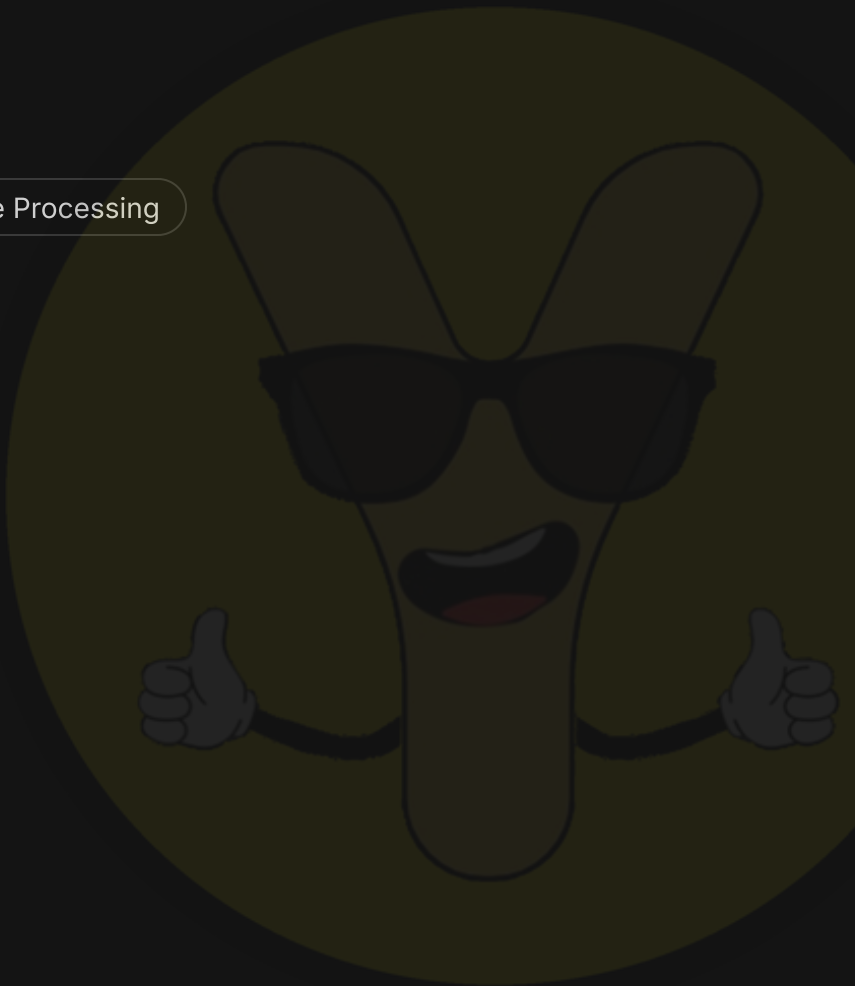
AKTU · 3RD YEAR · SEMESTER 5 · BCAI501

Artificial Intelligence

Unit 5 — Applications

AI Applications | Language Models | Information Retrieval | Information Extraction | Natural Language Processing | Machine Translation | Speech Recognition | Robot Hardware | Perception | Planning | Moving



DECODED BY

Chirag Jain

Founder, Ycotes · Gold Medalist in Artificial Intelligence, IIT Madras · taught 10,000+ students

