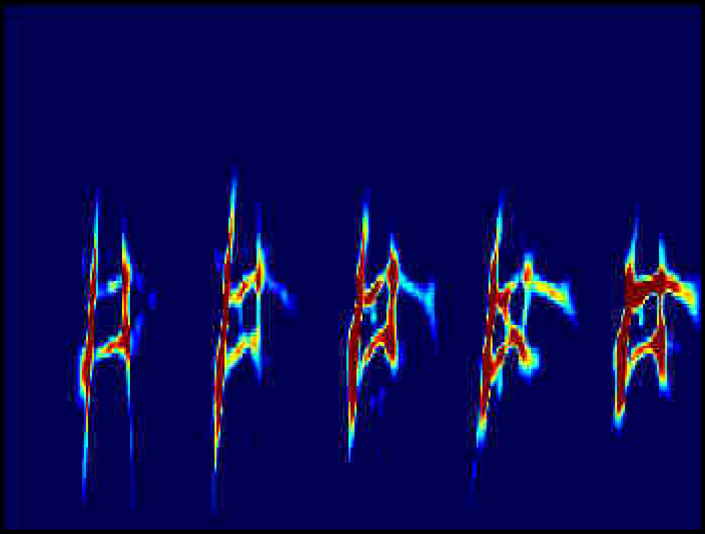
Excerpts from :

ORGANISATION OF COMMUNICATION SYSTEM IN TURSIOPS TRUNCATUS MONTAGU



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1. What kind of communicative system organisation can one expect to find in bottlenose dolphins?

The problem of the degree of complexity and semantic capabilities of the acoustic communicative system in bottlenose dolphins has been under discussion for over a quarter of a century, ever since John Lilly published his book "Man and Dolphin" Lilly, 19621.
Nowadays, there is an abundance of literature, with different viewpoints, but no consensus has been reached so far among researchers.

The problem proved to be very complicated, both methodologically and experimentally, while the methods used turned-out to be labour-consuming and, on the whole, inefficient; all kinds of straightforward attacks failed.

Meanwhile, one can try and assess potential capabilities of communicative system by analysing dolphins' mechanisms ensuring its productivity, i.e. the creation of signals and messages in amounts necessary for communication.

These mechanisms ensure the encoding of information and, in accordance with the theory, their functioning, in this way or other, affects the structure of signals and their sequences, in other words, it affects the organisation of communicative system.

(...)

What kind of communicative system organisation can one expect to find in bottlenose dolphins?
This species has a large, well-developed brain, with its cephalization index, absolute neocortex volume, relative area of non-projection fields and other "intelligence" indices close to those of the human brain (Ladygina and Supin, 1974; Morgane, 1978; Yablokov, 1983).

Bottlenose dolphins can solve various, sometimes complicated, logical problems, and their cognitive abilities reach a high level (Herman, 1980, 1986, 1987. Herman et al. 1984; Krushinskaya, 1983).

They have complex behavioural patterns in social groups which are typical for mammals with a rather highly-developed psychics; various patterns of co-operative behaviour are widely developed (Bel'kovitch et al., 1978a, 1978b).

Observations and experiments show that the co-ordination of individuals' actions in co-operative behaviour is achieved through exchange of acoustic signals (Bel'kovitch et al., 1978a; Morosov, 1970, Zanin et al., 1990).

All this indicates that the communicative system of bottlenose dolphins should posses great capabilities, which suggests a great complexity of organisation.
Therefore, bottlenose dolphins are most likely to have a syntactic or hierarchic communicative system (Markov, 1976).

2. Methods and materials

Signals were recorded on magnetic tape in situations allowing for the above conclusions: in free swimming isolated animals and during communication of isolated animals by the electro-acoustic link.

We recorded the signalization of animals in sea enclosures and in pools.
In all cases we got reverberation characteristics of the pools and sea enclosures for the working position of hydrophones. (...)

3. Organisation of signal structure

Bottlenose dolphins can produce signal structure with the help of 1 to 4 sound generators, each of them capable of working in a tonal or pulse regime (Markov, 1977, 1983; Markov and Ostrovskaya, 1983; Markov and Tarchevskaya, 1978).

A. WHISTLES

When working in the tonal regime, the generator produces narrow-band frequency-modulated signals (whistles). By varying the direction and rate of frequency variation, a dolphin can produce diverse and sometimes "queer" acoustic structures

FIG.1. Operation of one sound generator in the whistle regime. Graphic presentation of the sonograms.

(A) Generation of contours with various shapes.

(B-E) Ways of modifying the structure:

- (B) pauses in the contour, local spectral expansions, rhythmical pulsations of the contour;

- (C) local amplitude modulation of the contour by constant frequency, single and double "steps";

- (D) surges and waves in contours;

