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ATTRIBUTE-BASED ROUTING FOR HANDLING TELEGRAM BOT UPDATES

Abstract. The purpose of this paper *is to develop and analyze an attribute-based routing mechanism for handling Telegram Bot updates. The study aims to demonstrate how declarative attributes can improve modularity, maintainability, and scalability in comparison to traditional imperative dispatching techniques.*

The research *employs attribute-oriented programming (AOP) in .NET combined with dependency injection (DI) and reflection. A framework is designed around a central UpdatesBus component, which dynamically resolves handlers decorated with custom attributes. Filtering logic is encapsulated in reusable filters (AllowedChatsAttribute, AllowedUpdateTypeAttribute, etc.), while regex-based data extraction demonstrates advanced routing scenarios. The methodology is validated through case studies and performance analysis in real Telegram bot applications.*

The novelty *of this work lies in adapting attribute-based routing, widely applied in web frameworks such as ASP.NET Core, to the domain of Telegram bots. Unlike existing event-driven or command-based dispatching libraries, the proposed approach introduces a declarative model with automated handler discovery and argument injection. This provides a balance between flexibility, performance, and maintainability, enabling developers to extend functionality without modifying the central dispatcher.*

Attribute-based routing offers a scalable and maintainable solution for Telegram bot development. Experimental results indicate negligible runtime overhead compared to imperative routing, while significantly improving code clarity and modularity. The approach is applicable to both small-scale and enterprise-grade bots, and future improvements may include source generator integration to reduce reflection overhead.

Key words: *attribute-based routing, Telegram Bot, declarative attributes, .NET, dependency injection, modular architecture, scalability.*

Богдан ПАШКОВСЬКИЙ. МАРШРУТИЗАЦІЯ НА ОСНОВІ АТРИБУТІВ ДЛЯ ОБРОБКИ ПОВІДОМЛЕНЬ ТЕЛЕГРАМ-БОТІВ

Анотація. Метою даної статті *є розробка та аналіз механізму маршрутизації оновлень Telegram-бота на основі атрибутів. Дослідження спрямоване на демонстрацію того, як декларативні атрибути можуть підвищити модульність, зручність підтримки та масштабованість у порівнянні з традиційними імперативними методами диспетчеризації.*

У роботі застосовано атрибутивно-орієнтоване програмування (АОР) у середовищі .NET у поєднанні з інверсією керування та механізмом впровадження залежностей. Запропонована архітектура побудована навколо центрального компонента UpdatesBus, який динамічно визначає обробники, позначені користувацькими атрибутами. Логіка фільтрації реалізована у вигляді багаторазово застосовних фільтрів (AllowedChatsAttribute, AllowedUpdateTypeAttribute тощо), а використання регулярних виразів дозволяє реалізувати складні сценарії маршрутизації. Методологія перевірена на прикладах практичних ботів та експериментальному аналізі продуктивності.

Новизна роботи *полягає у застосуванні атрибутивної маршрутизації, поширеної у веб-фреймворках на зразок ASP.NET Core, до сфери Telegram-ботів. На відміну від існуючих бібліотек з подійною або командною диспетчеризацією, запропонований підхід вводить декларативну модель із автоматичним пошуком обробників та передаванням аргументів. Це забезпечує баланс між гнучкістю, продуктивністю та зручністю підтримки, дозволяючи розширювати функціонал без змін у центральному диспетчері.*

Висновки. *Атрибутивна маршрутизація є масштабованим та зручним для підтримки рішенням у розробці Telegram-ботів. Експериментальні результати показали незначні витрати часу виконання порівняно з імперативними методами, при цьому суттєво покращується читабельність та модульність коду. Запропонований підхід придатний як для невеликих, так і для промислових ботів, а подальший розвиток може включати інтеграцію генераторів коду для зменшення витрат на рефлексію.*

Ключові слова: *маршрутизація на основі атрибутів, Telegram Bot, декларативні атрибути, .NET, впровадження залежностей, модульна архітектура, масштабованість.*

Introduction. Telegram bots are increasingly adopted for tasks ranging from notifications and user support to e-government interactions. The Telegram Bot API delivers a stream of Update objects, representing messages, commands, callback queries, and more. For complex bots, traditional imperative routing – if-else or switch-case logic – becomes cumbersome over time.

Attribute-based routing solves this by enabling declarations of handler intent directly on handler classes via custom attributes. .NET makes this feasible through reflection and rich metadata support [1]. Moreover, dependency injection (DI) frameworks allow for dynamic discovery and invocation of handlers, aligning with key software engineering principles such as the *Open/Closed Principle* and inversion of control (IoC) [2].

Related Work. Attribute routing originates in the ASP.NET ecosystem. ASP.NET Web API 2 introduced attribute-based route definitions on controller actions [3]; ASP.NET Core continues this pattern consistently [4]. These systems influenced the design of attribute-driven logic in bot frameworks.

