

Semantic Analysis of Image-Based Learner Sentences

Levi King
Indiana University

August 6, 2021

Background & Motivation

- ▶ Most intelligent computer-assisted language learning (ICALL) applications (*Rosetta Stone*, *Duo Lingo*, etc.) rely on outdated, ineffective methods:
 - ▶ rote memorization & grammatical error detection; menu-based vs. free input;
 - ▶ “*engineering first*”: not informed by second language acquisition (SLA), pedagogy, psychometrics
- ▶ SLA research → communicative & task based learning

How can we bridge this gap between ICALL and SLA researchers?

- ▶ My vision: open source app; transparent; pipeline of existing tools;
- ▶ teachers create new games/stories by adding visual prompts and crowdsourcing native speaker (NS) responses;
- ▶ trains NS model to evaluate non-native speaker (NNS) responses

Research Questions

- RQ1. Are the responses of L2 English learners sufficiently similar to those of NSs to allow automatic evaluation based on a collection of NS responses? In other words, do learners demonstrate significant overlap with native-like usage in a picture description task (PDT) setting?
- RQ2. In the constrained communicative environment of a PDT, what are appropriate response and model representations for the purpose of providing meaning-oriented feedback or evaluation? In other words, which linguistic components are crucial and which are superfluous?
- RQ3. What kinds of existing NLP tools and language resources can be integrated to form a content analysis system for open response language learning tasks?

Research Questions

- RQ4. How do “bag-of-words” and “bag-of-dependencies” approaches compare in terms of performance? Is a bag-of-words approach alone adequate for our needs?
- RQ5. Can the accuracy of the system be improved by the inclusion of semantic information from tools like semantic role labelers, WordNet, or word and sentence embeddings?
- RQ6. What is the annotation scheme for this task and can the system perform within the range of human performance? Relatedly, what does it mean for a response to be *appropriate* and how can this be captured with annotation?

BACKUP: Pilot study: Data


	Response (L1)
	He is droning his wife pitcher. (Ar)
	The artist is drawing a pretty women. (Ch)
	The artist is painting a portrait of a lady. (En)
	The painter is painting a woman's paint. (Sp)

Figure: Example item from the pilot study showing responses from native speakers of Arabic (Ar), Chinese (Ch), English (En) and Spanish (Sp).

- ▶ 10 (transitive) PDT items \times 53 participants = 530 responses;
 - ▶ 14 NSs (grad students), 39 NNSs (ESL students);
- ▶ Annotation: *Given the prompt, would the response be acceptable to most English speakers? Acceptable/unacceptable*
 - ▶ 1 annotator (me)

BACKUP: Pilot study: Processing

First approach: **Rule-based** triple extraction and matching

Dependency parser \rightarrow lemmatizer $\rightarrow V(S,O)$ extraction rules;

Compare NNS $V(S,O)$ & NS $V(S,O)$ list \rightarrow covered / not covered;

- ▶ Dependency-based
 - ▶ Captures aspects of form and meaning;
 - ▶ Subjects, objects, verbs clearly labeled;
- ▶ $V(S,O)$ extraction
 - ▶ Decision tree based on dependency indexing & labels, POS;
 - ▶ Custom for my transitive PDT, not generalizable, not robust;
 - ▶ $\approx 92\%$ accurate, $\approx 8\%$ extraction errors;
- ▶ Overall accuracy: 58.9%
 - ▶ I.e., *Acceptable* covered, *unacceptable* not covered;

BACKUP: Pilot study: Processing

Second approach: **Semantic similarity** scoring

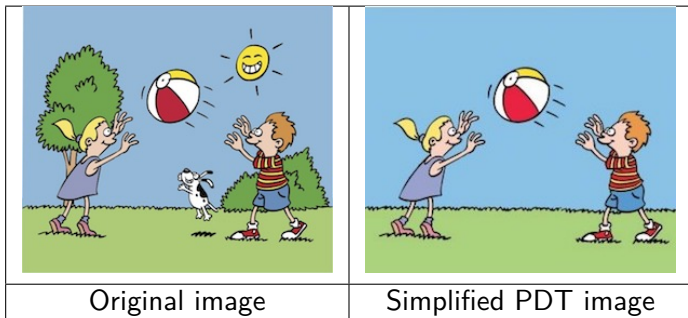
Dependency parser → lemmatizer → term frequency-inverse document frequency (tf-idf; “term” = lemmatized dependency);

