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A Computational Application of Syllabic Grouping for Discovering Possible Cognates to Decipher the Cretan Protolinear Script

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ABSTRACT
The purpose of this paper is to present a computational tool that will enable interested researchers to facilitate the decipherment of Linear-A script, as the oldest known occurrence of the Cretan Protolinear Script, excluding Cretan Hieroglyphics. Linear-A is a syllabic script that appeared during the 2nd millennium BCE in Minoan Crete, belonging to the Aegean family of scripts, which also includes Linear-B and Cretan Hieroglyphics. It yields a language that is still unknown or, at least, there is no unanimously accepted proposal for the underlying language. While it has been studied for over 70 years, due to its limited use, its complete understanding makes the task quite difficult. The program presented in this work is based on an older code model, which translates the Linear-B script, to which, in addition to adapting the script, the technique of Syllabic Grouping has been added, to facilitate the search for related words in many languages. The system presented consists of a machine-readable dictionary of ancient languages, where the user, through a virtual keyboard, enters the signs, which correspond to one or more words of the ancient languages. Thus, as a result, the corresponding word appears (if it exists) translated into English. The study of these languages will help to identify the possible underlying language and the origin of the people who used it.
KEYWORDS: *Aegean scripts, Cretan Protolinear Script, Linear-A script, Syllabic Grouping, decipherment, machine-readable dictionary, object-oriented interface, Minoan Crete.*
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I. INTRODUCTION

The Aegean scripts is a set of five (5) pre-alphabetic scripts, used in the broader Aegean region and Cyprus, during the 1st abd 2nd millennium BCE [1]. More specifically, the Cretan Hieroglyphic, Linear-A and Linear-B script were used in the Aegean area (mainly Crete, the Aegean islands, mainland Greece and the Minor Asia coasts), during the 2nd millennium BCE, while the Cypro-Minoan script and the Cypriot Syllabary were used in Cyprus, the former during the 2nd millennium BCE and the latter during the 1st millennium BCE. Two of them, namely Linear-B and the Cypriot Syllabary rendered the Greek language in very archaic dialects. The rest of them (3) conventionally rendered unknown languages, although there is a concise interpretation for Cypro-

Minoan [2], while there is also a concise interpretation for parts of Cretan Hieroglyphics [3],[4]. In this respect, Linear-A is still a script rendering one or potentially more unknown languages.

The observation that these scripts formed a family was expressed very early, since the Cypriot Syllabary, which was deciphered first due to bilingual inscriptions, had been very helpful for the decipherment of Linear-B, while it has pictorial resemblance to Cypro-Minoan. The rest three, i.e., Cretan Hieroglyphic, Linear-A and Linear-B have more than obvious evolutionary relationship. Papakitsos & Kenanidis [5] demonstrated that Cretan Hieroglyphic is mainly the ornamental version of Linear-A script. Moreover, Linear-A and Linear-B share many identical/common signs. This similarity probably led Willets [6] to express the opinion that these three scripts had a common ancestor, named the Cretan Protolinear Script, since the birthplace of theirs was Minoan (/Bronze Age) Crete. Indeed, the Cretan Protolinear script was reconstructed almost entirely by Kenanidis [7],[8], while it was standardized later on by Papakitsos [9]. Accordingly, the impression remained is that Linear-A is the earliest remnant of the Cretan Protolinear script [10], while Linear-B is the adaptation of the latter to render the most ancient known written form of Greek, conventionally termed "Mycenean Greek".

Since Linear-A script is still indisputably considered the most ancient known script of European origin in geographical terms [11], the efforts of researchers are focused on deciphering it, with both computational and linguistic methods. In the former case, there is a variety of computational tools, comprising both software programs and lexical databases [12]. Yet, especially in the latter case, the existing databases are not in the form of machine-readable dictionaries (henceforth MRDs), therefore, they cannot be directly and easily accessed and processed by programming code for decipherment purposes. The present work briefly describes such an MRD to assist interested scholars in both learning and especially deciphering the texts of Cretan Protolinear Script (henceforth CPS).

