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CAMeL Lab

Computational Morphology and Lexicography Modeling of Modern Standard Arabic Nominals

Christian Khairallah, Reham Marzouk, Salam Khalifa
Mayar Nassar and Nizar Habash

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CAMeL Lab

- **Motivations for Morphology Modeling**
  - Additive value of morphological analyzers to neural models in several NLP tasks
    - Grammatical Error Correction (Alhafni et al., 2023)
    - Controlled Generation (Alhafni et al., 2022)
    - Morphological Disambiguation (Inoue et al., 2022)
    - Machine Translation (Oudah et al., 2019)
  - Help with low resource languages
  - Help with morphologically rich languages
  - Filter method, feature source, augmentation support, explainability

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CAMeL Lab

- **Camel Morph Project** **(Habash et al., 2022)**
  - Build open-source Arabic morphological models
  - Maximize coverage of Arabic linguistic phenomena
  - Include Standard, Classical and Dialectal Arabic
  - Cover many genres and domains
  - Use linguistically grounded representations
  - Built models are readily usable within an existing Python open-source suite for Arabic NLP, Camel Tools (Obeid et al., 2020)

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CAMeL Lab

- **Contributions in this paper** …
  - Defining the space of challenges in modeling Modern Standard Arabic (MSA) nominals
  - Developing an extendable large-scale implementation using Camel Morph
  - Benchmarking our models against publicly available analyzers
  - Our data and code are publicly available

Arabic Morphology Challenges

- **Morphological Richness**
  - gender, number, person, aspect, mood, case, state and voice + many clitics
- **Morphological Complexity**
  - Allomorphs of many affixes and clitics
- **Dialectal Variations**
  - Many dialects with important differences
- **Orthographic Ambiguity**
  - MSA: 12 readings/word due to optional diacritics
- **Orthographic Inconsistency**

Arabic Nominal Modeling Challenges

- **Morphological Challenges**
  - Rich & Complex Morphology
    - Templatic and Concatenative, many features & interactions
  - Form-Function Mismatch
    - Broken plurals, irregular gender, case variants, syncretism
  - Prefix-Stem-Suffix interactions
    - Prefix, Stem and Suffix Allomorphs
- **Lexicographic Challenges**
  - Paradigm incompleteness
  - Stem variants
  - Inter-paradigm ambiguity

Arabic Nominal Modeling Challenges

- Gender-Number-Case-State Discrepancies

Function → Form

	ni	nd	nc	gi	gd	gc	
ms	ٌ ũ	ُ u		ٍ ĩ	ِ i		+MS
fs	ةٌ aħũ	ةُ aħu		ةٍ aħĩ	ةِ aħi		+FS
mp	ُونَ uwna		ُو uw	ِينَ iyna		ِي iy	+MP
fp	اتٌ aAtũ	اتُ aAtu		اتٍ aAtĩ	اتِ aAti		+FP

- Syncretism: definite/indefinite/construct
- Default Function-Form mappings

Arabic Nominal Modeling Challenges

- Gender-Number-Case-State Discrepancies

Function → Form

	ni	nd	nc	gi	gd	gc	
ms	ٌ ũ	ُ u		ٍ ĩ	ِ i		+MS
fs	ةٌ aħũ	ةُ aħu		ةٍ aħĩ	ةِ aħi		+FS
mp	ونَ uwna	وُ uw		ينَ iyna	يِ iy		+MP
fp	اتٌ aAtũ	اتُ aAtu		اتٍ aAtĩ	اتِ aAti		+FP

Lemma + Function → Stem + Form

			Features			
Lemma	Gloss	Stem	ms	mp	fs	fp
muwaĎ~af	employee	*muwaĎ~af*	+MS	+MP	+FS	+FP
safiyr	ambassador	*safiyr*	+MS		+FS	+FP
		sufaraA'		+MS		
nAr	fire	*nAr*			+MS	
		niyrAn				+MS
xaliyfaħ	caliph	*xaliyf*	+FS			
		xulafA'		+MS		

