
Bringing C# nullability into existing code
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JET BRAINS

Agenda

- Nullable reference types in C#
- Internals of C# nullable reference types
- Annotating your C# code
- Techniques and tools to update your project


Nullable reference types in C#

Reference types, value types, and `null`

What will be the output of this code?

```
string s = GetValue();
Console.WriteLine($"Length of '{s}': {s.Length}");

string GetValue() => null;
```

```
Unhandled exception. System.NullReferenceException:
Object reference not set to an instance of an object.
   at Program.<Main>$(String[] args) in Program.cs:line 2
```

Add a check for `null`

```
string s = GetValue();
Console.WriteLine(s != null
    ? $"Length of '{s}': {s.Length}"
    : "String is null.");

string GetValue() => null;
```

How do you know you need a check?

- For reference types, not particularly clear…
- For value types, easy!
  `int? bool? long? decimal? DateTime?`
- `?` denotes `null` is possible

Note: value types can't *really* be `null`:
compiler magic converts to `Nullable<T>`

Clear intent: `?` tells you if `null` is possible

Reference types

```
string s = GetValue();
Console.WriteLine(s != null
    ? $"Length of '{s}': {s.Length}"
    : "String is null.");

string GetValue() => null;
```

Value types

```
DateTime? s = GetValue();
Console.WriteLine(s.HasValue
    ? $"The date is: {s.Value:O}"
    : "No date was given.");

DateTime? GetValue() => null;
```

What are nullable reference types (NRT)?

Nullable reference types (NRT)

- Have always been a part of C#: every reference type is nullable
- C#8+ nullable reference types flip the idea:
  - Non-nullable by default
  - Syntax to annotate a reference type as nullable

- What will be the output of this code?

```
string s = GetValue();
Console.WriteLine($"Length of '{s}': {s.Length}");
```

```
Unhandled exception. System.NullReferenceException:
Object reference not set to an instance of an object.
   at Program.<Main>$(String[] args) in Program.cs:line 2
```

Nullable reference types (NRT)

```
string s = GetValue();
Console.WriteLine($"Length of '{s}': {s.Length}");

string? GetValue() => null;
```

- The above code will emit compiler warnings
  - CS8600 - Converting null literal or possible null value to non-nullable type.
  - CS8602 - Dereference of a possibly null reference.
- Your IDE will show them, too

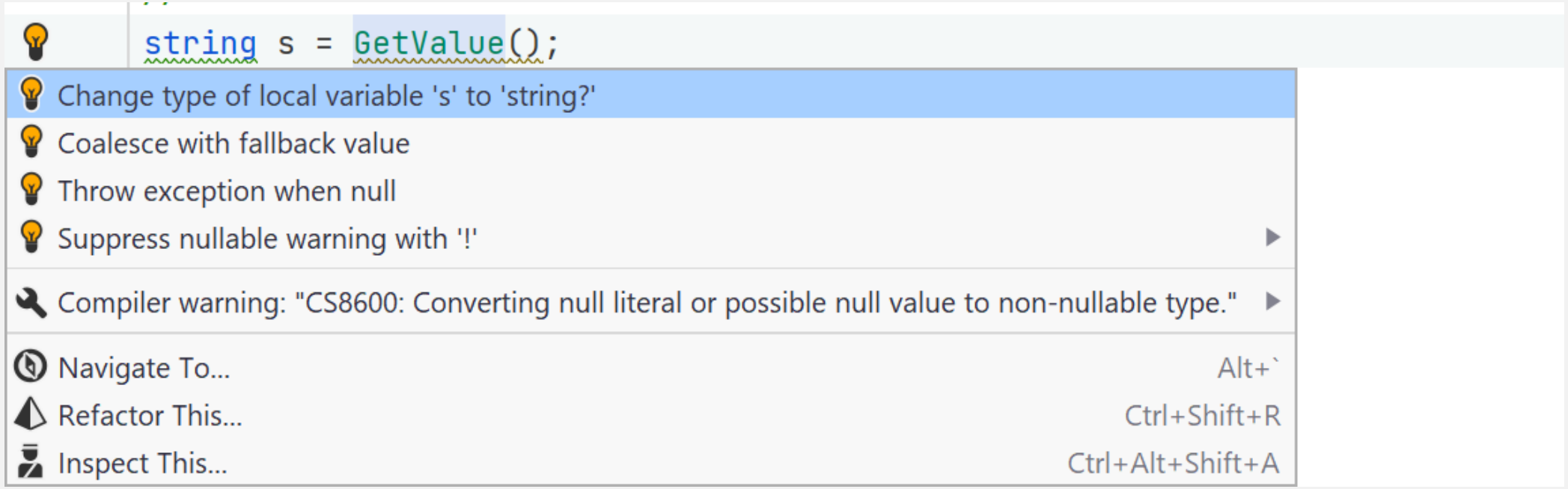
```
Console.WriteLine($"Length of '{s}': {s.Length}");
```

