Modeling Children's Trajectory of Event Conceptualization Based on the Transitivity of Clauses

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Abstract

This paper models the number of event participants children represent based on the transitivity of clauses, using the Tolerance and Sufficiency Principles in evaluating whether children's changing hypotheses about clause-to-event-participant mappings in development can be captured. The model successfully simulates the developmental trajectory of how children conceptualize events based on verb transitivity in previous experimental works. It replicates the increased likelihood of representing one-role events (e.g., squatting) based on intransitive clauses (*They're going to moop*) only in 19-month-olds but not in 15- or 27-month-olds. The results supports the use of the Tolerance Principle for determining the threshold of rule-compatible verb items needed for the learner to generalize about clause-to-event inferences.

1 Introduction

Languages present rich syntactic cues to word meanings. Young children, especially infants, have been assumed to exploit these cues to infer the meanings of new verbs in a process referred to as syntactic bootstrapping (Landau & Gleitman, 1985). For instance, they expect there to be two participant roles (a doer and an undergoer) involved when a verb is used in a transitive clause (*he's going to moop her*), but they are unbiased towards either one role (both doers) or two roles (a doer and an undergoer) for a verb used in an intransitive clause (*They're going to moop*) (Arunachalam & Waxman, 2010).

This paper investigates whether the abovementioned two clause-to-event-participant mapping tendencies hold true across developmental stages and whether the presence of the mapping tendencies can be predicted by the Tolerance and Sufficiency Principles (cf. Yang, 2005): children's mapping hypotheses change given the number of transitivity-alternating verbs (e.g., *roll* can be transitive, *she rolls the ball*, or intransitive, *the ball rolls*).

The model in this paper assumes that the learner tracks the transitivity of different verb items and labels them as being either transitive or intransitive compared to chance level. In addition, the model registers the frequency of transitivity label shifting for each verb item and evaluate their hypotheses of clause-to-event mappings based on the threshold of generalization indicated by the Tolerance and Sufficiency Principles.

The model also recognizes noises in distribution for tracking verb transitivity. That is, the paper assumes that in their earliest stage of acquisition, infants track verb transitivity with mixed clause types, namely ones with a canonical word order (SVO; *she kicks **the ball***) and ones with a non-canonical word order (OSV; displaced object, as in ***what** did she kick*).

Transitive verbs used in OSV order, here referred to as the noise (*kick* appears intransitive in *what did she kick*), is realized in the English input as object *wh*-questions and object relative clauses. The idea that infants only isolate clauses with a displaced object from those with a canonical object follows from infant studies suggesting that 18-month-olds, not younger ones, recognize object *wh*-questions (Perkins, 2019).

2 Learners' Belief of Events Across Clauses

Children's belief of event representations has been studied mostly in an intermodal preferential looking paradigm (IPLP). That is, children first listened to dialogs where a novel verb like *blick* was used in either transitive (*she's blicking the baby*) or intransitive (*she's blicking*) clauses without event-related visual information and were then asked to find *blicking* upon the presentation of two videos side by side, one showing a one-role, non-causative action (e.g., squatting) and the other a two-role, causative action (e.g., hitting).

Looking at children's mappings from clause structures (number of nouns) to event representations (number of participant roles), a series of experiments have been conducted with children from different age groups and with modifications on the videos. While the two-role actions all involve two participants in a causative scene, the one-role actions differ across studies regarding whether they feature only one participant doing the action (Yuan & Fisher, 2009), two participants doing the same action (Arunachalam & Waxman, 2010), or one participant with another bystander (Yuan, Fisher, & Snedeker, 2012; Jin & Fisher, 2014).

Regardless of the kind of videos being used, previous studies have shown that 1) children reliably favor two participant roles (in a causative scene) upon hearing novel verbs used in a transitive clause, and 2) they do not reliably show a bias towards either non-causative (one-role) or causative (two-role) scenes when given an intransitive clause (Naigles & Kako, 1993; Yuan & Fisher, 2009). Specifically, for the three age groups that have been tested, namely 15-month-olds, 19-month-olds, and 27- to 28-month-olds, after hearing intransitive contexts, only 19-month-olds (Yuan et al.,

2012) have the tendency to look less to the two-role action and more to the one-role action compared to the control condition, while children from the other two age groups, either the 15-month-olds (Jin & Fisher, 2014) or the 27- to 28-month-olds (Arunachalam & Waxman, 2010; Yuan & Fisher, 2009), do not show preference towards either one-role or two-role actions.

