

Lexicon, Syntax, Semantics IIb:
Modeling Meaning
Compositional Distributional Semantics

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Sentences in Google

6/13/2015

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8 Jan 2008 - Dog shoots and kills man in freak hunting accident ... Price, 46, then set the gun in the back of his truck and was about to open the tailgate to ...

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30 Dec 2014 - Guns don't kill people; dogs with guns kill people—or so it would seem from the recent rash of ... Dog Steps on Rifle and Shoots Wyoming Man.

Guns Don't Kill People, Dogs Kill People | Louis Klarevas

www.huffingtonpost.com/louis.../dog-shooting-accidents_b_4110822.ht...

17 Oct 2013 - Guns don't shoot and kill people. ... was shot in the leg when his dog jumped into his boat, landing on the man's shotgun and discharging it.

Friend with gun saves dog breeder from robber, kills thief

www.usatoday.com/story/news/nation/2015/01/30/dog.../22597495/

30 Jan 2015 - STONE MOUNTAIN, Ga. — A man who answered an online ad to buy a dog was killed Friday after attempting to rob the sellers, police said.

Rochester man allegedly shoots and kills dog - WMUR.com

www.wmur.com/news/rochester-man-allegedly...kills-dog/31597440/

3 Mar 2015 - A Rochester man was arrested Monday after he allegedly shot and killed a

Formal Semantics and Compositionality

- It is well known that linguistic structures are **compositional**, in that simpler elements are combined to form more complex ones



- It is through the compositional quality of the phrase that meaning and a cognitive reference are formed



Logic-based frameworks in Formal Semantics

(Montague, 1974)

- Premise: No theoretically relevant difference between artificial (formal) and natural (human) languages

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 - complex meanings are also constructed from simple meanings
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 - corresponding to Frege's Principle of Compositionality
- Note: This study is not necessarily interested in cognitive aspects, but an *elegant and simple mathematical framework* for natural language

Principle of Compositionality

(Frege, 1884)

The whole meaning of a phrase can be described according to the functional interdependency of the meanings of its well-formed parts.

1. *red manatee*
2. *fake gun* (not a gun)
3. *the horse ran* vs. *the color ran*

Frege (1884) cautions never to ask for the meaning of a word in isolation but only in the context of a statement

Principle of Compositionality

(Partee, 1995)

Partee (1995) refines the principle further by taking into account the role of syntax

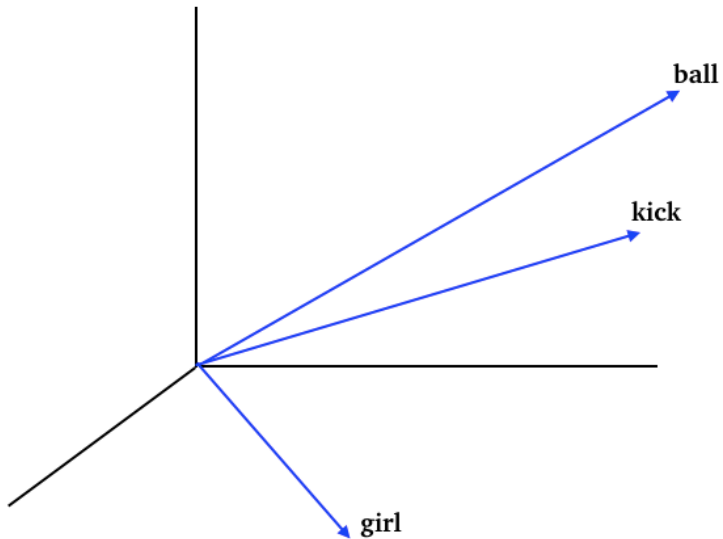
- The meaning of the whole is a function of the meaning of the parts and of the way they are syntactically combined
- In other words, each syntactic operation of a formal language should have a corresponding semantic operation
- Examples from Landauer et al. (1997)
 1. It was not the sales manager who hit the bottle that day, but the office worker with the serious drinking problem.
 2. That day the office manager, who was drinking, hit the problem sales worker with the bottle, but it was not serious.

