SET10117 Multi-Agent Tutorial Timetable Generation

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Introduction:

In this coursework, I was assigned the task of prototyping a decentralised multi-agent system which would assign timetable slots to students based on their preferences. Timetable slots are initially assigned to Student Agents (acting on behalf of a student) who attempt to swap their current slots until they receive preferential slots.

Design:

My Design report will address the following five requirements:

1. A meaningful and relevant ontology, allowing agents to communicate
2. A communication protocol, allowing agents to communicate without revealing their preferences
3. A utility function, allowing the student to know when they're satisfied with their slots
4. A strategy to determine which exchange requests to make, which to accept and which to reject
5. A metric to evaluate system effectiveness in terms of satisfying student preferences

1. Ontology Design:

I include my Ontological Relationships in Appendix A. and examine the Ontological elements here.

Element	Properties	Data Type	Restrictions	Type
Pleased With	Student Identifier	AID	Mandatory	Predicate
Timeslot	Day Time	Integer Integer	Mandatory Mandatory	Concept
Tutorial Group	**Timeslot** Tutorial ID Class Size Tutorial Number	Ontology Element String Integer Integer	Mandatory Mandatory Mandatory	Concept
Swap Initial	**Tutorial Group** Agent From	Ontology Element AID	Mandatory Mandatory	Agent Action
Swap Final	**Swap Initial** **Tutorial To** Agent To	Ontology Element Ontology Element AID	Mandatory Mandatory Mandatory	Agent Action
Unhappy Slot	**Swap Initial**	Ontology Element		Agent Action
Slots Requested	ArrayList<**Swap Final**>	List<Ontology Elements>	Mandatory	Predicate
Happy With	ArrayList<**Swap Final**>	List<Ontology Elements>	Mandatory	Agent Action
Message Board	ArrayList<**Swap Initial**>	List<Ontology Elements>		Concept
Slots Available	**Message Board**	Ontology Element	Mandatory	Predicate

2. Communication Protocol:

There were several ways I envisaged the communication protocol for my multi-agent system:

- A free-for-all messaging system
- Students sending slots to a central agent that broadcasted the slots
- Students sending slots to a central agent that iteratively swapped slots

My biggest concern when planning the communication protocol, was reducing the number of messages. This included live messages and total messages.

My concern with a free-for-all messaging system is it would pass too many messages (live and otherwise). This meant some messages may not be received and that the solution scaled badly. It may be reasonable for 5 agents to send and request slots at the same time, but there are n^n messages sent per step, where n is the number of agents. Plus, anyone who's been at a large Christmas gathering can tell you that everyone speaking over each other leads to inefficient communication.

An Agent receiving and broadcasting slots to Student Agents would help limit the number of messages of the prior protocol. Allowing for offering one slot per step, the complexity of this is still 2n per step (one message to the broadcaster, the message broadcasted, the broadcast reply and a reply from the broadcaster). You could attempt to limit messages by having disinterested agents not respond, but it still has most of the issues the free-for-all messaging system has.

An underlying reason for these issues is that Student Agents can't expose their timeslot preferences (i.e. can only respond yes/no). Since preferences can't be exposed, the receiver is unable to know gauge how much a slot would benefit each Student Agent and can't choose the result that maximises social welfare. This led me to understand, the best approach is present a selection of slots and have the Student Agent choose which slots best suit them, as opposed to passing single slots and returning yes or no. This further points towards a centralised approach – having the ability to store and pass slots simultaneously.

I realised that the Communication Protocol would require a controller agent to limit the number of live messages and store a bank or 'message board' of unwanted slots. I started using a 'Timetabling Agent', to hold a list of slots for agents to swap. This was how I started to design my Ontology.

I detail the Communication Protocol design in the Sequence Diagram in Appendix B.

3. Utility Function:

There were several ways that I saw the Agent utility being calculated:

- Individual calculation
- Mean utility
- Specialised calculation

You could individually calculate the utilities of each Student Agent module and use the calculated value to choose whether the Agent is 'happy' or needs to swap a slot by iterating through the values. This is suitable for selecting slots from a message board or comparing existing slots with a new slot. When it comes to evaluating an Agent's 'happiness', it becomes more difficult with >1 slot.

Using a mean utility function, you could still use a calculation to compare slots individually for posting or evaluating swap requests. Additionally, it allows a mean happiness to be calculated based on the Agent's slots. Mean utility appealed to me, as it makes sense that the 'happiness' of the Agent is based on the average slot happiness. From a human-based perspective: "I really hate that 5pm Friday tutorial, but my other slots are nice, so overall my timetable isn't too bad".

A specialised calculation, or an adaption of the mean utility, could be useful for the task. It's difficult to visualise this ahead of time, but it would likely include additional dissatisfaction if an Agent couldn't attend a slot.

Choice of Calculation:

I saw the choice as either use the preference number or using an inverse of the preference. For me, it made more sense using an inverted range to provide Agent preferences, since I'd like Student Agents to aim for 0. My Student Agent preferences range from 0-4:

0. Loves the slot (high preference)
1. Likes the slot
2. Indifferent about the slot (medium preference)
3. Doesn't like the slot
4. Can't attend the slot (low preference)

I found it made sense using a range of 0-4 instead of 0-2, to capture the range of human emotion (instead of liking/indifference/hating) more fully, without being too complex.

4. Strategy for Considering Requests and Exchanges to Make

In the system I designed, Student Agents had three opportunities to swap slots:

1. Informing the Timetable Agent of slots they were interested in
2. Agreeing to/Refusing slots that other agents had requested
3. Posting new slots on the message board they didn't want

I examine these more deeply below:

1. The Student Agent needed to evaluate its slots against slots on the message board. It would then select the best slot(s) and request those slots. I limited the number of unique slots a Student Agent could request to one per module. I found this a good balance between requesting enough slots each cycle and keeping the system running without having to iteratively verify a list of requests.
2. I had Student Agents refuse swaps if the new slot fitness was worse than their current slot fitness. They would only accept a new slot if it were better or equal to their current slot fitness. This meant that Agents would post slots they didn't like but wouldn't swap them if the one offered was worse. The reason for accepting equal slots is that the social welfare could increase, even if the Student didn't directly benefit.
3. Agents check the message board and then post their worst slot if it's not present and if they don't love the slot – alternately post no slots.

5. A Metric to Evaluate Overall Effectiveness of the System

I thought the best way to evaluate the system effectiveness was a Utilitarian approach in trying to understand the social welfare of Agents in the system.

Individually, I evaluate the 'happiness' of each Student. Since this is what I want the system to maximise, it seemed appropriate to average the 'happiness' of Students and get a Mean. The metric I'm using to evaluate overall system effectiveness is the mean value of the Utility Function – the social welfare of the system.

Implementation

My Implementation Report will address the following three requirements:

1. Show the utility calculation, where it decides which swap requests to accept and which to reject, and state where the student's preferences are represented
2. State where in the code the timetabling agent ensures that each student attends exactly one tutorial for each module.
3. For each conversation in your communication protocol, you should reference the relevant screenshot from the JADE sniffer, and state which agent behaviours implement it.

1. Student Utility Calculation and Preference Exchange:

I originally planned to implement a mean calculation. The mean utility function worked very well on my first 3 test cases (less users and modules). After testing the mean utility on my fourth test case, I realised I was still accepting Student Agents if they had a slot but couldn't attend. I tried to fix this by raising and dropping the fixed threshold for 'happy students', but this didn't solve the issue. I decided that the mean calculation was unfit for purpose. I adapted a specialised calculation from the original mean value calculation I was using. The formula I settled on was:

$$Slot\ Fitness = \sum \begin{cases} -5 : \text{if } p = 5 \\ \dfrac{1}{1+p} : \text{if } 0 \leq p \leq 4 \end{cases}$$

Where *p* = Slot Preference (ranging 0 – 5) – 0 means the Student Agent loves the slot; 5 means the student can't attend that slot. -5 is a low enough value where the student can never accept the slots without swapping all slots they can't attend. Slots the student loves and can't attend are heavily weighted. This calculation is shown in Appendix C.

Output values (for a single example):

Slot Pref:	0 - loves the slot	1 - likes the slot	2 - indifferent	3 - doesn't like	4 - can't attend
Value:	1.0	0.5	0.33°	0.25	-5

I found if I started the utility function's target happiness at a reachable near-optimal level (e.g. 0.7-0.9), Student Agents would swap several slots and then exit, without considering any other slots available. This left less Student Agents in the environment, with less opportunity for Student Agents to swap bad slots. I tested various happiness thresholds and found that 1.5 with a reduction of 0.02 upon each time they were notified to request slots was a good level. It didn't run for too long and allowed Student Agents that had selected optimal slots to exit the environment early.

Preference Representation & Swap Requests:

I examine the three areas above, in design section 4. For clarity, I will re-explain the areas of calculation below:

1. Informing the Timetable Agent of slots they were interested in
2. Agreeing to/Refusing slots that other agents had requested
3. Posting new slots on the message board they didn't want

Appendix D shows how the Student Agent selects 'interested slots' – the individual best slots to request for each tutorial class. This is in the **AwaitTimetableBehaviour** behaviour in the Student Agent class.

Appendix E shows how the Student Agent selects which slots to agree to swap and which to refuse. This is in the **AwaitSlotVerifyBehaviour** behaviour in the Student Agent class.

Appendix F shows how the Student Agent selects which new slots to post to the message board. This is in the **AwaitHappyBehaviour** behaviour in the Student Agent class.

I examine the example conversations in section 3 of the implementation, but the screenshots of the test case 1 conversation are shown in Appendix G.

The Student Agent slot preferences are generated in a 2D array:

```
int[][] slot_prefs_1 = new int[5][9];
```

Corresponding to slot_preferences[days][hours].

Shown below is how the slot preferences have been generated for the Test Case 1:

```
for (int i = 0; i < slot_prefs_1.length; i++) {
    for (int j = 0; j < slot_prefs_1[0].length; j++) {
        slot_prefs_1[i][j] = 0;
        slot_prefs_2[i][j] = 0;
    }
}

slot_prefs_1[0][0] = 5; // Make them unable to attend slots they have
slot_prefs_2[4][8] = 5;
```

2. Ensuring Unique Module Attendance:

When the program begins, Student Agents are each assigned their week's slot preferences, and the tutorial slots which they will be attending. The Timetable Agent is also passed the tutorial slots (but not the slot preferences).
After requesting the list of Student Agents from the DF Agent, the Timetable Agent then sorts a list of Student Agents, before assigning the Agent AIDs to a 2D Array of ArrayLists. This allows the Timetable Agent to track the requests that Agents make and verify they requests are valid.

The StudentSlots structure is in the format: - StudentSlots[day][time].
It uses references to the TutorialMap – a HashMap with the Tutorial ID as keys and a corresponding number, referring to the slot ordering.

Appendix H shows the Timetable Agent checking:

- The SETID of the slot requested is the same as the SET ID of the slot being given
- The Student Agent owns the slot it's trying to swap

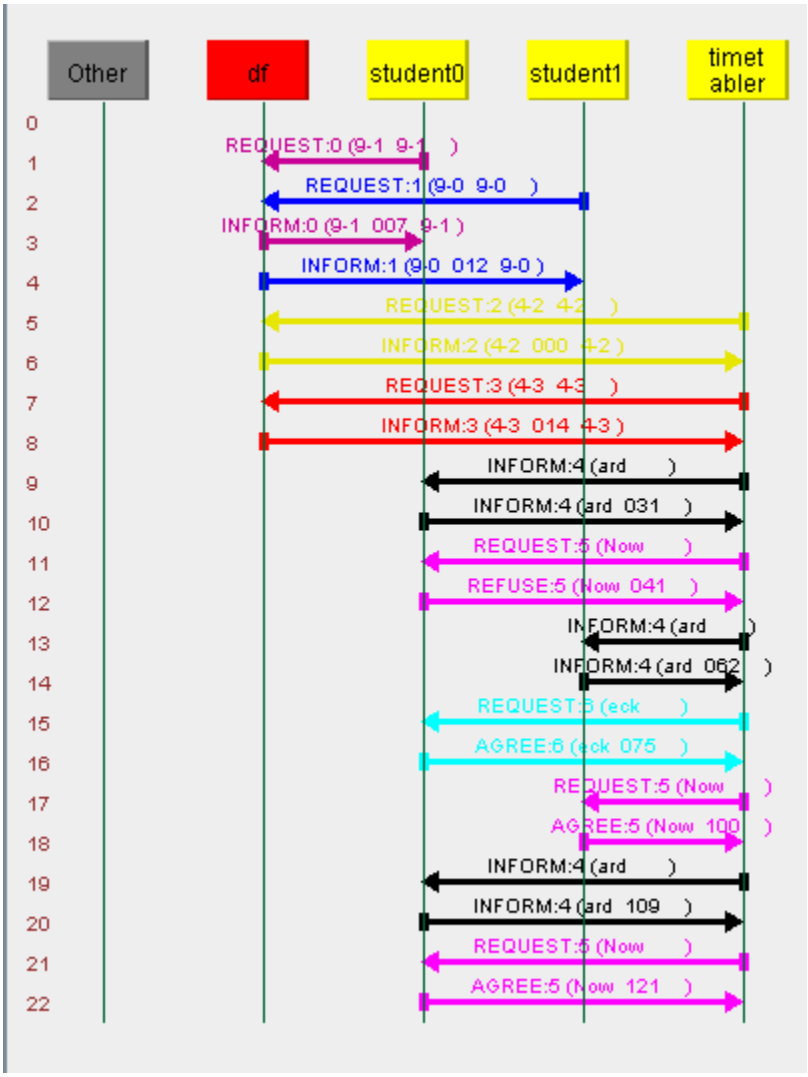
Appendix I shows the Timetable Agent updating the slots for Requester and Poster Agents.

Appendix J shows the Timetable Agent checking to ensure that the Poster Agent owns the posted slot.

This approach will work provided the Timetable Agent is correctly assigned slots. In the slot assignment, when Student Agents are assigned modules, they won't be assigned more than one module with a single SET ID.
When the Timetable Agent facilitates swaps from one Student Agent to another, it checks that the slots requested and offered belong to the same module, that the Poster Agent owns the slot being posted and the Requester Agent owns the slot it's requesting.

