Morphological Analysis and Generation of Arabic Nouns: A Morphemic Functional Approach

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Abstract
MAGEAD is a morphological analyzer and generator for Modern Standard Arabic (MSA) and its dialects. We introduced MAGEAD in previous work with an implementation of MSA and Levantine Arabic verbs. In this paper, we port that system to MSA nominals (nouns and adjectives), which are far more complex to model than verbs. Our system is a functional morphological analyzer and generator, i.e., it analyzes to and generates from a representation consisting of a lexeme and linguistic feature-value pairs, where the features are syntactically (and perhaps semantically) meaningful, rather than just morphologically. A detailed evaluation of the current implementation comparing it to a commonly used morphological analyzer shows that it has good morphological coverage with precision and recall scores in the 90s. An error analysis reveals that the majority of recall and precision errors are problems in the gold standard or a result of the discrepancy between different models of form-based/functional morphology.

1. Goal of This Paper
In previous work, we have presented MAGEAD, a morphological analyzer and generator for Modern Standard Arabic (MSA) verbs, and we have extended that work to cover Levantine Arabic as well (Habash et al., 2005; Habash and Rambow, 2006). In this paper, we port that system to MSA nominals (nouns and adjectives). Our system is a functional morphological analyzer and generator, i.e., it analyzes to and generates from a representation consisting of a lexeme and linguistic feature-value pairs, where the features are syntactically (and perhaps semantically) meaningful, rather than just morphologically. In this perspective, nouns turn out to be far more complex than verbs. This is because all variants (MSA and dialects) of Arabic have many “broken plurals” (irregular plurals), which are very common, and irregular feminine forms, which are less common. Furthermore, the same surface morpheme can have different morphological functions depending on context. For example, the morpheme Ta-Marbuta (šjr + h),† usually associated with the feminine singular (as in جَـثة تَـؤْلَم ‘heart’), can appear on the plural form of certain masculine nouns (as in أنظمة أنظَـة ‘systems’). This discrepancy between the surface form-based morphology and the functional morphology has only recently been addressed in depth in a computational system – see Smrž (2007)’s transformation of the form-based Buckwalter morphological analyzer (Buckwalter, 2004). This paper differs from (Smrž, 2007) in that we use “deep” morphemes throughout, i.e., our system includes both a model of roots, patterns, and morphophonemic/orthographic rules, and a complete functional account of morphology.

Because of the prevalence of irregular inflectional forms among Arabic nominals, the lexicon plays a very important role in a functional morphological analyzer or generator for Arabic: we need to be able to relate irregular forms to their lexemes, and this can only be done with a lexicon. In this paper, we do not present work on a lexicon, and concentrate on the computation of morphology instead, including the interface to the lexicon. Our evaluation aims at measuring performance on words which are in our lexicon, not the lexicon itself. Future work will address the crucial issue of creating and evaluating a comprehensive lexicon.

This paper is structured as follows. We present the relevant linguistic facts in more detail in Section 2. We compare our work to related work in Section 3. The computational machinery is presented in Section 4. We present the morphological behavior class hierarchy (the interface to the lexicon) in Section 5. Morphophonemic rules are presented in Section 6. We give an evaluation of MAGEAD in Section 7.

2. Overview of Arabic Nominal Morphology
Arabic is a morphologically rich and complex language. For nominals, the inflectional variants are as follows:

• Number: singular, dual, plural. Some lexemes only have a singular form, such as عَلَى ‘ants as a collective’.

• Gender: masculine, feminine. Note that only some lexemes (those nouns denoting types of humans, such as كَـتِب writers, and all adjectives) show inflection for gender; however, if the lexeme does not inflect for gender (for example أذن ‘ear’), it has an inherent gender (in this case, feminine).

• Case: nominative, accusative, genitive.

• State: definite, indefinite, construct. We follow Fischer (2001) in his analysis of the morphological determination system for MSA. State is expressed as a suffix and should not be confused with the presence of the +الَّة Al+ definite determiner; however, there is an interaction: state cannot be indefinite in the presence

†All Arabic transliterations are provided in the Habash-Soudi-Buckwalter transliteration scheme (Habash et al., 2007).
of $+\text{ال} Al^+$. We see definite state with no $+\text{ال} Al^+$ in the vocative! يَأ رَجُل! ‘Man!’.