- Syncretism: definite/indefinite/construct
- Default and non-default Function-Form mappings
- Incomplete Paradigms

Arabic Nominal Modeling Challenges

- Sound Plural vs Broken Plural
- Allomorphs
  - Stems
  - Buffers
  - Enclitics

			Features			
Lemma	**Gloss**	**Stem**	**ms**	**mp**	**fs**	**fp**
safiyr	ambassador	*safiyr*	+MS		+FS	+FP
		sufaraA'		+MS		

Word	(a) وَلِسَفِيرَاتِهِم walisafiyraAtihim *`and for their ambassadors [f]'*					
Surface Segmentation	**Proclitics**			**Baseword**		**Enclitic**
				Stem	**Suffixes**	
	wa+	li+		safiyr	+aAt	+i	+him

Word	(b) وَلِسُفَرَائِهِم walisufaraAŷihim *`and for their ambassadors [m]'*					
Surface Segmentation	**Proclitics**			**Baseword**		**Enclitic**
				Stem	**Suffixes**	
	wa+	li+		sufaraAŷ	+i	+him

Arabic Nominal Modeling Challenges

- Sound Plural
  vs Broken Plural

			Features			
Lemma	**Gloss**	**Stem**	**ms**	**mp**	**fs**	**fp**
safiyr	ambassador	*safiyr*	+MS		+FS	+FP
		sufaraA'		+MS		

Word	(a) وَلِسَفِيرَاتِهِم walisafiyraAtihim *`and for their ambassadors [f]'*										
Surface Segmentation	**Proclitics**			**Baseword**							**Enclitic**
				Stem			**Suffixes**				
	wa+	li+		safiyr			+aAt		+i		+him
Morpheme & Features	**prc2**	**prc1**	**prc0**	**lex**	**root**	**pattern**	**gen**	**num**	**cas**	**stt**	**enc0**
	wa+	li+	∅	safiyr	s.f.r	1a2iy3	f	p	g	c	+hum

Word	(b) وَلِسُفَرَائِهِم walisufaraAŷihim *`and for their ambassadors [m]'*									
Surface Segmentation	**Proclitics**			**Baseword**						**Enclitic**
				Stem				**Suffixes**		
	wa+	li+		sufaraAŷ				+i		+him
Morpheme & Features	**prc2**	**prc1**	**prc0**	**lex**	**root**	**pattern**	**gen**	**num**	**cas**	**stt**	**enc0**
	wa+	li+	∅	safiyr	s.f.r	1u2a3aA'	m	p	g	c	+hum

Arabic Nominal Modeling Challenges

- Sound Plural vs Broken Plural
- Allomorphs
  - Stems
  - Buffers
  - Enclitics

			Features			
Lemma	**Gloss**	**Stem**	**ms**	**mp**	**fs**	**fp**
safiyr	ambassador	*safiyr*	+MS		+FS	+FP
		sufaraA'		+MS		

sufaraA	*'*	*a*
sufaraA	*'*	*a +hum*
sufaraA	*'*	*u*
sufaraA	*ŵ*	*u +hum*
sufaraA	*'*	*i*
sufaraA	*ŷ*	*i +him*

Word	(a) وَلِسَفِيرَاتِهِم walisafiyraAtihim *`and for their ambassadors [f]'*										
Surface Segmentation	**Proclitics**			**Baseword**							**Enclitic**
				Stem			**Suffixes**				
	wa+	li+		safiyr			+aAt		+i		+him
Morpheme & Features	**prc2**	**prc1**	**prc0**	**lex**	**root**	**pattern**	**gen**	**num**	**cas**	**stt**	**enc0**
	wa+	li+	∅	safiyr	s.f.r	1a2iy3	f	p	g	c	+hum
Buckwalter Database	**DBPrefix**			**DBStem**			**DBSuffix**				
	wali+			safiyr			+aAtihim				
Camel Morph Specs	**[Conj]**	**[Prep]**	**[Art]**	**[Stem]**		**[Buffer]**	**[Suff]**				**[Pron]**
	wa+	li+	∅	safiyr		∅	+aAt		+i		+him

