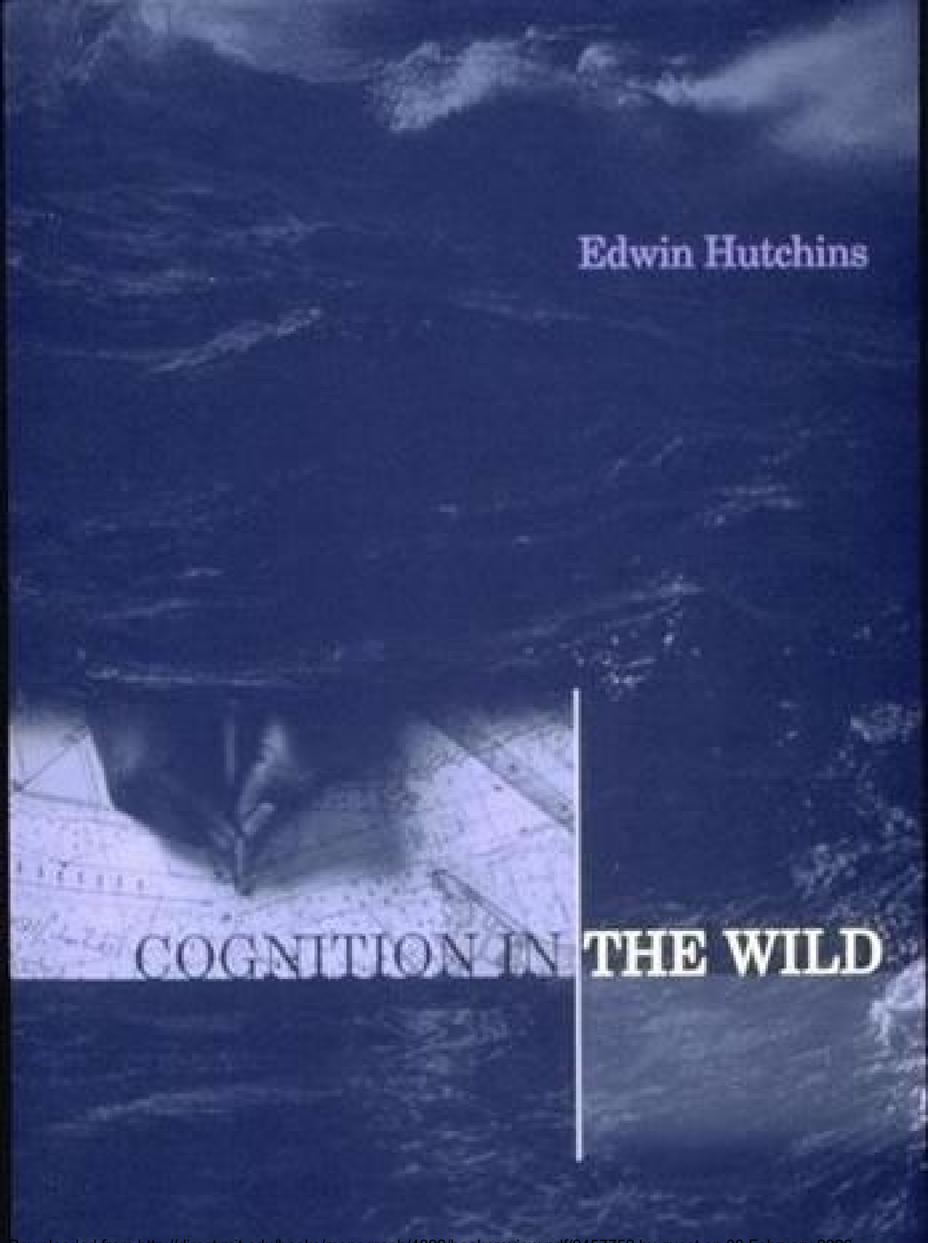
Edwin Hutchins
COGNITION IN THE WILD

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for Dona

Contents

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Introduction

The seed from which this book grew was planted in November 1980, when I spent most of a day on the navigation bridge of a U.S. Navy ship as it worked its way in from the open North Pacific, through the Straits of Juan de Fuca, and down Puget Sound to Seattle. I was aboard the ship to study what the operators of its steam propulsion plant knew and how they went about knowing it. I had spent most of the preceding week down in the bowels of the ship, observing engineering operations and talking to the boiler technicians and machinist's mates who inhabited that hot, wet, noisy tangle of boilers, pumps, and pipes called the engineering spaces. I'll admit to having felt a little claustrophobic after all that time spent below the water line, where there is no night or day and the only evidence of being at sea is the rhythmic tipping of the deck plates and sloshing of water in the bilge below one's feet as the ship rolls in the swell. A chief boiler technician confided to me that in 21 years on Navy ships he had never yet been on deck to experience either of those two most romantic seafaring events, a ship's arrival at or departure from a port.

I resolved, therefore, to take my last few hours aboard this ship on the navigation bridge, where I could see out the windows or even go out on the bridge wing to get a breath of cold fresh air. My professional rationalization for being on the bridge was that there I would be able to observe the process that generates the flurry of engine commands that always taxes the engineering crew when the ship nears the dock. And I did make a detailed record of all engine and helm commands given in the 75 minutes from the time the engines were first slowed until they were secured—there were 61 in all. But what really captured my attention was the work of the navigation team.

Three and a half years later, the project that became this book began in earnest. In the summer of 1984, I was still working for the Navy Personnel Research and Development Center in San Diego as a civilian scientist with the title Personnel Research Psychologist. By then I had participated in two successful and well-known projects. With these successes came the freedom to conduct an independent research project. I was given carte blanche to study whatever I thought was of most interest. I chose to study what I was then calling *naturally situated cognition*. Having a research position in a Navy laboratory made it possible for me to gain access to naval vessels, and my longtime love of navigation and experience as a racing yacht navigator made it easy for me to choose navigation as an activity to study afloat. I talked my way aboard a ship and set up shop on the navigation bridge. At the time, I really had no notion what an ideal subject navigation would turn out to be. When I began, I was thinking in terms of the naturally situated cognition of individuals. It was only after I completed my first study period at sea that I realized the importance of the fact that cognition was socially distributed.

A little earlier, I had been asked to write a book describing what is in cognitive anthropology for the rest of cognitive science. I began that project, but after I became disillusioned with my field I lost interest in it. The choice of naturally situated cognition as a topic came from my sense that it is what cognitive anthropology really should have been about but largely had not been. Clifford Geertz (1983) called for an "outdoor psychology," but cognitive anthropology was unable or unwilling to be that. The respondents may have been exotic, but the methods of investigation were largely borrowed from the indoor techniques of psychology and linguistics. When cognitive and symbolic anthropology split off from social anthropology, in the mid 1950s, they left society and practice behind.

As part of the cognitive revolution, cognitive anthropology made two crucial steps. First, it turned away from society by looking inward to the knowledge an individual had to have to function as a member of the culture. The question became "What does *a person* have to know?" The locus of knowledge was assumed to be inside the individual. The methods of research then available encouraged the analysis of language. But knowledge expressed or expressible in language tends to be declarative knowledge. It is what people can say about what they know. Skill went out the window of the "white room." The second turn was away from practice. In the quest to learn what people know, anthropologists lost track both of how people go about knowing what they know and of the contribution of the environments in which the knowing is accomplished. Perhaps these narrowing assumptions were necessary to get the project of cognitive anthropology off the ground. I will argue that, now that we are underway as a discipline, we should revoke these assumptions. They have become a burden, and they prevent us from seeing the nature of human cognition.

In particular, the ideational definition of culture prevents us seeing that systems of socially distributed cognition may have interesting cognitive properties of their own. In the history of anthropology, there is scarcely a more important concept than the division of labor. In terms of the energy budget of a human group and the efficiency with which a group exploits its physical environment, social organizational factors often produce group properties that differ considerably from the properties of individuals. Clearly, the same sorts of phenomena occur in the cognitive domain. Depending on their organization, groups must have cognitive properties that are not predictable from a knowledge of the properties of the individuals in the group. The emphasis on finding and describing "knowledge structures" that are somewhere "inside" the individual encourages us to overlook the fact that human cognition is always situated in a complex sociocultural world and cannot be unaffected by it.

Similar developments in the other behavioral sciences during the cognitive revolution of the late 1950s and the 1960s left a troubled legacy in cognitive science. It is notoriously difficult to generalize laboratory findings to real-world situations. The relationship between cognition seen as a solitary mental activity and cognition seen as an activity undertaken in social settings using various kinds of tools is not at all clear.

This book is about softening some boundaries that have been made rigid by previous approaches. It is about locating cognitive activity in context, where context is not a fixed set of surrounding conditions but a wider dynamical process of which the cognition of an individual is only a part. The boundaries to be softened or dissolved have been erected, primarily for analytic convenience, in social space, in physical space, and in time. Just as the construction of these boundaries was driven by a particular theoretical perspective, their dissolution or softening is driven by a different perspective—one that arose of necessity when cognition was confronted in the wild.

The phrase "cognition in the wild" refers to human cognition in its natural habitat—that is, to naturally occurring culturally constituted human activity. I do not intend "cognition in the wild" to be read as similar to Lévi-Strauss's "pensée sauvage," nor do I intend it to contrast with Jack Goody's (1977) notion of domesticated mind. Instead, I have in mind the distinction between the laboratory, where cognition is studied in captivity, and the everyday world, where human cognition adapts to its natural surroundings. I hope to evoke with this metaphor a sense of an ecology of thinking in which human cognition interacts with an environment rich in organizing resources.

The attempt is cultural in nature, giving recognition to the fact that human cognition differs from the cognition of all other animals primarily because it is intrinsically a cultural phenomenon. My aim is to provide better answers to questions like these: What do people use their cognitive abilities for? What kinds of tasks do they confront in the everyday world? Where shall we look for explanations of human cognitive accomplishment?

There is a common misconception among cognitive scientists, especially those who do their work in laboratory settings, that research conducted outside the laboratory is necessarily "applied" work. I will argue in what follows that there are many excellent reasons to look at the "real world" that are not concerned with hoped-for applications of the research findings (although funding sponsors often like to think in those terms). Pure research on the nature of real cognitive practices is needed. In this book, I emphasize practice not in order to support a utilitarian or functionalist perspective but because it is in real practice that culture is produced and reproduced. In practice we see the connection between history and the future and between cultural structure and social structure. One of my goals in writing this book is to make clear that the findings of pure research on cognition in the wild should change our ideas about the nature of human cognition in general. This is not news to anthropologists, who have been doing pure research in the form of ethnography for decades.

This book is an attempt to put cognition back into the social and cultural world. In doing this I hope to show that human cognition is not just influenced by culture and society, but that it is in a very fundamental sense a cultural and social process. To do this I will move the boundaries of the cognitive unit of analysis out beyond the skin of the individual person and treat the navigation team as a cognitive and computational system.

Chapter 1, "Welcome Aboard," attempts to locate the activity of ship navigation in the larger world of modern life. It weaves together three journeys: a movement through physical space from the "street" to the ship, a movement through social space from civilian to military life, and a movement through conceptual space from everyday notions of wayfinding to the technical domain of navigation. Both the researcher and the reader must make these journeys to arrive at the activity of navigation as practiced on the bridge of a Navy ship. Military ranks and the ways in which military identities are formed are presented here because these things affect individual's relationships to their work. An important aspect of the larger unit is that it contains computational elements (persons) who cannot be described entirely in computational terms. Who they talk to and how they talk to one another depend on these social organizational factors. This chapter also contains a discussion of the relationship of the researcher to the activity under study. (The name of the ship and the names of all the individuals mentioned in the book are pseudonyms. All the discourses reported, whether standing alone in transcript form or embedded in narrative passages were transcribed directly from audio recordings of actual events.)

Having taken navigation as it is performed by a team on the bridge of a ship as the unit of cognitive analysis, I attempt in chapter 2, "Navigation as Computation," to apply the principal metaphor of cognitive science—cognition as computation—to the operation of this system. I should note here that in doing so, I do not make any special commitment to the nature of the computations that are going on inside individuals except to say that whatever happens there is part of a larger computational system. This chapter describes the application of David Marr's notions of levels of analysis of cognitive systems to the navigation task and shows that, at the computational level, it is possible to give a single description of the computational constraints of all known technical forms of human navigation. A comparison of modern Western navigation with navigation as practiced in Micronesia shows that considerable differences between these traditions lie at the representational/algorithmic level and at the implementational level. A brief historical review of the development of modern navigation shows that the representational and implementational details of contemporary practice are contingent on complex historical processes and that the accumulation of structure in the tools of the trade is itself a cognitive process.

Chapters 3–5 explore the computational and cognitive properties of systems that are larger than an individual. The issues addressed in these chapters concern how these larger systems operate and how their cognitive properties are produced by interactions among their parts.

Chapter 3, "The Implementation of Contemporary Pilotage," describes the physical structures in which the navigation computations are implemented. This chapter elaborates a conception of computation as the propagation of representational state across a variety of media. This view of computation permits the use of a single language of description to cover cognitive and computational processes that lie inside and outside the heads of the practitioners of navigation. The first section of this chapter describes the "fix cycle" as a cognitive process. The second section describes how navigation tools are used and how local functional systems composed of a person in interaction with a tool have cognitive properties that are radically different from the cognitive properties of the person alone. The third section discusses the ways in which the computational activity can be distributed through time by precomputing not only partial results but also the means of computation. I show here how the environments of human thinking are not "natural" environments. They are artificial through and through. Humans create their cognitive powers by creating the environments in which they exercise those powers. This chapter concludes with a discussion of the relationship between the cognitive properties of the individuals performing a task and the cognitive properties of the system in which they participate.

