Understanding Micronesian Navigation

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For more than a thousand years long distance noninstrumental navigation has been practiced over large areas of Polynesia, Micronesia, and perhaps in parts of Melanesia. In Polynesia, the traditional techniques atrophied and were ultimately lost in the wake of contact with colonial powers. Only the Micronesians have maintained their traditional skills and in the past decade they have been the wellspring of navigation knowledge for a renaissance of traditional voyaging throughout the Pacific basin (Finney, 1979; Lewis, 1976, 1978).

Without recourse to mechanical or electrical or even magnetic devices the navigators of the Central Caroline Islands of Micronesia routinely embark on oceanic voyages that take them several days out of the sight of land. Their technique seems at first glance to be inadequate for the job demanded, yet it consistently passes what Lewis (1972) has called “the stern test of landfall.” Of the thousands of voyages made in the memory of living navigators only a few have ended with the loss of a canoe. Western researchers travelling with these people have found that at any time during the voyage the navigators can accurately indicate the bearings of the port of departure, the goal island, and other islands off to the side of the course steered even though all of these may be over

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The utility of a magnetic compass is not lost on the navigators of the Caroline Islands. Most canoes now carry magnetic compasses, but they are used only for secondary orientation purposes when the stars are not visible. Even when they are used, readings are not taken in degrees. The navigator simply identifies a point on the compass rose with the star course he wants to follow and uses the compass as a reference when the stars are not available. Some of the older navigators complain that the use of the compass by younger navigators is robbing them of the skills of maintaining orientation by reference to the direction of the swells (cf. Gladwin, 1970 and Lewis, 1972).
the horizon out of the sight of the navigator. These navigators are also able to
tack upwind to an unseen target keeping mental track of its changing bearing,
something that is simply impossible for a Western navigator without instruments.

The central issue of this chapter is how these Micronesian navigators accom-
plish these things. I offer a description of how their conception of the voyage
permits them to do things that are impossible for a Western navigator, stripped
of his instruments. But the description of how their mental models structure their
performance of this difficult task is only part of the story of cognitive structure
and task performance in this domain. An equally interesting cognitive task,
which is logically prior to our description of the Micronesian mental models is
the researcher’s task of coming to understand what the Micronesian navigator is
doing. There is a real methodological bind here due to the fact that we as
researchers use our culture’s notion of motion both to navigate ourselves and to
understand how others navigate. The enterprise is clearly fraught with oppor-
tunities to misinterpret observations and bias descriptions.

In order to weave the methodological and substantive strands together in a
coherent whole, the chapter is composed of four sections: The opening section
presents the basic “facts” of Micronesian navigation as they appear in the
literature. The second section describes some attempts to infer the nature of the
Navigators’ reasoning while doing the task. This section also points to a number
of apparent anomalies in the previous accounts which result from the imposition
of aspects of our own system of navigation onto the Micronesian case. The third
section presents an account of the mental model of a voyage employed by
Micronesian navigators that resolves the apparent anomalies, agrees with the
ethnographic record, and is capable of doing the observed task. In the final
section I discuss some of the methodological and substantive implications of the
preceeding sections.

CAROLINE ISLAND NAVIGATION

In the neighborhood of the Caroline Islands, less than two tenths of one percent
of the surface of the Earth is land. It is a vast expanse of water dotted with about
two dozen atolls and low islands. Experienced navigators in these waters rou-
tinely sail their outrigger canoes as many as 150 miles between islands. The
knowledge required to make these voyages is not held by all, but is the domain of
a small number of experts. The word of the navigator, however, contains more than a set of tiny islands
on an undifferentiated expanse of ocean. Deep below, the presence of submerged
reefs changes the apparent color of the water. The surface of the sea undulates

with swells born in distant weather systems, and the interaction of the swells with
islands produces distinctive swell patterns in the vicinity of land. Above the sea
surface are the winds and weather patterns that govern the fate of sailors. Sea
birds abound, especially in the vicinity of land. Finally, at night, there are the
stars. Here in the central Pacific, away from pollution and light sources on the
ground which make the atmosphere opaque, the stars shine brightly in incredible
numbers. All of these elements in the navigator’s world are sources of informa-
tion. The whole system of knowledge used by a master navigator is well beyond
the scope of this chapter. Here, we treat only a portion of the navigators’ use of
celestial cues(223,15),(368,112)

The most complete description of this system comes from the work of Thomas
Gladwin who worked with the navigators of Puluwat atoll (see Fig. 9.1). Gladwin
divides the pragmatics of Puluwat navigation into 3 parts (1970:147). First
one must set out in a direction such that, knowing the conditions to be expected
en route, one will arrive in the vicinity of the island of destination. Second, while
on the way to this island the canoe must be held steady on its course and a
running estimate maintained of its position. Finally, when the craft is near its
goal there should be available techniques for locating the destination island and
heading toward it.

One of the most widespread notions employed in Pacific noninstrumental
navigation is the concept of “star path.” From the point of view of the earth, the
positions of the stars relative to each other are fixed. As the earth rotates about its
axis the stars appear to move across the sky from east to west. As the earth moves
through its orbit about the sun, the stars that can be seen at night (that is, from the
side of the earth away from the sun) change. But from any fixed location on the
earth, any given star always rises from the same point on the eastern horizon and
always sets into the same point in the western horizon regardless of season. A
star path, also known as a linear constellation (Aven, 1981), is a set of stars
which all “follow the same path” (Gladwin, 1970). That is, they all rise in
succession from the same point in the eastern horizon, describe the same arc
across the sky, and set into the same point in the western horizon. Star paths are
typically composed of from six to ten stars fairly evenly spaced across the
heavens (Lewis, 1972). Thus, when one star in the linear constellation has risen
too far above the horizon to serve as an indication of direction, another will soon
take its place. In this way, each star path describes two directions on the horizon,
one in the east and one in the west, which are visible regardless of season or time
of night as long as the skies are clear.

