LSU EE 4720 Homework 8 Solution Due: 26 April 2017

Problem 1: Answer Spring 2016 Final Exam Problem 3, which asks about the performance of various branch predictors.

The solution to this problem is available. **Make a decent attempt to solve this problem on your own, without looking at the solution.** Only peek at the solution for hints and use the solution to check your work. Credit will only be given if there is some evidence of an attempt to solve the problem.

Problem 2: Compute the amount of storage needed for each predictor described at the beginning of Spring 2016 Final Exam Problem 3 (the same question used in the problem above) accounting for the following additional details: Each BHT stores a six-bit tag and a 16-bit displacement (in addition to whatever other data is needed).

Be sure to show the size of *each* table (BHT, PHT) that each predictor (bimodal, local, global) uses. Show the size in bits.

Bimodal Predictor:

Short Answer: BHT, $2^{14}(2 + 6 + 16)$ b.

Long Answer: The BHT, as stated in the problem, has 2^{14} entries. Each entry stores a 2-bit counter, a 6-bit tag, and a 16-bit displacement. The total size of an entry is therefore 24 bits, and the total storage used for the BHT is $24\,\text{b} \times 2^{14}$. Note that bimodal predictors do not have a PHT.

Local Predictor:

Short Answer: BHT, $2^{14}(10 + 6 + 16)$ b; PHT, $2^{10}2$ b.

Long Answer: The BHT contents is the same as the BHT used by the bimodal predictor **except** that the 2-bit counter is replaced by a 10-outcome local history (which is encoded in 10 bits). The size of a BHT entry is thus $10 + 6 + 16 = 32\,\text{b} = 4\,\text{B}$ and the total storage is 4×2^{10} B. Since the local history length is 10 outcomes the PHT (pattern history table) has 2^{10} entries. Each entry is a 2-bit counter, for a total size of $2 \times 2^{10} = 2048$ b.

Global Predictor:

Short Answer. BHT, $2^{14}(6 + 16)$ b; PHT, $2^{10}2$ b.

Long Answer: The BHT contents is the same as the contents of the BHT in the bimodal predictor **except** that there is no 2-bit counter. The total size of an entry is therefore $6 + 16 = 22$ b and there are 2^{14} entries for a total size of $2^{14}(6 + 16)\,\text{b} = 360448\,\text{b} = 45056\,\text{B} = 44\,\text{kiB}$. Because the global history size, 10 outcomes, is the same as the history size in the local predictor the PHT contents the same as the PHT in the local predictor, 2×2^{10} b.

Problem 3: In a bimodal predictor the size of the tag and displacement is much larger than the 2-bit counter used to actually make the prediction. Consider a design that uses two tables, a BHT and a *Branch Target Buffer (BTB)*. The BHT stores only the 2-bit counter, the BTB stores the tag and displacement. However, the tag and displacement are only written to the BTB if the branch will be predicted taken.

Draw a sketch of such a system and indicate the number of entries that should be in each table so that the amount of storage is the same as the original bimodal predictor.

Let m denote the number of bits in the original BHT address or, put another way, let m denote ceiling log-base-2 of the BHT size. For the exam problem $m = 14$ for a BHT size of $2^m = 2^{10}$ entries.

For our new predictor let m_h denote the number of bits in the BHT address and let m_t denote the number of bits in the BTB address. If $m_h = m_t = m$ then the two predictors are equivalent. The size of the new predictor is $2^{m_h} \times 2 + 2^{m_t}(6 + 16)$ b.

Since the BTB will only be used for taken branches, we can have fewer entries. Assuming half of all branch outcomes are taken we would need half the number of BTB entries as BHT entries. With this condition we can set $m_t = m_h - 1$.

To properly size the new predictor solve

$$2^m(2+6+16) = 2^{m_h} \times 2 + 2^{m_t}(6+16)\,\mathrm{b}$$

for m_h after substituting $m_t = m_h - 1$:

$$\begin{aligned} 2^m(2+6+16) =& 2^{m_h} \times 2 + 2^{m_t}(6+16) \\ =& 2^{m_h} \times 2 + 2^{m_h-1}(6+16) \\ =& 2 \times 2^{m_h-1} \times 2 + 2^{m_h-1}(6+16) \\ =& 2^{m_h-1}(4+6+16) \end{aligned}$$

$$2^{m_h-1} = 2^m \frac{2+6+16}{4+6+16}$$

Taking the log base 2 of both sizes:

$$m_h - 1 = m + \lg \frac{2+6+16}{4+6+16}$$

$$m_h = m + \lg \frac{2+6+16}{4+6+16} + 1$$

Substituting $m = 14$ gives us $m_h = 14.88$ and $m_t = 13.88$. If m_t is rounded up to 14 and if we limit the amount of storage to no more than the original bimodal predictor then we could not set $m_h = m_t + 1$ without running out of storage. So, lets set $m_t = 13$ and choose m_h to use of the remaining storage, $m_h = 16$.

An ordinary bimodal predictor appears below on the left, the bimodal predictor with the BTB appears below to the right. Notice that the bits indexing (connecting to the address input) of the BTB and BHT are different, and are based on $m_t = 13$ and $m_h = 16$ chosen above. For the BTB bits 14:2 of the address are used, a total of 13 bits. (The two low bits are omitted because the address of an instruction must be a multiple of 4 and so those two bits will always be zero.) Also notice that when the branch is resolved the new 2-bit counter value is checked to see whether the branch is taken. The BTB is only written if the branch is taken.