UNIVERSITY OF WARWICK	
Department	Computer Science
Module Code	CS922
Module Title	High Performance Computing
Exam Paper Code	CS9220_A
Duration	2 hours
Exam Paper Type	24-hour window

STUDENT INSTRUCTIONS

1. Read all instructions carefully. We recommend you read through the entire paper at least once before writing.

2. There are **FOUR** questions in total. All candidates should choose to answer **ONE** of the two questions in Section A and answer **BOTH** questions in Section B.

3. You should not submit answers to more than the required number of questions.

4. You should handwrite your answers either with paper and pen or using an electronic device with a stylus (unless you have special arrangements for exams which allow the use of a computer). Start each question on a new page and clearly mark each page with the page number, your student id and the question number.
Handwritten notes must be scanned or photographed and all individual solutions collated into a single PDF with pages in the correct order.

5. Please ensure that all your handwritten answers are written legibly, preferably in dark blue or black ink. If you use a pencil ensure that it is not too faint to be captured by a scan or photograph.

6. Please check for legibility before uploading. It is your responsibility to ensure your work can be read.

7. Add your student number to all uploaded files.

8. You are permitted to access module materials, notes, resources, references and the internet during the online assessment.

9. You must not communicate with any other candidate during the assessment period or seek assistance from anyone else in completing your answers. The Computer Science Department expects the conduct of all students taking this assessment to conform to the stated requirements. Measures will be in operation to check for possible misconduct. These will include the use of similarity detection tools and the right to require live interviews with selected students following the assessment.

10. By starting this assessment, you are declaring yourself fit to undertake it. You are expected to make a reasonable attempt at the assessment by answering the questions in the paper.

IMPORTANT INFORMATION

- We strongly recommend you use Google Chrome or Mozilla Firefox to access the Alternative Exams Portal.
- You are granted an additional 45 minutes beyond the stated duration of this assessment to allow for downloading/uploading your assessment, your files and any technical delays.
- Students with approved Alternative Exam Arrangements (Reasonable Adjustments) that permit extra time and/or rest breaks will have this time added on to the stated duration.
- You must have completed and uploaded the assessment before the 24-hour assessment window closes.
- Late submissions are not accepted.
- If you are unable to submit your assessment, you must submit Mitigating Circumstances immediately, attaching supporting evidence and your assessment. The Mitigating Circumstances Panel will consider the case and make a recommendation based on the evidence to the Board of Examiners.

SUPPORT DURING THE ASSESSMENT

Operational Support

- Use the Alternative Exams Portal to **seek advice immediately if during the assessment period:**
  - you cannot access the online assessment
  - you believe you have been given access to the wrong online assessment

  Operational support will be available between 09:00 and 17:00 BST for each examination (excluding Sunday)

Technical Support

- If you experience any technical difficulties with the Alternative Exam Portal please contact helpdesk@warwick.ac.uk

Technical support will be available between 09:00 and 17:00 BST for each examination (excluding Sunday)

Academic Support

- If you have an academic query, contact the invigilator (using the 'Contact an Invigilator' tool in AEP) to raise your issue. Please be aware that two-way communication in AEP is not currently possible

  Academic support will normally be provided for the duration of the examination (i.e. for a 2 hour exam starting at 09:00 BST, academic support will normally be provided between 09:00 and 11:45 BST). Academic support beyond this time is at the discretion of the department.

Other Support

- **if you cannot complete your assessment for the following reasons submit Mitigating Circumstances immediately**:

  - you lose your internet connection
  - your device fails
  - you become unwell and are unable to continue
  - you are affected by circumstances beyond your control

Section A (Choose to answer one question in the section)

1. *This question is about fundamental knowledge.*

(a) Solving partial differential equations is a common HPC application. What are the general steps taken when implementing numerical methods for solving partial differential equations? Explain why solving partial differential equations is a computation-intensive process. [7]

(b) A wide range of technologies are needed to achieve high performance computing. Give and discuss three technologies among them. [9]

(c) Discuss the differences between the thread level parallelism and the process level parallelism. [6]

(d) Given the following sequence of instructions, analyse what types of dependency exist between which instructions. Observe if some of the dependencies can be removed. If they can, give a reasonable solution to removing them. [8]

```
if(flag==0) then
    a=b;
else {
    a=b×b;
    d=c+a;
    a=d×d;
}
```

flow,
out
control
a=b*b

a)high performance cpu
high speed network
portability
scalability
b)
less ALU
has control unit
has cache
latency-oriented rather than throughput-oriented
c)
d)
degree: the number of nodes from/to a node
diameter: the shortest path between the furthest node
bisection width, the minimum number of link to divide it into two the same size network.

2. *This question is about high performance computing systems.*

(a) Why have Cluster systems gained in popularity for HPC?

(b) GPUs are much more powerful than CPUs in terms of FLOPs. Wh
the same FLOPs performance as GPUs?

(c) Each of 16 processes needs to read a column in a 16 by 16 array
array is stored on the hard disk in row-major order. Give a sol
processes can read the array efficiently and explain why your solu
I/O.

(d) The interconnection topology of the computing nodes plays an important role in the performance of an HPC system. Explain what aspect of networking performance the *node degree*, *diameter* and *bisection width* of a network topology represent. What are the node degree, diameter and bisection width of the 3-D torus typology with n nodes? [9]

Section B (Answer both questions in the section)

3.*This question is about parallel programming models*

(a) Analyse the following two "*for*" loops in Listing 1. Describe whether each of th
can be parallelised automatically by a compiler and explain how you re
conclusions.

