The University of Western Ontario
Computer Science 2035b
Final Examination - Monday, April 22th, 2019
Professor: John Barron

Yes, it is true, due to class size, this exam is split over 2 rooms. Please make sure you are in the correct room (-5% penalty is you write in the wrong room).

<table>
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<th>Room</th>
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<td>HSB 35</td>
<td>Akioya-J. Yan</td>
</tr>
<tr>
<td>SH 3305</td>
<td>K. Yan-Zhang</td>
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Please print you full name and student number, as they appear on your student card, in the space provided below before you start this exam.

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<th>Given Names</th>
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This exam consists of 10 questions (28 pages including this page) worth a total of 370 marks (which will be scaled to 100%). It is an open book exam, course notes and any MatLab book(s) are allowed. No calculators, laptops or cell phones are allowed. All answers are to be written in this booklet. Scrap work may be done on the back of each page; this will not be marked. The exam is 180 minutes long (3 hours) and comprises 35% of your final mark.

Should your final exam grade be higher than your midterm exam grade (worth 20% of your final grade), your final exam grade in this course will count for the full 55% of your exam grade.

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(1) (40 marks) Choose one answer (true or false) for each question. Wrong answers will be awarded -2 grade. Do not circle either true or false to receive a grade of 0.

(1) MatLab restores variables values in the workspace for a directory when MatLab is restarted in a same directory.  true  false

(2) The inverse of matrix \((A*B)\) is the same as the inverse of \((B*A)\).  true  false

(3) The dimension of the matrix produced by the MatLab statement \(squeeze(A(1:5,6,7:9))\) is 3.  true  false

(4) \(A=zeros(1,2,'double')\) is a 1D array.  true  false

(5) \(A=zeros(1,2,'double')\) is a 2D array.  true  false

(6) \(A=zeros(1,2,'double')\) is a column vector.  true  false

(7) \(A=zeros(1,2,'double')\) is a row vector.  true  false

(8) If \(\text{cond}(A)\) is 1558.379 then \(A\) cannot be inverted reliably.  true  false

(9) If \(x=1:3:9\) then \(\text{numel}(x)\) is 3.  true  false

(10) Is \(A=zeros(3,3,'double')\) then the size of \(A\) is 48 bytes.  true  false

(11) Is \(A=zeros(3,3,'double')\) then the size of \(\text{ sparse}(A)\) is 72 bytes.  true  false

(12) Handle graphics always allows us to change the appearance of graphical entities that were plotted earlier, even if the handles of those plots are known?  true  false

(13) If a function \(f(x,y)\) can be symbolically integrated than it can also always be numerically integrated as well?  true  false

(14) If a function \(f(x,y)\) can be numerically integrated than it can also always be symbolically integrated as well?  true  false

(16) The MatLab statement \(x=3.0*randn(1000000,1)+3.0\) means \(x\) has a mean and standard deviation of about 3.0.  true  false

(17) The scientific notation of 0.0002567 is \(2.5667 \times 10^{-3}\)?  true  false

(17) 00010100\(_2\) is the base 2 representation of base 10 number 20?  true  false

(18) \text{eps}\ is the smallest number where \(1+\text{eps}\) is zero.  true  false

(19) If \(Ax=B\) then \(x\) can always be computed as \(x=A/B\)?  true  false

(20) 123.45654 rounded to 2 digits to the right of the decimal point is 123.45?  true  false
(2) (40 marks) Consider a function \( f(a) \) that can be computed as:

\[
f(a) = \frac{\sqrt[3]{a}}{a + \sqrt[9]{a}},
\]

