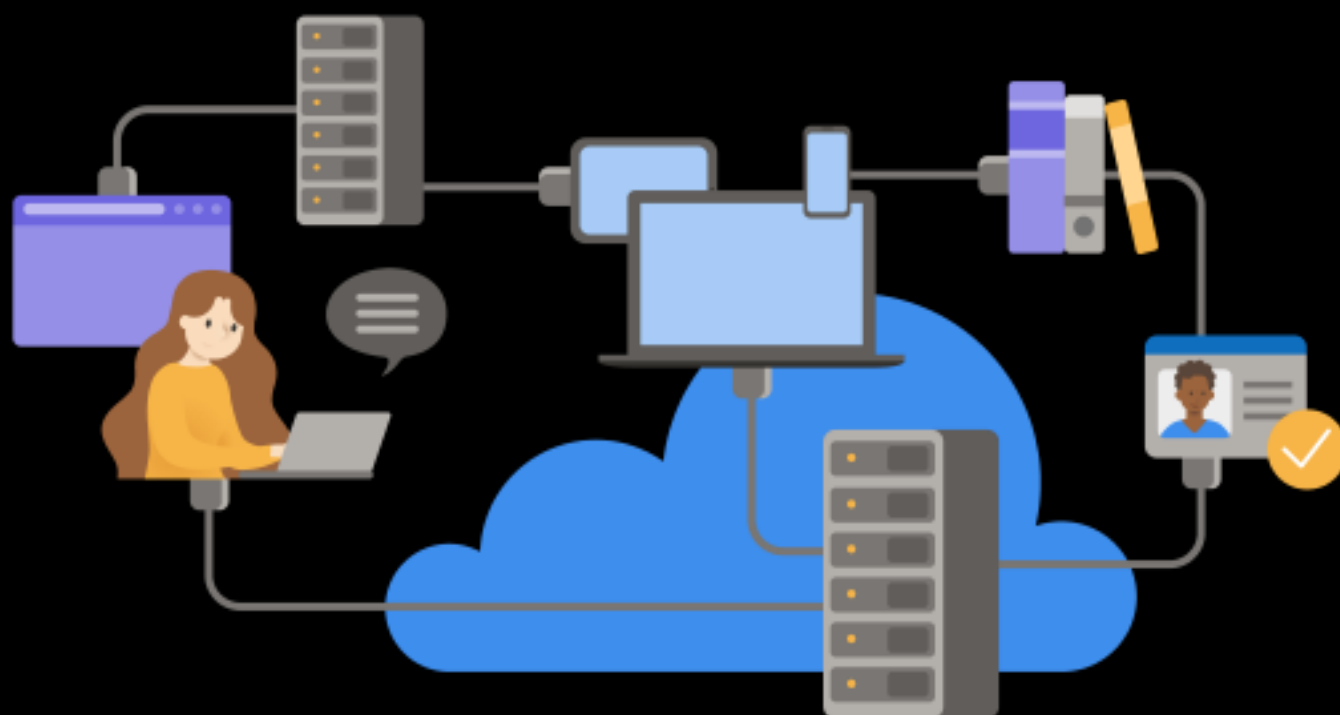


# gRPC for WCF Developers



Mark Rendle  
Miranda Steiner

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Author:

**Mark Rendle** - Chief Technical Officer - [Visual Recode](#)

**Miranda Steiner** - Technical Author

Editors:

**Maira Wenzel** - Sr Content Developer - Microsoft

# Introduction

gRPC is a modern framework for building networked services and distributed applications. Imagine the performance of WCF's NetTCP bindings with the cross-platform interoperability of SOAP. gRPC builds on HTTP/2 and the Protobuf message-encoding protocol to provide high performance, low-bandwidth communication between applications and services. It supports server and client code generation across most popular programming languages and platforms, including .NET, Java, Python, Node.js, Go, C++ and more. With the first-class support for gRPC in ASP.NET Core 3.0, alongside the existing gRPC tools and libraries for .NET 4.x, we think it is an excellent alternative to WCF for development teams looking to adopt .NET Core in their organizations.

## Who should use this guide

This guide was written for developers working in .NET Framework or .NET Core who have previously used WCF and who are seeking to migrate their applications to a modern RPC environment for .NET Core 3.0 and later versions. The guide may also be of use more generally for developers upgrading or considering upgrading to .NET Core 3.0 who want to use the built-in gRPC tools.

## How you can use this guide

This is a short introduction to building gRPC Services in ASP.NET Core 3.0 with particular reference to WCF as an analogous platform. It explains the principles of gRPC, relating each concept to the equivalent features of WCF, and offers guidance for migrating an existing WCF application to gRPC. It is also useful for developers who have experience of WCF and are looking to learn gRPC to build new services. The sample applications can be used as a template or reference for your own projects, and you are free to copy and reuse code from the book or its samples.

Feel free to forward this guide to your team to help ensure a common understanding of these considerations and opportunities. Having everybody working from a common set of terminology and underlying principles helps ensure consistent application of architectural patterns and practices.

## References

- **gRPC web site**  
<https://grpc.io>
- **Choosing between .NET Core and .NET Framework for server apps**  
<https://docs.microsoft.com/dotnet/standard/choosing-core-framework-server>

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# Introduction

Helping machines communicate with each other has been one of the primary preoccupations of the digital age. In particular, there is an ongoing effort to determine the optimal remote communication mechanism that will suit the interoperability demands of the current infrastructure. As you can imagine, that mechanism changes as either the demands or the infrastructure evolves.

The release of .NET Core 3.0 marks a shift in the way that Microsoft delivers remote communication solutions to developers who want to deliver services across a range of platforms. .NET Core doesn't offer Windows Communication Foundation (WCF) out of the box but, with the release of version ASP.NET Core 3.0, it does provide built-in gRPC functionality.

gRPC is a popular framework in the wider software community, used by developers across many programming languages for modern RPC scenarios. The community and the ecosystem are vibrant and active, with support for the gRPC protocol being added to infrastructure components like Kubernetes, service meshes, load balancers and more. These factors, as well as its performance, efficiency and cross-platform compatibility, make gRPC a natural choice for new apps and WCF apps moving to .NET Core.

## History

The fundamental principle of a computer network as nothing more than a group of computers exchanging data with each other to achieve a set of interrelated tasks hasn't changed since its inception. However, the complexity, scale, and expectations have grown exponentially.

During the 1990s, the emphasis had been mainly focused on improving internal networks using the same language and platforms. TCP/IP became the gold standard for this type of communication.

However, the focus soon shifted to how best to optimize communication across multiple platforms promoting a language agnostic approach. Service-oriented architecture (SOA) provided a structure for loosely coupling a broad collection of services that could be provided to an application.

The development of *Web Services* occurred once all major platforms could access the Internet, but they still couldn't interact with each other. Web services have open standards and protocols including:

- XML to tag and code data;
- Simple Object Access Protocol (SOAP) to transfer data;
- Web Services Definition Language (WSDL) – describes and connects the web service to the client application; *and*
- Universal Description Discovery Integration (UDDI)- enables Web Services to be discoverable by other Services



SOAP defines the rules by which distributed elements of an application can communicate with each other even if they are on different platforms. SOAP is based on XML, so it's human-readable. The sacrifice for making SOAP easily understood is size; SOAP messages are larger than messages in comparable protocols. SOAP was designed to break down monolithic applications into multi-component form without losing security or control. Therefore, WCF was designed to work with that kind of system, unlike gRPC, which began as a distributed system. WCF addressed some of these limitations by developing and documenting proprietary extension protocols for the SOAP stack, but at the cost of lack of support from other platforms.

Windows Communication Foundation is a framework for building services. It was designed in the early 2000s to help developers using early SOA to manage the complexities of working with SOAP. Although it removes the requirement for the developer to write their own SOAP protocols, WCF still uses SOAP to enable interoperability with other systems. WCF was also designed to deliver solutions across multiple protocols (HTTP/1.1, NetTCP, and so on).

## Microservices

In microservice architectures, large applications are built as a collection of smaller modular services. Each component does a specific task or process, and components are designed to work interoperably but can be isolated as necessary.

Advantages to microservices include:

- Changes and upgrades can be handled independently.
- Error handling becomes more efficient as problems can be traced to specific services that are then isolated, rebuilt, tested, and redeployed independent of the other services.
- Scalability can be confined to the specific instances or services rather than the whole application.
- Development can happen across multiple teams, with less friction than occurs when many teams work on a single codebase.

The move towards increasing virtualization, cloud computing, containers and the Internet of Things have contributed to the ongoing rise of microservices. However, microservices aren't without their challenges. The fragmented/decentralized infrastructure placed more emphasis on the need for simplicity and speed when communicating between services. This in turn drew attention to the sometimes laborious and contorted nature of SOAP.

It was into this environment that gRPC was launched, 10 years after Microsoft first released WCF. Evolved directly from Google's internal infrastructure RPC (Stubby), gRPC was never based on the same standards and protocols that had informed the parameters of many earlier RPCs. Additionally, gRPC was only ever based on HTTP/2 and that's why it could draw on the new capabilities that advanced transport protocol provided. In particular, bidirectional streaming, binary messaging, and multiplexing.

## About this guide

This guide covers the key features of gRPC. The early chapters take a high-level look at the main features of WCF and compare them to gRPC. It identifies where there are direct correlations between WCF and gRPC and also where gRPC offers an advantage. Where there's no correlation between WCF and gRPC or where gRPC isn't able to offer an equivalent solution to WCF, this guide will suggest workarounds or places to go for further information.

Using a set of sample WCF applications, Chapter 5 is a deep dive look at converting the main types of WCF service (simple request-reply, one-way, and streaming) to their equivalents in gRPC.

The final section of the book looks at how to get the best from gRPC in practice, including using additional tools like Docker containers or Kubernetes to leverage the efficiency of gRPC, and a detailed look at the monitoring with logging, metrics, and distributed tracing.

## Whom this guide is for

This guide was written for developers working in .NET Framework or .NET Core who have previously used WCF and who are seeking to migrate their applications to a modern RPC environment for .NET Core 3.0 and later versions. The guide may also be of use more generally for developers upgrading or considering upgrading to .NET Core 3.0 who want to use the built-in gRPC tools.

# gRPC overview

After looking at the genesis of both WCF and gRPC in the last chapter, this chapter will consider some of the key features of gRPC and how they compare to WCF.

ASP.NET Core 3.0 is the first release of ASP.NET that natively supports gRPC as a first-class citizen, with Microsoft teams contributing to the official .NET implementation of gRPC. It's recommended as the best approach for building distributed applications with .NET that can interoperate with all other major programming languages and frameworks.

## Key principles

As discussed in chapter 1, Google wanted to use the introduction of HTTP/2 to replace Stubby, its internal, general purpose RPC infrastructure. gRPC, based on Stubby, now could take advantage of standardization and would extend its applicability to mobile computing, the cloud, and the Internet of Things.

To achieve this, the [Cloud Native Computing Foundation \(CNCF\)](#) established a set of principles that would govern gRPC. The following list shows the most relevant ones, which are mainly concerned with maximizing accessibility and usability:

- **Free and open** – all artifacts should be open source with licensing that doesn't constrain developers from adopting gRPC.
- **Coverage and simplicity** – gRPC should be available across every popular platform and simple enough to build on any platform.
- **Interoperability and reach** – it should be possible to use gRPC on any network, regardless of bandwidth or latency, using widely available network standards.
- **General purpose and performant** – the framework should be usable by as broad a range of use-cases as possible without compromising performance.
- **Streaming** – the protocol should provide streaming semantics for large data-sets or asynchronous messaging.
- **Metadata exchange** – the protocol allow non-business data, such as authentication tokens, to be handled separately from actual business data.
- **Standardized status codes** – the variability of error codes should be reduced to make error handling decisions clearer and, where additional richer error handling is required, a mechanism should be provided for managing this within the metadata exchange.

## How gRPC approaches RPC

Windows Communication Foundation (WCF) and gRPC are both implementations of the *Remote Procedure Call* (RPC) pattern, which aims to make calls to services running on a different machine, or in a different process, seamlessly work as though they were just method calls in the client application. While the aims of WCF and gRPC are the same, the details of the implementation are quite different.

The following table sets out how the key features of WCF relate to gRPC and where you can find more detailed explanations in the rest of the book.

Features	WCF	gRPC
Objective	Separate business code from networking implementation	Separate business code from interface definition and networking implementation
Define Services and messages (chapter 3-4)	Service Contract, Operation Contract, and Data Contract	Uses proto file to declare services and messages
Language (chapter 3-5)	Contracts written in C# or Visual Basic	Protocol Buffer language
Wire format (chapter 3)	Configurable, including SOAP/XML, Plain XML, JSON, .NET Binary, and so on.	Protocol Buffer binary format (although it's possible to use other formats).
Interoperability (chapter 4)	When using SOAP over HTTP	Official support: .NET, Java, Python, JavaScript, C/C++, Go, Rust, Ruby, Swift, Dart, PHP. Unofficial support for other languages from the community.
Networking (chapter 4)	Configured at runtime. Switch between NetTCP, HTTP, MSMQ, and so on.	HTTP/2, currently over TCP only with ASP.NET Core gRPC.
Approach (chapter 4)	Runtime generation of serialization /deserialization and networking code in base classes	Build-time generation of serialization /deserialization and networking code in base classes
Security (chapter 6)	Authentication, WS-Security, message encryption	Credentials, ASP.NET Core security, TLS networking

## Interface Definition Language

With WCF, services can expose description metadata using the Web Service Definition Language (WSDL), which is generated dynamically using .NET Reflection at runtime. Developers can use this metadata to generate clients for those services, potentially in other languages if a platform-neutral binding such as SOAP over HTTP is used.

gRPC uses the Interface Definition Language (IDL) from Protocol Buffers. The Protocol Buffers IDL is a custom, platform-neutral language with an open specification. Developers hand-code .proto files to describe services along with their inputs and outputs. These .proto files can then be used to generate language- or platform-specific stubs for clients and servers, allowing multiple different platforms to communicate. By sharing .proto files, teams can generate code to use each others' services without needing to take a code dependency.

One of the advantages of the Protobuf IDL is that as a custom language it enables gRPC to be completely language and platform agnostic, not favoring any technology over another.

The Protobuf IDL is also designed for humans to both read and write, whereas WSDL is intended as a machine-readable/writable format. Changing the WSDL of a WCF service typically requires making the changes to the service code itself, running the service and regenerating the WSDL file from the server. By contrast, with a .proto file, changes are simple to apply with a text editor, and automatically flow through the generated code. Visual Studio 2019 builds .proto files in the background when they are saved; when using other editors such as VS Code the changes will be applied when the project is built.

When compared with XML, and particularly SOAP, messages encoded using Protobuf have many advantages. Protobuf messages tend to be smaller than the same data serialized as SOAP XML, and encoding, decoding and transmitting them over a network can be faster.

The potential disadvantage of Protobuf compared to SOAP is that, because the messages are not human readable, additional tooling is required to debug message content.

#### Tip

gRPC *does* support server reflection for dynamically accessing services without pre-compiled stubs, although it is intended more for general-purpose tools than application-specific clients. For more information about gRPC Server Reflection, see [grpc/grpc](#) repository on GitHub.

#### Note

WCF's binary format, used with the NetTCP binding, is much closer to Protobuf in terms of compactness and performance, but NetTCP is only usable between .NET clients and servers, whereas Protobuf is a cross-platform solution.

## Network protocols

Unlike WCF, gRPC uses HTTP/2 as a base for its networking. This offers significant advantages over WCF and SOAP, which only operate on HTTP/1.1. For developers wanting to use gRPC, given that there's no alternative to HTTP/2, it would seem to be the ideal moment to explore HTTP/2 in more detail and identify additional benefits to using gRPC.

HTTP/2, released by Internet Engineering Task Force in 2015, was derived from the experimental SPDY protocol, which was already being used by Google. It was specifically designed to be more efficient, faster, and more secure than HTTP/1.1.

## Key features of HTTP/2

The following list shows some of the key features and advantages of HTTP/2:

### Binary protocol

Request/response cycles no longer need text commands. This simplifies and speeds up implementation of commands. Specifically, parsing data is faster and uses less memory, network latency is reduced with obvious related improvements to speed, and there's an overall better use of network resources.

### Streams

Streams allow for the creation of long-lived connections between sender and receiver, over which multiple messages or frames can be sent asynchronously. Multiple streams can operate independently over a single HTTP/2 connection.

### Request multiplexing over a single TCP connection

This feature is one of the most important innovations of HTTP/2. By allowing multiple parallel requests for data, it's now possible to download web files concurrently from a single server. Websites load faster and the need for optimization is reduced. Head-of-line (HOL) blocking, where responses that are ready must wait to be sent until an earlier request is completed, is also mitigated (although HOL blocking can still occur at the TCP transport level).

### NetTCP-like performance, cross-platform

Fundamentally, the combination of gRPC and HTTP/2 offer developers at least the equivalent speed and efficiency of NetTCP bindings for WCF, and in some cases even greater speed and efficiency. However, unlike NetTCP, gRPC over HTTP/2 isn't constrained to .NET applications.

## Why gRPC is recommended for WCF developers

Before diving deeply into the language and techniques of gRPC, it's worth discussing why gRPC is the right solution for WCF developers who want to migrate to .NET Core, given there are alternatives available.

### Similarity to WCF

Although its implementation and approach is different, the actual experience of developing and consuming services with gRPC should be very intuitive for WCF developers. The underlying goal of making it possible to code as though the client and server were on the same platform, without needing to worry about networking, is the same. Both platforms share the principle of declaring and then implementing an interface, even though the process for declaring that interface is different. And as you'll see in chapter 5, the different types of RPC calls supported by gRPC map very well to the different bindings available to WCF services.

## Benefits of gRPC

Additional reasons why gRPC stands above other solutions are:

### Performance

As already discussed, using HTTP/2 rather than HTTP/1.1 removes the requirement for human-readable messages and instead uses the smaller faster binary protocol. This is more efficient for computers to parse. HTTP/2 also supports multiplexing requests over a single connection enabling responses to be sent as soon as they're ready without the need to wait in a queue (an issue in HTTP/1.1 known as "head-of-line (HOL) blocking"). Fewer resources are needed when using gRPC, which makes it a good solution to use for mobile devices and over slower networks.

### Interoperability

There are gRPC tools and libraries for all major programming languages and platforms, including .NET, Java, Python, Go, C++, Node.js, Swift, Dart, Ruby, and PHP. Thanks to the Protocol Buffers binary wire format and the efficient code generation for each platform, developers can build performant apps while still enjoying full cross-platform support.

### Usability and productivity

gRPC is a comprehensive RPC solution. It works consistently across multiple languages and platforms, and provides excellent tooling, with much of the necessary boilerplate code auto-generated, so more developer time is freed up to focus on business logic.

### Streaming

gRPC has full bidirectional streaming, which provides very similar functionality to WCF's full duplex services. gRPC streaming can operate over regular internet connections, load balancers, and service meshes.

### Deadline/timeouts and cancellation

gRPC allows clients to specify a maximum time for an RPC to complete. If the specified deadline is exceeded the server can cancel the operation independently of the client. Deadlines and cancellations can be propagated through further gRPC calls to help enforce resource usage limits. Clients may also abort operations when a deadline is exceeded, or earlier if necessary (e.g. due to a user interaction).

### Security

gRPC is implicitly secure when using HTTP/2 over an TLS end-to-end encrypted connection. Support for Client Certificate authentication (see chapter 6) further increases security and trust between client and server.

# Protocol buffers

gRPC services send and receive data as *Protocol Buffer (Protobuf) messages*, similar to WCF's data contracts. Protobuf is an efficient way of serializing structured data for machines to read and write, without the overhead that human-readable formats like XML or JSON incur.

This chapter covers how Protobuf works, and how to define your own Protobuf messages.

## How Protobuf works

Most .NET object serialization techniques, including WCF's data contracts, work by using reflection to analyze the object structure at run time. By contrast, most Protobuf libraries require you to define the structure up front using a dedicated language (*Protocol Buffer Language*) in a .proto file. This file is then used by a compiler to generate code for any of the supported platforms, including .NET, Java, C/C++, JavaScript, and many more. The Protobuf compiler, `protoc`, is maintained by Google, although alternative implementations are available. The generated code is efficient and optimized for fast serialization and deserialization of data.

The Protobuf wire format itself is a binary encoding, which uses some clever tricks to minimize the number of bytes used to represent messages. Knowledge of the binary encoding format isn't necessary to use Protobuf, but if you're interested you can learn more about it on [the Protocol Buffers web site](#).

## Protobuf messages

This section covers how to declare Protobuf messages in .proto files, explains the fundamental concepts of field numbers and types, and looks at the C# code that is generated by the `protoc` compiler. The rest of the chapter will look in more detail at how different types of data are represented in Protobuf.



## Declaring a message

In WCF, a `Stock` class for a stock market trading application might be defined like the following example:

```
namespace TraderSys
{
    [DataContract]
    public class Stock
    {
        [DataMember]
        public int Id { get; set; }
        [DataMember]
        public string Symbol { get; set; }
        [DataMember]
        public string DisplayName { get; set; }
        [DataMember]
        public int MarketId { get; set; }
    }
}
```

To implement the equivalent class in Protobuf, it must be declared in the `.proto` file. The protoc compiler will then generate the .NET class as part of the build process.

```
syntax "proto3";

option csharp_namespace = "TraderSys";

message Stock {

    int32 id = 1;
    string symbol = 2;
    string display_name = 3;
    int32 market_id = 4;
}
```

The first line declares the syntax version being used. Version 3 of the language was released in 2016 and is the recommended version for gRPC services.

The option `csharp_namespace` line specifies the namespace to be used for the generated C# types. This option will be ignored when the `.proto` file is compiled for other languages. It is common for Protobuf files to contain language-specific options for several languages.

The `Stock` message definition specifies four fields, each with a type, a name, and a field number.

## Field numbers

Field numbers are an important part of Protobuf. They're used to identify fields in the binary encoded data, which means they can't change from version to version of your service. The advantage is that backward and forward compatibility is possible. Clients and services will simply ignore field numbers they don't know about, as long as the possibility of missing values is handled.

In the binary format, the field number is combined with a type identifier. Field numbers from 1 to 15 can be encoded with their type as a single byte; numbers from 16 to 2047 take 2 bytes. You can go

higher if you need more than 2047 fields on a message for any reason. The single byte identifiers for field numbers 1 to 15 offer better performance, so you should use them for the most basic, frequently used fields.

## Types

The type declarations are using Protobuf's native scalar data types, which are discussed in more detail in [the next section](#). The rest of this chapter will cover Protobuf's built-in types and show how they relate to common .NET types.

### Note

Protobuf doesn't natively support a decimal type, so double is used instead. For applications that require full decimal precision, refer to the [section on Decimals](#) in the next part of this chapter.

## The generated code

When you build your application, Protobuf creates classes for each of your messages, mapping its native types to C# types. The generated Stock type would have the following signature:

```
public class Stock
{
    public int Id { get; set; }
    public string Symbol { get; set; }
    public string DisplayName { get; set; }
    public int MarketId { get; set; }
}
```

The actual code that is generated is far more complicated than this, because each class contains all the code necessary to serialize and deserialize itself to the binary wire format.

