Basics for a grammar engine to verbalize logical theories in isiZulu

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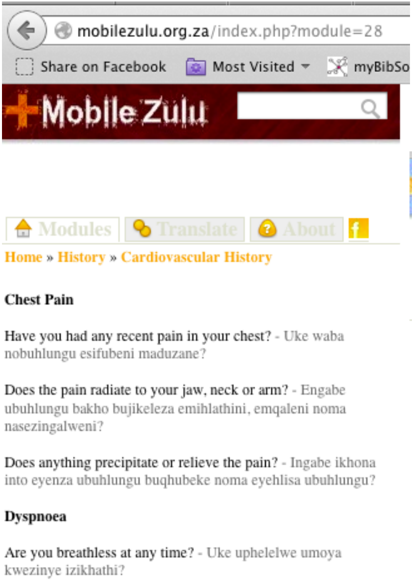
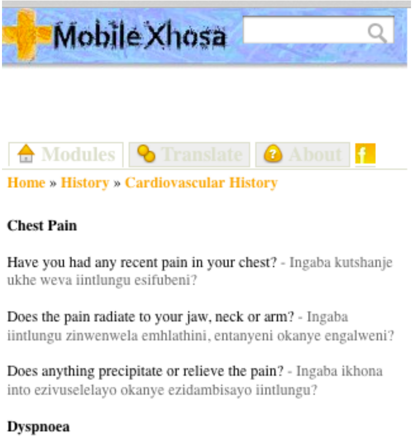
Outline

Natural language interfaces with some NLG

- Many tools, webpages, etc. with some natural language component
- Querying of information in natural language (cf. a query language SQL, SPARQL)
- Business rules typically specified in a natural language
- etc.

Example: Saadiq Moolla's mobile healthcare app





NLG, principal approaches

- Canned text
- Templates
  - Notably for English [Fuchs et al.(2010), Schwitter et al.(2008), Third et al.(2011), Curland and Halpin(2007)],
  - but also other languages [Jarrar et al.(2006)]
- Grammar engines, such as [Kuhn(2013)], Grammatical Framework (`http://www.grammaticalframework.org/`)

⇒ Controlled Natural Language

Question

- Can the template-based approach be used also for isiZulu NLG?
  - If so, create those templates
  - If not, start with basics for a grammar engine
- Use a practically useful language to benefit both ICT and linguists and, possibly, some subject domain (e.g., medicine, NRS [Alberts et al.(2012)])

A few features of isiZulu

- Most populous language in SA, first (home) language of $\pm 23\%$ ($\geq$ 10 million)
- Member of the Bantu language group, spoken by some 300 million people
- Bantu languages have characteristically agglutinating morphology
- System of noun classes, controls the concordance of all words in a sentence

Abafana abancane bazozithenga izincwadi ezinkulu

aba-fana	**aba**-ncane	**ba**-	zo-	**zi**- thenga	**izi**-ncwadi	e-**zi**-nkulu
2.boy	**2**.small	**2.SUBJ**-FUT-**10.OBJ**-buy			**10**.book	REL-**10**.big

'The little boys will buy the big books'

NC	AU	PRE	Stem (example)	Meaning	Example	
1 2	u- a-	m(u)- ba-	-fana -fana	humans and other animates	umfana abafana	boy boys
1a 2a	u- o-	- -	-baba -baba	kinship terms and proper names	ubaba obaba	father fathers
3a (2a)	u- o-	- -	-shizi -shizi	nonhuman	ushizi oshizi	cheese cheeses
3 4	u- i-	m(u)- mi-	-fula -fula	trees, plants, non-paired body parts	umfula imifula	river rivers
5 6	i- a-	(li)- ma-	-gama -gama	fruits, paired body parts, and natural phenomena	igama amagama	name names
7 8	i- i-	si- zi-	-hlalo -hlalo	inanimates and manner/ style	isihlalo izihlalo	chair chairs
9a (6)	i- a-	- ma-	-rabha -rabha	nonhuman	irabha amarabha	rubber rubbers
9 10	i(n)- i-	- zi(n)-	-ja -ja	animals	inja izinja	dog dogs
11 (10)	u- i-	(lu)- zi(n)-	-thi -thi	inanimates and long thin objects	uthi izinthi	stick sticks
14 15	u- u-	bu- ku-	-hle -cula	abstract nouns infinitives	ubuhle ukucula	beauty to sing
17		ku-		locatives, remote/ general		locative

