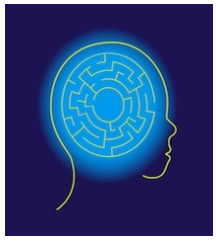
On Chomsky and the Two Cultures of Statistical Learning

At the Brains, Minds, and Machines symposium held during MIT's 150th birthday party in 2011, Technology Review reports that Prof. Noam Chomsky


MIT: 150

> derided researchers in machine learning who use purely statistical methods to produce behavior that mimics something in the world, but who don't try to understand the meaning of that behavior.

The transcript is now available, so let's quote Chomsky himself:

> It's true there's been a lot of work on trying to apply statistical models to various linguistic problems. I think there have been some successes, but a lot of failures. There is a notion of success ... which I think is novel in the history of science. It interprets success as approximating unanalyzed data.

Chomsky's remarks were in response to Steven Pinker's question about the success of probabilistic models trained with statistical methods. This essay is a response to Pinker and Chomsky, and will address these questions:


Noam Chomsky

1. What did Chomsky mean, and is he right?
2. What is a statistical model?
3. How successful are statistical language models?
4. Is there anything like their notion of success in the history of science?
5. What doesn't Chomsky like about statistical models?

What did Chomsky mean, and is he right?

I take Chomsky's points to be the following:

A. Statistical language models have had engineering success, but that is irrelevant to science.
B. Accurately modeling linguistic facts is just butterfly collecting; what matters in science (and specifically linguistics) is the underlying principles.
C. Statistical models are incomprehensible; they provide no insight.
D. Statistical models may provide an accurate simulation of some phenomena, but the simulation is done completely the wrong way; people don't decide what the third word of a sentence should be by consulting a probability table keyed on the previous words, rather they map from an internal semantic form to a syntactic tree-structure, which is then linearized into words. This is done without any probability or statistics.
E. Statistical models have been proven incapable of learning language; therefore language must be innate, so why are these statistical modelers wasting their time on the wrong enterprise?

Is he right? That's a long-standing debate. These are my short answers:

A. I agree that engineering success is not the sole goal or the measure of science. But I observe that science and engineering develop together, and that engineering success shows that something is working right, and so is evidence (but not proof) of a scientifically successful model.
B. Science is a combination of gathering facts and making theories; neither can progress on its own. In the history of science, the laborious accumulation of facts is the dominant mode, not a novelty. The science of understanding language is no different than other sciences in this respect.
C. I agree that it can be difficult to make sense of a model containing billions of parameters. Certainly a human can't understand such a model by inspecting the values of each parameter individually. But one can gain insight by examing the *properties* of the model—where it succeeds and fails, how well it learns as a function of data, etc.

D. I agree that a Markov model of word probabilities cannot model all of language. It is equally true that a concise tree-structure model without probabilities cannot model all of language. What is needed is a probabilistic model that covers words, syntax, semantics, context, discourse, etc. Chomsky dismisses all probabilistic models because of shortcomings of a particular 50-year old probabilistic model. I understand how Chomsky might arrive at the conclusion that probabilistic models are unnecessary, from his study of the *generation* of language. But the vast majority of people who study *interpretation* tasks (such as speech recognition) quickly see that interpretation is an inherently probabilistic problem: given a stream of noisy input to my ears, what did the speaker most likely mean? Einstein said to make everything as simple as possible, but no simpler. Many phenomena in science are stochastic, and the simplest model of them is a probabilistic model; I believe language is such a phenomenon and therefore that probabilistic models are our best tool for representing facts about language, for algorithmically processing language, and for understanding how humans process language.
E. In 1967, Gold's Theorem showed some theoretical limitations of logical deduction on formal mathematical languages. But this result has nothing to do with the task faced by learners of natural language. In any event, by 1969 we knew that probabilistic inference (over probabilistic context-free grammars) is not subject to those limitations (Horning showed that learning of PCFGs is possible). I agree with Chomsky that it is undeniable that humans have some innate capability to learn natural language, but we don't know enough about that capability to say how it works; it certainly could use something like probabilistic language representations and statistical learning. And we don't know if the innate ability is specific to language, or is part of a more general ability that works for language and other things.

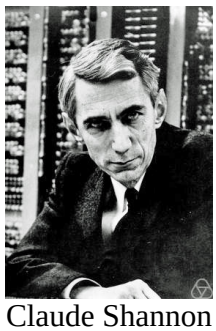
The rest of this essay consists of longer versions of each answer.

What is a statistical model?

A **statistical model** is a mathematical model which is modified or trained by the input of data points. Statistical models are often but not always probabilistic. Where the distinction is important we will be careful not to just say "statistical" but to use the following component terms:

- A **mathematical model** specifies a relation among variables, either in functional form that maps inputs to outputs (e.g. $y = m\,x + b$) or in relation form (e.g. the following (x, y) pairs are part of the relation).
- A **probabilistic model** specifies a probability distribution over possible values of random variables, e.g., $P(x, y)$, rather than a strict deterministic relationship, e.g., $y = f(x)$.
- A **trained model** uses some training/learning algorithm to take as input a collection of possible models and a collection of data points (e.g. (x, y) pairs) and select the best model. Often this is in the form of choosing the values of parameters (such as m and b above) through a process of statistical inference.

For example, a decade before Chomsky, Claude Shannon proposed probabilistic models of communication based on Markov chains of words. If you have a vocabulary of 100,000 words and a second-order Markov model in which the probability of a word depends on the previous two words, then you need a quadrillion (10^{15}) probability values to specify the model. The only feasible way to learn these 10^{15} values is to gather statistics from data and introduce some smoothing method for the many cases where there is no data. Therefore, most (but not all) probabilistic models are trained. Also, many (but not all) trained models are probabilistic.


Claude Shannon

As another example, consider the Newtonian model of gravitational attraction, which says that the force between two objects of mass m_1 and m_2 a distance r apart is given by

$$F = G\,m_1\,m_2 / r^2$$

where G is the universal gravitational constant. This is a trained model because the gravitational constant G is determined by statistical inference over the results of a series of experiments that contain stochastic experimental error. It is also a deterministic (non-probabilistic) model because it states an

exact functional relationship. I believe that Chomsky has no objection to this kind of statistical model. Rather, he seems to reserve his criticism for statistical models like Shannon's that have quadrillions of parameters, not just one or two.

(This example brings up another distinction: the gravitational model is **continuous** and **quantitative** whereas the linguistic tradition has favored models that are **discrete**, **categorical**, and **qualitative**: a word is or is not a verb, there is no question of its degree of verbiness. For more on these distinctions, see Chris Manning's article on Probabilistic Syntax.)

A relevant probabilistic statistical model is the ideal gas law, which describes the pressure P of a gas in terms of the the number of molecules, N, the temperature T, and Boltzmann's constant, K:

$$P = N k T / V.$$

The equation can be derived from first principles using the tools of statistical mechanics. It is an uncertain, incorrect model; the *true* model would have to describe the motions of individual gas molecules. This model ignores that complexity and *summarizes* our uncertainty about the location of individual molecules. Thus, even though it is statistical and probabilistic, even though it does not completely model reality, it does provide both good predictions and insight—insight that is not available from trying to understand the *true* movements of individual molecules.