3. Exploring Agent and Timetable Agent Conversations

In this section, I explore the messages exchanged between two Student Agents and the Timetable Agent in a simple environment. Below is a screenshot of messages exchanged, taken through the Sniffer agent:



Line(s)	Agent from	Agent to	Purpose	Code Function
0-6	All	DF	System registration	Register
7-8	Timetable	DF	Requesting Student list	FindStudentsBehaviour
9	Timetable	Student0	Informing of timetable slots (0 slots total)	SwapStudentBehaviour
10	Student0	Timetable	Informing of interested slots	AwaitTimetableBehaviour
11	Timetable	Student0	Asking if unhappy or has slots	SwapStudentBehaviour
12	Student0	Timetable	Unhappy – responds with slot	AwaitHappyBehaviour
13	Timetable	Student1	Informing of timetable slots (1 slot total)	SwapStudentBehaviour
14	Student1	Timetable	Informing of interested slots (Student0's slot)	AwaitTimetableBehaviour
15	Timetable	Student0	Ask if Student0 wishes to swap its slot for Student1's slot	SwapStudentBehaviour
16	Student0	Timetable	Agrees to swap for Student1's slot	AwaitSlotVerifyBehaviour
17	Timetable	Student1	Notifies of agreed swap and asks if happy	SwapStudentBehaviour
18	Student1	Timetable	Happy – responds and terminates	AwaitHappyBehaviour
19	Timetable	Student0	Informing of timetable slots (0 slots total)	SwapStudentBehaviour
20	Student0	Timetable	Informing of interested slots	AwaitTimetableBehaviour
21	Timetable	Student0	Asking if unhappy or has slots	SwapStudentBehaviour
22	Student0	Timetable	Happy – responds and terminates	AwaitHappyBehaviour

The conversation from lines 9-22 are captured in order in Appendix G. The implementation is faithful to the of the original Communication design.

Testing

My Test Report will address the following three requirements, across my 4 test cases:

1. Show the number of students in the system and their preferences.
2. Show the number of tutorial groups for each module and their timeslots.
3. Show the number of students each tutorial can hold.

I show the preferences accordingly:

Preference	0	1	2	3	4
Colour					

If there is a SET ID inside the coloured box, the Student Agent was initialised with that slot.

Note that for each example, the lower the Tutorial Number, the earlier in the week that tutorial is. For example, if SET010101 has a class Monday 9am, Tuesday 9am and Wednesday 9am; the Monday class would be number 0, the Tuesday class number 1 and the Wednesday class number 2.

My test sets are pre-defined. I will use between 2 and 6 'buckets' for my Student Agents, to assign different initial slots and preferences to each. I will define these buckets where appropriate.

Test Case 1:

Number of Students	Number of Modules	Number of Classes
2	1	2

My first test case was to swap two students between a Monday morning and a Friday afternoon slot. The goal of this test case was to see if two Student Agents would complete a swap of two slots they hated. I set the preferences as following:

Student 0 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday	SET010101								
Tuesday									
Wednesday									
Thursday									
Friday									

Student 1 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday									
Tuesday									
Wednesday									
Thursday									
Friday									SET010101

Expected Output:
Social welfare is 1.
Student 1 ends with Tutorial 0 and Student 0 ends with Tutorial 1.

Actual Output:

```
-----------------------------------------
student0 has ended with SET010101 on Friday at 5pm
FINAL HAPPINESS FOR student0 IS 1.0
student1 has ended with SET010101 on Monday at 9am
FINAL HAPPINESS FOR student1 IS 1.0

The program has finished
```

Test Case 2:

My second test case increased the complexity, by increasing the number of classes and students. It's also going to test how Student Agents react with different levels of slot preferences.

Number of Students	Number of Modules	Number of Classes
6	1	3

Student Buckets:

Bucket 1:	Bucket 2:	Bucket 3:
Student 0, Student 3	Student 1, Student 4	Student 2, Student 5

The goal of this test case is to get Student Agents swapping their slots for a 'sub-par' slot, and then getting the Student Agent to swap the slot again for their preferred slot.

Bucket 1 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday	SET010101								
Tuesday									
Wednesday									
Thursday									
Friday									

Bucket 2 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday									
Tuesday	SET010101								
Wednesday									
Thursday									
Friday									

Bucket 3 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday									
Tuesday									
Wednesday	SET010101								
Thursday									
Friday									

Expected Output:
Social welfare is 1.
Bucket 1 ends with Tutorial 0, Bucket 2 ends with Tutorial 1 and Bucket 3 ends with Tutorial 2.

Actual Output:

```
-----------------------------------------
student5 has ended with SET010101 on Monday at 9am
FINAL HAPPINESS FOR student5 IS 1.0
student3 has ended with SET010101 on Tuesday at 9am
FINAL HAPPINESS FOR student3 IS 1.0
student2 has ended with SET010101 on Monday at 9am
FINAL HAPPINESS FOR student2 IS 1.0
student4 has ended with SET010101 on Wednesday at 9am
FINAL HAPPINESS FOR student4 IS 1.0
student1 has ended with SET010101 on Wednesday at 9am
FINAL HAPPINESS FOR student1 IS 1.0
student0 has ended with SET010101 on Tuesday at 9am
FINAL HAPPINESS FOR student0 IS 1.0

The program has finished
```

Test Case 3:

My third test case increased the complexity again, by increasing the of students and SETs. It's going to further test how my system reacts to differing levels of slot preferences and multiple SETs.

Number of Students	Number of Modules	Number of Classes
8	2	2

Student Buckets:

Bucket 1:	Bucket 2:
Student 0, Student 2, Student 4, Student 6	Student 1, Student 3, Student 5, Student 7

The goal of this test case is to get Student Agents swapping their one of their slots for a 'decent' slot and another for a 'great' slot of a different SET at a different time.

Bucket 1 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday	SET010101	SET010102							
Tuesday									
Wednesday									
Thursday									
Friday									

Bucket 2 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday									
Tuesday	SET010102	SET010101							
Wednesday									
Thursday									
Friday									

Expected Output:
Social welfare is ~0.6 (Mean of 1 and 0.25).
Bucket 1 ends with Tuesday morning tutorials and Bucket 2 ends with Monday morning tutorials.

Actual Output:

```
-----------------------------------------
student5 has ended with SET010101 on Monday at 9am
FINAL HAPPINESS FOR student5 IS 1.0
student3 has ended with SET010101 on Tuesday at 9am
FINAL HAPPINESS FOR student3 IS 1.0
student2 has ended with SET010101 on Monday at 9am
FINAL HAPPINESS FOR student2 IS 1.0
student4 has ended with SET010101 on Wednesday at 9am
FINAL HAPPINESS FOR student4 IS 1.0
student1 has ended with SET010101 on Wednesday at 9am
FINAL HAPPINESS FOR student1 IS 1.0
student0 has ended with SET010101 on Tuesday at 9am
FINAL HAPPINESS FOR student0 IS 1.0

The program has finished
```

Test Case 4:

My fourth test case much further increased the complexity again. I increased the modules, increased the number of classes, and increased the number of students. I further altered the preferences. I tried to get this timetable as close to a 'regular student's' timetable as possible – blocking off unwanted 5pm slots and setting a distribution of preferences.

Number of Students	Number of Modules	Number of Classes
24	3	3

Student Buckets:

Bucket 1:	Bucket 2:	Bucket 3:	Bucket 4:	Bucket 5:	Bucket 6:
Student 0	Student 1	Student 2	Student 3	Student 4	Student 5
Student 6	Student 7	Student 8	Student 9	Student 10	Student 11
Student 12	Student 13	Student 14	Student 15	Student 16	Student 17
Student 18	Student 19	Student 20	Student 21	Student 22	Student 23

The goal of this test case is to get Student Agents swapping their one of their slots for a 'decent' slot and another for a 'great' slot of a different SET at a different time.

Bucket 1 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday									
Tuesday	SET010101		SET010103						
Wednesday		SET010102							
Thursday									
Friday									

Bucket 2 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday									
Tuesday		SET010102							
Wednesday	SET010101		SET010103						
Thursday									
Friday									

Bucket 3 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday	SET010101	SET010102							
Tuesday									
Wednesday			SET010103						
Thursday									
Friday									

Bucket 4 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday			SET010103						
Tuesday									
Wednesday	SET010101	SET010102							
Thursday									
Friday									

Bucket 5 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday	SET010101	SET010102	SET010103						
Tuesday									
Wednesday									
Thursday									
Friday									

Bucket 6 Preferences:

	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
Monday									
Tuesday	SET010101	SET010102	SET010103						
Wednesday									
Thursday									
Friday									

Expected Output:
Social welfare is ~0.6 (Mean of 1, 0.5 and 0.25).
Students end up with their preferred slots.

Actual Output:

```
-----------------------------------------
student17 has ended with SET010101 on Wednesday at 9am
student17 has ended with SET010102 on Wednesday at 10am
student17 has ended with SET010103 on Wednesday at 11am
FINAL HAPPINESS FOR student17 IS 0.611111111111111

student4 has ended with SET010101 on Wednesday at 9am
student4 has ended with SET010102 on Wednesday at 10am
student4 has ended with SET010103 on Wednesday at 11am
FINAL HAPPINESS FOR student4 IS 0.611111111111111

student12 has ended with SET010101 on Monday at 9am
student12 has ended with SET010102 on Monday at 10am
student12 has ended with SET010103 on Monday at 11am
FINAL HAPPINESS FOR student12 IS 0.611111111111111

student16 has ended with SET010101 on Wednesday at 9am
student16 has ended with SET010102 on Wednesday at 10am
student16 has ended with SET010103 on Wednesday at 11am
FINAL HAPPINESS FOR student16 IS 0.611111111111111

student20 has ended with SET010101 on Tuesday at 9am
student20 has ended with SET010102 on Tuesday at 10am
student20 has ended with SET010103 on Tuesday at 11am
FINAL HAPPINESS FOR student20 IS 0.611111111111111

student11 has ended with SET010101 on Wednesday at 9am
student11 has ended with SET010102 on Wednesday at 10am
student11 has ended with SET010103 on Wednesday at 11am
FINAL HAPPINESS FOR student11 IS 0.611111111111111

student9 has ended with SET010101 on Tuesday at 9am
student9 has ended with SET010102 on Tuesday at 10am
student9 has ended with SET010103 on Tuesday at 11am
FINAL HAPPINESS FOR student9 IS 0.611111111111111

student21 has ended with SET010101 on Tuesday at 9am
student21 has ended with SET010102 on Tuesday at 10am
student21 has ended with SET010103 on Tuesday at 11am
FINAL HAPPINESS FOR student21 IS 0.611111111111111

student14 has ended with SET010101 on Tuesday at 9am
student14 has ended with SET010102 on Tuesday at 10am
student14 has ended with SET010103 on Tuesday at 11am
FINAL HAPPINESS FOR student14 IS 0.611111111111111

student8 has ended with SET010101 on Tuesday at 9am
student8 has ended with SET010102 on Tuesday at 10am
student8 has ended with SET010103 on Tuesday at 11am
FINAL HAPPINESS FOR student8 IS 0.611111111111111

student18 has ended with SET010101 on Monday at 9am
student18 has ended with SET010102 on Monday at 10am
student18 has ended with SET010103 on Monday at 11am
FINAL HAPPINESS FOR student18 IS 0.611111111111111

FINAL HAPPINESS FOR student18 IS 0.611111111111111

student3 has ended with SET010101 on Tuesday at 9am
student3 has ended with SET010102 on Tuesday at 10am
student3 has ended with SET010103 on Tuesday at 11am
FINAL HAPPINESS FOR student3 IS 0.611111111111111

student7 has ended with SET010101 on Monday at 9am
student7 has ended with SET010102 on Monday at 10am
student7 has ended with SET010103 on Monday at 11am
FINAL HAPPINESS FOR student7 IS 0.611111111111111

student10 has ended with SET010101 on Wednesday at 9am
student10 has ended with SET010102 on Wednesday at 10am
student10 has ended with SET010103 on Wednesday at 11am
FINAL HAPPINESS FOR student10 IS 0.611111111111111

student1 has ended with SET010101 on Monday at 9am
student1 has ended with SET010102 on Monday at 10am
student1 has ended with SET010103 on Monday at 11am
FINAL HAPPINESS FOR student1 IS 0.611111111111111

student19 has ended with SET010101 on Monday at 9am
student19 has ended with SET010102 on Monday at 10am
student19 has ended with SET010103 on Monday at 11am
FINAL HAPPINESS FOR student19 IS 0.611111111111111

student2 has ended with SET010101 on Tuesday at 9am
student2 has ended with SET010102 on Tuesday at 10am
student2 has ended with SET010103 on Tuesday at 11am
FINAL HAPPINESS FOR student2 IS 0.611111111111111

student23 has ended with SET010101 on Wednesday at 9am
student23 has ended with SET010102 on Wednesday at 10am
student23 has ended with SET010103 on Wednesday at 11am
FINAL HAPPINESS FOR student23 IS 0.611111111111111

student0 has ended with SET010101 on Monday at 9am
student0 has ended with SET010102 on Monday at 10am
student0 has ended with SET010103 on Monday at 11am
FINAL HAPPINESS FOR student0 IS 0.611111111111111

student15 has ended with SET010101 on Tuesday at 9am
student15 has ended with SET010102 on Tuesday at 10am
student15 has ended with SET010103 on Tuesday at 11am
FINAL HAPPINESS FOR student15 IS 0.611111111111111

student22 has ended with SET010101 on Wednesday at 9am
student22 has ended with SET010102 on Wednesday at 10am
student22 has ended with SET010103 on Wednesday at 11am
FINAL HAPPINESS FOR student22 IS 0.611111111111111

student5 has ended with SET010101 on Wednesday at 9am
student5 has ended with SET010102 on Wednesday at 10am
student5 has ended with SET010103 on Wednesday at 11am
FINAL HAPPINESS FOR student5 IS 0.611111111111111

FINAL HAPPINESS FOR student5 IS 0.611111111111111

student13 has ended with SET010101 on Monday at 9am
student13 has ended with SET010102 on Monday at 10am
student13 has ended with SET010103 on Monday at 11am
FINAL HAPPINESS FOR student13 IS 0.611111111111111

student6 has ended with SET010101 on Monday at 9am
student6 has ended with SET010102 on Monday at 10am
student6 has ended with SET010103 on Monday at 11am
FINAL HAPPINESS FOR student6 IS 0.611111111111111

The program has finished
```

Evaluation and Future Work:

My Evaluation Report will address the following three requirements:

1. How effectively the system will interact and scale with difficulty
2. The advantages and disadvantages of a multi-agent systems approach to this problem
3. Considering 1 and 2, suggest and justify an improvement

Scalability and Efficiency of the System:

The approach I have taken scales well when additional agents are added. If additional agents were added to the system, the only increase would be the number of Student Agents the Timetable Agent would need to interact with. Since the Timetable Agent iteratively interacts with Student Agents, there would be no fundamental change as more Student Agents are added.

