Reference frames in language and cognition: Cross-population mismatches[1]

1. Introduction - In recent decades, numerous studies have found evidence that a speech community's referential practices in discourse are predictive of its members' behavior in nonverbal tasks, especially in recall and recognition memory studies (Bohnemeyer et al 2014, 2015; Haun et al 2011; Pederson et al 1998; Levinson 2003; Mishra et al 2003; Wassmann & Dasen 1998; inter alia). This research has focused on so-called **spatial frames of reference**, cognitive axis systems used to project directions and regions in space. Figure 1 gives an overview of frame types among which previous typological research has found it useful to distinguish.

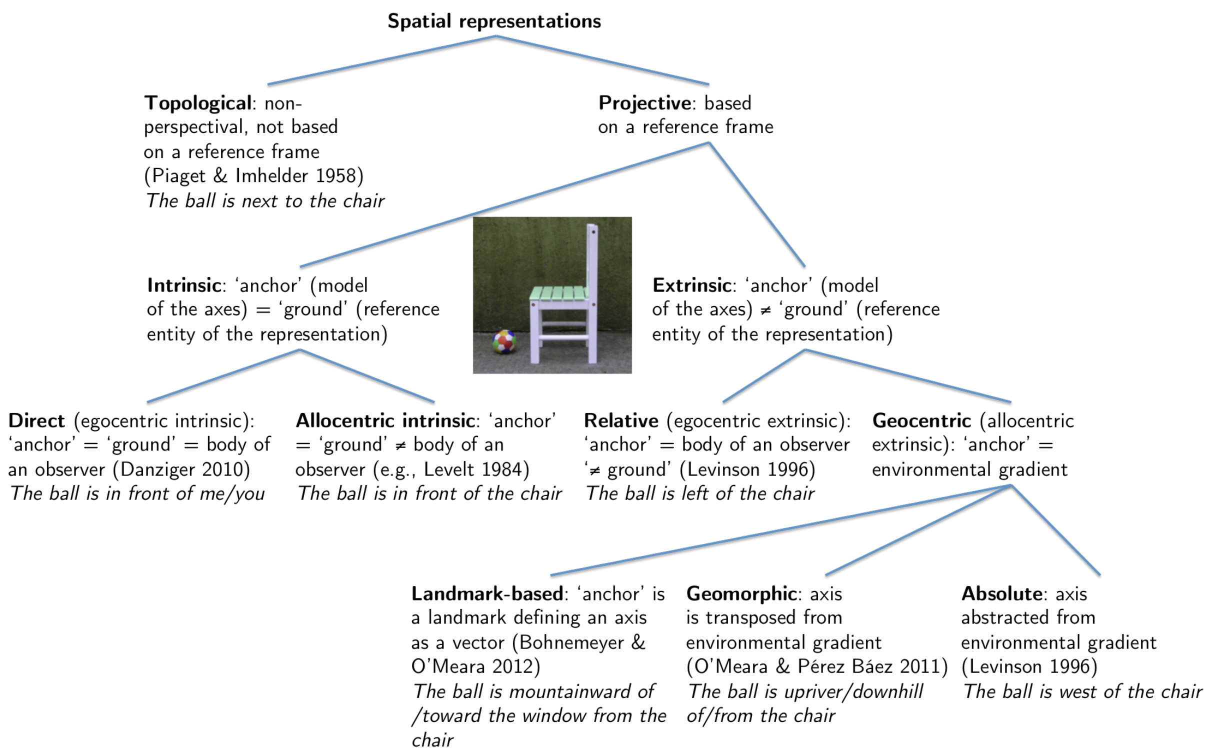

Figure 1. *A fine-grained classification of spatial representations in terms of the underlying reference frame types (cf. O'Meara & Pérez Báez 2011; Bohnemeyer et al. 2015)*

In this article, we discuss a series of exceptions to the much-discussed alignment between verbal and nonverbal frame use preferences. These exceptions occur in nine speech communities of Asia, Central and North America, Europe, and Oceania. Whereas studies which have shown alignment between verbal and nonverbal preferences have dealt with language varieties where <u>either</u> relative <u>or</u> geocentric frame use is dominant in discourse, in the communities of the

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[1] Supplemental materials for this manuscript can be accessed at https://osf.io/7gmsy/?view_only=9b1fe07f74334360912730e1733cad2a.

present study, the linguistic pattern is different. In these communities, where discourses refer to small-scale space, either intrinsic frame use is dominant (very little extrinsic frame usage), or both relative and geocentric frames are used frequently in addition to intrinsic frames. In such cases, there is no clear prediction for either relative or geocentric frame use in solving cognitive tasks (Danziger 2001). While these cases have been pointed out individually, they have not been discussed in conjunction with one another. Consequently, the striking commonality across the findings of these studies has gone unnoticed: in almost all of these cases, which lack a linguistic bias toward either geocentric or relative frame use in discourse, geocentric nonverbal coding is more common than relative nonverbal coding in tasks that involve stationary stimulus configurations. We discuss to what extent this distribution can be accounted for by three alternative proposals:

I. **Intrinsic default** (Danziger 2001)**:** Universal (innate?) availability of intrinsic frames (including egocentric 'direct' frames), whereas availability of extrinsic (relative or geocentric) frames is the result of cultural evolution and thus population-specific.

II. **Geocentric default** (Haun et al. 2006): Universal innate weak preference for anchoring to geocentric cues, which may be overridden by culturally transmitted egocentric practices.

III. **Emergence of the small scale** (Bohnemeyer et al. ms.): Small-scale space as a distinct cognitive domain has gradually evolved and grown in importance in human history. Geocentric frames are an optimal adaptation for the geographic scale, whereas (both direct and relative) egocentric frames are favored by certain demands of small-scale spatial reference.

