CSE140-W2025: Introduction to Intelligent Systems
Mid-sem

Date: 25/02/2025 **Total Time:** 1 hour **Total Marks:** 20 Marks

Instructions

- Attempt all questions.
- State any assumptions you have made clearly.
- Standard institute plagiarism policy holds.
- No evaluations without suitable justifications.

Q 1: Are reflex actions **(such as flinching from a hot stove)** rational? Are they intelligent? **1 Mark**

Answer: Reflex actions, like flinching from a hot stove, are not rational or intelligent in the traditional sense. They are automatic, involuntary responses to stimuli, designed to protect the body from harm. These responses occur without conscious thought or decision-making.

0.5 marks are given for rational and 0.5 for intelligent

Q 2: A hospital is developing an AI system to detect cancer in patients based on medical images. The system uses a machine learning model that classifies whether a patient has cancer (Positive) or does not have cancer (Negative) based on X-ray scans. If the hospital prioritizes minimizing false negatives (i.e., they want to ensure that no cancer case is missed), which model should they choose and explain why using appropriate metrics and it's calculation?

1 Mark

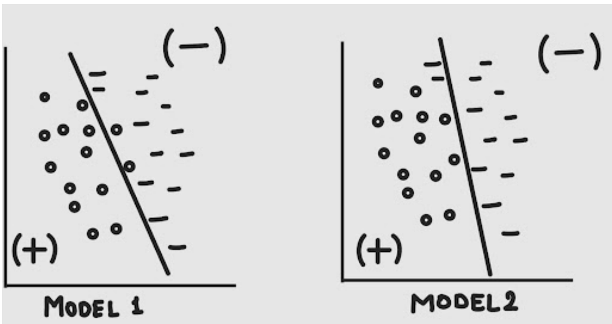

Figure 1: (o) - actual cancer , (-) non cancer

X	1	3	5	7
Y_actual	5.5	8.9	12	17.3

Figure 2: Data values for X and Y_actual

Answer: Minimizing false negatives is crucial. Recall is the appropriate evaluation metric to check which model has lower false negatives. The formula for recall is:

$$\text{Recall} = \frac{\text{TP}}{\text{TP} + \text{FN}}$$

Recall for Model 1:

$$\text{Recall}_1 = \frac{12}{12+2} = \frac{6}{7}$$

Recall for Model 2:

$$\text{Recall}_2 = \frac{14}{14} = 1$$

Model 1 has a low recall rate, whereas Model 2 has a high recall rate. Therefore, the hospital will adopt Model 2 for its higher accuracy in detecting true positives.

0.5 marks are given for calculation and 0.5 for correct model

Q 3: As we all know, loss is associated with cost, and that's why we try to minimize the MSE loss. Given a linear regression problem (a supervised learning), we aim to find the best-fitting equation for the given data points given in **Figure 2** above.Which of the three models would be the best fit? Will the choice of model change if we use the Mean Absolute Error (MAE) loss function? **2 Marks**

(a) Model 1: Y = 2x+3 (b) Model 2: Y = X - 2 (c) Model 3: Y = -3X-4

Answer: The models provided are evaluated based on both MSE and MAE loss functions given the data points $X = [1, 3, 5, 7]$ and $Y_{\text{actual}} = [5.5, 8.9, 12, 17.3]$:

- Model 1: $Y = 2X + 3$
- Model 2: $Y = X - 2$
- Model 3: $Y = -3X - 4$

We predict the values for each model and calculate the MSE and MAE:

Model 1 Predictions:

$$X = 1 \to Y = 5$$
$$X = 3 \to Y = 9$$
$$X = 5 \to Y = 13$$
$$X = 7 \to Y = 17$$

Model 2 Predictions:

$$X = 1 \to Y = -1$$
$$X = 3 \to Y = 1$$
$$X = 5 \to Y = 3$$
$$X = 7 \to Y = 5$$

Model 3 Predictions:

$$X = 1 \to Y = -7$$
$$X = 3 \to Y = -13$$
$$X = 5 \to Y = -19$$
$$X = 7 \to Y = -25$$

