



Part II

1

Agenda

- Deep dive into coroutines
- Coroutine Cancellation
- Coroutine Exception Handling
- Structured Concurrency

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Main Building Blocks of Coroutines

- CoroutineScope
- CoroutineContext } *What's the difference?*
 - Job
 - Coroutine Dispatchers
 - CoroutineName
 - CoroutineExceptionHandler
- CoroutineBuilder

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Coroutines ...

- A **coroutine** is an instance of a *suspendable* computation.
 - Computations can be *suspended* without blocking the thread at suspending points, and can later be resumed.
- Empowered **Runnable**
 - A coroutine can be introduced as a sequence of well managed sub-tasks, each of which can be suspended and resumed.



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Coroutines ...

- To some extent, coroutines can be thought of as *light-weight threads*;
 - Executed within threads
 - Can switch contexts

How many threads we can have?

100 😊

1000 😄

10 000 😞

100 000 🤯

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Threads vs. Coroutines

```
fun main() {  
    repeat(200_000) {  
        thread {  
            println("Hello thread $it")  
        }  
    }  
}
```

Supposed to crash, but ...



136615 ms

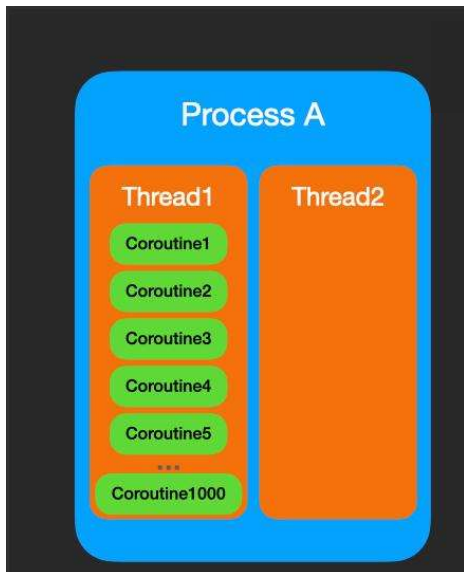
```
fun main() = runBlocking{  
    repeat(200_000) {  
        launch {  
            println("Hello coroutine $it")  
        }  
    }  
}
```

It is not just Ok, but it also very convenient to create coroutines as you need them, since they are so cheap.

437 ms

6

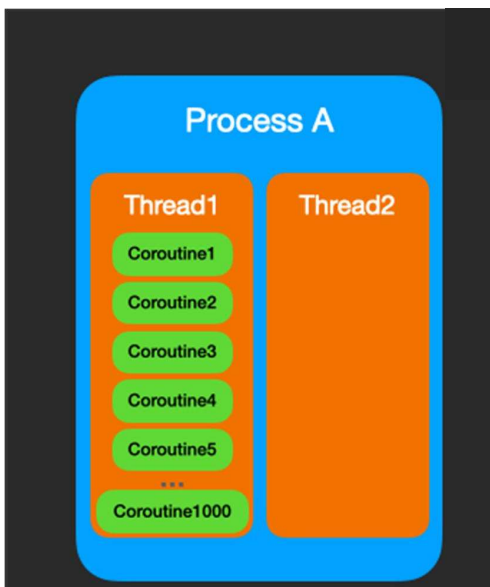
Coroutines ...



You can execute many coroutines in a single thread.

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Coroutines ...



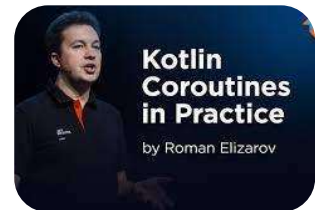
A coroutine can switch between threads.

A coroutine can suspend from one thread and resume from another thread.

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Coroutines in details

- Based on the abstraction of *Continuation Passing Style (CPS)*
- Actually, it is a sequence of *callbacks* behind the scenes.
- In kotlin, coroutine suspension/resume is implemented as a *state machine*.



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Continuation Passing Style (CPS)

```
fun add(a: Int, b: Int): Int = a + b
fun mult(a: Int, b: Int): Int = a * b
```

```
fun <R> addCPS(a: Int, b: Int, cont: (Int) -> R): R {
    return cont(add(a, b))
}
fun <R> multCPS(a: Int, b: Int, cont: (Int) -> R): R {
    return cont(mult(a, b))
}
```

```
// (3 + 4) * (5 + 6)
fun doWork(): Int {
    // label1
    val step1 = add(3, 4)
    // label2
    val step2 = add(5, 6)
    // label3
    val step3 = mult(step1, step2)
    return step3
}
```

```
fun doWorkCPS(): Int =
    addCPS(3, 4) { step1 ->
        addCPS(5, 6) { step2 ->
            multCPS(step1, step2) { step3 ->
                step3
            }
        }
    }
```

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Continuation Passing Style (CPS)

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                step3
            }
        }
    }
```

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Continuation Passing Style (CPS)

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fun add(a: Int, b: Int): Int = a + b
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            }
        }
    }
```

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Continuation Passing Style (CPS)

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fun add(a: Int, b: Int): Int = a + b
fun mult(a: Int, b: Int): Int = a * b
```

```
fun <R> addCPS(a: Int, b: Int, cont: (Int) -> R): R {
    return cont(add(a, b))
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```

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    return step3
}

fun doWorkCPS(): Int =
    addCPS(3, 4) { step1 ->
        addCPS(5, 6) { step2 ->
            multCPS(step1, step2) { step3 ->
                step3
            }
        }
    }
```

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Continuation

The Kotlin compiler converts the suspend function to an optimized version of **callbacks** using a **Finite State Machine**.

kotlin

```
suspend fun createPost(token: Token, item: Item): Post { ... }
```

Java/JVM

```
Object createPost(Token token, Item item, Continuation<Post> cont) { ... }
```

```
interface Continuation<in T> {
    val context: CoroutineContext
    fun resumeWith(result: Result<T>)
}
```

Continuation is a generic callback interface

The way suspend functions communicate with each other

```
inline fun <T> Continuation<T>.resume(value: T): Unit =
    resumeWith(Result.success(value))
```

```
inline fun <T> Continuation<T>.resumeWithException(exception: Throwable): Unit =
    resumeWith(Result.failure(exception))
```

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Convert to CPS Style

```
suspend fun postItem(item: Item) {  
    val token = requestToken()  
    val post = createPost(token, item)  
    showPost(post)  
}
```

```
fun postItem(item: Item) { _ ->  
    requestToken { token ->  
        createPost(token, item) { post ->  
            showPost(post)  
        }  
    }  
}
```

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CPS Transform

- The compiler replaces the `suspend` modifier with the extra parameter completion (of type `Continuation<Any?>`) that will be used to communicate the result of the suspend function to the coroutine that called it.

