ASP.NET Core Architecture overview

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Software Architect

What is ASP.NET Core?

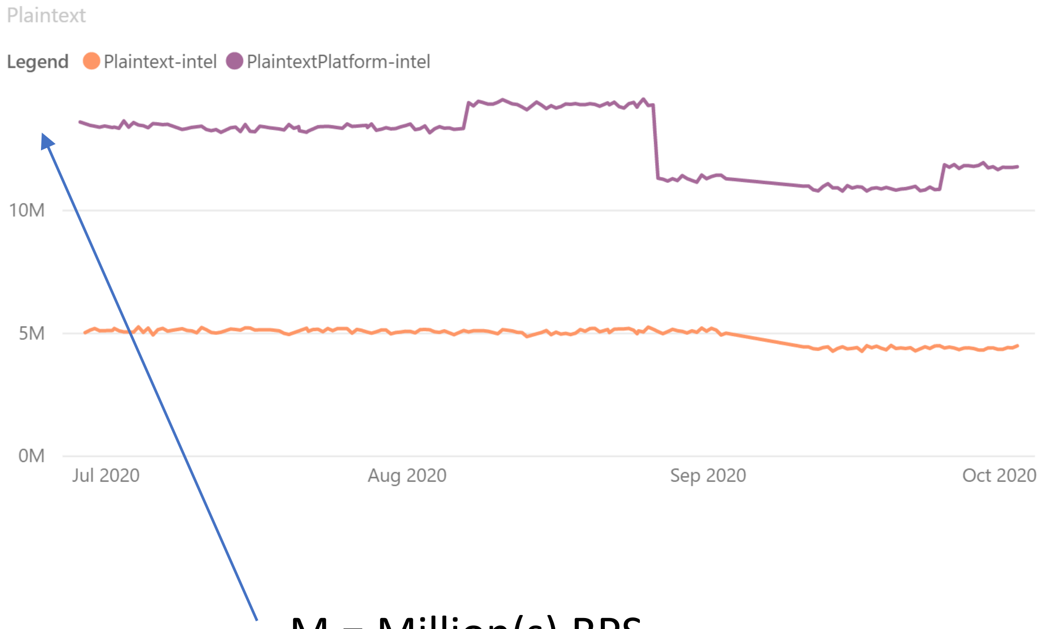
- Cross platform web platform from the .NET team
- Similar concepts as previous versions of ASP.NET but not binary compatible
- Can build a wide range of application types
  - REST APIs or gRPC services
  - Single Page Applications with Blazor
  - Server Rendered web applications with Razor Pages
  - Real time web applications with SignalR

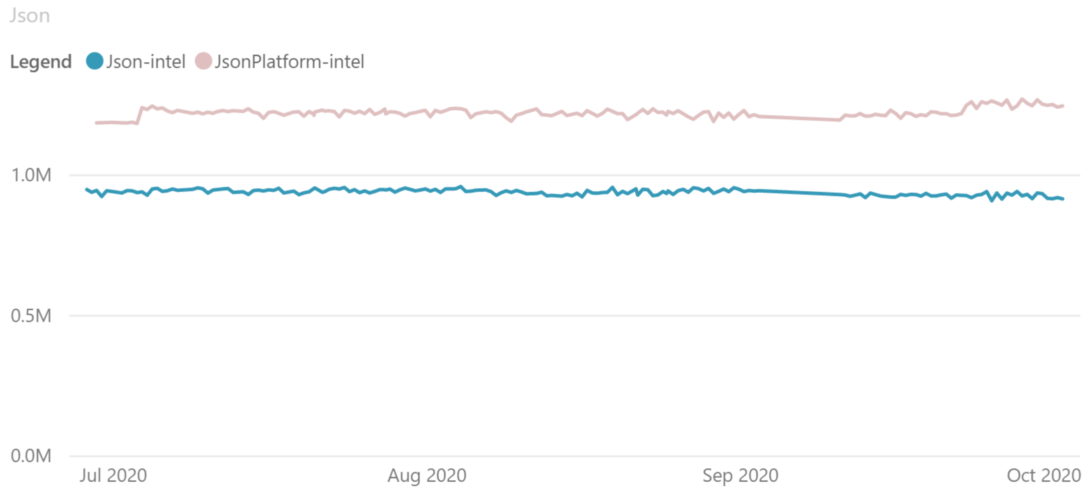
ASP.NET Core Design principles

- Various components of the stack should be independently usable
- Only pay for things you that you use
- Performance is paramount
- Code over configuration
- Composition via dependency injection
- Extensibility points used by the framework should be usable by anyone
- No statics, it should be possible to run multiple applications in the same process and not conflict.

ASP.NET Core is fast

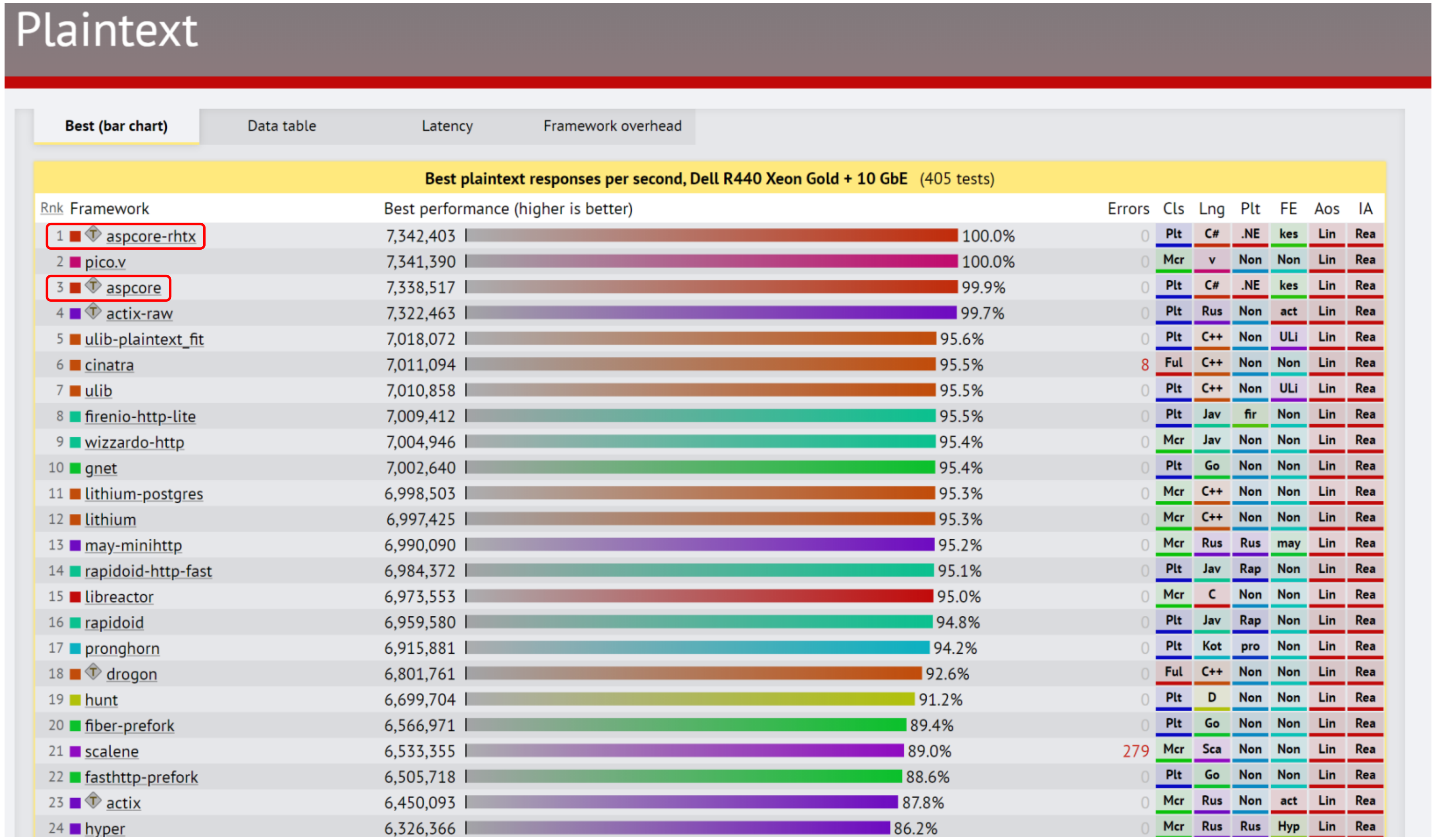
http://aka.ms/aspnet/benchmarks





M = Million(s) RPS

ASP.NET Core: TechEmpower benchmarks



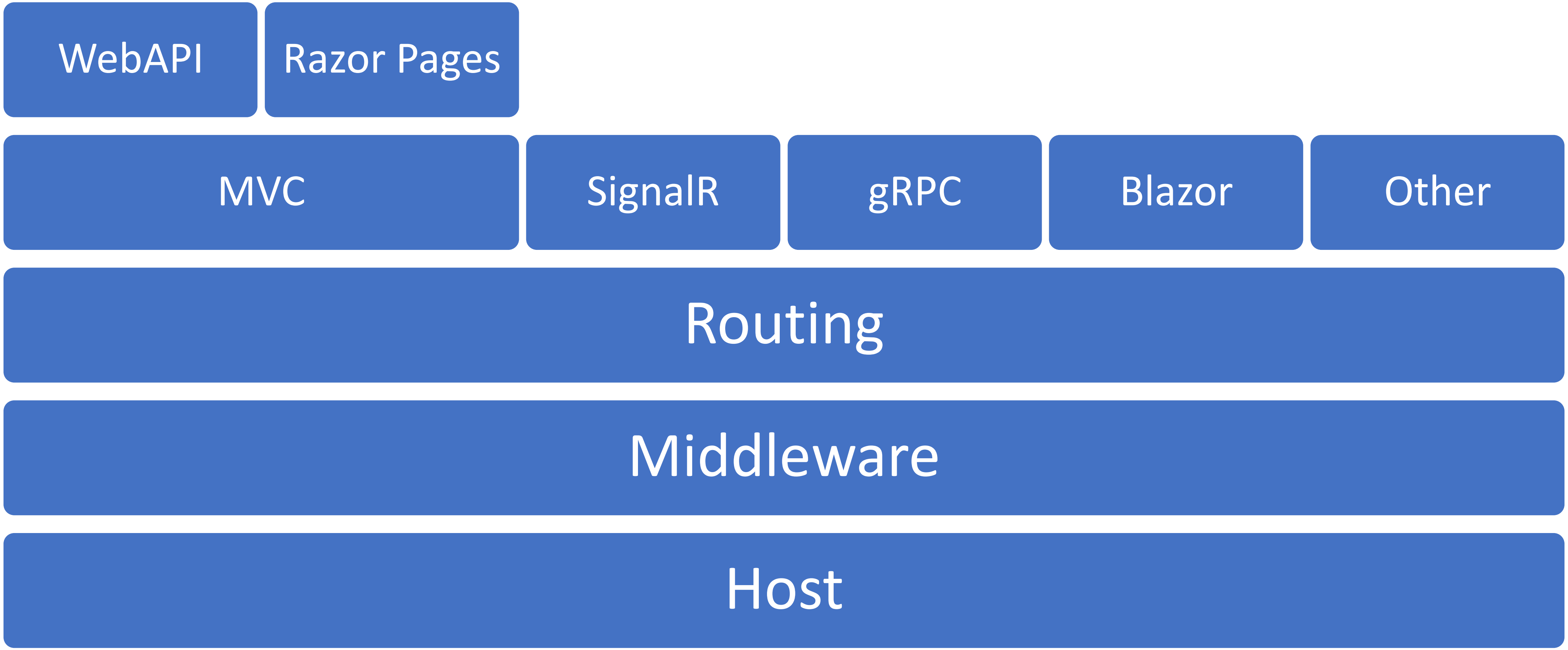
Plaintext

Best (bar chart) | Data table | Latency | Framework overhead

Best plaintext responses per second, Dell R440 Xeon Gold + 10 GbE (405 tests)

