Technical University of Denmark

42137 Optimization using Metaheuristics

University Timetabling

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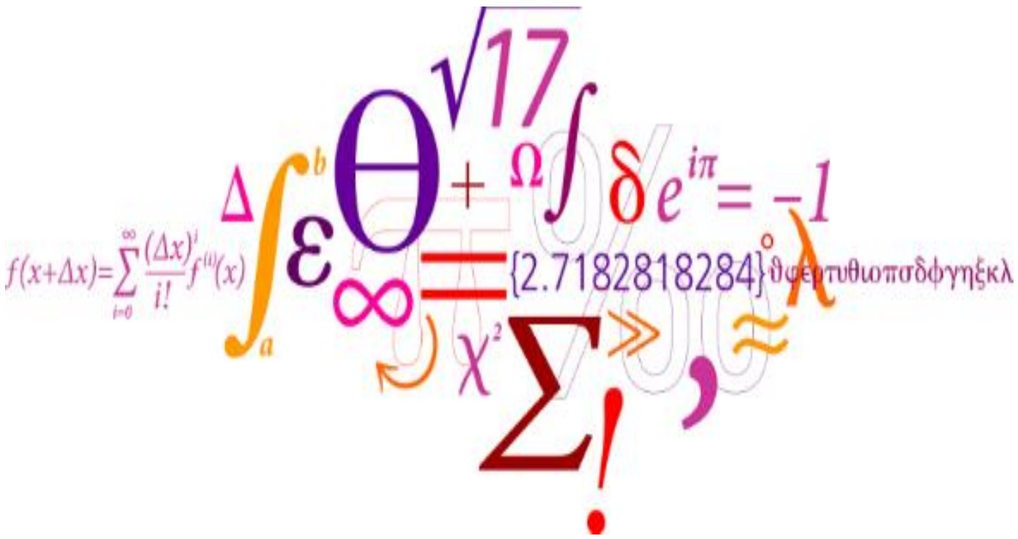

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Abstract

This report will investigate the implementation of Metaheuristic on the university timetabling problem and examine the outcomes. A brief introduction of the problem is initially outlined. Several Metaheuristic methods such as Hill Climber and Simulated Annealing with Taboo Search are applied to minimize and measure the objective value. Parameter tuning is also performed and the comparison of the results of each method is drawn.

1.0 Introduction

Every semester universities face the problem of creating good feasible timetable due to many complex constraints that have to be taken into consideration. Associated penalties will be assigned if the constraint is violated. The purpose of this report is to plan as many lectures as possible and avoid unwanted attributes to minimize the objective which is the penalty. Given a specific time limit, we can run Hill Climbing, Simulated Annealing and TABU to find the best solution (which may not be the best possible solution) to the problem. Providing the universities an optimization tool can help them to smooth out the planning and better utilize their resources.

2.0 Problem Description

This problem consists of weekly scheduling of the lectures of the courses within a certain number of rooms and time periods, where conflicts between courses are set according to the curricula published by the university. Due to the complexity, the formulation of the problem is simplified and more attributes could be added to enhance the quality of scheduling. In addition to that, this problem consists of several entities, constraints and components of the objective.

2.1 Entities

- Days, Periods and Timeslots
  Given a fixed number of days per week and each day is split into a certain number of periods. A timeslot is a pair of day and periods.

- Courses and Lectures
  Each course that taught by only a lecturer has a required number of lectures to be given and each course will be attended by an associated number of students. Lectures of each course must be spread into a minimum number of working days, moreover there are some periods that a lecture cannot be scheduled in.

- Rooms
  Each room has a capacity, expressed in term of available seats.

- Curricula
  A curriculum is a group of courses that any pair of the courses have students in common.

The solution of the problem is a number of assignments of lectures to a time slot (day and period) and a room.

2.2 Constraints

The following constraints have to be obeyed in order to produce a feasible timetable.

- **Lecture**

  A predetermined amount of lectures is assigned to each course. Each lecture must be scheduled in different time slot and the total number of lectures cannot be exceeded.

- **Room Occupancy**

  Each room can only accommodate one course in a specific time slot.

- **Conflicts**

  Lectures of courses in the same curriculum or taught by the same lecturer must be assigned in distinct time slots.

- **Availabilities**

  Some courses cannot be scheduled at specific time slots.

2.3 Objective

Several attributes contribute to the objective and each unwanted attribute has an associated penalty value.

Unscheduled Lectures

Each course has a lecture that is not scheduled will be penalized 10 points.

Room Capacity

For each lecture, the number of students attending the course must be less than or equal to the number of seats in the room. Each student over the capacity will be penalized 1 point.

Minimum Working Days

Lectures of each course must be spread into a minimum number of working days. Each day below the minimum working day will be penalized 5 points.

Curriculum Compactness

For any given curriculum, a lecture is considered as a secluded lecture if it is not adjacent to any other lecture from the same curriculum within the same day. Each secluded lecture will be penalized 2 points.

Room Stability

All lectures of a course should be given in the same room. Each extra room used will be penalized 1 point.

2.4 Mathematical Model

The problem is represented by a mathematical model. Sets and parameters are defined as well as variables, constraints and the objective.

Sets

C – The set of courses

L – The set of lecturers

R – The set of rooms

Q – The set of curricula

T – The set of time slots. I.e. all pairs of days and periods

D – The set of days

T (d) – The set of time slots that belongs to day $d \in D$

C (q) – The set of courses that belongs to curriculum $q \in Q$

Parameters

L_c – The predetermined amount of lecture of each course $\in C$

C_r – The capacity of a room $\in R$

S_c – Number of students attending course c

M_c – Minimum number of working days that the course should be spread to

$F_{c,t}$ – 1 if the course $c \in C$ is available at time slot $t \in T$, otherwise 0

$X(c_1,c_2)$ – 1 if course $c_1 \in C$ which is different from course $c_2 \in C$ ($c_1 \neq c_2$) and conflicting, otherwise 0

$V(t_1,t_2)$ – 1 if the timeslot t_1 and t_2 which belongs to the same day and adjacent to each other, otherwise 0

Decision Variables

$X_{c,t,r}$ – 1 if class c ϵ C is allocated to room r ϵ R and timeslot r ϵ R, otherwise 0

Constraints and Functions

Each course can at most be assigned one room at a specific timeslot and only if the course is available for the timeslot.

$$\sum_{r \in \mathrm{R}} Xc,t,r \ \le Fc,t \quad \forall c \in \mathrm{C}, \mathrm{t} \in \mathrm{T}$$

Each room can accommodate at most one course in a given timeslot.

$$\sum_{c \in \mathrm{C}} Xc,t,r = 1 \quad \forall t \in \mathrm{T}, \mathrm{r} \in \mathrm{R}$$

Each course can at most be assigned to a maximum number of lectures.

$$\sum_{t \in \mathrm{T}, \mathrm{r} \in \mathrm{R}} Xc,t,r \le Lc \quad \forall c \in \mathrm{C}$$

Conflicting course are not allowed to be scheduled in the same timeslot.

$$\sum_{r \in \mathrm{R}} Xc1,\mathrm{t},\mathrm{r} + \sum_{r \in \mathrm{R}} Xc2,t,r \ \le 1 \ \forall c1,c2 \in \mathrm{C}, \mathrm{t} \in \mathrm{T}: \mathrm{X}(\mathrm{c1},\mathrm{c2}) = 1$$

The function $V_{t,r}(x)$ indicates the amount of capacity that room r ϵ R is exceeded in timeslot t ϵ T.

$$Vt,r(x) = \max\{0, Cr - \sum_{c \in \mathrm{C}} Sc \cdot Xc,t,r\}$$

Function $U_{c}(x)$ indicates the amount of lectures by which course c ϵ C is scheduled below the specified value Lc.

$$Uc(x) = \max\{0, Lc - \sum_{t \in \mathrm{T}, \mathrm{r} \in \mathrm{R}} Xc,t,r\}$$

Function $P_{c}(x)$ indicates the number of room changes by a course c ϵ C.

$$Pc(x) = \max\{0, ||\{r \in \mathrm{R} \mid \sum_{t \in \mathrm{T}} Xc,t,r \ \ge 1\}|| - 1\}$$

Function $W_{c(x)}$ indicates the number of days that the course is scheduled below the minimum working number of days.

$$Wc(x) = \max\{0, Mc - ||\{d \in \mathrm{D}| \sum_{t \in \mathrm{T(d)}, \mathrm{r} \in \mathrm{R}} Xc,t,r \geq 1\}|| \}$$

Function $A_{q,t(x)}$ determines if a curriculum in a timeslot has a secluded lecture.

$$\mathrm{Aq,t(x)}=\{ 1 \text{ if } \sum_{c \in \mathrm{C(q)}, \mathrm{r} \in \mathrm{R}} \mathrm{Xc,t,r}=1 \wedge \sum_{\substack{c \in \mathrm{C(q)}, \mathrm{r} \in \mathrm{R}, \\ t' \in \mathrm{T:V(t,t')=1}}} Xc,t',r = 0, otherwise\ 0 \}$$

Objective

The objective function is the summation of the penalties.

$$10 \cdot \sum_{c \in \mathrm{C}} Uc(x) + 5 \cdot \sum_{c \in \mathrm{C}} Wc(x) + 2 \cdot \sum_{q \in \mathrm{Q}, \mathrm{t} \in \mathrm{T}} Aq,t(x) + 1 \cdot \sum_{c \in \mathrm{C}} Pc(x) + 1 \cdot \sum_{t \in \mathrm{T}, \mathrm{r} \in \mathrm{R}} Vt,r(x)$$

Complete Model

$$\min 10 \cdot \sum_{c \in \mathrm{C}} Uc(x) + 5 \cdot \sum_{c \in \mathrm{C}} Wc(x) + 2 \cdot \sum_{q \in \mathrm{Q}, \mathrm{t} \in \mathrm{T}} Aq,t(x) + 1 \cdot \sum_{c \in \mathrm{C}} Pc(x) + 1 \cdot \sum_{t \in \mathrm{T}, \mathrm{r} \in \mathrm{R}} Vt,r(x)$$

Subject to

$$\sum_{r \in \mathrm{R}} Xc,t,r \leq Fc,t \quad \forall c \in \mathrm{C}, \mathrm{t} \in \mathrm{T} \qquad (1)$$

$$\sum_{c \in \mathrm{C}} Xc,t,r = 1 \quad \forall t \in \mathrm{T}, \mathrm{r} \in \mathrm{R} \qquad (2)$$

$$\sum_{t \in \mathrm{T}, \mathrm{r} \in \mathrm{R}} Xc,t,r \leq Lc \quad \forall c \in \mathrm{C} \qquad (3)$$

$$\sum_{r \in \mathrm{R}} X\mathrm{c1,t,r} + \sum_{r \in \mathrm{R}} Xc2,t,r \leq 1 \ \forall c1, c2 \in \mathrm{C}, \mathrm{t} \in \mathrm{T}: \mathrm{X(c1,c2)} = 1 \qquad (4)$$

$$Xc,t,r \in \{0,1\} \qquad \forall c \in \mathrm{C}, \mathrm{t} \in \mathrm{T}, \mathrm{r} \in \mathrm{R}$$

3.0 Implementation of Classes

9 classes are created for easy maintenance which include University Timetabling, Heuristic, Basic Info, Courses, Curriculum, Lecturers, Rooms, Schedule, and Unavailability. Explanation of variables and functions created within the class will be discussed briefly as below.

3.1 University Timetabling

The purpose of this class is to read the data from given data files, find the best schedule which minimize the objective and write it into a CSV file for drawing chart and the purpose of parameter tuning.

3.1.1 Variables

Firstly, files such as basicFile, coursesFile, lecturersFile, roomsFile, curriculaFile, relationFile, unavailabilityFile are created to keep the information of input files. Then, a variable heuristic of type of Heuristic (self-defined class) is created to record the data from the files mentioned above. Followed by generating an initial schedule of type of Schedule (self-defined class) and searching for the optimum.

3.1.2 Functions

There are 2 functions operating in this class, which are the main function and startwithParameters function. In the main function, there are 2 options which the program can choose from to start running, one is solve the problem without benchmarking and another one is solve the problem several times and output the intermediate results. Meanwhile startWithParameters function operates as reading data from the input files.

3.2 Heuristic

This class is abstract and must be implemented according to the chosen heuristic. It will perform a search with the input schedule as a starting point and return the most optimal schedule.

3.2.1 Variables

Several variables are created such as basicInfo (type of Basic Info), curriculum (type of Curriculum), lecturers (type of Lecturers), courses (type of Courses), unavailability (type of Unavailability), rooms (type of Rooms) to contain the given data. In addition to that, other variables such as timeout (integer), countdownStartTime (long), iterationCount (int), int[] courseAssignmentCount are also created.

3.2.2 Functions

Numerous number of methods are created in Heuristic and some important functions are shown in the list below.

1. Public Boolean validateSameLecturerConstraint(Schedule schedule)
   - Check that the courses taught by same lecturer are not scheduled in the same timeslot.
   - Return true if the constraint is satisfied.

2. Public Boolean validateSameCurriculumConstraint(Schedule schedule)
   - Check that the courses grouped in same curriculum are not scheduled in the same timeslot.
   - Return true if the constraint is satisfied.

3. Public Boolean validateAvailabilityConstraint(Schedule schedule)
   - Check that courses are not scheduled in unavailable timeslot.
   - Return true if the constraint is satisfied.

4. Protected int[] getCourseAssignmentCount(Schedule schedule)
   - Returns an array containing the number of times of each course has been scheduled

5. Public Boolean validateMaximumScheduleCountConstraint(Schedule schedule)
   - Validate that no course has been scheduled more than minimum number of times
   - Return true if the constraint is not violated

6. Public Schedule getRandomInitialSolution()
   - Generate a random initial schedule

7. Public int evaluationFunction(Schedule schedule)
   - Calculate the objective value of the schedule

3.3 Classes Reading Input

3.3.1 Basic Info

A function, Public void loadFromFile(String file) is created to read the number of courses, rooms, days, period per day, curricula, constraints and lecturers from the input file.

3.3.2 Curriculum

The purpose of this class is to keep the relation between the courses and curriculum. If a course belongs to a curriculum, the Boolean array isCourseInCurriculum[][] will return true. A public void loadFromFile(String curriculaFile, String relationFile, int numberOfCourses) function is created to read the data from curriculaFile and relationFile and store assignments as an array of Booleans.

3.3.3 Courses

The purpose of this class is to store the information such as lecturer for each course, number of lectures of each course, minimum working days of each course and number of students of each course.

3.3.4 Lecturers

Integer array, int[] lecturers is created to store the identity of lecturers. A public void loadFromFile(String file) function is created to read the data from a lecturers file.

3.3.5 Rooms

Integer array, int[] capacityForRoom is created to store the number of seats in a given room. A public void loadFromFile(String file, int numberOfRooms) function is created to read the data from a Rooms file.

3.3.6 Schedule

The purpose of this class is to store the schedule that expressed in term of [day][period][room]. A public void Schedule(int days, int periods, int rooms) function is created and first initialized all assignments to -1, which means that no course is assigned to the timeslot and room. Another method which is public String toString() will print the solution.

3.3.7 Unavailability

Boolean array is created such as boolean[][][] courseUnavailable which expressed in term of [day][period][course]. Return true if a course is unavailable in the specific timeslot. A public void loadFromFile(String file, int numberOfDays, int numberOfPeriods, int numberOfCourses) function is created to read the data from a unavailability file.

3.4 XORShiftRandom

It is a faster, higher quality replacement for java.util.Random. This class is called when generating initial random solution.

4.0 Metaheuristics

4.1 Hill Climber Heuristic:

Hill Climbing heuristic is an iterative local search method. It starts with and arbitrary solution and it tries to find a better solution by searching in the neighborhood. If it finds a better solution then it saves it as a current state then in the next iteration it start from there. The algorithm terminates If the time limit reached and return the best solution.

Algorithm Hill Climber

```
$Select\ initial\ solution\ \ s_0$
$s^* = s_0$
$repeat$
        $select\ s\ \in N(s^*)$
        $if\ f(s) > f(s^*)\ then$
            $s^* = s$
$until\ time\ limit\ is\ reached$
$return\ s^*$
```

The problem with the Hill climber Heuristic algorithm it usually stocks in the local optima and couldn't find a good solution.

