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Biologically-Inspired Computing for the Arts

Scientific Data through Graphics

Anna Ursyn

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Table of Contents

Section 2
Visualizing the Invisible: Processes for the Visual Data Formation

Section 3
Scientific Communication through Visual Language

Section 4
Tools for Metaphors: Nature Described with the Use of Mathematics and Computing

Section 5
Analytical Discourse: Philosophy and Aesthetics of Nature Inspired Creations

Detailed Table of Contents

on a computer using a particle representation of the rotating portions of the flow. The straightforward method works in two or three dimensions and is amenable to instruction and easy application to a variety of visual media. Examples from digital flatwork and video art illustrate the method's potential to bring space, shape, and form to an otherwise ephemeral medium.

A novel approach of integrating two swarm intelligence algorithms is considered – one algorithm simulates the behaviour of birds flocking (Particle Swarm Optimisation), and the other algorithm (Stochastic Diffusion Search) mimics the recruitment behaviour of one species of ants – Leptothorax acervorum. This hybrid algorithm is assisted by a biological mechanism inspired by the behaviour of cells in blood vessels, where the concept of high and low blood pressure is utilised. The performance of the swarms and the cells in the hybrid algorithm is reflected through a cooperative attempt to make a drawing, which is created by the two nature-inspired algorithms – which lead the swarms – and one biologically inspired mechanism (blood vessel cells and blood flow) that assists the swarms with their performance on the canvas. The scientific value of the marriage between the two swarm intelligence algorithms is currently being investigated thoroughly on many benchmarks and the results reported suggest a promising prospect (al-Rifaie, Bishop, & Blackwell, 2011). The authors of this chapter also discuss whether or not the artworks generated by nature and biologically inspired algorithms can possibly be considered as computationally creative.

Ants represent a natural superorganism, an autopoietic machine, much like human society. Nevertheless, the ant society stands out due to self-organization. Ants accomplish the generation of bottom-up structures communicating mainly by pheromones, but they also produce modulatory vibrations. This phenomenon represents a fascinating subject of research that needs to be amplified in order to identify the connections between these social organisms and humans; they share the same environment with humans and thus participate in the construction and mutation of posthuman ecology. The human-ant relationship plays an important role in the creation of new ecosystems and the transformations of old ones. Artists can approach and embrace this relationship by means of artistic experiments that explore the bioacoustics involved in the social behavior of ants supported by the combination of cybernetics, autopoiesis, self-organization, and emergence.

The recent movement from mass production to mass customization enabled by digital fabrication has opened the door for new typologies in architecture and design. The author brought the idea of mass customization to material connection, which normally appears as orthogonal seams that are predominant in man-made objects. This chapter introduces gradient material transitions that seamlessly bridge synthetic and organic matter. Using digital image processing of organic forms, the fabrication process generates 3D tooling paths, culminating in the concept of bio customization, rather than mass customization, a new prospect of digital fabrication.

Section 2
Visualizing the Invisible: Processes for the Visual Data Formation

Quite often new light is cast on existing constructs or current state of knowledge. Many times it is vital to revisit approaches to laws and connections believed to govern the world. Disciplines are so interlocked and at the same time so specialized that the collaborative exchange of knowledge is necessary to deal with many invisible features of nature, those related to physical laws, the micro and macro scale, or the invisible forces (such as energy of wind or strength of underground currents) and dynamic processes that are described differently for each discipline. Thus, knowledge evolves with the developments of tools.

Humans' complex and dynamic relationship with nature has influenced not only the content but also the physical properties of the moving image since its beginnings. Throughout history, a subset of art and design has used the agency of natural forces on the actual materials as a way to consider the society's connection with the environment. Artists have attempted to harness the physics, biology, and ecology of the natural environment as artistic tools by integrating natural phenomena and by mimicking natural systems in their creative strategies. Today, digital media seems far removed from its organic and natural beginnings. However, as the global conversation shifts towards sustainable development, it is time to revisit artworks that considered the environment as a co-creator in their realization, and to make new works that comment on and even strengthen our relationship with nature. As one of several artists now working in sustainable energy, the author created a series of kinetic public sculptures that use natural power sources to create the moving image. These sculptures are presented here as a case study for a larger perspective on the continuing relationship between the forces of nature and the materials of the moving image.

To explore enlightened collaborations between art and science, and to probe the ideas, images, and mutual interests connecting art and science professionals and disciplines, the Synapse Group at the University of Akron was formed. This chapter presents selected artworks created by the artists associated with the group. Some of the works were created in collaborations with the scientists in the group, and some were inspired by the science of nature. A major theme of this chapter is visualizing water that is unseen, whether it is invisible underground water or imaginary virtual ocean water. The invisible are made visible by rendering water data with 3D computer graphics or by perceiving interactions between water and other objects. Artworks dealing with digital data in the forms of 2D and 3D imagery are also included. Such digital imagery is processed and interpreted to refocus the attention of the audience and to tell a story. Also explained in the chapter are the inspiration processes by which those artworks were created.

This chapter is an attempt to introduce NanoArt. First, it goes back in time to the first uses of nanomaterials and nanotechnologies to create art and continues with the beginnings of nano art. Then, it follows a status on this new artistic/scientific discipline and the movement that evolved from recent technological developments in the multidisciplinary area known as nanotechnology. The chapter informs about the international juried NanoArt competitions, displays select art works, mostly collected in the NanoArt21 Gallery, and finally presents selected nano artists' thoughts.

It has been generally accepted in history of art that nature ranks as a master and an ideal of the arts. Everybody knows examples of nature-related art works created over centuries in a conventional manner.. Curators of new media art exhibitions are involved in current developments in computing, discussing questions such as whether the computer as a tool be a means to generate new representations of nature-related art. This would demand results different from conventional works of art, as to the conceptual creation processes as well as the output. Some theoretical background and categorizing of such creations are discussed with illustrated by examples from artists participating in a series of "Computerkunst/ Computer Art" exhibitions since 1986. Though it might be too soon to judge computational art works concerning their importance in art history, a closer investigation in the creative processes and social contexts seems helpful and worthwhile.

Section 3
Scientific Communication through Visual Language

Most disciplines rely on visual communication. Visual quality of data presentation gains in importance, because the better it is, the more convincing becomes the message, thought, and even the product. Teams of specialists involve the artists to attain fast, effective, and efficient communication with visual quality.

This chapter explores the use of code, form, and interactivity in translating biological objects into mathematically generated digital environments. The existence of a mathematical language contained in all physical objects that is similar in function to DNA in organisms is proposed as a core component and driving force of this exploration. Code, form, and interactivity makes possible to explore, understand, and teach this hidden biological language by re-writing its algorithms in ways we may readily recognize and absorb. The designer's own works: "Clouds & Ichor," and "Stream" demonstrate and ground the concepts being discussed. "Clouds & Ichor" explores the possibilities of a material that exhibits a mixture of properties of both liquid (ex: water) and fabric (ex: silk or cloth). The resulting material has memory (something liquid does not), and the ability to split and/or combine at will (self healing, something fabric does not do). "Stream" looks into the combination of flocking organisms, curiosity, environmental color response, and human body language that respond interactively to a user's motion and gestures. In both projects, a natural learning experience is at the core of the biological process.

This chapter is focused on creating the visual approach to natural processes, concepts, and events, rather than their description for learning. It has been designed as an active, involving, action-based exercise in visual communication. Interactive reading is a visual tool aimed at communication, activation, and expansion of one's visual literacy. It addresses the interests of professionals who would like to further their developments in their domains. The reader is encouraged to read this chapter interactively by developing visual responses to the inspiring issues. This experience will be thus generated cooperatively with the readers who will construct interactively many different, meaningful pictorial interpretations. The chapter comprises two projects about water-related themes; each project invites the reader to create visual presentation of this theme. Selected themes involve: (1) States of matter exemplified by ice, water, and steam, and (2) Water habitats: lake, river, and swamp.

"Visual Tweet: Nature Inspired Visual Statements" explores connections between science, computing, and art in a similar way as it is done in a chapter "Looking at Science through Water." This chapter examines concepts and processes that relate to the domains of physics, biology, computing, and other sciences, and at the same time pertain to the planet's life and everyday experience. The reader is encouraged to solve the projects visually, through art, and/or through graphics. Exploration of science-based concepts and nature-related processes will support understanding of the project themes, trigger our imagination, and thus inspire enhancement of an ability to communicate with visual language and create artistic work. Comprehension of what will be noticed, the power of abstract thought, and one's own answer to some evolving issues will result in readers' personal visual projects – drawings, graphics, illustrations, animations, video clips, or web projects. This chapter comprises two projects about science-related themes: (1) Symmetry and pattern in animal world: geometry and art; and (2) Crystals. Each project invites the reader to create visual presentation of the themes.

