Appendix U: Dolphin Language & Speech[1]

by **James T. Fulton**

U.1 Introduction

Considerable progress has occurred during the last few years in determining whether or not dolphins, and particularly the bottlenose dolphins, *Tursiops truncatus,* are able to communicate with each other. It is well recognized that this species has the brain power (based on physical size, complexity, and brain weight to total body weight) and inquisitiveness to support language. Its ecological niche also supports a need for language communications; it feeds in groups patrolling large estuaries where visual communications is limited. It is a tribal animal with various tribes residing in specific areas for very long (evolutionary) times. This relative isolation of tribes with only occasional communications between tribes has led to identifiable differences in the sound patterns used by different tribes.

Man has attempted to communicate with the bottlenose dolphin since ancient times using man's communications tools. This has always required the dolphin to decode, or adopt, man's language. The ultimate goal of this work is to decode the dolphin's language.

Decoding an unknown language is a difficult but not impossible task. It has been done casually by sailors over the span of recorded time upon reaching a new population. Anthropologists have then followed the sailors and provided detailed analyses of the languages encountered. The process of decoding a new language is very similar to the decrypting of an encrypted message. This type of decryption was raised to a high art during the Second World War where messages in a foreign language were encrypted prior to radio transmission. Kahn ha provided a masterful book on the decryption of human coded messages by going back to the fundamental characteristics of a language, particularly the fundamental characteristics of its syntax and semantics[2]. By following the prescription described by Kahn, any language can be decoded. The effort to decode the language of dolphin has proceeded well along the path outlined by Kahn. The syntax and semantics, while not yet understood, appear to comply with all of the mathematical criteria required of an efficient language. The demonstration by Markov & Ostrovskaya that the sounds of the bottlenose dolphin are well described by a Zipf function provides strong assurance that the dolphins are communicating using a formal language of considerable power and flexibility.

U.2 Activities related to Jack Kassewitz, www.speakdolphin.com,

It is widely recognized that many species from different phyla exhibit behaviors that express an internal or symbolic processing of external reality (Roitblat, Bever, & Terrace, 1984). There is also no social behavior without communication (Evans & Bastian, 1969); few species exist which do not possess a substantial repertoire of symbolic communicative devices such as vocalizations, displays, postures, and/or gestures. But these two symbolic systems may remain separate systems with little conceptual or featural overlap in most species.

Kassewitz has a major program under way to learn more about the intraspecies communications among dolphins. His group has established a modern broadband recording system flat from a few hundred Hz to about 150 kHz. This provides a capability to observe all aspects of dolphin acoustic emissions. To support this program, the author has collected additional data about previous efforts to understand both intraspecies and interspecies (with humans) communications.

Lilly was an early investigator of dolphin vocalizations and potential interspecies communications. His 1978 book provides an extensive bibliography of his earlier work[3]. The material is primarily observational and lacked our current knowledge of dolphin physiology. As an example, he speaks of the dolphin making sound through its pharynx. But the pharynx is not part of the "rebreathing" apparatus that allows the dolphin to make sounds under water. In fact, the dolphin does not make sound via its mouth even when on the surface. He notes humans communicate through facial expressions, gestures of the body, physical contacts and the production of sounds in the

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[1]September 5, 2009

[2]Kahn, D. (1967) The Codebreakers; the Story of Secret Writing. NY: Macmillan

[3]Lilly, J. (1978) Communication between Man and Dolphin. NY: Crown Publishers

mouth, throat and larynx. A reading of his material did not locate a similar listing for the dolphin. He does note that dolphins release bubbles and turn their flippers perpendicular to the line of sight of adversaries when making a show of dominance. Such gestures are clearly visible to the high visual acuity of the dolphin.

U.2.1 An evaluation of dolphin cognitive abilities

Before attempting to understand Dolphinia (or Truncatese), it is important to circumscribe their potential speech capability. One aspect of that capability is the ability of dolphins to cogitate at the level of both concrete and abstract ideas. Herman et al. have reported on an extensive study of two dolphins trained to interpret and respond to a series of hand signals or a series of underwater acoustic whistles[4]. Their results are quite illuminating. Not only were the animals able to understand imperative sentences consisting of object + action + indirect object, they were able to respond properly to compound sentences, lexically novel sentences, structurally novel sentences and semantically reversible sentences. Interestingly, when given an impossible instruction the first time, they searched extensively for the missing object. After they were made aware that the instruction might be false (and with very little reinforcement), they performed a complete but more modest search before returning to their station and contacting the NO paddle. It was also clear that their interpretation of the object PERSON referred to the symbolic person, as it mattered little which attendant took the person-position next to the dolphin tank.

Their training extended up to five word instructions following a signature whistle describing which dolphin was to implement the instruction. This signature whistle was a computer-generated duplicate of the whistle the dolphin used to identify itself prior to the training program. One dolphin processed 168 sentences of various types with much higher performance than suggested by chance. The other dolphin processed 368 mixed sentences with similar performance. The specific words used are described in the Herman et al. paper. The acoustic words extended up to 35 kHz. The goal was to make the words members of an orthogonal set by varying their frequency, duration and modulation.

The lexical and semantic breadth of language the dolphins were able to understand insures, in this analysts eyes, the inherent ability of the dolphins to communicate using language. The task at hand is to attempt to determine the range of objects and actions a dolphin is likely to use in everyday communications before attempting to decode the available recordings of these communications.

The first step appears to have been accomplished. The dolphins respond to the names they have adopted for themselves previously. The challenge is to determine how they respond following a communication from another dolphin. If a sufficiently large set of detailed responses and detailed messages can be obtained, determining the meaning of the message content is reasonably straight forward using standard crytographic techniques. However, it is of primary importance that the symbol set used in communications be separated from other sounds and that this symbol set be determined as precisely as possible. The evidence strongly suggests that different pods use different symbol sets. Winn et al. have produced such a symbol set for the humpback whale[5]. The material is synopsized by Thompson, Winn & Perkins in Winn & Olla, 1979. More study of the literature will be necessary to determine if the appropriate analytical techniques have been applied to obtain more complete understanding. In 2002, Herman provided a good summary of the work he was aware of on The Dolphin Institute web page, www.dolphin-institute.org/resource_guide/animal_language.htm It expands on the recent work with the two dolphins described above as Akeakamai and Phoenix.

The very rapid ability of at least one bottlenose dolphin to mimic a synthesized whistle is another example of how cognitively capable the animal is (**Section U.1.3.3.6**).

Pack & Herman have recently reported on the ability of the bottlenose dolphin to interpret posturing by humans, specifically the ability of the dolphin to understand human gazing and pointing[6]. In this case, gazing refers to the orientation of the head ***and*** eyes toward a point of interest. Phoenix and Akeakamai did exceedingly well on the defined test program without any prior training. It was obvious from the first test that the animals had an innate

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[4]Herman, L. Richards, D. & Wolz, J. (1984) comprehension of sentences by bottlenosed dolphins *Cognition* vol 16, pp 129-219

[5]Winn. H. Perkins, P. & Poulter, T. (1971) Sounds of the Humpback Whale *Proc 7th Ann Conf Biol Sonar and Diving Mammals* Stanford, Calif: Stanford Research Inst pp 39-52

[6]Pack, A. & Herman, L. (2007) the dolphin's (tursiops truncatus) understanding of human gazing and pointing: Knowing what and where *J Comp Psych* vol. 121(1), pp 34-45

ability to interpret inter-species pointing and gazing that at least equaled that of the non-human great apes. It must be assumed that they are also aware of the posturing by their fellow dolphins. This posturing could be an important aspect of their intra-species communications.