It is known that star paths have long been used to define the courses between
islands in many parts of Oceania (Lewis, 1972). The navigators of the Caroline
Islands have combined 14 named star paths with the position of Polaris to form a

2 Longer voyages of up to 450 miles were once made on a regular basis, and are becoming more
frequent now as part of a revival of navigator’s skills.
3 See Gladwin (1970) for a discussion of the sociology of navigational knowledge.

4 Movement to the north or south does change the azimuth of the rising and setting positions of
any star. Withins the range of the Caroline Island navigator, however, the effects of such movements
are small; on the order of three degrees or less.
sidereal compass that defines 32 directions around the circle of the horizon. Figure 9.2 shows a schematic representation of the Caroline Island sidereal compass. As can be seen, most of the recognized star bearings are named for major stars whose paths intersect the horizon at those points. Those which are not so named are the true north bearing which is named for Polaris (the North Star) which from the Caroline Islands is always about eight degrees above the northern horizon and three bearings in the south which are defined by orientations of the Southern Cross above the horizon.

The inclusion of other stars that travel the same path guarantees that as long as the weather is clear the complete compass is available to the navigator no matter what time of year he is sailing. In fact, a practiced navigator can construct the whole compass mentally from a glimpse of only one or two stars near the horizon. This ability is crucial to the navigator's performance because the star bearings which concern him during a voyage may not be those which he can readily see. The star compass is an abstraction which can be oriented as a whole by determining the orientation of any part. During the day, the orientation of the star compass can be maintained by observing the star bearings from which the
major ocean swells come and/or the star bearings at which the sun and moon rise and set.

Courses among islands are defined in terms of this abstract sidereal compass. For every pair of islands in a navigator's sailing range, he knows the star under which he must sail from one island to reach any other.

Distance Judgments

The sidereal compass has a second function in navigation: the expression of distance travelled on a voyage. For every course from one island to another, a third island (over the horizon and out of sight of the first two) is taken as a reference for the expression of the distance travelled. In the language of Pulauat atoll, this system of expressing distance travelled in terms of the changing bearing of a reference island is called ETAK (Gladwin, 1970). The navigator knows the star bearing of the reference island from his voyage origin. Because he knows all interisland course star bearings in his area, he also knows the bearing of the reference island from his goal. In the navigator's conception, this reference island starts out under a particular star (at a particular star bearing) and moves back abreast of the canoe during the voyage through a succession of star bearings until the canoe reaches its goal at which time the reference island is under the point which defines the course from the goal island to the reference island. The changing star bearing of the reference island during the voyage is shown in Fig. 9.3. The movement of the reference island under the succession of star bearings divides the voyage conceptually into a set of segments called the ETAKs of the voyage. Each voyage has a known number of ETAK segments defined by the passage of the reference island under the star bearings.

A fundamental conception in Caroline Island navigation is that when underway on course between islands, the canoe is stationary and the islands move by the canoe. This is, of course, unlike our notion of what happens in a voyage. A passage from Gladwin (1970) captures the scene:

Picture yourself on a Pulauat canoe at night. The weather is clear, the stars are out, but no land is in sight. The canoe is a familiar little world. Men sit about, talk, perhaps move around a little within their microcosm. On either side of the canoe, water streams past, a line of turbulence and bubbles merging into a wake and disappearing into the darkness. Overhead there are stars, immovable, immutable. They swing in their paths across and out of the sky but invariably come up again in the same places. You may travel for days on the canoe, but the stars will not go away or change their positions aside from their nightly trajectories from horizon to horizon. Hours go by, miles of water have flowed past. Yet the canoe is still underneath and the stars are still above. Back along the wake however, the island you left falls farther and farther behind, while the one toward which you are heading is hopefully drawing closer. You can see neither of them, but you know this is happening. You know too that there are islands on either side of you, some

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**FIG. 9.3.** The changing bearing of the reference island as measured by the canoe. The line between Pulauat (Pulauat) and Ruk (Ruk) represents the course of the canoe to be steered. Biseras is the reference island. The numbers at the top of the diagram indicate star bearings as seen from the canoe. At the beginning of the voyage, the reference island is under bearing 1, and at the end of the voyage it is under bearing 9.
near, some far, some ahead, some behind. The ones that are ahead will, in due
course, fall behind. Everything passes by the little canoe—everything except the
stars by night and the sun in the day [p. 182].

Here we have a conceptualization in which the known geography is moving
past the navigator, his canoe, and the stars in the sky. Off to the side of the
course steered is the reference island. It cannot be seen because of its distance
over the horizon, yet the navigator imagines it to move back slowly under a
sequence of star points on the horizon. Observations of navigators during voy-
ages have shown that the navigators can accurately judge the relative bearing of
the reference island at any time during the voyage (Lewis, 1972). Because the
navigator has not actually seen the reference island at any point during the
voyage, his ability to indicate where it lies represents an inference that could not
be made by a Western navigator under the same conditions.

Gladwin (1970) describes the Micronesian navigator's use of this judgment as
follows:

When the navigator envisions in his mind's eye that the reference island is passing
under a particular star he notes that a certain number of segments have been
completed and a certain proportion of the voyage has therefore been accomplished
[p. 184].

The navigator uses this information to estimate when he will be in the vicinity
of his destination, and therefore when he should start looking for signs of land.
Because land based birds venture as far as 20 miles to sea, seeing them arrive at a
fishing ground from land, or seeing them depart a fishing ground for land can
give information at a distance about the direction in which land lies. This infor-
mation is only available in the early morning, and at dusk, when the birds are
moving from or to their island. A navigator who arrives at what he believes to be
the vicinity of his destination at midday is therefore well advised to drop sail and
wait for dusk. The danger of failing to make an accurate judgment of when land
is near is that one could sail near land when no signs were available and then sail
past and be far away from the destination when homing signs are available.