4.2 Simulated Annealing:

Algorithm Simulated Annealing

```
$p(\delta, t_i)\ select\ initial\ solution\ s$
$T = T_{start}$
$s^* = s_0$
$repeat$
        $select\ s\ \in N(s^*)$
        $\delta = f(s) - f(s^*)$
        $if\ \delta < 0\ or\ with\ probablity\ \ p(\delta, t_i)\ then$
                $s^* = s$
```

```
    $t_{i+1} = t_i * \alpha$
$until\ stopping\ criterion\ is\ true$
```

Simulated Annealing is a probabilistic optimization methods that uses the idea of annealing process of thermodynamics so that it calculates the acceptance probability as follows;

$$p(\delta, t_i) = e^{-\delta/t_i}$$

Where t_i is the temperature at step i . So that if the temperature value is high enough the algorithm will choose the candidate solution even if it's not better than the previous one when algorithm iterates though the temperature will decrease in each iteration with given temperature change (α) parameter thus after some iteration if the algorithm couldn't find a better solution then it won't accept the candidate solution.

4.3 TABU:

TABU is a metaheuristic method that uses both local search paradigm and memory for optimization. In every iteration TABU calculates the neighbors of current state and choose the best one. For the next iteration as a starting point If the best neighbor is better than the best solution then it saves as a best solution. The main advantage of the TABU is it escapes the local optima by choosing best neighbor state even if has worse solution. On the other hand using memory it remembers the action that accomplishes the best neighbor state and that it uses that information to break cycling. (It doesn't allow the action that is the reverse of the previous actions that accomplish the previous best neighbors).

Algorithm TABU Search

```
$Select\ initial\ solution\ \ s$
$s^* = s$
$k\ = 1$
$repeat$
    $Generate\ \ V\ \subseteq N(s,k) \subseteq N(s)$
    $select\ the\ best\ s'\ in\ V$
    $s = s'$
    $if(\ s) < f(\ s^*)\ then$
            $s^* =\ s$
    $k\ = k + 1$
$until\ time\ limit\ is\ reached$
$return\ s^*$
```

5.0 Implementation of Metaheuristics

Hill Climber Heuristic:

In our implementation of Hill Climber we use the idea of stochastic Hill Climber method. First, the algorithm chooses day, period and room randomly and acts depend on the chosen slot. If the randomly chosen slot is empty then it chooses a course randomly and calculate the new state if it assign the chosen course to chosen time slot if it's a better solution then it select it as current state. If the given day, period room slot is not empty then algorithm tries to remove the course in given slot and calculate the value if the new value is better than it applies the remove method to the current state and saves it. The algorithm runs until the time limits is reached. Thus in each iteration algorithm selects the best action (remove or assign) then saves the action output depend on the value it produce.

Since iteration though all day, periods and room is costly for each iteration we decided to get those values by randomly. The problem of the stochastic idea is every time we run the algorithm it can generate worse solution but with the enough time limit it finds a fusible solution because it is too fast.

Pseudo Code Stochastic Hill Climber

```
Search ($s_0$ )
repeat
        select day, period, room randomly
        if the $s_i$[ day][period][room] is empty then
            select course randomly
            $s_{i+1} = AssignCourse(s_i, day, period, room, course)$
            If f($s_{i+1}$) >f($s_i$) then
                $s_{i+1} = s_i$
        if the $s_i$[ day][period][room] is not empty then
            $s_{i+1} = RemoveCourse(s_i, day, period, room)$
            If f($s_{i+1}$) >f($s_i$) then
                $s_{i+1} = s_i$

until time limit is reached
return s
```

Simulated Annealing Heuristic:

In Simulated Annealing Heuristic we have 3 different action assign a course , remove a course , swap courses each iteration the algorithm calculates the new state values accomplished by those there actions and chooses the best action in current state. After deciding the best action, it calculates the delta and if the delta is negative (which means the best action gives better result) then it runs the best action and save the new state if the delta is not negative (which means the best action gives worse solution) then it calculates the probability of the state (with current delta and temperature) and it does it runs the best action and save the new state according to the probability value. Similar to stochastic Hill Climber, Simulated Annealing chooses the day, period, room slot randomly but tries to generate new slots until it finds an action that doesn't violate any hard constraint. The temperature is decreased at the end of each iteration. The speed of decrease is determined by the temperature change parameter.

Pseudo Code Simulated Annealing

```
Search ($s_0$ ,$T_{start}$, $\alpha$)
$T = T_{start}$
repeat
    repeat
        select day, period, room randomly
        Calculate new solution by assign, remove and swap operations
    Until at least one of the actions has no hard Constraint violations
    choose best action $m \in$ {Remove,Assign,Swap} has lowest $f(s_i \oplus m)$
        $\delta = f(s) - f(s_i \oplus m)$
    if $\delta < 0$ or with probablity $p(\delta, t_i)$ then
        $s_{i+1} = s_i \oplus m$
    $t_{i+1} = t_i * \alpha$

until time limit is reached
return s
```

TABU:

The algorithm iterates through all time slots and rooms, generating all possible neighbor based on the current time slot. The value change is computed for each neighbor, and the best solution encountered in the current iteration is kept in memory. The best neighbor encountered in an iteration becomes the current solution in the next iteration. To determine the possible number of neighbors, we calculate the following numbers:

d = number of days

p = number of periods per days

r = number of rooms

N(R) = number of neighbors from remove

N(S) = number of neighbors from swap

N(A) = number of neighbors from assign

N(R) = d*p*r (at most because program discards the day, period and room slots if it's already empty).

N(S) = d*(d-1)*p*(p-1)*r*(r-1) (at most because program discards the empty slots).

N(A) = d*p*r (at most because program discards the non-empty slots).

Thus the maximum number of neighbors calculated in one iteration

N(T) = N(R) + N(A) + N(S) = d*p*r + N(S) = d*p*r + d*(d-1)*p*(p-1)*r*(r-1) (if all the time slots are not empty)

After each iteration the algorithm chooses the best neighbors and save it for next iteration to start with. And if the current best neighbors has better solution than it also saves the best neighbor's schedule into the best schedule. And add the operation that gives the best neighbor to the taboo list.

Pseudo Code TABO

```
Search ($s_0$ , $tabooLength$)
$s^* = s_0$
$repeat$
    $for\ each\ slot\ t\ s\{day, period, room\}$
        $if\ \ t\ is\ not\ empty$
            $s_n\ = RemoveAt(t)$
                $if\ f(s_n) < f(s')$ and $RemoveAt(t)$ is not tabu
                    $s' =\ s_n$
            $for\ each\ slot\ in\ t_2\ s\{day, period, room\}$
                $if\ \ t_2\ is\ not\ empty$
```

```
                        $s_n = SwapAt(t, t_2)$
                        $if\ f(s_n) < f(s')$ and $SwapAt(t, t_2)$ is not tabu
                            $s' = s_n$
                end for
            $if\ t\ is\ empty$
                $for\ each\ courses\ c\ \in CourseList$
                    $s_n = AssignAt(t, c)$
                    $if\ f(s_n) < f(s')$ and$AssignAt(t, c)$ is not tabu
                    $s' = s_n$
                end for
        end for
            $s = s'$
            add$TabooAssignAt(s_n)$
    $if\ f(s') < f(s^*)$
            $s^* = s'$
$until\ time\ limit\ is\ reached$
$return\ s^*$
```

6.0 Neighborhood Function

The neighbors of a solution are the set of different solutions, that are in some sense “next to” the solution. The concept can be interpreted geometrically by imagining all the possible solutions to our problem mapped as points in some *n*-dimensional space. The neighbors of a solution are then those points that are reachable without going through some other point.

For the university time tabling problem, a solution consists of a set of assignments consisting of a course, a time slot and a room. Each solution has an associated *value*, which is given by the objective function. To manipulate the solution, we can either *add* or *remove* a course assignment. Using these two basic operations allows us to permute any solution into any other solution. Thus we can define the set of neighbors *N(s)* for a solution *s* to be any solution that can be reached by applying exactly one basic operation to that solution, subject to the constraints given in the problem description.

Using this definition of the neighborhood, each solution has at most *time slots* × *rooms* × *courses* neighbors. The definition does have the problem that we rarely increase the solution value by removing a course, and as such this operation will be relatively infrequent (though still present) during iteration with Hill Climbing and TABU search. It seems intuitively more appealing to *swap* two scheduled courses and evaluate the resulting change in solution value. We therefore define the neighborhood of a solution to be those solutions that can be reached by *adding* or *removing* a lecture or by *swapping* two scheduled lectures.

Amending the definition of the neighborhood increases its size, and therefore the work involved in each iteration, but will hopefully yield better solutions with fewer iterations. Informal testing during development shows that this is indeed the case for the provided test data sets.

7.0 Delta Evaluation

As the heuristic explores the neighborhood around a solution, it must evaluate the value of each neighbor. This can be implemented naïvely by simply running the objective function on each neighbor. This approach is correct, but will be prohibitively slow for any but the simplest problems. In our problem, the objective function will need to at least consider every room and time slot, yielding a running time of at least *O(time slots* × *rooms* × *courses)*. In addition to this, some of the penalties requires the algorithm to examine the curricula associated with each course and its neighbors.

Delta evaluation is an alternative approach that enables a faster evaluation of a proposed change to a solution. By keeping track of the solution state, we can determine the impact of a basic operation much faster than we can compute the value of an entire solution. In general, implementing delta evaluation is a tradeoff between running time improvements vs. added code complexity and increased memory consumption.

Our implementation of delta evaluation is based on the following key insights:

- *Adding* or *removing* a course lecture only affects the course itself, and possibly its neighbors due to the penalty associated with secluded lecture.
- The *swap* operation can be implemented as a series of *add* and *remove* operations.

- We must store the total solution value during execution and then adjust it when performing an operation.
- Most of the state can be efficiently maintained such that reading and updating it is a *O(1)* operation.

Our implementation uses counters and flags stored in arrays to enable constant-time lookup. Overall, computing the delta for an operation is done in *O(q)* time, with *q* being the number of curricula associated with the given course.

We use the following variables to perform delta evaluation:

```
// The total number of times that each course has been scheduled.
int[] courseAssignmentCount;
// The number of lectures assigned for a course on a given day.
int[][] courseLecturesOnDay;
// The number of working days for a course.
int[] courseWorkingDays;
// The number of lectures for a course scheduled in a given room.
int[][] lecturesInRoomForCourse;
// Is a lecturer busy on a given time?
boolean[][][] lecturerBusy;
// Is a given curriculum is assigned on a day and period.
boolean[][][] curriculumAssigned;
```

Each variable is updated when an operation is performed. The ability to evaluate neighbors in near-constant time allows us to iterate orders of magnitude faster than invoking the objective function for each neighbor. The state variables above also allows us to check constraints in O(1) (see the DeltaState class for implementation of this functionality.)

8.0 Parameter Tuning

In this section, the report will present a brief discussion about parameter tuning, followed by the parameter tuning of Simulated Annealing and TABU.

In Parameter tuning, it will calculate average (gap) performance which is $Ed = \frac{1}{N}\sum_{i=1}^{N}\frac{(z_i - z_{opt})}{z_{opt}} * 100$ where zopt stands for the optimal value among certain results. Meanwhile, standard deviation is measured by using this formula, std_d = $\sqrt{\frac{\sum_{i=1}^{N}(z_i - u_d)^2}{N}}$ $where\ u_d = \frac{\sum_{i=1}^{N} z_i}{N}$.

Hill Climbing

The case of Hill Climbing is the simplest, since it does not take any parameters. We simply run the algorithm 8 times for each data set to obtain the following table of statistics from each data set:

Dataset	Avg. value	Stdev	Optimal value
1	627	31	578
2	1276	60	1176
3	1023	50	951
4	1030	52	951
5	1312	38	1259
6	1717	52	1625
7	1962	57	1914
8	1298	82	1185
9	1102	69	1016
10	1566	53	1457
11	582	16	556
12	1686	62	1577
13	1186	32	1141

Simulated Annealing

For the case of Simulated Annealing Method, 2 parameters are used which are temperature and cooling temperature. In this project, 2 initial temperature which are 90 and 45 Celsius degree and 3 cooling temperature which are 0.95, 0.97 and 0.99 are used, making up 6 combinations. 13 different test data are tested and the final outcomes are shown in the tables below. In general, parameter with 90 as initial temperature and 0.97 as cooling temperature obtains more favourable and stable result compared to other parameters as this pair of parameters generates data with lower standard deviation and average gap. The pair (90, 0.95) works very well sometimes but it is less stable than the pair (90, 0.97).

Furthermore, Simulated Annealing with higher initial temperature produces more iteration counts and leads to lower mean value in general.

In the data analysis, green represents lower value while red represents higher value where green is favourable as the purpose of this project is to minimize the objective value.

Test 1

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean
90	0.95	19.7180	43.9598	331	396.2667
90	0.97	11.6219	36.3976	335	373.9333
90	0.99	9.4131	69.8086	284	329.3333
45	0.95	14.8955	36.8631	367	421.6667
45	0.97	30.3149	45.0526	307	400.0667
45	0.99	12.6220	39.6923	328	369.4000

Test 2

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean
90	0.95	16.2140	46.7668	567	658.9333
90	0.97	14.8956	50.7707	559	642.2667
90	0.99	11.5808	37.4643	582	649.4000
45	0.95	23.3987	67.5687	561	692.2667
45	0.97	15.3150	48.1427	582	671.1333
45	0.99	17.0900	52.2046	559	654.5333

Test 3

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean
90	0.95	18.1360	43.81019668	397	469
90	0.97	18.6423	39.09441563	383	454.4
90	0.99	18.2317	37.99029167	377	445.7333
45	0.95	30.1268	45.9156715	368	478.8667
45	0.97	14.0000	30.91666217	410	467.4
45	0.99	14.8768	29.29345775	406	466.4

Test 4

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean

90	0.95	19.0138	28.6018	338	402.2667
90	0.97	27.3354	40.6090	319	406.2000
90	0.99	42.3129	54.6624	294	418.4000
45	0.95	38.6932	58.1789	301	417.4667
45	0.97	25.1205	47.2607	332	415.4000
45	0.99	36.1876	45.9952	327	445.3333

Test 5

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean
90	0.95	4.3734	24.9652	939	980.0667
90	0.97	3.7271	25.2129	948	983.3333
90	0.99	8.8294	35.4235	897	976.2000
45	0.95	5.8112	39.3077	943	997.8000
45	0.97	6.2642	28.7181	911	968.0667
45	0.99	8.3371	42.2672	894	968.5333

Test 6

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean
90	0.95	11.4299	48.1330	739	823.4667
90	0.97	7.8453	51.2743	741	799.1333
90	0.99	20.3016	75.9040	619	744.6667
45	0.95	20.8980	62.3222	683	825.7333
45	0.97	19.7923	77.4388	674	807.4000
45	0.99	28.3842	99.9859	590	757.4667

Test 7

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean
90	0.95	14.1339	75.2582	891	1016.9333
90	0.97	8.3247	45.9066	965	1045.3333
90	0.99	5.9306	39.1644	942	997.8667
45	0.95	16.7943	77.3002	888	1037.1333
45	0.97	10.0566	60.6558	942	1036.7333
45	0.99	9.3467	58.0028	898	981.9333

Test 8

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean
90	0.95	20.3551	40.9039	413	497.0667
90	0.97	17.9831	44.2265	433	510.8667
90	0.99	25.6410	55.6880	403	506.3333
45	0.95	50.4583	64.6878	320	481.4667
45	0.97	24.7059	52.9140	408	508.8000
45	0.99	30.2302	48.9356	391	509.2000

Test 9

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean
90	0.95	25.7436	31.9910	325	408.6667
90	0.97	15.0185	42.5527	360	414.0667
90	0.99	16.7908	41.0119	349	407.6000
45	0.95	18.4964	47.7039	368	436.0667
45	0.97	11.4392	26.1418	359	400.0667
45	0.99	30.7395	40.3911	311	406.6000

Test 10

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean
90	0.95	10.7875	46.3261	673	745.6000
90	0.97	13.6170	46.9712	611	694.2000
90	0.99	17.5986	57.7232	583	685.6000
45	0.95	15.9473	64.7551	607	703.8000
45	0.97	8.9229	41.3045	653	711.2667
45	0.99	27.3345	55.5304	559	711.8000

Test 11

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean
90	0.95	62.4422	29.7869	101	164.0667
90	0.97	31.5288	29.0894	133	174.9333
90	0.99	30.0275	20.4765	121	157.3333
45	0.95	28.0000	32.1355	140	179.2000
45	0.97	25.6808	23.5340	142	178.4667
45	0.99	25.7210	23.7303	141	177.2667

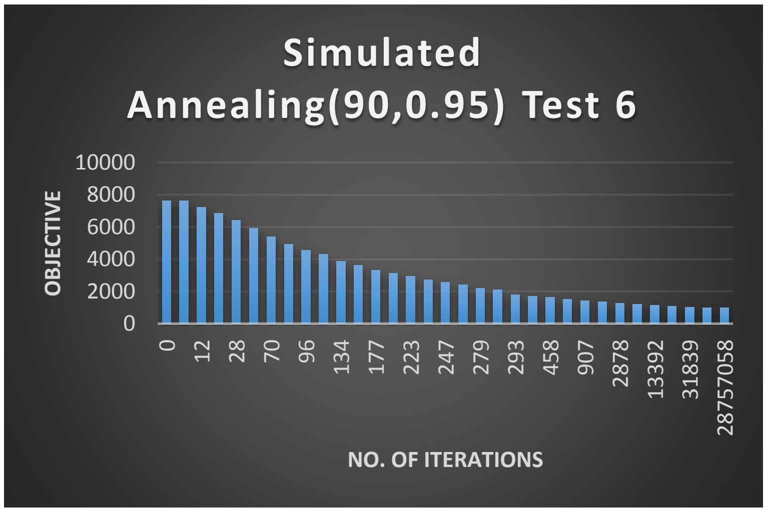
Test 12

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean
90	0.95	9.7128	61.5873	917	1006.0667
90	0.97	5.8891	39.6415	926	980.5333
90	0.99	4.9658	36.8555	925	970.9333
45	0.95	5.9944	31.7658	965	1009.0667
45	0.97	8.7963	31.9113	1085	1018.3333
45	0.99	7.7766	31.5743	1012	996.9333

Test 13

Initial Temperature	Cooling Temperature	Average Gap Performance	Standard Deviation	Optimal	Mean
90	0.95	26.0668	46.2656	389	490.4000
90	0.97	20.3365	54.3774	416	500.6000
90	0.99	42.6256	59.9154	325	463.5333
45	0.95	34.3270	60.3022	369	495.6667
45	0.97	15.4705	38.4268	418	482.6667
45	0.99	18.0521	50.0582	397	468.6667

Graph below shows that the result is converging to the optimal value.