Chapter 4, "The Organization of Team Performances," moves the boundaries of the unit of analysis even further out to consider the cognitive properties of the team as a whole. Here I note some of the problems that are encountered when cognitive activities are distributed across the members of a group. It is not the case that two or more heads are always better than one. This chapter describes the structures and processes involved in the group performance of the navigation task. The first section follows through on the application of Marr's concepts of computation to the navigation activity and discusses the properties of the activity as an explicitly computational system. The second section presents a problem in work organization encountered by the navigation team and shows why it is often difficult to apply the concepts that organize individual action to the organization of group action. The final section shows how the members of the navigation team form a flexible connective tissue that maintains the propagation of representational state in the face of a range of potentially disruptive events.

Chapter 5, "Communication," continues the theme of chapter 4 but looks at communication in more detail. It asks: How is it that patterns of communication could produce particular cognitive properties in a group? The chapter begins with a discussion of features of communication observed in the navigation team and their effects on the Team's computational properties. These observations lead to some simple hypotheses about the ways in which patterns of communication might affect the computational properties of a group. These hypotheses are explored using a computer simulation of communities of connectionist networks. The simulations lead to the surprising conclusion that more communication is not always better.

Chapters 6–8 concern learning or change in the organization of cognitive systems at several scales.

Chapter 6, "The Context of Learning," is a bridge between the descriptions of ongoing operations provided by the previous chapters and the descriptions of changes in the nature of ongoing operations provided by the following chapters. It describes the context in which novice navigators become experts. This chapter is an attempt to examine both the work that the system does in order to scaffold learning by practitioners and the opportunities for the development of new knowledge in the context of practice.

Whereas in chapter 6 I deal with the observable contexts surrounding learning, in chapter 7, "Learning in Context," I try to dissolve the boundaries of the skin and present navigation work as a system of interactions among media both inside and outside the individual. I look at learning or conceptual change as a kind of adaptation in a larger dynamical system. This chapter presents a functional notation and a framework for thinking about learning as local adaptation in a dynamic system of coordinations of representational media.

Chapter 8, "Organizational Learning," returns the focus to the larger unit of analysis: the team as a whole. It presents a case study of an incident in which the navigation team was forced to adapt to changes in its information environment. The analysis presented here examines a particular incident in which the microstructure of the development of the navigation practice can be seen clearly. It is an attempt to show the details of the kinds of processes that must be the engines of cultural change.

Chapter 9, "Cultural Cognition," attempts to pull the preceding chapters together into a coherent argument about the relationships of culture and cognition as they occur in the wild. I attempt first to illustrate the costs of ignoring the cultural nature of cognition. I argue that a new framework is needed to understand what is most characteristically human about human cognition. In order to construct a new framework, the old one must be deconstructed. I therefore provide two readings of the history of cognitive science: a history as seen by the proponents of the currently dominant paradigm and a rereading of the history of cognitive science from a sociocultural perspective. The differences between these two readings highlight a number of problems in contemporary cognitive science and give new meanings to some of the familiar events in its history.

Cognition in the Wild

1 Welcome Aboard

Narrative: A Crisis

After several days at sea, the U.S.S. *Palau* was returning to port, making approximately 10 knots in the narrow channel between Ballast Point and North Island at the entrance to San Diego Harbor. In the pilothouse or navigation bridge, two decks above the flight deck, a junior officer had the conn (i.e., was directing the steering of the ship), under the supervision of the navigator. The captain sat quietly in his chair on the port side of the pilothouse watching the work of the bridge team. Morale in the pilothouse had sagged during two frustrating hours of engineering drills conducted just outside the mouth of the harbor but was on the rise now that the ship was headed toward the pier. Some of the crew talked about where they should go for dinner ashore and joked about going all the way to the pier at 15 knots so they could get off the ship before nightfall.

The bearing recorder had just given the command "Stand by to mark time 3 8" and the fathometer operator was reporting the depth of the water under the ship when the intercom erupted with the voice of the engineer of the watch: "Bridge, Main Control. I am losing steam drum pressure. No apparent cause. I'm shutting my throttles." Moving quickly to the intercom, the conning officer acknowledged: "Shutting throttles, aye." The navigator moved to the captain's chair, repeating: "Captain, the engineer is losing steam on the boiler for no apparent cause." Possibly because he realized that the loss of steam might affect the steering of the ship, the conning officer ordered the rudder amidships. As the helmsman spun the wheel to bring the rudder angle indicator to the centerline, he answered the conning officer: "Rudder amidships, aye sir." The captain began to speak, saying "Notify," but the engineer was back on the intercom, alarm in his voice this time, speaking rapidly, almost shouting: "Bridge, Main Control, I'm going to secure number two boiler at this time. Recommend you drop the anchor!" The captain had been stopped in mid-sentence by the blaring intercom, but before the engineer could finish speaking the captain said, in a loud but cool voice, "Notify the bosun." It is standard procedure on large ships to have an anchor prepared to drop in case the ship loses its ability to maneuver while in restricted waters. With the propulsion plant out, the bosun, who was standing by with a crew forward ready to drop the anchor, was notified that he might be called into action. The falling intonation of the captain's command gave it a cast of resignation or perhaps boredom and made it sound entirely routine.

In fact, the situation was anything but routine. The occasional cracking voice, a muttered curse, or a perspiration-soaked shirt on this cool spring afternoon told the real story: the *Palau* was not fully under control, and careers and possibly lives were in jeopardy.

The immediate consequences of this event were potentially grave. Despite the crew's correct responses, the loss of main steam put the ship in danger. Without steam, it could not reverse its propeller—the only way to slow a large ship efficiently. The friction of the water on the ship's hull will eventually reduce its speed, but the *Palau* would coast for several miles before coming to a stop. The engineering officer's recommendation that the anchor be dropped was not appropriate. Since the ship was still traveling at a high rate of speed, the only viable option was to attempt to keep the ship in the deep water of the channel and coast until it had lost enough speed to safely drop anchor.

Within 40 seconds of the report of loss of steam pressure, the steam drum was exhausted. All steam-turbine-operated machinery came to a halt, including the turbine generators that produce the ship's electrical power. All electrical power was lost throughout the ship, and all electrical devices without emergency power backup ceased to operate. In the pilothouse a high-pitched alarm sounded for a few seconds, signaling an under-voltage condition for one piece of equipment. Then the pilothouse fell eerily silent as the electric motors in the radars and other devices spun down and stopped. Just outside the navigation bridge, the port wing pelorus operator watched the gyrocompass card in his pelorus swing wildly and then return to its original heading. He called in to the bearing recorder standing at the chart table: "John, this gyro just went nuts." The bearing recorder acknowledged the comment and told the pelorus operator that a breakdown was in progress: "Yeah, I know, I know, we're havin' a casualty."

Because the main steering gear is operated with electric motors, the ship now not only had no way to arrest its still-considerable forward motion; it also had no way to quickly change the angle of its rudder. The helm does have a manual backup system, located in a compartment called aftersteering in the stern of the ship: a worm-gear mechanism powered by two men on bicycle cranks. However, even strong men working hard with this mechanism can change the angle of the massive rudder only very slowly.

Shortly after the loss of power, the captain said to the navigator, who was the most experienced conning officer on board, "OK, Gator, I'd like you to take the conn." The navigator answered "Aye, sir" and, turning away from the captain, announced: "Attention in the pilothouse. This is the navigator. I have the conn." As required, the quartermaster of the watch acknowledged ("Quartermaster, aye") and the helmsman reported "Sir, my rudder is amidships." The navigator had been looking out over the bow of the ship, trying to detect any turning motion. He answered the helmsman: "Very well. Right 5 degrees rudder." Before the helmsman could reply, the navigator increased the ordered angle: "Increase your rudder right 10 degrees." (The rudder angle indicator on the helm station has two parts; one shows the rudder angle that is ordered and the other the actual angle of the rudder.) The helmsman spun the wheel, causing the indicator of the desired rudder angle to move to the right 10 degrees, but the indicator of the actual rudder angle seemed not to move at all. "Sir, I have no helm sir!" he reported.

Meanwhile, the men on the cranks in aftersteering were straining to move the rudder to the desired angle. Without direct helm control, the conning officer acknowledged the helmsman's report and sought to make contact with aftersteering by way of one of the phone talkers on the bridge: "Very well. Aftersteering, Bridge." The navigator then turned to the helmsman and said "Let me know if you get it back." Before he could finish his sentence, the helmsman responded, "I have it back, sir." When the navigator acknowledged the report, the ship was on the right side of the channel but heading far to the left of the desired course. "Very well, increase your rudder to right 15." "Aye sir. My rudder is right 15 degrees. No new course given." The navigator acknowledged—"Very well"—and then, looking out over the bow, whispered "Come on, damn it, swing!" Just then, the starboard wing pelorus operator spoke on the phone circuit: "John, it looks like we're gonna hit this buoy over here." The bearing recorder had been concentrating on the chart and hadn't quite heard. "Say again" he requested. The starboard wing pelorus operator leaned over the railing of his platform to watch the buoy pass beneath him. It moved quickly down the side of the ship, staying just a few feet from the hull. When it appeared that the *Palau* would not hit the buoy, the starboard wing pelorus operator said "Nothin'"; that ended the conversation. The men inside never knew how close they had come. Several subsequent helm commands were answered with "Sir, I have no helm." When asked by the captain how he was doing, the navigator, referring to their common background as helicopter pilots, quipped "First time I ever dead-sticked a ship, captain." (To "dead-stick" an aircraft is to fly it after the engine has died.) Steering a ship requires fine judgements of the ship's angular velocity. Even if helm response was instantaneous, there would still be a considerable lag between the time a helm command was given and the time when the ship's response to the changed rudder angle was first detectable as the movement of the bow with respect to objects in the distance. Operating with this manual system, the navigator did not always know what the actual rudder angle was, and could not know how long to expect to wait to see if the ordered command was having the desired effect. Because of the slowed response time of the rudder, the navigator ordered more extreme rudder angles than usual, causing the *Palau* to weave erratically from one side of the channel to the other.

Within 3 minutes, the diesel-powered emergency generators were brought on line and electrical power was restored to vital systems throughout the ship. Control of the rudder was partially restored, but remained intermittent for an additional 4 minutes. Although the ship still could not control its speed, it could at least now keep itself in the dredged portion of the narrow channel. On the basis of the slowing over the first 15 minutes after the casualty, it became possible to estimate when and where the *Palau* would be moving slowly enough to drop anchor. The navigator conned the ship toward the chosen spot.

About 500 yards short of the intended anchorage, a sailboat took a course that would lead it to cross close in front of the *Palau*. Normally the *Palau* would have sounded five blasts with its enormous horn to indicate disagreement with the actions taken by the other vessel. However, the *Palau*'s horn is a steam whistle, and without steam pressure it will not sound. The Navigation Department has among its equipment a small manual foghorn, basically a bicycle pump with a reed and a bell. The navigator remembered this piece of gear and instructed the keeper of the deck log to leave his post, find the manual horn, descend two levels to the flight deck, take the horn out to the bow, and sound the five warning blasts. The keeper of the deck log ran from the pilothouse, carrying a walkie-talkie to maintain communication with the bridge. The captain grabbed the microphone for the flight deck's public address system and asked "Can you hear me on the flight deck?" Men below on the deck turned and waved up at the pilothouse. "Sailboat crossing *Palau*'s bow be advised that I am not . . . I have no power. You cross at your own risk. I have no power." By this time, the hull of the sailboat had disappeared under the bow of the ship and only its sails were visible from the pilothouse. In the foreground, the men on the flight deck were now running to the bow to watch the impending collision. Meanwhile, the keeper of the deck log had run down two flights of stairs, emerged from the base of the island, and begun sprinting across the nearly 100 yards that lay between the island and the bow. Before he was halfway to his goal, it was clear that by the time he would reach the bow the signal from the horn would be meaningless. The navigator turned to a junior officer who was holding a walkie-talkie and exclaimed "Just tell him to put the sucker down and hit it five times!" The message was passed, and the five feeble blasts were sounded from the middle of the flight deck. There is no way to know whether the signal was heard by the sailboat, which by then was directly ahead of the *Palau* and so close that only the tip of its mast was visible from the pilothouse. A few seconds later, the sailboat emerged, still sailing, from under the starboard bow. The keeper of the deck log continued to the bow to take up a position there in case other warnings were required.

Twenty-five minutes after the engineering casualty and more than 2 miles from where the wild ride had begun, the *Palau* was brought to anchor at the intended location in ample water just outside the bounds of the navigation channel.

The safe arrival of the *Palau* at anchor was due in large part to the exceptional seamanship of the bridge crew, especially the navigator. But no single individual on the bridge acting alone—neither the captain nor the navigator nor the quartermaster chief supervising the navigation team—could have kept control of the ship and brought it safely to anchor. Many kinds of thinking were required to perform this task. Some of them were happening in parallel, some in coordination with others, some inside the heads of individuals, and some quite clearly both inside and outside the heads of the participants.

This book is about the above event and about the kind of system in which it took place. It is about human cognition—especially human cognition in settings like this one, where the problems that individuals confront and the means of solving them are culturally structured and where no individual acting alone is entirely responsible for the outcomes that are meaningful to the society at large.

