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Iterated Learning for Deep Learning

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What is Iterated Learning (IL)?

Iterated learning is the process by which the behavior of the individual is acquired, by observing the behavior of another individual, **who acquired that behavior in the same way.**

It is used to model language evolution, to illustrate the effect of generation transmission on the linguistic structure.

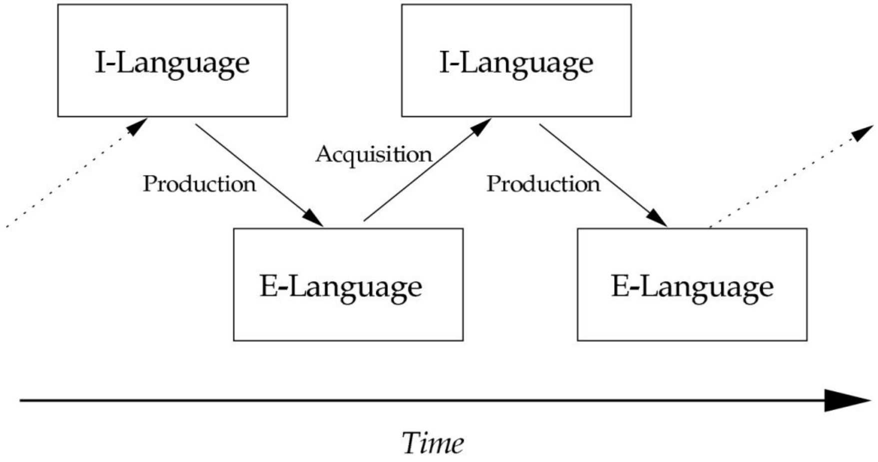
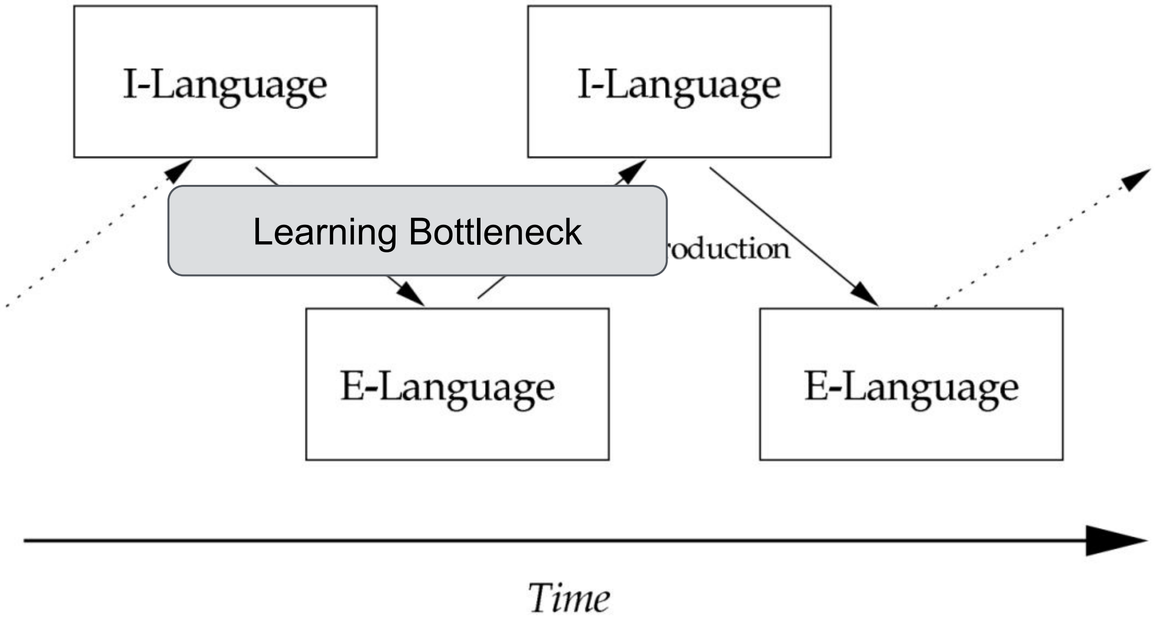


FIGURE 2.1 – Language transmission over time [32]. I-language is the internal language knowledge, while E-language is the external language like utterances.

Learning Bottleneck, aka *The Poverty of Stimulus*

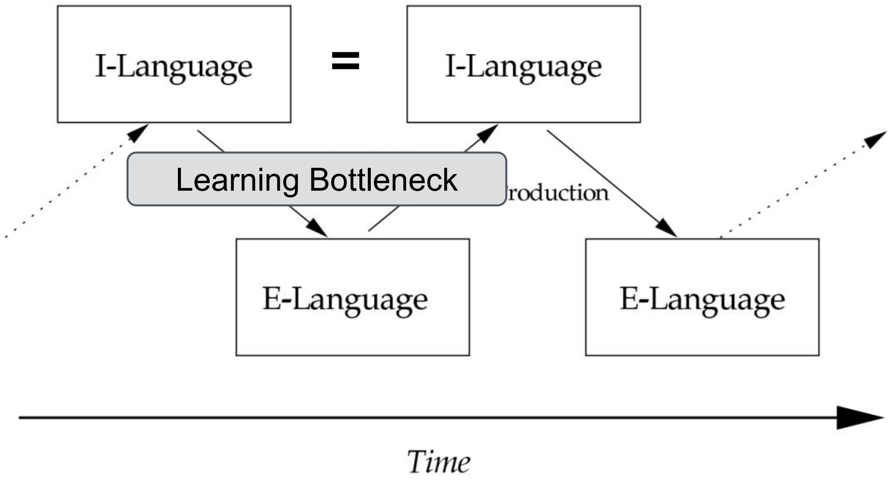
language learners must attempt to learn an **infinitely expressive linguistic system** on the basis of a relatively **small set of linguistic data**



IL leads to structured language

What can be derived if the I-language converge, meaning I-language of this generation is the same as I-language of previous language

I language should be **efficiently learnable** through limited number of example, and linguistic structure can be exploited to achieve that.



IL Principle: Linguistic structure is the solution found by the cultural evolution, in order for the language to survive the transmission with bottleneck.

IL leads to structured language

Kirby et al. 2004. Spontaneous Evolution of Linguistic Structure

Define the toy language to be represented by Definite Clause Grammar (DCG). Define a grammar induction algorithm. Define a “invention algorithm”. Each transmission only see a subset of meaning-message pairs.

