

Learning and Analytics in Intelligent Systems 39

George A. Tsihrintzis
Maria Virvou
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Advances in Artificial Intelligence-Empowered Decision Support Systems

Papers in Honour of Professor
John Psarras

 Springer

Learning and Analytics in Intelligent Systems

Volume 39

Series Editors

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George A. Tsihrintzis · Maria Virvou ·
Haris Doukas · Lakhmi C. Jain
Editors

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*A good decision is based on knowledge and
not on numbers.*

—Plato

Preface

It is certainly hard to understate the importance of decision-making¹ as everyone is faced with hard or not-so-hard decisions daily and the decisions we make often have a strong long-term impact on our lives or on the lives of others. Some decisions may even alter the course of history and history books are full of examples of the consequences of “bad” or “erroneous” decisions as well as the benefits of “good” or “correct” decisions.²

It is easier to pass a *posterior* judgement on a decision made, but making the right decision *in time* may turn out quite challenging. The question “how are good decisions made?” is, thus, of crucial importance. In the face of this question, educated/informed decisions are the best, as they consider accumulated knowledge, related facts, previous relevant experiences of others, as well as the outcome of past decisions in similar situations.³

When faced with a decision, analyzing all facts and using relevant knowledge certainly requires both time and effort.⁴ However, in many cases the required time and effort for this analysis may not be available and it may be critical to decide very fast. Moreover, only limited previous knowledge may be available on the matter on which the decision is to be made.

This is where Decision Support Systems (DSS) may prove particularly useful and helpful. DSS are software and information systems which support and facilitate decision-making processes in organizations, especially at the high, unstructured, and unspecified level. Toward their goal, DSS make use of various data and business models, employ advanced data analytics procedures, and access extensive databases and data warehouses to facilitate with a decision process or with organizational

¹ “Nothing is more difficult, and therefore more precious, than to be able to decide.”—Napoleon Bonaparte.

² “If your choices are beautiful, so too will you be.”—Epictetus.

³ “A good decision is based on knowledge and not on numbers.”—Plato.

⁴ “Hasty work and premature decisions may lead to penalties out of all proportion to the issues immediately involved.”—Winston Churchill.

issues. DSS have proven to be particularly useful at the strategic level, while they usually require only limited computer-proficiency skills from their users.

Contemporary DSS are undergoing a significant evolution, as they increasingly incorporate streamlined Artificial Intelligence (AI) technologies into their software. This integration enables DSS to provide recommendations and make informed decisions with reduced human intervention. AI-empowered DSS can effectively analyze vast datasets and extract valuable insights to support decision-making processes across diverse domains, while their applicability is constantly being extended to novel domains, industries, and sectors.

With this book, we are undertaking a dual task. On one hand, we are editing a special book in Prof. John E. Psarras's honor,⁵ while, on the other hand, we are attempting to update both specialized researchers and general readers, on the most recent advances in AI-empowered DSS. The book consists of 16 chapters, each of which has been authored by active and recognized researchers and reports on recent research and development findings. Overall, the book includes an editorial note (introductory chapter) and is structured into five parts, namely: (1) *AI-Empowered DSS in Medical Diagnosis and Biology* (three chapters), (2) *AI-Empowered DSS in Healthcare and Health Insurance* (three chapters), (3) *AI-Empowered DSS in Urban Matters* (three chapters), (4) *Various Applications of AI-Empowered DSS* (three chapters), and (5) *Novel AI-Empowered Methodologies in Decision-Making* (three chapters).

Even though the area of AI-empowered DSS is very broad, we attempted to cover it in terms of both *breadth* and *depth*. We hope that we were successful, at least to some extent. Of course, several aspects and areas of application of AI-empowered DSS may have been insufficiently addressed in this edition of the book. We hope to address them in future editions, especially as Society continuously presses for better DSS and novel DSS applications.

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Haris Doukas
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⁵ For selected impactful works of Prof. John E. Psarras, the reader is directed to https://scholar.google.com/citations?user=AMoT_2wAAAAJ&hl=en or to a list in the first book chapter.