Logic foundation for isiZulu NLG

- Roughly OWL 2 EL
- OWL 2 EL is a W3C-standardised profile of OWL 2
- Tools, ontologies in OWL 2 (notably SNOMED CT)
- On the 'roughly': minus transitivity, but with negation, amounting to $\mathcal{ALC}$
  - of that, we have patterns for universal and existential quantification, subsumption, negation (disjointness), and conjunction

Universal Quantification

- Consider here only the universal quantification at the start of the concept inclusion axiom (nominal head)
- 'all'/'each' uses *-onke*, prefixed with the oral prefix of the noun class of that first noun (OWL class/DL concept) on lhs of $\sqsubseteq$

(U1) Boy $\sqsubseteq$ ...

wonke umfana ...	('each boy...'; *u-* + *-onke*)
bonke abafana ...	('all boys...'; *ba-* + *-onke*)

(U2) Phone $\sqsubseteq$ ...

lonke ifoni ...	('each phone...'; *li-* + *-onke*)
onke amafoni ...	('all phones...'; *a-* + *-onke*)

NC	QC (all)		NEG SC	PRON	RC	QC_{dwa}	EC
	$QC_{oral+onke}$	QC_{nke}					
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Subsumption

- Two different ways of carving up the nouns to determine which rules apply: semantic and syntactic
- Syntactic: still two options for copulative, depending on second noun

(S1) `MedicinalHerb` $\sqsubseteq$ `Plant`

ikhambi <u>ng</u>umuthi ('medicinal herb <u>is a</u> plant')

(S2) `Giraffe` $\sqsubseteq$ `Animal`

indlulamithi <u>y</u>isilwane ('giraffe <u>is a</u> animal')

Subsumption: adding negation

- Copulative is omitted
- Combines the negative subject concord (NEG SC) of the noun class of the first noun (*azi-*) with the pronomial (PRON) of the noun class of second noun (*-yona*)

(SN1) $\texttt{Cup} \sqsubseteq \neg\texttt{Glass}$

<u>zonke</u> izindebe <u>aziyona</u> ingilazi ('<u>all</u> cups <u>not a</u> glass')

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Subsumption patterns

- Plain subsumption:
  - N_1 <copulative *ng*/*y* depending on first letter of N_2>N_2.
- And with negation:
  - <All-concord for NC_x>onke <plural N_1, being of NC_x> <NEG SC of NC_x><PRON of NC_y> <N_2 with NC_y>.

Algorithm 1 Determine the verbalization of simple taxonomic subsumption

$\mathcal{C}$ set of classes, language $\mathcal{L}$ with $\sqsubseteq$ for subsumption and $\neg$ for negation; variables: A axiom, NC_i nounclass, $c_1, c_2 \in \mathcal{C}$, a_1 term, a_2 letter; functions: $getFirstClass(A)$, $getSecondClass(A)$, $getNC(C)$, $pluralizeNoun(C, NC_i)$, $checkNegation(A)$, $getFirstChar(C)$, $getNSC(NC_i)$, $getPNC(NC_i)$.

Require: axiom A with a $\sqsubseteq$ has been retrieved

$c_1 \leftarrow getFirstClass(A)$ {get subclass}

$c_2 \leftarrow getSecondClass(A)$ {get superclass}

$NC_1 \leftarrow getNC(c_1)$ {determine noun class by augment and prefix or dictionary}

$NC_2 \leftarrow getNC(c_2)$ {determine noun class by augment and prefix or dictionary}

if $checkNegation(A) = true$ **then**

  $NC_1' \leftarrow$ lookup plural nounclass of NC_1 {from known list}

  $c_1' \leftarrow pluralizeNoun(c_1, NC_1')$

  $a_1 \leftarrow$ lookup quantitative concord for NC_1' {from quantitative concord (QC(all)) list}