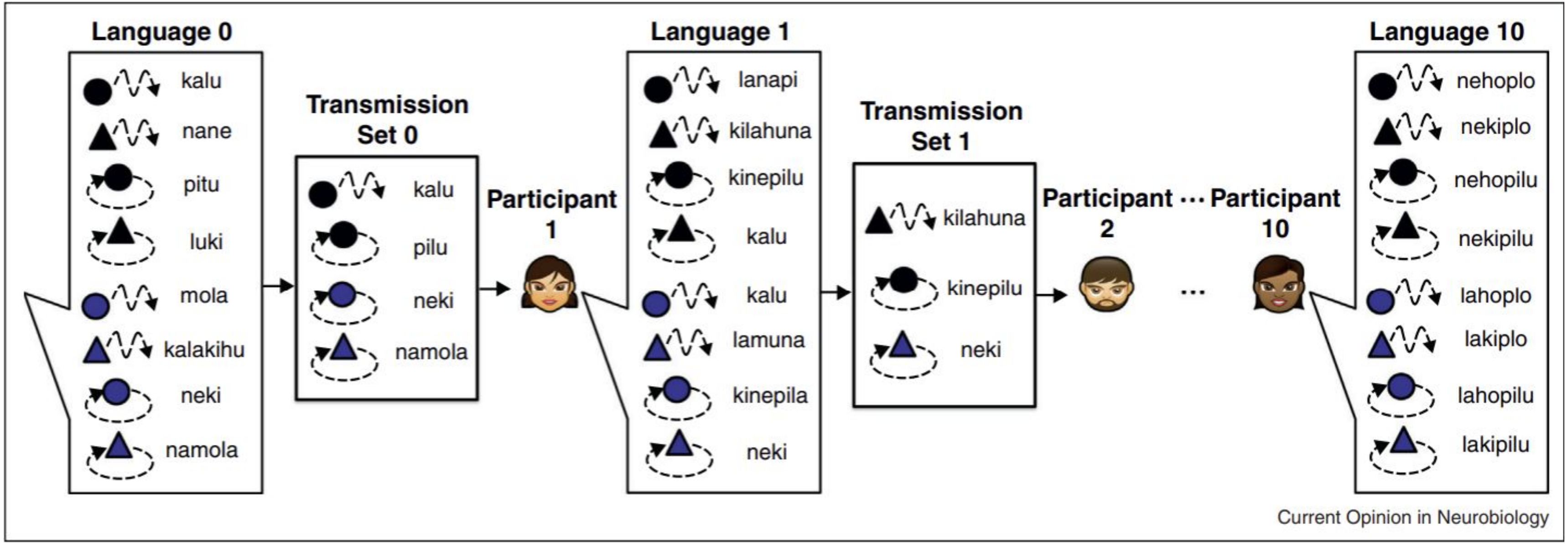
	a_0	a_1	a_2	a_3	a_4
b_0	s	sq	-	pnj	bjmjimsq
b_1	n	avvcf	jlimgttztp	pclcfho	kebae
b_2	ebhzyuyrl	afeeyykokz	-	pyuhu	hwrpg
b_3	rqbvtggjac	zrdleab	rxktywr	rbq	rkhxpbmx
b_4	drnlblwmo	afqjghvuw	gnbyq	pquztpi	wf

Initial

	a_0	a_1	a_2	a_3	a_4
b_0	wcpalsdqu	asdqu	hnqmxsdqu	gpmhmsdqu	bsdqu
b_1	wcpalp	ap	hnqmxp	gpmhmp	bp
b_2	wcpalihm	aihm	hnqmxihm	gpmhmihm	bihm
b_3	rkhxpwcpalmx	rkhxpamx	rkhxphnqmxmx	rkhxpgpmhmmx	rkhxpbmx
b_4	cswcpalbf	csabf	cshnqmxbf	csgpmhmbf	csbbf

Iteration 30

IL leads to structured language



(Kirby et al. 2008 PNAS)

Generation 0: Random string

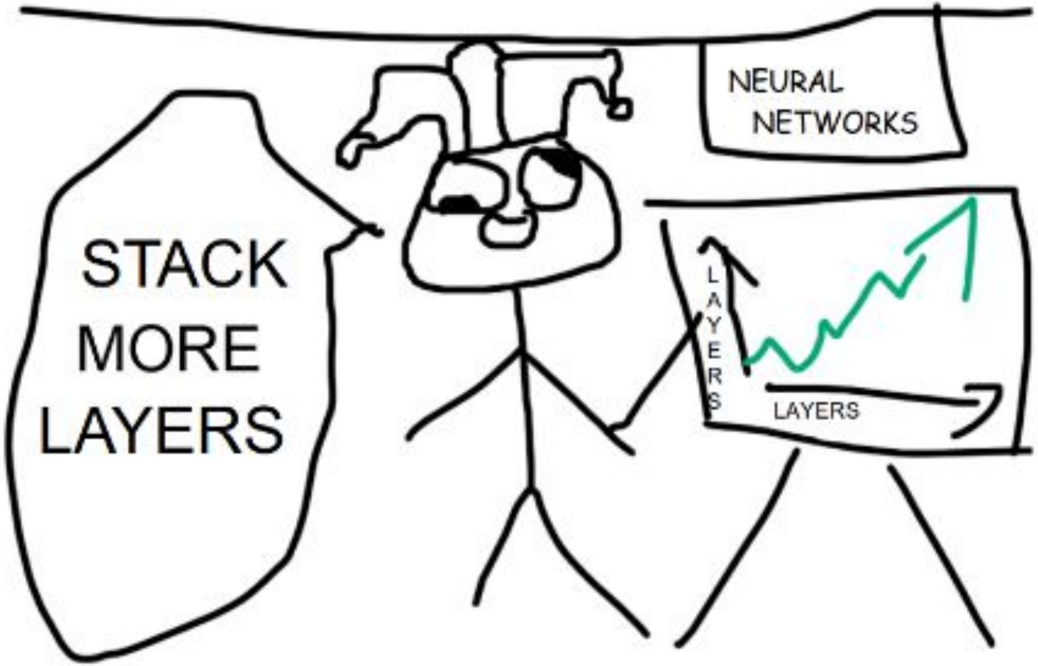
Generation 10: Somewhat compositional.

ne- for black, la- for blue

-ho- for circle, -ki- for triangle

-plo for bouncing, -pilu for looping

Time for some deep neural nets!



Neural Iterated Learning (Yi et al. ICLR2020)

The very first application of IL is in emergent communication, which is mainly modernizing the classic signalling games with deep neural networks.

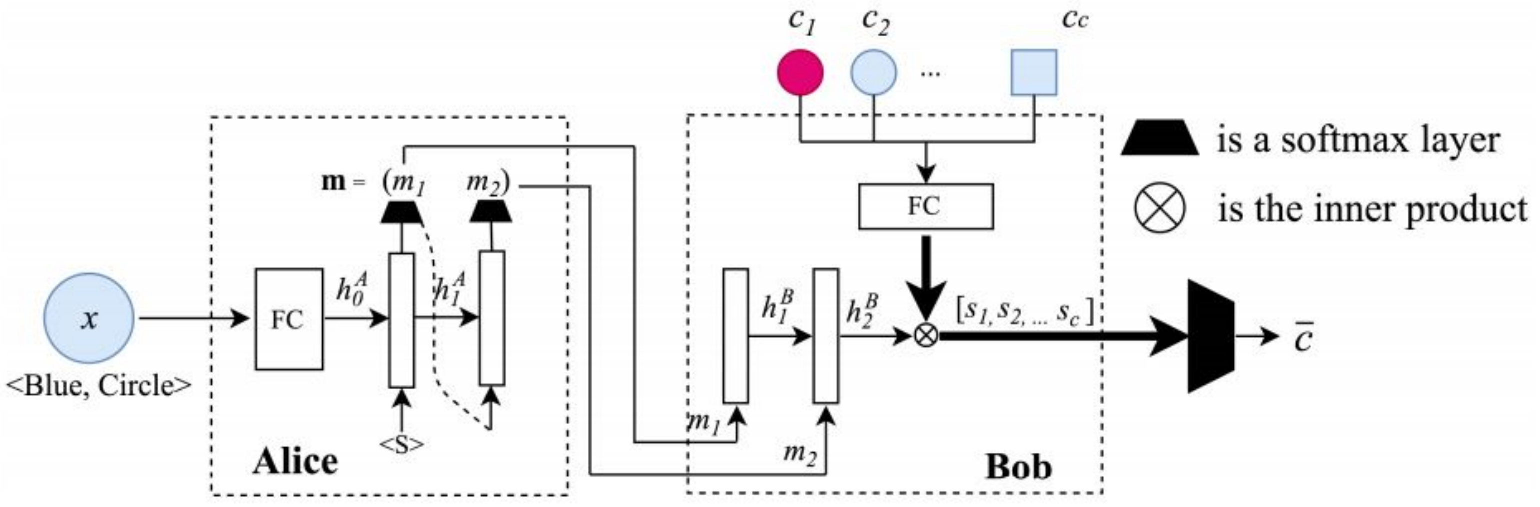
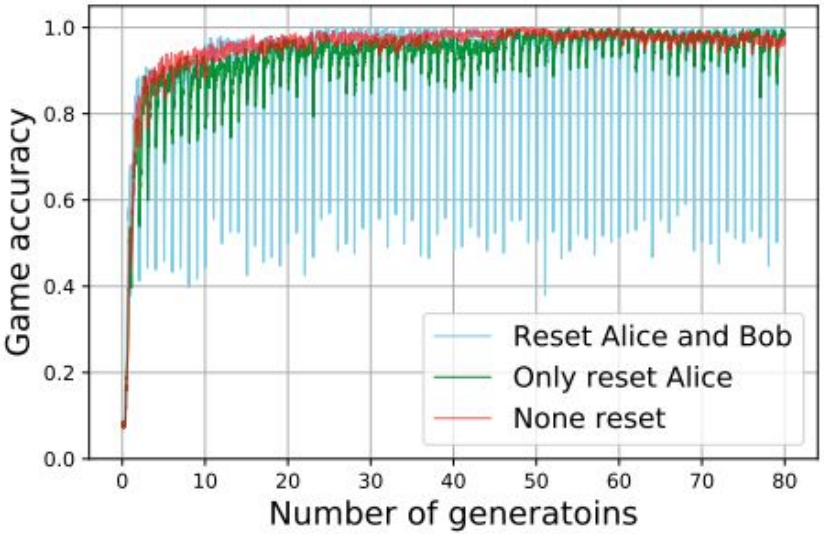