A question of degree

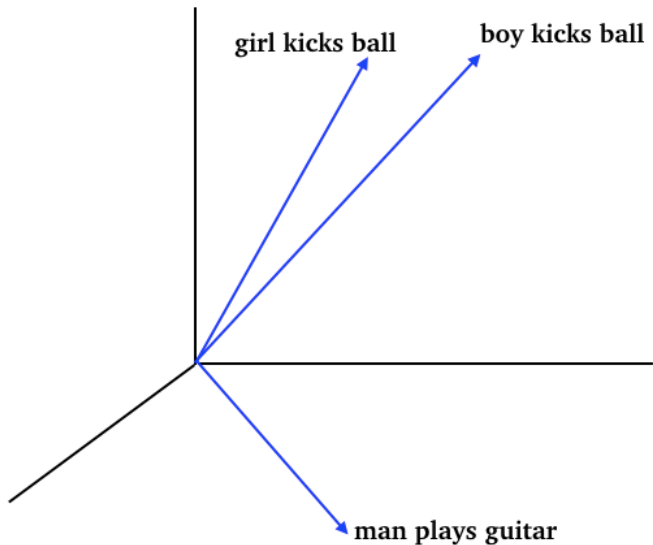
Compositionality is a matter of degree rather than a binary notion, since linguistic structures range across...

- **Fully compositional**, such as *black hair*
 - clear sense of set intersection
- **Partly compositional**: syntactically fixed expressions, such as *take advantage*, in which the constituents can still be assigned separate meaning
- **Non-compositional** phrases, such as *kick the bucket*, or **multiword expressions**, such as *by and large* whose meaning cannot be distributed across their constituents.

Word Space



From words to phrases



The "infinity" of sentence meaning

When you've got means such a see to me. I know a mouse, and he hasn't got a house. Who got all those things in your hair?
I was a king who ruled the land. Doctor Robert, you're a new and better man. There's one far you, nineteen for me. He'll be found when you're around. But now he's resigned to his
I was a boy who ruled the land. Ring my friend, I said you call Doctor Robert. Because I'm the taxman, yeah I'm the taxman, lying there and staring at the ceiling. If you don't want to pay some more. No fair, you can't hear me but I can you. But listen to the colour of your dreams. I've got
I was a boy who ruled the land. Good Day Sunshine. The black and green scarecrow is sadder than me. No fair, you can't hear me but I can you. But listen to the colour of your dreams. I've got
I was a boy who ruled the land. 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. Watching her eyes and hoping I'm always there. Leave me where
I was a boy who ruled the land. So we sailed up to the sun Till we found the sea of green. So play the game Existence to the end Of the beginning. What does he care?
I was a boy who ruled the land. There's people standing round Who serve 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 make them:
I was a boy who ruled the land. At the sky, look at the river Isn't it good? Cleaner Rigby died in the church and was buried along with her name. Eating, sleeping, drinking their wine. Someone is speaking but she doesn't
I was a boy who ruled the land. 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 butterflies cup the light Sleeping on a dandelion. As we
I was a boy who ruled the land. I'm blue never care but to love her is to need her everywhere. Everybody seems to think I'm lazy. Please, don't spoil my day. I'm miles away And after I'm all sleeping. Darning his socks in the
I was a boy who ruled the land. I'm blue and sea of green is our yellow submarine. Waits at the window, wearing 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. I
I was a boy who ruled the land. I'm blue 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
I was a boy who ruled the land. I'm blue lead works for the national health. Doctor Robert, Now my advice for those who die Declare the ponies on your eyes Because I'm the taxman, yeah. I'm the taxman.
I was a boy who ruled the land. I'm blue only have to read the lines They're scribbled black and everything shines. Oh Mother, tell me more. You can't see me But I can you. In the trust
I was a boy who ruled the land. I'm blue Cash 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!
I was a boy who ruled the land. I'm blue and limpid green The sounds surrounds the joy waters underground Lime and limpid green The sounds surrounds the joy waters underground. Waiting for a sleepy feeling... Please, don't spoil my day. I'm miles aw
I was a boy who ruled the land. I'm blue The seven is the number of the young light. Blinding signs flap. Flicker, flicker. Flicker, flicker. Flicker. Flicker. He does everything he can. Doctor Rob
I was a boy who ruled the land. I'm blue range returns success. Yes they did. Because I'm the taxman, yeah. I'm the taxman. Ah, look at all t
I was a boy who ruled the land. I'm blue ten I'm in the middle of a dream Stay in bed. float up stream. When your prized possessions start to wear you down Look in my direction. I'll be round Alone in the clouds all b
I was a boy who ruled the land. I'm blue ten I wake up early in the morning Lift my head. I'm still yawning. Action brings good fortune. I
I was a boy who ruled the land. I'm blue I good? Be a big cat Be a ship's cat. He didn't care. It is not dying. All the lonely p
I was a boy who ruled the land. I'm blue d and black. Lings return. Leaf for go to sea. All the lonely p
I was a boy who ruled the land. I'm blue news she's looking fine. g around on the ground. All the lonely people Where do they all come from? Even though you k
I was a boy who ruled the land. I'm blue ce a couple if you wish. u anything, everything if you want things. Wandering and dreaming The words have different meaning. He stood in a
I was a boy who ruled the land. I'm blue Good Day Sunshine. No one was saved. When your bird is broken will it bring you down you may be awoken. I'll be round. I feel good in a special way. Because you're making me fee
I was a boy who ruled the land. I'm blue ou don't understand what I said. Keeping an eye on the world going by my window. I said. Well, we
I was a boy who ruled the land. I'm blue or 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
I was a boy who ruled the land. I'm blue alway scare Dan Dare who's there? We all live in our yellow submarine. Nobody can deny that there's something there. I don't mind. I think they're crazy. Doctor kindly tell your wife that I'm alive - flowers thrive - realize - I
I was a boy who ruled the land. I'm blue nd 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
I was a boy who ruled the land. I'm blue I 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 ever/where
I was a boy who ruled the land. I'm blue ps that make me feel that I'm mad. You tell me that you've got everything you want And your bird can sing. You tell me that you've heard every sound there is And your bird can swim. Who is it for? Jupiter and
I was a boy who ruled the land. I'm blue down all thoughts, surrender to the void. Floating down, the sound surrounds Around the joy waters underground. If you drive a car, I'll tax the street. If you try to sit, I'll tax your seat. And we lived bene
I was a boy who ruled the land. I'm blue get too cold I'll tax the heat. If you take a walk, I'll tax your feet. Why'd you 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 a
I was a boy who ruled the land. I'm blue one what it is to be sad. Running everywhere at such a speed Till 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
I was a boy who ruled the land. I'm blue inf she's making me feel like I've never been born. He wore a scarlet tunic. A blue green hood. It looked quite good. Take a drink from his special cup. Doctor Robert. If you're down he'll pick you up. Doctor Rob
I was a boy who ruled the land. I'm blue I was a boy who ruled the land. I'm blue These remain my hands though her ha