```
fun postItem(item: Item, completion: Continuation<Any?>) {  
    val token = requestToken()  
    val post = createPost(token, item)  
    completion.resume(showPost(post))  
}
```

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CPS Transform

- Every *suspension point* will be represented as a *state* in the finite state machine. These states are represented with *labels* by the compiler.

```
fun postItem(item: Item, completion: Continuation<Any?>) {  
    // Label 0 -> first execution  
    val token = requestToken()  
    // Label 1 -> resumes from requestToken  
    val post = createPost(token, item)  
    // Label 2 -> resumes from createPost  
    completion.resume(showPost(post))  
}
```

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CPS Transform

```
fun postItem(item: Item, completion: Continuation<Any?>) {  
    when(label) {  
        0 -> { // Label 0 -> first execution  
            requestToken()  
        }  
        1 -> { // Label 1 -> resumes from requestToken  
            createPost(token, item)  
        }  
        2 -> { // Label 2 -> resumes from createPost  
            completion.resume(showPost(post))  
        }  
        else -> throw IllegalStateException(...)  
    }  
}
```

The compiler will use the same `Continuation` object in the function to share information between states.

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CPS Transform

The compiler will create a private class that

- 1) holds the required data and
- 2) calls the `postItem` recursively to resume execution.

```
fun postItem(item: Item?, completion: Continuation<Any?>) {
    class PostItemStateMachine(
        completion: Continuation<Any?> // callback to the fun that called postItem
    ): CoroutineImpl(completion) {
        // Local variables of the suspend function
        var token: Token? = null
        var post: Post? = null
        // Common objects for all CoroutineImpls
        var result: Any? = null
        var label: Int = 0
        // this function calls the `postItem` again to trigger the
        // state machine (label will be already in the next state)
        override fun invokeSuspend(result: Any?) {
            this.result = result // result of the previous state's computation
            postItem(null, this)
        }
    }
    ...
}
```

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```
fun postItem(item: Item?, completion: Continuation<Any?>) {
    ...
    val continuation = completion as? PostItemStateMachine
    ?: PostItemStateMachine(completion)

    when(continuation.label) {
        0 -> {
            throwOnFailure(continuation.result) // Checks for failures
            // next time this coroutine is called, it should go to state 1
            continuation.label = 1
            // The continuation object is passed to requestToken to resume
            // this state machine's execution when it finishes
            requestToken(continuation)
        }
        1 -> {
            throwOnFailure(continuation.result)
            // Gets the result of the previous state
            continuation.token = continuation.result as Token
            continuation.label = 2
            createPost(continuation.token, item, continuation)
        }
        ... // leaving out the last state on purpose
    }
}
```

Check if

- 1) it's the first time called or
- 2) resumed from a previous state.

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```

fun postItem(item: Item?, completion: Continuation<Any?>) {
    ...
    when(continuation.label) {
        ...
        2 -> {
            // Checks for failures
            throwOnFailure(continuation.result)
            // Gets the result of the previous state
            continuation.post = continuation.result as Post
            // Resumes the execution of the function that called this one
            continuation.cont.resume(showPost(continuation.post))
        }
        else -> throw IllegalStateException(...)
    }
}

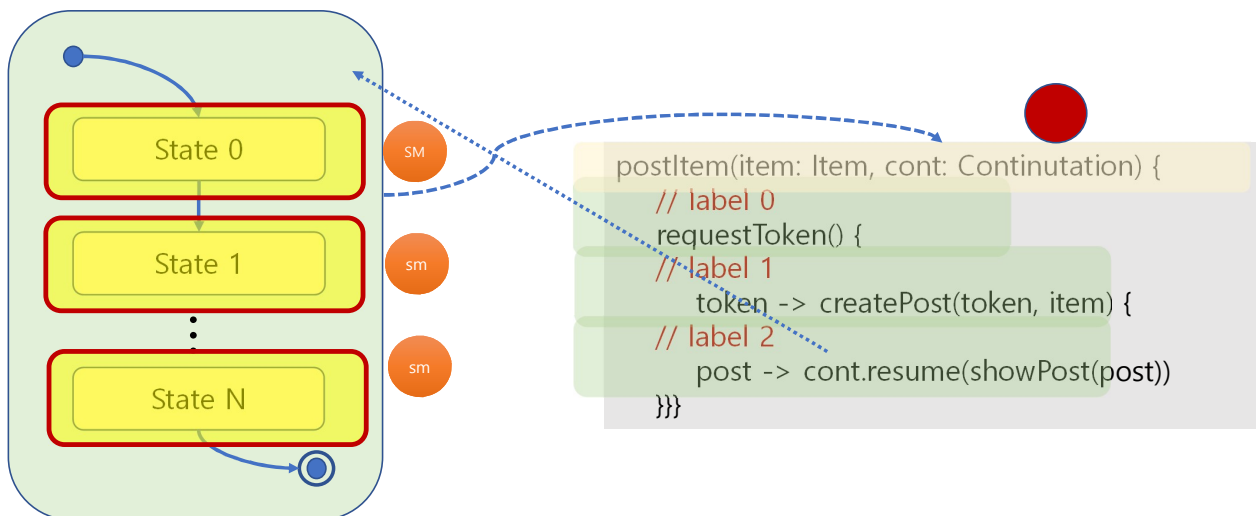
```

The last state is different since it has to resume the execution of the function that called this one, it calls resume on the `cont` variable stored (at construction time) in `PostItemStateMachine`:

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How Suspending Functions Evaluated?

State Machine (= Continuation)



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CoroutineContext vs. CoroutineScope

<https://elizarov.medium.com/coroutine-context-and-scope-c8b255d59055>

- Different uses of physically **near-identical things** are usually accompanied by giving those things **different names** to **emphasize the intended purpose**. Depending on the use, seamen have a dozen or more words for a rope though it might materially be the same thing. ([Wikipedia on Hindley-Milner type system](#))



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CoroutineContext

- Every coroutine has a **coroutine context** which is *immutable*.
 - **CoroutineContext** can be inherited from parent to child.
- Accessible via **coroutineContext** property:

```
fun main() = runBlocking {  
    println(Thread.currentThread().name)  
    println("${coroutineContext}")  
    println("${coroutineContext[Job]}")  
    println("${coroutineContext[ContinuationInterceptor]}")  
}
```

```
main  
[BlockingCoroutine{Active}@335eadca, BlockingEventLoop@210366b4]  
BlockingCoroutine{Active}@335eadca  
BlockingEventLoop@210366b4
```

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Elements of CoroutineContext

- The `CoroutineContext` is an indexed set of elements that define the behavior of a coroutine:
 - `Job`: controls the **lifecycle** of the coroutine.
 - `CoroutineDispatcher`: **dispatches** work to the appropriate thread.
 - `CoroutineName`: **name** of the coroutine, useful for debugging.
 - `CoroutineExceptionHandler`: handles **uncaught exceptions**.
- Each `Element` can be combined with plus('+') operator.

