370 Assignment 2: System Modeling

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1. ARCHITECTURAL DESIGN DOCUMENTATION

A. Major Design Considerations and Architectural Organization

The "A SMARTER APPROACH TO STUDENT WELL-BEING," implemented in C++ Random Forest classifier, aims to identify students at risk for depression and provide actionable recommendations via a Command Line Interface (CLI). Given its purpose and the nature of a CLI application with a self-contained ML model, the architectural design prioritizes simplicity, modularity for the core ML components, and data integrity for the single-user history.

Modularity: The system is designed with distinct logical components: data loading/preprocessing, the Decision Tree algorithm, the Random Forest ensemble, prediction logic, recommendation generation, and user interaction (CLI).

Data Flow: A clear, sequential data flow is established: User Input -> Preprocessing -> Model Prediction -> Risk Categorization -> Recommendation Generation -> Output to User. History is read before input and written after prediction.

Self-Contained ML Engine: The Random Forest, including its constituent Decision Trees, is implemented directly within the C++ application. This avoids external library dependencies for the core ML algorithm, aligning with the project's C++ focus, but places the onus of correctness and efficiency on the custom implementation.

Single-User Focus (CLI): The current architecture is tailored for a single-user experience with local data history storage (risk_history.txt). This simplifies data management and eliminates the need for user authentication or a database.

Performance (CLI Context): While not a high-throughput web server, efficient C++ implementation of the Random Forest and data handling is still a consideration to meet the non-functional requirement of quick response times in the CLI.

Maintainability: By encapsulating different functionalities into classes and distinct functions, the codebase aims for better readability and maintainability, crucial for this implementation.

Accuracy of Custom Model: A significant consideration is the accuracy and robustness of the Random Forest. Its effectiveness hinges on the correct implementation of tree-building heuristics (Gini impurity, splitting), bagging, and feature subsampling.

Architectural Organization (Conceptual Layers for CLI Application):

For this C++ CLI application, a strict multi-layer server architecture isn't directly applicable, but we can think of it in terms of logical components:

User Interaction Layer (CLI):

- Handles all input/output directly with the user via the console.
- Prompts for data, displays predictions, history, and recommendations.
- (Represented by functions within main() and get_simplified_user_input_and_transform, display_recommendations).

Application Logic/Control Layer:

- Orchestrates the flow of operations.
- Manages data transformation from simplified user input to the full feature vector.
- Invokes the prediction model.
- Calls the recommendation engine.
- Manages history file I/O.
- (Primarily within main() and the top-level logic of supporting functions).

Machine Learning Engine Layer:

DecisionTree Class: Encapsulates the logic for a single decision tree (node structure, splitting, training, prediction).

RandomForest Class: Manages an ensemble of DecisionTree objects, handles bootstrapping, feature subsampling (delegated to DecisionTree), training the ensemble, and aggregating predictions.

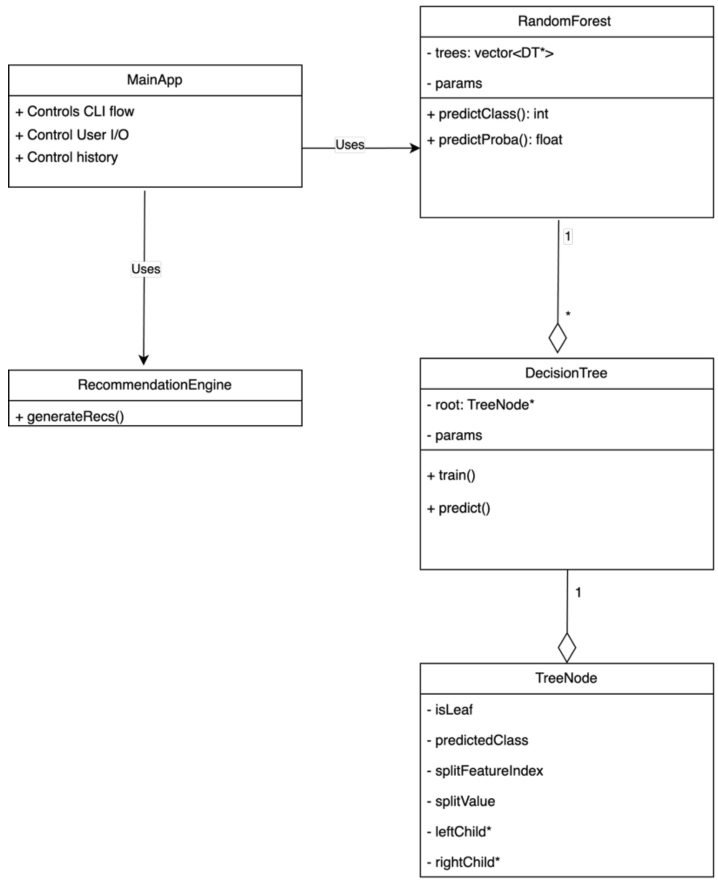
Data Preprocessing/Loading: Functions like load_numeric_csv and split_data.

Data Handling (Simplified for CLI):

Primarily in-memory data structures (std::vector for datasets).