How do children's belief of clause-to-event-participant mappings develop across stages? Why do children show increased bias for representing a one-role action upon hearing novel verbs in intransitive clauses only in the middle stage? To answer these questions, the next section introduces the model proposed for this paper.

3 Model

The present model aims to simulate learner's belief of clause-to-event-participant mappings at different stages of development and see whether the mapping tendencies identified in experimental works are derivable from children's linguistic input at different stages, under the Tolerance and Sufficiency Principles (explained in 3.2) as the learning mechanisms supporting children's dynamic learning assumptions. In this section, I elaborate the model by focusing on the input and the processes of inference involved.

3.1 Realistic Input

This model highlights three elements in the choice of input.

First, the input for the model comes from realistic infant-directed speech from the CHILDES database. This ensures that the model follows from the actual distribution of verbs.

Second, despite numerous verbs occurring in the input, the model zooms in on the top50 most frequent action verbs in the input for drawing inferences about clause-to-event mappings. Aside from focusing on verbs with observable participant roles that are suitable for the target of learning, this design of input also respects the modeling of inference procedures based on the most frequently updated source of verb occurrences.

Third, the model includes 500 iterations to allow for variabilities in the input structure. That is, the sequence of within-verb occurrences is randomized for each iteration, which creates the flexibility of the input required for interpreting the reliability of hypothesis over multiple trials.

3.2 Inference Processes

The model boils down to three steps of inference processes: register the transitivity of verbs, mark verbs of alternating transitivity, and evaluate the sufficiency of evidence for specific hypotheses about clause-to-event-participant mappings. Below explains all the processes involved.

First, to register verb transitivity, the model computes $\theta^{(v)}$, the probability of verb *v* being followed by a direct object. Verb *v* is registered as transitive if $\theta > 0.5$ (i.e. above chance level) and as intransitive if $\theta \leq 0.5$.

Second, the model marks verbs with alternating transitivity by tracking the percentage of transitivity alarm $k^{(v)}$ for a given verb *v*. A transitivity alarm occurs whenever the transitivity label runs counter to the expected number of participant roles associated with the verb *v*; that is, a verb linked to a causative event (with two participant roles) receives an alarm when $\theta \leq 0.5$, while a verb linked to a non-causative event (with one participant role) receives an alarm when $\theta > 0.5$.

Third, the sufficiency of evidence for deriving the final inferences is evaluated by the model. The model assumes that children decide on the reliability of a hypothesis based on explicit thresholds linked to the Tolerance and Sufficiency Principles. These principles are well-suited for evaluating whether hypotheses about certain properties of a language can be derived by tracking the lexical items in the input that are consistent with a generalization (Yang, 2005; Schuler, Yang, & Newport, 2016; Pearl, Ho, & Detrano, 2017).

With respect to step three, the model examines two hypotheses independently.

H1: Verbs linked to 1-role events are reliably intransitive.
H2: Verbs linked to 2-role events are reliably transitive.

For instance, regarding H2, for N items of verbs linked to two-role (causative) events, if the number of exclusively transitive verbs *P* (i.e. verbs with zero transitivity alarm $k^{(v)}$) exceeds the sufficiency threshold, namely that $P \geq N - N/\ln(N)$, the hypothesis is borne out; otherwise, the learner infers that verbs linked to 2-role events are not reliably transitive and thus can be intransitive, so upon hearing an intransitive verb, the learner thinks that the corresponding event could involve either one or two roles.

This threshold applies similarly to the testing of H1, where the model examines verbs linked to one-role (non-causative) events. If H1 is supported, the learner infers that a verb occurring in a transitive must entail or be linked to a 2-role event.

4 Data

The dataset for the model is composed of three different corpora of infant-directed speech from the CHILDES database corresponding to three different developmental stages (251,816 total words). The general information of the corpus details is given in Table 1.

