CS224 - Spring 2024- Lab #6 (V1: April 18, 9:28)

Examining the Effects of Cache Parameters and Program Factors on Cache Hit Rate

Dates (TAs – Tutor(s))
Section 1: In two stages: April 29 - May 3 (Mustafa, Yiğit)
Section 2: In two stages: April 29 - May 3 (Mustafa, Yiğit)
Section 3: In two stages: April 29 - May 3 (Kadri, Pouya) (Mehmet Can, 13:30 - 15:15)
Section 4: In two stages: April 29 - May 3 (Onur, Soheil) (Ece)
Section 5: In two stages: April 29 - May 3 (Kadri, Soheil)
Section 6: In two stages: April 29 - May 3 (Onur, Sepehr)

In this lab there will be no lab attendance. There are two stages and their timings are the same for all sections. Preliminary Work must be completed by April 29 Monday 5: 00 pm.
Lab Work must be completed by May 3 Friday 5:00.
Read the following sections for complete information.

TA Full Name (email address: @bilkent.edu.tr)
M. Kadri Gofralılar (kadri.gofralilar)
Mustafa Yasir Altunhan (yasir.altunhan)
Onur Yıldırım (o.yildirim)
Pouya Ghahramanian (ghahramanian)
Sepehr Bakhshi (sepehr.bakhshi)
Soheil Abadifard (soheil.abadifard)
Yiğit Ekin (yigit.ekin)

Tutor Full Name (email address: @ug.bilkent.edu.tr)
Ece Beyhan (ece.beyhan)
Mehmet Can Bıyık (can.biyik)

Purpose: In this lab you will study the effect of various cache design parameters. The first part includes problem solving and writing a program. The second part, the lab part, involves execution of the program with possible extensions etc. if suggested by your TA and preparing a report.

In your solutions and report make sure that you have proper tables, numbering etc. All tables must have subtitle and table number furthermore columns must have column names, etc. In your report make sure that you have a nice presentation. Make sure that you number the pages. Try to do everything before coming to the lab but make sure that you demonstrate your work to your TA.

Summary
Preliminary Work: 50 points
Problem solving and writing a matrix addition program with a simple user interface.

Lab Work: 50 points

Experimental observations using a program that finds the summation of the elements of a matrix with different cache conditions.

Important Notes for All Labs About Attendance, Performing and Presenting the Work

1. You are obliged to read this document word by word and are responsible for the mistakes you make by not following the rules.
2. In all labs if you are not told you may assume that inputs are correct.
3. In all labs when needed you have to provide a simple user interface for inputs and outputs.
4. Presentation of your work
   You have to provide a neat presentation prepared proper forms as defined below. Your programs must be easy to understand and well structured.
   Provide following six lines at the top of your submission for preliminary and lab work (make sure that you include the course no. CS224, important for ABET documentation).

   CS224
   Lab No.
   Section No.
   Your Full Name
   Bilkent ID
   Date

   Please also make sure that your work is identifiable: In terms of which program corresponds to which part of the lab.
5. **If we suspect that there is cheating we will send the work with the names of the students to the university disciplinary committee. You can experiment with ChatGPT for learning; however, you cannot use/modify the code generated by it. Such an act is classified as plagiarism. Note that MOSS is capable of detecting ChatGPT code. Furthermore remember that, the code you use from ChatGPT can also be used by another student in the course. Make sure that the code you submit is really yours and has been internalized.**

DUE DATE OF PRELIMINARY WORK: SAME FOR ALL SECTIONS

No late submission will be accepted.

a. Please upload your problem solutions and programs of preliminary work to Moodle by 17:00 (5:00 pm) on Monday April 29 for similarity testing by MOSS. We plan to use MOSS both for problems solutions and program.

For you preliminary work to be graded you have to submit the Lab Work part.

b. **Problems**: Use the filename **StudentID_FirstName_LastName_S ecNo_PRELIMproblem_LabNo.pdf** [A pdf file as its extension suggests, which contains your solutions to the Preliminary Part]. Only a pdf file is accepted. Any other form of submission receives 0 (zero).

