Joseph Camacho-Terrazas
09/26/2020
Programming #4 Comparing interpreted and compiled codes

The problem for this assignment is to implement Gaussian elimination with back substitution using 3 different implementations: Fortran, Python w/ NumPy, and Python w/o NumPy. Our goal is to compare the time it takes to perform Gaussian elimination on matrix squares with sizes 250, 500, 1000, 1500 and 2000. The program takes the size of the matrix as input and fills it with random numbers. We then start a timer and run Gaussian elimination, then stop the timer upon completion. The program only outputs the time, not the solution.

Note: I tried 2 implementations for Python with NumPy. One uses NumPy only to fill the arrays and then performs the elimination using loops. The other used NumPy to fill the arrays and then used the function numpy.linalg.solve to solve the matrix. I chose to not use the linalg function because one, there was a massive time difference between using it and for-loops, and two, because I couldn't find out exactly how it was working. The NumPy documentation said it's *similar* to LU decomposition. But I wanted to be absolutely sure that my program performed only Gaussian Elimination and back substitution without pivoting, and I can clearly see that by using traditional for-loops. I was also thrown off by the time disparity, with numpy.linalg.solve running the 2500 square matrix in only minutes compared to the hour with my implementation.

	Fortran	**Python with NumPy**	**Python without NumPy**
Avg Time in Seconds			
250 Matrix	0.01570280046 s avg	6.639442 s avg	2.219504 s avg
500 Matrix	0.15366939902 s avg	52.672484 s avg	17.820722 s avg
1000 Matrix	1.65147073268 s avg	421.845636 s avg	143.25374 s avg
1500 Matrix	6.16338310242 s avg	1430.918686 s avg	488.144448 s avg
2000 Matrix	14.69540252684 s avg	3559.784584 s avg	1139.258002 s avg
Standard Deviation			
250 Matrix	0.0003694526599503	0.074639372291037	0.025718965453532
500 Matrix	0.00020806425104947	0.25829618151262	0.078716773155409
1000 Matrix	0.740230406715	2.535437628013	1.6854007409397
1500 Matrix	1.1916958243583	11.500300559145	6.1976725030656
2000 Matrix	2.3759854142589	373.69900613805	10.752734259555

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	Fortran	Python with NumPy	Python without NumPy
Time In Seconds to Run Gaussian Elimination			
250 Matrix	0.0180960000	6.75859	2.22668
	0.0156580005	6.61317	2.18790
	0.0155510008	6.68965	2.24902
	0.0155420005	6.55762	2.19076
	0.0155060003	6.57818	2.24316
500 Matrix	0.1538799852	52.83777	17.81674
	0.1534840018	52.39568	17.86984
	0.1535440087	53.09123	17.93991
	0.1535570025	52.57846	17.75913
	0.1535899937	52.45928	17.71799
1000 Matrix	1.2932420969	426.37494	142.27477
	1.3175150156	420.63157	142.14290
	1.2824258804	422.81922	142.57945
	3.1488640308	419.63487	146.60248
	1.2904789448	419.76758	142.66910
1500 Matrix	7.1683769226	1428.37137	482.27168
	4.7121329308	1440.19472	492.74093
	7.1334838867	1427.67631	491.42062
	4.6960039139	1445.79118	495.00916
	7.1069178581	1412.55985	479.27985
2000 Matrix	11.8217601776	3406.68932	1136.19115
	16.6834888458	3356.21022	1160.47635
	16.6385231018	3364.32780	1135.26734
	11.7498779297	3365.34332	1133.24824
	16.5833625793	4306.35226	1131.10693

