A Universal Dependencies Treebank of Ancient Hebrew

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Abstract
In this paper we present the initial construction of a Universal Dependencies treebank with morphological annotations of Ancient Hebrew containing portions of the Hebrew Scriptures (1579 sentences, 27K tokens) for use in comparative study with ancient translations and for analysis of the development of Hebrew syntax. We construct this treebank by applying a rule-based parser (300 rules) to an existing morphologically-annotated corpus with minimal constituency structure and manually verifying the output and present the results of this semi-automated annotation process and some of the annotation decisions made in the process of applying the UD guidelines to a new language.

Keywords: treebank, UD, Hebrew

1. Introduction
The Hebrew Scriptures are a collection of 39 books primarily written in the first millennium BC in Ancient Hebrew (with a few passages in Aramaic) which were arranged and codified in their current form over the course of the first millennium AD. They are also known as the Tanakh, an acronym of the Hebrew names of the 3 main divisions: נָבִיאֵיָה/ "prophets" (a category which also includes several books of narrative history), and הֹדנֵי/ "writings".

The BHSA splits words on spaces except for a handful of proper nouns. It additionally separates the conjunctions ve, va, u/ “and”, prepositional prefixes, and the definite article. However, it does not split off pronominal suffixes. Thus an example of such a tree.

2. The Hebrew Corpus

The Biblia Hebraica Stuttgartensia Amstelodamensis (BHSA) is a complete copy of the text of the Tanakh with morphological annotations which is maintained by the Eep Talstra Centre for Bible and Computer (Peursen et al., 2015).

The corpus is stored as a table, where each row is a syntactic node, whether a word, phrase, clause, or sentence. The columns of the table specify various features of these these nodes such, for words, lemma, part of speech, person, gender, number, and whether there is a space before the following word. There are also columns specifying which larger nodes the node represented by a particular row is a part of. An example of this structure can be found in Table 1

Phrases are contained in clauses and clauses in sentences. Phrases and clauses are not necessarily contiguous, though sentences are. An example of the structure when they are not contiguous is given in Table 2. This structure can be used to construct a rudimentary constituency tree, but with a very flat structure. See Figure 1 for an example of such a tree.

3. Annotation Process

Our annotation process consisted of the creation of an automated procedure for adjusting and converting the BHSA tokenization and part-of-speech tags to match the UD annotation guidelines and then passing this through a rule-based parser and manually validating the output.

3.1. Tokenization

The BHSA splits words on spaces except for a handful of proper nouns. It additionally separates the conjunctions, prepositional prefixes, and the definite article. However, it does not split off pronominal suffixes. Thus an example of the maximal

1Instances of Hebrew script in this paper are followed by a transliteration in slashes according to the ALA-LC scheme (Barry, 1997) and an English translation in quotes.

2Pronominal suffixes in Hebrew can attach to prepositions as in י/ "to him", to nouns as possessors as in י/ "his hand", or to verbs as direct object as in י/ "to guard" vs י/ "to guard him".
Table 1: A segment of the data table of the BHSA showing Genesis 1:1. Each row of the table represents a linguistic unit (word, phrase, clause, or sentence), with the rows being sorted first from smallest to largest and then by order of occurrence within the text. The columns represent various features, with an empty cell indicating that that feature is not applicable to that node. The last three features indicate which rows are nodes which contain the current node.

Table 2: An example of the structure of the phrase, clause, and sentence annotations in the BHSA. The sentence is part of Genesis 7:21/7:21_yigya' kol-bašar haromes' al-'arets vekhol ha'adam/ “All flesh that crawled upon the earth and all humans perished.” Here the relative clause “that crawled upon the earth” intervenes between two members of a list, causing both phrase 2 and clause 6 to be non-contiguous. Note also that phrase 2 “all flesh and all humans”, phrase 3 “that crawled”, and phrase 4 “upon the earth” are all entirely separate from one another and there is no hierarchical relation between them.

