Activity Report 2018

Project-Team BIOVISION

Biological vision: integrative models and vision aid-systems for visually impaired people

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Computational Neuroscience and Medicine

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Project-Team BIOVISION

Creation of the Team: 2016 January 01, updated into Project-Team: 2018 August 01

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2. Overall Objectives

2.1. Overall Objectives

Vision is a key function to sense the world and perform complex tasks. It has a high sensitivity and a strong reliability, given 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: (i) developing of high tech vision aid-systems for low-vision patients and (ii) 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 and became an Equipe Projet Inria on August 1st, 2018 . 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, also known as vision loss, is a decreased ability to see to a degree that causes problems not fixable by usual means, such as glasses or lenses. Low-vision is a condition caused by eye disease, in which visual acuity is 20/70, meaning that the person is able to see, at 20 meters from a chart, what a normal person would see at 70 meters. Visual impairment affects some 285 million humans in the world, mostly in developed countries where this number is going to increase rapidly due to aging. 85% have low-vision or poorer. [1] There is a strong need to conceive new aid-systems to help these people in their daily living activities. Such systems 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) [34], [31]. 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 and algorithmic solutions that enhance salient scene characteristics [53], [43]. In Biovision team, we focus on this second category by targeting new vision aid-systems helping patients in their daily life, adapting to their own pathology.

[1] Source: VisionAware

We have strong contacts and collaborations with low-vision centers and associations in order to better understand low-vision patients needs, and have feedback on our prototypes aimed to be distributed to patients via transfer or company creation (startup). Our goal is to develop solutions based on head mounted displays, especially low cost and large public systems, with full consideration of comfort and **ergonomics**. In particular, we focus on three main goals:

1. Developing **reading aids in virtual reality**. This includes functional vision testing, allowing display and interaction to be personalized.
2. Developing broader **vision aid-systems in augmented reality** for other daily living activities, such as social interaction, visual search and navigation.
3. Proposing **image enhancements** which can be customized for each patient depending on their needs and **pathology**.

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 those main goals:

1. Proposing simplified mathematical models characterizing how the retina converts a visual scene into **spike population coding**, in normal and under specific pathological conditions.
2. Designing 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. Elaborating an **integrated numerical model** of the visual stream, with a focus on motion integration, from retina to early visual cortex (V1).
4. Developing 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 is to develop novel synergistic solutions to solve computer vision tasks based on bio-inspired mechanisms [7].

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 enhancement

Image enhancement is a natural type of image processing method to help low-vision people better understand visual scenes. An impressive number of techniques have been developed in the fields of computer vision and computer graphics to manipulate image content for a variety of applications. Some of these methods have a direct interest in the design of vision aid-systems. Only a few of them have been carefully evaluated with patients [28], [38], [39], [32], [29]. Our objective is to further exploit and evaluate them with patients, considering dedicated use-cases, using virtual and augmented reality technology (Sec. 3.2.2). We consider not only classical brightness manipulations (e.g., equalization, gamma correction, tone mapping, edge enhancement, image decomposition and cartoonization) but also more sophisticated approaches which can change the geometric information of the scene to highlight the most relevant informations (e.g., scene retargeting and seam carving). In addition, we investigate how image enhancements could be adapted to patients needs by relating tuning parameters to the patient pathology.

3.2.2. Virtual, mixed and augmented reality

Virtual, mixed and augmented reality technology (VR/MR/AR) is based on the idea of combining digital words with physical realities in different ways. It encompasses a wide spectrum of hardware. It is our conviction that this technology will play a major role in the domain of low-vision. Not only this technology can be useful to design novel vision aid-systems and rehabilitation programs, but also it has the potential to revolutionize how we study the behaviour of low-vision people (controlled condition, free head, eye tracking, possibilities for large scale studies). We have launched several projects using different platforms (see sections 5.3.1 and 6.1.1). These projects require a constant interaction with psychophysicists and ophtalmologists so as to design our solutions based on patients needs and capabilities.