This chapter describes visualization of the 19th century representations from a Japanese culture – a set of mathematical problems etched on wooden boards. Mathematicians, especially geometers followed the Shinto temples' carving tradition from the Edo period (1603-1867), where worshipers carved the likenesses of horses onto wooden tablets and used those tablets as offerings. The author describes the steps in the creation of artistic statements based on geometrical problems: selecting, scanning, and converting images into digital information followed by vectorization, converting into bitmaps, assigning colors, and then blending the monochrome sketches and colored templates. A QuickTime movie presents (online) the creative process. Discussion refers to the dissemination of the project in art galleries and online, its potential instructional use, and examines the audience responses.

Section 4
Tools for Metaphors: Nature Described with the Use of Mathematics and Computing

While examining and researching processes and events, specific ways to approach a problem are developed. Human needs mandate that the development of particular tools, and in turn, tools stimulate new ideas and solutions found both by scientists and artists.

Small elements in large numbers and densely arranged are a frequently observed phenomena in nature. The chapter uses an arbitrarily chosen stretch of landscape, a dry riverbed, to formulate artistic intentions and design programmed interpretations of them. From the database of recorded findings the author formulates concepts, which he then transforms into programs to generate drawings. This chapter experimentally addresses the formulation of a few concepts inspired by nature, aimed at generating line drawings executed on pen-plotters. Unlike in science and engineering, a piece of code does not produce a solution to a problem for concepts in generative art. Generative drawings are produced through a structured process including a sequence of discrete procedural steps, which are: finding and recording; concept and transformation; programming and testing; and drawing and interpretation.

The relation between the viewer and the artwork has been changed through the development of computer-augmented physical kinetic objects. To explore the specific performance of kinetic interactions, this chapter proposes a biomimetic perspective to demonstrate three kinetic interactive artworks through a modular design approach. MSOrgm is developed as a robot plant to interact with the viewer in a soothing way. Its body is assembled with a hybrid organization, composed of microprocessors, truss structure, and actuators. SSOrgan is designed as an organic skin to interact with the viewer's touch of the top of it. Each sensing cell acts as an individual sensor, which performs the gathering, transmitting, and exchanging the pressure values with neighboring cells in the form of color. LBSkeleton is a robotic instrument that produces pneumatic sound and emits soothing light into space. It consists of dense replicated foldable module, which can make the whole body transformation.

The author discusses her latest digital image series, A New Leaf Series, within the context of early photographic imaging and its connection to science and biology by investigating and connecting to the work of Thomas Wedgewood, William Henry Fox-Talbot, and the early pioneers of photographic technologies. Works of Hippolyte Bayard and Anna Atkins serve as early examples of the scientific fundamentals of photography; the technological advances of the medium still draw on the same subject matter to reveal the basic structure of conceptual and aesthetic investigation. The author discusses how contemporary electronic imaging has returned to its photographic origins through nature-related subject matter.

Section 5

Analytical Discourse: Philosophy and Aesthetics of Nature Inspired Creations

The speed and efficacy of media growth, accessibility, and easiness create a lot of challenges and discourses. Current media and tools cause discovering new solutions that are provoking to ponder how fast the novelty is exchanged with the even newer novelty, how the latest solutions support qualities of the ideas or products, and finally, how novel solutions find their permanent status.

This chapter discusses how both art and science proceed from an appreciation for and application of the natural proportions and forms associated with nature. Descriptions of the Golden Ratio, fractals, and the holographic metaphor are presented with examples from geometry, nature, science, and art. An outline of a personal theory follows, of aesthetics based on emulation of the structure of nature and the work of Thomas Aquinas and James Joyce. A collage series entitled The Elements in Golden Ratio illustrates application of the author's aesthetic theory. The author concludes with personal observations on the commonalities between art and science and how an appreciation of natural form and aesthetics can enhance the practice of both.

The term bio art covers the kind of art that seems to come from the biology lab, with simulations of life forms through generative processes, with data taken from organisms, or even through organisms themselves. This is often at the micro level, invisible to the naked eye, where seeing requires some degree of computer modeling. This chapter discusses works of artists who work alongside biologists to produce visual works of extraordinary quality, in both their decorative and intellectual aspects. Drawing manuals of a hundred years ago advocated the study of plant forms, sometimes as the basis for pattern design. The author describes his own use of scientific sources, arguing there is also a place for art that evokes the wonders of nature without being tied to the visible facts.

In the context of contemporary fine art, the chapter discusses the translation (the finding of equivalences) of a phenomenological experience of water during the activity of swimming into drawing with both traditional drawing media and a tablet computer – an Apple iPad. Firstly, the chapter furthers understanding and gives insights into interaction and relationship with water during this specific activity. Secondly, the author explores and discusses the premise that drawing is phenomenology, considering whether this premise is compromised when drawing with an Apple iPad rather than traditional drawing media. The phenomenological approach to both philosophy (including Merleau-Ponty) and theoretical research (including Rosand) aims at supporting understanding of experiences of water during the activity of swimming and the process of translation of those experiences into drawing.

Foreword

Two decades ago, I was at an international science conference in Japan where a few of the presentations there used the computer's emerging power for visualization. The response from the audience was mixed. "Eye-opening!" was the response of a tiny minority. "Irrelevant!" was the response from the greater majority. Of the latter opinion, what I heard was that, "Pictures don't tell us anything more than the equations can. In fact, they cloud and distract us from how we think."

Fast forward twenty years later, and it's interesting that this body of work on biologically-inspired computing for the arts has been collected, because it represents a kind of reversal in the audience (from scientists to artists), and because the utility of visualization is no longer in question the way it was before. The pragmatic usefulness of visualization is now more evident; and now the aesthetic, emotional satisfaction of visualization is coming into play. We are people, not machines. And we love to see things and experience them. And what better way to understand something than through beauty?

Having spent the last three years at Rhode Island School of Design, having moved here from MIT, I've noticed how artists think differently, and naturally, as a kind of *raison d'être*. Given that discovery is all about working from new perspectives, it is clear that the way artists think differently can have incredible value in the STEM (Science, Technology, Engineering, Mathematics) disciplines today. A STEAM-focused approach – add the A, Art to STEM – can expand the horizons of human discovery with impact to both utility and pleasure. Turning STEM to STEAM is exactly what this body of work represents for computing, arts, and the sciences. The world looks forward to more of it to come.

John Maeda
President, Rhode Island School of Design, USA
September 13, 2011

John Maeda *is a world-renowned artist, graphic designer, computer scientist, and educator whose career reflects his philosophy of humanizing technology. For over a decade, he has worked to integrate technology, education, and the arts into a 21st century synthesis of creativity and innovation. A recipient of the National Design Award and represented in the permanent collection of the Museum of Modern Art, Maeda became president of Rhode Island School of Design in June 2008. He seeks to connect RISD to political, economic, social, and business spheres where artists and designers make a difference, and has prioritized scholarships to ensure the broadest possible access to a RISD education. Maeda taught media arts and sciences at MIT for 12 years and served as associate director of research at MIT Media Lab. His books include The Laws of Simplicity, translated into 14 languages. Redesigning Leadership (2011, with Becky Bermont) expands on his Twitter posts. In 2008 Maeda was named one of the 75 most influential people of the 21st century by Esquire and in 2010 he was called the "Steve Jobs of academia" by Forbes.*

Preface

Art is a short word; however, since it is based on nature, long words cannot be avoided when talking about science and technology. Some words are new and others are forgotten after the school times had ended. The world may be experienced using the senses, but minuscule, invisible fragments of reality, abstract concepts, or even ideas can be visualized. Nature- or science-derived images may serve an artistic purpose, also when transformed into algorithmic structure. The book's contributors keep an eye on nature and its organic forms, from the tiniest nano particles to cosmos (we are all inhabitants of the cosmos, anyway), and then transform this info into art forms with the use of computing. Individual authors refine their study to particular fragments of nature. Some themes appear in more than one chapter, for example, several authors indicate their interest in flow and examine one concept from various perspectives: Mark Stock discusses in Chapter 2 how flow supports the variety and vitality of life on Earth and describes computational fluid dynamics that involves solving the fluid equations of motion, fluid simulations, and related biological computations, while Hans Dehlinger applies in Chapter 14 the generative drawing to offer metaphorical images of the riverbed and ocean; furthermore, chapters 11 and 12 examine water flow from several viewpoints. More themes, such as fractals, nano structures, or swarm computing are interwoven in the book in a similar way, and so are the people who contribute to the developments in the related domains.

This book comprises a collection of individual approaches to the relationship between nature, science, and art created with the use of computers. Themes of the chapters pertain to a wide spectrum of authors' interests; they involve nature and description of nature including mathematics and scientific disciplines. Thus, themes discussed in the book relate to the use of visual language in communication about biologically-inspired scientific data, visual literacy in science, and application of a practitioner's approach: people can understand things better when they can visualize and picture them theirselves. The notion of computing adopted in this book embraces any kind of activities that require the use or benefit from the use of computer hardware and software.

The topic of this book fits in the world today when the chapters explore connections between nature, science, and art, and discuss how art and design support science understanding by visualizing concepts and processes. Art creation benefits from learning about scientific processes and concepts. Processes and products provide inspiration for creation of meaningful art, while art creation helps understand and memorize data framework and structure. The action of designing materials and data helps understand concepts and processes.

