NLP & Linguistics

Natural Language Processing
CS 6120—Spring 2013
Northeastern University

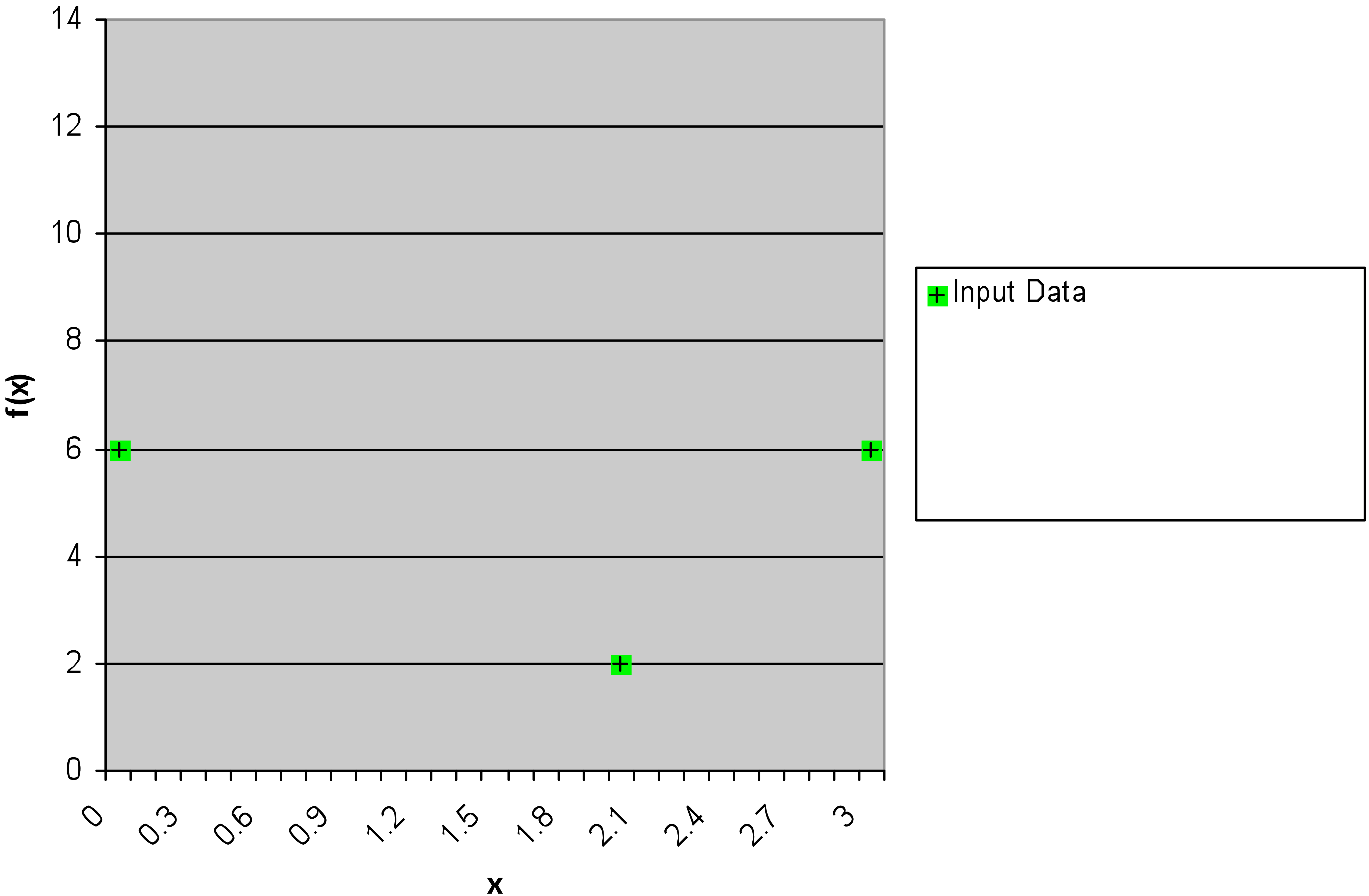
David Smith
some slides from
Jason Eisner & Chris Manning

Engineering vs. Science?