Loop 1:

```
for(i=1;i<=n;i++)
{
     d[i]= sqrt(a[i]);
     a[i]= b[i]*c[i];
}
```

Loop 2:

```
for(i=2;i<=n;i++)
     a[i]=a[i-1]+b[i];
```

Listing 1: Two loops for Question 2(a)

(b) A collective communication operation is performed by all relevant processes
time with the same set of parameters. However different processes may interpret the parameters differently. Describe, using illustrative examples if necessary, the operations of
owing two MPI collective communication calls. Further, discuss how different
s interpret the parameters in the functions differently.

Reduce(void **sendbuf*, void **recvbuf*, int *count*, MPI_Datatype *type*, MPI_Op *op*,
int *root*, MPI_Comm *Comm*) [5]

_Scatter(void **sendbuf*, int *sendcnt*, MPI_Datatype *sendtype*, void **recvbuf*,
int *recvcount*, MPI_Datatype *recvtype*, int *root*, MPI_Comm *comm*) [5]

the programmers are allowed to construct their own data types, called derived data

i) Discuss the benefits of supporting the derived data types in MPI. [7]

ii) MPI_Type_indexed is an MPI function that constructs the derived data type. The format of the function is as follows:

MPI_Type_indexed(int *count*,
int **array_of_blocklengths*,
int **array_of_displacements*,
MPI_Datatype *oldtype*,
MPI_Datatype **newtype*).

Let *oldtype*={(MPI_INT, 0), (MPI_CHAR, 2)} with the extent of 3 bytes

Let *a*[2]={2, 3} and *b*[2]={4, 8}.

b)
MPI_Bcast():
broadcast from 1 to all
MPI_Scatter():
scatter from 1 to all

MPI_Gather():
gather all to 1

MPI_Reduce():
apply collective operations

MPI_AllReduce():
MPI_Reduce
+MPI_Bcast

MPI_Alltoall():
MPI_Scatter
+MPI_Gather

i)
deal with noncontiguous memory.

improve performance
ii)

Work out the memory layout of *newtype* after calling MPI_Type_indexed(2, *a*, *b*, *oldtype*, *newtype*). [6]

(d) Assume eight threads, whose IDs are 0, 1, ..., 7, are generated to run the *for* loop with the *parallel* construct below. Which thread will run the iteration *i*=184? Show your workings. [6]

```
#pragma omp parallel for schedule(static, 5)
for(int i=1; i<=320; i++)
{
      …
}
```

4. *This question is about performance analysis methods.*

(a) Consider p processors that perform a calculation on a 3-D grid of points in parallel. Assume the sizes of the x, y and z dimension of the grid are $2a$, a, and $3a$, respectively.

i) Assume the grid is partitioned into p parts using the 1-D decomposition along the x dimension. Calculate the surface-to-volume ratio. [3]

ii) Assume the grid is partitioned into p parts using the 2-D decomposition along the x and the y dimension. Calculate the surface-to-volume ratio. [3]

iii) Assume the grid is partitioned into p parts using the 3-D decomposition. Calculate the surface-to-volume ratio. [3]

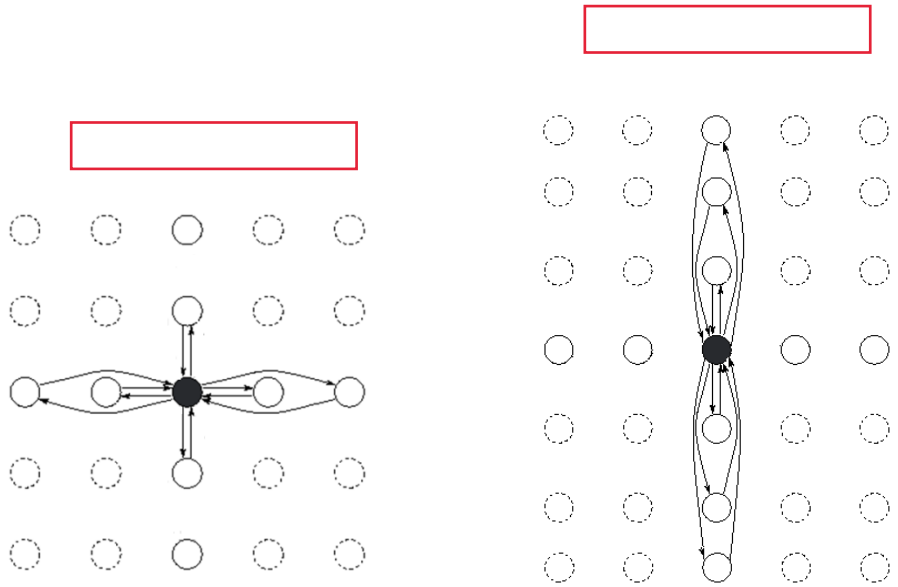
iv) What is the value range of p so that the 2-D decomposition is better than the 1D decomposition? [3]

(b) Assume that when a program performs a calculation on a point in a 3-D grid, it needs to obtain the data from some neighboring points. The communication pattern among the grid points is shown in Figure 1. Figure 1a is the communication pattern in the horizontal direction (i.e., the x and the y dimension), while Figure 1b is the communication pattern in the vertical direction (i.e., the z dimension). The size of each dimension of the grid is N.

i) Construct three performance models for the execution time of the program when the grid is partitioned using the 1-D, 2-D and 3-D decompositions. Note that the communication intensity in each direction of the grid is different. You should apply the sensible partition strategies when constructing the performance models. [9]

ii) Based on the constructed performance models, derive the parallel efficiency and iso-efficiency functions under these three decomposition methods. [9]

iii) Discuss which decomposition method is the best in terms of scalability by comparing their iso-efficiency functions. [5]



a) b)

Figure 1. The communication pattern among the grid points in Question 4b; a) the communication pattern among the points in the horizontal direction; b) the communication pattern among the points in the vertical direction