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The development of geographic categories and biases

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Abstract

Children and university students ($N = 58$) estimated the locations of major cities in North America. At age 9, a distinct home region was apparent, but no differentiation between northern US and Canadian cities. At 11, four developments were observed: Children divided North America into regions that were not based solely on national boundaries but were the same as university students' regions; psychological border zones between regions exaggerated distances between them; children used new location information to update their estimates for all cities in a seeded region and in adjacent and nonadjacent regions; children preserved the ordinal structure of their initial location estimates for cities in their home region but relied on regional prototype locations to adjust estimates in less familiar regions. The updating methods reflect fundamentally different mechanisms. Theoretical and educational implications are discussed.
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There is a contrast inherent in people's knowledge about geography. Although people have accurate knowledge about many geopolitical units (e.g., Bousfield & Sedgewick, 1944; Brown & Siegler, 1993; Saarinen, 1973) and the hierarchical and ordinal relations among them (Friedman & Brown, 2000a, 2000b; Glicksohn, 1994; McNamara, Hardy, & Hirtle, 1989; Stevens & Coupe, 1978; Tversky, 1981),

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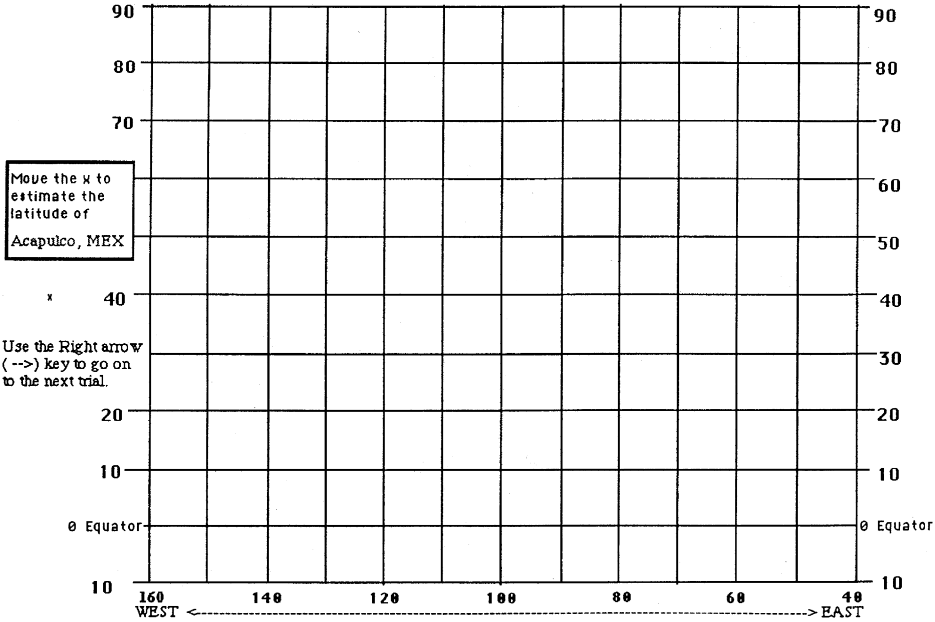
their knowledge of the actual locations of places is not just inaccurate, it is also distorted systematically (Downs & Stea, 1973; Friedman & Brown, 2000a, 2000b; Friedman, Brown, & McGaffey, 2002a; Friedman, Kerkman, & Brown, 2002b; Maki, 1981; Pinhiero, 1998; Saarinen, 1973, 1999; Saarinen & McCabe, 1995; Stea, 1969; Stea, Blaut, & Stephens, 1996; Stevens & Coupe, 1978; Tversky, 1981). Our research with adults led us to conclude that the quantitative inaccuracies and distortions observed in their location estimates reflect the categorical nature of their mental representations of world geography (Friedman & Brown, 2000a, 2000b; Friedman et al., 2002a; Friedman et al., 2002b).

In the present study we examined geographical representation in children and adolescents to examine four basic developmental issues: (1) the development of geographic categories in children's representation of North American geography, (2) the emergence of exaggerated "boundary zones" between these categories, (3) when and how location estimates become systematically biased, and (4) when and how children update their geographic representations when given new information.

We addressed these issues by having participants estimate the locations of 30 North American cities, both before and after receiving accurate information about the locations of two "seed facts" (i.e., that Dallas and Tijuana are both located at 33°N). Participants provided their estimates by "dragging and dropping" an X on a computer screen to the location on a grid where they thought each city belonged (see Fig. 1). Notably, university students' performance on this *grid task* was similar to their performance on numerical location judgments (Kerkman, Friedman, Brown, & Wilson, 2000). In particular, we observed the same geographical regions with relatively large boundary zones between them and relatively large and systematic biases in their estimated locations. Others who have studied children's reasoning about space have noted that the method used to assess knowledge of space can influence the results (e.g., Newcombe & Liben, 1982). We used the grid task in this study because we believed it would be more meaningful and less confusing for the younger participants than numeric estimates, and also, because the kind of spatial knowledge we attempted to assess is gained almost exclusively from two-dimensional representations (i.e., maps), rather than numbers or direct experience with the places in question.

Several studies have examined how children learn from maps (i.e., two-dimensional scale representations of three-dimensional places in the real world) (e.g., Blades et al., 1998; Huttenlocher, Newcombe, & Vasilyeva, 1999; Sandberg & Huttenlocher, 2001; Uttal, 1994; Uttal & Wellman, 1989). In this study, we are not examining children's map *use* per se. Rather, we examined how children locate North American cities on a blank, two-dimensional coordinate grid. These data, together with what we have learned from previous research with adults (Friedman & Brown, 2000a, 2000b), provide evidence for claims about the nature and development of representations and processes underlying the estimation of locations on a continental scale.

The present study is the first we know of to examine how children's knowledge of the locations of cities in North America develops and becomes organized into


Move the x to estimate the latitude of

Acapulco, MEX

Use the Right arrow (-->) key to go on to the next trial.