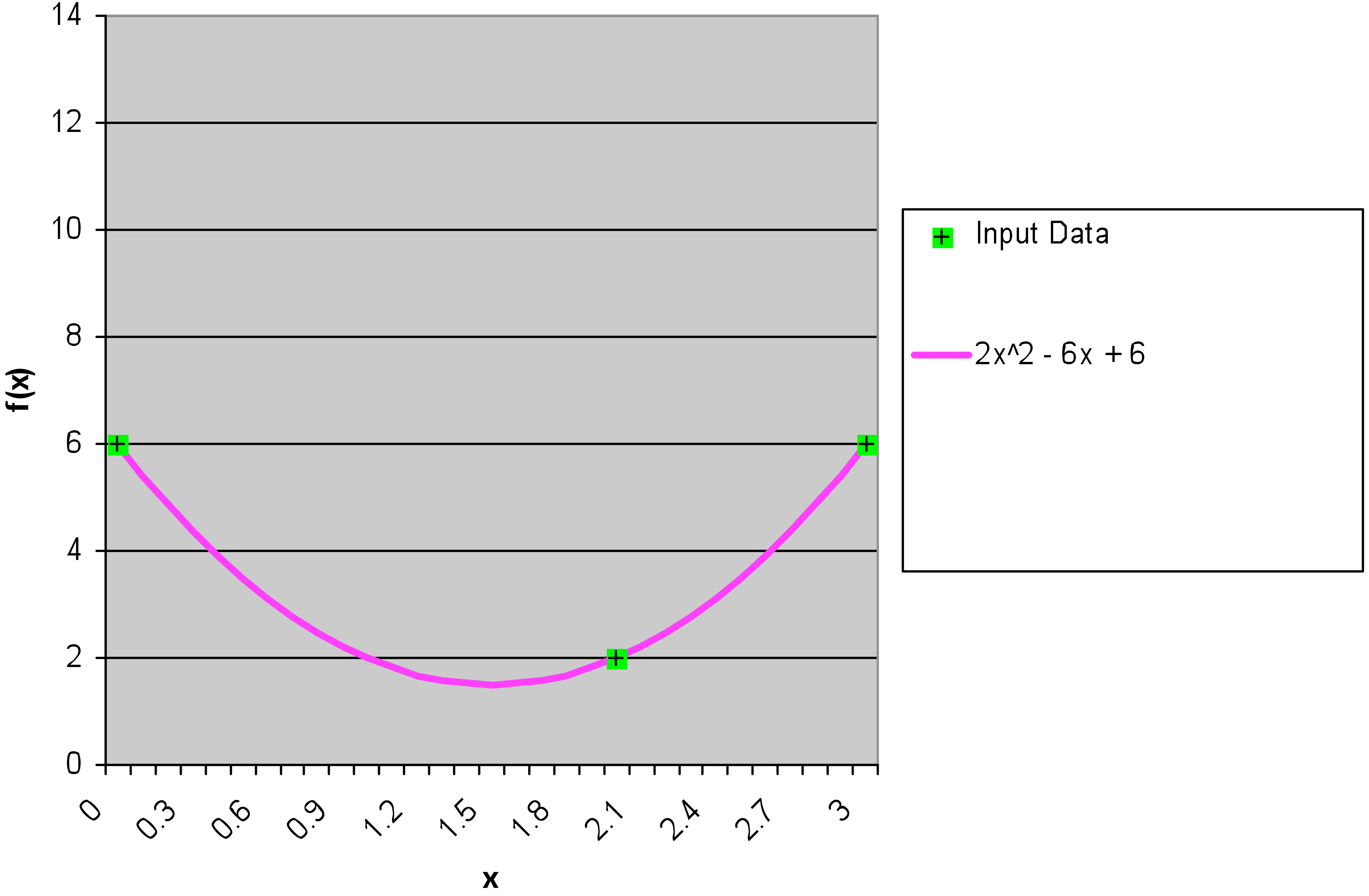
- One story
  - NLP took formal language theory and generative linguistics (same source?),
  - Built small AI systems for a while,
  - Then added statistics/machine learning.
- What now?
  - Shouldn't AI tell us about natural intelligence?
  - Are all NLP models lousy linguistics?