Word	(b) وَلِسُفَرَائِهِم walisufaraAŷihim *`and for their ambassadors [m]'*										
Surface Segmentation	**Proclitics**			**Baseword**							**Enclitic**
				Stem					**Suffixes**		
	wa+	li+		sufaraAŷ					+i		+him
Morpheme & Features	**prc2**	**prc1**	**prc0**	**lex**	**root**	**pattern**	**gen**	**num**	**cas**	**stt**	**enc0**
	wa+	li+	∅	safiyr	s.f.r	1u2a3aA'	m	p	g	c	+hum
Buckwalter Database	**DBPrefix**			**DBStem**					**DBSuffix**		
	wali+			sufaraAŷ					+ihim		
Camel Morph Specs	**[Conj]**	**[Prep]**	**[Art]**	**[Stem]**		**[Buffer]**	**[Suff]**				**[Pron]**
	wa	li	∅	sufaraA		ŷ	∅		+i		+him

Arabic Nominal Modeling Challenges

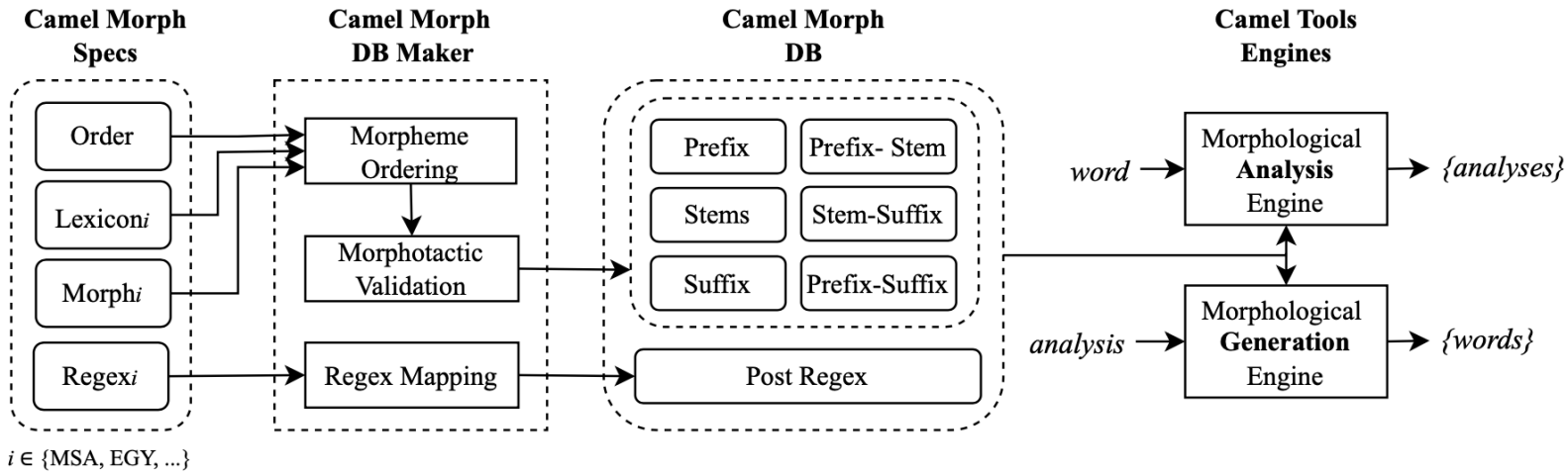
- Sound Plural vs Broken Plural
- Allomorphs
  - Stems
  - Buffers
  - Enclitics
- Buckwalter DBPrefix DBStem DBSuffix
- Camel Morph Specifications

			Features			
Lemma	**Gloss**	**Stem**	**ms**	**mp**	**fs**	**fp**
safiyr	ambassador	*safiyr*	+MS		+FS	+FP
		sufaraA'		+MS		