Figure 1: An example of the rather limited syntax encoded directly in the BHSA. Note especially the complete lack of internal structure in the second prepositional phrase. This is Genesis 1:1/bereshit bara' elohim 'et hashamayim ve'et ha'arets/ “In the beginning, God created the heavens and the earth.”
amount of splitting is

(1) הבית ובידוד
v. e

yik. ah.

b [a]h

bayit u

be yad o[hu']

in DEF house and in hand 3SG.M

“in the house and in his hand”

Note that the definite article has been reduced to a change in the vowel of the preceding preposition and thus is visible in the text with vowels but not in the plain consonantal text.

In this work, however, we follow the Modern Hebrew UD treebank (Tsarfaty, 2013; McDonald et al., 2013) in also splitting off prepositional suffixes as in (2).

(2) הבית ובידוד
וֹדֶנֶ/בְּרֶרֶא שָׁה הָ ב
b [a]h bayit u be yad o[hu']

in DEF house and in hand 3SG.M

“in the house and in his hand”

As shown in (3), we give the pronominal suffix the lemma of the corresponding independent pronoun. Additionally, in accordance with UD guidelines, we convert punctuation from a property of the preceding word to a full token so that it can be attached to the final dependency tree.

3.2. Part-of-Speech Tags

The conversion from BHSA POS tags to the POS tags used in UD is summarized in Table 3. The cases in which this conversion is not one-to-one are as follows:

| BHSA       | Description | UD     |
|------------|-------------|--------|
| adv        | adjective   | ADJ, NOUN |
| advb       | adverb      | ADV    |
| art        | article     | DET, SCONJ |
| conj       | conjunction | CCONJ, SCONJ |
| inrg       | interrogative particle | ADJ, PART |
| intj       | interjection | INTJ |
| nega       | negative particle | ADV |
| nmpr       | proper noun | PROP |
| prde       | demonstrative pronoun | PRON |
| prep       | preposition  | PRON |
| prin       | interrogative pronoun | PRON |
| pprps      | personal pronoun | PRON |
| subs       | noun | NOUN, ADP, ADV, VERB |
| prn*       | pronominal suffix | PRON |
| punct*     | punctuation | PUNCT |

Table 3: Mapping of POS tags from BHSA to UD. The tags prn and punct are not actually present in the BHSA, but are inserted by the tokenization procedure described in Section 3.1.

Here יָטָנָא, a form of the adjective יָטָנָא /zaken/ “old”, has the plural form of the nominal compound suffix, indicating that the following noun depends on it. As a result, we tag it as a noun.

Words denoting nationalities so frequently stand on their own rather than modifying a noun that the decision was made to also treat them as nouns in their own right, such as in (4).

(4) בֵּית יָטָנָא יָדֶנְא
bne yavan kitim ye

NOUN PROPN ADJ/NOUN CCONJ

son-PL.CNST Yavan Kittite-PL and

“Dodanites.” (Genesis 10:4)

3.2.2. Articles

The definite article is tagged as a subordinating conjunction when it attaches to a non-nominalized particle, such as in (5).

(5) בֵּית יָטָנָא יָדֶנְא
וֹדֶנֶ/בְּרֶרֶא שָׁה הָ ב
b [a]h bayit u be yad o[hu’]

in DEF house and in hand 3SG.M

“in the house and in his hand”

Although Hebrew text is written right-to-left, glossed examples in this paper present the words from left to right for readability.
2.2.3. Conjunctions

Unlike UD, the BHSA does not make a distinction between coordinating and subordinating conjunctions. We treat /vel/ “and” and /al/ “or” as coordinating conjunctions. Other conjunctions such as the relative clause marker /asher/ “that, because”, and /me’od/ “if” are all tagged as subordinating.

2.2.4. Interrogative Particle

The BHSA category of interrogative particle covers both question words, which are tagged as adverbs (ADV), and the question marker נ/הל/ha/, which is tagged as a particle (PART).

