which a process receives messages from multiple sources.

Cell storage storage organization consisting of cells of the same size and objects fitting exactly in one cell.

Central Limit Theorem (CLT) statistical theory stating that the sum of a large number of independent random variables has a normal distribution.

Chaining in vector computers mechanisms allowing vector operations to start as soon as individual elements of vector source operands become available. Chaining operates on *convoys*, sets of vector instructions that can potentially be executed together.

Chameleon an NSF facility that is an OpenStack KVM experimental environment for large-scale cloud research.

Command Line Interface (CLI) provides the means for a user to interact with a program.

Client-server paradigm software organization enforcing modularity. It allows systems with different processor architecture, different operating systems, libraries, and other system software to cooperate.

Clock condition a strong clock condition in a distributed system requires an equivalence between the causal precedence and the ordering of the time stamps of messages.

Closed-box platforms systems with embedded cryptographic key that allow themselves to reveal their true identity to remote systems and authenticate the software running on them. Found on some cellular phones, game consoles, and ATMs.

Clos network multistage nonblocking network with an odd number of stages. In a Clos network, all packets overshoot their destinations and then hop back to it.

Cloud Bigtable high-performance NoSQL database service for large analytical and operational workloads on the Google cloud platform.

Cloud Datastore highly scalable NoSQL database for web and mobile applications on the Google cloud platform.

CloudFormation AWS service for creation of a stack describing the application infrastructure.

Cloud Functions (CF) a lightweight, event-based, asynchronous system to create single-purpose functions that respond to cloud events on the Google cloud platform.

CloudLab an NSF facility that serves as a testbed allowing researchers to experiment with cloud architectures and new applications.

CloudWatch AWS monitoring infrastructure used to collect and track metrics important for optimizing the performance of applications and for increasing the efficiency of resource utilization. Without installing any software, a user can monitor preselected metrics and then view graphs and statistics for these metrics.

Coarse-grained parallelism execution mode in which large blocks of code are executed before the concurrent threads/processes communicate with one another.

Cognitive radio wireless communication in which an intelligent transceiver detects which communication channels are not in use and uses them while avoiding channels in use.

Cognitive radio trust trust regarding the information received by a intelligent transceiver from other nodes.

Combinatorial auction auction in which participants can bid on combinations of items or packages.

Community cloud a cloud infrastructure shared by several organizations and supporting a specific community with shared concerns (e.g., mission, security requirements, policy, and compliance considerations).

Communication channel physical system allowing two entities to communicate with one another.

Communication protocol a communication discipline involving a finite set of messages exchanged among entities. A protocol implements error control, flow control, and congestion control mechanisms.

Computation steering interactively guiding a computational experiment towards a region of interest.

Computer cloud a collection of systems in a single administrative domain offering a set of computing and storage services; a form of utility computing.

Computing grid a distributed system consisting of a large number of loosely coupled, heterogeneous, and geographically dispersed systems in different administrative domains. The name is a metaphor for accessing computer power with similar ease as accessing electric power provided by the electric grid.

Concurrency activities are executed simultaneously.

Concurrent write-sharing multiple clients can modify the data in a file at the same time.

Confidence interval statistical measure offering a guarantee of the quality of a result. A procedure is said to generate confidence intervals with a specified coverage $\alpha \in [0, 1]$ if, on a proportion exactly α of the set of experiments, the procedure generates an interval that includes the answer. For example, a 95% confidence interval $[a, b]$ means that, in 95% of the experiments, the result will be in $[a, b]$.

Conflict fraction average number of conflicts per successful transactions in a transaction processing system.

Congestion control mechanism ensuring that the offered load of a network does not exceed the network capacity.

Consistent hashing hashing technique for reducing the number of keys to be remapped when a hash table is resized. On average, only K/n keys need to be remapped with K the number of keys and n the number of slots.

Container Engine cluster manager and orchestration system for Docker containers built on the Kubernetes system. It schedules and manages containers automatically according to user specifications on the Google cloud platform.

Content any type or volume of media, be it static or dynamic, monolithic or modular, live or stored, produced by aggregation, or mixed.

Container software system emulating a separate physical server; a container has its own files, users, process tree, IP address, shared memory, semaphores, and messages. Each container can have its own disk quotas.

Control flow architecture computer architecture when the program counter of a processor core determines the next instruction to be loaded in the instruction register and then executed.

Control sensitive instructions machine instructions changing either the memory allocation, or the execution to kernel mode.

Cooperative spectrum sensing mode of operation in which each node determines the occupancy of the spectrum based on its own measurements, combines it with information from its neighbors, and then shares its own spectrum occupancy assessment with its neighbors.

Copy-on-write (COW) mechanism used by virtual memory operating systems to minimize the overhead of copying the virtual memory of a process when a process creates a copy of itself.

Cron a job scheduler for Unix-like systems used to periodically schedule jobs; often used to automate system maintenance and administration.

Cross-site scripting the most popular form of attack against web sites; a browser permits the attacker to insert client-scripts into the web pages, and thus to bypass the access controls at the web site.

Compute Unified Device Architecture (CUDA) programming model invented by NVIDIA for using graphics processing units (GPUs) for general-purpose processing.

Cut subset of the local history of all processes of a process group. *The frontier of the cut* is an n-tuple consisting of the last event of every process included in the cut.

Cut-through (wormhole) network routing routing mechanism when a packet is forwarded to its next hop as soon as the header is received and decoded. The packet can experience blocking if the outgoing channel expected to carry it to the next node is in use; in this case, the packet has to wait until the channel becomes free.

