Lecture 1: Basic Principles of Automated Systems

Instructor: GuangBing Yang, PhD

- My name: Guangbing Yang
- My research interest and experience focus on: Text summarization, Visual semantics, Natural Language Processing, Machine Learning/deep learning/ reinforcement learning algorithms, statistics, and data science.
- My Email: yguangbing@gmail.com (Chula's email coming soon)
- My brief CV:
  - Guangbing Yang, Ph.D. - Texas A&M University-Commerce
  - Guangbing Yang - Google Scholar

Evaluation

- **Four assignments**:
  - Assignment 1 worth 10%, Assignment 2 to 4 worth 20% for each
- Final project and presentation, worth 25%
- Attendance and activity, worth 5%

Tentative Dates - Check the MyCourseVille

Project: Proposal Due April 6, 2021

Presentation: May 11th, 2021

Project report: May 11th, 2021

Project

- The purpose of the final project is to provide you a bit of experience trying to do a very basic but original research in AI & reinforcement learning and coherently writing up your result.
- In this project, **what is expected:**
  - A simple but original idea, clearly describe and discussed.
  - Link it to existing methods
  - Implement and test (model performance evaluation) on a small scale problem
- **What is required**:
  - write some basic code to build an AI robotics simulator by applying reinforcement learning and train/test it on some environment models.
  - make some figures (e.g., architecture, system design, work flow, training/testing evaluation result plots, and others)
  - read some research papers, collect references, and
  - write an essay (no more than 3 pages) to discuss your model, algorithm, and results, etc.
  - So, a project proposal (no more than 2 pages) + an essay (maximum 3 pages) + presentation (demo your project, e.g., a simple robotics simulator or a simple game)

Text Books

As reference books

- Richard S. Sutton and Andrew G. Barto (2017)

Reinforcement Learning: An Introduction Second Edition , The MIT Press, ISBN 9780262039246

- Authors: Stuart Russell and Peter Norvig

Artificial Intelligence: A Modern Approach Third or Fourth Edition

What is automated system?

It is a system that can operate in the real-world environment without any external control from humans.

Characteristics of automated system

live in dynamic environment
self maintain its internal structures and processes
interact with environment
exhibit a variety of behaviours
adapt to environment change

Tasks, Control, Uncertainty

capable to operation — complete some tasks
operate without human supervision
desired behaviours and unexpected ones

- Without humans' control and having unexpected behaviours from these automated systems, the question is "how can one foresee the consequences of using them?"
- The fact is:
  - The greater the complexity of the environment and the task, the greater the uncertainty of the consequences of using the autonomous systems is.
- The approaches are:
  - some basic principles of automated systems are given as the foundations and guidelines when designing and building such autonomous (robotic) systems.

Basic Principles

- Simple and efficient, not just complex for autonomous
- Situational awareness
- A human control - a mechanism through which to intervene
- Predictability and reliability
- Algorithm, AI and Machine Learning

Types of "Automated"

- Basically, there are three types of "automated":
  - **Automatic**, **Automated**, and **Autonomous**
- **Automatic** systems perform prescribed actions that are fixed in advance and do not change in response to the environment. Such systems include industrial manufacturing robots. human control - a mechanism through which to intervene
- **Automated** systems initiate or adjust their actions or performance based on feedback from the environment.
- **Autonomous** systems combine environmental feedback with the system's own analysis regarding its current situation, in other words "automatic" + "automated".

Types of "Automated" - cont'

- Increasing autonomy requires more "intelligence" — more "Artificial Intelligence".
- There is no clear technical distinction between automated and autonomous systems.
- In this course, we use "automated" as the term to represent the systems that are both autonomous and AI. "Automated" = "Autonomous" + "AI"

"Automated = Autonomous + AI"

- As we know, autonomous includes automatic.
- Automatic considers human control, not just fully "Automated".
- Question is: how humans can control automated systems?