Word	(a) وَلِسَفِيرَاتِهِم walisafiyraAtihim `*and for their ambassadors [f]*'										
Surface Segmentation	**Proclitics**			**Baseword**							**Enclitic**
				Stem			**Suffixes**				
	wa+	li+		safiyr			+aAt		+i		+him
Morpheme & Features	**prc2**	**prc1**	**prc0**	**lex**	**root**	**pattern**	**gen**	**num**	**cas**	**stt**	**enc0**
	wa+	li+	∅	safiyr	s.f.r	1a2iy3	f	p	g	c	+hum
Buckwalter Database	**DBPrefix**			**DBStem**			**DBSuffix**				
	wali+			safiyr			+aAtihim				
Camel Morph Specs	**[Conj]**	**[Prep]**	**[Art]**	**[Stem]**		**[Buffer]**	**[Suff]**				**[Pron]**
	wa+	li+	∅	safiyr		∅	+aAt		+i		+him

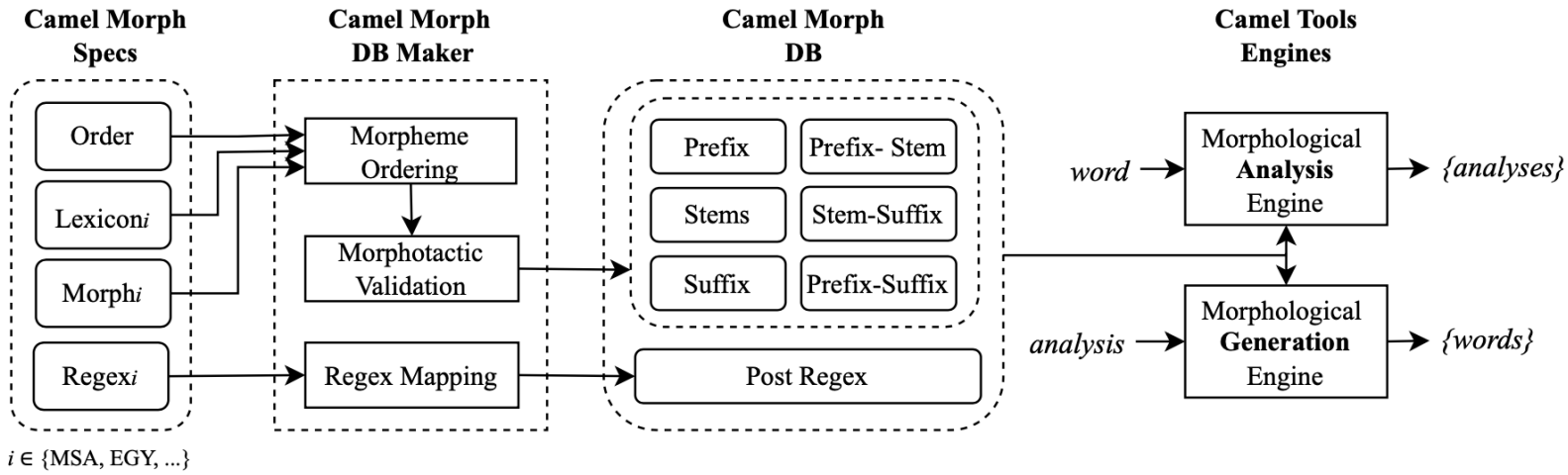
Word	(b) وَلِسُفَرَائِهِم walisufaraAŷihim `*and for their ambassadors [m]*'										
Surface Segmentation	**Proclitics**			**Baseword**							**Enclitic**
				Stem					**Suffixes**		
	wa+	li+		sufaraAŷ					+i		+him
Morpheme & Features	**prc2**	**prc1**	**prc0**	**lex**	**root**	**pattern**	**gen**	**num**	**cas**	**stt**	**enc0**
	wa+	li+	∅	safiyr	s.f.r	1u2a3aA'	m	p	g	c	+hum
Buckwalter Database	**DBPrefix**			**DBStem**					**DBSuffix**		
	wali+			sufaraAŷ					+ihim		
Camel Morph Specs	**[Conj]**	**[Prep]**	**[Art]**	**[Stem]**		**[Buffer]**	**[Suff]**				**[Pron]**
	wa	li	∅	sufaraA		ŷ	∅		+i		+him