Rnk	Framework	Best performance (higher is better)		Errors	Cls	Lng	Plt	FE	Aos	IA
1	aspcore-rhtx	7,342,403	100.0%	0	Plt	C#	.NE	kes	Lin	Rea
2	pico.v	7,341,390	100.0%	0	Mcr	v	Non	Non	Lin	Rea
3	aspcore	7,338,517	99.9%	0	Plt	C#	.NE	kes	Lin	Rea
4	actix-raw	7,322,463	99.7%	0	Plt	Rus	Non	act	Lin	Rea
5	ulib-plaintext_fit	7,018,072	95.6%	0	Plt	C++	Non	ULi	Lin	Rea
6	cinatra	7,011,094	95.5%	8	Ful	C++	Non	Non	Lin	Rea
7	ulib	7,010,858	95.5%	0	Plt	C++	Non	ULi	Lin	Rea
8	firenio-http-lite	7,009,412	95.5%	0	Plt	Jav	fir	Non	Lin	Rea
9	wizzardo-http	7,004,946	95.4%	0	Mcr	Jav	Non	Non	Lin	Rea
10	gnet	7,002,640	95.4%	0	Plt	Go	Non	Non	Lin	Rea
11	lithium-postgres	6,998,503	95.3%	0	Mcr	C++	Non	Non	Lin	Rea
12	lithium	6,997,425	95.3%	0	Mcr	C++	Non	Non	Lin	Rea
13	may-minihttp	6,990,090	95.2%	0	Mcr	Rus	Rus	may	Lin	Rea
14	rapidoid-http-fast	6,984,372	95.1%	0	Plt	Jav	Rap	Non	Lin	Rea
15	libreactor	6,973,553	95.0%	0	Mcr	C	Non	Non	Lin	Rea
16	rapidoid	6,959,580	94.8%	0	Plt	Jav	Rap	Non	Lin	Rea
17	pronghorn	6,915,881	94.2%	0	Plt	Kot	pro	Non	Lin	Rea
18	drogon	6,801,761	92.6%	0	Ful	C++	Non	Non	Lin	Rea
19	hunt	6,699,704	91.2%	0	Plt	D	Non	Non	Lin	Rea
20	fiber-prefork	6,566,971	89.4%	0	Plt	Go	Non	Non	Lin	Rea
21	scalene	6,533,355	89.0%	279	Mcr	Sca	Non	Non	Lin	Rea
22	fasthttp-prefork	6,505,718	88.6%	0	Plt	Go	Non	Non	Lin	Rea
23	actix	6,450,093	87.8%	0	Mcr	Rus	Non	act	Lin	Rea
24	hyper	6,326,366	86.2%	0	Mcr	Rus	Rus	Hyp	Lin	Rea

ASP.NET Core Architecture



WebAPI

Razor Pages

MVC

SignalR

gRPC

Blazor

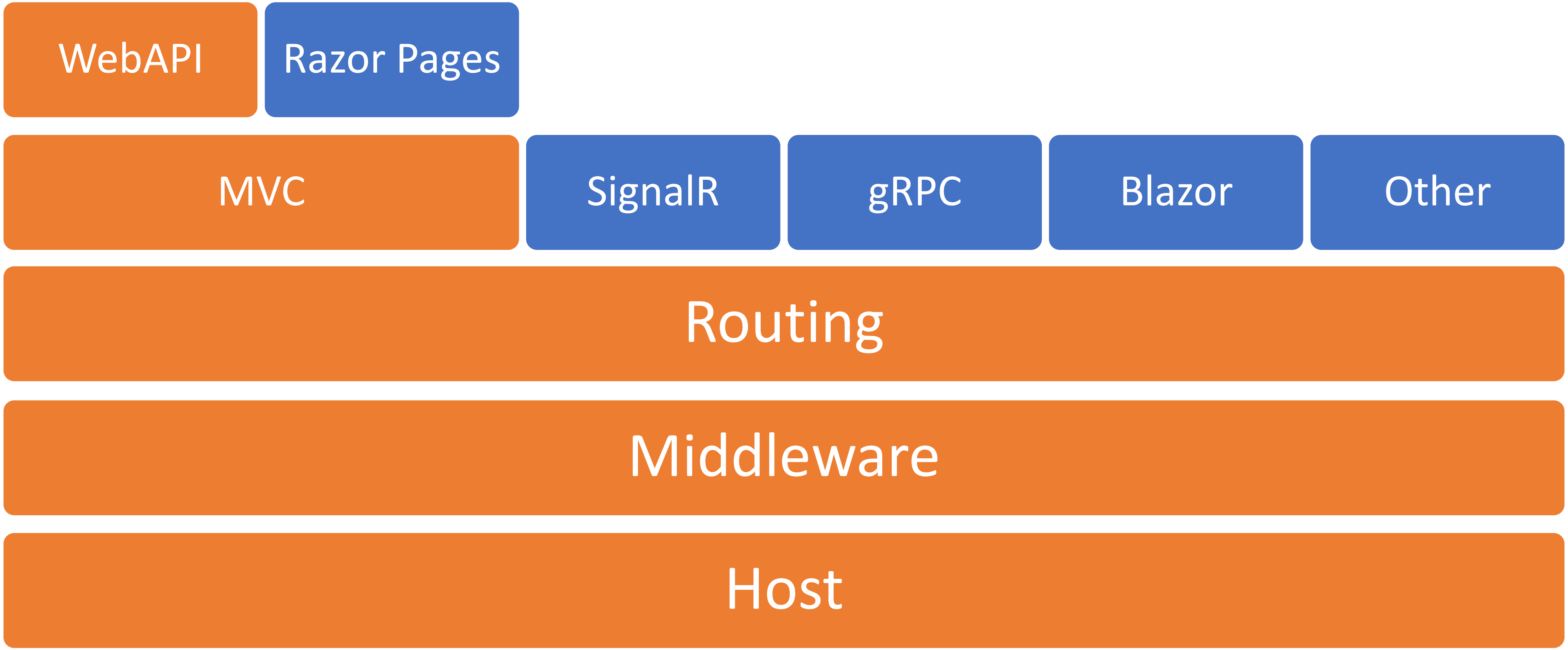
Other

Routing

Middleware

Host

The focus of this talk



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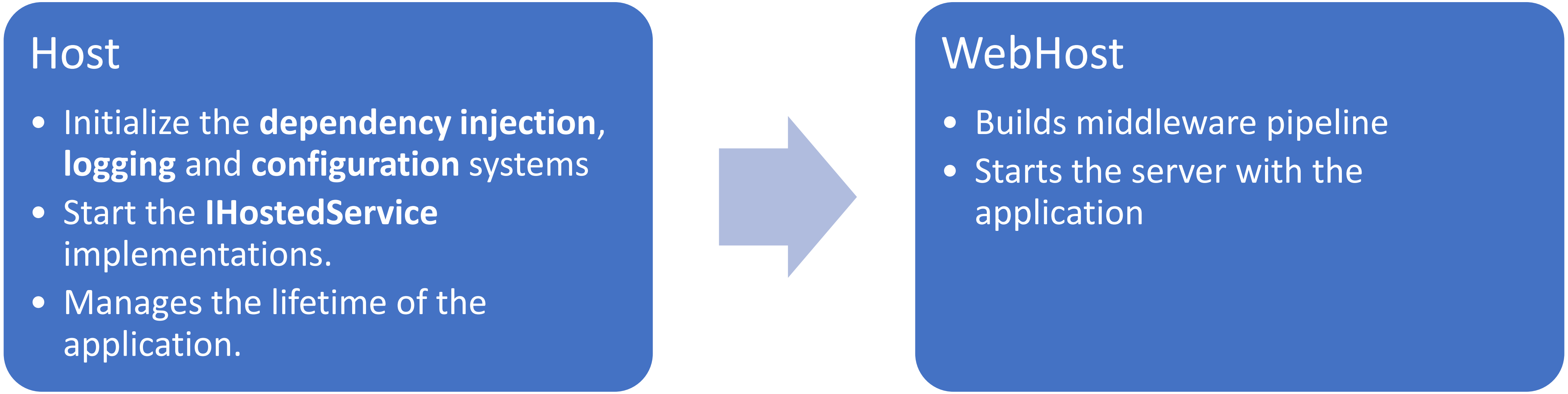
Overview

1. Application bootstrapping
2. Anatomy of a request

Application Bootstrapping



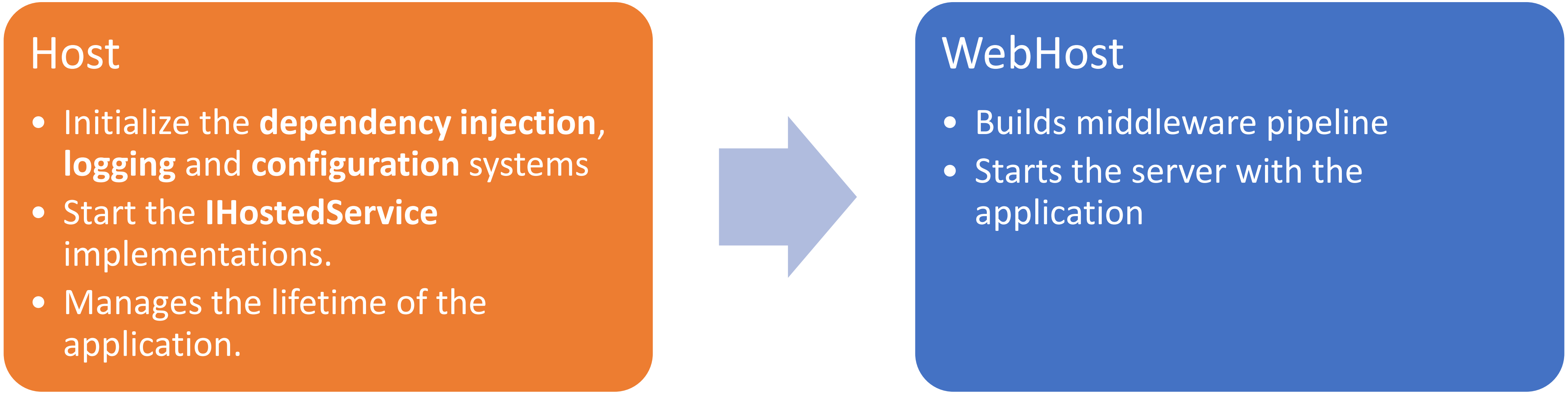
Host

- Initialize the **dependency injection**, **logging** and **configuration** systems
- Start the **IHostedService** implementations.
- Manages the lifetime of the application.

