What are the consequences of linguistic diversity for perception and thought?

Terry Regier

UC Berkeley
November 6, 2018
Semantic typology and the Sapir-Whorf hypothesis in computational perspective

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Bowerman & Pederson, 1992; Levinson et al., 2003
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Semantic typology

What category systems are found in the world’s languages, & why?

Bowerman & Pederson, 1992;
Levinson et al., 2003
Semantic typology
What category systems are found in the world’s languages, & why?

Sapir-Whorf hypothesis
Do native-language categories affect non-linguistic thought?

Bowerman & Pederson, 1992; Levinson et al., 2003
My goal today

Triangulate in on these questions from three perspectives.
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**Triangulate** in on these questions from three perspectives.

![Venn diagram with Language and Cognition sets intersecting](image-url)
My goal today

Triangulate in on these questions from three perspectives.

Language

Cognition

Computation
Semantic typology

The Sapir-Whorf hypothesis
Semantic typology

The Sapir-Whorf hypothesis
**Question:** Do word meanings across languages reflect a universal conceptual repertoire – or wide cultural variation?
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Existing evidence: Mixed – both universal tendencies, and cross-language variation.
**Question:** Do word meanings across languages reflect a universal conceptual repertoire – or wide cultural variation?

**Existing evidence:** Mixed – both universal tendencies, and cross-language variation.

**Claim:** Systems of word meanings support efficient, informative communication. Accounts for universals & variation.
Central idea

communication quality
Central idea

communication quality
Central idea

Haspelmath 1999; Croft 2003; Hopper & Traugott, 2003, ...
Central idea

This simple idea:
Central idea

This simple idea:

1. Accommodates data from different semantic domains traditionally treated separately;
Central idea

This simple idea:

1. Accommodates data from different semantic domains traditionally treated separately;

2. Explains several domain-specific generalizations from the literature.
1. Color
2. Kinship, space, number
3. Words for snow
1. Color
2. Kinship, space, number
3. Words for snow
1. Color

2. Kinship, space, number

3. Words for snow

Paul Kay, Charles Kemp, Naveen Khetarpal, Naftali Tishby, Noga Zaslavsky

*PNAS, 2007*  
*Language, 2009*  
*PNAS, 2018*
Color categories across languages
Color categories across languages

Berinmo, Papua New Guinea
Color categories across languages

Universals

Berinmo, Papua New Guinea

Sirionó, Bolivia

Jicaque, Honduras
Color categories across languages

Universals

Berinmo, Papua New Guinea

Sirionó, Bolivia

Jicaque, Honduras

Variation

Wobé, Ivory Coast

Chavacano, Philippines

Karajá, Brazil
Informative communication
Informative communication
Informative communication
Informative communication

red
Informative communication

red
Words should have meanings that allow accurate mental reconstruction by listener of speaker’s intended meaning.

Jameson & D’Andrade, 1997
Reconstruction error for object $t$: $e(t) = D_{KL}(s \| l)$
Reconstruction error for object $t$: $e(t) = D_{KL}(s \parallel l)$

Reconstruction error over domain universe $U$: $E = \sum_{t \in U} n(t)e(t)$
Reconstruction error for object \( t \): \[ e(t) = D_{KL}(s \parallel l) \]

Reconstruction error over domain universe \( U \): \[ E = \sum_{t \in U} n(t) e(t) \]
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Reconstruction error over domain universe \( U \): \[ E = \sum_{t \in U} n(t)e(t) \]

**Informative communication** = low reconstruction error

Piantadosi et al., 2011; Fedzechkina et al., 2012; Baddeley & Attewell, 2009
Optimal, n=3
Optimal, n=3