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 insist on the quality of the model in predicting and 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 [1], [2], [12].

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 [4], [8], [30].

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 [42] used by numerous authors in the context of the retina (see, e.g., [45], [47], [41], [40], [48]). These papers were restricted to a statistical description without memory neither causality: the time correlations between successive times is not considered. However, maximum entropy extends to spatio-temporal correlations as we have shown in, e.g., [2] [49], [33]. In this context, we study how the retina respond to transient stimuli (moving objects), i.e. how spatio-temporal correlations are modified when a moving object crosses the receptive fields of ganglion cells, taking into account the lateral connectivity due to amacrine cells [19], [26], [27].

4. Application Domains

4.1. Applications of virtual/augmented reality for low-vision

- **Rehabilitation**: 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. Virtual/augmented reality technology is a promising platform to develop such rehabilitation exercises targeted to specific pathologies. For example, with Age Macular Degeneration (AMD), our objective is to propose solutions allowing rehabilitation of visuo-perceptual-motor functions to optimally use residual portions of the peripheral retina and obtain efficient “eccentric viewing”.

- **Vision aid-systems**: A variety of aids for low-vision people are already on the market using different kinds of virtual/augmented reality platforms (dedicated or large public ones). They offer different functionalities (magnification, image enhancement, text to speech, face and object recognition). Our goal is to design new solutions allowing autonomous interaction in mixed reality environments, and take advantage of the improvement of functions obtained via rehabilitation protocols.
- **Cognitive research**: Virtual/augmented reality technology represents a new opportunity to conduct cognitive and behavioural research using virtual environments where all parameters can be psychophysically controlled. Our objective is to re-assess common theories by allowing patients to freely explore their environment in more ecological conditions.

4.2. Applications of vision modeling studies

- **Neuroscience research.** Making in-silico experiments 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, called Macular, 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 in modelling studies.
- **Education.** Macular is also targeted as a useful tool for educational purposes, illustrating for students how the retina works and respond to visual stimuli.

5. New Software and Platforms

5.1. Virtual Retina

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

- 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/

5.2. 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).

- 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/

5.3. Platforms

5.3.1. VRead

We are currently developing the VRead platform, a reading platform for digital content. We are now in the phase of building and testing prototypes with low-vision patients. We have started to conduct a qualitative Market research with patients to get a continuous feedback from them, discover their needs and thus better drive the developments. A special care is taken for ergonomics to optimize user experience in virtual reality. This is a crucial aspect in this project, especially because we primarily target a more fragile population so that we have to take into account their vision loss and cognitive skills. As for the technical aspect, we are using the Unity game engine along with the Oculus SDK, allowing us to deploy and test early on the Samsung GearVR mobile platform. For scripting the engine we code in C# using the proprietary directives of Unity. We ship the VRead Viewer with an operator application which allows for supervision and tuning of parameters of the reader in realtime. This application is written using the Unity SDK and is deployable under macOS, Windows and Linux.

This project received financial support from Université Côte d'Azur (France) (duration: 18 months, period: Aug. 2017– Jan. 2019 and Inria (via InriaHUB programme). It is done in collaboration with Aix-Marseille Université (CNRS, Laboratoire de Psychologie Cognitive, Marseille, France), Centre hospitalier Pasteur 2 (service d'ophtalmologie, Nice, France) and University of Genoa (DIBRIS, Genoa, Italy).

5.3.2. Macular

We are currently developing the platform Macular, 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. With this tool scientists will be able to design a simulation gui adapted to their need, so as to test hypotheses, make in-silico experiments prior to real experiments, test models, change the equations of a model and look at the impact of the dynamics. We hope it will become a standard for the community of modelers, experimentalists in the academic word, as well as for companies doing research and development. Macular will also help to better understand how to design algorithms to help visually impaired individuals. Especially, the Biovision team wants to develop computer algorithms for retinal prostheses that reproduce the functions performed by the bypassed parts of the eye: these algorithms can then be used as a "camera to eye translator" in retinal prosthetics.

