Module Interface Specification for OAR

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March 15, 2024

1 Revision History

Date	Version	Notes
March 8, 2024	1.0	Initial Revision
March 15, 2024	1.1	Changes made according to Dr. Smith's Initial Comments
April 10, 2024	1.2	Updates according to Comments from Primary and Secondary Reviewers

2 Symbols, Abbreviations and Acronyms

See SRS Documentation (Ceranic, 2024) at https://github.com/cer-hunter/OAR-CAS741/blob/main/docs/SRS/SRS.pdf

Contents

3 Introduction

The following document details the Module Interface Specifications for the OAR (Optical Alphabet Recognition) program. This document specifies how each module interfaces with other parts of the program.

Complementary documents include the System Requirement Specifications and Module Guide. The full documentation and implementation can be found at https://github.com/cer-hunter/OAR-CAS741.

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 mathematical notation comes from Chapter 3 of Hoffman and Strooper (1995). For instance, the symbol := is used for a multiple assignment statement and conditional rules follow the form $(c_1 \Rightarrow r_1 | c_2 \Rightarrow r_2 | ... | c_n \Rightarrow r_n)$.

The following table summarizes the primitive data types used by OAR.

Data Type	Notation	Description
character	char	a single symbol or digit
integer	$\mathbf{Z}$	a number without a fractional component in (-∞, ∞)
positive integer	$\mathbf{Z}_+$	a positive integer ($\mathbf{Z}$) in (0, ∞)
unsigned 8-bit integer	$\mathbf{U}$	a number without a fractional component in (0, 255)
natural number	$\mathbf{N}$	a number without a fractional component in [1, ∞)
real	$\mathbf{R}$	any number in (-∞, ∞)
positive real	$\mathbf{R}_+$	any real number ($\mathbf{R}$) in (0, ∞)
image data	$\mathbf{I}_{x,y}$	`data`: a one-dimensional array of unsigned 8-bit integers in order from the top-left pixel of the image to the bottom-right pixel. Has a `width`: $\mathbf{Z}_+$ width of x and `height`: $\mathbf{Z}_+$ height of y.
matrix	$\mathbf{M}_{x,y}$	`data`: a one-dimensional array of real numbers, with a `width`: $\mathbf{Z}_+$ width of x and `height`: $\mathbf{Z}_+$ height of y.

The specification of OAR uses some derived data types: sequences, strings, tuples, and booleans. Sequences are lists filled with elements of the same data type. Strings are sequences

of characters. Tuples contain a list of values, potentially of different types. Booleans can be represented in different ways but only have two possible values: true or false. In addition, OAR 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.

5 Module Decomposition

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

Level 1	**Level 2**
Hardware-Hiding Module	
Behaviour-Hiding Module	Application Control Graphics Display Output Calculator Input Data Read Input Classifier OAR Model Data OAR Model Equations OAR Model Training OAR Model Testing
Software Decision Module	Confusion Matrix Input Processing Graphical User Interface

Table 1: Module Hierarchy

6 MIS of Application Control Module

6.1 Module

`main`

6.2 Uses

- Graphics Display Module Specification (7)

6.3 Syntax

6.3.1 Exported Constants

None.

6.3.2 Exported Access Programs

Name	In	Out	Exceptions
`main`	-	-	-

6.4 Semantics

6.4.1 State Variables

None.

6.4.2 Environment Variables

- Screen ($\mathbf{Z}_+$ for width and height in pixels)

6.4.3 Assumptions

The GUI Display is running and displayed without issue.

6.4.4 Access Routine Semantics

`main`():

- transition: Initializes the program and the Graphics Display module 7

6.4.5 Local Functions

None.

7 MIS of Graphics Display

7.1 Module

`display`

7.2 Uses

- Hardware-Hiding Module
- Input Data Read Module (9)
- Output Module (8)
- Graphical User interface (GUI) Module (17)

7.3 Syntax

7.3.1 Exported Constants

- `GUI_BOXSIZE`: A value ($\mathbf{Z}_+$) describing both width and height (in pixels) used for the image display "box" (currently always a square)

7.3.2 Exported Access Programs

Name	In	Out	Exceptions
`display`	`inputImage` ($\mathbf{I}_{x,y}$), `resultLabel` (String), `resultConf` (String)	`displayWindow`, event handlers	`guiException`

7.4 Semantics

7.4.1 State Variables

- inputImage: The processed input image and given by the Output Calculator Module 8 as $\mathbf{I}_{x,y}$
- resultLabel: The label output as given by the Output Calculator Module 8 as a string.
- resultConf: The confidence probability output as given by the Output Calculator Module 8 as a string.