Dereference of a possibly null reference

local variable string s

Nullable reference types (NRT)

- C#8+ nullable reference types are just *annotations*
- Compiler and IDE help you detect potential `null` values
- Design-time and compile-time



Flow analysis

Flow analysis

Demo

Flow analysis

- IDE and compiler analyze code flow
  - Code path analysis determines warning/no warning
- Using `var` is always considered nullable
  - Until flow analysis determines otherwise
- The null-coalescing / null-forgiving operator (“dammit”)
  - Suppress warnings, postfix expression with `!`
  - May help with directing flow analysis (e.g. while migrating to NRT)…
  - …but should be considered an **antipattern**.

Summary: Nullable reference types in C#

- No runtime safety
- Design-time and compile-time help
  to determine if a variable may be `null` before dereferencing it
- Give better static flow analysis on your code
  - Your null checks will help flow analysis
  - Null-forgiving operator may help if really needed
    - But it is an **antipattern**!

Under the hood

Reference types vs. value types

- Value type: compiler magic to `Nullable<T>`
- Reference type: always nullable

- How do compiler and IDE know about reference type nullability?

Pre-C#8 code

```
#nullable disable
string GetString1() => "";


.method private hidebysig instance string
  GetString1() cil managed
{
  .maxstack 8

  IL_0000: ldstr        ""
  IL_0005: ret

}
```

Pre-C#8 code

```
#nullable disable
string GetString1() => "";
```

```
.method private hidebysig instance string
  GetString1() cil managed
{
  .maxstack 8

  IL_0000: ldstr        ""
  IL_0005: ret

}
```

C#8+

```
#nullable enable
string? GetString2() => "";
```

```
.method private hidebysig instance string
  GetString2() cil managed
{
  .custom instance void
System.Runtime.CompilerServices.NullableContextAttribute::.ctor([in] unsigned int8)
    = (01 00 02 00 00 ) // .....
    // unsigned int8(2) // 0x02
  .maxstack 8

  IL_0000: ldstr       ""
  IL_0005: ret

}
```

C#8+

```
#nullable enable
string? GetString2() => "";
```

```
.method private hidebysig instance string
  GetString2() cil managed
{
  .custom instance void
System.Runtime.CompilerServices.NullableContextAttribute::.ctor([in] unsigned int8)
    = (01 00 02 00 00 ) // .....
    // unsigned int8(2) // 0x02
  .maxstack 8

  IL_0000: ldstr       ""
  IL_0005: ret

}
```

Information for flow analysis

```
 .custom instance void
System.Runtime.CompilerServices.NullableContextAttribute::.ctor([in] unsigned int8)
    = (01 00 02 00 00 ) // .....
    // unsigned int8(2) // 0x02
```

- Oblivious: 0
  - Default, pre-C#8 behaviour (everything is maybe null)
- Not annotated: 1
  - Every reference type is non-nullable by default
- Annotated: 2
  - Every reference type has an implicit ?

More attributes!

```
#nullable enable
public string GetString3(string? a, string b, string? c) => "";
```

```
.method public hidebysig instance string GetString3(string a, string b, string c)
cil managed
{
  .custom instance void NullableContextAttribute::.ctor([in] unsigned int8)
    = (01 00 01 00 00 ) // int8(1) - by default treat ref. types as not annotated
  .param [1]
    .custom instance void NullableAttribute::.ctor([in] unsigned int8)
      = (01 00 02 00 00 ) // int8(2) - treat param[1] as annotated
  .param [3]
    .custom instance void NullableAttribute::.ctor([in] unsigned int8)
      = (01 00 02 00 00 ) // int8(2) - treat param[3] as annotated
  .maxstack 8
```

More attributes!

```
#nullable enable
public string GetString3(string? a, string b, string? c) => "";
```

```
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  .maxstack 8
```

More attributes!

```
#nullable enable
public string GetString3(string? a, string b, string? c) => "";
```

