# The Inspiration of John Holland

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When I moved to Ann Arbor to pursue my PhD study at the University of Michigan (UM) in 2006, I did not know who John Holland was and had no idea about complex adaptive systems (CAS). In my first summer at Ann Arbor, my adviser Dr. Dan Brown recommended to me Mitchell Waldrop's book, *Complexity - Emerging Science at the Edge of Order and Chaos*. I read it and instantly fell in love with CAS. I have always thought any science, to be a good science, must have something to say about the perpetual question of being and meaning. The science of CAS did just that. I still remember vividly from the book that as a group of brilliant people gathered in SFI and were grappling toward a new science, the Master of the Game stood up and explained the crucial properties of CAS with such clarity and elegance. Among the audience the Irish Hero Brian Arthur listened hard and scribbled furiously in his notebook. To me that was the highest moment in the book.

My first meeting with John Holland happened in my second semester at UM. It was on New Year's Day. While I was walking along the Huron River, it came to me that I could talk to him about my ideas of sustainability and CAS now that we were at the same university. Perhaps only after I had built my first agent-based model and tested myself in classes with subject matters that were completely new to me, did I dare to think so. And, of course, I was curious about the Master of the Game. UM has a program called “Take a Professor to Lunch.” Each semester the university pays a number of students to have lunch with their favorite professors. The purpose is to foster interactions between students and professors. I decided to take advantage of the program. So I emailed John Holland about my new year’s wish to take him to lunch. His reply came back quickly, suggesting we meet before or after his class *CAS and Emergence*. I went to his first class and sat there throughout the whole semester.

In the next five years during my study at UM, John Holland’s pioneering work in CAS had not only inspired my thinking on coupled human-environment systems (CHES) and sustainability - the topic of my dissertation - he was also a constant source of encouragement throughout my dissertation work. I looked at CHES as CAS and explained sustainability as a global property emerging from actions and interactions of multiple human agents under the large

social, economic, and institutional setting and interactions between the human system and the natural system. I proposed a framework that combines agent-based modeling with other research methods (GIS, remote sensing, social surveys, and interviews) to measure and assess the well-being of a CHES, to understand how complex interactions in the system shape its well-being and to explore possible future paths of the system. I applied the framework to a case study in the Poyang Lake Region of China on rural development amid flood hazards. I built an agent-based model to explore the potential effects of an alternative policy that subsidizes rural households that rent out land use rights for long terms in comparison with the current policy of subsidizing rice cultivation. John Holland took great interest in this work. He read and commented on my manuscripts. He even followed every major step of the development of the agent-based model and contributed to some of the ideas implemented in the model.

Near the end of my study at UM, I attended a meeting at SFI on stability of economic systems, fortunately with John Holland. It was my first visit to SFI. I got to meet some other legends in Waldrop's complexity world, such as Murray Gell-Mann. Although things may have changed since SFI first started, much of the spirit remains. The interest in CAS shared by all the participants was evidently strong. I read Waldrop's book again and realized that Murray Gell-Mann had a vision on sustainability even back then. In his vision a sustainable human society is adaptable, robust, and resilient to lesser disasters, can learn from mistakes and allows for growth in the quality of human life instead of just the quantity of it. He said the transformation to a sustainable society requires understanding economic, social, and political forces that are deeply intertwined. That was exactly what I was trying to do in my dissertation work. From Waldrop's book I also rediscovered Brian Arthur's insightful remarks on policy which would become part of a new course I would teach on *CAS and Policy* at George Mason University later. A loop thus closed and expanded.

Through our many interactions, I got to know some other sides of John Holland. John Holland is, first of all, an optimist. His optimism is constantly manifested in his bright smile and cheerful joking. In his quick steps rushing to pick up the first Mayapple on the ground and climb up boulders to watch the Potomac, I see a deep curiosity in him, the same kind of curiosity that has driven his scientific research. In his urgent tone of speaking, I hear an enthusiasm, with which he pursues science and approaches life in general. And he likes to play. He finds fun in plenty of things in life: flying a dragonfly in the field, picking up wild raspberries from bushes,

spotting a Lady's Slipper or Indian Paintbrush on the roadside ... Only such curiosity, enthusiasm, and playfulness from within can sustain the kind of efforts that are needed to teach and write in one's eighties. And this curiosity, enthusiasm, and playfulness, I think, distinguish true scientists from career climbers and great scientists from good ones. John Holland is truly a scientist and a great one.

