Flutter combines a Dart framework with a high-performance engine.

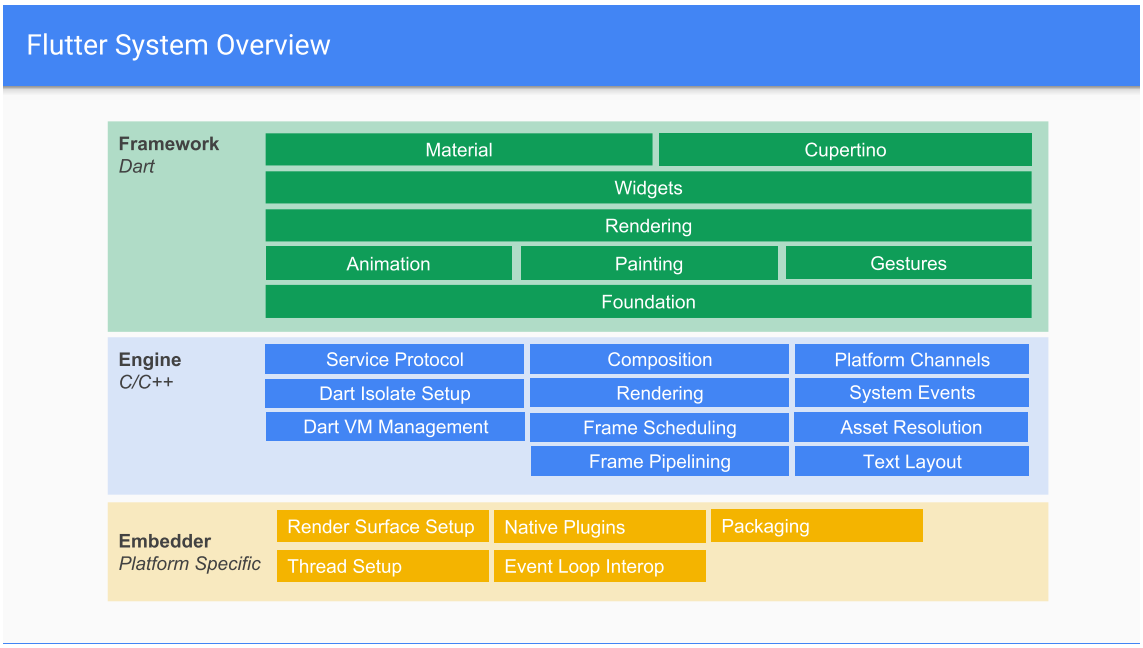
The Flutter Engine is a portable runtime for high-quality mobile applications. It implements Flutter's core libraries, including animation and graphics, file and network I/O, accessibility support, plugin architecture, and a Dart runtime and toolchain for developing, compiling, and running Flutter applications.

Architecture overview

Flutter's engine takes core technologies, Skia, a 2D graphics rendering library, and Dart, a VM for a garbage-collected object-oriented language, and hosts them in a shell. Different platforms have different shells, for example we have shells for Android and iOS. We also have an embedder API which allows Flutter's engine to be used as a library (see [[Custom Flutter Engine Embedders]]).

The shells implement platform-specific code such as communicating with IMEs (on-screen keyboards) and the system's application lifecycle events.

The Dart VM implements the normal Dart core libraries, plus an additional library called `dart:ui` to provide low-level access to Skia features and the shell. The shells can also communicate directly to Dart code via Platform Channels which bypass the engine.



Threading

Overview

The Flutter engine does not create or manage its own threads. Instead, it is the responsibility of the embedder to create and manage threads (and their message loops) for the Flutter engine. The embedder gives the Flutter engine task runners for the threads it manages. In addition to the threads managed by the embedder for the engine, the Dart VM also has its own thread pool. Neither the Flutter engine or the embedder have any access to the threads in this pool.

Task Runner Configuration

The Flutter engine requires the embedder to give it references to 4 task runners. The engine does not care if the references are to the same task runner, or, if multiple task runners are serviced on the same thread. For optimum performance, the embedder should create a dedicated thread per task runner. Though the engine does not care about the threads the task runners are serviced on, it does expect that the threading configuration remain stable for the entire lifetime of the engine. That is, once the embedder decides to service a task runner on a particular thread, it should execute tasks for that task runner only on that one thread (till the engine is torn down).

