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Multidimensional Exploration of Online Linguistic Field Data

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1 Abstract

Advances in storage technology make it possible to house virtually unlimited quantities of recorded speech data online. Advances in character-encoding technology make it possible to create platform-independent transcriptions. Advances in web technology make it possible to publish this data for essentially no marginal cost. These developments have profound consequences for the accessibility, quality and quantity of linguistic field data. Recordings become accessible. Transcriptions become verifiable. Large corpora become manageable. In order to illustrate the potential for this mode of operation in field linguistics, I describe a piece of online fieldwork involving a tone language of Cameroon. A complex verb paradigm for Bamileke Dschang has been collected and transcribed, and audio and laryngograph recordings have been digitised and segmented. A central insight of Hyman's analysis concerning the domain of tone rules has been applied to the new data. A program for multidimensional exploration of the data has been developed, and can be accessed through a web version of this paper. The web page also contains digitised speech recordings of all the data items presented here.

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These three lines of inquiry—primary description, theoretical analysis, and tool development—are synthesised, resulting in a new methodology for the investigation of linguistic field data.

2 Fieldwork as a Computational Problem

Linguistic fieldwork deals with essentially three kinds of data: lexicons, paradigms and texts. A lexicon is a database of words, minimally containing part of speech information and glosses. A paradigm (broadly construed) is any kind of rational tabulation of words or phrases to illustrate contrasts and systematic variation. Just about every data display in the *Handbook of Phonological Theory* (Goldsmith 1995) counts as a paradigm under this definition. A text is essentially any larger unit such as a narrative or a conversation. In addition to these three kinds of data, linguistic fieldwork deals with three main kinds of meta-data: field notes, descriptive reports and analytical papers.

These various kinds of data and meta-data enter into a complex web of relations. For example, the discovery of a new word in a text may require an update to the lexicon and the construction of a new paradigm (e.g., to correctly classify the word). Such updates may occasion the creation of some field notes, the extension of a descriptive report and possibly even the revision of the manuscript for an analytical paper. Progress on description and analysis gives fresh insights about how to organise existing data and it informs the quest for new data. Whether one is sorting data, or generating helpful tabulations, or gathering statistics, or searching for a (counter-)example, or verifying the transcriptions used in a manuscript, the principal challenge is computational.

Assuming that one could successfully address these issues, there are some obvious implications for theoretical linguistics. For example, the language index of the *Handbook of Phonological Theory* lists over 400 languages whose data informs contemporary theoretical investigations. The predominant distribution method for this data is print-based, relying on specialist journals and on descriptive works which are typically not in the form of archival publications.[1] Once the field data is available online, research papers can link directly to the recordings and transcriptions it contains. Readers can hear the examples, open a waveform viewer on the digitised speech, rerun the statistics, repeat database

[1]Phonology is better off in this regard than some other linguistic domains. For example, the *Handbook of Contemporary Semantic Theory* (Lappin 1996) has no need for a language index since it only considers English, a stark illustration of the inaccessibility of field data.

queries, issue different queries to see how well the reported findings generalise, and so on. In this way, each research paper provides a new springboard back into the data. Of course, these developments afford no protection against asking the wrong questions or failing to collect the right data.

This paper applies computational methods to field phonology. Surveys of computational approaches to other areas of phonology can be found in Bird 1994b, 1995, and by visiting the homepage of the ACL Special Interest Group in Computational Phonology at [`http://www.cogsci.ed.ac.uk/sigphon`].

In the next section I introduce tone languages in general, and Bamileke Dschang in particular. In section 4 I describe the construction of tone paradigms and how they can be represented online. Section 5 is a more detailed treatment of downstep in Dschang, along with a discussion of double downstep. A web page accompanies this paper, and is designed to be browsed alongside the paper version. The page reproduces all of the numbered linguistic examples and data tabulations of this paper. Each data item is a hyperlink to a speech recording. The tabulations have hyperlinks to queries which produce similar tabulations dynamically. A form-based interface permits users to modify the queries and conduct their own exploration of the data, accessing thousands of speech clips, pitch traces and tone transcriptions. The page can be reached at [`http://www.ldc.upenn.edu/sb/fieldwork/`].

3 An Empirical Challenge: Tone in Bamileke Dschang

Almost 2000 languages are spoken in sub-Saharan Africa (Grimes 1996). The Niger-Congo language family is the largest and by far the most important group as far as tone is concerned. This family stretches from Senegal in the west to Kenya in the east and down into South Africa, and includes the important Bantu language family. Comprehensive surveys of Niger-Congo are available (Welmers 1973, Bendor-Samuel 1989), and of tone in general (Fromkin 1978, Clements and Goldsmith 1984, van der Hulst and Snider 1993, Odden 1995). Phonetic investigations of African tone languages include: Connell and Ladd 1990, Inkelas and Leben 1990, Laniran 1992, Liberman et al. 1993, Herman 1996, and Snider 1998.

The vast majority of the Niger-Congo languages are *tonal*, i.e. voice pitch on an individual syllable may carry contrastive meaning, either lexical or grammatical. One such language is Dschang [ʧɑŋ] (known to its speakers as [jɛ́mbɑ̀], lit. 'I say!'). Dschang is spoken in the Ménoua region of the Western Province of Cameroon, itself situated in the continental 'hinge' between western and southern Africa. Dschang is classified as a Grassfields Bantu language (Watters and Leroy 1989). Grassfields languages manifest predominantly SVO word order and little morphology apart from a noun-class system which is simplified relative to the rest of the Bantu group (Hyman et al. 1970). The segmental phonology of Dschang has been described in detail by Haynes (1989) and Bird (1999a). A dictionary has been compiled (Bird and Tadadjeu 1997), and a short history of the development of the language has been written (Momo 1997). The phonetics of tone in Dschang is addressed by Bird (1994a), Bird and Stegen (1995) and Connell and Bird (1997). The second of these involved recordings of Maurice Tadadjeu, the original speaker on which all the data was based. The recordings are available on the web.

