The biological and cultural evolution of spatial cognition

Evidence from semantic typology

Jürgen Bohnemeyer;[1] Katharine Donelson;[1]

Yen-Ting Lin;[2] Randi Moore[1]

Symposium *From fieldwork to modeling:*
Explaining the variability of linguistic spatial referencing systems
ICSC 2018 – 7th International Conference on Spatial Cognition
Sapienza University Rome , September 12, 2018

1 University at Buffalo
The State University of New York

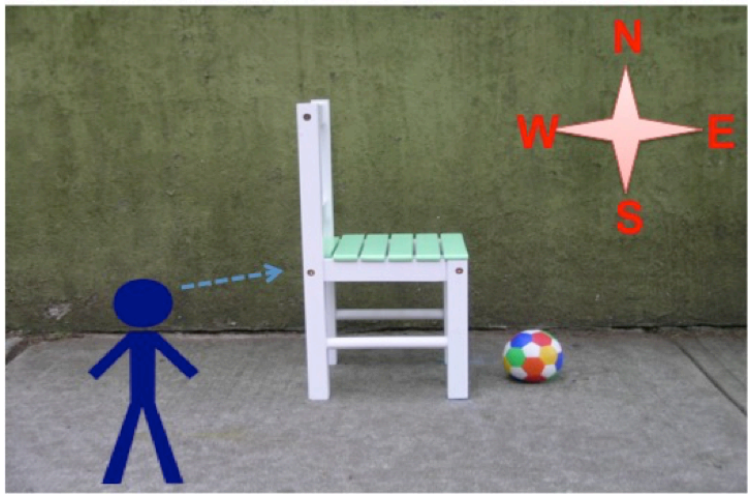
2 National Sun Yat-sen University

SYNOPSIS

- The typological distribution of referential practices
- Study I: reference frame use in recall memory
- Study II: reference frame use in discourse
- An evolutionary model
- Summary

THE TYPOLOGICAL DISTRIBUTION OF REFERENTIAL PRACTICES

- classifying spatial frames of reference



Cf. Bohnemeyer & O'Meara 2011; Carlso
Radvansky & Irwin 1993; Danziger 2011;
Friederici & Levelt 1990; Gallistel 1990; L
1984, 1996; Levinson 1996, 2003; Terrill &
Burenhult 2008; *inter alia*

Figure 1. *Reference frames and anchors*

Table 1. *Exemplifying frame types in Figure 1*

Frame type	Anchor	Description of Figure 1
Egocentric	Observer	*The ball is left of the chair*
Geocentric	Environmental gradient	*The ball is east of the chair*
Object-centered intrinsic	Reference entity (ground)	*The ball is in front of the chair*