Human Control Over Automated Systems

- Generally, there are three approaches that humans can be involved in the processes of the automated systems.
- Direct control, Shared control, and supervisory control.

Human Control Over Automated Systems - cont’

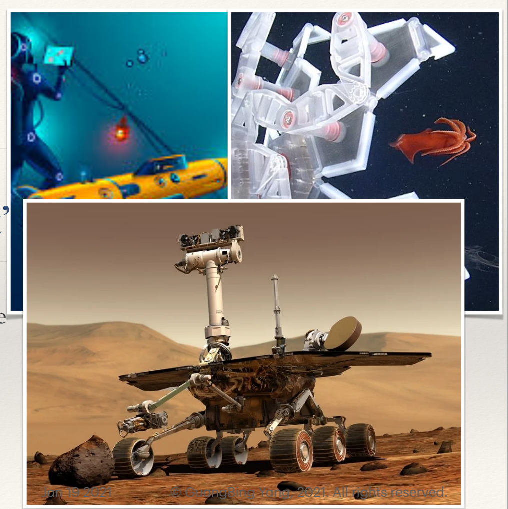
- Direct control requires constant intervention by a human operator to directly or remotely control the functions of the system, which are therefore not autonomous.

Human Control Over Automated Systems - cont’

- Shared control — The human operator directly controls some functions while the machine controls other functions under the supervision of the operator.

Human Control Over Automated Systems - cont’

- Supervisory control - A robotic system performs tasks autonomously while the human operator supervises, and the operator can provide instructions and / or intervene and take back control, as required. means “predictive control”



Human-on-the-Loop

- Effective human-on-the-loop supervision and intervention require:
  - Continuous situational awareness
  - Enough time to intervene
  - Mechanism for intervention
    - including a human operator override function – effectively a “big red button” to deactivate the system

Predictability & Reliability

- **Predictability** is about the **ability** to "say or estimate that a specified thing will happen in the future or will be a consequence of something".
- **Reliability** is "the **quality** of being trustworthy or performing consistently well".
- Factors affecting predictability and reliability:
  - The nature of the environment,
  - The interaction of the system with the environment, and
  - The complexity of the task.

Challenges to Verify Predictability & Reliability

- Verifying **Predictability** and **Reliability** is essential process in automated system design and development.
- Computer simulations and real-world physical tests
  - Real world testing is limit, e.g., rovers - Sojourner; landers - Mars Pathfinder;
  - Computer simulations bring their own difficulties
    - difficult to bring accurate enough simulation due to lack of knowledge of all critical scenarios, e.g., no humans have been in Mars yet, only observations from Earth.
    - difficult re-create it, generally replicate the real-world environment, even for simple tasks.
    - systemically bias in the testing results and in the functioning of AI algorithms trained using simulations

Review

- Linear Algebra
  - Matrix Multiplication
    - Vector-Vector Multiplication
    - Matrix-Vector Multiplication
    - Matrix-Matrix Products
    - Operations and Properties
  - Matrix Calculus
- Probability Theory
  - General Concepts
  - Expected Values
  - Common Probability Distributions

Linear Algebra Brief Review

- **Linear algebra** is a branch of mathematics providing a concise way to represent and operate on a set of linear equations via vectors and matrices.
- For example, system equations:

$$\begin{aligned} 2x_1 + 3x_2 &= 15 \\ -x_1 + 2x_2 &= 6 \end{aligned}$$

can be represented using matrix and matrix operations

$$Ax = y$$

$$A = \begin{bmatrix} 2 & 3 \\ -1 & 2 \end{bmatrix}, y = \begin{bmatrix} 15 \\ 6 \end{bmatrix}$$

- To solve this system equation, many steps may be needed, but later, you will see we can get it quickly and easily using matrix operations.