7.4.2 Environment Variables

- Keyboard ($\mathbf{Z}_+$ for keycodes describing the key pressed)
- Mouse (Boolean for click state and $\mathbf{Z}_+$ for cursor position)
- Screen ($\mathbf{Z}_+$ for width and height in pixels)
- `displayWindow` ($\mathbf{Z}_+$ for width and height in pixels) for the application interface
- `inputButton` (String for a file location) to provide an input image from the file system

7.4.3 Assumptions

- The file system is able to read and provide the image file as specified by the user through an OS file-open dialog. Otherwise if the file is not found, denied access or cancelled, no changes should occur.
- The OS is able to provide basic text or number input user controls with some basic built-in validation, and is able to handle events from Human Interface Devices (HIDs such as mouse, keyboard or touchscreen).

7.4.4 Access Routine Semantics

`display`():

- transition: Sets up user control event handlers (i.e., mouse clicks or drag, button presses, text input change, ...) as needed for the user input. Calls the Input Data Read Module 9 to accept a base image and Output Calculator Module 8 to classify the input image. The input image and output results are then pushed to the `displayWindow`.
- exception: `guiException` when `ValueError` is raised by the program, or incorrect user input.

7.4.5 Local Functions

None.

8 MIS of Output Calculator Module

8.1 Module

`output`

8.2 Uses

- Input Classifier Module Specification (10)

8.3 Syntax

8.3.1 Exported Constants

- `DEC_FIXED`: Used for fixed decimal number length rounding (ex. "5.8923" at fixed length "2" results in "5.89")

8.3.2 Exported Access Programs

Name	In	Out	Exceptions
`output`	`baseImage` ($\mathbf{M}_{x,y}$)	`inputImage` ($\mathbf{I}_{x,y}$), `resultLabel` (String), `resultConf` (String)	-

8.4 Semantics

8.4.1 State Variables

- `labelData` := $\mathbf{M}_{x,y}$ of outputs from `classify`(inputImage) containing the label string, and confidence in the prediction

8.4.2 Environment Variables

None.

8.4.3 Assumptions

The input image is valid.

8.4.4 Access Routine Semantics

`output`():

- transition: `inputImage` := `input`(baseImage)
- output: `resultLabel`, `resultConf` := `labelData` (String)

8.4.5 Local Functions

None.

9 MIS of Input Data Read Module

9.1 Module

`input`

9.2 Uses

- Input Processing Module Specification (16)

9.3 Syntax

9.3.1 Exported Constants

None.

9.3.2 Exported Access Programs

Name	In	Out	Exceptions
`input`	`baseImage` ($\mathbf{I}_{x,y}$)	`inputImage` ($\mathbf{I}_{x,y}$)	`ValueError`

9.4 Semantics

9.4.1 State Variables

- `maxSize`: A value ($\mathbf{Z}_+$) describing both width and height (in pixels) for maximum acceptable size of the input image (currently a square).
- `minSize`: A value ($\mathbf{Z}_+$) describing both width and height (in pixels) for minimum acceptable size of the input image (currently a square).
- `modelSize`: The required size of the input image matrix to be used by the classification model $\mathbf{I}_{x,y}$.

9.4.2 Environment Variables

- `baseImage`: The base input image in the form of a .BMP .JPG or .PNG file.

9.4.3 Assumptions

The input path location for base image is valid, readable and accessible.

9.4.4 Access Routine Semantics

`input`(inputPath):

- output: `inputImage` := `preprocess`(baseImage)
- exception: `ValueError` if the size of the base image is outside of the range of `minSize` to `maxSize`, `ValueError` if the file type of the `baseImage` is not supported by the OAR Program (according to R1)

9.4.5 Local Functions

None.

