Marion Gurfein originally painted the upper water color of the tiger in 1996. In 2006, four years after the onset of macular degeneration, she revisited her original painting as part of her artistic chronicles of the progression.
Artificial Sight

Basic Research, Biomedical Engineering, and Clinical Advances
Series Preface

The fields of biological and medical physics and biomedical engineering are broad, multidisciplinary and dynamic. They lie at the crossroads of frontier research in physics, biology, chemistry, and medicine. The Biological & Medical Physics/Biomedical Engineering Series is intended to be comprehensive, covering a broad range of topics important to the study of the physical, chemical and biological sciences. Its goal is to provide scientists and engineers with textbooks, monographs, and reference works to address the growing need for information.

Books in the series emphasize established and emergent areas of science including molecular, membrane, and mathematical biophysics; photosynthetic energy harvesting and conversion; information processing; physical principles of genetics; sensory communications; automata networks, neural networks, and cellular automata. Equally important will be coverage of applied aspects of biological and medical physics and biomedical engineering such as molecular electronic components and devices, biosensors, medicine, imaging, physical principles of renewable energy production, advanced prostheses, and environmental control and engineering.

Elias Greenbaum
Oak Ridge, TN
Preface

For over 50 years the U.S. Department of Energy’s Biological and Environmental Research (BER) program has advanced environmental and biomedical knowledge that promotes improved energy production, development, and use; international scientific and technological cooperation; and research that improves the quality of life for all peoples. BER supports these vital missions through competitive and peer-reviewed research at national laboratories, universities, and private institutions. This book, Artificial Sight: Basic Research, Biomedical Engineering, and Clinical Advances emerged mostly from the research programs of presenters at the Second DOE International Symposium on Artificial Sight. The book, however, is not a symposium proceedings. The editors encouraged the chapter authors to expand on the vision of their research in this field which lies at the intersection of physics, chemistry, biology and biomedical engineering. The members of the organizing committee for this DOE symposium are M.S. Humayun (chairman), E. Greenbaum (co-chairman), D.A. Cole, R. Iezzi, Y. Tano, M.V. Viola, J.D. Weiland and E. Zrenner. The work of the DOE Artificial Retina Program continues with the collaboration of the National Laboratory system, universities, and private industry. The members of this team have helped create micromachine technology design, mathematical modeling of retinal information processing, microelectrode arrays designed for retinal tissue stimulation, and telemetric communications. We thank Eugenie V. Mielczarek, Professor Emeritus of Physics at George Mason University, for bringing our attention to Marion Gurfein’s artwork which is exhibited in the frontispiece.

Mark S. Humayun
James D. Weiland
Gerald Chader
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Elias Greenbaum
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June 2007
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List of Acronyms

