⏱️ Cancellation Tokens in .NET

Deep Dive with Stephen Toub's Insights

💻 **Geeks Club**

📆 December 10, 2025

📋 Agenda

1. **Why Cancellation Matters** - Performance & Resource Management
2. **Evolution of Cancellation** - From `Thread.Abort` to `CancellationToken`
3. **The Modern Model** - Cooperative Cancellation
4. **Producer/Consumer Pattern** - `CancellationTokenSource` vs `CancellationToken`
5. **Implementation Deep Dive** - How it works under the hood
6. **The `volatile` Keyword** - Memory visibility
7. **Performance Evolution** - .NET Framework vs Modern .NET

❓ Why Cancellation?

> *"Some of the best optimizations possible are the ones where you just avoid work that you don't have to do."*
> *— Stephen Toub*

Key Benefits:

- ⚡ **Performance** - Avoid unnecessary work
- 💾 **Resource Management** - Free up resources for other tasks
- 👥 **User Experience** - Responsive applications

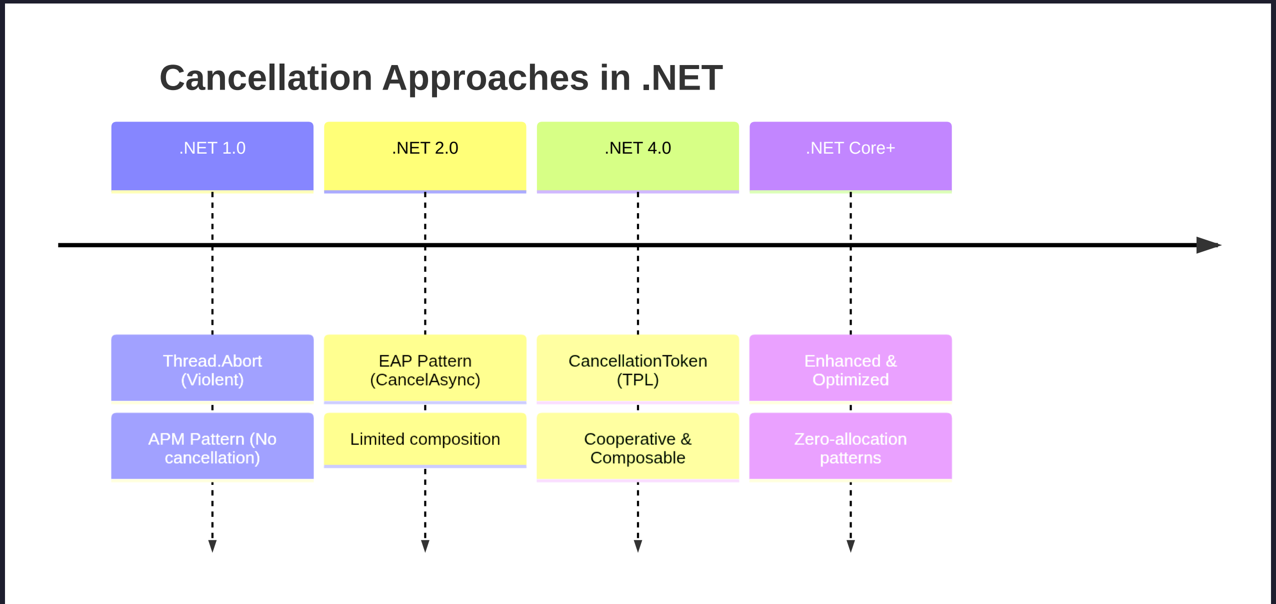
☠️ The Bad Old Days: Thread.Abort

```
// DON'T DO THIS - "Violent" cancellation
thread.Abort(); // ☠️ Extremely dangerous!
```

Problems:

- 💣 Could abort at ANY point in execution
- 🗄️ Data corruption risk
- 🔒 Lock state corruption
- 🚫 Removed in .NET Core (with exceptions)

📅 Evolution of Cancellation in .NET



🔗 APM Pattern - No Cancellation

```
// Asynchronous Programming Model (Begin/End)
stream.BeginRead(buffer, 0, buffer.Length, callback, state);

// ❌ No way to cancel!
// ❌ IAsyncResult has nothing about cancellation
// ❌ Thread.Abort doesn't help - there might not even be a thread!
```

The Problem:

> *"You might just have some little pending piece of work in memory waiting for a message to come back over a socket. There's nothing to 'shoot.'"*