TABU

For the case of TABU, 2 parameters, taboo lengths of 5 and 20 are benchmarked. The tables below show the result of running TABU 15 times on each of the 13 test data sets.

Test 1

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	24.93554328	20.31047896	181	226.1333
5	24.0530303	42.99715753	176	218.3333

Test 2

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	30.65527066	67.69526489	468	611.4667
5	24.0530303	42.99715753	176	218.3333

Test 3

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	25.37286613	66.61217773	371	465.1333
5	23.69281046	67.01508951	408	504.6667

Test 4

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	27.24043716	35.13946816	244	310.4667
5	20.70818071	40.82624428	273	329.5333

Test 5

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	10.03137255	52.04160729	850	935.2667
5	11.14859438	67.5365251	830	922.5333

Test 6

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	33.93393393	135.6587221	444	594.6667
5	21.90895742	53.54981066	454	553.4667

Test 7

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	27.54593176	59.8592423	508	647.9333
5	23.91242938	69.13548695	472	584.8667

Test 8

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	33.16312057	59.83139273	235	312.9333
5	20.65934066	46.71587881	273	329.4

Test 9

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	24.95575221	65.60975537	339	423.6
5	11.49911817	29.79679327	378	421.4667

Test 10

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	24.95575221	65.60975537	339	423.6
5	13.05691057	36.41403881	410	463.5333

Test 11

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	21.50641026	35.17284306	208	252.7333
5	20.95744681	28.44362846	188	227.4

Test 12

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	12.10176991	92.31309044	904	1013.4
5	14.4191344	102.247934	878	1004.6

Test 13

Taboo Length	Average Gap Performance	Standard Deviation	Optimal	Mean
20	33.92081737	58.80120936	261	349.5333
5	19.28057554	34.73480483	278	331.6

9.0 Conclusion

It is readily apparent that the TABU heuristic produces the best results overall. The average and optimal values are consistently lower than their Simulated Annealing and Hill Climbing counterparts. Furthermore, the values are more stable than the output of the other methods. Interestingly, the taboo list length of 5 was more efficient than a longer list. This might either be due to the longer list imposing too many restrictions neighbor exploration, or it might simply be due to the added work required to check a longer list. It would be feasible to refine our approach to enable O(1) check for taboos by using a hashing structure rather than a list.

It is interesting to consider the number of iterations performed by each heuristic. The Hill Climber algorithm will perform a number of iterations that is orders of magnitude greater than the TABU algorithm. However, its stochastic approach as well as its susceptibility to being trapped by a local optimum means that it consistently performs significantly worse than its competitors. It might be possible to alleviate this somewhat by introducing random restarts, but it is not clear that this would improve the situation significantly. Indeed, this would only be the case if the solution space of the university time tabling problem is reasonably “smooth” and without many local minima.

Given the work performed by the algorithm, it has been necessary to implement a fast and efficient evaluation of potential solutions. Our implementation of delta evaluation solves this need by evaluating a candidate solution in close to constant time. Further work could be done to improve this and achieve constant time execution in all cases.

Appendices

i) Source code

UniversityTimetabling.java

```
import com.opencsv.CSVWriter;

import java.io.FileWriter;
import java.io.Writer;
import java.util.Arrays;

/**
 * Created by Martin on 16-03-2015.
 */
public class UniversityTimeTabling {

    /**
     * This method is called when the program is started from the command
line
     * @param args Command-line arguments
     */
    public static void main(String[] args) throws Exception {
        // If we have less than 8 args, we are running in normal "non-
benchmark" mode
        // Simply solve the given problem and exit
        if (args.length <= 8) {
            // Simply solve the problem without benchmarking
            new UniversityTimeTabling().startWithParameters(args);
            return;
        }

        // Check that "benchmark" is present
        if (!args[0].equals("benchmark")) {
            print("Too many arguments -- use parameter benchmark <run_count>
to benchmark");
            return;
        }

        // solve the problem several times - and output intermediate results
        int iterationCount = Integer.parseInt(args[1]);

        // "cut off" the first two parameters
        String[] arguments = new String[args.length - 1];
        Arrays.asList(args).subList(2, args.length).toArray(arguments);

        Writer fi = new FileWriter("output.csv");
        CSVWriter w = new CSVWriter(fi, ',', CSVWriter.NO_QUOTE_CHARACTER);


        // SET THIS TO THE AMOUNT OF LOGICAL PROCESSORS IN YOUR MACHINE
        int threadCount = Runtime.getRuntime().availableProcessors();
        System.out.println("Running " + threadCount + " simultaneous
benchmarks");
        int i = 0;
        Thread[] threads = new Thread[threadCount];
        while (i < iterationCount)
        {
            int j = 0;
            while (j < threadCount && i < iterationCount) {
                BenchmarkLauncher b = new BenchmarkLauncher();
                b.arguments = arguments;
                b.iteration = i;
                b.writer = w;

                Thread t = new Thread(b);
                threads[j] = t;
                t.start();
                j++;
                i++;
            }

            for (int k = 0; k < j; k++)
                threads[k].join();
        }

        w.flush();
        fi.close();
    }




    public boolean enableBenchmarking = false;
    public CSVWriter writer = null;

    public void startWithParameters(String[] args) throws Exception {
        // Validate input parameter count and length
        if (args == null || args.length < 7) {
            print("Too few arguments -- expecting basic.utt courses.utt
lecturers.utt rooms.utt curricula.utt relation.utt unavailability.utt 300");
            System.exit(1);
        }

        // Final argument is the timeout, which is optional and defaults to
300
        int timeout = 300;
        if (args.length >= 8) try {
            timeout = Integer.parseInt(args[7], 10);
        } catch (NumberFormatException nEx) {
        }

        String basicFile = args[0];
        String coursesFile = args[1];
        String lecturersFile = args[2];
        String roomsFile = args[3];
        String curriculaFile = args[4];
        String relationFile = args[5];
        String unavailabilityFile = args[6];

        // Create the heuristic
        Heuristic heuristic = new SimulatedAnnealing(95,0.97); //
StochasticTABU(20);
        heuristic.setTimeout(timeout);
        print("Using heuristic " + heuristic.getClass().getSimpleName());
        print("Running for " + timeout + " seconds");

        // Load basic info about the problem
        debug("Loading basic info...");
        BasicInfo basicInfo = new BasicInfo();
        basicInfo.loadFromFile(basicFile);
        heuristic.basicInfo = basicInfo;

        // Load the curriculum<->course mappings
        debug("Loading curricula...");
        heuristic.curriculum = new Curriculum();
        heuristic.curriculum.loadFromFile(curriculaFile, relationFile,
basicInfo.courses);

        // Load the list of lecturers
        debug("Loading lecturers...");
        heuristic.lecturers = new Lecturers();
        heuristic.lecturers.loadFromFile(lecturersFile);

        // Load the list of courses
        debug("Loading courses...");
        heuristic.courses = new Courses();
        heuristic.courses.loadFromFile(coursesFile, basicInfo.courses);

        // Load unavailability times
        debug("Loading unavailability...");
        heuristic.unavailability = new Unavailability();
        heuristic.unavailability.loadFromFile(unavailabilityFile,
basicInfo.days, basicInfo.periodsPerDay, basicInfo.courses);

        // Load rooms capacity
        debug("Loading rooms...");
        heuristic.rooms = new Rooms();
        heuristic.rooms.loadFromFile(roomsFile, basicInfo.rooms);

        debug("Done loading problem definition");

        debug("Generating initial solution...");
        Schedule initialSchedule = heuristic.getRandomInitialSolution();
        debug("Starting search...");

        heuristic.deltaState.initialize(initialSchedule);
        Schedule solution = heuristic.search(initialSchedule);

        int objectiveValue;
        debug("Calculating objective value");
        objectiveValue = heuristic.evaluationFunction(solution);

        print("Found a solution in " + heuristic.iterationCount + "
iterations");
        print("The value is " + objectiveValue);

        if (!enableBenchmarking) {
            print(solution.toString());
        }
        if (enableBenchmarking && writer != null) {
            synchronized (writer) {
                // TODO write results to a CSV file
                String[] result = new String[]{"" + objectiveValue,
heuristic.getClass().getSimpleName(), heuristic.iterationCount + ""};
                writer.writeNext(result);
            }
        }
    }

    /**
     * Indicates whether to include detailed logging in the output.
     */
    public static boolean enableDebugOutput = false;

    /**
     * Print a debug message, if debug output is enabled.
     * @param message The message to print
     */
    private static void debug(String message) {
        if (enableDebugOutput)
            System.out.println(message);
    }

    /**
     * Print an output message.
     * @param message The message to print
     */
    private static void print(String message) {
        System.out.println(message);
    }
}
```

BasicInfo.java

```
import java.io.BufferedReader;
import java.io.FileNotFoundException;
import java.io.FileReader;
import java.util.Scanner;

public class BasicInfo {
    public int courses, rooms, days, periodsPerDay, curricula, constraints,
lecturers;

    public void loadFromFile(String file) throws FileNotFoundException {
        Scanner scanner = null;
        try {
            scanner = new Scanner(new BufferedReader(new FileReader(file)));
            // Skip the first line
            scanner.nextLine();

            // Read tokens from the file in the order
            // Courses Rooms Days Periods_per_day Curricula Constraints
Lecturers
            courses = scanner.nextInt(10);
            rooms = scanner.nextInt(10);
            days = scanner.nextInt(10);
            periodsPerDay = scanner.nextInt(10);
            curricula = scanner.nextInt(10);
            constraints = scanner.nextInt(10);
            lecturers = scanner.nextInt(10);

        } finally {
            if (scanner != null)
                scanner.close();
        }
    }
}
```

BenchMarkLauncher.java

```
import com.opencsv.CSVWriter;

import java.io.FileWriter;
import java.io.Writer;

public class BenchmarkLauncher implements Runnable {
    public int iteration = 0;
    public String[] arguments;
    public CSVWriter writer;

    @Override
    public void run() {
        try {
            // write results to a CSV file
            //Writer fi = new FileWriter("output_" + iteration + ".csv");
            //CSVWriter w = new CSVWriter(fi, ',',
CSVWriter.NO_QUOTE_CHARACTER);

            UniversityTimeTabling t = new UniversityTimeTabling();
            t.enableBenchmarking = true;
            t.writer = writer;
            t.startWithParameters(arguments);

        } catch (Exception ex) {
            System.err.println(ex.getMessage());
        }
    }
}
```

Courses.java

```
import java.io.BufferedReader;
import java.io.FileNotFoundException;
import java.io.FileReader;
import java.util.Scanner;
import java.util.regex.Matcher;
import java.util.regex.Pattern;

public class Courses {
    /**
     * The lecturer teaching the course.
     */
    public int[] lecturerForCourse;

    /**
     * The minimum number of lectures that should be scheduled for this
course.
     */
    public int[] numberOfLecturesForCourse;

    /**
     * The minimum number of distinct days that course lectures should be
scheduled on.
     */
    public int[] minimumWorkingDaysForCourse;

    /**
     * The number of students attending this course.
     */
    public int[] numberOfStudentsForCourse;


    public void loadFromFile(String file, int numberOfCourses) throws
FileNotFoundException {
        lecturerForCourse = new int[numberOfCourses];
        numberOfLecturesForCourse = new int[numberOfCourses];
        minimumWorkingDaysForCourse = new int[numberOfCourses];
        numberOfStudentsForCourse = new int[numberOfCourses];

        Pattern linePattern = Pattern.compile("C(\\d+) L(\\d+) (\\d+) (\\d+)
(\\d+)");

        Scanner scanner = null;
        try {
            scanner = new Scanner(new BufferedReader(new FileReader(file)));
            // Skip the first line
            scanner.nextLine();

            while (scanner.hasNextLine()) {
                // Read tokens from the file in the order
                // Course Lecturer Number_of_lectures Minimum_working_days
Number_of_students
                Matcher match = linePattern.matcher(scanner.nextLine());

                if (!match.matches())
                    continue;

                int courseId = Integer.parseInt(match.group(1));
                lecturerForCourse[courseId] =
Integer.parseInt(match.group(2));
                numberOfLecturesForCourse[courseId] =
Integer.parseInt(match.group(3));
                minimumWorkingDaysForCourse[courseId] =
Integer.parseInt(match.group(4));
                numberOfStudentsForCourse[courseId] =
Integer.parseInt(match.group(5));
            }
        } finally {
            if (scanner != null)
                scanner.close();
        }
    }
}
```

Curriculum.java

```
import java.io.*;
import java.util.ArrayList;
import java.util.LinkedList;
import java.util.regex.Matcher;
import java.util.regex.Pattern;

/**
```

```
 * Created by Martin on 16-03-2015.
 */
public class Curriculum {
    /**
     * Look up whether there is a relation between [course][curriculum]
     */
    boolean isCourseInCurriculum[][];

    /**
     * Contains a list of curricula for each course.
     */
    ArrayList<LinkedList<Integer>> curriculaForCourse;

    public void loadFromFile(String curriculaFile, String relationFile, int
numberOfCourses) {
        // Load the list of curricula
        try {
            // Parse the curricula file
            // Each line has the curriculum number and course count
            Reader reader = new FileReader(curriculaFile);
            BufferedReader bufferedReader = new BufferedReader(reader);
            Pattern p = Pattern.compile("Q(\\d{4}) (\\d)");
            String latestLine;
            int curriculaCount = 0;
            while ((latestLine = bufferedReader.readLine()) != null) {
                Matcher m = p.matcher(latestLine);
                if (!m.matches())
                    continue;

                // Index of the curriculum we just parsed
                int curriculumIndex = Integer.parseInt(m.group(1));

                // The number of curricula is always equal to highest index
+ 1
                curriculaCount = 1 + curriculumIndex;
            }
            bufferedReader.close();
            reader.close();

            curriculaForCourse = new
ArrayList<LinkedList<Integer>>(numberOfCourses);
            for (int i = 0; i < numberOfCourses; i++)
                curriculaForCourse.add(new LinkedList<Integer>());

            // Store assignments as an array of booleans
            isCourseInCurriculum = new
boolean[numberOfCourses][curriculaCount];

            // Parse the relation file
            // Each line has the index of a curriculum and a course
            Pattern relationPattern = Pattern.compile("Q(\\d{4})
C(\\d{4})");
```

```
            reader = new FileReader(relationFile);
            bufferedReader = new BufferedReader(reader);
            while ((latestLine = bufferedReader.readLine()) != null) {
                Matcher m = relationPattern.matcher(latestLine);
                if (!m.matches())
                    continue;

                // Indices we just read from the file
                int curriculumId = Integer.parseInt(m.group(1));
                int courseId = Integer.parseInt(m.group(2));
                isCourseInCurriculum[courseId][curriculumId] = true;
                curriculaForCourse.get(courseId).add(curriculumId);
            }
        } catch (IOException e) {
            e.printStackTrace();
        }
    }
}
```