10 MIS of Input Classifier Module

10.1 Module

`classify`

10.2 Uses

- OAR Model Data Module Specification (11)
- OAR Model Equations Module Specification (12)

10.3 Syntax

10.3.1 Exported Constants

`LABELS`:= (A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z)

10.3.2 Exported Access Programs

Name	In	Out	Exceptions
`classify`	`inputImage` ($\mathbf{I}_{x,y}$), `oarModel` ($\mathbf{M}_{x,y}$)	`resultLabel` (String), `confPercent` ($\mathbf{R}_{+}$)	-

10.4 Semantics

10.4.1 State Variables

- `weight`: the weight portion of the `oarModel` input as $\mathbf{M}_{x,y}$ for each label.
- `bias`: the bias portion of the `oarModel` input as $\mathbf{R}$ for each label.
- `predictionMatrix`: $\mathbf{M}_{x,y}$, where each entry is the output of `predict`(inputImage, weight, bias), corresponding to each label
- `bestPrediction`: $\mathbf{max}$(`predictionMatrix`) ≤ 1

10.4.2 Environment Variables

None.

10.4.3 Assumptions

The input image is valid.

10.4.4 Access Routine Semantics

`classify`(inputImage):

- output: `confPercent` := `bestPrediction`, `resultLabel`:= the letter in the list of `LABELS` corresponding to the index of `bestPrediction` in the `predictionMatrix`

10.4.5 Local Functions

None.

11 MIS of OAR Model Data Module

11.1 Module

`model`

11.2 Uses

- OAR Model Testing Module Specification (14)

11.3 Syntax

11.3.1 Exported Constants

None.

11.3.2 Exported Access Programs

Name	In	Out	Exceptions
`model`	-	-	-

11.4 Semantics

11.4.1 State Variables

- `oarModel`: Data structure designed to store the matrix of weights and biases associated with the trained OAR classification model as a tuple of $\mathbf{M}_{x,y}$ and $\mathbf{R}$.
- `performance`: Data structure designed to store the matrix of performance values associated with each label of the trained OAR classification model as a $\mathbf{M}_{x,y}$.

11.4.2 Environment Variables

None.

11.4.3 Assumptions

None.

11.4.4 Access Routine Semantics

`model`():

- transition: This module is a simple tuple ($\mathbf{M}_{x,y}$ and $\mathbf{R}$) data structure for storing the OAR classification model weights and biases and corresponding performance matrix.

11.4.5 Local Functions

None.

12 MIS of OAR Model Equations Module

12.1 Module

`oarUtils`

12.2 Uses

None.

12.3 Syntax

12.3.1 Exported Constants

None.

12.3.2 Exported Access Programs

Name	In	Out	Exceptions
`sigmoid`	`sigIn` ($\mathbf{R}$)	`sigOut` ($\mathbf{R}$)	-
`logLossFunc`	`trueVal` ($\mathbf{R}$), `predVal` ($\mathbf{R}$)	`logLoss` ($\mathbf{R}$)	`ValueError`
`predict`	`inputImage` ($\mathbf{I}_{x,y}$), `weight` ($\mathbf{M}_{x,y}$), `bias` ($\mathbf{R}$)	`predVal` ($\mathbf{R}$)	`ValueError`
`gradientW`	`inputImage` ($\mathbf{I}_{x,y}$), `trueVal` ($\mathbf{R}$), `weight` ($\mathbf{M}_{x,y}$), `bias` ($\mathbf{R}$), `regParam` ($\mathbf{R}$), `trainSize` ($\mathbf{Z}_+$)	`gradW` ($\mathbf{R}$)	`ValueError`
`gradientB`	`inputImage` ($\mathbf{I}_{x,y}$), `trueVal` ($\mathbf{R}$), `weight` ($\mathbf{M}_{x,y}$), `bias` ($\mathbf{R}$)	`gradB` ($\mathbf{R}$)	-

12.4 Semantics

12.4.1 State Variables

None.

12.4.2 Environment Variables

None.

12.4.3 Assumptions

The input image is valid.