WebHost

- Builds middleware pipeline
- Starts the server with the application

Application Bootstrapping: Host



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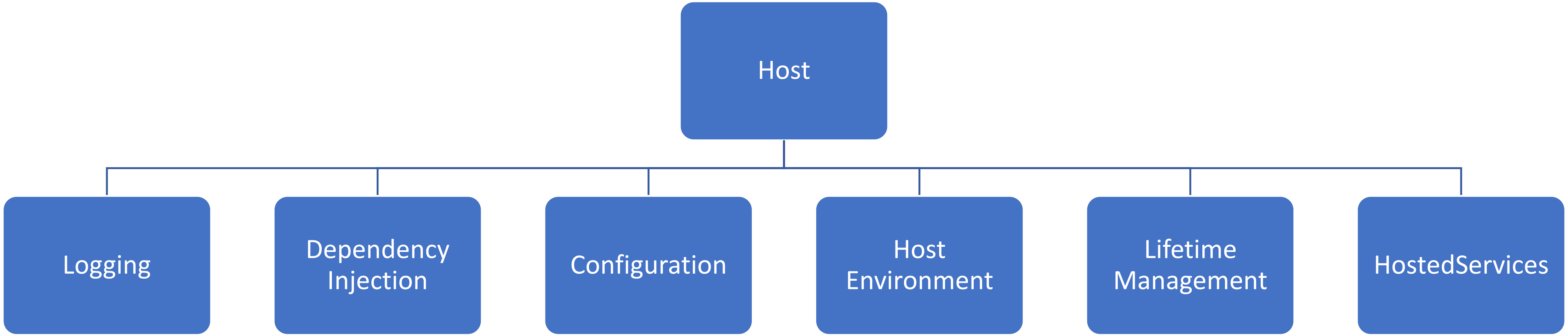
Host: Microsoft.Extensions.*

- Responsible for bootstrapping the dependency injection, logging and configuration systems.
- Abstracts how the underlying platform manages lifetime for startup and shutdown (e.g. windows services, cloud services)
- Provides abstractions for getting environment information.
- Notifies hosted services on start up and shutdown.

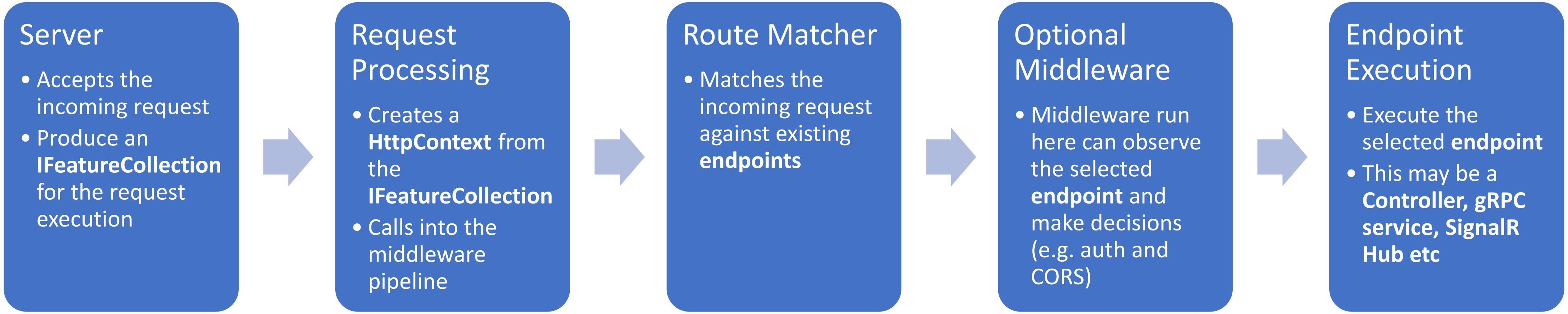
Host Architecture: Microsoft.Extensions.*



Microsoft.Extensions.* Design principles

- Decoupled from ASP.NET Core
- Built with dependency injection in mind
- netstandard2.0 compatible for the widest adoption
- Explicitly designed around provider model to allow extensibility (e.g. configuration, logging)

Anatomy of a request



Server

- Accepts the incoming request
- Produce an **IFeatureCollection** for the request execution

Request Processing

- Creates a **HttpContext** from the **IFeatureCollection**
- Calls into the middleware pipeline

Route Matcher

- Matches the incoming request against existing **endpoints**

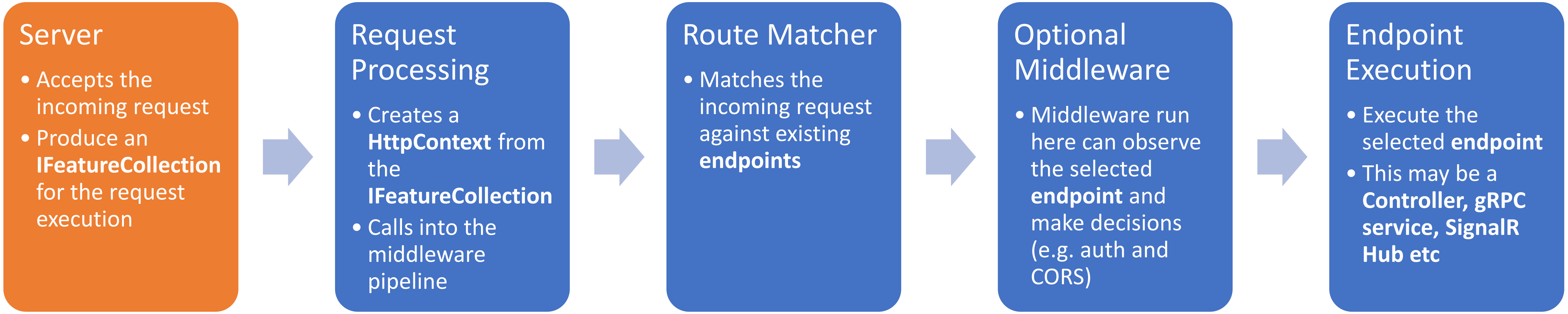
Optional Middleware

- Middleware run here can observe the selected **endpoint** and make decisions (e.g. auth and CORS)

Endpoint Execution

- Execute the selected **endpoint**
- This may be a **Controller, gRPC service, SignalR Hub etc**

Anatomy of a request: Server



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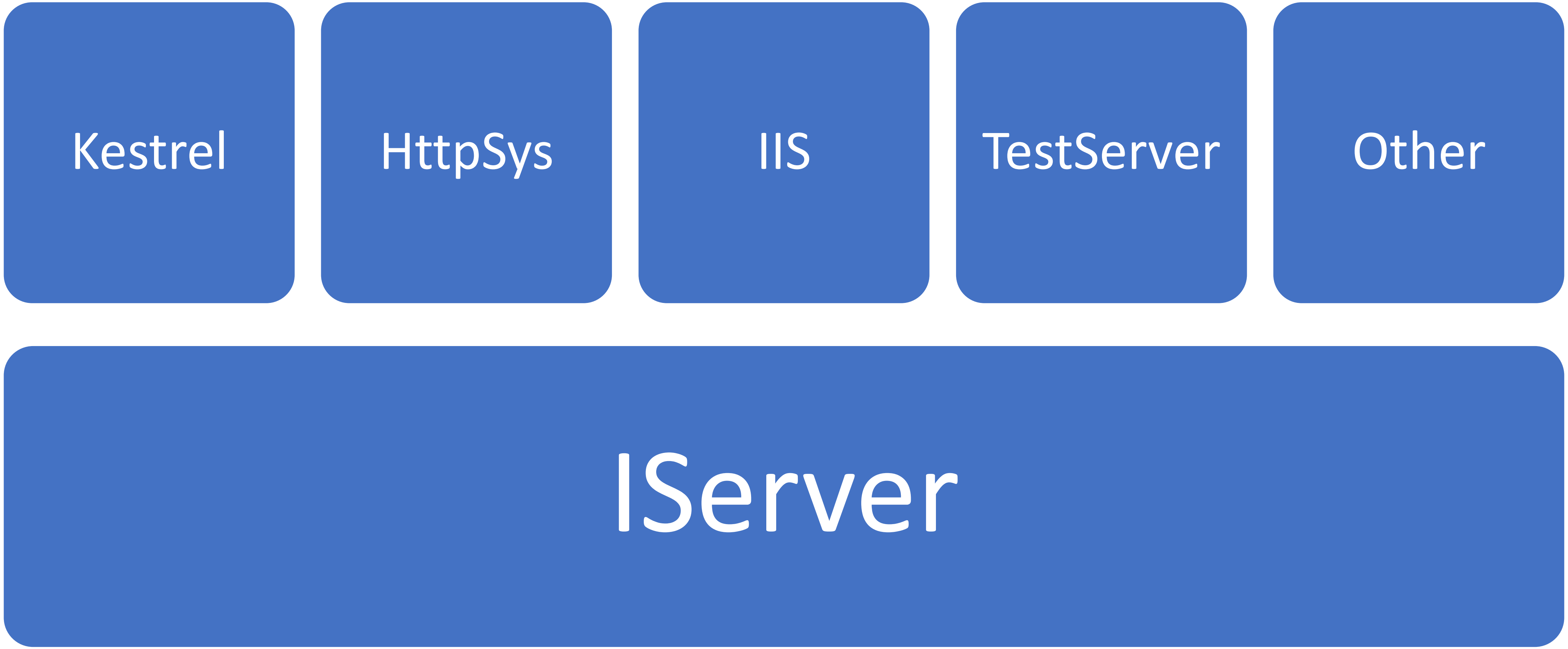
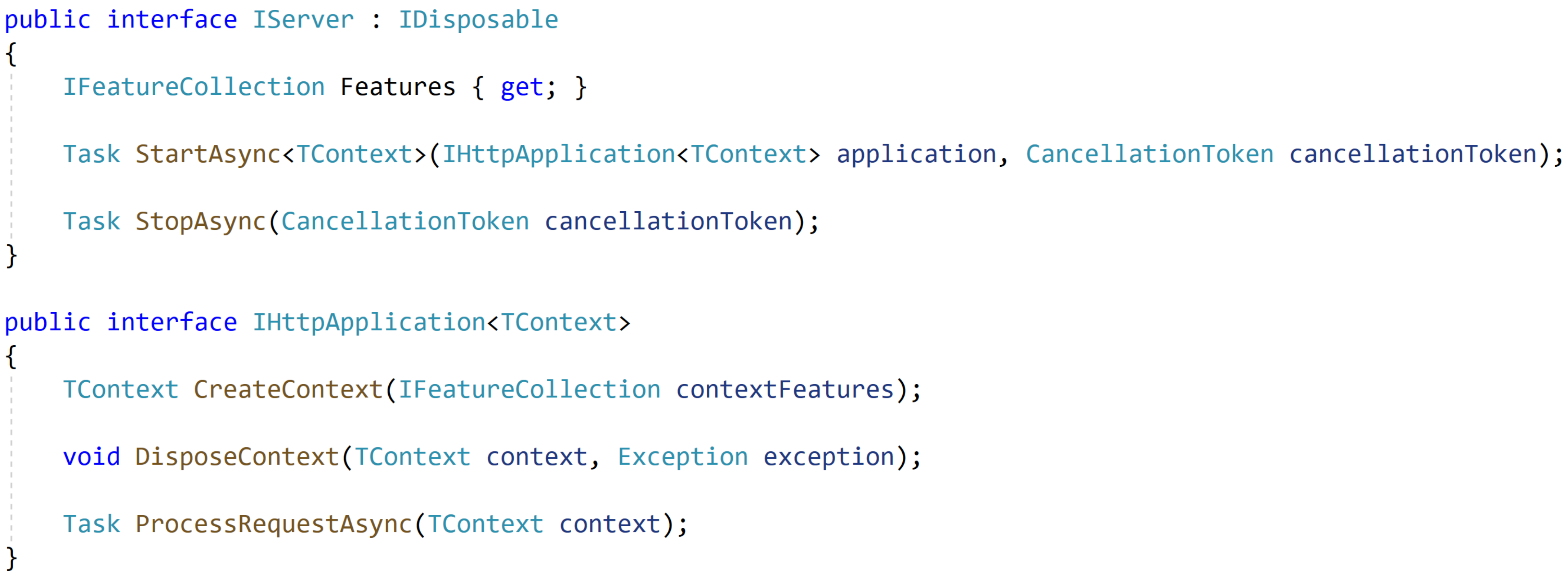
Server Architecture