Today I am no longer in Ann Arbor, Michigan, where my mind underwent a transformation through interactions also with many other great people in the complexity program. John Holland and the science of CAS he and others have started, however, will continue to be a source of inspiration as I pursue my academic career.

*Note: Included are two small pieces I wrote during my study at UM and a few email exchanges with John Holland on agent-based modeling. They sort of provide bits of evidence of John Holland's inspiration.*

Appendix I. **Summer 2006 – First Encounter**

It is my day again. But I am no longer in the suburb of Washington DC, where I used to weave C++ code into a piece of software and would take off from work on this day. I would buy flowers, lots of them, from the farmer's market in the early morning and arrange them carefully on my balcony. I would sit on the balcony looking into the lush woods and feel spring springing in the air. I would watch squirrels chase around cheerfully under the sun. I would let my thoughts drift, wondering about the perpetual questions of "being" - a human is born to this world without his/her own choice, is there a purpose? What is the purpose? And what is it to live?

Now I am in school. I am reading Mitchell Waldrop's book, Complexity - Emerging Science at the Edge of Order and Chaos. What beautiful minds they have, John Holland, Chris Langton, Stuart Kauffman, Brian Arthur! Complex Adaptive System (CAS), such a beautiful idea! "A dynamic network of agents," "interacting with and adapting to each other and the changing environment locally," "coherent behaviors or global properties of the system arise only from micro-level actions and interactions in a bottom-up fashion," "no central control," "no equilibrium," "non-linearity," "perpetual novelty," "the whole is larger than the sum of its parts." Stock markets, social insect colonies, the biosphere and ecosystems, body cells, the brain, the immune system, any human cultural and social societies all are complex adaptive systems! Suddenly Physics, Biology, Ecology, and Economics all come together under a much larger science. It seems as if the whole world had changed, but what has changed was just a view of looking at the world. "...A point of view? One with the twister in vista glide ..." John Holland quoted the poet Alice Fulton in his book Hidden Order, illustrating CAS to a general audience.

I am amazed, thrilled, overwhelmed. On my walk along the Huron River in the afternoon, my spirits soar high above the clouds all the way. Thoughts hit upon me from here and there. All

those questions that I have been asking myself for so many years, to which I have tried to look for answers from Socrates, Plato, Schopenhauer, Kant, Locke, Hegel, Nietzsche, Kierkegaard, Lao Zi, and Zhuang Zi, I realize, can be explained by science too, by this new science of complexity.

If the edge of chaos is where the complexity lies, where the system can do things, hence where the system is alive, it can well be the system is all about. The more complex it is, perhaps there is more meaning to it. Could this be true for being? Is being nothing but experiences? The richer the experience, the more meaningful a life is?

Fate is nothing but a path a human being makes for one's life. There could be infinite number of paths for each life, but at the end only one is walked. It is not because this is the optimal one, but it is what the individual can make based on his/her "internal models" interacting with others and the changing environments where accidents are ubiquitous. This path may be comprised by many short lines with one connected to another. Where the path has begun and how the earlier ones have gone might well shape how the later ones go ("path-dependence"). While the path of an easy life may appear as a simple straight line, the struggling of a lofty mind can write a very irregular curve. The complexity of the path, not where the path ends, tells the richness of experiences.

We human beings are proud of ourselves being thinking Homo sapiens, rationally following social customs, political orders, and economic rules. We have evolved into such a highly ordered society that all one does is to find a position in the big production machine, stay there and keep running. The mass are performing everyday this way. Stability, as John Holland said, is death, so the mass are dead. Isn't it ironical that we are becoming dead because of our intelligence?

