Paolo Grigolini and 50 Years of Statistical Physics

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Edited by

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Preface

Over the past half century Professor Paolo Grigolini has been at the frontier of statistical physics, developing new techniques and making applications that have grown into independent areas of investigation. These include finite dynamic complex networks that undergo phase transitions, which were used to model complex social and biological phenomena that in turn led to proving that networks of comparable complexity transfer information most efficiently. This result alone has led to remarkable applications in the area of rehabilitation. He has used the fractional calculus to model dynamic systems with non-local spatial interactions as well as those dependent on long-term memory. Professor Grigolini has contributed significantly to several fields of theoretical physics, from modern quantum mechanics to protein folding and neuroscience.

The impact of Paolo on modern statistical physics is hard to overstate. Since his early work combining statistical physics with quantum mechanics to his present involvement in understanding human consciousness, he has always looked for the most elegant and satisfactory answer to some of the most challenging questions in the field. Unsurprisingly, his most notable work has revolved around the theory of complexity and its application to a wide variety of interesting and important scientific issues. For example, a complex network is a mix of crucial and non-crucial events, with very different statistical properties. In fact, one can argue that Paolo has been a pioneer in a new view of the complexity that assumes the underlying physics is dominated by the statistical properties of crucial events generated by the critical dynamics of complex networks. It is the crucial events that determine the efficiency of information exchange between complex networks. For a large class of complex networks crucial events determine catastrophic failure - from heart attacks to stock market crashes. The phenomena in which he is interested are not the arcane events that we only encounter fleetingly but are those events which dominate our lives.

Just as impressive is Paolo's contribution to the development of generations of successful scientists, which in our opinion is impossible to overstate. There are very few outstanding scientists who have in addition to their technical ability the complimentary skill of mentor ship. Whether one was/is a student of his or a collaborator, everyone who has contributed to this book, as well as the scores of pupils and coauthors, can attest to the impact Paolo has had on their careers. We attribute this success to a number of factors.

First and foremost, Paolo brings to his mentoring the typical warmth of his Italian origins, which permeates every conversation, both social and professional, and makes him a truly likable person. For example, it is only after an extended technical discussion with him that one would realize what happened was something that with anyone else would have been an argument.

Secondly, Paolo is not shy about teaching his craft. Whether it is through painstaking sessions at the whiteboard or scheduled as well as improvised video-conference meetings, he is always excited to explain in detail his calculation, thinking, and speculations on where this or that partially formed idea might lead. His willingness to explore new ideas and develop hypotheses for testing is, in our opinion, what makes him such an attractive collaborator and a great friend. It certainly keeps his thinking on the cutting edge.

Last but not least he deeply cares for his students, whom he treats as an extended part of his family. Whether through extended periods of mentoring or during lunch breaks, he makes sure his students possess a working level of any and every part of their collaborations. In this way he is never reluctant to have his students take credit or be first author on joint publications, much like a bird pushing their progeny from the nest for their maiden flight. It is telling that every new discovery is immediately labeled with the name of the student. It becomes, forever and for everyone else, the "[student name] algorithm" or the "[student name] discovery" or the "[student name] calculation".

We hope that those who read this Festschrift and have not had the pleasure of knowing Paolo will be able to sense not just the respect and admiration we have for Professor Grigolini the scientist, but the warmth and friendship we have for Paolo the man. We hope you gain as much satisfaction in reading these contributions as we have had in putting them together.

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and
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Chapter 1

Paolo's Many Dimensions

by B.J. West

1.1 Motivation

The thought of how to begin a Festschrift for my good friend and colleague of over forty years, Paolo Grigolini, has been fermenting in the back of my brain for months. I wanted my remarks to be fitting to the subject, words that might even capture something of what it is like to work with Paolo. It was in considering the mismatch between my talents and the scope of what I wanted to achieve that I had my epiphany.

Most essays lauding the science people have done have remarkably little to say regarding the personalities of the scientists doing the work. These writings typically overlook the fact that science is a social activity and even those choosing the legendary solitude of Sir Isaac Newton, may act to claim priority, put in a good word for friends and some even undermine the aspirations of competitors. But documenting the all too human frailties of scientists is not my intention, besides, such documentation would require volumes for its completion. My more modest aim is to formulate and apply a taxonomy of the scientific personality types I have encountered over a fifty year career of doing contract research in the private sector, as a university professor and as a senior scientist working for the government. But to avoid the solemnity that such pontificating so often produces I have categorized these personality types into Sleepers, Keepers, Leapers, Creepers and Reapers.