MSE and MAE Computations for Model 1:

$$\text{MSE} = \frac{1}{4}\left((5 - 5.5)^2 + (9 - 8.9)^2 + (13 - 12)^2 + (17 - 17.3)^2\right)$$
$$\text{MAE} = \frac{1}{4}\left(|5 - 5.5| + |9 - 8.9| + |13 - 12| + |17 - 17.3|\right)$$

Given the data points $X = [1, 3, 5, 7]$ and $Y_{\text{actual}} = [5.5, 8.9, 12, 17.3]$, the predictions and errors for each model are calculated as follows:

Model 1 Predictions:

$$X = 1 \to Y = 5$$
$$X = 3 \to Y = 9$$
$$X = 5 \to Y = 13$$
$$X = 7 \to Y = 17$$

Model 2 Predictions:

$$X = 1 \to Y = -1$$
$$X = 3 \to Y = 1$$
$$X = 5 \to Y = 3$$
$$X = 7 \to Y = 5$$

Model 3 Predictions:

$$X = 1 \to Y = -7$$
$$X = 3 \to Y = -13$$
$$X = 5 \to Y = -19$$
$$X = 7 \to Y = -25$$

MSE and MAE Computations:

Model 1:

$$\text{MSE} = \frac{1}{4}\left((5-5.5)^2 + (9-8.9)^2 + (13-12)^2 + (17-17.3)^2\right) = \text{calculated value}$$
$$\text{MAE} = \frac{1}{4}\left(|5-5.5| + |9-8.9| + |13-12| + |17-17.3|\right) = \text{calculated value}$$

Model 2:

$$\text{MSE} = \frac{1}{4}\left((-1-5.5)^2 + (1-8.9)^2 + (3-12)^2 + (5-17.3)^2\right) = 84.34$$
$$\text{MAE} = \frac{1}{4}\left(|-1-5.5| + |1-8.9| + |3-12| + |5-17.3|\right) = 8.93$$

Model 3:

$$\text{MSE} = \frac{1}{4}\left((-7-5.5)^2 + (-13-8.9)^2 + (-19-12)^2 + (-25-17.3)^2\right) = 846.04$$
$$\text{MAE} = \frac{1}{4}\left(|-7-5.5| + |-13-8.9| + |-19-12| + |-25-17.3|\right) = 26.93$$

Based on the calculated MSE and MAE, Model 1 is the best fit for both loss functions as it consistently provides the lowest error values.
0.5 for prediction and 0.75 for MSE and 0.75 for MAE.
Marks are given if predictions, MAE and MSE values are calculated correctly for any one Model.

Q 4: Write down logical representations for the following sentences, suitable for use with Generalized Modus Ponens,written in First-Order Logic (FOL)::

(a) Horses, cows, and pigs are mammals.
(b) An offspring of a horse is a horse.
(c) Bluebeard is Charlie's parent.
(d) Every mammal has a parent. **2 Marks**

Answer:

(a) $\text{Horse}(x) \Rightarrow \text{Mammal}(x)$
$\text{Cow(x)} \Rightarrow Mammal(x)$
$Pig(x) \Rightarrow Mammal(x)$.

(b) $\text{Offspring(x, y)} \wedge Horse(y) \Rightarrow Horse(x)$.

(c) Parent(Bluebeard, Charlie).

(d) $\text{Mammal(x)} \Rightarrow Parent(G(x), x)$ (here G is a Skolem function).

Q 5: For each of the following scenarios, give reasons how machine learning techniques can be applied. If machine learning is not suitable, explain why.
0.5 marks are given for each answer if only correct answer is given with proper justification

(a) A retail store wants to apply discounts based on customer purchases as follows:
- 10% discount for purchases up to \$100
- 20% discount for purchases between \$100 and \$500
- 30% discount for purchases above \$500

Answer: Machine learning is not suitable here because the discount policy is explicitly defined by simple rules that do not require any pattern recognition or prediction capabilities which machine learning provides.

(b) A movie streaming platform wants to recommend movies to users. However, most users have rated only one or two movies, and the available data contains inconsistent ratings and missing user demographics.
Answer: Machine learning should not be applied. The sparse and inconsistent data can lead to poor recommendation quality.

