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SERVICE-ORIENTED ARCHITECTURE (SOA) SERIES

Cloud Computing and SOA

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Executive Summary

Cloud computing describes a broad movement toward the use of wide area networks (WANs), such as the Internet, to enable interaction between information technology (IT) service providers of many types and consumers. Service providers are expanding their offerings to include the entire traditional IT stack, ranging from foundational hardware and platforms to application components, software services, and whole software applications.

Considerations with cloud computing—Cloud computing brings with it a number of key benefits and risks that should be examined by any senior leadership team considering a realignment of their enterprise computing IT portfolio. These include:

- **Outsourcing to cloud providers:** Commercial cloud computing effectively outsources portions of the IT stack, ranging from hardware through to applications, to cloud providers. Cloud computing allows a consumer to benefit by incrementally leveraging a more significant capital investment made by a provider. The consumers also benefit significantly by being able to dynamically scale their demand of the cloud services.
- **Dependence on the network:** Cloud computing is fundamentally dependent on the network to connect the offeror with the consumer. For those who have redundant network connections with robust bandwidth this will not be an issue, but for those who do not, serious consideration should be given concerning singular dependence on network-based offerings, and how business continues when the network is unavailable or unreliable.
- **Dependence on individual cloud providers (lock-in):** Vendor lock-in is a risk with the current maturity of cloud computing. Vendor neutrality is often best achieved by utilizing industry or open standards, and these standards are currently evolving for several layers of the stack. Developing applications to leverage one cloud provider's offerings can lead to lock-in with one vendor's solution and limited or no competition.
- **Information assurance (IA):** Commercial cloud providers will have security solutions that meet the needs, risk profiles, and cost models of their commercial customers. These security solutions will not always be appropriate for Federal needs. Part of the benefit of cloud computing as a consumer is being able to abstract away the details of how a platform or service is provided. Federal consumers may often need a clear understanding of what is occurring inside the "black box" of a cloud offering; they may sometimes need to specify internal characteristics of an offering. This violates the spirit of cloud abstraction.

Cloud computing represents a profound change in the way Industry provides IT resources to an enterprise, and DoD can derive long-term benefit by employing cloud computing techniques.

Can Service-Oriented Architecture (SOA) be skipped for cloud computing?—SOA and cloud computing are complementary activities; both will play important roles in IT planning for senior leadership teams for years to come. Cloud computing and SOA can be pursued independently or concurrently, where cloud computing's platform and storage service offerings can provide a value-added underpinning for SOA efforts. Cloud computing does not replace SOA or the use of distributed software components as an integration technology. The need to support broader and more consistent integration of systems will continue. The growing trend by leadership teams to consider IT capabilities as a commodity will continue to put downward pressure on IT budgets; consequently, system integration and data exchange activities will have to get more streamlined and efficient across a portfolio of disparate systems. SOA inspired componentization efforts, where software leverages other network-based software using standards-based interfaces, are a response to this pressure. Similarly, considering platform and storage services as a scalable commodity will push organizations to use these less expensive service offerings, since the trend toward SOA and cloud computing has many of the same drivers, such as enterprise portfolio cost reduction.

How can the DoD leverage cloud computing?— Mission assurance considerations such as security and survivability will make the use of wholly commercial cloud offerings a challenge in the near term. However, the DoD can begin to work with industry to create cloud capabilities resident on DoD's own sensitive and classified networks as "private" clouds, enjoying many of the benefits of cloud computing such as more rapid and dynamic resource provisioning, but probably not resulting in the same economies of scale.

The DoD should initiate a cloud pilot effort to exercise cloud technologies on real-world DoD networks. This engineering effort would examine the commercial cloud computing marketplace and the cloud computing stack from hardware to applications, and compare it to the needs of select key DoD programs. The effort would apply commercial approaches and technologies cooperatively with industry, and exercise these offerings in a realistic sensitive or classified environment, recognizing cloud's inherent dependence on the underlying network. The value of the pilot to the programs and the DoD would be assessed.

DoD cloud computing considerations include:

- **Economies of scale:** Cloud computing, due to inherent cost advantages when implemented on a large scale, will continue to impact the commercial marketplace regarding how commercial IT infrastructure is acquired, maintained, and dynamically scaled. The DoD can apply these commercial concepts on DoD internal networks to create "private" cloud offerings.
- **Key obstacles:** Robust networks and trusted security are two of the biggest obstacles that the DoD should focus on in order to take advantage of cloud economics.
- **Enables services focus:** Because cloud computing "abstracts" away the details of the infrastructure's hardware and software, turning the lower levels into a utility whose implementation details are no longer visible to the user, cloud computing will advance the focus of DoD investments toward the composable services and software capabilities that sit on top of the cloud's commodities. As a result, more high-value end-user capability can be acquired in the long term by taking advantage of cloud and SOA concepts.

For more information on SOA, see http://www.mitre.org/soa.

