Teaching artificial intelligence in cyber-physical systems

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Abstract: *A training discipline "Basics if the Artificial Intelligence", taught in UCTM, Sofia is presented. The discipline is developed according to the requirements of ACM as well the methodises presented by Russel and Norvig in their seminal book "Artificial Intelligence: A modern approach, 3 ed.". As a tool for illustration of the AI algorithms to be studied, each student is equipped with a typical cyber-physical system – individual training stand, which includes a simplified robot (addressed here as passive agent) constructed of sensors and actuators only) controlled by an AI algorithm, subject to development by the students and housed on a PC. An outline of the lections is included.*

KEYWORDS: ARTIFICIAL INTELLIGENCE, TEACHING OF AI, TRAINING, RATIONAL AGENT, TRAINING PROGRAM

1. Introduction

There is an old saying - the engineers don't have to know everything; all they need is to know where to find the knowledge. Apparently there exist many levels between "to know everything and "not knowing but aware where to find the necessary information". The level of *knowing* and finding, combined with the skills of using the information, determines the life journey of the graduates – as scientists, technologists, or managers. One might say that the skilling of the delicate balance between memorizing of facts, methods, the ability to use the available information and to find the necessary information make the difference between the good and the bad engineer.

The task to build these abilities is assigned to the technical and technological universities. It is our opinion that an important step in the process of development of the mentioned set of skills is the creation of an intuitive sense to the logic, principles, philosophy laying in the foundation of the engineering courses of study.

The courses in University of Chemical Technology and Metallurgy (UCTM) are categorized to systems engineering, chemical technologies and metallurgy. Within the scope of the system engineering course, the students study the course "Automation and Information Technologies" (AIT). This year a new course was introduced - namely "Engineering informatics" (EI). In this paper we will discuss the discipline "Basics of the Artificial intelligence" (BAI), which is included in these courses.

A course of Artificial Intelligence naturally fits into the Systems engineering curriculum. At the same time, the valid mathematical training, received by all students, makes it possible, this course to be delivered to the other studying specialties.

As a starting point in the development of the BAI training program, as included in the AIT and EI disciplines, we have employed the Curriculum Guidelines for Intelligent Systems provided by the Association of Computing machinery (ACM) and IEEE Computer Society [1], [2].

The guidelines for the content of the program for training on AI, are included the section Intelligent systems, of the 2013 issue of the ACM Curriculum Guidelines for Undergraduate Degree Programs in Computer Science, [1].

According to ACM, the AI should provide the human with decisions related with:

- sensing (e.g., speech recognition, natural language understanding, computer vision),
- problem-solving (e.g., search, planning),
- and acting (e.g., robotics);
- and the architectures needed to support them (e.g., agents, multi-agents).

Also as a basis of the course, we have used the seminal book of Russel and Norvig *Artificial Intelligence: A modern approach* (AIMA) [3] – accepted as a standard in presenting the AI principles and used as a fundament for more than 1400 AI courses all over the worlds.

The AI training should provide the engineer with the ability to understand whether particular AI approach is appropriate for the solving of particular problem, to be able to apply it and evaluate the results.

Considering that AI is an important part of the cyber-physical systems, we aimed to assure, the students to become familiar with the necessary theoretical and practical background. In this way they will be able to apply and develop the necessary ideas and conceptions. Apparently, the AI training should be based on the already established foundations trough the others fundamental and specialized studying disciplines, already taught in UCTM.

In a nutshell – the training program should be structured in such a way, so the students be able to understand all important aspects of the AI. At the same time, they have to use the mathematical basis already received. All of this should be synchronized with the rest of the disciplines taught in the University.

There was one more goal, which we aimed. We tried to minimize the expenses, without affecting the reaching the general goals. We have used in great extend the wealth of free and open source tools available. This include the program language, development environments, operating systems.

The rest of this paper is organized as following. The Training program section is split on three subsections – Theory, Practice and Examination, In the **Theory**, one briefly presents the content of the theoretical part of the BAI course. The subjects covered in the training material are presented. Short information about the content of the theoretical lections is provided in a separate section called **Lections**. Then in the subsection **Practice**, we describe the way we organized the process of gaining of AI related practical skills. The working places provided to the students are presented. The examination options are mentioned in subsection **Examination**.