U.2.1.1 Mirror self-recognition (or awareness) in dolphin

Previously, only humans and the great apes (specifically the chimpanze) have been shown to exhibit mirror self-recognition. Reiss & Marino, of the New York Aquarium, have performed a very statistically convincing set of experiments that show the bottlenose dolphin will use a mirror to examine areas of its body that it believes were marked, or sham-marked by a trainer[7]. Two animals were tested under carefully defined conditions involving carefully constructed protocols. The animals, as usual surprised the test team on a number of occasions. In several cases, the animals left their stations immediately after marking, without waiting for the release signal, in order to examine the mark as soon as possible. A feature of the experiments was the length of time the animals spent examining an actual mark compared to the much shorter time spent after recognizing that they had been sham marked and there was nothing to examine in detail. In some cases, they exhibited highly unusual swimming postures in front of the mirror in order to examine a mark on the right pectoral fin. In a one-time experiment, the animal was marked on the tongue. It immediately swam to the mirror and engaged in a mouth opening and closing sequence never before observed by him during the study.

U.2.2 Efforts to document the phonemes in dolphin language

Markov & Ostrovskaya attempted to establish the grammar of the bottlenose dolphin[8]. They provided a broad description of the individually identified sounds of the animal but without any frequency scale on the spectrograms or amplitude scale on their temporal plots. They worked diligently on over 300,000 signals to determine many structural elements of a potential language. They did note the ability of the dolphin to use multiple sound generators simultaneously to create very complex sound structures (page 610). It may be necessary to segregate some of these signals as related to echolocation rather than intra-species communications. This applies particularly to what they describe as synchronous operation of two pulse generators. They did offer a transcription method to describe specific messages.

Morgan attempted to identify the individual sounds of Beluga Whales and play them back to the animals in a variety of synthetic sequences[9]. The reaction did not lead to significant new understanding.

Li, et al. have recently provided a stimulating introduction that suggests different species of *Cetacea* may speak individual languages[10] (and as noted elsewhere in this discussion, different pods of bottlenose dolphins appear to exhibit dialects).

In any comprehensive program to study dolphin language, it is important to consider the critical nature of the filter bandwidth used to prepare spectrograms as part of the study. Section 8.1.4.1 of this authors work on hearing is relevant, www.hearingresearch.net/pdf/8Manipulation.pdf . It shows the same English sentence analyzed with two different bandwidths. The features highlighted are quite different.

U.2.2.1 A potential pulse based language by Preben Wik

Preban Wik has recently presented a thesis that contains useful insights[11]. However, it did not culminate in any actual data collection. Below are a summary of my reading of the thesis as e-mailed to J Kassowitz.

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[7]Reiss, D. & Marino, L. (2001) Mirror self-recognition in the bottlenose dolphin: a case of cognitive convergence *PNAS* vol 98(10), pp 5937-5942

[8]Markov, V. & Ostrovskaya, V. (1989) Organization of communication system in *Tursiops truncatus montagu. In* Thomas, J. & Kastelein, R. *eds*. Sensory Abilities of Cetaceans. Op. Cit. Pp 599-611

[9]Morgan, D. (1979) The vocal and behavioral reactions of the Beluga, Delphinatperus leucas, to playback of its sounds *In* Winn, H. & Olla, B. *eds*. Op. Cit. pp 311-343

[10]Li, S. Wang, K. & Wang, D. et al. (2008) Simultaneous production of low- and high-frequency sounds by neonatal finless porsoises (L) J Acoust Soc Am vol 124(2), pp 716-718

[11]Wik, P. (2002) Building Bridges. Univ of Oslo in fulfillment of a Doctoral Degree

I read through the thesis by Preben Wik that you sent me. He did not investigate the physiology of the dolphin in any serious way (and I do not believe the dolphin can reach 200,000 Hz in any meaningful way). He did not seriously discuss the frequency range of dolphin pulse and tonal signals (a maximum in the 35---40 kHz region).

As you know, he ended it without actually collecting any data using his protocol.

His focus on the pulse signals of the dolphin in the development of his protocol does not appear as useful as your concentration on the tonal aspects in a "Fusional Contoured Tonal Language." I would argue that the dolphin employs both the pulse and tonal portions of its repertoire in its language.

As I noted this morning, his paper did include some useful ideas, and compared the guidelines of Chomsky versus Hockett. I had not seen the Hockett material before. He did note on page 53 that Hockett's list may be too granular to fit the general case.

He did contribute the concept that dolphinese might employ pulses as *suffixes* to tonal formants, instead of the way humans use unvoiced *prefixes* to tonal formants. This approach might be more useful in a noisy environment.

The question of order also extends to dolphinese syntax. He noted, "There are six possible permutations of the units used for word order: SVO, VOS, OVS, VSO, OSV, and SOV. He noted correctly, every combination is used on one human language or another. However, he did not speculate on the order preferred in native dolphinese. Making this determination alone would be a key factor in breaking the dolphinese language code.

He defined a small set of SMU's (symbolic message units). I do not believe he went far enough in establishing the complete range of potential morphenes (SMU's ?) that his data collection device should address.

It would be interesting to run some of your broadband tapes through an expanded variant of his LVQ Tab program on page 98 (with the purpose of isolating the various morphemes and syntactic sequences. The result could be a set of statistical tables that could lead to a serious code breaking activity.

U.2.3 Overview of the language facilities of the dolphin, May 19, 2007

Jack,

You ask intriguing questions. I'll try to summarize where I am on these points at this time. However, please understand that I have not dug into this subject deeply. However, the text I am just completing on Hearing does give me some perspective.

Because I have not dug into linguistics, I probably will use some terms that are not those accepted in the field. We can correct that as we go along.

First, we must separate what you have described as the building blocks needed to support language. Let us separate inter-species from intra-species communications for now. While inter-species communications is clearly quite common (based on living with our pets if nothing else), your two basic questions are; 1. Do dolphins have a language?
2. Can we learn to understand it?

I think you and I can agree that dolphins exhibit all of the traits associated with intra-species communications. From a functional perspective, the basic communications ability relies upon the ability of an animal to recognize a pattern delivered to the cognitive elements of its brain and the ability of that animal to reproduce that same pattern in the medium of interest, whether acoustic, visual or tactile. If the animal can recognize a number of individual patterns and reproduce them at will, it clearly has the ability to communicate ideas to another member of that same species. This group of patterns is known as a language. If the animal can rearrange these patterns, and generate them in the appropriate medium, we say it has expressed a new idea. The chimpanzees and other large primates are doing this regularly at the primate center in Atlanta. I expect the dolphins are doing this in the amusement parks around the country and world. Will dolphins signal to you that they prefer mackerel to squid, or vice versa?

That is the basic internal sequence. If two animals can exchange patterns back and forth, we say they can communicate using language.

There is every indication that the dolphin can perform all of these steps and many more. Therefore, I am forced to conclude they do communicate and share an acoustic based language. Interestingly, many other animals also appear able to do this, including dogs and cats. However, their ability to express complex acoustic patterns is quite restricted. The problem is man has not learned how to achieve inter-species communications except using our language (which dogs and cats can learn to understand but do not have the facilities to reproduce the auditory patterns we use). The dolphin is probably in this same category (along with the large primates).

Your second question is interesting but my answer may not be what you expect. Ridgeway, Au and probably you have worked with dolphins to the point you can ask them (by voice or whistle)to go to a certain point and carry out a task or respond to a situation (including return to you and press a button). These sequences constitute inter-species communications using patterns (symbols or signs if you prepare). You generate a pattern that the dolphin can view or hear. It takes an action and returns to generate a pattern that you understand.

Can we learn to understand the dolphins intra-species language. I have no doubt we can. However, many man-hours have been spent listening to dolphin communications (mostly by in-experienced and inadequately trained graduate students). The task is no different than that of code breaking as practiced during the second world war. There are several well defined steps:
A. Perform traffic analysis to determine what symbols are issued by a given dolphin under a clearly defined (and delimited) set of conditions.
B. Perform a statistical analysis of the potential symbols used in the above traffic analysis. (E appears more often than m in English).
C. Perform an after action analysis to determine what symbols a second dolphin produced in response to specific symbols.
D. Refine the process.

