

Scale invariance in neuronal networks through selective pruning and neuronal death

Kleber Neves¹, Rodrigo Kazu², Suzana Herculano-Houzel³ & Bruno Mota¹

INTRODUCTION

To a large extent, brain development is destructive, removing parts - neurons and synapses - generated in excess beforehand.

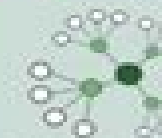
There is widespread neuronal death and synaptic pruning in the development of the nervous system.



Which neurons and synapses survive and which ones are eliminated is activity-dependent.

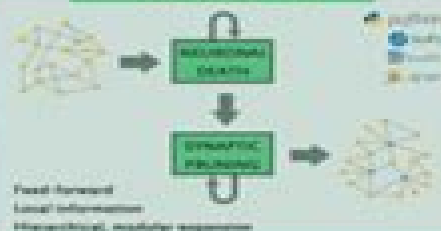
The regulation of synaptic strength is Hebbian - "neurons that fire together, wire together".

QUESTION



What effects might these ontogenetic events, as well as their timing and order, have on the low-level organization of the resulting neuronal networks? Could it be that the wastefulness is actually useful?

THE MODEL



MAIN RESULTS

Initial state of the network
Degree distribution of a random feed-forward graph



Network after neuronal death
Degree distribution of the network after 50% neurons of selective neuronal death



Network after synaptic pruning
Degree distribution of the network after 50% neurons of selective pruning



Kolmogorov-Smirnov test for a theoretical power law
 $p < 0.05$
 $\text{exponent} = 2.17$
(*Science*, March 1999, 285(5427), 1503-1506)

REMOVING INGREDIENTS

Without neuronal death

Degree distribution after 50% neurons of selective pruning without having gone through neuronal death (Heterocircuits)



Without selective pruning

Degree distribution after 50% neurons of selective pruning (without of selective pruning) (Heterocircuits)



Without feed-forward

Degree distribution after 50% neurons of selective pruning (without of selective pruning) (Heterocircuits)



Only feed-forward and selective pruning seem to be necessary to generate scale-free networks

Selective death does not seem to be necessary

CONCLUSIONS

Biologically-inspired selective pruning leads to a scale-free network. It could mean neuronal networks are robust to random failures.

Selective removal and preferential attachment ²⁰ of edges could be two separate but related mechanisms to generate scale-free networks: both rely on the reinforcement of inequalities.



Selective Neuronal Death

**Julian T. Hoff, Richard F. Keep, Guohua
Xi, Ya Hua**

Selective Neuronal Death:

Selective Neuronal Death Gregory R. Bock, Maeve O'Connor, 2008-04-30 Parkinson's disease Alzheimer's disease and motor neuron disease share a significant common feature selective death of neurons in restricted regions of the brain This international symposium held by the Ciba Foundation in 1986 is the first to bring together neurophysiologists working on neuronal death and neuropathologists dealing with human degenerative brain disease Participants describe the causes and sequence of events leading to neuronal death and discuss what can be done to prevent it Among the topics covered are recent advances in the understanding of agents such as trophic factors excitotoxins and poisons that are known to be involved in neuronal death examples of neuronal death during normal development and the role played by endocrine mechanisms and neuronal activity Also considers trophic factors controlling the survival of neuronal transplants and the therapeutic prospects for tissue transplantation

Selective Neuronal Death Gregory Rock, Gregory Bock, Maeve O'Connor, 1987-02-25 Parkinson's disease Alzheimer's disease and motor neuron disease share a significant common feature selective death of neurons in restricted regions of the brain This international symposium held by the Ciba Foundation in 1986 is the first to bring together neurophysiologists working on neuronal death and neuropathologists dealing with human degenerative brain disease Participants describe the causes and sequence of events leading to neuronal death and discuss what can be done to prevent it Among the topics covered are recent advances in the understanding of agents such as trophic factors excitotoxins and poisons that are known to be involved in neuronal death examples of neuronal death during normal development and the role played by endocrine mechanisms and neuronal activity Also considers trophic factors controlling the survival of neuronal transplants and the therapeutic prospects for tissue transplantation

