One only has to read the newspapers to understand the extent to which addictions are among the scourges of the day. They lead to wastage and wasting of innumerable individual lives, and a huge cost to the body politic, with gargantuan sums of illicit money supporting edifices of corruption. The blame for other modern solecisms, such as burgeoning obesity, is increasingly being laid at the same door.

From the perspective of neuroscience, addictions present a critical challenge. Substances with at least initially relatively immediate effects on more or less well-defined sets of receptors, have, in some individuals, a panoply of physiological and psychological consequences that unravel over the course of years. Understanding each domain of inquiry by itself, and the links between them, is critical for understanding the course of addictions, and in the longer run, conceiving more effective options for palliation or even cure. Although there is a near overwhelming volume of data, the complexities of the subject mean that there are also many apparent inconsistencies and contradictions.

The need to tie together phenomena at these multiple scales is a critical force leading to the current book’s focus on theoretical ideas. Indeed research in addiction is a paradigmatic example of modern systems biology. The task of providing a formal scaffolding for understanding the links across levels of inquiry, is the topic of one of three wings of theoretical neuroscience. In the top-down direction, this is a case of a formal scientific reduction, explaining phenomena observed at one scale by mechanistic models built from components that live at finer scales. These components are characterized either by descriptive models, or are themselves explained by models at yet finer scales. Building and proving such multi-scale models is a perfectly normal role for mathematical and (increasingly) simulation-based modeling
in a natural science. One might only cavil that, compared with some of its cousins, experimental neuroscience has sometimes seemed a little tardy in playing ball.

Chapter 4 is perhaps the purest example of this sort of analysis—providing, for instance, a formal way of resolving the apparent conflict between *in vivo* and *in vitro* data as to whether nicotine’s main action on the activity of dopaminergic cells (believed to be key to the drug’s addictive potential) is direct or indirect. However, many of the other chapters also contain elements of this *modus operandi* too, applied at different levels. For instance, the sophisticated agent modeling of Chap. 11 reminds us about the complexity of interactions between addicts and the environment which facilitates and hinders their addiction. Rich patterns of positive and negative feedback emerge. Thus, it is possible to examine and predict the effects of making manipulations at single points in the nexus of interactions—woe would, for instance, betide the policy-maker who attempts to intervene too simplistically in a system that is sufficiently non-linear as to be chaotic.

However, the chapters of the book also attest to the power of a second wing of theoretical neuroscience. This is the concept that brains must solve computational, information-processing and control-theoretic problems associated with surviving in a sometimes nasty and brutish world. Decision-making, in its fullest sense, is perhaps the critical competence for survival. The idea is to start from an understanding of the various ways that systems of any arbitrary sort can (learn to) make good decisions in the face of rewards and punishments. This topic lies at the intersection of economics, statistics, control theory, operations research and computer science. The resulting computational and algorithmic insights provide a foundation for, and constraints on, how humans and other animals actually make choices. Further, the sub-components of these models provide a parameterization of failure—points at which addictive substances can exert their intricately malign effects.

Somewhat alternative versions of these normative, and approximately normative, notions are apparent in many of the remaining chapters, differing according to the degree of abstraction, the intensity of focus on the computational level versus aspects of the algorithms and implementations of those computations, and also the extent to which the complexity of the neural substrate is included. There are also many different ways to formalize control theoretic problems, in terms of (a) the nature of the world (and the possible internal model thereof); (b) the goals of control, for instance the homeostatic intent of keeping variables within appropriate bounds as opposed to finding optimal solutions in the light of costs and returns; along with (c) assumptions about the possible solutions.

The relatively purer control theoretic approaches discussed in Chaps. 1, 2, 3 lie nearer one end of the spectrum. They pay particular attention to one of the central ideas in control theory, namely feedback as a way of keeping systems in order. Although one can imagine computational-level renditions, this is mostly an algorithmic idea, being rather divorced from possible computational underpinnings in terms of such things as being an optimal way of preventing divergence from a suitable operating point according to a justifiable cost function. Drugs can knock systems out of kilter, and so inspire immediate or predictive feedback to correct the state; the negative effects of withdrawal can also lead to a corrective policy of self-administration.
In these chapters, we can see something of the power of quantitatively characterizing the dynamical effects of drugs in systems with substantial adaptation.

The behavioral economic modeling of Chap. 10 has a somewhat similar quality. Here, the aliquots of computational analysis concern the relationship between price and demand and the effect of temporal delay on value. These then play out through psychological data and algorithmic realizations of these data.

The chapters based on modern reinforcement learning (RL) ideas (parts or all of Chaps. 5, 6, 7, 8) span the other end of the spectrum. As will become apparent in reviewing these chapters, reinforcement learning, which comprises forms of optimal, adaptive control, has become a dominant theoretical paradigm for modeling human and animal value-based decision-making. In some ways, it has taken over this role from cybernetics, its close control-theoretic cousin, which historically exerted a strong influence over systems thinking in areas in which value has played a lesser part. Aspects of the activity of dopaminergic cells offered one of the early strong ties between theory and experiment; it is only surprisingly recently that addiction, with its manifold involvement of dopamine, has become a target for this sort of effort.

