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# Cloud, Fog and Dew Computing: A Distributed Hierarchy

**Abstract**

After the phenomena that occurred in 2000, which we have denoted as the G-phenomena [1], the era of the fast development of high-performance and scalable distributed computing systems started. The primary predisposition for that development was achieving substantial speed improvements of processors and their interconnections, and the ability to process more data in memory. High-performance distributed computing systems were founded on Grid computing paradigm [2] [3], while scalable distributed computing systems evolved through *Cloud,* later *Fog* and now *Dew* computing paradigm. However, the complexity of interconnectivity, and even more the heterogeneity of equipment used through these paradigms is drastically growing as we approach the Dew Computing level, on which we can not any more hope to cope with raw Data, but have to introduce Information Processing, and solve the problems of High Productivity of the every-day end-user interfaces and the adaptability of the whole user environment system to the user needs and wishes for specific processing, as well as significantly raising the Efficiency of the whole system we use.

## Grid Computing (GC)

*Grid Computing* is a distributed paradigm suitable for scientific high performance computing. It emerged as an alternative to expensive supercomputers by virtually connecting a large number of computational clusters formed from computers connected through fast local network [4][5]. It is especially suitable for enforcement of large-scale many-task applications including High-Throughput and Data-Intensive applications. Although the first grid infrastructures were started in late 1990s through several Grid-oriented projects in the United States, the two major European projects started in early 2000s, the UK's e-Science program and European Union's Data Grid project, gave the shape of the European grid initiative. The availability of public Grid infrastructures stimulated the expansion of scientific computing research, and progressively through time Grid computing became one of the major paradigms for scientific applications. However, high utilization of public Grid infrastructures by many different groups with different applications, their technical and bureaucratic issues limited their widespread usage.

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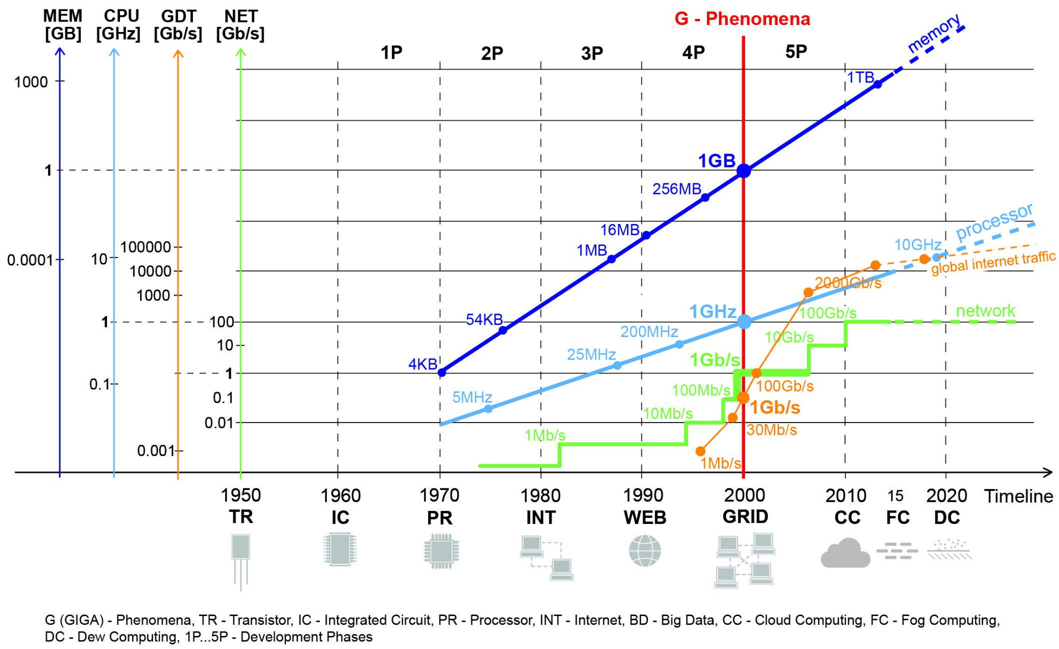