```
launch(Dispatchers.IO + CoroutineName("test")) {  
    ...  
}
```

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Job

- A coroutine itself is represented by a `Job`.
- Responsible for *coroutine's lifecycle*, *cancellation*, and *parent-child relations*. A current job can be retrieved from a current coroutine's context:

```
println("My job is: ${coroutineContext[Job]}")
```

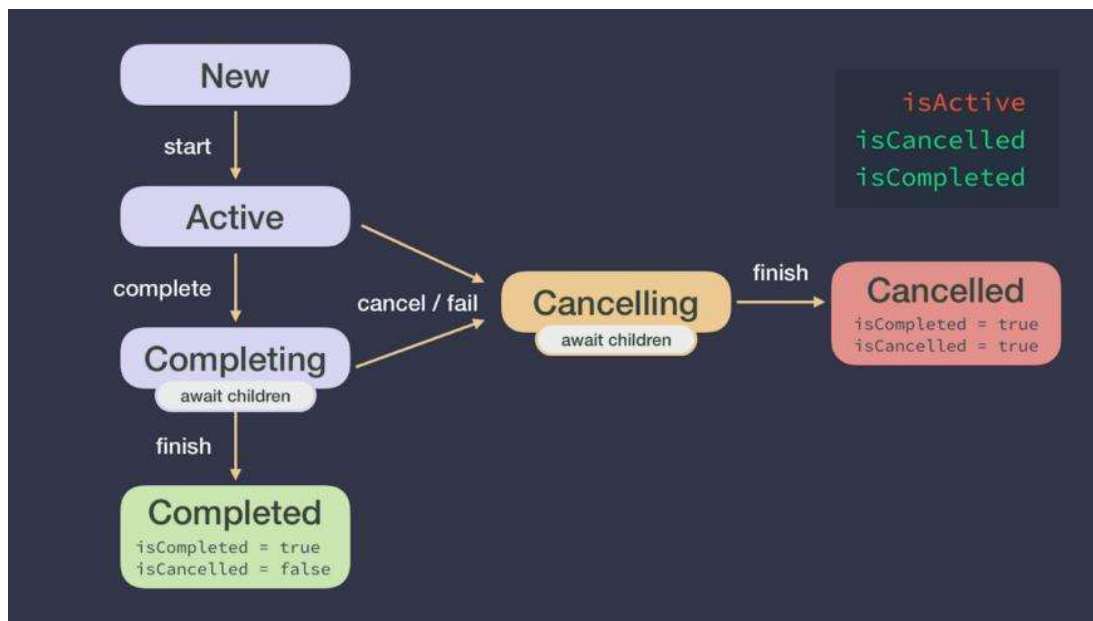
- Coroutine builders (`launch` or `async`) returns a `Job` instance that uniquely identifies the coroutine.
- You can also pass a `Job` to a `CoroutineScope` to keep a handle on its lifecycle. Otherwise, `default` Job created.

```
val scope = CoroutineScope(Job())
```

- `SupervisorJob` is a special kind of `Job` (*later!*)

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Job lifecycle



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State	<u><code>isActive</code></u>	<u><code>isCompleted</code></u>	<u><code>isCancelled</code></u>
<i>New</i> (optional initial state)	false	false	false
<i>Active</i> (default initial state)	true	false	false
<i>Completing</i> (transient state)	true	false	false
<i>Cancelling</i> (transient state)	false	false	true
<i>Cancelled</i> (final state)	false	true	true
<i>Completed</i> (final state)	false	true	false

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CoroutineScope

- Every coroutine must be created inside the **coroutine scope** to control lifecycle.

```
interface CoroutineScope {  
    // The context of this scope.  
    public val coroutineContext: CoroutineContext  
}
```

- A **CoroutineScope** keeps track of any coroutine created using **launch** or **async**.
- Coroutines can be canceled by calling **scope.cancel()** at any time.
- Predefined scopes in Android: **viewModelScope** and **lifecycleScope**

```
val scope = CoroutineScope(CoroutineContext(Job() + Dispatchers.Main))  
val job = scope.launch {  
    // new coroutine  
}
```

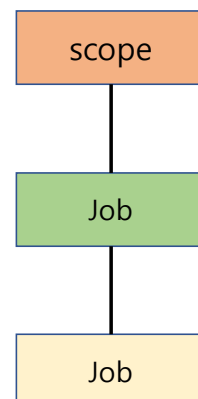
CoroutineScope

Keep track of coroutines
Ability to cancel ongoing work
Notified when a failure happens

Task Hierarchy

- Since a **CoroutineScope** can create coroutines and you can create more coroutines inside a coroutine, an implicit task hierarchy is created.

```
val scope = CoroutineScope(CoroutineContext(Job() + Dispatchers.Main))  
val job = scope.launch {  
    // New coroutine with CoroutineScope as a parent  
    val result = async {  
        // New coroutine that has the coroutine  
        // started by launch as a parent  
    }.await()  
}
```



What's the CoroutineContext of a new coroutine?

- Whenever a new coroutine is created using `launch` or `async`, a **new instance** of `Job` will be created, allowing us to control its lifecycle.
- The rest of the elements will be **inherited from** the `CoroutineContext` of its parent.

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Watch out quiz! Who's my parent?

Given the following code snippet, can you identify what kind of `Job` "child 1" has as a parent?

`Job` or `SupervisorJob`?

