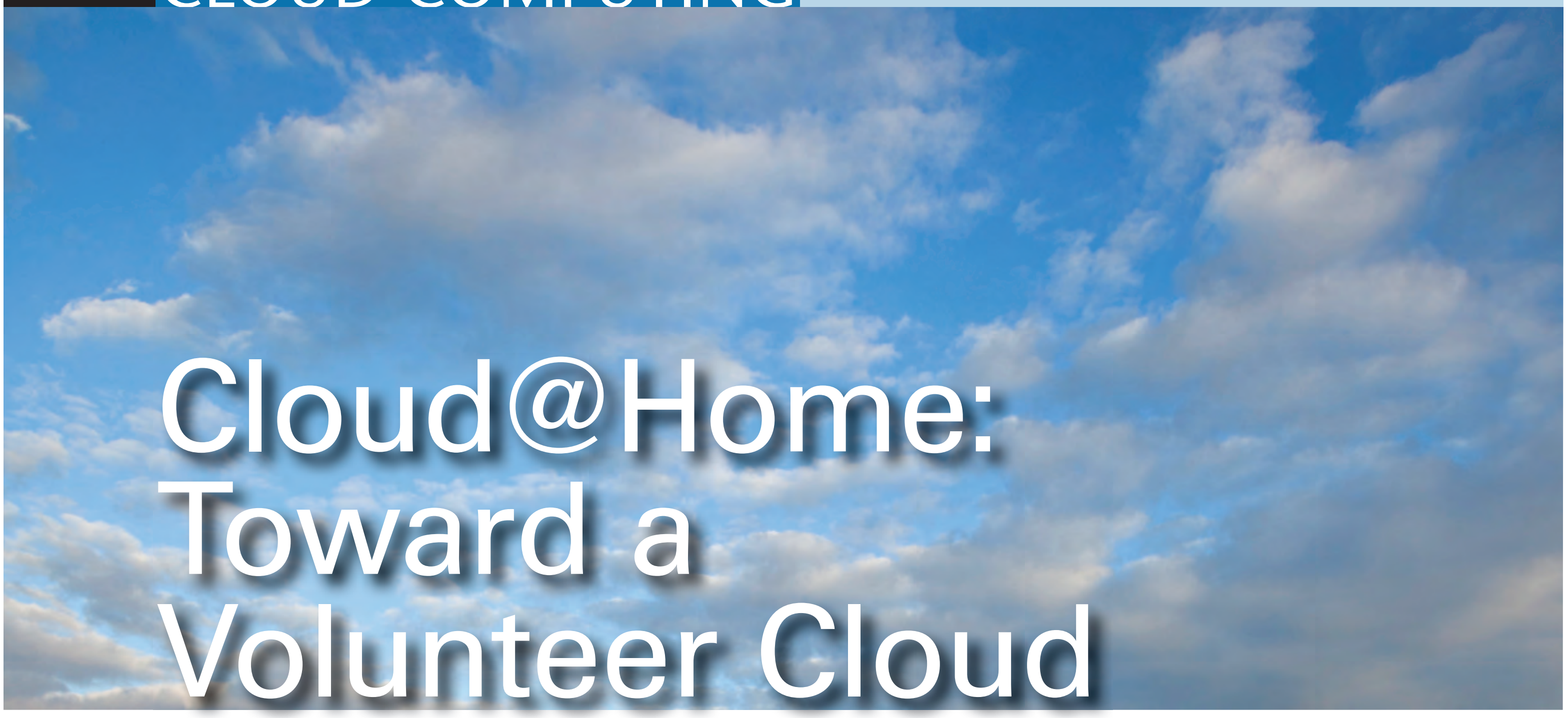

Cloud@Home: Toward a Volunteer Cloud

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A new Cloud@Home paradigm aims at merging the benefits of cloud computing—service-oriented interfaces, dynamic service provisioning, and guaranteed QoS—with those of volunteer computing—capitalized idle resources and reduced operational costs.

Cloud computing is emerging as a promising paradigm capable of providing a flexible, dynamic, resilient, and cost-effective infrastructure for both academic and business environments. It aims to raise the level of abstraction of physical resources toward a user-centric perspective, focused on the service as the elementary unit for building applications. Any cloud computing resource—whether physical hardware or logical/abstract software, data, and so on—is implemented *as a service*.

The cloud has had success in the commercial and business context, renting out computing resources through the Web using a client-server paradigm regulated by specific service-level agreements (SLAs). In fact, several commercial solutions and infrastructure providers—including Amazon EC2 and S3, Microsoft Azure, and Rackspace—use the cloud to do business. Cloud computing has started expanding into open contexts as well, owing to an increasing demand for computing resources in scientific, academic, and social communities. Several research activities, such as Nimbus, Eucalyptus, and OpenNebula, are exploiting the cloud to implement an open infrastructure within a specific framework.