Gaining access to this field site required me, as an ethnographer, to make three journeys at once. In this first chapter I will try to weave them together, for the reader will also have to make these journeys mentally in order to understand the world of military ship navigation. The first is a journey through physical space from my home and my usual workplace to the navigation bridge of the *Palau*. This journey took me through many gates, as I moved from the street to the military base, to the ship, and within the ship to the navigation bridge. I will try to convey the spatial organization of the setting in which navigation is performed. The second journey is a trip through social space in which I moved from the civilian social world past the ship's official gatekeepers into the social organization of the Navy, and then to the ship's Navigation Department. This journey closely parallels the journey through physical space because space is so often used as an element of social organization. As the spatial journey took me to regions with narrower and narrower boundaries, so the social journey leads us through successively narrower levels of social organization. The third journey is a movement through conceptual space, from the world of everyday spatial cognition into the technical world of navigation. This third journey does not really begin until I near the end of the other two.

Through the Main Gate

A crisp salute from a young marine in dress uniform at the main gate's guard shack marked the transition from the "street" to the "base"—from the civilian realm to the military. The base is a place of close-cropped haircuts and close-cropped lawns. Here nature and the human form are controlled, arranged, disciplined, ready to make a good impression. The boot camp inductee's credo is "If it moves, salute it. If it doesn't move, pick it up. If you can't pick it up, paint it white." The same mindset imposes an orderliness and a predictability on both the physical space and the social world of the military base.

As a civilian employee of the Navy, I was encouraged to occasionally ride a ship in order to better understand the nature of the "operational" world. But being encouraged by my own organization to ride a ship and being welcomed by the crew are two different things. From the perspectives of the people running a ship, there may be little to gain from permitting a civilian on board. Civilians, who are often ignorant of shipboard conventions, may require some tending to keep them out of trouble. They take up living space, which on many ships is at a premium, and if they do not have appropriate security clearances they may have to be escorted at all times.

The Ship

The *Palau* is an amphibious helicopter transport. Its warfare mission is to transport marines across the seas and then deliver them to the battlefields in the 25 helicopters that are carried on board. The helicopters also bring troops back to the ship, which has a small hospital and a complete operating theater. Ships of this class are often mistaken for true aircraft carriers of the sort that carry jet planes. As is the case with true aircraft carriers, the hull is capped by a large flat flight deck which creates an overhang on all sides of the ship. But this flight deck is only 592 feet long, just over half the length of a carrier deck and much too small to handle fixed-wing jets. About halfway between the bow and the stern, jutting up out of the smooth expanse of the flight deck on the starboard rail, stands a four-story structure called the island. The island occupies the rightmost 20 feet of the flight deck, which is about 100 feet wide. The ship extends 28 feet below the surface of the water and weighs 17,000 tons empty. It is pushed through the water by a single propeller driven by a 22,000-horsepower steam turbine engine.

Originally, the ships of the *Palau*'s class were planned to have been almost 200 feet longer and to have two propulsion plants and two propellers. However, budget cuts in the early 1960s led to a hasty redesign. In the original design, the off-center weight of the steel island was to be balanced by the second propulsion plant.

Unfortunately, the redesign failed to take into account the decrease in righting moment caused by the deletion of the second engine. When the hull that is now the *Palau* was launched, it capsized! It was refloated, and the steel island was replaced with an aluminum one. The ship was renamed and put into service. The aluminum island is attached to the steel deck with steel bolts. In a wet and salty environment, this forms an electrolyte that causes corrosion of the attachment points between the island and the deck. There is a standing joke among those who work in the island that someday, in a big beam swell, the ship will roll to starboard and the island will simply topple off the deck into the sea.

Two levels above the flight deck in the island is the navigation bridge. Also in the island are the air operations office, from which the helicopters are controlled, and a flag bridge where an admiral and his staff can work. The top of the island bristles with radar antennae.

The Gator Navy and the Other Navies

When I first went aboard the *Palau* it was tied up at pier 4 with several other amphibious ships. A frigate and a destroyer were tied up to an adjacent pier, but they are part of another navy within the Navy. Membership in these navies is an important component of naval identity.

Troop transport is not considered a glamorous job in the Navy. The *Palau* is part of what is called the *amphibious fleet*, the portion of the fleet that delivers marines to battlegrounds on land. The amphibious fleet is also known somewhat derogatorily as the "gator navy." The nickname is apparently derived from a reference to that amphibious reptile, the alligator. While the alligator is not a prototypical amphibian, its aggressiveness may be important in Navy culture; "salamander navy" or "frog navy" might be too disparaging.

The aviation community (the "airdales") claims to be the highest-status branch of the Navy. Most others would say that the submarine fleet (the "nukes") comes next, although the submariners consider themselves a breed apart. (They have a saying that there are only two kinds of ships in the navy: submarines and targets.) Then comes the surface fleet (the "black shoes"). Within each of these groups are subgroupings, which are also ranked. In the surface fleet the ranking descends from surface combatants (cruisers, destroyers, and frigates) to aircraft carriers, then the amphibious fleet, and finally tenders and supply ships.

While from the civilian point of view a sailor may be a sailor, in the Navy these distinctions mark important subcultural identities. The perceived differences are based on many factors, including the "glamor" of the expected mission, the sophistication of the equipment, the destructive potential, the stringency of requirements for entry into each area, the quality and extent of the training provided to the members of each community, and the general sense of the quality of the people involved. For a surface warfare officer who hopes to make a career out of the Navy and rise to a high rank, it is not good to be assigned to an amphibious ship for too long.

Ships that carry aircraft and air crewmen present a special situation with respect to these groups. Because they have aircraft they have members of the aviation community aboard, but because they are ships they must have members of the surface community aboard. The commanding officer of an aircraft carrier is always a member of the air community—a measure of the notion in the navy that the air wing is the *raison d'être* of a ship that carries aircraft. The friction between the air community and the surface community may be manifested in subtle and not-so-subtle ways. If members of the air community account for the majority of the high-ranking positions on a ship, junior surface warfare officers may complain that junior "airdales" are given more opportunities for qualification and advancement. An amphibious transport with an air wing is an even more complicated situation. Here members of the surface and air groups interact. And when marines are aboard an amphibious ship, there is also sometimes friction between the sailors and the marines.

These patterns of differentiation are present at all levels of organization in the military, from the broadest of interservice rivalries to distinctions between the occupants of adjacent spaces on the ship. Such effects are present to some degree in many social organizations, but they are highly elaborated in the military. Much of the establishment of identity is expressed in propositions like this: "We are the fighting X's. We are proud of what we are and what we do. We are unlike any other group." The unspoken inference is "If you do something else, you cannot be quite as good as we are." Identities are also signaled by insignia and emblems of various kinds. In the officer ranks, breast insignia denote which navy one is in. Aviators wear wings, submariners wear dolphins, surface warfare officers wear cutlasses.

Within each part of the surface fleet, there are strong identities associated with specific ships. Ships have stirring nationalistic or patriotic mottoes, which are often inscribed on plaques, baseball caps, t-shirts, and coffee mugs. Many ships produce yearbooks. The bond among shipmates is strongest when they are off ship. There is less of an identification with the class of one's ship, but some classes of ship are considered more advanced (less obsolete) and more glamorous than others.

The military institutionalizes competition at all levels of organization. Individuals compete with one another, and teams of individuals are pitted against other teams. Ships compete in exercises, and branches of the military compete for funding and the opportunity to participate in combat. Aboard a ship this competitiveness manifests itself in a general opinion that "we in our space know what we are doing, but the people just on the other side of the bulkhead do not." These sentiments can arise in situations where the successful completion of some task relies on cooperation between individuals in different spaces. Sometimes the larger system may fail for reasons having to do with the interactions of the units rather than with any particular unit; still, each unit needs to attach blame somewhere, and the alleged incompetence of some other unit is the easiest and most understandable explanation.

Across the Brow

A sailor standing outside a guard shack glances at the identification badge of each person passing onto the pier. Walking onto a pier between two ships of the *Palau*'s class is like walking into a deep canyon with overhanging gray walls and a dirty concrete floor. The canyon is vaguely threatening. It is noisy, and the hulls of the ships seem to box in the whine of motors and the hiss of compressed air. There are trucks and cranes on the pier, and cables are strewn across the pier and suspended in space over the narrow band of greenish water between the pier and the hulls. Floating in the water between each ship and the pier are several crude rafts called "camels" and a work barge. The camels keep the hull of the ship far enough away from the pier so that the broad flight deck flaring out at the top of the hull does not overhang the pier.

To board the *Palau*, I climbed a sort of scaffold up a few flights of gray metal stairs to a gangplank (in Navy parlance, the *brow*) that reached from the top of the scaffold to a huge hole in the side of the ship. The hole was at the level of the hangar deck (also called the *main deck*), still several levels below the flight deck. At the top of the brow was a security desk where the officer of the deck (OOD) checked the identification cards of sailors departing from and returning to the ship. Sailors stepping aboard turned to face the stern of the ship, came to attention and saluted the ship's ensign (flag), which flew on a staff over the fantail and was thus not visible from the brow.

Before visiting the ship, I had been given the NPRDC Fleet visitor's guide of basic information, which included the following instructions for proper performance of the boarding ritual: "At the top of the brow or accommodation ladder, face aft toward the colors (national ensign) and pause at attention. Then turn to the OOD, pause briefly at attention, and say, 'Request permission to come aboard, Sir.' State your name, where you are from, the purpose of your visit and the person you wish to see." This little ritual is a symbolic pledge of allegiance to the ship before boarding. Visitors to the ship wait in limbo at the security desk, neither ashore nor officially aboard, while word of their arrival is sent to their onboard host. The actual permission to go aboard must have been arranged in advance.

The ship's official gatekeeper is normally the executive officer (abbreviated XO). The commanding officer, the executive officer, and the department heads form the primary administrative structure of the ship. Every ship in the Navy is organized into a number of departments. Each department is supervised by an officer. In large departments, the department head may supervise less senior officers, who in turn supervise the enlisted personnel who do virtually all the actual work on the ship. Before embarking, I was required to convince the XO that I had something to offer the navy and that I would not cause undue aggravation while aboard. In a brief and somewhat discouraging interview with the XO, it was agreed that if the navigator was willing to tolerate my presence in his department, I could come aboard and work with the navigation team.

After getting past the XO, I made a date to have lunch with the navigator. I met him in the officer's dining area (the *wardroom*), and during our discussion we discovered a shared past. While a cadet at the Naval Academy, the navigator had served as racing tactician aboard a particular racing sloop that had been donated to the academy. The sloop was subsequently sold to a friend of mine, and I had sailed aboard it as navigator and racing tactician for 8 years. The discovery of this extraordinary coincidence helped cement our friendship and secured the navigator's permission for my work aboard the *Palau*. With my prearranged permission to sail, and with the navigator's blessing, I waited at the security desk.

An escort at the security desk led me through the huge dark cavern of the hangar deck. We detoured around several parked helicopters and skirted forklifts and pallets of materials. We ducked through a hatch in the wall of the hangar deck and began the climb up a series of narrow steep ladders to the navigation bridge. (On a ship, floors are called *decks*, walls are called *bulkheads* or *partitions*, corridors are called *passageways*, ceilings are called *overheads*, and stairs are called *ladders*.)

Reconciling the Chart and the World

Navigation is a collection of techniques for answering a small number of questions, perhaps the most central of which is "Where am I?"

What does the word 'where' mean in this question? When we say or understand or think where we are, we do so in terms of some representation of possible positions. "Where am I?" is a question about correspondences between the surrounding world and some representation of that world.

Where am I right now as I write this? I am at my desk, in my study. The window in front of me faces the garden; the door over there leads to the hallway that leads to the remainder of the house. My house is on the Pacific coast, north of the university. I'm on the western edge of the North American continent. I'm on the planet Earth circling a minor star in the outer portion of an arm of a spiral galaxy. In every one of these descriptions, there is a representation of space assumed. Each of these descriptions of my location has meaning only by virtue of the relationships between the location described and other locations in the representation of space implied by the description. This is an absolutely fundamental problem that must be solved by all mobile organisms.

Whether the map is internal or external, whether it is a mental image of surrounding space (on whatever scale and in whatever terms) or a symbolic description of the space on a piece of paper, I must establish the correspondence of map and territory in order to answer the question "Where am I?" One of the most exciting moments in navigation is making a landfall on an unfamiliar coast. If I am making a landfall on a high island or a mountainous coast, as I approach the land, I first see just the tops of mountains, then I see the lower slopes, then the hills, and finally the features on the shoreline itself. Now, where am I? Turning to my chart, I see that I had hoped to meet the coast just to the south of a major headland. Perhaps that big hill I can see across the water on the left is that headland. And perhaps that high peak off in the haze, inland, is this peak shown on the chart. Hmm, according to the chart it is only supposed to be 500 meters high. It seems far away and higher than that. Perhaps it is something else, something too far inland to be printed on the chart.

Through considerations like these, a navigator attempts to establish a coherent set of correspondences between what is visible in the world and what is depicted on a chart. Some charts even provide small profiles showing the appearance of prominent landmarks from particular sea-level vantage points. The same sort of task confronts any of us when, for example, we walk out of the back door of a theater onto an unfamiliar street. Which way am I facing? Where am I? The question is answered by establishing correspondences between the features of the environment and the features of some representation of that environment. When the navigator is satisfied that he has arrived at a coherent set of correspondences, he might look to the chart and say "Ah, yes; I am here, off this point of land." Now the navigator knows where he is. And it is in this sense that most of us feel we know where we are. We feel that we have achieved a reconciliation between the features we see in our world and a representation of that world. Things are not out of place. They are where we expect them to be. But now suppose someone asks a navigator "How far are we from the town at the head of that bay?" To answer that question, simply having a good sense of the correspondences between what one sees and what is depicted on some representation of the local space is not enough. Now more precision is required. To answer that question the navigator needs to have a more exact determination of where he is. In particular, he needs to have a sense of his location on a representation of space in a form that will permit him to compute the answer to the question. This is *position fixing*. It is what one does when just having a sense of reconciliation between the territory and the map is not enough.