Now let's consider the non-statistical model of spelling expressed by the rule "*I before E except after C.*" Compare that to the probabilistic, trained statistical model:

```
P(IE) = 0.0177        P(CIE) = 0.0014        P(*IE) = 0.163
P(EI) = 0.0046        P(CEI) = 0.0005        P(*EI) = 0.0041
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This model comes from statistics on a corpus of a trillion words of English text. The notation P(IE) is the probability that a word sampled from this corpus contains the consecutive letters "IE." P(CIE) is the probability that a word contains the consecutive letters "CIE", and P(*IE) is the probability of any letter other than C followed by IE. The statistical data confirms that IE is in fact more common than EI (by almost 4 to 1), and that the dominance of IE lessens when following a C, but contrary to the rule, CIE is still more common than CEI, by almost 3 to 1. Examples of "CIE" words include "science," "society," "ancient" and "species." The disadvantage of the "I before E except after C" model is that it is not very accurate. Consider:

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Accuracy("I before E") = 0.0177/(0.0177+0.0046) = 0.793
Accuracy("I before E except after C") = (0.0005+0.0163)/(0.0005+0.0163+0.0014+0.0041) = 0.753
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A more complex statistical model (say, one that gave the probability of all 4-letter sequences, and/or of all known words) could be ten times more accurate at the task of spelling, but does not offer concise **insight** into how spelling works. Insight would require a model that knows about phonemes, syllabification, and language of origin. Such a model could be trained (or not) and probabilistic (or not).

As another example of insight, consider the Theory of Supreme Court Justice Hand-Shaking: when the supreme court convenes, all attending justices shake hands with every other justice. The number of attendees, n, must be an integer in the range 0 to 9; what is the total number of handshakes, h for a given n? Here are three possible explanations:

A. Each of n justices shakes hands with the other n - 1 justices, but that counts Alito/Breyer and Breyer/Alito as two separate shakes, so we should cut the total in half, and we end up with $h = n \times (n - 1) / 2$.
B. To avoid double-counting, we will order the justices by seniority and only count a more-senior/more-junior handshake, not a more-junior/more-senior one. So we count, for each justice, the shakes with the more junior justices, and sum them up, giving $h = \Sigma_{i = 1 \,..\, n} (i - 1)$.
C. Just look at this table:

n:	0	1	2	3	4	5	6	7	8	9
h:	0	0	1	3	6	10	15	21	28	36

Some people might prefer A, some might prefer B, and if you are slow at doing multiplication or addition you might prefer C. Why? All three explanations describe *exactly the same theory* — the same function from *n* to *h*, over the entire domain of possible values of *n* (as long as there are no more than 9 supreme court justices). Thus we could prefer A (or B) over C only for reasons other than the theory itself. We might find that A or B gave us a better understanding of the problem. A and B are certainly more useful than C for figuring out what happens if Congress exercises its power to add an additional justice. Theory A might be most helpful in developing a theory of handshakes at the end of a hockey game (when each player shakes hands with players on the opposing team) or in proving that the number of people who shook an odd number of hands at the MIT Symposium is even.

How successful are statistical language models?

Chomsky said words to the effect that statistical language models have had some limited success in some application areas. Let's look at computer systems that deal with language, and at the notion of "success" defined by "making accurate predictions about the world." First, the major application areas:

- **Search engines:** 100% of major players are trained and probabilistic. Their operation cannot be described by a simple function.
- **Speech recognition:** 100% of major systems are trained and probabilistic, mostly relying on probabilistic hidden Markov models.
- **Machine translation:** 100% of top competitors in competitions such as NIST use statistical methods. Some commercial systems use a hybrid of trained and rule-based approaches. Of the 4000 language pairs covered by machine translation systems, a statistical system is by far the best for every pair except Japanese-English, where the top statistical system is roughly equal to the top hybrid system.
- **Question answering:** this application is less well-developed, and many systems build heavily on the statistical and probabilistic approach used by search engines. The IBM Watson system that recently won on Jeopardy is thoroughly probabilistic and trained, while Boris Katz's START is a hybrid. All systems use at least some statistical techniques.

Now let's look at some components that are of interest only to the computational linguist, not to the end user:

- **Word sense disambiguation:** 100% of top competitors at the SemEval-2 competition used statistical techniques; most are probabilistic; some use a hybrid approach incorporating rules from sources such as Wordnet.
- **Coreference resolution:** The majority of current systems are statistical, although we should mention the system of Haghighi and Klein, which can be described as a hybrid system that is mostly rule-based rather than trained, and performs on par with top statistical systems.
- **Part of speech tagging:** Most current systems are statistical. The Brill tagger stands out as a successful hybrid system: it learns a set of deterministic rules from statistical data.
- **Parsing:** There are many parsing systems, using multiple approaches. Almost all of the most successful are statistical, and the majority are probabilistic (with a substantial minority of deterministic parsers).

Clearly, it is inaccurate to say that statistical models (and probabilistic models) have achieved *limited* success; rather they have achieved an *overwhelmingly dominant* (although not exclusive) position.

Another measure of success is the degree to which an idea captures a community of researchers. As Steve Abney wrote in 1996, "In the space of the last ten years, statistical methods have gone from being virtually unknown in computational linguistics to being a fundamental given. ... anyone who cannot at least use the terminology persuasively risks being mistaken for kitchen help at the ACL [Association for Computational Linguistics] banquet."

Now of course, the majority doesn't rule -- just because everyone is jumping on some bandwagon, that doesn't make it right. But I made the switch: after about 14 years of trying to get language models to work using logical rules, I started to adopt probabilistic approaches (thanks to pioneers like Gene Charniak (and Judea Pearl for probability in general) and to my colleagues who were early adopters, like

Dekai Wu). And I saw everyone around me making the same switch. And I didn't see anyone going in the other direction. We all saw the limitations of the old tools, and the benefits of the new.

And while it may seem crass and anti-intellectual to consider a financial measure of success, it is worth noting that the intellectual offspring of Shannon's theory create several trillion dollars of revenue each year, while the offspring of Chomsky's theories generate well under a billion.

This section has shown that one reason why the vast majority of researchers in computational linguistics use statistical models is an *engineering* reason: statistical models have state-of-the-art performance, and in most cases non-statistical models perform worst. For the remainder of this essay we will concentrate on *scientific* reasons: that probabilistic models better represent linguistic facts, and statistical techniques make it easier for us to make sense of those facts.

Is there anything like it [the statistical notion of success] in the history of science?

When Chomsky said "*That's a notion of [scientific] success that's very novel. I don't know of anything like it in the history of science*" he apparently meant that the notion of success of "accurately modeling the world" is novel, and that the only true measure of success in the history of science is "providing insight" — of answering *why* things are the way they are, not just describing *how* they are.

A dictionary definition of science is "the systematic study of the structure and behavior of the physical and natural world through observation and experiment," which stresses accurate modeling over insight, but it seems to me that both notions have always coexisted as part of doing science. To test that, I consulted the epitome of doing science, namely *Science*. I looked at the current issue and chose a title and abstract at random:

> Chlorinated Indium Tin Oxide Electrodes with High Work Function for Organic Device Compatibility
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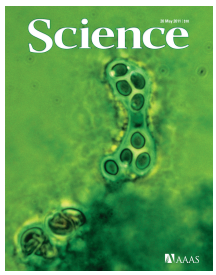
> 
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> In organic light-emitting diodes (OLEDs), a stack of multiple organic layers facilitates charge flow from the low work function [~4.7 electron volts (eV)] of the transparent electrode (tin-doped indium oxide, ITO) to the deep energy levels (~6 eV) of the active light-emitting organic materials. We demonstrate a chlorinated ITO transparent electrode with a work function of >6.1 eV that provides a direct match to the energy levels of the active light-emitting materials in state-of-the art OLEDs. A highly simplified green OLED with a maximum external quantum efficiency (EQE) of 54% and power efficiency of 230 lumens per watt using outcoupling enhancement was demonstrated, as were EQE of 50% and power efficiency of 110 lumens per watt at 10,000 candelas per square meter.

It certainly seems that this article is much more focused on "accurately modeling the world" than on "providing insight." The paper does indeed fit in to a body of theories, but it is mostly reporting on specific experiments and the results obtained from them (e.g. efficiency of 54%).

I then looked at all the titles and abstracts from the current issue of *Science*:

- Comparative Functional Genomics of the Fission Yeasts
- Dimensionality Control of Electronic Phase Transitions in Nickel-Oxide Superlattices
- Competition of Superconducting Phenomena and Kondo Screening at the Nanoscale
- Chlorinated Indium Tin Oxide Electrodes with High Work Function for Organic Device Compatibility
- Probing Asthenospheric Density, Temperature, and Elastic Moduli Below the Western United States
- Impact of Polar Ozone Depletion on Subtropical Precipitation
- Fossil Evidence on Origin of the Mammalian Brain
- Industrial Melanism in British Peppered Moths Has a Singular and Recent Mutational Origin
- The Selaginella Genome Identifies Genetic Changes Associated with the Evolution of Vascular Plants

- Chromatin "Prepattern" and Histone Modifiers in a Fate Choice for Liver and Pancreas
- Spatial Coupling of mTOR and Autophagy Augments Secretory Phenotypes
- Diet Drives Convergence in Gut Microbiome Functions Across Mammalian Phylogeny and Within Humans
