Class Diagram Design for Quiz Session, Persistence, and Prosody Evaluation

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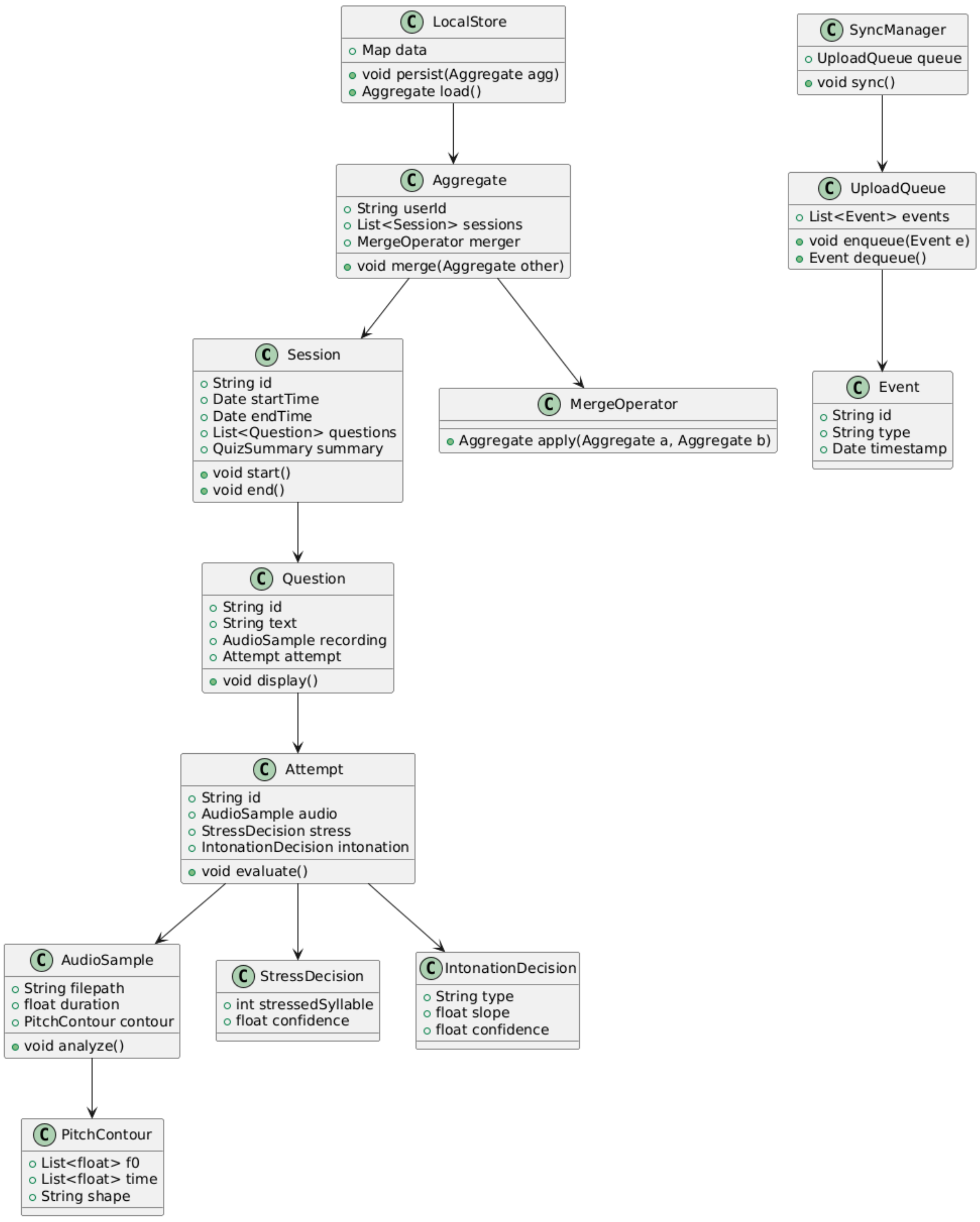
1. Introduction

This brief designs a class-level architecture that integrates concepts from previous artifacts — **statechart (session logic)**, **Petri net (resource concurrency)**, and **algebraic merge operators** (for offline-safe data). It proposes a unified class model that organizes quiz sessions, persistence, and prosody evaluation in a modular, testable structure.

2. Class Diagram Overview



3. Diagram explanation

Each box is a class: the top line is the class name, the middle lists key fields, and the bottom lists important methods. Arrows show ownership or usage (for example, a `Session` contains `Question` objects, and a `Question` references an `Attempt`).

The central vertical flow models the session lifecycle: a `Session` holds ``Question`s; answering creates an `Attempt`` that contains an `AudioSample` and evaluation results (`StressDecision`, `IntonationDecision`). `AudioSample` links to `PitchContour` used for intonation analysis.