Images enhance connections between biology, engineering, and material sciences resulting in growing partnership among academia, laboratories, and industry. Scientists focus on biology-inspired research to understand how biological systems work, and then create systems and materials that would have efficiency and precision of living structures. According to the National Research Council of the National Academies (National Research, 2008), strategies for creation of new materials and systems may be characterized as bio-mimicry, bio-inspiration, and bio-derivation.

Bio-mimicry refers to learning the principles used by a living system to achieve similar function in synthetic material and also create materials that mimic cells in their response to external stimuli. For example, certain cells such as T-lymphocytes can sense particular external stimuli, and then deal with pathogens. The challenge is to design bio-inspired systems and devices for detecting hazardous biological and chemical agents and strengthen national security systems.

Bio-inspiration means developing a system that performs the same function, even with a different scheme. For example, the adhesive gecko foot, the self-cleaning lotus leaf, and the fracture-resistant mollusk shell are examples of inspiring structures. The cutting-edge optical technology solutions can be found in nature: multilayer reflectors, diffraction gratings, optical fibers, liquid crystals, and structures that scatter light are found in animals as well. For instance, Morpho butterfly has iridescence sparkle and blue color visible from hundreds of meters due to periodic photonic structure in scales on wings, without any dye involved.

Bio-derivation is known as using existing biomaterial to create a hybrid with artificial material, such as incorporation of biologically derived protein into polymeric assemblies for targeted drug delivery. The eyes of higher organisms and the photosynthesis mechanism in plants are examples of biological structures and processes that can support harvesting light and also fuels (by converting cellulose polymer to ethanol). Deciphering force and motions in proteins driven by sub-cellular, molecular motors can advance clinical diagnostics, prosthetics, and drug delivery. Molecular motors convert chemical energy (usually in form of ATP - adenosine triphosphate) into mechanical energy. Contrary to Brownian movements, it is not driven solely by thermal effects. Scientists strive to create self-evolving, self-healing, self-cleaning, and self-replicating super-materials that could mimic the ability to evolve and adapt. The challenge is not easy to meet: for example, the gecko's adhesive works in vacuum and underwater, leaves no residue, and is self-cleaning; adhesion is reversible, so geckoes alternatively stick and unstuck themselves 15 times per second as they run up walls. As for now, "all attempts to mimic their design or to synthesize artificial polymers that are analogous to the bioadhesives in structure or function have been largely unsuccessful … and the magic of a gecko's 'dry' glue with its reversible attachments remains unsolved, unmatched, and more challenging than ever" (National Research, 2008, pp. 63-64).

In a process of nature-inspired inquiry about computing for art creation, artists and scientists examine those rules and formulas in science, which define natural processes by abstracting the essentials from specific events or objects, such as elements (e.g., carbon or oxygen) or molecules (e.g., water). One may see organic chemistry as a study of structure, properties, and reactions carbon-based compounds, such as hydrocarbons consisting of hydrogen and carbon, carbohydrates consisting of carbon, hydrogen, and oxygen (for example, with a ratio 2:1 as in water molecule), and other carbon-based compounds. Biological chemistry examines chemical processes in living matter, information transfer, and flow of energy through metabolism, mostly in cellular components such as proteins, carbohydrates, lipids, and nucleic acids, including DNA and RNA. At the atomic level, scientists examine soft condensed materials in states of matter neither liquid nor crystalline solid. Soft matter builds membranes and cytoplasm in human cells, and it is so omnipresent in biological systems that humans may be considered soft matter examples. Scientists apply abstract concepts, for example permeability or electromagnetism, to find rules and patterns that govern these materials. Explorations on structure and functions occurring in living and artificial matter involve intensive use of visualization techniques providing visual representation of information, data, and knowledge through pictures, information graphics, and also artistic display.

All these explorations connect science and art with computing. Art is needed not only in a quest for beauty, but because many times people can apprehend through art the essence of the concepts they attempt to grasp. Art provides the informative qualities of an idea, and thus communicates and explains ideas faster. The process of art creation has its inherent tendency to apply abstract thinking. Artists seek the principles that control the basic elements in art, such as line or color, and then convey the essence of their response to selected slice of reality. People may look at the works of art as if they were not only the aesthetical objects but also as information displays. Scientists and practitioners are showing a growing interest in aesthetics, especially aesthetics of visualization as related to the visual competence in the art, design, and technological solutions in visualization. Analyses of the images, forms, and motions in interactive generative design and art lead to new approaches in defining aesthetic criteria not only in terms of the work beauty. In a growing number of publications, the concept of aesthetics refers to the design effectiveness, efficiency, workability, usability, and easiness to understand (at a low cognitive cost) the visual display, not exclusively the beauty of an image.

In computer based data-, information-, or knowledge-visualization, the use of imaginative thinking leads to discovering new visual metaphors for abstract data, information, or concepts, and consequently to developing several kinds of visualization, for example, tag-cloud visualization of data. In computer science, imaginative approach to natural events and forces resulted in the development of biology-inspired computing, with several branches, such as artificial life, or fractal geometry of nature. Nature serves as a metaphor for developing new computing methods, for example, artificial neuronal networks, evolutionary algorithms, swarm intelligence, and also genetic engineering techniques, and bio-inspired hardware systems. Generative computing resulted in creating art and the developments in biology-inspired design, music, architecture, and other artistic fields.

Attitude towards the environment may influence one's art production, especially in the process of biology-inspired computing for the arts. Many art works obey mathematical order, repeat generative processes already existing in nature, follow randomized processes, rely on information theory, or otherwise support understanding of natural events. People may think about the physical and chemical laws as the essential rules that drive behavior and properties of natural structures and sustain the order in nature. Before examining the new media artists' inspiration with biology or science, people may first explore how the order in nature may apply to art. We may then wonder how physical and chemical laws relate to the elements and principles of art and design. Patterns existing in genetic codes such as the DNA code, or analogies coming from observation of swarm intelligence not only spur the scientists into computing for various technologies, but also inspire the new media artists to create art works built on biological systems. The generative approach makes possible exploring natural phenomena and at the same time allows the creative process. The artists' tools include systems defined by computer algorithms and/or software.

Biologically inspired art graphics may entail applying two-dimensional and three-dimensional graphics. They often present the processed images that show the steady state conditions (systems at equilibrium) or display dynamic conditions in real-time and/or in interactive way. Many times they may involve other techniques and fields of study, e.g., animation and visualization. Artistic rendering often supports creating models that represent empirical objects and allow making assumptions when it is hard to create experimental conditions. Artistic projects, in combination with simulations, aim at implementation of the model and may support testing, analysis, or training.

Generative art, which often uses digital tools such as mathematical or software algorithms, creates a program that displays certain behavior and reshapes our mental plan in computer terms. Such computer-related process may be seen as a task of abstracting essential codes to produce the efficient and evolvable solution. The final product of writing a computer program is often seen dependent on the choice of programming language (Iverson, 1980) in a similar manner as, according to the Sapir-Whorf hypothesis (Marshall, 1998), language shapes our perceptions of reality, so the way of somebody's thinking may depend on one's spoken language. The choice of digital media, a combination of art, science, and technology, often involving computing and programming, may shape the form and content of the new media art. New media art forms that involve or result from computing are widely used to communicate, interact, involve our senses, describe our social patterns, or socially interact. Creators of generative art often focus on the use of bio-inspired techniques, such as evolutionary computing, artificial life, neural networks, or swarm intelligence. Accordingly, notions about art aesthetics, theory, and classification have to follow the evolvements in art production.

The use of visual language supports communication with the readers. Imagination and creativity are needed in every professional or academic discipline and specialization. It has been often asserted that humans live in more and more visual world because of the ongoing changes in the means of communication (social network with videos and pictures), how concepts are defined (concept maps, visual mining), perceiving the meaning of art, learning (using online interactive visuals, videos), and socializing (exchanging visuals, using for example Skype and Facebook). To become habituated and better prepared for the changes in lifestyle and working habits, we need to expand our visual literacy. We need to be able to work with visual quality in mind.

DESCRIPTION OF THE STRUCTURE OF THE BOOK AND CONTRIBUTING CHAPTERS

The content of this book is divided into five sections.