where \( a \) is a large array of floating point numbers (you have to compute the size of this array). \( \sqrt[3]{a} \) and \( \sqrt[9]{a} \) are the 3\(^{rd} \) and 9\(^{th} \) roots of \( a \), which can also be computed as \( a^{\frac{1}{3}} \) and \( a^{\frac{1}{9}} \). Below you will be asked to write 3 MatLab functions to compute this function using the CPU and/or the GPU. Timing measurements are required using `tic` and `toc`. Only time the computation, and not any overhead required to setup the computation. Write the most efficient code you can. A run of the code below:

```matlab
function q2_2019
    %[a] is set here, the size of a is unknown to you.
    [f1,cp1]=calc_f1(a);
    [f2,cp2]=calc_f2(a);
    [f3,cp3]=calc_f3(a);
    fprintf('CPU sum(f1)=%12.6f cp1=%8.5f
',sum(f1),cp1);
    fprintf('VEC sum(f2)=%12.6f cp2=%8.5f
',sum(f2),cp2);
    fprintf('GPU sum(f3)=%12.6f cp3=%8.5f
',sum(f3),cp3);
end % q2_2019
```

produces the output:

```
CPU sum(f1)=83887.682627 cp1= 0.06915
VEC sum(f2)=83887.682627 cp2= 0.00970
GPU sum(f3)=83887.682627 cp3=46.25715
```

Note that the GPU solution is much slower that the CPU and VEC solutions here! This is irrelevant to the answers required here.
(2a) (10 marks) Give the MatLab code for function \( f, cp = \text{calc}_f1(a) \) an efficient calculation of this function using arrays and loops. \( f \) is the value of the sum of \( f(a) \) and \( cp \) is the computational measurement for this function.

\begin{verbatim}
function [f,cp]=calc_f1(a)
end % calc_f1
\end{verbatim}

(2b) (10 marks) Is your code in \texttt{calc}_f1 standard serial code or JIT compiled code? Why or why not? An answer without justification is worth nothing.
(2c) (10 marks) Give the MatLab code for function \([f, cp]=\text{calc}_f2(a)\), an efficient calculation of this function using vectorization. \(f\) is the value of the sum of \(f(a)\) and \(cp\) is the computational measurement for this function.

\begin{verbatim}
function [f, cp]=calc_f2(a)

end % calc_f2
\end{verbatim}

(2d) (10 marks) Give the MatLab code for function \([f, cp]=\text{calc}_f3(a)\) an efficient calculation of the function \(\text{calc}_f1\) using the GPU. \(f\) is the value of the sum of \(f(a)\) and \(cp\) is the computational measurement for this function.

\begin{verbatim}
function [f, cp]=calc_f3(a)

end % calc_f3
\end{verbatim}
(3) (30 marks) Consider the following MatLab code:

```matlab
A=[10 5 nan 6; -5 nan 3 8; -3 inf 6 inf; 2 -7 3 1];

fprintf('Original A:
');
A
fprintf('Original sum:
');
sum(A)

A(isnan(A))=0;
fprintf('isnan A:
');
A
fprintf('isnan sum:
');
sum(A)

A(isinf(A))=0;
fprintf('isinf A:
');
A
fprintf('isinf sum:
');
sum(A)
```

What is printed by this code?

Original A:

Original sum:
isnan A:

isnam sum:

isinf A:

isinf sum:
(4) (20 marks) This question is related to Assignment 1 in that you have to write some vectorized code (no loops) in MatLab. This question poses a calculation you did not do on the assignment. You are given the following arrays (which you may assume have been correctly computed):

1. The `names` cell array contains the hyphenated names of all students,

2. The `exams(:,1)` and `exams(:,2)` are the columns of the `exams`, giving the midterm and final exam grades as percentages (0% to 100%).

3. A `lab_mark` array (not on assignment 1) gives the lab marks for each student as a number from 0 to 10, while

4. An `assignment_mark` array (also not on the assignment) gives the assignment grades for each student as a number from 0 to 35.

5. `final` array gives the course grades for each student as a number from 0 to 100.

Write a single vectorized MatLab line of code that prints the names of all students whose lab mark is 10 and whose assignment and midterm exam mark are at least 30 and 40 while their final mark is greater than or equal to 50 or whose assignment and final exam marks are at least 33 and 43 respectively while their final mark is greater than or equal to 53.

