Probabilistic Syntax

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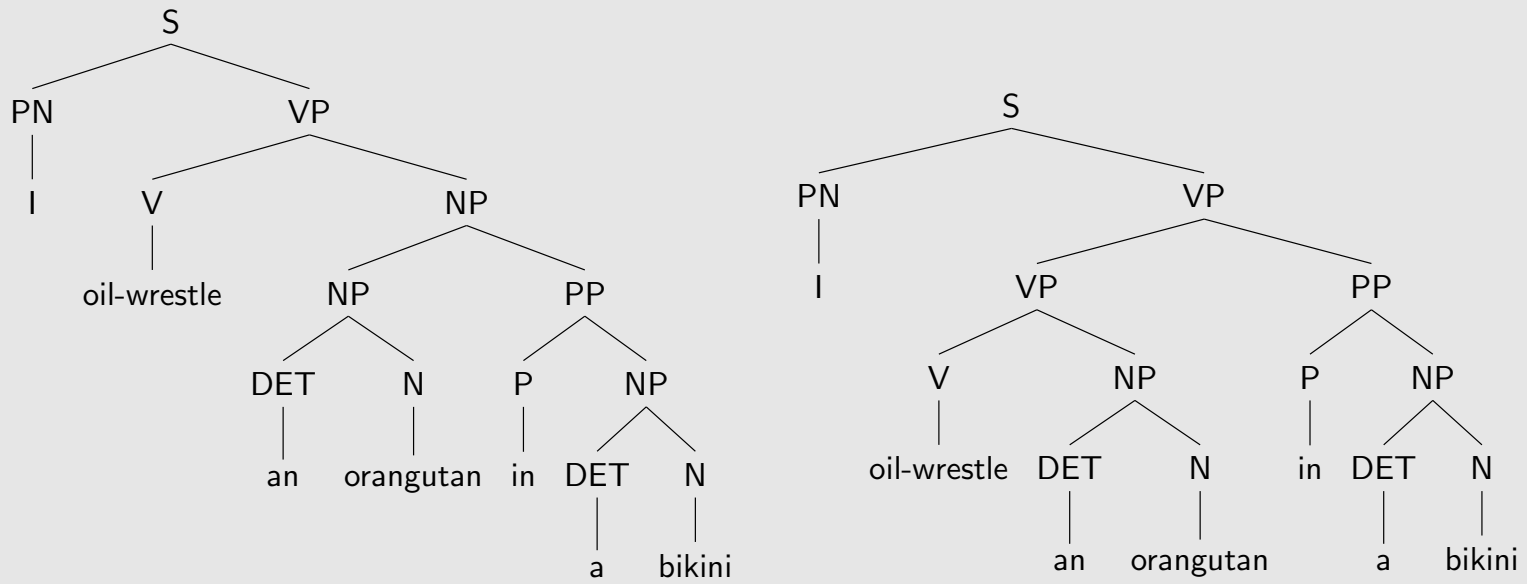
Today

The Problem

The parsing problem

I oil-wrestle an orangutan in a bikini.



Ambiguity

Which tree is preferable?

Ranking

我是歌手·第三期排名
1. 李克勤
▲4
遥远的她
2. 李玟
▼1
Price Tag
3. 黄致列
▼1
一路上有你
4. 徐佳莹
▲2
不醉不会
5. 苏运莹
NEW
野子
6. 赵传
▼3
Hotel California
7. 信
–
刀马旦

Ranking

湖南卫视《我是歌手》第四季听审团选票 第一轮淘馆赛 30组
座位号： 排 座
赵传
《Hotel California》
关喆
《你是爱我的》
HAYA乐团
《寂静的天空》
信
《万马巨》
李克勤
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( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( )
注意事项：1、请在括号中选择您心目中现场表现最好的四位歌手，多投或少投视为无效；
@我是歌手

Today

Weighted Context-Free Grammar

Weighted CFGs

Weights of a tree t with rules $A_1 \rightarrow \beta_1, A_2 \rightarrow \beta_2, ...$ is

$$p(t) = \prod_{i=1}^{n} q(A_i \rightarrow \beta_i)$$

where $q(A_i \rightarrow \beta_i)$ is the weight for rule $A_i \rightarrow \beta_i$, a "depth=1" sub-tree.