Section 1 - Visual Data Formation: Biology Inspired Generation of Objects and Processes - comprises five chapters. Rachel Zuanon (Brazil) describes in Chapter 1, "Bio-interfaces: Designing Wearable Devices to Organic Interactions," the process of building interaction governed by the biology of the users. The author presents applications of bio-interfaces as wearable devices in the areas of design, art, and games. Mark Stock (USA) describes in Chapter 2, "Flow Simulation with Vortex Elements," a novel method for creating realistic fluid-like forms and patterns via interacting elements presented on a computer using a particle representation of the rotating portions of the flow. The author illustrates the method's potential with examples from digital flatwork and video art and thus makes both fluid simulations and related biological computations deep, interesting, and ready for exploration. In Chapter 3, "Cooperation of Nature and Physiologically Inspired Mechanisms in Visualisation," Mohammad Majid al-Rifaie, Ahmed Aber, and Mark John Bishop (UK) describe a novel way to integrate two swarm intelligence algorithms; one algorithm simulates the behavior of birds flocking (Particle Swarm Optimisation) and the other algorithm (Stochastic Diffusion Search) mimics the recruitment behaviour of one species of ants. This hybrid algorithm is assisted by a biological mechanism inspired by the behavior of cells in blood vessels, where the concept of high and low blood pressure is utilised. Drawings on the canvas reflect the performance of the swarms and the cells in the hybrid swarm intelligence algorithm. The authors discuss whether or not the art works generated by nature and physiology inspired algorithms can possibly be considered as computationally creative. In Chapter 4: "0h!m1gas: a Biomimetic Stridulation Environment" Kuai Shen Auson (Ecuador and Germany) presents an artistic experiment that explores the bioacoustics involved in the social behavior of ants when they communicate by producing modulatory vibrations. The author investigates the connections between these social organisms and humans, as human-ant relationship plays an important role in the creation of new ecosystems and the construction and mutation of posthuman ecology. In Chapter 5, "Bridging Synthetic and Organic Materiality: Graded Transitions in Material Connections," Hironori Yoshida (USA) introduces gradient material transitions that seamlessly bridge synthetic and organic matter, and applies what he learned about nature to architectural and interior design applications using digital fabrication of hybridized materials. Using digital image processing of organic forms, this fabrication process generates 3D tooling paths, culminating in the concept of bio-customization rather than mass customization, a new prospect of digital fabrication.

Section 2: Visualizing the Invisible: Processes for the Visual Data Formation contains four chapters: Chapter 6, "Sustainable Cinema: the Moving Image and the Forces of Nature," by Scott Hessels (Hong Kong) discusses the continuing relationship between the forces of nature and the materials of the moving image. The author revisits artworks that considered the natural environment as a co-creator in their realization and then presents his own series of kinetic public sculptures that use natural power sources to create the moving image. In Chapter 7, "Seeing the Unseen," Eve Andrée Laramée, Kalyan Chakravarthy Thokala, Donna Webb, Eunsu Kang, Matthew Kolodziej, Peter Niewiarowski, and Yingcai Xiao (USA) present art works created by the artists associated with the Synapse Group at the University of Akron in collaborations with the scientists in the group and/or inspired by the science of nature. The invisible are made visible by rendering water data with 3D computer graphics or by perceiving interactions between water and other objects. In addition, art works dealing with digital data in the forms of 2D and 3D imagery are also included. Chapter 8, "NanoArt: Nanotechnology and Art," by Cristian Orfescu (USA) introduces nano art. First, it goes back in time to the first uses of nanomaterials and nanotechnologies to create art and continues with the beginnings of nano art. Then, it follows the movement that evolved from recent technological developments in the multidisciplinary area known as nanotechnology. The chapter informs about the NanoArt competitions, displays select art works, and finally presents selected nano artists' thoughts. Chapter 9, "Nature Related Computerkunst," by Wolfgang Schneider (Germany) discusses theoretical background, categorizes examples of nature related computer art, and then presents several examples from artists participating in a series of Computerkunst/Computer Art exhibitions during the years 1986-2010.

Section 3: Visual Communication: Scientific Communication through Visual Language comprises four chapters: Chapter 10, "Biological Translation: Virtual Code, Form, and Interactivity," by Collin Hover (USA) explores the use of code, form, and interactivity in translating biological objects into mathematically generated digital environments. The author's own works: "Clouds & Ichor" and "Stream" demonstrate and ground the concepts being discussed. In both projects, a natural learning experience is at the core of the biological process. Chapter 11, "Looking at Science through Water," by Anna Ursyn (USA) is focused on creating the visual approach to natural concepts and events, rather than on their description. It has been designed as an active, involved, action-based exercise in visual communication. The chapter comprises two projects about water-related themes: States of Matter exemplified by ice, water, and steam, and Water Habitats: lake, river, and swamp. Chapter 12, "Visual Tweet: Nature Inspired Visual Statements," by Anna Ursyn (USA), explores connections between science, computing, and art in a similar way as it is done in a previous chapter, examines concepts and processes that relate to particular fields in science, and pertain to Earth's life and personal, everyday experience. Two projects about science-related themes are: Symmetry and pattern in animal world: geometry and art, and Crystals. Chapter 13, "Visualizing Geometric Problems in Wooden Sangaku Tablets," by Jean Constant (Switzerland/USA) describes visualization of the 19th century scientific representations from a Japanese culture - a set of mathematical problems etched on wooden boards. The author describes the steps in the creation of artistic statements based on geometrical problems. Discussion refers to the dissemination of the project in art galleries and online, its potential instructional use, and examines the audience responses.

Section 4: Tools for Metaphors: Nature Described with the use of Mathematics and Computing contains three chapters. Chapter 14, "Drawings from Small Beginnings," by Hans Dehlinger (Germany) experimentally addresses the formulation of a few concepts inspired by nature, aimed at generating line drawings executed on pen-plotters. Generative drawings are produced through a structured process including a sequence of discrete procedural steps. Chapter 15, "On the Designing and Prototyping of Kinetic Objects," by Scottie Chih-Chieh Huang and Shen-Guan Shih (Taiwan) explores kinetic interactions with a biomimetic perspective and demonstrates three kinetic interactive artworks through a modular design approach. "MSOrgm" is developed as a robot plant to interact with the viewer in a soothing way, "SSOrgan" is designed as an organic skin to interact with the viewer's touch of the top of it, and "LBSkeleton" is a robotic instrument that produces pneumatic sound and emits soothing light into space and can make the whole body transformation. In a Chapter 16, "A New Leaf," Liz Lee (USA) discusses her latest digital image series, "A New Leaf Series", within the context of early photographic imaging and its connection to science and biology. The author discusses how contemporary electronic imaging has returned to its photographic origins through nature-related subject matter.

Section 5: Analytical Discourse: Philosophy and Aesthetics of Nature Inspired Creations contains chapters: Chapter 17, "Science with the Art: Aesthetics Based on the Fractal and Holographic Structure of Nature," by Doug Craft (USA) discusses how both art and science proceed from an appreciation for and application of the natural proportions and forms associated with nature: the Golden Ratio, fractals, and the holographic metaphor. An outline of a personal theory of aesthetics and a collage series entitled The Elements in Golden Ratio illustrate application of the author's aesthetic theory. In Chapter 18, "Getting Closer to Nature: Artists in the Lab," James Faure Walker (UK) discusses works of artists who work alongside biologists to produce visual works of extraordinary quality, in both their decorative and intellectual aspects. The author describes his own use of scientific sources, arguing that, there is also a place for art that evokes the wonders of nature without being tied to the visible facts. Chapter 19: "drawing//digital//data: A Phenomenological Approach to the Experience of Water" by Deborah Harty (UK) discusses the translation (the finding of equivalences) of a phenomenological experience of water during the activity of swimming into drawing with both traditional drawing media and a tablet computer - an Apple iPad. The author discusses the premise that drawing is phenomenology, considering whether this premise is compromised when drawing with an Apple iPad rather than traditional drawing media. In Chapter 20, "From Zero to Infinity: A Story of Everything," Clayton S. Spada and Victor Raphael (USA), a practicing artist and a practicing artist/scientist present examples of art works entitled From Zero to Infinity, to illustrate the commonalities that art and science share with respect to pragmatic and creative processes, while not equating art with science as similar cognitive domains. This chapter examines how a generalist perspective may counterbalance deconstruction of perceived elemental units, so as to avoid becoming bound by paradigm. Art and science are addressed as related observational methods to explore hypotheses and represent the varied aspects of existence.

In conclusion, discussion of the role of creativity in artistic process becomes even more complicated with the advent of many new types of art. Working on visual projects based on natural processes is one of possible ways to strengthen one's visual literacy, especially when related to scientific concepts. The resulting artistic projects may be seen as analogy for the way nature works. Many agree the increase in visual literacy and visual imagination supports man's creativity, problem solving, and problem finding abilities. The developments in computing and information science seem to alter the ways of perceiving the notions of creativity, imagination, problem solving, problem finding, and knowledge acquisition and retention. More active approach is observable, and it could happen due to the online interactive learning possibilities and the evolvement of social networks. Changes in the ways of perceiving art may run parallel and be seen comparable to the evolvements in technologies. First of all, art creating is now more often a collaborative process. Many times artists create generative art constructing their works in an algorithmic way, often in multidisciplinary, collaborative manner. The ways of seeking inspiration seem to evolve from non-participative observation of nature and people toward pursuing, researching, and understanding the principles how both the nature and humans work or act. Many artists connect with physical sources of inspiration. Developments in technology achieved in particular domains of knowledge catch an interest and inspire people from other disciplines. Recently developed tools open new possibilities for research, and thus the ascent of computing inspired study of nature through art and data graphics may be observed.

