Building A Cloud Computing Specification:
Fundamental Engineering for Optimizing Cloud Computing Initiatives

Version 1.0

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1. ABSTRACT

The need for a specification for Cloud Computing has emerged. The commoditization of the term “Cloud Computing” for various marketing purposes has diluted, and in some cases compromised the underlying intent of Cloud Computing. However, the recognition of the foundational computing model inferred by the generic term as a significant technique for computing in the 21st century is clear. Cloud Computing represents a disruptive, watershed event no less significant that the compute model revolutions that preceded it.

This paper will present a specification for Cloud Computing that will orient the term to the various component parts associated with the abstraction of Cloud Computing. The goal will be to align the elemental components related to the terminology providing engineered clarification for the concept of Cloud Computing. A byproduct of creating this specification is the articulation of an applied analytical method for understanding Cloud Computing within any business setting. This resulting method can be used by technical and business professionals to assist in design of an appropriate Cloud Computing strategy for their particular enterprise uninfluenced by marketing hype, misinterpretation of the term, or inappropriate architectural decisions based on incomplete knowledge.

Building a cloud specification for any particular organization should be articulated from a platform neutral and vendor independent perspective in order to clarify what “Cloud Computing” means when applied to that organization. This neutralizing approach drives the organization to a set of features that can then be aligned to products that meet requirements and solve mission issues or provide competitive value.

Only through an engineered perspective can realization of holistic end to end architectural specification for Cloud Computing be achieved. This will allow for the compartmentalization of the various vendor and product types into a common framework structure that can be used to understand and apply the concepts as needed. The audiences for this specification are the architects and engineers building and integrating these components as well as the owners and managers who will be seeking the benefits of the promise of Cloud Computing.

2. INTRODUCTION

Cloud Computing has recently seen enormous attention in the trade press around the world, and has become the latest “next-thing” in computing today. Large public and private enterprises have begun to recognize the significance of the Cloud Computing concept by the documented successes of Amazon and others in the hardware infrastructure arena. Success of newcomers like Google Apps and Amazon E2C, as well as those who have been operating for more than ten years like Salesforce, in the software area indicate the evolving cloud trend has arrived as a significant market
force. Many academic papers have been generated within the past 18-24 months around the topic that have tried to define the concept in one fashion or another. Many of these have usually approached the issue of the cloud from one or the other perspective in hardware or software orientation. These leave out completely the new ideas of compute platforms in the cloud, orchestration of an owned cloud, and the ability to outsource significant hardware infrastructure to support discrete functions like email security and filtering. Singular perspectives of the Cloud Computing landscape naturally leave out one or the other constituencies vested in achieving Cloud Computing for their particular organization. These monolithic, or myopic views become problematic in a complex heterogeneous compute environment found in large enterprises. Within these organizations there is a tendency to obscure a more holistic perspective vital in the success of a Cloud Computing endeavor. For example a particular constituency vested in hardware will have one perspective or Cloud Computing. The software aligned groups will have another possibly quite different view of what Cloud Computing means. Egregious misuse of the term by marketers to tag a particular product as a cloud has further added to the confusion around the holistic precepts of Cloud Computing.

Depending upon the particular viewpoint of a vendor, architect or engineer an ability to examine the concept from an unbiased perspective is required in order to fully address a business question considering Cloud Computing as a potential solution. By asserting features of any cloud independent of implementation, assures an unbiased and fully engineered set of characteristics a cloud solution should represent for an organization.

Because of the need to relate the business objectives with a particular cloud approach, the first step is to apply analytics to decompose the particular engineering problem into a target solution space. The best way to achieve this is to use the IEEE 1471 Standard to confirm a viewpoint, align to a business need and ultimately to derive a set of appropriate cloud oriented components to address the business needs.

2.1. UNDERSTANDING THE CLOUD COMPUTING SPECIFICATION

Complete understanding of a contemporary Cloud Computing specification requires knowing the evolution and roots of the concept. Historical understanding helps frame a vendor neutral scoping of a cloud endeavor for any particular entity today. Cloud Computing is far easier to declare once the fundamental components are recognized and understood. The following are key milestones shaping today’s Cloud Computing components.

2.1.1. Mainframe Computers • 1945

Tracing the roots of the Cloud Computing concept is grounded in foundational computing precepts exemplified by mainframe computing. Mainframe computing as opposed to distributed micro and mini-computer computing linked by Local Area and
Wide Area Networks known as LAN and WAN, and later the Internet. Mainframe computing is characterized by a powerful computing platform resident in a dedicated computing environment which is accessed through a terminal\(^1\) that possesses very little computing capability. While the technology continues to change and evolve, today with the advent of compute virtualization and ability to massively parallel computing resources resident in compact blade configurations of servers, Cloud Computing begins to resemble its mainframe computing roots.

Cloud Computing today relies upon browser technology that has very little computing capability. It also uses the Internet and its associated protocols as a transport mechanism. Globally distributed data centers the compute power behind the browser interface can be likened to mainframe computers of previous epochs.

