Bringing interactivity into engineering courses with BERT-based Excel®-R applications

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PRESENTATION OUTLINE

- Introduction
- Principles and implementation
- Examples in engineering education
- Conclusions

Introduction

- Engineers love Excel®!, perhaps the most (world)widely used "Engineer-Machine" interface for data processing.
- VBA (not a full OO programming language, as no inheritance nor function overloading, but includes classes and interfaces), interactive userform design, most engineers have some knowledge of VBA.
- Lacks power for data analysis, modeling and visualisation (not Excel®'s primary function).

BERT

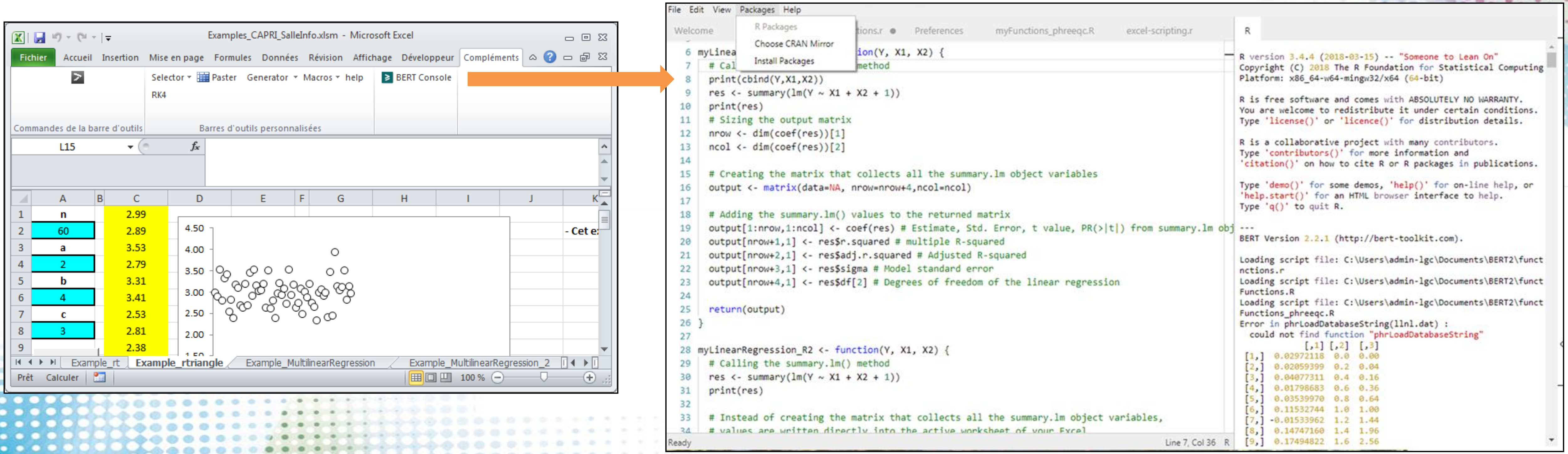
Basic Excel R Toolkit

- BERT: Basic Excel R Toolkit (R console for Excel®)
- Free (from Structured Data, LLC)
- BERT version 2 (bert-toolkit.com)

- Virtually limitless capability for data analysis, modeling and visualisation (R's primary function), not limited to statistical data analysis.
- Free
- Still limited use and visibility amongst mainstream engineering community

- Installation from https://bert-toolkit.com/download-bert
- Excel® add-in ➔ BERT console (R editor)

BERT console (.R code)



- BERT's default startup folder = ~\Documents\BERT2\functions\
- Recommendation:
  - Place your .R files in BERT's default startup folder (unless change in "Preferences" file)
  - In BERT consolde: "File > New File" to write your R code (this creates a new tag in the BERT console)
  - Packages necessary for the R code are installed using the "Packages" menu in the BERT console

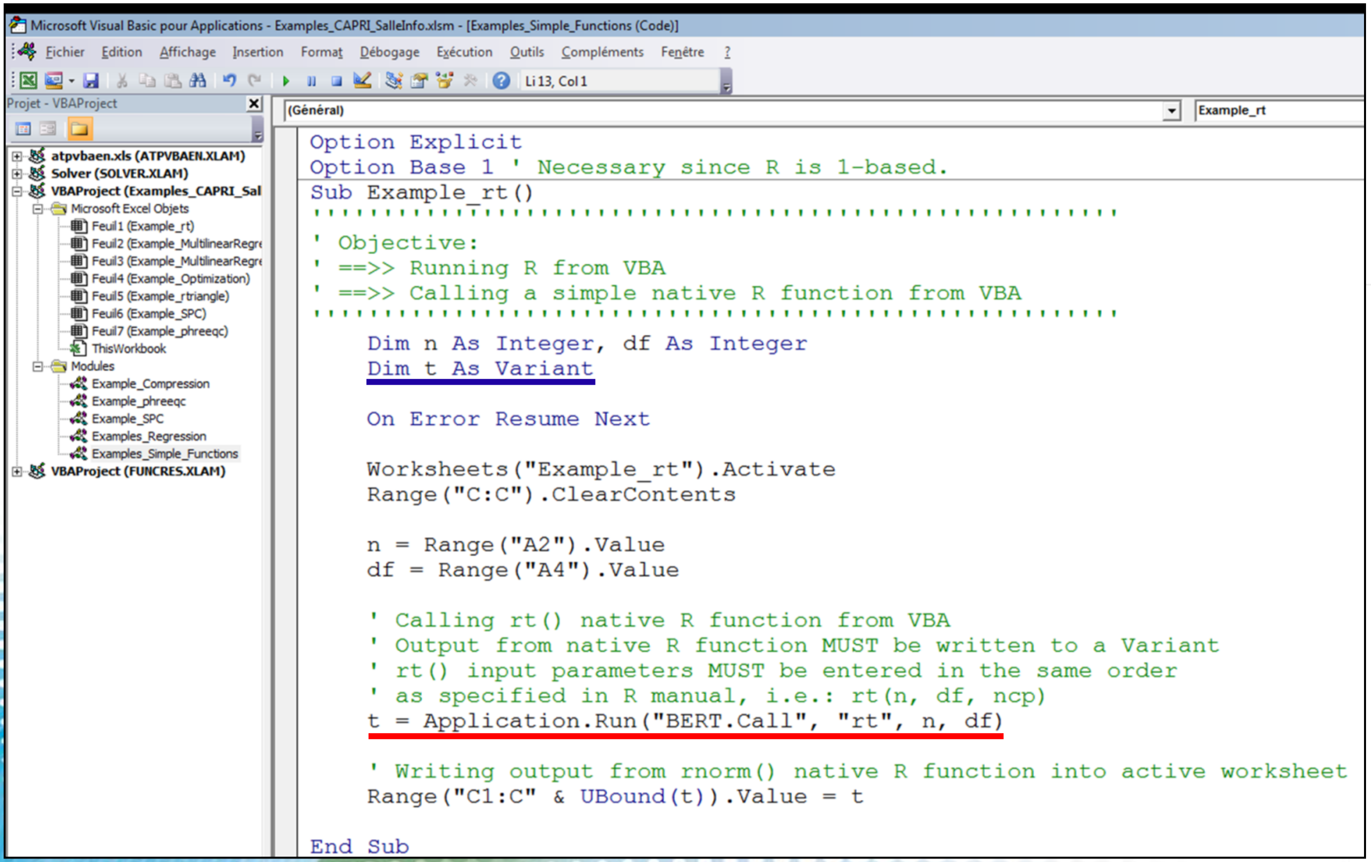
- **2 types of applications**
  - **Type 1**: Calling native and package-imported R functions from Excel® (VBA code, no R code, no use of the BERT console besides installation of R packages if needed)
  - **Type 2**: Calling user-defined R functions from Excel® (VBA code, R code, use of the BERT console)

- **Recommended VBA code structure for Type 1 applications**
  - **Section 1:** VBA reads the data from the Excel® spreadsheet as type Variant variables.
  - **Section 2:** VBA calls and pass Variant variables to (native, package-imported, own) R functions, using VBA Application.Run() call function.
  - **Section 3:** VBA and/or R writes the output from R functions into the Excel® spreadsheet.