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Section 1

Visual Data Formation: Biology Inspired Generation and Analysis of Objects and Processes

Chapter 1
Bio-Interfaces:
Designing Wearable Devices to Organic Interactions

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ABSTRACT

The bio-interfaces are widening the notions of complexity, affectiveness, and naturalness to an organic scale, in which the physiological information of the users acts as data to configure an interaction that responds to their emotional state in order to match the state of their body at that particular moment. In this context, the chapter discusses the role of the bio-interfaces in building a differentiated condition of interaction governed by the biology of the users. For this, the chapter presents applications of bio-interfaces in the areas of design, art, and games, considering their use as wearable devices that provide an organic interaction between man and machine, which could, in turn, lead these systems to a co-evolutionary relationship.

INTRODUCTION

The research and development of bio-interfaces constitute a transdisciplinary problem involving different fields of knowledge, such as: neurobiology, psychology, design, engineering, mathematics, and computer science. Unquestionably, growth of this research area is driven by the growing knowledge of biological functions, the advent of the computer - as a powerful and low-cost tool, the growing perception of the needs and potential of individuals with social and / or motor disabilities and, more specifically, the possibility of translating biological functions into numerical data that can be interpreted by computer systems that enable other channels of communication with the external world.

The context of bio-interfaces encompassed by this chapter includes the studies related to functional biometric interfaces as well as brain-computer interfaces, both focused on enabling communication processes between humans and machines and/or humans-machines-humans, based on a co-evolutionary relationship of bio-

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logical and technological systems. In this sense, aspects that are intrinsic to the application of these bio-interfaces will be addressed from a scientific perspective, considering the contributions by Sutter (1992), Picard (1998), Chapin et al. (1999), Bayliss & Ballard (2000), Wolpaw et al. (2002), among others, as well as within the scope of creation in arts, design and games, focusing on the productions by Gabriel (Wilson, 2002); Gilchrist, Bradley and Joelson (1997); Zuanon and Lima Jr. (2008 and 2010); Pfurtscheller (Friedman et al., 2007). Reflections will be emphasized based on the design of wearable bio-interfaces, specifically the characteristics essential to their design of interaction, taking into account future perspectives for the development of interactive bio-interfaces.

BIO-INTERFACES BACKGROUND

For several years, electrophysiological and electroencephalographic activities, and other measures of brain functions, have been considered means to new non-muscular channels of communication for sending messages and commands to the external world. This possibility becomes reality with the development and application of functional biometric interfaces and brain-computer interfaces (BCI) responsible for actually enabling this communication process between human-machine or human-machine-human, through the acquisition and encryption of the user's biological information. In this section, we will address the main aspects related to this context, to provide an ample understanding of the operation spectrum for both interfaces.

Functional biometric interfaces, based on checking ANS (autonomous nervous system) variability, provide information about the physical state or the behavior of those who use them, continuously gathering physiological data, that is, without interrupting user activity. For such, biosensors are used as input channels for a functional biometry system, such as: galvanic skin response sensor (GSR); blood volume pulse sensor (BVPS); breathing sensor (BS); and electromyogram sensor (EMG).

Galvanic Skin Response Sensor (GSR)

The GSR enables the possibility of measuring the parameters of electrical conductance from skin tissue through the application of two electrodes. This conductance is considered a function of the sweat gland activity, which is a part controlled by the sympathetic nervous system. Thus, when an individual suffers from anxiety or is frightened, a quick increase in skin conductance occurs due to the increase in sweat gland activity. This increase actually reflects the changes that are occurring at the stimulation level of the user's sympathetic nervous system as the result of an internal or external stimulus. The GSR then interprets these alterations and later they may be encrypted as actions in the environment external to the user's body, for example, the light of an environment that turns on after an increase in skin conductivity has been detected as a result of the person's apprehension in entering a dark room. It is important to underscore that an individual's skin conductance baseline is unique and it varies as a result of many parameters, such as: gender, food diet, skin type, social context, among others.

Blood Volume Pulse Sensor (BVPS)

The blood volume pulse sensor (BVPS) uses photoplethysmography to detect existing blood pressure at the extremities of the individual's body. This process consists of applying a light source and then measuring this light when it is reflected on the skin. With each contraction of the heart, the blood is forced through peripheral vessels, which causes their obstruction. In other words, what can be observed at this moment is an alteration in the amount of light that arrives at the photo sensor, thus allowing the reading of the user's blood pressure using BVPS. Also considering that the vasomotor activity is controlled by the sympathetic nervous system, the measurements determined by BVPS may reflect changes in sympathetic stimulation. More specifically, an increase in the pressure range read by BVPS indicates a reduction in sympathetic stimulation and greater blood flow at the tips of fingers. Likewise, with the data related to skin conductance, the reading and interpretation of the individual's blood pressure can also be used to trigger events, whether in the physical or digital environment.

Breathing Sensor (BS) and Electromyogram Sensor (EMG)

When positioned on the sternum, the breathing sensor (BS) enables monitoring the individual's thorax, or, when placed on the diaphragm, it allows monitoring diaphragm activity. This sensor consists of a Velcro belt that extends around the thorax, and a small elastic band that stretches with the expansion of the user's thorax. Thus, the depth as well as the breathing rate of the individual can be recorded based on the change in voltage resulting from the stretching of the elastic belt, working as data to control external actions to the user's body. The electrical activity produced by a muscle at the moment of contraction can be gauged by the electromyographical sensors that capture and amplify the signals. They then send them to the encrypter, where the necessary filtering will be carried out in order to obtain the ideal frequency band, taking into account the applicability of electromyographical activity for interacting with digital devices and/or systems.

All these biosensors also allow the reading of several of the user's physiological protocols, such as: control of anxiety / stress; emotional variability; emotional intensity; muscular variability; respiratory range and frequency; diaphragmatic respiration; sympathetic vascular tonus; cardiac variability; cardiac coherence; sympathetic and parasympathetic activity, among others. And, therefore, they can be used as input channels for an affective computing system, considering that they effectively contribute towards the detection of patterns in physiological information, which makes possible determining which signals are related to each of the user's emotional states (Picard, 1998). This occurs through the observation of physiological correlates, checked during situations projected to arouse and extract emotional responses. The system thus becomes aware of the user's immediate emotional state and is able to provide useful information about the interactor for applications that can use such data.

Brain-Computer Interface (BCI)

The context of functional biometric interfaces gains even more complex perspectives when brain signals are the substrate of biological information. A brain-computer interface (BCI) transforms the electrophysiological signals of central nervous system activity reflections into the products intended for that activity: messages and commands that act in the world. It transforms a signal, such as an EEG rhythm or a neural trigger rate from a brain function reflection into the final product of this function: an output that, as an output in conventional neuromuscular channels, carries out the person's intention. A BCI replaces nerves and muscles and produces movements with electrophysiological signals associated with the hardware and software that translates them into actions.

At present, BCI research programs are geared towards the exploitation of new technologies for increased control and communication for people with severe muscle disorders, such as lateral amyotrophic sclerosis, cerebral hemorrhage and muscle damage. Thus, the immediate objective of these programs is to provide these users – who may be completely paralyzed – with the capability for basic communication so they can express their desires to those who care for them, or to operate word processing programs and even neuroprosthesis. However, besides providing an option for control and communication for individuals with motor disabilities, BCI systems may also provide individuals with preserved motor abilities and channel for supplementary control or a useful channel for control in special circumstances.

A variety of methods for monitoring brain activity can function like a BCI. That includes, besides the electroencephalograph (EEG) and more invasive electrophysiological methods, magnetoencephalography (MEG), positron emission tomography (PET), functional magnetic resonance imaging (fMRI) and optical imaging. However, MEG, PET, fMRI and optical imaging are still expensive solutions, and from the technical perspective, they still require special care. Furthermore, since PET, fMRI and optical imaging depend on blood circulation, they require longer response time and for that reason they are less appropriate for quick communication. At the moment, only the EEG and related methods, which respond in a relatively short period of time, can function in most environments, because they require considerably simpler and economically more affordable equipment, and thus offer the possibility of a new channel of communication and non-muscular control (Wolpaw & Birbaumer, 2002).

The digital revolution promoted by continuous development and extremely fast computer hardware and software, provides the support for sophisticated online analyses of EEG multichannels and this leads to the appreciation of the fact that simple communication capability, such as "yes" or "no" and "on" or "off" can be configured in order to serve complex functions – such as word processing and prosthesis control. Many studies (Keirn & Aunon, 1990; Lang et al, 1996; Pfurtscheller 1997; Anderson 1998; Altenmüller & Gerloff, 1999; Mcfarland et al, 2000) have demonstrated correlations between EEG signals and real or imagined movements and between the EEG signals and those from mental tasks.

According to (Wolpaw & Birbaumer, 2002), epidural and subdural electrodes can provide EEGs with high topographic resolution, and the intracortical electrodes can follow the activity of individual neurons (Schmidt, 1980; Ikeda & Shibbasaki, 1992; Heetderks & Schmidt, 1995; (Levine et al., 1999), (Levine, 2000); Wolpaw et al., 2000). Besides that, studies (Georgopoulos et al., 1986; Schwartz, 1993; Chapin et al., 1999; Wessberg et al., 2000) demonstrate that the trigger rates for an appropriate selection of cortical neurons can offer a detailed portrait of simultaneous voluntary movement. However, since these methods are invasive, their use mainly occurs by individuals with extremely severe inabilities since they provide faster and more precise control and communication than the non-invasive EEG.