Code: For the program part use the filename **StudentID_FirstName_LastName_SecNo_PRELIMcode_LabNo.txt** [A NOTEPAD FILE as its extension suggests, which contains only the program part Only a NOTEPAD FILE (txt file) is accepted. Any other form of submission receives 0 (zero).

c. Note that the Moodle submission closes sharp at 17:00(5:00 pm) and no late submissions will be accepted. You can make resubmissions before the system closes, so do not wait for the last moment. Submit your work earlier and change your submitted work if necessary. Note that only the last submission will be graded.

d. Do not send your work by email attachment, they will not be processed. They have to be in the Moodle system to be processed.

DUE DATE OF LAB WORK): THE SAME FOR ALL SECTIONS

a. You have to upload your lab work to Moodle by 17:00 (5:00 pm) on Friday May 3.

Part 1. Preliminary Work (50 points)

You have to provide a neat presentation prepared by Word or a word processor with similar output quality. Handwritten answers will not be accepted.

1. (5 points: With 2 or more errors you get 0 points. Otherwise full point.) Fill in the empty cells of the following table. Assume that main memory size is 4GB. **Index Size**: No. of bits needed to express the set number in an address, **Block Offset**: No. of bits needed to indicate the word offset in a block, **Byte Offset**: No. of bits needed to indicate the byte offset in a word. **Block Replacement Policy Needed**: Indicate if a block replacement policy such as FIFO, LRU etc. is needed (yes) or not (no). If some combinations are not possible mark them.

No.	Cache Size KB	N way cache	Word Size in bits	Block size (no. of words)	No. of Sets	Tag Size in bits	Index Size (Set No.) in bits	Word Block Offset Size in bits[1]	Byte Offset Size in bits[2]	Block Replacement Policy Needed (Yes/No)
1	128	1	32	4						
2	128	4	32	16						
3	128	Full	32	16						
4	256	2	64	8						
5	256	4	64	32						
6	256	Full	16	16						

[1] **Word Block Offset Size in bits:** Log_2(No. of words in a block)
[2] **Byte Offset Size in bits:** Log_2(No. of bytes in a word)

2. **(5 points: With 2 or more incorrect answers you get 0 points. Otherwise full point.)** Consider the following memory configuration: Assume that main memory size is 4GB. N= 1 (direct mapped), Block size= 8 bytes, No. of sets= 4.

Consider the following consecutive memory accesses and indicate which set is selected and indicate if it is a hit or miss.

Memory Address Accessed (hex)	Set No.	Hit (yes/no)
00 00 20 24		
00 00 20 42		
00 00 20 68		
00 00 20 04		
00 00 20 0C		
00 00 20 4C		

3. **(5 points: With 2 or more incorrect answers you get 0 points. Otherwise full point.)** Consider the following memory configuration: The same as Section 2 above only difference is N= 2. Block replacement policy is FIFO.
Consider the following memory accesses and indicate which set is selected and indicate if it is a hit or miss. **(With 2 or more errors you get 0 points. Otherwise full point.)**

Memory Address Accessed (hex)	Set No.	Hit (yes/no)
00 00 00 2C		
00 00 00 48		
00 00 00 44		
00 00 00 0C		
00 00 00 04		
00 00 00 0C		

4. **(5 points, With 1 or more incorrect answers you get 0 points. Otherwise full point.)**
Physical memory size is 4 GB.
Word size is 2 bytes.
Block size is 32 words.
Cache memory data area size= 1KB.
N= 8. Assume that LRU is used for block replacement.
D (dirty bit) is used to keep track of the changes in the cache blocks.

a. Show the structure of the physical address structure when it is used to access the cache memory: show its sub fields, their names, their sizes in number of bits.
b. What is the size of a block in terms of number of bits (it includes both data area and the overheads like tag etc.)? Include D bit in your calculations. Show the components of your calculation (its name like tag and its size in bits).
c. What is the size of a set in bits? What is the total SRAM size in bits?
d. If you use random replacement for blocks of a set what will be its effect on the SRAM size. Is it going to make it smaller, how many bits? If it makes it larger, how many bits? Explain briefly

5. **(30 points)** Write a program to find the summation of the elements of a square matrix. Provide a user interface for user interaction to demonstrate that your program is working properly. Assume that in the main memory matrix elements are placed column by column. Create an array for the matrix elements and initialize them row by row with consecutive values. For example a 3 by 3 (N= 3) matrix would have the following values. Note that matrix elements are full words (4 bytes).