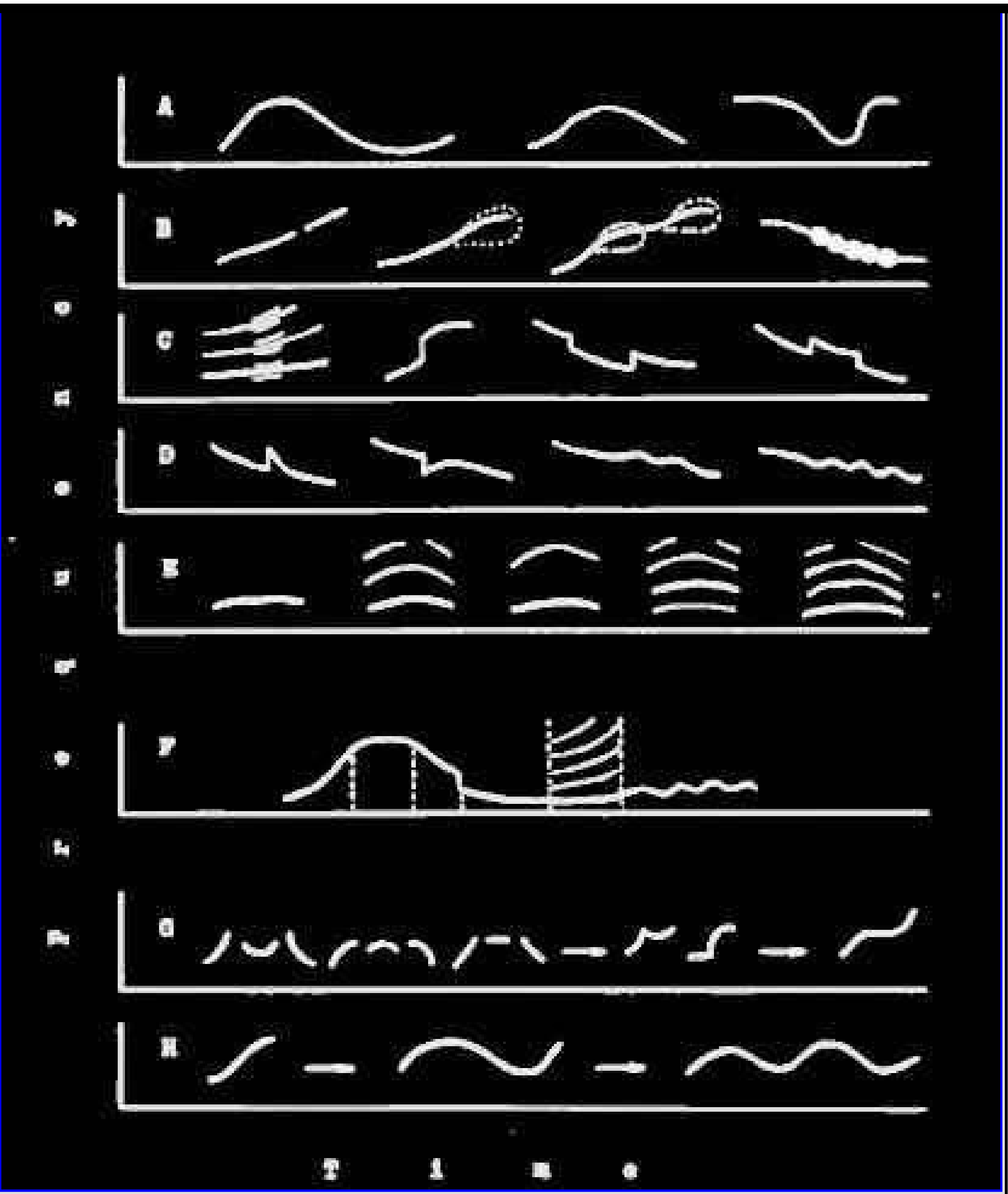
- (E) control of the number of overtones, generation of complete and incomplete harmonic rows, strengthening of the second harmonic, control of energy in harmonics.

(F) Discrete structure of the whistle obtained after successive application of

sound generation and modification methods.

(G) A set of simplest structural elements and generation of two- and three-element signals out of them.

(H) Successive stages in the generation of a complex rhythmical signal.



When analysing them, one notices that they are produced by arbitrarily alternating sections with a rather rapid increase or decrease of frequency and sections with a constant or slowly changing frequency.

As a result, signal structure becomes a chain of acoustically different elements and develops a contrast necessary for information encoding. Information capacities of such a system can be enhanced by changing the steepness of contour sections, by changing the limits frequency range, the register (the position of contour on the frequency axe) and duration, as well as by increasing the total number of elements in signal structure (its length).

Long, gently sloping sections of contours which are less informative, according to the information theory can be diversified by local contour modification.

Bottlenose dolphins possess a wide range of modification methods such as (Figs. 1-B, C, D, E) pauses (short-duration cessation of sound generation), local expansions and periodic pulsations of the spectrum, "steps" and surges of frequency in the contour, frequency and amplitude vibrato.

It is important for the discretization of monotonous contour sections that bottlenose dolphins can change the structure of the overtone part of the signal (change the number of overtones, create a complete or incomplete harmonic row and overtones which are not multiples of the principal tone, to strengthen or weaken certain overtones, to "transfer" energy from one harmonic to the other).

As a result of successive one-shot or repeated applications of various contour generating means, the structure of whistles becomes discrete and consists of several blocks with different phonations (Fig, I-F).

On the average, one can identify 5-7 blocks in the signal, though their number can reach 12.

Observations show that the structure of blocks is formed by the combination of simpler elements, i.e. there is a gradual complication of the structure.

Following the analysis of very short signals, we managed to identify 9 types of contours which can be regarded as analogs of initial structural elements which form the structure of signals (Fig. l-G).

They represent whistles ranging from 17 to 80 ms.

Actually, a whistle of any type amounts to an entire class of signals since, while having the same shape of the contour, they can differ in duration, frequency range, register and the rate of frequency modulation.

Successive combinations of several elements of the same type, but differing in register, makes it possible to generate signals or structural elements (blocks) of a second level which maintain the same operating regime of the sound generator throughout their duration (homotypical combination).
It is such blocks which we examined as discrete signal structure elements.

The boundaries between initial elements in homotypical signals and second-level blocks can be noticed only in very short structures consisting of 2-3 elements if the sound generator is operating to its utmost capacity.

Each element has a surge of amplitude.
With the increase of overall duration of second-level blocks and, consequently, with the increasing number in their structures, the frequency range of elements and the rate of frequency alteration the signal are decreasing.

So, the boundaries between elements are gradually smoothed and become less pronounced (Markov and Ostrovskaya, 1975).

Third-level structural blocks always are formed by a combination of second-level blocks with different characteristics (heterotypical combination).
The attachment between them is always smooth, with the existence of the structure transformation zone.

However, the boundaries between blocks are pronounced. At this stage, the signal's amplitude envelope becomes extremely complicated, because different second-level blocks have different amplitudes and amplitude peaks can be associated both with blocks and boundaries between them.

In general, heterotypical combining is characterised by clear-cut boundaries between structural elements, irrespective of their level; they also are fairly-well pronounced in very short second- level signals if those are formed by combining initial elements of different types (Fig 1-G). Third-level blocks are used for creating blocks of the next level or final signal structure.

B. PULSED SOUNDS

When operating in the pulse regime, the sound generator can produce batches of pulses, whose spectral and temporal characteristics in most cases depend on the preceding tuning of the generation system.

One can single-out three basic classes of pulsed sounds (below - "pulses"): clicks, clear blows and prolonged blows.

*** Clicks represent an aggregate class of 0.1-3 ms long pulses with various spectra, mostly differing in the distribution of energy in the spectrum and in duration: there exist wide-band and narrow-band clicks, clicks with several maxima in the spectrum.**

*** Clear blows are also an aggregate group. They are high-frequency pulses, 4-9 ms long. They are characterised by a triangular shape of the amplitude envelope.**

*** Prolonged blows are dense packages of strong low-frequency pulses whose duration can reach 60 ms.**

Fig. 2. Operation of one sound generator in the pulse regime.