If for each nonterminal A_i,

$$\sum_{\beta} q(A \rightarrow \beta | A) = 1$$

then we get a Probabilistic CFG (PCFG).

Probabilistic CFGs

Example

S	→	NP VP	1.0
VP	→	ADVP VP	0.4
VP	→	V NP	0.3
VP	→	V NP NP	0.3
NP	→	N N	0.7
NP	→	N	0.3
ADVP	→	AD	1.0

N	→	警察	0.4
N	→	事故	0.3
N	→	原因	0.3
AD	→	正在	0.5
AD	→	详细	0.5
V	→	调查	1.0

- PCFG generates random derivations of CFG.
- Each event (expanding nonterminal by production rules) is statistically independent of all the others.

An example

S S→NP VP 1.0

An example

	S	S→NP VP	1.0
⇒	NP VP	NP→N	0.3

An example

	S	S→NP VP	1.0
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⇒	警察 VP	VP→ADVP VP	0.4

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⇒	警察 AD VP	AD→正在	0.5

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⇒	警察 正在 AD VP	AD→详细	0.5

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An example

$1.0 \times 0.3 \times 0.4 \times 0.4 \times 1.0 \times 0.5 \times 0.4 \times 1.0 \times 0.5 \times 0.3 \times 1.0 \times 0.7 \times 0.3 \times 0.3$

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Properties of WCFGs

- Assigns a score to each parse-tree, allowed by the underlying CFG
- Say we have a sentence s, set of derivations for that sentence is $\mathcal{T}(s)$, as defined by a CFG. Then a WCFG assigns a score $p(t)$ to each member of $\mathcal{T}(s)$.
- We now have a ranking in order of score. The most appropriate parse tree for a sentence s is

$$\arg \max_{t \in \mathcal{T}(s)} p(t)$$

"correct" = parse tree with highest score

Data for parsing experiments

English Treebank

- Penn WSJ Treebank = 50000 sentences with associated trees
- Usual set-up: 40000 training sentences, 2400 test sentences

Chinese Treebank

- Chinese Treebank (CTB) = 132000+ sentences with associated trees
- Tsinghua Treebank
- HIT Dependency Treebank
- PKU treebank$_1$ = 50000 sentences

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- Tsinghua Treebank
- HIT Dependency Treebank
- PKU treebank$_1$ = 50000 sentences
- PKU treebank$_2$ = 200000+ sentences

Deriving a WCFG from a Treebank

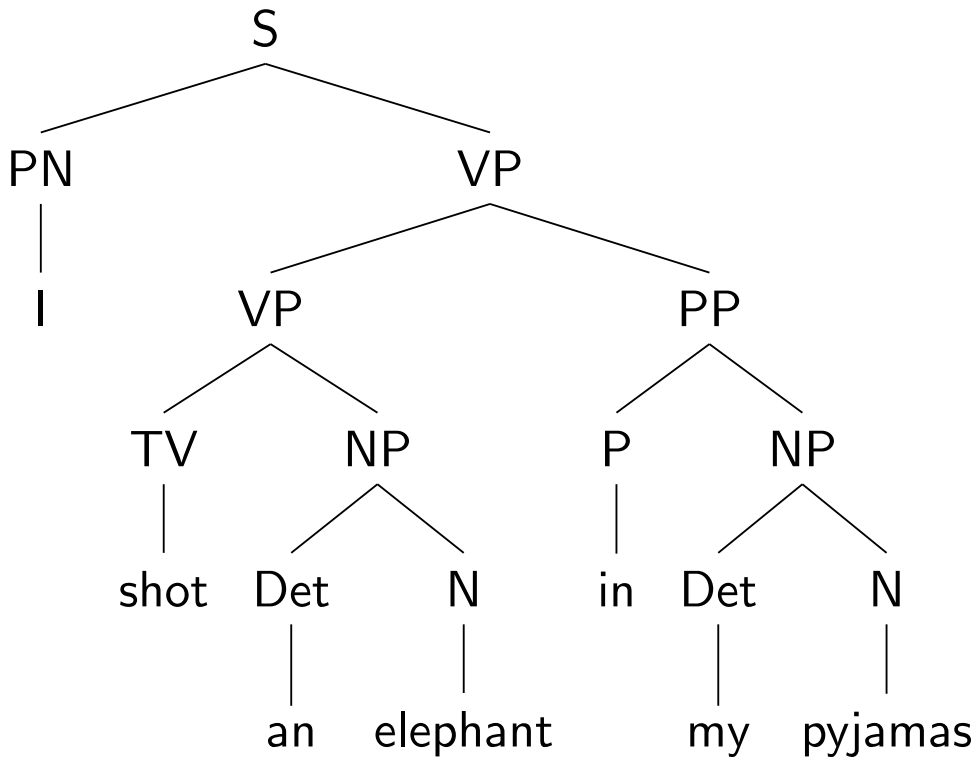
Given a set of example trees (a treebank), the underlying CFG can simply be all rules seen in the corpus

