

# Composition in distributional semantics

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COMPOSES:  
COMpositional Operations  
In SEMantic Space



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# Outline

Distributional semantics

Compositionality

Experiments and extensions



# The distributional hypothesis

Harris, Charles and Miller, Firth, Wittgenstein? ...

The meaning of a word is (can be approximated by, derived from) the set of contexts in which it occurs in texts

We found a little, hairy **wampimuk** sleeping behind the tree

See also MacDonald & Ramscar CogSci 2001

# Distributional semantics

Landauer and Dumais PsychRev 1997, Turney and Pantel JAIR 2010, ...

he curtains open and the moon shining in on the barely  
ars and the cold , close moon " . And neither of the w  
rough the night with the moon shining so brightly , it  
made in the light of the moon . It all boils down , wr  
surely under a crescent moon , thrilled by ice-white  
sun , the seasons of the moon ? Home , alone , Jay pla  
m is dazzling snow , the moon has risen full and cold  
un and the temple of the moon , driving out of the hug  
in the dark and now the moon rises , full and amber a  
bird on the shape of the moon over the trees in front  
But I could n't see the moon or the stars , only the  
rning , with a sliver of moon hanging among the stars  
they love the sun , the moon and the stars . None of  
the light of an enormous moon . The splash of flowing w  
man 's first step on the moon ; various exhibits , aer  
the inevitable piece of moon rock . Housing The Airsh  
oud obscured part of the moon . The Allied guns behind

# Distributional semantics

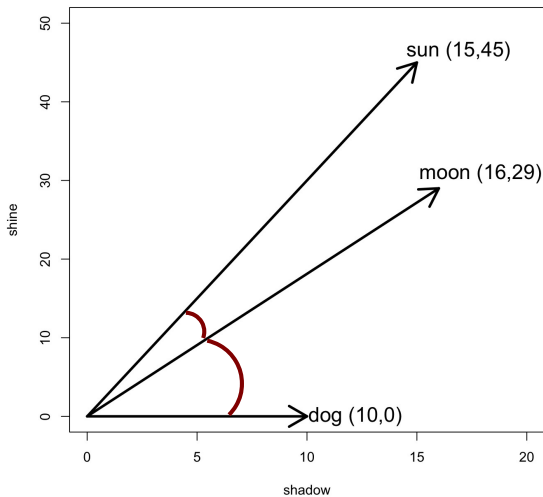
Distributional meaning encoded in co-occurrence vectors

	planet	night	full	shadow	shine	crescent
moon	10	22	43	16	29	12
sun	14	10	4	15	45	0
dog	0	4	2	10	0	0

# Distributional semantics

The geometry of meaning

	shadow	shine
moon	16	29
sun	15	45
dog	10	0





## Geometric neighbours $\approx$ semantic neighbours

rhino	fall	good	sing
woodpecker	rise	bad	dance
rhinoceros	increase	excellent	whistle
swan	fluctuation	superb	mime
whale	drop	poor	shout
ivory	decrease	improved	sound
plover	reduction	perfect	listen
elephant	logarithm	clever	recite
bear	decline	terrific	play
satin	cut	lucky	hear
sweatshirt	hike	smashing	hiss

# Distributional semantics: A general-purpose representation of lexical meaning

Baroni and Lenci 2010

- ▶ Similarity (*cord-string* vs. *cord-smile*)
- ▶ Synonymy (*zenith-pinnacle*)
- ▶ Concept categorization (*car* ISA *vehicle*; *banana* ISA *fruit*)
- ▶ Selectional preferences (*eat topinambur* vs. \**eat sympathy*)
- ▶ Analogy (*mason* is to *stone* like *carpenter* is to *wood*)
- ▶ Relation classification (*exam-anxiety* are in CAUSE-EFFECT relation)
- ▶ Qualia (TELIC ROLE of *novel* is *to entertain*)
- ▶ Salient properties (*car-wheels*, *dog-barking*)
- ▶ Argument alternations (*John broke the vase* - *the vase broke*, *John minces the meat* - \**the meat minced*)

# Selectional preferences in semantic space

Padó et al. EMNLP 2007

To kill. . .

