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Issue Article

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ASYNCHRONOUS PROGRAMMING FOR IMPROVING WEB APPLICATION PERFORMANCE

***Abstract**: The article explores the potential of using asynchronous programming (AP) to enhance the performance of web applications. It analyzes the principles of AP and its advantages over synchronous data processing methods, for example, increased request processing speed. Drawing on the experience of various companies, it highlights that the application of asynchronous technologies enables server optimization, which is particularly important for high-load applications. The article also examines tools and frameworks that facilitate the implementation of AP. The importance of selecting appropriate methods to achieve optimal results under different conditions is emphasized, and potential errors along with ways to prevent and resolve them are discussed.*

***Key words**: asynchronous programming (AP), performance, web applications (WA), request processing, server optimization, high-load systems.*
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Introduction

Web applications (WA) are an integral part of the modern digital ecosystem, providing a wide range of services and interactions between users and real-time data. With the growing volume of information and increasing requirements for response speed, the problem of improving the performance of WA has become one of the key tasks for developers.

Traditional programming methods based on synchronous methods often lead to performance degradation, especially in conditions of intensive data exchange with the server. Asynchronous programming (AP) avoids these problems by providing the ability to perform tasks in parallel, thereby increasing overall performance and reducing response time.

The purpose of this article is to analyze how the use of AP affects the performance of WA, what methods and tools are used to implement asynchronous operations, and how their integration into the application architecture allows optimizing the operation of server and client structures.

Main part. Concepts of AP

A method known as AP organizes code in a way that allows tasks to be performed in parallel or independently, ensuring that the main program flow is not blocked. This approach is especially important in web development, where it is often necessary to interact with slow resources such as databases, file systems, and external API (fig. 1).

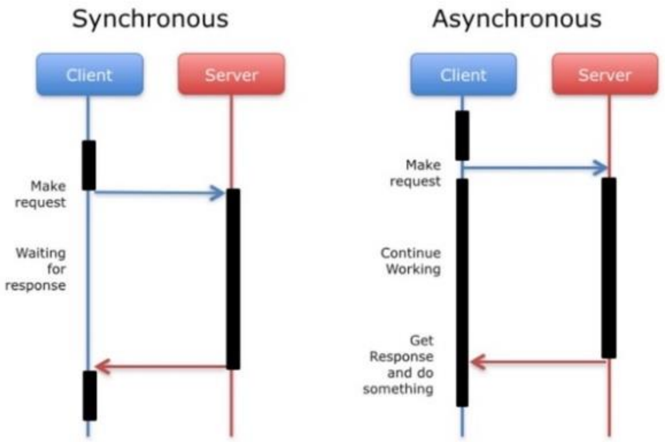

Figure 1. Comparison of synchronous and AP.

In synchronous programming, tasks are performed sequentially – each subsequent operation begins only after the previous one is completed. This approach is easy to implement, but it can lead to significant delays and performance degradation [1]. For example, if a web application makes a request to a database or an external API, it waits for this operation to complete before continuing with the next task. As a result, if the operation takes a long time (for example, network latency or slow database access), the entire system remains locked, which reduces the responsiveness of the application and can lead to a worse user experience.

A programming approach that allows running a command while continuing to perform other operations as the task executes is known as AP. It is based on the idea of an «event loop», which controls the execution of code, event processing and calling callback functions (fig. 2).

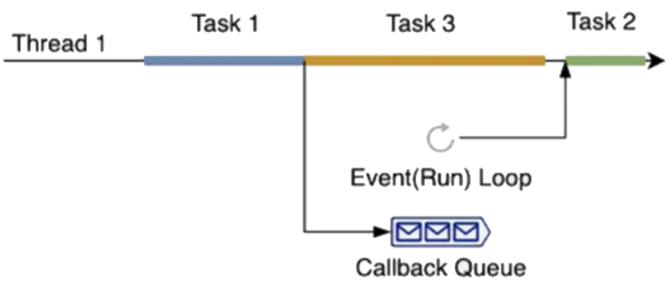

Figure 2. AP diagram.

When a task is initiated, it is registered in the «event loop» and executed once the resources required for its processing become available [2]. Meanwhile, the main thread continues working on other tasks, ensuring maximum resource utilization efficiency.

In this way, AP is a powerful technique that enhances the efficiency and responsiveness of applications, particularly in environments where multiple tasks must be managed concurrently. By leveraging non-blocking operations, AP allows developers to design systems that can handle multiple events simultaneously without waiting for each one to complete. This approach not only improves performance but also enhances the user experience by reducing delays and making applications more interactive and responsive.

Tools and technologies for AP

Modern WA require the use of various approaches and technologies to effectively manage asynchronous operations. Web developers can use a variety of tools and mechanisms to organize asynchronous code, while ensuring high performance and responsiveness of applications (table 1).

Table 1. Key tools and technologies of AP and their characteristics [3, 4].

Tool / Technology	Description	Application	Advantages
Promises	An object representing the result of an asynchronous operation. A promise can be in a state of pending, fulfilled, or rejected.	Managing asynchronous operations, such as API requests or database interactions.	Simplifies working with asynchronous code, supports chaining, and improves code readability.
Async/Await	Syntactic sugar over Promises that allows writing asynchronous code in a more linear style.	Used for executing asynchronous operations like data loading and I/O processing.	Improves code readability and manageability, reduces the complexity of error handling.
Threads	A mechanism for parallel execution of code, allowing tasks to be run in separate threads.	Performing computationally intensive tasks, parallel data processing, improving interface responsiveness.	Increases performance and avoids main thread blocking, especially in heavy computation tasks.
WebSockets	A protocol for establishing two-way communication between a client and server in real-time.	Used in chat applications, online games, monitoring systems, and other applications that require continuous data exchange.	Provides a persistent connection and asynchronous data transmission, reducing delays in communication.

