

**Can Wolfram's Cellular Automata Capture
the Greased Recursive Piglet of Human Brain Evolution?**
(Written to spark debate among my fellow participants of the Woframscience Forums)

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A recent article in *Science* (*The Faculty of Language: What Is It, Who Has It, and How Did It Evolve*) by Mark Hauser, Noam Chomsky, and W. Tecumseh Fitch (HCF) – three scholars counted among the world's leading specialists in linguistics, animal intelligence, and human brain functions and mechanisms – discusses several computational aspects of human intelligence that are shared between animals and humans and one uniquely human mental characteristic: *recursion*. This brief essay aims to douse students of machine learning, inductive processes, and Cellular Automata (CA) - who lack familiarity with ideas from linguistics and ethology – with a recursive bucketful of my thinking about HCF's recent thinking about scholarly thinking about thinking in humans and thinking animals. Recursion can often lead to redundancy and ambiguity in language and 'nesting' and 'repetition' in Wolfram's Cellular Automata. Redundancy and ambiguity are the symptoms (like spots) of an underlying computational recursive process (like measles).

<http://www.sciencemag.org/cgi/reprint/298/5598/1569.pdf>

HCF argue that the study of the faculty of language requires us to field a motley team of researchers. Their first sentence on the first page is this:

We argue that an understanding of the faculty of language requires substantial interdisciplinary cooperation. We suggest how current developments in linguistics can be profitably wedded to work in evolutionary biology, anthropology, psychology, and neuroscience. (HCF: 1569)

Reflecting on 'substantial interdisciplinary cooperation', I find it odd that Konrad Lorenz and Niko Tinbergen who won the Nobel Prize in the 1970s for their studies of the role of 'releasers' in animal intelligence are not mentioned in the text or footnotes. This seems unusual since concepts of 'constituent structure' and 'syntax' seem to play a crucial role in their Nobel prize winning work on animal intelligence, and in particular, in analysis of the innate versus learned aspects of duck, goose, and wolf languages. Perhaps what's-his-name with the funny hair who made phoney Campbell's soup cans said it all: We will all be famous for fifteen seconds. Nobel prize winners, perhaps for seventeen. Then, out of sight, out of mind and out of recent studies of the minds of humans, animals, and Martians.

More to the point for enthusiasts of Wolfram's Cellular Automata and Crutchfield's views of Inductive Emergent Machines (or whatever the system currently is called), this *Science* paper opens up a window on human brain mechanisms, functions, and data structures into which formal computational theory can shine a light. I feel rather strongly that Crutchfield's definitions and formalizations of problems of learning machines remain unsurpassed among current proposals, but I think statistics offers no solution to the problems posed by HCF but simply uses a 'lossy algorithm' to restate a complex problem in a new notation. Quite possibly the solutions to problems posed by Crutchfield's learning machines should be sought in the computational 'processing'

formulations of Wolfram's cellular automata. Using such a system, we could not only describe, but even partially explain why 'minds' and 'brains' work as they do to churn through perceptions to distill knowledge and ferment the whole to yield a yogurt of insight flavored with chunks of understanding. Such figurative speaking, I hope to show, can achieve a concrete realization in the systems of Wolfram and Crutchfield. Such computational systems would provide the underpinnings of the notions of 'complexity', 'recursion', and so on which spill out of the *Science* paper through various leaks in logic and design and here and there by intention of the authors.

Hauser & Co. hold that the definitive difference between humans and 'animals' derives from the fact that the human mental apparatus utilizes 'recursion' but 'animals' do not. BUT! To understand this, we must grasp 'recursion', a well-oiled pig that has been wrestled to the ground by able mathematicians, cyberneticists, and computationally inclined folk only squirm free of sloppy notations and suddenly to pop from our definitional grasp – owing to lack of formalisms generally – and bolt free. According to Chomsky, Humboldt in the 1800s merely grabbed the fleet pig by the tail, but as Chomsky acknowledges in somewhat different words than ours, Humboldt was the first to grab the oinker at all. Alas, slipping though the fingers of the elderly German scholar, it lived to oink on and taunt future generations who sought to understand how humans could make infinite use of finite means.

The recursive pig grunts in three distinct recursive dialects, only distinguishable in large sentences: The least complex dialect offers: (oink oink oink oink oink), the normal dialect offers: (((((oink) oink) oink) oink) oink) or (oink (oink (oink (oink (oink))))); and rumors abound that the recursive pig could say (oink_a (oink_b (oink) oink_b) oink_a), but in fact this 'self-embedded nesting' squeal is never heard. In a very strange argument, sort of like the dog that didn't bark (perhaps because the dog was really a cat, or a finite state grammar), the fact that center embedded recursion never occurs in any human language provides proof that the structure (and computational capacity) exists in all languages but is not used by any speaker. Loosely speaking, Chomsky says this self-embedded recursion remains a grammatical utterance for the recursive piglet, but is not used by the pig. Others, like me, think that human language structures are defined by a finite state grammar running on a rather simple push down storage machine with a fixed (small) number of registers, some of which are content addressable – hence center-embeddings are all but impossible to process except using registers. This is a subject for a later essay, but anyone interested can e-mail me and get an earful. See some figures illustrating 'recursion' in Chomsky's grammar in PROLOG here:

<http://www.nyu.edu/pages/linguistics/f0720w5.html> (left and right recursion)
<http://www.nyu.edu/pages/linguistics/f0801w5.html> (coordinate structure)
<http://www.nyu.edu/pages/linguistics/f0802.wt.html> (subordinate structure)

See also: f0718w5, f0719w5, f0808w5, f0809w5, and look around.