Fig. 1. The latitude × longitude grid as it appeared on the computer monitor. The monitors were 19.5 cm × 26 cm. Ten degrees of latitude (2 cm on the monitor) is 1113.17 km (691.69 miles) on the surface of the earth.

regions. Much as we have used adults' estimates of locations to establish the functional significance of regions and the validity of our representational claims, the present data clarifies the way representations of geographical information develop. Thus, in addition to the four issues described earlier, we can examine whether children develop the psychological regions seen in adults (e.g., between the northern and southern United States) at the same time as they develop regions based on national identities (e.g., between Canada, the US, and Mexico). Though regional organization is neither necessary nor sufficient, a priori, for the accommodation of new information, the systematic adjustment of groups of cities as a function of new information does indicate that those cities have been organized into psychologically functional regional units.

In the following section, we describe the results that led us to the view that regional knowledge underlies both geographic location estimates and the observed spatial biases of university students (Friedman & Brown, 2000a, 2000b; Friedman et al., 2002b). We briefly discuss how regional representations might develop and what pattern of data to expect under different assumptions about mechanisms. We conclude the introduction by noting relations between our findings and Huttenlocher, Hedges, and Duncan's (1991) theory of spatial categorization, and comparing its predictions with those of a plausible reasoning approach (Brown & Siegler, 1996; Friedman & Brown, 2000a, 2000b).

The regional nature of geographical beliefs

When Canadian university students estimated the latitudes of individual cities in the Old and New Worlds, they divided North America into four functional regions (Canada, the northern US, the southern US, and Mexico) and Europe into three (northern Europe, central Europe, and Mediterranean Europe). They discriminated very little among the locations of cities within each region. Furthermore, the specific locations of most of the cities were inaccurate and the locations of some of the regions showed pronounced biases. These biases were virtually eliminated by providing information about the location of four "seed fact" cities (two at each national border). Other research has shown that seed facts influence regions independently (Brown, 2002; Friedman & Brown, 2000a, 2000b), and that the psychological regions we observed using numeric location estimates also underlie performance on spatial geographical judgments (Friedman et al., 2002b; Kerkman et al., 2000).

We recently generalized our observations about the regional basis of geographical estimates and biases in a cross-national study of university students from Edmonton, Alberta and San Marcos, Texas (Friedman et al., 2002b). Although both groups divided North American cities into the same four regions (Canada, the northern US, the southern US, and Mexico), the Albertans were accurate in their placement of Canadian cities but the Texans estimated these locations to be much farther north than they actually are. Somewhat surprisingly, the Texans estimated Mexican cities to be much farther south than the Canadians. Because the Texans lived only 328 km from the nearest major US–Mexico border crossing (Nuevo Laredo, Mexico), whereas the Canadians lived 2928 km from it, Brown (2002) concluded that neither physical proximity nor familiarity could be the primary determinants of this bias.

In the plausible reasoning approach we have advocated (Friedman & Brown, 2000a, 2000b), category-based regional knowledge forms the basis of university students' representations of large-scale geographic space. From this perspective, inaccuracies in the placement of individual cities are largely the result of combining accurate and inaccurate beliefs about the regions to which the cities belong, resulting in systematic biases in the estimates of their locations relative to each other and to global landmarks like the equator, the oceans, and the poles (Friedman & Brown, 2000a, 2000b).

Spatial categories, bias, and the role of seeds as informative feedback

The idea that locations are coded at both a categorical level and a more fine-grained item level is central to Huttenlocher et al.'s (1991) model of spatial representation. In this model, bias in spatial location estimates arises from a Bayesian combination of accurate item-level information with information about the spatial category to which an item belongs. However, we have found that in the domain of geography, adults' knowledge of locations may not even exist at the item level and their knowledge of the locations of regions can be quite biased (Friedman & Brown, 2000a, 2000b). Nevertheless, the regions themselves are organized ordinally, and the ordinal relations among them hold after the introduction of seed facts. Huttenlocher et al.'s (1991) model does not allow for bias in spatial judgments to arise at the category level largely because they have dealt with other types of "regional" structures (e.g., quadrants in circles) for which the absolute placement of the categories is unambiguous. Plumert and Hund (2001) tested 7-, 9-, and 11-year-olds' and adults' memory for locations in a small-scale quadrangular space, similar to a dollhouse. Children and adults overestimated the distances between objects in different regions. When the rectangle was visibly subdivided into four quadrants, only the 11-year-olds and adults displaced objects toward the centers of the quadrants, a spatial category prototype effect. In this study, we examined the development of regional categories in a very large-scale space in which participants must draw upon their knowledge of geography in order to complete the task. Importantly, we are thus not addressing the link between a representation and an actual space that is perceived, but rather, the categorical structure used by participants to mentally represent the space itself.

We have used the effects of the seed facts on second estimates to provide evidence for the mechanism(s) used to update the representations. People use seeds to adjust the absolute locations of the regions; that information is propagated to the item level if it exists. But even if adults have no item-level knowledge, seed information was shown to propagate to both adjacent and distant regions (Friedman & Brown, 2000b). In the present study we examined when seed facts begin to assert an influence on performance and whether they improve the performance of children as they have with adults.

One might expect seed facts to act as prototype values and produce anchoring effects (Jacowitz & Kahneman, 1995; Strack & Mussweiler, 1997; Wilson, Houston, Etling, & Brekke, 1996). That is, all the cities in the seeded region should gravitate toward the seed's location from all directions. However, there is an increasing body of evidence that both assimilation and contrast effects can arise in the same set of post-seeding estimates (Brown & Siegler, 2001). This evidence implies that the role of seeds in updating real-world knowledge is one of *feedback induction* (Brown, 2002; Brown & Siegler, 2001): Seeds provide feedback on the accuracy of preexisting beliefs as well as the data necessary to induce more accurate beliefs. Thus, in the present study, the pattern of post-seeding shifts (towards the seed from all directions or both towards and away) provides direct evidence of whether seeds function as prototypes or as feedback; it is also possible that their role could shift as a function of age.

Correlations between the first and second estimates allowed us to examine how much of the internal category structure was preserved within each region. High correlations imply that the pre- and post-seeding internal structure of the category is similar; whereas low correlations imply that it is not. Preserving the spatial structure of a region also implicates feedback induction as the mechanism used for updating the knowledge representation.

