The .NET Stack Handbook

C#, VB, Databases, Web and the Operations Around Them

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Contents

Preface **1**
What this book is . . . 1
Who it is for . . . 1
What is checked, and what is not . . . 1
Conventions . . . 1
Licence . . . 2

I The Language **3**

1 The Language: C# and VB **5**
1.1 Variables . . . 5
1.1.1 Integers . . . 5
1.1.2 Strings . . . 6
1.1.2.1 StringBuilder . . . 6
1.1.3 Decimals . . . 7
1.1.4 Booleans . . . 7
1.1.5 Chars . . . 8
1.1.6 DateTime . . . 8
1.1.7 Doubles . . . 9
1.1.8 Objects . . . 9
1.2 Nullable reference types . . . 10
1.3 Objects . . . 12
1.3.1 Methods . . . 14
1.4 Interfaces . . . 15

2 Asynchronous Work and Threads **19**
2.1 Async/Await . . . 19
2.2 Threads . . . 21
2.2.1 Locks . . . 22
2.3 In Memory Work Queue . . . 24
2.3.1 Task Queue . . . 24
2.3.2 Thread Queue . . . 25

3 Structuring an Application **27**
3.1 IOC . . . 27
3.1.1 Registering and resolving services . . . 27
3.1.2 Lifetimes . . . 28
3.1.3 Registering by convention . . . 28
3.1.4 Why this makes testing easy . . . 28
3.1.5 Other containers . . . 29
3.2 Repository Pattern . . . 29

3.2.1 Do not put a repository and a unit of work over EF Core . . . 29
3.2.2 Use a base abstract class that is passed a connection . . . 30
3.2.3 No base abstract. Let individual repository classes do as they please . . . 32
3.2.4 Do something with the repository classes . . . 32
3.3 Events . . . 33
3.3.1 Use built in EventHandler . . . 33
3.3.2 Use custom delegate as event hander . . . 34
3.3.3 Subscribe to the event . . . 34
3.3.4 VB example of basic custom events . . . 34
3.3.5 Create a custom event . . . 35
3.3.6 Use the custom event . . . 35
3.4 Nuget . . . 36
3.4.1 Create a NuGet Package . . . 36
3.4.2 Add NuGet source . . . 36
3.4.3 Check if NuGet Source already Exists . . . 36
3.4.4 Start fresh with just nuget.org . . . 36
3.5 Testing and Coverage . . . 36
3.5.1 NUnit and Coverlet . . . 36
3.5.2 Other test frameworks . . . 38

II User Interfaces 39

4 Desktop User Interfaces 41
4.1 Winforms . . . 41
4.1.1 A form with a control and an event handler . . . 41
4.1.2 Keep the UI thread responsive . . . 42
4.1.3 Cross platform alternatives . . . 43
4.2 Microsoft Maui . . . 43
4.2.1 Pages and XAML . . . 43
4.2.2 Dependency injection . . . 44
4.2.3 Keeping the UI responsive . . . 45
4.2.4 Alternatives . . . 45

5 Crystal Reports 47
5.1 Set data using DataTables . . . 47
5.2 Set report parameters . . . 48
5.3 Move report objects . . . 49
5.4 Export to pdf or other file type . . . 49
5.5 CrystalCmd Server and Client . . . 49

III Data 51

6 SQLite 53
6.1 SQLite . . . 53
6.2 C# Examples . . . 53
6.3 SQLite with Dapper . . . 54
6.4 SQLite with Entity Framework Core . . . 55

7 PostgreSQL 57
7.1 PostgreSQL - Install . . . 57
7.2 PostgreSQL Examples . . . 57
7.2.1 Create a Table . . . 57
7.2.2 Insert Data . . . 57

7.2.3 Stored Procedure . . . 57
7.2.4 Stored Function . . . 58
7.2.5 View . . . 58
7.2.6 C# Example: Querying PostgreSQL . . . 58
7.3 PostgreSQL with Dapper . . . 59
7.4 PostgreSQL with Entity Framework Core . . . 59

8 Microsoft SQL Server 61
8.1 Adventure Works . . . 61
8.2 Create a database . . . 62
8.3 Create a table . . . 62
8.4 Alter a table . . . 62
8.5 Create indexes . . . 62
8.6 SELECT . . . 63
8.7 INSERT . . . 63
8.8 UPDATE . . . 63
8.9 DELETE . . . 63
8.10 Foreign Keys . . . 63
8.11 JOIN . . . 64
8.12 CTE . . . 64
8.13 Stored Procedures . . . 65
8.14 Stored Functions . . . 65
8.15 Views . . . 65
8.16 SQL - Install . . . 66
8.16.1 SQL server windows install . . . 66
8.16.2 SQL server linux install . . . 66
8.16.3 SQL server extra configuration after the install . . . 67
8.17 Reference - Admin . . . 67
8.18 Client tools . . . 68
8.19 SQL Profiler and Extended Events . . . 68
8.20 SQL Query Store . . . 69
8.21 SQL Watch . . . 69

9 Redis 71
9.1 Ubuntu Install . . . 71
9.1.1 Add redis password . . . 71
9.1.2 Connect to password protected redis server . . . 72
9.1.3 expose to the network . . . 72
9.1.4 Restart on failure . . . 72
9.1.5 TLS Connection Support . . . 73
9.1.5.1 1. Generate SSL/TLS Certificates . . . 73
9.1.5.2 2. Configure Redis to Use TLS . . . 73
9.1.5.3 3. Restart Redis Server . . . 74
9.2 Session . . . 74
9.3 Cache . . . 74
9.4 Publish and Subscribe . . . 75
9.4.1 Using Redis Pub/Sub in C . . . 75
9.5 Example: Redis Pub/Sub with Web Frontend and Worker Services . . . 75
9.5.1 1. Web Frontend (ASP.NET Core + JavaScript) . . . 76
9.5.2 2. Worker Service (C# Console App) . . . 77
9.5.3 3. Completion Notification Service . . . 77
9.6 Work and Message Queue with Redis in C . . . 78
9.6.1 Producer Example (Enqueue Work) . . . 78
9.6.2 Consumer Example (Worker) . . . 78

10 Data Access in .NET **81**
10.1 DbConnection . . . 81
10.2 DbCommand . . . 82
10.3 DataAdapters . . . 83
10.4 DbTransaction . . . 85
10.5 ORM - Dapper . . . 87
10.6 ORM - Entity Framework . . . 87
10.6.1 Entity Framework: Raw SQL Queries with FromSql and FromSqlInterpolated . . . 88
10.6.2 Entity Framework Core: Disabling Change Tracking . . . 88
10.7 Database Migrations - Entity Framework Core . . . 89
10.7.1 1. Add EF Core Tools . . . 89
10.7.2 2. Create a Migration . . . 89
10.7.3 3. Apply the Migration . . . 89
10.7.4 4. Example Migration Class . . . 89
10.7.5 5. Further Changes . . . 90
10.8 Database Migration - FluentMigrator . . . 90
10.8.1 Example: Creating a Table with Fluent Syntax . . . 90
10.8.2 Example: Executing Raw SQL in a Migration . . . 90
10.8.3 Running Migrations . . . 91
10.9 Transactions and Isolation Levels . . . 91
10.9.1 Common Isolation Levels . . . 91
10.9.2 Isolation Level Descriptions . . . 91
10.9.3 Example: Setting Isolation Level in SQL . . . 92
10.9.4 Example: Setting Isolation Level in C . . . 92
10.9.5 Summary Table . . . 93
10.10SQL Database Backup . . . 93

IV Web and Hosting **95**

11 ASP.NET Core **97**
11.1 Dependency Injection . . . 97
11.2 MVC . . . 98
11.3 Minimal API . . . 100
11.4 Blazor . . . 101

12 Containers, nginx and Kubernetes **103**
12.1 Containers - Docker . . . 103
12.1.1 Example: Dockerfile for a .NET Web Application . . . 103
12.1.2 Build and Publish with Docker Buildx and SBOM . . . 104
12.2 nginx . . . 104
12.2.1 Tell ASP.NET Core it is behind a proxy . . . 105
12.2.2 TLS with Let's Encrypt . . . 105
12.2.3 Run the application as a service . . . 105
12.3 Kubernetes . . . 106

13 JavaScript in the Browser **107**
13.1 Where the script goes . . . 107
13.2 Modules . . . 108
13.3 The DOM . . . 108
13.3.1 Rendering without an injection bug . . . 108
13.4 Events . . . 109
13.5 fetch . . . 110
13.5.1 GET . . . 110
13.5.2 POST json . . . 110

13.5.3 POST a form . . . 111
13.5.4 The antiforgery token . . . 111
13.5.5 Timeouts and cancellation . . . 112
13.6 Putting it together . . . 112
13.7 htmx, when you would rather not write any of this . . . 114
13.8 What to skip . . . 114

V Operations 115

14 Monitoring and Observability 117
14.1 Health checks . . . 117
14.2 OpenTelemetry . . . 118
14.2.1 The metrics you get for free . . . 119
14.2.2 Your own metrics . . . 120
14.2.3 Traces . . . 121
14.3 Logs . . . 121
14.4 Prometheus . . . 122
14.4.1 Service discovery . . . 123
14.5 Grafana . . . 124
14.6 Alerting . . . 124
14.7 When it is already broken . . . 125

15 Build Pipelines 127
15.1 The shape of a .NET pipeline . . . 127
15.1.1 Make CI stricter than your machine . . . 127
15.1.2 Make the build reproducible . . . 128
15.2 GitHub Actions . . . 129
15.2.1 Building for several platforms . . . 130
15.2.2 Versioning artifacts . . . 131
15.2.3 Publishing a NuGet package . . . 131
15.2.4 Containers . . . 131
15.2.5 Building Linux packages . . . 132
15.3 Tests that need a database . . . 133
15.3.1 Coverage that means something . . . 134
15.4 Security in the pipeline . . . 135
15.5 Deployment . . . 135
15.6 Jenkins . . . 136
15.6.1 Plugins . . . 136
15.6.2 A .NET pipeline . . . 137
15.7 What good looks like . . . 137

A Git Clients 139
A.1 Git Visual Studio . . . 139
A.2 Git Rider . . . 140
A.3 Tortoise Git . . . 140
A.4 Github Desktop . . . 140

Preface

What this book is

A working reference for building .NET software and running it once it is built, written by someone who does that for a living rather than someone documenting features in order.

It began as a single post on majorsilence.com. That post grew past five thousand lines, which is the point at which a post stops being a post. It is now fifteen chapters across five parts: the languages, the user interfaces, four databases and the .NET side of talking to them, the web stack, and the operations that keep the result alive.

Who it is for

Developers who already program, and who need the .NET answer to something specific. It does not teach programming from nothing, and it does not assume you have used .NET before.

The chapters are deliberately independent. Read one, take what you need, and leave. Where one chapter genuinely depends on another - and it happens most often with Structuring an Application, whose repository and dependency injection patterns reappear everywhere afterwards - there is a link rather than a repeated explanation.

What is checked, and what is not

Every listing targets .NET 10 (`net10.0`) unless a section says otherwise.

The C# and VB code is not typed into the page and hoped for. It lives in an `examples/` solution alongside the text, and every build compiles it, runs the tests, and executes the console examples. When a chapter states what a program prints, that is the output it actually produced. Writing that solution found seven bugs in the prose it was copied from, which is a fair estimate of how many are in any programming book that lacks one.

The rest is not machine checked and should be read with correspondingly more suspicion. SQL run against a live server, Dockerfiles, nginx configuration, Kubernetes manifests and CI pipeline definitions are all reviewed but not executed by the build. Where that distinction matters, the text says so.

Tooling ages faster than anything else in a book like this. Recommendations here are current as of writing and will not stay that way; the underlying commands and configuration outlast the graphical tools that wrap them, which is why the text prefers them.

Conventions

Examples are Linux first, because that is where most .NET now runs in production. Where Windows differs in a way that matters, both are given.

C# and VB appear side by side in the early chapters. Later chapters are mostly C#, not out of any judgement about VB, but because repeating every listing twice would double the length of the book without teaching anything the first two chapters have not already shown.

Nullable reference types are on, in the examples solution and in the listings, because they are on in every project `dotnet new` creates and a book whose code produces warnings the moment it is pasted somewhere real is not much use. A `string?` in a listing means the value can be null and the surrounding code deals with it. The Language: C# and VB covers the feature itself.

Licence

The prose is licensed CC BY-SA 4.0. The code samples, and everything in the `examples/` and `tools/` directories, are MIT.

That split is deliberate. Copy a listing into your own application freely, with no obligation beyond the copyright notice - a book that exists to be copied from should not force you to relicense your work for taking ten lines from it.

Part I

The Language

Chapter 1

The Language: C# and VB

C# and VB are two languages over one runtime. They compile to the same IL, use the same base class library, and can call each other freely inside one solution. Choosing between them is a matter of taste and of what the team already knows, not of capability.

This chapter covers the things everything else is built from: variables to hold values, nullability to say which of them can be missing, objects to group values with the code that operates on them, and interfaces to describe what an object can do without saying how. Both languages are shown side by side throughout, so a VB developer reading C# code, or the reverse, can see the same idea twice.

1.1 Variables

Variables are the basic working blocks in code. You use variables to hold values. There are several different variable types but in this lesson we will cover only four of them.

To declare a variable you use the language keyword “Dim” used with a name and “As”. So if you want a string called “Hello World” named TestVariable you would declare it like this.

```vb
Dim TestVariable As String = "Hello World"
```

```csharp
string TestVariable = "Hello World";
```

This example declares a variable and assigns a value at the same time. However you can declare a variable without assigning value. The value can always be assigned later. A good general rule is only declare a variable when it is ready to be used (assigned) when possible.

- Integer - are like whole numbers but can contain negatives
- String - contain multiple characters
- Decimal - numbers with decimals
- Boolean - is true or false

1.1.1 Integers

Integers are like whole numbers but can contain negatives. So they have negatives, zero, or positives.

For example -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5 are all integer values.

To declare an integer you can do this.

```vb
Dim i As Integer
```

```csharp
int i;
```

This example creates a new variable of type Integer name i. It does not assign any value to i. To assign a value to i you can do it like this.

```
i=1
```

```
i=1;
```

Now the value of i is 1.

```
i=2
```

```
i=2;
```

Now the value of i is 2.

1.1.2 Strings

Strings can hold any value. They can have letters, numbers, special characters. They can be long or short

To declare a string you can do this.

```
Dim s As String
```

```
string s;
```

This example creates an empty string called s. This string has no value

To assign the value "hello world" to the variable s we would do.

```
s = "hello world"
```

```
s = "hello world";
```

The value of the variable can be reassigned at any time so if we want to change the value to "purple monkey dishwasher" just do the same as above put with the new string.

```
s = "purple monkey dishwasher"
```

```
s = "purple monkey dishwasher";
```

If we want to see the value of a variable printed to the console we can write.

```
System.Console.WriteLine("The value of s is: " & s)
```

```
System.Console.WriteLine($"The value of s is: {s}");
```

We see here that the value of s is appended to the string "The value of s is:" and then printed to the console as "The value of s is: purple monkey dishwasher". You can append any string to any other string at any time using the & symbol in vb or the + symbol in c#.

1.1.2.1 StringBuilder

If you are appending to a string again and again or changing its value over and over again this can become very slow. String operations like this can be sped up using the StringBuilder class.

To use a string builder you need to initialize System.Text.StringBuilder.

```
Dim builder As New System.Text.StringBuilder
builder.Append("Hello World ")
builder.Append("Peter.  ")
builder.Append("Have a good day.")

System.Console.WriteLine(builder.ToString)
```

```
var builder = new System.Text.StringBuilder();
builder.Append("Hello World ");
builder.Append("Peter.  ");
builder.Append("Have a good day.");

System.Console.WriteLine(builder.ToString());
```

This will print "Hello World Peter. Have a good day.".

What this does is keep adding to a buffer and when you call the ToString method it finally creates a string. This is much faster than concatenating the string together like the following.

```
System.Console.WriteLine("Hello World " & "Peter.  " & "Have a good day.")
```

```
System.Console.WriteLine("Hello World " + "Peter.  " + "Have a good day.");
```

This example probably is not faster since it is so tiny but if you did this with 100 000 strings the string builder would be much faster.

1.1.3 Decimals

Decimals are used when you need numeric values that contain decimals places. It is essential if you are doing financial calculations that you use decimals and no other data type. Do not use doubles.

For example -5.32, -4.76, -3.7654, -2.1, -1.343, 0.13, 1.786555, 2.2, 3.765, 4.22, 5.3446 are all decimal values.

To declare a decimal you can do this.

```
Dim d As Decimal = 4.444D
```

```
decimal d = 4.444m;
```

This example creates a new variable of type Decimal with the name d and a value of 4.444d

To assign a new value to d you can do it like this.

```
d=5.437D
```

```
d = 5.437m;
```

Now the value of d is 5.437.

```
d=2.55
```

```
d = 2.55m;
```

Now the value of d is 2.55. As shown above variables in function can always be reassigned new values

1.1.4 Booleans

Booleans are variables that can be either True or False. That is all they hold. Booleans default to false.

To declare a boolean you can do this.

```
Dim b As Boolean = False
```

```
bool b = false;
```

This example creates a new variable of type Boolean named b. It does not assign any value to b. To assign a value to b you can do it like this.

```
b=True
```

```
b=true;
```

Now the value of b is True.

```
b=False
```

```
b=false;
```

Now the value of b is False.

There is no other value that a boolean can hold. If you do not set a value a boolean will default to False.

1.1.5 Chars

Chars are variables that can hold one character and only one character. It can be any character available but only one character at a time.

To declare a char you do this.

```
Dim c As Char
```

```
char c;
```

This example creates a new variable of type Char named c. It does not assign any value to c. To assign a value to c you can do it like this.

```
c="A"c
```

```
c='A';
```

Now the value of c is A.

```
c="~"c
```

```
c='~';
```

Now the value of c is ~.

As is written above any character can be held in a char variable but only one character at a time. Like any other variable type you can print the variable to the console using like this.

```
System.Console.WriteLine(c)
```

```
System.Console.WriteLine(c);
```

1.1.6 DateTime

DateTime variables can hold a date and time value. If you just want a date you can also use Date instead of DateTime.

To declare a DateTime you do this.

```
Dim t As DateTime
```

```
DateTime t;
```

This example creates a new variable of type DateTime named t. It does not assign any value to t. To assign a value to t you can do it like this.

```
t = DateTime.Now
```

```
t = DateTime.Now;
```

This assigns the current date and time to the variable t.

If you want to assign a specific date such as 01 may 2012, do it like this.

```
t = New DateTime(2012, 5, 1)
```

```
t = new DateTime(2012, 5, 1);
```

Now the date of t would now be 01 May 2012 with a time of 00:00:00.

If you want to print the date to the console you can use several of its functions to print in different formats.

```
System.Console.WriteLine(t.ToString)
System.Console.WriteLine(t.ToShortDateString)
```

```
System.Console.WriteLine(t.ToString());
System.Console.WriteLine(t.ToShortDateString());
```

There are several other functions that can be looked up and used but generally I find these are the two that I use most often.

1.1.7 Doubles

Doubles are variables that hold numeric values with decimal places. They are similar to the decimal variable type but are less accurate and accumulate rounding errors when calculations are performed.

To declare a double you do this.

```
Dim d As Double
```

```
double d;
```

This example creates a new variable of type Double named d. It does not assign any value to d. To assign a value to d you can do it like this.

```
d = 5.555567
```

```
d = 5.555567;
```

Now the value of d is 5.555567.

```
d = 2.1
```

```
d = 2.1;
```

Now the value of d is 2.1.

Like any other variable type you can print the variable to the console using like this.

```
System.Console.WriteLine(d)
```

```
System.Console.WriteLine(d);
```

1.1.8 Objects

Objects are a base type that all other objects are derived from. This means that any other variable no matter the type can be assigned to an object.

To declare an object you do this.

```
Dim o As Object
```

```
Object o;
```

This example creates a new variable of type Object named o. It does not assign any value to o. To assign a value to o you can do it like this.

```
o = "A"c
```

```
o = 'A';
```

Now the value of o is A. The type is Char stored in the object. If we assign an integer.

```
o = 120
```

```
o = 120;
```

Now the value of o is 120 and the type of the stored value is an Integer

We can do the same by assigning strings, decimals, doubles, or any other type or object into an object of type Object.

If we print the object when assigned an integer it will print the integer. If we print when it is assigned char it will print the char and so on with the other variable types.

```
System.Console.WriteLine(o)
```

```
System.Console.WriteLine(o);
```

Generally I suggest avoiding the Object type as it defeats type checking that a compiler does and in my experience causes a lot of run time errors. The runtime errors are caused when code attempts to do an operation on the object that is not supported by the stored variable type. If we declare the type we want to use in code the compiler can do all the checks that are needed when the program is compiled.

1.2 Nullable reference types

Every reference type - `string`, an array, a class you wrote - could always hold `null`, and nothing in the language distinguished a variable that might be empty from one that never is. `NullReferenceException` is the result, and it is still the most common exception in production .NET code.

Nullable reference types (NRT) move that distinction into the type. `string` means a string; `string?` means a string or nothing. The compiler then tracks which is which and warns when the two are confused. It is on by default in every project `dotnet new` creates, and it is on for every example in this book.

```
<PropertyGroup>
  <Nullable>enable</Nullable>
</PropertyGroup>
```

Three things follow from that one line.

A `?` on the type means null is expected. Dereferencing it without checking is a warning.

```
string name = "Star Trek";    // never null
string? summary = null;       // may be null

Console.WriteLine(name.Length);       // fine
Console.WriteLine(summary.Length);    // warning CS8602: may be null here

if (summary is not null)
{
    Console.WriteLine(summary.Length);    // fine, the check narrowed the type
}
```

```
// or shorter
Console.WriteLine(summary?.Length);         // null if summary is null
Console.WriteLine(summary ?? "no summary"); // a value either way
```

The narrowing is real flow analysis, not a special case for `is not null`. An early `return`, a `throw`, a `string.IsNullOrEmpty` check - the compiler follows all of them and stops warning on the branch where the value cannot be null.

A non-nullable field or property has to hold something by the time the constructor exits. That is where most of the warnings in an existing codebase come from, and there are three honest answers:

```
public class Show
{
    // 1. required: the caller must set it in an object initializer.
    public required string ShowName { get; init; }

    // 2. a default: there is a sensible empty value.
    public string Summary { get; init; } = string.Empty;

    // 3. nullable: it genuinely might not be there.
    public string? Episode { get; init; }
}

var show = new Show { ShowName = "Star Trek" };  // Summary and Episode optional
var broken = new Show();                          // error CS9035: ShowName required
```

`required` is the one to reach for first. It moves "this object is not valid without a name" from a comment to a compile error.

The `!` operator turns the warning off. It asserts that a value is not null and produces no runtime check whatsoever - if you are wrong, you get the same `NullReferenceException` you would have had anyway.

```
// Assigned by a test framework in [SetUp], which the compiler cannot see.
private HttpClient _client = null!;

// Checked on the line before, but by a method the compiler does not understand.
Assert.That(shows, Is.Not.Null);
Assert.That(shows!.Count, Is.GreaterThan(0));
```

Both of those are legitimate. `!` sprinkled through business logic to make warnings go away is not: it converts a compiler error into a production incident and hides the design question of what the code should do when the value really is missing.

Where the checking stops. The compiler only sees annotations, so nullability is advice and not a guarantee:

- Reflection, serialisation and ORMs set properties directly and never ask the compiler's permission. A JSON payload with a missing field will happily leave a non-nullable `string` holding `null`. Validate data crossing the boundary; do not trust the annotation to have done it.
- Code compiled without NRT, and older NuGet packages, are *oblivious* - the compiler assumes nothing and stays quiet.
- Nothing here changes what the program does at runtime. `Nullable` is entirely a compile time feature.

Nullable value types are a different feature with similar syntax. `int?` has existed since .NET 2.0 and is a real type, `Nullable<int>`, with `HasValue` and `Value`. It costs memory and generates code;

`string?` costs nothing.

```
int? episodesWatched = null;      // Nullable<int>, a struct
if (episodesWatched.HasValue) { }
```

VB does not have this. There is no `Nullable` project property for VB and no `string?` syntax; VB reference types are all nullable, as they always were. The nearest equivalents are `Option Strict On`, argument validation, and `If(value, fallback)` in place of `??`. Where a VB project consumes a C# library, the C# side keeps its annotations and the VB side simply does not see them.

```
Dim summary As String = Nothing
Console.WriteLine(If(summary, "no summary"))
```

1.3 Objects

VB and c# have built in types such as int, bool, string, and others. Now it is time to create types that is more specific to your application

For example if you are writing an application about tv channels/stations you probably do not want to use strings and integers. It will be easier to think about stations and channels. In VB, c#, and other object oriented languages we can define our own types and use them just like the built in types.

To use a class you must declare one as you would any other variable type. I will be using the word class and object interchangeably.

For example you declare an integer like this

```
Dim i As Integer = 0
```

```
int i = 0;
```

Below we create our own data type using the keyword Class. The best way to use a class is to think of it as an object. For the purpose of this example our object is going to be a tv show. Tv shows have many different aspects to them so we create an object that represent them.

Included in the class are a new class property (ShowName) as Public and a Private variable (_showName) that the property works with. Never declare a class variable as public. Always use a property or a function. I will not explain it here but I do encourage you to read some books on object oriented design.

Private variables are accessible from any function in the class but cannot be accessed from other classes.

```
Public Class TVShow
    Public Sub New()
        ' constructor
    End Sub

    Private _showName As String
    ' Public properties can be accessed from any function inside the
    ' class as well as other classes
    Public Property ShowName() As String
        Get
            ' Inside the get part the private variable is returned.
            ' You can do anything you want here such as data validation
            ' before returning the data if you need or want.
            Return _showName
        End Get
        Set(ByVal value As String)
            ' Inside the set part the private variable is set.
            ' You can do anything you want here such as data validation
```

```
            ' before the data is set.
            If value.Trim = "" Then
                Throw New Exception("ShowName cannot be empty")
            End If
            _showName = value
        End Set
    End Property

    ' The above property is long form.  A shorter form can be done as seen below
    Public Property ShowLength As Integer
    Public Property Summary As String
    Public Property Rating As Decimal
    Public Property Episode As String
End Class
```

```
public class TVShow
{
    public TVShow()
    {
    }

    // Nullable reference types are on, so a non-nullable field has to hold
    // something by the time the constructor exits.
    private string _showName = string.Empty;
    // Public properties can be accessed from any function inside the
    // class as well as other classes.  required means an object initializer
    // has to set it.
    public required string ShowName
    {
        get
        {
            // Inside the get part the private variable is returned.
            // You can do anything you want here such as data validation
            // before returning the data if you need or want.
            return _showName;
        }
        set
        {
            // Inside the set part the private variable is set.
            // You can do anything you want here such as data validation
            // before the data is set.
            if (value.Trim() == "")
                throw new Exception("ShowName cannot be empty");
            _showName = value;
        }
    }

    // The above property is long form.  A shorter form can be done as seen below
    public int ShowLength {get; init;}
    public required string Summary {get; init;}
    public decimal Rating {get; init;}
    public required string Episode {get; init;}
}
```

You create a new instance of a class the same way you would with an Integer. You create a new instance like this

```
Dim starTrek As New TVShow With {
    .ShowName = "Star Trek",
    .ShowLength = 1380,
    .Summary = "Teleport Disaster",
    .Rating = 5.0D,
    .Episode = "1x12"
}
```

```
var starTrek = new TVShow() {
    ShowName = "Star Trek",
    ShowLength = 1380,
    Summary = "Teleport Disaster",
    Rating = 5.0m,
    Episode = "1x12"
};
```

If you want a second object you just declare another one.

```
Dim dexter As New TVShow With {
    .ShowName = "Dexter",
    .ShowLength = 1380,
    .Summary = "Dexter kills again.",
    .Rating = 4.8D,
    .Episode = "10x01"
}
```

```
var dexter = new TVShow() {
    ShowName = "Dexter",
    ShowLength = 1380,
    Summary = "Dexter kills again.",
    Rating = 4.8m,
    Episode = "10x01"
};
```

1.3.1 Methods

Methods, also known as functions, are used to break code apart into smaller chunks. Functions should do one task and do it well. Functions can be called again and again. They are used to keep duplicate code from building up. This makes things easier to understand. They can be chained/used together to perform complex tasks.