HCF claim that 'Despite their attractive simplicity, such rule systems [finite-state grammars] are inadequate to capture any human language.' (HCF: 1577) I strongly disagree. To see an alternative view, search *INTEX* on Google. The *INTEX* finite state grammar forum is hosted at NYU, administratively by me but contentwise by Max Silberstein. Check also the pages of Cedrick Fairon, who was a post-doc with me for two years. All such proofs were offered in the 1960s or earlier and crucially hinged on the assumption that a language is a set. Since this assumption has been abandoned by HCF (I think), the proofs are no longer relevant for any research – presumably including that of HCF - that does not assume a human language is a set. If you understand the mathematics I am referring to and want to work with me to review and analyze all proofs that attempt to show that the complexity of a human language exceeds the powers of a finite-state grammar, e-mail me. Currently this is my highest priority research project. I particularly

need fluent German speakers since self-embedded recursion takes on a special meaning in languages that can place the verb at the end of the sentence. Papers by Kuno in the 1960-70 period neatly define the special problems of verb-final languages. Anyway, enough about me and my projects, on with the pursuit of the prancing dancing peccary!

Perhaps Wolfram's computational approach can wrestle down the recursive pig so we can slice and dice it into hocks and chitlins until we find the origins of its language capacity, and the dream of Hauser et al, the very source of the recursively echoing oink – apparently the current Holy Grail of brain science. My belief is that a combination of the 'problem statements' and the definitions of Crutchfield about 'learning machines' reanalyzed into the computational CA formalisms of Wolfram will offer a conceptual grasp of 'recursion' (as opposed say to 'iteration') that will relate directly to the concept of 'recursion' used by Hauser et. al. in their analysis of the fine distinction between human and non-human intelligence. The problem statement by Crutchfield and his group of the dazzling array of difficulties faced by a 'learning machine' far surpasses in detail and elegance anything to be found in previous literature. Although Quine and his chums write about 'inductive learning' in wittier prose, they have significantly less to say than does Crutchfield whose papers electrify those interested in the mechanical, logical, mathematical, linguistic, computational, whatever representation of a 'learning machine.' I thoroughly enjoy reading Crutchfield's works. Two especially relevant to the Hauser et. al *Science* paper and this essay are listed here. I am quite familiar with Crutchfield's papers and might be able to point you to a specific one if you are interested in statistical modeling of learning machines.

The Evolution of Emergent Computation: (my students liked this one)

<ftp://ftp.santafe.edu/pub/CompMech/papers/wlboac.pdf>

When Evolution is Revolution – Origins of Innovation:

<http://www.santafe.edu/projects/evca/Papers/evrevinno.html>

Roughly speaking, one might say that 'recursion' introduces a sort of 'redundancy' (and 'ambiguity', 'equivocation', etc.) into a language's structural complexity. Crutchfield's statistical methods and machines measure the *quantity* of the redundancy, but not the quality or type, since the redundancy in the primary data 'loses' something as the statistical algorithms are not 'loss-less' compressions or extractions of redundancy parameters. Wolfram's Cellular Automata measure (or characterize as computations) the *quality* of the redundancy and are 'loss-less'. What is crucial for the study of redundancy (recursion) in linguistics is more the *quality* than the *quantity* of redundancy. A child de-multiplexing the adult language continuously moves through stages at which it reformats the redundancy structures of the language altering the *quality* of the redundancy.

Quite possibly both Wolfram's 'discrete' CA devices and also Crutchfield's 'continuous' statistical induction strategies could characterize in a notation the syntactic and semantic properties of a human language as they are discussed in HCF. Wolfram's devices might be able to capture 'how' a child acquires a language by passing through stages, but I do not see how Crutchfield's devices can do that. Crutchfield's inductive procedures would be 'derailed' if any process or data structure existed at an early stage of language acquisition but was abandoned and rejected at a later stage. For 'commercial' purposes, a Crutchfield-type learning machine might do well, but for studying the unfolding of genetically based maturationally emergent behavior one sees in human language, the complexity of a CA seems more appropriate.