*Figure 1:* Computer technology decade jumps from G-phenomena to Dew Computing

## Cloud Computing (CC)

Cloud Computing has been defined as a "distributed computing paradigm where the boundaries of computing will be determined by economic rationale rather than technical limits". Cloud computing enables efficient management of data centers, time-sharing, and virtualization of resources with special emphasis on the business model. Through this paradigm, users and businesses are able to consume Infrastructure-as-a-Service, Platform-as-a-Service and Software-as-a-Service service models on demand from anywhere in the world. When Cloud services are made available by Cloud providers in a pay-as-you-go manner to the general public it is referred to as a Public Cloud while a Private Cloud refers to internal Cloud platforms owned and utilized only by particular organizations. Unlike Grids, Clouds can scale up or down according to the requirements of users and at the same time enable more flexible and isolated execution environments for applications. Over the past few years an increasing number of companies, especially from telecommunication and IT sector, are moving from static, centralized cluster environments to more elastic, scalable and potentially cheaper Cloud platforms. The fast growing SMEs have needs to quickly set-up required resources with minimal costs and time spent, but do not have the capital or the time to invest in deploying their own resources. In other words, by moving from the usual capital upfront investment model to an operational expense, cloud computing promises, especially to SMEs and entrepreneurs, to accelerate the development and adoption of innovative solutions. Similarly, many branches of modern research are computation- and data-intensive forms of discovery, encompassing the generation, analysis and interpretation of vast amounts of data against catalogues of existing knowledge in complex multi-stage workflows. These workflows, or analyses, are enabled by a combination of analysis platforms and computational infrastructure, which a Cloud can provide, while additionally offering scalable resources on demand. The new smart devices concentration means that data can be processed locally in smart devices rather than being sent to the cloud for processing and opens up the Fog Computing paradigm.

## Fog Computing (FC)

Fog Computing is a paradigm that extends Cloud computing and services to the edge of the network. Similar to CC, FC provides data, compute, storage, and application services even closer to end-users. The distinguishing Fog characteristics are its proximity to specific end-users, its dense geographical distribution, and its support for mobility. Services are hosted at the network edge or even end devices such as set-top-boxes or access points. By doing so, Fog reduces service latency, and improves QoS, resulting in superior user-experience. Fog Computing supports emerging Internet of Things (IoT) applications that demand real-time/predictable latency. The Fog paradigm is well positioned for real time Big data and real time analytics and knowledge extraction.

Fog computing is one approach to dealing with the demands of the ever-increasing number of Internet-connected devices sometimes referred to as the Internet of Things. In the IoT scenario, a thing is any natural or artificial object that can be assigned an IP address and provided with the ability of acquiring and transfering data over a network. Some such things can create a lot of data. Through the use of end-point connected equipment, Fog Computing extends the cloud computing paradigm to the edge of the network. While CC and FC use the same resources (networking, compute, and storage) and share many of the same mechanisms and attributes (virtualisation, multi-tenancy…) the extension is a non-trivial one in that there exist some fundamental differences stemming from the reason FC is being developed: to address applications and services that do not fit the paradigm of the CC. These applications and services include specifically the applications that require very low and predictable latency. The cloud frees the user from many implementation details, including the precise knowledge of where the computation or storage takes place. However, this freedom from choice, welcome in many circumstances becomes a liability when any significant degree of latency is unacceptable.

