



Part II

1

Agenda

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

2

Main Building Blocks of Coroutines

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

3

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.



4

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 🤪

5

Threads vs. Coroutines

```
val time = measureTimeMillis {  
    val jobs = List(100_000) {  
        thread {  
            Thread.sleep(1_000)  
            print(".")  
        }  
    }  
    jobs.forEach { it.join() }  
}  
println("\nElapses time = $time ms")
```

Supposed to crash, but ...



67105 ms

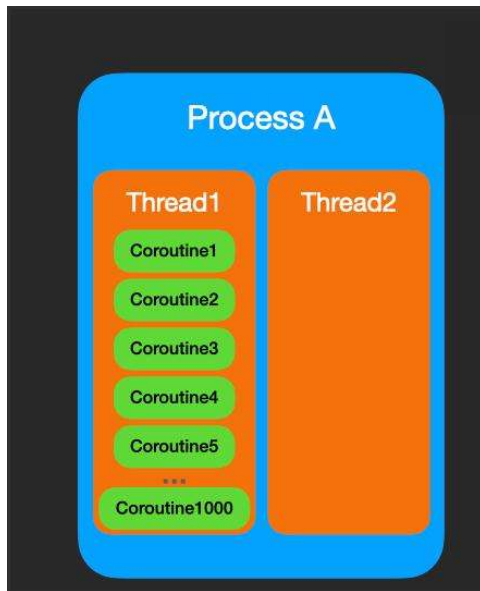
```
val time = measureTimeMillis {  
    val jobs = List(100_000) {  
        launch {  
            delay(1_000)  
            print(".")  
        }  
    }  
    jobs.forEach { it.join() }  
}  
println("\nElapses time = $time ms")
```

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

2113 ms

6

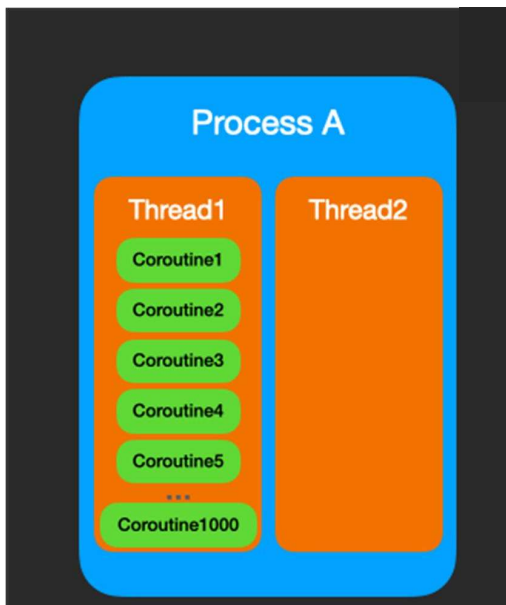
Coroutines ...



You can execute many coroutines in a single thread.

7

Coroutines ...



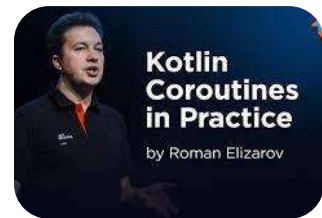
A coroutine can switch between threads.

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

8

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*.



9

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
            }
        }
    }
```

10

Continuation Passing Style (CPS)

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

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                step3
            }
        }
    }
```

11

Continuation Passing Style (CPS)

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}
```

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            multCPS(step1, step2) { step3 ->
                step3
            }
        }
    }
```

12

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 {
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    val step3 = mult(step1, step2)
    return step3
}
```

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

13

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))
```

14

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)  
        }  
    }  
}
```

15

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)  
        }  
    }  
}
```

First continuation

16

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)  
        }  
    }  
}
```

Second continuation

17

CPS Transform: by Compiler

suspension points

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

The compiler replaces the `suspend` modifier with the extra parameter of type `Continuation` that will be used to communicate the result of the suspend function to the coroutine that called it.

suspension points

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

`Unit | COROUTINE_SUSPENDED`

18

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.

suspension points

```
fun postItem(item: Item, completion: Continuation<Unit>): 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))  
}
```

19

CPS Transform