Current BCIs determine the user's intention based on different electrophysiological signals translated, in real time, into commands that operate a computer screen or some other device: slow cortical potentials, P300 potentials, beta rhythm or mu rhythm – recorded from the scalp – and cortical neural activity – recorded using implanted electrodes. In this sense, satisfactory operations require to encrypt the user commands in these signals since the BCI will derive the commands through these encrypted signals. Thus, the user and the BCI system need to continuously adapt to each other in order to ensure a stable performance (Wolpaw & Birbaumer, 2002).

BCIs are divided into two classes: dependent and independent. A dependent BCI does not use the brain's normal output circuits to send a message, but the activity in these circuits is necessary to generate the brain activity (EEG) that sends it. For example, a dependent BCI presents an individual with a matrix of letters that shine one at a time; then, the user selects a specific letter looking directly at it, so that the visually evoked potential (VEP) recorded from the scalp, just above the visual cortex, is much larger when that letter shines than the VEPs produced when other letters shine (Lauer et al., 2000; Pfurtscheller et al., 2000; Sutter, 1992). In this case, the brain output channel is the EEG, but the generation of the EEG signal depends on the direction of the look, and therefore, on the extra-ocular muscles and the cranial nerves that activate them. A dependent BCI is essentially an alternative method for detecting messages sent to the brain's normal output circuits, such as, the direction of the look.

On the other hand, an independent BCI does not depend in any way on the brain's normal output circuits. The message is not sent by the peripheral nerves and muscles, in other words, the activity of these circuits is not needed to generate brain activity (case of the EEG), which carries the message. For example, an independent BCI presents the user with a matrix of letters that shine one at a time, and the user selects a specific letter by producing a P300 evoked potential when the letter shines (Farwell & Donchin, 1988; Donchin et al., 2000). In this case, the brain output channel is the EEG, and the generation of the EEG signal mainly depends on the user's intention, and not on the precise direction of his / her eyes (Sutton et al., 1965; Donchin, 1981; Fabiani et al., 1987; Polich, 1999). In other words, the normal output circuits present in peripheral nerves and muscles do not play an essential role in the operation of an independent BCI. The fact that they are providing the brain with completely new output circuits makes the independent BCIs of greater theoretical interest than the dependent BCIs. Furthermore, for people with severe neuromuscular inabilities, which may be lacking in all normal output circuits (including extra-ocular muscular control), the independent BCIs are probably more useful.

In addition to the distinction between dependent and independent BCIs, electrophysiological BCIs may be categorized by non-invasive (for example, the EEG) or invasive (case of the intracortical procedure) methodology. They may also be categorized by the use of evoked inputs or spontaneous inputs. Evoked inputs (for example, the EEG produced by shining letters) result from the stereotypical sensory stimulation provided by the BCI. Spontaneous inputs (such as in the case of EEG rhythms on the sensory-motor cortex) do not depend on this stimulation. In this sense, there is presumably no determining reason that restricts a BCI from combining invasive and no-invasive methods or evoked and spontaneous inputs (Wolpaw & Birbaumer, 2002).

The substantial advances in non-invasive methods are evident for recording brain activity that enables control comparable to that of a computer mouse cursor movement. However, many differences between neural signals recorded with the use of invasive and non-invasive electrodes suggest implantable prostheses have a greater potential over the long term. EEG recordings reflect the average activity of millions of neurons, creating a signal with limited spatial and temporal resolution. In contrast, recordings with hundreds of microelectrodes, each one monitoring the activity of a single or of a small number of neurons, can create highly complex signs of control.

Studies conducted on animals reveal the need of obtaining three or fewer levels of control, since the implantable neuromotor prostheses are developed to foresee the movement the animal makes to reach a spatial target. However, human neural prostheses use a significantly higher number of degrees of control, since the subject's level of involvement for calibrating the device is much greater, and it may be much more complex if the individual is asked, for example, to move of his / her articulations separately (Scott, 2006).

In short, for (Wolpaw & Birbaumer, 2002), progress in the development of invasive and non-invasive brain-computer interfaces depends: on the identification of which signals – the evoked potentials, spontaneous rhythms or neural trigger rates –users are more capable of independently controlling the activity generated in conventional circuits of motor production; on the development of training methods to help users to achieve and to maintain this control; on outlining the best algorithms for translating these signals into commands for devices; on the attention given to the identification and elimination of artifacts; on the adoption of objective and precise procedures for evaluating BCI performance; on the recognition of the need for long and short evaluations of BCI performance; on the identification of the appropriate applications for BCIs; on the attention to factors that affect the acceptance of technologies increased by the user, including user-friendliness and the provision of those capacities for control and communication that are most important for the user.

THE BIO-INTERFACES AT DESIGN, ART, AND GAME AREAS: SOME APPLICATIONS

The adoption of bio-interfaces for the areas of design, art and games turns significantly the forms of participation and audience interaction with these systems. Different from the physicality proposed in the relations with tangible interfaces – of mice and keyboards; of joysticks; of touchscreens – and the ubiquity inherent to intangible interfaces – from position; face; gesture; voice mapping and recognition – the bio-interfaces go beyond both and propose a physicality and ubiquity of another order, of a physiological nature. This condition expands the notion of complexity, of affectivity and of naturalness to a biological scale in which the user's organism begins to provide the information (signals) that will configure the interactive processes between the individual / system in order to correspond to the emotions mapped at that specific moment.

In this section, interactive-media works will be presented and discussed, conducted within the contexts of art, design and games, which use physiological and / or brain activity of participants to propose a coauthor environment of creation. We shall emphasize our approach mainly in aspects involving the use of wearable devices to provide organic interaction between humans-machines that lead them to a relationship of permanent collaboration.

It is important to underscore that within the scope of the proposals considered herein, the applications of brain-computer interfaces occur at non-invasive dimensions.

"Terrain 01" (1993), by Ulrike Gabriel, proposes an interactive space in which robotic beetles are fed by light energy. Interaction with the visitor occurs through its brain waves, captured by a wearable interface comprised of electrodes sensitive to neural activities. The values obtained by this process provide the parameters for controlling the dimming of the facilities lights. In other words, the emotional state of the participant at that moment is responsible for controlling the quantity of energy emitted to the robotic objects. In this sense, the calmer the visitor is, the greater the intensity of light radiated to the beetles and consequently, the greater the speed of locomotion for these beetles when moving through space. The opposite occurs if the visitor presents any signs of stress or tension.[1]

In "Terrain 02: Solar Robot Environment for Two Users" (2001), the artist expands and makes the use of brain waves for the simultaneous control of robotic objects by two people more complex (Wilson, 2002). When placed one in front of the other, the neural signals of the participants, as in Terrain 01, are acquired by a wearable interface. However, in this case, the changes in brain patterns do not only control robot movements, but also affect the fluidity and synchrony of these movements.[2]

In the context of the creation in music, "Thought Conductor #1" (1997), by Bruce Gilchrist, Jonny Bradley, Jo Joelson, consists of a performance that uses software especially developed to translate the composers' brain waves in real time. Connected to a wearable brain interface and a digital biomonitor, the composer directs his / her thoughts to the memory of the largest number possible of details present in the musical structure of the previously created score. During this action, captured brain waves are then translated into musical notes, 'composed' for six interpreters and sent to six computer monitors. Thus, the new score, created through a coauthor process between the composer's organisms and the computer's artificial intelligence, is read and performed live by Nikki Yeoh & Piano Circus. In other words, a creative looping is established in which the composer's physiological information, produced during the practice of his / her creative activity, feed the technological system that returns this information to the composer as musical writing reframed by the collaborative action of both systems.

In "Thought Conductor #2" (2000) and "Thought Conductor #2.1" (2001), the composers Gilchrist and Bradley expand the performance proposal to the collaboration of the public present. In both cases, a previously created database was used with the composers' brain signals, captured when writing the musical notes. After acquired, these signals were associated to the corresponding notations and stored in the referred to database. Several members of the audience were invited to come on stage for the presentations and to contribute with a thought. While connected to a wearable brain interface and to the biomonitor, each was asked to think of a creative act they had already carried out: a jeweler thought of a gold ring he had recently created; a yogi meditated; a painter imagined the production process of his last painting, among others.

Thus, the neural waves of each participant generated original scores – from the association of brain activities acquired during this process to the available notations in the database – which were then sent to laptops to be read and played by a string quartet.[3,4]

In other words, a collaborative process for musical composition is observed mediated by technologies that provide the meeting between the composers' mental states, captured during execution of a creative act, with members of the audience, acquired when they recalled a creative action they had performed. Mental states that when hybridized still dialogue with the interpretation of the quartet musicians and the minds of the public present.

Within the scope of interaction with games, the wearable computers, "BioBodyGame" (2008) and "NeuroBodyGame" (2010), created by artists and designers Rachel Zuanon and Geraldo Lima, allow the user to interact with digital games through their physiological and cerebral signals, respectively.