You may use 0 or more built-in MatLab functions in your solution. Do not use `find` in your solution. Use continuation dots ... to spread you statement nicely over multiple lines. Note that 26 students in the assignment 1 data satisfy this compound boolean expression.
(5) (40 marks) Consider the following figures. Write MatLab code segments to generate these graphs. For all graphs, print and text with fontsize 14 and boldface the labels.

(5a) (15 marks) Consider the parametric functions, $x = \sin(2 \times t)$ and $y = \sin(3 \times t)$. Figure 1 show a plot of these functions for $t \in [-1 \ 1]$ and $x, y \in [-5 \ 5]$.

Figure 1: A plot of the parametric functions.

Your answer:
(5b) (25 marks) Consider Figure 2 showing the Lemniscate function. Give the MatLab code to produce Figure 2 below. One version of this function gives the function as:

\[
x = \cos(\theta) \times \sqrt{2 \times \cos(2 \times \theta)} \\
y = \sin(\theta) \times \sqrt{2 \times \cos(2 \times \theta)}
\]

for 100 values of \(\theta\) in the range \([-\pi/4, \pi/4]\). This draws the red part of the function shown in Figure 2 on the right. Use linewidth of 2.0, plot the right side of the function as a solid red closed curved and the left side of the function as a solid blue closed curved. Please give your answer on the next page.
Your answer:
Figure 3: A 3D plot of parametric functions, \( x = \cos(t) \), \( y = \sin(t) \) and \( z = \sin(5t) \), for 100 equally spaced \( t \) values in the range \([-\pi \, \pi]\).

(6) (40 marks) Consider the following 3D plots. Draw all text with fontsize 14 and boldface all labels.

(6a) (15 marks) Consider plot of 3 parametric functions shown in Figure 3. The functions are \( x = \cos(t) \), \( y = \sin(t) \) and \( z = \sin(5t) \) for 100 equally spaced values in the range \([-\pi \, \pi]\).

Give the MatLab code needed to produce this graph.

**Your answer:**
Question (6a) continued:
(6b) (25 marks) Consider the 3D function shown in Figure 4. The function can be specified as 3 parametric functions \( x = \sin(\pi \* u) \* \sin(\pi \* u) \* \cos(v), \) \( y = \sin(\pi \* u) \* \sin(\pi \* u) \* \sin(v) \) and \( z = u \) with 50 values of \( u \) in the range \([-1 1]\) and 50 values of \( v \) in the range \([0 2 \* \pi]\). Use an azimuth angle of 135 degrees and an elevation angle of 15 degrees to display your function. [Hint: use meshgrid and vectorization in your surf calculation.] Please put your answer on the next page.

Figure 4: 3D function with equations \( x = \sin(\pi \* u) \* \sin(\pi \* u) \* \cos(v), \) \( y = \sin(\pi \* u) \* \sin(\pi \* u) \* \sin(v) \) and \( z = u \).
Your answer:
(7) (30 marks) This question concerns sparse matrices. Show your calculations on sparse array sizes (in bytes) for full marks. Answers without justification are worthless.

(7a) (5 marks) Consider the following MatLab code:

```matlab
A(5,5)=5;
A(10,10)=10;
```

How many bytes are required by \( A \) as determined by `whos A`?

(7b) (10 marks) If the MatLab code is executed to change \( A \) to a sparse matrix, i.e. \( A=sparse(A) \), how many bytes are now required by \( A \) as determined by `whos`?

(7c) (5 marks) Consider the following MatLab code:

```matlab
A=randn(10,10);
```

How many bytes are required by \( A \) as determined by `whos A`?
(7d) (10 marks) If the MatLab code is executed to change A to a sparse matrix, i.e. \( A = \text{sparse}(A) \), how many bytes are required by \( A \) as determined by \texttt{whos}?

(7e) (5 marks) If we compute \( A = A \times A \) with \( A \) being sparse, how many bytes are required by \( A \) as determined by \texttt{whos}?
(8) (40 marks) This question concerns image processing and color edge detection and is partially based on lab 11.