The main task runners are:

- Platform Task Runner
- UI Task Runner
- Raster Task Runner
- IO Task Runner

Platform Task Runner

This is the task runner for the thread the embedder considers as its main thread. For example, this is typically the Android Main Thread or the Main Thread referenced by Foundation on Apple platforms.

Any significance assigned to the thread for this task runner is entirely assigned by the embedder. The Flutter engine assigns no special meaning to this thread. In fact, multiple Flutter engines can be launched with platform task runners based on different threads. This is how the Flutter Content Handler in Fuchsia works. A new Flutter engine is created in the process for each Flutter application and a new platform thread is created for each engine.

Interacting with the Flutter engine in any way must happen on the platform thread. Interacting with the engine on any other thread will trip assertions in unoptimized builds and is not thread safe in release builds. There are numerous components in the Flutter engine that are not thread safe. Once the Flutter engine is setup and running, the embedder does not have to post tasks to any of the task runners used to configure the engine as long as all accesses to the embedder API are made on the platform thread.

In addition to being the thread on which the embedder interacts with the engine after it is launched, this task runner also executes any pending platform messages. This is handy because accessing most platform APIs is only safe on the platform's main thread. Plugins don't have to rethread their calls to the main thread. If plugins manage their own worker threads, it is their responsibility to queue responses back onto the platform thread before they can be submitted back to the engine for processing by Dart code. The rule of always interacting with the engine on the platform thread holds here.

Even though blocking the platform thread for inordinate amounts of time will not block the Flutter rendering pipeline, platforms do impose restrictions on expensive operations on this thread. So it is advised that any expensive work in response to platform messages be performed on separate worker threads (unrelated to the four threads discussed above) before having the responses queued back on the the platform thread for submission to the engine. Not doing so may result in platform-specific watchdogs terminating the application. Embeddings such as Android and iOS also uses the platform thread to pipe through user input events. A blocked platform thread can also cause gestures to be dropped.

UI Task Runner

The UI task runner is where the engine executes all Dart code for the root isolate. The root isolate is a special isolate that has the necessary bindings for Flutter to function. This isolate runs the application's main Dart code. Bindings are set up on this isolate by the engine to schedule and submit frames. For each frame that Flutter has to render:

- The root isolate has to tell the engine that a frame needs to be rendered.
- The engine will ask the platform that it should be notified on the next vsync.
- The platform waits for the next vsync.

- On vsync, the engine will wake up the Dart code and perform the following:
  - Update animation interpolators.
  - Rebuild the widgets in the application in a build phase.
  - Lay out the newly constructed and widgets and paint them into a tree of layers that are immediately submitted to the engine. Nothing is actually rasterized here; only a description of what needs to be painted is constructed as part of the paint phase.
  - Construct or update a tree of nodes containing semantic information about widgets on screen. This is used to update platform specific accessibility components.

Apart from building frames for the engine to eventually render, the root isolate also executes all responses for platform plugin messages, timers, microtasks and asynchronous I/O (from sockets, file handles, etc.).

Since the UI thread constructs the layer tree that determines what the engine will eventually paint onto the screen, it is the source of truth for everything on the screen. Consequently, performing long synchronous operations on this thread will cause jank in Flutter applications (a few milliseconds is enough to miss the next frame!). Long operations can typically only be caused by Dart code since the engine will not schedule any native code tasks on this task runner. Because of this, this task runner (or thread) is typically referred to as the Dart thread. It is possible for the embedder to post tasks onto this task runner. This may cause jank in Flutter and embedders are advised not to do this and instead assign a dedicated thread for this task runner.

If it is unavoidable for Dart code to perform expensive work, it is advised that this code be moved into a separate Dart isolate (e.g. using the `compute` method). Dart code executing on a non-root isolate executes on a thread from a Dart VM managed thread pool. This cannot cause jank in a Flutter application. Terminating the root isolate will also terminate all isolates spawned by that root isolate. Also, non-root isolates are incapable of scheduling frames and do not have bindings that the Flutter framework depends on. Due to this, you cannot interact with the Flutter framework in any meaningful way on the secondary isolate. Use secondary isolates for tasks that require heavy computation.

