ODYSSEUS/EduCOSMOS Project #1: EduBfM Project Manual

Version 1.1

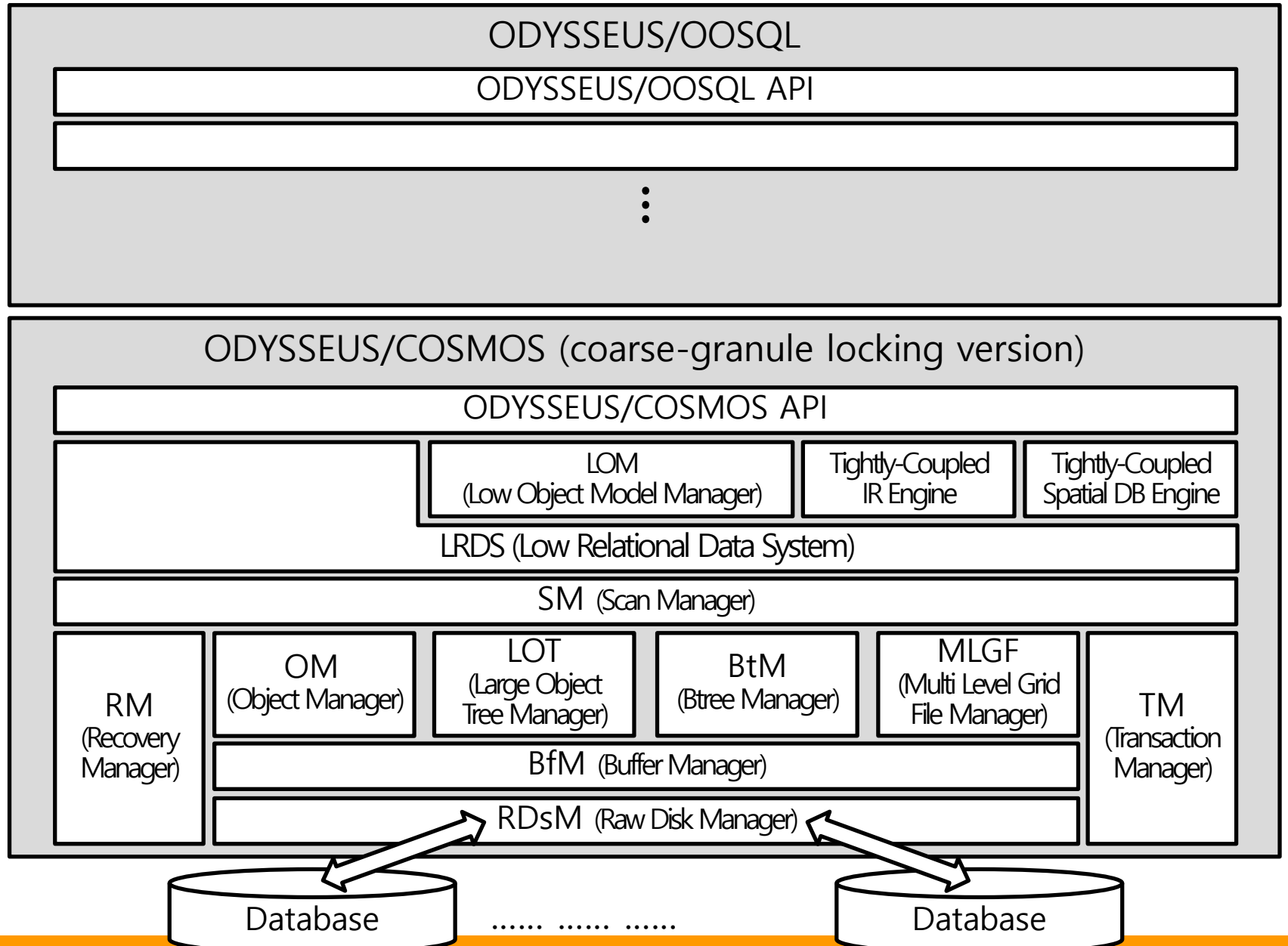
Contents

ODYSSEUS/COSMOS

- ODYSSEUS
  - An object-relational DBMS developed by Kyu-Young Whang et al. at Advanced Information Technology Research Center (AITrc) / Computer Science Department of KAIST. ODYSSEUS has been being developed since 1990.

- ODYSSEUS/COSMOS
  - The storage system of ODYSSEUS, which is used as an infrastructure for various database application softwares.

