Artificial Intelligence Methods PWP Hyper-Heuristic Report

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# Random Initialisation

Firstly, PWPInstanceReader creates a PWPInstance based off the square.pwp file; storing relevant information such as an array of locations(aoLocations).  
Each PWPSolution contains an int array used to store the indexes of these locations in the order they are to be visited.

When a PWPSolution is initialised, it is set to a random permutation by first creating an int array of length matching number of locations in the instance, representing the indexes of the different locations, then shuffling their order using Fisher–Yates shuffle as it is a simple and efficient way to produce an unbiased permutation.

When using seed ‘13032020l’ s0 is initialised to [4,5,3,1,2,0].

The shortest route, s1 is known to be [0,1,2,3,4,5]

Visual Representation of both solutions is seen below

|  |  |
| --- | --- |
| S0:[4,5,3,1,2,0] | S1:[0,1,2,3,4,5] |
|  |  |

# Inversion Mutation

A do-while loop is used to ensure I have picked 2 different random points followed by using the ternary operator to assign the lowest point as the startIndex and the highest point as the endIndex.

I then set two counters representing the indexes of the locations to swap, i initialised to the startIndex and j initialised to the endIndex.  
I then have a while loop repeat whilst i<j, swapping the locations at i and j then incrementing i and decrementing j.

Example:

* solution=[0,4,1,3,5,2]
* i1=4, i2=1
* startIndex=1, endIndex=4
* i=1, j=4 [ENTER LOOP]
* solution=[0,5,1,3,4,2]
* i=2, j=3 [CONTINUE LOOP]
* **solution=[0,5,3,1,4,2]**
* i=3, j=2 [BREAK LOOP]

# Delta Evaluation for Adjacent Swap

To use delta evaluation simply get the known cost of the solution before the application of the heuristic, then subtract the cost of the edges to be changed (before they are changed) then add the cost of those newly changed edges.

In Delta Evaluation for Adjacent Swap if you are swapping 2 Adjacent nodes (i1 and i2) you are subtracting the distance of the edges that have been removed and adding the distance of the edges they have been replaced with:

* When i1 and i2 are swapped the distance between i1 and the element before it (i1-1) will be removed and replaced with the distance between the element at i1 – 1 and element at i2.
  + if i1-1 is less than 0, then it is the DEPOT which is used in the calculations.
* When i1 and i2 are swapped the distance between i2 and the element after it (i2+1) will be removed and replaced with the distance between the element at i2 + 1 and element at i1
  + if i2+1 is greater than the size, then it is the HOME which is used in the calculations.
* The distance between i1 and i2 remains the same as i1 to i2 is the same as i2 to i1; so we don’t worry about recalculating that distance.
* As no other nodes have been affected by swapping i1 and i2 you don’t need to recalculate any of them either as they haven’t changed and hence neither has their distances.

However if you i1 is picked to be the last element, then i2 is calculated to be the first element (i2 = (i1+1)%size). In this case you add the cost of the following removed edges and add the cost of the edges which replace them:

* The same 4 rules apply as with 2 adjacent nodes but with the small adaption of not needing to check if i1-1 is the DEPOT, as i1 is known to be the last element so it cannot be; and checking if i2+1 is the HOME as i2 is known to be the first element so it cannot be (unless of course there is only 1 location but in which case the problem of finding the shortest route would make no sense).
* In addition to those 2 new rules exist as opposed to just swapping 2 adjacent nodes we are swapping the first and the last node so there are the additional costs of what comes after the first node (the HOME) and what comes before the second node (the DEPOT).
  + When i1 and i2 are swapped the distance between i1 and the element after it (the HOME) will be removed and replaced with the distance between the element at i2 and the HOME.
  + When i1 and i2 are swapped the distance between i2 and the element before it (the DEPOT) will be removed and replaced with the distance between the element at i1 and the DEPOT.

|  |  |
| --- | --- |
| **Diagrams** | |
| 2 Adjacent Nodes | Last and First Nodes |
|  |  |

Example swaps with solution S=[L1,L2,L3,L4,L5,L6]

* Swap(L1,L2)
  + f(si+1)=f(si);
  + f(si+1)-=C(L1,Depot)+C(L2,L3);
  + f(si+1)+=C(L2,Depot)+C(L1,L3);
* Swap(L3,L4)
  + f(si+1)=f(si);
  + f(si+1)-=C(L2,L3)+C(L4,L5);
  + f(si+1)+=C(L2,L4)+C(L3,L5);
* Swap(L6,L1)
  + f(si+1)=f(si);
  + f(si+1)-=C(L1,Depot)+(L1,L2)+(L6,Home)+(L6,L5);
  + f(si+1)+=C(L6,Depot)+(L6,L2)+(L1,Home)+(L1,L5);

# My Hyper-Heuristic

## Development Process

I initially chose to pair Roulette Wheel Selection with Simulated Annealing believing the 2 would synergise well with one another due to them both encouraging exploration at the start and exploitation at the end; RWS adjusting to give better performing heuristics a greater chance at running and SA ‘cooling’ down over time, accepting less worsening moves.

