Dolphin vocalizations are a strong candidate for natural animal language.

By Dorian Leger, 2018

Between 1969 and 2003, Louis Herman trained two captive dolphins to comprehend visual and acoustic based artificial languages. The dolphins conclusively demonstrated their comprehension of semantic elements and syntactic rules by correctly interpreting original five word sentences. Since dolphins display the cognitive capacity for language, researchers have asked whether wild dolphin communication is naturally underpinned by language. Miriam Webster defines language as a systematic means of communicating ideas or feelings by the use of conventionalized signs, sounds, gestures, or marks having understood meanings (Webster, 2017). By this definition, preliminary signs of language in dolphin communication were discovered decades ago. For instance, bottlenose dolphins (*Tursiopis truncates*) and Atlantic spotted dolphins (*Stenella frontalis*) use signature whistles in an evocative manner, as unique names for each other. More complex dolphin signals, such as the burst-pulse sounds, were challenging to study until the advent of machine learning algorithms. Nowadays, equipped with new computing tools, researchers have successfully isolated fundamental elements and syntactic rules in burst-pulse patterns. Taking these three pieces of evidence together, the existence of a native dolphin language, with some degree of complexity, is probable.

Akeakami and Phoenix learn artificial languages

Marine biologist Louis Herman used a wide range to experimental methods to establish that *Tursiopis truncates* possess the cognitive capacity to comprehend artificial language. Over a 34 year research period at the Kewalo basin in Hawaii, two female dolphins, Akeakami and Phoenix were trained to comprehend artificial languages. Akeakami's language was conveyed via gestures by a trainer standing near her pool. Phoenix's language was conveyed via computer generated acoustic signals underwater. Akeakami learned different semantic elements, such as: objects, actions, relationships, and modifiers. Her language had two major sentence structure rules: modifiers precede objects, and objects precede actions. Akeakami's language was structured in the Object – Subject – Verb format to prevent word by word processing. The semantic elements and example sentences are shown below.

Semantic components	
Type	**Examples**
OBJECTS	FRISBEE, PIPE, HOOP, WINDOW, WATER, PERSON, SURFBOARD
ACTIONS	UNDER, OVER
RELATIONSHIPS	IN, FETCH
MODIFIERS	LEFT, RIGHT
INTEROGATION	QUESTION

Example sentences			
Words	**Example**	**Sentence Structure**	**Behaviour**
2	HOOP QUESTION	(Object + Interogration)	(Respond yes or no to hoop presence)
2	FRISBEE OVER	(Object + Action)	(Jump over the frisbee)
3	LEFT FRISBEE UNDER	(Modifier + Object + Action)	(Swim under the left frisbee)
3	SURFBOARD PERSON FETCH	(Object1 + Object2 + Relationship)	(Bring the person to the surfboard)
3	PERSON SURFBOARD FETCH	(Object1 + Object2 + Relational)	(Bring the surfboard to the person)
4	LEFT HOOP SURFBOARD FETCH	(Modifier + Object1 + Object2 + Relational)	(Bring the surfboard to the left hoop)
5	RIGHT WATER LEFT BASKET FETCH	(Modifier + Object1 + Modifier + Object2 + Relational)	(Bring the left basket to the right water stream)

Information sourced from: What laboratory research has told us about dolphin cognition, Herman 2010.

Akeakami and Phoenix were the first animals to interpret sentences in which both word meaning and word order contributed to sentence implication (Herman, 2010). Sentences of the sort *bring the person to the surfboard* and *bring the surfboard to the person* were tested (as shown in example 3 and 4 above). Both dolphins scored almost perfectly on these tests (Herman, 2010). However, much more complex sentences were also tested (using a maximum of five words), such as combinations of a direct object and indirect object, two modifiers on each object, and a relational term. This is presented in the five word examples above. Here again, the dolphins scored almost perfectly (Herman, 2010).

In another test, Akeakami was instructed to report on the presence or absence of objects in her pool. In linguistics, "understanding a symbolic reference to an absent object is a hallmark indicant of referential understanding" (Herman, 2010). Akeakami responded by pressing a yes or no paddle after the sentence object + question. She correctly responded *Yes* to 92% of 36 object-present trials and correctly responded *No* to 94% of 18 object-absent trials (Herman, 2010). Akeakami's accurate objects absent trials suggest she understood symbols as abstract referents to real world objects. In other words, researchers believe Akeakami constructed mental images of the objects symbolized by gestures (Herman, 29). Herman argues that the capacity for referential language may have evolved in dolphins because "echolocation creates a mental representation (an "image") analogous to that formed through vision, such that the dolphin, on drawing within visual range of an ensonified object already knows the visual identity of the object" and furthermore that "physiologically, the integration of the senses in the dolphin might be aided by the adjacency of the auditory and visual cortical areas in the dolphin brain" (Herman, 2010). These results, and many more conducted at the Kewalo Basin, demonstrated that these two dolphins possessed the cognitive capacity to learn important aspects of complex language. Therefore, wild dolphin vocalizations are a suitable candidate for a natural animal language.

Wild dolphin communication: signature whistles

Dolphin vocalizations are classified into four major signal types: whistles, echolocation clicks, burst pulses and chirps. Within a subcategory of the whistles, signature whistles exhibit an obvious linguistic pattern since they are being used as names. Signature whistles are currently the most studied dolphin signal. *Tursiopis truncates* and *Stenella frontalis* use signature whistles as unique names to identify themselves and other individuals. Dolphins emit their own signal and mimic another dolphin's signature whistle to address each other (Herzing, 2010). Dolphins also mimic signature whistles of dolphins not in their area, so as to locate specific individuals in the ocean, which suggests that signature whistles function as symbolic referents for individuals stored in a dolphin's memory (Herman, 2010). Dolphins are currently the only non-human species known to use a referential function likes names for each other. The referential function of signature whistles are a first clue for the existence of a natural dolphin language. However, much more information is expected in other types of signals, such as burst-pulses.

