

I. Processor (25 points)

1. (5 points) In a modern out-of-order issue processor, each of instruction issue, register rename, and register bypass typically fit within one clock cycle. Why do these stages not exceed one cycle each?
2. (20 points) Assume an out-of-order issue processor pipeline that employs load value prediction (VP). VP predicts load values early in the pipeline and provides the predicted value to the immediately-following consumer instructions to avoid load-use stalls (i.e., the consumer instructions use the predicted value instead of waiting for the value from the cache). Without value prediction, the processor can hide all of the load-use stalls for 50% of loads and the remaining loads cause 3 stall cycles. With VP, every load is predicted so that the load-use stalls are completely removed but VP mispredictions incur 12-cycle bubbles due to pipeline flush.
 - (a) (10 points) Assume that 25% of all instructions are loads, a fraction x of loads have an immediately-following consumer, and VP's inaccuracy is y (i.e., y out of 100 predictions are incorrect in VP). Write an expression for CPI without and with VP, assuming an ideal CPI of 1.2 where load-use stalls are ignored.
 - (b) (5 points) Using the above expressions, determine under what conditions does VP improve performance.
 - (c) (5 points) Why is VP not profitable under all conditions, as is typically the case for branch prediction?

II. Memory (25 points)

1. (15 points) In this question, the goal is qualitative comparison of two L1 cache designs – a design that uses hashing to index into the L1 cache versus a conventional design that uses simple indexing.
 - (a) (10 points) What are the potential performance advantages of hashing over conventional and vice versa (there are two cases here)? **Note:** characteristics that help or hurt both designs will not receive any points.
 - (b) (5 points) How would out-of-order-issue processors offset the performance impact of the disadvantages of hashing over conventional indexing more than they would offset the disadvantages of conventional indexing over hashing?
2. (10 points) Modern operating systems often use multiple page sizes to capture spatial locality at multiple granularities.
 - (a) (5 points) For a system with two page sizes (e.g., 8KB and 8MB), what problem does the TLB face?
 - (b) (5 points) Describe a simple solution to this problem (your solution may be limited to the special case of just two page sizes).

Write in Exam Book Only

III. Multicore (25 points)

1. (15 points) Assume that before the following code segment runs $X=Y=0$.

Thread 1: $X = Y + 2$; PRINT Y;

Thread 2: $Y = X + 2$; PRINT X;

What are the possible sequentially-consistent combinations of values that can be output by the two threads? Give your answer(s) as ordered pairs (X,Y) that represent the X and Y values printed by the threads.

2. (10 points) Suppose that we are trying to compute the frequency of various characters in an array representing a large document. The parallel pseudocode for such a computation appears below:

```
for i = mypid * 256/P to (mypid+1) * 256/P -1
  LOCKINIT(histlock[i]); /* initialize a lock */
  hist[i] = 0;
```

BARRIER;

```
for i = mypid * N/P to (mypid+1) * N/P -1
  LOCK(histlock[arr[i]]);
  hist[arr[i]] = hist[arr[i]] + 1;
  UNLOCK(histlock[arr[i]]);
```

Describe and explain at least 2 reasons why you are likely to see poor parallel speedup with the above code. (NOTE: Assume that N is quite large, and that each processor sees the same number of iterations for each loop.) Only identify the problems – do not attempt to solve them.

IV. Fundamentals (25 points)

A new form of disk has been developed that has access time of the same order of magnitude as main memory latency, and completely independent of location (unlike regular disks that have location-dependent seek time and rotational latency). The transfer rate is faster than ordinary disk but still much slower than main memory.

- (10 points) Assuming that we use the disk as secondary storage for workloads that access disk directly (i.e., raw disk) rather than through the file system, what would you choose as the block size for this new disk, and why?
- (10 points) Why might your answer to the above part change if the disk were also used to support virtual memory swap space? **HINT: Think about the impact on structures related to virtual memory.**
- (5 points) Suppose we decided to use the new type of disk as a substitute for main memory. How would we organize the memory hierarchy to account for the slower transfer rate of the new device?

Write in Exam Book Only