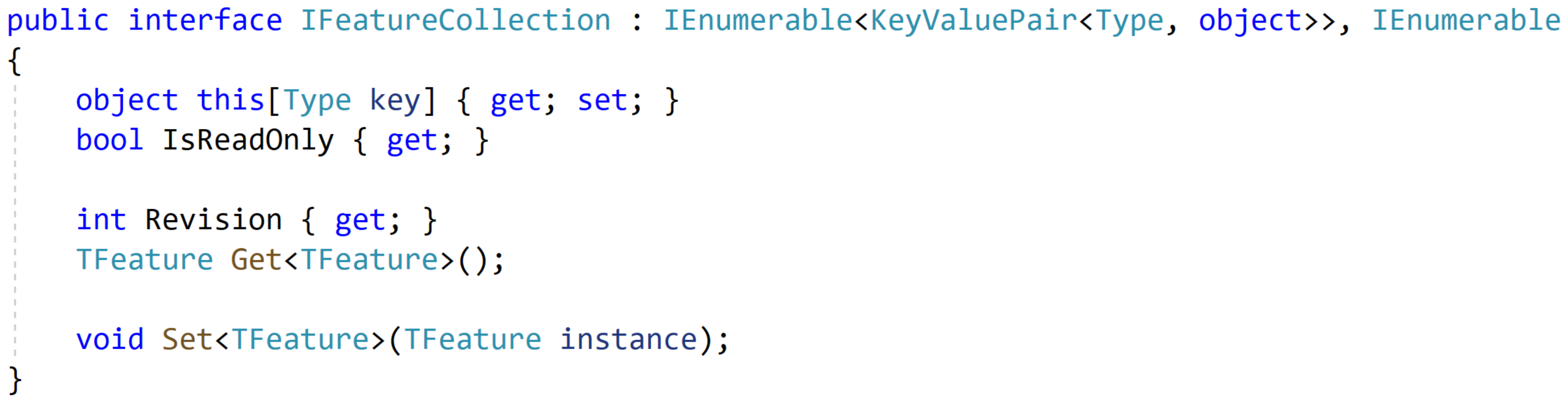




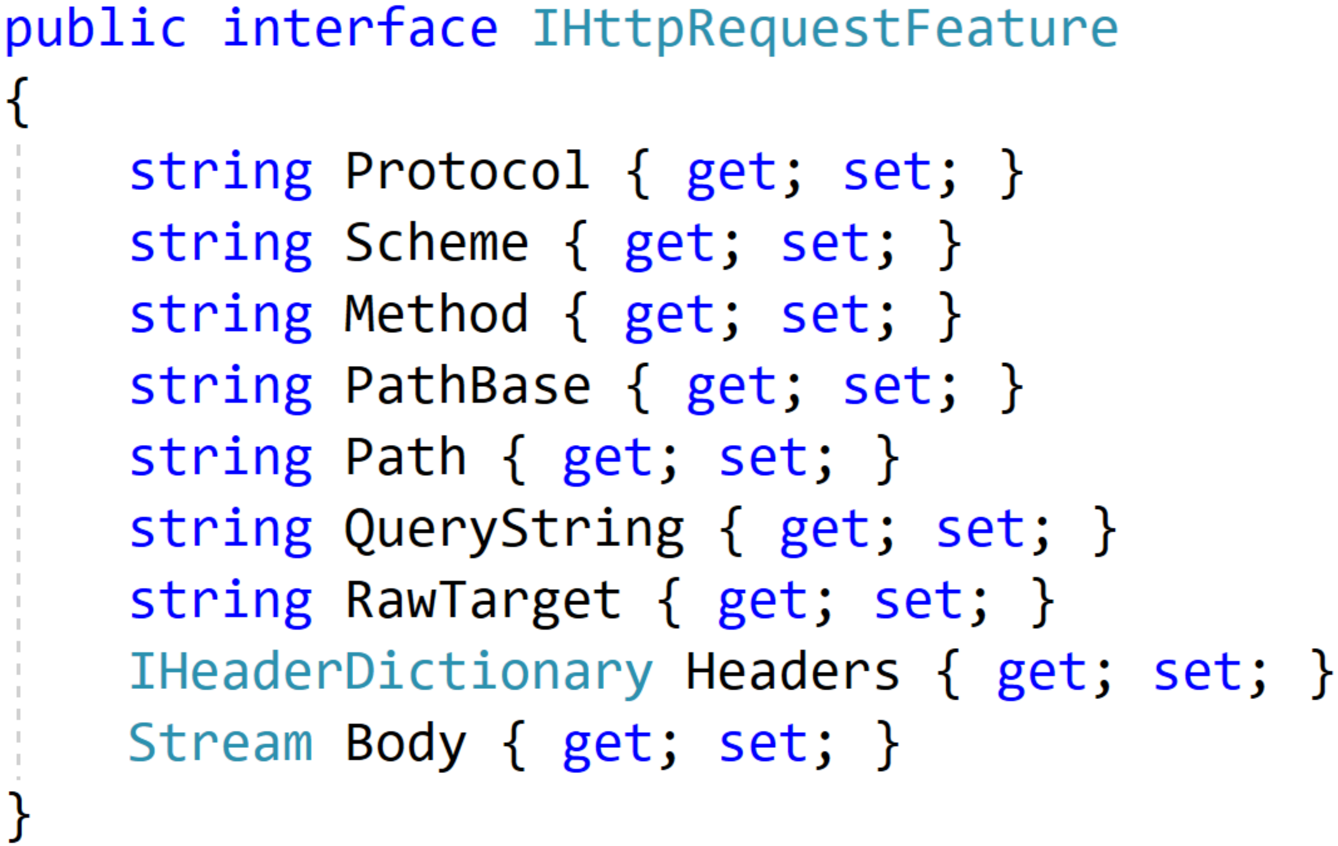
```
public interface IServer : IDisposable
{
    IFeatureCollection Features { get; }

    Task StartAsync<TContext>(IHttpApplication<TContext> application, CancellationToken cancellationToken);

    Task StopAsync(CancellationToken cancellationToken);
}

public interface IHttpApplication<TContext>
{
    TContext CreateContext(IFeatureCollection contextFeatures);

    void DisposeContext(TContext context, Exception exception);

    Task ProcessRequestAsync(TContext context);
}
```

Server

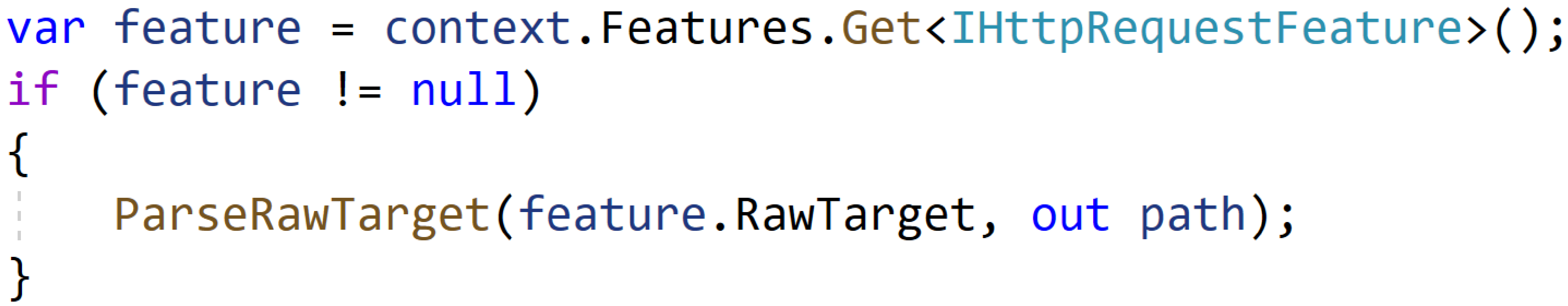
- Listen for incoming requests
- Responsible for the core request handling logic
- Produces an IFeatureCollection for request execution
  - ASP.NET Core has a minimum set of features it expects all IServers to implement.
  - May expose additional server specific functionality (e.g. server variables in IIS)
- Call into the IHttpApplication registered with the server when requests arrive



```csharp
public interface IFeatureCollection : IEnumerable<KeyValuePair<Type, object>>, IEnumerable
{
    object this[Type key] { get; set; }
    bool IsReadOnly { get; }

    int Revision { get; }
    TFeature Get<TFeature>();

    void Set<TFeature>(TFeature instance);
}
```



```
public interface IHttpRequestFeature
{
    string Protocol { get; set; }
    string Scheme { get; set; }
    string Method { get; set; }
    string PathBase { get; set; }
    string Path { get; set; }
    string QueryString { get; set; }
    string RawTarget { get; set; }
    IHeaderDictionary Headers { get; set; }
    Stream Body { get; set; }
}
```

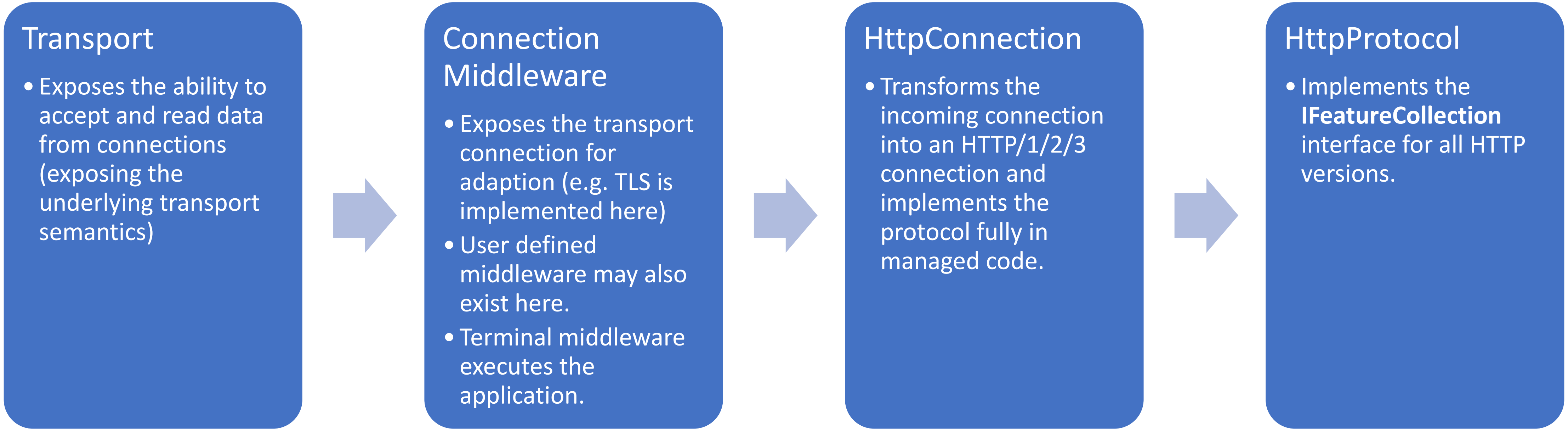


```
var feature = context.Features.Get<IHttpRequestFeature>();
if (feature != null)
{
    ParseRawTarget(feature.RawTarget, out path);
}
```

Server: Kestrel

- Cross platform
- Written entirely in managed code
- Extremely optimized
- Supports HTTP/1, HTTP/2, HTTP/3 (preview)
- Pluggable transports (see project bedrock)
    - Default transport uses Sockets
- Other protocols are possible on top of transport abstraction

Server: Kestrel Architecture



Transport

- Exposes the ability to accept and read data from connections (exposing the underlying transport semantics)

Connection Middleware

- Exposes the transport connection for adaption (e.g. TLS is implemented here)
- User defined middleware may also exist here.
- Terminal middleware executes the application.