📆 EAP Pattern - Limited Solution

```
// Event-based Asynchronous Pattern
var worker = new BackgroundWorker();
worker.DoWork += (s, e) => { /* work */ };
worker.RunWorkerAsync();

// Can cancel...
worker.CancelAsync();
```

⚠️ But Still Limited:

- Callback receives a boolean flag
- **No composition** - Can't flow cancellation to child operations
- Very short-lived pattern (.NET Framework 2.0 only)

🤝 The Modern Solution

Cooperative Cancellation with `CancellationToken`

🧩 CancellationToken - Composability

```
public async Task ProcessAsync(CancellationToken token)
{
    await DoWorkAsync(token);        // ✅ Pass it down
    await MoreWorkAsync(token);      // ✅ Everyone can observe
    await FinalWorkAsync(token);     // ✅ Entire chain is cancellable
}
```

Key Design Principles:

- 🔗 **Composable** - Thread it through all calls
- 👁️ **Observable** - Poll or register for callbacks
- 🤝 **Cooperative** - Not violent, everyone opts in

💻 Modern API Convention

```
// 99.999% of async APIs accept CancellationToken
await stream.ReadAsync(buffer, cancellationToken);
await httpClient.GetAsync(url, cancellationToken);
await dbContext.SaveChangesAsync(cancellationToken);
```

Static Analyzers Help:

- ⚠️ Warnings if you accept a token but don't forward it
- 🛡️ Enforces best practices

🚫 Why NOT Ambient/Implicit Cancellation?

Microsoft tried `CancellationScope` twice - **both times abandoned**

```
// ❌ This was considered and rejected
using (CancellationScope.Create())
{
    // Everything here would be "magically" cancellable
    await DoWorkAsync(); // No token needed?
}
```

🔥 Dangers of Ambient Cancellation

Problem	Description
🎲 **Dangerous Timing**	Cancellation at ANY point = back to "violent"
🔀 **Lack of Control**	Can't combine with timeouts easily
🗑️ **Resource Leaks**	Task to release resource might get cancelled
🔍 **Hard to Analyze**	Can't tell if you're in cancellable region

> *"With the explicit model, it's in your face."*

↔️ Propagating vs Checking

```
public async Task CopyAsync(Stream src, Stream dst,
                            CancellationToken ct)
{
    byte[] buffer = new byte[81920];
    int bytesRead;

    // Just PROPAGATE the token - don't check it yourself
    while ((bytesRead = await src.ReadAsync(buffer, ct)) > 0)
    {
        await dst.WriteAsync(buffer, 0, bytesRead, ct);
    }
}
```

