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# Developing and Deploying .NET Applications on AWS

**AWS Whitepaper**



## **Developing and Deploying .NET Applications on AWS: AWS Whitepaper**

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# Developing and Deploying .NET Applications on AWS

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## Abstract

Developing and deploying .NET applications on Amazon Web Services (AWS) is a key activity to help organizations achieve the scale and agility offered by cloud computing. It is the standard application development framework for Microsoft Windows, and its growing ecosystem of applications runs on Linux and other platforms,

This whitepaper introduces the AWS tools and services that are directly suited for .NET development and deployment. It serves as a starting point for .NET architects and developers who wish to develop, build, deploy, and maintain their applications on AWS. It describes the approaches that can be used to deploy .NET applications on AWS, and details the options, choices, and services that can help readers get the most business value from their cloud-based .NET workloads.

# Introduction

Whether you're migrating legacy .NET Framework applications or creating modern microservices using .NET Core/.NET 5, AWS offers a wide range of end-to-end services, tools, and solutions for application development, deployment, and maintenance. AWS is a preferred platform to run traditional and modern .NET applications.

Rapid and continuous development and deployment of applications are critical aspects of providing modern organizations with new and innovative services, while helping them to maintain and operate their existing capabilities. .NET has been the standard for Windows since it was first released by Microsoft. With the release of .NET Core and .NET 5, it is used for a variety of cross-platform workloads.

.NET applications depend on environments to execute in, and require a plethora of additional services, including, but not limited to:

- Relational databases
- Queuing middleware
- Authentication and authorization services
- File storage
- Networking
- Caching

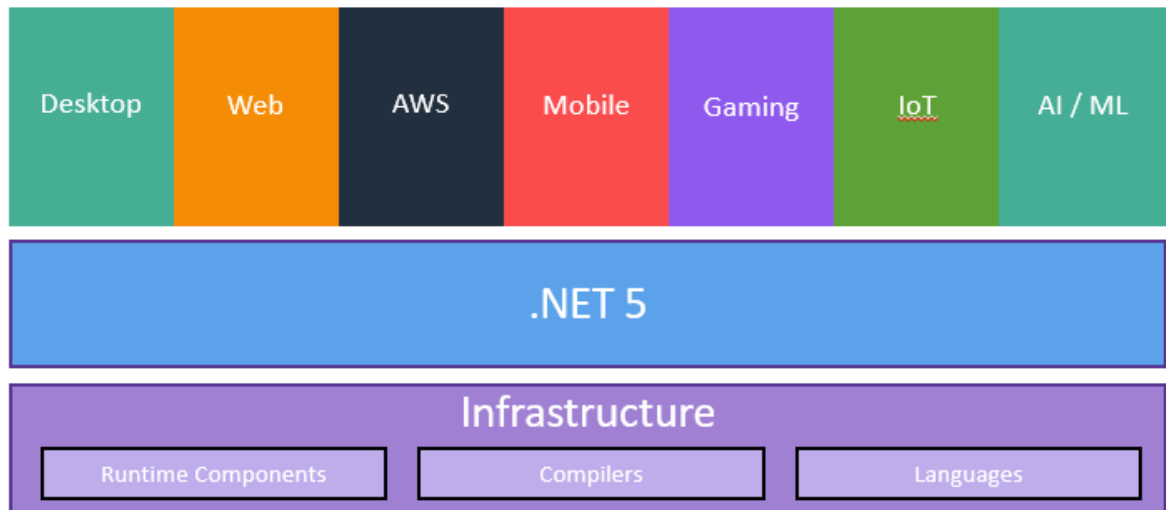
.NET also includes a variety of operational monitoring and logging services.

AWS provides a reliable, scalable, and global infrastructure platform with a broad set of global cloud-based services. With over 200 services that can be provisioned quickly without upfront capital expenses, AWS provides the ideal environment to deploy existing .NET applications and create new, modern, and innovative .NET applications.

This whitepaper focuses on the key AWS Services for developing and deploying .NET applications. For information on the full range of services, refer to the homepage on the [AWS website](#).

## Working with .NET

With the release of .NET 5, .NET is working to provide a uniform runtime to customers, allowing access to a single set of APIs, tools, and languages to target multiple platforms such as mobile, Internet of Things (IoT), and the cloud. The .NET Framework no longer receives any new features or updates, although it continues to be included in the Windows operating system. Although previous runtimes will continue to be supported for a while, both .NET Framework and .NET Core developers can now move on to use .NET 5 for new applications.



*.NET 5 unified runtime*

## .NET Core / .NET 5

.NET 5 is a modern, open-source, cross-platform implementation of .NET, and runs on Windows, Linux, macOS, and other devices. .NET 5 is the evolution of .NET Core. Although .NET Core provided many of the same interfaces and method signatures as the .NET Framework, there were a variety of differences, making it potentially difficult to migrate applications from the .NET Framework to .NET Core. However, .NET 5 removes most of those differences and has made it possible to unify those legacy platforms.

As the next generation after .NET Core, .NET 5 is now the recommended platform for modern scalable and high-performance applications, and, unlike .NET Framework, its design makes it ideal for targeting microservices architectures. You can run .NET 5 applications on AWS as direct deployments on Windows or Linux EC2 instances, on Windows or Linux containers running on EC2 instances, serverless Linux containers running on [AWS Fargate](#), or serverless [AWS Lambda](#) functions. These services are discussed in more detail in later sections of this whitepaper.

Going forward in this whitepaper, whenever .NET 5 is mentioned, the same statements also apply to .NET Core. We explicitly call out any differences for .NET 5 and .NET Core use.

# Running .NET Applications in the AWS Cloud

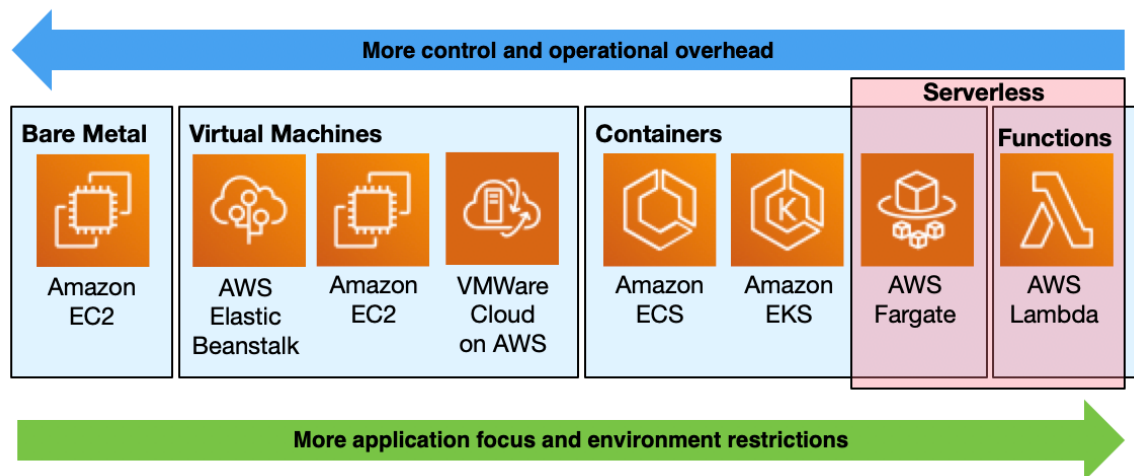
The AWS Cloud provides a number of benefits, including elasticity, scalability, and flexibility, but many legacy applications were designed with the server hardware and infrastructure as critical aspects of the application's design.

Architects and software engineers had little choice but to shape .NET applications into existing deployment environments, which generally involved a fixed set of resources that often needed to be shared across a number of applications or services.

For the many legacy .NET applications, the most suitable compute choice for running applications in AWS is using virtual machines, using either [AWS Elastic Beanstalk](#) or [Amazon Elastic Compute Cloud](#) (Amazon EC2). In some cases, it's also possible to run .NET applications in Windows containers, and you can also run .NET applications on Amazon EC2 bare metal instances, either by running directly on the Windows OS of the host instance, or by [running Hyper-V](#) on the instance.

In contrast, with the advent of .NET Core, modern .NET Core applications can be designed to take advantage of all the cloud benefits. Modern applications can use the traditional set of compute choices, and also target various types of serverless environment, including AWS Fargate or AWS Lambda.

.NET 5 now also allows performant hosting of workloads on [ARM64](#) EC2 instances such as the [Graviton2](#) EC2 families. This enables access to the latest generation of processors available on Amazon EC2, meaning your applications can be hosted on compute specialized to your workload type, such as video encoding, web servers, and high-performance computing (HPC).



## *AWS deployment targets for compute workloads*

For new applications, consider serverless options for innovative and highly-elastic workloads, and then consider the various container options or virtual machines when there are specific dependencies on the environment or when more precise control over the infrastructure is needed.

For legacy .NET applications, virtual machines are often considered the natural choice, although the integration of [Docker with Windows](#) means the use of containers is increasingly common. Containers have a number of benefits, including immutable deployment and improved resource utilization.

Subsequent sections cover each of these compute choices in more detail. However, prior to choosing a compute environment, you must choose an operating system for hosting an application, and choose a suitable architectural style.

