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CONCLUSIONS

A CROSS-DISCIPLINARY JOURNEY THROUGH SPATIAL ORIENTATION

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Multiple disciplines offer diverse intellectual tool-kits that can be brought to bear on studies in any one. In this concluding article, I use elements of physics and cognitive psychology to analyze the material reported in this collection. In the case of the articles on navigation at sea (Genz, Feinberg and Pyrek), the physics of ocean waves, climate, and the motion of stars can illuminate the reports of interlocutors. The sensitivity of long wavelength swells to the presence of land seems widespread and is in accordance with known wave behavior and reports. In addition, wave phenomena may be related to local bathymetry and point to further lines of inquiry. Likewise, wind-compass and star directions can be directly compared with climate data and known star motions. The four articles on language and spatial orientation predominantly on land (Montague, Feinberg, Schneider and Van Der Ryn), are examined via the question: Does social cognition follow spatial cognition? As has been reported elsewhere, the findings support the affirmative.

Keywords: spatial orientation, navigation, social cognition

Introduction

It is an honor to have been asked to comment on the work presented in this volume. I am particularly grateful to Professor Feinberg for inviting me to participate in the 2012 ASAO working session on spatial orientation, and review the works presented. My perspective is one of a physicist who is interested in many aspects of human navigation—the psychology, the neural mechanisms, and the physical constraints and clues provided by the environment. These conclusions are highly colored by my background, and perhaps can provide another perspective on the work presented here.

I teach a course on navigation with some—but not exclusive—emphasis on maritime navigation. The course has a strong cross-cultural component; I draw on both historical records and more recent investigations into the navigational strategies in such regions as Pacific Islands and Scandinavia, and I consider the rise of Western schemas. I have also written a book that parallels the material presented in the course (Huth 2013). One perhaps unique aspect of the course is that students participate in a number of navigational exercises that provide data that are then evaluated statistically to draw conclusions about their abilities to navigate under different conditions, and with varying degrees of instruction.

This special issue draws attention to the relationship between navigation and the culturing of space as evident in the divergent aspects of local languages. While much of the literature on spatial orientation relies on an analysis of language, however, it is not axiomatic that the language of spatial orientation is equivalent to spatial perception, nor do words necessarily correlate with behavior. There is much to be learned through an examination of the environment, the behavior of individuals, and the underlying neurological mechanisms that allow orientation. Such examination will open up questions like: Do we really understand what informants are saying, particularly when translated into Western terms? Can concepts in cognitive psychology and the neurosciences inform these studies? Can an understanding of the physical constraints imposed by the environment inform the studies? Below, I analyze the articles in this collection from these perspectives, and present some of my own conclusions.

Organization

Three important elements run through these contributions: environment, personal cognitive experience, and culture. Each element is linked in some way to each of the others. For example, the environment will affect individual cognition in ways that are predetermined by factors like familiarity and expectations. The aggregation of individuals defines and shapes culture. It is important also to note the feedbacks among the elements (see Figure 1).

The figure is not intended as an overarching theory of spatial cognition, but rather my way of organizing thoughts. Although it is only figurative, the feedbacks do contain some hints of the emergence of stable systems.

In control theory, feedback loops can create many possible behaviors in a system with multiple elements. Consider a microphone and a loudspeaker: the feedback of sound into the microphone can produce diverging oscillations that amplify a specific frequency. Consider the motion of a rocket: engineers design feedback from navigation equipment such as gyrocompasses to plates that direct thrust to produce a stable trajectory. The feedbacks in the above diagram hint at possible interrelations among the elements. For example, an individual's motion will alter his or her location in an environment. The individual must update his/her internal cognitive map as the motion takes place. If the feedback is broken in some way, the individual is lost. Likewise, culture may influence one's cogni-

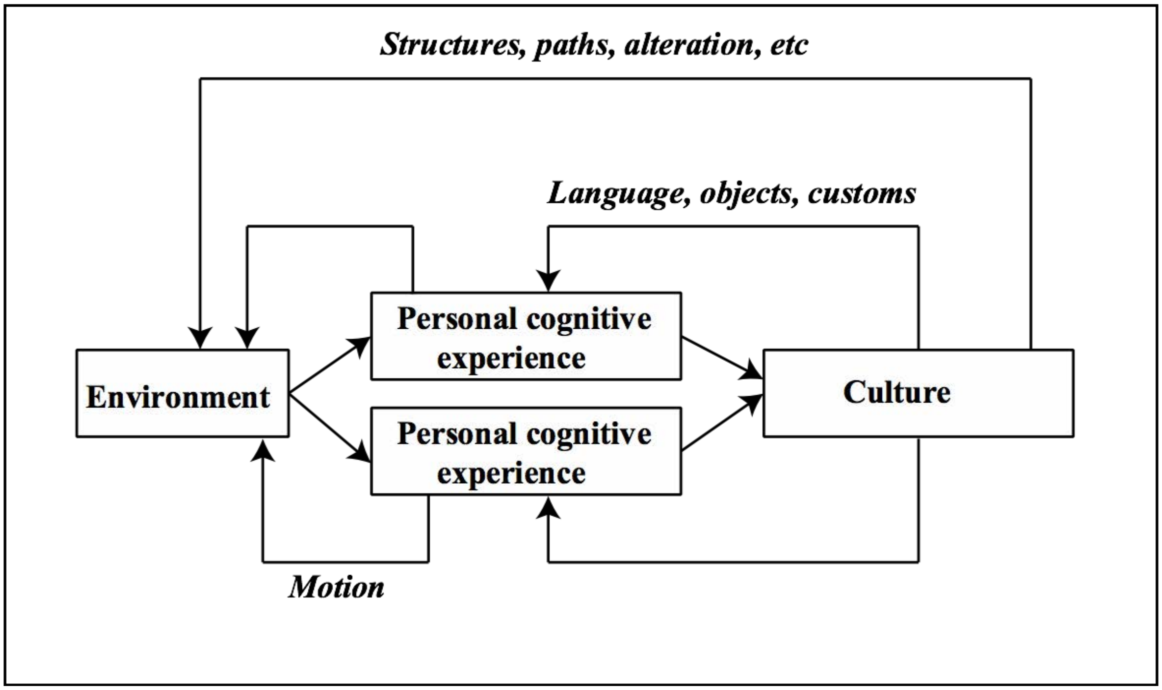

Figure 1. Diagram exhibiting the relation between environment, personal cognition, and culture as envisioned by the author.

tion through language and customs, creating a stable system. If multiple cultures come into play, as we see in some of these articles, some breakdown of cognitive functions could take place, with confusion or ambiguity resulting. "Inside" the boxes in the figure, feedback mechanisms are also active; many mental processes demonstrate feedback.

Broadly speaking, this collection includes contributions of two kinds. The first addresses navigation at sea by specialized subsets of the population (Genz; Pyrek and Feinberg), and there, the environment plays a major role. The second class of articles (by Schneider, Feinberg, Van der Ryn, and Montague), considers larger groups of individuals, inhabiting islands of varying sizes. Before launching into a discussion of the contributions it is worth taking an overview of what is understood about the cognitive aspects of spatial perception.

Cognitive Maps

Mammals, humans included, appear to have a representation of their surroundings that involves a specific kind of memory. Psychologists use two important concepts in describing the internal maps in mammals: *route knowledge* and *survey knowledge.* Route knowledge is a mental representation of paths through an environment and nodes of intersection. When moving through an environment, individuals with route knowledge can successfully navigate only if they restrict themselves to the paths they know and their intersections.

Survey knowledge is a fuller mental representation of an environment. A person possessing survey knowledge can visualize his or her environment as if viewing it from a distance overhead. Successful navigation through an environment in this case is not constrained by known paths. In fact, the behavioral manifestation used to distinguish whether cognitive maps are based on route or survey knowledge is shortcutting to move toward a destination.

