Fuzzy Logic++: Towards Developing Fuzzy Education Curricula Using ACM/IEEE/AAAI CS2023

Christian Servin, Brett A. Becker, Eric Eaton and Amruth Kumar

Abstract Fuzzy Logic education has been considered part of artificial intelligence, which in many cases, can be found in the *electives* curricula or, inclusively, at the graduate studies for the past decades. Because of the persistent emergence of computing areas, such as Artificial Intelligence and Machine Learning, Robotics, and others, there is an appetite for recognizing concepts on intelligent systems in undergraduate education. The ACM/IEEE/AAAI Computer Science Curricula, also known as CS2023, has proposed significant changes from the last version CS2013, particularly in artificial intelligence. These proposed recommendations will have an impact in the next ten years in computer science undergraduate education, including fundamentals of computer programming. This work presents the changes that may impact computer science education curricula, particularly the knowledge areas and competencies model that will influence fuzzy logic education and computing. We also present the intersection of knowledge areas in fuzzy logic, especially for explainable AI.

Christian Servin
Information Technology Systems Dept., El Paso Community College,
919 Hunter Dr., El Paso, TX 79915-1908, USA, e-mail: cservin1@epcc.edu

Brett A. Becker
School of Computer Science and Informatics, University College Dublin
Belfield, Dublin 4, Ireland e-mail: brett.becker@ucd.ie

Eric Eaton
Computer and Information Science Dept., University of Pennsylvania,
3330 Walnut Street, Philadelphia, PA 19104-6309, USA, e-mail: eeaton@seas.upenn.edu

Amruth Kumar
Computer Science, Ramapo College of New Jersey,
505 Ramapo Valley Road, Mahwah, NJ 07430-1680, USA, e-mail: amruth@ramapo.edu

1 Introduction

Fuzzy logic is a valuable tool for addressing the challenges of uncertainty and imprecision in AI applications. Its ability to model complex systems and make decisions based on incomplete or uncertain information makes it a valuable component of many AI systems, e.g., [2, 16, 17]. Therefore, there is a need to recognize concepts from fuzzy logic that can be intersected by curricula recommendations and then offer them in computer science programs.

Another important direction of artificial intelligence that has high-impact in society nowadays, specially with ideas on ethics, diversity, equity, inclusion, and justice is *Explainable AI (xAI)*[6, 19]. AI techniques such as deep learning, face challenges in proving explanations on their final results, specially when these generated conclusions and recommendations are not necessary the optimal ones or they rely in a set of rules from a ”black box” algorithm. Therefore, it is desirable to provide explanation to these solutions through xAI.

Fuzzy logic concepts and topics have been offered at higher-level computer science courses, such as special topics, electives, or even graduate studies. Recognizing these topics in other courses has been challenging unless it is a specialized study area, such as Artificial Intelligence (AI) or intelligent system study track. Due to the significant changes in technology and computing, such as the introduction of Large Language Models (LLM), intelligent systems, recognition, society, ethics, professionalism processing information, uncertainty, and ambiguity, these concepts on AI are now part of the CS curricula.

In this work, authors recognize several *knowledge areas* that are part of the CS2023 curricular guideline that highlights areas of interest in the fuzzy logic community. These areas promise topics, learning outcomes and professional competencies that potentially can increase the concepts in fuzzy logic through knowledge areas in artificial intelligence, specialized platforms development, and society, ethics, and professionalism.

2 About ACM/IEEE/AAAI CS2023: Updates and Concentrations

In the Spring of 2021, the joint work of the Association of Computing Machinery (ACM), the Institute of Electrical and Electronics Engineering – Computer Society (IEEE-CS), and the American Association of Artificial Intelligence (AAAI) started the effort to revise undergraduate Computer Science curricular guidelines issued once every ten years, currently referred to as CS2023. The work comprises 18 Knowledge Areas (KA), covering significant concepts in the most influential computer science areas: Algorithms and Complexity (AL), Architecture and Organization (AR), Artificial Intelligence (AI), Data Management (DM), Graphics and Interactive Techniques (GIT), Human-Computer Interaction (HCI), Mathematical and Statistical Foundations (MSF), Modeling (MOD), Networking and Communication (NC), Operating Systems (OS), Parallel and Distributed Computing (PDC), Programming Languages (PL), Security (SEC), Society, Ethics, and Professionalism (SEP), Software Development Fundamentals (SDF), Software Engineering (SE), Specialized Platform Development (SPD), and Systems Fundamentals (SF).