The nature of this system requires that the navigator commit to memory a
large body of information. Riesenberg (1972) has documented some of the
elaborate mnemonic devices used by navigators to organize their knowledge of
geography, star courses and ETAK segments. An interesting finding of Riesen-
berg's work is that the memorized systems of knowledge frequently make refer-
ence to islands which do not exist. Riesenberg (1972) explains:

In a few instances, when unknown geographical features were mentioned and when
enough courses from identifiable islands to them have been given, an attempt has
been made to locate them by projecting the courses on a chart. The intersections of
the projected courses generally coincide poorly with known bathemetric features
[p. 20].

The role of these phantom islands is an issue described in a later section.

Tacking

Tacking up wind when out of sight of the goal is the navigator's most difficult
task. A navigator will be forced to tack when the wind is coming from a direction
such that the canoe cannot sail directly to its target. Because these canoes are
normally not sailed closer than about 72 degrees from the direction of the true
wind, anytime the wind is coming from nearer the goal than 72 degrees on either
side, the navigator will face a tacking situation. Tacking is a set of maneuvers in
which the canoe sails as close to the wind as is possible and makes a zig-zag
course in order to reach its goal. The problem for the navigator is to know when
to begin the next tack of his voyage. This can be quite critical, because errors in
the judgment of the length of tacks can accumulate such that the goal island never
comes within sighting range. In the direct voyage situation, as long as the course
is correct, errors in the estimation of distance are not critical, because the goal
island will eventually come into view.

Of tacking Gladwin (1970) says:

The moving island construct provides the totality of the navigational guidance
when tacking, whereas ETAK, when it is used, deals only with one of several
aspects of the navigator's task, distance estimation. By the same token, since the
moving island is only a logical construct and thus does not contribute any factual
support for the navigator's decisions, tacking over long distance with only the
moving island for guidance necessarily places the greatest demands of any routine
navigational exercise upon the judgment and skill of the navigator [p. 189].

I have reproduced a diagram of tacking from Gladwin (1970) in Fig. 9.4. He
provides the following commentary on the navigator's task:

His guidance comes from the "movement" of the destination island "B," which is
more or less on his beam. In just the same way as an ETAK reference island, "B"
is moving south as long as the canoe is moving north (although ETAK itself is
disregarded during tacking). In doing so it passes under navigation stars. The
number of stars it will be allowed to slide beneath is a decision for the navigator.
The more stars, the longer the tack and the fewer changes in direction to be made.
It must be kept in mind that all this time the island "B" is out of sight and will remain
so until near the end of the voyage. Its position must be construed solely from the
navigator's knowledge of where it should be in both distance and bearing and how
much progress the canoe has made on its heading through the water [pp. 190-192].

This description provides some useful constraints on the navigator's actions,
but leaves a number of important questions unanswered. How does the navigator
know when it is an appropriate time to come about? If the navigator is basing his
decision to tack on his estimation of the distance he has travelled on a particular
Tacking with wind at 45 degrees


tack, how does he come to know what distance is appropriate for a given tack? In what units is the distance expressed? If it is expressed in ETAK-like units based on the movement of the goal island under star points, we notice that the unit defined by any two stars changes with each tack, getting shorter each time. How does the navigator know how much shorter a segment should be on each successive tack? (See Fig. 9.4).

SOME ANOMALOUS INTERPRETATIONS

The history of attempts to understand how the Micronesian navigators accomplish their feats reads like a detective story in which we know who did it, but not how it was done. Each of several researchers has provided us with useful clues, and in their attempts to fit the pieces together meaningfully, supplied a few red herrings as well. Inasmuch as these navigators are still practicing their art, one may well wonder why the researchers don’t just ask the navigators how they do it. Researchers do ask, but it is not that simple. As is the case with any truly expert performance in any culture, the experts themselves are often unable to specify just what it is they do while they are performing. Doing the task and explaining what one is doing require quite different ways of thinking. In addition, when the bounds of culture and language are crossed, one is never entirely sure what question the expert thought he was asked or what he intended his answer to mean.

There is little dispute about the nature of course-keeping with the sidereal compass. The earliest accounts of the star compass go back to at least 1722 (Schück, 1882), and its use seems relatively easy to observe and document. The most detailed description of the star compass of the Caroline Islands was provided by Goodenough in 1953. This is the star compass shown in Fig. 9.2 of the preceding section. Although this is, as far as we know, a completely accurate depiction of the stars used by the Caroline Island navigators and gives the first complete tabulation of the azimuths (true bearings on the horizon) and names of the star points, it contains a potentially misleading distortion that was probably incorporated to make the compass concept more accessible to readers from our culture. Goodenough has drawn the compass as a circular compass rose, the way compasses are traditionally represented in our culture. The original records of native depictions of the star compass, however, are all box shaped. Figure 9.5 shows such an early description of a Caroline Island star compass.

FIG. 9.5. Traditional box-shaped star compass. Note that the compass/chart does not depict the relative positions of the islands, but only the relative directions between selected pairs of islands.
To date there have been two attempts to explain just how the Caroline Island navigators use the concept of ETAK to keep track of their progress on a voyage. The first description of the use of the ETAK system appeared in a paper by E. Sarfert of Leipzig in 1911 and the second is Gladwin's (1970) description in *East is a Big Bird*. Sarfert's (1911) description is rich and compact and bears careful consideration:

In an arbitrary voyage between two determined islands, the native captains have still a third island in mind, besides the starting point and goal of the trip. For the voyage between every pair of islands this is a specific island. As of now I will refer to this island simply as "emergency island", (*notinsel* in the original German) corresponding to the purpose that it serves as a last place to flee to in case of extenuating circumstances that make it impossible to reach either the starting point or goal of the trip. This island is placed off to the side of the course. In rare situations the natives established two islands as emergency islands, specifically in such a way that one lies to the left and the other to the right of the direction of travel [p. 134].