Figure 1: Referential communication game and architectures of the agents.

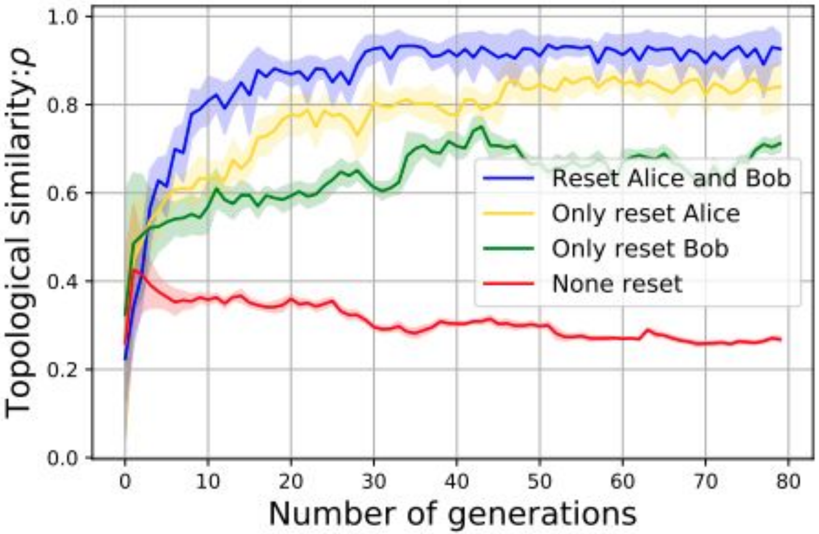
Neural Iterated Learning (Yi et al. ICLR2020)

Re-initialize Alice and Bob, get Alice$_i$ and Bob$_i$
// ======= Learning Phase =======
for $i_a = 1, 2, ..., I_a$ **do**
Randomly sample an example pair from D_i and use it to update Alice$_i$ with cross-entropy training
end for
for $i_b = 1, 2, ..., I_b$ **do**
Alice$_i$ generates message based on input objects
Bob$_i$ receives message and selects the target
Bob$_i$ updates its parameters if rewarded
end for
// ======= Interacting Phase =======
for $i_g = 1, 2, ..., I_g$ **do**
Alice$_i$ generates message based on input objects
Bob$_i$ receives message and selects the target
BOTH Alice$_i$ and Bob$_i$ update parameters if rewarded
end for
// ======= Transmitting Phase =======
for $i_s = 1, 2, ..., I_s$ **do**
Generate object-message pairs by feeding objects to Alice$_i$ and save them to data set D_{i+1}
end for

Neural Iterated Learning (Yi et al. ICLR2020)



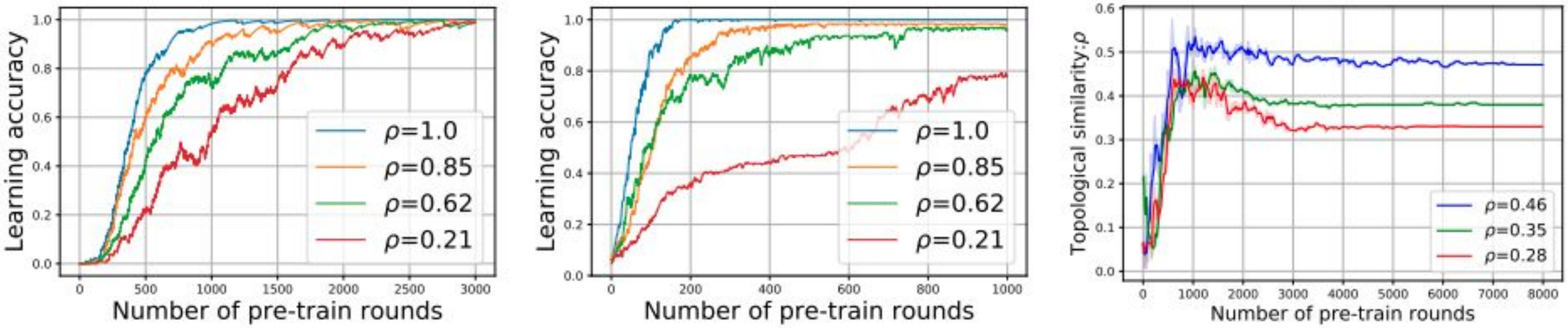
(a) Game performance



(b) Average ρ of emergent language

Topographical Similarity: The Spearman Correlation between object distance and message distance. Higher if similar meanings mapped to similar messages.

Neural Iterated Learning (Yi et al. ICLR2020)



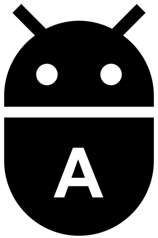
(a) Learning accuracy of Alice. (b) Learning accuracy of Bob. (c) Alice's ρ

Figure 2: Illustration of the learning speed of Alice and performance improving speed of Bob when pre-training is done with various languages of different topological similarities.

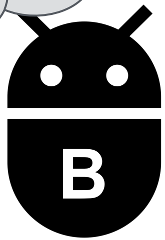
Countering Language Drift
(Lu et al. ICML2020, Lu et al. EMNLP2020)

For situated language learning, e.g. goal-oriented dialogue, we have the following pipeline: Supervised learning for pretraining, and finetune through interactions in a simulator.

Language Drift

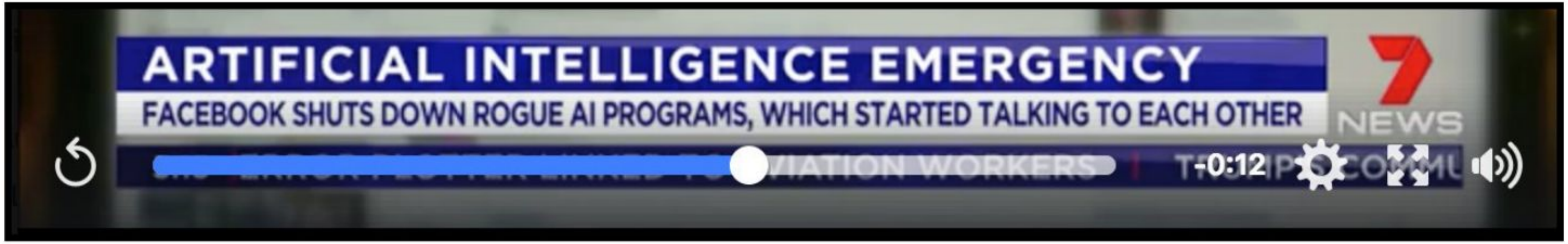


<Goal: Montreal, 7pm> A: I need a ticket to Paris. B: Wha time? A: pm 7 7 7 pm B: Deal. <Action: Book(Montreal, 7pm)>	<Goal: Toronto, 5am> A: I need need 5 am ticket B: Where A: Montreal B: Deal. <Action: Book(Toronto, 5am)>