II. BACKGROUND

CPS and its derivatives is a syllabary, i.e., most of its signs convey a syllable of one preceding consonant (C), followed by one vowel (V), e.g., DA, PE, TI, RU, etc., having the phonetic structure CV [10], which are consequently called "syllabograms" (Fig. 2.1: Syllabogram TO [13]). From the total estimated 120 syllabograms, six (6) convey a single-vowel (i.e., A, E, I, O, U, Ə), while 14 of them convey more composite sounds (e.g., PETE, NWA, DWO, etc.) [9]. From the 14 more composite syllabograms, four (4) are marginally attested and thus not certain [8].

Figure: 2.1

Initially, the presented herein Machine-Readable Dictionary (henceforth MRD) was intended to assist the study and decipherment of Linear-A [14],[15],[16]. Later on, though, it was decided to be extended in order to include the entire CPS, since Linear-A consists of less than 100 signs discovered, and this shortage would prevent the processing of future discoveries [17].

Another issue of the MRD's development was the number of inquired/target-languages. Namely, there have been many suggestions regarding the conveyed by CPS/Linear-A languages that more-or-less include all the contemporary language families of the Aegean, Near East and Anatolia (including Etruscan), which are 12 so far (plus two for future extensions). Therefore, a provision is made to have a multi-lingual MRD that will be rather easily expandable to include more languages in future developments. Moreover, facilities for the comparison of different results/proposals in different languages are being designed, for future inclusion in the computational system herein.

III. METHODOLOGY

The purpose of the developed computational tool is to assist scholars in comparing words of the target-languages to CPS's strings/words. Namely, the user of this system inserts a word of CPS (/Linear-A) as input, and the system returns a number of words from the target languages that potentially match the input, in terms of the conveyed sounds. Due to the different phonological and phonotactic rules of so many diverse target-languages, the above output is not a trivial task, therefore, the method of Syllabic Grouping [18] is applied to facilitate the discovery of possible cognates to CPS words.

The method of Syllabic Grouping is based on the relative stability of consonants in related words of common origin among languages, since consonants are more resistant to change. For example, the word "corps" (in Dutch, English and French) is found as "corpo" (in Italian and Portuguese), "cuerpo" (in Spanish), "corp" (in Romanian) and "korps" (in German), all with the exact same meaning. Stripping the vowels from one language to another, it can be observed that the core consonantal group is "crp", with "c" pronounced just like the German "k" in "korps" (i.e., "krp"). The observations on the similarities of words between Linear-A (unknown

language) and Linear-B (Mycenaean Greek) reveal similar relations between vowels also, as for example the interchangeability between O and U in anthroponyms like DI-DE-RU (Linear-A) and DI-DE-RO (Linear-B). The writing convention of the Aegean scripts should be noted here that the pronunciation of each syllabogram, when written in its Latin alphabetical transcription, is separated by a dash from the other syllabograms of a word, i.e., the word DI-DE-RU is written with three syllabograms (DI, DE and RU).
Consequently, the algorithm of Syllabic Grouping proceeds as follows:

1. All the adjacent to consonants vowels are stripped off from their syllabograms (i.e., their Latin transcription), with the exception of single-vowel syllabograms (i.e., A, E, I, O, U, Ə); e.g., the word DI-DE-RU becomes DDR and the word A-RU-MA becomes ARM.
2. All remaining consonants/vowels are replaced by a letter denoting their phonetic group (e.g., labials, dentals, nasals, etc.); e.g., the string DDR becomes DDL (D is dental and remains so, while R is liquid and becomes L).
3. The resulting string (e.g., DDL) is named Normalized Core Consonantal Form (NCCF) and it is added to the MRD in a new field corresponding to each word.
4. This process is also applied to all the words of all the target-languages in the MRD, while from now on the search for possible cognates is executed only through the NCCFs of the words.

