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Communicative intelligence: from biology to design perspectives

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Abstract: In nature, organisms communicate to each other exchanging key information, primarily for intra and interspecific recognition (e.g., between parents and offspring, predators, members in a herd's hierarchy), as well as for defense, attack, or attraction. The fundamental types of animal communication involve chemical signals, such as pheromones, as well as, auditory signals sound, tactile interactions and visual signals, including colors, shapes, patterns, and movements. All organisms aim to enhance their fitness, which refers to their ability of surviving and reproducing. In this perspective, communication plays a crucial role in pursuing these goals. Nearly every organism in nature employs complex visual strategies based on communicative hierarchies of colors and shapes to highlight, emphasize or conceal body parts, send messages, convey intentions or physical states, indicate gender or demonstrate social hierarchy. All of these communication aspects represent a vast repository of unconventional communication codes that designers can use and be inspired by. In this complex framework, the article presents case studies of natural communication processes and models from various branches of biology, exploring their potential application in communication protocols that can be applied to artifacts and diverse technical fields.

Keywords: Natural intelligence - Biological communication - Adaptiveness - Multisensorial design - Bioinspiration - Biomimetics - Colors - Sounds -Vibrations - Interactions

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Communication in nature

Communication in nature encompasses a vast array of methods through which organisms exchange intra- or interspecific information. This form of intelligence is fundamental to recognize and be recognized by others (parents and offspring, hierarchy position, predators and prey), to attack, defend and attract mates during courtship as well as support other critical interactions that enhance survival and reproductive success (Bradbury, Vehrencamp, 1998). The need to communicate involves all the kingdoms, from Bacteria to Eukarya in which the variety of conditions and necessities, determined the evolution of a wide variety of communication strategies and systems.
Organisms use a variety of signals to communicate with one another. These signals can be visual, chemical, acoustic, mechanical, or tactile, which must be decode by other organisms to respond and interact effectively. The concept of adaptation plays a crucial role in communication, as organisms must develop specific traits that enhance their ability to communicate within their species. These adaptations can involve specialized anatomical structures, such as intricate visual and acoustic signals, or complex behaviors that improve communication efficiency.
The biomimetic approach can draw inspiration from natural communication methodsabstracting and transferring them from biology to develop design codes to use in artifacts. Key biological communication pathways include the chemical signaling of pheromones and other substances (Wood & Resh, 1984), the creation of auditory signals (Hopp, Ow-

ren, Evans, 2012), tactile stimulation, and the display of visual cues such as colors, shapes, patterns and movements (Osorio, Vorobyev,2008). All organisms, or genotypes, aim to increase their fitness, a measure of survival and reproductive success, and communication is central to achieving this goal (Patricelli, Hebets, 2016). The study of biological communication systems provides designers with insights that can be translated into a variety of forms, whether concrete or conceptual, systematic or detailed.
Evolution shapes communication, with processes adapting over time to meet environmental changes or social dynamics. For example, some studies suggest that birdsong has evolved to become more complex over time, aiding in competition for resources and mates. This evolving complexity in communication is of great interest to designers, as it provides insights into creating more reliable and efficient systems, including multimodal and multisensory communication
In design, it is also crucial to understand the role of biological communication in relation to behaviors and physiological processes of the human species and their integration in social sciences (Penn, 2006).