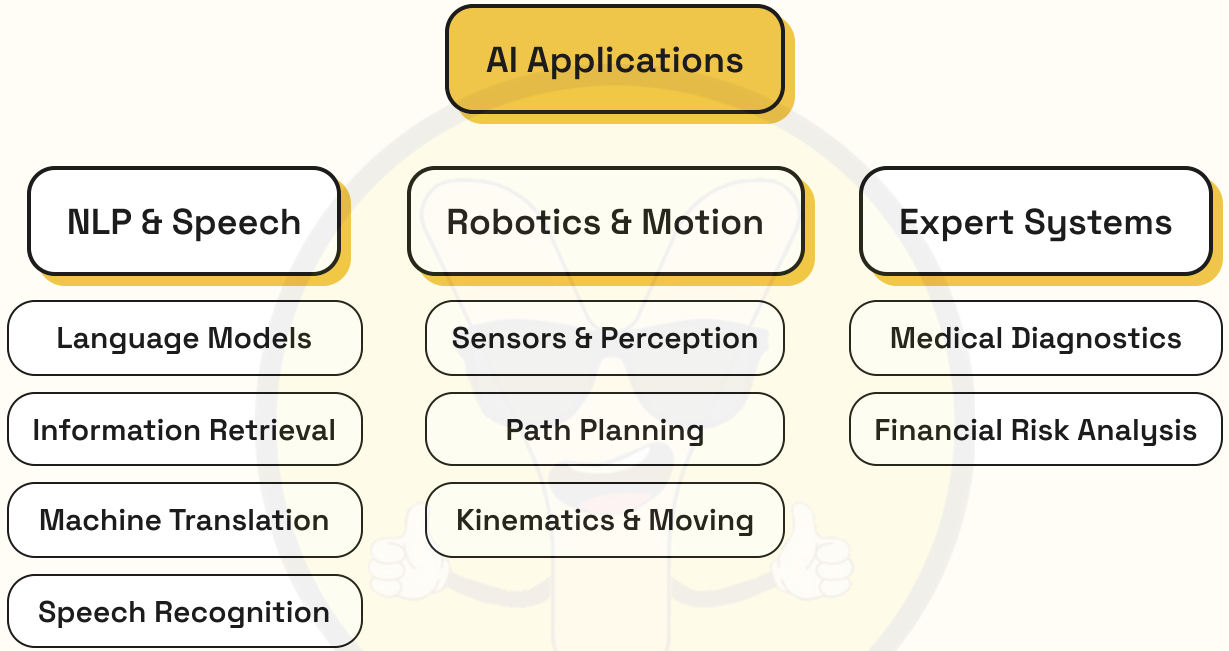
theycotes.com

Overview of AI Applications

Artificial Intelligence powers real-world autonomous, cognitive, and analytical systems across multiple operational domains.

- Healthcare: Disease diagnosis, medical imaging analysis, and drug discovery using deep learning.
- Finance: Algorithmic trading, credit scoring, and automated fraud detection.
- Autonomous Systems: Self-driving cars, unmanned aerial vehicles (UAVs), and automated guided vehicles.
- Smart Grids & IoT: Energy demand prediction, predictive maintenance, and smart home automation.
- Core Cognitive Domains
  - Natural Language Processing & Speech Understanding
  - Robotics, Vision, and Motion Control

Taxonomy of AI Applications



Hierarchical classification of modern AI applications examined in university curricula.

Language Models (LM)

Language models calculate probability distributions over sequences of words to model human language behavior.

- Mathematical Definition: Assigns probability $P(W) = P(w_1, w_2, \ldots, w_n)$ to a word sequence.
- Chain Rule Decomposition: $P(w_1, \ldots, w_n) = \prod_{i=1}^{n} P(w_i \mid w_1, \ldots, w_{i-1})$.
- N-gram Markov Assumption: $P(w_i \mid w_1, \ldots, w_{i-1}) \approx P(w_i \mid w_{i-N+1}, \ldots, w_{i-1})$.
- Model Types: Unigram (N=1), Bigram (N=2), Trigram (N=3).
- Evaluation Metric: Perplexity $PP(W) = P(w_1, w_2, \ldots, w_N)^{-1/N}$ (lower score indicates better performance).
- Smoothing Techniques: Laplace (Add-1) and Good-Turing smoothing resolve zero-probability errors for unseen N-grams.

Information Retrieval (IR) System Architecture



Flow of document processing, indexing, and user query retrieval in Information Retrieval systems.

IR Metric: TF-IDF Computation

Calculate the TF-IDF weight for a term 't' that occurs 4 times in a document containing 100 total words, given that 't' appears in 10 out of 1,000 total documents in the corpus.

1. Term Frequency: $TF(t, d) = \frac{4}{100} = 0.04$
2. Document Frequency ratio: $\frac{N}{DF} = \frac{1000}{10} = 100$
3. Inverse Document Frequency: $IDF(t) = \log_{10}(100) = 2.0$
4. TF-IDF Score Calculation: $TF\text{-}IDF(t, d) = TF(t, d) \times IDF(t) = 0.04 \times 2.0 = 0.08$

The calculated TF-IDF weight of term 't' in document 'd' is 0.08.