(A-C) - Graphic presentation of the oscillograms,

(D-H) - sonagrams,

(A) Temporal organisation of the trains of pulses (primary grouping)

(B) alteration in repetition rate of pulses;

(C) alteration in the grouping of pulses;

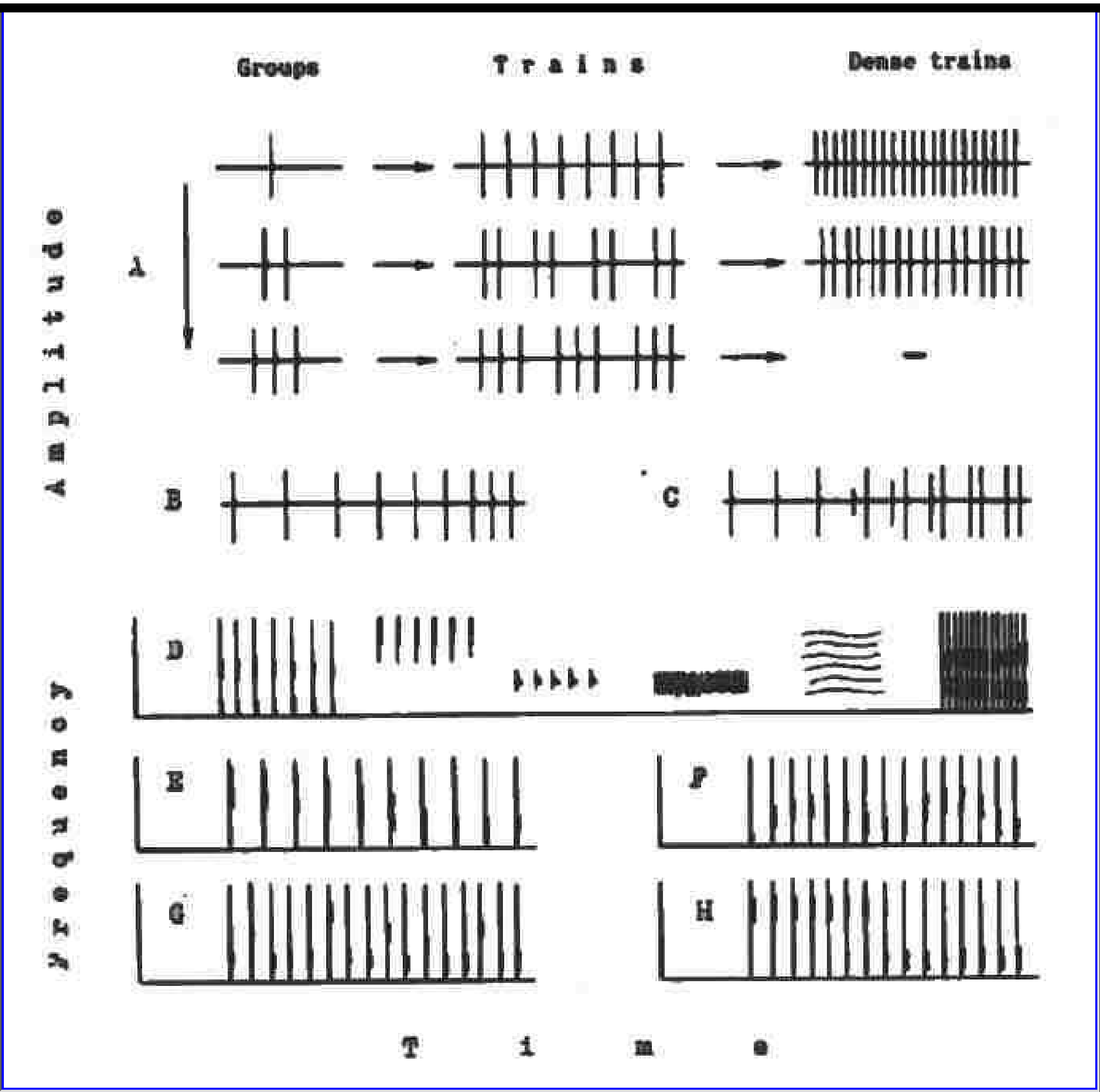
(D) examples of pulsed signals: three fragments of trains with different spectra, narrow-band noise signal, spectrum of a dense modulated train, dense train of pulses with a formant structure;

(E) shift in the location of the spectral peak;

(F) "spectral wave";

(G) energy "bursts";

(H) "pumping" of energy from one spectral maximum to the other.



By means of "primary grouping" (Fig. 2-A), pulses of the same type and with identical spectra can be organised in time in a certain way:

- single pulses are combined in groups containing 2-10 pulses;
- these groups, as well as single pulses, can be used to form train-sequences with different pulses density.

Though individual pulses and groups can be used occasionally as independent signals, it is trains which play the major role in pulsed signalization of bottlenose dolphins.

During sound generation, bottlenose dolphins can, either successively or simultaneously, change the density in a train, the grouping of constituent pulses or their spectrum, and such changes can be very rapid.

As a result, the ultimate structure of the signal will consist of different fragments connected by transformation zones, which result from successive combining of blocks with stable temporal and spectral characteristics.