Each of these proposals accounts for part of our data, while none can account for all of it without additional assumptions.

2. Methods - This article presents a metastudy comparing findings of eleven individual studies carried out with distinct though overlapping instruments. In this section, we briefly introduce those instruments, discussing nonverbal cognition tasks before discourse tasks.

2.1. Recall/recognition tasks - The instruments which we summarise here were used in the studies of cultural and individual variation in reference frame use in nonverbal cognition. All rely on a combination of two elements: participants first commit a stimulus configuration to memory, and then, after having undergone rotation (most commonly, by 180 degrees), they identify it from among a range of options or they reconstruct it from materials provided. The rationale is that if the participants memorize the configuration geocentrically, with respect to the environment, then under rotation, the configuration's orientation will remain constant relative to the environment, but change relative to the participants' body. In contrast, if participants memorize the configuration egocentrically, with respect to their own body, then under rotation, the configuration's orientation will remain invariant with respect to their body, but change in orientation with respect to the environment. Table 1 summarizes the task protocols used in the studies we compare here.

Table 1. *Recall/recognition tasks used in the studies reported on*

Task	Citations	Stimuli	Rotation	N test trials	Task
Animals in a row	Levinson & Schmitt (1993); Levinson (2003: 154-159); Pederson et al. (1998)	Array of 3 toy animals (participants asked to memorize correct 3 out of a set of 4)	180 degrees (b/w Table 1 and Table 2)	5 (chosen by the researcher from out of a set of options)	Recall and reconstruction
New animals	Pérez Báez (2008); Bohnemeyer et al. (2015)			6 (fixed)	
Chips recognition	Levinson et al. (1993); Levinson (2003:159-160)	2 sets of 5 identical playing cards showing two circles or squares of distinct colors		4 or 8[2]	Recognition (4 test cards are rotated at 90-degree intervals from one another)
Eric's maze	Pederson & Schmitt (1993a); Levinson (2003: 160-162)	2D "maze" plots: 1 training maze without pre-drawn paths; 1 testing maze with pre-drawn paths; toy man used by the experimenter to show the stimulus paths		5	Recognition (identify the path on the testing maze, which includes a relative solution, a geocentric solution, and a distractor)
Steve's mazes	Levinson (1993)	Simple schematic maps (1/trial) with incomplete paths drawn on them; three test cards per map that show potential completions: 1 geocentric, 1 relative, 1 distractor		5	Inference and recognition
Transitive inference	Pederson & Schmitt	5 unfeatured, non-directional Lego-style		5 or 10[3]	Inference and recognition

[2] The relevant instructions in Levinson et al. (1993: 111): "Number of trials: 4 per axis (Do left/right, front/back optional -- do the same for all subjects)."
[3] Instructions in Pederson & Schmitt (1993b: 83): "10 (two axes) or 5 (left/right only)."

	(1993b); Levinson (2003: 162-167)	block objects: 1 small (“A”); 2 identical small (“B”); 2 identical large (“C”)			(memorize AB on Table 1, BC on Table 2, then locate B wrt. A on Table 1)

The instructions given to the participants are deliberately vague so as to avoid any bias toward a particular strategy: e.g., in the case of Animals-in-a-row and New Animals, ‘Make it again!’. Li & Gleitman (2002) argue that this vagueness invites fallback on subvocal verbal encoding; cf. Levinson et al. (2002) for a response. However, Li & Gleitman’s alternative design type targets ability rather than preference, fundamentally altering the research question.

2.2. Referential communication tasks - All studies we compare here relied primarily on the same type of instrument for profiling populations in terms of their preferred strategies for spatial reference in discourse: so-called ‘referential communication tasks’, in which dyads of participants verbally coordinate on identical copies of nonverbal stimuli without sharing a visual field (Clark & Wilkes-Gibbs 1986). Typically, a screen, placed between the participants, blocks visual access to the stimulus configurations. It is generally acknowledged that this type of task is of low ecological validity. In particular, it suppresses discourse that relies on deictic demonstration (Danziger 2010). To compensate for this weakness, researchers rely on spontaneous observation and tasks such as local history narratives and procedural descriptions. The rationale for referential communication designs is that they force participants to be as explicit in their reference acts as is required to resolve whatever ambiguities are built into the stimulus configurations. Table 2 compares the referential communication tasks in the studies we draw on below.

Table 2. *Referential communication tasks used in the studies reported on*

Task	Citations	Stimuli	N test trials	Task
Men and tree (original version)	Levinson et al. (1992); Pederson et al. (1998)	2 x 4 x 12 photographs featuring dyadic configurations of toys (men, trees, balls)[4]	4 (each involving one set of 12 photos)	Participants instruct one another to match the photos
Ball and chair	Bohnemeyer & Pérez Báez (2008: 29-32); Bohnemeyer	2 x 4 x 12 photographs featuring dyadic configurations of a ball and a chair		

[4] Levinson et al. (1992: 7) comment as follows: “Note that “Men and Tree” is a notation for the full set of 4 photo-photo matching games which explore these questions. There is one training game in the set (game 1) and there are distractor photos -- intended to make the game more fun to play -- within games 2, 3 and 4 of the set. This means that all photos in the “Men and Tree” set do not necessarily depict a man or a tree. It also means that there is one entire game (game 1) of the “Men and Tree” set in which not a single man or a single tree appears.”