Up the Ladder

From the hangar deck the escort led the way up three steep ladders in a narrow stairwell filled with fluorescent light, stale air, and the clang of hard shoes on metal steps. The decks of a ship are numbered starting with the main deck. On most ships, the main deck is defined as the "uppermost deck that runs the length of the ship." On ships that have a flight deck above a hangar deck (this includes aircraft carriers and amphibious helicopter transports such as the *Palau*) the hangar deck is the main deck. Immediately below the main deck is the second deck, and below that the third deck, and so on down to the hold. Above the main deck, the decks are designated "levels" and are numbered 01, 02, . . . , increasing in number with altitude. We stopped periodically on deck platforms to allow sailors going down to pass. Foot traffic on ships generally moves up and forward on the starboard side and down and aft on the port side. However, the layout of the hangar deck limits the number and location of ladders, and in order to shorten the route my escort was taking me against the traffic. We climbed into a small busy foyer, and through an open hatch I caught a breath of fresh air and a glimpse of the flight deck in the sun. Men in overalls were working on the hot, rough black surface. We continued upward, now climbing inside the narrow island. One ladder pitch above the flight deck we came to the 04 level. The door leading to the flag bridge, where an admiral and his staff would work, was chained and padlocked. One more ladder brought us to the 05 level.

Military Identities

The men and women in the military are divided into two broad social classes: *officer* and *enlisted*. An officer must have a college degree and is *commissioned* (authorized to act in command). In the Navy, members of both classes believe in the reality of differences between officers and enlisted personnel. The lowest-ranking officer is superior in the command structure to the highest-ranking enlisted person. The distinction between officers and enlisted is marked by uniforms, by insignia, and by a complex set of rituals. The simplest of these rituals is the salute, of course, but the courtesies to be extended by enlisted to officers include clearing a passageway on the approach of an officer and refraining from overtaking an officer on foot until permission has been granted.

Enlisted Rates and Ratings

Enlisted personnel are classified according to pay grade (called *rate*) and technical specialization (called *rating*). As Bearden and Wedertz (1978) explain: "A rating is a Navy job—a duty calling for certain skills and attitudes. The rating of engineman, for example, calls for persons who are good with their hands and are mechanically inclined. A paygrade (such as E-4, E-5, E-6) within a rating is called a rate. Thus an engineman third class (EN3) would have a rating of engineman, and a rate of third class petty officer. The term petty officer (PO) applies to anyone in paygrades E-4 through E-9. E-1s through E-3s are called non-rated personnel."

The enlisted naval career begins with what is basically a socialization period in which the recruit is indoctrinated into basic military policy and acquires the fundamental skills of a sailor. The rates through which a recruit passes in this phase are seaman recruit, seaman apprentice, and able-bodied seaman. Once socialized, a seaman learns the skills of a particular job specialization or rating. An enlisted person is considered a real member of a rating when he becomes a petty officer (see below). The enlisted personnel in the Navigation Department are members of the quartermaster rating. They have an insignia (a ship's wheel) and an identity distinct from other ratings. They are generally considered to be relatively intelligent, although not as smart as data processing specialists. For enlisted personnel, rating insignia denote occupational fields.

A petty officer is not a kind of commissioned officer (the type of officer referred to by the unmarked term 'officer'); the label 'petty officer' simply designates an enlisted person who is a practicing member of some rating. There are two major levels of petty officer, with three rates within each. One moves through the lowest of these levels while learning the skills of the speciality of the rating. One advances through petty officer third class, petty officer second class, and petty officer first class. A petty officer third class is a novice in the speciality and may perform low-level activities in concert with others or more autonomous functions "under instruction." A petty officer first class is expected to be fully competent in the rating.

The next step up in rank moves one to the higher of the enlisted rates and is usually the most important transition of an enlisted person's career. This is the move to chief petty officer (CPO). This change in status is marked by a ritual of initiation which is shrouded in secrecy. Just what happens at a chief's initiation is supposed to be known only by chiefs. However, much of what happens apparently makes for such good story telling that it cannot be kept entirely in confidence. It is "common knowledge" that these initiations frequently include hazing of the initiate, drunkenness, and acts of special license. Making chief means more than getting a bigger pay packet or supervising more people. Chiefs have their own berthing spaces (more private that general enlisted berthing) and their own mess (eating facility). On many ships the chief's mess is reputed to be better than that of the officers. Chiefs are also important because they are the primary interface between officers and enlisted personnel. Since they typically have from 12 to 20 years of experience in their speciality, they often take part in problem-solving sessions with the officers who are their supervisors. Some chief petty officers have a considerable amount of autonomy on account of their expertise (or, perhaps, their expertise relative to the supervising officer.) Chiefs frequently talk about having to "break in" a new officer, by which they mean getting a supervising officer accustomed to the fact that the chief knows more than the officer does and is actually in charge of the space and the people in it. Officers who directly supervise lower-level enlisted personnel risk undermining the chain of command and incurring the resentment of a chief who feels that his authority has been usurped. Once one has made chief, there are still higher enlisted rates to be attained. After approximately 20 years of service a competent person may make senior chief, and after perhaps 25 years of service (being now of about the same age as a captain) one may make master chief. That is normally the end of the line for an enlisted person. There are, however, some ranks that fall between enlisted and officer. A chief may elect to become a chief warrant officer or a limited duty officer (LDO). A chief who becomes an LDO is commissioned as an ensign and may begin to rise through the officer ranks. Few chiefs take this path. As one senior chief asked rhetorically, "Why would I want to go from the top of one career to the bottom of another?"

While an enlistee may have preferences for certain ratings, the choice of a rating is not entirely up to the enlistee. Aptitude-test scores are also used to place people in various specialities. The fact that people are screened contributes to widely held stereotypes concerning the intelligence of those in various ratings. For example, boiler technicians (BTs) and machinist's mates (MMs), who run a ship's propulsion plant and who may go weeks without seeing the light of day, are often the butt of jokes about their low intelligence. Data processing specialists, on the other hand, are generally thought to be bright. The ship, as a microcosm, manifests the same patterns of competing identities that are seen among the specialties in the Navy as a whole. From the point of view of the bridge personnel there may be little apparent difference between machinist's mates and boiler technicians, but down in the propulsion spaces the perceived differences are many. Machinist mates call boiler technicians "bilge divers," while boiler technicians call machinist's mates "flange heads." Mostly, this is good-natured teasing; name calling is a way of asserting one's own identity.

At all levels of organization we see attempts to establish identity by distinguishing oneself from the other groups. This is relevant to the discussion that follows because the dynamics of the relationships among the people engaged in the task of navigation are in part constrained by these identities.

Officer Ranks

Military officers are managers of personnel and resources. In general, their job is not to get their hands dirty, but to ensure that those who do get their hands dirty are doing the right things. Unlike enlisted persons, officers do not have narrowly defined specialities. An officer pursues a career in one of the broad areas described above: air, surface, or submarine warfare. Within that area, there are subspecialties such as engineering and tactics.

Officers are initially commissioned as ensigns. Ensigns have a tough lot. They are more visible than the lowest enlisted rates, and they certainly are given more responsibility, but often a "fresh-caught" ensign knows little more about the world of the ship than the seaman recruit.

Finding One's Way Around a Ship

A ship is a complicated warren of passages and compartments. Every frame and compartment is numbered with a code that indicates which deck it is on, whether it is to port or starboard of the centerline, and where it is in the progression from stem to stern. Navigating inside a ship can be quite confusing to a newcomer. Inside the ship, the cardinal directions are forward and aft, port and starboard, topside and below, and inboard and outboard; north, south, east and west are irrelevant. On large ships, orientation can be a serious problem. In the early 1980's the Navy sponsored a research project to work on wayfinding in ships.

The ship is composed of a number of neighborhoods. Some are workplaces, some are residential. Some are officially dedicated to recreation, others are unofficially recreational. The fantail on some classes of ships, for example, is a place to hang out. Officers' accommodations and eating facilities are in a section of the ship called "officer country." The chief petty officers have a similar area, called "CPO country." Enlisted personnel are supposed to enter these areas only when they are on official business. They are supposed to remove their hats when entering any compartment in these neighborhoods. Some passageways inside the ship are major thoroughfares; others are alleys or culs-de-sac. A visitor quickly learns to search out alternative pathways, because corridors are frequently closed for cleaning or maintenance.

On the 05 Level

As my escort and I arrived at a small platform on the 05 level, to the right was a floor-to-ceiling partition painted flat black. Behind the partition stood an exterior doorway that led out to the starboard wing bridge. The partition forms a "light trap" that prevents light from leaking out at night when the ship is running dark. To the left was a dark corridor that led to a similar doorway on the port side of the island. Above us, the ladder continued upward one more level to the signal bridge. Ahead lay a narrow passageway. Forward along the left side of the passageway were two doors. Behind the first was the captain's at-sea cabin. He has a nicely appointed quarters below, but he takes meals and sleeps in this cabin during operations that require him to stay near the bridge. The next door opened on the charthouse. At the end of the passageway, about 25 feet away, was a door that led to the navigation bridge or pilothouse.

The charthouse is headquarters for the Navigation Department. This small room, crowded with navigation equipment, two desks, a safe, and a chart table, enjoys a luxury shared by only a few spaces on the ship: a single porthole through which natural light may enter and mix with light from the fluorescent lamps overhead. The charthouse is one of several spaces under the control of the Navigation Department. Navigation personnel not only work in these spaces, they are also responsible for keeping them clean. Since the bridge is one of the main work areas of the ship's captain, it is thought to be especially important to keep it looking nice. While in port, Navigation personnel polish the brass on the bridge. Because the captain's at-sea cabin is adjacent to the charthouse, members of the Navigation Department tend to work more quietly there than they might in other parts of the ship. Since the average age of a sailor is under 20 years, a certain amount of playful horsing around is expected in many parts of the ship, but is not tolerated on the 05 level.

The Navigation Department is responsible for all of the spaces on the 05 level with the exception of the captain's at-sea cabin. It is also responsible for the secondary or auxiliary conning station ("Secondary Conn")—a completely redundant navigation bridge located in the bow, just under the forward edge of the flight deck. Secondary Conn is manned by the ship's executive officer and a complete navigation team whenever the ship is at general quarters (battle stations). This is done because the primary navigation bridge in the island is very vulnerable if the ship comes under attack. Modern anti-ship missiles home in on electromagnetic radiation. Because the radar antennae on the top of the island are the principal sources of such radiation on the ship, the island is the most likely part to be hit by a missile. If the primary navigation bridge is destroyed, the ship can be controlled from Secondary Conn under the command of the executive officer. Secondary Conn is a space assigned to the Navigation Department and is a duty station for Navigation personnel, but it will be of little interest to us with regard to the normal practice of navigation. The ship's extensive library of charts and navigation forms is stored in this space.

The Navigation Department is supervised by the Navigator. At the time the observations reported here were made, the *Palau*'s Navigation Department consisted of the Navigator and seven enlisted men. The title "Navigator" refers to the position as head of the Navigation Department rather than to the officer's technical speciality. Though it is expected that an officer who serves as Navigator aboard any ship will know enough about navigation to supervise the working of the Navigation Department, Navigators seldom do any navigating themselves.

The work of the Navigation Department is carried out by enlisted personnel of the quartermaster rating under the direction of the Assistant Navigator (a quartermaster chief).

Navigating Large Ships

While a naval vessel is underway, a plot of its past and projected movements is maintained at all times. Such complete records are not always kept aboard merchant vessels and are not absolutely essential to the task of navigating a ship in restricted waters. It is possible for an experienced pilot to "eyeball" the passage and make judgements concerning control of the ship without the support of the computations that are carried out on the chart. Aboard naval vessels, however, such records are always kept—primarily for reasons of safety, but also for purposes of accountability. Should there be a problem, the crew will be able to show exactly where the ship was and what it was doing at the time of the mishap. Day and night, whenever a ship is neither tied to a pier nor at anchor, navigation computations are performed as frequently as is required to ensure safe navigation. During a long passage, navigation activities may be performed almost continuously for weeks or even months on end. Most of the time the work of navigation is conducted by one person working alone. However, when a ship leaves or enters port, or operates in any other environment where maneuverability is restricted, the computational requirements of the task may exceed the capabilities of any individual; then the navigation duties are carried out by a team.

The *conning officer* is nominally responsible for the decisions about the motion of the ship, but for the most part he does not make the actual decisions. Usually, such decisions are made by the Navigation Department and passed to the conning officer as recommendations, such as "Recommend coming right to 0 1 7 at this time." The conning officer considers the recommendation in the light of the ship's overall situation. If the recommendation is appropriate, he will act upon it by giving orders to the *helmsman*, who steers the ship, or to the *leehelmsman*, who controls the engines. At all times when the ship may have need of navigational information, someone from the Navigation Department is at work and ready to do whatever is required. The navigation team performs in a variety of configurations, with as few as one and as many as six members of the Navigation Department working together. In every configuration there is one individual, designated the *quartermaster of the watch*, who is responsible for the quality of the work performed and who serves as the department's official interface with other departments aboard ship.