To date, my traffic analysis shows that Cetacea make four distinctly different classes of acoustic signals,
(1) Signals at frequencies between 80-90 kHz and 150 kHz associated with the terminal predatory action (your kill sequence).
(2) Signals at frequencies between 20-30 kHz and 80-90 kHz used to search for food preliminary to predation. These would typically be whistles, potentially frequency swept whistles.
(2A) *The potential use of 20-90 kHz energy to stun fish within a few meters and generally directly in front of the dolphin (Ref. Castaway echo 3-23-2007).*
(3) Signals between 200 Hz and 20 kHz designed for intra-species communications within a pod.
(4) Signals at frequencies below 200 Hz designed to support long range communications among the whales.

The first three of the above categories are used by dolphins. I believe only the third one is used for intra-species communications.

The best studies I have found to date concerned with dolphin communications is the work of Santos, M. Caporin, G. et. al. (1989) Acoustic behaviour in a local population of bottlenose dolphins, In Thomas, J. & Kastelein, R. eds. Sensory Abilities of Cetaceans. NY: Plenum Press pp 585-598

Their tables represent the start of a symbol analysis (step B) that can be related in a preliminary way with their limited traffic analysis (step A). While they speak of signals in the frequency range of 4 to 16 kHz as a mixture of echolocation and communications (personal signatures is their term), I do not believe these low frequencies have anything to do with echolocation (other than coarse obstacle avoidance like humans use to avoid running into a wall in a darkened room). To me, their symbols are all intra-species communications. The duration of their symbols is also much too long for echolocation unless they are using a Doppler system. The duration of their contours suggest each is a word of multiple symbol length (multiple syllables within one word) or even a sentence. (I only have preliminary information but it looks like essentially all mammalian brains operate on a 30 ms integration interval.) One of these contours may say "I am proceeding to the left." The task is to figure out which one it is. This requires the very close delineation of what the dolphin did before or following this message (step C) followed by continuous repetition of the steps in order to build up a library.

The amplitude contours of Santos et al. without an accompanying spectrogram are of little value. Hickey has provided both amplitude profiles as well as spectrograms for the dolphins living around the island of Ireland (Eire).

A problem for humans is to determine what might be meaningful ideas to be shared between dolphins. They will clearly have a call for help, and more specifically a call for mother (ma ma is pretty universal among humans, although it begins to be tailored to fit a specific language after maybe 18 to 52 weeks). What is the equivalent among dolphins? You appear to be in a good position to find this out by following the above steps in a captive and controlled situation.

Breaking the code of dolphin language will not be an easy task. Very sophisticated analyses by very widely versed specialists will be required. Adding more graduate students (or novice graduates) to the task will not help.

As an aside, there is an interesting article on pages 138-151 of the June 2007 National Geographic suggesting that certain bat species can recognize the mating call of edible as opposed to poisonous frogs. To me this is inter-species communications, albeit one-way (just like used in war all the time).

I am looking forward to learning more about your recordings and spectrograms. I am sure you will annotate the collection conditions as precisely as possible. I would also like to know more about the scope of your current scientific program? Do you have a program plan of some sort in the communications area?

Have a good day

Jim

U.2.2.1 Low frequency vocalization parameters

Lilly has provided early data comparing the sounds made by humans and dolphins in the course of vocalizations in air[12]. The frequencies of the dolphin would not be expected to change when submerged since they still involve the movement of air through orifices, etc. **Figure U.2.3-1** begins with the fundamental (partial #1) and continues with the higher order harmonics versus the pulse rate of the enunciations. No discussions were provided concerning higher frequencies for the dolphin.

Winn & Olla have edited a volume on marine mammals including a major article by Caldwell & Caldwell[13]. The Caldwell & Caldwell paper focused on 126, mostly young, bottlenose dolphins. However, the data is seriously limited by the capabilities of the equipment of that era. Bandwidths were generally limited to 12 kHz. Most of the recordings only show a fundamental frequency in the 4 kHz region.

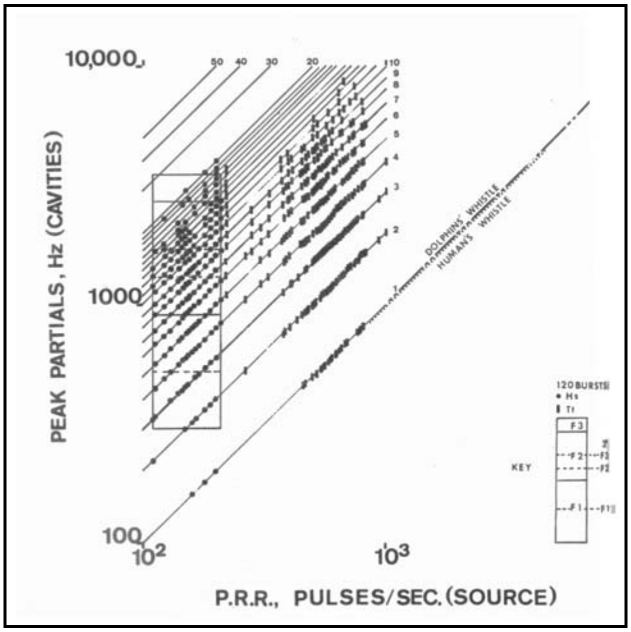

Figure U.2.3-1 Vocal exchanges in air between dolphin and human. Partials refer to the fundamental plus higher harmonics. Box on left represents the human range as explained by legend on the right. The dolphins vocalizations are systematically higher in frequency and in pulse rate. F1, F2 & F3 are conventional human formants. From Lilly, 1978.

U.3 Planning a program to discover the language of dolphins

Since the time of Lilly, and before, humans have attempted to communicate with dolphins. However, the methods have always been homeocentric, teaching the dolphin a "foreign language" by training it to respond to specific sounds in a prescribed way. Even when the sounds chosen are recorded from the same or other dolphins, the result is the same. We attempt to teach the dolphin to respond to its own name (signature whistle) or some sound with an entirely different meaning in its native language.

> An easy example of this is as follows. An English speaker encounters several Russians in conversation. He knows no Russian. He hears a phonetic sequence that corresponds to his understanding of the English word "ocean." He then attempts to communicate with one of the

[12] Lilly, J. (1978) Communication Between Man and Dolphin. NY: Crown Publishers

[13] Winn, H. & Olla, B. (1979) Behaviour of Marine Animals, Volume 3: Cetaceans. NY: Plenum Press

Russians with the word ocean as he understands it, implying a large body of water. By sufficient arm waving and gesturing, he may be able to get the Russian to associate the phonetic sound for the English word for ocean with a large sea, even though in the Russian's language the word ocean is an adverb meaning "very" or "very much."

Trying to teach any subject a foreign language, instead of learning his language, in order to communicate takes a lot of effort; and in an analogy to a cat, "bores the hell out of the cat."

It appears a more productive approach is to try and understand the language of the other species based on a sophisticated linguistic attack.

Before performing such a linquistic attack, it is important to know something about the social networking of the dolphins. Lusseau et al. have performed networking studies on at least one family of relatively isolated dolphins[14]. A literature search uncovers many more.

If a sophisticated linguistic attack is to be performed, this attack should be designed to discover the phonemes and other elements of their language and how these are used in a syntax that the other species understands. Since the dolphins language is not a "written language," the procedures involved must be highly statistical. Since the language is not written, the statistical analyses are much more complicated than typical code breaking where a limited symbol set is used. To learn Dolphinia or Truncates, a very large symbol set must be attacked until some associations with physical behaviour or intra-species communications can be ascertained.

An assumption can be made that the CNS of the dolphin employs a frame time similar to humans, nominally 30 milliseconds. As a starting point, it is reasonable to assume that a typical phoneme is three to five times longer than 30 ms based on experience with human languages. A complication arises because of the multiple sources of sound within the dolphin's nasal passages, recalling that the larynx of the dolphin is not in its throat (the passage along which food is ingested). These multiple acoustic sources suggest the dolphin can achieve an equivalent of the unique "throat singing" of the Inuit and Tuva people of Asia. Throat singing is also known as overtone singing. Wikipedia provides a good description of throat singing. In Dolphin, the equivalent is clearly nasal singing. Nasal singing in dolphin may be even more extensive.