Learning in the Limit
Gold's Theorem

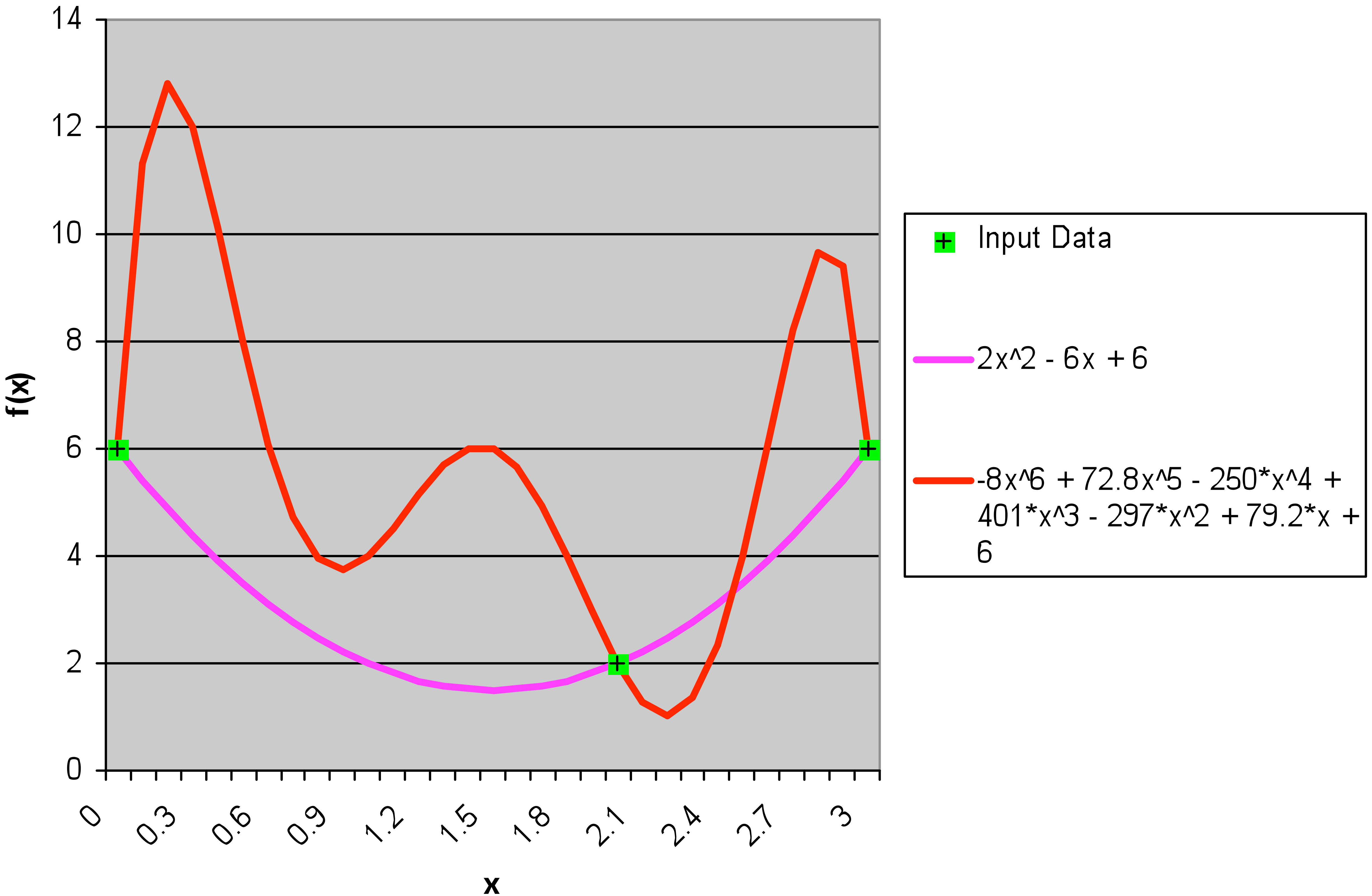
Observe some values of a function



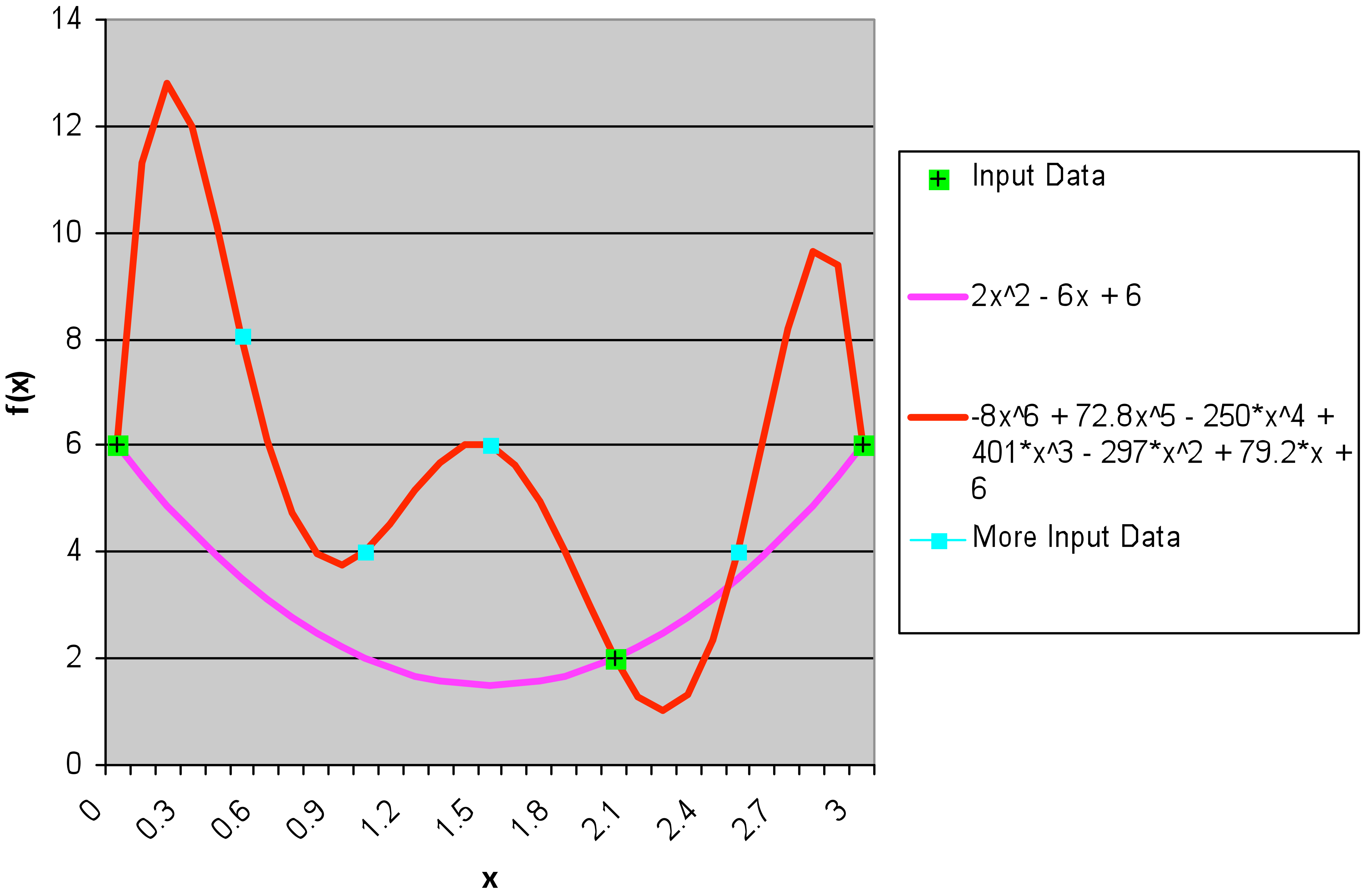
Guess the whole function



Another guess: Just as good?



More data needed to decide



Poverty of the Stimulus

Poverty of the Stimulus

- Never enough input data to completely determine the polynomial …
  - Always have infinitely many possibilities

- … unless you know the order of the polynomial ahead of time.
  - 2 points determine a line
  - 3 points determine a quadratic
  - etc.
- In language learning, is it enough to know that the target language is generated by a CFG?
  - without knowing the size of the CFG?

<u>Language</u> learning:

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- Children listen to language [unsupervised]

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- Children listen to language [unsupervised]
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Remember: Language = set of strings

Poverty of the Stimulus (1957)

- Children listen to language
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Poverty of the Stimulus (1957)