Navigation is a specialized task which, in its ordinary operation, confronts a limited set of problems, each of which has a well-understood structure. The problem that confronts a navigator is usually not one of figuring out how to process the information in order to get an answer; that has already been worked out. The problem, in most instances, is simply to use the existing tools and techniques to process the information gathered by the system and to produce an appropriate evaluation of the ship's situation or an appropriate recommendation about how the ship should proceed in order to get where it is supposed to go.

The navigation activity is event-driven in the sense that the navigation team must keep pace with the movements of the ship. In contrast with many other decision-making settings, when something goes wrong aboard a ship, it is not an option to quit the task, to set it aside momentarily, or to start over from scratch. The work must go on. In fact, the conditions under which the task is most difficult are usually the conditions under which its correct and timely performance is most important.

The Researcher's Identity

Having said something about how naval personnel establish their own identities, I should also say something about how they and I negotiated an identity for me.

In the course of this work I made firsthand observations of navigation practice at sea aboard two aircraft carriers (the *Constellation* and the *Ranger*) and two ships of the amphibious fleet (the one known here as the *Palau* and the *Denver*). Aboard the aircraft carriers, I worked both on the navigation bridge and in the combat information center. I made a passage from San Diego to Seattle, with several stops, aboard the *Denver*. I also interviewed members of the Navigation Departments of five other ships (the *Enterprise*, the *Beleau Wood*, the *Carl Vinson*, the *Cook*, and the *Berkeley*) and had a number of informal conversations with other navigation personnel.

The events reported here come mainly from operations in the Southern California Operations (SoCalOps) area aboard the *Palau*. I also worked with the crew while the ship was in port. I logged a total of 11 days at sea over a period of 4 months. First came a week-long trip during which I observed the team, got the members used to my presence, and got to know them. During this trip, I only took notes and made a few still photos and audio tape recordings of navigation tasks and interviews with crewmen. On a later trip, I mounted a video camera with a wide-angle lens in the overhead above the chart table in the pilothouse. I placed a stereo tape recorder on the chart table, with one channel capturing the ambient noise and conversation of the pilothouse. The other channel I wired into the sound-powered phone circuit. Because the chief was both plotting positions and supervising the work of the navigation team, I wanted to be sure to capture what he said. I therefore wired him with a remote transmitter and a lavaliere microphone. I used this signal to feed the audio track on the video recording. Thus, I had one video track and three audio tracks to work with.

During my time at sea, I took a normal watch rotation. I appeared on the bridge on one occasion or another during every watch period, including the one from midnight to 4 a.m. I was accorded privileges appropriate to the military equivalent of my civilian Government Service rank: lieutenant commander. I was assigned a cabin in "officer country," took my meals in the officer's mess, and spent my waking off-watch time either in the charthouse with the navigation crew or in the wardroom with officers.

As to what they thought of me, one must begin with the understanding that for military folk the military/civilian distinction stands just below the friend/foe distinction as an element of the establishment of identity. A civilian aboard a ship is an outsider by definition. It was important that the navigator treated me as a colleague and friend, and that the captain normally addressed me as Doctor when we met. Many of the members of the navigation team were also aware that I had lunched at least once in the captain's quarters, an honor reserved for visiting VIPs.

Some evidence of what the crew thought of me is available in the video record. Early on, a number of nervous jokes were made on camera about the dangerous potential of the videotaping. In the first 5 minutes of videotaping with this crew, the assistant navigator told the navigator "Everything you say around me is getting recorded for history, for your court-martial."

On more than one occasion while he was away from the chart table, the chief of the navigation team explained my work to other members. He apparently forgot that he was being recorded. I discovered these comments weeks later while doing transcription. During my second at sea period, the chief went into the charthouse to check on the fathometer. The fathometer operator asked who I was. The conversation proceeded as follows:

Chief: He's studying navigation on big ships. He's the guy, he makes computer programs for teaching stuff. Like they got a big computer program thing they use in ASW school to teach maneuvering boards. It's all computerized. He is the one that makes it. He is the one who makes things like that. He's a psychologist and anthropologist. Works for the navy. He's a Ph.D. Makes all kinds of strange things.

Fathometer operator: He makes all kinds of strange money too.

Chief: Yeah, does he? He knows what he is doing. He's swift. He just sits and watches and records everything you're doing. Then he puts it all in data, then he starts putting it in a program. Figuring out what to do, I don't know.

My most intensive data collection was carried out on a four-day exercise during which the *Palau* left port, steamed around the operations area for two days, reentered port, and anchored in the harbor overnight. The next morning the ship left port again for another day of exercises. Finally, it entered port again and returned to its berth at the 32nd Street Naval Station. It was during the last entry to port that the crisis reported in the opening pages of this book occurred. The quality of the recording from the sound-powered phone circuit was poor until I discovered a better way to capture the signal on the last entry to port. The two entries to and exits from port were recorded from the time Sea and Anchor Detail was set until the navigation team stood down. This procedure produced video and audio tape recordings of about 8 hours of team activity. Additional recordings were made at various times during Standard Steaming Watch. In addition to the video and audio records, I took notes during these events of any aspects of the situation that I noticed that could not be fully captured on the tapes. Even with the wide-angle lens, the video camera captured only the surface of the chart table. This permitted me to identify features on the chart and even to know which buttons of a calculator were pressed, but it meant that many events of interest were not captured on tape because they occurred out of camera range.

Transcribing the tape recordings was a very difficult process. At times there were four or more conversations happening simultaneously in the pilothouse. To make matters worse, ships are noisy places. There are many kinds of equipment on the bridge that create background noises. The bosun's mate pipes various announcements from a station just aft and inboard of the chart table, and his whistle blowing and his public-address messages sometimes drown out all other sounds. Helicopters may be operating on the flight deck or in the air just outside the pilothouse. It was often necessary to listen to each of the three audio tracks separately in order to reconstruct what was being said, and still in many cases the full content of the tapes cannot be deciphered. Because of the placement of the microphones, however, the coverage of the verbal behavior of the members of the navigation team was uniformly good. Only rarely was it impossible to determine what was being said with respect to the navigation task.

I did much of the transcription myself, for three reasons. First, this is a technical domain with many specialized words in it. We know that hearing is itself a constructive process and that ambiguous inputs are often unconsciously reconstructed and cleaned up on the basis of context. Lacking context, other transcribers could not hear what I could hear in the tapes. For example, an untrained transcriber without expectations about what might be said during an anchoring detail transcribed "thirty fathoms on deck" as "thirty phantoms on deck." Navigationese is a foreign language to most people, and quality transcription cannot be expected from a transcriber who is not fluent in it. Second, since there were many speakers, the fact that I knew them personally helped me distinguish the identity of speakers where it was not clearly evident from the content of a statement who was speaking. Third, and most important, there is no better way to learn what is actually in a recording than to listen to it the many times that one must in order to produce a good transcription. (Over a period of about a year, one transcription assistant did develop enough familiarity with the subject to provide usable transcriptions.)

The fact that listening is reconstructive introduces the possibility of distortions in the data driven by my expectations. I will attempt to deal with that by making the ethnographic grounds for my interpretations explicit.

In the pilothouse I tried not to participate, but only observe. On only one occasion did I intervene, and that was a case in which I felt that by failing to speak I would put a number of people in serious danger. My intervention was a brief *sotto voce* comment to the navigator, who resolved the situation without indicating my role in it.

It was clear that I knew more about the theory of navigation than the members of the crew I was studying with the exception of the ship's navigator and the quartermaster chief. Of course, knowing the theory and knowing the nature of the practice in a particular setting are two quite different things. In no case did I know more about an individual's relation to the practice of navigation than that individual. Still, this is an unusual situation for an ethnographer. The web of constraints provided by cultural practices is important both to the people doing the task and to the researcher. For the performers, it means that the universe of possible activities is closely bounded by the constraints. For the researcher, the activities that are observed are interpreted in terms of their reflection of the constraints. My many years of studying and practicing navigation made me a particular sort of instrument, one in which the constraints of the domain were present. My interpretations of the actions of the members of the navigation team were informed by many of the same constraints that were guiding their behaviors. But there was more. Because I attempted to continually make these constraints explicit, and to conceive of them in a computational sense as well as in the operational sense required of the navigation team, my interpretations were not simply those of a native.

A few months of field work is, for an anthropologist, a rather a short visit. Many aspects of the military culture go unreported here because I am not confident about their organization and meaning on the basis of such a short exposure. I did have 5 years of employment as a civilian scientist working for the Navy, and that gave me many opportunities to observe aspects of military organization. The coverage of navigation practice is adequate, I think, because of the opportunity on my second at-sea period to videotape the navigation operations on the bridge.

How different would the story be if the observations had been made aboard another ship? I do not believe that the culture would permit it to be very different. The information processed by the navigation team may move more or less efficiently, and the individual quartermasters may have better or poorer relationships with one another, but the tasks remain, and the means of performing the tasks are standardized throughout the fleet. The crews of different ships may meet the requirements of navigation more or less capably, but they must nevertheless solve these particular tasks in the limited number of ways possible.

In fact, I made observations aboard several ships, and my colleague, Colleen Siefert, did so on yet another ship. The differences we observed across ships were minor. The ship Colleen observed had more quartermasters available and was therefore able to organize its navigation team in a slightly different way; that however, does not present a challenge to my framework or to my basic descriptions of the nature of the cognition at either the individual or the group level.

On the Bridge: Standard Steaming Watch

At the forward end of the 05 level's passageway is the door to the navigation bridge or pilothouse. It is here that the most important part of the navigation work is done. The pilothouse occupies the forward 18 feet of the 05 level of the island (see figure 1.1). Outward-canting windows extend from chest height to the overhead on both sides and the front of the pilothouse. The windows on the port side and forward overlook the flight deck. All work tables are mounted on substantial bases on a light greenish linoleum floor. The walls, the cabinets, and the equipment stands are thickly coated in light gray paint. The overhead is flat black and tangled with pipes and cables, their identities stenciled on them in white. The polished brass of ship's wheel and the controls for the engine-order telegraph stand out in the otherwise drab space.

The activities of the Navigation Department revolve around a computational ritual called the *fix cycle*. The fix cycle has two major parts: determining the present position of the ship and projecting its future position. The fix cycle gathers various bits of information about the ship's location in the world and brings them together in a representation of the ship's position. The chart is the positional consciousness of the ship: the navigation fix is the ship's internal representation of its own location.

When I first made it known to a ship's navigator that I wanted to know how navigation work was performed, he referred me to the Navigation Department Watch Standing Procedures, a document that describes the watch configurations. "It's all in here," he said.

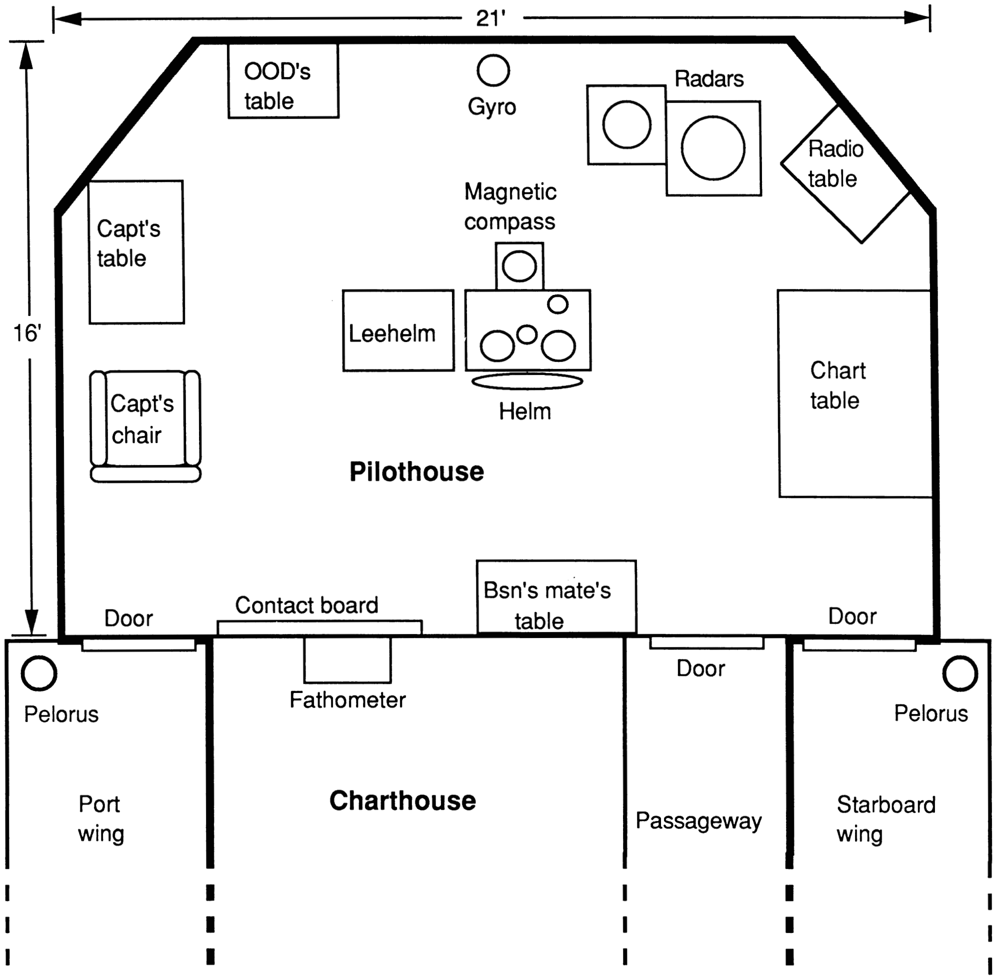

Figure 1.1 A plan view of the pilothouse and the charthouse. The members of the navigation team do most of their work at the chart table, on the wings, and in the charthouse. The heavy line represents the exterior skin of the ship. Up in the diagram is forward on the ship.