Aside from reduced costs, reasons for the cloud's success include its user-centric interface, on-demand service provisioning, and transparent management of the hardware, software, and data that address user needs.[1] However, the cloud infrastructure also poses problems that inhibit its use, such as concerns about information security (confidentiality and integrity), trustworthiness, interoperability, reliability, availability, and the ability to meet SLA-specified QoS requirements. Moreover, the rise of the "techno-utility complex" and the corresponding increase in demand for computing resources—in some cases, growing dramatically faster than Moore's law[2]—could move us toward an oligarchy in which a few big companies control the entire computing-resources market.[3]

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To avoid such a pessimistic scenario, we suggest a more "democratic" form of cloud computing that incorporates some elements of volunteer computing.[4] Instead of building costly private data centers, which Google Executive Chairman Eric Schmidt has compared to the prohibitively expensive cyclotrons,[5] we propose an infrastructure that enables users, companies, or communities already accessing the cloud to share their resources in solving complex problems.

The Cloud@Home Paradigm

Volunteer computing harvests the idle time of Internet-connected computers, widely distributed across the world, to run a very large and distributed application.[6] Such computing is behind the "@home" philosophy of sharing and donating network-connected resources to support distributed scientific computing.

We envision a volunteer cloud infrastructure built on resources voluntarily shared (for free or for a fee) by their owners or administrators, following a volunteer computing approach and provided to users through a cloud-service interface. This new Cloud@Home paradigm—a generalization and maturation of the @home philosophy—knocks down the hardware and software barriers of volunteer computing and supports shared general services. In this paradigm, the user resources and data centers aren't only a passive interface to cloud services; they can also interact with one or more interoperable clouds.

The Cloud@Home paradigm could also apply to commercial clouds, establishing an open computing-utility market where users can both buy and sell resources and services. From a utility computing perspective, as envisioned by John McCarthy,[7] the metered computing power could follow a "long-tailed" distribution—with an initially high-amplitude population (such as providers or commercial data centers) that gradually tails off asymptotically to a low-amplitude population (small data centers and private users). Cloud@Home can therefore catch the "Long Tail" effect,[8] providing similar or higher computing capabilities than commercial providers' data centers by grouping small computing resources from many single contributors.

The Cloud@Home paradigm also applies at lower scales, from the single contributing user who shares his or her desktop, to research groups, public administrations, social communities, and small and medium enterprises that make their distributed computing resources available to the cloud. Both free and by-charge models can be adopted in such scenarios, providing, in the former case, adequate incentives for end users to participate in Cloud@Home—for example, by introducing a credit system as in the Berkeley Open Infrastructure for Network Computing (BOINC).[5] In the latter case, you could introduce adequate pricing models (such as pay per usage) as well as accounting and billing services and solutions. It could be a good way to convert investments in Grid computing and similar distributed infrastructures toward cloud computing.

Aims and Goals

Cloud@Home enhances the grid-utility vision of cloud computing. The user's hosts are no longer passive interfaces to cloud services; rather, they can interact (for free or for a fee) with other clouds. The scenario we envision comprises several coexisting and interoperable clouds:

- *open clouds* composed of groups of shared resources and services operating for free;
- *commercial clouds* characterize entities or companies selling their computing resources for business;
- *hybrid clouds* can freely share or sell their services.

Both open and hybrid clouds can interoperate with any other cloud, including a commercial one, resulting in *cloud federations*. This could help establish an open market of computing resources: a private cloud in need of computing resources could buy them from a third party. Or, if the cloud had an abundance of resources, it could sell them to or share them with others.

Figure 1 depicts the Cloud@Home reference scenario, identifying different stakeholders according to their role as a consumer or contributor—or, in most cases, both. The outgoing arrows represent a Cloud@Home client consuming resources after submitting a request, while the cloud's incoming arrows represent stakeholders providing their resources and services to Cloud@Home clients. Infrastructure providers, data centers, grids, clusters, servers, desktops, and mobile devices can both contribute and consume, while sensor networks can only contribute to Cloud@Home. Data centers, grids, and clusters might adopt a