Psychologist Edward Tolman (1948) demonstrated that rats are able to acquire survey knowledge. Further experiments and observations show that a wide range of mammals gain survey knowledge of their environment, given sufficient time to explore it. Adult wolves, for example, show survey knowledge by short-cutting, while pups will either follow the adults or stick to paths they know, having only route knowledge (Peters 1978).

While route knowledge versus survey knowledge is one distinction in the descriptions of environmental perception, a number of others appear in the literature. Among the more prominent is that between egocentric and allocentric reference frames of reference (e.g., Shore 2012). Allocentric frames are descriptions of the environment that are divorced from the perspective of the individual and represent space in some objective sense. Egocentric frames of reference are organized around the position of a particular individual.

Neuroscientists use probes and a variety of non-invasive strategies to determine the location and functional representation of cognitive maps at a cellular level. Two neighboring regions of the brain are implicated: the hippocampus and the entorhinal cortex (Figure 2). These two regions of the brain have dense neural interconnections. There is some variation in the anatomical naming of the entorhinal cortex, but it is widely seen as an interface between the limbic system and the neocortex.

The details of the neural wiring of the hippocampal-entorhinal cortex are beyond the scope of this article. The interested reader can find numerous reviews (e.g., McNaughton et al. 2006). Studies demonstrate that the same pairing of activity in the hippocampus and entorhinal cortex found in other mammals is largely responsible for cognitive maps in humans (Maguire et al. 2000; Doeller et al. 2010). Perhaps not surprising is the plasticity of cognitive maps, both within individuals and variations from person to person. For example, taxi drivers engaged in complex navigation in an urban environment develop enlarged hippocampi relative to the population at large (Maguire et al. 2000). Different cognitive maps emerge depending on environment and mode of transportation (Terrazas et al. 2005).

Two other regions associated with spatial orientation and navigation are the retrosplenial and the parietal cortices (Figure 2). Recent fMRI studies implicate the retrosplenial cortex as playing a significant role in the identification of permanent landmarks, where "good" navigators could identify permanent landmarks better than "poor" naviga-

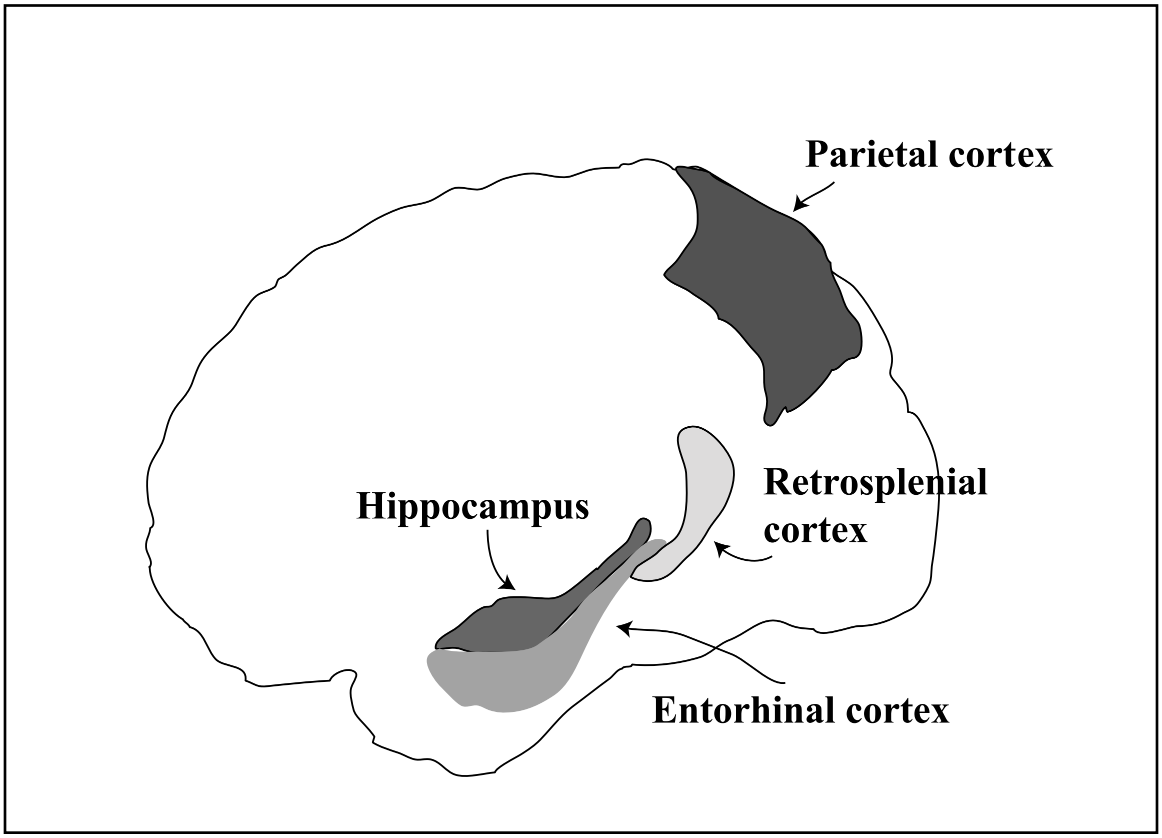

Figure 2. Major regions of the brain associated with navigation and spatial orientation.

tors (Auger et al. 2015). The parietal cortex is implicated in route finding between neighboring landmarks (Wolbers et al. 2004).

There is an emerging consensus that humans simultaneously possess both allocentric and egocentric representations of space in parallel, and each representation informs the other. Nandini *et al.* (2006) cited behavioral evidence that both develop in humans between the ages of three and five. There may be cultural and personal variations in the strength of egocentric versus allocentric representations. Levinson (1996a), for example, has called attention to the predominance of allocentric expressions in Austronesian (as compared to Western European) languages. In my experience, however, English-speaking students can develop and strengthen allocentric skills with practice, as demonstrated in way-finding exercises that focus exclusively on cardinal directions.

In addition to the location of cognitive maps, the hippocampus and entorhinal cortex are implicated in declarative memory (memories that can be consciously recalled), future imagining, and perhaps other functions. The mechanism of these other roles of the hippocampus and entorhinal cortex is not fully understood at this time, but the multiple roles are suggested by the fact that spatial cognition appears to be recapitulated in other modes of thought. Examples of this include verbal representations of social thoughts ("don't go down that path") or social constructs ("distant cousins" and "close relations"). The Roman orator Cicero in *De Oratore* invoked the *method of loci* whereby one enhances one's memory by picturing complex, linked topics as objects found an a large palace. Not limited to Cicero, this technique has been and continues to be in widespread use (*e.g.* Yates 1966, Raz et al. 2009). It should be pointed out that, while the areas in Figure 2 are well established as centers for both spatial cognition and declarative memory, they are not the regions associated with language, such as Broca's and Wernicke's areas.

How does all of this relate to the present collection? First, the internal representations of spatial orientation and navigation strategies are universal among humans, and significant aspects of these representations are found across all mammalian species that have been studied. In addition, spatial perceptions can differ substantially from one individual to the next, in different environments, and given different perspectives and landmarks. Another emergent concept is that intrinsic individual mechanisms of navigation exist independently of language.

Spatial Orientation At Sea

The topic of spatial orientation, and way-finding based on natural phenomena is a widespread theme in studies of Oceania. The articles by Genz and by Pyrek and Feinberg address this theme in two widely-separated island clusters, revealing fascinating similarities and divergences of practice. The setting of Genz's contribution is the Marshall Islands, just north of the equator and west of the 180th meridian, and the Vaeakau-Taumako cluster, discussed by Pyrek and Feinberg, is approximately ten degrees south of the equator and 15 degrees west of the antimeridian. While the weather and climate factors are quite similar in the two regions, the Marshall Islands are mostly atolls, whereas the Vaeakau-Taumako group comprises a mixture of volcanic and coral islands, with scattered and fringing reefs.

