Unconventional Computation

8th International Conference, UC 2009
Ponta Delgada, Portugal, September 7-11, 2009
Proceedings

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Preface

The 8th International Conference on Unconventional Computation, UC 2009, was held in Ponta Delgada during September 7–11, 2009, and was organized under the auspices of the European Association for Theoretical Computer Science (EATCS) by the University of Azores (Ponta Delgada, Portugal) and the Centre for Discrete Mathematics and Theoretical Computer Science (Auckland, New Zealand).

The venue was the University of Azores, with its modern and well-equipped auditoria, next to the magnificent rectory, and surrounded by a pleasant and peaceful garden. The university is located in the city of Ponta Delgada, on São Miguel Island, in the Archipelago of the Azores. São Miguel is famous for its beautiful landscapes and exceptional volcanic lakes. Depending on the surrounding countryside, some appear peaceful and relaxing, while others are more dramatic. Ponta Delgada has many magnificent buildings of tremendous architectural value portraying the urban architecture of the sixteenth to nineteenth centuries. The majority of these are presently used to accommodate various political, administrative, religious and cultural offices. There are several churches that are authentic works of art, with Gothic structures and Manueline exteriors. Others are in the baroque style, with interior embroideries in gold thread and rare wood pieces. Famous paintings are also easily found in Ponta Delgada.

The International Conference on Unconventional Computation (UC) series is devoted to all aspects of unconventional computation — theory as well as experiments and applications. (See https://www.cs.auckland.ac.nz/CDMTCS/conferences/uc/.) Typical, but not exclusive, topics are: natural computing including quantum, cellular, molecular, membrane, neural, and evolutionary computing, as well as chaos and dynamical system-based computing, and various proposals for computational mechanisms that go beyond the Turing model.

The first venue of the Unconventional Computation Conference (formerly called Unconventional Models of Computation) was Auckland, New Zealand in 1998. Subsequent sites of the conference were Brussels, Belgium in 2000, Kobe, Japan in 2002, Seville, Spain in 2005, York, UK in 2006, Kingston, Canada in 2007, and Vienna, Austria, in 2008. The proceedings of the previous UC conferences appeared as follows:

The eight keynote speakers at the 2009 conference were:

– Edwin Beggs (Swansea University): “Experimental Computation”
– Jarkko Kari (University of Turku): “Cellular Automata”
– Carlos Lourenço (University of Lisbon): “Brain Dynamics”
– James M. Nyce (Ball State University and Indiana School of Medicine): “Artifice, Interpretation and Nature: Key Categories in Radiology Work” (Action Event)
– Przemyslaw Prusinkiewicz (University of Calgary): “Developmental Computing”
– Lukáš Sekanina (Brno University of Technology): “Evolvable Hardware: From Successful Applications to Implications for the Theory of Computation”
– Philip Welch (University of Bristol): “Relativistic Computers and Transfinite Computation”

The conference also included three tutorials:

– Manuel Lameiras Campagnolo (Technical University of Lisbon): “Analogue Computation”
– James Crutchfield (University of California at Davis): “Computational Mechanics: Natural Computation and Self-Organization”
– Martin Davis (New York University and Visiting Scholar, Berkeley): “Diophantine Equations”

In a special lecture, Gabriela Queiroz, from the Volcanology and Geological Risks Evaluation Centre of University of Azores, spoke on “The Geology of the Island.” In this talk, the geological evolution of São Miguel Island was characterized in the context of the Azores geodynamic setting. The main active volcanic systems of the island were described, covering their eruptive history, volcanic hazard and historical eruptions.