I then realised that as, over a short period of time, RWS was unlikely to pick a worse solution it was actually working against SA so I switched it to a simpler, accept strictly improving moves only approach and saw the performance improve.

Due to the limitations of RWS I opted to create my own memory-based approach.  
The initial version would create a separate memory buffer for each heuristic, recording the scores from the last n times that heuristic was run then using those cumulative scores as the probability for picking each heuristic.   
This performed better than RWS but I realised it could be further improved as a heuristic could theoretically be used in an area of the search domain where it isn’t well suited and be given poor scores so it is unlikely to be picked again even if the hyper-heuristic has now moved to an area of the search domain well suited for that heuristic.  
In order to combat that I made a new version which has a single memory buffer storing pairs for the last n heuristics applied and their resulting percentage change. The probability of picking a heuristic is equal to the average percentage change it caused over the last n runs stored; and crucially if a heuristic hasn’t run in the last n runs its probability is set to 1 (meaning it is less likely to be picked than one which is known to cause an improvement but is more likely to be picked than one which is known not to). This means that all heuristics will be given a second chance if they resulted in a bad score.

## Final Version

As detailed above, my hyper-heuristic uses a memory based selection method which is an adaption of roulette wheel selection, instead of incrementing/decrementing the heuristics score if it improved/worsened; it uses the average percentage change caused by the hyper-heuristic over n moves , allowing it to make more accurate and informed choices based on the heuristics performance as well as not permanently punishing a heuristic if it performed poorly in the past.

My selection method works by maintaining a buffer of size n, storing the last n heuristic runs and their resulting percentage change. When selecting a heuristic, it uses the average score of each heuristic as the probability of picking that heuristic, and if a heuristic isn’t a buffer it is given the default probability of 1. The buffer is an ArrayList being used as a queue- when a score has been updated it is added to the ArrayList and if it’s size is now greater than n, it pops the element from the back (first in first out).  
This method allows my hyper-heuristic to adapt to the different search spaces it enters in the domain, being more likely to perform the heuristic that’s performing the best in the given search space but also giving the heuristics that haven’t performed within n moves (presumably due to them having a low score whilst they were on the buffer due to them being used in a search space that they weren’t well suited for) another chance to run as the problem may now have entered a better suited search space for that heuristic.

After experimentation with a few different acceptance methods I ended up deciding to use the Simple Acceptance of improving only as it resulted in a much better best solution at the end of each run on the larger instances.  
I believe this is because the time limit for the hyper-heuristic to run in was only 1 minute and thus the simple acceptance firstly ran quicker and so it allowed for more iterations of the hyper-heuristic, but secondly in that time it was unlikely to reach a local optima so exploitation was generally more useful than the exploration encouraged by approaches such as simulated annealing. If there was a larger problem with a longer time to run a more complex acceptance strategy may have performed better.

In the main loop, first my memory-based selection is run to pick the heuristic to run. That heuristic is then applied to the current solution and stored in the candidate solution next my memory-based selection is updated with the heuristics ID and percentage change from the currents cost to the candidates cost. After which I simply check if the candidate is a strict improvement on the current, and if it is, I accept it by copying the candidate to the current.

# Ranking Comparison

Both algorithms performed extremely similarly to one another for the small and medium problem sizes, finding results within similar ranges.  
The default heuristic marginally outperformed my one, in the small instance having a ratio of 6:3 (with 2 instances where they produced same result) and in the medium instance having a ratio of 6:5.  
In the large instance however, my algorithm performed much better- beating the default algorithm on every instance and achieving best solution costs which were roughly 20% smaller.

I believe that in the first two problem sizes that the fact the original algorithm out performed mine was likely luck of the draw as they both found very similar, near optimal solutions within a very small range of one another and that it is likely the more tests were run the closer they would get to outperforming each other at a 1:1 ratio.

# Statistical Comparison

I chose to use the Wilcoxon Signed Rank test from Social Science Statistics as it was the best fit for my data: Interval Data, the different scores for each run; Examining the difference between the costs generated for each instance by the different algorithms; Working with 2 algorithms; Using repeated measures, as each algorithm was running each respective run using the same seed for their randomness (and thus also initial solution); With two treatment conditions and also being non-parametric; I set the confidence level at 95% as specified and made it two tailed as we want the information relayed to be bi-directional as we comparing both.

The use of this tool supported my belief that the 2 algorithms were not significantly different in the small and medium problem sizes but were in the larger size.

# Conclusion

From what has been discussed above in the comparison I believe my algorithm is the better algorithm. The results of my statistical analysis give credence to the fact that there is not a significant difference in the performance of each algorithm on the small and medium sized problem but that my algorithm is significantly better in the larger problem.

However, I believe that due to the simple acceptance method used mine is likely to get stuck in a local optimum. I tested stochastic and adaptive acceptance methods and found they performed worse however I believe that is only because of the short-benchmarked time meaning it is unlikely to encounter a local optimum and thus the exploitation encouraged by the simple acceptance is much more useful than the exploration encouraged by the more complex acceptance methods as it is trying to avoid a local optimum it was unlikely to encounter nayway.