```
val scope = CoroutineScope(Job())
scope.launch(SupervisorJob()) {
    // coroutine -> can suspend

    launch {
        // Child 1
    }

    launch {
        // Child 2
    }
}
```

Job

Job

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Watch out quiz! Who's my parent?

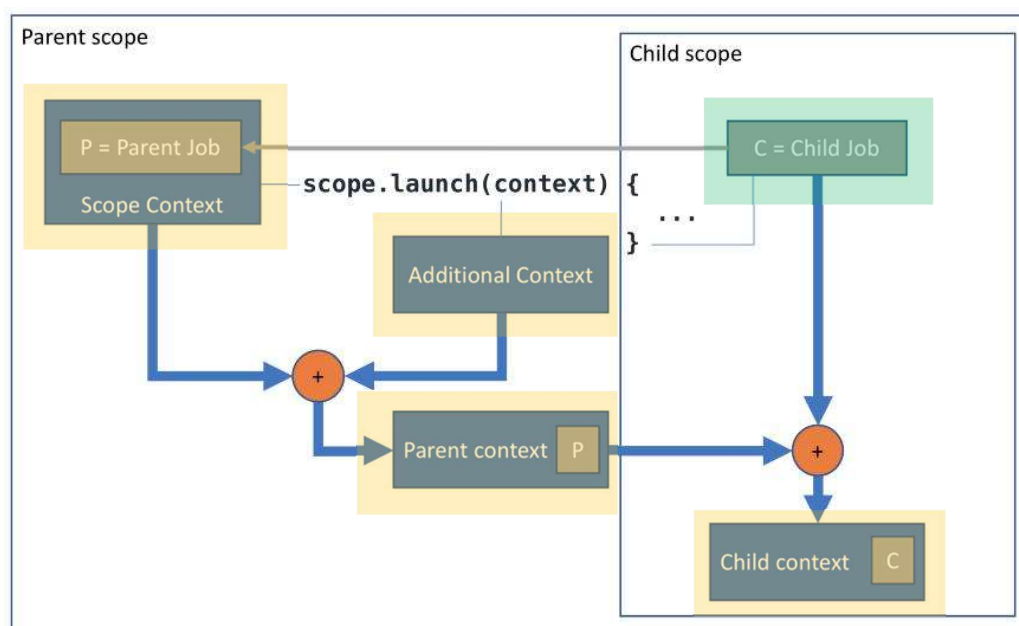
Given the following snippet of code, can you identify what kind of `Job` “child 1” has as a parent?

`Job` or `SupervisorJob`?

```
val scope = CoroutineScope(Job())
scope.launch(SupervisorJob()) {
    // coroutine -> can suspend
    launch {
        // Child 1
    }
    launch {
        // Child 2
    }
}
```

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Parent Scope vs Child Scope



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Parent CoroutineContext explained

- Child's parent `CoroutineContext` can be different from that of the parent:

| *Parent context = Defaults + inherited `CoroutineContext` + arguments*

Where:

- Some elements have **default** values: `Dispatchers.Default` is the default of `CoroutineDispatcher` and "coroutine" the default of `CoroutineName`.
- The **inherited `CoroutineContext`** is the `CoroutineContext` of the `CoroutineScope` or coroutine that created it.
- **Arguments** passed in the coroutine builder will take precedence over those elements in the inherited context.

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CoroutineContext of the Parent

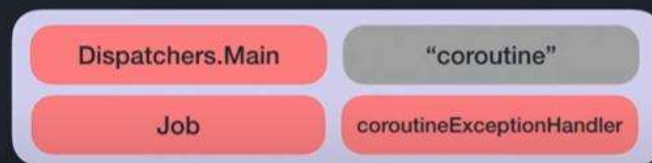


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CoroutineContext of the Parent

```
// Defaults: Dispatchers.Default, "coroutine"
val scope = CoroutineScope(
    Job() + Dispatchers.Main + coroutineExceptionHandler
)
```

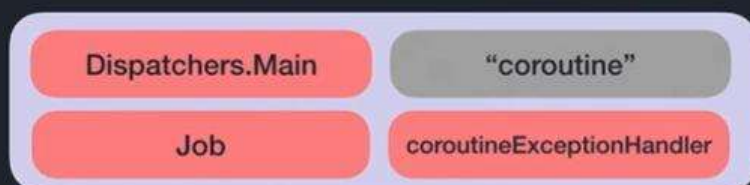
Parent context



Every coroutine started by this `CoroutineScope` will have at least those elements in the `CoroutineContext`. `CoroutineName` is gray because it comes from the default values.

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Parent context

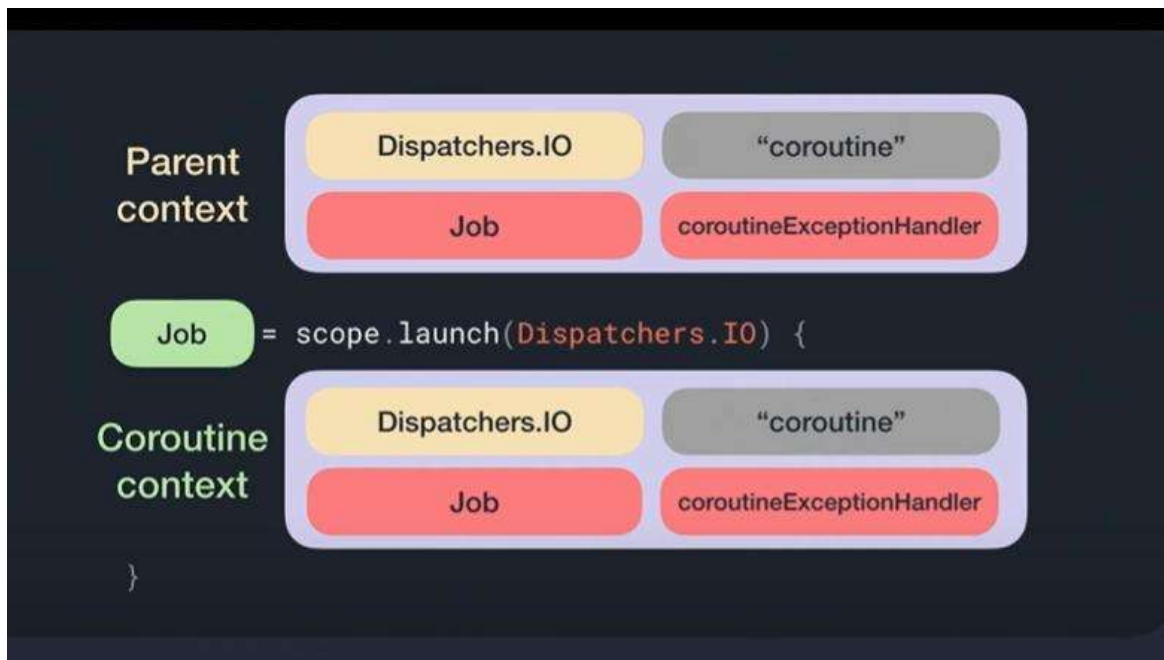