## Choosing a Host Operating System

Although Windows remains the natural choice for legacy applications using the .NET Framework, the cross-platform nature of .NET 5 means Linux is now an equally viable choice for new and future .NET applications. One of the challenges in choosing an OS is that they have broadly reached a state of commoditization. The current focus on OS evolution is largely about increased efficiency of resource use, as shown by the growing popularity of containers, and the future lure of library operating systems.

Another factor driving the choice of OS is the current architectural wisdom to explicitly declare and isolate dependencies, as promoted by the [12-factor app](#) approach, which also aligns to the [single process model of containers](#). Given the rich set of services built into Windows, it is common for legacy .NET Framework applications to implicitly depend on a variety of services, such as [Active Directory](#) for authentication and authorization, [COM+](#) for distributed transaction processing, or [Distributed File System](#) (DFS) for file sharing. However, with the move toward explicitly declaring and isolating such dependencies, relying on Windows' intrinsic features no longer holds the lure for .NET applications that it once did.

.NET 5 also makes it possible to avoid licensing cost and implications of the Windows operating system. .NET applications liberated from underlying operating system (OS) license restrictions can easily scale in and out to address contemporary IT demands.

## Building Monoliths or Microservices

One of the most common ways to build enterprise applications is as a single, unified application, in which all components are tightly coupled, and working from a shared database. When the .NET Framework was released, such monolithic applications were widespread. Even today it's not uncommon to see ASP.NET applications with over 100,000 lines of code that have to be deployed to a single internet information service (IIS) instance.

As enterprise applications grew bigger, new challenges emerge out of this approach. The first problem is managing the resources available to an application. As monolithic applications grow bigger, they invariably require more resources, from compute and memory requirements to storage and network bandwidth. Although these issues can be solved by scaling the application servers vertically up or horizontally out, this approach naturally scales the whole application, even if a single module needs the additional resources.

The second problem is complexity. Monolithic applications with tightly coupled modules grow increasingly complex over time, which can make maintenance so complicated that even the smallest changes require significant effort for development, testing, and deployment. The increasing complexity adds friction to the business need for agility.

Because of the challenges inherent in monolithic applications, many modern applications have shifted to a new paradigm, commonly known as a *microservices architecture*. Microservices are small services providing a bounded context of functionality, each using their own data store, and predominantly integrating with other services by using event-driven communication.

Although microservices introduce their own complexities, such as how to separate data or how to distribute services, breaking monolithic applications into loosely coupled microservices can help overcome many of the problems with monolithic applications. Aside from the architectural benefits of microservices, the loose coupling in microservices means each service can be deployed and scaled

independently. By ensuring each microservice has its own development lifecycle, DevOps teams are no longer tied to other team's release cycles, and can therefore increase their deployment frequency, improving their agility, and increasing the business's ability to respond to change.

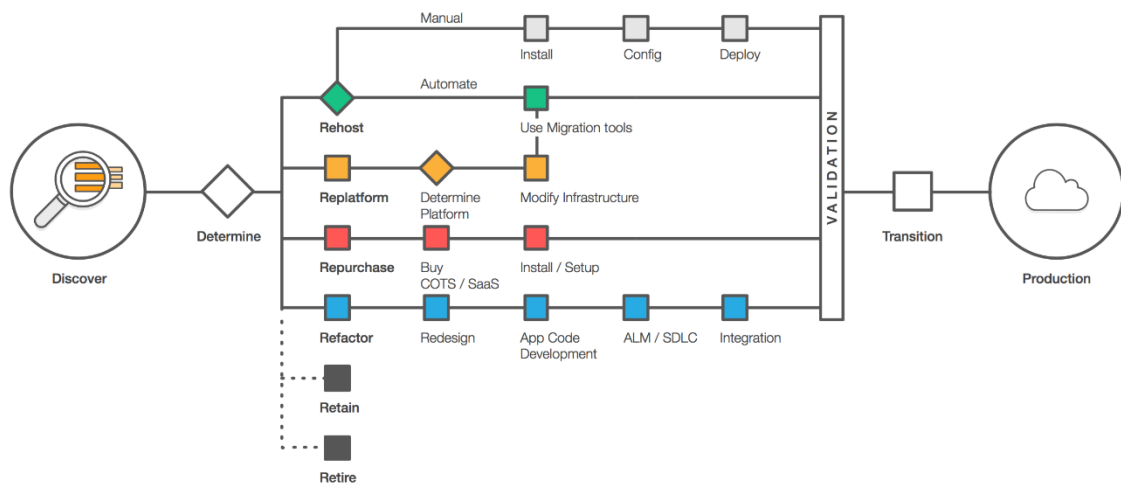
Although .NET 5 can be used for a variety of application architectures, its lighter footprint and cross-platform nature makes it ideal for microservices. .NET 5 is also highly suitable for deploying to modern execution environments, including containers and serverless functions.

The following sections of this paper include several ways you can deploy both monolithic and distributed applications in the AWS Cloud. Monolithic deployment patterns are mostly applicable for legacy enterprise applications, or for developing new applications with limited complexity or scaling requirements, whereas microservices are commonly chosen for building optimized modern applications.

For more information on how to design and develop microservices, see the [Implementing Microservices on AWS](#) whitepaper.

## Migrating and Rehosting .NET Applications

When migrating any type of application to AWS, including legacy .NET Framework applications, there are a number of different approaches. These approaches are known as the [six Rs of migration](#).



### *Six Rs of migration*

Although there are reasons to modernize applications by re-platforming or refactoring, including optimizing or adding new features, the simplest way to migrate .NET applications to AWS is to rehost the applications using either AWS Elastic Beanstalk or Amazon EC2.

## AWS Elastic Beanstalk

In many cases, you may not require full control over the underlying infrastructure used for hosting an application and may prefer a managed environment, which enables you to focus on the application and simply deploy application updates when needed.

[AWS Elastic Beanstalk](#) is the fastest and simplest way to deploy .NET applications on AWS. As a .NET developer, With AWS Elastic Beanstalk, you can continue using your favorite programming languages with .NET Framework or .NET 5. When you've completed developing your application on your computer, your application will be ready within minutes to use without any infrastructure or resource configuration work.

The key advantage of this model is that it's not too different from the way most existing and legacy applications work. It can be an excellent option to maximize the benefits of deploying legacy applications in the cloud, without a significant migration overhead.

For example, you can take an existing ASP.NET web application that uses IIS and move it into AWS Elastic Beanstalk. You can use [Windows Web Application Migration Assistant](#) to quickly select the application, and allow the tool to handle the rest of migration process, including packaging, creating the Elastic Beanstalk environment, and uploading the application package into it.

AWS Elastic Beanstalk provisions, operates, maintains, scales, monitors, heals, updates, and patches Windows and IIS for you, enabling you to focus on your application code rather than its operating environment. AWS Elastic Beanstalk also gives you complete control over your application resources, so you can seamlessly make changes to the way your applications run inside the AWS Elastic Beanstalk environment. For .NET 5 applications, Elastic Beanstalk gives you the choice of running your code on either Windows or Linux.

To get started with AWS Elastic Beanstalk, you create environments for your application, such as Dev, Test, or Production. Every time you make an application change, you compile and package your new build and upload it as a new application version in your Elastic Beanstalk application. This enables you to deploy any application versions across your application environments with a few clicks.

You can also choose to deploy one or more applications in each of your AWS Elastic Beanstalk environments, using [deployment manifests](#) to configure multiple applications to run in each IIS web server. It also enables you to control application pools associated with your web applications in IIS, which makes it possible to host multiple applications with a shared application pool, or assign dedicated application pools to each application.

You can further customize and configure your web server in Elastic Beanstalk using [configuration files](#), which let you install additional software packages, files, windows services, or other dependencies your application needs to run.

Elastic Beanstalk also supports several [deployment options](#), including:

- All at once
- Rolling
- Rolling with additional batch
- Immutable

Through integration with [Amazon Route 53](#), Elastic Beanstalk supports environment URL swapping, which makes it easy to implement a blue-green deployment model.

There are no additional costs associated with using Elastic Beanstalk, and you pay only for the underlying resources used to run your application, such as the EC2 instances, load balancers, and any [Amazon Relational Database Service](#) (Amazon RDS) database instances.

Elastic Beanstalk can help you quickly move your .NET applications to AWS with minimal changes. If you need more control of the underlying infrastructure, using Amazon EC2 virtual machines enables you to fine tune your infrastructure configuration.

## Amazon Elastic Compute Cloud (EC2) Instances

Amazon EC2 provides a flexible compute service with a wide variety of virtual machines and [bare metal](#) instance types.

AWS is responsible for operating all levels up to hypervisor and host OS, giving you full access and control over the guest operating system. AWS also provides tools, features, and services that enable you to create a fully automated and self-managing infrastructure, such as [AWS Auto Scaling](#) and [AWS](#)

[Systems Manager](#). You are responsible for patching, updating, securing, and maintaining the Windows or Linux OS, application server, web server, and any application code, either using AWS-provided tools or features, or any other custom methods. Because you have full control of your environment, you also have complete flexibility to configure your environment as needed. For example, you may want to use [Nginx](#) or [Apache HTTP Server](#) instead of IIS as your web server.

Amazon EC2 instances provide the highest level of flexibility and control in the cloud. This flexibility often proves essential for legacy applications, but can also be useful for many modern applications. You have the choice of x86 (32-bit), x64 (64-bit), and Arm-based platforms in Amazon EC2. You also have access to most popular Linux versions and all Windows Server versions, from Windows Server 2008 to Windows Server 2019. For modern Windows applications, you can also use Semi-Annual Channel Windows releases, including 1709, 1803, 1809 and 1903.