Functions can return a value or return no value. In vb functions that return a value use the key word **Function** and ones that do not return a value use the keyword **Sub**. In c# functions that return a value have a **type** such as a built-in type or object and functions that do not return a value use the keyword **void**.

```
public class TVShow
{
    public required string ShowName {get; init;}
    public int ShowLength {get; init;}
    public required string Summary {get; init;}
    public decimal Rating {get; init;}
    public required string Episode {get; init;}
```

```
    // includeSummary is a method parameter
    public void PrettyPrint(bool includeSummary){
        if (includeSummary)
        {
            Console.WriteLine($"{ShowName} {Episode} {Rating} {ShowLength} {Summary}");
        }
        else
        {
            Console.WriteLine($"{ShowName} {Episode} {Rating} {ShowLength}");
        }
    }

    public bool IsGoodRating(){
        return Rating >= 3.0m;
    }
}

var dexter = new TVShow() {
    ShowName = "Dexter",
    ShowLength = 1380,
    Summary = "Dexter kills again.",
    Rating = 4.8m,
    Episode = "10x01"
};

dexter.PrettyPrint(includeSummary: true);

if(dexter.IsGoodRating()){
    Console.WriteLine("Let's watch this episode.");
}
```

Method and function parameters are passed by reference for objects and by value for simple types.

1.4 Interfaces

> Interfaces - define behavior for multiple types. An interface contains definitions for a group of related functionalities that a non-abstract class or a struct must implement.

Interfaces in c# and vb is a way to specify what an object implements. It provides the ability to have different concrete class implementations and choose different ones at runtime.

A good example for further self study is the Microsoft ILogger.

We will build upon the TVShows class. We will define an interface. We will include a new property ParentalGuide.

Much of this will not make sense until Structuring an Application, which covers IOC and dependency injection.

The following code example defines an interface named TVShow. It is not necessary or necessarily recommended to prepend the name with an I but it is very common to see such interfaces in the c# and vb world. In code bases that do prepend an I the name would be ITVShow. The following code examples will not follow that pattern.

Imagine we have a large program involving tv shows. We could pass around the instances of TVShow but that will make our program brittle if and when we need to make changes.

```
public interface TVShow
{
    string ShowName {get; init;}
    int ShowLength {get; init;}
    string Summary {get; init;}
    decimal Rating {get; init;}
    string Episode {get; init;}
    string ParentalGuide {get; init;}

    void PrettyPrint(bool includeSummary);
    bool IsGoodRating();
}
```

An interface cannot be initialized. If we were to try to do so it would be a compile time error.

```
// Will not compile.
var inst = new TVShow();
```

Below a new class called ComedyShow implements TVShow. Notice line one with **:** **TVShow** after the class name. ComedyShow is a type of TVShow. Next notice that AdventureShow also implements TVShow.

```
public class ComedyShow : TVShow
{
    public required string ShowName {get; init;}
    public int ShowLength {get; init;}
    public required string Summary {get; init;}
    public decimal Rating {get; init;}
    public required string Episode {get; init;}
    public required string ParentalGuide {get; init;}

    // includeSummary is a method parameter
    public void PrettyPrint(bool includeSummary){
        if (includeSummary)
        {
            Console.WriteLine($"Comedy: {ShowName} {Episode} {Rating} {ShowLength} {Summary}");
        }
        else
        {
            Console.WriteLine($"Comedy: {ShowName} {Episode} {Rating} {ShowLength}");
        }
    }

    public bool IsGoodRating(){
        return Rating >= 3.0m;
    }
}

public class AdventureShow : TVShow
{
    public required string ShowName {get; init;}
    public int ShowLength {get; init;}
    public required string Summary {get; init;}
    public decimal Rating {get; init;}
    public required string Episode {get; init;}
```

```
    public required string ParentalGuide {get; init;}

    // includeSummary is a method parameter
    public void PrettyPrint(bool includeSummary){
        if (includeSummary)
        {
            Console.WriteLine($"Adventure: {ShowName} {Episode} {Rating} {ShowLength} {Summary}");
        }
        else
        {
            Console.WriteLine($"Adventure: {ShowName} {Episode} {Rating} {ShowLength}");
        }
    }

    public bool IsGoodRating(){
        return Rating >= 3.5m;
    }
}
```

Reviewing the code we can see that while both the ComedyShow and AdventureShow classes are similar they have different implementations of PrettyPrint and IsGoodRating. In addition to different internals to the interface methods they each could have different private helper methods or even other public methods.

Lets assume our application permits users to enter tv show information and as part of that entry they can add the show as a comedy or an adventure show. Let's store that information in a list. Notice how InsertShow has a parameter TVShow but lower in the code when calling the method all objects that implement the TVShow interface can be added and worked on.

```
public static class Shows
{
    static List<TVShow> _tvShows = new List<TVShow>();

    public static void InsertShow(TVShow show)
    {
        _tvShows.Add(show);
    }

    public static void PrintShows()
    {
        foreach (var show in _tvShows)
        {
            show.PrettyPrint(includeSummary: true);
        }
    }
}

public static void Main()
{
    Shows.InsertShow(new ComedyShow() {
        ShowName = "Friends",
        ShowLength = 1380,
        Summary = "The friends get coffee.",
        Rating = 4.8m,
```

```
        Episode = "4x05",
        ParentalGuide = "PG13"
    });
    Shows.InsertShow(new AdventureShow() {
        ShowName = "Rick and morty",
        ShowLength = 760,
        Summary = "A quick 20 minute in and out adventure.",
        Rating = 3.8m,
        Episode = "3x14",
        ParentalGuide = "18A"
    });

    Shows.PrintShows();
}
```

The output is

> Comedy: Friends 4x05 4.8 1380 The friends get coffee. Adventure: Rick and morty 3x14 3.8 760 A quick 20 minute in and out adventure.

For simplicity the example above is using a static Shows class. I almost always recommend against using static classes. I've shown their use in the above example as it is simple but in general I have found their use often coincides with global variables and long term they cause a maintenance quagmire. Static classes and variables have their place but try to avoid them.

Note: Read up about base classes and abstract bases classes as they are an alternative to using interfaces. Read about SOLID development.

Chapter 2

Asynchronous Work and Threads

Work that waits and work that computes are different problems, and .NET gives them different tools. Confusing the two is the usual source of both sluggish applications and mysterious data corruption.

Async and await are for waiting: a network call, a database query, a file read. The thread is released while the wait happens rather than sitting idle. Threads and the thread pool are for computing: work that genuinely needs a CPU. This chapter covers both, the locking that becomes necessary the moment two of them touch the same variable, and an in memory work queue for handing a slow job off and answering the caller straight away.

2.1 Async/Await

> Asynchronous programming . The core of async programming is the Task and Task objects, which model asynchronous operations. They are supported by the async and await keywords. The model is fairly simple in most cases: For I/O-bound code, you await an operation that returns a Task or Task inside of an async method. For CPU-bound code, you await an operation that is started on a background thread with the Task.Run method.

Async and await provides a way for more efficient use of threads. When a task is run it can be awaited later while doing more work while waiting.

Simple async/await example:

```
Private Async Function LoadPreviousSettings() As Task
    Await Task.Delay(5000)
End Function

Dim loadTask As Task = LoadPreviousSettings()

' Do some other crazy stuff

Await loadTask
```

```
private async Task LoadPreviousSettings()
{
    await Task.Delay(5000);
}

var loadTask = LoadPreviousSettings();
```

```
// Do some other crazy stuff

await loadTask;
```

The async and await pattern makes asynchronous programming easier and feels more like sequential development. Good places for async/await is I/O bound work such as when making network calls. Much of the time is spent waiting for a response and the thread could be doing other work while waiting. Network calls such as database connections, commands, updates, inserts, selects, deletes, and stored procedure and functions executions should be run with async and await pattern.

Another place async/await should be used is when making http calls. The example below demonstrates using async/await when using HttpClient to download a web site front page. In an asp.net core application IHttpClientFactory should be used to create an HttpClient.

```
using System;
using System.Collections.Generic;
using System.Diagnostics;
using System.Threading.Tasks;
using System.Net.Http;

public static async Task Main()
{
    // normally disposable objects should be disposed.
    // HttpClient is a special case and its norm is
    // that it should not be disposed until the program terminates
    using var client = new HttpClient();
    // add all tasks to a list and later await them.
    var tasks = new List<Task<string>>();
    Stopwatch stopWatch = new Stopwatch();
    stopWatch.Start();
    for(int i=0; i<10; i++)
    {
        var instDownloader = new Downloader();
        tasks.Add(instDownloader.DownloadSiteAsync(client, "https://majorsilence.com"));
    }
    Console.WriteLine("majorsilence.com is being downloaded 10 times.  Waiting...");
    foreach(var t in tasks)
    {
        string html = await t;
        Console.WriteLine(html.Substring(0, 100));
    }
    stopWatch.Stop();
    TimeSpan ts = stopWatch.Elapsed;
    Console.WriteLine($"Code Downloaded in {ts.TotalMilliseconds} Milliseconds");

    // sequential async calls
    Console.WriteLine("start sequential async calls to download majorsilence.com.  Waiting...");
    stopWatch.Restart();
    for(int i=0; i<10; i++)
    {
        var instDownloader = new Downloader();
        string html = await instDownloader.DownloadSiteAsync(client, "https://majorsilence.com");
        Console.WriteLine(html.Substring(0, 100));
    }
    stopWatch.Stop();
```

```
    TimeSpan ts2 = stopWatch.Elapsed;
    Console.WriteLine($"Sequential Code Downloaded in {ts2.TotalMilliseconds} Milliseconds");
}

public class Downloader{
    public async Task<string> DownloadSiteAsync(HttpClient httpClient,
        string url,
        System.Threading.CancellationToken cancellationToken = default(System.Threading.Cancellatio
    {
        var request = new HttpRequestMessage()
            {
                Method = HttpMethod.Get,
                RequestUri = new Uri(url)
            };

        // proceed past user agent sniffing
        request.Headers.Add("User-Agent", "Mozilla/5.0 (X11; CrOS x86_64 14541.0.0) AppleWebKit/537

        HttpResponseMessage response = await httpClient.SendAsync(request, cancellationToken).Confi

        response.EnsureSuccessStatusCode();
        return await response.Content.ReadAsStringAsync().ConfigureAwait(false);
    }
}
```

2.2 Threads

> In computer science, a thread of execution is the smallest sequence of programmed instructions that can be managed independently by a scheduler, which is typically a part of the operating system.

Dot net provides the Thread class.

Here is an example that starts a background tasks and checks every 500 millisecond if it is complete using the IsAlive property. If the background thread is still working it continues its work inside a while loop.

```
using System;
using System.Collections.Generic;
using System.Threading;
using System.Threading.Tasks;

public class Program
{
    public static async Task Main()
    {
        var t = new Thread(ThreadMethod);
        t.Start();

        Console.WriteLine("Do other things while waiting for the background thread to finish");

        while(t.IsAlive){
            Console.WriteLine("Alive");
            await Task.Delay(500);
        }
```

```
        Console.WriteLine("job completed");
    }

    static void ThreadMethod(){
        Console.WriteLine("The code in this method is running in its own thread.");
        Console.WriteLine("Sleep the thread 5000 milliseconds to demonstrate the main thread keeps wor
        Thread.Sleep(5000);
    }
}
```

This example starts a thread and does no work. The main thread stops work and waits for the background thread to complete using the Join method.

```
using System;
using System.Collections.Generic;
using System.Threading;
using System.Threading.Tasks;

public class Program
{
    public static async Task Main()
    {
        var t = new Thread(ThreadMethod);
        t.Start();
        Console.WriteLine("Wait for the background thread to complete");
        t.Join();
        Console.WriteLine("job completed");
    }

    static void ThreadMethod(){
        Console.WriteLine("The code in this method is running in its own thread.");
        for(int i = 1; i< 6; i++){
            Console.WriteLine($"background loop count {i}");
            Thread.Sleep(500);
        }
    }
}
```

2.2.1 Locks

If more than one thread or task is updating a variable you should lock the variable as necessary.

The example below create multiple tasks that all update the same “count” variable. As you can see it locks the variable before updating it.

```
Dim tasks As New List(Of Task)
Dim lockObject As New Object()

Dim count As Integer = 0

For i As Integer = 0 To 9
    tasks.Add(Task.Factory.StartNew(Sub()
        For j As Integer = 0 To 999
            SyncLock lockObject
                count = count + 1
```

```
            End SyncLock
        Next
    End Sub))
Next

For Each t In tasks
    Await t
Next

System.Console.WriteLine(count)
```

```
using System;
using System.Collections.Generic;
using System.Threading.Tasks;

public class Program
{
    public static async Task Main()
    {
        var tasks = new List<Task>();
        var lockObject = new object();

        int count = 0;
        for (int i = 0; i < 10; i++)
        {
            tasks.Add(Task.Factory.StartNew(() =>
            {
                for (int j = 0; j <= 999; j++)
                {
                    lock (lockObject)
                    {
                        count = count + 1;
                    }
                }
            }));
        }

        foreach(var t in tasks)
        {
            await t;
        }

        Console.WriteLine(count);
    }
}
```

On .NET 9 and newer prefer the dedicated System.Threading.Lock type over locking on a plain `object`. The c# compiler recognises it and emits the faster `Lock.EnterScope` path. The only change needed is the declaration.

```
// was: var lockObject = new object();
var lockObject = new System.Threading.Lock();

lock (lockObject)
{
```

```
    count = count + 1;
}
```

For the specific case of incrementing a counter, skip the lock entirely and use Interlocked, which is cheaper.

```
System.Threading.Interlocked.Increment(ref count);
```

2.3 In Memory Work Queue

Sometimes work should be accepted now and performed later, without involving Redis or any other external broker. A web request that triggers a slow report, or a desktop app that queues uploads, both want the same thing: hand the item off, return immediately, and let a background worker drain the queue.

The two approaches below are both in process. If the application restarts, anything still queued is lost. When that is unacceptable, use a durable queue such as the Redis one shown in the **Work and Message Queue with Redis** section, or a library such as Hangfire.

2.3.1 Task Queue

`System.Threading.Channels` is the modern way to do this. A channel is a thread safe producer/consumer queue that supports async reads, so a consumer waits without burning a thread.

Set a bounded capacity. An unbounded queue will happily grow until the process runs out of memory when producers outpace the consumer.

```
using System;
using System.Threading;
using System.Threading.Channels;
using System.Threading.Tasks;

public class WorkQueue
{
    private readonly Channel<Func<CancellationToken, Task>> _channel =
        Channel.CreateBounded<Func<CancellationToken, Task>>(
            new BoundedChannelOptions(capacity: 100)
            {
                // block the producer rather than dropping work
                FullMode = BoundedChannelFullMode.Wait
            });

    public async Task EnqueueAsync(Func<CancellationToken, Task> workItem)
    {
        ArgumentNullException.ThrowIfNull(workItem);
        await _channel.Writer.WriteAsync(workItem);
    }

    public IAsyncEnumerable<Func<CancellationToken, Task>> ReadAllAsync(
        CancellationToken cancellationToken) =>
            _channel.Reader.ReadAllAsync(cancellationToken);
}
```

The consumer loop. In asp.net core this belongs in a `BackgroundService`, registered with `services.AddHostedService<QueueWorker>()` and the queue itself as a singleton.

```
public class QueueWorker : BackgroundService
{
```

```
    private readonly WorkQueue _queue;
    private readonly ILogger<QueueWorker> _logger;

    public QueueWorker(WorkQueue queue, ILogger<QueueWorker> logger)
    {
        _queue = queue;
        _logger = logger;
    }

    protected override async Task ExecuteAsync(CancellationToken stoppingToken)
    {
        await foreach (var workItem in _queue.ReadAllAsync(stoppingToken))
        {
            try
            {
                await workItem(stoppingToken);
            }
            catch (Exception ex)
            {
                // one bad work item must not kill the worker
                _logger.LogError(ex, "Work item failed");
            }
        }
    }
}
```

Queueing work from a controller then costs one line, and the caller gets its response straight away.

```
await _queue.EnqueueAsync(async token =>
{
    await _reportBuilder.GenerateAsync(reportId, token);
});
```

The try/catch around `workItem` is the part people leave out. Without it, one unhandled exception ends the `await foreach` loop and the queue silently stops draining for the rest of the process lifetime.

2.3.2 Thread Queue

If the work is CPU bound rather than I/O bound, running it on the thread pool is usually all that is required. `Task.Run` queues the delegate to the pool, which already manages a pool of threads for you.

```
var work = Task.Run(() => ExpensiveCalculation(input));

// do other things

int result = await work;
```

For CPU bound work over a collection, `Parallel.ForEachAsync` limits how many run at once, which avoids swamping the pool.

```
await Parallel.ForEachAsync(
    shows,
    new ParallelOptions { MaxDegreeOfParallelism = Environment.ProcessorCount },
    async (show, token) =>
    {
        await ProcessShowAsync(show, token);
```

```
    });
```

Dedicated `Thread` objects, as shown in the **Threads** section, are worth the trouble only for long running work that should not occupy a pool thread for minutes at a time. In that case set `IsBackground = true` so the thread does not keep the process alive at shutdown.

```
var t = new Thread(ThreadMethod) { IsBackground = true };
t.Start();
```

Chapter 3

Structuring an Application

The previous chapters were about writing code that works. This one is about arranging it so that it keeps working after a year of changes and can be tested without standing up a database.

The three patterns here reinforce each other. Inversion of control means a class is handed what it depends on rather than constructing it. The repository pattern puts data access behind an interface, which is what gives inversion of control something worth injecting. Events let one part of an application tell others that something happened without knowing who is listening. The chapter closes on packaging code as NuGet, and on testing, which is the payoff for all of it.

3.1 IOC

Inversion of Control (IOC) means a class does not create the things it depends on. It is given them instead. **Dependency injection (DI)** is the usual way to do that: dependencies are passed into the constructor, and something else decides which concrete implementation to supply.

This is what makes the interfaces and repository classes shown in the previous sections worth writing. `TestStuff` takes an `ITestRepo` and never learns whether it is talking to SQL Server, SQLite, or a mock in a unit test.

.NET ships a DI container in `Microsoft.Extensions.DependencyInjection`. In an asp.net core app it is already wired up. For a console app or a Winforms app, add the package.

```
dotnet add package Microsoft.Extensions.DependencyInjection
```

3.1.1 Registering and resolving services

Registration maps an interface to the concrete class that implements it. Resolution walks the constructor parameters and builds the whole object graph for you.

```
using System;
using Microsoft.Extensions.DependencyInjection;

var services = new ServiceCollection();

// map the interface to the implementation
services.AddSingleton<ITestRepo>(sp =>
    new MajorSilence.DataAccess.TestRepo("Data Source=shows.db"));
services.AddTransient<MajorSilence.BusinessStuff.TestStuff>();

using var provider = services.BuildServiceProvider();
```

```
// TestStuff needs an ITestRepo.  The container supplies it.
var inst = provider.GetRequiredService<MajorSilence.BusinessStuff.TestStuff>();
inst.DoStuff();
```

Compare that with the manual wiring in the **Repository Pattern** section. For two classes the manual version is fine. Once an application has fifty of them, the container is what keeps `Main` from becoming a wall of `new`.

3.1.2 Lifetimes

Choosing the wrong lifetime is the most common source of DI bugs, so it is worth being deliberate about it.

- **Transient** - a new instance every time it is requested. The safe default for cheap, stateless classes.
- **Scoped** - one instance per scope. In asp.net core a scope is one http request. This is what `DbContext` should use.
- **Singleton** - one instance for the life of the application. Must be thread safe, since many threads can use it at once.

The rule that catches people out: a singleton must never depend on a scoped service. The singleton is built once and holds onto whatever it was given, so it would keep using the first request's scoped instance forever. The container will throw at startup if you try, provided scope validation is on, which it is by default in development.

3.1.3 Registering by convention

Registering interfaces one by one is tedious in a large solution. Scrutor scans an assembly and registers everything matching a convention.

```
dotnet add package Scrutor
```

```
services.Scan(scan => scan
    .FromAssemblyOf<MajorSilence.DataAccess.ITestRepo>()
        .AddClasses(classes => classes.Where(t => t.Name.EndsWith("Repo")))
        .AsImplementedInterfaces()
        .WithScopedLifetime());
```

3.1.4 Why this makes testing easy

Because `TestStuff` only ever sees `ITestRepo`, a test can hand it a stand-in and assert on what it did, with no database involved. See mocking.

```
using Moq;
using NUnit.Framework;

[Test]
public void DoStuffInsertsTheName()
{
    var repo = new Mock<ITestRepo>();
    repo.Setup(x => x.GetName()).Returns("The Name");

    var inst = new MajorSilence.BusinessStuff.TestStuff(repo.Object);
    inst.DoStuff();

    repo.Verify(x => x.InsertData("The Name"), Times.Once);
}
```

3.1.5 Other containers

The built in container covers most needs. Third party containers add features such as property injection, interception, and more advanced conditional registration.

- Autofac
- Lamar

3.2 Repository Pattern

Use the repository pattern to separate your business and data access layers. Makes it easy to test your business and data layer code separately.

There are different ways to do this. Here are a couple ways.

3.2.1 Do not put a repository and a unit of work over EF Core

This is the most contested piece of advice in the chapter, so here is the position stated plainly, followed by the reasoning.

Recommendation. Use the repository pattern when your data access is ADO.NET or Dapper - as in every listing in this section. Do **not** wrap Entity Framework Core in a generic `IRepository<T>` and an `IUnitOfWork`. EF Core already is both of those patterns, and adding a second copy on top costs you features and buys nothing.

`DbContext` **is** a unit of work. It tracks every change made through it and commits them together when `SaveChanges` is called; that is the definition of the pattern. `DbSet<T>` **is** a repository: a collection-like interface over a table with the query translation attached. So an `IUnitOfWork` holding an `IRepository<Show>` over EF Core is a unit of work wrapping a unit of work, and a repository wrapping a repository.

```
// The unit of work you were about to write.  It already exists.
using var db = new AppDbContext(connectionString);

db.TvShows.Add(new EfTvShow { ShowName = "Star Trek", Rating = 5.0m });
db.Episodes.Add(new Episode { Number = "1x12" });

// One transaction, both tables, committed together - or neither.
await db.SaveChangesAsync();
```

What the extra layer actually costs:

- **The query gets worse or the abstraction leaks.** A repository that returns `IEnumerable<T>` executes the query and fetches every row, so filtering happens in memory. A repository that returns `IQueryable<T>` keeps the performance but has leaked EF straight through the interface it was supposed to hide, along with every way callers can now break it.
- **The good parts become unreachable.** `Include`, `AsSplitQuery`, `AsNoTracking`, projection to a DTO, `ExecuteUpdate`, compiled queries, and interceptors are all things a `GetById/GetAll/Add/Delete` interface has no way to express. They come back as a growing pile of `GetShowWithEpisodesAndRatingsNoTracking` methods.
- **The portability argument does not survive contact with reality.** Repositories are usually justified as "so we can swap the database later". Swapping providers is what EF Core's provider model already does, and the projects that genuinely migrate stores rewrite their queries either way, because the query differences are the hard part and no interface hides them.
- **The testing argument is weaker than it was.** Mocking `DbSet` is unpleasant, which is where the pattern's popularity came from, but the modern answers are better: SQLite in memory for fast

tests, or the real engine in a container for the ones that must be honest. Both test the SQL rather than testing that a mock returns what the test told it to return.

When a repository over EF Core does earn its place, it is not a generic one. It is a small, hand-written, domain-shaped interface - `IShowCatalog` with `FindByName` and `TopRated` - hiding a query you want named and tested in one place. That is a query object with a nicer name, and it has three or four methods that mean something, not five methods generated per entity.

The listings below use Dapper, where none of this applies: Dapper gives you connections and SQL strings, and the repository is what turns those into a testable seam. `TestStuff` never learns whether the connection is SQLite, SQL Server, or a mock.

3.2.2 Use a base abstract class that is passed a connection

```
using System;
using System.Data;
using Microsoft.Data.Sqlite;
using System.Threading.Tasks;

namespace MajorSilence.DataAccess
{
    public abstract class BaseRepo
    {
        private readonly string cnStr;

        protected BaseRepo(string cnStr)
        {
            this.cnStr = cnStr;
        }

        protected T WithConnection<T>(Func<IDbConnection, T> sqlTransaction)
        {
            using (var connection = new SqliteConnection(cnStr))
            {
                connection.Open();
                return sqlTransaction(connection);
            }
        }

        protected void WithConnection(Action<IDbConnection> sqlTransaction)
        {
            using (var connection = new SqliteConnection(cnStr))
            {
                connection.Open();
                sqlTransaction(connection);
            }
        }

        protected async Task<T> WithConnectionAsync<T>(Func<IDbConnection, Task<T>> sqlTransaction)
        {
            using (var connection = new SqliteConnection(cnStr))
            {
                await connection.OpenAsync();
                return await sqlTransaction(connection);
            }
```

```
        }

        protected async Task WithConnectionAsync(Func<IDbConnection, Task> sqlTransaction)
        {
            using (var connection = new SqliteConnection(cnStr))
            {
                await connection.OpenAsync();
                await sqlTransaction(connection);
            }
        }
    }
}
```

And here is the repo class

```
using System;
using System.Linq;
using Dapper;

namespace MajorSilence.DataAccess
{
    public interface ITestRepo
    {
        // string? and not string: the table may be empty, and FirstOrDefault
        // returns null when it is.  The signature is where that belongs.
        string? GetName();
        void InsertData(string name);
    }

    public class TestRepo : BaseRepo, ITestRepo
    {
        public TestRepo(string cnStr) : base(cnStr) { }

        public string? GetName()
        {
            return this.WithConnection(cn =>
            {
                return cn.Query<string>("SELECT Name From TheTable LIMIT 1;").FirstOrDefault();
            });
        }

        public void InsertData(string name)
        {
            this.WithConnection(cn =>
            {
                cn.Execute("INSERT INTO TheTable (Name) VALUES (@Name);",
                    new { Name = name });
            });
        }
    }
}
```

3.2.3 No base abstract. Let individual repository classes do as they please

I generally prefer this way. It is simple.

```
using Microsoft.Data.Sqlite;
using System.Linq;
using Dapper;

namespace MajorSilence.DataAccess
{

    public class TestRepoNobase : ITestRepo
    {
        readonly string cnStr;
        public TestRepoNobase(string cnStr)
        {
            this.cnStr = cnStr;
        }

        public string? GetName()
        {
            using (var cn = new SqliteConnection(cnStr))
            {
                return cn.Query<string>("SELECT Name From TheTable LIMIT 1;").FirstOrDefault();
            };
        }

        public void InsertData(string name)
        {
            using (var cn = new SqliteConnection(cnStr))
            {
                cn.Execute("INSERT INTO TheTable (Name) VALUES (@Name);",
                    new { Name = name });
            };
        }
    }
}
```

3.2.4 Do something with the repository classes

A business class

```
using System;
namespace MajorSilence.BusinessStuff
{
    public class TestStuff
    {
        readonly DataAccess.ITestRepo repo;
        public TestStuff(DataAccess.ITestRepo repo)
        {
            this.repo = repo;
        }

        public void DoStuff()
        {
            repo.InsertData("The Name");
```

```
            // GetName returns string?, so the empty table case is handled here
            // instead of turning up later as a NullReferenceException.
            string name = repo.GetName() ?? "(no rows)";

            // Do stuff with the name
        }
    }
}
```

Combine everything. Manually initialize our two repository classes and initialize two copies of our TestStuff class. Our TestStuff never knows what or where the actual data layer is.

