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IBM PRESENTS STAGED APPROACH TO VIRTUALIZATION MANAGEMENT

June 2010

PREPARED FOR

IBM

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Executive Summary

A key challenge for virtualization management relates to its integration with the management of other tiers of IT infrastructure. The addition of a virtualization layer within systems potentially introduces uncertainty – and complexity – because the relationship between workloads and computing resources inherently becomes indirect. As a result, administrators may require new management tools that provide visibility over both the physical and virtual layers of infrastructure from a single interface.

IBM's solution to virtualization management provides administrators with a consistent interface to manage the virtualization functions on multiple server platforms and hypervisors, enabling the deployment of services that can span multiple virtualization platforms. IBM's approach is based on the combination of native and third-party hypervisors for IBM's server platforms, IBM Systems Director, IBM Systems Director VMControl, and key Service Management capabilities from Tivoli. IBM uses a staged approach for virtualization management, enabling administrators to exploit virtualization for maintaining service levels in complex workloads, spanning different classes of server systems. This staging allows virtualized infrastructure to be fully and seamlessly introduced into IT processes with Tivoli's Service Management capabilities. The approach also enables the unification of physical and virtual management across the server, storage, and network domains, which is an important concern for users as they gradually phase in virtualization while continuing to maintain existing systems.

Virtualization Is Mainstream

As virtualization enters the mainstream, it continues to have a major impact across the IT industry. It is certainly not new technology; virtualization has been used on mainframes for decades. What has been generating all the excitement recently is the growing maturity of virtualization technology on all platforms, including servers based on x86 and RISC architectures. Further, as virtualization is coupled more deeply with management tools and processes, it has the potential to enable many new benefits that can have far-reaching business impact.

In a variety of real-world environments, virtualization has already proven its ability to deliver some key business benefits, including:

» Consolidation and improved resource utilization: Consolidating servers and storage through virtualization enables administrators to reduce the number of physical machines that they have to acquire and manage. The improved resource utilization reduces the server and storage hardware footprint, which results in lower acquisition costs, and can also reduce some operational costs related to maintenance, cooling, and power consumption.

» Simplified resource provisioning: With virtualization, the time required to provision new systems is reduced dramatically, compared with physical servers. While the end-to-end time required to bring up a new physical server could span weeks or months from planning to

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actual deployment, virtual machines can be launched in minutes or seconds. Virtualization also makes it easier to reconfigure systems. Live migration of virtual machines between hosts provides flexibility for assigning computing resources to workloads. Storage virtualization allows storage resources to be expanded or migrated online, and it may enable virtual machines that are migrated to be accompanied by the storage Logical Units (LUNs) they need to ensure continued access to data. With these capabilities, organizations can respond more quickly to emerging business opportunities, making them more agile overall.

» Simplified High Availability (HA) / Disaster Recovery (DR): Virtualization can be used to fundamentally improve the overall reliability of a computing infrastructure. Virtualization enables fewer physical servers and storage systems to be deployed, which reduces the footprint for potential hardware failures that result in unplanned downtime. Moreover, the servers and storage systems that are deployed can be configured with HA features (such as redundancy and hot-plug components and storage replication) to reduce downtime. The ability to migrate virtual machines from one host to another with little or no interruption to processing provides yet another means to reduce planned downtime. Such migration allows workloads to be temporarily moved so that hardware maintenance can be performed on the hosts with minimal disruption. When coupled with HA clustering functions, virtualization can be used to restart workloads on a backup host in the wake of a primary host failure – dramatically simplifying the implementation of DR procedures. Traditional HA and DR implementation requires applications and their dependencies to be adapted so that they can be restarted on backup systems – which is a notoriously complex and error-prone process. With virtualization, the entire workload can easily be relaunched simply by restarting the virtual machine on which it is hosted.

» Legacy application support: Virtualization enables administrators to migrate legacy applications to new hardware without disturbing their environment. If an application depends on a particular OS version, migrating that application to new hardware will not be possible if that hardware does not support the OS version. Virtualization can be used to extend the life of such applications. The OS required for the legacy application can be hosted in a virtual machine running on the new platform until that application can be replaced or rewritten.