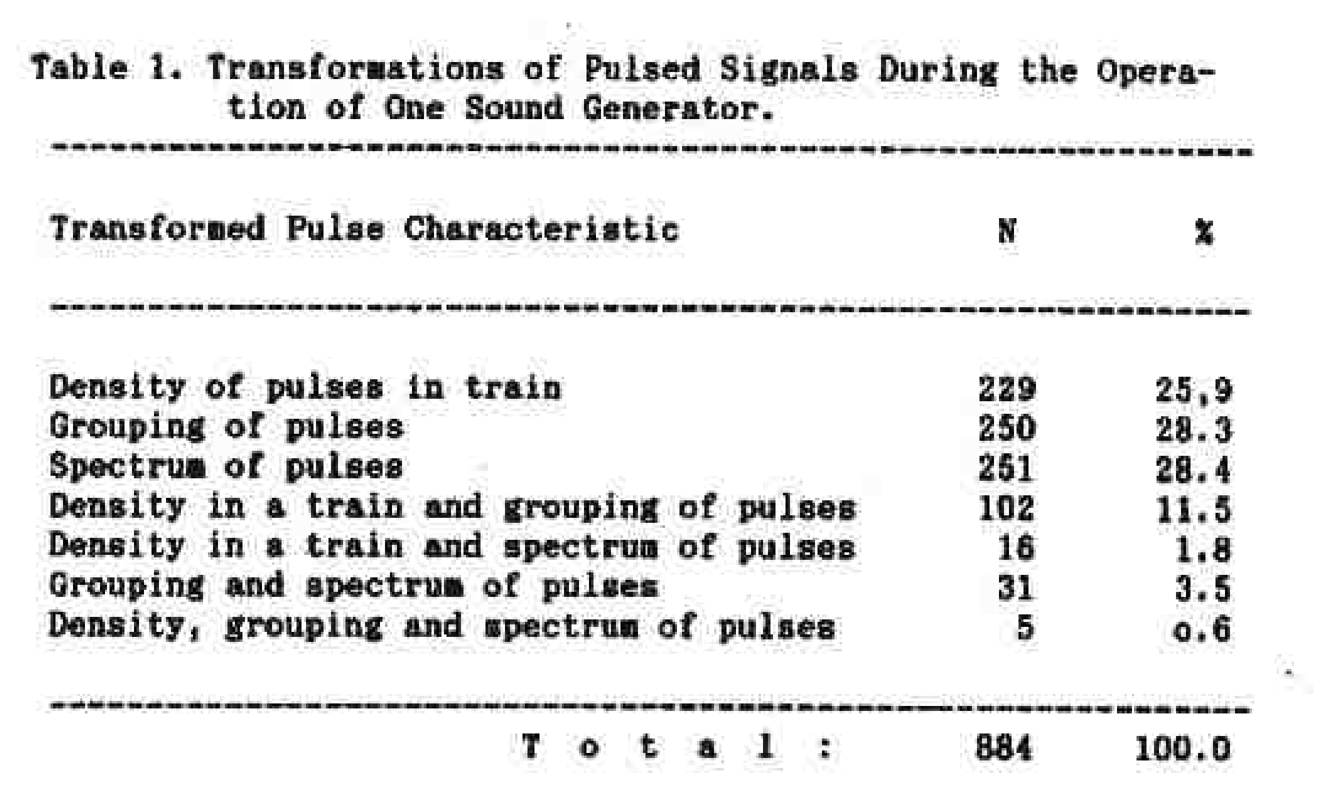


Table 1. Transformations of Pulsed Signals During the Operation of One Sound Generator.

Transformed Pulse Characteristic	N	%
Density of pulses in train	229	25,9
Grouping of pulses	250	28.3
Spectrum of pulses	251	28.4
Density in a train and grouping of pulses	102	11.5
Density in a train and spectrum of pulses	16	1.8
Grouping and spectrum of pulses	31	3.5
Density, grouping and spectrum of pulses	5	0.6
Total:	884	100.0

The analysis of events in transformation zones shows that when only one characteristic in a train has been changed (Table 1) various types of transformations occur with nearly the same frequency.

Simultaneous transformation of two or three characteristics is observed far less frequently which suggests limited combinatory capabilities of the sound generation system.

The data in the table allow us to make the conclusion that bottlenose dolphins have two different mechanisms of signal structure control, one of which controls temporal organisation of the train, while the other controls the spectrum of pulses.
The complexity of simultaneous control of their operation must be the cause of the above- mentioned limitations.

In addition, bottlenose dolphins have several specific types of spectral transformations.
They always are observed in prolonged simple (non-grouped) signal fragments with stabilised repetition rate of pulses and should be regarded as a way of modifying the train.

They include (Fig. 2-E, F, G, H) the shift of one of spectral peaks along the scale of frequencies, generation of a "spectral wave" in a train, "bursts" of energy, "pumping" of energy from one spectral peak to the other.

It might be possible that parts with such transformations should be treated as independent structural blocks of a signal.

It is interesting to note the existence of short signals in bottlenose dolphins signals, which are very dense trains (more than 200 pulses/s) wherein the area of spectral transformations covers the entire structure.

One can identify 4 major classes of such signals (Fig. 2-D) :

(1) narrow-band noise signals which, depending on the width of the spectral band, can sound like boots, hoarse whistles or frequency-coloured noises. They can have a certain of the second class can become trains of pulses (and back).
Signals from the third and fourth classes never make part of complex signals if their structure is formed by changing the sound generator's regime (they might become part of complex signals only if they are formed by two successively working sound generators).

The structure formation process of most pulsed signals is very similar to that of tonal signals, though, due to discreteness of initial elements, there are certain differences.
The primary grouping, which creates stable structural elements of the second (groups and non- grouped trains) or the third (grouped trains) level, can be regarded as an analogue for homotypical combining of initial tonal elements and the combination of those elements into higher-level blocks - as an analogue of heterotypical combining.

One can discover blocks of still higher levels in signalization.

If two sound generators participate in the formation of signal structures they can operate jointly in two ways : one after the other or simultaneously.

If two generators operate in succession, signal structure is formed by fragments alternately produced by different generators.
These fragments can be very diverse and are represented by

- trains of pulses differing in their grouping, spectral or density characteristics or the array thereof;
- tonal signals differing in register, contour shape, number of harmonics;
- noise signals, modulated trains.

In the formation of the ultimate structure of a signal, they are used as constructive elements.
Since there are no apparent restraints as to the compatibility of different types of elements and the nature of final construction is controlled only by requirements to information encoding, successive combining frequently results in generation of signals with peculiar structures (Fig. 3).
They are characterised by great internal contrasts on the boundary between fragments resulting from the rapid switch of generators.

In trains of pulses, the generators' switch-over time is extremely short. That is why, when different trains are joined together, generators' switching zone is typically unpronounced on signal structure; it sometimes can be detected through a certain change in the amplitude of pulses. However, the junction of fragments must be difficult if it is necessary to connect two fragments and to maintain the trend of the preceding fragment's contour (Fig. 3-B). In such cases, dolphins often make a 10-60 ms pause in signal, to give the second generator time for a finer tuning or switch the second generator a little earlier, so that there exists a little zone of overlapping fragments in the signal.

The last-mentioned way is used to generate signals whose structure emphasises the discreteness of its elements (Fig. 3-B, C, D).

One should bear in mind that each successively operating generators preserves all of its earlier- described capabilities, therefore one can also observe all earlier-described transformations and structural modifications within fragments.

C. WHISTLES AND CLICKS

In parallel operation, both generators work simultaneously for at least part of a signal's duration. New types of structural blocks are created in the zone of their joint operation, with combined levels higher than that of their components.
Since each generator can work in the tonal or pulse regime, such blocks can consist not only of either tonal or pulse component, but can include both, thus emerges a possibility to generate combined signals.

When generators are operating in parallel, they produce signals which are superimposed.
This enabled us (Markov et al., 1974) to give the name "superimposition" to this method of generating complex structures.

We observed no cases of both generators starting simultaneously.
One of them always started earlier than the other, thus forming the basis of the signal which was later overlaid by the output from the second generator ("superstructure").
Irrespective of the type of signals (pulsed or tonal) produced by a generator, the number of relationships between them might be limited:

Fig. 3 : Operation of two sound generators. Graphic presentation of the sonagrams.