I thought it would be interesting and fun to see how well I can position Paolo in such a five dimensional space. I know that those reading this essay will have an irresistible urge to locate both their scientific collaborators and competitors within this five dimensional hypercube, but I urge them to refrain from doing so until they have read the entire essay.

1.2 The Dimensions

The five dimensions of scientific personality types itemized in the taxonomy do not capture the full complexity of what it is to be listed within a given category, however. In order to make both the positive and negative aspects of belonging to a particular category visible I have drawn on my own experience to flesh out these dimensions and give them life. But enough of prologue, let us begin where the majority of non-scientists meet anyone with a science background and that is by interacting with a Sleeper.

Sleepers are individuals that have been trained in one or more of the sciences, but for a variety of reasons have abandoned actively contributing to new scientific knowledge, which is to say they no longer apply the scientific method to generate new knowledge. They often find satisfaction in teaching, the passing along of what they and others have learned to the next generation. Although they themselves no longer participate in research that produces new knowledge, as teachers they organize, categorize and put into a logical framework the rather disordered research contributions that others continue to make. Some who have not been gifted with the teaching gene elected to pursue the bureaucratic route of science administration along the academic line of becoming Department Chair, then Dean and so on. The right person in a sensitive position at the proper moment in history can make a tremendous difference in the future direction of science. One such person was V. Bush who was the founding Director of the *Office of Scientific Research and Development* at the entry of the United States into the Second World War, and who through his report [1] is considered by many to be the ideological architect of postwar science policy.

Those wanting to be closer to the research action may choose the path of scientific program manager (PM) in a government funding agency. A PM can guide the future direction of various areas of science through investing modest resources in research proposed to them by scientists from across the globe. In addition there are multiple levels of scientific editors for journals, which is another way to modulate science and promote or de-emphasize a scientific thematic area. There are probably a great many more in the category of research kibitzers that stand on the sidelines, interjecting advice and offering unsolicited council, than there are those that actually do the research.

Of all the areas of science from which a scientist may choose to continue working once they have decided to stop doing research, in my opinion, teaching is probably the most important. In keeping with this belief let me comment on a teacher I had in my first upper level course in physics, that being analytic mechanics.

Mechanics is one of the fundamental areas of physics and its purpose is to describe the motion of material bodies using Newton's laws. I was taught mechanics by Mr. Johnson (I never knew his first name); a person who would never achieve fame or fortune in science, but who loved to teach the formalism. There was something about capturing the physical world and the way things moved in a maze of symbols, which gave him deep satisfaction. Although he could not personally extend the formalism that others had developed he was an integral part of that knowledge chain. Mr. Johnson could appreciate the formal elegance of the mathematical infrastructure and passed along a sense of detailed wonder that came out of the pristine beauty of logical necessity. From the equations of motion, to the solution of a specific problem; the understanding of why a racetrack is banked on one side, to knowing how a parachute works; were wonders he shared with us. Mr. Johnson was not charismatic, in fact, one might say he was aloof. He was balding, always in a white shirt, dark tie and blue suit with chalk on his sleeves and he almost never smiled. But he loved to talk about physics, not to make it simple or even understandable, just to share it with the class (there were eight of us). No critique of Hamlet, no discussion of Socrates, no dissection of Tennessee Williams, ever matched the warmth Mr. Johnson radiated when he discussed the equations of a swinging pendulum or the motion of a spinning top. The Sleepers in science that teach novitiates are neither irrelevant nor unimportant, they prepare the next generation of scientists and when they do it well, it is like poetry, particularly when it is done with tenderness and affection as it was in the case of Mr. Johnson.

Paolo has this gift of warmingly and often excitedly sharing the physics he has been part of developing over his half century career with his students and collaborators alike. When I accepted the position of Chair of the Physics Department at the University of North Texas (UNT) in 1989, one of the conditions I insisted on was being able to name a person of my choice as a tenured full professor. Naming Paolo to that position was the smartest decision I made in my role as a academician. He has a natural curiosity that has helped him avoid the seductive trap of resting on his laurels. At the time I was transitioning from the private sector to the academic post at UNT my research interest was in the quantum manifestations of chaos and although Paolo had not, up to that time, published any work in that area I knew from his background in statistical physics and his research flexibility that we could do some interesting work together, which of course we did.