A contemporary browser begins to resemble the “dumb” VT-100 terminals of the mainframe era. Browsers access other compute resources often resident within data centers. These data centers contain hundreds or thousands of virtualized compute resources made possible by advanced hypervisor\(^2\) software and the commoditization, technical advances, and form factor compression of microcomputers. Powerful high density microcomputers, using inexpensive data storage and associated redundancy schemas such as RAID\(^3\) can be configured with server arrays that are expandable and are re-provisioned with smart software coordinating all aspects of the computing resources within them. These data centers begin to resemble the compute power of the mainframe era but with modern technological advances. Indeed they may in some instances, actually leverage true mainframe compute resources, but are today largely composed of highly dense server farms of less costly commodity machines linked together.

These new technologies allow for massively scalable compute and storage resources which is a hallmark of Cloud Computing.

2.1.2. ARPANET - 1969

ARPANET\(^4\) was a research project designed during the Cold War to build nuclear strike survivability into the computing and intelligence fabric of the United States. ARPANET birthed the Internet Protocol. Today the Internet Protocol or IP is the transport backbone technology of the global wide area network called the Internet.

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1. A simple terminal is exemplified by a device colloquially known as a “VT-100 Terminal” consisting of a monochromatic screen and a keyboard for data input attached to a computing platform such as a mainframe or mini-computer in use during much of the mainframe and mini computing era from 1945 to the mid 1980’s
2. A hypervisor, also called virtual machine monitor (VMM), is a computer hardware platform virtualization software that allows multiple operating systems to run on a host computer concurrently. (from Wikipedia definition)
3. Redundant Arrays of Inexpensive Disks (RAID)
4. Advanced Research Projects Agency Networks operated by the U.S. Department of Defense
which is a collection of thousands of computer server nodes resident on an worldwide IP based network.

This network today allows for the realization of new Cloud Computing concepts and is the fundamental transport for software and hardware virtualization that characterize another aspect of Cloud Computing.

2.1.3. Ethernet Networking - 1973

The Ethernet standard was developed at Xerox Palo Alto Research Center (PARC). Ethernet was a common standardized way to interconnect various computers in order to harness the computing power of linked computers in a distributed fashion. Later the idea of interconnecting individual microcomputers was used to build the first Local area Networks or LANs.

This idea of the exponential power of interconnecting computing machines to either leverage unused compute cycles of discrete machines, or to link various users helped to drive the next wave of advancement toward contemporary Cloud Computing. A key Cloud Computing precept is the ability to leverage idle computing cycles of interconnected compute resources. This concept is a basis for Hardware-as-a-Service (HaaS) and represents a fundamental component of Cloud Computing.

2.1.4. Micros, GUI’s and Client Server technologies - 1981

Development and continued advancement today of Microcomputers, GUIs and client-server technologies during the microcomputer revolution starting in 1981. This computing revolution took computing and processing away from mainframes and mini computers often located in a remote data center, and drove the development of software to the local users hard drive. This revolution spawned enormous advancements in software development that resided locally on users hard drives and continues to the present day.

For Cloud Computing, the look, feel and function of these formally locally resident application programs for word processing, spreadsheet production, presentation CRM, mail, and others is moved into “the Cloud”. This compute cloud is today composed of modern data center resident applications transported there by the Internet and high speed broadband networks. They present software running remotely in a browser pointed to the actual compute location and is the basis for providing Software-as-a-Service (SaaS), Platform-as-a-Service or (PaaS) and is another fundamental component of Cloud Computing.

2.1.5. The World Wide Web - 1992

Invented by Tim Beherens-Lee as a graduate student project, the World Wide Web is the graphical overlay to the text based ARPANET. The WWW employs ARPANET developed IP as the transport, and uses the Hypertext Transport Protocol (HTTP) and
Hypertext Markup Language (HTML). These core technologies allow for today’s presentation of data and information in graphical format across the world wide web.

For Cloud Computing HTTP is the presentation tier technology used for all cloud based data and information. Browsers parse these markup languages and display the compute functions. These compute functions typically happen in remote data centers or on other servers, and are not necessarily resident on the users machine.

2.1.6. Broadband Internet Access - 1993

Advances in telecommunications were necessary in order to carry the increased Internet traffic being generated by the WWW. Initially using dedicated connections, then later advancing to the telecommunications grid through POTS\(^5\) dial up connections. The expectations of the maturing Internet required advances in broadband telecommunications in order to handle the IP traffic that contained HTTP and HTML descriptions between computers worldwide.

For Cloud Computing to be fully realized, it requires the seamless interconnection of fundamental communications technologies. Broadband telecommunications becomes the “wire” that carries the Internet traffic. It must be of sufficient speed to assure low payload latency. Low latency is particularly important with users oriented software such as word processing, spread sheets and other software that was formally resident on users hard drives. Applications are today increasingly moving into computers running them not on a users hard drive at their local computer, but rather within a data center, often referred to as running the application …”in the cloud”.