As a starting point, the acoustic range of dolphin sounds (other than its forward focused echolocation sounds) potentially useful in communications (language) extends from about 2000 Hz to at least 80,000 Hz (with whistles extending up to about 40,000 Hz). In seeking to understand Dolphinia or Truncates, it makes no sense to restrict our analyses to frequencies that the human can hear. Nor is it rational to limit the dolphin's language to either a tonal or a stressed structure.

U.3.1 A conceptual sequence of dolphin acoustic activity

The following material will be restricted to, and focused on, a framework applicable to the study of Truncatese, the defined language of the bottlenose dolphin. This language probably involves significant dialects based on the isolation of pods over time. Whether the dialects are mutually understandable within the species is not clear. Whether it is understandable by other members of the genus and/or family is even less clear.

The sequence of sounds produced by bats during the target acquisition, tracking and terminal pursuit suggests that dolphins might also employ such a sequence of acoustic mechanisms. In the case of the dolphin, the sequence might be extended to include:
1. Intra-species communications to organize a search using low-band frequencies.
2. Passive location of potential schools of prey using low-band frequencies.
2. Location of potential prey using mid-band tonal echolocation to search.
3. Identification of potential prey using mid-band frequency sweeping in echolocation imaging (3-D).
4. Closing on and herding of prey using mid-band echolocation.
5. Potential stunning of prey using mid-band frequencies at maximum power level (0.12 ms pulses)
6. Closing on individual prey using high-band frequencies in echolocation and imaging mode (3-D).

This is only a skeleton of a strategy. Schusterman et al. provides a much broader discussion of dolphin foraging.

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[14]Lusseau, D. Schneider, K. et al. (2003) The bottlenose dolphin community of Doubtful Sound features a large proportion of long-lasting associations Behav Ecol Sociol vol 54(4), pp 396-405

Kaiser has provided a broad discussion of intraspecies communications among the bottlenose dolphins[15].

U.3.2 A scenario for learning about dolphin intra-species communications

Researchers have been attempting to learn the mechanisms and content of dolphin speech for a long time. The problem is more complex than mere code breaking. Particularly in telegraphic code breaking, one knows the complete extent of the symbol set, has good traffic analysis data and has a reasonable idea of what might be in the coded messages. The problem is more complex in verbal code breaking, especially inter-species code breaking, where the symbol set is not known. In the case of dolphins, the symbol set may not be the same between unrelated and distant pods, just as human populations have developed widely varying languages, and dialects within these languages, based on their isolation from each other.

Because of the range limitations on underwater sound and the known background noise level in literal waters, it is likely the intra-species communications within a large bay would use low-band frequencies (maybe 200-5,000 Hz). This needs to be confirmed. At close range frequencies up to 30 kHz or higher could easily be used.

It is not clear from the literature whether any investigators have explored the potential symbol-set among a given pod of dolphins. Richards has provided a bibliography up to 1986. Analysis of recordings of mimicry among a pod of dolphins might be a productive approach to determining their symbol-set, particularly if sufficient raw recordings are available. If examples of mimicry between different pairs of individuals were analyzed, it may be possible to order the two symbol-sets.

U.3.3 Elements of intra-species communications

Humans communicate using a wide variety of techniques:
1. Facial expressions
2. Body language (including posturing)
3. Touching
4. Speech
5. Non-speech vocalizations

It must be assumed that dolphins use the same techniques, plus at least one other (blowing bubbles at appropriate times). Cahill has formalized some of these techniques in brief text[16].

Signal/Behavior	Potential Meaning
1) Contacts between two or more dolphins	
Rubbing bodies	Affection or affiliation, strengthening social bonds, reaffirming relationships, quieting an excited peer (usually a youngster)
Pectoral fin to pectoral fin rub	A greeting between two dolphins
Pectoral fin to side of peduncle	A solicitation for a favor or help sometime in the near future (He called this “contact position” in his research.)
Hits, rams, slams, bites	Usually irritation or aggression from older dolphins but when accompanied by soft angles of approach these are playful
Melon to genital contact	When a mom and her calf are swimming in echelon, the calf will often touch her genital area with its melon maybe indicating it wants to nurse. If the mom initiates contact then maybe it is telling the calf to nurse.
2) Dolphin vocalizations	

[15]Kaiser, D. (1990) Linguistic Behavior in Nonhuman Species: A Paradigm for Testing Mental Continuity http://home.onemain.com/~dk1008206/html/cexam.htm

[16]Cahill, T. (2000) Dolphins. Washington, DC: National Geographic

Dolphins are relatively homogeneous in their sound generating and sensing capabilities. However, Ketten and Wartzok have noted differences in the curvature of the cochlear partition in some river species[17]. The river species (which may qualify as a separate genus) use echolocation frequencies up to 200 kHz. Their type I cochlear partitions are nearly planar and deviate significantly from the Hankel function of the type II partitions of othe dolphins. The ocean species exhibit the following sounds according to Cahill.

Whistles	Often dolphins produce a stereotypic whistle that is usually called a “signature” whistle. We now know this is used for maintaining a contact among individuals.
Chirps	Short in length sounds that resemble the sound of bird chirps, these sounds may signal a dolphin’s emotions. . . Sort of an “okay” message.
Click trains	Short pulsed vocalizations of high and wide-band frequency that are used to investigate objects or search for fish. Often these sound like creaky old doors opened slowly and have been called echolocation.
Squawks	Pulsed vocalizations that sound like “squawks” and are very high in repetition rate. They are used mostly in fights or during play by younger dolphins and may signal irritation or anger.

3) Bubbles

Bubble stream or trail	A stream or trail of little bubbles that escape from a dolphin’s blowhole. . . often seen from young dolphins during excited and playful swimming.
Bubble clouds	Large pockets of air from the dolphin’s blowhole (“clouds”) that are used to express anger or warning. They may also be used as a “shield” from another dolphin’s harsh vocalizations (*or attempts to injure acoustically*).

The italics were added by this author. Reynolds et al. gave a slightly different list including frequency ranges[18]:

Sound Type	Frequency Range	Function
Clicks	0.2-150 kHz	Echolocation
Whistles	0.2-24 kHz	Individual recognition–Group cohesion
Low freq., narrowband	0.3-0.9 kHz	Unknown
Rasps, grates, mews, barks,yelps	0.2-16 kHz	Communications?

The above descriptions are too brief for purposes of understanding the symbol set and potential messages used in acoustic communications. The rasps, grates, mews, etc. in particular need to be associated with individual spectrograms.

Santos et al. have provided a somewhat more detailed breakdown of dolphin sounds[19]. They describe the “Types of calls” along with sample spectrograms (limited generally to 24 kHz).

Whistles– continuous, tonal sounds, occurring in a variety of frequency modulated contours, sometimes repeated in series.

Pulses sounds– the broadband clicks generally assumed to be associated with echolocation, and which come in trains of variable length and repetition rate. As the pulse rate increases, these trains sound like creaks (such as those of a rusty hinge), low creaks and moans.

[17]Ketten, D. & Wartzok, D. (1989) Three-dimensional reconstruction of the dolphin ear *In* Thomas, J. & Kastelein, R. *eds*. Op. Cit.

[18]Reynolds, J. Wells, R. & Eide, S. (Xxx) The Bottlenose Dolphin. Gainsville, FL: Univ. Press of Florida pg 76

[19]Santos, M. Caporin, G. et. al. (1989) Op. Cit.

Creaks– which usually are broadband, have a pulse rate extending over 40 pps.

Moans– similar to creaks but occurring at higher pulse rates (>40 pps) and frequently exhibiting higher harmonics simultaneously.

