



Matthew Portnoy

# Virtualization

ESSENTIALS

Third Edition

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# **VIRTUALIZATION**

***ESSENTIALS***

**Third Edition**



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## ESSENTIALS

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Matthew Portnoy



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*To my friends  
and family,  
near and far.*

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# ABOUT THE AUTHOR

Matthew Portnoy has been an information technology professional for more than 30 years, working in organizations such as NCR, Sperry/Unisys, Stratus Computer, Oracle, VMware, and Splunk. He has been in the center of many of the core technological trends during this period, including the birth of the PC, client-server computing, fault tolerance and availability, the rise of the Internet, and now virtualization, which is the foundation for cloud computing. As both a presales and post-sales analyst, he has worked with all of the disciplines computing offers, including innumerable programming languages, operating systems, application design and development, database operations, networking, security, availability, and virtualization. He has spoken at the industry's largest virtualization conference, VMworld, and is a frequent speaker at user group meetings. He also taught virtualization and database classes for more than a decade as an adjunct professor at Wake Tech Community College in Raleigh, North Carolina.



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# INTRODUCTION

*We live in an* exciting time. The information age is exploding around us, giving us access to dizzying amounts of data the instant it becomes available. Smartphones and tablets provide an untethered experience that offers streaming video, audio, and other media formats to just about any place on the planet. Even people who are not “computer literate” use Facebook to catch up with friends and family, use Google to research a new restaurant choice and get directions to drive there, or tweet their reactions once they have sampled the fare. The budding Internet of Things will only catalyze this data eruption. The infrastructure supporting these services is also growing exponentially, and the technology that facilitates this rapid growth is virtualization.

On one hand, virtualization is nothing more than an increasingly efficient use of existing resources that delivers huge cost savings in a brief amount of time. On the other, virtualization offers organizations new models of application deployment for greater uptime to meet user expectations, modular packages to provide new services in minutes instead of weeks, and advanced features that bring automatic load balancing, scalability without downtime, self-healing, self-service provisioning, and many other capabilities to support business-critical applications that improve on traditional architecture. Large companies have been using this technology for more than 15 years, while smaller and medium-sized businesses also now rely on these solutions. Newer companies may skip the movement altogether and jump directly to cloud computing, the next evolution of application deployment. Virtualization is the foundation for cloud computing as well.

This quantum change in our world echoes similar trends from our recent history as electrical power and telephony capabilities spread and then changed our day-to-day lives. During those periods, whole industries sprang up out of nothing, providing employment and opportunity to people who had the foresight and chutzpah to seize the moment. That same spirit and opportunity is available today as this area is still being defined and created right before our eyes. If not virtualization vendors, there are hardware partners that provide servers, networking vendors for connectivity, storage partners for data storage, and everyone provides services. Software vendors are designing and deploying new applications specifically for these new architectures. Third parties are creating tools to monitor and manage these applications and infrastructure areas. As cloud computing becomes the de facto model for development, deployment, and maintaining application services, this area will expand even further.

The first generation of virtualization specialists acquired their knowledge out of necessity: they were server administrators who needed to understand the new infrastructure being deployed in their data centers. Along the way, they picked up some networking knowledge to manage the virtual networks, storage knowledge to connect to storage arrays, and application information to better interface with the application teams. Few people have experience in all of those areas. Whether you have some virtualization experience or none at all, this text will give you the foundation to understand what virtualization is, why it is a crucial portion of today's and tomorrow's information technology infrastructure, and the opportunity to explore and experience one of the most exciting and key areas in technology today.

Good reading and happy virtualizing!

## Who Should Read This Book

This text is designed to provide the basics of virtualization technology to someone who has little or no prior knowledge of the subject. This book will be of interest to you if you are an IT student looking for information about virtualization or if you are an IT manager who needs a better understanding of virtualization fundamentals as part of your role. *Virtualization Essentials* might also be of interest if you are an IT professional who specializes in a particular discipline (such as server administration, networking, or storage) and are looking for an introduction into virtualization or cloud computing as a way to advance inside your organization.