Many if not most tenure-track scientists display a marked reduction in quantity, if not quality, of their research output once tenure has been attained. But not Paolo. Of course coming into UNT with tenure he only had to concentrate on his students, research and funding without the distraction of pleasing the arbitrary goals of departmental politics. I had not thought about it, but he also opened up a steady stream of international graduate students from the University of Pizza who wanted to obtain their advanced degrees under his guidance. This lead to an average of three new top level graduate students per year coming into the department for the decade I was at UNT, and producing an outpouring of research publications in the nascent field of 'quantum chaos'. As a Professor Paolo was, and continues to be, one of those rarest of individuals that weaves his research into whatever course he is teaching and thereby makes it current and brings it to life.

Keepers are those researchers that refine, redo and carry out experiments that add to the next significant figure in the fine structure constant or the gravitational constant. On the theoretical side these investigators establish new proofs or new physical models of well-understood phenomena. As a group these scientists put forward all the objections to new theories and explain in extraordinary detail why this particular experiment is wrong or that proof is flawed. These are the maintainers of consistency, searching for the internal contradictions in theories and experimental results; these are the keepers of the status quo.

A Keeper's demand for consistency has a downside which goes by many names. A particularly recent name is a *contemporary pathology of science* [2], which suggests that "previous knowledge" drastically limits innovative thinking in science. These authors believe that true innovation suffers from a too tight embrace with a too big and too flexible corpus of previous knowledge. In some respects a Keeper appears to be the least agreeable of the psychological types, because this is the person who points out your misuse of a term and seems to enjoy finding other people's errors.

On the other hand, Keepers perform a valuable function in science. Forty odd years ago I had a colleague who read one of the more prestigious physics journals in which the maximum number of pages a paper could have was four. He would read this journal each week with an eye to finding errors. When he did find a mistake, he would write a letter to the editor pointing out the error and indicating how to correct it. The errors he sought were the misapplications of theory, logical inconsistencies, and subtle mistakes in mathematics. The mistakes he found were not trivial and the corrections were not easy to make, so my colleague was performing a useful, if difficult, service. But he was neither tactful nor apologetic in what he did, so that although he was smart and did good physics, he had few friends and was not well liked. Unfortunately at some point he had become stuck in this one mode of doing science.

This is in complete contrast to Paolo. For example, we have a mutual friend whose career has been narrowly focused on doing statistical physics using a particular formalism that Paolo adhered to at one time but now no longer believes to be the proper approach to understanding a given class of physical phenomena. Our friend knows that Paolo disagrees with him on this generic issue and after a number of pointed discussions over the years they have tacitly agreed not to discuss it any more. Rather than criticize his friend, Paolo continues to write papers in which the theoretical differences between the two perspectives are plainly stated in the context of newly emerging applications [281].

In fact, it is through the Keeper mode of thinking that Paolo continues to question his own work, sometimes to the consternation of his collaborators. For Paolo is about the process of doing science and not about the attaining of any particular result.

Consider the issue of irreversibility in quantum phenomena, about which he wrote a unique book [6]. The book examined the then current approaches to irreversibility, in classical and quantum physics, and shows that an objective theory of irreversibility did not exist, and that all the then current theories of irreversibility share with quantum mechanics elements of subjectivity, making crucial the role played by the observer. In addition to the traditional quantum mechanical paradoxes, concerning the quantum theory of measurement, the book also discusses the difficulties that the physics of chaos was/is causing and suggests that Boltzmann's dream of healing the fracture between mechanical dynamics and thermodynamics might, cannot be realized within the framework of the current physics, and that the establishment of a new physics is necessary for that ambitious purpose to be achieved. It is also worth pointing out that this book was based on his lecture notes from his quantum mechanics course. The point here is that even when functioning as a Keeper or a Sleeper Paolo cannot help making original scientific contributions.