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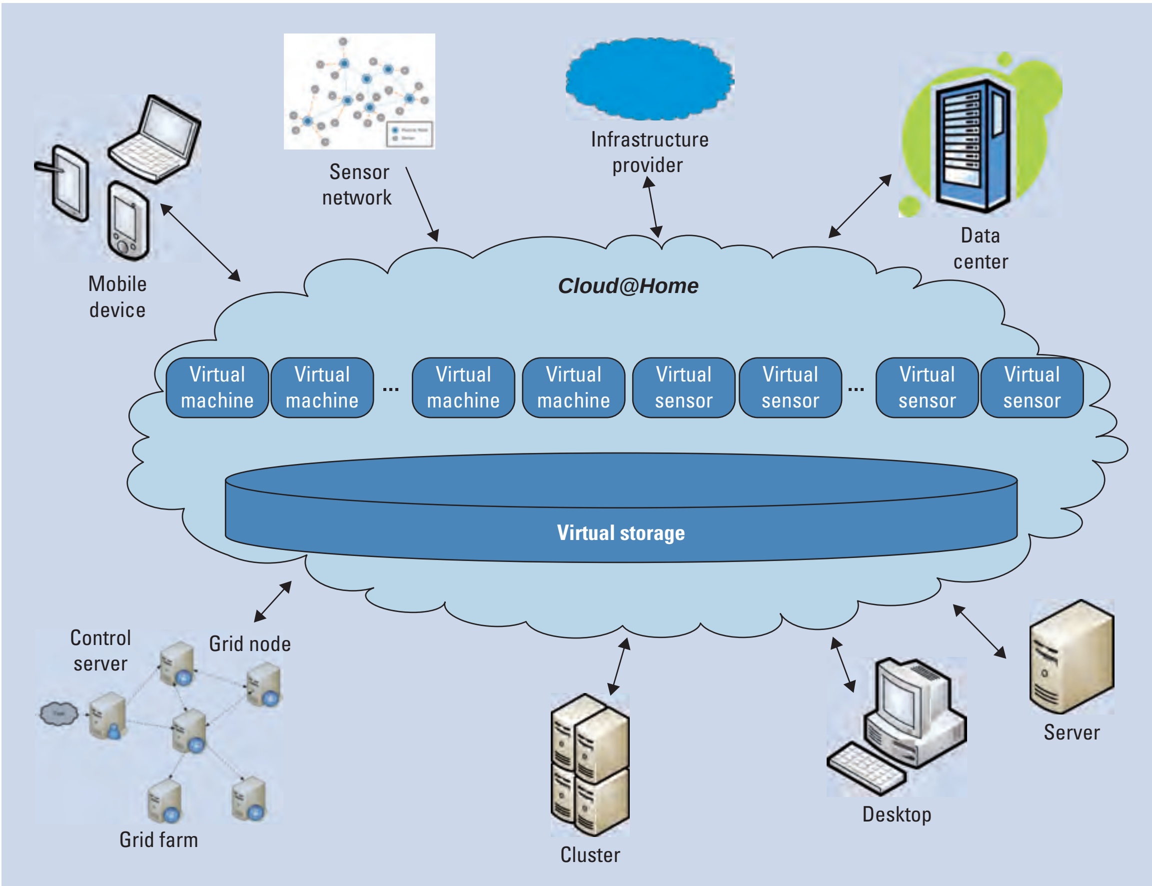

Figure 1. Cloud@Home reference scenario. The different stakeholders can be consumers, contributors, or both.

consumer policy of *cloud bursting*—that is, switching automatically to a cloud when they reach their internal capacity.

The Cloud@Home framework is based on a software system offering directory or information services, security services, and resource and data management. We suggest a three-layered implementation approach to address issues of resources management, networking reliability, user interface accessibility, security and privacy, abstraction and virtualization, interoperability and federation among heterogeneous clouds, business models, billing structures, and QoS and SLA management. The three layers, shown in Figure 2, help separate implementation concerns and thereby improve the framework development process.

Front-End Layer

The front-end layer globally manages resources and services (their coordination, discovery, and enrollment). It also implements the user interface for accessing the cloud, ensuring security through an identity management system. It also offers data encryption, secure communications, reliability, and interoperability. Finally, this layer provides QoS, business models, and policy-management facilities.

The Virtual Layer

The virtual layer implements a homogeneous view, from a software perspective, of the distributed cloud system offered to the higher front-end layer (and thus to users) in the form of two main basic services: the execution service sets up a virtual machine, and the storage service implements a distributed storage cloud to store data and files as a remote disk, locally mounted or accessed via the Web.

Virtual sensors provide access to the sensing infrastructure. The access is characterized by abstraction and independence from the actual sensing process and equipment.

The Physical Layer

The physical layer provides both the physical resources for answering the requests and the software for locally managing such resources.