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THE BIG PICTURE: Cloud computing describes a broad movement toward the use of wide area networks, such as the Internet, to enable interaction between information technology service providers and consumers. Cloud computing has a number of benefits and risks that should be examined by any senior leadership team considering the realignment of its enterprise computing IT portfolio. SOA and cloud computing are complementary activities, and both will play important roles in IT planning.

Cloud Computing and SOA

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Defining Cloud Computing

While cloud computing is currently a term without a single consensus meaning in the marketplace, it describes a broad movement toward the use of wide area networks, such as the Internet, to enable interaction between IT service providers of many types and consumers. Service providers are expanding their available offerings to include the entire traditional IT stack, from hardware and platforms to application components, software services, and whole applications, as shown in Figure 1. The common thread in cloud computing offerings across all levels of the stack is the consumer/provider relationship and a dependence on the network to connect the two parties.

The commercial cloud marketplace offers a wide range of cloud services that vary in complexity and value. Figure 1 organizes this marketplace into a general set of service categories layered in a notional stack, with foundational offerings toward the bottom and more complex offerings toward the top. For example, the Cloud Storage in the figure can describe the ability to safely store a file in the cloud, while Cloud Applications refers to executing more

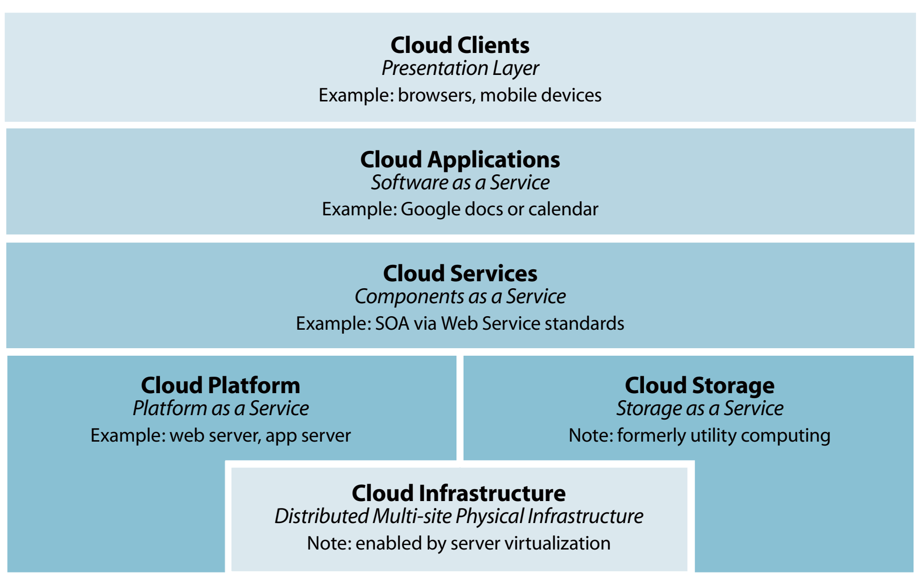


Figure 1. Cloud Computing Represented as a Stack of Service Offering Categories[1]

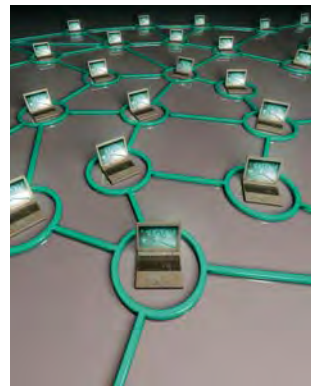
> "The computing stack, from the applications we write, to the platforms we build upon, to the operating systems we use, are now moving from a product- to a service-based economy."
> – Simon Wardley [2]

complex network-accessible software applications. The next paragraphs explore several of the key layers in the cloud computing stack, from the bottom up.

***Cloud Infrastructure*—**At the bottom of the cloud stack, Cloud Infrastructure provides the distributed multi-site physical components to support cloud computing, such as storage and processing resources. This layer allows the infrastructure provider to abstract away details such as which exact hardware an application is using and which data center the application is running in. Advances in server virtualization technologies have made this layer of the stack much more efficient over the past several years, allowing a higher utilization of processing resources than previously practical. Virtual machine concepts have also enabled a useful separation of underlying hardware implementation details from the view of developers, and the ability to more rapidly scale server resources in response to changing demand.

***Cloud Storage—Storage as a service*—**Building upon the Cloud Infrastructure, this layer of the cloud stack is focused on the incremental renting of storage on the Internet, formerly called Utility Computing. Many offerings in this area are also enabled by underlying advances in server virtualization. Network-based large-scale storage on demand is an example of this layer of cloud computing. Some offerings go further and offer platforms for service providers, including storage, security, identity management, and other functions. A good example of this type of offering is the Amazon Simple Storage Service (Amazon S3). Amazon S3 provides storage for the Internet, designed to make web-scale computing easier for application developers. Amazon S3 provides a Web Service interface that can be used to store and retrieve data, at any time, from anywhere on the Web. S3 gives developers access to scalable and reliable data storage for a fee.[3] S3 is decentralized in its implementation, fault tolerant, and built from a set of highly granular and simple service interfaces.