- The Toll-Like Receptor 2 Pathway Establishes Colonization by a Commensal of the Human Microbiota
- A Packing Mechanism for Nucleosome Organization Reconstituted Across a Eukaryotic Genome
- Structures of the Bacterial Ribosome in Classical and Hybrid States of tRNA Binding

and did the same for the current issue of *Cell*:

- Mapping the NPHP-JBTS-MKS Protein Network Reveals Ciliopathy Disease Genes and Pathways
- Double-Strand Break Repair-Independent Role for BRCA2 in Blocking Stalled Replication Fork Degradation by MRE11
- Establishment and Maintenance of Alternative Chromatin States at a Multicopy Gene Locus
- An Epigenetic Signature for Monoallelic Olfactory Receptor Expression
- Distinct p53 Transcriptional Programs Dictate Acute DNA-Damage Responses and Tumor Suppression
- An ADIOL-ERβ-CtBP Transrepression Pathway Negatively Regulates Microglia-Mediated Inflammation
- A Hormone-Dependent Module Regulating Energy Balance
- Class IIa Histone Deacetylases Are Hormone-Activated Regulators of FOXO and Mammalian Glucose Homeostasis

and for the 2010 Nobel Prizes in science:

- Physics: *for groundbreaking experiments regarding the two-dimensional material graphene*
- Chemistry: *for palladium-catalyzed cross couplings in organic synthesis*
- Physiology or Medicine: *for the development of in vitro fertilization*

My conclusion is that 100% of these articles and awards are more about "accurately modeling the world" than they are about "providing insight," although they all have some theoretical insight component as well. I recognize that judging one way or the other is a difficult ill-defined task, and that you shouldn't automatically accept my judgements, because I may have an inherent bias. (I was considering running an experiment on Mechanical Turk to get an unbiased answer, but those familiar with Mechanical Turk told me these questions are probably too hard for the average Turker. So you the reader can do your own experiment and see if you agree.)

What doesn't Chomsky like about statistical models?

I said that statistical models are sometimes confused with probabilistic models; let's first consider the extent to which Chomsky's objections are actually about probabilistic models. In 1969 he famously wrote:

> But it must be recognized that the notion of "probability of a sentence" is an entirely useless one, under any known interpretation of this term.

His main argument being that, under any interpretation known to him, the probability of a novel sentence must be zero, and since novel sentences are in fact generated all the time, there is a contradiction. The resolution of this contradiction is of course that it is not necessary to assign a probability of zero to a novel sentence; in fact, with current probabilistic models it is standard practice to do smoothing and assign a non-zero probability to novel occurrences. So this criticism is invalid, but was very influential for decades. Previously, in *Syntactic Structures* (1957) Chomsky wrote:

> I think we are forced to conclude that ... probabilistic models give no particular insight into some of the basic problems of syntactic structure.

In the footnote to this conclusion he considers the possibility of a useful probabilistic/statistical model, saying "I would certainly not care to argue that ... is unthinkable, but I know of no suggestion to this effect that does not have obvious flaws." The main "obvious flaw" is this: Consider:

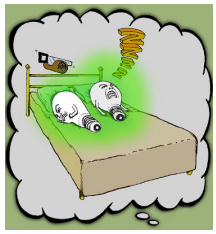
1. **I** never, ever, ever, ever, ... **fiddle** around in any way with electrical equipment.
2. **She** never, ever, ever, ever, ... **fiddles** around in any way with electrical equipment.
3. * **I** never, ever, ever, ever, ... **fiddles** around in any way with electrical equipment.
4. * **She** never, ever, ever, ever, ... **fiddle** around in any way with electrical equipment.

No matter how many repetitions of "ever" you insert, sentences 1 and 2 are grammatical and 3 and 4 are ungrammatical. A probabilistic Markov-chain model with *n* states can never make the necessary distinction (between 1 or 2 versus 3 or 4) when there are more than *n* copies of "ever." Therefore, a probabilistic Markov-chain model cannot handle all of English.

This criticism is correct, but it is a criticism only of Markov-chain models, not of probabilistic models (or trained models) in general. Since 1957 we have seen many types of probabilistic language models beyond the Markov-chain word models. Examples 1-4 above can in fact be distinguished with a finite-state model that is not a chain, but other examples require more sophisticated models. The best studied is probabilistic context-free grammar (PCFG), which operates over trees, categories of words, and individual lexical items, and has none of the restrictions of finite-state models. We find that PCFGs are state-of-the-art for parsing performance and are easier to learn from data than nonprobabilistic categorical context-free grammars. Other types of probabilistic models cover semantic and discourse structures.

Every probabilistic model is a superset of a deterministic model (because the deterministic model could be seen as a probabilistic model where the probabilities are restricted to be 0 or 1), so any valid criticism of probabilistic models would have to be because they are too expressive, not because they are not expressive enough.

In *Syntactic Structures*, Chomsky introduces a now-famous example that is another criticism of finite-state probabilistic models:



> Neither (a) 'colorless green ideas sleep furiously' nor (b) 'furiously sleep ideas green colorless', nor any of their parts, has ever occurred in the past linguistic experience of an English speaker. But (a) is grammatical, while (b) is not.

Chomsky appears to be correct that neither sentence appeared in the published literature before 1955. I'm not sure what he meant by "any of their parts," but certainly every two-word part had occurred, for example:

- "It is neutral green, **colorless green**, like the glaucous water lying in a cellar." The Paris we remember, Elisabeth Finley Thomas (1942).
- "To specify those **green ideas** is hardly necessary, but you may observe Mr. [D. H.] Lawrence in the role of the satiated aesthete." The New Republic: Volume 29 p. 184, William White (1922).
- "**Ideas sleep** in books." Current Opinion: Volume 52, (1912).

But regardless of what is meant by "part," a statistically-trained finite-state model *can* in fact distinguish between these two sentences. Pereira (2001) showed that such a model, augmented with word categories and trained by expectation maximization on newspaper text, computes that (a) is 200,000 times more probable than (b). To prove that this was not the result of Chomsky's sentence itself sneaking into newspaper text, I repeated the experiment, using a much cruder model with Laplacian smoothing and no categories, trained over the Google Book corpus from 1800 to 1954, and found that (a) is about 10,000 times more probable. If we had a probabilistic model over trees as well as word sequences, we could perhaps do an even better job of computing degree of grammaticality.

Furthermore, the statistical models are capable of delivering the judgment that both sentences are *extremely* improbable, when compared to, say, "Effective green products sell well." Chomsky's theory, being categorical, cannot make this distinction; all it can distinguish is grammatical/ungrammatical.

Another part of Chomsky's objection is "we cannot seriously propose that a child learns the values of 10^9 parameters in a childhood lasting only 10^8 seconds." (Note that modern models are much larger than the 10^9 parameters that were contemplated in the 1960s.) But of course nobody is proposing that these parameters are learned one-by-one; the right way to do learning is to set large swaths of near-zero parameters simultaneously with a smoothing or regularization procedure, and update the high-probability parameters continuously as observations comes in. Nobody is suggesting that Markov models by themselves are a serious model of human language performance. But I (and others) suggest that probabilistic, trained models are a better model of human language performance than are categorical, untrained models. And yes, it seems clear that an adult speaker of English does know billions of language facts (a speaker knows many facts about the appropriate uses of words in different contexts, such as that one says "the big game" rather than "the large game" when talking about an important football game). These facts must somehow be encoded in the brain.

It seems clear that probabilistic models are better for judging the likelihood of a sentence, or its degree of sensibility. But even if you are not interested in these factors and are only interested in the grammaticality of sentences, it still seems that probabilistic models do a better job at describing the linguistic facts. The *mathematical* theory of formal languages defines a language as a set of sentences. That is, every sentence is either grammatical or ungrammatical; there is no need for probability in this framework. But natural languages are not like that. A *scientific* theory of natural languages must account for the many phrases and sentences which leave a native speaker uncertain about their grammaticality (see Chris Manning's article and its discussion of the phrase "as least as"), and there are phrases which some speakers find perfectly grammatical, others perfectly ungrammatical, and still others will flip-flop from one occasion to the next. Finally, there are usages which are rare in a language, but cannot be dismissed if one is concerned with actual data. For example, the verb *quake* is listed as intransitive in dictionaries, meaning that (1) below is grammatical, and (2) is not, according to a categorical theory of grammar.

1. The earth quaked.
2. ? It quaked her bowels.

But (2) actually appears as a sentence of English. This poses a dilemma for the categorical theory. When (2) is observed we must either arbitrarily dismiss it as an error that is outside the bounds of our model (without any theoretical grounds for doing so), or we must change the theory to allow (2), which often results in the acceptance of a flood of sentences that we would prefer to remain ungrammatical. As Edward Sapir said in 1921, "All grammars leak." But in a probabilistic model there is no difficulty; we can say that *quake* has a high probability of being used intransitively, and a low probability of transitive use (and we can, if we care, further describe those uses through subcategorization).

Steve Abney points out that probabilistic models are better suited for modeling language change. He cites the example of a 15th century Englishman who goes to the pub every day and orders "Ale!" Under a categorical model, you could reasonably expect that one day he would be served eel, because the great vowel shift flipped a Boolean parameter in his mind a day before it flipped the parameter in the publican's. In a probabilistic framework, there will be multiple parameters, perhaps with continuous values, and it is easy to see how the shift can take place gradually over two centuries.

