L.A. Theatre Works Interview Regarding ARCADIA

Here are excerpts form Susan Loewenberg's LA Theatre Works July 16, 2009 interview about the history and significance of chaos theory and fractal geometry as they relate to the play with Steven Strogatz, the Jacob Gould Schurman Professor of Applied Mathematics at Cornell University. To listen to the entire interview go to http://www.stevenstrogatz.com/media.html

Susan Loewenberg: For most of us, wrapping our heads around chaos theory is as difficult as predicting the future, so we've invited Steven Strogatz to help bring some order to our understanding of chaos. He's a professor of applied mathematics at Cornell University and the author of Nonlinear Dynamics and Chaos. Steven, welcome back to LA Theatre Works and thanks for being with us.

Steven Strogatz: Thank you very much, Susan, it's a pleasure to be back.

Susan: What is chaos?
Steven: First there is the colloquial use of the word, we think of chaos as just randomness or disorder or mayhem, but when a scientist uses the term chaos it means something a little more subtle, it's got elements of the unpredictable and the disorderly but it also has mysterious patterns and order within it, so it's a kind of strange state that sits in between order and what you might have traditionally thought of as chaos.

Susan: How recent is the concept as we understand it now?
Steven: I would say that the first glimmerings of chaos are about a hundred years ago in the work of a French mathematician, Henri Poincare, then in a sort of a twist that echoes something that happens in the play, his work was lost until about 1960; that is, there is nobody except a very small group of mathematicians were aware of what Poincare had done in the late 1800s and so chaos theory didn't really have any impact at all until about 1960 and then another scientist working on weather prediction sort of rediscovered it in an even more striking form and yet he too was ignored and his work was lost. So neither of them really made their mark and it was only in the 1970s or 80s that chaos became a big story in science and Tom Stoppard, we know, was influenced by the book Chaos that the great science writer James Gleick wrote in 1987.

Susan: But why did chaos suddenly become a big story?
Steven: I guess the first thing to say as background – science for so long and especially physics has been dominated by the search for order, the opposite of chaos, for patterns and rules and so we think of the regular side of nature as the thing that physicists especially are interested in studying and so that blinded people really for centuries since Isaac Newton in the 1600s; for maybe three hundred fifty years or so there was this obsessive focus on the neat and tidy and orderly side of nature but there was always this sort of nagging feeling that we're missing half the story because there's all kinds of irregularity out there that's obvious to anybody. There's irregular ups and downs in the stock market, there's wild life population booms and busts, and turbulence in the atmosphere and in the ocean. You know, these things were considered monsters or pathologies that science couldn't really deal with and wanted to sweep under the rug so what chaos theory did in the 1970s and 80s was say actually its time to stop ignoring all those things we've got to address them and finally we have techniques for addressing them and for understanding them and they may not be as hopeless as we used to think.

Susan: How did that happen, was that just pure happenstance answer, was there a group of people who were beginning to talk about the importance of interdisciplinary discussion, what was in the air that made that happen?
Steven: I think you're putting your finger on it right there. There was something in the air and these people were all mavericks in their own fields, they were outsiders in the sense that, for instance, Ed Lorenz and weather prediction, a lot of people within the meteorology community said to him "look, give up on that, we all know that you can't really predict the weather, why don't you work on something more sensible. That's like tea leaves, you know, that's black art; we know that problem is hopeless but Lorenz was stubborn and within geometry there was a man named Benoit Mandelbrot who is usually thought of as the father of fractal

geometry who said, in fact there is practically a quote from him in the play when, I think it's Thomasina said towards the end that real nature is more irregular, not so simple, and Euclidian as we always thought. So there was Mandelbrot saying we've got to pay attention to irregularity in geometry and what I'm saying is that there were these people who had a taste for the taboo subject of the jagged and the disorderly and the irregular and somehow they found each other, they realized they were all thinking about the same thing, they were all thinking about how to make a science out of disorder, out of chaos.