Raster Task Runner

The raster task runner executes tasks that need to access the rasterizer (usually backed by GPU) on the device. The layer tree created by the Dart code on the UI task runner is client-rendering-API agnostic. That is, the same layer tree can be used to render a frame using OpenGL, Vulkan, software or really any other backend configured for Skia. Components on the GPU task runner take the layer tree and construct the appropriate draw commands. The raster task runner components are also responsible for setting up all the GPU resources for a particular frame. This includes talking to the platform to set up the framebuffer, managing surface lifecycle, and ensuring that textures and buffers for a particular frame are fully prepared.

Depending on how long it takes for the layer tree to be processed and the device to finish displaying the frame, the various components of the raster task runner may delay scheduling of further frames on the UI thread. Typically, the UI and raster task runners are on different threads. In such cases, the raster thread can be in the process of submitting a frame to the GPU while the UI thread is already preparing the next frame. The pipelining mechanism makes sure that the UI thread does not schedule too much work for the rasterizer.

Since the raster task runner components can introduce frame scheduling delays on the UI thread, performing too much work on the raster thread will cause jank in Flutter applications. Typically, there is no opportunity for the user to perform custom tasks on this task runner because neither platform code nor Dart code can access this task runner. However, it is still possible for the embedder to schedule tasks on this thread. For this reason, it is recommended that embedders provide a dedicated thread for the raster task runner per engine instance.

IO Task Runner

All the task runners mentioned so far have pretty strong restrictions on the kinds of operations that can be performed on this. Blocking the platform task runner for an inordinate amount of time may trigger the platform's

watchdog, and blocking either the UI or raster task runners will cause jank in Flutter applications. However, there are tasks necessary for the raster thread that require doing some very expensive work. This expensive work is performed on the IO task runner.

The main function of the IO task runner is reading compressed images from an asset store and making sure these images are ready for rendering on the raster task runner. To make sure a texture is ready for rendering, it first has to be read as a blob of compressed data (typically PNG, JPEG, etc.) from an asset store, decompressed into a GPU friendly format and uploaded to the GPU. These operations are expensive and will cause jank if performed on the raster task runner. Since only the raster task runner can access the GPU, the IO task runner components set up a special context that is in the same sharegroup as the main raster task runner context. This happens very early during engine setup and is also the reason there is a single task runner for IO tasks. In reality, the reading of the compressed bytes and decompression can happen on a thread pool. The IO task runner is special because access to the context is only safe from a specific thread. The only way to get a resource like `ui.Image` is via an async call; this allows the framework to talk to the IO runner so that it can asynchronously perform all the texture operations mentioned. The image can then be immediately used in a frame without the raster thread having to do expensive work.

There is no way for user code to access this thread either via Dart or native plugins. Even the embedder is free to schedule tasks on this thread that are fairly expensive. This won't cause jank in Flutter applications but may delay having the futures images and other resources be resolved in a timely manner. Even so, it is recommended that custom embedders set up a dedicated thread for this task runner.

Current Platform Specific Threading Configurations

As mentioned, the engine can support multiple threading configurations, the configurations currently used by the supported platforms are:

iOS

A dedicated thread is created for the UI, raster and IO task runners per engine instance. All engine instances share the same platform thread and task runner.

Android

A dedicated thread is created for the UI, raster and IO task runners per engine instance. All engine instances share the same platform thread and task runner.

Fuchsia

A dedicated thread is created for the UI, raster, IO and Platform task runners per engine instance.

Flutter Tester (used by `flutter test`)

The same main thread is used for the UI, raster, IO and Platform task runners for the single instance engine supported in the process.

Text rendering

Our text rendering stack is as follows:

- A minikin derivative we call libtxt (font selection, bidi, line breaking).
- HarfBuzz (glyph selection, shaping).
- Skia (rendering/GPU back-end), which uses FreeType for font rendering on Android and Fuchsia, and CoreGraphics for font rendering on iOS.