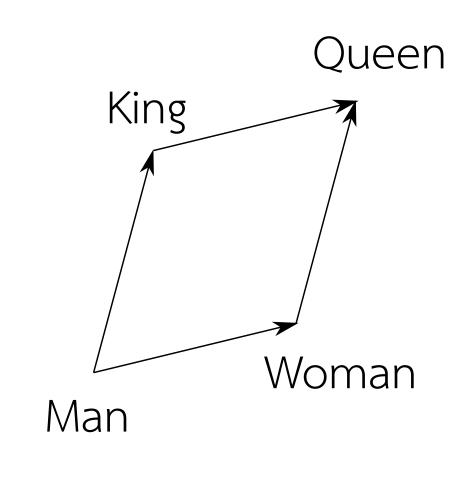
Discovering atomic, compositional, propositional language model by unsupervised learning

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Continuous distributed word embedding



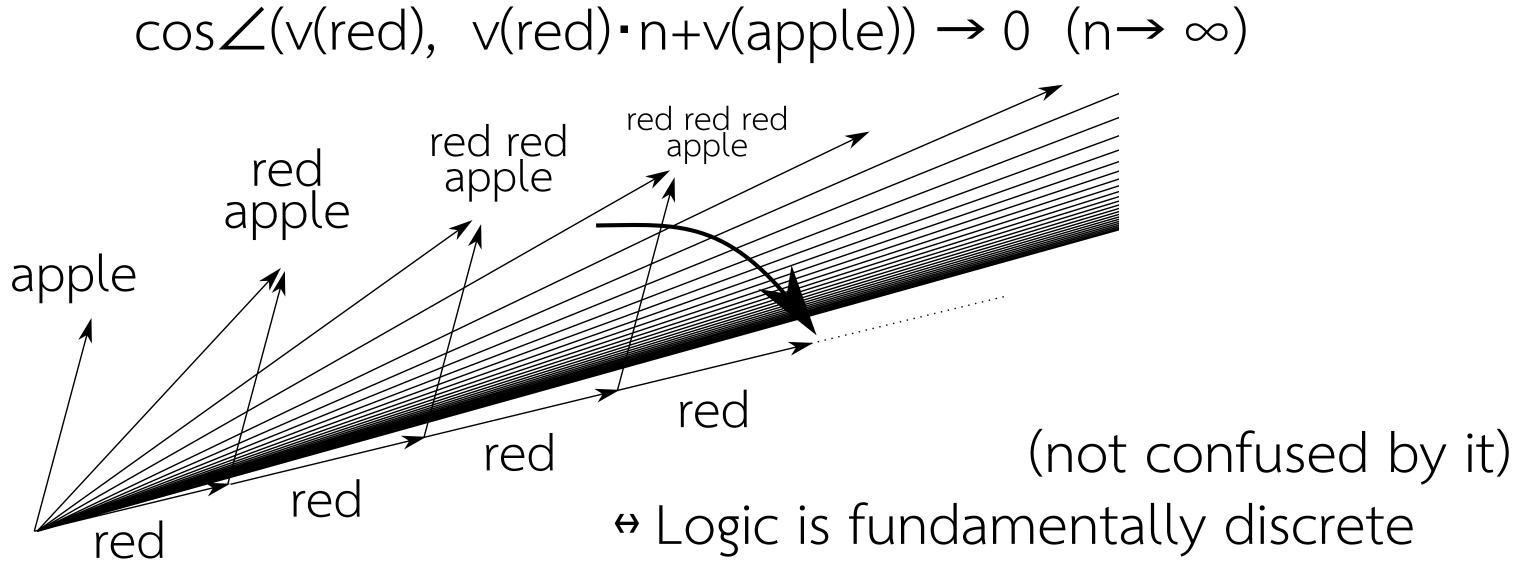
Nice vector-space property: e.g., king + (woman - man) = queen (despite critisisms [Nissim et al, 2020])

Logical correctness → ?

e.g. RNNs emit redundant entries:

"I want an apple apple apple ..." e.g. difficulty capturing the negation

It could be confused by imbalance/repetition



* Logic is fundamentally discrete → Symbolic algorithms

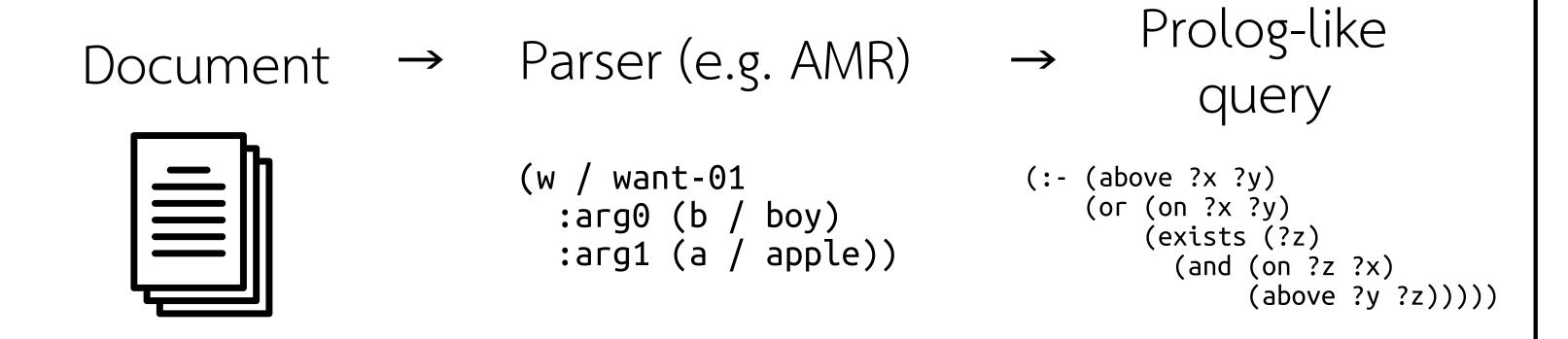
= Discrete math (e.g. graph search)

Instead, we want a better vector operation (+) that satisfy: v(red)+ ... + v(red)+v(apple) = v(red)+v(apple).

 \rightarrow The (+) operation uses the set operations, U, \cap , /.

But ... symbolic NLP?

Structural pattern matching with human symbols



Human symbols are brittle = lacks the vector space property E.g. Symbol "king" is opaque (no internal structure telling its gender)

Wittgenstein's "Logical Atomism" (blue book)

There must be a set of atomic concept (e.g. gender)

- = propositional symbols in human language
- → Learned propositional symbols address the weaknesses of both paradigms (neural / symbolic)
- → Discrete word embedding (from continuous relaxation)

Continuous relaxation of discrete activation: BinaryConcrete VAE (Maddison et al ICLR17)

BinConcrete(x) = Sigmoid((x + log u - log (1-u))) /
$$\tau$$
)
u ~ Uniform(0,1)
 $\tau \downarrow 0$
BinConrete(x) \rightarrow Heaviside(x)

Future work: logical reasoning in the embedded space using symbolic methods

Shortest path finding / planning

Q. What is the shortest phrase for an "black adult male bovine"?

A. black ox

Negation via boolean-SAT

background: (not red) apple Q: X apple. A: X=green

Discrete Vector arithmetic

Discretizing the word vector alone is insufficient.

Our discrete embedding has 2 vectors: Add, Del

Add represents the facts that are made True by the word

→ corresponding to increasing the value of a property **Del** represents the facts that are made False by the word

→ corresponding to decreasing the value of a property

If a state vector is [gender, social status],

Adding discrete vectors = executing the STRIPS actions sequentially.

STRIPS classical planning (Fikes 71): state transition defined as:

Let P a set of propositional variables (facts). P={have \$200k, have ferrari, happy} $s=\{have_{$200k}\}$ A **state** s is a subset of $P : s \subseteq P$,

where each proposition $p \in s$ is the one that holds (is true) in s.