- cross-population variation in frame use for small-scale space

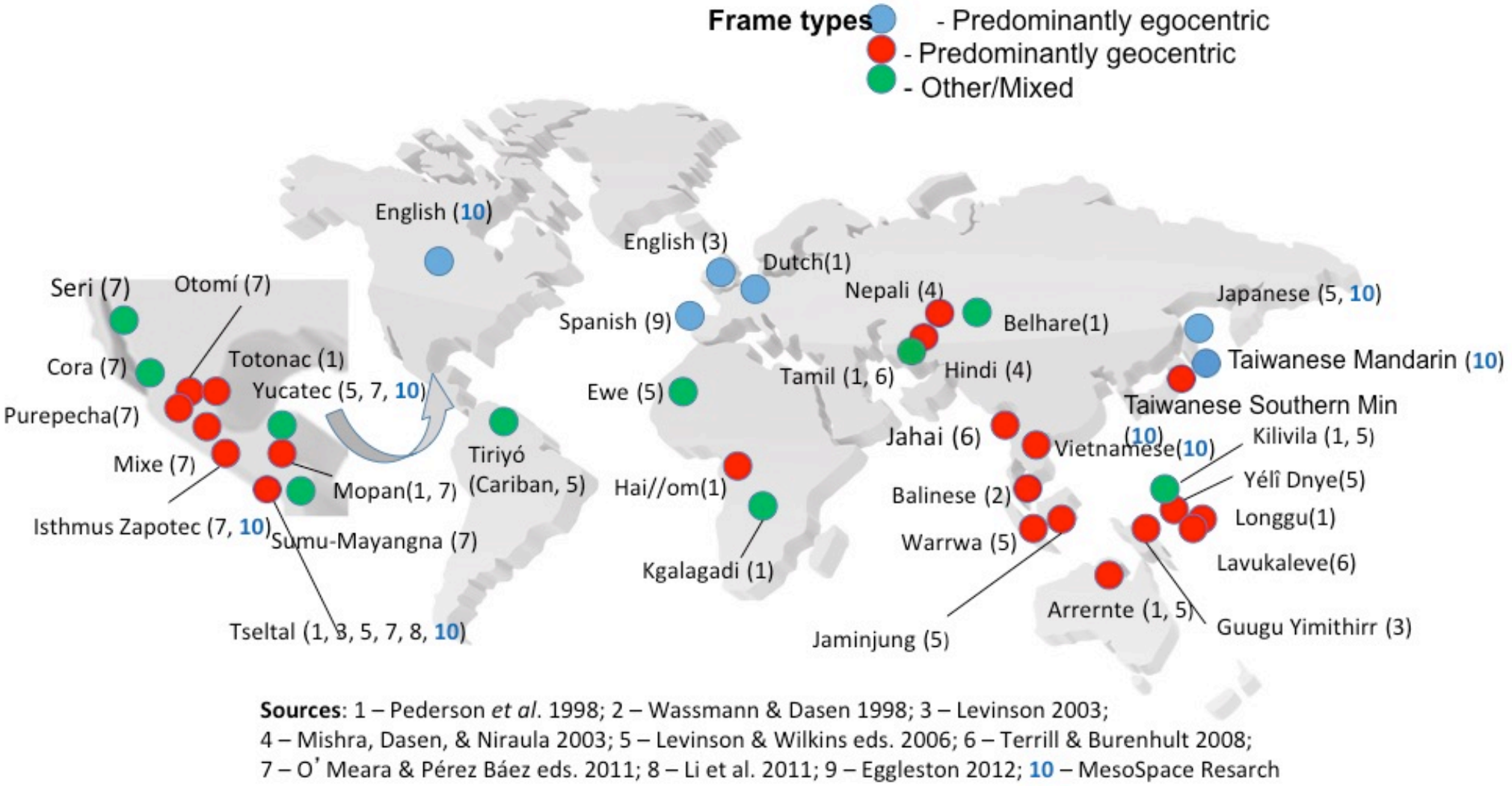


Figure 2. *Reference frame use in small-scale horizontal space across speech communities*

- how to account for this variation - existing proposals

Table 2. *Evidence from prior studies for factors influencing frame use*

Variable	Previously attested in
Age	Eggleston et al (2011); Polian & Bohnemeyer (2011)
First language (L1)	Bohnemeyer et al (2014, 2015); Donelson (2018); Eggleston (2012); Haun et al (2011); Levinson (1996, 2003); Lin (2017); Majid et al (2004); Pederson et al (1998); Wassmann & Dasen (1998)
Formal education	Lin (2017); Mishra et al (2003)
Gender	Ameka & Essegbey (2006); Bohnemeyer (2011); Bohnemeyer & Stolz (2006); Le Guen (2011)
Literacy	Danziger & Pederson (1998)
Occupation	Majid et al (2004); Shapero (2016)
Second language (L2)	Bohnemeyer et al (2015); Lin (2017)
Topography	Lin (2017); Moore (2018); Palmer (2015); Palmer et al (2017); Polian & Bohnemeyer (2011); Wassmann & Dasen (1998)
Urbanization and population density	Mishra et al (2003); Pederson et al (1998)

- the problem: these factors are massively confounded
  - different languages are spoken in different places
    - with different topographies
      and population geographies
    - by populations differing in average levels
      of literacy and education
    - etc.

- the method for unconfounding
  - multi-population studies
  - regression analyses on the results
    - predicting frame type use as dependent variable against the proposed factors as independent variables

- this presentation: two such studies
  - Study 1: frame use in recall memory
  - Study 2: frame use in discourse
- the study populations