Greenfield's Neuropathology Eighth Edition 2-Volume Set Seth Love, David Louis, David W Ellison, 2008-02-29 Greenfield's Neuropathology the world's leading neuropathology reference provides an authoritative comprehensive account of the pathological findings in neurological disease their biological basis and their clinical manifestations This account is underpinned throughout by a clear description of the molecular and cellular processes and reactions that are relevant to the development and normal and abnormal functioning of the nervous system While this scientific content is of paramount importance however care has been taken to ensure that the information is presented in a way that is accessible to readers working within a range of disciplines in the clinical neurosciences and that also places the neuropathological findings within the context of a broader diagnostic process The new eighth edition incorporates much new information new illustrations and many new authors while retaining the depth breadth and quality of content so praised in previous editions Each chapter opens with an introductory section designed to offer an integrated approach to diagnosis taking account of clinical manifestations neuroradiological and laboratory findings as well as the neuropathological and molecular genetic features of the diseases being considered Strong emphasis has been placed on facilitating the retrieval of neuropathological information by non neuropathologists grappling

with differential diagnoses or seeking information on broad categories of neurological disease and boxes and tables are used to present important symptoms and signs patterns of disease and other features for ease of reference High quality line and photographic illustrations the majority in full colour are all available on a companion CD to complete the offering

The Ischemic Penumbra Geoffrey A. Donnan, Jean-Claude Baron, Stephen M. Davis, Frank R. Sharp, 2007-04-13 The Ischemic Penumbra presents the current status of concepts and research on this topic and identifies the latest methods for clinicians to quickly and efficiently recognize viable cerebral tissue for enhanced stroke management Focusing on state of the science technologies and current trends the book examines imaging strategies utilizing PET SP

Greenfield's Neuropathology - Two Volume Set Seth Love, Arie Perry, James Ironside, Herbert Budka, 2018-10-08 Greenfield's Neuropathology the world's leading neuropathology reference provides a comprehensive account of the pathological findings in neurological disease their biological basis and their clinical manifestations The book's detailed advice on pathological assessment and interpretation is based on clear descriptions of molecular and cellular processes and reactions that are relevant to the development of the nervous system as well as its normal and abnormal functioning The information is presented in an accessible way to readers working within a range of disciplines in the clinical neurosciences and neuropathological findings are placed within the context of a broader diagnostic process New for the Ninth Edition Features online and downloadable digital formats with rapid search functions annotation and bookmarking facilities image collections and live reference links Contains many color illustrations and high quality clinical photographs to help with interpretation and understanding Includes more than 1000 new photographs and drawings Incorporates new design elements such as alternate colour coding of chapters for easier navigation Known for its thorough yet practical approach Greenfield's continues to provide trusted information to all neuropathologists and those in related specialties including neurologists neurosurgeons general pathologists neuroradiologists and clinical neuroscientists

Maturation Phenomenon in Cerebral Ischemia III Umeo Ito, Cesare Fieschi, Francesco Orzi, Toshihiko Kuroiwa, Igor Klatzo, 2012-12-06 The Maturation Phenomenon described by Ito et al in 1975 3 on the basis of his to logical observations in the hippocampus as well as other portions of the cerebral hemisphere refers to the hours or days of delay in the development of pathological changes in various parameters of ischemic injury following the restoration of blood flow to the ischemic brain There is a direct relationship between the intensity of ischemic insult and the speed and rate of maturation of ischemic injury a lesser intensity being associated with slower and less severe development of the lesions The delayed neuronal death of CA1 pyramidal cells of the hippocampus 8 is a classic example In the cerebral cortex with increasing intensity of the ischemic insult the maturation phenomenon of ischemic injuries intensifies seamlessly from less extensive to more extensive disseminated selective neuronal necrosis DSN and then further to cerebral infarction upon reaching a critical threshold 1 2 4 6 7 We also have found that following ischemic insults just under the threshold level required to induce infarction only disseminated selective neuronal necrosis DSN progresses while following ischemic

insults at the threshold level initially only DSNN develops followed by the evolution of a gradually enlarging infarcted focus 5