***Cloud Platform—Platform as a service*—**
Platform offerings provide an infrastructure for developing and operating web-based software applications. Examples include facilities for application design, application development, testing, deployment, and hosting, as well as application services such as team collaboration, security, application versioning, and application instrumentation.[4] Developer teams frequently work together through their browsers to leverage the virtual cloud platform. Virtual servers running in the cloud can include web servers, applications servers, and database engines. For some offerings, application programming interfaces (APIs) are provided to pre-defined network-based functions. ProgrammableWeb.com lists over 600 APIs on the Internet in 2008, with Google Maps, Flickr, Amazon, and YouTube capturing the greatest market share of calls.[5] Platform offerings are generally assumed to be a part of a multi-tenant architecture in which many unrelated organizations may be supported by the same platform infrastructure. Platforms can scale by adding processing and storage resources to dynamically support growth in the operational demands for a particular customer's web application. An example of a platform offering is Force.com, which began as a software application provider supporting SalesForce.com. APIs and development tools to support the SalesForce application became more general platform tools for any customer offering Internet-based software.



***Cloud Services—Components as a service*—**This layer of the cloud computing stack includes the definition of software components, run in a distributed fashion, across the commercial Internet. This definition is most like SOA, which is discussed below, with defined service interfaces as a basis for system-to-system integration.

Cloud Applications—Software as a service (SaaS)—This definition relies on the cloud for access to what would traditionally be local desktop software.[6] For example, Adobe's Photoshop, a program to manipulate images, was distributed to end users on disks for many years. Today, you still can install a version of Photoshop from an installation disk, or you can go to a completely online version of an analogous application, entitled Express.[7] In the online Express, you can upload your images into a hosted file area and work on the images with the same filters and capabilities that were found in the traditional software version. Express is an example of SaaS, though this is not the only form SaaS can take. For example, Google provides web applications, such as Gmail, Google Calendar, Talk, Docs, and Sites, with functionality similar to traditional office suites.

One advantage of this approach is that the application can be continuously updated by the application provider without issuing and shipping new installation disks. Each time the user logs in to the site, the user will get the latest version of the application. The application provider is also offering a very scalable web application using a multi-tiered web architecture, implemented on a considerable infrastructure. Disadvantages include the complete dependence on the underlying network to access the application. When the network is down, the user cannot do any work with the network-based application. In contrast, the desktop version of the software does not require network connectivity for productive work.

> *Software as a Service (SaaS) is a model of software deployment where an application is hosted as a service provided to customers across the Internet. By eliminating the need to install and run the application on the customer's own computer, SaaS alleviates the customer's burden of software maintenance, ongoing operation, and support. Conversely, customers relinquish control over software versions or changing requirements; moreover, costs to use the service become a continuous expense, rather than a single expense at time of purchase.*—Wikipedia (SaaS)[8]

With SaaS a significant amount of the processing occurs in the Internet "cloud," in remote data centers, and not on the local desktop. The local desktop becomes primarily a presentation layer device in this scenario. By using many online software applications, the user is distributing processing on their behalf across CPUs scattered in the cloud by software service offerors. For example, Wikipedia states, "[Cloud computing] is a style of computing in which IT-related capabilities are provided 'as a service,' allowing users to access technology-enabled services from the Internet ('in the cloud') without knowledge of, expertise with, or control over the technology infrastructure that supports them."[9]

Cloud Clients—Another application-related function of cloud computing focuses on the distribution of business and personal data across servers on the Internet. For example, an individual may have personal data in Facebook, digital photos in Flickr, banking data in bank servers, insurance data in insurance company servers, and on and on, all available in distributed servers and data centers around the world. In composite, these users are using the "cloud" to hold and maintain data on many aspects of daily life. This distribution of data across the Internet rather than in local desktop or local area network repositories resonates with end users because it often equates directly to the use of presentation layer Cloud Applications in Cloud Clients such as a browser, the top of the cloud stack. Forrester Research states, "Consumers are driving this new battle, with the huge volume of servers needed to dish up search, pictures, audio, and video, in addition to web email. This giant capacity creates a massive platform for leading consumer-focused companies such as Amazon, Facebook, Google, and Microsoft, which then look for ways to add incremental volume by servicing the needs of institutions as well."[10]

Figure 2 depicts a sampling of current commercial vendors with cloud computing offerings. The offerings fall into the same general groupings as the cloud IT stack described earlier, with foundational services on the left and more complex services on the right. Please note that this marketplace is dynamic and continues to grow rapidly.

Considerations with cloud computing—Cloud computing brings with it a number of key benefits and risks that should be examined by any senior leadership team considering a realignment of its enterprise computing IT portfolio.