<i>object</i>	<i>cosine</i>	<i>with</i>	<i>cosine</i>
kangaroo	0.51	hammer	0.26
person	0.45	stone	0.25
robot	0.15	brick	0.18
hate	0.11	smile	0.15
flower	0.11	flower	0.12
stone	0.05	antibiotic	0.12
fun	0.05	person	0.12
book	0.04	heroin	0.12
conversation	0.03	kindness	0.07
sympathy	0.01	graduation	0.04

# Outline

Distributional semantics

**Compositionality**

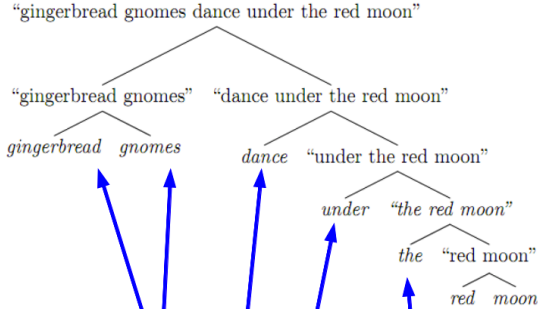
Experiments and extensions

# The infinity of sentence meaning

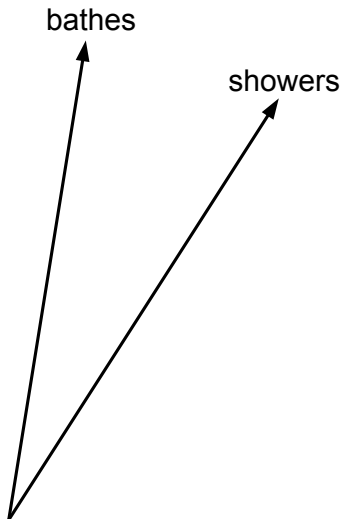
what you've got means such a lot to me. I know a mouse, and he hasn't got a house. Who put all those things in your hair? He'll be found when you're around. I know what it is was a king who ruled the land. Doctor Robert, you're a new and better man. There's one for you, nineteen for me. Lying there and staring at the ceiling. If you don't want to pay some more now what it is to be sad... Good Day Sunshine. Ring my friend, I said you call Doctor Robert. Because I'm the taxman, yeah I'm the taxman. But now he's resigned to his fate. No fair, you can't hear me but I can you. But listen to the colour of your dreams. I've got no. here we go Ever so high. He had a big adventure Amidst the grass Fresh air at last. Here a man, there a man, lots of gingerbread men. Watch her eyes and hoping I'm always there. Leave me where I'm proud to know that she is mine. There's a people standing round Who screw you in the ground. I want to tell you a story About a little man If I can. Let's go into the other room and care? At the sky, look at the river Isn't it good? Eleanor Rigby died in the church and was buried along with her name. Eating, sleeping, drinking their wine. Someone is speaking but she doesn't know I was a boy everything was right Everything was right I said. Doctor Robert, he's a man you must believe. Helping everyone in need. Watching butterscups cup the light Sleeping on a dandelion. As we fly of blue and sea of green in our yellow submarine. Waits at the window, seaming the face that she keeps in a jar by the door. Cleaner Rigby picks up the rice in the church where a wedding has been. S No one named Grumble Crumble. I need to laugh and when the sun is out I've got something I can laugh about. Knowing that love is to share. No one comes near. No, no, no, you're wrong. And I'm glad green The sounds surrounds the icy waters underground Lime and limpid green The sounds surrounds the icy waters underground. Waiting for a sleepy feeling... Please, don't spoil my day, I'm milos awl only have to read the lines They're scribbly black and everything shines. Oh Mother, tell me more. You can't see me But I can you. In the town With silver eyes Each one believing that love never dies Watching her eyes and hoping I'm always there. They'll fill your head with all the things you see. Day or night he'll be there any time at all. Doctor Robert Doctor Robert, you're and limpid green The sounds surrounds the icy waters underground. The seven is the number of the young light. Blinding signs flap. Flicker, flicker, flicker blam. He does everything he can, Doctor Robert change returns success. Yes they did. Because I'm the taxman, yeah, I'm the taxman. Ah, look at all the when I'm in the middle of a dream Stay in bed, float up stream. Action brings good fortune. S When I wake up early in the morning Lift my head, I'm still yawning. It is not dying. All the lonely p t good? Be a hip cat Be a ship's cat. He didn't care. Luofier go to sea. It forms when darkness d and black. Rings return. I know she's looking fine. ng around on the ground. ke a couple if you wish. All the lonely people Where do they all come from? Even though you k ou anything, everything if you want things. Wandering and dreaming The words have different meaning. He stood in a I feel good in a special way. Because you're making me fee Good Day Sunshine. No one was saved. When your bird is broken will it bring you down you may be awoken. I'll be found. I know a room full of musical tunes. It's got a bask ou don't understand what I said. I'm in bed Achin' head Gold is lead Choke on bread Underfed Gold is lead Jesus bled Pain is red Are grown Go Greasy spoon You swoon June bloom Miss You're the kind of girl that fits in with my world. I said, Well, we er McKenzie writing the words of a sermon that no one will hear. You're the kind of girl that fits in with my world. When I was a boy everything was right. Anoth airway scare Dan Dare who's there? We all live in our yellow submarine. Nobody can deny that there's something there. The black and green scarecrow as everyone knows stood and you're working for no one but me. I don't mind. I think they're crazy. Doctor kindly tell your wife that I'm alive - flowers thrive - realize - r ad a better life I need my love to be here... Here, making each day of the year. Changing my life with the wave of her hand. Look at him working. We take a walk, the sun is shining down. Burns my feet as they touch the ground. Please, don't wake me, no, don't then one day - hooray! Taking my time. Lime and limpid green, a second scene A fight between the blue you once knew. Yippee! Father McKenzie wiping love all day long. But to love her is to need her everywhere Knowing that love is to share. The time is with the month of winter solstice When the change is due to come. I want her everywhere down all thoughts, surrender to the void. Floating down, the sound resounds Around the icy waters underground. If you tell me that you've heard every sound there is And your bird can sing. Who is it for? Jupiter and get too cold I'll tax the heat. If you take a walk, I'll tax your feet. Why'd'ya have to leave me there Hanging in my infant air Waiting? Should five per cent appear too small Be thankful I don't take it al now what it is to be sad. Running everywhere at such a speed I'll they find there's no need. And you're making me feel like I've never been born. Don't pay money just to see yourself with Doctor Robert If you're down he'll pick you up. Doctor Robert av you've seen seven wonders and your bird is green. Some rhyme, some ching, most of them are clockwork. He's settin rather old, but he's a good mouse. There, running my hands through her hair