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Chapter 1

Introduction to Advances in Artificial Intelligence-Empowered Decision Support Systems



George A. Tsihrintzis, Maria Virvou, Haris Doukas, and Lakhmi C. Jain

Abstract Contemporary Decision Support Systems increasingly incorporate Artificial Intelligence technologies, enhancing their trustworthiness and robustness of autonomy and expanding their applicability across various new domains. These Artificial Intelligence-empowered approaches prove to be very effective and include: (1) Intelligent decision-making systems, in which expertise, knowledge, and Artificial Intelligence are integrated, (2) Decision support via tailored recommendations that provide personalized and group recommender systems, (3) Dynamic decision support to address limited and imbalanced data, (4) Transparent and ethical decision support, ensuring explainability, trust, and responsibility, and (5) Novel Software Engineering, verification and evaluation methodologies. The book at hand aims at exposing its readers to some of the most significant recent advances in Artificial Intelligence-empowered Decision Support Systems, while at the same time honouring Professor John E. Psarras, a world-renowned researcher in this area. The book is directed towards professors, researchers, scientists, engineers, and students in all Computer Science, Artificial Intelligence and Decision Support Systems disciplines. It is also directed towards readers who come from other disciplines and are interested in becoming versed in some of the most recent Artificial Intelligence

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technologies as they empower Decision Support Systems. An extensive list of bibliographic references at the end of each chapter guides its readers to probe further into the application areas of interest to them.

Keywords Artificial intelligence · Machine learning · Deep learning · Decision support system · Explainable artificial intelligence · Trustworthy and responsible artificial intelligence · Artificial intelligence-empowered system

1.1 Editorial Note

Decision Support Systems (DSS) can be defined as Software and Information Systems which make use of various data and business models, employ advanced data analytics procedures, and access extensive databases and data warehouses to facilitate with a decision process or with organizational issues. DSS have proven to be particularly useful at the high, unstructured, and unspecified strategic level, while they usually require only limited computer-proficiency skills from their users.

Contemporary DSS are undergoing a significant evolution, increasingly integrating state-of-the-art Artificial Intelligence (AI) technologies into software evolution as exemplified in [1, 2]. This integration enhances the autonomy of DSS, enabling them to make informed decisions and provide recommendations with reduced human intervention. By employing AI methodologies in knowledge-based software development as in [3], DSS can effectively analyze vast datasets and extract valuable insights to support decision-making processes across diverse domains. Furthermore, this AI-driven enhancement extends the applicability of DSS to novel domains, as noted by [4, 5]. Through advancements in machine learning [6], deep learning [7] and paradigm fusion [8] technologies, contemporary DSS are enabled to employ decision support across various industries and sectors, as highlighted in [9, 10], as well as in [11–13].

These Artificial Intelligence-empowered approaches prove to be very effective and include:

- *Intelligent Decision-Making Systems—Expertise, Knowledge, and AI Integration:* This category refers to DSS that incorporate expertise, knowledge, and AI technologies to facilitate informed decision-making processes in collaboration with humans resulting in the emerging era of human-AI interaction [14], emphasizing the importance of AI-experts in decision-making contexts [15].
- *Decision Support via Tailored Recommendations—Personalized and Group Recommender Systems:* This category pertains to DSS that provide tailored recommendations to individuals or groups, spanning many application sectors [16], such as the medical domain (e.g. [17]), production planning and scheduling [18], energy [19–25], education [26], human resources [27], environmental issues [28]. Tailored recommendations include many advances in personalization, such as

sentiment analysis and affect recognition [29], or fatigue [30], reasoning [31], or individual similarity perception based on objective feature subset selection [32].

- *Dynamic Decision Support—Addressing Limited and Imbalanced Data*: This category refers to DSS equipped to dynamically address the complexities of limited and imbalanced data. For instance, recent advancements in this area include efforts to address imbalanced data in predicting undeclared work [33].
- *Transparent and Ethical Decision Support—Ensuring Explainability, Trust, and Responsibility*: This category encompasses DSS that prioritize transparency, including explainability [34], trustworthiness [35], privacy [36], data protection [37] and other ethical considerations highlighting the need for responsible data usage and decision-making to assist humans [38].
- *Novel Methodologies for Software Engineering and Software Verification and Evaluation*: These methodologies include state-of-the-art advances towards the materialization of a vision in which AI and humans collaborate as partners to co-create business and social values in software development and operations [39]. They also include the application of AI in assisting with various programming tasks that arise as the increasing complexity and scale of software development has rendered traditional programming methods more time-consuming and more error prone [40]. Software verification and evaluation include AI-empowered methodologies for regression-based software defect estimation [41] or methodologies that aim at ensuring the overall safety of machine learning systems [42]. Moreover, evaluation of software is a challenging and ever evolving field that must be addressed with holistic approaches to ensure that new software products or AI-enhanced novelties are indeed progressing the technological methods without compromising any of the previously generally acknowledged quality standards (e.g. [43, 44]).