```
fun postItem(item: Item, completion: Continuation<Unit>): Any {  
    when(label) {  
        start here 0 -> { // Label 0 -> first execution  
            resume requestToken() suspend  
        }  
        next 1 -> { // Label 1 -> resumes from requestToken  
            resume createPost(token, item, ) suspend  
        }  
        next 2 -> { // Label 2 -> resumes from createPost  
            completion.resume(showPost(post))  
        }  
        else -> { return to calling coroutine  
            throw IllegalStateException(...) }  
    }  
}
```

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

20

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<Unit>): Any {
    class PostItemStateMachine(
        completion: Continuation<Unit> // callback to the fun that called postItem
    ): ContinuationImpl(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?): Any {
            this.result = result // result of the previous state's computation
            return postItem(null, this)
        }
    }
    ...
}
```

21

```
fun postItem(item: Item?, completion: Continuation<Unit>): 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.

22

```

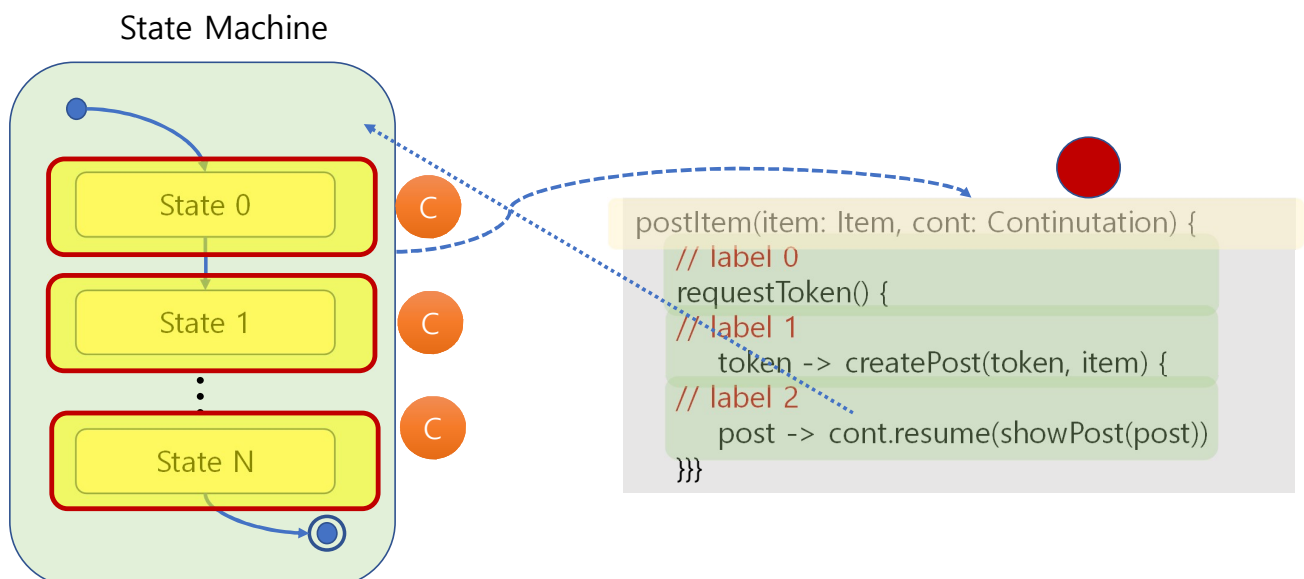
fun postItem(item: Item?, completion: Continuation<Unit>): Any {
    ...
    when(continuation.label) {
        ...
        2 -> {
            // Checks for failures
            throwOnFailure(continuation.result)
            // Gets the result of the previous state
            continuation.post = continuation.result 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`:

23

How Suspending Functions Evaluated?



24

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](#))

```
public interface CoroutineScope {  
    public val coroutineContext: CoroutineContext  
}
```

생태		갯 잡아 올리거나 얼리지 않은 명태
동태		얼린 명태
코다리		내장과 아가미를 빼고 코에 꿰어 반건조한 명태
복어		바싹 말린 명태
황태		얼렸다 녹이기를 반복해 노랑게 말린 명태
노가리		바싹 말린 새끼 명태