Dschang is noted for its rich system of terracing downstep (or progressive tonal lowering). Some unusual tone sequences H↓H, H↓L, L↓H and L↓L are attested (where ↓=downstep, H=high, L=low) and these enter into complex alternations. Dschang also manifests double downstep between high tones (H↓↓H). Dschang lacks so-called 'automatic downstep'—H lowering due to a preceding linked L. Some of the tonal alternations have been the subject of several published studies: Clark 1993, Hyman 1985, Hyman 1993, Hyman and Tadadjeu 1976, Pulleyblank 1986, Anderson 1980, Stewart 1981, Stewart 1993, Tadadjeu 1974. This paper presents a large body of new data, transcribed from laryngographic recordings of Dschang speakers in Cameroon. In marked contrast to the existing studies which have focussed on the associative construction, this study focuses on the verb phrase. The Dschang verb phrase is interesting for reasons other than tone (Hyman 1980), but only tone will be discussed here.

Example (1) demonstrates the use of tone to distinguish lexical meaning. All the forms are morphologically marked as nouns (viz. the class 5 *lə̀-* prefix). Tadadjeu (1974: 284) was the first to report this data, and the roots (i.e., the second syllables) have been tonally classified according to the scheme laid out by Hyman (1985:48).

(1)	a.	H	lə̀tɔ̌ŋ	[-ˊ]	'feather'
	b.	HL	lə̀t↓ɔ́ŋ	[-¯]	'reading'
	c.	LH	lə̀tɔ̀ŋ˚	[--]	'navel'
	d.	L	lə̀tɔ̀ŋ	[-ˎ]	'finishing'

Note that, following standard practice, acute accent (ə́) indicates high tone and grave accent (ə̀) indicates low tone. These diacritics are combined to create rising (ə̌) and falling (ə̂) tone. Phrase-final low tones are falling, except when transcribed with a following degree sign. In the northern (Bafou) dialect of Dschang (which has been the focus of most of the research on the language) a phrase-final H tone, when preceded by L, is realised as a rising tone. This accounts for the form we see in (1a). All data items in this paper are accompanied by line diagrams, i.e. 'pitch transcriptions', to avoid the ambiguities of interpretation that occur when only tone-marked segmental transcriptions are given.

Example (2) illustrates the use of tone to convey grammatical contrasts. The three examples use the same lexical items: *əfɔ̀* 'chief', *kə̀mtè* 'bury', *mə̀mbhꜜʉ́* 'dogs'. The vowels in isolation are concord markers that will be discussed later. (Note that the pitch transcriptions for phrases include vertical bars; these indicate word domain boundaries, and will be explained in section 5.3.)

(2)	a.	ə̀fɔ̂ ɔ́ ꜜkə̀mtè ꜜmə́mbhʉ́	[-|-¯|---|-]	'the chief buried dogs' '(immediate past)'
	b.	ə̀fɔ̂ ɔ̀ kə̀mtè mə̀mbhꜜʉ́	[-|--|---|¯]	'the chief buries dogs' '(simple present)'
	c.	ə̀fɔ̂ ɔ̀ ꜜkə̀mtè ꜜmə́mbhʉ́	[-|--|--|--]	'the chief will bury dogs' '(immediate future)'

The value of using a two-way tone contrast H/L along with what we now know as floating tones (to condition downstep) was recognised by Voorhoeve (1971) and exploited extensively by Hyman and Tadadjeu (1976) and most subsequent work on the language group.

The mere existence of lexical and grammatical tone might not be particularly interesting if it were not for the fact that Dschang manifests some particularly intriguing tonal alternations. Example (3) illustrates the alternations that *mə̀mbhꜜʉ́* 'dogs' enters into.[2]

(3)	a.	L↓H	ə̀fɔ̂ ɔ̀ mə̀mbhꜜʉ́	[-|---|¯]	'chief of dogs'
	b.	↓HH	ə̀fɔ̂ ɔ̀ ꜜkèmtè ꜜmə́mbhʉ́	[-|--|---|-]	'the chief will bury dogs'
	c.	H↓H	ə̀fɔ̂ ꜜɔ́ kɑ́pté mə́mbhꜜʉ́	[-|-¯|¯¯¯|-]	'the chief will cover dogs'
	d.	H↓L	ə̀fɔ̂ ꜜɔ́ kɑ́pté mə́mbhꜜʉ̀	[-|-¯|¯¯¯|_]	'will the chief cover dogs?'

[2]Needless to say, this state of affairs poses some interesting challenges for orthography. A reading experiment has demonstrated that a phonemic orthography for the tone system is unworkable (Bird 1999e).

4 Constructing Tone Paradigms and Putting Them Online

4.1 Selection of Nouns

We have already seen the four possible tone melodies of nouns in (1). Linking a noun with following material requires a vocalic concord marker (CM). The tone borne by this marker is L for nouns in classes 1 and 9, and H otherwise, i.e. for classes 2–8 (Hyman 1985: 49). This two-way choice leads to eight possibilities for the subject noun, as listed in (4). The subject nouns were required to be human so they could legitimately function as agents in the sentence constructions. Minimal pairs were avoided since it was found that these are too easily confused in elicitation sessions involving complex paradigms.

(4)	a.	H+L	ǹdɔ̆ŋ	[-ˊ]	‘lazy man’
	b.	HL+L	m̀bꜜúŋ	[-¯]	‘poor man’
	c.	LH+L	fòk˚	[-]	‘cowife’
	d.	L+L	ə̀fɔ̂	[-ˎ]	‘chief’
	e.	H+H	mə̀lɔ̆ŋ	[-ˊ]	‘lazy men’
	f.	HL+H	mə̀pꜜúŋ	[-¯]	‘poor men’
	g.	LH+H	mə̀fòk˚	[--]	‘cowives’
	h.	L+H	mə̀fɔ̂	[-ˎ]	‘chiefs’

For the object nouns I have retained Hyman’s set. This controls for the lexical tone of the noun, and the presence or absence of a low tone prefix. (Note that the tone of *sə́ŋ* and *ꜜmɔ́* are indistinguishable in isolation.)