File I/O for loading the initial dataset (cleaned_student_data.csv) and for reading/writing the single-user risk_history.txt. No complex database or encryption layer is implemented for this CLI version.

B. Conceptual Class Diagram of the System



Key Relationships:

MainApp (Conceptual, represented by main() and helper functions):

- Uses RandomForest for training and prediction.
- Uses RecommendationEngine (conceptually, implemented as display_recommendations function) to generate advice.
- Manages data loading and history file I/O.

RandomForest:

- Aggregates multiple DecisionTree objects. (A Random Forest "has-a" collection of Decision Trees).

DecisionTree:

- Aggregates TreeNode objects to form its structure (A Decision Tree "has-a" root TreeNode).

TreeNode:

- Can recursively point to other TreeNode objects (its children).

2. STRUCTURAL MODELING USING OBJECT CLASSES

A. Class Design Definitions

TreeNode

Definition: Represents a node within a decision tree. It can be an internal node (containing a split rule) or a leaf node (containing a class prediction).

Attributes:

- is_leaf: bool
- predicted_class: int (relevant if is_leaf is true)
- split_feature_index: int (relevant if is_leaf is false)
- split_value: double (relevant if is_leaf is false)
- left_child: TreeNode* (pointer to the left child node)
- right_child: TreeNode* (pointer to the right child node)
- Methods (Constructors/Destructor implicitly):
- TreeNode(predicted_class: int): Constructor for leaf node.
- TreeNode(split_feature_index: int, split_value: double): Constructor for internal node.
- ~TreeNode(): Destructor to manage memory of children.

Associations: Aggregates child TreeNodes (a tree is composed of nodes).

DecisionTree

Definition: It handles the logic for training the tree and making predictions.

Attributes:

- root: TreeNode* (pointer to the root node of the tree)
- params: DecisionTreeParams (struct holding max_depth, min_samples_leaf, num_features_to_consider for random feature subset at splits)
- rng_dt: std::mt19937 (random number generator for feature subsampling during splits)

Methods:

- DecisionTree(params: const DecisionTreeParams&, seed: unsigned int): Constructor.
- ~DecisionTree(): Destructor (deletes the root node, which triggers recursive deletion).
- train(features: const DatasetFeatures&, labels: const DatasetLabels&): Builds the tree.
- predict(sample: const Sample&): int - Predicts the class for a single sample.
- find_best_split(...): SplitInfo (private helper)
- build_tree_recursive(...): TreeNode* (private helper)

Associations: Aggregates a TreeNode (the root).

RandomForest

Definition: Encapsulates an ensemble of decision trees. Manages the creation, training, and prediction aggregation of these trees.

Attributes:

- trees: std::vector<DecisionTree*> (a collection of pointers to DecisionTree objects)
- params: RandomForestParams (struct holding num_trees, tree_params for individual trees, bootstrap_sample_ratio, random_seed)
- feature_names_internal: std::vector<std::string> (stores feature names used for training)

Methods:

- RandomForest(params: const RandomForestParams&): Constructor.
- ~RandomForest(): Destructor (iterates through trees and deletes each DecisionTree).
- train(features: const DatasetFeatures&, labels: const DatasetLabels&, feature_names: const std::vector<std::string>&): Trains all decision trees in the ensemble using bootstrapping and feature subsampling.
- predict_class(sample: const Sample&): int - Predicts the final class using majority vote from all trees.
- predict_probability_class1(sample: const Sample&): double - Predicts the probability of class 1.
- create_bootstrap_sample(...): std::vector<size_t> (private helper)

Associations: Aggregates multiple DecisionTree objects (a "has-many" relationship).

Helper Structs (Data Only):

- DecisionTreeParams: max_depth: int, min_samples_leaf: int, num_features_to_consider: int
- RandomForestParams: num_trees: int, tree_params: DecisionTreeParams, bootstrap_sample_ratio: double, random_seed: unsigned int
- SplitInfo: feature_index: int, split_value: double, gini_gain: double, left_indices: std::vector<size_t>, right_indices: std::vector<size_t>
- HistoryEntry: timestamp: std::string, probability_class1: double, risk_level_str: std::string

Generalization Hierarchies: In this implementation for a specific task, there are no explicit inheritance hierarchies defined for the core ML components. We are building concrete classes.

b. Notations for the Diagrams:

Class Boxes: A rectangle divided into three compartments:

Top: Class Name (e.g., RandomForest)

Middle: Attributes (e.g., trees: std::vector<DecisionTree*>, params: RandomForestParams)

Format: attributeName: dataType

Bottom: Methods/Operations (e.g., train(...), predict_class(...))

Format: methodName(parameterName: parameterType, ...): returnType

Associations:

Aggregation (Has-A): A line with an open (hollow) diamond on the side of the "whole" class, pointing to the "part" class.

Example:

RandomForest ◇-----> DecisionTree (A Random Forest has Decision Trees). Multiplicity like 1..* can be added near the DecisionTree end.

Example:

DecisionTree ◇-----> TreeNode (A Decision Tree has a root TreeNode).