Method

Several aspects of the grid task warrant noting. In all the previous studies of numeric estimates (Friedman & Brown, 2000a, 2000b; Friedman et al., 2002b) and in both the previous (Kerkman et al., 2000) and current study using the grid task, participants were asked to estimate only the latitudes of the cities. We constrained responses to one dimension for two important reasons. First, from our previous work (Friedman & Brown, 2000a, 2000b) we have a clear understanding of how adults make numeric latitude estimates and of the regionalization and biases in their knowledge of North American geography. As this was the main focus of the present study, having the participants estimate only latitudes permitted a cleaner comparison across studies. Second, we had pilot data indicating that, with numeric estimates of latitudes and longitudes, adult participants occasionally confuse the two. We felt it likely that one dimension was as much as we should try to explain to the children. Consequently, for purposes of comparison to previous research we chose to investigate only latitude estimates. Because we did not instruct the participants about longitudes, we do not know the relation between age and any assumptions participants had about how important longitudes were in the responses.

In addition to asking participants to estimate only latitudes, we used a disproportionate number of cities from the southern US region because we did not want to overwhelm the younger participants with too many unfamiliar place names. Similarly, we did not use seeds from the two (presumably) less familiar regions (Canada and the northern US). Finally, although the participants in this study and all our previous studies were told that latitudes run from +90° at the North Pole to −90° at the South Pole, in the present study the grid only displayed latitudes to −10° (see Fig. 1). Though this constrains our conclusions in terms of the absolute location of the regions, we are nevertheless examining the development of the pattern of responses shown previously by adults on both numeric estimates and using the same grid task (Kerkman et al., 2000).

Participants

All children resided in San Antonio, Texas, and were recruited from a children's bowling league. The university students were recruited from undergraduate psychology classes at Southwest Texas State University, San Marcos, Texas (51 km northeast of San Antonio). Ninety-seven percent of the students at Southwest Texas State University were in-state residents (Southwest Texas State University Fact Book, 2002). There were four age groups that will be referred to as the 9-, 11-, and 13-year-olds, and university students, respectively; the mean age in each group was 9.5, 11.5, 13.4, and 22.8 years. There were 10, 17, 13, and 18 participants in each group (5, 5, 7, and 11 females, respectively). Originally, there were five age groups that included 11 7- and 8-year olds. However, 3 of the 11 7-year-olds were removed from the sample because they did not understand the instructions. Furthermore, preliminary examination of the data from the remaining eight 7- and 8-year-olds showed that their responses bore virtually no resemblance to geographic fact and were highly variable. It was likely that many of the remaining 7-year-olds did not understand the task. Therefore, to increase the homogeneity of variances between age groups, the 7- and 8-year-olds were eliminated from the study.

Stimuli and design

The stimuli were 30 cities from Canada, the US, and Mexico. For purposes of analysis, the cities were divided into four regions, based on the data provided by several previous groups of adult participants (Friedman & Brown, 2000a, 2000b; Friedman et al., 2002b; Kerkman et al., 2000). Including the two seed cities (Dallas and Tijuana), there were 5 Canadian cities (Ottawa, Quebec City, Saskatoon, Toronto, and Winnipeg), 5 cities from the northern US (Buffalo, Chicago, Minneapolis, New York, and Seattle), 12 cities from the southern US (Atlanta, Dallas, Houston, Las Vegas, Los Angeles, Miami, Memphis, Phoenix, San Antonio, San Diego, Tampa, and Tucson), and 8 cities from Mexico (Acapulco, Cancun, Chihuahua, Mazatlan, Mexico City, Puerto Vallarta, Tijuana, and Vera Cruz). Dallas and Tijuana lie on the same parallel (33° N) but are in different countries. This information should correct the misconception that all cities in Mexico are south of all cities in the US (Friedman & Brown, 2000a, 2000b; Kerkman et al., 2000).

Procedure

Groups of 3–5 participants were tested by two experimenters in a quiet room. The children came in and each took a seat at a computer. They read the directions for the knowledge ratings, and almost all the children understood this task without needing further instructions. Some children occasionally said that they had never heard of a place; in that event the experimenters told them that it was okay, and repeated the instructions to rate it between 0 and 9, with 9 meaning they had “a lot of knowledge” and 0 meaning they had “no knowledge.” The computer presented the names of each city and its country (e.g., “Acapulco, Mexico”) and asked the child to rate “How much do you know about this city?” on a scale from 0 (no knowledge) to 9 (a lot of knowledge). The order of city presentation was randomized for each participant.

Next, the computer displayed instructions for the grid task. An experimenter read the instructions to the participant, and for the children, explained what latitudes were by showing them a 30 cm. blue rubber ball with latitude lines demarcated on it in 10° increments. The children were asked if they were familiar with a globe. All said they were. The experimenters then told them that the blue ball was supposed to represent a globe, and that the lines that were drawn on it represented the lines of latitude that were also drawn on the globes that they had seen before. The experimenters explained that 0° was the equator, and that the equator passed through the center of the earth. The line representing the equator was then indicated on the ball. Children were told that the grid on the screen “matched” the ball. For emphasis, the experimenter pointed to the 20° line on the ball, showed them the 20° on the screen, and then asked them if they understood that the line on the grid represented the line on the ball. If the child said “yes,” the experiment proceeded. All children indicated that they understood the instructions.

When the first city appeared on the screen the experimenters asked the child, “Okay, now where do you think (city name, country name) would be located on this globe (referring to the blue ball)? Now use your mouse, and move this X (on the screen) to the location that matches that place on the computer screen.” Similar to our previous studies in which adults provided latitude estimates, the instructions did not explicitly mention longitudes or east–west locations. The country names were included to maintain comparability with our previous work with adults, and to disambiguate city names that occur in more than one country (e.g., San Antonio occurs in both the US and Mexico). It should be noted that if participants were responding on the basis of only country names, we would have obtained only three North American regions in our previous studies, rather than the four regions we did observe.

The experimenters observed that approximately 75–80% of the children sometimes referred to the ball (i.e., looked back and forth between the ball and the screen) to decide where the locations should be on the screen, and about 25% of the children used the ball in this manner for every city. Thus, we are confident that even the youngest children included in this sample understood the task and the mapping we intended between the ball and the screen.[1]

Participants pressed the right arrow key to advance to a new trial. Each trial showed the empty grid with a dialog box that displayed a city’s name and its country. An X appeared directly below the city’s name (see Fig. 1). Each trial began with a blank grid so the participants had no overt record of their previous estimates.