BioBodyGame (Zuanon & Lima Jr., 2008) constitutes a wearable, wireless interface for functional biometric interaction with onboard games in the system, in which the games as well as the wearable computer react to the user's emotion during interaction. For such, the interactor's following physiological parameters are read during playability: emotional variability; anxiety control; emotional response; sympathetic and parasympathetic nervous system; functional oxygen; and cardiac frequency. The mapping of these parameters is done and associated in real time to game functionalities, which begin to react in accordance with the player's physiological state. In other words, playability is facilitated or made difficult based on the user's emotional state as well as how the wearable computer interprets these emotions and reacts to them, altering their color (front / back) and applying vibrations (back).

The NeuroBodyGame (Zuanon & Lima Jr., 2010) consists of a wearable computer that allows

Figure 1. BioBodyGame (© 2008, Rachel Zuanon. Used with permission.)

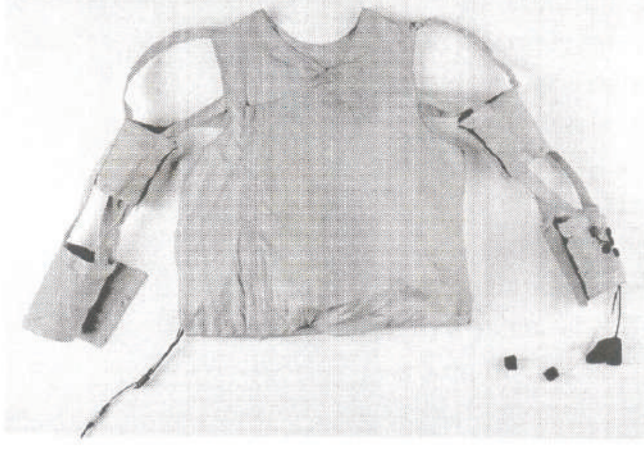
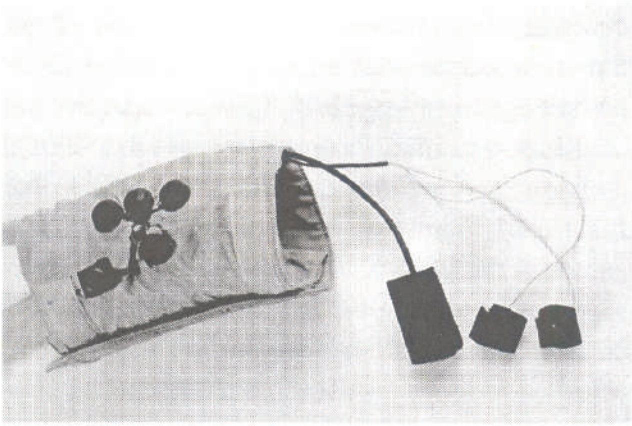


Figure 2. BioBodyGame bio-interface (© 2008, Rachel Zuanon. Used with permission.)



the user to play games with his / her brain signals. It is a wearable wireless interface for the brain to interact with the games bundled in the system. In this sense, games and wearable computers react to the user's brain wave frequencies captured at the moment of playability.

With a BioBodyGame upgrade, the NeuroBodyGame still provides the integration of the brain-computer interface to the functional biometric interaction system, associating user brain activity in real time to his / her physiological parameters related to blood flow; functional oxygen; cardiac frequency; and sympathetic and parasympathetic activities.

The design of both BioBodyGame and NeuroBodyGame is ergonomic and adjustable to different biotypes. That means that the wearable computers can be expanded or contracted in a manner to adjust to the user's body and ensure the interactor's comfort. Any possibility for discomfort can alter the player's physiological and brain signals and, consequently, compromise the organic information.

Other studies (Bayliss & Ballard, 2000; Leeb et al., 2004; Nelson et al., 1997) are carried out to permit applying wearable bio-interfaces as input devices for highly immersive virtual reality environments – such as caves and flight simulators. Pfurtscheller and collaborators (Friedman et al., 2007) propose two navigation experiences: one in which three volunteers rotate a digital room by imagining this movement being carried out by their right and left hands; and the other, in which the same volunteers cover a single dimension inside a digital street by imagining the movement of the feet and hands. In other words, moving physical or digital objects using the force of thought is also a bio-interface achievement.

Figure 3. NeuroBodyGame installation (© 2008, Rachel Zuanon. Used with permission.)

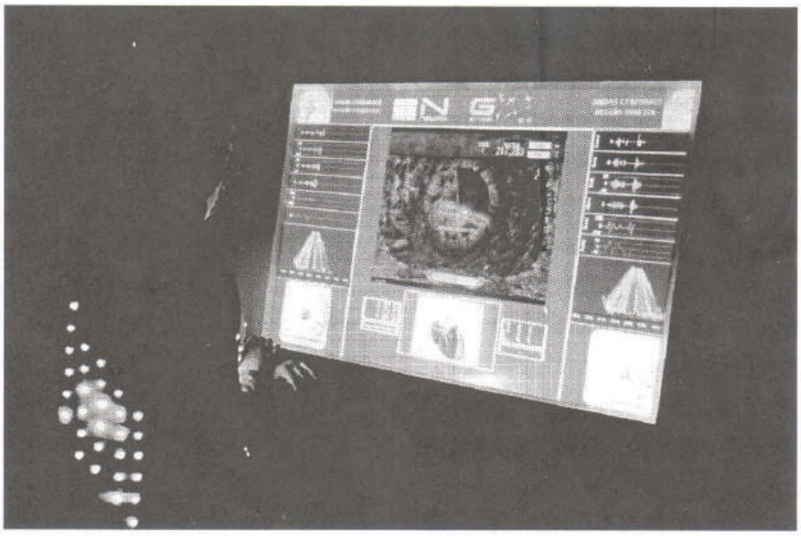


Figure 4. NeuroBodyGame bio-interfaces (© 2008, Rachel Zuanon. Used with permission.)

Figure 5. NeuroBodyGame design (© 2008, Rachel Zuanon. Used with permission.)

Solutions and Recommendations for Design of the Organic Interactions through Bio-Interfaces

From the applications addressed in the above section, it is possible to ascertain that bio-interfaces not only provide a differentiated relationship between the individual and technology, founded on reading, interpreting and associating neurophysiological data to control commands, but also a meeting between biological and technological systems for collaborative creation. This tends to become more popular as the use of bio-interfaces, once restricted to research laboratories, expands to artistic, educational and entertainment purposes, among others.

These advances have no doubt been stimulated by a new generation of non-invasive brain-computer interfaces, which come to market for direct use by the final consumer, associated with toys, games and virtual environments; applications geared towards accessibility for controlling physical interfaces (e.g., wheelchair) or computer applications by people with motor disabilities; neurofeedback; applications for marketing research and advertising; so as those developed by NeuroSky Incorporated and Emotiv Systems. While the first provides a wearable interface with only one sensor for detecting user brain waves and monitoring neural activity of controlling objects, the latter, using an Epoc wearable interface, foresees 14 sensors for acquiring interactor brain signals and association at three levels of interpretation: expressive; affective; and cognitive. The expressive level allows identifying the user's facial expressions in real time, providing the direct relationship between the interactor's facial movements and the character of a game. The affective level monitors the user's emotional state, enabling the game to respond to his / her emotions.

And the cognitive level reads and interprets the user's conscious thoughts, enabling the control of virtual objects by the action of thought.

Undoubtedly, the bio-interface design considers all aspects addressed herein to enable communication processes between the user's organism and the computer systems. However, those characteristics intrinsic to interaction design, fundamentally in relation to ergonomics, usability, mobility, as well as the quality of physiological and brain data (proportionally related to the level of existing artifacts in acquired signals) constitute the main concerns while developing bio-interfaces, since they all play a fundamental role in the construction of an effectively discrete and efficient relationship between the user and system.

In relation to ergonomics, anthropometric studies and research geared towards the technology of materials subsidize the elaboration of increasingly more adjustable bio-interfaces to different biotypes and thus promote full adaptation between the wearable device and the user's body. With regard to mobility, in relation to functional biometric interfaces, the wireless communication standard via Bluetooth used until now, although ensuring the user's full displacement without the restriction caused by cables and wires, faces problems related to possible interferences caused by the presence of another device that uses the same communication standard in the same environment. Within the ambit of brain-computer interfaces, studies conducted by researchers at Colorado State University aim to move the EEG analysis to be executed in cloud computing environments. Through this procedure, the current limitations faced by mobile BCIs are believed to be supplanted. For example, the one machine per user ratio is replaced by a set of hundreds of machines serving tens of thousands of users. This action aims at obtaining a significantly larger database for training artificial neural networks. In addition, the diverse small neural networks distributed in this data could act together to produce reports. Besides that, an increase is seen in the temporal aspect of brain signal flow analysis, which currently occurs after an immediate interval, to larger intervals, of around seconds or minutes.