Visual communication

Visual communication in nature involves specific colors or chromatic patterns that organisms use to communicate whether within their species or with other species. Nature often applies visual and complex strategies utilizing hierarchies of colors and shapes used to underline, accentuate or hide body parts, messages, conditions, positions or intentions. These strategies offer designers a wealth of unconventional and creative ideas for their work. The concept of using design to attract buyers or customers is similar to how organisms use visual signals to attract mates, providing a rich source of inspiration.
A captivating example is the Japanese snipe, *Gallinago hardwickii*, which amplifies its display flights during specific lunar cycles to attract female partners. The females are more easily identifiable in low-light conditions due to the reflection from their white feathers in the moonlight (Penteriani & Delgado, 2017). Peacocks and certain fish species use a unique form of color, known as structural color, which has a characteristic luminescence to attract mates. Structural color is an optical effect caused by the interaction of light with microscopic and nanoscopic surface structures. When examined under an electron microscope, some natural materials like the yellow beetle's shell, peacock feathers, or the wings of *Cyanophrys remus* or *Albulina metallica* butterflies, reveal complex nano-structures that reflect light to create vivid chromatic effects without pigments (Biró *et al.*, 2007).
The dichroic effect, a particular structural color present in transparent materials exposed to light that makes them iridescent and color changing depending on the point of view of the observatory, was already known by ancient Romans. Lycurgus's cup, a glass cup from Roman times collocated in the IV century and now exposed in London at the British Museum, presents a color variation from green to red. The iridescent effect is conferred by tiny gold and silver particles in the glass matrix that interfere with the environmental light (Whitehouse, 1989). Since then, many other complex techniques were developed to pro-

duce dichroic glasses with much higher costs compared to the glass' finishing and decorating. Plastic material factories produce translucent polymeric films, available in different tones, that overlapped on transparent or opaque surfaces consent to different products the possibility of manifesting dichroic effects, with affordable prices. Many designers accepted this new material with enthusiasm, interpreting it with aesthetic intentions primarily in many different applications, aiming to strengthen the experimental component of environment and artifacts, resulting in attractiveness and recognizability translated in marketing advantages (Bahadur, Sampica, Tchon, Marzen, 2013).

The dichroic effect is a type of structural color observed in transparent materials exposed to light, causing them to appear iridescent and change color depending on the angle of view. This effect was known to the ancient Romans; for example, Lycurgus's Cup, a Roman glass artifact from the 4th century and currently exposed at the British Museum in London, displays a color shift from green to red. This effect is due to tiny gold and silver particles in the glass that interact with ambient light (Whitehouse, 1989). Since then, various advanced techniques have been developed to produce dichroic glass, which is typically more expensive than traditional glass finishes and decorations. Today, manufacturers create translucent polymeric films in various hues that can be overlaid on transparent or opaque surfaces to achieve dichroic effects at a lower cost.

Many designers have embraced these new materials with enthusiasm, applying them creatively across a wide range of applications. By focusing on the experimental aspect of environments and artifacts, these designers aim to create visually appealing and recognizable works that offer marketing advantages (Bahadur, Sampica, Tchon, Marzen, 2013).

In 2011, New York-based design firm SO-IL created an installation for the porcelain brand Meissen at the Kunsthal KAdE in Amersfoort, Netherlands. The exhibit featured transparent dichroic film used to construct pyramidal display cases that protected the ceramics. These pyramid-shaped enclosures refracted light, creating colorful effects that shifted depending on the viewer's angle and the overlapping of the pyramid's surfaces. This made the all-white ceramics appear vibrant and dynamic, offering a unique visual experience. SO-IL applied a similar concept in other exhibitions. For example, during the 2019 Melbourne Design Week, the firm designed the Viewing China exhibition at the National Gallery of Victoria, showcasing Chinese ceramics on dichroic pyramid bases. These bases provided the same eye-catching chromatic effects, with the ceramics changing color based on the viewer's perspective. In 2014, at the Salone del Mobile in Milan, SO-IL designed the Dichroicarus installation for Wallpaper magazine. This installation featured a flying cube composed of multiple layers of dichroic film. The movement of induced wind created mesmerizing iridescent effects and reflections, adding an interactive element to the installation. Through these installations, SO-IL showcased their innovative use of dichroic film to create immersive, visually striking exhibits that transformed the appearance of the displayed objects based on the interplay of light and angles.