Riesenberg's (1972) discovery that the reference islands for some voyages are phantoms, however, makes the "emergency island" interpretation unlikely. No navigator would attempt to take refuge in a location known to be devoid of land. Another possibility is that knowing the location of the reference island as well as the origin and destination of the voyage allows the navigator to estimate accurately where many other islands in the area are, so that should he need to take refuge, a choice based on the existing conditions of the wind and sea might be made among several possible islands. The specification of the placement of the islands is no doubt important, but if they were places in which to take refuge, why would it not be just as well to have two "emergency islands" on the same side of the course?

Sarfert (1911) continues:

In Fig. 9.3 (of this paper), the island Bisersas, a small island of the Oonoa atoll, serves as emergency island in the already given voyage from Polowat to Ruk (Truk). If the emergency island is to fulfill its purpose, the captain must be capable of determining at any moment, the direction in which the island lies, and therefore the course to it, from an arbitrary point of the voyage. As far as I have experience about it, he (captain) does this by rather simple means:

1. The direction of the island Bisersas from Polowat as well as from Ruk is known.
2. The native captain may undertake a bearing of the area during the trip by means of calculating the already-traveled distance. This is done with the aid of experience, knowledge of the normal duration of the voyage and with the help of an estimate of the speed that the canoe travels through the water. This last means, the so-called dead reckoning, was also in general used by us for the same purpose before the introduction of the log at the end of the 16th century.

3. To determine the bearing of the emergency island from the vantage point of the canoe, the observation must necessarily be done such that, as Fig. 9.3 clearly demonstrates, it describes the emergency island. Bisersas, from the canoe as a visible movement on the horizon in the opposite direction of the voyage. This visible movement of the emergency island appears, with the interpretation of the horizon as a straight line, in direct relationship to the already-traversed distance. If the captain estimates, for example, the covered path as being a quarter of the total voyage length, then the emergency island must have completed likewise a quarter of its visible path along the horizon. If the total length of the visible path totals 8 (ETAK) lines, then after one quarter of the trip they would have reached, accordingly, the third line. By means of this simple calculation, the course to the emergency island is confirmed and the captain is capable of seeking it out [p. 135].

The major issue raised in Sarfert's proposed calculation technique involves the method used to express the proportion of the total voyage that has been completed. It is easy enough to imagine how the navigator might represent the fact that the "emergency island must have completed a quarter of its visible path along the horizon," although it is doubtful that proportions like "one quarter" are involved. But how does the captain compute that he has covered some proportion of the total voyage length? Further, the expression of the movement of the emergency island in terms of a proportion of the number of ETAK segments will work only if the ETAK segments themselves are all nearly the same size. We return to this point shortly.

Gladwin's descriptive model, like Sarfert's relates the bearing of the ETAK reference island to the distance travelled. They differ, however, in that Sarfert believed the navigator computed the apparent bearing of the ETAK island so that he could take refuge there whereas Gladwin asserts that the navigator uses that apparent position as an expression of the proportion of the voyage completed. Gladwin (1970) states:

When the navigator envisions in his mind's eye that the reference island is passing under a particular star he notes that a certain number of segments have been completed and a certain proportion of the voyage has therefore been accomplished [184].

This is similar to Sarfert's proportional derivation model, but the subtle difference raises an interesting issue. What is the nature of the computation? Is it, as Sarfert maintains, that the navigator uses his estimate of the proportion of the voyage completed to establish the bearing of the reference island, or, as Gladwin maintains, that the navigator uses his estimate of the bearing of the reference island to establish the proportion of the voyage that has been accomplished? Clearly these concepts are closely related for the navigator.

In practice, not every interisland course is situated such that there is an island to the side of the course with the desired properties of an ETAK island. Gladwin (1970) notes:
If the reference island is too close, it passes under many stars, dividing the journey into a lot of segments. Worse, the segments are of very unequal length. They start out rather long ("slow") and then as the canoe passes close by, they become shorter ("fast") as the reference island swings under one star after another, and then at the end they are long again, a confusing effect. A distant reference island has an opposite effect making the segments approximately equal, but so few in number that they do not divide the journey into components of a useful size [187].

The effect of having a close reference island is confusing because when a voyage is divided into segments of very different lengths, the estimation of the number of segments remaining is a poor measure of the distance remaining in the voyage. Gladwin described another situation, also noted by Sarfert, in which this same sort of confusion was bound to arise. In a discussion with the master navigator Ikulilman of the Warieng school ⁵, Gladwin (1970) discovered that for the voyage between Puluwat and Pulasuk atolls, a distance of about 30 miles, the Warieng school indicates two ETAK islands, one to the west of the course and nearby, the other to the east and quite distant.

This case well illustrates one of the difficulties with the practice: when two reference islands are used in this way, the segments are almost certain to be markedly different in length. Ikulilman was not able to offer a good explanation for using two islands, insisting only that this is the way it is taught. When I pressed him further, he observed dryly that Puluwat and Pulasuk are so close together that a navigator does not really need to use ETAK at all in order to establish his position on this seaway, so in this case my question was irrelevant [188].

Another feature of the system in use that seems to give rise to the same sort of conceptual difficulty is that the first and last two segments of all voyages are about the same length, regardless of the positioning of the reference island relative to the course and regardless of the density of star points in the portion of the horizon that the reference island is imagined to be moving through. Gladwin (1970) states:

Upon leaving an island, one enters upon the "ETAK of sighting," a segment which lasts as long as the island remains in view, usually about ten miles. When the island has at last disappeared, one enters the "ETAK of birds" which extends out as far as the flights of birds which sleep ashore each night. This is about twenty miles from land, making the first two and therefore also the last two, segments each about ten miles long. Having four segments of the voyage absolute in length is logically incongruous (by our criteria) with the proportional derivation of the remainder of the ETAK divisions [188].