2.2.5. Nouns

Words that the BHSA treats as nouns are retagged in a variety of situations because the BHSA tagging is based more on etymology than on the current behavior of a word. As a result, some words such as /him/ “after” and /me’od/ “very” are retagged as prepositions and adverbs, respectively, such as in (6).

(6) הלך ב אלoultry אראקם כי יברך אותם ונואך
lo’ yiyada’ /ahare
ADV VERB NOUN/ADP
NEG 3SG-remember.IMPF.PASS after

“[The abundance] will not be remembered after this because it [the famine] will be very great.” (Genesis 41:31)

In addition, there are two existential verbs, ש/ויודע/ “there exists” and /ye/ “there does not exist”, which we tag as verbs (VERB), such as in (7).

(7) ולא יהיה כל רוחם של אראקם
lehem en be khol
COP NOUN/VERB ADP NOUN
and all NEG in all

“And there was no bread in all the land.” (Genesis 47:13)

3.2.6. Verbs

Words tagged as verbs in the BHSA are also tagged as verbs in UD, except for the copula /hayah/, which is tagged as an auxiliary. Verbs in participial form are also sometimes treated as nominalized and so tagged as nouns. This case is described in more detail in Section 4.1.

3.3. Parsing

To produce dependency annotations, we constructed a rule-based parser using the VISL Constraint Grammar formalism (Bick and Didriksen, 2015) as it has been successfully used for prior annotation projects (Bick, 2005; Antonsen et al., 2010; Tyers and Sheyanova, 2017) and can easily process arbitrarily many annotation labels. Most of the annotation layers of the BHSA (excluding text-formatting directives) are converted to the Constraint Grammar input format. Tokens marking boundaries between phrases, clauses, and sentences are also inserted.

For this treebank, we have chosen to follow the traditional verse boundaries rather than the BHSA sentence boundaries since BHSA puts quotations and subordinate clauses expressing conditions or causes in separate sentences from their parent clauses. BHSA thus often annotates multiple sentences for a single verse, though the verse boundaries usually align with sentence boundaries. When they do not align, we automatically merge adjacent verses into a single tree.

After splitting into sentences, a further pre-processing step uses the BHSA phrase function labels and clause ids to mark the phrase in each clause which most likely contains the root of that clause.

Each tree is then passed through a parser consisting of 307 Constraint Grammar rules. These include 121 head-assignment rules, 114 relation-assignment rules, and 63 rules manipulating the tags. Examples of these types of rules are shown in Table 4 and the process for an entire sentence is shown in Figure 2. The remaining 9 rules deal with instances where the BHSA tokenization disagrees with the UD guidelines and with removing the phrase boundaries before the output is converted to CoNLL-U format.

Finally, a script converts the dependency tree to CoNLL-U format together with all morphological an-
MAP @case Pr ;
SET AfterPrep = Det OR @case OR @nummod ;
SETPARENT @case TO (1* Noun OR PRON BARRIER (*) - AfterPrep) ;
MAP @det Det ;
SETPARENT Det TO (1 Noun OR ADJ OR PRON) ;

Attach prepositions to following nouns or pronouns as case, skipping any intervening determiners, prepositions, or numbers and attach determiners to immediately following nouns, adjectives, or pronouns with det.

MAP @cc (conj) - (Rela) ;
SETPARENT @cc TO (1* NPHead OR PPHead BARRIER PB) ;

Attach non-relative conjunctions to a following NPHead or PPHead (any noun not already attached to another noun) in the same phrase.

MAP @conj NPHead + HasConj + (/ˆ(ph\d+)$/r)
IF (-1* NPHead + (VSTR:$1)) ;
SETPARENT NPHead + @conj + (/ˆ(ph\d+)$/r)
TO (-1* NPHead - @appos - @conj + (VSTR:$1)) ;

In an NPHead has coordinating conjunction dependent and there is a preceding NPHead with the same phrase id, attach it to that as conj.