  $n \leftarrow getNSC(NC_1')$ {get negative subject concord for c_1'}

  $p \leftarrow getPNC(NC_2)$ {get pronomial for c_2}

  RESULT $\leftarrow$ ' a_1 c_1' np c_2. ' {verbalise the disjointness}

else

  $a_2 \leftarrow getFirstChar(c_2)$ {retrieve first letter of c_2}

  select case

    $a_2 =$ 'i' **then**

      RESULT $\leftarrow$ ' c_1 yc_2 ' {verbalise as taxonomic subsumption with y}

    $a_2 =$ {'a', 'o', 'u'} **then**

      RESULT $\leftarrow$ ' c_1 ngc_2 ' {verbalise as taxonomic subsumption with ng}

    $a_2 \notin$ {'a', 'i', 'o', 'u',} **then**

      RESULT $\leftarrow$ 'this is not a well-formed isiZulu noun'

  end select case

end if

return RESULT

Algorithm 1 Determine the verbalization of simple taxonomic subsumption

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retrieve class and get its noun class

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    $a_2 = \{$'a', 'o', 'u'$\}$ **then**
      RESULT $\leftarrow$ ' c_1 ngc_2 ' {verbalise as taxonomic subsumption with ng}
    $a_2 \notin \{$'a', 'i', 'o', 'u',$\}$ **then**
      RESULT $\leftarrow$ 'this is not a well-formed isiZulu noun'
  end select case
end if
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    - $a_2 =$ {‘a’, ‘o’, ‘u’} **then**
      - RESULT $\leftarrow$ ‘ c_1 ngc_2 ’ {verbalise as taxonomic subsumption with ng}
    - $a_2 \notin$ {‘a’, ‘i’, ‘o’, ‘u’,} **then**
      - RESULT $\leftarrow$ ‘this is not a well-formed isiZulu noun’
  - **end select case**
- **end if**
- **return** RESULT

'simple' ISA

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 $a_2 \leftarrow getFirstChar(c_2)$ {retrieve first letter of c_2}
 select case
  $a_2 =$ ‘i’ **then**
   RESULT $\leftarrow$ ‘ c_1 yc_2 ’ {verbalise as taxonomic subsumption with y}
  $a_2 =$ {‘a’, ‘o’, ‘u’} **then**
   RESULT $\leftarrow$ ‘ c_1 ngc_2 ’ {verbalise as taxonomic subsumption with ng}
  $a_2 \notin$ {‘a’, ‘i’, ‘o’, ‘u’,} **then**
   RESULT $\leftarrow$ ‘this is not a well-formed isiZulu noun’
 end select case
end if
return RESULT

negation (disjointness)

Conjunction

- Conjunction as enumeration uses *na*
- Changes into (a + i =) *ne* or (a + u =) *no*, depending on the first letter of the second noun
- Prefixed to the second noun that drops its first letter
- Conjunction as connective of clauses: *kanye* or *futhi*

(C1) $\texttt{Milk} \sqcap \texttt{Butter}$

Ubisi <u>ne</u>bhotela (*Ubisi* + *na* + *Ibhotela*)

(C2) $\texttt{Butter} \sqcap \texttt{Milk}$

Ibhotela <u>no</u>bisi (*Ibhotela* + *na* + *Ubisi*)

(C3) $\ldots \exists \texttt{has\_filling.Cream} \sqcap \exists \texttt{has\_Icing.Lemon\_flavour} \ldots$

...kune zigcwalisa ukhilimu <u>kanye</u> nezinye uqweqwe olunambitheka_ulamula...

Algorithm 2 Determine the verbalization of conjunction in an axiom

$\mathcal{R}$ is the set of relationships, $\mathcal{A}$ of attributes, $\mathcal{C}$ of classes, and language $\mathcal{L}$ uses $\sqcap$ to denote conjunction; variables: e_2, c_1 a letter, A axiom; functions: $getNextVocabularyElement(A)$, $getFirstChar(e_2)$.

Require: axiom with a $\sqcap$ has been retrieved and position in string is known

$e_2 \leftarrow getNextVocabularyElement(A)$ {retrieve element after the $\sqcap$}
if $e_2 \in \mathcal{R} \cup \mathcal{A}$ **then**
 RESULT $\leftarrow$ ' kanye ' {verbalise $\sqcap$ as kanye}
else
 if $e_2 \in \mathcal{C}$ **then**
  $c_1 \leftarrow getFirstChar(e_2)$ {retrieve first letter of e_2}
  select case
   c_1 = 'i' **then**
    $e_2^- \leftarrow$ drop c_1 from e_2
    RESULT $\leftarrow$ ' nee_2^- ' {verbalise $\sqcap$ with ne- prefix}
   c_1 = 'u' **then**
    $e_2^- \leftarrow$ drop c_1 from e_2
    RESULT $\leftarrow$ ' noe_2^- ' {verbalise $\sqcap$ with no- prefix}
   c_1 = 'a' **then**
    $e_2^- \leftarrow$ drop c_1 from e_2
    RESULT $\leftarrow$ ' nae_2^- ' {verbalise $\sqcap$ with na- prefix}
   $c_1 \notin$ {'i', 'u', 'a'} **then**
    RESULT $\leftarrow$ 'this is not a well-formed isiZulu noun'
  end select case
 else
  RESULT $\leftarrow$ 'this is not a well-formed axiom'
 end if
end if
return RESULT