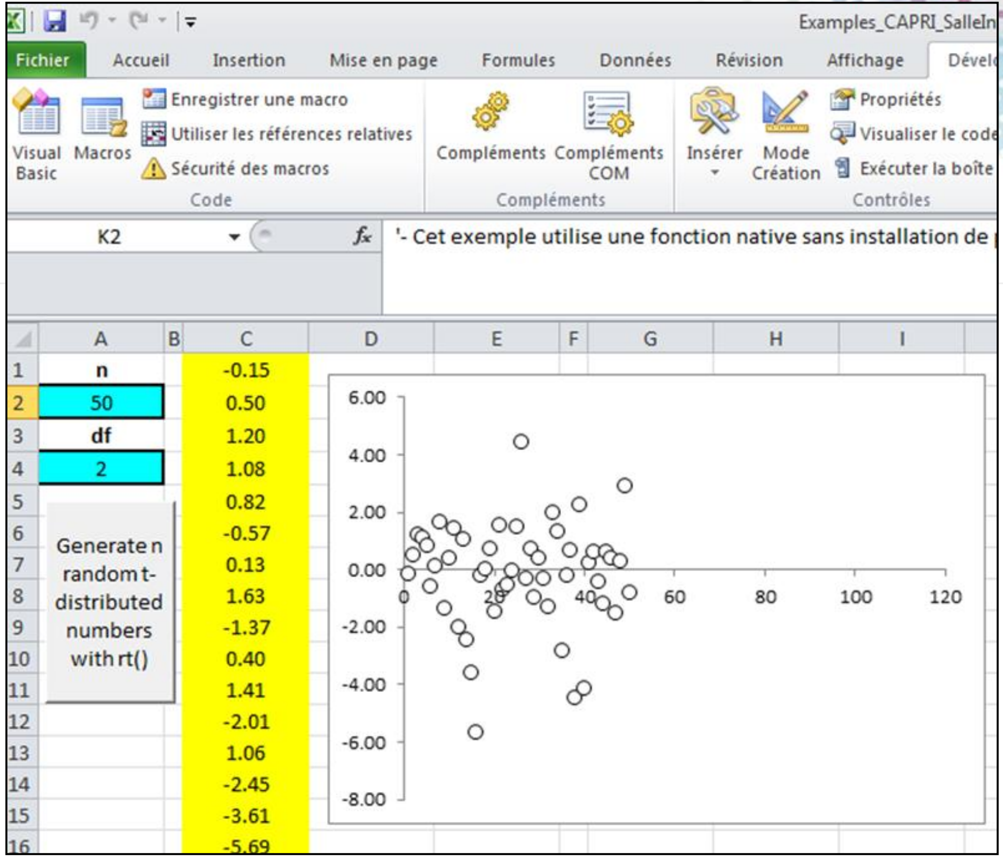
- **Note**
  - When running the Excel® file with built-in R code, there is no need to open the BERT console. The R code is therefore invisible to the end-user.

Type 1: Calling native and package-imported R functions from Excel® (VBA code, no R code, no use of the BERT console besides installation of R packages)

VBA editor



Excel® spreadsheet



Type 1: Calling native and package-imported R functions from Excel® (VBA code, no R code, no use of the BERT console besides installation of R packages)

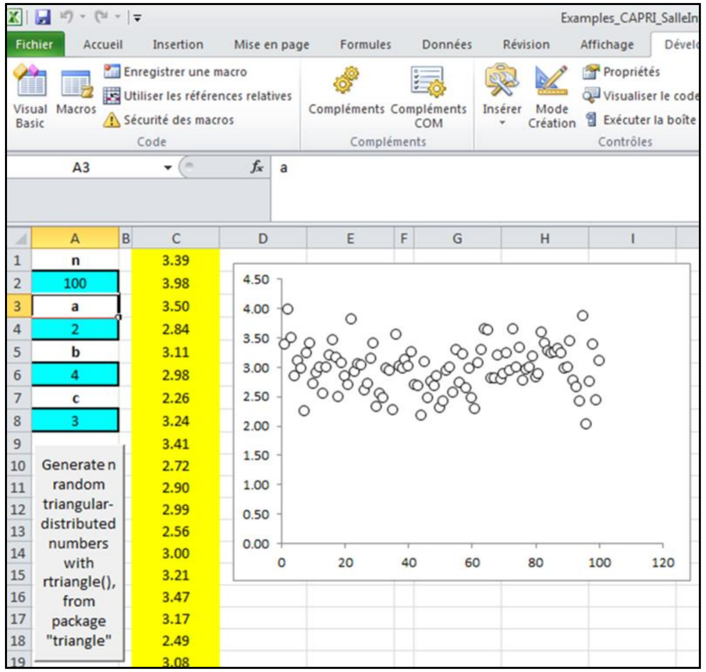
VBA editor

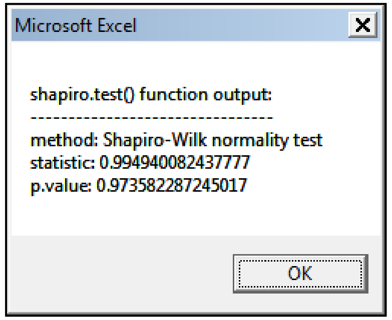
```
Sub Example_rtriangle()
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' Objective:
' ==>> Running R from VBA
' ==>> Calling a simple R function from a specific R package.
'
' BEFORE RUNNING THIS CODE: R packages used by the VBA code must be installed prior to running
' In this example, install the "triangle" package from the BERT console:
' Packages > install Packages > ... Install
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    Dim n As Integer, a As Double, b As Double, c As Double

    ' Variables used to call R functions from VBA
    Dim lib As Variant ' Variable used to load a library when running the macro
    Dim var1, var2, var3, var4 'Variant variables used as output to calls to Application.Run()

    On Error Resume Next

    ' Loading an R package from VBA
    ''''''''''''''''''''''''''''''''
    lib = Application.Run("BERT.Call", "library", "triangle")

    Worksheets("Example_rtriangle").Activate
    Range("C:C").ClearContents

    n = Range("A2").Value
    a = Range("A4").Value
    b = Range("A6").Value
    c = Range("A8").Value

    ' Calling rtriangle() function from R package "triangle" from VBA
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Output from native R function MUST be written to a Variant
    ' rtriangle() input parameters MUST be entered in the same order as specified in R manual,
    ' rtriangle(n, a=0, b=1, c=(a+b)/2)
    var1 = Application.Run("BERT.Call", "rtriangle", n, a, b, c)

    ' Writing output from rnorm() native R function into active worksheet
    Range("C1:C" & UBound(var1)).Value = var1
    Application.ScreenUpdating = True 'Useful so the Excel graphs are updated without delay
```