In addition, UC 2009 hosted three workshops — one on “Hyper-computation” organized by Mike Stannett (University of Sheffield), one on “Novel Computing Substrates” organized by Andrew Adamatzky (University of the West of England, Bristol), and one on “Physics and Computation” organized by Olivier Bournez (École Polytechnique), and Gilles Dowek (École Polytechnique and INRIA).
The Program Committee consisting of Andrew Adamatzky (Bristol, UK), Selim G. Akl (Kingston, Canada), Masashi Aono (Tokyo, Japan), Edwin Beggs (Swansea, UK), Olivier Bournez (Paris, France), Mark Burgin (California, Los Angeles, USA), Cristian S. Calude (Auckland, New Zealand), Luca Cardelli (Cambridge, UK), S. Barry Cooper (Leeds, UK), José Félix Costa (Lisbon, Portugal and Swansea, UK, Co-chair), James Crutchfield (California, Davis, USA), Martin Davis (New York and Berkeley, USA), Nachum Dershowitz (Tel Aviv, Israel, Co-chair), Michael J. Dinneen (Auckland, New Zealand), Gilles Dowek (Paris, France), Rudolf Freund (Vienna, Austria), Dina Q. Goldin (Providence, USA), Masami Hagiya (Tokyo, Japan), Mark Hogarth (Cambridge, UK), Natasha Jonoska (Tampa, FL, USA), Lila Kari (London, Ontario, Canada), Julia Kempe (Tel Aviv, Israel), Yasser Omar (Lisbon, Portugal), Ferdinand Peper (Kobe, Japan), Mario J. Pérez-Jiménez (Seville, Spain), Petrus H. Potgieter (Pretoria, South Africa), Kai Salomaa (Kingston, Canada), Hava Siegelmann (Massachusetts, USA), Darko Stefanovic (Albuquerque, USA), Susan Stepney (York, UK), Christof Teuscher (Portland, USA), and Jon Timmis (York, UK), selected 18 papers (out of 40), 2 posters (out of 3), and 3 papers converted to posters to be presented as full-length talks.

The Program Committee is grateful for the highly appreciated work done by the additional reviewers, and for their help in improving the papers for this volume. These experts included: Jack Copeland, Felipe Cucker, Bo Cui, Michael Domaratzki, Emmanuel Hainry, Carlos Lourenço, Benoit Masson, Marius Nagy, Naya Nagy, Mark Olah, Shinnosuke Seki, Petr Sosik, Karl Svozil, Klaus Weihrauch, Damien Woods, and Martin Ziegler.

The Steering Committee of the International Conference on Unconventional Computation series comprised Thomas Bäck (Leiden, The Netherlands), Cristian S. Calude (Auckland, New Zealand, Co-chair), Lov K. Grover (Murray Hill, NJ, USA), Jan van Leeuwen (Utrecht, The Netherlands), Seth Lloyd (Cambridge, MA, USA), Gheorghe Păun (Bucharest, Romania), Tommaso Toffoli (Boston, MA, USA), Carme Torras (Barcelona, Spain), Grzegorz Rozenberg (Leiden, The Netherlands, Co-chair), and Arto Salomaa (Turku, Finland).

We extend our thanks to all members of the local Conference Organizing Committee, particularly to José Félix Costa (Chair) of the Technical University of Lisbon and Swansea University, and Elisabete Freire, Matthias Funk, Luís Mendes Gomes, and Hélia Guerra of the University of Azores for their invaluable organizational work.

The conference was partially supported by the University of Azores, Centro de Matemática e Aplicações Fundamentais of the University of Lisbon, the Regional Government of Azores, FLAD – Acordo Mobilidade Antero de Quental, Fundação para a Ciência e a Tecnologia (FCT), and Banco Internacional do Funchal (BANIF). We extend to all of them our deep gratitude.

It is a great pleasure to acknowledge the developers of the EasyChair system, and the fine cooperation with the Lecture Notes in Computer Science team of
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Springer which made possible the production of this volume in time for the conference.

Finally, we thank all the authors for the high quality of their contributions.