Lecturers.java

```
import java.io.BufferedReader;
import java.io.FileNotFoundException;
import java.io.FileReader;
import java.util.*;

public class Lecturers {
    public int[] lecturers;

    public void loadFromFile(String file) throws FileNotFoundException {
        Scanner scanner = null;
        List idList = new LinkedList<Integer>();

        try {
            scanner = new Scanner(new BufferedReader(new FileReader(file)));
            // Skip the first line
            scanner.nextLine();
            //scanner.useDelimiter("\\s*L");
            // Read tokens from the file
            // Each line contains an id
            System.out.println("Starting scan...");
            String pattern = "L\\d+";
            while (scanner.hasNext(pattern)) {
                String line = scanner.next(pattern);
                int id = Integer.parseInt(line.substring(1));
                idList.add(id);
            }

            lecturers = new int[idList.size()];
            Iterator<Integer> iter = idList.iterator();
            for (int i=0; iter.hasNext(); i++) {
                lecturers[i] = iter.next();
            }

        } finally {
            if (scanner != null)
                scanner.close();
        }
    }
}
```

Rooms.java

```
import java.io.BufferedReader;
import java.io.FileNotFoundException;
import java.io.FileReader;
import java.util.Scanner;
import java.util.regex.Matcher;
import java.util.regex.Pattern;

public class Rooms {
    /**
     * Look up whether a course is unavailable on [day][period][course]
     */
    public int[] capacityForRoom;


    public void loadFromFile(String file, int numberOfRooms) throws
FileNotFoundException {
        capacityForRoom = new int[numberOfRooms];
        Pattern linePattern = Pattern.compile("R(\\d+) (\\d+)");

        Scanner scanner = null;
        try {
            scanner = new Scanner(new BufferedReader(new FileReader(file)));
            // Skip the first line
            scanner.nextLine();

            while (scanner.hasNextLine()) {
                // Read tokens from the file in the order
                // Course Day Period
                Matcher match = linePattern.matcher(scanner.nextLine());

                if (!match.matches())
                    continue;

                int room = Integer.parseInt(match.group(1));
                int capacity = Integer.parseInt(match.group(2));
                capacityForRoom[room] = capacity;
            }
        } finally {
            if (scanner != null)
                scanner.close();
        }
    }
}
```

Schedule.java

```
public class Schedule {
    public int[][][] assignments; //The array of scheduled courses, look up
using [day][period][room],Value is -1 if the room is empty

     public Schedule(int days, int periods, int rooms) {
          assignments = new int[days][periods][rooms];

          // initialize all assignments to -1, meaning no course
          for (int d = 0; d < assignments.length; d++) {
               for (int p = 0; p < assignments[d].length; p++) {
                    for (int r = 0; r < assignments[d][p].length; r++) {
                         assignments[d][p][r] = -1;
                    }
               }
          }
     }

     @Override
```

```
	public String toString() {
		StringBuilder builder = new StringBuilder();
		for (int d = 0; d < assignments.length; d++) {
			for (int p = 0; p < assignments[d].length; p++) {
				for (int r = 0; r < assignments[d][p].length; r++) {
					int course = assignments[d][p][r];
					if (course == -1)
						continue;

					builder.append(String.format("C%04d %d %d
R%04d\n", course, d, p, r));
				}
			}
		}
		return builder.toString();
	}
}
```

Unavailability.java

```
import java.io.BufferedReader;
import java.io.FileNotFoundException;
import java.io.FileReader;
import java.util.LinkedList;
import java.util.List;
import java.util.Scanner;
import java.util.regex.Matcher;
import java.util.regex.Pattern;

public class Unavailability {
    /**
     * Look up whether a course is unavailable on [day][period][course]
     */
    public boolean[][][] courseUnavailable;
    public List<UnavailabilityConstraint> constraints;
    public void loadFromFile(String file, int numberOfDays, int
numberOfPeriods, int numberOfCourses) throws FileNotFoundException {
        courseUnavailable = new
boolean[numberOfDays][numberOfPeriods][numberOfCourses];
        constraints = new LinkedList<UnavailabilityConstraint>();

        Pattern linePattern = Pattern.compile("C(\\d+) (\\d+) (\\d+)");

        Scanner scanner = null;
        try {
            scanner = new Scanner(new BufferedReader(new FileReader(file)));
            // Skip the first line
            scanner.nextLine();

            while (scanner.hasNextLine()) {
                // Read tokens from the file in the order
                // Course Day Period
                Matcher match = linePattern.matcher(scanner.nextLine());

                if (!match.matches())
                    continue;
                UnavailabilityConstraint constraint = new
UnavailabilityConstraint();
                constraint.course = Integer.parseInt(match.group(1));
                constraint.day = Integer.parseInt(match.group(2));
                constraint.period  = Integer.parseInt(match.group(3));
                constraints.add(constraint);


courseUnavailable[constraint.day][constraint.period][constraint.course] =
true;
            }
        } finally {
            if (scanner != null)
                scanner.close();
        }
    }
}
```

UnavailabilityConstraint.java

```
public class UnavailabilityConstraint {
    public int day, period, course;
}
```

XORShiftRandom.java

```
import java.util.Random;
```

```
/**
 * A faster, higher-quality replacement for java.util.Random.
 * See http://www.javamex.com/tutorials/random_numbers/xorshift.shtml
 */
public class XORShiftRandom extends Random {
    private long seed = System.nanoTime();

    public XORShiftRandom() {
    }
    protected int next(int nbits) {
        // N.B. Not thread-safe!
        long x = this.seed;
        x ^= (x << 21);
        x ^= (x >>> 35);
        x ^= (x << 4);
        this.seed = x;
        x &= ((1L << nbits) -1);
        return (int) x;
    }
}
```