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
```

Elements of CoroutineContext

- The `CoroutineContext` is an indexed set of elements (set + map) 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` is a singleton context by itself.
- Each `Element` can be combined with plus('+') operator.

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

27

Job

Job

Provides lifecycle

Coroutine hierarchy

- A coroutine itself is represented by a `Job`.
- Responsible for *coroutine's lifecycle*, *cancellation*, and *parent-child relations*.

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

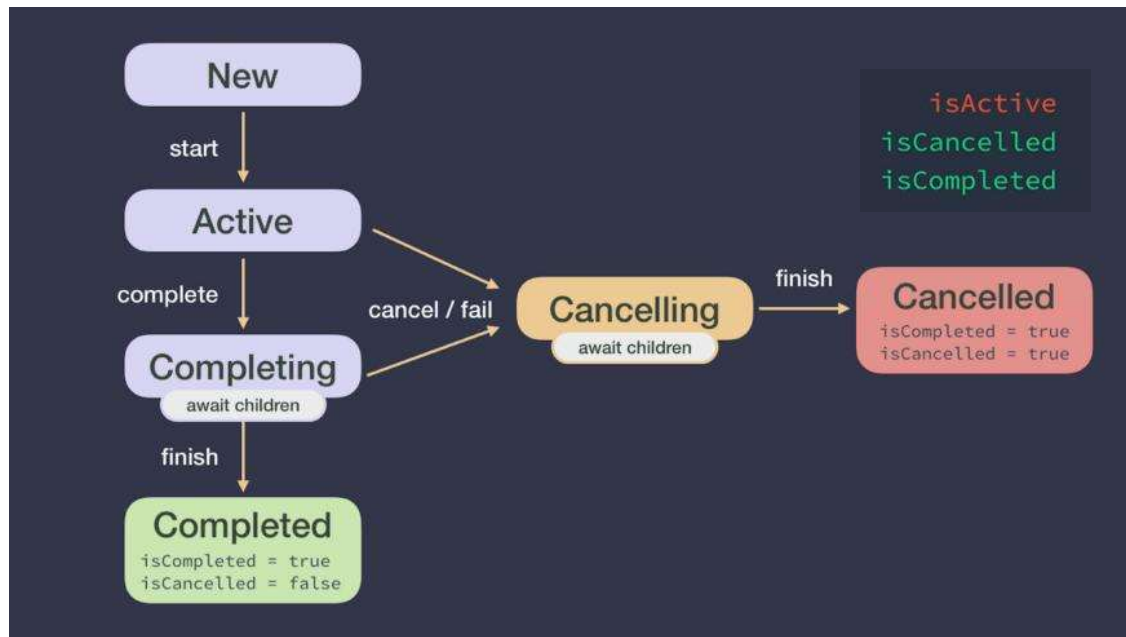
- Coroutine builders (`launch` or `async`) returns a `Job` instance that uniquely identifies the coroutine.
- You can also pass a `Job` to a `CoroutineScope` to keep a handle on its lifecycle. Otherwise, `default` Job created.

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

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

28

Job lifecycle



29

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

30

CoroutineScope

To guarantee structural concurrency

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

CoroutineContext

CoroutineScope

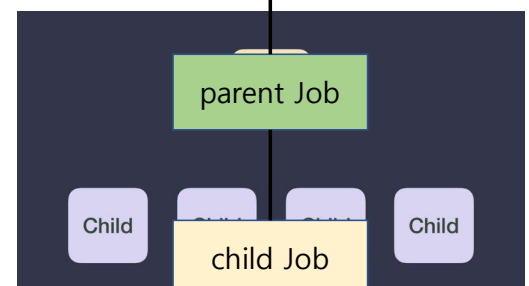
Keep track of coroutines
Ability to cancel ongoing work
Notified when a failure happens

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(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()  
}
```

The parent
CoroutineScope or another coroutine.



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.