# Compositionality

The meaning of an utterance is a function of the meaning of its parts and their composition rules (Frege 1892)



# The unavoidability of distributional representations of phrases



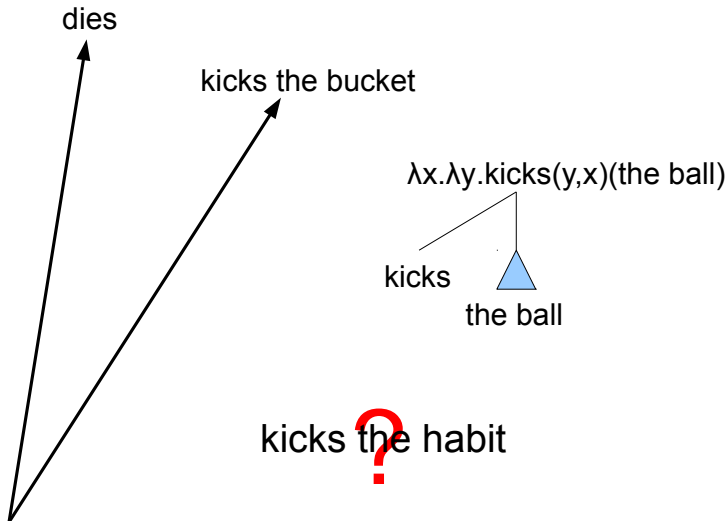
$\lambda x.\lambda y.\text{takes}(y,x)(\text{a shower})$

takes

a shower



# The unavoidability of distributional representations of phrases

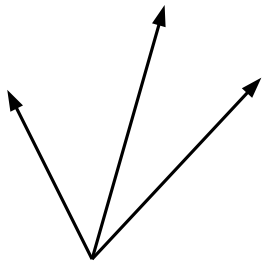




# What can you do with distributional representations of phrases and sentences?

**NOT** this:

every farmer who owns a donkey beats it



$\forall x \forall y (\text{FARMER}(x) \wedge \text{DONKEY}(y) \wedge \text{OWNS}(x, y) \rightarrow \text{BEAT}(x, y))$

What can you do with distributional representations of phrases and sentences?