- ODYSSEUS architecture

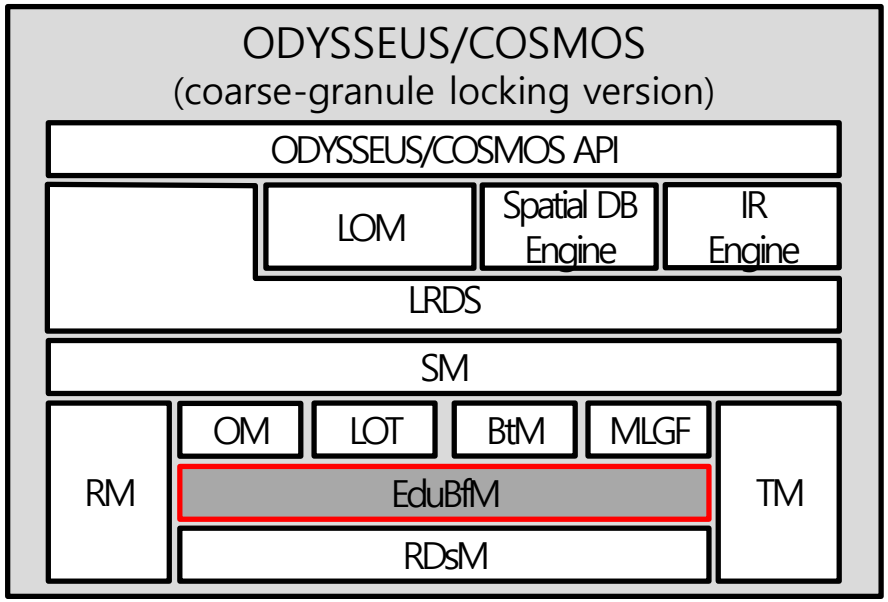


ODYSSEUS/EduCOSMOS Project

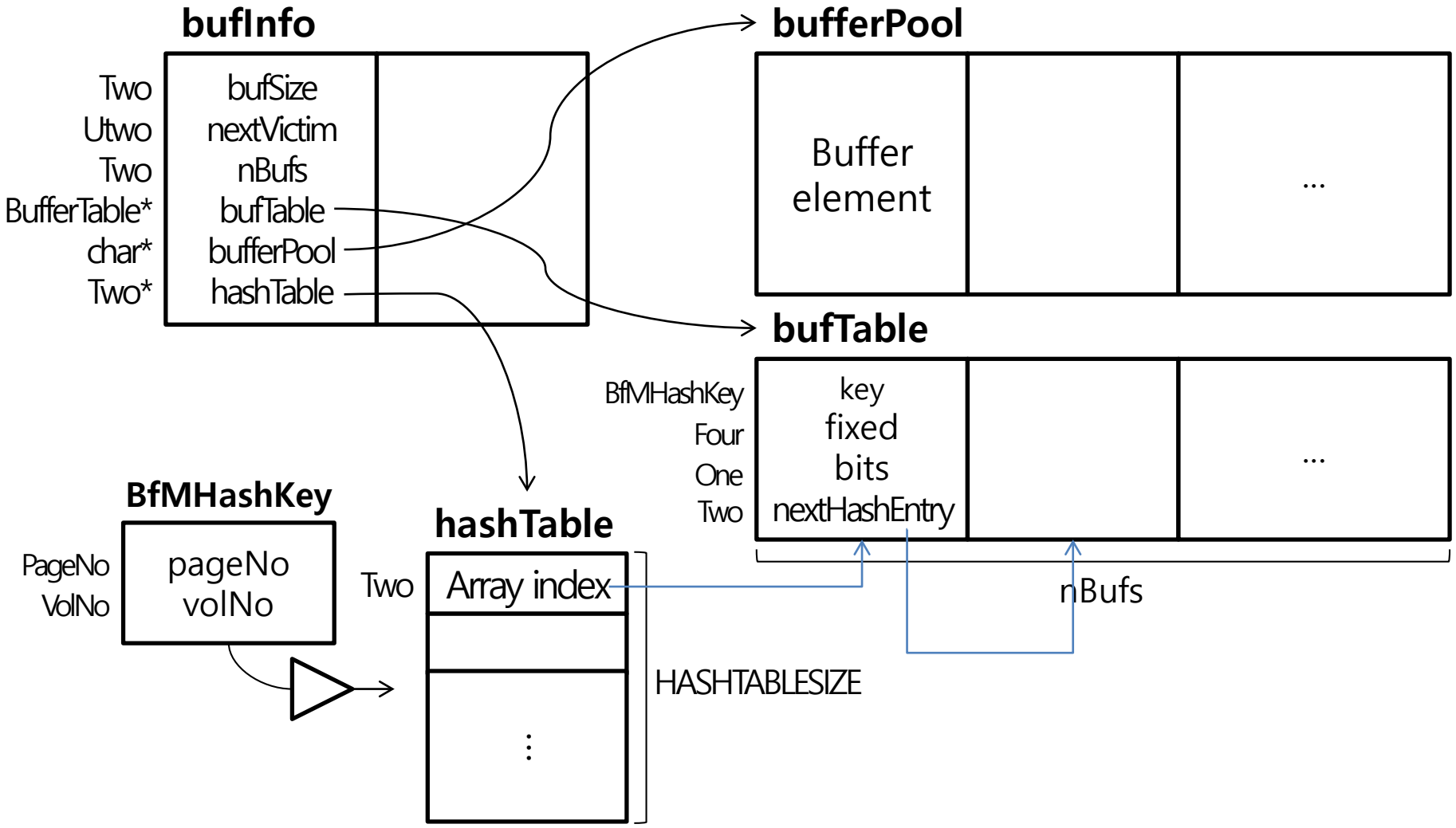
- Overview
  - A project for educational purposes where students implement a part of the coarse-granule locking version of the ODYSSEUS/COSMOS storage system
    - Prerequisites for the project: basic C programming skill
- Objective
  - To learn the functions of each module of a DBMS by implementing a part of the ODYSSEUS/COSMOS storage system
- Project types
  - EduBfM
    - We implement the operations of the buffer manager.
  - EduOM
    - We implement the operations of the object manager and the page-related structures.
  - EduBtM
    - We implement the operations of the B+ tree index manager.

EduBfM Project

- Objective
  - We implement the data structures and operations of the buffer manager which maintains the in-memory copy of disk pages or trains.
    - Train: set of pages to store the large object whose size is larger than that of the data area of a page
  - In EduBfM, we handle only a very limited subset of original ODYSSEUS/COSMOS BfM functionality.



Data Structures



bufInfo

- Overview
  - Data structures for buffer pools and related information
  - There are two types of buffer pools, and a separate *bufInfo* is kept for each.
    - PAGE_BUF: the page buffer pool to store pages containing small objects, index entries, etc., whose size is smaller than that of the total data area of a page
    - LOT_LEAF_BUF: the train buffer pool to store a leaf node (currently, composed of four pages) of the Large Object Tree, representing a large object (one larger than that of the total data area of a page).

