Project 3: Knowledge-Based AI (CS7637)

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1 INTRODUCTION

Similar to project 2, this project is also to construct an AI agent to solve 3×3 human intelligent test problems, as Fig. 1 shows. Compared with project 2, the problems in this project are more challenging, and more advanced techniques are needed to solve those problems.

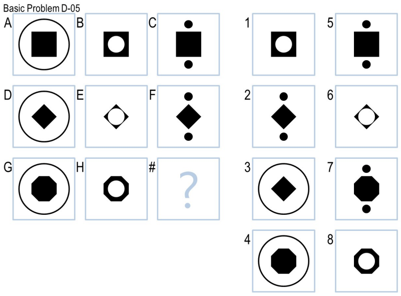

Figure 1— An 3×3 intelligence test problem example

As my project 2 agents perform pretty well and run very efficiently, **my project 3 builds on my project 2**. As a result, there is no need to re-write the rules included in project 2, such as identical, mirror and black pixel ratios. However, the rules of project 2 may be modified to generalize or specialize for problems of project 3. In addition, the basic approach used in project 2 will also be used to add new rules for project 3. **First, each figure of the problem, including the figures of the answers, is transformed into a binary matrix. Then, matrix operations are performed on the figures A to H to identify the transformation patterns both horizontally and vertically. Finally, check each answer against the identified transformation patterns to identify the correct answer.**

To start this project, the last agent of project 2 will be first run against project 3. Then, the failed problems will be investigated to see why they fail. The reason for a failed problem could be the existing rules do not cover this problem or certain existing rules are too general or too specific. Finally, the existing rules of project 2 will be generalized or specialized and new rules will be added to solve project 3 problems.

2 SUBMISSION LOG

The table below is my submission log.

Table 1 — Submission log

Submission number	Timestamp	Basic D+E Correct	Test D+E Correct	Challenge D+E Correct	Raven's D+E Correct
1	*11/16/2020 at 11:00:05PM*	17 (8+9)	17 (9+8)	10 (5+5)	12 (5+7)
2	*11/19/2020 at 12:28:46AM*	19 (10+9)	18 (10+8)	9 (4+5)	14 (7+7)
3	*11/20/2020 at 11:09:37PM*	20 (10+10)	18 (10+8)	9 (4+5)	14 (7+7)
4	*11/21/2020 at 11:57:55PM*	22 (10+12)	20 (10+10)	9 (4+5)	15 (7+8)
5	*11/22/2020 at 11:25:02PM*	23 (11+12)	22 (12+10)	11 (6+5)	16 (8+8)
6	*11/23/2020 at 9:57:49PM*	24 (12+12)	22 (12+10)	12 (6+6)	15 (7+8)
7	*11/26/2020 at 1:21:18PM*	24 (12+12)	23 (12+11)	12 (6+6)	13 (7+6)
8	*11/26/2020 at 11:10:51PM*	24 (12+12)	23 (12+11)	13 (7+6)	14 (8+6)

3 REFLECTION OF EACH SUBMISSION

3.1 Reflection of submission 1

3.1.1 *When was this submission sent in?*

This submission is sent in at 11:00:05PM of 11/16/2020.

3.1.2 *Design of this agent*

As mentioned in the introduction, the last agent of project 2 was first run against problem 3 problems. Be checking the failed problems, I found several simple problems in problem E failed, which are basic problem E-02, basic problem E-05, basic problem E-08 and basic problem E-11. With further investigation, I found those problems are not covered by current rules. So the following rules are added to solve those problems.