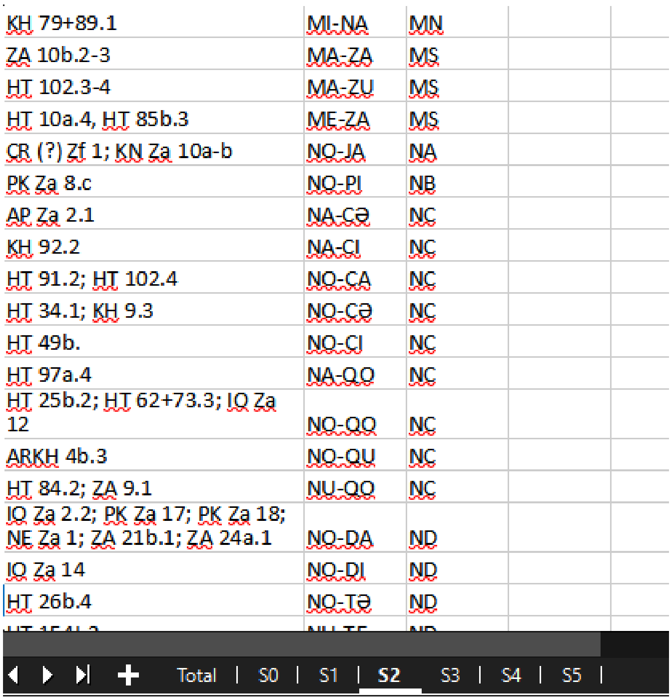
The result of the above process will be demonstrated in the next section.
The last methodological issue of the MRD's development was its computational implementation. Since this tool is intended to be used by scholars of the Humanities (as well), it was decided that the MRD should be implemented in a way easy for almost anyone to access, use and amend. Thus, its implementation was realized through spreadsheets, a common and convenient tool for data processing, also directly accessible from modern programming languages. This methodology has been also successfully used for other ancient scripts [19]-[26].

IV. RESULTS

The process of development resulted firstly in three computational components: the MRD, the object-oriented interface and the search-engine.

The Machine-Readable Dictionary (MRD)

The first component is the MRD, implemented as Excel files for the words of Linear-A and for the words of the target-languages. To increase the processing speed, all the words are grouped in different sheets, according to the number of their syllables, i.e., monosyllabic, disyllabic, trisyllabic and up to five-plus syllables for each and every language. Thus, the search is always confined to the words of the corresponding size, minimizing so the search space. Some details are presented next.
A screenshot of the MRD is presented in Fig. 4.1, regarding Linear-A's lexicon [17].