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.method public hidebysig instance string GetString3(string a, string b, string c)
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    = (01 00 01 00 00 ) // int8(1) - by default treat ref. types as not annotated
  .param [1]
    .custom instance void NullableAttribute::.ctor([in] unsigned int8)
      = (01 00 02 00 00 ) // int8(2) - treat param[1] as annotated
  .param [3]
    .custom instance void NullableAttribute::.ctor([in] unsigned int8)
      = (01 00 02 00 00 ) // int8(2) - treat param[3] as annotated
  .maxstack 8
```

Information for flow analysis

- Default for method: `NullableContextAttribute`
- Per-parameter overrides: `NullableAttribute`

- C# compiler tries to emit as few attributes as possible
  - Default that applies to most parameters
  - Overrides to that default where needed
  - Reduce overhead when analyzing code during compilation or in IDE

How do you want to surface NRT?

- Nullable *annotation* context
- In code, using `#nullable` *`value`*
- In project file `<Nullable>`*`value`*`</Nullable>`
- Possible values:
  - `disable` - pre-C# 8.0 behavior (no NRT)
  - `enable` - all analysis and language features
  - `warnings` - all analysis, and warnings when code might dereference null
  - `annotations` - no analysis, but lets you use `?`

Which annotation context to use?

- New projects: enable it.
- Migration: “It depends” 🤷
  - Disable as the default, enable file-per-file until done
  - Enable as the default, live with many warnings as you go through
  - Warnings as the default, enable file-per-file until done
    - See warnings where you can improve
  - Annotations as the default
    - Allow adding ?, but no real benefit.

Summary: Nullable reference types in C#

- Nullable context: what the compiler emits and consumes
- Nullable annotation context: what you want to surface
  - `enable` by default for new projects
  - `disable` by default for existing, gradual `#nullable enable`

Annotating your C# code

Is ? enough…

```
#nullable enable

public static string? Slugify(string? value)
{
    if (value == null)
    {
        return null;
    }

    return value.Replace(" ", "-").ToLowerInvariant();
}
```

```
var slug :string? = Slugify("this is fine");
Console.WriteLine(slug.Length);
```

Dereference of a possibly null reference

Is ? enough…

```
public static string? Slugify(string? value)
```

- Returns a non-null string when a non-null parameter is passed
- Returns a null string when a null parameter is passed

Fine-grained annotations!

```
[return: NotNullIfNotNull("value")]
public static string? Slugify(string? value)
```

```
var slug1 :string? = Slugify(null);
var slug2 :string  = Slugify("this is fine");

Console.WriteLine(slug1.Length);
Console.WriteLine(slug2.Length);
```

Fine-grained annotations!

```
public static bool IsNullOrEmpty(
    [NotNullWhen(false)] string? value)
{
    return value == null || 0 == value.Length;
}
```

```
var s :string? = DateTime.Now.Day == 1 ? "" : null;

Console.WriteLine(s.Length);

if (string.IsNullOrEmpty(s)) return;

Console.WriteLine(s.Length);
```

Fine-grained annotations!

- Preconditions
  - When writing to a parameter, field, or property setter
- Postconditions
  - When reading from a field, property or return value
- Conditional postconditions
  - Make arguments dependent on return value
- Failure conditions
  - Further analysis is not needed

https://docs.microsoft.com/en-us/dotnet/csharp/language-reference/attributes/nullable-analysis

Annotations

Demo

JetBrains.Annotations

- Many libraries ship them, can help with migration
  - Entity Framework Core, Unity, Hangfire, …
- More powerful, but only in ReSharper and JetBrains Rider
  - `[CanBeNull]`, `[NotNull]`
  - `[ItemNotNull]`, `[ItemCanBeNull]`
  - `[ContractAnnotation]`

```
[ContractAnnotation("json:null => false,person:null")]
public bool TryDeserialize(string? json, out Person? person)
{
    // ...
}
```

https://www.jetbrains.com/help/resharper/Reference__Code_Annotation_Attributes.html

Nullability and generics

- Use ? where needed

```
List<string>
List<string?>
List<string?>?
```

- Use annotations

```
[return: MaybeNull]
public T Find<T>(IEnumerable<T> sequence, Func<T, bool> predicate)
```

- Use `notnull` constraint