Requires installing the "triangle" package from the BERT console

```
    ' Calling shapiro.test() function and printing the function outputs
    ' The shapiro.test function outputs an instance of the "htest" class
    ' whose components include: statistic, p.value, method.
    ' Use the VBA debugger to see what's in var3.
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    var3 = Application.Run("BERT.Call", "shapiro.test", var1)
    Call MsgBox("shapiro.test() function output:" & vbCrLf & _
               "--------------------------------" & vbCrLf & _
               "method: " & var3(3, 1) & vbCrLf & _
               "statistic: " & var3(1, 1) & vbCrLf & _
               "p.value: " & var3(2, 1))

End Sub
```

Excel® spreadsheet





Type 2: Calling user-defined R functions from Excel® (VBA code, R code, use of the BERT console)

- **Purpose**
  - Ideal when needing to develop an "engineer friendly'" interface for a running R code.
  - Ideal for educators seeking to embed more advanced R functions, related to their engineering courses, into Excel®. This brings interactivity (and fun) into the teaching, which helps with student learning.

- **Principles**
  - Keep all calculations inside your R functions, limiting VBA to pass data back and forth between the Excel® spreadsheet and the R functions.

- **Recommended VBA code structure for Type 2 applications**
  - **Section 1:** VBA reads the data from the Excel® spreadsheet and stores them as type Variant variables.
  - **Section 2:** VBA calls and pass Variant variables to user-defined R functions, whose code (.R files) is in the ~\Documents\BERT2\functions\ folder.
  - **Section 3:** VBA and/or R writes the output from the R functions into the Excel® spreadsheet.

Type 2: Calling user-defined R functions from Excel® (VBA code, R code, use of the BERT console)

VBA editor

```
Sub myLinearRegression_VBA()
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' Objective:
' ==>> Running R from VBA
' ==>> Calling your own R functions from VBA.
    Dim Ndata As Integer, i As Integer
    Dim X1 As Variant, X2 As Variant, Y As Variant
    Dim var1 As Variant 'Variant variables used as output to calls to Application.Run()

    On Error Resume Next

    Worksheets("Example_MultilinearRegression").Activate
    Ndata = Application.WorksheetFunction.CountA(Range("B:B")) - 1

    ' Reading the values in the Excel spreadsheet
    X1 = Range(Cells(2, 2), Cells(Ndata + 1, 2)).Value
    X2 = Range(Cells(2, 3), Cells(Ndata + 1, 3)).Value
    Y = Range(Cells(2, 4), Cells(Ndata + 1, 4)).Value

    ' Calling myLinearRegression() function from R-Script from VBA
    ' to estimate the linear model parameter: Y = b0 + b1*X1 + b2*X2
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    var1 = Application.Run("BERT.Call", "myLinearRegression_R", Y, X1, X2)
    Range(Cells(2, 7), Cells(2 + UBound(var1, 1) - 1, 7 + UBound(var1, 2) - 1)).Value = var1
End Sub
```

BERT console (.R code)

bert2-console

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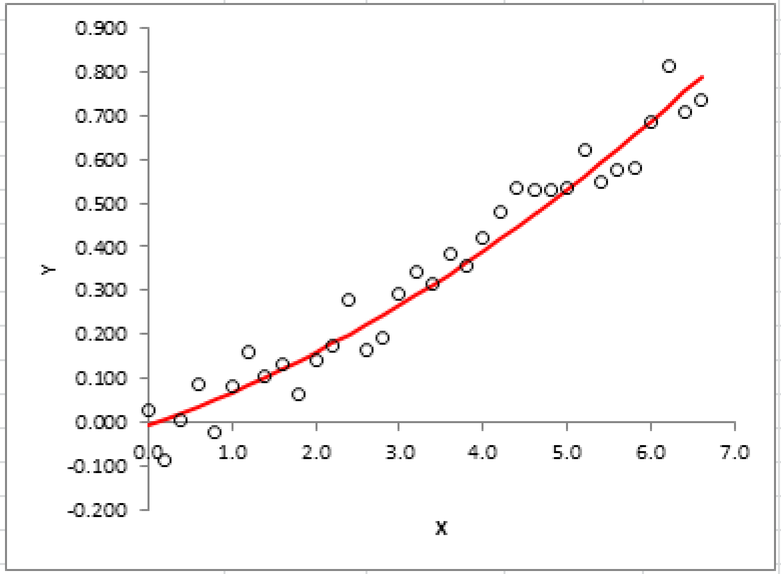
```
myLinearRegression_R <- function(Y, X1, X2) {
  # Calling the summary.lm() method
  print(cbind(Y,X1,X2))
  res <- summary(lm(Y ~ X1 + X2 + 1))
  print(res)
  # Sizing the output matrix
  nrow <- dim(coef(res))[1]
  ncol <- dim(coef(res))[2]

  # Creating the matrix that collects all the summary.lm object varia
  output <- matrix(data=NA, nrow=nrow+4,ncol=ncol)

  # Adding the summary.lm() values to the returned matrix
  output[1:nrow,1:ncol] <- coef(res) # Estimate, Std. Error, t value,
  output[nrow+1,1] <- res$r.squared # multiple R-squared
  output[nrow+2,1] <- res$adj.r.squared # Adjusted R-squared
  output[nrow+3,1] <- res$sigma # Model standard error
  output[nrow+4,1] <- res$df[2] # Degrees of freedom of the linear re

  return(output)
}
```

Type 2: Calling user-defined R functions from Excel® (VBA code, R code, use of the BERT console)

	A	B	C	D	E	F	G	H	I	J
1		X	X^2	Y	Ymod	Multilinear model: Y = b0+b1*X+b2*X^2		Estimate	Std. Error	t value
2	Click and Run your VBA code	0.0	0.0	0.028	-0.006	Intercept b0		-0.00592123	0.02610861	-0.226792
3		0.2	0.0	-0.085	0.007	b1		0.06540543	0.01830726	3.572649
4		0.4	0.2	0.005	0.022	b2		0.00837007	0.00268090	3.122106
5		0.6	0.4	0.087	0.036	Multiple R-squared	0.9557	Output values from lm() are written into the active Excel worksheet directly from your own R function.		
6		0.8	0.6	-0.024	0.052	Adjusted R-squared	0.9529			
7		1.0	1.0	0.082	0.068	Model Std. Error	0.0538			
8		1.2	1.4	0.161	0.085	df	31			
9		1.4	2.0	0.105	0.102					
10		1.6	2.6	0.131	0.120					
11		1.8	3.2	0.065	0.139					
12		2.0	4.0	0.143	0.158					
13		2.2	4.8	0.173	0.178					
14		2.4	5.8	0.278	0.199					
15		2.6	6.8	0.163	0.221					
16		2.8	7.8	0.192	0.243					
17		3.0	9.0	0.292	0.266					
18		3.2	10.2	0.341	0.289					
19		3.4	11.6	0.316	0.313					
20		3.6	13.0	0.386	0.338					
21		3.8	14.4	0.357	0.363					
22		4.0	16.0	0.423	0.390					
23		4.2	17.6	0.480	0.416					
24		4.4	19.4	0.537	0.444					
25		4.6	21.2	0.532	0.472					
26		4.8	23.0	0.529	0.501					