Note the file backed connection string. Both repository classes open a fresh connection per call, and with SQLite a plain `Data Source=:memory:` gives every connection its own private, empty database - so the insert and the select would not see each other. If you want an in memory database that survives across connections, use `Data Source=shows;Mode=Memory;Cache=Shared` and keep one connection open for as long as the database should live.

TestStuff is now easily tested with tools such as as moq.

```
using System;

namespace MajorSilence.TestStuff
{
    class Program
    {
        static void Main(string[] args)
        {

            // Our repository layer that will talk to the data source.
            // This could be inject with a dependency injection framework
            var repo = new MajorSilence.DataAccess.TestRepo("Data Source=shows.db");
            var repo2 = new MajorSilence.DataAccess.TestRepoNobase("Data Source=shows.db");

            // Our business class.  Takes an interface and does not care
            // what the actual data source is.
            var inst = new MajorSilence.BusinessStuff.TestStuff(repo);
            inst.DoStuff();

            var inst2 = new MajorSilence.BusinessStuff.TestStuff(repo2);
            inst2.DoStuff();

        }
    }
}
```

3.3 Events

Custom Event and Event Handlers

3.3.1 Use built in EventHandler

```
public class TheExample
{
```

```
    public event System.EventHandler DoSomething;

    public void TheTest(){
        // option 1 to raise event
        this.DoSomething?.Invoke(this, new System.EventArgs());

        // option 2 to raise event
        if (DoSomething != null)
        {
            DoSomething(this, new System.EventArgs());
        }
    }
}
```

3.3.2 Use custom delegate as event hander

```
public class TheExample
{
    public delegate void MyCustomEventHandler(object sender, System.EventArgs e);
    public event MyCustomEventHandler DoSomething;

    public void TheTest(){
        // option 1 to raise event
        this.DoSomething?.Invoke(this, new System.EventArgs());

        // option 2 to raise event
        if (DoSomething != null)
        {
            DoSomething(this, new System.EventArgs());
        }
    }
}
```

3.3.3 Subscribe to the event

```
// subscribe using lamba expression

var x = new TheExample();

x.DoSomething += (s,e) => {
    Console.WriteLine("hi, the event has been raised");
};
x.TheTest();
```

3.3.4 VB example of basic custom events

```
Public Class TheExample
    Public Delegate Sub MyCustomEventHandler(ByVal sender As Object, ByVal e As System.EventArgs)
    Public Event DoSomething As MyCustomEventHandler

    Public Sub TheTest()
        RaiseEvent DoSomething(Me, New EventArgs())
```

```
    End Sub
End Class
```

Subscribe to the event

```
Dim x As New TheExample
AddHandler x.DoSomething, AddressOf EventCallback
x.TheTest()

RemoveHandler x.DoSomething, AddressOf EventCallback

Sub EventCallback(ByVal sender As Object, ByVal e As System.EventArgs)
    Console.WriteLine("Hi, the event has been raised")
End Sub
```

3.3.5 Create a custom event

Setup a new custom event class inheriting from EventArgs and setup a new delegate.

```
public delegate void MyCustomEventHandler(object sender, MyCustomEvent e);

public class MyCustomEvent : System.EventArgs
{
        private string _msg;
        private float _value;

    public MyCustomEvent(string m)
    {
        _msg = m;
        _value = 0;
    }

    public MyCustomEvent(float v)
    {
        _msg = "";
        _value = v;
    }

    public string Message
    {
        get { return _msg; }
    }

    public float Value
    {
        get { return _value; }
    }
}
```

3.3.6 Use the custom event

```
public event MyCustomEventHandler DoSomething;

this.DoSomething?.Invoke(this, new MyCustomEvent(123.95f));
```

3.4 Nuget

Generally using nuget is very simple. Using Visual Studio right click your solution or project and select "Add Nuget Package". Find your package and add it. It is auto added. Any time you now clone your project on a new computer the first time you build your project it will restore your nuget references.

3.4.1 Create a NuGet Package

Given a .csproj or .vbproj file with a PropertyGroup like the following, add the **GeneratePackageOnBuild**, **PackageProjectUrl**, **Description**, **Authors**, **RepositoryUrl**, **PackageLicenseExpression**, **Version**.

```
<PropertyGroup>
  <TargetFrameworks>netstandard2.0;net10.0</TargetFrameworks>
</PropertyGroup>
```

PropertyGroup that generates a nuget package on build and fills in many useful details.

```
<PropertyGroup>
  <TargetFrameworks>netstandard2.0;net10.0</TargetFrameworks>
  <GeneratePackageOnBuild>true</GeneratePackageOnBuild>
  <PackageProjectUrl>https://PLACEHOLDER</PackageProjectUrl>
  <Description>PLACEHOLDER</Description>
  <Authors>PLACEHOLDER</Authors>
  <RepositoryUrl>https://PLACEHOLDER</RepositoryUrl>
  <PackageLicenseExpression>MIT</PackageLicenseExpression>
  <Version>1.0.1</Version>
</PropertyGroup>
```

3.4.2 Add NuGet source

The following command will add a nuget source to your computer other than the default. This is good for self hosted nuget servers. Use –store-password-in-clear-text if a mac or linux workstation is being used.

```
dotnet nuget add source "https://your.source.url/v3/index.json" -n [Feed Name] -u YourUserName -p Your
```

3.4.3 Check if NuGet Source already Exists

The following powershell script will check if a nuget source already exists on your computer.

```
dotnet nuget list source
```

3.4.4 Start fresh with just nuget.org

```
dotnet new nugetconfig
```

3.5 Testing and Coverage

3.5.1 NUnit and Coverlet

NUnit is a fine testing framework for c#, vb and other .net based languages.

The nuget package **NUnit** must be referenced for base NUnit support in a test project, and **NUnit3TestAdapter** is what actually lets the test runner find the tests - leave it out and `dotnet test` reports zero tests without ever saying why. Despite the 3 in its name it is the current adapter for NUnit 4 as well. **NunitXml.TestLogger** produces NUnit format result files for CI systems that expect them.

For integration within visual studio and rider **Microsoft.NET.Test.Sdk** should also be added to the test project. **coverlet.collector** is used to generate the code coverage report. Note, for large solutions and projects coverlet can add a considerable overhead.

```
dotnet add package NUnit
dotnet add package NUnit3TestAdapter
dotnet add package NunitXml.TestLogger
dotnet add package Microsoft.NET.Test.Sdk
dotnet add package coverlet.collector
```

To demonstrate the the nunit testing framework we will work with a contrived example. The test class will test a modified threaded lock example from above.

Within the test class **ComplexAdditionTests** the code will confirm that the calculation works. This is helpful if a developer ever changes the CalculateWithLock method and breaks it. The test will fail and the developer will know that the change causes problems. The test will test the class **ComplexAddition**.

```
using System;
using System.Collections.Generic;
using System.Threading.Tasks;
using NUnit.Framework;

[TestFixture]
public class ComplexAdditionTests
{
    [Test]
    public async Task CalculationsCalculatesTest()
    {
        var complexAdds = new ComplexAddition();

        // 10 outer iterations, each adding 1 once per inner value 0..999
        const int expectedResult = 10 * 1000;
        int actualResult = await complexAdds.CalculateWithLock(10, 999);

        Assert.That(actualResult, Is.EqualTo(expectedResult));
    }
}

public class ComplexAddition
{
    public async Task<int> CalculateWithLock(int outerLimit = 10, int innerLimit = 999)
    {
        var tasks = new List<Task>();
        var lockObject = new object();

        int count = 0;
        for (int i = 0; i < outerLimit; i++)
        {
            tasks.Add(Task.Factory.StartNew(() =>
            {
                for (int j = 0; j <= innerLimit; j++)
                {
                    lock (lockObject)
                    {
                        count = count + 1;
                    }
```

```
                }
            }));
        }

        foreach(var t in tasks)
        {
            await t;
        }

        return count;
    }
}
```

The tests can be run from within visual studios test explorer or from the command line with either **dotnet test**.

```
dotnet test
```

To test and collect coverage data run dotnet test with collector arguments.

```
dotnet test -c Release YourSolutionFile.sln --collect:"XPlat Code Coverage" --logger:"nunit"
```

Passing extra args example with exclude by file.

```
dotnet test -c Release YourSolutionFile.sln --collect:"XPlat Code Coverage" --logger:"nunit" -- DataCo
```

3.5.2 Other test frameworks

Unit test frameworks:

- xUnit
- MSTest

Acceptance testing framework

- FitNesse

BDD (Behavior-driven development) testing

- Reqnroll

Part II

User Interfaces

Chapter 4

Desktop User Interfaces

Desktop applications did not go away, and .NET still has good answers for them.

Windows Forms is the older of the two covered here and the more direct: a form, a designer, controls with events. It remains the fastest way to put a working tool in front of somebody, and via Majorsilence.Forms the same code can now run beyond Windows. .NET MAUI is the newer, cross platform framework, with one project targeting Windows, mac, Android and iOS, and XAML rather than a Windows only designer. Which to reach for depends mostly on whether you need to leave Windows and whether the application already exists.

4.1 Winforms

Windows Forms is the desktop UI framework that has shipped with .NET since the beginning. It is still supported and still a reasonable choice for line of business applications on Windows, especially when a team already knows it. On modern .NET it is Windows only, so set the target framework accordingly.

```
<PropertyGroup>
  <OutputType>WinExe</OutputType>
  <TargetFramework>net10.0-windows</TargetFramework>
  <UseWindowsForms>true</UseWindowsForms>
  <Nullable>enable</Nullable>
</PropertyGroup>
```

Create a new project from the command line.

```
dotnet new winforms -o YourApp
cd YourApp
dotnet run
```

4.1.1 A form with a control and an event handler

The designer generates most of this for you, but it is useful to see what it produces. A form is a class that inherits from `Form`, controls are fields on that class, and user interaction is handled by subscribing to events.

```
using System;
using System.Windows.Forms;

public class ShowForm : Form
{
    private readonly TextBox _showName = new TextBox { Left = 10, Top = 10, Width = 200 };
```

```
    private readonly Button _save = new Button { Left = 220, Top = 10, Text = "Save" };
    private readonly ListBox _shows = new ListBox { Left = 10, Top = 45, Width = 410, Height = 200 };

    public ShowForm()
    {
        Text = "TV Shows";
        ClientSize = new System.Drawing.Size(440, 260);
        Controls.AddRange(new Control[] { _showName, _save, _shows });

        _save.Click += Save_Click;
    }

    private void Save_Click(object sender, EventArgs e)
    {
        if (string.IsNullOrWhiteSpace(_showName.Text))
        {
            MessageBox.Show("Show name cannot be empty", "Validation");
            return;
        }

        _shows.Items.Add(_showName.Text);
        _showName.Clear();
    }
}
```

4.1.2 Keep the UI thread responsive

Everything in the paragraphs above about async/await applies here, and it matters more in a desktop app than anywhere else. Any slow work performed directly in an event handler freezes the window, because the same thread that runs your handler also paints the form and processes input.

Mark the handler `async` and await the slow work. Winforms installs a synchronization context, so execution resumes on the UI thread after the await and it is safe to touch controls again. Do not use `ConfigureAwait(false)` in code that will go on to update the UI.

```
private async void Load_Click(object sender, EventArgs e)
{
    _load.Enabled = false;
    try
    {
        // runs off the UI thread, window stays responsive
        var shows = await _repo.GetShowsAsync();

        // back on the UI thread here
        _shows.Items.Clear();
        _shows.Items.AddRange(shows.ToArray());
    }
    finally
    {
        _load.Enabled = true;
    }
}
```

`async void` is normally something to avoid, but event handlers are the one place it is correct, because the event signature returns void. Wrap the body in a try/catch or an unhandled exception will take down

the process.

If you have work running on a background thread that is not awaited, you cannot update controls from it directly. Marshal back to the UI thread with `Invoke`.

```
if (_shows.InvokeRequired)
{
    _shows.Invoke(() => _shows.Items.Add(name));
}
else
{
    _shows.Items.Add(name);
}
```

4.1.3 Cross platform alternatives

Winforms does not run on linux or mac. If that matters:

- Majorsilence.Forms - a Winforms compatibility layer, useful for porting an existing Winforms codebase.
- Avalonia - a mature cross platform XAML UI framework.
- .NET MAUI - Microsoft's cross platform framework, see Microsoft Maui below.

4.2 Microsoft Maui

.NET MAUI (Multi-platform App UI) builds native desktop and mobile applications from a single c# codebase, targeting android, iOS, mac, and windows. It is the successor to Xamarin.Forms.

Unlike Winforms above, which is windows only, MAUI renders through each platform's own native controls, so an app looks like an android app on android and a mac app on mac.

Install the workload and create a project.

```
dotnet workload install maui
dotnet new maui -o YourApp
cd YourApp

# run on a specific platform
dotnet build -t:Run -f net10.0-android
dotnet build -t:Run -f net10.0-windows10.0.19041.0
```

A MAUI project targets several frameworks at once from one csproj.

```
<PropertyGroup>
  <TargetFrameworks>net10.0-android;net10.0-ios;net10.0-maccatalyst</TargetFrameworks>
  <TargetFrameworks Condition="$([MSBuild]::IsOSPlatform('windows'))">
    $(TargetFrameworks);net10.0-windows10.0.19041.0
  </TargetFrameworks>
  <OutputType>Exe</OutputType>
  <UseMaui>true</UseMaui>
  <SingleProject>true</SingleProject>
</PropertyGroup>
```

Building for iOS or mac requires a mac. Android and windows build anywhere.

4.2.1 Pages and XAML

UI is normally written in XAML, with the logic in a matching code behind file.

```
<?xml version="1.0" encoding="utf-8" ?>
<ContentPage xmlns="http://schemas.microsoft.com/dotnet/2021/maui"
             xmlns:x="http://schemas.microsoft.com/winfx/2009/xaml"
             x:Class="YourApp.ShowsPage"
             Title="TV Shows">
    <VerticalStackLayout Padding="20" Spacing="10">
        <Entry x:Name="ShowNameEntry" Placeholder="Show name" />
        <Button Text="Add" Clicked="OnAddClicked" />
        <CollectionView x:Name="ShowsList">
            <CollectionView.ItemTemplate>
                <DataTemplate>
                    <Label Text="{Binding ShowName}" FontSize="18" />
                </DataTemplate>
            </CollectionView.ItemTemplate>
        </CollectionView>
    </VerticalStackLayout>
</ContentPage>
```

```
public partial class ShowsPage : ContentPage
{
    private readonly ObservableCollection<TvShow> _shows = new();

    public ShowsPage()
    {
        InitializeComponent();
        ShowsList.ItemsSource = _shows;
    }

    private void OnAddClicked(object sender, EventArgs e)
    {
        if (string.IsNullOrWhiteSpace(ShowNameEntry.Text))
        {
            return;
        }

        _shows.Add(new TvShow { ShowName = ShowNameEntry.Text });
        ShowNameEntry.Text = "";
    }
}
```

`ObservableCollection<T>` is what makes the list update itself. It raises a change notification on add and remove, which the `CollectionView` listens for. A plain `List<T>` will not refresh the UI.

4.2.2 Dependency injection

MAUI uses the same container described in the **IOC** section. Register services in `MauiProgram.cs` and pages resolve their dependencies through the constructor.

```
public static class MauiProgram
{
    public static MauiApp CreateMauiApp()
    {
        var builder = MauiApp.CreateBuilder();
        builder.UseMauiApp<App>();
```

```
        builder.Services.AddSingleton<ITestRepo>(sp =>
            new TestRepoNobase("Data Source=shows.db"));
        builder.Services.AddTransient<ShowsPage>();

        return builder.Build();
    }
}
```

4.2.3 Keeping the UI responsive

The same rule as Winforms applies: slow work in a handler freezes the UI. Await it instead, and marshal back to the UI thread from any background work using `MainThread`.

```
private async void OnLoadClicked(object sender, EventArgs e)
{
    var shows = await _repo.GetShowsAsync();

    MainThread.BeginInvokeOnMainThread(() =>
    {
        _shows.Clear();
        foreach (var show in shows)
        {
            _shows.Add(show);
        }
    });
}
```

4.2.4 Alternatives

- Avalonia - cross platform XAML UI, also runs on linux, which MAUI does not target.
- Uno Platform - WinUI style markup across mobile, desktop, and WebAssembly.

Chapter 5

Crystal Reports

Examples to use crystal reports from c#. Crystal reports for .net currently only supports running on .net framework 4.8 and older. If reports need to be generated on modern .net see CrystalCmd Server and Client below.

Make sure you have the crystal reports runtime installed. It can be downloaded from https://wiki.scn.sap.com/wiki/display/BOBJ/Crystal+Reports%2C+Developer+for+Visual+Studio+Downloads.

All examples below require references for **CrystalDecisions.CrystalReports.Engine** and **CrystalDecisions.Shared** to be added to your project.

Ensure the CrystalReports Version and PublicKey token match the installed version of Crystal Reports.

```
<ItemGroup>
    <Reference Include="CrystalDecisions.Windows.Forms, Version=13.0.4000.0, Culture=neutral, Publi
        <HintPath>C:\Windows\Microsoft.NET\assembly\GAC_MSIL\CrystalDecisions.Windows.Forms\v4.0_13
    </Reference>
    <Reference Include="CrystalDecisions.CrystalReports.Engine, Version=13.0.4000.0, Culture=neutra
        <HintPath>C:\Windows\Microsoft.NET\assembly\GAC_MSIL\CrystalDecisions.CrystalReports.Engine
    </Reference>
    <Reference Include="CrystalDecisions.Shared, Version=13.0.4000.0, Culture=neutral, PublicKeyTok
        <HintPath>C:\Windows\Microsoft.NET\assembly\GAC_MSIL\CrystalDecisions.Shared\v4.0_13.0.4000
    </Reference>
</ItemGroup>
```

5.1 Set data using DataTables

Example initializing a report and passing in a DataTable.

```
using CrystalDecisions.CrystalReports.Engine;
using CrystalDecisions.Shared;

// Pass a DataTable to a crystal report table
public static void SetData(string crystalTemplateFilePath,
    string tableName, DataSet val)
{
    using (var rpt = new ReportDocument())
    {
        rpt.Load(crystalTemplateFilePath);
```

```
        rpt.Database.Tables[tableName].SetDataSource(val);
    }
}

// Pass any generic IEnumerable data to a crystal report DataTable
public static void SetData<T>(string crystalTemplateFilePath,
    string tableName, IEnumerable<T> val)
{
    using (var rpt = new ReportDocument())
    {
        rpt.Load(crystalTemplateFilePath);

        var dt = ConvertGenericListToDatatable(val);
        rpt.Database.Tables[tableName].SetDataSource(dt);
    }
}

// Found somewhere on the internet.  I know longer remember where.
public static DataTable ConvertGenericListToDatatable<T>(IEnumerable<T> dataLst)
{
    DataTable dt = new DataTable();

    foreach (var info in dataLst.FirstOrDefault().GetType().GetProperties())
    {
        dt.Columns.Add(info.Name, info.PropertyType);
    }

    foreach (var tp in dataLst)
    {
        DataRow row = dt.NewRow();
        foreach (var info in typeof(T).GetProperties())
        {
            if (info.Name == "Item") continue;
            row[info.Name] = info.GetValue(tp, null) == null ? DBNull.Value : info.GetValue(tp, null);
        }
        dt.Rows.Add(row);
    }
    dt.AcceptChanges();
    return dt;
}
```

5.2 Set report parameters

Set report parameters from code.

```
using CrystalDecisions.CrystalReports.Engine;
using CrystalDecisions.Shared;

public static void SetParameterValueName(string crystalTemplateFilePath, object val)
{
    using (var rpt = new ReportDocument())
    {
        rpt.Load(crystalTemplateFilePath);
```

```
        string name = "ParameterName";
        if (rpt.ParameterFields[name] != null)
        {
            rpt.SetParameterValue(name, val);
        }
    }
}
```

5.3 Move report objects

Example moving an object.

```
using CrystalDecisions.CrystalReports.Engine;
using CrystalDecisions.Shared;

public static void MoveObject(string crystalTemplateFilePath)
{
    using (var rpt = new ReportDocument())
    {
        rpt.Load(crystalTemplateFilePath);

        rpt.ReportDefinition.ReportObjects["objectName"].Left = 15;
        rpt.ReportDefinition.ReportObjects["objectName"].Top = 15;
    }
}
```

5.4 Export to pdf or other file type

Load a report and export it to pdf. You can pass in data or set other properties before the export.

```
using CrystalDecisions.CrystalReports.Engine;
using CrystalDecisions.Shared;

public static void ExportPdf(string crystalTemplateFilePath,
    string pdfFilename)
{
    using (var rpt = new ReportDocument())
    {
        rpt.Load(crystalTemplateFilePath);

        var exp = ExportFormatType.PortableDocFormat;
        rpt.ExportToDisk(exp, pdfFilename);
    }
}
```

5.5 CrystalCmd Server and Client

crystalcmd is a:

> Java and c# program to load json files into crystal reports and produce PDFs.

- https://github.com/majorsilence/CrystalCmd

tldr: use crystal reports with dotnet netstandard2.0, net48, net8.0, net9.0, net10.0 on linux, windows, mac, android, and iOS.

To host the cyrstalcmd .net server browse to https://github.com/majorsilence/CrystalCmd/tree/main/dotnet and build the **Dockerfile.wine** and **Dockerfile.crystalcmd**. If a java server is required use the prebuilt image at https://hub.docker.com/r/majorsilence/crystalcmd. The c# server is recommended.

With a crystalcmd server running crystal report templates and data can be sent to it to produce pdf files. The docker images can run on any system that supports docker such as mac, windows, and linux.

Add the package Majorsilence.CrystalCmd.Client to your project.

To call a crystalcmd server use the nuget package **Majorsilence.CrystalCmd.Client**.

```
dotnet add package Majorsilence.CrystalCmd.Client
```

This example will call the server and return the pdf report as a stream.

```
DataTable dt = new DataTable();

// init report data
var reportData = new Majorsilence.CrystalCmd.Common.Data()
{
    DataTables = new Dictionary<string, string>(),
    MoveObjectPosition = new List<Majorsilence.CrystalCmd.Common.MoveObjects>(),
    Parameters = new Dictionary<string, object>(),
    SubReportDataTables = new List<Majorsilence.CrystalCmd.Common.SubReports>()
};

// add as many data tables as needed.  The client library will do the necessary conversions to json/cs
reportData.AddData("report name goes here", "table name goes here", dt);

// export to pdf
var crystalReport = System.IO.File.ReadAllBytes("The rpt template file path goes here");
using (var instream = new MemoryStream(crystalReport))
using (var outstream = new MemoryStream())
{

    //var rpt = new Majorsilence.CrystalCmd.Client.Report(serverUrl, username: "The server username go
    var rpt = new Majorsilence.CrystalCmd.Client.ReportWithPolling(serverUrl, username: "The server us
    using (var stream = await rpt.GenerateAsync(reportData, instream, _httpClient))
    {
        stream.CopyTo(outstream);
        return outstream.ToArray();
    }
}
```

Part III

Data

Chapter 6

SQLite

SQLite is a database that is a file. There is no server to install, no port to open, no user to create; an application opens the file and starts querying. That single property makes it the right choice far more often than people expect: desktop application storage, a cache, test fixtures, and small web applications all work well on it.

This chapter shows the same small task three ways - raw ADO.NET, Dapper, and Entity Framework Core - because those three layers reappear for every other database in this part of the book. Seeing them against the simplest possible store makes the differences between them easy to see. Data Access in .NET covers each in more depth.

6.1 SQLite

SQLite is a lightweight, serverless, self-contained SQL database engine. It stores the entire database as a single file on disk, requires no separate server process, and is included in .NET by default. SQLite is ideal for development, prototyping, desktop, mobile, and small-to-medium web applications.

Why use SQLite for new projects?

- **Zero configuration:** No server setup or management required.
- **Easy to use:** Simple file-based deployment—just copy the database file.
- **Reliable and fast:** ACID-compliant and performant for most workloads.
- **Portable:** Works across platforms (Windows, Linux, macOS).
- **Scalable for prototyping:** Start with SQLite, then migrate to a larger DBMS, PostgreSQL, if/when needed.

See Why you should probably be using SQLite.

6.2 C# Examples

Install the NuGet package:

```
dotnet add package Microsoft.Data.Sqlite
```

Create and query a database:

```
using Microsoft.Data.Sqlite;

var connectionString = "Data Source=tvshows.db";
using var connection = new SqliteConnection(connectionString);
connection.Open();
```

```
// Create table
var createCmd = connection.CreateCommand();
createCmd.CommandText = @"
    CREATE TABLE IF NOT EXISTS TvShows (
        Id INTEGER PRIMARY KEY AUTOINCREMENT,
        ShowName TEXT NOT NULL,
        Rating REAL
    );";
createCmd.ExecuteNonQuery();

// Insert data
var insertCmd = connection.CreateCommand();
insertCmd.CommandText = "INSERT INTO TvShows (ShowName, Rating) VALUES ($name, $rating);";
insertCmd.Parameters.AddWithValue("$name", "Friends");
insertCmd.Parameters.AddWithValue("$rating", 4.8);
insertCmd.ExecuteNonQuery();

// Query data
var selectCmd = connection.CreateCommand();
selectCmd.CommandText = "SELECT Id, ShowName, Rating FROM TvShows;";
using var reader = selectCmd.ExecuteReader();
while (reader.Read())
{
    Console.WriteLine($"{reader.GetInt32(0)}: {reader.GetString(1)} ({reader.GetDouble(2)})");
}
```

Note: For more advanced scenarios, consider using Dapper or Entity Framework Core with SQLite as the provider.