For any of these, you can choose from [Amazon Machine Images](#) (AMIs) provided by AWS, numerous community and AWS Partner AMIs available in the [AWS Marketplace](#), or you can create or import your own images.

You can also benefit from various features such as automatic scaling, self-healing, and deep integration with other services, such as [AWS Identity and Access Management](#) (AWS IAM), [AWS Key Management Service](#) (AWS KMS), or [Amazon Elastic Block Storage](#) (Amazon EBS).

There are a variety of ways you can deploy your .NET applications on Amazon EC2 instances, from manual deployments to using Infrastructure as Code with [AWS CloudFormation](#) templates and Continuous Integration / Continuous Deployment pipelines.

## AWS Systems Manager

[AWS Systems Manager](#) is a service for hybrid and cross-platform infrastructure management. Although it is designed to help system administrators maintain their infrastructure resources, some of its capabilities are also useful for developers and DevOps engineers.

One of the most basic application requirements is the need for configuration variables; for example, an external service's URL, or a database connection string. A common practice is to store these variables in an app.config or web.config configuration file, or to store them in environment variables. However, this requires updating the configuration on all the application servers, which requires a significant effort when working with a multi-server environment. The AWS Systems Manager [Parameter Store](#) provides the alternative of a centralized location for storing configuration variables, allowing configuration values to be updated in a single place and retrieved by all application instances.

Another common use case handled by Systems Manager is the ability to run a particular command or script on multiple servers. For example, you may have a simple PowerShell cmdlet to delete files from a local application cache. One way to run the command is to open a Remote Desktop Protocol (RDP) session to the target servers and manually run the command. However, if the command must run on dozens, hundreds, or even thousands of servers, this approach becomes impractical. Fortunately, you can use the AWS Systems Manager [Run Command](#) to securely run the command at any scale.

You can also use AWS Systems Manager [State Manager](#) for handling drift-management and ensuring compliance of your target server configurations. State Manager supports [PowerShell Desired State Configuration](#) (DSC) and enables you to use DSC [Managed Object Format](#) (MOF) files to define your desired state using declarative language. For example, you can specify the installed state of [Windows Communication Foundation](#) (WCF) as the desired state on a server, and DSC will ensure WCF is installed. AWS Systems Manager augments PowerShell DSC through integration with [Parameter Store](#), [Amazon Simple Storage Service](#) (Amazon S3) and [Amazon CloudWatch](#).

For more details, see [this entry](#) on the [AWS Management Tools Blog](#).

Finally, you can use AWS Systems Manager [Automation](#) to simplify complex operations and define dynamic workflows that orchestrate invocation of AWS Systems Manager or any other AWS APIs in fully automated runbooks.

For example, you can define these steps in a document to update EC2 instances:

- Provision a new EC2 instance using an updated AMI
- Bootstrap the new instance and deploy the application in offline mode
- Shut down the old instance
- Switch the new instance into online mode

By specifying these steps in a Systems Manager Automation document, the steps can be saved as a reusable runbook, ensuring updates can be carried out consistently and shared between members of the development and operations teams.

## Modernizing and Re-platforming .NET Applications

With the push to unlock business agility by using modern development and operations practices known as DevOps, modern applications are increasingly designed for flexibility using the principles of evolutionary design and a variety of best practices.

From the use of immutable infrastructure to increase deployment consistency, to the use of automation, Continuous Integration (CI), and Continuous Deployment (CD) to speed up delivery, there are a growing number of practices that help deliver business value.

Although many of these approaches can be partially applied to traditional architectures, modern application architectures are evolving to best take advantage of these new development practices. With the AWS Cloud increasing the speed of evolution, now is the perfect time to design or re-platform .NET applications to align with modern practices.

### Porting Assistant for .NET

[Porting Assistant for .NET](#) is an analysis tool provided by AWS that scans .NET Framework applications and generates a .NET 5 compatibility assessment. .NET 5 is the future of .NET. New features and contributions will be available exclusively in .NET 5. .NET 5 applications are cross platform, and porting existing .NET Framework applications to .NET 5 gives you extra versatility and ability to run those applications on Linux to save cost and improve performance. In most cases, porting an application with the same code from .NET Framework to .NET 5 immediately yields significant performance gains.

However, porting applications to .NET 5 can be a significant manual effort. Application owners must spend valuable time identifying the dependencies and APIs that are incompatible with .NET 5, and estimating the level of effort involved. Porting Assistant for .NET quickly scans .NET Framework applications to identify incompatibilities with .NET 5, finds known replacements, and generates a detailed compatibility assessment. This reduces the manual effort involved in modernizing your applications to Linux. AWS Porting Assistant for .NET supports .NET Core 3.1 and .NET 5 as target.

## Running Applications in Containers

Containers allow applications to be bundled with their own libraries and configuration files, and then executed in isolation on a single OS kernel, bringing a number of benefits, including:

- **Isolation and high-density** — Containerization ensures application isolation in terms of security and data access, and as resource allocation. It's a reliable solution to run multiple tasks or applications on the same host. This approach enables you to maximize overall resource utilization and minimize idle capacity, also known as a "high-density" deployment.
- **Runtime packaging and seamless deployment** — Containers include application code or binaries along with all the dependencies needed to keep the application running. This approach ensures

the application behaves consistently in all environments, from a developer laptop to a production environment. It also simplifies migrating applications from one host to another.

- **High availability (HA)** — Container orchestrators provide an abstraction layer on top of conventional hosting environments and keep track of running containers. You don't have to run applications, just tell the orchestrator which applications are expected to run. The orchestration engine keeps track of the existing state, evaluates it against the expected state, and corrects as needed. If an application goes down, the orchestrator immediately spins up another container to run your application in the next available host.
- **Resource management for distributed systems** — Containerization is an effective approach to run microservices and other types of distributed systems. The deployment abstraction provided by containers enables you to focus on your applications rather than their dependencies with underlying hosts and infrastructure.

The following sections discuss the four container services available in AWS.

## Amazon Elastic Container Service

[Amazon Elastic Container Service](#) (Amazon ECS) is a highly scalable and high-performance container orchestration service. It was natively developed in AWS, and offers deep integration with AWS services such as [Elastic Load Balancing](#), [Amazon Virtual Private Cloud](#) (Amazon VPC), [IAM](#), [AWS Batch](#), and [Amazon CloudWatch](#).

Amazon ECS is suitable for a broad range of containerized applications, from long-running applications and microservices to batch jobs and High-Performance Computing workloads, and supports both Linux and Windows containers. Linux containers are available in Amazon Linux and other Linux distributions, and Windows containers are available in Windows 2016 and later.

To use Amazon ECS, you can either use one of the prebuilt Amazon ECS optimized AMIs to spin up a cluster of host instances, or build your own AMIs by adding the Amazon ECS container agent to an existing or custom-built EC2 host.

For more information on running Windows containers on ECS, see [this entry](#) on the [AWS Compute Blog](#).

## Amazon Elastic Kubernetes Service

[Amazon Elastic Kubernetes Service](#) (Amazon EKS) is one of the most popular open-source orchestration engines for containerized workloads. Amazon EKS enables you to run containerized applications using the same toolset on-premises and in the cloud.

Amazon EKS enables you to deploy, manage, and scale containerized applications using Kubernetes on AWS by managing clusters of Amazon EC2 instances, and running containers on those instances. Amazon EKS provides a management plane for a highly available Multi-AZ Kubernetes cluster, which you can join to your additional worker nodes as EC2 instances.

Because Linux containers are available in all versions of Kubernetes, you can run .NET Core applications on any version of it. In contrast, Windows containers are only available starting with Kubernetes 1.14, and they are supported only in Windows 2019 and later.

## Amazon Elastic Container Registry

[Amazon Elastic Container Registry](#) (Amazon ECR) is a fully-managed, highly-available and secure [Docker](#) container registry that helps developers store, manage, and deploy Docker container images.

Amazon ECR is integrated with other AWS services, such as AWS IAM, and provides a repository to store container images which you can use from Amazon ECS, AWS Fargate, and Amazon EKS.

## AWS Fargate

[AWS Fargate](#) is a serverless compute engine for Amazon ECS and EKS that abstracts away details of the underlying host infrastructure such as the instance types, instance sizes, and host OS version.

By letting you focus on designing and building your applications and removing the need to manage the underlying infrastructure, AWS Fargate can help reduce the operational overheads of using containers.

AWS Fargate supports Linux containers and is a powerful option for running .NET 5 applications. For details, see [this entry](#) on the [AWS Compute Blog](#).

### AWS App2Container (A2C)

[AWS App2Container](#) is a tool provided by AWS to help you modernize .NET and Java applications into containerized applications. Containerizing existing applications requires you to identify application dependencies, network port configurations, and software delivery process. These tasks can be manual, time consuming, and error prone.

Using App2Container, you simply select the applications you want to containerize, and A2C analyzes your applications and automatically generates a container image that is configured with the correct dependencies, network configurations, and deployment instructions for ECS or Kubernetes. A2C provisions, through CloudFormation, the cloud infrastructure and [CI/CD](#) pipelines required to deploy the containerized .NET or Java application into production.

## Creating Serverless Applications with AWS Lambda

Containers provide a high level of flexibility; however, you still need to manage your container images, including the guest OS and any application dependencies.