Table 1: Selected corpora for three developmental stages

Corpus	#Child	Age	#Word	#Sentence
Soderstrom	2	0;6-1;0	89,185	24,228
Brown: Eve	1	1;6-2;3	42,242	10,450
Brown: Sarah	1	2;3-5;1	120,389	29,457

The CLAN program was used to search for the 'v|' tag in all the morphological tiers of all mother's utterances and generate a list of all the verbs that occur in the corpora (Scott & Fisher, 2009). For each of the three corpora, I selected the 50 most frequent action verbs from each of the lists. The excluded verbs were ditransitive verbs and non-action verbs, including mental state verbs (e.g. *think*), modals (e.g. *can*), auxiliaries (e.g. *have*), light verbs (e.g. *take*), perception verbs (e.g. *hear*), learn verbs (e.g. *learn*), aspectual verbs (e.g.

finish), measure verbs (e.g. *bet*), judgment verbs (e.g. *thank*), verbs of occurrence (e.g. *happen*), and psych-verbs (e.g. *relax*)

Table 2: Total counts and percentage transitive uses of the top50 action verbs in the Soderstrom corpus

Verb	Total	%DO
2-role verbs		
shake	17	100.00%
shut	13	100.00%
feed	11	100.00%
fix	17	94.12%
help	66	93.94%
knock	22	90.91%
wash	22	90.91%
use	20	90.00%
drop	35	88.57%
move	22	86.36%
turn	80	86.25%
change	21	85.71%
push	55	85.45%
grab	24	83.33%
touch	24	83.33%
catch	12	83.33%
throw	51	82.35%
kiss	18	77.78%
close	16	75.00%
bring	30	73.33%
hold	53	71.70%
call	12	66.67%
pick	34	64.71%
eat	73	64.38%
bang	42	64.29%
read	30	63.33%
2-role verbs		
open	24	62.50%
check	28	60.71%
wear	38	60.53%
reach	15	60.00%
bump	22	54.55%
pull	83	51.81%
roll	45	46.67%
build	30	43.33%
clean	19	42.11%
stop	23	39.13%
draw	16	31.25%
hang	19	15.79%
chew	58	15.52%
play	194	5.67%
1-role verbs		
spit	18	11.11%
run	11	9.09%
wait	13	7.69%
talk	16	6.25%
sit	114	3.51%
stand	39	2.56%
fall	49	0.00%
crawl	31	0.00%
cry	14	0.00%
wave	14	0.00%

(Levin, 1993).

For the coding of the utterances, an utterance containing the target verb was coded as transitive if the verb was followed immediately by a pronoun, a noun, a determiner, or a quantifier (e.g., *some*, *every*) and was coded as intransitive if the verb was followed immediately by a preposition, a conjunction (e.g., *and*), an adverb, a punctuation or a question mark. Instances of phrasal verbs were hand-corrected and treated as transitive utterances. Table 2 presents the verb lists derived through automated search of the Soderstrom corpus for their total occurrences (in all inflections) and transitive occurrences (i.e. where a direct object immediately follows the verb).

For the counts of total occurrences, SVO (*she broke the stick*) and OSV (*What did she break*) clauses were both included for the first stage, while only SVO clauses were included for the second and third stages (assuming children figured out OSVs are derived from SVOs). The filtering of clauses for the latter two stages is motivated by experimental works that show infants' sensitivity to object *wh*-questions (not requiring direct objects after transitive verbs) only after 18 months of age (Perkins, 2019). Table 3 presents the list of verbs that occur in both local (SVO) and non-local (OSV with a displaced O) positions for Stage 2 and 3.

Table 3: Verb counts in both local and non-local contexts

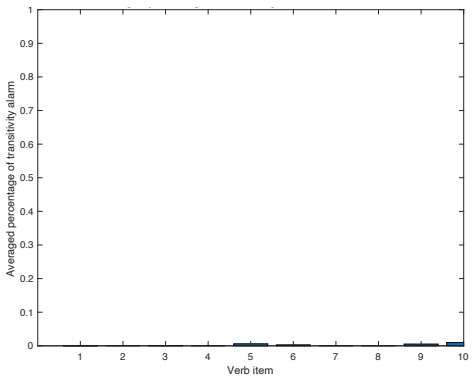
Verb	Non-local	Local
Stage 2		
bring	2	43
spill	1	21
cut	1	19
fold	1	12
use	1	11
wear	1	8
touch	1	13
drop	1	18
drink	1	44
eat	2	130
draw	2	14
hurt	3	7
read	1	86
sing	1	16
write	1	54
fall	1	15
Stage 3		
fix	1	67
buy	6	136
break	1	99
bring	3	117
use	2	45
turn	2	36
catch	1	25
draw	2	29
cut	1	48
wear	3	31
pick	1	57
eat	5	150
sing	6	108
write	1	91
work	3	37
sleep	1	31
play	8	117
sit	2	156
fall	1	67
cry	1	26