	et al. (2015)			
Man and Tree (Senghas version)	Senghas (2000); Terrill & Burenhult (2008)	2 x 16 photographs featuring dyadic configurations of a toy man and toy tree	1 or 2 (each involving a set of 16 photos)	Participants instruct one another to match the photos
Route descriptions	Wilkins (1993)	2 identical toy town models; a chain to define a path; 2 identical human dolls	4 (each with a unique path)	Participants instruct one another to lead the dolls along the same path
Farm animals	Levinson et al. (1992)	Set of toy farm animals[5] and 12 photographs showing configurations of them	12 (each with a unique photo)	Participants instruct one another to rebuild the stimulus configuration
Talking animals	Bohnemeyer (2012)	4 identical sets of toy animals; stimulus configurations built by researcher for 1 participant according to schematic drawings	4 (each with a unique configuration)	

3. The individual studies - Table 3 provides basic information about the nine study populations.

Table 3. *Language populations, field sites, and researchers of the studies under comparison*

Language	ISO 639-3	Family	Genus or proximal major sub-branch	Population	Fieldsite	Studies
Aṣ-Ṣāniʕ Arabic	ajp	Afro-Asiatic	Arabian	20,000 (estimate Cerqueglini)	Lakiya (Negev, Israel)	Cerqueglini (2015, 2019); unpublished work by Cerqueglini
Hijazi Arabic	acw	Afro-Asiatic	Arabian	14.5 million (2011)	Asir (Saudi Arabia)	Alshehri et al. (2018); unpublished work by Alshehri
Bashkir	bak	Turkic	Kipchak	1.2 million (2010)	Bashkorto-stan (Russia)	Nikitina (2018)

[5] The number of animals is unknown. The protocol for this task is rudimentary. The task was intended to be exploratory only.

Dhivehi	div	Indo-European	Indo-Aryan	335,000 - 410,000 (Gnanadesikan 2017)	Laamu Atoll, Maldives	Lum (2018); Palmer et al. (2017)
Kilivila	kij	Austronesian	Papuan Tip Linkage	20,000 (2000; Lewis et al. 2015)	Trobriand Islands (Papua New Guinea)	Senft (2001, 2006)
L2 Mandarin (L1 Min Nan)	cmn	Sino-Tibetan	Sinitic	13.8 million (2010 Population and Housing Census)	Keelung, Taichung, Tainan, Taipei (Taiwan)	Lin (2017)
Mopan	mop	Mayan	Yucatecan	9,000-12,000 (2008; Hofling 2011)	San Antonio, Toledo district, Belize	Danziger (1996, 1999, 2001, 2011)
Murrinhpatha	mwf	Southern Daly	N/A	3,000 (Mansfield 2019)	Wadeye (Australia)	Blythe et al. (2016); Gaby et al. (2016)
Rural Mexican and Nicaraguan Spanish	spa	Indo-European	Romance	≧ 22.4 million[6]	San Miguel Balderas, Mexico; Rosita, Nicaragua	Bohnemeyer et al. (2014, 2015); Eggleston (2012)
Yucatec	yua	Mayan	Yucatecan	774,755 (2020)[7]	Rural communities in central Quintana Roo, Mexico	Bohnemeyer & Stolz (2006); Bohnemeyer (2011); Le Guen (2011); Bohnemeyer et al. (2014, 2015)

[6] 2020 Mexican census data shows a population of 126,014,024. 6.2% were identified as speakers of indigenous languages aged 3 or older (https://www.inegi.org.mx/temas/lengua/, last accessed 06/16/2021). 80.7% of the population lived in urban communities (www.cia.gov). Based on these numbers, one can safely estimate the number of rural Spanish speakers to lie upwards of 20 million. For Nicaragua, at a population of 6,200,000 in 2020, with 95.3% Spanish speakers in 2005 and 59% urban population in 2020 (all www.cia.gov), the comparable estimate yields upward of 2.4 million rural Spanish speakers.

[7] https://www.inegi.org.mx/temas/lengua/, last consulted 06/16/2021.

The bar charts below summarize the quantitative results of the studies on reference frame use in discourse and nonverbal cognition by population. More detailed information can be found in the supplemental materials.

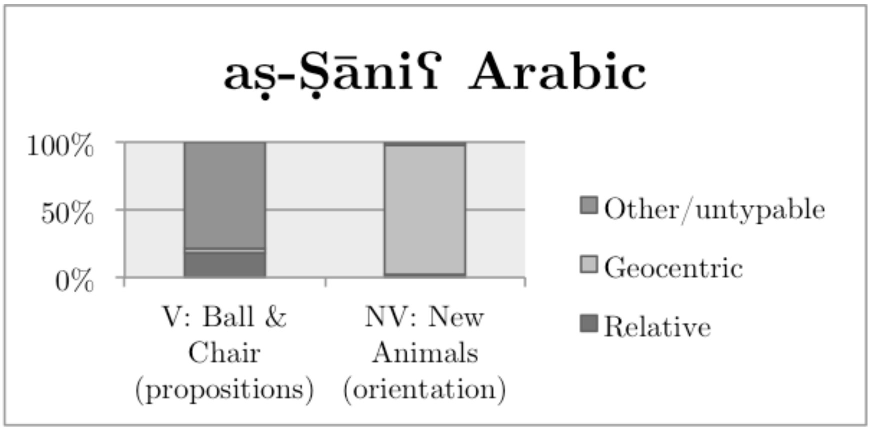

Figure 2. *Quantitative results of the aṣ-Ṣāniʕ Arabic studies (*V*: verbal studies;* NV*: nonverbal studies)*