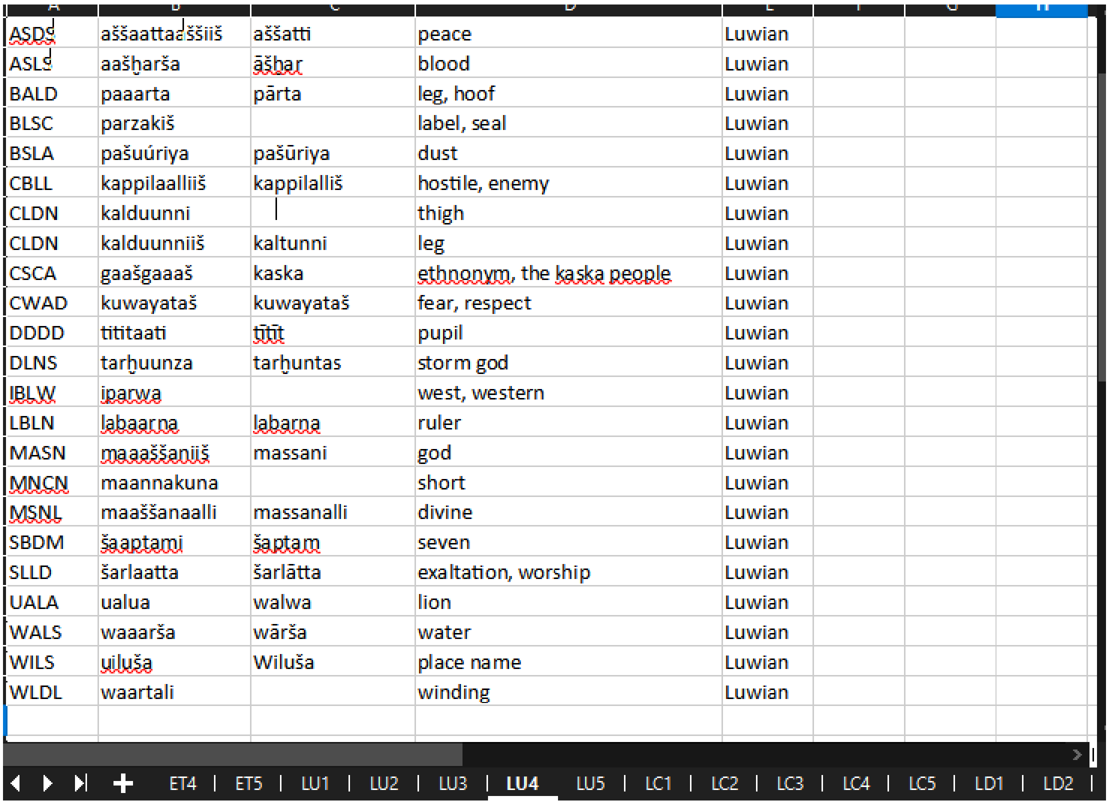


KH 79+89.1	MI-NA	MN
ZA 10b.2-3	MA-ZA	MS
HT 102.3-4	MA-ZU	MS
HT 10a.4, HT 85b.3	ME-ZA	MS
CR (?) Zf 1; KN Za 10a-b	NO-JA	NA
PK Za 8.c	NO-PI	NB
AP Za 2.1	NA-CƏ	NC
KH 92.2	NA-CI	NC
HT 91.2; HT 102.4	NO-CA	NC
HT 34.1; KH 9.3	NO-CƏ	NC
HT 49b.	NO-CI	NC
HT 97a.4	NA-QO	NC
HT 25b.2; HT 62+73.3; IO Za 12	NO-QO	NC
ARKH 4b.3	NO-QU	NC
HT 84.2; ZA 9.1	NU-QO	NC
IO Za 2.2; PK Za 17; PK Za 18; NE Za 1; ZA 21b.1; ZA 24a.1	NO-DA	ND
IO Za 14	NO-DI	ND
HT 26b.4	NO-TƏ	ND

Figure: 4.1

A small part of the Linear-A's disyllabic words is visible in Fig. 4.1 (sheet "S2"). The first column (always from left) contains the formal designation of the artifact that the corresponding word in the second column is inscribed on. For example, the first word, MI-NA, is composed of two syllabograms of the relevant pronunciation ("mina"), found on the clay tablet designated KH 79+89.1. The letters of the designation (i.e., KH) denote the place of discovery (specifically the excavation area of Khania, Crete) and the following numbers are a serial order (it can be seen in the database lineara.xyz). The third column contains the corresponding NCCF of the word MI-NA in the second column, that is "MN". It can be observed that the NCCF consists of so many characters (letters) as the number of syllables of the corresponding word (i.e., 2).

A screenshot of a target-language is presented in Fig. 4.2 [17], where a small part of the Luwian's language lexicon is visible, consisting of Luwian words with four syllables (sheet "LU4"). Luwian was a language of the Anatolian linguistic family of the Indo-European languages, spoken in the neighboring to Crete Minor Asia during the Bronze Age, therefore contemporary to Linear-A script.