June 2009

Cristian S. Calude
José Félix Costa
Nachum Dershowitz
Elisabete Freire
Grzegorz Rozenberg
Geology of São Miguel Island

Introduction

São Miguel is the largest of the nine volcanic islands that constitute the Azores archipelago, located in the North Atlantic Ocean between 36° – 43° latitude north and 25° – 31° longitude west. The islands are situated in a complex geodynamic setting dominated by the interplay between Eurasian, African and American tectonic plates. Accordingly, main tectonic structures affecting the region are the Mid-Atlantic Ridge (MAR), which crosses the archipelago between the islands of Faial and Flores with a general N–S direction, the East Azores Fracture Zone, which extends E–W from the MAR to the Strait of Gibraltar, including the Gloria Fault, and the Terceira Rift [1], which, in a strict approach, trends NW–SE along a line defined by Graciosa, Terceira and São Miguel islands, and in a larger scale comprises, the WNW–ESE fracture systems of Faial, Pico and São Jorge islands.

Historical Volcanism and Seismicity

Despite some uncertainties about the exact date of the discovery, it is known that the Azores were settled by the Portuguese in the second quarter of the 15th century. Throughout more than 500 years of history, the region experienced about 27 volcanic eruptions and more than 20 strong earthquakes, due to this complex geodynamic environment. The initial reports of volcanic manifestations go back to the fifteenth century and are related to an eruption at Furnas Valley, at about the time of the São Miguel island settlement, sometime between 1439 and 1443 [2]. The last volcanic event with serious social-economic repercussions took place on the NW end of Faial Island, during 1957–1958, and gave rise to the Capelinhos Volcano [3]. More recently, a submarine eruption occurred about 10 km west of Terceira island, between 1998 and 2002 [4] with no direct consequences for the community. The Azores region is frequently affected by earthquakes, either linked to tectonic movements or related with volcanic activity. The first strong earthquake reported took place on October 22, 1522 and reached the maximum intensity of X (Modified Mercalli Scale, MM–56) on São Miguel Island [5, 6]. Vila Franca do Campo, the capital of the Azores at that time, was destroyed by the earthquake, and, subsequently, was buried by a large landslide produced by the collapse of an adjacent hill [7]. About 5,000 people died, houses were destroyed and all the existing infrastructures were disrupted. The most recent event with social-economic impact occurred on July 9, 1998 and reached a maximum intensity of VIII (MM–56) on Faial Island. It caused eight deaths and significant destruction in most of the rural villages, due to the fragility of the constructions and some recognized geological site effects.
São Miguel Geology

At present, about 250,000 people live in the Azores, the São Miguel island being the most populated, with approximately 132,000 inhabitants. The island has an area of about 745 km$^2$ and its highest point reaches 1,103 m at Pico da Vara, north of Povoação Caldera. Volcanic structures and the morphological expression of some fractures and scarp faults dominate the landscape in São Miguel. Also notorious are the erosion processes, particularly in the streamlines and sea cliffs. Six distinct volcanic regions can be defined in São Miguel island, which are from east to west (1) Nordeste/Povoação Volcanic Region, (2) Furnas Central Volcano, (3) Achada das Furnas Volcanic System, (4) Fogo Central Volcano, (5) Picos Region Volcanic System, and (6) Sete Cidades Central Volcano (Fig. 1).

![Fig. 1. Location of the different volcanic systems in São Miguel island](image)

The Nordeste/Povoação Volcanic Region comprises the thick sequences of lava flows of the Nordeste region and the Povoação Caldera. With about 4 million years [8], the oldest volcanic structures and deposits in the island can be observed at this region. The landscape shows deep valleys resultant from erosion processes. At the southeastern part of the area the Povoação Caldera is a volcanic depression with 6 km × 8 km across and walls as high as 700 m. The Povoação Volcano is considered to be extinct and its surface is mantled by deposits originating mainly in the adjacent Furnas Volcano. Furnas, Fogo and Sete Cidades are the three active central volcanoes in São Miguel. They have recent eruptive histories marked by a predominance of explosive activity and all of them developed summit calderas that are now partially occupied by lakes. Unlike the other two, Furnas does not have a well-defined edifice, but consists of a steep-sided caldera complex 7 km × 4.5 km across (Fig. 2). The eruptive history at Furnas appears to have been essentially explosive, producing thick deposits of pumice, and registering at least two
major caldera collapses [9]. There have been 10 recognized eruptions over the last 5,000 years, of which two occurred in historical times, the first, as previously mentioned, in 1439 – 1443 AD and the second in 1630 AD. During the latter about 100 people lost their lives due to the formation of pyroclastic surges [10]. Moreover, pumice and ash covered almost the entire island, reaching as far as Santa Maria island about 80 km to the south.

