Introduction to Artifical Intelligence

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November 19, 2025

Part I

AI Laboratory Research Projects

Course Context

Syllabus Coverage (Labs + Projects)

- Artificial Neural Networks, learning algorithms (supervised/unsupervised)
- Evolutionary algorithms (GA/PSO/DE) and applications
- Expert systems, knowledge representation, reasoning
- Agent-based systems, basic architectures
- Fuzzy logic, uncertainty handling, hybrid AI
- Search / planning (used inside routing and task allocation)

Outcome: Each group completes *one* project with:

- A working AI system (ANN/EA/Agent/Fuzzy Hybrid)
- Experiments, figures, tables, and statistical tests
- A short paper draft suitable for GECCO Student Workshop / CEC / IJCNN

Lab Flow (Common to All Projects)

Lab	Theme and Output
1	Setup, dataset/simulation understanding, metrics $\Rightarrow$ baseline stats
2	ANN from scratch (MLP) $\Rightarrow$ working classifier/regressor
3	Optimizers (SGD/Momentum/Adam) $\Rightarrow$ comparison table
4	Intro to GA (EA baseline) $\Rightarrow$ simple optimizer integrated
5	Small novelty: e.g. self-adaptive / chaotic mutation
6	Choose project: one of the four routing/dispatch problems
7	Application layer: maps, routes, explanations, membership plots
8	Benchmarking + statistics: Wilcoxon/Friedman tables
9	Paper writing (IEEE LaTeX) $\Rightarrow$ full draft
10	Final validation + presentation $\Rightarrow$ submission-ready package

Each project *inherits* this structure and adds domain-specific details.

The Four Project Themes

Each group chooses **one** theme:

- **Robust School-Bus Routing Under Uncertainty**
  (ANN + GA under traffic uncertainty; Track A: ML + EA)
- **Smart Waste-Collection Routing with Uncertain Bin Levels**
  (Agent-based + Expert rules; Track B: Agents + Knowledge Systems)
- **Ambulance Dispatch Optimization Under Random Demand**
  (Fuzzy severity + EA; Track C: Hybrid Fuzzy + EA)
- **Energy-Efficient EV Routing in a Smart Campus**
  (Hybrid ML/EA/Fuzzy; Track A or C)

All projects:

- Use **synthetic or semi-simulated data** for locations and uncertainty.
- Use **ANN** (Labs 2–3) and **EA** (Labs 4–5) as core tools.
- Require one **small, clearly explained novelty**.

Common Expectations for All Projects

By the end of the semester, each group must deliver:

- A **code repository** (Python) with:
  - data generation / loading script,
  - ANN training script,
  - EA/GA optimization script,
  - plotting utilities.
- A **short paper** (IEEE LaTeX):
  - 6–8 pages, clear structure, reproducible details.
- A **5-minute presentation** in Lab 10.

Assessment (indicative):

Implementation: 35% Experiments: 25% Analysis: 20%

Writing: 15% Presentation: 5%

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Part II

Robust School-Bus Routing Under Uncertainty

Motivation and Problem Statement

Title (example):
"An Averaging-Based Evolutionary Approach to Robust School-Bus Routing Under Traffic Uncertainty"

Motivation

- School buses must pick up pupils from multiple stops and deliver them to school.
- Traffic conditions and travel times are *uncertain* (accidents, congestion).
- We want routes that are not only short, but *robust* under random delays.

Problem (simplified)

- Given:
  - A set of student stops (coordinates),
  - One or more buses with capacities,
  - A school location (depot).
- Find bus routes that minimize *expected total travel time* under uncertainty.

Dataset / Simulation Setup

Data Type: Synthetic, small-city abstraction.

What we will generate in code:

- N student locations: (x_i, y_i) in a 2D plane.
- School (depot) at a fixed coordinate.
- Distance matrix $D[i, j]$ = Euclidean distance between locations.
- Travel-time uncertainty:

$$T_{ij} = D_{ij} \cdot (1 + \epsilon), \quad \epsilon \sim \mathcal{N}(0, \sigma^2)$$

- Bus capacity: max number of students per bus (optional constraint).

Expected Student Task:

- Write a `generate_bus_data()` function that:
  - creates coordinates,
  - computes D,
  - stores them in `.csv` or Python objects.

Algorithmic Design (High-Level)

Two layers: ANN + GA under uncertainty

ANN (Labs 2–3):

Input: route features (e.g. total distance, number of stops).
Output (optional): predicted travel time (or delay factor).
Use for analysis / as part of fitness if desired.

GA (Labs 4–5):

Chromosome: a permutation of stops (ordering).
Fitness: expected total travel time under random traffic.
Operators: selection, crossover, mutation, elitism.

Novelty (Lab 5):

Averaging-based robust fitness (evaluate route over multiple traffic scenarios).

Self-adaptive or chaotic mutation rate based on variance of cost.

Work Flow

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1–4 (common core):

W1: Generate base coordinates; plot scatter of stops and depot.

W2: Implement ANN (even if not strictly required for routing yet).