SETPARENT (/ˆ(c\d+)$/r) - CR TO (0* (VSTR:$1) + CR) ;

Attach the head of each phrase to the phrase with the same clause id which has the highest-precedence function label. In this case, the phrases are (from right to left) Time (temporal oblique), Pred (predicative verb), Subj (subject), and Objc (object). Since the verb is not a copula, it was marked as the clause root (CR) in a preprocessing step.

MAP @nsubj (Subj) - CR IF (p CR LINK NEGATE c @nsubj) ;
MAP @obj (Objc) - CR IF (p CR LINK NEGATE c @obj) ;
LIST OblIsh = Time Loca Modi Adju ;
MAP @obl OblIsh - CR IF (p CR) ;

Having attached various phrases within the clause, assign relations based on their function labels: Subj is nsubj, Objc is obj, and most other noun phrase functions are obl. The subject and object rules also check that there is at most one of each and other rules are applied if this is not the case.

MAP @root CR IF (NOT -1* CR - @advcl - @acl) ;
SETPARENT @root TO (00 (*) ) ;

Make a clause root the root of the sentence if there is no full clause preceding it.

MAP @root CR IF (NOT -1* CR - @advcl - @acl) ;
SETPARENT @root TO (00 (*) ) ;

Make a clause root the root of the sentence if there is no full clause preceding it.

Figure 2: The process of parsing Genesis 1:1

/bereshit bara’ 'elohim 'et hashamayim ve’et ha’arets/ “In the beginning, God created the heavens and the earth.” PB represents a boundary between phrases. The corresponding constituency tree is given in Figure 1.
### Rule Type | Count | Example
--- | --- | ---
SETPARENT | 121 | SETPARENT @cc (NOT p (+)) TO (l (subs @conj))

Set the head of a word with relation cc that does not already have a head to the immediately following word if that word has the part-of-speech tag subs (BHSA tag for common nouns) and the relation conj.

MAP | 114 | MAP @obj (prn) IF (-1 (verb))

Set the relation of a pronominal suffix to obj if the preceding word is a verb.

ADD | 26 | ADD HasConj NPHead IF (NOT 0 HasConj) (c @cc)

If a word is marked as the head of a noun phrase (label NPHead) and has a dependent which is a coordinating conjunction (relation cc), then add the label HasConj.

SUBSTITUTE | 37 | SUBSTITUTE (art) (conj retag:art) (CP Rela)

If a word is tagged as a determiner in a conjunction phrase (CP) which is functioning as a relativizer (Rela), then change its part-of-speech tag from art to conj (conjunction).

| Rule Type | Count | Example |
--- | --- | ---

Table 4: Examples of the main types of Constraint Grammar rules used in the parser. SETPARENT creates a dependency arc, MAP assigns a relation, ADD assigns helper labels, and SUBSTITUTE changes annotations decisions in the BHSA corpus.

notations which correspond to features described either in the guidelines of the UD project in general or of the Modern Hebrew treebank in particular. Every time the rules are changed, all sentences are re-parsed and compared against the previously verified versions to ensure that there have been no regressions. All the code involved in this process is available on Github under an open-source license.

#### 4. Annotation Decisions

The most significant annotation challenges we encountered involved participles, a marker for direct quotations, and an emphatic construction using infinitives.

### 4.1. Participial Relative Clauses

Like other Semitic languages, Ancient Hebrew nouns have a form known as ‘construct state’ which is used when combining them with other nouns. For example, compare (8) and (9).

(8) יְשֶׁבָּנְיָלִים

בָּנִים יִשָּׁרָאֵל

yesh ban-im le-yisra’el

exist son-PL to-Israel

“Israel had sons.”