NNS response score = cosine distance of NS and NNS tf-idf scores;

- ▶ tf-idf: Score dependencies according to importance;
- ▶ Vectorize & Score
 - ▶ Get *sorted union set* of NS and NNS dependencies;
 - ▶ NNS vector: Replace deps with their **NNS** tf-idf scores;
 - ▶ NS vector: Replace deps with their **NS** tf-idf scores;
 - ▶ Response score = *cosine distance* for NNS & NS vectors;
- ▶ Rank by scores & calculate Mean Average Precision (MAP);
 - ▶ MAP *acceptable* responses: $\approx 51\%$
- ▶ Process is more robust & generalizable;
- ▶ Dataset (especially NS models) and annotation are weak;

BACKUP, combine 1/4; Main study: Data collection



PDT with very simple images only:



Intended to focus participants' attention on the main action

BACKUP, combine 2/4; Main study: Data collection

Two PDT prompt versions:

Targeted	Untargeted
	
<i>What is the baby doing?</i>	<i>What is happening?</i>

Intended for exploring the specificity needed for my approach

BACKUP, combine 3/4; Main study: Data collection

The pilot study *rake* problem:

- ▶ For one PDT item, 100% of NS used the verb *rake*;
- ▶ NNS responses without *rake* are penalized;



NNS Responses

The gardener is *cleaning* the street.

a man *removing* the tree leafs.




The man is *sweeping* the floor.

A man is *gathering* lots of leafs.

- ▶ I address this by asking NSs for two non-identical responses.

BACKUP, combine 4/4; Main study: Data collection

3 verb types:

10 intransitive items	10 transitive items	10 ditransitive items
		
What is the girl doing?	What is the boy doing?	What is the girl doing?

Intended for exploring whether my approach can generalize to a broader range of sentence types

Main study: Data collection

499 participants, 13,533 responses:

- ▶ 141 NNSs (ELIP at IU), 4,290 responses;
 - ▶ 125 Mandarin, 4 Korean, 3 Burmese, 2 Hindi; 1 each: Arabic, Indonesian, German, Gujarati, Spanish, Thai, Vietnamese;
- ▶ 358 NSs, 9,243 responses:
 - ▶ 329 crowdsourced, purchased via SurveyMonkey;
 - ▶ 7,960 responses;
 - ▶ 29 familiar, unpaid colleagues;
 - ▶ 1,283 responses;

Annotation features

First iteration: **accuracy (A)** & **native-likeness (NL)**

- ▶ **2:** +A, +NL > **1:** +A, -NL > **0:** -A, -NL
- ▶ Not operationalizable: e.g., response is accurate w.r.t. prompt but adds unverifiable details; is this still *accurate*?
- ▶ Not *reliable*, not *valid*;

Several iterations later, 5 binary features:

- ▶ **CORE EVENT:** Does response capture main action?
- ▶ **ANSWERHOOD:** Does response directly answer prompt?
- ▶ **GRAMMATICALITY:** Is response free from grammar problems?
- ▶ **INTERPRETABILITY:** Does response evoke a clear mental image?
- ▶ **VERIFIABILITY:** Is all response info supported by image?

Annotation features


					
<i>What is the boy doing?</i>	C	A	G	I	V
He is eating food.	0	1	1	1	1
he eating pizza.	1	1	0	1	1
The boy is smiling pizza.	0	1	0	0	0
He may get fat eating.	0	0	1	1	0

Table: Annotated for five features: Core event (C), Answerhood (A), Grammaticality (G), Interpretability (I) and Verifiability (V).