In addition, nominals take several classes of clitics, which we also handle in MAGEAD in the same way as inflectional affixes:

- **Article**: presence or absence of the $+\text{ال} Al^+$ proclitic ‘the’
- **Preposition**: presence of a particular preposition ($+\text{ال} k^+ ‘as’$, $+b^+ ‘by/with’$, or $+\text{ال} f^+ ‘for’$)
- **Conjunction**: presence of a particular conjunction ($+w^+ ‘and’$, $+f^+ ‘then’$)
- **Possessive pronoun**: presence of a particular possessive pronoun, e.g., $\text{هم} + hm ‘their’$

Not only does Arabic have a large number of inflectional features, they are expressed morphologically using both templatic (i.e., root,\(^2\) pattern, vocalism), and concatenative (prefix and suffix) morphemes. These morphemes do not all have a one-to-one correspondence to linguistic features. For example, the various values of state are often confused because they realize in different ambiguous ways in combination with other features. Compare the singular masculine forms كتاب $kitAb+u$ ‘book [indef]’ and كتاب $kitAb+u$ ‘book [def/construct]’ with the dual masculine forms كتاب $kitAb+Ani$ ‘two books [indef/def]' and كتاب $kitAb+A$ ‘two books [construct]’. The combination (interdigitation and affixation) of the various morphemes is further complicated as it may involve various phonological and orthographic adjustments. Additionally, there are optional diacritical marks used for short vowels and consonantal duplication. For example, the word الموارين $ellmawAzyn$ ‘for the scales’ (typically written as الموارين $lmwAzyn$) can be analyzed into the following morphemes: لي$Al^+ [wzn]$+$[mV1V2V3]$+$[aAl]+i ‘for the+[scales]+[genitive]’; the symbols the square brackets are templatic morphemes: the root $wzn$ ‘weight-related’ and the pattern and vocalism often used with plurals of instruments/tools. In this example, the number feature is expressed as a pattern choice – compare the plural موارين $mawAzyn$+$[wzn]+$+$[mV1V2V3]+$+[aAl]$ to the singular form مي$AzAn$+$[wzn]+$+$[mV1V2V3]+$+[IA]$. This phenomenon is called broken plurals and it accounts for almost half of all plurals in Arabic nominals, the rest being sound plurals which use suffixation, e.g., موظفون $mw\tilde{D}f+A$ ‘employee+ fem.plural’.

Furthermore, although the morpheme $+At$ is primarily used to indicate the feminine and plural features, it is also used with some masculine nouns to indicate plurality, e.g., مأجونات $AmHAna+At$ ‘test+plural’. Arabic nouns have peculiar agreement rules that depend on lexical features such as humanness/rationality and collectiveness. Specifically, adjectives modifying Arabic nouns agree in gender and number except when the head is an irrational plural noun, in which case the adjective is feminine singular. Compare موظفة حديدة $mw\tilde{D}f+y+jyd\tilde{h}$ ‘employee+fem.sg new+fem.sg’ and معلومات جديدات $mw\tilde{D}fAt+jyd\tilde{d}At$ ‘employee+fem.pl new+fem.pl’ with مي$An$ $jyd$ ‘scales+ masc.sg new+ masc.sg’ and موارين حديدة $mwAzyn$ $jyd\tilde{h}$ ‘scales+ masc.pl new+fem.singular’.

The discrepancy between surface and actual gender/number only makes these cases more complex: the word موارين $mwAzyn$ in terms of its surface morphology is masculine singular (since it lacks any plural or gender suffix), but functionally it is masculine plural; and being irrational, it takes a feminine singular adjective. Because of these agreement rules, we also record for each lexeme whether it is rational or irrational.

Within the computational approach we use here, a central concept is the lexeme, the set of all related inflectional variants. The lemma is a chosen representative of a lexeme; for Arabic nominals, it is the singular nominative definite without any clitics.

We consider all other morphological variation derivational, which means that two words that differ in derivational morphology are from different lexemes. We are aware of the fuzzy cases that border inflectional and derivational morphology, such as the collective plural (compare $\text{تن} nmAt ‘ant’ and its plural $nmAt$ ‘ants’, versus $\text{مل} mlAt ‘book [collective]’ or the archaic plurals of paucity/plenty. These words are from different lexemes. See the even more subtle case of $kAtib ‘writer’ in Section 5. In Arabic, all lexemes linked by derivational morphology share a common root: the root is to derivational morphology what the lexeme is to inflectional morphology; the root is a more abstract morphological notion than the lexeme.