Wobé, Ivory Coast
Optimal, n=3

Wobé, Ivory Coast

Optimal, n=4

Culina, Peru/Brazil

Optimal, n=5

Cayapa, Ecuador

Optimal, n=6

Buglere, Panama
Explaining known constraints
Explaining known constraints

Color terms in the world’s languages appear in a specific order:

\[
\begin{align*}
\text{white} & < \text{red} & < \text{green} & < \text{blue} & < \text{brown} & < \\
\text{black} & & \text{yellow} & & \text{purple} & & \text{pink} & & \text{orange} & & \text{grey}
\end{align*}
\]

Berlin & Kay 1969
Explaining known constraints

Color terms in the world’s languages appear in a specific order:

\[
\begin{align*}
\text{white} & < \text{black} < \text{red} < \text{green} < \text{yellow} < \text{blue} < \text{brown} < \text{purple} < \\
& \quad \text{pink} < \text{orange} < \text{grey}
\end{align*}
\]

Berlin & Kay 1969

This order is explained by informativeness:

...
Many languages don’t fit exactly

Abidji, Ivory Coast

Gunu, Cameroon

Karajá, Brazil

Cree, Canada
Many languages don’t fit exactly

Abidji, Ivory Coast

Gunu, Cameroon

Karajá, Brazil

Cree, Canada

But almost all are at least near-optimally informative.
Recent findings

- An independent information-theoretic efficiency principle also explains graded categories and continuous evolutionary progression (Zaslavsky et al., 2018, *PNAS*)

<table>
<thead>
<tr>
<th>Culina</th>
<th>Agarabi</th>
<th>Dyimini</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
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<tr>
<td>IB</td>
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</tbody>
</table>
Recent findings

- An **independent** information-theoretic efficiency principle also explains **graded** categories and **continuous** evolutionary progression (Zaslavsky et al., 2018, *PNAS*)

- Color naming reflects both **perceptual structure** and **communicative need** (Zaslavsky et al., 2018, *Cognitive Science conference*)
Initial conclusions: Color

- Universals and variation in color naming across languages are explained by the principle of informative communication.

- The same principle also explains existing descriptive generalizations.
1. Color

2. Kinship, space, number

3. Words for snow
Kinship
Kinship

Charles Kemp

Science, 2012
Alice (♀)
Kinship

Alice (♀)

D  S

DD  DS  SD  SS

Charles Kemp

Science, 2012
Kinship

Charles Kemp

Science, 2012
English
MM, DD, DS fall in the same category: reciprocal MM

Representation:
Kinship grammars, based on assumed universal primitives from literature.

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\[
\begin{align*}
\text{mother}(x, y) & \rightarrow \text{PARENT}(x, y) \land \text{FEMALE}(x) \\
\text{father}(x, y) & \rightarrow \text{PARENT}(x, y) \land \text{MALE}(x) \\
\text{daughter}(x, y) & \rightarrow \text{CHILD}(x, y) \land \text{FEMALE}(x) \\
\text{son}(x, y) & \rightarrow \text{CHILD}(x, y) \land \text{MALE}(x) \\
\text{sister}(x, y) & \rightarrow \exists z \, \text{PARENT}(z, x) \land \text{daughter}(y, z) \\
\text{brother}(x, y) & \rightarrow \exists z \, \text{PARENT}(z, x) \land \text{son}(y, z) \\
\text{aunt}(x, y) & \rightarrow \exists z \, \text{sister}(x, z) \land \text{PARENT}(z, y) \\
\text{uncle}(x, y) & \rightarrow \exists z \, \text{brother}(x, z) \land \text{PARENT}(z, y) \\
\text{grandmother}(x, y) & \rightarrow \exists z \, \text{mother}(x, z) \land \text{PARENT}(z, y) \\
\text{grandfather}(x, y) & \rightarrow \exists z \, \text{father}(x, z) \land \text{PARENT}(z, y) \\
\text{granddaughter}(x, y) & \rightarrow \exists z \, \text{daughter}(x, z) \land \text{CHILD}(z, y) \\
\text{grandon}(x, y) & \rightarrow \exists z \, \text{son}(x, z) \land \text{CHILD}(z, y)
\end{align*}
\]

Representation: Kinship grammars, based on assumed universal primitives from literature.

