Strictly Local Multi-Tape Transducers for Templatic Morphology

Hossep Dolatian and Jonathan Rawski
hossep.dolatian,jonathan.rawski@stonybrook.edu

Stony Brook University

Department of Linguistics, Stony Brook University

Introduction: computation

Objectives & Introduction

Goals: Want to compute templatic morphology such that...

1. **Model** it as productive process
2. **Understand** its computational properties
3. **Limit** its expressive power

Contribution: Use multi-tape finite-state transducers with local subclasses

Templatic morphology

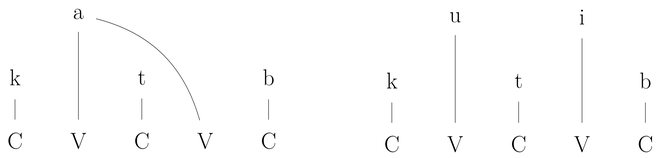
Most languages use concatenative morphology

- English progressive: *hold* → *hold-ing*

Semitic has templatic morphology (McCarthy, 1981)

Active verbs
katab 'it wrote'

1. Inflectional vowels V: *a*
2. Root consonants C: *ktb*
3. Template T: *CV.CVC*



Passive verbs
kutib 'it was written'

1. Inflectional vowels V: *ui*
2. Root consonants C: *ktb*
3. Template T: *CV.CVC*

Locality in Natural language

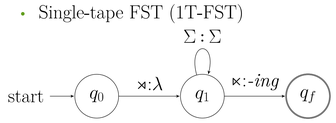
Most natural language processes are local
= uses *bounded* finite window (Chandlee, 2014)
= computed with N-grams
Our question:

- Are Semitic templates local?

Computing morphology

Computing concatenation

- *hold* → *hold-ing*
- Easy to compute
  - Single-tape FST (1T-FST)



- Computationally local
  - Input-Strictly Local (ISL)

Templatic morphology

- ***kutib*** 'to be written'
- How to compute?
  - 1T-FSTs aren't for non-linearity
  - State-explosion = large finite language
  - Modifications redirect state-explosion (Bird and Ellison, 1994; Beesley and Karttunen, 2003)
- Is it local?
  - *seems* non-local because of discontinuity
  - Unknown locality

Multi-tape FSTs for templates

MT-FSTs are elegant formalism for template-filling

1. **Modeling**: models productivity of Arabic templates
2. **Locality**: template-filling is local over multiple tapes
3. **Expressivity**: expressivity is constrained by locality + morphology

Single vs. Multi-tape FSTs

Single-tape FST (1T-FST)

1. read input as linear string
2. Most common formalism in CL + NLP (Mohri, 1997)
3. Advances on only one tape

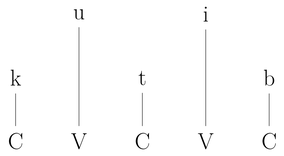
Multi-tape FST (MT-FST)

1. Input is multiple items that are read together
2. Early and intuitive model for Semitic (Kay, 1987; Kiraz, 2001)
3. Advance on every input tape either
   - **synchronously** *or* (= 1T FST)
   - **asynchronously** (» 1T FST)

What does an Arabic MT-FST look like?

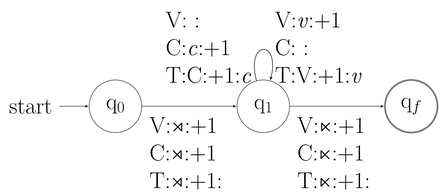
Morphology has 3 input items

1. Inflectional V: *ui*
2. Root C: *ktb*
3. Template T: *CV.CVC*



MT-FST has 4

1. Read input on each input tape (3)
2. Advance on each input tape
3. Create one output tape (1)



Watch it!

	Current State	C-tape		V-tape		T-tape		Output Symbol	Output String
1.	q_0	⋊ktb⋉		⋊ui⋉		⋊CVCVC⋉			
2.	q_1	⋊ktb⋉	C:⋊:+1	⋊ui⋉	V:⋊:+1	⋊CVCVC⋉	T:⋊:+1	ϵ	
3.	q_1	⋊ktb⋉	C:*k*:+1	⋊ui⋉	V:ϵ:0	⋊CVCVC⋉	T:*C*:+1	*k*	*k*
4.	q_1	⋊ktb⋉	C:ϵ:0	⋊ui⋉	V:*u*:+1	⋊CVCVC⋉	T:*V*:+1	*u*	*ku*
5.	q_1	⋊ktb⋉	C:*t*:+1	⋊ui⋉	V:ϵ:0	⋊CVCVC⋉	T:*t*:+1	*t*	*kut*
6.	q_1	⋊ktb⋉	C:ϵ:0	⋊ui⋉,	V:*i*:+1	⋊CVCVC⋉	T:*V*:+1	*i*	*kuti*
7.	q_1	⋊ktb⋉,	C:*b*:+1	⋊ui⋉,	V:ϵ:0	⋊CVCVC⋉	T:*C*:+1	*b*	*kutib*
8.	q_1	⋊ktb⋉	C:⋉:+1	⋊ui⋉	C:⋉:+1	⋊CVCVC⋉	T:⋉:+1	ϵ	*kutib*

Computing locality

Concatenation (=suffixation) is computationally weak = *k-Input Strictly Local* subclass
= keep track of **ONLY** last k segments in input
Suffixation is 1-ISL:
= 1-ISL states keep track of last *k-1* (=0) seen input (*empty string*)
Template-filling (1-1 match) is 1-ISL *over* multiple tapes
= Change is based on *current* input symbol on *two* tapes

Locality across template types

Locality in template-filling depends on # of vowels, consonants, and slots

Matching	Input			Output	Power
1-1 Matching	*ktb*	*ui*	*CVCVC*	*ku.tib*	MT-1-ISL
Final spread	*ktb*	***a***	*CVCVC*	*k**a**.t**a**b*	MT-2-ISL
Gemination	*ktb*	*ui*	*CVC.**G**VC*	*ka**t**.t**a**b*	MT-2-ISL
Pre-association	*ksb*	*a*	*C**t**VCVC*	*k**t**a.sab*	MT-1-ISL
Partial copying	*brd*	*a*	*CVC.**F**VC*	*bar.**b**ad*	2-way
Total copying	*zl*	*ia*	*CVC.CVC*	***zil.zal***	2-way
Edge-in	*ktb*	*ua**i***	*mV-tV-CVC.CVC*	*mu-ta-kas.s**i**b*	unclear...
C-spreading	*trʒm*	*ui*	*CVC.CVC*	*tar.ʒam*	MT-3-ISL
	ktb	*ui*	*CVC.CVC*	*kut.ʈib*	MT-3-ISL

Discussion

Finiteness

- Arabic has at most 2 syllable templates
- Could model Arabic with just large finite language-language mapping
- But finiteness costs you generalizations (Savitch, 1993)

Phonological emergence

- MT-FST took *template T* as morphological input
- Contemporary theories argue there is *NO* template T, it's phonologically emergent
- But the phonology still needs to create a template (= MT-FST)

Expressivity

- Expressivity of MT-FST depends on how you encode your input
- With the right encoding, majority rules is MT-ISL
- Problem is curtailed by letting morphology dictate your encoding

Conclusions

Semitic templates are

- Typologically rare
- Theoretically cool
- Computationally local ... with the right representation = MT-FSTs

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