12.4.4 Access Routine Semantics

`sigmoid`(sigIn):

- output: `sigOut` := $\frac{1}{1+e^{-\texttt{sigIn}}}$

`logLossFunc`(trueVal, predVal):

- output: `logLoss` := $\texttt{trueVal} \cdot \log(\texttt{predVal}) + (1 - \texttt{trueVal}) \cdot \log(1 - \texttt{predVal})$
- exception: `ValueError` if `predVal` or $1-$ `predVal` is negative

`predict`(inputImage, weight, bias):

- output: sigIn:= $\texttt{weight}^{\mathbf{T}} \cdot \texttt{inputImage} + \texttt{bias}$, predVal := `sigmoid`(sigIn)
- exception: `ValueError` if `inputImage` and `weight` are matrices of the same size

`gradientW`(inputImage, trueVal, weight, bias, regParam, trainSize):

- transition: `predVal` := `predict`(inputImage, weight, bias)
- output: `gradW`:= $\texttt{inputImage} \cdot (\texttt{trueVal} - \texttt{predVal}) - \frac{\texttt{regParam}}{\texttt{trainSize}} \cdot \texttt{weight}^2$
- exception: `ValueError` if `trainSize` is 0

`gradientB`(inputImage, trueVal, weight, bias):

- transition: `predVal` := `predict`(inputImage, weight, bias)
- output: `gradB`:= $\texttt{trueVal} - \texttt{predVal}$

12.4.5 Local Functions

None.

13 MIS of OAR Model Training Module

13.1 Module

`train`

13.2 Uses

- OAR Model Equations Module Specification (12)

13.3 Syntax

13.3.1 Exported Constants

- `REG_PARAM`: The regularization parameter used during model training as $\mathbf{R}_+$.
- `ALPHA`: The learning rate parameter used during model training as $\mathbf{R}_+$.

13.3.2 Exported Access Programs

Name	In	Out	Exceptions
`train`	`trainData` ($\mathbf{M}_{x,y}$),`trainLabels` ($\mathbf{M}_{x,y}$), `weightBiasMatrix` (tuple of $\mathbf{M}_{x,y}$ and $\mathbf{R}$), `trainSize` ($\mathbf{Z}_+$)	`weightBiasMatrix` (tuple of $\mathbf{M}_{x,y}$ and $\mathbf{R}$)	-

13.4 Semantics

13.4.1 State Variables

- `weight`: the weight portion of the `weightBiasMatrix` input as $\mathbf{M}_{x,y}$ for each label.
- `bias`: the bias portion of the `weightBiasMatrix` input as $\mathbf{R}$ for each label.
- `gradW`:= `gradientW`(trainData, trainLabels, REG_PARAM, trainSize)
- `gradB`:= `gradientB`(trainData, trainLabels, weight, bias)

13.4.2 Environment Variables

None.

13.4.3 Assumptions

None.

13.4.4 Access Routine Semantics

`train`(trainData, trainLabels, weightBiasMatrix, trainSize):

- transition: `weight`:= `weight` + `ALPHA`·`gradW`, `bias`:= `bias` + `ALPHA`·`gradB`
- output: `weightBiasMatrix`:= (`weight`,`bias`)

13.4.5 Local Functions

None.

14 MIS of OAR Model Testing Module

14.1 Module

`test`

14.2 Uses

- OAR Model Data Module Specification (12)
- OAR Model Equations Module Specification (12)
- OAR Model Training Module Specification (13)
- Metrics Module Specification (15)

14.3 Syntax

14.3.1 Exported Constants

- `EPOCHS`: The the number of times the model training regression algorithm is ran as $\mathbf{Z}_+$.
- `LABELS`:= (A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U, V, W, X, Y, Z)
- `TRAIN_SIZE`: The size of the training data used during model training as $\mathbf{Z}_+$.
- `TEST_SIZE`: The size of the testing data used during model training as $\mathbf{Z}_+$.

14.3.2 Exported Access Programs

Name	In	Out	Exceptions
`test`	-	`oarModel` (tuple of $\mathbf{M}_{x,y}$ and $\mathbf{R}$), `performance` (tuple of $\mathbf{M}_{x,y}$ and $\mathbf{I}_{x,y}$)	-

14.4 Semantics

14.4.1 State Variables

- `dataSize`: The size of the input image matrix used during model training as $\mathbf{I}_{x,y}$.
- `dataSet`: The set of pre-processed images and their associated labels that will be used for training the classification model as a tuple of $\mathbf{I}_{x,y}$ and $\mathbf{Z}_+$.
- `weight`: the weight portion of the `weightBiasMatrix` input as $\mathbf{M}_{x,y}$ for each label.
- `bias`: the bias portion of the `weightBiasMatrix` input as $\mathbf{R}$ for each label.
- `predictionData`: matrix which tracks the number predictions made for each test image as $\mathbf{M}_{x,y}$.

14.4.2 Environment Variables

None.