6.3 SQLite with Dapper

Install NuGet packages:

```
dotnet add package Dapper
dotnet add package Microsoft.Data.Sqlite
```

Example: Querying SQLite with Dapper

```
using System;
using System.Collections.Generic;
using Dapper;
using Microsoft.Data.Sqlite;

public class TvShow
{
    public int Id { get; set; }
    public string ShowName { get; set; }
    public double Rating { get; set; }
}

public class Example
{
    public IEnumerable<TvShow> GetShows()
    {
```

```
        using var conn = new SqliteConnection("Data Source=tvshows.db");
        conn.Open();
        return conn.Query<TvShow>("SELECT Id, ShowName, Rating FROM TvShows WHERE Rating > @minRati
    }
}
```

6.4 SQLite with Entity Framework Core

Install NuGet packages:

```
dotnet add package Microsoft.EntityFrameworkCore
dotnet add package Microsoft.EntityFrameworkCore.Sqlite
```

Example: DbContext and Model

```
using Microsoft.EntityFrameworkCore;

public class TvShow
{
    public int Id { get; set; }
    public string ShowName { get; set; }
    public double Rating { get; set; }
}

public class AppDbContext : DbContext
{
    public DbSet<TvShow> TvShows { get; set; }

    protected override void OnConfiguring(DbContextOptionsBuilder options)
        => options.UseSqlite("Data Source=tvshows.db");
}

// Usage
using var db = new AppDbContext();
db.TvShows.Add(new TvShow { ShowName = "Friends", Rating = 4.8 });
db.SaveChanges();

var highRated = db.TvShows.Where(t => t.Rating > 4.0).ToList();
```

Chapter 7

PostgreSQL

PostgreSQL is the default choice for a serious relational database when nothing forces another one. It is open source, runs everywhere, and has spent decades accumulating features - JSON columns, full text search, window functions, extensions like PostGIS - without giving up correctness.

The structure here mirrors SQLite: install it, then the same work through raw ADO.NET with Npgsql, through Dapper, and through Entity Framework Core. The .NET side barely changes between the two databases, which is the point of the provider model.

7.1 PostgreSQL - Install

Follow the instructions found at https://www.postgresql.org/download/.

See the majorsilence PostgreSQL page for fedora and ubuntu configuration instructions instructions.

For managing PostgreSQL databases use pgAdmin.

7.2 PostgreSQL Examples

7.2.1 Create a Table

```
CREATE TABLE tv_shows (
    id SERIAL PRIMARY KEY,
    show_name VARCHAR(100) NOT NULL,
    rating NUMERIC(3,1)
);
```

7.2.2 Insert Data

```
INSERT INTO tv_shows (show_name, rating) VALUES ('Friends', 4.8);
INSERT INTO tv_shows (show_name, rating) VALUES ('Dexter', 4.5);
```

7.2.3 Stored Procedure

A stored procedure to insert a new TV show:

```
CREATE OR REPLACE PROCEDURE insert_tv_show(p_show_name VARCHAR, p_rating NUMERIC)
LANGUAGE plpgsql
AS $$
```

```
BEGIN
    INSERT INTO tv_shows (show_name, rating) VALUES (p_show_name, p_rating);
END;
$$;
```

Call the procedure:

```
CALL insert_tv_show('Frasier', 4.6);
```

7.2.4 Stored Function

A function to get the average rating:

```
CREATE OR REPLACE FUNCTION get_average_rating()
RETURNS NUMERIC AS $$
BEGIN
    RETURN (SELECT AVG(rating) FROM tv_shows);
END;
$$ LANGUAGE plpgsql;
```

Usage:

```
SELECT get_average_rating();
```

7.2.5 View

A view showing only highly rated shows:

```
CREATE OR REPLACE VIEW high_rated_shows AS
SELECT id, show_name, rating
FROM tv_shows
WHERE rating >= 4.5;
```

Query the view:

```
SELECT * FROM high_rated_shows;
```

7.2.6 C# Example: Querying PostgreSQL

Install the Npgsql NuGet package:

```
dotnet add package Npgsql
```

Sample C# code:

```
using Npgsql;

var connString = "Host=localhost;Username=postgres;Password=yourpassword;Database=yourdb";
using var conn = new NpgsqlConnection(connString);
conn.Open();

// Query data
using var cmd = new NpgsqlCommand("SELECT id, show_name, rating FROM tv_shows", conn);
using var reader = cmd.ExecuteReader();
while (reader.Read())
{
    Console.WriteLine($"{reader.GetInt32(0)}: {reader.GetString(1)} ({reader.GetDecimal(2)})");
}
```

```
// Call a function
using var avgCmd = new NpgsqlCommand("SELECT get_average_rating()", conn);
var avg = avgCmd.ExecuteScalar();
Console.WriteLine($"Average rating: {avg}");
```

Note: For async usage, use `await conn.OpenAsync()` and `await cmd.ExecuteReaderAsync()`.

7.3 PostgreSQL with Dapper

Dapper is a lightweight ORM for .NET that works well with PostgreSQL via the Npgsql driver.

Install NuGet packages:

```
dotnet add package Dapper
dotnet add package Npgsql
```

Example: Querying PostgreSQL with Dapper

```
using System;
using System.Collections.Generic;
using System.Threading.Tasks;
using Dapper;
using Npgsql;

public class TvShow
{
    public int Id { get; set; }
    public string ShowName { get; set; }
    public decimal Rating { get; set; }
}

public class Example
{
    public async Task<IEnumerable<TvShow>> GetShowsAsync()
    {
        var connString = "Host=localhost;Username=postgres;Password=yourpassword;Database=yourdb";
        using var conn = new NpgsqlConnection(connString);
        await conn.OpenAsync();

        var sql = "SELECT id, show_name AS ShowName, rating FROM tv_shows WHERE rating > @minRating
        return await conn.QueryAsync<TvShow>(sql, new { minRating = 4.0m });
    }
}
```

7.4 PostgreSQL with Entity Framework Core

Install NuGet packages:

```
dotnet add package Microsoft.EntityFrameworkCore
dotnet add package Npgsql.EntityFrameworkCore.PostgreSQL
```

Example: DbContext and Model

```
using Microsoft.EntityFrameworkCore;
```

```
public class TvShow
{
    public int Id { get; set; }
    public string ShowName { get; set; }
    public decimal Rating { get; set; }
}

public class AppDbContext : DbContext
{
    public DbSet<TvShow> TvShows { get; set; }

    protected override void OnConfiguring(DbContextOptionsBuilder options)
        => options.UseNpgsql("Host=localhost;Username=postgres;Password=yourpassword;Database=yourdb");
}

// Usage
using var db = new AppDbContext();
db.TvShows.Add(new TvShow { ShowName = "Friends", Rating = 4.8m });
db.SaveChanges();

var highRated = db.TvShows.Where(t => t.Rating > 4.0m).ToList();
```

Note:
- Use migrations to create/update your PostgreSQL schema:
`dotnet ef migrations add InitialCreate`
`dotnet ef database update` - See Npgsql EF Core docs for advanced usage.

Chapter 8

Microsoft SQL Server

All sql scripts included in this section expect to be run in your preferred sql tool. If you need to install sql server skip to SQL - Install.

Azure Data Studio, which earlier versions of this text recommended, was retired by Microsoft and stopped receiving support in February 2026. See Client tools for what to use instead.

8.1 Adventure Works

While many of the sql examples shown will not use the adventure works sample database I suggest that it is restored and used to investigate sql server.

For a more detailed sample database download and restore Microsoft's AdventureWorks database.

Before restoring the bak change the owner to mssql and move it to a folder that sql server has permissions to access.

```
sudo mkdir -p /var/opt/mssql/backup/
sudo chown mssql /var/opt/mssql/backup/
sudo chgrp mssql /var/opt/mssql/backup/
chown mssql AdventureWorksLT2019.bak
chgrp mssql AdventureWorksLT2019.bak
sudo mv AdventureWorksLT2019.bak  /var/opt/mssql/backup/
```

Find the logical names

```
USE [master];
GO
RESTORE FILELISTONLY
FROM DISK = '/var/opt/mssql/backup/AdventureWorksLT2019.bak'
```

Restore the database.

```
USE [master];
GO
RESTORE DATABASE [AdventureWorks2019]
FROM DISK = '/var/opt/mssql/backup/AdventureWorksLT2019.bak'
WITH
    MOVE 'AdventureWorksLT2012_Data' TO '/var/opt/mssql/data/AdventureWorks2019.mdf',
    MOVE 'AdventureWorksLT2012_Log' TO '/var/opt/mssql/data/AdventureWorks2019_log.ldf',
    FILE = 1,
    NOUNLOAD,
```

```
    STATS = 5;
GO
```

8.2 Create a database

```
use master;
create database SqlPlayground;
```

8.3 Create a table

Create a table using a UNIQUEIDENTIFIER (sequential guid) column as the primary key.

```
use SqlPlayground;

create table [dbo].[TvShows]
(
    Id UNIQUEIDENTIFIER NOT NULL PRIMARY KEY DEFAULT NEWSEQUENTIALID(),
    ShowName nvarchar(50) not null,
    ShowLength int not null,
    Summary nvarchar(max) not null,
    Rating decimal(18,2) null,
    Episode nvarchar(200) not null,
    ParentalGuide nvarchar(5) null
)
```

As an alternative, create the table with a bigint identity column as the primary key.

```
create table [dbo].[TvShows]
(
    Id BIGINT NOT NULL IDENTITY PRIMARY KEY,
    ShowName nvarchar(50) not null,
    ShowLength int not null,
    Summary nvarchar(max) not null,
    Rating decimal(18,2) null,
    Episode nvarchar(200) not null,
    ParentalGuide nvarchar(5) null
)
```

Note: schemas, tables, and column names can be surrounded in square brackets []. This is for when special characters or reserved keywords are part of the name.

8.4 Alter a table

```
alter table TvShows
add FirstAiredUtc DateTime;
```

8.5 Create indexes

Review Clustered and nonclustered indexes described and CREATE INDEX.

```
create index index_tvshows_showname ON dbo.TvShows (ShowName);
```

8.6 SELECT

```
select * from TvShows;
select * from TvShows where ShowName = 'Dexter';
select Id, ShowName, ShowLength, Summary, FirstAiredUtc
from TvShows;
```

8.7 INSERT

Insert a new row into a table.

```
insert into TvShows (ShowName, ShowLength, Summary, Rating, Episode, ParentalGuide)
values ('Frasier', '30', 'Frasier goes home.', 4.56, '1e01', 'PG');
```

Insert a new row into a table and select back the new unique identifier of that row.

```
declare @InsertedRowIds table(InsertedId UNIQUEIDENTIFIER);

insert into TvShows (ShowName, ShowLength, Summary, Rating, Episode, ParentalGuide)
OUTPUT inserted.Id INTO  @InsertedRowIds(InsertedId)
values ('Frasier', '30', 'Frasier does it again.', 3.68, '2e01', 'PG');

select * FROM @InsertedRowIds;
```

Insert a new row into a table that uses a bigint identity column and select back the new id of that row.

```
insert into TvShows (ShowName, ShowLength, Summary, Rating, Episode, ParentalGuide)
values ('Frasier', '30', 'Frasier does it again.', 3.68, '2e01', 'PG');

select SCOPE_IDENTITY();
```

Further reading

- INSERT
- OUTPUT clause

8.8 UPDATE

When executing updates be sure to include a where clause to avoid updating every record in a table.

```
update TvShows set ParentalGuide = 'PG13' where ShowName='Friends';
update TvShows set ParentalGuide = 'PG' where ShowName = 'Frasier';
update TvShows set ParentalGuide = '18A' where ShowName = 'Dexter';
update TvShows set ParentalGuide = 'PG' where ShowName in ('Friends', 'Frasier');
```

8.9 DELETE

When executing deletes be sure to include a where clause to avoid deleting every record in a table.

```
delete from TvShows where ShowName = 'Dexter';
```

8.10 Foreign Keys

A **foreign key** is a constraint that enforces a relationship between columns in two tables, ensuring that the value in one table matches a value in another. This maintains referential integrity between related

data.

For example, suppose you have a `TvShows` table and an `Episodes` table. Each episode references a TV show by its `TvShowId`:

```
CREATE TABLE TvShows (
    Id BIGINT NOT NULL IDENTITY PRIMARY KEY,
    ShowName NVARCHAR(50) NOT NULL
);

CREATE TABLE Episodes (
    Id BIGINT NOT NULL IDENTITY PRIMARY KEY,
    TvShowId BIGINT NOT NULL,
    EpisodeName NVARCHAR(100) NOT NULL,
    FOREIGN KEY (TvShowId) REFERENCES TvShows(Id)
);
```

In this example, `Episodes.TvShowId` must match an existing `TvShows.Id`, ensuring episodes are always linked to a valid TV show.

8.11 JOIN

A **JOIN** in SQL combines rows from two or more tables based on a related column between them. The most common type is an **INNER JOIN**, which returns only the rows where there is a match in both tables.

Example:

Suppose you have `TvShows` and `Episodes` tables. To list all episodes with their show names:

```
SELECT
    TvShows.ShowName,
    Episodes.EpisodeName
FROM
    TvShows
INNER JOIN
    Episodes ON TvShows.Id = Episodes.TvShowId;
```

This query returns each episode along with the name of its TV show.

8.12 CTE

A **Common Table Expression (CTE)** is a temporary result set in SQL that you can reference within a `SELECT`, `INSERT`, `UPDATE`, or `DELETE` statement. CTEs make complex queries easier to read and maintain, and are especially useful for recursive queries or breaking down large queries into logical building blocks.

Example:

Suppose you want to select all TV shows with a rating above 4.0 and then count them.

```
WITH HighRatedShows AS (
    SELECT *
    FROM TvShows
    WHERE Rating > 4.0
)
SELECT COUNT(*) AS HighRatedShowCount
FROM HighRatedShows;
```

In this example, the CTE `HighRatedShows` selects all shows with a rating above 4.0, and the main query counts how many such shows exist.

8.13 Stored Procedures

A **stored procedure** in SQL Server is a precompiled collection of one or more T-SQL statements that can be executed as a single unit. Stored procedures help encapsulate logic, improve performance, and promote code reuse.

Example:

This stored procedure selects all TV shows with a rating above a specified value:

```
CREATE PROCEDURE GetHighRatedTvShows
    @MinRating DECIMAL(18,2)
AS
BEGIN
    SELECT *
    FROM TvShows
    WHERE Rating >= @MinRating;
END
```

To execute the procedure:

```
EXEC GetHighRatedTvShows @MinRating = 4.5;
```

This will return all rows from `TvShows` where the `Rating` is 4.5 or higher.

8.14 Stored Functions

A **stored function** in SQL Server is a user-defined function (UDF) that returns a single value or a table. Functions can be used in queries, computed columns, or as part of expressions. Unlike stored procedures, functions must return a value and cannot modify database state (no `INSERT`, `UPDATE`, or `DELETE`).

Example:
This scalar-valued function returns the full name of a TV show episode by combining the show name and episode name.

```
CREATE FUNCTION dbo.GetFullEpisodeName
(
    @ShowName NVARCHAR(50),
    @EpisodeName NVARCHAR(100)
)
RETURNS NVARCHAR(200)
AS
BEGIN
    RETURN @ShowName + ' - ' + @EpisodeName
END
```

Usage:

```
SELECT dbo.GetFullEpisodeName('Friends', 'The One Where It All Began') AS FullEpisodeName;
```

8.15 Views

A **view** in SQL Server is a virtual table based on the result of a `SELECT` query. Views simplify complex queries, encapsulate logic, and can help restrict access to specific data.

Example:

Create a view that lists only TV shows with a rating above 4.0:

```
CREATE VIEW HighRatedTvShows AS
SELECT Id, ShowName, Rating
FROM TvShows
WHERE Rating > 4.0;
```

You can then query the view like a table:

```
SELECT * FROM HighRatedTvShows;
```

8.16 SQL - Install

8.16.1 SQL server windows install

Download sql server from Microsoft. The simple install method is to double click the setup.exe and use the user interface to complete the install.

If it is a non production environment, for development choose the developer edition.

If you wish to automate the install it can be script with options similar to the below example.

```
setup.exe /ACTION=INSTALL /IACCEPTSQLSERVERLICENSETERMS /FEATURES="SQL,Tools" /SECURITYMODE=SQL /SAPWD
```

Review the Install SQL Server on Windows from the command prompt page for up to date options and documentation.

8.16.2 SQL server linux install

See Quickstart: Install SQL Server and create a database on Ubuntu for further details.

Run these commands to install sql server 2022 on a ubuntu server.

```
# Download the Microsoft repository GPG keys
wget -qO- https://packages.microsoft.com/keys/microsoft.asc | sudo tee /etc/apt/trusted.gpg.d/microsof
sudo add-apt-repository "$(wget -qO- https://packages.microsoft.com/config/ubuntu/$(lsb_release -rs)/m
# Update the list of packages after we added packages.microsoft.com
sudo apt-get update
# Install SQL Server
sudo apt-get install mssql-server
sudo /opt/mssql/bin/mssql-conf setup
```

To enable the sql agent feature run this command:

```
sudo /opt/mssql/bin/mssql-conf set sqlagent.enabled true
sudo systemctl restart mssql-server
```

If the command line tools are also required run these commands:

```
wget -qO- https://packages.microsoft.com/keys/microsoft.asc | sudo tee /etc/apt/trusted.gpg.d/microsof
wget -qO- https://packages.microsoft.com/config/ubuntu/$(lsb_release -rs)/prod.list | sudo tee /etc/ap
sudo apt-get update
sudo apt-get install mssql-tools unixodbc-dev

echo 'export PATH="$PATH:/opt/mssql-tools/bin"' >> ~/.bash_profile
```

8.16.3 SQL server extra configuration after the install

Set some initial configuration options from any of the tools in Client tools. Run the following sql.

```
sp_configure 'show advanced options', 1
reconfigure with override

sp_configure 'max server memory (MB)', -- 90% of OS MEM
reconfigure with override
```

The per database settings worth changing are all reachable from T-SQL, which means the same script works from every tool and on Linux, where there is no Configuration Manager to click through.

```
-- Full recovery keeps point in time restore available.  If the data is non
-- production or not important, SIMPLE is fine and the log stops growing.
ALTER DATABASE YourDatabase SET RECOVERY FULL;

-- Percentage growth on both files.  The default 1 MB log growth produces
-- thousands of tiny virtual log files on a busy database.
ALTER DATABASE YourDatabase MODIFY FILE (NAME = 'YourDatabase',     FILEGROWTH = 10%);
ALTER DATABASE YourDatabase MODIFY FILE (NAME = 'YourDatabase_log', FILEGROWTH = 10%);

-- Match the engine version so the current query optimiser is used.
ALTER DATABASE YourDatabase SET COMPATIBILITY_LEVEL = 170;  -- SQL Server 2025

-- Query Store, read write, so it is actually collecting.
ALTER DATABASE YourDatabase SET QUERY_STORE = ON;
ALTER DATABASE YourDatabase SET QUERY_STORE (OPERATION_MODE = READ_WRITE);
```

On Windows, force encryption lives in SQL Server Configuration Manager under Protocols. On Linux, set it with `mssql-conf` instead.

```
sudo /opt/mssql/bin/mssql-conf set network.forceencryption 1
sudo systemctl restart mssql-server
```

8.17 Reference - Admin

Use spBlitz (SQL First Responder Kit) to detect problems with sql server. Follow the instructions on the spBlitz site.

A few examples:

```
-- Realtime performance advice that should be run first when responding to an incident or case
exec sp_BlitzFirst

-- Overall Health Check
exec sp_Blitz

-- Find the Most Resource-Intensive Queries
exec sp_BlitzCache

-- Tune Your Indexes
exec sp_BlitzIndex
```

Use the Ola Hallengren SQL Server Maintenance Solutions for excellent pre-made community backed maintenance jobs.

Both of those install as stored procedures, so they are run the same way from any client, and scheduled with SQL Server Agent jobs.

8.18 Client tools

Azure Data Studio was the cross platform answer here for years. Microsoft retired it, with support ending in February 2026, and folded its functionality into the VS Code extension below. Anything still recommending it is out of date.

- **MSSQL extension for VS Code** - Microsoft's replacement for Azure Data Studio, and where the effort now goes. Free, runs on linux, mac and windows, and includes query editing, a results grid, schema browsing and query plan viewing.
- **Beekeeper Studio** - open source, cross platform, and the most pleasant of these to actually sit in front of. Covers SQL Server, PostgreSQL, SQLite and Redis, so like DBeaver it is one tool for most of the Data part of this book. The free community edition is enough for querying and editing day to day; the paid edition adds things like the query magics and backup/restore UI.
- **DBeaver** - open source and cross platform, and the one to pick when breadth matters most. It reaches databases nothing else here does, and the community edition is fully featured, at the cost of a heavier, more cluttered interface than Beekeeper's.
- **DataGrip** - JetBrains, commercial, cross platform, and included with an All Products subscription if you already use Rider.
- **SSMS** - still the most complete tool for administration, and still windows only. Reach for it when you need the deeper admin surface; do not build a workflow around it if your team is on linux or mac.
- **sqlcmd** - the command line client, and the one that works over ssh, inside a container, and in a build pipeline.

The lesson worth taking from the retirement is to prefer T-SQL over a GUI workflow when writing anything down. A script in source control outlives whichever client is fashionable.

8.19 SQL Profiler and Extended Events

The old SQL Profiler and its trace API are deprecated, and the graphical XEvent Profiler was an Azure Data Studio feature that went away with it. **Extended Events** is the supported mechanism, and because a session is created and read with T-SQL, it works from any client on any platform.

Capture statements that took longer than a second.

```
CREATE EVENT SESSION slow_queries ON SERVER
ADD EVENT sqlserver.sql_batch_completed (
    ACTION (sqlserver.client_app_name, sqlserver.database_name, sqlserver.sql_text)
    -- duration is in microseconds
    WHERE duration > 1000000
),
ADD EVENT sqlserver.rpc_completed (
    ACTION (sqlserver.client_app_name, sqlserver.database_name, sqlserver.sql_text)
    WHERE duration > 1000000
)
ADD TARGET package0.ring_buffer
WITH (MAX_MEMORY = 4096 KB, TRACK_CAUSALITY = ON, STARTUP_STATE = OFF);

ALTER EVENT SESSION slow_queries ON SERVER STATE = START;
```

The ring buffer target holds the results in memory. Read it by shredding the XML.

```
SELECT
    x.e.value('(@timestamp)[1]', 'datetime2') AS occurred,
    x.e.value('(data[@name="duration"]/value)[1]', 'bigint') / 1000 AS duration_ms,
    x.e.value('(action[@name="database_name"]/value)[1]', 'nvarchar(128)') AS database_name,
    x.e.value('(action[@name="client_app_name"]/value)[1]', 'nvarchar(256)') AS client_app,
    x.e.value('(action[@name="sql_text"]/value)[1]', 'nvarchar(max)') AS sql_text
FROM (
    SELECT CAST(st.target_data AS xml) AS target_data
    FROM sys.dm_xe_session_targets AS st
    JOIN sys.dm_xe_sessions AS s ON s.address = st.event_session_address
    WHERE s.name = 'slow_queries' AND st.target_name = 'ring_buffer'
) AS raw
CROSS APPLY raw.target_data.nodes('RingBufferTarget/event') AS x(e)
ORDER BY occurred DESC;
```

Stop it when finished. An event session left running on a busy server is overhead nobody remembers enabling.

```
ALTER EVENT SESSION slow_queries ON SERVER STATE = STOP;
DROP EVENT SESSION slow_queries ON SERVER;
```

Use a `package0.event_file` target instead of the ring buffer when a session should survive a restart or capture more than a few thousand events. For day to day “why was this slow”, the Query Store below is usually the better first stop, because it is always on and keeps its history.

8.20 SQL Query Store

Monitor performance by using the Query Store

8.21 SQL Watch

SQL Watch - sql monitor.

Chapter 9

Redis

Redis is an open-source, in-memory data store commonly used as a database, cache, and message broker. It supports data structures such as strings, hashes, lists, sets, and more, and is known for its high performance and simplicity.

forks:

- Valkey: A community-driven fork supported by the Linux Foundation, aiming to maintain an open-source alternative.
- Redict: Another fork focused on preserving the original open-source spirit of Redis.

These forks are compatible with Redis and are intended to provide drop-in replacements for users who require a fully open-source solution.

Other redis compatible solutions:

- DragonflyDB

9.1 Ubuntu Install

```
sudo apt update
sudo apt install redis-server
sudo cp /etc/redis/redis.conf /etc/redis/redis.conf.backup

sudo ufw allow ssh
sudo ufw allow redis
sudo ufw allow 6380/tcp
sudo ufw enable
sudo ufw status
```

9.1.1 Add redis password

/etc/redis/redis.conf

add

```
user default on >[PLACEHOLDER] ~* +@all
acl-pubsub-default allchannels
```

9.1.2 Connect to password protected redis server

```
redis-cli -h 127.0.0.1 -p 6379
AUTH [PLACEHOLDER]
```

9.1.3 expose to the network

sudo vim /etc/redis/redis.conf

```
bind 0.0.0.0
```

9.1.4 Restart on failure

Ensure restart on failure is enabled

```
sudo cat /lib/systemd/system/redis-server.service
```

2. **Look for Restart Policies**: Within the service file, look for directives related to the restart policy. Common directives include `Restart` and `RestartSec`.

Example:

```
[Service]
Type=notify
ExecStart=/usr/bin/redis-server /etc/redis/redis.conf
ExecStop=/usr/bin/redis-shutdown
User=redis
Group=redis
RuntimeDirectory=redis
RuntimeDirectoryMode=2755
PIDFile=/run/redis/redis-server.pid
TimeoutStopSec=0
Restart=on-failure
RestartSec=5
```

3. **Modify the Service Configuration if Necessary**: If the `Restart` directive is not set or you want to customize it, you can create a systemd override file to modify the service configuration without changing the original service file.

```
sudo systemctl edit redis-server
```

This command opens an editor where you can add or override directives. For example, to ensure the service restarts on failure, you can add:

```
[Unit]
StartLimitIntervalSec=0  # Disable the limit on the time window
StartLimitBurst=0        # Disable the limit on the number of restart attempts

[Service]
Restart=always           # Always restart the service
RestartSec=10            # Wait 10 seconds before restarting
```

4. **Reload Systemd and Restart the Service**: After making changes, reload the systemd configuration and restart the Redis service to apply the changes.

```
sudo systemctl daemon-reload
sudo systemctl restart redis-server
```

5. **Verify the Configuration**: Finally, you can verify that the service is configured correctly by checking its status.

```
sudo systemctl status redis-server
```

9.1.5 TLS Connection Support

If TLS support is enabled the client connection strings must be configured to use it.