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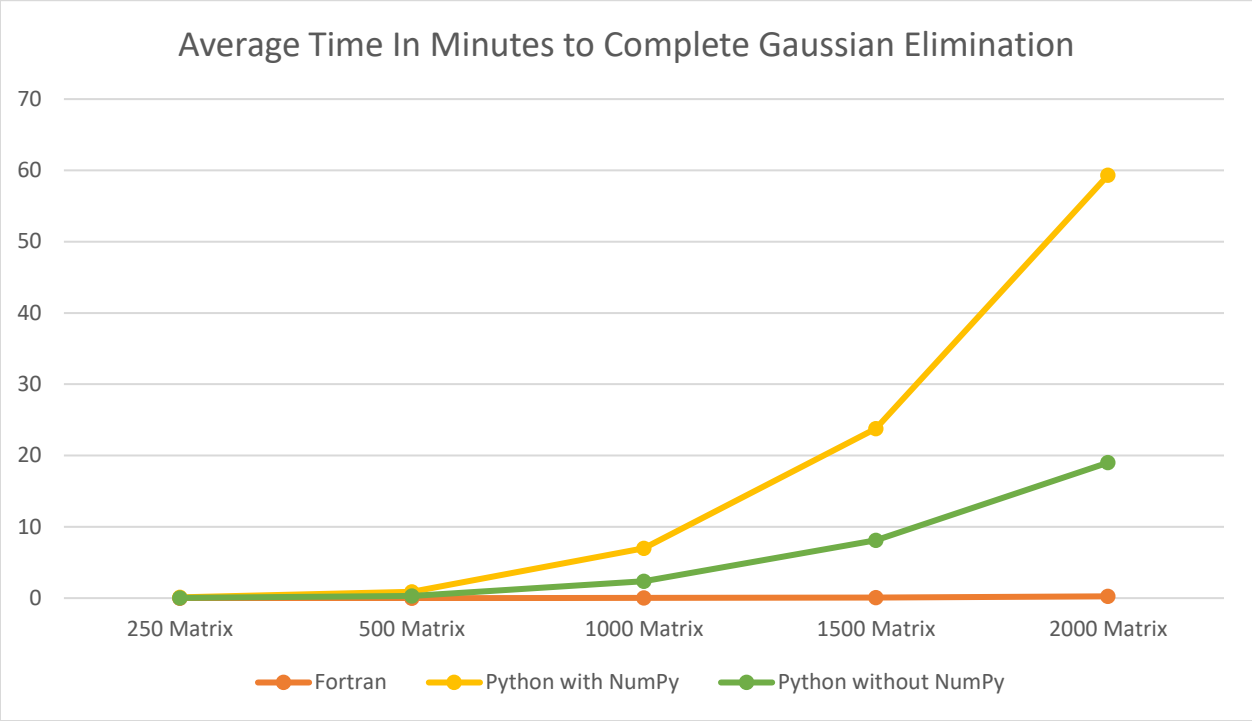

As we can see by the data, the Fortran implementation is the quickest, followed by Python without NumPy, and lastly Python with NumPy. Based on the data, we can see that a compiled language runs the quickest, which I would attribute to the compiler being able to optimize certain operations. I think Python without NumPy runs faster because it can directly fill the arrays via for-loops, whereas the NumPy implementation runs slower because the program has to access the NumPy library and the functions may just run slower than a for loop and the random library.

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Fortran

```
!Joseph Camacho-Terrazas
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!Input: Takes a command line argument for the matrix size
!Output: The time it takes for Gaussian Elimination to run on the matrix
!Preconditions: Program must be run with 1 argument. Argument must allow for Gaus
sian Elimination to run without error.
!Postconditions: Program will output the total time it took to run Gaussian Elimi
nation on the matrix.

PROGRAM program4
    IMPLICIT NONE

    !Matrix declarations
    INTEGER::i,j
    REAL::s
    !Create dynamic arrays to allow for command line args
    REAL,DIMENSION(:,:),allocatable::a
    REAL,DIMENSION(:),allocatable::x
    !Char and int for casting arg to integer
    CHARACTER(100)::numinputchar
    INTEGER::numinput
    !Trackers for CPU time
    REAL::start, finish

    !Get arg1 and cast to int
    CALL getarg(1,numinputchar)
    READ(numinputchar,'(I10)')numinput

    !Construct the arrays using arg1 input
    ALLOCATE(a(numinput,numinput))
    ALLOCATE(x(numinput))

    !Fills the array with random numbers
    CALL random_number(a)

    !Start timer
    CALL cpu_time(start)

    !----------Fortran Gaussian Elimination Without Pivoting Source----------
    !https://labmathdu.wordpress.com/gaussian-elimination-without-pivoting/

    !File related stuff is not needed for this implementation, but I left it to s
how the full source
```

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```
    !OPEN(1,FILE='input.txt')
    !OPEN(2,FILE='output.txt')

    !READ(1,*)((a(i,j),j=1,n+1),i=1,n)

    !WRITE(2,8)"Augmented Matrix",((a(i,j),j=1,numinput+1),i=1,numinput)

    DO j=1,numinput
        DO i=j+1,numinput
            a(i,:)=a(i,:)-a(j,:)*a(i,j)/a(j,j)
        END DO
    END DO