Matrix Multiplication

- The **product** of two matrices $A \in \mathbb{R}^{m\times n}$ and $B \in \mathbb{R}^{n\times p}$ is the matrix:

  $C = AB \in \mathbb{R}^{m\times p}$

  where $C_{ij} = \sum_{k=1}^{n} A_{ik}B_{kj}$

  Note that in order for the matrix product to exist, the number of columns in A must equal the number of rows in B.

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Vector - Vector Multiplication

- The **product** of two vectors, $a, b \in \mathbb{R}^n$, the outcome of the product a^Tb, also called the ***inner product*** or ***dot product*** of vectors, is a real number calculated by
- In this case, $a^Tb = b^Ta$ because the size of the vector a and b are the same, which is n.

$$a^Tb \in \mathbb{R} = [a_1a_2...a_n]\begin{bmatrix} b_1 \\ b_2 \\ . \\ . \\ b_n \end{bmatrix} = \sum_{i=1}^{n} a_ib_i = (a_1b_1 + a_2b_2 + ... + a_nb_n)$$

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Vector - Vector Multiplication

- In contrast, for two vectors, $a \in \mathbb{R}^m, b \in \mathbb{R}^n$ with different size, the ***outer product*** of $ab^T \in \mathbb{R}^{m\times n}$, is defined as,
- In this case, ab^T is a $m \times n$ matrix rather than a real scaler value.
- For others, matrix - vector, vector - matrix and matrix - matrix, please see lecture note: 'review-linear-algebra.pdf'

$$ab^T \in \mathbb{R}^{m\times n} = \begin{bmatrix} a_1 \\ a_2 \\ . \\ . \\ a_m \end{bmatrix}[b_1b_2...b_n] = \begin{bmatrix} a_1b1 & a_1b_2 & ... & a_1b_n \\ a_2b_1 & a_2b_2 & ... & a_2b_n \\ . & . & ... & . \\ . & . & ... & . \\ . & . & ... & . \\ a_mb_1 & a_mb_2 & ... & a_mb_n \end{bmatrix}$$

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Operations and Properties

- **Identity Matrix & Diagonal Matrix**
  - a square matrix with ones on the diagonal and zeros everywhere else. It is denoted as: $\mathrm{I} \in \mathbb{R}^{n\times n}, I_{ij} = \begin{cases} 1 & \text{if i = j} \\ 0 & \text{if } i \neq j \end{cases}$
  - property of identity matrix: for all $A \in \mathbb{R}^{m\times n}, AI = A = IA$
  - diagonal matrix is a matrix where all non-diagonal elements are zeros, denoted as $D = \mathrm{diag}(d_1, d_2, \ldots, d_n)$. It is not necessary a square matrix, with $D_{ij} = \begin{cases} d_i & \text{if i = j} \\ 0 & \text{if } i \neq j \end{cases}$

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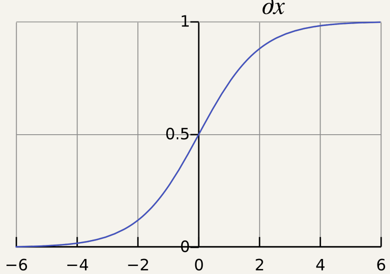
Operations and Properties

- **The Transpose**
  - The transpose of a matrix results from flipping the rows and columns.
  - Given a matrix $A \in \mathbb{R}^{m \times n}$, its transpose, written $A^T \in \mathbb{R}^{n \times m}$, is the $n \times m$ matrix whose entries are given by $(A^T)_{ij} = A_{ji}$
  - The properties:
    - $(A^T)^T = A$
    - $(AB)^T = B^T A^T$
    - $(A + B)^T = A^T + B^T$

Operations and Properties

- **The Inverse**
  - The inverse of a square matrix $A \in \mathbb{R}^{n \times n}$ is denoted as $A^{-1} \in \mathbb{R}^{n \times n}$.
  - It is unique and $A^{-1}A = I = AA^{-1}$
  - Note that not all matrices, including same square matrices, have inverses. By definition, non-square matrices have no inverses.
  - Particularly, if A^{-1}exists, we say A is ***invertible*** or ***non-singular***, otherwise, it is ***non-invertible*** or ***singular***. Also, the determinant of the A (detA) is not zero, and is vice versa.
  - The properties:
    - $(A^{-1})^{-1} = A$
    - $(AB)^{-1} = B^{-1}A^{-1}$
    - $(A^{-1})^T = (A^T)^{-1}$