9.1.5.1 1. Generate SSL/TLS Certificates

You can generate self-signed certificates for testing purposes or obtain certificates from a trusted Certificate Authority (CA) for production use. Here's how to generate self-signed certificates using OpenSSL:

```
# Create a directory to store the certificates
mkdir -p /etc/redis/ssl
cd /etc/redis/ssl

# Generate a private key
openssl genrsa -out redis-server.key 2048

# Generate a self-signed certificate
openssl req -new -x509 -key redis-server.key -out redis-server.crt -days 3652

# Generate a private key for the client
openssl genrsa -out redis-client.key 2048

# Generate a certificate signing request (CSR) for the client
openssl req -new -key redis-client.key -out redis-client.csr

# Generate a self-signed certificate for the client
openssl x509 -req -in redis-client.csr -CA redis-server.crt -CAkey redis-server.key -CAcreateserial

chgrp -R redis /etc/redis/ssl
chown -R redis /etc/redis/ssl
```

9.1.5.2 2. Configure Redis to Use TLS

Edit the Redis configuration file (`/etc/redis/redis.conf`) to enable TLS and specify the paths to your certificates and keys.

```
# Non-TLS port, disable for enhanced security
port 6379

# Enable TLS
tls-port 6380

# Specify the paths to the certificates and keys
tls-cert-file /etc/redis/ssl/redis-server.crt
tls-key-file /etc/redis/ssl/redis-server.key
tls-ca-cert-file /etc/redis/ssl/redis-server.crt

# Optional: Require clients to authenticate using a client certificate
tls-auth-clients no
```

9.1.5.3 3. Restart Redis Server

After making these changes, restart the Redis server to apply the new configuration.

```
sudo systemctl restart redis-server
```

9.2 Session

To use Redis for web sessions in C#, add the `Microsoft.Extensions.Caching.StackExchangeRedis` NuGet package to your ASP.NET Core project. In `Program.cs`, configure session state to use Redis as the backing store:

```
builder.Services.AddStackExchangeRedisCache(options =>
{
    options.Configuration = "localhost:6379,password=yourpassword";
    options.InstanceName = "SampleInstance";
});

builder.Services.AddSession(options =>
{
    options.Cookie.HttpOnly = true;
    options.Cookie.IsEssential = true;
    options.IdleTimeout = TimeSpan.FromMinutes(30);
});

app.UseSession();
```

You can then use `HttpContext.Session` to store and retrieve session data. Redis will persist session state across web server restarts and scale-out scenarios.

9.3 Cache

To use Redis as a distributed cache in a C# ASP.NET Core application, add the `Microsoft.Extensions.Caching.StackExc` NuGet package. Configure Redis in `Program.cs`:

```
builder.Services.AddStackExchangeRedisCache(options =>
{
    options.Configuration = "localhost:6379,password=yourpassword";
    options.InstanceName = "SampleInstance";
});
```

You can then use `IDistributedCache` to store and retrieve cached data:

```
public class MyController : Controller
{
    private readonly IDistributedCache _cache;

    public MyController(IDistributedCache cache)
    {
        _cache = cache;
    }

    public async Task<IActionResult> Index()
    {
        var value = await _cache.GetStringAsync("myKey");
        if (value == null)
```

```
        {
            value = "Hello from Redis cache!";
            await _cache.SetStringAsync("myKey", value, new DistributedCacheEntryOptions
            {
                AbsoluteExpirationRelativeToNow = TimeSpan.FromMinutes(10)
            });
        }
        return Content(value);
    }
}
```

This enables fast, centralized caching for web applications, improving performance and scalability.

9.4 Publish and Subscribe

Publish/Subscribe (Pub/Sub) is a messaging pattern where senders (publishers) send messages to channels without knowing who will receive them, and receivers (subscribers) listen for messages on those channels. Redis provides built-in support for Pub/Sub, enabling real-time messaging between distributed components.

9.4.1 Using Redis Pub/Sub in C

To use Redis Pub/Sub in a C# application, add the `StackExchange.Redis` NuGet package. You can then publish and subscribe to messages as shown below:

```
using StackExchange.Redis;

var redis = ConnectionMultiplexer.Connect("localhost:6379,password=yourpassword");
var pubsub = redis.GetSubscriber();

// Subscribe to a channel
pubsub.Subscribe("notifications", (channel, message) => {
    Console.WriteLine($"Received: {message}");
});

// Publish a message to the channel
pubsub.Publish("notifications", "Hello from publisher!");

// Keep the application running to receive messages
Console.ReadLine();
```

This allows different parts of your application (or different applications) to communicate in real time using Redis channels.

9.5 Example: Redis Pub/Sub with Web Frontend and Worker Services

This example demonstrates a simple architecture where:

- A web frontend allows users to submit work (e.g., a “task”).
- The frontend publishes the task to a Redis channel.
- One or more worker services (in separate processes) subscribe to the channel, process the task, and publish a completion message to another channel.
- The frontend listens for completion messages and notifies the user when their task is done.

9.5.1 1. Web Frontend (ASP.NET Core + JavaScript)

Backend Controller (C#):

```
// Controller to accept user input and publish to Redis
[ApiController]
[Route("api/[controller]")]
public class TasksController : ControllerBase
{
    private readonly IConnectionMultiplexer _redis;
    public TasksController(IConnectionMultiplexer redis) => _redis = redis;

    [HttpPost]
    public async Task<IActionResult> SubmitTask([FromBody] TaskRequest request)
    {
        var id = Guid.NewGuid().ToString();
        var pub = _redis.GetSubscriber();
        await pub.PublishAsync("tasks", $"{id}:{request.Payload}");
        return Ok(new { taskId = id });
    }
}

public class TaskRequest
{
    public string Payload { get; set; }
}
```

Frontend (HTML + JavaScript):

```
<input id="taskInput" placeholder="Enter task" />
<button onclick="submitTask()">Submit</button>
<div id="status"></div>
<script>
let taskId = null;
function submitTask() {
    const payload = document.getElementById('taskInput').value;
    fetch('/api/tasks', {
        method: 'POST',
        headers: { 'Content-Type': 'application/json' },
        body: JSON.stringify({ payload })
    })
    .then(r => r.json())
    .then(data => {
        taskId = data.taskId;
        document.getElementById('status').innerText = 'Task submitted. Waiting for completion...';
    });
}

// Listen for completion via WebSocket (SignalR or custom implementation)
const ws = new WebSocket('wss://yourserver/ws');
ws.onmessage = function(event) {
    const msg = JSON.parse(event.data);
    if (msg.taskId === taskId) {
        document.getElementById('status').innerText = 'Task complete: ' + msg.result;
    }
};
```

```
</script>
```

Note: The backend should push completion messages to the frontend via WebSocket (e.g., using SignalR).

9.5.2 2. Worker Service (C# Console App)

```
using StackExchange.Redis;

var redis = ConnectionMultiplexer.Connect("localhost:6379,password=yourpassword");
var sub = redis.GetSubscriber();

sub.Subscribe("tasks", async (channel, message) => {
    var parts = message.ToString().Split(':', 2);
    var taskId = parts[0];
    var payload = parts[1];

    // Simulate work
    await Task.Delay(2000);
    var result = payload.ToUpperInvariant();

    // Publish completion
    await sub.PublishAsync("tasks-complete", $"{taskId}:{result}");
});

Console.WriteLine("Worker running. Press Enter to exit.");
Console.ReadLine();
```

9.5.3 3. Completion Notification Service

A background service (e.g., in your ASP.NET Core app) subscribes to `"tasks-complete"` and pushes updates to the frontend via WebSocket/SignalR.

```
public class CompletionNotifier : BackgroundService
{
    private readonly IConnectionMultiplexer _redis;
    private readonly IHubContext<NotifyHub> _hub;
    public CompletionNotifier(IConnectionMultiplexer redis, IHubContext<NotifyHub> hub)
    {
        _redis = redis; _hub = hub;
    }

    protected override Task ExecuteAsync(CancellationToken stoppingToken)
    {
        var sub = _redis.GetSubscriber();
        return sub.SubscribeAsync("tasks-complete", async (ch, msg) => {
            var parts = msg.ToString().Split(':', 2);
            var taskId = parts[0];
            var result = parts[1];
            await _hub.Clients.All.SendAsync("TaskCompleted", new { taskId, result });
        });
    }
}
```

SignalR Hub:

```
public class NotifyHub : Hub { }
```

Frontend SignalR Listener:

```
const connection = new signalR.HubConnectionBuilder().withUrl("/notifyhub").build();
connection.on("TaskCompleted", function(msg) {
    if (msg.taskId === taskId) {
        document.getElementById('status').innerText = 'Task complete: ' + msg.result;
    }
});
connection.start();
```

This pattern enables real-time user feedback for background work using Redis Pub/Sub, web frontend, and worker services.

9.6 Work and Message Queue with Redis in C

A work queue (also known as a message queue or task queue) allows producers to enqueue work items, and one or more consumers (workers) to process them asynchronously. Redis is commonly used for this pattern using its list commands (`LPUSH`/`RPUSH` to enqueue, `BRPOP`/`BLPOP` to dequeue).

9.6.1 Producer Example (Enqueue Work)

```
using StackExchange.Redis;

var redis = ConnectionMultiplexer.Connect("localhost:6379,password=yourpassword");
var db = redis.GetDatabase();

// Enqueue a work item (e.g., a JSON string or simple string)
await db.ListRightPushAsync("work-queue", "do_something:12345");
```

9.6.2 Consumer Example (Worker)

```
using StackExchange.Redis;

var redis = ConnectionMultiplexer.Connect("localhost:6379,password=yourpassword");
var db = redis.GetDatabase();

while (true)
{
    // Atomically move an item off the work queue and onto a processing
    // queue, so the item is not lost if this worker crashes mid-job.
    var result = await db.ListRightPopLeftPushAsync("work-queue", "processing-queue");
    if (!result.HasValue)
    {
        // Nothing waiting.  StackExchange.Redis has no blocking pop, so
        // back off briefly instead of spinning on an empty queue.
        await Task.Delay(TimeSpan.FromMilliseconds(500));
        continue;
    }

    var workItem = result.ToString();
    Console.WriteLine($"Processing: {workItem}");
```

```
    // Do work here...

    // Remove from processing-queue only after successful processing
    await db.ListRemoveAsync("processing-queue", workItem);
}
```

Notes: - Use `ListRightPushAsync` to enqueue work and `ListRightPopLeftPushAsync` to dequeue it. - StackExchange.Redis deliberately does not expose the blocking `BRPOP`/`BLPOP` commands, because a blocked connection would stall every other operation sharing that multiplexer. Poll with a short delay, as above. - The "processing" queue is what makes this reliable. Anything left sitting in it belongs to a worker that died and can be moved back to `work-queue` by a reaper process. - For more advanced scenarios, consider libraries like Hangfire.

Chapter 10

Data Access in .NET

Every database chapter in this part showed the same three approaches. This one takes them apart properly.

At the bottom is ADO.NET - `DbConnection`, `DbCommand`, `DbTransaction` - which every provider implements and every higher layer is built on. In the middle is Dapper, which maps query results onto objects and leaves the SQL to you. At the top is Entity Framework Core, which generates the SQL as well and adds change tracking and migrations.

None of them is the correct answer. Knowing all three is what lets you drop a layer when a query needs hand written SQL, without abandoning the ORM everywhere else.

10.1 DbConnection

A `DbConnection` represents an open connection to a database. It is the base class for database-specific connection classes like `SqlConnection` (SQL Server), `NpgsqlConnection` (PostgreSQL), and `SqliteConnection` (SQLite).

Example: Using DbConnection with SQL Server

```
using System.Data.Common;
using Microsoft.Data.SqlClient;

string connectionString = "Server=localhost;Database=SqlPlayground;User Id=sa;Password=yourpassword
using DbConnection conn = new SqlConnection(connectionString);
conn.Open();

using var cmd = conn.CreateCommand();
cmd.CommandText = "SELECT COUNT(*) FROM TvShows";
var count = cmd.ExecuteScalar();
Console.WriteLine($"Number of TV shows: {count}");
```

Example: Using DbConnection with PostgreSQL

```
using System.Data.Common;
using Npgsql;

string connectionString = "Host=localhost;Username=postgres;Password=yourpassword;Database=yourdb";
using DbConnection conn = new NpgsqlConnection(connectionString);
conn.Open();
```

```
using var cmd = conn.CreateCommand();
cmd.CommandText = "SELECT COUNT(*) FROM tv_shows";
var count = cmd.ExecuteScalar();
Console.WriteLine($"Number of TV shows: {count}");
```

Example: Using DbConnection with SQLite

```
using System.Data.Common;
using Microsoft.Data.Sqlite;

string connectionString = "Data Source=tvshows.db";
using DbConnection conn = new SqliteConnection(connectionString);
conn.Open();

using var cmd = conn.CreateCommand();
cmd.CommandText = "SELECT COUNT(*) FROM TvShows";
var count = cmd.ExecuteScalar();
Console.WriteLine($"Number of TV shows: {count}");
```

Note: Always dispose connections (use `using` or `await using` for async) to free resources.

10.2 DbCommand

A `DbCommand` represents a SQL statement or stored procedure to execute against a database. It is the base class for provider-specific commands like `SqlCommand` (SQL Server), `NpgsqlCommand` (PostgreSQL), and `SqliteCommand` (SQLite).

Example: Using DbCommand with SQL Server

```
using System.Data.Common;
using Microsoft.Data.SqlClient;

string connectionString = "Server=localhost;Database=SqlPlayground;User Id=sa;Password=yourpassword;";
using DbConnection conn = new SqlConnection(connectionString);
conn.Open();

using DbCommand cmd = conn.CreateCommand();
cmd.CommandText = "SELECT ShowName, Rating FROM TvShows WHERE Rating > @minRating";
var param = cmd.CreateParameter();
param.ParameterName = "@minRating";
param.Value = 4.0m;
cmd.Parameters.Add(param);

using var reader = cmd.ExecuteReader();
while (reader.Read())
{
    Console.WriteLine($"{reader.GetString(0)} ({reader.GetDecimal(1)})");
}
```

Example: Using DbCommand with PostgreSQL

```
using System.Data.Common;
using Npgsql;

string connectionString = "Host=localhost;Username=postgres;Password=yourpassword;Database=yourdb";
using DbConnection conn = new NpgsqlConnection(connectionString);
```

```
conn.Open();

using DbCommand cmd = conn.CreateCommand();
cmd.CommandText = "SELECT show_name, rating FROM tv_shows WHERE rating > @minRating";
var param = cmd.CreateParameter();
param.ParameterName = "@minRating";
param.Value = 4.0m;
cmd.Parameters.Add(param);

using var reader = cmd.ExecuteReader();
while (reader.Read())
{
    Console.WriteLine($"{reader.GetString(0)} ({reader.GetDecimal(1)})");
}
```

Example: Using DbCommand with SQLite

```
using System.Data.Common;
using Microsoft.Data.Sqlite;

string connectionString = "Data Source=tvshows.db";
using DbConnection conn = new SqliteConnection(connectionString);
conn.Open();

using DbCommand cmd = conn.CreateCommand();
cmd.CommandText = "SELECT ShowName, Rating FROM TvShows WHERE Rating > $minRating";
var param = cmd.CreateParameter();
param.ParameterName = "$minRating";
param.Value = 4.0;
cmd.Parameters.Add(param);

using var reader = cmd.ExecuteReader();
while (reader.Read())
{
    Console.WriteLine($"{reader.GetString(0)} ({reader.GetDouble(1)})");
}
```

Note:
- Always use parameters to avoid SQL injection. - Use `ExecuteReader()` for queries, `ExecuteNonQuery()` for inserts/updates/deletes, and `ExecuteScalar()` for single-value results. - Dispose commands and readers properly (using `using` statements).

10.3 DataAdapters

A `DataAdapter` acts as a bridge between a `DataSet` and a database, allowing you to fill in-memory tables and update the database with changes. It is commonly used in ADO.NET for disconnected data access.

Example: Using SqlDataAdapter with SQL Server

```
using System.Data;
using Microsoft.Data.SqlClient;

string connectionString = "Server=localhost;Database=SqlPlayground;User Id=sa;Password=yourpassword
using var conn = new SqlConnection(connectionString);
using var adapter = new SqlDataAdapter("SELECT * FROM TvShows", conn);
```

```
var dataSet = new DataSet();
adapter.Fill(dataSet, "TvShows");

// Access data
foreach (DataRow row in dataSet.Tables["TvShows"].Rows)
{
    Console.WriteLine($"{row["ShowName"]} ({row["Rating"]})");
}
```

Example: Updating Data with SqlDataAdapter

```
using System.Data;
using Microsoft.Data.SqlClient;

string connectionString = "Server=localhost;Database=SqlPlayground;User Id=sa;Password=yourpassword;";
using var conn = new SqlConnection(connectionString);
using var adapter = new SqlDataAdapter("SELECT * FROM TvShows", conn);

// Auto-generate commands for update/insert/delete
var builder = new SqlCommandBuilder(adapter);

var dataSet = new DataSet();
adapter.Fill(dataSet, "TvShows");

// Modify data in-memory
var table = dataSet.Tables["TvShows"];
table.Rows[0]["Rating"] = 5.0m;

// Push changes back to the database
adapter.Update(dataSet, "TvShows");
```

Example: Using SQLiteDataAdapter with SQLite

`Microsoft.Data.Sqlite` does not ship a `DataAdapter`. The older `System.Data.SQLite` provider does.

```
using System.Data;
using System.Data.SQLite;

string connectionString = "Data Source=tvshows.db";
using var conn = new SQLiteConnection(connectionString);
using var adapter = new SQLiteDataAdapter("SELECT * FROM TvShows", conn);

var dataSet = new DataSet();
adapter.Fill(dataSet, "TvShows");
```

If you are already using `Microsoft.Data.Sqlite` and only need a `DataTable`, load one from the reader instead of pulling in a second provider.

```
using System.Data;
using Microsoft.Data.Sqlite;

using var conn = new SqliteConnection("Data Source=tvshows.db");
conn.Open();

using var cmd = conn.CreateCommand();
cmd.CommandText = "SELECT * FROM TvShows";
```

```
var table = new DataTable();
using var reader = cmd.ExecuteReader();
table.Load(reader);
```

Notes: - DataAdapters are best for simple, disconnected scenarios. - For large-scale or modern applications, consider using ORMs like Dapper or Entity Framework. - Always dispose connections and adapters properly.

10.4 DbTransaction

A `DbTransaction` represents a database transaction, allowing you to execute multiple operations as a single unit of work. If any operation fails, you can roll back all changes to maintain data integrity.

Example: Using DbTransaction with SQL Server

```
using System.Data.Common;
using Microsoft.Data.SqlClient;

string connectionString = "Server=localhost;Database=SqlPlayground;User Id=sa;Password=yourpassword
using DbConnection conn = new SqlConnection(connectionString);
conn.Open();

using var transaction = conn.BeginTransaction();
try
{
    using var cmd1 = conn.CreateCommand();
    cmd1.Transaction = transaction;
    cmd1.CommandText = "INSERT INTO TvShows (ShowName, ShowLength, Summary, Rating, Episode, Parent
    cmd1.Parameters.Add(new SqlParameter("@name", "New Show"));
    cmd1.Parameters.Add(new SqlParameter("@length", 1200));
    cmd1.Parameters.Add(new SqlParameter("@summary", "A new show summary"));
    cmd1.Parameters.Add(new SqlParameter("@rating", 4.5m));
    cmd1.Parameters.Add(new SqlParameter("@episode", "1x01"));
    cmd1.Parameters.Add(new SqlParameter("@guide", "PG"));
    cmd1.ExecuteNonQuery();

    using var cmd2 = conn.CreateCommand();
    cmd2.Transaction = transaction;
    cmd2.CommandText = "UPDATE TvShows SET Rating = Rating + 0.1 WHERE ShowName = @name";
    cmd2.Parameters.Add(new SqlParameter("@name", "New Show"));
    cmd2.ExecuteNonQuery();

    transaction.Commit();
    Console.WriteLine("Transaction committed.");
}
catch
{
    transaction.Rollback();
    Console.WriteLine("Transaction rolled back.");
}
```

Example: Using DbTransaction with PostgreSQL

```
using System.Data.Common;
using Npgsql;
```

```
string connectionString = "Host=localhost;Username=postgres;Password=yourpassword;Database=yourdb";
using DbConnection conn = new NpgsqlConnection(connectionString);
conn.Open();

using var transaction = conn.BeginTransaction();
try
{
    using var cmd = conn.CreateCommand();
    cmd.Transaction = transaction;
    cmd.CommandText = "INSERT INTO tv_shows (show_name, rating) VALUES (@name, @rating)";
    cmd.Parameters.Add(new NpgsqlParameter("@name", "Another Show"));
    cmd.Parameters.Add(new NpgsqlParameter("@rating", 4.2m));
    cmd.ExecuteNonQuery();

    transaction.Commit();
}
catch
{
    transaction.Rollback();
}
```

Example: Using DbTransaction with SQLite

```
using System.Data.Common;
using Microsoft.Data.Sqlite;

string connectionString = "Data Source=tvshows.db";
using DbConnection conn = new SqliteConnection(connectionString);
conn.Open();

using var transaction = conn.BeginTransaction();
try
{
    using var cmd = conn.CreateCommand();
    cmd.Transaction = transaction;
    cmd.CommandText = "UPDATE TvShows SET Rating = Rating + 0.1 WHERE ShowName = $name";
    // conn is declared as DbConnection, so cmd.Parameters is a
    // DbParameterCollection, which has no AddWithValue.  CreateParameter is the
    // provider neutral equivalent.  Declare conn as SqliteConnection instead and
    // AddWithValue is available again.
    var nameParam = cmd.CreateParameter();
    nameParam.ParameterName = "$name";
    nameParam.Value = "Friends";
    cmd.Parameters.Add(nameParam);
    cmd.ExecuteNonQuery();

    transaction.Commit();
}
catch
{
    transaction.Rollback();
}
```

Notes: - Always associate commands with the transaction (`cmd.Transaction = transaction`). - Use

`Commit()` to save changes or `Rollback()` to undo on error. - Transactions help ensure data consistency and integrity. - For async code, use `BeginTransactionAsync()`, `CommitAsync()`, and `RollbackAsync()`.

10.5 ORM - Dapper

```
dotnet add package Dapper
```

```
using Microsoft.Data.SqlClient;
using Dapper;

await cn.OpenAsync();
var shows = await cn.QueryAsync<TvShow>("select * from TvShows");

public class TvShow
{
    public long Id {get; init;}
    public string ShowName {get; init;}
    public int ShowLength {get; init;}
    public string Summary {get; init;}
    public decimal Rating {get; init;}
    public string Episode {get; init;}
    public string ParentalGuide {get; init;}
}
```

10.6 ORM - Entity Framework

Before the listings: EF Core is already a unit of work and `DbSet<T>` is already a repository, so resist the urge to build a second set of both on top of it. Structuring an Application makes that case in full.

Entity Framework Core (EF Core) is a modern, open-source, object-database mapper for .NET. It enables developers to work with databases using .NET objects, eliminating most of the data-access code typically required. EF Core supports LINQ queries, change tracking, updates, and schema migrations across multiple database providers.

Example: Basic Usage with a DbContext and Model

```
using Microsoft.EntityFrameworkCore;

public class TvShow
{
    public int Id { get; set; }
    public string ShowName { get; set; }
    public decimal Rating { get; set; }
}

public class AppDbContext : DbContext
{
    public DbSet<TvShow> TvShows { get; set; }

    protected override void OnConfiguring(DbContextOptionsBuilder options)
        => options.UseSqlServer("YourConnectionStringHere");
}

// Usage
```

```
using var db = new AppDbContext();
db.TvShows.Add(new TvShow { ShowName = "Friends", Rating = 4.8m });
db.SaveChanges();

var highRated = db.TvShows.Where(t => t.Rating > 4.0m).ToList();
```

10.6.1 Entity Framework: Raw SQL Queries with FromSql and FromSqlInterpolated

Entity Framework Core allows you to execute SQL queries using the `FromSql` and `FromSqlInterpolated` methods. These methods are safe against SQL injection because they always treat parameter values as SQL parameters, not as part of the SQL command text.

Example: Using FromSql with Parameters

```
using Microsoft.EntityFrameworkCore;

var minRating = 4.0m;
var shows = db.TvShows
    .FromSql($"SELECT * FROM TvShows WHERE Rating > {minRating}")
    .ToList();
```

Example: Using FromSqlInterpolated

```
var showName = "Friends";
var result = db.TvShows
    .FromSqlInterpolated($"SELECT * FROM TvShows WHERE ShowName = {showName}")
    .ToList();
```

Note:
- These methods can only be used on queries that return entity types (not arbitrary projections).

For more details, see the official documentation.

10.6.2 Entity Framework Core: Disabling Change Tracking

By default, EF Core tracks changes to entities for automatic updates. For read-only scenarios, you can disable change tracking to improve performance using `.AsNoTracking()`.

Example:

```
using Microsoft.EntityFrameworkCore;

public class TvShow
{
    public int Id { get; set; }
    public string ShowName { get; set; }
    public decimal Rating { get; set; }
}

public class AppDbContext : DbContext
{
    public DbSet<TvShow> TvShows { get; set; }

    protected override void OnConfiguring(DbContextOptionsBuilder options)
        => options.UseSqlServer("YourConnectionStringHere");
}
```

```
// Usage: Query with change tracking disabled
using var db = new AppDbContext();
var shows = db.TvShows
    .AsNoTracking()
    .Where(t => t.Rating > 4.0m)
    .ToList();
```

Use `.AsNoTracking()` for queries where you do not intend to update the returned entities.

10.7 Database Migrations - Entity Framework Core

Entity Framework Core supports code-based migrations to evolve your database schema alongside your models. Migrations are tracked in code and can be applied to the database as needed.

10.7.1 1. Add EF Core Tools

Install the EF Core CLI tools if not already present:

```
dotnet tool install --global dotnet-ef
```

Add the EF Core packages to your project:

```
dotnet add package Microsoft.EntityFrameworkCore
dotnet add package Microsoft.EntityFrameworkCore.Design
```

10.7.2 2. Create a Migration

After defining or updating your `DbContext` and models, create a migration:

```
dotnet ef migrations add InitialCreate
```

This generates a migration file in the `Migrations` folder.

10.7.3 3. Apply the Migration

Update the database to apply the migration:

```
dotnet ef database update
```

10.7.4 4. Example Migration Class

A generated migration might look like:

```
public partial class InitialCreate : Migration
{
    protected override void Up(MigrationBuilder migrationBuilder)
    {
        migrationBuilder.CreateTable(
            name: "TvShows",
            columns: table => new
            {
                Id = table.Column<int>(nullable: false)
                    .Annotation("SqlServer:Identity", "1, 1"),
                ShowName = table.Column<string>(nullable: false),
                Rating = table.Column<decimal>(type: "decimal(18,2)", nullable: false)
            },
```

```
            constraints: table =>
            {
                table.PrimaryKey("PK_TvShows", x => x.Id);
            });
    }

    protected override void Down(MigrationBuilder migrationBuilder)
    {
        migrationBuilder.DropTable(name: "TvShows");
    }
}
```

10.7.5 5. Further Changes

To modify the schema, update your models and repeat the `dotnet ef migrations add` and `dotnet ef database update` steps.

For more, see the official EF Core migrations documentation.