7 The reporting of this phenomenon boosted research in the field as it became evident that ischemic damage is not a sudden event but a process potentially susceptible to therapeutic intervention Primer on Cerebrovascular Diseases Louis R. Caplan, Jose Biller, Megan C. Leary, Eng H. Lo, Ajith J Thomas, Midori Yenari, John H. Zhang, 2017-02-10 Primer on Cerebrovascular Diseases Second Edition is a handy reference source for scientists students and physicians needing reliable up to date information on basic mechanisms physiology pathophysiology and medical issues related to brain vasculature The book consists of short specific chapters written by international experts on cerebral vasculature presenting the information in a comprehensive and easily accessible manner Numerous changes have occurred in the field since the publication of the first edition in 1997 particularly our understanding of the genetic aspects of cerebrovascular disease This updated edition reflects the advances made over the last two decades not only demonstrating the promise for therapy but also for a molecular understanding of cerebrovascular diseases The new edition includes new and expanded topics including carotid stenting Iatrogenic causes of stroke axonal transport and injury RNAs proteomics and more 2018 BMA Medical Book Awards Highly Commended in Neurology Provides concise chapters on topics in cerebral blood flow and metabolism pathogenesis of cerebrovascular disorders diagnostic testing and management in a comprehensive and accessible format Written by international leading authorities on cerebral vasculature Provides up to date information on practical applications of basic research and the main clinical issues facing the community such as axonal transport and proteomics Cardiac Arrest Norman A. Paradis, Henry R. Halperin, Karl B. Kern, Volker Wenzel, Douglas A. Chamberlain, 2007-10-18 Cardiac Arrest is the definitive and most comprehensive reference in advanced life support and resuscitation medicine This new edition brings the reader completely up to date with developments in the field focusing on practical issues of decision making clinical management and prevention as well as providing clear explanations of the science informing the practice The coverage includes information on the latest pharmacotherapeutic options the latest chest compression techniques and airway management protocols all backed by clearly explained evidence based scientific research The content is consistent with the latest guidelines for practice in this area as detailed by the major international governing organisations This volume is essential reading for all those working in the hospital environments of emergency medicine critical care cardiology and anesthesia as well as those providing care in the pre hospital setting including paramedics and other staff from the emergency services **The Role of Neurotransmitters in Brain Injury** W.D. Dietrich, M.Y.T. Globus, 2012-12-06 Neuroscientists from various disciplines have given extraordinary attention to the role of neurotransmitters in the field of neuronal injury This volume summarizes the original oral and poster contributions which were presented at the symposium The Role of Neurotransmitters in Brain Injury in Key West Florida between June 7 9 1991 This symposium was the official Satellite of Brain 91 the Fifteenth International Symposium on Cerebral Blood Flow and Metabolism held in Miami the

previous week The two principal goals of the Key West satellite meeting were to document recent progress and more importantly to explore future directions for investigative studies of the role of neurotransmitters in brain injury To achieve these goals we assembled participants from diverse scientific fields and specialties who brought their collective expertise to discussions on the importance of neurotransmitters in neuronal and vascular injury following brain ischemia trauma and epilepsy Their contributions are reflected in this volume An important section of this volume is devoted to the role of glutamate and glutamatergic receptors in the development of ischemic neuronal damage Topics covered include the mechanisms of glutamate and other excitatory amino acids and the role of underlying injury induced release different glutamatergic receptors in brain injury including the NMDA and the non NMDA receptors The involvement of other neurotransmitters in the process of ischemic brain injury is well established

Stroke E-Book James C. Grotta, Gregory W Albers, Joseph P Broderick, Scott E Kasner, Eng H. Lo, Ralph L Sacco, Lawrence KS Wong, Arthur L. Day, 2021-02-06 Authored by the world s foremost stroke experts this classic text brings you fully up to date with current research findings and management approaches for cerebrovascular disease *Stroke Pathophysiology Diagnosis and Management 7th Edition* covers every aspect of this fast moving field and is an ideal resource for stroke specialists general neurologists and other medical professionals with an interest in stroke You ll find expert clinical guidance comprehensive pathophysiology coverage data from recent trials advances in diagnostic tests full color CT images pathology slides and much more for a complete picture of today s stroke medicine Helps you recognize the clinical manifestations of stroke use the latest laboratory and imaging studies to arrive at a diagnosis and generate an effective medical and surgical treatment plan Keeps you abreast of the overwhelming volume of studies and guidelines in this dynamic field providing clear summaries and practical evaluations of all relevant data Contains updates throughout including the latest clinical trials thrombectomy DAWN DEFUSE genetics research prevention research new therapies and the new guidelines from the ASA Includes new slides for lectures covering basic science case studies and interventional treatment overviews Features a Key Points summary at the beginning of each chapter so you can quickly find important information Provides abundant full color CT images and pathology slides that help you make efficient and accurate diagnoses

Stroke A David Mendelow, 2015-08-24 Offered in print online and downloadable formats this updated edition of *Stroke Pathophysiology Diagnosis and Management* delivers convenient access to the latest research findings and management approaches for cerebrovascular disease Picking up from where J P Mohr and colleagues left off a new team of editors Drs Grotta Albers Broderick Kasner Lo Mendelow Sacco and Wong head the sixth edition of this classic text which is authored by the world s foremost stroke experts Comprehensive expert clinical guidance enables you to recognize the clinical manifestations of stroke use the latest laboratory and imaging studies to arrive at a diagnosis and generate an effective medical and surgical treatment plan Abundant full color CT images and pathology slides help you make efficient and accurate diagnoses Data from late breaking endovascular trials equips you with recent findings