After all 30 locations were estimated, participants were told that they were going to estimate the city locations again, but this time they would be given two “hints.” They were told that on every trial the actual, correct locations of Dallas, US, and Tijuana, Mexico would be displayed on the grid (“Where they really are on the map”) and labeled in red letters. Participants then estimated the locations of the cities again. The location of the seed cities remained on the screen during each trial. Previous research with adults using this method (Brown & Siegler, 1993) showed no improvement in estimation accuracy as the result of up to four blocks of practice; their accuracy only improved as a function of being given seed information. If adults’ estimation accuracy did not improve as a result of mere practice, it seemed reasonable to assume that children’s performance would not improve. Therefore, we did not control for the order of administration of the seed and no seed conditions.

Results

The seed cities were excluded from all statistical analyses because their actual locations were displayed to the participants while the second estimates were collected. We computed the mean knowledge ratings, the first and second latitude estimates,

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[1] There is no “best way” to transform the spherical surface of the globe onto the two-dimensional surface of a map. Numerous projections are in use. Each has its positive values as well as its drawbacks. The Cartesian grid used to respond in this study amounts to requiring the participant to generate an equirectangular projection from the spherical globe, as represented by the ball, to a two-dimensional grid. In the response grid, the meridians of longitude are equally spaced, the parallels of latitude remain parallel and equally spaced, and the unit of distance is the same on both dimensions.

the bias in the first and second latitude estimates (signed errors), and the accuracy of the first and second latitude estimates (absolute errors). Signed errors were obtained by subtracting the actual from the estimated latitudes for each city and then averaging over cities within a region for each participant; positive values mean the estimates for the region were biased to the north and negative values mean they were biased to the south. Because the same constant latitude is subtracted from each participant's estimate for a given city to obtained signed error, for the Age by Region interaction the mean estimates and signed errors yield identical results in the ANOVA but provide different information. Absolute errors were computed as the absolute values of the signed errors for each city, again averaged over cities within a region for each individual. It is possible for there to be no bias in the average estimates (e.g., if positive and negative signed errors cancel each other out) but large absolute errors. Rank-order correlations between actual and estimated latitudes over the 28 cities were also used to assess accuracy.

For the analyses of variance (ANOVAs), the participants' average estimate for the cities in each region was analyzed in a mixed design in which age was between-participants and region was within-participants. The .05 probability level was adopted for all statistical comparisons. Results with probability levels between .05 and .10 are reported as statistical trends.

We have used regional analyses of this sort in prior studies (Friedman & Brown, 2000a, 2000b; Friedman et al., 2002b). Thus, their use in the present study facilitates comparisons with adult performance. We provide evidence for the development of separate regions by a priori tests of whether their mean location estimates were reliably different from each other for each age group, and by the rank-order correlations between estimated and actual latitudes for the individual cities. Similar analyses of the signed errors provide evidence for the existence and direction of biases exhibited for each of the regions.

Knowledge ratings

The only reliable effect in the ANOVA was that of region, $F(3, 162) = 99.38$, $MSe = 1.28$. As one would expect on the basis of differences in direct experience and/or media exposure, all age groups reported knowing most about the cities in the southern US, their home region, followed by cities in the northern US (see Table 1 for means). Canadian cities were the least well known for all the groups.

First latitude estimates

Table 1 shows the mean first latitude estimates, signed errors, and absolute errors; Fig. 2 shows the mean first and second latitude estimates for the cities in each region at each age, together with the actual mean latitudes; and Fig. 3 shows the data for all 30 cities, including the seed cities, Tijuana, Mexico, and Dallas, US. The ordering of cities along the abscissa of Fig. 3 is empirically determined by the mean subjective location estimate, rather than the cities' objective latitudes. This reveals the subjective regionalization for each age group, and means that the exact ordering of cities

Table 1
Mean (and *SD*) knowledge ratings, latitude estimates, signed errors, and absolute errors for the first set of estimates as a function of age and region

Age	Canada	Northern US	Southern US	Mexico
Knowledge ratings				
9–10 years	.10 (0.1)	2.54 (0.6)	2.99 (0.7)	.66 (0.2)
11–12 years	1.09 (0.4)	3.94 (0.6)	4.56 (0.5)	1.85 (0.4)
13–15 years	.68 (0.3)	3.12 (0.7)	4.03 (0.5)	1.41 (0.4)
University	1.18 (0.4)	3.80 (0.5)	4.73 (0.4)	2.69 (0.5)
Mean	.86 (0.2)	3.47 (0.3)	4.22 (0.3)	1.81 (0.2)
Latitude estimate				
9–10 years	57.9 (7.2)	53.4 (2.8)	42.0 (3.1)	29.4 (5.3)
11–12 years	69.5 (3.8)	55.8 (2.9)	35.9 (2.0)	13.0 (4.1)
13–15 years	71.2 (2.6)	56.8 (2.6)	38.9 (1.9)	15.8 (2.3)
University	68.0 (4.1)	53.0 (3.0)	28.8 (2.7)	9.2 (2.3)
Mean	67.4 (2.2)	54.7 (1.5)	35.4 (1.4)	15.3 (1.9)
Signed error				
9–10 years	10.3 (7.2)	9.6 (2.8)	10.2 (3.1)	8.1 (5.3)
11–12 years	21.9 (3.8)	12.0 (2.9)	4.1 (2.0)	−8.3 (4.1)
13–15 years	23.6 (2.6)	13.0 (2.6)	7.1 (1.9)	−5.5 (2.3)
University	20.4 (4.1)	9.2 (3.0)	−3.0 (2.7)	−12.0 (2.3)
Mean	19.8 (2.2)	10.9 (1.5)	3.6 (1.4)	−6.0 (1.9)
Absolute error				
9–10 years	25.7 (1.9)	14.1 (1.8)	17.6 (2.3)	19.9 (3.4)
11–12 years	25.3 (3.0)	17.3 (1.8)	13.7 (1.0)	17.0 (2.3)
13–15 years	25.2 (2.4)	15.7 (2.1)	11.9 (1.7)	10.7 (1.3)
University	24.4 (2.5)	14.5 (2.6)	11.4 (1.8)	13.9 (1.9)
Mean	25.1 (1.3)	15.5 (1.1)	13.2 (0.9)	15.1 (1.2)

on the abscissa changes from one age group to another. Importantly, the cities within each category do not change from age 11 and up.