Heuristic.java

```
import java.io.IOException;
import java.io.Writer;
import java.util.Date;
import java.util.LinkedList;
import java.util.Random;

import com.opencsv.CSVWriter;

public abstract class Heuristic {
    public static final int EMPTY_ROOM = -1;

    /**
     * Perform a search with the input schedule as a starting point. The
method will return the best schedule
```

```
     * found before timeout.
     * This method is abstract and must be implemented according to the
chosen heuristic.
     * @param schedule The Schedule to start from
     * @return The most optimal schedule found during search.
     * @throws IOException
     */
    public abstract Schedule search(Schedule schedule) throws IOException;

    private int timeout = 300;

    /**
     * Sets the duration, in seconds, that the heuristic is allowed to
search for solutions.
     * @param seconds the duration in seconds. Must be a positive value.
     */
    public void setTimeout(int seconds) {
        if (seconds <= 0)
            return;
        timeout = seconds;
    }

    /**
     * Clones an array by copying its contents to an existing destination
array.
     */
    protected static void cloneArray(int[][][] array, int[][][] destination)
{
        for (int i = 0; i < array.length; i++) {
            for (int j = 0; j < array[i].length; j++) {
                System.arraycopy(array[i][j], 0, destination[i][j], 0,
                        array[i][j].length);
            }
        }
    }

    /**
     * The millisecond time when the countdown was started.
     */
    private long countdownStartTime;

    /**
     * Starts the countdown timer. Call timeoutReached() to determine when
the timeout has been reached.
     */
    protected void startCountdown() {
        countdownStartTime = new Date().getTime();
    }

    /**
     * Returns a value indicating whether the timeout has currently been
reached.
```

```
     * startCountdown() must be called prior to calling this method.
     * @return true if the timeout has been reached, or if the countdown has
not yet started. If not, false.
     */
    protected boolean timeoutReached() {
        Date currentTime = new Date();
        long delta = (currentTime.getTime() - countdownStartTime) / 1000;
        return delta > timeout;
    }

     public int iterationCount = 0;
    public BasicInfo basicInfo;
    public Curriculum curriculum;
    public Lecturers lecturers;
    public Courses courses;
    public Unavailability unavailability;
    public Rooms rooms;

    /**
     * Returns an array containing the number of times each course has been
scheduled
     */
     protected int[] getCourseAssignmentCount(Schedule schedule) {
        int[] result = new int[basicInfo.courses];
        for (int day = 0; day < basicInfo.days; day++) {
            for (int period = 0; period < basicInfo.periodsPerDay; period++)
{
                for (int room = 0; room < basicInfo.rooms; room++){
                    int assignedCourse =
schedule.assignments[day][period][room];
                    if(assignedCourse == -1)
                        continue;
                    result[assignedCourse]++;
                }
            }
        }

        return result;
    }

     private Random rand = new XORShiftRandom();

    public Schedule getRandomInitialSolution(){
        Schedule result = new Schedule(basicInfo.days,
basicInfo.periodsPerDay, basicInfo.rooms);
        int[] courseAssignmentCount = new int[basicInfo.courses];

        for (int day = 0; day < basicInfo.days; day++) {
           boolean[] courseAlreadyAssigned = new boolean[basicInfo.courses];

           for (int period = 0; period < basicInfo.periodsPerDay; period++)
{
```

```
                boolean[] lecturerBusy = new boolean[basicInfo.lecturers];
                boolean[] curriculumBusy = new
boolean[basicInfo.curricula];
                for (int room = 0; room < basicInfo.rooms; room++) {
                     int assignedCourse = -1; // fix
                     int candidatecourse = -1;

                          int attempts = 0;

                     while (assignedCourse == -1) {
                       candidatecourse = rand.nextInt(basicInfo.courses);
// maybe use a priority queue instead?
                           attempts++;
                       if (attempts == basicInfo.courses * 2)
                           break;

                          // course not already assigned in time slot
                          if (courseAlreadyAssigned[candidatecourse])
                               continue;

                          // course not unavailable in time slot
                          if
(unavailability.courseUnavailable[day][period][candidatecourse])
                               continue;

                          // course lecturer cannot be busy
                          if
(lecturerBusy[courses.lecturerForCourse[candidatecourse]])
                               continue;

                          // course curriculum cannot be busy
                          boolean curriculumConflict = false;
                        for (int curriculum = 0; curriculum <
basicInfo.curricula; curriculum++) {
                            if
(this.curriculum.isCourseInCurriculum[candidatecourse][curriculum]) {
                                if (curriculumBusy[curriculum])
                                    curriculumConflict = true;
                            }
                        }
                        if (curriculumConflict)
                          continue;

                          // course max lectures cannot be reached
                        if (courseAssignmentCount[candidatecourse] ==
courses.numberOfLecturesForCourse[candidatecourse])
                          continue;

                        // no constraints violated! assign this course
                        assignedCourse = candidatecourse;
                     }
```

```
                      if (assignedCourse == -1)
                           continue;

                      // increment constraints
                      courseAlreadyAssigned[assignedCourse] = true;

      lecturerBusy[courses.lecturerForCourse[candidatecourse]] = true;
                      for (int curriculum = 0; curriculum <
basicInfo.curricula; curriculum++) {
                        if
(this.curriculum.isCourseInCurriculum[assignedCourse][curriculum]) {
                             curriculumBusy[curriculum] = true;
                        }
                    }
                      courseAssignmentCount[candidatecourse]++;

                      result.assignments[day][period][room] =
assignedCourse;
                 }
            }
        }

        return result;
    }

    public int evaluationFunction(Schedule schedule)
    {
      int[] numberOfLecturesOfCourse = new int[basicInfo.courses];

        System.arraycopy(courses.numberOfLecturesForCourse, 0,
numberOfLecturesOfCourse, 0, basicInfo.courses);

      //to calculate the number of unallocated lectures of each course
      for(int day= 0; day < basicInfo.days; day++){
           for(int period = 0; period < basicInfo.periodsPerDay; period++){
                for(int room = 0; room < basicInfo.rooms; room++){
                      int assignedCourse =
schedule.assignments[day][period][room];
                      if(assignedCourse == -1)
                           continue;
                      numberOfLecturesOfCourse[assignedCourse]--;
                }
           }
      }

      //to calculate the number of days of each course that is scheduled
below the minimum number of working days
      int[] minimumWorkingDaysOfCourse = new int[basicInfo.courses];

        System.arraycopy(courses.minimumWorkingDaysForCourse, 0,
minimumWorkingDaysOfCourse, 0, basicInfo.courses);
```

```
      for(int day = 0; day < basicInfo.days; day++){
            // to avoid overcount working days of each course
            boolean[] dayFulfilled = new boolean[basicInfo.courses];
            for(int i = 0; i < basicInfo.courses; i++){
                  dayFulfilled[i] = false;
            }

            for(int period = 0; period < basicInfo.periodsPerDay; period++){
                  for(int room = 0; room < basicInfo.rooms; room++){
                        int assignedCourse =
schedule.assignments[day][period][room];
                        if(assignedCourse == EMPTY_ROOM)
                              continue;
                        if(dayFulfilled[assignedCourse])
                              continue;
                        dayFulfilled[assignedCourse] = true;
                        minimumWorkingDaysOfCourse[assignedCourse]--;
                  }
            }
      }

      int[][][] secludedLecture = new
int[basicInfo.days][basicInfo.periodsPerDay][basicInfo.curricula];

      //Initialise the value of each slot in secludedLecture, 1 if a
curriculum in a timeslot has a secluded lecture
      for(int day = 0; day < basicInfo.days; day++){
            for(int period = 0; period < basicInfo.periodsPerDay; period++){
                  for(int curriculum = 0; curriculum < basicInfo.curricula;
curriculum++){
                        secludedLecture[day][period][curriculum] = 0;
                  }
            }
      }

      //to calculate the number of secluded lectures of each curriculum
      for(int day = 0; day < basicInfo.days; day++){
            for(int period = 0; period < basicInfo.periodsPerDay; period++){
                  for(int curriculum = 0; curriculum < basicInfo.curricula;
curriculum++){
                        int count1 = 0; // to calculate X_c,t,r
                        int count2 = 0; // to calculate X_c',t',r'
                        for(int course = 0; course < basicInfo.courses;
course++){
                              if
(this.curriculum.isCourseInCurriculum[course][curriculum]){
                                    for(int room = 0; room < basicInfo.rooms;
room++){
                                    if(schedule.assignments[day][period][room]
== course)
                                          count1++;
                              }
                              }
                         }
                         int adjacentPeriod1 = period - 1;
                         int adjacentPeriod2 = period + 1;

                         if(adjacentPeriod1 >= 0){
                              for(int course = 0;course < basicInfo.courses;
course++){

     if(this.curriculum.isCourseInCurriculum[course][curriculum]){
                                        for(int room = 0; room <
basicInfo.rooms;room++){

     if(schedule.assignments[day][adjacentPeriod1][room] == course)
                                                  count2++;
                                        }
                                   }
                              }
                         }

                         if(adjacentPeriod2 < basicInfo.periodsPerDay){
                              for(int course = 0;course < basicInfo.courses;
course++){

     if(this.curriculum.isCourseInCurriculum[course][curriculum]){
                                        for(int room = 0; room <
basicInfo.rooms;room++){

     if(schedule.assignments[day][adjacentPeriod2][room] == course)
                                                  count2++;
                                        }
                                   }
                              }
                         }

                         if(count1 == 1 && count2 == 0)
                              secludedLecture[day][period][curriculum] = 1;
                    }
               }
          }

     //to calculate number of room changes of each courses
     int[] numberOfRoomChanges = new int[basicInfo.courses];

     //if the course is always taught in same room, the value is 0
     //if the course is never allocated, the value is -1
     for(int course = 0; course < basicInfo.courses; course++){
          numberOfRoomChanges[course] = -1;
     }

     for(int course = 0; course < basicInfo.courses; course++){
          boolean[] roomChanged = new boolean[basicInfo.rooms];
```

```
            for(int room = 0; room < basicInfo.rooms; room++){
                  roomChanged[room] = false;
            }

            for(int day = 0; day < basicInfo.days; day++){
                  for(int period = 0; period < basicInfo.periodsPerDay;
period++){
                        for(int room = 0; room < basicInfo.rooms; room++){
                              if(schedule.assignments[day][period][room] ==
course)
                                    roomChanged[room] = true;
                        }
                  }
            }

            for(int room = 0; room < basicInfo.rooms; room++){
                  if(roomChanged[room])
                        numberOfRoomChanges[course]++;
            }
      }

      //to calculate the amount of capacity that room is exceeded in a
timeslot
      int capacityExceeding = 0;

      for(int day = 0; day < basicInfo.days; day++){
            for(int period = 0; period < basicInfo.periodsPerDay; period++){
                  for(int room = 0; room < basicInfo.rooms; room++){

                        int course = schedule.assignments[day][period][room];
                        if(course != -1){
                              if(this.rooms.capacityForRoom[room] <
this.courses.numberOfStudentsForCourse[course])
                                    capacityExceeding +=
(this.courses.numberOfStudentsForCourse[course] -
this.rooms.capacityForRoom[room]);
                        }
                  }
            }
      }

      int objective; // calculate the penalties
      int unscheduled = 0;
      int minimumWorkingDays = 0;
      int curriculumCompactness = 0;
      int roomStability = 0;

      for(int i = 0; i < basicInfo.courses; i++){
            unscheduled += numberOfLecturesOfCourse[i];
      }
      for(int course = 0; course < basicInfo.courses; course++){
           if(minimumWorkingDaysOfCourse[course] > 0)
           minimumWorkingDays += minimumWorkingDaysOfCourse[course];
      }

      for(int day = 0; day < basicInfo.days; day++){
           for(int period = 0; period < basicInfo.periodsPerDay; period++){
                for(int curriculum = 0; curriculum < basicInfo.curricula;
curriculum++){
                     curriculumCompactness +=
secludedLecture[day][period][curriculum];
                }
           }
      }

      for(int course = 0; course < basicInfo.courses; course++){
           if(numberOfRoomChanges[course] > 0)
           roomStability += numberOfRoomChanges[course];
      }

      objective = 10*unscheduled + 5*minimumWorkingDays +
2*curriculumCompactness + roomStability + capacityExceeding;

      return objective;
    }

    /**
     * Gets the value of the solution if it is altered by assigning a
specific course in a given time slot and room.
     * This method return Integer.MAX_VALUE if the room is already occupied.
     * @return The value of the modified solution, or Integer.MAX_VALUE if a
constraint is violated.
     */
    protected int valueIfAssigningCourse(Schedule schedule, int
currentValue, int day, int period, int room, int courseId) {
        // Room must currently be empty
        if (schedule.assignments[day][period][room] != Heuristic.EMPTY_ROOM)
{
            return Integer.MAX_VALUE;
        }

        // Ensure that the move is valid
        boolean moveIsValid = deltaState.deltaValidateAllConstraints(day,
period, courseId);
        if (!moveIsValid) {
            // Return a large value to indicate that the move is invalid
            return Integer.MAX_VALUE;
        }

        int delta = deltaState.getDeltaWhenAdding(day, period, room,
courseId);
```

```
        return currentValue + delta;
    }
    /**
     * Gets the value of the solution if the given time slot and room is
emptied
     * @return The value of the modified solution, or Integer.MAX_VALUE if a
constraint is violated
     */
    protected int valueIfRemovingCourse(Schedule schedule, int currentValue,
int day, int period, int room) {
        // Room must currently be occupied
        int currentCourse = schedule.assignments[day][period][room];
        if (currentCourse == Heuristic.EMPTY_ROOM) {
            return Integer.MAX_VALUE;
        }

        // Return the delta value plus the current value
        int delta = deltaState.getDeltaWhenRemoving(day, period, room,
currentCourse);
        return currentValue + delta;
    }

    /**
     * Gets the value of the solution if two lectures are swapped
     * @return The value of the modified solution, or Integer.MAX_VALUE if a
constraint is violated
     */
    protected int valueIfSwappingCourses(Schedule schedule, int
currentValue, int day, int period,int room,int day2,int period2,int room2) {
        // Both rooms must currently be occupied
        int currentCourse = schedule.assignments[day][period][room];
        int currentCourse2 = schedule.assignments[day2][period2][room2];

        if (currentCourse == EMPTY_ROOM || currentCourse2 == EMPTY_ROOM)
            return Integer.MAX_VALUE;

        int totalDelta = 0;

        // First clear both rooms -- this does not require constraint
validation
        totalDelta += deltaState.getDeltaWhenRemoving(day, period, room,
currentCourse);
        removeCourse(schedule, day, period, room);

        totalDelta += deltaState.getDeltaWhenRemoving(day2, period2, room2,
currentCourse2);
        removeCourse(schedule, day2, period2, room2);

        // Then check the delta values if adding the swapped courses
        boolean constraintsSatisfied;
        totalDelta += deltaState.getDeltaWhenAdding(day2, period2, room2,
currentCourse);
```

```
        constraintsSatisfied = deltaState.deltaValidateAllConstraints(day2,
period2, currentCourse);

        // Assign the course so we can compute the delta
        // Only assign course in slot 2
        assignCourse(schedule, day2, period2, room2, currentCourse);

        if (constraintsSatisfied) {
            // Only compute the second delta if the first constraint is
satistified
            totalDelta += deltaState.getDeltaWhenAdding(day, period, room,
currentCourse2);
            constraintsSatisfied =
deltaState.deltaValidateAllConstraints(day, period, currentCourse2);
            // It is not necessary to actually assign the course in slot 1
        }

        // Only course assigned at this point is time slot 2

        // Revert the changes by reassigning the courses. Then return the
computed value.
        // Remove course in time slot 2, so both slots are empty
        removeCourse(schedule, day2, period2, room2);

        // An reassign both courses
        assignCourse(schedule, day, period, room, currentCourse);
        assignCourse(schedule, day2, period2, room2, currentCourse2);

        if (!constraintsSatisfied) {
            return Integer.MAX_VALUE;
        }

        return currentValue + totalDelta;
    }

    /**
     * Assigns the given course to the given room and time slot.
     * If the room is already occupied, this method does nothing.
     */
    protected void assignCourse(Schedule schedule, int day, int period, int
room, int course) {
        // Make sure the room is empty
        removeCourse(schedule, day, period, room);
        if(course == Heuristic.EMPTY_ROOM)
           return;

        // Perform the assignment and increment the counter
        schedule.assignments[day][period][room] = course;
        deltaState.courseAssignmentCount[course]++;

        int lecturesOnDay = ++deltaState.courseLecturesOnDay[course][day];
        if (lecturesOnDay == 1)
```

```
            deltaState.courseWorkingDays[course]++;
        deltaState.lecturesInRoomForCourse[room][course]++;

        for (int q : curriculum.curriculaForCourse.get(course)) {
            deltaState.curriculumAssigned[q][day][period]++;
        }


deltaState.lecturerBusy[courses.lecturerForCourse[course]][day][period]++;
    }

    /**
     * Empties the given room in the given time slot.
     * If the room is already empty, this method does nothing.
     */
    protected void removeCourse(Schedule schedule, int day, int period, int
room) {
        int assignedCourse = schedule.assignments[day][period][room];
        if (assignedCourse == Heuristic.EMPTY_ROOM)
            return;

        // Perform the assignment and decrement the counter
        schedule.assignments[day][period][room] = EMPTY_ROOM;
        deltaState.courseAssignmentCount[assignedCourse]--;

        int lecturesOnDay = --
deltaState.courseLecturesOnDay[assignedCourse][day];
        if (lecturesOnDay == 0)
            deltaState.courseWorkingDays[assignedCourse]--;
        deltaState.lecturesInRoomForCourse[room][assignedCourse]--;

        for (int q : curriculum.curriculaForCourse.get(assignedCourse)) {
            deltaState.curriculumAssigned[q][day][period]--;
        }


deltaState.lecturerBusy[courses.lecturerForCourse[assignedCourse]][day][peri
od]--;
    }

    protected enum Type { REMOVE, ASSIGN, SWAP, NOTHING }
    protected CSVWriter writer = null;
    protected Writer f;

    protected DeltaEvaluationState deltaState = new DeltaEvaluationState();

    protected class DeltaEvaluationState {
        final int UNSCHEDULED_PENALTY = 10;
        final int ROOM_CAPACITY_PENALTY = 1; // per student
        final int MINIMUM_WORKING_DAYS_PENALTY = 5;
        final int CURRICULUM_COMPACTNESS_PENALTY = 2;
        /**
         * Get the change in Unscheduled penalty if a lecture is assigned in
the given course.
         */
        private int getUnscheduledPenaltyAfterAdding(int course) {
            // Get the current number of lectures, and the minimum number
allowed
            int assignments = courseAssignmentCount[course];
            int minimumAssignments =
courses.numberOfLecturesForCourse[course];

            // If we are already at the minimum, adding an extra assignment
does not change the solution value
            if (assignments >= minimumAssignments)
                return 0;

            // But in other cases the solution value is reduced by one
UNSCHEDULED_PENALTY
            return -UNSCHEDULED_PENALTY;
        }

        /**
         * Get the change in Unscheduled penalty if one lecture of the given
course is removed.
         */
        private int getUnscheduledPenaltyAfterRemoving(int course) {
            // Get the current number of lectures, and the minimum number
allowed
            int assignments = courseAssignmentCount[course];
            int minimumAssignments =
courses.numberOfLecturesForCourse[course];

            // If we are already above the minimum, adding an extra lecture
does not change the solution value
            if (assignments > minimumAssignments)
                return 0;

            // But in other cases the solution value is increased by one
UNSCHEDULED_PENALTY
            return UNSCHEDULED_PENALTY;
        }

        /**
         * Gets the change in RoomCapacity penalty if one lecture in the
given course is scheduled in the given room.
         */
        private int roomCapacityPenaltyAfterAdding(int room, int course) {
            int numberOfStudents =
courses.numberOfStudentsForCourse[course];
            int roomCapacity = rooms.capacityForRoom[room];
            return Math.max((numberOfStudents - roomCapacity) *
ROOM_CAPACITY_PENALTY, 0);
        }

        /**
         * Gets the change in RoomCapacity penalty if one lecture in the
given course is removed from the given room.
         */
        private int roomCapacityPenaltyAfterRemoving(int room, int course) {
            return -roomCapacityPenaltyAfterAdding(room, course);
        }

        /**
         * The total number of times that each course has been scheduled.
         */
        public int[] courseAssignmentCount;

        private int[][] courseLecturesOnDay;

        private int[] courseWorkingDays;

        public int[][] lecturesInRoomForCourse;

        /**
         * Look up whether a lecturer is busy on a give time using
[lecturer][day][period]
         */
        public byte[][][] lecturerBusy;

        /**
         * Look up whether a given curriculum is assigned on a day and
period.
         * Use indexing [curriculum][day][period]
         */
        private byte[][][] curriculumAssigned;

        public void initialize(Schedule schedule) {
            curriculumAssigned = new
byte[basicInfo.curricula][basicInfo.days][basicInfo.periodsPerDay];
            courseAssignmentCount = getCourseAssignmentCount(schedule);
            courseLecturesOnDay = new
int[basicInfo.courses][basicInfo.days];
            courseWorkingDays = new int[basicInfo.courses];
            lecturesInRoomForCourse = new
int[basicInfo.rooms][basicInfo.courses];
            lecturerBusy = new
byte[basicInfo.lecturers][basicInfo.days][basicInfo.periodsPerDay];

            for (int day = 0; day < basicInfo.days; day++) {
                for (int period = 0; period < basicInfo.periodsPerDay;
period++) {
                    for (int room = 0; room < basicInfo.rooms; room++) {
                        int course =
schedule.assignments[day][period][room];
                        if (course == EMPTY_ROOM)
                            continue;

                        courseLecturesOnDay[course][day]++;
                        lecturesInRoomForCourse[room][course]++;

                        int lecturerId = courses.lecturerForCourse[course];
                        lecturerBusy[lecturerId][day][period]++;
                        assert lecturerBusy[lecturerId][day][period] == 1;

                        for (int q :
curriculum.curriculaForCourse.get(course)) {
                            curriculumAssigned[q][day][period] = 1;
                        }
                    }
                }
            }

            for (int course = 0; course < basicInfo.courses; course++) {
                for (int day = 0; day < basicInfo.days; day++) {
                    if (courseLecturesOnDay[course][day] > 0)
                        courseWorkingDays[course]++;
                }
            }
        }

        /**
         * Gets the change in MinimumWorkingDays penalty by scheduling one
lecture in the given course on the given day.
         */
        public int minWorkingDaysPenaltyAfterAdding(int day, int course) {
            // What is the number of course lectures scheduled on this day?
            int lecturesScheduled = courseLecturesOnDay[course][day];

            // If the course is already scheduled on this day, there is no
change
            // So the delta is 0
            if (lecturesScheduled > 0)
                return 0;

            int minimumWorkingDays =
courses.minimumWorkingDaysForCourse[course];
            int currentWorkingDays = courseWorkingDays[course];

            // If we are already at a sufficient number of working days,
adding one does not reduce solution value
            if (minimumWorkingDays <= currentWorkingDays)
                return 0;

            // Decreasing the working days deficit will reduce the penalty
            return -MINIMUM_WORKING_DAYS_PENALTY;
        }

        public int minWorkingDaysPenaltyAfterRemoving(int day, int course) {
            // What is the number of course lectures scheduled on this day?
            int lecturesScheduled = courseLecturesOnDay[course][day];

            // If the course is already scheduled at least twice on this
day, there is no change
            // So the delta is 0
            if (lecturesScheduled > 1)
                return 0;

            int minimumWorkingDays =
courses.minimumWorkingDaysForCourse[course];
            int currentWorkingDays = courseWorkingDays[course];

            // If we are already at a sufficient number of working days,
removing one does not increase solution value
            if (minimumWorkingDays < currentWorkingDays)
                return 0;

            // Increasing the working days deficit will increase the penalty
            return MINIMUM_WORKING_DAYS_PENALTY;
        }

        public int roomStabilityPenaltyAfterAdding(int room, int course) {
            // If this is the first lecture for the course, or the room is
already in use by the course,
            // there is no change -- return 0
            if (courseAssignmentCount[course] == 0 ||
lecturesInRoomForCourse[room][course] > 0)
                return 0;

            // If we get to this point, the change means an extra room in
use
            return 1;
        }

        public int roomStabilityPenaltyAfterRemoving(int room, int course) {
            // If this is the first lecture for the course, or the room is
already in use by the course
            // for several lectures, there is no change -- return 0
            if (courseAssignmentCount[course] == 1 ||
lecturesInRoomForCourse[room][course] > 1)
                return 0;

            // If we get to this point, the change means an extra room in
use
            return -1;
        }
        public int curriculumCompactnessPenaltyAfterAdding(int day, int 
period, int course) {
            LinkedList<Integer> curriculaForCourse = 
curriculum.curriculaForCourse.get(course);

            int ownSeclusionPenalty = 0;
            int otherSeclusionPenalty = 0;

            for (int curriculum : curriculaForCourse) {
                // Determine whether the added course is secluded with 
respect to this curriculum
                boolean hasNeighbor = false;
                boolean earlierNeighorIsSecluded = false;
                boolean hasNeighborEarlier = false;
                boolean hasNeighborLater = false;
                boolean laterNeighborIsSecluded = false;
                if (period > 0) {
                    hasNeighborEarlier = 
curriculumAssigned[curriculum][day][period - 1] > 0;

                    if (hasNeighborEarlier) {
                        // We have an earlier neighbor -- compute whether 
that neighbor already had a neighbor

                        earlierNeighorIsSecluded = period < 2 || 
curriculumAssigned[curriculum][day][period - 2] == 0;
                    }
                    hasNeighbor = hasNeighborEarlier;
                }

                if (period + 1 < basicInfo.periodsPerDay) {
                    hasNeighborLater = 
curriculumAssigned[curriculum][day][period + 1] > 0;

                    if (hasNeighborLater) {
                        // We have a later neighbor -- compute whether that 
neighbor was already secluded
                        laterNeighborIsSecluded = period > 
basicInfo.periodsPerDay - 3 || curriculumAssigned[curriculum][day][period + 
2] == 0;
                    }

                    hasNeighbor = hasNeighbor || hasNeighborLater;
                }

                if (!hasNeighbor)
                    ownSeclusionPenalty += CURRICULUM_COMPACTNESS_PENALTY;

                if (hasNeighborEarlier && earlierNeighorIsSecluded)
                    otherSeclusionPenalty -= CURRICULUM_COMPACTNESS_PENALTY;

                if (hasNeighborLater && laterNeighborIsSecluded)
```

```
                    otherSeclusionPenalty -= CURRICULUM_COMPACTNESS_PENALTY;
            }

            return ownSeclusionPenalty + otherSeclusionPenalty;
        }

        public int curriculumCompactnessPenaltyAfterRemoving(int day, int
period, int course) {
            LinkedList<Integer> curriculaForCourse =
curriculum.curriculaForCourse.get(course);

            int ownSeclusionPenalty = 0;
            int otherSeclusionPenalty = 0;

            for (int curriculum : curriculaForCourse) {
                // Determine whether the added course is secluded with
respect to this curriculum
                boolean hasNeighbor = false;
                boolean earlierNeighorIsSecluded = false;
                boolean hasNeighborEarlier = false;
                boolean hasNeighborLater = false;
                boolean laterNeighborIsSecluded = false;
                if (period > 0) {
                    hasNeighborEarlier =
curriculumAssigned[curriculum][day][period - 1] > 0;

                    if (hasNeighborEarlier) {
                        // We have an earlier neighbor -- compute whether
that neighbor already had a neighbor

                        earlierNeighorIsSecluded = period < 2 ||
curriculumAssigned[curriculum][day][period - 2] == 0;
                    }
                    hasNeighbor = hasNeighborEarlier;
                }

                if (period + 1 < basicInfo.periodsPerDay) {
                    hasNeighborLater =
curriculumAssigned[curriculum][day][period + 1] > 0;

                    if (hasNeighborLater) {
                        // We have a later neighbor -- compute whether that
neighbor was already secluded
                        laterNeighborIsSecluded = period >
basicInfo.periodsPerDay - 3 || curriculumAssigned[curriculum][day][period +
2] == 0;
                    }

                    hasNeighbor = hasNeighbor || hasNeighborLater;
                }

                if (!hasNeighbor)
```

```
                    ownSeclusionPenalty -= CURRICULUM_COMPACTNESS_PENALTY;

                if (hasNeighborEarlier && earlierNeighorIsSecluded)
                    otherSeclusionPenalty += CURRICULUM_COMPACTNESS_PENALTY;

                if (hasNeighborLater && laterNeighborIsSecluded)
                    otherSeclusionPenalty += CURRICULUM_COMPACTNESS_PENALTY;
            }

            return ownSeclusionPenalty + otherSeclusionPenalty;
        }

        public int getDeltaWhenAdding(int day, int period, int room, int
course) {
            int penaltyDelta = 0;

            // Unscheduled
            penaltyDelta += getUnscheduledPenaltyAfterAdding(course);

            // RoomCapacity
            penaltyDelta += roomCapacityPenaltyAfterAdding(room, course);

            // MinimumWorkingDays
            penaltyDelta += minWorkingDaysPenaltyAfterAdding(day, course);

            // CurriculumCompactness
            penaltyDelta += curriculumCompactnessPenaltyAfterAdding(day,
period, course);

            // RoomStability
            penaltyDelta += roomStabilityPenaltyAfterAdding(room, course);

            return penaltyDelta;
        }


        public int getDeltaWhenRemoving(int day, int period, int room, int
course) {
            int penaltyDelta = 0;

            // Unscheduled
            penaltyDelta += getUnscheduledPenaltyAfterRemoving(course);

            // RoomCapacity
            penaltyDelta += roomCapacityPenaltyAfterRemoving(room, course);

            // MinimumWorkingDays
            penaltyDelta += minWorkingDaysPenaltyAfterRemoving(day, course);

            // CurriculumCompactness
            penaltyDelta += curriculumCompactnessPenaltyAfterRemoving(day,
period, course);
```

```
            // RoomStability
            penaltyDelta += roomStabilityPenaltyAfterRemoving(room, course);

            return penaltyDelta;
        }

        /**
         * Checks that a given course can be added in the given time slot
without violating the SameCurriculum constraint.
         * @return true if the constraint is satisfied
         */
        public boolean deltaValidateSameCurriculumConstraint(int day, int
period, int course) {
            LinkedList<Integer> curricula =
curriculum.curriculaForCourse.get(course);
            for (int curriculum : curricula) {
                if (curriculumAssigned[curriculum][day][period] > 0)
                    return false;
            }
            return true;
        }

        /**
         * Checks that a given course can be added in the given time slot
without violating the SameLecturer constraint.
         * @return true if the constraint is satisfied
         */
        public boolean deltaValidateSameLecturerConstraint(int day, int
period, int course) {
            int lecturer = courses.lecturerForCourse[course];
            return lecturerBusy[lecturer][day][period] == 0;
        }

        /**
         * Checks that a given course can be added in the given time slot
without violating the Unavailability constraint.
         * @return true if the constraint is satisfied
         */
        public boolean deltaValidateUnavailabilityConstraint(int day, int
period, int course) {
            return !unavailability.courseUnavailable[day][period][course];
        }

        /**
         * Checks that a lecture can be added for a given course without
violating the MaximimumLectures constraint
         * @return true if the constraint is not violated by the current
schedule
         */
        public boolean deltaValidateMaximumScheduleCountConstraint(int
course) {
```

```
            return courseAssignmentCount[course] <
courses.numberOfLecturesForCourse[course];
        }

        /**
         * Checks that all constraints are satisfied if the given course is
assigned to the given time slot.
         * @return true if the assignment does not violate constraint, false
otherwise.
         */
        public boolean deltaValidateAllConstraints(int day, int period, int
course) {
            boolean allConstraintsSatisfied;

            allConstraintsSatisfied =
deltaValidateMaximumScheduleCountConstraint(course);
            allConstraintsSatisfied = allConstraintsSatisfied &&
deltaValidateUnavailabilityConstraint(day, period, course);
            allConstraintsSatisfied = allConstraintsSatisfied &&
deltaValidateSameLecturerConstraint(day, period, course);
            allConstraintsSatisfied = allConstraintsSatisfied &&
deltaValidateSameCurriculumConstraint(day, period, course);

            return allConstraintsSatisfied;
        }
    }
}
```