Susan: So, how does chaos differ from randomness?
Steven: That's an excellent question. We do need to talk about because some people think from the sound of the word that chaos must be part of randomness or probability theory or statistics, all the things that have to do with chance. It absolutely is related to those but it's not those things because the way that word "chaos" is used technically is that it is a seemingly random behavior system governed by deterministic rules. So when I say deterministic rules I mean, and this is a theme that runs throughout the play, a system is deterministic if it's present completely determines its future. That is, if I know where everything is right now and how it's moving then there are rules that tell me what will happen an instant from now and an instant after that and I can just march forward through time moment by moment into the indefinite future so the future would be predetermined by the present, the way Newton's laws work in physics and we've had this picture now since the 1660s that's what our universe is like, we know where all the particles are moving and obeying Newton's laws and later, Einstein's laws, that we should be able to predict everything. You know this is a very scary thought because even though only in principle we could do it but still philosophically it would mean there is no free will. Everything that you could possibly think or do was predetermined by the state of the universe and the state of you and your surroundings at the current moment. You really had a choice.

***************************SPOILER ALERT***
The next Question & Answer divulge plot turns near the end of the play. If you have not seen/read the play, you may want to skip to the next Question/Answer on the bottom of this page and continue there.

Susan: So what is the meaning, for example, of Thomasina's untimely death. How can you work backwards from that event and talk about randomness or chaos?
Steven: Well, what chaos says now is that even when laws are completely determined and there's no noise, to use a word that comes up later in the play, there's no randomness inherent in the way that things evolve, they just follow a little computer program, and you might think the universe is sort of running like a machine. Even if that were true, says chaos theory, there's still an element of unpredictability, it's inescapable and the reason is that any slight uncertainties or any little unknown effects in the current time can amplify and snowball so rapidly that things rapidly become unpredictable. That's something, by the way, that we knew for ever really, I mean that's an ancient concept. There's an old poem from the 1300s that you may be familiar with, it starts 'for want of a nail the shoe was lost." It's a story about the fall of the kingdom. It says, you know, because there wasn't a nail you couldn't put the shoe on the horse, then because the horse didn't have its proper horse shoe on, it couldn't ride into the battle correctly and so the battle was lost and ultimately the kingdom was lost. So, the point was that just the absence of this one horse shoe nail led to this unforeseen or unintended consequence of the whole kingdom falling down. In the case of Thomasina in that last scene, near the end she goes in and she's got a candle because she wants to finally go and kiss Septimus and he tells her "be careful with that flame" but presumably something, some little flickering of the flame caught fire with something and that's it. So, it's sort of the case that even if all of that was predetermined the little flickering of the flame may have been enough to lead to this tragic end and if it had just flickered a little differently the other direction it wouldn't have hit the curtain and it wouldn't have killed her. That's the universe we live in, unpredictable.
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Susan: In light of all of that, what would you say is the goal of chaos theory?
Steven: Well, chaos theory has these two sides to it. I mean, the negative side of chaos, if you like, is the one that sounds like its name. It's to say that even much simpler systems than human affairs, or wars, or people

in love, we knew that those things were unpredictable, we've known that forever, there's nothing new in chaos theory, that's not news to tell me that little things can cascade and snowball and create unpredictability. It's true, we have known that forever but what's new about chaos, and this is the negative side of it, is that this kind of unpredictability infects even systems that we thought we did understand like something as simple as the swinging of a pendulum back and forth or the monotonous pendulum that's supposed to put people to sleep or hypnotize them, even that, if you just jiggle it the right way can become unpredictable and that was not suppose to happen. Isaac Newton and his like thought that, you know, we had at least solved the motions of a pendulums and now in 1970 and 80 we're finding out even those paradigms of order turn out to have disorder lurking in them. So, the downside of chaos is that we're seeing unpredictability even in the things we thought we had mastered. But, the positive side of chaos is that there are certain things that look random that are not, that actually have subtle structure in them, that as we are starting through chaos theory to have new eyes for disorder, ways of seeing patterns within chaos that's not classical, totally new patterns that no one had ever expected were there or thought of. You know that offers hope for something like arrhythmia of the heart which doctors usually think of as just wild, irregular beating, there might be a kind of pattern in it that could allow us to design better defibrillators, for example.

