

# Lab 2 - SimpleDB

Database Systems, CS-UH 2214

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Assigned: March 13, 2020

Due: April 8, 2020

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*This lab is based on MIT's 6.830 - Database Systems course. The labs were initially created by Prof. Sam Madden.*

## 1 Overview

In this lab assignment, you will write a set of operators for SimpleDB to implement table modifications (e.g., insert and delete records), selections, joins, and aggregates. These will build on top of the foundation that you wrote in Lab 1 to provide you with a database system that can perform simple queries over multiple tables.

Additionally, we ignored the issue of buffer pool management in Lab 1: we have not dealt with the problem that arises when we reference more pages than we can fit in memory over the lifetime of the database. In Lab 2, you will design an eviction policy to flush stale pages from the buffer pool.

You do not need to implement transactions or locking in this lab.

The remainder of this document gives some suggestions about how to start coding, describes a set of exercises to help you work through the lab, and discusses how to hand in your code. This lab requires you to write a fair amount of code, so we encourage you to **start early**!

## 2 Getting started

You should begin with the code you submitted for Lab 1 (if you did not submit code for Lab 1, or your solution didn't work properly, contact us to discuss options).

### 2.1 Implementation hints

As before, we **strongly encourage** you to read through this entire document to get a feel for the high-level design of SimpleDB before you write code.

We suggest exercises along this document to guide your implementation, but you may find that a different order makes more sense for you. As before, we will grade your assignment by looking at your code and verifying that you have passed the test for the ant targets test and systemtest. Note the code only needs to pass the tests we indicate in this lab, not all of unit and system tests. See Section 4.3 for a complete discussion of grading and list of the tests you will need to pass.

Here's a rough outline of one way you might proceed with your SimpleDB implementation; more details on the steps in this outline, including exercises, are given in Section 3 below.

- Implement the operators `Filter` and `Join` and verify that their corresponding tests work. The Javadoc comments for these operators contain details about how they should work. We have given you implementations of `Project` and `OrderBy` which may help you understand how other operators work.
- Implement `IntegerAggregator` and `StringAggregator`. Here, you will write the logic that actually computes an aggregate over a particular field across multiple groups in a sequence of input tuples. Use integer division for computing the average, since SimpleDB only supports integers. `StringAggregator` only needs to support the `COUNT` aggregate, since the other operations do not make sense for strings.
- Implement the `Aggregate` operator. As with other operators, aggregates implement the `OpIterator` interface so that they can be placed in SimpleDB query plans. Note that the output of an `Aggregate` operator is an aggregate value of an entire group for each call to `next()`, and that the aggregate constructor takes the aggregation and grouping fields.
- Implement the methods related to tuple insertion, deletion, and page eviction in `BufferPool`. You do not need to worry about transactions.
- Implement the `Insert` and `Delete` operators. Like all operators, `Insert` and `Delete` implement `OpIterator`, accepting a stream of tuples to insert or delete and outputting a single tuple with an integer field that indicates the number of tuples inserted or deleted. These operators will need to call the appropriate methods in `BufferPool` that actually modify the pages on disk. Check that the tests for inserting and deleting tuples work properly.

Note that SimpleDB does not implement any kind of consistency or integrity checking, so it is possible to insert duplicate records into a file and there is no way to enforce primary or foreign key constraints.

At this point you should be able to pass the tests in the `ant systemtest` target, which is the goal of this lab.

You'll also be able to use the provided SQL parser to run SQL queries against your database!

Finally, you might notice that the iterators in this lab extend the `Operator` class instead of implementing the `OpIterator` interface. Because the implementation of `next/hasNext` is often repetitive, annoying, and error-prone, `Operator` implements this logic generically, and only requires that you implement a simpler `readNext`. Feel free to use this style of implementation, or just implement the `OpIterator` interface if you prefer. To implement the `OpIterator` interface, remove `extends Operator` from iterator classes, and in its place put `implements OpIterator`.