Output is formatted to resemble that of Excel's REGLIN() worksheet function

BERT console (.R code)

BERT Console

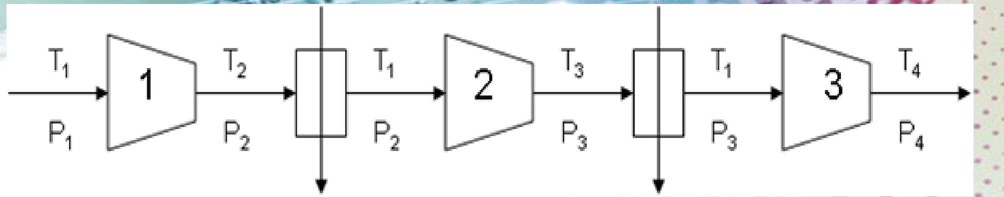
File Edit View Packages Help

Welcome | myFunctions.R | functions.r | Preferences | myFunctions_phreeqc.R

```r
myLinearRegression_R2 <- function(Y, X1, X2) {
  # Calling the summary.lm() method
  res <- summary(lm(Y ~ X1 + X2 + 1))
  print(res)

  # Instead of creating the matrix that collects all the summary.lm object v
  # values are written directly into the active worksheet of your Excel.
  range <- EXCEL$Application$get_Range("G1:J4")
  range$put_Value(coef(res)) # Estimate, Std. Error, t value, PR(>|t|) from
  range <- EXCEL$Application$get_Range("G5")
  range$put_Value(res$r.squared) # multiple R-squared
  range <- EXCEL$Application$get_Range("G6")
  range$put_Value(res$adj.r.squared) # Adjusted R-squared
  range <- EXCEL$Application$get_Range("G7")
  range$put_Value(res$sigma) # Model standard error
  range <- EXCEL$Application$get_Range("G8")
  range$put_Value(res$df[2]) # Degrees of freedom of the linear regression

  #return(res)
}
```

Rather than formatting R's output in the Excel spreadsheet using VBA, you can address an Excel® spreadsheet directly from one's R code using BERT's Excel® Scripting (COM) interface (e.g. for reading from and writing to specific cells in the Excel® spreadsheet).

Numerical optimization and chemical engineering example



- **The problem:**
  - 3-stage compression problem for ideal gas and adiabatic conditions.
  - Starting with inlet temperature T_1 and pressure P_1, and seeking an outlet pressure P_4, the problem consists in finding the inlet and outlet pressures P_2 and P_3 of the intermediate compression stage that yield the minimum compression work W. With $P_1<P_2<P_3<P_4$, k=1.4 and R the ideal gas constant, the compression work W can be expressed as

$$W = \frac{kRT_1}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{(k-1)/k} + \left(\frac{P_3}{P_2}\right)^{(k-1)/k} + \left(\frac{P_4}{P_3}\right)^{(k-1)/k} - 1\right]$$

  - Students are invited to try the Nelder-Meade algorithm to solve the problem.

- **Step 1 :**
  - Search the CRAN archive for the R package you need. A quick web search indicates that Nelder-Mead algorithm is available in several R packages, e.g. "*optimization*" (https://cran.r-project.org/web/packages/optimization/index.html, Husmann et al.).
  - The "Package > Install Packages" menu from the BERT console is used to install the "*optimization*" package.
  - Write your (user-defined) R function, adding it to the ~\BERT2\functions\ folder.

- **Step 2 :**
  - Use of a Type 2 application, i.e. the whole numerical optimization solution to the problem is coded in a user-defined R function, and VBA is simply used to pass the data between the Excel® spreadsheet and the R code.
  - The VBA code makes a single call to the R function *Compression_R()*. The function loads the "*optimization*" package and uses the *optim_nm()* function, which implements the Nelder-Meade algorithm.

VBA editor

```
Sub Optimization_VBA()

' Section 0: variables déclaration
'--------------------------------
    ' All variables passed to your R function should be defined as Variant
    Dim k As Variant, R As Variant, T1 As Variant, P1 As Variant, P4 As Variant, P2init As Variant,
    'Variant variables used as output to Excel API function Application.Run()
    Dim var1 As Variant

    On Error Resume Next

    ' Clear the output range
    Range("B8").ClearContents

' SECTION 1: importing data from the Excel spreadsheet
'-----------------------------------------------------------
    Worksheets("Example_Optimization").Select
    k = Range("B1").Value
    R = Range("B2").Value
    T1 = Range("B3").Value
    P1 = Range("B4").Value
    P4 = Range("B5").Value
    P2init = Range("B6").Value
    P3init = Range("B7").Value

' SECTION 2 : Calling your own R function
' This is where all the calculations are done, VBA does none !
'-------------------------------------------------------------
    var1 = Application.Run("BERT.Call", "Compression_R", k, R, T1, P1, P4, P2init, P3init)

' SECTION 3: Writing output from your own R function back into the Excel spreadsheet
'-----------------------------------------------------------------------------------
' In this example, outputs from your R function are writtent to the active
' Excel spreadsheet directly from the R function utself.

End Sub
```

	A	B	C	D
1	k	1.4		Optimization example
2	R	8.3144598	J·mol−1·K−1	
3	T1	273	K	
4	P1	200	kPa	
5	P4	1000	kPa	
6	P2	342	kPa	
7	P3	585	kPa	
8	W	19837	J	

BERT console (.R code)