"You can read this and save yourself the trouble of standing watch." Of course it is not all in there, but the normative description in the Procedures is not a bad place to start. It is the Navigation Department's "official" version of the organization of its work. This document is one of many symbolic forms in which navigators "represent themselves to themselves and to one another" (Geertz 1983).

Because the procedures refer to objects and places that are part of shipboard navigation culture, understanding these procedures will require us to explore the environment of navigation. While conducting this exploration, we should keep in mind that the descriptions of navigation work that appear in a ship's documents and in various navigation publications must be taken as data rather than analysis.

In this section I will attempt to use the ship's documents as a guide to the task of navigation. The specifications presented in the Watch Standing Procedures describe actions to be taken and equipment and techniques to be used. First I will present the normative descriptions and try to provide the sort of background information that might be provided by a native of the navigation culture, in the hope that this will make these things meaningful to a reader who is not a practitioner of the art. Later I will present an analysis of the procedures, tools, and techniques that will be grounded in information-processing theory rather than in the world of ship navigation.

The *Palau*'s normal steaming watch procedures are introduced as follows:

> While in normal steaming condition at sea, the following watch procedures will be adhered to as closely as possible, modified as necessary by situations beyond the control of the watch stander.

In normal steaming, a single quartermaster is responsible for all the navigation duties. The procedures described in the document are taken seriously, although it is recognized that it may not be possible to execute them as described in all circumstances. The normative procedures are an ideal that is seldom achieved, or seldom achieved as described.

The Primary Duty of the QMOW

When the Navigation Department is providing navigation services to the ship, a particular quartermaster is designated as the quarter master of the watch (QMOW) at all times. According to the procedures,

> The Primary Duty of the QMOW is the safe navigation of the ship. To this end he shall:
>
> (a) Fix the position of the ship by any and all methods available.
>
> (1) All fixes will be plotted.
> (2) When information is available, a fix will be plotted at least every hour, when in open ocean transit.
> (3) When within Visual or Radar sight of land, a fix will be plotted at least every fifteen minutes.
> (i) Visual bearings will take priority.
> (ii) Fill in with Radar as necessary.
> (4) Fixes may be obtained from any combination of the following sources:
> (i) Visual bearings

(ii) Radar ranges
(iii) Radar bearings
(iv) Fathometer (line of soundings, bottom contouring, or guyout hopping)
(v) NavSat
(vi) Omega
(vii) Celestial observations

(5) Fixes obtained from visual or radar sources will consist of at least three LOPs.

(b) Project the ship's track by dead reckoning to a sufficient length of time that any danger presented to the ship from land, shoals or other fixed dangers, or violation of international waters will be noticed well in advance of the ship actually standing into danger or departing legal/assigned waters.

Items a and b in this document describe the two main parts of the fix cycle: fixing the ship's position and projecting its track. The procedures of dead reckoning will be explained in detail in chapter 2. The plotted fix is a residue on the chart of a process that gathers and transforms information about the ship's position. A succession of fixes is both a history of the positions of the ship and a history of the workings of the process that produced the position information. The requirement that *all* fixes be plotted ensures a complete history of positions and provides certain opportunities to detect and correct faults in the process that creates the history. The interval between fixes is set to 60 minutes in open waters and no more than 15 minutes when the ship is in visual or radar contact with land. Near land, the ship may stand into danger more quickly than when in the open ocean. Sailors know that it is not the open ocean that sinks ships, it's all that hard stuff around the edges. The increased frequency of fixes near land is intended to ensure that dangers are anticipated and avoided. Visual bearings are given priority because they are the most accurate means of fixing position. The potential sources of position information are listed roughly in order of their accuracy and reliability.

The procedure states that fixes may be obtained from any combination of a number of sources. Let us briefly consider the nature of these sources and the kinds of information they contribute to fixing the position of the ship.

Sources of Information for Position Fixing

VISUAL BEARINGS

The simplest way of fixing position, and the one that will concern us most in this book, is by visual bearings. For this one needs a chart of the region around the ship and a way to measure the direction (conventionally with respect to north) of the line of sight connecting the ship and some landmark on the shore. The direction of a landmark from the ship is called the landmark's *bearing*. Imagine the line of sight in space between the ship and a known landmark. Although we know that one end of the line is at the landmark and we know the direction of the line, we can't just draw a line on the chart that corresponds to the line of sight between ship and landmark, because we don't know where the other end of the line is. The other end of the line is where the ship is, and that is what we are trying to discover.

Suppose we draw a line on the chart starting at the location of the symbol for the landmark on the chart and extend it past where we think the ship is—perhaps off the edge of the chart if we are really unsure. We still don't know just where the ship is, but we do know it must have been somewhere on that line when the bearing was observed. Such a line is called a *line of position* (LOP). If we have another line of position, constructed on the basis of the direction of the line of sight to another known landmark, then we know that the ship is also on that line. If the ship was on both of these lines at the same time, the only place it can have been is where the lines intersect. The intersection of two lines of position uniquely constrains the location from which the observations were made. In practice, a third line of position with respect to another landmark is constructed. The three lines of position form a triangle, and the size of that triangle is an indication of the quality of the position fix. It is sometimes said that the navigator's level of anxiety is proportional to the size of the fix triangle.

The observations of visual bearings of the landmarks (direction with respect to north) are made with a special telescopic sighting device called an *alidade*. The true-north directional reference is provided by a *gyrocompass* repeater that is mounted under the alidade. A prism in the alidade permits the image of the gyrocompass's scale to be superimposed on the view of the landmark. (The view through such a sight is illustrated in figure 1.2.) The gyrocompass repeaters are located on the wings outside the bridge. Each one is mounted on a solid metal stand just tall enough to extend above the chest-high metal railing that bounds the wing.

The most direct access to the port wing from the chart table is through a door at the back of the pilothouse just behind the captain's chair. In cold weather, the captain of the *Palau* does not permit traffic through this door. The only other way to get from the

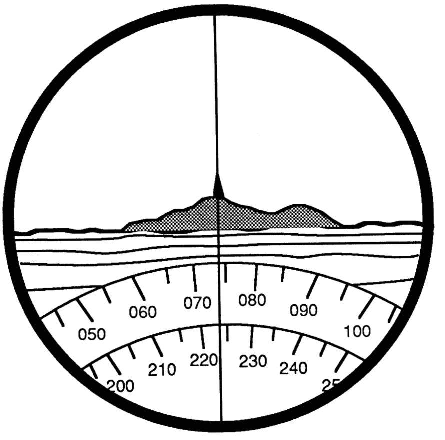

Figure 1.2 A view through an alidade. A prism inside the alidade superimposes the images of two compass scales onto whatever is seen through the telescopic sight. The inner scale is a gyrocompass repeater; the outer scale is fastened to the ship and indicates bearings relative to the ship's head.

port wing position to the chart table is to go aft on the wing to the hatch that leads to the island stairwell and then come forward through the interior passageway past the captain's at-sea cabin and the charthouse. This makes it difficult to get bearings sometimes, because it takes a long time to go around the entire 05 level.

RADAR

Radar also provides information for position fixing. The radar antenna on the ship's mast transmits pulses of radiomagnetic energy as it rotates. When the pulse strikes a solid object, the pulse reflects off the object. Some of that reflection may return to the radar antenna that transmitted it. By measuring the time required for the pulse to travel to the object and return, the radar can compute the distance to the object. This distance is called the *range* of the object. The direction in which the antenna is pointing when the reflected pulse returns gives the bearing of the object.

Radar ranges are more accurate than radar bearings, so they are given priority in position plotting. In practice, radar ranges plotted as circles of position are often combined with visual bearings to produce position fixes. The surface search radar displays are located at the front of the pilothouse on the starboard side. Each is equipped with a heavy black rubber glare shield that improves the visibility of the display in high ambient light. This glare shield prevents two or more people from looking at the scope at the same time. The surface search radar also has non-navigational uses. The officer of the deck may use the radar to observe and track other ship traffic. For this, a short range is usually desired. The navigation tasks often require a long range, and there is sometimes conflict between the two users of the scopes. It is not difficult to change from one range to another; however, in order to obtain the required information after changing ranges, the operator may have to wait for a full rotation of the radar antenna at the new range setting.

FATHOMETER

The fathometer is a device for measuring the depth of the water under a ship. It emits a pulse of sound and measures the time it takes the sound pulse to bounce off the sea bottom and return to the ship. The time delay is recorded by the movement of a pen across a piece of paper. The sound pulse is emitted when the pen is at the top of the paper. The pen moves down the paper at a constant speed and is brought into contact with the paper when the echo is detected. The distance the pen travels down the paper before making its mark is proportional to the time required for the echo to return, which is in turn proportional to the depth of the water. If the water is deep, the sound will take longer to return, and the pen will have traveled farther down the paper before coming into contact with it. The depth of the water can be read from the scale printed on the paper. Changing the scale of the fathometer to operate in deeper or shallower water is accomplished by changing the speed at which the pen travels. The paper is mounted on a motor drive that moves the paper to the side a small amount just before each pulse. This results in a continuous graphical record of the depth of the water under the ship.

The *Palau*'s fathometer is located in the charthouse, so the QMOW must leave the bridge to use it.

NAVSAT

Satellite navigation systems have now become commonplace. They are easy to use, and they provide high-quality position information. Their major drawback at the time this research was carried out was that with the number of navigation satellites then available the mean interval between fixes was about 90 minutes. After computing the ship's position from the reception of satellite signals, the satellite navigation system continuously updates the position of the ship on the basis of inputs from the gyrocompass (for direction) and the ship's log (for speed). The NavSat system aboard the *Palau* (located in the charthouse) was a box, about the size of a small suitcase that continuously displayed a digital readout of the latitude and longitude of the ship.

The fact that NavSat systems must update position with dead reckoning during the long wait between fixes puts NavSat near the bottom of the list of sources of information. With the implementation of the Global Positioning System (GPS), continuous satellite fixes are now available; the need for dead-reckoning updates of position has been eliminated. The military version of GPS is accurate to within less than a meter in three dimensions. The civilian versions are intentionally degraded to a considerably lower accuracy. GPS will very likely transform the way navigation is done, perhaps rendering most of the procedures described in this book obsolete.

OMEGA

Omega measures the phase difference between the arrival of signals from multiple stations. Omega was intended to provide accurate worldwide position-fixing capability. In practice it is unreliable. Whatever the source of the problems, they are perceived to be so serious that the following warning appears in the Watch Standing Manual.

CAUTION: Positions obtained from Omega are highly suspect, unless substantiated by information from another source. In recent years, a number of costly and embarrassing groundings have been directly attributable to trusting Omega. No drastic decisions are ever to be made on unsubstantiated Omega fixes without the explicit permission of the navigator.

If this system is considered to be so unreliable that it merits this strongly worded caution in the written procedures, what is it doing on the ship? I believe the answer involves an interaction of the organization of military research and funding with the development of technology. Omega is a system that not only went into service before all the bugs could be worked out, it has been overtaken by other superior technologies before the bugs could be worked out. Still, it was bought and paid for by the military, and can, on occasion, provide useful navigation information.

The *Palau*'s Omega is located in the charthouse.

CELESTIAL OBSERVATIONS

By measuring the angular distance of a star above the horizon, an observer can determine his distance from the point on the surface of the earth that the star is directly above. This point forms the center of a circle of position. In a celestial sight reduction, each observed celestial body defines a circle of position, and the vessel from which the observations were made must be located at the intersections of the circles of position. Celestial observations appear at the bottom of the list of sources of information. When properly performed, celestial observations provide fairly good position information.

There are, however, two major drawbacks to celestial observations. First, they can be performed only under certain meteorological circumstances. This makes celestial navigation hard to use and hard to teach. Several senior quartermasters have told me that they would like to teach celestial navigation on training missions in the Southern California operations area, but the combination of air pollution and light pollution (which makes the night sky bright, masking all but the brightest stars and obscuring the line of the horizon) produces very few occasions suitable for it. Second, the procedures are so computationally complex that, even using a specialized calculator, a proficient celestial navigator needs about half an hour to compute a good celestial position fix. Together these factors lead to infrequent practice of this skill. I believe that in the near future the only navigators who will know how to fix position by star sights will be those sailing on cruising yachts who cannot afford a thousand dollars for a SatNav system.

DRAI

The Dead Reckoning Analyzer Instrument (DRAI) is one of the most interesting navigational devices. A mechanical analog computer, it takes input from the ship's speed log and the gyrocompass and, by way of a system of motors, gears, belts, and cams, continuously computes changes in latitude and longitude. The output of the DRAI is expressed in the positions of two dials: one reads latitude and the other longitude. If these dials are set to the current latitude and longitude, the changes computed by the motions of the internal parts of the DRAI will move them so that their readings follow the latitude and longitude of the ship. The crew of the *Palau* claimed that when, properly cared for, the DRAI is quite accurate and reliable. Older versions of the DRAI, such as the one aboard the *Palau,* have been around since the 1940s. Newer versions that do the same computations electronically are installed on some of the newer ships.