Camel Morph Approach



- Camel Morph Specifications
- Camel Morph DB
- Camel Tools analysis and generation engines (Obeid et al., 2020)

Camel Morph Approach



- In between two different approaches
  - Top down; linguistic representations; FSM; rules
  - Bottom up; lists of surface complex prefixes and suffixes, stems, and their compatibilities

	Morph Order		
	DBPrefix	**DBStem**	**DBSuffix**
O1	[Conj] [Prep]	[NomStem] [NomBuff]	[NomSuff.IG]
O2	[Conj] [Prep]	[NomStem] [NomBuff]	[NomSuff.CG] [Pronoun]
O3	[Conj] [Prep] [Determiner]	[NomStem] [NomBuff]	[NomSuff.DG]

		Class	Lemma/ Morpheme	Form	Gloss	gen	num	stt	cas	Set Conds	Required Conds				
Lexicon	L1a	[NomStem]	*safiyr*	*safiyr*	ambassador	-	-	-	-		MS|FS|FP		✓		✓
	L1b	[NomStem]	*safiyr*	*sufaraA*	ambassador	m	p	-	-	#A' #dip	MS	✓		✓	
Prc	P1	[Determiner]													
	P2	[Determiner]	Prc.Al	Al	the										✓
Buffers	B1	[NomBuff]									else				
	B2a	[NomBuff]		'							#A'	✓			
	B2b	[NomBuff]		ŷ							#A' obj suff-i			✓	
	B2c	[NomBuff]		ŵ							#A' obj suff-u				
Suffixes	S1a	[NomSuff.IG]	Suff.MSIG	ĩ		m	s	i	g	MS	else				
	S1b	[NomSuff.IG]	Suff.MSIG	a		m	s	i	g	MS	#dip	✓			
	S2	[NomSuff.IG]	Suff.FPIG	aAt+ĩ		f	p	i	g	FP					
	S3	[NomSuff.CG]	Suff.MSCG	i		m	s	c	g	MS suff-i				✓	
	S4	[NomSuff.CG]	Suff.FPCG	aAt+i		f	p	c	g	FP suff-i			✓		
	S5	[NomSuff.DG]	Suff.MSDG	i		m	s	d	g	MS					
	S6	[NomSuff.DG]	Suff.FPDG	aAt+i		f	p	d	g	FP					✓
Enclitics	C1	[Pronoun]													
	C2a	[Pronoun]	Pron.3MP	hum	their					obj	else				
	C2c	[Pronoun]	Pron.3MP	him	their					obj	suff-i		✓	✓	

sufaraA+'+a	O1
safiyr+aAt+i+him	O2
sufaraA+ŷ+i+him	O2
Al+safiyr+aAt+i	O3

- Morph order defines the full space of all morphemes that can co-occur by their class.

	Morph Order		
	DBPrefix	**DBStem**	**DBSuffix**
O1	[Conj] [Prep]	[NomStem] [NomBuff]	[NomSuff.IG]
O2	[Conj] [Prep]	[NomStem] [NomBuff]	[NomSuff.CG] [Pronoun]
O3	[Conj] [Prep] [Determiner]	[NomStem] [NomBuff]	[NomSuff.DG]