```
val job = scope.launch(Dispatchers.IO) {
    // CoroutineContext?
```

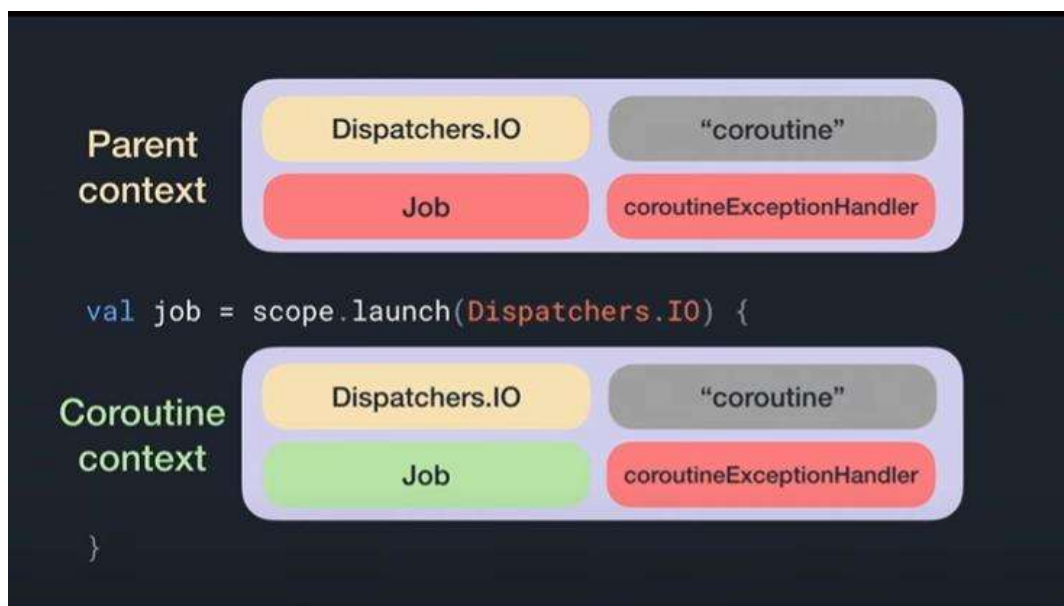
New coroutine context = parent `CoroutineContext` + `Job()`

```
}
```

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The Job in the CoroutineContext and in the parent context will never be the same instance as a new coroutine always get a new instance of a Job

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Dispatchers

- `Dispatchers.Default`
 - CPU-intensive computation
- `Dispatchers.Main`  Exception in thread "DefaultDispatcher-worker-3" java.lang.IllegalStateException: **Module with the Main dispatcher is missing.** Add dependency providing the Main dispatcher, e.g. 'kotlinx-coroutines-android'
 - UI events
 - Need to include dependencies like Android, Swing, JavaFX, etc.
- `Dispatchers.IO`
 - Network IO, Disk IO, etc.
- `Dispatchers.Unconfined`
 - Not recommended

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Coroutine Scope Builders

- `CoroutineScope` (*already covered*)
- `MainScope`
- `GlobalScope`
- `viewModelScope`/`lifecycleScope` in Android (*will talk later!*)
- `coroutineScope`/`supervisorScope` (*will talk in coroutine scope functions*)

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MainScope

- Creates the main **CoroutineScope** for UI components.

```
public fun MainScope(): CoroutineScope =  
    ContextScope(SupervisorJob() + Dispatchers.Main)
```

```
class MyActivity : AppCompatActivity() {  
    private val scope = MainScope() + CoroutineName("MyActivity")  
  
    override fun onDestroy() {  
        super.onDestroy()  
        scope.cancel()  
    }  
}
```

kotlinx-coroutines-android — for Android Main thread dispatcher
kotlinx-coroutines-javafx — for JavaFx Application thread dispatcher
kotlinx-coroutines-swing — for Swing EDT dispatcher

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! GlobalScope

```
public object GlobalScope : CoroutineScope {  
    // Returns [EmptyCoroutineContext].  
    override val coroutineContext: CoroutineContext  
        get() = EmptyCoroutineContext  
}
```

- Not associated with any **Job** and launches **top-level** coroutines.
- Makes the coroutine lifecycle bound to the lifecycle of the **application**.
- An option when you don't care about coroutine results, posting to the UI thread or about the job completion.
- Use when you don't want to bind the jobs to the lifecycle of a certain object instance, like **Activity**, **Fragment**, **ViewModel** etc. in Android.

But, lose all the benefits you get from structural concurrency

The Reason to avoid GlobalScope

<https://medium.com/@elizarov/the-reason-to-avoid-globalscope-835337445abc>

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Coroutine Builders (Revisited)

- launch
 - async
- } Coroutine scope extension functions
- runBlocking – regular functions
 - runBlockingTest – regular functions (*later!*)
 - withContext – suspending function

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Coroutine Scope Functions

Functions that create a scope and behave similar to `coroutineScope`:

- **coroutineScope**
- **supervisorScope** is like `coroutineScope` using `SupervisorJob` instead of `Job`.
- **withContext** is `coroutineScope` that can modify coroutine context.
- **withTimeout/withTimeoutOrNull** is `coroutineScope` with a timeout.

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Motivation for coroutineScope

- Imagine that in a suspending function you need to concurrently get data from two (or more) endpoints.

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Approaches before ... sequential

- The first approach is calling suspending functions from a suspending function. The problem with this solution is that it is not concurrent.

```
// Data loaded sequentially, not simultaneously
suspend fun getUserProfile(): UserProfileData {
    val user = getUserData()
    val notifications = getNotifications()

    return UserProfileData(
        user = user,
        notifications = notifications,
    )
}
```

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Approaches before ...

- To make two suspending calls concurrently, the easiest way is by wrapping them with `async`. But, using `GlobalScope` is not a good idea.

```
// DON'T DO THAT
suspend fun getUserProfile1(): UserProfileData {
    ↗ val user = GlobalScope.async { getUserData() }
    ↗ val notifications = GlobalScope.async {
        getNotifications()
    }

    return UserProfileData(
        ↗ user = user.await(),
        ↗ notifications = notifications.await(),
    )
}
```

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Why not a good idea to use GlobalScope?

If we call `async` on a `GlobalScope`, we will have no relationship to the parent coroutine. It means:

- it cannot be canceled even if the parent canceled.
- it is not inheriting scope from any parent (it will always run on the default dispatcher, and will not respect any context from the parent).

The most important consequences are:

- potential memory leaks and unnecessary calculations,
- the tools for unit testing coroutines will not work here, and so testing this function is very hard.

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Other Solutions?

- Passing scope as an argument, or make as an extension function on `CoroutineScope`. Now, cancellation and proper unit testing are now possible.

