LRU Cache Implementation

Difficulty Level : Hard

How to implement LRU caching scheme? What data structures should be used?
We are given total possible page numbers that can be referred. We are also given cache (or memory) size (Number of page frames that cache can hold at a time). The LRU caching scheme is to remove the least recently used frame when the cache is full and a new page is referenced which is not there in cache. Please see the Galvin book for more details (see the LRU page replacement slide here).

Recommended: Please solve it on "***PRACTICE***" first, before moving on to the solution.

We use two data structures to implement an LRU Cache.

1. **Queue** which is implemented using a doubly linked list. The maximum size of the queue will be equal to the total number of frames available (cache size). The most recently used pages will be near front end and least recently pages will be near the rear end.
2. **A Hash** with page number as key and address of the corresponding queue node as value.

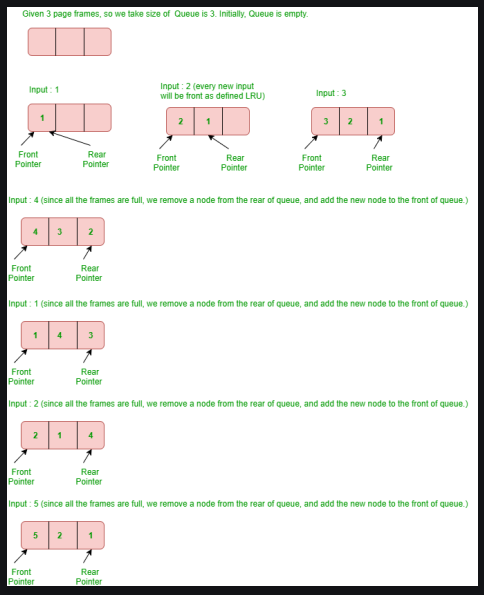
When a page is referenced, the required page may be in the memory. If it is in the memory, we need to detach the node of the list and bring it to the front of the queue.
If the required page is not in memory, we bring that in memory. In simple words, we add a new node to the front of the queue and update the corresponding node address in the hash. If the queue is full, i.e. all the frames are full, we remove a node from the rear of the queue, and add the new node to the front of the queue.

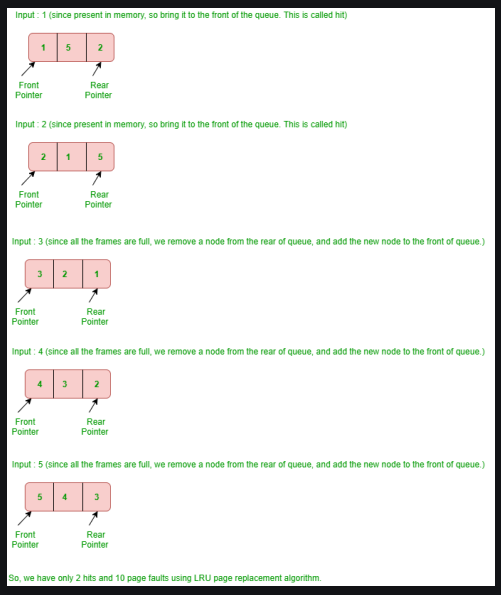
Example – Consider the following reference string :

```
, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5
```

Find the number of page faults using least recently used (LRU) page replacement algorithm with 3 page frames.

Explanation –





Note: Initially no page is in the memory.

C++ using STL

```
// We can use stl container list as a double
// ended queue to store the cache keys, with
// the descending time of reference from front
// to back and a set container to check presence
```

```
// of a key. But to fetch the address of the key
// in the list using find(), it takes O(N) time.
// This can be optimized by storing a reference
//     (iterator) to each key in a hash map.
#include <bits/stdc++.h>
using namespace std;

class LRUCache {
    // store keys of cache
    list<int> dq;

    // store references of key in cache
    unordered_map<int, list<int>::iterator> ma;
    int csize; // maximum capacity of cache

public:
    LRUCache(int);
    void refer(int);
    void display();
};

// Declare the size
LRUCache::LRUCache(int n)
{
    csize = n;
}

// Refers key x with in the LRU cache
void LRUCache::refer(int x)
{
    // not present in cache
    if (ma.find(x) == ma.end()) {
        // cache is full
        if (dq.size() == csize) {
            // delete least recently used element
            int last = dq.back();

            // Pops the last element
            dq.pop_back();

            // Erase the last
            ma.erase(last);
        }
    }

    // present in cache
    else
        dq.erase(ma[x]);

    // update reference
    dq.push_front(x);
    ma[x] = dq.begin();


// Function to display contents of cache
void LRUCache::display()
{
```

```
    // Iterate in the deque and print
    // all the elements in it
    for (auto it = dq.begin(); it != dq.end();
         it++)
        cout << (*it) << " ";

    cout << endl;
}

// Driver Code
int main()
{
    LRUCache ca(4);

    ca.refer(1);
    ca.refer(2);
    ca.refer(3);
    ca.refer(1);
    ca.refer(4);
    ca.refer(5);
    ca.display();

    return 0;
}
// This code is contributed by Satish Srinivas
```