1) **One figure of each row or each column is the OR of the other two figures, i.e., the adding of the other two figures of that row or that column.** For example, in basic problem E-02, figure C equals figure A+ figure B, figure F equals figure D + figure E, figure G equals figure A + figure D, and figure H equals figure B + figure E.
2) **One figure of each row or each column is the subtraction of the other two figures of that row or that column.** For example, in basic problem E-05, figure C equals figure A–figure B, figure F equals figure D–figure E, figure G equals figure A–figure D, and figure H equals figure B–figure E.
3) **One figure of each row or each column is the XOR of the other two figures of that row or that column.** For example, in basic problem E-08, figure C equals the XOR of figure A and figure B, figure F equals the XOR of figure D and figure E, figure G equals the XOR of figure A and figure D, and figure H equals the XOR of figure B and figure E.
4) **One figure of each row or each column is the AND of the other two figures of that row or that column.** For example, in basic problem E-11, figure C equals the AND of figure A and figure B, figure F equals the AND of figure D and figure E, figure G equals the AND of figure A and figure D, and figure H equals the AND of figure B and figure E.

Those rules are all implemented on matrix operations, such as *numpy.logical_and*, *numpy.logical_xor* and *numpy.logical_or*. One thing needs to be pointed out that in the above discussion, "equal" does not mean exactly the same. There are always small errors such as edge misalignment. There are thresholds in the program to determine if the results are "equal".

3.1.3 *How would you compare this version of the agent to the way you feel you approach the problems? Does it think similarly to how you think, or differently?*

As a human, I would also solve the target problems of this agent in a similar way. First, I would also identify the transformation pattern from the perspectives of subtraction, addition, XOR and AND. Based on the identified transformation pattern, I would then find the answer that best matches the identified transformation.

However, one difference I noticed between human beings and the agent is we can focus on the overall pictures of the problems while the agent needs very precise and accurate rules in order to solve the problems. I actually adjusted some thresholds several times in order to correctly solve the target problems.

3.1.4 *How did it perform? What problems or types of problems did it do well on? Where did it struggle? How is its efficiency?*

Overall, the agent performed pretty well. It solved 17 basic problems (8 for set D and 9 for set E), 17 test problems (9 for set D and 8 for set E), 10 challenge problems (5 for set D and 5 for set E) and 12 Ravens problems (5 for set D and 7 for set E). More importantly, this agent correctly solved the target problems, i.e. basic problem E-02, basic problem E-05, basic problem E-08 and basic problem E-11.

I think the agent mainly struggled with problems that are not covered by any rules. However, I also believe some rules need to be generalized or specialized for problems of project 3.

The run time of this agent was 3.18 seconds to solve the total 96 problems, which is pretty efficient. The reason behind this is mainly matrix operations were performed and no pixel by pixel comparison was performed.

3.2 Reflection of submission 2

3.2.1 *When was this submission sent in?*

This submission is sent in at 12:28:46AM of 11/19/2020.

3.2.2 *What did you change for this version? Why?*

This version mainly targeted basic problem D-06 and basic problem D-09. For basic problem D-06, the summary of each column is the same. For basic problem D-09, the summary of each row of each column is the same and the summary of each column is also the same. So, one rule is added on that the summary of each row or the summary of each column is the same. This is implemented based on a rule of project 2, where only the total black pixels are compared. In addition, I also adjusted the threshold of AND rule, which is targeted for basic problem E-11 and is mentioned in 3.1.2, to exclude basic problem D-06 from this rule.

3.2.3 *How would you compare this version of the agent to the way you feel you approach the problems? Does it think similarly to how you think, or differently?*

I would also use the summary of each row or each column to identify the transformation pattern. So I would say this agent solved the problems in a similar way as I approach the problems. However, as a human, I would also use other characteristics of the figures to solve the problems. For example, I would also identify the shapes in the figures and use the shape information to help me find the correct answers. There are probably algorithms to make AI agent to identify shapes. But currently, my AI agent is only identifying the correct answer based on the matrix of the whole figure and there is no shape identification. This is one difference between the AI agent and human beings.

3.2.4 *How did it perform? What problems or types of problems did it do well on? Where did it struggle? How is its efficiency?*

As expected, this agent correctly solved the basic problem D-06 and basic problem D-09. In addition, it solved one more test problem and 2 more Ravens problems correctly. However, it solved one less challenge problem.

Overall, the agent struggled on problems that are not covered by current rules and struggled on how to correctly use its current rules. Moving forward, new rules and generalizations and specializations of current rules are needed to solve the rest of the problems.