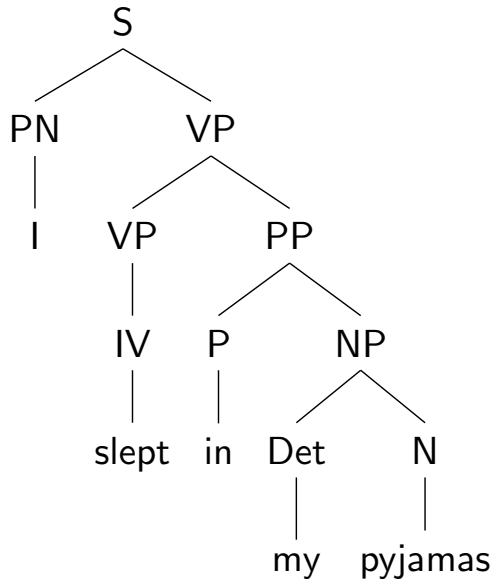
Maximum Likelihood estimates

$$q_{ML}(\alpha \rightarrow \beta) = \frac{\text{Count}(\alpha \rightarrow \beta)}{\text{Count}(\alpha)} \quad (1)$$

The counts are taken from a training set of example trees.

An example





$\mathsf{N} \rightarrow \mathsf{N\ PP}\ (0)$ $\quad$ $\mathsf{VP} \rightarrow \mathsf{TV\ NP}\ (\frac{1}{4})$

$\mathsf{N} \rightarrow \mathsf{elephant}\ (\frac{1}{3})$ $\quad$ $\mathsf{VP} \rightarrow \mathsf{IV}\ (\frac{1}{4})$

$\mathsf{N} \rightarrow \mathsf{pyjamas}\ (\frac{2}{3})$ $\quad$ $\mathsf{VP} \rightarrow \mathsf{VP\ PP}\ (\frac{1}{2})$

Parsing Again

Parsing with a WCFG

- Given a WCFG and a sentence s, define $\mathcal{T}(s)$ to be the set of trees with s as the yield.
- Given a WCFG and a sentence s, how do we find

$$\arg \max_{t \in \mathcal{T}(s)} p(t) \tag{2}$$

Solution

Augmenting CKY

An example

S → NP VP	1.0	VP → VP PP	0.5	VP → V NP	0.5
NP → Det N	0.6	NP → NP PP	0.3	NP → Penny	0.1
PP → P NP	1.0				
V → oil-wrestles	1.0	Det → an	0.4	Det → a	0.6
N → orangutan	0.5	N → bikini	0.5	P → in	1.0

Sentence

$\cdot_0$ Penny $\cdot_1$ oil-wrestles $\cdot_2$ an $\cdot_3$ orangutan $\cdot_4$ in $\cdot_5$ a $\cdot_6$ bikini $\cdot_7$