## Property names

Note that the Protobuf compiler applied PascalCase to the property names although they were snake\_case in the .proto file. The [Protobuf style guide](#) recommends using snake\_case in your message definitions so that the code generation for other platforms produces the expected case for their conventions.

## Protobuf scalar data types

Protobuf supports a range of native scalar value types. The following table lists them all with their equivalent C# type:

Protobuf type	C# type	Notes
double	double	
float	float	
int32	int	1
int64	long	1
uint32	uint	
uint64	ulong	
sint32	int	1
sint64	long	1
fixed32	uint	2
fixed64	ulong	2
sfixed32	int	2
sfixed64	long	2
bool	bool	
string	string	3
bytes	ByteString	4

### Notes

1. The standard encoding for `int32` and `int64` is inefficient when working with signed values. If your field is likely to contain negative numbers, use `sint32` or `sint64` instead. Both types map to the C# `int` and `long` types, respectively.
2. The fixed fields always use the same number of bytes no matter what the value is. This behavior makes serialization and deserialization faster for larger values.
3. Protobuf strings are UTF-8 (or 7-bit ASCII) encoded, and the encoded length can't be greater than 232.
4. The Protobuf runtime provides a `ByteString` type that maps easily to and from C# `byte[]` arrays.

## Other .NET primitive types

### Dates and times

The native scalar types don't provide for date and time values, equivalent to C#'s [DateTimeOffset](#), [DateTime](#), and [TimeSpan](#). These types can be specified using some of Google's "Well Known Types"

extensions, which provide code generation and runtime support for more complex field types across the supported platforms. The following table shows the date and time types:

C# type	Protobuf well-known type
DateTimeOffset	google.protobuf.Timestamp
DateTime	google.protobuf.Timestamp
TimeSpan	google.protobuf.Duration

```
syntax = "proto3"

import "google/protobuf/duration.proto";
import "google/protobuf/timestamp.proto";

message Meeting {

    string subject = 1;
    google.protobuf.Timestamp time = 2;
    google.protobuf.Duration duration = 3;
}
```

The generated properties in the C# class aren't the .NET date and time types. The properties use the `Timestamp` and `Duration` classes in the `Google.Protobuf.WellKnownTypes` namespace, which provide methods for converting to and from `DateTimeOffset`, `DateTime`, and `TimeSpan`.

```
// Create Timestamp and Duration from .NET DateTimeOffset and TimeSpan
var meeting = new Meeting
{
    Time = Timestamp.FromDateTimeOffset(meetingTime), // also FromDateTime()
    Duration = Duration.FromTimeSpan(meetingLength)
};

// Convert Timestamp and Duration to .NET DateTimeOffset and TimeSpan
DateTimeOffset time = meeting.Time.ToDateTimeOffset();
TimeSpan? duration = meeting.Duration?.ToTimeSpan();
```

### Note

The `Timestamp` type works with UTC times; `DateTimeOffset` values always have an offset of zero, and the `DateTime.Kind` property will always be `DateTimeKind.Utc`.

## System.Guid

The [Guid](#) type, known as UUID on other platforms, isn't directly supported by Protobuf and there's no well-known type for it. The best approach is to handle Guid values as string field, using the standard 8-4-4-4-12 hexadecimal format (for example, 45a9fda3-bd01-47a9-8460-c1cd7484b0b3), which can be parsed by all languages and platforms. Don't use a bytes field for Guid values, as problems with endianness can result in erratic behavior when interacting with other platforms, such as Java.

## Nullable types

The Protobuf code generation for C# uses the native types, such as `int` for `int32`. This means that the values are always included and can't be null. For values that require explicit null, such as using `int?` in your C# code, Protobuf's "Well Known Types" include wrappers that are compiled to nullable C# types. To use them, import `wrappers.proto` into your `.proto` file, like this:

```
syntax = "proto3"

import "google/protobuf/wrappers.proto"

message Person {
    ...
    google.protobuf.Int32Value age = 5;
}
```

Protobuf will use the simple `T?` (for example, `int?`) for the generated message property.

The following table shows the complete list of wrapper types with their equivalent C# type:

C# type	Well Known Type wrapper
<code>double?</code>	<code>google.protobuf.DoubleValue</code>
<code>float?</code>	<code>google.protobuf.FloatValue</code>
<code>int?</code>	<code>google.protobuf.Int32Value</code>
<code>long?</code>	<code>google.protobuf.Int64Value</code>
<code>uint?</code>	<code>google.protobuf.UInt32Value</code>
<code>ulong?</code>	<code>google.protobuf.UInt64Value</code>

The well-known types `Timestamp` and `Duration` are represented in .NET as classes, so there's no need for a nullable version, but it's important to check for null on properties of those types when converting to `DateTimeOffset` or `TimeSpan`.

## Decimals

Protobuf doesn't natively support the .NET `decimal` type, just `double` and `float`. There's an ongoing discussion in the Protobuf project about the possibility of adding a standard `Decimal` type to the well-known types, with platform support for languages and frameworks that support it, but nothing has been implemented yet.

It's possible to create a message definition to represent the `decimal` type that would work for safe serialization between .NET clients and servers, but developers on other platforms would have to understand the format being used and implement their own handling for it.

## Creating a custom Decimal type for Protobuf

A very simple implementation could be similar to the non-standard `Money` type used by some Google APIs, without the currency field.

```

package CustomTypes;

// Example: 12345.6789 -> { units = 12345, nanos = 678900000 }
message Decimal {

    // Whole units part of the amount
    int64 units = 1;

    // Nano units of the amount (10^-9)
    // Must be same sign as units
    sfixed32 nanos = 2;
}

```

The nanos field represents values from 0.999\_999\_999 to -0.999\_999\_999. For example, the decimal value 1.5m would be represented as { units = 1, nanos = 500\_000\_000 } (this is why the nanos field in this example uses the sfixed32 type, which encodes more efficiently than int32 for larger values). If the units field is negative, the nanos field should also be negative.

### Note

There are multiple other algorithms for encoding decimal values as byte strings, but this message is much easier to understand than any of them, and the values are not affected by [endianness](#) on different platforms.

Conversion between this type and the BCL decimal type could be implemented in C# like this.

```

namespace CustomTypes
{
    public partial class GrpcDecimal
    {
        private const decimal NanoFactor = 1_000_000_000;
        public GrpcDecimal(long units, int nanos)
        {
            Units = units;
            Nanos = nanos;
        }

        public long Units { get; }
        public int Nanos { get; }

        public static implicit operator decimal(CustomTypes.Decimal grpcDecimal)
        {
            return grpcDecimal.Units + grpcDecimal.Nanos / NanoFactor;
        }

        public static implicit operator CustomTypes.Decimal(decimal value)
        {
            var units = decimal.ToInt64(value);
            var nanos = decimal.ToInt32((value - units) * NanoFactor);
            return new CustomTypes.Decimal(units, nanos);
        }
    }
}

```

### Important

Whenever you use custom utility message types like this, you **must** document them with comments in the .proto so that other developers can implement conversion to and from the equivalent type in their own language or framework.

## Protobuf nested types

Just like C# allows you to declare classes inside other classes, Protobuf allows you to nest message definitions within other messages. The following example shows how to create nested message types:

```
message Outer {  
    message Inner {  
        string text = 1;  
    }  
    Inner inner = 1;  
}
```

In the generated C# code, the Inner type will be declared in a nested static Types class within the HelloRequest class:

```
var inner = new Outer.Types.Inner { Text = "Hello" };
```

## Repeated fields for lists and arrays

Lists are specified in Protobuf using the repeated prefix keyword. The following example shows how to create a list:

```
message Person {  
    // Other fields elided  
    repeated string aliases = 8;  
}
```

In the generated code, repeated fields are represented by the `Google.Protobuf.Collections.RepeatedField<T>` generic type rather than any of the built-in .NET collection types. The `RepeatedField<T>` type includes the code required to serialize and deserialize the list to the binary wire format. It implements all the standard .NET collection interfaces such as [IEnumerable](#) and [IList](#), so you can use LINQ queries or convert it to an array or a list easily.

## Protobuf reserved fields

Protobuf's backward-compatibility guarantees rely on field numbers always representing the same data item. If a field is removed from a message in a new version of the service, that field number should never be reused. This can be enforced using the reserved keyword. If the `displayName` and `marketId` fields were removed from the `Stock` message defined earlier, their field numbers should be reserved as in the following example.

```
syntax "proto3";

message Stock {

    reserved 3, 4;
    int32 id = 1;
    string symbol = 2;
}
```

The reserved keyword can also be used as a placeholder for fields that might be added in the future. Contiguous field numbers can be expressed as a range using the to keyword.

```
syntax "proto3";

message Info {

    reserved 2, 9 to 11, 15;
    // ...
}
```

## Protobuf Any and Oneof fields for variant types

Handling dynamic property types (that is, properties of type object) in WCF is complicated. Serializers must be specified, [KnownType](#) attributes must be provided, and so on.

Protobuf provides two simpler options for dealing with values that may be of more than one type. The Any type can represent any known Protobuf message type, while the oneof keyword allows you to specify that only one of a range of fields can be set in any given message.

### Any

Any is one of Protobuf's "well-known types": a collection of useful, reusable message types with implementations in all supported languages. To use the Any type, you must import the `google/protobuf/any.proto` definition.

```
syntax "proto3"

import "google/protobuf/any.proto"

message Stock {
    // Stock-specific data
}

message Currency {
    // Currency-specific data
}

message ChangeNotification {
    int32 id = 1;
    google.protobuf.Any instrument = 2;
}
```

In the C# code, the Any class provides methods for setting the field, extracting the message, and checking the type.



```

public void FormatChangeNotification(ChangeNotification change)
{
    if (change.Instrument.Is(Stock.Descriptor))
    {
        FormatStock(change.Instrument.Unpack<Stock>());
    }
    else if (change.Instrument.Is(Currency.Descriptor))
    {
        FormatCurrency(change.Instrument.Unpack<Currency>());
    }
    else
    {
        throw new ArgumentException("Unknown instrument type");
    }
}

```

The Descriptor static field on each generated type is used by Protobuf's internal reflection code to resolve Any field types. There's also a TryUnpack<T> method, but that creates an uninitialized instance of T even when it fails, so it's better to use the Is method as shown above.

## Oneof

Oneof fields are a language feature: the oneof keyword is handled by the compiler when it generates the message class. Using oneof to specify the ChangeNotification message might look like this:

```

message Stock {
    // Stock-specific data
}

message Currency {
    // Currency-specific data
}

message ChangeNotification {
    int32 id = 1;
    oneof instrument {
        Stock stock = 2;
        Currency currency = 3;
    }
}

```

Fields within the oneof set must have unique field numbers within the overall message declaration.

When you use oneof, the generated C# code includes an enum that specifies which of the fields has been set. You can test the enum to find which field is set. Fields that aren't set return null or the default value, rather than throwing an exception.

```

public void FormatChangeNotification(ChangeNotification change)
{
    switch (change.InstrumentCase)
    {
        case ChangeNotification.InstrumentOneofCase.None:
            return;
        case ChangeNotification.InstrumentOneofCase.Stock:
            FormatStock(change.Stock);
            break;
        case ChangeNotification.InstrumentOneofCase.Currency:
            FormatCurrency(change.Currency);
            break;
        default:
            throw new ArgumentException("Unknown instrument type");
    }
}

```

Setting any field that is part of a oneof set will automatically clear any other fields in the set. You can't use repeated with oneof. Instead, you can create a nested message with either the repeated field or the oneof set to work around this limitation.

## Protobuf enumerations

Protobuf supports enumeration types, as seen in the previous section where an enum was used to determine the type of a oneof field. You can define your own enumeration types and Protobuf will compile them to C# enum types. Since Protobuf can be used with different languages, the naming conventions for enumerations are different from the C# conventions. However, the code generator is clever and converts the names to the traditional C# case. If the Pascal-case equivalent of the field name starts with the enumeration name, then it's removed.

For example, in this Protobuf enumeration the fields are prefixed with `ACCOUNT_STATUS`, which is equivalent to the Pascal case enum name: `AccountStatus`.

```

enum AccountStatus {
    ACCOUNT_STATUS_UNKNOWN = 0;
    ACCOUNT_STATUS_PENDING = 1;
    ACCOUNT_STATUS_ACTIVE = 2;
    ACCOUNT_STATUS_SUSPENDED = 3;
    ACCOUNT_STATUS_CLOSED = 4;
}

```

So, the generator creates a C# enum equivalent to the following code:

```

public enum AccountStatus
{
    Unknown = 0,
    Pending = 1,
    Active = 2,
    Suspended = 3,
    Closed = 4
}

```

Protobuf enumeration definitions **must** have a zero constant as their first field. As in C#, you can declare multiple fields with the same value, but you must explicitly enable this option using the `allow_alias` option in the enum:

```
enum AccountStatus {
  option allow_alias = true;
  ACCOUNT_STATUS_UNKNOWN = 0;
  ACCOUNT_STATUS_PENDING = 1;
  ACCOUNT_STATUS_ACTIVE = 2;
  ACCOUNT_STATUS_SUSPENDED = 3;
  ACCOUNT_STATUS_CLOSED = 4;
  ACCOUNT_STATUS_CANCELLED = 4;
}
```

You can declare enumerations at the top level in a .proto file, or nested within a message definition. Nested enumerations—like nested messages—will be declared within the .Types static class in the generated message class.

There's no way to apply the [\[Flags\]](#) attribute to a Protobuf-generated enum, and Protobuf doesn't understand bitwise enum combinations. Take a look at the following example:

```
enum Region {
  REGION_NONE = 0;
  REGION_NORTH_AMERICA = 1;
  REGION_SOUTH_AMERICA = 2;
  REGION_EMEA = 4;
  REGION_APAC = 8;
}

message Product {
  Region available_in = 1;
}
```

If you set `product.AvailableIn` to `Region.NorthAmerica` | `Region.SouthAmerica`, it's serialized as the integer value 3. When a client or server tries to deserialize the value, it won't find a match in the enum definition for 3 and the result will be `Region.None`.

The best way to work with multiple enum values in Protobuf is to use a repeated field of the enum type.

## Protobuf maps for dictionaries

It's important to be able to represent arbitrary collections of named values in messages. In .NET this is commonly handled using dictionary types. Protobuf's equivalent of the .NET [IDictionary<TKey,TValue>](#) type is the `map<key_type, value_type>` type. This section shows how to declare a map in Protobuf, and how to use the generated code.

```
message StockPrices {
  map<string, double> prices = 1;
}
```

In the generated code, map fields use the `Google.Protobuf.Collections.MapField<TKey, TValue>` class, which implements the standard .NET collection interfaces, including [IDictionary<TKey,TValue>](#).

Map fields can't be directly repeated in a message definition, but you can create a nested message containing a map and use repeated on the message type, like in the following example:

```
message Order {  
    message Attributes {  
        map<string, string> values = 1;  
    }  
    repeated Attributes attributes = 1;  
}
```

## Using MapField properties in code

The MapField properties generated from map fields are read-only, and will never be null. To set a map property, use the `Add(IDictionary<TKey, TValue> values)` method on the empty MapField property to copy values from any .NET dictionary.

```
public Order CreateOrder(Dictionary<string, string> attributes)  
{  
    var order = new Order();  
    order.Attributes.Add(attributes);  
    return order;  
}
```

## Further reading

For more information about Protobuf, see the official [Protobuf documentation](#).

# Comparing WCF to gRPC

The previous chapter should have given you a good look at Protobuf and how gRPC handles messages. Before working through a detailed conversion from WCF to gRPC, it's important to look at how the range of features currently available in WCF are handled in gRPC and what workarounds you can use when there doesn't appear to be a gRPC equivalent. In particular, this chapter will cover the following subjects:

- Operations and methods
- Bindings and transports
- RPC types
- Metadata
- Error handling
- WS-\* protocols

## gRPC example

When you create a new ASP.NET Core 3.0 gRPC project from Visual Studio 2019 or the command line, the gRPC equivalent of "Hello World" is generated for you. It consists of a `greeter.proto` file that defines the service and its messages, and a `GreeterService.cs` file with an implementation of the service.

```
syntax = "proto3";

option csharp_namespace = "HelloGrpc";

package Greet;

// The greeting service definition.
service Greeter {
  // Sends a greeting
  rpc SayHello (HelloRequest) returns (HelloReply);
}

// The request message containing the user's name.
message HelloRequest {
  string name = 1;
}

// The response message containing the greetings.
message HelloReply {
  string message = 1;
}
```

```

using System.Threading.Tasks;
using Grpc.Core;
using Microsoft.Extensions.Logging;

namespace HelloGrpc
{
    public class GreeterService : Greeter.GreeterBase
    {
        private readonly ILogger<GreeterService> _logger;
        public GreeterService(ILogger<GreeterService> logger)
        {
            _logger = logger;
        }

        public override Task<HelloReply> SayHello(HelloRequest request, ServerCallContext
context)
        {
            return Task.FromResult(new HelloReply
            {
                Message = "Hello " + request.Name
            });
        }
    }
}

```

This chapter will refer to this example code when explaining various concepts and features of gRPC.

## WCF endpoints and gRPC methods

In WCF, when you're writing your application code, you use one of the following methods:

- You write the application code in a class and decorate methods with the [OperationContract](#) attribute.
- You declare an interface for the service and add [OperationContract](#) attributes to the interface.

For example, the WCF equivalent of the greet.proto Greeter service might be written as follows:

```

[ServiceContract]
public interface IGreeterService
{
    [OperationContract]
    string SayHello(string name);
}

```

Chapter 3 showed that Protobuf message definitions are used to generate data classes. Service and method declarations are used to generate base classes that you inherit from to implement the service. You just declare the methods to be implemented in the .proto file, and the compiler generates a base class with virtual methods you must override.

## OperationContract properties

The [OperationContract](#) attribute has properties to control or refine how it works. gRPC methods don't offer this type of control. The following table sets out those OperationContract properties and how the functionality they specify is (or isn't) dealt with in gRPC:

OperationContract property	gRPC
<a href="#">Action</a>	URI identifying the operation. gRPC uses the name of the package, service and rpc from the .proto file.
<a href="#">AsyncPattern</a>	All gRPC service methods return Task objects.
<a href="#">IsInitiating</a>	See note below.
<a href="#">IsOneWay</a>	One-way gRPC methods return Empty results or use client streaming.
<a href="#">IsTerminating</a>	See note below.
<a href="#">Name</a>	SOAP-related, no meaning in gRPC.
<a href="#">ProtectionLevel</a>	No message encryption; network encryption handled at the transport layer (TLS over HTTP/2).
<a href="#">ReplyAction</a>	SOAP-related, no meaning in gRPC.

The [IsInitiating](#) property lets you indicate that a method within a [ServiceContract](#) can't be the first method called as part of a session. The [IsTerminating](#) property causes the server to close the session after an operation is called (or the client, if used on a callback client). In gRPC, streams are created by single methods and closed explicitly. See [gRPC streaming](#).

For more information on gRPC security and encryption, see [chapter 6](#).

## WCF bindings and transports

WCF has lots of different built-in *bindings* that specify different network protocols, wire formats, and other implementation details. gRPC effectively has just one network protocol and one wire format (technically the wire format *may* be customized, but that is beyond the scope of this book). You are likely to discover that gRPC offers the best solution in most cases. What follows is a short discussion about the most relevant WCF bindings and how they compare to their equivalent in gRPC.

### NetTCP

WCF's NetTCP binding allows for persistent connections, small messages, and two-way messaging but only works between .NET clients and servers. gRPC allows the same functionality but is supported across multiple programming languages and platforms. gRPC has many of the features of WCF NetTCP binding, although not always implemented in the same way. For example, in WCF, encryption is controlled through configuration and handled in the framework. In gRPC, encryption is achieved at the connection level using HTTP/2 over TLS.

## HTTP

WCF's BasicHttpBinding is usually text based, using SOAP as the wire format, and is slow compared to the NetTCP binding. It's generally used to provide cross-platform interoperability, or connection over internet infrastructure. The equivalent in gRPC—because it uses HTTP/2 as the underlying transport layer with the binary Protobuf wire format for messages—can offer NetTCP service level performance but with full cross-platform interoperability with all modern programming languages and frameworks.

## Named Pipes

WCF provided a Named Pipes binding for communication between processes on the same physical machine. Named pipes are not supported by the first release of ASP.NET Core gRPC. Adding client and server support for named pipes (and Unix domain sockets) is a goal for a future release.

## MSMQ

MSMQ is a proprietary Windows message queue. WCF's binding to MSMQ enables “fire and forget” requests from clients that may be processed at any time in the future. gRPC doesn't natively provide any message queue functionality. The best alternative would be to directly use a messaging system like Azure Service Bus, RabbitMQ, or Kafka. This could be implemented with the client placing messages directly onto the queue, or a gRPC client streaming service that enqueues the messages.

## WebHttpBinding

The WebHttpBinding (also known as WCF ReST), with the WebGet and WebInvoke attributes, enabled you to develop ReSTful APIs that could speak JSON at a time when this was less common than now. Therefore, if you have a RESTful API built with WCF REST, consider migrating it to a regular ASP.NET Core MVC Web API application, which would provide equivalent functionality, rather than converting to gRPC.

## Types of RPC

As a Windows Communication Foundation (WCF) developer, you're probably used to dealing with the following types of Remote Procedure Call (RPC):

- Request/Reply
- Duplex:
  - One-way duplex with session
  - Full duplex with session
- One-way



It's possible to map these RPC types fairly naturally to existing gRPC concepts and this chapter will look at each of these areas in turn. Similar examples will be explored in much greater depth in [Chapter 5](#).

WCF	gRPC
Regular request/reply	Unary
Duplex service with session using a client callback interface	Server streaming
Full duplex service with session	Bidirectional streaming
One-way operations	Client streaming

## Request/reply

For simple request/reply methods that take and return small amounts of data, use the simplest gRPC pattern, the unary RPC.

```
service Things {  
    rpc Get(GetThingRequest) returns (GetThingResponse);  
}
```

```
public class ThingService : Things.ThingsBase  
{  
    public override async Task<GetThingResponse> Get(GetThingRequest request,  
        ServerCallContext context)  
    {  
        // Get thing from database  
        return new GetThingResponse { Thing = thing };  
    }  
}
```

```
public async Task ShowThing(int thingId)  
{  
    var thing = await _thingsClient.GetAsync(new GetThingRequest { ThingId = thingId });  
    Console.WriteLine($"{thing.Name}");  
}
```

As you can see, implementing a gRPC unary RPC service method is very similar to implementing a WCF operation, except that with gRPC you override a base class method instead of implementing an interface. Note that on the server, gRPC base methods always return a [Task](#), although the client provides both async and blocking methods to call the service.

## WCF duplex, one-way to client

WCF applications (with certain bindings) can create a persistent connection between client and server, and the server can asynchronously send data to the client until the connection is closed, using a *callback interface* specified in the [ServiceContractAttribute.CallbackContract](#) property.

gRPC services provide similar functionality with message streams. Streams don't map *exactly* to WCF duplex services in terms of implementation, but the same results can be achieved.