» Improved test and development processes: Virtualization simplifies and improves the quality of testing and development. IT managers can rapidly allocate resources as needed to support test processes. If necessary, the resources required to perform testing can be assigned by tapping into production resources temporarily. Production systems can be copied easily for testing purposes, and developers can easily test applications on different operating systems. Virtual machines also help to isolate bugs during the testing process by neutralizing hardware variability.

While these benefits have been proven in organizations of all sizes, there are in fact many different ways in which to implement virtualization. Some form of virtualization technology, based on hypervisors or other partitioning mechanisms, is now available on most server platforms. Moreover, on platforms such as x86, users actually have a choice of virtual machine platforms, each with its own set of differentiations that result in a unique value proposition.

Key Technology Trends with Virtualization

Virtualization technology continues to evolve rapidly. As virtualization becomes more deeply integrated into datacenters and IT infrastructure, IT managers are focusing on some key functional issues related to virtualization platforms, including the following:

» Basic virtualization functionality, including hypervisor capabilities and advanced mechanisms for deploying virtual infrastructure on top of hypervisors. Hypervisors may vary in their relative scalability and efficiency, which are critical factors in maximizing the consolidation ratios that can be achieved through virtualization. While no industry-standard methods exist yet for empirically comparing the performance of virtualization platforms, some platforms

One way to make the management of heterogeneous virtualization platforms more efficient is to introduce a management framework that has the capability to control multiple classes of virtualization functions from a single interface . . .

may be differentiated by optimizations for managing memory, or in the integration of hypervisor functions with hardware, both of which can fundamentally affect the performance of virtualized workloads.

» Virtualization impact on I/O. As ever-more demanding and complex workloads are virtualized, the integration between virtual machines, storage, and networking becomes more critical. Users are concerned with both maximizing the performance of I/O in virtualized environments, and achieving the same flexibility for reconfiguring storage and networking that is possible with reconfiguring virtual machines. Storage virtualization options are becoming prevalent, with the growing trend toward the orchestration of server and storage virtualization functions as a unified operation leveraging hypervisor-aware storage offerings and new management offerings such as IBM's Systems Director. The integration of hypervisors with I/O subsystems therefore becomes a critical point of optimization for virtualization platforms.

Virtualization platforms may vary in their scalability and I/O integration, and the differences in these areas, along with other factors, will determine which platform users find most appropriate for virtualizing particular workloads. However, aside from tradeoffs in the basic virtualization capabilities of hypervisor platforms, users are becoming increasingly concerned with the management of virtualization platforms, particularly the integration of virtualization management with the management tools and processes for other parts of their operations.

Virtualization Management Requirements

A key challenge for virtualization management relates to its integration with the management of other tiers of IT infrastructure. Virtual machines inherently decouple workloads from the details about the hardware on which they are deployed, giving administrators significant flexibility in matching applications with their required computing resources. In general, because virtual machines run the same operating systems as physical hardware, they do not introduce any major operational changes. As a result, virtual machines represent a powerful and intuitive mechanism for assigning resources to workloads with a new degree of freedom.

However, the addition of a virtualization layer within systems also potentially introduces uncertainty – and complexity – because the relationship between workloads and computing resources inherently becomes indirect. As a result, administrators require new management tools that can provide visibility over both the physical and virtual layers of infrastructure. If possible, administrators should also have consistent visibility and control over other layers of infrastructure, such as storage and networks. The closer the relationship between the management of all these components, the easier it will be for administrators to achieve the operational benefits that virtualization promises.

Further, as users extend the scope of virtualization from single servers to multiple systems throughout a datacenter or organization, they will likely become interested in automating some virtualization management tasks. Indeed, successful automation of virtualization management becomes essential to achieving significant reductions in operational costs from the use of virtualization. Higher-level services based on multiple virtualized applications require sophisticated tools that can maintain service levels across multiple virtualized systems, possibly spanning different classes of servers.

Thus, the ability to manage different virtualization platforms, either on the same hardware platform or different platforms, from a single interface is becoming increasingly important. Virtualized workloads may span multiple departments or business units, some of which may be deploying different virtualization technologies. Heterogeneous virtualization management will therefore be essential to bridging the organizational and technology silos that currently prevail in many customer infrastructures.