3. Related Work

Much work has been done on Arabic morphological analysis and generation in a variety of approaches and at different degrees of linguistic depths (Al-Sughayer and Al-Kharashi, 2004). The focus on the lexeme as a central morphological concept is comparable to efforts by (Soudi et al., 2001; Habash, 2004; Smrž, 2007; Dichy and Farghaly, 2007). The implementation using finite state morphology (FSM) is comparable to early work on Arabic morphology, most notably (Kiraz, 1994; Beesley, 1996) and more recent efforts following the multi-tier approach by the authors (Habash et al., 2005; Habash and Rambow, 2006). FSM implementations naturally handle analysis and generation. We compare MAGEAD to the commonly used Buckwalter Arabic Morphological Analyzer (BAMA) (Buckwalter, 2004) and to the EliXir-FM functional morphology system for Arabic (Smrž, 2007). The development and evaluation of our system were heavily influenced by these two systems. EliXir-FM and MAGEAD are both functional morphology systems compared to BAMA, which models form-based morphology. These systems also differ in how they model their form-based components. BAMA does not explicitly model templatic morphology or morphological interactions, instead it uses a simple break up of words into prefixes, stems and suffixes that already collapse all templatic,

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\(^2\)The root is the traditional notion from Arabic grammar: a sequence typically of three or (rarely) four consonants that abstracts over derivational morphology.
morphophonemic and orthographic decisions. In contrast, Elixir-FM models templatic morphology and orthographic rules; however, some of these are handled by spell out the allomorphs of a morpheme. For example, the pattern for my\text{An} ‘scales’, mi12A3, is represented as its al-

Despite these differences, the BAMA lexicon was heavily used in the creation of Elixir-FM, which extended it to handle functional morphology. Our lexicon is developed by extending Elixir-FM’s lexicon.

4. The MAGEAD System: Implementation

MAGEAD is a morphological analyzer and generator for the Arabic language family, by which we mean both MSA and dialects. Building an instance of MAGEAD for a member of the Arabic language family and a class of words, such as MSA nouns or Egyptian verbs, goes through three main phases. Figure 1 shows the overall architecture.

The first phase (shown in Figure 1 in the doted L-shape diagram) involves creating by hand the linguistic resources that are used by a specific MAGEAD instance. Theses resources are: the Morphological Behavior Class Hierarchy MBCH, the context free grammar (CFG) that orders mor-

In the generation direction, tiers 1 through 3 are always in-

The second phase (shown in Figure 1 in the dashed rectangle) is the compilation of the instance’s linguistic resources to produce two finite state transducers (FSTs), one for generation and the other, its inverse, for analysis. MAGEAD is implemented as a multi-tape finite state automata layer on top of the AT&T two-tape finite state transducers (Mohri et al., 2000). We extend the analysis of Kiraz (2000) by introducing a fifth tier. The five tiers are used as follows:

- Tier 1: pattern and affixational morphemes;
- Tier 2: root;
- Tier 3: vocalism;
- Tier 4: phonological representation;
- Tier 5: orthographic representation.

In the generation direction, tiers 1 through 3 are always input tiers. Tier 4 is first an output tier, and subsequently an input tier. Tier 5 is always an output tier. All tiers are read or written at the same time, so that the rules of the multi-tier automaton are rules that scan the input tiers and, depending on the state, write to the output tier.

The compilation phase runs through three consecutive steps. Each step’s output is the input to the following step. As a first step, the rules, the MBCH and the CFG as inputs are coded in the Morphotools format, a specification language that we defined for the multi-tape machine used in MAGEAD. Then the Morphotools format is compiled to the Lextools format, an NLP-oriented extension of the AT&T toolkit for finite-state machines (Sproat, 1995). The Lex-

The third phase is simply the use of MAGEAD for mor-

5. A Lexical Hierarchy

This section describes the lexical hierarchy which we use as interface between the morphological engine and the lexicon. This hierarchy lets us relate morphological processes to those lexical items which can undergo them. Within MAGEAD, our operational definition of a lexeme is as a triple of root, morphological behavior class (MBC) and meaning index. The MBC defines exactly how morphemes (both templatic and affixival morphemes) and features are paired for a particular lexeme. Additionally, the MBC spec-

The meaning index disambiguates between lexemes that have identical word forms, but different meaning; in our current work, we do not use the meaning index, as it pertains only to lexicography and not to morphology. We illustrate our approach with some examples.