(c) An autonomous driving system needs to detect pedestrians in real-time to avoid collisions. A single misclassification (failing to detect a pedestrian) could lead to fatal accidents.
Answer: Machine learning can be applied for real-time detection tasks in autonomous driving. However, the high stakes of potential misclassification require very reliable and extensively tested models, possibly augmented by additional safety mechanisms or redundant systems.
Marks are given if the Supervised or Reinforcement technique is mentioned with proper justification.

(d) An insurance company uses a deep neural network to assess customer claims for fraud detection. Although the model shows high accuracy, it cannot explain the reasons behind labeling some legitimate claims as fraudulent, leading to customer dissatisfaction.
Answer: Machine learning, particularly deep learning, is suitable for detecting patterns of fraud but suffers from a lack of explainability. Alternative approaches like decision trees or the integration of explainable AI (XAI) techniques might be necessary to provide transparency and improve customer satisfaction.
Marks are given if Machine learning technique is mentioned with proper justification

Q 6: Consider the following statements about self-awareness and Large Language Models (LLMs) like GPT-4. For each statement, indicate whether it is True (T) or False (F) and provide a brief justification for your answer (1-2 sentences).

(a) The mirror test is a definitive measure of self-awareness in all organisms, including AI systems.

(b) LLMs like GPT-4 can recognize patterns in text that refer to themselves, but this does not imply self-awareness.

(c) If an LLM generates a response that seems to "recognize" itself, it has passed a digital version of the mirror test.

(d) The mirror test is based on visual recognition, which is not applicable to LLMs since they lack sensory perception. **2 marks**

Answer : 0.5 marks are given for each answer only if correct answer is given with proper justification

- **False** The mirror test is not a definitive measure of self-awareness for all organisms, especially AI systems. It is designed for animals with sensory perception and does not account for non-biological entities like LLMs.
- **True** LLMs can recognize patterns in text, including text that refers to themselves, but this is based on statistical pattern recognition, not self-awareness.
- **False** Generating a response that seems to "recognize" itself is not equivalent to passing the mirror test. The mirror test requires conscious self-recognition, which LLMs cannot achieve.
- **True** The mirror test relies on visual recognition, which is not applicable to LLMs since they do not have sensory perception or the ability to interact with visual stimuli.

Q 7: You are preprocessing text data for a topic modelling task. The text data contains the following paragraph:

> "Last Monday, Dr. Smith from Google watched a quick brown fox jump over her lazy dog near Central Park. The dog calmly observed the visitor at 3 PM, and they became friends. Now the fox and the dog meet every Friday to chase 5 butterflies!"

Perform the following preprocessing steps:
Note: Convert the text to lowercase before applying the Preprocessing steps.

(a) Perform tokenization. **1 Mark**

(b) Remove stop words and punctuation. **1 Mark**

(c) Perform POS (Part-of-Speech) tagging. **1 Mark**
Use the following common POS tags as a reference:
i. **NN**: Noun (singular) ii. **NNS**: Noun (plural) iii. **JJ**: Adjective iv. **VB**: Verb (base form) v. **VBD**: Verb (past tense) vi. **VBZ**: Verb (third-person singular present) vii. **DT**: Determiner viii. **IN**: Preposition ix. **PRP**: Personal pronoun x. **RB**: Adverb

(d) Perform Named Entity Recognition (NER). **1 Mark**
Use the following common NER tags as a reference:
i. **PERSON**: People, including fictional characters ii. **ORG**: Companies, agencies, institutions iii. **LOC**: Non-GPE locations, mountain ranges, water bodies iv. **GPE**: Countries, cities, states v. **TIME**: Times smaller than a day vi. **DATE**: Absolute or relative dates vii. **CARDINAL**: Numerals not falling under another type viii. **ANIMAL**: Living creatures (not human)

Answer :