D

Database as a Service (DBaaS) a cloud service where the database runs on the physical infrastructure of the cloud service provider.

Data Description Language (DDL) syntax similar to a computer programming language for defining data structures; it is widely used for database schemas.

Data Manipulation Language (DML) programming language used to retrieve, store, modify, delete, insert, and update data in database; SELECT, UPDATE, INSERT statements or query statements are examples of DML statements.

Dataflow architecture computer architecture in which operations are carried out at the time that their input becomes available.

Datagram basic transfer unit in a packet-switched network; it consists of a header containing control information necessary to transport its payload through the network.

Data hazards in pipelining potential danger situations in which the instructions in a pipeline are dependent upon one another.

Data-level parallelism an extreme form of coarse-grained parallelism, based on partitioning the data into chunks/blocks/segments and running concurrently either multiple programs or copies of the same program, each on a different data block.

Data portability the ability to transfer data from one system to another without being required to recreate or reenter data descriptions or to modify significantly the application being transported.

Data object a logical container of data that can be accessed over a network, e.g., a blob; it may be an archive, such as specified by the *tar* format.

Data-shipping allows fine-grained data sharing; an alternative to byte-range locking.

Deadlock synchronization anomaly occurring when concurrent processes or threads compete with one another for resources and reach a state from which none of them can proceed.

Denial-of-service attack (DOS attack) internet attack targeting a widely used network service that prevents legitimate access to the service. Forces the operating system of the targeted host(s) to fill the connection tables with illegitimate entries.

De-perimeterization process allowing systems to span the boundaries of multiple organizations and cross the security borders.

Direct Memory Access (DMA) hardware feature allowing I/O devices and other hardware subsystems direct access to the system memory without the CPU involvement. Also used for memory-to-memory copying and for offloading expensive memory operations, such as scatter-gather operations, from the CPU to the dedicated DMA engine. Intel includes I/O Acceleration Technology (I/OAT) on high-end servers.

Distributed system collection of computers interconnected via a network. Users perceive the system as a single, integrated computing facility.

Dynamic binary translation conversion of blocks of guest instructions from a portable code format to the instructions understood by a host system. Such blocks can be cached and reused to improve performance.

Dynamic instruction scheduling architectural feature of modern processors supporting out-of-order instruction execution. It can reduce the number of pipeline stalls but adds to circuit complexity.

Dynamic power range interval between the lower and the upper limit of the device power consumption. A large dynamic range means that the device is able to operate at a lower fraction of its peak power when its load is low.

Dynamic voltage scaling a power conservation technique; often used together with frequency scaling under the name *dynamic voltage and frequency scaling* (DVFS).

Dynamic voltage and frequency scaling (DVFS) power management technique to increase or decrease the operating voltage or the clock frequency of a processor to increase the instruction execution rate and, respectively, to reduce the amount of heat generated and to conserve power.

E

EC2 Placement Group a logical grouping of instances that allows the creation of a virtual cluster.

Elastic Beanstalk AWS service handling automatically the deployment, the capacity provisioning, the load balancing, the autoscaling, and the application monitoring functions. It interacts with other AWS services, including EC2, S3, SNS, Elastic Load Balance, and AutoScaling.

Elastic Block Store (EBS) AWS service providing persistent block-level storage volumes for use with EC2 instances. EBS supports the creation of snapshots of the volumes attached to an instance and then uses them to restart an instance. The storage strategy provided by EBS is suitable for database applications, file systems, and applications using raw data devices.

Elastic Compute Cloud (EC2) AWS service for launching instances of an application under several operating systems, such as several Linux distributions, Windows, OpenSolaris, FreeBSD, and NetBSD.

Elastic IP address AWS feature enabling an EC2 user to mask the failure of an instance and remap a public IP address to any instance of the account, without the need to interact with the software support team.

Embarrassingly parallel application application when little or no effort is needed to extract parallelism and to run a number of concurrent threads with little communication among them.

Emergence generally understood as a property of a system that is not predictable from the properties of individual system components.

Energy proportional system the energy consumed by the system is proportional with its workload.

Enforced modularity software organization supported by the *client–server* paradigm when modules are forced to interact only by sending and receiving messages. The clients and the servers are independent modules and may fail separately. The servers are stateless; they do not have to maintain state information. Servers may fail and then come up without the clients being affected, or even noticing the failure.

Explicitly Parallel Instruction Computing (EPIC) processor architecture enabling the processor to execute multiple instructions in each clock cycle. EPIC implements a form of Very Long Instruction Word (VLIW) architecture.

Error bar a line segment through a point on a graph, parallel to one of the axes that represents the uncertainty or error of the corresponding coordinate of the point.

Event a change of state of a process or thread.

Event time the wall clock time when the event occurred.

Exception anomalous or exceptional conditions requiring special processing during the execution of a process. An exception breaks the normal flow of execution of a process/thread and executes a preregistered exception handler from a known memory location provided by the first-level interrupt handler (FLIV).

Exception behavior preservation condition required for dynamic instruction scheduling. Any change in instruction order must not change the order in which exceptions are raised.

F

Fabric controller a distributed Windows Azure application replicated across a group of machines that owns all resources in its environment and is aware of every application; it ensures scaling, load balancing, memory management, and reliability.

Facility layer heating, ventilation, air conditioning (HVAC), power, communications, and other aspects of the physical plant in a data center.

Failover-based software systems systems less affected by data center-level failures; such systems only run at one site, but checkpoints are created periodically and sent to backup data centers.