Traditional navigators in both areas have some common environmental clues, but with different emphases: wind, stars, and long wavelength swells that interact with land. In the Vaeakau-Taumako group, in addition to these way-finding signs, flashes of light called *te lapa* are used, along with certain birds. In the Marshall Islands, there is a strong emphasis placed on wave piloting above other environmental features. Wind and stars still play a role, but they are not as central. Vaeakau-Taumako navigators place a broader emphasis on wind directions and an integration of multiple environmental features into a kind of toolkit that has redundancy as a critical feature.

The traditional forms of ocean navigation in many Pacific Islands are in danger of fading away, with few of the elder practitioners remaining. The loss of navigational knowledge is presumably related to a reduction in the number of voyages, and fewer practitioners. With fewer voyages, the important feedback of experience on the ocean is weak, and with fewer practitioners, the traditions of a culture of navigation are weakly connected back to individuals. Nonetheless there are attempts at revival via organizations like the Polynesian Voyaging Society (Hawai'i), Waan Aelõñ in Majel (Canoes of the Marshall Islands), and the Vaka Taumako Project.

I begin the discussion with wave piloting, a major traditional navigation tool in the Marshall Islands. It is also practiced in other Pacific Island groups, such as Kiribati (Lewis 1994:225-233) and the Vaeakau-Taumako group (Pyrek and Feinberg, this issue), albeit with less elaborate schemas than in the Marshall Islands. Wave piloting involves a keen observation of multiple swell patterns, indicating the presence of distant islands and atolls, and it can be used as a means of orientation.

While many people are familiar with basic concepts of generic waves such as height, period, wavelength, reflection, and refraction, it must be emphasized that water waves are complex and a challenge to model, even on powerful computers (Holthuijsen 2007). On a short distance scale, ocean waves are the result of wind blowing over water—the interface between two fluids in motion. At present, there is no fully solved mathematical or computer model of a single fluid in motion, let alone two. In part, this stems from the non-linear nature of fluid dynamics. One important term in characterizing ocean waves is ***fetch***, which is the distance over which wind blows, creating successively larger and longer wavelength waves over longer durations, producing a spectrum of wave heights and frequencies called a ***sea state***. When the wind dies out, swells persist and can propagate for very long distances. In the computer modeling of a sea state, one has to invoke numerous approximations and parameterizations to achieve a rough reconstruction of a sea state.

Two striking features of Genz's studies are the similarities ***and*** divergences among his consultants' descriptions of wave piloting. Here are the general features of agreement:

1. Four dominant swells are observed throughout the year: east, west, north, and south.
2. Paths of disturbed water link pairs of atolls: *dilep.*
3. There are leeward indications of islands.
4. Zones of currents: *jukae, rubukae,* and *jeljeltae.*
5. The teaching stick charts of *wapepe, niñeañ kab rōkeañ,* and *meto*, all of which have axes of symmetry and can be interpreted with the canoe at the center, an atoll at the center, or with two or four atolls at the periphery.
6. The large scale stick charts all accurately depict the relative positions of atolls. Wave piloting is a navigational tool to voyage between atolls of known positions.

Here is where they diverge:

1. *Dilep* is two opposing swells causing a rolling motion of the vessel (Captain Korent and Lapedpedin).

2. *Dilep* is caused by reflected swells, causing a pitching motion of the vessel (Isao Eknilang).
3. In the lee of an island or atoll, one finds crossing swell from refraction called *nit in kōt* (Captain Korent and Isao Eknilang).
4. In the lee of an island or atoll, there is only a blockage of the swell; waves do not refract (Thomas Bokin and Lapedpedin).
5. The sequence of current zones in crossing from one atoll to another is: *jukae, rubukae,* and *jeljeltae* on departure from one, a gap, and then *jeljeltae, rubukae,* and *jukae* on approach to the other (Captain Korent and Isao Eknilang).
6. The sequence of current zones in crossing from one atoll to another is *jukae, rubukae,* and *jeljeltae* extending across the entire path (Thomas Bokin).

As Genz points out, due to occupation by the Germans, Japanese, and in particular, the nuclear weapons testing by the U.S. in the Marshall Islands, his informants have limited practical exposure to wave piloting. It is not surprising that it is fragmented and sometimes contradictory. On the other hand, the similarities suggest an earlier period when this form of navigation was widely practiced.

The four dominant swells have a plausible root in reality. The Southern Ocean is a 10,000 mile long fetch of the South Atlantic, South Pacific, and Indian Ocean that produces the biggest average waves on this planet. Swells from the Southern Ocean are known to penetrate to the equator and north. Likewise, the north Pacific experiences significant storms and the long fetch there can create significant swells that penetrate southward toward the Marshall Islands. The influence of Trade Winds can create both local wind-blown chop, and also long-distance swells sweeping from east to west.

While the Marshall Islands navigators speak of four swells, present all year round, Vaeakau-Taumako navigators recognize two swells whose strengths vary with season.[1] Quoting Pyrek and Feinberg (this issue):

> *Te hokohua loa te ngatae* and *te hokohua loa te angeho* are both detectable throughout the year, but their relative strength varies with the season. *Te ngatae* and *te angeho* identify the two seasons and the directions from which the prevailing winds emanate during those seasons.

Te ngatae is generally said to run from May or June through sometime in December and is the season of trade winds from *te tonga*, the southeast. *Hokohua loa te ngatae* are the long swells from the southeast that one expects as driven by the Trade Winds. Likewise *te hokohua loa te angeho* are swells that predominate during the *angeho* season from December to April or May, with winds that blow roughly from the north (northeast through northwest). Figure 3 shows the distribution of ocean swells (as opposed to local wind driven waves) near the Marshall Islands as a function of date on the horizontal axis and azimuth (angle along the horizon from due north) on the vertical axis. This provides something of a first impression of the wave climate in the area. The data are courtesy of Gerbrant van Vledder of Delft University (personal communication, 2015). There is a

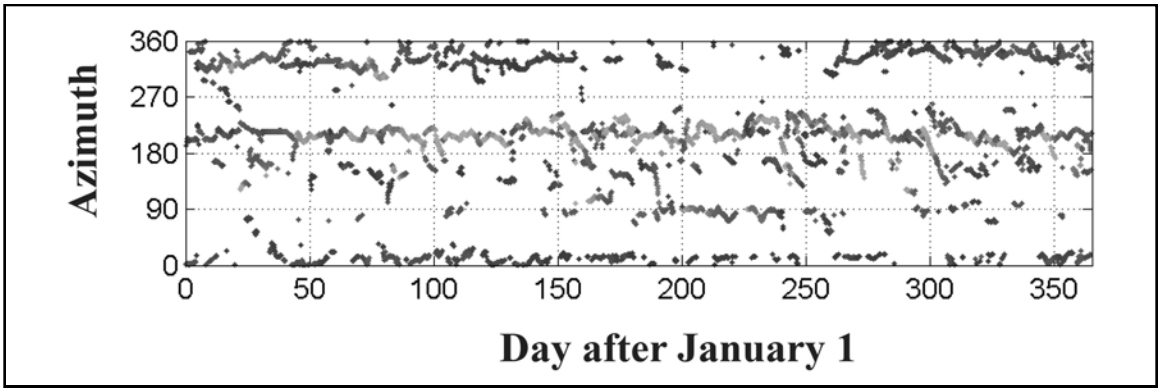

Figure 3. Distribution of swells in the Marshall Islands versus date and azimuth in the Marshall Islands during 2003.

clear band present all year long around 200 degrees, presumably a swell from the Southern Ocean. There is also a seasonal eastern swell at 90 degrees, extending roughly from day 180 (mid-June) to day 270 (end of October). In addition, there appears some clustering between 320 and 20 degrees, plausibly a northern swell. A detailed analysis of data like these will shed some light on the concept of "four dominant swells" as indicated on the stick charts.

One should be cautious about drawing too strong a conclusion from the above graph, as it represents only one year, but it shows both seasonality and multiple swells. A similar plot for the Vaeakau-Taumako region would be useful to gain insight into the two-swell reports. One speculation on the absence of a swell from the southern ocean in this region is that it may be related to blocking by Australia, New Caledonia, and New Zealand.