FIGURES 1 AND 2

Figure 1 *– Separate Tools for Managing Virtualization and Host Hardware*

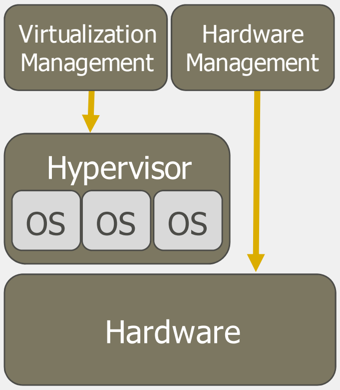
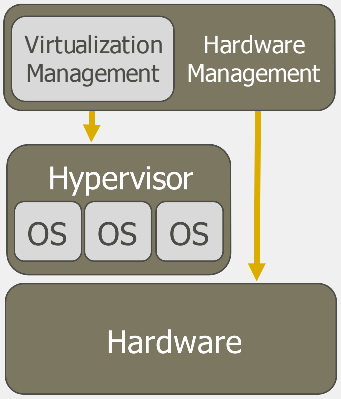


Figure 2 *– Integrated Tools for Managing Virtualization and Host Hardware*



In some organizations, the ultimate goal for the use of virtualization may be enabling cloud computing. For many users, the term "cloud" represents the convergence of server virtualization with the virtualization of storage and networking, so that servers, storage, and networking can be managed as a single pool of computing resources that workloads can draw upon as needed, in response to changing workload conditions. Despite fascination with the prospect of tapping into third-party computing infrastructures, the most pressing concern for most users today is to virtualize as much as possible of their internal infrastructure into what might be called "private" clouds. The management of these pooled resources is one of the most immediate requirements for building such private clouds, and the management tools to do so will become critical for eventually introducing computing resources from third-party cloud computing services.

How can managers address these various requirements as they start to put virtualization management into place? Following is a roadmap for how the introduction of virtualization management can be staged in various tiers of IT infrastructure.

Staging Management Layers in Virtualized Infrastructure

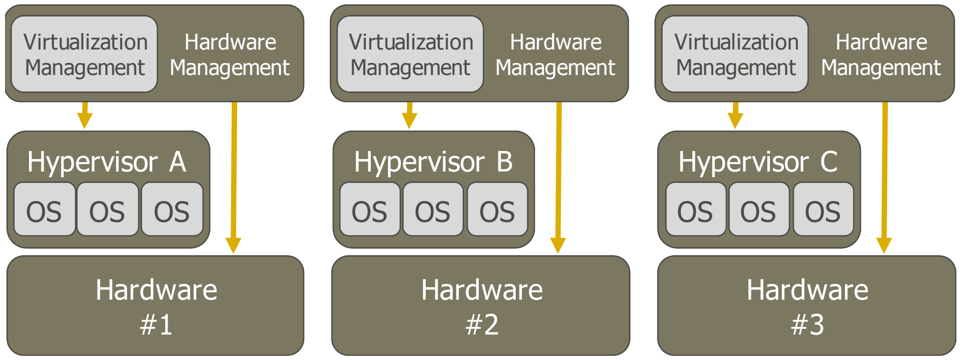
Basic virtualization management requires oversight and control over both virtual and physical system layers. Normally, managers would use one set of tools to control the virtualization platform (i.e., on x86 servers, administrators would use vCenter Server to control VMware, or Microsoft SystemCenter to control Hyper-V), and another to control the server hardware on which the virtual machines are hosted (see Figure 1, left). While this approach is effective, it requires administrators to learn two separate interfaces. Moreover, without explicit connections between hardware and virtualization layers, it can be difficult to monitor and control virtual and physical resources in a coordinated fashion.

By integrating the virtualization management with the hardware management, administrators gain the ability to control hardware and virtualization functions from same interface, increasing administrator productivity (see Figure 2, left). Administrators can then use the same interface to monitor resources and events at both the physical and virtual layers, making it possible to coordinate the operation of server hardware and hypervisor functions. For example, the converged management interface could start or stop virtual machines in response to load conditions on the physical host. The load condition would be determined based on machine-specific instrumentation data that is fed up from the hardware-management part of the interface, and the interface would trigger a hypervisor configuration command in the virtualization management layer.