Thus it seems that grammaticality is not a categorical, deterministic judgment but rather an inherently probabilistic one. This becomes clear to anyone who spends time making *observations* of a corpus of actual sentences, but can remain unknown to those who think that the object of study is their own set of *intuitions* about grammaticality. Both observation and intuition have been used in the history of science, so neither is "novel," but it is observation, not intuition that is the dominant model for science.

Now let's consider what I think is Chomsky's main point of disagreement with statistical models: the tension between "accurate description" and "insight." This is an old distinction. Charles Darwin (biologist, 1809–1882) is best known for his insightful theories but he stressed the importance of accurate description, saying "False facts are highly injurious to the progress of science, for they often endure long; but false views, if supported by some evidence, do little harm, for every one takes a salutary pleasure in proving their falseness." More recently, Richard Feynman (physicist, 1918–1988) wrote "Physics can progress without the proofs, but we can't go on without the facts."

On the other side, Ernest Rutherford (physicist, 1871–1937) disdained mere description, saying "All science is either physics or stamp collecting." Chomsky stands with him: "You can also collect butterflies and make many observations. If you like butterflies, that's fine; but such work must not be confounded with research, which is concerned to discover explanatory principles."


Butterflies

Acknowledging both sides is Robert Millikan (physicist, 1868–1953) who said in his Nobel acceptance speech "Science walks forward on two feet, namely theory and experiment ... Sometimes it is one foot that is put forward first, sometimes the other, but continuous progress is only made by the use of both."

The two cultures

After all those distinguished scientists have weighed in, I think the most relevant contribution to the current discussion is the 2001 paper by Leo Breiman (statistician, 1928–2005), Statistical Modeling: The Two Cultures. In this paper Breiman, alluding to C. P. Snow, describes two cultures:


Leo Breiman

First the **data modeling culture** (to which, Breiman estimates, 98% of statisticians subscribe) holds that nature can be described as a black box that has a relatively simple underlying model which maps from input variables to output variables (with perhaps some random noise thrown in). It is the job of the statistician to wisely choose an underlying model that reflects the reality of nature, and then use statistical data to estimate the parameters of the model.

Second the **algorithmic modeling culture** (subscribed to by 2% of statisticians and many researchers in biology, artificial intelligence, and other fields that deal with complex phenomena), which holds that nature's black box cannot necessarily be described by a simple model. Complex algorithmic approaches (such as support vector machines or boosted decision trees or deep belief networks) are used to estimate the function that maps from input to output variables, but we have no expectation that the *form* of the function that emerges from this complex algorithm reflects the true underlying nature.

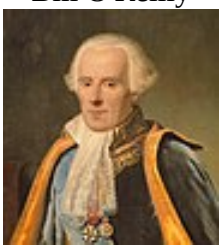
It seems that the algorithmic modeling culture is what Chomsky is objecting to most vigorously. It is not just that the models are statistical (or probabilistic), it is that they produce a form that, while accurately modeling reality, is not easily interpretable by humans, and makes no claim to correspond to the generative process used by nature. In other words, algorithmic modeling describes what *does* happen, but it doesn't answer the question of *why*.

Breiman's article explains his objections to the first culture, data modeling. Basically, the conclusions made by data modeling are about the model, not about nature. (Aside: I remember in 2000 hearing James Martin, the leader of the Viking missions to Mars, saying that his job as a spacecraft engineer was not to land on Mars, but to land on the model of Mars provided by the geologists.) The problem is, if the model does not emulate nature well, then the conclusions may be wrong. For example, linear regression is one of the most powerful tools in the statistician's toolbox. Therefore, many analyses start out with "Assume the data are generated by a linear model..." and lack sufficient analysis of what happens if the data are not in fact generated that way. In addition, for complex problems there are usually many alternative good models, each with very similar measures of goodness of fit. How is the data modeler to choose between them? Something has to give. Breiman is inviting us to give up on the idea that we can uniquely model the true underlying *form* of nature's function from inputs to outputs. Instead he asks us to be satisfied with a function that accounts for the observed data well, and generalizes to new, previously unseen data well, but may be expressed in a complex mathematical form that may bear no relation to the "true" function's form (if such a true function even exists). Chomsky takes the opposite approach: he prefers to keep a simple, elegant model, and give up on the idea that the model will represent the data well. Instead, he declares that what he calls *performance* data—what people actually do—is off limits to linguistics; what really matters is *competence*—what he imagines that they should do.

In January of 2011, television personality Bill O'Reilly weighed in on more than one culture war with his statement "*tide goes in, tide goes out. Never a miscommunication. You can't explain that*," which he

proposed as an argument for the existence of God. O'Reilly was ridiculed by his detractors for not knowing that tides can be readily and concisely explained by a system of partial differential equations describing the gravitational interaction of sun, earth, and moon (a fact that was first worked out by Laplace in 1776 and has been considerably refined since; when asked by Napoleon why the creator did not enter into his calculations, Laplace said "I had no need of that hypothesis."). (O'Reilly also seems not to know about Deimos and Phobos (two of my favorite moons in the entire solar system, along with Europa, Io, and Titan), nor that Mars and Venus orbit the sun, nor that the reason Venus has no moons is because it is so close to the sun that there is scant room for a stable lunar orbit.)

Bill O'Reilly


Laplace

But O'Reilly realizes that it doesn't matter what his detractors think of his astronomical ignorance, because his supporters think he has gotten exactly to the key issue: *why?* He doesn't care *how* the tides work, tell him *why* they work. *Why* is the moon at the right distance to provide a gentle tide, and exert a stabilizing effect on earth's axis of rotation, thus protecting life here? *Why* does gravity work the way it does? *Why* does anything at all exist rather than not exist? O'Reilly is correct that these *why* questions can only be addressed by mythmaking, religion or philosophy, not by science.

Chomsky has a philosophy based on the idea that we should focus on the deep *whys* and that mere explanations of reality don't matter. In this, Chomsky is in complete agreement with O'Reilly. (I recognize that the previous sentence would have an extremely low probability in a probabilistic model trained on a newspaper or TV corpus.) Chomsky believes a theory of language should be simple and understandable, like a linear regression model where we know the underlying process is a straight line, and all we have to do is estimate the slope and intercept.

For example, consider the notion of a pro-drop language from Chomsky's Lectures on Government and Binding (1981). In English we say, for example, "I'm hungry," expressing the pronoun "I". But in Spanish, one expresses the same thought with "Tengo hambre" (literally "have hunger"), dropping the pronoun "Yo". Chomsky's theory is that there is a "pro-drop parameter" which is "true" in Spanish and "false" in English, and that once we discover the small set of parameters that describe all languages, and the values of those parameters for each language, we will have achieved true understanding.

The problem is that reality is messier than this theory. Here are some dropped pronouns in English:


Dana Carvey

- "Not gonna do it. Wouldn't be prudent." (Dana Carvey, impersonating George H. W. Bush)
- "Thinks he can outsmart us, does he?" (Evelyn Waugh, The Loved One)
- "Likes to fight, does he?" (S.M. Stirling, The Sunrise Lands)
- "Thinks he's all that." (Kate Brian, Lucky T)
- "Go for a walk?" (countless dog owners)
- "Gotcha!" "Found it!" "Looks good to me!" (common expressions)

Linguists can argue over the interpretation of these facts for hours on end, but the diversity of language seems to be much more complex than a single Boolean value for a pro-drop parameter. We shouldn't accept a theoretical framework that places a priority on making the model simple over making it accurately reflect reality.

From the beginning, Chomsky has focused on the *generative* side of language. From this side, it is reasonable to tell a non-probabilistic story: I *know* definitively the idea I want to express—I'm starting from a single semantic form—thus all I have to do is choose the words to say it; why can't that be a deterministic, categorical process? If Chomsky had focused on the other side, *interpretation*, as Claude Shannon did, he may have changed his tune. In interpretation (such as speech recognition) the listener receives a noisy, ambiguous signal and needs to decide which of many possible intended messages is most likely. Thus, it is obvious that this is inherently a probabilistic problem, as was recognized early on by all researchers in speech recognition, and by scientists in other fields that do interpretation: the astronomer Laplace said in 1819 "Probability theory is nothing more than common sense reduced to calculation," and the physicist James Maxwell said in 1850 "The true logic for this world is the calculus

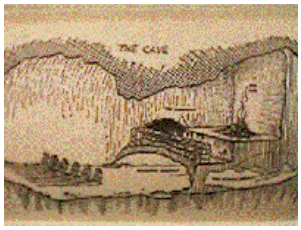
of Probabilities, which takes account of the magnitude of the probability which is, or ought to be, in a reasonable man's mind."

Finally, one more reason why Chomsky dislikes statistical models is that they tend to make linguistics an empirical science (a science about how people actually use language) rather than a mathematical science (an investigation of the mathematical properties of *models* of formal language, not of language itself). Chomsky prefers the later, as evidenced by his statement in *Aspects of the Theory of Syntax* (1965):

> Linguistic theory is mentalistic, since it is concerned with discovering a mental reality underlying actual behavior. Observed use of language ... may provide evidence ... but surely cannot constitute the subject-matter of linguistics, if this is to be a serious discipline.

I can't imagine Laplace saying that observations of the planets cannot constitute the subject-matter of orbital mechanics, or Maxwell saying that observations of electrical charge cannot constitute the subject-matter of electromagnetism. It is true that physics considers idealizations that are abstractions from the messy real world. For example, a class of mechanics problems ignores friction. But that doesn't mean that friction is not considered part of the subject-matter of physics.