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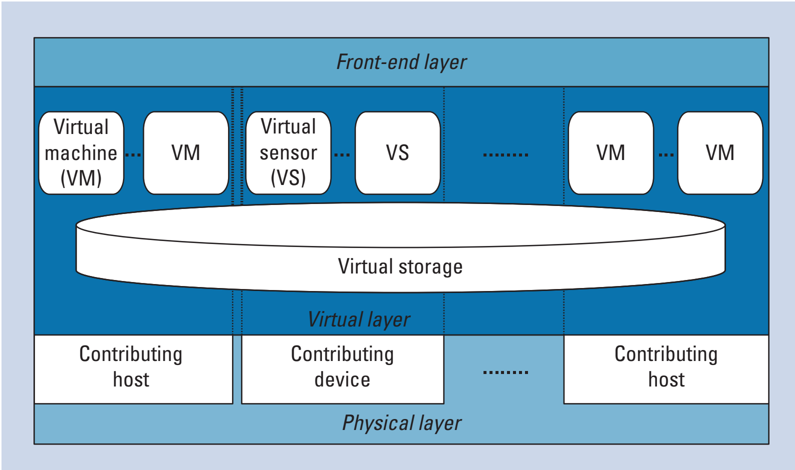

Figure 2. **The Cloud@Home's layered model. A three-layer architecture helps separate development and design concerns and improve the framework development process.**

It's composed of a "cloud" of generic nodes or devices geographically distributed across the Internet.

Application Scenarios

Several possible Cloud@Home application scenarios exist.

Extending @Home Support

Cloud@Home can offer open, interoperable clouds to support scientific research, overcoming the portability and compatibility problems of @home projects. Public administrations and open communities (such as social-networking, peer-to-peer, and gaming communities) could experience similar benefits.

Furthermore, volunteer computing doesn't address QoS requirements, which are critical for many scientific projects. Cloud@Home could overcome this limitation by implementing policies for managing (rating) resources and services according to QoS specifications (using reward and credit systems).

Expanding Enterprises

Planting a Cloud@Home computing infrastructure in business environments could bring considerable benefits, especially in small and medium enterprises. A company might implement its own data center with local, existing, and off-the-shelf resources. Most companies have stand-alone computing resources dedicated to a specific task (office automation, monitoring, designing, and so on). Such resources are typically only used during office hours, so using an Internet connection to combine them with other resources could result in a Cloud@Home data center for allocating shared services (Web servers, file servers, archives, databases, and so on) without any compatibility constraints or problems.

The interoperability among clouds would let clients buy computing resources from commercial cloud providers, or they could sell local cloud computing resources to the same or different providers. This would reduce and optimize business costs according to QoS and SLA policies and improve performance and reliability. For example, data centers could be sized to manage the average caseload. Then, for worst-case peak scenarios, the company could buy computing resources from cloud providers.

Moreover, Cloud@Home would let companies securely manage their business processes online, allocating resources and services as needed. This could improve e-commerce marketing and trading services by making them customizable. Additionally, because of the interoperability, private companies could act as subcontractors, buying and then reselling computing resources.

Addressing Device Heterogeneity and Mobility

The cloud computing approach, in which providers own and manage both software and computing resources, eases programmers' efforts to address problems of device heterogeneity. Mobile application designers should start to consider use scenarios beyond just small devices and should account for interaction with the cloud. Service discovery, brokering, and reliability are important issues, and services are usually designed to interoperate (see www.programmableweb.com).

To address consequences arising from mobile users accessing a service-oriented grid architecture, researchers have proposed new concepts, such as a mobile dynamic virtual organization.[9] New distributed infrastructures are extending clouds to the wireless edge of the Internet. Mobile service clouds enable dynamic instantiation, composition, configuration, and reconfiguration of services on an overlay network to support mobile computing.[10]

A still open research issue is whether to consider a mobile device as a cloud service provider. Researchers have discussed using modern mobile terminals, such as smartphones, not just as Web

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service requesters but also as mobile hosts that offer services in a true mobile peer-to-peer setting.[11] Context-aware operations involving control and monitoring, data sharing, and synchronization could be implemented and exposed as Cloud@Home Web services involving wireless and Bluetooth devices, laptops, tablets, smartphones, household appliances, and so on. Cloud@Home could help implement ubiquitous and pervasive computing, engaging many computational devices and systems simultaneously to perform ordinary activities in a seamless and agnostic way, transparent to users.

Cloud@Home can be viewed as the first step toward a new computing paradigm that can actively involve

- any resource type (including desktops, laptops, farms, clusters, data centers, network-attached storage, storage or system area networks, sensor networks, mobile devices, or the Internet of Things);
- all known and emerging distributed paradigms (including cloud, grid, peer-to-peer, or volunteer computing); and
- stakeholders of any kind (business, academic, community, or public).

This requires further efforts, such as a synergy between projects aimed at implementing open communication infrastructures—for example Commotion (https://tech.chambana.net/projects/commotion) and Netsukuku (http://netsukuku.freaknet.org).

We're currently working on the design and development of a framework for achieving the Cloud@Home goals, adopting an aspect-oriented approach and following an agile software development process. We hope to define a specific cloud software development process.

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