Annotation features

Inter-rater reliability for two annotators and 10% of the dataset:
yes annotations for Annotator 1 (note skewedness), expected
chance agreement (*Chance*), actual observed agreement
(*Observed*) and Cohen's kappa (*Kappa*)

Set	A1Yes	Chance	Observed	Kappa
Core Event	0.733	0.601	0.923	0.808
Answerhood	0.834	0.721	0.982	0.936
Grammaticality	0.861	0.768	0.960	0.827
Interpretability	0.818	0.682	0.919	0.744
Verifiability	0.845	0.719	0.968	0.884
Intransitive	0.863	0.758	0.978	0.910
Transitive	0.780	0.653	0.949	0.853
Ditransitive	0.812	0.678	0.924	0.764

Evaluating performance

Problem: My system scores are between 0 and 1, but annotation is 5 binary scores. How can I evaluate system performance?

I need **benchmark rankings** for the NNS test set.

Feature-level performance:

- ▶ **MAP** to see how system rankings predict **individual features**;
 - ▶ Compare with? Some *holistic benchmark ranking* MAP;

Holistic performance (response quality):

- ▶ **Spearman** rank correlation: Compare system rankings with some *holistic benchmark ranking*;

Solution: Determine feature weights and apply to annotations to obtain benchmark holistic scores and then rankings.

BACKUP: Weighting features

Raters perform holistic preference test (blind to annotations)

<i>What is the boy doing?</i>	Pref?	Core	Ansr	Gram	Intrp	Verif
He is eating food.	yes	0	1	1	1	1
He may get fat eating.	no	0	0	1	1	0
He is hungry.	no	0	0	1	0	1
the boy is eating pizza	yes	1	1	1	1	1
The child is about to eat pizza.	yes	1	0	1	1	1
he eating.	no	0	1	0	1	1
Totals preferred responses		2	2	3	3	3
Totals dispreferred responses		0	1	2	2	2
Net preferred (pref - dispref)		2	1	1	1	1
Feature weight		.333	.167	.167	.167	.167
*Real feature weight		.365	.093	.055	.224	.263

Weighting features

Annotators performed a preference task for pairs of responses.

Feature weights were derived according to how frequently each feature is “yes” among preferred responses.

Core	Answr	Gramm	Interp	Verif
.365	.093	.055	.224	.263

Preferences are reliable:

Agreement for two annotators on a sample of 300 response pairs:

Chance Agree	Observed Agree	Cohen's Kappa
0.621	0.883 (265/300)	0.692

Benchmark rankings

- ▶ Apply feature weights for weighted annotation scores (WAS);
- ▶ Rank NNS test set by WAS for weighted annotation ranking (WAR);

<i>What is happening?</i>	C	A	G	I	V	WAS	WAR
The boy is eating pizza	0.365	0.093	0.055	0.224	0.263	1.000	1
Child is eating pizza	0.365	0.093	0.000	0.224	0.263	0.945	2
Tommy is eating pizza	0.365	0.093	0.055	0.224	0.000	0.737	3
The boy's eating his favorite food	0.000	0.093	0.055	0.000	0.000	0.513	4
Pizza is this boy's favorite food	0.000	0.000	0.055	0.000	0.000	0.055	5

SBERT for comparison

I also use SBERT for comparing my system's performance.

- ▶ State-of-the-art sentence embeddings for semantic textual similarity.
- ▶ Replaces dependency parser + lemmatizer + tf-idf cosine pipeline.
- ▶ Provides distance between NNS response and NS model.

System configuration

Optimizing means finding the best system settings:

- ▶ **Transitivity:** intransitive, transitive, ditransitive;
- ▶ **Targeting:**
 - ▶ targeted: *What is <the subject> doing?*
 - ▶ untargeted: *What is happening?*
- ▶ **Familiarity:** familiar, crowdsourced
- ▶ **Primacy:**
 - ▶ primary: NS model contains only 1st responses;
 - ▶ mixed: NS model: 1st & 2nd responses (50-50);
- ▶ **Term Representation:**
 - ▶ ldh: label-dependent-head; i.e., labeled dependencies;
 - ▶ xdh: dependent-head; i.e., unlabeled dependencies;
 - ▶ xdx: dependent only; cf. *bag of words*;
 - ▶ Does not apply to SBERT (operates on plain text);

BACKUP: System configuration

All parameters or variables and their settings:

Transitivity	Targeting	Familiarity	Primacy	Term Rep.
intransitive	targeted	familiar	primary	ldh
transitive	untargeted	crowdsourced	mixed	x dh
ditransitive				x dx

A **system configuration** combines one setting from each column.