C

```
// A C program to show implementation of LRU cache
#include <stdio.h>
#include <stdlib.h>

// A Queue Node (Queue is implemented using Doubly Linked List)
typedef struct QNode {
    struct QNode *prev, *next;
    unsigned pageNumber; // the page number stored in this QNode
} QNode;

// A Queue (A FIFO collection of Queue Nodes)
typedef struct Queue {
    unsigned count; // Number of filled frames
    unsigned numberOfFrames; // total number of frames
    QNode *front, *rear;
} Queue;

// A hash (Collection of pointers to Queue Nodes)
typedef struct Hash {
    int capacity; // how many pages can be there
    QNode** array; // an array of queue nodes
} Hash;

// A utility function to create a new Queue Node. The queue Node
// will store the given 'pageNumber'
```

```
QNode* newQNode(unsigned pageNumber)
{
    // Allocate memory and assign 'pageNumber'
    QNode* temp = (QNode*)malloc(sizeof(QNode));
    temp->pageNumber = pageNumber;

    // Initialize prev and next as NULL
    temp->prev = temp->next = NULL;

    return temp;
}

// A utility function to create an empty Queue.
// The queue can have at most 'numberOfFrames' nodes
Queue* createQueue(int numberOfFrames)
{
    Queue* queue = (Queue*)malloc(sizeof(Queue));

    // The queue is empty
    queue->count = 0;
    queue->front = queue->rear = NULL;

    // Number of frames that can be stored in memory
    queue->numberOfFrames = numberOfFrames;

    return queue;
}

// A utility function to create an empty Hash of given capacity
Hash* createHash(int capacity)
{
    // Allocate memory for hash
    Hash* hash = (Hash*)malloc(sizeof(Hash));
    hash->capacity = capacity;

    // Create an array of pointers for referring queue nodes
    hash->array = (QNode**)malloc(hash->capacity * sizeof(QNode*));

    // Initialize all hash entries as empty
    int i;
    for (i = 0; i < hash->capacity; ++i)
        hash->array[i] = NULL;

    return hash;
}

// A function to check if there is slot available in memory
int AreAllFramesFull(Queue* queue)
{
    return queue->count == queue->numberOfFrames;
}

// A utility function to check if queue is empty
int isQueueEmpty(Queue* queue)
{
    return queue->rear == NULL;
}
```

```
// A utility function to delete a frame from queue
void deQueue(Queue* queue)
{
    if (isQueueEmpty(queue))
        return;

    // If this is the only node in list, then change front
    if (queue->front == queue->rear)
        queue->front = NULL;

    // Change rear and remove the previous rear
    QNode* temp = queue->rear;
    queue->rear = queue->rear->prev;

    if (queue->rear)
        queue->rear->next = NULL;

    free(temp);

    // decrement the number of full frames by 1
    queue->count--;
}

// A function to add a page with given 'pageNumber' to both queue
// and hash
void Enqueue(Queue* queue, Hash* hash, unsigned pageNumber)
{
    // If all frames are full, remove the page at the rear
    if (AreAllFramesFull(queue)) {
        // remove page from hash
        hash->array[queue->rear->pageNumber] = NULL;
        deQueue(queue);
    }

    // Create a new node with given page number,
    // And add the new node to the front of queue
    QNode* temp = newQNode(pageNumber);
    temp->next = queue->front;

    // If queue is empty, change both front and rear pointers
    if (isQueueEmpty(queue))
        queue->rear = queue->front = temp;
    else // Else change the front
    {
        queue->front->prev = temp;
        queue->front = temp;
    }

    // Add page entry to hash also
    hash->array[pageNumber] = temp;

    // increment number of full frames
    queue->count++;
}

// This function is called when a page with given 'pageNumber' is referenced
```

```
// from cache (or memory). There are two cases:
// 1. Frame is not there in memory, we bring it in memory and add to the fron
// of queue
// 2. Frame is there in memory, we move the frame to front of queue
void ReferencePage(Queue* queue, Hash* hash, unsigned pageNumber)
{
    QNode* reqPage = hash->array[pageNumber];

    // the page is not in cache, bring it
    if (reqPage == NULL)
        Enqueue(queue, hash, pageNumber);

    // page is there and not at front, change pointer
    else if (reqPage != queue->front) {
        // Unlink rquested page from its current location
        // in queue.
        reqPage->prev->next = reqPage->next;
        if (reqPage->next)
            reqPage->next->prev = reqPage->prev;

        // If the requested page is rear, then change rear
        // as this node will be moved to front
        if (reqPage == queue->rear) {
            queue->rear = reqPage->prev;
            queue->rear->next = NULL;
        }

        // Put the requested page before current front
        reqPage->next = queue->front;
        reqPage->prev = NULL;

        // Change prev of current front
        reqPage->next->prev = reqPage;

        // Change front to the requested page
        queue->front = reqPage;
    }
}

// Driver program to test above functions
int main()
{
    // Let cache can hold 4 pages
    Queue* q = createQueue(4);

    // Let 10 different pages can be requested (pages to be
    // referenced are numbered from 0 to 9
    Hash* hash = createHash(10);

    // Let us refer pages 1, 2, 3, 1, 4, 5
    ReferencePage(q, hash, 1);
    ReferencePage(q, hash, 2);
    ReferencePage(q, hash, 3);
    ReferencePage(q, hash, 1);
    ReferencePage(q, hash, 4);
    ReferencePage(q, hash, 5);
```

```
    // Let us print cache frames after the above referenced pages
    printf("%d ", q->front->pageNumber);
    printf("%d ", q->front->next->pageNumber);
    printf("%d ", q->front->next->next->pageNumber);
    printf("%d ", q->front->next->next->next->pageNumber);

    return 0;
}
```