FedRAMP common security model enabling joint authorizations and continuous security monitoring services for government and commercial cloud computing systems intended for multiagency use. The use of this common security risk model provides a consistent baseline for cloud-based technologies and ensures that the benefits of cloud-based technologies are effectively integrated across a variety of cloud computing solutions. The risk model will enable the government to "approve once, and use often" by ensuring multiple agencies gain the benefit and insight of the FedRAMP's authorization and access to service provider's authorization packages.

Field-programmable gate array (FPGA) an integrated circuit designed to be configured, adapted, and programmed in the field to perform a well-defined function.

Fine-grained parallelism concurrency when only relatively small blocks of the code can be executed in parallel, without the need to communicate or synchronize with other threads or processes.

FISMA compliant environment environment that meets the requirements of the Federal Information Security Management Act of 2002. The law requires an inventory of information systems, the categorization of information and information systems according to risk level, security controls, a risk assessment, a system security plan, certification and accreditation of the system's controls, and continuous monitoring.

First-In-First-Out delivery delivery rule requiring that messages are delivered in the same order they are sent.

First-level interrupt handler (FLIH) software component of the kernel of an operating system activated in case of an interrupt or exception. It saves the registers of current process in the PCB (Process Control Block), determines the source of interrupt, and initiates the service of the interrupt.

Flash crowds an event that disrupts the life of a very significant segment of the population, such as an earthquake in a very populated area, and dramatically increases the load of computing and communication service, e.g., an earthquake increases the phone and internet traffic.

Flynn's taxonomy classification of computer architectures proposed by Michael J. Flynn in 1966. Classifies the systems based on the number of control and data flows as: Single Instruction Single Data (SISD), Single Instruction Multiple Data (SIMD), or Multiple Instruction Multiple Data (MIMD).

Flow control mechanism used to control the traffic in a network. Feedback from the receiver forces the sender to transmit only the amount of data the receiver is able to buffer and then process.

Front-end system component of a server system tasked to dispatch the client requests to multiple *back-end* systems for processing.

Full virtualization type of virtualization in which each virtual machine runs on an exact copy of the actual hardware.

Future Internet a generic concept referring to all research and development activities involved in development of new architectures and protocols for the internet.

G

Geo replication operation in which a system runs at multiple sites concurrently.

Gather operation operation supported by vector processing units to deal with sparse vectors. It takes an index vector and fetches the vector elements at the addresses given by adding a base address to the offsets given by the index vector; as a result a dense vector is loaded into a vector register. In parallel computing it is an operation supported by MPI (Message Passing Interface) to take elements from many processes and gather them into one single process.

Global agreement on time a necessary condition to trigger actions that should occur concurrently.

Go or Golang open-source compiled, statically typed language like Algol and C; has garbage collection, limited structural typing, memory safety features, and CSP-style concurrent programming.

Guest operating system an operating system that runs under the control of a hypervisor, rather than directly on the hardware.

H

Hadoop extension of MapReduce with programming support for iterative applications and improved efficiency. Adds various caching mechanisms and makes the task scheduler loop-aware.

Hard deadline strict deadline with penalties, expressed precisely as milliseconds, or possibly seconds.

Hardware layer includes computers (CPU, memory), network (router, firewall, switch, network link, and interface) and storage components (hard disk), and other physical computing infrastructure elements.

Hash function function used to map data of arbitrary size to data of fixed size. For example, a function applied to the name of the file when the n low-order bits of the hash value give the block number of the directory where the file information can be found. *Extensible hashing* is used to add a new directory block.

Head-of-line blocking situation where a long-running task cannot be preempted and other tasks waiting for the same resource are blocked.

Hedged requests short-term tail-tolerant techniques; the client issues multiple replicas of the request to increase the chance of a prompt reply.

Hot standby a method to achieve redundancy. The primary and the secondary (backup) systems run simultaneously. The data is mirrored to the secondary system in real time so that both systems contain identical information.

Horizontal scaling application scaling by increasing the number of VMs as load increases and reducing this number when load decreases; most common form of cloud application scaling.

Hybrid cloud an infrastructure consisting of two or more clouds (private, community, or public) that remain unique entities but are bound together by standardized or proprietary technology that enables data and application portability.

HyperText Transfer Protocol (HTTP) application-level protocol built on top of the TCP transport protocol used by the web browser (the client) to communicate with the server.

HTTP-tunneling technique most often as a means of communication from network locations with restricted connectivity. Tunneling means the encapsulation of a network protocol. In this case, HTTP acts as a wrapper for the communication channel between the HTTP client and the HTTP server.

Hyper-convergence a software-centric architecture that tightly integrates compute, storage, networking, virtualization, and possibly other technologies into a commodity hardware box supported by a single vendor.

Hypervisor or virtual machine monitor (VMM) software that securely partitions the computer's resources of a physical processor into one or more virtual machines. Each virtual machine appears to be running on the bare hardware, giving the appearance of multiple instances of the same computer, but all are supported on a single physical system.

Hyper-threading term used to describe multiple execution threads possibly running concurrently but on a single-core processor.

I

Idempotent action action that repeated several times has the same effect as when the action is executed only once.

IEEE 754 Standard for Floating-Point Arithmetic defines arithmetic formats, interchange formats, rounding rules, operations, and exception handling for floating-point numbers.

Incommensurate scaling attribute of complex systems; when the size of the system, or when one of its important attributes such as speed increases, or when different system components are subject to different scaling rules.

InfiniBand switched fabric for supercomputer and data-center interconnects. The serial link can operate at several data rates: single (SDR), double (DDR), quad (QDR), fourteen (FDR), and enhanced (EDR). The highest speed supported is 300 Gbps.