(5)	a.	L+H	mə̀tsɔ̆ŋ	[-ˊ]	‘thieves’
	b.	L+HL	mə̀mbhꜜʉ́	[-¯]	‘dogs’
	c.	L+LH	mə̀ŋkʉ̀ɔ̀ʔ˚	[--]	‘roosters’
	d.	L+L	mə̀nzwì	[-ˎ]	‘leopards’
	e.	H	sə́ŋ	[¯]	‘bird’
	f.	HL	ꜜmɔ́	[¯]	‘child’
	g.	LH	kɑ̀ŋ˚	[-]	‘squirrel’
	h.	L	nɑ̀	[ˎ]	‘animal’

For the associative (or genitive) construction, one juxtaposes these two sets of nouns in all possible ways to get 64 combinations: $noun_1$-CM-$noun_2$. However, here we shall employ the nouns in the construction of verb paradigms.

4.2 Verb Paradigms

In constructing verb paradigms some additional steps were necessary. Unlike nouns, verbs exhibit a two-way tone contrast between H and L. Verbs may be mono- or bisyllabic, but the second syllable (a CV verbal extension) is never contrastive for tone. Simplifying somewhat, in forming an SVO phrase two concord markers and one or more tense-aspect markers (TAM) are required: subject-CM_1-TAM-verb-CM_2-object. This looks rather like two copies of the associative construction, and yet in this construction we can observe tone sequences like H↓L and H↓↓H which are not attested in the associative construction. The same can be said for certain longer sequences. For example, the L↓HL sequence does not appear in the associative construction and Hyman (1985: 62) has a rule converting it to L↓LL. However, in the verb paradigm we find L↓HL on low toned verbs in the immediate past conditional when followed by a prefixed noun. For example: *əfɔ̀ ɔ̀ kə̀mt↓é mə̀mbh↓ʉ́* [-|--|-‾_|-] 'if the chief just buried dogs'. These new possibilities provide a useful testbed for evaluating existing analyses of the tone system.

The tone of CM_1 depends on the class of the subject noun, as before. The tense-aspect marker contributes tonal material, and sometimes segmental material as well. The tone contributed by CM_2 depends on the tense-aspect. Table 1 illustrates the situation, fixing the subject and object nouns, inserting two verbs, and running through nine traditionally recognised 'tenses'.[3]

Note that the transcriptions reported in Table 1 are being continually updated as part of the online fieldwork. Please refer to the online transcriptions rather than this snapshot for updates. Note also that there is a degree of arbitrariness about ↓↓ placement in Table 1. If we have a sequence [‾--] and there is aindependent evidence that the initial and final pitches both correspond to H, then we could have H↓↓HH or HL↓↓H, an indeterminacy which can only be resolved by analysis. Bird (1994a) documents other transcriptional indeterminacies in the context of the parametric system of tone interpretation proposed by Liberman et al. (1993). The pitch transcriptions are immune to this indeterminacy problem.

Fortunately, it is not necessary to repeat the above process with each of the 64 noun pairs. The addition of the verb permits a simplification of the tonal paradigm. We can fix the object noun and elicit all combinations of the eight

[3]The tense labels, following (Hyman 1980), are P5=remote past, P3=yesterday past, P2=today past, P1=immediate past, PR=present, PP=present progressive, F1=immediate future, F4=after tomorrow future, F5=remote future. The following pairs of tenses appear to be tonally identical and so have been represented by one member: P4=P3, F2=F5, F3=F4.

<table>
<tr><th></th><th colspan="2">High tone verb: kɑpte cover</th><th colspan="2">Low tone verb: kəmte bury</th></tr>
<tr><td>P5</td><td>əfɔ̀ ɔ̀ lèláʔ ŋ́k↓ɑ́pté máts↓ɔ́ŋ</td><td>[-|---|‾‾|‾‾‾|-]</td><td>əfɔ̀ ɔ̀ lèláʔ ŋ́kəmtè ↓mátsɔ́ŋ</td><td>[-|---|‾‾|--‾|‾]</td></tr>
<tr><td>P3</td><td>əfɔ̀ ɔ̀ kè kɑ́pté mətsɔ̌ŋ</td><td>[-|---|‾‾-|/]</td><td>əfɔ̀ ɔ̀ kè ↓kə́mté mətsɔ̌ŋ</td><td>[-|---|‾‾-|/]</td></tr>
<tr><td>P2</td><td>əfɔ̀ ɔ́ ŋ̀k↓ɑ́pté máts↓ɔ́ŋ</td><td>[-|-‾-|‾‾‾|-]</td><td>əfɔ̀ ɔ́ ↓↓ŋ́kə́mté máts↓ɔ́ŋ</td><td>[-|-‾-|---|-]</td></tr>
<tr><td>P1</td><td>əfɔ̀ ɔ́ ↓↓kɑ́pté máts↓ɔ́ŋ</td><td>[-|-‾|---|-]</td><td>əfɔ̀ ɔ́ ↓kəmtè ↓mátsɔ́ŋ</td><td>[-|-‾|--‾|-]</td></tr>
<tr><td>PR</td><td>əfɔ̀ ɔ̀ ↓kɑ̀ptè mətsɔ̌ŋ</td><td>[-|--|---|/]</td><td>əfɔ̀ ɔ̀ kəmtè mətsɔ̌ŋ</td><td>[-|--|---|/]</td></tr>
<tr><td>PP</td><td>əfɔ̀ ɔ́ ↓↓sé ŋ́kɑ́pté máts↓ɔ́ŋ</td><td>[-|-‾|--|---|-]</td><td>əfɔ̀ ɔ́ ↓↓sé ŋ́k↓ə́mté máts↓ɔ́ŋ</td><td>[-|-‾|--|---|_]</td></tr>
<tr><td>F1</td><td>əfɔ̀ ↓ɔ́ kɑ́pté máts↓ɔ́ŋ</td><td>[-|-‾|‾‾‾|-]</td><td>əfɔ̀ ɔ̀ ↓kəmtè ↓mátsɔ́ŋ</td><td>[-|--|--‾|-]</td></tr>
<tr><td>F4</td><td>əfɔ̀ ɔ̀ ↓lù↓ú kɑ́pté máts↓ɔ́ŋ</td><td>[-|--|-‾|---|-]</td><td>əfɔ̀ ɔ̀ ↓lùù ↓kəmtè ↓mátsɔ́ŋ</td><td>[-|--|--|__-|-]</td></tr>
<tr><td>F5</td><td>əfɔ̀ ↓ɔ́ fú ↓kɑ́pté máts↓ɔ́ŋ</td><td>[-|-‾‾|---|-]</td><td>əfɔ̀ ↓ɔ́ fú kəmtè ↓mátsɔ́ŋ</td><td>[-|-‾‾|--‾|-]</td></tr>
</table>