- Components
  - bufSize
    - Size of a buffer element of a buffer pool (unit: # of pages)
      - PAGE_BUF: 1
      - LOT_LEAF_BUF: 4 (configurable)

- nextVictim
  - An array index of the next buffer element to be visited to determine whether or not to replace the buffer element by the buffer replacement algorithm
- nBufs
  - The number of buffer elements of a buffer pool
- bufTable
  - Table to store information of each buffer element of a buffer pool
- bufferPool
  - Buffer pool (a set of buffer elements to maintain pages/trains read in from the disk in main memory)
- hashTable
  - Hash table to support efficient search for pages/trains residing in a buffer pool

bufTable

- Overview
  - Data structure to store information about the page/train residing in the buffer element of *bufferPool*
  - The *n*-th element of *bufTable* stores information for the page/train stored in the *n*-th buffer element of *bufferPool*.

- Components
  - Key
    - Hash key of the page/train residing in the buffer element (= ID of the page or the first page of the train)
      - ID of a page consists of the page number and the volume number.
  - fixed
    - The number of transactions fixing (accessing) the page/train residing in the buffer element

- bits
  - A set of bits indicating the state of the buffer element
    - bit 1 (DIRTY): A bit indicating that the page/train residing in the buffer element has been modified.
    - bit 3 (REFER): A bit indicating whether the buffer element has been visited or not by the buffer replacement algorithm.
    - Other bits are not used in EduBfM. (You may ignore them when implementing the EduBfM function.)
- nextHashEntry
  - The array index of the buffer element containing the next page/train having the identical hash value

BfMHashKey

- Overview
  - Data structure to store the hash key of a page/train

- Components
  - pageNo
    - The number of the page or the first page of the train
      - A unique number for the page within a volume
  - volNo
    - Volume number of the disk volume storing the page/train
      - A unique number of the volume within the system

※ A hash value is the output of a hash function whose input is a hash key.

Hash value = (*pageNo* + *volNo*) % HASHTABLESIZE

hashTable

- Overview
  - Table to store the array index of the buffer element containing the page/train; consists of *hashTable* entries. Each *hashTable* entry contains an array index of a buffer element in *bufTable*.
  - The array index of the buffer element is stored in an entry of *hashTable* by using the hash value of the page/train residing in the buffer element.
    - The array index of the buffer element containing the most recent page/train read from the disk having the same hash value of *n* is stored in the *n*-th entry of *hashTable*.
      - Array indexes of the buffer elements storing pages/trains with the same hash value are maintained as a linked list through the variable *nextHashEntry* of *bufTable*.
  - The *NIL*(-1) value is stored in the entry of *hashTable* that does not store any array index

Related Operations

- Fix the page/train
  - To access a page/train, fix the page/train in *bufferPool*.
    - Every transaction should fix the page/train in *bufferPool* before accessing it.
    - Increment the variable *fixed* by 1.

- Unfix the page/train
  - Unfix the page/train from *bufferPool*.
    - Every transaction should unfix the page/train from *bufferPool* after completing the access to it.
    - Decrement the variable *fixed* by 1.

- Set the Dirty bit
  - To indicate that the page/train residing in *bufferPool* has been modified, set its DIRTY bit to 1.
- Flush pages/trains in *bufferPool*
  - Write out the modified pages/trains residing in *bufferPool* to the disk.
- Discard pages/trains in *bufferPool*
  - Delete a pages/trains residing in *bufferPool* from *bufferPool*.

API Functions to Implement

- EduBfM_GetTrain()
- EduBfM_FreeTrain()
- EduBfM_SetDirty()
- EduBfM_FlushAll()
- EduBfM_DiscardAll()

(※ API functions mean they are part of the ODYSSEUS/COSMOS API shown in p.4)
(※ API: Application Programming Interface)

EduBfM_GetTrain()

- File: EduBfM_GetTrain.c

- Description
  - Fix the page/train in *bufferPool*, and return the pointer to the buffer element containing the page/train.
    - Search for the array index of the buffer element containing the page/train to be fixed from *hashTable* using its hash value.
    - If the page/train to be fixed does not exist in *bufferPool*,
      - Allocate a buffer element to store the page/train from *bufferPool*.
      - Store the page/train in the allocated buffer element reading it from the disk.
      - Update the element of *bufTable* corresponding to the allocated buffer element.
        - » *key*: set to the hash key of the page/train to be fixed.
        - » *fixed*: set to 1.

    - » *bits*: set the REFER bit to 1.
        - You do not need to update the DIRTY bit, which is managed by EduBfM_SetDirty(), EduBfM_DiscardAll(), edubfm_AllocTrain(), and edubfm_FlushTrain().
    - » *nextHashEntry*: you do not need to update *nextHashEntry* which is managed by edubfm_Insert() and edubfm_Delete().
  - Insert the array index of the allocated buffer element into *hashTable*.
  - Return the pointer to the allocated buffer element.
- If the page/train to be fixed exists in *bufferPool*,
  - Update the element of *bufTable* corresponding to the buffer element containing the page/train.
    - » *fixed*: increase by 1.
    - » *bits*: set the REFER bit to 1.
  - Return the pointer to the buffer element.

- Parameters
  - PageID/TrainID *trainId
    (IN) ID of the page or the first page of the train to be fixed
  - char **retbuf
    (OUT) Pointer to the buffer element storing the page/train fixed
  - Four type
    (IN) Type of *bufferPool*

- Return value
  - Four error code
    - Error code returned by the function
    - eNOERROR: Execution completed without error.