As the use of virtualization becomes a part of standard operating procedure across the industry, administrators will increasingly be confronted with the need to manage virtualization on multiple platforms. Each platform will have its own characteristics, both at the level of server hardware (which may have unique functionality to support virtualization, or may require coordination with hypervisor operation), and also within the hypervisor (see Figure 3, next page). Even on the same hardware platforms, each hypervisor typically has its own interface for controlling virtualization functions.

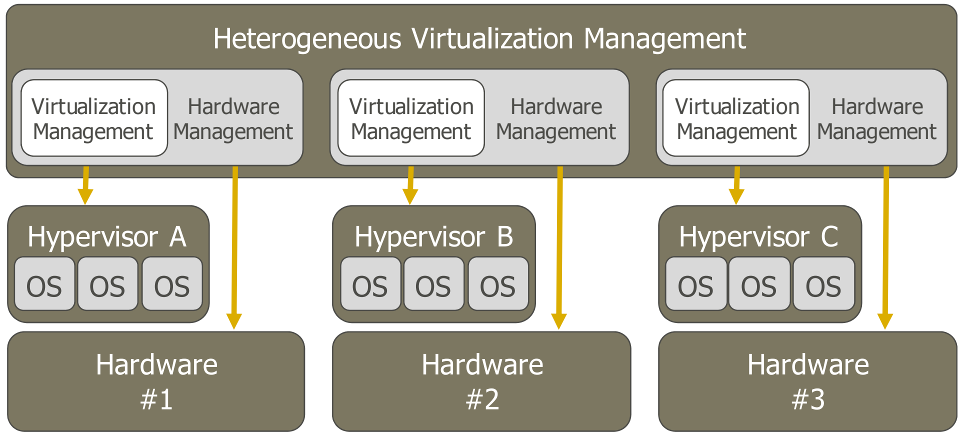
Not only do administrators need to manage physical hardware associated with a virtualized infrastructure, they also have to manage, provision, monitor, and automate physical infrastructure that is not virtualized. A layered framework enables companies to gradually introduce virtualization while preserving their existing management processes.

Figure 3 – Unique Controls for Heterogeneous Virtualization and Host Platforms



One way to make the management of heterogeneous virtualization platforms more efficient is to introduce a management framework that has the capability to control multiple classes of virtualization functions from a single interface (see Figure 4, below). Such a framework would provide a consistent interface for administrators to perform canonical virtualization functions (i.e., creating, moving, and destroying virtual machines; provisioning workloads on virtual machines; and managing libraries of preconfigured virtual machine images). These kinds of operations usually have similar methods of control, so they can be performed in a generic manner, even if the actual implementation of the functions is unique to the underlying hypervisor and/or hardware platforms. By shielding administrators from details about individual virtualization platforms, the framework can help to break down barriers between management silos. Administrators can then develop virtualization management policies for orchestrating the use of virtualized resources in collaboration with lower-level management functions, which in turn are optimized for specific hypervisors and hardware platforms. For example, if an administrator were to request that a virtual machine be migrated from one x86 host to another, the command would work the same way regardless of whether the virtual machine hypervisor were Microsoft Hyper-V or VMware ESX Server.

Figure 4 – Deploying Framework for Heterogeneous Virtualization Management



A heterogeneous virtualization management framework can serve as the foundation for higher-level services that are deployed on top of virtual machines and managed with some degree of automation. These services may span multiple classes of servers and/or virtual machine platforms, and thus require coordinated management of the different platforms. This could be the case if the service has a multi-tier architecture (i.e., with a web-based front end on industry-standard x86 servers, a middle tier on x86 or RISC, and a back end for databases hosted on large