Information Extraction (IE)

Information Extraction extracts structured relational database entries from unstructured text documents.

- Named Entity Recognition (NER): Identifies named entities such as Persons, Organizations, Locations, and Dates.
- Relation Extraction: Detects semantic relationships between recognized entities (e.g., 'WorksFor', 'LocatedIn').
- Coreference Resolution: Determines when different text tokens refer to the same entity (e.g., 'Steve Jobs' → 'He').
- Event Extraction: Identifies complex event structures involving triggers, actors, locations, and timestamps.
- Typical IE Pipeline: Tokenization → POS Tagging → Chunking → Named Entity Recognition → Relation Mapping.

Natural Language Processing (NLP)

NATURAL LANGUAGE PROCESSING

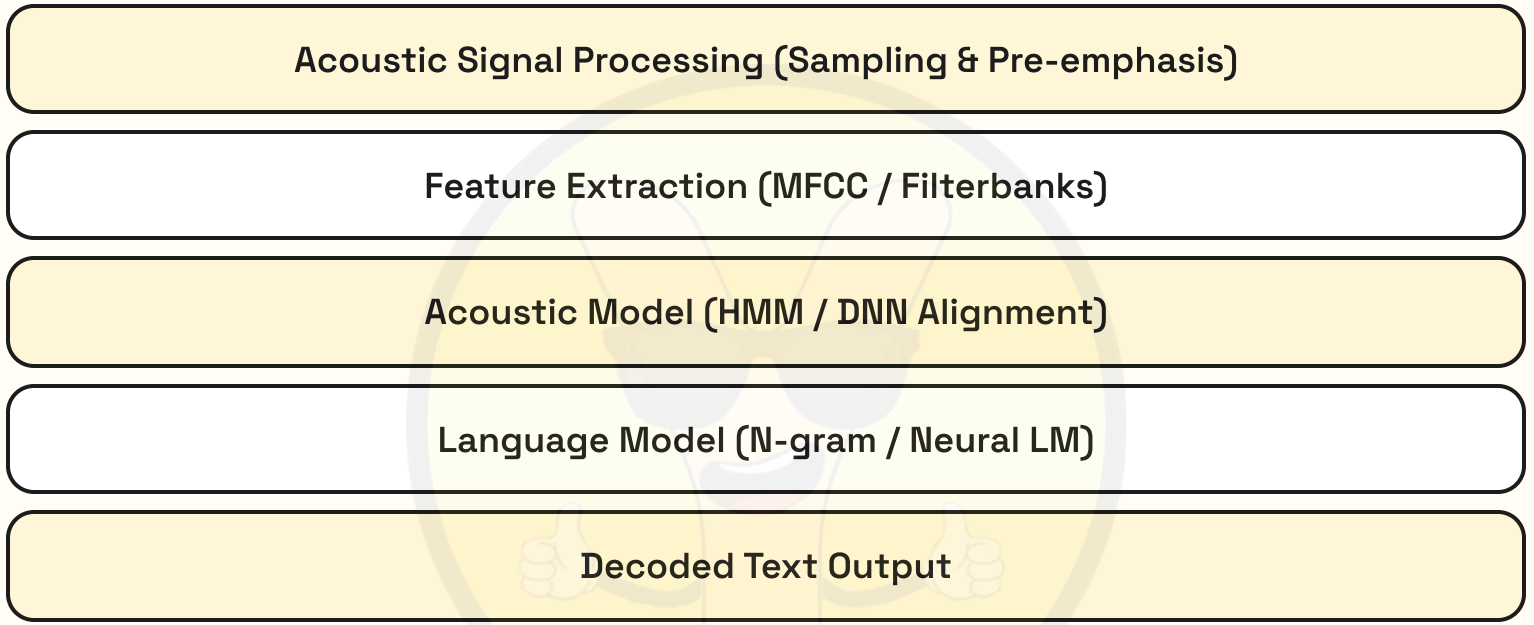
A computational branch of AI concerned with enabling algorithms to analyze, interpret, synthesize, and understand human language.