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Neuropathology 10e Set Colin Smith,Arie Perry,Gabor Kovacs,Thomas Jacques,2024-11-07 Greenfield's is the world's leading neuropathology reference It provides a comprehensive account of the pathological findings in neurological disease their biological basis and their clinical manifestations The two volume work provides a remarkable text which is clear comprehensive and precise with exceptional illustrations The tenth edition features fully updated sections covering CNS tumours neurodegeneration skeletal muscle epilepsy paediatric and forensic neuropathology Expert coverage from an international team of Editors and contributors ensures authoritative and up to date content The two volume set includes a downloadable and easily used e version This is a tried and tested reference for scientists clinicians researchers and students who wish to learn more about neurological disease **Microglia in the Regenerating and Degenerating Central Nervous System** Wolfgang J. Streit,2013-03-14 Over the past decade the study of microglial cells has gained increasing importance in particular for those working in the fields of degeneration and regeneration Microglia in the Regenerating and Degenerating CNS supports the assertion that understanding microglial biology could perhaps be pivotal for unraveling the pathogenetic mechanisms that underlie Alzheimer's disease currently the most widely studied disorder of the central nervous system In addition microglia are also critical for understanding the sequelae of traumatic brain and spinal cord injury and for the vitally important post traumatic repair processes This book gives an up to date account of the role of microglia in degeneration and regeneration of the nervous system and also reviews microglial cell function and physiology Cellular neurobiologists will find that this is a valuable guide to the importance and role of microglia in the CNS

Neurotherapeutics Linda M. Pullan,Jitendra Patel,1995-11-13 Neuroscience's inherent complexity and rapid growth mean that no one can keep abreast of all the changes across the field We each bring a necessarily narrow perspective

Neurotherapeutics Emerging Strategies is an attempt to provide some diverse perspectives within the hunt for new drugs to treat central nervous system diseases. The book's premise is that the search for new drugs is based on an understanding of both clinical and basic sciences. Neurotherapeutics Emerging Strategies begins with psychiatry and concludes with neurological disorders. Each chapter examines a disease including clinical features and existing treatments but the emphasis is on current concepts of underlying causes and novel strategies for drug discovery arising from these possible mechanisms. Participating authors include basic neuroscientists, industry-based pharmacologists and chemists and clinicians. The chapters describe the status of the existing disease treatments and when treatments are lacking the approach is more basic science oriented. When there is a long history of treatment there is greater emphasis on those therapies. However, all the chapters seem to reflect the benefits of cloning since the availability of receptor subtypes now promises the opportunity for greater specificity of drug effects. Modulation of second messengers is another new and recurring theme. And in the chapter on cachexia, cytokines are explored both as drugs and drug targets. Neurotherapeutics Emerging Strategies reflects the complexity of the nervous system but the overriding message is hope for new and better drugs to treat those diseases that rob us of ourselves.

The Clinical Neurobiology of the Hippocampus Thorsten Bartsch, 2012-07-26. The hippocampus is one of the most studied structures in the human brain and plays a pivotal role in human memory function. Its recognized function is reflected by the presence of an extensive body of neurophysiological, neuropsychological, anatomical and neurocomputational literature that presents basic mechanisms, theoretical models and psychological concepts. However, in the rapidly growing field of hippocampal research, the clinical aspects of diseases that affect the hippocampus are greatly underrepresented in current literature and clinical approaches and concepts are scattered throughout various clinical and basic scientific disciplines. The Clinical Neurobiology of the Hippocampus explores clinical approaches to the range of diseases that affect the hippocampus. It brings together and reviews the common methods, clinical findings, concepts, mechanisms and where applicable therapeutic strategies for these clinical approaches. The clinical spectrum of hippocampal dysfunction encompasses a wide range of neurological, behavioural and psychiatric symptoms and surpasses the ability to encode, store and retrieve information. The relevance of hippocampal involvement in clinical diseases goes beyond mere neuropsychological deficits and includes psychopathological states in various conditions such as acute amnesic syndromes, Alzheimer's disease, temporal lobe epilepsy, TLE, sleep, stroke, medicine, limbic encephalitis, neurodevelopmental disorders, stress and trauma-related disorders, depression and schizophrenia. The first part of the book covers the basic and integrative features of the hippocampus such as the anatomy and imaging of this structure and the basic mechanisms of hippocampal function including the principles of hippocampus-dependent memory processing in amnesia and sleep, the mechanisms of vulnerability and adult neurogenesis as well as the effects of stress. The second part covers the various clinical manifestations in which the hippocampus is involved and in which the preceding basic mechanisms are reflected. Bringing together a broad team of