```
// DON'T DO THAT
suspend fun getUserProfile(scope: CoroutineScope): UserProfileData {
    ↗ val user = scope.async { getUserData() }
    ↗ val notifications = scope.async { getNotifications() }

    return UserProfileData(
        ↗ user = user.await(),
        ↗ notifications = notifications.await(),
    )
}

// DON'T DO THAT
suspend fun CoroutineScope.getUserProfile(): UserProfileData {
    ...
}
```

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But, can be tricky and potentially dangerous

- Requires passing the scope from function to function.
- If there would be an exception in one `async`, the whole scope would be shut down (unless using `SupervisorJob`).
- Any function that has access to the scope could easily abuse this access and for instance, cancel this scope with the cancel method.

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What will happen?

Exception in thread "main" java.lang.Error: Service exception

```
data class Details(val name: String, val followers: Int)
data class Tweet(val text: String)

fun getFollowersNumber(): Int = throw Error("Service exception")

suspend fun getUserName(): String { delay(500); return "geremy" }

suspend fun getTweets(): List<Tweet> { delay(500); listOf(Tweet("Hello, world")) }

suspend fun CoroutineScope.getUserDetails(): Details {
    val userName = async { getUserName() }
    val followersNumber = async { getFollowersNumber() }
    return Details(userName.await(), followersNumber.await())
}

fun main() = runBlocking {
    val details = try {
        getUserDetails()
    } catch (e: Error) {
        null
    }
    val tweets = async { getTweets() }
    println("User: $details")
    println("Tweets: ${tweets.await()}")
}
```

We would like to see at least tweets, even if we have a problem calculating user details.

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coroutineScope

```
suspend fun <R> coroutineScope(
    block: suspend CoroutineScope.() -> R
): R
```

- `coroutineScope` is a provided suspending function that starts a scope.
- Unlike `async` or `launch`, it does **not** really create new coroutines. The code block is *called in-place*.
- It inherits its `coroutineContext` from the outer scope, but overrides the context's `Job`.
- This way, the produced scope respects parental responsibilities:
 - inherits a context from its parent,
 - awaits for all children before it can finish itself,
 - cancels all its children, when the parent is canceled.
- An exception in `coroutineScope` or any of its children cancels other children and rethrows it.
- Designed for *parallel decomposition* of work.

```
fun main() = runBlocking {
    ↪ val a = coroutineScope {
    ↪     delay(1000)
    ↪     10
    ↪ }
    ↪ println("a is calculated")
    ↪ val b = coroutineScope {
    ↪     delay(1000)
    ↪     20
    ↪ }
    ↪ println(a) // 10
    ↪ println(b) // 20
    ↪ }
    // (1 sec)
    // a is calculated
    // (1 sec)
    // 10
    // 20
```

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```

data class Details(val name: String, val followers: Int)
data class Tweet(val text: String)
class ApiException(val code: Int, message: String) : Throwable(message)

fun getFollowersNumber(): Int = throw ApiException(500, "Service unavailable")

suspend fun getUsername(): String { delay(500); return "marcinmoskala" }

suspend fun getTweets(): List<Tweet> { delay(500); return listOf(Tweet("Hello, world")) }

suspend fun getUserDetails(): Details = coroutineScope {
    val userName = async { getUsername() }
    val followersNumber = async { getFollowersNumber() }
    Details(userName.await(), followersNumber.await())
}

fun main() = runBlocking<Unit> {
    val details = try {
        getUserDetails()
    } catch (e: ApiException) {
        null
    }
    val tweets = async { getTweets() }
    println("User: $details")
    println("Tweets: ${tweets.await()}")
}
// User: null
// Tweets: [Tweet(text=Hello, world)]

```

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Proper Example of Parallel Decomposition

OK

```

suspend fun loadAndCombine(
    name1: String, name2: String, scope: CoroutineScope): Image {
    → val deferred1 = scope.async { loadImage(name1) }
    → val deferred2 = scope.async { loadImage(name2) }
    → return combineImages(deferred1.await(), deferred2.await())
}

```

Better

```

suspend fun loadAndCombine(name1: String, name2: String): Image {
    → coroutineScope {
    →     val deferred1 = async { loadImage(name1) }
    →     val deferred2 = async { loadImage(name2) }
    →     return combineImages(deferred1.await(), deferred2.await())
    }
}

```

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Final Solution

- This all makes `coroutineScope` a perfect candidate for most cases when we just need to start a few concurrent calls in a suspending function.

```
suspend fun getUserProfile(): UserProfileData =  
    coroutineScope {  
        ↪ val user = async { getUserData() }  
        ↪ val notifications = async { getNotifications() }  
  
        UserProfileData(  
            ↪ user = user.await(),  
            ↪ notifications = notifications.await(),  
        )  
    }
```

- `coroutineScope` is nowadays often used to wrap suspending main body. Think of it as the modern replacement for the `runBlocking` function.

```
suspend fun main(): Unit = coroutineScope { ... }
```

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supervisorScope

- The function `supervisorScope` also behaves a lot like `coroutineScope`.
- The difference is that it overrides context's `Job` with `SupervisorJob`, so it is not canceled when a child raises an exception.
- `supervisorScope` is mainly used in functions that start multiple independent tasks.

```
suspend fun notifyAnalytics(actions: List<UserAction>) =  
    ↪ supervisorScope {  
        actions.forEach { action ->  
            ↪ launch {  
                doSomething(action)  
            }  
        }  
    }
```

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Pro Tip: if you want parallel decomposition, then use a `coroutineScope` or, possibly a `supervisorScope` block

```
coroutineScope {  
    launch {  
        // ... task to run in the background  
    }  
    // ... more work while the launched task runs in parallel  
}  
// All work done by the time we reach this line
```

- `coroutineScope/supervisorScope` is a suspendable function and it won't complete until all the coroutines it launched complete.