- **Outsourcing to cloud providers:** Commercial cloud computing effectively outsources portions

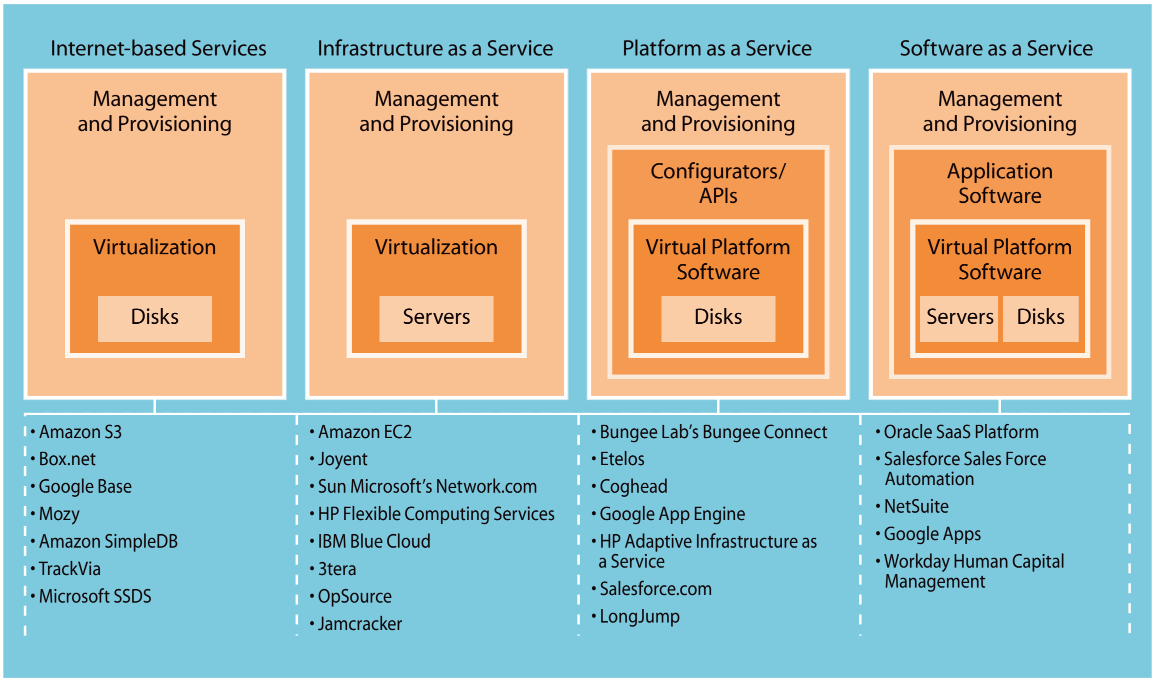


Figure 2. Example Cloud Computing Vendors [11]

of the IT stack, ranging from hardware through applications, to cloud providers. Cloud computing allows a consumer to benefit by incrementally leveraging a more significant capital investment made by a provider. The consumers also benefit significantly by being able to dynamically scale their demand of the cloud services. As Ted Schadler states, "The service provider pricing model of cloud computing is particularly valuable when economic uncertainty limits the capital and IT resources available to firms." [12]

- **Dependence on the network:** Cloud computing is fundamentally dependent on the network to connect the offeror with the consumer. For those who have redundant network connections with robust bandwidth this will not be an issue, but for those who don't, serious consideration should be given concerning singular dependence on network-based offerings, and how business continues when the network is unavailable or unreliable.
- **Dependence on specific cloud providers (lock-in):** Vendor lock-in is a risk with the current maturity of cloud computing. Vendor neutrality is often best achieved by utilizing industry or open standards, but these standards are currently evolving for several layers of the stack. Developing applications to leverage one cloud provider's offerings can lead to lock-in with one vendor's solution and limited or no competition.
- **Contracts and service-level agreements (SLAs):** Cloud offerings are defined with a discrete interface and performance expectation. This agreement can be captured in an SLA between the provider and consumer, and this document can be made a part of the contractual relationship between the two.
- **IA:** Commercial cloud providers will have security solutions that meet the needs, risk profiles, and cost models of their commercial customers. These security solutions will not always be appropriate for Federal needs. Part of the benefit of cloud computing as a consumer is being able to abstract away the details of how a platform or service is provided. Federal consumers may often need a clear understanding of (and need to specify the characteristics of) what is occurring inside the "black box" of a cloud offering to ensure secure operations.

Defining SOA

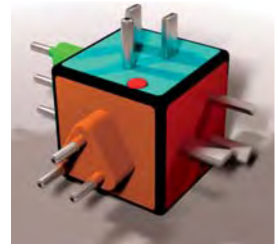
SOA builds on computer engineering approaches of the past to offer an architectural approach for enterprise systems, oriented around the offering of

> "After creating islands of automation through generations of technology, users and business managers are demanding that seamless bridges be built to join them."
> – David Linthicum [8]

services on a network of consumers. A focus of this service-oriented approach is on the definition of service interfaces and predictable service behaviors. A set of industry standards, collectively labeled "Web Service" standards in this paper, provide and implement the general SOA concept and have become the predominant set of practical tools used by enterprise engineers for current SOA projects. Some Web Service standards have become foundational and more widely adopted, while many are still seeking broad industry or Government acceptance.