A	B	C	D	E	F	G	H
ASDS	aššaattaaššiiš	aššatti	peace	Luwian			
ASLS	aašḫarša	āšḫar	blood	Luwian			
BALD	paaarta	pārta	leg, hoof	Luwian			
BLSC	parzakiš		label, seal	Luwian			
BSLA	pašuúriya	pašūriya	dust	Luwian			
CBLL	kappilaalliiš	kappilalliš	hostile, enemy	Luwian			
CLDN	kalduunni		thigh	Luwian			
CLDN	kalduunniiš	kaltunni	leg	Luwian			
CSCA	gaašgaaaš	kaska	ethnonym, the kaska people	Luwian			
CWAD	kuwayataš	kuwayataš	fear, respect	Luwian			
DDDD	tititaati	tītīt	pupil	Luwian			
DLNS	tarḫuunza	tarḫuntas	storm god	Luwian			
IBLW	iparwa		west, western	Luwian			
LBLN	labaarna	labarna	ruler	Luwian			
MASN	maaaššaniiš	massani	god	Luwian			
MNCN	maannakuna		short	Luwian			
MSNL	maaššanaalli	massanalli	divine	Luwian			
SBDM	šaaptami	šaptam	seven	Luwian			
SLLD	šarlaatta	šarlātta	exaltation, worship	Luwian			
UALA	ualua	walwa	lion	Luwian			
WALS	waaarša	wārša	water	Luwian			
WILS	uilušа	Wiluša	place name	Luwian			
WLDL	waartali		winding	Luwian			

Figure: 4.2

In Fig. 4.2, the NCCF of a word is located in the first column, with its corresponding word in the second column. For example, the last word of sheet LU4 is "waartali", having the NCCF of "WLDL". The word (actually, every word of the target-languages) is written in a transcription manner, regarding their original signs of their relevant script (i.e., the Luwian script), as they appear in Palaeolexicon (palaeolexicon.com). The closer actual pronunciation of a word is written in the third column; in the case of "waartali", this is the same (i.e., /waartali/), with its meaning in English located in the fourth column (i.e., "winding"). Finally, the fifth column contains the name of the said language (i.e., Luwian). The same structure is common for all target-languages.

The Object-Oriented Interface

The second computational component is the object-oriented interface, consisting of three areas: the virtual keyboard, the control area and the results area.

The virtual keyboard with all the syllabograms of CPS is located left, realized as buttons through C# programming language (Fig. 4.3 [17]). The syllabograms are arranged according to the conventional grid, which is a matrix with 18 rows and 6 columns (Fig. 4.3: left part). Below the grid there are also some syllabograms of irregular pronunciation, standing alone (Fig. 4.3: right part). Every row of the grid contains all the syllabograms that convey the syllables of the same first consonant, which is visible at the left of every row, except the first row, which include the single-vowel syllables. Every column contains all the syllabograms of the same vowel that follows the preceding consonant of the conveyed syllable, which is visible above every column. For example, the second row of the grid contains the syllabograms that convey syllables BA, BE, BI, BO, BU and BƏ). With this arrangement, even novice users can recognize the pronunciation of every syllabograms and learn them in time, therefore the grid also serving as educational software.