DoNothingHeuristic.java

```
/**
 * Created by Martin on 05-04-2015.
 */
public class DoNothingHeuristic extends Heuristic {
    @Override
    public Schedule search(Schedule schedule) {
        return schedule;
    }
}
```

ExhaustiveTABU.java

```
public class ExhaustiveTABU extends TABUHeuristic {
    public boolean considerSwaps = true;

    @Override
    protected TABUOperationResult bestSolutionInNeighborhood() {
        TABUOperationResult result = new TABUOperationResult();
        result.scheduleValueAfterApplying = Integer.MAX_VALUE;

        for (int day = 0; day < basicInfo.days; day++) {
            for (int period = 0; period < basicInfo.periodsPerDay; period++)
{
                for (int room = 0; room < basicInfo.rooms; room++) {
                    int assignedCourse =
currentSchedule.assignments[day][period][room];
                    if (assignedCourse != EMPTY_ROOM) {
                        int newValue =
valueIfRemovingCourse(currentSchedule, currentScheduleValue, day, period,
room);
                        if (newValue < result.scheduleValueAfterApplying) {
                            TABUOperation operation = new TABUOperation();
                            operation.day = day;
                            operation.period = period;
                            operation.room = room;
                            operation.type = OperationType.Remove;

                            if (!isTaboo(operation)) {
                                result.operation = operation;
                                result.scheduleValueAfterApplying =
newValue;
                            }
                        }

                        // Consider swapping with all other courses
                        if (considerSwaps) {
                            for (int day2 = 0; day2 < basicInfo.days;
day2++) {
                                for (int period2 = 0; period2 <
basicInfo.periodsPerDay; period2++) {
                                    for (int room2 = 0; room2 <
basicInfo.rooms; room2++) {
                                        int otherCourse =
currentSchedule.assignments[day2][period2][room2];
                                        if (otherCourse == EMPTY_ROOM ||
otherCourse <= assignedCourse)
                                            continue;


                                        int newValueAfterSwap =
valueIfSwappingCourses(currentSchedule, currentScheduleValue, day, period,
room, day2, period2, room2);
                                        if (newValueAfterSwap <
result.scheduleValueAfterApplying) {
                                            TABUOperation operation = new
TABUOperation();
```

```
                                            operation.day = day;
                                            operation.period = period;
                                            operation.room = room;
                                            operation.otherDay = day2;
                                            operation.otherPeriod = period2;
                                            operation.otherRoom = room2;
                                            operation.type =
OperationType.Swap;

                                            if (!isTaboo(operation)) {
                                                result.operation =
operation;

result.scheduleValueAfterApplying = newValueAfterSwap;
                                            }
                                        }

                                    }
                                }
                            }
                        }

                    } else {
                        for (int course = 0; course < basicInfo.courses;
course++) {
                            int newValue =
valueIfAssigningCourse(currentSchedule, currentScheduleValue, day, period,
room, course);
                            if (newValue <
result.scheduleValueAfterApplying) {
                                TABUOperation operation = new
TABUOperation();
                                operation.day = day;
                                operation.period = period;
                                operation.room = room;
                                operation.course = course;
                                operation.type = OperationType.Assign;

                                if (!isTaboo(operation)) {
                                    result.operation = operation;
                                    result.scheduleValueAfterApplying =
newValue;
                                }
                            }
                        }
                    }
                }
            }
        }

        return result;
    }
```

```
}
```

StochasticHillClimber.java

```
import java.io.FileWriter;
import java.io.IOException;
import java.util.Random;
import java.util.UUID;

import com.opencsv.CSVWriter;

/**
 * Created by Burak on 08-04-2015.
 */
public class StochasticHillClimber extends Heuristic {

	protected int currentValue;
	protected int previousValue  = Integer.MAX_VALUE;

	private Random random = new XORShiftRandom();
	public  StochasticHillClimber() throws IOException {
		super();
		String uuid = UUID.randomUUID().toString();
		f = new FileWriter(this.getClass()+uuid+"iterationValue.csv");
		writer = new CSVWriter(f, ',', CSVWriter.NO_QUOTE_CHARACTER);
	}

	@Override
	public Schedule search(Schedule schedule) throws IOException {
		startCountdown();
		currentValue = evaluationFunction(schedule); // value of the
current solution
	    deltaState.courseAssignmentCount =
getCourseAssignmentCount(schedule);
		String[] result = new String[] { "" + iterationCount,
currentValue + "" };
		writer.writeNext(result);
		int rooms = this.basicInfo.rooms;
		int days = this.basicInfo.days;
		int periods = this.basicInfo.periodsPerDay;

		while (!timeoutReached()) {
			this.iterationCount++; //Adds to the iteration count

			// Find a candidate for changing
			int room = random.nextInt(rooms);
			int day = random.nextInt(days);
			int period = random.nextInt(periods);

			// If the room is empty, check the impact of adding a
course
			int currentlyAssignedCourse =
schedule.assignments[day][period][room];
			if (currentlyAssignedCourse == EMPTY_ROOM) {
				// Find a course to assign
				int courseToAssign =
random.nextInt(basicInfo.courses);

		        int valueIfThisCourseIsAssigned =
valueIfAssigningCourse(schedule, currentValue, day, period, room,
courseToAssign);

				if (valueIfThisCourseIsAssigned < currentValue) {
					assignCourse(schedule, day, period, room,
courseToAssign);
					currentValue = valueIfThisCourseIsAssigned;
				}
			} else {
				// Maybe we should remove the assigned course?
		        int valueIfThisCourseIsRemoved =
valueIfRemovingCourse(schedule, currentValue, day, period, room);
```

```
                        if (valueIfThisCourseIsRemoved < currentValue) {
                              removeCourse(schedule, day, period, room);
                              currentValue = valueIfThisCourseIsRemoved;
                        }
                  }
                  if((float)Math.abs(previousValue-
currentValue)/currentValue >= 0.05 ) {
                        result = new String[] { "" + iterationCount,
currentValue + "" };
                        writer.writeNext(result);
                        previousValue = currentValue;
                  }


            }

            result = new String[] { "" + iterationCount, currentValue + "" };
            writer.writeNext(result);
            writer.flush();
            f.close();
            return schedule;
      }
}
```