⁵There are two major schools of navigation in the Central Caroline Islands. Both schools use the same concepts, although there are differences among them in the choice of reference islands and in the details of the lore and language that distinguish navigators from others.
On one occasion I was trying to determine the identity of an island called Ngatik—there were no charts to be consulted of course—that lay somewhere south-west of Ponape. It had not been visited by Central Carolinian canoes for several generations but was an ETAK reference island for the Oroluk—Ponape voyage and as such, its star bearings from both these islands were known to Hipour. On his telling me what they were I drew a diagram to illustrate that Ngatik must necessarily lie where these ETAK bearings intersected (see Fig. 9.6). Hipour could not grasp this idea at all. His concept is the wholly dynamic one of moving islands [142].

This passage raises several important questions. Why did Lewis use the technique of drawing the intersecting bearings in order to determine the location of the island called Ngatik? Why did Lewis assume that posing the question the way he did would make sense to Hipour? Why did Hipour not grasp the idea of the intersecting bearings?

Let's consider the questions about Lewis first. The technique Lewis used is clearly an effective one for the solution of this particular problem, but it contains some very powerful assumptions about the relation of the problem solver to the space in which the problem is being solved. First it requires a global representation of the locations of the various pieces of land relative to each other. In addition, it requires a point of view on that space which we might call the "bird's eye" view. The problem solver does not (and cannot without an aircraft) actually assume this relation to the real world in which the problem is posed. But he does assume this relation to a chart or a diagram which is an abstract representation of the space. This strategy, then, involves at least creating an abstract representation of a space and then assuming an imaginary point of view relative to the abstract representation. We can guess that Lewis did this because it is for him a natural framework in which to pose questions and solve problems having to do with the relative locations of objects in a two dimensional space. Part of his training tells him that it is appropriate to use this strategy even when he is one of the objects in the relevant space. Posing the question this way also seems justified by the fact that these navigators are, and long have been, capable of creating chart-like representations of the islands among which they sail (Schück, 1882).

Western navigators make incessant use of this change in point of view. When the navigator takes a compass bearing on a landmark from the bridge of a boat he has a real point of view on a real space, but as soon as he leans over his chart, he is no longer conceptually on the boat, he is over the sea surface looking down on the position of his craft in a representation of the real local space. Novice navigators sometimes find this change of point of view disorienting especially if the orientation of their chart table does not happen to correspond to the orientations of objects in the world. We all face this same problem when in using a road map we have to decide whether to keep the northern edge or the edge toward our destination away from us. Regardless of problems of orientation, the change of point of view is manifest in the reconciliation of the map to the terrain.

Beiong was also puzzled by Lewis's (1972) assertion, and in reaching an understanding of it he provides us with an important insight into the operation of the conceptual system.

He eventually succeeded in achieving the mental tour de force of visualizing himself sailing simultaneously from Oroluk to Ponape and from Ponape to Oroluk and picturing the ETAK bearings to Ngatik at the start of both voyages. In this way he managed to comprehend the diagram and confirmed that it showed the island's position correctly [143].

The nature of Beiong's understanding indicates that for the Caroline Island navigator, the star bearing of an island is not simply the orientation of a line in space, but the direction of a star point from the position of the navigator. In order to see that the star bearings would indeed intersect each other at the island, he had to imagine himself (in the role of navigator) to be at both ends of the voyage at once. This allowed him to visualize the star bearing from Oroluk to Ngatik radiating from a navigator at Oroluk and the star bearing from Ponape to Ngatik radiating from a navigator at Ponape. What Hipour probably imagined when Lewis asserted that the island lies where the bearings cross must have been something like the situation depicted in Fig. 9.7. Contrast this with what Lewis imagined he was asserting (Fig. 9.6). Hipour's constellation is now perhaps more understandable. The star bearings of the ETAK reference island are bearings which radiate out from the navigator. From his perspective they meet only at him. In his conception of the voyage in question the ETAK reference island begins under one of these bearings and ends under the other. That two relative bearings might meet anywhere other than at the navigator himself is literally inconceivable.

Because the Caroline Island navigator takes a real point of view on the real local space to determine the star bearings, it does not seem likely that the
mapping of ETAK segments onto an abstract representation of the expanse of water between the islands is faithful to his conception. Gladwin's (1970) statement about the navigator noting that a "certain number of segments have been completed" and the diagrams that Lewis, Gladwin, and Sarfert use to represent the changing relative bearing of the ETAK reference island all contain the implicit assumptions (1) that the navigator uses some sort of "birds eye view" of the space he is in and (2) that he conceives of a voyage in terms of changes in the position of his canoe in a space upon which he has an unchanging point of view. These assumptions are true of the Western navigator's conception of a voyage, but they appear not to be true of the Caroline Island navigator's conception of a voyage. These assumptions are at odds with the verbal data (i.e., descriptions of islands moving relative to the navigator) and the behavioral data (i.e., consternation in the face of what ought to be a trivial inference).

It is tempting to criticize the Caroline Island navigators for maintaining an egocentric perspective on the voyage when the global perspective seems so much more powerful. But consider the following exercise: Go at dawn to a high place and point directly to the center of the rising sun. That defines a line. Return to that same high place at noon and point again to the center of the sun. That defines a second line. I assert that the sun is located in space where those two lines intersect. Think about it. In spite of the fact that the lines seem to be orthogonal to each other, it happens to be true. It is not intuitively obvious to us because our usual way of conceiving of the sun's location is not to conceive of its location at all. It is to think of its orientation relative to a frame defined by the horizons and the zenith on earth. The rotation of the earth is not experienced as a movement of the surface of the earth about its center, but as the movement of celestial bodies about the earth. From a point of view outside the solar system, however, the intersection of the lines is obvious and it is immediately apparent that the sun is in fact located where the lines cross (see Fig. 9.8).