The expectation is that you have the following:

- ▶ Some basic PC experience
- ▶ An understanding of what an operating system is and does
- ▶ Conceptual knowledge of computing resources (CPU, memory, storage, and network)
- ▶ A high-level understanding of how programs use resources

This text would *not* be of interest if you are already a virtualization professional and you are looking for a guidebook or reference.

## What You Need

The exercises and illustrations used in this text were created on a system with Windows 11 as the operating system. VMware Workstation Player version 16 is used as the virtualization platform. It is available as a free download from

downloads.vmware.com/d. It is recommended that you have at least 2 GB of memory, though more will be better. The installation requires a minimum of 1.5 GB of disk storage, but virtual machines will require more. Also used is Oracle VirtualBox version 7. It is available as a free download from [www.virtualbox.org](http://www.virtualbox.org). It is recommended that you have at least 2 GB of memory. VirtualBox itself requires only about 30 MB of disk storage, but virtual machines will require more.

The examples demonstrate the creation and use of two virtual machines: one running Windows 11, the other running Ubuntu Linux. You will need the installation media for those as well. Each of the virtual machines requires about 60 GB of disk space.

## What Is Covered in This Book

Here's a glance at what is in each chapter.

**Chapter 1: Understanding Virtualization** Introduces the basic concepts of computer virtualization beginning with mainframes and continues with the computing trends that have led to current technologies.

**Chapter 2: Understanding Hypervisors** Focuses on hypervisors, the software that provides the virtualization layer, and compares some of the current offerings in today's marketplace.

**Chapter 3: Understanding Virtual Machines** Describes what a virtual machine is composed of, explains how it interacts with the hypervisor that supports its existence, and provides an overview of managing virtual machine resources.

**Chapter 4: Creating a Virtual Machine** Begins with the topic of converting existing physical servers into virtual machines and provides a walkthrough of installing VMware Workstation Player and Oracle VirtualBox, the virtualization platforms used in this text, and a walkthrough of the creation of a virtual machine.

**Chapter 5: Installing Windows on a Virtual Machine** Provides a guide for loading Microsoft Windows in the created virtual machine and then describes configuration and tuning options.

**Chapter 6: Installing Linux on a Virtual Machine** Provides a guide for loading Ubuntu Linux in a virtual machine and then walks through a number of configuration and optimization options.

**Chapter 7: Managing CPUs for a Virtual Machine** Discusses how CPU resources are virtualized and then describes various tuning options and optimizations. Included topics are hyperthreading and Intel versus AMD.

**Chapter 8: Managing Memory for a Virtual Machine** Covers how memory is managed in a virtual environment and the configuration options available. It concludes with a discussion of various memory optimization technologies that are available and how they work.

**Chapter 9: Managing Storage for a Virtual Machine** Examines how virtual machines access storage arrays and the different connection options they can utilize. Included are virtual machine storage options and storage optimization technologies such as deduplication.

**Chapter 10: Managing Networking for a Virtual Machine** Begins with a discussion of virtual networking and how virtual machines use virtual switches to communicate with each other and the outside world. It concludes with virtual network configuration options and optimization practices.

**Chapter 11: Copying a Virtual Machine** Discusses how virtual machines are backed up and provisioned through techniques such as cloning and using templates. It finishes with a powerful feature called *snapshots* that can preserve a virtual machine state.

**Chapter 12: Managing Additional Devices in Virtual Machines** Begins by discussing virtual machine tools, vendor-provided application packages that optimize a virtual machine's performance, and concludes with individual discussions of virtual support for other peripheral devices like CD/DVD drives and USB devices.

**Chapter 13: Understanding Availability** Positions the importance of availability in the virtual environment and then discusses various availability technologies that protect individual virtual machines, virtualization servers, and entire data centers from planned and unplanned downtime.

**Chapter 14: Understanding Applications in a Virtual Machine** Focuses on the methodology and practices for deploying applications in a virtual environment. Topics include application performance, using resource pools, and deploying virtual appliances.