2.1.7. GRID Computing 1995

The Globus GRID project was designed to be a specification for the linking together of commodity hardware like microcomputer servers to work on a single problem. A compute GRID is essentially a supercomputer composed of discrete machines performing computing in a coordinated fashion. A cloud is a collection of these commodity machines performing together however the next advancement was required in order to shape contemporary Cloud Computing as we know it today, that of virtualization.

2.1.8. Turn of the century watersheds in Cloud Computing

2.1.8.1. Hypervisor Technology: VMware to Xen – 1999

The team of Diane Greene, Mendel Rosenblum, Scott Devine, Edward Wang and Edouard Bugnion, invented VMware and released their first product in 1999. This product abstracted a hardware platform on a single computer so that a virtual compute environment existed. Thus one machine running a particular operating system such as

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\(^5\) Plain Old Telephone Service (POTS) - referring to the telephone switched network.
Microsoft’s Windows Server Operating system, could spawn in instance of a completely different operating environment such as a UNIX variant like Red Hat Linux.

The underlying hypervisor technology paired with virtualization compliant processor chips can now be combined with inexpensive servers, fast broadband connections and software applications to form a completely new computing paradigm. This powerful paradigm can abstract multiple instances of computer operating systems into a hardware based “Cloud Computing” system. Thus hypervisor technologies support the ability to emulate physical machines and help to provide hardware as a service.

Orchestration, or management of these virtualized component becomes a niche extension of this initial abstraction capability and evolves into orchestration as a service or (OaaS). This becomes fully manifested in products such as Elastra, Appistry, Right Scale and others by 2009.

2.1.8.2. Salesforce.com - 1999

Salesforce.com was built in response to the new computing infrastructure of the World Wide Web circa 1999 to deliver CRM6 application functionality. The ability to reside application not on a discrete hard drive but rather to reside them in a data center Salesforce.com remains one of the earliest software-as-a-service (SaaS) models that was distributed on the web.

Cloud Computing and specifically applications other than email, delivered within the Cloud Computing concept, are all variants of this early exemplar of a “cloud” based application.

2.1.8.3. Thin Client Computing - 1999

In 1999 Sun introduced its Sun Ray 1 system that was effectively a back-to-the-future version of mainframe centric computing but leveraging ethernet networks and a very thin client7 workstation with very little or no compute capacity. The thin client continued to evolve as vendors IBM, HP, and Sun competed to establish an enterprise computing model worthy of the cost savings it represented, however the ability to actually virtualize the compute environment would take several more years to mature. This basic variant on the mainframe/data center centric computing model represents one form of a hardware based “Private Cloud” model.

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6 Customer Relationship Management
7 from Wikipedia: A thin client (sometimes also called a lean or slim client) is a client computer or client software in client-server architecture networks which depends primarily on the central server for processing activities, and mainly focuses on conveying input and output between the user and the remote server.
This Firmware Bound\(^8\) Private Cloud model leverages a powerful data center to deliver user applications typically in an enterprise setting but employs vendor specific thin client hardware to form the user interface. This model is wholly appropriate in contexts where security is paramount and the ability to rely on open Internet based applications is either unfeasible due to security constraints, or unlawful as might be the case in municipal, federal or defense settings. Many vendors entered this space in the late 1990’s because of the enormous cost savings it represented however the concept was slow to become accepted in enterprise settings. Since hardware is still owned the tremendous economies of scale cannot be leveraged, and cost savings typically arrive from lower touch labor costs and reduction in rich client workstation maintenance costs.

Another Private Cloud model is exemplified by Network Bound IP networks. Using switching schemas, network isolation topologies or dedicated VPN’s. These forms of Private Clouds still leverage IP, WWW and web services technologies but are not using specific vendor hardware. They use only the network to form the cloud. Browsers are used to access compute resources and resemble the Internet oriented public cloud. These are isolated and typically share compute resources such as a Compute GRID.

2.1.9. REST - 2000

Roy Fielding’s doctoral dissertation introduced the concept of representational state transfer or REST\(^9\). RESTful services were necessary to address the computing paradigm inherent in attempting to maintain application state for complex application functions. This is due to the stateless design of HTTP/HTML oriented computing grammar outside of using proprietary solutions. This grammar limits transactions to PUT, GET, POST and DELETE and is stateless. Maintaining application state is a challenge on the WWW because of the limits of HTTP. However state is critical for a WWW based application such as for example the ability to manage the state of a shopping cart presented on a merchandising website.

REST application state maintenance specifications are vital in decoupling proprietary vendor solutions in state maintenance and to advance the cloud based application development to follow. SaaS generally is characterized by a RESTful design.

2.1.10. Writely/Google Docs and Zoho - 2005

Once the ability to abstract the computing power within a data center and build complex applications using web protocol was achieved, new application solutions from Writely/Google and Zoho evolved. Their intent at first was to bring standard office productivity applications like word processing spread sheet and presentation software

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\(^8\) Meaning a vendor specific thin client computing environment such as Sun Ray, or other similar vendor offerings.