So how could Chomsky say that observations of language cannot be the subject-matter of linguistics? It seems to come from his viewpoint as a Platonist and a Rationalist and perhaps a bit of a Mystic. As in Plato's allegory of the cave, Chomsky thinks we should focus on the ideal, abstract forms that underlie language, not on the superficial manifestations of language that happen to be perceivable in the real world. That is why he is not interested in language performance. But Chomsky, like Plato, has to answer where these ideal forms come from. Chomsky (1991) shows that he is happy with a Mystical answer, although he shifts vocabulary from "soul" to "biological endowment."



Plato's cave

> Plato's answer was that the knowledge is 'remembered' from an earlier existence. The answer calls for a mechanism: perhaps the immortal soul ... rephrasing Plato's answer in terms more congenial to us today, we will say that the basic properties of cognitive systems are innate to the mind, part of human biological endowment.

It was reasonable for Plato to think that the ideal of, say, a horse, was more important than any individual horse we can perceive in the world. In 400BC, species were thought to be eternal and unchanging. We now know that is not true; that the horses on another cave wall—in Lascaux—are now extinct, and that current horses continue to evolve slowly over time. Thus there is no such thing as a single ideal eternal "horse" form.


Lascaux Horse

We also now know that language is like that as well: languages are complex, random, contingent biological processes that are subject to the whims of evolution and cultural change. What constitutes a language is not an eternal ideal form, represented by the settings of a small number of parameters, but rather is the contingent outcome of complex processes. Since they are contingent, it seems they can only be analyzed with probabilistic models. Since people have to continually understand the uncertain, ambiguous, noisy speech of others, it seems they must be using something like probabilistic reasoning. Chomsky for some reason wants to avoid this, and therefore he must declare the actual facts of language use out of bounds and declare that true linguistics only exists in the mathematical realm, where he can impose the formalism he wants. Then, to get language from this abstract, eternal, mathematical realm into the heads of people, he must fabricate a mystical facility that is exactly tuned to the eternal realm. This may be very interesting from a mathematical point of view, but it misses the point about what language is, and how it works.

Thanks

Thanks to Ann Farmer, Fernando Pereira, Dan Jurafsky, Hal Varian, and others for comments and suggestions on this essay.

Annotated Bibliography

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   An excellent overall introduction to the statistical approach to language processing, and covers some ground that is not addressed often, such as language change and individual differences.

2. Breiman, Leo (2001) Statistical Modeling: The Two Cultures, *Statistical Science*, Vol. 16, No. 3, 199-231.

   Breiman does a great job of describing the two approaches, explaining the benefits of his approach, and defending his points in the vary interesting commentary with eminent statisticians: Cox, Efron, Hoadley, and Parzen.

3. Chomsky, Noam (1956) Three Models for the Description of Language, *IRE Transactions on Information theory* (2), pp. 113-124.

   Compares finite state, phrase structure, and transformational grammars. Introduces "colorless green ideas sleep furiously."

4. Chomsky, Noam (1967) Syntactic Structures, Mouton.

   A book-length exposition of Chomsky's theory that was the leading exposition of linguistics for a decade. Claims that probabilistic models give no insight into syntax.

5. Chomsky, Noam (1969) Some Empirical Assumptions in Modern Philosophy of Language, in *Philosophy, Science and Method: Essays in Honor or Ernest Nagel*, St. Martin's Press.

   Claims that the notion "probability of a sentence" is an entirely useless notion.

6. Chomsky, Noam (1981) Lectures on government and binding, de Gruyer.

   A revision of Chomsky's theory; this version introduces Universal Grammar. We cite it for the coverage of parameters such as pro-drop.

7. Chomsky, Noam (1991) Linguistics and adjacent fields: a personal view, in Kasher (ed.), *A Chomskyan Turn*, Oxford.

   I found the Plato quotes in this article, published by the Communist Party of Great Britain, and apparently published by someone with no linguistics training whatsoever, but with a political agenda.

8. Gold, E. M. (1967) Language Identification in the Limit, *Information and Control*, Vol. 10, No. 5, pp. 447-474.

   Gold proved a result in formal language theory that we can state (with some artistic license) as this: imagine a game between two players, guesser and chooser. Chooser says to guesser, "Here is an infinite number of languages. I'm going to choose one of them, and start reading sentences to you that come from that language. On your N-th birthday there will be a True-False quiz where I give you 100 sentences you haven't heard yet, and you have to say whether they come from the language or not." There are some limits on what the infinite set looks like and on how the chooser can pick sentences (he can be deliberately tricky, but he can't just repeat the same sentence over and over, for example). Gold's result is that if the infinite set of languages are all generated by context-free grammars then there is no strategy for guesser that guarantees she gets 100% correct every time, no matter what N you choose for the birthday. This result was taken by Chomsky and others to mean that it is impossible for children to learn human languages without having an innate "language organ."

As Johnson (2004) and others show, this was an invalid conclusion; the task of getting 100% on the quiz (which Gold called language identification) really has nothing in common with the task of language acquisition performed by children, so Gold's Theorem has no relevance.

9. Horning, J. J. (1969) A study of grammatical inference, Ph.D. thesis, Stanford Univ.

   Where Gold found a negative result—that context-free languages were not identifiable from examples, Horning found a positive result—that probabilistic context-free languages are identifiable (to within an arbitrarily small level of error). Nobody doubts that humans have unique innate capabilities for understanding language (although it is unknown to what extent these capabilities are specific to language and to what extent they are general cognitive abilities related to sequencing and forming abstractions). But Horning proved in 1969 that Gold cannot be used as a convincing argument for an innate language organ that specifies all of language except for the setting of a few parameters.

10. Johnson, Kent (2004) Gold's Theorem and cognitive science, *Philosophy of Science*, Vol. 71, pp. 571-592.

    The best article I've seen on what Gold's Theorem actually says and what has been claimed about it (correctly and incorrectly). Concludes that Gold has something to say about formal languages, but nothing about child language acquisition.

11. Lappin, Shalom and Shieber, Stuart M. (2007) Machine learning theory and practice as a source of insight into universal grammar., *Journal of Linguistics*, Vol. 43, No. 2, pp. 393-427.

    An excellent article discussing the poverty of the stimulus, the fact that all models have bias, the difference between supervised and unsupervised learning, and modern (PAC or VC) learning theory. It provides alternatives to the model of Universal Grammar consisting of a fixed set of binary parameters.

12. Manning, Christopher (2002) Probabilistic Syntax, in Bod, Hay, and Jannedy (eds.), *Probabilistic Linguistics*, MIT Press.

    A compelling introduction to probabilistic syntax, and how it is a better model for linguistic facts than categorical syntax. Covers "the joys and perils of corpus linguistics."

13. Norvig, Peter (2007) How to Write a Spelling Corrector, unpublished web page.

    Shows working code to implement a probabilistic, statistical spelling correction algorithm.

14. Norvig, Peter (2009) Natural Language Corpus Data, in Seagran and Hammerbacher (eds.), *Beautiful Data*, O'Reilly.

    Expands on the essay above; shows how to implement three tasks: text segmentation, cryptographic decoding, and spelling correction (in a slightly more complete form than the previous essay).

15. Pereira, Fernando (2002) Formal grammar and information theory: together again?, in Nevin and Johnson (eds.), *The Legacy of Zellig Harris*, Benjamins.

    When I set out to write the page you are reading now, I was concentrating on the events that took place in Cambridge, Mass., 4800 km from home. After doing some research I was surprised to learn that the authors of two of the three best articles on this subject sit within a total of 10 meters from my desk: Fernando Pereira and Chris Manning. (The third, Steve Abney, sits 3700 km away.) But perhaps I shouldn't have been surprised. I remember giving a talk at ACL on the corpus-based language models used at Google, and having Fernando, then a professor at U. Penn., comment

"I feel like I'm a particle physicist and you've got the only super-collider." A few years later he moved to Google. Fernando is also famous for his quote "The older I get, the further down the Chomsky Hierarchy I go." His article here covers some of the same ground as mine, but he goes farther in explaining the range of probabilistic models available and how they are useful.

16. Plato (c. 380BC) The Republic.

    Cited here for the allegory of the cave.

17. Shannon, C.E. (1948) A Mathematical Theory of Communication, *The Bell System Technical Journal*, Vol. 27, pp. 379-423.

    An enormously influential article that started the field of information theory and introduced the term "bit" and the noisy channel model, demonstrated successive n-gram approximations of English, described Markov models of language, defined entropy with respect to these models, and enabled the growth of the telecommunications industry.

Peter Norvig

SIH
6 years ago

I think the debate was about understanding the nature of intelligence. Interestingly the arguments of Mr Norvig move to Why vs How debate. Reminds me of the extremely popular ted talk about "How Leaders Inspire Action" where Simon Sinek focuses on the "Why" being more important than How or What. Is Mr Norvig's argument "Stupid is as stupid does" in Forrest Gump. Is the success of google in pulling out sensible meanings of "physicist Issac Newton" means that the retrieval system is intelligent?

29 0 Reply • Share ›

Vijay L
12 years ago

> if Vijay thinks I was condescending, I sincerely apologize.

I didn't.

29 0 Reply • Share ›

guest
12 years ago

Found a small typo:
"concise tree-structure model without
probabilities cannot model of all language"
did you mean model *all of* language

I'll be looking for my 2.56 in the mail.

17 0 Reply • Share ›

Peter Norvig Mod → guest