Thanks to a variety of tools such as Promises, async/await, streams and web sockets, developers can flexibly choose approaches and optimize the architecture of the application depending on its specifics and requirements. AP not only improves performance, but also provides new opportunities for building complex and scalable systems such as microservice architectures or real-time applications, ensuring continuous and stable operation even under high loads.

However, the implementation of an asynchronous approach requires careful planning and proper organization of the code, since improperly managed asynchronous operations can lead to difficulties in debugging and maintaining applications.

Integration of asynchronous operations into WA architecture

When developing WA, it is important to take into account architectural principles that contribute to the effective use of AP. The most common approaches include the use of event-oriented architectures and microservices, as well as the use of special libraries and frameworks such as Node.js (in JavaScript) or asyncio (in Python). These tools support asynchronous code execution and allow you to implement operations without blocking the main thread, which ensures high productivity and development efficiency [5].

For example, asynchronous API requests in Node.js using async/await allow operations to be performed without blocking the main thread:

```
async function fetchData(url) {
  const response = await fetch(url);
  const data = await response.json();
  console.log(data);
}
fetchData('https://api.example.com/data');
```

This example demonstrates how the fetchData function retrieves data from the server, using await to wait for the operation to complete, which prevents blocking other processes.

Another popular approach is using asynchronous functions in Python with the asyncio library. This allows for efficient management of input/output operations:

```
import asyncio
import aiohttp
async def fetch_data(url):
  async with aiohttp.ClientSession() as session:
    async with session.get(url) as response:
      print(await response.text())
asyncio.run(fetch_data('https://api.example.com/data'))
```

In this example, the asynchronous function fetch_data makes an API request and outputs the result without blocking the execution of other tasks in the program.

To ensure real-time functionality and user interaction, WebSocket connections are often used, allowing data to be transmitted asynchronously:

```
const ws = new WebSocket('ws://example.com/socket');
ws.onopen = () => ws.send('Hello Server');
ws.onmessage = (message) => console.log(message.data);
```

In this example, the WebSocket connects to the server and sends data when the connection is established, allowing the application to remain responsive and maintain a persistent connection.

Thus, the use of AP and relevant tools such as async/await, asyncio, and WebSockets helps optimize web application architecture, enhancing performance and resilience under high loads.

Examples of successful implementation of AP in leading tech companies in the USA

The significant role of AP in enhancing performance and scalability of WA is supported by the successful track record of its adoption by major American corporations. **Netflix** efficiently delivers streaming content to millions of users worldwide by using asynchronous operations for communication between servers and clients. Asynchronous requests and parallel data processing reduce delays, guaranteeing smooth video playback even with high traffic [6].

Facebook uses AP to instantly update the news feed and send notifications, leveraging web sockets to maintain a constant connection between the client and the server. This allows the platform to quickly transmit data about new posts and interactions without delay, creating the effect of a «live» update, which is critically important for a social network with high user activity [7].

Uber implements asynchronous processes to handle real-time location data for drivers and passengers, ensuring that information on the map is updated and routes are calculated with minimal delay. Asynchronous calls allow the system to quickly update data and maintain the application's high responsiveness, which is crucial for fast service delivery and accurate arrival time calculations.

Amazon Web Services (AWS) actively uses asynchronous functions in its AWS Lambda cloud service, enabling developers to execute code in response to events (e.g., when data changes in a database) without blocking other processes. This increases the flexibility and scalability of services, allowing client companies to process thousands of requests simultaneously and adapt to load changes in real time.

These examples demonstrate how leading American companies are implementing AP to enhance the performance of their applications, ensuring parallel data processing and high responsiveness even under heavy loads.

Typical errors in AP

Despite its clear advantages, AP can lead to several issues that reduce the performance and stability of WA. One such error is **race conditions,** which occur when multiple asynchronous tasks simultaneously access a shared resource, resulting in incorrect outcomes. To prevent this, synchronization mechanisms such as locks, semaphores, or mutexes are used, especially when dealing with mutable data [8].

Another potential problem is **improper exception handling**, where errors in asynchronous tasks remain unhandled, leading to application instability. To avoid this, it is recommended to use `try/catch` constructs in `async/await` functions and `.catch()` methods when working with Promises to catch and handle errors promptly.

Memory and resource leaks are also a risk, occurring when the application creates too many asynchronous tasks at once, overwhelming the system and depleting resources. A solution to this can be using thread pools or limiting the number of tasks running concurrently.

In event-loop-based languages such as JavaScript, there is a risk of **blocking the event loop** when resource-intensive operations run on the main thread, which reduces application responsiveness. To minimize delays, heavy computations should be moved to separate threads or use web workers.

Improper use of asynchronous constructs, such as `async/await` and Promises, can also lead to unpredictable behavior if the code does not correctly wait for task completion. It is important to ensure proper syntax and use static code analyzers to detect errors.

Another issue is **poor timeout management**, particularly when working with slow external services [9]. If timeouts are not set, tasks may hang, degrading application performance. Implementing timeouts and retry mechanisms helps avoid such situations, ensuring tasks complete within reasonable time frames.

Thus, while AP requires careful planning and management, it can significantly improve the reliability, performance, and scalability of WA when organized correctly.

Conclusion

A powerful tool for enhancing the performance and responsiveness of WA, especially under high load conditions and when processing multiple parallel tasks, is AP. Approaches such as `async/await`, Promises, and WebSocket enable developers to build systems that efficiently manage events and execute tasks without blocking the main thread, ensuring smooth operation and minimizing delays. However, implementing AP requires careful architectural planning and proper task management to avoid common errors like race conditions, improper exception handling, and resource leaks.

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