## gRPC streaming

gRPC supports the creation of persistent streams from client to server, and from server to client. Both types of stream may be active concurrently; this is called bidirectional streaming. Streams can be used for arbitrary, asynchronous messaging over time, or for passing large datasets that are too big to generate and send in a single request or response.

The following example shows a server streaming RPC.

```
service ClockStreamer {  
    rpc Subscribe(ClockSubscribeRequest) returns (stream ClockMessage);  
}
```

```
public class ClockStreamerService : ClockStreamer.ClockStreamerBase  
{  
    public override async Task Subscribe(ClockSubscribeRequest request,  
        IServerStreamWriter<ClockMessage> responseStream,  
        ServerCallContext context)  
    {  
        while (!context.CancellationToken.IsCancellationRequested)  
        {  
            var time = DateTimeOffset.UtcNow;  
            await responseStream.WriteAsync(new ClockMessage { message = $"The time is  
{time:t}." });  
            await Task.Delay(TimeSpan.FromSeconds(10), context.CancellationToken);  
        }  
    }  
}
```

This server stream could be consumed from a client application as shown in the following code:

```
public async Task TellTheTimeAsync(Cancellation token)  
{  
    var channel = GrpcChannel.ForAddress("https://localhost:5001");  
    var client = new ClockStreamer.ClockStreamerClient(channel);  
  
    var request = new ClockSubscribeRequest();  
    var response = client.Subscribe(request);  
  
    await foreach (var update in response.ResponseStream.ReadAllAsync(token))  
    {  
        Console.WriteLine(update.Message);  
    }  
}
```

### Note

Server streaming RPCs are useful for subscription-style services, and also for sending very large datasets when it would be inefficient or impossible to build the entire dataset in memory. However, streaming responses isn't as fast as sending repeated fields in a single message, so as a rule streaming shouldn't be used for small datasets.

## Differences to WCF

A WCF duplex service uses a client callback interface that can have multiple methods. A gRPC server streaming service can only send messages over a single stream. If you need multiple methods, use a message type with either [an Any field or a oneof field](#) to send different messages, and write code in the client to handle them.

In WCF, the [ServiceContract](#) class with the session is kept alive until the connection is closed, and multiple methods may be called within the session. In gRPC, the Task returned by the implementation method shouldn't complete until the connection is closed.

## WCF one-way operations and gRPC client streaming

WCF provides one-way operations (marked with [OperationContract(IsOneWay = true)]) that return a transport-specific acknowledgement. gRPC service methods always return a response, even if it's empty, and the client should always await that response. For "fire-and-forget" style messaging in gRPC, you can create a client streaming service.

### thing\_log.proto

```
service ThingLog {  
  rpc OpenConnection(stream Thing) returns (ConnectionClosedResponse);  
}
```

### ThingLogService.cs

```
public class ThingLogService : Protos.ThingLog.ThingLogBase  
{  
    private static readonly ConnectionClosedResponse EmptyResponse = new  
    ConnectionClosedResponse();  
    private readonly ILogger<ThingLogService> _logger;  
    public ThingLogService(ILogger<ThingLogService> logger)  
    {  
        _logger = logger;  
    }  
  
    public override async Task<CompletedResponse> OpenConnection(IAsyncStreamReader<Thing>  
    requestStream, ServerCallContext context)  
    {  
        while (await requestStream.MoveNext(context.CancellationToken))  
        {  
            _logger.LogInformation(requestStream.Current.Description);  
        }  
        return EmptyResponse;  
    }  
}
```

## ThingLog client example

```
public class ThingLogger : IAsyncDisposable
{
    private readonly ThingLog.ThingLogClient _client;
    private readonly AsyncClientStreamingCall<ThingLogRequest, CompletedResponse> _stream;

    public ThingLogger(ThingLog.ThingLogClient client)
    {
        _client = client;
        _stream = client.OpenConnection();
    }

    public async Task WriteAsync(string description)
    {
        await _stream.RequestStream.WriteAsync(new Thing
        {
            Description = description,
            Time = Timestamp.FromDateTimeOffset(DateTimeOffset.UtcNow)
        });
    }

    public async ValueTask DisposeAsync()
    {
        await _stream.RequestStream.CompleteAsync();
        _stream.Dispose();
    }
}
```

Again, client streaming RPCs can be used for fire-and-forget messaging as shown in the previous example, but also for sending very large datasets to the server. The same warning about performance applies: for smaller datasets, use repeated fields in regular messages.

## WCF full duplex services

WCF duplex binding supports multiple one-way operations on both the service interface and the client callback interface, allowing ongoing conversations between client and server. gRPC supports something similar with bidirectional streaming RPCs, where both parameters are marked with the stream modifier.

### chat.proto

```
service Chatter {
    rpc Connect(stream IncomingMessage) returns (stream OutgoingMessage);
}
```

## ChatterService.cs

```
public class ChatterService : Chatter.ChatterBase
{
    private readonly IChatHub _hub;

    public ChatterService(IChatHub hub)
    {
        _hub = hub;
    }

    public override async Task Connect(IAsyncStreamReader<MessageRequest> requestStream,
        IServerStreamWriter<MessageResponse> responseStream, ServerCallContext context)
    {
        _hub.MessageReceived += async (sender, args) =>
            await responseStream.WriteAsync(new MessageResponse {Text = args.Message});

        while (await requestStream.MoveNext(context.CancellationToken))
        {
            await _hub.SendAsync(requestStream.Current.Text);
        }
    }
}
```

In the previous example, you can see that the implementation method receives both a request stream (*IAsyncStreamReader<MessageRequest>*) and a response stream (*IServerStreamWriter<MessageResponse>*), and can read and write messages until the connection is closed.

## Chatter client

```
public class Chat : IAsyncDisposable
{
    private readonly Chatter.ChatterClient _client;
    private readonly AsyncDuplexStreamingCall<MessageRequest, MessageResponse> _stream;
    private readonly CancellationTokenSource _cancellationTokenSource;
    private readonly Task _readTask;

    public Chat(Chatter.ChatterClient client)
    {
        _client = client;
        _stream = _client.Connect();
        _cancellationTokenSource = new CancellationTokenSource();
        _readTask = ReadAsync(_cancellationTokenSource.Token);
    }

    public async Task SendAsync(string message)
    {
        await _stream.RequestStream.WriteAsync(new MessageRequest {Text = message});
    }

    private async Task ReadAsync(CancellationToken token)
    {
        while (await _stream.ResponseStream.MoveNext(token))
        {
            Console.WriteLine(_stream.ResponseStream.Current.Text);
        }
    }
}
```

```

public async ValueTask DisposeAsync()
{
    await _stream.RequestStream.CompleteAsync();
    await _readTask;
    _stream.Dispose();
}
}

```

## Metadata

“Metadata” refers to additional data that may be useful while processing requests and responses but is not part of the actual application data. Metadata might include authentication tokens, request identifiers and tags for monitoring purposes, or information about the data like the number of records in a dataset.

It’s possible to add generic key/value headers to WCF messages using an [OperationContextScope](#) and the [OperationContext.OutgoingMessageHeaders](#) property, and handle them using [MessageProperties](#).

gRPC calls and responses can also include metadata similar to HTTP headers. These are mostly invisible to gRPC itself and are passed through to be processed by your application code or middleware. Metadata is represented as key/value pairs where the key is a string and the value is either a string or binary data. You don’t need to specify metadata in the .proto file.

Metadata is handled using the Metadata class from the [Grpc.Core.Api](#) NuGet package. This class can be used with collection initializer syntax.

The following example shows how to add metadata to a call from a C# client:

```

var metadata = new Metadata
{
    { "Requester", _clientName }
};

var request = new GetPortfolioRequest
{
    Id = portfolioId
};

var response = await client.GetPortfolioAsync(request, metadata);

```

gRPC services can access metadata from the ServerCallContext argument’s RequestHeaders property:

```

public async Task<GetPortfolioResponse> GetPortfolio(GetPortfolioRequest request,
ServerCallContext context)
{
    var requesterHeader = context.RequestHeaders.FirstOrDefault(e => e.Key == "Requester");
    if (requesterHeader != null)
    {
        _logger.LogInformation($"Request from {requesterHeader.Value}");
    }
    // ...
}

```

Services can send metadata to clients using the `ResponseTrailers` property of `ServerCallContext`:

```
public async Task<GetPortfolioResponse> GetPortfolio(GetPortfolioRequest request,
ServerCallContext context)
{
    // ...
    context.ResponseTrailers.Add("Responder", _serverName);
    // ...
}
```

## Error handling

WCF uses `FaultException<T>` and `FaultContract` to provide detailed error information, including supporting the SOAP Fault standard.

Unfortunately, the current version of gRPC lacks the sophistication found with WCF and only has limited built-in error handling based on simple status codes and metadata. The following table is a quick guide to the most commonly used status codes:

Status Code	Problem
GRPC_STATUS_UNIMPLEMENTED	Method hasn't been written.
GRPC_STATUS_UNAVAILABLE	Problem with the whole service.
GRPC_STATUS_UNKNOWN	Invalid response.
GRPC_STATUS_INTERNAL	Problem with encoding/decoding.
GRPC_STATUS_UNAUTHENTICATED	Authentication failed.
GRPC_STATUS_PERMISSION_DENIED	Authorization failed.
GRPC_STATUS_CANCELLED	Call was canceled, usually by the caller.

## Raising errors in ASP.NET Core gRPC

An ASP.NET Core gRPC service can send an error response by throwing an `RpcException`, which can be caught by the client as if it were in the same process. The `RpcException` must include a status code and description, and can optionally include metadata and a longer exception message. The metadata can be used to send supporting data, similar to how `FaultContract` objects could carry additional data for WCF errors.

```
public async Task<GetPortfolioResponse> GetPortfolio(GetPortfolioRequest request,
ServerCallContext context)
{
    var user = context.GetHttpContext().User;
    if (!ValidateUser(user))
    {
        var metadata = new Metadata
        {
            { "User", user.Identity.Name }
        };
        throw new RpcException(new Status(StatusCode.PermissionDenied, "Permission
denied"), metadata);
    }
}
```

```
}  
}
```

## Catching errors in gRPC clients

Just like WCF clients can catch [FaultException](#) errors, a gRPC client can catch an `RpcException` to handle errors. Since `RpcException` isn't a generic type, you can't catch different error types in different blocks, but you can use C#'s *exception filters* feature to declare separate catch blocks for different status codes, as shown in the following example:

```
try  
{  
    var portfolio = await client.GetPortfolioAsync(new GetPortfolioRequest { Id = id });  
}  
catch (RpcException ex) when (ex.StatusCode == StatusCode.PermissionDenied)  
{  
    var userEntry = ex.Trailers.FirstOrDefault(e => e.Key == "User");  
    Console.WriteLine($"User '{userEntry.Value}' does not have permission to view this  
portfolio.");  
}  
catch (RpcException)  
{  
    // Handle any other error type ...  
}
```

### Important

When you provide additional metadata for errors, be sure to document the relevant keys and values in your API documentation, or in comments in your `.proto` file.

## gRPC Richer Error Model

Looking ahead, Google has developed a [richer error model](#) that is more like WCF's [FaultContract](#), but isn't supported in C# yet. Currently, it's only available for Go, Java, Python and C++, but support for C# is expected to come next year.

## WS-\* protocols

One of the real benefits of working with Windows Communication Foundation (WCF) was that it supported many of the existing WS-\* standard protocols. This section will briefly cover how gRPC manages the same WS-\* protocols and discuss what options are available when there's no alternative.

### Metadata Exchange - WS-Policy, WS-Discovery, and so on

SOAP services expose Web Services Description Language (WSDL) schema documents with information such as data formats, operations, or communication options. This schema could be used to generate the client code.

gRPC works best when servers and clients are generated from the same `.proto` files, but a server reflection optional extension does provide a way to expose dynamic information from a running



server. For more information, see the [Grpc.Reflection](#) NuGet package and the [gRPC C# Server Reflection](#) article.

The WS-Discovery protocol is used to locate services on a local network. gRPC services are generally located using DNS or a service registry such as Consul or ZooKeeper.

## Security – WS-Security, WS-Federation, XML Encryption, and so on

Security, authentication, and authorization are covered in much more detail in [Chapter 6](#). But it's worth noting here that, unlike WCF, gRPC doesn't support WS-Security, WS Federation, or XML Encryption. Even so, gRPC provides excellent security; all gRPC network traffic is automatically encrypted when using HTTP/2 over TLS, and X509 certificates may be used for mutual client/server authentication.

## WS-ReliableMessaging

gRPC does not provide an equivalent to WS-ReliableMessaging. Retry semantics should be handled in code, possibly with a library like [Polly](#). When running in Kubernetes or similar orchestration environments, [service meshes](#) can also help to provide reliable messaging between services.

## WS-Transaction, WS-Coordination

WCF's implementation of distributed transactions uses Windows' Microsoft Distributed Transaction Coordinator or MSDTC. It works with resource managers that specifically support it, like SQL Server, MSMQ, or Windows file systems. In the modern microservices world, in part due to the wider range of technologies in use, there is no equivalent as yet. For a discussion of transactions, see [Appendix A](#).

# Migrate a WCF solution to gRPC

This chapter will look at how to work with ASP.NET Core 3.0 gRPC projects and demonstrate migrating different types of WCF service to the gRPC equivalent:

- Create an ASP.NET Core 3.0 gRPC project.
- Simple Request-Reply operations to gRPC unary RPC.
- One-way operations to gRPC client streaming RPC.
- Full Duplex services to gRPC bidirectional streaming RPC.

There's also a comparison of using streaming services versus repeated fields for returning data sets, and the use of client libraries at the end of the chapter.

The sample WCF application is a minimal stub of a set of stock trading services, using the open-source Inversion of Control (IoC) container library called *Autofac* for dependency injection. It includes three services, one for each WCF service type. The services will be discussed in more detail in the following sections. The solutions can be downloaded from [dotnet-architecture/grpc-for-wcf-developers](https://github.com/dotnet-architecture/grpc-for-wcf-developers) on GitHub. The services use fake data to minimize external dependencies.

The samples include the WCF and gRPC implementations of each service.

## Create a new ASP.NET Core gRPC project

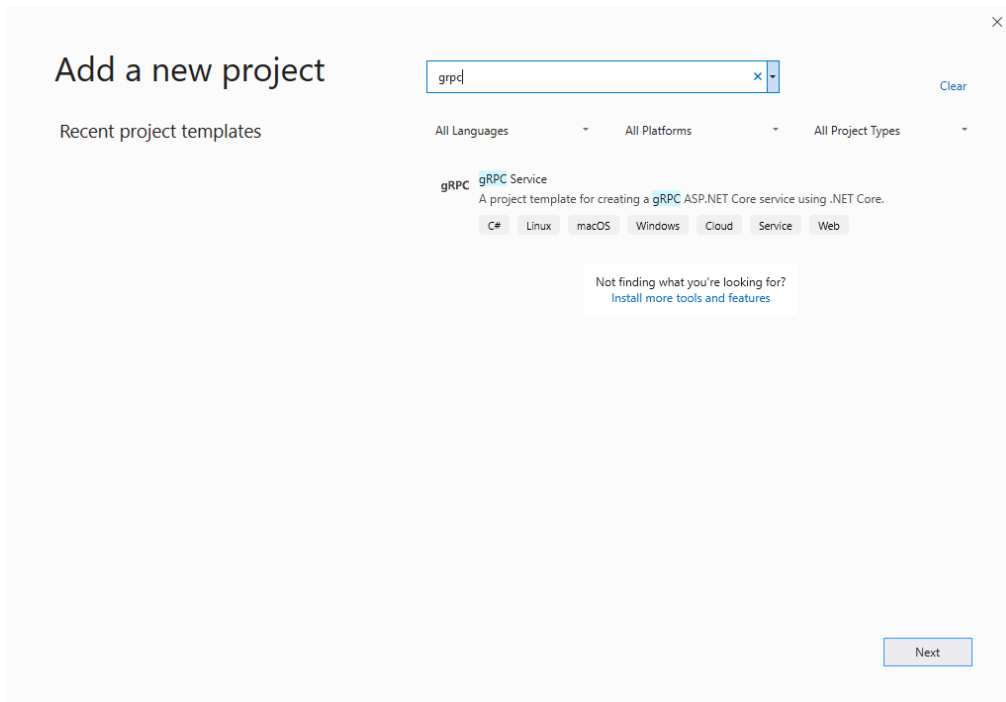
.NET Core comes with a powerful CLI tool, *dotnet*, which enables you to create and manage projects and solutions from the command line. The tool is closely integrated with Visual Studio, so everything is also available through the familiar GUI interface. This chapter will show both ways to create a new ASP.NET Core gRPC project: first with Visual Studio, then with the .NET Core CLI.

### Create the project using Visual Studio

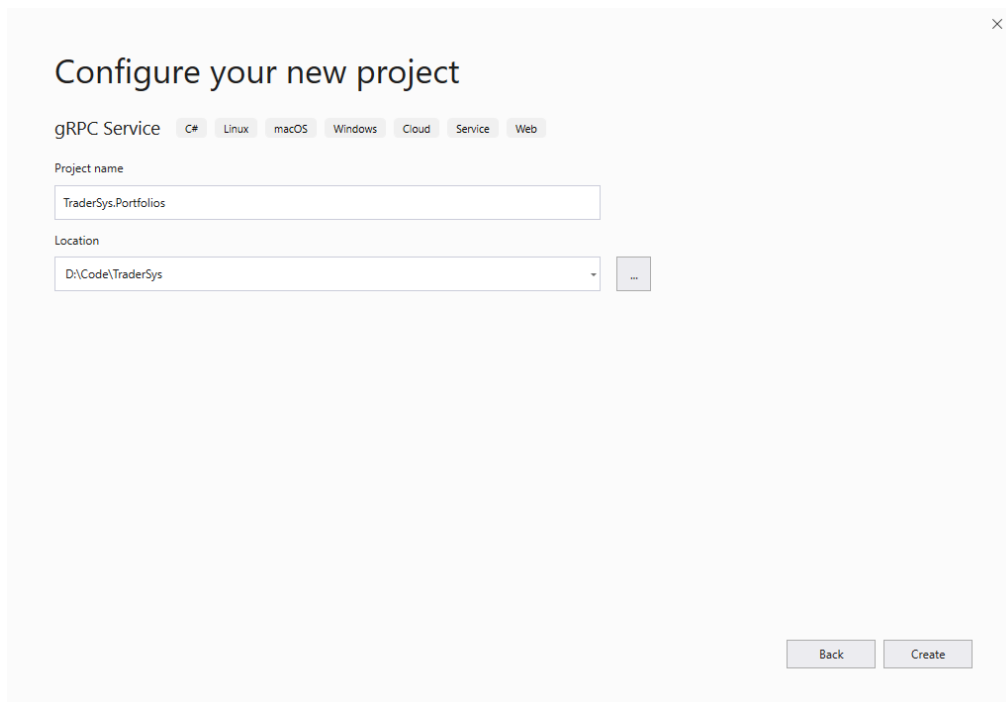
#### Important

To develop any ASP.NET Core 3.0 app, you need Visual Studio 2019.3 or later with the **ASP.NET and web development** workload installed.

Create an empty solution called **TraderSys** from the *Blank Solution* template. Add a Solution Folder called `src`, then right-click on the folder and choose **Add > New Project** from the context menu. Enter `grpc` in the template search box and you should see a project template called `gRPC Service`.



Click **Next** to continue to the **Configure project** dialog and name the project `TraderSys.Portfolios`, and add an `src` subdirectory to the **Location**.



Click **Next** to continue to the **New gRPC project** dialog.

**Create a new gRPC service**

**gRPC gRPC Service**  
A project template for creating a gRPC ASP.NET Core service.

**Authentication**  
No Authentication  
[Change](#)

**Advanced**  
☐ Enable Docker Support  
(Requires [Docker Desktop](#))  
Linux

Author: Microsoft  
Source: .NET Core 3.0.0-rc1-014190

[Get additional project templates](#)

[Back](#) [Create](#)

At present, there are limited options for the service creation. Docker will be introduced later in the book, so leave that checkbox unchecked for now and just click **Create**. Your first ASP.NET Core 3.0 gRPC project is generated and added to the solution. If you don't want to know about working with the dotnet CLI, skip to the [Clean up the example code](#) section.

## Create the project using the .NET Core CLI

This section covers the creation of solutions and projects from the command line.

Create the solution as shown below. The `-o` (or `--output`) flag specifies the output directory, which will be created in the current directory if it does not exist. The solution will be given the same name as the directory, i.e. `TraderSys.sln`. You can provide a different name using the `-n` (or `--name`) flag.

```
dotnet new sln -o TraderSys
cd TraderSys
```

ASP.NET Core 3.0 comes with a CLI template for gRPC services. Create the new project using this template, putting it into an `src` subdirectory as is the convention for ASP.NET Core projects. The project will be named after the directory (i.e. `TraderSys.Portfolios.csproj`) unless you specify a different name with the `-n` flag.

```
dotnet new grpc -o src/TraderSys.Portfolios
```

Finally, add the project to the solution using the `dotnet sln` command.

```
dotnet sln add src/TraderSys.Portfolios
```

### Tip

Since the given directory only contains a single .csproj file, you can get away with specifying just the directory to save typing.

You can now open this solution in Visual Studio 2019, Visual Studio Code, or whatever editor you prefer.

## Clean up the example code

You've now created an example service using the gRPC template, which was reviewed earlier in the book. This isn't useful in our stock trading context, so we'll edit things for our first project.

### Rename and edit the proto file

Go ahead and rename the Protos/greet.proto file to Protos/portfolios.proto and open it in your editor. Delete everything after the package line, then change the option `csharp_namespace`, package and service names, and remove the default `SayHello` service, so the code looks like this.

```
syntax = "proto3";

option csharp_namespace = "TraderSys.Portfolios.Protos";

package PortfolioServer;

service Portfolios {
    // RPCs will go here
}
```

### Tip

The template doesn't add the Protos namespace part by default, but adding it makes it easier to keep gRPC-generated classes and your own classes clearly separated in your code.

If you rename the `greet.proto` file in an integrated development environment (IDE) like Visual Studio, a reference to this file is automatically updated in the .csproj file. But in some other editor, such as Visual Studio Code, this reference isn't updated automatically, so you need to edit the project file manually.

In the gRPC build targets, there's a `Protobuf` item element that lets you specify which .proto files should be compiled and which form of code generation is required (that is, "Server" or "Client").

```
<ItemGroup>
  <Protobuf Include="Protos\portfolios.proto" GrpcServices="Server" />
</ItemGroup>
```

## Rename the GreeterService class

The GreeterService class is in the Services folder and inherits from Greeter.GreeterBase. Rename it to PortfolioService and change the base class to Portfolios.PortfoliosBase. Delete the override methods.

```
public class PortfolioService : Portfolios.PortfoliosBase
{
}
```

There was a reference to the GreeterService class in the Configure method in the Startup class. If you used refactoring to rename the class, this reference should have been updated automatically. However, if you didn't, you need to edit it manually.

```
public void Configure(IApplicationBuilder app, IWebHostEnvironment env)
{
    if (env.IsDevelopment())
    {
        app.UseDeveloperExceptionPage();
    }

    app.UseRouting();

    app.UseEndpoints(endpoints =>
    {
        endpoints.MapGrpcService<PortfolioService>();
    });
}
```

In the next section, we'll add functionality to this new service.