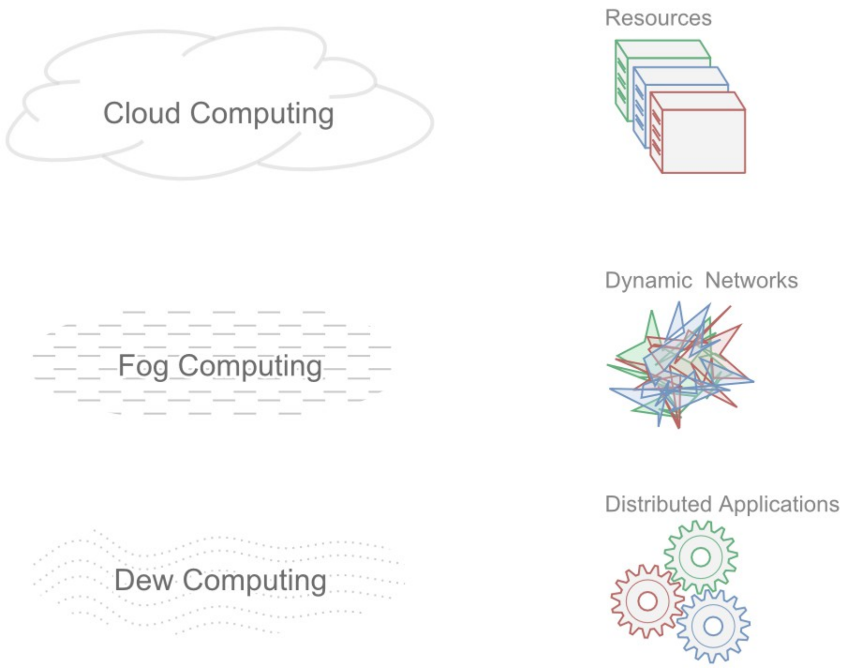


*Figure 2:* Distributed Computing Hierarchy

## Dew Computing (DC)

**End user application service mobility and integrity.** Dew computing goes beyond the concept of network, storage and service to cross platform, cross operation issues associated with application collaboration and integration in the Internet of Things environment. Dew Computing is pushing the frontier of computing applications, data, and services away from centralized nodes to the logical extremes of a network, to the end users. It enables knowledge and analytics generation. This approach requires leveraging resources that are continuously connected to a network such as smartphones, tablets and sensors. Dew Computing covers a wide range of technologies including wireless sensor networks, mobile data acquisition, cooperative applications on distributed peer-to-peer ad hoc networking and processing environment also classifiable as Local Cloud/Fog supported computing, autonomic self-healing networks, virtual cloudlets, remote cloud/fog application services, augmented reality applications, and other general purpose usage, every day working and living environments, down to the level of simplest and special purpose equipment.

Whereas in Grid Computing the logical choice was to keep the heterogeinity of the computing equipment to the minimum possible (same type of Operating System, processor compatibility etc., particularly at specific Grid nodes, but also accross the whole of the infrastructure), in Cloud Computing we have a much wider possibility of choices. As the end-users perceive most of the Cloud services actually as a service, that means that their needs will be processed by already existing hardware/software combination, there is no inherent restriction in the CC paradigm which would dissalow (or at least make hard) the usage of very heterogeneous computing equipment. The user is not actually aware of the OS/Processor/Memory/Disk combinations used by a particular part of the Cloud. Even more, the Fog Computing addresses a huge amount of often vastly differing types of equipment, from smartphones up to possible supercomputers. Still, all of the active equipment in Fog computing, though highly heterogeneous, is able to perform complex operating system tasks and actively perform a full spectrum of algorithms, in addition to being "ad-hoc" programmable, i.e. executing programmes defined by for example Web developers and Fog Computing Integrators.

However, the intention of the "Internet of Things" is to connect into a viable integrated system, using the principles of Dew Computing, a whole miriad of data gathering and simple processing systems. Such systems are not, as mentioned, "ad-hoc" programmable, or even re-programmable at all, and their heterogeinity is extremely high. A simple fixed programme 1 MHz 8-bit processor with only several tens of bytes of storage, or even a much slower special purpose data gathering/processing equipment is very common between the "Things" we use. Their communication means are also very diverse. Be it the I2C bus, or even the JTAG chain, analog or digital inputs/outputs, parallel, serial... radio communication or twisted pairs... Consequently the main paradigms of Dew Computing are quite different from the Grid/Cloud and Fog Computing paradigms, not only from the aspect of integration, but specially from the aspect of "programming". Probably the most important paradigm change necessary for Dew Computing is the change from Data-processing to Information-processing. This is necessitated by the huge amount of raw Data which is produced by specific "Things", and which, as Data, have absolutely no meaning - except for specific equipment/software which "knows" what that specific Data actually Means. However, building an integrated Computing environment (IoT, DC...) from this level is not plausible (or viable), as it dissalows the generic integration of such equipment.