12 years ago

A check for $2.56 made out to "guest" has been issued from the First National Bank of Bayes.

59 0 Reply • Share ›

Paul Kinarsky

10 years ago

I'd like to make a general point about rules versus statistical generalizations, illustrating it with your example of the rule "i before e except after c". You take it as being about the order of these letters in English words generally. I rather think it is intended as a rule of thumb about the choice of "ie" or "ei" as a spelling of the vowel [i:], a difficulty for learners. On this narrower understanding, it is actually rather accurate: for example, "bier", "achieve", "mien", "tier", "Siemens", "field", "fierce", "lien", "mien", "pier", "Nietzsche", "Riesling", versus "ceiling", "receipt", "conceive". The residue of idiosyncratic exceptions is relatively small: "weird", "weir", "Neil", "seize", and "(n)either", if you pronounce it with [i:].

Words like "science," "society," "ancient" and "species" are then not exceptions. Neither are words like "deign", "reign", "eight", "feint", "feisty", "feign", "heist", "seismic", "Geiger", "neighbor", "neigh", "Meissen", "reify", "reimburse", "vein", "skein", "Einstein". Everybody understands that such words don't fall under the "i before e except after c" rule, but are covered by other spelling conventions, probably not taught but implicitly learned. From the pronunciation of "vein", and "reify", for example, we can be pretty sure that they are not spelled "vien" and "riefy".

The general point is that a hierarchical rule system --- general rules ("i before e") superseded by special rules ("except after c") and finally by individual exceptions ("weird") --- is a useful and natural way to present grammatical information concisely. That's why it is used in practical grammars. Moreover, a lot of work, beginning with Panini (ca. 500 BC) and continuing with generative grammar, shows that it also leads to deep theoretical insights about the organization of language. Do statistical models have comparable results to show?

16 0 Reply • Share ›

Ralph Dratman ↗ Paul Kiparsky

6 years ago

Nobody mentioned the last, key clause of the mnemonic poem: "Except when it sounds like A, as in neighbor and weigh."

0 0 Reply • Share ›

Atalay

10 years ago

Regarding the point about Newton's derivation of the gravitational constant, had Newton, instead of driving an equation, ran a brute force information processing algorithm on his empirical measurements and generated a black box statistical gravitational model such that given the masses of the objects and their distance, the model predicted the gravitational force with some error, I think the analogy would have been more convincing.
It is quite likely that Newton obtained the gravitational constant by statistical methods. But it seems to me that Newton's model of gravitational attraction was not intended to characterize the universal gravitational constant. It was intended to capture the relationship between objects masses, their distance and the gravitational force that acts upon them. The formula is considered to be a monumental scientific discovery because it makes this relationship quite clear. In fact, it does so quite elegantly by relying only on elemetary mathematics, one may argue.
My understanding of Chomsky's view is that, an equation that reveals an underlying natural phenomena is a discovery from scientific point of view, but a black box system is not regardless of how sucessful it is.

12 0 Reply ● Share ›

T **Theo Pavlidis**

12 years ago

Modern statistical models are the descendants of empirical models. Compare Kepler's model of the solar system with Newton's theory of gravity. The current language models correspond to the former. I take Chomsky's comment to mean that we do not have anything for language like Newton's theory. Of course Newton could not have developed his theory without Kepler's model that "compressed" a huge amount of astronomical observations to three empirical laws.

As an aside, science usually follows engineering. Thermodynamics came into existence after the steam engine and, in Mathematics, the Theory of Distributions came after the work of Heavyside who once said "I am not going to stop eating because I do not understand the process of digestion".

12 1 Reply ● Share ›

C **Charles Reiss**

10 years ago

I suggest taking a look at Chomsky's 1986 Knowledge of Language and 2000 New Horizons in the Study of Language and Mind if you want to know what he actually means by "mentalistic". Contrary to your interpretation, Chomsky is strongly empirical when it comes to studying the human language faculty. This is reflected in one of my favorite quotations from Knowledge of Language, below. What the quote reveals is the connection between Chomsky's internalism (languages are things inside of people's minds) and his universalism (UG--the idea that there IS a human language faculty). S$_0$, sometimes called Universal Grammar, is the initial state of the human language faculty, before exposure to a particular linguistic system, basically before birth.

"Because evidence from Japanese can evidently bear on the correctness of a theory of S$_0$, it can have indirect---but very powerful-- bearing on the choice of the grammar that attempts to characterize the I-language attained by a speaker of English." [Chomsky 1986 p.38]

The quotation means that we can have several extensionally equivalent models of an English type grammar, E1, E2, etc., , each built from a different candidate for the correct theory of UG, that is UG1, UG2, etc., respectively. Since, by hypothesis, the models are extensionally equivalent--they each generate the same corpora--NO NEW ENGLISH DATA CAN HELP US DECIDE AMONG E1, E2, etc. The insight shown in the quotation actually just makes explicit what linguists have alway

see more

5 0 Reply ● Share ›

N **Novice**

11 years ago

As a novice, may I present one slightly off-topic set of questions?

Regarding the study of languages, would it be worthwhile to focus on purpose - communication of meaning - a bit more than structure and mechanism? Yes, we have grammar as a motif, with syntax as a mechanism and semantics as sometimes a cause, sometimes an effect in terms of the way language is used. But what about a slightly different perspective such as mapping the ways meaning can be generated by languages rather than just the specifics of syntax and semantics? That is, by including more would we eventually have more tools available for the effort?

This would be more qualitative and less amenable to computer analysis, at present, but is there

This would be more qualitative and less amenable to computer analysis, at present, but is there potential value in the further development of semiotics as an analytical method of language study and comparison?

As an example where syntax and semantics might be confounded, please consider the meaningful but ungrammatical Dinah Washington song title, "Is you or is you ain't my baby?"

5 0 Reply • Share ›

Дмитрий Зеленский Novice

6 years ago

Chomsky does not believe that communication of meaning is the primary purpose of language to begin with - nor do I, considering how inaccurate it is for that task. The perspective you describe is widely used by typologists and some functionalists, which does not make it the right perspective.

0 0 Reply • Share ›

G

guest Novice

11 years ago

The lyrics are: Is you IS or is you ain't my baby? Even more ungrammatical (in a probabilistic interpretation).
(Sorry to be 7 months late; I just came by the Norvig essay via a current (i.e. Nov 2012) article in Atlantic Magazine about Chomsky.)

0 0 Reply • Share ›

Barbara H Partee

12 years ago edited

I'd like to suggest a distinction that might be useful to make in addressing the formal linguists. You wrote,

"But the vast majority of people who study interpretation tasks, such as speech recognition, quickly see that interpretation is an inherently probabilistic problem: given a stream of noisy input to my ears, what did the speaker most likely mean?"

That's one kind of interpretation task (I'll call it the 'real-world interpretation task'), and I guess it's the central one for applications. Another interpretation problem is this: given a stream of input, what are the possible things the speaker could have meant? (Of course it's non-trivial to formulate this question in a useful way -- it's natural to make idealizations both about the input stream and about the 'competence' of the speaker, but I don't want to get into such topics, since that could seem to be suggesting that this is about whether to ignore real-world data or not.) I'd like to see inclusion of a version of the interpretation problem that reflects my own work as a working formal semanticist and is not inherently more probabilistic than the formal 'generation task' (which, by the way, has very little in common with the real-world sentence production task, a task that is probably just as probabilistic as the real-world interpretation task).

You've said in your replies to earlier comments that you plan to write a follow-up essay centered on the thesis that the best model for explaining long-ago is a probabilistic model. I think that's the

see more

7 1 Reply • Share ›

Peter Norvig Mod Barbara H Partee

12 years ago

12 years ago

Thanks, Barbara. I meant to include some of your very interesting comments at the Symposium, but couldn't find room -- maybe for the next piece, as you suggest.

I support your notion of merging efforts. I think different communities will have different priorities, and thus different emphasis on what they do, but there is a chance to bring them together where there is overlap.Google does not use formal semantic analysis of the kind you work on for search queries, because the language we see in search queries is so far removed from full grammatical sentences. (If you see mostly 3 words or so for a query, you don't have to worry about nested embedded clauses, etc.) We are starting to experiment with more serious semantic analysis for understanding text in documents which does have grammatical structure.

2 0 Reply • Share ›

Barbara H Partee ➚ Peter Norvig

12 years ago

Thanks.
I had neglected to post my own symposium comments anywhere; at Mark Liberman's urging (he wrote about your article today on Language Log), I've posted them now: https://udrive.oit.umass.ed... .
- Have a good vacation -- I don't expect any more replies now. And thanks again for your very thoughtful essay.

0 0 Reply • Share ›

I

Iliyan Bobev

11 years ago

I don't think Chomsky wants to avoid the use of probabilistic methodology, but rather that he's "concerned with discovering a mental reality underlying actual behavior" in humans. He believes that such is the goal of linguistics, and you believe it's the creation of "statistical (or probabilistic) models, which while accurately modeling reality, do not make claims to correspond to the generative process used by nature".
Conclusion: So the whole thing is comparing apples and oranges -- you simply strive for different things.

I personally do not care what's the goal of linguistics as a science, but I tend to side with Chomsky in the view that efforts for making models which "make no claim to correspond to the generative process used by nature" are of no use (or are detrimental) for discovering what underlines actual behavior in language use.