Table 1: A tense-based slice through the paradigm, for indicative mood

subject nouns and the two verbs (i.e., 16 sentences), then fix the subject noun and elicit all combinations of the two verbs with the eight object nouns (i.e., another 16 sentences). Discarding the two sentences that are duplicated in this process, we have a total of 30 sentences to elicit for each tense-aspect. Table 2 illustrates part of this process for the H verb.[4]

<table>
<tr><th></th><th colspan="2">Varying object nouns</th><th colspan="2">Varying subject nouns</th></tr>
<tr><td>L</td><td>əfɔ̀ ↓ɔ́ kɑ́pté mə́nzwì ↓ì</td><td>[-|-‾|‾‾‾|-_]</td><td>əfɔ̀ ↓ɔ́ kɑ́pté máts↓ɔ̂ŋ ŋ̀</td><td>[-|-‾|‾‾‾|_]</td></tr>
<tr><td>LH</td><td>əfɔ̀ ↓ɔ́ kɑ́pté mə́ŋk↓ʉ̀ɔ̀ʔ ì</td><td>[-|-‾|‾‾‾|__]</td><td>fòk ↓ó kɑ́pté máts↓ɔ̂ŋ ŋ̀</td><td>[-‾|‾‾‾|_]</td></tr>
<tr><td>HL</td><td>əfɔ̀ ↓ɔ́ kɑ́pté mə́mbh↓ʉ̀ ʉ̀</td><td>[-|-‾|‾‾‾|__]</td><td>m̀b↓ùŋ ↓ɔ́ kɑ́pté máts↓ɔ̂ŋ ŋ̀</td><td>[-|-|---|_]</td></tr>
<tr><td>H</td><td>əfɔ̀ ↓ɔ́ kɑ́pté máts↓ɔ̂ŋ ŋ̀</td><td>[-|-‾|‾‾‾|_]</td><td>ǹd↓ɔ́ŋ ɔ́ kɑ́pté máts↓ɔ̂ŋ ŋ̀</td><td>[-|‾‾|‾‾‾|_]</td></tr>
<tr><td>L</td><td>əfɔ̀ ↓ɔ́ kɑ́ptɛ́ nà ↓à</td><td>[-|-‾|‾‾-|_]</td><td>məfɔ̀ ɔ́ ↓kɑ́pté máts↓ɔ̂ŋ ŋ̀</td><td>[-|-‾|‾‾‾|_]</td></tr>
<tr><td>LH</td><td>əfɔ̀ ↓ɔ́ kɑ́ptɛ́ kàŋ ↓ŋ̀</td><td>[-|-‾|‾‾-|_]</td><td>məf↓ók ↓kɑ́pté máts↓ɔ̂ŋ ŋ̀</td><td>[-|‾|---|_]</td></tr>
<tr><td>HL</td><td>əfɔ̀ ↓ɔ́ kɑ́ptɛ́ ↓mɔ̀ ɔ̀</td><td>[-|-‾|‾‾|__]</td><td>məp↓úŋ ŋ́ ↓kɑ́pté máts↓ɔ̂ŋ ŋ̀</td><td>[-|‾‾|---|_]</td></tr>
<tr><td>H</td><td>əfɔ̀ ↓ɔ́ kɑ́ptɛ́ sə̂ŋ ↓ŋ̀</td><td>[-|-‾|‾‾|_]</td><td>məlɔ́ŋ ŋ́ ↓kɑ́pté máts↓ɔ̂ŋ ŋ̀</td><td>[-|‾‾|‾‾‾|_]</td></tr>
</table>

Table 2: A noun-based slice through the paradigm, for F1 interrogative

These 30 items were then elicited for the nine tenses listed in Table 1, to create a paradigm of 270 items. This process was repeated for five mood/voice

[4] The $e{\sim}\varepsilon$ alternation in the verb in the left column of Table 2 is addressed in section 5.3.

possibilities: indicative, negative, interrogative, conditional and focus, each adding interesting new tonal information to the sentences. The full dataset of 1350 items was digitally recorded for three speakers (with audio and laryngograph channels) and then uploaded and segmented to create 8100 speech clips.

4.3 Paradigm Tool

A flexible tool has been developed for navigating the data along any of its dimensions, constructing tabulations of interesting slices through the hypercube of data, viewing pitch traces, and listening to digitised speech data. The tool is written in Perl (Wall et al. 1996) and operates as a 'Common Gateway Interface' (CGI) program on the web, providing users with a familiar forms-based interface. Its design is based on *HyperLex* (Bird 1997), with influences from the SIL programs Shoebox (Buseman et al. 1996) and FindPhone (Bevan 1995) [`http://www.sil.org/computing/`].

The internal format of the data uses the SIL STANDARD FORMAT, as used, for example, by Shoebox. Table 3 contains a record from the database. Non-roman characters are encoded using capital letters, for example ɔ appears as 'O' in the database, but is correctly rendered in the web browser.

```
\re 0001                             # record id
\va                                  # validation status
\sp pn                               # speaker
\tn f1                               # tense
\md a                                # mood
\au OH1                              # audio file pointer
\ts L                                # tone on subject
\cl 1                                # noun class
\tv H                                # tone on verb
\op y                                # object pronoun (y/n)
\to L                                # tone on object
\dt [RH]                             # domain type
\tr efO kapte menzwi                 # ascii transcription
\pi 3 3  1 1   1  1   35             # pitch numbers
\se e fO a kap te men zwi            # segmental tier
\as | |  | |   |/  |   |             # associations
\t  L L *H H  *H   L   L             # tone tier
\cm                                  # comment
```

Table 3: Shoebox entry for the utterance əfɔ̀ ɔ́ kɑ́pté mə́nzwì

This format is very flexible, and new fields can be added as the need arises. For example, we may want to have multiple pitch-number transcriptions, contributed by different transcribers. Different assumptions about the nature of downstep lead to different tone transcriptions (cf. Stewart 1993). We could equally represent tone sequences at varying levels of abstractness or adopt different theoretical positions (e.g., an analysis using three basic tones instead of two). One could expand the database in these ways, or construct a derived database which retains certain fields while replacing others.