Algorithm 2 Determine the verbalization of conjunction in an axiom

$\mathcal{R}$ is the set of relationships, $\mathcal{A}$ of attributes … language $\mathcal{L}$ uses $\sqcap$ to denote conjunction; variables: … tions: $getNextVocabularyElement(A)$, $getFirstCha$…

enum-and or conn-and?

Require: axiom with a $\sqcap$ has been retrieved and positio… string is known

$e_2 \leftarrow getNextVocabularyElement(A)$ {retrieve element after the $\sqcap$}
if $e_2 \in \mathcal{R} \cup \mathcal{A}$ **then**
  RESULT ← ' kanye ' {verbalise $\sqcap$ as kanye}
else
  if $e_2 \in \mathcal{C}$ **then**
    $c_1 \leftarrow getFirstChar(e_2)$ {retrieve first letter of e_2}
    select case
      c_1 = 'i' **then**
        $e_2^- \leftarrow$ drop c_1 from e_2
        RESULT ← ' nee$_2^-$ ' {verbalise $\sqcap$ with ne- prefix}
      c_1 = 'u' **then**
        $e_2^- \leftarrow$ drop c_1 from e_2
        RESULT ← ' noe$_2^-$ ' {verbalise $\sqcap$ with no- prefix}
      c_1 = 'a' **then**
        $e_2^- \leftarrow$ drop c_1 from e_2
        RESULT ← ' nae$_2^-$ ' {verbalise $\sqcap$ with na- prefix}
      $c_1 \notin$ {'i', 'u', 'a'} **then**
        RESULT ← 'this is not a well-formed isiZulu noun'
    end select case
  else
    RESULT ← 'this is not a well-formed axiom'
  end if
end if
return RESULT

Algorithm 2 Determine the verbalization of conjunction in an axiom

$\mathcal{R}$ is the set of relationships, $\mathcal{A}$ of attributes, $\mathcal{C}$ of classes, and language $\mathcal{L}$ uses $\sqcap$ to denote conjunction; variables: e_2, c_1 a letter, A axiom; functions: $getNextVocabularyElement(A)$, $getFirstChar(e_2)$

Require: axiom with a $\sqcap$ has been retrieved and positi

connective-and

$e_2 \leftarrow getNextVocabularyElement(A)$ {…eve element after the $\sqcap$}

if $e_2 \in \mathcal{R} \cup \mathcal{A}$ **then**

  RESULT $\leftarrow$ ' kanye ' {verbalise $\sqcap$ as kanye}

else

  if $e_2 \in \mathcal{C}$ **then**

    $c_1 \leftarrow getFirstChar(e_2)$ {retrieve first letter of e_2}

    select case

      c_1 = 'i' **then**

        $e_2^- \leftarrow$ drop c_1 from e_2

        RESULT $\leftarrow$ ' nee_2^- ' {verbalise $\sqcap$ with ne- prefix}

      c_1 = 'u' **then**

        $e_2^- \leftarrow$ drop c_1 from e_2

        RESULT $\leftarrow$ ' noe_2^- ' {verbalise $\sqcap$ with no- prefix}

      c_1 = 'a' **then**

        $e_2^- \leftarrow$ drop c_1 from e_2

        RESULT $\leftarrow$ ' nae_2^- ' {verbalise $\sqcap$ with na- prefix}

      $c_1 \notin \{$'i', 'u', 'a'$\}$ **then**

        RESULT $\leftarrow$ 'this is not a well-formed isiZulu noun'

    end select case

  else

    RESULT $\leftarrow$ 'this is not a well-formed axiom'

  end if

end if

return RESULT

Algorithm 2 Determine the verbalization of conjunction in an axiom

$\mathcal{R}$ is the set of relationships, $\mathcal{A}$ of attributes, $\mathcal{C}$ of classes, and language $\mathcal{L}$ uses $\sqcap$ to denote conjunction; variables: e_2, c_1 a letter, A axiom; functions: $getNextVocabularyElement(A)$, $getFirstChar(e_2)$.