HttpConnection

- Transforms the incoming connection into an HTTP/1/2/3 connection and implements the protocol fully in managed code.

HttpProtocol

- Implements the **IFeatureCollection** interface for all HTTP versions.

Server: Kestrel Optimizations

- Buffering pooling at all the layers
- Uses the pinned object heap to reduce fragmentation
- Non-allocating HTTP parsers using Span
- Headers are dictionaries optimized for known header access
  - We never allocate known header keys
  - We can reuse header values
- Pooled HttpContext objects and associated state across requests
- Low level knobs exposed to optimize threading

Server: HttpSys (Windows Only)

- Managed wrapper over HTTP.sys
- Supports advanced HTTP.sys features
    - Port sharing
    - Request queue creation
    - Kernel caching
    - Sendfile
    - Windows Auth (NTLM, Kerberos)
    - Request queue delegation

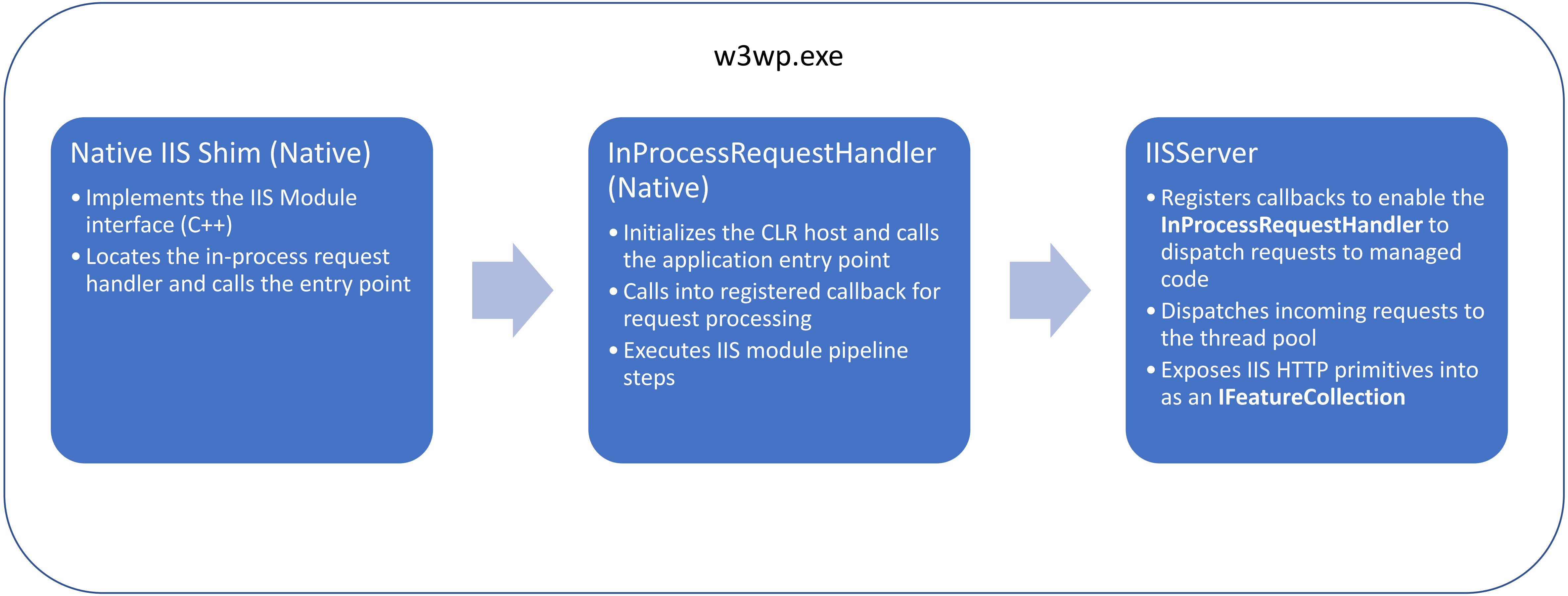
Server: HttpSys Architecture

- Dequeue request from HTTP.sys request queue
- Dispatches to the request to the ThreadPool
- Wraps the HTTP API primitives in an **IFeatureCollection**

Server: IIS (Windows Only)

- Managed wrapper around native IIS Module
- Runs in 2 modes
  - In process – Application code runs in the IIS worker process
    - Does not support running multiple applications in a single worker process
    - Does not support handling IIS module events
  - Out of process – Application code runs in a separate process
- Deployed as 2 separate components
  - A native shim installed globally
  - A request handler that ships with ASP.NET or the application
- Not built into Windows (it’s a separate installer)

Server: IIS Architecture In-Process



w3wp.exe

Native IIS Shim (Native)

- Implements the IIS Module interface (C++)
- Locates the in-process request handler and calls the entry point

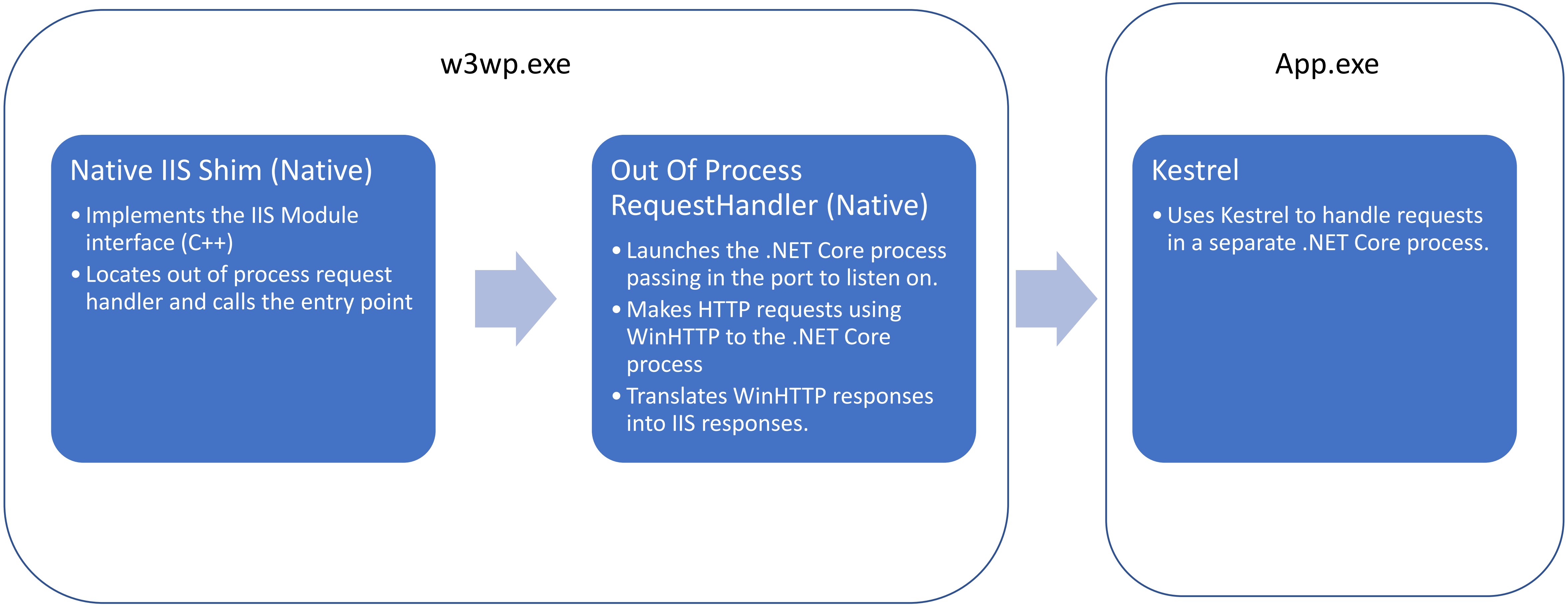
InProcessRequestHandler (Native)

- Initializes the CLR host and calls the application entry point
- Calls into registered callback for request processing
- Executes IIS module pipeline steps

IISServer

- Registers callbacks to enable the **InProcessRequestHandler** to dispatch requests to managed code
- Dispatches incoming requests to the thread pool
- Exposes IIS HTTP primitives into as an **IFeatureCollection**

Server: IIS Architecture Out-Of-Process



w3wp.exe

Native IIS Shim (Native)

- Implements the IIS Module interface (C++)
- Locates out of process request handler and calls the entry point

Out Of Process RequestHandler (Native)

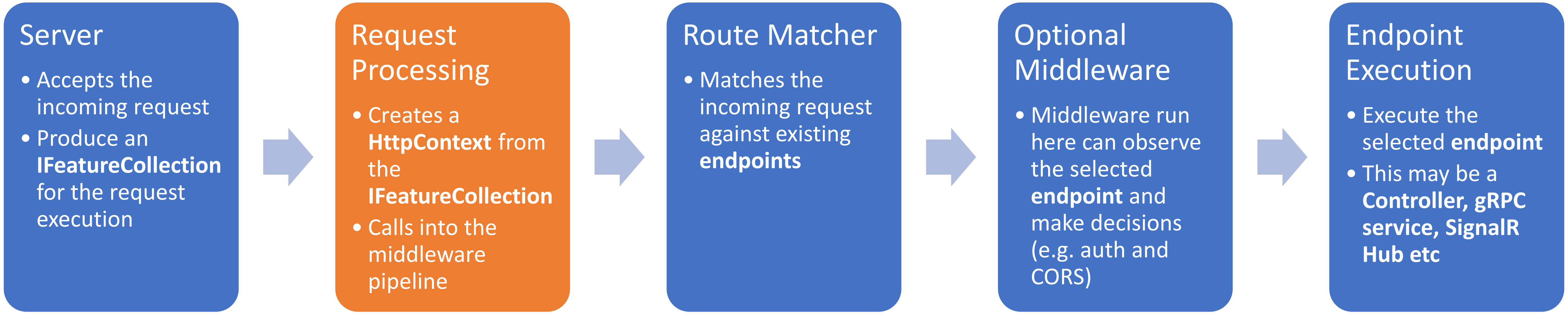
- Launches the .NET Core process passing in the port to listen on.
- Makes HTTP requests using WinHTTP to the .NET Core process
- Translates WinHTTP responses into IIS responses.