> There appears to be a problem leaving the pulse frequency of moans unlimited. It is suggested that pulse rates above 100 pps be describes as a **Buzz** as perceived by human attendants. The moans would then cover 40 to 100 pps.

Bangs– a relatively loud broadband pulse (duration about 20 ms). These resemble a typical click waveform but on a longer time scale.

Brays– (resembling a donkey bray) a series of squeak-like sound followed by grunts. Typically 390 ms between the squeak sequence and the grunt sequence.

"Buzz Effect"– bursts of variable duration that seem to be modifications of other sounds, making them noisy, with the appearance of a buzzing wasp.

Blasts– noisy sounds appearing in sequences of 3 bursts each lasting about 150 ms. The whole set lasts about 700 ms.

They also noted long periods of silence, particularly when the group was traveling (Fast Directional Moving), when passing through sensitive areas like the mouth of the river or when they had to pass close to our stationary boat.. They also noticed an absence of calls during presumed prey-searching, Erratic Group Movements or Slow Directional Moving.

Fast Directional Movement–

Slow Directional Movement– [xxx missing pages of Santos text]

Erratic Group Movement–

Spread Erratic Movements– the animals surface in a dispersed fashion, mostly alone but also in dyads or triads, spreading over a wide area. Seems to be a feeding or searching for prey activity.

Localized Surface Feeding– the animals surface close together, but in different directions, showing fast movements. All dives are very short. Many leaps of different types are visible. Appears to be a collective attack on a fish school.

Localized Surface Interaction– unrelated to feeding. Considered episodes of social interactions and play.

Some of these movement categories may be associated with passive listening for prey detection.

Lilly has also commented about the first sounds of baby and juvenile dolphins[20]. "Initial sounds: distress whistle for calling mother, "putts" for localization (release of air from blowhole). At 9 months, postpartum, control of clicking without air loss matures. Whistle control suddenly complex."

Kasselwitz (private communications, 15 June 2007) has recently recorded the first sounds of a newborn dolphin (within two seconds of birth). They included an initially constant then rising whistle with dominant frequency of 9 kHz rising to 18 kHz at 0.14 seconds, one distinct click of less than 0.01 seconds with most of its energy below 20 kHz, and a series of broadband sounds extending up to at least 90 kHz with durations of about 0.014 seconds repeated at a rate of 60 pps for 12 to 22 times The energy density of each pulse was highest at the beginning.

U.3.3.1 Elements of human speech as a potential model

[20] Lilly, J. (1978) Communication between Man and Dolphin. NY: Crown Publishers pp 47

Crystal has provided a comprehensive text on human language from the perspective of a linguist[21], has provided a useful bibliography and has provided a copy of the current International Phonetic Alphabet. He notes there are 44 distinct phonemes in English out of a potentially much larger group. Some available combinations are not used in English but may be used in other human languages. He describes these 44 distinct phonemes (20 vowels and 24 consonants) in considerable detail. He also develops how they are typically used in groups of two or three and occasionally four phonemes to form syllables.

Fletcher, writing at a different time and using marginally different notation, provides spectrograms of 300 combinations of one consonant and one vowel[22]. The sequences look remarkably like dolphin sounds reported in the literature using low frequency recording techniques (less than 24 kHz).

U.3.4 Potential sentence content in dolphin communications

Crystal has provided a brief discussion of how languages might have evolved. He describes five theories described by Jespersen in the early 20th Century (page 350). They do not include the navigation hypothesis described below. Crystal listed Jespersen's categories using fanciful names.

1. The *bow-wow theory*–Speech arose through people imitating the sounds of the environment, especially animal calls.
2. The *pooh-pooh theory*–Speech arose through people making instinctive sound, caused by pain, anger, or other emotions, such as ooh or tut-tut.
3. The *ding-ding theory*–Speech arose because people reacted to the stimuli in the world around them.
4. The *yo-he-ho theory*–Speech arose because, as people worked together, their physical efforts produced communal, rhythmical grunts, which in due course developed into chants.
5. The *la-la theory*– Speech arose through the romantic activities of humans, sound associated with love, play, poetic feeling, perhaps even song.

These theoretical evolutionary routes appear less than satisfying (convincing) even with the short justifications given by Crystal.

Kazakov & Bartlett have speculated on the potential for "Navigation" to form the instigating mode of intra-species communications[23]. They have noted the use of songlines by the Australian aborigines for this purpose during their development prior to the appearance of writing and maps. It appears likely that communicating routes to specific reefs, beaches and mouths of estuaries may be particularly important to dolphins.

Beyond the evolution of language, Crystal has also addressed the structure of languages. He describes the structure in terms of:

1. The vocabulary of the language–the ensemble of words used to express individual meanings.
2. The grammar of the language–the order in which words are presented.
3. The phonology of the language–the tone of voice in which a sentence is presented.

Phonology subdivides into pure phonology, how sounds are used in a language and phonetics, how speech sounds are made, transmitted and received. Pure phonology is often subdivided into segmental phonology (the study of vowels, consonants and syllables) and non-segmental phonology (the study of prosody–the style of word presentation as in verse).

Semantics is concerned with the choice of specific words of similar meaning within the vocabulary to more specifically shape the meaning of a sentence.

Grammar can be broken down into the study of word structure (morphology) and the study of word order (syntax).

The syntax of a sentence is straight-forward. Complex sentences contain clauses, that contain phrases, that contain words, that contain morphemes. The parts of a sentence can be diagramed using a tree diagram.

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[21] Crystal, D. (2006) How Language Works. NY: Overlook Press

[22] Fletcher, H. (1953) Speech and Hearing in Communications. NY: Van Nostrand pg 61

[23] Kazakov, D. & Bartlett, M. (2005) Could navigation be the key to language Proc 2nd Symp Emerg Lang @ York Univ.

However, the grammar (i.e. the order of presentation of the elements in the tree diagram) is highly variable and depends on the language involved.

Two recent books provide significant background relative to human speech. McWhorter, has provided "The power of Babel : a natural history of language[24]" describing many of the common attributes of languages. Anthony has provided "The Horse, the Wheel and Language" as an exposition on how human languages have evolved beginning about 4500 years ago[25].

Ostrovskaya & Markov have defined a structure for describing the short interval-type sounds of dolphin[26]. They have allowed for up to four simultaneous sources. This complicates their framework considerably. The paper suffers somewhat at the technical level in translation. It appears an initial exploration using their symbology but limiting the sources to one could be productive. However, it appears from recordings observed to date that a realistic model must include tonal sounds. The dolphin language appears to blend tonal– and stressed–language elements.

U.3.5 The complexity of word-semantics

Words take on a broad range of meanings in any language over time. Some meanings are merely nuanced groups and others are entirely independent. Pinkal & Thater provided the following breakout of word-semantics[27].

Major word-semantic categories
• **Function words**:
– Connectives and quantifiers
– Auxiliary and modal verbs
– Temporal and modal adverbials
– Anaphoric pronouns, articles
– Degree modifiers, Copula, ...
• **Content words**
– Common nouns
– Full verbs
– Adjectives
• **Other**
– Named Entities (Persons, institutions, geographic entities, dates)
– Numbers
– Etc.

A major challenge is to determine how complex any dolphin language is. Does it use both function and content words? Does it use named entities (tied to signature whistles)? Do the function and content words exhibit multiple meanings when used in different contexts?

