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CSE 415

The UNAIDS Initiative
Final Project Report

I.   The Teamwork

A majority of this project was done by peer programming and the both of us researched the topic to get relatively accurate data. Then we each designed and worked on our own heuristics which is evaluated the A* algorithm. However, designing the heuristics for the program, was the most difficult part, we often had to consult with one another.

II.   The Program

We chose project option 1 and the wicked problem we selected was disease prevention, specifically HIV/AIDs. From our research we found that there are eight primary regions in the world in which HIV/AIDs data is collected by: Eastern and Southern Africa, West and Central Africa, Asia and Pacific, Western and Central Europe and North America, Latin America, Easter Europe and Central Asia, Caribbean, and Middle East and North Africa. We also found that there are 3 primary actions that can be done in the fight against HIV/AIDS: research, distribution of ART (antiretroviral therapy) drugs, and education. However, with 8 regions and 2 operations that can be done on each region, there were 17 (8 regions * 2 operations + research + nothing) potential possible successor states for each state (17^d potential nodes at depth d). From running search algorithms, we found that this state space was way too big, so as a way to simplify the problem to a smaller scope, we combined regions and their statistics to give only a total of five regions. By doing this we limit the number of actions to 12. In other words, our branching factor is approximately 12.

The purpose of the program is to create a problem space and to user heuristics to find the best path to the goal state. The UNAIDS campaign defines the goal to the HIV/AIDs fight as 90-90-90: diagnose 90% of those with, treat 90% of those diagnose, and 90% of those under treatment have the disease suppressed. However, to fit the scope of this project, we chose to set the goal state in this problem as to get 90% people diagnosed treatment and to decrease the spreading factor to less than half of the spreading factor today. We utilize two heuristics to find "better" solution paths by using the A* algorithm built in Assignment 3. As defined by Rittel and Webber, a wicked problem does not have a true or false solution but rather just good and bad. In other words, our heuristics produce different solutions as a wicked problem does not have a definitive solution (which is why they are wicked!).

III. The Program Techniques

In our program, we defined the initial state by using the values we retrieved from our research (links can be referenced via citations in section X). We did this by creating two dictionaries: one that maps to the name of regions with ints and one that maps to the statistics correlated with that regions key. Then we defined the state class in the same fashion that Assignment 2 (Farmer-Fox) was made in. Each state was given attributes of the condition dictionary, current quarter, current year, yearly cost, and research information. Furthermore, the operations were generated with triples: {name, precondition_function, state_transformation_function}. The preconditions that were being checked was if the action's cost was within the yearly budget and if there was any ongoing region. If the precondition was satisfied, the state would then undergo a transformation every quarter of a year. Depending on the action, the conditions of the region selected would be affected by a specified amount. One special unique feature we added was the research. If the user chooses to do research, research would be conducted in the background for 2 years, then once the research is complete, it affects all the regions in the following quarters.

The last major programming technique we used were search algorithms and heuristics. The blind searches were almost impossible to run (took many tries and about 25 minutes when it did), and this is because of the large state space we selected (branching factor of 12). However, A* with heuristics was much faster. In our problem, the edge distance is defined as the number of quarter apart. Two heuristics were made: (1) predict the number of quarter it will take to reach the goal state and consider the differences in the spreading factors and treatment percentages with the goal state, and (2) reward for completed research cycle and takes into the account of beginning research too late in the process. Both heuristics were admissible and produced different optimal solution paths.

IV. Demo Instructions

Similar to assignments 2, users can input their operation choice by typing in a digit to the console. The program will only provide legal operations based on the current state and budget. When the user reached the goal state, the program ends. If the user wishes to find the "better" policies, the user can run A* algorithm on the problem space with a choice out of two heuristics. BFS did not work effectively simply due to the large state space.

