Programming Assignment 4
Cache Simulation

Objective:

To write a C program that simulates reading and writing to a custom-sized **direct-mapped cache**, involving a custom-sized main memory.

The program will read all values from the ZyLab as Test Bench inputs.

Main Menu Options:

The program simulates reading from and writing to a cache based on choosing from a menu of choices, where each choice calls the appropriate procedure, where the choices are:

1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program

Note that when you read from ZyLab, the input values are not displayed on the screen as they are in the sample run at the end of this document.

Inputs:

- Enter Parameters
  - The total size of accessible main memory (in words)
  - The total size of the cache (in words)
  - The block size (words/block)
- Read from Cache
  - The main memory address to read
- Write to Cache
  - The main memory address to write
  - The contents of the address for writing to the cache

Input Value Checks:

- All the parameter values must be powers of 2.
- The block size must never be larger than the size of accessible main memory.
- The total cache size must be some multiple of the block size.
- Your program should verify that all input variables are within limits as they are entered.

Output Messages:

All messages should be display ***EXACTLY*** as shown in the sample run; that is, prefixed by three asterisks, a space and hyphen and one more space. The message should be followed by a blank line.

- **Data Accepted Message** is comprised of two sentences:

  *** All Input Parameters Accepted.
  Starting to Process Write/Read Requests

- **Error Messages are preceded by "*** Error –". A list of possible errors is given below. Note that one earlier error message has been deleted from this Specification and three new ones have been added.**

  *** Error - Main Memory Size is not a Power of 2

  *** Error - Block Size is not a Power of 2

  *** Error - Cache Size is not a Power of 2

  *** Error – Block size is larger than cache size

- **Deleted Error Message**

  *** Error – Cache Size is not a multiple of Block Size

- **Newly Added Error Messages**

  *** Error – Read Address Exceeds Memory Address Space

  *** Error – Write Address Exceeds Memory Address Space

  The write value following the invalid address value should be read and then discarded.

  *** Error – Invalid Menu Option Selected

  Until valid configuration data has been accepted, the only menu options that can be selected are "1" or "4." Options "2" and "3" should be flagged as errors and ignored.

Whenever any one of these errors occurs, the program should loop back to the Main Menu.

- **Content Message resulting from reading/writing to the cache**

  *** Word WW of Cache Line LL with Tag TT contains Value VV

  This message should appear after all successful reads or writes

  WW is the word number in the cache line, LL is the line number in the cache, TT is the line's tag value and VV is the content value in the cache.

  All values are in decimal.

- **Read Messages (two possible messages)**

  *** Read Miss - First Load Block from Memory (followed on the next line by the Content Message above)

  *** Cache Hit (followed on the next line by the Content Message above)

- **Write Messages**

  *** Write Miss - First Load Block from Memory (followed on the next line by the Content Message above)

  *** Cache Hit (followed on the next line by the Content Message above)

- **Quit Program Message**

  *** Memory Freed Up – Program Terminated Normally

  When option 4 is entered, the memory should be freed up and the message "Memory Freed Up – Program Terminated Normally", followed by a blank line, should be displayed before exiting the program.

Program Requirements:

- Use a **structure** (struct) to represent a cache line consisting of a tag (integer) and a block (integer pointer). Define the cache to be a **pointer** to the struct.
- Upon entering the parameters, the main memory and cache are to be **dynamically allocated** (use ***malloc***) based on their respective total sizes.

  Each word *i* of main memory is initialized with the value *M*–*i*, where *M* is the size of main memory in words. So, memory location 0 will contain the address of the last memory location and the last memory location will contain the address of the first memory location (i.e. 0).

- Reading/writing from/to a new block in the cache results in dynamically allocating a block for that instance, based on the previously entered block size.

Prologue & Comments:

At the very beginning of your source code (the very first lines), please include a prologue which looks like the following:

```
/*

Dr. George Lazik            (use your full name not mine)
Programming Assignment 4: Cache Simulation
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Meeting Time: 0800-0915     (your meeting time)

*/
```

- Include simple (**brief**) comments strategically throughout your program so that someone else can readily follow what you are doing, but don't overdo it. Examples might look like these:

```
// Reading input values from ZyLab

// Determining the contents of memory
```

ZyLab Test Benches:

- **<u>You will be permitted unlimited submission attempts on ZyLab until the due date. Afterwards, the inputs will be changed, the point value of the assignment will be increased to 100 and only one submission will be permitted. This last submission will be on the day following the due date and should be the one with the highest score.</u>**

- **<u>Hardcopy printed listing of your program.</u>** Please place this on the Professor's desk at the beginning of class on day the assignment is due. It should be properly C formatted listing and not one from programs such as Word.

  Make sure your full name appears on each page of the listing and that all pages are stapled together in their correct order **BEFORE** you come to class.

  Failure to provide this listing will result in no grade for the assignment.