Fig. 2. View of Furnas Caldera in the area of the village. The hill present at the top of the picture is the eastern wall of Povoação Caldera.

Fogo is a central volcano formed by a series of hills, with the summit truncated by a depression with a diameter of about 3 km, partially occupied by the Fogo Lake (Fig.3). The main edifice was built by the accumulation of lava flows, domes and pyroclasts. One major caldera-forming eruption was recognized between 46,500 and 26,500 years ago [11]. In the last 5,000 years 7 explosive eruptions marked the activity of this volcano, including the historical event of 1563 AD originating inside the caldera, which produced ash deposits that mantled the eastern part of the island.

Sete Cidades is the westernmost central volcano of the island. It has an approximately circular summit caldera of about 5 km diameter partly occupied by two connecting lakes — Lagoa Azul and Lagoa Verde, and several secondary pumice cones and tuff cones (Fig. 4). The oldest dated rocks revealed more than 200,000 years of age. The actual caldera is interpreted as been formed in three main phases as a result of three paroxysmal eruptions at about 36,000 years, 29,000 years and 16,000 years ago [12]. In the last 5,000 years at least 17 intracaldera eruptions occurred, the latest of which formed the Caldeira Seca.
Fig. 3. Partial view of Fogo Caldera and Fogo lake

Fig. 4. View of Sete Cidades Volcano with Azul and Verde lakes and the caldera steep northern wall
cone, some 700 years ago [13]. The recent eruptive history of Sete Cidades makes it one of the most active volcanoes of the Azores.

The two volcanic systems of the Achada das Furnas and Picos Region occupy the area between Furnas and Fogo volcanoes and Fogo and Sete Cidades volcanoes, respectively. Achada das Furnas is a relatively flat region with dispersed cinder cones. The smooth landscape is made up of lava flows intercalated with scoria deposits from the closest cinder cones and pumice layers from the adjacent central volcanoes. The Volcanic System of the Picos Region is dominated by the presence of numerous alignments of cinder cones. From these eruptive centers were several lava flows produced and built large low-slope surfaces which extend toward the north and south seashores. This volcanic system is strongly affected by a fault system, trending NW–SE, clearly made evident by the spatial distribution of the eruptive centers and the direction of important eruptive fissures [14]. In this region historical eruptions occurred (1) in 1563, on Pico do Sapateiro, three days after the explosion centered inside Fogo’s caldera, and (2) in 1652, on Pico do Fogo, in three eruptive vents aligned along a NW–SE fracture.

![Fig. 5. Asmodeu fumarole in Furnas village](image)

**Hydrothermal Activity**

The current normal levels of volcanic activity in São Miguel are displayed in several fumarolic fields, hot springs and extensive soil degassing, particularly well expressed in some areas of Furnas and Fogo volcanoes. In general, the
fumaroles present temperatures close to the boiling point of the fluids and their compositions are CO$_2$ dominated (Fig. 5).

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Using Physical Experiments as Oracles

Edwin J. Beggs

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In my talk I will consider how a digital computer (a Turing machine for the sake of being definite) could communicate with the physical world. Turing himself gave a mythological name to an external source of information for a computer - an oracle. We shall consider how a physical experiment can be used to function as an oracle for a computer - a physical oracle. Thought experiments can be constructed using various physical theories, and we will examine their properties when used as oracles. The fundamental ideas we have to introduce into oracles for this are the time taken to perform the experiment, and the possibility of error in the answer.

On the side of the Turing machine, we ask what such an augmented machine can compute. To do this we consider the established area of nonuniform complexity, and how physical oracles act as advice functions. We can also look at the occurrence of error in the physical experiment, and show how this can also be expressed in terms of nonuniform complexity classes.