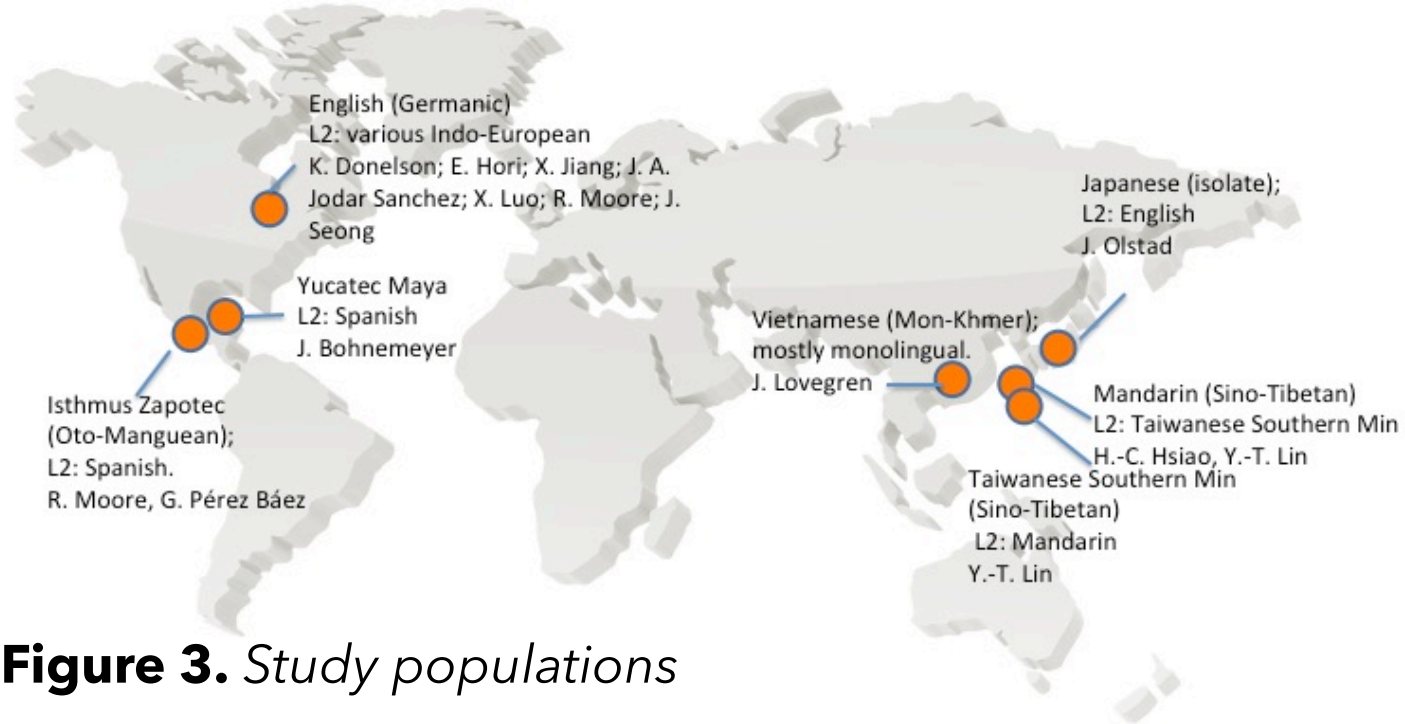


Figure 3. *Study populations*

- this presentation: two such studies (cont.)
  - the field sites

Table 3. *Geographic variables*

Participants by L1	Locality	Country	Density (population/km^2)	Density Log Scale	Topographic Classification
English	Buffalo	United States	2569	3.41	Flat
Isthmus Zapotec	La Ventosa	Mexico	3126	3.5	Flat
Japanese	Setagaya	Japan (Honshu)	15551	4.19	Flat
	Naha	Japan (Okinawa)	8244	3.92	Hills
	Yomitan	Japan (Okinawa)	1200	3.08	Hills
	Fujinomiya	Japan (Honshu)	339	2.53	Low Mountains
	Aizuwakamatsu	Japan (Honshu)	321	2.51	Low Mountains
	Nago	Japan (Okinawa)	293	2.47	Low Mountains
	Miyakojima	Japan (Okinawa)	268	2.43	Hills
	Shiso	Japan (Honshu)	49	1.81	Low Mountains
	Yonaguni	Japan (Okinawa)	58	1.76	Hills
Mandarin Chinese	Taipei	Taiwan	9949	4.00	Flat
	Taichung		1250	3.10	Hills
	Tainan		855	2.93	Flat
Taiwanese Southern Min	Taipei	Taiwan	9949	4.00	Flat
	Keelung		2802	3.45	Hills
	Taichung		1250	3.10	Hills
	Tainan		855	2.93	Flat
Vietnamese	Long Mỹ	Vietnam	406	2.61	Flat
Yucatec	Yaxley	Mexico	2812	3.45	Flat