Chomsky: Just like polynomials: never enough data unless you know something in advance. So kids must be born knowing what to expect in language.

- Children listen to language
- Children are corrected??
- Children observe language in context
- Children observe frequencies of language

Gold's Theorem (1967)

a simple negative result along these lines:
kids (or computers) can't learn much
without supervision, inborn knowledge, or statistics

- Children listen to language
- Children are corrected??
- Children observe language in context
- Children observe frequencies of language

The Idealized Situation

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- Mom talks

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- Mom talks
- Baby listens

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- 1. Mom outputs a sentence

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  (given all sentences so far)

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- 1. Mom outputs a sentence
- 2. Baby hypothesizes what the language is (given all sentences so far)
- 3. Goto step 1

- Guarantee: Mom's language *is* in the set of hypotheses that Baby is choosing among
- Guarantee: Any sentence of Mom's language is *eventually* uttered by Mom (even if infinitely many)
- Assumption: Vocabulary (or alphabet) is finite.

Can Baby learn under these conditions?

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- Learning in the limit:
  - There is some point at which Baby's hypothesis is correct and never changes again. Baby has converged!
  - Baby doesn't have to **know** that it's reached this point – it can keep an open mind about new evidence – but if its hypothesis is right, no such new evidence will ever come along.

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- Is there a perfect finite-state Baby?
- Is there a perfect context-free Baby?

Languages vs. Grammars

- Does Baby have to get the right grammar?
- (E.g., does VP have to be called VP?)

- Assumption: Finite vocabulary.

Conservative Strategy

- Baby's hypothesis should always be smallest language consistent with the data

- Works for finite languages? Let's try it …
  - Language 1: {aa,ab,ac}
  - Language 2: {aa,ab,ac,ad,ae}
  - Language 3: {aa,ac}
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Mom
Baby