Regular inflection معلم muEal~im ‘teacher’ is regular in both number and gender: the feminine singular form is معلومة muEal~ima, the masculine plural form is معلمان muEal~imawn, and the feminine plural is معلمات muEal~imaAt. Put differently, all inflectional feature combinations map to the same pattern and vocalism morpheme [m\text{VIV22V3}]+[\text{uai}]; however, for the same case and state features, say [CAS:NOM STT:INDEF], [GEN:MAS NUM:SG] gets mapped to the masculine singular morpheme معلم muEal~imah, the plural masculine plural form is معلمه muEal~imamah, and the feminine plural is معلمات muEal~imawn. [GEN:MAS NUM:PL] to the masculine plural morpheme معلم muEal~imawna, [GEN:FEM NUM:SG] to the feminine singular morpheme معلم muEal~imawna, and [GEN:FEM NUM:PL] to the feminine plural morpheme معلمات muEal~imawa.

The MBC is thus ر\text{A} mou1a22i3~im, where the R indicates it is rational, A that it can be either masculine or feminine, and mou1a22i3~im says
that the vocalized pattern is the same for all forms, and regular inflectional morphology is used to derive them.

**Simple broken plural** (ضافي miahi ‘key’ is a masculine irrational noun which has the plural مضافي mafatiyh ‘keys’.

Its MBC is thus mbc:noun-I-M-mi12A3-ma1A2i3y3. This MBC maps [GEN:MAS NUM:SG] to the pattern and vocalism morphemes [mv12V3]+[iA] and the masculine singular morpheme, and [GEN:MAS NUM:PL] to the pattern and vocalism morphemes [mv12V2V3]+[aAI] and (also) the masculine singular morpheme. The fact the mafatiyh is a diptote is handled in with pattern-aware rules, not in the MBC.

**Multiple plurals** Some words have multiple broken plurals, often with slight meaning variations. Consider the singular form كتاب kAtib ‘writer’. There are three plural morphologies, forms of which are broken and one of which is regular: كتابكت الكتاب ‘authors, novelists’, كتابكت الكتاب ‘keys’. The feminine forms for all three meanings of kAtib are the same: كتابكت الكتاب kAtibAtbun ‘persons writing’. The feminine forms for all three meanings of kAtib are thus: مكسُتِهْ کَاتِبَاتْ کَاتِباَتْ kAtibat (singular) and کاتِباَتْ kAtibat (plural). We represent this situation by saying that there are in fact three distinct lexemes (all rational), which is necessary as we can only specify one plural form per lexeme per gender, but which is additionally supported by the meaning differences in the plural forms. The three MBCs we have for kAtib are thus: mbc:noun-R-A-1A2i3-1u22A3-*, mbc:noun-R-A-1A2i3-1a2a3+ap-*, and mbc:noun-R-A-1A2i3-*. Here, 1A2i3-1a2a3+ap-* (to take one example) means that the masculine singular pattern and vocalism morphemes are [1V2V3]+[aAI] with a masculine singular affix, the masculine plural pattern and vocalism morphemes are [1V2V3]+[aAI] with the feminine singular affix, and the feminine forms use the masculine singular pattern and vocalism morphemes and the regular feminine affixes.

We define MBCs using a special language, in which we can define a hierarchical representation with non-monotonic inheritance. The hierarchy allows us to specify only those feature-to-morpheme mappings for all MBCs which share them. For example, the root node of our MBC hierarchy is a word, and all Arabic words share certain mappings, such as that from the linguistic feature conj:w to the clitic w+. This means that all Arabic words can take a cliticized conjunction. Similarly, the possessive pronounal clitics are the same for all nouns, no matter what their templatic pattern is, and no matter whether the plural is sound or broken. Our current MBC hierarchy specification for MSA nouns comprises 962 classes that can be instantiated in our lexicon, which comprises 32,110 nouns.

We built our lexicon using the lexicon of the Elixir-FM system (Smrž, 2007) with major extensions to convert its allomorphic templatic patterns to something consistent with MAGEAD’s representation. The extension was done semi-automatically. We plan to discuss lexicon development for MAGEAD in a future publication.

6. **Morphological, Phonological, and Orthographic Rules**

This section provides a list of morphological rules for Arabic MSA nomininals. Crucially, the rules we present for MSA are different from previous approaches in the explicit separation between orthography and phonology.

We have two basic types of rules. First, morphophone/phonological rules map from the morphemic representation to the phonological and orthographic representations. Our nominal system has 79 multi-tier rules of this type. Second, orthographic rules rewrite only the orthographic representation. We use 77 two-tier rules of this type. A large number of these rules is similar to those we previously presented for verbs (Habash and Rambow, 2007).