Vectors are too “small”

“You can’t cram the meaning of a whole sentence into a single vector!” (Ray Mooney)

Sentence vectors?

- A fixed-size vector can't hold enough information (languages are infinite)
 - are languages really infinite? (not in practice, and maybe not in theory¹)
 - the sentence vector could be a structured object (e.g. density matrix)
 - the sentence space doesn't have to solve all of semantics (necessarily)
 - (and wouldn't this argument apply to lexical semantics as well?)

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- What about (formal) semantics?
 - compositionality, inference, logical operators, quantification, ...

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Element-wise operations on word vectors: Addition

black	0.34	0.64	...	-0.06	...
--------------	------	------	-----	-------	-----

+

cat	0.15	0.29	...	-0.03	...
------------	------	------	-----	-------	-----

=

black + cat	0.49	0.93	...	-0.09	...
------------------------------	------	------	-----	-------	-----

Element-wise operations on word vectors: Multiplication

black	0.34	0.64	...	-0.06	...
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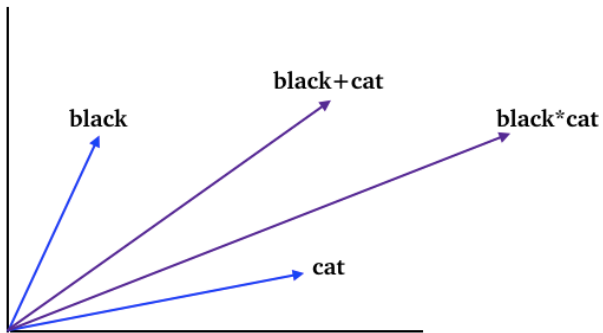
\odot

cat	0.15	0.29	...	-0.03	...
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=

black	0.05	0.19	...	-0.002	...
\odot cat					

Class Discussion: Pros and Cons?