This agent took about 3.32 seconds to solve all the problems, which is almost the same as that of the last agent and seems reasonable.

3.3 Reflection of submission 3

3.3.1 *When was this submission sent in?*

This submission is sent in at 11:09:37PM of 11/20/2020.

3.3.2 *What did you change for this version? Why?*

This version mainly targeted the basic problem E-09. Based on figure A, figure B and figure C, it can be seen that figure C is the combination of the top half of figure A and the bottom half of figure B. The same transformation pattern can be found in each row and each column. So a new rule is added to identify this kind of transformation pattern. Then, based on the transformation pattern, the correct answer can be found.

3.3.3 *How would you compare this version of the agent to the way you feel you approach the problems? Does it think similarly to how you think, or differently?*

This agent solves the basic problem E-09 as how I would approach the problems. I also first identify the transformation pattern, i.e. one figure in each row or each column is the combination of the top half and the bottom half of the other two figures. Then, I would use this transformation pattern to identify the correct answer. This is how I implement the agent. Similar as before, the agent needs a clear threshold to identify this kind of transformation while I can focus on the overall picture and ignore some details, such as edge in-alignment. This is one difference between how the agent and I solve the basic problem E-09.

3.3.4 *How did it perform? What problems or types of problems did it do well on? Where did it struggle? How is its efficiency?*

As expected, the agent correctly solved the problem E-09. But apart from this problem, it did not solve any additional problem. This is probably due to the fact that this rule can only apply to this problem. The test problem E-09 had already been solved with another rule in the previous agent.

This agent took about 4.3 seconds to solve all the problems, which is slightly longer than that of the previous version and is within a reasonable range. Overall, the agent still solved the problems very efficiently due to the fact that only matrix operations are performed

3.4 Reflection of submission 4

3.4.1 *When was this submission sent in?*

This submission is sent in at 11:57:55PM of 11/21/2020.

3.4.2 *What did you change for this version? Why?*

This submission mainly targeted basic problem E-04. To solve this problem, two rules are added. First, the total number of the black pixel of the first figure of each row or each column is equal to the summary of the total number of the black pixel of the other two figures of that row or that column. With this rule, only answer 2 and answer 8 are left. The second rule is that the averaged coordinate of dark pixels (summary of black pixel coordinates over the total pixels) is equal to the summary of the averaged coordinates of dark pixel of the other two figures either along vertical direction or along horizontal directions. With this rule, answer 8 can be identified as the correct answer.

3.4.3 *How would you compare this version of the agent to the way you feel you approach the problems? Does it think similarly to how you think, or differently?*

This agent solved this problem in a different way as how I would approach this problem. For example, as I human, I can easily identify that figure A is the combination of figure B and figure C. However, since there are edge in-alignments in either vertical or horizontal directions, figure A does not directly equal the summary of figure B and figure C. The two rules mentioned above seems an easier way for AI agents compare to the way I solve this problem. So the relationships of the total black pixels and the averaged coordinate of dark pixels are implemented to solve this problem.

3.4.4 *How did it perform? What problems or types of problems did it do well on? Where did it struggle? How is its efficiency?*

This agent correctly solved basic problem E-04 and test problem E-08. Interestingly, it also correctly solved basic problem E-12 and test problem E-12. This is because the first rule can apply to basic problem E-12 and the second rule excluded answer 7 while answer 6 is within the threshold of the second rule. So this agent solved two additional basic problems and two additional test problems. In addition, it also solved one additional Ravens Problem.

It took about 3.5 seconds for the agent to solve all the problems, which is shorter than that of the previous agent. This is probably due to the inaccuracy of the run time calculation or the differences of the available computation resources at the times of these submissions.

3.5 Reflection of submission 5

3.5.1 *When was this submission sent in?*

This submission is sent in at 11:25:02PM of 11/22/2020.