As opposed to Data, Information is context aware, i.e. shortly we could define Information for our purposes as Data with Meta-data. Therefore also the main programming principles of Dew computing have to be paradigmatically quite different, as common over-simple serial programming languages (as e.g. C, Java, Fortran, Pascal...) can not cope efficiently with the necessities of the Internet of Things, and can not be integrating elements for Dew Computing. And, as completely oriented towards the "end user", that is the common-educated human wishing to use the full spectrum of possible possibilities the all-pervasive computing infrastructure could offer, Dew Computing has to solve a major problem: High Productivity. What is meant here by High Productivity is the possibility for a human users to explain to the Information (not data-only) Processing Equipment, of whatever form or level, what are their processing needs, necessities and wishes, in a reasonable amount of time.

However, there is also the other side of High Productivity Computing, which may be well exploited inside the principles of Dew Computing, and that is High Productivity from the side of the equipment, or something probably best called Efficiency. Modern day processing (computing) equipment is based on overthrottled speeds of processing elements (below 10 cm of light travel, that is over 3 GHz per a complex operation!). However, anything further away from the main processing element than those magical 10 cm of light (the signal speed is quite slower!) can actually physically not be able to be part of this processing speed. The main reason all our computing equipment is so small is not actually our "inherent wish to use fingernails for typing on coin sized computers", but the necessity of high speed and consequently very short distances. None of our computing equipment would be able to work if it would be only a few times bigger! This "drive for speed" was mostly prompted by the laic reception of computers, where people had a perception that a bigger clock rate means a-priory faster processing - which, extremely depending on the application, may or may not be true, given even the possibility of reversal - and which fell well on the ever-expansionist buy-use-throwaway conception of modern economics, and the almost paradigmatical modern-day notion that "newer is better". Although the scientific use of computing equipment partially gained from this Giga/Tera/Peta/Zeta/Eta... drive, the expansion was not primarily driven from the side of scientific needs, but from the common consumers. This is quite obvious if one looks at the scientific efforts into alternate computer construction and architecture models specifically adapted to specific needs or generic types of programming principles throughout the last several decades of Computing.

With the introduction of the all-pervasive Internet-of-Things, a rethinking of some of the basic development avenues of future Information Processing Equipment and its interconnectivity, and particularly the programmability, of the extremely heterogeineous information environment will have to be done. The Dew Computing paradigm introduces into integrated systems a mirriad of simple devices which were until now not generally regarded as computing, data or infromation processors. Therefore generic abstractions of particular "terms", or "meanings" in the general data/information production/consumption have to be defined and human/computer interaction systems developed, which will allow reasonably productive end-user "programmability" of our Human immediate environment - all the little dropplets of equipment and information defining our every-day information-processing equipment enhanced life - the Dew of modern life.

## Conclusion

G-phenomena, as an observation of Giga measure of different parameters at the turn of the millennial transition, reaches new changes in the emergence of distributed systems. Started by the Grid and Cloud and followed by Fog and Dew computing paradigms, it has led to the current development of ICT technologies. This has dramatically increased the generic role of electronics and digital network computing in nearly every segment of the world, in science, economy and everyday life. Thus, G-phenomena can be observed as a basis of scalable distributed computing systems experienced as a millennium cornerstone.

The Cloud, Fog and Dew Computing metaphors come from the fact that actually the dew, through the fog, is the cloud close to the ground, just as Fog, and even more Dew Computing concentrates processing at the wide user needs in the environment covered all over by sensors and networks. According to that Dew, Fog and Cloud computing extends the computing systems in a geographically distributed and hierarchical organization.

GC, CC, FC and DC distributed computing systems are the result of the exponential development rate of computing and related technologies over the past 50 years. This development is the most prominent driving force of the human society. It is expected that new computing technologies will continue to emerge, such as today's researched photonic and quantum computing paradigms, that will make computers even more powerful than all the other current computers combined. This predicted development, and the ever increasing heterogeinity span, obviously shows that many of the present day notions of programmability, user-interaction and ad-hoc definition of user needs will have to be heavily adapted, defined and/or re-defined to enable the user-experience of a simple and integrated living environment.

Therefore the Dew Computing paradigm is actually focused on three major points: Information (and not any more data) processing, High Productivity of user-request (wish) interface (programmability / reconfigurability) and High Efficiency of the equipment dealing with the complexities of everyday Human information environment on all levels.

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