## 3 SimpleDB Architecture and Implementation Guide

### 3.1 Filter and Join

Recall that SimpleDB `OpIterator` classes implement the operations of the relational algebra. You will now implement two operators that will enable you to perform queries that are slightly more interesting than a table scan.

- *Filter*: This operator only returns tuples that satisfy a `Predicate` that is specified as part of its constructor. Hence, it filters out any tuples that do not match the predicate.
- *Join*: This operator joins tuples from its two children according to a `JoinPredicate` that is passed in as part of its constructor. We only require a simple nested loops join, but you may explore more interesting join implementations. Describe your implementation in your lab writeup.

**Exercise 1: [3 points] Implement the skeleton methods in:**

1. src/simpledb/Predicate.java
2. src/simpledb/JoinPredicate.java
3. src/simpledb/Filter.java
4. src/simpledb/Join.java

**Unit Tests to Pass:** At this point, your code should pass the unit tests in `PredicateTest`, `JoinPredicateTest`, `FilterTest`, and `JoinTest`. Furthermore, you should be able to pass the system tests `FilterTest` and `JoinTest`.

### 3.2 Aggregates

An additional SimpleDB operator implements basic SQL aggregates with a `GROUP BY` clause. You should implement the five SQL aggregates (`COUNT`, `SUM`, `AVG`, `MIN`, `MAX`) and support grouping. You only need to support aggregates over a single field, and grouping by a single field. Note that for Strings it is not required to support the aggregates `SUM` and `AVG`.

In order to calculate aggregates, we use an `Aggregator` interface which merges a new tuple into the existing calculation of an aggregate. The `Aggregator` is told during construction what operation it should use for aggregation. Subsequently, the client code should call `Aggregator.mergeTupleIntoGroup()` for every tuple in the child iterator. After all tuples have been merged, the client can retrieve a `OpIterator` of aggregation results. Each tuple in the result is a pair of the form `(groupValue, aggregateValue)`, unless the value of the group by field was `Aggregator.NO_GROUPING`, in which case the result is a single tuple of the form `(aggregateValue)`.

Note that this implementation requires space linear in the number of distinct groups. For the purposes of this lab, you do not need to worry about the situation where the number of groups exceeds available memory.

**Exercise 2: [3 points] Implement the skeleton methods in:**

1. src/simpledb/IntegerAggregator.java
2. src/simpledb/StringAggregator.java
3. src/simpledb/Aggregate.java

**Unit Tests to Pass:** At this point, your code should pass the unit tests `IntegerAggregatorTest`, `StringAggregatorTest`, and `AggregateTest`. Furthermore, you should be able to pass the `AggregateTest` system test.

### 3.3 HeapFile Mutability

Now, we will begin to implement methods to support modifying tables. We begin at the level of individual pages and files. There are two main sets of operations: adding tuples and removing tuples.

**Removing tuples:** To remove a tuple, you will need to implement `deleteTuple`. Tuples contain `RecordIDs` which allow you to find the page they reside on, so this should be as simple as locating the page a tuple belongs to and modifying the headers of the page appropriately.

**Adding tuples:** The `insertTuple` method in `HeapFile.java` is responsible for adding a tuple to a heap file. To add a new tuple to a `HeapFile`, you will have to find a page with an empty slot. If no such pages exist in the `HeapFile`, you need to create a new page and append it to the physical file on disk. You will need to ensure that the `RecordID` in the tuple is updated correctly.

**Exercise 3: [5 points] Implement the skeleton methods in:**

1. `src/simpledb/HeapPage.java`
2. `src/simpledb/HeapFile.java` (Note that you do not necessarily need to implement `writePage` at this point).
3. `src/simpledb/BufferPool.java/insertTuple()`
4. `src/simpledb/BufferPool.java/deleteTuple()`

To implement `HeapPage`, you will need to modify the header bitmap for methods such as `insertTuple()` and `deleteTuple()`. You may find that the `getNumEmptySlots()` and `isSlotUsed()` methods we asked you to implement in Lab 1 serve as useful abstractions. Note that there is a `markSlotUsed` method provided as an abstraction to modify the filled or cleared status of a tuple in the page header.