3.5.2 *What did you change for this version? Why?*

This submission mainly targeted the basic problem D-12. From figure A to figure H, it can be seen the black pixel ratio of figure A, figure F, and figure H is 3:4:5, and the black pixel ratio of figure E, figure G and figure C is 3:4:5. Therefore, it is expected that the black pixel ratio of the correct answer, figure B and figure D is 3:4:5. This transformation pattern was added as a new rule to solve the basic problem D-12.

3.5.3 *How would you compare this version of the agent to the way you feel you approach the problems? Does it think similarly to how you think, or differently?*

This agent solved the basic problem D-12 differently to how I would approach the basic problem D-12. As a human, I would identify each row and each column has to include square, star, and triangle; and the numbers of shapes in each row and each column has to include 3, 4 and 5. These two rules can help me identify the correct answer. However, these rules are hard to implement since they need shape identifications.

3.5.4 *How did it perform? What problems or types of problems did it do well on? Where did it struggle? How is its efficiency?*

This problem correctly solved basic problem D-12 and the test problem D-12. In addition, it correctly solved one more test problem, two additional challenge problems and one additional Ravens problem. Overall, the agent works pretty well, especially considering there is no shape identification involved.

It took about 3.48 seconds for the agent to solve all the problems, which is almost the same as the last agent. Overall, the agent runs very efficiently.

3.6 Reflection of submission 6

3.6.1 *When was this submission sent in?*

This submission is sent in at 9:57:49PM of 11/23/2020.

3.6.2 *What did you change for this version? Why?*

This submission mainly targeted the basic problem D-8. First, a diagonal line is drawn in each figure. It is then found that in the drawn lines, the transition times from black to white or from white to black of figure A equal to that of figure E; the transition times of figure B, figure F and figure G are the same; the transition times of figure C, figure D and figure H are the same. So it is expected that the transition time of the correct answer equals to that of figure A and figure E. This is the first rule added. With this rule, answer 2 and answer 4 are possible answers. Then, it is found in the drawn lines, the distance from the first black pixel to the last black pixel of figure A and figure F are the same, and the distance of figure E and figure G are the same. So, it is expected in the diagonal lines, the distance from the first black pixel to the last black pixel of figure B and that of the correct answer are the same. This is the second rule implemented. With those two rules, answer 4 can be identified as the correct answer.

3.6.3 *How would you compare this version of the agent to the way you feel you approach the problems? Does it think similarly to how you think, or differently?*

This agent solved the basic problem D-08 in a different way to how I solve this problem. Instead of just based on the information of the diagonal lines, I would probably solve the problem by identifying the shapes in the figures and extracting the characteristic of the shapes. However, shape identifications and shape characteristics extraction are hard to implement. So, the rules based on the diagonal lines are implemented to solve the problem.

3.6.4 *How did it perform? What problems or types of problems did it do well on? Where did it struggle? How is its efficiency?*

This problem correctly solved basic problem D-08. Test problem D-08 has been solved by other rules in the last agent. In addition, it correctly solved one more challenge problem. However, it solved one less Ravens problem, which means the implemented rules need to be specified for some problems.

It took about 3.3 seconds for the agent to solve all the problems, which is slightly less than that of the last agent and is reasonable.

3.7 Reflection of submission 7

3.7.1 *When was this submission sent in?*

This submission is sent in at 1:21:18PM of 11/26/2020.

3.7.2 *What did you change for this version? Why?*

This submission mainly targeted the failed test problem E-07. Basic problem E07 was solved with the XOR rule design in 3.1.2, i.e. the last figure in each row or each column is the XOR of the other two figures. Since I do not have access to test problems, I can only guess what may happen. I changed two things to solve test problems E-07. First, I changed the figure comparison threshold in the XOR rule to make this rule apply to test problem E-07, which should be similar to the basic problem E-07. Second, not only the last figure in each row or each column is the XOR of the other two figures, any figure in each row or column is the XOR of the other two figures. So I extend this rule to all the figures in each row or column to make sure this rule can be applied to problems it should be used.

