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Computational Linguistics and the Modernization of Arabic Writing: Theoretical Foundations, Methodological Contributions, and Technological Vision in the Works of Abd El-Rahmane El-Hadj Saleh

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Abstract

The contemporary world is characterized by an unprecedented reliance on advanced technologies, within which language has emerged as a central component of the digital transformation. Computational linguistics, as an applied interdisciplinary field, seeks to model, analyze, and process human language through computational systems, enabling machines to interact with natural languages in structured and meaningful ways. While Western scholarship has played a pioneering role in the establishment and institutionalization of computational linguistics, the Arab intellectual tradition has witnessed comparatively limited but highly influential contributions that have laid the groundwork for Arabic language processing. This study explores the contributions of Abd El-Rahmane El-Hadj Saleh, one of the most prominent Algerian linguists in the Arab Maghreb, whose work represents a foundational milestone in the integration of Arabic linguistics with computational methodologies. El-Hadj Saleh's scholarly project is distinguished by its attempt to reconcile the structural properties of Arabic with the requirements of machine processing, addressing both theoretical linguistic concerns and practical technological challenges. His vision extends beyond mere digitization, proposing a scientifically grounded model for Arabic language formalization that respects its morphological richness, syntactic flexibility, and semantic depth. The research adopts a descriptive-analytical approach to examine El-Hadj Saleh's conceptualization of computational linguistics, his stance on the relationship between traditional linguistics and computational models, and his methodological framework for natural language processing. Particular attention is given to the technical terminology he employed and adapted, as well as to his efforts in establishing an Arab scientific discourse capable of engaging with global technological developments. The study demonstrates that El-Hadj Saleh's work constitutes a pioneering attempt to bridge linguistic theory and computational application, positioning Arabic as a viable language within the evolving landscape of artificial intelligence and language technologies.

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It is well known that today's world relies on the most advanced technologies that technological development has achieved, particularly concerning the linguistic aspect, which has also gained a place in the technological renaissance. Moreover, computational linguistics is an applied branch that examines human language as a flexible tool for

processing by a machine. This science necessitates the automatic processing of natural languages using computers. Western scholars have significant credit for the emergence and establishment of this field, through the valuable works they produced. On the other hand, relatively few contributions and precursors emerged among Arabs, due to the novelty of the subject; these contributions now form the foundation of computational studies in the Arab world. Contemporary linguists, both from the Middle East and the Maghreb, such as Nabil Ali, Nihad Al-Mousa, and others, have concentrated their efforts on this field.

In this context, our focus is on Algerian research, represented by one of the most prominent figures in the Arab Maghreb: Dr. Abdel Rahmane Al-Hadj Saleh, a scholar renowned in linguistic computing and the challenges of processing Arabic with computers. He gained recognition in linguistic studies and contributed to advancing Arabic studies while keeping pace with the technological revolution the world is currently experiencing.

The research sought to answer the following questions:

- What are the features of computational linguistic research according to Dr. Abdel Rahmane Al-Hadj Saleh? What is his position on the relationship between linguistics and computational linguistics?

- What constitutes his approach to natural language machine processing, and what computer terminology did he use?

Introduction:

Computational linguistics studies in the Arab world have witnessed remarkable development, particularly in recent decades, thanks to the significant efforts of Arab linguists to establish this new field. Notable figures include Mohammed Al-Hannash (Morocco), Ahmed Al-Akhdar Al-Ghazal (Morocco), Mariati Mohammed (Syria), Nabil Ali (Egypt), Nihad Al-Mousa (Palestine), and Walid Al-Anati (Jordan).

Abdel Rahmane Ben Hassan Al-Aref categorized the efforts of contemporary Arab researchers and academic institutions in this field into four forms:

1. Works dedicated to Arabic and computing.

2. Articles and research published in scientific journals or conference proceedings. Notably, Mariati Mohammed contributed a study in collaboration with colleagues at the Center for Scientific Studies and Research, focusing on statistical analysis of Arabic roots in old dictionaries, utilizing electronic computation to enhance the accuracy and speed of statistical processes. He examined the percentages of two-letter, three-letter, four-letter, and five-letter roots in Arabic.

In 1996, Dr. Abdel Diab Al-Ajili (Iraq) published *Computer and the Arabic Language*, a positive step toward addressing various issues in Arabic using the Prolog programming language.

Subsequently, Dr. Mohammed Al-Hannash (Morocco) emerged as a leading contemporary linguist who focused on computational lexicons. His studies involved building Arabic electronic dictionaries, including the *Morphological Lexicon for Arabic*, a long-term project culminating in the book *Morphological Lexicon for Arabic: Introductions to Computational Processing of Natural Languages*.