In general, older participants' Canadian and northern US estimates were more northerly and their estimates for Mexican cities were more southerly than were those of the younger participants. The ANOVA on the latitude estimates yielded a reliable effect of region, $F(3, 162) = 192.95,\ MSe = 135.17$, and an Age × Region interaction, $F(9, 162) = 3.13,\ MSe = 135.17$. Subsequent analyses of the differences between the mean latitude estimates of adjacent regions revealed that for the 9-year-olds, the difference between the northern and southern US was reliable, $t(9) = 3.77$, as was the difference between the mean estimates for the southern US and Mexico, $t(9) = 2.70$. However, there was no difference between their means for the northern US cities and the Canadian cities. For the three oldest groups (the 11-year-olds, 13-year-olds, and university students), all three differences between adjacent regions were reliable (*t*-values ranged between 3.92 with 12 *df* and 10.89 with 17 *df*).

The regional analysis of the mean estimates allows us to conclude that, by age 9, children had a concept of their home region as distinct from a region to its south (Mexico) and a region to its north that included a mixture of the Canadian and

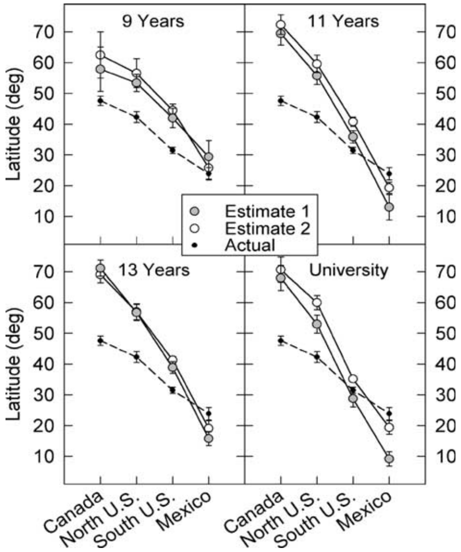

Fig. 2. Average first and second latitude estimates for cities in the four regions, excluding seed cities, for four age groups.

northern US cities. Clearly, their responses were not the result of the country labels. By age 11, children made a further distinction between the northern US and Canada. This four-category regional organization persisted among the adolescents and university students.

These conclusions were also supported by the rank-order correlations $(r_s, df = 26)$ between each participant's first estimate for each city and the city's actual latitude, averaged across participants within each age group. The average correlation was relatively small but significant for the 9-year-olds, $r_s = .46$, and increased dramatically by age 11, $r_s = .86$, and remained at this level among 13-year-olds $r_s = .84$, and university students, $r_s = .87$. Thus, the significance of the correlations across all the cities indicates the correct rank ordering began to emerge at age 9 and was fully formed by age 11. Within regions, however, the only correlation between estimated and actual latitudes that was significant was the correlation for university students' estimates of locations in their home region, $r_s(9) = .61$.

Bias in first estimates. To determine when biases in location estimates developed, we examined whether the average signed errors for each region were reliably different than zero for each age group (the means are shown in Table 1). The 9-year-olds provided clear evidence that they distinguished among at least some of the regions. They also show some clear biases: They overestimated all four regions by about the same amount (between 8° and 10°). Though the northward bias was not reliable for Canadian or Mexican cities, it was reliable for the northern and southern US, $t(9) = 3.41$ and 3.24, respectively.

A difference in the pattern of bias emerged among the 11-year-olds. Their estimates for Canadian, northern US, and southern US cities were 22°, 12°, and 4° to

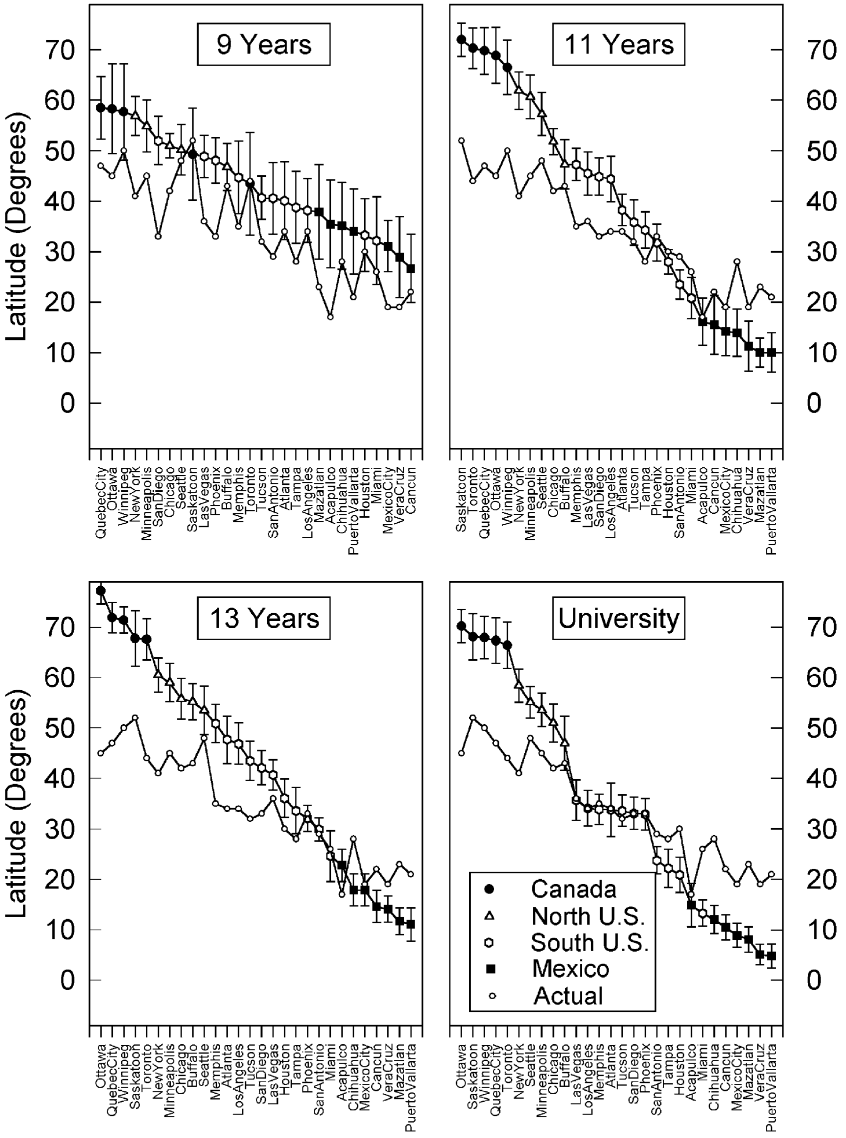

Fig. 3. Subjective location profiles of average first location estimates and actual locations of each city for four age groups.

the north of their actual locations; all of these biases were reliably different than zero, $t(16) = 5.75, 4.20$, and 2.08, respectively. In contrast, Mexican cities were estimated to be 8° to the south of their actual locations, $t(16) = -2.00$, $p < .06$. The difference between the 9- and 11-year olds in the north–south placement of Mexican cities was a remarkable 16° (1,120 miles).

