

## Computer Architecture HW #3

Due: Wednesday, Sept. 22 (5 PM in ITT 305 mailbox or under my office door, ITT 313)

1. Consider the following insertion sort algorithm that sorts an array numbers:

```
InsertionSort(numbers - address to integer array, length - integer)
  integer firstUnsortedIndex, testIndex, elementToInsert;
  for firstUnsortedIndex = 1 to (length-1) do
    testIndex = firstUnsortedIndex-1;
    elementToInsert = numbers[firstUnsortedIndex];
    while (testIndex >=0) AND (numbers[testIndex] > elementToInsert ) do
      numbers[ testIndex + 1 ] = numbers[ testIndex ];
      testIndex = testIndex - 1;
    end while
    numbers[ testIndex + 1 ] = elementToInsert;
  end for
end InsertionSort
```

- Where in the code would unconditional branches be used and where would conditional branches be used?
- If the compiler could predict by opcode for the conditional branches (i.e., select whether to use machine language statements like: "BRANCH\_LE\_PREDICT\_NOT\_TAKEN" or "BRANCH\_LE\_PREDICT\_TAKEN"), then which conditional branches would be "PREDICT\_NOT\_TAKEN" and which would be "PREDICT\_TAKEN"?
- Assumptions:
  - length = 100 and the numbers are initially in **descending** order before the insertion sort algorithm is called
  - the five-stage pipeline of the text
  - the outcome of conditional branches is known at the end of the ID stage
  - target addresses of all branches is known at the end of the ID stage
  - ignore any data hazards

Under the above assumptions, answer the following questions:

- If fixed predict-never-taken is used by the hardware, then what will be the total branch penalty (# cycles wasted) for the algorithm? (Here assume NO branch target buffer)
- If a branch target buffer with one history bit per entry is used, then what will be the total branch penalty (# cycles wasted) for the algorithm? (Assume predict-not taken is used if there is no match in the branch target buffer) Explain your answer.
- If a branch target buffer with two history bit per entry is used, then what will be the total branch penalty (# cycles wasted) for the algorithm? (Assume predict-not taken is used if there is no match in the branch target buffer) Explain your answer.