33

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
    }

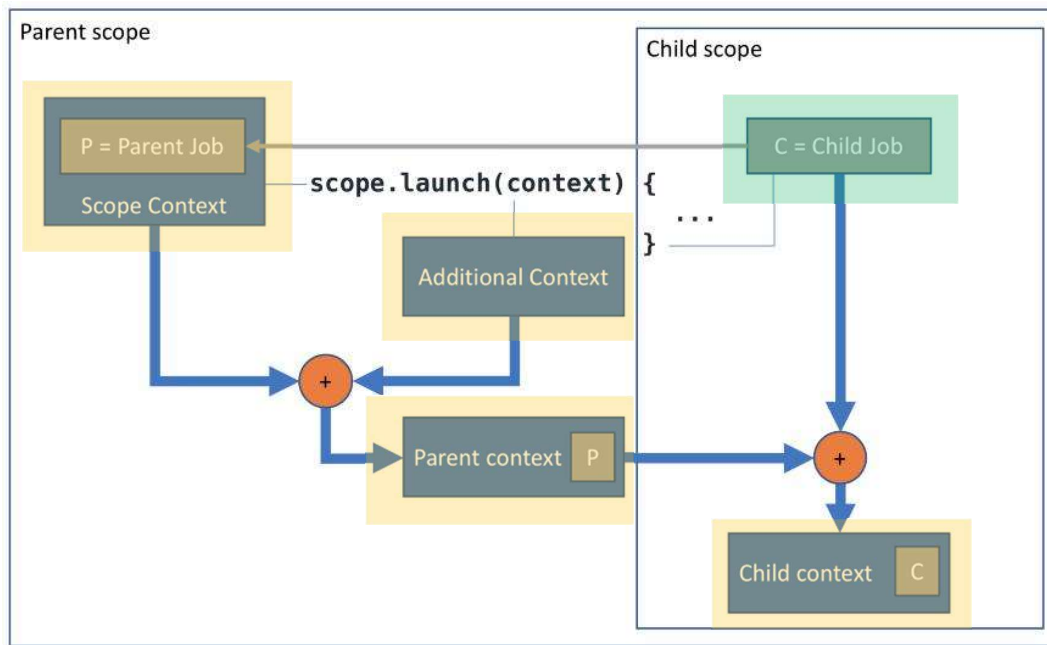
    launch {
        // Child 2
    }
}
```

Job

Job

34

Parent Scope vs. Child Scope



35

Parent CoroutineContext explained

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

$$\text{Parent context} = \text{Defaults} + \text{inherited CoroutineContext} + \text{arguments}$$

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.



CoroutineContext

Parent context
= Defaults + inherited context + arguments

Coroutine context
= parent context + Job()

36

Parent Context

```
// Defaults: Dispatchers.Default, "coroutine"
```

Parent context

Dispatchers.Default

"coroutine"

37

Parent Context

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

Parent context

Dispatchers.Main

"coroutine"


Job

coroutineExceptionHandler

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.

38

Parent context



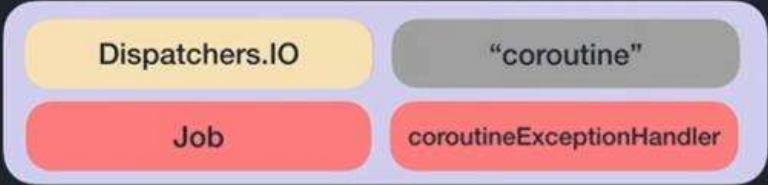
```

val job = scope.launch(Dispatchers.IO) {
    // CoroutineContext?
    | New coroutine context = parent CoroutineContext + Job()
}


```

39

Parent context



Coroutine context

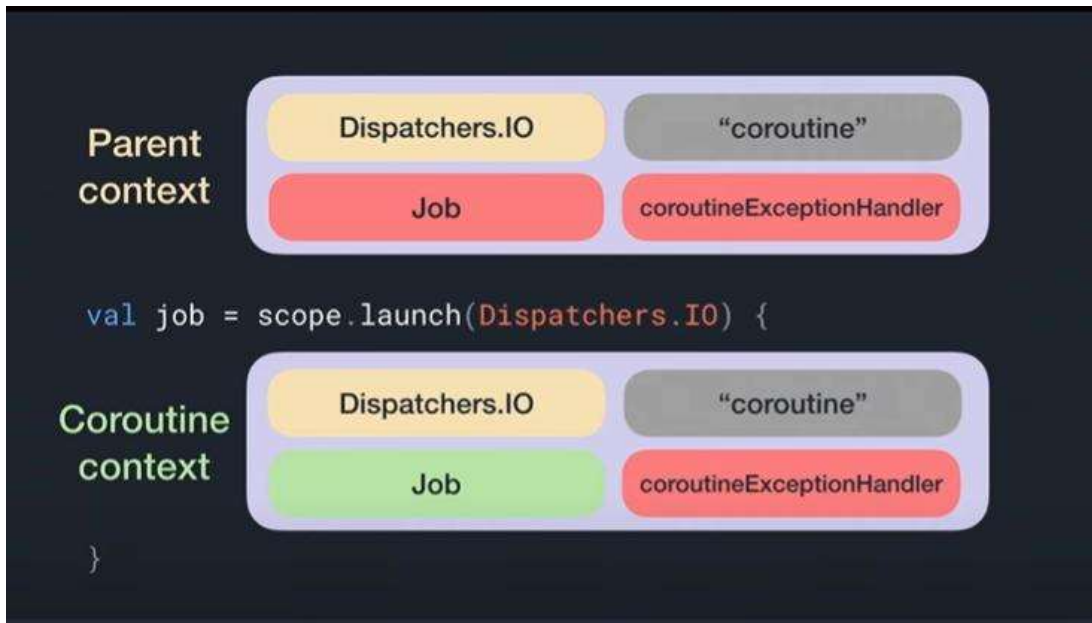