The time taken to perform an experiment can be unpredictable. If we consider how to get round this by implementing timers on the experiments we see that there are unexpected consequences for our ability to measure physical quantities.

On the side of physical theory, we ask whether there are limits on how much (or rather how quickly) information can be read from an experiment. This translates into the question of the trade off between the accuracy of an experiment and the time it takes to perform. By considering various experiments with various degrees of ‘realism’ we can suggest a common form of lower bound on the time taken to obtain a required accuracy.

Finally we can put the ideas of nonuniform complexity together with our proposed lower bound on the time for an experiment to formulate a conjecture on the upper bound of what a Turing machine connected to a physical oracle can compute in polynomial time - the class BPP//log*.

Joint work with John Tucker and Jose Felix Costa.
The best known programmable analog computing device is the differential analyser. The concept for the device dates back to Lord Kelvin and his brother James Thomson in 1876, and was constructed in 1932 at MIT under the supervision of Vannevar Bush. The MIT differential analyser used wheel-and-disk mechanical integrators and was able to solve sixth-order differential equations. During the 1930’s, more powerful differential analysers were built. In 1941 Claude Shannon showed that given a sufficient numbers of integrators the machines could, in theory, precisely generate the solutions of all differentially algebraic equations. Shannon’s mathematical model of the differential analyser is known as the GPAC.

Graça and Costa improved the GPAC model and showed that all of the interesting functions it can define are solutions of polynomial differential equations. From the point of view of computability two natural questions arise: Are all those functions computable? Are all computable functions definable by a GPAC? To answer those questions one has to agree upon a notion of computability of real functions. We will use Computable Analysis, which is a model of computation based on type-2 Turing machines. Roughly, a function $f$ is considered computable if from a sequence that converges rapidly to $x$ the machine can compute in discrete steps a sequence that converges rapidly to $f(x)$. Computable analysis is an effective model of computation over the real numbers and it cannot use real numbers with infinite precision.

In this tutorial, we consider that analog models of computation handle real numbers represented exactly rather than by strings of digits. We also consider that the state of the model evolves in a continuum. The GPAC, other continuous dynamical systems, and more general real recursive functions fit into that framework and will also be addressed.

A series of papers from Bournez, Campagnolo, Hainry, Graça and Ojakian establish equivalences between several analog models and Computable Analysis, showing that in that sense digital and analog computation are ultimately not too far apart. In the tutorial a unified view of those results will be provided, using a technique called “approximation”. If two classes approximate each other sufficiently, we can derive an equality using the notion of limit which is implicit in Computable Analysis.

In short, the goal of this tutorial is to relate various computational models over the reals, using the notion of approximation as a unifying tool and language.
Abstract. The tutorial explores how nature’s structure reflects how nature computes. It reviews intrinsic unpredictability (deterministic chaos) and the emergence of structure (self-organization) in natural complex systems. Using statistical mechanics, information theory, and computation theory, it develops a systematic framework for analyzing processes in terms of their causal architecture. This is determined by answering three questions: (i) How much historical information does a process store? (ii) In what architecture is that information stored? And (iii) how is the stored information used to produce future behavior? The answers to these questions tell one how a system intrinsically computes.

Readings. For the tutorial, see the articles, going from less to more technical (that is, the recommended reading order):

1. Is Anything Ever New? Considering Emergence
2. Regularities Unseen, Randomness Observed: Levels of Entropy Convergence
   http://cse.ucdavis.edu/~cmg/compmech/pubs/ruro.htm
3. The Calculi of Emergence: Computation, Dynamics, and Induction
   http://cse.ucdavis.edu/~cmg/compmech/pubs/cmppss.htm
5. The Organization of Intrinsic Computation: Complexity-Entropy Diagrams and the Diversity of Natural Information Processing
   http://cse.ucdavis.edu/~cmg/compmech/pubs/oic.htm
6. Structure or Noise?
   http://cse.ucdavis.edu/~cmg/compmech/pubs/son.htm
Diophantine Equations and Computation