The Prism installation, designed by Taipei's 22 Studio, is a unique sculpture that explores the concept of volume. It features a parallelepiped structure filled with dichroic panels set at different angles, creating optical effects that play with the intersections of solidity and emptiness, colors, and light. This results in a disorienting experience for viewers. The A1

version of this installation was exhibited at the Fuorisalone in Ventura Lambrate, Milan, in April 2015.
In 2016, designer and light artist Chris Wood presented a series of special works for Fendi's fashion house showcases around the world. These works consisted of small rectangular pieces of transparent dichroic material, arranged and fitted together to hang on vertical walls at various angles. This arrangement created a dynamic effect that seemed to change as one moved past the installation. Following this success, Wood applied the same concept to a series of decorative panels with different geometric patterns. He also created site-specific installations such as "Light Shower," where small dichroic parallelepipeds were placed on a window pane in a circular arrangement, casting a spectrum of colors into the indoor space.
Another of Wood's site-specific works is "Corona," a sculpture installed in a water tub. Here, dichroic glass is arranged in a radial pattern, reflecting sunlight in an iridescent manner and creating a captivating interplay of light and water. In "Chroma," located on the southern façade of Cambridge's Premier Inn tower, the dichroic panels reflect daylight in various ways, depending on the angle of incidence, which changes with the seasons, weather conditions, and time of day. Chris Wood's work demonstrates how dichroic materials can create interactive experiences without the need for digital or electronic technologies. These materials are valued for their ability to produce a sensory experience through simple manipulation of light and color, making them attractive to companies that wish to convey innovation and creativity through their installations. Beyond art installations, dichroic materials are also used in the creation of accessories and furniture, emphasizing their versatility and broad appeal.
The foldable screen "And A And Be And Not", created by Camilla Richter, features small dichroic glass pieces that interact to produce light interface, darkness, transparency, reflections and color changing. Sponsored as a communication medium by Prinz Optics, this piece exemplifies the innovative use of materials in design. Jean-Baptiste Fastrez designed the "Moto" wall lamp for Moustache, where light is filtered through a helmet visor-inspired diffuser made of dichroic material. Fastrez also created the Scarabée vase, inspired by the jewel beetle's structural color. This hand-made glazed ceramic vase consists of two interlocking shells connected by an elastic band. The Scarabée vase won the Wallpaper Design Award in 2015. In 2015, Patricia Urquiola designed the Shimmer collection for Glas Italia, which includes glass furniture and dichroic laminate pieces such as tables, mirrors, shelves, and consoles. Sicilian designers Formafantasma explored this captivating material in their LED lamp projects like Colore-Test3, Colore-Test7, and Colore-Test1. These lamps, displayed at the Anno Tropico exhibit by Peep-Hole at Fonderia Battaglia in Milan in February 2016, highlight the chromatic effects of light passing through dichroic glass. The exhibit sought to investigate the functional and expressive qualities of modular light, allowing for a dialogue between different materials, techniques, and optical effects such as biconvex lenses, color overlaps, enlargements, and reductions.
Elise Luttik's Prismania Chair is another example of innovative design using dichroic materials. The chair appears transparent or changes color based on the viewer's perspective. Modern sunglasses, like the Oakley Plutonite Thermonuclear Protector, use dichroic effects to shield harmful ultraviolet rays while allowing visible light to pass through.