Note that it is important that the `HeapFile.insertTuple()` and `HeapFile.deleteTuple()` methods access pages using the `BufferPool.getPage()` method.

In order to do that, implement the following skeleton methods in `src/simpledb/BufferPool.java`: `insertTuple()` and `deleteTuple()`

**Unit Tests to Pass:** At this point, your code should pass the unit tests in `HeapPageWriteTest` and `HeapFileWriteTest`, as well as `BufferPoolWriteTest`.

### 3.4 Insertion and deletion

Now that you have written all of the `HeapFile` machinery to add and remove tuples, you will implement the `Insert` and `Delete` operators.

For plans that implement `insert` and `delete` queries, the top-most operator is a special `Insert` or `Delete` operator that modifies the pages on disk. These operators return the number of affected tuples. This is implemented by returning a single tuple with one integer field, containing the count.

- *Insert*: This operator adds the tuples it reads from its child operator to the `tableid` specified in its constructor. It should use the `BufferPool.insertTuple()` method to do this.
- *Delete*: This operator deletes the tuples it reads from its child operator from the `tableid` specified in its constructor. It should use the `BufferPool.deleteTuple()` method to do this.

**Exercise 4: [2 points] Implement the skeleton methods in:**

1. `src/simpledb/Insert.java`
2. `src/simpledb/Delete.java`

**Unit Tests to Pass:** At this point, your code should pass the unit tests in `InsertTest`. We have not provided unit tests for `Delete`. Furthermore, you should be able to pass the `InsertTest` and `DeleteTest` system tests.

### 3.5 Page eviction

In Lab 1, we did not correctly observe the limit on the maximum number of pages in the buffer pool defined by the constructor argument `numPages`. Now, you will choose a page eviction policy and instrument any previous code that reads or creates pages to implement your policy.

When more than `numPages` pages are in the buffer pool, one page should be evicted from the pool before the next is loaded. The choice of eviction policy is up to you; it is not necessary to do something sophisticated. Describe your policy in the lab writeup.

Notice that BufferPool asks you to implement a flushAllPages() method. This is not something you would ever need in a real implementation of a buffer pool. However, we need this method for testing purposes. You should never call this method from any real code.

Because of the way we have implemented ScanTest.cacheTest, you will need to ensure that your flushPage and flushAllPages methods do not evict pages from the buffer pool to properly pass this test.

flushAllPages should call flushPage on all pages in the BufferPool, and flushPage should write any dirty page to disk and mark it as not dirty, while leaving it in the BufferPool.

The only method which should remove page from the buffer pool is evictPage, which should call flushPage on any dirty page it evicts.

**Exercise 5: [2 points] Fill in the flushPage() method and additional helper methods to implement page eviction in:**

- src/simplydb/BufferPool.java

If you did not implement writePage() in HeapFile.java above, you will also need to do that here. Finally, you should also implement discardPage() to remove a page from the buffer pool *without* flushing it to disk. We will not test discardPage() in this lab, but it will be necessary for future labs.

**Unit Tests to Pass:** At this point, your code should pass the EvictionTest system test.

Since we will not be checking for any particular eviction policy, this test works by creating a BufferPool with 16 pages (NOTE: while DEFAULT\_PAGES is 50, we are initializing the BufferPool with less!), scanning a file with many more than 16 pages, and seeing if the memory usage of the JVM increases by more than 5 MB. If you do not implement an eviction policy correctly, you will not evict enough pages, and will go over the size limitation, thus failing the test.

You have now completed this lab. Good work!