The system has also been shown to work with additional tutorials and classes, and I expect this to scale efficiently (at least to a number of modules that's sensible).

Advantages and Disadvantages of the System

An advantage of a multi-agent systems approach to the problem is that Student preferences can be fully accounted for when slots are given to Student Agents. As each Student Agent is representative of one student, each student's requirements and preferences can be fully considered. In theory you could survey students to find their preferred timeslots and then have the multi-agent system act this out.

Another advantage of a multi-agent systems approach is that student preferences can remain hidden from the Timetable Agent. Students may not want their availability known and this approach allows students to hide their preferences.

A disadvantage of a multi-agent systems approach is that it can be hard to differentiate between hard and soft constraints within the preferences for students. If some slots are subjectively better than others (Wednesday 2pm vs Friday 5pm), a lot of students may wish for the former slot and mark their availability as 'not available' for the latter. This could leave the slot being assigned to students who cannot attend the slot.

Improvement

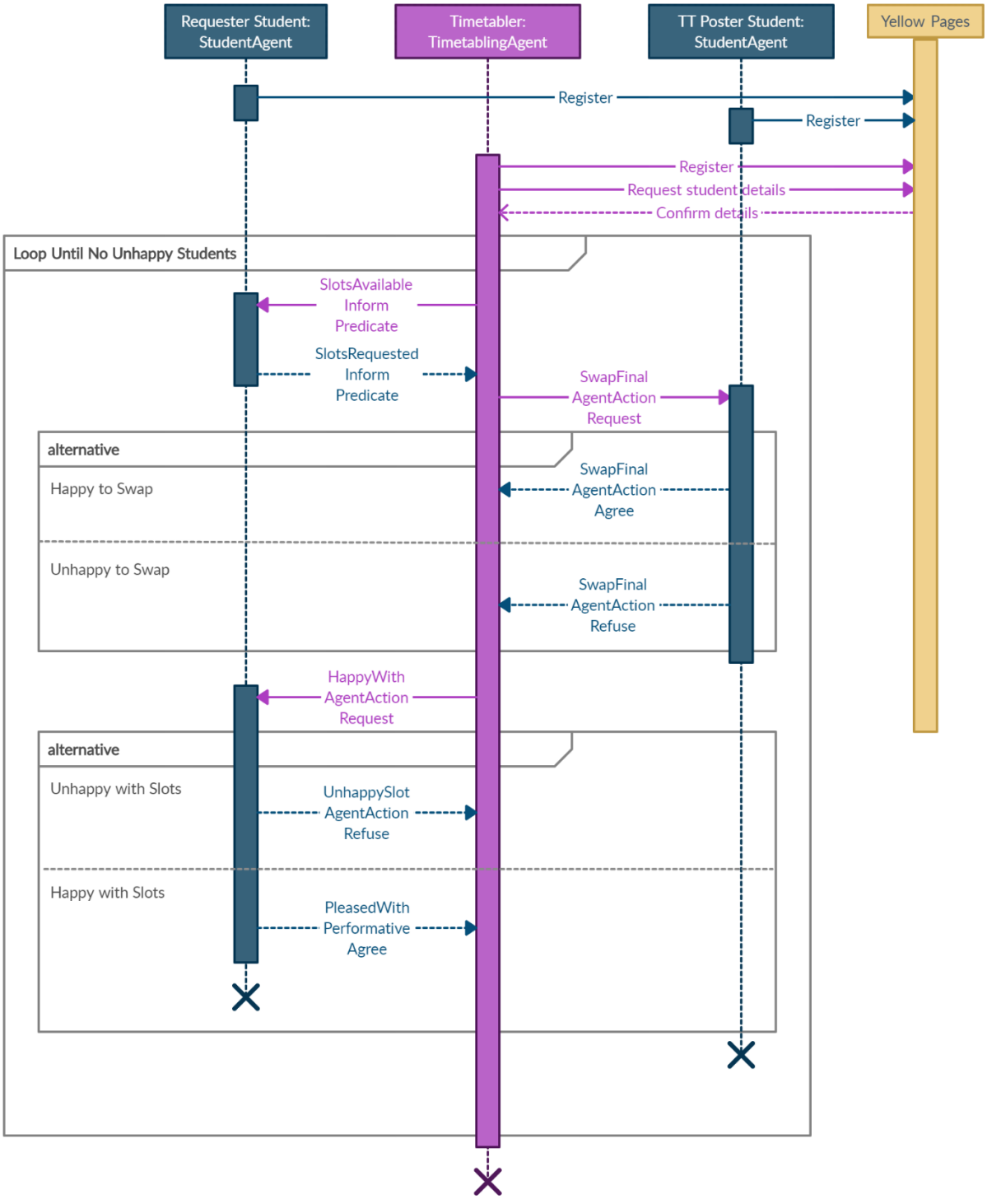
An improvement I would make to the system would be to allow the posting of multiple slots by Student Agents at once. This would allow slots to be put on the message board quicker and allow them to be swapped earlier on (since slots have been revealed to potential requesters).

I would advocate for a system where the Timetable Agent would select slots on behalf of students, and then allow students to swap the slots with each other if they didn't suit their own preferences (similar to the current system).

Appendix:

Appendix A – Ontology Association

Appendix B – Message Sequence Diagram



Appendix C – Student Agent Preference Calculation

```
// Calculates timeslot fitness
private double SlotFitness(Timeslot slot) {
    if (SlotPreferences[slot.getDay()][slot.getTime()]==5) { // Heavily punished if they can't attend
        return -5.0;
    }
    return (1.0 / (SlotPreferences[slot.getDay()][slot.getTime()] + 1));
}
```

Appendix D – Selecting and Requesting 'Interested Slots' from the Timetable Agent

```
slotsMessageBoard = available.getBoard();
List<SwapInitial> messageBoard = slotsMessageBoard.getMessageBoard();

// Checking for messages in the message board
if (messageBoard.size() > 0) {
    SwapInitial[] interestedSlots = new SwapInitial[CurrentTutorials.length]; // Hold interested slots for each tutorial group

    // Fill the 'interested slots'
    for (int i = 0; i < interestedSlots.length; i++) {
        for (SwapInitial boardSwap : messageBoard) {
            if (boardSwap.getTutorial().getTutorialID().equals(CurrentTutorials[i].getTutorialID())) { // If matching tutorial
                if (interestedSlots[i] == null) {
                    if (SlotFitness(boardSwap.getTutorial().getTimeslot()) >
                            SlotFitness(CurrentTutorials[i].getTimeslot())) { // If no current 'better slot'
                        interestedSlots[i] = boardSwap;
                    }
                }else if (SlotFitness(boardSwap.getTutorial().getTimeslot()) >
                            SlotFitness(interestedSlots[i].getTutorial().getTimeslot())){ // Better than 'best' slot
                    interestedSlots[i] = boardSwap;
                }
            }
        }
    }

    SlotsRequested wishedSlots = new SlotsRequested();
    SwapFinal swapRequest;
    ArrayList<SwapFinal> swapsRequested = new ArrayList<>();

    // Checking interested slots
    for (SwapInitial swap : interestedSlots){
        if (swap != null) {
            swapRequest = new SwapFinal();
            swapRequest.setInitalSwapRequest(swap);
            swapRequest.setAgentTo(getAID());

            for (TutorialGroup currentTutorial : CurrentTutorials) {
                if (currentTutorial.getTutorialID().equals(swap.getTutorial().getTutorialID())) {
                    swapRequest.setTutorialTo(currentTutorial); // Get the current tutorial
                    break;
                }
            }
            swapsRequested.add(swapRequest);
        }
    }
    wishedSlots.setSlots(swapsRequested);

    ACLMessage reply = msg.createReply();
    reply.setPerformative(ACLMessage.INFORM);
    try {
        getContentManager().fillContent(reply, wishedSlots);
        send(reply); // >0 wished slots
    }
```

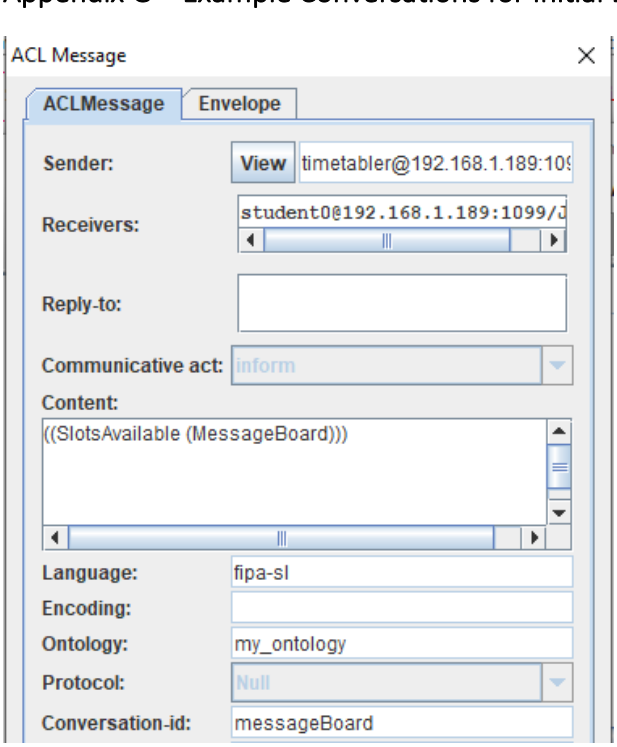
Appendix E – Agreeing to or Refusing 'Requested Slots' from the Timetable Agent

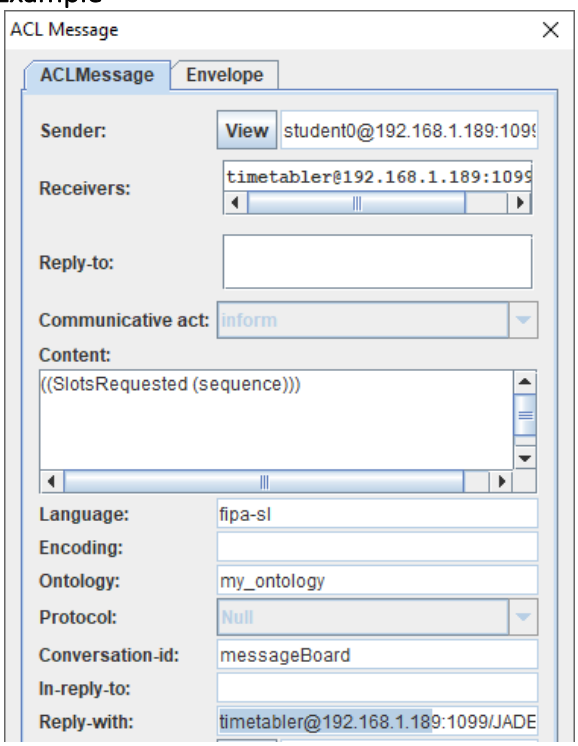
```
ACLMessage reply = msg.createReply();
getContentManager().fillContent(reply, swapRequest);

int count = 0;
// Checking if they want the tutorial
for (TutorialGroup tutorial : CurrentTutorials) {
    if (tutorial.getTutorialID().equals(swapRequest.getTutorialTo().getTutorialID())) { // Checking same tutorial
        if (SlotFitness(tutorial.getTimeslot()) <=
                SlotFitness(swapRequest.getTutorialTo().getTimeslot())) { // If indifferent or prefers slot
            reply.setPerformative(ACLMessage.AGREE); // Agree because want to swap slot
            CurrentTutorials[count] = swapRequest.getTutorialTo();
            break;
        }
        else {
            reply.setPerformative(ACLMessage.REFUSE); // Refuse because not interested
            break;
        }
    }
    else {
        reply.setPerformative(ACLMessage.REFUSE); // Refuse as not the same tutorial ID
    }
    count++;
}

Action actionReply = new Action();
actionReply.setAction(swapRequest);
actionReply.setActor(getAID());

try {
    getContentManager().fillContent(reply, actionReply);
    send(reply);
}
```