Leapers are the type of scientist defined in myth, those individuals that against all odds and popular scientific belief create the new laws, have the penetrating insights that change a discipline forever, who function as magicians completely outside the circumscribed rules of science. The mathematical physicist Mark Kac, once remarked in talking about such scientists as Sir Isaac Newton and the Noble Laureate Richard Feynman, that they were magicians. He explained that we could do what a genius did if only we were a lot smarter. However, Kac maintained that it was not clear how we could ever do what a magician does. These scientists make connections within and among phenomena in ways that logic cannot readily follow and that often take Creepers many years to reliably test. They are the adventurous spirits who leap to conclusions that solve difficult physics problems, or leap across disciplines taking an insight from one discipline to make a remarkable but unfounded contribution in another discipline.

Paolo functioned as a Leaper and brought a number of us along with him in our introducing the complexity matching effect (CME) [280], wherein we hypothesized that the maximum information exchanged between two complex dynamic network is achieved when the complexity of the two networks is the same. He hosted and guided a number of graduate students in proving a modified form of this hypothesis both analytically and computationally over the next few years and we wrote a book synthesizing that work and put it into a larger formal context [4]. This was followed by the application of CME to arm-in-arm walking, turn-taking in conversation, as well as in multiple other disciplines across the scientific community, as subsequently discussed in more detail.

Creepers are the worker bees of science research. They are the investigators that take us from what is presently known, to what has been hypothesized, conjectured, and/or predicted, but in any event is not yet established. Creepers carry out the systematic investigations that build out and away from our present understanding to what has been guessed, divined or postulated through intuition and/or the extrapolation of theory. These are the experimenters and theoreticians that fill in the blank spaces on the landscape at the frontiers of science, the mapmakers that show us how to creep (cautiously make our way) from one oasis of knowledge to the next and in doing so make permanent the contributions of all the other scientists.

Creepers are brilliant people. They do not have the magic of the Leapers, but they build the infrastructure that enables the rest of us to understand the science revealed through the magic. I mentioned Mark Kac and his remark about some scientists being magicians and others only being very clever. Mark retired from Rockefeller University in the middle 1980s and took a position at the University of Southern California. Once a week he would fly down to San Diego and visit the La Jolla Institute, where I was Associate Director. Since I lived nearest the airport it fell to me to pick him up and take him to La Jolla, which I did with pleasure.

Mark was a short, round man, with a white fringe around his shining cranium. He had a perpetual smile on his face and was always on the verge of laughing, particularly about some problem in science. He remarked more than once that his entire career had been focused on understanding what we mean by statistical independence. One of his remarkable papers, frequently quoted after three-quarters of a century is: “Can you hear the shape of a drum?” He was a physicist/mathematician who pursued new problems the way some people go after a good meal, with appetite and good fellowship. The intellectual connections he made in statistical physics and quantum mechanics are continually being rediscovered by each new generation of physicists. He avoided the fashionable and modern, preferring to stay with the fundamental. He thought about such things as the central limit theorem, how it is violated and what the implications of such violations might be. His eyes would dance when he talked about the distribution of eigenvalues in quantum mechanical systems, but no more than when he talked about music or art, or a good book he had just read.

In writing these remarks about Creepers it became clear to me that Mark and Paolo are cut from the same cloth. For the rest of us a large part of the pleasure in doing science is derived from sharing our insight with such people. Those who opinions we respect and who we know will be able to appreciate our contributions to their work. Thus, it is an ongoing pleasure to collaborate with Paolo.

Reapers are those scientists that seem to acquire, sometimes earned and sometimes not, all the accolades and recognition afforded a specific scientific discovery or theoretical insight. It is very often not the originator of a scientific theory, nor the first to perform an extraordinary experiment, who is recognized for their original contribution. It is often the last person to coherently discuss a new phenomenon, not the first, who is credited with its understanding. This does not imply any deception on the part of the beneficiary, although that does occasionally happen, but merely points out one of the foibles of being human. We prefer to give the credit for an idea, discovery or scientific breakthrough to a single individual rather than to a group or to a sequence of individuals, and the most recent is usually the most obvious recipient of our attention.

Einstein functioned as a creeper in his five papers on the nature of physical diffusion. While it is true that his 1905 work on diffusion is completely original, this work was not the first to accurately describe diffusive phenomena. A French physicist named Bachelier, a student of Poincaré, published a paper in 1900 on the diffusion of profit in the French stock market. Bachelier developed the same equations and found the same solutions to those equations, as did Einstein five years later. Consequently Einstein was a reaper with regard to recognition that, one could argue, should have more properly gone to another. It is not that Einstein sought such recognition, it was thrust on him and as a consequence it was denied to others. But in an even greater sense naming diffusion Brownian motion ascribes to Robert Brown much more than he would have willingly accepted, particularly since he was not the first to first describe this behavior. It was the Dutch physician, Jan Ingenhousz (1785), who first observed that finely powdered charcoal floating on an alcohol surface executed a highly erratic random motion.