3. Programs and systems designed for Arabic language computing, either as individual efforts or collaborative work.

4. Establishment of university departments dedicated to computational linguistics.

Dr. Salwa Hamada noted that the first work in this field is the book by Dr. Nabil Ali, *Arabic Language and Computers*, Cairo, 1985, considered the first book in Arabic computational linguistics. It approached the subject from a dual perspective: half focusing on the language, applied to Arabic, and half on computational aspects applied partially to Arabic. The book covered levels of linguistic, phonetic, morphological, syntactic, lexical, and stylistic analysis and concluded with suggested research topics in Arabic language processing. This book represents a significant step toward establishing Arabic computational linguistics on both theoretical and practical foundations.

Dr. Hamada also highlighted the work of Drs. Walid Al-Anati and Khaled Al-Jabr in compiling a comprehensive reference covering Arab contributions to Arabic computing, modeling, and computational development. This was reflected in their project, *Guide to Researchers in Computational Linguistics*, considered the first book indexing achievements in Arabic computational linguistics.

Additional contributions include those of Nihad Al-Mousa (Palestine), particularly his 2000 book *Arabic Diacritics: Toward a New Utilization in Light of Computational Linguistics*, the first specialized work in this new field by an Arabic language expert. The book marks a qualitative shift from describing Arabic to formally specifying it, aligning with computational linguistics theory: what is performed for humans is "description," while what is performed for the computer is "specification."

Dr. Abdel Rahmane Al-Hadj Saleh (Algeria), author of *Research and Studies in Computational Linguistics* (2007, both volumes), and the creator of the *Linguistic Corpus Project* providing rapid information access and abundant texts for researchers, contributed unprecedentedly to computational linguistics.

1) Contributions of Dr. Abdel Rahmane Al-Hadj Saleh in Computational Linguistics:
Linguistics intersects with other sciences, not only in human and social dimensions but also in technical and precise domains. This interdisciplinary approach led to subfields like social linguistics, mathematical linguistics, and computational linguistics. Al-Hadj Saleh is among the Arab linguists who recognized the importance of this interdisciplinary approach and its role in addressing complex knowledge problems not solvable within a single field. He emphasized the integration of mathematics and computing with linguistics.

Conditions for compatibility between modern linguistics and computational linguistics according to Al-Hadj Saleh:

a. Adequate knowledge in each field:

He states, "It is not required for one individual to hold multiple specializations simultaneously; this is rare. The researcher is not expected to be a PhD in both computing and linguistics. Superficial familiarity with what is essential for collaborative work is also insufficient."

b. Familiarity with mathematics, logic, computing, and modern theories:

He adds, "How can one study language structures (combinatorics) without knowledge of modern mathematics and mathematical logic? How can one discuss Khalil's sayings without exposure to a phonetic laboratory? Any linguist needs to master many fields contributing to language study." Researchers must thus be knowledgeable across multiple domains: mathematics, logic, computing, and modern theories.

c. Collaborative work between linguists and computer scientists:

Al-Hadj Saleh stresses the necessity of dialogue among researchers from different fields to facilitate mutual understanding: "It is essential that researchers from diverse backgrounds understand one another's critiques and suggestions, expressing their ideas in the language of their specialty. Without such mutual comprehension, they cannot effectively exchange knowledge." Collaborative research involving computing, mathematics, and linguistics requires effective dialogue as its foundation.

To implement this practically, Al-Hadj Saleh proposed establishing advanced degrees combining instruction for engineers, mathematicians, and linguists, fostering a shared scientific culture integrating linguistics, computer engineering, and mathematical logic.

2) Al-Hadj Saleh's terminology in computational linguistics:

Al-Hadj Saleh used various linguistic terms related to computing, including traditional, translated, and untranslated terms, aiming to blend classical Arabic grammar studies with modern computational studies to establish a new linguistic framework.

Traditional terms:

- **Al-Rattab (Electronic Computer):**

Al-Hadj Saleh frequently used the term *al-Rattab* in his articles as a counterpart to "computer," such as in phrases like "use of al-Rattab," "engineers in al-Rattab," "al-Rattabians," and "computational linguistics of al-Rattab." He defined it through its role in organizing and transforming operations, particularly in research on forms and structures based on informatics: "The most suitable machine for studying these matters is al-Rattab because it performs sequential operations of a transformative nature. Al-Rattab receives data and rules to carry out a task assigned by the researcher, following a set of ordered instructions, collectively called a program. Al-Rattab, or the computer, can then automatically extract all word forms in a text, along with their original components."