There are some important differences that stem from particulars of verb and noun morphology differences. For example, nouns have the Ta-Marbuta and definite article morphemes but verbs don’t. Similarly, verbs have particular morphemes that require their own rules such as the Waw-of-Plurality. Some of the shared rules

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**Figure 1:** Overview of MAGEAD’s Architecture. The asterisk * means that compiled output is input to the following step.
never apply for some cases due to the different contexts. For example a verb can have no vowels following its last radical in some of its forms (e.g., imperative; perfective with consonant-initial subject suffixes), but nouns always require a case vowels (in MSA). This interacts with Geminate rules. So, whereas the verb *madad+tu ‘he extended’ has the form *madad+tu ‘I extended’; the noun *muHtal+u ‘occupier’ never appears as *muHtala.

We organize this section by the phenomena we handle rather than the types of rules. As such, each phenomenon will be handled with a combination of different types of rules. We cluster the different phenomena discussed at a coarse level as follows: general default cases, templatic rules, affixational rules, and finally general orthographic rules. We only discuss a portion of the rules for space limitations. We do not discuss the not-so-interesting issue of rule-ordering, which is irrelevant to making sure the whole system functions smoothly.

6.1. Default Rules

The default cases are sufficiently handled with simple default morphophonemic and orthographic rules that map symbols from tier to appropriate tier. These cases all require the general cleaning of morphemic boundary markers, such as ‘+’, stem initial/final, word initial/final markers, e.g., *[AI+IV2V3+u]+[kTk]+[ua] ⇒ */AI+ktub+u/ ⇒ Alkutubu ‘the books’.

6.2. Templatic Rules

Form VIII Rules Nominals derived from verb form VIII (i1ta2a3) experience a change in the pattern consonant *t based on the form of the first root radical. The pattern consonant *t changes to d when the first root radical is د، ﾆ، ﾆ or د. Similarly, the same pattern consonant changes to ط when the first root radical is an emphatic consonant (כ S، ض D، ط T or ط D). For example, compare the following verbs all of which are in Form VIII deverbal [Masdar: أتستمال AistiAm ‘reception’ (root sAlm, default case), أديزة AizdihAr ‘prosperity’ (root zhr) and أصبار AiSThAr ‘longanimity/fearlessness’ (root Sbr).

Weak Radical Rules The root radicals w and y are called weak because they often change form due to the application of various morphophonemic rules. There are numerous vocalic and consonantal conditions that cause these changes to take place. We only illustrate some examples of these changes without further discussion:

- [IV2V3]+[wDH]+[aA] ⇒ ’iyDAH ⇒ ’IDAH ⇒ ﺎّiyDAH ‘clarification’
- [IV1V2V3]+[bwr]+[ua] ⇒ muθwir ⇒ muθAlr ⇒ muθiyr ‘exigency’
- [IV2V3]+[jw]+[aA] ⇒ jaleAw ⇒ jaleA ‘جلاء ‘withdrawal’

Geminate Rules Geminate radicals rules are applied when second and third root radicals have the same consonantal value, e.g., Hll or mdd. A common geminate rule deletes a vocalism short vowel when preceded by a vocalism vowel and a geminate radical and followed by a geminate radical and a vowel suffix, e.g.,

\[mV1V2V3+u]+[Hll]+[uai] ⇒ muHtal+u ⇒ muHtal+u ⇒ محتل ‘occupier’.

6.3. Affixational Rules

Ta-Marbuta When followed by a pronominal enclitic, word-final Ta-Marbuta is rewritten as تا: مكتبة ‘our library’.

Alif-Maqsura When followed by a pronominal enclitic, Alif-Maqsura typically becomes Alif in nominals, e.g., مستشفى+h+ becomes mstšf+h+ ‘their hospital’.

Pronominal Clitic Form The u vowel in the +hu-pronominal enclitics, ه+ +hu، ه+ +humA، ه+ +him، and ه+ +hum~a، undergoes phonological assimilation to i when following a word that ends with i as in the nominal genitive case. For example, كابي ‘his book’ can be dia- critized as kitAb+hu، kitAb+a+i+hu or kitAb+i+hi. Similarly, the 1st person singular pronom clitic ه+iy+ has an allo- morph ه+iya with words ending with the letters Alif, Ya or Alif-Maqsura, e.g., عائش ‘my eyes [nominative]’ (مودي ‘my lord’ (mawlay+iya)، مودي ‘my lady’ (mawlay+iya). The same pronominal clitic overrides word- final case markers effectively normalizing case for such words, e.g., كابي ‘my book’ can be underlyingly kitAb+u+i+y، kitAb+a+i+y or kitAb+i+i+y (nominative, accusative or genitive, respectively).