```
public static void WriteToConsole<T>(T item) where T : notnull

WriteToConsole(null); // CS8714 doesn't match 'notnull' constraint
```

Referenced code, libraries & frameworks

- Using NRT is easy if your dependencies use it
  - .NET BCL is annotated
  - Many OSS libraries are annotated
- Annotate your own code for dependents
  - Provide design-time and compile-time hints
- Remember NRT are not runtime safety!
  - Consider `null` checks for code that others consume
  - They may not use C#, or have `#nullable disable`

Summary: Annotating your C# code

- There are more annotations than ?
- Clearly communicates intent with flow analyzer
- Compiler annotations and JetBrains.Annotations
- You may still need null checks for your libraries


Techniques and tools
to update your C# project

Default nullable annotation context

- `#nullable enable/disable/warnings/annotations`

- New projects: enable it
- Existing projects:
  - Small: enable it and plow through
  - Large:
    - Enable file by file
    - Combine with warnings at project level

Start at the center and work outwards

- Classes with few or zero dependencies on others
  - Often: DTOs / POCOs
- Typically used by many dependents
  - Small change flows to many places

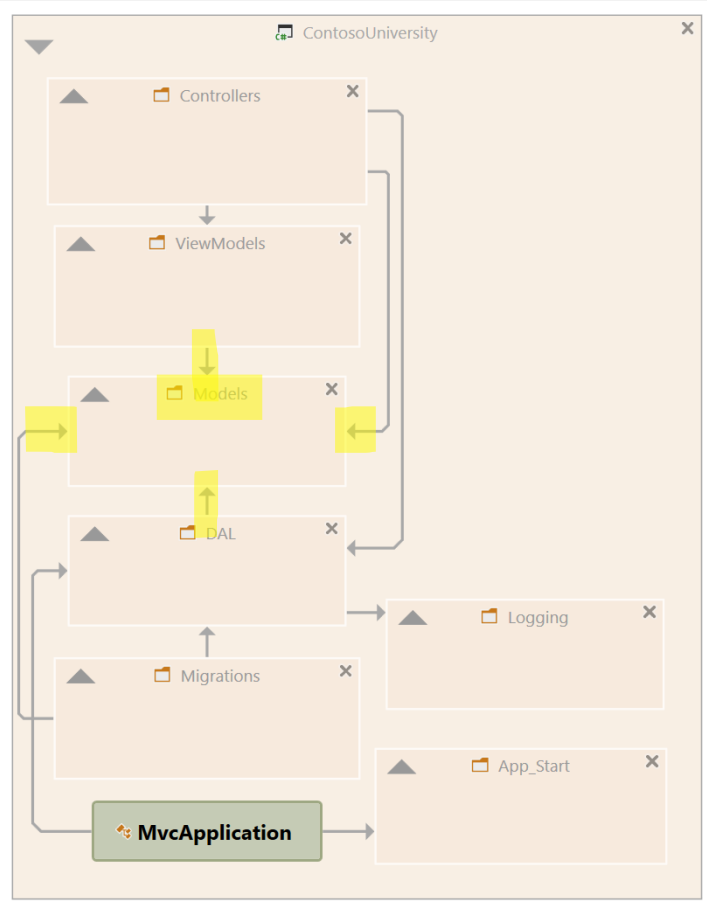
Start at the center and work outwards

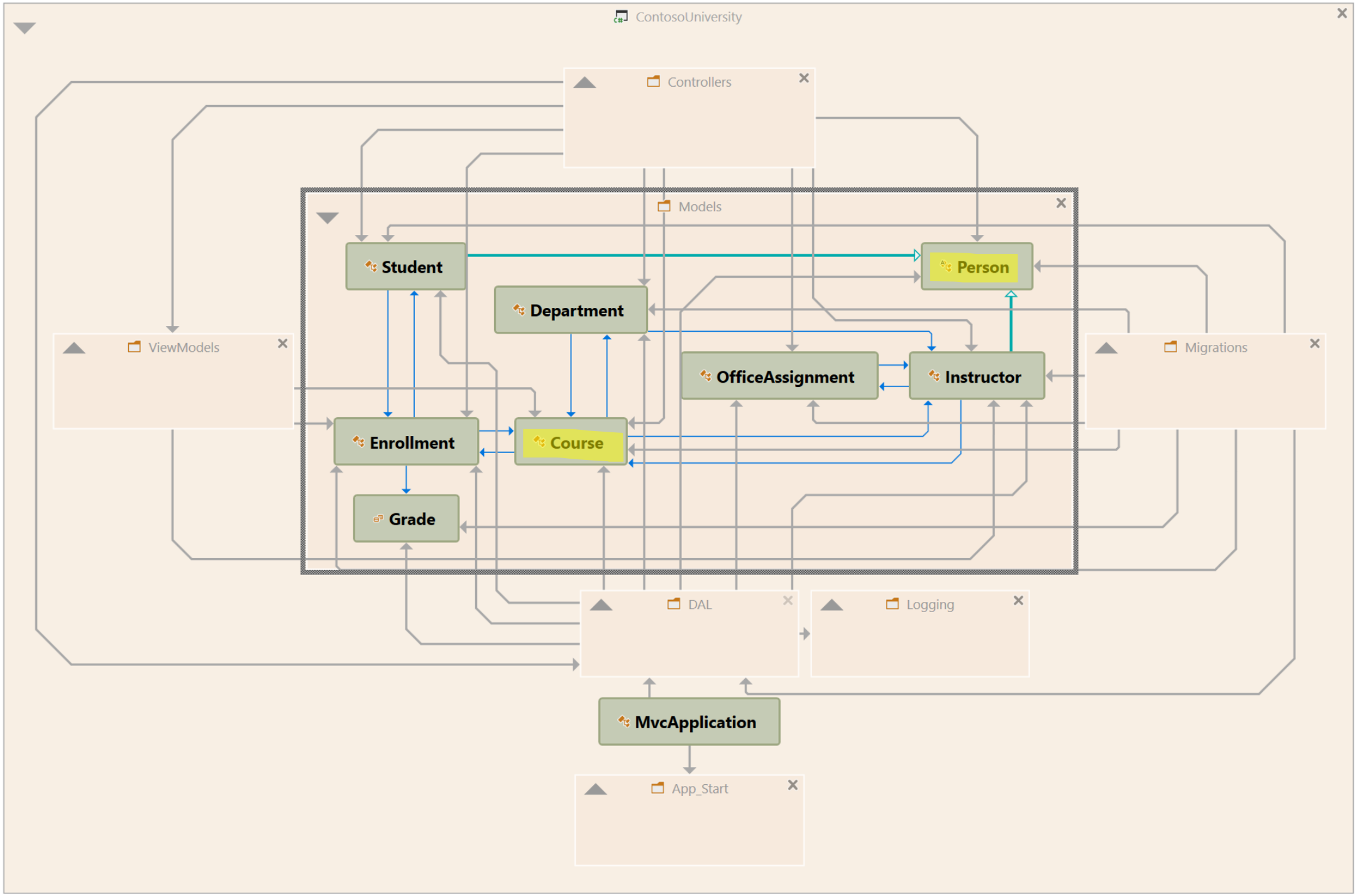
ReSharper Type Hierarchy Diagram

Visual Studio architecture tools

NDepend

…




ContosoUniversity
Controllers
Models
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ViewModels
Migrations
OfficeAssignment
Instructor
Enrollment
Course
Grade
DAL
Logging
MvcApplication
App_Start