2. The training program: Theory

This part of the program includes a set of subjects, aimed to be taught in auditoriums. The goal is the students to be provided with some theoretical knowledge about the subject.

The theoretical part of the BAI course includes the following basic subjects:

- Base concepts – intelligent behavior, problem solving the concept of agent
- Search strategies – problem formulation, heuristic, informed and uninformed search. Knowledge collection.
- Knowledge representation. Methods for collecting and storing of knowledge.
- Machine learning – which is defined [3] as methods to adapt to new circumstances and to detect and extrapolate patterns.
- Knowledge processing.

During the of the structuring of the BAI course, we followed from one side – the agent-oriented approach, adopted by AIMA. And from another the necessity this approach to be supported by the appropriate mathematical tools. We tried to assure that the students will receive a balanced volume of knowledge in the following three areas:

- Rational agents,
- Search (including classification) methods,
- Training methods.

The acquaintance with these three basic areas is supported by introducing the basic terms, history, and AI theory as well as its practical applications. This separation, which is big extend corresponds to the directions where the AI follows at the moment, will allow the students, interested in their development as scientists to be able to choose the most appropriate for themselves area for specialization.

The subjects are oriented to the apparatus, necessary to manage the rational agents. In the same time it is supported by the theoretical knowledge, received in UCTM during the general courses on Mathematics, Physics, Electronics, taken during their first and second year, and courses on Statistical modeling, Theory of Automation etc.

A separate set of subjects to serve as a extension of the already received mathematical knowledge we included also:

- Mathematical logic,
- Probability theory,
- Linear algebra.

Lectures

An outline of the lectures, which will be included in the BAI discipline.

- AI history, basic definitions
- Agents – intelligent agent, environment
- Uninformed search. Search strategies
- Heuristic informed search
- Adversarial search
- Machine learning
- Probabilities – motivated search, hidden Markov models
- Logics – knowledge operating agents, logical agents
- AI applications
- Deep learning. Convolution networks, Generative adversarial networks (GAN)
- Robotics
- The TinyML concept

The AI theory in terms of applications, tools, concepts and even taxonomy develops so rapidly, that the set of lectures most probably will be reshaped significantly in the near future.

3. The training program: Practice

In the traditional setup of the technology education, the students should be provided with appropriately equipped laboratory, able to provide an environment, where a direct contact between the teacher and the students is provided. Also it should be possible some theoretical or practical lessons to be presented. Apparently, this environment should be open to online education methods.

A lot of experience, in the facilitating of the AI teaching was accumulated in the recent years. This includes development of an AI software able to play a game [4], inclusion of the science fiction themes [5], involving the game theory [6]. The involvement of robots is widely practiced in teaching robotics [7] as well as AI [8], [9]. The experience of usage in teaching AI of Neural as well Bayes networks is reported in [10], [11].

The technical solutions employed in AI teaching include the readymade solutions of LEGO и Handy Board [7], [12]. The used software usually is the one which is accompanying the respective platforms – usually based on C and JAVA [7]. It was reported that in *Bryn Mawr College*, UK [13] an entire training environment, based on Python, [14], [15], [16] has been developed and implemented. It is quite common the robots to be used (having price 200-250 USD), to be purchased by the students [14], [17].

There are two general approaches to illustrate the taught material – by using computer simulation and trough physical devices. Despite its obvious advantages a serious drawback of the usage of simulated objects is the lack of physical sense about the behavior of the agent [18]. The development of the simulation software as activity, evades the emphasis from the development of the AI algorithms (collecting data and reacting accordingly) to the attempts to increase the level of imitation of the real conditions (e.g. friction, centrifugal force etc.) which is not the main goal.

The idea to use the robot just as a tool for illustration of the behavior of a rational agent, by leaving enough space for development AI related algorithms is reported in [10], [11].

Greenwald и Artz [10] provide a detailed description of their experience in usage of a robot, developed by them, as an aide in teaching AI. In their solution they use IR sensors to determine the position of the robot. Additionally to the well-known fact that the IR sensors have difficulties to determine transparent objects, the authors notes that is the IR source is close and in the same time the IR source also emit heat – the readings of the sensor will be affected additionally.