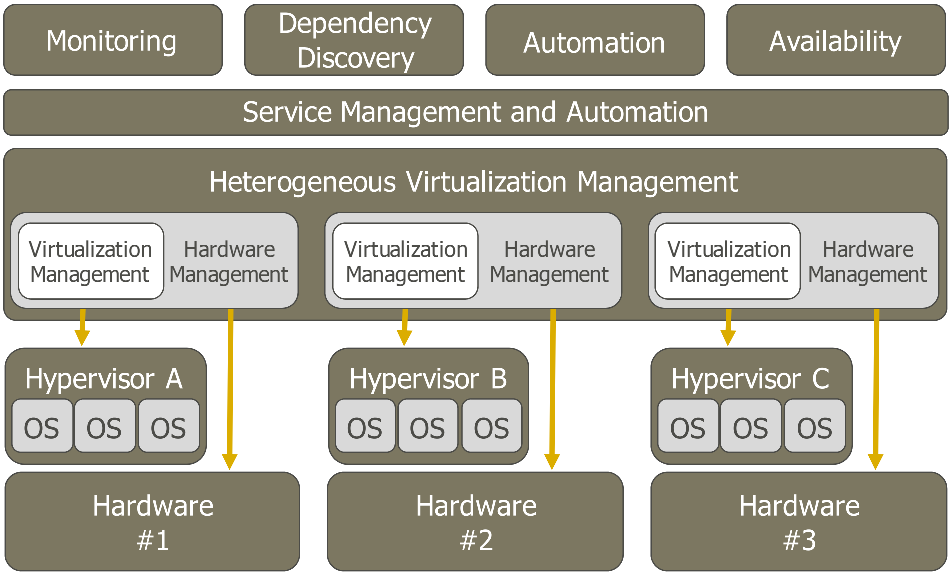
All of IBM's server platforms can be managed with the same interface, called IBM Systems Director, which is optimized to measure and control low-level functions in IBM's servers, including power draw. IBM Systems Director also interfaces with IBM's Tivoli Productivity Center storage manager to orchestrate coordinated server/storage management.

RISC or mainframe servers). It could also be the case if the service crosses systems in multiple departments or business units, each of which might have a different virtualization platform.

Automating the management of these services in a virtualized environment requires four broad classes of higher-level functions (see Figure 5), roughly defined as follows:

- Monitoring operational conditions at every level of the stack, starting with the underlying hardware and hypervisor functions, through the generic virtualization parameters that apply across all platforms, and up to the applications and services that are layered on top. For example, if a response time monitoring agent detects that an application's performance is beginning to dip below acceptable bounds, it will quickly correct the problem by driving automated actions between application performance management and virtualization platform management. Through this comprehensive monitoring, problems are addressed before service levels are affected.
- Dependency Discovery and Configuration Management, i.e., mapping the relationship between all of the components in the stack, so that administrators can determine the impact of making changes at any level and quickly isolate any changes that cause performance degradation. For example, if a datacenter administrator made a low-level change (such as unplugging a network adapter) that resulted in reduced service levels for a key workload, this dependency discovery mechanism would reveal the connection between the root cause and its effect. It could also determine if configurations complied with organizational policies by comparing discovered configurations to a "reference master" to reveal policy violations.
- Automation, i.e., the ability for administrators to define policies in which management actions are triggered automatically in response to specific operating conditions, as determined by the monitoring facilities described above. A key use of automation is to enable services to be reconfigured dynamically in response to downtime conditions, either planned or unplanned. This capability typically requires the implementation of some HA clustering techniques.
- HA clustering techniques allow services to be automatically reassigned to alternate resources in the event that a failure is detected in the service's primary resources. For example, if the automation mechanism were to determine that the responsiveness of a service had decreased because a virtual machine host that it depended on had suffered a hardware failure, it would automatically restart the affected virtual machine(s) on another host.

Figure 5 – Managing Services Deployed on Virtual Infrastructure



IBM Systems Director VMControl is an extension to Systems Director that can be used to manage multiple virtualization platforms from the same interface. VMControl works with the virtualization functions on all of IBM's hardware platforms, including System x, Power Systems, and System z, and it is available in different versions.