Definite Article The Lam of the definite article ﺖ summarizes if followed by a so-called Sun letter.4 Assimilation is indicated by doubling the first letter of the word (with a Shadda diacritic) and counterintuitively not deleting the assimilating letter in the definite article (to preserve the word’s morphemic spelling). For example، الشمس Alš ‘the sun’ is written as شمس Alš+qamaru ‘the sun’, which is pronounced /bilkitAbi/ but written شمس. The Sun letters are أزهر أزهار ‘prosperity’ (root zhr) and أصبار AiSThAr ‘longanimity/fearlessness’ (root Sbr).

Weak Radical Rules The root radicals w and y are called weak because they often change form due to the application of various morphophonemic rules. There are numerous vocalic and consonantal conditions that cause these changes to take place. We only illustrate some examples of these changes without further discussion:

- [IV2V3]+[wDH]+[aA] ⇒ ’iyDAH ⇒ ’IDAH ⇒ ﺎّiyDAH ‘clarification’
- [IV1V2V3]+[bwr]+[ua] ⇒ muθwir ⇒ muθAlr ⇒ muθiyr ‘exigency’
- [IV2V3]+[jw]+[aA] ⇒ jaleAw ⇒ jaleA ‘جلاء ‘withdrawal’

Geminate Rules Geminate radicals rules are applied when second and third root radicals have the same consonantal value, e.g., Hll or mdd. A common geminate rule deletes a vocalism short vowel when preceded by a vocalism vowel and a geminate radical and followed by a geminate radical and a vowel suffix, e.g.,

\([mV1V2V3+u]+[Hll]+[uai] ⇒ muHtal+u ⇒ muHtal+u ⇒ محتل ‘occupier’.

6.4. General Orthographic Non-Lexical Rules

These rules are purely orthographic rules that do not interact with any other tiers of information. They are the last step in generation mode and the first step in analysis mode. They are presented below in their order of application in generation mode.

Long Vowel Spelling Rule The long vowels are spelled using a short vowel and a glide: i is written as iy and û as uv.
Sukun Rule  A Sukun (no vowel diacritic) is added between any two adjacent consonants or after a consonant at the end of a word.

Shadda Rule  The second of two repeated consonants (separated by a Sukun) is replaced with a Shadda diacritic. The Sukun is deleted. For example, kuttAb becomes 

Hamza Rules  The phoneme Hamza (glottal stop) is written using six orthographic symbols (ø, ˆA, ˇA, ¯A, Ā and {text.alt}). The correct symbol is dependent on the context of the Hamza. Buckley (2004) describes over 18 rules for Hamza writing, which we implemented here. Rare exceptions and allowed (less common) alternatives are not handled. The following are some of the rules we used. First a word-initial Hamza followed by a short vowel diacritic is written with Alif Hamza Below (Ø) when followed by i and with Alif Hamza Above (Ø) otherwise. The Hamza is written on a Ya (Ø) when either followed or preceded by u or when following a consonant letter Ya. Alternatively, it is written on a Waw when either followed or preceded by u. Otherwise Hamza is written on Alif. Also, Alif Hamza Above followed by a long a (a) is rewritten as Alif Madda (Ø). At the end of base word, the default is to have the Hamza written on the line. The exceptions depend on the preceding short vowel. Some Hamza rules are more complex and involve letter shape. For example, a Hamza at the end of a word directly following a connective letter changes its shape to Ya-Hamza before the suffix +Aa, but not if the letter is disconnective, e.g. 姣/kA/grounds/‘warmth’ but 姣/kA/grounds/‘part’.

Vowel Initial Spelling Rule  Since initial vowel diacritics cannot appear on their own, we add an additional Alif at the beginning of words with initial vowels. For example, izdihAru is modified to its final form ÀizdihÀru.

7. Evaluation

In this section, we evaluate MAGEAD’s nominal implementation in terms of coverage and correctness.

7.1. Testing Corpora

We use the Penn Arabic Treebank (PATB) (Maamouri et al., 2004), specifically Part 3 v 3.1 (Maamouri et al., 2009), as our evaluation corpus. This release of the PATB only provides the analysis choice made by the annotators per word and not all the possible analyses (unlike previous releases). We use the files in the pos/afters-treebank directory. The entries in these files are tokenized words with links to their surface segments (INPUT STRING). We recreate the surface untokenized forms by concatenating the segments and use a concatenation of the POS of each segment as the gold choice for the whole word. The LEMMA associated with the base word token (as opposed to clitics) is taken to be the lexeme of the whole word.