Good Task Performance but **Poor Language**

Drift happens



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ADRIENNE LAFRANCE JUNE 15, 2017

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Experts have called the incident exciting but also incredibly scary

By James Beal and Andy Jehring
1st August 2017, 12:03 am | Updated: 2nd August 2017, 4:56 am

NEWS

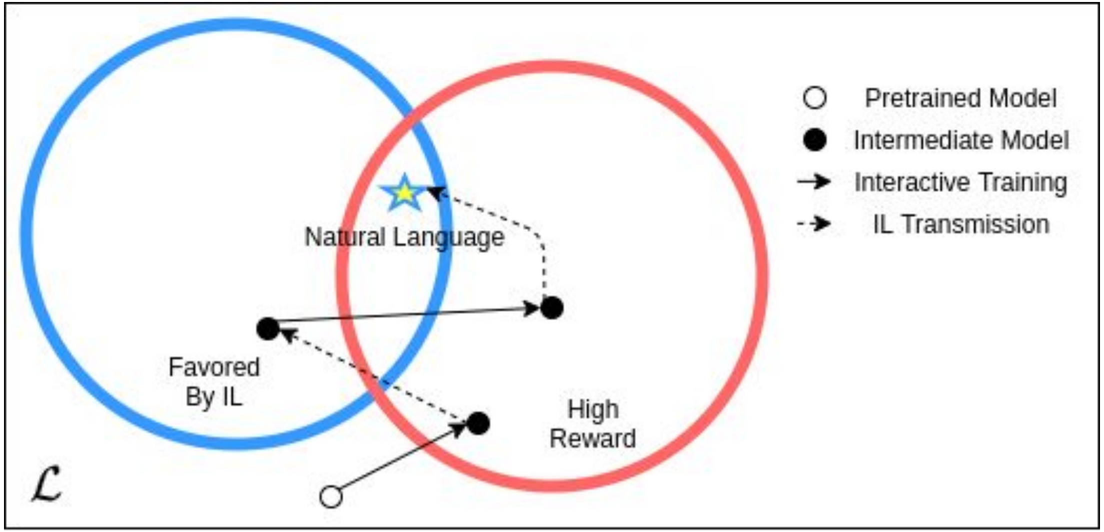
Facebook AI project halted after bots invent new language

By Malek Murison - August 1, 2017

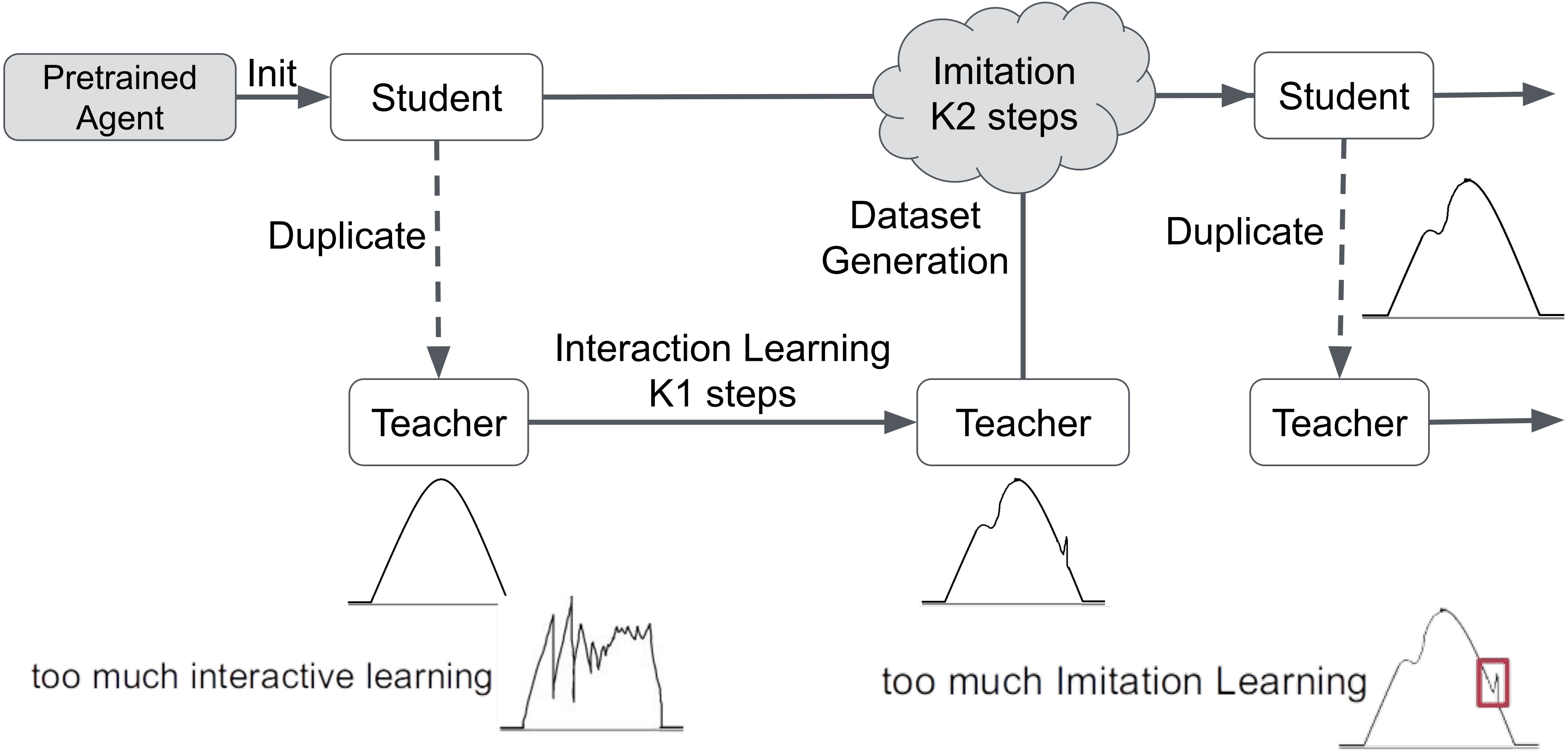
Iterated Learning to Counter Language Drift

Hypothesis: Language drift might exist in a form of **co-adaptation** and **over-specialization** among pair of agents.

IL Principle: IL favours language with structure. Each transmission with bottleneck would “filter out” the drift part of the language which cannot generalize