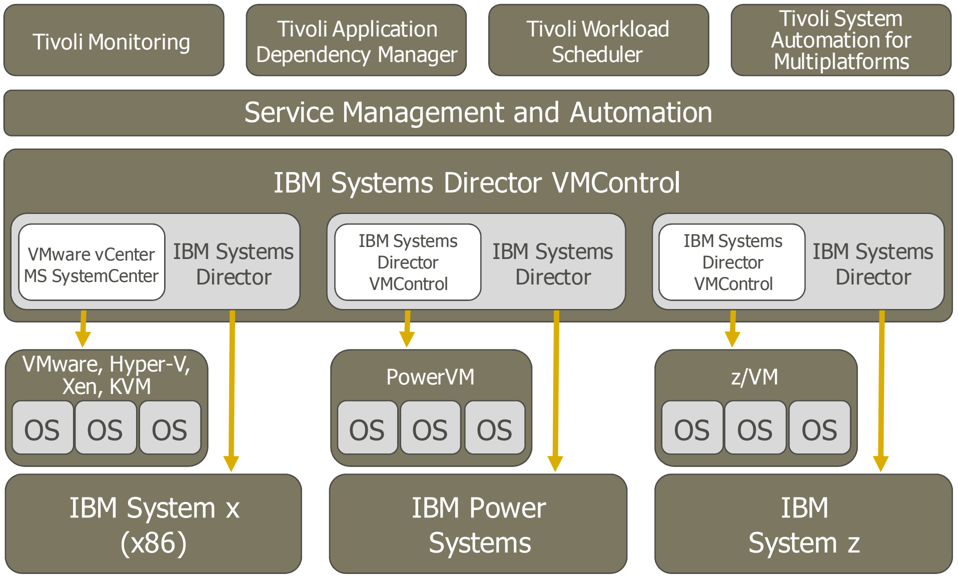
With the implementation of this layered approach to virtualization management, it becomes possible to deploy complex services on top of virtualized resources, independently of management requirements for specific virtualization and server platforms. As a result, administrators can monitor events and model relationships between essential service components, while using a single consistent interface to assign virtualized resources to the services. These two capabilities then enable the development of business-driven policies to automate the provisioning of available resources to services, and to handle failure or downtime associated with underlying resources in a consistent manner.

Further, most companies will virtualize infrastructure over time. For the foreseeable future, these companies will need to manage both physical and virtual infrastructure in parallel. Not only do administrators need to manage physical hardware associated with a virtualized infrastructure, they also have to manage, provision, monitor, and automate physical infrastructure that is not virtualized. A layered framework enables companies to gradually introduce virtualization while preserving their existing management processes.

IBM's Approach to Virtualization Management

The IBM solution to virtualization management uses the approach described above to provide administrators with a consistent interface to manage the virtualization functions on all of its strategic server platforms. It also enables the deployment of services that can span a variety of system configurations, including multiple virtualization platforms, physical and virtual systems together, or physical systems only (see Figure 6).

Figure 6 – IBM Virtualization Management Solution



Starting at the bottom of the stack, IBM supports multiple virtualization platforms on its three strategic server platforms:

» IBM System x is IBM's line of industry-standard x86 servers. IBM supports several virtual machine platforms on System x, including VMware, Microsoft Hyper-V, and the native virtualization management functions that are built into the leading Linux distributions (i.e., Xen and Kernel-based Virtual Machine [KVM]). IBM also supports the native management functions for these hypervisors on System x, including VMware vCenter and Microsoft SystemCenter. IBM's higher-level virtualization management tools "collaborate" with these

IBM Tivoli tools provide integrated visibility, control, and automation across multiple business units and heterogeneous server platforms, including systems from vendors other than IBM. Tivoli is optimized for aligning IT operations with business at a high level, while enabling governance and control of automated business processes independently of specific hardware attributes.

native management systems in order to trigger specific actions at the level of virtual infrastructure.