Sigmoid function & its derivative

- **The Sigmoid function**
  - $S(x) = \frac{1}{1 + e^{-x}}$ is denoted as $x \in \mathbb{R}^n$.
  - Its derivative or gradient defined as $\frac{\partial S(x)}{\partial x} = S(x)(1 - S(x))$
  - 

Sigmoid function-chart from Wikipedia page: Sigmoid function

Probability Theory Brief Review

- **Probability Theory** studies the **uncertainty.**
- **Statistics** somehow apply probability theory to explain the variation in some measure of interest. In other words, probability quantifies uncertainty, statistics explains variation.
- For example,
  - Roll a 6-side die. What is the probability of obtaining a 6? (a probability problem)
  - Observe the variation of the annual income of a person. What factors explain the variation in a person's income.(a statistic problem, which is 'variation = factors of observation + random errors'. Clearly, no way to account for all factors that affect person's income, have to leave any remaining variation to uncertainty.
- In later lectures, you will see a error function (or cost function) can be taken as the random error in the variation expression list above.
- That is why we say AI and machine learning use statistics and probability to address the uncertainty and variation problem.

Probability Theory Brief Review

- **Elements of Probability**
  - **Sample space:** the sample space is denoted by Ω**,** it is the event set
  - **Events**: a particular subset of Ω, denoted as A, $A \subseteq \Omega$.
  - **Probability measure**: A function $P : F \rightarrow R$ that satisfies the following properties:
    - $P(w) \geq 0$
    - $\sum_{w \in \Omega} P(w) = 1$
    - If A_1 and A_2 are disjoint, then $P(A_1 \cup A_2) = P(A_1) + P(A_2)$, more generally, if $A_1, A_2, ... A_n$ are mutually disjoint, then $P(\cup_{i=1}^{\infty} A_i) = \sum_{i=1}^{\infty} P(A_i)$

Probability Theory Brief Review

- **Properties of Probability:**
  - If $A \subseteq B, P(A) \leq P(B)$
  - $P(A \cap B) = min(P(A), P(B))$
  - $P(A \cup B) \leq P(A) + P(B)$ - (Union Bound)
  - $P(A^c) = 1 - P(A)$ since A^c is called A`s complement, A^c and A are disjoint. $A^c \cup A = \Omega$, and $P(A^c \cup A) = P(\Omega) = 1 = P(A^c) + P(A)$
  - If $A_1, ..., A_k$ are a set of disjoint events such that $\sum_{i=1}^{k} A_k = \Omega$, then $\sum_{i=1}^{k} P(A_k) = P(\Omega) = 1$ (Law of Total Probability)
  - Independence: A and B are said to be independent events if $P(A \cap B) = P(A)P(B)$, or
    - conditional independence: $P(A \mid B) = P(A)$ or, $P(B \mid A) = P(B)$

Probability Theory Brief Review

- **Product Law**:
  - Let A and B be events and assume $P(B) \neq 0$, then $P(A \cap B) = P(A \mid B)P(B)$.
- **Random Variable**: In probability, it is a **function** from Ω to a real number. Because the outcome of the experiment with sample space Ω is random, the number produced by the function is also random as well.
  - Consider an experiment in which a coin is flipped three times, and the sequence of heads and tails is observed as: $\Omega = \{hhh, hht, htt, hth, ttt, tth, thh, tht\}$**.**
  - Define the random variables such as
    - (1) the total number of heads,
    - (2) the total number of tails, and
    - (3) the number of heads minus the number of tails.
  - Each of these is a real-valued function defined on Ω. In other words, each of them is a rule that assigns a real number to every point w $\in \Omega$.