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Baby L3

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Mom	aa	ab
Baby	L3	L1

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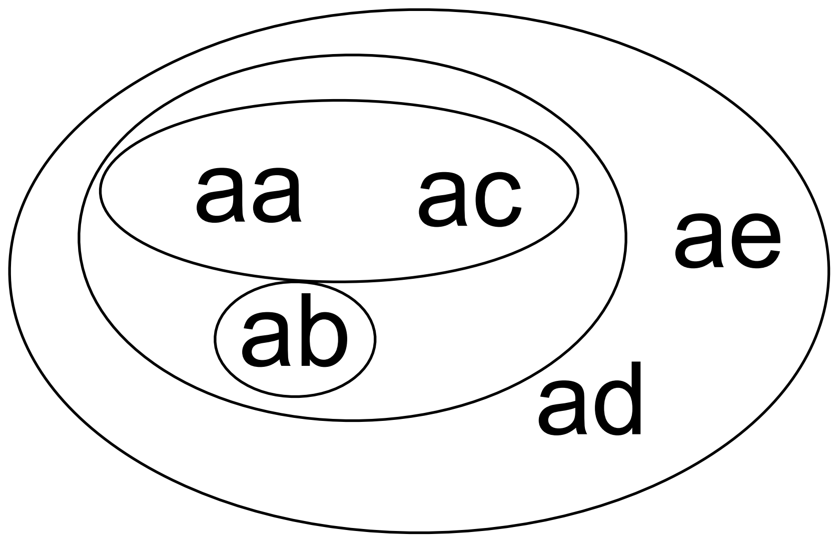

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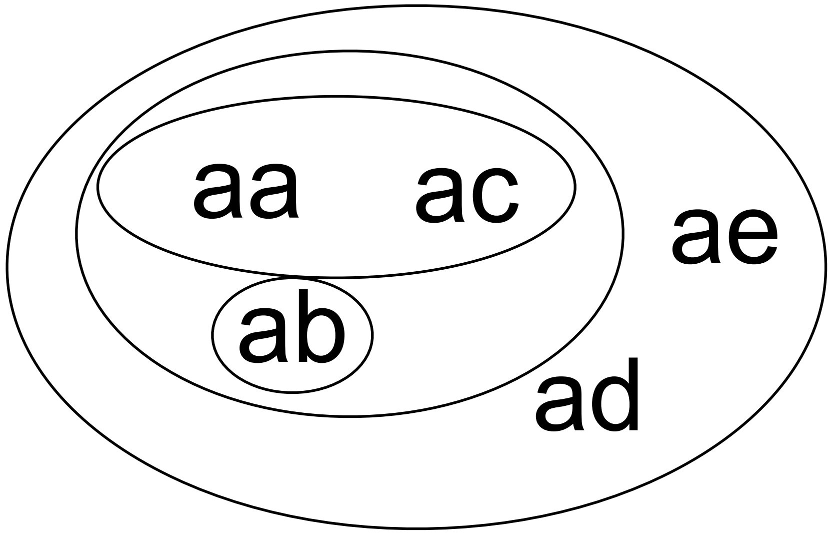

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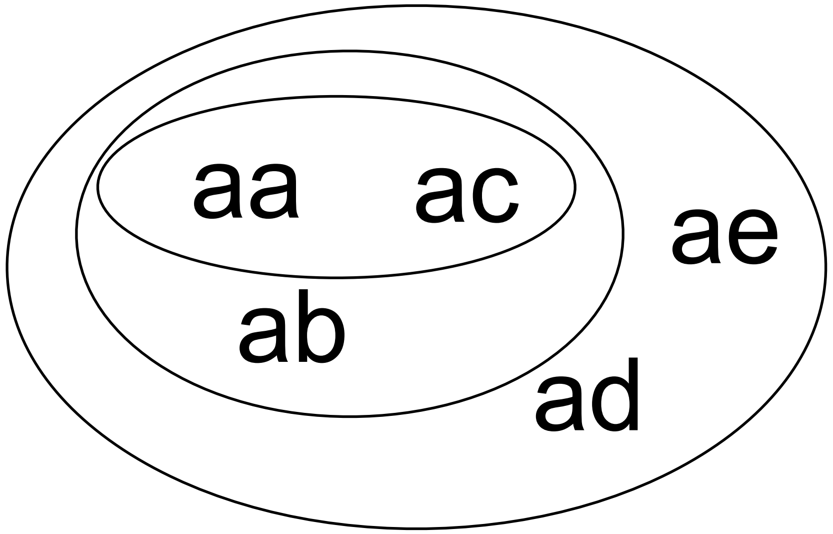