Our everyday models of the sun's movement are exactly analogous to the navigator's conception of the location of the reference island. The choice of representations limits the sorts of inferences which make sense. Because we have all been exposed to the ideas of Copernicus, we can sit down and convince

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**FIG. 9.7** Where Marques have imagined. The stars lying in the line from the navigator himself. He "sees," then, where the stars rise from or set into the horizon. From the navigator's point of view, the stars are rising to the north or setting to the south. From Rat, some of these stars have their bearing of Nagual, from Ponge (under the Southern Cross setting), and the others under which Nagual would pass on a voyage between Orofis and Ponge.

**FIG. 9.8** The view from outside the solar system. The sun is located in space where the line defined by pointing to it at dawn intersects the line defined by pointing to it at noon.
ourselves that what we experience is an artifact of our being on the face of a spinning planet. That is, after all the "correct" way to conceive of it, but it is not necessarily the most useful way. Modern celestial navigation is deliberately pre-Copernican because a geocentric conception of the apparent movements of bodies on a rigid celestial sphere makes the requisite inferences about the apparent positions of celestial bodies much easier than a heliocentric conception. From a perspective outside the galaxy of course, the heliocentric conception itself is seen to be a fiction which gives an improved account of the relative movements of bodies within the solar system, but which is incapable of accounting for the motion of the solar system relative to the other stars in the universe. Such a "vertical" cosmology that describes the real movements of bodies through space, however, is irrelevant to any present-day navigator's concerns.

The findings of this section place strong constraints on the candidate models of how the navigators use the ETAK system. Viable candidates must not rely on arbitrary units of distance, nor should they involve a birds-eye view of the navigator and his craft situated in some represented space.

AN ALTERNATIVE MODEL

We are now ready to consider what the Caroline Island navigator might gain by using the conception of the moving reference island. Gladwin was no doubt correct in claiming that the ETAK system is a way to express how much of a voyage has been completed and how much remains. In Gladwin's model the ETAK conception performs the recording function of a chart. According to Gladwin, the navigator, by means unknown, performs mental dead reckoning on the movement of his canoe and having determined where his canoe is along its track from island to island he then infers where the reference island must lie over the horizon. In that model, the ETAK concept and the use of the reference island are only ways to arrange the information at hand so that it can be remembered. This section shows how the ETAK conception does in a more elegant and direct way for the Caroline Island navigator just what a chart does for the Western navigator, that is, how it provides not only a framework for remembering, but a framework for computation as well.

Western navigators find the use of a chart or other model indispensable for expressing and keeping track of how much of a journey has been completed and how much remains. I have argued earlier that although the Caroline Island navigators are fully capable of imagining and even drawing charts of their island group, these conceptions are not compatible with the moving island and star bearing conceptions they use while navigating. Remember that Hipour's problem was the difficulty of getting to a bird's eye point of view when he was thinking about star bearings. In addition, even though the necessary technology is available to them, we know that the navigators carry nothing like a chart with them on their voyages.

Consider the navigator's conception in its context of use. At the outset of any voyage, the navigator imagines that the reference island is off over the horizon ahead of him and to one side. It is for him under the point on the horizon marked by the rising or setting of a particular line of stars. During the course of the voyage, the reference island will move back along its track remaining out of sight of the navigator. As it does so, it will assume positions under a succession of star bearings until it lies under the star bearing which marks the course from the destination to the reference island. If the helmsman has kept a straight course, then the canoe will be at the destination when this happens. An important aspect of this imagined sweep of the reference island back along its track, out of sight of the navigator has been ignored by recent writers on Caroline navigation but was noticed by Sarfert (1911). Sarfert was struck by the fact that the navigators conceive of the horizon as being a straight line which lies parallel to the course of the canoe. For a Western navigator who normally conceives of the horizon as a circle around him, this is a puzzling observation. Why should these navigators make such a counterfactual assumption?

As Sarfert pointed out, if the navigator conceives of the horizon as a straight line, and he imagines the apparent movement of the reference island beyond it, then the horizon itself becomes a line parallel to the course steered on which the progress of the reference island from beginning bearing, through a set of intermediate bearings, and to final bearing is exactly proportional to the progress of the canoe from the island of departure across the sea between and to the goal island. That is, the imagined movement of the ETAK reference island just under the horizon is a complete model of the voyage which is visualizable (but not visible) from the natural point of view of the navigator in the canoe (see Fig. 9.9). It is a representation of the spatial extent of the voyage and one's progress along it that does not require either the construction of a map or a change of point of view. The straight line horizon conception is essential to the transformation of angular displacement into linear displacement.

The image of the ETAK reference island moving along just below the horizon can be quite naturally tied to the passage of time. Part of the knowledge that a navigator has about every voyage is the amount of time he can expect the trip to take under various conditions. Suppose that the navigator knows for a particular voyage that under good conditions, he will arrive at his goal after one day of sailing. If he leaves his island of departure at noon for instance (a common departure time) he can estimate that he will arrive at his destination about noon the following day. In terms of the movement of the reference island, that means that the island will move from under the beginning bearing to the position under the final bearing in one day. This image is shown in Fig. 9.10. Still assuming a

6See for example, Bowditch (1977, Vol. 1) or Maloney (1978) for discussions of the pre-Copernican fictions employed in modern celestial navigation.
FIG. 9.9. The imagined movement of the ETAk reference island. Imagine that you are in a canoe moving from left to right. As you look out at the horizon to the side of the canoe, you see at your right (ahead of you) the star bearing under which the reference island lies at the outset of the voyage. As you travel, the ETAk reference island moves back along its apparent course beyond the horizon from right to left. At the end of the voyage it will be under its final star bearing, that is, the bearing from the goal island to the reference island.

normal rate, he can associate other times during the voyage with other bearings of the reference island as shown in Fig. 9.11. In so doing, he not only has a visual image that represents the extent of the voyage in space, he also has one that represents the voyage and its subparts in time as well. If the voyage was in fact sailed under the expected conditions, the task of determining where the reference island is positioned over the horizon at any point in time would be trivial. All the navigator need do is to determine what time of day it is and refer to the image of the reference island moving along under the horizon. By pointing to the position on the horizon that represents the present time of day, the navigator has pointed directly at the reference island. The imagery described is depicted in Fig. 9.12.