App.exe

Kestrel

- Uses Kestrel to handle requests in a separate .NET Core process.

Anatomy of a request: Request Processing



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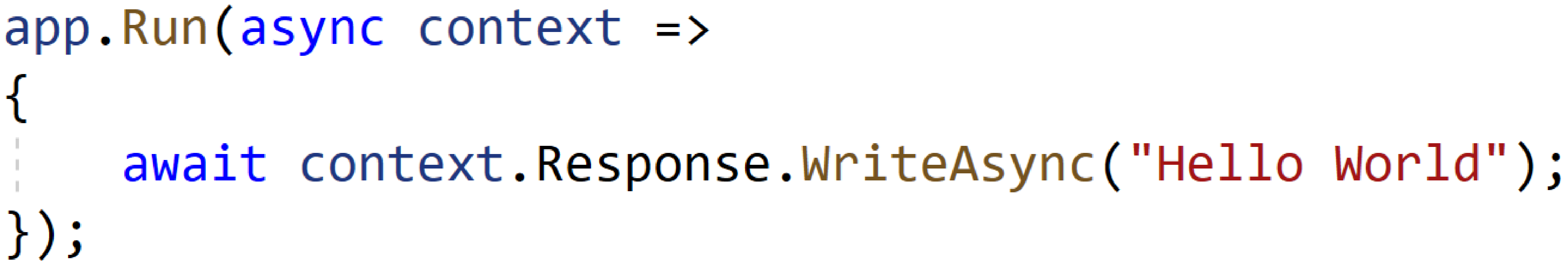
Endpoint Execution

- Execute the selected **endpoint**
- This may be a **Controller, gRPC service, SignalR Hub etc**

Request Processing

- Creates a HttpContext from the IFeatureCollection
- The HttpContext wraps the server’s IFeatureCollection and exposes a convenience layer on top
- Application code is written against this layer and is **server agnostic**
- Everything is asynchronous!

```
public delegate Task RequestDelegate(HttpContext context);
```

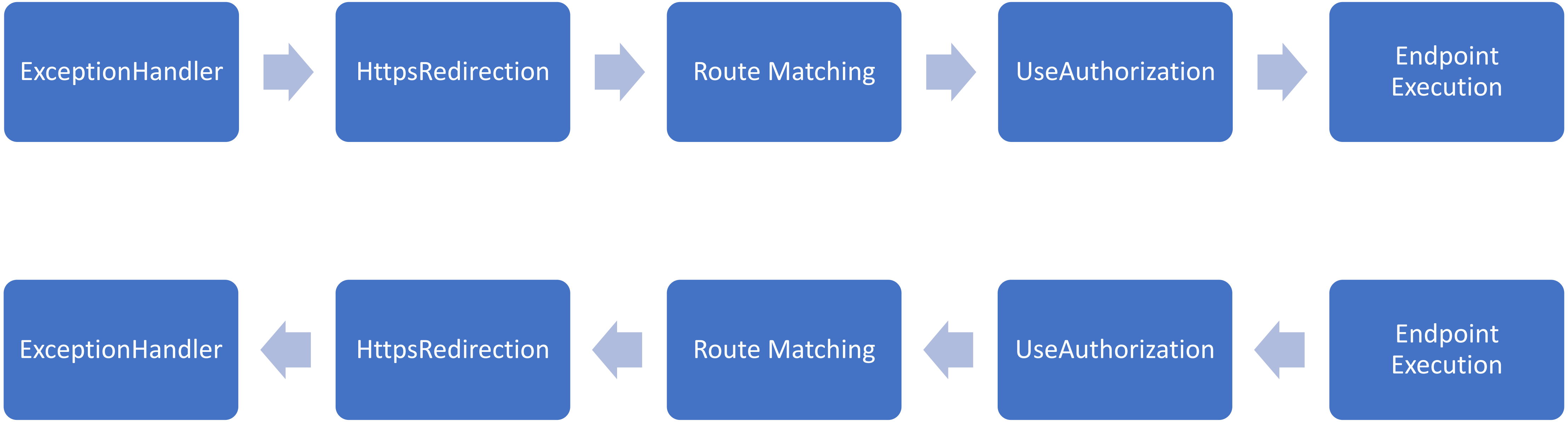


```
app.Run(async context =>
{
    await context.Response.WriteAsync("Hello World");
});
```

Middleware

- Central extensibility point of request processing.
- Execute cross cutting concerns that apply to either request and response.
- Russian doll pattern
- Exposes a wide variety of options for modifying the request and pipeline
    - Branching the pipeline
    - Short circuiting the incoming requests
    - Decorate state on the HttpContext
    - Wrapping the entire pipeline for exception handling
    - …

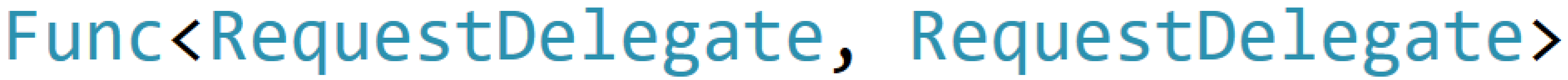
Request Processing: Middleware Architecture



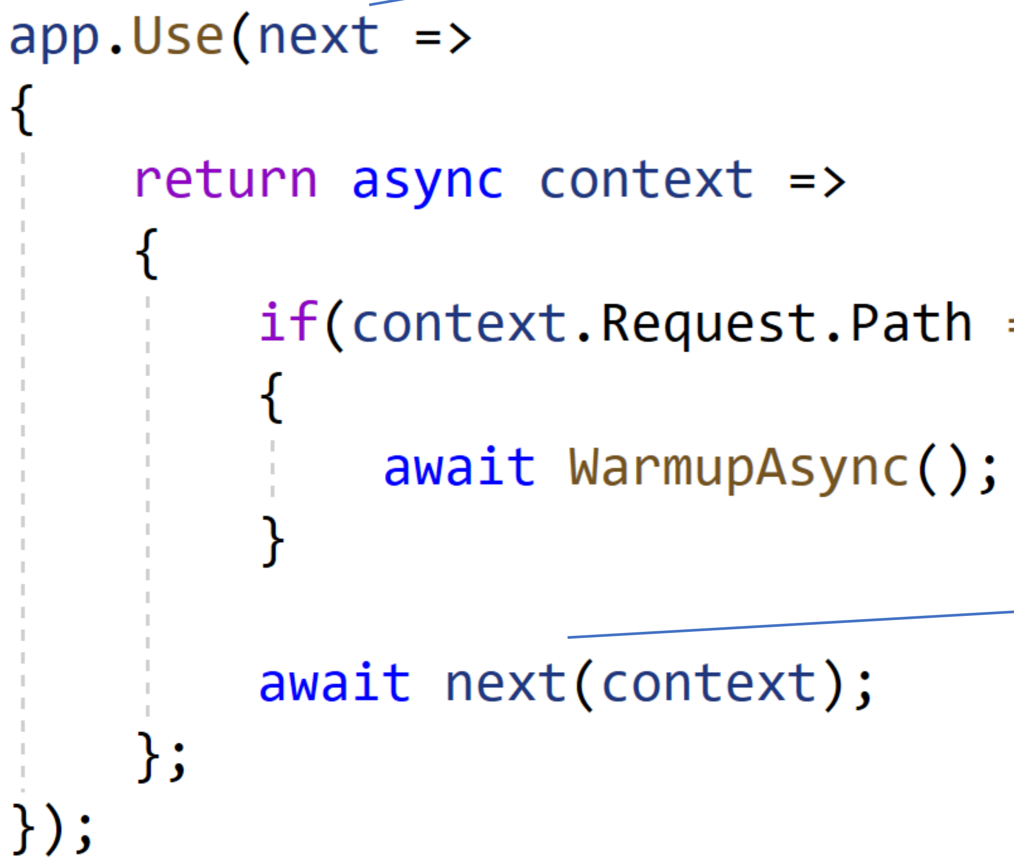
ExceptionHandler → HttpsRedirection → Route Matching → UseAuthorization → Endpoint Execution

ExceptionHandler ← HttpsRedirection ← Route Matching ← UseAuthorization ← Endpoint Execution

Middleware definition



```
Func<RequestDelegate, RequestDelegate>
```



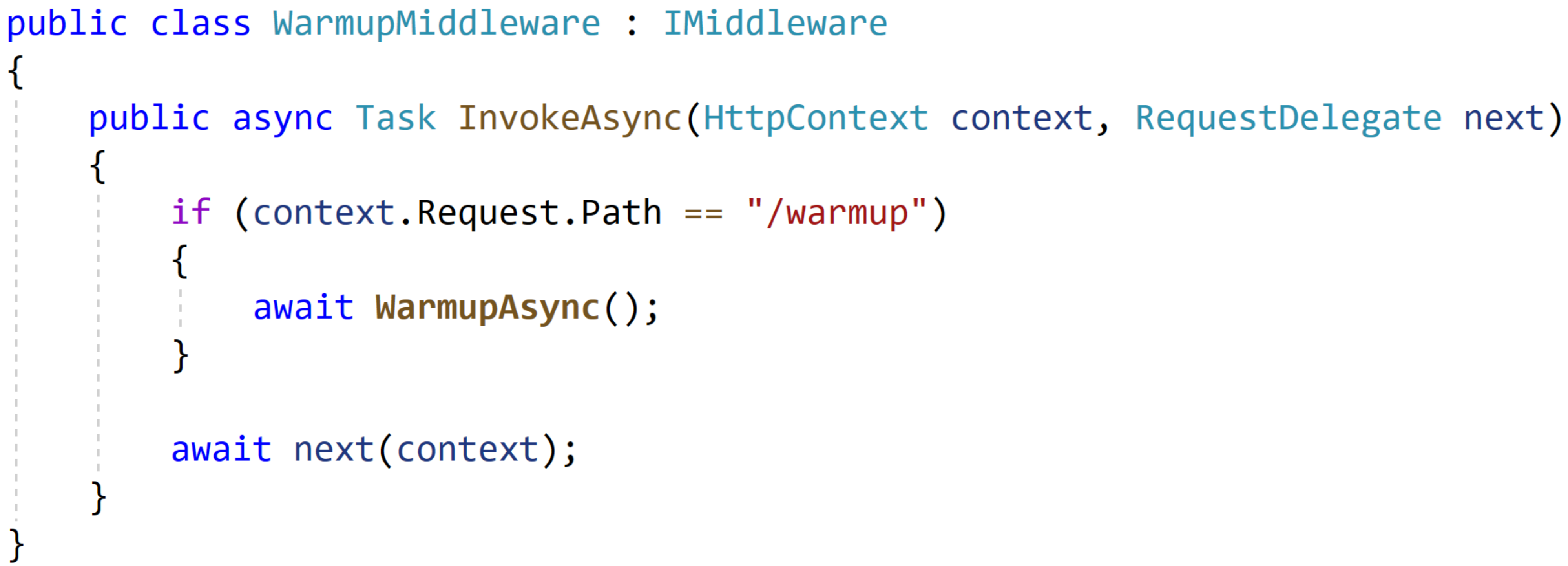
```
app.Use(next =>
{
    return async context =>
    {
        if(context.Request.Path == "/Warmup")
        {
            await WarmupAsync();
        }

        await next(context);
    };
});
```