## Migrate a WCF request-reply service to a gRPC unary RPC

This section covers how to migrate a basic request-reply service in WCF to a unary RPC service in ASP.NET Core gRPC. These services are the simplest service types in both Windows Communication Foundation (WCF) and gRPC, so it's an excellent place to start. After migrating the service, you'll learn how to generate a client library from the same .proto file to consume the service from a .NET client application.

### The WCF solution

The [PortfoliosSample solution](#) includes a simple Request-Reply Portfolio service to download a single portfolio, or all portfolios for a given Trader. The service is defined in the interface IPortfolioService with a ServiceContract attribute:

```
[ServiceContract]
public interface IPortfolioService
{
    [OperationContract]
    Task<Portfolio> Get(Guid traderId, int portfolioId);

    [OperationContract]
    Task<List<Portfolio>> GetAll(Guid traderId);
}
```

The Portfolio model is a simple C# class marked with [DataContract](#), including a list of PortfolioItem objects. These models are defined in the TraderSys.PortfolioData project, along with a repository class representing a data access abstraction.

```
[DataContract]
public class Portfolio
{
    [DataMember]
    public int Id { get; set; }

    [DataMember]
    public Guid TraderId { get; set; }

    [DataMember]
    public List<PortfolioItem> Items { get; set; }
}

[DataContract]
public class PortfolioItem
{
    [DataMember]
    public int Id { get; set; }

    [DataMember]
    public int ShareId { get; set; }

    [DataMember]
    public int Holding { get; set; }

    [DataMember]
    public decimal Cost { get; set; }
}
```

The ServiceContract implementation uses a repository class provided via dependency injection that returns instances of the DataContract types.

```

public class PortfolioService : IPortfolioService
{
    private readonly IPortfolioRepository _repository;

    public PortfolioService(IPortfolioRepository repository)
    {
        _repository = repository;
    }

    public async Task<Portfolio> Get(Guid traderId, int portfolioId)
    {
        return await _repository.GetAsync(traderId, portfolioId);
    }

    public async Task<List<Portfolio>> GetAll(Guid traderId)
    {
        return await _repository.GetAllAsync(traderId);
    }
}

```

## The portfolios.proto file

If you followed the instructions in the previous section, you should have a gRPC project with a `portfolios.proto` file that looks like this.

```

syntax = "proto3";

option csharp_namespace = "TraderSys.Portfolios.Protos";

package PortfolioServer;

service Portfolios {
    // RPCs will go here
}

```

The first step is to migrate the `DataContract` classes to their Protobuf equivalents.

## Convert the DataContracts to gRPC messages

The `PortfolioItem` class will be converted to a Protobuf message first, as the `Portfolio` class depends on it. The class is very simple, and three of the properties map directly to gRPC data types. The `Cost` property, representing the price paid for the shares at purchase, is a decimal field, and gRPC only supports `float` or `double` for real numbers, which aren't suitable for currency. Since share prices vary by a minimum of one cent, the cost can be expressed as an `int32` of cents.

### Note

Remember to use camelCase for field names in your `.proto` file; the C# code generator will convert them to PascalCase for you, and users of other languages will thank you for respecting their different coding standards.



```
message PortfolioItem {
    int32 id = 1;
    int32 share_id = 2;
    int32 holding = 3;
    int32 cost_cents = 4;
}
```

The Portfolio class is a little more complicated. In the WCF code, the developer used a Guid for the TraderId property, and contains a List<PortfolioItem>. In Protobuf, which doesn't have a first-class UUID type, you should use a string for the traderId field and parse it in your own code. For the list of items, use the repeated keyword on the field.

```
message Portfolio {
    int32 id = 1;
    string trader_id = 2;
    repeated PortfolioItem items = 3;
}
```

Now we have our data messages, we can declare the service RPC endpoints.

## Convert the ServiceContract to a gRPC service

The WCF Get method takes two parameters: Guid traderId and int portfolioId. gRPC service methods can only take a single parameter, so a message must be created to hold the two values. It's common practice to name these request objects with the same name as the method and the suffix Request. Again, string is being used for the traderId field instead of Guid.

The service could just return a Portfolio message directly, but again, this could impact backward compatibility in the future. It's a good practice to define separate Request and Response messages for every method in a service, even if many of them are the same right now, so declare a GetResponse message with a single Portfolio field.

The following example shows the declaration of the gRPC service method using the GetRequest message:

```
message GetRequest {
    string trader_id = 1;
    int32 portfolio_id = 2;
}

message GetResponse {
    Portfolio portfolio = 1;
}

service Portfolios {
    rpc Get(GetRequest) returns (GetResponse);
}
```

The WCF GetAll method only takes a single parameter, traderId, so it might seem that one could specify string as the parameter type, but gRPC requires a defined message type. This requirement helps to enforce the practice of using custom messages for all inputs and outputs, for future backward compatibility.

The WCF method also returned a `List<Portfolio>`, but for the same reason it doesn't allow simple parameter types, gRPC won't allow repeated `Portfolio` as a return type. Instead, create a `GetAllResponse` type to wrap the list.

### Warning

You may be tempted to create a `PortfolioList` message or similar and use it across multiple service methods, but you should resist this temptation. It's impossible to know how the various methods on a service may evolve in the future, so keep their messages specific and cleanly separated.

```
message GetAllRequest {
    string trader_id = 1;
}

message PortfolioList {
    repeated Portfolio portfolios = 1;
}

service Portfolios {
    rpc Get(GetRequest) returns (Portfolio);
    rpc GetAll(GetAllRequest) returns (GetAllResponse);
}
```

If you save your project with these changes, the gRPC build target will run in the background and generate all the Protobuf message types and a base class you can inherit to implement the service.

Open up the `Services/GreeterService.cs` class and delete the example code. Now you can add the `Portfolio` service implementation. The generated base class will be in the `Protos` namespace and is generated as a nested class. gRPC creates a static class with the same name as the service in the `.proto` file, and then a base class with the suffix `Base` inside that static class, so the full identifier for the base type is `TraderSys.Portfolios.Protos.Portfolios.PortfoliosBase`.

```
namespace TraderSys.Portfolios.Services
{
    public class PortfolioService : Protos.Portfolios.PortfoliosBase
    {
    }
}
```

The base class declares virtual methods for `Get` and `GetAll` that can be overridden to implement the service. The methods are virtual rather than abstract so that if you don't implement them, the service can return an explicit gRPC `Unimplemented` status code, much like you might throw a `NotImplementedException` in regular C# code.

The signature for all gRPC unary service methods in ASP.NET Core is consistent. There are two parameters: the first is the message type declared in the `.proto` file, and the second is a `ServerCallContext` that works similarly to the `HttpContext` from ASP.NET Core. In fact, there's an extension method called `GetHttpContext` on the `ServerCallContext` class that you can use to get the underlying `HttpContext`, although you shouldn't need to use it often. We'll take a look at `ServerCallContext` later in this chapter, and also in the chapter that discusses authentication.

The method's return type is a `Task<T>` where `T` is the response message type. All gRPC service methods are asynchronous.

## Migrate the PortfolioData library to .NET Core

At this point, the project needs the Portfolio repository and models contained in the `TraderSys.PortfolioData` class library in the WCF solution. The easiest way to bring them across is to create a new class library using either the Visual Studio **New project** dialog with the *Class Library (.NET Standard)* template, or from the command line using the .NET Core CLI, running the following commands from the directory containing the `TraderSys.sln` file.

```
dotnet new classlib -o src/TraderSys.PortfolioData
dotnet sln add src/TraderSys.PortfolioData
```

Once the library has been created and added to the solution, delete the generated `Class1.cs` file and copy the files from the WCF solution's library into the new class library's folder, keeping the folder structure.

```
Models
  Portfolio.cs
  PortfolioItem.cs
IPortfolioRepository.cs
PortfolioRepository.cs
```

SDK-style .NET projects automatically include any .cs files in or under their own directory, so there's no need to explicitly add them to the project. The only step remaining is to remove the `DataContract` and `DataMember` attributes from the `Portfolio` and `PortfolioItem` classes so they're plain old C# classes.

```
public class Portfolio
{
    public int Id { get; set; }
    public Guid TraderId { get; set; }
    public List<PortfolioItem> Items { get; set; }
}

public class PortfolioItem
{
    public int Id { get; set; }
    public int ShareId { get; set; }
    public int Holding { get; set; }
    public decimal Cost { get; set; }
}
```

## Use ASP.NET Core dependency injection

Now you can add a reference to this library to the gRPC application project and consume the `PortfolioRepository` class using dependency injection in the gRPC service implementation. In the WCF application, dependency injection was provided by the Autofac IoC container. ASP.NET Core has dependency injection baked in; the repository can be registered in the `ConfigureServices` method in the `Startup` class.

```

public class Startup
{
    public void ConfigureServices(IServiceCollection services)
    {
        // Register the repository class as a scoped service (instance per request)
        services.AddScoped<IPortfolioRepository, PortfolioRepository>();

        services.AddGrpc();
    }

    // ...
}

```

The `IPortfolioRepository` implementation can now be specified as a constructor parameter in the `PortfolioService` class, as follows:

```

public class PortfolioService : Protos.Portfolios.PortfoliosBase
{
    private readonly IPortfolioRepository _repository;

    public PortfolioService(IPortfolioRepository repository)
    {
        _repository = repository;
    }
}

```

## Implement the gRPC service

Now that you've declared your messages and your service in the `portfolios.proto` file, you have to implement the service methods in the `PortfolioService` class that inherits from the gRPC-generated `Portfolios.PortfoliosBase` class. The methods are declared as `virtual` in the base class. If you don't override them, they'll return a gRPC "Not Implemented" status code by default.

Start by implementing the `Get` method. The default override looks like the following example:

```

public override Task<GetResponse> Get(GetRequest request, ServerCallContext context)
{
    return base.Get(request, context);
}

```

The first issue is that `request.TraderId` is a string, and the service requires a `Guid`. Even though the expected format for the string is a UUID, the code has to deal with the possibility that a caller has sent an invalid value and respond appropriately. The service can respond with errors by throwing an `RpcException`, and use the standard `InvalidArgument` status code to express the problem.

```

public override Task<GetResponse> Get(GetRequest request, ServerCallContext context)
{
    if (!Guid.TryParse(request.TraderId, out var traderId))
    {
        throw new RpcException(new Status(StatusCode.InvalidArgument, "traderId must be a UUID"));
    }

    return base.Get(request, context);
}

```

Once there's a proper Guid value for `traderId`, the repository can be used to retrieve the `Portfolio` and return it to the client.

```
var response = new GetResponse
{
    Portfolio = await _repository.GetAsync(request.TraderId, request.PortfolioId)
};
```

## Map internal models to gRPC messages

The previous code doesn't actually work because the repository is returning its own POCO model `Portfolio`, but gRPC needs *its* own Protobuf message `Portfolio`. Much like mapping Entity Framework types to data transfer types, the best solution is to provide conversion between the two. A good place to put the code for this is in the Protobuf-generated class, which is declared as a partial class so it can be extended.

```
namespace TraderSys.Portfolios.Protos
{
    public partial class PortfolioItem
    {
        public static PortfolioItem FromRepositoryModel(PortfolioData.Models.PortfolioItem
source)
        {
            if (source is null) return null;

            return new PortfolioItem
            {
                Id = source.Id,
                ShareId = source.ShareId,
                Holding = source.Holding,
                CostCents = (int)(source.Cost * 100)
            };
        }
    }

    public partial class Portfolio
    {
        public static Portfolio FromRepositoryModel(PortfolioData.Models.Portfolio source)
        {
            if (source is null) return null;

            var target = new Portfolio
            {
                Id = source.Id,
                TraderId = source.TraderId.ToString(),
            };

            target.Items.AddRange(source.Items.Select(PortfolioItem.FromRepositoryModel));

            return target;
        }
    }
}
```

## Note

You could use a library like [AutoMapper](#) to handle this conversion from internal model classes to Protobuf types, as long as you configure the lower-level type conversions like string/Guid or decimal/double and the list mapping.

With the conversion code in place, the Get method implementation can be completed.

```
public override async Task<GetResponse> Get(GetRequest request, ServerCallContext context)
{
    if (!Guid.TryParse(request.TraderId, out var traderId))
    {
        throw new RpcException(new Status(StatusCode.InvalidArgument, "traderId must be a UUID"));
    }

    var portfolio = await _repository.GetAsync(traderId, request.PortfolioId);

    return new GetResponse
    {
        Portfolio = Portfolio.FromRepositoryModel(portfolio)
    };
}
```

The implementation of the GetAll method is similar. Note that the repeated fields on Protobuf messages are generated as readonly properties of type `RepeatedField<T>`, so you have to add items to them using the `AddRange` method, like in the following example:

```
public override async Task<GetAllResponse> GetAll(GetAllRequest request, ServerCallContext context)
{
    if (!Guid.TryParse(request.TraderId, out var traderId))
    {
        throw new RpcException(new Status(StatusCode.InvalidArgument, "traderId must be a UUID"));
    }

    var portfolios = await _repository.GetAllAsync(traderId);

    var response = new GetAllResponse();
    response.Portfolios.AddRange(portfolios.Select(Portfolio.FromRepositoryModel));

    return response;
}
```

Having successfully migrated the WCF request-reply service to gRPC, let's look at creating a client for it from the `.proto` file.

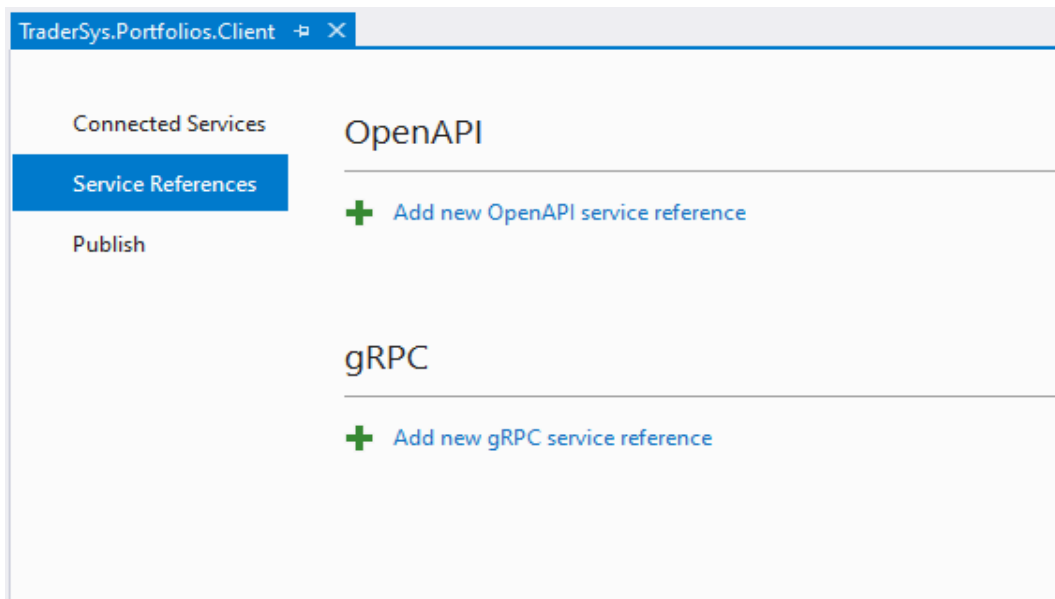
## Generate client code

Create a .NET Standard class library in the same solution to contain the client. This is primarily an example of creating client code, but you could package such a library using NuGet and distribute it on an internal repository for other .NET teams to consume. Go ahead and add a new .NET Standard Class Library called `TraderSys.Portfolios.Client` to the solution and delete the `Class1.cs` file.

### Caution

The [Grpc.Net.Client](#) NuGet package requires .NET Core 3.0 (or another .NET Standard 2.1-compliant runtime). Earlier versions of .NET Framework and .NET Core are supported by the [Grpc.Core](#) NuGet package.

In Visual Studio 2019, you can add references to gRPC services similar to the way you'd add Service References to WCF projects in earlier versions of Visual Studio. Service References and Connected Services are all managed under the same UI now, which you can access by right-clicking the **Dependencies** node in the `TraderSys.Portfolios.Client` project in Solution Explorer and selecting **Add Connected Service**. In the tool window that appears, select the **Service References** section and click **Add new gRPC service reference**.



Browse to the `portfolios.proto` file in the `TraderSys.Portfolios` project, leave the **type of class to be generated** as **Client**, and click **OK**.

Close (X)

## Add new gRPC service reference

Select a file or URL

☒ File

D:\Code\TraderSys\src\TraderSys.Portfolios\Protos\portfolios.proto Browse...

☐ URL

Select the type of class to be generated

Client

OK Cancel

### Tip

Notice that this dialog also provides a URL field. If your organization maintains a web-accessible directory of .proto files, you can create clients just by setting this URL address.

When using the Visual Studio **Add Connected Service** feature, the portfolios.proto file is added to the Class Library project as a *linked file*, rather than copied, so changes to the file in the service project will automatically be applied in the client project. The <Protobuf> element in the csproj file looks like this:

```
<Protobuf Include="..\TraderSys.Portfolios\Protos\portfolios.proto" GrpcServices="Client">  
  <Link>Protos\portfolios.proto</Link>  
</Protobuf>
```

### Tip

If you are not using Visual Studio or prefer to work from the command line, you can use the **dotnet-grpc** global tool to manage Protobuf references within a .NET gRPC project. [Refer to the dotnet-grpc documentation for more information.](#)



## Use the Portfolios service from a client application

The following code is a brief example of using the generated client in a console application. A more detailed exploration of the gRPC client code is at the end of this chapter.

```
public class Program
{
    public async Task Main(string[] args)
    {
        GetResponse response;

        using (var channel = GrpcChannel.ForAddress("https://localhost:5001"))
        {
            var client = new Protos.Portfolios.PortfoliosClient(channel);

            response = await client.GetAsync(new GetRequest
            {
                TraderId = args[0],
                PortfolioId = int.Parse(args[1])
            });

            foreach (var item in response.Portfolio.Items)
            {
                Console.WriteLine($"Holding {item.Holding} of Share ID {item.ShareId}.");
            }
        }
    }
}
```

Now, you’ve migrated a basic WCF application to an ASP.NET Core gRPC service and created a client to consume the service from a .NET application. The next section will cover the more involved “duplex” services.

## Migrate WCF duplex services to gRPC

Now that the basic concepts are in place, this section will look at the more complicated *streaming* gRPC services.

There are multiple ways to use duplex services in Windows Communication Foundation (WCF). Some services are initiated by the client and then they stream data from the server. Other full-duplex services might involve more ongoing two-way communication like the classic “Calculator” example from the WCF documentation. This chapter will take two possible WCF “Stock Ticker” implementations and migrate them to gRPC: one using a server streaming RPC, and the other one using a bidirectional streaming RPC.

### Server streaming RPC

In the [sample SimpleStockTicker WCF solution](#), *SimpleStockPriceTicker*, there’s a duplex service where the client starts the connection with a list of stock symbols, and the server uses the *callback interface* to send updates as they become available. The client implements that interface to respond to calls from the server.

## The WCF solution

The WCF solution is implemented as a self-hosted NetTCP server in a .NET Framework 4.x console application.

### The ServiceContract

```
[ServiceContract(SessionMode = SessionMode.Required, CallbackContract =  
typeof(ISimpleStockTickerCallback))]  
public interface ISimpleStockTickerService  
{  
    [OperationContract(IsOneWay = true)]  
    void Subscribe(string[] symbols);  
}
```

The service has a single method with no return type, because it will be using the callback interface `ISimpleStockTickerCallback` to send data to the client in real time.

### The callback interface

```
[ServiceContract]  
public interface ISimpleStockTickerCallback  
{  
    [OperationContract(IsOneWay = true)]  
    void Update(string symbol, decimal price);  
}
```

The implementations of these interfaces can be found in the solution, along with faked external dependencies to provide test data.

## gRPC streaming

The gRPC way of handling real-time data is different. A call from client to server can create a persistent stream, which can be monitored for messages arriving asynchronously. Despite the difference, streams can be a more intuitive way of dealing with this data and are more relevant in modern programming with the emphasis on LINQ, Reactive Streams, functional programming, and so on.

The service definition needs two messages: one for the request, and one for the stream. The service returns a stream of the `StockTickerUpdate` message using the `stream` keyword in its return declaration. It's recommended that you add a `Timestamp` to the update to show the exact time the price changed.

## simple\_stock\_ticker.proto

```
syntax = "proto3";

option csharp_namespace = "TraderSys.SimpleStockTickerServer.Protos";

import "google/protobuf/timestamp.proto";

package SimpleStockTickerServer;

service SimpleStockTicker {
  rpc Subscribe (SubscribeRequest) returns (stream StockTickerUpdate);
}

message SubscribeRequest {
  repeated string symbols = 1;
}

message StockTickerUpdate {
  string symbol = 1;
  int32 price_cents = 2;
  google.protobuf.Timestamp time = 3;
}
```

## Implement the SimpleStockTicker

Reuse the fake `StockPriceSubscriber` from the WCF project by copying the three classes from the `TraderSys.StockMarket` class library into a new .NET Standard class library in the target solution. To better follow best practices, add a `Factory` type to create instances of it and register the `IStockPriceSubscriberFactory` with ASP.NET Core's dependency injection services.

### The factory implementation

```
public interface IStockPriceSubscriberFactory
{
    IStockPriceSubscriber GetSubscriber(string[] symbols);
}

public class StockPriceSubscriberFactory : IStockPriceSubscriberFactory
{
    public IStockPriceSubscriber GetSubscriber(string[] symbols)
    {
        return new StockPriceSubscriber(symbols);
    }
}
```

### Registering the factory

```
public void ConfigureServices(IServiceCollection services)
{
    services.AddGrpc();
    services.AddSingleton<IStockPriceSubscriberFactory, StockPriceSubscriberFactory>();
}
```

Now, this class can be used to implement the gRPC `StockTicker` service.