BERT Console

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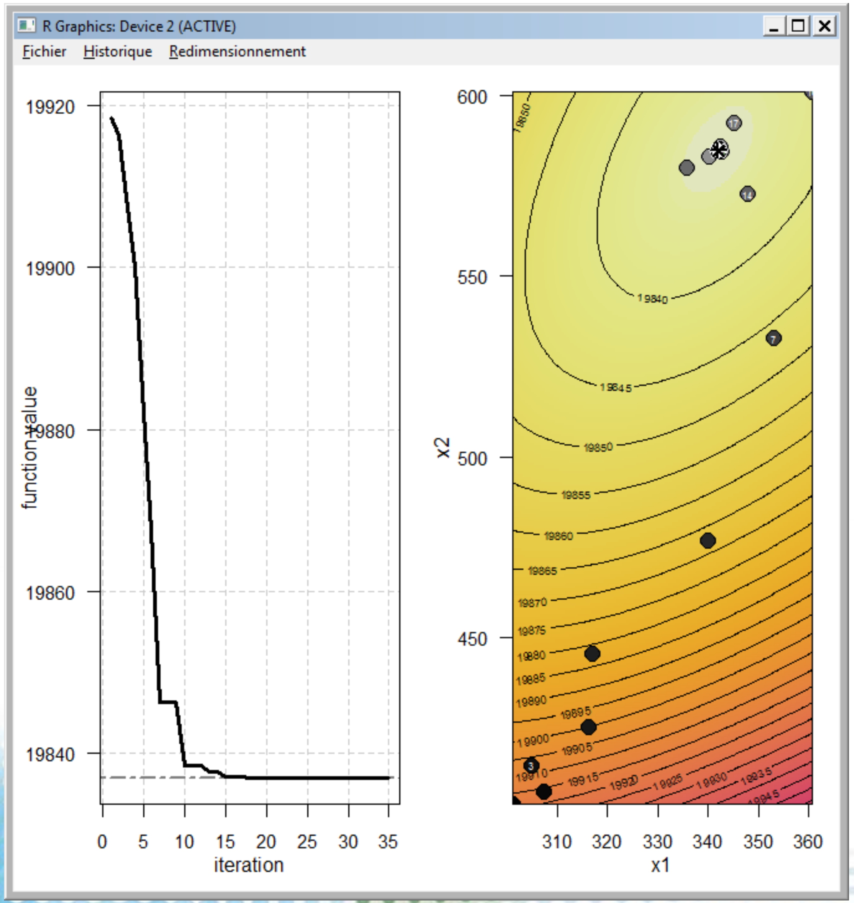
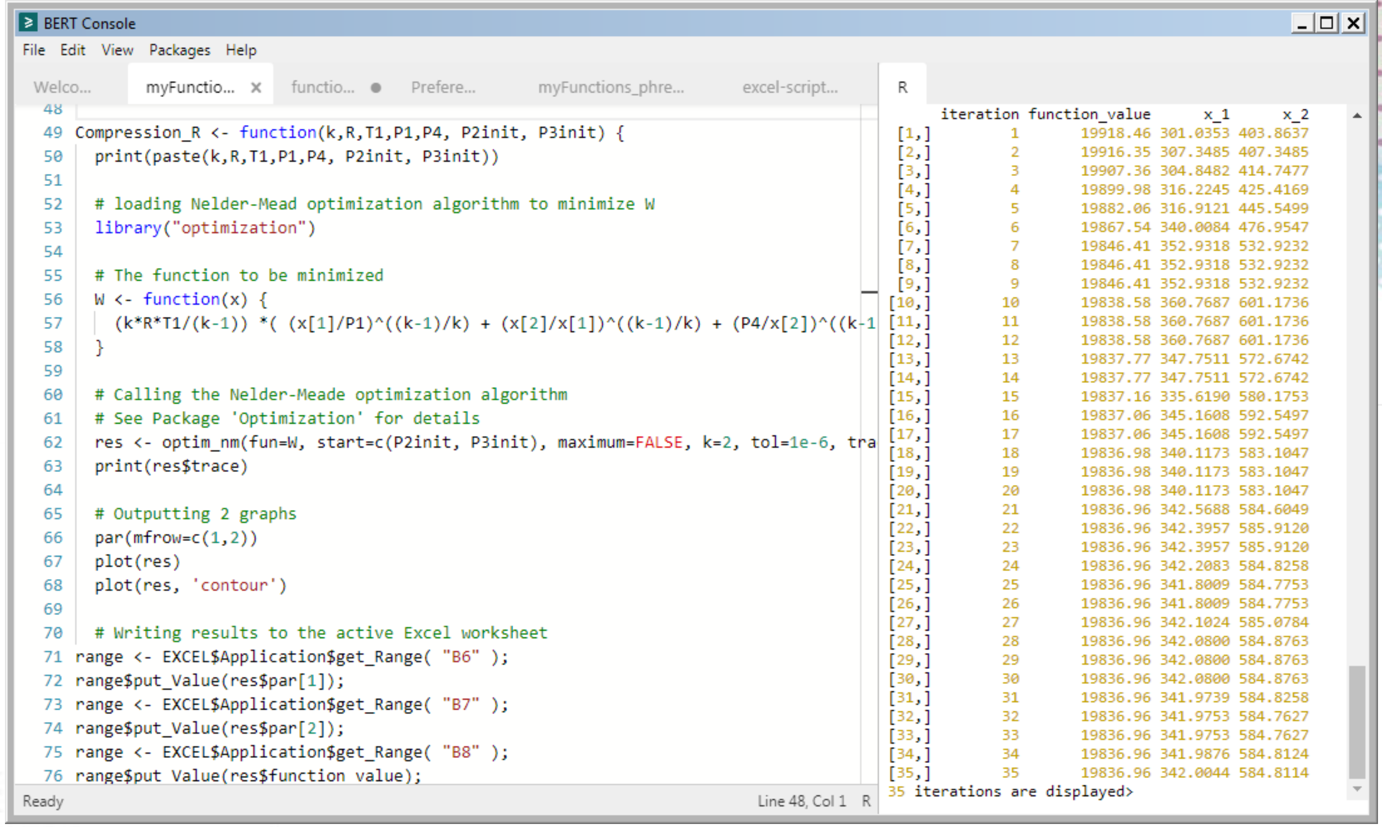
Welcome | myFunctions.R | functions.r | Preferences | myFunctions_phreeqc.R | excel-scripting.r

```r
Compression_R <- function(k,R,T1,P1,P4, P2init, P3init) {
  print(paste(k,R,T1,P1,P4, P2init, P3init))

  # loading Nelder-Mead optimization algorithm to minimize W
  library("optimization")

  # The function to be minimized
  W <- function(x) {
    (k*R*T1/(k-1)) *( (x[1]/P1)^((k-1)/k) + (x[2]/x[1])^((k-1)/k) + (P4/x[2])^((k-1)/k) - 1)
  }

  # Calling the Nelder-Meade optimization algorithm
  # See Package 'Optimization' for details
  res <- optim_nm(fun=W, start=c(P2init, P3init), maximum=FALSE, k=2, tol=1e-6, trace=TRUE)
  print(res$trace)

  # Outputting 2 graphs
  par(mfrow=c(1,2))
  plot(res)
  plot(res, 'contour')

  # Writing results to the active Excel worksheet
range <- EXCEL$Application$get_Range( "B6" );
range$put_Value(res$par[1]); # Pressure P2
range <- EXCEL$Application$get_Range( "B7" );
range$put_Value(res$par[2]); # Pressure P3
range <- EXCEL$Application$get_Range( "B8" );
range$put_Value(res$function_value); # Work W

}
```

- Pressures P_1 and P_2 are initialized in the Excel® spreadsheet.
- The VBA code calls the *compression_R()* function, which returns the work *W*.
- Here, the R code writes directly to the Excel® spreadsheet.



BERT console



- Graphs (here, a contour plot) and data (here, the trace of the optimization path) returned from the R functions are produced, as expected. **Data output by R functions are written to the BERT console.**
- Interfacing between Excel® and R is done in a few minutes time, top!
- Students can modify the Excel® interface as they wish, making the work interactive and fun while giving them the opportunity to interactively test the behaviour of the numerical algorithm, such as its sensivity to initialisation, or experiment with the design of the pumping system and more.

Statistical process control example : drawing and analysing control charts using the qcc package (https://cran.r-project.org/web/packages/qcc/index.html , Scrucca et al.)

