Cognitive Computation Trends 1
Series Editor: Amir Hussain

Irini Giannopulu

Neuroscience, Robotics and Virtual Reality: Internalised vs Externalised Mind/Brain

Springer

Cognitive Computation Trends

Volume 1

Series Editor
Amir Hussain
School of Computing
Edinburgh Napier University
Edinburgh, Scotland, UK

Cognitive Computation Trends is an exciting new Book Series covering cutting-edge research, practical applications and future trends covering the whole spectrum of multi-disciplinary fields encompassed by the emerging discipline of Cognitive Computation. The Series aims to bridge the existing gap between life sciences, social sciences, engineering, physical and mathematical sciences, and humanities. The broad scope of Cognitive Computation Trends covers basic and applied work involving bio-inspired computational, theoretical, experimental and integrative accounts of all aspects of natural and artificial cognitive systems, including: perception, action, attention, learning and memory, decision making, language processing, communication, reasoning, problem solving, and consciousness.

More information about this series at http://www.springer.com/series/15648

Irini Giannopulu

Neuroscience, Robotics and Virtual Reality: Internalised vs Externalised Mind/Brain

Springer

Irini Giannopulu
Interdisciplinary Centre for the Artificial Mind (iCAM)
Faculty of Society and Design, Bond University
Gold Coast, QLD, Australia

ISSN 2524-5341 ISSN 2524-535X (electronic)
Cognitive Computation Trends
ISBN 978-3-319-95557-5 ISBN 978-3-319-95558-2 (eBook)
https://doi.org/10.1007/978-3-319-95558-2

Library of Congress Control Number: 2018955564

© Springer International Publishing AG, part of Springer Nature 2018
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

To my lovely family

Preface

Scientists of the mind have always sought to understand how human beings assemble the visual information of a scene, hear the sounds of the environment, move their limbs, reason, learn, memorise, forget, develop emotion and build consciousness. There are functions that are, in reality, mysteries that neuroscience is beginning to unveil. Scientists have also used materials to try to simulate life artificially. There is no disruption but continuity between these processes. The aim of this book is to discuss the relationship between neuroscience, robotics and virtual/augmented reality. More than a simple description of these three domains, this book is a reflection on the brain-mind-machine concept, on its internalised and externalised expressions. Starting with the historical foundations of brain and mind, it explains how brain-mind-machine is internalised and the neuroimaging techniques we currently use to analyse brain-mind activities. Without ignoring the several limitations of these techniques, the relationship of structure-function is defined and analysed. The ambition is to understand the enactment from the real to artificial world rendered possible via robots and virtual/augmented reality: the externalised mind. Robots and virtual reality are therefore considered *oeuvres de l'esprit* (i.e. *creations of the mind*). Just as importantly, what has been internalised and symbolised has been simulated and externalised. This is the main idea of enrobotment.

All the writings include articles and books showing the origins of neuroscience, robotics and virtual reality. Each chapter includes a historical approach of the domain, both classic and current studies. Different approaches currently look at each domain: neuroscience or robotics or virtual reality or augmented reality. To my knowledge, there is no writing trying to establish a bridge between them. Although in our world of innovation where robots and virtual/augmented reality are more and more present, we need to better understand how our brain develops in interaction. Putting three domains together gives one the occasion to appreciate the virtue of neuroscience and the magic of robotics and virtual/augmented reality. The book aspires to pose question of what makes us human.