The pace of these significant advancements has created a noticeable gap in the literature concerning the latest developments in DSS technology. This book aims to fill the gap, offering valuable insights to a wide range of readers.

More specifically, the objectives of the book are twofold: Firstly, it pays tribute to Prof. John E. Psarras for his extensive contributions to the DSS field, both in theoretical frameworks and practical applications, as listed in the section on **John E. Psarras: Selected Impactful Research Works**.¹ Secondly, the book aims to introduce readers to the latest advancements in AI-empowered DSS and related technologies. Targeted towards academics, researchers, practitioners, and students in Computer Science, Artificial Intelligence and Management, this work is also accessible to individuals from other disciplines interested in the cutting-edge developments of AI-empowered DSS technologies. Our aspiration is that it will serve as a source of inspiration and a useful resource in professional endeavours and research activities.

The book consists of an editorial chapter (this chapter) and an additional fifteen (15) chapters. All chapters in the book were invited from authors who work in the

¹ Also see https://scholar.google.com/citations?user=AMoT_2wAAAAJ&hl=en.

corresponding chapter area and are recognized for their significant research contributions. In more detail, the chapters in the book are organized into five parts, as follows:

The *first part* of the book consists of three chapters devoted to *AI-empowered DSS in Medical Diagnosis and Biology*.

Specifically, Chap. 2, by Evangelos Karampotsis, Evangelia Panourgias and Georgios Dounias, is on “Artificial Intelligence in Breast Cancer Diagnosis: A Review”. The authors present an in-depth review of a large number of intelligent approaches related to the support of breast cancer diagnosis taken in recent years.

Chapter 3, by Adesh Rukmangad, Ajinkya Deshpande, Ankush Jamthikar, Deep Gupta, Ankit Bhurane, and Nisha B Meshram, is on “Classification of H&E-stained Liver Histopathology Images Using Ensemble Learning Techniques for Detection of the Level of Malignancy of Hepatocellular Carcinoma (HCC)”. The authors propose and comparatively evaluate a novel deep learning-based ensemble model, which shows a better HCC prediction accuracy than most previously published works.

Chapter 4, by Swapnil Sharma Sarker, Kazi Toufique Elahi, Raufun Talukder Raktim, Anika Tasnim Aurin, and Shamim Akhter, is on “Performance Analysis of Deep Learning Models on Chemokines Protein Group Using Structure-Based Pattern Detection”. The authors assess the performance of AlphaFold 2 deep learning model on the Chemokines protein group and identify patterns in which the model performs very poorly.

The *second part* of the book consists of three chapters devoted to *AI-empowered DSS in Healthcare and Health Insurance*.

Specifically, Chap. 5, by Evgenia Psarra and Dimitris Apostolou, is on “Dynamic and Personalized Access Control to Electronic Health Records”. The authors present their research work on creating machine learning methods dependent on patients’ medical information and integrating them with an Attribute Based Access Control (ABAC) paradigm in e-Health.

Chapter 6, by Laura Verde, Michele Caterino, Raffaele Chianese, Margherita de Maria, Rosario Iorio, and Stefano Marrone, is on “A Care Oriented Decision Support System based on Ensemble Methods”. The authors describe a Machine Learning-based Decision Support System able to estimate the capability of patients to sustain oncologic therapy.

Chapter 7, by Raúl G. Sanchis, Francisco Moraleda and Arminda Moreno, is on “Clustering Analysis of Spain at the Regional Level for the Life Insurance Sector”. The authors use four different models to conduct a clustering analysis of regions of Spain which, in turn, allows the region ranking with respect to two distinct criteria.

The *third part* of the book consists of three chapters devoted to *AI-empowered DSS in Urban Matters*.

Specifically, Chap. 8, by Margarita N. Favorskaya, is on “Knowledge-based Commercial Real Estate Recommender System”. The author introduces the theoretical foundations of decision marking for finding commercial real estate based on collaborative filtering, content, knowledge, and hybrid filtering, with special attention paid to methods using knowledge representation models.