Infrastructure as a Service (IaaS) cloud delivery model that supplies resources for processing, storage, and communication and allows the user to run arbitrary software, including operating systems and applications. The user does not manage or control the underlying cloud infrastructure, but has control over operating systems, storage, deployed applications, and possibly limited control of select networking components (e.g., host firewalls).

Initial value problem computational problem when all conditions are specified at the same value of the independent variable in the equation.

Input/Output Memory Management Unit (IOMMU) connects the main memory with a DMA-capable I/O bus; it maps device-visible virtual addresses to physical memory addresses and provides memory protection from misbehaving devices.

Instruction flow preservation preservation of the flow of data between the instructions producing results and the ones consuming these results.

Instruction-level parallelism simultaneous execution of independent instructions of an execution thread.

Instruction Set Architecture (ISA) interface between the computer software and hardware. It defines the valid instructions that a processor may execute. ISA allows the independent development of hardware and software.

Instruction pipelining technique implementing a form of parallelism called instruction-level parallelism within a single core or processor. A pipeline has multiple stages, and at any given time, several instructions are in different stages of processing. Each pipeline stage requires its own hardware.

Integrated Drive Electronics (IDE) interface for connecting disk drives; the drive controller is integrated into the drive, as opposed to a separate controller on, or connected to, the motherboard.

Intelligent Platform Management Interface (IPMI) standardized computer system interface developed by Intel and used by system administrators to manage a computer system and monitor its operation.

Interoperability capability to communicate, execute programs, or transfer data among various functional units under specified conditions.

Interrupt flag (IF) flag in the EFLAGS register used to control interrupt masking.

J

Jarvis short for *Just A Rather Very Intelligent Scheduler*; used to support Siri.

Java Database Connectivity (JDBC) API for Java defining how a client may access a database.

JobTracker and *TaskTracker* daemons handling processing of MapReduce jobs in Hadoop.

Journal storage storage for composite objects, such as records consisting of multiple fields.

Java Message Service (JMS) middleware of the Java Platform for sending messages between two or more clients.

L

Large-scale-dynamic-data data captured by sensing instruments and controlled in engineered, natural, and societal systems.

Last level cache (LLC) the cache called before accessing memory. Multicore processors have multiple level caches. Each core has its own L1 I-cache (instruction cache) and D-cache (data cache). Sometimes, two cores share the same unified (instruction+ data) L2 cache, and all cores share an L3 cache. In this case the highest shared LLC is L3.

Latch a counter that triggers an event when it reaches zero.

Late binding dynamical correlation of tasks with data, depending on the state of the cluster.

Latency the time elapsed from the instance an operation is initiated until the instance its effect is sensed. Latency is context dependent.

LRU (Least Recently Used), MRU (Most Recently Used), and LFU (Least Frequently Used) replacement policies used by memory hierarchies for caching and paging.

Livelock condition appearing when two or more processes/threads continually change their state in response to changes in the other processes and none of the processes can complete execution.

Logical clock abstraction necessary to ensure the clock condition in the absence of a global clock.

Loopback file system (LOFS) virtual file system providing an alternate path to an existing file system. When other file systems are mounted onto an LOFS file system, the original file system does not change.

M

MAC address unique identifier permanently assigned to a network interface by the manufacturer. MAC stands for Media Access Control.

Maintainability a measure of the ease of maintenance of a functional unit—synonymous with serviceability.

Malicious software (Malware) software designed to circumvent the authorization mechanisms and gain access to a computer system, gather private information, block access to a system, or disrupt the normal operation of a system; computer viruses, worms, spyware, and Trojan horses are examples of malware.

Man-in-the-middle attack attacker impersonates the agents at both ends of a communication channel making them believe that they communicate through a secure channel.

Mapping a computation assign suitable physical servers to the application.

Mashup application that uses and combines data, presentations, or functionality from two or more sources to create a service.

Megastore a scalable storage for online services.

Memcaching a general-purpose distributed memory system that caches objects in main memory.

Message-Digest Algorithm (MD5) cryptographic hash function used for checksums. MD5 produces a 128-bit hash value. SHA-i (Secure Hash Algorithm, $0 \leq i \leq 3$) is a family of cryptographic hash functions; SHA-1 is a 160-bit hash function resembling MD5.

Merkle tree hash tree in which leaves are hashes of the values of individual keys. Parent nodes higher in the tree are hashes of their respective children.

Message delivery rule an additional assumption about the channel-process interface. Establishes when a message received is actually delivered to the destination process.

Metering providing a measurement capability at some level of abstraction appropriate to the type of service.

Microkernel (μ-kernel) system software supporting only the basic functionality of an operating system kernel, including low-level address space management, thread management, and inter-process communication. Traditional operating system components, such as device drivers, protocol stacks, and file systems, are removed from the microkernel and run in user space.

Middleware software enabling computers of a distributed system to coordinate their activities and to share their resources.

Mode-sensitive instructions machine instructions whose behavior is different in the privileged mode.

Modularity basic concept in the design of man-made systems; a system is made out of components, or modules, with well-defined functions. A strong requirement for modularity is to define very clearly the interfaces between modules and to enable the modules to work together. Modularity can be *soft* or *enforced*.

Modularly divisible application application whose workload partitioning is decided a priori and cannot be changed.

Monitor process responsible for determining the state of a system.

Message Passing Interface (MPI) communication standard and communication library for a portable message-passing system.

Multi-homing a strategy to support high availability.

Multiple Instructions, Multiple Data architecture (MIMD) system with several processors/cores that function asynchronously and independently.