- Related functions

  edubfm_AllocTrain(), edubfm_Insert(), edubfm_LookUp(), edubfm_ReadTrain()

EduBfM_FreeTrain()

- File: EduBfM_FreeTrain.c

- Description
  - Unfix the page/train from *bufferPool*.
    - Search for the array index of the buffer element containing the page/train to be unfixed from *hashTable* using its hash value.
    - Decrease the variable *fixed* of the buffer element by 1.
      - If the value of *fixed* becomes less than 0,
        - » Print out the warning message, "Warning: Fixed counter is less than 0!!!".
        - » Set the value of *fixed* to 0.

- Parameters
  - PageID/TrainID *trainId
    (IN) ID of the page or the first page of the train to be unfixed
  - Four type
    (IN) Type of *bufferPool*

- Return value
  - Four error code
    - eNOERROR: Execution completed without error.
    - eNOTFOUND_BFM: The page/train does not exist in *bufferPool*.

- Related function
  edubfm_LookUp()

EduBfM_SetDirty()

- File: EduBfM_SetDirty.c

- Description
  - Set the DIRTY bit to 1 to indicate that the page/train residing in the buffer element has been modified.
    - Search for the array index of the buffer element containing the page/train modified from *hashTable* using the hash value of the page/train.
    - Set the DIRTY bit of the buffer element to 1.

- Parameters
  - PageID/TrainID *trainId
    (IN) ID of the page or the first page of the train modified
  - Four type
    (IN) Type of *bufferPool*

- Return value
  - Four error code
    - eNOERROR: Execution completed without error.
    - eNOTFOUND_BFM: The page/train does not exist in *bufferPool*.

- Related function
  edubfm_LookUp()

EduBfM_FlushAll()

- File: EduBfM_FlushAll.c

- Description
  - Write out the modified pages/trains residing in each *bufferPool* to the disk.
    - Write out each page/train residing in the buffer element whose DIRTY bit is set to 1 to the disk by calling edubfm_FlushTrain().

- No parameters

- Return value
  - Four error code
    - Error code returned by the function
    - eNOERROR: Execution completed without error.

- Related function

  edubfm_FlushTrain()

EduBfM_DiscardAll()

- File: EduBfM_DiscardAll.c

- Description
  - Delete pages/trains residing in each *bufferPool* without writing them out to disk
    - Initialize every element in *bufTable*.
      - *key*: set *pageNo* to *NIL*(-1).
      - *fixed*: you do not need to initialize *fixed*, which is managed by EduBfM_GetTrain() and EduBfM_FreeTrain().
      - *bits*: reset all bits.
      - *nextHashEntry*: you do not need to initialize *nextHashEntry,* which is managed by edubfm_Insert() and edubfm_Delete().
    - Delete every entry (i.e., array index) in *hashTable*.

- No parameters

- Return value
  - Four error code
    - Error code returned by the function
    - eNOERROR: Execution completed without error.

- Related function

  edubfm_DeleteAll()

Internal Functions to Implement

- edubfm_ReadTrain()
- edubfm_AllocTrain()
- edubfm_Insert()
- edubfm_Delete()
- edubfm_Deleteall()
- edubfm_LookUp()
- edubfm_FlushTrain()

edubfm_ReadTrain()

- File: edubfm_ReadTrain.c

- Description
  - Store the page/train in a buffer element reading it from the disk, and return the pointer to the corresponding buffer element.

- Parameters
  - PageID/TrainID *trainId
    (IN) ID of the page or the first page of the train to be read
  - char *aTrain
    (OUT) Pointer to the buffer element storing the page/train read
  - Four type
    (IN) Type of *bufferPool*

- Return value
  - Four error code
    - Error code returned by the function
    - eNOERROR: Execution completed without error.

- Related function

  RDsM_ReadTrain() (See p.44~45)

edubfm_AllocTrain()

- File: edubfm_AllocTrain.c

- Description
  - Allocate a buffer element in *bufferPool* to store a page/train, and return the array index of the buffer element.
    - Use the second chance buffer replacement algorithm to select the buffer element to be allocated.
      - To select the buffer element, sequentially visit buffer elements in *bufferPool*, whose variable *fixed* is 0.
        - » Visiting order

          1) the buffer element whose array index is *bufInfo.nextVictim*.
          2) the buffer element whose array index is (*bufInfo.nextVictim*+1)%*bufInfo.nBufs*.
          ...
          n) the buffer element whose array index is (*bufInfo.nextVictim*+n-1)%*bufInfo.nBufs*.
      - Check the REFER bit when visiting each buffer element, and if the same buffer element has been visited twice (REFER bit == 0), select it as the buffer element to be allocated, otherwise (REFER bit == 1), set the REFER bit to 0.

- Initialize the data structure related to the buffer element selected.
  - If the page/train residing in the selected buffer element has been modified, flush the contents of the buffer element into the disk.
  - Initialize the element of *bufTable* corresponding to the buffer element selected.
    - » *key*: you do not need to initialize *key*, which is managed by EduBfM_GetTrain() and EduBfM_DiscardAll().
    - » *fixed*: you do not need to initialize *fixed*, which is managed by EduBfM_GetTrain() and EduBfM_FreeTrain().
    - » *bits*: reset all bits.
    - » *nextHashEntry*: you do not need to initialize *nextHashEntry*, which is managed by edubfm_Insert() and edubfm_Delete().
  - Set *bufInfo.nextVictim* to ((the array index of the buffer element selected + 1) % *bufInfo.nBufs)*.
  - Delete the array index of the buffer element (*hashTable* entry) from *hashTable* (linked list).
- Return the array index of the buffer element selected.

