

Module Interface Specification for CFS

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1 Revision History

| Date | Version | Notes |
|--------------|---------|---|
| Nov 10, 2018 | 1.0 | First draft by Malavika |
| Nov 21, 2018 | 1.1 | Corrections based on presentation by Malavika |
| Nov 24, 2018 | 1.2 | MIS submission draft by Malavika |

2 Symbols, Abbreviations and Acronyms

See CA Documentation at <https://github.com/Malavika-Srinivasan/CAS741/blob/master/docs/SRS/CA.pdf>

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3 Introduction

The following document details the Module Interface Specifications for CFS(Curve Fitting Software). The goal of CFS is to find the parameters of the curve which is the best possible fit through the given set of ‘n’ data points, where $n \geq 2$.

Complementary documents include the Commonality Analysis and Module Guide. The full documentation and implementation can be found at the repository <https://github.com/Malavika-Srinivasan/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 $(c_1 \Rightarrow r_1 | c_2 \Rightarrow r_2 | \dots | c_n \Rightarrow r_n)$.

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

| Data Type | Notation | Description |
|----------------|--------------|---|
| character | char | a single symbol or digit |
| integer | \mathbb{Z} | a number without a fractional component in $(-\infty, \infty)$ |
| natural number | \mathbb{N} | a number without a fractional component in $[1, \infty)$ |
| real | \mathbb{R} | any number in $(-\infty, \infty)$ |
| boolean | \mathbb{B} | a value from the set $\{True, False\}$ |

The specification of CFS uses some derived data types: sequences, strings, and tuples. 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. In addition, CFS 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

[Needs to be changed in MG based on Dr.Smith’s suggestion —Malavika] The following table is taken directly from the Module Guide document for this project.

| Level 1 | Level 2 |
|--------------------------|--|
| Hardware-Hiding Module | |
| Behaviour-Hiding Module | Input Output |
| Software Decision Module | Sequence Services Interpolation Regression Plot |

Table 1: Module Hierarchy

6 MIS of Input module

This module corresponds to R??, R?? and R?? in the CA document. The secrets of this module are how the data points are input and how they are verified. The load and verify secrets are isolated to their own access programs.

6.1 Module

input

6.2 Uses

??[Sequence services —Malavika]

6.3 Syntax

| Name | In | Out | Exceptions |
|--------------|-----------------|-----|----------------------|
| loadInput | inFile : string | - | FileError |
| verifyInput | - | - | ValueError,TypeError |
| verifyDegree | - | - | ValueError |

6.3.1 Exported Constants

NA

6.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|--------------|----|--------------|------------|
| verifyDegree | | \mathbb{N} | ValueError |

[I need the verifyInput as an exported access program because I will be verifying the degree input from regression module if necessary. —Malavika]

6.4 Semantics

6.4.1 State Variables

From R?? in CA

$t: \mathbb{R}^n$

$y: \mathbb{R}^n$

$degVerify: boolean$

[This will say if the degree input to regression module has been verified or not. This may be changed after]

6.4.2 Environment Variables

inFile: sequence of string

6.4.3 Assumptions

- The loadInput will be called before the calling the verifyInput method.
- Regression module will be called before calling verifyDegree method.
- The loadInput will be called before the values of any state variables will be accessed.

6.4.4 Access Routine Semantics

input.t:

- transition: NA
- output: $out := t$
- exception: None

input.y:

- transition: NA
- output: $out := y$
- exception: None

input.degVerify:

- transition: NA
- output: $out := degVerify$
- exception: None

loadInput(s):

- transition: inputFile is used to modify the state variables using the following procedural specification:
 1. Read data sequentially from inputFile to populate the state variables t and y .
 2. verifyInput()
- output: NA

- exception: $\text{exc} :=$ a file name s cannot be found \vee the format of inFile is incorrect
 $\Rightarrow \text{FileError}$. [I am yet to decide if the library will take a .txt and .csv or both. This specification will become formal once we decide the type of the input file. —Malavika]

verifyInput():