Interdisciplinary Centre for the artificial Mind (iCAM) Irini Giannopulu
Faculty of Society and Design, Bond University
Gold Coast, QLD, Australia

Contents

1 Introduction 1

2 The Mind 5
1 The Past Is Prologue: A Brief History of Mind and Brain 5
2 The Internalised Brain-Machine 11
3 The Theory of Mind Localisation 14
3.1 Anatomical Observation 14
3.2 Physiological Observation 16
3.3 Anatomo-Clinical Observation 18
4 Cerebral Transparency Techniques 20
5 Neuro-Cognitivism/Neuro-Constructivism 25
5.1 Multimodal Interactions at Microscopic and Macroscopic Levels 26
5.2 Emerging Representations: The Child and the External Objects 27
5.3 From Perception to Action: The Transition 28
6 Neurosymbolism or How Wor(l)d Meaning May Be Grounded in Perceptual Experience 29
6.1 The Representation of the World 30
6.2 A Logic Model of the Mind: Turing Machine 31
References 33

3 Dynamic Embrained Systems 37
1 Cognitive Models and Neural Support for Memory Systems 37
1.1 From Short-Term Memory to Working Memory 39
1.2 Long-Term Memory or Old Memory 40
1.3 The Neuroanatomy of Memory 42
2 Dynamic Multimodal Perceptual Processes: A Neural Network 44
2.1 Visual Perception 47
2.2 Acoustic Perception 56
2.3 Somatosensory Perception 61
2.4 Olfactory and Gustative Perception 66

2.5 Somatognosia 68
2.6 Spatial Perception 70
3 From Perception to Action 73
3.1 Active Spatial Navigation 73
3.2 Movement Perception and Associated Intentionality 74
4 From Motor Action to Verbal Action 79
4.1 Spoken Language 80
4.2 Written Language 85
4.3 Cognitive and Neural Processing of Numbers and Calculation 87
5 Neural Correlates of Emotional and Cognitive Interaction 91
5.1 "Bottom-Up" vs "Top-Down" Model of Appreciation 92
5.2 Neuro-Anatomo-Functional Emotion 94
6 Self-Consciousness vs Consciousness 102
References 107

4 Externalised Mind 1 123
1 Real vs Artificial Environments: Robots 123
2 Enrobotment 132
2.1 Playing with Objects/Toys 134
2.2 Attribute Intentions 136
3 Neuro-Robotics Based on Neurocognition 137
4 From Deus Ex Machina to Conscientia Ex Machina 143
5 Toy Robots and Children with Neuro-Developmental ASD 148
5.1 Toy Robot as Neural Agent 151
5.2 Multimodal Non Verbal Explorations in Dyadic and Triadic Robot-Child Interaction 152
5.3 Multimodal Non Verbal, Verbal and Emotional Components in Dyadic Robot-Child Interaction 154
References 156

5 Externalised Mind 2 163
1 Self-Motion Perception (i.e. Vection), Virtual vs Augmented Reality 163
2 Virtual Self-Motion 166
2.1 Virtual Self-Motion in Three Steps 169
2.2 Optokinetic Information in the Context of Virtual Self-Motion 170
2.3 Influence of Physical and Structural Parameters of Visual Information in Virtual Self-Motion 171
2.4 Explanatory Components of Virtual Self-Motion 173
3 Real and Virtual Brain 175
3.1 Peripheral Vestibular System 175
3.2 Anatomical and Functional Structure of Vestibular Receptors 176
3.3 Otolithic Afferent Signals 178

4 Perception of Linear Motion in Real Environments 181
5 Navigation in the Virtual World 183
5.1 Direct Virtual Self-Motion 183
5.2 Virtual Inferential Self-Motion 185
5.3 Virtual Motion and Visuo-Vestibular Conflict..... 187
5.4 Visual-Vestibular Conflict in a Behavioural and Neurophysiological Context..... 188
5.5 Somesthetic and Visuo-Vestibular Conflict in Virtual Motion 191
5.6 Cognitive and Vestibular Effects in Virtual Self-Motion..... 193
6 Perceiving Three-Dimensional Objects 197
7 Virtual Mirror vs Virtual Presence 198
8 Virtual Environments Presence and Transfer..... 201
References..... 203

Index..... 215

Chapter 1
Introduction

Neuroscience, Robotics and Virtual Reality: internalised vs externalised mind-brain is the fruit of an interdisciplinary work I started early in my studies. It is concerned with the conceptual foundation of internal and external worlds and their relation with the mind. It is also concerned with the foundation established by the neuroanatomical networks supporting human cognitive, emotional, conscious and unconscious abilities and the human inclination to reproduce life artificially. Going through logical relations between the outer and inner world based on the mind and embrained systems requires both neurocognitive and philosophical efforts; accompanying these efforts with concepts of artificial expression of the mind (robots and virtual/augmented reality) proposed by humans is a new interdisciplinary attempt.