(9) בָּנָיִים יִשָּׁרָאֵל

בָּנָיִים יִשָּׁרָאֵל

bn-e yišra’el son-PL.CNST Israel

“the sons of Israel”

In (9), the noun in construct state immediately precedes another noun, which determines its definiteness. Since only a definite article can be placed between two nouns in this construction, we follow the Modern Hebrew treebank (Tsarfaty, 2013; McDonald et al., 2013) in annotating this as a compound relation, with the first noun as the head. The equivalent construction in some other Semitic languages such as Akkadian (Lukkko et al., 2020) has a strictly genitive function and thus uses nmod:poss. We do not take the latter approach because the Hebrew construction is more general than possession but there are no morphosyntactic criteria that would distinguish possessive instances from non-possessive ones.

However, a problem then arises with participles, which can appear as either piece of a construct phrase, as in (10) or with an argument structure comparable to that of finite verbs as in (11).

(10) הוָאָדָה אֵבִי יִשָּׁרָאֵל

אָבְיִים יִדִּים הָאָדָה

hu’ hayah ‘avi

3SG.M be.PERF.P3.SG.M father.CNST

yoshev ‘ohel
dwell.PART.CNST tent

“He was the father of those who live in tents.”

(Genesis 4:20)
In (10), בָשָׁה /yoshev/ “dwell, inhabit” is a participle in a nominal compound construction, while in (11) לֶמְרוּ/hamakeh/ “strike” is followed by the definite direct object marker לֶהוֹר/le’mor/, a definitely verbal construction, though it does also have a definite article, suggesting a nominal interpretation.

We concluded that the approach most consistent with the UD guidelines was to treat participles as nominalized if they occur in construct state and have no verbal argument structure since in such cases the morphology and the syntax are both nominal. Conveniently, the BHSA marks such participles as part of the surrounding noun phrase rather than as a verb phrase in a separate clause. Thus we tag participles in the same phrase with NOUN and attach them with comp while other participles are tagged as VERB and usually attached with acl. In the latter case, if the participle has a definite article, this is retagged as a subordinating conjunction (SCONJ) and attached with the usual relation of mark.

4.2. Quotations

Direct quotations in Biblical Hebrew are frequently preceded by לֹא/le’mor/, which is both etymologically and in the BHSA an infinitive of “say” with the prepositional prefix ל/le/, which occurs in many constructions involving infinitives in addition to marking the dative on nouns and pronouns.

If the לֹא is taken as a verb, then the question arises of whether the quotation should depend on the infinitival speaking verb immediately before it or on the finite one earlier in the clause. There is also the question of how לֹא should relate to the finite verb. Other verbs in this form are usually either controlled clausal complements (xcomp) or purpose clauses (advcl).

On the other hand, לֹא is not required in the sentence and when it is absent, the quotation has to depend on the finite verb. For consistency with this case, the quotation could always be attached to the finite verb and לֹא could be attached to the quote if it is present. These two alternative trees are shown in Figure 3.

In the end we decided to follow the lead of the Coptic Scriptorium treebank (Zeldes and Abrams, 2018) and analyze לֹא as a subordinating conjunction which depends on the following quotation.

4.3. Infinitive Absolute

Biblical Hebrew has two verbal forms which are traditionanly called infinitives, the infinitive construct and the infinitive absolute (named on analogy to the construct and absolute states of nouns discussed in Section 4.1). The infinitive construct is used in a variety of dependent clause constructions while the less common infinitive absolute occurs primarily in a single emphatic construction.

The typical appearance of the infinitive absolute is immediately preceding a conjugated finite version of the same verb, such as in (12).

(12) נַשַׁר אֶת שָׁר יָרְשֵׁת עֲשָׂר נַכ/לָנִי/לֹא

Here the infinitive absolute of the verb נַשַׁר /a’sar/ “tithe, give a tenth” emphasizes the immediately following conjugated form נַשַׁר /a’serenu/ “I will give a tenth of it”.

The equivalent construction in Arabic takes accusative marking, suggesting that this should be analyzed as a nominal form, similarly to what happens in (13).