### 3.6 Query walkthrough

The following code implements a simple join query between two tables, each consisting of three columns of integers. (The file some\_data\_file1.dat and some\_data\_file2.dat are binary representation of the pages from this file). This code is equivalent to the SQL statement:

```
SELECT *
FROM some_data_file1, some_data_file2
WHERE some_data_file1.field1 = some_data_file2.field1
AND some_data_file1.id > 1
```

For more extensive examples of query operations, you may find it helpful to browse the unit tests for joins, filters, and aggregates.

```
package simplydb;
import java.io.*;

public class jointest {

    public static void main(String[] argv) {
        // construct a 3-column table schema
        Type types[] = new Type[]{ Type.INT_TYPE, Type.INT_TYPE, Type.INT_TYPE };
        String names[] = new String[]{ "field0", "field1", "field2" };

        TupleDesc td = new TupleDesc(types, names);
```

```

// create the tables, associate them with the data files
// and tell the catalog about the schema the tables.
HeapFile table1 = new HeapFile(new File("some_data_file1.dat"), td);
Database.getCatalog().addTable(table1, "t1");

HeapFile table2 = new HeapFile(new File("some_data_file2.dat"), td);
Database.getCatalog().addTable(table2, "t2");

// construct the query: we use two SeqScans, which spoonfeed
// tuples via iterators into join
TransactionId tid = new TransactionId();

SeqScan ss1 = new SeqScan(tid, table1.getId(), "t1");
SeqScan ss2 = new SeqScan(tid, table2.getId(), "t2");

// create a filter for the where condition
Filter sf1 = new Filter(new Predicate(0,
    Predicate.Op.GREATER_THAN, new IntField(1)), ss1);

JoinPredicate p = new JoinPredicate(1, Predicate.Op.EQUALS, 1);
Join j = new Join(p, sf1, ss2);

// and run it
try {
    j.open();
    while (j.hasNext()) {
        Tuple tup = j.next();
        System.out.println(tup);
    }
    j.close();
    Database.getBufferPool().transactionComplete(tid);
} catch (Exception e) {
    e.printStackTrace();
}
}
}

```

Both tables have three integer fields. To express this, we create a `TupleDesc` object and pass it an array of `Type` objects indicating field types and `String` objects indicating field names. Once we have created this `TupleDesc`, we initialize two `HeapFile` objects representing the tables. Once we have created the tables, we add them to the Catalog. (If this were a database server that was already running, we would have this catalog information loaded; we need to load this only for the purposes of this test).

Once we have finished initializing the database system, we create a query plan. Our plan consists of two `SeqScan` operators that scan the tuples from each file on disk, connected to a `Filter` operator on the first `HeapFile`, connected to a `Join` operator that joins the tuples in the tables according to the `JoinPredicate`. In general, these operators are instantiated with references to the appropriate table (in the case of `SeqScan`) or child operator (in the case of e.g., `Join`). The test program then repeatedly calls `next` on the `Join` operator, which in turn pulls tuples from its children. As tuples are output from the `Join`, they are printed out on the command line.

### 3.7 Query Parser

We've provided you with a query parser for SimpleDB that you can use to write and run SQL queries against your database once you have completed the exercises in this lab.

The first step is to create some data tables and a catalog. Suppose you have a file `data.txt` with the following contents:

```
1,10
2,20
3,30
4,40
5,50
5,50
```

You can convert this into a SimpleDB table using the `convert` command (make sure to type `ant` first!):

```
java -jar dist/simplydb.jar convert data.txt 2 "int,int"
```

This creates a file `data.dat`. In addition to the table's raw data, the two additional parameters specify that each record has two fields and that their types are `int` and `int`.

Next, create a catalog file, `catalog.txt`, with the following contents:

```
data (f1 int, f2 int)
```

This tells SimpleDB that there is one table, `data` (stored in `data.dat`) with two integer fields named `f1` and `f2`.

