

Module Interface Specification for TTE RecSys

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1 Revision History

| Date | Version | Notes |
|--------------|---------|-------------|
| March 2 2025 | 1.0 | First Draft |

2 Symbols, Abbreviations and Acronyms

See SRS Documentation at <https://github.com/V-AS/Two-tower-recommender-system/blob/main/docs/SRS/SRS.pdf>

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3 Introduction

The following document details the Module Interface Specifications for TTE RecSys

Complementary documents include the System Requirement Specifications and Module Guide. The full documentation and implementation can be found at <https://github.com/V-AS/Two-tower-recommender-system>

4 Notation

The structure of the MIS for modules comes from Hoffman and Strooper (1995), with the addition that template modules have been adapted from Ghezzi et al. (2003).

The following table summarizes the primitive data types used by TTE RecSys.

| Data Type | Notation | Description |
|-----------|--------------------|--|
| character | char | A sequence of characters |
| Array | $[T]$ | A sequence of elements of type T |
| Matrix | $[T]^{m \times n}$ | A 2D array of type T with m rows and n columns |
| Boolean | \mathbb{B} | True or False value |
| Integer | \mathbb{Z} | A number without a fractional component in $(-\infty, \infty)$ |
| real | \mathbb{R} | Any number in $(-\infty, \infty)$ |

TTE RecSys uses functions, which are defined by the data types of their inputs and outputs. Local functions are described by giving their type signature followed by their specification.

The specification also uses derived data types:

- Embedding: A vector of real numbers
- Tensors: Multi-dimensional arrays
- User: A type representing user features
- Item: A type representing item features

5 Module Decomposition

The following table is taken directly from the Module Guide document for this project.

| Level 1 | Level 2 |
|--------------------------|------------------------------------|
| Hardware-Hiding Module | |
| | Data Processing Module |
| | Model Training Module |
| | Embedding Generation Module |
| Behaviour-Hiding Module | Recommendation Module |
| | |
| Software Decision Module | Neural Network Architecture Module |
| | ANN Search Module |
| | Vector Operations Module |

Table 1: Module Hierarchy

6 MIS of Hardware-Hiding Module

6.1 Module

SystemInterface

6.2 Uses

None

6.3 Syntax

6.3.1 Exported Constants

None

6.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|------------|---------------------------------------|-------------------------|----------------------|
| save_model | model: Model, path: String | success: \mathbb{B} | IOError |
| load_model | path: String | model: Model | IOError, FormatError |
| save_emds | embeddings: [Embedding], path: String | success: \mathbb{B} | IOError |
| load_emds | path: String | embeddings: [Embedding] | IOError |

6.4 Semantics

6.4.1 State Variables

None

6.4.2 Environment Variables

FileSystem: The file system where models and embeddings are stored

6.4.3 Assumptions

- The file system is accessible and has sufficient space
- The paths provided are valid

6.4.4 Access Routine Semantics

save_model(model, path):

- output: success = true if operation succeeds
- exception: IOError if file cannot be written

load_model(path):

- output: model
- exception: IOError if file cannot be read, FormatError if file format is invalid

save_embeddings(embeddings, path):

- output: success = true if operation succeeds
- exception: IOError if file cannot be written

oad_embeddings(path):

- output: embeddings
- exception: IOError if file cannot be read, FormatError if file format is invalid

7 MIS of Data Processing Module

7.1 Module

DataProcessor

7.2 Uses

SystemInterface

7.3 Syntax

7.3.1 Exported Constants

None

7.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|---------------|---|--|-------------------------|
| load_data | path: String | data: DataSet | IOError, FormatError |
| validate_data | data: DataSet | is_valid: \mathbb{B} | - |
| prep_data | data: DataSet | processed_dataset | - |
| split_data | data: DataSet, train_ratio: \mathbb{R} | train_data: DataSet, test_data: DataSet | IOError |

7.4 Semantics

7.4.1 State Variables

None

7.4.2 Environment Variables

None

7.4.3 Assumptions

- Input data follows the expected schema

7.4.4 Access Routine Semantics

`load_data(path):`

- `data` = parsed data from file at `path`
- exception: `IOError` if file cannot be read, `FormatError` if file format is invalid

`validate_data(data)::`

- output: `is_valid` = true if data meets all validation criteria

`preprocess_data(data):`

- output: `processed_data` = dataset after applying preprocessing transformations

`split_data(data, train_ratio):`

- output: (`train_data`, `test_data`) where:
 - `train_data` = subset of data for training (size \approx `train_ratio` * $|data|$)
 - `test_data` = subset of data for training (size \approx (1-`train_ratio`) * $|data|$)
- exception: `ValueError` if `train_ratio` is not in (0, 1)