The *Science* article reads more technically than my humble oblique view. My goal here is not to eat and digest the meat, rather, I aim to sink chompers into the jugular. Wolfram-ites should bare their canines and leap to bite into the article when they eye succulent meaty passages like this morsel, given here totally out of context:

We believe that if explorations into the problem of language evolution are to progress, we need a clear explication of the computational requirements for language, the role of evolutionary theory in testing hypotheses of character evolution, and a research program that will enable a productive interchange between linguists and biologists. (HCF: 1570)

The total regularity (deductive, deterministic, algorithmic...) in the irregularities and jumps in behavior that dominate Class III and IV CA come to mind to help explicate passages like this:

...The evolutionary puzzle, therefore, lies in working out how we got from there to here, given this apparent discontinuity [in computational capacity and behavior, RCD]. A second issue revolves around whether the evolution of language was gradual versus saltational; this differs from the first issue because a qualitative discontinuity between extant species could have evolved gradually, involving no discontinuities during human evolution. Finally, the 'continuity versus exaptation' issue revolves around the problem of whether human language evolved by gradual extension of preexisting communication systems, or whether important aspects of language have been exapted away from their previous adaptive function (e.g., spatial or numerical reasoning, Machiavellian social scheming, tool-making). (HCF: 1570)

Let us ignore crucial distinctions as well as fundamental concepts that underlie the *Science* formalization in order to get right to the main point. HCF define the *Faculty of Language* – narrow sense (*FLN*), which 'is the abstract linguistic computational system alone, which is independent of the other systems [of the brain] with which it interacts and interfaces'. (HCF: 1571) They offer a definition of recursion while discussing *FLB*. Basically *FLN* is the recursive computational component of *FLB*:

FLB includes a sensory-motor system, a conceptual-intentional system, and [*FLN*, RCD] the computational mechanisms for recursion, providing the capacity to generate an infinite range of expressions from a finite set of elements. (HCF: 1569)

They give the heart and soul of human mentation and point out the nature of the gulf between human and animal cogitations:

...We hypothesize that *FLN* only includes recursion and is the only uniquely human component of the faculty of language. (HCF: 1569)

...the core recursive aspect of *FLN* currently appears to lack any analog in animal communication and possibly other domains as well. This point, therefore, represents the deepest challenge for a comparative evolutionary approach to language. We believe that investigations of this capacity should include domains other than communication (e.g., number, social relationships, navigation). (HSF: 1571)

...In contrast, we suggest that *FLN* – the computational mechanism of recursion – is recently evolved and unique to our species... (HSF: 1573)

...But only those mechanisms underlying *FLN* – particularly its capacity for discrete infinity – are uniquely human. (HSF: 1573)

The above computationally titillating passages brought a broad, but short lived grin to my face. This next passage almost caused me to choke on my croissant. If you are easily upset by people who glibly pass from recursive rewrite rules to rudimentary finite state processors, be forewarned in order that you do not choke. ‘Complexity’ and ‘computational capacity’ are less than well-defined in the Hauser et al. article. To hire two workers each with an IQ of 70 is not the same as hiring one worker with an IQ of 140. But anyway, let us rush on. Continuing to quote them out of context, we see they state at some point in their extremely well-thought out and logically arranged essay:

At present, however, we see little reason to believe either that *FLN* can be anatomized into many independent but interacting traits, each with its own independent evolutionary history, or that each of these traits could have been strongly shaped by natural selection given their tenuous connection to communicative efficiency (the surface or phenotypic function upon which selection presumably acted). (HSF: 1574)

I can imagine how the recursive processes underlying human language structures can be atomized into a few (buffers mainly) independent but interacting computational mechanisms. Students, colleagues, and fellow travelers could work with me to develop ‘interfaces’ to the *NKS* and *Mathematica* software to permit CA experiments to see the levels of ‘possible complexity’ in models that implement finite state grammars – not on universal machines – but on machines with limited depth, buffer types (structural, content addressable where content can be ‘meaning’ or ‘sound’), and machine architectures (how do the buffers work to pass information around). Of great interest to me is Wolfram’s discussion of how the ‘carry digit’ in a CA adder gets ‘moved’, or perhaps ‘moves by itself’ to the left. This ‘leftward movement’ of a ‘carry digit’ might well bear on the questions involving the ‘odd’ properties of what linguists call ‘*wh*-’ movement. I have not had sufficient time to examine the problem, and worse, I do not quite understand what Wolfram says about the issues. The ‘carry digits’ in a multiplier ‘move leftward’ in a far ‘jumper’ way than they do in an adder, or anyway, so it seems. What would be ‘carry digits’ in a CA that ‘took square roots’? Would they move to the right?

This, to me curious, property of CA that leads to ‘movement’ of complex structures apparently drew Lawrence Gray to use CA to study traffic movement patterns in which cars, and groups of cars, move jerkily as jams form and dissipate for no apparent reason and in response to nothing, although of course, sometimes in response to an accident. While I thoroughly enjoyed Kurzweil’s review of Wolfram’s book (check the web), the most intriguing by far to linguists and cognitive scientists would be that of Gray, which in fact is quite readable.

Gray, Lawrence. (2003) *A Mathematician Looks at Wolfram’s New Kind of Science*. Notices of the AMS, *Journal of the American Mathematical Society*, Vol. 50, N. 2.: 200-211.