Require: axiom with a $\sqcap$ has been retrieved and position in string is known

$e_2 \leftarrow getNextVocabularyElement(A)$ {retrieve element after the $\sqcap$}
if $e_2 \in \mathcal{R} \cup \mathcal{A}$ **then**
    RESULT $\leftarrow$ ' kanye ' {...s kanye}
else
    if $e_2 \in \mathcal{C}$ **then**
        $c_1 \leftarrow getFirstChar(e_2)$ {retrieve first letter of e_2}
        select case
            c_1 = 'i' **then**
                $e_2^- \leftarrow$ drop c_1 from e_2
                RESULT $\leftarrow$ ' nee_2^- ' {verbalise $\sqcap$ with ne- prefix}
            c_1 = 'u' **then**
                $e_2^- \leftarrow$ drop c_1 from e_2
                RESULT $\leftarrow$ ' noe_2^- ' {verbalise $\sqcap$ with no- prefix}
            c_1 = 'a' **then**
                $e_2^- \leftarrow$ drop c_1 from e_2
                RESULT $\leftarrow$ ' nae_2^- ' {verbalise $\sqcap$ with na- prefix}
            $c_1 \notin$ {'i', 'u', 'a'} **then**
                RESULT $\leftarrow$ 'this is not a well-formed isiZulu noun'
        end select case
    else
        RESULT $\leftarrow$ 'this is not a well-formed axiom'
    end if
end if
return RESULT

enumerative-and

Existential Quantification

- 'simple' option in front of the object property

(E1) Giraffe $\sqsubseteq \exists$eats.Twig
zonke izindlulamithi zidla ihlamvana elilodwa
('all giraffes eat at least one twig')

- Some other examples, and breakdown:

noun	NC	RC	QC	QSuffix
ihlamvana ('twig')	class 5	*eli-*	*-lo-*	*-dwa*
isifundo ('module')	class 7	*esi-*	*-so-*	*-dwa*
ushizi ('cheese')	class 3a	*o-*	*-ye-*	*-dwa*

- Pattern: <All-concord for NC_x>onke <pl. N_1, is in NC_x> <conjugated verb> <N_2 of NC_y> <RC for NC_y><QC for NC_y>dwa.

NC	QC (all)		NEG SC	PRON	RC	QC_{dwa}	EC
	$QC_{oral+onke}$	QC_{nke}					
1 2	u-onke → wonke ba-onke → bonke	wo- bo-	aka- aba-	yena bona	o- aba-	ye- bo-	mu- ba-
1a 2a	u-onke → wonke ba-onke → bonke	wo- bo-	aka- aba-	yena bona	o- aba-	ye- bo-	mu- ba-
3a (2a)	u-onke → wonke ba-onke → bonke	wo- bo-	aka- aba-	wona bona	o- aba-	ye- bo-	mu- ba-
3 4	u-onke → wonke i-onke → yonke	wo- yo-	awu- ayi-	wona yona	o- e-	wo- yo-	mu- mi-
5 6	li-onke → lonke a-onke → onke	lo- o-	ali- awa-	lona wona	eli- a-	lo- wo-	li- ma-
7 8	si-onke → sonke zi-onke → zonke	so- zo-	asi- azi-	sona zona	esi- ezi	so- zo-	si- zi-
9a (6)	i-onke → yonke a-onke → onke	yo- o-	ayi- awa-	yona wona	e- a-	yo- wo-	yi- ma-
9 10	i-onke → yonke zi-onke → zonke	yo- zo-	ayi- azi-	yona zona	e- ezi-	yo- zo-	yi- zi-
11 (10)	lu-onke → lonke zi-onke → zonke	lo- zo-	alu- azi-	lona zona	olu- ezi-	lo- zo-	lu- zi-
14 15	ba-onke → bonke ku-onke → konke	bo- zo-	abu- aku-	bona khona	obu- oku-	bo- zo-	bu- ku-