Usage/Dependency (Uses): A dashed arrow -----> pointing from the using class to the used class.

Example: MainApp (represented by main()) -----> RandomForest.

Pointers: Indicated by * (e.g., TreeNode*).

Visibility:

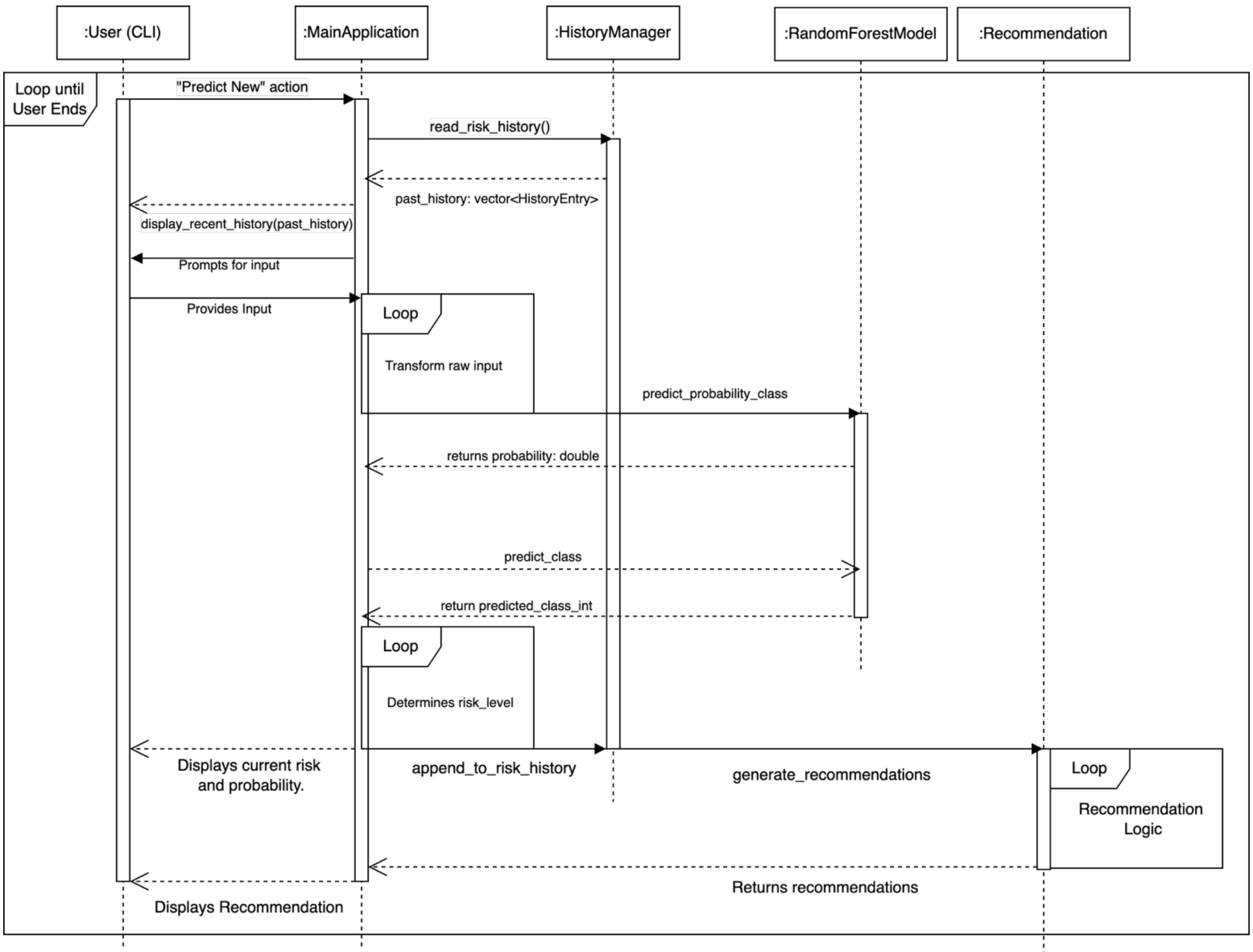
+ public

- private

protected

3. Interaction Modeling using Sequence Diagrams

a. Sequence Diagrams by Functional Requirement:



b. Notations for the Diagrams:

Lifelines: A vertical dashed line for each object/participant (e.g., User (CLI), MainApplication, RandomForestModel, HistoryManager, RecommendationLogic). A box with the object name (and class) is at the top.

Activation Bars (Execution Occurrence): Thin rectangles drawn on the lifelines, indicating the period during which an object is performing an operation (i.e., a method is active).

Messages: Horizontal arrows between lifelines.

Synchronous Call: Solid line with a filled arrowhead, labeled with the method name and parameters (e.g., predict_class(sample)).

Return Message: Dashed line with an open arrowhead, pointing back to the caller, labeled with the return value (e.g., predictedClass).

Loops/Conditionals: Frames can be drawn around parts of the diagram with labels like loop or alt (for if/else).

Execution Order: Time progresses downwards. Messages are ordered vertically based on their sequence.