- Parameter
  - Four type
    (IN) Type of *bufferPool*

- Return value
  - Four array index of the buffer element allocated
    or, error code
    - Error code returned by the function
    - eNOUNFIXEDBUF_BFM: There is no unfixed buffer element (i.e., whose value of *fixed* is 0).

- Related functions

  edubfm_Delete(), edubfm_FlushTrain()

edubfm_Insert()

- File: edubfm_Hash.c

- Description
  - Insert the array index of the buffer element into *hashTable*.
    - Determine the position in *hashTable* to insert the array index of the buffer element by using the hash value of the page/train residing in the buffer element.
      - The array index of the buffer element containing the page/train having the hash value of *n* is inserted into the *n*-th entry of *hashTable*.
    - If there is no collision, insert the array index into the position determined.
    - If there is a collision, use the chaining method to handle the collision.
      - Store the existing *hashTable* entry (array index) into the variable *nextHashEntry* of the buffer element.
      - Insert the array index into the position determined.

      ⇒ Array indexes of the buffer elements storing pages/trains with the same hash value are kept as a linked list.

- Parameters
  - BfMHashKey *key
    (IN) Hash key of the page/train residing in the buffer element
  - Two index
    (IN) Array index to be inserted
  - Four type
    (IN) Type of *bufferPool*

- Return value
  - Four error code
    - eNOERROR: Execution completed without error.

- No related functions

edubfm_Delete()

- File: edubfm_Hash.c

- Description
  - Delete the array index of the buffer element from *hashTable*.
    - Search for the array index of the buffer element containing the page/train to be deleted from *hashTable* by using the hash value of the page/train residing in the buffer element.
    - Delete the entry (array index) found from *hashTable*.
      - Delete the array index maintaining the remaining array indexes of the buffer elements storing pages/trains with the same hash value as a linked list.

- Parameters
  - BfMHashKey *key
    (IN) Hash key of the page/train residing in the buffer element
  - Four type
    (IN) Type of *bufferPool*

- Return value
  - Four error code
    - eNOERROR: Execution completed without error.
    - eNOTFOUND_BFM: *key* does not exist in *hashTable*.

- No related functions

edubfm_DeleteAll()

- File: edubfm_Hash.c

- Description
  - Delete every entry (array index of the buffer element) from each *hashTable*.
    - Set each *hashTable* entry to *NIL*(-1).

- No parameters
- Return value
  - Four error code
    - eNOERROR: Execution completed without error.
- No related functions

edubfm_LookUp()

- File: edubfm_Hash.c

- Description
  - Search for the array index of the buffer element having the page/train whose hash key (BfMHashKey) is the same with that given as a parameter from *hashTable,* and return it.
    - Using the hash key, search for the array index of the buffer element containing the page/train having the hash key from *hashTable*.
      - Calculate the hash value (*hashValue*) by using the hash key (*key*).
        - » *hashValue* = (*key->volNo* + *key->pageNo*) % HASHTABLESIZE
      - Starting from the buffer element pointed to by the array index stored in the *hashValue*-th *hashTable* entry, visit the buffer elements linked by *nextHashEntry,* and find the buffer element containing the page/train having the hash key.
    - Return the array index found.

- Parameters
  - BfMHashKey *key
    (IN) Hash key to be used to search the array index
  - Four type
    (IN) Type of *bufferPool*

- Return value
  - Four array index of the buffer element found
    or, error code
    - NOTFOUND_IN_HTABLE: *key* does not exist in *hashTable*.

- No related functions

edubfm_FlushTrain()

- File: edubfm_FlushTrain.c

- Description
  - Write out a modified page/train into the disk.
    - Search for the array index of the buffer element containing the page/train to be flushed from *hashTable* by using the hash value of the page/train residing in the buffer element.
    - If the DIRTY bit of the buffer element is set to 1, write out the page/train into the disk.
    - Reset the DIRTY bit.

- Parameters
  - PageID/TrainID *trainId
    (IN) ID of the page or the first page of the train to be flushed
  - Four type
    (IN) Type of *bufferPool*

- Return value
  - Four error code
    - Error code returned by the function
    - eNOERROR: Execution completed without error.
    - eNOTFOUND_BFM: The page/train does not exist in *bufferPool*.

- Related functions
  edubfm_LookUp(), RDsM_WriteTrain() (See p.46~47)

Given Functions

- RDsM_ReadTrain()
  - Read a page/train from the disk.
  - Parameters
    - PageID/TrainID *trainId
      (IN) ID of the page or the first page of the train to be read
    - char *bufPtr
      (OUT) Pointer to the buffer element storing the page/train read
    - Two sizeOfTrain
      (IN) Size of the train to be read (unit: # of pages)
      (※ set *sizeOfTrain* to 1 to read the page.)
  - Return value
    - Four error code

– Example

```
Four edubfm_ReadTrain(
    TrainID *trainId,     /* IN: ID of the page to be read */
    char     *aTrain,     /* OUT: pointer to the buffer */
    Four     type)     /* IN: buffer type */
{
    ...
    /* Read the page from the disk */
    e = RDsM_ReadTrain(trainId, aTrain, BI_BUFSIZE(type));
                        // the page/train read by RDsM_ReadTrain() is stored in the location aTrain points to
    if( e < 0 ) ERR( e );
    ...
}
```

- RDsM_WriteTrain()
  - Write a page/train into the disk.
  - Parameters
    - char *bufPtr

      (IN) Pointer to the buffer element containing the page/train to be written
    - PageID *trainId

      (IN) ID of the page or the first page of the train to be written
    - Two sizeOfTrain

      (IN) Size of the train to be written (unit: # of pages)