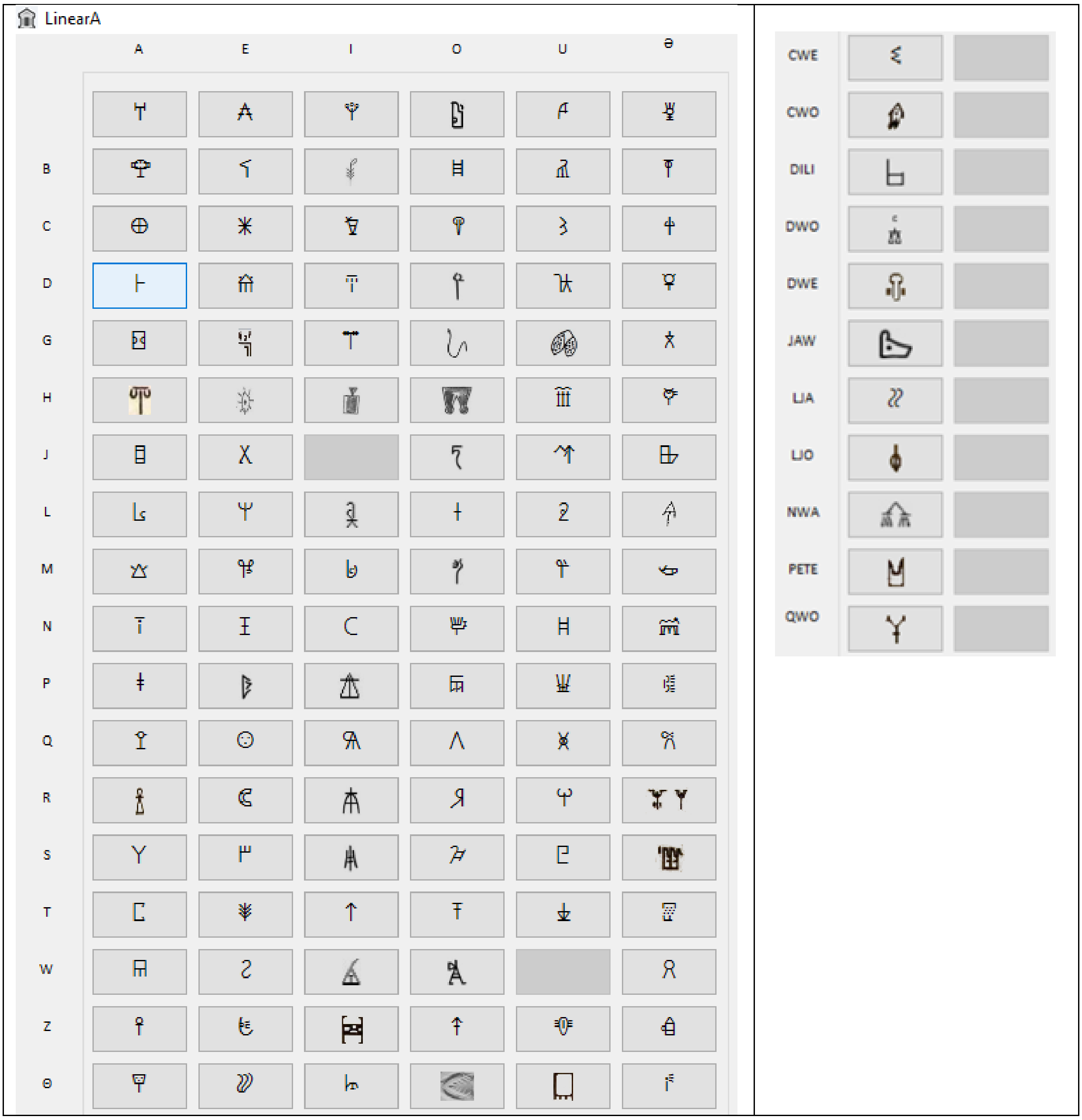


Figure: 4.3

Then, the user chooses the sequence of a word's syllabograms in Linear-A, e.g., the emblematic word CU-LO, the only non-onomastic word of Linear-A that has been undoubtably deciphered, meaning "sum/total" (Fig. 4.4 [17]). These actions of the user are visible in the control area of the interface (Fig. 4.4), which is located at the upper right of the screen. In this area, the user can see the selected word, both in its original form with the selected syllabograms (Fig. 4.4: upper left, "Typed") and in its Latin transcription, i.e., CU-LO (Fig. 4.4: middle left, "Typed: Transliteration"). Finally, the user clicks on the "Search !" control button (Fig. 4.4: lower left), which activates the third component of the computational system, that is the search-engine. On the right of the "Search !" control button, the rest of the control buttons are located. The control button "Back" erases a syllabograms, if wrongly typed, in order to give to the user the ability to correct a word. The control button "Clear", when activated, erases the previous word after the related search, so as the search may proceed to a next word. The control button "Help" provides help information about the functions of the tool on screen. Finally, the control button "Exit" finishes the whole process.