(A) Simultaneously (parallell operation of two generators in tonal regime;

(B) successive operation;

(C) junction of different

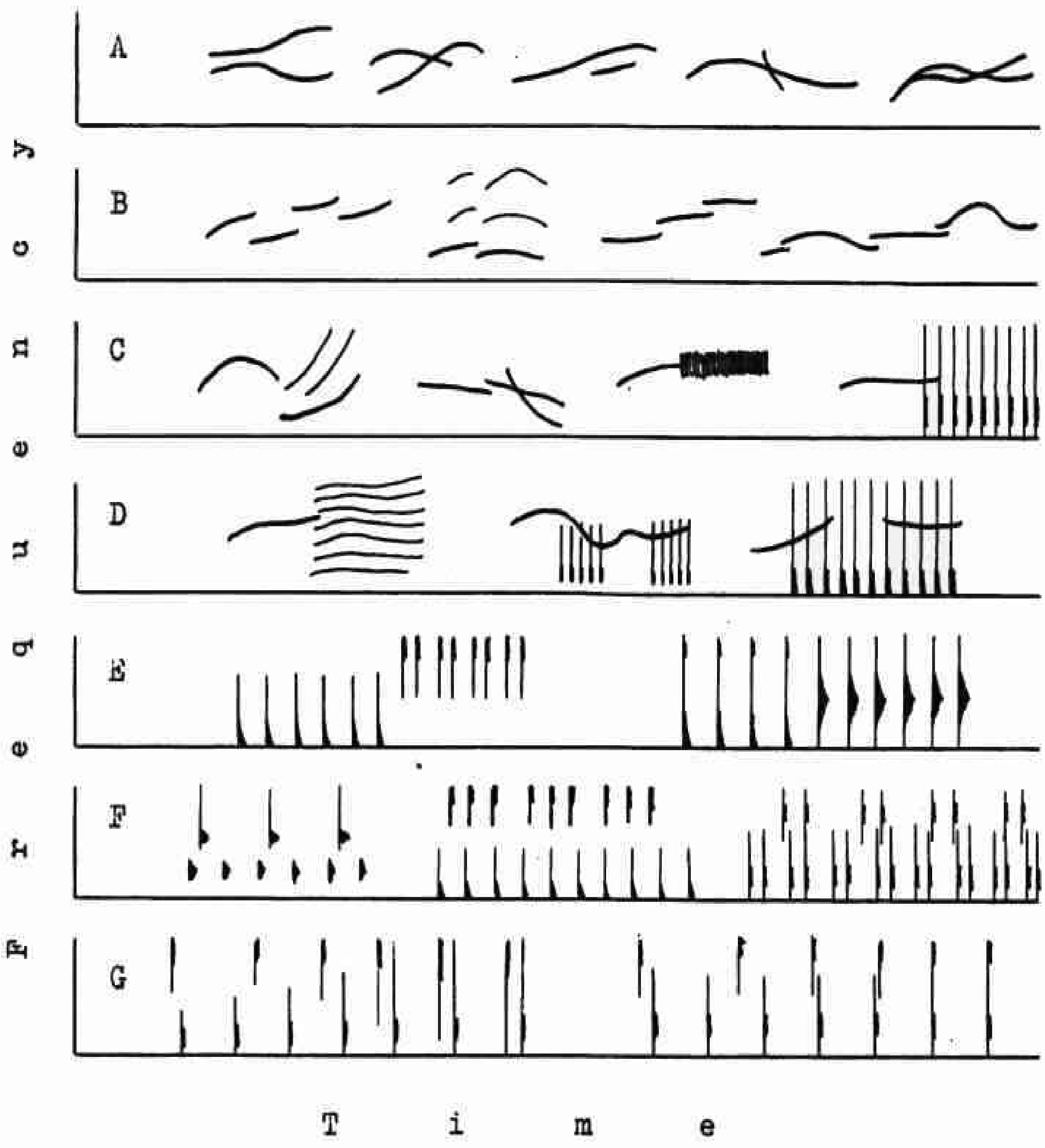
elements: various tonal components, tonal component and train of pulses;

(D) junction of a tonal component and a modulated train of pulses, examples of signals formed during simultaneous operatition of two generators, one working in the tonal regime, the other in the pulse regime;

(E) junction of two trains of pulses with different groupings and pulse spectra;

(F) parallel operation of both generators in the pulse regime;

(G) conjugation and synchronization.



(1) the superstructure alteration of the average frequency of pulse spectra;

(2) dense wide-hand trains pronounced formant structure.
The ration between formant frequencies can be multiple or not, and frequencies of formants can either remain constant or change in the course of signal duration;

(3) modulated trains of pulses which have a discrete spectrum and sound like bleating;

(4) dense trains of narrow-band pulses wherein the width of spectral peaks and location thereof on the frequency axis change simultaneously during signal generation.

Depending on the way these characteristics change, signals of this class sound like growling, howling, barking, mewing.

Signals from the first two classes can be used occasionally as second-level structural blocks in the formation of complex signals.