U.3.6 The probability of a dolphin language

Observers have been noting the actions of dolphins since antiquity. They have virtually all noted that dolphins are social animals usually traveling in pods. They are also known to cooperate in carefully choreographed (planned?) strategies when hunting. They are noted for their posturing and interpersonal rubbing (body language). They are also noted for their large vocabulary of sounds that cover a spectrum much wider than that of humans. In terms of their phonetics, they have multiple sound producing mechanisms (compared to the single larynx of humans). Finally, they are noted for their considerable volume of vocalizations during a variety of group activities. Recently, it has been shown that dolphins can learn to correctly interpret complex semantics and even complex grammar when participating in one-way inter-species communications with humans. It has also been shown that they quickly learn

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[24] McWhorter, J (2001) The power of Babel : a natural history of language. NY: W. H. Freeman

[25] Anthony, D. (2007) The Horse, the Wheel and Language. Princeton, NJ: Princeton Univ Press

[26] Ostrovskaya, V. & Markov, V. (1992) A language to describe the structure of pulsed sounds in bottlenose dolphins (*Tursiops truncatus montagu*) *In* Thomas, J. Kastelein, R. & Supin, A. *eds*. Marine Mammal Sensory Systems. NY: Plenum pp 393-414

[27] Pinkal, M. Thater, S. (2007) Semantic Theory: Lexical semantics I www.coli.uni-saarland.de/courses/

that the human may mislead them and they will adopt compensating strategies almost instantly. It has also been shown that they exhibit considerable self-awareness (a property presumed to relate to intelligence and cognitive ability)

Based on this long list of traits alone, it is difficult to deny that dolphins have the capability for intra-species communications by auditory methods generally described as language. When the apparent physical capacity of their brains are explored, they seem to have at least the potential of humans in cognitive ability. Their hearing capability vastly exceeds that of the human in frequency response and although its environment is fluid instead of gaseous, it seems to have excellent hearing sensitivity. The dolphin appears to have individually steerable external ears that are closely tied to its hydrodynamic form at any given instant. Its visual capabilities appear to exceed those of the human in the since they are comparable to that of the human, in both air and water. Besides these cognitive abilities, they are also well known for their apparently purposeful help to other dolphins and to humans in distress (even to the extent of protecting a human consort from potential shark attack).

Recently, a newborn calf named Wilson was found to be generating a wide variety of sounds (including multiple sequential whistles), and ranging with its echolocation capabilities within tens of minutes of its birth (Wilson first sound second hour.wav, 1.5 sec). The ranging sequence was preceded by at most a few independent ranging pulses during the previous hour. The ranging sequence coincided with physical closure on its mother. These activities would suggest that dolphins have a considerable genetically-encoded acoustic repertoire at the time of their birth.

The only rational conclusion is that dolphins have all of the tools necessary to carry on intra-species communications using a rich and completely adequate auditory and body language. These tools are available, at least in primitive form, within minutes of birth. The challenge is to determine the characteristics of the auditory language, its phonology, vocabulary (at least the most common words), and its grammar. Killebrew et al. provide similar data on another neonate although the bandwidth of their recording equipment was severely limited at 12 kHz[28].

U.3.7 Attempts to analyze and describe dolphin speech

Since Lilly, many people have attempted to describe the linguistic aspects of dolphin speech from a variety of perspectives. Most of these attempts have been heavily philosophical and generated by members of the general population. Most rely heavily upon anecdotal data and folklore. Win Wenger has recently prepared a treatise on "How to Understand the Dolphin Language[29]." He has attempted to define the character of ideas that two dolphins would find useful to exchange. The discussion is very brief and is based entirely on thought experiments which he describes as part of a "Borrowed Genius" technique. He asserts that formal researchers will eventually conclude that "the dolphin language uses only internal states of feeling and being as its referent. No nouns. Sometimes as modulated by circumstance, but always the internal state as the central issue."

The vast literature using the terms dolphin and language, or dolphin and speech, have actually been concerned with inter-species (human/dolphin) communications generally using hand or body signals on the part of the human. Occasionally, experiments using recorded dolphin sounds in an apparently completely irrelevant context have been performed (requiring the dolphin to treat these sounds as a foreign language that is only casually similar to the dolphin's native language).

Preliminary analyses by this author suggest the sounds produced by dolphins are extremely complex and rival those of humans, except in a different frequency range. They are quite capable of generating two distinct whistles simultaneously that actually cross in frequency in the middle of the morpheme(s). Because of the multiple sources of sound in the dolphin system, their sound vocabulary may be even more versatile than that of humans. As a result, it appears a meaningful analysis leading to understand dolphin language will require establishing at least a framework representing the broad phonology of the dolphin and a skeleton of a vocabulary. Only with such a framework and skeleton in hand can any attempt be made to determine the grammar and syntax of the dolphins.

McCowan and her team have attacked understanding dolphin language from a different perspective, starting from the simple phonemes and working up toward semantics. Her groups 1999 paper is very well structured and provides

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[28]Killebrew, D. Mercado III, E. Herman, L. & Pack, A. (2001) Sound production of a Neonate bottlenose dolphin *Aquat mammals* vol 27.1, pp 34-44

[29]Wenger, W. (2002) How to understand the dolphin language www.winwenger.com/dolphin.htm

very provocative data[30]. The work relies upon a set of dolphin whistles collected previously[31,32]. It is also careful to define its terms. The most important term is information, that they point out can be defined in at least three seemingly conflicting ways. Most commonly, information can be defined in the “contextual” sense, that is, what information is conveyed during a communicative exchange (i.e. meaning). Information can also be defined in the “communicative” sense, that is, how much information can be transferred during a communicative exchange. Finally, information can be defined in the “statistical” sense (as Shannon defined it), as the degree to which data are noncompressible, that is how much redundancy remains in the language. The latter term leads to the concept of entropy within a signaling stream. There is a minor semantic problem concerning the term random. They used the expression random to describe the symbology of a signal of maximum content. In fact, the signal is pseudo-random. It appears random using conventional statistical tests but hides a structure known only to the communicating parties. Pseudo-random signaling is now widely used in spread-spectrum radio transmission. Without the key, the signal appears completely random. However, with the key, the message becomes perfectly clear text (that includes spaces, pauses, etc). McCowan, Hanser & Doyle defined *information* in the statistical context of Shannon, as the entropy of a message, in the 1999 paper. They defined entropy exactly as Shannon did, a measure of the information degree of organization, a construct distantly related to the entropy of thermodynamics. Information in the communicative sense was defined as the communication capacity of the system, i.e. the complexity of the signaling system. They avoided any discussion of contextual information in their paper.

The ‘first principle’ developed by Shannon[33] in 1948 has been expanded by the work of Zipf[34]. Shannon focused on the entropy of a single symbol used in a message. Zipf focused on the entropic relationship between the first and second symbols, the first, second and third symbols, etc. They are generally described as the zero order entropy (single symbol space), first order entropy (pair of adjacent symbol spaces), etc. They summarized the value of these entropies as follows:

1. Zero-order entropy measures repertoire diversity.
2. First-order entropy begins to measure simple repertoire internal organizational structure.
3. Higher-order entropies measure the communication system complexity by examining how signals interact within a repertoire at the two-symbol sequence level, the three-symbol sequence level, and so forth.

While Shannon worked in a logarithm to the base 2 space, Zipf worked in a more common logarithm to the base 10 space. Zipf also developed an additional relationship. He plotted the distribution of the logarithm of the signal rank plotted against the logarithm of actual frequency of occurrence (i.e. percentage repetition of that signal), and asserted an ideal system exhibited a slope of minus one. This slope is independent of the base of the logarithms used.

To develop these entropies, they emphasized the need for very large data sets. Just to obtain statistically relevant first-order entropy for a 27 symbol language (English letters plus a space) requires at least 351 two-symbol groups. For a seventh-order entropy, including a majority of English words in common usage, 888,030 multi-symbol groups would be needed. The task appears to be greater in dolphins where McCowan, Hanser & Doyle identified 102 whistle types among a sampling of 600 classified whistles. Considering whistles as vowels, their study did not include any consonants. This situation says the dolphin system studied was an open system. Including the additional symbols associated with the consonants would raise the number of symbols well above 102 and require exponentially more data samples to define the information capability of the language adequately.

They defined a whistle sequence by an intersequence interval of 1600 ms and a typical interwhistle interval within a sequence as 300 ms. **Figure U.3.7-1** shows a second-order probability tree for a two-whistle sequence. Illustrating a probability tree for a three-whistle sequence is awkward.