**NOT** this:

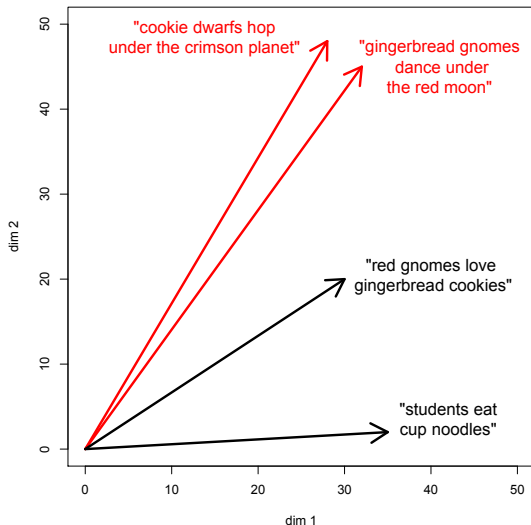


A dog **F** is barking

A dog **T** is flying

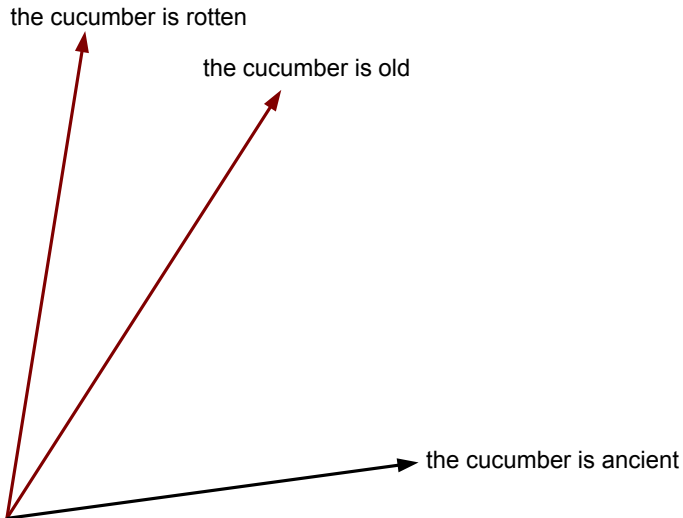
# What can you do with distributional representations of phrases and sentences?

## Paraphrasing



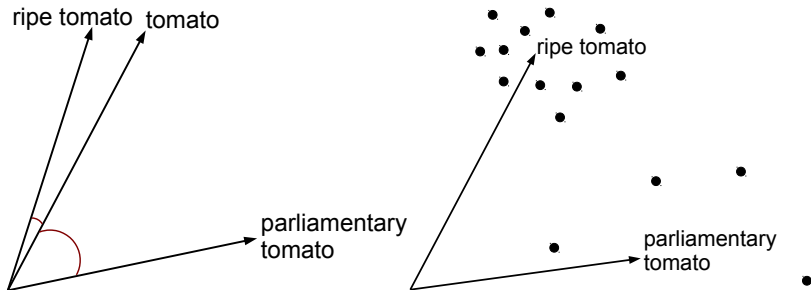
# What can you do with distributional representations of phrases and sentences?

## Contextual disambiguation



# What can you do with distributional representations of phrases and sentences?

## Semantic acceptability



# Compositional distributional semantics

How?

	planet	night	space	color	blood	brown
red	15.3	3.7	2.2	24.3	19.1	20.2
moon	24.3	15.2	20.1	3.0	1.2	0.5
red+moon	39.6	18.9	22.3	27.3	20.3	20.7
red⊙moon	371.8	56.2	44.2	72.9	22.9	10.1
red(moon)	24.6	19.3	12.4	22.6	23.9	7.1

# (Weighted) additive model

Mitchell and Lapata 2010

$$\vec{p} = \alpha \vec{u} + \beta \vec{v}$$

	music	solution	economy	craft	reasonable
practical	0	6	2	10	4
difficulty	1	8	4	4	0
practical + difficulty	1	14	6	14	4
0.4×practical + 0.6×difficulty	0.6	5.6	3.2	6.4	1.6