The Day&Night Light lamp, designed by Eleonore Delisse, exemplifies the use of dichroic materials aimed at mitigating circadian rhythm dysfunctions. The human sleep-wake system can be disrupted by seasonal variations or diverse lifestyles, leading to Seasonal Affective Disorder (SAD) affecting millions worldwide. Fluctuating illumination levels during winter or summer can disturb hormonal synthesis and disrupt these cycles. Addressing this issue, the Day&Night lamp adjusts light intensity based on the season or time of day. Its LED light passes through dichroic glass that varies its color emission depending on the angle of incidence. Guided by an automatic system operating on a twenty-four-hour cycle, the lamp moves to synchronize with the user's day-night rhythms. In the morning, it emits a gentle blue light to reduce melatonin and enhance alertness, while in the evening, a warm amber light promotes melatonin production to aid relaxation. This cyclic modulation aims to rebalance individuals' biological clocks and alleviate circadian imbalances.
In the realm of communicative visual design, natural references provide abundant inspiration, particularly through sophisticated forms of mimicry and emulation seen in various organisms. Two primary types of mimicry include cryptic (Quicke, 2017), where organisms blend into their environment through color and pattern adaptation to evade predators or prey, and faneric mimicry (Pasteur, 1982), where one organism mimics another to benefit from the latter's perceived characteristics. Batesian mimicry is a specific form within faneric mimicry, where harmless organisms mimic dangerous or undesirable ones (Mappes, Alatalo, 1997). For example, the owl head butterfly (*Caligo idomeneus*) has wing markings that resemble owl eyes, deterring predators (Quesnel & Stradling, 2012). Mimicry also occurs in plants; certain orchids emulate wasp bodies to attract pollinators (Brodmann *et al*., 2009). In Müllerian mimicry, species like Zygaena moths, *Cercopis planthoppers*, and *Cleridae beetles* share aposematic red and black colorations, benefiting all involved species by reducing the number of individuals sacrificed for predator learning (Sherratt, 2008). This shared strategy benefits all species involved, as predators spend less time learning to recognize one type of warning signal rather than a different one for each species.
For instance, the red and black aposematic colorations are shared among various *Zygaena* moth species, the *Cercopis bloody* planthopper, and the *Cleridae Trichodes* apiarus. In design, this strategy could be applied to co-branding systems, conveying a common message efficiently through shared codes, even if they come from different and distant sectors.
In Batesian mimicry, harmless species imitate more dangerous ones, as seen with the coral snake (*Micrurus fulvius*) mimicking the milk snake (*Lampropeltis triangulum*) (Greene & McDiarmid, 1981). The biological motivation behind this mimicry is that if an organism is always lethal, no predator would survive to learn and share the level of danger in the prey's behavior. Using an aposematic code recognized by predators benefits the mimicking organism.
In design, this strategy can translate into a communication pattern that allows a message to be conveyed from one context to another, such as promoting sustainability through natural elements or translating a successful product's aesthetics to another product as a connector. In design, the need to camouflage artifacts in natural or artificial environments is often a priority. For example, beach decor should adapt to the environment and draw inspiration from nature's strategies. These strategies should use dynamic mimicry to adapt to

various environments, incorporating color schemes or textures that make them functional and reactive. An example could be imitating animal skins.

Acoustic communication

In nature, acoustic communication systems refer to the ability of living organisms to use sound waves of varying lengths to transmit information and communicate with others. Both visual and acoustic communication have significantly influenced design throughout history, inspiring the development of forms, systems, devices, and communication technologies.

Birds, for example, use their singing to convey information about their territory, food availability, possible dangers or reproductive status. Many wireless design communication systems were inspired by how birds communicate with one another to create resilient and adaptive communication webs. Bats' echolocation, where they use reflected echoes from distant objects to navigate and hunt, has inspired the design of sonars and acoustic sensors for submarine monitoring and aeronautics. Some researchers are exploring the use of this echolocation principle in devices for visually impaired people to help them map their surroundings and navigate safely.

Whales can communicate over long distances through water by producing melodic and complex sounds. This characteristic has been used in the design of underwater acoustic sensors for monitoring marine environments. Insects, such as grasshoppers and crickets, use acoustic signals during courtship and to coordinate social behaviors. Directional microphone designs were inspired by insects' ability to locate the source of a sound, leading to more precise and sensitive recording devices. These principles could also inform the design of new musical instruments or interaction systems where acoustic feedback plays a key role in cognitive ergonomics.

Another example of acoustic communication in nature is the first documented case of interspecific mimicry between mammals and insects. It was observed that greater mouse-eared bats (*Myotis myotis*), when threatened by predatory owls, can mimic the sounds of hymenopterans to avoid capture (Ancillotto *et al.*, 2022). This type of interspecies communication could inform the design of devices that enable people to communicate with animals, such as pets, or facilitate interactions between humans and digital devices as if they were different species.