10.8 Database Migration - FluentMigrator

FluentMigrator is a migration framework for .NET that enables you to define database schema changes in C# using a fluent, expressive API. It supports versioned migrations, rollbacks, and can execute both fluent and raw SQL commands.

10.8.1 Example: Creating a Table with Fluent Syntax

```
using FluentMigrator;

[Migration(2023040701)]
public class CreateTvShowsTable : Migration
{
    public override void Up()
    {
        Create.Table("TvShows")
            .WithColumn("Id").AsInt64().PrimaryKey().Identity()
            .WithColumn("ShowName").AsString(50).NotNullable()
            .WithColumn("ShowLength").AsInt32().NotNullable()
            .WithColumn("Rating").AsDecimal(18,2).Nullable();
    }

    public override void Down()
    {
        Delete.Table("TvShows");
    }
}
```

10.8.2 Example: Executing Raw SQL in a Migration

```
using FluentMigrator;

[Migration(2023040702)]
public class InsertSampleData : Migration
```

```
{
    public override void Up()
    {
        Execute.Sql("INSERT INTO TvShows (ShowName, ShowLength, Rating) VALUES ('Friends', 1380, 4.
    }

    public override void Down()
    {
        Execute.Sql("DELETE FROM TvShows WHERE ShowName = 'Friends'");
    }
}
```

10.8.3 Running Migrations

To run migrations, use the FluentMigrator CLI or integrate it into your build pipeline:

```
dotnet tool install -g FluentMigrator.DotNet.Cli

fluentmigrator migrate --assembly path/to/Your.Migrations.dll --provider sqlserver --connection "Se
```

10.9 Transactions and Isolation Levels

Transaction isolation levels determine how and when the changes made by one transaction become visible to other concurrent transactions. They help balance data consistency with system performance and concurrency.

10.9.1 Common Isolation Levels

Isolation Level	Dirty Reads	Non-Repeatable Reads	Phantom Reads	Supported By
Read Uncommitted	Yes	Yes	Yes	SQL Server, SQLite
Read Committed	No	Yes	Yes	SQL Server, PostgreSQL, SQLite*
Repeatable Read	No	No	Yes	SQL Server, PostgreSQL
Serializable	No	No	No	SQL Server, PostgreSQL, SQLite
Snapshot	No	No	No*	SQL Server, PostgreSQL†

* SQLite uses a simplified model; see notes below.
† PostgreSQL implements snapshot isolation as its default for `REPEATABLE READ`.

10.9.2 Isolation Level Descriptions

- **Read Uncommitted**: Allows reading uncommitted changes ("dirty reads") from other transactions. Fastest, but least safe.
- **Read Committed**: Only reads data that has been committed. Prevents dirty reads, but non-repeatable and phantom reads are possible. Default in SQL Server and PostgreSQL.
- **Repeatable Read**: Ensures that if a row is read twice in the same transaction, it will not change. Prevents dirty and non-repeatable reads, but phantom reads can still occur.
- **Serializable**: Highest isolation; transactions are completely isolated from each other. Prevents dirty, non-repeatable, and phantom reads. May reduce concurrency.

- **Snapshot**: Each transaction sees a snapshot of the data as it was at the start of the transaction. Prevents dirty and non-repeatable reads, and usually phantom reads.

10.9.3 Example: Setting Isolation Level in SQL

SQL Server:

```
SET TRANSACTION ISOLATION LEVEL REPEATABLE READ;
BEGIN TRANSACTION;

SELECT * FROM TvShows WHERE Rating > 4.0;

-- ... do work ...

COMMIT TRANSACTION;
```

PostgreSQL:

```
BEGIN TRANSACTION ISOLATION LEVEL SERIALIZABLE;

SELECT * FROM tv_shows WHERE rating > 4.0;

-- ... do work ...

COMMIT;
```

SQLite: SQLite supports `DEFERRED`, `IMMEDIATE`, and `EXCLUSIVE` transactions, but you can simulate isolation levels:

```
BEGIN IMMEDIATE TRANSACTION;

SELECT * FROM TvShows WHERE Rating > 4.0;

-- ... do work ...

COMMIT;
```

- By default, SQLite is closest to SERIALIZABLE, but with some caveats due to its file-based locking.

10.9.4 Example: Setting Isolation Level in C

SQL Server:

```
using (var conn = new SqlConnection(connectionString))
{
    conn.Open();
    using (var tran = conn.BeginTransaction(System.Data.IsolationLevel.Serializable))
    {
        // All commands here use the specified isolation level
        // ...
        tran.Commit();
    }
}
```

PostgreSQL:

```
using (var conn = new NpgsqlConnection(connectionString))
{
```

```
    conn.Open();
    using (var tran = conn.BeginTransaction(System.Data.IsolationLevel.RepeatableRead))
    {
        // All commands here use the specified isolation level
        // ...
        tran.Commit();
    }
}
```

SQLite:

```
using (var conn = new SqliteConnection(connectionString))
{
    conn.Open();
    using (var tran = conn.BeginTransaction(System.Data.IsolationLevel.Serializable))
    {
        // All commands here use the specified isolation level
        // ...
        tran.Commit();
    }
}
```

Note: SQLite only supports `Serializable` and `Read Uncommitted` isolation levels. `Read Committed` is emulated by default.

10.9.5 Summary Table

Isolation Level	Dirty Reads	Non-Repeatable Reads	Phantom Reads	SQL Server	PostgreSQL	SQLite
Read Uncommitted	Yes	Yes	Yes	Yes	No	Yes
Read Committed	No	Yes	Yes	Yes	Yes*	Emulated
Repeatable Read	No	No	Yes	Yes	Yes	No
Serializable	No	No	No	Yes	Yes	Yes
Snapshot	No	No	No*	Yes	Yes†	No

* PostgreSQL's default is `Read Committed`, but its `Repeatable Read` is implemented as snapshot isolation.
† PostgreSQL's `Repeatable Read` is snapshot isolation; true `Serializable` is stricter.

Tip: Choose the lowest isolation level that meets your consistency requirements to maximize performance and concurrency.

10.10 SQL Database Backup

Use SqlConnection and SqlCommand to create a bak copy only backup of a database.

```
using Microsoft.Data.SqlClient;

public async Task Backup(string connection, string saveFile,
    TimeSpan timeout)
{
```

```
    string backupDir = System.IO.Path.GetDirectoryName(saveFile);
    if (System.IO.Directory.Exists(backupDir) == false)
    {
        System.IO.Directory.CreateDirectory(backupDir);
    }

    if (System.IO.File.Exists(saveFile)){
        System.IO.File.Delete(saveFile);
    }

    var csb = new SqlConnectionStringBuilder(connection);
    string database = csb.InitialCatalog;

    var sql = $@"
        BACKUP DATABASE [{database}]
        TO DISK = '{saveFile}'
        WITH FORMAT, COMPRESSION,
             MEDIANAME = '{database}-Data',
             NAME = 'Full Backup of {database}',
             COPY_ONLY;
    ";

    using var cn = new SqlConnection(connection);
    using var cmd = new SqlCommand();

    // CommandTimeout is an int measured in seconds
    cmd.CommandTimeout = (int)timeout.TotalSeconds;
    await cn.OpenAsync();
    cmd.CommandText = sql;
    cmd.Connection = cn;

    await cmd.ExecuteNonQueryAsync();
}
```

Part IV

Web and Hosting

Chapter 11

ASP.NET Core

ASP.NET Core is the cross platform web framework for .NET. The same runtime serves web pages, json APIs, and background services, and it runs on linux, windows, and mac.

Every ASP.NET Core application starts from a `Program.cs` that builds a host, registers services, configures the request pipeline, and runs.

```
var builder = WebApplication.CreateBuilder(args);

// 1. register services
builder.Services.AddControllersWithViews();

var app = builder.Build();

// 2. configure the middleware pipeline
app.UseHttpsRedirection();
app.UseStaticFiles();
app.UseRouting();
app.UseAuthorization();
app.MapDefaultControllerRoute();

// 3. run
app.Run();
```

Middleware order is significant. Each `Use...` call wraps the ones after it, so authentication must be registered before authorization, and routing before either. Getting the order wrong produces confusing behaviour rather than a compile error.

11.1 Dependency Injection

Structuring an Application covers the concepts. ASP.NET Core builds them in: the container is already there, and the framework resolves your controllers, pages, and hosted services through it.

Register the repository and business classes from the **Repository Pattern** section on `builder.Services`.

```
var builder = WebApplication.CreateBuilder(args);

builder.Services.AddScoped<MajorSilence.DataAccess.ITestRepo>(sp =>
    new MajorSilence.DataAccess.TestRepo(
        builder.Configuration.GetConnectionString("Default")));
```

```
builder.Services.AddScoped<MajorSilence.BusinessStuff.TestStuff>();

builder.Services.AddControllers();

var app = builder.Build();
app.MapControllers();
app.Run();
```

A controller then declares what it needs in its constructor and the framework supplies it.

```
[ApiController]
[Route("api/[controller]")]
public class ShowsController : ControllerBase
{
    private readonly MajorSilence.BusinessStuff.TestStuff _stuff;

    public ShowsController(MajorSilence.BusinessStuff.TestStuff stuff)
    {
        _stuff = stuff;
    }

    [HttpGet]
    public IActionResult Get()
    {
        _stuff.DoStuff();
        return Ok();
    }
}
```

Scoped is the right lifetime for anything touching a database, because a scope is one http request. Two classes used in the same request share the connection and transaction; a later request gets fresh ones.

Do not resolve services by calling `provider.GetRequiredService` from inside your own code. That is the service locator pattern, and it hides dependencies that a constructor would have made obvious.

Connection strings belong in configuration rather than in code. `appsettings.json` holds the development value, and environment variables or a secret store override it in production.

```
{
  "ConnectionStrings": {
    "Default": "Server=localhost;Database=SqlPlayground;Trusted_Connection=True;"
  }
}
```

11.2 MVC

MVC splits a request into three parts: a **model** holding the data, a **view** rendering it, and a **controller** deciding what happens. It suits applications that serve rendered html pages.

Create a project.

```
dotnet new mvc -o YourWebApp
```

The rest of this chapter uses an `IShowRepo`, which is the same idea as chapter 3's `ITestRepo` but with methods that return shows: `GetShowsAsync`, `GetShowAsync`, `InsertAsync` and `DeleteAsync`.

A controller action returns a view along with the model it should render.

```
using Microsoft.AspNetCore.Mvc;

public class ShowsController : Controller
{
    private readonly IShowRepo _repo;

    public ShowsController(IShowRepo repo)
    {
        _repo = repo;
    }

    // GET /Shows
    public async Task<IActionResult> Index()
    {
        var shows = await _repo.GetShowsAsync();
        return View(shows);
    }

    // POST /Shows/Create
    [HttpPost]
    [ValidateAntiForgeryToken]
    public async Task<IActionResult> Create(TvShow show)
    {
        if (!ModelState.IsValid)
        {
            return View(show);
        }

        await _repo.InsertAsync(show);
        return RedirectToAction(nameof(Index));
    }
}
```

By convention the view for `Index` lives at `Views/Shows/Index.cshtml`. `@model` declares what the view was handed, and the razor syntax mixes c# into html.

```
@model IEnumerable<TvShow>

<h1>TV Shows</h1>

<table class="table">
    <thead>
        <tr><th>Name</th><th>Episode</th><th>Rating</th></tr>
    </thead>
    <tbody>
    @foreach (var show in Model)
    {
        <tr>
            <td>@show.ShowName</td>
            <td>@show.Episode</td>
            <td>@show.Rating</td>
        </tr>
    }
    </tbody>
```

```
</table>
```

Razor html encodes anything written with `@` by default, so user supplied values cannot inject script. Only `@Html.Raw` bypasses that, which is why it should be rare and deliberate.

Validation attributes on the model drive both the client side and server side checks. `ModelState.IsValid` is the server side half and must never be skipped, because client side validation is trivially bypassed.

```
public class TvShow
{
    [Required]
    [StringLength(50)]
    public string ShowName { get; set; }

    [Range(0, 5)]
    public decimal Rating { get; set; }
}
```

Razor Pages is a lighter alternative that pairs each page with its own handler class instead of routing through controllers. For a site that is mostly pages rather than shared logic it is usually the simpler choice.

11.3 Minimal API

Minimal APIs express an http endpoint as a lambda, with no controller class. They suit small json services and are measurably faster to start.

```
dotnet new web -o YourApi
```

An entire service can fit in one file.

```
var builder = WebApplication.CreateBuilder(args);

builder.Services.AddScoped<IShowRepo>(sp =>
    new ShowRepo(builder.Configuration.GetConnectionString("Default")));

var app = builder.Build();

app.MapGet("/shows", async (IShowRepo repo) =>
    Results.Ok(await repo.GetShowsAsync()));

app.MapGet("/shows/{id:long}", async (long id, IShowRepo repo) =>
{
    var show = await repo.GetShowAsync(id);
    return show is null ? Results.NotFound() : Results.Ok(show);
});

app.MapPost("/shows", async (TvShow show, IShowRepo repo) =>
{
    var id = await repo.InsertAsync(show);
    return Results.Created($"/shows/{id}", show);
});

app.Run();
```

Parameters are bound by source without any attributes: route values by name (`id`), registered services

from the container (`IShowRepo`), and a complex type from the json body (`TvShow`).

Group related endpoints so shared configuration is written once.

```
var shows = app.MapGroup("/shows").RequireAuthorization();

shows.MapGet("/", async (IShowRepo repo) => await repo.GetShowsAsync());
shows.MapDelete("/{id:long}", async (long id, IShowRepo repo) =>
{
    await repo.DeleteAsync(id);
    return Results.NoContent();
});
```

Minimal APIs and controllers can coexist in one application. Reach for controllers when the endpoint count grows, when filters and model binding conventions start being worth it, or when the team simply prefers the structure.

When they do coexist, keep them on separate path prefixes. Route matching is case insensitive, so a minimal API mapped at `/shows` and a `ShowsController` whose conventional route is `/Shows` are the same route. There is no error at startup; the minimal API simply wins and the controller action is never reached. Putting the json endpoints under `/api` avoids the whole class of problem.

Use controllers or Minimal APIs, but be consistent within a project. Mixing both for the same resource makes the routing hard to follow.

11.4 Blazor

Blazor builds interactive web UI in c# instead of javascript. Components are `.razor` files that combine markup, state, and event handlers.

```
dotnet new blazor -o YourBlazorApp
```

A component is a class with markup attached.

```
@page "/shows"
@inject IShowRepo Repo

<h1>TV Shows</h1>

@if (_shows is null)
{
    <p>Loading...</p>
}
else
{
    <ul>
        @foreach (var show in _shows)
        {
            <li>@show.ShowName (@show.Rating)</li>
        }
    </ul>
}

<input @bind="_newName" placeholder="Show name" />
<button @onclick="AddShow">Add</button>

@code {
```

```
    private List<TvShow> _shows;
    private string _newName = "";

    protected override async Task OnInitializedAsync()
    {
        _shows = (await Repo.GetShowsAsync()).ToList();
    }

    private async Task AddShow()
    {
        if (string.IsNullOrWhiteSpace(_newName))
        {
            return;
        }

        await Repo.InsertAsync(new TvShow { ShowName = _newName });
        _shows = (await Repo.GetShowsAsync()).ToList();
        _newName = "";
    }
}
```

The part that decides everything else is the **render mode**, which controls where the component actually executes.

- **Static server rendering** - html is rendered once on the server and sent. No interactivity. Fastest, and the default in a new project.
- **Interactive Server** - the component runs on the server, and UI updates travel over a SignalR connection. Small download, but every user holds an open connection and all state lives in server memory.
- **Interactive WebAssembly** - the component runs in the browser on a .NET runtime. No connection to maintain and it works offline, at the cost of a larger initial download.
- **Interactive Auto** - server rendering on the first visit while the WebAssembly runtime downloads in the background, then WebAssembly afterwards.

Set the mode per component, so only the parts that need interactivity pay for it.

```
@rendermode InteractiveServer
```

The catch worth knowing up front: with WebAssembly, the component runs on the user's machine. It cannot open a database connection, and any secret it holds is readable. Components running in the browser must go through an http API, exactly as a javascript frontend would. The `@inject IShowRepo` shown above only works under server rendering.

Chapter 12

Containers, nginx and Kubernetes

Code that runs on your machine is not yet software anyone can use. This chapter is about the gap.

A container packages the application with the runtime it needs, so that what was tested is what ships. nginx sits in front of it as a reverse proxy, terminating TLS and serving static files, because Kestrel should not be the thing facing the internet directly. Kubernetes runs many containers across many machines and restarts them when they fail, which is worth its considerable complexity only once you actually have that problem.

Each step here adds capability and cost. Plenty of applications should stop after the first.

12.1 Containers - Docker

A Docker container is a lightweight, portable, and self-sufficient unit that packages an application and all its dependencies, ensuring consistent execution across different environments. Containers are isolated from each other and the host system, making deployment and scaling straightforward.

12.1.1 Example: Dockerfile for a .NET Web Application

```
# Use the official .NET SDK image for build
FROM mcr.microsoft.com/dotnet/sdk:10.0 AS build
WORKDIR /src

# Copy project files and restore first, so the restore layer is
# cached and only re-runs when a dependency actually changes.
COPY *.sln .
COPY YourWebApp/*.csproj ./YourWebApp/
RUN dotnet restore

COPY . .
RUN dotnet publish YourWebApp -c Release -o /app --no-restore

# Use the ASP.NET runtime image for hosting
FROM mcr.microsoft.com/dotnet/aspnet:10.0 AS runtime
WORKDIR /app
COPY --from=build /app ./
EXPOSE 8080
ENTRYPOINT ["dotnet", "YourWebApp.dll"]
```

Note the port. The official .NET container images run as a non root user and listen on 8080, not 80, since .NET 8. A non root user cannot bind a port below 1024.

12.1.2 Build and Publish with Docker Buildx and SBOM

one time setup

```
docker buildx create --use --name=buildkit-container --driver=docker-container
```

regular builds

```
# Build the image with SBOM (Software Bill of Materials) generation
docker buildx build --sbom=true -t yourusername/yourwebapp:latest .

# Publish (push) the image to a container registry (e.g., Docker Hub)
docker push yourusername/yourwebapp:latest
```

The `--sbom=true` flag generates a Software Bill of Materials, providing transparency into the components included in the image for improved security and compliance.

12.2 nginx

nginx is commonly placed in front of an ASP.NET Core application as a reverse proxy. Kestrel, the built in web server, is perfectly capable of serving traffic directly, but a proxy in front gives you TLS termination, a single entry point for several applications on one host, and static file serving without touching the runtime.

Install it on ubuntu.

```
sudo apt-get update
sudo apt-get install nginx
sudo systemctl enable --now nginx
```

Configure a site at `/etc/nginx/sites-available/yourapp`, then symlink it into `sites-enabled`.

```
server {
    listen 80;
    server_name yourapp.example.com;

    location / {
        proxy_pass         http://127.0.0.1:5000;
        proxy_http_version 1.1;

        # required for websockets, SignalR, and Blazor Server
        proxy_set_header Upgrade    $http_upgrade;
        proxy_set_header Connection $connection_upgrade;

        proxy_set_header Host              $host;
        proxy_set_header X-Real-IP         $remote_addr;
        proxy_set_header X-Forwarded-For   $proxy_add_x_forwarded_for;
        proxy_set_header X-Forwarded-Proto $scheme;
        proxy_cache_bypass $http_upgrade;
    }
}
```

`$connection_upgrade` is not built in and must be defined in the `http` block, usually in `/etc/nginx/nginx.conf`.

```
map $http_upgrade $connection_upgrade {
    default upgrade;
    ''      close;
}
```

Enable the site and reload. `nginx -t` checks the configuration before you apply it, which is worth doing every time.

```
sudo ln -s /etc/nginx/sites-available/yourapp /etc/nginx/sites-enabled/
sudo nginx -t
sudo systemctl reload nginx
```

12.2.1 Tell ASP.NET Core it is behind a proxy

Without this step the application sees every request as coming from `127.0.0.1` over plain http. Logging, rate limiting, and any redirect to https will all be wrong. `UseForwardedHeaders` must run before anything that depends on the scheme or client address.

```
dotnet add package Microsoft.AspNetCore.HttpOverrides
```

```
var builder = WebApplication.CreateBuilder(args);

builder.Services.Configure<ForwardedHeadersOptions>(options =>
{
    options.ForwardedHeaders =
        ForwardedHeaders.XForwardedFor | ForwardedHeaders.XForwardedProto;

    // Only trust the proxy in front of us.  Clearing these lists
    // without setting KnownProxies would trust any caller's headers.
    options.KnownProxies.Add(System.Net.IPAddress.Parse("127.0.0.1"));
});

var app = builder.Build();

app.UseForwardedHeaders();
```

12.2.2 TLS with Let's Encrypt

Terminate TLS at nginx rather than in Kestrel. certbot obtains the certificate, edits the site configuration, and installs a renewal timer.

```
sudo apt-get install certbot python3-certbot-nginx
sudo certbot --nginx -d yourapp.example.com
```

12.2.3 Run the application as a service

systemd keeps the application running and restarts it after a crash or a reboot. Create `/etc/systemd/system/yourapp.s`

```
[Unit]
Description=Your ASP.NET Core application
After=network.target

[Service]
WorkingDirectory=/var/www/yourapp
ExecStart=/usr/bin/dotnet /var/www/yourapp/YourWebApp.dll
Restart=always
```

```
RestartSec=10
User=www-data
Environment=ASPNETCORE_ENVIRONMENT=Production
Environment=ASPNETCORE_URLS=http://127.0.0.1:5000

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

```
sudo systemctl daemon-reload
sudo systemctl enable --now yourapp
sudo systemctl status yourapp
```

Binding to `127.0.0.1` rather than `0.0.0.0` means the application is only reachable through nginx, not directly from the network.

12.3 Kubernetes

```
# use multiple kubeconfig files at the same time and view merged config
KUBECONFIG=~/.kube/config:~/.kube/kubconfig2
kubectl config view
kubectl config get-contexts
kubectl config current-context
kubectl get nodes
kubectl get namespaces
kubectl -n theNamespace get all
kubectl -n theNamespace get pods
kubectl -n theNamespace get deployments
kubectl -n theNamespace get service
kubectl -n theNamespace get ingress
kubectl -n theNamespace describe deployment theDeployment

# create a new pod yaml file.  Edit the pod.yaml file to your needs.
kubectl run nginx --image=nginx --dry-run=client -o yaml > pod.yaml
kubectl create -f pod.yaml
```

Further reading:

- kubectl cheat sheet
- Kubernetes Health Checks and Resource Reservations

Chapter 13

JavaScript in the Browser

The browser has caught up. The things jQuery was indispensable for - selecting elements, ajax, animation, papering over browser differences - are all in the platform now, and have been for years. A server rendered ASP.NET Core application needs a modest amount of JavaScript to feel alive, and that amount is small enough to write by hand.

This chapter is plain JavaScript: no framework, no build step, no TypeScript. Everything here runs as written in any current browser. That is a deliberate position rather than a limitation - the code that survives longest in a .NET shop is usually the code with nothing underneath it to go stale. Where you genuinely need a component framework, Blazor is already in the stack and is a better answer than bolting a second ecosystem onto the side.

13.1 Where the script goes

Static files live under `wwwroot`, served by `app.UseStaticFiles()`. Put scripts in `wwwroot/js` and reference them from the layout.

```
<!-- type="module" gives you imports, strict mode, and deferred execution.
     It is the default worth using for anything past a couple of lines. -->
<script type="module" src="~/js/shows.js" asp-append-version="true"></script>
```

`asp-append-version="true"` appends a content hash to the URL, so a changed file is a different URL and the browser cannot serve a stale copy. Without it you will spend an afternoon debugging a fix that shipped fine and was cached.

Two rules cover most of the mistakes:

- **Never inline data into a script tag by string concatenation.** Rendering `var id = @Model.Id;` into JavaScript is how you get script injection. Put values in `data-` attributes on an element and read them from there.
- **`type="module"` scripts are deferred automatically.** They run after the document is parsed, so there is no need for a `DOMContentLoaded` wrapper and no need to put the tag at the bottom of the body.

```
<div id="shows" data-api="/api/shows" data-page-size="20"></div>
```

```
const el = document.querySelector("#shows");
const api = el.dataset.api;                    // "/api/shows"
const pageSize = Number(el.dataset.pageSize);  // 20
```

13.2 Modules

Files are modules. Each has its own scope, exports what it wants to share, and imports what it needs. There are no globals to collide and no load order to get right.

```
// wwwroot/js/api.js
export async function getShows() {
  return await getJson("/api/shows");
}

// A single place where every call's error handling lives.
async function getJson(url) {
  const response = await fetch(url, { headers: { Accept: "application/json" } });
  if (!response.ok) {
    throw new Error(`${response.status} ${response.statusText}`);
  }
  return await response.json();
}
```

```
// wwwroot/js/shows.js
import { getShows } from "./api.js";

const shows = await getShows();
console.log(shows.length);
```

Note the file extension in the import. Browsers resolve module specifiers as URLs, not the way Node does, so `./api.js` is required and `./api` will 404. Top level `await` works in a module, which is why the last listing needs no wrapper function.

13.3 The DOM

Four methods cover almost everything.

```
const el = document.querySelector("#shows");         // first match, or null
const all = document.querySelectorAll(".show-row"); // every match, a NodeList
const row = document.createElement("tr");
el.append(row);                                      // also accepts plain strings
```

`querySelectorAll` returns a `NodeList`. It is iterable with `for...of` and has `forEach`, but it is not an array; `Array.from(all)` when you want `map` or `filter`.

Class and attribute changes are direct:

```
row.classList.add("is-selected");
row.classList.toggle("is-open", isOpen);   // second argument forces the state
row.hidden = true;                          // better than a display:none class
row.setAttribute("aria-expanded", "true");
```

13.3.1 Rendering without an injection bug

This is the one place where a careless line becomes a security bug, so it gets its own section.

`textContent` is safe. `innerHTML` is not. Anything assigned to `textContent` is text, always. Anything assigned to `innerHTML` is parsed as markup, so a show name of `<img src=x onerror=alert(1)>` stored by one user runs in the next user's browser. That is stored XSS, and no amount of encoding on the server saves you if the browser is handed the raw value and told to parse it.

```
// Safe: the value is text no matter what it contains.
cell.textContent = show.showName;

// Unsafe with any value that came from a user, a database, or an api.
cell.innerHTML = show.showName;
```

For a row of several fields, build elements and let the browser do the escaping:

```
function renderRow(show) {
  const tr = document.createElement("tr");
  for (const value of [show.showName, show.episode ?? "", show.rating]) {
    const td = document.createElement("td");
    td.textContent = value;
    tr.append(td);
  }
  return tr;
}
```

When the markup is more than a couple of elements, use a `<template>`. The browser parses it once, `cloneNode` is cheap, and the structure stays in the HTML file where it is easy to read.

```
<template id="show-row">
  <tr>
    <td class="name"></td>
    <td class="episode"></td>
    <td class="rating"></td>
  </tr>
</template>
```

```
const template = document.querySelector("#show-row");

function renderRow(show) {
  const row = template.content.firstElementChild.cloneNode(true);
  row.querySelector(".name").textContent = show.showName;
  row.querySelector(".episode").textContent = show.episode ?? "";
  row.querySelector(".rating").textContent = show.rating;
  return row;
}
```

Build the whole list into a `DocumentFragment` and append once. Appending inside the loop makes the browser recalculate layout on every iteration.