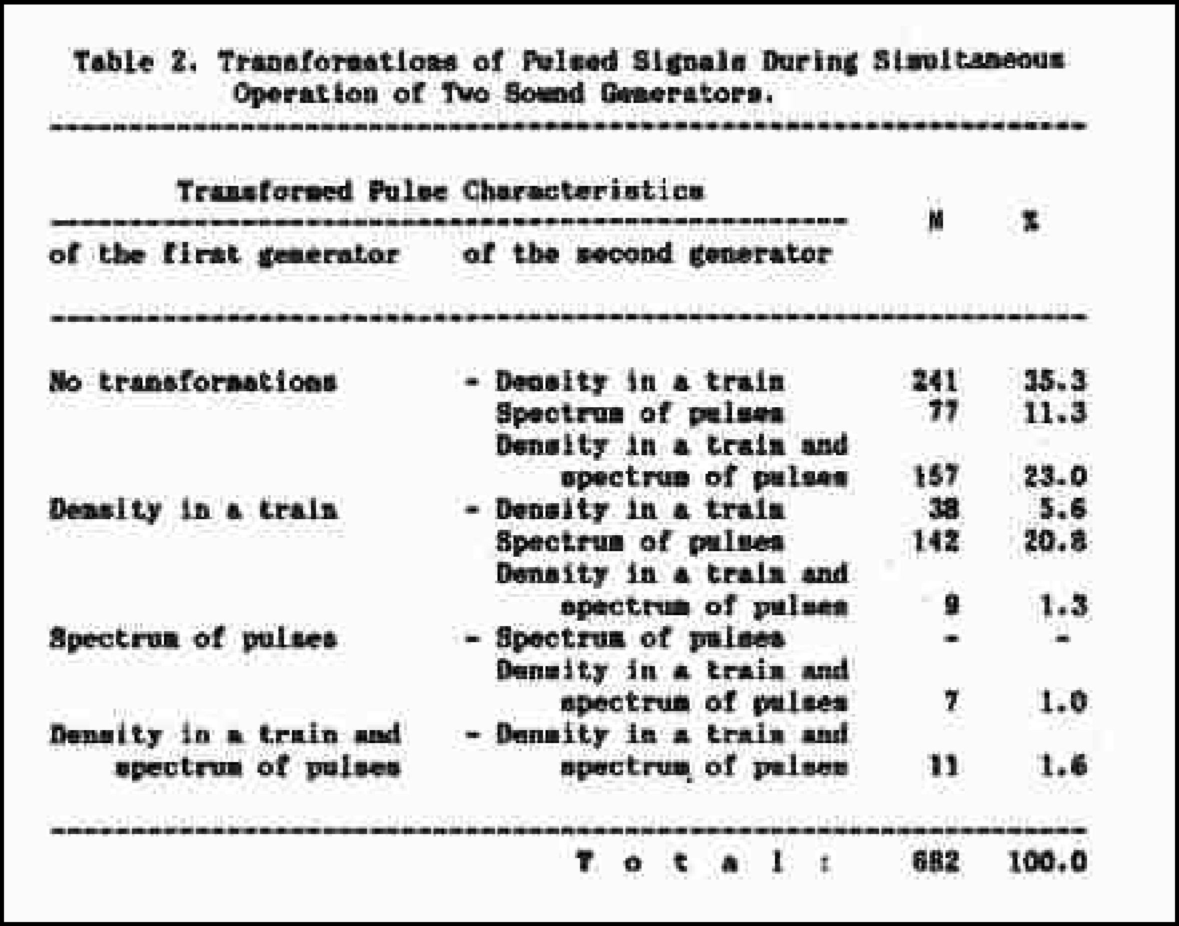


Table 2. Transformations of Pulsed Signals During Simultaneous Operation of Two Sound Generators.

Transformed Pulse Characteristics		N	%
of the first generator	of the second generator		
No transformations	- Density in a train	241	35.3
	Spectrum of pulses	77	11.3
	Density in a train and spectrum of pulses	157	23.0
Density in a train	- Density in a train	38	5.6
	Spectrum of pulses	142	20.8
	Density in a train and spectrum of pulses	9	1.3
Spectrum of pulses	- Spectrum of pulses	-	-
	Density in a train and spectrum of pulses	7	1.0
Density in a train and spectrum of pulses	- Density in a train and spectrum of pulses	11	1.6
	T o t a l :	682	100.0

In this, first class signals can turn into whistles, while those is superimposed on the basis in such a way that it stops sounding simultaneously with the basis or earlier;

(2) the superstructure is superimposed onto the end of the basis so that it stops sounding after the basis in which case inversion is possible (That is, later on the superstructure can be used as the basis);

(3) a pause in the superstructure in which case the sounding of the superstructure is interrupted for some time and is resumed, the signal having the same or absolutely different parameters after being resumed. These relationships make it possible to create complex signal structures, especially if they are used repeatedly.

Observations and study of signal structure make it possible to conclude that dolphins use these relationships between generators in a meaningful way.
Thus, in combined signals groups of pulses are confined to a certain contour area, and there are many instances when the same combinations of structural blocks with a high level of complexity are used in different signals.

However, the most illustrative example is the use of synchronization and conjugation (Markov and Tarchevckaya, 1978; Markov and Ostrovskaya, 1983) - two methods of mutual adjustment of generators aimed at creating rigid acoustic constructions (Fig, 3-G).

This is possible unly when both generators are working in the pulse regime and producing trains with different spectra of pulses and their frequency repetition rate.

During synchronization, the frequency repetition rate pulses in one train changes to become equal to their frequency repetition rate in a second train; at the same time, pulses produced by different generators are precisely matched to form pulses with an integral spectrum.

Synchronization of trains consisting of single pulses or of trains with the same grouping results in the formation of trains with a more complex spectrum than in initial trains. But if synchronization involves a train of single pulses and a grouped train, then pulses from the first train always are timed with the first pulse of the second train to form a grouped train where the first pulses in a group are spectrally different from other pulses; the total number of pulses in groups of the resulting train is equal to their number in groups of the initial grouped train.

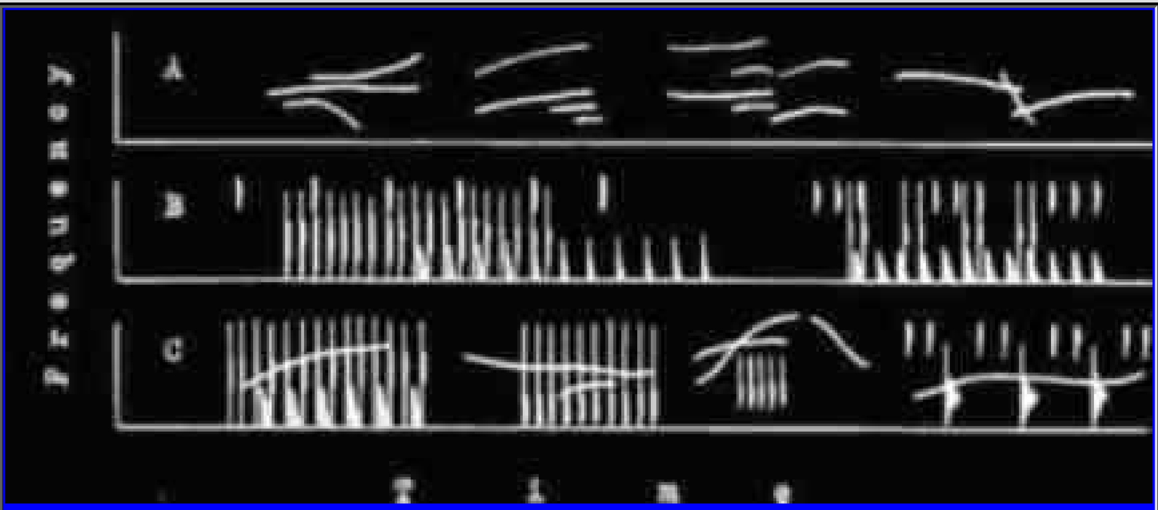


Fig 4 : Operation of three sound generators. Graphic presentation of the sonagrams,

(A) All generators norking in the tonal regime;

(B) all generators norking in the pulse regime;

(C) different versions of combined signals

The dolphins use synchronization abundantly : about 22% of pulsed signals with superimposition involve synchronization.

The mechanism of conjugation is very similar to that of synchronization, but in conjugation,pulses are not matched absolutely and the process consists in the formation of a train out of groups which are composed of pulses produced by different generators.