SOA, as implemented through the common Web Services standards, offers Federal senior leadership teams a path forward, given the diverse and complex IT portfolio that they have inherited, allowing for incremental and focused improvement of their IT support systems. With thoughtful engineering and an enterprise point of view, SOA offers positive benefits such as:

- **Language-neutral integration:** The foundational contemporary Web Services standards use eXtensible Markup Language, which is focused on the creation and consumption of delimited text. Regardless of the development language used, these systems can offer and invoke services through a common mechanism. Programming language neutrality is a key differentiator from past integration approaches.
- **Component reuse:** Given current Web Service technology, once an organization has built a software component and offered it as a service, the rest of the organization can then utilize that service. With proper service governance, emphasizing topics such as service provider trust, service security, and reliability, Web Services offer the potential for aiding the more effective management of an enterprise portfolio, allowing a capability to be built well once and then shared. Multiple components can be combined to offer greater capabilities in what is often termed "orchestration."
- **Organizational agility:** SOA defines building blocks of software capability in terms of offered services that meet some portion of the organization's requirements. These building blocks, once defined and reliably operated, can be recombined and integrated rapidly.



- **Leveraging existing systems:** One common use of SOA is to define elements or functions of existing application systems and make them available to the enterprise in a standard agreed-upon way, leveraging the substantial investment already made in existing applications. The most compelling business case for SOA is often made regarding leveraging this legacy investment, enabling integration between new and old systems components.

SOA and its implementing standards, such as the Web Services standards, come to us at a particular point in computing history. While several key improvements, such as language neutrality, differentiate today's Web Service technologies, there has been a long history of integrating technologies with qualities analogous to Web Services, including a field of study often referred to as enterprise application integration (EAI).[13]

One of the key trends driving the adoption of Web Services is the increasing span of integration being attempted in organizations today. Systems integration is increasing both in complexity within organizations and across external organizations. We can expect this trend to continue as we combine greater numbers of data sources to provide higher value information. Ronan Bradley writes, "CIOs often have difficulty in justifying the substantial costs associated with integration but, nevertheless, in order to deliver compelling solutions to customers or improve operational efficiency, sooner or later an organization is faced with an integration challenge." [14] Figure 3 depicts a few waypoints in the trend toward increasing systems integration complexity.

SOA attempts to streamline integration across systems by providing components that are architected and described in a consistent fashion.

Considerations with SOA—Like cloud computing, SOA brings with it a number of key benefits and risks, including:

- **Dependence on the network:** SOA is fundamentally dependent on the network to connect the service provider with the consumer. For example, Web Service protocols ride on Internet protocols to invoke software functions distributed across the network. Poorly performing networks can make a large impact on the availability of Web Services to the consumer.
- **Provider costs:** Creating a generic reusable software component for a broad audience takes more resources (20 percent to 100 percent more) than creating a less generic point solution.[15] The cost of reuse, therefore, shifts to the service providers, which benefits the consumers.
- **Enterprise standards**: When many components are being simultaneously developed by individual teams, it becomes critical for the interface of a provider's service to match up to the "call" of a consumer. Similarly, it helps everyone involved if the interfaces across services have some commonality in structure and security access mechanisms. Choosing and communicating a comprehensive set of enterprise standards is a responsible approach to aid in enterprise SOA integration.
- **Agility:** When we discuss "agility" as it relates to SOA, we are often referring to organizational agility, or the ability to more rapidly adapt a Federal organization's tools to meet their current requirements. An organization's requirements of IT might change over time for a number of reasons, including changes in the business or mission, changes in organizational reporting requirements, changes in the law, new technologies in the commercial marketplace, attempts to combine diverse data sources to improve the organization's operational picture, and many other reasons. The larger promise of an enterprise SOA is that once a sufficient quantity of legacy-wrapped components exist, and are accessible on the internet protocol (IP) wide area network (WAN), they can be reassembled more rapidly to solve new problems.

Comparing Cloud Computing and SOA

Cloud computing and SOA have important overlapping concerns and common considerations, as shown in Figure 4. The most important overlap occurs near the top of the cloud computing stack, in the area of Cloud Services, which are network-accessible application components and software services, such as contemporary Web Services. (See the notional cloud stack in Figure 1.)