Getting back to the *Science* article, the intermediate stages would be finite state grammars with simple push down storage buffers, and the ‘degree’ of intermediacy would be the order of the Markov processes and the nature and architecture of the buffers. Experiments with children and the ill do I not do, preferring to leave such research to the more skilled, the kinder, and the gentler. But I think that one can observe the specific forms of ‘garblement’ in the data structures defined by various sorts of Markov processes aided by an assortment of different memory buffer types when one studies the ‘errors’ of children and the brain damaged. Such people produce a different sort of ‘error’ and ‘deviance’ than do adult second language learners with presumably normal adult

Markov processes and the full array of normal memory buffers, albeit aligned and calibrated to the data structures of their first language.

Extremely strange to select ‘recursion’ (which smacks of infinity) as ‘the’ mental property of humans, especially when in any and all data that have been – or ever can be - observed, the ‘recursive processes’ rarely go much beyond a dozen or so. Twelve nested push down buffers, or thirteen for Bakers, would permit a dozen levels of ‘recursion’. Since with pencil and paper one can do giant recursions, one might think that ‘recursion’, relying on external aids for ‘deep’ cases, reflects performance. Who cares? I do. I study these things.

So, why do I like Wolfram’s CA? Mainly because CA enables us to see that perhaps the issue of ‘saltation’ (jumps) versus ‘continuity’ reflect an underlying Class III or IV automaton – and our lack of understanding of the computational processes of human cognition – more than any ‘real’ discontinuity in the data. Questions to be looked at include such exciting cocktail party conversation openers as: (A) What is recursion in Cellular Automata and how does it differ from iteration? (B) A personal favorite to kick off a conversation: How do Cellular Automata fare when characterizing the stages of signal processing capacity for a time domain multiplexer? (C) What would be the ‘complexity’ of a language that was defined by a Markov grammar with order 0, 1, 2, 3, 4... and with 0, 1, 2, 3... memory buffers (to handle center-embeddings)? While such questions might bring stars to the eyes of those who have Wolfram’s Summer Institute 2004 circled on their calendar, they do not normally generate interest. I read these questions aloud and people moved away from me on the subway. Wolfram’s stuff, despite its ‘best-seller’ aura, still has not reached the level of popular banter. But that, perhaps, is because using existing language structures, people only talk to people and do not try to lower their levels of recursion in order to permit discussions with squirrels, rodents, fish, birds, and pigeons – the latter often approach us squawking iteratively but not recursively, perhaps? Perhaps? Perhaps trying to engage us in non-recursive discourse structures? To rub elbows and sip suds with CA enthusiasts who keep conversation churning late into the night by asking questions like the above, be sure to attend NKS2004. I thoroughly enjoyed the NKS2003 shindig in Waltham.

<http://www.wolframscience.com/conferene/2004>

So what do I want to find students to do? Simple. I am interested in finding students who, as said in the *Science* article, think ‘that an understanding of the faculty of language requires substantial interdisciplinary cooperation.’ (HSF: 1569) I need folks who can understand how to ‘formalize’ the ideas of biologists, ethologist, psychologists, linguists, and so on into the problem statements posed today mainly by Crutchfield in term of ‘learning machines’, but earlier in terms of ‘self-reproducing machines’ by Weiner, von Neuman, and so on. When the problems are ‘properly formulated’ –usually in terms of data structures and statistics – we will offer possible ‘solutions’ in terms of cellular automata and computational processes.

Wolfram’s system enables one to formalize the computational mechanisms that underly the possible ‘continuous’, ‘saltational’, ‘regular’, ‘discontinuous’, and so on data structures one observes in development of animal and human intelligence *in a single organism* moving from the egg to the grave. A swimming pollywog has three degrees of freedom of movement, a frog only two –it cannot go straight up. A creepy crawly caterpillar has two degree of freedom of movement, but when linearly, deductively, and deterministically metamorphosed into a butterfly by a genetic Wolfram-like Cellular Automata commands three. The cognitive system of the ‘wog loses a degree as it loses it tail, but the ‘pillar gains a degree as it sheds its many legs for wings. The sensory system of a caterpillar involves taste and touch, but a butterfly orients itself by ‘stereoscopic smell’ having a ‘nose’ at the end of each antenna. Such cognitive saltations – in a single animal and

governed by DNA/RNA (Wolfram CA) genetics - are totally normal in the animal kingdom, and in observing the human language system, we see a lulu first hand. If we could 'see' the language organ of a human being, it would go from a pollywog, to a frog, to a... and eventually to a medusa-like item. But it is not 'visually' seeable, rather it remains only 'cognitively' sensible. The human mental apparatus develops by jerks, starts, and stops in such a convoluted and contorted way (giving rise to multiplex data structures) such that if we could 'see it' it would make the tadpole to frog transition or the 'pillar to 'fly metamorphosis look trivial.