The 13-year-olds' regional biases were similar to the 11-year-olds, except that all four regions were reliably different than zero (*t*-values ranged from 8.99 to −2.43 with 12 *df*). The university students' biases for Canadian and northern US cities were similar to the 13-year-olds' and were reliably different than zero, $t(17) = 5.03$ and 3.06, respectively, but their estimates for the southern US did not differ significantly from zero (−3°). However, their estimates for Mexico were significantly biased, $t(17) = -5.35$, and were about 7° (nearly 500 miles) farther south than the 13-year-olds.'

To summarize: Biases in the estimates emerged at the earliest age where we were able to obtain data that bore any correspondence to geographic fact. Furthermore, the direction of the biases shifted as a function of both age and region. A home region that was distinct from cities to its north (both northern US and Canadian cities) and cities to its south (Mexican cities) was apparent at age 9. The adult pattern of bias first emerged at 11 years of age, and biases for Mexican cities became more pronounced among university students than they were for 11- and 13-year-olds. The observed differences in the pattern of bias as a function of age and region was supported by an interaction in the overall ANOVA, $F(9, 162) = 3.13$, $MSe = 135.27$.

Accuracy of first estimates. For the absolute error, the only reliable effect in the first estimates was that of region, $F(3, 162) = 29.73$, $MSe = 50.98$ (see Table 1 for means). The range of absolute error across regions was 12° for the 9-year-olds and remained relatively constant thereafter. In general, first latitude estimates were least accurate for Canadian cities and (except for the 13-year-olds) most accurate for cities in the southern US. This pattern of accuracy mirrored the pattern for knowledge ratings.

As noted earlier, the rank-order correlations over all 28 cities were significant at age 9, indicating that participants had a relatively accurate rank ordering at that age. However, none of the within-region correlations between the first estimates and the actual latitudes were significant until the university level, and then only within the southern US, their home region.

Second latitude estimates

Table 2 shows the mean estimates, signed errors, and absolute errors for the second set of estimates. Unlike the first estimates, there was no significant Age by Region interaction for any of the measures. Only the region main effect was reliable, $F(3, 162) = 203.35$, $MSe = 119.02$ for the estimates, $F(3, 162) = 38.33$, $MSe = 119.07$ for signed error, and $F(3, 162) = 64.51$, $MSe = 41.32$, for absolute error. Thus, the seed facts brought all three groups into correspondence on their estimates. Importantly, for all the groups, the estimates for cities in the seeded regions (Mexico and the southern US) shifted to the north, which means that the southern US cities shifted in a direction away from the seeds while the Mexican cities shifted towards the seeds. Consequently, the data are consistent with an interpretation that in familiar territory, seeds function via feedback induction, rather than functioning as prototypes.

Table 2
Mean (and *SD*) latitude estimates, signed errors, and absolute errors for the second set of estimates as a function of age and region

Age	Canada	Northern US	Southern US	Mexico
Latitude estimates				
9–10 years	62.5 (7.5)	56.6 (4.7)	44.5 (2.0)	25.8 (3.7)
11–12 years	72.4 (3.2)	59.6 (2.8)	40.8 (1.5)	19.3 (1.8)
13–15 years	69.1 (2.7)	57.0 (2.6)	41.3 (1.2)	19.1 (2.5)
University	70.7 (4.1)	60.0 (2.3)	35.2 (0.7)	19.4 (2.2)
Mean	69.4 (2.1)	58.6 (1.4)	39.8 (0.8)	20.4 (1.2)
Signed error				
9–10 years	14.9 (7.5)	12.8 (4.7)	12.7 (2.0)	4.5 (3.7)
11–12 years	24.8 (3.2)	15.8 (2.8)	9.0 (1.5)	−2.0 (1.8)
13–15 years	21.5 (2.7)	13.2 (2.6)	9.5 (1.2)	−2.2 (2.5)
University	23.1 (4.1)	16.2 (2.3)	3.4 (0.7)	−1.9 (2.2)
Mean	21.8 (2.1)	14.8 (1.4)	8.0 (0.8)	−0.9 (1.2)
Absolute error				
9–10 years	26.7 (2.9)	20.0 (2.6)	17.2 (1.5)	13.2 (3.0)
11–12 years	26.0 (2.8)	18.0 (2.3)	14.1 (1.4)	8.8 (0.9)
13–15 years	24.7 (1.6)	15.9 (1.8)	13.3 (1.3)	9.9 (1.6)
University	26.9 (2.3)	17.5 (2.1)	7.9 (1.0)	8.6 (1.5)
Mean	26.1 (1.2)	17.7 (1.1)	12.5 (0.8)	9.8 (0.8)

Bias in second estimates. The Dallas–Tijuana seeds improved the second estimates for Mexican cities in the three oldest groups to the point where the signed errors were no longer significantly different from zero, $t(16) = -1.11$, $t(12) = -0.91$, and $t(15) = -0.84$ for 11-year-olds, 13-year-olds, and university students, respectively. However, this improvement came at the expense of the other regions: For the three oldest groups, not only were the biases for Canadian, northern US, and southern US cities still reliably different than zero (and biased to the north, t-values ranged between 5.63 and 7.72 with 16 *df* for the 11-year olds, 5.03 and 8.06 with 12 *df* for the 13-year olds, and 4.81 and 7.11 with 17 *df* for the university students), they were actually larger than the original biases in 8 of the 9 cases (compare Tables 1 and 2). Thus, though the Dallas and Tijuana seeds improved the accuracy of performance in their respective regions, there were no seeds to provide an upper bound on the estimates, so bias increased as cities in the other two regions were also shifted to the north.