Conceding that we are trying to understand the highest functions and their relationships with the brain, it seems fundamental to me to explore the historiographical literature of the relationship between the mind and the brain. The mind-brain relationship intrigues not only philosophers but also anatomists, physiologists, surgeons and neurologists considering that the mind is formed by the brain. Nevertheless, the relationship between mind and brain, and between function and neural structure, are confused. Bewilderment regarding these concepts including their relationships and interconnections has typified cognitive neuroscience since its beginning. I will initiate my investigation in Chap. 2 with an archival scrutiny of the mind, the mind-brain and the mind-brain-machine. Regardless of the brilliant advances in neuroscience in the twentieth century, the mind-brain and mind-brain-machine arguments remain as challenging as ever. Conceiving that the mind is identical to the brain, modern cognitive neuroscientists commonly attribute, although not uniformly, the mind to the brain and the brain to the machine. Using sophisticated mechanical components, several neuroimaging techniques are utilised to capture the mind. However, the mind is neither different from the brain nor interchangeable with the brain. From my viewpoint, the brain-mind pattern is an organic system of high allegorical architecture and value. The brain-mind-machine scheme is fundamentally symbolic.

© Springer International Publishing AG, part of Springer Nature 2018

I. Giannopulu, *Neuroscience, Robotics and Virtual Reality: Internalised vs Externalised Mind/Brain*, Cognitive Computation Trends 1,
https://doi.org/10.1007/978-3-319-95558-2_1

The neural structures that make the highest functions such as memory, perception, motor and verbal actions, emotion, consciousness and unconsciousness embrained, and clarity about this embrainment are fundamental. Exploratory investigations about the facts regarding neural structures and cognitive operations belong to the area of neuroscience. These investigations are confirmed or infirmed as explained in Chap. 3. We human beings can memorise and forget, perceive and/or not perceive, act intentionally, verbally express ourselves including performing various mathematical operations, have positive and/or negative emotions and feelings, and be conscious or not of our way of being. Our neural structures, our brain, make our abilities feasible. The brain itself or its various parts, both cortical and subcortical, associated with the left and/or right hemisphere, cannot thoroughly explain how we think, perceive, imagine, feel, hope and/or express ourselves. There is a continuum between the inner and outer world: the elements that compose a given environment can act or enact as extensions of the mind. The role of the brain is to integrate them. There are significant questions regarding our design of representations. In my approach, our representations are based on internal allegorical traces that mirror the direct and/or indirect relationship between the mind-brain and the outer world. In relation to allegorical traces and representations, the development of artificial systems, and robots in particular, is one way to understand how our mind-brain perform, whilst also showing what it means to have a human identity. In my approach, the development of artificial systems cannot be separated from the dasein of imagination.

The idea of human being to imitate life, inherent in humanity, is an old one. The enigmatic and allegoric legends of Golem and Talos would have inspired many figures of modern imagination including the monster Frankenstein or Superman. From the Antikythera mechanism in classic hellenistic antiquity to humanoid automaton in medieval times and to Gemonoid HI-1 and F, Diamantini and Sophia in modern times, artificial life emanates from the mind-brain-machine relationship. As explain in Chap. 4 entitled “Externalised mind 1”, our representations are based on allegorical traces and are consciously and unconsciously embrained. The result is that life reproduction rendered possible through robots is the result of the interaction between external information (i.e. objects including their shadows) and internal interpretations: enrobotment. The act to create robots is of high symbolical and allegorical sense. Simulating a human being via a robot might mirror our ability to express our representation. Robots are creations of the mind. The construction of animate robots and humanoid robots in particular signifies that they have been incorporated into the mind. Our self-consciousness is enroboted. What has been internalised and symbolised, has been simulated and externalised. This may be the continuum from Deus ex Machina to Conscientia ex Machina.