For example, suppose you need to deploy an ASP.NET Core application. In addition to the application, the container image must also include a choice of guest OS, the .NET Core runtime library, the ASP.NET [Kestrel](#) engine, and a web server such as [Nginx](#) or Apache. Although this gives you more control over your runtime environment, it also means additional undifferentiated efforts, and in most cases this level of control is not required.

[AWS Lambda](#) solves this problem by providing a serverless Function-as-a-Service (FaaS) model, which automatically manages the underlying compute resources for you. C# code can be uploaded into a Lambda function, and everything else is handled by Lambda.

Lambda provides the highest level of abstraction, simplicity, efficiency and scalability for running .NET code in the cloud. It is simple because it allows developers to run their code without having to worry about the infrastructure that runs it; efficient because there is no charge when the code is not running; and scalable because it seamlessly handles load fluctuations. Lambda supports many popular programming languages, including C# and PowerShell. Lambda already includes .NET Core 2.1 and 3.1 as managed runtime environments. You can also run .NET 5 applications on Lambda using an event-driven [custom container image](#) as your function, or using [custom runtimes](#).

Lambda functions are often deployed behind API instances in [Amazon API Gateway](#), which provide managed endpoints that act as front doors for consuming applications to access data or backend functionality. API Gateway handles all the tasks involved in accepting and processing up to hundreds of thousands of concurrent API calls, including traffic management, authorization and access control, monitoring, and API version management. API Gateway can also be used with workloads running on EC2 instances or ECS tasks.

When you don't need the governance features API Gateway offers, you can deploy Lambda functions behind an Application Load Balancer (ALB), which allows load to scale elastically without having to maintain a set of managed APIs.

For more information on how to create applications using AWS Lambda, see the [Serverless Architectures with AWS Lambda](#) whitepaper.

## Load Balancing .NET Applications on AWS

Load balancing is a common problem for building and deploying scalable applications. AWS provides a variety of solutions for load balancing. Each solution is optimized to address a specific set of requirements.

- **Application Load Balancer (ALB)** is best suited for load balancing of HTTP and HTTPS traffic, and provides advanced request routing targeted at the delivery of modern application architectures, including microservices and containers. Application Load Balancer routes traffic to targets within the [Amazon Virtual Private Cloud \(Amazon VPC\)](#) based on the content of the request. AWS ALB also supports end-to-end HTTP/2 and [gRPC](#), with health-check on target endpoints. This is a popular solution for microservice integration and client-server communications. For more information, see [this blog post](#).
- **Network Load Balancer (NLB)** is best suited for load balancing of Transmission Control Protocol (TCP), User Datagram Protocol (UDP), and Transport Layer Security (TLS) traffic where extreme performance is required. Network Load Balancer routes traffic to targets within the Amazon VPC, and is capable of handling millions of requests per second while maintaining ultra-low latencies.
- **Gateway Load Balancer** makes it easy to deploy, scale, and run third-party virtual networking appliances. Providing load balancing and auto scaling for fleets of third-party appliances, Gateway Load Balancer is transparent to the source and destination of traffic. This capability makes it well suited for working with third-party appliances for security, network analytics, and other use cases.

## Storage Solutions for .NET Applications on AWS

Most applications need various storage requirements, such as relational or NoSQL databases, flat files, object storage, block storage, or various types of in-memory cache tiers. .NET applications are no exception and depending on their functionalities, may require one or more of these solutions.

AWS includes a number of purpose-built relational database services, such as [Amazon Relational Database Service \(Amazon RDS\)](#), [Amazon Aurora](#), and [Amazon Redshift](#), the fastest growing cloud data warehouse service. Amazon RDS supports popular open-source engines (MySQL, PostgreSQL, and MariaDB), as well as commercial engines (Microsoft SQL Server and Oracle). You can run these or any other engine on Amazon EC2 instances.

There are a number of specialized databases, including [Amazon DynamoDB](#) for key-value and document storage, [Amazon Neptune](#) for graph data, [Amazon Quantum Ledger Database](#), and [Amazon Managed Blockchain](#).

.NET applications can use [Amazon S3](#) for object storage, and [Amazon EFS](#) for Linux-based shared file systems, or [Amazon FSx for Windows](#) file shares.

Finally, [Amazon Elastic Block Storage](#) is an easy to use, high performance block storage service designed for use with Amazon EC2 for both throughput and transaction intensive workloads at any scale.

You can build extremely high-performance .NET applications using elasticity and flexibility of managed AWS services for in-memory caching, such as [Amazon ElastiCache](#) for [Redis](#) and [Memcached](#), or [Amazon Elasticsearch Service](#).

## Artificial Intelligence and Machine Learning with .NET

Artificial Intelligence (AI) and Machine Learning (ML) are increasingly used to solve new types of problems, and are becoming fundamental parts of many modern applications.

AWS provides a rich set of services that aim to put AI and ML in the hands of every developer. You can either choose from a set of pre-trained AI services, including computer vision, language, recommendations, and forecasting, or you can build, train and deploy custom models with support for all the popular open-source frameworks.

[Amazon Rekognition](#) allows you to add image and video analysis to your applications, and can identify objects, text, and activities, and can also be used for facial recognition.

There are a number of services for working with language, allowing you to easily add intelligence and process natural language in your .NET applications. [Amazon Transcribe](#) automatically converts speech to text, making it simple to enable speech in your applications. [Amazon Textract](#) extracts text from scanned documents, after which you can use [Amazon Comprehend](#) to find insights or relationships in text, helping you to extract key phrases, classify text, or analyze sentiment. [Amazon Translate](#) enables you to translate text between more than 25 languages, and helps you build .NET applications that can localize content.

[Amazon Polly](#) turns text into lifelike speech, and [Amazon Lex](#) enables you to build conversational interfaces and chatbots into any application using voice and text. Amazon Lex can recognize the intent from a piece of text, enabling you to orchestrate a conversation and build applications with highly engaging user experiences.

[Amazon Personalize](#) enables you to enhance your applications with real-time personalization and recommendations, by working with an activity stream from your application, identifying what is meaningful, and helping you serve personalized content to users.

Finally, [Amazon Forecast](#) is an accurate time-series forecasting service, allowing your application to process historical time-series data and to produce meaningful forecasts based on trends in the data.

Although the pre-trained AI services enable you to enhance your .NET applications with a rich set of capabilities, you can also build your own machine learning models. [Amazon SageMaker](#) is a managed service that enables developers and data scientists to quickly build, train, and deploy machine learning models. Using the AWS .NET SDK, you can set up, configure, and execute Amazon SageMaker jobs, enabling you to push new ML boundaries.

Access from .NET applications to all the pre-trained services and to Amazon SageMaker is available through the [AWS SDK for .NET](#).

# Developing .NET Applications

One of the fundamental requirements when developing .NET applications to run or integrate with AWS Services is having easy-to-use tools to help access the services, integrate with the development workflow and tooling, and enable higher levels of developer productivity.

Choosing the right tools depends on numerous factors, including development approach, team composition, and organizational standards. AWS provides a rich set of tools that can be used together or alone to help .NET developers make the most of the services.

## AWS .NET SDKs

One of the great advantages AWS offers over traditional, on-premises resources is that its services can be accessed through REST APIs, enabling integration from any programming or scripting environment capable of stringing together HTTPS requests and sending them over the internet.

Although REST APIs are flexible, it's easier for developers to work in their native language than to work with REST APIs, and the [AWS SDK for .NET](#) helps developers get started quickly by providing native .NET APIs to the AWS Services. Calling an AWS Service is as easy as calling a method on an object using the SDK.

The AWS SDK for .NET is distributed as multiple [NuGet](#) packages, and contains assemblies for .NET Standard 2.0, .NET Framework 3.5, and .NET Framework 4.x.

As the standard for .NET package management, NuGet is the preferred option for installing the SDK, and provides a number of service-specific packages, such as [AWSSDK.EC2](#) or [AWSSDK.S3](#), each of which depends on the [AWSSDK.Core](#) package, which is automatically installed when you reference a service package in the NuGet Package Manager.

If you're working with older versions of .NET that don't support .NET Standard 2.0, then the versions of the SDK prior to v3.5 also contain Portable Class Library assemblies, and the [AWS Mobile SDK for Unity](#) and [AWS Mobile SDK for .NET and Xamarin](#) are available for older versions of Unity and Xamarin.

## AWS Toolkit for Visual Studio

The AWS Toolkit for Visual Studio is a plugin for Visual Studio that makes it easier to develop, debug, and deploy .NET applications that use AWS.

The toolkit is available from the Visual Studio Marketplace and supports Visual Studio 2017 and 2019.

You can use NuGet to include the AWS SDK for .NET in your projects, so you can get started building .NET applications on AWS infrastructure services in Visual Studio, including Amazon S3, Amazon EC2, AWS Elastic Beanstalk, and [Amazon DynamoDB](#).

The toolkit allows you to create, configure, edit, or query resources in your AWS account, directly from within Visual Studio and without having to visit [AWS Management Console](#) or use any other secondary tool.

The toolkit contains a rich set of features that help configure and deploy new solutions, and can be broken down into a number of core features, most of which are available from the **AWS Explorer** in Visual Studio's **View** menu. For example, you can use Visual Studio to build a CloudFormation template (Infrastructure as Code) with the convenience of IntelliSense and deploy to AWS with AWS CloudFormation. The AWS Toolkit for Visual Studio also includes project templates for Lambda

functions, CloudFormation templates and sample projects showing how to use various AWS Services. It also makes it easy to deploy your applications into AWS runtime platforms, such as Elastic Beanstalk, Lambda and API Gateway, and ECS containers.