N

NAS Parallel Benchmarks benchmarks used to evaluate the performance of supercomputers. The original benchmark included five kernels: IS—Integer Sort; random memory access; EP—Embarrassingly Parallel; CG—Conjugate Gradient; MG—Multi-Grid on a sequence of meshes, long- and short-distance communication, memory intensive; FT—discrete 3D Fast Fourier Transform, and all-to-all communication.

Network bisection bandwidth network attribute, measures the communication bandwidth between the two partitions when a network is partitioned into two networks of the same size.

Network bisection width minimum number of links cut when dividing the network into two halves.

Network diameter average distance between all pairs of two nodes; if a network is fully connected, its diameter is equal to one.

Network Interface Controller (NIC) the hardware component connecting a computer to a Local Area Network (LAN); also known as a network interface card, network adapter, or LAN adapter.

Network layer layer of a communication network responsible for routing packets through a packet switched network from the source to the destination.

NMap a security tool running on most operating systems to map the network, that is, to discover hosts and services in the network. The systems include *Linux, Microsoft Windows, Solaris, HP-UX, SGI-IRIX,* and BSD variants, such as *Mac OS X*.

Nonce a random or pseudorandom number issued in an authentication protocol to ensure that old communications cannot be reused in replay attacks. Each time the authentication challenge response code is presented, the nonces are different, and so replay attacks are virtually impossible.

Nonprivileged instruction machine instruction executed in user mode.

O

Object Request Broker (ORB) the middleware that facilitates communication of networked applications.

Ontology branch of metaphysics dealing with the nature of being. Provides the means for knowledge representation within a domain; it consists of a set of domain concepts and the relationships among these concepts.

Open-box platforms traditional hardware designed for commodity operating systems that does not have the same facilities as the *closed-box platforms*.

Open Database Connectivity (ODBC) open standard application API for database access.

Overclocking technique-based on DVFS; increases the clock frequency of processor cores above the nominal rate when the workload increases.

Overlay network a virtual network superimposed over a physical network.

Over-provisioning investment in a larger infrastructure than the *typical* workload warrants.

Over-subscription the ratio of the worst-case achievable aggregate bandwidth among the servers to the total bisection bandwidth of an interconnect.

P

Packet-switched network network transporting data units called *packets* through a maze of *switches* where packets are queued and routed towards their destinations.

Pane a well-defined area within a window for the display of, or interaction with, a part of that window's application or output.

Paragon Intel family of supercomputers launched in 1992 based on the Touchstone Delta supercomputer installed at CalTech for the Concurrent Supercomputing Consortium.

Parallel slackness method of hiding communication latency by providing each processor with a large pool of ready-to-run threads, while other threads wait for either a message or for the completion of another operation.

Paravirtualization virtualization when each virtual machine runs on a slightly modified copy of the actual hardware; the reasons for paravirtualization: (i) some aspects of the hardware cannot be virtualized; (ii) to improve performance; (iii) to present a simpler interface.

Passphrase a sequence of words used to control access to a computer system; it is the analog of a password but provides added security.

Paxos protocols a family of protocols to reach consensus based on a finite-state machine approach.

Peer-to-Peer system (P2P) distributed computing system in which resources (storage, CPU cycles) are provided by participant systems.

Peripheral Component Interconnect (PCI) computer bus for attaching hardware devices to a computer. The PCI bus supports the functions found on a processor bus, but in a standardized format independent of any particular processor.

Perf profiler tool for Linux 2.6+ systems; it abstracts CPU hardware differences in Linux performance measurements.

Petri nets bipartite graphs used to model the dynamic behavior of systems.

Phase transition thermodynamics concept describing the transformation, often discontinuous, of a system from one phase/state to another, as a result of a change in the environment.

Phishing attacks aiming to gain information from a site database by masquerading as a trustworthy entity.

Physical data container storage device suitable for transferring data between cloud-subscribers and clouds.

Physical resource layer includes all physical resources used to provide cloud services.

Pinhole mapping between the pair *(external address, external port)* and the *(internal address, internal port)* tuple carried by the network address translation function of the router firewall.

Pipelining splitting of an instruction into a sequence of steps that can be executed concurrently by multiple circuitry on the chip.

Pipeline scheduling separates dependent instruction from the source instruction by the pipeline latency of the source instruction. Its effect is to reduce the number of stalls.

Pipeline stages execution units of a pipeline. A basic pipeline has five stages for instruction execution: IF = Instruction Fetch, ID = Instruction Decode, EX = Execute, MEM = Memory access, WB = Register write back.

Pipeline stall the delay in the execution of an instruction in an instruction pipeline to resolve a hazard. Such stalls could drastically affect the performance.

Platform architecture layer software layer consisting of compilers, libraries, utilities, and other software tools and development environments needed to implement applications.

Platform as a Service (PaaS) cloud delivery model supporting consumer-created or acquired applications created using programming languages and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure, including network, servers, operating systems, or storage, but has control over the deployed applications.

Plesiochronous operation operation in which various parts of a system are almost, but not quite perfectly, synchronized, for example, when the core logic of a router operates at a frequency different from that of the I/O channels.

Pontryagin's principle method used in optimal control theory to find the best possible control that leads a dynamic system from one state to another, subject to a set of constrains.

Power consumption *P* of a CMOS-based circuit describes the power consumption function of the operating voltage frequency, $P = \alpha \cdot C_{eff} \cdot V^2 \cdot f$ with: α—the switching factor, C_{eff} —the effective capacitance, V —the operating voltage, and f—the operating frequency.