# Multiplicative model

Mitchell and Lapata 2010

$$\vec{p} = \vec{u} \odot \vec{v}$$

$$p_i = u_i v_i$$

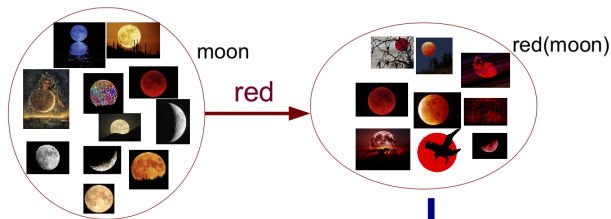
	music	solution	economy	craft	reasonable
practical	0	6	2	10	4
difficulty	1	8	4	4	0
practical + difficulty	1	14	6	14	4
0.4×practical + 0.6×difficulty	0.6	5.6	3.2	6.4	1.6
practical $\odot$ difficulty	0	48	8	40	0



## Composition as dimension averaging/mixing

- ▶ red moon
- ▶ red face? fake gun?? buy guns??
- ▶ the car??? of the car????
- ▶ pandas eat bamboo  
vs. bamboo eats pandas???
- ▶ lice and dogs  
vs. lice on dogs???
- ▶ some children walk happily in the valley of the moon????

# Composition as (distributional) function application



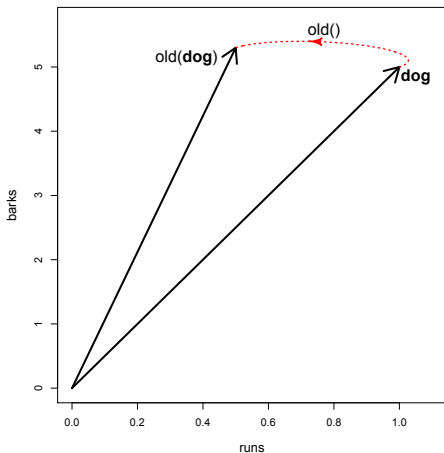
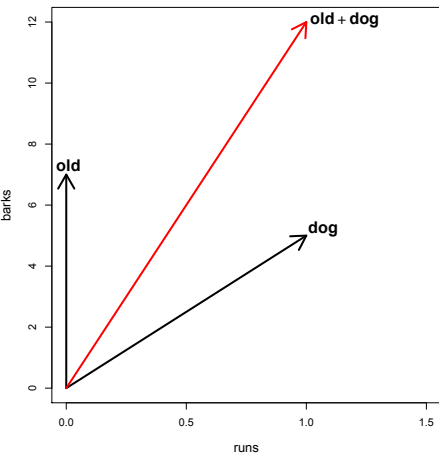
$$\vec{\text{moon}} = \begin{bmatrix} \text{shine} & 301 \\ \text{eclipse} & 250 \\ \text{blood} & 93 \\ \dots & \dots \end{bmatrix} \xrightarrow{\text{red}} \vec{\text{red}(\text{moon})} = \begin{bmatrix} \text{shine} & 11 \\ \text{eclipse} & 245 \\ \text{blood} & 90 \\ \dots & \dots \end{bmatrix}$$

Coecke+Clark+Grefenstette+Sadrzadeh et al.,

Baroni and Zamparelli

Related: Guevara, Socher et al., Zanzotto et al.

# Composition as (distributional) function application



# Baroni and Zamparelli's EMNLP 2010 proposal

- ▶ How do we implement the idea of function application in a vector space?
  - ▶ Functions as **linear maps** between vector spaces
  - ▶ Functions are matrices, function application is function-by-vector multiplication:

$$F\vec{a}$$

- ▶ How do we induce a compositional function from corpus data?
  - ▶ The weights in the matrix/function are learned with **least-squares techniques** from corpus-extracted examples of how their input and output vectors look like (see also Guevara GEMS 2010)

# Learning distributional composition functions

n and the moon shining i  
with the moon shining s  
rainbowed moon . And the  
crescent moon , thrille  
in a blue moon only , wi  
now , the moon has risen  
d now the moon rises , f  
y at full moon , get up  
crescent moon . Mr Angu

f a large red moon , Campana  
, a blood red moon hung over  
glorious red moon turning t  
The round red moon , she 's  
l a blood red moon emerged f  
n rains , red moon blows , w  
monstrous red moon had climb  
. A very red moon rising is  
under the red moon a vampire

	shine	blood	Soviet
moon	301	93	1
red moon	11	90	0
army	2	454	20
red army	0	22	18

# Outline

Distributional semantics

Compositionality

Experiments and extensions

# Contextual disambiguation

- ▶ Composed sentence cosine distance correlates with human similarity judgments for ambiguous verbs in simple
  - ▶ intransitive sentences:  
*fire glows*  $\approx$  *fire burns*  $\not\approx$  *fire beams* (cf. *face glows/beams*)  
(Mitchell and Lapata ACL 2008)
  - ▶ transitive sentences:  
*table shows results*  $\approx$  *table expresses results*  $\not\approx$  *table pictures results* (cf. *map shows/pictures location*)  
(Grefenstette and Sadrzadeh EMNLP 2011)
- ▶ Best Spearman correlations with functional approach: .32 for both intransitives (Li et al. EACL 2014) and transitives (Grefenstette et al. IWCS 2013)