Wild dolphin communication: burst-pulses

Of the four major types of dolphin signals, burst-pulses, one of the most social vocalizations in dolphin communication, are now the subject of intensive study. Burst-pulses have high repetition rates between 200-1200 pulses per second (Luis et. al, 2016). Therefore, these vocalizations have been the most difficult to record, categorize, and study (Luis et. al 2016). However, based on their prolific use during socializing behavior, researchers believe they play a significant role in all odontocete[1] communication (Herzing, 1996). Researchers at the Wild Dolphin Project (WDP), in the Bahamas, are now applying machine learning to burst-pulse vocalization data, which is providing new results. The primary computational tool being used at the WDP is pattern recognition software called UHURA. UHURA is a system developed by Daniel Kohlsdorff at Georgia Institute of Technology that uses multiple algorithms to discover fundamental elements and regular expressions in vocalization datasets.

Evidence of linguistic structure

Dolphin datasets are first converted into spectrograms which track frequency of vocalizations on the y-axis against time on the x-axis. UHURA then learns distinct fundamental elements contained in the dataset, for instance an upsweep followed by a plateau may be repeatedly observed and labeled as a unit. Importantly, UHURA regroups these units together regardless of two typical transformations found in dolphin communication (and human communication), “frequency shift", the

[1] The taxonomic group of all toothed whales

whole signal is moved up an octave, and “time warping", the signal is stretched (Kohlsdorff, 2015). An illustration of a signal being recognized despite time warping is given below.

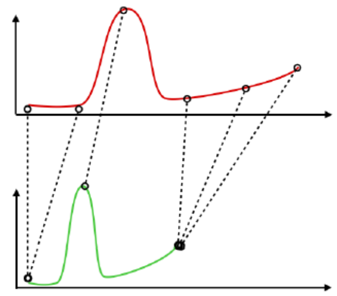

Figure 8: A Dynamic time warping example for two hypothetical time series X (Top) and Y (Bottom). The dashed lines indicate which sample from X aligns to which sample in Y.

Graphic from: Data mining in large audio collections of dolphin signals (Kohlsdorff, 2015)

If the above signal were commonly repeated, regardless of time-warp and frequency shift, it would be entered into a codebook. In human language, this would correspond to isolating all the phonemes of a speech. The whole dataset is then compared to the codebook and discretized into fundamental units. In a WDP dataset, fundamental units were discovered and labeled as letters. UHURA then discovered structural rules governing how these fundamental units were combined. Several rules were found, for instance, the fundamental unit labeled C often followed the fundamental unit J (Kohlsdorff, 2015). However, much more complex regular expressions were found. For example, the following patterns recurred often: the fundamental unit B or G, was followed by a B, then by B or Q, and so forth as illustrated bellow. This diagram shows two common expressions in dolphin vocalization datasets.

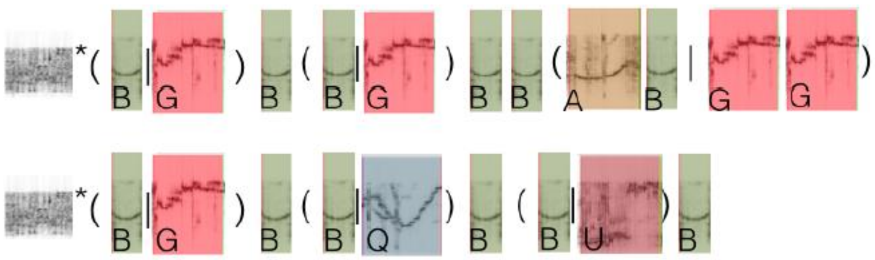

Figure 17: Two rules extracted from our data set. $(x|y)$ represents OR and $*$ represents a repetition of the previous symbol as often as needed to match the rule.

Graphic from: Data mining in large audio collections of dolphin signals (Kohlsdorff, 2015)

Data scientists believe these patterns indicate that dolphin communication encodes information using syntactic structure (Herzing, 2017). The discovery of fundamental units and structural rules in dolphin vocalization datasets suggests that dolphin communication is comprised of semantic elements and follows syntactic sense; both are a strong indication of complex language.

Conclusion

Contemporary evidence for the use of language in Bottlenose dolphins and Atlantic spotted dolphins is becoming significant. First, in captivity, Bottlenose dolphins have displayed the ability to learn and process artificial languages. Second, signature whistles are used a systematic symbolic references to identify individuals and therefore fulfill, to an extent, the definition of language. Finally, the study of burst-pulses is revealing complex patterns in dolphin communication, which are characteristic of semantic elements and syntactic sense. Considering this evidence, it is probable that dolphin communication is encoding a natural language. Yet, in the event that wild dolphin communication does not currently encode a language, this may not remain so for long. While the WDP works to decode dolphin language, they are also developing an underwater wearable two-way communication system, and teaching wild Atlantic spotted dolphins to communicate with divers. Given dolphins' propensity for language, whether researchers discover a fully formed natural language or whether they help to design one based on existing communication features in wild dolphins, it appears inevitable that humans will ultimately know another intelligent species using language on Earth.

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