experts on the basic and clinical aspects of the hippocampus the book provides an integrative view of the hippocampus It is invaluable for neurologists neuroscientists and psychiatrists and will stimulate interdisciplinary discussions in clinical neuroscience Metabolic Encephalopathy David W. McCandless,2009-05-17 Metabolic Encephalopathy is meant to combine and correlate animal and human studies It is hoped that increased awareness of the importance of early diagnosis and treatment of these disorders may result in a lowering of the incidence of structural changes and morbidity These disorders hold a special fascination for both basic scientists and clinical investigators because they are accessible treatable and there exists good animal models for study Therefore this book will pull together basic and clinical neuroscience issue in the treatment of specific metabolic encephalopathies **Neurology for the Non-Neurologist** William J.

Weiner,Christopher G. Goetz,Robert K. Shin,Steven L. Lewis,2012-03-28 This book is a practical guide for primary care physicians psychiatrists and other non neurologist clinicians who encounter patients with neurologic problems The book begins with overviews of neurologic symptoms the neurologic examination diagnostic tests and neuroradiology and then covers the full range of neurologic disorders that non neurologists encounter Chapters follow a consistent structure with key elements highlighted for quick scanning Each chapter begins with Key Points and includes Special Clinical Points Special Considerations in the Hospitalized Patient and When a Non neurologist Should Consider Referring to a Neurologist Each chapter ends with an Always Remembersection emphasizing the most important practical issues and a series of self study questions Mental Disorders: New Insights for the Healthcare Professional: 2011 Edition ,2012-01-09 Mental Disorders New Insights for the Healthcare Professional 2011 Edition is a ScholarlyEditions eBook that delivers timely authoritative and comprehensive information about Mental Disorders The editors have built Mental Disorders New Insights for the Healthcare Professional 2011 Edition on the vast information databases of ScholarlyNews You can expect the information about Mental Disorders in this eBook to be deeper than what you can access anywhere else as well as consistently reliable authoritative informed and relevant The content of Mental Disorders New Insights for the Healthcare Professional 2011 Edition has been produced by the world s leading scientists engineers analysts research institutions and companies All of the content is from peer reviewed sources and all of it is written assembled and edited by the editors at ScholarlyEditions and available exclusively from us You now have a source you can cite with authority confidence and credibility More information is available at <http://www.ScholarlyEditions.com> **Brain Edema XIII** Julian T. Hoff,Richard F. Keep,Guohua Xi,Ya

Hua,2006-06-22 The XIII International Symposium on Brain Edema intracerebral hemorrhage including the primary event and Tissue Injury was held June 1 3 2005 in Ann Ar and the secondary injury that follows prompted a o bor Michigan USA This volume includes papers pre day satellite conference on the subject The conference sented at the symposium as well as papers that were was held immediately after the Brain Edema Sym presented at a satellite Intracerebral Hemorrhage Con sium Most participants in the Brain Edema Sym ference on June 4 2005 In keeping with the outstand sium stayed an extra

day to learn about the latest in XII Symposium held in Hakone Japan in 2002 we developments in intracerebral hemorrhage research chose to include brain tissue injury as well as brain including ongoing clinical trials and basic research edema as the subject matter for this meeting Brain investigation focusing primarily on the secondary events edema in many respects is a marker of underlying which develop after the hemorrhage pathological processes which include tissue injury There was considerable enthusiasm to continue the from many diseases Brain Edema Symposium series at the conclusion of The scientific sessions included invited speakers the thirteenth meeting The Advisory Board chose oral presentations poster sessions and panel discuss Warsaw Poland as the next site for the meeting under sions *Neuronal Calcium Sensors in Health and Disease* Karl-Wilhelm Koch, Jose R. Naranjo, Beat Schwaller, Daniele Dell'Orco, Michael R. Kreutz, 2020-01-16

Decoding **Selective Neuronal Death**: Revealing the Captivating Potential of Verbal Expression

In a period characterized by interconnectedness and an insatiable thirst for knowledge, the captivating potential of verbal expression has emerged as a formidable force. Its power to evoke sentiments, stimulate introspection, and incite profound transformations is genuinely awe-inspiring. Within the pages of "**Selective Neuronal Death**," a mesmerizing literary creation penned by a celebrated wordsmith, readers set about an enlightening odyssey, unraveling the intricate significance of language and its enduring impact on our lives. In this appraisal, we shall explore the book's central themes, evaluate its distinctive writing style, and gauge its pervasive influence on the hearts and minds of its readership.

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