## StockTickerService.cs

```
public class StockTickerService : Protos.SimpleStockTicker.SimpleStockTickerBase
{
    private readonly IStockPriceSubscriberFactory _subscriberFactory;

    public StockTickerService(IStockPriceSubscriberFactory subscriberFactory)
    {
        _subscriberFactory = subscriberFactory;
    }

    public override async Task Subscribe(SubscribeRequest request,
        IServerStreamWriter<StockTickerUpdate> responseStream, ServerCallContext context)
    {
        var subscriber = _subscriberFactory.GetSubscriber(request.Symbols.ToArray());

        subscriber.Update += async (sender, args) =>
            await WriteUpdateAsync(responseStream, args.Symbol, args.Price);

        await AwaitCancellation(context.CancellationToken);
    }

    private async Task WriteUpdateAsync(IServerStreamWriter<StockTickerUpdate> stream,
        string symbol, decimal price)
    {
        try
        {
            await stream.WriteAsync(new StockTickerUpdate
            {
                Symbol = symbol,
                PriceCents = (int)(price * 100),
                Time = Timestamp.FromDateTimeOffset(DateTimeOffset.UtcNow)
            });
        }
        catch (Exception e)
        {
            // Handle any errors due to broken connection etc.
            _logger.LogError($"Failed to write message: {e.Message}");
        }
    }

    private static Task AwaitCancellation(Cancellation token)
    {
        {
            var completion = new TaskCompletionSource<object>();
            token.Register(() => completion.SetResult(null));
            return completion.Task;
        }
    }
}
```

As you can see, although the declaration in the .proto file says the method “returns” a stream of StockTickerUpdate messages, in fact it returns a vanilla Task. The job of creating the stream is handled by the generated code and the gRPC runtime libraries, which provide the IServerStreamWriter<StockTickerUpdate> response stream, ready to use.

Unlike a WCF duplex service, where the instance of the service class is kept alive while the connection is open, the gRPC service uses the returned Task to keep the service alive. The Task shouldn’t complete until the connection is closed.

The service can tell when the client has closed the connection by using the `CancellationToken` from the `ServerCallContext`. A simple static method, `AwaitCancellation`, is used to create a `Task` that completes when the token is canceled.

In the `Subscribe` method, then, get a `StockPriceSubscriber` and add an event handler that writes to the response stream. Then wait for the connection to be closed, before immediately disposing the subscriber to prevent it trying to write data to the closed stream.

The `WriteUpdateAsync` method has a try/catch block to handle any errors that might happen when writing a message to the stream. This is an important consideration in persistent connections over networks, which could be broken at any millisecond, whether intentionally or because of a failure somewhere.

## Using the `StockTickerService` from a client application

Follow the same steps in the previous section to create a shareable client class library from the `.proto` file. In the sample, there's a .NET Core 3.0 console application that demonstrates how to use the client.

### Example `Program.cs`

```
class Program
{
    static async Task Main(string[] args)
    {
        using var channel = GrpcChannel.ForAddress("https://localhost:5001");
        var client = new SimpleStockTicker.SimpleStockTickerClient(channel);

        var request = new SubscribeRequest();
        request.Symbols.AddRange(args);

        using var stream = client.Subscribe(request);

        var tokenSource = new CancellationTokenSource();

        var task = DisplayAsync(stream.ResponseStream, tokenSource.Token);

        WaitForExitKey();

        tokenSource.Cancel();
        await task;
    }
}
```

In this case, the `Subscribe` method on the generated client isn't asynchronous. The stream is created and usable right away, because its `MoveNext` method is asynchronous and the first time it's called it won't complete until the connection is alive.

The stream is passed to an async `DisplayAsync` method; the application then waits for the user to press a key, then cancels the `DisplayAsync` method and waits for the task to complete before exiting.

## Note

This code is using the new C# 8 “using declaration” syntax to dispose of the stream and the channel when the Main method exits. It’s a small change, but a nice one that reduces indentations and empty lines.

## Consume the stream

WCF used callback interfaces to allow the server to call methods directly on the client. gRPC streams work differently. The client iterates over the returned stream and processes messages, just as though they were returned from a local method returning an `IEnumerable`.

The `IAsyncStreamReader<T>` type works much like an `IEnumerator<T>`: there’s a `MoveNext` method that will return true as long as there’s more data, and a `Current` property that returns the latest value. The only difference is that the `MoveNext` method returns a `Task<bool>` instead of just a `bool`. The `ReadAllAsync` extension method wraps the stream in a standard C# 8 `IAsyncEnumerable` that can be used with the new `await foreach` syntax.

```
static async Task DisplayAsync(IAsyncStreamReader<StockTickerUpdate> stream,
    CancellationToken token)
{
    try
    {
        await foreach (var update in stream.ReadAllAsync(token))
        {
            Console.WriteLine($"{update.Symbol}: {update.Price}");
        }
    }
    catch (RpcException e) when (e.StatusCode == StatusCode.Cancelled)
    {
        return;
    }
    catch (OperationCanceledException)
    {
        Console.WriteLine("Finished.");
    }
}
```

## Tip

The section on [client libraries](#) at the end of this chapter looks at how to add an extension method and classes to wrap `IAsyncStreamReader<T>` in an `IObservable<T>` for developers using reactive programming patterns.

Again, be careful to catch exceptions here because of the possibility of network failure, as well as the [OperationCanceledException](#) that will inevitably be thrown because the code is using a [CancellationToken](#) to break the loop. The `RpcException` type has a lot of useful information about gRPC runtime errors, including the `StatusCode`. For more information, see [Error handling in Chapter 4](#).

## Bidirectional streaming

A WCF full-duplex service allows for asynchronous, real-time messaging in both directions. In the server streaming example, the client starts a request, then receives a stream of updates. A better version of that service would allow the client to add and remove stocks from the list without having to stop and create a new subscription. That functionality has been implemented in the [FullStockTicker sample solution](#).

The `IFullStockTickerService` interface provides three methods:

- `Subscribe` starts the connection.
- `AddSymbol` adds a stock symbol to watch.
- `RemoveSymbol` removes a symbol from the watched list.

```
[ServiceContract(SessionMode = SessionMode.Required, CallbackContract =  
typeof(IFullStockTickerCallback))]  
public interface IFullStockTickerService  
{  
    [OperationContract(IsOneWay = true)]  
    void Subscribe();  
  
    [OperationContract(IsOneWay = true)]  
    void AddSymbol(string symbol);  
  
    [OperationContract(IsOneWay = true)]  
    void RemoveSymbol(string symbol);  
}
```

The callback interface remains the same.

Implementing this pattern in gRPC is less straightforward, because there are now two streams of data with messages being passed: one from client to server, and another from server to client. It isn't possible to use multiple methods to implement the Add and Remove operation, but more than one type of message can be passed on a single stream, using either the `Any` type or `oneof` keyword, which were covered in [Chapter 3](#).

For a case where there's a specific set of types that are acceptable, `oneof` is a better way to go. Use an `ActionMessage` that can hold either an `AddSymbolRequest` or a `RemoveSymbolRequest`.

```
message ActionMessage {  
    oneof action {  
        AddSymbolRequest add = 1;  
        RemoveSymbolRequest remove = 2;  
    }  
}  
  
message AddSymbolRequest {  
    string symbol = 1;  
}  
  
message RemoveSymbolRequest {  
    string symbol = 1;  
}
```

Declare a bi-directional streaming service that takes a stream of `ActionMessage` messages.

```

service FullStockTicker {
    rpc Subscribe (stream ActionMessage) returns (stream StockTickerUpdate);
}

```

The implementation for this service is similar to the previous example, except the first parameter of the Subscribe method is now an `IAsyncStreamReader<ActionMessage>`, which can be used to handle the Add and Remove requests.

```

public override async Task Subscribe(IAsyncStreamReader<ActionMessage> requestStream,
IServerStreamWriter<StockTickerUpdate> responseStream, ServerCallContext context)
{
    using var subscriber = _subscriberFactory.GetSubscriber();

    subscriber.Update += async (sender, args) =>
        await WriteUpdateAsync(responseStream, args.Symbol, args.Price);

    var actionsTask = HandleActions(requestStream, subscriber, context.CancellationToken);

    _logger.LogInformation("Subscription started.");
    await AwaitCancellation(context.CancellationToken);

    try { await actionsTask; } catch { /* Ignored */ }

    _logger.LogInformation("Subscription finished.");
}

private async Task WriteUpdateAsync(IServerStreamWriter<StockTickerUpdate> stream, string
symbol, decimal price)
{
    try
    {
        await stream.WriteAsync(new StockTickerUpdate
        {
            Symbol = symbol,
            PriceCents = (int)(price * 100),
            Time = Timestamp.FromDateTimeOffset(DateTimeOffset.UtcNow)
        });
    }
    catch (Exception e)
    {
        // Handle any errors due to broken connection etc.
        _logger.LogError($"Failed to write message: {e.Message}");
    }
}

private static Task AwaitCancellation(Cancellation token)
{
    {
        var completion = new TaskCompletionSource<object>();
        token.Register(() => completion.SetResult(null));
        return completion.Task;
    }
}

```

The `ActionMessage` class that gRPC has generated for us guarantees that only one of the Add and Remove properties can be set, and finding which one isn't null is a valid way of finding which type of message is used, but there's a better way. The code generation also created an enum `ActionOneOfCase` in the `ActionMessage` class, which looks like this:



```
public enum ActionOneofCase {
    None = 0,
    Add = 1,
    Remove = 2,
}
```

The property `ActionCase` on the `ActionMessage` object can be used with a `switch` statement to determine which field is set.

```
private async Task HandleActions(IAsyncStreamReader<ActionMessage> requestStream,
IFullStockPriceSubscriber subscriber, CancellationToken token)
{
    await foreach (var action in requestStream.ReadAllAsync(token))
    {
        switch (action.ActionCase)
        {
            case ActionMessage.ActionOneofCase.None:
                _logger.LogWarning("No Action specified.");
                break;
            case ActionMessage.ActionOneofCase.Add:
                subscriber.Add(action.Add.Symbol);
                break;
            case ActionMessage.ActionOneofCase.Remove:
                subscriber.Remove(action.Remove.Symbol);
                break;
            default:
                _logger.LogWarning($"Unknown Action '{action.ActionCase}'.");
                break;
        }
    }
}
```

### Tip

The `switch` statement has a default case that logs a warning if an unknown `ActionOneOfCase` value is encountered. This could be useful in indicating that a client is using a later version of the `.proto` file which has added more actions. This is one reason why using a `switch` is better than testing for null on known fields.

## Use the `FullStockTickerService` from a client application

There's a simple .NET Core 3.0 WPF application to demonstrate use of this more complex client. The full application can be found [on GitHub](#).

The client is used in the `MainWindowViewModel` class, which gets an instance of the `FullStockTicker.FullStockTickerClient` type from dependency injection.

```

public class MainWindowViewModel : IAsyncDisposable, INotifyPropertyChanged
{
    private readonly FullStockTicker.FullStockTickerClient _client;
    private readonly AsyncDuplexStreamingCall<ActionMessage, StockTickerUpdate>
        _duplexStream;
    private readonly CancellationTokenSource _cancellationTokenSource;
    private readonly Task _responseTask;
    private string _addSymbol;

    public MainWindowViewModel(FullStockTicker.FullStockTickerClient client)
    {
        _cancellationTokenSource = new CancellationTokenSource();
        _client = client;
        _duplexStream = _client.Subscribe();
        _responseTask = HandleResponsesAsync(_cancellationTokenSource.Token);

        AddCommand = new AsyncCommand(Add, CanAdd);
    }
}

```

The object returned by the `client.Subscribe()` method is now an instance of the gRPC library type `AsyncDuplexStreamingCall<TRequest, TResponse>`, which provides a `RequestStream` for sending requests to the server, and a `ResponseStream` for handling responses.

The request stream is used from some WPF `ICommand` methods to add and remove symbols. For each operation, set the relevant field on an `ActionMessage` object:

```

private async Task Add()
{
    if (CanAdd())
    {
        await _duplexStream.RequestStream.WriteAsync(new ActionMessage {Add = new
        AddSymbolRequest {Symbol = AddSymbol}});
    }
}

public async Task Remove(PricingViewModel priceViewModel)
{
    await _duplexStream.RequestStream.WriteAsync(new ActionMessage {Remove = new
    RemoveSymbolRequest {Symbol = priceViewModel.Symbol}});
    Prices.Remove(priceViewModel);
}
}

```

### Important

Setting a oneof field's value on a message automatically clears any fields that have been previously set.

The stream of responses is handled in an async method, and the `Task` it returns is held to be disposed when the window is closed.

```

private async Task HandleResponsesAsync(CancellationToken token)
{
    var stream = _duplexStream.ResponseStream;

    try
    {
        await foreach (var update in stream.ReadAllAsync(token))
        {
            var price = Prices.FirstOrDefault(p => p.Symbol.Equals(update.Symbol));
            if (price == null)
            {
                price = new PriceViewModel(this) {Symbol = update.Symbol, Price =
update.PriceCents / 100m};
                Prices.Add(price);
            }
            else
            {
                price.Price = update.PriceCents / 100m;
            }
        }
    }
    catch (OperationCancelledException) { }
}

```

## Client clean-up

When the window is closed and the `MainWindowViewModel` is disposed (from the `Closed` event of `MainWindow`), it's recommended that you properly dispose the `AsyncDuplexStreamingCall` object. In particular, the `CompleteAsync` method on the `RequestStream` should be called to gracefully close the stream on the server. The following example shows the `DisposeAsync` method from the sample view-model:

```

public ValueTask DisposeAsync()
{
    try
    {
        await _duplexStream.RequestStream.CompleteAsync().ConfigureAwait(false);
        await _responseTask.ConfigureAwait(false);
    }
    finally
    {
        _duplexStream.Dispose();
    }
}

```

Closing request streams enables the server to dispose of its own resources in a timely manner. This improves the efficiency and scalability of services and prevents exceptions.

## gRPC streaming services versus repeated fields

gRPC services provide two ways of returning datasets, or lists of objects. The Protocol Buffers message specification uses the `repeated` keyword for declaring lists or arrays of messages within another message. The gRPC service specification uses the `stream` keyword to declare a long-running persistent connection over which multiple messages are sent, and can be processed, individually. The

stream feature can also be used for long-running temporal data such as notifications or log messages, but this chapter will consider its use for returning a single dataset.

Which you should use depends on various factors, such as the overall size of the dataset, the time it took to create the dataset at either the client or server end, and whether the consumer of the dataset can start acting on it as soon as the first item is available, or needs the complete dataset to do anything useful.

## When to use repeated fields

For any dataset that is constrained in size and that can be generated in its entirety in a short time—say, under one second—you should use a repeated field in a regular Protobuf message. For example, in an e-commerce system, to build a list of items within an order is probably quick and the list won't be very large. Returning a single message with a repeated field is an order of magnitude faster than using a stream and incurs less network overhead.

If the client needs all the data before starting to process it and the dataset is small enough to construct in memory, then consider using a repeated field even if the actual creation of the dataset in memory on the server is slower.

## When to use stream methods

Datasets where the message objects are potentially very large are best transferred using streaming requests or responses. It's more efficient to construct a large object in memory, write it to the network and then free up the resources. This approach will improve the scalability of your service.

Similarly, datasets of unconstrained size should be sent over streams to avoid running out of memory while constructing them.

For datasets where each individual item can be processed separately by the consumer, you should consider using a stream if it means that progress can be indicated to the end user. This could improve the apparent responsiveness of an application, although this should be balanced against the overall performance of the application.

Another scenario where streams can be useful is where a message is being processed across multiple services. If each service in a chain returns a stream, then the terminal service (that is, the last one in the chain) can start returning messages that can be processed and passed back along the chain to the original requestor, which can either return a stream or aggregate the results into a single response message. This approach lends itself well to patterns like Map/Reduce.

## Create gRPC client libraries

It isn't necessary to distribute client libraries for a gRPC application. You can create a shared library of .proto files within your organization, and other teams can use those files to generate client code in their own projects. But if you have a private NuGet repository and many other teams are using .NET Core, creating and publishing client NuGet packages as part of your service project may be a good way of sharing and promoting your service.

One advantage of distributing a client library is that you can enhance the generated gRPC and Protobuf classes with helpful “convenience” methods and properties. In the client code, as in the server, all the classes are declared as `partial` so you can extend them without editing the generated code. This means it’s easy to add constructors, methods, calculated properties, and more to the basic types.

### Caution

You should **not** use custom code to provide essential functionality, as this would mean that functionality would be restricted to .NET teams using the shared library, and not to teams using other languages or platforms such as Python or Java.

In a multi-platform environment where different teams frequently use different programming languages and frameworks, or where your API is externally accessible, simply sharing `.proto` files so developers can generate their own clients is the best way to ensure as many teams as possible can access your gRPC service.

## Useful extensions

There are two commonly used interfaces in .NET for dealing with streams of objects: [IEnumerable](#) and [IObservable](#). Starting with .NET Core 3.0 and C# 8.0, there’s an [IAsyncEnumerable](#) interface for processing streams asynchronously, and an `await foreach` syntax for using the interface. This section presents reusable code for applying these interfaces to gRPC streams.

With the .NET Core gRPC client libraries, there’s a `ReadAllAsync` extension method for `IAsyncStreamReader<T>` that creates an `IAsyncEnumerable<T>`. For developers using reactive programming, an equivalent extension method to create an `IObservable<T>` might look like this.

### IObservable

The `IObservable<T>` interface is the “reactive” inverse of `IEnumerable<T>`. Rather than pulling items from a stream, the reactive approach lets the stream push items to a subscriber. This is very similar to gRPC streams, and it’s easy to wrap an `IObservable<T>` around an `IAsyncStreamReader<T>`.

This code is longer than the `IAsyncEnumerable<T>` code because C# doesn’t have built-in support for working with observables, so the implementation class has to be created manually. It’s a generic class, though, so a single implementation will work across all types.

```

using System;
using System.Diagnostics;
using System.Threading;
using System.Threading.Tasks;

namespace Grpc.Core
{
    public class GrpcStreamObservable<T> : IObservable<T>
    {
        private readonly IAsyncStreamReader<T> _reader;
        private readonly CancellationToken _token;
        private int _used;

        public Observable(IAsyncStreamReader<T> reader, CancellationToken token = default)
        {
            _reader = reader;
            _token = token;
            _used = 0;
        }

        public IDisposable Subscribe(IObserver<T> observer) =>
            Interlocked.Exchange(ref _used, 1) == 0
                ? new GrpcStreamSubscription(_reader, observer, _token)
                : throw new InvalidOperationException("Subscribe can only be called
once.");
    }
}

```

### Important

This observable implementation only allows the Subscribe method to be called once, as having multiple subscribers trying to read from the stream would result in chaos. There are operators such as Replay in the [System.Reactive.Linq](https://docs.microsoft.com/en-us/dotnet/api/system.reactive.linq) that enable buffering and repeatable sharing of observables, which can be used with this implementation.

The GrpcStreamSubscription class handles the enumeration of the IAsyncStreamReader.

```

public class GrpcStreamSubscription : IDisposable
{
    private readonly Task _task;
    private readonly CancellationTokenSource _tokenSource;
    private bool _completed;

    public Subscription(IAsyncStreamReader<T> reader, IObserver<T> observer,
        CancellationToken token)
    {
        Debug.Assert(reader != null);
        Debug.Assert(observer != null);
        _tokenSource = new CancellationTokenSource();
        token.Register(_tokenSource.Cancel);
        _task = Run(reader, observer, _tokenSource.Token);
    }

    private async Task Run(IAsyncStreamReader<T> reader, IObserver<T> observer,
        CancellationToken token)
    {

```

```

        while (!token.IsCancellationRequested)
        {
            try
            {
                if (!await reader.MoveNext(token)) break;
            }
            catch (RpcException e) when (e.StatusCode == Grpc.Core.StatusCode.NotFound)
            {
                break;
            }
            catch (OperationCanceledException)
            {
                break;
            }
            catch (Exception e)
            {
                observer.OnError(e);
                _completed = true;
                return;
            }

            observer.OnNext(reader.Current);
        }

        _completed = true;
        observer.OnCompleted();
    }

    public void Dispose()
    {
        if (!_completed && !_tokenSource.IsCancellationRequested)
        {
            _tokenSource.Cancel();
        }

        _tokenSource.Dispose();
        _task.Dispose();
    }
}

```

All that is required now is a simple extension method to create the observable from the stream reader.

```

using System;
using System.Diagnostics;
using System.Threading;
using System.Threading.Tasks;

namespace Grpc.Core
{
    public static class AsyncStreamReaderObservableExtensions
    {
        public static IObservable<T> AsObservable<T>(this IAsyncStreamReader<T> reader) =>
            new GrpcStreamObservable<T>(reader);
    }
}

```

## Summary

The `IAsyncEnumerable` and `IObservable` models are both well-supported and well-documented ways of dealing with asynchronous streams of data in .NET. gRPC streams map well to both paradigms, offering close integration with the modern .NET Core framework and reactive/asynchronous programming styles.



# Security in gRPC applications

In any real-world scenario, securing applications and services is essential. Security covers three key areas: encrypting network traffic to prevent it from being intercepted by bad actors; authenticating clients and servers to establish identity and trust; and authorizing clients to control access to systems and apply permissions based on identity.

**Note**

**Authentication** is concerned with establishing the identity of a client or server. **Authorization** is concerned with determining whether a client has permission to access a resource or issue a command.

This chapter will cover the facilities for authentication and authorization in gRPC for ASP.NET Core, and discuss network security using TLS encrypted connections.

## WCF authentication and authorization

In WCF, authentication and authorization were handled in different ways depending on the transports and bindings being used. WCF supported various WS-\* security standards, as well as Windows authentication for HTTP services running in IIS or NetTCP services between Windows systems.

## gRPC authentication and authorization

gRPC authentication and authorization works on two levels. Call-level authentication/authorization is usually handled using tokens that are applied in metadata when the call is made. Channel-level authentication uses a client certificate that is applied at the connection level, and can also include call-level authentication/authorization credentials to be applied to every call on the channel automatically. You can use either or both of these mechanisms to secure your service.

The ASP.NET Core implementation of gRPC supports authentication and authorization using most of the standard ASP.NET Core mechanisms:

- Call authentication
  - Azure Active Directory
  - IdentityServer
  - JWT Bearer Token
  - OAuth 2.0
  - OpenID Connect
  - WS-Federation
- Channel authentication
  - Client Certificate

The call authentication methods are all based on *tokens*. The only real difference is how the token is generated and the libraries that are used to validate the tokens in the ASP.NET Core service.

For more information, see the [Authentication and authorization documentation on Microsoft Docs](#).

#### Note

When using gRPC over a TLS-encrypted HTTP/2 connection, all traffic between clients and servers is encrypted, even if you don't use channel-level authentication.

This chapter will show how to apply call credentials and channel credentials to a gRPC service, and how to use credentials from a .NET Core gRPC client to authenticate with the service.

## Call credentials

Call credentials are all based on some kind of token passed in metadata with each request.

### WS-Federation

ASP.NET Core supports WS-Federation using the [WsFederation](#) NuGet package. WS-Federation is the closest available alternative to Windows Authentication, which is not supported over HTTP/2. Users are authenticated using Active Directory Federation Services (ADFS), which provides a token that can be used to authenticate with ASP.NET Core.

For more information on how to get started with this authentication method, see the [Authenticate users with WS-Federation in ASP.NET Core](#) article.

### JWT Bearer tokens

The [JSON Web Token](#) standard provides a way to encode information about a user and their claims in an encoded string, and to sign that token in such a way that the consumer can verify the integrity of the token using public key cryptography. You can use various services, such as IdentityServer4, to authenticate users and generate OpenID Connect (OIDC) tokens to use with gRPC and HTTP APIs.

ASP.NET Core 3.0 can handle JSON Web Tokens using the JWT Bearer package. The configuration is exactly the same for a gRPC application as an ASP.NET Core MVC application.