- Lexical & Morphological Analysis: Analyzing individual words and word structural units (morphemes).
- Syntactic Analysis (Parsing): Evaluating grammatical hierarchy and sentence parse trees.
- Semantic Analysis: Extracting literal meaning and context-independent semantic structures.
- Pragmatic Analysis: Understanding intent, discourse context, and communicative purpose.
- Key Challenges: Structural ambiguity, lexical polysemy, and context dependence.

Machine Translation (MT) Approaches

Feature	Rule-Based MT (RBMT)	Statistical MT (SMT)	Neural MT (NMT)
Core Engine	Linguistic rules & dictionaries	Bilingual corpus probabilities	Deep Neural Encoder-Decoder
Data Needs	Low parallel text, high manual effort	Large parallel corpora	Massive parallel training data
Fluency	Rigid, grammatically strict	Fluent locally, lacks long context	Highly fluent, captures global context
Out-of-Vocabulary	Handled via dictionary rules	Fails or drops unseen words	Handled via subword tokenizers (BPE)
Context Window	Local rule boundary	N-gram phrase tables	Global self-attention (Transformer)

Automatic Speech Recognition (ASR) Pipeline



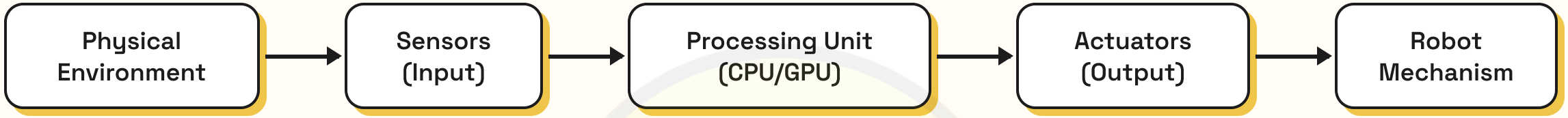
Layered architecture of an Automatic Speech Recognition system converting audio signals to text.

Speech Recognition Fundamentals

Speech Recognition translates raw acoustic wave signals into written textual representations.

- Preprocessing: Audio signal sampling (16 kHz standard) and short-time windowing (20-30 ms frames).
- Feature Extraction: Computes Mel-Frequency Cepstral Coefficients (MFCCs) capturing human spectral sensitivity.
- Fundamental ASR Formula: $\hat{W} = \arg\max_W P(W \mid O) = \arg\max_W \frac{P(O|W)P(W)}{P(O)}$.
- Acoustic Model $P(O \mid W)$: Measures likelihood of acoustic features O given candidate word sequence W.
- Language Model $P(W)$: Estimates prior probability distribution of candidate target sentence W.
- Decoding Algorithms: Viterbi search and Beam Search find optimal word paths through acoustic-language networks.

Robot Hardware System Architecture



Hardware feedback topology connecting environment, perception sensors, computation, and actuators.

Robot Hardware: Sensors vs Actuators

Category	Hardware Component	Function	AKTU Exam Example
Proprioceptive Sensor	Optical Encoders & IMUs	Measures internal state (joint angle, velocity)	Shaft Encoder, Gyroscope
Exteroceptive Sensor	LiDAR, Cameras, Sonar	Measures external environment features	Time-of-Flight LiDAR, RGB-D Camera
Electric Actuator	DC Motors & Steppers	Converts electric energy into angular motion	Servo Motor for arm joint
Hydraulic/Pneumatic	Fluid/Air Cylinders	Converts high-pressure fluid/air into force	Industrial Heavy-lift Arm

Robot Perception & SLAM

ROBOT PERCEPTION

The process by which a robot transforms raw sensory readings into a structured internal model of its environment.

- Sensor Fusion: Combines noisy readings from multiple sensors using Extended Kalman Filters (EKF) or Particle Filters.
- Computer Vision Tasks: Object detection, semantic segmentation, and visual odometry.
- SLAM Definition: Simultaneous Localization and Mapping — building an unknown environment map while updating position within it.
- SLAM Problem Formulation: Estimates state x_t and map m given observations $z_{1:t}$ and controls $u_{1:t}$.