Privacy the assured, proper, and consistent collection, processing, communication, use, and disposition of personal information and personally identifiable information.

Private cloud infrastructure operated solely for the benefit of one organization; it may be managed by the organization or a third party and may exist on the premises or off the premises of the organization.

Privileged instructions machine instruction that can only be executed in kernel mode.

Process a program in execution.

Process group collection of cooperating processes.

Process/thread state ensemble of information needed to restart a process/thread after it was suspended.

Process or application virtual machine virtual machine running under the control of a normal OS and providing a platform-independent host for a single application, e.g., Java Virtual Machine (JVM).

Public-Key Infrastructure (PKI) model to create, distribute, revoke, use, and store digital certificates.

Pull paradigm distributed processing when resources are stored at the server site and the client pulls them from the server.

Q

Quick emulator (QEMU) a machine emulator; it runs unmodified OS images and emulates the guest architecture instructions on the host architecture it runs on.

R

Rapid provisioning automatically deploying cloud system based on the requested service, resources, and capabilities.

Recommender system system for predicting the preference of a user for an item by filtering information from multiple users regarding that item; used to recommend research articles, books, movies, music, news, and any imaginable item.

Red-black tree a self-balancing binary search tree where each node has a "color" bit (red or black) to ensure the tree remains approximately balanced during insertions and deletions.

Reference data infrequently used data such as archived copies of medical or financial records and customer account statements.

Reliability measure of the ability of a functional unit to perform a required function under given conditions for a given time interval.

Remote Procedure Call (RPC) procedure for inter-process communication. RPC allows a procedure on a system to invoke a procedure running in another address space, possibly on a remote system.

Resilience ability to reduce the magnitude and/or duration of the events disruptive to critical infrastructure.

Resilient Distributed Dataset (RDD) storage concept allowing a user to keep intermediate results and optimizes their placement in the memory of a large cluster; used for fault-tolerant, parallel data structures.

Resource abstraction and control layer software elements used to realize the infrastructure upon which a cloud service can be established, e.g., hypervisor, virtual machines, and virtual data storage.

Resource scale-out allocation of more servers to an application.

Resource scale up allocation of more resources to servers already allocated to an application.

Reservation station hardware used for dynamic instruction scheduling. A reservation station fetches and buffers an operand as soon as it becomes available. A pending instruction designates the reservation station it will send its output to.

Response time the time from the instance a request is sent until the response arrives.

Round-Trip Time (RTT) the time it takes a packet to cross the network from the sender to the receiver and back. Used to estimate the network load and detect network congestion.

Run total ordering of all the events in the global history of a distributed computation consistent with the local history of each participant process.

runC implementation of the Open Containers Runtime specification and the default executor bundled with Docker Engine.

S

Same Program Multiple Data (SPMD) parallel computing paradigm when multiple instances of one program run concurrently and each instance processes a distinct segments of the input data.

Scala general-purpose programming language with a strong static-type system and support for functional programming. Scala code is compiled as Java byte code and runs on JVM (Java Virtual Machine).

Scalability ability of a system to grow without affecting its global function(s).

Scatter operation vector processing operation, the inverse of a gather operation; it scatters the elements of a vector register to addresses given by the index vector and the base address. In distributed computing, MPI scatters data from one processor to a number of processors.

Searchable symmetric encryption (SSE) encryption method used when an encrypted databases is outsourced to a cloud or to a different organization. It supports conjunctive search and general Boolean queries on symmetrically encrypted data. SSE hides information about the database and the queries.

Secondary spectrum data falsification (SSDF) in software-defined radio, the occupancy report from a malicious node showing that channels used by the primary node are free.

Security accreditation the organization authorizes (i.e., accredits) the cloud system for processing before operations and updates the authorization when there is a significant change to the system.

Security assessment risk assessment of the management, operational, and technical controls of the cloud system.

Security certification certification for the accreditation of a cloud system.

Self-organization process in which some form of global order is the result of local interactions between parts of an initially disordered system. No single element acts as a coordinator, and the global patterns of behavior are distributed.

Semantic Web term coined by Tim Berners-Lee to describe "a web of data that can be processed directly and indirectly by machines."

Sensitive instructions machine instructions behaving differently when executed in kernel and in user mode.

Sequential write-sharing condition when a file cannot be opened simultaneously for reading and writing by several clients.

Service aggregation operation when an aggregation brokerage service combines multiple services into one or more new services.

Service arbitrage/service aggregation grouping of cloud services. In service aggregation, the services being aggregated are not fixed. Arbitrage provides flexibility and opportunistic choices for the service aggregator, e.g., provides multiple e-mail services through one service provider, or provides a credit-scoring service that checks multiple scoring agencies and selects the best score.

Service deployment activities and organization needed to make a cloud service available.

Service intermediation operation when an intermediation broker provides a service that directly enhances a given service delivered to one or more service consumers.

Service interoperability the capability to communicate, execute programs, or transfer data among various cloud services under specified conditions.

Service layer defines the basic services provided by cloud providers.

Service Level Agreement (SLA) a negotiated contract between the customer and the service provider explaining expected quality of service and legal guarantees. An agreement usually covers: services to be delivered, performance, tracking and reporting, problem management, legal compliance and resolution of disputes, customer duties and responsibilities, security, handling of confidential information, and termination.

Shard a horizontal partitioning of a database; a row in a table structured data.

Shared channel architecture network organization when all physical devices share the same bandwidth; the higher the number of devices connected to the channel, the less bandwidth is available to each one of them.

Simple Object Access Protocol (SOAP) an application protocol developed in 1998 for web applications.