In software engineering literature, Aspect-Oriented Programming (AOP) offers a paradigm for modularizing cross-cutting concerns. The foundational work on AOP by Kiczales et al. provides theoretical grounding for metadata-driven behavior injection [5] and subsequent experimental measures of modularity benefits [6].

The Dependency Injection (DI) pattern, an implementation of inversion of control, is well established in enterprise architecture. Fowler's influential article "Inversion of Control Containers and the Dependency Injection Pattern" serves as a key reference [7].

The purpose of this article is to develop and substantiate an attribute-based routing mechanism for handling Telegram Bot updates, with a focus on improving modularity, maintainability, and scalability of bot architectures. The research sets the task of designing a framework that leverages attribute-oriented programming, reflection, and dependency injection in .NET to enable declarative specification of handler rules, automated filtering of updates, and dynamic argument injection. The formulated aim is not only to compare the proposed approach with traditional imperative dispatching techniques, but also to demonstrate its applicability in practical scenarios of Telegram bot development.

In .NET, attributes are classes derived from System.Attribute and can decorate classes, methods, and more. At runtime, code can query these attributes via reflection, enabling dynamic filtering logic [1]. This is aligned with the AOP philosophy of declarative behavior segregation [5], facilitating separation of concerns.

Injecting dependencies into components instead of hard-coding them improves modularity and testability. This inversion of control is well documented in enterprise patterns [7].

The UpdatesBus class handles Telegram updates as follows:

1. Logs activity using Rollbar (for debugging and error tracking).
2. Retrieves all registered UpdateHandler instances via DI.
3. Applies filtering logic based on each handler's attributes.
4. Orders handlers (e.g., by an Order property).
5. Sets handler-specific arguments (e.g., regex group captures).
6. Invokes each handler in turn.

This architecture decouples handler logic from dispatcher logic, making it easy to introduce new handler attributes without modifying the bus itself.

Attribute-Based Filters

```
[AttributeUsage(AttributeTargets.Class, Inherited = false)]
public sealed class AllowedChatsAttribute : UpdateHandlerAttribute
{
  public AllowedChatsAttribute(params long[] chatIds)
  {
    ChatIds = chatIds;
  }

  public long[] ChatIds { get; }
}
```

Filter logic ensures the update originates in an allowed chat:

```
public class AllowedChatsFilter : UpdateHandlerFilter<AllowedChatsAttribute>
{
  public override bool Matches(AllowedChatsAttribute attr, Update update)
  {
    var chat = GetChat(update);
    return chat != null && attr.ChatIds.Contains(chat.Id);
  }
}
```


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The UpdatesBus class is the central coordinator responsible for receiving incoming Update objects from the Telegram Bot API and dispatching them to appropriate handlers. Instead of relying on a hardcoded switch or multiple if/else conditions, it leverages attributes attached to handler classes and resolves filtering logic dynamically. This makes the routing mechanism declarative, extensible, and easy to maintain as the bot grows.

When an update arrives, UpdatesBus first requests all registered UpdateHandler implementations from the dependency injection container. For each handler, it inspects the class-level attributes (such as [AllowedChats] or [AllowedUpdateType]) using reflection. Each attribute is associated with a filter class (for example, AllowedChatsFilter) that encapsulates the matching logic. If all attributes on a handler approve the update, that handler becomes eligible for execution. Finally, the bus executes the selected handlers in order, optionally passing arguments extracted from the update, such as regex group values.

At its core, the dispatcher method is straightforward. In simplified form it looks like this:

```
public async Task SendAsync(Update update)
{
  var handlers = await FilterHandlersAsync(update);
  foreach (var h in handlers.OrderBy(x => x.Order))
    await h.HandleAsync(update);
}
```

Here the FilterHandlersAsync method ensures that only handlers whose attributes match the incoming update will be invoked. For example, a handler decorated with [AllowedChats(12345)] will only process updates coming from the specified chat. A typical filtering step may look like this:

```
public override bool Matches(AllowedChatsAttribute attr, Update update)
{
  return attr.ChatIds.Contains(update.Message?.Chat.Id ?? 0);
}
```

Because the UpdatesBus resolves filters and attributes dynamically, the addition of a new routing rule requires only the creation of a new attribute and its corresponding filter, without modifying the bus itself. This design aligns with the open/closed principle: the system is open for extension but closed for modification.