There seems to be no 'scale' of 'developmental complexity' in emergent behavior and structure in a single egg-to-grave animal generally accepted by all, but if there were, and 0 meant 'simplest', perhaps an amoeba splitting, then as we passed the normal animal kingdom and dealt with the 'wog/frog type animals, this *metamorphosis problem* might be called a 'lulu'. Going farther out, we encounter genetically governed maturationally emergent behavior in the human passing from toddler to taxpayer, and this would define the *multiplex problem*, a 'lalapalooza'. I wish to develop such a scale of complexity by incorporating into cognitive study the formalisms from cybernetics, following the lead of Konrad Lorenz and Niko Tinbergen, and to use the mathematics of communication theory (Shannon, Weiner) and self-reproducing machines (von Neuman, Weiner) to study the relation of adult human language to the semiotic performance data available from children, the ill, and the leaping and creeping of the animal kingdom. While I agree with much of Wolfram's analysis of these people, here and there I think his view offers only an oblique glimpse of their work. When I read Wolfram's summaries of previous researchers that looked at data like his, I often think back to the letters from the 1600's in which the Pope discussed Martin Luther. It is a style that discusses other people and points out that even if they are right they are wrong, not because they are wrong, but because they cannot be right. But this is for another time.

For those not in the know and who could not immediately define any and all terms in this essay, you should run, not walk, to get: Richard L. Gregory. (latest paper edition). *The Oxford Companion to the Mind*. Oxford University Press.

To do justice to the ideas presented in this essay one would have to cast the whole business in the Semiotic and Pragmatic perspective of C.S. Peirce. An excellent introduction to Peirce, is the biography by Joseph Brent. 1993. *Charles Sanders Peirce: A Life*. Indiana University Press. I have studied Peirce more than any other scholar and find him an unending source of remarkable ideas. As odd as the combination may seem, the only other person in all history that I think might have been like Peirce was St. Augustine back in 400AD. Quite different life styles of course. But obsessed by the same questions. My favorite work by St. Augustine is *The Master*, a thoroughly linguistic text that analyzes what is today called 'autonomous syntax'. St. Augustine presents a curious 'dialogue' with his son Adeodatus that basically goes over many of the issues in Plato's *Meno*. *The Master* appears to be a document written to honor Adeodatus after the boy died.

Rumor has it that when Kant was first told about Newton's theory of gravity and planetary movements, he responded that Newton's theory had nothing to do with the solar system but told us how our minds grapple with data concerning movements. According to some biographers, Kant first interpreted the gravitation theory as a theory of human perception and cognition, not as a theory of 'things' and how they 'really' moved. I thoroughly enjoy reading Wolfram's notes, but disagree here and there a little, some places a lot, and almost totally with much of the gab on 1125-1127. Quite possibly Wolfram has a theory of human/animal perception and cognition (the CA being the primitive operators) and not a Cartesian-like theory of the mechanism underlying 'things' outside us. The recent translation of Descartes' works by Cottingham et al. from Cambridge I

consider superb. The idea that the world is a 'machine' held by Wolfram has much in common with the view of Descartes. Strongly recommended are these. My students liked the biography.

Cottingham, Stoothoff, Murdoch, and Kenny. 1991. *The Philosophical Writings of Descartes*, Vol. I, II, and III. Cambridge University Press.

Gaukroger, 1995. *Descartes: An intellectual biography*. Oxford University Press.

I also like the Logical Based language (PROgramming in LOGic, PROLOG), see <http://www.nyu.edu/pages/linguistics/anlcbk.html> and massively parallel processors. I published an introductory book (*Natural Language Computing*, Erlbaum Press) showing how to program Chomsky's grammar into PROLOG. All the software (free) is on the website. This savvy book, a paragon of excellence that cleanly merges form and function, neatly defines all technical terms in a witty piquant sauce full of facts and examples – although some bigoted and biased reviewers less objective than I am did not see it this way. I concede, however, that some did have a point. Eons ago, I published a book, quite formal and mathematical for those that like formalisms, dealing with 'digital/analog interfacing':

Stanley, William, Gary Dougherty, and Ray Dougherty. 1984. *Digital Signal Processing*. Prentice Hall.

I enjoyed the Wolfram Bash 2003 in Waltham, Mass. During the day I absorbed Wolfram-isms, but during the night I stayed in Cambridge with Lyle Jenkins chatting about many things, including biolinguistics. For those interested in the state of the art, this book by Jenkins figures into the presentation in *Science* by HCF.

Jenkins, Lyle. 2001. *Biolinguistics: Exploring The Biology of the Brain*. Cambridge University Press.