PIT SWORD AND DUMMY LOG

The pit sword is a device that is extended through the hull and into the water to measure a ship's actual speed through the water. The pit sword extends several feet outside the hull and measures speed by measuring the water's distortion of a magnetic field. The speed signal generated by the pit sword is fed to speed indicators on the bridge and to all the automated instruments that do dead reckoning: the NavSat, the DRAI, and the inertial navigation systems (if present).

If the ship is operating in shallow water, the pit sword cannot be extended from the hull. In this case, or if for any other reason the pit sword cannot be used, the dummy log is used. When a ship is neither accelerating nor decelerating, its speed can be estimated fairly accurately from the rate of rotation of the propeller. The dummy log is a device that senses this rate and provides a signal that mimics what the pit sword would produce at the corresponding speed.

Both of these devices are remote from the location of the navigation team's normal activities. A display of speed through the water is available on the forward port side of the pilothouse, but it is rarely consulted by the navigation team.

CHRONOMETERS

Three traditional spring-driven clocks are kept in a special box in the *Palau*'s charthouse. Readings are recorded daily so that trends in the behavior of these chronometer's can be noted. These records are maintained while time signals are available on radio so that if time signals should become unavailable the behavior of the clocks will be known. If, for example, the log shows that a particular chronometer loses a second every day, that same rate of change will be assumed until more reliable time sources are restored.

The diversity of the many sources of navigation information and the many methods for generating constraints on the ship's position produces an important system property: the fact that positions are determined by combining information from multiple, sometimes independent, sources of information permits the navigation team to check the consistency of the multiple representations with each other. The probability that several, independently derived, representations are in agreement with one another and are in error is much smaller than the probability that any one representation is in error.

At the Chart Table

The previous section described the sources of information that the quartermaster of the watch may use while discharging his primary duty: ensuring the safe navigation of the ship. The information provided by these sources converges on the chart table, where positions are plotted and tracks are projected.

The Watch Standing Procedures specify additional constraints on the QMOW that bring us to other aspects of the navigation team's task setting:

The chart table and environs will be kept free of extraneous material at all times. Only the chart(s) in use, necessary publications, the logs of the watch, and necessary writing/plotting paraphernalia will be on the chart table.

The chart table is mounted against the starboard wall of the pilothouse, just under the large outward-canted windows. It is large enough for full-size navigation charts and tools—about 4 by 6 feet. Under the chart table are a number of locking drawers in which charts, publications, and plotting tools are stored. A locking cabinet for binoculars is mounted on the aft edge of the chart table.

Navigation Charts

The most important piece of technology in the position-fixing task is the navigation chart. A navigation chart is a specially constructed model of a real geographical space. The ship is somewhere in space, and to determine or "fix" the position of the ship is to find the point on the appropriate chart that corresponds to the ship's position in space. The lines of position derived from visual observations, radar bearings, radar ranges, celestial observations, and depth-contour matches are all graphically constructed on the chart. Latitude and longitude positions determined by NavSat, Omega, or Loran are plotted directly on the chart. A fix may be constructed from a combination of these types of information.

Navigation charts are printed on high-quality paper in color. Natural and "cultural" features are depicted in a complex symbology (see figure 1.3).

The *Palau* keeps an inventory of about 5400 charts depicting ports and coastlines around the world. A complete set of charts for current operations are kept on the chart table, and a second complete set in the table's drawers. The rest of the charts are kept in a chart library in Secondary Conn.

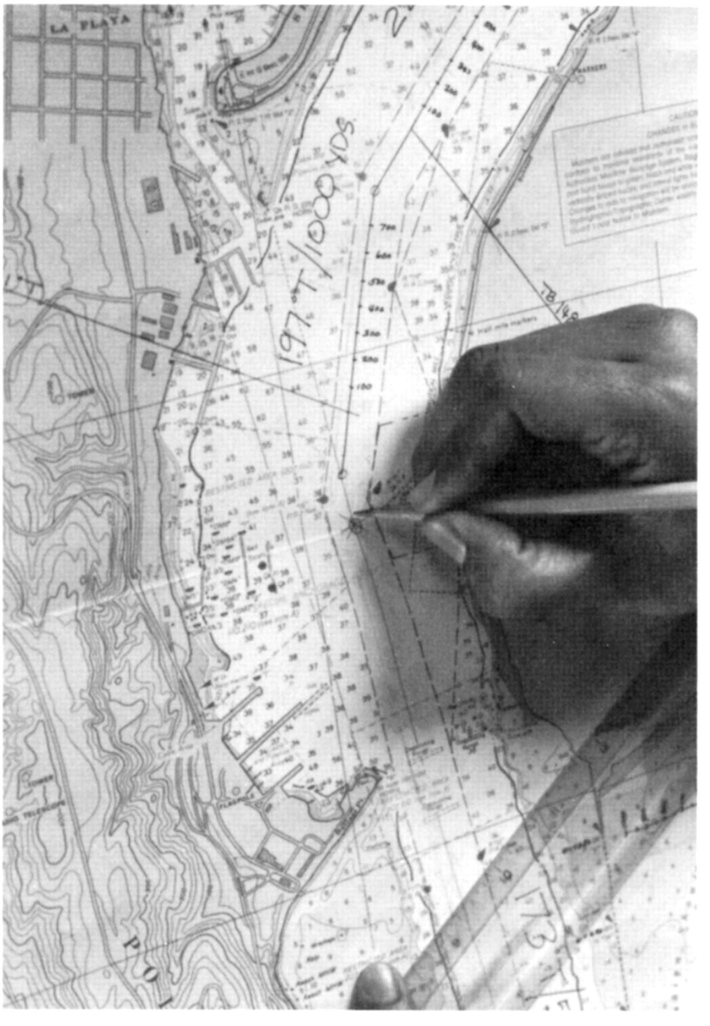

Figure 1.3 A navigation chart in use. Such a chart includes information about features both above and below the water. This chart shows the entrance to San Diego Harbor.

The Secondary Duty of the QMOW

According to the Watch Standing Procedures,

The secondary duty of the QMOW is the keeping of the logs of the watch.

Those who have experience in the merchant fleet often say that it is not necessary to do all the work of piloting in order to get a large ship into port. A good ship driver can, after all, "eyeball" the movement of the ship and get it down the channel without having positions plotted on short intervals. To say that it is possible to guide a ship down a narrow channel without maintaining the piloting record is not to say that it is easier to do it that way. Even if nothing goes wrong, the plotted and projected positions of the ship on the chart are a useful resource to the conning officer, and while it does require a navigation team to do the work of plotting positions and computing turn points, the task of the conning officer is greatly simplified by the advice he receives from the navigation team. If something does go wrong, the work of the navigation team becomes indispensable in two ways. First, depending upon what it is that goes wrong, computing the ship's position and track may become essential to the process of figuring out how to keep the ship out of trouble (see chapter 8 for an example). Second, the records kept by the navigation team—the chart, the deck log, and the bearing log—are all legal documents. If the ship is involved in a mishap, as soon as it is prudent to do so, all these documents are removed from the chart table and locked in the Executive Officer's safe. This precaution is taken to ensure that they will not be tampered with before they are turned over to a board of inquiry investigating the incident. These records may be needed to protect the navigation team, the captain, the ship, and ultimately the Navy from accusations of negligence or incompetence. The *Palau*'s Assistant Navigator offered the following justification:

You can *go into San Diego by eye. But legally, you can't. If you haven't matched all the things and something happens, not necessarily to you, it don't have to. One of those buoys can float loose in the goddamn bay and rub up along side you. Boy, you better have everything covered here, because they are going to try to hang the captain. They will try to hang him. Unless he can prove with data that everything he did was right. Now ... the merchant ship wouldn't. They would just say, "We were in the middle of the channel. The damn thing hit us, and if there is an expense, fine, charge the company."*

Other records are kept as well. There is a separate log for the gyrocompasses (with entries made twice daily), and another for the magnetic compasses. (The DRAI reading is also recorded in the magnetic compass log at the beginning of each watch.) There is yet another log for the ship's chronometers. A fathometer log is kept with the fathometer during maneuvers in restricted waters. A log of the ship's position is updated daily.

The Tertiary Duty of the QMOW

The tertiary duty of the quartermaster of the watch is "to give all possible aid to the Officer of the Deck in the conduct of his watch." The Officer of the Deck (OOD) is also normally the conning officer, although he may delegate this duty to a Junior Officer of the Deck. The importance of the relationship between the QMOW and the OOD is reflected in the following excerpt from the Watch Standing Procedures:

> The QMOW will not leave the Bridge except to take DRAI and Fathometer readings, and collect NavSat and Omega fixes as necessary. If he leaves the bridge, he will inform the OOD, and will absent himself for as short a period of time as possible. (If a Charthouse Quartermaster is assigned, there no necessity for the QMOW to leave the bridge unless properly relieved.)

The control of the ship is a partially closed information loop. The conning officer senses the ship's situation in the world by looking out the window of the bridge. The members of the navigation team also sense the world by looking at it; in addition, however, they gather information from other sources, and from that other information they synthesize a more comprehensive and accurate representation of the situation of the ship. The navigation team uses its representation to generate advice to the conning officer, who by acting (or not acting) on that advice affects the actual situation of the ship in the world which is sensed and interpreted.

The navigation team relies on the conning officer to the extent that if the conning officer turns the ship or changes its speed in other than the recommended places then the workload of the navigation team is increased. When the quartermasters project the position of the ship into the future, the projections sometimes involve changes in course and or speed. When this is the case, the projected track is carefully planned, pre-computed, and plotted. If the ship remains on the pre-computed track, many parts of the required computation will have been performed in advance. When the ship deviates from planned track, new computations may be required to establish when and where various maneuvers are appropriate. For example, on one of the *Palau*'s departures from port an inexperienced conning officer made several turns before the recommended point. This happened because the deck of the ship is so big and so high off the water that from the point of view of the navigation bridge the surface of the water for several hundred yards in front of the ship is hidden from view. When a channel is narrow and some of the turns are tight, channel buoys disappear beneath the deck before the turn is commenced. For an inexperienced conning officer, the temptation to turn before the buoy disappears under the bow is great. Once a buoy disappears beneath the deck, it is difficult to estimate whether or not the ship will hit it. To keep the ship on track, a conning officer must be disciplined and must trust the navigation team.

The conning officer has other obligations and cannot always do what is easiest for the navigation team. On one occasion the *Palau*'s engineering department detected a rumbling noise in the propeller shaft. In order to diagnose the problem, the engineers requested 5° right rudder, then 5° left rudder, then 10° right rudder followed by 10° left rudder. The ship was slaloming along through 80° turns. This happened while the ship was out of visual and radar range of land, so its position had to be maintained by dead reckoning, a very difficult task under these conditions.

THE COMBAT INFORMATION CENTER

The navigation team also coordinates its activities with the Combat Information Center (CIC), which is located below the flight deck. Duplicate position plots are maintained by the Operations Specialists (OSs) who work in CIC. They use radar bearings and ranges to fix the position of the ship. Under conditions of reduced visibility, CIC is supposed to be the primary source of navigation advice for the conning officer. The quartermaster chief in charge of the Navigation Department on the *Palau* said the following about this shift in responsibility:

They've got a whole team down there [in CIC] and they are pretty good at what they are doing. They are supposed to be like a backup on what happens up here. They've got good radars, and for reduced visibility, they are supposed to be primary. Now the only way that is going to happen is if I drop dead. As long as I am on a ship, and this is the same thing I tell my navigator, as soon as I walk on *board, "Everything that has to do with navigation while I am on board, I'm it. I'll hand you papers to sign, I'll back you up in any way you need. You will never get in trouble, navigation is my business." For OSs, it is a secondary business to them. There are people in my business who will let CIC take it. I won't.*

I never saw this claim put to the test.

AIR BOSS
The Navigation Department provides position information to the Air Boss, who is responsible for controlling the aircraft that operate from the flight deck. The most frequent requests for information from the air boss consist of position or projected position information to be used by aircraft coming to the ship, and directions and distances to land bases for aircraft departing the ship.

Sea and Anchor Detail

Guiding a large ship into or out of a harbor is a difficult task. A ship is a massive object; its inertia makes it slow to respond to changes in propeller speed or rudder position. Putting the rudder over will have no immediate effect, but once the ship has started turning it will tend to continue turning. Similarly, stopping the engines will not stop the ship. Depending on its speed, a ship may coast without power for many miles. To stop in less distance, the propeller must be turned in the reverse direction, but even this results in only a gradual slowing. Because of this response lag, changes in direction or speed must be anticipated and planned well in advance. Depending on the characteristics and the velocity of the ship, the actions that will bring it to a stop or turn it around may need to be taken tens of seconds or many minutes before the ship arrives at the desired turning or stopping point.

In order to satisfy the OOD's need for information about the location and movement of the ship when it is near hazards, the Navigation Departments of Navy ships take on a watch configuration called Sea and Anchor Piloting Detail. Piloting waters are defined as follows in the Watch Standing Procedures:

Piloting waters—within five miles of land, shoals, or hazards to navigation, or inside of the fifty fathom curve, whichever is further from land.

Restricted waters—Inside of the outermost aid to navigation or inside of the ten fathom curve, whichever is further from land.