The 9-year-olds' first estimates for both the northern and southern US regions had been significantly biased to the north. Not only were these regions still biased to the north in the second estimates, $t(9) = 2.73$ and 6.49, respectively, but, as with the three older groups, they were more biased than the initial estimates for these regions. Their bias to Canadian and Mexican cities remained insignificant.

Overall, and in contrast to the first estimates, the second estimates were sufficiently similar across the groups that the Age by Region interaction was not reliable, $F(9, 162) = 1.56$, $MSe = 119.07$, $p > .10$.

Accuracy of second estimates. To examine improvements in accuracy, we conducted Region × Age × Estimate Number ANOVAs on the absolute error data, using the means from all four regions. The new effects of interest were the interaction between estimate number and region, $F(3, 162) = 15.68$, $MSe = 19.29$, and the interaction between age, estimate number, and region, $F(9, 162) = 2.40$, $MSe = 19.29$. Second estimates improved more for the southern than the northern regions, especially for older participants' Mexican location estimates (see Fig. 2 and Table 2). Furthermore, because of the general tendency for the cities to move northward, post-seeding accuracy for the older groups was actually somewhat worse for cities in the northern US and Canada.

Developmental differences in the effects of seeds. We refer to *category structure* as the degree to which the rank ordering of the cities in each region was preserved when participants adjusted their second estimates. The correlation between first and second estimates provides a statistical index of the extent to which the initial category structure is preserved in the face of new information from the knowledge seeds.

Rank-order correlations (r_s) between the first and second estimates for each city were computed for each participant then averaged across participants. Across all 28 cities (excluding the seed cities), the internal consistency of the rank ordering was apparent at age 9, $r_s = .58$, and remained significantly correlated among the 11-year-olds, 13-year-olds, and university students, $r_s = .77$, .83, and .86, respectively. However, the only region to show internal consistency was the home region. For this region, significant correlations between the first and second estimates first appeared at age 11, $r_s = .53$, and remained significant among the 13-year-olds and university students, $r_s = .52$ and .69, respectively.

These results highlight the development of the ability to preserve the north–south rank ordering of the regions and of the cities within the southern US region. The results are most consistent with the notion that children develop knowledge of the rank order of regions relative to one another and knowledge of the cities that belong to each region without developing accurate or consistent beliefs of the locations of cities within regions other than their own. Again, it needs to be emphasized that the two within-US regions were not differentially marked by country names. Consequently, nothing in the stimulus presentation methodology could have produced these results.

The development of regions and border zones

Fig. 3 shows each age group's subjective location profile of the mean latitude estimates for each city, as well as the cities' correct latitudes. We use the average latitude estimate for each city to illustrate the development of the psychological boundary zones that adult participants exhibit between regions (e.g., Friedman & Brown, 2000a, 2000b; Friedman et al., 2002b).

For 9-year-olds, all of the Canadian and northern US cities and 3 southern US cities (Las Vegas, San Diego, and Memphis) were intermixed into a single region located north of the 9 remaining southern US cities and all of the Mexican cities. Two Mexican cities (Mazatlan, and Acapulco) were intermixed with the southern US cities. However, the internal spatial relations among the cities were not accurate in any of the regions. Nevertheless, the basic grouping of the cities into three subjective regions is evident, and provides the underlying basis for the reliable differences in mean latitudes observed between the northern and southern US and the southern US and Mexico.

The emergence of the categorization of North American geography into four regions is reflected in the striking differences between the 9- and 11-year-olds. Fig. 3 shows that, with the exception of Memphis, 11-year-olds organized the cities into the same four regions as those found previously with Canadian and US university students (Friedman et al., 2002b). At the same time, clear subjective boundary zones emerged between Canada and the northern US and between the southern US and Mexico.

The 13-year-olds' estimates were clearly organized according to both national and psychological regions; again, the boundary zones between all four regions are obvious. Finally, the four-region organization not only persisted for the university students, but the boundary zones separating the northern from the southern US and the southern US from Mexico were even more exaggerated than they were among 13-year-olds.

Fig. 3 also illustrates that the Canadian and Mexican cities became increasingly compressed about subjective regional prototype locations with increasing age. In addition, for the three oldest groups, the estimates for the southern US expanded dramatically, and the locations of southern US cities became relatively accurate among university students. Thus, across the four age groups, there is evidence for a developmental progression from the 9-year-olds' crude distinction between their home region versus places to its north (including a mixture of both Canadian and Northern US cities) and places to its south (Miami and all of the Mexican cities except Mazatlan), into a four-region representation beginning at age 11 and persisting thereafter. The four-region representation becomes more exaggerated among university students, especially with respect to the Mexican cities. The cities of the two least familiar regions (Canada and Mexico) became increasingly clustered around a subjective regional prototype location, while cities in the two US regions became increasingly dispersed, and increasingly accurate in an ordinal sense. It should be noted that we do not believe that any particular cities necessarily function as prototypes in the location estimate task, though our theoretical stance does not preclude this (Friedman & Brown, 2000a, 2000b). Rather, the regional prototypes seen in adults' performance reflect the average estimate for all the cities within a region. These means often reflect numerical prototypes or geographical landmarks (e.g., longitude 100° for South American cities, Friedman & Brown, 2000a; the equator for Mexican and southern European cities, Friedman & Brown, 2000a, 2000b; Friedman et al., 2002b). Furthermore, the values of the prototypes may change, depending upon what participants are told about the range or other contextual information (e.g., that 180° longitude goes through either Fiji or the western Aleutians; Friedman & Brown, 2000a).

Discussion

The present study examined four developmental issues. The first was the development of the subjective representation of North American geography. Beginning at age 9, children evidenced some regional knowledge, distinguishing the cities in their home region from those to its north and south. This is consistent with the "expanding horizons" curriculum that is ubiquitous in geography education in Texas and throughout the US (Texas Education Agency, 1999). The expanding horizons curriculum is based on the notion that geographic knowledge begins with familiar perceptible spaces, such as the child's desktop, or classroom, then proceeds to large spaces, such as the schoolyard, the neighborhood, the town or city, nearby towns and cities, the state, country, continent, hemisphere, and finally the globe, solar system, and beyond. Some systematic bias also first became evident at this age. By age 11, children developed the four-fold regional organization of North America previously observed in both Canadian and US university students (Friedman et al., 2002b). Notably, the subjective regions did not correspond to the country names presented with the city names: 9-year-olds distinguished their home region from a region to its north that included an undifferentiated mixture of northern US and Canadian cities (as well as a few southern US cities). Similarly, the older groups all differentiated a northern and a southern US region despite the fact that none of the city names indicated whether they belonged to a northern or southern US region. It is noteworthy that the adult-like, four-region representation first appeared at the age of 11. This age corresponds to that at which Plumert and Hund (2001) found regional prototypicality effects in a much smaller scale space where the locations of objects were random and the regions were defined geometrically, rather than geographically. Again, the potential influence of the measurement method on the results observed should be noted. Conceivably, different results might be obtained if participants responded on an empty rectangular space rather than the grid. Future research should address this issue. The grid technique used here has a certain ecological validity in as much as it resembles the external representation from which most people learn about geographic knowledge on a continental scale.