CS2023: Selected Updates

Several updates are considered in the CS2023 version; many of these details can be found at [15]. This section discusses selected changes/updates that impact the fuzzy logic education aspects.

Knowledge Area Renamed. A total of eight knowledge areas have been renamed to emphasize their focus that contemporary contextualizes in computer science. Three of these areas are:

- Intelligent Systems (IS), now is called *Artificial Intelligence (AI)*
- Platform Based Development (PBD), now is called *Specialized Platform Development (SPD)*
- Social Issues and Professional Practice (SP), now is called *Society, Ethics, and Professionalism (SEP)*

Core and Knowledge Hours. In the previous CS2013 work, core hours were defined in *Tier I* and *Tier II*, implying that computer science programs were expected to cover 100% of Tier I (165 hours covered) core topics and at least 80% of Tier II (143 hours) topics. In the CS2023 adopted the definition of the Computer Science (CS) Core and the Knowledge Area (KA) core, where

- CS core – topics that every Computer Science graduate must know
- KA core – topics that any coverage of the Knowledge Area must include.

Several KAs have grown significantly in CS Core, including Artificial Intelligence, Specialized Platform Development, Society, Ethics, and Professionalism.

Incorporating Society, Ethics, and Professionalism as a Knowledge Unit Due to the emerging changes in society and technology, the computer science society recognizes the need to incorporate the SEP considerations and responsibilities in each knowledge area from this work. These aspects influence each knowledge area depending on the competency area to which they belong, i.e., *software*, *systems*, *applications*, and the *theoretical foundations of computer science.*

Characteristics of Computer Science Graduates. Based on the computer science education community and industry's input, the CS2023 lists several characteristics that CS Graduates should have. Some of the ones include:

- Algorithmic problem-solver – Good solutions to common problems at an appropriate level of abstraction

- Cross-disciplinary – understanding of non-computing disciplines
- Handle ambiguity and uncertainty
- Strong mathematical and logical skills

The fuzzy logic community shares similar characteristics to computer science graduates, especially since: many of the applications in fuzzy require an understanding of cross-disciplinary work; how to incorporate effective solutions to cover different levels of abstraction; the fact that fuzzy logic requires an understanding of mathematical concepts such as fuzzy sets and, perhaps the most significant one that is, handle uncertainty, since fuzzy systems are designed to process ambiguity and uncertainty.

3 Knowledge Areas Intersecting Fuzzy

Although there are 18 KA in CS2023 that have impact in fuzzy logic education, there are three main ones that have a thoroughgoing impact in fuzzy: Artificial Intelligence, Specialized Platform Development, and SEP.

Fuzzy Logic Intersecting Artificial Intelligence Education. Fuzzy logic is related to artificial intelligence (AI) in several ways. Fuzzy logic is a mathematical framework for dealing with uncertainty and imprecision, an important component of many AI applications. Fuzzy logic can be used to:

- model complex systems and make decisions based on incomplete or uncertain information. This is crucial in many AI applications, such as expert systems, decision support systems, and autonomous agents, e.g., see [29];
- basis for machine learning algorithms. For example, fuzzy clustering algorithms can be used to group data points based on their similarity. In contrast, fuzzy decision trees can classify data based on a set of rules, e.g., see [13, 22, 28];
- model human reasoning and decision-making. This can be useful in developing intelligent systems that are more natural and intuitive for humans to interact with, e.g., see [1, 4, 32];
- control complex systems like robots or industrial processes. These systems can be made more flexible and adaptive to changing conditions by using fuzzy logic controllers, e.g., see [3, 5, 9, 31];

Specialized Platform Development is Important to Support Intelligent Computing Curricula: Because of the new emerging technology and rapid growth of technology and ubiquitous computing, there is a need for:

- platforms that support mobile and web development to provide accessibility to many applications and software available;
- platforms that support iterative development, such as Large Language Models (LLM) and tools that employ deep generative models (e.g., *ChatGPT*, *DALL-E*, *Midjourney*);

- platforms that support Robotics/Drone development focus on hardware, constraints/considerations, and software architectures.

From the education viewpoint, there are several best practices that use specialized platforms to disseminate and demonstrate computing curricula. For example, in [21], authors have successfully demonstrate software development principles using various low-cost and accessible environments, such as *Raspberry PIs* and *Arduinos* for Robotics and Drone programming. In [7], authors demonstrate computational thinking principles using Robotics in a Middle School environment. In [11], authors used a mobile platform called *App Inventor* to teach CS principles.