- transition: NA
- output: NA
- exception: $\text{exc} :=$

| Name | Exception |
|--|--|
| $(t \leq 1 \vee y \leq 1)$ | $\Rightarrow \text{LengthError}$ |
| $(t \neq y)$ | $\Rightarrow \text{LengthMismatchError}$ |
| $(\forall x \in t \wedge x \notin \mathbb{R})$ | $\Rightarrow \text{TypeError}$ |
| $(\forall x \in y \wedge x \notin \mathbb{R})$ | $\Rightarrow \text{TypeError}$ |

verifyDegree():

- transition:
 - $(deg > 0 \wedge deg \in \mathbb{N}) \implies degVerify = True$
- output:
- exception: $\text{exc} :=$

| Name | Exception |
|---|---------------------------------|
| $(deg \leq 0 \vee deg \notin \mathbb{N})$ | $\Rightarrow \text{ValueError}$ |

6.4.5 Local Functions

NA

7 MIS of Interpolation module

This module corresponds to R??, R??, R??, R?? and R?? in section ?? of CA document.

7.1 Module

interp

7.2 Uses

6, 9, ??[Sequence services —Malavika]

7.3 Syntax

7.3.1 Exported Constants

NA

7.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|--------------------|----------------------------------|---------------------|------------|
| interpMonomial | $t:\mathbb{R}^n, y:\mathbb{R}^n$ | - | - |
| interpLagrange | $t:\mathbb{R}^n, y:\mathbb{R}^n$ | - | - |
| interpNewton | $t:\mathbb{R}^n, y:\mathbb{R}^n$ | - | - |
| interpHermiteCubic | $t:\mathbb{R}^n, y:\mathbb{R}^n$ | - | - |
| interpBSpline | $t:\mathbb{R}^n, y:\mathbb{R}^n$ | - | - |
| evalMonomial | $t:\mathbb{R}^n, y:\mathbb{R}^n$ | $yNew:\mathbb{R}^n$ | - |
| evalLagrange | $t:\mathbb{R}^n, y:\mathbb{R}^n$ | $yNew:\mathbb{R}^n$ | - |
| evalNewton | $t:\mathbb{R}^n, y:\mathbb{R}^n$ | $yNew:\mathbb{R}^n$ | - |
| evalHermiteCubic | $t:\mathbb{R}^n, y:\mathbb{R}^n$ | $yNew:\mathbb{R}^n$ | - |
| evalBSpline | $t:\mathbb{R}^n, y:\mathbb{R}^n$ | $yNew:\mathbb{R}^n$ | - |

7.4 Semantics

7.4.1 State Variables

- $x:\mathbb{R}^{n-1 \times m}$, Where $m = \text{degree of polynomial} + 1$ and n is the number of data points.
- $\text{interval}:\mathbb{R}^k$, Where k is the number of sections

7.4.2 Environment Variables

NA

7.4.3 Assumptions

- `evalMonomial()` will be called after `interpMonomial()`.
- `evalLagrange()` will be called after `interpLagrange()`.
- `evalNewton()` will be called after `interpNewton()`.
- `evalHermiteCubic()` will be called after `interpHermiteCubic()`.
- `evalBSpline()` will be called after `interpBSpline()`.