Bottlenose dolphins (*Tursiops truncatus*) produce unique signature whistles that carry specific information, including recognition among individuals and sexual availability. These whistles can be altered in various ways to adapt to the environment or respond to other organisms' sounds. Dolphins can also associate a whistle with specific objects and produce it regardless of the object's presence. This demonstrates an advanced form of learned referential signaling in animals (Janik & Sayigh, 2013). Understanding these unique communication methods can inspire the design of musical instruments that produce sounds similar to those found in nature, creating relaxing or immersive experiences.

Chemical communication

Chemical communication is one of the most common forms of signaling in nature, but it's much less prevalent in man-made artifacts, if not in perfumes. In the natural world, chemical signals play a crucial role in the life cycles of nearly all organisms. However, many aspects of how these signals work and the principles that govern them remain largely unknown. One of the primary objectives of biology is to understand the types of information conveyed through chemical signals. In vertebrates, the fields of Genomics, Proteomics, Metabolomics, and other Omic sciences –branches that explore biological components like DNA, proteins, and RNA through detailed analysis– offer promising avenues for advancing this research goal. The discovery of genes that code for olfactory receptors marked a significant advancement in this field, though many mysteries remain unsolved. For instance, some plants, like maple trees, can communicate through volatile chemical signals to defend against various natural threats. When exposed to danger, the affected plant releases airborne molecules that neighboring plants detect, prompting them to produce protective substances, such as antioxidants, to mitigate further damage (Baldwin & Schultz, 1983). This phenomenon has valuable lessons for Community Design. Chemical signals, like olfactory cues, can disperse across large areas, discretely and non-invasively engaging numerous people. Designing alarm systems or olfactory alerts (similar to those historically used to indicate the need to replace domestic gas cylinders) could signal non-catastrophic events (such as the need to replace or refill resources) more effectively than acoustic signals, which might be too faint in noisy environments like discos or sports halls or too disruptive in quiet locations.

In nature, chemical signals often take precedence when other communication forms are ineffective. For example, the fireflies of the species *Phosphaenus hemipterus* switch to chemical communication during daylight, as their luminescent signals, primarily used for reproduction, are ineffective. Female fireflies produce pheromones, volatile chemical signals that males recognize as a courtship invitation (De Cock & Matthysen, 2005). A significant challenge in biology is uncovering how organisms produce and recognize chemical signals. In design, this phenomenon can be reinterpreted by transferring the emission and reception modes of chemical signals to anthropic contexts such as cultural, wellness, safety, agricultural, and marketing sectors. Odors play a crucial role in daily life, influencing us emotionally, psychologically, and physically. Olfactory signals are increasingly used to create immersive environments, allowing visitors to experience different eras or places, enhancing their understanding of artifacts in their original contexts (Drobnick, 2014).

In museums displaying artifacts from specific historical periods, vaporized odor emitters can diffuse characteristic scents from that era. By creating olfactory landscapes, museum designers can leverage nature's ability to imprint experiences in memory through smell (Keller, 2014; Verbeek & Van Campen, 2013). Some researchers even suggest that certain odors, like the scent of ancient book paper, should be considered cultural heritage worthy of study and preservation (Bembibre & Strlič, 2017). Emerging technologies and sciences, such as artificial intelligence and synthetic biology, could enable designers to develop artificial chemical signals for communication, emulating nature's methods. The sense of smell, closely linked to human instinct, can penetrate deep into individuals' consciousness, mak-