A *functional* approach to composition in DS

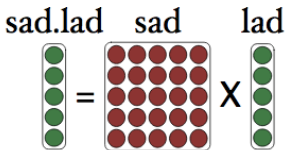
Baroni & Zamparelli EMNLP 2010, Baroni et al. LILT 2014, Paperno et al. ACL 2014
See also Coecke et al. LA 2010, Socher et al. EMNLP 2012

- Composition carried out by words that operate as **functions** on the representation of their input **arguments**

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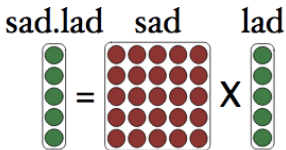
- Composition carried out by words that operate as **functions** on the representation of their input **arguments**
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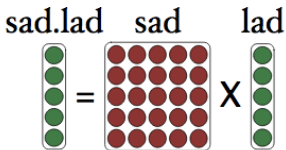


- Approach generalizes to multiple-argument functions (e.g., transitive verbs) through the tools of multi-linear algebra

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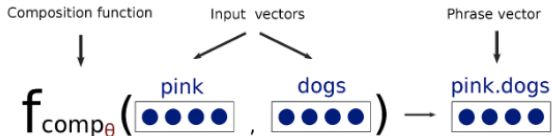
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- Approach generalizes to multiple-argument functions (e.g., transitive verbs) through the tools of multi-linear algebra
- Efficient methods to induce function representations from natural data (training corpus) in an unsupervised manner

General estimation of composition

Dinu, Pham & Baroni 2013; also: Guevara 2010, Baroni & Zamparelli 2010



- Use (reasonably frequent) corpus-extracted phrase vectors to learn the parameters of composition functions:

$$\theta^* = \underset{\theta}{\operatorname{argmin}} \|\mathbf{P} - f_{\text{comp}_{\theta}}(\mathbf{U}, \mathbf{V})\|^2$$

$\mathbf{P}/\mathbf{U}, \mathbf{V}$ - Phrase/Input occurrence matrices

The linear Full Additive composition model

Guevara GEMS 2010, Zanzotto et al. COLING 2010

- Given two word vectors \vec{u} and \vec{v} in syntactic relation R compute phrase vector \vec{p}

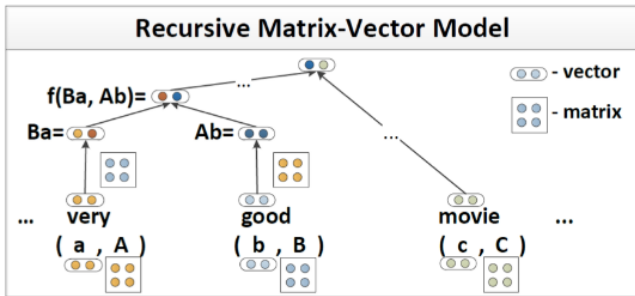
$$\vec{p} = \mathbf{A}_R \vec{u} = \mathbf{B}_R \vec{v} = [\mathbf{A}_R, \mathbf{B}_R] \begin{bmatrix} \vec{u} \\ \vec{v} \end{bmatrix}$$

- Parameters: syntax-dependent matrices \mathbf{A}_R and \mathbf{B}_R
- General estimation from corpus-extracted phrase and word vectors as least-squares regression problem:

$$\operatorname{argmin}_{\mathbf{A}_R, \mathbf{B}_R} \|\mathbf{P} - [\mathbf{A}_R, \mathbf{B}_R] \begin{bmatrix} \mathbf{U} \\ \mathbf{V} \end{bmatrix}\|^2$$

Composition in Neural Models

Socher et al. (2012, 2013)



- assigning a vector and a matrix to every word
- learning an input-specific, nonlinear, compositional function for computing vector and matrix representations for multi-word sequences of any syntactic type

Functional composition in morphology

Lazaridou et al. ACL 2013, Marelli & Baroni PsychRev 2015

<i>word</i>	<i>nearest neighbors</i>
carve.er	potter, engraver, goldsmith
broil.er	oven, stove, cooking, kebab, done
column	arch, pillar, bracket, numeric
column.ist	publicist, journalist, correspondent
industry.al	environmental, land-use, agriculture
industry.ous	frugal, studious, hard-working
nervous	anxious, excitability, panicky
nerve.ous	bronchial, nasal, intestinal

Phrase similarity data

Mitchell & Lapata (2008, 2010), Grefenstette and Sadrzadeh (2011)

AN	national government	cold air	1
	new information	further evidence	6
NN	environment secretary	party leader	5
	telephone number	future development	2
VO	offer support	provide help	7
	fight war	win battle	5

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	fight war	win battle	5
SV	fire glows	fire burns	6
	face glows	face burns	1
	discussion strays	discussion digresses	7
	child strays	child digresses	2
SVO	table shows result	table expresses result	7
	map shows location	map expresses location	1