What is apparent is that Paolo was never a Reaper, even though he has moved with ease and without contradiction from one personality type to the other depending on the problem he was addressing. Of course no one fits neatly into these categories all the time. Individual scientists at various stages of his/her career may function as one type of personality at one time and as a different type of personality at another time. For some the change is much more frequent, being determined by the individuals level of adaptability.

1.3 Complexity Management Effect

Thinking about what area of Paolo's research I ought to emphasize in these remarks I reviewed his CV to see if I could at least authoritatively summarize the areas of study we investigated together. But even that was too great an undertaking because of the number of our collaborations, which surprised me since we have not worked at the same institution for the past 22 years. But when I thought about it, I remembered that two decades ago Paolo had initiated a Saturday morning Skype meeting of our group associated with the Center for Nonlinear Science at UNT. These are always chaired by Paolo. The meetings typically last three hours and run the gamut from which student is working on what piece of research, to hour-long talks by members covering recent breakthroughs, to introducing new areas of research interest, potential workshops and debating possible sources of funding.

So, all in all, I would say that we have had and continue to have, over and above our a productive collaborations, a warm friendship that is only deepened by our shared love of science. Given this record I have selected the area of the statistics of crucial events to qualitatively discuss how crucial events facilitates the information exchange between complex networks. This is also timely since we have just published a book on that research [281].

Requisite Variety

It is slightly over a half century since Ross Ashby, in his masterful book [7], alerted scientists to be aware of the difficulty of regulating biological systems: "the main cause of difficulty is the variety in the disturbances that must be regulated against". This insightful observation led to the conclusion that it is possible to regulate complex systems if the regulators share the same high intelligence (complexity) as the systems being regulated. Herein we refer to the Ashby's *requisite variety* with the modern term *complexity matching effect* (CME). The term CME has been widely used in the recent past [8, 9, 10, 11, 12, 13] to denote the synchronization between the finger tapping and a complex metronome interpreted to be a system as complex as the human brain. These synchronizations are today's realizations of the regulation of the brain, in conformity with the observations of Ashby.

It is important to stress that there exists further research directed toward the foundation of social learning [14, 15, 16, 17] that is also closely connected to the ambitious challenge made by Ashby. In fact, this research aims at evaluating the transfer of information from the brain of one player to that of another, by way of the interaction the two players established through their avatars [14]. The results are exciting in that the trajectories of the two players turn out to be significantly synchronized. But even more important than synchronization is the fact that the trajectories of the two avatars have a universal structure based on the shared EEGs of the human brain.

Doing research with Paolo means working also with his students who, without exception, were and are excellent. For example, Mahmoodi et al. [18] established a physiological foundation of the above important results based on the recent advances on the dynamics of the brain, interpreted as a network whose dynamics are critical. Criticality is a phenomenon requiring the cooperative interaction of units, in this case the neurons of the brain, and is hypothesized as the main source of cognition. Using the criticality-induced intelligence, they define complexity as a property of crucial events, a form of temporal complexity, and they proved that the perfect synchronization is due to the interaction between the two networks, with the more complex network restoring additional temporal complexity to the less complex network. The phenomenon of temporal complexity is characterized by ergodicity breaking that has made it difficult in the past to derive the perfect synchronization generated by complexity matching. For this reason, they supplemented the main result of CME [280] with an extension of complexity matching to complexity management.

This afforded a proper theory to understand the universal structure representing the brain of two interacting individuals. In addition, the theory can be adapted to the communication between the heart and the brain [19] of a single individual. The transfer of information between interacting systems has been addressed using different theoretical tools, examples of which include: *chaos synchronization* [20], *self-organization* [21], and *resonance* [22]. On the other hand, for a network as complex as the brain there is experimental evidence for the existence of crucial events [281]. These crucial events in the neuronal context can be interpreted as organization rearrangements, or renewal failures. The intervals between consecutive crucial events are statistically independent, so that crucial events are renewal, and are described by a waiting-time IPL PDF:

$$\psi(\tau) \propto \frac{1}{\tau^{\mu}},$$

with $1 < \mu < 3$. The crucial events are generators of ergodicity breaking and are widely studied to reveal fundamental biological statistical properties [159, 281].