ing olfactory communication an effective means to convey messages on urgent issues like environmental awareness.
Designer Alexandra Daisy Ginsberg explored the possibility of resurrecting the scents of extinct flowers lost due to human impact. Her project, "Resurrecting the Sublime" (Ginsberg, 2021), was developed in collaboration with perfumer Sissel Tolaas and an interdisciplinary team from the biotechnology group Ginkgo Bioworks, led by creative director Christina Agapakis, with contributions from IFF Inc. The project debuted as an immersive installation at La Fabrique du Vivant at the Pompidou Centre in February 2019. Using small amounts of DNA from three preserved flowers at the Harvard University herbarium, the Ginkgo team employed the latest synthetic biology techniques to recreate genetic sequences that produce enzymes capable of generating fragrances. Sissel Tolaas used this data to reproduce the flowers' scents in her laboratory with similar or identical aromatic molecules. These essences were then separated from those extinct due to colonial activities. For example, *Hibiscadelphus wilderianus* Rock, or Maui hau kuahiwi in Hawaiian, originally from ancient lava fields on Maui's Haleakalā Mountain, had its habitat devastated by colonial cattle farming, with the last known tree dying in 1912. *Orbexilum stipulatum*, or Falls-of-the-Ohio Scurfpea, last seen in 1881 at Rock Island on the Ohio River near Louisville, Kentucky, lost its habitat to the construction of a dam in the 1920s. *Leucadendron grandiflorum*'s history is even more complex, last seen in 1806 at a collector's garden in London, originally from Wynberg hill in Cape Town, South Africa, its habitat destroyed by colonial vineyards. Projects like this aim to maintain rigorous research and narrative, engaging the public to raise awareness about complex phenomena.

Mechanical communication

Design can draw inspiration from other intriguing communication methods, such as the mechanical ones. Mechanical communication involves the transmission of signals through physical contact or the transfer of mechanical energy, such as vibrations, pressure, or touch. Besides the well-known touch-based communication, particularly interesting is the one based on vibrations. For example, Honeybees use a form of mechanical communication called the "waggle dance" to convey information about the location of food sources to other bees in the hive. When a foraging bee discovers a good source of nectar or pollen, it returns to the hive and performs a dance on the honeycomb. The bee vibrates its body while moving in specific patterns, with the direction and duration of the dance indicating the direction and distance of the food source relative to the hive. Other bees detect the vibrations through the honeycomb and interpret the message to locate the food. This form of communication relies on mechanical energy transfer through vibrations and is a key aspect of how honeybees coordinate their foraging activities. Transferring the ability to transmit mechanical movement from one individual to another could be highly beneficial in developing high-energy kinetic devices that amplify the motor energy of users while reducing reliance on non-renewable energy sources. This concept could be applied to repetitive-motion devices, such as fans or massagers, allowing them to generate energy from the user's small movements.Another example of vibration-based communication is the classic example of spiders using their webs to detect the size of prey through vibrational signals. Less commonly known examples include subterranean species like *Coptotermes acinaciformis*, which avoids collisions underground by detecting vibrations from other organisms, or insects like treehoppers (*Tylopelta gibbera*) and leafhoppers (*Scaphoideus titanus*), which emit specific vibrations to disrupt rival males attempting to breed with a desired female (Cividini & Montesanto, 2020). These examples of vibration-based communication in nature can inspire wearable devices. Smartwatches already use vibrations for notifications, but by studying the nuances of natural vibrational signals, we could broaden the range of vibrational messages these devices can convey. A fascinating example of mechanical contact can also be used by plants to manage their growth, not just for their own benefit but also for the surrounding flora. An example is the "crown shyness" phenomenon, in which certain trees, like the *Castanopsis cuspidata*, limit their branch growth to avoid intersecting with other trees. This reduces the risk of damage from events like strong winds that could break entangled branches (Onoda & Bando, 2021). This reciprocal and shared defense strategy could be applied to self-driving cars, where it could inform systems designed to avoid collisions.

Electric communication

Certain fish, such as *Brachyhypopomus pinnicaudatus*, have the unique ability to produce small electric shocks over a limited range. These electric discharges are used for both territorial defense and attracting mates. In this species, females select their mates based on these electrical signals. Although producing these electric shocks requires a considerable amount of energy, it's the only way males can be chosen by females for mating. This mechanism also ensures that female's mate with males who are likely to enhance the females' fitness and the survival of their offspring (Hopkins, 1999).