The record in Table 3 also contains an ASCII version of an autosegmental diagram, with asterisks denoting grammatical tones. This format is simple to maintain in the database, and it can be used to generate more readily recognisable diagrams inside a web browser.

For run-time efficiency, the SIL Standard Format for each entry is compiled into a one-line format consisting of colon-separated fields, where many of the fields are preprocessed into HTML. As a temporary measure until Unicode [`http://www.unicode.org`] is more widely implemented and adopted, special characters are represented using dynamic fonts, and also translated into small graphics images.[5]

The web interface provides a fill-in form for querying the database. Search expressions can be applied to any of the database fields, and employ 'regular expression' syntax. A pull-down menu is used to select the field. Beside this, there is a checkbox to indicate whether the result should be tabulated according to the values found for this field. And alongside this, there is an area for the constraint to be entered; see Table 4 for examples. This triple—the field name, axis-control checkbox and constraint—queries a single field. The form has room for up to eight fields to be queried in parallel, permitting fine control of the search. Only fields which are to be used to constrain the output need to be explicitly constrained. The form also allows the user to control which field(s) should be displayed in the resulting table.

5 Downstep in Bamileke Dschang

This section presents a sketch of downstep patterning in Dschang. It is not my intention here to provide another analysis relating surface forms right back to the underlying (or proto-) forms. Rather, I wish to provide a descriptive discussion of the interesting cases which any theoretical account has to deal with, and illustrate the use of the paradigm system to generate useful tabulations.

[5]These occupy about 160 bytes each and do not represent a significant overhead for use on the web. In any case, each character only needs to be downloaded once.

<table>
<tr><th>Field Name</th><th>Values</th><th>Notes</th></tr>
<tr><td>Tense</td><td>p5, p3, p2, p1</td><td>past 5 ... past 1</td></tr>
<tr><td></td><td>pr, pp</td><td>simple present, present progressive</td></tr>
<tr><td></td><td>f1, f4, f5</td><td>future 1 ... future 5</td></tr>
<tr><td></td><td>f.</td><td>any future tense ('.' matches any single character)</td></tr>
<tr><td></td><td>.1</td><td>immediate past (p1) or immediate future (f1)</td></tr>
<tr><td>Mood</td><td>a, n</td><td>affirmative (=indicative), negative</td></tr>
<tr><td></td><td>i, c, f</td><td>interrogative, conditional, focus</td></tr>
<tr><td></td><td>[an]</td><td>any affirmative or negative form</td></tr>
<tr><td>Tone (subj)</td><td>H, HL, LH, L</td><td>the lexical tone of the subject noun (after Hyman)</td></tr>
<tr><td></td><td>HL</td><td>HL subject nouns: m̀b↓úŋ, mə̀p↓úŋ</td></tr>
<tr><td>Class</td><td>1, 2</td><td>the noun class of the subject noun</td></tr>
<tr><td></td><td>2</td><td>the class 2 (i.e. plural) subject nouns (e.g. mə̀lɔ̌ŋ)</td></tr>
<tr><td>Tone (verb)</td><td>H, L</td><td>the lexical tone of the verb</td></tr>
<tr><td></td><td>H</td><td>the H subject nouns: m̀b↓úŋ, mə̀p↓úŋ</td></tr>
<tr><td>Obj prefix</td><td>y, n</td><td>whether the object has the mə- prefix (yes/no)</td></tr>
<tr><td></td><td>n</td><td>the prefixless object nouns: sə́ŋ, mə̀mbh↓ʉ́, kàŋ˚, nà</td></tr>
<tr><td>Tone (obj)</td><td>H, HL, LH, L</td><td>the lexical tone of the object noun</td></tr>
<tr><td></td><td>.*L</td><td>the tone patterns ending in L (i.e. HL, L)</td></tr>
<tr><td>Pitches</td><td>1 ... 6</td><td>the pitch transcription</td></tr>
<tr><td></td><td>(213|324|435)</td><td>pitch sequences corresponding to L↓HL</td></tr>
</table>

Table 4: Database field values and their use in constructing queries

Readers are encouraged to use this discussion as a starting point for their own exploration of the data, sharing intermediate results in the same manner as I have done here.

5.1 Downstep Conditioned by Low Tone

A pervasive kind of downstep in many Niger-Congo languages can be treated using the theoretical construct of 'floating low tones', symbolised here using parentheses, as (L). In this section we review two kinds of (L) tone, one which only lowers a following H tone, and one which lowers all following tones.

Example (6a) shows *mə̀tsɔ̌ŋ* 'thieves' as it appears following a low concord tone. This is the same as the isolation form of the word. We see the plural prefix *mə-* followed by the high tone root *tsɔ́ŋ*, which is realised as rising tone in phrase-final position. In (6b) we see a rather different situation, where the high concord tone is copied (or spread) onto the *mə-* prefix, and the low tone of this prefix shows up as downstep.

(6) a. èfɔ̂ ɔ̀ mə̀tsɔ̌ŋ [-|---|/] ‘chief of thieves’

b. àsáŋ á mə́ts↓ɔ́ŋ [-|¯¯¯|¯] ‘tail of thieves’

This downstep only lowers high tone; the lexical contrast between H and ↓H is neutralised here. Consider example (7), which illustrates this neutralisation for *mə̀mbh↓ʉ́* ‘dogs’ and *mə̀tsɔ̌ŋ* ‘thieves’.

(7) a. àsáŋ á mə́mbh↓ʉ́ [-|¯¯¯|¯] ‘tail of dogs’

b. àsáŋ á mə́ts↓ɔ́ŋ [-|¯¯¯|¯] ‘tail of thieves’

Regardless of how one chooses to represent the various tones and how one provides explicit formal mechanisms for tones to influence each other, the fact remains that this type of (L) is sensitive to the identity of the following tone. Now we turn to a kind of (L) which is not sensitive in this way. In fact, it lowers *every* tone after H, regardless of its identity, as shown in Table 5 (cf. Hyman and Tadadjeu 1976).[6] Observe that the final word of each indicative form is downstepped relative to the final word of the corresponding conditional form.