StochasticTabu.java

```
import java.io.FileWriter;
import java.io.IOException;
import java.util.Random;
import java.util.UUID;
import java.util.Vector;

import javax.swing.text.html.HTMLDocument.HTMLReader.IsindexAction;

import com.opencsv.CSVWriter;


/**
 * Created by Burak on 08-04-2015.
 */
public class StochasticTABU extends Heuristic {


      protected int previousBestValue = Integer.MAX_VALUE;
      private int tabooLength;
      private int bestCourse1;
	private int bestCourse2;
	private Random random = new XORShiftRandom();
	protected Vector<Integer> tabooList1; //The first taboolist - ONLY 
TABOOSEARCH
	protected Vector<Integer> tabooList2; //The second taboolist - ONLY 
TABOOSEARCH
	private Integer[] bestdayPeriodRoom1;
	private Integer [] bestdayPeriodRoom2;
	protected Vector<Integer[]> tabooListSlots1; //The first taboolist - 
ONLY TABOOSEARCH
	protected Vector<Integer[]> tabooListSlots2; //The second taboolist - 
ONLY TABOOSEARCH
	private static final int ASSIGNNO = -2;
	private static final int REMOVENO = -3;
	public StochasticTABU(int TabooLength) throws IOException
	{
		this.tabooLength = TabooLength;
		//tabooList1  = new Vector<Integer>();
		//tabooList2  = new Vector<Integer>();
		tabooListSlots1 = new Vector<Integer[]>();
		tabooListSlots2 = new  Vector<Integer[]>();
		String uuid = UUID.randomUUID().toString();
		f = new 
FileWriter(this.getClass()+Integer.toString(tabooLength)+uuid+"iterationValu
e.csv");
		writer = new CSVWriter(f, ',', CSVWriter.NO_QUOTE_CHARACTER);

	}

	@Override
	public Schedule search(Schedule currentSchedule) throws IOException {
		startCountdown();
		Schedule currentBestSchedule;
		Schedule bestSchedule;
		currentBestSchedule  =new Schedule(this.basicInfo.days, 
this.basicInfo.periodsPerDay, this.basicInfo.rooms);
		bestSchedule  =new Schedule(this.basicInfo.days, 
this.basicInfo.periodsPerDay, this.basicInfo.rooms);
		cloneArray(currentSchedule.assignments, 
currentBestSchedule.assignments);
		int currentValue;
		int currentBestValue ;
		int bestValue = Integer.MAX_VALUE;
		currentValue = evaluationFunction(currentSchedule); // value of 
the current solution
		String[] result = new String[] { "" + iterationCount, 
currentValue + "" };
		writer.writeNext(result);
		deltaState.courseAssignmentCount = 
getCourseAssignmentCount(currentSchedule);
		int rooms = this.basicInfo.rooms;
		int days = this.basicInfo.days;
```

```
            int periods = this.basicInfo.periodsPerDay;
            System.out.println("Start");

            while(timeoutReached() == false) {
                  currentBestValue = Integer.MAX_VALUE;

                  this.iterationCount++; //Adds to the iteration count


                  for(int day=0;day<this.basicInfo.days;day++) { //run
thorough all the days

                        for(int period =
0;period<this.basicInfo.periodsPerDay;period++) { //all the periods

                              for(int room =
0;room<this.basicInfo.rooms;room++){ //all the rooms
                                    int room2 = random.nextInt(rooms);
                                    int day2 = random.nextInt(days);
                                    int period2 = random.nextInt(periods);


      while((day==day2)&&(period==period2)&&(room==room2) ) {
                                          room2 = random.nextInt(rooms);
                                          day2 = random.nextInt(days);
                                          period2 = random.nextInt(periods);
                                    }

                                    int valueIfThisCourseIsAssigned  =
Integer.MAX_VALUE;
                                    int valueIfThisCourseIsRemoved  =
Integer.MAX_VALUE;
                                    int valueIfThisCoursesAreSwapped  =
Integer.MAX_VALUE;
                                    int courseId =
random.nextInt(this.basicInfo.courses);

      if(currentSchedule.assignments[day][period][room] !=
StochasticHillClimber.EMPTY_ROOM) {
                                          valueIfThisCourseIsRemoved  =
valueIfRemovingCourse(currentSchedule, currentValue, day,period, room );
//calculate the value if we remove the course given timeslot
                                    }
                                    else {
                                          valueIfThisCourseIsAssigned  =
valueIfAssigningCourse(currentSchedule, currentValue, day,period, room ,
courseId); //calculate the value if we swap the courses given timeslots
                                    }


                                    valueIfThisCoursesAreSwapped  =
valueIfSwappingCourses(currentSchedule, currentValue, day, period, room,
day2, period2, room2);//calculate the value if we add the course given
timeslot

      //System.err.println("valueIfThisCourseIsRemoved =  " +
valueIfThisCourseIsRemoved + " valueIfThisCourseIsAssigned  ="+
valueIfThisCourseIsAssigned+ " valueIfThisCoursesAreSwapped  =" +
valueIfThisCoursesAreSwapped);
                                 /*if(currentValue<0) {
                                 System.err.println("currentValue  =
"+currentValue );
                                 System.exit(0);
                                 }

      System.err.println("valueIfThisCoursesAreSwapped  =
"+valueIfThisCoursesAreSwapped );

      System.err.println("valueIfThisCourseIsAssigned  =
"+valueIfThisCourseIsAssigned );

      System.err.println("valueIfThisCourseIsRemoved  =
"+valueIfThisCourseIsRemoved );
                                 */

                                 Type change;
                                 //we have the new values now we need to
choose which action would be the best according to new values (find the best
neighboor)

      if(valueIfThisCourseIsRemoved<=valueIfThisCourseIsAssigned){

      if(valueIfThisCourseIsRemoved<=valueIfThisCoursesAreSwapped) {
                                            if(valueIfThisCourseIsRemoved !=
Integer.MAX_VALUE)
                                                 change = Type.REMOVE;//if
removing the course gives the best value then choose remove
                                            else
                                                 change =
Type.NOTHING;//that means we have Max_int value so we do nothing in this
iteration
                                       }
                                       else {
                                            change = Type.SWAP;//choose swap
if the swapping gives the best value
                                       }
                                 }
                                 else {

      if(valueIfThisCourseIsAssigned<valueIfThisCoursesAreSwapped)
                                            change = Type.ASSIGN; //choose
assign if the assigning gives the best value
                                       else
```

```
                                            change = Type.SWAP;//choose swap
if the swapping gives the best value
                                 }
                                 //System.err.println("" +
currentBestValue);
                                 switch (change) {
                                 case REMOVE:{

                                            bestdayPeriodRoom1 = new
Integer[3];
                                            bestdayPeriodRoom1[0] = day;
                                            bestdayPeriodRoom1[1] = period;
                                            bestdayPeriodRoom1[2] = room;
                                            bestdayPeriodRoom2 = new
Integer[3];
                                            bestdayPeriodRoom2[0] =
REMOVENO;
                                            bestdayPeriodRoom2[1] =
REMOVENO;
                                            bestdayPeriodRoom2[2] =
REMOVENO;

                                            if(valueIfThisCourseIsRemoved <
currentBestValue && !IsTaboo(bestdayPeriodRoom1,bestdayPeriodRoom2)) {
                                                 currentBestValue =
valueIfThisCourseIsRemoved;
                                                 int courseName =
currentSchedule.assignments[day][period][room];//Remembers the course for
change back

     removeCourse(currentSchedule, day, period, room);

     cloneArray(currentSchedule.assignments,
currentBestSchedule.assignments);

     assignCourse(currentSchedule, day, period, room, courseName);
                                            }
                                            //swap back changes in current
schedule


                                            break;
                                 }
                                 case ASSIGN: {

                                            bestdayPeriodRoom1 = new
Integer[3];
                                            bestdayPeriodRoom1[0] = day;
                                            bestdayPeriodRoom1[1] = period;
                                            bestdayPeriodRoom1[2] = room;
                                            bestdayPeriodRoom2 = new
Integer[3];
```

```
                                            bestdayPeriodRoom2[0] =
ASSIGNNO;
                                            bestdayPeriodRoom2[1] =
ASSIGNNO;
                                            bestdayPeriodRoom2[2] =
ASSIGNNO;

                                            if(valueIfThisCourseIsAssigned <
currentBestValue && !IsTaboo(bestdayPeriodRoom1,bestdayPeriodRoom2)) {

      assignCourse(currentSchedule, day, period, room, courseId);
                                                 currentBestValue =
valueIfThisCourseIsAssigned;

      cloneArray(currentSchedule.assignments,
currentBestSchedule.assignments);
                                                 //swap back changes in
current schedule

      removeCourse(currentSchedule, day, period, room);
                                            }


                                            break;
                                 }
                                 case SWAP: {
                                      bestdayPeriodRoom1 = new Integer[3];
                                      bestdayPeriodRoom1[0] = day;
                                      bestdayPeriodRoom1[1] = period;
                                      bestdayPeriodRoom1[2] = room;
                                      bestdayPeriodRoom2 = new Integer[3];
                                      bestdayPeriodRoom2[0] = day2;
                                      bestdayPeriodRoom2[1] = period2;
                                      bestdayPeriodRoom2[2] = room2;

                                      if(valueIfThisCoursesAreSwapped <
currentBestValue && !IsTaboo(bestdayPeriodRoom1,bestdayPeriodRoom2)) {
                                            bestCourse1 =
currentSchedule.assignments[day][period][room];//Remembers the course for to
assign
                                            bestCourse2 =
currentSchedule.assignments[day2][period2][room2]; //Remembers the course
for to assign
                                            removeCourse(currentSchedule,
day2, period2, room2);
                                            removeCourse(currentSchedule,
day, period, room);
                                            assignCourse(currentSchedule,
day2, period2, room2, bestCourse1);
                                            assignCourse(currentSchedule,
day, period, room, bestCourse2);
```

```
                                            currentBestValue =
valueIfThisCoursesAreSwapped;

     cloneArray(currentSchedule.assignments,
currentBestSchedule.assignments);
                                            //swap back changes in current
schedule
                                            removeCourse(currentSchedule,
day2, period2, room2);
                                            removeCourse(currentSchedule,
day, period, room);
                                            assignCourse(currentSchedule,
day, period, room, bestCourse1);
                                            assignCourse(currentSchedule,
day2, period2, room2, bestCourse2);
                                       }

                                       break;
                                  }
                                  default:
                                       break;
                                  }

                             }
                        }
                   }
                   //save the current best schedule we are going to start
searching there next iteration

     cloneArray( currentBestSchedule.assignments,currentSchedule.assignment
s);
                   if(currentBestValue!=Integer.MAX_VALUE)
                        currentValue = currentBestValue;
                   AddTaboo(bestdayPeriodRoom1, bestdayPeriodRoom2);//we add
the course in the tabo list with the REMOVENO so when we check the taboo
list we will know its assigned
                   if( currentBestValue<bestValue) {
                        bestValue = currentBestValue;

     cloneArray( currentBestSchedule.assignments,bestSchedule.assignments);
                   }

                   if((float)Math.abs(previousBestValue-
bestValue)/bestValue >= 0.05 ) {
                        result = new String[] { "" + iterationCount, bestValue
+ "" };
                        writer.writeNext(result);
                        previousBestValue = bestValue;
                   }


              }
```

```
            result = new String[] { "" + iterationCount, bestValue + "" };
            writer.writeNext(result);
            writer.flush();
            f.close();
            //System.out.println("Tabu  Found A Solution!");
            //System.out.println("Value  = 
"+evaluationFunction(currentBestSchedule));

      cloneArray( bestSchedule.assignments,currentBestSchedule.assignments);
            return currentBestSchedule;
      }

      /**
       * Adds this swap to the taboolist - ONLY TABOOSEARCH
       * @param course1
       * @param course2
       */
      public void AddTaboo(int course1, int course2)
      {
            //If the list is full, the first added is now removed
            if(this.tabooList1.size() == this.tabooLength)
            {
                  this.tabooList1.remove(0);
                  this.tabooList2.remove(0);
            }
            this.tabooList1.add(course1);
            this.tabooList2.add(course2);
      }

      /**
       * Finds out if the swap is tabooed - ONLY TABOO SEARCH
       * @param course1
       * @param course2
       * @return
       */
      public boolean IsTaboo(int course1, int course2)
      {
            for (int i = 0 ; i < this.tabooList1.size(); i++)
            {
                  if(course2==ASSIGNNO) { //that means we need to check TABU 
list for assign

                        if(tabooList1.elementAt(i) == course1)
                        {
                              if(tabooList2.elementAt(i) == REMOVENO) //that 
means if we remove the course before dont assign that course again it is 
TABU
                              {
                                    return true;
                              }
                        }
```

```
                }
                else if (course2 == REMOVENO) {//check TABU list for remove
                     if(tabooList1.elementAt(i) == course1)
                     {
                          if(tabooList2.elementAt(i) == ASSIGNNO) //that
means if we assign the course before dont remove that course again it is
TABU
                          {
                               return true;
                          }
                     }
                }
                else { //finaly if course2 is not ASSIGNNO or REMOVENO then
check TABU list for Swap
                     if(tabooList1.elementAt(i) == course1)
                     {
                          if(tabooList2.elementAt(i) == course2)
                          {
                               return true;
                          }
                     }
                     if(tabooList1.elementAt(i) == course2)
                     {
                          if(tabooList2.elementAt(i) == course1)
                          {
                               return true;
                          }
                     }
                }
           }

           return false;

      }
      /**
       * Adds this swap to the taboolist - ONLY TABOOSEARCH
       * @param dayPeriodRoom1
       * @param dayPeriodRoom2
       */
      public void AddTaboo(Integer[] dayPeriodRoom1,Integer[]
dayPeriodRoom2)
      {
           //If the list is full, the first added is now removed
           if(this.tabooListSlots1.size() == this.tabooLength)
           {
                this.tabooListSlots1.remove(0);
                this.tabooListSlots1.remove(0);
           }
           this.tabooListSlots1.add(dayPeriodRoom1);
           this.tabooListSlots2.add(dayPeriodRoom2);
      }
```

```
	/**
	 * Finds out if the swap is tabooed - ONLY TABOO SEARCH
	 */
	public boolean IsTaboo(Integer[] dayPeriodRoom1,Integer[] 
dayPeriodRoom2)
	{

		if(dayPeriodRoom2[0] == REMOVENO) {
			for (int i = 0 ; i < this.tabooListSlots1.size(); i++)
			{

				if(tabooListSlots1.elementAt(i)[0] == 
dayPeriodRoom1[0] && tabooListSlots1.elementAt(i)[1] == dayPeriodRoom1[1] && 
tabooListSlots1.elementAt(i)[2] == dayPeriodRoom1[2] )
				{


					if(tabooListSlots2.elementAt(i)[0] == ASSIGNNO)
					{
						return true;
					}
				}
			}
		}
		else if (dayPeriodRoom2[0] == ASSIGNNO) {
			for (int i = 0 ; i < this.tabooListSlots1.size(); i++)

			{
				//System.err.println(" size = " + 
tabooListSlots1.size() + " index = " +i);
				if(tabooListSlots1.elementAt(i)[0] == 
dayPeriodRoom1[0] && tabooListSlots1.elementAt(i)[1] == dayPeriodRoom1[1] && 
tabooListSlots1.elementAt(i)[2] == dayPeriodRoom1[2] )
				{
					if(tabooListSlots2.elementAt(i)[0] == REMOVENO)
					{
						return true;
					}
				}
			}
		}

		else {
			for (int i = 0 ; i < this.tabooListSlots1.size(); i++)
			{

				if(tabooListSlots1.elementAt(i)[0] == 
dayPeriodRoom1[0] && tabooListSlots1.elementAt(i)[1] == dayPeriodRoom1[1] && 
tabooListSlots1.elementAt(i)[2] == dayPeriodRoom1[2] )
				{
```

```
                              if(tabooListSlots2.elementAt(i)[0] ==
dayPeriodRoom2[0] && tabooListSlots2.elementAt(i)[1] == dayPeriodRoom2[1] &&
tabooListSlots2.elementAt(i)[2] == dayPeriodRoom2[2])
                              {
                                    return true;
                              }
                        }
                        if(tabooListSlots1.elementAt(i)[0] ==
dayPeriodRoom2[0] && tabooListSlots1.elementAt(i)[1] == dayPeriodRoom2[1] &&
tabooListSlots1.elementAt(i)[2] == dayPeriodRoom2[2] )
                        {
                              if(tabooListSlots2.elementAt(i)[0] ==
dayPeriodRoom1[0] && tabooListSlots2.elementAt(i)[1] == dayPeriodRoom1[1] &&
tabooListSlots2.elementAt(i)[2] == dayPeriodRoom1[2])
                              {
                                    return true;
                              }
                        }


                  }
            }

            return false;

      }
}
```

TABU.java

```
import java.io.FileWriter;
import java.io.IOException;
import java.lang.reflect.Array;
import java.util.UUID;
import java.util.Vector;

import com.opencsv.CSVWriter;


/**
 * Created by Burak on 08-04-2015.
 */
public class TABU extends Heuristic {

      protected Schedule schedule; //current schedule
      protected Schedule currentSchedule; //the copy of the current schedule
where changes are made, that are not certain to be saved
      protected int currentValue;
      protected int previousValue = Integer.MAX_VALUE;
	private int tabooLength;
	private Integer[] bestdayPeriodRoom1;
	private Integer [] bestdayPeriodRoom2;
	protected Vector<Integer[]> tabooList1; //The first taboolist - ONLY 
TABOOSEARCH
	protected Vector<Integer[]> tabooList2; //The second taboolist - ONLY 
TABOOSEARCH
	public TABU(int TabooLength) throws IOException
	{
		super();
		this.tabooLength = TabooLength;
		tabooList1  = new Vector<Integer[]>();
		tabooList2  = new Vector<Integer[]>();
		String uuid = UUID.randomUUID().toString();
		f = new 
FileWriter(this.getClass()+Integer.toString(tabooLength)+uuid+"iterationValu
e.csv");
		writer = new CSVWriter(f, ',', CSVWriter.NO_QUOTE_CHARACTER);

	}

	@Override
	public Schedule search(Schedule schedule) throws IOException {
		startCountdown();
		currentValue = evaluationFunction(schedule); // value of the 
current solution
		deltaState.courseAssignmentCount = 
getCourseAssignmentCount(schedule);
		String[] result = new String[] { "" + iterationCount, 
currentValue + "" };
		writer.writeNext(result);
		System.out.println("Start");
		while(timeoutReached() == false) {

			this.iterationCount++; //Adds to the iteration count
			for(int day=0;day<this.basicInfo.days;day++) { //run 
thorough all the days

				for(int period = 
0;period<this.basicInfo.periodsPerDay;period++) { //all the periods

					for(int room = 
0;room<this.basicInfo.rooms;room++){ //all the rooms

						for(int 
day2=0;day2<this.basicInfo.days;day2++) { //all the days can be swap to

							for(int period2 = 
0;period2<this.basicInfo.periodsPerDay;period2++) { //all the periods can be 
swap to
```

```
                                            for(int room2 = 
0;room2<this.basicInfo.rooms;room2++){ //all the rooms can be swap to
                                                 //int 
valueIfThisCourseIsAssigned  = Integer.MAX_VALUE;
                                                 //int 
valueIfThisCourseIsRemoved  = Integer.MAX_VALUE;
                                                 int 
valueIfThisCoursesAreSwapped  = Integer.MAX_VALUE;
                                                 //TODO:also check the 
values if with emoving and adding methods

     valueIfThisCoursesAreSwapped = valueIfSwappingCourses(schedule, 
currentValue, day, period,room, day2, period2, room2);

     if(currentValue>valueIfThisCoursesAreSwapped && 
IsTaboo(day,period,room, day2,period2,room2) == false) {
                                                      currentValue = 
valueIfThisCoursesAreSwapped;


                                                      bestdayPeriodRoom1 = 
new Integer[3];
                                                      bestdayPeriodRoom1[0] 
= day;
                                                      bestdayPeriodRoom1[1] 
= period;
                                                      bestdayPeriodRoom1[2] 
= room;
                                                      bestdayPeriodRoom2 = 
new Integer[3];
                                                      bestdayPeriodRoom2[0] 
= day2;
                                                      bestdayPeriodRoom2[1] 
= period2;
                                                      bestdayPeriodRoom2[2] 
= room2;


                                                      int bestCourse1 = 
schedule.assignments[day][period][room];//Remembers the course for the 
assign
                                                      int bestCourse2 = 
schedule.assignments[day2][period2][room2]; //Remembers the course for the 
assign

     removeCourse(schedule, day2, period2, room2);

     removeCourse(schedule, day, period, room);

     assignCourse(schedule, day2, period2, room2, bestCourse1);

     assignCourse(schedule, day, period, room, bestCourse2);
```

```
                                                    }

                                               }

                                          }

                                     }
                                }
                           }

                      }
                      AddTaboo(bestdayPeriodRoom1, bestdayPeriodRoom2); //Makes
the swap back taboo.
                      if((float)Math.abs(previousValue-
currentValue)/currentValue >= 0.05 ) {
                           result = new String[] { "" + iterationCount,
currentValue + "" };
                           writer.writeNext(result);
                           previousValue = currentValue;
                      }


                 }

                 result = new String[] { "" + iterationCount, currentValue + "" };
                 writer.writeNext(result);
                 writer.flush();
                 f.close();
                 System.out.println("Tabu  Found A Solution!");
                 System.out.println("Value  = "+evaluationFunction(schedule));
                 return schedule;
           }

           /**
            * Adds this swap to the taboolist - ONLY TABOOSEARCH
            * @param dayPeriodRoom1
            * @param dayPeriodRoom2
            */
           public void AddTaboo(Integer[] dayPeriodRoom1,Integer[]
dayPeriodRoom2)
           {
                 //If the list is full, the first added is now removed
                 if(this.tabooList1.size() == this.tabooLength)
                 {
                      this.tabooList1.remove(0);
                      this.tabooList2.remove(0);
                 }
                 this.tabooList1.add(dayPeriodRoom1);
                 this.tabooList2.add(dayPeriodRoom2);
           }

           /**
```

```
	 * Finds out if the swap is tabooed - ONLY TABOO SEARCH
	 * @param course1
	 * @param course2
	 * @return
	 */
	public boolean IsTaboo(int day1,int period1, int room1,int day2,int
period2,int room2)
	{
		for (int i = 0 ; i < this.tabooList1.size(); i++)
		{
			if(tabooList1.elementAt(i)[0] == day1 &&
tabooList1.elementAt(i)[1] == period1 && tabooList1.elementAt(i)[2] ==
room1 )
			{
				if(tabooList2.elementAt(i)[0] == day2 &&
tabooList2.elementAt(i)[1] == period2 && tabooList2.elementAt(i)[2] ==
room2)
				{
					return true;
				}
			}
			if(tabooList1.elementAt(i)[0] == day2 &&
tabooList1.elementAt(i)[1] == period2 && tabooList1.elementAt(i)[2] ==
room2 )
			{
				if(tabooList2.elementAt(i)[0] == day1 &&
tabooList2.elementAt(i)[1] == period1 && tabooList2.elementAt(i)[2] ==
room1)
				{
					return true;
				}
			}
		}
		return false;

	}
}
```