Many *kōkḷaḷ* (navigation signs) in the Marshall Islands are associated with wave/swell interactions with atolls: reflections, refractions, and wave-shadowing. In Genz's article there is some divergence in the detectability and perception of these. It may be partly related to limited experience in a wide range of situations—both sea states and bathymetry.

The nature of wave patterns associated with islands and atolls can vary. Figure 4 shows some idealized configurations of islands and wave phenomena associated with swells passing islands with varying bathymetry. In all three cases, a swell is shown as coming from the east, which is common in the Marshall Islands during the voyaging season when the Trade Winds are active (typically June through October). In the first case, there is a steep drop-off under water, but a shallow reef on the surface that extinguishes all of the wave energy as the swells break on the reef. In this case, there is a "wave shadow" in the lee of the island. In the second case, not only is there a steep drop-off under water, but also a steep cliff above sea level. In this case, most of the energy is reflected back out to sea onto the windward side. The third case shows an island with a low-slop-

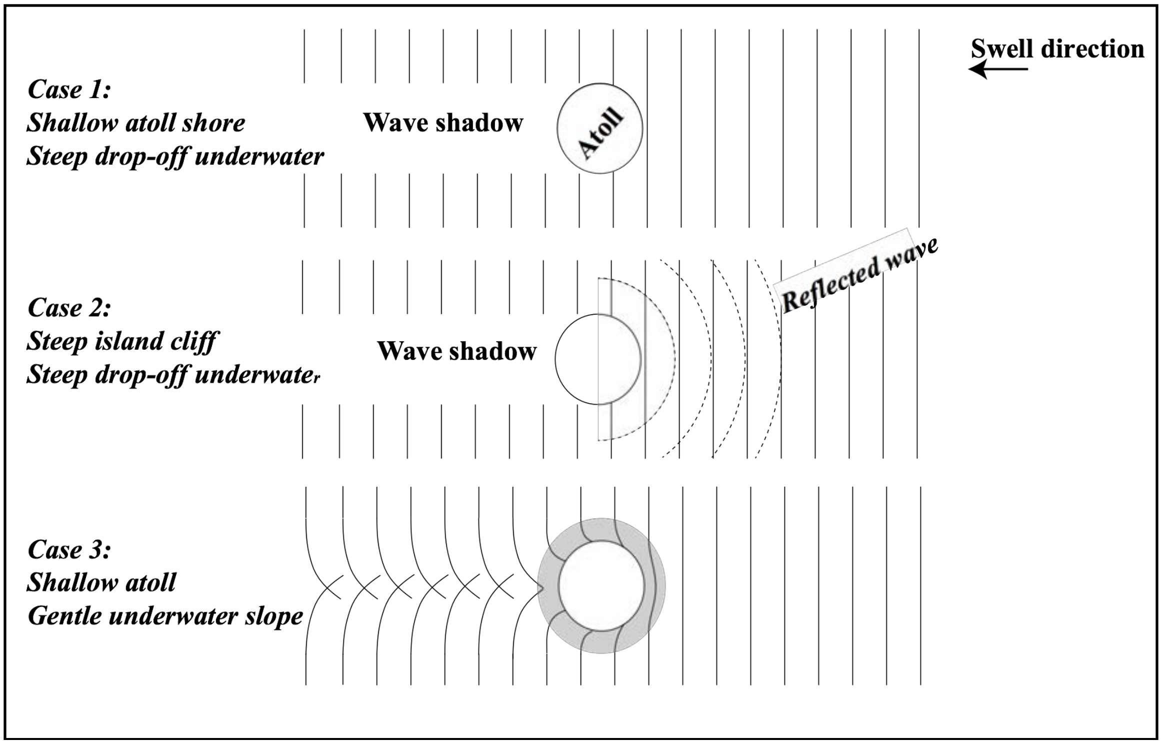

Figure 4. Three extreme cases of wave interactions with an island or an atoll as described in the text.

ing approach to the island underwater. Here, waves will refract around the island, creating a crossing wave pattern on the lee side. Each of these cases is an extreme example, and most islands will produce reflected and refracted waves, along with some extinction of the swell on the leeward side of the island.

Nit in kōt is a name associated with wave patterns in the lee of an island. One of Genz's older informants, Isao, describes *nit in kōt* as a crossing pattern of refracted swells. The origin of the name comes from a cage used for fighting birds and seems to be related to this crossing pattern. This pattern is consistent with case 3 in Figure 4. During field studies with Captain Korent on the lee side of Majuro Atoll, Korent observed a clear crossing pattern of swells. These observations were verified by Genz, satellite imagery, buoy data, and computer simulation.

On the other hand, two older navigators, Thomas and Lapedpedin maintain that one should only observe wave extinction on the lee side of an island. This is consistent with cases 1 and 2 in Figure 4. On the return voyage from Ujae to Kwajalein, Captain Korent used the wave extinction in the lee of Lae as a guide to his progress. From a physical perspective all three cases are possible, and the relative expression of each of these depends on local conditions. Lapedpedin's assertion that "No swell of this world know how to bend," may be a strongly held opinion, but is simply not consistent with Captain Korent's experience or with scientific studies of wave behavior (Genz, this issue). It is possible that neither Thomas nor Lapedpedin had experienced the crossing patterns of swells in the lee of an island. This may be due to limited experience on their part, or it may simply be dogma. Still, it is curious that Isao affirmed the crossing pattern of swells, yet was Lapedpedin's student.

An additional curiosity is that Captain Korent describes the two refracted swells on the lee side of an island as independent phenomena. From a Western point of view, an easterly swell impinging on an island produces a northeast and a southeast "swell" on the lee side that are simply transformations of the dominant swell.

Other aspects of wave piloting emerge in Genz's investigation of *kāāj in rōjep, jur in okme,* and *dilep.* Both *kāāj in rōjep* and *jur in okme* are formed on the side of the atoll facing an incoming swell. These are often described in terms of the interference between the dominant incoming swell and its reflections from the atoll. Case 2 in Figure 4 shows the conditions under which one would expect reflected signals resulting in these conditions. *Jur in okme* is found in a region where the crest of the reflected swell is roughly parallel to the incoming swell, but moving in the opposite direction. *Kāāj in rōjep* occurs where the reflected swell moves at roughly a 45^{o} angle with respect to the incoming swell, producing a more choppy interference pattern. Genz and investigators took Captain Korent out to investigate these two phenomena. The deployed wave buoys could not detect the reflected swell, nor was it immediately obvious to observers other than Captain Korent. Captain Korent, however, pointed out the *jur in okme* on a video. An examination of the video reveals a visible weak reflected swell that is consistent with his description.

The absence of a reflected signal in the buoys does not necessarily mean that there is no reflection; the signal could be too weak to be detected by the instrumentation. A major issue in wave reflections is the amount of energy lost when swells encounter a shore. Shores with a very steep drop above sea level, continuing to a depth well beyond a number of wavelengths of the swell will show a substantial reflection. On the other hand, shallow coral reefs will cause the waves to break, diminishing the height of the reflected swell dramatically.

Some versions of computer wave models lack reflections, although more advanced ones include them. Ocean waves are known to reflect from shorelines, but the size of the reflected swell can be substantially smaller than the incoming swell. In a study performed with an array of buoys off the coast of North Carolina, researchers characterized the nature of reflected swells (Elgar et al. 1994). This study demonstrated that reflected energy was seen preferentially in the lower frequency (longer wavelength) swells, and that the reflected wave energy was at most $1/10^{th}$ of the incoming energy. This study provides some plausible directions for understanding of wave piloting. Swells that are the product of large, distant wind systems are likely to produce low frequency components and would thus produce more noticeable reflections. In this study, an array of buoys was employed and analyzed in aggregate in order to obtain sufficiently sensitive reflection information. Often, single buoys are not sensitive to the weaker reflected signals, which may explain the lack of a reflected signal in the buoy data by Genz et al.