<table>
<tr><th></th><th>Indicative</th><th></th><th>Conditional</th><th></th></tr>
<tr><td>L</td><td>èfɔ̂ ɔ̀ kè káptɛ́ ↓nà</td><td>[-|---|¯¯|\]</td><td>èfɔ̂ ɔ̀ kè káptɛ́ nà</td><td>[-|---|¯¯|\]</td></tr>
<tr><td>LH</td><td>èfɔ̂ ɔ̀ kè káptɛ́ ↓kàŋ</td><td>[-|---|¯¯|\]</td><td>èfɔ̂ ɔ̀ kè káptɛ́ kàŋ</td><td>[-|---|¯¯|\]</td></tr>
<tr><td>HL</td><td>èfɔ̂ ɔ̀ kè káptɛ́ ↓↓mɔ́</td><td>[-|---|¯¯|-]</td><td>èfɔ̂ ɔ̀ kè káptɛ́ ↓mɔ́</td><td>[-|---|¯¯|¯]</td></tr>
<tr><td>H</td><td>èfɔ̂ ɔ̀ kè káptɛ́ ↓sə́ŋ</td><td>[-|---|¯¯|¯]</td><td>èfɔ̂ ɔ̀ kè káptɛ́ sə́ŋ</td><td>[-|---|¯¯|¯]</td></tr>
</table>

Table 5: Yesterday past indicative for H verbs with prefixless object nouns

Accordingly, we have evidence for a ‘weak’ (L) which only downsteps H tone, and a ‘strong’ (L) which can downstep any tone. Now we turn to (H) and observe analogous behaviour.

[6]Note that the informant did not tonally distinguish *kàŋ* and *nà*, even though the former is supposed to be non-falling (cf. (5f)) and has been verified as such in the speech of Maurice Tadadjeu. I noted significant variation across speakers for the L/L̊ contrast, with a tendency for collapsing the distinction in many contexts.

5.2 Downstep Conditioned by High Tone

Consider the ↓H∼↓L alternation in example (8). In (8a) we have the ↓H root *ꜜpúŋ* while in (8b) we see the same root (with allophonic voicing) with ↓L tone: *ꜜbùŋ*.

(8) a. mə̀pꜜúŋ ŋ́ kə̀mtè mə̀tsɔ̆ŋ[-|‾‾|---|/] 'poor men bury thieves'
    b. m̀bꜜùŋ ɔ̀ kə̀mtè mə̀tsɔ̆ŋ [-|--|---|/] 'the poor man buries thieves'

Assuming that the phonological representation of ↓H contains a H tone (e.g., as (L)H), this H is absent from any vowel in *m̀ꜜbùŋ*, though it explains the presence of the downstep. Similar examples exist in the associative construction, cf. (9), and with the possessive marker, cf. (10).

(9) a. èfɔ̀ ɔ̀ mə̀nzwì [-|---|\] 'chief of leopards'
    b. ɑ̀lə̀ŋ ə̀ mə̀nzwꜜì [-|---|\] 'stool of leopards'

(10) a. ǹdꜜɔ́ŋ [-|‾] 'horn'
     b. ǹdꜜɔ̀ŋ zɑ̀ [-|-\] 'my horn'

Note, however, that in all these cases, (H)L only shows up as ↓L if there is a preceding L tone. Although (11a) has a ↓L, the conditions are not right for ↓L in (11b).

(11) a. ɑ̀lə̀ŋ ə̀ mènzwꜜì [-|---|\] 'stool of leopards'
     b. ɑ̀sɑ́ŋ ɑ́ ménzwì [-|‾‾‾|\] 'tail of leopards'

Now we consider a variety of (H) which downsteps the following L regardless of the preceding tone. Consider the items in Table 6. Looking across each row, observe that the only difference is the presence of a ↓L for the H verb and just a plain L for the L verb. Evidently the lexical tone of the H verb is showing up as downstep, and this is not sensitive to prior context. A promising way to approach the problem systematically is provided by Hyman's notion of word domains (Hyman 1985).

5.3 Word Domains

Hyman (1985: 59ff) has identified the *phonological word* as the prosodic domain in which the majority of Dschang tone rules apply.[7] According to

[7] For another example of tonal behaviour which is sensitive to prosodic constituency, see Leben and Ahoua 1997.

<table>
<tr><th></th><th colspan="2">High tone verb: kɑpte cover</th><th colspan="2">Low tone verb: kəmte bury</th></tr>
<tr><td>L</td><td>əfɔ̀ ɔ̀ ↓kɑ̀ptè mətsɔ̆ŋ</td><td>[-|--|---|/]</td><td>əfɔ̀ ɔ̀ kəmtè mətsɔ̆ŋ</td><td>[-|--|---|/]</td></tr>
<tr><td>LH</td><td>fòk ò ↓kɑ̀ptè mətsɔ̆ŋ</td><td>[--|---|/]</td><td>fòk ò kəmtè mətsɔ̆ŋ</td><td>[--|---|/]</td></tr>
<tr><td>HL</td><td>m̀b↓ùŋ ɔ̀ ↓kɑ̀ptè mətsɔ̆ŋ</td><td>[-|--|___|/]</td><td>m̀b↓ùŋ ɔ̀ kəmtè mətsɔ̆ŋ</td><td>[-|--|---|/]</td></tr>
<tr><td>H</td><td>ǹdɔ̀ŋ ɔ̀ ↓kɑ̀ptè mətsɔ̆ŋ</td><td>[-|--|---|/]</td><td>ǹdɔ̀ŋ ɔ̀ kəmtè mətsɔ̆ŋ</td><td>[-|--|---|/]</td></tr>
<tr><td>L</td><td>məfɔ̀ ɔ́ ↓kɑ̀ptè mətsɔ̆ŋ</td><td>[-|-¯|---|/]</td><td>məfɔ̀ ɔ́ kəmtè mətsɔ̆ŋ</td><td>[-|-¯|---|/]</td></tr>
<tr><td>LH</td><td>məf↓ók ↓kɑ̀ptè mətsɔ̆ŋ</td><td>[-|¯|___|/]</td><td>məf↓ók kəmtè mətsɔ̆ŋ</td><td>[-|¯|---|/]</td></tr>
<tr><td>HL</td><td>məp↓úŋ ŋ́ ↓kɑ̀ptè mətsɔ̆ŋ</td><td>[-|¯¯|___|/]</td><td>məp↓úŋ ŋ́ kəmtè mətsɔ̆ŋ</td><td>[-|¯¯|---|/]</td></tr>
<tr><td>H</td><td>məlɔ́ŋ ŋ́ ↓kɑ̀ptè mətsɔ̆ŋ</td><td>[-|¯¯|---|/]</td><td>məlɔ́ŋ ŋ́ kəmtè mətsɔ̆ŋ</td><td>[-|¯¯|---|/]</td></tr>
</table>