6. New Results

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

6.1.1. Improving social interaction through augmented reality

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

Today's visual enhancement systems for low-vision people consist of dedicated augmented reality hardware allowing to magnify or enhance the overall scene, independently of the image content or patient needs. For example, for patients with central vision loss, interacting with others may become a painful activity when faces and expressions can hardly be recognized. In [17], we introduce a new augmented reality system allowing to selectively enhance faces, using two image processing techniques [44], [50]. Our system is based on a Fove 0 head-mounted display (FOVE Inc, San Mateo, CA, USA). It has the capacity to adjust the enhancement to the detected faces' size and distance, hence maintaining a constant boost in the critical range of spatial frequency. It offers a binocular and large Field-of-View and performs at near real-time with a modest laptop computer using multithreading. Preliminary experiments with three patients with central vision loss suggest that the enhancements chosen strongly depends on each patient's condition and lead to improved recognition abilities when patients find their optimal settings.

This work is presented in [17].

6.1.2. Text auto-illustration for improving reading accessibility to low-vision people

Participants: Paula Pawlowski, Pierre Kornprobst, Elena Cabrio [Inria, EPI WIMMICS], Marco Benzi [Université Côte d'Azur (France)].

We have started to explore how to make reading more efficient and more enjoyable for low-vision patients through text auto-illustration. Text auto-illustration consists in automatically extracting images from the web which are related to a given text, using natural language processing methods.

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

6.2.1. Retinal waves

Participants: Dora Karvouniari, Lionel Gil [Institut Non Linéaire de Nice - Institut de Physique 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 [51], [36], [46], [37]. 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 [35]. This could have deep consequences on therapy for several degenerative retinal diseases. The mechanism of their generation, in developing, or adult retinas, remains however incompletely understood [52].

We have proposed a model for stage II retinal waves - induced by bursting Starburst Amacrine Cells (SACs) coupled by acetylcholine - with two 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 analysed 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 [11], [13], [14], [16], [20], [12], [24].

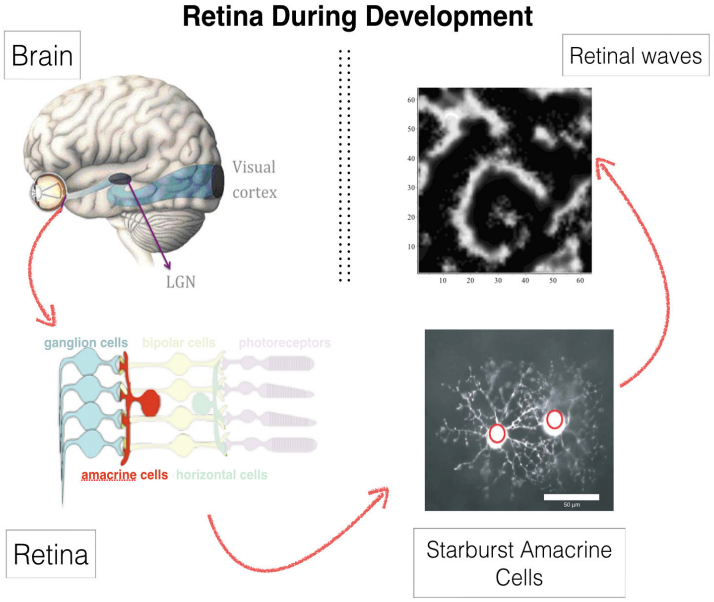

Figure 1. Multiscale dynamics of retinal waves

6.2.2. Trajectory anticipation, from retina to V1

Participants: Bruno Cessac, Selma Souihel, Frédéric Chavane, Alain Destexhe, Matteo Di Volo, Olivier Marre.