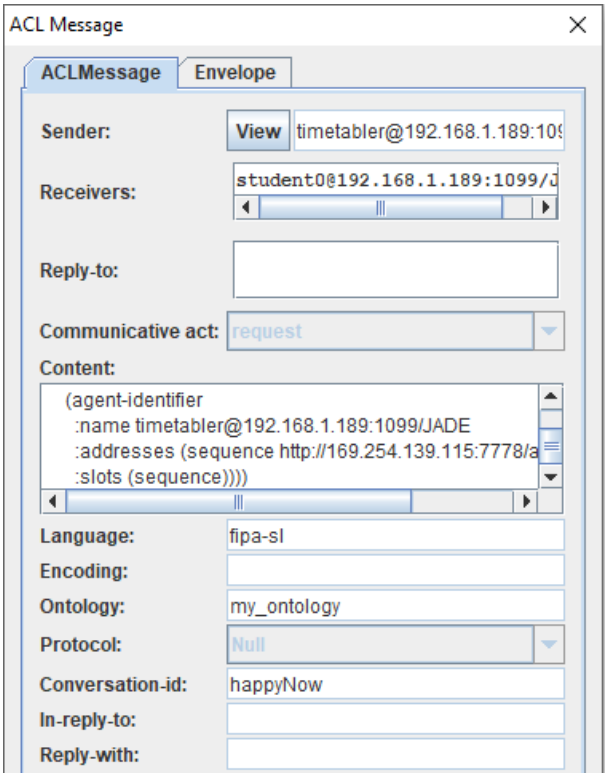
Appendix F – Checking new Slots to Post

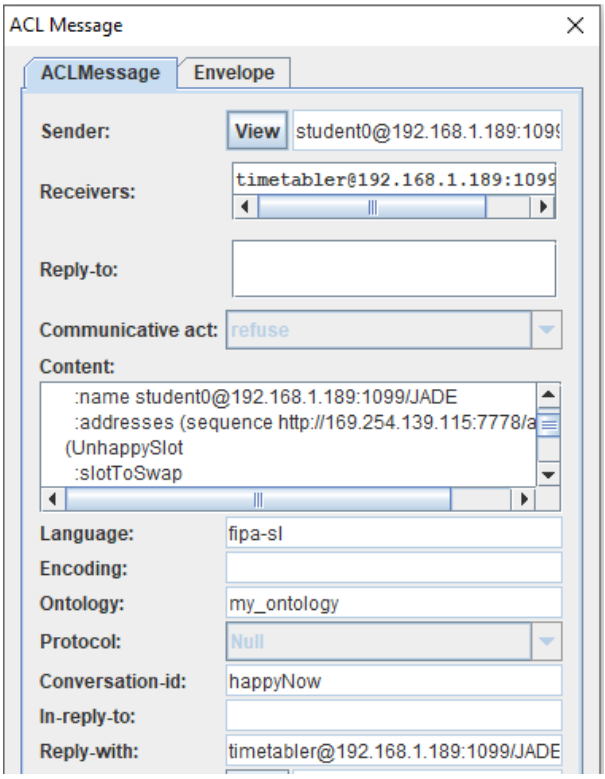
```
// If high enough overall happiness -- 0 or 1 slots accepted
if (meanHappiness <= meanHappinessTarget) {

    // Checking slots that haven't been advertised yet
    List<Integer> slotsNotAdvertised = new ArrayList<>();

    // Getting current slots not on messageboard
    for (int i = 0; i < CurrentTutorials.length; i++) {
        boolean advertisedAlready = false;
        for (SwapInitial item : slotsMessageBoard.getMessageBoard()) {
            if (item.getAgentFrom().equals(getAID()) &&
                    item.getTutorial().getTutorialID().equals(CurrentTutorials[i].getTutorialID())) {
                advertisedAlready = true;
                continue;
            }
        }
        if (!advertisedAlready) {
            if (SlotFitness(CurrentTutorials[i].getTimeslot()) < 1.0) { // Don't post slot if happy already
                slotsNotAdvertised.add(i);
            }
        }
    }

    int worstTutorial = -1; // Worst tutorial is slotsNotAdvertised positional reference

    // Comparing slots - if all slots posted (or no slots student wishes to post) then nothing
    if (slotsNotAdvertised.size() > 0) {
        worstTutorial = 0;
        // Select worst slot not currently on timetable
        for (int i = 1; i < slotsNotAdvertised.size(); i++) {
            if (SlotFitness(CurrentTutorials[slotsNotAdvertised.get(i)].getTimeslot()) <
                    SlotFitness(CurrentTutorials[slotsNotAdvertised.get(worstTutorial)].getTimeslot())) {
                worstTutorial = i;
            }
        }
    }

    UnhappySlot slot = new UnhappySlot();
    // Add slot found (if found) to 'Unhappy Slot' posting
    if (worstTutorial != -1) {
        SwapInitial si = new SwapInitial();
        si.setAgentFrom(myAgent.getAID());
        si.setTutorial(CurrentTutorials[slotsNotAdvertised.get(worstTutorial)]);
        slot.setSlotToSwap(si);
    }

    Action newAction = new Action();
    newAction.setActor(getAID());
    newAction.setAction(slot);

    ACLMessage reply = msg.createReply();
    reply.setPerformative(ACLMessage.REFUSE);

    try {
        getContentManager().fillContent(reply, newAction);
        send(reply);
    }
```

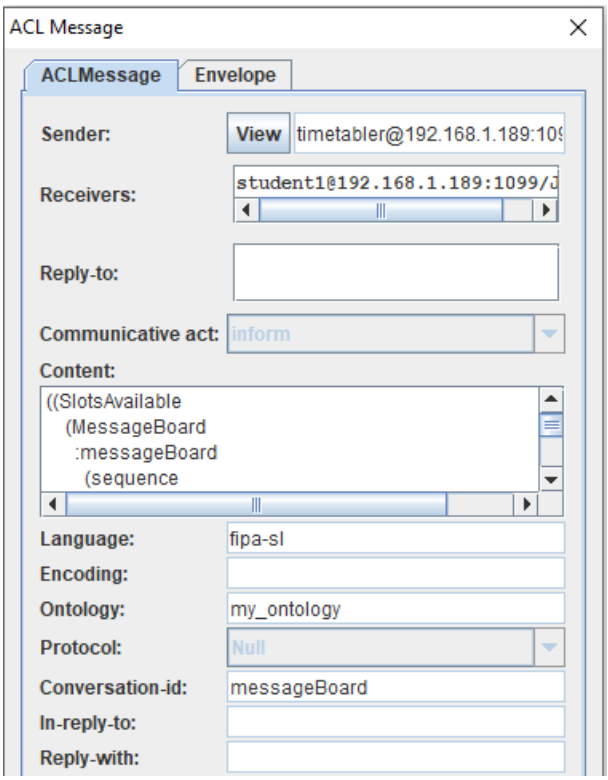
Appendix G – Example Conversations for Initial Example

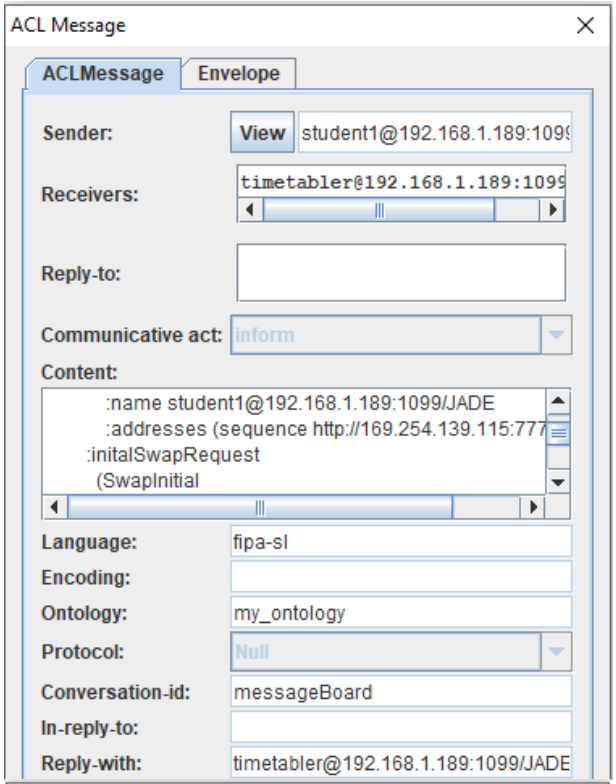









ACL Message
ACLMessage
Envelope
Sender:
View
timetabler@192.168.1.189:10
Receivers:
student1@192.168.1.189:1099/J
Reply-to:
Communicative act:
inform
Content:
((SlotsAvailable
(MessageBoard
:messageBoard
(sequence
Language:
fipa-sl
Encoding:
Ontology:
my_ontology
Protocol:
Null
Conversation-id:
messageBoard
In-reply-to:
Reply-with: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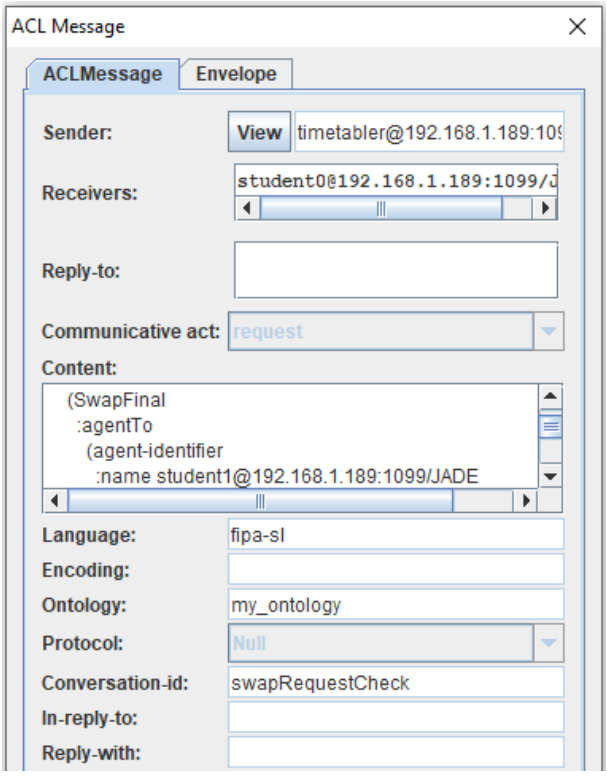
ACLMessage
Envelope
Sender:
View
student1@192.168.1.189:109
Receivers:
timetabler@192.168.1.189:109
Reply-to:
Communicative act:
inform
Content:
:name student1@192.168.1.189:1099/JADE
:addresses (sequence http://169.254.139.115:777
:initalSwapRequest
(SwapInitial
Language:
fipa-sl
Encoding:
Ontology:
my_ontology
Protocol:
Null
Conversation-id:
messageBoard
In-reply-to:
Reply-with:
timetabler@192.168.1.189:1099/JADE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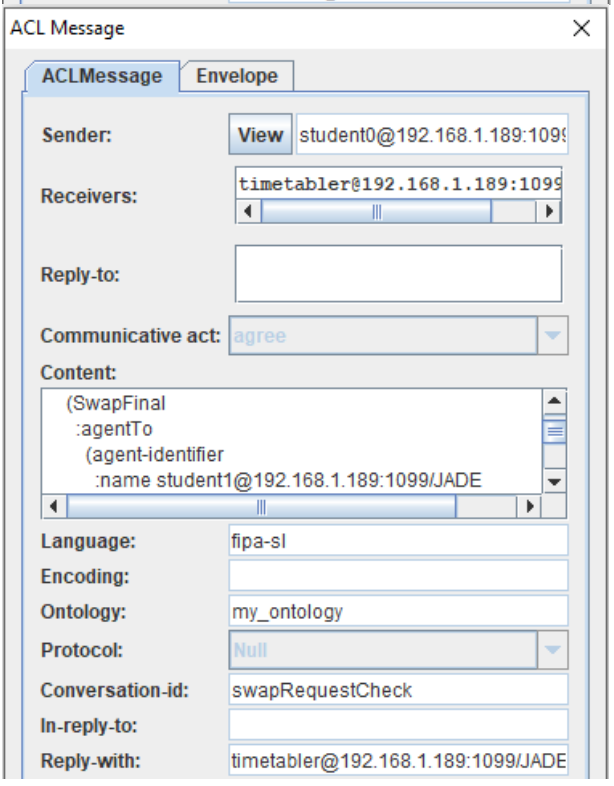
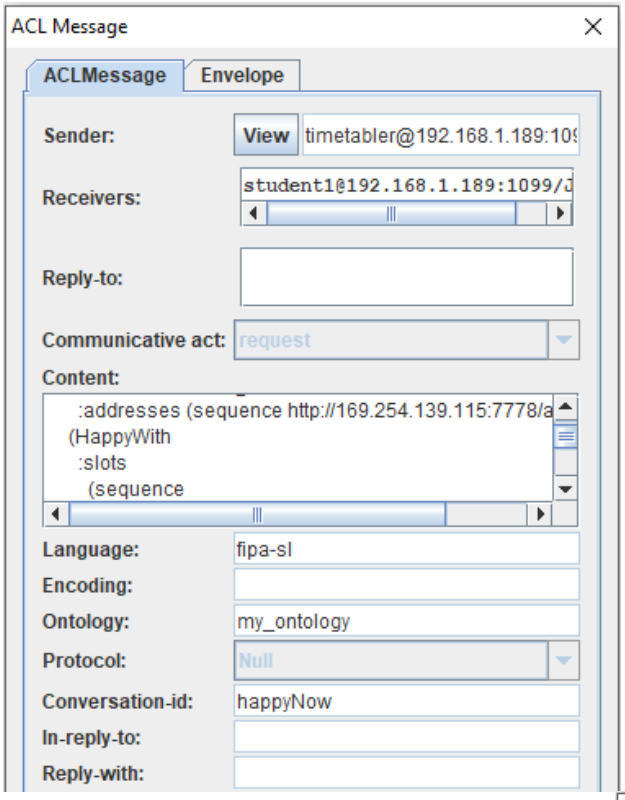
ACLMessage
Envelope
Sender:
View
timetabler@192.168.1.189:10
Receivers:
student0@192.168.1.189:1099/J
Reply-to:
Communicative act:
request
Content:
(SwapFinal
:agentTo
(agent-identifier
:name student1@192.168.1.189:1099/JADE
Language:
fipa-sl
Encoding:
Ontology:
my_ontology
Protocol:
Null
Conversation-id:
swapRequestCheck
In-reply-to:
Reply-with:


ACL Message
ACLMessage
Envelope
Sender:
View
student0@192.168.1.189:109
Receivers:
timetabler@192.168.1.189:109
Reply-to:
Communicative act:
agree
Content:
(SwapFinal
:agentTo
(agent-identifier
:name student1@192.168.1.189:1099/JADE
Language:
fipa-sl
Encoding:
Ontology:
my_ontology
Protocol:
Null
Conversation-id:
swapRequestCheck
In-reply-to:
Reply-with:
timetabler@192.168.1.189:1099/JADE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ACLMessage
Envelope
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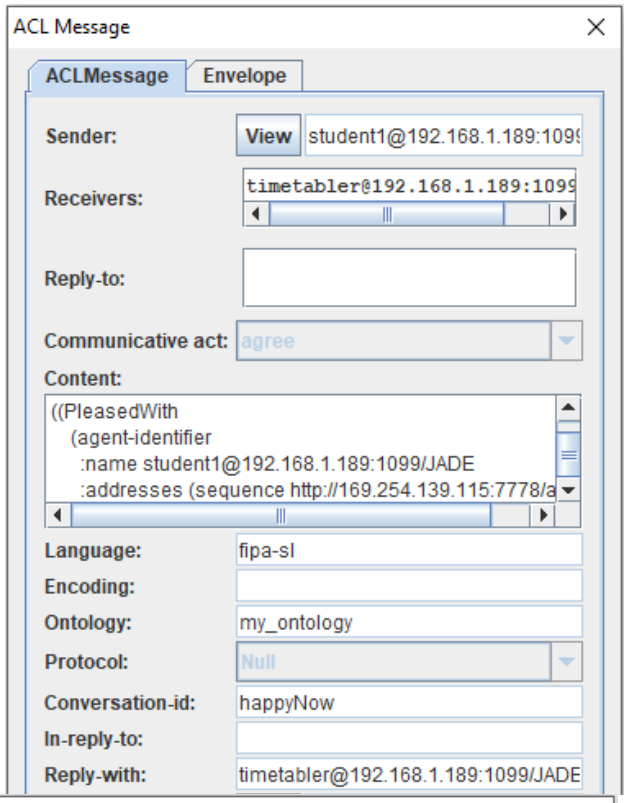
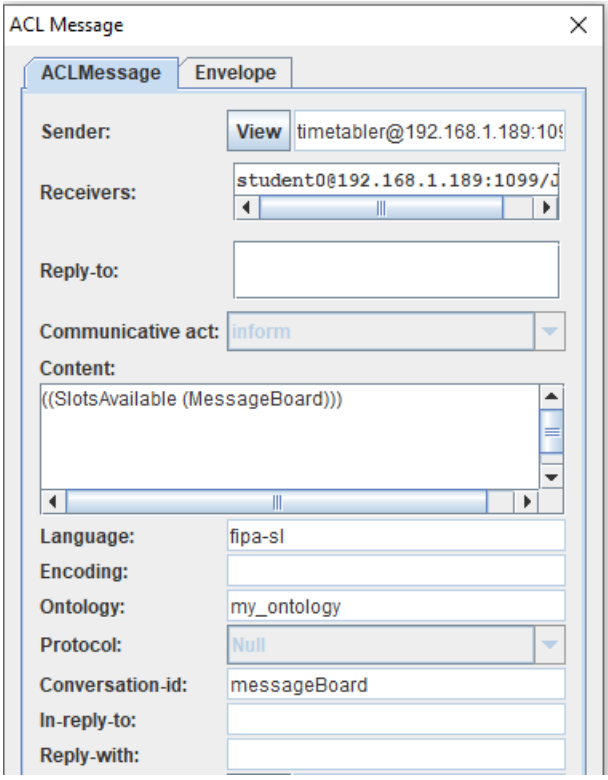
View
timetabler@192.168.1.189:109
Receivers:
student1@192.168.1.189:1099/J
Reply-to:
Communicative act:
request
Content:
:addresses (sequence http://169.254.139.115:7778/a
(HappyWith
:slots
(sequence
Language:
fipa-sl
Encoding:
Ontology:
my_ontology
Protocol:
Null
Conversation-id:
happyNow
In-reply-to:
Reply-with:


ACL Message
ACLMessage
Envelope
Sender:
View
student1@192.168.1.189:1099
Receivers:
timetabler@192.168.1.189:1099
Reply-to:
Communicative act:
agree
Content:
((PleasedWith
(agent-identifier
:name student1@192.168.1.189:1099/JADE
:addresses (sequence http://169.254.139.115:7778/a
Language:
fipa-sl
Encoding:
Ontology:
my_ontology
Protocol:
Null
Conversation-id:
happyNow
In-reply-to:
Reply-with:
timetabler@192.168.1.189:1099/JADE


ACL Message
ACLMessage
Envelope
Sender:
View
timetabler@192.168.1.189:109
Receivers:
student0@192.168.1.189:1099/J
Reply-to:
Communicative act:
inform
Content:
((SlotsAvailable (MessageBoard)))
Language:
fipa-sl
Encoding:
Ontology:
my_ontology
Protocol:
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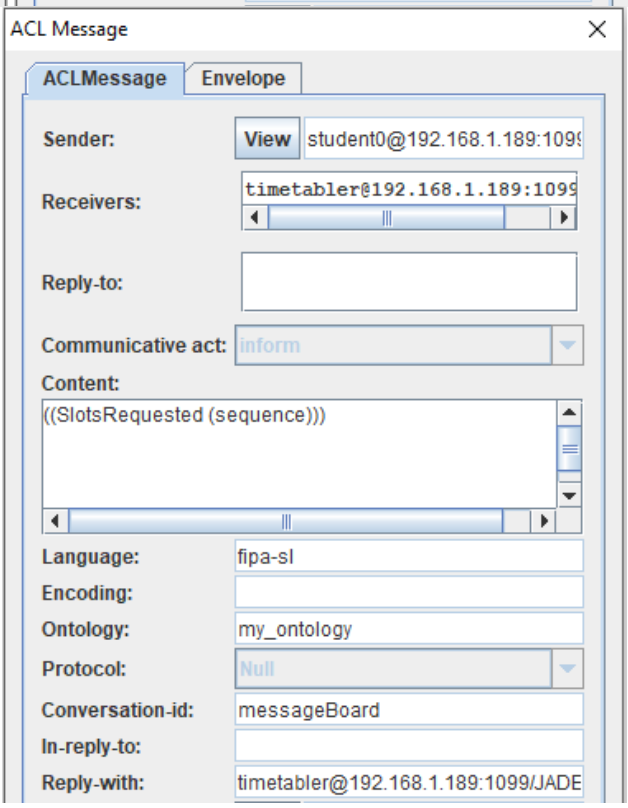
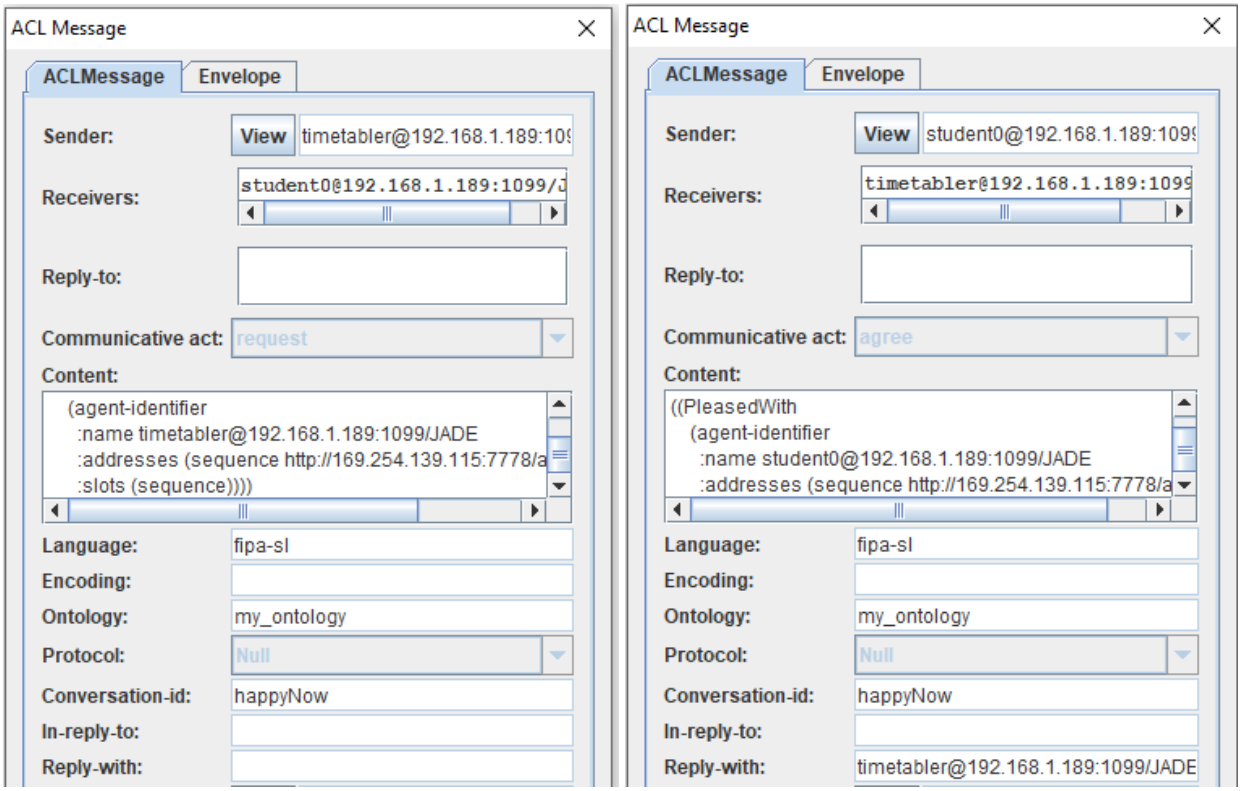
Conversation-id:
messageBoard
In-reply-to:
Reply-with:


ACL Message
ACLMessage
Envelope
Sender:
View
student0@192.168.1.189:109
Receivers:
timetabler@192.168.1.189:1099
Reply-to:
Communicative act:
inform
Content:
((SlotsRequested (sequence)))
Language:
fipa-sl
Encoding:
Ontology:
my_ontology
Protocol:
Null
Conversation-id:
messageBoard
In-reply-to:
Reply-with:
timetabler@192.168.1.189:1099/JADE



Appendix H – Denying Slot Request if Invalid

```
// Checking the student has the slot it says it does
Iterator<SwapFinal> it = slotsRequested.getSlots().iterator();
while (it.hasNext()) {
    SwapFinal itSwap = it.next();
    boolean present = false;
    // Looping through requester agent to check if agent has those tutorial slots
    for (AID agent : StudentSlots
            [TutorialMap.get(itSwap.getTutorialTo().getTutorialID())][itSwap.getTutorialTo().getTutNum()]) {
        if (itSwap.getAgentTo().equals(agent)) {
            present = true;
            break;
        }
    }
    if (!present) { // If student doesn't own the slot
        it.remove();
    }
    else if (!itSwap.getTutorialTo().getTutorialID().equals
            (itSwap.getInitalSwapRequest().getTutorial().getTutorialID())) { // Refuse to accept if different module
        it.remove();
    }
}
```

Appendix I – Updating the Requester Agent and Poster Agent's slots

```
// Updating the slots for the Requester Agent and the Poster Agent
for (SwapFinal swap : slotsConfirmed.getSlots()) {

    // Update requester agent to the new slot
    Iterator<AID> it = StudentSlots[TutorialMap.get(swap.getTutorialTo().getTutorialID())]
                                                [swap.getTutorialTo().getTutNum()].iterator();
    while (it.hasNext()) {
        AID aidRem = it.next();
        if (aidRem.equals(swap.getAgentTo())) {
            it.remove();
            break;
        }
    }
    StudentSlots[TutorialMap.get(swap.getTutorialTo().getTutorialID())]
            [swap.getTutorialTo().getTutNum()].add(swap.getInitalSwapRequest().getAgentFrom());

    // Update the initial agent on the timetable to the agreed slot
    Iterator<AID> receiverit = StudentSlots[TutorialMap.get(swap.getInitalSwapRequest().getTutorial().getTutorialID())]
                                                    [swap.getInitalSwapRequest().getTutorial().getTutNum()].iterator();
    while (receiverit.hasNext()) {
        AID aidRem = receiverit.next();
        if (aidRem.equals(swap.getInitalSwapRequest().getAgentFrom())) {
            receiverit.remove();
            break;
        }
    }
    StudentSlots[TutorialMap.get(swap.getInitalSwapRequest().getTutorial().getTutorialID())]
                [swap.getInitalSwapRequest().getTutorial().getTutNum()].add(swap.getAgentTo());
}
```

Appendix J – Checking the Poster Agent Owns the Posted Slot

```
// Checking if timetabler has student as owning slot
boolean found = false;
for (AID student : StudentSlots
        [TutorialMap.get(initSwap.getTutorial().getTutorialID())][initSwap.getTutorial().getTutNum()]) {
    if (student.equals(initSwap.getAgentFrom())) {
        found = true;
        break;
    }
}
// If not found, student not present
if (!found) {
    present = false;
}
if (!present) {
    messageBoard.addToMessageBoard(initSwap);
}
```