- IBM POWER includes a native virtualization platform called PowerVM, which offers a complete set of virtualization capabilities that are optimized for the POWER platform. The key components of PowerVM include the following:
  - PowerVM's Micro-Partitions enable many distinct workloads to share a processor and memory simultaneously while running on different operating systems. The Virtual I/O Server (VIOS) allows a single Micro-Partition to provide I/O connectivity for the other Micro-Partitions in the server and eliminates the need for I/O devices (storage and network adapters) in each partition, reducing cost and complexity. Micro-Partitions and VIOS enable hardware resources to be better utilized. A single processor can host up to 10 Micro-Partitions.
  - PowerVM's Partition Load Manager can automatically adjust processor and memory resources in a Micro-Partition based on current utilization and user-defined priorities (the size of a Micro-Partition can be adjusted in increments of 1/100 of a processor).
  - PowerVM's Active Memory Sharing feature improves utilization of system memory by allowing physical memory in a machine to be assigned into a shared pool and allocated to partitions on the fly. Active Memory Sharing also includes support for memory overcommitment, so that if all partitions in the machine request more virtual memory than is physically available, the partitions can use the Virtual I/O Server partition as a paging device.
  - PowerVM Live Partition Mobility allows a virtual machine to migrate from one physical host to another without interrupting its processing.
- IBM System z has some of the most mature and efficient virtualization functions in the industry. The z/VM virtual machine platform for System z has proven its scalability with deployments of thousands of virtual machines running concurrently on a single host. With z/VM, Linux environments that need the highest qualities of service can be virtualized on the System z platform using standard distributions from Red Hat and Novell. System z also has some of the most robust and efficient I/O virtualization capabilities of any server platform, based on its Intelligent Resource Director (IRD) functions.

All of IBM's server platforms can be managed with the same interface, called IBM Systems Director, which is optimized to measure and control low-level functions in IBM's servers, including power draw. IBM Systems Director also interfaces with IBM's Tivoli Productivity Center storage manager to orchestrate coordinated server/storage management. IBM Systems Director VMControl is an extension to Systems Director that can be used to manage multiple virtualization platforms from the same interface. VMControl works with the virtualization functions on all of IBM's hardware platforms, including System x, Power Systems, and System z, and it is available in different versions. The most basic version, VMControl Express Edition, can be used to create, modify, and delete virtual machines, or trigger the live migration of VMs from one host to another. A more advanced version, called VMControl Standard Edition, adds more powerful functions for performing virtual machine relocation; importing, editing, creating, and deleting virtual images; maintaining virtual images in a repository; and deploying virtual images. VMControl Enterprise Edition can be used to create pools of virtualized resources (both server and storage pools), which workloads can tap into on demand in response to changing workload conditions. Another extension for IBM Systems Director, the Storage Management plug-in, can be used to coordinate VM provisioning and mobility for server, storage, and network resources. The plug-in can be used to perform lifecycle management of storage systems, including discovery, health and status monitoring, configuration, updates, and management of storage virtualization functions.

IBM Tivoli tools provide integrated visibility, control, and automation across multiple business units and heterogeneous server platforms, including systems from vendors other than IBM.

. . . IBM Systems Director and Tivoli address the key requirements for deploying services on virtualized infrastructures, allowing the underlying virtualized resources to be managed on an end-to-end basis, spanning multiple server and virtualization platforms.

Tivoli is optimized for aligning IT operations with business at a high level, while enabling governance and control of automated business processes independently of specific hardware attributes. Some key IBM Tivoli products that play a role in managing virtualized services include the following:

» Tivoli Monitoring can be used to monitor a variety of performance indicators and store them in a common warehouse for reporting and analysis. Administrators can mine the collected data for performance analysis as well as capacity analysis, and perform predictive trending to see when capacity will be exceeded. By working in conjunction with IBM Systems Director, Tivoli Monitoring can monitor server energy consumption via the Active Energy Manager component. Tivoli Monitoring can import power and thermal metrics from Active Energy Manager into its warehouse to perform predictive trending based on environmental data, as well as develop power-driven provisioning policies. For example, by integrating the power data with VMControl, administrators can locate and provision a new virtual server that will have the least impact on cooling cost. Tivoli monitoring can also monitor energy usage of other datacenter assets (e.g., HVAC, CRAC systems), providing a complete picture of energy usage in the data center.

» Tivoli Application Dependency Discovery Manager (TADDM) visualizes interdependencies and relationships between applications, systems, and network devices. It can be used to gain visibility into the relationship between services and the supporting infrastructure, including cross-tier dependencies, runtime configuration values, and change history. TADDM can be essential for determining whether changes that are being made in an infrastructure will affect availability. In particular, it allows administrators to understand if performance problems with a service are the result of specific changes that were made at a lower level.