To get all possible analyses for each word, we use the Standard Arabic Morphological Analyzer (SAMA) (Graff et al., 2009) – which is version 3.1 of the BAMA analyzer (Buckwalter, 2004).

The test set we report on in this section is based on the nominal nouns appearing among the first 10,000 words in the PATB. These add up to a total of 4,870 nominal word tokens (non-unique). We exclude three kinds of analyses for specific reasons. First, since we are not evaluating our lexicon coverage, we exclude all analyses not in our lexicon. Second, we also exclude all analyses involving non-trilateral roots and non-templatic word stems since we do not even attempt to handle them in the current version of our rules. Finally, SAMA uses orthographic backoff to allow finding matches for words with common spelling errors, e.g., Hamzated Alif form confusion (ø/ø/øA/A), Ta-Marbuts/Ha confusion (ø/ø/øh/øh) and Alif-Maqsura/Ya confusion (ø/ø/ø/ø/ø). We only model the first of these three, the Hamzated Alif confusions, which represent over 97% of all cases of spelling confusion.

Analyses involving the other cases are excluded. The total number of exclusions is 682 word tokens (14% of all nominal word tokens). The remaining 4,188 word tokens (2,405 unique word types) constitute the test set we report on here. The same exclusion criteria are applied to the SAMA analyses.

We convert all analyses to a morphological feature-value representation that specifies for each word its proclitics, enclitic, gender, number, case and state, in addition to the diacritized word form and the lexeme. We do not distinguish among different types of nominals and do not consider non-nominal analyses. As such, the POS value is not included in this evaluation.

7.2. Testing Metrics

We consider five evaluation metrics that fall into three categories:

- Average Recall (ATyR for type recall, AToR for token recall): on average, what proportion of the analyses in the gold standard does MAGEAD get for each type/token respectively?
- Average Precision (ATyP for type precision, AToP for token precision): on average, what proportion of the analyses that MAGEAD gets are also in the gold standard for each type/token respectively?
- Context Token Recall (CToR): how often does MAGEAD get the contextually correct analysis for all token?

We do not give context precision figures, as MAGEAD does not determine the contextually correct analysis – this is a tagging problem (Habash and Rambow, 2005). Rather, we interpret the context token recall figures as a measure of how often MAGEAD gets the most important of the analyses (i.e., the correct one) for each token.

Words that return no analysis in MAGEAD are reported separately and not included in the metrics since precision in such cases is not defined.

For each of these metrics, we consider the following subsets of morphological aspects to measure against. These aspects

\(^3\)nouns, adjectives, adverbs, comparative adjectives, noun numbers, adjective numbers and quantitative nouns

\(^4\)Statistic computed over the Penn Arabic Treebank and their difference from input word.
are considered in isolation and in selected combinations for evaluation in the next section.

- **DIAC** is the fully diacritized word form. Due to inconsistencies between our gold standard and MAGEAD in how the Sukun diacritic (or no vowel diacritic) is used, we drop it and consider the absence of a diacritic in a fully diacritized word to be a sufficient representative of the Sukun.
- **DIACNE** is the same as DIAC except that the last (typically case marking) diacritic is dropped.
- **LEXEME** is the lemma representation of the lexeme.
- **FEATCL** is the set of clitic features: the definite article, the preposition clitics, the conjunction clitics and the pronominal clitics.

The inflectional features (case, state, gender and number) are ignored in our evaluation because MAGEAD uses functional morphology while SAMA uses form-based morphology. We discuss this issue in more detail below in Section 7.4.

### 7.3. Quantitative Analysis

Of the 4,188 word tokens (2,405 unique word types) in our test set, MAGEAD fails to produce an analysis in 243 word tokens (5.8% of all word tokens) corresponding to 153 word types (6.4% of all word types). For 124 word types, MAGEAD produces analyses that do not have a matching MBC in the lexicon. For the remaining 29 word types, MAGEAD does not produce a single analysis. The results of our performance on the remaining 3,945 word tokens (2,252 word types) in terms of the metrics discussed above are presented in Table 1. We consider six sets of morphological aspects to compare.

| FEATCL | LEX        | LEX+FEATCL | DIACNE     | DIAC       | DIACNE+LEX+FEATCL |
|--------|------------|------------|------------|------------|-------------------|
| ATyP   | 99.7       | 97.7       | 99.7       | 98.1       | 99.7              |
| AToP   | 94.6       | 95.1       | 93.8       | 95.5       | 97.6              |
| AToR   | 94.5       | 94.7       | 93.8       | 95.3       | 97.5              |
| CToR   | 95.9       | 72.3       | 94.5       | 73.2       | 94.7              |
|        | 92.8       | 91.3       | 92.2       | 92.4       | 95.9              |