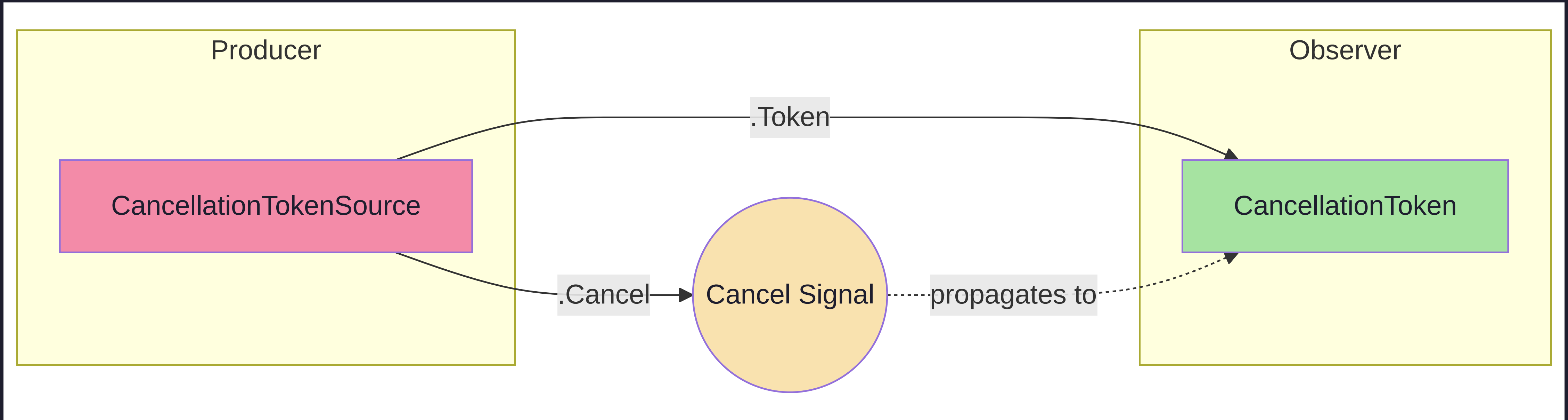
💡 Most code just forwards the token

The **leaf operations** (`ReadAsync`, `WriteAsync`) do the actual checking

✂️ Producer/Consumer Pattern

`CancellationTokenSource` vs `CancellationToken`

Separation of Concerns



💻 The Pattern in Action

```
// PRODUCER - Controls cancellation
var cts = new CancellationTokenSource();

// Start work with the token
_ = ProcessAsync(cts.Token);

// Later... request cancellation
cts.Cancel();

// CONSUMER - Only observes
async Task ProcessAsync(CancellationToken token)
{
    // ✅ Can check: token.IsCancellationRequested
    // ✅ Can throw: token.ThrowIfCancellationRequested()
    // ❌ Cannot cancel for others
}
```

❓ Why the Separation?

> *"It would be super surprising if one of [the methods receiving a token] actually caused cancellation to occur for everyone else."*

Who Produces?

- 🖥️ Server shutting down
- 👤 User clicking "Cancel"
- ⏰ Timeout timer firing
- 🔌 Connection closing

Who Consumes?

- 💻 Everything else! (99.999% of code)

🔧 Simplified Implementation

```
public readonly struct MyCancellationToken
{
    private readonly MyCancellationTokenSource _source;

    public bool IsCancellationRequested =>
        _source?.IsCancellationRequested ?? false;
}

public class MyCancellationTokenSource
{
    private volatile bool _isCancellationRequested;

    public MyCancellationToken Token => new(this);

    public void Cancel() => _isCancellationRequested = true;
}
```

🔬 The `volatile` Keyword

Memory Visibility in Multi-threaded Code

🐛 The Problem Without `volatile`

```
bool requested = false;

// Worker thread polling
while (!requested)
{
    // do work
}
```

✨ JIT Compiler "Optimization":

```
// Compiler can transform to:
if (!requested)
{
    while (true) { } // ♾️ INFINITE LOOP!
}
```

🙈 Why Does This Happen?

The JIT compiler can:

- 🗜️ **Coalesce reads** - "I already read it, why read again?"
- ⬆️ **Hoist checks** - Move invariant checks outside loops

```
// These three reads...
var r1 = someField;
var r2 = someField;
var r3 = someField;

// Can become just one!
var r1 = someField;
var r2 = r1;
var r3 = r1;
```

🛡️ `volatile` to the Rescue

```
private volatile bool _isCancellationRequested;
```

What `volatile` Does:

- 🚫 **Prevents read elimination** - Every read must happen
- 👁️ **Visibility guarantee** - All threads see updates
- 🔄 **Memory barrier** - Prevents reordering

What `volatile` Does NOT Do:

- 🔒 Does NOT replace locks
- 🔁 Does NOT synchronize operations
- 🛡️ Does NOT prevent race conditions

⚠️ When to Use `volatile`

> *"It is used if you are doing **lock-free programming**, which very few people should actually be doing."*
> *— Stephen Toub*

✅ Use if:

- Writing low-level, lock-free framework code
- Super high-performance scenarios
- You really know what you're doing

❌ Don't use if:

- Building normal applications
- "Text boxes over data" work

💬 Stephen's Advice

> *"If you see [volatile] too much, it means something's wrong."*

> *"I have a 200-something page blog post on performance improvements in .NET 10, and I don't know if `volatile` shows up there at all."*

📈 Performance Evolution

.NET Framework vs Modern .NET

🧪 The Benchmark

```
var cts = new CancellationTokenSource();

Parallel.For(0, 1_000_000, i =>
{
    using (cts.Token.Register(() => { }))
    {
        // Register and immediately unregister
    }
});
```

🔄 Surprising Results

Metric	.NET Framework	.NET 10
Speed	~25-30 ns/op 🏆	~50-60 ns/op
Memory	56 bytes/op	**0 bytes** 🏆