The second and third issues addressed by the present study concerned when the boundary zones between regions developed and when the placement of the regions became biased. The age at which significant biases first appeared was the same earliest age where we were able to obtain data that bore any correspondence to geographic fact and the earliest age at which we first observed any evidence of regional organization: 9 years. However, the biases in geographic knowledge that we previously identified in university students (i.e., overestimates of Canadian locations and underestimates of Mexican locations) emerged at age 11, at the same time that the pronounced psychological boundary zones separating the regions appeared. This four-region organization and pattern of bias persisted from age 11 to the university level.

Finally, we examined how geographic representations are updated at different ages. The seed facts caused all regions to move northward for all groups, thereby improving the accuracy of the seeded regions, albeit at the expense of accuracy in the unseeded regions.

It was not until participants reached university that they were relatively accurate in estimating the latitudes of cities in their home region. Their estimates for regions other than their own never evidenced any accurate knowledge of latitudinal rank order. However, from age 11 onward, participants preserved their initial category structure of their home region while updating their estimates for cities in that region.

To summarize: The earliest age at which we were able to obtain meaningful data indicates that children began to display geographic categories on a continental scale at the same time they displayed biases in their location estimates: 9 years of age. They also incorporated new information into their second estimates by this age, though not to the extent of improvements in accuracy. Children exhibited the adult pattern of regions, boundary zones, regional biases, and use of new information by age 11.

Theoretical implications

Some of our results are consistent with the theory of spatial reasoning proposed by Huttenlocher et al. (1991), although they are not explicitly predicted by it. In particular, city locations were coded at a categorical level, which begins to emerge at age 9 and is fully developed at the age of 11. Children developed a second, fined-grained representation of city locations in their home region, in that they preserved their initial rank ordering of the cities in this region from their first to second estimates, although the rank-ordering was far from accurate. This fine-grained representation also first emerged at age 11, at the same age when they first showed a four-region organization of the cities as well as the first indication that they were able to use seed information to adjust specific regions rather than the entire set of all North American cities, as the 9-year-olds did. Their use of seed facts to update a coherent set of knowledge is consistent with Brown and Siegler's (2001) feedback induction mechanism (see also Friedman & Brown, 2000b). By 11 years, children are likely to employ feedback induction for adjusting the estimates to accommodate new information about cities in the home region, whereas they are likely to adjust the cities in less familiar regions based on regional prototypes. These strategies reflect fundamentally different mechanisms that appear to be developmentally determined.

The development of the regions we observed is reminiscent of re-organization into higher-order units, or *chunks* (Miller, 1956), and has previously been demonstrated in spatial reasoning about smaller, perceptible spaces, such as rooms (McNamara et al., 1989; Reed, 1974). In geography, although even adults display poor performance in location estimates for some regions, their performance is clearly dominated by the organization of the knowledge into chunks (regions) and the ordinal relations among them (Friedman & Brown, 2000a, 2000b; Friedman et al., 2002b). This study traced the development of spatial chunks on a continental scale as children's performance becomes increasingly adult-like.

The evidence clearly indicates that children's knowledge of North American geography develops as a system that is primarily category-driven, and is not an analog spatial system, as has been hypothesized by some (Glicksohn, 1994; Tversky, 1981). The emergence of psychological boundary zones provides a telltale signature of the representational system's categorical nature, and attests to the psychological importance of maintaining unambiguous, nonoverlapping conceptual categories in the domain of geography from a relatively early age.

There have been reports that young children have some ability to comprehend and use simple maps of small-scale spaces (e.g., Blades et al., 1998; Huttenlocher et al., 1999; Sandberg & Huttenlocher, 2001; Uttal & Wellman, 1989; Uttal, 1994). However, Inhelder and Piaget (1964) as well as Liben and her associates (Liben & Downs, 1990; Liben & Downs, 1992; Liben & Downs, 1993; Liben & Downs, 1994; Liben, Moore, & Golbeck, 1982) found that children do not comprehend certain maps of real-world situations until 10 or 11 years of age. Our results also indicate that the ability to produce location estimates on maps of continental scale first emerges at age 9, but is not fully formed until the age of 11. This corresponds to the age at which class inclusion develops in some domains. (Inhelder & Piaget, 1964; Winer, 1980). Political geography is a domain in which class inclusion relationships play a primary role; for example, continents include countries, countries include regions, and regions include cities. Some previous work has addressed this issue (Downs, Liben, & Daggs, 1988; Jahoda, 1963, 1964). Future research should address the relation of class inclusion to the development of knowledge about geographic regions.

In conclusion, these results cast some light on the developmental origins of the contrast we set out to explain: The reason people's knowledge of geography is qualitatively accurate, but quantitatively inaccurate and systematically biased is that as people grow up, they impose categorical reasoning on continuous space. This cognitive developmental trend was first apparent at age 9 and in their home region, emerged fully formed at age 11, and continued into adulthood, when the border zone between the southern US and Mexico became even more exaggerated. Reliance on category-driven spatial reasoning results in relatively accurate rank-order estimates for cities in different regions but virtually no accuracy within regions other than one's own. The psychological border zones serve to keep the regions conceptually distinct. Our data show that the biases observed in the location estimates become larger with age. Future research should examine why these psychological border zones develop, why some of them become increasingly exaggerated with increases in age, and how techniques such as seeding the knowledge base can be applied to counteract biases in geographic knowledge. It would be especially useful to know whether children show the same kinds of long-term educational benefits from knowledge seeds that have been demonstrated for adults' population estimates (Brown & Siegler, 1996; LaVoie, Bourne, & Healy, 2002).

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