Alma Mater Studiorum - Università di Bologna
Dipartimento di Elettronica Informatica Sistemistica
Dipartimento di Matematica

Accademia delle Scienze di Bologna

From Neuroscience to Phenomenology

Mathematical Models of Visual Perception

Aula Prodi - Piazza San Giovanni in Monte, 2 - Bologna

1-3 July 2004

The conference is sponsored by

Rector of Bologna University

GNAMPA-INdAM

COFIN MIUR: "Equazioni subellittiche", unità locale di Bologna

COFIN MIUR: "Calcolo delle variazioni", unità locale di Trento

IST Project VISU 1999 20226 EUTIST-M

Cambridge Research System LTD

Convenzione Dianoema "Gestione Integrata dell'Analisi Microbiologica"

http://www.vision.unibo.it/mmvp/

Program

July 1st

14.30

Welcome of:
Pier Ugo Calzolari (Rector of Bologna University)
Fabrizio Bolletta (Dean of Faculty of Science)
Guido Masetti (Dean of I Faculty of Engineering)
Franco Persiani (Dean of the II Faculty of Engineering)
Claudio Bonivento (Director of DEIS)
Giovanni Dore (Director of Mathematics Department)
Ilio Galligani (President of Accademia delle Scienze of Bologna)

15.00

Jean Petitot:
Introductory talk

16.00

Jan Koenderink (Utrech University):
"Fechner's Law and Visual Field Effects"

Coffee break

17.15

Mario Zanforlin, Luigi Beghi, Elisabetta Xausa (Università di Padova):
"Stereokinetic phenomena: demonstrations and a possible explanation"

18.30

Visit at Accademia delle Scienze

July 2nd

9.00

Steven Zucker (University of Yale):
"Visual Computations and the Geometry of Connections in V1"

10.00

Paul Bressloff (Utah University):
"Neural pattern formation and the functional architecture of V1"

Coffee break

11.15

Raul Serapioni (Università di Trento):
"Elements of Sub-Riemannian Geometry"

12.15

Ermanno Lanconelli (Università di Bologna):
"Non-variational sub-elliptic equations: fundamental solutions and pointwise estimates"

Lunch

15.00

Giulio Sandini (Genova University and MIT):
"Learning Visuomotor Coordination in a Developing Robot"

16.00

Alessandra Angelucci (Utah University):
"Spatial and functional organization of lateral, feedforward and feedback pathways in the primate visual cortex"

Coffee break

17.15 - 18.00

Mauro Ursino (Università di Bologna):
"Computer simulations of the vision early processing stages: feature selection, contour extraction, segmentation and attention"

July 3rd

8.30

Walter Gerbino (Università di Trieste)

9.30

Nicola Fusco (Università di Napoli):
"An overview of the Mumford-Shah model"

Coffee break

10.45

Simon Masnou (Paris VI):
"From amodal completion to image compression"

11.45

Riccardo March (CNR, Roma):
"Image segmentation by minimizing a curvature depending functional: approximation by Gamma;-convergence"

Contents

Spatial and functional organization of lateral, feedforward and feedback pathways in the primate visual cortex

Alessandra Angelucci

Utah University

Classical receptive field (cRF) concepts and feedforward models of vision have traditionally been used to explain local perceptual effects, but cannot explain complex aspects of visual perception involving distant visual field locations, such as the perception of illusory or occluded contours. Neuronal correlates have been described for these perceptual effects, that require neurophysiological mechanisms enabling neurons to respond not only to stimulus features within a localized area of visual space (their cRF), but also to the context in which they appear (i.e. beyond their cRF).

Research in my lab is focused on identifying the neural circuitry underlying macaque visual cortex neurons responses to stimuli within and beyond their cRF, and ultimately visual perception. Long-range intra-areal horizontal (or lateral) connections and feedforward and feedback connections between different visual cortical areas are a prominent feature of visual cortical circuitry and inter-areal relationships whose roles remain poorly understood. To disentangle the relative roles of these connectional systems in visual processing, we have determined their spatial extent and functional organization and relate them to the spatial extent and functional properties of visual cortex neurons responses to stimuli within and beyond their cRF. The rationale behind these studies is that the spatial scale of each connectional system must be commensurate with the spatial scale of the specific neuronal response that it underlies. Furthermore, uncovering the functional specificity of a connectional system can reveal the kinds of functional interactions that the system may underlie.

We found that inter-areal feedforward connections underlie the spatial and tuning properties of V1 neurons responses to stimuli within their cRF. Intra-areal horizontal connections may underlie contrast-dependent spatial summation properties of cortical neurons, and lateral facilitation effects that may mediate the perceptual integration of local feature elements into coherent contours. Feedback connections from higher to lower order areas instead are likely to mediate the global-to-local computations underlying long-range contextual effects and possibly, contour integration at larger scales than horizontal connections. I will present a circuit model of how cortical neurons in primary visual cortex may integrate inputs from feedforward thalamic afferents, long-range intra-areal horizontal connections and feedback connections from higher visual areas.