Similarity intuitions (often) affected by verb-argument interactions

Results

Rank correlation (ρ) with subject scores

	SV	SVO
Verb only	0.06	0.08
Vector addition	0.13	0.12
Functional approach	0.23	0.32
Human	0.40	0.62

Sentence Similarity Data

- Semantic Textual Similarity (STS) datasets from SEMEVAL
- MSR Par dataset (1,500 pairs):
 - The fines are part of failed Republican efforts to force or entice the Democrats to return.
 - Perry said he backs the Senates efforts, including fines, to force the Democrats to return. 2.8
 - The bill says that a woman who undergoes such an abortion couldn't be prosecuted.
 - A woman who underwent such an abortion could not be prosecuted under the bill. 5.0

SICK: the Turing Test of compositional semantics

Marelli et al. 2014, 10K sentence pairs

sentence pair	relatedness	entailment
two men are taking a break from a trip on a snowy road two men are taking a break from a trip on a road covered by snow	4.9	A entails B
the girl is spraying the plants with water the girl is watering the plants	4.6	A entails B
the turtle is following the fish the fish is following the turtle	3.8	A contradicts B
the girl is spraying the plants with water the boy is spraying the plants with water	3.4	neutral
masked people are looking in the same direction in a forest a little girl is looking at a woman in costume	1.3	neutral

SICK Performance

Marelli et al. 2014

- Entailment: evaluated through classification accuracy wrt majority annotation
- Relatedness: evaluated through Pearson r with averaged subject rating

Model	relatedness	entailment
Majority baseline	NA	57%
Vector addition	0.70	74%
Functional approach	0.57	72%

What's going on?

- Word order is largely redundant
- Proportion of times a word sequence appears in more than one order in the British National Corpus (100M words of written and spoken English): **0.1%**
 - (Counting only sequences that form full sentences)
- Even in these cases, meaning is rarely deeply affected:
 - *however this is not the case*
his however is not the case
 - *yesterday Mr. Andrews said it will never go away*
Mr. Andrews said yesterday it will never go away
 - *no thank you I'm fine*
no I'm fine thank you

What's going on?

Context-based representations might capture typical syntactic roles of words

*Every **boy** in the country will be **kicking** a soccer **ball** about.*

*A man and a **boy** were **kicking** a football through the foot-high grass.*

*The **boys** were **kicking** a cheap rubber **ball**.*

*The only variation was during the first ten days, when players were not allowed to **kick** a **ball**.*

*After a few laps of the track we could **kick** a **ball** about or even have a go at throwing a javelin.*

Popular tasks and core sentence meaning

1. Paraphrasing

A woman cuts up broccoli.

A woman is cutting broccoli.

A woman is slipping in the water-tub.

A woman is lying in a raft.

2. Sentiment analysis

3. Question Answering

4. Entailment (RTE4, SICK)

5. Modeling relations between sentences

Assignment: Start composing!

- Get to know the DISSECT toolkit² (python)
 - Install the toolkit (link in course website)
 - Follow the tutorial on course website to become familiar with composition functions
 - Complete assignment posted online (*tbp*)

²G. Dinu, N. The Pham, and M. Baroni. 2013. DISSECT: DIStributional SEMantics Composition Toolkit. In *Proceedings of the System Demonstrations of ACL 2013*, Sofia, Bulgaria.

Assignment: Readings

- Background Readings
 - Baroni et al. (2014). Don't count, predict! A systematic comparison of context-counting vs. context-predicting semantic vector
 - Mikolov et al. (2013). Efficient Estimation of Word Representations in Vector Space
 - Mikolov et al. (2013). Linguistic Regularities in Continuous Space Word Representations
 - Levy et al. (2015) Improving Distributional Similarity with Lessons Learned from Word Embeddings
- Readings
 - Socher et al. (2012). Semantic Compositionality through Recursive Matrix-Vector Spaces (Slides)
 - Levy & Goldberg (2014, CoNLL best paper) Linguistic Regularities in Sparse and Explicit Word Representations (Slides)
 - Moritz Hermann & Blunsom (2014, ACL). Multilingual Models for Compositional Distributed Semantics (Slides)
 - Faruqui et al. (2015, best paper at NAACL). Retrofitting Word Vectors to Semantic Lexicons
 - Norouzi et al. (2014, ICLR) Zero-Shot Learning by Convex Combination of Semantic Embeddings (Slides)

Thanks, see you in next week!

<https://www.vecchi.com/eva/teaching/modelingmeaning.html>