IMHO the only way to advance both aspects (accurate modeling and discovering the process used by nature) is to go hybrid.

4 0 Reply • Share ›

S

Sainamdar

12 years ago

Why are Deimos and
Phobos two of your favorite moons in the Solar System?

4 0 Reply • Share ›

Peter Norvig Mod ➚ Sainamdar

Peter Norvig Mod ↗ Salmandar

12 years ago

Two reasons: first, I've worked more with Mars than any other planet, and its moons have been considered for sample-return missions and as a base for human missions (it is easier to land and take off from these low-gravity airless moons than from Mars itself). Second, they are marvelously asymmetric and thus more interesting than other moons. Their close-in orbit and fast orbit times are also interesting.

10 0 Reply • Share ›

lawrence mcdonell ↗ Peter Norvig

a year ago edited

With respect, would you say your real interests lie in the study of the inanimate rather than the animate?

0 0 Reply • Share ›

lawrence mcdonell

7 years ago edited

The "Data-modeling and Algorithmic modeling cultures" distinction is an unhelpful distinction, as used by Norvig.
Data was originally defined as that which resists category, otherwise, after being categorised, each erstwhile datum becomes then a specific member of a class and no longer a datum.
Algorithms are a means of processing data. They are not facts, as data are.

(Even here, facts, data, and category are eternally and intrinsically problematic concepts, in natural language. And so how can formal language affect the words used to describe it?)

Confusing algohithms with data is symptomatic of giving up on understanding data as "the data of experience", its original and only meaningful definition.
This is as a result of the endless infinitesimilitude and therefore lack of determinacy of data which is only confirmed further, the greater the algorithmic contortions that are applied in the pursuit of data's "mystery". The mystery must be brought to the data, not extracted from it, as is imagined by scientists and engineers. For them, it is always a mystery of extracting form, and utility "from" the data; but actually, there is nothing to be found "in" the data; it can only be engineered.

The "Big Data" scientific enterprise should be seen for what it is, an unapologetic bid for control, not understanding. It is a complete failure to take responsibility for one's own concepts and scientific activity, as a scientist, let alone as a human being - or is that the same thing? These people think it is possible to have ideas given to them, without having to make the effort of thinking them, let alone their consequences, attributes and properties.

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C **Charles Reiss**

10 years ago

There is a confusion and lack of parallelism in this paragraph:

"I can't imagine Laplace saying that observations of the planets cannot constitute the subject-matter of orbital mechanics, or Maxwell saying that observations of electrical charge cannot constitute the subject-matter of electromagnetism. It is true that physics considers idealizations that are abstractions from the messy real world. For example, a class of mechanics problems ignores friction. But that doesn't mean that friction is not considered part of the subject-matter of physics."

I don't pretend to know what Laplace would have thought, but I hope he WOULD distinguish sources of evidence, like observations of the planets, from the actual object of study, orbital mechanics. This is a distinction that Chomsky is always careful about, for example in discussing the use of grammaticality judgments. Moving to the last sentence in this quotation: FRICTION is part of the subject-matter of physics, everyone agrees. OBSERVATIONS concerning friction are not part of the subject matter, they are part of the evidence for our models. The mis-analogy is between OBSERVATIONS OF THE PLANETS and FRICTION. There's the rub (pun intended).

3 0 Reply • Share ›

Tim Pizey

11 years ago

Thankyou. Picky, picky: "lessens wehn following a C,"

3 0 Reply • Share ›

MJ

Martin J Sallberg

12 years ago

The whole idea of distinguishing fundamentally between modeling and explanation is based on sheer ignorance of the existence of emergent phenomena. Real neurology shows that human brains and all other animal brains are fundamentally probabilistic. They have to be to survive in nature, because a 1 and 0 brain would be unable to tackle any situation it is not detail-hardwired for, so evolution ensures binary, tree-structure brains cannot evolve. There is also the fact that learning sorts among synapses just like evolution sorts among alleles, so claiming that something fundamentally unlearnable is innate just moves the problem. Neural networks must be trained, they cannot be programmed like conventional computers, and real brains store information as change in the "processing units" themselves and not in a separate memory unit, so "innateness" cannot be hardwired in the computer sense either. The only way any kind of instinct can exist is genes imitating the effect of learning by creating hallucinations during brain development. There is absolutely nothing that can evolve to be innate that learning without implicit assumptions cannot do as good or better. Given enough associations in different situations exposing both the similarities and the differences, anything like a real brain will spontaneously emergentize that into explanation without preconceptions. Animals admittedly have too few neurons to learn true language, but it is merely about neuron count and no specific instinct. Modern linguistics also shows that there is no single grammatical rule that is totally exceptionless around the world. There is examples of children successfully learning constructed languages with extremely different grammar (in experiments where they were deliberately exposed to a bilingual environment with one natural language and one "weird" constructed language), but at the end of the day they prefer natural languages due to their functional efficiency (that is, instead of modifying the constructed language, they just used the natural language in the situations it fitted best instead). This means that functional aspects alone are capable of explaining the development of creole languages and that innate preconceptions about language, if they even exist at all, are at most vague preferential influences and patently NOT any kind of inability to learn other kinds of advanced language.

4 1 Reply • Share ›

LI

Linguist in hiding ➚ Martin J Sallberg

12 years ago

> Modern linguistics also shows that there is no single grammatical rule that is totally exceptionless around the world.

What about:

What about:

In any language, there are vowels and consonants.

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T **tommy** ➚ Linguist in hiding
10 years ago

sign languages are recognized as full language and have none. Some have noted the stop/start rhythm in signing as analogous to v/c, but the point stands.

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C **cacarr** ➚ Linguist in hiding
10 years ago

One can easily think of grammatical rules that exist in _no_ natural languages.

0 0 Reply • Share ›

G **Guest** ➚ Linguist in hiding
10 years ago

What about Tswana?

0 0 Reply • Share ›

 **Carlo Sciolla** ➚ Linguist in hiding
11 years ago

Is the distinction between vowels and consonants within the realm of grammar?

0 0 Reply • Share ›

G **Guest** ➚ Linguist in hiding
12 years ago

Please identify the vowels and consonants in Brainfuck.

0 0 Reply • Share ›

FL **fellow linguist in hiding** ➚ Guest
12 years ago

Just in case this wasn't just a joke: Brainfuck is not a natural language and, as such, is not relevant to Linguistics.

5 0 Reply • Share ›

 **Дмитрий Зеленский** ➚ Martin J Sallberg
6 years ago

First - natural languages are NOT functionally more efficient than most conlangs.
Second - the neurology of brains is... irrelevant. There are learnable (corresponding to UG) and unlearnable (not corresponding to it) languages - and they CAN or CANNOT be learnt accordingly. For example, only conservative quantifying words can be learnt. Neural network interfaces are trained using some theory behind them, some choice of parameters and algorythm - and these things are hardcoded.
Third - the standard typological claim "there is no single grammatical rule that is totally exceptionless around the world" was never properly tested because the rules suggested by

typologists were not in the slightest close to what formal grammars generate. For example, at least third part of them involves the term "subject", which is meaningless in generative grammar.
Fourth - whatever happened to "poverty of stimulus"? Efficient computer neural networks are trained on giant corpuses, child meets nothing even closely comparable.

1 0 Reply • Share ›

L **Lukáš Banič** → Дмитрий Зеленский
6 years ago

To the irrelevancy of the neurology of brains, I feel like mentioning a famous computer scientist:

"People who are more than casually interested in computers should have at least some idea of what the underlying hardware is like. Otherwise the programs they write will be pretty weird." Donald Knuth

We can translate it into linguistics as: "People who are more than casually interested in languages should have at least some idea of what the underlying hardware (human brain) is like. Otherwise the theories they propose will be pretty weird."

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Дмитрий Зеленский → Lukáš Banič
6 years ago

Neurology is as of date incapable to tell how our brains compute things. Moreover, it seems until some principal revolution it will never be. Continuing the computer metaphor, neurology is looking with a microscope at a processor, which is not even closely enough to tell what algorythm it uses.

0 0 Reply • Share ›

L **Lukáš Banič** → Дмитрий Зеленский
6 years ago

How can you compare the amount of data on the machine side with the amount of data on the child's side? It's ridiculous, completely meaningless.

A computer neural network consumes nothing but a stream of characters. Contrary, a child sees, hears, touches, interacts with the world -- it can interconnect the language with things, feelings, situations, et cetera. It has a brain fine-tuned by hundreds of millions of years of evolution + approximatelly three times more neurons than what would be expected for an animal of human's weight.

There's no need for an innate grammar to explain why a child can learn much more than a machine with far less linguistic input.

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Дмитрий Зеленский → Lukáš Banič
6 years ago

And do I really need to call for the information theory and explain everything can be counted in bits?

0 0 Reply • Share ›

Дмитрий Зеленский → Lukáš Banič

6 years ago

Child sees etc. a lot, but most of it is not lingustic. Linguistic input is incredibly poor. And the pretty thing about language is it is not really "interconnected". It's a system capable of mixing whatever you give to it.

0 0 Reply • Share ›

L

Lukáš Banič → Дмитрий Зеленский

6 years ago