\(^9\) from Wikipedia: Representational state transfer (REST) is a style of software architecture for distributed hypermedia systems such as the World Wide Web.
to the web. Later many other application types followed using RESTful architecture designs. All of their underlying compute power was resident in a remote data center that was accessed using a simple browser.

Writely was the original company that built the initial web based office productivity applications. Writely was acquired by Google in a move to augment their mail offering with more enterprise oriented productivity suites. Today Google Apps and Zoho represent the more forward looking general office productivity applications available for low or no cost to users and businesses on the Internet. They are the highest manifestations of delivering SaaS.

From a Cloud Computing perspective, all elements are now in place within the market and technical infrastructure that allow the ability to deliver web based applications independent of the underlying compute infrastructure using only a web browser.

**Figure 1: Zoho Suite of Cloud Applications**

This new application delivery paradigm marks the mature advancement of the web based application that lives “in the (Internet) cloud”. The major drivers of this computing model are the ability to actually deliver fully functional web based applications that meet most, if not all of the business needs of a particular organization at either a very low, or free pricing threshold. This new paradigm represents an
enormous market disruption within the current client server compute model that has bundled feature rich client server based applications for over twenty five years.

Development of applications in the new paradigm of software resident on remote servers as opposed to a local computer hard disk, has given rise to the idea of Platform as a service or (PaaS). This describes provision of a development and production environment for building and presenting new software and are exemplified by the Google application engine, Coghead, and 3Tera.

2.1.11. Amazon Elastic Compute Cloud EC2 and Mature HaaS - 2006

Hardware as a Service (HaaS) came of age when IBM partnered with Amazon in a move to be able to present their IBM Websphere application foundations on the Amazon cloud in 2008. Amazon however had run its service in selling compute power by the hour pay-as-you-go model since 2006. Initially this service was primarily used as a COOP/DR\textsuperscript{10} or temporary surge service by many enterprise level firms. Later the lease/pay as you go business model become a viable alternative to the failed business model represented by early turn of the century pure play server leasing arrangements. Today the overall viability of the HaaS business model is being emulated by Microsoft with their Azure Cloud, EMC and Google in various service offerings. For Cloud Computing, this HaaS oriented model will continue to advance and fill a market niche for the various businesses needing to purchase compute power on an hourly or usage basis. For some this capability represents variously infrastructure as a service (IaaS) or hardware as a service capability (HaaS) depending on the organizations goals and the service such as Amazon AWS, and the definitions chosen.

2.1.12. Historical Trace Conclusions

Technological advancement in the areas of hardware, software and network have today enabled the new platform called cloud. On this new platform hardware, software, and their related aspects of orchestration, infrastructure and platform reside. They are provided as services, meaning cost is based on a lease model as opposed to an owned model. The one exception to this lease/own service is orchestration as a service. This confluence of technology has enormous implications for all firms in the future.

Because these advances have allow the ability to leverage heretofore owned elements as a service, significant cost options now enter into the cost/benefit trades of technology portfolios. Having an entire development model cloud resident without the encumbrance of hardware elements engenders a far different software construction environment than traditional coding tethered to a developers machine. Significant cost savings due to massive economies of scale disrupt traditional software license models,

\textsuperscript{10} Continuity of Operations and Disaster Recovery
and the flexibility of extending and contracting compute power as needed present enormously compelling cost savings drivers.

**Figure 2: Historical component evolution forming today’s “Cloud”**

![Diagram of historical component evolution forming today’s “Cloud”]

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### 2.2. Contemporary Technology Forecasts

As shown in the historical tracing, maturation of various technologies has given rise to a new product types and styles. The general idea of remote computing power leveraging the Internet, Internet technologies or similar technology is the common complexion of this style called Cloud Computing. Generally speaking the ability to lower costs and increase utility is the driving factor that will be very disruptive to traditional client server, and fat client based software.

Technology forecasts performed by various sources recognize the disruptive nature of Cloud Computing when applied to the existing enterprise landscape. Very large economies of scale are enabled by the advance of technologies discussed thus far in hardware and software compute capability. These economies allow for efficiencies in the market today which is currently driving the competitive landscape.

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**Note:**

11 from Wikipedia: A fat client or rich client is a computer (client) in client-server architecture networks which typically provides rich functionality independently of the central server.
The following illustration is one market analysis performed by CSC which indicates various technology and its impact and expected time frame to peak impact. It is generally believed this is a conservative estimate and that cloud is making an impact today in 2009, but what is lacking is a clear unambiguous specification and analytical framework for the style known as Cloud Computing.