Need probability: Estimated via corpus frequencies in English and German.

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Tradeoff: Between informativeness and simplicity.

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Explaining known constraints

More semantic distinctions in:
1. Near relatives (e.g. siblings), relative to distant relatives (e.g. maternal siblings)

Greenberg 1966
Explaining known constraints

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\[ n(i) \propto \]

Greenberg 1966
Explaining known constraints

More semantic distinctions in:
1. Near relatives (e.g. siblings), relative to distant relatives (e.g. maternal siblings)

\[ E = \sum_{i \in U} n(i)e(i) \]
Explaining known constraints

More semantic distinctions in:

1. Near relatives (e.g. siblings), relative to distant relatives (e.g. maternal siblings)
2. Ascending generations (e.g. grandparents), relative to descending generations (e.g. grandchildren)

$E = \sum_{i \in U} n(i) e(i)$

Greenberg 1966
Explaining known constraints

More semantic distinctions in:

1. Near relatives (e.g. siblings), relative to distant relatives (e.g. maternal siblings)

2. Ascending generations (e.g. grandparents), relative to descending generations (e.g. grandchildren)

\[ E = \sum_{i \in U} n(i)e(i) \]

Greenberg 1966
Spatial terms
Spatial terms
Spatial terms

**Data:** 9 languages (Levinson et al. 2003), + English, + Maijîki.

**Similarity:** Assessed by pile-sorting of spatial scenes, by speakers of English and Dutch.

Maijîki  
Basque  
Yukatek

Khetarpal et al., 2013.
Numeral systems
Xu & Regier, 2014.
**Data:** 25 languages from Comrie 2013 and Pica et al. 2004; all 20 “restricted” systems + 5 others.
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Representation: Numeral system grammars, grounded in semantic primitives of exact and approximate numerosity.
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**Need probabilities:** Google n-gram English corpus, 2000.

Xu & Regier, 2014.
Numeral systems

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Xu & Regier, 2014.
Interim conclusions

Semantic systems of color, kinship, space, and number in the world’s languages support efficient communication.
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Semantic systems of color, kinship, space, and number in the world’s languages support **efficient communication**.

Wide but constrained variation may reflect **adaptation** to functional pressure.
1. Color

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3. Words for snow
1. Color
2. Kinship, space, number
3. Words for snow
ENGLISH - ONE WORD (SNOW)
ESKIMO - THREE WORDS

Benjamin Lee Whorf, 1956
“unredeemed piffle”

Geoffrey Pullum, 1991
If the Eskimos have 500 words for snow, then surely we in our internet-stuff age should have 1000 words for "meh"!

T-REX THAT LINGUISTIC PREMISE IS ACTUALLY FULL OF LIES

*gasp*
Environment

Communicative need

Category system
snow (English)
snow (English)

ثلج (Arabic)
snow (English)

ثلج (Arabic)
snow (English)

ثلج (Arabic)
Environment \rightarrow \text{Communicative need} \rightarrow \text{Category system}
Environment

Communicative need

Category system
Environment

Communicative need

Category system
Environment

Communicative need

Category system
different terms for ice, snow

Regier, Carstensen, & Kemp, 2016, *PLOS ONE*
same term for ice, snow

different terms for ice, snow

Regier, Carstensen, & Kemp, 2016, *PLOS ONE*
same term

different terms

mean temperature (°C)

same term for ice, snow

different terms for ice, snow

Regier, Carstensen, & Kemp, 2016, *PLOS ONE*
Similar results from another cross-language dataset.

Regier, Carstensen, & Kemp, 2016, *PLOS ONE*
Similar results from another cross-language dataset.

Twitter analyses confirm that need probability for ice and snow drops off with mean temperature.

Regier, Carstensen, & Kemp, 2016, PLOS ONE
Environment → Communicative need → Category system
Conclusions: Semantic typology
Conclusions: Semantic typology

- Semantic systems across languages may reflect functional adaptation in support of efficient communication.
Conclusions: Semantic typology

- Semantic systems across languages may reflect functional adaptation in support of efficient communication.