V. Example Transcript from Interesting Sample Session

The following output is from the one BFS search done. The solution path was put into an excel file for better readability.

```
BFS "Best" Route Transcript:
Solution path:
Year: 0 Quarter: 1
$28000000000 left to invest this year
East and Southern Africa:
cases:      19600000 sf:        0.0408 deaths:      426666 treatment:      0.66
Western and Central Africa / Middle East and North Africa:
cases:       6320000 sf:        0.0713 deaths:      206933 treatment:      0.345
Asia and Pacific / Eastern Europe and Central Asia:
cases:       6600000 sf:        0.0734 deaths:      218667 treatment:      0.445
Latin America / Carribean:
cases:       2110000 sf:         0.052 deaths:       61329 treatment:      0.59
Western and Central Europe and North America
cases:       2200000 sf:        0.0318 deaths:       37351 treatment:      0.76


Year: 0 Quarter: 1
Research in progress.
$16000000000 left to invest this year
East and Southern Africa:
cases:      20399680 sf:        0.0408 deaths:      426666 treatment:      0.66
Western and Central Africa / Middle East and North Africa:
cases:       6770616 sf:        0.0713 deaths:      206933 treatment:      0.345
Asia and Pacific / Eastern Europe and Central Asia:
cases:       7084440 sf:        0.0734 deaths:      218667 treatment:      0.445
Latin America / Carribean:
cases:       2219720 sf:         0.052 deaths:       61329 treatment:      0.59
Western and Central Europe and North America
cases:       2269960 sf:        0.0318 deaths:       37351 treatment:      0.76


Year: 0 Quarter: 2
Research in progress.
$8000000000 left to invest this year
East and Southern Africa:
cases:    21065525.6 sf:       0.03264 deaths:      383999 treatment:      0.858
Western and Central Africa / Middle East and North Africa:
cases:    7253360.92 sf:        0.0713 deaths:      206933 treatment:      0.345
Asia and Pacific / Eastern Europe and Central Asia:
cases:     7604437.9 sf:        0.0734 deaths:      218667 treatment:      0.445
Latin America / Carribean:
cases:    2335145.44 sf:         0.052 deaths:       61329 treatment:      0.59
Western and Central Europe and North America
cases:    2342144.73 sf:        0.0318 deaths:       37351 treatment:      0.76


Year: 0 Quarter: 3
Research in progress.
$0 left to invest this year
East and Southern Africa:
cases:    21753104.3 sf:       0.03264 deaths:      383999 treatment:      0.858
Western and Central Africa / Middle East and North Africa:
cases:    7770525.55 sf:        0.0713 deaths:      206933 treatment:      0.345
Asia and Pacific / Eastern Europe and Central Asia:
cases:    8162603.64 sf:        0.0734 deaths:      218667 treatment:      0.445
Latin America / Carribean:
cases:       2456573 sf:         0.052 deaths:       61329 treatment:      0.59
Western and Central Europe and North America
cases:    2416624.93 sf:        0.0318 deaths:       37351 treatment:      0.76


Year: 0 Quarter: 4
Research in progress.
$28000000000 left to invest this year
East and Southern Africa:
cases:    22463125.6 sf:       0.03264 deaths:      383999 treatment:      0.858
Western and Central Africa / Middle East and North Africa:
cases:    8324564.03 sf:        0.0713 deaths:      206933 treatment:      0.345
Asia and Pacific / Eastern Europe and Central Asia:
cases:    8761738.74 sf:        0.0734 deaths:      218667 treatment:      0.445
Latin America / Carribean:
cases:     2584314.8 sf:         0.052 deaths:       61329 treatment:      0.59
Western and Central Europe and North America
cases:     2493473.6 sf:        0.0318 deaths:       37351 treatment:      0.76
```

```
Year: 1 Quarter: 1
Research in progress.
$20000000000 left to invest this year
East and Southern Africa:
cases:     23049682.8 sf:     0.026112 deaths:     345599 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:     8918105.44 sf:     0.0713 deaths:      206933 treatment:    0.345
Asia and Pacific / Eastern Europe and Central Asia:
cases:     9404850.37 sf:     0.0734 deaths:      218667 treatment:    0.445
Latin America / Carribean:
cases:     2718699.17 sf:     0.052 deaths:        61329 treatment:     0.59
Western and Central Europe and North America
cases:     2572766.06 sf:     0.0318 deaths:       37351 treatment:     0.76

Year: 1 Quarter: 2
Research in progress.
$12000000000 left to invest this year
East and Southern Africa:
cases:     23531181.4 sf:     0.0208896 deaths:    311039 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:     9553966.36 sf:     0.0713 deaths:      206933 treatment:    0.345
Asia and Pacific / Eastern Europe and Central Asia:
cases:     10095166.4 sf:     0.0734 deaths:      218667 treatment:    0.445
Latin America / Carribean:
cases:     2860071.53 sf:     0.052 deaths:        61329 treatment:     0.59
Western and Central Europe and North America
cases:     2654580.02 sf:     0.0318 deaths:       37351 treatment:     0.76

Year: 1 Quarter: 3
Research in progress.
$6000000000 left to invest this year
East and Southern Africa:
cases:     24022738.4 sf:     0.0208896 deaths:    279935 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:     9027724.34 sf:     0.04991 deaths:     206933 treatment:    0.3795
Asia and Pacific / Eastern Europe and Central Asia:
cases:     10836151.6 sf:     0.0734 deaths:      218667 treatment:    0.445
Latin America / Carribean:
cases:     3008795.24 sf:     0.052 deaths:        61329 treatment:     0.59
Western and Central Europe and North America
cases:     2738995.67 sf:     0.0318 deaths:       37351 treatment:     0.76


Year: 1 Quarter: 4
Research in progress.
$28000000000 left to invest this year
East and Southern Africa:
cases:     24524563.8 sf:     0.0208896 deaths:    279935 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:     8408813.35 sf:     0.034937 deaths:    206933 treatment:    0.41745
Asia and Pacific / Eastern Europe and Central Asia:
cases:     11631525.1 sf:     0.0734 deaths:      218667 treatment:    0.445
Latin America / Carribean:
cases:     3165252.6 sf:     0.052 deaths:         61329 treatment:     0.59
Western and Central Europe and North America
cases:     2826095.73 sf:     0.0318 deaths:       37351 treatment:     0.76

Year: 2 Quarter: 1
1 research cycle complete
$16000000000 left to invest this year
East and Southern Africa:
cases:     22487077.2 sf:     0.0188006 deaths:    223948 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:     7805892.77 sf:     0.0314433 deaths:   165546 treatment:    0.41745
Asia and Pacific / Eastern Europe and Central Asia:
cases:     11159913.3 sf:     0.06606 deaths:     174933 treatment:    0.445
Latin America / Carribean:
cases:     2982047.78 sf:     0.0468 deaths:       49063 treatment:     0.59
Western and Central Europe and North America
cases:     2616280.73 sf:     0.02862 deaths:      29880 treatment:     0.76

Year: 2 Quarter: 2
Research in progress.
$8000000000 left to invest this year
East and Southern Africa:
cases:     20580814.3 sf:     0.0169206 deaths:    161242 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:     7204231.46 sf:     0.0254691 deaths:   132436 treatment:    0.54269
Asia and Pacific / Eastern Europe and Central Asia:
cases:     10641073.3 sf:     0.059454 deaths:    125951 treatment:    0.445
Latin America / Carribean:
cases:     2796886.47 sf:     0.04212 deaths:      39250 treatment:     0.59
Western and Central Europe and North America
cases:     2415303.8 sf:     0.025758 deaths:      23904 treatment:     0.76
```

```
Year: 2 Quarter: 3
Research in progress.
$000000000 left to invest this year
East and Southern Africa:
cases:    18804806.7 sf:    0.0152285 deaths:    116094 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:    6617568.95 sf:    0.0206299 deaths:    105948 treatment:    0.70549
Asia and Pacific / Eastern Europe and Central Asia:
cases:    10089416 sf:    0.0535086 deaths:    90684 treatment:    0.445
Latin America / Carribean:
cases:    2612619.75 sf:    0.037908 deaths:    31400 treatment:    0.59
Western and Central Europe and North America
cases:    2224166.27 sf:    0.0231822 deaths:    19123 treatment:    0.76

Year: 2 Quarter: 4
Research in progress.
$28000000000 left to invest this year
East and Southern Africa:
cases:    17156285.2 sf:    0.0137057 deaths:    92875 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:    6066393.35 sf:    0.018567 deaths:    84758 treatment:    0.70549
Asia and Pacific / Eastern Europe and Central Asia:
cases:    9517769.55 sf:    0.0481577 deaths:    72547 treatment:    0.445
Latin America / Carribean:
cases:    2431579.52 sf:    0.0341172 deaths:    25120 treatment:    0.59
Western and Central Europe and North America
cases:    2043514.11 sf:    0.020864 deaths:    15298 treatment:    0.76

Year: 3 Quarter: 1
Research in progress.
$20000000000 left to invest this year
East and Southern Africa:
cases:    15631118.7 sf:    0.0123351 deaths:    74300 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:    5532741.13 sf:    0.0133682 deaths:    61025 treatment:    0.91714
Asia and Pacific / Eastern Europe and Central Asia:
cases:    8937259.55 sf:    0.043342 deaths:    58037 treatment:    0.445
Latin America / Carribean:
cases:    2255618.11 sf:    0.0307055 deaths:    20096 treatment:    0.59
Western and Central Europe and North America
cases:    1873697.73 sf:    0.0187776 deaths:    12238 treatment:    0.76


Year: 3 Quarter: 2
Research in progress.
$120000000000 left to invest this year
East and Southern Africa:
cases:    14224184.1 sf:    0.0111016 deaths:    59440 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:    5039376.91 sf:    0.0120314 deaths:    48820 treatment:    0.999
Asia and Pacific / Eastern Europe and Central Asia:
cases:    8294541.84 sf:    0.0312062 deaths:    41786 treatment:    0.5785
Latin America / Carribean:
cases:    2086156.76 sf:    0.0276349 deaths:    16076 treatment:    0.59
Western and Central Europe and North America
cases:    1714826.6 sf:    0.0168998 deaths:    9790 treatment:    0.76

Year: 3 Quarter: 3
Research in progress.
$60000000000 left to invest this year
East and Southern Africa:
cases:    12929673.6 sf:    0.0099914 deaths:    47552 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:    4584550.08 sf:    0.0108282 deaths:    39056 treatment:    0.999
Asia and Pacific / Eastern Europe and Central Asia:
cases:    6850665.59 sf:    0.0196599 deaths:    30085 treatment:    0.63635
Latin America / Carribean:
cases:    1924238.23 sf:    0.0248714 deaths:    12860 treatment:    0.59
Western and Central Europe and North America
cases:    1566817.96 sf:    0.0152098 deaths:    7832 treatment:    0.76

Year: 3 Quarter: 4
Research in progress.
$280000000000 left to invest this year
East and Southern Africa:
cases:    11741346.9 sf:    0.0089923 deaths:    38041 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:    4166305.61 sf:    0.0097454 deaths:    31244 treatment:    0.999
Asia and Pacific / Eastern Europe and Central Asia:
cases:    5617768.12 sf:    0.0123857 deaths:    21661 treatment:    0.69999
Latin America / Carribean:
cases:    1770579.86 sf:    0.0223843 deaths:    10288 treatment:    0.59
Western and Central Europe and North America
cases:    1429439.31 sf:    0.0136889 deaths:    6265 treatment:    0.76
```

```
Year: 4 Quarter: 1
2 research cycle complete
$160000000000 left to invest this year
East and Southern Africa:
cases:    10643230.9 sf:     0.0071938 deaths:       30432 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:    3778908.79 sf:     0.0077963 deaths:       24995 treatment:    0.999
Asia and Pacific / Eastern Europe and Central Asia:
cases:    5106089.09 sf:     0.0099086 deaths:       17328 treatment:  0.76998
Latin America / Carribean:
cases:    1622057.76 sf:     0.0179074 deaths:        8230 treatment:     0.59
Western and Central Europe and North America
cases:     1300583.9 sf:     0.0109511 deaths:        5012 treatment:     0.76

Year: 4 Quarter: 2
Research in Progress
$80000000000 left to invest this year
East and Southern Africa:
cases:    9634035.04 sf:     0.0057551 deaths:       24345 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:     3422230.3 sf:     0.0062371 deaths:       19996 treatment:    0.999
Asia and Pacific / Eastern Europe and Central Asia:
cases:    4624622.43 sf:     0.0063415 deaths:       13862 treatment:    0.999
Latin America / Carribean:
cases:    1480765.75 sf:     0.0143259 deaths:        6584 treatment:     0.59
Western and Central Europe and North America
cases:    1180780.33 sf:     0.0087609 deaths:        4009 treatment:     0.76

Year: 4 Quarter: 3
Research in Progress
$00000000000 left to invest this year
East and Southern Africa:
cases:    8710551.57 sf:     0.0046041 deaths:       19476 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:    3095375.45 sf:     0.0049897 deaths:       15996 treatment:    0.999
Asia and Pacific / Eastern Europe and Central Asia:
cases:    4183275.67 sf:     0.0050732 deaths:       11089 treatment:    0.999
Latin America / Carribean:
cases:    1344908.08 sf:     0.0091686 deaths:        4740 treatment:    0.767
Western and Central Europe and North America
cases:    1070150.46 sf:     0.0070087 deaths:        3207 treatment:     0.76


Year: 4 Quarter: 4
Research in Progress
$2800000000000 left to invest this year
East and Southern Africa:
cases:    7868371.17 sf:     0.0036832 deaths:       15580 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:     2796958.2 sf:     0.0039917 deaths:       12796 treatment:    0.999
Asia and Pacific / Eastern Europe and Central Asia:
cases:    3780228.37 sf:     0.0040586 deaths:        8871 treatment:    0.999
Latin America / Carribean:
cases:    1219295.54 sf:     0.0073349 deaths:        3792 treatment:    0.767
Western and Central Europe and North America
cases:    968535.668 sf:      0.005607 deaths:        2565 treatment:     0.76

Year: 5 Quarter: 1
Research in Progress
$2000000000000 left to invest this year
East and Southern Africa:
cases:    7102400.45 sf:     0.0029466 deaths:       12464 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:    2525300.96 sf:     0.0031934 deaths:       10236 treatment:    0.999
Asia and Pacific / Eastern Europe and Central Asia:
cases:    3413251.98 sf:     0.0032468 deaths:        7096 treatment:    0.999
Latin America / Carribean:
cases:    1102517.38 sf:     0.0046943 deaths:        2730 treatment:   0.9971
Western and Central Europe and North America
cases:    875592.088 sf:     0.0044856 deaths:        2052 treatment:     0.76

Year: 5 Quarter: 2
Research in Progress
$1200000000000 left to invest this year
East and Southern Africa:
cases:    6407228.48 sf:     0.0023573 deaths:        9971 treatment:    0.999
Western and Central Africa / Middle East and North Africa:
cases:    2278577.12 sf:     0.0025547 deaths:        8188 treatment:    0.999
Asia and Pacific / Eastern Europe and Central Asia:
cases:    3079906.05 sf:     0.0025975 deaths:        5676 treatment:    0.999
Latin America / Carribean:
cases:     995992.06 sf:     0.0037555 deaths:        2184 treatment:   0.9971
Western and Central Europe and North America
cases:    790295.134 sf:     0.0028708 deaths:        1477 treatment:    0.988
```