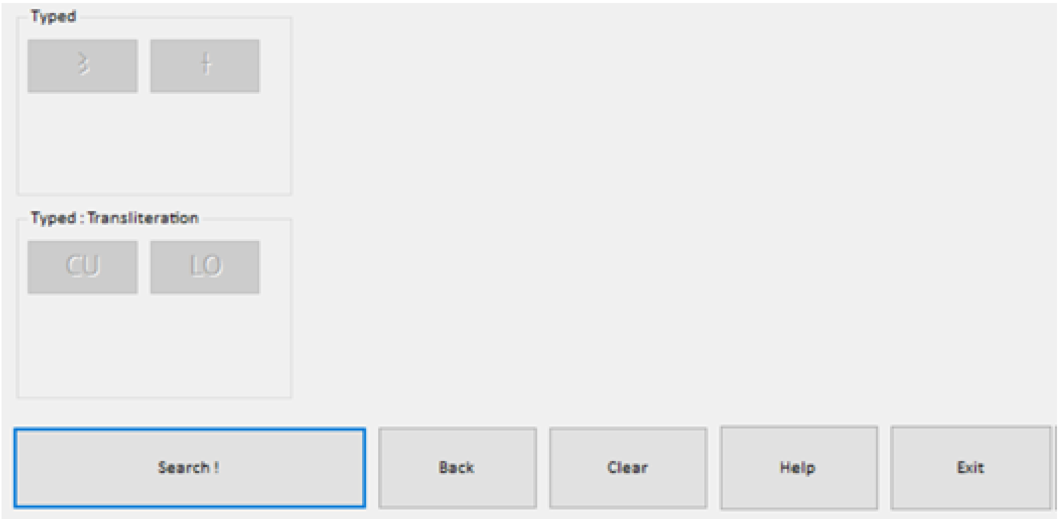


Figure: 4.4

The results of the search are presented both on screen (Fig. 4.5 [17]) and recorded in an output text file.

The Search-Engine

The search-engine, which is the third computational component, seeks for possible cognates through Syllabic Grouping, as exemplified in Fig. 4.5, where a screenshot of the results is presented, regarding the disyllabic word CU-LO ("sum/total") that is visible on the first line of the "Search Results". The "Search Results" area is located on the lower right of the interface's screen, below the control area (Fig. 4.4) and to the right of the grid (Fig. 4.3).

Figure: 4.5

After the word (i.e., "CU-LO") given by the user, its NCCF (i.e., "CL") is sought in the lexica of all the target-languages. The results of the search are returned below the original word. In the visible part of the results box (Fig. 4.5), it can be seen that many words with the same NCCF (i.e., "CL") have been returned. More specifically, there are five (5) Carian words, nine (9) Etruscan, two (2) Hattic and five (5) Hittite ones visible. In this occasion, none is correct ("sum/total"). In other instances, the user will have to assess the proposed similarities, where, in case of artifacts with a single word, practically anything could be correct, while the criteria for judging so are not linguistic but rather cultural. In case of artifacts with many words, they will have to be aligned per language in combinations and assess which combination makes more sense (if any). This task is not easy at all; it requires computational tools that are currently designed to facilitate the assessment of different combinations of words per language.

V. CONCLUSION

Linear-A is found on seals, clay tablets and discs, in 1427 inscriptions on these objects, mainly of an administrative nature, which have been discovered mainly in Crete, but also in other areas of the Aegean islands and coasts, and even beyond. Linear-A consists of syllabograms, i.e., symbols that represent mainly phonetic syllabic values of the consonant-vowel (CV) pattern or simply vowels (e.g., DA, PA, TE, E, etc.) and are the visible remnant of the CPS, from which all Aegean syllabaries (Linear-A, Cretan Hieroglyphics and Linear-B) evolved.

The present computational application aims to facilitate the decipherment of Linear-A script, with the potential for future manipulation of CPS findings. The software tool consists of a menu in which all the options available to the user are available. That is, the programming environment consists of a single screen and there are no additional windows, which makes the application quite understandable by the user, and within just a few minutes the content of this application is clear to the user. The environment consists of the following contents:

A virtual keyboard, in which the user searches for “words”, depending on the desired syllabograms. It is available to the user to search for words from one syllable to five syllables and more. In case the syllables exceed this limit, a corresponding message is displayed to the user. The program works with the help of an MRD of Linear-A and the target-languages.

The computational application is very easy and understandable to use, as its usage information are also provided. The program was created in such a way that it is easily expandable to new target-languages.

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