Even though human societies have evolved into a highly ordered state, it doesn't ensure we are going to have this security forever. As one of many complex adaptive systems in a much larger complex system, the universe, we have to co-live and co-evolve with many others. Will global environmental change alter human destiny? James Lovelock has claimed that the world has passed the point of no return for climate change, and civilization is unlikely to survive. Will the energy crisis transform the human landscape into chaos? Gasoline price has been rising; oil production has reached the peak; it seems the time is coming that there won't be enough energy supply for those big suburban houses and SUVs. If this happens, will another "self-organization" start again? Will it be a better world after self-reorganization? Who will be the new world power? Will there be humans at all? Nothing seems impossible in a vast space of possibilities.

Nature is beautiful because it is not completely settled into order, neither is it in total chaos. At the edge of chaos, new lives keep emerging while the old die out. That's where the loveliness comes from. It is constantly changing and full of surprises.

Nature is beautiful, but we are destroying our beautiful home at an ever increasing speed. Urbanization has taken up more and more forests and precious croplands; wild life species go extinct faster due to habitat loss associated with human activities; fisheries have collapsed in many oceans because of over fishing; water resources have been contaminated by pollutions; severe natural hazards occur more frequently as a result of man-made climate change. What is sustainability then?

Sustainability or unsustainability is but a global property of coupled human-environment systems emergent from the actions of humans and laws of nature, the interactions between humans and nature, and the long term feedbacks. Does sustainability mean that humanity and nature get to a state of equilibrium? Is it possible to achieve such a state? The new science of

complexity tells us it's meaningless to talk about equilibrium in a complex adaptive system as the system is constantly in flux and in "perpetual novelty". Then what can we do? Can we really do anything? Maybe the best we can try is to better understand ourselves and our partners and the interactions, respect each other as equals, so the game can at least continue even if we can't play together happily.

...

When I finish up the last page lifting my eyes from Waldrop's book, right outside the window, the sun is setting with a wholly new color palette and cloud pattern. I run downstairs to replace my old car license plate with the Michigan one - I am so glad that I have chosen to come back to school. It's the first time in my life I have become excited about a science. It's the first time on this day things seem to become a little clear. I even forget to eat my long-life noodles, the ritual I usually perform on my day. Guess it doesn't matter, if being is not about how long a life lasts, but "hanging on at the edge of chaos, be alive." I feel alive.

## Appendix II. **Fall 2010 - A loop closes and expands**

So, I have made my pilgrimage to SFI
A bright place on a bright hill, from where
The bright ideas of some bright people
Have brightened my mind
As a Buddhist to Bodh Gaya
A Muslim to Mecca
A Christian to Jerusalem

Sitting between the fathers of CAS, in a conference room
I become lost in some kind of aura
While the father of Quarks quickly relates my Chinese name to Japanese
"It's a square plus a cross," he says
The father of Genetic Algorithm jokes (as he always does)
"She is a peasant." (Tian means agricultural field)
But the father of Q says I am a good-looking peasant (which makes me laugh)

It seemed as if just yesterday
Those legends in Waldrop's Complexity world gathered here
Launching a scientific journey on CAS
But when I watch Don Farmer (one of the legends) on the podium
Who is talking about regulation and stability of the economy
I have to believe
Twenty five years have passed

In twenty five years, people do age, and things change
But the spirit remains
The father of GA still has the highest volume of voice in the room
His remarks are sharp (just as his eyes)
The father of Q still has beautiful dense curly hair (despite it is gray)
His head is up and face alive when it comes across names
Like Faraday, Maxwell, Albert

Not just them though

The Yale economist, the Stanford demographer, the UCLA neurologist
The Harvard biologist, the UM archeologist...
The staff members, even the waitress in a restaurant
And those businessmen from Intel, Lockheed, Citicorp...
All are enthusiastic (and interesting too) -
Enthusiastic about CAS

So twenty five years have passed, how much progress have we made? I ask
It's very little, the father of Q says
We need LOTS LOTS of people to work on it, he continues
And we need theorists besides data mining, the father of GA adds
Let us get on and carry on what the legends have begun
Let us march on, as we must
No matter how hard it is

**P.S.**

Retracing footprints of the legends
I drive up the mesa from Santa Fe to Los Alamos
Stopping at the Valley of the Rio Grande, I watch
Sangre de Cristo Mountains above and far
As the legends did
The father of GA tells me
Sangre means blood and Rio is river