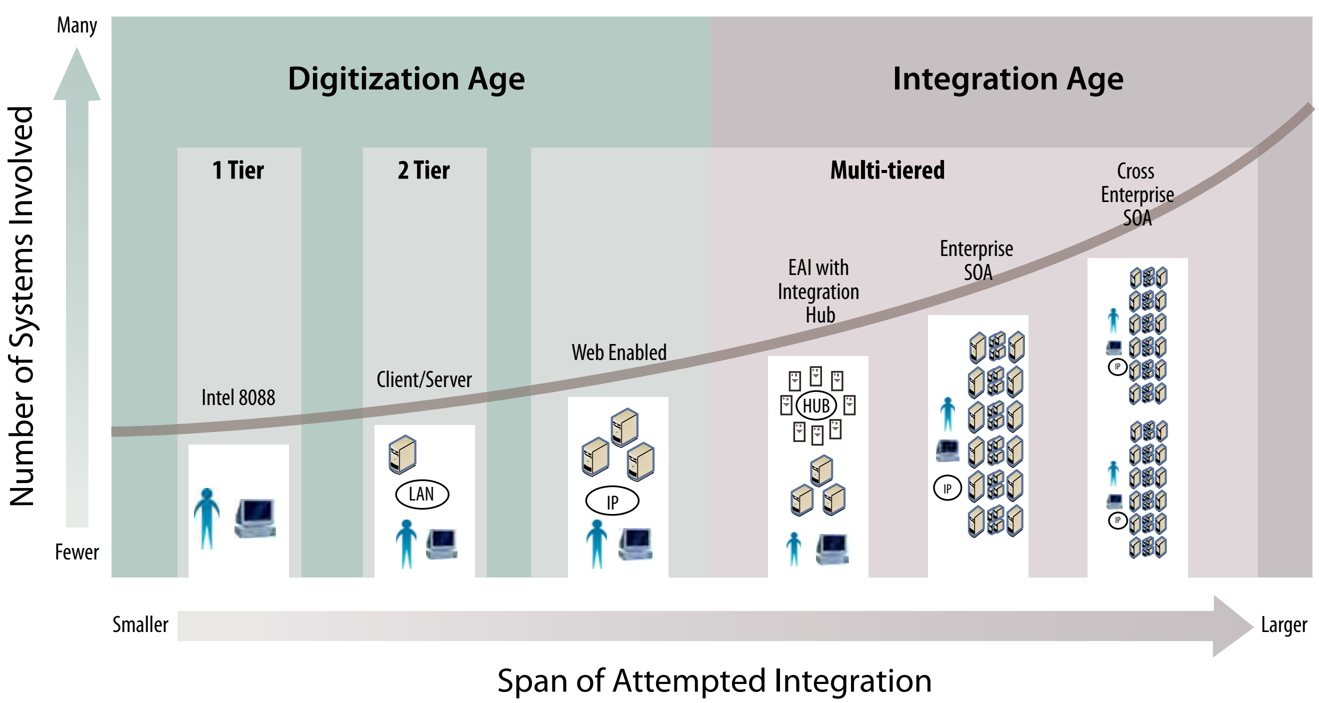


Figure 3. Integration is Increasing in Scope and Complexity.

Cloud Computing	Overlap	SOA via Web Services
• Software as a Service (SaaS) • Utility Computing • Terabytes on Demand • Data Distributed in a Cloud • Platform as a Service • Standards Evolving for Different Layers of the Stack	• Application Layer Components/Services • Network Dependence • Cloud/IP Wide Area Network (WAN)-supported Service Invocations • Leveraging Distributed Software Assets • Producer/Consumer Model	• System of Systems Integration Focus • Driving Consistency of Integration • Enterprise Application Integration (EAI) • Reasonably Mature Implementing Standards (REST, SOAP, WSDL, UDDI, etc.)

Figure 4. Overlapping Concepts for Cloud Computing and SOA Implementations

Both cloud computing and SOA share concepts of service orientation.[16] Services of many types are available on a common network for use by consumers. Cloud computing focuses on turning aspects of the IT computing stack into commodities[17] that can be purchased incrementally from the cloud-based providers and can be considered a type of outsourcing in many cases. For example, large-scale online storage can be procured and automatically allocated in terabyte units from the cloud. Similarly, a platform to operate web-based applications can be rented from redundant data centers in the cloud. However, cloud computing is currently a broader term than SOA and covers the entire stack from hardware through the presentation layer software systems. SOA, though not restricted conceptually to software, is often implemented in practice as components or software services, as exemplified by the Web Service standards used in many implementations. These components can be tied together and executed on many platforms across the network to provide a business function.

***Network dependence*—**Both cloud computing and SOA count on a robust network to connect consumers and producers, and in that sense, both have the same foundational structural weakness when the network is not performing or is unavailable. John Naughton elaborates on this concern when he writes that "with gigabit ethernet connections in local area networks, and increasingly fast broadband, network performance has improved to the point where cloud computing looks like a feasible proposition .... If we are betting our futures on the network being the computer, we ought to be sure that it can stand the strain." [18]

***Forms of outsourcing*—**Both concepts require forms of contractual relationships and trust between service providers and service consumers. Reuse of an SOA service by a group of other systems is in effect an "outsourcing" of that capability to another organization. With cloud computing, the outsourcing is more overt and often has a fully commercial flavor. Storage, platforms, and servers are rented from commercial providers who have economies of scale in providing those commodities to a very large audience. Cloud computing allows the consumer organization to leave the detailed IT administration issues to the service providers.