```

Job = scope.launch(Dispatchers.IO) {
}

```

40

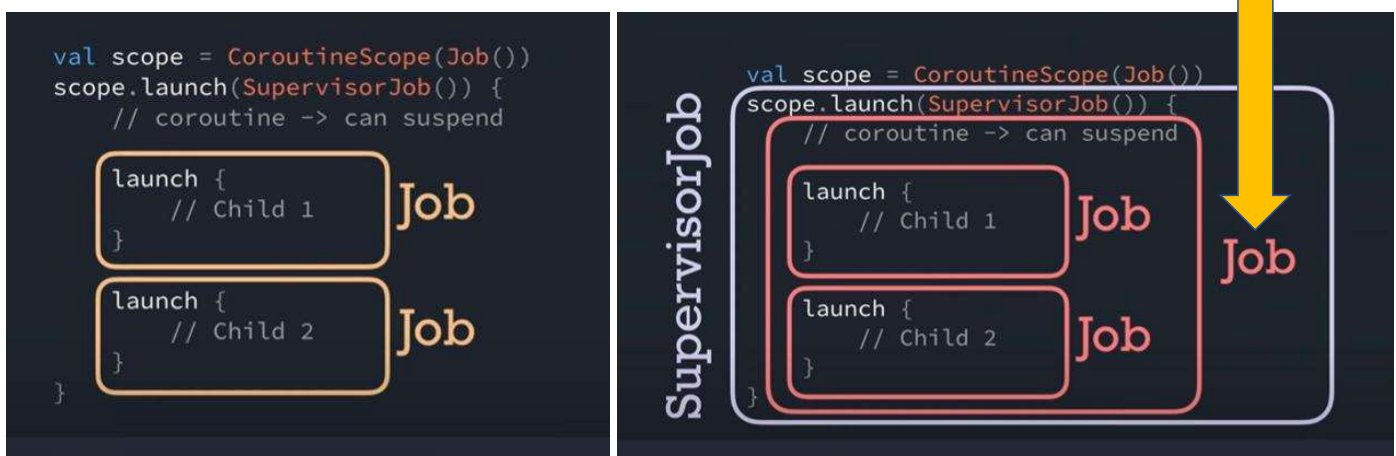


The Job in the CoroutineContext and in the parent context will never be the same instance as a new coroutine always get a new instance of a Job

41

Who's my parent again? 🎯

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



42

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

43

Coroutine Scope Builders

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

44

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

45

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>

46

Coroutine Builders (Revisited)

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

47

Coroutine Scope Functions

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

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

48

Motivation for `coroutineScope`

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

49

Approach 1: 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,
    )
}
```

50

Approach 2: Concurrent, but not good idea

- 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(),
    )
}
```

51

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.

52

Other Solutions?

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

```
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 {  
    ...  
}
```

potentially ambiguous coroutineContext!

53

But, can be tricky and potentially dangerous

- **Good!**
 - If there would be an exception in one `async`, the whole scope would be shut down (unless using `SupervisorJob`).
- **Problematic**
 - Requires passing the scope from function to function.
 - Any function that has access to the scope could easily abuse this access and for instance, cancel this scope with the `cancel` method.
 - **Parent coroutine that called `getUserProfile` cancels for no good reason.**

54

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)

suspend fun getUsername(): String { delay(500); return "jeremy" }
suspend fun getFollowersNumber(): Int = throw Error("Service exception")

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

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

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

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

55

coroutineScope

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

- `coroutineScope` is a suspending function that starts a (sub) 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`.
- 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
```

56

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 { ... }
```

57

```
data class Details(val name: String, val followers: Int)  
data class Tweet(val text: String)  
class ApiException(val code: Int, message: String) : Throwable(message)  
  
suspend fun getUsername(): String { delay(500); return "paula abdul" }  
suspend fun getFollowersNumber(): Int = throw ApiException(500, "Service unavailable")  
  
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 {  
    val details = try {  
        getUserDetails()  
    } catch (e: ApiException) {  
        null  
    }  
    println("User: $details")  
    val tweets = async { getTweets() }  
    println("Tweets: ${tweets.await()}")  
}
```

```
// User: null  
// Tweets: [Tweet(text=Hello, world)]
```

58

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())
    }
}
```

59

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)
            }
        }
    }
```

60

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.

61

withContext Very important for Main-Safety

```
public suspend fun <T> withContext(  
    context: CoroutineContext, // caller's 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 dispatcher**.
- 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**.