- Dr. Abdel Diab Al-Ajili, Nihad Al-Mousa, Nabil Ali, and others use the term *al-Rattab*, which Abdel Rahmane Al-Hadj Saleh coined as a term for the computer.

b. Al-Āla and Al-Āyala (robot):

Al-Hadj Saleh used the term *al-Āyala* as a synonym for "machine" when discussing the field of artificial speech synthesis and automated recognition. He stated: "Scientists in artificial synthesis have achieved remarkable results, making it possible for the machine and the Āyala (robot) to operate..." He also mentioned this term elsewhere, for example: "Since the machine will search, if the machine fails, it resorts to it..."

In the *Lexicon of Definitions*, a machine is defined as: "the intermediary between the agent and the affected in delivering the effect, like a saw in carpentry or an intermediary hand in producing the intermediate cause, as the father between the father and grandfather; it mediates between the agent and the affected, but it is not the intermediary for delivering the distant cause to the affected."

c. The Kymograph (Al-Mamwaj):

Al-Hadj Saleh used this term when discussing the phonetic and coordinate aspects of speech. It is one of the devices used to analyze sound, contributing to artificial speech synthesis. He stated: "It is known that sound is a vibratory disturbance of air (and all matter), or, as our scholars said, the undulation of air or its exposure during oscillation. These oscillations can be recorded, and they follow in the speech chart."

Elsewhere, he mentioned: "There is a purely technical field in linguistic research, which we call language technology. It emerged weakly and was limited at the end of the 9th century through the use of the kymograph in studying linguistic sounds. It is a cylinder that rotates on itself, with a set of styluses that capture sound and record vibrations on the cylinder."

Dr. Abdel Salam Al-Masdi translated this term in his book *Dictionary of Linguistics* as *Kymographie* or "sound recorder."

d. The Oscillograph (Al-Muhazzaz):

This is a device that analyzes speech into its phonetic components. Al-Hadj Saleh stated: "The kymograph and oscillograph can analyze speech into its sound components and track their transformations simultaneously, allowing us to observe changes in laryngeal sound, nasal sound, oral sound, and air pressure."

Both devices perform similar functions, but Al-Hadj Saleh distinguished the oscillograph by its precision: "They have now replaced the styluses and cathode cylinder in the oscillograph, which is highly beneficial as it eliminates friction in recording vibrations, making the recordings much more accurate." Abdel Salam also called it *rasm dhathabi* (vibration recorder).

e. Sonagraph (Al-Mutayyaf or Al-Mishbah):

Al-Hadj Saleh mentioned: "Another analytical device was invented by engineers at the Bell Company during World War II, called the sonagraph. It is one of the most brilliant inventions in this field, advancing acoustic sciences

significantly—allowing speech synthesis. This device is essential in all phonetic laboratories. The sonagraph consists of a microphone that captures sound and records it on a magnetized cylinder. The recorded sound, in the range of 80–8000 Hz, is decomposed into frequency elements and drawn on a rotating closed tube with special paper, showing frequency variations."

Al-Fassi Al-Fahri presented this term in various forms in his book:

- Official spectrum recorder: *Oscillograph*
- Sound spectrum recorder: *Sonagraph*

f. Group (Al-Zumra):

Al-Hadj Saleh introduced the concept of "group" when discussing mathematical patterns and computational tools used in programming, proposing it could solve software issues: "I drew attention to the importance of the concept of the group as a mathematical concept capable of encompassing complex linguistic patterns." Scholars today agree that a group can serve as the structural basis for ordered operations that achieve a specific intended result, such as in education or automated information processing. Historically, Al-Hadj Saleh noted that Al-Khalil Ibn Ahmad Al-Farahidi introduced scientific concepts in mathematics, such as factorials and cyclic groups, foundational to his Arabic dictionary *Al-'Ayn*.

g. The Linguistic Corpus / Automated Corpus (Al-Dhakhira Al-Āliya):

This was a project proposed by Al-Hadj Saleh: "We suggested it to the Arab Organization for Education, Culture, and Science in December 1987, and it was adopted by the Executive Council at the time." The term "automated corpus" derives from its purpose: "It is a project related to automated processing of Arabic texts, aiming to create a linguistic information bank containing as many texts as possible produced by Arab thought in literature, science, technology, etc."