This chapter will focus on JWT Bearer tokens as they're easier to develop with than WS-Federation.

## Adding authentication and authorization to the server

The JWT Bearer package isn't included in ASP.NET Core 3.0 by default. Install the [Microsoft.AspNetCore.Authentication.JwtBearer](#) NuGet package in your app.

Add the Authentication service in the Startup class and configure the JWT Bearer handler.

```
public void ConfigureServices(IServiceCollection services)
{
    services.AddGrpc();

    var signingKey = ObtainSigningKeySomehow();

    services.AddAuthentication(JwtBearerDefaults.AuthenticationScheme)
        .AddJwtBearer(options =>
        {
            options.TokenValidationParameters =
                new TokenValidationParameters
                {
                    ValidateAudience = false,
                    ValidateIssuer = false,
                    ValidateActor = false,
                    ValidateLifetime = true,
                    IssuerSigningKey = signingKey
                };
        });
}
```

The IssuerSigningKey property requires an implementation of `Microsoft.IdentityModels.Tokens.SecurityKey` with the cryptographic data necessary to validate the signed tokens. This token should be stored securely in a *secrets server* like Azure KeyVault.

Next add the Authorization service, which controls access to the system.

```
services.AddAuthorization(options =>
{
    options.AddPolicy(JwtBearerDefaults.AuthenticationScheme, policy =>
    {
        policy.AddAuthenticationSchemes(JwtBearerDefaults.AuthenticationScheme);
        policy.RequireClaim(ClaimTypes.Name);
    });
});
```

### Tip

Authentication and Authorization are two separate steps. Authentication is used to determine the user's identity. Authorization decides whether that user is allowed to access various parts of the system.

Now add the Authentication and Authorization middleware to the ASP.NET Core pipeline in the `Configure` method.

```
public void Configure(IApplicationBuilder app, IWebHostEnvironment env)
{
    if (env.IsDevelopment())
    {
        app.UseDeveloperExceptionPage();
    }

    app.UseRouting();

    // Authenticate, then Authorize
    app.UseAuthentication();
    app.UseAuthorization();

    app.UseEndpoints(endpoints =>
    {
        endpoints.MapGrpcService<PortfolioService>();
    });
}
```

Finally, apply the `[Authorize]` attribute to any services or methods to be secured, and use the `User` property from the underlying `HttpContext` to verify permissions.

```
[Authorize]
public override async Task<GetResponse> Get(GetRequest request, ServerCallContext context)
{
    if (!TryValidateUser(request.TraderId, context.GetHttpContext().User))
    {
        throw new RpcException(new Status(StatusCode.PermissionDenied, "Denied."));
    }

    var portfolio = await _repository.GetAsync(traderId, request.PortfolioId);

    return new GetResponse
    {
        Portfolio = Portfolio.FromRepositoryModel(portfolio)
    };
}
```

## Providing call credentials in the client application

Once you've obtained a JWT token from an identity server, you can use it to authenticate gRPC calls from the client by adding it as a metadata header on the call, as follows:

```

public async Task ShowPortfolioAsync(int portfolioId)
{
    var headers = new Grpc.Core.Metadata
    {
        { "Authorization", $"Bearer {_userToken}" }
    };
    var request = new GetRequest
    {
        TraderId = _userId,
        PortfolioId = portfolioId
    };
    var response = await _portfoliosClient.GetAsync(request, headers);

    // Display portfolio
}

```

Now, you've secured your gRPC service using JWT bearer tokens as call credentials. A version of the [Portfolios sample gRPC application with authentication and authorization added](#) is on GitHub.

## Channel credentials

As the name implies, channel credentials are attached to the underlying gRPC channel. The standard form of channel credentials uses Client Certificate authentication, where the client provides a TLS certificate when it's making the connection, which is verified by the server before allowing any calls to be made.

Channel credentials can be combined with call credentials to provide comprehensive security for a gRPC service. The channel credentials prove that the client application is allowed to access the service, and the call credentials provide information about the person using the client application.

Client certificate authentication works for gRPC the same way it works for ASP.NET Core. The configuration process will be summarized here, but more information is available in the [Configure certificate authentication in ASP.NET Core](#) article.

For development purposes you can use a self-signed certificate, but for production you should use a proper HTTPS certificate signed by a trusted authority.

## Adding certificate authentication to the server

You need to configure certificate authentication both at the host level, for example on the Kestrel server, and in the ASP.NET Core pipeline.

### Configuring certificate validation on Kestrel

You can configure Kestrel (the ASP.NET Core HTTP server) to require a client certificate, and optionally to carry out some validation of the supplied certificate before accepting incoming connections. This configuration is done in the `CreateWebHostBuilder` method of the `Program` class, rather than in `Startup`.

```

public static IHostBuilder CreateHostBuilder(string[] args) =>
    Host.CreateDefaultBuilder(args)
        .ConfigureWebHostDefaults(webBuilder =>
        {
            var serverCert = ObtainServerCertificate();
            webBuilder.UseStartup<Startup>()
                .ConfigureKestrel(kestrelServerOptions => {
                    kestrelServerOptions.ConfigureHttpsDefaults(opt =>
                    {
                        opt.ClientCertificateMode =
ClientCertificateMode.RequireCertificate;

                        // Verify that client certificate was issued by same CA as server
certificate
                        opt.ClientCertificateValidation = (certificate, chain, errors) =>
                            certificate.Issuer == serverCert.Issuer;
                    });
                });
        });

```

The `ClientCertificateMode.RequireCertificate` setting will cause Kestrel to immediately reject any connection request that doesn't provide a client certificate, but it won't validate the certificate. Adding the `ClientCertificateValidation` callback enables Kestrel to validate the client certificate (in this case, ensuring that it was issued by the same *Certificate Authority* as the server certificate) at the point the connection is made, before the ASP.NET Core pipeline is engaged.

## Adding ASP.NET Core certificate authentication

Certificate authentication is provided by the [Microsoft.AspNetCore.Authentication.Certificate](#) NuGet package.

Add the certificate authentication service in the `ConfigureServices` method, and add authentication and authorization to the ASP.NET Core pipeline in the `Configure` method.

```

public class Startup
{
    private readonly bool _isDevelopment;

    public Startup(IWebHostEnvironment env)
    {
        _isDevelopment = env.IsDevelopment();
    }

    public void ConfigureServices(IServiceCollection services)
    {
        services.AddAuthentication(CertificateAuthenticationDefaults.AuthenticationScheme)
            .AddCertificate(options =>
            {
                if (_isDevelopment)
                {
                    // DO NOT DO THIS IN PRODUCTION!
                    options.RevocationMode = X509RevocationMode.NoCheck;
                }
            });
        services.AddAuthorization();
        services.AddGrpc();
    }
}

```

```

public void Configure(IApplicationBuilder app, IWebHostEnvironment env)
{
    app.UseRouting();

    app.UseAuthentication();
    app.UseAuthorization();

    app.UseEndpoints(endpoints => { endpoints.MapGrpcService<GreeterService>(); });
}
}

```

## Providing channel credentials in the client application

With the `Grpc.Net.Client` package, certificates are configured on an [HttpClient](#) instance that is provided to the `GrpcChannel` used for the connection.

```

class Program
{
    static async Task Main(string[] args)
    {
        // Assume path to a client .pfx file and password are passed from command line
        // On Windows this would probably be a reference to the Certificate Store
        var cert = new X509Certificate2(args[0], args[1]);

        var handler = new HttpClientHandler();
        handler.ClientCertificates.Add(cert);
        var httpClient = new HttpClient(handler);

        var channel = GrpcChannel.ForAddress("https://localhost:5001/", new
GrpcChannelOptions
        {
            HttpClient = httpClient
        });

        var grpc = new Greeter.GreeterClient(channel);
        var response = await grpc.SayHelloAsync(new HelloRequest { Name = "Bob" });
        System.Console.WriteLine(response.Message);
    }
}

```

## Combining ChannelCredentials and CallCredentials

You can configure your server to use both certificate and token authentication by applying the certificate changes to the Kestrel server and using the JWT bearer middleware in ASP.NET Core.

To provide both `ChannelCredentials` and `CallCredentials` on the client, use the `ChannelCredentials.Create` method to apply the call credentials. Certificate authentication still needs to be applied using the [HttpClient](#) instance: if you pass any arguments to the `SslCredentials` constructor, the internal client code throws an exception. The `SslCredentials` parameter is only included in the `Grpc.Net.Client` package's `Create` method to maintain compatibility with the `Grpc.Core` package.

```

var handler = new HttpClientHandler();
handler.ClientCertificates.Add(cert);

var httpClient = new HttpClient(handler);

var callCredentials = CallCredentials.FromInterceptor(((context, metadata) =>
{
    metadata.Add("Authorization", $"Bearer {_token}");
}));

var channelCredentials = ChannelCredentials.Create(new SslCredentials(), callCredentials);

var channel = GrpcChannel.ForAddress("https://localhost:5001/", new GrpcChannelOptions
{
    HttpClient = httpClient,
    Credentials = channelCredentials
});

var grpc = new Portfolios.PortfoliosClient(channel);

```

### Tip

You can use the `ChannelCredentials.Create` method for a client without certificate authentication, as a useful way to pass token credentials with every call made on the channel.

A version of the [FullStockTicker sample gRPC application with certificate authentication added](#) is on GitHub.

## Encryption and network security

WCF's network security model is extensive and complex, including transport-level security using HTTPS or TLS-over-TCP, and message-level security using the WS-Security specification to encrypt individual messages.

gRPC leaves secure networking to the underlying HTTP/2 protocol, which can be secured using regular TLS certificates.

Web browsers insist on using TLS connections for HTTP/2, but most programmatic clients, including .NET's `HttpClient`, can use HTTP/2 over unencrypted connections. `HttpClient` *does* require encryption by default, but you can override this using an [AppContext](#) switch.

```
AppContext.SetSwitch("System.Net.Http.SocketsHttpHandler.Http2UnencryptedSupport", true);
```

For public APIs, you should always use TLS connections and provide valid certificates for your services from a proper SSL authority. [LetsEncrypt](#) provide free, automated SSL certificates, and most hosting infrastructure today supports the LetsEncrypt standard with common plug-ins or extensions.

For internal services across a corporate network, you should still consider using TLS to secure network traffic to and from your gRPC services.

Communication between microservices in a cluster like Kubernetes or Docker Swarm is in general automatically encrypted by the container networking layer, so implementing TLS in services running



exclusively in such a cluster isn't necessary. There will be more on this subject in the "Service Mesh" section of the next chapter.

If you need to use explicit TLS between services running in Kubernetes, consider using an in-cluster Certificate Authority and a Certificate Manager Controller like [cert-manager](#) to assign automatically certificates to services at deployment time.

# gRPC in production

ASP.NET Core 3.0 applications, including gRPC services, can be run on Windows, Linux, and in containers using modern platforms like Docker and Kubernetes. This chapter will explore the various options for running your gRPC services in production, and look at monitoring and logging options to ensure the optimal operation of systems.

## Self-hosted gRPC applications

Although ASP.NET Core 3.0 applications can be hosted in IIS on Windows Server, currently it isn't possible to host a gRPC application in IIS because some of the HTTP/2 functionality isn't yet supported. This functionality is expected in a future update to Windows Server.

You can run your application as a Windows Service, or as a Linux service controlled by [systemd](#), thanks to some new features in the .NET Core 3.0 hosting extensions.

### Run your app as a Windows service

To configure your ASP.NET Core application to run as a Windows service, install the [Microsoft.Extensions.Hosting.WindowsServices](#) package from NuGet. Then add a call to `UseWindowsService` to the `CreateHostBuilder` method in `Program.cs`.

```
public static IHostBuilder CreateHostBuilder(string[] args) =>
    Host.CreateDefaultBuilder(args)
        .UseWindowsService() // Enable running as a Windows service
        .ConfigureWebHostDefaults(webBuilder =>
        {
            webBuilder.UseStartup<Startup>();
        });
```

#### Note

If the application isn't running as a Windows service, the `UseWindowsService` method doesn't do anything.

Now publish your application, either from Visual Studio by right-clicking the project and choosing *Publish* from the context menu, or from the .NET Core CLI.

When you publish a .NET Core application, you can choose to create a *framework-dependent* deployment or a *self-contained* deployment. Framework-dependent deployments require the .NET Core Shared Runtime to be installed on the host where they are run. Self-contained deployments are published with a complete copy of the .NET Core runtime and framework and can be run on any host.

For more information, including the advantages and disadvantages of each approach, refer to the [.NET Core application deployment](#) documentation.

To publish a self-contained build of the application that does not require the .NET Core 3.0 runtime to be installed on the host, specify the runtime to be included with the application using the `-r` (or `--runtime`) flag.

```
dotnet publish -c Release -r win-x64 -o ./publish
```

To publish a framework-dependent build, omit the `-r` flag.

```
dotnet publish -c Release -o ./publish
```

Copy the complete contents of the publish directory to an installation folder, and use the [sc utility](#) to create a Windows service for the executable.

```
sc create MyService binPath=C:\MyService\MyService.exe
```

## Log to Windows Event Log

The `UseWindowsService` method automatically adds a [Logging](#) provider that writes log messages to the Windows Event Log. You can configure logging for this provider by adding an `EventLog` entry to the Logging section of `appsettings.json` or other configuration source. The source name used in Event Log can be overridden by setting a `SourceName` property in these settings; if you don't specify a name, the default application name (normally the executable assembly name) will be used.

More information on logging is at the end of this chapter.

## Run your app as a Linux service with systemd

To configure your ASP.NET Core application to run as a Linux service (or *daemon* in Linux parlance), install the [Microsoft.Extensions.Hosting.Systemd](#) package from NuGet. Then add a call to `UseSystemd` to the `CreateHostBuilder` method in `Program.cs`.

```
public static IHostBuilder CreateHostBuilder(string[] args) =>
    Host.CreateDefaultBuilder(args)
        .UseSystemd() // Enable running as a Systemd service
        .ConfigureWebHostDefaults(webBuilder =>
        {
            webBuilder.UseStartup<Startup>();
        });
```

### Note

If the application isn't running as a Linux service, the `UseSystemd` method doesn't do anything.

Now publish your application (either framework-dependent, or self-contained for the relevant Linux runtime, e.g. `linux-x64`), either from Visual Studio by right-clicking the project and choosing *Publish* from the context menu, or from the .NET Core CLI using the following command.

```
dotnet publish -c Release -r linux-x64 -o ./publish
```

Copy the complete contents of the publish directory to an installation folder on the Linux host. Registering the service requires a special file, called a “unit file”, to be added to the /etc/systemd/system directory. You’ll need root permission to create a file in this folder. Name the file with the identifier you want systemd to use and the .service extension. For example, /etc/systemd/system/myapp.service.

The service file uses INI format, as shown in this example.

```
[Unit]
Description=My gRPC Application

[Service]
Type=notify
ExecStart=/usr/sbin/myapp

[Install]
WantedBy=multi-user.target
```

The Type=notify property tells systemd that the application will notify it on startup and shutdown. The WantedBy=multi-user.target setting will cause the service to start when the Linux system reaches “runlevel 2”, meaning a non-graphical multi-user shell is active.

Before systemd will recognize the service, it needs to reload its configuration. You control systemd using the systemctl command. After reloading, use the status subcommand to confirm the application has registered successfully.

```
sudo systemctl daemon-reload
sudo systemctl status myapp
```

If you’ve configured the service correctly, the following output will be shown:

```
myapp.service - My gRPC Application
  Loaded: loaded (/etc/systemd/system/myapp.service; disabled; vendor preset: enabled)
  Active: inactive (dead)
```

Use the start command to start the service.

```
sudo systemctl start myapp.service
```

### Tip

The .service extension is optional when using systemctl start.

To tell systemd to start the service automatically on system startup, use the enable command.

```
sudo systemctl enable myapp
```

## Log to journald

The Linux equivalent of the Windows Event Log is journald, a structured logging system service that is part of systemd. Log messages written to the standard output by a Linux daemon are automatically written to journald, so to configure logging levels, use the Console section of the logging

configuration. The UseSystemd host builder method automatically configures the console output format to suit the journal.

Because `journald` is the standard for Linux logs, there are a variety of tools that integrate with it, and you can easily route logs from `journald` to an external logging system. Working locally on the host, you can use the `journalctl` command to view logs from the command line.

```
sudo journalctl -u myapp
```

### Tip

If you have a GUI environment available on your host, a few graphical log viewers are available for Linux, such as *QJournalctl* and *gnome-logs*.

To learn more about querying the systemd journal from the command line with `journalctl`, see [the man pages](#).

## HTTPS Certificates for self-hosted applications

When running a gRPC application in production, you should use a TLS certificate from a trusted Certificate Authority (CA). This CA could be a public CA, or an internal one for your organization.

On Windows hosts, the certificate may be loaded from a secure [Certificate Store](#) using the [X509Store class](#). The `X509Store` class can also be used with the OpenSSL key-store on some Linux hosts.

Certificates may also be created using one of the [X509Certificate2 constructors](#), either from a file (for example a `.pfx` file protected by a strong password), or from binary data retrieved from a secure storage service such as [Azure Key Vault](#).

Kestrel can be configured to use a certificate in two ways: from configuration, or in code.

### Set HTTPS certificates using configuration

The configuration approach requires setting the path to the certificate `.pfx` file and the password in the Kestrel configuration section. In `appsettings.json` that would look like this.

```
{
  "Kestrel": {
    "Certificates": {
      "Default": {
        "Path": "cert.pfx",
        "Password": "DO NOT STORE PLAINTEXT PASSWORDS IN APPSETTINGS FILES"
      }
    }
  }
}
```

The password should be provided using a secure configuration source such as Azure KeyVault or Hashicorp Vault.

You SHOULD NOT store unencrypted passwords in configuration files.

## Set HTTPS certificates in code

To configure HTTPS on Kestrel in code, use the `ConfigureKestrel` method on `IWebHostBuilder` in the `Program` class.

```
public static IHostBuilder CreateHostBuilder(string[] args) =>
    Host.CreateDefaultBuilder(args)
        .ConfigureWebHostDefaults(webBuilder =>
        {
            webBuilder.UseStartup<Startup>();
            webBuilder.ConfigureKestrel(kestrel =>
            {
                kestrel.ConfigureHttpsDefaults(https =>
                {
                    https.ServerCertificate = new X509Certificate2("mycert.pfx",
"password");
                });
            });
        });
```

Again, the password for the .pfx file should be stored in and retrieved from a secure configuration source.

## Docker

This section will cover the creation of Docker images for ASP.NET Core gRPC applications, ready to run in Docker, Kubernetes, or other container environments. The sample application used, with an ASP.NET Core MVC web app and a gRPC service, is available on the [dotnet-architecture/grpc-for-wcf-developers](https://github.com/dotnet-architecture/grpc-for-wcf-developers) repository on GitHub.

### Microsoft base images for ASP.NET Core applications

Microsoft provides a range of base images for building and running .NET Core applications. To create an ASP.NET Core 3.0 image, two base images are used: an SDK image to build and publish the application, and a runtime image for deployment.

Image	Description
<a href="https://mcr.microsoft.com/dotnet/core/sdk">mcr.microsoft.com/dotnet/core/sdk</a>	For building applications with docker build. Not to be used in production.
<a href="https://mcr.microsoft.com/dotnet/core/aspnet">mcr.microsoft.com/dotnet/core/aspnet</a>	Contains the runtime and ASP.NET Core dependencies. For production.

For each image, there are four variants based on different Linux distributions, distinguished by tags.

Image tag(s)	Linux	Notes
3.0-buster, 3.0	Debian 10	The default image if no OS variant is specified.
3.0-alpine	Alpine 3.9	Alpine base images are much smaller than Debian or Ubuntu ones.
3.0-disco	Ubuntu 19.04	
3.0-bionic	Ubuntu 18.04	

The Alpine base image is around 100 MB, compared to 200 MB for the Debian and Ubuntu images, but some software packages or libraries may not be available in Alpine's package management. If you're not sure which image to use, it's best to stick to the default Debian unless you have a compelling need to use a different distro.

### Important

Make sure you use the same variant of Linux for the build and the runtime. Applications built and published on one variant may not work on another.

## Create a Docker image

A Docker image is defined by a *Dockerfile*, a text file that contains all the commands that are needed to build the application and install any dependencies that are required for either building or running the application. The following example shows the simplest Dockerfile for an ASP.NET Core 3.0 application:

```
# Application build steps
FROM mcr.microsoft.com/dotnet/core/sdk:3.0 as builder

WORKDIR /src

COPY . .

RUN dotnet restore

RUN dotnet publish -c Release -o /published src/StockData/StockData.csproj

# Runtime image creation
FROM mcr.microsoft.com/dotnet/core/aspnet:3.0

# Uncomment the line below if running with HTTPS
# ENV ASPNETCORE_URLS=https://+:443

WORKDIR /app

COPY --from=builder /published .

ENTRYPOINT [ "dotnet", "StockData.dll" ]
```

The Dockerfile has two parts: the first uses the sdk base image to build and publish the application; the second creates a runtime image from the aspnet base. This is because the sdk image is around

900 MB compared to around 200 MB for the runtime image, and most of its contents are unnecessary at runtime.

## The build steps

Step	Description
FROM ...	Declares the base image and assigns the builder alias (see next section for explanation).
WORKDIR /src	Creates the /src directory and sets it as the current working directory.
COPY . .	Copies everything below the current directory on the host into the current directory on the image.
RUN dotnet restore	Restores any external packages (ASP.NET Core 3.0 framework is pre-installed with the SDK).
RUN dotnet publish ...	Builds and publishes a Release build. Note that the --runtime flag isn't required.

## The runtime image steps

Step	Description
FROM ...	Declares a new base image.
WORKDIR /app	Creates the /app directory and sets it as the current working directory.
COPY --from=builder ...	Copies the published application from the previous image, using the builder alias from the first FROM line.
ENTRYPOINT [ ... ]	Sets the command to run when the container starts. The dotnet command in the runtime image can only run DLL files.

## HTTPS in Docker

Microsoft's base images for Docker set the ASPNETCORE\_URLS environment variable to `http://+:80`, meaning that Kestrel will run without HTTPS on that port. If you're using HTTPS with a custom certificate (as described in [the previous section](#)), you should override this by setting the environment variable **in the runtime image creation part** of your Dockerfile.

```
# Runtime image creation
FROM mcr.microsoft.com/dotnet/core/aspnet:3.0

ENV ASPNETCORE_URLS=https://+:443
```

## The .dockerignore file

Much like `.gitignore` files that exclude certain files and directories from source control, the `.dockerignore` file can be used to exclude files and directories from being copied to the image during build. This not only saves time copying, but can also avoid some confusing errors that arise from having (particularly) the `obj` directory from your PC copied into the image. You should add at least entries for `bin` and `obj` to your `.dockerignore` file.



```
bin/  
obj/
```

## Build the image

For a solution with a single application, and thus a single Dockerfile, it is simplest to put the Dockerfile in the base directory; that is, the same directory as the `.sln` file. In that case, to build the image, use the following `docker build` command from the directory containing the Dockerfile.

```
docker build --tag stockdata .
```

The confusingly named `--tag` flag (which can be shortened to `-t`) specifies the whole name of the image, *including* the actual tag if specified. The `.` at the end specifies the *context* in which the build will be run; the current working directory for the `COPY` commands in the Dockerfile.