Another important property of biological processes is homeodynamics [24], which seems to be in conflict with homeostasis as understood and advocated by Ashby. Lloyd et al [24] invoke the existence of bifurcation points to explain the transition from homeostasis to homeodynamics. This transition, moving away from Ashby's emphasis on the fundamental role of homeostasis, has been studied by Ikegami and Suzuki [25] and by Oka et al. [26] who coined the term *dynamic homeostasis*. They used Ashby's cybernetics to deepen the concept of self and to establish if the behavior of the Internet is similar to that of the human brain.

Experiments and Theory

Experimental results exist for the correlation between the dynamics of two distinct physiological networks [27], but they are not explained using any of the earlier mentioned theoretical approaches. Herein we relate this correlation to the occurrence of crucial events. These crucial events are responsible for the generation of 1/f–noise, [39]:

$$S(f) \propto 1/f^{3-\mu},$$

and the results of the psychological experiment of Correll [29]. The experimental data imply that activating cognition has the effect of making the IPL index $<$ 3 cross the barrier between the Lévy and Gauss basin of attraction, namely inducing the IPL index to be $\mu > 3$ [30].

The basin crossing is a manifestation of the devastating effect of violating the linear response condition, according to which a perturbation should be sufficiently weak as to not affect a system's dynamic complexity [14]. The experimental observation obliged us to go beyond the linear response theory adopted in earlier works in order to explain the transfer of information from one complex system to another. This transfer was accomplished through the matching of the IPL index of the crucial events of the regulator with the IPL index of the crucial events of the system being regulated [33, 214]. This is in line with the general idea of complexity matching [280] with the main limitation, though, that the perturbation intensity has to be so small as to make it possible to observe the influence of the perturbing network on the perturbed through ensemble averages, namely an average over many realizations [33], or through time averages, if we know the occurrence time of crucial events [214].

Earlier work [35], based on the direct use of the dynamics of two complex networks, studied the case when a small fraction of the units of the driven system perceive the mean field of the driving system. At criticality the choice done by these units is interpreted as swarm intelligence [269] and, in the case of the Decision Making Model adopted in [278] is associated to the index $\mu = 1.5$. In [278] this synchronization is observed when both systems are in the supercritical condition and it is destroyed if one system is in the subcritical regime and the other in the supercritical regime, or vice-versa. This suggests that the maximal synchronization is realized when both networks are at criticality, namely, they share the same IPL index.

1.4 What others say about him.

I thought it would be interesting for the broader audience to learn the perspective of those that do not know Paolo personally, but have only been treated to his ideas through his publication. What could be more revealing than the impression left by works which synthesize significant portions of the collaborative work done in the areas of fractional calculus and network science.

For this purpose I selected reviews of the two books given here because the reviews contain what I consider to be the most well thought out comments regarding the research and the potential impact that research had and will continue to have on the fields addressed.

Physics of Fractal Operators by B.J. West, M. Bologna and P. Grigolini ;

From Amazon reviews:

"Have you ever wondered about whether one can define differential derivative of non integer order and how useful these fractal derivatives would be? If the answer is yes this is the book to look at. The book is written by physicists with a pragmatic audience in mind. It contains a very thorough and clearly written discussion of the mathematical foundation as well as the applications to important and interesting mathematical and physical problems. All the topics are very main stream and of great general relevance...

"I am glad I got to know this book. I don't know yet whether fractal calculus will be of crucial importance to my own research in statistical mechanics and complex systems. But I got the feeling from this book that this might very well be the case. And if this happens, I now know exactly where to go for a highly readable and thorough introduction to the field. I think the book deserves to be present in mathematics and physics libraries. And I believe many interesting undergraduate and graduate projects in mathematics and its applications can start out from this book."