**Appendix: Answers to Additional Exercises** Contains all of the answers to the additional exercises found at the end of every chapter.

**Glossary** Lists the most commonly used terms throughout the book.

## How to Contact the Author

I welcome your feedback about this book or about books you'd like to see from me in the future. You can reach me by writing to [mportnoyvm@gmail.com](mailto:mportnoyvm@gmail.com).

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# Understanding Virtualization

*We are in the* midst of a substantial change in the way computing services are provided. As a consumer, you surf the Web on your cell phone, get directions from a GPS device, and stream movies and music from the cloud. At the heart of these services is *virtualization*—the ability to abstract a physical server into a virtual machine.

In this chapter, you will explore some of the basic concepts of virtualization, review how the need for virtualization came about, and learn why virtualization is a key building block to the future of computing.

- ▶ **Describing virtualization**
- ▶ **Understanding the importance of virtualization**
- ▶ **Understanding virtualization software operation**

## Describing Virtualization

Over the last 60 years, certain key trends created fundamental changes in how computing services are provided. Mainframe processing drove the 1960s and 1970s. Personal computers, the digitization of the physical desktop, and client/server technology headlined the 1980s and 1990s. The Internet boom and bubble spanned the last and current centuries and continues today. Today, application and infrastructure services are available via cloud computing. We are, though, in the midst of another of those model-changing trends: virtualization.

Virtualization is a disruptive technology, shattering the status quo of how physical computers are handled, services are delivered, and budgets are allocated. To understand why virtualization has had such a profound effect on today's computing environment, you need to have a better understanding of what has gone on in the past.

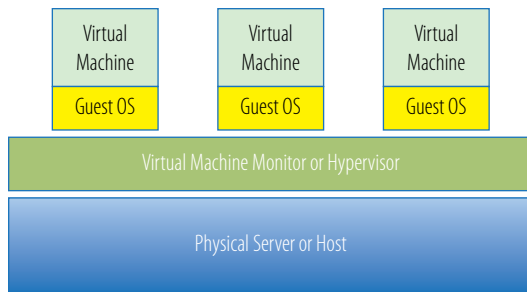
The word *virtual* has undergone a change in recent years. Not the word itself, of course, but its usage has been expanded in conjunction with the expansion of computing, especially with the widespread use of the Internet and smart phones. Online applications have allowed us to shop in virtual stores, examine potential vacation spots through virtual tours, and even keep our virtual books in virtual libraries. Many people invest considerable time and actual dollars as they explore and adventure through entire worlds that exist only in someone’s imagination and on a gaming server.

Virtualization in computing often refers to the abstraction of some physical component into a logical object. By virtualizing an object, you can obtain some greater measure of utility from the resource the object provides. For example, virtual local area networks (VLANs) provide greater network performance and improved manageability by being separated from the physical hardware. Likewise, storage area networks (SANs) provide greater flexibility, improved availability, and more efficient use of storage resources by abstracting the physical devices into logical objects that can be quickly and easily manipulated. Our focus, however, will be on the virtualization of entire computers.

If you are not yet familiar with the idea of computer virtualization, your initial thoughts might be along the lines of *virtual reality*—the technology that, through the use of sophisticated visual projection and sensory feedback, can give a person the experience of actually being in that created environment. At a fundamental level, this is exactly what computer virtualization is all about: it is how a computer application experiences its created environment.

The first mainstream virtualization was done on IBM mainframes in the 1960s, but Gerald J. Popek and Robert P. Goldberg codified the framework that describes the requirements for a computer system to support virtualization. Their 1974 article “Formal Requirements for Virtualizable Third Generation Architectures” describes the roles and properties of virtual machines and virtual machine monitors that we still use today. The article is available for purchase or rent at [dl.acm.org/citation.cfm?doid=361011.361073](http://dl.acm.org/citation.cfm?doid=361011.361073). By their definition, a virtual machine (VM) can virtualize all of the hardware resources, including processors, memory, storage, and network connectivity. A virtual machine monitor (VMM), which today is commonly called a *hypervisor*, is the software that provides the environment in which the VMs operate. Figure 1.1 shows a simple illustration of a VMM.