If you have multiple applications within a single solution, you can keep the Dockerfile for each application in its own folder, beside the `.csproj` file, but you should still run the `docker build` command from the base directory to ensure that the solution and all the projects are copied into the image. You can specify a Dockerfile below the current directory using the `--file` (or `-f`) flag.

```
docker build --tag stockdata --file src/StockData/Dockerfile .
```

## Run the image in a container on your machine

To run the image in your local Docker instance, use the `docker run` command.

```
docker run -ti -p 5000:80 stockdata
```

The `-ti` flag connects your current terminal to the container's terminal and runs in interactive mode. The `-p 5000:80` publishes (links) port 80 on the container to port 80 on the localhost network interface.

## Push the image to a registry

Once you've verified that the image works, you need to push it to a Docker registry to make it available on other systems. Internal networks will need to provision a Docker registry. This can be as simple as running [Docker's own registry image](#) (that's right, the Docker registry runs in a Docker container), but there are various more comprehensive solutions available. For external sharing and cloud use, there are various managed registries available, such as [Azure Container Registry](#) or [Docker Hub](#).

To push to the Docker Hub, prefix the image name with your user or organization name.

```
docker tag stockdata myorg/stockdata  
docker push myorg/stockdata
```

To push to a private registry, prefix the image name with the registry host name and the organization name.

```
docker tag stockdata internal-registry:5000/myorg/stockdata  
docker push internal-registry:5000/myorg/stockdata
```

Once the image is in a registry, you can deploy it to individual Docker hosts or to a container orchestration engine like Kubernetes.

## Kubernetes

Although it's possible to run containers manually on Docker hosts, for reliable production systems it's preferable to use a Container Orchestration Engine to manage multiple instances running across several servers in a cluster. There are various Container Orchestration Engines available, including Kubernetes, Docker Swarm and Apache Mesos. But of these engines, Kubernetes is far and away the most widely used, so it will be the focus of this chapter.

Kubernetes includes the following functionality:

- **Scheduling** runs containers on multiple nodes within a cluster, ensuring balanced usage of the available resource, keeping containers running if there are outages, and handling rolling updates to new versions of images or new configurations.
- **Health checks** monitor containers to ensure continued service.
- **DNS & service discovery** handles routing between services within a cluster.
- **Ingress** exposes selected services externally, and generally provides load-balancing across instances of those services.
- **Resource management** attaches external resources such as storage to containers.

This chapter will detail how to deploy an ASP.NET Core gRPC service and a website that consumes the service into a Kubernetes cluster. The sample application used is available from on the [dotnet-architecture/grpc-for-wcf-developers](#) repository on GitHub,

## Kubernetes terminology

Kubernetes uses *desired state configuration*: the API is used to describe objects such as *Pods*, *Deployments* and *Services*, and the *Control Plane* takes care of implementing the desired state across all the *nodes* in a *cluster*. A Kubernetes cluster has a *Master* node that runs the *Kubernetes API*, which can be communicated with programmatically or using the `kubectl` command-line tool. `kubectl` can create and manage objects using command-line arguments, but works best with YAML files that contain declaration data for Kubernetes objects.

## Kubernetes YAML files

Every Kubernetes YAML file will have at least three top-level properties.

```
apiVersion: v1
kind: Namespace
metadata:
  # Object properties
```

The `apiVersion` property is used to specify which version (and which API) the file is intended for. The `kind` property specifies the kind of object the YAML represents. The `metadata` property contains object properties such as `name`, `namespace`, or `labels`.

Most Kubernetes YAML files will also have a `spec` section that describes the resources and configuration necessary to create the object.

## Pods

Pods are the basic units of execution in Kubernetes. They can run multiple containers, but are also used to run single containers. The pod also includes any storage resources required by the container(s), and the network IP address.

## Services

Services are meta-objects that describe pods (or sets of pods) and provide a way to access them within the cluster, such as mapping a service name to a set of pod IP addresses using the cluster DNS service.

## Deployments

Deployments are the *described state* objects for Pods. If you create a Pod manually, when it terminates it won't be restarted. Deployments are used to tell the cluster which pods, and how many replicas of those pods, should be running at the present time.

## Other objects

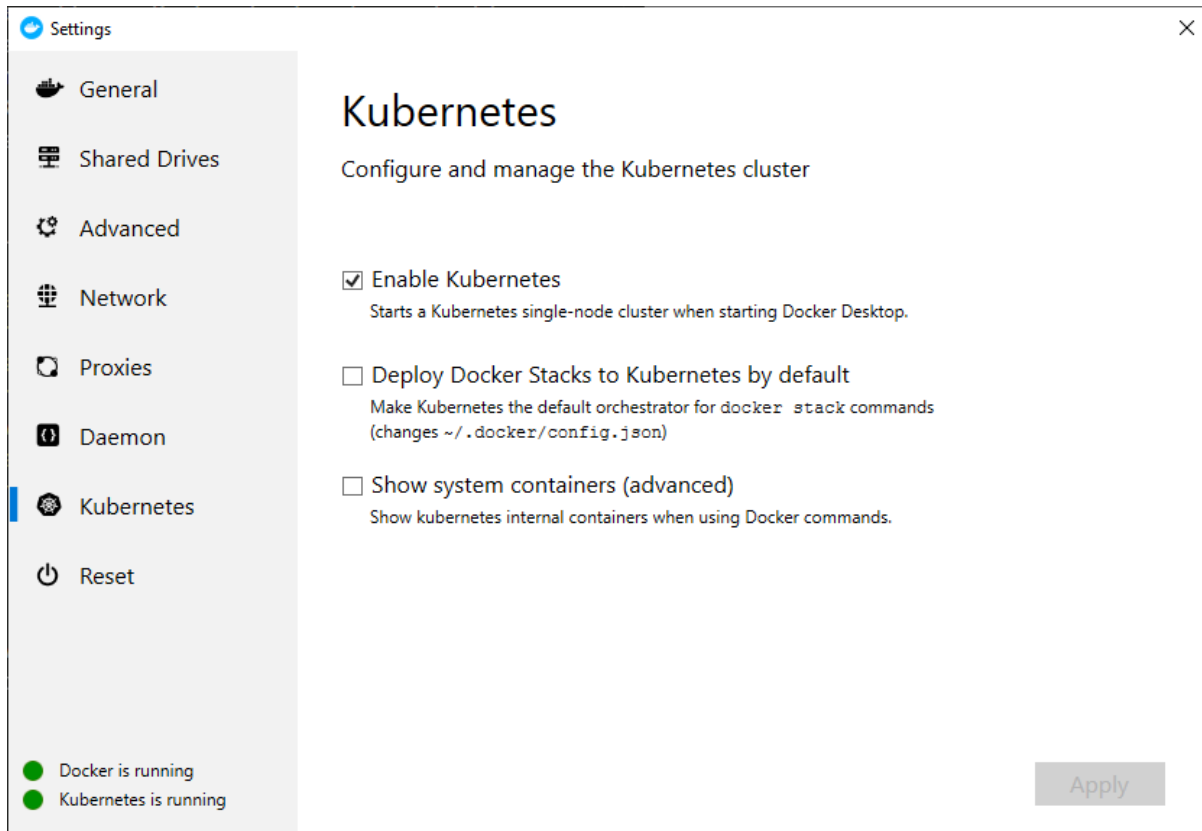
Pods, Services, and Deployments are just three of the most basic object types. There are dozens of other types of object that are managed by a Kubernetes cluster. For more information, see the [Kubernetes Concepts](#) documentation.

## Namespaces

Kubernetes clusters are designed to scale to hundreds or thousands of nodes, and run similar numbers of services. To avoid clashes between object names, namespaces are used to group objects together as part of larger applications. Kubernetes own services run in a default namespace. All user objects should be created in their own namespaces to avoid potential clashes with default objects or other tenants in the cluster.

## Get started with Kubernetes

If you're running Docker Desktop for Windows or macOS, Kubernetes is already available. Just enable it in the Kubernetes section of the Settings window.



To run a local Kubernetes cluster in Linux, look at [minikube](#), or [MicroK8s](#) if your Linux distribution supports [snaps](#).

To check that your cluster is running and accessible, run the `kubectl version` command.

```
kubectl version
Client Version: version.Info{Major:"1", Minor:"14", GitVersion:"v1.14.6",
GitCommit:"96fac5cd13a5dc064f7d9f4f23030a6aeface6cc", GitTreeState:"clean",
BuildDate:"2019-08-19T11:13:49Z", GoVersion:"go1.12.9", Compiler:"gc",
Platform:"windows/amd64"}
Server Version: version.Info{Major:"1", Minor:"14", GitVersion:"v1.14.6",
GitCommit:"96fac5cd13a5dc064f7d9f4f23030a6aeface6cc", GitTreeState:"clean",
BuildDate:"2019-08-19T11:05:16Z", GoVersion:"go1.12.9", Compiler:"gc",
Platform:"linux/amd64"}
```

In this example, both the `kubectl` CLI and the Kubernetes server are running version 1.14.6. Each version of `kubectl` is supposed to support the previous and next version of the server, so `kubectl` 1.14 should work with server versions 1.13 and 1.15 as well.

## Run services on Kubernetes

The sample application has a `kube` directory containing three YAML files. The `namespace.yml` file declares a custom namespace, `stocks`. The `stockdata.yml` file declares the Deployment and the Service for the gRPC application, and the `stockweb.yml` file declares the Deployment and Service for an ASP.NET Core 3.0 MVC web application that consumes the gRPC service.

To use a YAML file with `kubectl`, use the `apply -f` command.

```
kubectl apply -f object.yml
```

The `apply` command will check the validity of the YAML file and display any errors received from the API, but doesn't wait until all the objects declared in the file have been created as this can take some time. Use the `kubectl get` command with the relevant object types to check on object creation in the cluster.

## The namespace declaration

Namespace declaration is simple and requires only assigning a name.

```
apiVersion: v1
kind: Namespace
metadata:
  name: stocks
```

Use `kubectl` to apply the `namespace.yml` file and check the namespace is created successfully.

```
> kubectl apply -f namespace.yml
namespace/stocks created

> kubectl get namespaces
NAME          STATUS   AGE
stocks        Active   2m53s
```

## The StockData application

The `stockdata.yml` file declares two objects: a Deployment and a Service.

### The StockData Deployment

The Deployment part provides the spec for the deployment itself, including the number of replicas required, and a template for the Pod objects to be created and managed by the deployment. Note that Deployment objects are managed with the apps API, as specified in `apiVersion`, rather than the main Kubernetes API.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: stockdata
  namespace: stocks
spec:
  selector:
    matchLabels:
      run: stockdata
  replicas: 1
  template:
    metadata:
      labels:
        run: stockdata
    spec:
      containers:
        - name: stockdata
          image: stockdata:1.0.0
```

```
imagePullPolicy: Never
resources:
  limits:
    cpu: 100m
    memory: 100Mi
  ports:
  - containerPort: 80
```

The `spec.selector` property is used to match running Pods to the Deployment. The Pod's `metadata.labels` property must match the `matchLabels` property or the API call will fail.

The `template.spec` section declares the container to be run. When working with a local Kubernetes cluster, such as the one provided by Docker Desktop, you can specify images that were built locally as long as they have a version tag.

### Important

By default, Kubernetes will always check for and try to pull a new image. If it can't find the image in any of its known repositories, the Pod creation will fail. To work with local images, set the `imagePullPolicy` to `Never`.

The `ports` property specifies which container ports should be published on the Pod. The `stockservice` image runs the service on the standard HTTP port, so port 80 is published.

The `resources` section applies resource limits to the container running within the pod. This is good practice as it prevents an individual pod from consuming all the available CPU or memory on a node.

### Note

ASP.NET Core 3.0 has been optimized and tuned to run in resource-limited containers, and the `dotnet/core/aspnet` Docker image sets an environment variable to tell the dotnet runtime that it's in a container.

## The StockData Service

The Service part of the YAML file declares the service that provides access to the Pods within the cluster.

```
apiVersion: v1
kind: Service
metadata:
  name: stockdata
  namespace: stocks
spec:
  ports:
  - port: 80
  selector:
    run: stockdata
```

The Service spec uses the `selector` property to match running Pods, in this case looking for Pods with a label `run: stockdata`. The specified port on matching Pods are published by the named service. Other Pods running in the `stocks` namespace can access HTTP on this service using `http://stockdata` as the address. Pods running in other namespaces can use the

`http://stockdata.stocks` hostname. You can control cross-namespace service access using [Network Policies](#).

## Deploy the StockData application

Use `kubectl` to apply the `stockdata.yml` file and check that the Deployment and Service were created.

```
> kubectl apply -f .\stockdata.yml
deployment.apps/stockdata created
service/stockdata created

> kubectl get deployment stockdata --namespace stocks
NAME          READY   UP-TO-DATE   AVAILABLE   AGE
stockdata     1/1     1            1           17s

> kubectl get service stockdata --namespace stocks
NAME          TYPE          CLUSTER-IP   EXTERNAL-IP   PORT(S)    AGE
stockdata     ClusterIP     10.97.132.103 <none>        80/TCP     33s
```

## The StockWeb application

The `stockweb.yml` file declares the Deployment and Service for the MVC application.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: stockweb
  namespace: stocks
spec:
  selector:
    matchLabels:
      run: stockweb
  replicas: 1
  template:
    metadata:
      labels:
        run: stockweb
    spec:
      containers:
        - name: stockweb
          image: stockweb:1.0.0
          imagePullPolicy: Never
          resources:
            limits:
              cpu: 100m
              memory: 100Mi
          ports:
            - containerPort: 80
          env:
            - name: StockData__Address
              value: "http://stockdata"
            - name: DOTNET_SYSTEM_NET_HTTP_SOCKETSHTTPHANDLER_HTTP2UNENCRYPTEDSUPPORT
              value: "true"
      ---
apiVersion: v1
```

```
kind: Service
metadata:
  name: stockweb
  namespace: stocks
spec:
  type: NodePort
  ports:
    - port: 80
  selector:
    run: stockweb
```

## Environment variables

The `env` section of the Deployment object specifies environment variables to be set in the container running the `stockweb:1.0.0` images.

The `StockData__Address` environment variable will map to the `StockData:Address` configuration setting thanks to the `EnvironmentVariables` configuration provider. This setting uses double underscores between names to separate sections. The address uses the service name of the `stockdata` Service, which is running in the same Kubernetes namespace.

The `DOTNET_SYSTEM_NET_HTTP_SOCKETSHTTPHANDLER_HTTP2UNENCRYPTEDSUPPORT` environment variable sets an [AppContext](#) switch that enables unencrypted HTTP/2 connections for [HttpClient](#). This environment variable is the equivalent of setting the switch in code as shown here.

```
AppContext.SetSwitch("System.Net.Http.SocketsHttpHandler.Http2UnencryptedSupport", true);
```

Using an environment variable for the switch means the setting can easily be changed depending on the context in which the application is running.

## Service types

To make the Web application accessible from outside the cluster, the `type: NodePort` property is used. This property type causes Kubernetes to publish port 80 on the Service to an arbitrary port on the cluster's external network sockets. The port assigned can be found using the `kubectl get service` command.

The `stockdata` service shouldn't be accessible from outside the cluster, so it used the default type, `ClusterIP`.

Production systems will most likely use an integrated load-balancer to expose public applications to external consumers. Services exposed in this way should use the `LoadBalancer` type.

For more information on service types, see the [Kubernetes' Publishing Services](#) documentation.



## Deploy the StockWeb application

Use `kubectl` to apply the `stockweb.yml` file and check that the Deployment and Service were created.

```
> kubectl apply -f .\stockweb.yml
deployment.apps/stockweb created
service/stockweb created

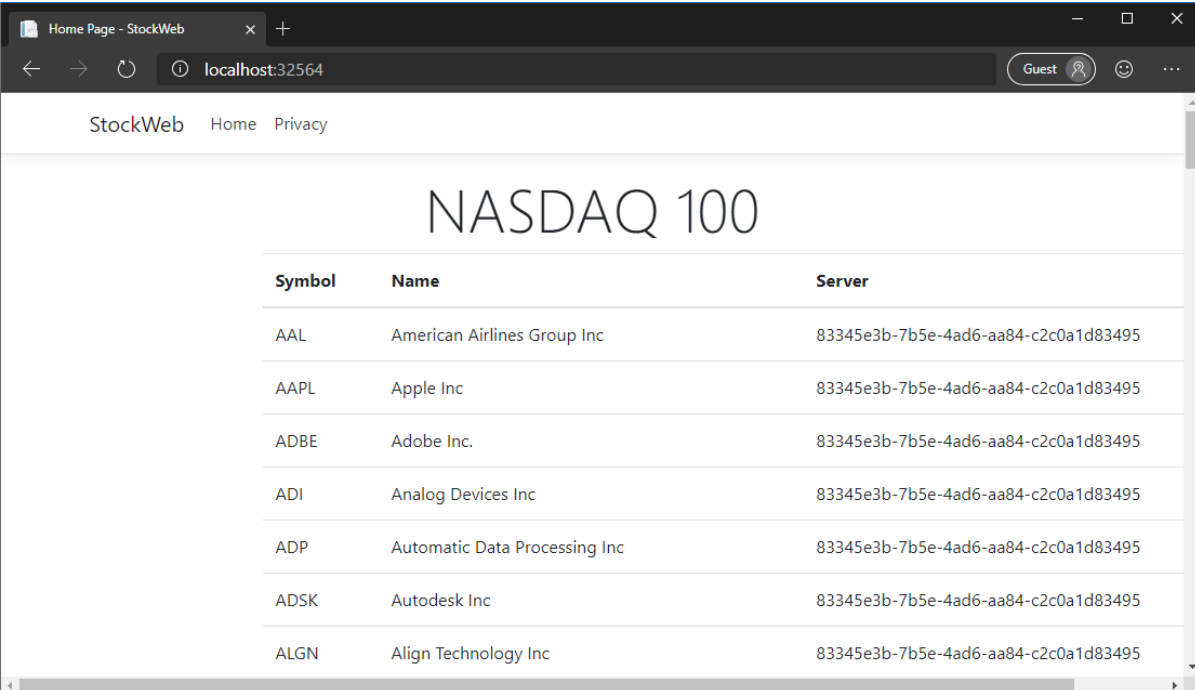
> kubectl get deployment stockweb --namespace stocks
NAME          READY   UP-TO-DATE   AVAILABLE   AGE
stockweb      1/1     1            1           8s

> kubectl get service stockweb --namespace stocks
NAME          TYPE        CLUSTER-IP   EXTERNAL-IP   PORT(S)          AGE
stockweb      NodePort    10.106.141.5 <none>        80:32564/TCP     13s
```

The output from the `get service` command shows that the HTTP port has been published to port 32564 on the external network; for Docker Desktop, this will be localhost. The application can be accessed by browsing to `http://localhost:32564`.

## Testing the application

The StockWeb application displays a list of NASDAQ stocks that are retrieved from a simple request-reply service. For demonstration purposes, each line also shows the unique ID of the service instance that returned it.



Symbol	Name	Server
AAL	American Airlines Group Inc	83345e3b-7b5e-4ad6-aa84-c2c0a1d83495
AAPL	Apple Inc	83345e3b-7b5e-4ad6-aa84-c2c0a1d83495
ADBE	Adobe Inc.	83345e3b-7b5e-4ad6-aa84-c2c0a1d83495
ADI	Analog Devices Inc	83345e3b-7b5e-4ad6-aa84-c2c0a1d83495
ADP	Automatic Data Processing Inc	83345e3b-7b5e-4ad6-aa84-c2c0a1d83495
ADSK	Autodesk Inc	83345e3b-7b5e-4ad6-aa84-c2c0a1d83495
ALGN	Align Technology Inc	83345e3b-7b5e-4ad6-aa84-c2c0a1d83495

If the number of replicas of the `stockdata` service were increased, you might expect the **Server** value to change from line to line, but in fact all 100 records are always returned from the same instance. If you refresh the page every few seconds, the server ID remains the same. Why does this happen? There are two factors at play here.

First, the Kubernetes service discovery system uses “round-robin” load-balancing by default. The first time the DNS server is queried, it will return the first matching IP address for the service. The next time, the next IP address in the list, and so on, until the end, at which point it loops back to the start.

Second, the `HttpClient` used for the `StockWeb` application’s gRPC client is created and managed by the [ASP.NET Core HttpClientFactory](#), and a single instance of this client is used for every call to the page. The client only does one DNS lookup, so all requests are routed to the same IP address. Furthermore, because the `HttpClientHandler` is cached for performance reasons, multiple requests in quick succession will *all* use the same IP address, until the cached DNS entry expires or the handler instance is disposed for some reason.

This means that by default requests to a gRPC service aren’t balanced across all instances of that service in the cluster. Different consumers will use different instances, but that doesn’t guarantee a good distribution of requests and a balanced use of resources.

The next chapter, [Service Meshes](#), will look at how to address this problem.

## Service meshes

A service mesh is an infrastructure component that takes control of routing service requests within a network. Service meshes can handle all kinds of network-level concerns within a Kubernetes cluster, including:

- Service discovery
- Load balancing
- Fault tolerance
- Encryption
- Monitoring

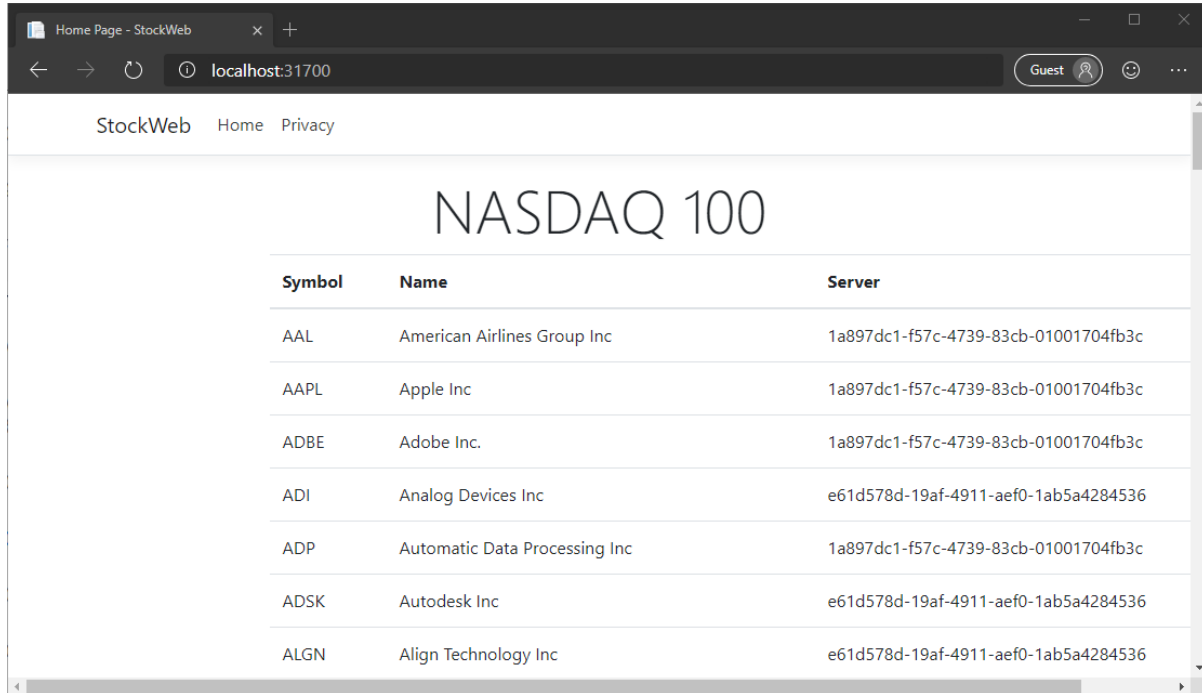
Kubernetes service meshes work by adding an extra container, called a *sidecar proxy*, to each pod included in the mesh. The proxy takes over handling all inbound and outbound network requests, allowing configuration and management of networking matters to be kept separate from the application containers and, in many cases, without requiring any changes to the application code.