Rereading Waldrop's Complexity
I realize
Twenty five years ago, the father of Q
Who helped set up World Resources Institute
already had a vision on sustainability
which is exactly what my dissertation is about
I must study hard to get my "union card"

Luckily sitting next to Cormac McCarthy at breakfast
I get to have a small conversation with the Pulitzer winner writer
who said it is more important to be good
than it is to be smart
which I can't agree more
And he looks genuine and surprisingly gentle
Thus my pilgrimage to SFI goes beyond satisfaction

Appendix III. **On Agent-based Modeling: Email Exchanges with John Holland**

*03/17/2007*

Dear professor,

Thank you very much for the nice comments on my paper. I was very excited when I was writing it. But when I thought about it again, I started to have a mixed feeling. This mixed feeling is not just about the model I built but also about the modeling approach in general. How could I validate my model? Did not I interpret the model results in an overly stretched way? Somehow I feel I got those nice insights from the model only because I had them in my mind, and I then chose the factors (only part of the system) and a representation (one of many possible representations of the same system) and constructed the model in a way that could prove those subjective points of mine.

In general, how do we know that a model really captures the key mechanism in this system (comparing the generated patterns with observed patterns in the real world does not tell anything as we know that we could produce the same pattern by making up totally different mechanisms)? In addition there are so many possible representations of the same system in models, which could all generate the same patterns and people usually only model part of the system that favors their points.

For instance, I am sure somebody who has totally different views than those of mine, could build a model that also gives rise to cities/towns and proves his points as well. Actually the readings from Rick's class were all about this matter and came right after I started to think about these issues. Some people have expressed their deep doubts on modeling in their papers. These are the questions they asked:

Are we pretending to do what cannot be done?

Are we trying to predict the unpredictable?

After all, what good are models?

Qing

*03/18/2007*

*Dear Qing,*

*Model validation is, of course, an important question: Are the mechanisms postulated the ones that are really operating? Even Maxwell's equations require validation, and the mechanisms postulated change over time. We go from fields, to photons exchanging energy, to quantum interactions, and so on. The interpretation determines what we consider as validation.*

*Here we're back to the purpose of the model. If it is "data-driven" then prediction is the key. That has been the strength of Newton, Maxwell, and Einstein in the equation-based models they propose. However, in some cases, it is extremely difficult to think of ANY set of mechanisms that will produce the desired outcome. That was the strength of von Neumann's mechanistic model of self-reproduction -- no one had been able to exhibit a mechanistic model before that.*

*This is what we called an existence proof model in class. I think your model falls in this category -- choosing relevant factors is part of the "art form" (and it depends upon your subjective insights). As with von N., you had an objective and you showed it could be implemented with certain mechanisms.*

*If there is a second set of mechanisms that will yield the same result, then the objective is to find "real world" experiments that will distinguish between the two models. That's the difference between the work of Einstein (theorist) and the work of Eddington (experimenter). Good models, like good theories, tell us where to make new observations in the real world. Even cas have repeating, controllable patterns. The object of theory is to help us to find them.*

*Now, what do you think about THIS tirade?*

*John*

*03/18/2007*

Dear professor,

THIS tirade is well received. But I am not quite sure I understand "The interpretation determines what we consider as validation." Do you think every model should be validated in one way or another? Do you think generating patterns that match the real world is enough for validating my model?

Probably science, not just modeling, itself cannot be totally objective. Just came across an article for Rachel's class. Here are some quotes from it:

"Science is more art than truth, created by people, who operate, like all of us, in a conscious and unconscious universe. Guided by "inner voices", researchers are inspired to discovery."

"Scientists are more like artists, assembling and mixing the colors of an awesome, complex and dynamic story into a coherent picture. Data maybe the paint on their pallet that creates a picture, but, inevitably, what we see is the artists' rendition. Decisions are made at multiple steps along the way: on relevant facts; on the boundaries between what we know and don't know; and on what we care about."

"Data are not just data. Information is always accompanied by interpretation."