Singular Value Decomposition (SVD) given an $m \times n$ matrix $A = [a_{ij}]$, $1 \leq i \leq n$, $1 \leq j \leq m$ with entries either real or complex numbers, $a_{ij} \in \mathbb{R}$ or $a_{ij} \in \mathbb{C}$, there exits a factorization

$$A = U \Sigma V^* \tag{1}$$

with: U is an $m \times n$ unitary matrix, Σ is a diagonal $m \times n$ matrix with nonnegative real numbers on the diagonal, V is an $n \times n$ unitary matrix over the field, $\mathbb{R}$ or $\mathbb{C}$, and V^* is the complex conjugate transpose of V.

SLA management the ensemble of activities related to SLAs, including SLA contract definition (basic schema with the quality of service parameters), SLA monitoring, and SLA enforcement.

Service management all service-related functions necessary for the management and operations of those services required by customers.

Service orchestration the arrangement, coordination, and management of cloud infrastructure to provide multiple cloud services to meet IT and business requirements.

Service provider entity responsible for making a service available to service consumers.

Servless computer service AWS service when applications are triggered by conditions and/or events specified by the end user. Lambda is an example of such service.

Shared cluster state a resilient master copy of the state of all cluster resources.

Sigmoid function $S(t)$ an "S-shaped" function defined as $S(t) = \frac{1}{1-e^{-t}}$. Its derivative can be expressed as a function of itself, $S'(t) = S(t)(1 - S(t))$.

Simple DB AWS nonrelational data store that allows developers to store and query data items via web services requests; it creates multiple geographically distributed copies of each data item and supports high-performance web applications.

Simple Queue Service (SQS) AWS service for hosted message queues. It allows multiple EC2 instances to coordinate their activities by sending and receiving SQS messages.

Simple Storage System (S3) AWS storage service for large objects. It supports a minimal set of functions: write, read, and delete. S3 allows an application to handle an unlimited number of objects, ranging in size from one byte to five terabytes.

Single Instruction, Multiple Data architecture (SIMD) computer architecture in which one instruction processes multiple data elements. Used in vector processing.

Single Instruction, Single Data architecture (SISD) computer architecture supporting the execution of a single thread or process at any given time. Individual cores of a modern multicore processor are SISD.

Soft modularity dividing a program into modules that call each other and communicate using shared memory or follow the procedure call convention. It hides the details of the implementation of a module. Once the interfaces of the modules are defined, the modules can be independently developed even in multiple programming languages, replaced, and tested.

Software as a Service (SaaS) cloud delivery model in which cloud applications are accessible from various client devices through a thin client interface, such as a web browser. The user does not manage or control the underlying cloud infrastructure.

S/KEY password system based on the Leslie Lamport scheme. The real password of the user is combined with a short set of characters and a counter that is decremented at each use to form a single-use password. Used by several operating systems, including Linux, OpenBSD, and NetBSD.

Skype communication system using a proprietary voice-over-IP protocol. The system was developed in 2003 and acquired by Microsoft in 2011. Nowadays, it is a hybrid P2P and client–server system. It allows close to 700 million registered users from many countries around the globe to communicate.

Simultaneous multithreading (SMT) architectural feature allowing instructions from more than one thread to be executed in any given pipeline stage at the same time.

Simple Mail Transfer Protocol (SMTP) application protocol defined in the early 1980s to support email services.

Snapshot isolation guarantee that all reads made in a transaction will see a consistent snapshot of the database.

Soft deadlines deadline that can be missed by fractions of the units. It is more of a guideline; no penalties are involved.

Software development kit (SDK) a set of software tools for the creation of applications in a specific software environment.

Speed term used informally to describe the maximum data transmission rate, or the capacity of a communication channel; this capacity is determined by the physical bandwidth of the channel, and this explains why the term channel "bandwidth" is also used to measure the channel capacity, or the maximum data rate.

Speedup measure of parallelization effectiveness.

SQL injection attack typically used against a web site; an SQL command entered in a web form causes the contents of a database used by the web site to be altered or to be dumped to the attacker site.

ssh (Secure Shell) network protocol that allows data to be exchanged using a secure channel between two networked devices; *ssh* uses public-key cryptography to authenticate the remote computer and allow the remote computer to authenticate the user. It also allows remote control of a device.

Store-and-forward network packet switched network where a router buffers a packet, verifies its checksum, and then forwards it to the next router along the path from its source to the destination.

Streaming SIMD Extension (SSE) SIMD instruction set extension to the x86 architecture introduced by Intel in 1999. Its latest expansion is SSE4. It supports floating-point operations and has a wider application than the MMX introduced in 1996.

Structural hazards in pipelining hazards occurring when a part of the processor hardware is needed by two or more instructions at the same time.

Structured overlay network network where each node has a unique key that determines its position in the structure. The keys are selected to guarantee a uniform distribution in a very large name space. Structured overlay networks use *key-based routing* (KBR); given a starting node v_0 and a key k, the function $KBR(v_0, k)$ returns the path in the graph from v_0 to the vertex with key k.

Structured Query Language (SQL) special-purpose language for managing structured data in a relational database system (RDBMS). SQL has three components: a data definition language, a data manipulation language, and a data control language.

Superscalar processor processor able to execute more than one instruction per clock cycle.

System history information about the past system evolution expressed as a sequence of events, each event corresponding to a change of the state of the system.

System portability the ability of a service to run on more than one type or size of cloud.

T

Task-level parallelism parallelism when the tasks of an application run concurrently on different processors. A job consists of multiple tasks scheduled either independently or co-scheduled when they need to communicate with one another.