Different RL approaches, such as model-based methods (which make choices by building and searching models of the decision-making domain) and model-free methods (which attempt to make the same optimal choices, but by learning how to favor actions from experience, without building models) are suggested as being realized in structurally and functionally-segregated parts of the brain, and have each been provided with normative rationales. The various chapters also speak to a fecund collaboration between theory and experiment, for instance winkling out potentially suboptimal interactions between the systems, and roles for evolutionarily prespecified control in the form of Pavlovian influences.

These chapters take rather different perspectives on the overall problem of addiction, even if generally adopting a rather common language. Indeed, although this language is powerful, uniting as it does information-processing notions with psychological and anatomical, physiological and pharmacological data, it is fair to say that it reveals rather than reduces the complexity of the individual systems, a complexity which is then hugely magnified in the way the systems interact. However, the multiple influences of drugs acting over the systems and their interactions all at diverse timescales, can at least be laid bare, and reasoned about, given this formal vocabulary.

Chapter 9 comes from another, subtly different, tradition of normative modeling, associated originally more with unsupervised learning (or probabilistic modeling of the statistical structure of the environment with no consideration of valence) than RL, and indeed comes to suggest a rather different (and, currently rather restricted) way that drugs can act. Nevertheless, there are ties both the RL models and indeed the control theoretic ones—for instance, Chap. 3’s discussion of the limits of homeostasis is nicely recapitulated in Chap. 9’s notion of itinerant policies, for which fixed points are an anathema.

Finally, note a critical lesson from the diversity of the chapters. Chapter 4’s whole contribution concerns important (but still doubtless not comprehensive) details about the complex effects over time of one particular drug of addiction on one
key circuit. Consider how these effects would be rendered in the abstract, impres-
sionistic, terms of pretty much all the other chapters. These latter models simply
lack the sophistication to capture the details—but, sadly, without being able to pro-
vide a guarantee that in the complex systems they do model, omitting the details is
benign.

If one regards the diversity as a mark of adolescent effervescence in this field
of computational addiction; the fact that such a fascinating book is possible is a
mark of impending maturity. Theoretical ideas and mathematical and computational
models are rapidly becoming deeply embedded in the field as a whole, and, most
critically, are providing new, and more powerful, ways to conceive of the multiple,
interacting, problems wrought by addictive substances. Providing the guarantees
mentioned above, and indeed a more systematic tying together of all the different
levels and types of investigation across different forms and causes of addiction, is
the challenge for early adulthood.

Acknowledgements

I am very grateful to the Gatsby Charitable Foundation for funding.

London, UK

Peter Dayan
Acknowledgements

The editors would like to acknowledge the support from the French Research Council (CNRS) (BSG and SHA), the Université Victor Segalen-Bordeaux (SHA), the Conseil Régional d’Aquitaine (SHA), Ecole Normale Superieure and INSERM (BSG), the French National Research Agency (ANR) (BSG and SHA), NERF (BSG) and Fondation Pierre-Gilles de Genes. Boris Gutkin would like to thank Prof. J.P. Changeux for launching into the field of addiction research and his continuing support.
Contents

Part I  Pharmacological-Based Models of Addiction

1 Simple Deterministic Mathematical Model of Maintained Drug Self-administration Behavior and Its Pharmacological Applications  3
   Vladimir L. Tsibulsky and Andrew B. Norman

2 Intermittent Adaptation: A Mathematical Model of Drug Tolerance, Dependence and Addiction  19
   Abraham Peper

3 Control Theory and Addictive Behavior  57
   David B. Newlin, Phillip A. Regalia, Thomas I. Seidman, and Georgiy Bobashev

Part II  Neurocomputational Models of Addiction

4 Modelling Local Circuit Mechanisms for Nicotine Control of Dopamine Activity  111
   Michael Graupner and Boris Gutkin

5 Dual-System Learning Models and Drugs of Abuse  145
   Dylan A. Simon and Nathaniel D. Daw

6 Modeling Decision-Making Systems in Addiction  163
   Zeb Kurth-Nelson and A. David Redish

7 Computational Models of Incentive-Sensitization in Addiction: Dynamic Limbic Transformation of Learning into Motivation  189
   Jun Zhang, Kent C. Berridge, and J. Wayne Aldridge

8 Understanding Addiction as a Pathological State of Multiple Decision Making Processes: A Neurocomputational Perspective  205
   Mehdi Keramati, Amir Dezfooli, and Payam Piray
Part III Economic-Based Models of Addiction

9 Policies and Priors ......................................................... 237
   Karl Friston

10 Toward a Computationally Unified Behavioral-Economic Model of Addiction ......................................................... 285
   E. Terry Mueller, Laurence P. Carter, and Warren K. Bickel

11 Simulating Patterns of Heroin Addiction Within the Social Context of a Local Heroin Market ................................. 313
   Lee Hoffer, Georgiy Bobashev, and Robert J. Morris

Index .................................................................................. 333
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