- **Tokenization: (1 marks)** [MARKS = CORRECT TERMS/ TOTAL TERMS] ["last", "monday", "dr.", "smith", "from", "google", "watched", "a", "quick", "brown", "fox", "jump", "over", "her", "lazy", "dog", "near", "central", "park", ".", "the", "dog", "calmly", "observed", "the", "visitor", "at", "3", "pm", "," "and", "they", "became", "friends", ".", "now", "the", "fox", "and", "the", "dog", "meet", "every", "friday", "to", "chase", "5", "butterflies", "!"]
- **After Stop Words and Punctuation: (1 marks)** [MARKS = CORRECT TERMS/ TOTAL TERMS] ["monday", "dr", "smith", "google", "watched", "quick", "brown", "fox", "jump", "lazy", "dog", "central", "park", "calmly", "observed", "visitor", "3", "pm", "friends", "fox", "dog", "meet", "friday", "chase", "5", "butterflies"]

- **POS Tags: (1 marks)** **[MARKS = CORRECT TERMS/ TOTAL TERMS(=16)]**
  - Nouns (NN): fox, dog, park, visitor, Monday, Smith, Google, Central Park, Friday
  - Proper Nouns (NNS): butterflies
  - Adjectives (JJ): quick, brown, lazy
  - Verbs (VBD): watched, observed, became
- **NER Tags: (1 marks)** **[MARKS = CORRECTLY TAGGED TERMS/ TOTAL TERMS(=10)]**
  - DATE: Monday, Friday
  - PERSON: Dr. Smith
  - ORG: Google
  - LOC: Central Park
  - TIME: 3 PM
  - ANIMAL: fox, dog, butterflies
  - CARDINAL: 5

Q 8: (a) Provide the mathematical equation for performing a 2D convolution operation between an input matrix I and a kernel (or filter) K . Explain how each element of the output matrix is computed by applying the kernel to the input matrix. Assume that both the input matrix and the kernel are square matrices of size $n \times n$ and $k \times k$ respectively . **1 Mark**

(b) Following the mathematical equation you provided, write the pseudocode for implementing the 2D convolution operation. Assume that the input matrix I and the kernel K are given as two-dimensional lists, and the output should be stored in a matrix O. Include handling for zero-padding the input matrix to maintain the size of the output matrix equal to the input matrix size. **1 + 1 Marks**

Answer

(a) Mathematical Equation for 2D Convolution

The 2D convolution operation between an input matrix I of size $n \times m$ and a kernel K of size $k \times k$ is given by:

$$O(i, j) = \sum_{p=0}^{k-1} \sum_{q=0}^{k-1} I(i + p, j + q) \times K(p, q)$$

Where:

- $O(i, j)$ is the output matrix element at position (i, j).
- $I(i + p, j + q)$ represents the corresponding element of the input matrix.
- $K(p, q)$ represents the corresponding element of the kernel.
- n and m are the number of rows and columns of the input matrix, respectively.
- k is the dimension of the (square) kernel.

(b) Pseudocode for 2D Convolution with Zero-Padding

The following pseudocode describes how to implement a 2D convolution operation with zero-padding to ensure that the output matrix size matches the input matrix size $n \times m$:

Listing 1: Pseudocode for 2D Convolution with Zero-Padding (n x m input)

```
def convolution_2d(input_matrix, kernel):
    # Get dimensions of the input and kernel
    n = len(input_matrix)           # Number of rows in input
    m = len(input_matrix[0])        # Number of columns in input
    k = len(kernel)                 # Assuming square kernel (k x k)

    # Calculate padding size
    pad = k // 2

    # Initialize the output matrix with zeros
    output_matrix = [[0 for _ in range(m)] for _ in range(n)]

    # Apply zero-padding to the input matrix
    padded_matrix = [[0 for _ in range(m + 2 * pad)] for _ in range(n + 2 * pad)]
    for i in range(n):
        for j in range(m):
```

```python
            padded_matrix[i + pad][j + pad] = input_matrix[i][j]

    # Perform the convolution operation
    for i in range(n):
        for j in range(m):
            sum = 0
            for p in range(k):
                for q in range(k):
                    sum += padded_matrix[i + p][j + q] * kernel[p][q]
            output_matrix[i][j] = sum

    return output_matrix
```