TABUHeuristic.java

```
import sun.awt.image.ImageWatched;

import java.io.IOException;
import java.util.LinkedList;

public abstract class TABUHeuristic extends Heuristic {
    protected Schedule currentSchedule, bestSchedule;
    protected int currentScheduleValue, bestScheduleValue;

    public enum OperationType {
        Assign,
        Remove,
        Swap
    }

    public int tabooListLength = 20;

    public class TABUOperation {
        public int day = -1;
        public int period = -1;
        public int room = -1;
        public int course = -1;
        public int otherDay = -1;
        public int otherPeriod = -1;
        public int otherRoom = -1;
        public int otherCourse = -1;

        public OperationType type;
    }

    public class TABUOperationResult {
        public TABUOperation operation;
        public int scheduleValueAfterApplying;
    }

    private void applyOperation(Schedule schedule, TABUOperation operation)
{
        if (operation == null)
            return;

        switch (operation.type) {
            case Assign:
                assignCourse(schedule, operation.day, operation.period,
operation.room, operation.course);
                break;

            case Remove:
                removeCourse(schedule, operation.day, operation.period,
operation.room);
                break;

            case Swap:
                removeCourse(schedule, operation.day, operation.period,
operation.room);
                removeCourse(schedule, operation.otherDay,
operation.otherPeriod, operation.otherRoom);
                assignCourse(schedule, operation.day, operation.period,
operation.room, operation.otherCourse);
                assignCourse(schedule, operation.otherDay,
operation.otherPeriod, operation.otherRoom, operation.course);
                break;
        }
    }
    @Override
    public Schedule search(Schedule schedule) throws IOException {
        currentSchedule = schedule;
        currentScheduleValue = evaluationFunction(currentSchedule);

        bestSchedule = new Schedule(basicInfo.days, basicInfo.periodsPerDay,
basicInfo.rooms);

        cloneArray(schedule.assignments, bestSchedule.assignments);
        bestScheduleValue = currentScheduleValue;

        startCountdown();

        while(!timeoutReached()) {
            iterationCount++;

            // Determine the operation needed to get the best solution in
neighborhood
            TABUOperationResult operation = bestSolutionInNeighborhood();

            // Apply that operation to the currentSchedule
            applyOperation(currentSchedule, operation.operation);
            currentScheduleValue = operation.scheduleValueAfterApplying;

            // If we just encountered a better solution than earlier, store
it
            if (currentScheduleValue < bestScheduleValue) {
                cloneArray(schedule.assignments, bestSchedule.assignments);
                bestScheduleValue = currentScheduleValue;
            }
        }

        return bestSchedule;
    }

    protected LinkedList<TABUOperation> tabooList = new
LinkedList<TABUOperation>();

    private void addTaboo(TABUOperation operation) {
        tabooList.addLast(operation);
        while (tabooList.size() > tabooListLength)
            tabooList.removeFirst();
    }

    protected boolean isTaboo(TABUOperation operation) {
        switch (operation.type) {
            case Assign:
            case Swap:
                for (TABUOperation taboo : tabooList) {
                    if (taboo.course == operation.course || taboo.course ==
operation.otherCourse || taboo.otherCourse == operation.course ||
taboo.otherCourse == operation.otherCourse)
                        return true;
                }
                return false;

            case Remove:
            default:
                for (TABUOperation taboo : tabooList) {
                    if (taboo.day == operation.day && taboo.period ==
operation.period && taboo.room == operation.room)
                        return true;
                }
                return false;
        }
    }

    protected abstract TABUOperationResult bestSolutionInNeighborhood();
}
```

HillClimber.java

```
import java.util.HashMap;
import java.util.Map;
import java.util.Random;


/**
 * Created by Burak on 08-04-2015.
 */
public class HillClimber extends Heuristic {

    protected Schedule schedule; //current schedule
    //protected Schedule currentSchedule; //the copy of the current schedule
where changes are made, that are not certain to be saved
    protected int IterationCount = 0;
    protected int currentValue;
    private Random Rand = new XORShiftRandom();
    private Map<Integer, Integer> unScheduledCourses;
    @Override
    public Schedule search(Schedule schedule) {
        startCountdown();
        currentValue = evaluationFunction(schedule); // value of the current
solution
        deltaState.courseAssignmentCount =
getCourseAssignmentCount(schedule);
        unScheduledCourses = new HashMap<Integer, Integer>();
        for (int courseNo = 0; courseNo < this.basicInfo.courses;
courseNo++) { //checked the unscheduled course and the number of unscheduled
lectures
            int numberOfLecturesUnAssigned =
this.deltaState.courseAssignmentCount[courseNo] -
this.courses.numberOfLecturesForCourse[courseNo];
            if (numberOfLecturesUnAssigned != 0)
                unScheduledCourses.put(courseNo,
Math.abs(numberOfLecturesUnAssigned));
        }

        boolean done = false;

        System.out.println("Start");
        while (timeoutReached() == false) { //TODO: we need to deal with the
d
            done = true; //Runs while there are still changes being made
            //System.out.println("Iteration Count = " + IterationCount);
            this.IterationCount++; //Adds to the iteration count
            if (this.IterationCount % 1000 == 0)
                System.err.println("Iteration Count  = " +
this.IterationCount);
            int currentBestValue = currentValue;

            for (int day = 0; day < this.basicInfo.days; day++) { //run
thorough all the days

                for (int period = 0; period < this.basicInfo.periodsPerDay;
period++) { //all the periods

                    for (int room = 0; room < this.basicInfo.rooms; room++)
{ //all the rooms

                        // System.out.println("day = "+ day +" period = " +
period + " room = " + room + " course  = " +
schedule.assignments[day][period][room]);
                        for (Map.Entry<Integer, Integer> entry :
unScheduledCourses.entrySet()) {
                            int unScheduledCourseNo = entry.getKey();
                            int unScheduledCourseValue = entry.getValue();
                            if (schedule.assignments[day][period][room] ==
Heuristic.EMPTY_ROOM) {// room is empty
```

```
                                int valueIfThisCourseIsAssigned =
valueIfAssigningCourse(schedule, currentValue, day, period, room,
unScheduledCourseNo);
                                if (valueIfThisCourseIsAssigned <=
currentValue) {
                                    assignCourse(schedule, day, period,
room, unScheduledCourseNo);
                                    unScheduledCourseValue--;
                                    if (unScheduledCourseValue == 0) {

unScheduledCourses.remove(unScheduledCourseNo);
                                    }
                                }

                            } else { //room is not epmty first we need to
check the

                            }


                            // remove the course in current time slot and
then add the unscheduled course
                            removeCourse(schedule, day, period, room);
                            assignCourse(schedule, day, period, room,
unScheduledCourseNo);
                        }

                    int valueIfThisCourseIsAssigned,
valueIfThisCourseIsRemoved, valueIfThisCoursesAreSwapped;
                    int day2, period2, room2;
                    day2 = Rand.nextInt(this.basicInfo.days);
                    room2 = Rand.nextInt(this.basicInfo.rooms);
                    period2 = Rand.nextInt(this.basicInfo.periodsPerDay);
                    valueIfThisCourseIsRemoved =
valueIfRemovingCourse(schedule, currentValue, day, period, room);
                    int courseId = Rand.nextInt(this.basicInfo.courses);
                    valueIfThisCourseIsAssigned =
valueIfAssigningCourse(schedule, currentValue, day, period, room, courseId);
                    valueIfThisCoursesAreSwapped =
valueIfSwappingCourses(schedule, currentValue, day, period, room, day2,
period2, room2);
                    Type change;
                    if (valueIfThisCourseIsRemoved <=
valueIfThisCourseIsAssigned) {
                        if (valueIfThisCourseIsRemoved <=
valueIfThisCoursesAreSwapped) {
                            if (valueIfThisCourseIsRemoved !=
Integer.MAX_VALUE)
                                change = Type.REMOVE;
                            else
                                change = Type.NOTHING;
                        } else {
                            change = Type.SWAP;
                        }
                    } else {
                        if (valueIfThisCourseIsAssigned <
valueIfThisCoursesAreSwapped)
                            change = Type.ASSIGN;
                        else
                            change = Type.SWAP;
                    }

                    int bestCourse1;
                    int bestCourse2;
                    int deltaval;
                    switch (change) {
                        case REMOVE: {
                            deltaval = valueIfThisCourseIsRemoved -
currentValue;
                            if (deltaval < 0) {
                                currentValue += deltaval;
                                removeCourse(schedule, day, period, room);
                            }
                            break;
                        }
                        case ASSIGN: {
                            deltaval = valueIfThisCourseIsAssigned -
currentValue;
                            if (deltaval < 0) {
                                currentValue += deltaval;
                                assignCourse(schedule, day, period, room,
courseId);
                            }
                            break;
                        }
                        case SWAP: {
                            deltaval = valueIfThisCoursesAreSwapped -
currentValue;
                            if (deltaval < 0) {
                                currentValue = valueIfThisCoursesAreSwapped;
                                bestCourse1 =
schedule.assignments[day][period][room];//Remembers the person for the
taboolist
                                bestCourse2 =
schedule.assignments[day2][period2][room2]; //Remembers the person for the
taboolist
                                removeCourse(schedule, day2, period2,
room2);
                                removeCourse(schedule, day, period, room);
                                assignCourse(schedule, day2, period2, room2,
bestCourse1);
                                assignCourse(schedule, day, period, room,
bestCourse2);
                            }
                            break;
                        }

                        default:
                            break;
                    }
                }

            }


        }
        if (currentBestValue < currentValue) {
            done = false;
            currentValue = currentBestValue;
        }

    }

    return schedule;
}
}
```

SimulatedAnnealing.java

```
import java.io.FileWriter;
import java.io.IOException;
import java.util.Random;
import java.util.UUID;

import com.opencsv.CSVWriter;


public class SimulatedAnnealing extends Heuristic{

     protected Schedule schedule; //current schedule
     protected Schedule currentSchedule; //the copy of the current schedule
where changes are made, that are not certain to be saved
     protected int currentValue;
     protected int previousValue = Integer.MAX_VALUE;
    private double temperature;
    private double tempchange;
    private int deltaval;
    private int day1;
    private int period1;
    private int room1;
    private int day2;
    private int period2;
    private int room2;
    private int bestCourse1;
    private int bestCourse2;
    private Random Rand = new XORShiftRandom();


     public SimulatedAnnealing(double temperature,double tempchange) throws
IOException {
           super();
           this.temperature = temperature;
           this.tempchange = tempchange;
           // write iteration value to a CSV file
           String uuid = UUID.randomUUID().toString();
           f = new FileWriter(this.getClass()+Float.toString((float)
temperature)+Float.toString((float) tempchange)+uuid+"iterationValue.csv");
           writer = new CSVWriter(f, ',', CSVWriter.NO_QUOTE_CHARACTER);
     }


     @Override
     public Schedule search(Schedule schedule) throws IOException {


           System.out.println("Start");
           startCountdown();
        currentValue = evaluationFunction(schedule); // value of the current
solution
        deltaState.courseAssignmentCount =
getCourseAssignmentCount(schedule);
        String[] result = new String[] { "" + iterationCount, currentValue +
"" };
          writer.writeNext(result);
          while(!timeoutReached()) {
           this.iterationCount++; //Adds to the iteration count
           if(iterationCount % 100000 == 0)
           System.out.println("Iteation count = " + iterationCount);
           day1  = day2 = period1 = period2 = room1 = room2 = 0;
           boolean hardConstraintViolation = true;
           int valueIfThisCourseIsAssigned  = Integer.MAX_VALUE;
                int valueIfThisCourseIsRemoved  = Integer.MAX_VALUE;
                int valueIfThisCoursesAreSwapped  = Integer.MAX_VALUE;
                int courseId = -1;
           while(((day1==day2)&&(period1==period2)&&(room1==room2) ||
hardConstraintViolation) ) {
                day1 = Rand.nextInt(this.basicInfo.days);
                day2 = Rand.nextInt(this.basicInfo.days);
                period1 = Rand.nextInt(this.basicInfo.periodsPerDay);
                period2 = Rand.nextInt(this.basicInfo.periodsPerDay);
                room1  = Rand.nextInt(this.basicInfo.rooms);
                room2  = Rand.nextInt(this.basicInfo.rooms);
                valueIfThisCoursesAreSwapped =
valueIfSwappingCourses(schedule, currentValue, day1,
period1,room1,day2,period2,room2);
                valueIfThisCourseIsRemoved  =
valueIfRemovingCourse(schedule, currentValue, day1, period1, room1);
                courseId = Rand.nextInt(this.basicInfo.courses);
                valueIfThisCourseIsAssigned  =
valueIfAssigningCourse(schedule, currentValue, day1, period1, room1,
courseId);
                if(!( valueIfThisCourseIsRemoved == Integer.MAX_VALUE &&
valueIfThisCourseIsAssigned == Integer.MAX_VALUE))
                     hardConstraintViolation =  false;

           }

           Type change;
           if(valueIfThisCourseIsRemoved<=valueIfThisCourseIsAssigned){

      if(valueIfThisCourseIsRemoved<=valueIfThisCoursesAreSwapped) {
                     if(valueIfThisCourseIsRemoved != Integer.MAX_VALUE)
                      change = Type.REMOVE;
                     else
                          change = Type.NOTHING;
                }
                else {
                      change = Type.SWAP;
                }
           }
           else {

      if(valueIfThisCourseIsAssigned<valueIfThisCoursesAreSwapped)
                     change = Type.ASSIGN;
                else
                     change = Type.SWAP;
           }
           switch (change) {
                case REMOVE:{
                     deltaval =  valueIfThisCourseIsRemoved - currentValue;
                if(deltaval < 0) {
                     currentValue  +=deltaval;
                          removeCourse(schedule, day1, period1, room1);
                }
                else if(GetProbability() > Rand.nextDouble()  &&
deltaval!=0) {
                     currentValue +=deltaval;
                          removeCourse(schedule, day1, period1, room1);
                }
                     break;
                }
                case ASSIGN: {
                     deltaval =  valueIfThisCourseIsAssigned -
currentValue;
                if(deltaval < 0) {
                     currentValue  +=deltaval;
                          assignCourse(schedule, day1, period1, room1,
courseId);
                }
                else if(GetProbability() > Rand.nextDouble()  &&
deltaval!=0) {
                     currentValue +=deltaval;
                     assignCourse(schedule, day1, period1, room1,
courseId);
                }
                     break;
                }
                case SWAP: {
                     deltaval = valueIfThisCoursesAreSwapped -
currentValue;
                if(deltaval < 0) {
                     currentValue  = valueIfThisCoursesAreSwapped;
                     bestCourse1 =
schedule.assignments[day1][period1][room1];//Remembers the person for the
taboolist
                          bestCourse2 =
schedule.assignments[day2][period2][room2]; //Remembers the person for the
taboolist
                          removeCourse(schedule, day2, period2, room2);
                          removeCourse(schedule, day1, period1, room1);
                          assignCourse(schedule, day2, period2, room2,
bestCourse1);
                          assignCourse(schedule, day1, period1, room1,
bestCourse2);
                }
                else if(GetProbability() > Rand.nextDouble()  &&
deltaval!=0 ) {
                     currentValue  = valueIfThisCoursesAreSwapped;
                     bestCourse1 =
schedule.assignments[day1][period1][room1];//Remembers the person for the
taboolist
                          bestCourse2 =
schedule.assignments[day2][period2][room2]; //Remembers the person for the
taboolist
                          removeCourse(schedule, day2, period2, room2);
                          removeCourse(schedule, day1, period1, room1);
                          assignCourse(schedule, day2, period2, room2,
bestCourse1);
                          assignCourse(schedule, day1, period1, room1,
bestCourse2);
                }
                     break;
                }

                default:
                     break;
                }

           // TODO write results to a CSV file

                 temperature= temperature*tempchange; //Reduces the
temperature
                 if((float)Math.abs(previousValue-
currentValue)/currentValue >= 0.05 ) {
                      result = new String[] { "" + iterationCount,
currentValue + "" };
                     writer.writeNext(result);
                     previousValue = currentValue;
                 }


     }

          result = new String[] { "" + iterationCount, currentValue + "" };
          writer.writeNext(result);
          writer.flush();
        f.close();
           return schedule;
     }

    private double GetProbability()
    {
        return Math.exp(-deltaval/temperature);
    }

}
```