- Local communicative needs may leave their imprint on semantic systems, by modulating pressure for efficiency.
Semantic typology

The Sapir-Whorf hypothesis
Semantic typology

The Sapir-Whorf hypothesis

Emily Cibelli, Yang Xu, Joe Austerweil, Tom Griffiths

PLOS ONE, 2016
WIREs Cog. Sci., 2017
The Sapir-Whorf hypothesis
The Sapir-Whorf hypothesis

Our thoughts are shaped by our native language, and speakers of different languages therefore think differently.
The Sapir-Whorf hypothesis

Controversial
The Sapir-Whorf hypothesis

Controversial

- Appears to deny the possibility of a universal groundwork for cognition.
The Sapir-Whorf hypothesis

Controversial

• Appears to deny the possibility of a universal groundwork for cognition.
• Evidence for it has not always reliably replicated.
The Sapir-Whorf hypothesis

Controversial

• Appears to deny the possibility of a universal groundwork for cognition.
• Evidence for it has not always reliably replicated.

Claim: Viewing this hypothesis through the lens of probabilistic inference has the potential to resolve both issues.
None | Max

Whorf
Uncertainty

None  Max

Whorf
Category adjustment model
Huttenlocher et al., 1991; Bae et al., 2015; Persaud & Hemmer, 2014
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Bias toward prototype

Category adjustment model
Huttenlocher et al., 1991; Bae et al., 2015; Persaud & Hemmer, 2014
Bias toward prototype
More bias with more uncertainty

Category adjustment model
Huttenlocher et al., 1991; Bae et al., 2015; Persaud & Hemmer, 2014
Ideas with broad application
Ideas with broad application

Memory for when an event occurred, affected by temporal categories. Huttenlocher et al. 1988
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Memory for when an event occurred, affected by temporal categories. Huttenlocher et al. 1988

Judgments of object size, integrating cues from vision and touch. Ernst and Banks 2002
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Memory for when an event occurred, affected by temporal categories. Huttenlocher et al. 1988

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Predictions
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- **English speakers** should show bias in color reconstruction, toward prototypes of English color terms.
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Cibelli et al., 2016

_PLOS ONE_
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Predictions

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✓

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• Model should account for existing **cross-language** data on color memory.
Predictions

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English vs. Berinmo

Davidoff et al., 1999, *Nature*
• Color discrimination from memory

Davidoff et al., 1999, *Nature*
English vs. Berinmo

- Color discrimination from memory
- Cross-category vs. within-category

Davidoff et al., 1999, *Nature*
English vs. Berinmo

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Davidoff et al., 1999, Nature
- **Color discrimination from memory**
- **Cross-category vs. within-category**

Davidoff et al., 1999, *Nature*
Data from Roberson et al. (2000)
One model per language
Data from Roberson et al. (2000)
One model per language
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Predictions

- **English speakers** should show bias in color reconstruction, toward prototypes of English color terms.
- Bias should be greater with delay than without.
- Model should account for existing **cross-language** data on color memory.
Cross-language differences in color memory are consistent with reconstruction bias under uncertainty, guided by native-language categories, in a universal color space.
Conclusions: Sapir-Whorf hypothesis
Conclusions: Sapir-Whorf hypothesis

Viewing the Sapir-Whorf hypothesis in terms of probabilistic inference:
Conclusions: Sapir-Whorf hypothesis

Viewing the Sapir-Whorf hypothesis in terms of probabilistic inference:

- May resolve two major sources of controversy concerning this hypothesis
Conclusions: Sapir-Whorf hypothesis

Viewing the Sapir-Whorf hypothesis in terms of probabilistic inference:

• May resolve two major sources of controversy concerning this hypothesis

• Links this hypothesis to independent principles and phenomena
Supported by:

- NSF and DTRA
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