Two trains can be conjugated only if one of them is simple (that is, composed of single pulses). If both rons are simple, conjugation results in the formation of a train composed of pairs of spectrally different pulses.

But if one of them is a grouped train, groups in final sequence will contain one additional pulse, and pulses from the simple train always will be first and will be spectrally different from others.

Sometimes conjugation involves trains consisting of spectrally similar pulses.
Simultaneous use of two sound generators considerably enhances dolphins' combination capabilities. However, this also brings about problems of sound generation control which inevitably results in certain

losses.

Even a cursory analysis shows that if both generators are operating in the tonal regime, each of them loses the possibility to dynamically control the number and energy of harmonics.

If they are operating in the pulse regime, they lose the possibility to change the grouping of pulses in the process of signal generation.

The latter partially is made-up for by the possibility to pre-tune generators to any group regime.
In combined signals, if complex whistling is used as the basis, superimposition typically involves simple trains and if the basis is made-up of a train of pulses, superimposition involves tonal components with uncomplicated contour shapes (usually second-level blocks).

A more careful analysis reveals further constraints which are most seen clearly in train transformation zones when both generators are operating in the pulse regime.
Data in Table 2 show that it is so difficult to control the work of two generators that, in order to make any transformation in the structure of a train produced by one generator, dolphins stabilize the work of the second generator in 70% of cases.

Simultaneous alternation of two characteristics in one train or of one characteristic in each train (if these characteristics are associated with the work of different mechanisms) occur with the same frequency.
But if these transformations are associated with the operation of the same mechanisms, the frequency repetition rate of corresponding combinations goes down.

Up to 4 characteristics (for two in each train instead of three during the work of a single generator) can be altered simultaneously in the signal which more than makes-up for the losses, since it creates 9 versions of signal transformation.

If three generators participate in the formation of signal's structure, then, like in the case of two generators, they can work in succession or in parallel.
Unfortunately, the structure of signals formed by successive switching of generators does not allow one to determine how many generators are working.
This can be reliably determined only in some cases (if all generators produce tonal signals and are switched on with a certain lead-time to create an overlapping zone at the juncture of fragments - Fig. 4-A).

When working in parallel, generators can produce tonal or pulsed signals and, consequently, create structural blocks formed by superimposition of three tonal, three pulsed, two tonal and one pulsed, one tonal and two pulsed components ("double superimposition", Fig. 4-B,C).

Naturally, such blocks are more complex than their components and blocks formed by ordinary superimposition, The analysis of generators' capabilities shows that in case of double superimposition of tonal signals, each generator retains its ability to change signal frequency, though the range and the rate of alteration of frequency in most cases are reduced.

In case of double superimposition of pulse trains, only one characteristic can change at a time - density in a train or spectrum of pulses, since only one generator can change its work, while other generators work steadily in the pre-tuning regime.

Such superimposition rules out the possibility to conjugate trains of pulses, but creates the pO6sibility of successive double synchronization (i.e. synchronization of a simple train of pulses with a synchronized train).

Blocks by combining tonal and pulsed components are most diverse (Fig. 4-C), but their pulsed components have very stable characteristics. Synchronized trains are extremely widely used as part of combined blocks (up to 40% out of the number of blocks consisting of one tonal and two pulsed components).

Signals whose structure is formed with the participation of four sound generators are observed rarely in bottlenose dolphins.
While the share of signals formed by one generator accounts for about 55%, by two generators - 40%, by three generators - somewhat less than 5%, the share of signals formed by four generators constitute less than 0.1%.

This is in good correlation with observed losses in structure transformation capabilities which the growing number of simultaneously working generators, and undoubtedly is associated with increasing difficulties in the sound generation system control.

Evidently, these difficulties become maximum during simultaneous operation of four generators. Therefore, one should not expect generators to have great capabilities in such case. Unfortunately,we actually could not assess them, since all identified signals were a combination of tonal components with trains formed by double synchronization.

One can conclude that bottlenose dolphins have a wide array of tools to ensure operational control of the sound generation system.
Dolphins can create signals with a very complex structure by changing the working regime of certain elements of the system in the course of sound generation.
As it has been shown, this structure is discrete and consists of blocks with different levels of organization which were constructed by successive combining of simple "initial" elements from some basic set.

D. STRCTURAL FORMULAS OF SIGNALS

The complication of block structure can be traced reliably in the analysed material only as far as the first stages of heterotypical combining.
The identification of higher-level blocks (except when they are formed by ordinarv and double superimposition) and estimation of their stability and complexity (i.e. the number of combination levels) proves difficult because of a vast volume of analytical material and also because it is impossible to make direct comparisons of data to identify blocks.

That is why we made of graphic-symbolic language mentioned earlier in Chapter "Methods and Materials" which makes it possible to make a non-ambiguous description of signals and to construct their structural formulas within the limits of our asssumptions.

Ways of solving the above problems can be illustated without a detailed description of principles used for constructing the language and for developing exact structural formulas of signals. Therefore, here we will describe the simplest version.

However, let us agree that whenever we say that certain blocks are similar, the reader is to understand that we have made the required dierct comparison of analytical material and proved the identity of structures.

In order to describe the structure of signals, one has to introduce markers for participating elements and svmbols for. describing lincages between them.
Here we only will introduce symbols which are necessary for readin'g the examples given below (for instance, we will omit the description of whistle contours and of spectral characteristics of pulses).

Let us agree that:

- (W) stands for tonal components of signals, irrespective of the complexity of their structure.

- (C) pulses from the class of clicks;

- (B) pulses from the class of "clear blows".

- (P) - pulses from the class of "prolonged blows".

Stages of primary grouping and the structure of trains of pulses will be described by general formula :

I_n^m where

(I) - is the class of pulses,

(M) - the number of pulses in a group,

(N) the train density index.

Let us agree that

* M = 0, if we are describing single pulses or groups (in which case the index is not mentioned);

* M= l, if train density does not exceed 40 pulses/s.;

* M = 2, if train density ranges from 41 to 100 pulses/s.

Trains with still higher density (from 101 to 1200 pulses/s) will be denoted by **(Cr)**.

Thus, a single group of 4 clicks will be described as **C4** , a dense train consisting of pairs of prolonged blows as : P_2^2 etc.

Symbol (---->) will denote a smooth changes in characteristics of trains of pulses (density, grouping, spectrum of pulses or a simultaneous change of two or three of them);

(+) is junction of stable fragments of pulse trains produced bv differnt sound generators or junction of tonal and pulse components;

$\left(\frac{K^2}{K^1}\right)$ is superimposition;

K1 and **K2** are components produced by different sound generators, K1- being the basis, K2 the superstructure ;

$\left(\frac{K^2}{K^1}\rceil\!\lfloor\frac{K^3}{K^2}\right)$ is inversion (i.e. the use of the superstructure as the basis of the next structural block; the signal always has a section with only K2 sounding);

(:) is a pause in the superstucture (that is, a short break in the work of its generator).