BERT console

BERT Console

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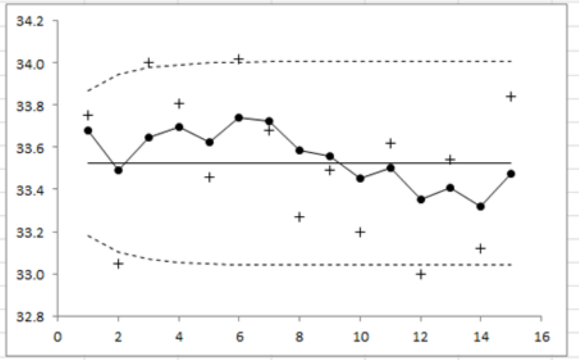
```r
ewma_R <- function(x, lambda, nsigmas) {

 # loading the 'qcc' ppackage
  library("qcc")

  # calling the ewma() function from the "qcc" package
  q <- ewma(data=x, lambda=lambda, nsigmas=nsigmas)
  summary(q)

  # Writing output values to the active Excel worksheet
  range <- EXCEL$Application$get_Range( "F2:G16" );
  range$put_Value(q$limits);
  range <- EXCEL$Application$get_Range( "H3" );
  range$put_Value(q$center);
  range <- EXCEL$Application$get_Range( "H5" );
  range$put_Value(q$std.dev);
}
```

VBA editor

```vb
Sub ewma_VBA()

' Section 0: variables déclaration
'-----------------------------------
    ' All variables passed to your R function should be defined as Variant
    Dim X As Variant, lambda As Variant, nsigmas As Variant
    'Variant variables used as output to Excel API function Application.Run()
    Dim var1 As Variant

    On Error Resume Next

' SECTION 1: importing data from the Excel spreadsheet
'-------------------------------------------------------
    Worksheets("Example_SPC").Activate
    X = Range("B2:B16").Value
    lambda = Range("C2").Value
    nsigmas = Range("C4").Value


' SECTION 2 : Calling your own R function
' This is where all the calculations are done, VBA does none !
'-------------------------------------------------------------
    var1 = Application.Run("BERT.Call", "ewma_R", X, lambda, nsigmas)

' SECTION 3: Writing output from your own R function back into the Excel spreadsheet
'-------------------------------------------------------------------------------------
' In this example, outputs from your R function are writtent to the active
' Excel spreadsheet directly from the R function utself.

End Sub
```

x	lambda	Sample	LCL	UCL		ewma variable
33.75	0.3	1	33.18	33.87	center	33.68
33.05	nsigmas	2	33.10	33.94	33.5233333	33.49
34	2.7	3	33.07	33.98	std.dev	33.64
33.81		4	33.05	33.99	0.42616515	33.69
33.46	Call ewma_VBA()	5	33.05	34.00		33.62
34.02		6	33.04	34.00		33.74
33.68		7	33.04	34.01		33.72
33.27		8	33.04	34.01		33.59
33.49		9	33.04	34.01		33.56
33.2		10	33.04	34.01		33.45
33.62		11	33.04	34.01		33.50
33		12	33.04	34.01		33.35
33.54		13	33.04	34.01		33.41
33.12		14	33.04	34.01		33.32
33.84		15	33.04	34.01		33.48



- Not discussed here, it is implicit that you can use all the interfacing capability built into VBA (with userforms) to quickly and simply produce neat interactive user interfaces.

Geochemical example: Study of the relative thermodynamic stability (dissolution/precipitation) of two minerals in pure water, namely gypsum and anhydrite, as a function of temperature at 1 atm. (https://cran.r-project.org/web/packages/phreeqc/index.html , Charlton et al.)

VBA editor

```
Sub phreeqc_VBA()

' Section 0: variables déclaration
'---------------------------------
    ' All variables passed to your R function should be defined as Variant
    Dim Tmin As Variant, Tmax As Variant, Nsteps As Variant
    'Variant variables used as output to Excel API function Application.Run()
    Dim var1 As Variant
    ' variables used to get the size of the R output variable var1
    Dim nrow As Integer, ncol As Integer

    On Error Resume Next

    ' Clear the output range
    Range("C:N").ClearContents

' SECTION 1: importing data from the Excel spreadsheet
'------------------------------------------------------
    Worksheets("Example_phreeqc").Activate
    Tmin = Range("A2").Value
    Tmax = Range("A4").Value
    Nsteps = Range("A6").Value

' SECTION 2 : Calling your own R function
' This is where all the calculations are done, VBA does none !
'------------------------------------------------------------
    var1 = Application.Run("BERT.Call", "phreeqc_R", Tmin, Tmax, Nsteps)

' SECTION 3: Writing output from your own R function back into the Excel spreadsheet
'-----------------------------------------------------------------------------------
    nrow = UBound(var1, 1)
    ncol = UBound(var1, 2)
    Range(Cells(1, 3), Cells(nrow, ncol + 2)).Value = var1


End Sub
```

BERT console

BERT Console

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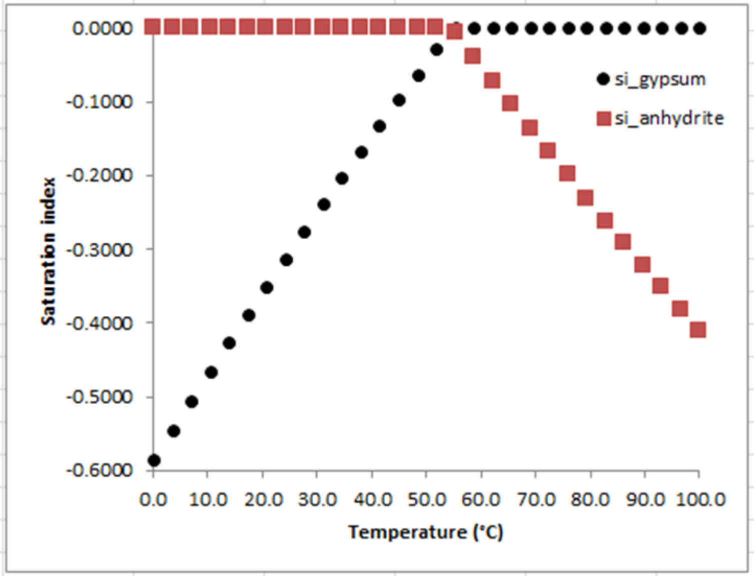
```
phreeqc_R <- function(Tmin, Tmax, Nsteps) {

# loading the 'phreeqc' package
library("phreeqc")

range <- EXCEL$Application$get_Range( "A4" )
x <- range$get_Value()
print(paste("x=",x))

# load the phreeqc.dat database
phrLoadDatabaseString(phreeqc.dat)

# Building a PHREEQC script and passing it the input temperatures
phrRunString(phreeqc_script(Tmin, Tmax, Nsteps))

# retrieve selected_output as a list of data.frame
so <- phrGetSelectedOutput()

 # returning the results output by PHREEQC
return(so$n1)
}

phreeqc_script <- function(Tmin, Tmax, Nsteps) {
# writing the PHREEQC script
input <- vector()

input <- c(input, "TITLE Example 2.--Temperature dependence of solubility")
input <- paste(input, "of gypsum and anhydrite")
input <- c(input, "SOLUTION 1 Pure water")
input <- c(input, "pH      7.0")
input <- c(input, "temp    25.0")
input <- c(input, "EQUILIBRIUM_PHASES 1")
input <- c(input, "Gypsum          0.0     1.0")
input <- c(input, "Anhydrite       0.0     1.0")
input <- c(input, "REACTION_TEMPERATURE 1")
# Creation of the modified line with new entries
Excel_input <- paste(Tmin," ",Tmax," in ",Nsteps," steps")
input <- c(input, Excel_input)
input <- c(input, "SELECTED_OUTPUT")
input <- c(input, "-file    ex2.sel")
input <- c(input, "-temperature")
input <- c(input, "-si      anhydrite  gypsum")
input <- c(input, "END")

return(input)
}
```

Geochemical example: Study of the relative thermodynamic stability (dissolution/precipitation) of two minerals in pure water, namely gypsum and anhydrite, as a function of temperature at 1 atm. (https://cran.r-project.org/web/packages/phreeqc/index.html , Charlton et al.)