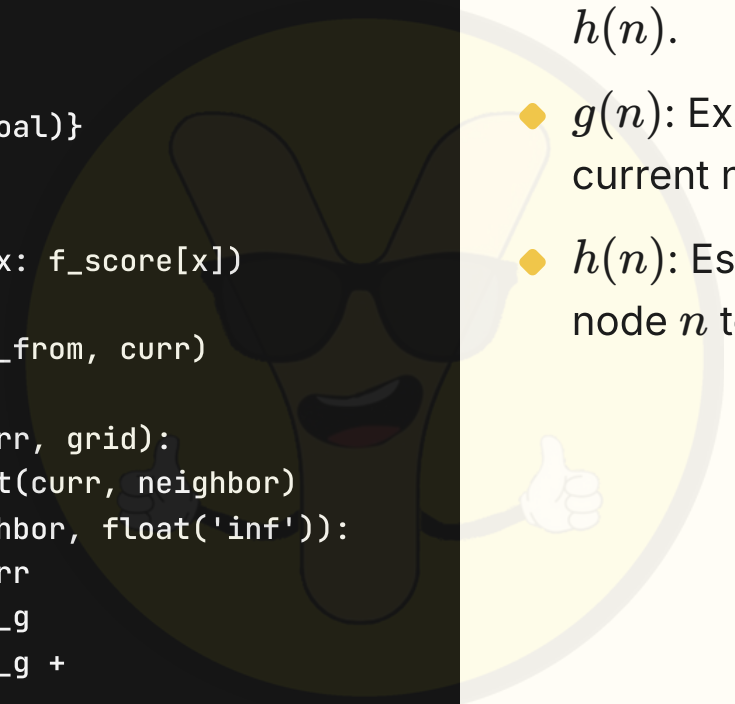
Robot Planning & Configuration Space

Robot planning generates a valid sequence of actions to transition a robot from an initial state to a goal state.

- Configuration Space (C-space): Set of all possible robot positions and orientations, parameterized by joint angles.
- Free Configuration Space (C_{free}): Subspace of C-space where the robot experiences zero physical collisions.
- Obstacle Space (C_{obs}): Subspace where the robot collides with physical environment obstacles.
- Task Planning: High-level symbolic decision making (e.g., automated STRIPS action selection).
- Motion Planning: Finding a continuous collision-free path through C_{free} from q_{start} to q_{goal}.
- Sampling Algorithms: Probabilistic Roadmaps (PRM) and Rapidly-exploring Random Trees (RRT).

Path Planning: A* Search Algorithm

```
def a_star_path(start, goal, grid):
    open_set = {start}
    g_score = {start: 0}
    f_score = {start: heuristic(start, goal)}
    came_from = {}
    while open_set:
        curr = min(open_set, key=lambda x: f_score[x])
        if curr == goal:
            return reconstruct_path(came_from, curr)
        open_set.remove(curr)
        for neighbor in get_neighbors(curr, grid):
            temp_g = g_score[curr] + cost(curr, neighbor)
            if temp_g < g_score.get(neighbor, float('inf')):
                came_from[neighbor] = curr
                g_score[neighbor] = temp_g
                f_score[neighbor] = temp_g +
heuristic(neighbor, goal)
                open_set.add(neighbor)
    return None
```