If particular settings correlate highly with item characteristics (intransitive / transitive / ditransitive; response complexity), I can optimize the system for new items.

Sampling data

NNS test sets:

- ▶ All experiments rank the same randomly sampled NNS test sets;
- ▶ 70 responses per PDT item (max available for NNS data);
 - ▶ 70 targeted, 70 untargeted

NS models:

- ▶ 14-response models (max available for familiar data);
 - ▶ I.e., I compare 14-response familiar models and 14-response crowdsourced models;
- ▶ 50-response models (max available for crowdsourced data);

Sampling data: Complexity

Standardized type-to-token ratio (STTR) for the response samples.
Tokens here are *dependencies*.

	n14		n50	n70
	Fam	Crd	Crd	NNS
Intrans	0.55	0.52	0.53	0.39
Trans	0.56	0.58	0.58	0.51
Ditrans	0.59	0.64	0.63	0.60
Target	0.54	0.53	0.54	0.48
Untarg	0.61	0.63	0.62	0.52
primary	N/A	0.51	0.52	0.50
mixed	0.57	0.65	0.64	N/A
xdx	0.36	0.42	0.42	0.36
x dh	0.65	0.66	0.66	0.57
l dh	0.66	0.66	0.67	0.57
Total	0.57	0.58	0.58	0.50

Annotation features experiments: CORE EVENT MAP

	Crowd NS model = 14					Crowd NS model = 50				
	ldh	x dh	x dx	WAR	SBERT	ldh	x dh	x dx	WAR	SBERT
Intr	0.85	0.85	0.85	0.86	0.83	0.85	0.85	0.85	0.86	0.83
Tran	0.73	0.73	0.72	0.74	0.70	0.73	0.73	0.72	0.74	0.70
Ditr	0.66	0.66	0.66	0.66	0.63	0.65	0.65	0.66	0.66	0.62
Targ	0.73	0.73	0.73	0.73	0.70	0.73	0.73	0.72	0.73	0.70
Untg	0.76	0.76	0.76	0.77	0.74	0.76	0.75	0.76	0.77	0.73
Prim	0.75	0.75	0.74	0.75	0.72	0.75	0.74	0.74	0.75	0.71
Mix	0.75	0.74	0.75	0.75	0.72	0.74	0.74	0.74	0.75	0.72
Total	0.75	0.75	0.74	0.75	0.72	0.75	0.74	0.74	0.75	0.72

- ▶ In all cases, ldh + 14NS is best;
- ▶ x dx becomes more competitive for larger model (50NS);
 - ▶ ditransitive, untargeted: responses to these are *least homogenous*—i.e., highest TTRs;
 - ▶ In general: ldh TTR > x dh TTR > x dx TTR

Annotation features experiments: CORE EVENT MAP

	Familiar NS model = 14					Crowd NS model = 14				
	ldh	x dh	x dx	WAR	SBERT	ldh	x dh	x dx	WAR	SBERT
Intr	0.85	0.85	0.86	0.86	0.83	0.85	0.85	0.84	0.86	0.83
Tran	0.74	0.73	0.72	0.74	0.70	0.73	0.73	0.72	0.74	0.70
Ditr	0.65	0.64	0.66	0.66	0.62	0.66	0.65	0.67	0.66	0.64
Targ	0.73	0.73	0.73	0.73	0.70	0.73	0.73	0.73	0.73	0.70
Untg	0.76	0.76	0.76	0.77	0.73	0.76	0.76	0.76	0.77	0.74
Total	0.75	0.74	0.75	0.75	0.72	0.75	0.74	0.75	0.75	0.72

- ▶ Totals: crowdsourced outperforms familiar (slightly);
- ▶ crowdsourced works best with ldh;
- ▶ familiar works best with xdx;

Annotation features experiments: MAP Results

For all 5 features, my system outperforms SBERT.