Appendix K – The Student Agent Code

```
package timetable;

import java.util.ArrayList;
import java.util.HashMap;
import java.util.List;

import jade.content.Concept;
import jade.content.ContentElement;
import jade.content.lang.Codec;
import jade.content.lang.Codec.CodecException;
import jade.content.lang.sl.SLCodec;
import jade.content.onto.Ontology;
import jade.content.onto.OntologyException;
import jade.content.onto.basic.Action;
import jade.core.AID;
import jade.core.Agent;
import jade.core.behaviours.CyclicBehaviour;
import jade.domain.DFService;
import jade.domain.FIPAException;
import jade.domain.FIPAAgentManagement.DFAgentDescription;
import jade.domain.FIPAAgentManagement.ServiceDescription;
import jade.lang.acl.ACLMessage;
import jade.lang.acl.MessageTemplate;
import timetable_ontology.TimetableOntology;
import timetable_ontology.elements.HappyWith;
import timetable_ontology.elements.MessageBoard;
import timetable_ontology.elements.PleasedWith;
import timetable_ontology.elements.SlotsAvailable;
import timetable_ontology.elements.SlotsRequested;
import timetable_ontology.elements.SwapFinal;
import timetable_ontology.elements.SwapInitial;
import timetable_ontology.elements.Timeslot;
import timetable_ontology.elements.TutorialGroup;
import timetable_ontology.elements.UnhappySlot;

// Student Agent
public class StudentAgent extends Agent{
	private Codec codec = new SLCodec();
	private Ontology ontology = TimetableOntology.getInstance();
	MessageBoard slotsMessageBoard;

	private int[][] SlotPreferences;
	private TutorialGroup[] CurrentTutorials;
	private double meanHappinessTarget = 1.50; // Decreases slowly over time to allow the Agent to be 'Happy' later in the program
	private double minMeanHappinessTarget = 0.5; // Minimum meanHappinessTarget
	private HashMap<Integer, String> dayHM = new HashMap<>();
	private HashMap<Integer, String> timeHM = new HashMap<>();

	@Override
	protected void setup() {
		register();
		initHMs();
		getContentManager().registerLanguage(codec);
		getContentManager().registerOntology(ontology);

		Object[] arguments = getArguments();
		SlotPreferences = (int[][]) arguments[0];
		CurrentTutorials = (TutorialGroup[]) arguments[1];

		addBehaviour(new AwaitTimetableBehaviour()); // Message board received by the Timetable Agent
		addBehaviour(new AwaitSlotVerifyBehaviour()); // Agrees / Refuses Slot Request confirmations from the Timetable Agent
		addBehaviour(new AwaitHappyBehaviour()); // Updates slots confirmed by the Timetable Agent and then confirms if happy or have a slot
to give
	}


	// Waiting for the message board to be passed from the Timetable Agent
	public class AwaitTimetableBehaviour extends CyclicBehaviour {

		@Override
		public void action() {
			ACLMessage msg = myAgent.receive(MessageTemplate.MatchConversationId("messageBoard"));
			if (msg != null) {
				try {
```

```
                                        //System.out.println(getAID().getLocalName() + " - Initiating timetable check"); //print out the
message content in SL
                                        ContentElement ce = getContentManager().extractContent(msg);

                                        if (ce instanceof SlotsAvailable) {
                                                SlotsAvailable available = (SlotsAvailable) ce;
                                                slotsMessageBoard = available.getBoard();
                                                List<SwapInitial> messageBoard = slotsMessageBoard.getMessageBoard();

                                                // Checking for messages in the message board
                                                if (messageBoard.size() > 0) {
                                                        SwapInitial[] interestedSlots = new SwapInitial[CurrentTutorials.length]; //
Hold interested slots for each tutorial group

                                                        // Fill the 'interested slots'
                                                        for (int i = 0; i < interestedSlots.length; i++) {
                                                                for (SwapInitial boardSwap : messageBoard) {
                                                                        if
(boardSwap.getTutorial().getTutorialID().equals(CurrentTutorials[i].getTutorialID())) { // If matching tutorial
                                                                                if (interestedSlots[i] == null) {
                                                                                        if
(SlotFitness(boardSwap.getTutorial().getTimeslot()) >

        SlotFitness(CurrentTutorials[i].getTimeslot())) { // If no current 'better slot'

        interestedSlots[i] = boardSwap;
                                                                                        }
                                                                                }else if
(SlotFitness(boardSwap.getTutorial().getTimeslot()) >

        SlotFitness(interestedSlots[i].getTutorial().getTimeslot())){ // Better than 'best' slot
                                                                                        interestedSlots[i] =
boardSwap;
                                                                                }
                                                                        }
                                                                }
                                                        }

                                                        SlotsRequested wishedSlots = new SlotsRequested();
                                                        SwapFinal swapRequest;
                                                        ArrayList<SwapFinal> swapsRequested = new ArrayList<>();

                                                        // Checking interested slots
                                                        for (SwapInitial swap : interestedSlots){
                                                                if (swap != null) {
                                                                        swapRequest = new SwapFinal();
                                                                        swapRequest.setInitalSwapRequest(swap);
                                                                        swapRequest.setAgentTo(getAID());

                                                                        for (TutorialGroup currentTutorial :
CurrentTutorials) {
                                                                                if
(currentTutorial.getTutorialID().equals(swap.getTutorial().getTutorialID())) {

        swapRequest.setTutorialTo(currentTutorial); // Get the current tutorial
                                                                                        break;
                                                                                }
                                                                        }
                                                                        swapsRequested.add(swapRequest);
                                                                }
                                                        }
                                                        wishedSlots.setSlots(swapsRequested);

                                                        ACLMessage reply = msg.createReply();
                                                        reply.setPerformative(ACLMessage.INFORM);
                                                        try {
                                                                getContentManager().fillContent(reply, wishedSlots);
                                                                send(reply); // >0 wished slots
                                                        }
                                                        catch (Exception e) {
                                                                e.printStackTrace();
                                                        }
                                                }
                                                else { // If message board has no slots
                                                        SlotsRequested wishedSlots = new SlotsRequested();
```

```
                                                                        wishedSlots.setSlots(new ArrayList<>());
                                                                        ACLMessage reply = msg.createReply(); // 0 wished slots
                                                                        reply.setPerformative(ACLMessage.INFORM);
                                                                        try {
                                                                                getContentManager().fillContent(reply, wishedSlots);
                                                                                send(reply);
                                                                        }
                                                                        catch (Exception e) {
                                                                                e.printStackTrace();
                                                                        }
                                                                }
                                                        }
                                                }
                                                catch(Exception e) {
                                                        e.printStackTrace();
                                                }
                                        }
                                        else {
                                                block();
                                        }
                                }
                        }


                        // Responds to SwapFinal requests
                        public class AwaitSlotVerifyBehaviour extends CyclicBehaviour {
                                @Override
                                public void action() {
                                        MessageTemplate mt = MessageTemplate.MatchConversationId("swapRequestCheck");
                                        ACLMessage msg = myAgent.receive(mt);
                                        if (msg != null) {
                                                try {
                                                        //System.out.println(getAID().getLocalName() + " - Checking slot request");
                                                        ContentElement ce = getContentManager().extractContent(msg);
                                                        if (ce instanceof Action) {
                                                                Concept action = ((Action)ce).getAction();
                                                                if (action instanceof SwapFinal) {
                                                                        SwapFinal swapRequest = (SwapFinal) action;

                                                                        ACLMessage reply = msg.createReply();
                                                                        getContentManager().fillContent(reply, swapRequest);

                                                                        int count = 0;
                                                                        // Checking if they want the tutorial
                                                                        for (TutorialGroup tutorial : CurrentTutorials) {
                                                                                if
(tutorial.getTutorialID().equals(swapRequest.getTutorialTo().getTutorialID())) { // Checking same tutorial
                                                                                        if (SlotFitness(tutorial.getTimeslot()) <=

                        SlotFitness(swapRequest.getTutorialTo().getTimeslot())) { // If indifferent or prefers slot

                        reply.setPerformative(ACLMessage.AGREE); // Agree because want to swap slot
                                                                                                CurrentTutorials[count] =
swapRequest.getTutorialTo();
                                                                                                break;
                                                                                        }
                                                                                        else {

                        reply.setPerformative(ACLMessage.REFUSE); // Refuse because not interested
                                                                                                break;
                                                                                        }
                                                                                }
                                                                                else {
                                                                                        reply.setPerformative(ACLMessage.REFUSE); //
Refuse as not the same tutorial ID
                                                                                }
                                                                                count++;
                                                                        }

                                                                        Action actionReply = new Action();
                                                                        actionReply.setAction(swapRequest);
                                                                        actionReply.setActor(getAID());

                                                                        try {
                                                                                getContentManager().fillContent(reply, actionReply);
```

```
                                                                        send(reply);
                                                                }
                                                                catch(CodecException codecE) {
                                                                        codecE.printStackTrace();
                                                                }
                                                                catch(OntologyException oe) {
                                                                        oe.printStackTrace();
                                                                }
                                                        }
                                                }
                                        }
                                        catch (CodecException ce) {
                                                ce.printStackTrace();
                                        }
                                        catch (OntologyException oe) {
                                                oe.printStackTrace();
                                        }
                                }
                                else {
                                        block();
                                }
                        }
                }

                // Sends worst slot to Timetable Agent OR check AGENT IS HAPPY HERE
                public class AwaitHappyBehaviour extends CyclicBehaviour {

                        @Override
                        public void action() {
                                MessageTemplate mt = MessageTemplate.MatchConversationId("happyNow");
                                ACLMessage msg = myAgent.receive(mt);
                                if (msg != null) {
                                        //System.out.println(getAID().getLocalName() + " - Happy? or Post worst slot");
                                        try {
                                                ContentElement ce = getContentManager().extractContent(msg);
                                                if (ce instanceof Action) {
                                                        Concept action = ((Action)ce).getAction();

                                                        if (action instanceof HappyWith) {
                                                                HappyWith happy = ((HappyWith)action);

                                                                for (SwapFinal slot : happy.getSlots()) {
                                                                        for (int i = 0; i < CurrentTutorials.length; i++) {
                                                                                if
(slot.getTutorialTo().getTutorialID().equals(CurrentTutorials[i].getTutorialID())) {
                                                                                        CurrentTutorials[i] =
slot.getInitalSwapRequest().getTutorial();
                                                                                        break;
                                                                                }
                                                                        }
                                                                }

                                                                double meanHappiness = 0;

                                                                // Get Mean unhappiness across slots
                                                                for (int i = 0; i < CurrentTutorials.length; i++) {
                                                                        meanHappiness +=
SlotFitness(CurrentTutorials[i].getTimeslot());
                                                                }

                                                                meanHappiness /= CurrentTutorials.length;

                                                                // Reducing happiness required each run
                                                                if (meanHappinessTarget > minMeanHappinessTarget) {
                                                                        meanHappinessTarget -= 0.02;
                                                                }

                                                                // If high enough overall happiness -- 0 or 1 slots accepted
                                                                if (meanHappiness <= meanHappinessTarget) {

                                                                        // Checking slots that haven't been advertised yet
                                                                        List<Integer> slotsNotAdvertised = new ArrayList<>();

                                                                        // Getting current slots not on messageboard
```

```
                                                                        for (int i = 0; i < CurrentTutorials.length; i++) {
                                                                                boolean advertisedAlready = false;
                                                                                for (SwapInitial item :
slotsMessageBoard.getMessageBoard()) {
                                                                                        if
(item.getAgentFrom().equals(getAID()) &&
                item.getTutorial().getTutorialID().equals(CurrentTutorials[i].getTutorialID())) {
                                                                                                advertisedAlready =
true;
                                                                                                continue;
                                                                                        }
                                                                                }
                                                                                if (!advertisedAlready) {
                                                                                        if
(SlotFitness(CurrentTutorials[i].getTimeslot()) < 1.0) { // Don't post slot if happy already
                slotsNotAdvertised.add(i);
                                                                                        }
                                                                                }
                                                                        }

                                                                        int worstTutorial = -1; // Worst tutorial is slotsNotAdvertised
positional reference
                                                                        // Comparing slots - if all slots posted (or no slots student
wishes to post) then nothing
                                                                        if (slotsNotAdvertised.size() > 0) {
                                                                                worstTutorial = 0;
                                                                                // Select worst slot not currently on timetable
                                                                                for (int i = 1; i < slotsNotAdvertised.size(); i++) {
                                                                                        if
(SlotFitness(CurrentTutorials[slotsNotAdvertised.get(i)].getTimeslot()) <
                SlotFitness(CurrentTutorials[slotsNotAdvertised.get(worstTutorial)].getTimeslot())) {
                                                                                                worstTutorial = i;
                                                                                        }
                                                                                }
                                                                        }

                                                                        UnhappySlot slot = new UnhappySlot();
                                                                        // Add slot found (if found) to 'Unhappy Slot' posting
                                                                        if (worstTutorial != -1) {
                                                                                SwapInitial si = new SwapInitial();
                                                                                si.setAgentFrom(myAgent.getAID());
                si.setTutorial(CurrentTutorials[slotsNotAdvertised.get(worstTutorial)]);
                                                                                slot.setSlotToSwap(si);
                                                                        }

                                                                        Action newAction = new Action();
                                                                        newAction.setActor(getAID());
                                                                        newAction.setAction(slot);

                                                                        ACLMessage reply = msg.createReply();
                                                                        reply.setPerformative(ACLMessage.REFUSE);

                                                                        try {
                                                                                getContentManager().fillContent(reply,
newAction);
                                                                                send(reply);
                                                                        }
                                                                        catch(CodecException codecE) {
                                                                                codecE.printStackTrace();
                                                                        }
                                                                        catch(OntologyException oe) {
                                                                                oe.printStackTrace();
                                                                        }
                                                                }else {

                                                                        for (TutorialGroup tg : CurrentTutorials) {
                                                                                System.out.println(getAID().getLocalName() + "
has ended with " + tg.getTutorialID() + " on " + dayHM.get(tg.getTimeslot().getDay()) + " at " + timeHM.get(tg.getTimeslot().getTime()));
                                                                        }
```

```
                                                                                ACLMessage reply = msg.createReply();
                                                                                PleasedWith pleased = new PleasedWith();
                                                                                pleased.setStudent(getAID());
                                                                                reply.setPerformative(ACLMessage.AGREE);

                                                                                try {
                                                                                        getContentManager().fillContent(reply, pleased);
                                                                                        send(reply);

                                                                                        System.out.println("FINAL HAPPINESS FOR " +
getAID().getLocalName() + " IS " + meanHappiness);

                                                                                        System.out.println("");
                                                                                        doDelete();
                                                                                }
                                                                                catch(CodecException codecE) {
                                                                                        codecE.printStackTrace();
                                                                                }
                                                                                catch(OntologyException oe) {
                                                                                        oe.printStackTrace();
                                                                                }
                                                                        }
                                                                }
                                                        }
                                                }
                                                catch (CodecException ce) {
                                                        ce.printStackTrace();
                                                }
                                                catch (OntologyException oe) {
                                                        oe.printStackTrace();
                                                }
                                        }
                                        else {
                                                block();
                                        }
                                }
                        }

                        // Calculates timeslot fitness
                        private double SlotFitness(Timeslot slot) {
                                if (SlotPreferences[slot.getDay()][slot.getTime()]==5) { // Heavily punished if they can't attend
                                        return -5.0;
                                }
                                return (1.0 / (SlotPreferences[slot.getDay()][slot.getTime()] + 1));
                        }


                        // Register with the DFD
                        protected void register() {
                                DFAgentDescription dfd = new DFAgentDescription ();
                                dfd.setName(getAID());

                                ServiceDescription sd = new ServiceDescription();
                                sd.setType("student-agent");
                                sd.setName( getLocalName() + "-student-agent");
                                dfd.addServices(sd);

                                try{
                                        DFService.register(this , dfd);
                                }
                                catch(FIPAException e) {
                                        e.printStackTrace();
                                }
                        }

                        private void initHMs() {
                                dayHM.put(0, "Monday");
                                dayHM.put(1, "Tuesday");
                                dayHM.put(2, "Wednesday");
                                dayHM.put(3, "Thursday");
                                dayHM.put(4, "Friday");
                                dayHM.put(5, "Saturday");
                                dayHM.put(6, "Sunday");

                                timeHM.put(0, "9am");
```

```
                    timeHM.put(1, "10am");
                    timeHM.put(2, "11am");
                    timeHM.put(3, "12pm");
                    timeHM.put(4, "1pm");
                    timeHM.put(5, "2pm");
                    timeHM.put(6, "3pm");
                    timeHM.put(7, "4pm");
                    timeHM.put(8, "5pm");
          }
}
```