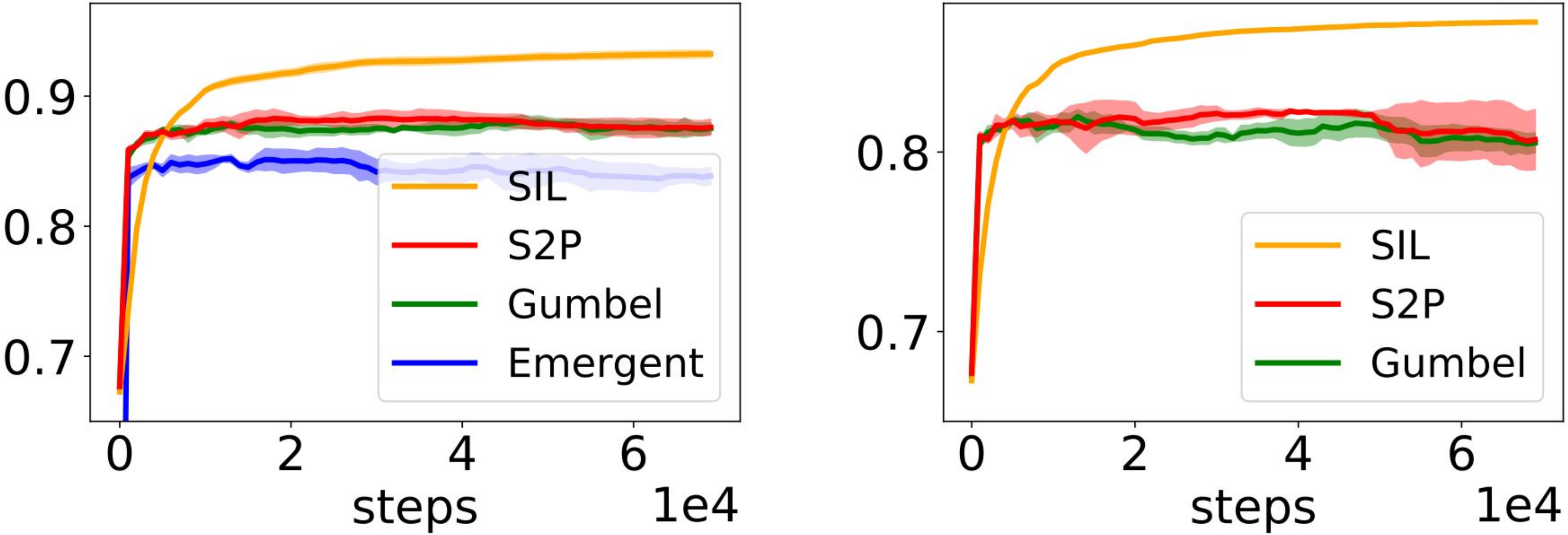


Seeded Iterated Learning (SIL)



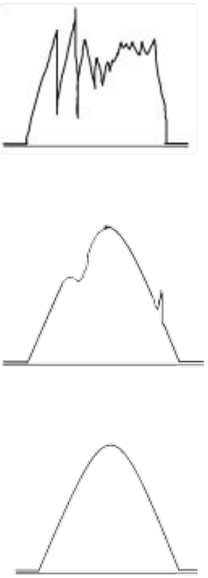
Lewis Game: Results

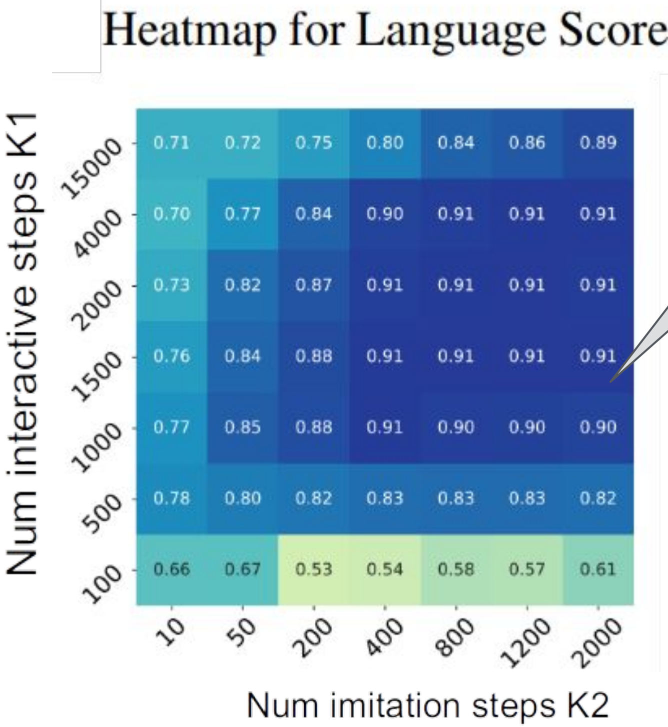
X axis is the number of interactive training steps
Pretrain Task/Language score: 65~70%



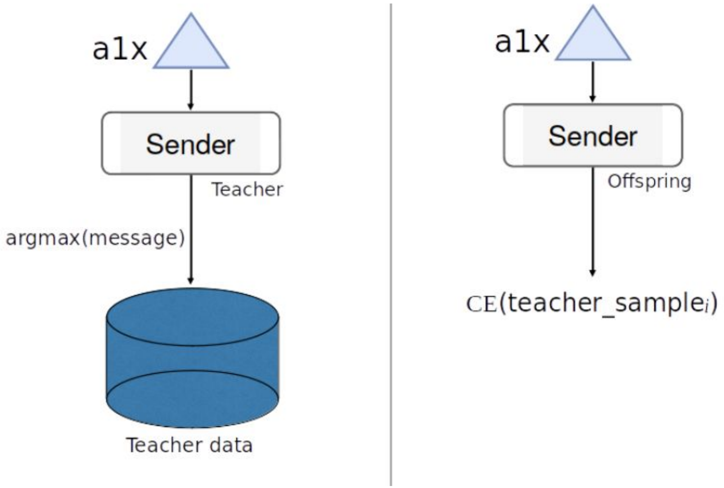
(a) Task Score (b) Sender Language Score

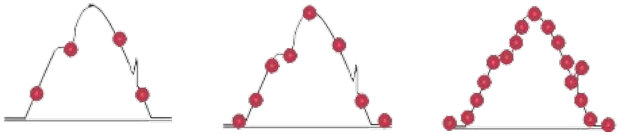
Lewis Game: K1/K2 Heatmap





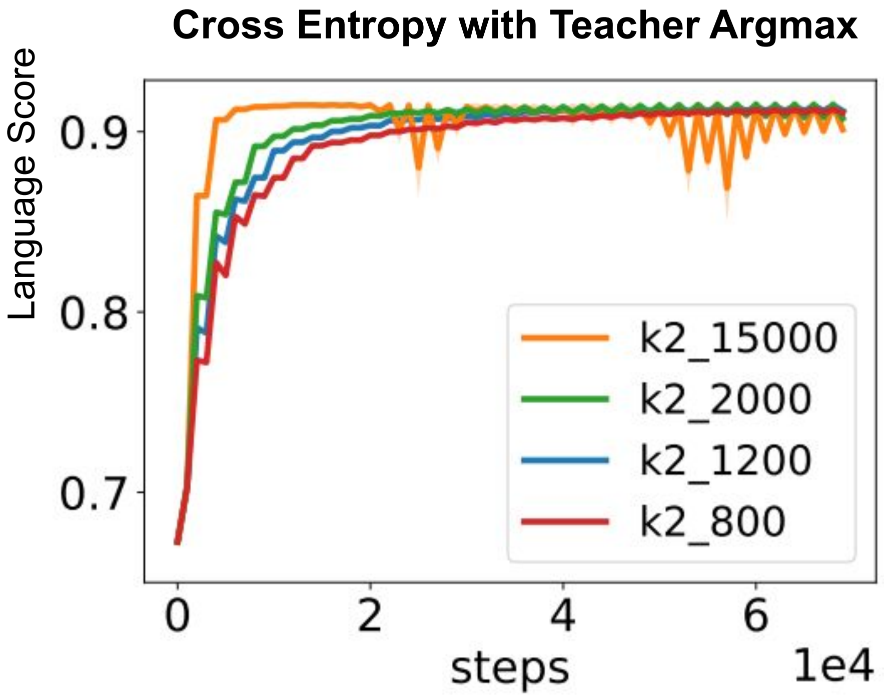
No Overfitting?