With one exception, DIAC recall, all of our scores are in the 90s. All of the CToR scores are above 94%, which suggests that the errors MAGEAD is making have less effect on the correct in-context choices. Precision is higher than recall except for LEX and LEX+FEATCL cases. This is likely to be the result of lexicon errors or mismatches – see Section 7.4. The best performance we have is on **FEATCL**: this is significant as it suggests that this implementation of MAGEAD can be used for certain NLP applications such as tokenization and simple stemming. The sharp increase in ATyR and AToR when ignoring the last diacritic (in DIACNE compared to DIAC) together with the small increase in precision suggests that MAGEAD is failing to produce some diacritizations but is not over-generating. In fact, we see in the next section that the largest recall error type is related to an extraneous diacritization that SAMA produces and MAGEAD doesn’t. The DIACNE+LEX+FEATCL combination still shows good performance, although there is a lot of potential for improvement still.

### 7.4. Qualitative Analysis

To understand in more detail the types of errors in our systems, we took a random sample of 100 word types, of which six cases produced no analysis (three complete failures and three lexicon misses). The failures seem to be mostly a result of missing/incorrect rules and in two cases incorrect lexical entries. For the remaining 94 cases, we classify all of the recall and precision errors when comparing all morphological features including gender-number-case-state. Under this harsh comparison condition, the ATyP is 47.5%, ATyR is 53.7%.

#### Recall Errors

As for recall errors, only 22.2% (relative) are valid errors that are the result of missing lexical items, incorrect or missing morphophonemic rules or uncommon particles that MAGEAD does not model. All of these errors are recoverable and will be addressed in the future.

The rest of the errors are actually SAMA issues that should not reflect negatively on MAGEAD: the largest contributor (34.1% relative) is an additional analysis that SAMA adds which contains no case choice, when case otherwise would not be indicated with a written letter, e.g., producing the analysis kitAb ‘book’ in addition to kitAb[a,a,i,i,c]. For some of these words, SAMA does not produce a case marker since the surface form of the case marker is nil, سحراذ, SaHAry ‘deserts [nom/acc/gen]’.

The second largest class (22.9% relative) are cases of mismatches in form and function of the gender and number features, e.g. دول DuAwlu ‘states is masculine-singular in SAM la but it is feminine-plural in MAGEAD (plural of دوالاب ‘state’). Finally, the last class of errors (20.8% relative) are cases where SAMA has an incorrect morphological prefix or lexeme. The large majority of these cases are the result of a very rare preposition تاء الاسم ‘Ta of Oath’, which is reserved for a few number of words, being applied to any word. For example, the word تأليف ‘Azylf commonly analyzable as ‘authoring’ is also analyzed as تأليف ‘by+domesticated’, a very odd analysis.

#### Precision Errors

As for precision errors, only 18% are real problems in MAGEAD. Half of these roughly are rule and morpheme-specification errors and the rest are lexicon errors. An example of a rule errors is a missing exception to the geminate rules that leads to extra vowel deletion, e.g. analyzing in ‘investigator’ as mHuQ ‘-q instead of mhuQ ‘-iq. An example of a wrong lexical entry is using the lemma جرية γarba’d ‘lit. west [indef.acc]’ but translated
commonly as ‘westward’ instead of the correct غرب.

The rest of the precision errors (82%) are false errors that are the result of functional morphology modeling. Around 60% are due solely to the over-generation of definite-construct variants, while the rest are mostly due to mismatches of functional/form-based gender and number cases.

This analysis shows that the majority of errors are in fact either problems in the gold standard or a result of the discrepancy between different models of form-based/functional morphology. Interestingly, these results are comparable to our previously published error analysis of verbs (Habash and Rambow, 2006). None of the real errors are theoretically challenging to our framework and approach. They can and will be addressed in future work on MAGEAD.

8. Conclusion and Future Work

In this paper, we presented the details of an implementation of MSA nominals in MAGEAD, a morphological analyzer and generator for Modern Standard Arabic (MSA) and its dialects. A detailed evaluation of the current implementation comparing it to a commonly used morphological analyzer shows that it has good coverage and usability with high precision and recall.

In the immediate future, we plan to continue improving the morphological rules used in MAGEAD. We also plan to work on creating an improved lexicon and extending MAGEAD’s nominal implementation to Arabic dialects.

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