Table 6: Simple present indicative varying subject and verb

Hyman's definition, phonological words extend from the root of one word, through any suffix or concord marker, up to and including any prefix on the next word. As mentioned above, the pitch transcriptions used throughout this paper indicate phonological word boundaries using a vertical bar.

Phrase-internal phonological words appear to be minimally bimoraic. The apparent counterexample of *məf↓ók* in Table 6 evidently contains a silent beat after the *k* in order to satisfy this constraint. (The reader is encouraged to verify this claim by listening to the recording.) The other apparent counterexamples are the mono-moraic auxiliaries for yesterday past (P3) and distant future (F5) in Table 1. The short duration and low intensity of these morphemes seem to place them on a par with affixes rather than full roots, and so they are not assigned their own word domains.

As independent confirmation for the existence of word domains, there is an interesting vowel alternation that may be explained with reference to a limitation on the complexity of phonological words. Consider the phrases in (12), with surface forms on the left and putative underlying forms of the main phonological word on the right. The first two lines use the bisyllabic verb root *kapte*, while the last two lines use the monosyllabic verb root *pok* plus an echo vowel whose morphological status is unclear.

(12) a.	ləkɑpte mətsɔŋ	[kɑp te mə]$_{PW}$	'to cover thieves'
b.	ləkɑptɛ nɑ	[kɑp te ɑ]$_{PW}$	'to cover the animal'
c.	ləpoko mətsɔŋ	[pok o mə]$_{PW}$	'to anoint thieves'
d.	ləpokɔ nɑ	[pok o ɑ]$_{PW}$	'to anoint the animal'

The data in (12) shows that the the concord marker (at least, its segmental content) is only present when the object noun lacks a prefix.

5.4 Towards an Inventory of Domain Types

Table 7 contains pitch transcriptions which were selected and tabulated using the paradigm system. The left side shows the indicative mood, for H and L tone verbs respectively (see Table 1 for the segmental transcription), and the right side shows the negative mood. As before, each row represents a different 'tense'.

<table>
<tr><th></th><th colspan="2">Indicative</th><th colspan="2">Negative</th></tr>
<tr><th></th><th>H verb: kɑpte</th><th>L verb: kəmte</th><th>H verb: kɑpte</th><th>L verb: kəmte</th></tr>
<tr><td>P5</td><td>[-|--|¯¯|---|-]</td><td>[-|--|¯¯|--¯|¯]</td><td>[-|--|¯-|¯¯¯|-¯]</td><td>[-|--|¯-|¯--|--]</td></tr>
<tr><td>P3</td><td>[-|--|¯¯-|/]</td><td>[-|--|¯¯_|/]</td><td>[-̇|--|¯¯¯|-¯]</td><td>[-|--|¯--|--]</td></tr>
<tr><td>P2</td><td>[-|-¯-|¯--|-]</td><td>[-|-¯-|---|_]</td><td>[-|-/-|¯--|--]</td><td>[-|-/-|---|__]</td></tr>
<tr><td>P1</td><td>[-|-¯|---|_]</td><td>[-|-¯|__-|-]</td><td>[-|--|¯¯¯|-¯]</td><td>[-|--|¯--|--]</td></tr>
<tr><td>PR</td><td>[-|-|---|/]</td><td>[-|-|---|/]</td><td>[-|---|¯¯¯|-¯]</td><td>[-|---|¯--|--]</td></tr>
<tr><td>PP</td><td>[-|-¯|--|---|_]</td><td>[-|-¯|--|---|_]</td><td>[-|--|¯-|¯--|--]</td><td>[-|--|¯-|---|__]</td></tr>
<tr><td>F1</td><td>[-|-¯|¯--|-]</td><td>[-|--|__-|-]</td><td>[-|--¯|¯--|--]</td><td>[-|--|__-|--]</td></tr>
<tr><td>F4</td><td>[-|--|_-|---|_]</td><td>[-|--|--|__-|-]</td><td>[-|--|_-|---|--]</td><td>[-|--|--|__-|--]</td></tr>
<tr><td>F5</td><td>[-|-¯¯|---|_]</td><td>[-|-¯¯|__-|-]</td><td>[-|--¯¯|---|__]</td><td>[-|--¯¯|--¯|¯-]</td></tr>
</table>

Table 7: Pitch transcriptions for əfɔ ... mətsɔŋ

Although there is too much going on in this data to adequately address here, there are some interesting facts about domain types to be gleaned from it. First, consider the final domain boundary of each pitch transcription, along with the relative pitch value on either side. These two pitch values correspond to the word *mətsɔŋ*. Ignoring relative pitch height, there are only three possibilities: [-|_], [-|-], and [-|/]. (But recall that another possibility for *mətsɔŋ* was shown in Table 2.) The three possibilities in Table 7 are the same three that we see for *mətsɔŋ* in the associative construction (Hyman 1985:50), and are laid out in (13), where X stands for either H or L.

(13) a. radical = X, CM = L: [-|/], [_|/]

b. radical = L, CM = H: [¯|¯], [-|-], [_|_]

c. radical = H, CM = H: [¯|¯], [¯|-], [-|_], [_|_]

A tabulation of just the relevant data from Table 7 is given in Table 8. Note that the tabulation is inverted from Table 7; tense and verb tone are classified with respect to pitch information, rather than the other way around. The row labels have been grouped so that the tones on either side of the domain boundary stand in the same relationship to each other. The five non-empty cells are themselves structured according to the lexical tone of the verb. (Thus, Table 8 really has three dimensions.)