Appendix L – The Timetable Agent Code

```
package timetable;

import java.util.ArrayList;
import java.util.Collections;
import java.util.HashMap;
import java.util.Iterator;
import java.util.List;

import timetable_ontology.TimetableOntology;
import timetable_ontology.elements.HappyWith;
import timetable_ontology.elements.MessageBoard;
import timetable_ontology.elements.PleasedWith;
import timetable_ontology.elements.SlotsAvailable;
import timetable_ontology.elements.SlotsRequested;
import timetable_ontology.elements.SwapFinal;
import timetable_ontology.elements.SwapInitial;
import timetable_ontology.elements.TutorialGroup;
import timetable_ontology.elements.UnhappySlot;
import jade.content.Concept;
import jade.content.ContentElement;
import jade.content.lang.Codec;
import jade.content.lang.Codec.CodecException;
import jade.content.lang.sl.SLCodec;
import jade.content.onto.Ontology;
import jade.content.onto.OntologyException;
import jade.content.onto.basic.Action;
import jade.core.AID;
import jade.core.Agent;
import jade.core.behaviours.Behaviour;
import jade.core.behaviours.OneShotBehaviour;
import jade.domain.DFService;
import jade.domain.FIPAException;
import jade.domain.FIPAAgentManagement.DFAgentDescription;
import jade.domain.FIPAAgentManagement.ServiceDescription;
import jade.lang.acl.ACLMessage;
import jade.lang.acl.MessageTemplate;

// Timetabling agent
public class TimetablingAgent extends Agent{
          private Codec codec = new SLCodec();
          private Ontology ontology = TimetableOntology.getInstance();

          private MessageBoard messageBoard = new MessageBoard(); // WHEN MESSAGEBOARD PASSED - NEED TO TAKE ALL ELEMENTS
OF THIS BOARD AND ADD THEM TO A NEW BOARD

          // Tracks Student Slots
          private ArrayList<AID>[][] StudentSlots;

          // Maps
          private HashMap<String, Integer> TutorialMap = new HashMap<>();

          // Keep the 'happy students' since you could run over them in theory to check if there's a few unhappy agents
left..
          //                 ..may find an even better slot
          private List<AID> happyAgents = new ArrayList<AID>(); // StudentAgents 'happy' with their tutorial assignment
          private List<AID> unhappyAgents = new ArrayList<AID>(); // StudentAgents 'unhappy' with their tutorial
assignment

          @SuppressWarnings("unchecked")
          @Override
          protected void setup() {
                    register();
                    getContentManager().registerLanguage(codec);
                    getContentManager().registerOntology(ontology);
```

```
		Object[] arguments = getArguments();
		List<String> studentString = (List<String>) arguments[0];
		List<TutorialGroup[]> tutorialList = (List<TutorialGroup[]>) arguments[1];

		doWait(5000); // Wait for student agents to load
		addBehaviour(new FindStudentsBehaviour(this)); // Finds the students
		addBehaviour(new SetupTTBehaviour(studentString, tutorialList));
		addBehaviour(new SwapStudentSlotBehaviour()); // Runs the Student Swapping Behaviour
	}


	// Runs the Student Swapping Behaviour for the whole agent
	public class SwapStudentSlotBehaviour extends Behaviour {
		private AID currentAgent;
		private int studentIndex = 0;
		private int step = 0;
		private SlotsRequested slotsRequested = new SlotsRequested(); // Slots requested by StudentAgents
		private SlotsRequested slotsConfirmed = new SlotsRequested(); // Slots confirmed by TimetablingAgent
		private SlotsRequested slotsDenied = new SlotsRequested(); // Slots denied by StudentAgents

		@Override
		public void action() {
			switch(step) {
			case 0:
				currentAgent = unhappyAgents.get(studentIndex);
				addBehaviour(new InitiateStudentBehaviour(currentAgent)); // Notifies the
swapperAgent they're 'live'
				step++;
				break;
			case 1:
				MessageTemplate swapConfirmMt =
MessageTemplate.and(MessageTemplate.MatchConversationId("messageBoard")
						,MessageTemplate.MatchSender(currentAgent)); // Listens
for request from 'live' agent
				ACLMessage msg = myAgent.receive(swapConfirmMt);
				if (msg != null) {
					try {
						ContentElement ce = getContentManager().extractContent(msg);
						if (ce instanceof SlotsRequested) {
							slotsRequested = ((SlotsRequested)ce);
							step++;

							// Checking the student has the slot it says it does
							Iterator<SwapFinal> it =
slotsRequested.getSlots().iterator();

							while (it.hasNext()) {
								SwapFinal itSwap = it.next();
								boolean present = false;
								// Looping through requester agent to check if
agent has those tutorial slots

								for (AID agent : StudentSlots

	[TutorialMap.get(itSwap.getTutorialTo().getTutorialID())][itSwap.getTutorialTo().getTutNum()]) {
									if
(itSwap.getAgentTo().equals(agent)) {

										present = true;
										break;

									}
								}
								if (!present) { // If student doesn't own the
slot
									it.remove();
								}
								else if
(!itSwap.getTutorialTo().getTutorialID().equals

	(itSwap.getInitalSwapRequest().getTutorial().getTutorialID())) { // Refuse to accept if different module
									it.remove();
								}
							}
						}
					}
					catch (Exception e) {
						e.printStackTrace();
					}
				}
				else {
					block();
				}
```

```
                                        break;
                                case 2:
                                        slotsConfirmed.setSlots(new ArrayList<>()); // Setting slotsConfirmed slots
                                        slotsDenied.setSlots(new ArrayList<>());

                                        // This allows the Timetable Agent to only ask for slots if slots have been selected
                                        // (Reduced message passing)
                                        if (slotsRequested.getSlots().size() == 0) { // Go to step requesting slots if no
slots selected
                                                step=4;
                                        }
                                        else {
                                                addBehaviour(new VerifySlotBehaviour(slotsRequested)); // Verifies slot
with swappedAgent
                                                step++;
                                        }
                                        break;
                                case 3:
                                        MessageTemplate swapRequestFinalMt =
MessageTemplate.MatchConversationId("swapRequestCheck"); // Listens for response from swappedAgent
                                        msg = myAgent.receive(swapRequestFinalMt);

                                        if (msg != null) { // Check for swapped slots and un-swapped slots
                                                try {
                                                        ContentElement ce = getContentManager().extractContent(msg);
                                                        if (ce instanceof Action) {
                                                                Concept action = ((Action)ce).getAction();
                                                                if (ce instanceof Action) {
                                                                        SwapFinal swapRequest = (SwapFinal) action;
                                                                        if (msg.getPerformative() == ACLMessage.AGREE)
{
                                                                                slotsConfirmed.addSlot(swapRequest);
                                                                        }else {
                                                                                slotsDenied.addSlot(swapRequest);
                                                                        }
                                                                }
                                                        }
                                                        if ((slotsConfirmed.getSlots().size() +
slotsDenied.getSlots().size()) == slotsRequested.getSlots().size()) { // Increase step if received all replies

                                                                // Updating the slots for the Requester Agent and the
Poster Agent
                                                                for (SwapFinal swap : slotsConfirmed.getSlots()) {
                                                                        // Update requester agent to the new slot
                                                                        Iterator<AID> it =
StudentSlots[TutorialMap.get(swap.getTutorialTo().getTutorialID())]

                                                                [swap.getTutorialTo().getTutNum()].iterator();
                                                                        while (it.hasNext()) {
                                                                                AID aidRem = it.next();
                                                                                if (aidRem.equals(swap.getAgentTo()))
{
                                                                                        it.remove();
                                                                                        break;
                                                                                }
                                                                        }

        StudentSlots[TutorialMap.get(swap.getTutorialTo().getTutorialID())]

        [swap.getTutorialTo().getTutNum()].add(swap.getInitalSwapRequest().getAgentFrom());

                                                                        // Update the initial agent on the timetable
to the agreed slot
                                                                        Iterator<AID> receiverit =
StudentSlots[TutorialMap.get(swap.getInitalSwapRequest().getTutorial().getTutorialID())]


        [swap.getInitalSwapRequest().getTutorial().getTutNum()].iterator();
                                                                        while (receiverit.hasNext()) {
                                                                                AID aidRem = receiverit.next();
                                                                                if
(aidRem.equals(swap.getInitalSwapRequest().getAgentFrom())) {
                                                                                        receiverit.remove();
                                                                                        break;
                                                                                }
                                                                        }

        StudentSlots[TutorialMap.get(swap.getInitalSwapRequest().getTutorial().getTutorialID())]
```

```
[swap.getInitalSwapRequest().getTutorial().getTutNum()].add(swap.getAgentTo());
                                                        }

                                                        step++;
                                                }
                                        }
                                        catch (Exception e) {
                                                e.printStackTrace();
                                        }
                                }
                                else {
                                        block();
                                }
                                break;
                        case 4:
                                addBehaviour(new InitiateStudentHappyBehaviour(slotsConfirmed, currentAgent)); //
Initiates response verification with swapperAgent
                                step++;
                                break;
                        case 5:
                                boolean happy = false;
                                boolean done = false;
                                MessageTemplate SlotRequestMt = MessageTemplate.and

        (MessageTemplate.MatchConversationId("happyNow"),MessageTemplate.MatchSender(currentAgent));
                                msg = myAgent.receive(SlotRequestMt);
                                if (msg != null) {
                                        try {
                                                ContentElement ce = getContentManager().extractContent(msg);
                                                if (ce instanceof Action) {
                                                        Concept action = ((Action)ce).getAction();

                                                        if (action instanceof UnhappySlot) {
                                                                UnhappySlot slot = (UnhappySlot) action;
                                                                SwapInitial initSwap = slot.getSlotToSwap();
                                                                if (initSwap != null) {
                                                                        boolean present = false;

                                                                        // Checking if duplicate slot
                                                                        for (SwapInitial checkSlot :
messageBoard.getMessageBoard()) {
                                                                                if
(checkSlot.getTutorial().getTutorialID().equals

        (initSwap.getTutorial().getTutorialID()) && checkSlot.getAgentFrom().equals(initSwap.getAgentFrom())) {
                                                                                        present = true;
                                                                                }
                                                                        }

                                                                        // Checking if timetabler has student
as owning slot
                                                                        boolean found = false;
                                                                        for (AID student : StudentSlots

        [TutorialMap.get(initSwap.getTutorial().getTutorialID())][initSwap.getTutorial().getTutNum()]) {
                                                                                if
(student.equals(initSwap.getAgentFrom())) {
                                                                                        found = true;
                                                                                        break;
                                                                                }
                                                                        }
                                                                        // If not found, student not present
                                                                        if (!found) {
                                                                                present = false;
                                                                        }
                                                                        if (!present) {

        messageBoard.addToMessageBoard(initSwap);
                                                                        }


                                                                }
                                                                done = true;
                                                                step = 0;
                                                        }
                                                }
                                                else if (ce instanceof PleasedWith) { // Agent is pleased with
slot
```

```
                                                                happy = true;
                                                                done = true;
                                                                step = 0;
                                                        }
                                                }
                                                catch (Exception e) {
                                                        e.printStackTrace();
                                                }
                                        }
                                        else {
                                                block();
                                        }

                                        // If happy, add to happier list increment student index
                                        if (done) {
                                                if (happy) {

                                                        // Remove agent's slots from the timetable if they're happy
                                                        List<Integer> slotLocs = new ArrayList<>();
                                                        for (int i = 0; i < messageBoard.getMessageBoard().size(); i++) {
                                                                if
(messageBoard.getMessageBoard().get(i).getAgentFrom().equals(currentAgent)) {
                                                                        slotLocs.add(i);
                                                                }
                                                        }

                                                        // Remove slot locations from the message board
                                                        // and then negatively increment all slot locations
                                                        for (int i = 0; i < slotLocs.size(); i++) {
                                                                messageBoard.removeFromMessageBoard(slotLocs.get(i));
                                                                for (int j = i+1; j < slotLocs.size(); j++) {
                                                                        slotLocs.set(j, slotLocs.get(j)-1);
                                                                }
                                                        }

                                                        happyAgents.add(currentAgent);
                                                        unhappyAgents.remove(currentAgent); // Remove agent
                                                }

                                                if (studentIndex >= (unhappyAgents.size()-1)) { // -1 because used for
indexing
                                                        studentIndex = 0;
                                                }else {
                                                        studentIndex++;
                                                }
                                        }
                                        break;
                                }
                        }

                        @Override
                        public boolean done() {
                                if (unhappyAgents.size() > 0) {
                                        return false;
                                }
                                System.out.println("");
                                System.out.println("The program has finished");

                                doDelete();
                                return true;
                        }

                        @Override
                        public void reset() {
                                System.out.println("Resetting program");
                                super.reset();
                                step = 0;
                        }
                }


                // Notifies the swapperAgent they're 'live'
                // Receives a done message if students are finished their activity
                public class InitiateStudentBehaviour extends OneShotBehaviour {
                        private AID studentAid;

                        // Called at the moment the behaviour is added
                        public InitiateStudentBehaviour (AID studentAgent) {
                                this.studentAid = studentAgent;
```

```
		}

		@Override
		public void action() {
			List<SwapInitial> siList = new ArrayList<SwapInitial>();
			for (SwapInitial m : messageBoard.getMessageBoard()) {
				siList.add(m);
			}
			MessageBoard mb = new MessageBoard();
			mb.setMessageBoard(siList);

			SlotsAvailable available = new SlotsAvailable();
			available.setBoard(mb);

			ACLMessage msg = new ACLMessage(ACLMessage.INFORM);
			msg.addReceiver(studentAid);
			msg.setConversationId("messageBoard");
			msg.setLanguage(codec.getName());
			msg.setOntology(ontology.getName());

			try {
				getContentManager().fillContent(msg, available);
				send(msg);
			}
			catch (CodecException ce) {
				ce.printStackTrace();
			}
			catch (OntologyException oe) {
				oe.printStackTrace();
			}
		}
}


// Confirms the validity of the slots requested with other agents
public class VerifySlotBehaviour extends OneShotBehaviour {
		SlotsRequested slotsRequested;

		public VerifySlotBehaviour(SlotsRequested slotsRequested) {
			this.slotsRequested = slotsRequested;
		}

		@Override
		public void action() {
			for (SwapFinal swap : slotsRequested.getSlots()) {
				ACLMessage msg = new ACLMessage(ACLMessage.REQUEST);
				msg.setLanguage(codec.getName());
				msg.setOntology(ontology.getName());
				msg.addReceiver(swap.getInitalSwapRequest().getAgentFrom());
				msg.setConversationId("swapRequestCheck");

				Action action = new Action();
				action.setAction(swap);
				action.setActor(getAID()); // set itself as the actor - since it's requesting swap

				try {
					getContentManager().fillContent(msg, action);
					send(msg);
				}
				catch(CodecException codecE) {
					codecE.printStackTrace();
				}
				catch(OntologyException oe) {
					oe.printStackTrace();
				}
			}
		}
}


// Initiates response verification with the swapperAgent
public class InitiateStudentHappyBehaviour extends OneShotBehaviour {
		SlotsRequested slotsConfirmed;
		AID receiver;

		public InitiateStudentHappyBehaviour(SlotsRequested slotsConfirmed, AID agentTo) {
			this.slotsConfirmed = slotsConfirmed;
			this.receiver = agentTo;
		}
```

```
		@Override
		public void action() {
			try {
				HappyWith happy = new HappyWith();
				happy.setSlots(new ArrayList<>());

				// Make sure slots are removed from the message board if they've been swapped to
another agent
				for (SwapFinal slot : slotsConfirmed.getSlots()) {
					happy.addSlots(slot);

					for (int i = 0; i < messageBoard.getMessageBoard().size(); i++) {
						if
(slot.getInitalSwapRequest().getAgentFrom().equals(messageBoard.getMessageBoard().get(i).getAgentFrom()) &&

	slot.getInitalSwapRequest().getTutorial().getTutorialID().equals(messageBoard.getMessageBoard().get(i).getTutori
al().getTutorialID())) {
							messageBoard.getMessageBoard().remove(i);
							break;
						}
					}
				}

				ACLMessage msg = new ACLMessage(ACLMessage.REQUEST);
				msg.setLanguage(codec.getName());
				msg.setOntology(ontology.getName());
				msg.addReceiver(receiver);
				msg.setConversationId("happyNow");

				Action action = new Action();
				action.setAction(happy);
				action.setActor(getAID());

				getContentManager().fillContent(msg, action);
				send(msg);
			}
			catch(CodecException codecE) {
				codecE.printStackTrace();
			}
			catch(OntologyException oe) {
				oe.printStackTrace();
			}
		}
	}


	// Finds the Student Agents and adds them to the UnhappyAgents list
	public class FindStudentsBehaviour extends OneShotBehaviour {
		public FindStudentsBehaviour(Agent a) {
			super(a);
		}
		@Override
		public void action() {

			DFAgentDescription studentTemplate = new DFAgentDescription();
			ServiceDescription sd = new ServiceDescription();
			sd.setType("student-agent");
			studentTemplate.addServices(sd);

			try{
				unhappyAgents.clear();
				DFAgentDescription[] agentsType1  = DFService.search(myAgent,studentTemplate);
				for(int i=0; i<agentsType1.length; i++){
					unhappyAgents.add(agentsType1[i].getName()); // this is the AID
				}
			}
			catch(FIPAException e) {
				e.printStackTrace();
			}
		}
	}


	// Sets up the timetable agent with a list of all the modules
	public class SetupTTBehaviour extends OneShotBehaviour {
		List<String> students;
		List<TutorialGroup[]> tutorials;
```

```
		public SetupTTBehaviour(List<String> students, List<TutorialGroup[]> tutorials) {
			this.students = students;
			this.tutorials = tutorials;
		}

		@SuppressWarnings("unchecked")
		@Override
		public void action() {

			// Gets the maximum number of tutorials and tutorial groups
			int maxTuts = 0;
			List<AID> tempAIDs = new ArrayList<>();
			List<String> tempTuts = new ArrayList<>();

			// Getting Student AIDs in order
			for (String student : students) {
				for (AID agent : unhappyAgents) {
					if (agent.getName().equals(student)) {
						tempAIDs.add(agent);
						break;
					}
				}
			}

			// Getting the Unique Tutorials in a sorted ArrayList
			for (TutorialGroup[] group : tutorials) {
				for (TutorialGroup tutorial : group) {
					if (tutorial.getTutNum() > maxTuts) {
						maxTuts = tutorial.getTutNum();
					}
					if (!tempTuts.contains(tutorial.getTutorialID())) {
						tempTuts.add(tutorial.getTutorialID());
					}
				}
			}
			maxTuts++; // Since the tutorial numbers are 0 upwards
			Collections.sort(tempTuts);

			// Adding tutorials to the Tutorial HashMap
			for (int i = 0; i < tempTuts.size(); i++) {
				TutorialMap.put(tempTuts.get(i), i);
			}

			StudentSlots = new ArrayList[TutorialMap.size()][maxTuts]; // Initialising the student slots
			for (int i = 0; i < TutorialMap.size(); i++) {
				for (int j = 0; j < maxTuts; j++) {
					StudentSlots[i][j] = new ArrayList<AID>(); // Initialise the ArrayList
correctly for each element
				}
			}

			int loopVal = 0;
			// Adding students to the correct tutorial group
			for (int i = 0; i < tempAIDs.size(); i++){
				for (int j = 0; j < TutorialMap.size(); j++) { // SET ID HashMap (e.g. SET010101,
SET010102)
					// Adds Students to the 2d array ArrayList based on tutorial and class
number (allows tracking of students in tutorials)

	StudentSlots[TutorialMap.get(tutorials.get(loopVal)[j].getTutorialID())][tutorials.get(loopVal)[j].getTutNum()].
add(tempAIDs.get(i));
				}
				// LoopVal tracks the correct arguments (e.g. 9 students created with 3 arguments)
				if (loopVal >= tutorials.size()-1) {
					loopVal = 0;
				}else {
					loopVal++;
				}
			}
		}
	}

	// Register with the DFD
	protected void register() {
		DFAgentDescription dfd = new DFAgentDescription ();
		dfd.setName(getAID());

		ServiceDescription sd = new ServiceDescription();
```

```
                sd.setType("timetabling-agent");
                sd.setName( getLocalName() + "-timetabling-agent");
                dfd.addServices(sd);

                try{
                        DFService.register(this , dfd);
                }
                catch(FIPAException e) {
                        e.printStackTrace() ;
                }
        }
}
```