	A	B	I	J	K	L	M
1	Tmin		pH	pe	temp.C.	si_anhydrite	si_gypsum
2	0		7	4	25.0	65535.0000	65535
3	Tmax		7.41	12.66	0.0	-0.5854	0
4	100		7.37	12.37	3.4	-0.5448	0
5	Nsteps		7.32	12.09	6.9	-0.5048	0
6	30		7.27	11.81	10.3	-0.4653	0
7			7.22	11.55	13.8	-0.4263	0
8	Call to VBA subroutine phreeqc_R		7.17	11.30	17.2	-0.3878	0
9			7.13	11.05	20.7	-0.3498	0
10			7.08	10.80	24.1	-0.3123	0
11			7.03	10.57	27.6	-0.2753	0
12			6.99	10.34	31.0	-0.2387	0
13			6.94	10.11	34.5	-0.2026	0
14			6.90	9.89	37.9	-0.1669	0
15			6.86	9.67	41.4	-0.1317	0
16			6.82	9.45	44.8	-0.0968	0
17			6.78	9.24	48.3	-0.0624	0
18			6.74	9.03	51.7	-0.0284	0
19			6.71	8.85	55.2	0	-0.0053
20			6.67	8.63	58.6	0	-0.0385
21			6.64	8.43	62.1	0	-0.0714
22			6.60	8.24	65.5	0	-0.1039
23			6.57	8.06	69.0	0	-0.1360
24			6.54	7.87	72.4	0	-0.1678
25			6.51	7.70	75.9	0	-0.1993
26			6.48	7.51	79.3	0	-0.2304
27			6.45	7.30	82.8	0	-0.2612
28			6.43	7.20	86.2	0	-0.2917
29			6.40	7.00	89.7	0	-0.3219
30			6.38	6.83	93.1	0	-0.3517
31			6.36	6.67	96.6	0	-0.3813
32			6.33	6.51	100.0	0	-0.4106



Conclusions

- With Excel®'s inescapability in the engineering community, both at university and at the work place, the ability to bring all of R's numerical strength into Excel® applications is a highly attractive proposition.
- BERT is a simple, efficient and free R-Excel® interoperability solution. Interfacing an existing R code with an Excel® worksheet adds interactivity and acceptability to one's R code. Very few lines of code (VBA and/or R) are necessary to embed your R code into Excel®.
- Interfacing Excel® and R for undergraduate engineering courses brings interactivity and fun into the learning of engineering courses, which can only help with the understanding of the course material.
- Beyond engineering education:
  - Development of excel® applications that take advantage of R's capabilities can be highly beneficial for practicing engineers.
  - Mixing advanced VBA and R computing can produce rather "sophisticated" engineering applications, with a user-interface that will never be a turn-off for any practicing engineer, as engineers (and others…) do love Excel® !
  - The combination of Excel® and R offers a highly competitive environment, technically and financially, for all engineering professionals and companies.

Thank you for youR Excellent attention

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Slide 2

Good morning to you.

Today, I stand before you to make a brief presentation about the merit of merging R and Excel® for engineers, using BERT as the interface.

The outline of my presentation will be a short introduction, followed by principles and implementation tips, then a few simple examples, and then I'll wrap up with some conclusions.

Slide 3

Engineers do love Excel®!

Without question, Excel® is engineers' favorite tool when it comes to data processing. Most engineering education programs include VBA courses, and most engineers in the field today develop their own applications using VBA.

VBA is not a full object-oriented language, and well, engineers do not often use of VBA's object-oriented capability. What engineers do appreciate with Excel® is the tabulated data, their simple handling and the easy and fast way by which Excel® allows them to build interactive interfaces with Userforms and ActiveX controls.

Excel however offers only basic functions to analyze, model and visualize data.

R's primary function and strength, on the other hand, is precisely to analyze, model and visualize data, and not just statistical data as it is too often being reduced to.

Clearly, merging R and Excel makes a very desirable proposition not only for learning engineering, but also for "doing" engineering if I may say so.

Today, I would like to talk about interfacing Excel® and R using BERT, which stands for Basic Excel R Toolkit. It is developed by Structured Data in the United States, and you can find them on riskamp.com.

Slide 4

Installation of BERT will add the BERT Console add-in to Excel®. Clicking on this add-in opens the BERT console, which is an R editor. You could use it as such, but it is not a full-fledged editor like RStudio.

The BERT console will let you install R packages, and you should note that you will need to install them <u>from the BERT console</u> if you want your Excel® applications to use them.

Also, you'll have to put your R codes into a folder known to the BERT console, and there is a default folder for this, which you may change.

Slide 5

In this presentation, I will make the distinction between 2 types of applications that are the most useful ones, at least from my experience and that of my students.

<u>The first type</u> consists in calling standard and package- imported R functions from Excel®.

The interfacing part requires concise and basic VBA programming only. You would need however to install R packages from the BERT console if you want to use them.

<u>The second type</u> consists in calling user-defined R functions from Excel®.

The key difference here is that you will be able to call your own R code from Excel®, and obviously, this is the most interesting type as it literally <u>pours</u> all of R's capability into Excel®.

Let me start with Type 1 applications, where you just want to call standard or package imported R functions into Excel®.

Through practice, we have templated the way by which you could structure your applications so that it requires minimum coding and runs on first try.

You are invited to structure your VBA code using a 3 sections template.

- First, your VBA code reads the data from the Excel® spreadsheet into variables of Type Variant, <u>using 1-based indexing</u> to match R's indexing convention.
- Second, your VBA code calls the R functions you need, passing the Variant variables as arguments.
- Third and last, you use VBA or R to write R's outputs into your Excel spreadsheet.

Really, that's a no-brainer for the programmer!

And it's painless also for the end-user! I

Indeed, when running an Excel® file with built-in R code using BERT, the end-user will see nothing but Excel® and therefore won't be turned off by the mention of using something other than Excel®.

Slide 6

This here shows the simplest type of application one may think of. The VBA code reads inputs from the Excel spreadsheet, and calls R's native functions, here the rt() function, which returns a vector of Student's t-distributed values.

You can see here the simple syntax for calling an R function from VBA.

The VBA code then writes the Student's t-distributed values to the spreadsheet, which are plotted into an Excel® scatter plot. You can just click on the control button on the Excel® spreadsheet and the process repeats itself. Only 2 lines of VBA code were necessary here to interface Excel and R.