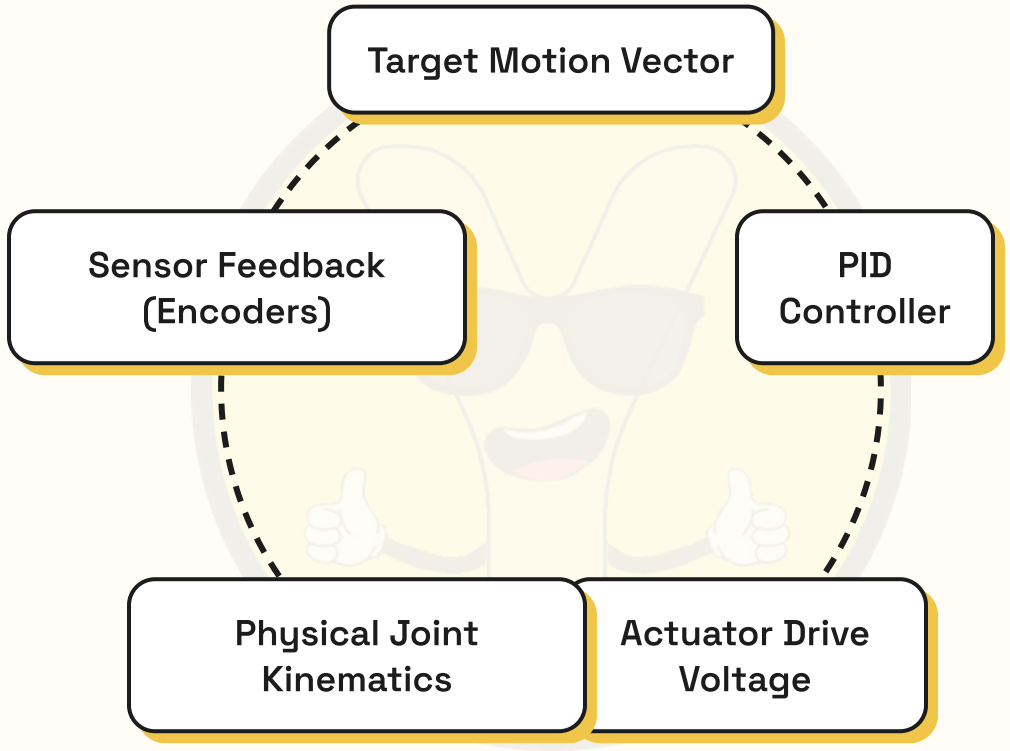


- A* uses heuristic evaluation: $f(n) = g(n) + h(n)$.
- $g(n)$: Exact movement cost from start node to current node n.
- $h(n)$: Estimated admissible heuristic cost from node n to goal.

Robot Moving: Forward vs Inverse Kinematics

Attribute	Forward Kinematics (FK)	Inverse Kinematics (IK)
Input Provided	Joint angles $(\theta_1, \theta_2, \ldots, \theta_n)$	Target end-effector pose $(x, y, z, roll, pitch, yaw)$
Computed Output	End-effector Cartesian pose	Required joint angles $(\theta_1, \theta_2, \ldots, \theta_n)$
Mathematical Complexity	Direct matrix multiplication (Unique solution)	Non-linear trigonometric equations (Multiple/No solutions)
Mathematical Formulation	$X = f(\Theta)$	$\Theta = f^{-1}(X)$
Primary Usage	Robot simulation, visualization, trajectory logging	Target reaching, object manipulation, Cartesian path control

Robot Motion Control Feedback Loop



Closed-loop dynamic control cycle governing precise physical motion execution.

AKTU Exam Corner: Unit 5 Applications

- **Q1** Explain N-gram language models. Write the mathematical formulation for chain rule probability and explain perplexity.
- **Q2** Differentiate between Rule-Based Machine Translation (RBMT), Statistical Machine Translation (SMT), and Neural Machine Translation (NMT).
- **Q3** Describe the architecture of an Information Retrieval (IR) system. Derive and calculate TF-IDF with a numerical example.
- **Q4** What is Named Entity Recognition (NER) and Relation Extraction? Explain their role in Information Extraction (IE).
- **Q5** Explain the working mechanism of an Automatic Speech Recognition (ASR) system with its acoustic and language model components.
- **Q6** Define Configuration Space (C-space), C-free, and C-obs in robot motion planning with illustrative diagrams.
- **Q7** Differentiate between Forward Kinematics and Inverse Kinematics. Write their general mathematical forms.
- **Q8** Explain the SLAM (Simultaneous Localization and Mapping) problem in robotics and discuss sensor fusion techniques used to solve it.

Unit 5 done. You are exam-ready.

Revise the Exam corner once more, then open Unit 1 on theycotes.com. Every AKTU subject, unit by unit, free. Notes by Chirag Jain, Ycotes.