TCP segmentation offload (TSO) procedure enabling a network adapter to compute the TCP checksum on transmit and receive; it saves the host CPU the overhead for computing the checksum; large packets have larger savings.

Tera Watt Hour (TWh) measure of energy consumption; one TWh is equal to 10^9 KWh.

Thread of execution the smallest unit of processing that can be scheduled by an operating system.

Thread-level parallelism term describing the data-parallel execution using a GPU. A thread is a subset of vector elements processed by one of the lanes of a multithreaded processor.

Thread block scheduler GPU control software assigning thread blocks to multithreaded SIMD processors.

Thread scheduler GPU control software running on each multithreaded SIMD processor to assign threads to the SIMD lanes.

Three-way handshake process to establish a TCP connection between the client and the server. The client provides an arbitrary initial sequence number in a special segment with the *SYN* control bit on; then, the server acknowledges the segment and adds its own arbitrarily chosen initial sequence number; finally, the client sends its own acknowledgment *ACK* and also the HTTP request, and the connection is established.

Threshold value of a parameter related to the system state that triggers a change in the system behavior.

Thrift framework for cross-language services.

Timestamps patterns used for event ordering using a global time-base constructed on local virtual clocks.

Top-Down methodology hierarchical organization of event-based metrics that identifies the dominant performance bottlenecks in an application.

TPC BenchmarkH (TPC-H) decision-support benchmark relevant for applications that examine large volumes of data and execute queries with a high degree of complexity; it consists of a suite of business-oriented ad hoc queries and concurrent data modifications with broad industry-wide relevance.

TPC-DS de facto industry standard benchmark for assessing the performance of decision- support systems.

Trusted application application with special privileges for performing security-related functions.

Translation look-aside buffer (TLB) cache for dynamic address translation; it holds the physical address of recently used pages in virtual memory.

Transport layer network layer responsible for end-to-end communication, from the sending host to the destination host.

Trusted Computer Base (TCB) totality of protection mechanisms within a computer system, including hardware, firmware, and software, the combination of which is responsible for enforcing a security policy.

Turing complete computer model of computation equivalent to a universal Turing machine, except for memory limitations.

U

Ubuntu open-source operating system for personal computers. Ubuntu is an African humanist philosophy; "ubuntu" is a word in the Bantu language of South Africa meaning "humanity towards others."

Unbounded input data concept related to data streaming; the computing engine processes a dynamic data set when one never knows if the set is complete because new records are continually added and old ones are retracted.

Usability extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.

Utility function relates the "benefits" of an activity or service with the "cost" to provide the service.

V

Vector computer computer operating on vector registers holding as many as 64 or 128 vector elements. Vector functional units carry out arithmetic and logic operations using data from vector registers as input and disperse the results back to memory.

Vector length register register of a SIMD processor for handling of vectors whose length is not a multiple of the length of the physical vector registers.

Vector mask register register of a SIMD processor used by conditional statements to disable/select vector elements.

Vertical scaling method to increase the resources of a cloud application. It keeps the number of VMs of an application constant, but increases the amount of resources allocated to each one of them.

Virtual Machine (VM) an isolated environment with access to a subset of the physical resources of a computer system. Each virtual machine appears to be running on the bare hardware, giving the appearance of multiple instances of the same computer, though all are supported by a single physical system.

Virtual Private Cloud (VPC) cloud organization providing a connection, via a Virtual Private Network, between an existing IT infrastructure of an organization and a set of isolated compute resources in the AWS cloud.

Virtual time warp abstraction allowing a thread to acquire an earlier effective virtual time, in other words, to borrow virtual time from its future CPU allocation.

Virtualization abstraction of hardware resources.

Virtualized infrastructure layer software elements, such as hypervisors, virtual machines, virtual data storage, and supporting middleware components, used to realize the infrastructure upon which a computing platform can be established. While virtual machine technology is commonly used at this layer, other means of providing the necessary software abstractions are not precluded.

W

WebSphere Extended Deployment (WXD) middleware supporting setting performance targets for individual web applications and for monitoring response time.

Where-provenance information describing the relationship between the source and the output locations of data in a database.

Why-provenance information describing the relationship between the source tuples and the output tuples in the result of a database query.

Wide Area Network (WAN) packet switched network connecting systems located throughout a very large area.

Witness of database record the subset of database records ensuring that the record is the output of a query.

Work-conserving scheduler scheduler with the goal keeping the resources busy if there is work to be done; a *non-work conserving scheduler* may leave resources idle while there is work to be done.

Work-conserving scheduling policy scheduling policy when the server cannot be idle while there is work to be done.

Workflow description of a complex activity involving an ensemble of multiple interdependent tasks.

Write-ahead database technique that writes updates to persistent storage only after the log records have been written.

X

x86-32, i386, x86 and IA-32 CISC-based instruction set architecture of Intel processors. Now supplanted by x86-64, which supports vastly larger physical and virtual address spaces. The x86-64 specification is distinct from Itanium, initially known as IA-64 architecture.

x86 architecture architecture of Intel processors supporting memory segmentation with a segment size of 64 K. The CR (code-segment register) points to the code segment. *MOV, POP*, and *PUSH* instructions serve to load and store segment registers, including CR.

Z

Zero-configuration networking (zeroconf) computer network based on the TCP/IP and characterized by automatic assignment of numeric network addresses for networked devices, automatic distribution and resolution of computer hostnames, and automatic location of network services.

ZooKeeper a distributed coordination service implementing a version of the Paxos consensus algorithm.