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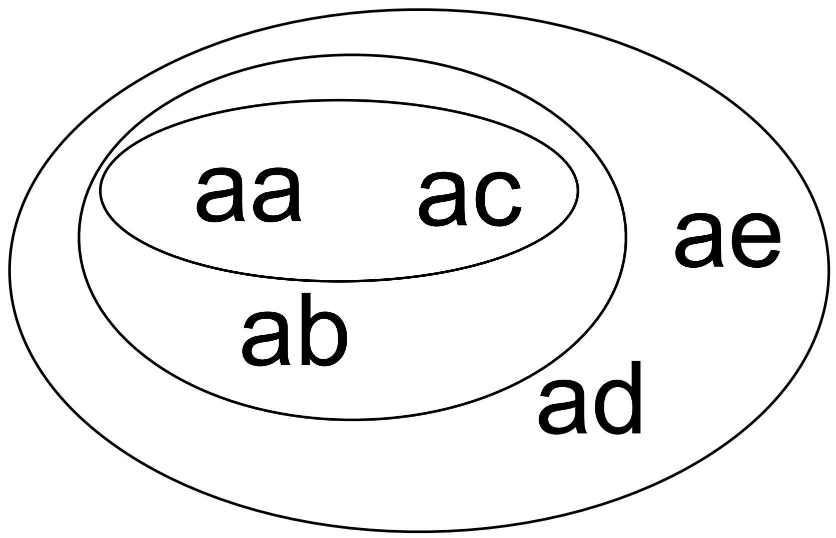

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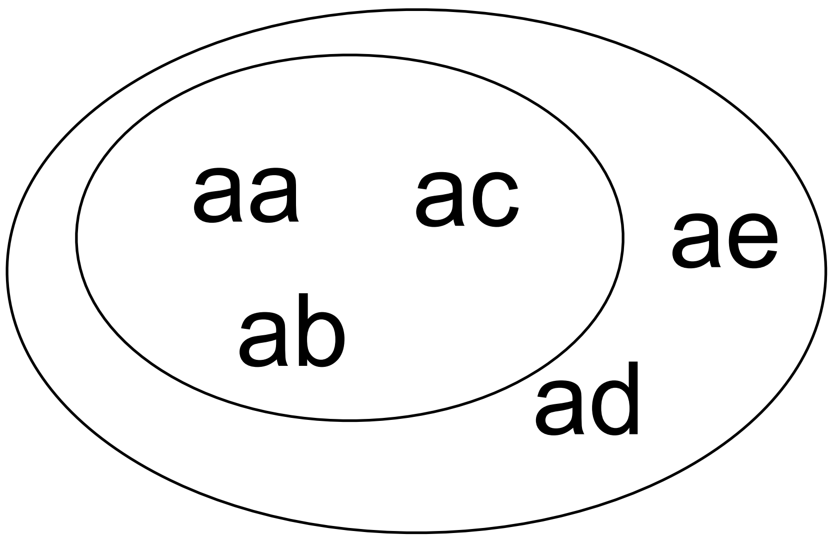