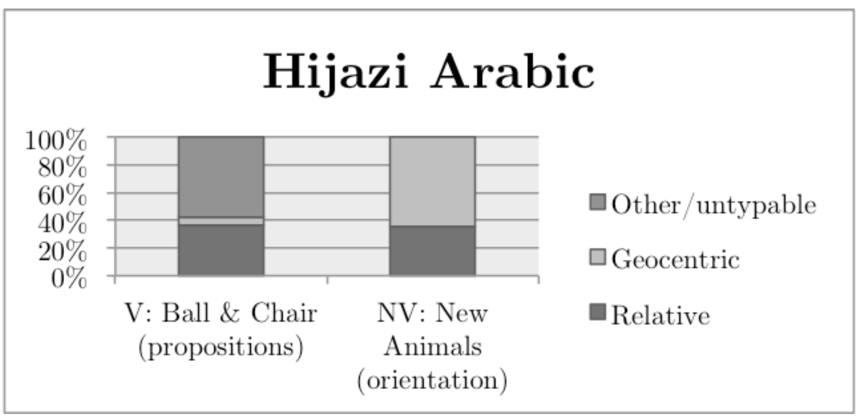

Figure 3. *Quantitative results of the Hijazi Arabic studies (*V*: verbal studies;* NV*: nonverbal studies)*

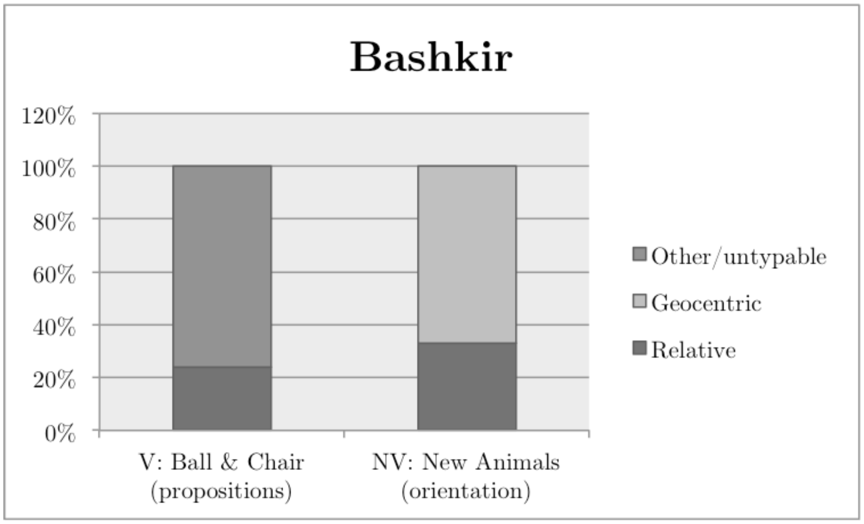

Figure 4. *Quantitative results of the Bashkir studies (*V*: verbal studies;* NV*: nonverbal studies)*

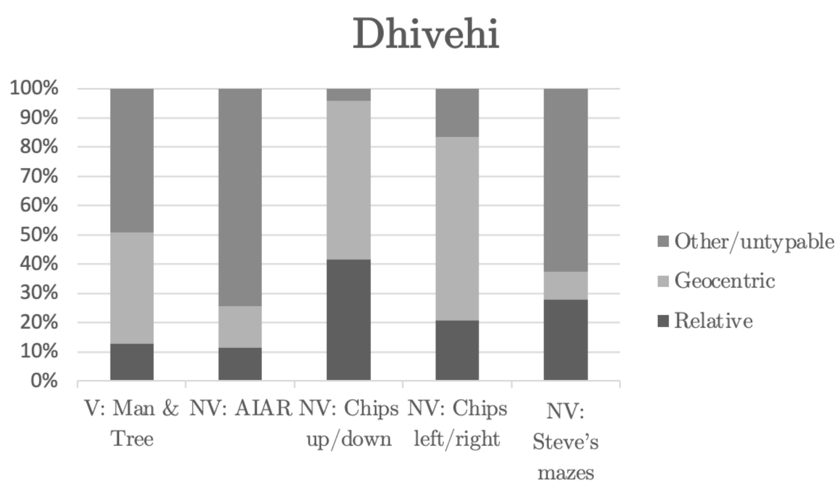

Figure 5. *Quantitative results of the Dhivehi studies (*V*: verbal studies;* NV*: nonverbal studies)*

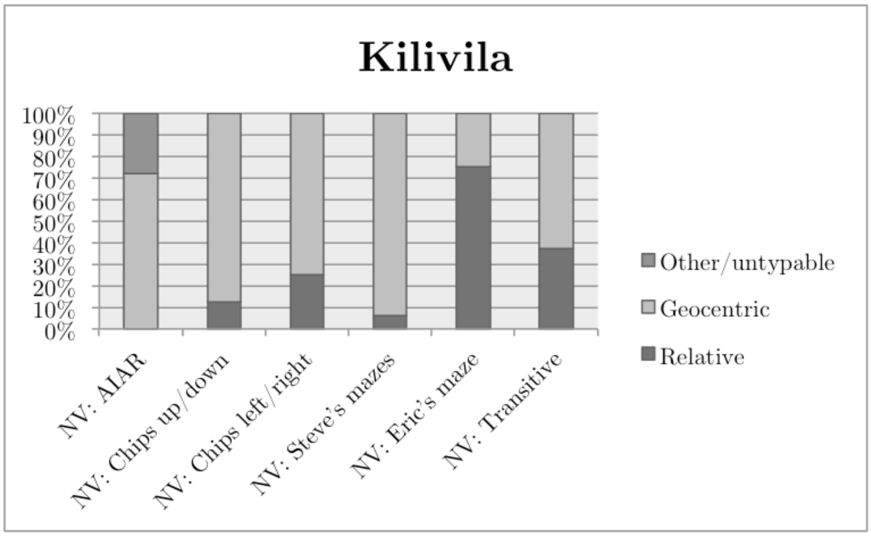

Figure 6. *Quantitative results of the Kilivila studies (*NV*: nonverbal studies; percentages for verbal studies are unavailable)*