1	2	3
4	5	6
7	8	9

The column by column placement means that you will have the values of the above 3 x 3 matrix are stored as follows in the memory.

Matrix Index (Row No., Col. No.)	(1, 1)	(2, 1)	(3, 1)	(1, 2)	(2, 2)	(3, 2)	(1, 3)	(2, 3)	(3, 3)
Displacement With respect the beginning of the array containing the matrix	0	4	8	12	16	20	24	28	32
Value stored	1	2	3	4	5	6	7	8	9

In this configuration accessing the matrix element (i, j) simply involves computation of its displacement from the beginning of the array that stores the matrix elements. For example, the displacement of the matrix element with the index (i, j) with respect to the beginning of the array is (j - 1) x N x 4 + (i - 1) x 4, for a matrix of size N x N.

Your user interface/program must provide at least the following functionalities,

1. Ask the user the matrix size in terms of its dimensions (N),
2. Allocate an array with proper size using syscall code 9,
3. Display desired elements of the matrix by specifying its row and column member,
4. Obtain summation of matrix elements column-major (column by column) summation,
5. Obtain summation of matrix elements row-major (row by row) summation,

When appropriate; such as items no. 3, 4, 5 above; use a subprogram and make sure that you follow the MIPS assembly language programming conventions (use of $a, $s registers etc.).

2. [50 pts] Part 2 Lab Work / Experiments with Data Cache Parameters

Run your program with two reasonably large different matrix sizes that would provide meaningful observations.

Report for Matrix Size 1: 25 Points

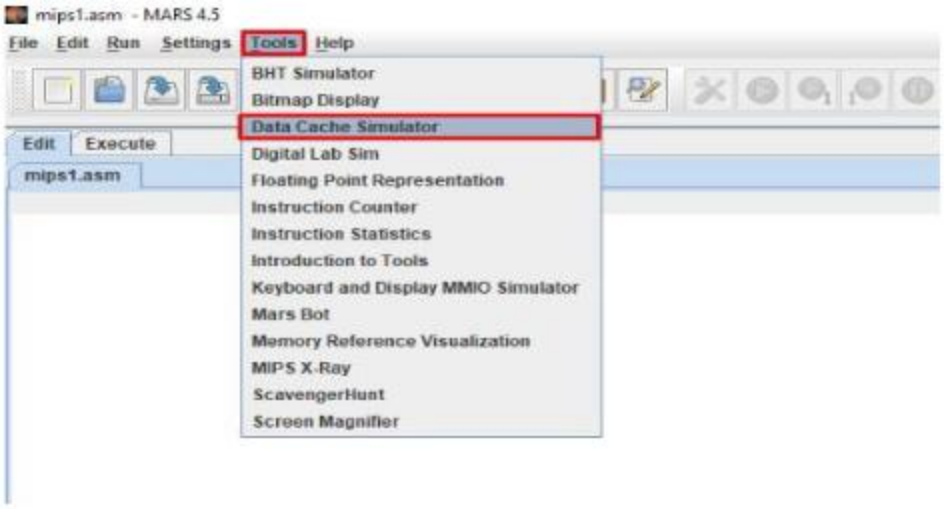
Report for Matrix Size 2: 25 Points

As described above make sure that you have a easy to follow presentation with numbered tables having proper heading etc.

Make sure that you find the summation of matrix elements by performing row-major and column-major addition. Note that the row-major addition is a simple array addition from the beginning to the end; however, the column-major addition is somewhat tricky.

a) **Direct Mapped Caches**: For the matrix sizes you have chosen, conduct tests with various cache sizes and block sizes, to determine the hit rate, miss rate and number of misses. Use at least 5 different cache sizes and 5 different block sizes (make sure your values are reasonable) in order to obtain curves like those of Figure 8.18 in the textbook (see below). Make a 5 x 5 table with your values, with miss rate and # of misses as the data at each row-column location. Make a graph of miss rate versus block size, parameterized by cache size, like Figure 8.18.