An overview of the Mumford-Shah model

Nicola Fusco

Università di Napoli

The Mumford-Shah model is probably the best known variational model for image segmentation. It is also one for which the mathematical analysis has been particularly rich. We shall describe the main features of this model, the state of the art of mathematical research and some open problems.

Fechner's Law and Visual Field Effects

Jan Koenderink

Utrech University

Fechner's 'psychophysical law' states that the natural intensity scale is logarithmic. This has evoked many 'explanations', most of them having to do with Weber's law, ecological optics (independence of absolute level of illumination), or optimal channel capacity. I show that a totally different interpretation is possible. This interpretation is somewhat in the sense of Fechner as it identifies the 'natural' structure. I generalise the law to regions of the visual field in order to be able to describe spatial structure: then the problem of comparison of intensities at different locations arises. One needs a formal structure that accounts for the many familiar 'congruences', such as brightness and contrast (gamma) changes that somehow leave the image invariant. The solution to this problem is a Cayley-Klein geometry with one isotropic dimension. The aforementioned congruences are the motions of this space. One obtains a very general framework that is of immediate use in image processing (algorithmic vision) and may serve as a model of the visual field (biological vision).

Non-variational sub-elliptic equations: fundamental solutions and pointwise estimates

Ermanno Lanconelli

Università di Bologna

We present some recent results on non-variational second order equations constructed with smooth vector fields, satisfying the Hormander' rank conditions. We focus on the existence of the fundamental solutions, on Harnack inequalities and on Schauder estimates. The presented results are a first achievement in the study of linear and nonlinear equations arising in curvature problems and mathematical models of the vision.

Image segmentation by minimizing a curvature depending functional: approximation by Γ-convergence

Riccardo March and Andrea Braides

CNR, Roma

We consider a variational model for image segmentation which is based on the minimization of a functional defined on families of curves. The functional, originally proposed by Terzopoulos, penalizes curvature, length, and number of endpoints of the curves. We show how this functional can be approximated by elliptic functionals defined on smooth functions. The approximation takes place in the sense of De Giorgi's Γ-convergence, and it is close in spirit to the Ambrosio and Tortorelli approximation of the Mumford-Shah functional. The Γ-convergence result allows the use of numerical methods developed for related problems, such as image inpainting.

From amodal completion to image compression

Simon Masnou

Paris VI

It is well-known that the classical wavelet methods for image compression, like those incorporated in the JPEG2000 standard, perform generally very well but have several theoretical and numerical limitations, in particular for the coding of geometric information at very high compression rates.

Several approaches, not always based on wavelets, have been proposed in recent years to overcome these limitations.

The work I shall present, done in collaboration with Albert Cohen (Paris 6, France), Justin Romberg (Caltech, USA) and Thomas Capricelli (Paris 6, France), falls in this category.

We propose to combine a multiscale prediction/correction approach with a nonlinear interpolation operator that was first introduced in the context of image missing parts reconstruction.

This operator interpolates the image level lines by curves minimizing an energy that involves both their length and their curvature.

It is directly inspired by a natural ability of our visual system to reconstruct partially occluded objects, the well-known "amodal completion" process.

Learning Visuomotor Coordination in a Developing Robot [1]

Giulio Sandini, Giorgio Metta, Lorenzo Natale

LIRA-Lab, DIST University of Genova

In this talk I will claim that if future robots have to have cognitive abilities, they will have to go through developmental phases similar to those found in human babies. I will do that from a multidisciplinary perspective by presenting findings derived from studies of human visuomotor coordination and cognitive development as well as a robotic implementation of the first few months of existence of a robot cub. In doing so I will stress

i) the peculiarities of visual cortical architecture in supporting visuo-motor coordination;

ii) the consequences that a multidisciplinary approach has in discovering new technologies

iii) the relevance that robotics research will continue to have as a research tool to understand human cognition.

[1]Acknowledgements: Research decribed here is supported by the EU project COGVIS (IST-2000-29375) and MIRROR (IST-2000-28159), ADAPT.

Bibliography

[1] Sandini, G., G. Metta, and J. Konczak. *Human Sensori-motor Development and Artificial Systems.* in International Symposium on Artificial Intelligence, Robotics and Intellectual Human Activity Support(AIR& IHAS '97). 1997. RIKEN - Japan.

[2] Metta, G., G. Sandini, and J. Konczak, *A Developmental Approach to Visually-Guided Reaching in Artificial Systems.* Neural Networks, 1999. 12(10): p. 1413-1427.

[3] Natale, L., S. Rao, and G. Sandini.*Learning To Act On Objetcs.* in 2nd Workshop on Biologically Motivated Computer Vision. 2002. Tuebingen, Germany.