What makes this transcript interesting is that at the end, the state conditions begin to converge to the goal state even when not many actions were directed towards the region. This is because the two research cycles were completed by the fifth year. The operation, research, affects all regions each quarter on top of the operation done to a specific quarter. This was an interesting feature because the operation has a high cost and high reward as it takes two years for a research cycle to be complete and is the highest costing operation.

VI.   Selected Interesting Code

```python
def move(self, a, loc):
    news = self.copy()
    news.quarter += 1
    if news.quarter == 5:
        news.year += 1
        news.quarter = 1
    if news.quarter == 1:
        news.yearly_cost = 0
    if news.research_start > -1:
        news.research_start += 1
    if news.research_start == 8:
        news.research_start = -1
        news.rc_complete += 1
    if news.rc_complete > 0:
        for i in range(5):
            news.d[i]['deaths'] = int(self.d[i]['deaths'] * 0.8)
            news.d[i]['cases'] = int(self.d[i]['cases'] * 0.9)
            news.d[i]['sf'] = round(self.d[i]['sf'] * (1.0 - 0.1 * news.rc_complete), 4)

            if news.d[i]['sf'] > 1:
                news.d[loc]['sf'] = 0.999
```

This code dealt with storing research cycles that were in progress so that this higher risk action of initiating research could be realized with reward further down the line. For every research cycle completed, there was a larger change towards the goal state in all regions rather than just one.

VII.   Potential Future Work

In the future, this program could benefit from rolling back some of the simplifications that were made to the problem. The available actions could be more nuanced allowing for more flexibility and the cost of implementing actions could vary by region. Furthermore, we could consider more factors when evaluating the goal state as well as developing heuristics that take into account more factors. For example, we would have liked to develop a heuristic that properly rewards moving towards a completed research cycle.

VIII.   <u>What We Learned</u>

Lisa Qing

During this project, I learned the importance of state space size in blind search algorithms, and how effective heuristics have in finding solutions (good or bad). Initially, our state space was exceptionally large. The projected time to find a solution was between 4 to 10 years, and there are 4 quarters where actions could be done in a year on 5 different regions. We were only able to run BFS on the code only once as it just took way too much computing power and time. However, the heuristics had a humongous impact on finding a path in terms of computing time as it guided the program towards the goal state more.

Hari Kaushik

I learned how important it was to make sure that heuristic functions return unique enough values depending on the size of the state space. I found that it was necessary to make simplifications to the state space in order to limit it to a size that could be explored by our algorithms and an imperfect heuristic. I also learned that inadmissible heuristics often appear to come up with a reasonable solution but may break the guarantees of A*.

IX.   <u>Partnership Reflections</u>

Lisa Qing

In this project, we were able to successfully use github to contribute work to the program in separate environments. Furthermore, we were able to effectively communicate if there was anything we did not understand or had issues with. We worked together for the most part of the project towards the end as the heuristics caused a lot of trouble. However, in the end we were able to figure it out, and I was able to get good practice with git!

Hari Kaushik

I think we worked well together especially when peer programming. We were able to bounce ideas off of each other and hand off code when one or the other hit a roadblock. We also used git very effectively to work remotely and control our separate versions of the code.

X. **Citations**

1. CSE 415 Slide Decks (State Space, Heuristics, A* Algorithm, and etc.)
     Programming techniques in terms of designing a state space and how to design good, admissible heuristics.
2. https://www.avert.org/professionals/hiv-around-world/
     Regional statistics about treatment percentages.
3. https://www.avert.org/global-hiv-and-aids-statistics
     Global statistics for HIV related deaths.
4. https://www.unaids.org/sites/default/files/media_asset/UNAIDS_FactSheet_en.pdf
     Further statistics for number of new cases of HIV yearly.