So you're suggesting that a child inprisoned in a dark room, only receiving a long stream of characters (just like the machines do), would magically learn a language thanks to some mysterious innate knowledge?

Ultimately, every child acquires a language as something deeply interconnected with its embodied experience. For a child, it is a large-scale multi-task learning in which every component boosts every other. A very complex phenomenon that requires much more than theorizing about abstract symbolic structures. Modeling, statistics, experiments, simulations, consulting with neurology... that all will eventually prove as indispensable for understanding language.

0 0 Reply • Share ›

Дмитрий Зеленский → Lukáš Banič

6 years ago

If s/he could percieve the characters s/he would. Language is an abstract symbolic structure by the very definition, so...
Neurology is incapable of giving answers about mind's algorythms as for now and until some magical boost.

0 0 Reply • Share ›

Građani imaju moć

9 years ago

There is a lot of reading into ideas and thoughts that are not there in this article. In your heading 'What did Chomsky mean?' what you've posited from A-E is ludicrously off point and can not possibly be extracted from that quote. You've essentially put words into his mouth to prove him wrong. And that is intellectual dishonesty. FFS you produced sentences with more information than the quote originally contained. And you proceed to create an article with the purpose of refuting based on information that popped out of your head...holy sh*t!

Chomsky NEVER made such hard claims. Get acquainted with his work without cherry picking.

Also, you would do well to learn something about 'interpretation' when you attempt to understand language as a system. How you've 'over-interpreted' his quote is a great example to start from.

Perhaps you should contemplate your biases. You did say your essay 'speculates', but it is absurd to what an extent.

What does his quote mean? Nothing special:

The approach is wrong, this is evident from how many failures were made (more failures and successes). And yet the authors present this approach as though it is not a failure. They even go so far as to present it as 'scientific advancement' (or the like) in the field. That is not the case.

see more

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kosmas poulianos

11 years ago

How do probabilistic models and Chomsky's approach interpret, say, poetry? Modern poetry in particular can be meaningful and comprehensible by humans while ignoring all gramatical rules or even inventing new words.

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Дмитрий Зеленский → kosmas poulianos

6 years ago

You can't invent a word glfshmlmad. You can only either create a word from existing roots by certain rules, or take it from another language, or combine the two.
Nor can poetry freely ignore _all_ grammatical rules.
And, finally, comprehensible never ever meant grammatical. "Mesa knows yousa" (yeah, I'm using Gungan) is (more or less) comprehensible, yet every English speaker will say that it's wrong, that it's not English.

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LC

Lewis Carroll Heinlein → Дмитрий Зеленский

2 years ago

If you truly *groked* language, you wouldn't make a statement so obviously severed from reality by a *vorpal* blade.

0 0 Reply • Share ›

MJ

Martin J Sallberg

12 years ago

@Linguist in hiding
The distinction between wowels and consonants are phonetics determined by physical speech organs, not grammar as such. And yes, there is exceptions from the existence of wowels and consonants in languages that does not rely on the mouth, that is, sign language. The point I was making is that no single rule about syntactic structure is truly global. Yes, there is statistical biases favoring some rules over others, shown, for instance, in creolization, but I think, as I wrote, that is because the statistically favored rules are more functionally efficient and therefore children prefer them when they experiment with language, and NOT that humans are anyhow machinistically dumb-wired in the brain to use particular rules without reason.

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RA **Ravi Annaswamy**
12 years ago

Excellent, thought provoking article Dr.Norvig. Wanted to share my thoughts provoked by a quick read. These are not specifically for or against any views presented, but my brain firings on this fascinating topic.

Science starts with data (observations) and slowly moves in stages: (first accounting, then predicting and explaining). First it accounts for ALL observed data, then it predicts and verifies through experiments new data and then it simplifies its 'equations' to give rise to explanations.

Ancient astronomers simply collected data on planetary positions for long long times and were able to 'predict' fairly accurately which planet would appear where now.

Kepler used three 'summarizing rules and a visual placement of sun-centered system' to explain quite a lot of data, in other words, he replaced memory with calculation.

This system was a great explanation, until, Newton gave just one rule from which all three laws could be derived. It became the 'explanation'.
However, as Feynman humorously points out in his lecture, 'People explained planet movements by imagining angels
pushing the planets. Newton said that is not true. and he explained with his equations and 'new kinds

see more

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RA **Ravi Annaswamy** → Ravi Annaswamy
12 years ago

I wrote: "If a system needs a million ngrams to aid search, correctly translate, search for patterns and even new facts, it is still clever engineering.
As the effort goes into shrinking the ngram database to smaller and smaller sets (even automatic shrinking), the system is gaining more explaining power."

I read what I wrote again and found a fallacy. A system can need million ngrams but still can be a simple system as long as the number of moving parts in the system is small. ngrams are just hte data that feeds the 'process' which is the one that needs to be simple and flexible. So what needs shrunk is not the ngram database but the process that uses the ngram db. And what data-model of solving allows is that it keeps the 'rules process' or the 'logic application' simple, uniform and small and keeps the complexity in the data. Many rules become data configurations.

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M **Mindsi** → Ravi Annaswamy
10 years ago

Ravi, sounds like u were trying hard to impress Peter for potential job inquary

1 0 Reply • Share ›

RA **Ravi Annaswamy** → Ravi Annaswamy
12 years ago

I also think Google's approach to machine translation being called 'statistical mt' is a misnomer. It is more appropriately 'a simple dumb mt' with statistics being used more to

misnomer. It is more appropriately 'example-driven mt' with statistics being used more to locate the example fragments, or is it so named because its learning is statistical?

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Simon Thompson

12 years ago

I haven't tried to replicate the work you have done on "colorless green sleep..." vs. the google book corpus because I haven't taken the time to properly understand it and do it yet, but I have tried the bigrams and trigrams in the two sentences because that was quick and easy :)
I thought the results were interesting: http://ngrams.googlelabs.co... of the trigrams seems to feature in 1899, though it's not clear from the results how they feature - I can't see them in the actual search results (it says "no results for - showing without quotes"). They are both from the grammatically correct construction. http://ngrams.googlelabs.co... bigram picture is much cloudier, but looking at the results I wonder if the appearance of many of the bigrams is due to stemming
removing apostrophes from proper nouns (the name Green in particular as in "Green's ideas").

Is this the effect that makes the probabilities of occurrence for the grammatically correct sentence ? If so does this change the informativeness of the distinction, in particular if we replaced, for example Green with Azure or Vermillion?

http://ngrams.googlelabs.co...

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benjamin

12 years ago

A very interesting article, here are some questions I have and I would be very thankful if you found the time to answer them:

"Third, I believe that language understanding is an inherently a process
of reasoning with uncertainty, and that since probability theory is
axiomatically the way to deal with uncertainty, I find it inescapable
that probability should be used to model language."

Would you mind elaborating on what exactly you mean by this? In particular, what is the connection between the fact that 'understanding is an inherently a [sic] process of reasoning with uncertainty' and your assertion that 'probability should be used to model language'. Whatever language is, and whatever the process of understanding is, they seem to be to different kinds of things. So I would agree that we should use probability to model language understanding (and, say, language learning) but I do not quite see why this should argue for using probability to model language. By the way. what IS a language? "languages are
complex, random, contingent biological processes that are subject to
the whims of evolution and cultural change." ? Quite frankly, I don't find that very enlightening, and in particular I do not understand what 'random' is supposed to mean here. (I have no trouble

see more

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Peter Norvig Mod ↗ benjamin

12 years ago

Good questions, Benjamin

Good questions, Benjamin.

You are right that the process of interpreting language is distinct from language itself. (Another commenter made the same point.) Thus, the question of how to best represent each is also distinct. It seems you accept that probability is a good tool for interpretation; I need to be clearer about why I think it is also appropriate to represent language facts. Part of the reason is evolutionary: language evolved in such a way that it would be possible to produce and understand, so the understanding process is tied in to language itself (as we see in things like Gricean maxims). Part of it is biological: the brain seems to be very bad at long chains of logical reasoning, and very good at more statistical/probabilistic tasks.

But you are right that before proceeding, we need to define what language is. I think some of the confusion comes in because the same tools that I claim are good for modeling all of language have also been deployed to model small portions of language. For example, in machine translation, the best systems are built on statistical models of P(phrase appeared in a corpus of English | phrase appeared as the corresponding phrase in the translation into the foreign language). You need to work out the details of what "corresponding" means, and how phrases are combined, Some statistical MT systems use syntactic structure as part of the model, others don't (they ha... a "phrases" but don't identify them as "no... phrases"

see more

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