Susan: So, this is fascinating, in a sense what you're saying is you really can apply chaos theory across all disciplines.
Steven: Exactly, it expands our repertoire of patterns. This is the theme in the play about landscape architecture whether it's the classical beauty of Arcadia or this new romantic style of picturesque, you know, where it's suppose to look very decadent but in fact there's new kinds of patterns there just that the classical eye doesn't see them. It's not the absence of pattern, it's new patterns so Thomasina touches on that when she says "can't I make a leaf, why do I have to be confined to these simple circles and lines in geometry or she says "if there's a curve for a bell why isn't there a curve for a blue bell or a rose," and Septimus says "well, there isn't", so she invents a new way of doing geometry so that there is. That's all real, that has really happened. I mean it didn't really happen in the 1800s, that's the conceit of the play, but it did happen in the 1970s, people were finding ways to find new structures that were not the classical geometric structure and then to use those for all kinds of practical purposes. For instance, people who have epileptic seizures, it's a very serious problem for them because they don't necessarily know when they're going to have one and, so, if they're giving their baby a bath and suddenly have a seizure it's very dangerous , the kid is in the bath without a parent there so, if an epileptic person can be told ahead of time you're about to have a seizure or you're about to have one ten minutes from now that person could, you know, lie down, take the kid out of the bath or whatever. Well, people are using chaos theory to produce brain wave detection systems, that is, a person can now have a fairly noninvasive thing recording their brain waves which tells them this is now the signature, a precursor of an impending seizure and with pretty good predictability using chaos theory they get it right using chaos math. I mean, it's being used to design space missions, you can get to the moon with much less fuel than we ever thought possible, using chaotic trajectories to get us there. See, it's a very radical paradigm shift because a NASA engineer doesn't like the idea of sending a very expensive space craft on a chaotic path to the moon, that sounds dangerous but it can actually, if done right, save a lot of money. It can cost a hundred thousand dollars per pounds of dollars of stuff you send into space so if you can do it a lot more cheaply, that is make things lighter… fuel weighs a lot, if you can get by with a lot less fuel your saving NASA a lot of money. I mean, I could go on and on, it's useful in every branch of science and technology that we know.

Susan: Well, getting back to the play and what was real and what was a conceit, is Tom Stoppard true to the history of chaos theory? In other words, are the discussions of chaos theory in the play consistent with mathematical knowledge at the time both in the world of the play in the 19th century and in the present?
Steven: No, he's not, he's not at all and I don't feel too concerned about that because the play, I mean aside from being a great play and very emotionally poignant and funny and everything, I mean it's a fantastic play dramatically speaking, but scientifically speaking and mathematically it's fantastic, too, because he gives

some of the best explanations of the core ideas of chaos theory that you can find anywhere, better than in text books. I'm not just saying that to flatter him. I'm astounded at his level of understanding and insight and the pithy way he expresses the key ideas of chaos. So, that part is magnificent, but it's not historically accurate at all, to say that in whenever it is, 1810 or thereabouts, when the early scenes take place there's no evidence that anyone at that time had the understanding that Thomasina had. As I say, the first work in chaos that we know of is something about 1890 or thereabout by Henri Poincare in France. On the other hand, he gets something qualitatively right, Stoppard does, when he says that whole bit about Thomasina complains about how terrible it is about the Alexandrian library and all that knowledge has been lost and Septimus says, well, whatever it'll come back, you know, knowledge is never really lost, it comes back. There is some element of that in the chaos theory and in the play, that is what Thomasina discovered is lost and then rediscovered in the era of Valentine and Hannah when they're talking about contemporary times. Well, the same was true of Poincare's work in the 1890s and 1900s which was lost for about 60 years until rediscovered by Lorenz and that was lost for another 10 years, so that does happen.

Susan: I was just thinking about the fact that, there's also the element of being ready to accept a discovery. Sometimes the world, it's too early. The surrounding conditions, I think, of accepting certain kinds of new knowledge have to be right.
Steven: Well, that's such an interesting point, and you could be right and for that matter Stoppard could be right. I mean part of the play is about the mysteries of history, that is, what things are lost and we don't know about it. So, we do know from the historical record in the development of chaos theory that there were things, for instance, that were exactly like what you just described where people were not psychologically ready to see what they were literally seeing. That is, I am thinking here of a case of engineers in the 1920s electrical engineers working on the development of radio who were listening to some of the electrical circuits they had built and they heard a strange hissing sound which they, you know, it sounds like noise or static of some kind, they didn't know what it was and, in fact, they were hearing the sound of chaos and they reported that they heard this strange hiss but they thought there was something wrong with their circuit and, you know, didn't make much of it but they weren't psychologically ready to see or, in this case, to hear what they were actually hearing. And, so, they heard it but it meant nothing to them so it wasn't followed up. I mean, this happened repeatedly in the development of chaos, people would see things that were later realized to be true manifestations of what is now recognized as modern chaos, deterministic chaos and they just ignored it even though they saw it.