Putting it all together, I want, or need, students who can ~~do my work for me~~ program Wolfram's automata onto parallel processors - using PROLOG perhaps - in order to solve what once were called problems in 'self-reproducing machines' but slyly pass today under the moniker 'computer and machine learning' or as 'animal intelligence'. Basically, I think that a human language presents a multiplex data base (three levels of multiplexing), the adult is a multiplexer (hence all the redundancy, ambiguity, and regularity among the irregularities in adult language) and the child (passing through stages of selective structure blindness) is a time domain de-multiplexer. Roughly speaking, the 2nd level of multiplexing is 'coordinate' structures (iteration) and the 3rd level is 'subordinate' structures (recursion). We must differentiate coordinate (*He smokes but is not dead yet*) recursion from subordinate (*Although he smokes, he is not dead yet*) recursion. In German, with *obwohl*, the verb jumps to the end, hence, subordinate, but with *aber* does not, and so on into linguistic arcana. According to the psychologist Luria, there are brain damaged patients that can understand 'but' constructions but not 'although' constructions, and that can understand 'John's brother' but not 'the brother of John'. One (coordination, iteration, juxtaposition) is 'less complex' than the other (subordination, recursion, embedding).

If my ideas were sketched by a cartoonist, I would have a grinning but terrified well-oiled pig running into a conceptual net (a crisp definition of 'learning machines') held taught by Crutchfield, and have Wolfram perched ready to stab and butcher it with a spear that morphs into a knife looking all the while like the behavior of a Class III cellular automata, with Hauser, Chomsky, and Fitch pointing and yelling, 'Gavagai! Lo, the recursive pig!' Perhaps Quine looking down from a cloud searchingly at the horizon might say: 'Was that Noam Chomsky calling "Gavagai!"? Was 'Gavagai' used appropriately in context?'

On good days, when my research progresses nicely, I imagine the pig looking more terrified with less of a grin. But on days when even Wolfram's computational tools for dealing with the incomprehensible seem to leave pockets of incomprehensibility amid the order – giving me the sensation that I have eaten a delicious but sandy oyster – I imagine the piglet with a toothy sneering grin and a less terrified mellower demeanor. Although the greased pig may escape to pose challenges for future generations of computational linguists, I have the feeling that we are much closer to catching the rascal than in the past. If, as Chomsky claims (sort of) Humboldt working alone managed to grab the tail single handedly a century ago, quite possibly the unlikely SWAT team of Hauser, Chomsky, Fitch, Crutchfield, and Wolfram may each be able to seize a leg, enabling one of them to more firmly grasp the tail, or crunchingly grab some other part that might truly impede its motion and hinder its escape.

Me, myself, and I

Personally: I have a BS and MS in Electrical Engineering, and studied control, guidance, and navigation systems at the MIT Instrumentation Lab way back then when the I-Lab still was. I studied cash flow accounting related to bond and currency trading at Tuck Business School for a year, but left to go study Linguistics at the University of Munich. Returning to the US, I earned through blood, sweat, and tears a PhD in Linguistics at MIT, where I worked with Noam Chomsky on aspects of recursion, mainly in coordinate (iterative) structures. I have been at NYU thirty so years. On a Fulbright to Salzburg, Austria I met and briefly worked with Konrad Lorenz at Altenberg in 1976. I worked with him again for a short time in 1979. I attended Wolfram's lecture at Courant Institute at NYU and immediately bought two copies of his vastly overweight book, one for the office and one for home, since it is too big to carry around. I did not buy one for the car because I heard that there will be a Spoken Arts cassette with Woody Allen reading Wolfram's book.

There are strong parallels between the work and career trajectories of Rene Descartes and Wolfram, but that I leave for a future essay should there be anyone interested in 17th century math, science, and Descartes' sweaty unbridled wild passion (for math and science), gossip, and turmoil in the years when the recursive pig roamed free and undetected merely leaving footprints and soil in various manuscripts. I have gathered all the dirt and am ready to share it with you. Let me know if you have any interest in, for instance, Pascal and the pig: ray.dougherty@nyu.edu. In any and all e-mail, place the sequence 'greased-pig' in the subject line, and do not use the words 'increase' or 'enlarge' anywhere in your letter, although 'decrease', 'diminish', 'shrink' and various cognates, synonyms, and hyponyms will not be speared by the NYU Spam detector.

I teach graduate and undergraduate classes on the above topics at New York University Linguistics Department (linguistics@nyu.edu). I wrote this essay in response to letters I have received from the Wolfram forum from CA enthusiasts who wanted to know what I did with the automata. I adopted the style of writing of the essay in response to a lunch I had with some NYU film students who wondered if anyone could ever make an interesting movie about anything in linguistics. While I thought cognitive science abounded with classical 'hero' types and one might simply make an encyclopedic documentary or a Platonic epic, most students thought we would need some 'external' – like the spelling spider in Charlotte's Web – to produce a hit, hence, the cognitive recursive pig. The following graduate class offers a more orthodox kosher view.