Rational agent

Following AIMA [3], where the rational agent is the basic subject of the AI, as an illustrative tool we use a device, which is a simplified model of autonomic car. The main idea is, during the practical training, the students to develop AI algorithms (e.g. machine learning) aimed to provide the car with the ability to avoid obstacles.

Also, as long the agent represent a system of physical system (the sensors and actuators); a cyber system (the model housed in the PC); and the communications between the PC - the agent can be considered as a cyber-physical system of systems [19], [20].

According to the definition, provided by AIMA [3], "*agent* is anything that can be viewed as perceiving its environment through sensors acting upon that environments through actuators". AIMA also provides an explanation of several types of agents: "*A human agent has eyes, ears and other organs for sensors and hands, legs vocal tract and so on for actuators. The robotic agent might have cameras, and IR range finders for sensors and various motors for actuators. A software agent receives keystrokes, file contents, and network packets, as sensory inputs and acts on the environment by displaying on the screen …*"([3], page 34).

If we consider that the acceptable behavior of the agent is to avoid obstacles, then according to [3] a *rational agent* is an agent which based on the received information acts in order to maximize the result – for example to minimize the number of collisions.

Autonomous cars

Undoubtedly the autonomous cars become more and more challenging field of application of AI. Considering the level of autonomy one can classify them on six categories [21], [22] varying from zero level – All functionality and systems of the car are controlled by humans, to level five – The car is completely capable of self-driving in every situation. The basic elements of an autonomous car are as follows [23]:

- Sensors;
- Computer vision systems;
- Driving system, made of computer engine and memory

At this stage of the development of the technology all elements are mounted within the car. Only the systems used for observing the condition and the position of the car are placed outside. There is some progress towards taking out of its systems into a cloud. An idea for placing the memory of the car into a cloud is discussed in [24].

Students' individual working places

As it was mentioned above, one of our goals is to build up a system for AI teaching with minimal expenses, without affecting the efficiency of the training as well its attractivity to the students. Also we aimed not to be hooked with particular software or hardware vendor. This is the reason why we have chosen to use mainly free or open source software. Also, we decided to avoid that the option, where the students are supposed to buy some of the equipment (e.g [14], [17]). This will increase the expenses of the students; they will buy equipment which probably will not be used after the end pf the term. Also this will make us dependent of particular supplier. The robots, which will be used by the students are based on Arduino UNO R3 controller and are prepared in our department. The ML software is prepared on Python 3.xx.

As we aimed to concentrate the students' attention on the development of AI algorithms, while the robot to serve just as illustration, we choose a solution foe rational agent, where the controlled object (actuator) is separated from the computing engine.

This is the reason why one of the elements of the autonomous car – the computer and the memory is positioned outside the car in a desktop personal computer standing nearby. In this way the "passive agent" will possess only sensors and actuators, while the "intelligent block" will be housed in the nearby PC. The connection between the passive agent and the intelligent block will be performed trough Bluetooth connection. The system "passive agent" + "intelligent block" can be regarded as rational agent in the meaning defined in [3]. From another side, the passive agents conform with the SAE's definition [22] of autonomous car of level 5. Where the computing and memory storage resources are housed in a cloud.

The passive agent will have some memory and computing resources as long as they are provided with the Arduino UNO hardware. The main computing power as well the Internet connection will be stored as the "intelligent block" in the PC. The PC will be used both as development station, where the models will be developed, trained, and stored. The "passive agent" will provide data through its sensors, the data will be transferred to the "intelligent block", then appropriate commands will be directed back to the agent and its actuators.

The exercises will take place on individual working spots. The students will be given tasks to develop, train and apply AI algorithms, intended to manage the passive agents. Agents will collect data during the training stage. These data will be stored and manipulated in the PC. After that the trained models will control and rule the agents.

The working spot is made of:

- A personal computer with, equipped with AI development tools, also it will keep the already developed AI algorithm (e.g. Neural Net) and
- A passive agent.