In relation to usability, the implementation of high fidelity prototypes appear as more favorable solutions for obtaining final bio-interfaces, fully adapted to user needs, since, through them, it is possible to map use experiences in advance and thus enable the correction and necessary adjustments, during the wearable device's development process. Also in relation to usability, we see that successive training sessions held during the use of bio-interfaces are fundamental to provide better adaptation by the user to the system.

In relation to the quality of the physiological and brain data, the use of specific algorithms and filters has been presenting itself as one of the most efficient means to annul the possible interferences caused by external stimuli, which introduce artifacts in the biological signals.

INTERACTIVE BIO-INTERFACES

The research geared towards developing increasingly more complex bio-interfaces points to the challenge of these devices to act as output channels while also providing feedback directly to the human organism, in the case of functional biometric interfaces, or the brain, in the case of brain-computer interfaces. In other words, that means considering the possibility of bio-interfaces to also function as information input channels for the human body and thus be interactive.

At present, the operation of a bio-interface depends on the interaction of two adaptive controllers: the user's organism, which produces the signals measured by the bio-interface and the bio-interface itself, which translates these signals into specific commands. An interactive bio-interface shall provide feedback and thus interact in a productive manner with the adaptations that occurred in the user's organism after this feedback.

In this sense, for most neuroscientists, the next step is to introduce a sensory input in the bio-interfaces. Within the scope of brain-computer interfaces, several researchers are already investigating where and how to stimulate the sensory nervous system to reproduce the type of information a member should send to the sensory cortex. Theoretically, this may in the nerves that go from the members to the spinal cord, or in the spinal cord itself. Or it could be in the thalamus, where input sensory signals are integrated and redirected to the appropriate parts of the cortex, or the sensory cortex.

How to stimulate the sensory nervous system refers to the design of the electrical signal to be fed in the cortex. This can imitate the sensory system's natural nervous impulses, based on parameters such as frequency and amplitude. Or it can involve the creation of artificial signals the sensory cortex is apt to distinguish, in the hope that the brain may be trained to associate certain signals to certain parameters (Abbott, 2006).

Andrew Schwartz and Douglas Weber have been working at developing a scientific model for studying sensory inputs. This involves two stimulus procedures for recording neural activity. The first considers the use of electrodes to stimulate the sensory nerves of an anesthetized cat's members, and simultaneously record the neuron activity in the sensory cortex. In the second, the cat's members are moved manually (Schwartz et al., 2006).

After obtaining the data, the researchers compare the standard of neural activity in the cortex in both situations. Weber affirms that, even when encountering disagreements, a more satisfactory context is observed when the central nervous system receives an external stimulus, since stimulation by electrodes at the most central points of the cortex competes with a great convergence of different inputs, and with that obtaining signals without artifacts becomes more difficult.

Lee Miller (London et al., 2008) agrees that Weber may be right, however, stimulation of the body's peripheral nerves, such as in the members, according to Miller, will not function for patients with serious spinal cord injuries. Working with monkeys, the Miller group electrically stimulates the part of the cortex that processes proprioception, and simultaneously records neural activity in the motor cortex. The experiment demonstrated that monkeys recognize and distinguish between low and high frequency stimulations. The researcher expects this to eventually reveal the design of stimulation patterns that can imitate the brain's proprioception processes, the same way Weber plans on imitating the movement processing. These same monkeys are also trained to move a "virtual" arm, created on a computer screen by an algorithm fed by both recordings - from the motor cortex and from the simulated proprioception return.

In his experimental system with monkeys, John Chapin (Chapin et al., 1999) electrically stimulates the thalamus that retransmits signals related to touch and, simultaneously, records the neural activities in the sensory cortex areas that process touch information. Animals, with one of their arms tied, were taught to point with their free arm at an area on their immobilized arm that they felt was being touched. According to Chapin, based on this experience it is possible to produce a sort of natural response in the cortex when stimulating the thalamus. The response proves to be equal to the one normally produced when a specific part of the monkey's arm is touched. With that, he can somehow plan the extension of his research into proprioception studies.

All of the experiments that aim at studying sensory inputs point directly to aspects of adaptability between the user's nervous system and the bio-interface, both involved in this other condition of communication. This suggests a change in paradigm, as the current generation of bio-interfaces, with only one output, constitutes an open circuit systems. In this sense, the notion of co-evolution seems appropriate here, taking into account an instance of correlation between the systems involved, which encompasses non-supervised, that is, non-hierarchical adaptability as a preponderant factor in this communication process.

CONCLUSION

The wearable bio-interfaces presented and discussed in this chapter include the functional biometric interfaces and the brain-computer interfaces. Both consist of solutions that originated in the scientific environment aimed at promoting a differentiated channel of communication for the user with the outside environment, whether through reading and interpreting the variability of the autonomous nervous system or specifically of its brain signals, for controlling digital applications or physical devices.

Within the ambit of art, design, and games, the wearable bio-interfaces play the role of mediators in a collaborative creation process between the user and computer or between the biological and technological systems. However, regardless of the context for wearable bio-interface applications, their design requires attention and special care, considering that this presents itself directly related to the quality of promoted organic interaction. Several parameters guide the design of wearable bio-interfaces. However, ergonomics, usability, mobility, and quality of the acquired biological signals stand out as essential aspects to the interaction design of these devices. In this sense, future perspectives also point to the development of interactive bio-interfaces capable of also providing feedback to the user's organism, from the possibility of bidirectional interactivity, with an output channel (from the user to the external system) and an input channel (from the external system to the user). This condition reconstructs the communication circuit present until this moment since with that, the flows of biological information will not only be used to control the technological systems (hardware and software), but they will also return to the user's organism, thus constructing an effectively co-evolutionary cycle.

When this stage of bio-interface development is reached, certainly other parameters will be considered from a co-evolutionary perspective, in other words, from project definitions that guide the co-evolutionary design of these devices.

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KEY TERMS AND DEFINITIONS

Affective Computing: Is a term coined by researcher Rosalind Picard to propose to assign to computers emotional skills and ability to respond intelligently to human emotion.

Artificial Neural Networks: They are based on studies of the structure of the human brain to try to emulate, in a system of programs and computational data structures, its intelligent way to process information. Structurally, the artificial neural network, also known as connectionist model of computing, resembles the biological neural network because of the composition of its neurons and the connection between them.

Beta rhythm or Mu Rhythm: Is a spontaneous rhythm captured by the electroencephalogram (EEG) in the frequency of 8-12 Hz. It is associated to the motor activities and recorded with best potential over the sensorimotor cortex. The alpha rhythm is in the same frequency but it is recorded on the occipital cortex. However, the Biofeedback training can modify the amplitudes of these rhythms.

Brain Computer Interface (BCI): Consists of a communication system that interprets and analyzes brain signals in order to improve human cognitive or sensory-motor functions. In this sense, it allows controlling devices in the external world (prosthetic limb, mouse cursor, wheelchair, etc.) by means of brain signals.

Cardiac coherence: Is related to the variability between the phases of acceleration and decreased heart rate. The balance between these phases is called heart coherence. The absence of this equilibrium characterizes a chaotic heart rhythm.

Co-evolution: In biology, co-evolution is associated with the reciprocal evolutionary change between two species that have dependencies on each other, so that one exerts selective pressure on the other. In evolutionary computation, co-evolutionary algorithms are deployed in order to carry out experiments in artificial life, solve optimization problems, learning games strategies, and other applications.

Functional Biometric Interfaces: They capture, analyze and evaluate neurophysiological user data under different parameters. Such neurophysiological mapping can provide another channel of communication with the external world or, when coupled with knowledge relating to Functional Nutrition and Behavioral Medicine, can be applied to the autonomic rehabilitation through physical and mental training.

Interactive Bio-Interfaces: Consist of biological interfaces that in addition to capture, analyze and evaluate the neurophysiological data of users, enabling their application to control digital systems or devices in the external world; they also promote a return channel to the body of the user. In other words, they provide feedback on actions taken (control systems or devices) in order to set up a co-evolutionary relationship between the systems involved.

Interactor: Individual who establishes an interactive relationship with the interactive digital systems.

P300 Potentials: The P300 consists of a positive potential that arises 300 milliseconds after the stimulus trigger. However, the P300 is related only to stimuli that have some degree of novelty or significance to the individual. The P300 is more evident in the parietal cortex and it is used normally in implementations of BCIs where the individual's expectation is an important factor, as in the case of spellers.

Slow Cortical Potentials: The slow cortical potential denominates the lowest frequencies captured by the EEG, those with periods of oscillation between 0.5 s and 10.0 s. While the negative cortical potentials are related to body movement and other forms of cortical activation, the positive is related to a low cortical activation.

Wearable Computer: Consists of a wearable system, controlled and reconfigurable by the user. Always connected and accessible, a wearable computer allows the user to execute commands while performing other activities.

ENDNOTES

1. For more information see: http://www.medienkunstnetz.de/works/terrain/
2. For more information see: http://netzspannung.org/cat/servlet/ CatServlet?cmd=netzkollektor&subCommand=showEntry&forward=&entryId=147923&lang=en
3. For more information see: http://www.artemergent.org.uk/tc/tc2.html
4. For more information see: http://www.artemergent.org.uk/tc/tc2.1.html