A Tutorial

Martin Davis

Unless otherwise stated, we'll work with the natural numbers:

\[ N = \{0, 1, 2, 3, \ldots \} \]

Consider a Diophantine equation \( F(a_1, a_2, \ldots, a_n, x_1, x_2, \ldots, x_m) = 0 \) with parameters \( a_1, a_2, \ldots, a_n \) and unknowns \( x_1, x_2, \ldots, x_m \). For such a given equation, it is usual to ask: For which values of the parameters does the equation have a solution in the unknowns? In other words, find the set:

\[ \{ \langle a_1, \ldots, a_n \rangle \mid \exists x_1, \ldots, x_m [F(a_1, \ldots, x_1, \ldots) = 0] \} \]

Inverting this, we think of the equation \( F = 0 \) furnishing a definition of this set, and we distinguish three classes:

- A set is called Diophantine if it has such a definition in which \( F \) is a polynomial with integer coefficients. We write \( \mathcal{D} \) for the class of Diophantine sets.
- A set is called exponential Diophantine if it has such a definition in which \( F \) is an exponential polynomial with integer coefficients. We write \( \mathcal{E} \) for the class of exponential Diophantine sets.
- A set is called recursively enumerable (or listable) if it has such a definition in which \( F \) is a computable function. We write \( \mathcal{R} \) for the class of recursively enumerable sets.

Evidently: \( \mathcal{D} \subseteq \mathcal{E} \subseteq \mathcal{R} \). Remarkably, the converse inclusions hold as well so that \( \mathcal{R} = \mathcal{D} \). This connection between Diophantine equations and computation has many interesting applications. In particular it is a consequence that there is no algorithmic solution to the tenth problem in Hilbert’s famous list, in which he had asked for such an algorithm to determine whether a given polynomial Diophantine equation has a solution. In addition it has led to Diophantine forms of various famous problems, to a prime-representing polynomial, and to a Diophantine form of Gödel’s incompleteness theorem.

A key step in the proof was finding a Diophantine definition of the exponential function

\[ \{ \langle a, b, c \rangle \mid c = a^b \} \]

since that implies \( \mathcal{D} = \mathcal{E} \). Julia Robinson initiated this effort making use of the Pell equation

\[ x^2 - (a^2 - 1)y^2 = 1 \]

to show that such a Diophantine definition could be found if there is a Diophantine set \( J \) of pairs \( \langle a, b \rangle \) such that \( b \leq a^a \) for all \( \langle a, b \rangle \in J \) while for every
there are pairs \( <a, b> \in J \) for which \( b > a^k \). Using the Fibonacci numbers, Yuri Matiyasevich found such a set \( J \) two decades after Robinson has begun her efforts. A decade earlier Hilary Putnam, Julia Robinson and the author had proved that \( R = E \), so Matiyasevich’s work completed the proof.
Structure of Reversible Cellular Automata

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Abstract. Cellular automata are examples of discrete complex systems where non-trivial global behavior emerges from the local interaction of trivial components. Cellular automata have been studied, among other perspectives, as models of massively parallel computation tightly connected to the microscopic physics. Physics is time reversible and satisfies various conservation laws, and by a careful design these properties can be implemented in cellular automata as well. The concept of time reversibility is important in this context, as irreversible logical operations such as AND and OR are "wasteful" and necessarily lead to dissipation of energy. It is well known that simple cellular automata rules can be computationally universal, and universal cellular automata exist even under the additional constraints of reversibility and conservation laws.