Finally, invoke the parser. You must run `java` from the command line (`ant` doesn't work properly with interactive targets.) From the `simplydb/` directory, type:

```
java -jar dist/simplydb.jar parser catalog.txt
```

You should see output like:

```
Added table : data with schema INT(f1), INT(f2),
SimpleDB>
```

Finally, you can run a query:

```
SimpleDB> select d.f1, d.f2 from data d;
Started a new transaction tid = 1221852405823
  ADDING TABLE d(data) TO tableMap
    TABLE HAS tupleDesc INT(d.f1), INT(d.f2),
1      10
2      20
3      30
4      40
5      50
5      50

  6 rows.
-----
0.16 seconds

SimpleDB>
```

The parser is relatively full featured (including support for `SELECT`s, `INSERT`s, `DELETE`s, and transactions), but does have some problems and does not necessarily report completely informative error messages. Here are some limitations to bear in mind:

- You must preface every field name with its table name, even if the field name is unique (you can use table name aliases, as in the example above, but you cannot use the `AS` keyword.)
- Nested queries are supported in the `WHERE` clause, but not the `FROM` clause.
- No arithmetic expressions are supported (for example, you can't take the sum of two fields.)
- At most one `GROUP BY` and one aggregate column are allowed.
- Set-oriented operators like `IN`, `UNION`, and `EXCEPT` are not allowed.
- Only `AND` expressions in the `WHERE` clause are allowed.
- `UPDATE` expressions are not supported.
- The string operator `LIKE` is allowed, but must be written out fully (that is, the Postgres tilde [`~`] shorthand is not allowed.)

## 4 Logistics

You must submit your code (see below) as well as a short (2 pages maximum) writeup describing your approach. This writeup should:

- Describe any design decisions you made, including your choice of page eviction policy. If you used something other than a nested-loops join, describe the tradeoffs of the algorithm you chose.
- Discuss and justify any changes you made to the API.
- Describe any missing or incomplete elements of your code.
- Describe how long you spent on the lab, and whether there was anything you found particularly difficult or confusing.

### 4.1 Submission

You will package your entire project into a folder with the title: 'Lab1-netID1-netID2-netID3'. **Zip this folder** and submit via Dropbox using this link.

<http://bit.ly/CSUH2214-S20-Lab2>

Only one student per group should submit and that student should always submit/resubmit to avoid multiple submissions per group.

In each folder, please include a readme file that includes a comma separated list of each member's full name.

**We will not grade any submission that does not strictly follow the submission rules.**

### 4.2 Collaboration

This lab should be manageable for a single person, but if you prefer to work in a group of up to three students, this is also OK. Larger groups are not allowed.

*If you choose to work in a group, you need to determine how best to meet and work together online. In line with the university policy, group in-person gatherings are discouraged. If you cannot agree on a suitable and safe online meeting method before starting the lab, we strongly discourage you from working in a group.*



### 4.3 Grading

Most of your grade will be based on whether or not your code passes the system test suite we will run over it. These tests will be a superset of the tests we have provided. Before handing in your code, you should make sure it produces no errors (passes all of the tests) from both `ant test` and `ant systemtest`.

**Important:** before testing, we will replace your `build.xml`, `HeapFileEncoder.java`, and the entire contents of the `test/` directory with our version of these files! This means you cannot change the format of `.dat` files! You should therefore be careful changing our APIs. This also means you need to test whether your code compiles with our test programs.

In other words, we will pull your repo, replace the files mentioned above, compile it, and then grade it. It will look roughly like this:

```
[replace build.xml, HeapFileEncoder.java, and test]
$ #our tool to replace build.xml, HeapFileEncoder.java, and test
$ ant test
$ ant systemtest
[additional tests]
```

If any of these commands fail, we'll be unhappy, and, therefore, so will your grade.

An **additional significant portion** of your grade will be based on the quality of your writeup and our subjective evaluation of your code.