1 for correct logic
1 for correctly padding the input matrix

Q 9: You apply a 3×3 filter to an image region with the following pixel values:

$$\text{Image Region: } \begin{bmatrix} 138 & 135 & 77 & 107 \\ 133 & 120 & 79 & 106 \\ 128 & 87 & 84 & 104 \\ 139 & 85 & 108 & 100 \end{bmatrix} \quad \text{Filter: } \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

(a) Apply the given kernel to the image. What is the resulting output? Provide detailed steps to compute the output and explain the results obtained. **1 Mark**

(b) Perform a max pooling operation on the resulting output obtained from the convolution operation in part (a). Use a pooling size of 2x2. **1 Mark**

(c) Based on the output obtained from the previous steps, what inferences can you draw about potential applications for this type of filter? Discuss its utility in specific image processing or analysis tasks.

1 Mark

Answer:

(a) Applying the Kernel to the Image

Given Image Region:

$$\begin{bmatrix} 138 & 135 & 77 & 107 \\ 133 & 120 & 79 & 106 \\ 128 & 87 & 84 & 104 \\ 139 & 85 & 108 & 100 \end{bmatrix}$$

Given Filter (Kernel):

$$\begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$$

Step-by-Step Convolution Calculation:

1. **Top-left 3x3 region:**

$$\begin{bmatrix} 138 & 135 & 77 \\ 133 & 120 & 79 \\ 128 & 87 & 84 \end{bmatrix}$$

$$O(1,1) = (1 \times 138) + (0 \times 135) + (-1 \times 77) + (2 \times 133) + (0 \times 120) + (-2 \times 79) + (1 \times 128) + (0 \times 87) + (-1 \times 84)$$

$$O(1,1) = 138 - 77 + 266 - 158 + 128 - 84 = 213$$

2. **Top-right 3x3 region:**

$$\begin{bmatrix} 135 & 77 & 107 \\ 120 & 79 & 106 \\ 87 & 84 & 104 \end{bmatrix}$$

$$O(1,2) = (1 \times 135) + (0 \times 77) + (-1 \times 107) + (2 \times 120) + (0 \times 79) + (-2 \times 106) + (1 \times 87) + (0 \times 84) + (-1 \times 104)$$

$$O(1,2) = 135 - 107 + 240 - 212 + 87 - 104 = 39$$

3. **Bottom-left 3x3 region:**

$$\begin{bmatrix} 133 & 120 & 79 \\ 128 & 87 & 84 \\ 139 & 85 & 108 \end{bmatrix}$$

$$O(2,1) = (1 \times 133) + (0 \times 120) + (-1 \times 79) + (2 \times 128) + (0 \times 87) + (-2 \times 84) + (1 \times 139) + (0 \times 85) + (-1 \times 108)$$

$$O(2,1) = 133 - 79 + 256 - 168 + 139 - 108 = 173$$

4. **Bottom-right 3x3 region:**

$$\begin{bmatrix} 120 & 79 & 106 \\ 87 & 84 & 104 \\ 85 & 108 & 100 \end{bmatrix}$$

$$O(2,2) = (1 \times 120) + (0 \times 79) + (-1 \times 106) + (2 \times 87) + (0 \times 84) + (-2 \times 104) + (1 \times 85) + (0 \times 108) + (-1 \times 100)$$

$$O(2,2) = 120 - 106 + 174 - 208 + 85 - 100 = -35$$

Resulting Output Matrix:

$$O = \begin{bmatrix} 213 & 39 \\ 173 & -35 \end{bmatrix}$$

0.25 for every correctly computed value

(b) Max Pooling Operation (2x2 Pooling Size)

Max pooling with a 2x2 window on the above output matrix:

$$\begin{bmatrix} 213 & 39 \\ 173 & -35 \end{bmatrix}$$

Max value in the 2x2 window: $\max(213, 39, 173, -35) = 213$.

$$\text{Pooled Output} = \begin{bmatrix} 213 \end{bmatrix}$$

1 for correctly finding the maximum value

(c) Inference and Applications of the Filter

Inference: The given kernel resembles the **Sobel filter** for detecting vertical edges. The high positive values indicate strong vertical edge presence, while negative or lower values highlight less prominent edges.

0.5 for correctly specifying the inference
0.5 for specifying its utility