- this presentation: two such studies (cont.)
  - the demographics

Table 4. *Demographic variables*

Participants by L1	Mean age (SD) 1 = <30; 0 = ≥30	Mean frequency of L2 use (SD) 0 = never 1 = sometimes 2 = often	Mean highest level of formal education (SD) 0 – no more than primary; 1 - any amount of secondary; 2 - any amount of post-secondary	Mean combined reading/writing frequency (SD) 3 = regularly; 2 = occasionally; 1 = rarely; 0 = I don't
English	0.87(0.34)	0.92(0.86)	1.82(0.38)	2.80(0.52)
Isthmus Zapotec	0.31(0.46)	1.54(0.63)	0.73(0.78)	1.74(1.01)
Japanese	0.56(0.50)	1.28(0.53)	1.85(0.36)	2.79(0.50)
Mandarin Chinese	0.91(0.29)	0.00(0.00)	1.97(0.16)	2.99(0.12)
Taiwanese Southern Min	0.10(0.31)	0.83(0.90)	0.70(0.80)	1.64(1.29)
Vietnamese	0.63(0.48)	0.01(0.10)	0.93(0.45)	2.29(0.93)
Yucatec	0.58(0.49)	1.02(0.65)	0.99(0.75)	2.32(0.63)

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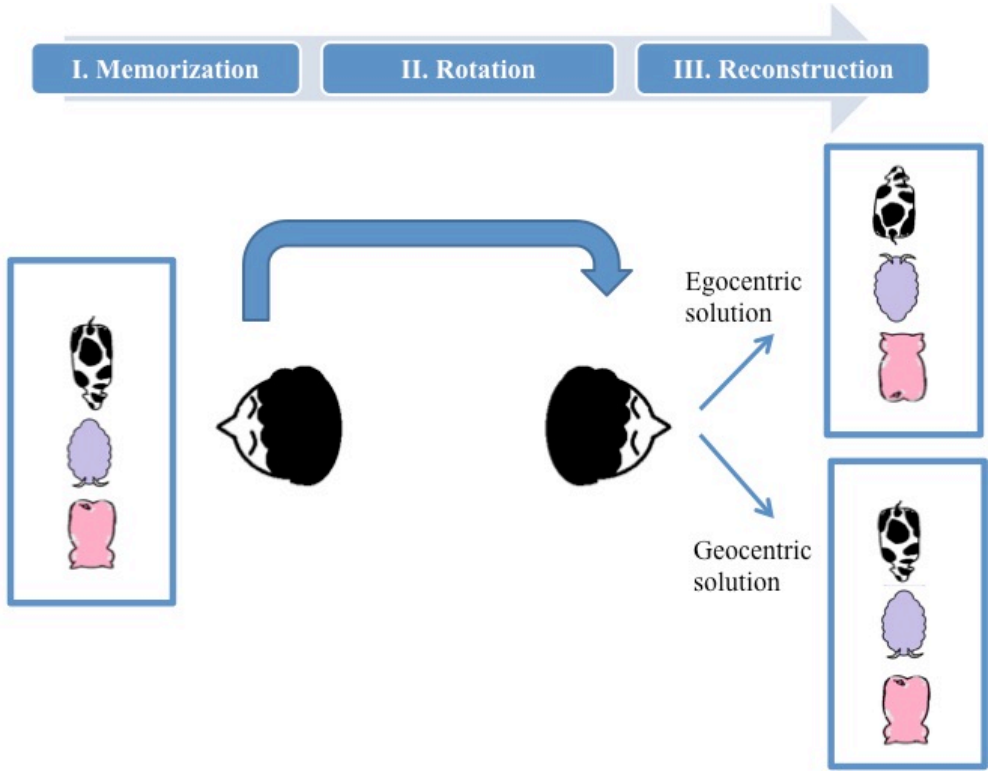
STUDY I: REFERENCE FRAME USE IN RECALL MEMORY

- design: array reconstruction under rotation



- Practice trials until participants have clearly understood the task
- Six test trials
- Responses coded for facing direction and order of the animals
  - egocentric, geocentric, mixed/neither
- Trial exclusions: no array, multiple arrays, wrong animal, wrong number of animals, wrong order, inconsistent orientation
- Participant exclusions: more than 2 errors

Figure 4. *Design: New Animals array reconstruction task*

Cf. Levinson 2003: 156-158, 338-339; Pederson et al 1998

- participants after exclusions

Table 4. *Study I participants after exclusions*

Speech community	Linguistic area	Country where tested	Researcher	N participants tested		Totals
				Male	Female	
English	N/A	U.S.	K. T. Donelson; J. A. Jódar Sánchez; R. E. Moore; J. Seong	5	10	15
Japanese	N/A	Japan	J. Olstad	32	15	47
Isthmus Zapotec	Mesoamerican	Mexico	G. Pérez Báez; R. E. Moore	7	9	16
Mandarin Chinese	Southeast Asian	Taiwan	H.-C. Hsiao; Y.-T. Lin	9	17	26
Taiwanese Southern Min	Southeast Asian	Taiwan	Y.-T. Lin	21	32	53
Vietnamese	Southeast Asian	Vietnam	J. Lovegren	2	15	17
Yucatec Maya	Mesoamerican	Mexico	J. Bohnemeyer	2	7	9
Totals				78	105	183