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[30] McCowan, B. Hanser, S. & Doyle, L. (1999) Quantitative tools for comparing animal communication systems: information theory applied to bottlenose dolphin whistle repertoires *Anim Behav* vol 57, pp 409-419

[31] McCowan, B. & Reiss, D. (1995) Quantitative comparison of whistle repertoires from captive adult bottlenose dolphins: a re-evaluation of the signature whistle hypothesis *Ethology* vol 100, pp 194-209

[32] McCowan, B. & Reiss, D. (1995) Whistle contour development in captive-born infant bottlenose dolphins: role of learing *J Comp Psychol* vol 109, pp 242-260

[33] Shannon, C. (1948) A mathematical theory of communication *Bell Sys Tech J* vol 27, pp 379-423 & pp 623-656

[34] Zipf, G. (1949) Human Behavior and the Principle of Least Effort. Cambridge: Addison-Wesley

Their paper contained much more information that clearly demonstrated (within the confines of the available data set) that the dolphin whistle repertoire was as sophisticated statistically as human language.

Markov & Ostrovskaya have demonstrated the entropy of the wide band sounds (0.5 to 120 kHz) of the bottlenose dolphin of the Black Sea can be described by a Zipf function. They provide a variety of functions obtained under two-way and one-way communications between calm dolphins and Sidorova et al. extended the studies to highly stressed animals[35]. They all but assert their findings confirm the use of language by dolphins. The suggested language consists of at least 100 structural types of blocks with the potential of well over 10^5 identifiable signal groups. They did not succeed in defining the semantic meaning of any individual words in their messages.

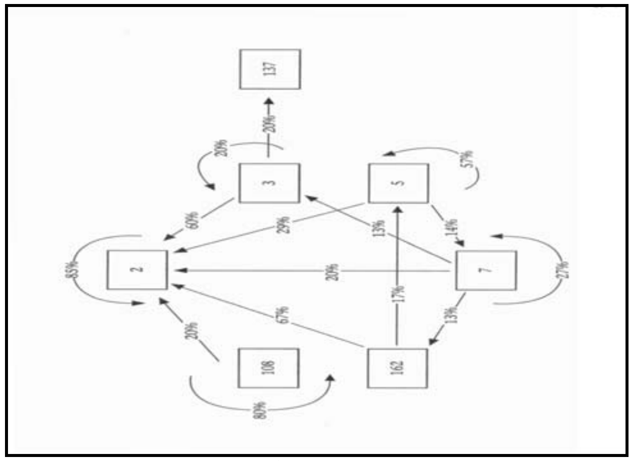

Figure U.3.7-1 One set of two-whistle sequences shown as a probability tree based on a Markovian first-order (i.e. Shannon second-order entropy) analysis. Percentages and direction of arrows shown represent the probability of one whistle type immediately following a second whistle type. A curved arrow indicates the probability that a whistle of one type immediately follows itself. From McCowan, Hanser & Doyle, 1999.

Boisseau has recently reported on bottlenose dolphins living in several fiords along the New Zealand coastline in considerable detail based on both broad and narrow band recordings[36]. Using a variety of correlation techniques, including principal component analysis and spectrographic cross-correlation, he has defined 12 principal sound components that may constitute principal speech components. His figure 1 providing a comparison of simultaneous broad band and narrow band recordings and assignment of potential semantic or phoneme labels is very useful.

U.3.8 A potential protocol for moving ahead

The material in the previous two three-level sections shows that the dolphin exhibits all of the cognitive, verbal and hearing capabilities to carry on sophisticated intra-species communications using acoustic techniques that are normally defined as language.

Reznikova has discussed the three primary potential methods of discovering the features of language in different species and given examples of the fragmentary cases where humans have discovered scattered elements of those languages[37]

Achieving a probable framework and initial vocabulary appears to be a tall order. As noted earlier, it will be much more difficult than standard code breaking where the character pool used is already known and traffic analysis can provide additional clues. The challenge appears to be to create a simple situation that is sufficiently stylized to involve only simple messages that do not involve a large potential for the appearance of synonyms or changes in grammatical order. This has come to be known as the “Rochefort test” in some communities. Rochefort suggests a scenario during the Second World War that caused the Japanese to use a specific expression in one of their encrypted messages that concerned their planned attack on Wake Island. Such a scenario could be arranged to cause one dolphin to send a message to another, such as “the portal to the other pool is open.” If this message could be recorded on multiple relevant occasions, some of the syntax and words in the message could be defined.

The initial attempt in this work will be:

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[35]Sidorova, I. Markov, V. & Ostrovskaya, V. (1989) Signalization of the bottlenose dolphin during the adaptation to different stressors *In* Thomas, J. & Kastelein, R. *eds*. Sensory Abilities of Cetaceans. NY: Plenum Press pp 623-xxx

[36]Boisseau, O. (2005) Quantifying the acoustic repertoire of a population: the vocalization of free-ranging bottlenose dolphins in Fiordland, New Zealand *JASA* vol 117(4), pt 1, pp 2318-2329

[37]Reznikova, Z. (2007) Dialog with black box: using information theory to study animal language behaviour Acta Ethol vol xxx, pp xxx

1. To adopt navigation as the initial basis for dolphin language as proposed by Kazakov & Bartlett.
2. To ignore the dictum of Wenger and assume the language includes nouns (and particularly personal nouns such as signature whistles).
3. To define a sufficiently restricted scenario that would be likely to contain a single sentence that would consist of a minimum number of grammatical variances and would be frequently repeated in the wild.
4. To design an experiment that would acquire sufficient communications records to allow a statistical search for this sentence.

Several potential scenarios can be developed through thought experiments.

Scenario A. This scenario will assume:
1. The presence of two dolphins in an estuary separated sufficiently that they cannot see each other but are close enough to communicate orally, and that they have not participated in any recent auditory communications.
2. The estuary exhibits a net positive flow toward the ocean even in the presence of tidal action.
3. The desire of the first dolphin to determine the location of the second dolphin and to proceed to arrange a rendevous.

Even this scenario involves a variety of options. The first dolphin can wait for the second dolphin to utter an irrelevant sentence or to issue its signature whistle, or it can call to the second dolphin to utter a relevant sentence.

Scenario B. This scenario will assume:
1. A first dolphin and a second dolphin from different pods meet in open ocean.

Scenario X. A potential scenario encountered by Jack Kassewitz.

Kassewitz has reported that at least one of his dolphins in Mexico has recently been observed uttering the same sound following a human whistle releasing them from a common acrobatic maneuver ***on multiple occasions***. This may be some sort of "OK" type of declarative statement, possibly like the "good day" used by flight controllers to terminate communications with a pilot. Since the maneuver involved a pair of dolphins, it may have been some sort of comment to its partner. Efforts are under way to check previous recordings and observe future exercises that might involve this same type of utterance. An effort will also be made to correlate this behavior with similar sounds from other dolphins (even within the potential range supported by different dialects).

U.3.8.1 A path ahead

To establish a starting point in exploring whether the dolphins use language, a number of propositions need to be addressed.

U. The difference between language and communications needs to be addressed in regard to oral signaling. It can be argued that animals communicate but do not employ language where language is identified by having a grammar. Some investigators attempt to define a dividing line between communications and the use of language based on the number of words a species can understand and/or the richness of the concepts that can be conveyed. Sometimes the presence of past and future tenses are considered a criteria.

2. A grammar can take many forms. It consists of arrangements of words representing a thought. The words are generally subdivided into those relating to a subject (S) performing some act, those describing the act and known as verbs (V), and those describing the object (O) acted upon. Clearly, there are less than a dozen orders in which these terms can be used. In English, the dominant grammatical form is a subject followed by a verb, followed by an object (S-V-O). In German, a more common form is a subject followed by an object followed by a verb (S-O-V). Professor McWhorter suggests this order is more common world-wide. Virtually all other combinations can be found in the languages of the world, including languages that consist of only single words combining S, O & V and expressing a sophisticated thought.