<http://www.nyu.edu/pages/linguistics/CA/G611025.pdf>

How to lose friends and alienate everybody with ~~your, their, our~~ whose? computer
Or
How interdisciplinary research on brains snags on interdepartmental barriers
Or
An 'Iceberg' warning blast to fellow professors

Over the years I have used computers in my research and teaching (Fortran, Algol, C, AWK, SED, UNIX, LISP, HTML, CGI, PERL, PROLOG, and on and on). In all past cases, my students could share usage of a PC or MAC with other students. After 15 or so minutes, a student programming in LISP for example, could stop and let another student use the machine, and then later come back to what they were doing. One might even politely compile C code in the background while other students glacially ran foreground tasks. PROLOG, utilizing mainly massive exhaustive searches of data bases, often taxed the machine, but still one student could share usage with another. If you have students in a class all trying to run Wolfram's *NKS* or *Mathematica* to experiment with Cellular Automata, be forewarned that even a 'simple' (this might not be definable in CA research) experiment can run on a fast machine for an hour – and you cannot interrupt it without loss of everything, and it does not run in the background. Also, if one runs an experiment overnight to search out a thousand or so iterations, the file produced ends up in the gigabyte range, and, AND!: As one should have been able to guess reading the book, the file is almost guaranteed not to compress using any known algorithm. Hence, a student almost needs a dedicated machine with an immense hard drive (200 gig) to run this stuff if they are going to do serious research on the types of questions raised in this essay. And these only scratch the surface. Write me for some real brain teasers.

Until students get the hang of it (six weeks for stone cold beginners, two weeks for a LISP programmer), the student often has to sit in front of the machine for the hour(s) it computes since at any time the MathKernel may suffer some injustice and flash you a message that you must respond to in order to continue.

Although participants from assorted departments show enthusiasm for studying 'recursion' – an apparent focal point of modern brain studies at Harvard and MIT - the persons in charge of department computer resources balk at 'outsiders' coming in to their department and hogging all the CPU time and disk space running 'alien' software. My own research and teaching has hit this *iceberg floating between departments* that crushes and sinks efforts at interdisciplinary research: Which department must fund the resources to host the computer programs? Which department is ready to allocate 2 hours of CPU time per student per day and dedicate 10 or 20 gigabytes of disc space per student to students from *another* department or school? One could easily have a class of twenty students. Posed thusly, while rabidly endorsing interdisciplinary research in the abstract, department chairs will not all raise their hands at once. I completely understand.

For reasons I agree with totally, the *NKS* software in the Linguistics Department at NYU will be removed from the computers in the syntax-semantics laboratory Nov. 10, a few weeks before final exams, so that the machines will be usable by everyone. In many smaller colleges, students would be at a loss – sunk by the interdepartmental iceberg. Luckily NYU, a major research university, offers extensive resources. Fortunately the Courant Institute at NYU, and some other divisions, have immense computer power that our students can use. *NKS* research is massively computer and memory intensive if one begins to investigate questions involving the relative complexity of various finite state grammars with an assortment of memory buffer structures.

When you decide to use *NKS* – and you ~~should~~ must if you want to begin to grasp the materials in the Hauser, Chomsky, and Fitch paper – think seriously of asking the dean, that generous soul, for a \$2,000 computer. I can give you specific advice about the particular configuration I use. NYU provided me with basically a 2.8 gig Pentium 4, 1 gig ram, two built in 80 gig drives, 10 external 200gig firewire drives, 3 external USB drives, a dual head graphics card, and two 19 inch monitors connected as one big screen. The machine was built optimized for video editing, which is not surprising since CA amounts basically to a visual system. This does a slick job. If you go external hard drives, go firewire and not USB. Although they must daisy chain, each becomes basically a network drive. If students want to run programs and save their work, you should think of a R/W DVD drive, but this writing process is s-l-o-w. An external 40-80 gig USB drive runs about \$100, and suits most students very well. Some of my students have bought such devices already for backups and so on.

Anyway, do not think you will simply load the *NKS* software on the IBM PC's in your department and all will be honky dory. What will happen in your department when students from other departments and divisions start to use all of your department's computer resources? This tiny *NKS* program thinks big.

My recommendation for professors who want to get their feet wet with students but not step on the toes of their colleagues is this. Buy one or more portables (Toshiba Satellite: 2455-S305, \$1899 list (really 1600) is superb and writes DVDs). One portable will serve 5-8 students if they work on projects in groups. You need no dedicated space, and further, students can learn to give presentations on the portable. I recently supervised the installation of 5 of these Toshibas and can heartily recommend them without any qualification. I personally use Compaq/HP portables in my own research since I am basically a 'hardware' person and admire the circuit design and board configurations of the Com/HP devices. I have bought Dell equipment, but beware, it is hard to upgrade Dell equipment without buying Dell products. You cannot just easily buy a 200gig Maxtor and plunk it in. I am one of the sorry folks who struggled with the infamous Dell L800r, a Pentium III 800 gig machine that was condemned by its designers to have a max limit of a 10 gig hard drive and no possibility of installing a second hard drive. I now have a \$700 door stop. Dell? Once burned, twice shy.

Currently my Wolfram-stuff classes only have 3-4 students who *seriously* use the software and perhaps another 20-30 that dabble. If I had 20 students working on finite state grammars, I do not know what machines they could use. I'm looking into this and would welcome suggestions.

