

THE UNIVERSITY OF WARWICK

MSc Examinations: Summer 2017

High Performance Computing

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Time allowed: 2 hours

Choose to answer TWO questions from Questions 1, 2 and 3.

Question 4 is compulsory.

Calculators may be used.

Read carefully the instructions on the answer book and make sure that the particulars required are entered on each answer book.

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1. *This question is about the fundamental knowledge.*

- (a) FLOPS is one of the important metrics to measure the performance of a computing system. What does FLOPS stand for? Explain what processing capability of a computing system the FLOPS performance represents and what benchmark can be used to measure the FLOPS performance. Discuss why FLOPS is an important performance metric. Also discuss what parts of a computing system play the important roles in achieving high FLOPS performance and explain why. [12]
- (b) A wide range of technologies are needed to achieve high performance computing. Give and discuss three technologies among them. [9]
- (c) Give four types of parallelism in order of the granularity of parallelism and give an example for each type of parallelism. [8]
- (d) What types of dependency are there between instructions? Given the following sequence of instructions, analyse what types of dependency exist between the instructions. [6]

*if(flag==0) then*

*{ a=b; }*

*a=b×b;*

*d=c+a;*

*a=d×d;*

2. *This question is about parallel programming models*

- (a) What type of computer system is OpenMP used to write parallel programs on? Explain how parallel computing is realized in OpenMP. [9]
- (b) Analyse the following two “for” loops in Listing 1. Describe whether the iterations of these two loops can be parallelised automatically by compilers and explain how you reached your conclusions. [6]

```
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(b)

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

i) `MPI_Reduce(void *sendbuf, void *recvbuf, int count, MPI_Datatype type, MPI_Op op, int root, MPI_Comm Comm)` [4]

ii) `MPI_Scatter(void *sendbuf, int sendcnt, MPI_Datatype sendtype, void *recvbuf, int recvcnt, MPI_Datatype recvtype, int root, MPI_Comm comm)` [4]

- (d) In MPI, the programmers are allowed to construct their own data types.
- i) `MPI_Type_indexed` is one of the MPI functions serving this purpose. The format of the function is as follows:

```
MPI_Type_indexed ( int count,
                  int *blocklengths,
                  int *array_of_displacements,
                  MPI_Datatype oldtype,
                  MPI_Datatype *newtype)
```

Let  $oldtype = \{(MPI\_DOUBLE, 0), (MPI\_CHAR, 64)\}$  with the extent of 72 bits. Let  $a[2]=\{2, 1\}$  and  $b[2]=\{2, 10\}$ .

Give the memory layout of  $newtype$  after calling  
 $MPI\_Type\_indexed(2, a, b, oldtype, newtype)$  [6]

ii) Discuss the benefits of supporting programmer-defined data types in MPI. [6]

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

- (a) Explain differences between Cluster systems and Grid systems. Also explain what types of high performance computing applications that the Cluster and the Grid systems are suitable to run. [10]
- (b) Explain how CPU interacts with the GPU card and how parallel computing is supported in GPU. Further, discuss the designing objective of a GPU card. [15]
- (c) Explain the five typical activities performed by the cluster management software such as PBS. [5]
- (d) The topology of node interconnection plays an important role in the performance of a HPC system. What are the node degree and bisection width of the *2D mesh* topology? Draw an exemplar 2D mesh topology. [5]

4. This question is about performance analysis methods.

Assume that when a program performs computations at each point in a 3-Dimensional grid, it needs to obtain the data from neighboring points. The communication pattern among the grid points is shown in Figure 1. Figure 1a is the communication pattern among the grid points in the horizontal direction, while Figure 1b is the communication pattern among the grid points in the vertical direction. The size of each dimension of the grid is  $N$ .

- i) Construct performance models for the program's execution time when the grid is partitioned using 1-D, 2-D and 3-D decompositions. [15]
- ii) Based on the constructed performance models, derive parallel efficiency and iso-efficiency functions under these three decomposition methods. [9]
- iii) Discuss which decomposition method is better in terms of scalability by comparing their iso-efficiency functions. [6]

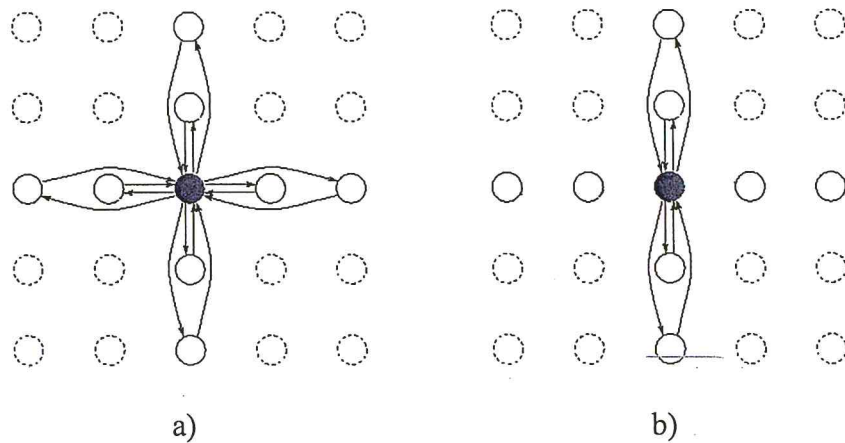


Figure 1. The communication pattern among the grid points in Question 4; a) the communication pattern among the points in the horizontal direction; b) the communication pattern among the points in the vertical direction