In this talk we discuss computational universality in (reversible) cellular automata and the connection to reversible logic. We demonstrate how any globally reversible one-dimensional cellular automaton can be implemented using locally reversible logical gates. Analogous result is true also among two-dimensional cellular automata, while in higher dimensions the question is open. Note that locally reversible cellular automata are the classical counterpart part of quantum cellular automata, which can be most conveniently defined as infinite, regular arrays of locally unitary operators. Many of the structure results concerning reversible cellular automata can then be naturally extended to hold for the quantum cellular automata as well.
Brain Dynamics Promotes Function

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Abstract. Dynamical structure in the brain promotes biological function. Natural scientists look for correlations between measured electrical signals and behavior or mental states. Computational scientists have new opportunities to receive ‘algorithmic’ inspiration from brain processes and propose computational paradigms. Thus a tradition which dates back to the 1940s with neural nets research is renewed. Real processes in the brain are ‘complex’ and withstand trivial descriptions. However, dynamical complexity need not be at odds with a computational description of the phenomena and with the inspiration for algorithms that actually compute something in an engineering sense. We engage this complexity from a computational viewpoint, not excluding dynamical regimes that a number of authors are willing to label as chaos. The key question is: what may we be missing computation-wise if we overlook brain dynamics? At this point in brain research, we are happy if we can at least provide a partial answer.

Keywords: Brain dynamics, spatiotemporal dynamics, chaos, computation.

1 Natural Computing

Natural computing is regarded as belonging to two strands: computation taking place in nature and human-designed computation inspired by nature [1]. Our work takes the understanding of the former as a starting point, and aims to contribute to the latter by proposing abstractions leading to computing paradigms or actual analog devices.

2 Natural Neurons and Artificial Neural Networks

Classical neural nets research has emphasized the structure and the role of the individual neuron, either through trying to infer the formal function that would be best approximated by a given biological neuron, or through using synaptic adaptation as inspiration for automatic learning procedures in computation [2].
This lead to a bottom-up engineering approach, and quite naturally to initial examples of emergent behavior in artificial networks. Such emergence or self-organization is most evident in recurrent networks, which are believed to mimic the structure of the biological brain better than non-recurrent ones.

3 Dynamics

Despite researchers having studied processes involving neural populations, the dynamical aspects thereof have been viewed as somewhat secondary in artificial computation. The dynamics has mainly consisted in periodic cycles of synchronized populations, or in transients to equilibrium states. A modern stream of research goes one step further by considering the so-called dynamical complexity as revealed e.g. by the measurement of the brain’s electrical activity [3,5,6,7,8]. Inspired by such experiments with the biological brain, our own work and that of others tries to assess the computational role of the brain’s complex dynamics, as well as to obtain inspiration for possible artificial computing paradigms. In this extended abstract we refer the reader e.g. to Refs. [9,10,11] and references therein. Here we briefly point out a few interpretations of the so-called dynamical state of the brain, providing as many implementation ideas for the computer scientist. The definition of dynamical state is left somewhat open. The approach evolves from viewing dynamics as a tag, up to viewing it as a structural explanation or a functional necessity.

The Dynamical State Is a Label

Under this ‘passive’ view, the dynamical state labels what the animal is able to process at a given time, which can be related to anticipation or predisposition. It can also label whatever the animal is already computing in a broad sense. Either way, the observed dynamics is regarded as an epiphenomenon, secondary to some other, deeper, process which is taking place and which is what really matters in terms of computation.

The Dynamical State Is a Substrate

Freeman and co-workers [12] have identified amplitude and phase modulation patterns over a spatiotemporal wave of electrical activity in the animal’s brain. The underlying wave is a so-called carrier wave. The identified modulation patterns convey meaning, e.g., by identifying particular odors that are being sensed.

The Dynamical State Modulates Attention

With enough control available, a seemingly complex dynamics—or mixture of dynamical regimes—can be driven into a particular state, which is specialized in a processing task, or class of tasks. In biological terms, we would say that the animal (or the bio-inspired device) is ‘attentive’ to input data with certain characteristics [9].
The Dynamical State Provides an Operator for Input Data

Input data can itself generally be described as a function of time and space. Several scenarios can be envisaged whereby external input data perturbs an internal dynamical state \[9\text{][10][11]. The way in which the internal state is perturbed depends on its own details and on details of the input data.

The Dynamical State Is the Output of a Computation

Traditionally, the concept of computation implies that some output is read out. An observed dynamics can constitute such a readout, or ‘result’ of the computation. Output functions need not be as complicated as full spatiotemporal waves of activity, and the reduction of complexity can happen at several levels \[9\].