Figure 5: The original Yosemite grayvalue images and its Sobel, Prewitt and Roberts edge maps.
Figure 6: The color edge map of the Yosemite image computed from the Sobel, Prewitt and Roberts edge maps.
(8a) (15 marks) Write MatLab code to compute and display the Sobel, Prewitt and Roberts edge maps using the MatLab function `edge`. Remember that `edge` returns a white edge map with black background. Display the images with a white background and black edges. Note that `edge` produces a binary image with 0 being black and 1 being white. Figure 5 above shows the original grayvalue images and the 3 edge maps. You do not have to put boxes around the edge maps as is done here.

**Your answer:**

```matlab
I = imread('yos.9');
```
(8b) (25 marks) Write MatLab code to compute a color image from these 3 edge maps. Compute a color edge map by computing red (255,0,0) from the Sobel edge map, green (0,255,0) from the Prewitt edge maps and blue (0,0,255) from the Roberts edge map. Note that black is now (0,0,0) and white is (255,255,255). It is possible for 2 of the edge maps to have a common edge at some location, in that case, we get a secondary color. For example, if a common edge exists in the Sobel and Prewitt edge maps then the color edge has the yellow color (255,255,0). If all three edge maps have a common edge, then the color edge has the color orange (255,127,0) [rather than the color white (255,255,255)]. Figure 6 shows the color edge map. There are many blue edgels but only a few red and green edgels. There are numerous yellow images (common Sobel and Prewitt edgels) but few orange edgels.

Your answer:
(9) (40 marks) This question is concerned least squares fitting polynomials to data. Consider the following MatLab code:

```matlab
x=linspace(0,0,7);
A=vander(x)
cond(A)
min(A(:))
max(A(:))
```

(9a) (5 marks) What is values printed by `min(A(:))`?

(9b) (5 marks) What is values printed by `max(A(:))`?

(9c) (5 marks) What is the value of matrix A?

(9d) (5 marks) What is the condition number of A?
(9e) (10 marks) Consider the MatLab code:

```matlab
x=0:3;
y=x.^2;
xp=linspace(0,3,4);
p1y=polyfit(x,y,3);
yorder3=polyval(p1y,xp);
figure
plot(x,y,'ok','linewidth',2.0);
figure
plot(x,y,'-ok','linewidth',2.0);
hold on
plot(xp,yorder3,'-r','linewidth',2.0);
```

Show what is plotted on the graph below (the data is already plotted as black circles). Indicate the colors of all curves that appear.

**Your answer:**
(9f) (10 marks) Consider the MatLab code:

```matlab
x=0:3;
y=x.^2;
xp=linspace(0,3,100);
p1y=polyfit(x,y,3);
yorder3=polyval(p1y,xp);
figure
plot(x,y,'-ok','linewidth',2.0);
hold on
plot(xp,yorder3,'-r','linewidth',2.0);
```

Show what is plotted on the graph below (the data is already plotted as black circles). Indicate the colors of all curves that appear.
(10) (35 marks) This question is based on assignment 4 of this year. Write MatLab code to draw the 2D and 3D graphs shown below. Use MatLab defaults whenever possible. Line width should be 2.0. This question tests your ability to manipulate the 4D climate array as well as writing MatLab code that draws the graphs.

(10a) (15 marks) Consider writing MatLab code to draw an errorbar graph that plots the average daily temperature for the month of February, 1965. You will need a handle for your figure. Your code should produce the graph shown below. Note that you have to write code to pull the minimum, maximum and average daily temperature data from the `climate` array.

Your answer:

```matlab
% read the 4D climate array
load london_weather_1941_2013.mat 'climate';
```
Question (10a) continued here:
(10b) (15 marks) Consider plotting a 3D `surf` of the average monthly temperature of London from 1941 to 2013. The graph showing this is given below. Give the MATLAB code to produce this graph.

```
% read the 4D climate array
load london_weather_1941_2013.mat 'climate';
```

Your answer:
(10c) (5 marks) Consider changing the graph in (10a) so that the red line is changed from red to blue through the average temperature. Use that figure’s handle to do this. You should get the graph shown below.

![Graph showing temperature data with error bars.](image-url)

Your answer: