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Institute: Illinois Institute of Technology

CS 525: Advanced Database Organization

Spring 2025 - Assignment 2 - Buffer Manager

1. INTRODUCTION

This assignment aims to develop a Buffer Manager that controls a designated number of memory pages. These pages correspond to a page file overseen by a storage manager (introduced in Assignment 1). The buffer manager optimizes page access and replacement using specific strategies.

2. BUFFER MANAGER OVERVIEW

The buffer manager provides access to pages within a buffer pool and communicates with the page file controlled by the storage manager. It ensures that requested pages are readily available in memory, manages page replacements, and preserves consistency by monitoring pinned and modified pages.

3. FUNCTIONALITIES AND CONCEPTS

3.1 Buffer Pool Management

The buffer pool consists of fixed-size page frames that store disk pages. Clients can pin and unpin pages as needed. When a page is pinned, it is either retrieved from memory if already present or loaded from disk. Conversely, when a page is unpinned and its fix count reaches zero, it becomes eligible for eviction.

3.2 Page Replacement Strategies

The buffer manager supports two-page replacement strategies

- FIFO (First-In-First-Out)
- LRU (Least Recently Used)

Additional strategies used

- CLOCK
- LFU (Least Frequently Used)
- LRU-k

4. INTERFACE AND IMPLEMENTATION

The interface for the buffer manager is defined in **buffer_mgr.h**. The key data structures and functions are as follows:

4.1 Data Structures

- **BM_BufferPool:** Represents a buffer pool with attributes:
  - ✓ **pageFile:** The associated page file.
  - ✓ **numPages:** Number of page frames.
  - ✓ **strategy:** Page replacement strategy.
  - ✓ **mgmtData:** Bookkeeping data for buffer pool management.
- **BM_PageHandle**: Represents a page in memory with:
  - ✓ **pageNum:** The page number.
  - ✓ **data:** Pointer to the memory storing the page content.

4.2 Buffer Pool Functions

- **initBufferPool():** Initializes a buffer pool with a given page file and strategy.
- **shutdownBufferPool():** Cleans up resources and writes dirty pages to disk.
- **forceFlushPool():** Writes all dirty pages (with fix count 0) to disk.

4.3 Page Management Functions

- **pinPage():** Loads a page from disk (if not already cached) and pins it.
- **unpinPage():** Decreases the fixed count of a page.
- **markDirty():** Marks a page as modified.
- **forcePage():** Writes a modified page back to disk immediately.

4.4 Statistics Functions

- **getFrameContents():** Retrieves an array of pages currently stored in the buffer pool.
- **getDirtyFlags():** Indicates which pages are dirty.
- **getFixCounts():** Returns fix counts for pages.
- **getNumReadIO():** Counts total page reads from disk.
- **getNumWriteIO():** Counts total page writes to disk.

5. ERROR HANDLING AND DEBUGGING

- **Error Handling**: Implemented in dberror.h, providing error codes and logging functions.
- **Debugging**:
  - ✓ **printPageContent():** Displays the contents of a memory page.
  - ✓ **printPoolContent():** Summarizes the buffer pool's state, including page numbers, dirty flags, and fix counts.

6. SOURCE CODE STRUCTURE

The project directory follows this structure:

```
assign2/
├── README.md
├── Makefile
├── buffer_mgr.h
├── buffer_mgr.c
├── buffer_mgr_stat.c
├── buffer_mgr_stat.h
├── dberror.c
├── dberror.h
├── dt.h
├── storage_mgr.c
├── storage_mgr.h
├── test_assign2_1.c
├── test_assign2_2.c
└── test_helper.h
```

7. TESTING AND VALIDATION

The provided test cases (test_assign2_1.c and test_assign2_2.c) validate FIFO and LRU strategies.

Additional test cases can be created to verify correctness under concurrent operations.

8. OPTIONAL EXTENSIONS ADDED

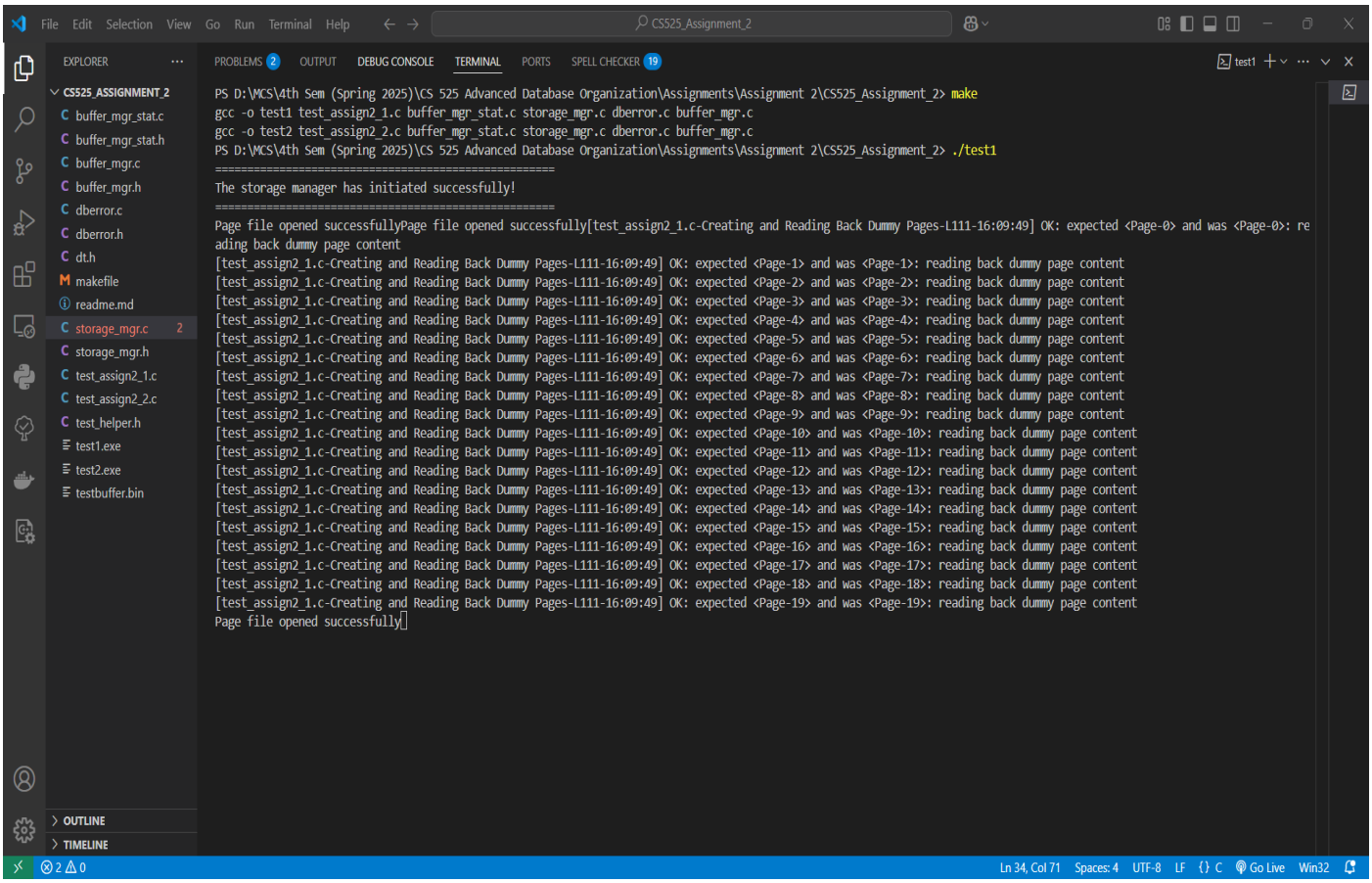
- **Thread Safety:** Enhancing the buffer manager with thread safety allows multiple clients to access the buffer pool simultaneously without encountering race conditions or concurrency issues. This improvement makes the buffer manager more comparable to real-world database systems.
- **Advanced Page Replacement Strategies:** Incorporating additional strategies like CLOCK or LRU-k (Least Recently Used with k references) or LFU offers more refined page replacement methods, optimizing performance for specific workloads.

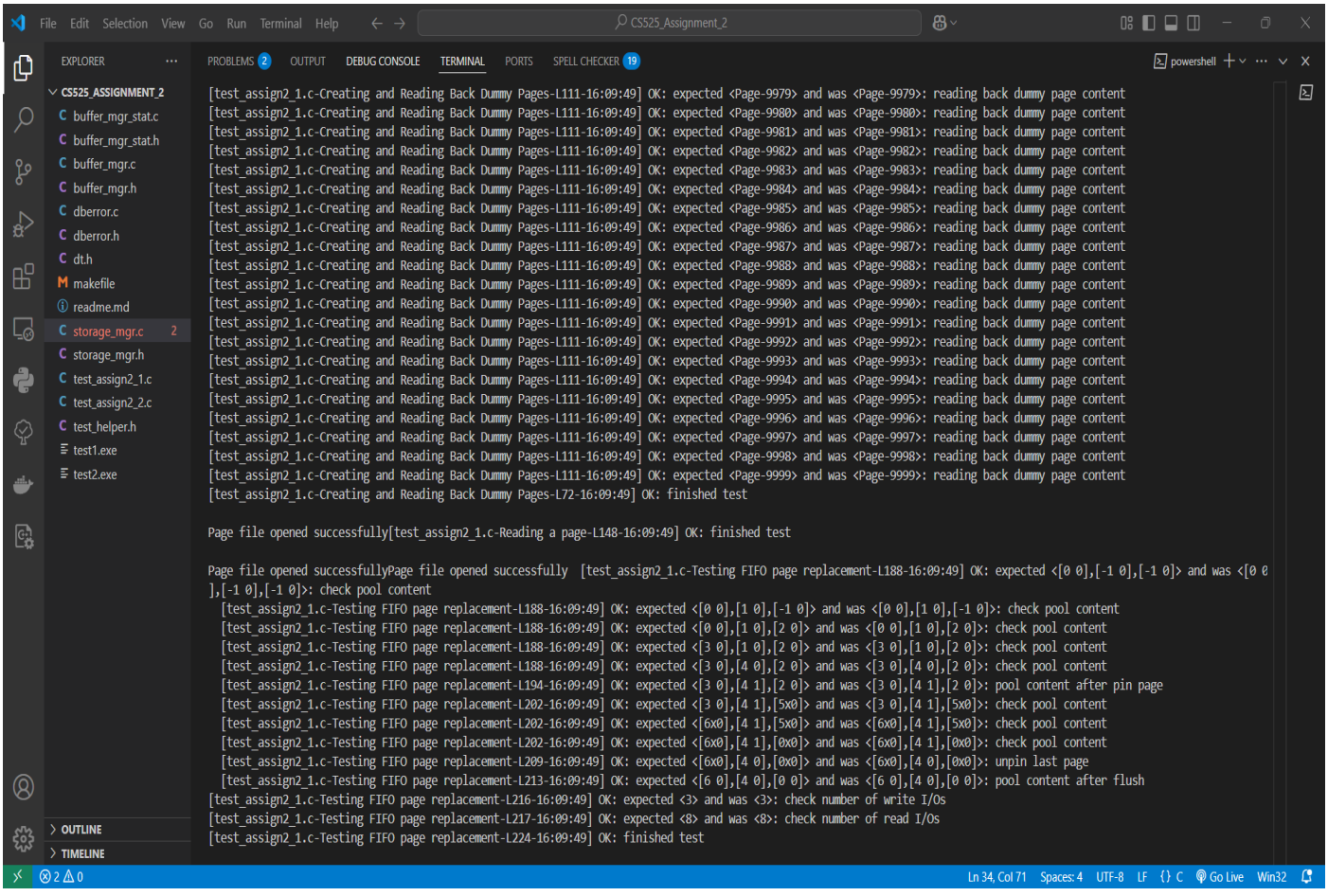
9. CONCLUSION

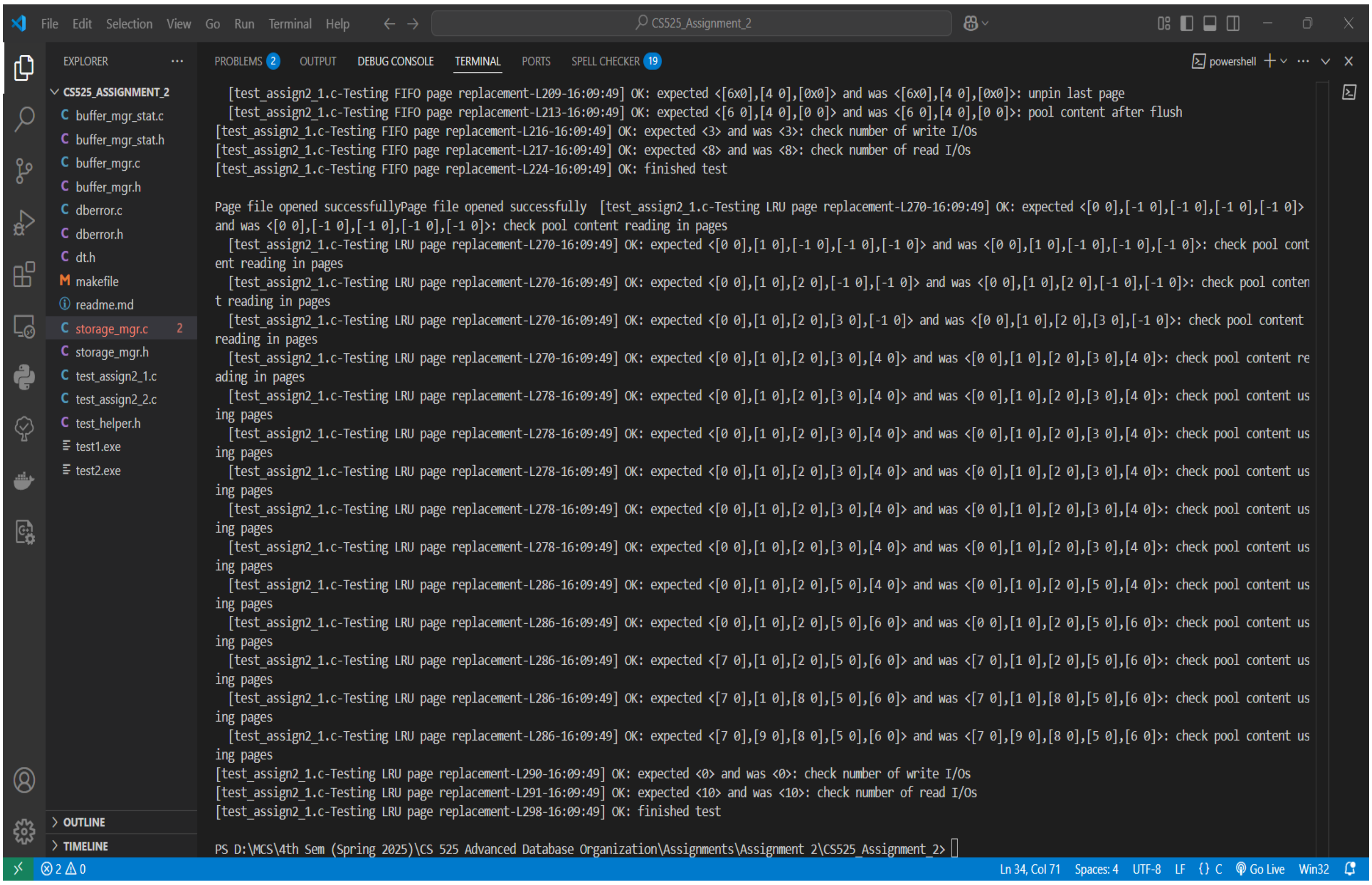
This assignment focuses on developing a Buffer Manager that effectively manages memory pages using FIFO, LRU, CLOCK, and LFU strategies. By properly handling page pinning, unpinning, and eviction, the buffer manager enhances database efficiency. Additional improvements, such as implementing thread safety and advanced replacement strategies, can further increase its robustness and align it more closely with real-world applications.

10. OUTPUT

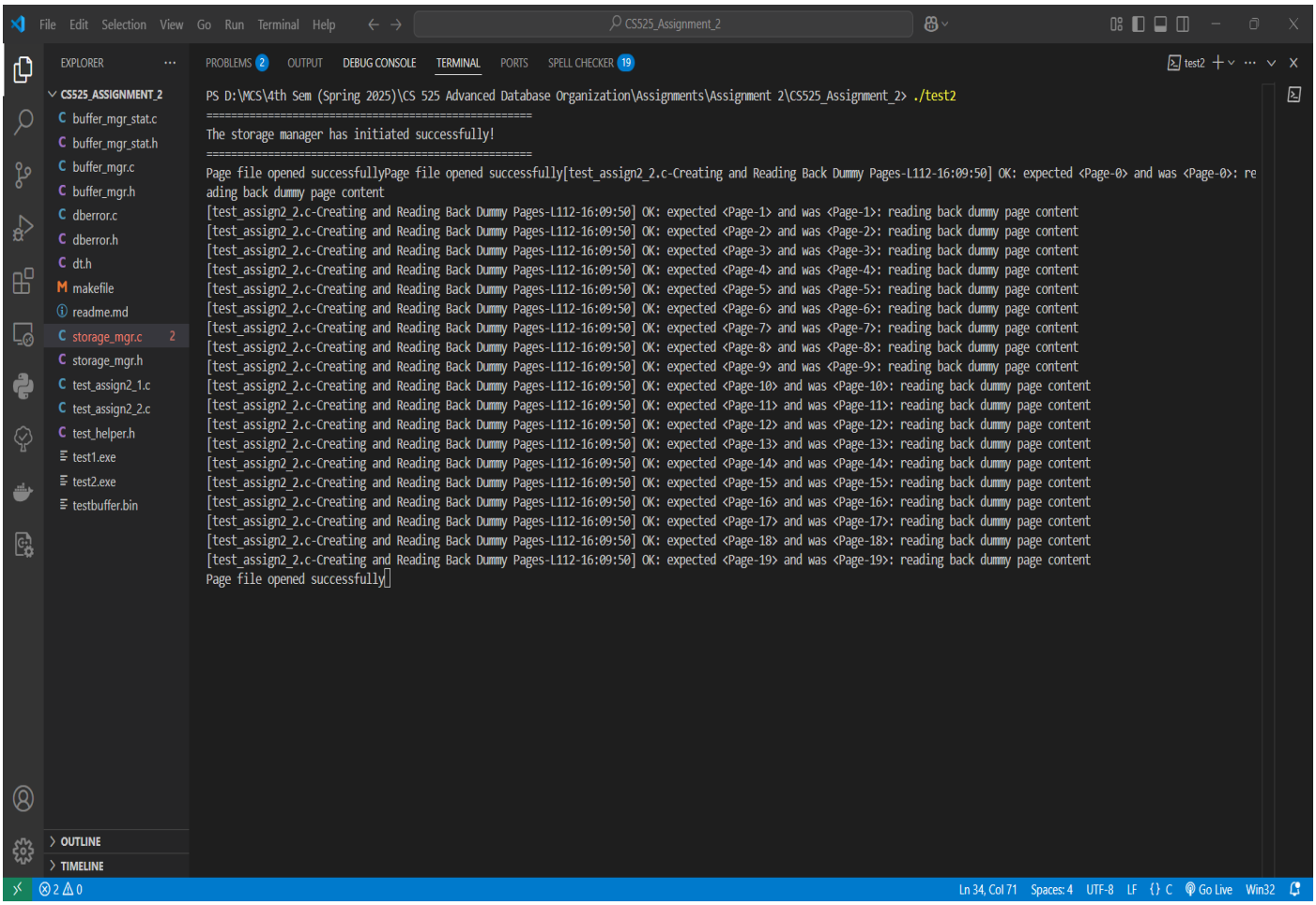
A. Using FIFO and LRU page replacement strategies

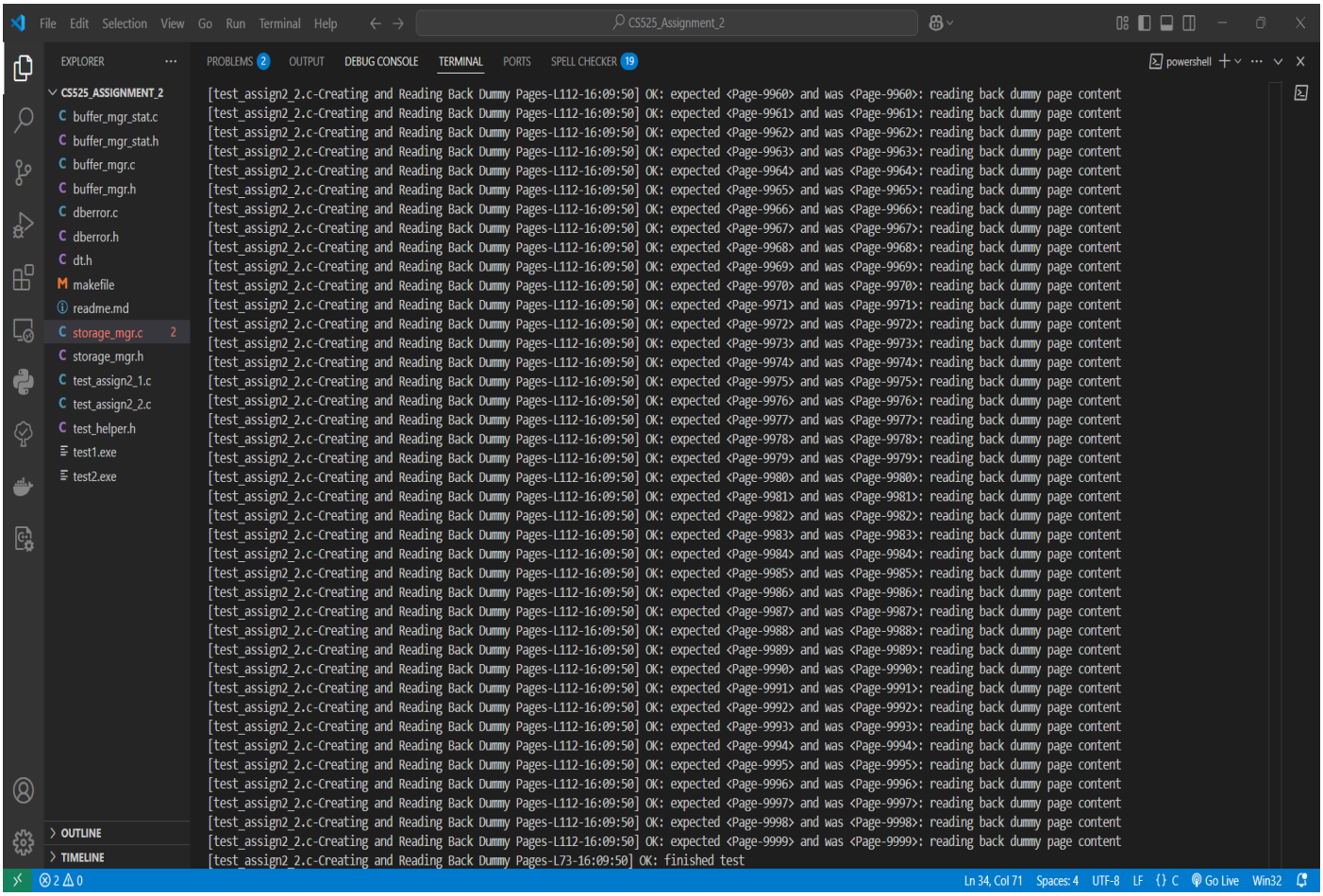


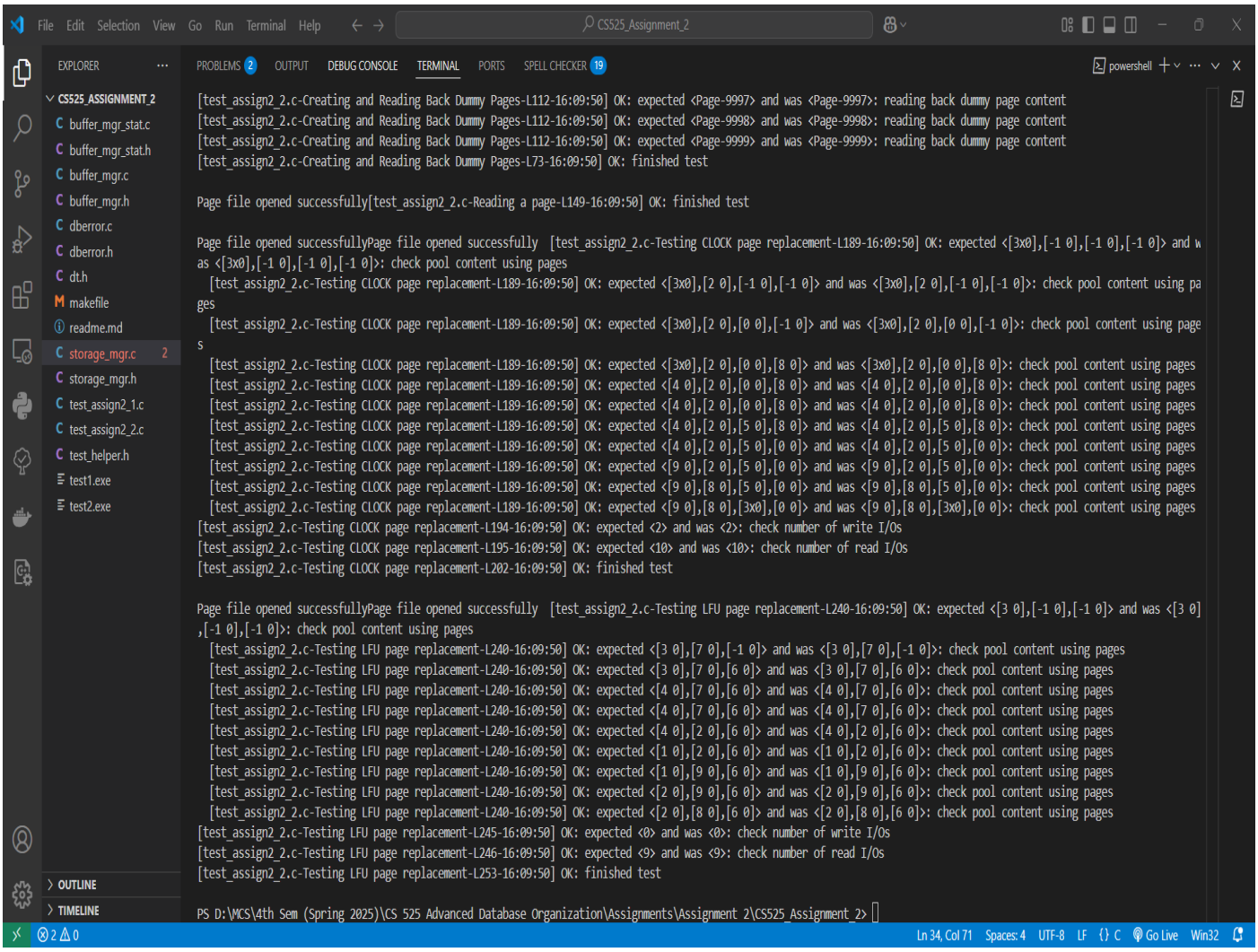



File Edit Selection View Go Run Terminal Help
CS525_Assignment_2
EXPLORER
CS525_ASSIGNMENT_2
buffer_mgr_stat.c
buffer_mgr_stat.h
buffer_mgr.c
buffer_mgr.h
dberror.c
dberror.h
dt.h
makefile
readme.md
storage_mgr.c 2
storage_mgr.h
test_assign2_1.c
test_assign2_2.c
test_helper.h
test1.exe
test2.exe
OUTLINE
TIMELINE
PROBLEMS 2 OUTPUT DEBUG CONSOLE TERMINAL PORTS SPELL CHECKER 19
powershell
[test_assign2_1.c-Testing FIFO page replacement-L209-16:09:49] OK: expected <[6x0],[4 0],[0x0]> and was <[6x0],[4 0],[0x0]>: unpin last page
[test_assign2_1.c-Testing FIFO page replacement-L213-16:09:49] OK: expected <[6 0],[4 0],[0 0]> and was <[6 0],[4 0],[0 0]>: pool content after flush
[test_assign2_1.c-Testing FIFO page replacement-L216-16:09:49] OK: expected <3> and was <3>: check number of write I/Os
[test_assign2_1.c-Testing FIFO page replacement-L217-16:09:49] OK: expected <8> and was <8>: check number of read I/Os
[test_assign2_1.c-Testing FIFO page replacement-L224-16:09:49] OK: finished test
Page file opened successfullyPage file opened successfully [test_assign2_1.c-Testing LRU page replacement-L270-16:09:49] OK: expected <[0 0],[-1 0],[-1 0],[-1 0],[-1 0]>
and was <[0 0],[-1 0],[-1 0],[-1 0],[-1 0]>: check pool content reading in pages
[test_assign2_1.c-Testing LRU page replacement-L270-16:09:49] OK: expected <[0 0],[1 0],[-1 0],[-1 0],[-1 0]> and was <[0 0],[1 0],[-1 0],[-1 0],[-1 0]>: check pool cont
ent reading in pages
[test_assign2_1.c-Testing LRU page replacement-L270-16:09:49] OK: expected <[0 0],[1 0],[2 0],[-1 0],[-1 0]> and was <[0 0],[1 0],[2 0],[-1 0],[-1 0]>: check pool conten
t reading in pages
[test_assign2_1.c-Testing LRU page replacement-L270-16:09:49] OK: expected <[0 0],[1 0],[2 0],[3 0],[-1 0]> and was <[0 0],[1 0],[2 0],[3 0],[-1 0]>: check pool content
reading in pages
[test_assign2_1.c-Testing LRU page replacement-L270-16:09:49] OK: expected <[0 0],[1 0],[2 0],[3 0],[4 0]> and was <[0 0],[1 0],[2 0],[3 0],[4 0]>: check pool content re
ading in pages
[test_assign2_1.c-Testing LRU page replacement-L278-16:09:49] OK: expected <[0 0],[1 0],[2 0],[3 0],[4 0]> and was <[0 0],[1 0],[2 0],[3 0],[4 0]>: check pool content us
ing pages
[test_assign2_1.c-Testing LRU page replacement-L278-16:09:49] OK: expected <[0 0],[1 0],[2 0],[3 0],[4 0]> and was <[0 0],[1 0],[2 0],[3 0],[4 0]>: check pool content us
ing pages
[test_assign2_1.c-Testing LRU page replacement-L278-16:09:49] OK: expected <[0 0],[1 0],[2 0],[3 0],[4 0]> and was <[0 0],[1 0],[2 0],[3 0],[4 0]>: check pool content us
ing pages
[test_assign2_1.c-Testing LRU page replacement-L278-16:09:49] OK: expected <[0 0],[1 0],[2 0],[3 0],[4 0]> and was <[0 0],[1 0],[2 0],[3 0],[4 0]>: check pool content us
ing pages
[test_assign2_1.c-Testing LRU page replacement-L278-16:09:49] OK: expected <[0 0],[1 0],[2 0],[3 0],[4 0]> and was <[0 0],[1 0],[2 0],[3 0],[4 0]>: check pool content us
ing pages
[test_assign2_1.c-Testing LRU page replacement-L286-16:09:49] OK: expected <[0 0],[1 0],[2 0],[5 0],[4 0]> and was <[0 0],[1 0],[2 0],[5 0],[4 0]>: check pool content us
ing pages
[test_assign2_1.c-Testing LRU page replacement-L286-16:09:49] OK: expected <[0 0],[1 0],[2 0],[5 0],[6 0]> and was <[0 0],[1 0],[2 0],[5 0],[6 0]>: check pool content us
ing pages
[test_assign2_1.c-Testing LRU page replacement-L286-16:09:49] OK: expected <[7 0],[1 0],[2 0],[5 0],[6 0]> and was <[7 0],[1 0],[2 0],[5 0],[6 0]>: check pool content us
ing pages
[test_assign2_1.c-Testing LRU page replacement-L286-16:09:49] OK: expected <[7 0],[1 0],[8 0],[5 0],[6 0]> and was <[7 0],[1 0],[8 0],[5 0],[6 0]>: check pool content us
ing pages
[test_assign2_1.c-Testing LRU page replacement-L286-16:09:49] OK: expected <[7 0],[9 0],[8 0],[5 0],[6 0]> and was <[7 0],[9 0],[8 0],[5 0],[6 0]>: check pool content us
ing pages
[test_assign2_1.c-Testing LRU page replacement-L290-16:09:49] OK: expected <0> and was <0>: check number of write I/Os
[test_assign2_1.c-Testing LRU page replacement-L291-16:09:49] OK: expected <10> and was <10>: check number of read I/Os
[test_assign2_1.c-Testing LRU page replacement-L298-16:09:49] OK: finished test
PS D:\MCS\4th Sem (Spring 2025)\CS 525 Advanced Database Organization\Assignments\Assignment 2\CS525_Assignment_2>
2 0
Ln 34, Col 71 Spaces: 4 UTF-8 LF {} C Go Live Win32

B. Using CLOCK and LFU page replacement strategies (For Extra Credit)






File Edit Selection View Go Run Terminal Help
CS525_Assignment_2
EXPLORER
CS525_ASSIGNMENT_2
buffer_mgr_stat.c
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buffer_mgr.c
buffer_mgr.h
dberror.c
dberror.h
dt.h
makefile
readme.md
storage_mgr.c 2
storage_mgr.h
test_assign2_1.c
test_assign2_2.c
test_helper.h
test1.exe
test2.exe
OUTLINE
TIMELINE
PROBLEMS 2
OUTPUT
DEBUG CONSOLE
TERMINAL
PORTS
SPELL CHECKER 19
powershell
[test_assign2_2.c-Creating and Reading Back Dummy Pages-L112-16:09:50] OK: expected <Page-9997> and was <Page-9997>: reading back dummy page content
[test_assign2_2.c-Creating and Reading Back Dummy Pages-L112-16:09:50] OK: expected <Page-9998> and was <Page-9998>: reading back dummy page content
[test_assign2_2.c-Creating and Reading Back Dummy Pages-L112-16:09:50] OK: expected <Page-9999> and was <Page-9999>: reading back dummy page content
[test_assign2_2.c-Creating and Reading Back Dummy Pages-L73-16:09:50] OK: finished test
Page file opened successfully[test_assign2_2.c-Reading a page-L149-16:09:50] OK: finished test
Page file opened successfullyPage file opened successfully [test_assign2_2.c-Testing CLOCK page replacement-L189-16:09:50] OK: expected <[3x0],[-1 0],[-1 0],[-1 0]> and was <[3x0],[-1 0],[-1 0],[-1 0]>: check pool content using pages
[test_assign2_2.c-Testing CLOCK page replacement-L189-16:09:50] OK: expected <[3x0],[2 0],[-1 0],[-1 0]> and was <[3x0],[2 0],[-1 0],[-1 0]>: check pool content using pages
[test_assign2_2.c-Testing CLOCK page replacement-L189-16:09:50] OK: expected <[3x0],[2 0],[0 0],[-1 0]> and was <[3x0],[2 0],[0 0],[-1 0]>: check pool content using pages
[test_assign2_2.c-Testing CLOCK page replacement-L189-16:09:50] OK: expected <[3x0],[2 0],[0 0],[8 0]> and was <[3x0],[2 0],[0 0],[8 0]>: check pool content using pages
[test_assign2_2.c-Testing CLOCK page replacement-L189-16:09:50] OK: expected <[4 0],[2 0],[0 0],[8 0]> and was <[4 0],[2 0],[0 0],[8 0]>: check pool content using pages
[test_assign2_2.c-Testing CLOCK page replacement-L189-16:09:50] OK: expected <[4 0],[2 0],[0 0],[8 0]> and was <[4 0],[2 0],[0 0],[8 0]>: check pool content using pages
[test_assign2_2.c-Testing CLOCK page replacement-L189-16:09:50] OK: expected <[4 0],[2 0],[5 0],[8 0]> and was <[4 0],[2 0],[5 0],[8 0]>: check pool content using pages
[test_assign2_2.c-Testing CLOCK page replacement-L189-16:09:50] OK: expected <[4 0],[2 0],[5 0],[0 0]> and was <[4 0],[2 0],[5 0],[0 0]>: check pool content using pages
[test_assign2_2.c-Testing CLOCK page replacement-L189-16:09:50] OK: expected <[9 0],[2 0],[5 0],[0 0]> and was <[9 0],[2 0],[5 0],[0 0]>: check pool content using pages
[test_assign2_2.c-Testing CLOCK page replacement-L189-16:09:50] OK: expected <[9 0],[8 0],[5 0],[0 0]> and was <[9 0],[8 0],[5 0],[0 0]>: check pool content using pages
[test_assign2_2.c-Testing CLOCK page replacement-L189-16:09:50] OK: expected <[9 0],[8 0],[3x0],[0 0]> and was <[9 0],[8 0],[3x0],[0 0]>: check pool content using pages
[test_assign2_2.c-Testing CLOCK page replacement-L194-16:09:50] OK: expected <2> and was <2>: check number of write I/Os
[test_assign2_2.c-Testing CLOCK page replacement-L195-16:09:50] OK: expected <10> and was <10>: check number of read I/Os
[test_assign2_2.c-Testing CLOCK page replacement-L202-16:09:50] OK: finished test
Page file opened successfullyPage file opened successfully [test_assign2_2.c-Testing LFU page replacement-L240-16:09:50] OK: expected <[3 0],[-1 0],[-1 0]> and was <[3 0],[-1 0],[-1 0]>: check pool content using pages
[test_assign2_2.c-Testing LFU page replacement-L240-16:09:50] OK: expected <[3 0],[7 0],[-1 0]> and was <[3 0],[7 0],[-1 0]>: check pool content using pages
[test_assign2_2.c-Testing LFU page replacement-L240-16:09:50] OK: expected <[3 0],[7 0],[6 0]> and was <[3 0],[7 0],[6 0]>: check pool content using pages
[test_assign2_2.c-Testing LFU page replacement-L240-16:09:50] OK: expected <[4 0],[7 0],[6 0]> and was <[4 0],[7 0],[6 0]>: check pool content using pages
[test_assign2_2.c-Testing LFU page replacement-L240-16:09:50] OK: expected <[4 0],[7 0],[6 0]> and was <[4 0],[7 0],[6 0]>: check pool content using pages
[test_assign2_2.c-Testing LFU page replacement-L240-16:09:50] OK: expected <[4 0],[2 0],[6 0]> and was <[4 0],[2 0],[6 0]>: check pool content using pages
[test_assign2_2.c-Testing LFU page replacement-L240-16:09:50] OK: expected <[1 0],[2 0],[6 0]> and was <[1 0],[2 0],[6 0]>: check pool content using pages
[test_assign2_2.c-Testing LFU page replacement-L240-16:09:50] OK: expected <[1 0],[9 0],[6 0]> and was <[1 0],[9 0],[6 0]>: check pool content using pages
[test_assign2_2.c-Testing LFU page replacement-L240-16:09:50] OK: expected <[2 0],[9 0],[6 0]> and was <[2 0],[9 0],[6 0]>: check pool content using pages
[test_assign2_2.c-Testing LFU page replacement-L240-16:09:50] OK: expected <[2 0],[8 0],[6 0]> and was <[2 0],[8 0],[6 0]>: check pool content using pages
[test_assign2_2.c-Testing LFU page replacement-L245-16:09:50] OK: expected <0> and was <0>: check number of write I/Os
[test_assign2_2.c-Testing LFU page replacement-L246-16:09:50] OK: expected <9> and was <9>: check number of read I/Os
[test_assign2_2.c-Testing LFU page replacement-L253-16:09:50] OK: finished test
PS D:\MCS\4th Sem (Spring 2025)\CS 525 Advanced Database Organization\Assignments\Assignment 2\CS525_Assignment_2>
Ln 34, Col 71 Spaces: 4 UTF-8 LF {} C Go Live Win32