I do not offer any 'correspondence' type courses, and never will, although I am happy to help students with their research over the Internet. There is little doubt in my mind however that one could develop a graduated web-based soup-to-nuts correspondence course to teach Wolfram's CA, and in particular, to show how CA play a role in explicating theories of mind and language. In such a situation, each student would presumably have their own computational devices.

NYU Linguistics Department

NYU is in the heart of Greenwich Village in New York City. Our graduate department has limited openings for students wishing to obtain a PhD in linguistics and to study materials like that in the *Science* article in our state-of-the-art syntax-semantics laboratory. We can occasionally specially configure the computers in the syntax-semantics lab to run 'alien' – read *NKS* - software in order to pursue issues, like those posed by Hauser, Chomsky, and Fitch to study 'questions concerning the computations underlying this system, such as those underlying recursion'. (HCF: 1569) NYU's Courant Institute and Computer Science Department count among the best in the world. All

students accepted into our graduate program are given full tuition and support throughout their PhD studies. Interested students should contact arto.antilla@nyu.edu, Director of Graduate Study.

NYU's Common Enterprise Initiative

Recently President John Sexton of New York University offered his views of *The role of faculty in the common enterprise university*. http://www.nyu.edu/president/faculty_enterprise President Sexton's definition of the 'Common Enterprise University' includes a vision of cognitive science in which linguistics, philosophy, and psychology interact productively to forge a new view of traditional problems. We hope at NYU to establish a forum for research into the language faculty that will accord with the basic ideas of Marc D. Hauser and W. Tecumseh Fitch (both Harvard Psychology) and Noam Chomsky (MIT Linguistics and Philosophy), when they say: 'We argue that an understanding of the faculty of language requires substantial interdisciplinary cooperation. We suggest how current developments in linguistics can be profitably wedded to work in evolutionary biology, anthropology, psychology, and neuroscience. (HCF: 1569) A fusion of disciplines following their suggestion can readily be accommodated at NYU following President Sexton's suggestions for the Common Enterprise Research University.

President Sexton states:

Knowledge creation requires subjecting ideas to scrutiny and review - and the university provides the broadest, deepest and most immediate forum for a rich array of conversations and criticism. Even as it observes and enforces the established norms of the disciplines, the university by its very nature is a rebuke to intellectual silos, in its essence insisting on the widest and most rigorous exploration and testing of ideas. The methods of research integral to one field carry over to others; what is taken as orthodoxy within one discipline must be revisited in the light of insights gained elsewhere. So, for example, the disciplines of philosophy, linguistics and psychology were seed ground for cognitive science, only to find themselves transformed in turn by it. This is not unusual; indeed, the general lesson is that when disciplines engage seriously with each other, the influence typically is reciprocal and the benefits mutual.

And there is something more, an explicit connection of knowledge creation to knowledge transmission. The great researcher is in command of advanced materials and a subject at an advanced level, and that command is tested and developed in an ability to convey it not only to peers but to students at all levels. Teaching is not merely a matter of passing on information; it is the act of engaging students in a field, in a frame of mind, in a spirit of inquiry and the excitement of the creative endeavor. As knowledge creators hone their thoughts in teaching students, both advanced and novice, so also students delight in witnessing knowledge creators at work. And through their interactions with leading scholars and artists, students at research universities have direct access to new breakthroughs as they occur — with some even joining the creative process early in their careers. This is a defining premise of the research university: the affirmative integration of knowledge creation and knowledge transmission at all levels in a rich and synthetic engagement, a multilayered immersion in the world of ideas and the growth of knowledge. (Sexton: 4)

Following President Sexton's Common Enterprise Initiative, we are forming a research group composed of undergraduate and graduate students, post-doctoral students, alumni, and faculty from NYU and outside colleges to facilitate the involvement of students into the processes of creation and transmission of knowledge in the cognitive sciences. We expect to host the *Journal of Psycholinguistic Research* in the Linguistics Department, and students will work to process the submitted manuscripts, reviewers' comments, and so on to gain a hands-on understanding of the professional process of dissemination of information via refereed journals. We plan events at which current students can interact informally with recent and less recent alumni to help them become

involved in ongoing research and to facilitate the transition from student to professional, from students of the professor to peers of the professor, to colleagues engaged in the creation and dissemination of knowledge. Many alumni of the Linguistics Department are actively engaged in research and hold major research positions or are Professors at colleges in the New York Metropolitan area.

Prof. Ray Dougherty (NYU Linguistics), Prof. Robert Rieber (John Jay Psychology), and Prof. Murray Alpert (NYU Medical) - and alumni too numerous to mention - constitute the current organizing committee. Initially this triumvirate plus alumni will do the organizing, but as soon as possible, we hope to have it become totally governed by alumni from cognitive science departments in the New York Area. A main mandate of the group is to set up informal situations in which undergraduate and graduate students can interact one-on-one with alumni who are professionals in the field the students are contemplating entering. We are currently forming this group, and if you would like to become an active part, or simply be on our mailing list, contact rwieber@yahoo.com or rcd2@nyu.edu with the phrase 'students-alumni' in the subject field.