5 Results

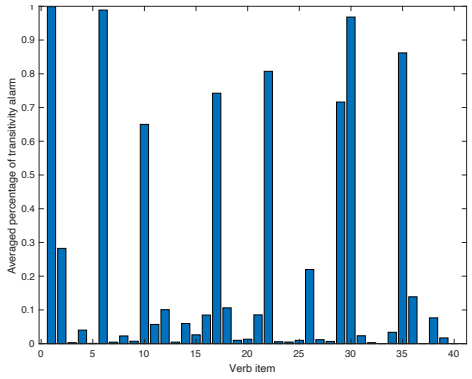
This section displays the modeling results in terms of the averaged percentage of transitivity alarm *k* for each verb and the probability of the two hypotheses given verbs in the respective categories.

5.1 Averaged Percentage of Transitivity Alarm

Figure 1 to 3 demonstrate the percentage of transitivity alarm averaged across 500 iterations, with (a) of verbs linked to 1-role (non-causative) events and (b) of verbs linked to 2-role (causative) events.

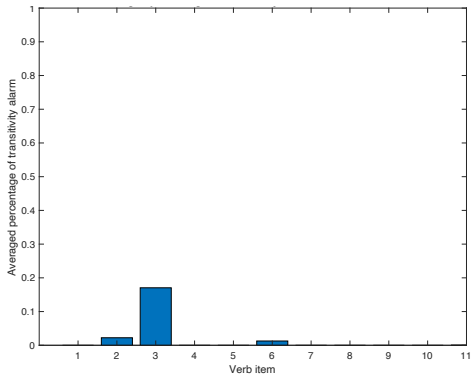


(a) verbs linked to 1-role events

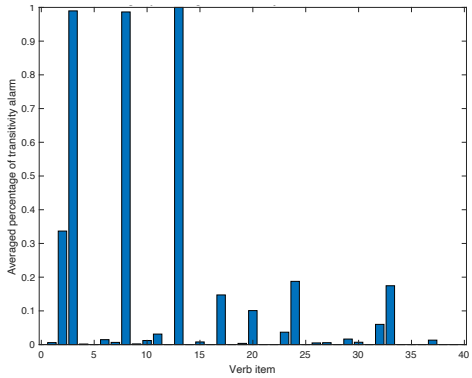


(b) verbs linked to 2-role events

Figure 1: Averaged percentage of transitivity alarm *k* in Stage 1

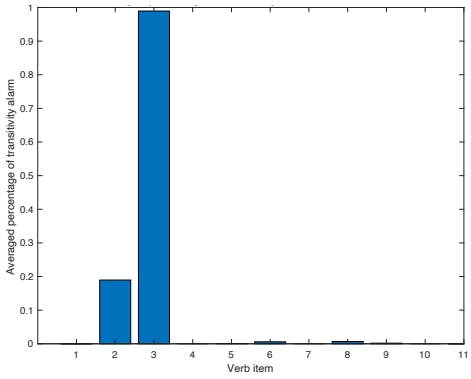


(a) verbs linked to 1-role events

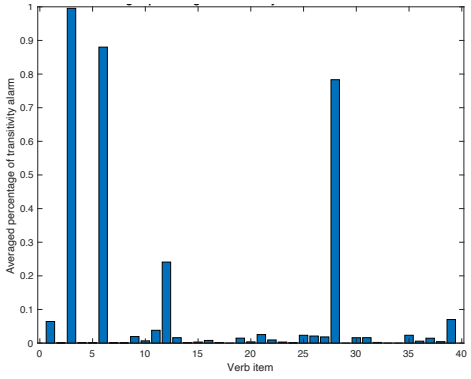


(b) verbs linked to 2-role events

Figure 2: Averaged percentage of transitivity alarm *k* in Stage 2



(a) verbs linked to 1-role events



(b) verbs linked to 2-role events

Figure 3: Averaged percentage of transitivity alarm *k* in Stage 3

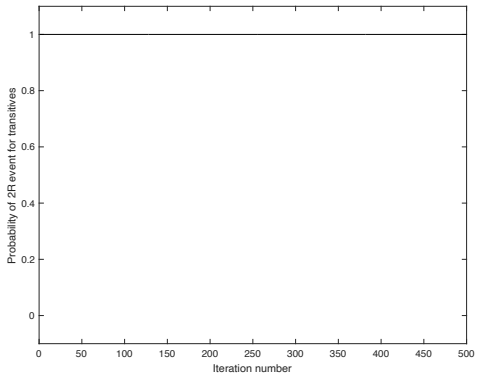
As the model did not filter OSV clauses (where objects are displaced) for Stage 1, numerous verbs can be observed to receive transitivity alarms in Stage 1 over half of the time (i.e., $k > 0.5$) across the iterations. However, such verbs with considerably high alarm rate are significantly fewer for Stage 2 and 3, where OSV clauses were removed from the utterances under analysis.