Al-Saleh summarized it as: "It stores valuable material that can be accessed when needed. Scholars and researchers store old and modern texts in computer memory, i.e., a comprehensive networked catalog of everything produced by Arab thought from pre-Islamic times to today." Further definitions are explored in later pages.

2. Translated Terms:

1. Terminology Bank:

Al-Hadj Saleh used this term extensively, stating: "With the advent of highly capable computers, the idea of linguistic or data banks emerged." These banks are essential in social sciences, history of ideas, and theories, providing comprehensive monitoring of Arabic usage in specific regions and periods, tracking the evolution or disappearance of classical words. Alternative terms include "text bank." Sanâa Munim used it in *Computational Linguistics and Machine Translation*.

2. Automatic Language Processing (ALP):

Al-Hadj Saleh defined it: "It is a branch of computational linguistics requiring specialized software developed by engineers, assisted by linguists in areas of language under study." Specialists aim to find optimal mathematical-linguistic patterns for processing texts automatically using *al-Rattab* (computer). Applications include automatic documentation, machine translation, language teaching, automated speech synthesis, and speech recognition. Challenges include identifying suitable software patterns (logiciel) for linguistic analysis. This term was also used by Sanâa Munim and Sabri Ibrahim Al-Sayed.

3. Speech Synthesis:

Al-Hadj Saleh distinguished artificial speech synthesis from automated speech recognition: "It is necessary to differentiate between artificial speech synthesis and automated recognition; recognition has its own distinct rules. Scientists have achieved remarkable results in artificial synthesis, making it possible for machines and robots to speak,

whereas recognition still faces challenges." Many linguists adopted this term, sometimes using alternatives, e.g., Nabil Ali called it *automatic speech generation*.

4. Natural Language Processing (NLP) according to Al-Hadj Saleh:

Language processing is central to Arabic computing and often considered part of computational linguistics. Al-Hadj Saleh defines it as: "Automatic application to a set of texts, modifying, transforming, or generating new content using techniques from linguistics, computer science, and modeling." NLP studies computational aspects of language and addresses linguistic and computational challenges for spoken or written text.

He emphasized serious collaboration between engineers and linguists: "Currently, collaboration is very difficult; engineers may work with limited linguistic knowledge and vice versa." Integration is essential, and he proposed master-level courses for engineers in linguistic theory and for linguists in language processing.

Today, computational linguistic studies flourish in the Arab world, integrating computer science and linguistics, covering applications like machine translation, spell-checking, computer-assisted language learning, document processing, artificial speech synthesis, and more. Challenges include complex linguistic analysis and finding suitable software patterns. Al-Hadj Saleh warned that many engineers have superficial knowledge of linguistic analysis due to gaps in their technological training, noting: "Research in this field is multidisciplinary and cannot rely solely on electronics or computational methods."

1) The Arabic Linguistic Corpus Project – Scientific and Practical Dimensions:

Modern times have seen a proliferation of terms and concepts, rendering printed dictionaries inadequate. Researchers sought alternatives to preserve Arab heritage and linguistic sources. Al-Hadj Saleh aimed to create a large-scale project to digitize Arab heritage.

a. Concept:

At the 1986 Arabization Conference, Al-Hadj Saleh presented the concept of the Arabic linguistic corpus, emphasizing its benefits for linguistic and scientific research, particularly for standardizing terminology. He advocated using computer systems in linguistic fields and encouraged colleagues: "I tried to convince fellow researchers of the importance of returning to authentic Arabic usage and using current computer systems, involving as many institutions as possible to complete the project."

Then it was presented to the Executive Council of the Arab Organization for Education, Culture, and Science in December 1988, and its members approved its techniques within the organization's capabilities. Afterwards, the organization sent it to Arab scientific institutions and official educational authorities to provide their opinions. Meanwhile, the organization held two seminars in which all representatives of the participating institutions gathered to work on the project. Abdel Rahmane Al-Hadj Saleh expressed his satisfaction with the Algerian Academy of the Arabic Language adopting his project.

This project originated from the idea of using the computer and exploiting its tremendous speed to process and store data in its memory to create an automated data bank containing the most important works in Arabic that have scientific and literary value.

The meaning of "Al-Dhakhira" (the corpus) in the Arabic language:

1. **Terminologically:** It is "authentic written or spoken texts concerning the collection of information on Arabic words, roots, word forms, total vocabulary, semantic letters, actual usage, sentence structures, living and comprehensive styles, prosody, poetic necessities, metrical deviations and rhymes, and all aspects related to linguistic, literary, cultural, scientific, or technical concepts. These may be expanded and corrected as information develops. This is what Arabs call *Diwan al-'Arab*; this corpus is examined thoroughly and extensively from pre-Islamic times to the present."