Take the [previous chapter’s example](#), where the gRPC requests from the web application were all routed to a single instance of the gRPC service. This happens because the service’s hostname is resolved to an IP address, and that IP address is cached for the lifetime of the `HttpClientHandler` instance. It might be possible to work around this by handling DNS lookups manually or creating multiple clients, but this would complicate the application code considerably without adding any business or customer value.

Using a service mesh, the requests from the application container are sent to the sidecar proxy, which can distribute them intelligently across all instances of the other service. The mesh can also:

- Respond seamlessly to failures of individual instances of a service.
- Handle retry semantics for failed calls or timeouts
- Reroute failed requests to an alternate instance without returning to the client application at all.

The following screenshot shows the StockWeb application running with the Linkerd service mesh, with no changes to the application code, or even the Docker image being used. The only change required was the addition of an annotation to the Deployment in the YAML files for the `stockdata` and `stockweb` services.



Symbol	Name	Server
AAL	American Airlines Group Inc	1a897dc1-f57c-4739-83cb-01001704fb3c
AAPL	Apple Inc	1a897dc1-f57c-4739-83cb-01001704fb3c
ADBE	Adobe Inc.	1a897dc1-f57c-4739-83cb-01001704fb3c
ADI	Analog Devices Inc	e61d578d-19af-4911-aef0-1ab5a4284536
ADP	Automatic Data Processing Inc	1a897dc1-f57c-4739-83cb-01001704fb3c
ADSK	Autodesk Inc	e61d578d-19af-4911-aef0-1ab5a4284536
ALGN	Align Technology Inc	e61d578d-19af-4911-aef0-1ab5a4284536

You can see from the `Server` column that the requests from the StockWeb application have been routed to both replicas of the StockData service, despite originating from a single `HttpClient` instance in the application code. In fact, if you review the code, you'll see that all 100 requests to the StockData service are made simultaneously using the same `HttpClient` instance, yet with the service mesh, those requests will be balanced across however many service instances are available.

Service meshes only apply to traffic within a cluster. For external clients, see [the next chapter, Load Balancing](#).

## Service mesh options

There are three general-purpose service mesh implementations currently available for use with Kubernetes: Istio, Linkerd, and Consul Connect. All three provide request routing/proxying, traffic encryption, resilience, host-to-host authentication, and traffic control.

Choosing a service mesh depends multiple factors:

- The organization's specific requirements around costs, compliance, paid support plans, and so on.
- The nature of the cluster, its size, the number of services deployed, and the volume of traffic within the cluster network.
- Ease of deploying and managing the mesh and using it with services.

More information on each service mesh is available from their respective websites.

- [Istio](https://istio.io) - [istio.io](https://istio.io)
- [Linkerd](https://linkerd.io) - [linkerd.io](https://linkerd.io)
- [Consul](https://consul.io/mesh.html) - [consul.io/mesh.html](https://consul.io/mesh.html)

## Example: add Linkerd to a deployment

In this example, you'll learn how to use the Linkerd service mesh with the *StockKube* application from [the previous section](#). To follow this example, you'll need to [install the Linkerd CLI](#). Windows binaries can be downloaded from the GitHub releases section; make sure to use the most recent **stable** release and not one of the edge releases.

With the Linkerd CLI installed, follow the [Getting Started instructions on the Linkerd web site] to install the Linkerd components on your Kubernetes cluster. The instructions are straight-forward and installation should only take a couple of minutes on a local Kubernetes instance.

## Add Linkerd to Kubernetes deployments

The Linkerd CLI provides an `inject` command to add the necessary sections and properties to Kubernetes files. You can run the command and write the output to a new file.

```
linkerd inject stockdata.yml > stockdata-with-mesh.yml  
linkerd inject stockweb.yml > stockweb-with-mesh.yml
```

You can inspect the new files to see what changes have been made. For Deployment objects, a metadata annotation is added to tell Linkerd to inject a sidecar proxy container into the Pod when it's created.

It's also possible to pipe the output of the `linkerd inject` command to `kubectl` directly. The following commands will work in PowerShell or any Linux shell.

```
linkerd inject stockdata.yml | kubectl apply -f -  
linkerd inject stockweb.yml | kubectl apply -f -
```

## Inspect services in the Linkerd dashboard

Launch the Linkerd dashboard using the `linkerd` CLI.

```
linkerd dashboard
```

The dashboard provides detailed information about all services that are connected to the mesh.

The screenshot shows the Linkerd dashboard for the 'stocks' namespace. The left sidebar contains navigation links: Overview, Tap, Top, Top Routes, Service Mesh, Resources, Documentation, Community, Join the Mailing List, Join us on Slack, and File an Issue. The main content area displays the 'Namespace: stocks' page. It features two tables: 'Deployments' and 'Pods'. The 'Deployments' table has columns for Deployment, Meshed, Success Rate, RPS, P50 Latency, P95 Latency, P99 Latency, and Grafana. It lists two deployments: 'stockdata' (2/2 replicas) and 'stockweb' (1/1 replicas). The 'Pods' table has columns for Pod, Meshed, Success Rate, RPS, P50 Latency, P95 Latency, P99 Latency, and Grafana. It lists three pods: 'stockdata-558d4f55ff-7tcxv' (1/1 replicas), 'stockdata-558d4f55ff-854g4' (1/1 replicas), and 'stockweb-6df4f86777-cpptv' (1/1 replicas). The status bar at the bottom indicates 'Running Linkerd 2.5.0 (stable). Linkerd is up to date.'

If you increase the number of replicas of the StockData gRPC service as shown in the following example, and refresh the StockWeb page in the browser, you should see a mix of IDs in the Server column, indicating that requests are being served by all the available instances.

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: stockdata
  namespace: stocks
spec:
  selector:
    matchLabels:
      run: stockdata
  replicas: 2 # Increase the target number of instances
  template:
    metadata:
      annotations:
        linkerd.io/inject: enabled
      creationTimestamp: null
      labels:
        run: stockdata
    spec:
      containers:
        - name: stockdata
          image: stockdata:1.0.0
          imagePullPolicy: Never
          resources:
            limits:
              cpu: 100m
              memory: 100Mi
          ports:
            - containerPort: 80
```

# Load balancing gRPC

A typical deployment of a gRPC application includes a number of identical instances of the service, providing resilience and horizontal scalability. Load balancing distributed incoming requests across these instances to provide full usage of all available resources. To make this load balancing invisible to the client, it's common to use a proxy load balancer server to handle requests from clients and route them to back-end instances.

Load balancers are classified according to the *layer* they operate on. Layer 4 load balancers work on the *transport* level, for example, with TCP sockets, connections and packets. Layer 7 load balancers work at the *application* level, specifically handling HTTP/2 requests for gRPC applications.

## L4 load balancers

An L4 load balancer accepts a TCP connection request from a client, opens another connection to one of the back-end instances, and copies data between the two connections with no real processing. L4 offers excellent performance and low latency, but very little control or intelligence. As long as the client keeps the connection open, all requests will be directed to the same back-end instance.

An example of an L4 load balancer is the [Azure Load Balancer](#).

## L7 load balancers

An L7 load balancer parses incoming HTTP/2 requests and passes them on to back-end instances on a request-by-request basis, no matter how long the connection is held by the client.

Examples of L7 load balancers include:

- [Nginx](#)
- [HAproxy](#)
- [Traefik](#)

As a rule of thumb, L7 load balancers are the best choice for gRPC and other HTTP/2 applications (and for HTTP applications generally, in fact). L4 load balancers will *work* with gRPC applications, but are primarily useful when low latency and low overhead are of paramount importance.

### Important

At the time of this writing, not all L7 load balancers support all parts of the HTTP/2 specification required by gRPC services, such as trailing headers.

When using TLS encryption, load balancers can terminate the TLS connection and pass unencrypted requests to the back-end application, or pass the encrypted request along. Either way, the load balancer will need to be configured with the server's public and private key, so that it can decrypt requests for processing.

Refer to the documentation for your preferred load balancer to find out how to configure it to handle HTTP/2 requests with your back-end services.

## Load balancing within Kubernetes

See [the section on Service Meshes](#) for a discussion of load balancing across internal services on Kubernetes.

## Application Performance Management

In modern production environments like Kubernetes, it's very important to be able to monitor applications to ensure they're running optimally. Concerns like logging and metrics have never been more important. ASP.NET Core, including gRPC, has first-class support for producing and managing log messages and metrics data, as well as *tracing* data. This section will explore these areas in more details.

### Logging vs Metrics

Before looking at the implementation details, it's necessary to understand the difference between logging and metrics.

Logging is concerned with text messages that record detailed information about things that have happened in the system. Log messages may include exception data like stack traces, or structured data that provides context about the message. Logging output is commonly written to a searchable text store.

Metrics refers to numeric data that is designed to be aggregated and presented using charts and graphs in a dashboard that provides a view of the overall health and performance of an application. Metrics data can also be used to trigger automated alerts when a threshold is exceeded. The following list shows some examples of metrics data:

- Time taken to process requests.
- The number of requests per second being handled by an instance of a service.
- The number of failed requests on an instance.

### Logging in ASP.NET Core gRPC

ASP.NET Core provides built-in support for logging, in the form of the [Microsoft.Extensions.Logging](#) NuGet package. The core parts of this library are included with the Web SDK, so there's no need to install it manually. By default, log messages are written to the standard output (the "console") and to any attached debugger. To write logs to persistent external data stores, you may need to import [optional logging sink packages](#).

The ASP.NET Core gRPC framework writes detailed diagnostic logging messages to this logging framework so they can be processed/stored along with your application's own messages.

### Produce log messages

The logging extension is automatically registered with ASP.NET Core's dependency injection system, so you can specify loggers as a constructor parameter on gRPC service types.

```
public class StockData : Stocks.StocksBase
{
    private readonly ILogger<StockData> _logger;

    public StockData(ILogger<StockData> logger)
    {
        _logger = logger;
    }
}
```

Many log messages around requests, exceptions, and so on, are provided by the ASP.NET Core and gRPC framework components. Add your own log messages to provide detail and context about application logic rather than lower-level concerns.

For more information about writing log messages and available logging sinks and targets, see the [Logging in .NET Core and ASP.NET Core](#) article.

## Metrics in ASP.NET Core gRPC

The .NET Core runtime provides a set of components for emitting and observing metrics that includes APIs such as the [EventSource](#) and [EventCounter](#) classes. These APIs can be used to emit basic numeric data that can be consumed by external processes like the [dotnet-counters global tool](#), or Event Tracing for Windows. For more information about using EventCounter in your own code, see the [EventCounter Introduction](#) tutorial.

For more advanced metrics and for writing metric data to a wider range of data stores, there's an excellent open-source project called [App Metrics](#). This suite of libraries provides an extensive set of types to instrument your code. It also offers packages to write metrics to different kinds of targets that include time-series databases, such as Prometheus and InfluxDB, [Azure Application Insights](#), and more. The [App.Metrics.AspNetCore.Mvc](#) NuGet package even adds a comprehensive set of basic metrics that are automatically generated via integration with the ASP.NET Core framework, and the web site provides [templates](#) for displaying those metrics with the [Grafana](#) visualization platform.

For more information and documentation about App Metrics, see the [app-metrics.io](#) website.

## Produce metrics

Most metrics platforms support five basic types of metric, outlined in the following table:

Metric type	Description
Counter	Tracks how often something happens, such as requests, errors, and so on.
Gauge	Records a single value that changes over time, such as active connections.
Histogram	Measures a distribution of values across arbitrary limits. For example, a histogram could track data set size, counting how many contained <10 records, how many 11-100 and 101-1000, and >1000 records.
Meter	Measures the rate at which an event occurs in various time spans.
Timer	Tracks the duration of events and the rate at which it occurs, stored as a histogram.



Using *App Metrics*, an *IMetrics* interface can be obtained via dependency injection and used to record any of these metrics for a gRPC service. The following example shows how to count the number of Get requests made over time:

```
public class StockData : Stocks.StocksBase
{
    private static readonly CounterOptions GetRequestCounter = new CounterOptions
    {
        Name = "StockData_Get_Requests",
        MeasurementUnit = Unit.Calls
    };

    private readonly IStockRepository _repository;
    private readonly IMetrics _metrics;

    public StockData(IStockRepository repository, IMetrics metrics)
    {
        _repository = repository;
        _metrics = metrics;
    }

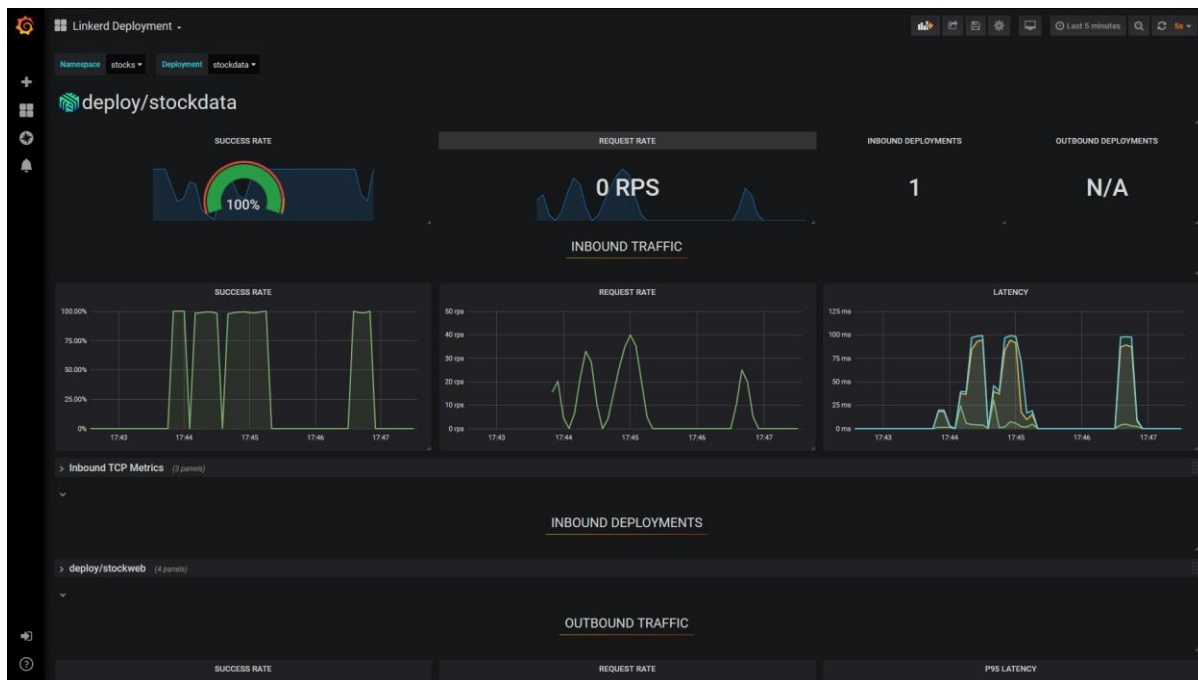
    public override async Task<GetResponse> Get(GetRequest request, ServerCallContext
context)
    {
        _metrics.Measure.Counter.Increment(GetRequestCounter);

        // Serve request...
    }
}
```

## Store and visualize metrics data

The best way to store metrics data is in a *time-series database*, a specialized data store designed to record numerical data series marked with timestamps. The most popular of these databases are [Prometheus](#) and [InfluxDB](#). Microsoft Azure also provides dedicated metrics storage through the [Azure Monitor](#) service.

The current go-to solution for visualizing metrics data is [Grafana](#), which works with a wide range of storage providers including Azure Monitor, InfluxDB and Prometheus. The following image shows an example Grafana dashboard that displays metrics from the Linkerd service mesh running the StockData sample:



## Metrics-based alerting

The numerical nature of metrics data means that it's ideally suited to drive alerting systems, notifying developers or support engineers when a value falls outside of some defined tolerance. The platforms already mentioned all provide support for alerting via a range of options, including emails, text messages, or in-dashboard visualizations.

## Distributed tracing

*Distributed tracing* is a relatively recent development in monitoring, which has arisen from the increasing use of microservices and distributed architectures. A single request from a client browser, application, or device may be broken down into many steps and sub-requests, and involve the use of many services across a network. This makes it difficult to correlate log messages and metrics with the specific request that triggered them. Distributed tracing applies identifiers to requests that allow logs and metrics to be correlated with a particular operation. This is similar to [WCF's end-to-end tracing](#), but applied across multiple platforms.

Although it's still a nascent technology area, distributed tracing has grown quickly in popularity and is now going through a standardization process. The Cloud Native Computing Foundation created the [the Open Tracing standard](#), attempting to provide vendor-neutral libraries for working with backends like [Jaeger](#) and [Elastic APM](#). At the same time, Google created the [OpenCensus project](#) to address the same set of problems. These two projects are now being merged into a new project, [OpenTelemetry](#), which aims to be the future industry standard.

## How distributed tracing works

Distributed tracing is based on the concept of *Spans*: named, timed operations that are part of a single *Trace*, which may involve processing on multiple nodes of a system. When a new operation is

initiated, a trace is created with a unique identifier. For each sub-operation, a span is created with its own identifier and trace identifier. As the request passes around the system, various components can create *child* spans that include the identifier of their *parent*. A span has a *context*, which contains the trace and span identifiers, as well as useful data in the form of key/value pairs (called *baggage*).

## Distributed tracing with DiagnosticSource

.NET Core has an internal module that maps well to distributed traces and spans: [DiagnosticSource](#). As well as providing a simple way to produce and consume diagnostics within a process, the DiagnosticSource module has the concept of an *Activity*, which is effectively an implementation of a distributed trace, or a span within a trace. The internals of the module take care of parent/child activities, including allocating identifiers. For more information about using the Activity type, see the [Activity User Guide on GitHub](#)

Because DiagnosticSource is a part of the core framework, it's supported by several core components, including [HttpClient](#), Entity Framework Core and ASP.NET Core, including explicit support in the gRPC framework. When ASP.NET Core receives a request, it checks for a pair of HTTP headers matching the [W3C Trace Context](#) standard. If the headers are found, an Activity is started using the identity values and context from the headers. If no headers are found, an Activity is started with generated identity values that match the standard format. Any diagnostics generated by the framework or by application code during the lifetime of this Activity can be tagged with the trace and span identifiers. The HttpClient support extends this further by checking for a current Activity on every request and automatically adding the trace headers to the outgoing request.

The ASP.NET Core gRPC client and server libraries include explicit support for DiagnosticSource and Activity, and will create activities and apply and use header information automatically.

### Note

All of this only happens if a *listener* is consuming the diagnostic information. If there's no listener, no diagnostics are written and no activities are created.

## Add your own DiagnosticSources and Activities

Although a good quantity of data is automatically generated by ASP.NET Core, including gRPC, as well as Entity Framework Core and HttpClient, you may wish to add your own diagnostics or create explicit spans within your application code. Refer to the [DiagnosticSource User Guide](#) and [Activity User Guide](#) for details on how to implement your own diagnostics.

## Store distributed trace data

At the time of writing the OpenTelemetry project is still in the early stages, and only alpha-quality packages are available for .NET applications. The OpenTracing project offers more mature libraries, but these will be superseded by the OpenTelemetry libraries in the future.

The OpenTracing API is described below. If you would prefer to use the newer OpenTelemetry API in your application, refer to the [OpenTelemetry .NET SDK repository on GitHub](#).

## Use the OpenTracing package to store distributed trace data

The [an OpenTracing NuGet package](#) that supports all OpenTracing-compliant back-ends (which can be used independently of DiagnosticSource). There's an additional package from the OpenTracing API Contributions project, [OpenTracing.Contrib.NetCore](#), which adds a DiagnosticSource listener and writes events and activities to a back-end automatically. Enabling this package is as simple as installing it from NuGet and adding it as a service in your Startup class.

```
public class Startup
{
    public void ConfigureServices(IServiceCollection services)
    {
        services.AddOpenTracing();
    }
}
```

The OpenTracing package is an abstraction layer and as such it requires a back-end-specific implementation. OpenTracing API implementations are available for the following open source back-ends.

Name	Package	Web site
Jaeger	<a href="#">Jaeger</a>	<a href="#">jaegertracing.io</a>
Elastic APM	<a href="#">Elastic.Apm.NetCoreAll</a>	<a href="#">elastic.co/products/apm</a>

For more information on the OpenTracing API for .NET, see the [OpenTracing for C#](#) and the [OpenTracing Contrib C#/.NET Core](#) repositories on GitHub.

# Appendix A - Transactions

Windows Communication Foundation (WCF) supported distributed transactions, allowing atomic operations to be performed across multiple services. This functionality was based on the [Microsoft Distributed Transaction Coordinator](#).

In the modern microservices landscape, this type of automated distributed transaction processing isn't possible. There are too many different technologies at play, including relational databases, NoSQL data stores, and messaging systems, not to mention the mix of operating systems, programming languages and frameworks that may be used in a single environment.

The WCF distributed transaction is an implementation of what is known as a [two-phase commit \(2PC\)](#). It's possible to implement 2PC transactions manually by coordinating messages across services, creating open transactions within each service and sending "commit" or "rollback" messages depending upon success or failure. However, the complexity that is involved in managing 2PC can increase exponentially as systems evolve, and open transactions hold database locks that can negatively impact performance or, worse, cause cross-service deadlocks.

If possible, it's best to avoid distributed transactions altogether. If two items of data are so linked as to require atomic updates, consider handling them both with the same service, and applying those atomic changes using a single request or message to that service.

If that isn't possible, then one alternative is to use the [Saga pattern](#). In a saga, updates are processing sequentially; as each update succeeds the next one is triggered. These triggers can be propagated from service to service, or managed by a saga coordinator or "orchestrator". If an update fails at any point during the process, the services that have already completed their updates apply specific logic to reverse them.

Another option is to use Domain Driven Design (DDD) and Command/Query Responsibility Segregation (CQRS), as described in the [.NET Microservices e-book](#). In particular, using domain events or [event sourcing](#) can help to ensure that updates are consistently—if not immediately—applied.