Susan: When did real life mathematicians start thinking seriously about the idea of representing nature through algorithms?
Steven: That's a parallel development to chaos theory, this question of algorithms and iteration. In the late 1800s, mathematicians, for their own reasons, started to worry about algorithms and iterations repeating an operation over and over and they produced what at the time seemed like monstrous, bizarre shapes totally different from anything in classical geometry, not smooth, not undulating and gentle, really jaggedy-looking strange shapes that we now think of as fractals but they were creating these for reasons internal to math, that is to produce counter examples, that is examples that would show that intuitive things were false, certain things that people thought had to be true. These monstrous counter examples showed, well, they're not always true and you could create these weird counter-examples through algorithms and iteration.

Susan: Can you give us an example of that?
Steven: Well, sure, there's an example of it around the turn of the 20th century – there was a big debate in math; what do we mean by a curve, that is, we know what a straight line is and we know what a circle is, so think of a thread, you know, I mean, you can think of bending a thread of a piece of rope into a shape of any kind of curve you want, an inclined curve if you want, that is what people think a curve is, it is some kind of path followed by a string or a rope or something so then the question was – is that really what we mean by a curve? For instance, could a curve bend back on itself so much that it fills up every point in a square area like it can go through every point in a two dimensional region? It turns out you can if you make a weird enough fractal thing called a space filling curve you can fill two dimensions or three dimensions or any number of

dimensions just with a curve. So, mathematicians created these weird examples and no one knew what to make of them, they were described as unnatural. This was my point that these things were described at the time as completely unnatural and freakish and, this is the great irony, it turned out that about 70 years later when fractal geometry started to be invented that these were exactly the things that were natural were these weird iterations and algorithms that were the best descriptions of mountains and coast lines and leaves and ferns and trees and all the things that are totally natural. Their much more like these weird objects than they are like cones and cylinders. So, Thomasina says why am I studying all the geometry that has to do with manufactured things, where's the geometry of real things, of natural things and Septimus doesn't know, there is no geometry at that time but that's fractal geometry. But, what's so funny is that what is called baroque and bizarre and unnatural and it is exactly the opposite, it's the most natural kind of geometry. I mean, if you want, this is the same theme that's happening in the landscape with Sidley Park, you know, it's being changed from its classical landscape which is much more Euclidian and manufactured to this supposedly naturalistic thing.

Susan: When Thomasina makes her initial hypothesis it's the year 1809, how long did it take mathematics to catch up with her?
Steven: Well, I'd say about 90 years. It's really the turn of the 20th century and those people at that time, Poincare and his disciples, were the Thomasinas, the real Thomasinas and they were - now, Poincare was known as one of the world's great mathematicians so he was not obscure in the way that we have to think of Thomasina as obscure but, nevertheless, his work was not picked up, it was a backwater, it was not the direction science or math was going. You know, the turn of the 20th century was the era of, in science, of the Albert Einstein and relativity theory and then 20 years later quantum mechanics so those were the big stories in physics for the 20th century and to work on classical things like Newton's laws and finding strange disorder in Newton's laws, that was really retro. I mean, people thought, c'mon, Newton's laws, that's been picked over for 200 years, we're not doing that any more, but yet Poincare did find something shocking in there but no one could see it, no one could really even understand what he was saying.

Susan: One of the unusual aspects of Arcadia is that it presents a layman mathematician in the play in the person of Valentine Coverly, is Valentine credible? Does he explain the concepts well?
Steven: I find Valentine completely credible because he's a graduate student is the way I would see him. His explanations are magnificent, I mean, they're really spot-on, very poetic, I would be happy and proud to be able to explain things that well in any class I've given.

