Activity Report 2017

Team BIOVISION

Biologically plausible Integrative mOdels of the Visual system : towards synergIstic Solutions for visually-Impaired people and artificial visiON

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Computational Neuroscience and Medicine

Table of contents

Team BIOVISION

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Keywords:

Computer Science and Digital Science:

A5.3. - Image processing and analysis
A5.4. - Computer vision
A5.6. - Virtual reality, augmented reality
A6.1.1. - Continuous Modeling (PDE, ODE)
A6.1.4. - Multiscale modeling
A6.1.5. - Multiphysics modeling
A6.2.4. - Statistical methods

Other Research Topics and Application Domains:

B1.1.10. - Mathematical biology
B1.2.1. - Understanding and simulation of the brain and the nervous system
B2.1. - Well being
B2.5.1. - Sensorimotor disabilities
B9.4.2. - Mathematics
B9.4.3. - Physics

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2. Overall Objectives

2.1. Overall Objectives

Vision is a key function to sense the world and perform complex tasks, with a high sensitivity and a strong reliability, given the fact that most of its input is noisy, changing and ambiguous. Better understanding biological vision will have a strong scientific, medical, societal and technological impact in the near future. In this context, Biovision aims at developing fundamental research as well as technological transfer along two axes: developing of high tech vision aid systems for low-vision patients and modeling of the visual system for normal and distrophic conditions, targeting applications for low-vision and blind patients. These axes are developed in strong synergy, involving a large network of national and international collaborators with neuroscientists, physicians, and modellers.

3. Research Program

3.1. Introduction

The Biovision team has started on January 1st, 2016. It aims at developing fundamental research as well as technological developments along two axes.

3.1.1. Axis 1: High tech vision aid systems for low-vision patients

Visual impairment affects some 285 million people in the world, mostly in developed countries: 85% have low-vision [1] or poorer in the better-seeing eye and cannot be corrected or improved with regular eyeglasses (Source: VisionAware), i.e., have remaining sight. For these people, there is a strong need to conceive new aid-systems to help them in their daily living activities. Such aids already exist and can be divided into two categories according to their function. The first category concerns aids that translate visual information into alternative sensory information, such as touch or sound, called Sensory Substitution Devices (SSDs) [53], [47]. The second category concerns aids that adapt visual information to render it more visible to the patients using scene processing methods and suitable devices. These are based on technological solutions and algorithmic solutions that will enhance important scene characteristics [79], [68]. In Biovision, we focus on this second category by targeting new vision aid systems that will help patients perform the task they primary need in their daily life while investigating solutions which adapt to their own pathology. In our approach, we have these main goals :

1. We aim at developing contacts and collaborations with low-vision center and associations in order to better understand low-vision patients needs and have feedback on our prototypes. We are currently focusing on reading and navigation (indoor or outdoor).
2. We aim at proposing new **scene enhancements** which can be adapted depending on **pathologies**.
3. We want to develop solutions based on head mounted displays and especially low cost and large public systems with full consideration of comfort and **ergonomics**. Our objective is that some of our prototypes could be distributed to patients via transfer or company creation.

[1] low-vision is a condition caused by eye disease, in which visual acuity is 20/70 (meaning that the person is not able to see, at 20 meters from a chart, what a normal person would see at 70 meters).

3.1.2. Axis 2: Human vision understanding through joint experimental and modeling studies, for normal and distrophic retinas

A holistic point of view is emerging in neuroscience where one can observe simultaneously how vision works at different levels of the hierarchy in the visual system. Multiple scales functional analysis and connectomics are also exploding in brain science, and studies of visual systems are upfront on this fast move. These integrated studies call for new classes of theoretical and integrated models where the goal is the modeling of visual functions such as motion integration.

In Biovision we contribute to a better understanding of the visual system with three main goals:

1. We aim at proposing simplified mathematical models characterizing how the retina converts a visual scene into spike population coding, in normal and under specific pathological conditions.
2. We design biophysical models allowing to better understand the multiscale dynamics of the retina, from dynamics of individual cells to their collective activity, and how changes in biophysical parameters (development, pharmacology, pathology) impacts this dynamics.
3. We want to design an integrated numerical model of the visual stream, with a focus on motion integration, from retina to early visual cortex (V1).
4. We develop a simulation platform emulating the retinal spike-response to visual and prosthetic simulations, in normal and pathological conditions.

Finally, although this is not the main goal of our team, another natural avenue of our research will be to develop novel synergistic solutions to solve computer vision tasks based on bio-inspired mechanisms [10].

3.2. Scientific methodology

In this section we briefly describe the scientific methods we use to achieve our research goals.

3.2.1. Adaptive image processing

An impressive range of techniques have been developed in the fields of image processing, computer vision and computer graphics to manipulate and interpret image content for a variety of applications. So far, only a few of these techniques have been applied in the context of vision aid systems and even less have been carefully evaluated with patients. However, it is worth noticing a recent gain of interest from the artificial vision side to low-vision applications [2]. A possible explanation for this comes from the technological side, as new hardware are now available (e.g., head-mounted platforms, depth cams), which make it easier to design prototypes that patients could test.

Enhancing and manipulating image content is the first natural type of image processing to consider. This covers a variety of approaches such as equalization, gamma correction, tone mapping, edge enhancement, image decomposition or cartoonization. Some of these methods have already been tested with low-vision patients [44], [58], [59] or even in retina prosthesis systems as pre-processing steps [43]. More sophisticated approaches have also been tested to help patients focus on the most relevant information, such as scene retargeting [62] and seam carving [48], [45]. Using depth information can be another way to highlight specific features of a scene. Depth can be obtained from stereo head systems or RGB-D cameras. It can be used to make 3D-based enhancements [67], [66] and in the context of assisting visually impaired people, depth information can help them navigating in cluttered environments [64], [52].

Our goal is to investigate which image processing could bring a real advantage to the patients in the design of vision aid systems. We study how to combine them and how to make them adapted to patients pathologies, so that they can not only "see" an image but understand it more efficiently. We work on doing this using virtual and augmented reality technology (Sec. 3.2.2).

[2] See, e.g., the Special issue on Assistive Computer Vision and Robotics - "Assistive Solutions for Mobility, Communication and HMI" from Computer Vision and Image Understanding (August 2016) or the International Workshop on Assistive Computer Vision and Robotics (ECCV 2016 Satelite workshop)

3.2.2. Virtual, mixed and augmented reality

Virtual, mixed and augmented reality technology (VR/MR/AR) is becoming an important technology in many areas. It is based on the idea of combining digital words with physical realities in different ways, and it encompasses a wide spectrum of hardware. A new term is increasingly being used, which is cross reality (XR), to refer to this continuum of immersive experiences. Initially pushed by game and film industries, it appears that this technology could change our experiences in many domains such as education, journalism, media, training and healthcare.

To start experiencing XR, some cheap solutions work in conjunction with mobile phones like the Samsung GR or the simple Google Cardboard. Integrated solutions are also the market such as Oculus, OSVR (open source). New solutions appear on the market with increased capacities. Just to cite a few, let us mention the Oculus Go, the Oculus Rift or the HTC vive. For many of them, it is also planed to have eye tracking inside, as done for example in the FOVE.

Given this recent evolution and the promising perspectives, it is our conviction that this technology will play a major role in the domain of low-vision. Not only it can be useful to design novel vision aid systems and rehabilitation programs, but also this technology can help us to study the behaviour of low-vision people more precisely. Following these goals, we develop new immersive experiences to help low-vision people in their daily tasks.

3.2.3. Biophysical modeling

Modeling in neuroscience has to cope with several competing objective. On one hand describing the biological realm as close as possible, and, on the other hand, providing tractable equations at least at the descriptive level (simulation, qualitative description) and, when possible, at the mathematical level (i.e., affording a rigorous description). These objectives are rarely achieved simultaneously and most of the time one has to make compromises. In Biovision team we adopt the point of view of physicists: try to capture the phenomenological description of a biophysical mechanism, removing irrelevant details in the description, and try to have a qualitative description of equations behaviour at least at the numerical simulation level, and, when possible, get out analytic results. We do not focus on mathematical proofs, instead insisting on the quality of the model in predicting, and, if possible proposing new experiments. This requires a constant interaction with neuroscientists so as to keep the model on the tracks, warning of too crude approximation, still trying to construct equations from canonical principles [4], [5],[36].

3.2.4. Methods from theoretical physics

Biophysical models mainly consist of differential equations (ODEs or PDEs) or integro-differential equations (neural fields). We study them using dynamical systems and bifurcation theory as well as techniques coming from nonlinear physics (amplitude equations, stability analysis, Lyapunov spectrum, correlation analysis, multi-scales methods).

For the study of large scale populations (e.g., when studying population coding) we use methods coming from statistical physics. This branch of physics gave birth to mean-field methods as well statistical methods for large population analysis. We use both of them. Mean-field methods are applied for large scale activity in the retina and in the cortex [7], [11], [46].

For the study of retina population coding we use the so-called Gibbs distribution, initially introduced by Boltzmann and Gibbs. This concept includes, but *is not limited to*, maximum entropy models [63] used by numerous authors in the context of the retina (see, e.g., [71], [73], [61], [60], [74]). These papers were restricted to a statistical description without memory neither causality: the time correlations between successive times is not considered. A paradigmatic example of this is the Ising model, used to describe the retinal activity in, e.g., [71], [73]. However, maximum entropy extends to spatio-temporal correlations as we have shown in, e.g., [5] [75], [33].

More generally, while maximum entropy models rely heavily on the questionable assumption of stationarity, the concept of Gibbs distribution does not need this hypothesis. Beside, it allows to handle models with large memory; it also provides a framework to model anticipation [17]. It includes as well existing models to explain retina statistics such as the Generalized Linear Model (GLM) [51].

4. Application Domains

4.1. Applications of cross reality technologies for low-vision

- High tech vision aid systems for low-vision patients: Vision aid systems for low-vision patients is an application domain with commercial products already existing. A variety of XR solutions are on the market using different kinds of platforms (dedicated or large public ones) and offering different kinds of functionalities (magnification, enhancement, text to speech, face and object recognition). Our goal is to propose new solutions to help patients in a given task.
- Serious games [3] for rehabilitation: Since cross reality technology is now becoming available for the large public, it is a promising platform to develop new rehabilitation exercises.
- Cognitive research: A new trend in cross reality technology is to include eye-tracking so that these platforms could also be very efficient to conduct cognitive and behavioural research on a large scale.

4.2. Applications of vision modeling studies

- Neuroscience research: Making in-silico experiment is a way to reduce the experimental costs, to test hypotheses and design models, and to test algorithms. Our goal is to develop a large-scale simulations platform of impaired retinas, allowing to mimic specific degeneracies or pharmacologically induced impairments, as well as to emulate electric stimulation by prostheses. In addition, the plateform provides a realistic entry to models or simulators of the thalamus or the visual cortex, in contrast to the entries usually considered.
- Education: The simulation plateform we develop could also be a useful tool for educational purposes, illustrating for students how the retina works and respond to visual stimuli.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

The article "Bio-inspired computer vision: towards a synergistic approach of artificial and biological vision" (published in Computer Vision and Image Understanding in 2016 [10]) was selected as part of the 21st Annual Best of Computing.

6. New Software and Platforms

6.1. Virtual Retina

A biological retina modèle with contrast gain control for large scale simulations
KEYWORDS: Neurosciences - Simulation - Biology - Health

[3] Serious games are games designed for a primary purpose which is not pure entertainment. In our context, we think about serious games as a way to help low vision patients in performing rehabilitation exercises.

SCIENTIFIC DESCRIPTION: Virtual Retina has a variety of biological features implemented such as (i) spatio-temporal linear filter implementing the basic center/surround organization of retinal filtering, (ii) non-linear contrast gain control mechanism providing instantaneous adaptation to the local level of contrast, (iii) spike generation by one or several layers of ganglion cells paving the visual field.
FUNCTIONAL DESCRIPTION: Virtual Retina is a simulation software that allows large-scale simulations of biologically-plausible retinas.
NEWS OF THE YEAR: Virtual Retina software has been integrated into the platform PRANAS allowing to simulate retinal output via a graphical user interface (see paper published in Frontiers in Neuroinformatics, 2017)

- Participants: Adrien Wohrer, Pierre Kornprobst, Bruno Cessac, Maria-Jose Escobar and Thierry Viéville
- Contact: Pierre Kornprobst
- Publication: Virtual Retina: A biological retina model and simulator, with contrast gain control
- URL: https://team.inria.fr/biovision/virtualretina/

6.2. PRANAS

Platform for Retinal ANalysis And Simulation
KEYWORDS: Retina - Neural Code - Data management - Statistics - Modeling - Vision
SCIENTIFIC DESCRIPTION: PRANAS was designed as a user-friendly tool dedicated to neuroscientist community in a large sense, i.e., not only experienced computational neuroscientists. It has two main goals : (i) to analyze retina data, especially spatio-temporal correlations, at single cell but also population levels, (ii) to simulate the spike response of the retina to a visual flow with a customizable retina simulator which evolves in synergy with experimental data analysis. In general, PRANAS allows to explore several aspects of retinal image processing such as understanding how to reproduce accurately the statistics of the spiking activity at the population level, or reconciling connectomics and simple computational rules for visual motion detection. This makes this tool a unique platform to better understand how the retina works.
FUNCTIONAL DESCRIPTION: The retina encodes a visual scene by trains of action potentials sent to the brain via the optic nerve. PRANAS brings to neuroscientists and modelers tools to better understand this coding. It integrates a retina simulator allowing large scale simulations while keeping a strong biological plausibility and a toolbox for the analysis of spike trains population statistics. The statistical method (entropy maximization under constraints) takes into account both spatial and temporal correlations as constraints, allowing to analyze the effects of memory on statistics. PRANAS also integrates a tool computing and representing in 3D (time-space) receptive fields. All these tools are accessible through a friendly graphical user interface. The most CPU-costly of them has been implemented to run in parallel. The actual version simulates healty retinas but the long term goal is to study retinas with a pathology (DMLA, Retinitis Pigmentosa, Glaucoma).
NEWS OF THE YEAR: PRANAS software is described in an article published in Frontiers in Neuroinformatics (2017), and it is available for downoad.

- Authors: Bruno Cessac, Pierre Kornprobst, Sélim Kraria, Hassan Nasser, Daniela Pamplona, Geoffrey Portelli and Adrien Wohrer
- Contact: Bruno Cessac
- Publication: PRANAS: A New Platform for Retinal Analysis and Simulation
- URL: https://team.inria.fr/biovision/pranas-software/

7. New Results

7.1. High tech vision aid systems for low-vision patients

7.1.1. Using virtual reality to helping low-vision people read depending on their pathology

Participants: Marco Benzi [Université Côte d'Azur (France)], Stéphanie Baillif [Centre hospitalier Pasteur 2 (service d'ophtalmologie, Nice, France)], Annick Martin ["27Delvalle" (Centre d'Innovation Santé de la ville de Nice, France)], Eric Castet [Aix-Marseille Université (CNRS, Laboratoire de Psychologie Cognitive, Marseille, France)], Fabio Solari [University of Genoa (DIBRIS, Genoa, Italy)], Manuela Chessa [University of Genoa (DIBRIS, Genoa, Italy)].

By stimulating imagination, reading can be considered as the first immersive media that we are experimenting in our life. We read for leisure, to learn or to be informed. Nowadays, we read not only on printed books or newspaper but on a variety of electronic platforms (computers, tablets, phones), thus extending the possibilities to read. However, reading poses problems for almost everyone with low-vision and it is amongst the strongest need reported by patients [55], [65]. Electronic equipments such as CCTV have offered new possibilities for the patients to tune their prefered display and many studies have been done to understand the impact of most parameters in reading performance [50], [70], [42], [49], [65]. However, display is still highly limited by the small field of view offered by CCTVs, the navigation issues, and the fact that they are constrained to sit at their desk in order to read, thus providing a limited comfort to patients. Our goal is to investigate how virtual reality could be used to overcome these limitations and study new reading aid strategies depending on patients' pathologies.

This project received funding from Université Côte d'Azur (France), in the "Pré-maturation" call which finances actions that transform existing proof of concept into an operational laboratory prototype allowing either the realization of "robust" demonstrators or the complete experimental validation of concept (see Sec. 9.1.1).

7.1.2. Real-time image enhancement in virtual reality applications for low-vision people

Participants: Manuela Chessa [University of Genoa (DIBRIS, Genoa, Italy)], Alberto Patino [University of Genoa (DIBRIS, Genoa, Italy)], Horacio Rostro [University of Guanajuato (Guanajuato, Mexico)], Eric Castet [Aix-Marseille Université (CNRS, Laboratoire de Psychologie Cognitive, Marseille, France)], Fabio Solari [University of Genoa (DIBRIS, Genoa, Italy)], Pierre Kornprobst.

In the last years, virtual reality technology has experienced a boost in affordability, and an increasing number of applications have emerged proposing new immersive 360 degrees visual content. To make this content accessible for low-vision people, one should adopt the same strategies as in traditional displays, i.e., use dedicated image enhancement methods to facilitate their interpretation. This work introduces a virtual reality application for mobile devices that implements real-time content enhancement. It is implemented as a visual search task in a set of static 360 degrees environments: the immersed user can manipulate the parameters of the enhancement algorithm in a intuitive way, using an external controller. In particular, we focus on the transform proposed by Peli et al [69], which is based on an adaptive filter that controls the local contrast as a function of the local mean luminance of an image. Such a transform has been shown to improve recognition tasks in patients with moderate visual loss, central scotoma or cataracts. Our application is, to our knowledge, the first attempt to evaluate the impact of this image enhancement in an immersive virtual reality environment. In particular, our system allows the real time tuning of the transform, and provides all the quantitative data to analyse a posteriori users' behaviour and how parameters may impact their performance. Designed as a game, it is perceived as more enjoyable than traditional ophthalmologic experiments. More generally, this application could be a way for low-vision people to adjust vision enhancements to their needs in everyday virtual reality applications, also for entertainment purposes

This work was presented at the Vision conference [27].

7.1.3. ARVIP: Augmented reality for visually impaired people

Participants: Josselin Gautier, Pierre Kornprobst, Frédéric Dosière [Bosch Visiontec (Sophia Antipolis, France)], David Coupé [Bosch Visiontec (Sophia Antipolis, France)].

In Biovision, we want to develop new augmented reality systems for low-vision people, to facilitate scene interpretation by enhancing important scene characteristics. Research and investigations are conducted using automotive industry HW solutions, thanks to a partnership with Bosch Visiontec (Sophia Antipolis, France, see Sec. 8.1.1).

7.2. Human vision understanding through joint experimental and modeling studies, for normal and distrophic vision

7.2.1. Recurrent network dynamics reconciles visual motion segmentation and integration

Participants: N.v. Kartheek Medathati, James Rankin [University of Exeter (Department of Mathematics, Exeter, UK)], Andrew I. Meso [Institut de Neurosciences de la Timone (CNRS and Aix-Marseille Université, France)], Pierre Kornprobst, Guillaume S. Masson [Institut de Neurosciences de la Timone (CNRS and Aix-Marseille Université, France)].

In sensory systems, different computational rules are postulated to be implemented by different neuronal subpopulations characterised by their tuning function. For instance, in primate cortical area MT, different classes of direction-selective cells have been identified and related to either motion integration, segmentation or transparency. Still, how such different tuning properties are constructed is unclear. The dominant theoretical viewpoint based on linear-nonlinear feedforward cascade does not account for their complex temporal dynamics and their versatility when facing different input statistics. Here, we demonstrate that a recurrent network model of visual motion processing can reconcile these different properties. Using a ring network, we show how excitatory and inhibitory interactions can implement different computational rules such as vector averaging, winner-take-all or superposition. The model also captures ordered temporal transitions between these behaviours. In particular, depending on the inhibition regime the ring network can switch from motion integration to motion segmentation, thus being able to compute either a single pattern motion or to superpose multiple inputs as in motion transparency. We thus demonstrate that recurrent architectures can adaptively give rise to different cortical computational regimes depending upon the input statistics, thus reconciling the twin blows of sensory processing: integration and segmentation.

This work was published in [20]

7.2.2. Retinal waves

Participants: Dora Karvouniari, Lionel Gil [Institut Non Linéaire de Nice (INLN, Université Côte d'Azur (France), France)], Olivier Marre [Institut de la Vision (Paris, France)], Serge Picaud [Institut de la Vision (Paris, France)], Bruno Cessac.

Retinal waves are bursts of activity occurring spontaneously in the developing retina of vertebrate species, contributing to the shaping of the visual system organization: retina circuitry shaping, retinotopy, eye segregation [77], [56], [72], [57]. They stop a few weeks after birth. Wave activity begins in the early development, long before the retina is responsive to light. It was recently found that they can be reinitiated pharmacologically in the adult mammalian retina [54]. This could have deep consequences on therapy for several degenerative retinal diseases. The mechanism of their generation, in imature, or adult retinas, remains however incompletely understood [78].

We have proposed a model for stage II retinal waves - induced by bursting Starburst Amacrine Cells (SACs) coupled by acetylcholine - with 2 objectives: (i) being sufficiently close to biophysics to explain and propose experiments and (ii) affording a mathematical analysis. From a bifurcations analysis we have highlighted several relevant biophysical parameters controlling waves generation, mainly regulating potassium and calcium dynamics. We thus explain how SACs in different species exhibit a large variability in their bursting periods with a common mechanism. We have proposed a testable experimental prediction providing

a possible link of the evolution of voltage-dependent potassium channels along development with their role on the excitability properties of SACs. We have reproduced experimental findings (statistical characteristics of waves size, duration and frequency of appearance) and analyzed how the evolution of cholinergic conductance due to the maturation of nicotinic receptors dramatically changes the retinal wave characteristics. We have also shown that the nonlinear dynamics generates heterogeneous local spatial structures inside which retinal waves propagate. This induces a wide variability in waves characteristics even though the network is perfectly homogeneous.

This work has been presented in [36], [34], [24], [25], [38], [37]

7.2.3. Pan-retinal characterisation of light responses from ganglion cells in the developing mouse retina

Participants: Gerrit Hilgen [Institute of Neuroscience (ION, Newcastle, UK)], Sahar Pirmoradian [Institute for Adaptive and Neural Computation (ANC, School of Informatics University of Edinburgh, UK)], Daniela Pamplona [ENSTA ParisTech, Autonomous Systems and Robotics (Paris, France)], Pierre Kornprobst, Bruno Cessac, Matthias H. Hennig [Institute for Adaptive and Neural Computation (ANC, School of Informatics University of Edinburgh, UK)], Evelyne Sernagor [Institute of Neuroscience (ION, Newcastle, UK)].

We have investigated the ontogeny of light-driven responses in mouse retinal ganglion cells (RGCs). Using a large-scale, high-density multielectrode array, we recorded from hundreds to thousands of RGCs simultaneously at pan-retinal level, including dorsal and ventral locations. Responses to different contrasts not only revealed a complex developmental profile for ON, OFF and ON-OFF RGC types, but also unveiled differences between dorsal and ventral RGCs. At eye-opening, dorsal RGCs of all types were more responsive to light, perhaps indicating an environmental priority to nest viewing for pre-weaning pups. The developmental profile of ON and OFF RGCs exhibited antagonistic behaviour, with the strongest ON responses shortly after eye-opening, followed by an increase in the strength of OFF responses later on. Further, we found that with maturation receptive field (RF) center sizes decrease, responses to light get stronger, and centers become more circular while seeing differences in all of them between RGC types. These findings show that retinal functionality is not spatially homogeneous, likely reflecting ecological requirements that favour the early development of dorsal retina, and reflecting different roles in vision in the mature animal.

This work has been published in [19].

7.2.4. Trajectory anticipation, from retina to V1

Participants: Selma Souihel, Bruno Cessac.

Global motion processing is a major computational task of biological visual systems. When an object moves across the visual field, the sequence of visited positions is strongly correlated in space and time, forming a trajectory. These correlated images generate a sequence of local activation of the feedforward stream. At the present stage of knowledge, it is still unclear how the early visual system processes motion trajectories. Motion integration, anticipation and prediction would be jointly achieved through the interactions between feed-forward, lateral and feedback propagations within a common spatial reference frame, the retinotopic maps. Addressing this problem is particularly challenging, as it requires to probe these sequences of events at multiple scales (from individual cells to large networks) and multiple stages (retina, primary visual cortex (V1).

In the context of the ANR Trajectory we are working on such an integrated approach. We aim at modelling the population responses at two key stages of visual motion encoding: the retina and V1 based on simultaneous micro- and mesoscopic recordings made by our partners Institut de Neurosciences de la Timone (CNRS and Aix-Marseille Université, France) and Institut de la Vision (Paris, France), and design a simulator of retinal output feeding V1. This study is a step toward understanding mechanisms of motion coding and anticipation with strong impact on our understanding of the visual system.

We have implemented in our retina simulator, PRANAS, gain control mechanisms allowing to reproduce motion anticipation for simple motions. We developed a simple decoding algorithm that reconstructs the stimulus using firing rates, with the goal of comparing the performance of the different models of gain control. We have also designed a biologically inspired model of connectivity, mimicking short and long range connections between ganglion cells via amacrine cells. This has allowed us to compare the pairwise correlations between ganglion cells, under the influence of a moving object both, in vivo and in silico. These results have been presented in [40], [41], [39]

7.2.5. Dimensionality reduction in spatio-temporal MaxEnt models and analysis of retinal ganglion cell spiking activity in experiments

Participants: Rubén Herzog [Centro Interdisciplinario de Neurociencia de Valparaíso (CINV, Valparaíso, Chile)], Maria-Jose Escobar [Universidad Tecnico Federico Santa María (Electronics Engineering Department, Valparaíso, Chile)], Adrian Palacios [Centro Interdisciplinario de Neurociencia de Valparaíso (CINV, Valparaíso, Chile)], Bruno Cessac.

Retinal spike response to stimuli is constrained, on one hand by short range correlations (receptive field overlap) and on the other hand by lateral connectivity (cells connectivity). This last effect is difficult to handle from statistics because it requires to consider spatio-temporal correlations with a time delay long enough to take into account the time of propagation along synapses. Although MaxEnt models are useful to fit optimal model (maximizing entropy) under the constraints of reproducing observed correlations, they do address spatio-temporal correlations in their classical form (Ising or higher order interactions but without time delay). Binning in such models somewhat integrates propagation effects, but in an implicit form, and increasing binning severely bias data. To resolve this issue we have considered spatio-temporal MaxEnt model formerly developed e.g. by Vasquez et al. [75]. The price to pay, however is a huge set of parameters that must be fitted to experimental data to explain the observed spiking patterns statistics. There is no a priori knowledge of which parameters are relevant and which ones are contributing to overfitting. We propose here a method of dimension reduction, i.e. a projection on a relevant subset of parameters, relying on the so-called Susceptibility matrix closely related to the Fisher information. In contrast to standard methods in information geometry though, this matrix handles space and time correlations. We have applied this method for retina data obtained in a diurnal rodent (Octodon degus, having 30% of cones photoreceptors) and a 252-MEA system. Three types of stimuli were used: spatio-temporal uniform light, white noise and a natural movie. We show the role played by time-delayed pairwise interactions in the neural response to stimuli both for close and distant cells. Our conclusion is that, to explain the population spiking statistics we need both short-distance interactions as well as long-distance interactions, meaning that the relevant functional correlations are mediated not only by common input (i.e. receptive field overlap, electrical coupling; spillover) but also by long range connections.

This work has been submitted to Plos Comp Bio.

7.2.6. On the mathematical consequences of binning spike trains

Participants: Bruno Cessac, Arnaud Le Ny [Laboratoire d'Analyse et de Mathématiques Appliquées (LAMA, (Université Paris-Est, France)], Eva Loecherbach [Laboratoire d'Analyse, Géométrie et Modélisation (AGM) and Département de Mathématiques (Cergy-Pontoise, France)].

We initiate a mathematical analysis of hidden effects induced by binning spike trains of neurons. Assuming that the original spike train has been generated by a discrete Markov process, we show that binning generates a stochastic process which is not Markovian any more, but is instead a Variable Length Markov Chain (VLMC) with unbounded memory. We also show that the law of the binned raster is a Gibbs measure in the DLR (Dobrushin-Lanford-Ruelle) sense coined in mathematical statistical mechanics. This allows the derivation of several important consequences on statistical properties of binned spike trains. In particular, we introduce the DLR framework as a natural setting to mathematically formalize anticipation, i.e. to tell "how good" our nervous system is at making predictions. In a probabilistic sense, this corresponds to condition a process by its future and we discuss how binning may affect our conclusions on this ability. We finally comment what could be the consequences of binning in the detection of spurious phase transitions or in the detection of wrong evidences of criticality.

This work has been published in [17].

7.2.7. Linear response of general observables in spiking neuronal network models

Participants: Bruno Cessac, Rodrigo Cofré [Université de Genève (Switzerland) and Centro Interdisciplinario de Neurociencia de Valparaíso (CINV, Valparaíso, Chile)].

The activity of a neuronal network, characterized by action potentials (spikes), is constrained by the intrinsic properties of neurons and their interactions. When a neuronal network is submitted to external stimuli, the statistics of spikes changes, and it is difficult to disentangle the influence of the stimuli from the intrinsic dynamics. Using the formalism of Gibbs distributions, which are a generalization of Maximum Entropy distributions to non-stationary distributions, and generalization of Markov chains to infinite memory, we analyze this problem in a specific model (Conductance-based Integrate-and-Fire), where the neuronal dynamics depends on the history of spikes of the network. We derive a linear response formula allowing to quantify the influence of a weak amplitude external stimuli on the average value of arbitrary observables. This formula clearly disentangles the effect of the stimuli, intrinsic neuronal dynamics, and network connectivity. Upon some approximations, it reduces to a convolution, allowing to recover a standard formulation in computational neuroscience.

This work has been submitted to Journal of Mathematical Neurosciences [33].

7.2.8. A bio-inspired synergistic virtual retina model for tone mapping

Participants: Marco Benzi, Maria-Jose Escobar [Universidad Tecnico Federico Santa María (Electronics Engineering Department, Valparaíso, Chile)], Pierre Kornprobst.

Real-world radiance values span several orders of magnitudes which have to be processed by artificial systems in order to capture visual scenes with a high visual sensitivity. Interestingly, it has been found that similar processing happens in biological systems, starting at the retina level. So our motivation in this paper is to develop a new video tone mapping operator (TMO) based on a synergistic model of the retina. We start from the so-called Virtual Retina model [76], which has been developed in computational neuroscience. We show how to enrich this model with new features to use it as a TMO, such as color management, luminance adaptation at photoreceptor level and readout from a heterogeneous population activity. Our method works for video but can also be applied to static images (by repeating images in time). It has been carefully evaluated on standard benchmarks in the static case, giving comparable results to the state-of-the-art using default parameters, while offering user control for finer tuning. Results on HDR videos are also promising, specifically w.r.t. temporal luminance coherency. As a whole, this paper shows a promising way to address computational photography challenges by exploiting the current research in neuroscience about retina processing.

This work was published in [15].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

8.1.1. ARVIP: Augmented reality for visually impaired people

Participants: Josselin Gautier, Pierre Kornprobst, Frédéric Dosière [Bosch Visiontec], David Coupé [Bosch Visiontec]

Duration: August 2017 to March 2018

In Biovision, we want to develop new augmented reality systems for low-vision people, to facilitate scene interpretation by enhancing important scene characteristics. Research and investigations are conducted using automotive industry HW solutions, thanks to a partnership with Bosch Visiontec. Our goal is to investigate how such hardware could be used to design efficient vision aid systems. The case-study that we are considering is the one of improving the social interaction which is amongst the first reported needs. We are studying methods to selectively enhance faces in real time, thus

allowing low-vision people to better capture faces and emotions of their interlocutors. This work is also conducted in collaboration with Centre hospitalier Pasteur 2 (service d'ophtalmologie, Nice, France) and "27Delvalle" (Centre d'Innovation Santé de la ville de Nice, France) in order to have feedback on our prototype as we develop it.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. VREAD: Making reading enjoyable again

Participants: Marco Benzi, Pierre Kornprobst, Stéphanie Baillif [Centre hospitalier Pasteur 2 (service d'ophtalmologie, Nice, France)], Annick Martin ["27Delvalle" (Centre d'Innovation Santé de la ville de Nice, France)], Eric Castet [Aix-Marseille Université (CNRS, Laboratoire de Psychologie Cognitive, Marseille, France)], Fabio Solari [University of Genoa (DIBRIS, Genoa, Italy)], Manuela Chessa [University of Genoa (DIBRIS, Genoa, Italy)]

Coordinator: Pierre Kornprobst

Duration: August 2017 to January 2019

Our goal is to develop a new platform to bring reading experience to a higher level of immersivity, making reading enjoyable again for low-vision people. This project received funding from Université Côte d'Azur (France), in the "Pré-maturation" call which finances actions that transform existing proof of concept into an operational laboratory prototype allowing either the realization of "robust" demonstrators or the complete experimental validation of concept. The perspective is industrialisation, through transfer or start-up creation.

9.1.2. Modélisation Théorique et Computationnelle en Neurosciences et Sciences Cognitives

The Biovision team is a member of this "Axe Interdisciplinaire de Recherche de l'Université de Nice – Sophia Antipolis". It has participated to the Rencontre C@UCA 2017 in Fréjus (April 2017). This axe is partly funding our work on retinal waves.

9.2. National Initiatives

9.2.1. ANR

9.2.1.1. Trajectory

Title: Encoding and predicting motion trajectories in early visual networks

Programme: ANR

Duration: October 2015 - September 2020

Coordinator: Invibe Team, Institut des Neurosciences de la Timone, Frédéric Chavane,

Partners:

Institut de Neurosciences de la Timone (CNRS and Aix-Marseille Université, France)

Institut de la Vision (Paris, France)

Universidad Tecnico Federico Santa María (Electronics Engineering Department, Valparaíso, Chile)

Inria contact: Bruno Cessac

Global motion processing is a major computational task of biological visual systems. When an object moves across the visual field, the sequence of visited positions is strongly correlated in space and time, forming a trajectory. These correlated images generate a sequence of local activation of the feed-forward stream. Local properties such as position, direction and orientation can be extracted at each time step by a feed-forward cascade of linear filters and static non-linearities. However such local, piecewise, analysis ignores the recent history of motion and faces several difficulties, such as systematic delays, ambiguous information processing (e.g., aperture and correspondence problems) high sensitivity to noise and segmentation problems when several objects are present. Indeed, two main aspects of visual processing have been largely ignored by the dominant, classical feed-forward scheme. First, natural inputs are often ambiguous, dynamic and non-stationary as, e.g., objects moving along complex trajectories. To process them, the visual system must segment them from the scene, estimate their position and direction over time and predict their future location and velocity. Second, each of these processing steps, from the retina to the highest cortical areas, is implemented by an intricate interplay of feed-forward, feedback and horizontal interactions. Thus, at each stage, a moving object will not only be processed locally, but also generate a lateral propagation of information. Despite decades of motion processing research, it is still unclear how the early visual system processes motion trajectories. We, among others, have proposed that anisotropic diffusion of motion information in retinotopic maps can contribute resolving many of these difficulties. Under this perspective, motion integration, anticipation and prediction would be jointly achieved through the interactions between feed-forward, lateral and feedback propagations within a common spatial reference frame, the retinotopic maps. Addressing this question is particularly challenging, as it requires to probe these sequences of events at multiple scales (from individual cells to large networks) and multiple stages (retina, primary visual cortex (V1)). “TRAJECTORY” proposes such an integrated approach. Using state-of-the-art micro- and mesoscopic recording techniques combined with modeling approaches, we aim at dissecting, for the first time, the population responses at two key stages of visual motion encoding: the retina and V1. Preliminary experiments and previous computational studies demonstrate the feasibility of our work. We plan three coordinated physiology and modeling work-packages aimed to explore two crucial early visual stages in order to answer the following questions: How is a translating bar represented and encoded within a hierarchy of visual networks and for which condition does it elicit anticipatory responses? How is visual processing shaped by the recent history of motion along a more or less predictable trajectory? How much processing happens in V1 as opposed to simply reflecting transformations occurring already in the retina? The project is timely because partners master new tools such as multi-electrode arrays and voltage-sensitive dye imaging for investigating the dynamics of neuronal populations covering a large segment of the motion trajectory, both in retina and V1. Second, it is strategic: motion trajectories are a fundamental aspect of visual processing that is also a technological obstacle in computer vision and neuroprostheses design. Third, this project is unique by proposing to jointly investigate retinal and V1 levels within a single experimental and theoretical framework. Lastly, it is mature being grounded on (i) preliminary data paving the way of the three different aims and (ii) a history of strong interactions between the different groups that have decided to join their efforts.

9.3. European Initiatives

9.3.1. Collaborations in European Programs, Except FP7 & H2020

- Program: Leverhulme Trust
- Project acronym:
- Project title: A novel approach to functional classification of retinal ganglion cells
- Duration: 2017-2020
- Coordinator: Evelyne Sernagor, Institute of Neuroscience (ION, Newcastle, UK)

- Other partners:

  Melissa Bateson Institute of Neuroscience (ION, Newcastle, UK)

  Matthias Hennig Institute for Adaptive and Neural Computation (ANC, School of Informatics University of Edinburgh, UK)

- Abstract: Vision begins with photoreceptors converting light from different parts of the visual scene into electrical signals, compressing our visual world into a parsimonious code of impulses at the retinal output level, the retinal ganglion cells (RGCs). This information is sent to the brain via only ≈1m RGCs (45,000 in mouse). Amazingly, the brain can recreate images from interpreting these "barcodes" or trains of impulses. This ability is partly due to the astonishing functional diversity of RGCs, each interpreting a different feature of the visual scene. It is all these parallel streams of information that impart the complexity of visual scenes to our brain visual areas. At present, at least 30 RGC subtypes have been identified. Classification is typically based on common anatomical features, or on basic functions (e.g. whether cells respond to the onset or offset of the light, or whether they are sensitive to motion direction) and it has recently progressed to include molecular markers. Recent studies have successfully characterised common physiological properties between RGCs sharing gene expression, suggesting that their molecular signature may indeed be a good indicator of function. However, according to mouse genetics repositories (e.g., the Allen Brain Project) many genes are expressed in subpopulations of RGCs for which we have no phenotype yet. Genes that are expressed in most RGCs probably do not reflect specific functional populations, but some other genes are expressed only in sparse RGC groups. Each gene-specific class exhibits a distinct spatial mosaic pattern across the retina, suggesting that the cells belong to a common group. Many classes, even sparse, exhibit asymmetric distributions across the retina, e.g., with larger numbers on the ventral or dorsal side, suggesting specific roles in ecological vision, e.g., specialised in detecting moving objects in the sky (ventral) or on the ground (dorsal).

9.4. International Initiatives

9.4.1. International Research Network to Study Predictive Coding in the Retina

Program: CHILEAN SUPPORT OF INTERNATIONAL NETWORKING BETWEEN RESEARCH CENTRES

Project title: International Research Network to Study Predictive Coding in the Retina

Duration: 2018-2020

Coordinator: Maria-José Escobar, Advanced Center for Electrical and Electronic Engineering, Universidad Técnica Federico Santa María, Chile

Other partners:

Advanced Center for Electrical and Electronic Engineering (Valparaiso, Chili)

Centro Interdisciplinario de Neurociencia de Valparaíso (CINV, Valparaíso, Chile)

Abstract: The retina, a well-structured multilayer neural system, encodes the visual information of the environment from an input of photon flux to a series of electrical pulses that are ultimately readout by the brain to create perception and program motor actions. The retina, from an engineering point of view, can be seen as a series of circuits computing visual features from the visual world in parallel encoding only informative inputs that are then sent to the brain. Regarding all the visual features that can be detected from the outer world, motion processing represents a fundamental visual computation ruling many visuomotor behaviours. Motion sensitive neurons have been early reported in the retina, but recently additional features have been added to the pool of capabilities present in this organ: especially motion direction selectivity and predictive coding. Motion processing presents predictive coding characteristics, in the sense that there is an anticipatory response of the visual system when an object in motion follows a trajectory in the visual field. Motion anticipation is fundamental for survival. Interestingly, this mechanism, observed in the visual cortex, has been also

reported in the retina. Understanding how the visual system accumulates information along a certain trajectory raises fundamental questions about neural computation, its dynamics, and implementation. This understanding could be also extended to new algorithms to image/video processing, and also, autonomous navigation of robots.

In this project, we propose the formal establishment of a collaborative network between the AC3E Biomedical System group (AC3E-UTFSM), Centro Interdisciplinario de Neurociencia de Valparaíso (CINV -UV) and Biovision team (Inria Sophia-Antipolis Mediterranée), gathering together skills related with physiological recording in the retina, data analysis and theoretical tools to implement functional and biophysical models. This network aims to study the anticipatory response observed in the mammalian retina, characterizing its underlying mechanisms and the predictive coding capabilities present in this part of the nervous system.

9.4.2. Inria International Partners

Institute of Neuroscience (ION, Newcastle, UK)
Institute for Adaptive and Neural Computation (ANC, School of Informatics University of Edinburgh, UK)
Universidad Tecnico Federico Santa María (Electronics Engineering Department, Valparaíso, Chile)
Centro Interdisciplinario de Neurociencia de Valparaíso (CINV, Valparaíso, Chile)
University of Genoa (DIBRIS, Genoa, Italy)

9.5. International Research Visitors

9.5.1. Visits of International Scientists

- Harold E. Bedell (University of Houston College of Optometry, USA)
- Fabio Anselmi (University of Genoa, Italy)
- Jennifer Sarah Goldman (McGill University, Montreal Neurological Institute and Hospital, Canada)

9.5.1.1. Internships

- Jenny Kartsaki, Greek Msc student, March-August 2017. Now a PhD student supervised by Bruno Cessac.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. General Chair, Scientific Chair

Workshop UCAGATE: Pour une Plateforme d'Intelligence Territoriale de la Recherche @UCA, organized by Pierre Kornprobst and Mylène Leitzelman (Mnemotix), on May 16 at Inria Sophia Antipolis - Méditerranée (Amphi Kahn).

10.1.1.2. Member of the Conference Program Committees

- Le MOnde des Mathématiques Industrielles (MOMI 2017). Dora Karvouniari, Biovision participated to the organizing committee. This is a two-day workshop on applied and industrial mathematics that took place on the 27th and 28th of February, 2017. It was supported by Inria and financed by the Société des Mathématiques Appliquées (SMAI), the Agence pour les Mathématiques en Interaction avec l'Entreprise et la Société (AMIES), and by the Maison de la Modélisation, de la Simulation et des Interactions of Université Côte d'Azur (MSI – UCA). In total, 13 invited speakers and 62 participants (researchers, PhDs, and engineers) attended MOMI 2017.
- Pierre Kornprobst was a Technical Program Committee (TPC) member for the 25th European Signal Processing Conference (EUSIPCO 2017).

10.1.2. Journal

10.1.2.1. Member of the Editorial Boards

Pierre Kornprobst is associate editor for the Computer Vision and Image Understanding Journal (CVIU).

10.1.3. Invited Talks

- Bruno Cessac, "Handling spatio-temporal correlations in neuronal systems", in: LACONEU 2017 - Computational Neuroscience Summer School, Valparaiso, Chile, January 2017
- Bruno Cessac, Multi scale dynamics in retinal waves, in: Brain Dynamics on Multiple Scales - Paradigms, their Relations, and Integrated Approaches, Dresde, Germany, June 2017.
- Bruno Cessac, "Gibbs distribution: from neural network dynamics to spike train statistics estimation", in: Advanced theoretical approaches to collective network phenomena: Bernstein Conference Satellite Workshop, Goettingen, Germany, September 2017.
- Bruno Cessac, "Statistical analysis of retinal responses", in: Random Structures on the Brain, Leiden, Netherlands, December 2017.
- Bruno Cessac, "Multi scale dynamics in retinal waves", in: Winter School on Deterministic and Stochastic Models in Neuroscience, Toulouse, France, December 2017.
- Bruno Cessac, "Multi scale dynamics in retinal waves", in: 2nd Systems Biology meeting at Sorbonne University, Paris, France, December 2017.
- Josselin Gautier, "Mesure de la vision et application au diagnostique et dispositifs de Réalité Mixte pour les malvoyants", école Centrale Supélec de Rennes, November 2017.
- Dora Karvouniari, "Dynamics in retinal waves", Institut de la Vision (Paris, France), February 2017.
- Dora Karvouniari, "Dynamics in retinal waves", Institute of Neuroscience (ION, Newcastle, UK), July 2017.

10.1.4. Research Administration

- The PhD Seminars of Inria Sophia Antipolis - Méditerranée are organized and held by PhD candidates every two weeks and aim to share knowledge, and to promote collaborations, all in a friendly and interactive way. Dora Karvouniari, Selma Souihel and Evgenia Kartsaki as past and current members of the organizing committee have been involved in the scheduling, communication and diffusion. These tasks include calls for presentations, calendar planning and promotion of each seminar. Finally, they are also involved in the organization of the MOMI 2017 conference.
- Pierre Kornprobst is an elected member of the Academic Board of UCA (since Nov. 2015). The role of this council is to proceed with the appointment of selection committees and the recruitment of public servants. Also, it validates the global training offer of Nice area, is involved in the global policy of doctoral training, and awards research funding. The council meets one a month and each member also participate to the evaluation of research proposals submitted to UCA JEDI calls.
- Pierre Kornprobst leads the working group UCA GATE (since May 2016). UCA commissioned an internal task force called UCA GATE to set-up an innovative tool that will extract and exploit the richness of skills present in UCA. This tool should (i) foster the emergence of new synergies inside UCA, (ii) enable external visitors and industrial partners to find in UCA expertise they need, (iii) provide analytics to UCA to be used in reporting periods. His role is to animate this working group and guide the development of the software done by the company Mnemotix according to users needs (first prototype in January 2017).
- Pierre Kornprobst is a member of the Comité de Suivi Doctoral (since March 2017).
- Pierre Kornprobst has been appointed by Inria Direction representative of the administration in the advisory committee of Inria contractual doctoral candidates [4] (on July 2016, for two years).

[4] Représentant de l'administration suppléant au sein de la Commission consultative des doctorants contractuels d'Inria

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Licence :

- Dora Karvouniari, "Transmissions numériques", 1ere année de l'IUT, Département Réseaux et Télécommunications, 64h/year, 50 students.
- Selma Souihel "Advanced network administration and security: architecture of a company network, services installation and configuration, users management, system and network security, cryptography, virtual private networks and secured protocols, and supervision tools", 1ere année de l'IUT, Département Réseaux et Télécommunications, 64h/year, 50 students.
- Bruno Cessac and Dora Karvouniari: "A mathematical approach to retinal waves", January 2017, LACONEU Summer school [34].

10.2.2. Supervision

- PhD in progress: Theodora Karvouniari, "Retinal waves in the retina: theory and experiments". Started in October 2014. Defense scheduled in March 2018. Supervisor, B. Cessac.
- PhD in progress: Selma Souihel, "Generic and specific computational principles for the visual anticipation of motion trajectories". Started in November 2016. Supervisor B. Cessac
- PhD in progress: Evgenia Kartsaki. "How Specific Classes of Retinal Cells Contribute to Vision: a Computational Model", Started in October 2017. Supervisor B. Cessac codirection with E. Sernagor, ION.

10.2.3. Juries

- Bruno Cessac was reviewer of the thesis of Gregor Chliamovitch, University of Geneva, January 2017
- Bruno Cessac was reviewer of the thesis of Christophe Gardella, University Pierre et Marie Curie, Paris, September 2017
- Pierre Kornprobst chaired the PhD jury of Effrosyni Doutsi, Université Côte d'Azur, March 2017.

10.3. Popularization

- Dora Karvouniari participated in "Maths C2+" at Inria week 19-23 June 2017. Maths C2+ hosts schoolboys and schoolgirls in a research environment. The goal is to allow young people to imagine the scientific future.
- Selma Souihel participated to the "fête de la science" as part of the scientific animation commission "MASTIC". She was in charge of vulgarizing her PhD research subject in order to make it intelligible by a public of young scholars, and their parents. She also took part in a pedagogical robot training "Poppy Ergo", aimed at introducing robotics and sequential programming to students in primary school.

11. Bibliography

Major publications by the team in recent years

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