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), Institut de la Vision (Paris, France) and Unité de Neurosciences Information et Complexité, Gif sur Yvette, France. We are designing a simulator of retinal output + V1, reproducing both the retinal anticipation and the cortical response measured by optical imaging. We are also analyzing the effects of lateral connectivity in the retina, via amacrine cells, in processing motion. This lateral connectivity is accountable for the correlated activity of RGCs in experimental data. We are measuring these correlations to add further biological plausibility to our model. This study is a step toward understanding mechanisms of motion coding and anticipation with strong impact on our understanding of the visual system.

These results have been presented in [26], [27]

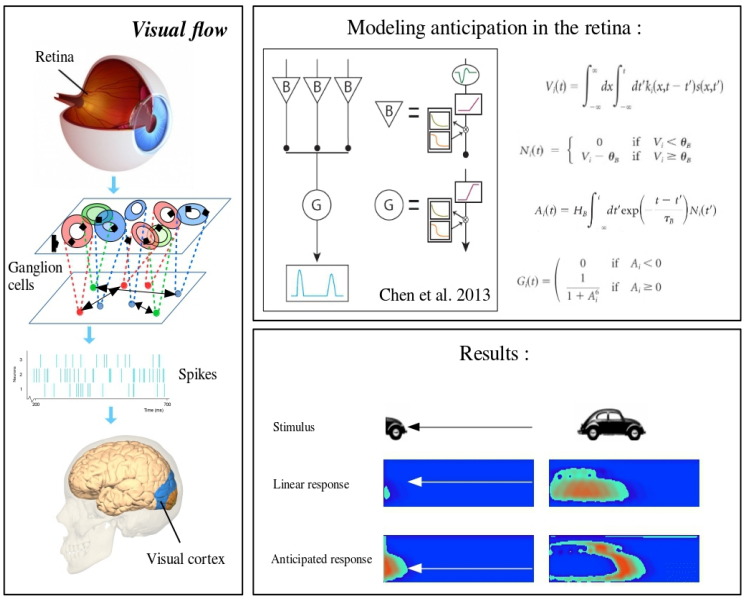

Figure 2. Motion anticipation

6.2.3. 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)], Rodrigo Cofré [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. [49]. 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.

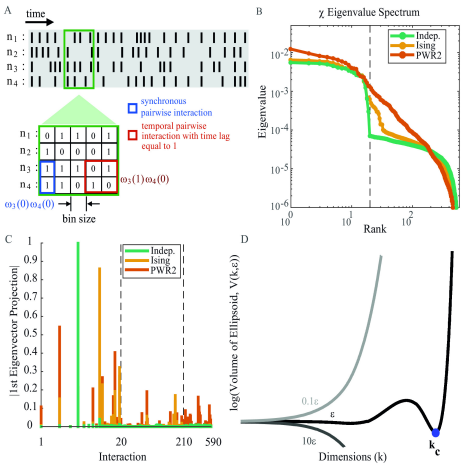

Figure 3. Dimension reduction method

This work has been submitted to Plos Comp Bio [22].

6.2.4. Linear response for spiking neuronal networks with unbounded memory

Participants: Bruno Cessac, Rodrigo Cofré [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. We have established a general linear response relation for spiking neuronal networks, based on chains with unbounded memory. This relation allows quantifying the influence of a weak amplitude external stimuli on spatio-temporal spike correlations, in a general context where the memory in spike dynamics can go arbitrarily far in the past. With this approach, we show how linear response is explicitly related to neuron dynamics with an example, the gIF model, introduced by M. Rudolph and A. Destexhe [91]. This illustrates the effect of the stimuli, intrinsic neuronal dynamics, and network connectivity on spike statistics.

This work has been submitted to Journal of Mathematical Neurosciences [19].

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

7.1.1. Could hardware solutions coming from the automotive industry be useful in the context of low vision?

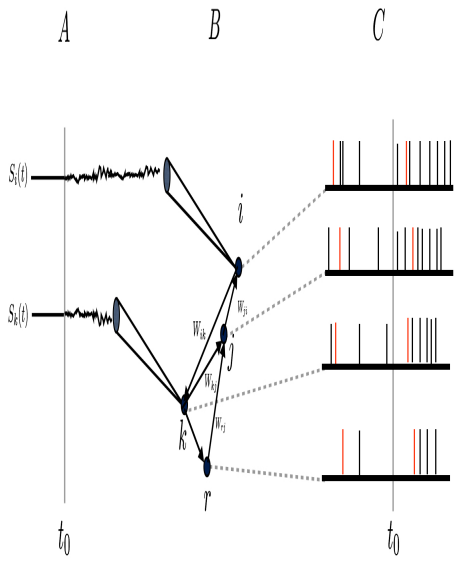

Figure 4. Linear response. The excitation of some neurons in a network will induce a variation in spike correlations between all connected neurons, even those which are not excited. We have computed this effect in [19].

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

Duration: August 2017 to March 2018

Thanks to a partnership with Bosch Visiontec (Sophia Antipolis, France), we have investigated how hardware solutions coming from the automotive industry (RENESAS Starter-Kit RCar H3) could be used to design real-time vision-aid-systems based on augmented reality. We focused on the detection and enhancement of faces. We analysed the performance of a selection of enhancement algorithms and optimised them taking into consideration the hardware limitations.

Based on the same ideas, a working prototype has also been developed using a Fove 0 head-mounted display and tested with three patients with central vision loss (see Sec.6.1.1).

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. 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" and of the Institute Neuromod of neuroscience modelling . Biovision team has participated to the Rencontre C@UCA 2018 in Fréjus (June 2018). This axe is partly funding our work on retinal waves.

8.2. National Initiatives

8.2.1. ANR

8.2.1.1. 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.

8.3. European Initiatives

- 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)
- Inria contact: Bruno Cessac
- 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 $\approx$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).

  We propose to develop a multidisciplinary approach to functionally phenotype "new" RGC subclasses sharing gene expression. Rather than inferring knowledge about the entire population from studying individual cells, we will take a global approach based on large-scale, high-density pan-retinal recordings, pharmacogenetics (allowing us to selectively silence defined cell populations at will) and high-resolution imaging combined with computational approaches and behaviour. This novel approach necessitates collaboration between retinal neurophysiologists, animal behaviour specialists (Newcastle) and modellers (Inria) who specialise in visual processing and have sophisticated mathematical tools and software to handle and interpret the encoding of visual information at the pan-retinal level.

8.4. International Initiatives

8.4.1. 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.

8.4.2. Inria International Partners

8.4.2.1. Declared 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)

8.5. International Research Visitors

8.5.1. Visits of International Scientists

Prof. Sarah Barman (School of Computer Science and Mathematics, Kingston University)

Dr Matteo Di Volo (Unité de Neurosciences Information et Complexité, Gif sur Yvette, France)

Dr Cyril Eleftheriou (IIT, Genova)

Dr Maria-José Escobar (Universidad Tecnico Federico Santa María (Electronics Engineering Department, Valparaíso, Chile))

8.5.1.1. Internships

Téva Andréoletti (Apr–Aug 2018)

Adrianna Janik (Oct 2017–Mar 2018)

Paula Pawlowski (Apr–Sept 2018)

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. General Chair, Scientific Chair,Member of the Organizing Committees

- Bruno Cessac has co-organized the conference Inspire New Insights on Complex Neural Dynamics, Cergy-Pontoise, France, June 2018 https://inspire2018parisseine.wordpress.com/
- Bruno Cessac has co-organized the scientific event 2nd structuring event UCA Cognitive systems, normality and pathology of the human brain, computational neuroscience http://univ-cotedazur.fr/events/deuxieme-rencontre-c@uca
- Selma Souihel and Evgenia Kartsaki participated to the organizing committee of "Le MOnde des Mathématiques Industrielles (MOMI 2018)", a two-day workshop on applied and industrial mathematics. The workshop took place on the 26th and 27th of February, 2018 at the Inria Sophia Antipolis-Mediteranée research center. It was supported by Inria and financed by the Société des Mathématiques Appliquées (SMAI) as a BOUge tes Maths (BOUM) project, by the Agence pour les Mathématiques en Interaction avec l'Entreprise et la Société (AMIES) and by the Labex User Centric Network @ Sophia within the context of Investissement d'Avenir (IA) projects – projets "Laboratoires d'excellence", and by the Université Côte d'Azur within the context of the "Joint, Excellent and Dynamic Initiative" (JEDI) projects. In total, 3 keynote speakers, 8 industrial speakers and 80 participants (researchers, PhDs , and engineers) attended MOMI 2018.
- Pierre Kornprobst was a Technical Program Committee (TPC) member for the 25th European Signal Processing Conference (EUSIPCO 2017).

9.1.2. Reviewer

Bruno Cessac was a reviewer for the conference ICMNS, International Conference on Mathematical Neuro-Science .

9.1.3. Journal

9.1.3.1. Member of the Editorial Boards

Pierre Kornprobst has been associate editor for the Computer Vision and Image Understanding Journal (CVIU) since Jul 2016.

9.1.4. Invited Talks

- B. Cessac, D. Karvouniari, L. Gil, O. Marre, S. Picaud. Multi scale dynamics in retinal waves, in: Inspire New Insights on Complex Neural Dynamics, Cergy-Pontoise, France, June 2018.
- B. Cessac, Ion channels and properties of large neuronal networks: a computational study of re.nal waves during development, in: Symposium on Ion channels and Channelopathies - IPMC, Sophia Antipolis, France, November 2018.

9.1.5. 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. Selma Souihel and Evgenia Kartsaki are 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 2018 conference.
- Bruno Cessac is a member of the scientific council of the Institut NeuroMod de "Modélisation en Neurosciences et Cognition".
- Pierre Kornprobst is an elected member of the Academic Board of UCA (since November 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 has been a member of the Comité de Suivi Doctoral (CSD) since March 2017.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence :

- 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, Numeric transmission : data acquisition, satellite and cable transmission, numeric modulation", 1ere année de l'IUT, Département Réseaux et Télécommunications, 64h/year, 50 students.

Master 1: Bruno Cessac (with D. Karvouniari and F. Lavigne), *Introduction to Modelling in Neuroscience*, 36 hours, Master Mod4NeuCog, Université Nice Sophia Antipolis, France.

9.2.2. Supervision

- PhD defended on March 15th, 2018. 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.

9.2.3. Juries

- Bruno Cessac was member of the Comité de suivi de thèse of Matthieu Sarrazin (U. Paris Sorbonne).
- Pierre Kornprobst was reviewer of the PhD of Charles Hessel, entitled "The automatic decomposition of an image in base and detail: Application to contrast enhancement", from Université de Paris-Saclay, Ecole Normale Supérieure de Paris-Saclay, France.

- Pierre Kornprobst was reviewer of the HDR of David Tschumperlé, entitled “Champs tensoriels pour la modélisation géométrique locale et non-locale des images et leurs applications”, from Université de Caen, France.

9.3. Popularization

9.3.1. Internal or external Inria responsibilities

- E. Kartsaki and S. Souihel are participating to the organization of the Inria Sophia PhD seminars.

9.3.2. Interventions

- The Biovision team participated to the "fête de la science 2018".

10. Bibliography

Major publications by the team in recent years

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[2] R. COFRÉ, B. CESSAC. *Exact computation of the maximum-entropy potential of spiking neural-network models*, in "Phys. Rev. E", 2014, vol. 89, n^{o} 052117

[3] M.-J. ESCOBAR, G. S. MASSON, T. VIÉVILLE, P. KORNPROBST. *Action Recognition Using a Bio-Inspired Feedforward Spiking Network*, in "International Journal of Computer Vision", 2009, vol. 82, n^{o} 3, 284 p. , ftp://ftp-sop.inria.fr/neuromathcomp/publications/2009/escobar-masson-etal:09.pdf