"The book is written by physicists with a pragmatic audience in mind. It contains a very thorough and clearly written discussion of the mathematical foundation as well as the applications to important and interesting mathematical and physical problems. All the topics are very mainstream and of great general relevance. . . . Obviously, the book is also of great relevance to the researcher who may need to become acquainted with Fractal Calculus . . . . I am glad I got to know this book." (Henrik Jensen, UK Nonlinear News, February, 2004)

"Physics of Fractal Operators . . . is a timely introduction that discusses the basics of fractional calculus. ... Physics of Fractal Operators, which actively promotes the use of fractional calculus in physics, may help teachers develop an appropriate curriculum. . . . the book's abundance of material makes it very useful to researchers working in the field of complex systems and stochastic processes. It should help those who want to teach fractional calculus and it will definitely motivate those who want to learn ... ." (Igor M. Sokolov, Physics Today, December, 2003)

"The main merit of this well-written book is that it brings out rather clearly the relevance of the fractional calculus leading to the fractal operators and fractal functions. ... Each chapter contains an extensive list of relevant references. ... The overall style of presentation of the material covered in this book makes it rather useful for physicists and applied mathematicians carrying out a self-study of the fractal calculus and its applications." (Suresh V. Lawande, Mathematical Reviews, 2004)

"'Physics of Fractal Operators' is one of the great ideas books of our time. It may well become one of the most influential books with the paradigm of using fractional calculus to describe systems with emerging and evolving fractal complexities becoming widely used across the sciences. This important book should be mandatory reading for all PhD students in physics, and it should be at the side of all scientists working with fractals and complexity." (B I Henry, The Physicist, Vol. 40 (5), 2003)

"This book introduces the reader to the interesting mathematical notion of fractal operators and its usefulness to physics. ... a comprehensive, well written introduction to the subject ... useful to researchers and teachers alike. It is indeed targeted towards a wide, non specialist audience and provides the mathematical basis of fractional calculus ... . This book offers a lot of high-quality material to learn from and was definitely a very interesting and enjoyable read for me." (Yves Caudano, Physicalia, Vol. 28 (4-6), 2006)

Complex Webs, Anticipating the Improbable by B.J. West and P. Grigolini

"From taking an airplane to how much we earn, many aspects of our daily lives are connected to webs and networks. That idea is stressed by Bruce West and Paolo Grigolini in their eminently readable inquiry, *Complex Webs: Anticipating the Improbable*, in which they note the global pursuit by scientists and engineers to develop the field of network science. Past attempts have met with limited and often disappointing results; those attempts include generalized systems theory, complexity theory, catastrophe theory, and the theory of complex adaptive systems. The present search for a network science differs from past efforts in that the theory is now guided by large empirical data sets."

"Recent books highlighting different aspects of network science can be roughly separated into popular works that lay out an integrated scientific view of humans and modern technology; manuals and references focused on specific application areas such as biophysics, econophysics, psychophysics, or sociophysics; and texts that explore advanced networks-related topics that go beyond particular disciplines. Complex Webs most closely matches the last (and smallest) category, as it interweaves various topics from statistical physics to support the understanding of complex networks; perhaps in the future those topics will form the foundation of a network science."

"*Complex Webs* is mathematically rigorous, data rich, and entertaining. The first two chapters emphasize that hundreds of complex phenomena dominating our lives have statistical properties described by inverse power laws instead of by the normal Gauss distribution. An unpredictable bridge collapse, the bursting of an economic bubble, or the onset of a heart attack—each is part of a different elaborate web. Gaussian statistics cannot predict those phenomena because such events have their roots in the complexity of webs that represent the flow of such commodities as information, finance, food, and transportation."

"This web complexity is manifest in time series that have divergent second moments and that are nonstationary, nonergodic, and non-Poisson. How the new perspective influences fields of investigation such as physiology and bioengineering is an interesting story and provides a context for the authors to introduce many of the mathematical ideas used in understanding webs. For example, in their discussion of fractal physiology and like phenomena, the authors introduce fractal geometry and fractal statistics that follow from the scaling behaviors of power laws."

"Our ability to predict the operation of inanimate objects but not of living things means that we can understand the devices cluttering up our world but not much about their relationship to us. To model the lack of understanding, in chapter three the authors provide the physicist's rationale for randomness. They discuss the shift in prediction from a single trajectory that solves the equations of motion to an ensemble of such trajectories, whose distribution solves the phase-space equations for the probability density. Thus, a preliminary understanding of nature is expressed in terms of averages, fluctuations, and non-Gaussian distributions."