W3: Try different optimizers (SGD/Adam); record metrics on a simple supervised task (e.g. predict travel time from distance).

W4: Implement GA for TSP-style route optimization (no uncertainty yet).

5–10 (project-specialization):

W5: Add uncertainty in travel times; implement averaging-based fitness (5–10 scenarios).

W6: Fix hyperparameters (population size, mutation rates) and run multiple trials.

W7: Generate route plots, convergence curves, boxplots of travel time under uncertainty.

W8: Perform statistical comparison (baseline GA vs improved GA).

W9: Write paper draft (Intro, Method, Experiments, Results).

W10: Final reruns, polish figures, 5-minute project presentation.

Deliverables & Evaluation

Code Deliverables

- Data generator: bus stops + depot + distance matrix.
- GA optimizer with robust fitness evaluation.
- Plotting scripts: routes, convergence, uncertainty distributions.

Paper Components

- Clear problem formulation.
- Description of GA + robust/averaging approach.
- Figures: map of stops, best route, convergence, boxplots.
- Tables: average cost, std deviation, p-values.

Target venues:

- GECCO Student Workshop (very suitable).
- CEC special sessions on routing / stochastic optimization.

Part III

Smart Waste-Collection Routing

Motivation and Problem Statement

Title (example):
"An Agent-Based Evolutionary Approach to Smart Waste-Collection Routing Under Uncertain Bin Levels"

Motivation

- Cities need efficient waste collection from distributed bins.
- Bin fill levels are uncertain and vary over time.
- Poor routing increases fuel use, congestion, and emissions.

Simplified Problem

- Given:
  - Locations of waste bins,
  - One or more trucks with limited capacity,
  - Estimates of bin fill levels with uncertainty,
- Design routes and decisions (visit/skip) to minimize cost while avoiding overflow.

Dataset / Simulation Setup

Data Type: Synthetic city grid.

Components to simulate:

- N bin locations (x_i, y_i).
- Fill level estimate $f_i \in [0, 100]\%$.
- Uncertainty in fill: $f_i' = f_i + \eta$, $\eta \sim \mathcal{N}(0, \sigma^2)$, clipped to $[0, 100]$.
- Truck capacity: capacity in units of "total fill".
- Distance/cost matrix between bins and depot.

In Lab 1: students will:

- Generate bin coordinates & fill levels.
- Visualize them on a scatter plot (size $\propto$ fill).

Agent / Expert / EA Design

Three layers:

- **Expert rules:**
  - Simple rules like: “IF fill $<$ 40% THEN skip bin”, etc.
  - Conflict resolution when capacity is tight.
- **Agent layer:**
  - Each truck is an agent traversing bins.
  - Agents can use rules and local decisions.
- **GA layer:**
  - Chromosome: visiting order + decisions about which bins to serve.
  - Fitness: distance cost + penalty for overflow/unserved full bins.

Novelty possibilities:

- Uncertainty-averaged fitness.
- Hybrid: agent decisions + GA optimization.

Work Flow

1–4:

W1: Generate bin data (locations, fill levels) and visualize.

W2: ANN (optional) to predict future fill from current + features.

W3: Compare optimizers on a simple supervised task if ANN used.

W4: Implement GA for simple routing (ignoring uncertainty and rules initially).

5–10:

W5: Add expert rules and/or agent logic; integrate uncertainty in fill.

W6: Combine GA with rules/agents; define final fitness.

W7: Generate route plots, rule firing traces, and agent interaction diagrams.

W8: Compare baseline GA vs GA+rules vs GA+agents (statistics).

W9: Write paper describing agent-expert-EA architecture and results.

W10: Final reruns, finalize visuals, present.

Deliverables & Evaluation

Code

Data generator for bins and uncertainty.

Agent simulation loop + expert rules.

GA optimizer integrated with agent decisions.

Paper

System architecture diagram (agents + GA + rules).

Explanation of uncertainty model.

Figures: routes, agent traces, bin fill before/after.

Results tables with mean cost and violation counts.

Part IV

Project 3: Ambulance Dispatch Under Random Demand

Motivation and Problem Statement

Title (example):
"A Fuzzy-Evolutionary Approach to Robust Ambulance Dispatch Under Random Emergency Demand"

Motivation

- Emergency services must respond quickly to random calls.
- Demand (where, when, severity) is highly uncertain.
- Need to allocate ambulances and hospitals efficiently.

Simplified Problem

- Given:
  - Hospital / station locations,
  - Randomly generated emergency calls,
  - Estimated severity and travel times,
- Assign ambulances to calls to minimize response time and prioritize severe cases.

Dataset / Simulation Setup

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Data Type: Synthetic.

What to simulate:

- H hospitals, A ambulance bases (coordinates).
- Random emergency call points over a map.
- Severity score (e.g. 1–5) and time-of-day.
- Distance/travel time matrix between bases, calls, and hospitals.

Uncertainty:

- Severity may be misclassified; travel times affected by random delays.
- Use stochastic or fuzzy models to capture this.