	1	2	3	4	5	6	7
0	$\langle NP, 0.1\rangle$			$\langle S, 0.006\rangle$			$\langle S\rangle$
1		$\langle V, 1.0\rangle$		$\langle VP, 0.06\rangle$			$\langle VP, 0.0054\rangle$
2			$\langle Det, 0.4\rangle$	$\langle NP, 0.2\rangle$			$\langle NP, 0.00648\rangle$
3				$\langle N, 0.5\rangle$			
4					$\langle P, 1.0\rangle$		$\langle PP, 0.18\rangle$
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0	$\langle NP, 0.1\rangle$			$\langle S, 0.006\rangle$			$\langle S\rangle$
1		$\langle V, 1.0\rangle$		$\langle VP, 0.06\rangle$			$\langle VP, 0.0054\rangle$
2			$\langle Det, 0.4\rangle$	$\langle NP, 0.2\rangle$			$\langle NP, 0.00648\rangle$
3				$\langle N, 0.5\rangle$			
4					$\langle P, 1.0\rangle$		$\langle PP, 0.18\rangle$
5						$\langle Det, 0.6\rangle$	$\langle NP, 0.18\rangle$
6							$\langle N, 0.5\rangle$

An example

S → NP VP	1.0	VP → VP PP	0.5	VP → V NP	0.5
NP → Det N	0.6	NP → NP PP	0.3	NP → Penny	0.1
PP → P NP	1.0				
V → oil-wrestles	1.0	Det → an	0.4	Det → a	0.6
N → orangutan	0.5	N → bikini	0.5	P → in	1.0

Sentence

$\cdot_0$ Penny $\cdot_1$ oil-wrestles $\cdot_2$ an $\cdot_3$ orangutan $\cdot_4$ in $\cdot_5$ a $\cdot_6$ bikini $\cdot_7$

	1	2	3	4	5	6	7
0	$\langle NP, 0.1\rangle$	☹		$\langle S, 0.006\rangle$			$\langle S\rangle$
1		$\langle V, 1.0\rangle$		$\langle VP, 0.06\rangle$			$\langle VP, 0.0054\rangle$
2			$\langle Det, 0.4\rangle$	$\langle NP, 0.2\rangle$			$\langle NP, 0.00648\rangle$
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0	$\langle NP, 0.1 \rangle$			$\langle S, 0.006 \rangle$			$\langle S \rangle$
1		$\langle V, 1.0 \rangle$	☹	$\langle VP, 0.06 \rangle$			$\langle VP, 0.0054 \rangle$
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3				$\langle N, 0.5\rangle$	☹		
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Sentence

$\cdot_0$ Penny $\cdot_1$ oil-wrestles $\cdot_2$ an $\cdot_3$ orangutan $\cdot_4$ in $\cdot_5$ a $\cdot_6$ bikini $\cdot_7$

	1	2	3	4	5	6	7
0	$\langle NP, 0.1\rangle$			$\langle S, 0.006\rangle$			$\langle S\rangle$
1		$\langle V, 1.0\rangle$		$\langle VP, 0.06\rangle$			$\langle VP, 0.0054\rangle$
2			$\langle Det, 0.4\rangle$	$\langle NP, 0.2\rangle$			$\langle NP, 0.00648\rangle$
3				$\langle N, 0.5\rangle$			
4					$\langle P, 1.0\rangle$		$\langle PP, 0.18\rangle$
5						$\langle Det, 0.6\rangle$	$\langle NP, 0.18\rangle$
6							$\langle N, 0.5\rangle$

An example

S → NP VP	1.0	VP → VP PP	0.5	VP → V NP	0.5
NP → Det N	0.6	NP → NP PP	0.3	NP → Penny	0.1
PP → P NP	1.0				
V → oil-wrestles	1.0	Det → an	0.4	Det → a	0.6
N → orangutan	0.5	N → bikini	0.5	P → in	1.0

Sentence

$\cdot_0$ Penny $\cdot_1$ oil-wrestles $\cdot_2$ an $\cdot_3$ orangutan $\cdot_4$ in $\cdot_5$ a $\cdot_6$ bikini $\cdot_7$

	1	2	3	4	5	6	7
0	$\langle NP, 0.1\rangle$			$\langle S, 0.006\rangle$			$\langle S\rangle$
1		$\langle V, 1.0\rangle$		$\langle VP, 0.06\rangle$			$\langle VP, 0.0054\rangle$
2			$\langle Det, 0.4\rangle$	$\langle NP, 0.2\rangle$			$\langle NP, 0.00648\rangle$
3				$\langle N, 0.5\rangle$			
4					$\langle P, 1.0\rangle$		$\langle PP, 0.18\rangle$
5						$\langle Det, 0.6\rangle$	$\langle NP, 0.18\rangle$
6							$\langle N, 0.5\rangle$