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References

Awakening the Analogue Computer: Rubel’s Extended Analog Computer Workshop

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Shannon’s General Purpose Analog Computer (GPAC) was unable to directly solve many problems that Lee A. Rubel believed were critical to implement the functions of the human brain. In response Rubel defined the Extended Analog Computer (EAC) in 1993, which was able to directly compute partial differential equations, solve the inverse of functions and implement spatial continuity, among other operations.

Rubel believed that the EAC was an ideal machine, never capable of being built physically. However, research has shown that close approximations to the EAC can be constructed whose functionality is partially contained in the physical structure (implicit computation via the laws of nature), partially contained in the configuration chosen for the material and its energy budget (explicit in the physical computer’s structure) and partially, and finally, completed by analogies defined between the EAC and the problem it solves.

This tri-partite solution to problems using the EAC represents a new paradigm for computing, and one that is foreign to most first-time users. During Unconventional Computing 2009 attendees at this workshop will be given a tutorial pamphlet to learn about the EAC, then have the opportunity to conduct experiments on physical EACs available at the conference. They will also learn techniques for the design of “smart matter,” that is, applications that run on the EAC supercomputer simulator available at Indiana University.

“Smart matter” as implemented with the EAC is a configuration that is reflexive, limitedly self-aware and self-modifying, and that runs on the large-array hybrid supercomputer simulator sEAC (in the future, our goal is to build a VLSI sEAC supercomputer). A large-array sEAC configuration resembles a proprioceptic cellular automaton that can be configured to solve problems such as protein folding, graph reduction and data mining, among many others. Expressed as a general analogy, smart matter is a kind of “computronium” that allows its users, by a tongue-in-cheek definition of new “elements,” to think of their applications as “Proteinium,” “NP-Celium,” “Dataminium,” and other varieties of designed materials.

Techniques for designing smart matter will be presented in the workshop, at a plenary talk at the conference and in Professor Andrew Adamatzky’s session on Novel Computing Substrates.
Artifice, Interpretation and Nature: Key Categories in Radiology Work

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Abstract. This paper extends on some prior work on nature, culture and computation. This paper will look at “image work” in a radiology department, i.e., how radiologists use images and other kinds of knowledge in daily clinical work. In particular, the paper will look at the role tacit knowledge and categories have in the work radiologists carry out. How radiologists make use of and contrast analog and digital representations of nature will be explored here because this is key to how radiologists work and think. In other words, the role that computer derived artifacts, correspondence theory and mimesis play in the clinical work of radiology will be discussed.

Keywords: Representation, Memesis, Correspondence theory, Analog computation, Radiology.

There has been some discussion of how radiologists have learned over time to translate images into medical findings. Pasveer talks about this process as though radiologists “lived in a world of shadows, [which] they had to make relevant to those who were supposed to need it” (1). There has been more research done on those changes in technology, work, and organizational forms that have led to and made radiology part of modern medicine. What this literature has tended to ignore the epistemological and ontological issues regarding representation in radiology and medicine more generally (2). Even though for example radiology is in the midst of a transition from analog to digital images and technology, these higher order issues have received little attention (3).

What has been noted is that there has been some “resistance” on the part of radiologists to the introduction and use of digital, networked PAC ([digital] Picture Archiving and Communication) platforms. PAC vendors have responded to these user complaints with “screen level” solutions, e.g., new desktop tools. Vendors have also provided a variety of hardware/software updates.

Given that the specialty’s history is characterized by the quick uptake of (and innovation with) a variety of technologies, it seems unwise to dismiss their responses to PACs as either some kind of “off the wall” (inexplicable) or as a resurgent Ludditism. Further, when looked at closely, the radiologists’ objections to PACs have little to do with what usually in computer science falls under the rubric of “useability”.

Before we go on however, we have to say a few things about the word “digital”. What this term means here is not limited to the more technical meaning related to how