```
const fragment = document.createDocumentFragment();
for (const show of shows) {
  fragment.append(renderRow(show));
}
document.querySelector("#show-body").replaceChildren(fragment);
```

`replaceChildren` empties the element and fills it in one call, which is the modern replacement for `innerHTML = ""` followed by a loop.

13.4 Events

`addEventListener` on the element, and nothing else. Inline `onclick` attributes mix behaviour into markup and are blocked by a strict Content Security Policy anyway.

```
document.querySelector("#refresh").addEventListener("click", async () => {
  await load();
});
```

For a list whose rows come and go, attach one listener to the container instead of one per row. The event bubbles up and `closest` finds which row it came from. This is **event delegation**, and it keeps working for rows added after the listener was attached.

```
document.querySelector("#show-body").addEventListener("click", (event) => {
  const button = event.target.closest("button[data-delete-id]");
  if (!button) return;   // the click was somewhere else in the table

  remove(Number(button.dataset.deleteId));
});
```

For forms, listen for `submit` on the form rather than `click` on the button, so the keyboard path works too.

```
form.addEventListener("submit", async (event) => {
  event.preventDefault();   // stop the normal navigation
  await save(new FormData(form));
});
```

13.5 fetch

`fetch` returns a promise for a `Response`. Two things about it catch people out on the first day:

- **A 404 or a 500 is not a rejection.** The promise resolves; only a network failure rejects. You have to check `response.ok` yourself, which is why every listing here does.
- **The body is read separately.** `await response.json()` or `await response.text()` is a second await, because the headers arrive before the body does.

13.5.1 GET

```
async function getShows() {
  const response = await fetch("/api/shows", {
    headers: { Accept: "application/json" },
  });

  if (!response.ok) {
    throw new Error(`GET /api/shows failed: ${response.status}`);
  }

  return await response.json();
}
```

Query strings are built with `URLSearchParams`, which handles the encoding.

```
const query = new URLSearchParams({ page: 2, search: "star trek" });
const response = await fetch(`/api/shows?${query}`);   // ?page=2&search=star+trek
```

13.5.2 POST json

This is what a minimal API endpoint taking a `TvShow` expects.

```
async function addShow(show) {
  const response = await fetch("/api/shows", {
    method: "POST",
    headers: { "Content-Type": "application/json" },
    body: JSON.stringify(show),
  });

  if (!response.ok) {
    throw new Error(`POST /api/shows failed: ${response.status}`);
  }

  return await response.json();
}

await addShow({ showName: "Rick and morty", episode: "3x14", rating: 3.8 });
```

The property names are camel case because that is what `System.Text.Json` produces and accepts by default, matching the `TvShow` class in ASP.NET Core.

13.5.3 POST a form

`URLSearchParams` also serialises to `application/x-www-form-urlencoded`, so the hand written serialise helper that used to live in this chapter is unnecessary.

```
const body = new URLSearchParams({
  showName: "Star Trek",
  episode: "1x12",
});

const response = await fetch("/shows/create", { method: "POST", body });
```

Setting the body to a `URLSearchParams` sets the content type for you. Do not set it by hand.

For a form that already exists in the page, `FormData` reads it in one line - including file inputs, which `URLSearchParams` cannot carry.

```
const response = await fetch("/shows/create", {
  method: "POST",
  body: new FormData(form),   // multipart/form-data, boundary and all
});
```

13.5.4 The antiforgery token

An MVC action marked `[ValidateAntiForgeryToken]` will reject a fetch POST with a 400 unless the token goes with it. `FormData` built from a razor `<form>` carries the hidden field automatically. A json POST does not, so send it as a header instead.

```
@inject Microsoft.AspNetCore.Antiforgery.IAntiforgery Antiforgery
<div id="app" data-antiforgery="@Antiforgery.GetAndStoreTokens(Context).RequestToken"></div>
```

```
const token = document.querySelector("#app").dataset.antiforgery;

await fetch("/api/shows", {
  method: "POST",
  headers: {
    "Content-Type": "application/json",
```

```
    "RequestVerificationToken": token,
  },
  body: JSON.stringify(show),
});
```

```
// Program.cs - tell the framework to look at that header.
builder.Services.AddAntiforgery(options =>
    options.HeaderName = "RequestVerificationToken");
```

13.5.5 Timeouts and cancellation

`fetch` has no timeout of its own. A request against a hung server waits forever, which in a browser tab means a spinner that never stops.

```
const response = await fetch("/api/shows", {
  signal: AbortSignal.timeout(10_000),   // throws TimeoutError after 10s
});
```

For a search box, keep the signal so the previous request can be cancelled when the next keystroke arrives. Otherwise responses race and the slower, older one can land last and win.

```
let inFlight;

async function search(term) {
  inFlight?.abort();
  inFlight = new AbortController();

  try {
    const response = await fetch(`/api/shows?${new URLSearchParams({ term })}`, {
      signal: inFlight.signal,
    });
    render(await response.json());
  } catch (error) {
    if (error.name === "AbortError") return;   // superseded, not a failure
    throw error;
  }
}
```

13.6 Putting it together

The whole client for the `/api/shows` endpoints from ASP.NET Core: load, render, add, delete. This is the amount of JavaScript a server rendered page usually needs, and it is roughly sixty lines with no dependencies.

```
// wwwroot/js/shows.js
const table = document.querySelector("#show-body");
const form = document.querySelector("#add-show");
const status = document.querySelector("#status");
const template = document.querySelector("#show-row");

async function send(url, options = {}) {
  const response = await fetch(url, {
    headers: { Accept: "application/json", ...options.headers },
    signal: AbortSignal.timeout(10_000),
    ...options,
```

```
  });

  if (!response.ok) {
    throw new Error(`${options.method ?? "GET"} ${url}: ${response.status}`);
  }

  return response.status === 204 ? null : await response.json();
}

function renderRow(show) {
  const row = template.content.firstElementChild.cloneNode(true);
  row.querySelector(".name").textContent = show.showName;
  row.querySelector(".episode").textContent = show.episode ?? "";
  row.querySelector(".rating").textContent = show.rating;
  row.querySelector("button").dataset.deleteId = show.id;
  return row;
}

async function load() {
  status.textContent = "Loading...";
  try {
    const shows = await send("/api/shows");
    const fragment = document.createDocumentFragment();
    for (const show of shows) {
      fragment.append(renderRow(show));
    }
    table.replaceChildren(fragment);
    status.textContent = `${shows.length} show(s)`;
  } catch (error) {
    status.textContent = `Could not load shows: ${error.message}`;
  }
}

form.addEventListener("submit", async (event) => {
  event.preventDefault();
  const data = Object.fromEntries(new FormData(form));

  await send("/api/shows", {
    method: "POST",
    headers: { "Content-Type": "application/json" },
    body: JSON.stringify({ ...data, rating: Number(data.rating) }),
  });

  form.reset();
  await load();
});

table.addEventListener("click", async (event) => {
  const button = event.target.closest("button[data-delete-id]");
  if (!button) return;

  await send(`/api/shows/${button.dataset.deleteId}`, { method: "DELETE" });
  await load();
```

```
});

await load();
```

Two habits in there are worth naming. Every failure path writes to `#status`, because a fetch that silently does nothing is the most common bug in hand written frontends. And every mutation reloads the list rather than patching the row it changed - slower in theory, but it keeps the page and the database from drifting apart, which for a table of tens or hundreds of rows is the right trade.

13.7 htmx, when you would rather not write any of this

htmx puts the ajax in the HTML. The server keeps rendering markup, and attributes say which element to swap when a request comes back. There is no JSON, no client side rendering, and nothing to keep in sync.

```
<button hx-delete="/shows/12" hx-target="closest tr" hx-swap="outerHTML">
    Delete
</button>

<input type="search" name="term"
       hx-get="/shows/search" hx-trigger="keyup changed delay:300ms"
       hx-target="#show-body">
```

That second listing is the debounced, cancel-the-previous-request search from earlier, in three attributes. Razor partials are exactly the "return a fragment of html" endpoint it wants, so the fit with ASP.NET Core is unusually good.

Reach for htmx when the page is server rendered and you want interactivity without a client side state model. Write the plain JavaScript above when the interaction is local to the page - a chart, a drag and drop reorder, a form that validates as you type - and there is no server round trip to hang it on. The two combine fine in one page.

13.8 What to skip

jQuery. Do not add it to new work. `$("#id")` is `document.querySelector("#id")`, `$.ajax` is `fetch`, `$(el).addClass` is `el.classList.add`, and `$(document).ready` is what `type="module"` already does for you. It is still perfectly good code and there is no reason to rip it out of an application that works - but every line of it in a new page is a dependency and a lookup in someone's memory that the platform no longer needs.

Kendo UI and the other commercial control suites. They are worth the licence for one specific thing: a grid with virtualised scrolling, grouping, frozen columns and Excel export, on a deadline. That is a real requirement and building it yourself is weeks. Everything else in the suite - buttons, dropdowns, date pickers, tabs - is a heavy way to get what `<dialog>`, `<details>`, `<input type="date">` and thirty lines of CSS already do, and it dictates the styling of a page for as long as the page exists.

A build step, until something forces it. No bundler, no transpiler, no `node_modules` in a .NET repository, until a real dependency needs one. Modules load fine unbundled over HTTP/2, and the moment you add a build you have added a second toolchain that must be installed on every developer machine and in every CI job.

TypeScript, in this context specifically. It is a good language and the argument for it is real. But it needs the build step above, and in an ASP.NET Core application the types that matter - the shape of the API contract - are already declared in C#. If the frontend grows to where you want types across a few thousand lines of it, that is the signal to reconsider the whole approach and use Blazor, not to add a compiler to the JavaScript.

Part V

Operations

Chapter 14

Monitoring and Observability

The application is running behind nginx, in a container, on a machine you are not looking at. Monitoring is how you find out that it is unwell before a user tells you, and observability is whether you can then work out *why* without deploying new code to find out.

Those are different jobs and they need different things. A dashboard that goes red answers "is it broken". Answering "why is it broken, for whom, since when" needs the request that failed, the query it ran, and the log line it wrote, joined together. This chapter builds that from the inside out: health checks first, because they are ten minutes of work and Kubernetes needs them; then OpenTelemetry, which is how a .NET application emits metrics, traces and logs in 2026; then Prometheus and Grafana to store and draw them; then alerting, which is where most of the value and all of the pain lives.

The three signals, in the order they earn their keep:

- **Metrics** are cheap numbers over time - request rate, error rate, duration, queue depth. They tell you something is wrong and are what alerts fire on.
- **Traces** follow one request across every service and database call it touched. They tell you *where* the time went.
- **Logs** are the detail for one moment. They tell you what the code thought it was doing.

14.1 Health checks

Start here. A health check is an endpoint that says whether the process is alive and whether it is ready to take traffic, and it is what the container orchestrator in Containers, nginx and Kubernetes polls to decide whether to restart or route to your pod.

```
dotnet add package AspNetCore.HealthChecks.NpgSql
dotnet add package AspNetCore.HealthChecks.Redis
```

```
builder.Services.AddHealthChecks()
    // Liveness: is this process wedged?  Nothing external, or a restart loop
    // is one slow database away.
    .AddCheck("self", () => HealthCheckResult.Healthy(), tags: ["live"])
    // Readiness: can it actually serve?  Dependencies belong here.
    .AddNpgSql(builder.Configuration.GetConnectionString("Shows")!,
        name: "postgres", tags: ["ready"])
    .AddRedis(builder.Configuration.GetConnectionString("Redis")!,
        name: "redis", tags: ["ready"]);

var app = builder.Build();
```

```
app.MapHealthChecks("/healthz/live", new HealthCheckOptions
{
    Predicate = check => check.Tags.Contains("live"),
});

app.MapHealthChecks("/healthz/ready", new HealthCheckOptions
{
    Predicate = check => check.Tags.Contains("ready"),
});
```

The split matters more than it looks. Liveness failing means "kill this process"; readiness failing means "stop sending it requests, but leave it alone". Put the database check in the liveness probe and a thirty second database blip restarts every replica you have, simultaneously, which turns a blip into an outage. The rule: liveness checks only things a restart could fix.

A custom check is one method.

```
public class QueueDepthCheck : IHealthCheck
{
    private readonly IWorkQueue _queue;

    public QueueDepthCheck(IWorkQueue queue) => _queue = queue;

    public Task<HealthCheckResult> CheckHealthAsync(
        HealthCheckContext context, CancellationToken cancellationToken = default)
    {
        var depth = _queue.Count;

        return Task.FromResult(depth switch
        {
            > 10_000 => HealthCheckResult.Unhealthy($"queue depth {depth}"),
            > 1_000 => HealthCheckResult.Degraded($"queue depth {depth}"),
            _ => HealthCheckResult.Healthy(),
        });
    }
}
```

Health endpoints should not need authentication - the thing polling them is a kubelet - but they should not leak either. The default response is the word `Healthy` and nothing else, which is right. If you add a detailed json writer that names every dependency and its connection string, put it on a separate, protected route.

14.2 OpenTelemetry

OpenTelemetry is the vendor neutral standard for emitting telemetry, and in .NET it is not a bolt-on: `ILogger`, `System.Diagnostics.Metrics` and `System.Diagnostics.Activity` are already the OpenTelemetry data model. The packages below are wiring and exporters, not a new logging framework.

This matters commercially as much as technically. Instrument once against OTel and the backend becomes a configuration value - Prometheus and Grafana today, a hosted vendor next year, both at once during a migration - with no change to application code.

```
dotnet add package OpenTelemetry.Extensions.Hosting
dotnet add package OpenTelemetry.Instrumentation.AspNetCore
dotnet add package OpenTelemetry.Instrumentation.Http
```

```
dotnet add package OpenTelemetry.Instrumentation.Runtime
dotnet add package OpenTelemetry.Exporter.OpenTelemetryProtocol
```

```
using OpenTelemetry.Logs;
using OpenTelemetry.Metrics;
using OpenTelemetry.Resources;
using OpenTelemetry.Trace;

builder.Services.AddOpenTelemetry()
    // Who is speaking.  Without this everything arrives labelled "unknown_service".
    .ConfigureResource(resource => resource.AddService(
        serviceName: "shows-api",
        serviceVersion: typeof(Program).Assembly.GetName().Version?.ToString() ?? "0.0.0",
        serviceInstanceId: Environment.MachineName))
    .WithMetrics(metrics => metrics
        .AddAspNetCoreInstrumentation()   // request rate, duration, active requests
        .AddHttpClientInstrumentation()   // outbound calls
        .AddRuntimeInstrumentation()      // GC, heap, thread pool, exceptions
        .AddMeter("Shows.Api")            // your own, below
        .AddOtlpExporter())
    .WithTracing(tracing => tracing
        .AddAspNetCoreInstrumentation()
        .AddHttpClientInstrumentation()
        .AddSource("Shows.Api")
        .AddOtlpExporter());

// Logs go through the same pipeline, which is what correlates them with traces.
builder.Logging.AddOpenTelemetry(logging =>
{
    logging.IncludeScopes = true;
    logging.IncludeFormattedMessage = true;
    logging.AddOtlpExporter();
});
```

The exporter reads standard environment variables, so the endpoint is deployment configuration rather than code:

```
OTEL_EXPORTER_OTLP_ENDPOINT=http://otel-collector:4317
OTEL_EXPORTER_OTLP_PROTOCOL=grpc
OTEL_RESOURCE_ATTRIBUTES=deployment.environment=production
```

Point that at an **OpenTelemetry Collector** rather than directly at a backend. The collector is one process per host or per cluster that receives, batches, filters and fans out - so retention, sampling and "also send traces to this second system while we evaluate it" become collector config instead of a redeploy of every service.

Add `OpenTelemetry.Instrumentation.EntityFrameworkCore` and call `.AddEntityFrameworkCoreInstrumentation(` if you use EF Core; it puts every query on the trace as its own span, which is usually where the answer is. The equivalent for Npgsql, `StackExchange.Redis` and SQL Client all exist as separate instrumentation packages.

14.2.1 The metrics you get for free

`AddAspNetCoreInstrumentation` and `AddRuntimeInstrumentation` emit the standard .NET meters. These are the ones worth knowing by name, because dashboards and alerts are built on them:

Metric	What it tells you
`http.server.request.duration`	Histogram of request latency, tagged by route, method and status. The single most useful metric you have.
`http.server.active_requests`	How many are in flight. Rising while duration is flat means saturation.
`http.client.request.duration`	The same for calls your service makes outbound.
`kestrel.active_connections`	Connections, as distinct from requests.
`dotnet.gc.pause.time`	Time spent in GC. A latency problem with no matching database time is often here.
`dotnet.thread_pool.queue.length`	Work waiting for a thread. Sustained non-zero means blocking calls in async code - see Asynchronous Work and Threads.

14.2.2 Your own metrics

Business metrics are what let you spot a broken deploy that is technically returning 200s. Create them through `IMeterFactory` so the meter is disposed with the container and is testable.

```
using System.Diagnostics.Metrics;

public sealed class ShowMetrics
{
    public const string MeterName = "Shows.Api";

    private readonly Counter<long> _created;
    private readonly Histogram<double> _importDuration;

    public ShowMetrics(IMeterFactory factory)
    {
        var meter = factory.Create(MeterName);

        _created = meter.CreateCounter<long>(
            "shows.created",
            unit: "{show}",
            description: "Shows added, by where the request came from.");

        _importDuration = meter.CreateHistogram<double>(
            "shows.import.duration",
            unit: "ms",
            description: "How long a catalogue import took.");
    }

    public void ShowCreated(string source) =>
        _created.Add(1, new KeyValuePair<string, object?>("source", source));

    public void ImportCompleted(TimeSpan elapsed) =>
        _importDuration.Record(elapsed.TotalMilliseconds);
}

// Program.cs
builder.Services.AddSingleton<ShowMetrics>();
```

Watch the tags. Every distinct combination of tag values is a separate time series stored forever. `source`

with four values is fine. A tag holding a show id, a user id, a full URL or an error message is how a monitoring bill goes from tens of pounds to thousands, and how a Prometheus server runs out of memory. Tags are for things with a small, bounded set of values.

14.2.3 Traces

The instrumentation packages already create a span per incoming request, per outbound HTTP call and per database query, and propagate the trace id across service boundaries through the `traceparent` header. You add spans for the parts of your own code that are worth seeing separately.

```
using System.Diagnostics;

public sealed class ShowImporter
{
    // The name here is what AddSource("Shows.Api") above subscribes to.
    private static readonly ActivitySource Source = new("Shows.Api");

    public async Task ImportAsync(IReadOnlyList<TvShow> shows, CancellationToken ct)
    {
        using var activity = Source.StartActivity("import shows");
        activity?.SetTag("show.count", shows.Count);

        try
        {
            foreach (var show in shows)
            {
                using var _ = Source.StartActivity("import show");
                await _repo.InsertAsync(show, ct);
            }
        }
        catch (Exception ex)
        {
            activity?.SetStatus(ActivityStatusCode.Error, ex.Message);
            activity?.AddException(ex);
            throw;
        }
    }
}
```

`StartActivity` returns null when nobody is listening, which is why every call is `activity?.`. That null check is the entire cost of instrumentation in a process with tracing turned off.

Sampling is how tracing stays affordable. Tracing every request at volume is expensive and mostly redundant; the default parent-based sampler keeps a decision consistent across a whole distributed trace, and head sampling by ratio is set with an environment variable.

```
OTEL_TRACES_SAMPLER=parentbased_traceidratio
OTEL_TRACES_SAMPLER_ARG=0.1     # 10% of traces
```

The refinement worth knowing about is **tail sampling** in the collector: buffer each trace briefly, then keep it if it was slow or errored and drop it otherwise. That keeps exactly the traces you would have wanted while discarding the boring 99%.

14.3 Logs

Logging is the signal people already have and use worst. Three changes fix most of it.

Log structured, not interpolated. The message template with named placeholders is not cosmetic - the placeholders become queryable fields.

```
// Yes: ShowId and User arrive as fields you can filter on.
logger.LogInformation("Show {ShowId} deleted by {User}", id, user);

// No: one opaque string, and a needless allocation on every call even when
// the level is disabled.
logger.LogInformation($"Show {id} deleted by {user}");
```

For hot paths, the source generator gives you the same thing with no boxing and no allocation:

```
public static partial class Log
{
    [LoggerMessage(Level = LogLevel.Information,
        Message = "Show {ShowId} deleted by {User}")]
    public static partial void ShowDeleted(this ILogger logger, long showId, string user);
}

logger.ShowDeleted(id, user);
```

Use scopes for context that spans several lines. Anything logged inside the scope carries the fields, including from code further down the stack that knows nothing about them.

```
using (logger.BeginScope(new Dictionary<string, object>
{
    ["TenantId"] = tenantId,
    ["ImportBatch"] = batchId,
}))
{
    await importer.ImportAsync(shows, ct);
}
```

Let the trace id do the joining. With logs going through the OpenTelemetry pipeline, every log record carries the `trace_id` and `span_id` of the request that produced it. That is the link that turns three tools into one workflow: alert fires on a metric, dashboard shows which route, trace shows which call was slow, log lines for that exact trace explain why. Building that link by hand with a correlation id you thread through every method is the thing you no longer have to do.

Two things to get right and then stop thinking about:

- **Levels mean something.** `Information` for events an operator would want in normal running, `Warning` for something recovered from, `Error` for a request that failed, `Critical` for the process being in trouble. If everything is `Information` the level is not carrying information. Default the framework's own categories to `Warning` or your logs are 90% ASP.NET routing chatter.
- **Never log secrets or personal data.** Connection strings, tokens, card numbers, full request bodies, whole exception objects containing user rows. Logs get shipped to third parties, indexed, and kept for a year; treat every log line as public, and see the security notes in ASP.NET Core.

14.4 Prometheus

Prometheus stores metrics as time series and pulls them from targets over HTTP. It is the default open source metrics store, and it is what Grafana was built to draw.

Two ways to get .NET metrics into it:

1. **Through the collector.** The application speaks OTLP to the OpenTelemetry Collector, and the collector exposes a Prometheus endpoint. One instrumentation path for everything, and the

application does not know Prometheus exists. This is the arrangement to prefer.

2. **Directly.** Add `OpenTelemetry.Exporter.Prometheus.AspNetCore` and call `.AddPrometheusExporter()` alongside the OTLP one, then `app.MapPrometheusScrapingEndpoint()` to serve `/metrics`. Simpler when Prometheus is all you have and all you plan to have.

```
.WithMetrics(metrics => metrics
    .AddAspNetCoreInstrumentation()
    .AddRuntimeInstrumentation()
    .AddPrometheusExporter());

app.MapPrometheusScrapingEndpoint();   // GET /metrics
```

Do not expose `/metrics` to the internet. It is an inventory of your internals - route names, dependency versions, traffic volumes. Bind it to an internal port, or restrict it in nginx as shown in Containers, nginx and Kubernetes.

Names change on the way in. OpenTelemetry's `http.server.request.duration`, measured in seconds, arrives in Prometheus as `http_server_request_duration_seconds_bucket` and friends. Dots become underscores and the unit joins the name; this trips up every first PromQL query written from the OTel docs.

14.4.1 Service discovery

Prometheus finds targets rather than being told about them, which is what makes it work in an environment where pods come and go. In Kubernetes it queries the API server; elsewhere there is DNS, file based discovery, and cloud provider integrations.

```
scrape_configs:
  - job_name: 'shows-api'
    kubernetes_sd_configs:
      - role: pod
    relabel_configs:
      # Only scrape pods that opted in with an annotation.
      - source_labels: [__meta_kubernetes_pod_annotation_prometheus_io_scrape]
        action: keep
        regex: "true"
      # Carry the namespace and pod name through as labels.
      - source_labels: [__meta_kubernetes_namespace]
        target_label: namespace
      - source_labels: [__meta_kubernetes_pod_name]
        target_label: pod
```

Exporters do the same job for things that cannot expose metrics themselves: `node_exporter` for machine metrics, `postgres_exporter`, `redis_exporter`, and `blackbox_exporter` for probing an endpoint from outside.

That last one is worth having even when everything else is instrumented, because it is the only check that tests the whole path a user takes - DNS, TLS, proxy, application - from somewhere that is not the machine you are monitoring.

```
scrape_configs:
  - job_name: 'blackbox'
    metrics_path: /probe
    params:
      module: [http_2xx]
    static_configs:
      - targets:
```

```
          - https://shows.example.com/healthz/ready
    relabel_configs:
      - source_labels: [__address__]
        target_label: __param_target
      - source_labels: [__param_target]
        target_label: instance
      - target_label: __address__
        replacement: blackbox-exporter:9115
```

14.5 Grafana

Grafana draws the dashboards, over Prometheus and most other stores. Add Prometheus as a data source at `http://prometheus:9090`, then either import a community dashboard from the dashboards library - there are good ones for ASP.NET Core and for .NET runtime metrics - or build the four panels that actually get looked at during an incident.

The **RED method** for a request driven service: rate, errors, duration. In PromQL, against the standard ASP.NET metric:

```
# Rate: requests per second, by route
sum by (http_route) (rate(http_server_request_duration_seconds_count[5m]))

# Errors: proportion of 5xx
sum(rate(http_server_request_duration_seconds_count{http_response_status_code=~"5.."}[5m]))
  / sum(rate(http_server_request_duration_seconds_count[5m]))

# Duration: 95th percentile latency, by route
histogram_quantile(0.95,
  sum by (le, http_route) (rate(http_server_request_duration_seconds_bucket[5m])))
```

Add saturation - CPU, memory, thread pool queue length, database connections in use - and you have the four golden signals on one screen. Resist the urge to add forty more panels. A dashboard nobody can read at 3am is decoration.

Grafana also reads logs from Loki, traces from Tempo and continuous-profiling data from Pyroscope, which is the free way to get the metric → trace → log → profile workflow described above in a single UI. Jaeger for traces alone and Seq for structured logs alone are both good and both simpler to run if you only need the one signal.

14.6 Alerting

An alert should mean "a human must do something now". Everything else is a dashboard or a report. Get this wrong and the team learns to ignore the channel, at which point the entire monitoring stack has negative value.

Alert on symptoms, not causes. Users care that requests are failing or slow; they do not care that CPU is at 90%, and a rule that fires on CPU will page you during every harmless batch job while missing the outage caused by a deadlock at 5% CPU.