## Phrase paraphrasing

- ▶ Find right single-noun paraphrase of adjective-noun phrase (*false believe/fallacy*, *personal appeal/charisma*) in lexicon of 20K nouns (Turney JAIR 2012, Dinu et al. CVSC 2013)
  - ▶ Best median rank of correct noun: 11/20K, with syntactic-slot-based functional approach (Dinu and Baroni ACL 2014)
- ▶ Select right determiner-noun paraphrase of noun among 6 alternatives (*duel: two opponents or three opponents?* *homeless: no home or too few homes?*) (Bernardi et al. ACL 2013)
  - ▶ Best accuracy: 40% with functional approach (Li et al. EACL 2014)



## Sentence paraphrasing

- ▶ Semeval-2012 Semantic Textual Similarity (STS) MSR Video description data, with subject similarity ratings (very similar: *A man with a hard hat is dancing/A man wearing a hard hat is dancing*; not so similar: *A woman is playing the guitar/A man is playing guitar*)
  - ▶ Best Spearman correlation: .79 with functional approach (Paperno et al. ACL 2014), would have attained 25/89 ranking at STS 2012
  
- ▶ \*SEM-2013 STS gloss similarity ratings (very similar: *break up a solid, usually into a solution/ become or cause to become soft or liquid*; quite dissimilar: *a large truck used to haul material or goods/a long truck for carrying motor vehicles*)
  - ▶ Best Spearman correlation: .67 with functional approach (Paperno et al. 2014), would have attained 20/90 ranking at STS 2012



## Measuring adjective-noun phrase plausibility

- ▶ Distinguish, among phrases unattested in large corpus, the ones that make sense (*vulnerable gunman*, *huge joystick*, *academic crusade*) from those that do not (*academic bladder*, *parliamentary tomato*, *blind pronunciation*)
  - ▶ Functional composition model generates vectors that reside in significantly *denser* area of semantic space for acceptable vs. unacceptable nonce phrases (Vecchi et al. DISCO 2011)
- ▶ Composed-vector plausibility measures can be successfully used to predict right bracketing of noun phrases (*miracle [home run]* vs. *[miracle home] run*) (Lazaridou et al. EMNLP 2013)

# Predicting the recursive behaviour of adjectives

Vecchi et al. EMNLP 2013

- ▶ “Flexible” (*daily national newspaper/daily national newspaper*) vs. “rigid” (*rapid social change/\*social rapid change*) adjective-adjective-noun phrases
- ▶ Proximity of recursively-constructed phrase vector to components predict if adjective is flexible or rigid, and correct order for rigid phrases
- ▶ Adjective nearest to noun has strongest effect on phrase meaning

# Functional composition in morphology

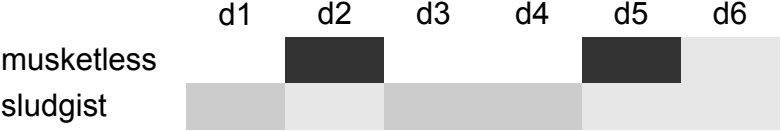
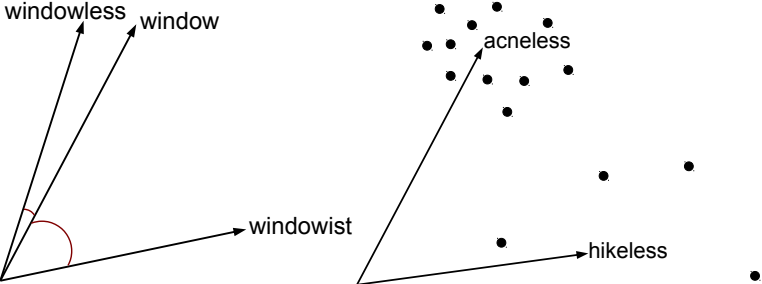
Lazaridou et al. ACL 2013, Marelli and Baroni *submitted*