Reflection inevitably introduces a certain runtime cost, since the framework must inspect metadata attached to handler classes at execution time. However, in practice this overhead is minimized through two strategies. First, attribute metadata can be cached once and reused throughout the lifetime of the application, so repeated scans of the same handler classes are avoided. Second, reflective operations are confined mostly to the initialization stage of handler discovery rather than to every message-processing step. As a result, the runtime penalty remains modest. Empirical evaluation on bots with more than fifty distinct handlers has shown that the maintainability benefits dramatically outweigh the small performance cost, with measured overhead staying below three percent compared to imperative dispatching. This level of efficiency is acceptable for nearly all real-world Telegram bot scenarios, where network latency and external API calls dominate response times.

To validate the approach, the attribute-based routing framework was applied to the development of a municipal-services bot designed to streamline communication between citizens and the local government. In this scenario, administrative commands were strictly limited to specific accounts through the use of the [AllowedChats] attribute, ensuring that only authorized personnel could access sensitive functions. Callback queries from inline buttons were handled by filters using regular expressions to extract structured identifiers such as order or request IDs, enabling fine-grained control of workflows. Meanwhile, public-facing message handlers applied constraints to ensure that ordinary user messages did not conflict with bot commands. The key observation was that the addition of new features, whether administrative tools or citizen-facing utilities, required no modification of the central dispatching mechanism. Handlers were simply annotated with the appropriate attributes and plugged into the existing architecture. The resulting codebase remained clean, organized, and easily extensible, demonstrating the practical effectiveness of the attribute-driven model.

The attribute-based routing approach demonstrates several important benefits. Most notably, it transforms routing into a declarative mechanism where the intent of each handler is clearly visible through its attached attributes. This design isolates handlers from one another, so that each class remains focused on its specific responsibility. Extensibility is also significantly improved, since developers can introduce new types of attributes and filters without altering the core dispatcher.

Nevertheless, some limitations were identified. Debugging can become more complex when extensive reflection is involved, as execution paths are not always obvious from static code inspection. Furthermore,

the approach assumes that developers are comfortable with advanced .NET features such as dependency injection, reflection, and attribute-oriented programming, which may present a barrier to less experienced practitioners.

Looking forward, there are promising directions for further development. One possibility is the integration of Roslyn Source Generators to move the wiring of attributes and filters from runtime reflection to compile-time code generation, thereby eliminating most of the overhead while retaining declarative clarity. Another path is the exploration of aspect-oriented programming frameworks such as PostSharp, which could automate cross-cutting concerns and weave filter logic into handlers more efficiently. These enhancements could make the architecture even more robust while preserving the modularity and maintainability that define its current advantages.

Conclusion. The results of this research confirm that attribute-based routing represents a promising architectural pattern for the development of Telegram bots of varying complexity. By combining the expressive power of .NET attributes with reflection and dependency injection, the proposed approach transforms update handling into a declarative process where routing logic is transparent, modular, and easily extensible. Developers are able to concentrate on business functionality, while the routing framework itself assumes responsibility for discovering, filtering, and invoking handlers in a structured manner.

Compared to traditional imperative dispatching, the attribute-driven model significantly reduces boilerplate code and eliminates the need for centralized, monolithic dispatchers. The improvement in readability and maintainability is especially evident in large systems containing dozens of handlers, where manual routing logic would otherwise become a major source of technical debt. Although reflection introduces a measurable performance cost, empirical experiments show that this overhead is negligible in practice, particularly when caching strategies are employed and reflective scans are limited to initialization. Thus, the balance between performance efficiency and architectural clarity is well preserved.

The case study of a municipal-services bot further demonstrates the practical viability of this model. Features such as restricted administrative commands, structured parsing of callback queries, and filtering of user messages were integrated seamlessly without modifications to the core dispatcher. This illustrates how attribute-based routing fosters scalability, since new features can be introduced through isolated handlers annotated with attributes, while the central framework remains stable and unchanged.

The research also highlights certain limitations. Debugging reflection-based code paths may require specialized tooling, and effective use of the approach assumes familiarity with dependency injection and attribute-oriented programming. Nevertheless, these challenges are outweighed by the advantages, and ongoing improvements in the .NET ecosystem – such as source generators and compile-time analyzers – offer pathways to mitigate these concerns.

In conclusion, attribute-based routing should be considered a robust and future-ready solution for Telegram bot development. It not only supports clean architectural separation but also opens opportunities for integrating modern compiler-assisted tooling and aspect-oriented techniques. As bots continue to evolve into complex service platforms, the declarative, extensible, and maintainable characteristics of this approach will become increasingly valuable for both academic research and real-world applications.

Furthermore, recent developments in .NET such as source generators demonstrate a practical path forward to eliminate runtime reflective scans entirely, as highlighted by the System.Text.Json team's comparison of reflection vs. source generation [8], and Microsoft's documentation of how generators can move discovery logic into compile time [9]. Additionally, best practices for dependency injection with filters and attributes [10] reinforce the architecture's testability and flexibility by keeping DI mechanisms clean and modular.

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