**Figure 3: Technology Forecasts: Cloud/SaaS Computing's Disruptive Impact**

<table>
<thead>
<tr>
<th>Category</th>
<th>Market development</th>
<th>Peak impact</th>
<th>Impact on enterprise IT environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical developments Required for competitive parity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business intelligence</td>
<td>Now</td>
<td>4 yrs</td>
<td>Moderate</td>
</tr>
<tr>
<td>SOA and BPM</td>
<td></td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>Identity and access management</td>
<td></td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>Enterprise IT drivers</td>
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<td></td>
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<tr>
<td>Small service opportunity</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Large potential client impact</td>
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<td></td>
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<tr>
<td>New driver of core services</td>
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<td></td>
</tr>
<tr>
<td>Cloud computing</td>
<td></td>
<td></td>
<td>Disruptive</td>
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<tr>
<td>Web 2.0</td>
<td></td>
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<tr>
<td>Open source</td>
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<td></td>
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<tr>
<td>Mass Collaboration</td>
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<tr>
<td>Business-driven requirements</td>
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<td></td>
<td></td>
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<tr>
<td>Aligned with customer strategies</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Risk and compliance technology</td>
<td></td>
<td></td>
<td>Incremental</td>
</tr>
<tr>
<td>Product lifecycle management</td>
<td></td>
<td></td>
<td>Incremental</td>
</tr>
<tr>
<td>Manufacturing operations</td>
<td></td>
<td></td>
<td>Incremental</td>
</tr>
</tbody>
</table>

2.3. **Engineering a Cloud Computing Specification**

There are historical thresholds marked by advances in technology and computing styles discussed herein that lead to today’s Cloud Computing furor. Because of the resulting economies engendered by many aspects of Cloud Computing, enterprises are attempting to adopt a Cloud Computing strategy for their organizations. However there is no roadmap to successfully engineering a viable solution. Thus it becomes vitally important to recognize and orient to the proper perspective when engineering any particular Cloud Computing initiative.

As discussed there can generally be identified three core elements of a Cloud Computing system that mirror traditional computing components. The hardware, the software and the transport mechanism characterize the fundamentals of any compute system. Knowing the elemental core precepts of Cloud Computing are required when considering the engineered decomposition of a particular cloud solution.

But what is a cloud architecture, and more importantly what is the right answer for any particular organization relative to the Cloud Computing style? Determining this requires applied analytics within a framework that can assist in determining the correct solution for any particular firm.
Cloud Computing requires the application of IEEE 1471 Standard (IEEE) to further articulate the appropriate Cloud architecture. There are strong reasons for adopting IEEE 1471 for cloud analytics and architecture development presented in the following matrix.

**Table 1: IEEE 1471 Supporting a Cloud Specification**

<table>
<thead>
<tr>
<th>IEEE 1471 can specify a cloud by:</th>
<th>This in important because:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Providing definitions and a meta-model for the description of an appropriate Cloud Architecture</td>
<td>This is vital in determining product fit, implementation strategy and alignment to strategic goals through the technological facilitation Cloud Computing can offer an organization.</td>
</tr>
<tr>
<td>Stating that a Cloud Architecture exists to address to specific stakeholder concerns</td>
<td>These stakeholders are the requirements builders and validators of a cloud initiative</td>
</tr>
<tr>
<td>Asserting that Cloud Architecture descriptions are inherently multi-view, no single view captures all stakeholder concerns</td>
<td>This eliminates a silver bullet for cloud mentality and assures a the appropriate technology is applied to the cloud endeavor</td>
</tr>
<tr>
<td>Separating the notion of view from viewpoint, where a viewpoint identifies the set of concerns and the representations/modeling techniques, etc. used to describe the appropriate cloud architecture to address those concerns.</td>
<td>Constituents have viewpoints which are their expectations of the capabilities of a cloud initiative. Their respective viewpoints based on their organizational role can be vastly divergent. Normalization and recognition of this avoids conflict, sub-optimization and a one size fits all technology mistake for Cloud Computing initiatives.</td>
</tr>
<tr>
<td>Establishing that a conforming Cloud Architecture description has a 1-to-1 correspondence between its viewpoints and its views.</td>
<td>This provides an unambiguous alignment of technology solution to a users needs. It also defines the trade space for various solution technologies within the Cloud Computing paradigm</td>
</tr>
<tr>
<td>Providing for capturing rationale and inconsistencies/unresolved issues between the views within a single Cloud Architecture description</td>
<td>This provides requisite gap analysis of a particular endeavor and is the fundamental methodology within which to perform what if analytics for technology evaluation and portfolio efficacy of any cloud solution.</td>
</tr>
</tbody>
</table>

Thus there is a strong affinity to engineer the examination of a Cloud Computing endeavor against the organization provided by IEEE 1471. It is important to note that the IEEE 1471 standard was originally intended for software intensive systems. However it has been proven to be effective in its ability to support the needs of those systems such as cloud that have hardware/infrastructure elements.
The following figure is a highly simplified adaptation of IEEE 1471 to engineering a cloud perspective for any organization for illustration proposes.