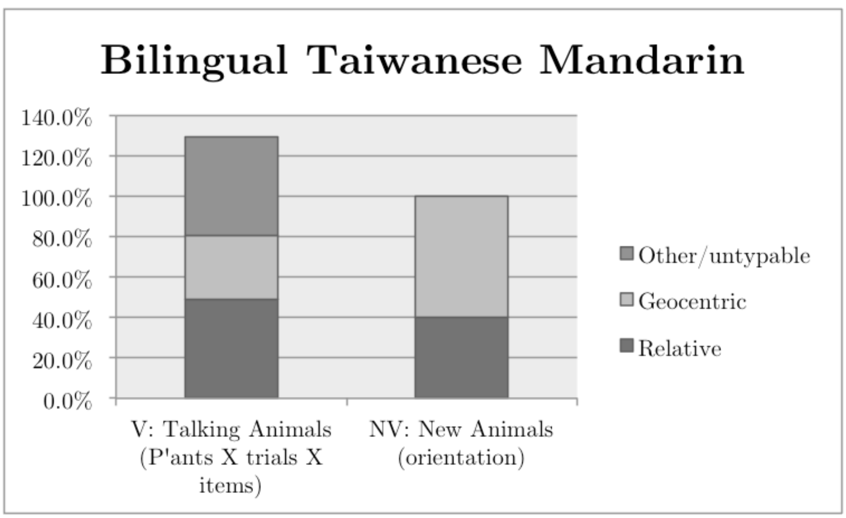

Figure 7. *Quantitative results of the Bilingual L2 Taiwanese Mandarin studies (*V*: verbal studies;* NV*: nonverbal studies; reported percentages of verbal responses do not sum to 100 because observations may instantiate multiple frame types simultaneously)*

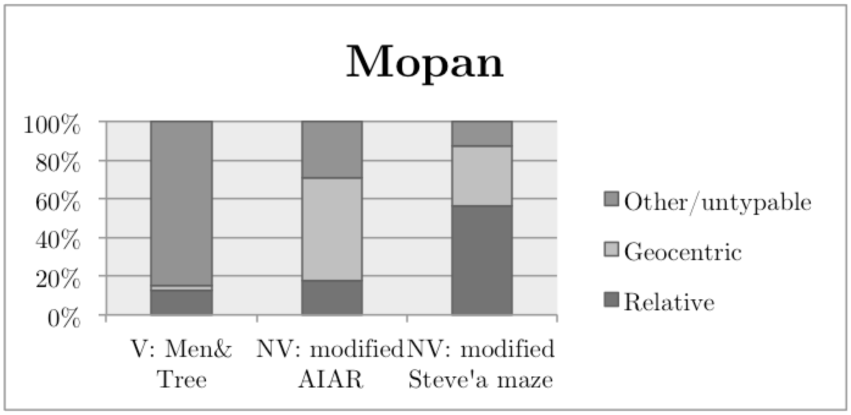

Figure 8. *Quantitative results of the Mopan studies (cf. A6;* V*: verbal studies;* NV*: nonverbal studies)*[8]

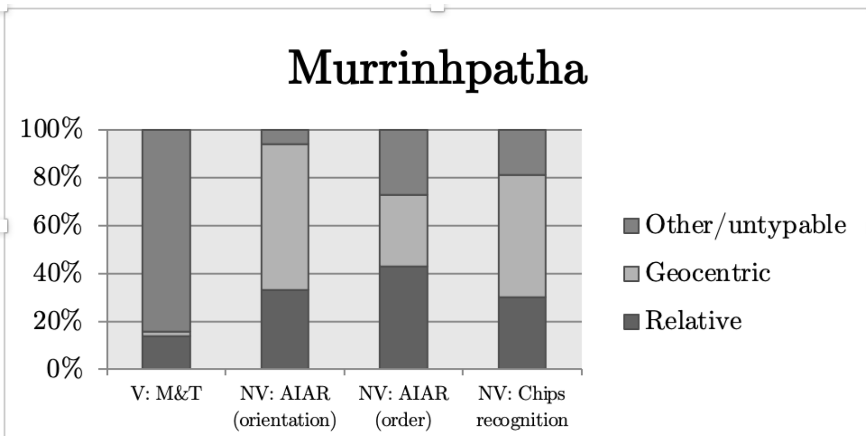

Figure 9. *Quantitative results of the Murrinhpatha studies (cf. Table A7;* V*: verbal studies;* NV*: nonverbal studies)*

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[8] After several attempts with the standard protocol yielded only untypable results, both the AIAR and Steve's Maze task instructions were modified for Mopan speakers. Mopan participants in AIAR were told to pay attention to the animals and "where they are looking". Mopan participants in the Steve's maze task were told to draw the path that they would follow onto a laminated version of the maze on Table 1, before being rotated to consider options on Table 2. Reported results are from these modified versions of the tasks. See Danziger (2001) for details.