Virtual reality itself is a computer based technology that modifies the way humans interact with the environment. It gives users the possibility to navigate and interact with and within a 3D virtual space. Immersion is possible when humans have all the required conditions including sensory, behavioural, cognitive and neuroanatomical. Once again virtuality is not a new technology. In Chap. 5 designated “Externalise mind 2”, I give elements significantly related to virtual environments

(virtual, mixed and augmented reality). I begin with real environments and explain the importance of theater, paintings, design and science fiction in the conception of virtual environments: *mise en scène*. Whole-body virtual motion is considered the archetypal expression of virtual reality. From virtual self-motion to virtual environments (virtual reality but also mixed and augmented reality), abundant elements exist to describe the mechanisms that allow the externalisation of body-mind, in terms of representations, and the internalisation of virtual experiences as real. Virtual reality is understood in the context of visuo-vestibular and somesthetic conflict; mixed and augmented reality are analysed in the context of visuo-vestibular and somesthetic interaction. Virtual environments are a kind of intuitive interfaces that give a person the possibility to interact with other persons or objects in a naturalistic way. In that context, virtual environments can contribute to the understanding of brain development and plasticity. The general structure of the brain when immersed in virtual environments is still to be identified. It requires the collaboration of neuroscientists and engineers with the aim to analyse the core of knowledge utilising the results acquired not only in virtual/mixed/augmented reality but also to better discern the relationship between the brain and the mind.

My work may appear meaningless or worse, a confrontation between Neuroscience, Robotics and Computer scientists. Although, I wrote this book with the hope to contribute to the emergent interdisciplinary tendency. To my point of view, there is no disruption but continuity between the past, the present and the future, and of course, between Neuroscience, Robotics and Computer sciences. Putting the concept in the centre of each domain, my analysis and combination are constructive and wish that it will be a conceptual reference for neuroscientists, roboticians, and computer scientists when considering their investigations. In my approach, Neuroscience, robots and virtual/augmented reality are *oeuvres de l'esprit.*

Chapter 2
The Mind

Abstract This chapter gives the historical foundations of mind and brain separately and then analyses the relationship between the brain/mind-machine. This relationship is considered internalised. With the aim to better understand the association between the brain and the mind, are examined the links between structure and function via neuroimaging techniques. Based on the above, NeuroCognitivism vs. NeuroConstructivism and Neurosymbolism are defined and explained.

1 The Past Is Prologue: A Brief History of Mind and Brain

Our ancestors, homo erectus, regarded the brain as a "vital organ". Skulls that date back a million years or more have been found in archaeological museums and show traces of mortal cranial lesions. About 10,000 years ago, in the modern man homo sapien sapien period, surgical operations were already practiced at the cerebral level to cure certain diseases. However, in some cases the purpose of these "surgeons" was not always clear. Did they operate to treat mental disorders or simply to open a doorway to "evil" spirits? The writings and expositions of the first physicians of ancient Egypt, about 3000 years ago, suggest that these doctors had already recognised several diseases related to brain lesions and the spinal cord. From the ancient Egyptians, we have one of the first descriptions of the brain and its different parts. However, the heart more so than the brain was considered the seat of the soul, memories, thought and consciousness.