Figure 4: IEEE 1471 Adapted to Cloud Computing Architecture Development

An architectural description is engineered by consolidating a view which is a technical diagram, and uses an associated model which is a derivation template that considers viewpoints and concerns of stakeholders. These are balanced, tempered and derived through careful and detailed examination of system, environment, business mission and incumbent architecture elements. Use of an Enterprise Architecture Technique supports the synthesis of representational views to build the architecture description.

2.4. ELABORATING IEEE 1471 FOR CLOUD COMPUTING SPECIFICATION

The detailing of IEEE 1471 for derivation of a specification to a normative model can be decomposed into perspectives that activate a set of engineered enterprise architecture elements. These elements are a set of activities that become the “how to” guide for applying IEEE 1471 to a particular Cloud Computing endeavor. A set of architectural activities is used to begin modeling cloud details. Representation of these activities flows from a model driven architectural approach (Soley) to form any particular Cloud Domain Model. This model of the Cloud is realized by various actors.
within any organization according to their particular role. This concept is presented in the following diagram.

Figure 5: MDA Driven Cloud Representation Activities

Drawing from works by Victor Harrison and the OMG in model driven architectural Development (Harrison) we can formalize the various perspectives to assist in building the requisite views. The cloud domain is formed by architectural activities. These architectural activities are broken down into Business Process Management (BPM) areas of Capabilities and Requirements and Opportunity and Scope in the business process area. Deployment and Delivery Models present the physical implementations and the Assessment and Computationally Independent models provide perspectives into those areas providing conceptual models and the use cases needed to form the complete system. Generally there are realizations of the cloud domain model from typically three internal corporate constituent actors that can be classified as executives, managers and operations.
These roles are perspectives on the cloud architecture that require different vernaculars and perceive the cloud architecture from their respective viewpoints. These roles are evidenced by various formal titles within any given organization however their functions are easily identified by the people providing strategic organizational direction to the entity, those response for the execution at technical levels and those managing delivery. Often these roles are comingle within a single person but are familiar, and traditional to those within the craft.

Normalizing Cloud Specifications to Harrisons model, Capabilities and Requirements would contain Cloud Scenarios and Capabilities; the requirements model for the Cloud and Key Performance parameters: The Opportunity and Scope construction would include Stakeholders; Business Context; Strategies; Principles and Drivers for the Cloud architectures and the allied success criteria expected of the cloud endeavor for an organization. Computationally Independent models for Conceptual Architectures and Use Cases would influence the Allied Deployment and Delivery models and the Assembly of Components, Service Interfaces, information and data schemas user interfaces and testing representations would complete the holistic views of any cloud system.

2.5. Applied Analytics for Developing Cloud Computing Architectures

Representing the cloud architectures using MDA is activated by IEEE 1471. This standard provides a sound engineering basis within which to understand viewpoints of stakeholders and to help form a Cloud Architecture. However, it is Applied Analytics that forms and validates a particular set of cloud architecture decisions that lead to the development of a cloud architecture for any given concern. Applied Analytics takes the fundamental meta-model components of the IEEE 1471 Standard specialized for understanding Cloud Computing architectures and overlays Enterprise Architecture\(^{12}\) (EA) techniques. EA techniques help derive the proper view and viewpoints that describe the characteristics of Cloud Computing system. IEEE 1471 assist in engineering the essential linkage between the business needs and the allied compute resources needed to fill them.

Often it may be sufficient to merely heuristically interpolate the IEEE 1471 framework elements of Mission, System, Environment, Architecture, Stakeholder, Concern and Viewpoint. Other times it becomes necessary to drive out fine grained details to gain a richer understanding of the IEEE 1471 meta-model elements using Zachman (Zachman), TOGAF (Group), or FEAF (Council) EA techniques. There are a myriad of tools available to assist in the understanding of relationships between the various MDA parts to assist in the analytical review. A what if scenario completeness is required in order to achieve a full understanding of technical and business impacts to

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\(^{12}\) (Research)From MIT: Enterprise Architecture is the organizing logic for business processes and IT infrastructure reflecting the integration and standardization requirements of the firm’s operating model
the introduction of a cloud architecture for any organization. The simplistic perspective is shown in the following illustration.

**Figure 6: Applied Analytics for Cloud Computing**

Activation of the MDA analytical perspectives discussed in the previous section requires a thorough understanding of the various interactions and relationships of the component parts and often drives “what if” reviews, trade space analysis and scenario derivations that an overlay of Enterprise Architecture Techniques can provide.

Impacts across the various MDA views relative to this has been summarized by Harrison within the context of his statement which is an engineered extension of Soley’s OMG MDA perspective to applied IEEE 1471. The formal statement is detailed in the following illustration wherein the light and dark blue classes are the elaboration of the Applied Analytics for Cloud Computing Class called Enterprise Architecture Technique shown in Figure 6.
Figure 7: OMG MDA - the Meta Model to drive IEEE 1471 Analysis

(Source Citation: from Victor L Harrison Model Driven Architecture Foundations 2008)
The myriad of potential interrelationships of particular enterprises MDA views can cross the neatly compartmentalized boundaries. This happens in the real world when for example the requirements for business performance described by the BPM Capabilities and Requirements view is impacted by the BPM Opportunity and Scope Value Proposition as being too expensive to execute.