Hint: You can reach the Cache Simulator from MARS/Tools/Data Cache Simulator as shown in the following image: (In the Simulator interface make sure that you Enable it and Connect it to MARS).



b) **Fully Associative Caches**: Pick 3 of your parameter points obtained in part for column-major addition a), one with good hit rate, one with medium hit rate, and one with poor hit rate. For these 3 results, there were 3 configuration pairs of cache size and block size that resulted in the data. Take the same 3 configuration pairs, but this time run the simulation with a fully associate cache, using LRU replacement policy. Compare the results obtained: the Direct Mapped good result versus the Fully Associative good result, the Direct Mapped medium result versus the Fully Associative medium result, and the Direct Mapped poor result versus the Fully Associative poor result. How much difference did the change to fully associative architecture make? Now change the replacement policy to Random replacement, and run the 3 tests again (using the same 3 configuration pairs). Does replacement policy make a significant difference? Record these 9 values in a new table, with 3 lines: for Direct Mapped, for Fully Associative-LRU and for Fully Associative-Random.

c) **N-way Set Associative Caches**: to save on hardware costs, fully set-associative caches are rarely used. Instead, most of the benefit can be obtained with an N-way set associative cache. Pick the medium hit rate configuration that you found in a) and used again in b), and change the architecture to N-way set associative. For several different set sizes (at least 4) and LRU replacement policy, run the program and record the hit rate, miss rate and number of misses. What set size gives the best result? How much improvement is gained as N (the number of blocks in a set) increases each step? Now repeat the tests, but for the good hit rate configuration from a) and b). Record these data and answer the same question again. Finally, repeat for the poor hit rate configuration.

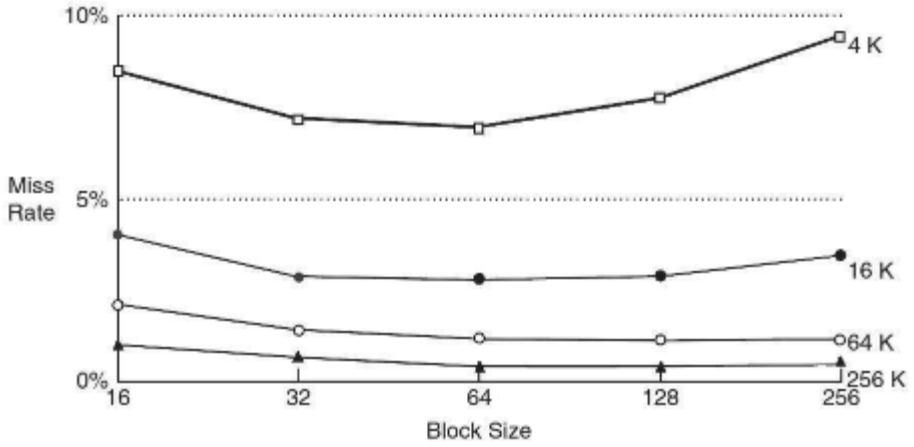


Figure 8.18 **Miss rate versus block size and cache size on SPEC92 benchmark**
Adapted with permission from Hennessy and Patterson, *Computer Architecture: A Quantitative Approach*, 5th ed., Morgan Kaufmann, 2012.

Part 3. Submit Lab Work for MOSS Similarity Testing

1. Submit your Lab Work MIPS codes for similarity testing to Moodle. See instructions below.
2. **Report**: Put your experiment results for Part 2 (including the tables and graphs) in a single PDF file. Use filename **StudentID_FirstName_LastName_SecNo_Lab6_lab_report.pdf** [pdf FILE as its extension suggests, which contains all the work done for the Lab Experiment Report Part].

   Code: Put your MIPS code for Part 1.5 into a .txt file. Use filename . Note that as you do the experiments your program may or may not involve changes. Whichever the case upload. **StudentID_FirstName_LastName_SecNo_Lab6_lab_code.txt** [A NOTEPAD FILE as its extension suggests, which contains the Program Code Part]
   Your program (code) will be compared against all the other programs in the class, by the MOSS program, to determine how similar it is (as an indication of plagiarism). So be sure that the code you submit is code that you actually wrote yourself! The same type of comparison is also planned for the reports.
3. *Even if you didn't finish, or didn't get the MIPS codes working, you must submit your code to the Moodle Assignment for similarity checking.*
4. Your codes will be compared against all the other codes in the class, by the MOSS program, to determine how similar it is (as an indication of plagiarism). So be sure that the code you submit is code that you actually wrote yourself!
5. At the beginning of your submission files include the following make sure that each of them is in a separate line: CS224, Lab No., Section No., Your Full Name, Bilkent ID.
6. For your preliminary and lab works to be graded you must attend the lab.