Some examples of virtual reality in popular culture are in *The Matrix*, *Tron*, *Ready Player One*, and *Star Trek: The Next Generation*. Facebook recently renamed its company to Meta, and in 2021 revealed plans to build its Metaverse, a collection of digital worlds or spaces for everything from work-related experiences to immersive education to shopping to virtual reality gaming.



**FIGURE 1.1** A basic VMM

According to Popek and Goldberg, a VMM needs to exhibit three properties to correctly satisfy their definition.

**Fidelity** The environment it creates for the VM is essentially identical to the original (hardware) physical machine.

**Isolation or Safety** The VMM must have complete control of the system resources.

**Performance** There should be little or no difference in performance between the VM and a physical equivalent.

Because most VMMs have the first two properties, VMMs that also meet the final criterion are considered *efficient* VMMs. We will go into these properties in much more depth as we examine hypervisors in Chapter 2, “Understanding Hypervisors,” and virtual machines in Chapter 3, “Understanding Virtual Machines.”

Let’s go back to the virtual reality analogy. Why would you want to give a computer program a virtual world to work in anyway? It turns out that it was necessary. To help explain that necessity, we should review a little history. It would be outside the scope of this text to cover all the details about how server-based computing evolved, but for our purposes, we can compress it to a number of key occurrences.

## Microsoft Windows Drives Server Growth

Microsoft Windows was developed during the 1980s primarily as a personal computer operating system. Others existed, such as Digital Research’s CP/M and IBM’s OS/2, for example, but as you know, Windows eventually dominated

Between the late 1970s and mid-1980s, there were more than 70 different personal computer operating systems.

the market, and today it is still the primary operating system deployed on PCs. During that same time frame, businesses were depending more and more on computers for their day-to-day operations. Companies moved from paper-based records to running their accounting, human resources, and many other industry-specific and custom-built applications on mainframes or minicomputers. These computers usually ran vendor-specific operating systems, making it difficult, if not impossible, for companies and IT professionals to easily transfer information among incompatible systems. This led to the need for *standards*, agreed upon methods for exchanging information, but also the idea that the same, or similar, operating systems and programs should be able to run on many different vendors' hardware. The first of these was Bell Laboratories' commercially available Unix operating systems.

Companies had both Windows-based PCs and other operating systems in-house, managed and maintained by their IT staffs, but it wasn't cost effective to train IT staffs on multiple platforms. With increasing amounts of memory, faster processors, and larger and faster storage subsystems, the hardware that Windows could run on became capable of hosting more powerful applications that had in the past primarily run on minicomputers and mainframes. These applications were being migrated to, or being designed to run on, Windows servers. This worked well for companies because they already had Windows expertise in house and no longer required multiple teams to support their IT infrastructure. This move, however, also led to a number of challenges. Because Windows was originally designed to be a single-user operating system, a single application on a single Windows server ran fine, but often when a second program was introduced, the requirements of each program caused various types of resource contention and even outright operating system failures. This behavior drove many companies, application designers, developers, IT professionals, and vendors to adopt a "one server, one application" best practice; so for every application that was deployed, one or more servers needed to be acquired, provisioned, and managed.

Current versions of Microsoft Windows run concurrent applications much more efficiently than their predecessors.



Another factor that drove the growing server population was corporate politics. The various organizations within a single company did not want any common infrastructure. Human Resource and Payroll departments declared their data was too sensitive to allow the potential of another group using their systems. Marketing, Finance, and Sales all believed the same thing to protect their fiscal information. Research and Development also had dedicated servers to ensure the safety of their corporate intellectual property. Because of this proprietary ownership attitude, companies sometimes had redundant applications, such as four or more email systems, maybe from different vendors. By demanding solitary

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