- modeling the data
  - binary logistic mixed-effects regression models
    - using the lme4 package in R (Bates et al 2015)
    - dependent variable: probability of egocentric reconstruction of facing direction in a given trial

- modeling the data (cont.)
  - fixed factors
    - participant variables
      - age (2-point scale)
      - formal education level (3-point scale)
      - frequency of L2 use (3-point scale)
      - gender
      - max. reading/writing frequency (4-point scale)

- modeling the data (cont.)
  - fixed factors (cont.)
    - field site variables
      - population density (census data)
      - topographic profile (ESRI)

- modeling the data (cont.)
  - fixed factors (cont.)
    - population variables
      - linguistic area
        - English (N = 15)
        - Japanese (N = 47)
        - Mesoamerican (Yucatec, Zapotec; N = 25)
        - SEA (Mandarin, Taiwanese Southern Min, Vietnamese; N = 96)
      - models with an individual-language variable failed to converge

- modeling the data (cont.)
  - nested random factors
    - participant; trial
  - exhaustive model comparisons to address the overfitting problem due to sparsely populated cells
    - using the anova function of the R core
    - not all levels of all variables are represented in all populations
    - model comparisons identify the best-fit models
      - and the most conservative factor estimates

- results

Table 7. *Study I results*

Predictor	Persistence across models	Performance in top five models by AiC	Interpretation
AGE	Not consistently significant	Never significant	N/A
EDUCATION	Not consistently significant	Not included in best-fit models	N/A
GENDER	Not consistently significant	Never significant	N/A
L2 USE	Never significant	Never significant	N/A
LINGUISTIC AREA			
ENGLISH	Baseline		N/A
JAPANESE	Significant in all models	$3.2 < \beta < 3.4$; $p < 0.001$	Boosting egocentric reconstructions
MESOAMERICAN	Significant in all models	$-3.5 < \beta < -3.4$; $p < 0.001$	Boosting geocentric reconstructions
SOUTHEAST ASIAN	Significant in all models	$-2.3 < \beta < -2.1$; $p < 0.001$	Boosting geocentric reconstructions
LITERACY	Not consistently significant	Not included in best-fit models	N/A
POPULATION DENSITY	Not consistently significant	$0.5 < \beta < 0.6$; $p < 0.001$	Boosting egocentric reconstructions
TOPOGRAPHY			
FLAT	Baseline		N/A
HILLS	Not consistently significant	$-2.4 < \beta < -1.9$; $p < 0.01$	Boosting geocentric reconstructions
LOW MOUNTAINS	Not consistently significant	Never significant	N/A

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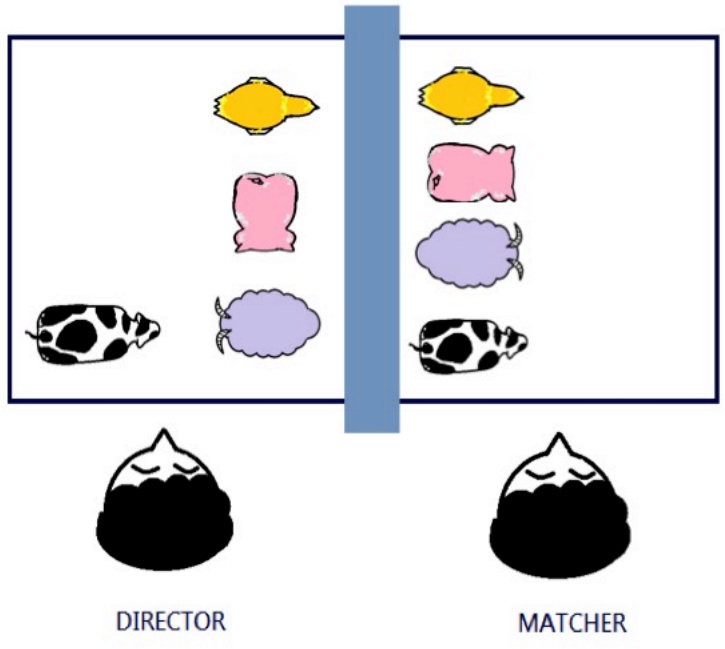
STUDY II: REFERENCE FRAME USE IN DISCOURSE