Pitch Sequence	Indicative	Negative
[-|/], [-|/]	H: P3, PR L: P3, PR	
[¯|¯], [-|-], [_|_]	L: P5, P1, F1, F4, F5	L: P2, F1, F4, F5
[¯|-], [-|-], [-|_], [-|_]	H: P5, P2, P1, PP, F1, F4, F5 L: P2, PP	H: P5, P3, P2, P1, PR, PP, F1, F4, F5 L: P5, P3, P1, PR, PP

Table 8: Tense and verb-tone classified by domain boundary type

The first row of Table 8 corresponds to (13a). The tone on the radical contributes nothing to the tonal behaviour at the domain boundary, showing up elsewhere. I posit a L tone concord marker, provided by tenses P3 and PR in the indicative. This will be classified as [RL]—a domain consisting of the radical tone plus a L grammatical tone. The second row corresponds to (13b). Observe that all the radicals are L. In order to get the desired pitch sequence at the boundary we can posit a H tone concord marker for all L tone verbs in any future tense, and for L tone verbs in P5 indicative, P1 indicative and P2 negative. These will be classified as [RH]. The most interesting case is the third row, which we would like to put into correspondence with (13c). The H tone verbs fit the pattern, so long as we stipulate a H tone concord marker as well, and so these can also be classified as [RH]. However, the L tone verbs break the pattern. Evidently the lexical contrast is not expressed at this position. Nevertheless, we can go ahead and attribute a grammatically conditioned H tone to the L radical in these cases, observing that this radical never shows up overtly, but only as downstep at the preceding domain boundary. This category will be labelled [↓HH].

Since each possibility for *mətsɔŋ* represents a set of patterns for the other object nouns, the above procedure can be generalised after the necessary checks have been carried out; it is not necessary to start afresh with each new object noun. In this way, with the help of various stipulations concerning the grammatical tone contributed by the tense and mood, we can see how any analysis of the associative construction can be generalised to cover this position. The next exercise is to work leftwards through each item in Table 7, attempting to classify each domain and each domain boundary in order to determine the tonal contribution of the grammatical construction and to determine the fate of the lexical tones. Those who attempt this exercise—and it is not recommended for the faint-hearted—will soon discover that the word domains familiar from the associative construction do not cover all the necessary cases. Attributing tone behaviour at boundaries to the preceding or following domain is especially tricky. I believe it is helpful to consider the possibility that domains condition downstep *to their right*, taking no account of the identity of the tones to be found there (since those tones cannot be seen). This requires the creation of domain types like [RH↓]. We can now distinguish ...H][↓... 'weak (L)' from ...H↓][... 'strong (L)' and ...↓][L... 'weak (H)' from ...][↓L... 'strong (H)'. Furthermore, the occurrence of H↓↓H, only possible at domain boundaries, may then be represented as the sequence ...H↓][↓H...

Whatever the details may be, we proceed by constructing new classifications (in this case, the domain type) for the existing data, and then using this classification in subsequent searching and display. In this way the tool helps to systematise a large body of data, collapsing multiple cases to representative examples, and guaranteeing an analysis having wide coverage.

6 Conclusion

There are many ways to address the challenges posed by the Dschang data. One can enrich the representation of tones by adopting register tones and tonal root nodes (Snider 1990)—the 'paradigmatic dimension'. One can explore the prosodic structures to which tones are associated, assigning tones to non-terminal nodes and to boundaries or providing alignment constraints (Pierrehumbert and Beckman 1988, Hyman 1990)—the 'syntagmatic dimension'. One can refine and elaborate the system of phonetic interpretation, and parameterise it in various ways (Liberman et al. 1993, Bird 1994a). The wealth of analytical possibilities—compounded with the sheer difficulty of providing a complete analysis—underscores the value of making large amounts of primary data accessible in paradigm-like form, and making it simpler for researchers to address one another's datasets in a responsible fashion.

In advocating a technological approach, it has not been my intention to argue against the use of impressionistic transcriptions. In fact, the database described here makes heavy use of such transcriptions, and the interface helps linguists to derive maximum benefit from those transcriptions. Inconsistencies stand out and are discovered at an early stage. Searching transcriptions using numerical sequences avoids the needle-in-a-haystack approach to finding counter-examples, as was neatly illustrated for the L↓HL sequence discussed in section 4.2. Equally, it has not been my intention to argue against the use of pencil and paper for exploring field data. After all, working with a page-size quantity of data at a time is about the most someone can handle without suffering cognitive overload, plus it helps the investigator to see and intuitively grasp complex relationships between forms. Again, the technological approach actually facilitates the pencil-and-paper mode of exploration. The program makes it possible to experiment with a variety of different tabulations of the same data, a useful preliminary step to generating hardcopy tabulations to be analysed away from the computer screen. There are several other advantages. First, it avoids the time-consuming process of producing each new tabulation by hand, for the once-off overhead of entering the data. Second, it avoids the painful process of recopying tabulations in order to rearrange some rows and columns, or substitute new rows and columns, or propagate corrections. Third, it avoids the risk of introducing scribal errors into each new version. Finally, right from the start we are producing layouts that can be reproduced inside physical documents.

In this paper I have argued for a new mode of investigation in linguistic research based on field data, an approach which combines primary description, theoretical analysis, and tool development. I hope to have demonstrated that this synthesis is both possible and desirable, and I hope to have stimulated the production of improved linguistic software and the construction of shared linguistic resources. Putting digitised speech data and transcriptions on the web along with a powerful search tool makes field recordings accessible, transcriptions verifiable, and a large dataset manageable. Articles whose empirical content is too large for journal publication can make the majority of the material available on the web, avoiding the need for extended appendices in the print document (which have to be laboriously retyped by subsequent analysts). Published analyses of data from relatively inaccessible languages can be scrutinised on external grounds without mounting an expedition. Reanalyses are not limited to endless rearrangements of the data contained in an initial description, driven by purely internal arguments about prior analyses. On the contrary, publishing large datasets supports restudies going right back to the empirical foundations, which is crucial in any discipline having multiple paradigms. The success of this methodology will be measured to the extent that others make new observations about the patterning of tone in the data I have reported here, and devise better analyses.

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