Reference to the next middleware

Calling the next middleware in the pipeline

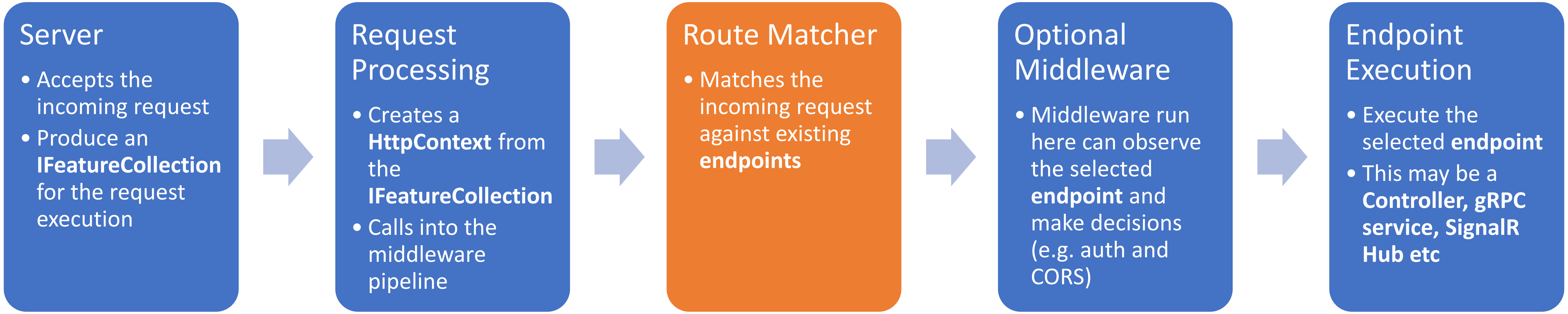
Middleware interface



```
public class WarmupMiddleware : IMiddleware
{
    public async Task InvokeAsync(HttpContext context, RequestDelegate next)
    {
        if (context.Request.Path == "/warmup")
        {
            await WarmupAsync();
        }

        await next(context);
    }
}
```

Anatomy of a request: Routing



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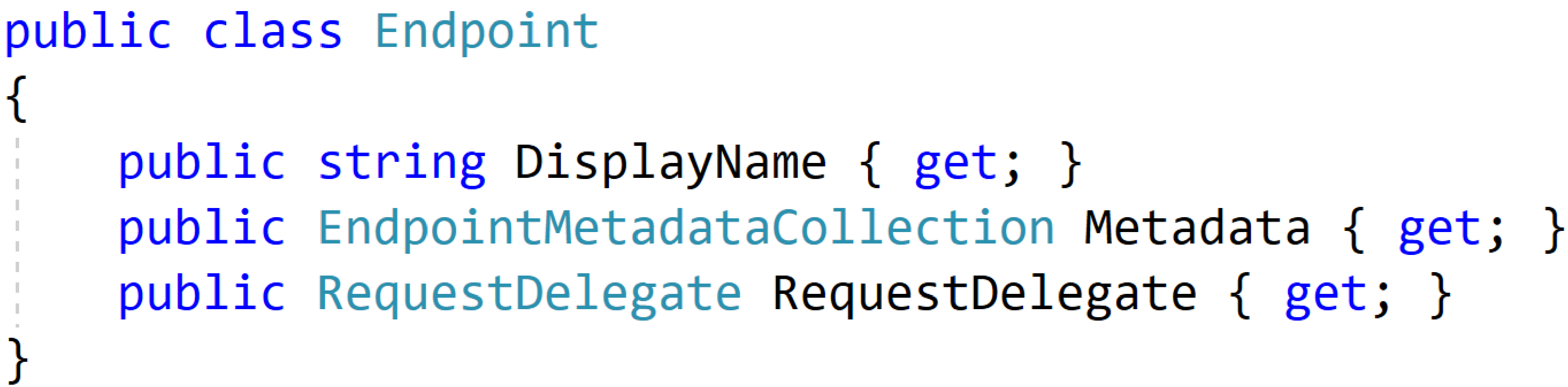
Routing

- Matches the incoming request against a set of **endpoints** and their criteria
- Supports Link/URL generation for registered routes
- Highly optimized route table and matching algorithm

Endpoints

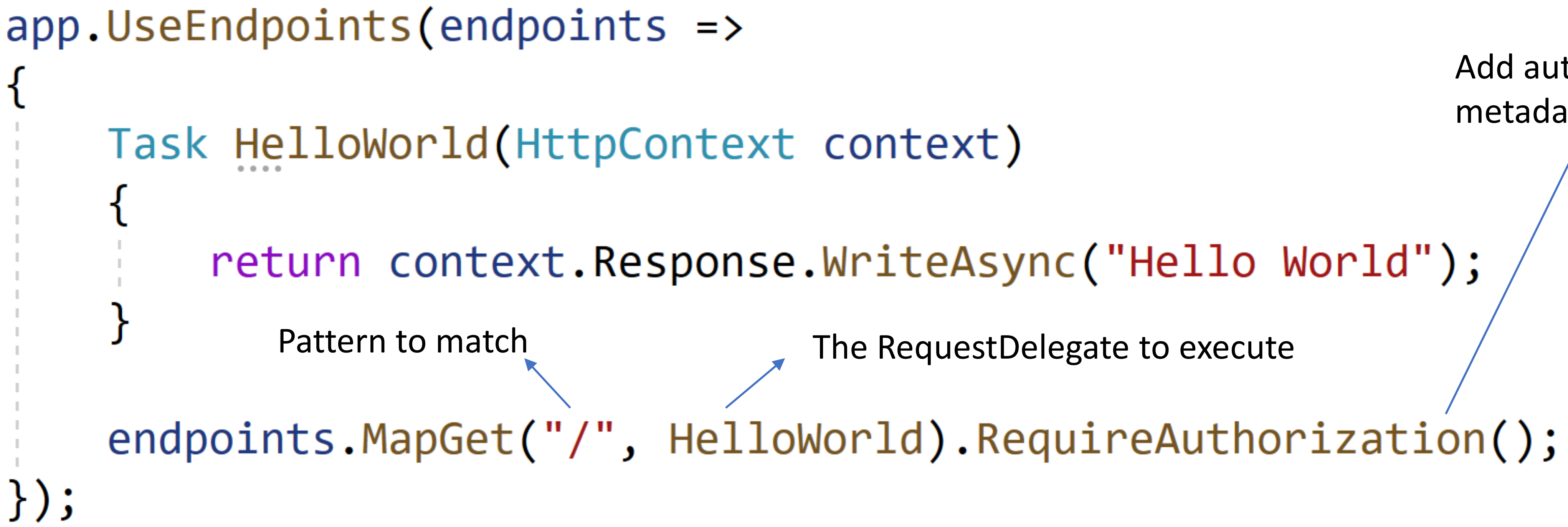
- A RequestDelegate to execute
- Metadata about the code to execute
  - For example, authorization metadata
- Decoupled from routing
- Middleware can be “endpoint aware”
  - CORS
  - Authorization

Endpoints



```
public class Endpoint
{
    public string DisplayName { get; }
    public EndpointMetadataCollection Metadata { get; }
    public RequestDelegate RequestDelegate { get; }
}
```

Endpoints



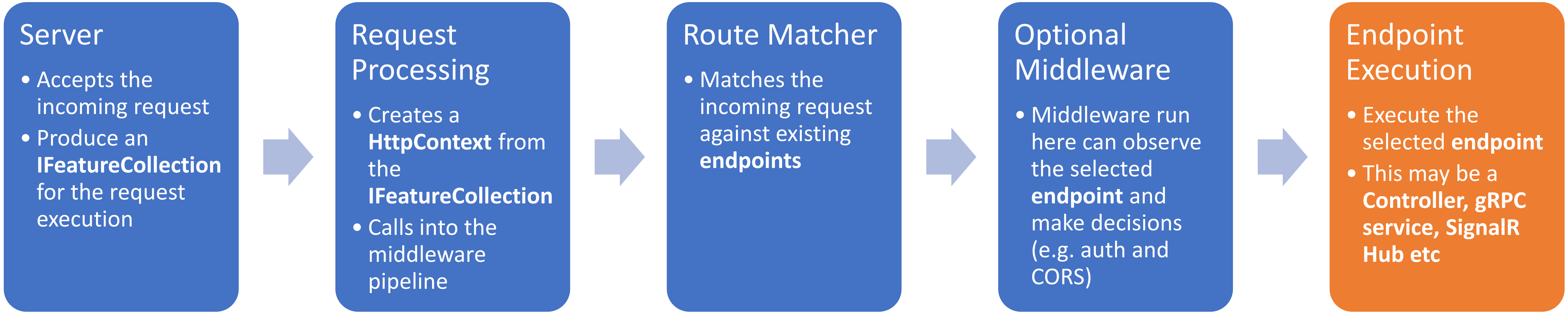
```
app.UseEndpoints(endpoints =>
{
    Task HelloWorld(HttpContext context)
    {
        return context.Response.WriteAsync("Hello World");
    }

    endpoints.MapGet("/", HelloWorld).RequireAuthorization();
});
```

Pattern to match

The RequestDelegate to execute

Add authorization metadata

Anatomy of a request: Endpoint Execution MVC



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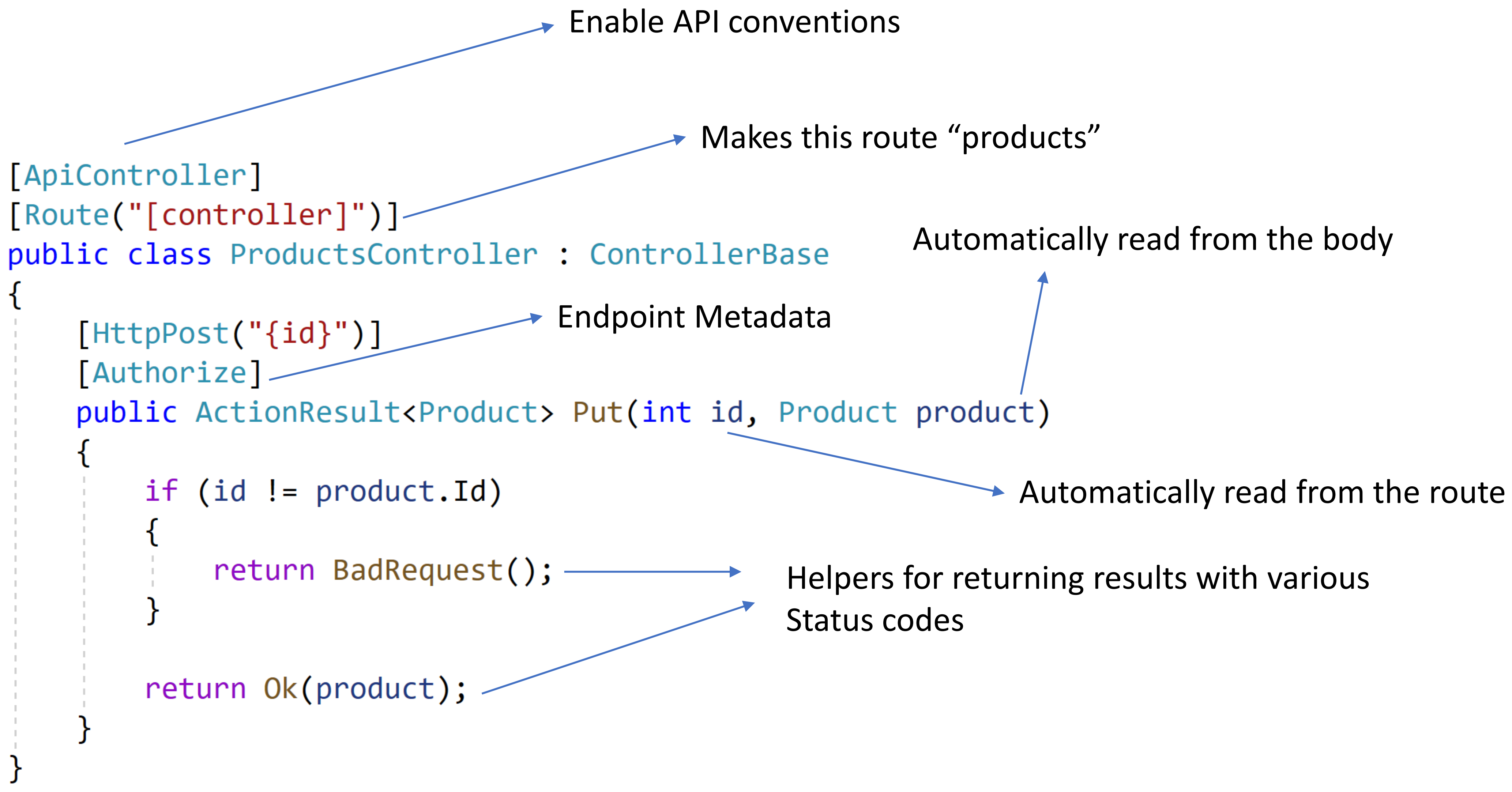
MVC for APIs