Understanding how these electric shocks are generated and transmitted through a non-linear medium like water, with relatively low energy expenditure, could be valuable in developing new communication methods for watercraft. This knowledge could also lead to innovative and sustainable approaches to powering electronic devices wirelessly.

Transferring the behavior and organization of nature into artifacts

The most complex level of access pertains to the transfer of behavioral and organizational logics inherent in biological systems, which are designed to meet their needs for protection, attraction, defense, and aggression. These logics also encompass collective organizational forms, such as superorganisms created by structured social insects (Sasaki & Pratt, 2018). This level further considers human entomology, a field rich with inspiration, models, and ideas valuable for projects aiming to influence user behaviors towards healthier and socially beneficial practices through products and services. Design can mediate and modulate relationships between individuals by addressing complex and dynamic contemporary relational dynamics, increasingly shaped by digital devices. It can foster empathy among people by encouraging eye contact, presence perception, physiological reactions related to proximity and touch, and the decoding and interpretation of signals to facilitate dialogue and understanding in the workplace. Such interventions require knowledge of the principles and latest discoveries in human entomology, while also integrating insights from psychology, anthropology, and sociology. Additionally, they can draw on the similarities between human and animal behaviors and their relational mechanisms. This level includes aspects related to the complex organization of living beings, such as self-organization, self-assembly, self-adaptation, resilience, repetitiveness, cyclicity, reactivity, cooperation abilities, and synergy. Biological systems often employ strategies that foster cooperative relationships, based on their tendency to integrate with other systems to activate synergistic and collaborative interactions, following a coevolutionary and mutualistic approach. Examples include symbiosis and coevolution between species, where coevolution involves two species evolving through natural selection in response to reciprocal actions and responses. Competition between species can lead to the sharing or transfer of traits or resources. This process is particularly evident in symbiotic relationships, where intimate associations between two or more organisms are crucial for their mutual preservation. If both species benefit, the relationship is "mutualistic"; if one benefits at the expense of the other, it is "parasitism"; and if one benefits without harming the other, it is "commensalism" (Leung & Poulin, 2008).

Natural organisms also maintain their integrity through self-renewal strategies, such as self-regeneration, repair, and updating. For instance, the sea urchin's tooth sharpens itself through selective wear, ensuring it remains effective (Reich & Smith, 2009).

Other important natural organizational strategies include resilience through variation, redundancy, and decentralization. In biology, resilience is the ability of a system to self-repair and restore integrity after exposure to perturbation or damage. Some biological systems possess elements with seemingly redundant features that, under normal conditions, remain inactive but, when needed, enhance performance. Properties like porosity, elasticity, and density enable structures to adapt to changing conditions and respond to various stresses in diverse ways. Diversification also contributes to resilience. "Natural selection thrives on diversity and tends to increase it. Resilient ecosystems contain a variety of species. Similarly, prolific cities offer a wide range of work opportunities, and successful companies present a diverse array of products and flexible employees who can adapt and reinvent themselves in response to ever-changing markets" (West, 2018, p. 158). Integrating the unexpected refers to biological systems' capability to incorporate unpredictable events. Self-organization allows systems to adapt to variable contexts and external conditions. Multifunctionality in nature refers to structures and strategies that perform multiple functions, ensuring coherence, coordination, and efficiency.

Conclusions

The field of design that applies nature's communicative intelligence to artifacts involves understanding how living organisms adapt, solve problems, and thrive in their natural habitats. Different forms of communication vary in complexity, ranging from simple methods like visual or acoustic signals to more complex ones such as mechanical, chemical, or molecular processes. Interestingly, the simplest organisms, like bacteria, often exhibit surprisingly complex communication patterns.