Moreover, verb items that receive relatively high averaged percentage of transitivity alarm (i.e., the bars that stand out in the figures, with *k* values above 0.1) are patently identified as alternating verbs (e.g., *pull*, *roll*, *hang*, *draw*) that can be either transitive or intransitive.

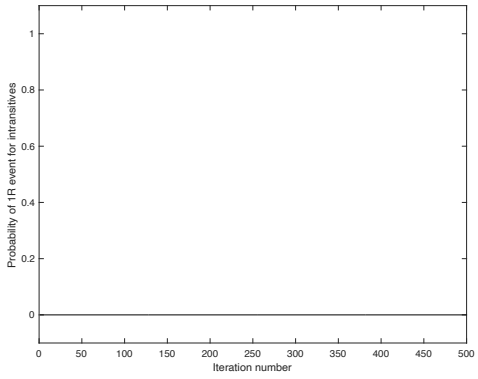
Generally, transitivity alarms are more frequent for verbs linked to 2-role events than for verbs linked to 1-role events.

5.2 Probability of the clause-to-event hypotheses

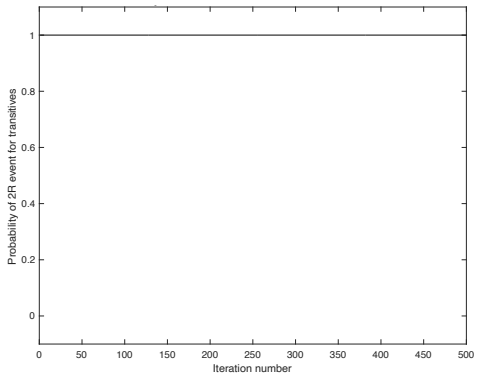
Figure 4 to 6 present the probability of the two hypotheses (a for H1 and b for H2) across 500 iterations.



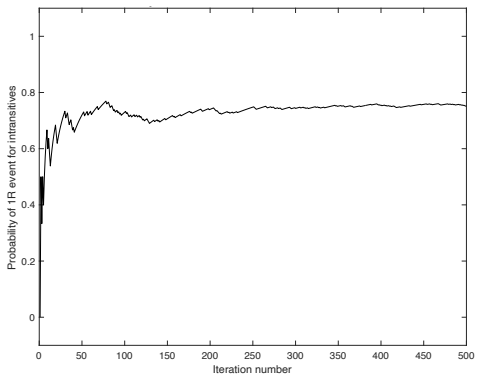
(a) H1: Verbs linked to 1-role events are reliably intransitive



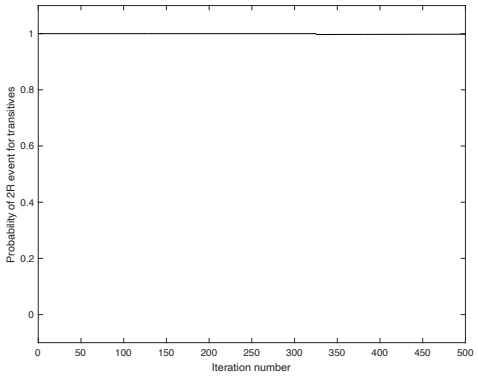
(b) H2: Verbs linked to 2-role events are reliably transitive
Figure 4: Probability of H1(a) and H2(b) in Stage 1



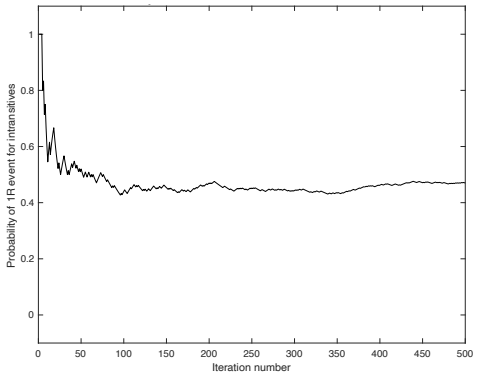
(a) H1: Verbs linked to 1-role events are reliably intransitive