## AWS Toolkit for Visual Studio Code

Software development teams working on codebases written in multiple programming languages and for multiple platforms increasingly choose Visual Studio Code as their Integrated Development Environment (IDE), due to its flexibility and low resource requirements.

The [AWS Toolkit for Visual Studio Code](#) is an open-source plug-in for Visual Studio Code that helps developers get started faster and provides an integrated experience for developing, deploying, and testing serverless applications.

## AWS Toolkit for Rider

[Rider](#) is .NET IDE created by [JetBrains](#). The [AWS Toolkit for Rider](#) is an open-source plug-in for the Rider IDE that makes it easier to create, debug, and deploy .NET applications on AWS. The plugin is open-source and makes it easier for developers to develop, debug, and deploy serverless applications that use AWS.

Using the AWS Toolkit for Rider, you can select a quick start serverless application template to initially scaffold your code. After you develop an application, you can use the tool to your serverless application in a few clicks. It enables you to set breakpoints and debug serverless applications locally, and view and search for specific error codes or patterns from CloudWatch log streams.

## AWS Tools for PowerShell

PowerShell is a scripting environment built on .NET, and is widely used as the standard scripting tool on Windows, but is also available for MacOS, and Linux. Although primarily used for executing OS-level management scripts, PowerShell is frequently used by .NET developers as part of their build and deployment pipelines.

[AWS Tools for PowerShell](#) enables developers to directly access AWS Services from within PowerShell scripts, enabling them to manage and interact with AWS Services with their standard toolset, and removing the need to call the AWS SDK for .NET directly from within scripts.

### **AWS Tools for .NET CLI**

[These tool extensions](#) are focused on building .NET Core and ASP.NET Core applications and deploying them to AWS Services (AWS Elastic Beanstalk, Amazon ECS, and AWS Lambda). Many of these deployment commands are the same commands the AWS Toolkit for Visual Studio uses to perform its deployment features. This enables you to do initial deployment in Visual Studio, and then transition from Visual Studio to the command line and automate the deployment.

For example, with the AWS Lambda .NET CLI tool extension configured, you can deploy a Lambda function from the command line in the Lambda function's project root directory.

## Test Tools

Test automation plays a critical part in DevOps, and is the fundamental development practice that enables continuous integration and continuous delivery.

Many developers opt to run their integration tests in environments hosted in AWS. However, if you prefer to execute some tests locally, [AWS SAM Local](#) and the [AWS .NET Mock Lambda Test Tool](#) can help when developing Lambda functions. The [Localstack](#) project is an open-source tool that runs AWS APIs locally, and can be called directly from your test suites.

When creating mobile applications using [Xamarin](#), the [AWS Device Farm](#) gives access to a wide variety of physical phones and devices, providing an effective environment for testing Android and iOS applications.

# Continuous Integration and Continuous Delivery

Software development has always included a number of delivery activities, such as building and packaging new releases, testing release integration with other systems, and finally deploying new application releases in a production environment.

In the traditional delivery approach, when projects took months to deliver a functioning application, these activities were mostly manual. However, as the frequency of software delivery grows to multiple versions per week or per day, these undifferentiated activities become delivery bottlenecks.

Continuous Integration and Continuous Delivery are the combination of tools and techniques to help overcome these bottlenecks by automating the integration and delivery of applications.

## Infrastructure as Code

Modern deployment patterns require that applications, and the services and infrastructure and those applications depend on, can be provisioned and deployed reliably and consistently.

Given the complexity of deploying modern applications and infrastructure, doing so in a repeatable manner requires the deployment to be automated, and the practice and processes of automating infrastructure deployment are commonly known as Infrastructure as Code.

## AWS CloudFormation

[AWS CloudFormation](#) provides a declarative language that allows you to describe and provision all the infrastructure resources in your AWS Cloud environment.

Using a simple text file called an [AWS CloudFormation template](#), you can model resources across all [Regions](#) and accounts, with the file serving as the single source of truth for your cloud environment. By keeping CloudFormation templates along with your application code in the same code repository, you can ensure code changes are bundled together with infrastructure changes, ensuring integrity and enabling reliable deployment.

Templates can be written using [JavaScript Object Notation \(JSON\)](#) or [YAML](#). There are many predeveloped templates you can use as starting point, or you can create your templates from scratch.

You can use a variety of methods to deploy templates and provision resources, including the AWS Management Console, AWS Command Line Interface (AWS CLI), and PowerShell or the AWS SDK for .NET. You can also use the [AWS Toolkit for Visual Studio](#) to create and develop CloudFormation templates, with assistance of [Intellisense](#), and also directly deploy them into AWS from within the IDE.

A deployed version of a CloudFormation template is called a [CloudFormation stack](#). You can instantiate one or multiple stacks based on each CloudFormation template, and delete deployed stacks and all resources associated with them. AWS CloudFormation is a powerful way to quickly deploy, duplicate, provision or deprovision resources of your applications.

CloudFormation stacks are always deployed in a single AWS Account and Region, but you can use [CloudFormation StackSets](#) to deploy your templates across multiple AWS Accounts and Regions.

## AWS Cloud Development Kit (CDK)

Although CloudFormation provides a flexible mechanism to define cloud infrastructure as code, its use of declarative syntax is not well suited in all situations.

For infrastructure requiring a high number of interrelated services, or that is best defined using iteration, the resulting CloudFormation template can easily grow to hundreds or thousands of lines, which raises its own complications.

The [AWS Cloud Development Kit \(CDK\)](#) (AWS CDK) enables you to define cloud resources in various programming languages, including TypeScript, JavaScript, Python, C#, and Java. Developers use one of the supported languages to write code that defines reusable cloud components known as Constructs, which can then be composed into Stacks and Apps.

After you've defined an AWS CDK App, you can use the AWS CDK toolkit to synthesize a CloudFormation template, and then to deploy the defined resources to AWS.

Although using the AWS CDK adds an additional level of complexity to your Infrastructure as Code, by using an imperative language it allows you to work with high-level abstractions, rich logic, and enables the sharing of infrastructure definitions as reusable libraries of components.

## Using AWS Developer Tools

There are a number of services collectively known as the [AWS Developer Tools](#), which are designed to solve common DevOps requirements and provide development agility and continuous innovation.

You may already be using a CI/CD pipeline. Although you can continue using your favorite tools and easily integrate them with AWS Services, you can also use AWS developer tools to create a complete pipeline, or complement or extend the other tools you are using. Using AWS Developer Tools relieves you from managing infrastructure of your CI/CD pipeline tools, and helps you increase the efficiency and productivity of your infrastructure and developers.

## Version Control

Most .NET developers are familiar with GitHub repositories, and are well versed in using them to collaborate on software development projects.

Maintaining a Git repository for a single project is simple, but as the number of projects grows, managing a Git repository can become burdensome. You have to make sure your source control server is available all the time, its performance does not degrade, and its storage is scaled to cater for increasing demand.

[AWS CodeCommit](#) is a fully managed source control service that enables you to securely host private Git repositories in a highly scalable way. You can use AWS CodeCommit to store anything from your source code to other binaries and dependencies that go with your code. AWS Toolkit for Visual Studio integrates AWS CodeCommit.

For example, you might be developing an ASP.NET web application that also includes external DLL dependency files and several gigabytes of graphics and other multimedia files. Separating source code from binary files increases the risk of inconsistencies and bugs that have nothing to do with the code. Using AWS CodeCommit, you can store all of these in one repository and avoid such problems.

As an alternative to AWS CodeCommit, both [AWS CodeBuild](#) and [AWS CodePipeline](#) integrate with GitHub, and AWS CodeBuild also integrates with [Bitbucket](#).

## Build and Package Applications

Building the source code is one of the key steps in any CI/CD pipeline. Once a new version is committed in your source control system, you need a build service to pull the latest version, build and package it so the new version can be deployed in a target environment.

One way to do this is using build servers that you dedicate for this purpose. However, as the number of concurrent projects and number of builds in each project grows, these build servers have to be scaled out to provide more build capacity. Otherwise, your builds wait in a queue, which can result in decreased productivity of your developers.

[AWS CodeBuild](#) is a fully managed build service that compiles source code, runs tests, and produces software packages that are ready to deploy. It seamlessly scales and concurrently processes multiple builds, eliminating waiting time and increasing developer productivity. You only pay for time the build container is running.

AWS CodeBuild includes a pre-packaged build environment for .NET Core and/or .NET 5 on Linux and Windows. Alternatively, you can use pre-built Docker images such as official Microsoft images for the .NET, or create your own custom build environment by creating a Docker image.

For details about creating a custom build environment for .NET Framework, see [this entry](#) on the [AWS DevOps Blog](#).

Development teams often rely on both open-source software packages, and those packages are built within their organization. IT leaders must be able to control access to and validate the safety of these software packages. Teams need a way to find up-to-date packages that have been approved for use by their IT leaders. To address these challenges, IT leaders turn to central artifact repository services to store and share packages. However, existing solutions often require teams to purchase licenses for software solutions that are complex to set up, scale, and operate. You can use [AWS CodeArtifact](#) to overcome these challenges.