NC	QC (all)		NEG SC	PRON	RC	QC_{dwa}	EC
	$QC_{oral+onke}$	QC_{nke}					
1	u-onke → wonke	wo-	aka-	yena	o-	ye-	mu-
2	ba-onke → bonke	bo-	aba-	bona	aba-	bo-	ba-
1a	u-onke → wonke	wo-	aka-	yena	o-	ye-	mu-
2a	ba-onke → bonke	bo-	aba-	bona	aba-	bo-	ba-
3a	u-onke → wonke	wo-	aka-	wona	o-	ye-	mu-
(2a)	ba-onke → bonke	bo-	aba-	bona	aba-	bo-	ba-
3	u-onke → wonke	wo-	awu-	wona	o-	wo-	mu-
4	i-onke → yonke	yo-	ayi-	yona	e-	yo-	mi-
5	li-onke → lonke	lo-	ali-	lona	eli-	lo-	li-
6	a-onke → onke	o-	awa-	wona	a-	wo-	ma-
7	si-onke → sonke	so-	asi-	sona	esi-	so-	si-
8	zi-onke → zonke	zo-	azi-	zona	ezi	zo-	zi-
9a	i-onke → yonke	yo-	ayi-	yona	e-	yo-	yi-
(6)	a-onke → onke	o-	awa-	wona	a-	wo-	ma-
9	i-onke → yonke	yo-	ayi-	yona	e-	yo-	yi-
10	zi-onke → zonke	zo-	azi-	zona	ezi-	zo-	zi-
11	lu-onke → lonke	lo-	alu-	lona	olu-	lo-	lu-
(10)	zi-onke → zonke	zo-	azi-	zona	ezi-	zo-	zi-
14	ba-onke → bonke	bo-	abu-	bona	obu-	bo-	bu-
15	ku-onke → konke	zo-	aku-	khona	oku-	zo-	ku-

NC	QC (all)		NEG SC	PRON	RC	QC_{dwa}	EC
	$QC_{oral+onke}$	QC_{nke}					
1	u-onke → wonke	wo-	aka-	yena	o-	ye-	mu-
2	ba-onke → bonke	bo-	aba-	bona	aba-	bo-	ba-
1a	u-onke → wonke	wo-	aka-	yena	o-	ye-	mu-
2a	ba-onke → bonke	bo-	aba-	bona	aba-	bo-	ba-
3a	u-onke → wonke	wo-	aka-	wona	o-	ye-	mu-
(2a)	ba-onke → bonke	bo-	aba-	bona	aba-	bo-	ba-
3	u-onke → wonke	wo-	awu-	wona	o-	wo-	mu-
4	i-onke → yonke	yo-	ayi-	yona	e-	yo-	mi-
5	li-onke → lonke	lo-	ali-	lona	eli-	lo-	li-
6	a-onke → onke	o-	awa-	wona	a-	wo-	ma-
7	si-onke → sonke	so-	asi-	sona	esi-	so-	si-
8	zi-onke → zonke	zo-	azi-	zona	ezi	zo-	zi-
9a	i-onke → yonke	yo-	ayi-	yona	e-	yo-	yi-
(6)	a-onke → onke	o-	awa-	wona	a-	wo-	ma-
9	i-onke → yonke	yo-	ayi-	yona	e-	yo-	yi-
10	zi-onke → zonke	zo-	azi-	zona	ezi-	zo-	zi-
11	lu-onke → lonke	lo-	alu-	lona	olu-	lo-	lu-
(10)	zi-onke → zonke	zo-	azi-	zona	ezi-	zo-	zi-
14	ba-onke → bonke	bo-	abu-	bona	obu-	bo-	bu-
15	ku-onke → konke	zo-	aku-	khona	oku-	zo-	ku-

Algorithm 3 Determine the verbalization of existential quantification with object property (first, basic, version)

$\mathcal{C}$ set of classes, language $\mathcal{L}$ with $\sqsubseteq$ for subsumption and $\exists$ for existential quantification; variables: A axiom, NC_i noun class, $c_1, c_2 \in \mathcal{C}$, $o \in \mathcal{R}$, a_1 a term; r_2, q_2 concords; functions: $getFirstClass(A)$, $getSecondClass(A)$, $getNC(C)$, $pluralizeNoun(C, NC_i)$, $getRC(NC_i)$ $getQC(NC_i)$.