Using these and other symbols, we described the structure of great number of signals produced by several adult animals.

With the help of analysis of formulas, we established that signals produced by bottlenose dolphins contain stable blocks of fourth and higher levels of complexity which are used as an entity in different signals.

Sometimes such blocks are used as independent signals.

For instance, block : $\boxed{C_1^2 \longrightarrow \frac{W}{C_2^1}}$ can be used both as an independent signal and as constructive element in various parts of complex signals :

1) $C_3^1 \longrightarrow \boxed{C_1^2 \longrightarrow \frac{W}{C_2^1}} \longrightarrow C_2^2 \longrightarrow C_1^1$

2) $\frac{P_1^2}{C_2^2} \longrightarrow \boxed{C_1^2 \longrightarrow \frac{W}{C_2^1}} \rceil\!\!\lfloor W$

3) $\boxed{C_1^2 \longrightarrow \frac{W}{C_2^1}} \longrightarrow \frac{P_1^1 : W + C_2^2 + C_2^2 \longrightarrow C_1^2 \longrightarrow Cr}{C_4^2}$

$$4)\ \frac{C_2^1}{W} \rceil\!\lfloor C_2^1 \to \boxed{C_1^2 \to \frac{W}{C_2^1}} \to \frac{W:W:W:W:P_2^1}{C_4^2} \rceil\!\lfloor P_2^1 \to C_1^1$$

$$5)\ \frac{\dfrac{P_1^1}{W}}{C_4^2} \to \frac{P_1^1}{C_2^1} \to \frac{W+B_2:B_2^2}{\boxed{C_1^2 \to \frac{W}{C_2^1}}}$$

$$6)\ \frac{C_1^2}{\boxed{C_1^2 \to \frac{W}{C_2^1}}} \rceil\!\lfloor C_1^2 \to \frac{W:W}{Cr}$$

Stable blocks with a more complex structure are also rather frequently observed, for instance :

$\boxed{\frac{W}{C_2^1} \to Cr \to \frac{C_1^2}{C_1^2}}$ as a structural unit makes-up part of

$$C_2^1 \to \frac{Cr}{C_1^1} \rceil\!\lfloor Cr \to \boxed{\frac{W}{C_2^1} \to Cr \to \frac{C_1^2}{C_1^2}}$$

Analys is shows that when producing a sequence of purely tonal signals, dolphins tend to combine two or three signals into one construction (uniting blocks of the 4th and 5th levels), the same type of combination also has been observed in pulses and combined signals.

It is quite possible that most signals are a combination of several large blocks.
The last-mentioned fact made us assume that hierarchical combining of structural elements observed at earlier stages, is a common principle used for creating signal structures and that any structural block can be used both as an independent part of a signal, and as a structural element for the formation of blocks with a higher degree of complexity.

The above examples support this idea, nevertheless, we conducted additional analysis of data to construct the entire hierarchical staircase for large blocks, starting from initial elements. One example is the formation of

block $\boxed{\dfrac{Cr}{B_1^2}}$ from **Cr** and B_1^2 which also can be observed as independent signals. This block

is used both as an independent signal and as a structural unit in the formation of complex $\boxed{\begin{array}{c} Cr \\ \hline B_1^2 \\ \hline C_2^1 \end{array}}$

which, as a stable block, forms part of complex signals:

$$1)\ C_2^2 \longrightarrow C_1^1 \longrightarrow \boxed{\begin{array}{c} Cr \\ \hline B_1^2 \\ \hline C_2^1 \end{array}} \qquad 2)\ Cr + C_2^1 + Cr + \boxed{\begin{array}{c} Cr \\ \hline B_1^2 \\ \hline C_2^1 \end{array}}\ ,etc.$$

We identified structural blocks formed with the participation of seven combination levels, but in most cases dolphins use simpler blocks (with three to six combination levels).
The structure of real signals is a combination of blocks with various degrees of complexity.

Multi-level combination is a tool for creating a variety of acoustic constructions with different qualities. If we know the set of initial elements, the number of combination levels, the indices describing the participation of blocks from different levels in the formation of signal structure, as well as the indices

describing the increase in the number of combinations attainable at each combination level, we can estimate the potentially attainable vocabulary, but at present we do not have enough data for such estimations.
That is why we will apply a different method.

Since signal structure is generated in time, a signal is a chain of differently sounding blocks (irrespective of their complexity).
The number of such blocks in a in a signal arises from 1 to 24, averaging to 5-7.
The number of structural types of blocks has not been established definitely, but it is well over one hundred.

Using this data and standard formulas from Games Theory, one can calculate easily that 1012 signals could be produced by means of free combining.
True, it is a potential estimate, but even if we assume that, because of code-associated or physical block combination bans, only one tenmillionth of them actually is used, still there remain 105 signals available for communicationt which certainly is more than required for actual communication.
All this makes it possible to think that the communicative system of bottlenose dolphins is "open" in terms of vocahulary formation.
This conclusion is indirectly supported by the fact that dolphins use hundreds of structural types of signals for communication (see, for instance, Table 3).

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4. Organisation of signal sequences

It is rare that bottlenose dolphins produce single signals. As a rule, this is typical of very young or isolated adult animals.

In normal communication, the intensity of signalization is very high, reaching sometimes 50 signals per minute.

In free dialogue (for instance, during communication of isolated animals through electroacoustic communication link), signals with different structures are combined into groups, the way human words are combined to construct phrases.

Grouping is well-pronoulnced in normal conditions of communication between calm animals but it drastically changes or disappears in stressed situations, when the frequency range of communication is severely restricted or communication between individuals is broken.

In a number of situations, when dolphins mostly are using tonal signals, one can indentify sets of tonal signals with a common structure component.
The analyses of variability of signals from the set, has shown that their middle sections are most stable, while edge sections (especially those at the end) are extremely variable.

Variability behaves differently in groups composed of different signals.
This allows one to assume that the order in which signals follow each other in groups, is meaningful for

the animals and that the described variability depends on the interaction of signals and, consequently, on the existence of organization in a sequence of signals.

This assumption is supported indirectly by dolphins producing groups with identical composition, sometimes consisting of signals with very complicated structure.
This assumption is rather non-trivial and actually recognizes the ability of bottlenose dolphins to generate organized messages (text).

Certainly, it still has to he proved. Unfortunately, semantic control of messages is impossihle for our case, so such proof has to be obtained with the help of different method. We will applied the rank distribution method which is used widely in systems analysis. (to be continued....) .

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