If, indeed, Captain Korent was sensing low frequency, low wave-height reflections, this speaks to the human ability to pick up a relatively weak signal in the presence of "noise." It also could corroborate the importance of long-period swells in the reports of navigators. As Genz points out, the storm during the outgoing voyage to Ujae created a large enough sea as to likely mask most *kōkḷaḷ* (navigation signs), while on the return voyage, the sea state was calm enough to admit observation of *kōkḷaḷ.*

As in the Marshall Islands, wave piloting appears in the Vaeakau-Taumako toolkit, and swells (*hokohua loa* 'long waves'*)* are recognized as useful direction indicators. Long wavelength (low frequency) waves are typically the product of long fetches and, in addition to persistence, have little angular spread, unlike shorter local wind driven waves. Since they are detectable during the day and on overcast nights, they have added value.

As in the Marshall Islands and elsewhere (Lewis 1994:225-251), reflected swells show a proximity to islands. Another observation consistent with the Marshall Islands wave piloting experience reported by Genz is that the reflected swells are said to be much weaker than the incoming dominant swell and are only detectable about 25 miles from land. In both regions, the perception of waves through the motion of the vessel is the primary means of detection. It is not entirely clear what drives the importance of proprioceptive experience of wave/swell phenomena; possibly, the length of the vessel averages out the contribution of short wind-driven chop to allow the navigator to feel the longer wavelength components.

The phenomenon of *dilep* is the most perplexing of the wave phenomena investigated by Genz. *Dilep* is described by Captain Korent and another consultant, Thomas Bokin, as the product of two opposing swells. The opposing swells intersect along a path connecting two islands. At their intersection, a series of anti-nodes, called *booj* are formed that create a path linking the two islands. The navigator tries to keep the vessel on the path of the *booj* or *dilep*. According to Captain Korent, while on the *dilep*, the vessel has a symmetric rolling motion; if the boat strays off the *dilep*, the vessel acquires a more asymmetric motion. The navigator's art is to monitor the motion of the vessel to stay on the *dilep*.

In Figure 5, I show a computer simulation of reflection and refraction around the Marshall Islands. In the simulation, a swell from due east (right) is created that impinges on the islands. The darker coloration depicts regions of more wave action. The most obvious feature is the relatively strong power of waves to the east of the island cluster and a prominent wave shadow to the west. At a more fine-grained level, some expected features emerge: refraction producing a *nit in kōt* on the lee side of islands is observable, particularly with respect to Taongi Atoll, the northernmost and most isolated of the group. Both *jur in okme* and *kāāj in rōjep* are visible on the eastern side (right) of Taongi in a manner consistent with expectations. It should be pointed out that this simulation is very crude,

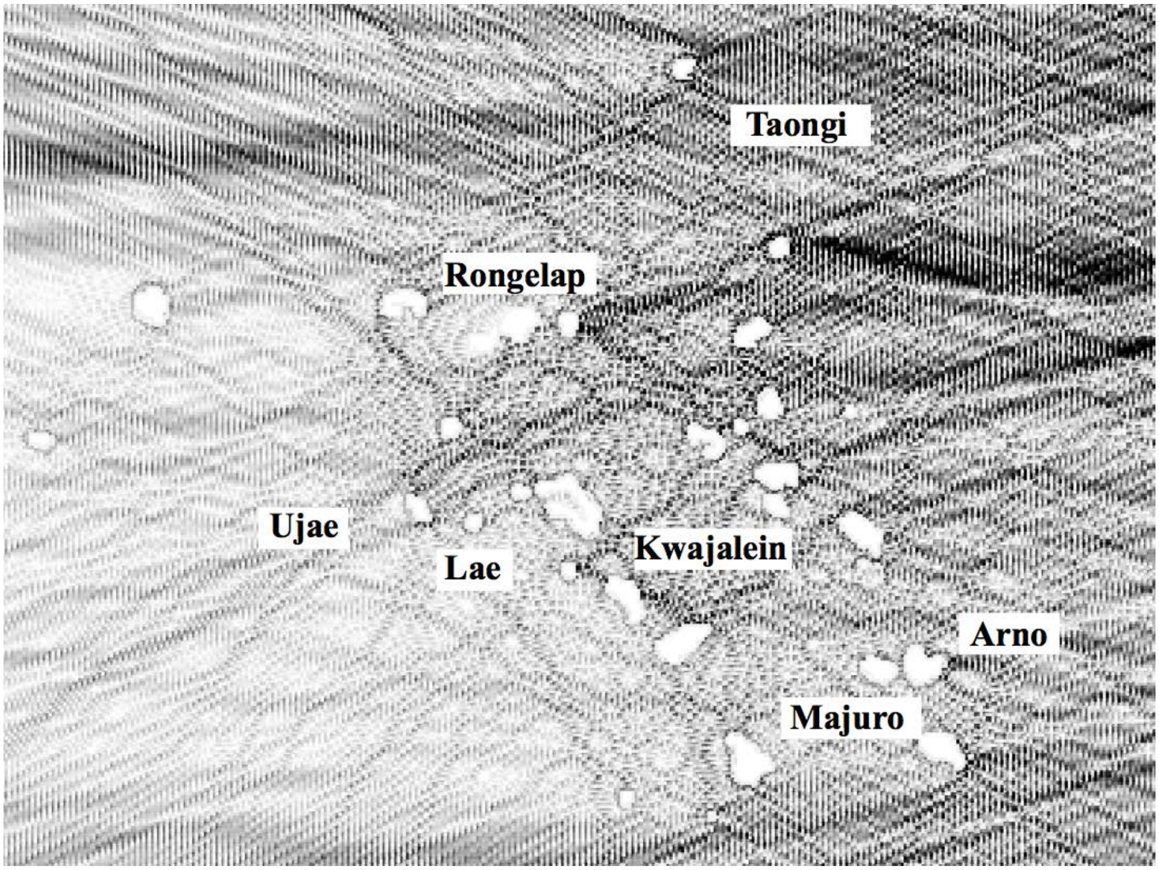

Figure 5. Crude simulation of waves reflecting and refracting on the atolls of the Marshall Islands.

with reflections at roughly the magnitude of the incoming swell, and the wavelengths between crests are far larger than one expects in reality. This is meant to be illustrative. More detailed computer simulations with realistic reflections are necessary to understand the nature of the *kōkļaļ*.

A curious emergent feature in Figure 5 is the existence of filaments of disturbed water extending between some pairs of islands. For example, the dark bands of disturbed water pointing toward the northeast and southeast from Rongelap, could, in my mind be considered a "filament" of disturbed water linking this atoll to neighboring ones to the east. These "filaments" appear, at least in some cases, to be the result of reflections of the dominant swell off the atolls' eastern-facing shores, and possibly the result of interference between reflected and refracted waves with the dominant swell. It is a matter of speculation whether these features in the simulation are related to *dilep* as articulated by the Captain Korent. If so, they are certainly not the result of opposing swells as understood by Westerners.

Unlike Thomas and Captain Korent, Genz's consultant Isao described *dilep* as the product of reflections from islands. If the filamentary structures displayed in Figure 5 are *dilep*, then Isao's explanation is more in line with Western understanding of wave behavior. There is a clear distinction between Isao's and Korent's descriptions of a vessel's motion under the influence of *dilep*. Isao asserts that vessels undergo a pitching motion, consistent with a reflected wave, while Korent asserts a rolling motion, in accord with the opposing-swell model. Isao's viewpoint that the *dilep* is the result of weak reflected swells from islands is plausibly consistent with the phenomenon articulated in the Pyrek/Feinberg contribution as islands being "reflectors." The major problem with reflections as an explanation is that the distance over which *dilep* is reported is much greater than one normally expects with reflected swells.