Divide and Conquer

理学部

数学科学学院	物理学院	化学与分子工程学院	生命科学学院
城市与环境学院	地球与空间科学学院	心理与认知科学学院	建筑与景观设计学院

信息与工程科学部

信息科学技术学院	工学院	计算机科学技术研究所	软件与微电子学院
环境科学与工程学院	软件工程国家工程研究中心		

人文学部

中国语言文学系	历史学系	考古文博学院	哲学系（宗教学系）
外国语学院	艺术学院	对外汉语教育学院	歌剧研究院

社会科学学部

国际关系学院	法学院	信息管理系	社会学系
政府管理学院	马克思主义学院	教育学院	新闻与传播学院
体育教研部	新媒体研究院		

经济与管理学部

经济学院	光华管理学院	人口研究所	国家发展研究院

医学部

基础医学院	药学院	公共卫生学院	护理学院
医学人文研究院/公共教学	医学网络教育学院	第一医院	人民医院

Divide and Conquer?

“语言认知”本科项目

- 以自然语言的高阶认知问题为核心，在探索和思考相关的科学问题基础上建立合理的课程体系
- 三个学部(文理工), 四个学科(语哲心计), 五个院系
- 围绕形式语言和自然语言的多角度多面向的模块化课程设计
- 导师制+个性化学习与研究计划
- 跨学科讨论班+本科毕业设计展示平台

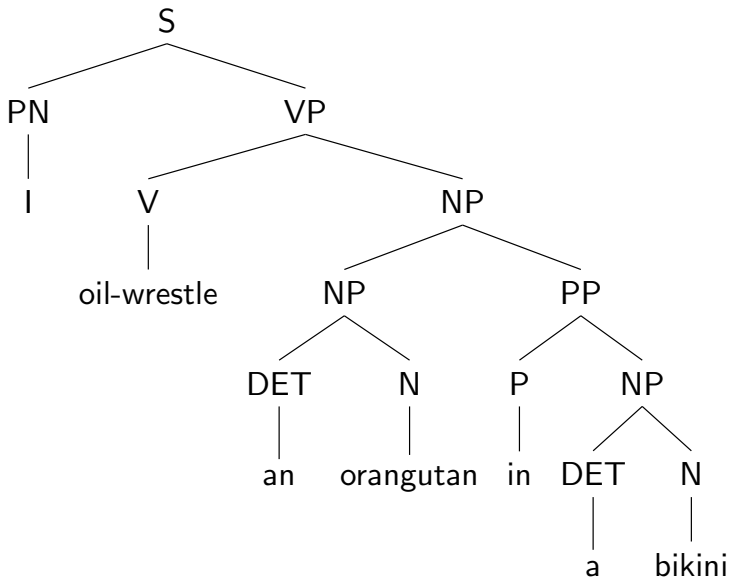
Dynamic programming

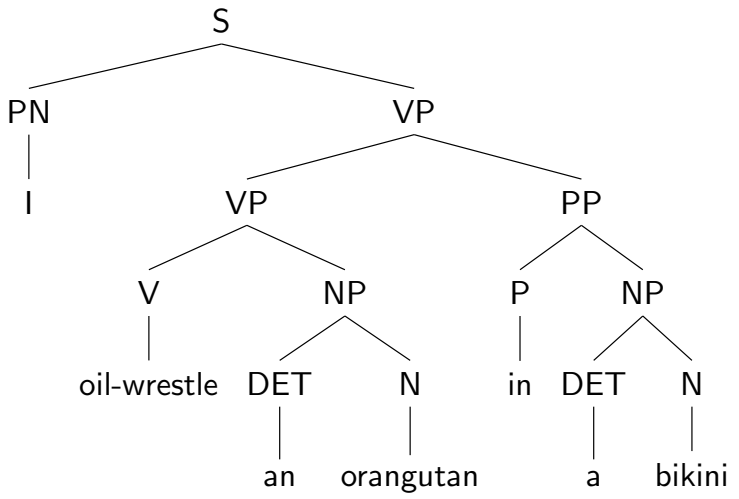
Principle of compositionality

The meaning of a complex expression is determined by the meanings of its constituent expressions and the rules used to combine them.

Optimal substructure

An optimal solution can be constructed from optimal solutions of its subproblems.