Remember what James said about perceptions: perceptions are never pure sensations but more of interpretations based on the past experiences.

So I guess it is OK to have subjectivity in models now that it is inevitable. Still I think we need to be careful about models: sometimes people tend to take it for granted without any validation. Even if it is an exploratory model, there should be a certain level of rigor in them.

Qing

*03/19/2007*

*Dear Qing,*

*This is a good dialogue!*

*I try to think of the model as a kind of axiom system: First, I try to make the basis of the model (the axioms) as clear as possible. I actually try to write an explicit list of assumptions. Then I try to make sure that the construction adheres to just these assumptions and no others. This is hard, but possible.*

*The whole purpose of setting up axioms is to move all questions of interpretation to them. From that point onward, the rules of deduction, or the program, are a "mechanical" working out of consequences, with no interpretation involved in that part (unlike arguments of rhetoric and persuasion). That is what, in my mind, separates the scientific method from other methods (say, philosophical argument).*

*In short, when the "axiomatic" approach can be followed, the art and interpretative cleverness are concentrated in selecting the axioms. Then consequences are "proved" without*

*resort to interpretation.*

*Note, however, that intuition usually guides us in what consequences we would LIKE to show. But you cannot "cheat" the deductive method -- the consequences may, or may not, follow from the axioms chosen.*

*Do you agree?*

*John*

*P.S. The quotes you give, in my opinion, mix up these two aspects of science. There is certainly all sorts of interpretation and intuition in setting up the axioms (say, Maxwell's equation), but the deductive consequences are then fixed (and no amount of social opinion can change them).*

*03/20/2007*

## Reflection on what is a good agent-based model

I can't stop thinking about this business of model validation. Let us still use Professor John Holland's "axiom system." In my mind I see three types of axiom systems.

Not much is known about the processes of a system, but we observe some patterns at the macro level. The purpose is to explain mechanisms underlying those macro patterns. In this case, the modeler can list all the axioms, including his assumptions about the mechanism. It is all right even if he "manipulates" the axioms. As long as his model generates the observed patterns, he can say that the mechanism postulated is plausible, which can then guide where empirical studies look. The ant model and John Holland's language model (how grammars emerge and how languages evolve) fall into this category. I would think these models are so called "existence proof model."

The model is used to test/explore abstract ideas. The modeler believes that a system works in a certain way. He kind of "proves" his belief (intuition) by generating macro patterns observed in the real world using his model. The purpose of the model is, however, not to prove his belief on the mechanism but to illustrate further insight about the system. In this case, it is OK to move all the assumptions to axioms and then let the program work out, whatever results are. But there is a limitation: whatever additional insights drawn from the model are claims of the modeler based on his belief of how the system works. My model on *Towns, Cities, and the Happiness of*

*Humanity* and some of the early social ABMs, like Axelrod's culture dissemination model, fall into this category. I tend to think such models are more about brain exercise to illustrate an insight.

The model simulates a real world system and has clear policy implications (such as Dan Brown et al.'s land-use models). In this case, only producing macro patterns that match real world observations is not sufficient. It is necessary to combine other empirical research methods to understand the essential elements and dynamics of the system, including how agents actually make decisions. In short, such models need to be validated at conceptual, micro, and macro levels. Of course, no model is a complete representation of the real world system, and it is impossible to fully validate a model. But we do need to have a high level of confidence on our models so we can convince policy makers – if we want to make a difference in the real world.

These three types of models are all useful. Because they are intended for different purposes, the requirements for validation are different too. While the first type does not need validation, the validation of the second type only involves matching macro patterns, and the third type requires validation at conceptual, micro, and macro levels. In addition, if a model can generate MULTIPLE macro patterns observed in the real world, its credibility is enhanced.

To make agent-based modeling a rigorous research tool, we should explicitly state all the assumptions we make in any agent-based models (just as mathematicians list the axioms) and discuss how they may affect the conclusions drawn from model experiments. For example, a common implicit assumption for many social ABMs is that agents can go through a very large number of steps in one model run. This could have important implications on model outcomes. One may think about Schelling's famous segregation model.

## A Serious and Playful Professor