In ancient mythology, a Titan named Prometheus, (i.e. "forethought"), was the creator of mankind using clay. Following the legend, the goddess of wisdom, Athena introduced the "breath of life" into the bodies of clay. To accomplish his performance, Prometheus stole the "divine knowledge" (i.e. light) from Mount Olympus and gave it to his creature. The breath of life (i.e. the souffle), and its relationship with the divine knowledge has parallels in the legend of Pygmalion and his ivory statue. Pygmalion created an elegant and realistic statue and felt in love with it. He wanted to bring it to life. He made offerings at the altar to Aphrodite who granted Pygmalion's wish and gave "breath of life" to his statue. The blowing of the "breath

© Springer International Publishing AG, part of Springer Nature 2018

I. Giannopulu, *Neuroscience, Robotics and Virtual Reality: Internalised vs Externalised Mind/Brain*, Cognitive Computation Trends 1,
https://doi.org/10.1007/978-3-319-95558-2_2

of life" in a statue, (i.e. body), also has similarities in the legend of Daedalus, who used mercury to introduce a voice to his effigies. Hephaestus built automata and he also gave life to Talos, an artificial man made of bronze. The "breath of life", (i.e. vital breath), is an internal strength. "Breath" is the term which has been used to symbolise the "mind".

The word "mind" is a linguistic reconstruction from a Proto-Indo-European language "men-, meaning". "Mens" is the Latin word associated with the mind, whereas "manas" is the Sanskrit term linked to the mind. Ancient Greeks used the word "μένος" to signify mind, desire, and wish. One controversial question regarding the "mind" is its relation with the "body vs brain". Still today, there is no unanimous agreement of what the mind is and what its relation with the body is. One way to understand what the mind is, as well as its connection(s) with the body, is to analyse its possible relation with the psyche. In Greek mythology, Psyche (Ψυχή), is a mortal woman, who becomes the wife of Eros, (ʼΕρως). Psyche is a personification of a human, a female. This myth, written by Lucius Apuleius, in the the second century AD, is reported as the history of Cupid and Psyche. Following the allegory of Psyche and Eros, the psyche, i.e. the mind, is related to the God.

In both poems, Iliad and Odyssey, Homer (8-9th Century BCE) (Fig. 2.1) defines two sorts of psyche: the "breath-psyche" which activates the body, as well as the "body psyche" named thymos (θυμός), noos, (Νούς), and menos, (Μένος). Etymologically speaking, the word *psyche* is associated with the verb psychein, (ψύχειν), which signifies "to breathe"; thymos is considered as the source of

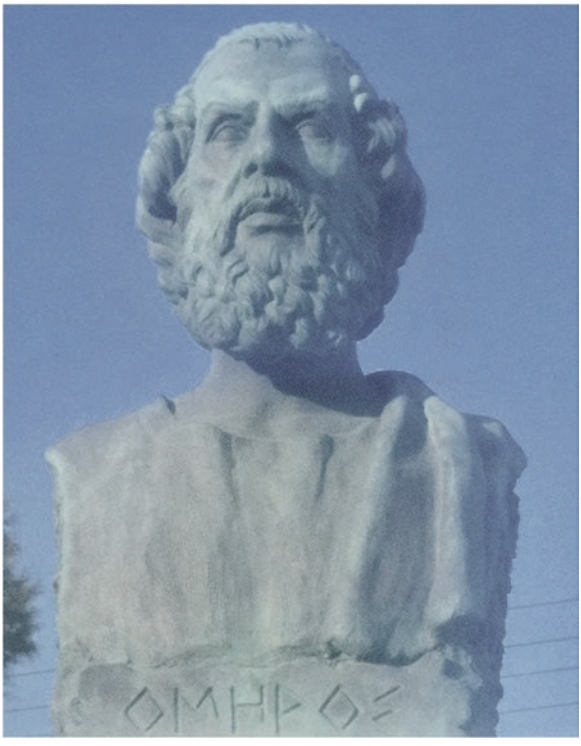

Fig. 2.1 Homer (8-9 BCE). He defines various sorts of psyche: the "breath-psyche" which activates the body, as well as the "body psyche" named thymos (θυμός), noos, (Νούς), and menos, (Μένος). He also used the word kradia, (καρδιά), which is translated as "heart". In Homeric writing, the heart is related to feelings