Some possible explanations might reconcile Captain Korent's description of *dilep* with Western understandings. First, his language of swells may have been misunderstood, and it could refer to a localized phenomenon rather than a transformed swell in the Western sense. A related possibility is that he conceptualizes swells only as wave patterns that interfere with each other, whereas a dominant swell, such as the eastern swell driven by the trades is just a kind of "background." Third, his understanding of *dilep* might be based on his experience at the training island, which does not adequately simulate *dilep* on the open ocean. Finally, there is the possibility that *dilep* is nonexistent, or practically nonexistent, save for a few limited cases, and these are simply accidents of coastlines that are perpendicular to the direction of a major incoming swell, causing reflections back toward a neighboring windward island.

It is difficult to form a fully coherent picture, given the weak and fragmented tradition of Marshallese wave piloting today. One plausible conclusion is that the traditions articulated to Genz represent some mixture of real phenomena, limited experience, and some amount of dogma. While the crossing pattern of *nit in kōt* appears to have real validation, Lapedpedin and Thomas persisted in denying its existence. Isao's description of *dilep* seems plausible and consistent with another description. Captain Korent's explanation of *dilep* seems less plausible, although it may have some basis in the passage of swells between neighboring atolls and wave extinction.

From both Genz's and the Pyrek and Feinberg contributions and the known behavior of ocean waves, the most consistent picture that emerges is of the importance of long wavelength waves/swells and a near-island signature created by reflections. The simplified simulation in Figure 5 shows a complex pattern of reflected and refracted swells in an idealized situation. Reality is more complex than the figure indicates, and it will take detailed computer modeling to understand in a realistic fashion. Teaching of traditions and skills is often a reductionist enterprise. A conjecture I put forth is that the wave piloting tradition prior to Western contact was quite sophisticated. Stick charts and extant lore may represent artifacts of a more sophisticated era and were the first introduction of novice pilots to the techniques. Only through time on the ocean on many voyages did the navigators acquire the necessary observational skills to distinguish among fairly weak signals in an environment with "noise," produced by a dominant swell and local wind-generated chop overlying reflected and refracted waves. Through generations since Western contact, exposure to lore and stick charts rather than experience on the ocean may have produced the current situation. Concepts that were intended as abstractions to teach initiates developed a more literal meaning for later practitioners. Experience can be an important corrective in this case, as Captain Korent apparently learned in his voyage from Ujae to Kwajalein.

Perhaps the Vaeakau-Taumako toolkit's most important feature is redundancy and successive approximation. While one means of orientation might fail or be uncertain, multiple means provide some assurance that a navigator is successfully making progress toward a destination.

Wind "compasses" feature prominently in the Vaeakau-Taumako region. The naming of directions based on winds is not exclusive to the Pacific Islands. Orientation based on wind properties is known among communities that range from the Native American tribes to ancient Greece. For many cultures, the wind's character and seasonality distinguishes them. For example, wind blowing from the Gulf of Mexico toward the northeastern part of the U.S. is prevalent in the summer months and is warm and moist. Many cultures reference eight divisions of wind, as is the case with the Vaeakau-Taumako wind compass system.

In the case of Vaeakau-Taumako navigators, seasons are the most closely associated with the prevailing winds, a practice that can help navigators plan voyages by taking advantage of known patterns. Pyrek and Feinberg report, "Thus, a wind from *te tonga* is a *ngatae* [approximately June through December] wind, and a wind from *te laki* or *te tokelau* is an *angeho* [cyclone season] wind."

Wind compasses have an inherent imprecision. A distinguishable wind can vary in direction by 60 degrees or more and still retain its characteristics, such as warmth, moisture, seasonality, and cloud formations. For example, Pyrek and Feinberg report that the direction of *te tonga* varies from roughly 100º to 160º in azimuth by the reports of their interlocutors. Perhaps one difficulty in labeling the concept as a wind "compass" is that it calls to mind the Western conception of 360 degrees, where regularity and the precision of a degree are implicit. Distinguishable winds and their characteristics are much less regular, so variation in pronouncements is not surprising. This spread is roughly consistent with the natural variation in Trade Wind directionality over the course of a season. Figure 6 depicts a wind rose from an observatory in American Samoa (NOAA data) that shows a variation in Trade Wind direction consistent with the reports they assembled. The location of Samoa and the Vaeakau-Taumako cluster are similar enough that the wind rose for Samoa is relevant. In contrast to the use of winds for naming directions, the use of winds for direction finding appears to be less common, if not absent, in the Marshall Islands, where 'upwind' and 'downwind' are the only operative directions.

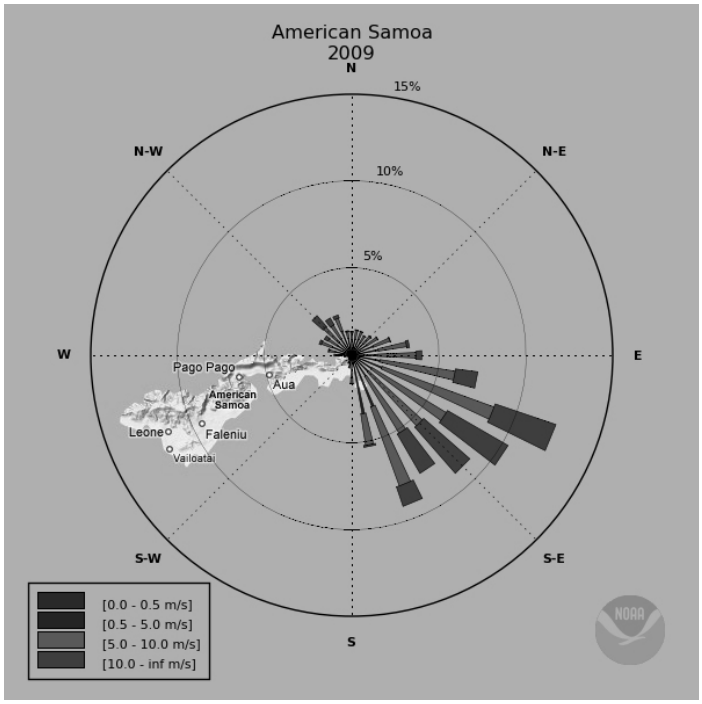

Figure 6. Wind rose data from American Samoa, 2009 from NOAA.

Star compasses have potentially greater precision than wind compasses. As with the wind, these do not divide the azimuth into equal swaths, as does the European magnetic compass. Nonetheless, the rising and setting positions of stars in the tropics have azimuths that vary by only a few degrees over a wide range of latitudes. The utility of star compasses appears to vary substantially from one navigational culture to another. In conversations with Feinberg, Kaveia emphasized a number of reference stars, and it is not unheard of for Pacific Island navigators to memorize upward of one hundred (Grimble 1972:218). On the other hand, Feinberg and Genz (2012:343) report that Clement Teniau of Nukapu, one of the Vaeakau islands, is more comfortable using swells than stars because, "the stars move around; the waves are always there." In my teaching experience, I have seen a large variation in students' abilities to learn the skills required for effective use of stars for orientation. Such individual variation might be operative in the differences between Teniau's and Kaveia's use of stars for navigation. However, given the inherent precision of stars over waves and wind, the investment of time to understand star motions can reap substantial returns.

Kaveia spoke of a hypothetical voyage to Tikopia and Anuta from Taumako as an illustration of how one might use guide stars. He cited Sino (Sirius) as a guide star for Tikopia and Orion's shoulders as guide stars for Anuta. This description is highly figurative, and presumably was not intended for precise sailing directions, as these would be off by as much as 30°. However, since Tikopia is south of Anuta, the relative placement of the guide stars is illustrative.

A zenith star is a star that passes directly over the zenith of a location, once in a 24-hour cycle of day/night. By knowing the latitude of an island, one can sail to a point where the zenith star crosses the zenith of the target island and then sail east or west to the island. The purported role of Sino as a zenith star is interesting. While Taumako is at a latitude of 10° S, Tikopia is at 12° S. Sino, being at 17° south, is five degrees farther south than a precise zenith-star. Nonetheless, as Sino passes south of the zenith in Taumako, Kaveia seems to be using this mostly as an illustrative, rather than practical example. Over short voyages (less than 200 nautical miles), the use of a zenith star is not terribly practical, as there is not sufficient precision to use such a concept to create a crude measure of latitude.