- Declarative programming model that provides productivity features for writing APIs
  - **Model binding** – Convert incoming request objects into strongly typed models
  - **Model validation** – Makes sure the bound models are valid
  - **Formatters** – Read and write objects from/to the request/response
  - **Filters** – Run custom logic on code that runs before/after application logic
  - **Content negotiation**
  - **OpenAPI** support via Swashbuckle
- Built on top of routing



```
[ApiController]
[Route("[controller]")]
public class ProductsController : ControllerBase
{
    [HttpPost("{id}")]
    [Authorize]
    public ActionResult<Product> Put(int id, Product product)
    {
        if (id != product.Id)
        {
            return BadRequest();
        }

        return Ok(product);
    }
}
```

Enable API conventions

Makes this route “products”

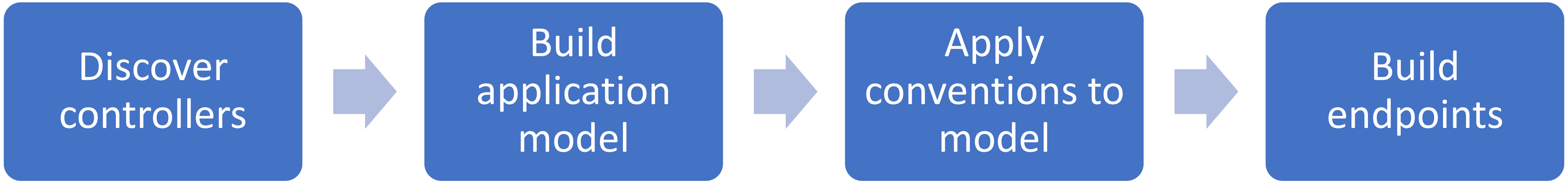
Automatically read from the body

Endpoint Metadata

Automatically read from the route

Helpers for returning results with various Status codes

MVC : Bootstrapping



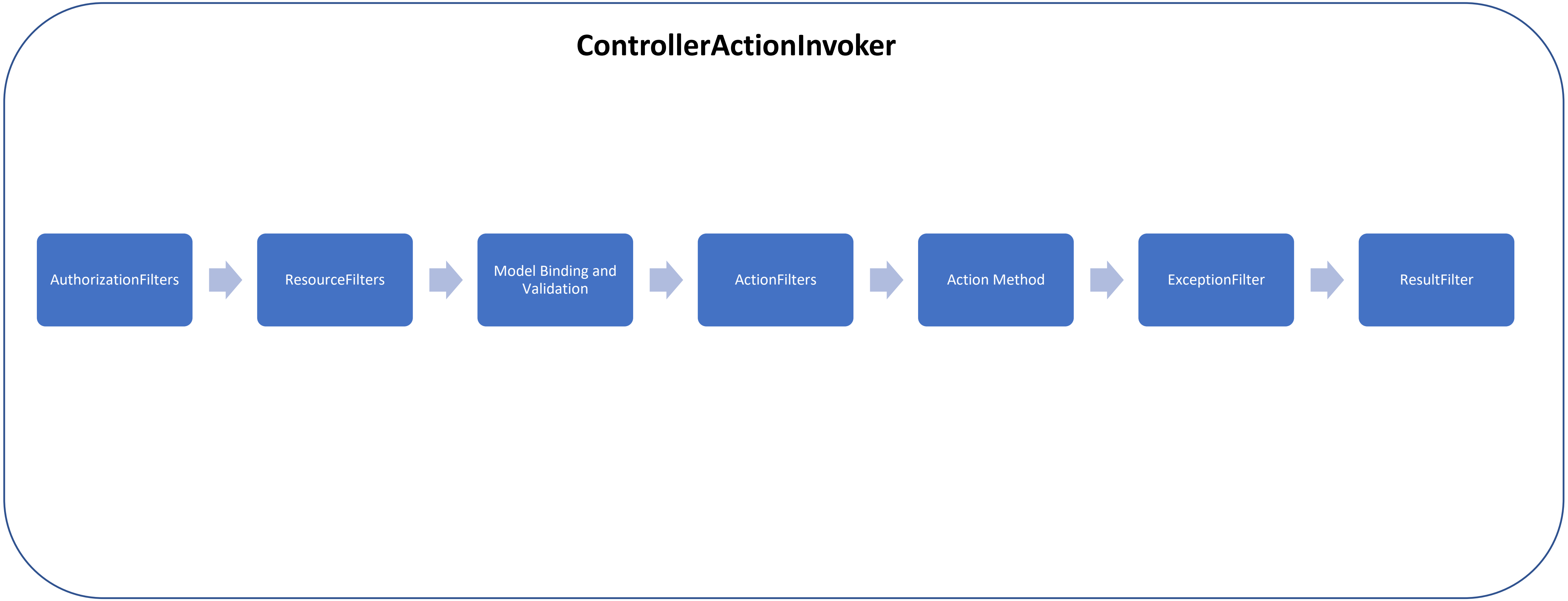
Discover controllers

Build application model

Apply conventions to model

Build endpoints

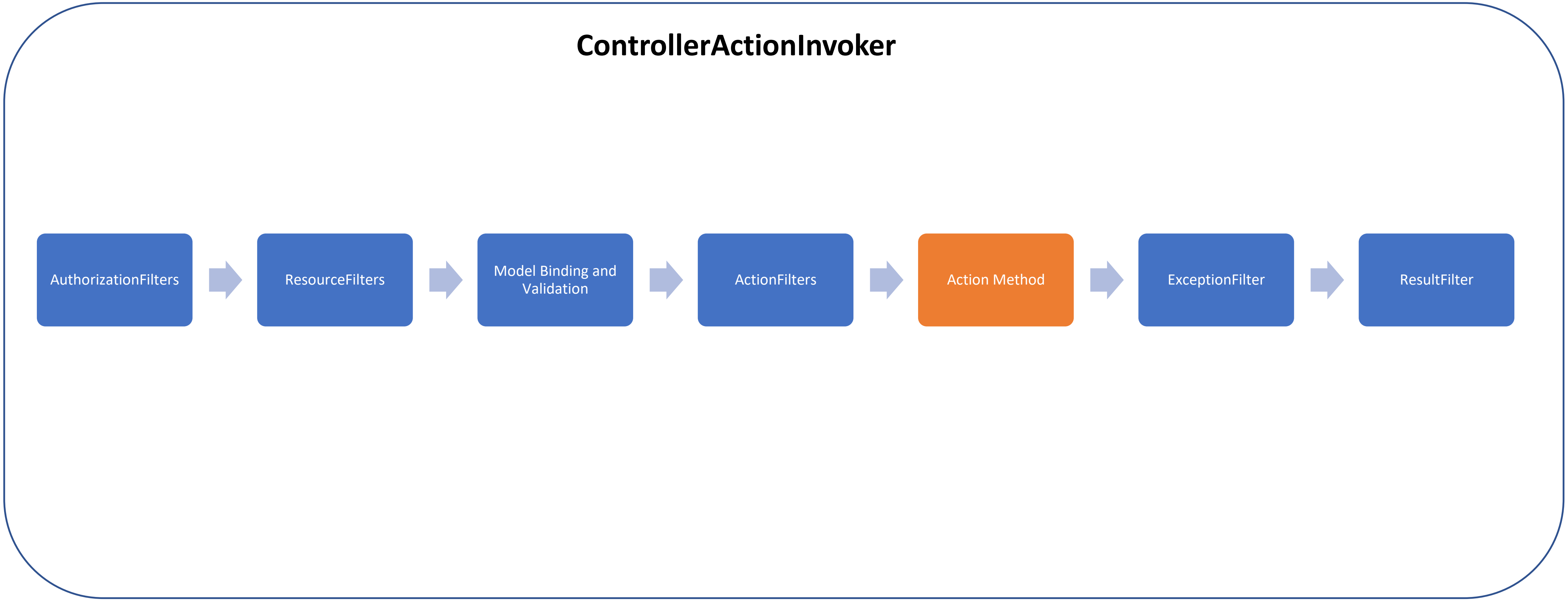
MVC : Request Processing



ControllerActionInvoker

AuthorizationFilters → ResourceFilters → Model Binding and Validation → ActionFilters → Action Method → ExceptionFilter → ResultFilter

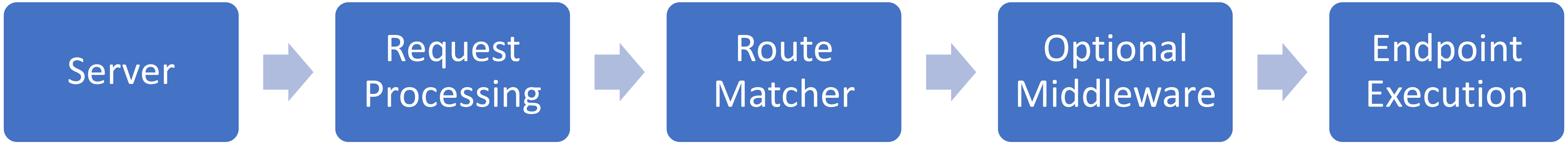
MVC : Request Processing



ControllerActionInvoker

AuthorizationFilters → ResourceFilters → Model Binding and Validation → ActionFilters → Action Method → ExceptionFilter → ResultFilter

Anatomy of a request: Review



Server

Request Processing

Route Matcher

Optional Middleware

Endpoint Execution

There’s more…

- ASP.NET Core is *huge*
- I couldn’t fit it all into this talk
- Hopefully, this gives you a good idea where to look for more details
- Read the source on https://github.com/dotnet/aspnetcore

Future: Houdini

- Project to make MVC’s disappear (hence the name)
  - Push productivity features into the core of the stack
- Make the jump from imperative routing to declarative MVC smaller
  - Improving the performance along the way

Questions?

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