Fuzzy + EA Design

Fuzzy Layer (Labs 6–7):

- Fuzzy variables:
  - Severity: low / medium / high.
  - Distance: short / medium / long.
  - Congestion: low / high (optional).
- Rules:
  - E.g. "IF severity is high AND distance is short THEN priority is very high".

EA Layer (Labs 4–5, 8):

- Chromosome: assignment of ambulances to calls.
- Fitness: weighted combination of response time, severity coverage, fairness.
- Novelty: GA tunes fuzzy membership parameters or rule weights.

Work Flow

1–4:

- W1: Generate hospitals, bases, emergency calls.
- W2: ANN to predict simple risk index (optional).
- W3: Train ANN with different optimizers (optional).
- W4: Implement basic GA for assigning calls to ambulances ignoring fuzziness.

5–10:

- W5: Introduce uncertainty (random delays, severity noise).
- W6: Design fuzzy variables and rules for severity-based prioritization.
- W7: Integrate fuzzy priority into GA fitness; visualize membership functions.
- W8: Compare baseline GA vs GA+Fuzzy; run multiple trials; statistical tests.
- W9: Write paper draft (focus on hybrid Fuzzy+EA system).
- W10: Final reruns, refine plots, present.

Deliverables & Evaluation

Code

- Emergency call simulator.
- Fuzzy inference system.
- GA-based dispatcher integrated with fuzzy priority.

Paper

- Fuzzy membership plots and rule base.
- Architecture of Fuzzy+EA dispatcher.
- Response time statistics, priority coverage metrics.

Target: Strong candidate for IJCNN / WCCI student tracks (if well executed).

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Part V

Energy-Efficient EV Routing in Smart Campus

Motivation and Problem Statement

Title (example):
"Hybrid Evolutionary-Fuzzy Routing for Energy-Efficient Electric Vehicles in Smart Campus Networks"

Motivation

- EVs have limited battery; routing impacts energy usage.
- Buildings in a campus generate trips; we want energy-aware routing.
- Weather, load, and driving conditions are uncertain.

Simplified Problem

- Given:
  - Campus building locations,
  - Trip requests and demands,
  - EV battery capacities and consumption model,
- Design routes minimizing total energy and travel time.

Dataset / Simulation Setup

Data Type: Semi-synthetic.

Possible setup:

- Use simple synthetic campus (grid of buildings) or real coordinates (optional).
- Define trips as pickup/delivery tasks between buildings.
- Energy usage per edge:

$$E_{ij} = \alpha D_{ij} + \beta \cdot \text{load} + \gamma \cdot \text{grade} + \epsilon$$

- Uncertainty from weather (temperature, wind) or random term ϵ.

Lab 1 task:

- Generate building nodes and trip requests.
- Visualize campus graph.

Hybrid ANN / Fuzzy / EA Design

Core Components:

- **ANN (Labs 2–3):**
  - Predict energy consumption (or travel time) from edge features.
- **Fuzzy module (optional, Lab 6–7):**
  - Fuzzy rules for “energy-efficient vs risky” segments.
- **GA/DE (Labs 4–5, 8):**
  - Optimize route sequences, subject to battery constraints.
  - Novelty: tune fuzzy membership, or adaptive penalties for energy overuse.

Work Flow

1–4:

- W1: Generate campus graph and trip data.
- W2: ANN to predict energy usage per edge or per trip.
- W3: Optimizer comparison on ANN training (SGD vs Adam).
- W4: Basic GA for route optimization ignoring energy uncertainty.

5–10:

- W5: Add battery constraints and random variation in energy usage.
- W6: Optionally add fuzzy labels for “low/med/high energy” edges.
- W7: Generate route visualizations and energy vs distance plots.
- W8: Statistical comparison of baseline vs improved hybrid method.
- W9: Write paper emphasizing energy-optimization aspects.
- W10: Final reruns and project presentation.

Deliverables & Evaluation

Code

- Campus graph generator.
- ANN energy predictor.
- GA/DE-based EV router with constraints.

Paper

- Diagrams of campus network and EV routes.
- Figures: trade-off curves (energy vs distance vs time).
- Tables with performance metrics; p-value tests.

Common Paper Structure (All Projects)

Suggested IEEE-style structure

Introduction
Problem, motivation, contributions (what is new?).

Related Work (short, focused)
Mention routing/dispatch/EA/uncertainty papers.

Problem Formulation
Sets, variables, objective(s), and constraints (at least conceptually).

Methodology
ANN, EA, fuzzy/agent components; novelty described clearly.

Experimental Setup
Data generation, parameters, metrics, protocol.

Results and Discussion
Tables, figures, statistical tests; interpretation.

Conclusion and Future Work

Final Notes for Students

- Start **simple** (small graphs, fewer nodes), then scale up gradually.
- Focus on **clarity**: explain every design decision.
- A small but **well-justified** novelty + solid experiments is better than an over-complicated, unstable system.
- Keep all code **versioned** and seeds fixed for reproducibility.
- Ask for help early with:
  - GA operators,
  - fuzzy rule design,
  - plotting and LaTeX integration.

Questions?