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[5] D. KARVOUNIARI, L. GIL, O. MARRE, S. PICAUD, B. CESSAC. *A biophysical model explains the oscillatory behaviour of immature starburst amacrine cells*, 2018, submitted to Scientific Reports, https://hal.inria.fr/hal-01484133

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Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] T. KARVOUNIARI. *Retinal waves : theory, numerics, experiments*, Université Côte d'Azur, March 2018, https://tel.archives-ouvertes.fr/tel-01818522

Articles in International Peer-Reviewed Journals

[12] D. KARVOUNIARI, L. GIL, O. MARRE, S. PICAUD, B. CESSAC. *A biophysical model explains the oscillatory behaviour of immature starburst amacrine cells*, in "Scientific Reports", 2018, https://arxiv.org/abs/1711.09199 - 25 pages, 15 figures, submitted, https://hal.inria.fr/hal-01484133

Invited Conferences

[13] B. CESSAC, D. KARVOUNIARI, L. GIL, O. MARRE, S. PICAUD. *Ion channels and properties of large neuronal networks: a computational study of re.nal waves during development*, in "Symposium on Ion channels and Channelopathies - IPMC", Sophia Antipolis, France, November 2018, https://hal.archives-ouvertes.fr/hal-01925829

[14] B. CESSAC, D. KARVOUNIARI, L. GIL, O. MARRE, S. PICAUD. *Multi scale dynamics in retinal waves*, in "Inspire New Insights on Complex Neural Dynamics", Cergy-Pontoise, France, June 2018, https://hal.inria.fr/hal-01816919

International Conferences with Proceedings

[15] B. CESSAC, R. COFRÉ. *Linear Response of General Observables in Spiking Neuronal Network Models*, in "ICMNS 2018 - 4th International Conférence on Mathematical Neuroscience", Juan les Pins, France, June 2018, pp. 1-70, https://hal.inria.fr/hal-01816920

Scientific Books (or Scientific Book chapters)

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Research Reports

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[18] T. ANDRÉOLETTI, B. CESSAC, F. CHAVANE. *Decoding cortical activity evoked by artificial retinal implants*, ENSEA-Inria, August 2018, https://hal.inria.fr/hal-01895100

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[21] B. CESSAC, P. KORNPROBST, M. BENZI, I. CAUGANT, D. KARVOUNIARI, E. KARTSAKI, S. SOUIHEL. *Biovision project-team: Biological vision: integrative models and vision aid systems for visually impaired people*, October 2018, Fête de la science, Poster, https://hal.inria.fr/hal-01896505

[22] R. HERZOG, M.-J. ESCOBAR, R. COFRÉ, A. PALACIOS, B. CESSAC. *Dimensionality Reduction on Spatio-Temporal Maximum Entropy Models of Spiking Networks*, November 2018, working paper or preprint [*DOI :* 10.1101/278606], https://hal.inria.fr/hal-01917485

[23] E. KARTSAKI, B. CESSAC, G. HILGEN, E. SERNAGOR. *How specific classes of retinal cells contribute to vision: A Computational Model*, June 2018, C@uca 2018 Meeting, Poster, https://hal.inria.fr/hal-01816921

[24] D. KARVOUNIARI, L. GIL, O. MARRE, S. PICAUD, B. CESSAC. *Pattern formation and criticality in the developing retina*, June 2018, International Conference on Mathematical Neuroscience, Poster, https://hal.archives-ouvertes.fr/hal-01807929

[25] S. SOUIHEL, B. CESSAC. *A computational study of anticipation in the retina*, September 2018, Bernstein conference 2018, Poster, https://hal.inria.fr/hal-01942516

[26] S. SOUIHEL, F. CHAVANE, O. MARRE, B. CESSAC. *Processing various motion features and measuring RGCs pairwise correlations with a 2D retinal model*, June 2018, International Conference on Mathematical Neuroscience ICMNS 2018, Poster, https://hal.inria.fr/hal-01809589

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