Require: axiom A with a $\sqsubseteq$ and a $\exists$ on the rhs of the inclusion has been retrieved

$c_1 \leftarrow getFirstClass(A)$ {get subclass}

$c_2 \leftarrow getSecondClass(A)$ {get superclass}

$o \leftarrow getObjProp(A)$ {get object property}

$NC_1 \leftarrow getNC(c_1)$ {determine noun class by augment and prefix or dictionary}

$NC_2 \leftarrow getNC(c_2)$ {determine noun class by augment and prefix or dictionary}

$NC'_1 \leftarrow$ lookup plural nounclass of NC_1 {from known list}

$c'_1 \leftarrow pluralizeNoun(c_1, NC'_1)$

$a_1 \leftarrow$ lookup quantitative concord for NC'_1 {from quantitative concord (QC(all)) list}

$o' \leftarrow AlgoConjugate(o, NC_1)$ {call algorithm $AlgoConjugate$ to conjugate o}

$r_2 \leftarrow getRC(NC_2)$ {get relative concord for c_2}

$q_2 \leftarrow getQC(NC_2)$ {get quantitative concord for c_2 from the QC_{dwa}-list}

RESULT $\leftarrow$ ' a_1 c'_1 o' c_2 $r_2q_2$dwa. ' {verbalise the simple axiom}

return RESULT

Example

- $\forall x\ (\text{Professor}(x) \rightarrow \exists y\ (\text{teaches}(x,y) \land \text{Course}(y)))$
- $\text{Professor} \sqsubseteq \exists\ \text{teaches}.\text{Course}$
- **Each** Professor teaches **at least one** Course
- $\forall x\ (\text{uSolwazi}(x) \rightarrow \exists y\ (\text{ufundisa}(x,y) \land \text{Isifundo}(y)))$
- $\text{uSolwazi} \sqsubseteq \exists\ \text{ufundisa}.\text{Isifundo}$
- ?

Example

- $\forall x\ (\text{Professor}(x) \rightarrow \exists y\ (\text{teaches}(x, y) \wedge \text{Course}(y)))$
- Professor $\sqsubseteq$ $\exists$ teaches.Course
- **Each** Professor teaches **at least one** Course
- $\forall x\ (\text{uSolwazi}(x) \rightarrow \exists y\ (\text{ufundisa}(x, y) \wedge \text{Isifundo}(y)))$
- uSolwazi $\sqsubseteq$ $\exists$ ufundisa.Isifundo
- ?

$$\forall x\ (\text{uSolwazi}(x) \rightarrow \exists y\ (\text{ufundisa}(x, y) \wedge \text{Isifundo}(y)))$$

$$\text{uSolwazi} \sqsubseteq \exists\ \text{ufundisa}.\text{Isifundo}$$

$\forall x\ (\text{uSolwazi}(x) \rightarrow$ ... $x, y) \wedge \text{Isifundo}(y)))$

$\text{uSolwazi} \sqsubseteq \exists\ \text{ufun}$...

look-up NC

pluralise

for-all

NC	AU	PRE
1	u-	m(u)-
2	a-	ba-
1a	u-	-
2a	o-	-
3a	u-	-
(2a)	o-	-
3	u-	m(u)-
4	i-	mi-
5	i-	(li)-
6	a-	ma-
7	i-	si-
8	i-	zi-
9a	i-	-
(6)	a-	ma-
9	i(n)-	-
10	i-	zi(n)-
11	u-	(lu)-
(10)	i-	zi(n)-
14	u-	bu-
15	u-	ku-
17		ku-

NC	QC (all) $\text{QC}_{\text{oral+onke}}$
1	u-onke → wonke
2	ba-onke → bonke
1a	u-onke → wonke
2a	ba-onke → bonke
3a	u-onke → wonke
(2a)	ba-onke → bonke
3	u-onke → wonke
4	i-onke → yonke
5	li-onke → lonke
6	a-onke → onke
7	si-onke → sonke
8	zi-onke → zonke
9a	i-onke → yonke
(6)	a-onke → onke
9	i-onke → yonke
10	zi-onke → zonke
11	lu-onke → lonke
(10)	zi-onke → zonke
14	ba-onke → bonke
15	ku-onke → konke

Bonke oSolwazi

$$\forall x\ (\text{uSolwazi}(x) \rightarrow \exists y\ (\text{ufundisa}(x, y) \wedge \text{Isifundo}(y)))$$