Thus the MDA models become the foundational Meta-Model for gaining deeper understanding of exactly what form of Cloud Computing is required for an organization. Activating these models for gaining complete understanding of all the possible interrelationships however can become very complex. Spreadsheets can become unwieldy, and usually to perform complete analysis of impact and review some automation that can assist in the visualization of the potential and actual relationships is required.

Today various software vendors provide excellent visualization software to aid in the applied analysis and to rapidly assist in fully engineered what if scenario trade space reviews.

3. A CLOUD COMPUTING CONTEXT

3.1. CLOUD COMPUTING CLASS MODEL

Packages of classes for a Cloud Computing specification can be modeled within four areas: The Applied Analytics necessary and sufficient to articulate a particular set of Cloud Computing views for an entity, the allied Framework supporting the execution of the analysis and the Hardware and Software elements provided as services needed to build the cloud solution.

Bifurcation of all Cloud Computing semantics into two simple elements, Hardware and Software eliminates the temptation to use improper definitions or neologisms. Hardware for a cloud describes all the physical components. Software is the entire set of programs, procedures, and related documentation. As noted there is ample historical basis to engineer to these common and accepted definitions in order to clarify the emergent taxonomy evolving around the term Cloud Computing. All other taxonomic decomposition that may exist today or be forthcoming, can be typed into these two simple definitions based on the physical nature or lack thereof of any cloud components.

The perspective to apply is that of the stakeholder viewpoint to derive the exact semantics of any particular cloud oriented technology being proposed. This will always result in the proper alignment of any particular technological system, its allied architecture and the operational environment it functions in for any enterprise.

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13 Merriam-Webster online dictionary definition for Hardware
14 Ibid: Merriam-Webster online dictionary definition for Software
3.2. CLOUD COMPUTING FRAMEWORK

A Cloud Computing Framework is characterized by the application of a fully engineered analytical framework in order to establish particular cloud view(s) and viewpoint(s). This is a vital because without the application of an engineered approach to view and viewpoint discovery, sub-optimized choices will be made relative to a cloud solution. For Cloud Computing, the IEEE-1471 standard is used to provide the architecture description of the cloud solution. As noted in section 2.5 Applied Analytics for developing Cloud Compute Architectures, IEEE-1471 as a framework and an appropriate MDA can be used to help derive the views and viewpoints. Clouds are composed of tangible hardware and intangible software elements. These fundamental elements must be secured and managed and they operate in two distinct arenas which are public and private systems. A private system is one characterized by hardware and or software owned by the entity and a public system is one that is not owned but is used on a leased or licensed basis.

These precepts are aggregated within the following illustration and elaborated further following the graphic.
A Cloud Solution may be composed of software and/or hardware depending upon the particular architecture view. Cloud oriented software services, such as Google Apps or Zoho cloud applications rely upon Representational State Transfer (ReST) architectures and use Web Services\(^{15}\) to deliver the various applications illustrated within a browser. Cloud hardware can be either owned, which necessitates a data center, or remote which indicates an outsourcing hardware lease arrangement of some type is in place. Outsourcing arrangements are composed of proper contractual constraints, costs, and SLA agreements fully documented within a legally binding instrument. Cloud Management Services employ multi-domain management techniques in the coordination of all aspects of software, hardware and network operation. A provisioning system is used to manage the various aspects of software, hardware, and network, and is critical in operation of data centers that use hypervisor technologies to operate virtualized server architectures.

Cloud Security can be a combination standards based or vendor proprietary solutions. Typically security will have several layers at the software and firmware tiers of a cloud architecture. Cloud security is usually composed of a heterogeneous mix of vendor specific and standards based elements.

For example a Google Apps solution might employ an integration of existing mail LDAP coupled with a web services based broker that integrates to the standard Google

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\(^{15}\) Typically using HTTP, XML and SOAP within a Broker/Requestor/Provider model but not strictly limited to these protocols
Apps security configuration. Alternatively for a hardware and infrastructure, IP level filtering might dictate a failover set of servers for standby disaster recovery that are leased from Amazon E2C.

3.3. **Cloud based SaaS characteristics**

A cloud based SaaS solution has a view that was developed as an articulation derived from the application of applied analytics driven by the IEEE 1471 standard for software system descriptions. This could be a singular view, or series of views of the software architecture. These views will always have a particular viewpoint as described from a constituent stakeholder.

The views of software as a service are delivered within the context of a vendors Cloud Container. This is opposed to historical client server or web oriented paradigms that reside software code containers within a single, or set of load balanced application servers. Cloud Containers for software are vendor specific, and resemble designs of early (circa 1995) template driven and wizard based turnkey web publishing tools such as Microsoft’s FrontPage. Such tools describe functionality within a set of rules and templates to allow for competent execution of a set of development tasks during construction of a software element or a complete application system. These tools are sometimes, but not always feature rich and all describe a development methodology and programming model.