The assumption that ETAk segments are units of distance lead Gladwin (1970) to three related apparent inconsistencies. They are (1) the supposedly confusing effect of having ETAk segments be of different lengths, (2) the conflicting boundaries of ETAk segments defined by using more than one ETAk island at a time, and (3) the conflicting boundaries of ETAk segments at the beginning and end of a voyage caused by using the ETAk of birds and the ETAk of sighting in addition to the star bearing defined ETAk segments. Gladwin (1970) found these conceptions to be, "completely inconsistent with the theory as described above [p. 189]."
In this model, there is no need to assume that the ETAK segments are units of distance. We dispense with the notion that they enter into a numerical computation of the proportion of the voyage completed or remaining. The inequality of their lengths is not an awkward conceptual problem, it simply means that on a typical voyage, the navigator will have more conceptual landmarks defined by star bearings in the middle of the voyage than at the ends. In fact, if we listen to the navigators, we find that they are not talking about the spatial duration (length) of the ETAK segments, but of their temporal duration. Gladwin (1970) states:

They start out being rather long ("slow") and then as the canoe passes close by, they become shorter ("fast") as the reference island swings under one star after another, and then at the end they are long again, a confusing effect [p. 187].

The concern of the navigator is not how far he travels in a particular ETAK segment, but how long he will travel before asserting that the reference island has moved back under the next star bearing.

When the concept of the ETAK segment is freed from the notion of a unit of distance, the apparent problems of using more than one ETAK island at one time, or overlapping the star bearing determined ETAK segments with those determined by the range of birds and the range of sighting, disappear. Using one ETAK island to each side of a voyage gives the navigator more conceptual landmarks on his voyage. There is no reason for it to be a problem to the
The strategy of including the ETAK of sighting and the ETAK of birds is entirely consistent with the notion of the ETAK division as a conceptual landmark. The star bearing defined ETAK segments are conceptual landmarks derived in a particular way, and the ETAK of sighting is a conceptual landmark determined in another way. But once established, they function for the navigator in the same way. They do not enter into a numerical computation, but give the navigator a more direct representation of where he is, or rather where land is. In addition, because the star bearing ETAK segments are slow in coming near the beginning and end of the voyage, it may be helpful to the navigator to have these other conceptual landmarks at these points.

This conception and technique make the judgment of the location of land a trivial computation when conditions are favorable. Suppose, however, that the voyage must be made under conditions that differ from those expected at the outset of the voyage. How could the navigator update his image of the movement of the reference island to reflect what is happening to his rate of travel? The key to this problem lies in the judgment of rate and in the way that the judgment is expressed. Any experienced Western yachtsman may make fairly accurate judgments of his boat's speed through the water without the aid of instruments. By attending to the feel of the boat as it moves through the water, the accelerations developed as it moves over waves, the feel of the apparent wind, the appearance and sound of the wake (it sizzles at speeds in excess of about five knots), the response of the helm, and many other sensations, the small boat sailor can make judgments that he normally expresses as a number of units, usually knots. The knot is a good choice for the yachtsman, because as one nautical mile per hour, it is a convenient form for the sorts of subsequent numerical calculations he is likely to make. He might have expressed the rate as furlongs-per-fortnight or on a scale of how thrilling it is, but neither of these fits especially well with the useful subsequent calculations. The same must be true for the Caroline Island navigators. There is no doubt that they can make accurate judgments of rate, but expressing those judgments in terms of knots would not be advantageous at all because that unit is not compatible with any interesting computations on a visual image of the moving reference island.

Clearly what is wanted is an expression of the rate that bears a compatible relationship to the imagery. Consider the following hypothetical scheme. At some point in the voyage (and it could be any point including the very beginning) the rate of the canoe changes. The navigator reconstructs his image of the movement of the reference island with the time landmarks placed in accordance with the previous rate. If the change occurs at the very beginning of the voyage, the usual or default rate will be taken as the previous rate. Let the segment of the horizon from the present position of the reference island to any convenient future time landmark represent the previous rate (see Segment 1, Fig. 9.15). This represents the expected movement of the reference island at the previous rate during the period between the present time and the temporal landmark chosen.
The problem is to determine the movement of the reference island during the same time period at the new rate. If the new rate is greater than the old rate, then the reference island will move further along the horizon in the same period, if the rate is less, the movement will be less. Using Segment 1 as a scale, imagine another segment (Segment 2, Fig. 9.15) starting at the present position of the reference island and extending in the direction of the apparent movement of the reference island which represents a judgment of the magnitude of the new rate relative to the old rate. Now simply move the time landmark from the end of Segment 1 to the end of Segment 2. Segment 2 now defines the new time scale for the new rate. The other time landmarks for subsequent portions of the voyage can be moved in accordance, as in Fig. 9.16 and a complete new set of expectations for the times at which the ETAK reference island will assume future positions is achieved. This procedure can of course be applied anytime there is a noticeable change in the rate of travel of the canoe through the water. Thus, the
navigator can always keep an updated set of time/bearing correspondences for the ETAK reference island which allows him to gauge how much of his voyage has been completed and how much remains.