Chapter 9, by Rafael Ramírez Eudave, Tiago Miguel Ferreira and Romeu Vicente, is on “Machine Learning-assisted Identification of Vulnerable Historic Buildings in Urban Environments”. The authors make use of parameter-based screenings of historical cities to assemble an urban-scale database that is further used for assessing the analytical vulnerability of historical constructions based on existing intensity/damage models.

Chapter 10, by Yuliya Kuvayskova, Vladimir Klyachkin and Victor Krasheninikov, is on “Potable Water Quality Assessment using Machine Training Methods”. The authors make use of several Machine Learning and Fuzzy Logic approaches to assess the quality of potable water.

The *fourth part* of the book consists of three chapters devoted to *Various Applications of AI-empowered DSS*.

Specifically, Chap. 11, by Konstantinos Liagkouras and Konstantinos Metaxiotis, is on “Extracting Sentiment from Business News Announcements for more Efficient Decision Making”. The authors propose a novel system that extracts sentiment from regulatory news announcements which can help achieve more efficient decision making.

Chapter 12, by Nikita Andriyanov, is on “Intelligent Computer Vision Systems in the Processing of Baggage and Hand Luggage X-ray Images”. The author addresses the problem of automating the monitoring of items allowed and prohibited to be brought on board an airplane and proposes optimized deep learning models towards its solution.

Chapter 13, by Ekaterina Cherskikh and Andrey Ronzhin, is on “Sensor Functional Clustering for Data Reducing at Making Robot Control Decisions”. The authors present and experimentally evaluate a novel method for reducing data generated by the sensor system of distributed ground robots, which is based on choosing a limited set of embedded devices measuring environmental parameters for the implementation of the current task.

Finally, the *fifth part* of the book consists of three chapters devoted to *Novel AI-empowered Methodologies in Decision Making*.

Specifically, Chap. 14, by Gianfranco Lamperti, Stefano Trerotola and Marina Zanella, is on “Supporting Decision-Making in Diagnosis of Discrete-Event Systems by Model-Based Temporal Techniques”. The authors address the problem of decision support provided by a model-based temporal-oriented approach to diagnosis of partially observable discrete-event systems.

Chapter 15, by Urszula Stańczyk, is on “Discretisation and Attribute Relevance in Knowledge Mining Problems”. The author presents research dedicated to the relevance of attributes in Machine Learning tasks, observed from various perspectives.

Finally, Chap. 16, by Vesa A. Niskanen, is on “Methodological Aspects on Integrating Fuzzy Systems with Explainable Artificial Intelligence”. The author first presents criteria for Explainable Artificial Intelligence, then considers the basic principles for constructing the typical fuzzy models at a general methodological level and finally provides justifications for applying these models to Explainable Artificial Intelligence.

As the book is intended to provide a concise coverage to the topic, each chapter is complete within itself and includes an abstract, keywords and a bibliography of references to additional works for further reading.

1.2 Book Summary and Future Volumes

In this book, we are presenting some very significant advances in Artificial Intelligence-empowered Decision Support Systems, while honoring Professor John E. Psarras who has been conducting leading relevant research for several decades and has inspired, advised, and mentored tens of students, fellow researchers, and colleagues. The book is directed towards professors, researchers, scientists, engineers, and students in related disciplines. It is also directed towards readers who come from other disciplines and are interested in becoming versed in some of the most significant advances in Artificial Intelligence-empowered Decision Support Systems. We hope that all of them will find the book useful and its content inspiring in their works and research.

On the other hand, researchers are constantly faced with societal demands for novel theories, approaches, methodologies, and algorithms to address the development of ever more sophisticated, efficient, and accurate DSS. Thus, the readers may expect that additional related volumes will appear in the future.

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Part I
AI-Empowered DSS in Medical Diagnosis
and Biology

Chapter 2

Artificial Intelligence in Breast Cancer Diagnosis: A Review



Evangelos Karampotsis, Evangelia Panourgias, and Georgios Dounias

Abstract The impact of human errors in imaging interpretation and the fact that decision support systems can improve the reliability and accuracy of radiology reporting have led to the more widespread use of these techniques. Developing decision support systems that assist radiologists in accurate diagnoses and improving the medical decision-making process has always been a challenge for the data analysis industry. This paper presents an in-depth review of a large number of intelligent approaches related to the support of breast cancer diagnosis taken in recent years. Specifically, the present review includes 230 corresponding approaches presented in the last 30 years in scientific journals in the field of artificial intelligence, as well as in medical journals. The search for the scientific reports included and presented in this paper was carried out in the databases of well-known scientific publishing houses using related keywords and phrases. The review briefly presents the main findings of each paper and classifies them according to their medical topic of specific interest (diagnosis, breast lesion classification, detection, abnormality classification, estimation of cancer risk, etc.). A statistical analysis is also provided, regarding the popularity of the approaches both, from the medical and AI viewpoint.