To better understand natural communication, designers must interpret all the functional adaptations and modalities that enables organisms to effectively survive and prosper in their environment. These adaptations may include specialized anatomical structures, unique behaviors or advanced sensorial capabilities. In many living systems, communication plays a crucial role in facilitating learning, driving behavioral changes, and increasing problem-solving capacity, which can, in turn, lead to acquiring new skills and beneficially altering the environment. Communication, whether in nature or design, can coordinate social behavior, warn of dangers, or exchange valuable information. Designers can learn from nature by observing how many species collaborate to achieve shared goals, such as hunting, defending territory, or caring for offspring. These cooperative behaviors require sophisticated communication strategies, which are becoming better understood through biological and natural sciences. The knowledge gained from these studies could be invaluable to social design. Nature, like design, benefits from innovation, which involves developing new strategies or inventive behaviors to address environmental challenges. For contemporary design, it is essential to draw from this natural intelligence and innovative approaches to create strategies, tools, methods, and projects that meet the growing demands of scientific and technological progress. By doing so, designers can better respond to the increasing complexity and rapid changes of the modern world.

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Resumen: En la naturaleza, los organismos se comunican entre sí intercambiando información clave, principalmente para el reconocimiento intra e interespecífico (por ejemplo, entre padres e hijos, depredadores, miembros de la jerarquía de una manada), así como para defensa, ataque o atracción. Los tipos fundamentales de comunicación animal involucran señales químicas, como feromonas, así como señales auditivas, sonoras, interacciones táctiles y señales visuales, incluidos colores, formas, patrones y movimientos. Todos los organismos tienen como objetivo mejorar su aptitud, que se refiere a su capacidad de sobrevivir y reproducirse. Desde esta perspectiva, la comunicación juega un papel crucial en la consecución de estos objetivos. Casi todos los organismos de la naturaleza emplean estrategias visuales complejas basadas en jerarquías comunicativas de colores y formas para resaltar, enfatizar u ocultar partes del cuerpo, enviar mensajes, transmitir intenciones o estados físicos, indicar género o demostrar jerarquía social. Todos estos aspectos de la comunicación representan un vasto depósito de códigos de comunicación no convencionales que los diseñadores pueden utilizar e inspirarse. En este complejo marco, el artículo presenta estudios de casos de procesos y modelos de comunicación natural de diversas ramas de la biología, explorando su posible aplicación en protocolos de comunicación que pueden aplicarse a artefactos y diversos campos técnicos.

Palabras clave: Inteligencia natural - Comunicación biológica - Adaptación - Diseño multisensorial - Bioinspiración - Biomimética - Colores - Sonidos -Vibraciones - Interacciones

Resumo: Na natureza, os organismos comunicam-se entre si trocando informações importantes, principalmente para reconhecimento intra e interespecífico (por exemplo, entre pais e descendentes, predadores, membros da hierarquia de um rebanho), bem como para defesa, ataque ou atração. Os tipos fundamentais de comunicação animal envolvem sinais químicos, como feromônios, bem como sinais auditivos, sons, interações táteis e sinais visuais, incluindo cores, formas, padrões e movimentos. Todos os organismos visam melhorar a sua aptidão, que se refere à sua capacidade de sobreviver e reproduzir. Nesta perspectiva, a comunicação desempenha um papel crucial na prossecução destes objectivos. Quase todos os organismos na natureza empregam estratégias visuais complexas baseadas em hierarquias comunicativas de cores e formas para realçar, enfatizar ou ocultar partes do corpo, enviar mensagens, transmitir intenções ou estados físicos, indicar género ou demonstrar hierarquia social. Todos esses aspectos de comunicação representam um vasto repositório de códigos de comunicação não convencionais que os designers podem usar e nos quais se inspirar. Nesta estrutura complexa, o artigo apresenta estudos de caso de processos e modelos de comunicação natural de vários ramos da biologia, explorando sua aplicação potencial em protocolos de comunicação que podem ser aplicados a artefatos e diversos campos técnicos.

Palavras-chave: Inteligência natural - Comunicação biológica - Adaptabilidade - Design multisensorial - Bioinspiração - Biomimética - Cores - Sons -Vibrações - Interações

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