- design: referential communication (Clark & Wilkes-Gibbs 1990)



- One practice trial without the screen
- Four test trials
- Directors' responses coded for location and orientation of the animals
  - Six categories: egocentric intrinsic ('direct'); egocentric extrinsic ('relative'); allocentric intrinsic; landmark-based geocentric; absolute geocentric; 'topological' (Piaget & Inhelder (1956))

Figure 5. *Design: Talking Animals referential communication task*

- participants

Table 8. *Study II participants*

Speech community	Linguistic area	Country where tested	Researcher	N participants tested in discourse study		Totals
				Male	Female	
English	N/A	U.S.	K. T. Donelson; J. A. Jódar Sánchez; R. E. Moore; J. Seong	24	19	43
Japanese	N/A	Japan	J. Olstad	26	14	40
Isthmus Zapotec	Mesoamerican	Mexico	G. Pérez Báez; R. E. Moore	24	65	89
Mandarin Chinese	Southeast Asian	Taiwan	H.-C. Hsiao; Y.-T. Lin	7	22	29
Taiwanese Southern Min	Southeast Asian	Taiwan	Y.-T. Lin	25	63	88
Vietnamese	Southeast Asian	Vietnam	J. Lovegren	26	54	80
Yucatec Maya	Mesoamerican	Mexico	J. Bohnemeyer	41	39	80
Totals				173	276	449

- analysis
  - binary logistic mixed-effects regression models
  - same predictors as in Study I
    - except this time we were able to use an individual language variable
  - two dependent variables
    - probability of geocentric frame use
    - probability of 'relative' egocentric frame use
      - in this task, a response can include multiple propositions encoded in different frames of reference

- results: geocentric models

Table 9. *Study II results: geocentric frames*

Predictor	Persistence across models	Performance in top five models by AiC	Interpretation
AGE	Not consistently significant	$-0.48 < \beta < -0.43$; $p < 0.05$	Boosting geocentric reconstructions (variable is inversely coded)
EDUCATION	Not consistently significant	Never significant	N/A
GENDER	Never significant	Never significant	N/A
L2 USE	Not consistently significant	Never significant	N/A
LANGUAGE			
ENGLISH	Baseline		N/A
JAPANESE	Significant in all models	$-2.64 < \beta < -2.61$; $p < 0.001$	Neg. correlated with geocentric frame use
ISTHMUS ZAPOTEC	Significant in all models	$3.48 < \beta < 3.62$; $p < 0.001$	Boosting geocentric frame use
MANDARIN	Never significant	Never significant	N/A
TAIWANESE SOUTHERN MIN	Not consistently significant	Never significant	N/A
VIETNAMESE	Significant in all models	$0.81 < \beta < 0.93$; $p < 0.01$	Boosting geocentric frame use
YUCATEC MAYA	Significant in all models	$1.41 < \beta < 1.5$; $p < 0.001$	Boosting geocentric frame use
LITERACY	Significant in all models	$-0.38 < \beta < -0.31$; $p < 0.001$	Neg. correlated with geocentric frame use
POPULATION DENSITY	Significant in all models	$-0.48 < \beta < -0.45$; $p < 0.001$	Neg. correlated with geocentric frame use
TOPOGRAPHY			
FLAT	Baseline		N/A
HILLS	Significant in all models, but with inconsistent polarity	$1.65 < \beta < 1.71$; $p < 0.001$	Effects not trustworthy due to inconsistent polarity
LOW MOUNTAINS	Significant in all models, but with inconsistent polarity	$1.67 < \beta < 1.71$; $p < 0.01$	Effects not trustworthy due to inconsistent polarity

- results: relative (egocentric) models

Table 10. *Study II results: relative frames*

Predictor	Persistence across models	Performance in top five models by AiC	Interpretation
AGE	Not consistently significant	Never significant	N/A
EDUCATION	Not consistently significant	Not consistently significant	N/A
GENDER	Never significant	Not included in best models	N/A
L2 USE	Not consistently significant	Not consistently significant	N/A
LANGUAGE			
ENGLISH	Baseline		N/A
JAPANESE	Never significant	Never significant	N/A
ISTHMUS ZAPOTEC	Significant in all models	$-2.57 < \beta < -2.24$; $p < 0.001$	Neg. correlated with relative frame use
MANDARIN	Not consistently significant	Not consistently significant	N/A
TAIWANESE SOUTHERN MIN	Significant in all models	$-1.63 < \beta < -1.44$; $p < 0.001$	Neg. correlated with relative frame use
VIETNAMESE	Significant in all models	$-1.42 < \beta < -1.18$; $p < 0.001$	Neg. correlated with relative frame use
YUCATEC MAYA	Significant in all models	$-2.03 < \beta < -1.69$; $p < 0.001$	Neg. correlated with relative frame use
LITERACY	Significant in all models	$0.31 < \beta < 0.43$; $p < 0.001$	Boosting relative frame use
POPULATION DENSITY	Not consistently significant	Never significant	N/A
TOPOGRAPHY			
FLAT	Baseline		N/A
HILLS	Not consistently significant	Not included in best-fit models	N/A
LOW MOUNTAINS	Not consistently significant	Not included in best-fit models	N/A