14.4.3 Assumptions

None.

14.4.4 Access Routine Semantics

`test`():

- transition: weightBiasMatrix:= $\mathbf{M}_{x,y}$ of randomized values from 0 to 1, `train`(trainData, trainLabels, weightBiasMatrix, trainSize)
- output: `oarModel`:= weightBiasMatrix, `performance`:= `confMatrix`(predictionData, trainLabels), `loss`(trainLoss).

14.4.5 Local Functions

- `splitDataSet`(dataSet):
  - output: Takes the `dataSet` as an input and splits it into distinct parts for training and testing the classification model. The following values are output:
    - `trainData`:= The part of the `dataSet` used to train the model as $\mathbf{M}_{x,y}$.
    - `trainLabels`:= The part of the `dataSet` corresponding to the true labels of the `trainData` as $\mathbf{M}_{x,y}$.
    - `testData`:= The part of the `dataSet` used to test the model as $\mathbf{M}_{x,y}$.
    - `testLabels`:= The part of the `dataSet` corresponding to the true labels of the `testData` as $\mathbf{M}_{x,y}$.

15 MIS of Metrics Module

15.1 Module

`metrics`

15.2 Uses

None.

15.3 Syntax

15.3.1 Exported Constants

None.

15.3.2 Exported Access Programs

Name	In	Out	Exceptions
confMatrix	predictionData ($\mathbf{M}_{x,y}$), trainLabels ($\mathbf{M}_{x,y}$)	confusionMatrix ($\mathbf{I}_{x,y}$), matrixData ($\mathbf{M}_{x,y}$)	-
loss	trainLoss ($\mathbf{M}_{x,y}$)	lossGraph ($\mathbf{I}_{x,y}$)	-

15.4 Semantics

15.4.1 State Variables

None.

15.4.2 Environment Variables

None.

15.4.3 Assumptions

None.

15.4.4 Access Routine Semantics

confMatrix(predictionData, trainLabels):

- output: confusionMatrix:= ($\mathbf{M}_{x,y}$) of the form ($\sum$predictionData == True & trainLabels == True, $\sum$predictionData == True & trainLabels == False, $\sum$predictionData == False & trainLabels == True, $\sum$predictionData == False & trainLabels == False) and it's graphical representation as $\mathbf{I}_{x,y}$.

loss(trainLoss):

- output: lossGraph:= trainLoss as a graphical representation over some number of epochs.

15.4.5 Local Functions

None.

16 MIS of Input Processing Module

16.1 Module

preprocess

16.2 Uses

None.

16.3 Syntax

16.3.1 Exported Constants

None.

16.3.2 Exported Access Programs

Name	In	Out	Exceptions
`preprocess`	`baseImage` ($\mathbf{I}_{x,y}$)	`inputImage` ($\mathbf{I}_{x,y}$)	-

16.4 Semantics

16.4.1 State Variables

None.

16.4.2 Environment Variables

None.

16.4.3 Assumptions

The format and parameters of the base image was already verified to be within the requirements.

16.4.4 Access Routine Semantics

`preprocess`(baseImage):

- output: Performs transformations on the `baseImage` using functions provided by the sci-kit learn library, such that the resulting `inputImage` as $\mathbf{I}_{x,y}$, is normalized to be able to be used by the classification model.

16.4.5 Local Functions

None.

17 MIS of Graphical User Interface

17.1 Module

`gui`

17.2 Uses

None.

17.3 Syntax

17.3.1 Exported Constants

None.

17.3.2 Exported Access Programs

Name	In	Out	Exceptions
gui	None	None	-

17.4 Semantics

17.4.1 State Variables

None.

17.4.2 Environment Variables

- Keyboard ($\mathbf{Z}_+$ for keycodes describing the key pressed)
- Mouse (Boolean for click state and $\mathbf{Z}_+$ for cursor position)
- Screen ($\mathbf{Z}_+$ for width and height in pixels)
- Button (String for a file location) to provide an input image from the file system

17.4.3 Assumptions

None.

17.4.4 Access Routine Semantics

gui():

- transition: Provides methods from the TKinter Library to build and deploy a GUI to Graphics Display Module 7

17.4.5 Local Functions

None.

References

Hunter Ceranic. System requirements specification. https://github.com/cer-hunter/OAR-CAS741/blob/main/docs/SRS/SRS.pdf, 2024.

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