Per class…

- Enable NRT (`#nullable enable`)
- For every property and constructor parameter
  - Find all *write* usages
  - If potentially set to `null`, annotating with `?` is needed

Adding #nullable enable

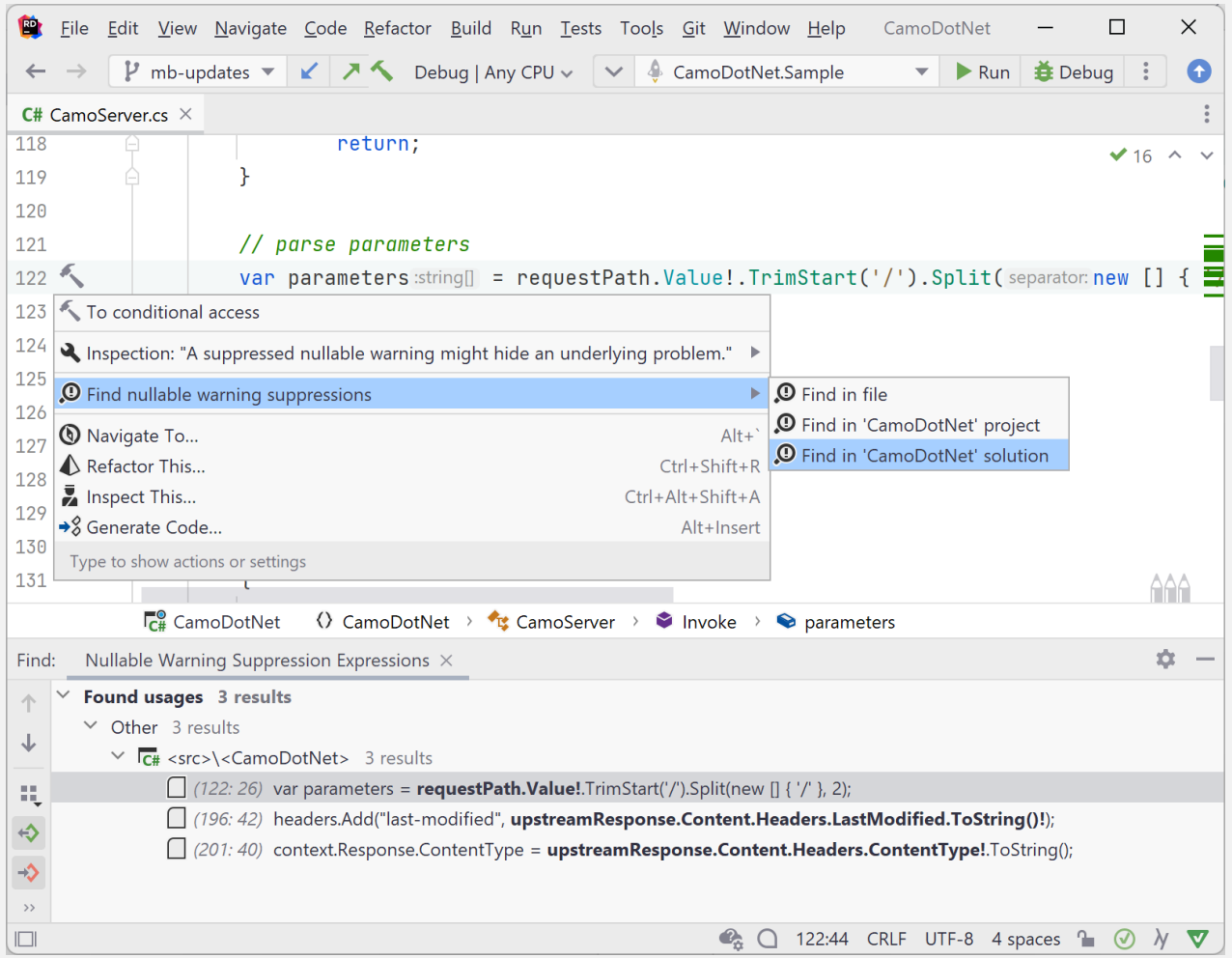
Demo

Annotate, and redesign!

- Sometimes redesign makes more sense
- Nullable annotations surface through code base (like `async`/`await`)
  - Do you want to check for null at every current and future usage?
  - Or do it once and return a "null object"?
- "It depends"

Suppressions should be temporary

- Temporarily disable flow analysis
  - “what if this was non-null”?
- Remove suppressions



Don’t be afraid of `null`

- ✅ Gain more confidence in compiler/IDE flow analysis
- ⛔ Completely get rid of all `null` usages in code

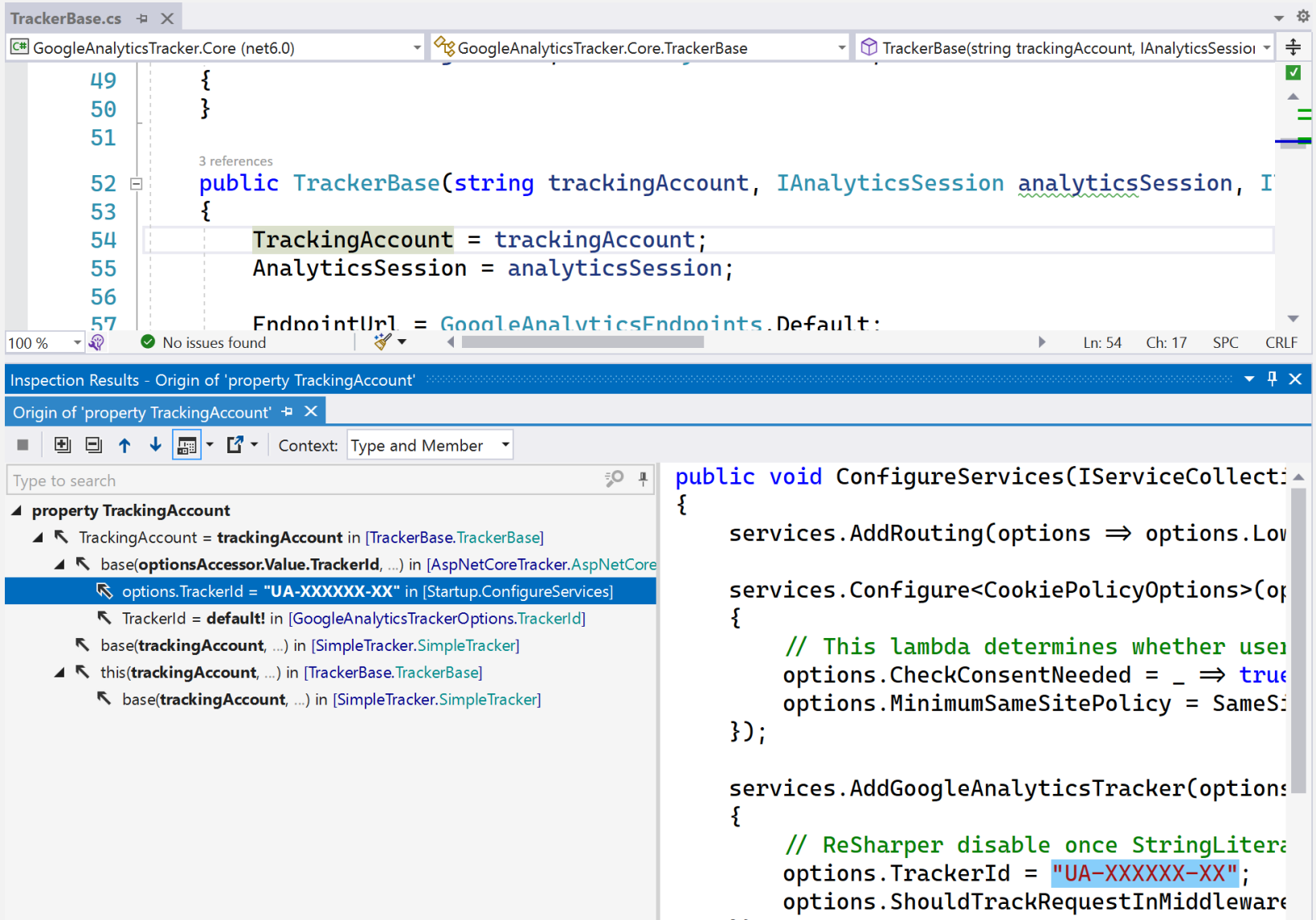