(b) H2: Verbs linked to 2-role events are reliably transitive
Figure 5: Probability of H1(a) and H2(b) in Stage 2



(a) H1: Verbs linked to 1-role events are intransitive



(b) H2: Verbs linked to 2-role events are transitive
Figure 6: Probability of H1(a) and H2(b) in Stage 3

H1 is reliably confirmed across all stages, $p(\text{H1}) = 1$, while H2 only becomes increasingly plausible during Stage 2 (Fig5b), $p(\text{H2}) > 0.5$, but becomes less reliable during Stage 3 (Fig6b). The modeling results are consistent with what has been found in previous experimental studies.

In brief, the learner finds H1 reliable throughout developmental stages, but H2 only appears to be plausible and deepens in the middle stage but is eventually abandoned in the final stage.

5.3 Summary

The model successfully simulates the developmental dynamics of clause-to-event inferences that a young learner is likely to draw based on realistic infant-directed speech. The results replicate the trends observed in experimental studies, where 15- and 27-month-olds, not 19-month-olds, endorse that transitive verbs entail a causative 2-role event, while intransitive verbs do not entail a non-causative 1-role event. This indicates that the Tolerance and Sufficiency Principles underlying the learner's generalizations in this model predict the correct thresholds for deriving the inferences, suggesting that children's inference about clause-to-event mappings may follow from a lexicalist approach, where they generalize a rule only when exceptions to the rule are tolerable.

6 Discussions

The paper tests a model which exploits the Tolerance and Sufficiency Principles in modeling how children generalize hypotheses about clause-to-event mappings based on verbs and the events they are linked to in their observed input. The model correctly simulates the probability of two hypotheses, based on which it should infer that an event involves two roles if the verb describing it is transitive (following from H1), and it involves one role if the verb for it is intransitive (following from H2). The results successfully capture the behaviors observed in young human learners across stages of learning in terms of what event a novel verb might be mapped onto given its transitivity (Arunachalam & Waxman, 2010; Jin & Fisher, 2014; Yuan & Fisher, 2009; Yuan et al., 2012). That is, H1 is reliably borne out at all stages, but H2 only increases in likelihood during Stage 2, consistent with what was found with 19-month-olds.

The model sheds new light on how the structure of input can impact children's predictions about verb meanings. In the earliest stage or Stage 1 (i.e., before 18 months of age), learners receive an overwhelming amount of transitivity alarms (that certain verbs are sometimes transitive and sometimes intransitive) due to the presence of both alternating verbs and fake intransitives (*What did she kick*, with no surface direct object) in their input. As alternating verbs (like *roll*) are allowed in both transitive and intransitive clauses, if these verbs are common in verbs linked to 2-role, causative events, the one-role-if-intransitive inference (following from H2) will be penalized. In addition, learners can be misled by fake intransitives like *Look what they found for him to wear*, where the direct object (*what*) is fronted and displaced from their canonical positions after the verb (*wear*). That is, without adult-like representation of these derived structures, young learners may take this as the intransitive use of the verb, which increases the chances of learners receiving transitivity alarms. For Stage 2, learners start to filter out fake intransitives as they recognize structures involving non-local arguments (like direct objects), and due to the small number of alternating verbs that trigger transitivity alarms, the one-role-if-intransitive bias arises and deepens temporarily. This bias, however, mitigates to chance level, as the expansion of the input enables more alternating verbs to show their "true colors", penalizing the bias.

Furthermore, the model supports the possibility that the inferences children draw in learning verb meanings might be based on the list of verbs they have in storage. Specifically, the model addresses the learnability issue in learning from realistic input. Though the model in this paper only investigates how English-learning children might learn about clause-to-event mappings given English input, it is able to accommodate input from other languages in modeling whether children learning different languages are also able to derive such clause-to-event inferences and whether the results of modeling agree with behavioral studies probing for their inference of the corresponding event representations under different clausal contexts of verb use.

In a nutshell, the paper presents a learning model that derives inferences about clause-to-event mappings. The results align with previous experimental on how children conceptualize events from verb use and capture developmental differences in inference processes. By integrating the Tolerance and Sufficiency Principles, the model successfully simulates how rule generalization interacts with the number of observed exceptions. This approach offers insights into how children's language assumptions shift based on a threshold for efficient rule generalization.

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