Java

```
/* We can use Java inbuilt Deque as a double
   ended queue to store the cache keys, with
   the descending time of reference from front
   to back and a set container to check presence
   of a key. But remove a key from the Deque using
   remove(), it takes O(N) time. This can be
   optimized by storing a reference (iterator) to
   each key in a hash map. */
import java.util.Deque;
import java.util.HashSet;
import java.util.LinkedList;
import java.util.Iterator;

public class LRUCache {

    // store keys of cache
    private Deque<Integer> doublyQueue;

    // store references of key in cache
    private HashSet<Integer> hashSet;

    // maximum capacity of cache
    private final int CACHE_SIZE;

    LRUCache(int capacity) {
        doublyQueue = new LinkedList<>();
        hashSet = new HashSet<>();
        CACHE_SIZE = capacity;
    }

    /* Refer the page within the LRU cache */
    public void refer(int page) {
        if (!hashSet.contains(page)) {
            if (doublyQueue.size() == CACHE_SIZE) {
                int last = doublyQueue.removeLast();
                hashSet.remove(last);
            }
        }
        else {/* The found page may not be always the last element, even if
                intermediate element that needs to be removed and added to the
                of the Queue */
            doublyQueue.remove(page);
        }
```

```
        doublyQueue.push(page);
        hashSet.add(page);
    }

    // display contents of cache
    public void display() {
        Iterator<Integer> itr = doublyQueue.iterator();
        while (itr.hasNext()) {
            System.out.print(itr.next() + " ");
        }
    }

    public static void main(String[] args) {
        LRUCache cache = new LRUCache(4);
        cache.refer(1);
        cache.refer(2);
        cache.refer(3);
        cache.refer(1);
        cache.refer(4);
        cache.refer(5);
        cache.refer(2);
        cache.refer(2);
        cache.refer(1);
        cache.display();
    }
}
// This code is contributed by Niraj Kumar
```

Output

```
5 4 1 3
```

Java Implementation using LinkedHashMap.

The idea is to use a LinkedHashSet that maintains insertion order of elements. This way implementation becomes short and easy.

Java

```
// Java program to implement LRU cache
// using LinkedHashSet
import java.util.*;

class LRUCache {

    Set<Integer> cache;
    int capacity;

    public LRUCache(int capacity)
    {
        this.cache = new LinkedHashSet<Integer>(capacity);
        this.capacity = capacity;
```

```
    }

    // This function returns false if key is not
    // present in cache. Else it moves the key to
    // front by first removing it and then adding
    // it, and returns true.
    public boolean get(int key)
    {
        if (!cache.contains(key))
            return false;
        cache.remove(key);
        cache.add(key);
        return true;
    }

    /* Refers key x with in the LRU cache */
    public void refer(int key)
    {
        if (get(key) == false)
           put(key);
    }

    // displays contents of cache in Reverse Order
    public void display()
    {
      LinkedList<Integer> list = new LinkedList<>(cache);

      // The descendingIterator() method of java.util.LinkedList
      // class is used to return an iterator over the elements
      // in this LinkedList in reverse sequential order
      Iterator<Integer> itr = list.descendingIterator();

      while (itr.hasNext())
            System.out.print(itr.next() + " ");
    }

    public void put(int key)
    {

      if (cache.size() == capacity) {
            int firstKey = cache.iterator().next();
            cache.remove(firstKey);
        }

        cache.add(key);
    }

    public static void main(String[] args)
    {
        LRUCache ca = new LRUCache(4);
        ca.refer(1);
        ca.refer(2);
        ca.refer(3);
        ca.refer(1);
        ca.refer(4);
        ca.refer(5);
        ca.display();
```

```
    }
}
```

Output

```
5 4 1 3
```

Python implementation using OrderedDict

This article is compiled by Aashish Barnwal and reviewed by GeeksforGeeks team. Please write comments if you find anything incorrect, or you want to share more information about the topic discussed above.

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