Probability Theory Brief Review

- **Bayes Rule**:
  - defined as: Let A and $B_1, ..., B_n$ be events where the B_i are disjoint, $\cup_{i=1}^{n} B_i = \Omega$, and $P(B_i) > 0$ for all i, Then,
  - $P(B_j \mid A) = \dfrac{P(A \mid B_j)P(B_j)}{\sum_{i=1}^{n} P(A \mid B_i)P(B_i)}$
  - Where $\sum_{i=1}^{n} P(A \mid B_i)P(B_i) = P(A)$ is called evidence or marginal distribution of joint probability of A and B over B.
  - If let $P(B_j)$ as the **prior** probability, and $P(A \mid B_j)$ as the likelihood function, then the **posterior** probability is given by: $P(B_j \mid A) = \dfrac{P(A \mid B_j)P(B_j)}{\sum_{i=1}^{n} P(A \mid B_i)P(B_i)}$. Since the evidence P(A) does not change with B, so $P(B_j \mid A) \propto P(A \mid B_j)P(B_j)$,
  - Based on above expression, we often say '$posterior \propto likelihood \times prior$' — This is a very important concept in machine learning, particularly in *generative* approaches.

Probability Theory Brief Review

- **Expected Values**:
  - **Expectation:** If X is a discrete random variable with PMF $p_X(x)$ and $g : \mathbb{R} \to \mathbb{R}$ is an arbitrary function. In this case, g(X) can be considered a random variable, the expected value of g(X), denoted by $E(g(X))$ is
    - $E(g(X)) = \sum_{x \in X} g(x)p_X(x)$, provided that $\sum_{x \in X} |g(x)| p_X(x) < \infty$. If the sum diverges, the expectation is undefined.
    - For continues random variables: $E(g(X)) = \int_{-\infty}^{\infty} g(x)f_X(x)dx$
  - **Variance**: $Var(X) = E\{[X - E(X)]^2\}$ or $Var(X) = E[X^2] - [E(X)]^2$

Probability Theory Brief Review

- **Common probability distributions**:
  - **Discrete distribution:**
    - *Bernoulli distribution:* $p(x) = \begin{cases} p & \textbf{if } p = 1 \\ 1 - p & \textbf{if } p = 0 \end{cases}$, or $p(x) = \begin{cases} p^x(1-p)^{1-x} & \text{if x = 0 or x=1} \\ 0 & \text{otherwise} \end{cases}$.
  - **Continuous distribution**:
    - Uniform: (where $a < b$): equal probability density to every value between ***a*** and ***b*** on the real line. $f(x) = \begin{cases} \frac{1}{b-a} & \text{if a } \leq x \leq \text{b} \\ 0 & \text{otherwise} \end{cases}$
    - Normal distribution or Gaussian distribution: $f(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2\sigma^2}(x-\mu)^2}$
    - It depends on two parameters: μ, called **mean**, and σ, called **variance**.

Assignment 1

- Assignment 1 worth 10%, and is about reviews of mathematics and Python programming. Very easy (bonus!).
- Google Colab is a Jupiter Notebook running in the cloud.
- Copy and download my Colab to your Google drive (Important note: Don't modify my Colab notebook, otherwise other classmates will see your work.)
- Working on your copy of the Colab notebook. Don't forget to add your name and student id in it.
- After finishing it, share it with me (only me, do not share your work with others.)
- All programming exercises MUST be running correctly in Colab without any errors and exceptions. If your code cannot run at all, and I cannot see any kind of outputs, you receive no grade points for that part.
- Before you submit your Colab notebook, make sure to leave the outputs (results) of the functions in the notebook. I ONLY review the outputs of your functions or the final results.
- The assignment due at Feb 2nd, 2021. It is an individual assignment.
- Just remind you to beware of academic integrity and responsible behaviour.

Any questions?
Next section, the lab