ADL/O Activities of daily living and orientation
adRP Autosomal dominant retinitis pigmentosa
AER Averaged evoked response
AMD Age-related macular degeneration
ANOVA Analysis of variance
APB 2-amino-4-phosphonobutyrate
ARVO Association for Research on Vision and Ophthalmology
ASP Aspartate
AVD Artificial vision device
BaGa Basic grating acuity
BaLM Basic light and motion
BCC Biphasic current controller
BDNF Brain-derived neurotrophic factor
bFGF Basic fibroblast growth factor
BHE Bioheat equation
BSI Brief symptom inventory
CCD Charge coupled device
CMG Common mode gain
CMOS Complementary metal oxide semiconductor
CMRR Common mode rejection ratio
CNTF Ciliary neurotrophic factor
CNV Choroidal neovascular membrane
CT Computed tomography
CV Cyclic voltammetry
DAC Digital-to-analog converter
DACC Digital to analog current converter
DC Direct current
DI Deionized
DMG Differential mode gain
DPLL Digital phase-locked loop
DSP Digital signal processing
ECG Electrocardiogram
EEG Electroencephalogram
EEP Electrically evoked potential
EER Electrically evoked response
eERG Electrically elicited ERG
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>EIS</td>
<td>Electrochemical impedance spectroscopy</td>
</tr>
<tr>
<td>EKG</td>
<td>Electrocardiogram</td>
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<tr>
<td>EP</td>
<td>Evoked potential</td>
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<tr>
<td>ERG</td>
<td>Electroretinogram</td>
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<tr>
<td>ETDRS</td>
<td>Early Treatment Diabetic Retinopathy Study</td>
</tr>
<tr>
<td>FA</td>
<td>Fluorescein angiogram</td>
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<tr>
<td>FDTD</td>
<td>Finite-Difference Time-Domain</td>
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<tr>
<td>fERG</td>
<td>Focal ERG</td>
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<tr>
<td>fMRI</td>
<td>Functional magnetic resonance imaging</td>
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<td>FrACT</td>
<td>Freiburg visual acuity and contrast test</td>
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<tr>
<td>GABA</td>
<td>Glutamate and γ-aminobutyric acid</td>
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<td>GCL</td>
<td>Ganglion cell layer</td>
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<td>GS</td>
<td>Glutamine synthetase</td>
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<td>HMD</td>
<td>Head-mounted display</td>
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<td>IC</td>
<td>Integrated circuit</td>
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<td>ICMS</td>
<td>Intracortical microstimulation</td>
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<tr>
<td>ID</td>
<td>Identification</td>
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<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
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<td>IGF-1</td>
<td>Insulin-like growth factor-1</td>
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<td>IIP</td>
<td>IIP-Technologies gmbh</td>
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<tr>
<td>ILM</td>
<td>Inner limiting membrane</td>
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<tr>
<td>INL</td>
<td>Inner nuclear layer</td>
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<tr>
<td>IOP</td>
<td>Intraocular pressure</td>
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<tr>
<td>IR</td>
<td>Infrared</td>
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<tr>
<td>IrOx</td>
<td>Iridium oxide</td>
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<td>ISCEV</td>
<td>International Society for Clinical Electrophysiology of Vision</td>
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<tr>
<td>IT</td>
<td>Inferotemporal cortex</td>
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<tr>
<td>LEP</td>
<td>Light evoked potential</td>
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<tr>
<td>LFP</td>
<td>Local field potential</td>
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<tr>
<td>LGN</td>
<td>Lateral geniculate nucleus</td>
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<tr>
<td>LSI</td>
<td>Large-scale integration</td>
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<tr>
<td>LVES</td>
<td>Low vision enhancement system</td>
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<tr>
<td>mfERG</td>
<td>Multifocal ERG</td>
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<tr>
<td>MOEMS</td>
<td>Micro-optoelectromechanical systems</td>
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<td>MRI</td>
<td>Magnetic resonance imaging</td>
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<td>NAIST</td>
<td>Nara Institute of Science and Technology</td>
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<td>NEDO</td>
<td>New Energy Development Organization</td>
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<tr>
<td>NFL</td>
<td>Nerve fiber layer</td>
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<tr>
<td>NIR</td>
<td>Near-infrared</td>
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<tr>
<td>NMDA</td>
<td>N-methyl-d-aspartic acid</td>
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<tr>
<td>NMOS</td>
<td>n-Channel metal-oxide semiconductor</td>
</tr>
<tr>
<td>OCT</td>
<td>Optical coherence tomography</td>
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<tr>
<td>ON</td>
<td>Optic nerve</td>
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<tr>
<td>ONL</td>
<td>Outer nuclear layer</td>
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<tr>
<td>PBS</td>
<td>Phosphate buffered saline</td>
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<tr>
<td>Acronym</td>
<td>Definition</td>
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<tr>
<td>PDA</td>
<td>cis-2,3-piperidinecarboxylate</td>
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<tr>
<td>PDE</td>
<td>Partial differential equation</td>
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<tr>
<td>PDMS</td>
<td>Poly-dimethylsiloxane</td>
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<tr>
<td>pERG</td>
<td>Pattern ERG</td>
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<tr>
<td>PFCL</td>
<td>Perfluorodecaline</td>
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<tr>
<td>pfERG</td>
<td>Paired-flash ERG</td>
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<tr>
<td>PFM</td>
<td>Pulse frequency modulation</td>
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<tr>
<td>PIM</td>
<td>Partial inductance method</td>
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<tr>
<td>PLL</td>
<td>Phase-locked loop</td>
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<tr>
<td>PMMA</td>
<td>Polymethyl-methacrylate</td>
</tr>
<tr>
<td>PMOS</td>
<td>p-channel metal-oxide semiconductor</td>
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