Sample Test Run

The following is a sample run of one of the tests in Assignment 4's Test Bench on ZyBooks.

```
3
1
32768
1027
16
1
32768
1024
4096
1
32768
1024
16
3
72764
32
3
32764
32
2
72764
2
32764
3
32764
512
2
32764
2
0
4
```

Your output

```
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Main Menu - Main Memory to Cache Memory Mapping
```

```
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

*** Error - Invalid Menu Option Selected


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** Error - Cache Size is not a Power of 2


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):
```

```
Enter cache size (words):

Enter block size (words/block):

*** Error - Block Size is Larger than Cache Size


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** All Input Parameters Accepted.  Starting to Process
Write/Read Requests


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter Main Memory Address to Write:

*** Error – Write Address Exceeds Memory Address Space
```

```
Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter Main Memory Address to Write:

Enter Value to Write:

*** Write Miss - First load block from memory

*** Word 12 of Cache Line 63 with Tag 31 contains the
Value 32


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter Main Memory Address to Read:

*** Error – Read Address Exceeds Memory Address Space


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program
```

```
Enter selection:

Enter Main Memory Address to Read:

*** Cache Hit

*** Word 12 of Cache Line 63 with Tag 31 contains the
Value 32


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter Main Memory Address to Write:

Enter Value to Write:

*** Cache Hit

*** Word 12 of Cache Line 63 with Tag 31 contains the
Value 512


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:
```

```
Enter Main Memory Address to Read:

*** Cache Hit

*** Word 12 of Cache Line 63 with Tag 31 contains the
Value 512


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter Main Memory Address to Read:

Read Miss - First Load Block from Memory!

*** Word 0 of Cache Line 0 with Tag 0 contains the Value
32768


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

*** Memory Freed Up - Program Terminated Normally

1
65536
512
1024
```

```
4
```

Your output

```
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Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** Error - Block Size is Larger than Cache Size


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

*** Memory Freed Up - Program Terminated Normally

1
65536
1027
16
4
```

```
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Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** Error - Cache Size is not a Power of 2


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

*** Memory Freed Up - Program Terminated Normally
```

```
1
65536
1024
24
4
```

```
Programming Assignment 4: Cache Simulation
```

```
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Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** Error - Block Size is not a Power of 2


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

*** Memory Freed Up - Program Terminated Normally
```

```
1
65537
1024
4096
4
```

```
Programming Assignment 4: Cache Simulation
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```

```
Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** Error - Main Memory Size is not a Power of 2


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

*** Memory Freed Up - Program Terminated Normally
```

```
3
1
65536
1024
768
4
```

```
Programming Assignment 4: Cache Simulation
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Main Menu - Main Memory to Cache Memory Mapping
```

```
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

*** Error - Invalid Menu Option Selected


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** Error - Block Size is not a Power of 2


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

*** Memory Freed Up - Program Terminated Normally
```

```
1
65536
512
1024
1
65536
1027
16
1
65536
1024
15
1
65537
1026
4096
1
65536
1024
18
1
65536
1024
16
3
65535
14
2
65535
3
65534
512
2
71023
2
1023
4
```

```
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```

```
Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** Error - Block Size is Larger than Cache Size


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** Error - Cache Size is not a Power of 2


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
```

```
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** Error - Block Size is not a Power of 2


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** Error - Main Memory Size is not a Power of 2


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program
```

```
Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** Error - Block Size is not a Power of 2


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter main memory size (words):

Enter cache size (words):

Enter block size (words/block):

*** All Input Parameters Accepted.  Starting to Process
Write/Read Requests


Main Menu - Main Memory to Cache Memory Mapping
------------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter Main Memory Address to Write:
```

```
Enter Value to Write:

*** Write Miss - First load block from memory

*** Word 15 of Cache Line 63 with Tag 63 contains the
Value 14


Main Menu - Main Memory to Cache Memory Mapping
-----------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter Main Memory Address to Read:

*** Cache Hit

*** Word 15 of Cache Line 63 with Tag 63 contains the
Value 14


Main Menu - Main Memory to Cache Memory Mapping
-----------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter Main Memory Address to Write:

Enter Value to Write:

*** Cache Hit
```

```
*** Word 14 of Cache Line 63 with Tag 63 contains the
Value 512


Main Menu - Main Memory to Cache Memory Mapping
-----------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter Main Memory Address to Read:

*** Error – Read Address Exceeds Memory Address Space


Main Menu - Main Memory to Cache Memory Mapping
-----------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
3) Write to Cache
4) Quit Program


Enter selection:

Enter Main Memory Address to Read:

Read Miss - First Load Block from Memory!

*** Word 15 of Cache Line 63 with Tag 0 contains the
Value 64513


Main Menu - Main Memory to Cache Memory Mapping
-----------------------------------------------
1) Enter Configuration Parameters
2) Read from Cache
```

```
3) Write to Cache
4) Quit Program


Enter selection:

*** Memory Freed Up - Program Terminated Normally
```