ANSWERHOOD, in *all* cases:

- ▶ `xdx > xdh > ldh`;
- ▶ Model size makes no difference;
- ▶ `familiar > crowdsourced`;

GRAMMATICALITY, in *most* cases:

- ▶ `xdx > xdh > ldh`;
- ▶ `familiar 14NS > crowd 14NS > crowd 50NS`;

Predicting ANSWERHOOD or GRAMMATICALITY is relatively simple; requires only small model and bag-of-words representation.

Annotation features experiments: MAP Results

INTERPRETABILITY:

- ▶ 14NS crowd > 14NS familiar > 50NS crowd;

VERIFIABILITY:

- ▶ 14NS crowd > 50NS crowd > 14NS familiar;
- ▶ Model size effect is most pronounced with untargeted & mixed;
 - ▶ Unconstrained settings; larger models have more noise;

For both INTERPRETABILITY & VERIFIABILITY:

- ▶ intransitives & ditransitives work best with xdx;
- ▶ transitives work best with ldh;
 - ▶ Why? Transitive responses are relatively homogenous;
Annotators relatively strict;

Holistic experiments

Holistic experiments use one set of 360 Spearman correlations:
targeting (2) \times primacy (2) \times term rep (3) \times items (30) = 360.
(Familiar vs. Crowd handled separately due to sparse data.)

Each experiment focuses on one variable, e.g., targeting:
Divide 360 into 180 targeted scores and 180 untargeted scores;
compare mean, median, etc.

SBERT uses plain text (no term rep), thus only 120 total.
(SBERT always wins over system.)

Holistic experiments: Transitivity

		intrans		trans		ditrans	
		Sys	SBERT	Sys	SBERT	Sys	SBERT
	count	120	40	120	40	120	40
14NS	mean	0.439	0.497	0.314	0.563	0.267	0.400
	median	0.416	0.479	0.304	0.555	0.276	0.444
50NS	mean	0.423	0.516	0.345	0.566	0.278	0.446
	median	0.426	0.517	0.331	0.561	0.286	0.471

- ▶ SBERT, regardless of model size: trans > intrans > ditrans;
- ▶ System, regardless of model size: intrans > trans > ditrans;
- ▶ More complex items (TTR) work best with larger models;
 - ▶ trans & ditrans: 50NS model is best;
 - ▶ intrans: 14NS gives best mean, 50NS gives best median;

Holistic experiments: Results

Targeting:

- ▶ `targeted > untargeted`
- ▶ `50NS models > 14NS models`
 - ▶ Model size effect is most pronounced for targeted

Familiarity (14NS models only):

- ▶ System: No discernible difference for familiar vs crowdsourced
- ▶ SBERT: `familiar > crowdsourced`
 - ▶ `NNS STTR < familiar STTR < crowdsourced STTR`

Holistic experiments: Results

Primacy:

- ▶ System: 14NS: primary < mixed (slight difference)
- ▶ System: 50NS: primary \approx mixed
- ▶ SBERT: primary > mixed
- ▶ System & SBERT: 50NS > 14NS
 - ▶ System: model size effect is greatest for primary

Term representation:

- ▶ SBERT: 50NS > 14NS
- ▶ System: for 1dh & xdh: 50NS > 14NS;
 - ▶ Model size effect is greater for 1dh
- ▶ System: for xdx: NS14 > NS50 (very slight)

Summary

NTS: one slide

Outlook

NTS: one slide

References

Sampling data: Response length

	n=14		n=50	n=70
	Fam	Crowd	Crowd	NNS
Intrans	5.5	4.9	4.9	4.9
Trans	6.9	6.3	6.2	6.7
Ditrans	7.8	7.2	7.2	8.3
Target	6.5	5.4	5.4	6.3
Untarg	6.9	6.8	6.8	6.9
primary	N/A	5.7	5.8	6.6
mixed	6.7	6.5	6.4	N/A
Total	6.7	6.1	6.1	6.6

Table: Comparing average response length (in words) for the samples used throughout this chapter as NS models and NNS test sets, in total and by parameter setting.