- Build a safety net!
  - Annotate, suppress, redesign – passing `null` is totally fine
  - Know where it is potentially passed
  - Reduce chance of `NullReferenceException`

Summary: Techniques

- Always enable NRT for new projects
- Start at the center and work outwards
- Annotate, and redesign
- Suppressions should be temporary
- Don’t be afraid of `null`

Tools that can help

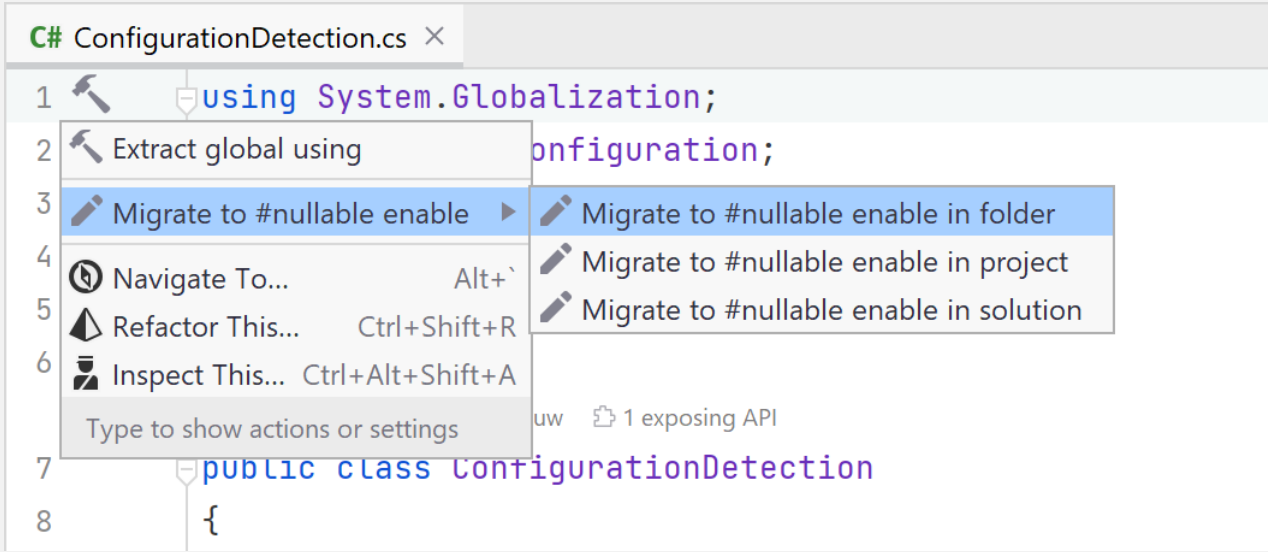
Value tracking (origin/destination)



JetBrains Annotations to C# annotations

Automatic migration*

- Inserts `[NotNull]` and `[CanBeNull]` from base classes
- Infers annotations by looking at usages
  - If `null` anywhere, gets annotated



*Not a silver bullet, but a great help

Infer from existing `null` checks

- Your code has clear hints about nullability
- Quiz: should we annotate?