7.4.4 Access Routine Semantics

interp.x:

- transition: NA
- output: $out := x$
- exception: None

interpMonomial(t,y):

- transition:
 - 1. $x: \mathbb{R}^{n-1 \times m} = 0.0$, this is initialization. This is necessary as all the methods will be using the same state variable.
 - 2. $x: \mathbb{R}^{n-1 \times m}$ obtained by solving for x using the equation below.

$$\begin{bmatrix} 1 & t_1 & t_1^2 & \dots & t_1^{n-1} \\ 1 & t_2 & t_2^2 & \dots & t_2^{n-1} \\ \vdots & \vdots & \vdots & \vdots & \\ 1 & t_n & t_n^2 & \dots & t_n^{n-1} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$$

- interval: $\mathbb{R}^k = t[0]$, this is initialized to starting point for non piecewise functions.
- output: NA
- exception: NA

evalMonomial(t, y):

- transition: NA
- output: $out := yNew$
 $\forall t_i \in t, yNew.append(y1)$ where $y1$ is obtained as shown below.

$$y1 = x_1 + x_2 t_i + x_3 t_i^2 + x_4 t_i^3 + \dots x_n t_i^{n-1}$$

- exception: NA

interpLagrange(t, y):

- transition:
 - 1. $x: \mathbb{R}^{n-1 \times m} = 0.0$, this is initialization. This is necessary as all the methods will be using the same state variable.
 - 2. $x: \mathbb{R}^{n-1 \times m}$ obtained by solving for x using the equation below.

$$\begin{bmatrix} 1 & 0 & 0 & \dots & 0 \\ 0 & 1 & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \\ 0 & 0 & 0 & \dots & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$$

- interval: $\mathbb{R}^k = t[0]$, this is initialized to starting point for non piecewise functions.

- output: NA
- exception: NA

evalLagrange(t, y):

- transition: NA
- output: $out := yNew$
 $\forall t_i \in t, yNew.append(y_0)$ where y_0 is obtained as shown below.

$$y_0 = y_1 l_1(t) + y_2 l_2(t) + \dots y_n l_n(t).$$

where $l_j(t)$ is given by,

$$l_j(t) = \frac{\prod_{k=1, k \neq j}^n (t - t_k)}{\prod_{k=1, k \neq j}^n (t_j - t_k)}$$

- exception: NA

interpNewton(t, y):

- transition:
 - 1. $x: \mathbb{R}^{n-1 \times m} = 0.0$, this is initialization. This is necessary as all the methods will be using the same state variable.
 - 2. $x: \mathbb{R}^{n-1 \times m}$ obtained by solving for x using the equation below.

$$\begin{bmatrix} \pi_0(t_0) & 0 & 0 & \dots & 0 \\ \pi_0(t_1) & \pi_1(t_1) & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & 0 \\ \pi_0(t_n) & \pi_1(t_n) & \pi_2(t_n) & \dots & \pi_n(t_n) \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$$

where,

$$i < j \implies \pi_j(t) = 0, i \geq j \implies \pi(t) = \Pi_{k=1}^{j-1}(t - t_k)$$

- interval: $\mathbb{R}^k = t[0]$, this is initialized to starting point for non piecewise functions.

- output: NA
- exception: NA

evalNewton(t, y):

- transition: NA
- output: $out := yNew$
 $\forall t_i \in t, yNew.append(y_0)$ where y_0 is obtained as shown below.

$$y_0 = x_1 + x_2(t - t_1) + x_3(t - t_1)(t - t_2) + \dots x_n(t - t_1)(t - t_2) \dots (t - t_{n-1})$$

- exception: NA

interpHermiteCubic(t, y):

- transition:
 - 1. $x: \mathbb{R}^{n-1 \times m} = 0.0$, this is initialization. This is necessary as all the methods will be using the same state variable.

2. x : $\mathbb{R}^{n-1 \times m}$ obtained by solving for x using the equation below.

$$\begin{bmatrix} 1 & t_0 & t_0^2 & t_0^3 \\ \vdots & \vdots & \vdots & \vdots \\ 1 & t_n & t_n^2 & t_n^3 \\ 0 & 1 & 2t_0 & 3t_0^2 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 1 & 2t_n & 3t_n^2 \\ 0 & 0 & 2 & 6t_0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 2 & 6t_n \\ 0 & 0 & 0 & 6 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 6 \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ x_{n(m+1)} \end{bmatrix} = \begin{bmatrix} y_0 \\ \vdots \\ y_0^{(1)} \\ y_1^{(1)} \\ \vdots \\ y_n^{(1)} \\ y_1^{(2)} \\ \vdots \\ y_n^{(2)} \\ y_1^{(3)} \\ \vdots \\ y_n^{(3)} \end{bmatrix}$$

– interval: $\mathbb{R}^k = t[0]$ to $t[n-2]$, by default we make each point a breakpoint and hence there is a piecewise polynomial between $[t_{i-1}, t_i)$.