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AN EVOLUTIONARY MODEL

- making sense of the effects we've seen so far
  - language
    - some languages seem to promote geocentrism, others egocentrism
    - we have argued that language/speech may serve as one conduit of the cultural transmission of frame use
      - along with other observable behaviors such as gesture, agricultural or religious practices, etc.
        - cf. Bohnemeyer (2011); Le Guen (2011); *inter alia*
      - we call this the **Linguistic Transmission Hypothesis** (Bohnemeyer et al 2015)

- making sense of the effects we've seen so far (cont.)
  - literacy (only in the referential communication study)
    - higher levels of literacy are consistently associated with more egocentric frame use in our data
    - hypothesis: the habitual use of visual representations, especially reading/writing, favors egocentric encoding

- making sense of the effects we've seen so far (cont.)
  - population density
    - we find higher population density of the field site consistently associated with more egocentric frame use
    - we interpret this as an effect of urbanization
      - urbanization reduces access to geocentric cues
      - we also hypothesize that habituation to navigating urban roadway systems may favor egocentrism

- making sense of the effects we've seen so far (cont.)
  - topography (only in the recall memory study)
    - ready access to geocentric cues in the environment facilitates geocentric frame use
    - whether such cues are indeed exploited seems to be a matter of the practices of the community

- an illuminating wrinkle: mismatches in individual populations
  - speakers of languages with either no overall linguistic bias or a bias for intrinsic frame use
    - tend to pattern with speakers of predominantly geocentric languages on nonverbal tasks

Language population	Genus	Field site	Original study	Instru-ments	Linguistic frame use profile	Recall memory profile
Bashkir	Turkic	Bashkortostan (central Russia)	Nikitina in press	B&C; AIAR	I > R	G > E
Kilivila	Oceanic	Trobriand Islands (Papua New Guinea)	Senft 2001	M&T; AIAR	I > R	G > E
Bilingual Mandarin (Min Nan L1)	Sinitic	Taiwan	Lin 2017	TA; NA	R > G > I	G > E
Mopan	Mayan	Belize	Danziger 2001	M&T; AIAR; RC	I	G > E / E > G (task-specific)
Murrinhpatha	Southern Daily	Northern Territories, Australia	Gaby et al in press	M&T; AIAR; CR	I > {R?; L}	G > E
Spanish	Romance	Rosita, Nicaragua; San Miguel Balderas, Mexico State	Bohnemeyer et al 2014	B&C; NA	R > I = L	G > E
Yucatec	Mayan	Quintana Roo, Mexico	Bohnemeyer 2011, Bohnemeyer & Stolz 2006, Le Guen 2011	M&T; B&C; TA; NA	I = A = L = R	G > E

Table 11. *Mismatches between verbal and nonverbal behavior in individual populations (Bohnemeyer et al in preparation)*