    !WRITE(2,8)"After Gaussian Elimination",((a(i,j),j=1,numinput+1),i=1,numinput
)

    DO i=numinput,1,-1
        s=a(i,numinput+1)
        DO j=i+1,numinput
            s=s-a(i,j)*x(j)
        END DO
        x(i)=s/a(i,i)
    END DO

    !WRITE(2,9)"X=",(x(i),i=1,numinput)

    !8 FORMAT(a,/,3(4(f7.2,3x),/))
    !9 FORMAT(a,/,3(f7.2,/))

    !End the timer and print result
    CALL cpu_time(finish)
    print '("Time = ",f20.10," seconds")',finish-start

END PROGRAM
```

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Python with NumPy

```
#Joseph Camacho-Terrazas
#Program4 Python Numpy Implementation
#9/26/2020
#Input: Takes a command line argument for the matrix size
#Output: The time it takes for Gaussian Elimination to run on the matrix
#Preconditions: Program must be run with 1 argument. Argument must allow for Gaus
sian Elimination to run without error.
#Postconditions: Program will output the total time it took to run Gaussian Elimi
nation on the matrix.

# Imports
import sys
import time
import numpy as np

# Read command line arguments as an int to pass to array size
n = int(sys.argv[1])

#----------Python Gaussian Elimination with Numpy Source----------
# Credit: https://www.codesansar.com/numerical-methods/gauss-elimination-method-
python-program.htm

# Making numpy array of n size and initializing
# to zero for storing solution vector
x = np.zeros(n)

# Fill array with random numbers
a = np.random.rand(n, n+1)

# Applying Gauss Elimination

# Start Timer
start = time.time()

for i in range(n):
    if a[i][i] == 0.0:
        sys.exit('Divide by zero detected!')

    for j in range(i+1, n):
        ratio = a[j][i]/a[i][i]

        for k in range(n+1):
            a[j][k] = a[j][k] - ratio * a[i][k]
```

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```
# Back Substitution
x[n-1] = a[n-1][n]/a[n-1][n-1]

for i in range(n-2,-1,-1):
    x[i] = a[i][n]

    for j in range(i+1,n):
        x[i] = x[i] - a[i][j]*x[j]

    x[i] = x[i]/a[i][i]

#End Timer and print results
finish = time.time()
print('Time = %.5f seconds'%(finish-start))
```

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Python without NumPy

```
#Joseph Camacho-Terrazas
#Program4 Python Numpy Implementation
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#Input: Takes a command line argument for the matrix size
#Output: The time it takes for Gaussian Elimination to run on the matrix
#Preconditions: Program must be run with 1 argument. Argument must allow for Gaus
sian Elimination to run without error.
#Postconditions: Program will output the total time it took to run Gaussian Elimi
nation on the matrix.

# Imports
import sys
import time
import random

#Read command line arguments as an int to create the array dimensions
n = int(sys.argv[1])

#Set the size of the matrix
cols = n+1
rows = n

#Create 2 dimensional array of zeroes
x = [[0 for _ in range(cols)]for _ in range(rows)]

#Create 2 dimensional array of random floats
a = [[random.uniform(1.50,10.50) for _ in range(cols)]for _ in range(rows)]

#----------Python Gaussian Elimination with Numpy Source----------
# Credit: https://www.codesansar.com/numerical-methods/gauss-elimination-method-
python-program.htm

# ----
Numpy code is not used in this implementation, I just left it in to show the full
 source-----

# Making numpy array of n size and initializing
# to zero for storing solution vector
#x = np.zeros(n)

# Fill array with random numbers
#a = np.random.rand(n, n+1)
```

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```
# Applying Gauss Elimination

# Start Timer
start = time.time()

for i in range(n):
    if a[i][i] == 0.0:
        sys.exit('Divide by zero detected!')

    for j in range(i+1, n):
        ratio = a[j][i]/a[i][i]

        for k in range(n+1):
            a[j][k] = a[j][k] - ratio * a[i][k]

# Back Substitution
x[n-1] = a[n-1][n]/a[n-1][n-1]

for i in range(n-2,-1,-1):
    x[i] = a[i][n]

    for j in range(i+1,n):
        x[i] = x[i] - a[i][j]*x[j]

    x[i] = x[i]/a[i][i]

#End Timer and print results
finish = time.time()
print('Time = %.5f seconds'%(finish-start))
```