Keywords Artificial intelligence · Machine learning · Breast cancer · Medical imaging · Medical decision support systems

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Abbreviations

Ac	Classification Accuracy
ACFNN	Associative Classifier Using Fuzzy Feed-Forward Backpropagation Neural Network
AIRS	Artificial Immune Recognition System
AMMLP	Artificial Metaplasticity Multilayer Perceptrons
ANN	Artificial Neural Networks
BIRADS	Breast Imaging-Reporting and Data System
BP-a	Back Propagation (BP) Training Algorithm
BRB-NN	Back-Propagation Networks
CART	Classification and Regression Trees
CCL	Connected Component Labeling
CHAID	Chi-Square Automatic Interaction Detection
CNN	Convolutional Neural Networks
DCNN	Deep Convolutional Neural Network
DEA	Data Envelopment Analysis
DE-a	Differential Evolution
ELM	Extreme Learning Machine
EP	Evolutionary Programming
FCM	Fuzzy-C-Means
FISH	Fisher classifier
FLD	Fisher's Linear Discriminant
FLS	Fuzzy Logic System
FS	Fuzzy Systems
GB-a	Gentleboost Classifier (GB) Algorithm
GDA	Quadratic Discriminant Analysis
GRNN	General Regression Neural Networks
IDT	Inductive Decision Tree
IG	Information Gain
k-CV	K-Fold Cross Validation
Kernel PCA	Kernel Principal Component Analysis
KNN	K-Nearest Neighbors
LBN	Linear Bayes Normal Classifier
LDA	Linear Discriminant Analysis
LOO	Leave-1-Out
LR	Logistic Regression
LYNA	LYmph Node Assistant
MDSS	Medical Decision Support System
MLP	Multilayer Perceptron
NAÏVE	Naive Bayes Classifier
OBL-a	Opposition-Based Learning Algorithm
PCA	Principal Component-Analysis

PDE	Pareto-Differential Evolution
PNN	Probabilistic Neural Networks
PSO	Particle Swarm Optimization
QD	Quadratic Classifier
RBFN	Radial Basis Function Network
RF	Random Forest
ROI	Regions of Interest
RVM	Relevance Vector Machine
SFFS	Sequential Forward Floating Selection
SFS	Sequential Forward Selection
SMO	Sequential Minimal Optimization
Sn	Sensitivity
SOM	Self-Organizing Map
Sp	Specificity
SVM	Support Vector Machines
UTS	Use-Test-Set
WPSO	Weighted-Particle Swarm Optimization
YOLO	You Only Look Once

2.1 Introduction

Cancer is the second leading cause of death worldwide, with about 17% of deaths, that have been recorded by the World Health Organization (WHO), due to some form of cancer, listing 9.6 million deaths for the year 2018. Approximately 70% of deaths from cancer have been recorded in low/middle-income countries and are due to the five (5) main causes of cancer (high body mass index, lack of exercise, alcohol, smoking and limited consumption of fruits/vegetables). Breast cancer, although the fifth leading cause of cancer death, is the most common form of cancer in women with an incidence of 2.1 million cases per year and the leading cause of cancer death in women, listing 627,000 reported deaths in 2018, facts and observations that intensify even more the needs for early and valid diagnosis of breast cancer [1].

The early and valid diagnosis of breast cancer was the impetus for the development of a personalized field of research in the context of supporting medical decision-making processes using computational intelligence methods. This research field aims at the development of intelligent systems for the analysis of relevant medical data and has as ultimate goal the mining of new relevant medical knowledge, that may be used by expert doctors in the diagnostic process of breast cancer.

Over the years, a number of different Artificial Intelligence based (AI-based) approaches applied to various breast cancer data (image recognition, classification, clustering etc.) as well as integrated Computer-Aided Diagnosis systems (CAD systems) have appeared in international literature. It is also interesting that medical