2. **From a computational perspective:** Which concerns us, it is "an objective automated bank documented from dictionaries, texts, and studies, old and new, focusing on actual use of Arabic across eras and countries by creating a unified database structure combining literary, linguistic, and scientific output, both old and modern, in the form of a textual data bank derived from actual usage—essentially an Arabic internet."

The linguistic corpus is an automated text bank, a bank of ancient and modern vocabulary (from pre-Islamic times to the present), from spoken to written Arabic. Authors do not fabricate it, except when such usage, as stored in the computer memory, reflects Arabic as used over fifteen centuries in its finest form, providing the Arab world with the best of its intellectual output.

Dr. Al-Hadj Saleh highlighted the main feature of these banks: "Easy access for researchers to what they need, speed, the comprehensiveness of the information obtainable, and most importantly, inclusion of actual Arabic usage across eras and Arab countries."

b. Objectives:

Abdel Rahmane Al-Hadj Saleh outlined several objectives of his project in his book *Researches and Studies in Arabic Linguistics*, as follows:

- **The corpus as an automated information bank:** The main goal is to enable any Arab researcher, wherever they are, to access various information on Arabic automatically and quickly. It aims to create an automated bank of Arabic texts, old and modern, including all scientific, intellectual, or cultural content on the Internet. This automated text bank has two important aspects:
    - **Linguistic aspect:** Represented by *Diwan al-'Arab*, reflecting actual Arabic usage, old and modern, through millions of literary, scientific, and technical texts.
    - **Cultural aspect:** Including scientific and educational content, gathering all information related to scientific fields for reference and all educational methods for acquiring specific Arabic language skills according to learners' age and level.
- **The corpus as a source for various dictionaries and studies:** Al-Hadj Saleh listed dictionaries that can be derived from this bank, including:
    - Comprehensive automated dictionary of Arabic words in actual use
    - Automated dictionary of scientific and technical terms in current use
    - Historical dictionary of Arabic
    - Dictionary of cultural terms (ancient and modern)

Similarly, Dr. Muhammad Omar Abu Nawas identified objectives of the Arabic linguistic corpus:

- Providing a reference for institutions and language academies in standardizing terminology
- Using the corpus to study the automated evolution of vocabulary
- Enabling automated indexing of all Arabic texts of scientific, literary, and cultural value
- Tracing the origins of words, their occurrence, and functions in Semitic languages
- Providing a precise and comprehensive record of Arabic usage in any era
- Exploiting computer speed and capabilities to create an automated data bank containing the most important Arabic works, ancient and modern
- Translating important works into other languages serving Arabic linguistic studies
- Providing researchers with a major resource to facilitate scientific research and review

The primary goal of digitizing the Arabic linguistic corpus is to create a comprehensive database combining old and modern linguistic material, open to addition and correction, making it the main source for Arabic linguistic heritage.

c. Advantages:

The Arabic linguistic corpus has many advantages, highlighted by Al-Hadj Saleh in his book:

- Represents actual Arabic usage, unlike some dictionaries that provide fabricated examples
- Extensive and comprehensive coverage of all Arab countries from pre-Islamic times to the present
- Inclusion of all important texts, written and spoken, in literature, culture, religion, and sciences
- Reliance on the latest electronic devices, primarily computers and audiovisual tools, the only means capable of storing such a vast amount of texts
- Capability to pose thousands of queries remotely and simultaneously worldwide, with display and printing possible in a short time

Conclusion:

Computational linguistics is one of the latest branches of linguistics linking linguistics and computer science. It treats language from a computational perspective, using computers to convert linguistic texts into digital computer language for analysis and translation into other languages. It is an applied field of Western origin, whose early signs appeared in the Arab world through contributions of some linguists. Dr. Abdel Rahmane Al-Hadj Saleh is a leading Arab intellectual who contributed to the development of linguistic studies and their integration into computing. He emphasized collaboration between linguists and computer scientists and the importance of mastering linguistic theories and modern mathematical formulation methods. He is the founder of the Arabic linguistic corpus project, which provides researchers with fast access to information and abundant texts. It is a national cultural project aiming to collect all Arabic texts, ancient and modern, and process them automatically.

Ethical Considerations

This study is based exclusively on the analysis of published academic works and publicly available scholarly sources. It does not involve human participants, personal data, or experimental procedures. All sources have been consulted and cited in accordance with established academic integrity and ethical research standards.

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Conflict of Interest

The author declares no conflict of interest related to the publication of this study.

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