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Coroutine Scope Functions vs. Coroutine Builders

Coroutine Builders (except `runBlocking`)

- `launch`, `async`, `produce`
- Extension functions on `CoroutineScope`
- Take coroutine context from `CoroutineScope` receiver
- Starts another coroutine
- Exception propagates to parent Job

Coroutine Scope Functions

- `coroutineScope`, `supervisorScope`, `withContext`, `withTimeout`
- suspending functions
- Take coroutine context from suspending function continuation
- Runs on parent coroutine in-place
- Exception rethrows

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withContext



Very important for Main-Safety

```
public suspend fun <T> withContext(  
    context: CoroutineContext, // coroutineContext + context  
    block: suspend CoroutineScope.() -> T  
): T { ... }
```

- Calls the suspending lambda with a given coroutine context, suspends until it completes, and returns the result.
- The resulting context for the block is derived by merging:
 - Caller's **coroutineContext** + the specified context.
- Often used to set a different coroutine scope for part of our code. Most often together with dispatchers.
- if a new dispatcher specified, *shift execution of the block into the different thread, and back to the original dispatcher* when it completes.
- Note that the **result of withContext invocation is dispatched into the original context.**

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Suspending Convention: suspending functions do not block the caller thread

- To implement this convention, use **withContext** function.

```
suspend fun findBigPrime(): BigInteger =  
-> withContext(Dispatchers.Default) {  
    BigInteger.probablePrime(4096, Random())  
}
```

```
suspend fun BufferedReader.readMessage(): Message? =  
-> withContext(Dispatchers.IO) {  
    readLine()?.parseMessage()  
}
```

- Now you can call these suspending functions from the coroutine launched in the main thread of your UI application without blocking its main thread!

Main Safety

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Roman Elizarov

Project Lead for the Kotlin
Programming Language
@JetBrains

“Once you’ve isolated and encapsulated blocking code used by your application into suspending functions, you can call them at will from anywhere without having to double-check whether they are blocking or not.”

*“You should always use **withContext()** inside a suspend function when you need **main-safety**, such as when reading from or writing to disk, performing network operations, or running CPU-intensive operations.”*

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withTimeout and withTimeoutOrNull

- `withTimeout` sets time limit for its body execution. If it takes too long, it cancels this body, and throws `TimeoutCancellationException`.
- `withTimeoutOrNull` just cancels its body and returns null instead of throwing an exception in case of exceeded timeout.
- Both are useful for testing.

```
suspend fun main(): Unit = coroutineScope {  
    launch {  
        launch { // cancelled by its parent  
            delay(2000)  
            println("Will not be printed")  
        }  
        withTimeout(1000) { // cancel launch  
            delay(1500)  
        }  
    }  
    launch {  
        delay(2000)  
        println("Done")  
    }  
}  
// (2 sec)  
// Done
```

```
class User()  
  
suspend fun fetchUser(): User {  
    while (true) { yield() } // Run forever  
}  
  
suspend fun getUserOrNull(): User? =  
    withTimeoutOrNull(1000) {  
        fetchUser()  
    }  
  
suspend fun main(): Unit = coroutineScope {  
    val user = getUserOrNull()  
    println("User: $user")  
}  
// (1 sec)  
// User: null
```

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When to or NOT to mark a function as suspend

Whenever it calls other suspend function

```
suspend fun loadData() {  
    val data = networkRequest()  
    show(data)  
}
```

When it doesn't call suspend functions

```
fun onClicked() {  
    scope.launch() {  
        loadData()  
    }  
}
```

Don't mark a function suspend unless you're forced to.

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Suspension Points: Exactly When?

- A **suspension point** is a point where the execution of the coroutine may be suspended.
- Syntactically, a suspension point is an invocation of suspending function, **but** the actual suspension happens when the suspending function invokes the following standard library primitive.

```
suspend fun <T> suspendCoroutine(  
    block: (Continuation<T>) -> Unit  
) : T
```

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suspendCoroutine or suspendCancellableCoroutine

```
suspend fun <T> Call<T>.await(): T = suspendCoroutine { cont ->
    enqueue(object : Callback<T> {
        override fun onResponse(call: Call<T>, response: Response<T>) {
            if (response.isSuccessful)
                cont.resume(response.body()!!)
            else
                cont.resumeWithException(ErrorResponse(response))
        }
        override fun onFailure(call: Call<T>, t: Throwable) {
            cont.resumeWithException(t)
        }
    })
}
```

Inspired by **call/cc** from Scheme

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Coroutines in Android

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2018 Solution Alternatives

- **LiveData**

- Observable data holder
- Love it, but want a complete solution

- **RxJava**

- Observable + Schedulers + Observer
- Powerful, highly adopted but often misused and perceived as an overkill solution to concurrency

- **Coroutines**

- Suspendable computations
- Seems like the best solution, but here is a need for maturation of the extensions and developers feel that a steep learning curve awaits ...

Desired Solution

Simplified

Comprehensive

Robust

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Posting to the UI thread (**Main-Safety**)

- Using `Dispatchers.Main` as the context, you can post to the main thread in **Android**, **Swing** and **JavaFx** applications.

```
suspend fun loadData() {  
    // Main safety  
    val data = withContext {  
        apiService.networkRequest()  
    }  
    show(data)  
}
```



Exception in thread "DefaultDispatcher-worker-3" java.lang.IllegalStateException: **Module with the Main dispatcher is missing.** Add dependency providing the Main dispatcher, e.g. 'kotlinx-coroutines-android'

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Autocancellation with lifecycleScope and viewModelScope

The two extension `CoroutineScope` properties *automatically* cancel the coroutine on the lifecycle's destroy event using built-in cancellation mechanism:

- `viewModelScope`
- `lifecycleScope`

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viewModelScope

- An extension property of the `ViewModel` class.
- This scope is bound to `Dispatchers.Main.immediate` and will automatically be cancelled when the `ViewModel` is cleared.

```
public val ViewModel.viewModelScope: CoroutineScope
    get() { ...
        CloseableCoroutineScope(
            SupervisorJob() + Dispatchers.Main.immediate))
    }
```

Executes coroutines immediately when they are launched from the main thread.

```
dependencies {
    implementation "androidx.lifecycle:lifecycle-viewmodel-ktx:$version"
}
```

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viewModelScope

```
class MyViewModel: ViewModel() {
    init {
        viewModelScope.launch {
            // Coroutine that will be canceled when the ViewModel is cleared.
        }
    }
}

override fun onCleared() {
    super.onCleared()
    viewModelScope.cancel() // you don't need this!
}
```

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lifecycleScope

- An extension property of the [LifecycleOwner](#) instance and it's bounded to the Lifecycle of the [Activity](#) or [Fragment](#).
- Bound to [Dispatchers.Main.immediate](#) and will automatically be cancelled when the [Lifecycle](#) is destroyed.
- You can access the [CoroutineScope](#) of the Lifecycle either via [lifecycle.coroutineScope](#) or [lifecycleOwner.lifecycleScope](#) properties.

```
public val LifecycleOwner.lifecycleScope: LifecycleCoroutineScope
    get() = lifecycle.coroutineScope
```

```
dependencies {
    implementation "androidx.lifecycle:lifecycle-runtime-ktx:$version"
}
```