```
groups:
  - name: shows-api
    rules:
      - alert: HighErrorRate
        expr: |
          sum(rate(http_server_request_duration_seconds_count{
```

```
            job="shows-api", http_response_status_code=~"5.."}[5m]))
        / sum(rate(http_server_request_duration_seconds_count{job="shows-api"}[5m]))
        > 0.05
    for: 10m
    labels:
      severity: page
    annotations:
      summary: "5% of requests failing for 10 minutes"
      runbook: "https://wiki.example.com/runbooks/shows-api-errors"

  - alert: LatencyRegression
    expr: |
      histogram_quantile(0.95, sum by (le) (
        rate(http_server_request_duration_seconds_bucket{job="shows-api"}[5m]))) > 1.5
    for: 15m
    labels:
      severity: ticket
```

Three details in there do most of the work:

- **`for:`** requires the condition to hold for a sustained period, which is what stops a ten second blip waking anyone.
- **`severity`** separates "wake someone" from "make a ticket". Alertmanager routes on that label. If everything is `page`, nothing is.
- **`runbook`** is a link to what to do about it. An alert without one is a puzzle handed to whoever is least equipped to solve it, at the worst possible hour.

Two rules that should exist on every service and usually do not: an alert for **no data at all** (a service that stopped reporting looks healthy to a rule that only checks error ratios), and an alert on the **certificate expiry** the blackbox exporter reports, because TLS expiry is the most predictable outage there is and still the most common.

Once the basics are in place, express the target as an **SLO** - "99.5% of requests succeed over 30 days" - and alert on the *burn rate* of the error budget rather than an instantaneous threshold. A fast burn pages immediately; a slow burn opens a ticket. It is more setup than the rules above and it is the difference between alerts that track user pain and alerts that track a number someone picked.

14.7 When it is already broken

Telemetry tells you which process is unhappy. These tools tell you what it is doing right now, and they attach to a running process without a restart, in a container, in production.

```
dotnet tool install -g dotnet-counters
dotnet tool install -g dotnet-trace
dotnet tool install -g dotnet-dump
dotnet tool install -g dotnet-gcdump
```

```
# Live counters: GC, thread pool, exception rate, request rate.
dotnet-counters monitor -p 1 --counters System.Runtime,Microsoft.AspNetCore.Hosting

# 30 seconds of CPU samples, opened in Visual Studio or PerfView or speedscope.
dotnet-trace collect -p 1 --duration 00:00:30 --format speedscope

# A full dump, for the ones that only happen at 4am.
dotnet-dump collect -p 1
```

```
dotnet-dump analyze core_20260817

# Heap only, much smaller, for "why is memory climbing".
dotnet-gcdump collect -p 1
```

The three symptoms these answer fastest:

- **Memory climbing and never falling.** `dotnet-gcdump` twice, ten minutes apart, and compare object counts. The type whose count grew is the leak, and it is usually a static collection, an event handler never unsubscribed, or an `HttpClient` per request.
- **CPU pinned at 100%.** `dotnet-trace` for thirty seconds and read the flame graph. Regular expressions, JSON serialisation and accidental `O(n²)` loops account for most of it.
- **Everything slow, CPU idle.** Thread pool starvation: synchronous blocking (`.Result`, `.Wait()`) inside async code, so requests queue for threads that are all parked. `dotnet-counters` shows the queue length climbing while CPU sits idle, which is the signature.

These tools are reactive: you run them once you already know a process is unhappy, and they only see the thirty seconds you happened to capture. **Continuous profiling** closes that gap. Grafana Pyroscope collects low-overhead CPU and allocation profiles from every instance all the time, stores them as time series the way Prometheus stores metrics, and lets you pull up the flame graph for *last Tuesday at 03:00* after the incident is over. There are two ways to deploy it. The Pyroscope .NET SDK runs as a CLR profiler and gives the full picture - CPU, wall time, allocations, lock contention and exceptions - with no application code change, but its native library and a handful of `CORECLR_*` environment variables have to be present *in the container*, either baked into the image or dropped in by an init container the way the OpenTelemetry operator injects auto-instrumentation. The genuinely host-wide option is Grafana Alloy with its eBPF profiler: one privileged DaemonSet per node samples every dotnet container with no image or environment change, at the cost of CPU and wall time only and less dependable managed stack unwinding. Because profiles carry the same trace and span ids, a slow span in Tempo links straight to the code that was running during it - the metric → trace → log → profile chain from the Grafana section, with the last hop being an actual stack.

Set `DOTNET_DiagnosticPorts` or run the tools in a sidecar to reach a process inside a container, and make sure the image is not so stripped down that it lacks the diagnostic socket. A production image you cannot attach to is a production image you cannot debug.

Chapter 15

Build Pipelines

A build pipeline is the machine that turns a commit into something you can install, and its real job is not automation for its own sake. It is answering three questions without argument: does this change build on a machine that is not yours, do the tests still pass, and what exactly is in the artifact that went to production.

Everything in this chapter serves those three. The examples are GitHub Actions and Jenkins, because between them they cover most .NET shops, but the shape - restore, build, test, publish, sign, ship - is the same in Azure DevOps, GitLab CI and TeamCity.

15.1 The shape of a .NET pipeline

Six steps, in this order, each depending on the last:

```
dotnet restore [YourSolution].slnx
dotnet build [YourSolution].slnx --no-restore -c Release
dotnet test [YourSolution].slnx --no-build -c Release
dotnet publish [YourProject] --no-build -c Release -o out
dotnet pack [YourLibrary] --no-build -c Release -o packages   # if you ship NuGet
```

The `--no-restore` and `--no-build` flags are not micro-optimisation. Without them each command silently redoes the previous one, which doubles the build time and - worse - can build with different arguments than the ones you tested, so the artifact you ship is not the artifact that passed. State the dependency once and let each step consume the previous step's output.

.NET 10 reads `.slnx`, the XML solution format, as well as the old `.sln`. New solutions should use it; it merges without conflicts, which the old format famously does not.

15.1.1 Make CI stricter than your machine

The build on a developer's machine is optimised for iteration speed. The build in CI is optimised for catching what iteration missed, and there are three settings that pay for themselves:

```
<!-- Directory.Build.props at the repo root, applying to every project. -->
<Project>
  <PropertyGroup>
    <TreatWarningsAsErrors Condition="'$(ContinuousIntegrationBuild)' == 'true'">true</TreatWarning
    <ContinuousIntegrationBuild Condition="'$(GITHUB_ACTIONS)' == 'true'">true</ContinuousIntegrati
    <!-- Deterministic paths in the PDBs, so two builds of one commit match. -->
    <Deterministic>true</Deterministic>
    <EnableNETAnalyzers>true</EnableNETAnalyzers>
```

```
    <AnalysisLevel>latest</AnalysisLevel>
  </PropertyGroup>
</Project>
```

Warnings as errors is the one people push back on, and the objection is fair for a legacy codebase where the count is in the thousands. The middle path is to promote the categories that matter first - nullable warnings, `CA2007`, obsolete APIs - and add the rest as the count comes down:

```
<WarningsAsErrors>$(WarningsAsErrors);Nullable</WarningsAsErrors>
```

Formatting belongs in the pipeline too, as a check rather than a fix, so that review comments are about the code and not the whitespace.

```
dotnet format --verify-no-changes --severity warn
```

15.1.2 Make the build reproducible

"Works in CI" is worth very little if CI means something different next week. Three files pin it down.

`global.json` pins the SDK. Without it, a runner image update moves you to a new SDK mid-sprint and something subtle changes.

```
{
  "sdk": {
    "version": "10.0.100",
    "rollForward": "latestFeature"
  }
}
```

`Directory.Packages.props` puts every package version in one file, and stops the situation where three projects reference three versions of the same library and the winner is decided by build order.

```
<Project>
  <PropertyGroup>
    <ManagePackageVersionsCentrally>true</ManagePackageVersionsCentrally>
    <CentralPackageTransitivePinningEnabled>true</CentralPackageTransitivePinningEnabled>
  </PropertyGroup>
  <ItemGroup>
    <PackageVersion Include="Dapper" Version="2.1.66" />
    <PackageVersion Include="Microsoft.Data.Sqlite" Version="10.0.0" />
    <PackageVersion Include="Npgsql" Version="10.0.0" />
  </ItemGroup>
</Project>
```

Projects then reference packages without a version:

```
<ItemGroup>
  <PackageReference Include="Dapper" />
</ItemGroup>
```

`packages.lock.json` pins the transitive graph, the part central versions do not cover. Enable it once, commit the files, and have CI refuse to restore anything the lock file does not name.

```
<RestorePackagesWithLockFile>true</RestorePackagesWithLockFile>
```

```
dotnet restore --locked-mode
```

That last flag is the point: it fails the build if a dependency resolved differently than when the lock file was written, rather than quietly shipping a version nobody chose.

15.2 GitHub Actions

Workflows live in `.github/workflows`. The file name does not matter; the `name:` inside it is what appears in the UI.

```yaml
name: .NET

on:
  push:
    branches: [main]
  pull_request:
    branches: [main]

# Cancel superseded runs on a branch, but never a run on main.
concurrency:
  group: ${{ github.workflow }}-${{ github.ref }}
  cancel-in-progress: ${{ github.ref != 'refs/heads/main' }}

# Least privilege by default; jobs opt into more.
permissions:
  contents: read

jobs:
  build:
    runs-on: ubuntu-latest
    steps:
      - uses: actions/checkout@v4

      - name: Setup .NET
        uses: actions/setup-dotnet@v4
        with:
          dotnet-version: 10.0.x
          cache: true                       # caches ~/.nuget/packages
          cache-dependency-path: '**/packages.lock.json'

      - name: Restore
        run: dotnet restore [YourSolution].slnx --locked-mode

      - name: Format check
        run: dotnet format --verify-no-changes --severity warn --no-restore

      - name: Build
        run: dotnet build [YourSolution].slnx --no-restore -c Release

      - name: Test
        run: >-
          dotnet test [YourSolution].slnx --no-build -c Release
          --collect:"XPlat Code Coverage" --logger:"trx"

      - name: Publish test results
        uses: dorny/test-reporter@v2
        if: success() || failure()      # report failures too, or it is useless
        with:
          name: unit tests
          path: "**/TestResults/*.trx"
```

```
          reporter: dotnet-trx
```

The NuGet cache is the single biggest speed win available and costs one line. `if: success() || failure()` on the reporting step is the second: a test report that only publishes when tests pass tells you nothing you did not already know.

15.2.1 Building for several platforms

The three near-identical jobs this chapter used to carry are one job with a matrix. Less to keep in sync, and adding `linux-arm64` becomes one line.

```yaml
jobs:
  publish:
    runs-on: ${{ matrix.os }}
    strategy:
      fail-fast: false        # one platform failing should not hide the others
      matrix:
        include:
          - os: ubuntu-latest
            rid: linux-x64
          - os: ubuntu-24.04-arm
            rid: linux-arm64
          - os: windows-latest
            rid: win-x64
          - os: macos-latest
            rid: osx-arm64
    steps:
      - uses: actions/checkout@v4
      - uses: actions/setup-dotnet@v4
        with:
          dotnet-version: 10.0.x

      - name: Publish
        run: >-
          dotnet publish [YourProject] -c Release -r ${{ matrix.rid }}
          --self-contained true
          -p:PublishSingleFile=true
          -p:EnableCompressionInSingleFile=true
          -p:PublishReadyToRun=true
          -p:Version=${{ github.ref_type == 'tag' && github.ref_name || '0.0.0-ci' }}
          -o publish/${{ matrix.rid }}

      - uses: actions/upload-artifact@v4
        with:
          name: [YourProject]-${{ matrix.rid }}
          path: publish/${{ matrix.rid }}
          retention-days: 7
```

Cross compiling matters here: a `linux-arm64` build runs on any runner, but `PublishReadyToRun` needs a matching host, which is why arm64 gets its own runner rather than a flag on the x64 one.

Self contained or framework dependent? Self contained ships the runtime with the app: about 70MB, no prerequisites, and you own patching it. Framework dependent is a few MB and needs the right runtime installed. For a desktop tool handed to users, self contained. For a container, framework dependent - the base image already has the runtime and gets patched when you rebuild.

15.2.2 Versioning artifacts

An artifact that cannot be traced to a commit is a liability. The cheap version is the snippet above: tags produce a real version, everything else produces `0.0.0-ci`. The better version derives it from git history with MinVer or Nerdbank.GitVersioning.

```
dotnet add package MinVer
```

MinVer walks back to the nearest tag, so `v1.4.0` plus two commits builds as `1.4.1-alpha.0.2`, with no version number in any file to forget to bump. Set `fetch-depth: 0` on the checkout step or it cannot see the tags.

Whichever you use, stamp the commit into the assembly so a support ticket can be answered from the binary:

```
<PropertyGroup>
  <SourceRevisionId>$(GITHUB_SHA)</SourceRevisionId>
  <RepositoryUrl>https://github.com/majorsilence/[YourProject]</RepositoryUrl>
  <PublishRepositoryUrl>true</PublishRepositoryUrl>
  <EmbedUntrackedSources>true</EmbedUntrackedSources>
  <IncludeSymbols>true</IncludeSymbols>
  <SymbolPackageFormat>snupkg</SymbolPackageFormat>
</PropertyGroup>
```

15.2.3 Publishing a NuGet package

```
  pack:
    needs: build
    if: github.ref_type == 'tag'
    runs-on: ubuntu-latest
    steps:
      - uses: actions/checkout@v4
        with:
          fetch-depth: 0        # MinVer needs the tag history
      - uses: actions/setup-dotnet@v4
        with:
          dotnet-version: 10.0.x

      - run: dotnet pack [YourLibrary] -c Release -o packages

      - name: Push to nuget.org
        run: >-
          dotnet nuget push "packages/*.nupkg"
          --api-key ${{ secrets.NUGET_API_KEY }}
          --source https://api.nuget.org/v3/index.json
          --skip-duplicate
```

`--skip-duplicate` stops a re-run of the job from failing on a version that is already published. Push the `.snupkg` symbols too; six months from now a stack trace with line numbers is worth the thirty seconds it took.

15.2.4 Containers

The SDK builds a container image without a Dockerfile, which for a plain ASP.NET Core service is enough and removes a file that tends to drift:

```
dotnet publish [YourProject] -c Release \
  -p:PublishProfile=DefaultContainer \
  -p:ContainerRegistry=ghcr.io \
  -p:ContainerRepository=majorsilence/shows-api \
  -p:ContainerImageTag=1.4.0
```

When you need control over the image - extra native packages, a non-root user, a multi-stage build - use the Dockerfile from Containers, nginx and Kubernetes with buildx, and produce an SBOM and provenance attestation while you are there.

```
  image:
    needs: build
    runs-on: ubuntu-latest
    permissions:
      contents: read
      packages: write
      id-token: write          # for attestations
    steps:
      - uses: actions/checkout@v4
      - uses: docker/setup-buildx-action@v3
      - uses: docker/login-action@v3
        with:
          registry: ghcr.io
          username: ${{ github.actor }}
          password: ${{ secrets.GITHUB_TOKEN }}

      - uses: docker/build-push-action@v6
        with:
          push: true
          tags: ghcr.io/majorsilence/shows-api:${{ github.sha }}
          sbom: true
          provenance: mode=max
          cache-from: type=gha
          cache-to: type=gha,mode=max
```

Tag with the commit sha, not just `latest`. A rollback needs a name for the exact image that worked, and `latest` is not a name - it is a moving pointer that makes "which build is running in production" unanswerable.

15.2.5 Building Linux packages

For a tool people install rather than a service you host, `fpm` turns a published folder into a `.deb` or `.rpm`.

```
jobs:
  package:
    runs-on: ubuntu-latest
    env:
      SOLUTION_NAME: "YourSolution"
      DEVELOPER: "majorsilence"
      PROJECT: "Your Project"
      MAIN_EXE: "The Main Exe filename"
      PRODUCT: "product name"
      MAINTAINER: "Your Name <your@example.com>"
      VERSION: "1.0.0"
    steps:
```

```
    - uses: actions/checkout@v4
    - uses: actions/setup-dotnet@v4
      with:
        dotnet-version: 10.0.x
    - name: Build
      run: |
        dotnet restore ${{ env.SOLUTION_NAME }}.slnx
        dotnet build -c Release ${{ env.SOLUTION_NAME }}.slnx --no-restore
        dotnet publish -c Release -r linux-x64 --self-contained true
    - name: Prep for fpm
      run: |
        mkdir -p build/linux/opt/${{ env.DEVELOPER }}/${{ env.PROJECT }}
        cp -r ${{ env.PROJECT }}/bin/Release/net10.0/linux-x64/publish/* build/linux/opt/${{ env.DE
        chmod +x build/linux/opt/${{ env.DEVELOPER }}/${{ env.PROJECT }}/${{ env.MAIN_EXE }}
        mkdir -p build/linux/usr/bin
        cat > build/linux/usr/bin/${{ env.DEVELOPER }}-${{ env.PRODUCT }} << 'EOF'
        #!/bin/sh
        /opt/${{ env.DEVELOPER }}/${{ env.PROJECT }}/${{ env.MAIN_EXE }} "$@"
        rc=$?
        exit $rc
        EOF
        chmod +x build/linux/usr/bin/${{ env.DEVELOPER }}-${{ env.PRODUCT }}
    - name: Build deb package
      run: |
        cd build/linux
        fpm -s dir -t deb \
        --name ${{ env.DEVELOPER }}-${{ env.PRODUCT }} \
        --version ${{ env.VERSION }} \
        --description "${{ env.DEVELOPER }} ${{ env.PRODUCT }} tool." \
        --maintainer "${{ env.MAINTAINER }}" \
        --license "MIT" \
        --architecture all \
        --deb-no-default-config-files \
        --url "https://github.com/${{ env.DEVELOPER }}/${{ env.PROJECT }}" \
        ./
```

Swap `-t deb` for `-t rpm` and the same folder produces a Fedora package. Windows installers are a separate problem: WiX or Inno Setup for an MSI, MSIX for the Store, and the binaries need signing - see the notes on code signing certificates in Desktop User Interfaces.

15.3 Tests that need a database

Unit tests run anywhere. The tests that catch real bugs usually need PostgreSQL, SQL Server or Redis, and there are two honest ways to give them one.

Service containers are the simplest: the runner starts the container, the test connects to it on localhost.

```
    services:
      postgres:
        image: postgres:17
        env:
          POSTGRES_PASSWORD: testing
        ports: ["5432:5432"]
        options: >-
```

```
          --health-cmd pg_isready --health-interval 5s
          --health-timeout 5s --health-retries 10
```

The health options matter. Without them the test step starts before PostgreSQL is accepting connections and the failure looks like a flaky test rather than a race.

Testcontainers puts the same thing in the test code, which means it also works when a developer runs the suite locally - no docker-compose to remember, no shared database to corrupt.

```
dotnet add package Testcontainers.PostgreSql
```

```
[TestFixture]
public class ShowRepoTests
{
    private PostgreSqlContainer _db = null!;

    [OneTimeSetUp]
    public async Task StartDatabase()
    {
        _db = new PostgreSqlBuilder()
            .WithImage("postgres:17")
            .Build();

        await _db.StartAsync();
        await Migrate(_db.GetConnectionString());
    }

    [OneTimeTearDown]
    public async Task StopDatabase() => await _db.DisposeAsync();

    [Test]
    public async Task InsertThenGetRoundTrips()
    {
        var repo = new ShowRepo(_db.GetConnectionString());
        var id = await repo.InsertAsync(new TvShow { ShowName = "Star Trek" });

        var show = await repo.GetShowAsync(id);

        Assert.That(show!.ShowName, Is.EqualTo("Star Trek"));
    }
}
```

It needs Docker on the machine running the tests, which every GitHub-hosted Linux runner has. The payoff is that the SQL is tested against the engine it will run on, rather than against SQLite pretending to be PostgreSQL.

15.3.1 Coverage that means something

`--collect:"XPlat Code Coverage"` writes Cobertura XML. Turning that into a number and a trend takes one more tool.

```
dotnet tool install -g dotnet-reportgenerator-globaltool

reportgenerator -reports:"**/coverage.cobertura.xml" \
  -targetdir:coverage -reporttypes:"Html;MarkdownSummaryGithub"
```

```
cat coverage/SummaryGithub.md >> $GITHUB_STEP_SUMMARY
```

Setting a hard coverage gate is a decision to make carefully. A threshold on **new code** in a pull request is useful and rarely gamed. A global "80% or the build fails" on an old codebase mostly produces tests that assert nothing while executing a lot of lines.

15.4 Security in the pipeline

The pipeline has credentials to your registry, your cloud account and your package feed. It is a production system, and these are the cheap controls that matter most.

Know what you depend on. One command, no packages to install:

```
dotnet list package --vulnerable --include-transitive
dotnet list package --deprecated
```

Run it in CI and fail on anything with a known critical advisory. Add Dependabot or Renovate to open the update PRs, grouped weekly so they are reviewable rather than a hundred separate ones nobody reads.

Do not store long lived cloud credentials. GitHub can mint a short lived token per run via OIDC, which the cloud provider trusts. A leaked log line then leaks something that expired an hour ago rather than a key that works until someone notices.

```
    permissions:
      id-token: write
      contents: read
```

Pin third party actions to a commit sha. A tag is mutable; `@v2` can become different code tomorrow without your involvement, and supply chain attacks against popular actions have happened.

```
      - uses: dorny/test-reporter@31a54ee7ebcacc03a09ea97a7e5465a47b84aea5   # v2.1.0
```

Set permissions explicitly. `permissions: contents: read` at the top of the workflow, and each job adding only what it needs. The default token can otherwise push to your repository.

Static analysis. CodeQL has good C# support and runs as an action; add it on a schedule as well as on pull requests, because new rules find old bugs. `dotnet format --verify-no-changes` and the .NET analyzers above catch a different class of problem earlier and faster.

Ship an SBOM with anything you distribute. `docker buildx` produces one for images, as shown above; for a published application, `dotnet CycloneDX` produces one from the project graph. When the next widely used library turns out to be compromised, an SBOM is the difference between answering "are we affected" in minutes and in days.

15.5 Deployment

Getting a tested artifact onto a server is the last step, and the ordering questions are where the outages live.

Database migrations run before the new code, and must work with the old code. During any rolling deploy both versions run at once. That forces expand and contract: add the nullable column, deploy code that writes both, backfill, deploy code that reads the new one, drop the old column in a later release. A migration that renames a column in one step will take the site down in the window between the two, no matter how good the pipeline is. See Data Access in .NET for the migration tooling itself.

Deploy to an environment with a gate. GitHub environments carry their own secrets and optional required reviewers, so production credentials do not exist in a pull request build.

```
  deploy:
    needs: [build, image]
    if: github.ref == 'refs/heads/main'
    runs-on: ubuntu-latest
    environment:
      name: production
      url: https://shows.example.com
    steps:
      - name: Roll out
        run: kubectl set image deployment/shows-api api=ghcr.io/majorsilence/shows-api:${{ github.sha

      - name: Wait for the rollout
        run: kubectl rollout status deployment/shows-api --timeout=5m

      - name: Smoke test
        run: |
          curl --fail --retry 10 --retry-delay 5 --retry-all-errors \
            https://shows.example.com/healthz/ready
```

A deploy that does not verify itself is not finished. `kubectl rollout status` fails if the new pods never become ready, and the smoke test against `/healthz/ready` from Monitoring and Observability catches the case where they are ready but wrong. Both are two lines, and together they turn a silent bad deploy into a red build.

Rollback is `kubectl rollout undo`, or redeploying the previous sha. Both need the previous image to still exist, which is the practical argument against a registry retention policy that deletes anything from last week.

15.6 Jenkins

Jenkins remains common where builds must run inside a network that GitHub's runners cannot reach, or on hardware nobody is going to move. Installation instructions are at jenkins.io/download.

```
curl -fsSL https://pkg.jenkins.io/debian-stable/jenkins.io.key | sudo tee \
    /usr/share/keyrings/jenkins-keyring.asc > /dev/null

echo deb [signed-by=/usr/share/keyrings/jenkins-keyring.asc] \
    https://pkg.jenkins.io/debian-stable binary/ | sudo tee \
    /etc/apt/sources.list.d/jenkins.list > /dev/null

sudo apt-get update
sudo apt-get install jenkins openjdk-21-jdk-headless docker.io -y
sudo usermod -a -G docker jenkins
```

15.6.1 Plugins

- docker-workflow - run build steps inside a container
- github-branch-source - multibranch pipelines from a repository
- nunit - test results
- coverage - Cobertura coverage reports

15.6.2 A .NET pipeline

Save this as `Jenkinsfile` in the root of the repository. Running the build inside the official SDK image means the agent needs Docker and nothing else - no .NET installs to keep in step across a fleet of build machines.

```
pipeline {
    agent none
    options {
        timeout(time: 30, unit: 'MINUTES')
        buildDiscarder(logRotator(numToKeepStr: '30'))
    }
    environment {
        DOTNET_CLI_HOME = "/tmp/DOTNET_CLI_HOME"
        DOTNET_CLI_TELEMETRY_OPTOUT = "1"
        DOTNET_NOLOGO = "1"
    }
    stages {
        stage('build and test') {
            agent {
                docker {
                    image 'mcr.microsoft.com/dotnet/sdk:10.0'
                    // Reuse the NuGet cache between builds on this agent.
                    args '-v $HOME/.nuget/packages:/tmp/nuget'
                }
            }
            environment {
                NUGET_PACKAGES = "/tmp/nuget"
            }
            steps {
                sh '''
                dotnet restore [YourSolution].slnx --locked-mode
                dotnet build [YourSolution].slnx --no-restore -c Release
                dotnet test [YourSolution].slnx --no-build -c Release \
                    --collect:"XPlat Code Coverage" --logger:"nunit"
                '''
            }
            post {
                always {
                    nunit testResultsPattern: '**/TestResults/*.xml'
                    recordCoverage(tools: [[parser: 'COBERTURA',
                        pattern: '**/TestResults/**/*cobertura.xml']])
                }
            }
        }
    }
}
```

More examples in Jenkins and pipelines, Jenkinsfile.

15.7 What good looks like

A pipeline worth having, in the order to build it:

1. Every push builds and tests, and a failure blocks the merge.

2. Restore is locked and the SDK is pinned, so the build means the same thing next month.
3. Tests that need a database get a real one, from a container.
4. Test results and coverage are published where a reviewer sees them without digging through logs.
5. Artifacts are versioned from git and tagged with the commit sha.
6. Dependencies are scanned, and updates arrive as reviewable pull requests.
7. Deployment is gated by an environment, verified by a health check, and reversible by name.
8. The whole thing finishes in under ten minutes, because a pipeline slower than a developer's patience gets worked around.

Appendix A

Git Clients

Github new repo example.

```
mkdir your_repo
cd your_repo
echo "" >> README.md
git init
git add README.md
git commit -m "first commit"
git branch -M main
git remote add origin git@github.com:YOUR_USERNAME/YOUR_REPO.git
git push -u origin main
```

Push an existing local repo to a new github repo.

```
git remote add origin git@github.com:YOUR_USERNAME/YOUR_REPO.git
git branch -M main
git push -u origin main
```

Git, show current branch.

```
git branch --show-current
```

Git, show remotes.

```
git branch --remotes
```

Git commit changes.

```
git commit -m "hello world"
```

Git pull/rebase from

```
git pull --rebase
```

Git pull from remote and branch.

```
git pull --rebase upstream main
```

A.1 Git Visual Studio

About Git in Visual Studio

A.2 Git Rider

How to efficiently use Git integration in JetBrains Rider

A.3 Tortoise Git

The Power of Git – in a Windows Shell

Tortoise Git - windows shell git integration

A.4 Github Desktop

Experience Git without the struggle

GitHub Desktop