***Standards*—**Both cloud computing and SOA provide an organization with an opportunity to select common standards for network accessible capabilities. SOA has a fairly mature set of standards with which to implement software services, such as Representational State Transfer (REST), SOAP,[19] and Web Services Description Language (WSDL), among many others. Cloud computing is not as mature, and many of the interfaces offered are unique to a particular vendor, thus raising the risk of vendor lock-in. Simon Wardley writes, "The ability to switch between providers overcomes the largest concerns of using such service providers, the lack of second sourcing options and the fear of vendor lock-in (and the subsequent weaknesses in strategic control and lack of pricing competition)." [20] This is likely to change over time as offerings at each layer in the stack become more homogenous. Wardley continues, "The computing stack, from the applications we write, to the platforms we build upon, to the operating systems we use are now moving from a product- to a service-based economy. The shift towards services will also lead to standardization of lower orders of the computing stack to internet provided components."[21]

Summary: A difference in emphasis—While there are important overlaps between cloud computing and SOA, they have a different emphasis, resulting from their original focus on different problem sets. SOA implementations are fundamentally enterprise integration technologies for exchanging information between systems of systems. SOA focuses on the problem of making systems integration more efficient, and if systems integration as a trend continues to increase as described, efficiency in this task will become increasingly important to Federal leadership teams. SOA implementation technologies, such as the group of Web Service standards, allow a consumer software application to invoke services across a common network. Further, they allow integration across a variety of development languages and platforms, providing a language-neutral software layer. A key benefit of enterprise SOA efforts is the ability to make system-to-system interfaces consistent in the enterprise architecture, thus saving resources on future integration and hopefully improving the speed at which integration can occur—or organizational agility. The emphasis of cloud computing is to leverage the network to outsource IT functions across the entire stack. While this can include software services as in an SOA, it goes much further. Cloud computing allows the marketplace to offer many IT functions as commodities, thus lowering the cost to consumers when compared to operating them internally. John Foley describes cloud computing as "on-demand access to virtualized IT resources that are housed outside of your own data center, shared by others, simple to use, paid for via subscription, and accessed over the Web."[22] Therefore, while the two concepts share many common characteristics, they are not synonymous and can be pursued either independently or as concurrent activities.

Can SOA Be Skipped for Cloud Computing?

SOA and cloud computing are complementary activities, and both will play important roles in IT planning for senior leadership teams for years to come. Cloud computing and SOA can be pursued independently, or concurrently, where cloud computing's platform and storage service offerings can provide a value-added underpinning for SOA efforts. Requirements unique to Federal organizations will determine the depth to which they can employ wholly commercial solutions, commercial-off-the-shelf products used to implement SOA service portfolios or cloud service providers on the public Internet. Regardless, the network-based concepts inherent in each will shape thinking about the architecture and economies of scale of large enterprise IT solutions, even when the Government finds it needs to create its own versions for policy, privacy, topology, or security reasons.

Enterprise application integration continues— Cloud computing does not replace SOA, or the use of distributed software components, as an integration technology. The need to support broader and more consistent integration of systems will continue. The trend by leadership teams to consider IT capabilities as a commodity will continue to put downward pressure on IT budgets and, consequently, integration and data exchange will have to get more streamlined and efficient, across a portfolio of disparate systems. SOA-inspired componentization efforts, where software leverages other network-based software, are a response to this pressure.

Cloud computing does not replace SOA, or the use of distributed software components, as an integration technology.

Cloud computing and SOA are not synonymous, though they share many characteristics. Solving one does not complete the other. For example, consistently integrating your software systems as distributed components or services (SOA) will not inherently virtualize your hardware, or outsource your presentation layer to a third-party provider (cloud computing). Accomplishing successful outsourcing of commodity IT functions (cloud computing) does not integrate systems custom to your business, or aggregate data into a single display "mash-up" (SOA). While SOA and cloud computing share many of the same concerns, considering all the layers of the IT support stack will require coordinating multiple dependent efforts.

In summary, both cloud computing and SOA can support good engineering practices by enabling fundamental concepts such as abstraction, loose coupling, and encapsulation. Both approaches rely on the definition of clear and unambiguous interfaces, predictable performance and behavior, interface standards selection, and clear separations of functionality. Finally, cloud computing and SOA can be pursued independently, or concurrently as complementary activities.

How Can the DoD Take Advantage of Cloud Computing?

The cloud computing capabilities discussed here have many potential benefits for DoD and Federal agencies, and while it will be tempting to immediately use public Internet-based commercial resources, the existing commercial marketplace service providers will present a challenge for the majority of the DoD for the following reasons:

- **Information assurance:** Part of the benefit of cloud computing as a consumer is being able to abstract oneself away from the details of how a platform or service is provided. This abstraction can include not knowing where one's data is actually being kept, including how many data centers are involved and which national borders these data centers fall in. Security considerations go beyond the actual location of the data. Commercial cloud providers will have security solutions that meet the needs and cost models of their commercial customers, and these approaches can be insufficient for direct connection to classified DoD networks according to current policies.
- **Survivability:** While commercial firms and the DoD share many similar general business continuity concerns, there comes a point where commercial and Government requirements for survivability diverge. The DoD will require a comprehensive understanding of the redundancy of cloud infrastructure that will go beyond the due diligence of most commercial firms. Either driven by policy or law, the DoD will need to specify architecture details usually within the offeror's purview, and not specified by the typical commercial consumer.
- **Chaining of outsourcing:** Many of the cloud providers outsource infrastructure layers beneath the service they are providing. For example, a service provider may use a platform from another commercial organization. While the immediate provider may endeavor to meet DoD requirements, the outsourced provider may not.