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lifecycleScope

```
class MyFragment: Fragment() {
    override fun onCreateView(view: View, savedInstanceState: Bundle?) {
        super.onCreateView(view, savedInstanceState)

        viewLifecycleOwner.lifecycleScope.launch {
            val params = TextViewCompat.getTextMetricsParams(textView)
            val precomputedText = withContext(Dispatchers.Default) {
                PrecomputedTextCompat.create(longTextContent, params)
            }
            TextViewCompat.setPrecomputedText(textView, precomputedText)
        }
    }
}
```

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Associating coroutine launch time with Lifecycle state

- **LifecycleCoroutineScope.launchWhenCreated()**
 - It launches when the is at least in the Lifecycle.State.CREATED state.
- **LifecycleCoroutineScope.launchWhenStarted()**
 - It launches when the Lifecycle is at least in the Lifecycle.State.STARTED state.
- **LifecycleCoroutineScope.launchWhenResumed()**
 - It launches when the is at least in the Lifecycle.State.RESUMED state.

```
class MainActivity : AppCompatActivity() {
    override fun onCreate(savedInstanceState: Bundle?) {
        lifecycleScope.launchWhenResumed {
            doSomeLongRunningJob()
        }
    }
}
```

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LiveData Exercise

```
interface ApiService {  
    /**  
     * Get all articles  
     */  
    suspend fun getArticles(): Resource<List<Article>>  
  
    /**  
     * Get the most recommended (i.e., top-ranked) article  
     */  
    suspend fun getTopArticle(): Resource<Article>  
  
    /**  
     * Get all the articles written by the author of the current top-ranked article  
     */  
    suspend fun getArticlesByAuthorId(id: String): LiveData<Resource<List<Article>>>  
}
```

```
data class Article(val id: String,  
                  val author: String,  
                  val title: String)
```

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LiveData in ViewModel

```
class ArticleViewModel(private val apiService: ApiService) : ViewModel() {  
    val scope = CoroutineScope(SupervisorJob())
```

```
    private val _articles = MutableLiveData<Resource<List<Article>>>()  
    val articles: LiveData<Resource<List<Article>>> = _articles
```

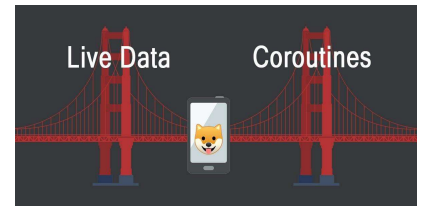
```
    init {  
        scope.launch {  
            withContext(Dispatchers.IO) {  
                _articles.postValue(apiService.getArticles())  
            }  
        }  
    }  
  
    val topArticle: LiveData<Resource<Article>> = ...  
    val articlesByTopAuthor: LiveData<Resource<List<Article>>> = ...  
    ...  
}
```

canonical style

Try this ...

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liveData Builder



- Runs a coroutine when observed
- Automatically cancelled if no active observers within *timeout*
- No scope needed!!
- Emit values or streams

```
public fun <T> liveData(  
    context: CoroutineContext = EmptyCoroutineContext,  
    timeout: Duration,  
    block: suspend LiveDataScope<T>().() -> Unit  
) : LiveData<T> = CoroutineLiveData(context, ..., block)
```

Default: Dispatchers.Main.immediate

```
dependencies {  
    implementation "androidx.lifecycle:lifecycle-livedata-ktx:$version"  
}
```

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Creating *LiveData* emitting values (1)

```
val recipe = MutableLiveData<Resource<Recipe>>().apply {  
    viewModelScope.launch {  
        this@apply.postValue(Resource.Loading)  
        this@apply.postValue(longRunningTask())  
    }  
}
```

```
val recipe: LiveData<Resource<Recipe>> = liveData {  
    emit(Resource.Loading)  
    emit(longRunningTask())  
}
```

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Creating *LiveData* emitting values (2)

```
// a LiveData that fetches a `User` object based on a `userId`  
// and refreshes it every 30 seconds as long as it is observed  
val userId: LiveData<String> = MutableLiveData<>()  
val user: LiveData<User> = userId.switchMap { id ->  
    LiveData {  
        while(true) {  
            // note that `while(true)` is fine because the `delay(30_000)`  
            // below will cooperate in cancellation if LiveData is not  
            // actively observed anymore  
            val user = api.fetch(id) // errors are ignored for brevity  
            emit(user)  
            delay(30_000)  
        }  
    }  
}
```

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Creating *LiveData* that changes emitting source

```
// a LiveData that immediately receives a LiveData<User> from the  
// database and yields it as a source but also tries to back-fill  
// the database from the server  
val user = LiveData {  
    val fromDb: LiveData<User> = roomDatabase.loadUser(id)  
    emitSource(fromDb)  
    val updated = api.fetch(id) // errors are ignored for brevity  
  
    // Since we are using Room here, updating the database will  
    // update the `fromDb` LiveData that was obtained above.  
    roomDatabase.insert(updated)  
}
```

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Coroutines are good for ...

There are two types of tasks that coroutines are a great solution for:

1. **One shot requests** run each time they are called — they always complete after the result is ready.
2. **Streaming requests** continue to observe changes and report them to caller — they don't complete when the first result is ready.

(This topic will be covered in Flow!)

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The one shot request pattern

Add coroutines to the `ViewModel`, `Repository`, and `Room`, and each layer has a different responsibility.

- `ViewModel` launches a coroutine on the *main* thread — it completes when it has a result.
- `Repository` exposes regular suspend functions and ensures they are *main-safe*.
- The database and network expose regular suspend functions and ensures they are *main-safe*.

Note: `Room` uses its own dispatcher to run queries on a background thread. Your code should **not** use `withContext(Dispatchers.IO)` to call suspending room queries. It will complicate the code and make your queries run slower.

Likewise, `Retrofit` is also *main-safe* and run on a custom dispatcher.

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The one shot request pattern (Cont'd)

- `suspendCoroutine/suspendCancellableCoroutine`
 - A typical use of this function is to suspend a coroutine while waiting for a result from a single-shot callback API and to return the result to the caller.
- `runCatching`

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Tips

<https://medium.com/androiddevelopers/coroutines-on-android-part-iii-real-work-2ba8a2ec2f45>

- As a general pattern, *start coroutines in the `ViewModel`*.
- A one shot request is performed each time it's called. It stops executing as soon as a result is ready.
- A repository should *prefer to expose suspend functions* that are *main-safe*.
- **Note:** Some background save operations may want to continue after user leaves a screen — and it makes sense to have those saves run without a lifecycle. In most other cases the `viewModelScope` is a reasonable choice.
- When starting a new coroutine in response to a UI event, consider what happens if the user starts another before this one completes.

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