      (※ set *sizeOfTrain* to 1 to write the page.)
  - Return value
    - Four error code

– Example

```
Four edubfm_FlushTrain(
    TrainID *trainId,    /* IN: ID of the page to be flushed */
    Four    type)    /* IN: buffer type */
{
    Four index;    /* array index of the buffer element that contains the page */
    ...
    /* Write the page into the disk */
    e = RDsM_WriteTrain(BI_BUFFER(type, index), trainId, BI_BUFSIZE(type));
    if( e < 0 ) ERR( e );
    ...
}
```

Error Handling

- Error handling macro
  - ERR(e)
    - Write the error code *e* given as a parameter, the file name, and the position where the error occurred into the error log file (odysseus_error.log); return the error code.
    - Usage example

      ```
      if(retBuf == NULL) ERR(eBADBUFFER_BFM)
      ```

- Error code

  See the $(EduBfM_HOME_DIR)/Header/EduBfM_errorcodes.h file.

How to Do the Project

- Files used in the project
  - Files that students are to implement
    - Skeleton file (.c file)
      Files containing the functions whose implementation part is omitted
  - Files given to students
    - Object file (.o file)
      File that ODYSSEUS/COSMOS, which is the underlying system, is compiled as an object file. It contains all the functions in ODYSSEUS/COSMOS storage system including the given lower-level functions that are called in the modules to be implemented.
    - Header file (.h file)
      Files containing the definition of data structures and function prototypes used in the modules to be implemented and the test module
    - Source code file of the test module
      Source code file of the test module to test the functions in the implemented module
    - Executable solution file
      Executable file showing a correct test result
  - 기타 파일
    - Volume file (.vol file)
      File storing the data used during the test

- How to perform the project
  - Implement the functions in the skeleton files.
    - For the implementation, a variety of macros are available in the header files in the $(EduBfM_HOME_DIR)/Header directory.
  - Use the command make clean (deleting the object files and DB volumes) and make (compiling) to compile the skeleton files implemented and link them with the given object file.
    - As a result of compiling and linking, an executable file is created to test functions of the modules implemented.
  - Compare the execution results of your executable file with those of the given executable solution file.

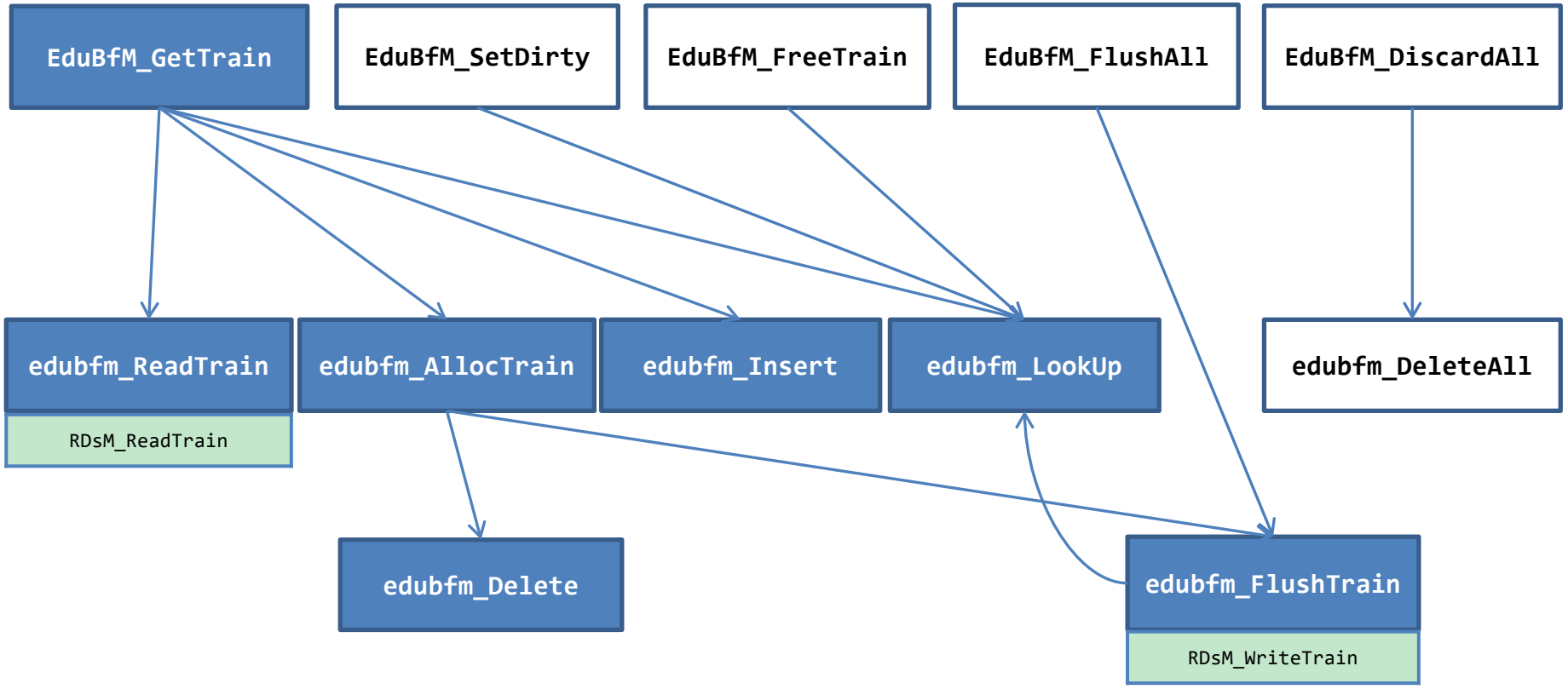
❖ How to test a function without implementing other functions
  ❖ In the file $(EduBfM_HOME_DIR)/Header/EduBfM_TestModule.h,
    ❖ For the API function that you have implemented, define the value of the corresponding macro to TRUE.
    ❖ For the API function that you have not implemented, define the value of the corresponding macro to FALSE.
  ❖ Enter the Make command to recompile the project.

