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KIRIRI WOMENS' UNIVERSITY OF SCIENCE AND TECHNOLOGY
UNIVERSITY EXAMINATIONS, 2024/2025 ACADEMIC YEAR
THIRD YEAR, SECOND SEMESTER EXAMINATION
FOR THE DEGREE OF BACHELOR OF SCIENCE (COMPUTER SCIENCE)
KCS 2311: SCIENTIFIC COMPUTING

DATE: 13TH DECEMBER, 2024

TIME: 8:30AM-10:30AM

INSTRUCTIONS TO CANDIDATES

ANSWER QUESTION ONE (COMPULSORY) AND ANY OTHER TWO QUESTIONS

QUESTION ONE: COMPULSORY (30 MARKS)

- a) Given a scenario where a researcher needs to run a complex simulation involving climate modeling, explain how HPC can facilitate this task (3 Marks)
- b) State the performance metrics commonly used to evaluate HPC systems (3 Marks)
- c) Highlight the main components of high-performance computing (HPC) and how they contribute to its overall function (6 Marks)
- d) Distinguish between
 - i) point-to-point communication and collective communication in MPI (2 Marks)
 - ii) linear and non-linear equations (2 Marks)
 - iii) a tree and a graph in terms of hierarchical data structures (2 Marks)
 - iv) NumPy and Pandas as applied within scientific computing (4 Marks)
- e) Write a Python code snippet that
 - i) uses a while loop to print the numbers from 1 to 10 (2 Marks)
 - ii) demonstrates the use of both an expression and a statement (2 Marks)
- f) State the importance of the loop statement in a python program (2 Marks)
- g) Given a scenario where HPC memory is a significant factor. Highlight when you would opt for either OpenMP and MPI as parallel programming models (2 Marks)

QUESTION TWO: (20 MARKS)

A researcher is investigating the area under the curve of the function $f(x)=x^2$ over the interval $[1,3]$ using different numerical integration methods.

- a) The researcher applied $n=2$ as the subintervals to approximate the integral of $f(x)$. Use the below methods to obtain approximations for the integral
 - i) Trapezoidal rule (4 Marks)
 - ii) Simpson's rule (4 Marks)
 - iii) Midpoint rule (4 Marks)
- b) Compare and contrast the trapezoidal rule and Simpson's rule for numerical integration. (4 Marks)
- c) Discuss the error associated with the above numerical integration methods (2 Marks)
- d) Highlight how the choice of n (number of subintervals) affects the accuracy of the approximation (2 Marks)

QUESTION THREE: (20 MARKS)

Alice, a fourth-year student at KWUST, is required to collect experimental data for her final year project. She approaches some of her siblings with minimal knowledge on data collection to assist her do the experiments and document the data collected. After the experiment phase, Alice does some numerical computations using the constant $\pi = 3.14$ and while analyzing her experimental data she realizes that she requires polynomial interpolation to estimate missing values. She is considering Lagrange and Newton interpolation methods for this purpose.

- a) Discuss **TWO** ways in which error can be introduced into Alice's computations (4 Marks)
- b) State **ONE** reason why Alice should perform an error analysis (2 Marks)
- c) Alice approximates π^2 to ten. Identify the absolute and relative errors in this approximation (2 Marks)
- d) Given the polynomial $P(x)=2x^2+3x+1$, calculate $P(2)$ and find the absolute error if the true value is known to be 15 (2 Marks)
- e) Provide Alice with **TWO** advantages of using Lagrange interpolation over Newton interpolation when working with a small set of data points (4 Marks)
- f) Given the points (1,2) (2,3) (3,5) use the Lagrange interpolation formula to find the polynomial $P(x)$ that passes through these points (6 Marks)

QUESTION FOUR: (20 MARKS)

Your classmate Jane was sick and missed a class on scientific computing assignments where you were taught how to analyze a linear system to optimize the design of a structure involving three variables: x , y , and z .

- a) Explain to Jane the difference between a consistent and an inconsistent linear system of equations (4 Marks)
- b) Given the following linear system derived from the design parameters:

$$\begin{aligned}x + y + z &= 6 \\2x + 3y + 2z &= 12 \\3x + 5y + 4z &= 18\end{aligned}$$

Analyze whether the system is consistent or inconsistent and provide a brief explanation of your reasoning (4 Marks)

- c) Solve the following linear system using the substitution method: (4 Marks)
$$\begin{aligned}x + 2y &= 10 \\3x - y &= 5\end{aligned}$$
- d) Other than substitution method, linear systems can also be solved using Gaussian elimination. Solve the linear system in (ii) above using the gaussian elimination method (4 Marks)
- e) Use matrix inversion to find the solution to the following linear system: (4 Marks)
$$\begin{aligned}2x + y &= 8 \\x + 3y &= 9\end{aligned}$$

QUESTION FIVE (20 MARKS)

KWUST desires to put up a lab for the simulation of fluid dynamics and they envision it using parallel model but the key stakeholders have little to no knowledge of the scientific computing principles therein. KWUST recently underwent a benchmarking at Mazina University and discovered that they were using MPI to distribute the computational load across multiple nodes. The benchmarking also revealed that Mazina was facing significant challenges with synchronization and communication overhead.

- a) Explain **TWO** reasons why parallel computing will be the best approach to take (4 Marks)
- b) State **TWO** potential synchronization issues that Mazina might be encountering during their simulations (4 Marks)
- c) Discuss how these issues identified in (ii) above can impact the overall performance of the parallel model (2 Marks)
- d) Suggest **THREE** strategies Mazina can implement to minimize communication overhead when using MPI for their fluid dynamics simulation and highlight how each strategy contributes to improving efficiency (6 Marks)
- e) Explain the significance of load balancing in achieving optimal performance in the context of parallel processing (4 Marks)