CodeArtifact is a pay-as-you go artifact repository service that scales based on the needs of the organization. With CodeArtifact, there is no software to update or servers to manage. In just a few clicks, IT leaders can set up central repositories that enable development teams to find and use the software packages they need. IT leaders can also approve packages and control distribution across the organization, ensuring development teams consume software packages that are safe for use.

CodeArtifact is a fully managed artifact repository service that enables organizations of any size to securely store, publish, and share software packages used in their software development process. CodeArtifact can be configured to automatically fetch software packages and dependencies from public artifact repositories so developers have access to the latest versions. CodeArtifact works with commonly used package managers and build tools such as [NuGet](#), [Apache Maven](#), [Gradle](#), [npm](#), [yarn](#), [twine](#), and [pip](#), making it easy to integrate into existing development workflows.

## Application Deployment

After a new application version is built and packaged, it must be deployed in a target environment for end users to access it. There are a couple of common deployment strategies, including mutable in-place deployment, or immutable deployments when the entire infrastructure stack is replaced.

There are a variety of ways to deploy .NET applications, and [AWS CodeDeploy](#) is a deployment service that integrates with [AWS CodePipeline](#) and helps automate application deployments to Amazon EC2 instances, Amazon ECS services, on-premises instances, and serverless Lambda functions. It supports in-place mutable deployment, and immutable deployment using the blue-green deployment model.

The AWS CodePipeline Service can also be used for deployment and integrates with a number of deployment providers, including AWS CloudFormation, AWS Elastic Beanstalk, Amazon ECS, AWS Service Catalog, and AWS CodeDeploy.

## Building a CI/CD Pipeline

Each of the previously discussed developer tools can be used individually or in combination with your existing tools, but you can also integrate them together to form a complete end-to-end CI/CD pipeline.

[AWS CodePipeline](#) is an orchestration service that enables you to model the different stages of your software release process. It can be integrated with other AWS developer tools for building, testing and deploying your software versions. It can also easily be extended to adapt to your specific needs. You can use its pre-built plugins or your own custom plugins in any step of your release process.

For example, you can pull your source code from GitHub, use your on-premises [Jenkins](#) build server, run load tests using a third-party service, or pass on deployment information to your custom operations dashboard.

## Seamless Integration with Azure DevOps

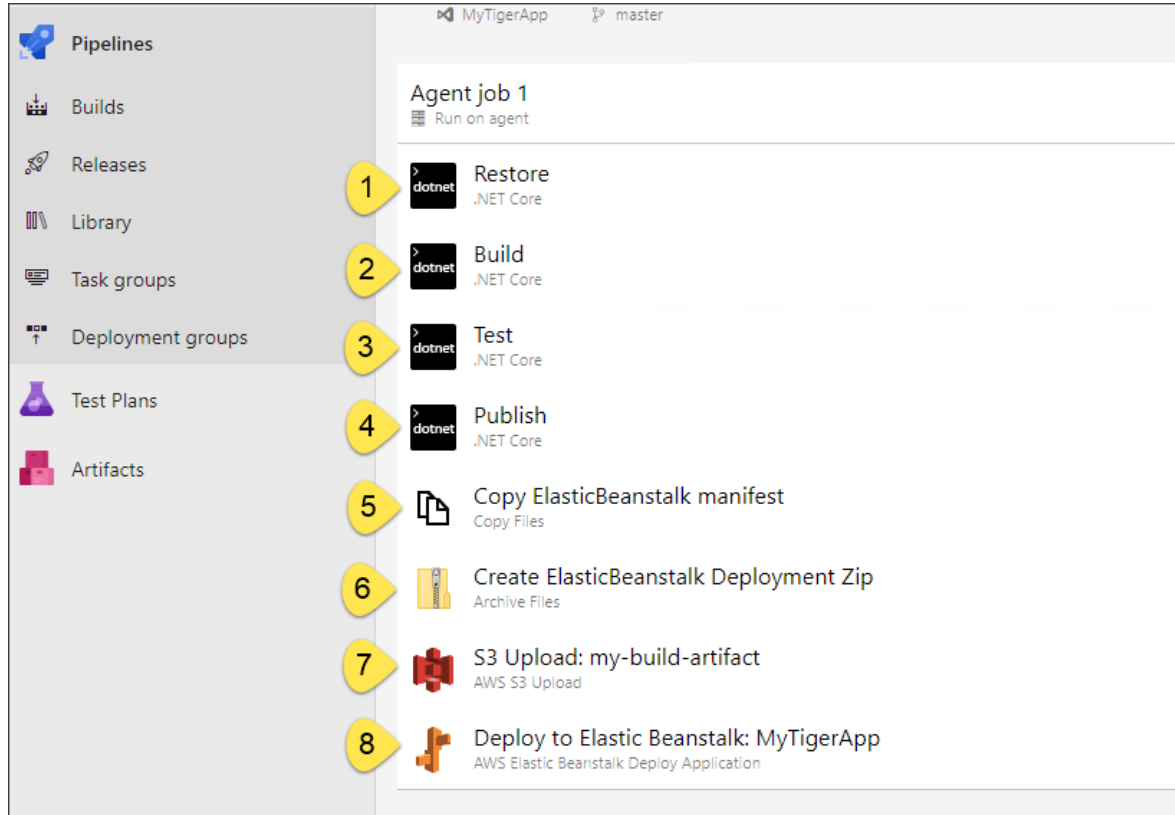
The main integration point for Azure DevOps with AWS is through Azure DevOps pipelines. You can configure Azure DevOps pipeline to build, test, package and release software to different AWS environments. You can use the following methods for this integration.

### AWS Tools for Azure DevOps

[AWS Tools for Azure DevOps](#) is available on the [Azure DevOps Extension Marketplace](#). To install these extensions, navigate to the Extensions Marketplace through Azure DevOps. You can also install them on your on-premises Azure DevOps Server.

After installation, you can choose from a set of pipeline tasks that can be included in your pipeline to integrate with AWS.

These building blocks can then be used to construct complex deployment pipelines. The following figure shows an example pipeline designed to build, test, and publish an ASP.NET Core web application to an AWS Elastic Beanstalk environment.



*Pipeline for building, testing, and deploying an ASP.NET Core application to AWS Elastic Beanstalk*

### Pipeline step descriptions

1. Executes .NET Core build task, such as Git pull
2. Executes .NET Core build task
3. Executes .NET Core test task
4. Executes .NET Core publish task
5. Copies an AWS Elastic Beanstalk manifest file into the bundle
6. Creates a zip archive from newly published website content.
7. Uploads the zip archive to an S3 bucket.
8. Deploys the application in an AWS Elastic Beanstalk environment.

## Custom Scripts

If you need functionalities beyond those provided through extensions published by AWS, or if you need more fine-grained control over your pipeline, you can use AWS CLI or AWS Tools for Windows PowerShell to create a custom task or step in Azure DevOps pipeline.

# Security and Operations

## Application Security

Application security posture and requirements vary based on the type of application, scale of deployment, and choice of environment, but there are common principles and practices that serve as solid foundations across all types of applications.

The key principle for developing secure .NET applications is ensuring that requests from upstream users and systems are trusted, and ensuring that requests sent to downstream systems are also trusted. Applications need to safeguard any credentials or sensitive information they require to operate, control the exposure of the data they process, and integrate with security providers in a protected and maintainable way.

Running applications in a secure manner starts with developing secure applications, but also requires operating them in a secure environment. Security is the highest priority at AWS, and there are various AWS Services that can help meet the requirements of the most security-sensitive organizations.

The following sections focus on developing secure applications. For more information on security, including auditing, data governance, network security, and encryption in transit and at rest, see [AWS Cloud Security](#).

## Programmatic Authentication and Authorization

AWS IAM provides a comprehensive set of authentication and authorization features. IAM enables granular permissions to be granted to AWS Services. Permissions can then be assigned to users, groups of users, and users or services running with a particular role.

## Developer Access Control

Users can be assigned access keys consisting of an access key ID and a secret access key, which can be used to authenticate them for using AWS CLI, AWS Tools for PowerShell, or SDK tools. Access keys grant the same access rights as the associated IAM user, and must be handled securely. For example, hard-coding these keys into the code is not a good practice; that would reveal [secrets](#) to anyone who can access application code or binaries, and also requires application change every time secrets are rotated. It is best to separate these keys from the application code.

For more details on working with Account Profiles in Microsoft Visual Studio, see [Providing AWS Credentials](#).

There are many other best practices for using the access keys, such as key rotation and using least privilege. To learn more, see [Best Practices for Managing AWS Access Keys](#).

## Runtime Access Control

Although access keys are well-suited for developers, when deploying .NET applications to an AWS environment, we recommend that you use IAM role-based access in place of access keys.

You can create an IAM role with permissions based on the principle of least privilege. The role is then assigned to the compute environment hosting the .NET application, whether it requires EC2 virtual machines, ECS containers, or Lambda serverless functions. This way, you no longer need to manually create and rotate programming keys to authenticate your applications. Instead, IAM generates temporary keys and automatically rotates them on your behalf, allowing your applications running on AWS to get authenticated and authorized to use AWS resources securely and seamlessly.

To learn more about role-based access, see [Granting Access Using an IAM Role](#).

## Runtime Access Control with Temporary Credentials

Although IAM role-based access works well for .NET applications running in AWS, for applications hosted outside of AWS, such as desktop or mobile applications, or for applications that execute with multiple roles, or across multiple AWS Accounts, it's better to provide an additional level of access control by using temporary credentials.

The [AWS Security Token Service](#) (AWS STS) can be used to generate temporary credentials, and can either be accessed through a single, global endpoint or from a series of regional endpoints.

Temporary credentials are generated dynamically when requested, and can last from a few minutes to several hours. After credentials expire, they can no longer be used to make API requests. However, the user can request new credentials, as long as they still have permissions to do so.

To learn about how to program with AWS STS using .NET, see [Making Requests Using IAM User Temporary Credentials - AWS SDK for .NET](#).

## Active Directory

Active Directory is Microsoft's directory service and provides a wide set of capabilities to authenticate and authorize users, services and computers in Windows domains.

Although there are a number of reasons why .NET applications may need to interact with Active Directory, the most common use case is that .NET applications running on Windows are more likely run under a process whose permissions have been authorized by Active Directory.

Since Linux doesn't natively use Active Directory, .NET applications are more likely to need Active Directory on AWS when they're being run on Windows hosts. However, Active Directory integration is also possible for Linux-based applications. In any of these cases, you can either use [AWS Managed Microsoft AD](#), which runs an actual Active Directory instance on AWS managed infrastructure, or you can use [Active Directory Connector](#) (AD Connector), a directory gateway which redirects requests to your on-premises Active Directory servers. Many businesses also choose to self-manage their Active Directory infrastructure to maintain full control over it, while running it on AWS and leveraging the flexibility, scalability and efficiency of the AWS Cloud.

More information on Microsoft Active Directory on AWS is covered in the [Active Directory Domain Services on AWS](#) whitepaper, and additional details can be found in the [Securing the Microsoft Platform on Amazon Web Services](#) whitepaper.

## User Identity Management

Successful web or mobile applications can reach millions of users, and it is critical that such applications have a robust and scalable approach for user and identity management.

Applications can have specific requirements, such as using their own identity store, or leveraging an existing identity provider such as Facebook, Google, or Amazon. Some need to use a combination of their own identity store with existing identity providers. This is often coupled with requirements for a user interface that handles user registration, login, user verification, and forgotten passwords.

[Amazon Cognito](#) enables you to add user sign-up, sign-in, and access control to your web and mobile apps quickly and easily. Amazon Cognito scales to millions of users and supports sign-in with social identity providers, including Facebook, Google, and Amazon, and enterprise identity providers via SAML 2.0.

Amazon Cognito can also be used to control access to REST APIs through integration with the Amazon API Gateway service, and can reduce the work to authenticate web application users by [integrating with the Application Load Balancer](#).

Security features include multi-factor authentication, checks for compromised credentials, account takeover protection, and phone and email verification. Amazon Cognito also supports application specific identity stores, user profiles, and customized workflows and user migration through Lambda triggers.

For more information, see [Getting Started with Amazon Cognito](#). To learn how you can authenticate .NET application using Amazon Cognito, see [Authenticating Users with Amazon Cognito](#).

## Storing and Retrieving Secrets

Your .NET application probably connects to one or more external systems, from database servers, through to cache servers, message queues, or even other applications.

Connections to external systems are secured using some form of secret information, including connection strings and a variety of system credentials. Storing and retrieving secret information in a secure manner is vital to the security of the overall application. Although .NET applications frequently use configuration files to store secrets, they come with an inherent risk of being stolen, as frequently seen when a developer mistakenly checks a configuration file into a public repository along with the source code.

A better approach is to store secrets in a secure repository, and [AWS Secrets Manager](#) can help by storing and retrieving secret information in an encrypted format. Secrets can be stored as a JSON string, allowing the application to store secrets in a variety of formats. When a .NET application needs the secret, it makes an API call to AWS Secrets Manager to fetch the secret using the secret name.

Access to AWS Secrets Manager APIs is granted through IAM policies. Applications need explicit permissions to access these secrets. The best practice is to have these IAM policies attached to an IAM role, which is then assigned to the runtime environment of your application (that is, the EC2 instance, ECS task, or Lambda function that hosts your application). This approach ensures, not only that those secrets do not leave the boundaries of AWS Services, but also credentials that authorize access to those secrets are also confined within your AWS account and never leave it.

For ASP.NET Core applications, there is a NuGet package available called the [AWS .NET Configuration Extension for Systems Manager](#), which automatically loads and refreshes secrets from Parameter Store and AWS Secrets Manager into the configuration object for easy consumption by application code.

Another best practice is to periodically rotate secrets to minimize risk of their potential compromise. AWS Secrets Manager provides features that help automatically rotate secrets.

You can also use the AWS Secrets Manager local cache library for .NET to improve availability, reduce latency and lower costs. For more information, see [this entry](#) on the [AWS Security Blog](#).

AWS Secrets Manager provides additional benefits, such as centralized secret management, allowing secrets to be shared by multiple users or applications.

For more information on managing secrets with AWS Secret Manager, see [Tutorial: Storing and Retrieving a Secret](#).

## Monitoring

Successful DevOps requires excellent communication between the development of new application capabilities and their subsequent operation. One of the key benefits over other approaches is that it shortens the feedback loop between development and operations.

Although structuring teams to include development and operations improves human communication, running modern and distributed systems is complicated, and it is critical that the team has a good understanding of the current state and the performance of the system components, the interactivity between components, as well as the historic view of the system's behavior.

Designing a suitable approach to monitor .NET application behavior is relatively simple but requires a combination of approaches. Approaches include logging events and errors from your application and AWS resources, recording metrics, showing current status dashboards, sending and automating responses to alerts, and providing tracing to help isolate problems.

While the traditional .NET monitoring approaches and third-party libraries still work in AWS, implementing a modern, approach generally requires introducing one or more additional AWS Services or third-party tools. Although it's not necessary to use all these tools, mature DevOps teams invariably use a multi-layered approach to monitor the system, track performance, and provide alerts when notable or exceptional events occur.

## Amazon CloudWatch

The cornerstone for monitoring applications running on AWS is [Amazon CloudWatch](#), a group of services that can store log files, track metrics, send alarms, and execute automated actions when specific events are triggered.

Sending data to CloudWatch from Windows applications can be handled automatically using the Amazon CloudWatch agent, which runs as a Windows service to integrate with CloudWatch from .NET applications hosted on Amazon EC2, Amazon ECS, or Amazon EKS.

Amazon CloudWatch provides a number of key features. CloudWatch dashboards are customizable home pages in the CloudWatch console that can be used to monitor resources and view the metrics and alarms for your AWS resources. [CloudWatch Metrics](#) stores data about the performance of your systems, and allows publishing your own application metrics. [CloudWatch Alarms](#) can monitor one or more metrics, and can trigger a variety of actions, including automatic scaling, or sending a notification to an [Amazon Simple Notification Service](#) (Amazon SNS) topic.

[Amazon CloudWatch Logs](#) stores and monitors log files, and can be used for centralized access to log files from a variety of applications, systems, and AWS Services. Although logs can be sent from Windows using the CloudWatch agent, you can configure many [.NET logging libraries](#), including [Apache log4net](#), [NLog](#), [Serilog](#), and [ASP.NET Core logging](#), to send log entries to CloudWatch, and call CloudWatch directly using the AWS SDK for .NET. For .NET serverless functions running in AWS Lambda, you can send messages to CloudWatch Logs by either writing output to stdout or stderr using the Console class, or by using the `ILambdaContext` object.

Once logs are stored, you can view the logs from multiple sources as a time-ordered flow of events, search the logs, and display them in custom dashboards. Although CloudWatch Logs provides a number of common logging features, sometimes there are use cases that fit more closely with other logging tools. Common tools used alongside or instead of CloudWatch Logs include [Amazon Elasticsearch Service](#), [Splunk](#), or [Loggly](#).

Amazon CloudWatch Events receives system events from AWS resources, and can be used to send notifications or run automated scripts when specific conditions are met. Rules are defined to match particular sets of events and conditions, and, once triggered, events can be routed to target actions, allowing notifications to be sent, or custom actions to execute. CloudWatch Events can also be run on a schedule, and provides a flexible tool to trigger various types of system automation.

## Amazon CloudWatch Application Insights for .NET and SQL Server

Whereas CloudWatch gives you a rich set of tools to customize your approach to monitoring, [Amazon CloudWatch Application Insights for .NET and SQL Server](#) enables application owners to easily monitor their application stack. It automatically sets up and analyses important metrics and logs from across their application resources in real time, and uses machine learning techniques to discover anomalies and errors. CloudWatch Application Insights for .NET and SQL Server creates automated dashboards

for detected problems, helping application owners troubleshoot faster and reduce the mean time to resolution (MTTR) for their application issues and improve Service Level Agreements (SLAs).

- **Automatically recognized application metrics and logs** — CloudWatch Application Insights for .NET and SQL Server scans your application resources and provides a list of recommended metrics and logs to monitor, and sets them up automatically, reducing your effort spent in setting up monitoring for your applications.
- **Intelligent problem detection** — CloudWatch Application Insights for .NET and SQL Server uses prebuilt rules and machine learning algorithms to dynamically monitor and analyze symptoms of a problem across your application stack and detect application problems. It helps you reduce the overhead of dealing with individual metric spikes, or events, or log exceptions, and instead get notified on real problems, along with contextual information about these problems.
- **Faster troubleshooting** — CloudWatch Application Insights for .NET and SQL Server assesses the detected problems to give you insights on them, such as the possible root cause of the detected problem and list of metrics and logs impacted because of the problem. You can provide feedback on generated insights to make the problem detection engine specific to your use case.