Concepts in SEP are important to Explainable Fuzzy (xAI). The KA Society, Ethics, and Professionalism is now part of every KA for CS2023 as a KU. Since AI is ubiquitous, some important ethical considerations and responsibilities are essential for computer science education. The Intelligent computing considerations include *transparency*, *privacy*, *accountability*, *safety*, *human oversight*, and *fairness*. The last two, in particular, partly motivate this section. Humans should be able to intervene and correct errors or biases in AI systems when necessary. This will lead to recognizing aspects on **j**ustice, **e**quity, **d**iversity, and **i**nclusion, often referred to as JEDI. This AI ubiquity has reactivated ethical dilemmas that have been in humanity for decades or centuries, such as the *trolley dilemma* [10, 25, 27], in addition, to introduce challenges in the engineering, biometric technologies, and algorithmic decision-making systems, in civic life through recognizing human characteristics including facial recognition, skin colors, bringing concerns on diversity, equity, and inclusion, e.g., see: [12, 20, 30]. The xAI introduces flexibility in determining solutions in a more *humanistic* perspective. The concept of *justice* is quite often hard to define in intelligent systems, especially since the main concept is completely *ambiguous* and *"blind"*, it has a degree of matter and is defined based on expert consideration. In other words, it is *fuzzy*.

Therefore, this work is an opportunity to incorporate educational recommendations into multidisciplinary areas. Mainly, this work focuses on the following knowledge areas of interest: Artificial Intelligence, Specialized Platform Development and Society, Ethics, and Professionalism.

4 Fuzzy Education: Beyond Knowledge Areas

Educators have proposed strategies and techniques for teaching fuzzy concepts/topics in higher education, such as [14, 24, 26]. Authors have even proposed a "fuzzy" flavor on concepts covered in computer science fundamentals, such as Data Structures and Algorithms courses, e.g., [8] or [18]. These works introduce fuzzy in the first two years of computer science. Additionally, there is existing *mapping* to learning outcomes proposed to the previous CS2013 version [23] that can help educators introduce fuzzy-based concepts in computer science fundamentals.

These are several of the topics proposed in the current version of the CS2023 project that impacts fuzzy. In this section, we concentrate on the following three areas.

Artificial Intelligence (AI)

Artificial intelligence has become commonplace in many areas, such as businesses, news articles, and everyday conversation, for years, primarily driven by high-impact machine learning applications. These advances were made possible by the widespread availability of large datasets, increased computational power, and algorithmic improvements. In particular, a shift from engineered representations to representations learned automatically through optimization over large datasets. The resulting advances have put such terms as “neural networks” and “deep learning” into everyday vernacular. These are some of the knowledge units with their corresponding learning outcomes under Artificial Intelligence KA that are now part of the computer science core and that can be applied to topics of fuzzy logic.

- AI: Fundamental Issues
  - **AI-FUN-01** Additional depth on problem characteristics with examples
  - **AI-FUN-02** Additional depth on nature of agents with examples
  - **AI-FUN-03** Additional depth on AI Applications, growth, and Impact (economic, societal, ethics)
- AI: Algorithms Search / Fundamental Data Structures and Algorithms
  - **AI-SEA-01** Design the state space representation for a puzzle (e.g., N-queens or 3-jug problem)
  - **AI-SEA-02** Select and implement an appropriate uninformed search algorithm for a problem (e.g., tic-tac-toe), and characterize its time and space complexities.
  - **AI-SEA-03** Select and implement an appropriate informed search algorithm for a problem after designing a helpful heuristic function (e.g., a robot navigating a 2D gridworld).
  - **AI-SEA-04** Evaluate whether a heuristic for a given problem is admissible/can guarantee an optimal solution
  - **AI-SEA-05** Design and implement a genetic algorithm solution to a problem.
  - **AI-SEA-06** Design and implement a simulated annealing schedule to avoid local minima in a problem.
  - **AI-SEA-07** Apply minimax search with alpha-beta pruning to prune search space in a two-player adversarial game (e.g., connect four).
- AI: Fundamental Knowledge Representation and Reasoning
  - **AI-REP-01** Given a natural language problem statement, encode it as a symbolic or logical representation.

- **AI-REP-02** Explain how we can make decisions under uncertainty, using concepts such as Bayes theorem and utility.
- **AI-REP-03** Make a probabilistic inference in a real-world problem using Bayes' theorem to determine the probability of a hypothesis given evidence.
- **AI-REP-04** Apply Bayes' rule to determine the probability of a hypothesis given evidence.
- **AI-REP-05** Compute the probability of outcomes and test whether outcomes are independent.