Of course, you could use the INV.T() worksheet function to do just that. But considering Excel®'s very limited support for probability distributions needed for real world applications, how do you propose to repeat this with non-basic statistical distributions?

And what about all the other numerical functions you may need to solve your engineering problems, which are unknown to the standard Excel® environment?

Slide 7

With BERT, this is just a walk in the park !

This example uses the same VBA code as before, the difference being that it calls an R package-imported function.

Here, we call R's rtriangle() function to sample the triangular distribution. This function was made available simply by installing the triangle package from the package install menu in the BERT console.

Also for sake of illustration, the VBA code calls R's standard shapiro.test() function, whose output is written to a msgbox in Excel®.

This is very simple stuff of course, but I am hoping that you can start seeing the potential value it may bring to engineering students learning, and not just about random variables and statistical distributions.

Slide 8

Now, I'll move on to what I've called type 2 applications, where you call your own R functions from Excel®. It is clearly very useful for developing an "engineer friendly" interface to an R code.

The recommendation I would make is to mostly keep all the data analysis calculations in your R code, and simply use VBA to pass data between the Excel® spreadsheet and the R code.

The recommended structure of type 2 applications is very close to that of type 1.

The only difference lies with the 2nd section, where you call your own R functions instead of standard and packaged R functions. This requires that you place your R code in a dedicated BERT folder.

Slide 9

Here is an illustration of type 2 applications.

We have created a simple R function called myLinearRegression_R(), which runs a multilinear regression using R's lm() function. It takes 3 vectors, Y, X1 and X2 as inputs. The R code calls the lm() function and returns a matrix that contains some of the outputs from the lm() function.

Now, the VBA code on the left calls the R function we have created, passing the Y, X1 and X2 vectors to it, and then writes R's output matrix to the spreadsheet.

Slide 10

Here is the Excel®spreadsheet, with an activeX control button that runs the VBA code.

To the right, you can see a slightly different version of the R code, which writes directly into the Excel® spreadsheet instead of letting VBA do it, as with the previous example. BERT offers different functions to address the spreadsheet directly, which can be useful to write nicely formatted outputs into Excel.

You may recognize that the spreadsheet output was made to resemble that of Excel®'s REGLIN function.

Slide 11

Now that we have seen how simple it is to interface Excel® and R using BERT, I'll move on to 3 examples to illustrate the value to engineering courses and engineering problem solving.

The first example is used by a colleague of mine in a numerical optimization course for chemical engineers.

It is a 3 stage compression problem. The aim is to find the operating conditions of the intermediate compression stage in order to minimize the work, that is the energy consumption, of the overall system. Students are asked to produce an Excel® application that uses the Nelder-Mead optimization algorithm for this.

Of course, we could search for an implementation of the Nelder-Mead algorithm in VBA, and you'll find some VBA implementations on the web, or we could ask students to code one in VBA, but what would be the point, besides a course on VBA?

A quick web search identifies several R packages that implement this algorithm, among which the *optimization* package. We first install the package with the BERT console as usual.

Slide 12

We then start by writing our R code, as we would do if we were only using R to solve the problem. This requires defining a function that calculates the compression work, and calling the optim_nl() function that implements the Nelder-Mead algorithm.

Here, we chose to write the output into the Excel® spreadsheet directly from the R code. We could have decided instead to return the results and let VBA do the writing into the Excel® spreadsheet.

Now back to the Excel part of the code. Input values are entered in the spreadsheet by the user, they are read by the VBA code, which then passes them on to the R function, which we have named Compression_R().

End of story!

Slide 13

The interfacing between Excel® and R using BERT <u>does not change anything</u> about the way the R functions work.

For instance, calling the R's optim_nl() function will output the optim_nl() graphs to the screen.

Moreover, the console output from the R functions are written to the BERT console should you want to take a look at them.

Solving this problem by interfacing the R code with Excel® took only a very few lines of code.

What it provided students with is an interactive Excel®worksheet that allows them to play with all the intricacies of this optimization and compression problem, helping them with their learning and understanding in a rather fun, easily personalizable and interactive manner.

I would like to point out that we could go further and design a much neater interactive interface using Excel®'s userform capability, where the user would change input values using ActiveX controls and make this engineering problem very interactive indeed.

Slide 14

This 2nd example is relevant to a Statistical Process Control course, a subject that is widely being taught to engineers as it relates to quality control.

Here, we interface Excel® with R in order to draw an EWMA control chart, which is a particular type of control chart.

The R package of interest is qcc, which is installed from the BERT console.

The observations are read from the Excel® spreadsheet by the VBA code, which then passes them on to a user-defined function called ewma_R(). The function loads the qcc library, calls the ewma() function from the package and writes the function outputs to the spreadsheet. This calculates key values for the control chart, which are highlighted in yellow here, and Excel® is used to draw the control chart.

Students may here again build an interactive interface that will help them learn about control charts, their settings and performance.

Slide 15

I'll move on to the third and last example, the possibilities being virtually limitless considering the sheer number of packages available in R that are relevant to solving engineering problems, some of which being highly specialized.

This example relates to geochemistry, which is a rather complex subject.

Here, students are asked to look at the thermodynamic stability of 2 minerals in water as a function of temperature. To this end, we want to use PhreeqC. It is a renowned and free geochemical modelling software developed by the US Geological Survey, and there is now an R Interface to Phreeqc.

And so we go again with our Excel®-R interfacing using BERT, with a type 2 application. We start by writing the R code that runs our problem with PhreeqC, as if we'd use R only to solve the problem.

We then install the PhreeqC package from the BERT console, and code the few lines of VBA that allows us to call our user-defined R function. Here, VBA is used to write the results into the spreadsheet as you can see.

Slide 16

This slide shows the results from this simple call to the PhreeqC library, where start and end temperatures are entered in the spreadsheet, and the saturation indices of the 2 minerals that are output by PhreeqC are written to the spreadsheet and plotted using Excel®'s scatter plot.

This is a trivial use of PhreeqC, but given its capability, I am hoping you can see the potential here. Indeed, it goes without saying that you can build far more complex calls to PhreeqC, with more interactive Excel® interfaces, and hence build really neat applications to learn geochemistry with a great deal of interaction and (hopefully) fun.

Slide 17

Now to some concluding remarks.

Given the omnipresence of Excel® in engineering education and the engineering community at large, I believe that bringing all of R's numerical strength into Excel® makes a highly attractive and pragmatic proposition for engineers.

We have found through use that BERT offers a very simple and efficient environment for doing just that.

Interfacing Excel® and R in engineering courses brings interactivity, personalization and fun into the learning process, which are powerful ingredients for learning and understanding, while keeping the numerical analysis level high.

Going beyond engineering education, I think practicing engineers should consider developing Excel® applications that take advantage of R's capabilities for all their data analysis work.

Mixing advanced VBA and R programming has the potential to build really serious engineering applications, with very interactive user-interfaces that are familiar to the engineering community, and that will not turn off even the most recalcitrant engineers.

Finally, I'd just like to point out that the combination of Excel® and R using BERT offers a highly competitive environment, technically and financially, for all engineering professionals and companies, SME's in particular.

Slide 18

Thank you very much for youR EXCELlent attention !