3.7.3 *How would you compare this version of the agent to the way you feel you approach the problems? Does it think similarly to how you think, or differently?*

This agent solved this kind of problem in a similar way as how I would approach this kind of problem. For example, for basic problem E-07, I also first identify the transformation pattern that each figure in each row or each column is the XOR of the other two figures. Then, based on this rule, I can find the correct answer. However, one difference is I mainly focus on the overall picture while the AI agent needs a clear threshold and explicit comparison method for the XOR check. For example, the AI agent compares two figures based on their corresponding matrices, i.e. pixels at the same locations will be compared. As a result, figure edge in-alignments or small shifts will introduce errors.

3.7.4 *How did it perform? What problems or types of problems did it do well on? Where did it struggle? How is its efficiency?*

This problem did correctly solve the test problem E-07. However, it solved two less Ravens problems. Overall, the agent performed well on my targeted problems. But its performance is limited for new problems and it could not solve problems that current rules cannot cover.

It took about 4.76 seconds for the agent to solve all the problems, which is slightly longer than that of the last agent. This is probably due to the additional comparisons added

3.8 Reflection of submission 8

3.8.1 *When was this submission sent in?*

This submission is sent in at 11:10:51PM of 11/26/2020.

3.8.2 *What did you change for this version? Why?*

This submission mainly targeted the test problem E-10. For basic problem E-10, the AND rule in 3.1.2 can solve it, i.e., the last figure of each rule or each column is the AND of the other two figures. To solve test problem E-10, I moved the location of the AND rule forward. This is to avoid that inappropriate rules are applied to test problem E-10 before the AND rule.

3.8.3 *How would you compare this version of the agent to the way you feel you approach the problems? Does it think similarly to how you think, or differently?*

I think the agent solved this kind of problem in a similar way as how I approach the problems. It first identifies the AND transformation and then selects the correct answer based on this rule. But again, the agent needs precise information, explicit threshold and comparison method to solve the problem.

3.8.4 *How did it perform? What problems or types of problems did it do well on? Where did it struggle? How is its efficiency?*

Unfortunately, the agent did not correctly solve the test problem E-10 even though it solved one additional challenging problem and one additional Ravens problem. I guess the reason for the failed test problem E-10 can be incorrect threshold, incorrect comparison method or the figure relationship of test problem E-10 is slightly different as that of based problem E-10.

It took about 8.4 seconds for the agent to solve all the problems, which is longer than that of the last agent and is probably due to the location move of the AND rule. But overall, the agent is pretty efficient since only matrix operations are involved and there is no pixel to pixel comparison.

4 CONCLUSION

4.1 How would you characterize the process of designing your agent? Trial-and-error? Deliberate improvement? Targeting one type of problem at a time?

Building on project 2, the overall process of designing the agent is **targeting one type of problem at a time.** This is like an incremental learning process for the agent. From each submission, there are one or several new rules added for the agent to solve certain types of problems. However, **trial and error** is also used to adjust thresholds, generalizations and specifications to make sure the rules can be correctly used.

4.2 How similar do you feel your final agent is to how you, a human, would approach the test? Why and why not?

The overall process of the agent is quite similar to how I approach the problems. First, the transformation patterns are identified. Then, the correct answer is selected based on the identified transformation patterns.

However, there are indeed some differences between the agent and a human, which mainly includes:

1) The agent needs accurate threshold and clear rules to solve problems while I mainly focus on the overall picture of the figures or the problems.
2) Some problems are pretty simple for me, but they may be hard for the agent. For example, shape identifications are pretty easy for me which is mainly because I have a lot of background knowledge.
3) The agent can only solve problems based on existing rules designed while I can create new rules and use the existing rules more adaptively, such as slightly modify the rules based on problems observed.

4.3 What improvements would you make if you had more time and/or more computational resources?

With more time and more computational resources, I would work on **shape and shape characteristic identifications,** such as triangle, square, solid, big or small. This would open opportunities for many new rules. In addition, **other rules may also be added** and **existing rules may be improved** to address some of the failed problems. But since my final agent can already solve nearly all the basic and test problems, I did not include those improvements.