Kaveia describes the Southern Cross as a guide on a voyage from Taumako to Utupua or Vanikoro. Rather than being a hypothetical voyage, it is one that was likely taken, and the sailing directions reflect a higher degree of precision than the illustrative Taumako to Tikopia example. For the Taumako to Utupua/Vanikoro journey, Kaveia is quoted as saying that the Southern Cross sets between Utupua and Vanikoro as seen from Taumako. Utupua and Vanikoro can be reached from Taumako on headings of 205° and 188° respectively, and the Southern Cross sets at an azimuth of roughly 210°. If one sets off from Taumako, to either island (100 miles distant) with a heading toward the Southern Cross, the difference of a few degrees in heading is a negligible effect, given that the tall islands would be visible from at least 30 miles away. In addition, reflected swells and birds would reinforce one's sense of position on approach. In a sense, this is using the toolkit as a means of successive approximation, starting with a coarse sense of direction from the stars and using proximate signs of land to fine tune the voyage at the end. In both cases, the precision of the use of guide stars is no better than about 10°, the width of a human fist at the end of an extended arm.

Although the wave/swell/current patterns take prominence in the Marshall Islands, as Genz points out, there are guides stars employed by navigators in the Marshall Islands. The Southern Cross is *Būbwin Epoon* 'the black trigger fish of Ebon', Ebon being the southernmost atoll in the Rallik (western) chain. The alpha star of Canes Venatici, *Wōd-wāto-eņ,* named after the reef Wāto en in the Aerōk Passage of Ailinglaplap, is the guiding star for the voyage from Jaluit to Ailinglaplap. The alpha, beta, and 5 stars of Ursa Minor are *Jemānuwe*, the guiding stars for the northerly voyage from Kwajalein to Ailinginae. *Limanman* 'the husking stick of the north' is Polaris and is the guide star for voyages from Kwajalein to Rongelap and from Lae to Wotho (Stone 2001). The principal disadvantage of stars, as both articles point out, is that they are only useful at night and with minimal cloud cover, so other more persistent phenomena, such as swells and wind can be useful to maintain a course heading during the day and under cloudy conditions.

Te lapa, said to resemble "underwater lightning," is a mysterious occurrence. David Lewis related some of the first reports of this phenomenon from informants in the Gilbert Islands, Tonga, and the Santa Cruz Islands. He and Marianne George have both reported witnessing *te lapa* firsthand (Lewis 1994:253; George 2012). Both Richard Feinberg and Marianne George have subsequently interviewed a number of islanders who reported *te lapa* under varying circumstances, although Feinberg was unable to observe it (Feinberg 2011).

There is currently no definitive explanation of the origin of *te lapa*. One possibility is that it is the byproduct of fish darting in a patch of sea that is rich in dinoflagellates, which emit light in response to pressure waves (personal communication from Prof. W. Hastings, Harvard University, 2009). If this were the case, one would then have to explain the directionality of fish movements.

One problem in understanding *te lapa* is the difficulty of reproducing sightings. Further studies would require some kind of imaging device that is sensitive to relatively faint light. Comparisons of spectral distributions of *te lapa* to known phenomena, such as dinoflagellate bioluminescence might be informative, if one could get the data. There does not appear to be any corresponding use of *te lapa* in the Marshall Islands. One does not know whether this is due to differences in local conditions or if the use of wave piloting is just more reliable in the Marshalls, as opposed to the Vaeakau-Taumako region. Since environmental conditions (water temperature, wind patterns, general biological diversity) are similar, if *te lapa* is indeed real, it may just not be as reliable as other schemas, or simply so transient that sightings are a matter of chance.

What are the differences and similarities between the Vaeakau-Taumako toolkit and the Marshallese navigation schema? Clearly, the heavy reliance on swell and current patterns distinguish the Marshallese navigators from Vaeakau-Taumako region. This may be partly due to personal and cultural divergences, but it may also be environmental. The Marshall Islands arose from two hot-spots under the Pacific plate and created two atoll-chains that stretch from the southeast to the northwest due to plate motion. There is some degree of regularity in the spacing and structure of the atolls and their orientation, which may give rise to fairly predictable wave/swell/current patterns that are not found in the Vaeakau-Taumako area. Another point is that the Marshall Islands are low-lying atolls whose islets are only visible, at most, from ten miles out. Some of the high islands in the Santa Cruz group are quite high and visible at a greater range. Taumako is visible from 40 miles on a clear day. Both groups do recognize long wavelength waves/swells as being useful.

An interesting feature of both contributions is what is ***not*** discussed in this collection: dead reckoning. While there is an elaborate and articulated system of dead reckoning in the Caroline Islands as found in the *etak* system, there must also be a sense of dead reckoning in the Marshall Islands and the Vaeakau-Taumako region. When a sailor sets off to a destination island, he or she has some rough awareness of how long the voyage will take, and if the island has not been found in that time-frame, it would generate concern. It is likely that a sense of dead-reckoning is so ubiquitous and ingrained that the common-sense use of it is not often discussed. Certainly, it is a potential topic for future investigations.

A final observation is the language of navigation in the Marshall Islands. Many of the navigation signs are derived from objects known on land, e.g., *nit in kōt* is a cage for fighting birds. Only a few individuals practice navigation, and the ability to communicate among the cognoscenti creates a kind of linguistic vacuum that might naturally borrow land-based terms. Likewise, the mental state of being lost at sea, *wiwijet*, is a word that appears to fill a linguistic vacuum. This sense of anxiety at being lost may originate when the feedback process of updating the cognitive map of position with navigational signs breaks down and the individual is not able to become reoriented. Such anxiety at being lost is not unique to Marshall Island navigation. For example, in Norse sagas of voyages in the North Atlantic, the term, *hafvilla*, was used for the sense of being lost at sea with no way of regaining bearings (Marcus 1955). The term *woods shock* is used in North America for a similar reaction. In this case, an internal emotional state creates the need for a descriptive term, and the culture finds one.

Spatial Orientation on Land

Four contributions cover the topic of spatial orientation primarily on land. Katharina Schneider contrasts the "mainland" people of Buka with the "saltwater" people of Pororan Island. Micah Van der Ryn considers the language and nature of spatial orientation in Samoan villages. Richard Feinberg examines use of terms for 'front' and 'back' on Taumako Island. And Susan Montague looks at the culture of *wa* and *o* space by Trobriand Islanders. The islands in these studies vary in size from 1.4x1 mile (Pororan Island) to 45x13 miles (Upolu, Samoa), and they exhibit a range of subsistence means and geography.

Some background inflects the studies. Van der Ryn and Feinberg consider "frames of reference" (FoRs) used in Samoa and Taumako, respectively (Levinson 1996b; Palmer 2002; Bennardo 2002) to distinguish 'front' from 'back'. In addition, Van der Ryn discusses the utility of "point field" as opposed to container models for understanding spatial orientation in Samoa (Lehman and Herdrich 2002). Schneider and Montague explore the relationship between spatial and social orientation in two quite different regions of Papua New Guinea.

One particularly telling comparison was the use of *muli* (back) and *mua* (front) in the context of sailing. Roughly speaking, Feinberg finds that the use of the terms can point to an east-west system of orientation, or be determined by the direction of the motion of the canoe. The variability may simply reflect the lack of a need to communicate with precision, or it can be related to the multiple contexts in which one communicates. It may be obvious, for example, whether one is speaking of a specific voyage or the relative positions of a cluster of islands. An interesting discussion might involve how an apprentice is taught the relative locations of islands. In this case careful invocation of directions and references for sailing directions would be appropriate (e.g., directions with respect to rising and setting stars.