❖ How to implement an API function without implementing some of its internal functions
  ❖ Use the default solution function (internal function name with the prefix "edu" omitted).
    ❖ e.g., the default solution function of the internal function edubfm_ReadTrain() is bfm_ReadTrain().

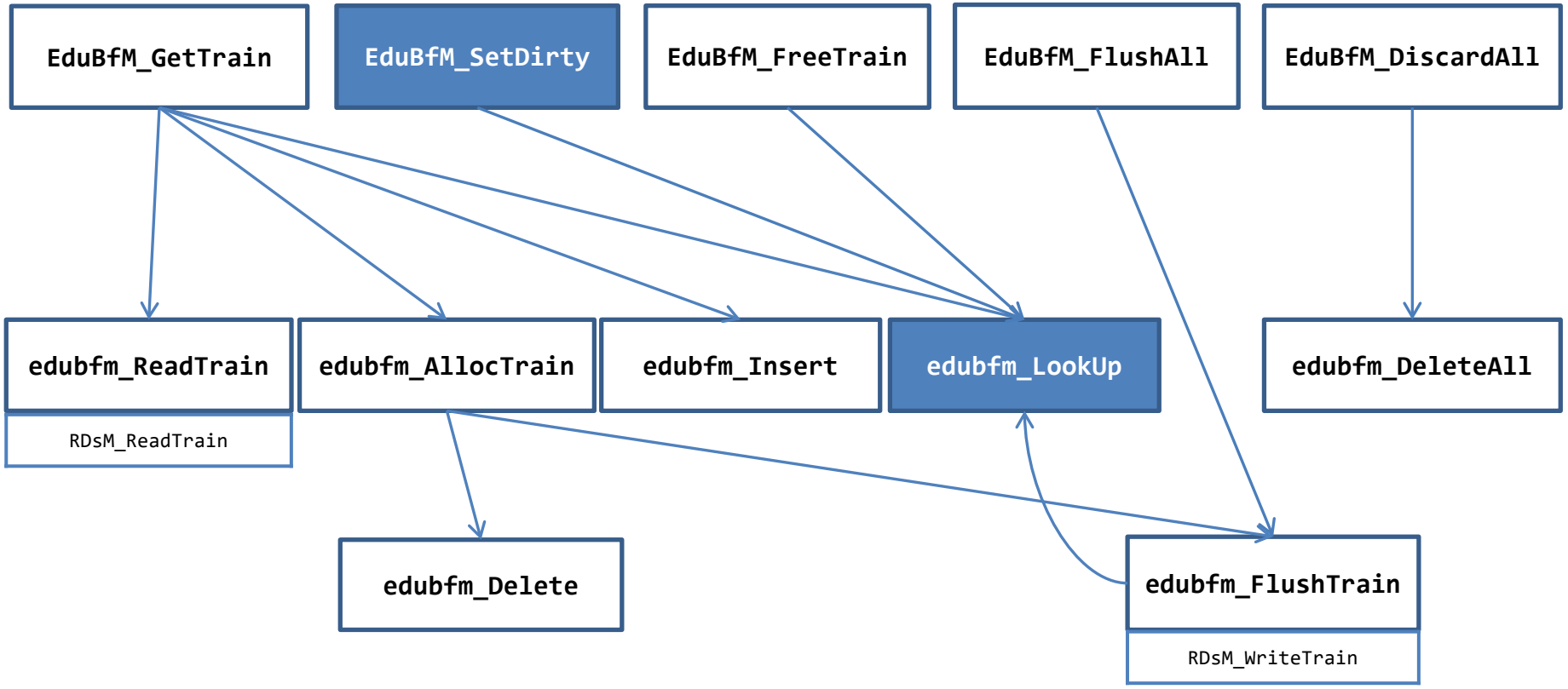
Appendix

Function Call Graph

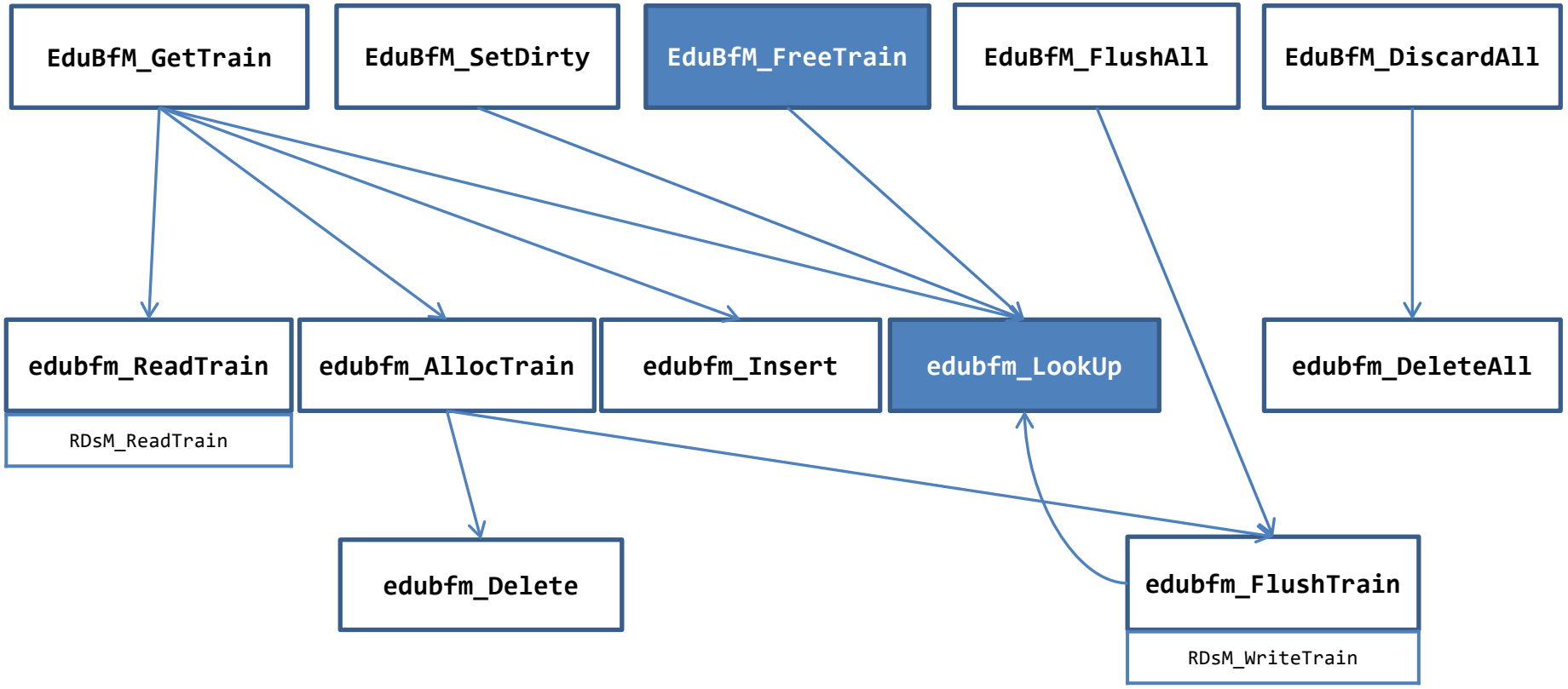
EduBfM_GetTrain



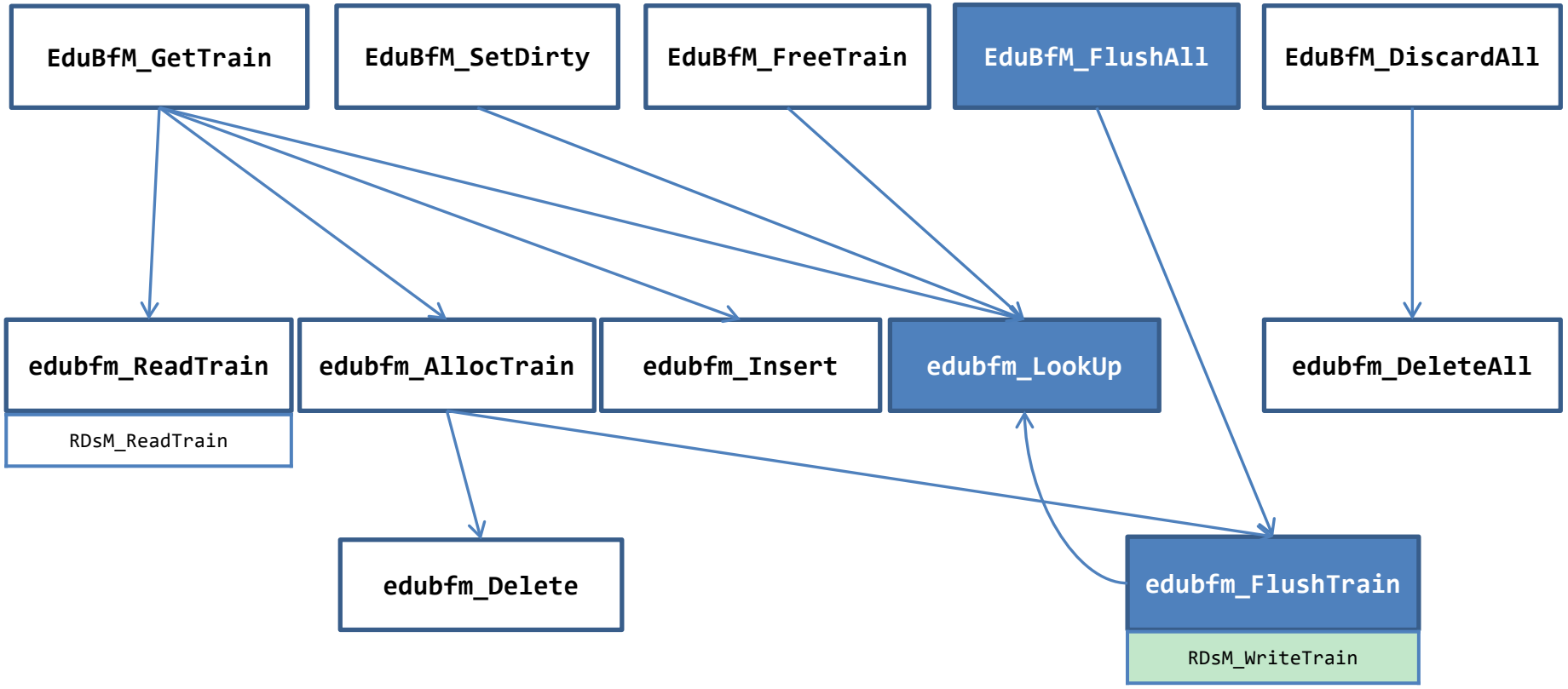
EduBfM_SetDirty



EduBfM_FreeTrain



EduBfM_FlushAll



EduBfM_DiscardAll