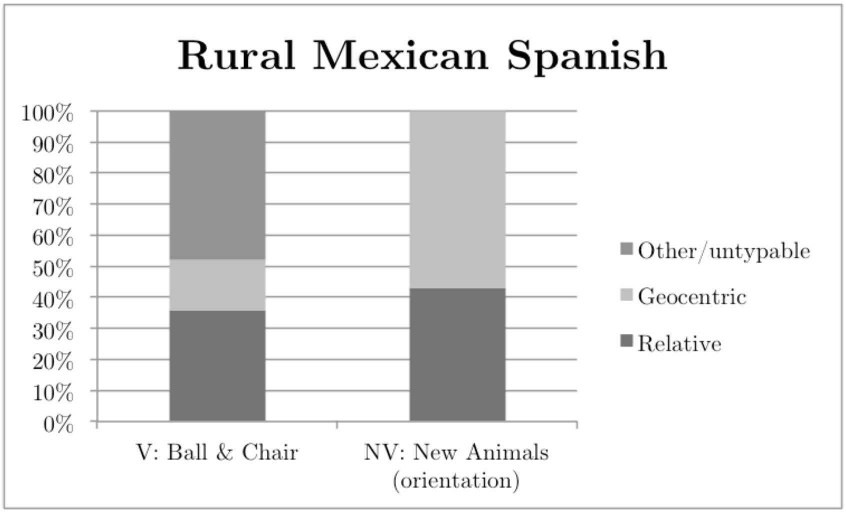

Figure 10. *Quantitative results of the* rural Mexican Spanish *studies (cf. Table A8; ;* V*: verbal studies;* NV*: nonverbal studies)*

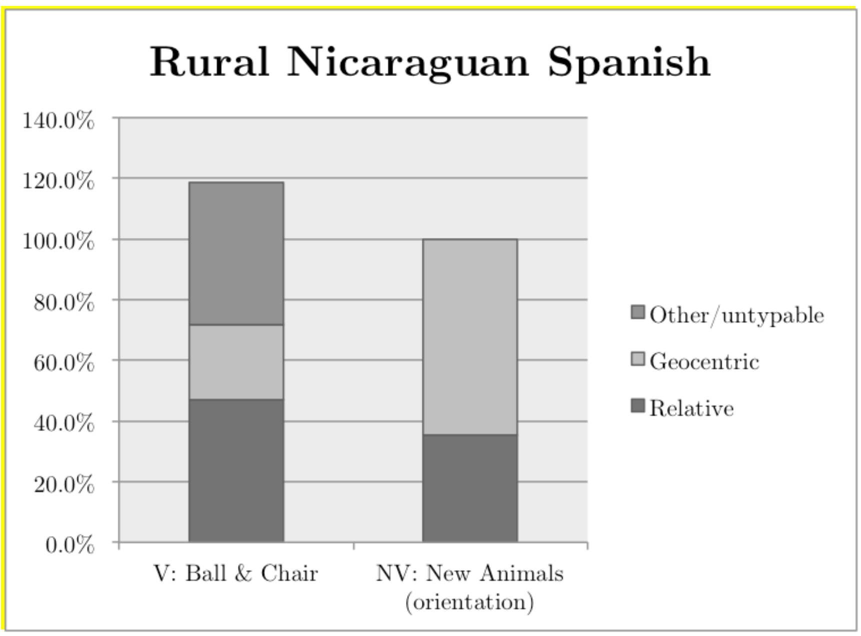

Figure 11. *Quantitative results of the* rural Nicaraguan Spanish *studies (cf. Table A9;* V*: verbal studies;* NV*: nonverbal studies; reported percentages of verbal responses do not sum to 100 because observations may instantiate multiple frame types simultaneously)*

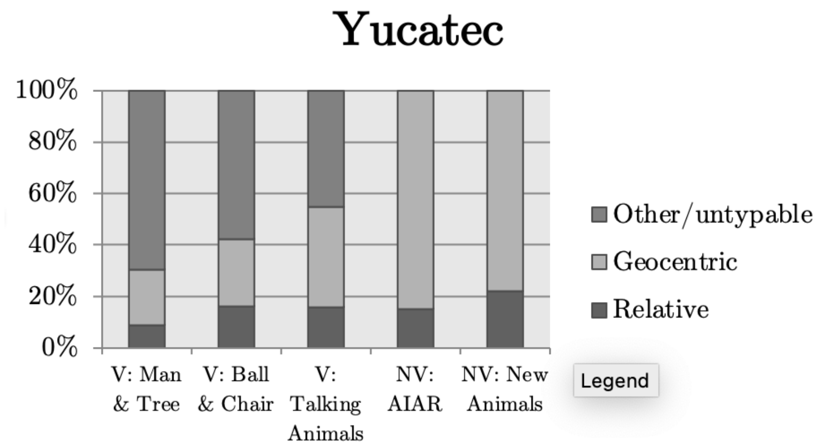

Figure 12. *Quantitative results of the Yucatec studies (cf. Table A10)*

Before we proceed to discuss these findings, a few comments are in order. Frequency counts are represented in terms of percentages with varying denominators depending on how the individual researchers coded the data. The denominators are made explicit in the Appendix. In some instances, verbal frequencies are based on units that can instantiate multiple frame types simultaneously (e.g., descriptions of a particular item), so that sums of percentages may exceed 100. For Kilivila, no exact verbal frequency data has been published. Senft (2001: 549-550) offers the following generalizations:

> "On the one hand, speakers of this language obviously prefer the intrinsic frame of reference for the location of objects with respect to each other in a given spatial configuration — especially if these objects themselves have inherent intrinsic features. On the other hand, Kilivila speakers clearly prefer the absolute [i.e., geocentric; AUTHORS.] ad-hoc landmark frame of reference system in referring to the spatial orientation of objects in a given spatial configuration. Moreover, speakers may also use the relative frame of reference and deixis for referring both to the location and to the orientation of objects in space, however this is rather the exception than the rule."

Examples illustrating these generalizations can be found in the supplemental materials, along with examples of preferred strategies and ethnographic background on all 11 populations. The results of the Kilivila, Mopan and Dhivehi dynamic nonverbal tasks are specifically addressed in the next section.