$\text{uSolwazi} \sqsubseteq \exists \text{ufundisa}.\text{I}$

... for relevant NC. Here:

ngi-

u-

u-

si-

ni-

ba-

AlgoConjugate

Bonke oSolwazi bafundisa

$$\forall x\ (\text{uSolwazi}(x) \rightarrow \exists y\ (\text{ufundisa}(x, y) \land \text{Isifundo}(y)))$$

$$\text{uSolwazi} \sqsubseteq \exists\ \text{ufundisa}.\text{Isifundo}$$

Bonke oSolwazi bafundisa Isifundo

$\forall x\ (\text{uSolwazi}(x) \rightarrow \exists y\ ($ … $) \wedge$ … $))$

uSolwazi $\sqsubseteq$ $\exists$ ufundisa.I…

look-up NC

get RC

get QC

add -dwa

NC	AU	PRE
1	u-	m(u)-
2	a-	ba-
1a	u-	-
2a	o-	-
3a	u-	-
(2a)	o-	-
3	u-	m(u)-
4	i-	mi-
5	i-	(li)-
6	a-	ma-
7	i-	si-
8	i-	zi-
9a	i-	-
(6)	a-	ma-
9	i(n)-	-
10	i-	zi(n)-
11	u-	(lu)-
(10)	i-	zi(n)-
14	u-	bu-
15	u-	ku-
17		ku-

RC	QC_{dwa}
o-	ye-
aba-	bo-
o-	ye-
aba-	bo-
o-	ye-
aba-	bo-
o-	wo-
e-	yo-
eli-	lo-
a-	wo-
esi-	so-
ezi	zo-
e-	yo-
a-	wo-
e-	yo-
ezi-	zo-
olu-	lo-
ezi-	zo-
obu-	bo-
oku-	zo-

Bonke oSolwazi bafundisa Isifundo esisodwa

Discussion

- Template-based approach is not applicable to isiZulu (and, more generally: Bantu languages that have noun classes)
  - Or: grammar engine needed
- Devising the patterns hampered by outdated literature
- Several preferences for patterns
- Algorithms nontrivial; covering:
  - ‘simple’ existential and universal quantification
  - taxonomic subsumption
  - negation (class disjointness)
  - conjunction

Conclusions

- Verbalizing formally represented knowledge in isiZulu requires a grammar engine even for the relatively basic language constructs
- Due to, principally:
  - the system of noun classes,
  - the system of complex agreement,
  - phonological conditioned copulatives, and
  - verb conjugation

A few constructors, their typical verbalization in English, and the basic options in isiZulu

DL symbol	Sample verbalization English	Sample verbalization in isiZulu (see text for additional rules)
$\sqsubseteq$	... is a ...	Depends on what is on the rhs of $\sqsubseteq$ and desideratum: A) semantic distinction i) yi/ongu/uyi/ngu (living thing) ii) iyi (non-living thing) B) syntactic distinction iii) ng (nouns commencing with a, o, or u) iv) y (nouns commencing with i)
$\sqcap$	... and ...	Depends on the use of the $\sqcap$: i) ... na/ne/no ... (list of things) ii) 1) ... futhi ... (connective) 2) ... kanye ... (connective)
$\neg$	not ...	angi/akusiso/akusona/akubona/akulona/asibona/ akalona/akuyona
$\exists$	1) some ... 2) there exists ... 3) at least one ...	Depends on position in axiom: I. quantified over class, depends on meaning of class: i) kuno (living thing) ii) kune (non-living thing) II. includes relation (preposition issue omitted): 1) ... [concords]dwa 2) ... noma [copulative + concord]phi ... 3) thize
$\forall$	1) for all ... 2) each ...	Depends on what it is quantified over: A) semantic distinction i) wonke/bonke/sonke/zonke (living thing) ii) onke/konke/lonke/yonke (non-living thing) B) another semantic distinction i) use noun class (see Table 8)

Future work

- To be done for 'full' OWL 2 EL and $\mathcal{ALC}$, mainly:
  - Transitivity
  - More elaborate axioms, such as $\forall R.C \sqsubseteq \exists S.(D \sqcap E)$
  - Negation in other cases
  - Union
- Conjugation of verbs present and past tense, and the prepositions (*taught* by, works *for*)
- Implement it

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Thank you!