For example, consider you have an ASP .NET application backed by a SQL Server database, and your database starts malfunctioning due to high memory pressure, leading to HTTP 500 errors in your application server. Previously, to identify the problem and triage, you would have to go through your metrics dashboards, sift through server, application error and database logs, and possibly use third-party tools.

With CloudWatch Application Insights for .NET and SQL Server and its intelligent analytics, you can find the layer (SQL database, in this case) in your application stack causing the problem just by looking at the dynamically created dashboard of the related metrics anomalies, and log file snippets. This significantly reduces alert fatigue and the time and effort required to troubleshoot and return your application to a healthy state.

## Auditability and Change Tracking

Effective DevOps requires that teams have a transparent view of changes made to the services and infrastructure running their applications. [AWS CloudTrail](#) helps provide this transparency by monitoring and logging AWS API calls, effectively recording actions taken by users, roles, or AWS Services as CloudTrail events. These events include actions in the AWS Management Console, AWS CLI, and AWS SDKs and APIs, allowing changes to be audited.

You can view and monitor CloudTrail events in the CloudTrail console, and you can store log files in Amazon S3 or send them to CloudWatch Logs. You can use CloudTrail events sent to CloudWatch to trigger alarms based on metrics, and to trigger CloudWatch events, allowing automated actions to be executed when specific API calls are logged. This combination of using CloudTrail and CloudWatch can be a highly effective approach for creating auto-healing scripts for your environment, or can form part of an advanced infrastructure automation strategy.

[AWS Config](#) is a service that evaluates the configuration of your AWS resources, monitors configuration changes and compares them against desired configurations. AWS Config can send notifications of changes using Amazon SNS, or you can create automated responses using CloudWatch Events, and automated remediation using [AWS Systems Manager Automation](#).

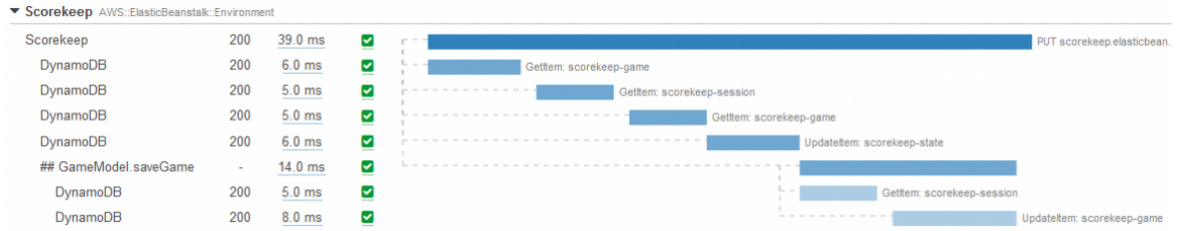
## AWS X-Ray

One of the challenges of modern applications is they are built from a number of distributed components and services, making it difficult to determine the cause of issues and isolate the underlying responsible service or component. For example, a ASP.NET application may be running on a number of load-balanced EC2 instances, with each instance depending on a SQL Server database hosted on Amazon RDS, and

additional functionality being provided by a number of microservices hosted across EC2 instances, containers, and Lambda functions. Although CloudWatch provides rich capabilities to monitor each individual component, trying to isolate which distributed components is causing a problem is a challenge in its own right.

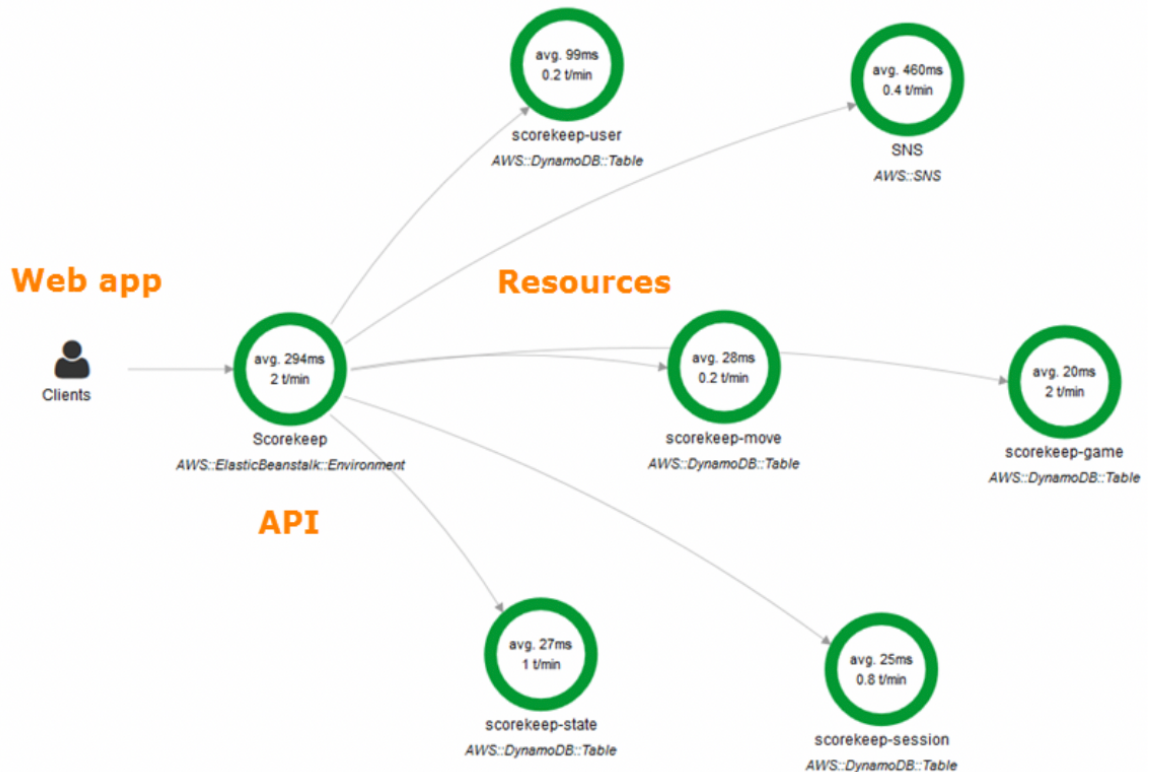
[AWS X-Ray](#) provides an SDK that allows you to trace incoming requests to your application, and trace requests from your application to AWS Services, HTTP services, and databases. You can enable AWS X-Ray tracing [without having to modify your application](#).

For each request into your application, data is recorded as a series of segments that are grouped into a trace. Once a trace is recorded, you can view it from the trace history, allowing you to inspect your application's performance and behavior to help focus on potential problems.



### AWS X-Ray trace example

AWS X-Ray can also display service graphs, which show graphical views of the services used by your application, helping to isolate various issues, including faults, latency spikes, and possible bottlenecks.



### AWS X-Ray service graph example showing integration across various components

By providing a cohesive view of end-to-end application behavior, AWS X-Ray makes it possible to accurately and quickly identify sources of problems in distributed systems. At a glance, it helps locate an

API, microservice, or component with problems, allowing you to drill down farther with more detailed tools, such as Amazon CloudWatch.

## Additional AWS Service Logs

Although application and operating system monitoring can give a focused view on how an application is behaving, sometimes it's necessary to monitor the wider environment of AWS Services.

[Amazon VPC Flow Logs](#) allow you to monitor IP traffic for your AWS resources. Flow Logs creates logs for network traffic going in and out of your VPC networks. For each flow log, you can choose to filter the traffic it records and also choose to store the logs in Amazon CloudWatch or S3. Flow logs are useful for troubleshooting a number of networking issues, such as overly-restrictive security group rules, and can also be used to audit the traffic passing through the network.

Closely related to Flow Logs, [Amazon Route 53 Query Logging](#) can track queries for DNS public hosted zones and can send logs to CloudWatch Logs.

When running .NET applications on EC2 instances or in containers, Elastic Load Balancing allows you to spread load across multiple instances, letting your application scale and letting you take advantage of elasticity. You can use ELB Access Logs to monitor HTTP/HTTPS traffic to Application Load Balancers and TCP traffic to Network Load Balancers. Logs are captured as compressed files and stored in an S3 bucket, and can be used to analyze traffic patterns and troubleshoot load-balancing issues.

For high volume ASP.NET websites with a global presence, it's a common requirement to reduce load on the web servers. The Amazon CloudFront Content Delivery Network helps by moving static content closer to users, tracking detailed information about every request, and storing the resulting logs in an S3 bucket.

For applications that need to store or share files, S3 provides a simple service to store and serve objects at scale. You can use [S3 Server Access Logging](#) to track access requests to your S3 buckets for troubleshooting and security audit purposes.

# Conclusion

Delivering business value by fully taking advantage of the AWS Cloud requires agile ways of working, flexible application architectures, and modern development practices.

Although .NET was considered as an exclusive Windows technology, the use of [Xamarin](#) for cross-platform mobile development, and the advent of .NET 5 has helped turn .NET into a truly diverse cross-platform application framework.

This paper serves as a starting point for developing and deploying .NET applications on AWS; the real value of running .NET applications on AWS is in integrating them with the growing platform of innovative AWS Services.

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