A software solution running as a cloud based service has characteristics that are largely inherited from the application style instanced by a particular vendor. Today the characteristics of the application container can be described by a proprietary container type that either uses unique vendor specific code (such as Apex used by Salesforce) or leverages standards such as Python. Integrated development environments (known by the acronym of IDE) of cloud SaaS vendors

These IDE’s are either “closed” in that they do not allow for developer extensibility or are “open” in the sense of allowing a set of rules and programming tools that can be freely extended by a developer to contemplate a very wide range of programming task and integrations.
Cloud Software is secured by a vendor’s specific security solution, or by a multi-domain architecture integration comprised of LDAP\textsuperscript{16}, single sign-on, proxy, x.509 certificate, Kerberos (Toolkit), SGML (OASIS) or other such security integration architectures.

Management of the software solution in the cloud is executed within a proprietary management container such as Google’s Postini product combined with Google Sites for eMail management, or by using a Standards based container manager. Examples of a standards based container manager include custom built Multi Domain Management components in a standard language such as Python that have fully exposed API’s. Another example of an MDM component can be a COTS software management tool that has a standard programming interface like Java, COM for.Net or other extensible management tooling with open published interfaces and API’s.

The incumbent infrastructure as a detailed operationally deployed topology is required to be a part of the cloud SaaS software architecture solution. Cloud software has either some residence (such as hard drive storage) or interface touch points with the operational infrastructure topology and thus becomes a required component of an SaaS software solution.

Closely related to current infrastructure is the Internet access architecture design consisting of the Internet carrier and the allied service level agreements as a part of the contractual service agreement. Cloud software whether sourced to a vendor or resident within an owned or leased data center requires Internet connectivity or private access to operate.

\begin{itemize}
  \item \textsuperscript{16} Lightweight Directory Access Protocol or LDAP
\end{itemize}
Each cloud software design has a particular data migration schema for larger enterprise level migrations that is often targeted for a particular vendor as a competitive tool. These are accompanied by a published API that can be used to build unique migration solutions for a particular customized migration task. Today the largest portion of vendor specific migration tooling is in the email application realm since this is viewed as a gateway application to consolidated suites of vendor tools.

3.4. CLOUD BASED HaaS

Cloud based HaaS can be typed into owned or leased configurations. This configuration bifurcation is an organizational business decision principally driven by security concerns with data by organizations seeking infrastructure consolidation.

Cloud based hardware as a service leased is best exemplified by commercial hosting by vendors like Amazon EC2 Elastic Cloud, IBM, Terramark, GoDaddy, Intuit Quick Base and others who present infrastructure components for rent. These services present Internet accessible, on demand hardware infrastructure delivered over the Internet. Characterized by delivery of just-in-time infrastructures that have near zero upfront costs, these models represent a highly efficient form of computing infrastructure architecture available today.

Figure 11: Cloud Based HaaS Model Characteristics

Owned HaaS is a data center centric configuration that is useful in designing an owned infrastructure. Owned network infrastructure configuration includes all elements needed within an architecture topology including, physical location, power and cooling, cabling, COOP data, fault tolerance, machine security, switching and load
balancing having compute centric infrastructure. Several virtualization approaches, depending upon a particular viewpoint, can be leveraged including thin client, controller based virtualization schemas such as Hadoop and BerkleyDB configurations for initializing server virtualization. GRID (Alliance) architecture for compute or application oriented configurations is another possible attribute for virtualization as well as hypervisor technologies for VMware or Citrix. Mainframe or commodity blade supercompute architectures are very robust and have many years of proven virtualization capabilities.

Management of the owned data center relies upon vendor, customized or a combination of these two into a consolidated end to end management overlay to the core data center systems.

For leased HaaS the greatly simplified components include the cost model and the SLA’s since there is no infrastructure to operate and manage only the contractual obligations of the outsourced vendor take precedence.

Today because the ubiquitous transport for outsourced HaaS is the Internet the Internet access carrier plays a crucial role in the delivery of extended hardware infrastructure in the cloud. The carrier, contractual arrangements and details and the allied service level agreements are vitally important to the architecture of an outsourced HaaS solution.

4. CONCLUDING REMARKS

A platform independent, vendor neutral specification of a cloud architecture is necessary in order to avoid sub-optimization or failure of a cloud implementation. Establishing a view, which is an architectural perspective drawn at a conceptual, specified or deployment level of elaboration is reached through the understanding of constituent stakeholder viewpoints. View and viewpoints are reached through the application of applied analytics using the IEEE 1471 Standard as a meta model framework. This approach allows for the ability to reach vital understanding of the influencing elements of a view, viewpoint and ultimately, a fully engineered architectural description that will meet expectations. Application of Enterprise Architecture techniques to perform applied analysis relative to formation of the particular views supports well engineered cloud implementations.

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6. WORKS CITED


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END OF REPORT