		Class	Lemma/ Morpheme	Form	Gloss	gen	num	stt	cas	Set Conds	Required Conds	sufaraA+'+a O1	safiyr+aAt+i+him O2	sufaraA+ŷ+i+him O2	Al+safiyr+aAt+i O3
Lexicon	L1a	[NomStem]	*safiyr*	*safiyr*	ambassador	-	-	-	-		MS|FS|FP		✓		✓
	L1b	[NomStem]	*safiyr*	*sufaraA*	ambassador	m	p	-	-	#A' #dip	MS	✓		✓	
Prc	P1	[Determiner]													
	P2	[Determiner]	Prc.Al	Al	the										✓
Buffers	B1	[NomBuff]									else				
	B2a	[NomBuff]		'							#A'	✓			
	B2b	[NomBuff]		ŷ							#A' obj suff-i			✓	
	B2c	[NomBuff]		ŵ							#A' obj suff-u				
Suffixes	S1a	[NomSuff.IG]	Suff.MSIG	ĩ		m	s	i	g	MS	else				
	S1b	[NomSuff.IG]	Suff.MSIG	a		m	s	i	g	MS	#dip	✓			
	S2	[NomSuff.IG]	Suff.FPIG	aAt+ĩ		f	p	i	g	FP					
	S3	[NomSuff.CG]	Suff.MSCG	i		m	s	c	g	MS suff-i				✓	
	S4	[NomSuff.CG]	Suff.FPCG	aAt+i		f	p	c	g	FP suff-i			✓		
	S5	[NomSuff.DG]	Suff.MSDG	i		m	s	d	g	MS					
	S6	[NomSuff.DG]	Suff.FPDG	aAt+i		f	p	d	g	FP					✓
Enclitics	C1	[Pronoun]													
	C2a	[Pronoun]	Pron.3MP	hum	their					obj	else				
	C2c	[Pronoun]	Pron.3MP	him	their					obj	suff-i		✓	✓	

- Each form (allomorph) sets some truth conditions to be true.
- For a word to be valid, the required truth conditions of every form (allomorphs) in it must be already set by some other allomorph.

	Morph Order		
	DBPrefix	**DBStem**	**DBSuffix**
O1	[Conj] [Prep]	[NomStem] [NomBuff]	[NomSuff.IG]
O2	[Conj] [Prep]	[NomStem] [NomBuff]	[NomSuff.CG] [Pronoun]
O3	[Conj] [Prep] [Determiner]	[NomStem] [NomBuff]	[NomSuff.DG]

		Class	Lemma/ Morpheme	Form	Gloss	gen	num	stt	cas	Set Conds	Required Conds
Lexicon	L1a	[NomStem]	*safiyr*	*safiyr*	ambassador	-	-	-	-		MS|FS|FP
	L1b	[NomStem]	*safiyr*	*sufaraA*	ambassador	m	p	-	-	#A' #dip	MS
Prc	P1	[Determiner]									
	P2	[Determiner]	Prc.Al	Al	the						
Buffers	B1	[NomBuff]									else
	B2a	[NomBuff]		'							#A'
	B2b	[NomBuff]		ŷ							#A' obj suff-i
	B2c	[NomBuff]		ŵ							#A' obj suff-u
Suffixes	S1a	[NomSuff.IG]	Suff.MSIG	ĩ		m	s	i	g	MS	else
	S1b	[NomSuff.IG]	Suff.MSIG	a		m	s	i	g	MS	#dip
	S2	[NomSuff.IG]	Suff.FPIG	aAt+ĩ		f	p	i	g	FP	
	S3	[NomSuff.CG]	Suff.MSCG	i		m	s	c	g	MS suff-i	
	S4	[NomSuff.CG]	Suff.FPCG	aAt+i		f	p	c	g	FP suff-i	
	S5	[NomSuff.DG]	Suff.MSDG	i		m	s	d	g	MS	
	S6	[NomSuff.DG]	Suff.FPDG	aAt+i		f	p	d	g	FP	
Enclitics	C1	[Pronoun]									
	C2a	[Pronoun]	Pron.3MP	hum	their					obj	else
	C2c	[Pronoun]	Pron.3MP	him	their					obj	suff-i

sufaraA+'+a	O1
safiyr+aAt+i+him	O2
sufaraA+ŷ+i+him	O2
Al+safiyr+aAt+i	O3

	✓		✓	
✓		✓		
				✓
✓				
		✓		
✓				
		✓		
	✓			
				✓
	✓	✓		

- Each form (allomorph) sets some truth conditions to be true.
- For a word to be valid, the required truth conditions of every form (allomorphs) in it must be already set by some other allomorph.