An **action** a is a tuple <pre(a), add(a), del(a)>:

→ preconditions, add effects, delete effects. (we don't use preconditions) Given the current state s and an action a, the next state t is:

del(buy ferrari) = { have \$200k }, t = apply(a, s) = (s / del(a))U add(a)add(buy ferrari) = { have_ferrari, happy }. v(man) + v(king):

 $t = s / del(man) \cup add(man) / del(king) \cup add(king)$

= s / {gender} U {social status} ←The effects do not accumulate v(man) - v(king) by **undoing** "king"

t = s / del(man) U add(man) / add(king) U del(king)

= s / {gender} U {} / {social status} U {gender}

= s / {social status}

v(king) + v(woman) - v(man) = v(queen)

t = s / {gender} U {social status}

/{} U {gender} / {} U {gender} = s U {gender, social status}

add(queen)=[1, 1]

Discrete state CBOW (3-gram) BN=BatchNorm BC=BinConcrete Discrete Bernoulli(0.5) states Logit initial state Continuous states $s_0 = [0,0,0]$ effect Del(5)=[?,0,0]Add(5)=[0,1,1] $s_1 = [0,1,1]$ Del(3)=[0,1,0]Add(3)=[1,0,?]

k-NN (excluding itself) (prelim. results)

				_						
:	cheapest	subcompact	saloon	mechanic	king	:	tut	birendra	gyanendra	lich
:	motorbike	lawnmower	50cc	megane	queen	:	sirikit	latifah	rania	ifrica
:	bike	stationary	bicycles	bikes	prince	:	ashwell	vajiralongkorn	dipendra	epiphanny
:	automobili	murcielago			princess	:	diana	leia	galyani	cruises
		rosso	•		sea					urchin
	•								•	havasu
	•		•				•			yalu
	•		•		_				•	blacktop
					•			5		necker
										cordillera
			_							ch2m
		•							•	rift
	-		•		_				•	
				•			_		_	petrified
			• •				_			stricker
			•	-	apple			•	•	itunes
					grape				vines	oysters
	-	equinox	hhr	sedan	orange	:	county	bright	magenta	monterey
	•	vitara	maruti	tas	potato	:	potatoes	gnocchi	crispy	tart
:	kisen	boonsboro	phrasemaking	takfiris	carrot	:	parfait	cornbread	tarragon	parsnips
:	pramac	meddwl	200c	icex	onion	:	zucchini	pickled	broth	tacos
•	rider	aprilia	suzuki	honda	garlic	:	thvme	potatoes	cloves	chopped
		<pre>: cheapest : motorbike : bike : automobili : massa : quattroporte : punto : megane : sauber : benz : rs4 : nissan : hyundai : cx : altima : wrx : mondeo : chrysler : gmc : ichiro : kisen : pramac : rider</pre>	<pre>: motorbike</pre>	<pre>: motorbike lawnmower 50cc : bike stationary bicycles : automobili murcielago tonino : massa rosso gtb : quattroporte 8688 mobtown : punto abarth cinquecento : megane clio hyundai : sauber z4 oracle : benz benzes bmw : rs4 acura a6 : nissan prius lexus : hyundai motor toyota : cx camaro hatchback : altima micra qashqai : wrx isuzu impreza : mondeo madox motor : chrysler digiovanni motors : gmc equinox hhr : ichiro vitara maruti : kisen boonsboro phrasemaking : pramac</pre>	<pre>: motorbike lawnmower 50cc megane : bike stationary bicycles bikes : automobili murcielago tonino gallardo : massa rosso gtb scuderia : quattroporte 8688 mobtown twinn : punto abarth cinquecento eni : megane clio hyundai nissan : sauber z4 oracle daimler : benz benzes bmw 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hhr sedan potato : kisen boonsboro phrasemaking takfiris carrot i pramac meddwl 200c icex</pre>	<pre>: motorbike lawnmower 50cc megane queen : bike stationary bicycles bikes prince : automobili murcielago tonino gallardo princess : massa rosso gtb scuderia sea : quattroporte 8688 mobtown twinn lake : punto abarth cinquecento eni lake : megane clio hyundai nissan river : sauber z4 oracle daimler pond : benz benzes bmw cosworth island : rs4 acura a6 a4 mountain : nissan prius lexus aygo hill : hyundai motor toyota fireblade valley : cx camaro hatchback changan forest : altima micra qashqai xterra woods : wrx isuzu impreza volkswagen apple : mondeo madox motor chadds chrysler digiovanni motors delphi grape : gmc equinox hhr sedan orange : kisen boonsboro phrasemaking takfiris carrot : pramac meddwl 200c icex onion :</pre>	<pre>: motorbike lawnmower 50cc megane queen : sirikit : bike stationary bicycles bikes prince : ashwell : automobili murcielago tonino gallardo princess : diana : massa 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Future work: extension to RNN, attention model (e.g. BERT)

training data: 1-billion monolingual dataset