"In chapter four, the authors introduce the mathematical techniques used to describe randomness and chaos, and in chapter five they transition to applications of the fractional calculus. **64** There are two distinct strategies for modeling the dynamics of complex webs: “dynamic” dynamics describing the phenomenon and the evolution of the associated probability density. The authors systematically develop both methods and explain the extension into the fractional calculus to incorporate memory; those methods give rise to fractional stochastic differential equations in the first approach and fractional diffusion equations in the second."

"Chapter six contains an all-too-brief review of some contemporary developments in network theory. It reflects the authors’ tastes instead of presenting exhaustive coverage of a vast amount of high-quality research from the past decade. The authors tell the familiar story of the progression in our understanding from random networks, to small-world networks, to scale-free networks, and they discuss various measures that allow comparisons of real-world networks to mathematical idealizations."

"In chapter seven, the authors discuss recent research findings, including some they themselves have published; they somehow avoid being dogmatic in their presentation. Among the new results described is a generalization of linear response theory clarifying a misconception that appeared in the physics literature a few years ago. The generalization is used to explain how information transfer between complex networks depends on the measures of complexity. It is also used to derive a generalized Onsager principle."

"West and Grigolini artfully develop mathematical models for understanding data sets drawn from a variety of venues, and they highlight examples, anecdotes, and historical vignettes that bring the mathematics and its application to life. Consequently, *Complex Webs* presents a distinctive perspective that makes it stand out. I strongly recommend this remarkable book to those interested in learning the mathematical underpinnings of the science of networks and, more importantly, to those thinking of teaching a course in it."

Physics Today **64**, pgs. 58-60 (2011), H. Eugene Stanley, Boston University, Boston, Massachusetts

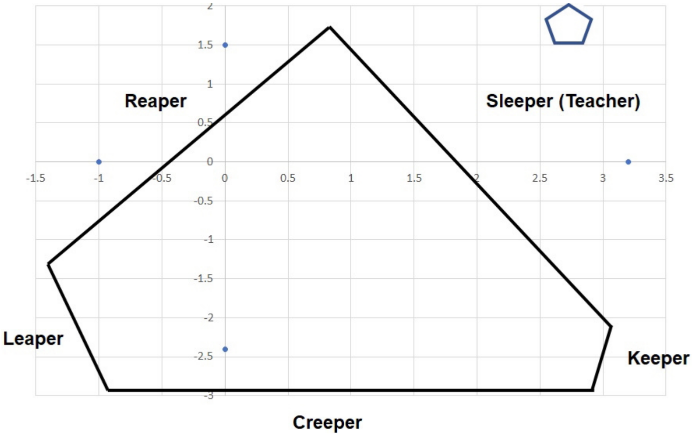

Figure 1.1: This is an estimate of the five dimensional profile of Paolo Grigolini. Note that a perfectly balanced scientific personality would have the shape of the regular (equilateral) pentagon in the upper right hand corner. That one, in turn, has maximum five-fold symmetry allowed for a face of a Platonic solid and demonstrates Paolo's affinty for Platonic ideals.

1.5 Paolo's Profile

I will close these remarks with the promised sketch of Paolo's profile. I used the citations to his publications listed on Google Scholar and organized them according to my subjective placement of a publication to a given personality type. The relative size of the Sleeper, Keeper, Leaper, Creeper and Reaper dimensions contributing to his personality type is determined by the relative number of citations in each of the five types. A completely symmetric scientific personality type would have the shape of a pentagon, but as we know scientists are typically atypical or asymmetric. Paolo's profile consists of five dimensions depicted in Figure 1.1 the smallest two types are those of Keeper and Leaper, as it is for all of us that are not magicians.

One might get the wrong impression given the size of the Reaper type in the figure, since Paolo is a modest person. When it comes to reaping credit for contributions he has made to science he is more concerned with understanding a process or phenomenon than he is with establishing who ought to get credit for that understanding. In my experience Paolo follows a dictum expressed on a plaque that President Ronald Reagan kept on his desk in the Oval Office of the White House:

> There is no limit to what a man can do or where he can go if he doesn't mind who gets the credit.

The large Reaper score in Paolo's profile is a consequence of my deciding that the books he published could easily be included in this category. Therefore, I included all the citations to books in both the Creeper and Reaper categories and determined the remaining contributions from all the papers that had over one hundred citations.