- output: NA.
- exception: NA

evalHermiteCubic(t, y):

- transition:
- output: $out := yNew$

$\forall t_i \in t, yNew.append(y_0)$ where y_0 is obtained as shown below.

$$y_0 = x_{k0} + x_{k1}t + x_{k2}t^2 + x_{k3}t^3 \text{ for } k = 0 \text{ to } n-2$$

- exception: NA

interpBSpline(t, y):

- transition:

– 1. x : $\mathbb{R}^{n-1 \times m} = 0.0$, this is initialization. This is necessary as all the methods will be using the same state variable.

2. x : obtained by using the formula below.
for $k > 0$.

$$x = v_i^k = \frac{t - t_i}{t_{i+k} - t_i}$$

[BSpline gives the v values which will be used recursively in formula defined in IM?? of the CA document —Malavika]

- interval: $\mathbb{R}^k = t[0]$ to $t[n - 2]$, by default we make each point a breakpoint and hence there is a piecewise polynomial between $[t_{i-1}, t_i)$.

- output: NA
- exception: NA

evalBSpline(t, y):

- transition:
- output: $out := yNew$

$\forall t_i \in t, yNew.append(y_0)$ where y_0 is obtained as shown below.

$$y_0 = B_i^k(t) = v_i^k(t)B_i^{k-1}(t) + (1 - v_{i+1}^k(t))B_{i+1}^{k-1}(t)$$

for $k > 0$.

[I want the notation of ‘B’ so that it is easy to understand the coefficients, thats why I have $y_0 = B...$ —Malavika]

- exception: NA

7.4.5 Local Functions

NA

8 MIS of Regression module

This module corresponds to R??, R?? and R?? in section ?? of CA document.

8.1 Module

reg

8.2 Uses

6, 9

8.3 Syntax

8.3.1 Exported Constants

NA

8.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|-----------------|---|-------------------------------|------------|
| regNormalEq | $t:\mathbb{R}^n, y:\mathbb{R}^n, \text{deg}:\mathbb{N}$ | - | - |
| regAugSys | $t:\mathbb{R}^n, y:\mathbb{R}^n, \text{deg}:\mathbb{N}$ | - | - |
| regOrthogonalTn | $t:\mathbb{R}^n, y:\mathbb{R}^n, \text{deg}:\mathbb{N}$ | - | - |
| evalReg | $t:\mathbb{R}^n$ | $y_{\text{New}}:\mathbb{R}^n$ | - |

8.4 Semantics

8.4.1 State Variables

- $x: \mathbb{R}^m$

8.4.2 Environment Variables

NA

8.4.3 Assumptions

- `input.verifyDegree()` will be called before any of the access programs will be used.
- `evalReg()` will be called after calling `(regNormalEq() \vee regAugSys() \vee regOrthogonalTn())`.

8.4.4 Access Routine Semantics

`reg.x:`

- transition: NA
- output: $out := x$
- exception: None

`regNormalEq(t, y, deg):`

- transition:

- `degVerify = verifyDegree(deg)`
- `(degVerify == True) $\implies x^n = 0.0$` [This is initialization with maximum length possible. For a data of length `n`, you can maximum get `n` coefficients in the polynomial. —Malavika]
- `$x^m = \mathbb{R}^m$` , obtained by solving for `x` in the equation below. [`m` is the degree of the coefficients of the polynomial. —Malavika]

$$A^T A x = A^T y$$

- output: NA
- exception: NA

regAugSys(`t,y,deg`):