Similarly the front/back usage of *mata/mua/alohi* (variations of 'front') versus *muli/tua* (variations of 'back') designating sides of islands, houses, and places for toilet functions seems to be extremely fluid among different individuals, and usage depends largely on context. In some cases, interlocutors indicated that they did not typically talk in these terms with respect to houses. Given the wide variety of usage, it seems to me that the taxonomy of frames of references may not be the best descriptor. One might consider the relation to landmarks instead, particularly if the term, "landmark," is considered in a broader context. A landmark may be considered to be a house, the demarcation of the ocean and coastline, the direction of the Trade Wind, the passage of the sun, or the motion of a canoe. The context of an activity, combined with the salience of landmarks can combine to create a different perspective of a scene and how one then articulates it to another.

In Van der Ryn's contribution, one finds somewhat similar difficulties with frames-of-reference analysis, but these appear to be partly the result of the construction of roads and, in one case, a church. In this case, he examines the use of *luma* 'front' and *tua* 'back'. These concepts are fundamental to the structure of villages, starting from the central *malae* and extending increasingly 'backward' or away in a manner reflecting the social hierarchy, with the highest status being nearest the *malae*. As in Feinberg's examination, the areas for bathroom functions are farthest from houses. With the introduction of roads by the government, the value placed on facing the *malae* has competition from the value placed on facing the road. Van der Ryn's interlocutors expressed confusion over what to designate as 'front' or 'back' with respect to the road. This problem was partly resolved with the 'front' facing the road gaining precedence. Similar confusion arose in the orientation of a church. Which might be considered the front: the narthex (main entrance), long axis, or altar? An early design favored the long axis, but a subsequent reconfiguration favored the narthex, which, perhaps coincidentally, corresponds to a classic east-west orientation.

As discussed previously, there is evidence to suggest that humans conceptualize an environment in different ways based on landmark salience and viewpoint, and that allocentric and egocentric views may coexist. Certainly one cannot rule out upbringing, culture, learning experience in an environment, just that there is not a "one size fits all" explanation rooted in language. Still, the ability to navigate successfully suggests a more universal mechanism at play. How spatial cognition is shaped by experience in the environment and other factors remains an open question.

Schneider contrasts the "mainlander" Buka sense of space and social hierarchy, which is relatively fixed, with that of the "saltwater" people of Pororan Island, which has a much more fluid sense of space and social structure. Her investigations emphasize behavior, going beyond a pure linguistic analysis. In part, they address the concept that social cognition correlates with spatial cognition, discussed by Bradd Shore (2014). Rather than focus on a front/back construction, Schneider looks at 'above' and 'below'. It has been recognized that an upward direction often denotes power and control, while a downward direction denotes subservience and lower social standing (Lakoff and Johnson 1980).

There are clear distinctions between the Buka people and the Pororans in Schneider's findings. The most striking to me is in all senses of permanence. On Buka, one has a relatively permanent mapping of personal space onto geography, including well-prescribed routes among dwellings, well-mapped means of food production (gardening), and a fairly fixed set of interpersonal relations. Overlaid on this is a stable hierarchical ordering of society and explicit physical route strictures that follow. The paths that emanate from the highest mountain are a geographical realization of ancestral connections and motion along these paths is highly oriented along these ancestral lines. These regimented paths that people must follow seem to reinforce (or provide feedback to) the social structure, and women of Buka are keepers of this knowledge.

The "above-ness" in both Buka and Pororan is modeled on the body: the head being up and the feet being down. In Buka, sleeping positions are relatively stable and informed by the location in a house and social hierarchy within a village. Quoting Schneider, "Heads are above even when a body is in a horizontal rather than a vertical position. For instance, people carefully avoid walking by the side of the house toward which the *tsunon* [leader] points his head when he sleeps."

In contrast to Buka, Pororan space is highly non-permanent, with positioning of dwellings, routes, and social hierarchy all shifting with time. The ocean constantly alters the shoreline, and the main food-gathering activity is fishing on the ocean, which is inherently non-fixed in location. As the routes people take are constantly shifting, it is tempting to suggest that there is likewise a cultural instantiation of shortcutting behavior. Clearly, the two groups differ in the emphasis given to one modality of spatial and social conception rather than the other. Due to the nature of Pororan dwellings and the shifting paths that people take, sleeping positions are likewise in flux. Although the concepts of 'above' and 'below' are maintained, they are fluid, changing, and the subject of negotiation.

The parallelism between spatial organization and social organization in the two cultures is remarkable. Particularly telling is that mainland women married on Pororan Island find its social customs confusing, implying that it is not so easy to for an adult unaccustomed to navigating the culture to adapt. The parallelism is suggestive in the following sense: if indeed humans organize their thinking in terms of spatial constructs or the equivalent, then there is a kind of conservation principle at work where the thinking about social structure follows the same cognitive models as does thinking about physical navigation. I say "conservation" in the sense that parts of the mind may have to work together in a certain modality for navigating an environment, and a certain modality for negotiating social structures. It is much easier if the modalities are the same: it takes less energy than shifting from one to another. This is speculative, but it does illustrate that one could bring in more perspectives from cognitive psychology beyond the allocentric/egocentric distinction to achieve a fuller understanding of the relation between spatial cognition and social structure.

One such area for exploration might be the sense of permanence, and the notion that it is involved in allocentric/egocentric translations (Vann et al. 2009). It also seems that the starting point may not be spatial cognition, but rather that the environment first molds spatial cognition in individuals, and this in turn influences social cognition throughout the culture as a common view evolves. In this sense, it is suggestive that the more permanent spatial orientations are found on the larger territory of Buka, where gardening is practiced, and a less permanent sense is seen on the smaller Pororan Island, where fishing is a mainstay.

Montague describes two kinds of space in the Trobriands, *o* space and *wa* space. *O* space is a space that is commonly viewed by people in a community, and hence has a greater sense of "realism," whereas *wa* space is more amorphous, and does not have the same sense of concrete realism. *Wa* space is also considered the space of the dead.

Montague's detailed exploration of Trobriand cosmology merits a brief recapitulation here. The world's surface, inhabited by the living, is solid. The underworld, inhabited by the spirits of the dead, is amorphous, fluid. Holes in the earth allow the dead to enter into the living world. A curious meta-theory of the mind seems to exist among the Trobrianders. The dead souls have a kind of universal and powerful, but non-specific, knowledge. As a soul becomes instantiated as a living being, the mind acquires knowledge specific to the environment (e.g., cognitive maps) and culture (e.g., language).

Among neuroscientists and cognitive psychologists, there is an emerging picture of parts of the brain that are predisposed to acquiring particular forms of knowledge, such as languages or cognitive maps. Within these regions of the mind, the specialized regions are capable of absorbing a huge—seemingly infinite—number of permutations of spatial maps and languages. While Westerners often focus on the details of the instantiations, it appears that the Trobrianders incorporate the concept of immense plasticity of parts of the human mind. This seems to be embodied in their views of the distinction between the living mind, which retains the amorphous component, and the more concrete realizations of a specific environment and culture. This seems to reflect an awareness of the multiplicity of internal states of the mind, which not only emerges in language, but in the cosmology, as well. The amorphous nature of the gaseous and fluid underworld, *wa*-space of the dead, is contrasted with the solid form of the region of the living, the *o*-world.

Closing Thoughts

The articles in this special issue illustrate an eye-opening range of spatial cognition. The spectrum of modalities that emerge with the interdependence of the individual with the environment on the one hand and with culture on the other is striking. In marine environments, navigators develop the ability to feel weak wave reflections up to 25 miles from land. In densely populated villages, people become mindful to orient themselves when they sleep to preserve a social concept of 'above' and 'below'. That these behaviors emerge from the same cognitive tool-kit speaks to an adaptability of the mind and culture that allowed humans to inhabit nearly every corner of the earth in a relatively short period of time.

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[1] Pyrek and Feinberg differ from Marianne George (2012), who reports four swells in this region: two originating from trade winds both north and south of the equator (from NE and SE), and two storm swells, one from the northern and one from the southern hemisphere.

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