The top-center `Aggregate` is the offline, mergeable summary of a user's history. `LocalStore` persists aggregates locally and `MergeOperator` defines how two aggregates combine deterministically during sync. Treat `Aggregate.merge()` as the place to enforce associativity and deduplication.

The right column models sync and export: `SyncManager` owns an `UploadQueue` of \`Event\`s that are uploaded in the background. This maps to the Petri-net resource region and highlights the need for bounded queues and upload backoff.

Typical runtime sequence: create a `Session`; show a `Question`; produce an `Attempt`; run `Attempt.evaluate()` which fills `StressDecision`/`IntonationDecision`; fold the result into an `Aggregate` and call `LocalStore.persist()`; enqueue an `Event` for the `UploadQueue`; `SyncManager` later uploads and uses `MergeOperator` to reconcile remote state.

Implementation notes: prefer immutable `Aggregate` objects or copy-on-write updates; use a single background uploader (single-writer) to drain `UploadQueue`; generate stable `Event.id` values so merges can deduplicate safely; and enforce bounds + exponential backoff on the queue to avoid unbounded growth under poor network conditions.

4. Dart Type Sketches

The sample Dart types below are minimal sketches to communicate the shape of the core domain objects and the API surface. They are not full implementations — they show the fields and primary methods developers should expect. Use these as a starting point for concrete data classes, interfaces, and unit tests.

```dart
class Session {
  String id;
  DateTime startTime;
  DateTime endTime;
  List<Question> questions;
  QuizSummary summary;

  void start() {}
  void end() {}
}

class Question {
  String id;
  String text;
  AudioSample? recording;
  Attempt? attempt;

  void display() {}
}

class Attempt {
  String id;
  AudioSample audio;
  StressDecision? stress;
  IntonationDecision? intonation;

  void evaluate() {}
}

class AudioSample {
  String filepath;
  double duration;
  PitchContour? contour;

  void analyze() {}
}

class PitchContour {
  List<double> f0;   // Hz values
  List<double> time; // corresponding timestamps
  String shape;      // e.g., "rising", "falling", "flat"
}

class StressDecision {
  int stressedSyllable;
  double confidence;
}

class IntonationDecision {
  String type;      // 'rising', 'falling', 'flat'
  double slope;
  double confidence;
}

class Aggregate {
  String userId;
  List<Session> sessions;
  MergeOperator merger;

  Aggregate merge(Aggregate other) => merger.apply(this, other);
}

class MergeOperator {
  Aggregate apply(Aggregate a, Aggregate b) { /* returns merged aggregate */ }
```

```
}

class LocalStore {
  Map<String, dynamic> data;

  void persist(Aggregate agg) {}
  Aggregate load(String userId) => /* ... */;
}

class SyncManager {
  UploadQueue queue;

  void sync() {}
}

class UploadQueue {
  List<Event> events;

  void enqueue(Event e) {}
  Event? dequeue() {}
}

class Event {
  String id;
  String type;
  DateTime timestamp;
}
```

Notes on the Dart sketches:

Use nullable types (`?`) where fields are optional (e.g., `recording` before audio exists). Prefer small, focused classes (single responsibility per class) to help testing and reduce coupling. Make `Aggregate` immutable if possible: return new merged instances rather than mutating the stored one; this simplifies reasoning about concurrency and rollback. Keep `MergeOperator` pluggable so different merge semantics (compact deduper, last-writer-wins, CRDT-like merges) can be experimented with without changing the rest of the codebase.

5. Concurrency and Resource Design

- **Single-writer pattern** — Only one active `Session` may write to the `LocalStore` at a time.
- **Immutable Aggregates** — `Aggregate` objects are immutable; merges produce new versions rather than mutating existing ones.
- **Event-driven synchronization** — `UploadQueue` batches `Event` objects asynchronously.
- **Algebraic merge guarantees** — Associativity and idempotence ensure consistent merges even under duplicate events or retries.
- **Petri net alignment** — `MicFree` ensures mutual exclusion on recording, while `UploadQueue` bounds concurrency on network uploads.

6. Risks and Mitigations

Risk	Mitigation
Duplicate events on sync	Use event IDs and an idempotent merge operator that deduplicates by event id.
Queue overflow	Bounded `UploadQueue` + exponential backoff policy; persist queue state to disk to avoid data loss on restart.
Memory growth from aggregates	Periodic pruning or summarization: compact old sessions into statistical summaries and remove raw payloads.
Race between persist and sync	Use version tags or atomic replace semantics (write temp file + rename) to avoid partial reads; use single-writer uploader pattern.

7. Conclusion

This class-model design ties previous formal artifacts (statechart, Petri net, algebraic merge) into a practical object model for Dart/Flutter implementation. The sketches provide a clear starting point for engineers to implement session management, local persistence, offline-safe merges, and the prosody evaluation pipeline.