(13) הָבֵה נָלֵמָה לָמִים

Here the verb נָלֵמָה /nilbenah/ “we will make bricks” takes as a direct object a noun derived from the same consonantal root לָמִים /leven-im/ “bricks”.

Figure 3: Two potential approaches according to the UD guidelines to analyzing the quotation marker לֶמְרוּ in the sentence לֶמְרוּ אֶלֹהִים בְּרָאשָׁה "God blessed them saying ‘Be fruitful and multiply!’” (Genesis 1:22). The relation parataxis would be another possibility, if the verb for “bless” were not analyzed as a verb which introduces a quotation. (Internal structure of multi-word tokens is not shown.)
### Table 5: Size of the texts included in the Ancient Hebrew treebank.

| Book   | Trees | Words    | Tokens  |
|--------|-------|----------|---------|
| Genesis | 1,494 | 36,741   | 25,282  |
| Ruth   | 85    | 2,294    | 1564    |
| **Total:** | 1,579 | 39,035   | 26,846  |

### Table 6: The 12 morphological feature categories included in the Ancient Hebrew treebank along with how many distinct values they have and how many words they appear on.

| Feature        | Values | Occurrences |
|----------------|--------|-------------|
| Aspect         | 2      | 1,965       |
| Gender         | 2      | 16,621      |
| HebBinyan      | 6      | 5,301       |
| Mood           | 2      | 4,532       |
| Number         | 3      | 20,018      |
| NumType        | 1      | 477         |
| Person         | 3      | 8,526       |
| Polarity       | 1      | 277         |
| PronType       | 3      | 4,300       |
| Tense          | 1      | 2,244       |
| VerbForm       | 3      | 5,347       |
| Voice          | 1      | 49          |

### Table 7: Results of training a parser to determine whether the annotations were consistent enough to be memorized by a model.

| Metric  | Score |
|---------|-------|
| UAS     | 96.27 |
| LAS     | 94.65 |

### Table 8: Occurrences of error types in the parser output.

| Error Type                        | Occurrences |
|-----------------------------------|-------------|
| Attachment                        | 830         |
| Verb Argument Identification      | 424         |
| NP vs Clausal Modifier            | 159         |
| Clause Type                       | 144         |
| Ellipsis                          | 75          |
| NP Structure                      | 57          |
| Other                             | 399         |

However, this causes problems with transitive verbs since the UD guidelines disallow having multiple words marked as objects (obj) of the same verb. Another option would be to mark these as iobj (indirect object), though the guidelines for iobj are mainly focused on recipients. In addition, the fact that this construction is entirely optional argues against using the core argument relations, which then suggests making them obliques (obl) instead.

We posed this question to the broader UD project and as of this writing that discussion has yet to reach a consensus. As a temporary solution, we have attached the infinitive absolute to the following verb with advmod and correspondingly tagged them as ADV, which will be easy to update once the appropriate UD standard has been established.

### 5. Treebank Statistics

For this study we have parsed the books of Genesis and Ruth. Statistics about the texts can be found in Table 5. In addition, nouns, verbs, adjectives, and pronouns all have morphological annotations directly converted from the underlying corpus, the distribution of which is summarized in Table 6. Validating the output of the conversion process was done entirely by the first author, making it impossible

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5 The discussion can be found at https://github.com/UniversalDependencies/docs/issues/832

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### 6. Concluding Remarks

In this paper we presented our approach to semi-automatically annotating an Ancient Hebrew treebank and discussed some of the difficulties involved in applying the UD guidelines to a new language. The rule-based parser developed in this paper has been successfully applied to over 1500 sentences containing about 39000 words. It is thus likely that it can be applied with minimal adjustments to the remaining books of the Hebrew Scriptures, especially those from a similar time period and in a similar genre (narrative). The treebank will be released as Ancient Hebrew-PTNK in UD version 2.10.

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