8 MIS of Model Training Module

8.1 Module

`ModelTrainer`

8.2 Uses

`DataProcessor`, `NeuralNetworkArchitecture`, `VectorOperations`

8.3 Syntax

8.3.1 Exported Constants

DEFAULT_LEARNING_RATE = 0.01
DEFAULT_BATCH_SIZE = 128
DEFAULT_REGULARIZATION = 0.01

8.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|----------------|--|---------------------------------|-------------------------|
| initialize | config: TrainingCon- fig | - | ValueError |
| train | train_data: DataSet, epochs: \mathbb{Z} | model: Model | IOError, FormatError |
| evaluate | test_data: DataSet, | metrics: Evaluation- Metrics | - |
| get_user_model | - | user_model: Model | NotInitializedError |
| get_item_model | - | item_model: Model | NotInitializedError |

8.4 Semantics

8.4.1 State Variables

- UserModel: The neural network model for the user tower
- ItemModel: The neural network model for the item tower
- IsInitialized: Boolean indicating if the module has been initialized

8.4.2 Environment Variables

None

8.4.3 Assumptions

- The training data is preprocessed and valid
- The model configuration is valid

8.4.4 Access Routine Semantics

initialize(config):

- transition:
 - UserModel = create_user_model(config.user_architecture)

- ItemModel = create_item_model(config.item_architecture)
- IsInitialized = true

- exception: ValueError if config contains invalid parameters

train(train_data, epochs):

- transition:
 - Update UserModel and ItemModel parameters through training
- output: history = record of loss values and metrics during training
- exception: NotInitializedError if IsInitialized is false

evaluate(test_data):

- output: metrics = evaluation metrics on test data
- exception: NotInitializedError if IsInitialized is false

get_user_model():

- output: user_model = UserModel
- exception: NotInitializedError if IsInitialized is false

get_item_model():

- output: item_model = UserModel
- exception: NotInitializedError if IsInitialized is false

8.4.5 Local Functions

compute_loss(user_embeddings, item_embeddings, ratings):

- Type: $[\mathbb{R}^k] \times \mathbb{R}^k \times \mathbb{R}$
- Description: Computes MSE loss between predicted and actual ratings

9 MIS of Embedding Generation Module

9.1 Module

EmbeddingGenerator

9.2 Uses

NeuralNetworkArchitecture, VectorOperations

9.3 Syntax

9.3.1 Exported Constants

EMBEDDING_DIMENSION = 128

9.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|-------------------------|---|-------------------------------|---------------------|
| initialize | user_model: Model,item_model: Model | - | ValueError |
| generate_user_embedding | users: [ProcessedUser] | embeddings: [Embedding] | NotInitializedError |
| generate_item_embedding | items: [ProcessedItem] | [Pro- embeddings: [Embedding] | NotInitializedError |

9.4 Semantics

9.4.1 State Variables

- UserModel: The neural network model for the user tower
- ItemModel: The neural network model for the item tower
- IsInitialized: Boolean indicating if the module has been initialized

9.4.2 Environment Variables

None

9.4.3 Assumptions

- The models have been trained

9.4.4 Access Routine Semantics

initialize(user_model, item_model):

- transition:
 - UserModel = user_model

- ItemModel = item_model
- IsInitialized = true

- exception: ValueError if models are incompatible

generate_user_embedding(users):

- output: embeddings := [UserModel(user) for user in users]
- exception: NotInitializedError if IsInitialized is false

generate_item_embedding(items):

- output: embeddings := [ItemModel(item) for item in items]
- exception: NotInitializedError if IsInitialized is false

10 MIS of Recommendation Module

10.1 Module

Recommender

10.2 Uses

EmbeddingGenerator, ANNSearch, VectorOperations

10.3 Syntax

10.3.1 Exported Constants

DEFAULT_NUM_RECOMMENDATIONS = 10 SIMILARITY_THRESHOLD = 0.5

10.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|---------------------|---|--------------------------------------|-------------------------------------|
| initialize | ann_index : ANNIndex | - | ValueError |
| get_recommendations | user: ProcessedUser, num_results: \mathbb{Z} | recommendations: [Recommendation] | NotInitializedError, FormatError |
| evaluate_rec | test_data: DataSet, path: String | metrics: RecommendationMetrics | NotInitializedError |

10.4 Semantics

10.4.1 State Variables

ANNIndex: The index for approximate nearest neighbor search
EmbeddingGen: Reference to the embedding generator
IsInitialized: Boolean indicating if the module has been initialized

10.4.2 Environment Variables

None

10.4.3 Assumptions

- The ANN index has been built with item embeddings
- The embedding generator has been initialized with trained models

10.4.4 Access Routine Semantics

initialize(ann_index):

- transition:
 - ANNIndex = ann_index
 - IsInitialized = true
- exception: ValueError if ann_index is invalid

get_recommendations(user, num_results):