1. When operating within Restricted Waters, the Sea and Anchor Piloting Detail will be stationed.
2. The QMOW will ensure that all members of the Sea and Anchor Piloting Detail are called at least thirty minutes prior to entering restricted waters.
3. The Sea and Anchor Piloting Detail will consist of:
    a. The Navigator
    b. The Assistant to the Navigator
    c. Navigation Plotter
    d. Navigation Bearing Recorder/Timer
    e. Starboard Pelorus Operator
    f. Port Pelorus Operator
    g. Restricted Maneuvering Helmsman
    h. Quartermaster of the Watch
    i Restricted Maneuvering Helmsman in After Steering
    j. Fathometer Operator

As long as the visibility is adequate for visual bearings, the primary work of the sea and anchor piloting detail is to fix the position of the ship by visual bearings. The pelorus operators stationed on the port and starboard wings, just outside the doors to the pilothouse, measure the bearings of specified landmarks and report the bearings to the bearing recorder/timer (henceforth referred to as "the recorder"), who records them in the bearing log. The recorder stands at the after edge of the chart table in the pilothouse. The bearing log is kept on the chart table, adjacent to the chart. The navigation plotter stands at the chart table and plots the recorded bearings as lines of position on the chart, thus fixing the position of the ship. The plotter also projects the future positions of the ship, and together with the recorder he chooses landmarks for the pelorus operators to use on future fixes. The restricted-maneuvering helmsman stands at the helm station in the center of the pilothouse and steers the ship in accordance with commands from the conning officer. In sea and anchor detail, the quartermaster of the watch is mainly responsible for maintaining the ship's log, in which all engine and helm commands and other events of consequence to the navigation of the ship are recorded. The quartermaster of the watch stands at the forward edge of the chart table and keeps the ships log on the chart table. The restricted-maneuvering helmsman is stationed in the after steering compartment, at the head of the rudder post in the stern of the ship. In case of a problem with the ship's wheel, the steering function can be taken over more directly by the helmsman in aftersteering. The fathometer operator is stationed in the charthouse, which is separated from the pilothouse by a bulkhead. The fathometer operator reports the depth of the water under the ship for each position fix. The navigator is responsible for the work of the navigation team but does not normally participate directly in that work. Aboard the *Palau*, even the supervision of the navigation team was done by the quartermaster chief, who acted as Assistant to the Navigator. If the crew had been more experienced, the Assistant to the Navigator would not have taken up a functional role in the performance of the task. Because the *Palau* was understaffed and the available personnel were inexperienced, however, the assistant to the navigator also served as navigation plotter.

Narrative: Sighting

In the late afternoon of a clear spring day the U.S.S. *Palau* completed several hours of engineering drills that left it alternately steaming in tight circles and lying dead in the water. The *Palau* had been at sea for a few days on local maneuvers and was now just south of the entrance to San Diego Harbor. The crew was anxious to go ashore, and going in circles and lying dead in the water when home was in plain sight was very frustrating. It was therefore something of a cause for celebration in the pilothouse when the engineering officer of the watch called the bridge on the intercom and said "Main engine warmed, ready to answer all bells." The officer of the deck acknowledged the ready state of the propulsion plant and advised the engineering officer to "stand by for 15," meaning that they should be prepared to respond to an order for 15 knots of speed. Shortly thereafter, the conning officer ordered the engine ahead standard speed. Pilothouse morale rose swiftly.

Quartermaster Second Class (QM2) John Silver stood at the chart table in the pilothouse. He was wearing a sound-powered telephone set (headphones and a collar-mounted microphone) that connected him to other members of the navigation team who were not in the pilothouse. When he learned that the ship would be getting underway again soon, he pressed the transmit button on his microphone and said "We're baggin' ass!"

On a platform on the starboard side of the ship, just outside the door to the pilothouse and about 50 feet above the surface of the water, Seaman Steve Wheeler had been leaning on the rail, studying the patches of foam that lay motionless next to the hull, and wondering when the engineering drills would end and the ship would move again. When he heard Silver's exclamation in his headphones, he looked up and began to scan the city skyline for major landmarks. Wheeler was the starboard pelorus operator, and it was his job to sight landmarks and measure their direction from the ship. A novice, he had done this job only once before, and was not sure how to identify all the landmarks, nor was he entirely clear on the procedure he was to perform.

Inside the pilothouse, Quartermaster Chief Rick Richards moved to the forward edge of the chart table and looked over the shoulder of QM2 James Smith as Smith recorded the conning officer's orders in the deck log. "Ahead standard, left 10 degrees rudder, come to course 3 0 5."

Chief Richards turned and leaned over the chart table with QM2 Silver. As happy as they were to be heading for their pier at last, they also knew it was time to begin the high-workload job of bringing the *Palau* into port. They examined the chart of the approaches to San Diego Harbor. Silver found the symbolic depictions of several important landmarks on the chart and used his fingers to draw imaginary lines from them to the last charted position of the ship. These imaginary lines represented the lines of sight from the ship to the landmarks. He checked the angles at which the lines intersected. Pointing to the chart, he said to Richards "How about these?" "Yeah, those are fine," the chief replied.

Silver was the navigation team's bearing recorder. It was his job to control the pelorus operators on the wings of the ship and record the measurements they made. Once Silver had chosen his landmarks, he assigned them to the pelorus operators: "Hey Steve, you'll be keeping Hotel del and Dive Tower as we go in, and John, you got Point Loma." Steve Wheeler answered "OK" and heard his opposite number on the port wing, Seaman John Painter, say "Aye."

Wheeler looked out across the water, found the conical red roofs of the Hotel del Coronado on the beach, and searched to the south along the strand for the building called the Dive Tower. There it was. Wheeler's hands were resting on the alidade that was mounted on a shoulder-high pedestal at his station. He quickly pointed the alidade in the rough direction of the Dive Tower and leaned down, pressing his right eye against the rubber eyepiece to look through the sight. He saw the beach and some low buildings back from the water's edge. He swung the sight left and then right until the Dive Tower came into view, then carefully rotated the sight on its pedestal until the vertical hairline in the sight fell right down the middle of the tower. Near the bottom of his field of view through the alidade, he could see a portion of the scale of a gyrocompass card. The hairline crossed the scale three small tick marks to the right of a large mark labeled 030. Another large tick mark, labeled 040, was still further to the right. Wheeler counted the little tick marks and noted that the the Dive Tower bore 033°.

Once Silver had assigned the landmarks to the pelorus operators, he wrote the name of each of the chosen landmarks at the head of a column in the bearing record log, which was lying on the chart table between him and the chart.

Silver kept an eye on his wristwatch. It was a digital model, and when he had come to his duty station several hours ago he had synchronized it with the ship's clock on the wall at the back of the pilothouse. Now he had taken the watch off his wrist and placed it on the chart table in front of him, just above the pages of his bearing record log. As the ship began to move and turn to its course for home, the plotter, Chief Richards, told Silver to take a round of bearings. It was 13 minutes and 40 seconds after 4 pm. Silver decided to make the official time of the next set of bearing observations 16:14, using the 24-hour notation standard in the military. He wrote "1614" in the time column of the bearing record log, and at 16:13:50 he said into his phone set: "Stand by to mark. Time 14."

Seaman Ron White sat on a high stool at the chart table, looking at the display of the fathometer. On the chart table in front of him was a depth sounder logbook. When he heard the "Stand by to mark" signal in his headset, he read the depth of the water under the ship from the display and reported on the phone circuit: "Fifteen fathoms." He then logged the time and the depth in his book. Silver recorded the depth in the bearing record log.

Out on the starboard wing, Wheeler heard the recorder say "Stand by to mark, time 14." As he made a small adjustment to bring the hairline to the center of the Dive Tower, he heard the fathometer operator report the depth of the water under the ship as 15 fathoms. The hairline now crossed the scale at 034°. Wheeler pressed the button on the microphone of his phone set and reported "Dive Tower, 0 3 4." That was a mistake. The bearing was correct; however, in his excitement Wheeler blurted out his bearing immediately after the fathometer operator's report. He was supposed to track the landmark and report its bearing only after the recorder gave a "mark" signal. The port pelorus operator noticed the mistake and barked, "He didn't say 'Mark'."

But by then it *was* time to mark the bearings. Wheeler's mistake was not a serious timing error; he was only a few seconds early. The important thing was to make the observations as close the "mark" time as was possible. Stopping to discuss the mistake would have been more disruptive than continuing on. There was no time for lessons or corrections now. The bearing recorder quickly restarted the procedure from its current state by giving the "mark" signal, acknowledging the premature bearing, and urging the pelorus operators to get on with their reports: "Mark it. I got Dive Tower, Steve. Go ahead." Silver then wrote "0 3 4" in the column labeled Dive Tower in the bearing record log.

The plotter, Chief Richards, was standing next to Silver, waiting for the bearings. He leaned across the chart table and read the bearing of Dive Tower even as Silver was writing it in the log. Silver noticed that Richards was craning his neck to read the bearing from the book. Softly he said "0 3 4" to Richards, whose face was close to his. As Richards moved away from the bearing log, he looked to the plotting tool in his hands and acknowledged: "Uh huh."

Chief Richards held in his hands a one-armed protractor called a *hoey*. The hoey has a circular scale of 180 degrees on it, and a straight-edged arm about 18 inches long that pivots in the center of the scale. It is used to construct lines on the chart that correspond to the lines of sight between the ship and the landmarks. Richards aligned the straightedge with the fourth tick mark to the right of the large mark labeled 030 on the scale of the hoey and turned a knob at the pivot point of the arm to lock its position with respect to the scale. He then laid the hoey on the chart and found the symbol on the chart that represented the Dive Tower. He put the point of his pencil on the symbol on the chart. Holding it there, he brought the straightedge up against the pencil point. Keeping the straightedge against the tip of the pencil and keeping the protractor scale further away from the charted location of the landmark than the anticipated location of the fix, Richards slid the hoey itself around on the chart until the directional frame of the protractor scale was aligned with the directional frame of the chart. The edge of the arm now lay on the chart along a line representing the line of sight from the ship to the landmark. Richards held the hoey firmly in place while he removed his pencil from the symbol for the landmark and drew a line segment along the protractor arm in the vicinity of the expected location of the ship on the chart. By drawing only the sections of the lines of position that were in the vicinity of the expected location of the ship, Richards kept the chart neat and avoided the creation of spurious triangles formed by the intersection of lines of position from different fixes.

While Chief Richards was plotting the line of position for the Dive Tower, the port wing pelorus operator reported the bearing of Point Loma. By the time Silver had acknowledged the port pelorus operator's report ("Three three nine, Point Loma"), Richards was ready for the next bearing. Because he was standing right next to Silver, he could hear everything that Silver said into his phone-circuit microphone. He could not hear what the pelorus operators or others on the circuit were saying to Silver or to one another; however, he could hear what Silver said, and he got the bearing to Point Loma by hearing Silver's acknowledgement.

While the port pelorus operator was making his report, "Point Loma, 3 3 9" and while Chief Richards was plotting Dive Tower, Seaman Wheeler swung his sight to the tallest spire of the Hotel del Coronado, aligned the hairline, and read the bearing from the scale. In his headset he heard the recorder acknowledge "Three 3 9, Point Loma." But he was trying not to listen, because he had his own numbers to report as soon as the phone circuit became quiet: "Hotel del, 0 2 4." Then he listened as the recorder acknowledged his report: "0 2 4, Hotel del." The report was heard and echoed without error, so Wheeler said no more.

About 30 seconds passed between the "Stand by to mark" signal and the acknowledgement of the third bearing. The pelorus operators relaxed at their stations for a minute or so while the bearings they had reported were processed by other members of the navigation team to determine the position of the ship at the time of the observations. The pelorus operators themselves did not know exactly what had been done with the bearings after they had reported them.

Less than 10 seconds after the acknowledgement of the last bearing, Chief Richards had his fix triangle constructed and was ready to label it with the time of the observations. He asked Silver "OK, what time was that?" Silver looked in the 'time' column of the bearing record log and replied "One 4," meaning 14 minutes after the hour.

With the fix plotted and labeled, Richards and Silver turned to the tasks of predicting the position of the ship at the time of the next fix (3 minutes hence) and deciding which course to take for the best approach to the harbor. Speaking slowly while plotting, Chief Richards said: "He's still turning. That's gonna put us about right here." He made a mark on the chart at the end of an arc he had drawn to represent the track of the ship through the turn. Silver looked at the projected position and determined that the same three landmarks used for the previous fix would be appropriate for the next fix.

At 16:16:50 Silver pressed the transmit button on his mike and said: "Stand by to mark. Time 1 7."

"Fifteen fathoms," said the fathometer operator.

Silver said "Mark it." The pelorus operators reported their bearings, and Silver read each one back.

"Point Loma, 3 3 8."

"3 3 8, Point Loma."

"Dive Tower, 0 3 5."

"0 3 5, Dive Tower."

"Hotel del, 0 2 4."

"0 2 4, Hotel del."

Chief Richards plotted the ship's position, but it was not as far along the track as he had projected it would be. Silver commented on the radius of the projected turn: "That was a big ellipse." Richards looked at the plot. "Oh, yeah," he said. "It's just that propulsion is coming up really slooooow. I only figured it to come up to 9, but it didn't even come up to 4." Both men laughed, and Silver said "Recompute." For half a minute they worked together silently, jointly redoing the computations of the speed calculation. They checked the lines of position for the new fix and measured the distance between the previous position and the latest one: 400 yards. Chief Richards shook his head and said "Four knots." Silver nodded and said "Right." Richards pointed to the projected track of the ship up the channel. "Four knots for the first 3 minutes," he said. "At this rate we better change the timing a little."

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