62

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()  
}
```

63

Suspending Convention: (Cont'd) 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

64



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.”*

65

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
```

66

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 except `supervisorScope` (except ...)

67

When to or NOT to mark a function as suspend

Mark it whenever it calls other suspending function

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

Do not mark it when it doesn't call suspending functions

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

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

68

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
```

69

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(HttpException(response))  
        }  
        override fun onFailure(call: Call<T>, t: Throwable) {  
            cont.resumeWithException(t)  
        }  
    })  
}
```

Inspired by **call/cc** from Scheme

70

Coroutines in Android

71



Understand Kotlin Coroutines on Android (Google I/O'19)

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 ...



72

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

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

```
suspend fun loadData() {  
->  val data = apiService.networkRequest()  
->  withContext(Dispatchers.Main) {  
    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'

73

Posting to the UI thread (Main-Safety)

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

74

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`

75

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"
}
```

76

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!
}
```

77

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"
}
```

78

lifecycleScope

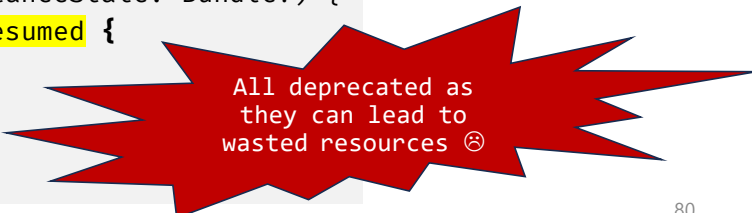
```
class MyFragment: Fragment() {  
    override fun onCreateView(view: View, savedInstanceState: Bundle?) {  
        super.onCreateView(view, savedInstanceState)  
  
        viewLifecycleOwner.lifecycleScope.launch {  
            val params = TextViewCompat.getTextMetricsParams(textView)  
            val precomputedText = withContext(Dispatchers.Default) {  
                PrecomputedTextCompat.create(longTextContent, params)  
            }  
            TextViewCompat.setPrecomputedText(textView, precomputedText)  
        }  
    }  
}
```

79

Associating coroutine launch time with Lifecycle state

- `LifecycleCoroutineScope.launchWhenCreated()`
 - It launches when the Lifecycle 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 Lifecycle is at least in the `Lifecycle.State.RESUMED` state.