- transition:
 - `degVerify = verifyDegree(deg)`
 - `(degVerify == True) $\implies x^n = 0.0$` [This is initialization with maximum length possible. For a data of length `n`, you can maximum get `n` coefficients in the polynomial. —Malavika]
 - `$x^m = \mathbb{R}^m$` , obtained by solving for `x` in the equation below. [`m` is the degree of the coefficients of the polynomial. —Malavika]

$$r + A x = y$$

$$A^T r = 0$$

Where `r` is the residual vector.

- output: NA
- exception: NA

regOrthogonalTn(`t,y,deg`):

- transition:
 - `degVerify = verifyDegree(deg)`

- $(degVerify == True) \implies x^n = 0.0$ [This is initialization with maximum length possible. For a data of length n , you can maximum get n coefficients in the polynomial. —Malavika]
- $x^m = \mathbb{R}^m$, obtained by solving for x in the equation below.[m is the degree of the coefficients of the polynomial. —Malavika]

$$Ax = Py$$

Where P is the orthogonality matrix.

- output: NA
- exception: NA

evalReg(t):

- transition: NA
- output: $out := yNew$, where $\forall t_i \in t$,

$$ynew.append(np.poly1d(x)(t_i))$$

- exception: NA

8.4.5 Local Functions

NA

9 MIS of Output module

This module corresponds to R?? in the CA document. The secrets of this module are how the output is given to user program.

9.1 Module

output

9.2 Uses

matplotlib(Python)

9.3 Syntax

| Name | In | Out | Exceptions |
|-----------------|--|-------------------------|------------|
| plotDataFit | $t:\mathbb{R}^n, y:\mathbb{R}^n$ | | - |
| coeffPlotScreen | $t:\mathbb{R}^n, y:\mathbb{R}^n, x:\mathbb{R}^m$ | $x:\mathbb{R}^m$, plot | - |
| coeffFile | $x:\mathbb{R}^m, t:\mathbb{R}^n, y:\mathbb{R}^n$ | $x:\mathbb{R}^m$ | - |

9.3.1 Exported Constants

NA

9.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|-----------------|--|-------------------------|------------|
| plotDataFit | $t:\mathbb{R}^n, y:\mathbb{R}^n$ | | - |
| coeffPlotScreen | $t:\mathbb{R}^n, y:\mathbb{R}^n, x:\mathbb{R}^m$ | $x:\mathbb{R}^m$, plot | - |
| coeffFile | $x:\mathbb{R}^m, t:\mathbb{R}^n, y:\mathbb{R}^n$ | $x:\mathbb{R}^m$ | - |

9.4 Semantics

9.4.1 State Variables

NA

9.4.2 Environment Variables

OutputFile: Results.csv

9.4.3 Assumptions

- The interpolation or the regression module will be called before the output module.

9.4.4 Access Routine Semantics

plotDataFit(t, y):

- transition:
 - Call the appropriate evaluate method from the interpolation or regression module as shown below..
 - 1. $y_{New} = \text{interp.evalMonomial}(t, y) \vee \text{interp.evalLagrange}(t, y) \vee \text{interp.evalNewton}(t, y) \vee \text{interp.evalHermiteCubic}(t, y) \vee \text{interp.evalBSpline}(t, y) \vee \text{reg.evalReg}(t)$

2. `plot(t,y)` and `plot(t,yNew)`

- output: `Out:= plot`
- exception: NA

coeffPlotScreen(*t,y*):

- transition :
 - `plotDataFit(t,y)`
- output: `Out:= interp.x \vee reg.x, plot`
- exception: NA

coeffFile():

- transition:
 - Create a csv file named ‘Result’
 - write `interp.x \vee reg.x`
- output: NA
- exception: NA

9.4.5 Local Functions

NA

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>.

10 Appendix

[Extra information if required —SS]