Computer simulations of the vision early processing stages: feature selection, contour extraction, segmentation and attention

Mauro Ursino

Università di Bologna

The present work describes some mathematical models and computer simulations of the early vision processing stages. The models aspire to represent a good compromise between neurophysiological reliability and computational simplicity. Three distinct but related problems are analyzed:

1. the genesis of orientation and direction preference in simple and complex cells in V1. These properties emerge due to the interaction of feedforward and feedback intracortical mechanisms.

2. Contour extraction according to contextual influences among intracortical neurons. Excitatory influences respect co-axial and co-modularity criteria, while a long-range isotropic feedback inhibition contributes to noise suppression. Examples of contour exctraction from real images are shown.

3. Segmentation of distinct objects in the visual scene modulated by an attention mechanism. Model assumes that segmentation is realized by a two-layer process: The first layer extracts all object contours from the image. Information on contour is used to selectively inhibit neural oscillators in the second layer, thus realizing a strong separation among neurons in different objects. Moreover, the model uses a global inhibitor which realizes an attention mechanism to segment objects at different detail levels.

The main models assumptions and results are presented and discussed, their integration into a comprehensive structure is proposed, and lines for future investigation pointed out.

Stereokinetic phenomena: demonstrations and a possible explanation

Mario Zanforlin*, Luigi Beghi, Elisabetta Xausa***

Università di Padova, *Dipartimento di Psicologia, **Dipartimento di Matematica

Stereokinetic phenomena first investigated by Musatti (1924, 1955) are three-dimensional objects produced by 2-D figures in slow rotatory motion, that appear solid and real. A circle with an eccentric dot inside appears as a cone with well defined dimensions. An ellipse of uniform colour appears as a rigid disc or as an ellipsoid with its major axe slanted in depth. A uniform rectangle with semi-circular minor sides appears as a cylinder. A bar of constant length appears slanted in depth and 1.5 longer than when it is stationary on the frontal plain. Three aspects of these objects are theoretically interesting: 1) they do not appear to rotate but describe a circular translation, 2) they appear as 3-D and solid, 3) they appear of a well defined length in depth. These three aspects were explained by Musatti and others as due to different perceptual mechanisms. The first as due to a tendency to a constant orientation in space or to the limited aperture of peripheral movement receptor (misperception). The second as due to a constancy of form (Musatti) similar to the rigidity hypothesis (Ullman, 1979,1983). The third aspect, the apparent length in depth, cannot be explained by either of these hypotheses.

The hypothesis posited here will consider these three aspects of stereokinetic phenomena as strictly connected and due to the same visual process. This process minimizes the relative velocity differences between all the points of the moving configuration. It is based on the fact that the different velocities of two points on the frontal plane can be equalized by adding to the velocity of one point a depth component such that this will appear to move in depth describing, in the same period of time, a distance equal to that of the point moving on the frontal plane.

The hypothesis can be mathematically formulated and can predict the apparent length in depth of the stereokinetic objects. The predictions are in good agreement with experimental results. Moreover, the hypothesis can be applied to translatory movement on the frontal plain.

Bibliography

[1] Musatti C L, 1924 *Sui fenomeni stereocinetici* Archivio Italiano di Psicologia 3 105-120

[2] Musatti C L, 1955 *La stereocinesi e il problema della struttura dello spazio visibile* Rivista di Psicologia 49 3-57

[3] Ullman S, 1979 *The Interpretation of Visual Motion* (Cambridge, Mass., MIT Press)

[4] Ullman S, 1984 *Maximizing rigidity. The incremental recovery of 3-D structure from rigid and non-rigid motion* Perception 13 255-274

Visual Computations and the Geometry of Connections in V1

Steven Zucker

University of Yale

Neurons in primary visual cortex respond selectively to oriented stimuli such as edges and lines. The long-range horizontal connections between them are thought to facilitate contour integration. While many physiological and psychophysical findings suggest that colinear or association-field models of good continuation dictate particular projection patterns of horizontal connections to guide this integration process, significant evidence of interactions inconsistent with these hypotheses is accumulating.

We show that natural random variations around the colinear and association-field models cannot account for these inconsistencies, a fact that motivates the search for more principled explanations.

We then develop a model of long-range projection fields that formalizes good continuation based on differential geometry. The analysis implicates curvature(s) in a fundamental way and the resulting model explains both consistent data and apparent outliers. It quantitatively predicts the (typically ignored) spread in projection distribution, its non-monotonic variance, and the differences found between individual neurons.

Surprisingly, and for the first time, this model also indicates that texture (and shading) continuation can serve as alternative and complimentary functional explanations to contour integration.

Finally, we extend the model into the hue domain, to predict the form and function of long-range horizontal connections between cells in the cytochrome oxidase blobs.