```
public static string ReadColumn(
    string columnName,
    string defaultValue = "")
{
    if (columnName != null)
    {
        if (_mappings.TryGetValue(columnName, out var columnIndex)
            && _data.TryGetValue(columnIndex, out var columnData))
        {
            return columnData ?? defaultValue;
        }
    }

    return defaultValue;
}
```

Third-party libraries

- .NET BCL and some libraries are annotated – great!
- Some libraries use JetBrains.Annotations – great!
- Many (most 😔) are *not* annotated
  - Have to assume `null` everywhere
  - R#/Rider – try pessimistic analysis
    https://www.jetbrains.com/help/resharper/Code_Analysis__Value_Analysis.html#modes_

(De)serializing JSON

How do you go about this warning?

```
[JsonProperty("name")]
public string Name { get; set; }
```

Non-nullable property 'Name' is uninitialized. Consider declaring the property as nullable.

```
[JsonProperty("name")]
public string Name { get; set; }
in class User
```

(De)serializing JSON

- ```
  // 1
  [JsonProperty("name")]
  public string? Name { get; set; }
  ```

  Loses nullability information

- ```
  // 2
  [JsonProperty("name")]
  public string Name { get; set; } = default!;
  ```

  antipattern (incorrect information)

- ```
  // 3
  [JsonProperty("name")]
  public string Name { get; set; } = "Unknown";
  ```

  Good alternative

- ```
  // 4
  private readonly string _name;

  [AllowNull]
  [JsonProperty("name")]
  public string Name
  {
      get => _name;
      init => _name = value ?? "Unknown";
  }
  ```

  Good (cumbersome) alternative

(De)serializing JSON

- ```
  // 5
  [JsonProperty("name")]
  public required string Name { get; set; }
  ```

Personal recommendation*

*Your JSON data may still be null…
Checking input in the property or using `IJsonOnDeserialized` may be helpful.
  ```

Be careful with Entity Framework Core

*A **property is considered optional if it is valid for it to contain `null`**. If `null` is not a valid value to be assigned to a property then it is considered to be a required property. When mapping to a relational database schema, required properties are created as non-nullable columns, and **optional properties are created as nullable columns**.*

TL;DR: When you enable NRT in a project or file, your database schema may change unexpectedly.

https://docs.microsoft.com/en-us/ef/core/modeling/entity-properties?tabs=data-annotations%2Cwithout-nrt#:~:text=A%20property%20is,as%20nullable%20columns

https://docs.microsoft.com/en-us/ef/core/miscellaneous/nullable-reference-types#required-and-optional-properties

Summary: Tools

- Value tracking (value origin/destination)
- Convert JetBrains Annotations to C# nullable annotations
- Automatic migration
- Infer from existing `null` checks
- Third-party libraries…
  - JSON
  - Entity Framework Core

Summary

Nullable reference types in C#

- Design-time and compile-time safety net. Not runtime!
- Nullable annotation context to determine level of help
- Annotations to communicate intent
  (`null` is fine if you know where)
- Null-forgiving operator is an **antipattern**
- Tools and techniques to migrate

Thank you!

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