Susan: Well, except that I think that he didn't think of himself as a professional. I mean, he thought of himself as an amateur.
Steven: I guess so because he's a member of the family so he's looking at the game books for those hundreds of years. Well, maybe a 180 years, whatever it is. To me he reminds me of – I was a graduate student at the time that chaos was just getting big so maybe I identify with him because what he was trying to do with those grouse population numbers and looking for, trying to find a pattern in the ups and downs of how many grouse were shot over the years, that was a lot like what I was trying to do, I was trying to look at patterns of human sleep/wake cycles and use chaos to figure out rules about our sleep rhythms.

Susan: Did you succeed or were you in Valentine's position?
Steven: I was a little more in his position. I empathize with him because, as he says, there's too much noise, you know, there were too many contaminates polluting his data. That was something a lot of young people were doing in the 1980s, trying to apply chaos theory to all kinds of things where people had not seen patterns before and trying to look at it through the lens of this new theory and suddenly extract something magnificent and, in a few cases, they did. I just didn't happen to be one of them.

Susan: And neither was Valentine. So, let's just go deeper into this trying to understand it. He basically gives up because he comes to realize that calculating grouse populations in reverse is impossible. Why is it impossible?

Steven: There's a few things that could be working against him, or against anyone who's trying to do anything like what he tried to do. The cases where this trick has worked, where chaos has been successful, he mentions that with goldfish it would be easy. So, what does he mean? I think he's describing a case where you imagine a very idealized little pond with the gold fish, how many goldfish there are now will determine how many will be next week or next year maybe because there aren't any predators in the pond, it's just the goldfish and what little food they can eat. It's a super simple eco-system is I think what he has in mind. So, the grouse, I think the problem is supposed to be – doesn't he say something about if the heather was burned it messes up, is that same speech in the monologue?

Susan: Yes, he's trying to talk about all the different factors in what he calls noise.
Steven: Yes, so noise here means, Stoppard says it very well that, you know, you're trying to pick out the tune, there's all this background noise and you're trying to find the pattern. So, in science what this would mean is that there's a simple rule that governs how many grouse there are this year determines how many there are next year but that rule is obscured because there's all kinds of fluctuations from weather conditions, the condition of the land, because of humidity or how much rainfall, I don't know, whatever migration thing, or some other predator you didn't factor into your problem. So, all of those things make the problem much harder than, as you say, the enclosed, little self contained system of the goldfish. Maybe I should just say, in case anyone out there listening is wondering about it, just how successful, you know, if you're going to be a real hard-boiled skeptic and say why haven't I heard of great successes of chaos theory, have there been any really thunderously great successes, I would say that is fair skepticism. It was a field that was hyped and maybe over-hyped. That is, we thought, or some people claimed, you know, that it would be more successful than it turned out to be. The reason it has been not as successful as was once hoped is this issue of noise; that is, the world is more complicated than chaos theory can handle, even something called chaos theory is not up to the complexity of the real world.

Susan: Another aspect of chaos theory that you've written about is the so-called butterfly effect. Could you explain this concept?
Steven: Well, the butterfly effect is the poetic way of trying to describe the idea that little things can make a big difference. So, you're supposed to imagine in the parable that a butterfly flapping its wings in Brazil is creating enough of a change in the air currents that it ultimately leads to a tornado in Texas. So, this is another version of the horse and the nail leading to the downfall of a kingdom, that little changes can have these propagating effects that get magnified over and over can make all the difference.

Susan: So, how do you see the butterfly effect at work in Arcadia?
Steven: The three little items that are put in the book that are then later discovered a 180 years later caused so much confusion about who actually was shooting who in the duel or who was giving the perpendicular poke to who in the gazebo. Well, I think that is the perfect example because you see Septimus puts something in the book, he lends the book to Byron, and the professor [in modern times] makes some assumptions about Byron based on his assumption of what he thinks happened. Well, what I was thinking there was whether a piece of paper makes it into the book or not changes our interpretation of Byron one way or another based on whether this one little sheet of paper or two or three make it into the book. There are other cases, too, I suppose, he probably has dozens of these throughout the play, there must be dozens of critics who spend their lives working on all the instances of chaos theory in the play.

Susan: I'm so sorry this conversation is coming to an end. It has been absolutely fascinating and thank you so much, Steven Strogatz, for speaking with us today
Steven: Well, thank you, it's been really a lot of fun.

Susan: I've been speaking with Steven Strogatz, the Jacob Gould Schurman Professor of Applied Mathematics at Cornell University and the author of <u>Nonlinear Dynamics and Chaos</u>.