Tacking

This same set of concepts provides a solution to the problem of tacking upwind to an unseen target. Gladwin (1970) tells us that when tacking is necessary, the navigator dispenses with the reference island and concentrates his attention on the goal island. When it becomes necessary to tack, the navigator can consult his imagery of the ETAK reference island to determine how long it would have taken him to reach his goal had he been able to continue to sail toward it (the time duration of the segment A in Fig. 9.17a). At this time, the goal island still lies under its original star bearing. As the canoe turns and settles onto its new course, the goal island, which was previously straight ahead of the canoe now lies ahead and off to one side of the canoe's course. Like an ETAK reference island, the goal island is out of sight, over the horizon and will move back under the star bearings off to one side of the canoe. The problem for the navigator in keeping track of the movement of the goal island now that he has come onto a new course is that he needs a set of temporal landmarks to calibrate the movement of the island.

There may be several ways of constructing such landmarks. In this section I present a hypothetical method, based on a simple geometric construction. This construction exploits the fact that a straight line forms a set of triangles when it intersects the radiating grid of star bearings (see Fig. 9.14b). Further, the set of triangles formed by any line parallel to the course of the canoe is congruent with the set formed by any other line which is parallel to the course (try moving a straight edge parallel to the course line toward the canoe in Fig. 9.14b). The ratios of the lengths of the segments is the same regardless of the distance of the line from the origin of the grid. As we know, the horizon is conceived of as one such straight line. The bearing to the goal island is an imaginary line from where the navigator sits across the canoe deck, across the outrigger, (because the canoe is sailing upwind and the outrigger is always kept to windward) and out to the horizon. Notice how the star bearings cross the outrigger. The outrigger lies in a line roughly parallel to the course of the canoe\(^7\) and it has all the same attributes as the horizon as a frame for the imagery. The navigator can map the star bearings onto locations on the outrigger. If he could determine a set of temporal landmarks there too, he would have solved his problem. Imagine a bearing line emanating from the navigator and extending toward the goal island. Let the

\(^7\)Being of shallow draft, these canoes make considerable leeway. The course made good, however, is near enough to the course steered that the differences do not affect the use of the outrigger as a frame for the imagery.
the image of the movement of the reference island on the horizon is almost certainly correct. The mechanisms of rate adjustment and of mapping star bearings onto the outrigger in tacking are more speculative. There are, at present, no data bearing directly on these issues because the models entertained by previous researchers gave no indication that these phenomena existed. Until further field research is conducted, they remain hypotheses generated by a theory of the task.

**DISCUSSION**

The contrast between the Micronesian navigation techniques and the techniques employed by Western navigators is a reflection of more general differences in computational style. With the advent of literacy and of arithmetic operations as models of events in the world, our cultural tradition made a radical break with previous styles. The prototypical computation in our tradition is a digital arithmetic procedure. The relations of our computations to the world we wish to know about are mediated by analogue to digital (A/D) converters, which provide numerical representation of physical events, and by digital to analogue (D/A) converters that provide for the physical interpretation of calculation results.

The tool box of the Western navigator contains scales and compass roses on charts, dividers, sextants, and chronometers. These are all A/D and D/A converters. In our tradition, the operations of observation, computation, and interpretation are each a different sort of activity and they are executed serially. The Micronesian navigator's tool box is in his mind. There are no A/D or D/A converters because all of the computations are analogue. The interpretation of the result (bearing of the reference island, for example) is embedded in the computation (construction of the horizon image) which is itself embedded in the observation (time of day).

The two techniques for solving navigation problems evolved in different intellectual environments. The Micronesian technique is elegant and effective. It is organized in a way that allows the navigator to solve in his head, problems that a Western navigator would not attempt without substantial technological supports. Other nonliterate cultures, applying themselves over the course of millennia to their own important problems, must have evolved systems that organize the thinking of the problem solver in equally elegant and efficient ways. It is likely, however, that many if not most of these systems have been lost to us. The European colonization of the world must have lead to the extinction of many species of ideas. This would happen not so much by direct refutation, although religions often take this route, as by the destruction of habitat—the removal of the contexts in which the ideas evolved and functioned. This was the fate of navigation knowledge in Polynesia when long distance voyaging there was suppressed.
When one considers documenting the range of mental models mankind has developed, other problems arise. The history of attempts to understand Micronesian navigation shows how difficult it can be to get away from the fundamental assumptions of one's own cultural tradition.

An obvious beginning for this sort of endeavor is to ask the question: "Given the nature of the task they are facing, what would one have to do to accomplish it?" But there are nearly always many ways to solve any complex problem, and the solutions most likely to occur to the cross-cultural researcher are those that arise from the assumptions of his own cultural tradition. In this chapter I have tried to show how easily that can happen, and how convincing such an explanation can be to its formulator even in the face of relatively serious anomalies. What we want to do is not to model a theory of the task, but to model the problem solver's theory of the task. In doing this we identify the real task to be solved as an internal one. It is the set of operations required to operate on the problem solver's representation of the task, rather than the set of operations required in the world. This means that we need to look first at what the problem solver thinks the task is and then ask the question: "How could one operate on that representation to produce the decisions required to accomplish that task?"

Failure to take the utility of alien mental models seriously cheats us out of important insights. Akerblom (1968) ends his discussion of Polynesian and Micronesian navigation with the following passage:

Polynesians and Micronesians accomplished their voyages, not thanks to, but in spite of their navigational methods. We must admire them for their daring, their enterprise and their first rate seamanship [p. 156].

I hope this chapter succeeds in laying such notions as Akerblom's to rest. In fact, it seems more likely to me that we who have studied Pacific navigation have accomplished what understanding we have, not thanks to, but in spite of our own cultural belief systems.

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