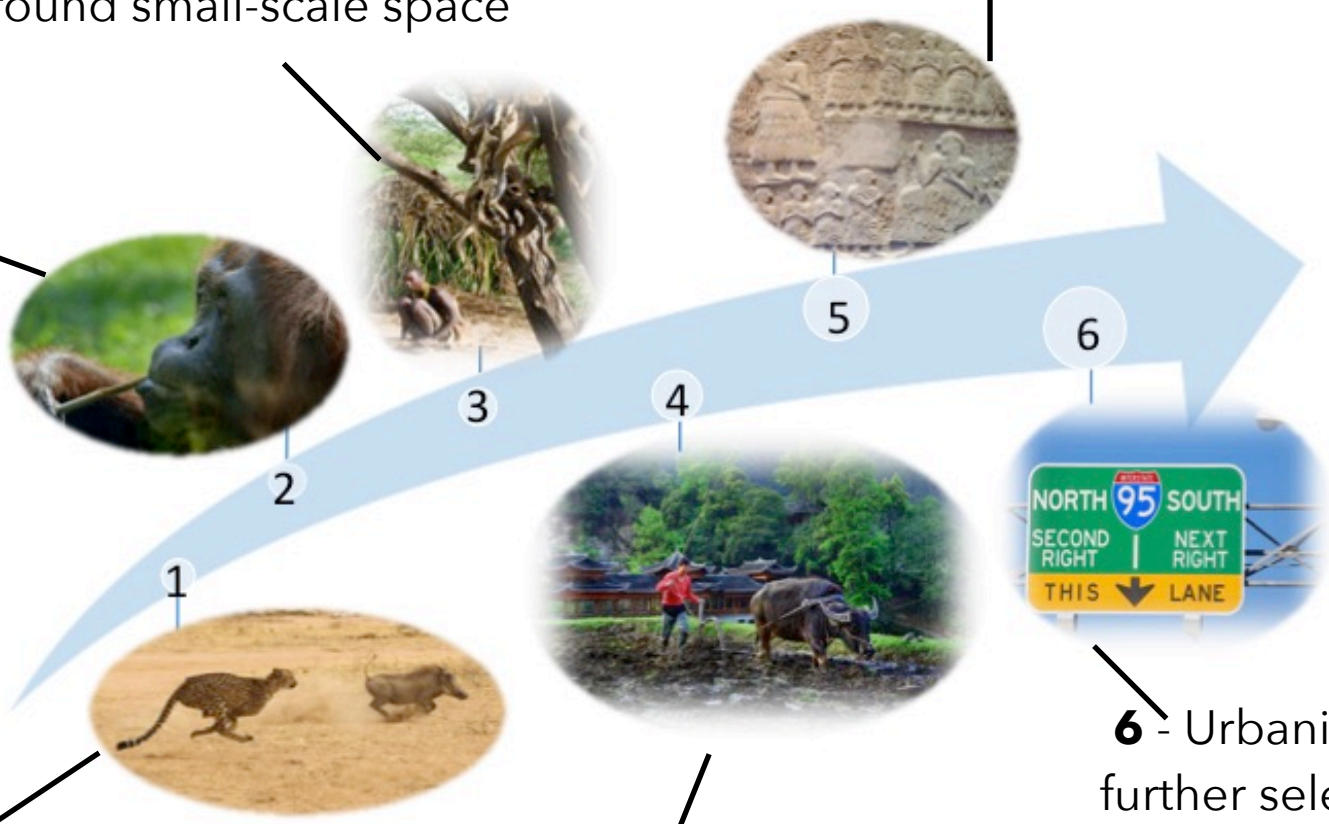
- an illuminating wrinkle: mismatches (cont.)
  - these mismatches are consistent with an innate geocentrism bias
    - which may become overridden by a culturally transmitted egocentrism bias
      - cultural practices involving geocentric use may counteract this process
    - independent evidence for an innate geocentrism bias in primates and human infants: Haun et al (2006)

- synopsis of the evolutionary account: the emergence of small-scale space

3 - Hunter-gatherer camps: make-shift physical boundaries around small-scale space

5 - Visual art and writing: selectional pressures favoring egocentrism

2 - Tool use: the beginning of the emergence of small-scale space



1 - Before the onset of cultural evolution: no separate domain of small-scale space

4 - Agricultural settlements: walling off small-scale space

6 - Urbanization: further selectional advantages for egocentrism

SUMMARY

- the typological distribution of reference frame preferences across languages and cultures can be studied
  - by collecting large-scale multi-population data samples
    - and fitting regression models on the resulting data sets
      - using exhaustive model comparison to guard against overfitting as a result of sparsely populated cells

- the studies presented here have found robust effects of literacy, population density, and language
  - and a minor topography effect
- these effects are in line with an evolutionary model
  - in which cultural evolution leads to egocentric biases that override an innate geocentrism bias
- independent support for this model comes from
  - primate and infant research
  - the distribution of linguistic and nonverbal frame use preferences in populations in which they do not align

ACKNOWLEDGMENTS

- This material is based upon work supported by the National Science Foundation under Grant BCS-1053123
  - *Spatial language and cognition beyond Mesoamerica*
- we gratefully acknowledge
  - the contribution of the participants in our studies
  - advice from Erika Bellingham, Eve Danziger, Matthew Dryer, Alice Gaby, Jeff Good, Marianne Gullberg, Florian Jaeger, Jean-Pierre Koenig, Steve Levinson, David Mark, Gunter Senft, Wolfgang Wölck
    - and the members of the UB Semantic Typology Lab
- and thank YOU for listening 😀

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Thanks!