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



All deprecated as
they can lead to
wasted resources ☹

80

Restartable Lifecycle-aware coroutines

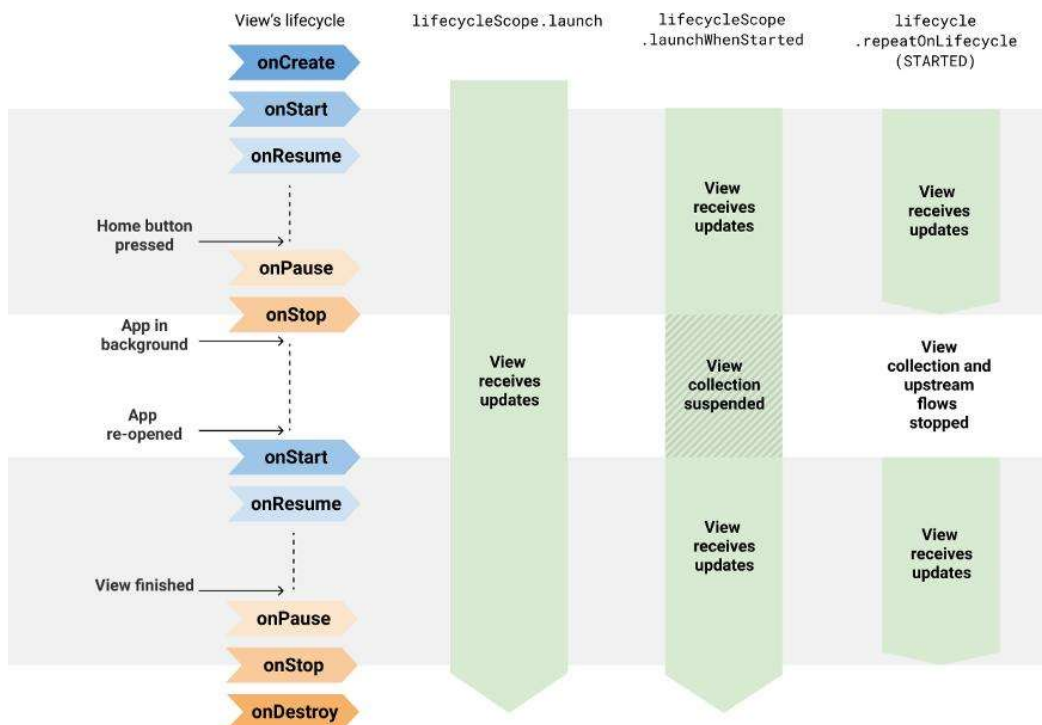
- Start the execution of a code block when the Lifecycle is in a certain state, and cancel when it is in another state.

```
// Create a new coroutine in the lifecycleScope
viewLifecycleOwner.lifecycleScope.launch {
    // repeatOnLifecycle launches the block in a new coroutine every time the
    // lifecycle is in the STARTED state (or above) and cancels it when it's STOPPED.
    viewLifecycleOwner.repeatOnLifecycle(Lifecycle.State.STARTED) {
        // Trigger the flow and start listening for values.
        // This happens when lifecycle is STARTED and stops
        // collecting when the lifecycle is STOPPED
        viewModel.myUiState.collect {
            // Process item
        }
    }
}
```

Most Recommended!

Note: The `repeatOnLifecycle` API is available only in versions of the `androidx.lifecycle:lifecycle-runtime-ktx:2.4.0-alpha01` library and higher.

81



82

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  
     */  
    fun getArticlesByAuthorId(id: String): LiveData<Resource<List<Article>>>  
}
```

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

83

LiveData in ViewModel

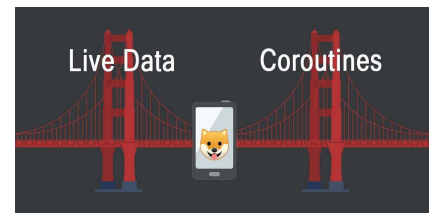
```
class ArticleViewModel(private val apiService: ApiService) : ViewModel() {  
    private val _articles = MutableLiveData<Resource<List<Article>>>()  
    val articles: LiveData<Resource<List<Article>>> = _articles  
  
    init {  
        scope.launch {  
            withContext(Dispatchers.IO) {  
                articles.postValue(apiService.getArticles())  
            }  
        }  
    }  
  
    val topArticle: LiveData<Resource<Article>> = ...  
    val articlesByTopAuthor: LiveData<Resource<List<Article>>> = ...  
    ...  
}
```

canonical style

Try this ...

84

liveData Builder



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

```
public fun <T> liveData(  
    context: CoroutineContext = EmptyCoroutineContext,  
    timeout: Duration = DEFAULT_TIMEOUT, // 5000L  
    block: suspend LiveDataScope<T>().() -> Unit  
) : LiveData<T> = CoroutineLiveData(context, ..., block)
```

Default: Dispatchers.Main.immediate

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

85

Creating *LiveData* emitting values (1)

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

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

86

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)  
        }  
    }  
}
```

87

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)  
}
```

88

Coroutines are good for ...

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

1. **One shot requests** are requests that are run each time they are called: they always complete after the result is ready.
 - Use **suspending functions**
2. **Streaming requests** are requests that continue to observe changes and report them to caller: they don't complete when the first result is ready.
 - Use **Kotlin Flow** (*This topic will be covered in Flow Course*)

89

The one shot request pattern

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



Sean McQuillan

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

- **ViewModel** starts 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 queries run slower. Likewise, **Retrofit** is also **main-safe** and run on a custom dispatcher.

90

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`

```
fun <R> runCatching(block: () -> R): Result<R> {  
    return try {  
        Result.success(block())  
    } catch (e: Throwable) {  
        Result.failure(e)  
    }  
}
```

- When starting a new coroutine in response to a UI event, consider what happens if the user starts another before this one completes.