- output: recommendations = ranked list of recommended items with similarity scores
- exception: NotInitializedError if IsInitialized is false

evaluate_recommendations(test_data):

- output: metrics = evaluation metrics for recommendations
- exception: NotInitializedError if IsInitialized is false

10.4.5 Local Functions

rank_candidates(user_embedding, candidate_embeddings):

- Description: Ranks candidates by similarity score (dot product)
- Type: $\mathbb{R}^k \times [\mathbb{R}^k] \rightarrow [(\mathbb{Z}, \mathbb{R})]$

11 MIS of Neural Network Architecture Module

11.1 Module

NeuralNetworkArchitecture

11.2 Uses

VectorOperations

11.3 Syntax

11.3.1 Exported Constants

DEFAULT_HIDDEN_LAYERS = [256, 128] DEFAULT_ACTIVATION = "relu"

11.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|-------------------|---|---------------------|------------|
| create_user_tower | input_dim: \mathbb{Z} , hidden_layers: [\mathbb{Z}] , embedding_dim: \mathbb{Z} | model: Model | ValueError |
| create_item_tower | input_dim: \mathbb{Z} , hidden_layers: [\mathbb{Z}] , embedding_dim: \mathbb{Z} | model: Model | ValueError |
| get_layer_config | model: Model | config: LayerConfig | ValueError |

11.4 Semantics

11.4.1 State Variables

None

11.4.2 Environment Variables

None

11.4.3 Assumptions

None

11.4.4 Access Routine Semantics

create_user_tower(input_dim, hidden_layers, embedding_dim):

- output: model = neural network model for user tower

- exception: ValueError if dimensions are invalid

create_item_tower(input_dim, hidden_layers, embedding_dim):

- output: model = neural network model for item tower
- exception: ValueError if dimensions are invalid

get_layer_config(model):

- output: config := configuration of layers in the model
- exception: ValueError if model is invalid

12 MIS of ANN Search Module

12.1 Module

ANNSearch

12.2 Uses

VectorOperations

12.3 Syntax

12.3.1 Exported Constants

DEFAULT_SEARCH_NPROBE := 10 DEFAULT_INDEX_TYPE := "IVF"

12.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|-------------|---|-------------------|-------------------------|
| build_index | embeddings: [Embedding] , item_ids: [Z], index_type: String | index: ANNIndex | ValueError |
| search | index: ANNIndex, query: Embedding, k: Z | results: [(Z, R)] | ValueError |
| save_index | index: ANNIndex, path: String | success: B | IOError |
| load_index | path: String | index: ANNIndex | IOError, FormatError |

12.4 Semantics

12.4.1 State Variables

None

12.4.2 Environment Variables

None

12.4.3 Assumptions

- Embeddings are of consistent dimension
- Query vector is of same dimension as indexed vectors

12.4.4 Access Routine Semantics

`build_index(embeddings, item_ids, index_type):`

- output: `index` = ANN index built from embeddings and associated item IDs
- exception: `ValueError` if parameters are invalid

`search(index, query, k):`

- output: `results` = list of `(item_id, similarity_score)` tuples for `k` nearest neighbors
- exception: `ValueError` if parameters are invalid

`save_index(index, path):`

- output: `success := true` if operation succeeds
- exception: `IOError` if file cannot be written

`load_index(path):`

- output: `index := ANNIndex` loaded from file
- exception: `IOError` if file cannot be read, `FormatError` if file format is invalid

13 MIS of Vector Operations Module

13.1 Module

`VectorOperations`

13.2 Uses

None

13.3 Syntax

13.3.1 Exported Constants

EPSILON := 1e-8 (small value to prevent division by zero)

13.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|-------------|---|----------------------|------------------------|
| dot_product | v1: $[\mathbb{R}]$, v2: $[\mathbb{R}]$ | result: \mathbb{R} | DimensionMismatchError |

13.4 Semantics

13.4.1 State Variables

None

13.4.2 Environment Variables

None

13.4.3 Assumptions

None

13.4.4 Access Routine Semantics

dot_product(v1, v2):

- output: result = $\sum_i^{len(v1)} v1[i] * v2[i]$
- exception: DimensionMismatchError if $len(v1) \neq len(v2)$

References

- Carlo Ghezzi, Mehdi Jazayeri, and Dino Mandrioli. *Fundamentals of Software Engineering*. Prentice Hall, Upper Saddle River, NJ, USA, 2nd edition, 2003.
- Daniel M. Hoffman and Paul A. Strooper. *Software Design, Automated Testing, and Maintenance: A Practical Approach*. International Thomson Computer Press, New York, NY, USA, 1995. URL <http://citeseer.ist.psu.edu/428727.html>.