Today

Debate

巨佬锵锵锵

Probabilistic syntax

- Human languages are the prototypical example of a symbolic system. From very early on, logics and logical reasoning were invented for handling natural language understanding.
- In the 1950s there were prospects for probabilistic methods taking hold in linguistics. Chomsky's influential remarks had the effect of killing off interest in probabilistic methods for syntax.

> *I think we are forced to conclude that [...] probabilistic models give no particular insight into some of the basic problems of syntactic structure.*
>
> *Syntactic Structures, 1957*

> *it must be recognized that the notion of "probability of a sentence" is an entirely useless one, under any known interpretation of this term.*
>
> *Quine's Empirical Assumptions, 1969*

Chomsky's words

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's a lot work which tries to do sophisticated statistical analysis [...] without any concern for the actual structure of language, as far as I'm aware that only achieves success in a very odd sense of success. [...] There is a notion of success [...] which I think is novel in the history of science. It interprets success as approximating unanalyzed data.

Noam Chomsky

from

`languagelog.ldc.upenn.edu/myl/PinkerChomskyMIT.html`

Peter Norvig's argument

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?

from `http://norvig.com/chomsky.html`

Peter Norvig's argument

I take Chomsky's points to be the following:

1. Statistical language models have had engineering success, but that is irrelevant to science.
2. Accurately modeling linguistic facts is just butterfly collecting; what matters in science (and specifically linguistics) is the underlying principles.
3. Statistical models are incomprehensible; they provide no insight.

Peter Norvig's argument

I take Chomsky's points to be the following:

4. 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 two 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.
5. 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?

Peter Norvig's argument

Statistical language models have had engineering success, but that is irrelevant to science.

I agree that engineering success is not the 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.

Peter Norvig's argument

Accurately modeling linguistic facts is just butterfly collecting; what matters in science is the underlying principles.

Science is a combination of gathering facts and making theories; neither can progress on its own. I think Chomsky is wrong to push the needle so far towards theory over facts; 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.

> *The linguistics of the twentieth century has been the linguistics of scarcity of evidence.*
>
> *Sinclair (1997)*

Reading

Joan Bresnan. Linguistics: The Garden and the Bush

`https://web.stanford.edu/~bresnan/jbLTA.pdf`

Peter Norvig's argument

Statistical models are incomprehensible; they provide no insight.

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.

Peter Norvig's argument

Statistical models may provide an accurate simulation of some phenomena, but the simulation is done completely the wrong way; [...]

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, trees, semantics, context, discourse, etc. Chomsky dismisses all probabilistic models because of shortcomings of particular 50-year old models. I understand how Chomsky arrives 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 [...]

Peter Norvig's argument

Statistical models may provide an accurate simulation of some phenomena, but the simulation is done completely the wrong way; [...]

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, f or algorithmically processing language, and for understanding how humans process language.

Peter Norvig's argument

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?

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 rule out probabilistic language representations, nor statistical learning. I think it is much more likely that human language learning involves something like probabilistic and statistical inference, but we just don't know yet.

Chris Manning

- Categorical linguistic theories claim too much. They place a hard categorical boundary of grammaticality where really there is a fuzzy edge, determined by many conflicting constraints and issues of conventionality vs. human creativity.
- Categorical linguistic theories explain too little. They say nothing at all about the soft constraints which explain how people choose to say things (or how they choose to understand them).

Joan Bresnan

I began to realize that we theoretical linguists had no privileged way of distinguishing the possible formal patterns of a language from the merely probable. Many of the kinds of sentences reported by theorists to be ungrammatical are actually used quite grammatically in rare contexts. Authentic examples can be found in very large collections of language use, such as the World Wide Web. [...] Moreover, judgments of ungrammaticality are often unstable and can be manipulated simply by raising or lowering the probability of the context. Most remarkably, language users have powerful predictive capacities, which can be measured using statistical models of spontaneous language use. From all these discoveries I have come to believe that our implicit knowledge of language has been vastly underestimated by theoretical linguistics of the kind I had practiced.

Fair warning

Every time I fire a linguist, the performance of the speech recognizer goes up.

Frederick Jelinek

Reading

http://lingo.stanford.edu/sag/L204/