💡 **Wait... Framework is FASTER?**

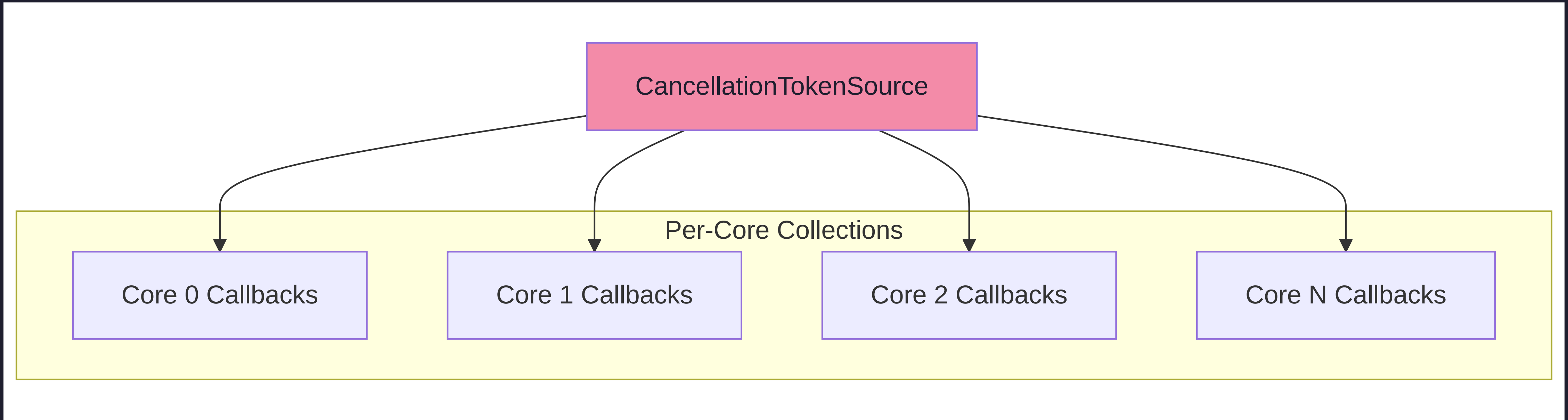
📜 What Were They Optimizing For?

.NET Framework Era (~2010):

- 🔬 "Many-core" future (32, 64, 1024 cores!)
- 🗺️ Parallel algorithms (Quicksort, PLINQ)
- 👥 Thousands of parallel registrations

```
// Imagined scenario: Parallel Quicksort
// Many cores registering/unregistering simultaneously
Parallel.ForEach(partitions, partition =>
{
    QuickSort(partition, cancellationToken);
});
```

🏗️ .NET Framework Implementation



- 🔓 Lock-free algorithms
- 📚 Per-core data structures
- 🔄 No synchronization between cores

💻 Modern Reality

How CancellationToken is Actually Used:

```
// ASP.NET Request - Sequential, not parallel!
app.MapGet("/api/data", async (CancellationToken ct) =>
{
    var data = await db.QueryAsync(ct);      // 1
    var result = await Transform(data, ct); // 2
    await cache.SetAsync(result, ct);       // 3
    return result;
});
```

➡️ Sequential register/unregister, not parallel

⚖️ The Trade-off

Aspect	.NET Framework	Modern .NET
Algorithm	Complex, lock-free	Simple, uses locks
Parallel Perf	🏆 Faster	Slower
Serial Perf	Slower	🏆 Faster
Memory	Allocates per op	🏆 Zero allocation (pooling)
Maintainability	Complex	Simple

🧠 Philosophy of Optimization

> *"The vast majority of optimizations are **trade-offs**. They're penalizing something you expect to be relatively rare in exchange for making something you expect to be more common faster."*
> *— Stephen Toub*

👓 **With 20/20 Hindsight:**

- Parallel register/unregister is rare
- Serial async I/O is the dominant pattern
- Zero allocation > raw speed for most scenarios

🎓 Key Takeaways

📋 Summary

1. 🤝 **Cooperative cancellation** is the .NET way - not violent
2. 🧩 **CancellationToken** enables composition across async boundaries
3. 🛡️ **Separation of concerns**: Source produces, Token observes
4. ➡️ **Just propagate** the token - let leaf operations check it
5. ❗ **Explicit > Implicit** - Ambient cancellation was tried and rejected
6. 🔬 `volatile` is for visibility, not synchronization
7. 📈 **Optimizations are trade-offs** - Modern .NET optimizes for real-world patterns

📚 Resources

- 🎬 Deep.net - Cancellation Tokens with Stephen Toub
- 📝 Stephen Toub's Performance Blog Posts
- 📖 Microsoft Docs: Cancellation in Managed Threads

💬 Questions?

Thank you! ❤️