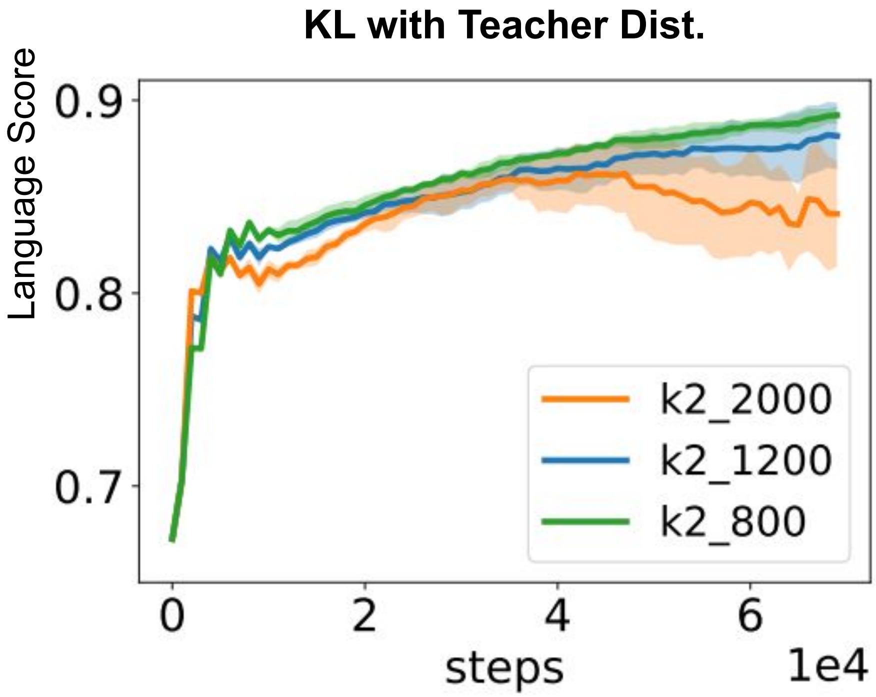




Lewis Game: Results

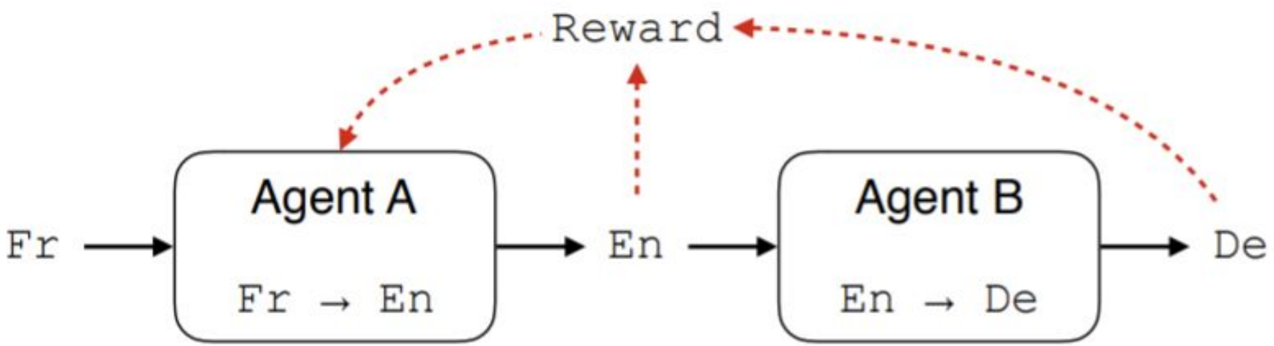
Data production is part of the “Learning Bottleneck”





Translation Game: Setup

Lee et al. EMNLP 2019



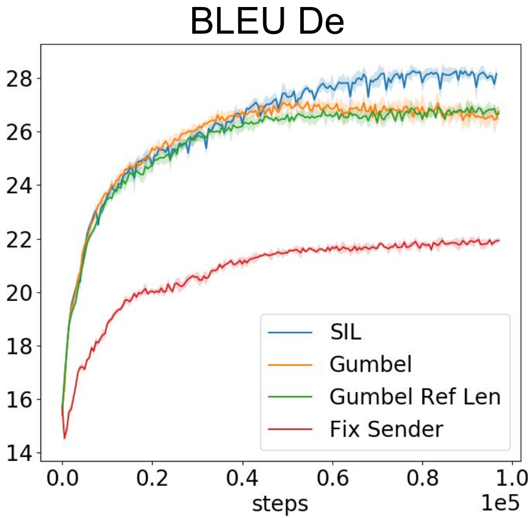
Task Score

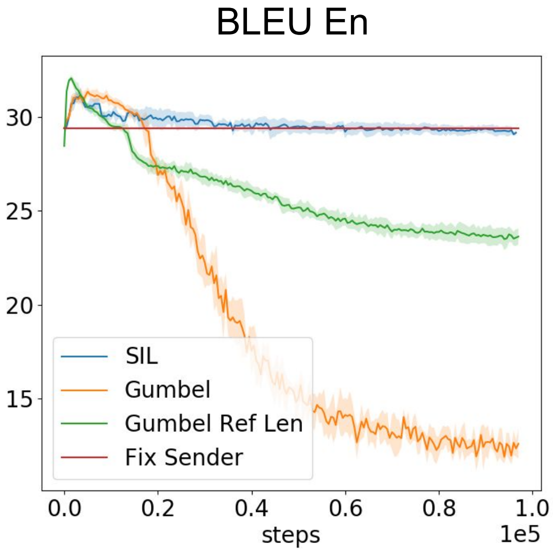
- BLEU DE (German BLEU score)

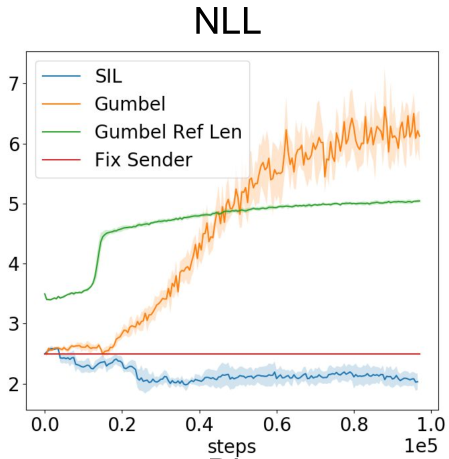
Language Score

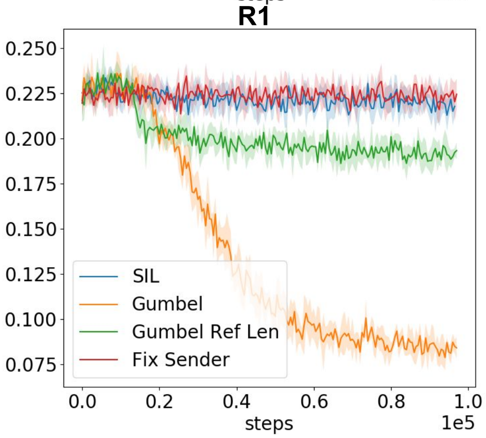
- BLEU EN (English BLEU score)
- English NLL of generated language a pretrained language model.
- R1 (Image retrieval accuracy from sender generated language)

