# UNIVERSITY OF EDINBURGH

## FACULTY OF SCIENCE AND ENGINEERING

## MASTER OF SCIENCE IN COMPUTER SCIENCE

## SYSTEM INTEGRATION 1

**Tuesday 2 May 2000**

**9:30 to 11:00**

**Examiners:**

**I. Watson (External)**

**R.N. Ibbett (Chairman)**

## INSTRUCTIONS TO CANDIDATES

**Answer any TWO questions.**

**All questions carry equal weight.**

1. (a) Explain the following loop transformations and illustrate your answers with examples:

    i. Loop skewing
    ii. Loop tiling
    iii. Loop peeling

    *[9 marks]*

   (b) Define the following terms in loop dependence analysis:

    i. Loop-carried dependence
    ii. Dependence distance
    iii. Direction vector

    *[6 marks]*

   (c) Describe the dependences between statements $S1$, $S2$ and $S3$ and derive the dependence distances and direction vectors in the following loops:

    i.

```
      DO X = 1, N
         DO Y = 2, N
S1:         P(X, Y) = P(X, Y-1) + Q(X, Y)
S2:         R(X, Y) = P(X, Y) + S(X+1, Y)
S3:         S(X, Y) = 5.0
         END DO
      END DO
```

    ii.

```
      DO X = 1, N
         DO Y = 2, N
S1:         P(X, Y) = Q(X, Y) + R(X, Y)
S2:         R(X, Y) = S(X, Y)/3
S3:         T(X, Y) = P(X, Y-1) * 5 + T(X, Y-1)
         END DO
      END DO
```

    *[10 marks]*

2. (a) What are the important features of Superscalar and Very Large Instruction Word (VLIW) architectures? [*6 marks* ]

(b) Describe the role of the following techniques in exploiting instruction-level parallelism in programs:

i. Control dependence analysis

ii. Simultaneous execution of multiple flows of control

iii. Speculative execution

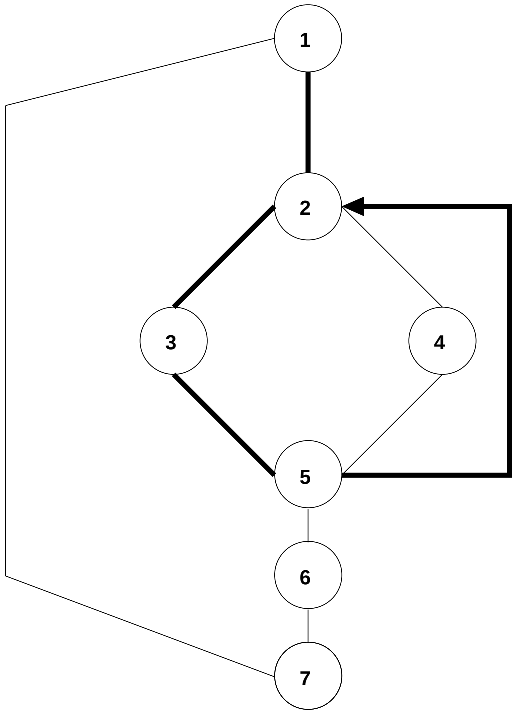
[*6 marks* ]

(c) Consider the following abstract machine models which use either one or more of the techniques listed in 2(b).

- Model A - An instruction cannot execute until its control dependence branches are resolved. Branch instructions must execute in order, one per cycle
- Model B - An instruction cannot execute until its control dependence branches are resolved. Multiple branch instructions can execute in parallel and need not be ordered.
- Model C - An instruction cannot execute until its incorrectly predicted control dependence branches are resolved. In addition, a branch instruction must wait for all preceding misdirected branches, not just the one it is control dependent on.
- Model D - An instruction cannot execute until its incorrectly predicted control dependence branches are resolved. There are no additional constraints on branches.

*QUESTION CONTINUES ON NEXT PAGE*

In the flow graph shown in the following figure, each node represents a single instruction and the edges represent possible flows of control with the more likely branch outcome highlighted.




i. For each node, derive the set of branch instructions on which it is immediately control dependent [*2 marks* ]

ii. Sketch a possible instruction trace with at least two instances where branches are incorrectly predicted [*3 marks* ]

iii. Sketch the execution of this trace on the four abstract machine models. Clearly indicate the instructions which execute concurrently. [*8 marks* ]

3. (a) Derive declarations for **neutrality** and **independence** in systolic computation for the inner-product step in the following cases:

   i. The multiplication of two banded matrices $A$ and $B$, where $p_A$ and $q_A$, and $p_B$ and $q_B$ are the band widths of the upper and lower triangles of matrices $A$ and $B$, respectively.

   ii. The multiplication of a matrix $A$ with a vector $X$, where $p$ and $q$ are the band widths of the upper and lower triangles, respectively. [*12 marks* ]

   (b) Recall that the **step** and **place** functions for the inner-product step, $(i : j : k)$, in the multiplication of two banded matrices on a rectangular array of processes is given by:

   $\text{step}((i : j : k)) = i + j + k$; $\text{place}((i : j : k)) = (i, j)$

   Propose a new **place** function such that the array size is now independent of the matrix sizes. Derive an expression for the array size in terms of the band widths, and the **flow** and **pattern** functions. [*13 marks* ]