» Tivoli Workload Scheduler (TWS) dynamically matches workloads with the best available resources. It eliminates the manually intensive processes of matching workloads with resources that may be distributed across multiple, heterogeneous systems, so that services can automatically adapt to unplanned changes in the underlying IT infrastructure.

» Tivoli System Automation for Multiple Platforms is an HA option for heterogeneous workloads – i.e., workloads depending on application resources that may be spread across different systems (possible with different architectures). It is typically used for maintaining availability of composite applications, in which the service depends on multiple components. For example, with a three-tier application, administrators can synchronize the uptime of all three tiers, so that each tier can be failed over on its appropriate architecture.

In IBM's layered approach to virtualization management, IBM Systems Director and VMControl can capture operational data and events at the level of hardware and specific virtualization platforms. IBM Systems Director can then feed this data to the Tivoli management tools described above, which can be used to manage advanced functions such as failover, disaster recovery (DR), and maintenance of Service Level Agreements (SLAs). In this way, IBM Systems Director and Tivoli address the key requirements for deploying services on virtualized infrastructures, allowing the underlying virtualized resources to be managed on an end-to-end basis, spanning multiple server and virtualization platforms.

The IDEAS Bottom Line

The rise of virtualization, potentially followed by an industry shift toward cloud computing, clearly introduces new systems management requirements. While the relative ease of allocating virtual resources facilitates the task of adapting computing infrastructure in response to changing conditions, it also increases the challenge of maintaining service levels for workloads deployed on top of the virtualized infrastructure. Administrators now have more variables than ever to consider when matching an application workload with the resources it needs, and deploying management tools and processes to effectively exploit virtualization in complex workloads requires careful thought.

Virtualization management solutions should be able to address several common challenges, including the following:

- **Manage heterogeneous virtualization:** Virtualized workloads may span multiple system tiers or departments, each of which may be standardized on different virtualization technologies. To effectively manage such complex workloads, administrators require the ability to control multiple hardware platforms, hypervisors, and physical and virtual infrastructure from a single interface.
- **Contain complexity:** Virtualization introduces an additional layer of functionality in IT infrastructure, and the resulting complexity risks increasing costs of operations. Virtualization management tools should therefore be optimized for simplicity, consolidating as many tasks as possible into the fewest required interfaces.
- **Monitor and correlate conditions at multiple levels of infrastructure:** Virtualization management solutions should provide visibility over all of the system layers underlying virtualized services, including hardware, hypervisors, and higher-level service management functions. Only with end-to-end visibility can administrators form accurate pictures of the factors that are causing particular behavior in virtualized services.
- **Manage power consumption:** Efficient use of energy resources requires power-driven workload management policies. Therefore, virtualization management tools should allow the power consumption of underlying hardware to be used as triggers at every level of the management stack, from low-level configuration of virtual machines to placement of high-level services.
- **Manage availability:** Virtualization management solutions should be able to detect and respond to outages at every level of the system stack, dynamically reconfiguring virtual infrastructure and relocating high-level services in response.
- **Orchestrate virtual machine functions:** Virtualization management solutions should be able to coordinate the effects of virtual machine-related processes such as provisioning and migration across server, storage, and network resources.

IBM's approach to virtualization management – based on the combination of native and third-party hypervisors for IBM's server platforms, IBM Systems Director, IBM Systems Director VMControl, and key Tivoli add-ons– empowers administrators to take on all of these challenges. Moreover, the layered nature of IBM's virtualization management solution allows the components to be introduced gradually, starting with IBM Systems Director VMControl and moving up to more advanced Tivoli service management functions as appropriate. This staged approach enables users to incrementally adopt the discipline of provisioning and measuring computing resources in pools. As users gain the ability to flexibly assign resources to higher-level services from multiple classes of virtualization platforms, instead of specific hardware instances, the power of virtual machines can be applied to complex workloads. Comprehensive virtualization management solutions like IBM's are thus essential for unlocking the operational cost benefits of virtualization on a large scale.

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