Translation Game: Baselines

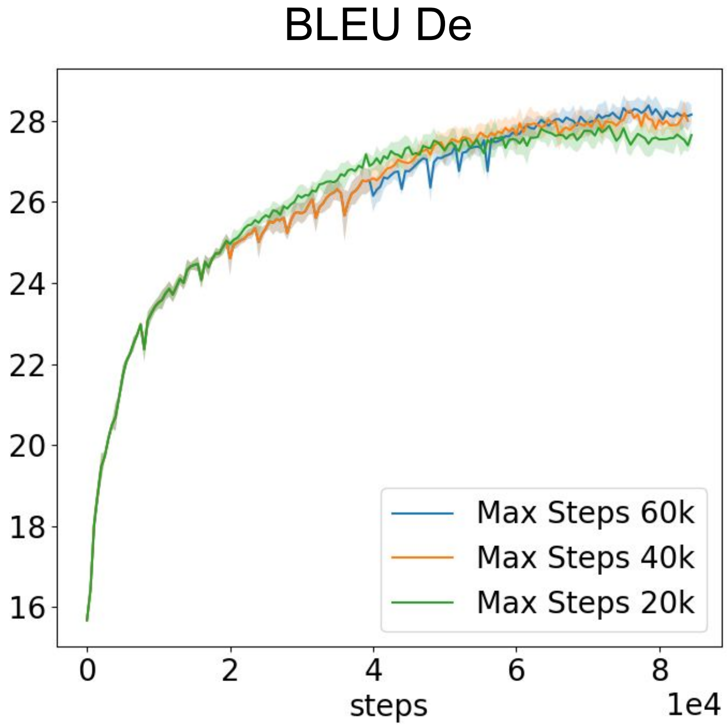


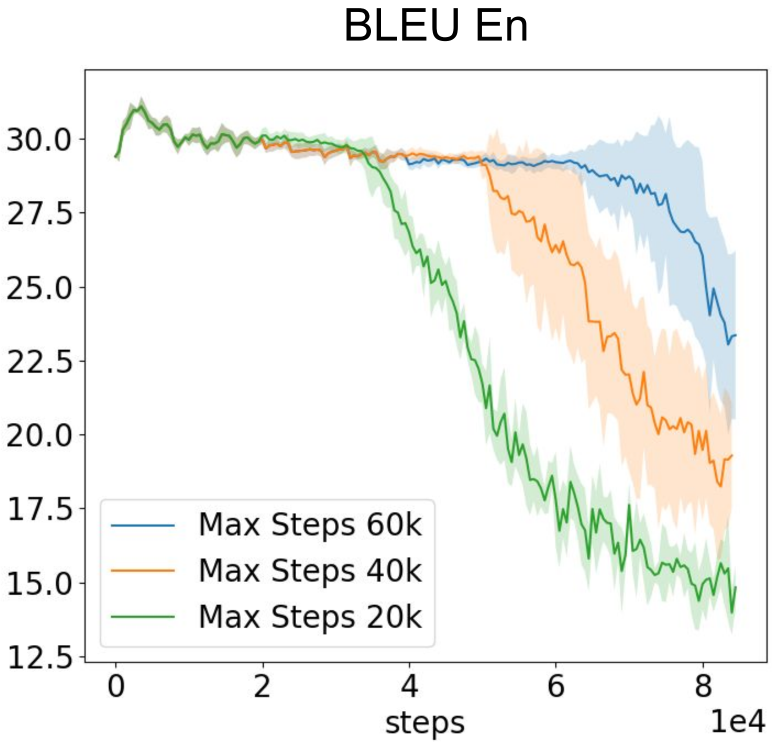




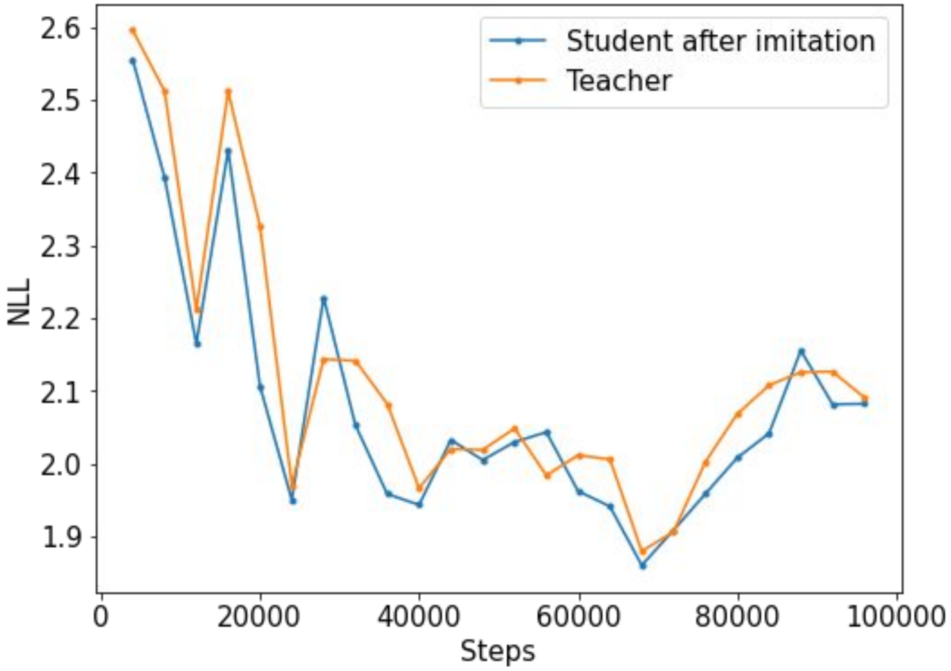


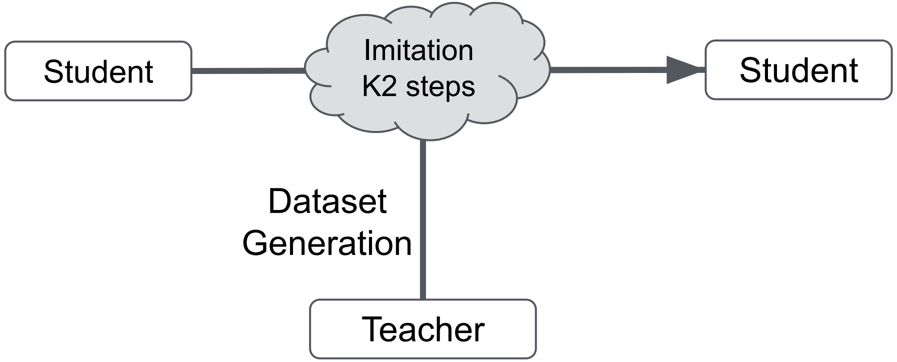
Translation Game: Effects of SIL

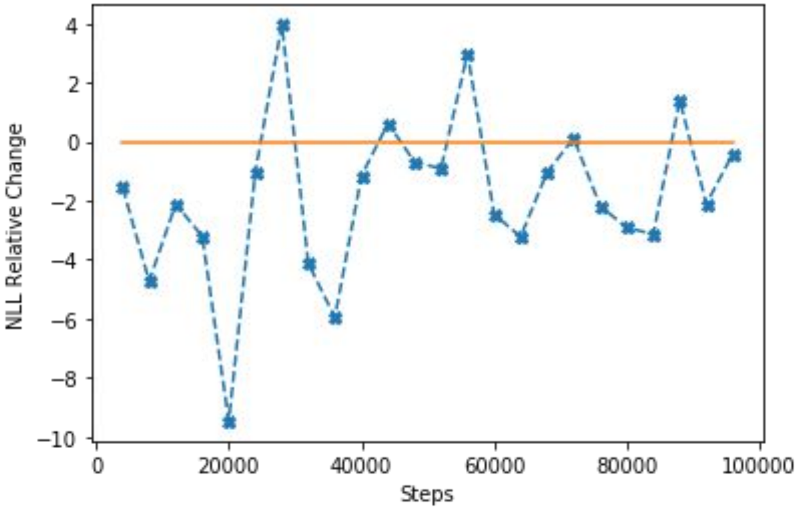




Effect of Imitation Learning



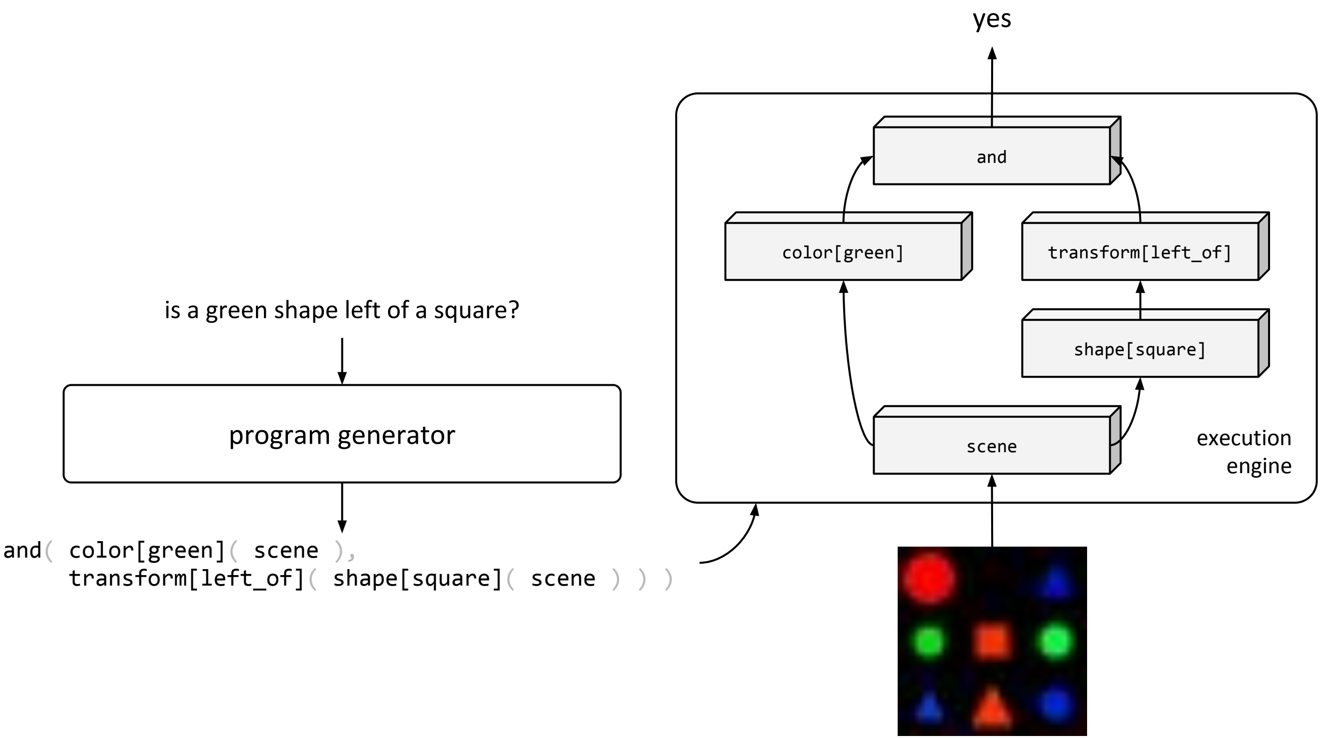




Mostly imitation learning brings the agent more favoured by pretrained language models

IL for VQA and Neural Module Network (NMN)

Recent work has proposed to use Neural Module Network (NMM) to achieve systematic generalization in VQA.



IL for VQA and Neural Module Network (NMN)

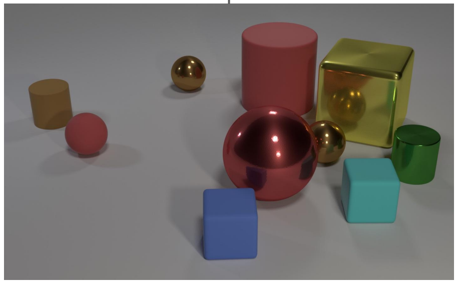
Yes

Are there an equal number of large things and metal spheres?

Program generator agent

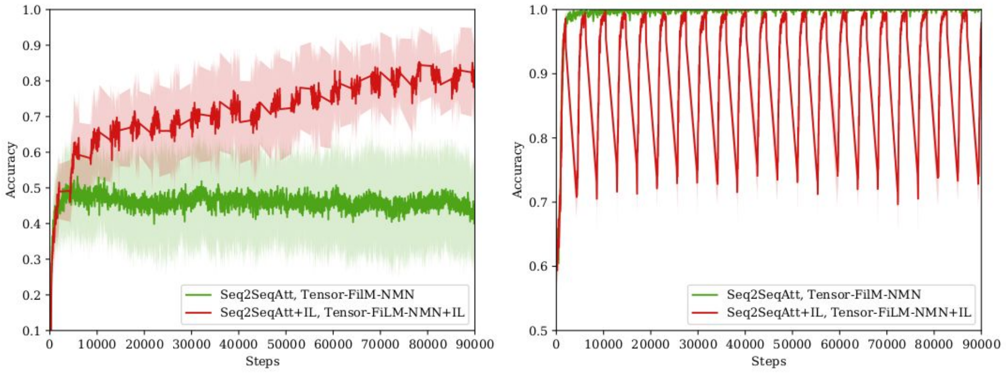
equal count
filter_large scene
count filter_metal
filter_sphere scene

Execution agent



Emergent language of our agents,
Applying IL?

IL for VQA and Neural Module Network (NMN)

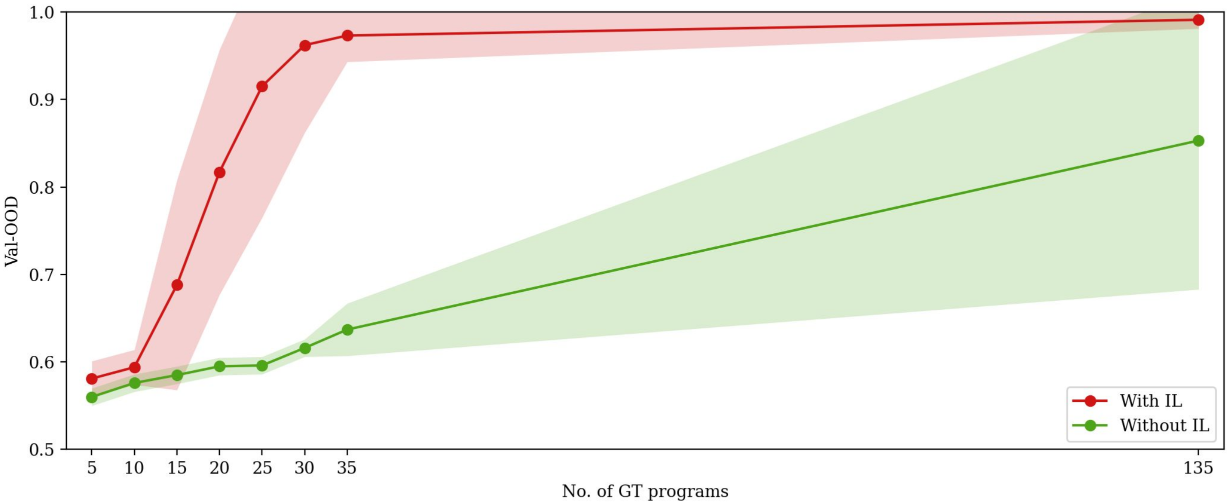


(a) Program accuracy. (b) Training accuracy.

(c) Val-IID accuracy. (d) Val-OOD accuracy.

- Experiment on a newly proposed benchmark called SHAPES-SyGeT
- Both models achieve perfect training accuracy in 5000 steps
- Learning bottleneck encourages consistent improvement in program accuracy
    - Leads to better Val-IID and Val-OOD

IL for VQA and Neural Module Network (NMN)



- With 35 GT programs, IL approaches the OOD performance with 135 GT programs
- Do not see the same data efficiency without IL

Summary

- Iterated Learning (IL) is proposed as language evolution framework. It states that linguistic structure is the solution of cultural evolution finds to the problem of being efficiently learnable.
- IL has been applied in deep learning, beyond emergent communication and beyond natural language

- More questions: How to explain the success of IL? If IL magnify the learner’s bias, does it depend on the model architecture? Can we explain it from the statistical learning theory?
- Can apply it to representation learning? Is it connected to existing practice like self-training?

Thanks!

“Human children appear preadapted to guess the rules of syntax correctly, precisely because languages evolve so as to embody in their syntax the most frequently guessed patterns. The brain has co-evolved with respect to language, but languages have done most of the adapting.”

-Deacon, T. W. (1997). *The symbolic species*

Iterated learning for deep learning will be exciting!