- ▶ Affixes as functions from stems to derived forms:

$$\vec{redo} = \mathbf{RE} \times \vec{do}$$

- ▶ Affix matrices learned with least-squares techniques from corpus-extracted stem/derived vector pair examples (*try/retry*, *climb/reclimb*, *open/reopen*)

# Plausibility measures for morphology



# Predicting nonce derived-form acceptability

Marelli and Baroni *submitted*

- ▶ Subject ratings of unattested forms
  - ▶ Acceptable: *sketchable, hologramist*
  - ▶ Unacceptable: *happenable, windowist*
- ▶ Plausibility measures applied to vectors derived by functional composition
- ▶ Entropy and proximity (non-linear effect) predict subject intuitions (both  $p < 0.001$  in mixed model regression)

# Phrase generation in distributional semantics

Dinu and Baroni ACL 2014 (slides courtesy of Georgiana Dinu)

**From vectors  
to  
words**



gingerbread gnomes dance under the red moon

What for?

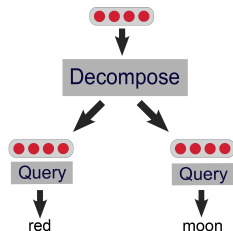
- ▶ Paraphrase generation, Machine translation
- ▶ Caption generation, Brain activation patterns to language?



# Paraphrasing

Noun phrase generation through:

- ▶ Syntax-aware decomposition functions
- ▶ Nearest neighbor queries



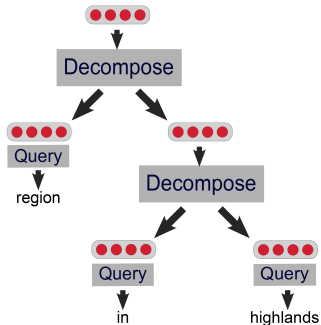
Examples

	Noun	→	Adj Noun
✓	reasoning		deductive thinking
✓	jurisdiction		legal authority
×	superstition		old-fashioned religion
×	zoom		fantastic camera

# Paraphrasing

Noun phrase generation through:

- ▶ Syntax-aware decomposition functions
- ▶ Nearest neighbor queries



Examples

Adj Noun

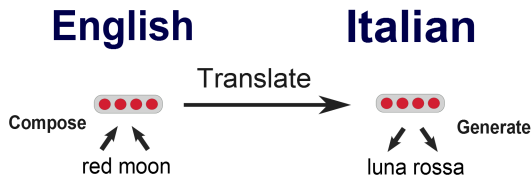
→

Noun Prep Noun

- ✓ mountainous region
- ✓ undersea cable
- ? inter-war years
- × superficial level

region in highlands  
cable through ocean  
years during 1930s  
level between levels

# Cross-lingually



Noun phrase translation:

- ▶ Use small dictionary to learn cross-lingual mapping
- ▶ Translate source language space into target space
- ▶ Learn joint (de)composition functions
- ▶ Test on 3000 Adjective-Noun English-Italian phrases

## Adjective-noun English-Italian translation

Accuracy when using generation confidence (cosine to nearest neighbor) as a threshold.

	En→It		It→En	
Thr.	Accuracy	Cov.	Accuracy	Cov.
0.00	0.21	100%	0.32	100%
0.55	0.25	70%	0.40	63%
0.60	0.31	32%	0.45	37%
0.65	0.45	9%	0.52	16%

### Examples

English

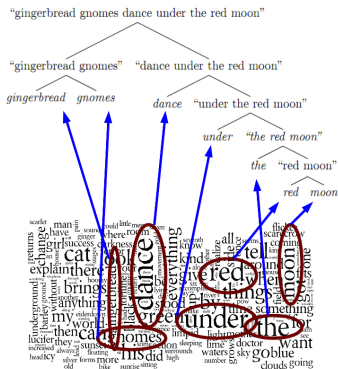
→

Italian

- ✓ black **tie**                                    **cravatta** nera
- ✓ indissoluble **tie**                           **alleanza** indissolubile
- × rough neighborhood                        zona **malfamata** (ill-repute zone)
- × mortal sin                                      peccato **eterno** (eternal sin)

That's all, folks!

# Thank you!



<http://clic.cimec.unitn.it/marco>