4. Discussion

We have presented data from 11populations all of which fit the following pattern:

- Linguistically, these groups either show no clear preference for a particular frame type, or they show a preference for intrinsic frames. In some of these populations, such as Kilivila and Mopan speakers, intrinsic frames strongly dominate in locative descriptions.

- In nonverbal tasks, all populations showed evidence of a geocentrism bias, with three partialexceptions:
    - First, the Kilivila speakers produced predominantly relative responses in one task, Eric's maze. In the other five nonverbal tasks Gunter Senft conducted with Kilivila participants, a clear geocentrism bias emerged.
    - Second, Mopan speakers initially produced mostly 'untypable' responses in both cognitive tasks. In the array reconstruction study (Animals in a row), they initially produced a 'monodirectional' pattern, facing the animals consistently the same way (e.g., leftward) across all five trials, but preserving the intrinsic properties of the array. However, the participants switched to predominantly allocentric patterns after Danziger altered the protocol by inducing the participants to pay explicit attention to the orientation of the animals. In the path completion task (Steve's mazes), most participants adopted an egocentric strategy once Danziger modified the protocol here too, by having the participants draw the inferred path onto the stimulus map prior to testing. Danziger's main conclusion (2001: 213) is that "no monolithic Mopan preference toward Absolute [geocentric] or Relative nonlinguistic strategies is identifiable."
    - Third, Dhivehi speakers produced mostly 'untypable' responses in two nonverbal tasks: Animals in a row and Steve's mazes. In Animals in a row, most participants produced a 'monodirectional' pattern consistent with intrinsic coding, like the Mopan participants prior to the change in experimental procedure. In Steve's mazes, most participants selected a mixture of geocentric and egocentric completion cards; however, of those that had a clear preference, there were more egocentric coders than geocentric coders. In a third nonverbal task, Chips recognition, there was a preference towards geocentric responses, especially on the transverse (left-right) axis.

It is possible that some participants' distinct behavior in the maze tasks can be explained with reference to the dynamic nature of the stimuli (see also Dasen & Mishra 2010: 132-134). Since the participants were asked to memorize or infer motion paths, it seems plausible that they would do so by mentally assuming the perspective of the moving figure, thereby simplifying the representation of the path to a sequence of turns, each of which is either a left turn or a right turn. The association between motion and egocentrism has been noted in the literature on descriptions of spatial layouts, such as apartment floor plans (Taylor & Tversky 1996).

To our knowledge, every single population-specific or cross-population study that has ever been conducted in which both verbal and nonverbal reference frame preferences in the small-scale domain were tested and in which either an intrinsic bias or no bias was found on the linguistic side has been included in our sample. We can thus say with confidence that the evidence of cognitive geocentrism in nine of the eleven studies represents a statistically improbable outcome (with a binomial probability $p < 0.03$). The general absence of evidence of a relative bias in all 11populations (except for some instances involving maze tasks which may involve dynamic or other interpretations) represents an even less likely finding ($p < 0.001$). What can account for this significant distribution?[9]

We are aware of three approaches to explaining the patterns we found:

- **Intrinsic default** (Danziger 2001)**:** The intrinsic frame type -- including the egocentric intrinsic (i.e. direct FoR) -- is the sole frame type that is universally available in both language and cognition. Cultural or ad hoc task factors may facilitate use of either geocentric or relative frames in cognition. One such factor is use of extrinsic reference frames in language. For populations without a dominant extrinsic frame in speech, solutions to nonverbal tasks that force a choice between geocentric and relative encoding will depend on a variety of cultural and/or task-specific factors. This hypothesis is motivated by the following facts: (i) the standard versions of the nonverbal Animals in a row and Steve's mazes tasks yielded 'untypable' results from two communities (Mopan and Dhivehi) where intrinsic frames are dominant in discourse - in fact, the 'monodirectional' response pattern observed in these communities most likely reflects an intrinsic solution to the task (Lum 2018: 302-309); (ii) no language has been documented in which the intrinsic frame is never used, whereas (small-scale) geocentric and/or relative frames are absent from some languages; and (iii) the observation that there are languages in which intrinsic frames are the dominant or exclusive strategy for small-scale locative representations (Danziger 2001; Lum 2018; Senft 2001; Terrill & Burenhult 2008). This proposal also harmonizes with the developmental sequence in (1), proposed by Piaget & Inhelder (1956):

(1) Topological > intrinsic > extrinsic (i.e., relative /geocentric; cf. Figure 1)

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[9] One might object that the data from the two Arabic varieties should not be treated as reflecting independent observations since they are relatively closely related. The same holds for the two Spanish dialects. However, previous research has shown significant variation even among mutually fully intelligible varieties (e.g., Bohnemeyer et al. 2015 and Calderón et al. 2019 on Spanish; Pederson et al. 1998 on Tamil), and even at the community level (Moore 2018 on Diidxazá or Isthmus Zapotec). If the Arabic and Spanish varieties are grouped by language, the probability of the observed distribution being a chance outcome is less than 0.090 if Mopan and Dhivehi speakers are considered *not* to conform to the pattern of cognitive geocentrism of our other populations and less than 0.002 if they are in fact considered to fit the pattern. We consider the Kilivila results to show a geocentric bias on the whole, despite a relative preference on one of six tasks

The sequence is well supported by research on European languages (Johnston & Slobin 1979). Additionally, Brown & Levinson (2000), Dasen & Mishra (2010), and De León (1994) observe that geocentric usage is acquired early by children in languages where this usage is common (perhaps earlier than is relative usage in European languages). This indicates that (1) may not hold for (all) languages with a geocentric preference (cf. Cablitz (2002) for a possible counter example). But these studies also present evidence suggesting that intrinsic usage may be acquired equally early.