3.Human languages can be described using the expressions;

• tonal, those varying relatively continuously in intensity of the tones.
• stressed, those varying abruptly in intensity with definitive separation between syllables forming a single word.
• inflected, those varying in tone (frequency) between syllables.

To understand the variations in signaling that the dolphins might use to communicate, it is useful to review the recorded lectures of Professor McWhorter on human language[38].

Professor McWhorter discusses why languages developed, as well as why they differentiated over time. Many of the features of a language can be related to the environment and the culture of the speaker. As he pointed out, Proto-Indo-European had no word for palm tree, vine or Oak because of its origins on the plains (Steppes) of Southern Russia.

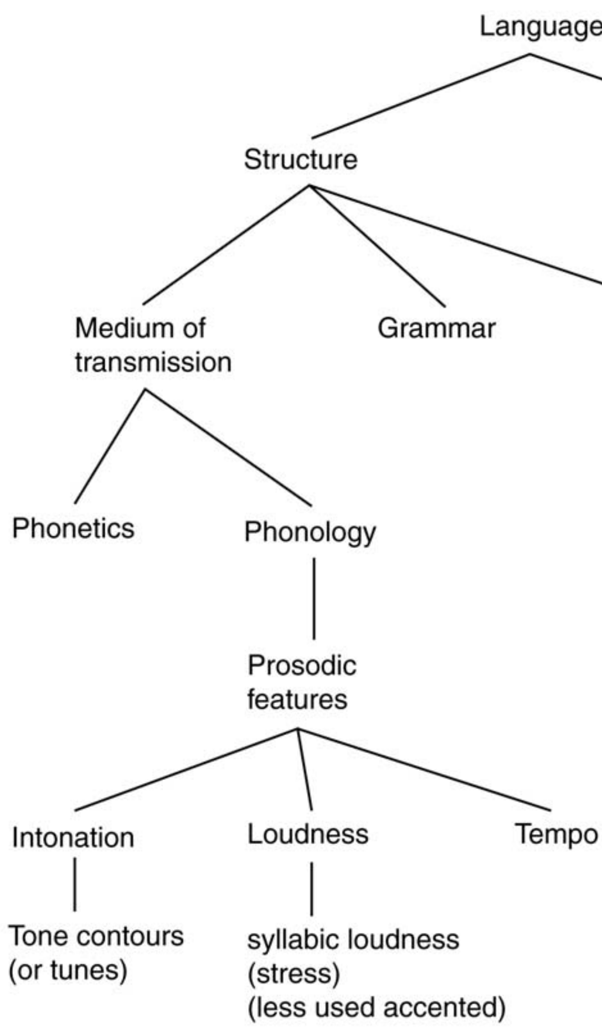
It is important to develop a scenario as to how and why dolphins might use language. A particular feature is their habit of hunting in packs in order to corral large numbers of fish before consuming them. The practice of river dolphins to proceed individually up river estuaries before coming together in a pack would suggest communications over distances of several miles and at least rudimentary language might be useful in achieving their goal. They clearly have the necessary communications skills. Whether they have the language skills is a subject of this discussion.

Many people have attempted inter-species communications with dolphins, typically using the audio bandwidth of the human, 200-15,000 Hz. Modern spectrograms of dolphins show their native audio bandwidth is approximately 2000-40,000 Hz. Initial wide band recordings of intra-species communications among dolphis suggest they use the entire bandwidth available for intra-species communications.

To attempt to discover whether dolphins use language in communications is a major code-breaking activity, not unlike some of the activities of the Second World War, including the Code-Talkers comprised of American Indians speaking a previously unwritten language.

The tree drawn based on Crystal helps understand the phonology of language. Prosodic refers to the metrics of speech and singing. Different languages adopt different rhythms. There are four sources of human sound as listed at upper right. They affect the timbre or quality of the voice.

[38]McWhorter, J. (2004) The Story of Human Language. Chantilly, VA: The Teaching Company (36 lectures over about 18 hours)



See David Crystal
Cambridge Encyldop.
of Language
NBPL 403 Crystal

Pharangeal
Laryngeal
Oral
Nasal

Pitch, loudness & tempo contribute to rythm

English is stress-timed
(stressed syllables at regular intervals)

French is syllable-timed
(all syllables ar regular intervals)

Latin: syllable length defines rythm

Oriental: Pithc height is defining feature

A means of decoding dolphinese has recently been studied in the human context by Park & Glass[39]. The technique is described as unsupervised in that it records isolated speakers on the same subject vebatim. It then cross correlates their speech sounds to determine similar phonetic sequences in both recordings. These sequences are then analyzed with respect to their adjacent context.

U.3.9 Dolphin sounds in the whistle range, 4 to 16 kHz

A problem with most of the recorded dolphin sounds to date has been their limited bandwidth. Most recordings have not exceeded a bandwidth of 24 kHz whereas the communications range of dolphins extends to at least 40 kHz.

Richards, Wolz & Herman have quantified the repertoire of the bottlenose dolphin in preparation for their mimicry experiments[40]. They reported their dolphin was comfortable whistling in the 4 to 16 kHz range with modulation rates of 0 to 11 Hz. Abrupt square, sine and triangle waveforms were mimicked with relative ease. Akeakamai preferred to whistle in the 5 to 10 kHz range. For sounds outside of that range, she generally transposed her mimicry to a frequency within that range. **Figure U.3.9-1** shows a sampling of whistles obtained from a pair of dolphins.

Because of the limitations of their equipment, Richards, Wolz & Herman could not know if the dolphin preferred a higher range or was in fact emitting a more complex signal that included a higher range. Most bottlenose dolphins are comfortable making sounds up to 40 kHz or higher.

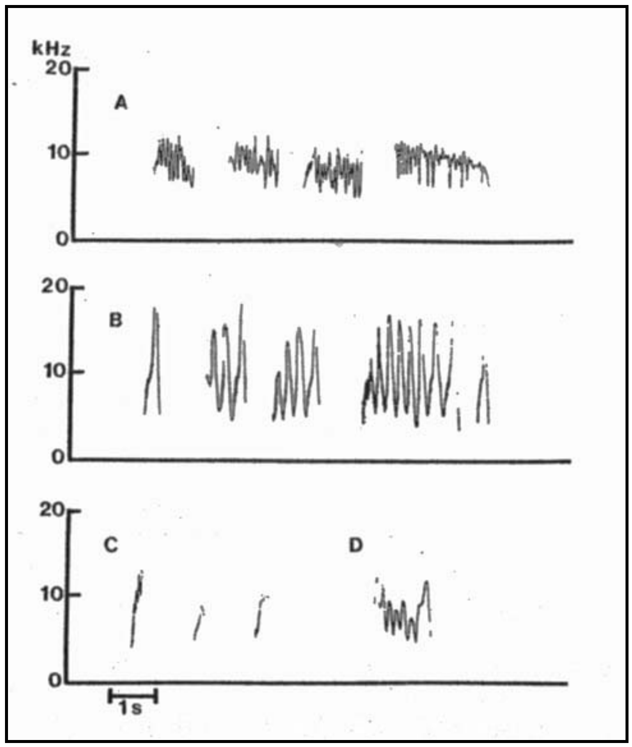


Figure U.3.9-1 Spectrograms at 50 Hz resolution from two dolphins. A; whistles characteristic of Akeakamai. B; whistles characteristic to Phoenix. C; short whistles of unknown origin. D; long whistles similar to those produced by both dolphins. From Richards et al., 1984.

[39]Park, A. & Glass, J. (2008) Unsupervised pattern discovery in speech IEEE trans audio, speech, and lang proces, vol. 16(1), pp 186-197

[40]Richards, D. Wolz, J. & German, L. (1984) Vocal mimicry of computer generated sounds and vocal labeling of objects by a bottlenosed dolphin, *Tursiops truncatus. J Comp Psych* vol 98(1), pp 10-28

Table of Contents

List of Figures