Appendix M – Ontology Code

HappyWith Code

```
package timetable_ontology.elements;

import java.util.ArrayList;
import jade.content.AgentAction;
import jade.content.onto.annotations.Slot;

public class HappyWith implements AgentAction{

	private ArrayList<SwapFinal> slots;

	@Slot (mandatory = true)
	public ArrayList<SwapFinal> getSlots() {
		return slots;
	}

	public void setSlots(ArrayList<SwapFinal> slots) {
		this.slots = slots;
	}

	public void addSlots(SwapFinal slots) {
		this.slots.add(slots);
	}
}
```

MessageBoard Code

```
package timetable_ontology.elements;

import java.util.ArrayList;
import java.util.List;
import jade.content.Concept;
import jade.content.onto.annotations.Slot;

public class MessageBoard implements Concept {

	private List<SwapInitial> messageBoard = new ArrayList<SwapInitial>();

	public void setMessageBoard(List<SwapInitial> message) {
		messageBoard = message;
	}

	public List<SwapInitial> getMessageBoard() {
		return messageBoard;
	}

	public void addToMessageBoard(SwapInitial message) {
		this.messageBoard.add(message);
	}

	public void removeFromMessageBoard(int index) {
		messageBoard.remove(index);
	}
}
```

PleasedWith Code

```
package timetable_ontology.elements;

import java.util.List;

import jade.content.Predicate;
import jade.core.AID;

public class PleasedWith implements Predicate{

		private AID student;

		public AID getStudent() {
			return student;
		}
		public void setStudent(AID student) {
			this.student = student;
		}
}
```

SlotsAvailable Code

```
package timetable_ontology.elements;

import jade.content.Predicate;
import jade.content.onto.annotations.Slot;
import jade.core.AID;

public class SlotsAvailable implements Predicate {

		private MessageBoard board;

		@Slot (mandatory = true)
		public MessageBoard getBoard() {
			return board;
		}
		public void setBoard(MessageBoard board) {
			this.board = board;
		}
}
```

SlotsRequested Code

```
package timetable_ontology.elements;

import java.util.ArrayList;

import jade.content.Predicate;
import jade.content.onto.annotations.Slot;

public class SlotsRequested implements Predicate {

		private ArrayList<SwapFinal> slots;

		@Slot (mandatory = true)
		public ArrayList<SwapFinal> getSlots() {
			return slots;
		}

		public void setSlots(ArrayList<SwapFinal> slots) {
			this.slots = slots;
		}

		public void addSlot(SwapFinal slot) {
			this.slots.add(slot);
		}
}
```

SwapFinal Code

```
package timetable_ontology.elements;

import jade.content.AgentAction;
import jade.content.onto.annotations.Slot;
import jade.core.AID;

public class SwapFinal implements AgentAction{

		private SwapInitial swapInitial; // Initial slot on the timetable
		private AID agentTo; // Agent requesting tutorial (REQUESTER)
		private TutorialGroup tutorialTo;

		@Slot (mandatory = true)
		public AID getAgentTo() {
			return agentTo;
		}
		public void setAgentTo(AID agentTo) {
			this.agentTo = agentTo;
		}

		@Slot (mandatory = true)
		public SwapInitial getInitalSwapRequest() {
			return swapInitial;
		}
		public void setInitalSwapRequest(SwapInitial initalRequest) {
			this.swapInitial = initalRequest;
		}

		@Slot (mandatory = true)
		public TutorialGroup getTutorialTo() {
			return tutorialTo;
		}
		public void setTutorialTo(TutorialGroup tutorialTo) {
			this.tutorialTo = tutorialTo;
		}
}
```

SwapInitial Code

```
package timetable_ontology.elements;

import jade.content.AgentAction;
import jade.content.onto.annotations.Slot;
import jade.core.AID;

// MessageBoard is an ArrayList of SwapInitials
// Requester details always listed in SwapFinal
public class SwapInitial implements AgentAction {

		private TutorialGroup tutorialFrom;
		private AID agentFrom; // Agent receiving request

		@Slot (mandatory = true)
		public AID getAgentFrom() {
			return agentFrom;
		}
		public void setAgentFrom(AID agentFrom) {
			this.agentFrom = agentFrom;
		}

		@Slot (mandatory = true)
		public TutorialGroup getTutorial() {
			return tutorialFrom;
		}
		public void setTutorial(TutorialGroup tutorial) {
			this.tutorialFrom = tutorial;
		}
}
```

Timeslot Code

```
package timetable_ontology.elements;

import jade.content.Concept;
import jade.content.onto.annotations.Slot;


public class Timeslot implements Concept {

		public Timeslot() {

		}

		// Used by main
		public Timeslot(int day, int time) {
			this.day = day;
			this.time = time;
		}

		private int day;
		private int time;

		@Slot (mandatory = true)
		public int getDay() {
			return day;
		}

		public void setDay(int day) {
			this.day = day;
		}

		@Slot (mandatory = true)
		public int getTime() {
			return time;
		}

		public void setTime(int time) {
			this.time = time;
		}
}
```

UnhappySlot Code

```
package timetable_ontology.elements;

import jade.content.AgentAction;

public class UnhappySlot implements AgentAction {

		private SwapInitial slotToSwap;

		public SwapInitial getSlotToSwap() {
			return slotToSwap;
		}

		public void setSlotToSwap(SwapInitial slotToSwap) {
			this.slotToSwap = slotToSwap;
		}
}
```

TutorialGroup Code

```
package timetable_ontology.elements;

import java.util.ArrayList;

import jade.content.Concept;
import jade.content.onto.annotations.AggregateSlot;
import jade.content.onto.annotations.Slot;
import jade.core.AID;

public class TutorialGroup implements Concept {

	public TutorialGroup() {

	}

	// Used by main
	public TutorialGroup(Timeslot slot, String tutorialID, int tutNum) {
		this.slot = slot;
		this.tutorialID = tutorialID;
		this.setTutNum(tutNum);
	}


	private Timeslot slot;
	private String tutorialID; // The set code (e.g. SET10101)
	private int classSize;
	private int tutNum;

	@Slot (mandatory = true)
	public Timeslot getTimeslot() {
		return slot;
	}
	public void setTimeslot(Timeslot slot) {
		this.slot = slot;
	}

	@Slot (mandatory = true)
	public String getTutorialID() {
		return tutorialID;
	}
	public void setTutorialID(String tutorialID) {
		this.tutorialID = tutorialID;
	}

	@Slot (mandatory = true)
	public int getTutNum() {
		return tutNum;
	}

	public void setTutNum(int tutNum) {
		this.tutNum = tutNum;
	}
}
```