- AI: Machine Learning
  - **AI-ML-01** Describe the differences among the three main styles of learning: supervised, reinforcement, and unsupervised.
  - **AI-ML-02** Differentiate the terms of AI, machine learning, and deep learning.
  - **AI-ML-03** Frame an application as a classification problem, including the available input features and output to be predicted (e.g., identifying alphabetic characters from pixel grid input).
  - **AI-ML-04** Apply two or more simple statistical learning algorithms (such as k-nearest-neighbors and logistic regression) to a classification task and measure the classifiers' accuracy.
  - **AI-ML-05** Identify overfitting in the context of a problem and learning curves and describe solutions to overfitting.
  - **AI-ML-06** Explain how machine learning works as an optimization/search process.

Specialized Platforms Development (SPD)

Emerging Computing Areas such as data science/analytics – use multi-platforms to retrieve sensing data. Cybersecurity – involves protecting specific data extraction, recognizing protocols to protect network transfer ability, and manipulating it. Artificial intelligence and machine learning – use artifacts that retrieve information for robotics, drones to perform specific tasks, and other platforms that perform data analysis and visualizations. These are some of the learning outcomes from selected knowledge units under SPD KA that are now part of the computer science core and that can be applied to topics of fuzzy logic.

- Describe how the state is maintained in web programming
- Implement a location-aware mobile application that uses data APIs.
- Implement a sensor-driven mobile application that logs data on a server
- Compare robot-specific languages and techniques with those used for general-purpose software development
- Discuss the constraints a given robotic platform imposes on developers
- Interactively analyze large datasets
- Create a program that performs a task using LLM systems
- Contrast a program developed by an AI platform and by a human

Society Ethics and Professionalism (SEP)

The SEP KA is extensible. Each KA in CS2023 possesses a KU that focuses on SEP. These knowledge units under SEP KA are now part of the computer science core and can potentially be topics of fuzzy logic, particularly Explainable Fuzzy AI.

- Social implications of computing in a hyper-networked world where the capabilities of artificial intelligence are rapidly evolving
- Impact of involving computing technologies, particularly artificial intelligence, biometric technologies and algorithmic decision-making systems, in civic life (e.g. facial recognition technology, biometric tags, resource distribution algorithms, policing software)
- Interpret the social context of a given design and its implementation.
- Articulate the implications of social media use for different identities, cultures, and communities.
- Ethical theories and decision-making (philosophical and social frameworks)
- Define and distinguish equity, equality, diversity, and inclusion
- From AI: Applications and Societal Impact
  - **AI-SEP-01** Given a real-world application domain and problem, formulate an AI solution to it, identifying proper data/input, preprocessing, representations, AI techniques, and evaluation metrics/methodology.
  - **AI-SEP-02** Analyze the societal impact of one or more specific real-world AI applications, identifying issues regarding ethics, fairness, bias, trust, and explainability
  - **AI-SEP-03** Describe some of the failure modes of current deep generative models for language or images, and how this could affect their use in an application.

5 Summary and Discussion

This paper describes selected knowledge areas of fuzzy logic from the new ACM/IEEE/AAAI CS2023 curricula project. The CS2023 project proposes significant changes from its previous version CS2013. Significant changes include increasing computer science core hours in knowledge areas related to fuzzy logic, such as artificial intelligence, specialized platform development, society, ethics, and professionalism, impacting xAI areas. Another feature of the project is the recognition of the ability to process uncertainty/ambiguity as one of the characteristics of graduate students. This characteristic governs the philosophy behind fuzzy logic. The Artificial Intelligence KA recognizes areas and topics that impact curricular considerations in computer science. Many of these topics cover fundamentals knowledge representation and reasoning and machine learning – topics that are often used in the fuzzy community. The specialized platform development KA is used to provide vehicles for development. Software and applications are now developed in specialized platforms such as mobile, robotics, and interactive ones. Therefore, this area connects learning outcomes and platforms for the future development of fuzzy systems. Finally, society, ethics, and professionalism cover topics that impact society and humankind. Explainable AI frameworks help systems to understand and interpret predictions made by machine learning models, especially the ones that are a matter of degree, i.e., concerns/inquiries provided under the SEP. Future work includes: packaging a course in Fuzzy Logic or Explainable Fuzzy Logic that can cover several knowledge units from various KAs, emphasizing fuzzy challenges. Fuzzy logic aligned to Artificial Intelligence recognizes real-world applications and challenges for the following years; it is of interest to this curricular practice to capture many aspects that infuse into the computing curriculum. Finally, one of the ultimate objectives of this work is to create best practices for these KAs and discover competencies that can impact areas in fuzzy logic.

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