The working spot should provide enough space for movement of the passive agent. The passive agents are constructed of a platform, which houses wheels with servo motors, Ultrasound sensor and Bluetooth communication with the PC. One can use four or more Ultrasound sensors, directed around the platform, or one sensor, which is continuously turning on 360^{o}. Also, a temperature/humidity/ Atmospheric pressure/ Height above mean sea level is added to provide a way for calibration of the readings of Ultrasound sensor.

An exersize

The goal is the students to get familiar with the process of training and usage of Neural Network.

The input layer of the Neural Net will consist the readings of the ultrasound sensor and the combined atmospheric sensor.

The output layer will consist of nodes, which corresponds to the servo motors and respectively – the wheels.

Training. The Student prepares a training filed, where some obstacles are positioned. The agent is connected through Bluetooth to the PC. The *training mode* is started.

The Student manages the agent to go through the training field by directing it through the arow keys of the PC keyboard. The student chooses the best way, the agent to avoid the obstacles, for instance providing enough space the agent to make a turn and where necessary to move backwards. Each step, which corresponds to a particular turning angle of the motor, represents one measurement. During each measurement the sensor readings (input data) and the motor movements (output data) are recorded.

All data from the measurements are transferred to the PC, where they are stored. In parallel the training of the Neural Net is performed. An appropriate algorithm for adjustment of the weights between the nodes is applied.

In this way the student can perform several training tours, where each tour has different ordering of the obstacles. In this way during the training process the Neural Net accumulate a big volume pf data containing different readings of the sensors and the respective correct movements of the motors.

Usage. The student prepares new ordering of the obstacles. This ordering should be used in the training phase. This is equivalent of the testing phase in the Neural Nets training. The Agent is started in *working mode.* The sensors start to provide data to the already trained Neural Net, which in turn controls the motors of the wheels. Depending of the commands the agent goes ahead, back or turns left/right.

The main goal of this exercise is the student to gain intuitive understanding about the type and quantity of the data, the necessary for training of an AI system. Also to get some practical skills about the physics of the movement of the agent, friction of the wheels, how important is the time for reaction, compared with the time for data transmission between the car (agent) and the cloud (the network in the PC) etc.

One can consider the organization of tournaments between the students, where the time of training and the number of violated obstacles can be scored.

As a concluding stage the accumulated knowledge and experience can be communicated in after-class "group conversations" [25], where the instructor can provide video recordings of the tournaments, while te students can discuss and share knowledge and opinions regarding the AI algorithms, their efficiency, the difficulties of any kind etc.

4. The training program: Examination

An appropriate system for evaluation of the level of the theoretical knowledge and practical skills, received by the students should be provided too.

The presented both theoretical and practical training programs, allow different types of examination. They can be performed separately or in combination

- Classical written exam, where the student writes an essay on a subject based on the themes included in the Lections presented during the term.
- Project based examinations, which include teamwork for choosing and applying of AI algorithm, which will allow the robot to avoid the obstacles.
- Tournaments on robot training to handle particular scheme of obstacles for a time, based on particular algorithm. In this case the students should balance between the need of many data for training and time necessary to perform the training. So, they have to be creative in designing the training process;

- Essays on subjects, related with conceptual AI problems. E.g. benefits of AI, threats from AI, moral and ethical issues, etc.

5. Conclusion

The paper presents a concept for a training AI program. The concept is based on the ACM requirements for AI training as well as the methodic described in AIMA [3].

As a tool for illustration of the theoretical concepts, to facilitate the gaining of practical and intuitive understanding of the AI concept, the students are provided with low cost but effective individual exercise spots. Each spot is equipped with a small robot, a computer and an environment for development and usage of AI tools.

The teaching methodology described here also familiarizes the students with a typical cyber-physical system, where the typical components of the CPS are involved – computing, physical and communication.

Additionally, the student will receive base knowledge for some of the specifics of the cloud architectures used in controlling of autonomous cars.

Contrary to the widely applied training programs, which include robots, here the emphasis is put on gaining of practical experience in the development and usage of AI algorithms, rather than usage of the robots. In this case the robot, which is used as passive agent, is employed as a demonstration tool.

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