- **Geocentric default** (Haun et al. 2006): Humans have a universal innate weak preference for cognitive anchoring to geocentric cues, which may be overridden by culturally transmitted egocentric practices. Relative language use may be one such practice. This proposal resulted from a study by Haun et al. (2006) of spatial cognition in members of all five great ape species and in preverbal human infants in Germany. Using versions of a recognition paradigm that involves a mix of the recall and recognition tasks summarized in Table 2, Haun et al. find evidence of geocentrism in all six study populations. They interpret this as evidence of a soft innate geocentrism bias that is overridden by a culturally transmitted relative bias in some modern human populations.

- **Emergence of the small scale** (Bohnemeyer et al. ms.): Geocentric frames afford more efficient representations of geographic-scale space, whereas intrinsic and particularly relative frames are more adaptive for small-scale reference. For illustration, **to say** that Lake Erie is 'left of Buffalo' makes the representation of the highly stable relative locations of that lake and city dependent on the comparatively much less stable location of an observer.[10] At the same time, 'My western arm hurts' identifies the arm in question only dependent on the speaker's orientation at the moment of utterance, whereas 'My left arm hurts' does so regardless of the speaker's orientation. Small-scale spatial reference as a distinct cognitive domain has gradually emerged and gained in importance over the course of human cultural evolution. In cultures that do not develop distinct practices of small-scale spatial reference (or do so only to a lesser extent), all spatial reference is functionally large-scale. The point of departure of this hypothesis is a combination of two observations. First, default use of relative frames for small-scale reference is restricted to globalized postindustrial societies of East Asia, Europe, and North America. This group of populations is also heavily interconnected as a result of globalization, allowing for intensive diffusion of linguistic and cognitive practices. In stark contrast, to date, no indigenous minority population has been attested to have an autochthonous preference for relative frames. As in all instances of cultural evolution, communities do not simply automatically drift toward developing distinct small-scale practices over time. All

[10] We ignore here the special scenario in which the description is uttered with the presupposition of a map as frame.

cultural practices are inherently self-perpetuating. All cultural practices may be reinforced by other cultural practices that refer to them. And all cultural practices are potentially subject to contact diffusion across communities.

Table 4 compares how these accounts perform against the available data.

Table 4. Three approaches to explaining the patterns presented in Section 3, and how they fare against the relevant sources of evidence. Cells code whether the proposals (column headers) are predicted, unexpected, or neutral given the observations (row headers).

	Intrinsic default (Danziger 2001)	Geocentric default (Haun et al. 2006)	Emergence of the small scale (Bohnemeyer et al. ms.)
Developmental sequence observed in the acquisition of languages with relative bias (Piaget & Inhelder 1956; Johnston & Slobin 1979):[11] topological > intrinsic > extrinsic	Predicted	Unexpected	Neutral
Developmental sequence observed in the acquisition of languages with geocentric bias (Brown & Levinson 2000; De Leon 1994): geocentric > intrinsic	Unexpected	Predicted	Neutral
(Near-)universal availability of intrinsic frames in contrast to large amount of crosslinguistic variation in the use of extrinsic frames	Predicted	Unexpected	Neutral
Evidence of geocentric bias in nonhuman primates and preverbal human infants (Haun et al. 2006)	Unexpected	Predicted	Neutral
Relative frame bias restricted to large-scale globalized societies (Bohnemeyer et al. ms.)	Neutral	Consonant (weakly predicted)	Predicted
Existence of populations	Predicted	(Weakly) unexpected	Neutral

[11] For additional references, cf. Brown & Levinson (2000: 193).

without a clear linguistic extrinsic bias (present study)			
Evidence of cognitive geocentrism in most populations that lack a clear linguistic bias for relative or geocentric frames (present study)	Unexpected	Predicted	Predicted
Lack of clear evidence of cognitive geocentrism in Mopan speakers (Danziger 2001) and in Dhivehi speakers (Lum 2018)	Predicted	Unexpected	Neutral

Table 4 makes it clear that none of the three hypotheses is perfectly aligned with the available evidence. Clearly, additional evidence is needed to adjudicate among them or reject all three in favor of an as-yet unknown superior fourth hypothesis. This evidence must come from a variety of sources: ethnographic and linguistic studies of additional populations, cultural history studies of the evolution of spatial reference, experiments with humans, non-human primates, and other animals in the lab and in the wild, computer simulations and robotic experiments.

5. Conclusions

Previous research has shown that across populations, verbal practices of spatial reference are highly variable. At the same time, a group's verbal practices tend to reliably predict the members's preferred strategies of cognitive encoding. The work presented here has identified a second, complementary pattern: populations whose members either prefer intrinsic frames for verbal representations of small-scale locative relations or make free use of all major reference frames without a clear preference all converge on merely infrequent or task-specific use of relative (extrinsic egocentric) strategies in nonverbal cognition. This aligns with the observation that population biases in favor of relative frames appear to be restricted to globalized post-industrial societies. We have considered three possible routes toward accounting for this pattern. The first of these assumes that reference frame use is not subject to any innate bias and that the computationally simplest frame type, intrinsic frames, is the only universally available one (Danziger 2001, 2011 based on Piaget & Inhelder 1956). The second approach argues for a weak innate geocentrism bias that may be overridden by culturally (including linguistically) transmitted practices of relative frame use (Haun et al. 2006). And the third account argues that small-scale reference is itself the product of cultural evolution and favors relative frame use. These hypotheses can only account for part of the data presented here, and they account for complementary parts. We conclude that we do not yet hold all the parts to the puzzle we have uncovered.

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