Given that contemporary, wholly commercial instances of cloud providers may not currently meet all of DoD's mission-critical needs, it is also possible for DoD to take beneficial cloud concepts and apply them internally on their own sensitive or classified networks. However, establishing a cloud computing infrastructure is not a small undertaking, as it requires that analogous instances of the commercial capabilities be established on the internal networks of the DoD. Cloud offerings are fundamentally network-based offerings and therefore must be present on the same network-addressable space as the DoD consumers. For example, for a cloud offering to be available on NIPRnet, it must be addressable through TCP/IP in the network address space of the NIPRnet. In this sense, each network address space is an island and will need its own cloud capabilities.

The approach of providing DoD-homed cloud services can be considered individually at each layer in the cloud stack. For example, DoD could decide to leverage economies of scale by offering highly virtualized servers and secure storage on a grand scale. Individual DoD programs that require these survivable multi-data-centered cloud IT resources could choose to use these standard cloud platforms instead of defining and procuring custom server solutions and operating them in separate data centers with additional continuity of operations solutions. Examples of potential DoD cloud offerings can be found in each layer of the stack, ranging from infrastructure and storage to platforms, services, and software as a service. Just as in the commercial marketplace, the key to introducing these offerings to DoD programs is understanding how they add value to senior leadership teams controlling DoD IT portfolios.

Examples of potential DoD cloud offerings can be found in each layer of the cloud stack, ranging from infrastructure and storage to platforms, services, and software as a service.

Introducing cloud computing to DoD—A potential process for establishing a cloud computing infrastructure in DoD includes the following broad steps:

- **Determine DoD's initial cloud offerings:** This is an engineering effort that would examine the cloud computing commercial marketplace, the cloud computing stack, and compare them to the needs of select DoD programs. The requirements of the DoD IT programs and the offerings in the marketplace are both moving targets, and this adds a challenge to the analysis, as cloud computing is evolving rapidly. Still, this analysis would provide a valuable comparison to determine the scope of the application of cloud computing for real DoD programs. Part of this analysis would be to assess the applicability of cloud computing to areas of the DoD where network characteristics may hamper receiving full benefit from contemporary network-based cloud offerings. Similarly, solutions with overlapping combinations of locally accessible offerings and WAN-accessible cloud offerings should be considered.

  The cloud computing engineering analysis should make a special effort to determine where industry or open standards can be used in each layer in the cloud stack. For example, the Distributed Management Task Force, whose members include Dell, EMC, Hewlett-Packard, IBM, Intel, Microsoft, Sun, and VMware, has been working on a standard for virtual servers, known as Open Virtualization Format (OVF), as part of its work to enable management interoperability among multi-vendor systems, tools, and solutions.[23] OVF creates a standard way to package and distribute virtual machines.[24] This is an example of an upcoming open standard that would be important in the Cloud Infrastructure layer. One goal for the use of standards like this is to avoid vendor lock-in in the cloud offerings.
- **Choose pilots for each layer of the stack:** In this step, the DoD would select key cloud offerings to pilot on its internal networks. The concept is to apply commercial approaches and technologies cooperatively with industry and exercise these offerings in a realistic sensitive or classified environment, recognizing cloud's inherent dependence on the underlying network. The DoD has early cloud efforts already underway, such as DISA's Rapid Access Computing Environment initiative, which provides Platform as a Service functions.[25] From the point of view of an integrated master schedule, it would be helpful to organize offerings lower in the stack, such as platform computing offerings or storage utility computing, to be available first, so that higher levels of the stack, such as services, could make later use of them.

  The pilots should rely on the active participation of industry. Cloud computing initiatives in industry are likely to be years ahead of the Government for the near term, and DoD would benefit from an open dialogue on commercial architectures and approaches as cloud computing evolves.
- **Analyze the value of the cloud pilots:** In this step the initial results of DoD-focused cloud computing as demonstrated by the pilots on DoD networks would be examined. Lessons learned in the pilots would be analyzed, and determinations of the value of the cloud offerings to DoD IT leadership teams frankly assessed. Technical and programmatic risks with cloud technologies would also be reexamined.
- **Determine if pilots should be made operational:** Here the cloud offerings would be considered for broader implementation across a greater range of programs. Since the network is essential to the cloud, a network analysis would be considered for a wider range of cloud customers. A cost/benefit analysis would be performed to determine if the expansion of the cloud offering was advantageous.

Acquisition—Acquisition activities will be central to piloting and possibly expanding the use of cloud technology. The DoD will have to make some key trade-off decisions regarding how the cloud services are procured. For example, will the DoD procure the offerings as turnkey solutions where the vendor provides all aspects of the offering as a managed service provider with defined SLAs, or will the DoD own and operate the infrastructure with labor and expertise provided by vendors, more in the form of a system integrator's subject matter experts? Will the DoD or the vendor capitalize and own the infrastructure? Will this effort be separately funded or funded by programs that will leverage the cloud? These types of strategic decisions will be part of an overall acquisition strategy for the DoD that must balance costs, program risks, and long-term goals.

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