Results

		Our Specs	
(a)	**Lemmas (Stems)**	27,023	(33,497)
	Noun	19,858	(25,293)
	Adjective	6,922	(7,921)
	Comparative Adjective	243	(283)
(b)	**DBPrefix Morphemes (Allom.)**	18	(20)
	DBSuffix Morphs (Allom.)	99	(197)
	Stem Buffers	22	
	Unique Condition Terms	51	
	Morph Order Lines	42	

- Intensive semi-automatic process for creating all the entries and quality checking them.
- Multiple annotators involved in Morphological and Lexicography design.

Results

		Our Specs		Our DB		Calima MSA			
(a)	**Lemmas (Stems)**	27,023	(33,497)	27,023	(37,910)	26,990	(38,323)	**Lemmas (Stems)**	(a)
	Noun	19,858	(25,293)	19,858	(28,302)	19,970	(29,370)	*Noun*	
	Adjective	6,922	(7,921)	6,922	(9,184)	6,808	(8,703)	*Adjective*	
	Comparative Adjective	243	(283)	243	(424)	212	(250)	*Comparative Adjective*	
(b)	**DBPrefix Morphemes (Allom.)**	18	(20)	213		77		**DBPrefix Sequences**	(c)
	DBSuffix Morphs (Allom.)	99	(197)	614		391		**DBSuffix Sequences**	
	Stem Buffers	22		3,442		1,423		**Compatibility Tables**	
	Unique Condition Terms	51		83,649,166		28,359,701		**Unique Diacritized Forms**	(d)
	Morph Order Lines	42		246,880,683		126,176,265		**Unique Analyses**	
				1,300,068		1,041,949		**Unique Analyses (no Clitics)**	

- We compare our compiled DB with Calima MSA (Taji et al. 2018), based on SAMA (Graff et al., 2009)/BAMA (Buckwalter, 2004)
- Lemmas: Comparable
- Stems: Our Specs < Our DB ≈ Calima MSA
- Forms + Analyses : Our DB >> Calima MSA
  - Consistent and extended modeling of features and affixes

Results

		Our Specs		Our DB		Calima MSA			
(a)	**Lemmas (Stems)**	27,023	(33,497)	27,023	(37,910)	26,990	(38,323)	**Lemmas (Stems)**	(a)
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	Comparative Adjective	243	(283)	243	(424)	212	(250)	*Comparative Adjective*	
(b)	**DBPrefix Morphemes (Allom.)**	18	(20)	213		77		**DBPrefix Sequences**	(c)
	DBSuffix Morphs (Allom.)	99	(197)	614		391		**DBSuffix Sequences**	
	Stem Buffers	22		3,442		1,423		**Compatibility Tables**	
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	Morph Order Lines	42		246,880,683		126,176,265		**Unique Analyses**	
				1,300,068		1,041,949		**Unique Analyses (no Clitics)**	

- Coverage evaluation of Penn Arabic Treebank (Maamouri et al., 2004)
  - Recall 95.3% of analyses
  - 86% of mismatches due to gold errors.

Conclusions & Future Work

- Presented a review of challenges in modeling MSA nominals
- Developed and benchmarked a large-scale implementation using Camel Morph
- All models and code are publicly available

- We plan to work on other POS and other Arabic dialects
- We want to tackle challenges such as noisy spelling, dialect-MSA intra-word code switching, template-based backoff modeling, and automatic learning of lexicon entries
- We plan to evaluate our models on downstream applications

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NYU | ABU DHABI

مختبر كامل

CAMeL Lab

Thank you!

morph.camel-lab.com

nizar.habash@nyu.edu