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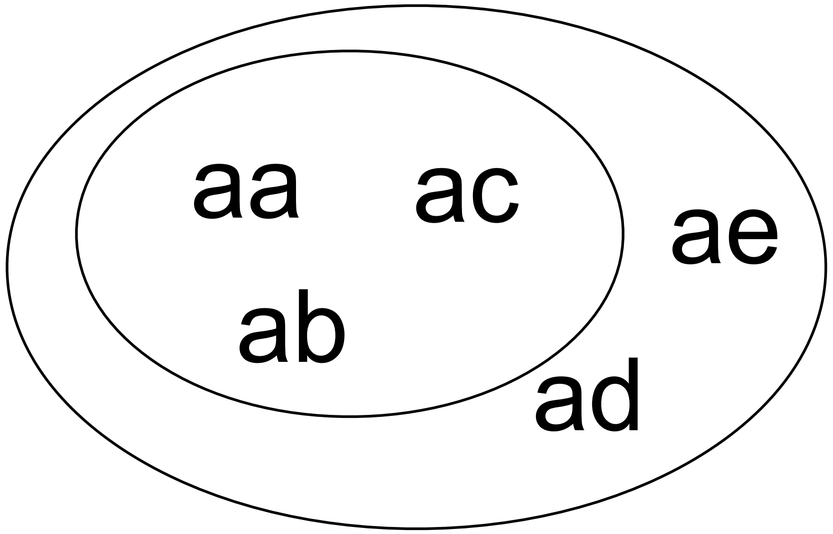

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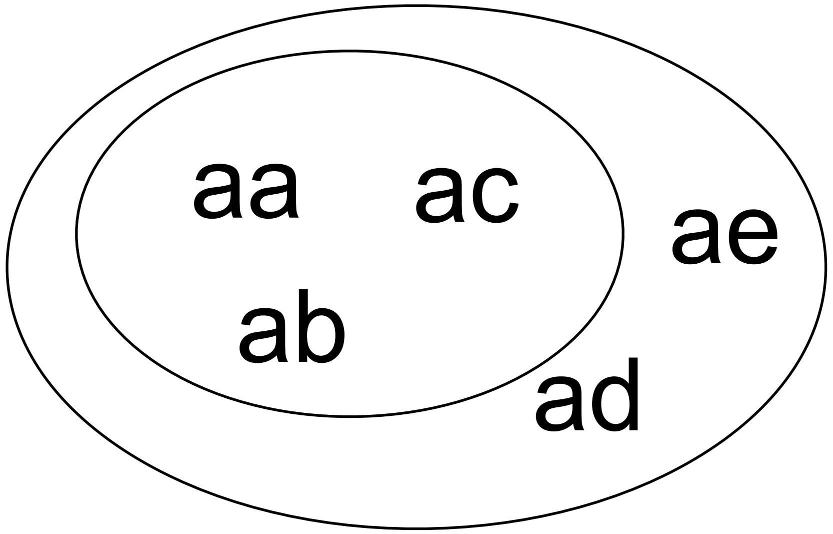

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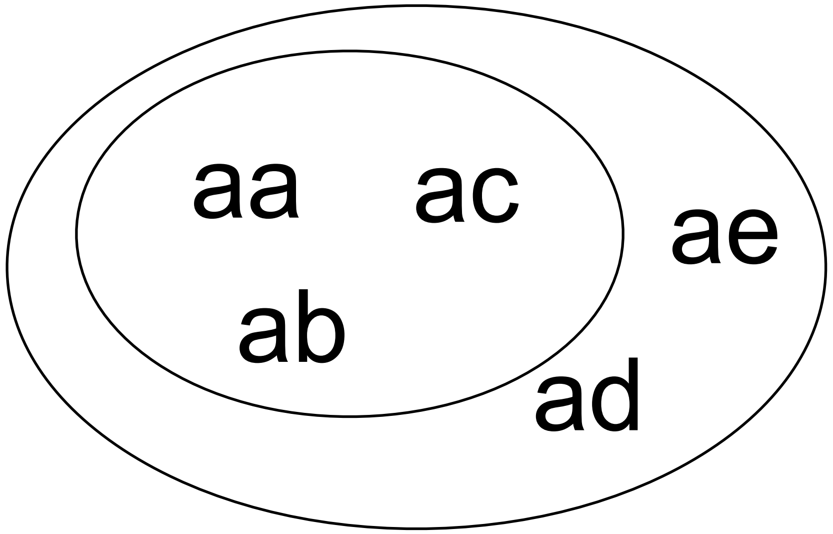

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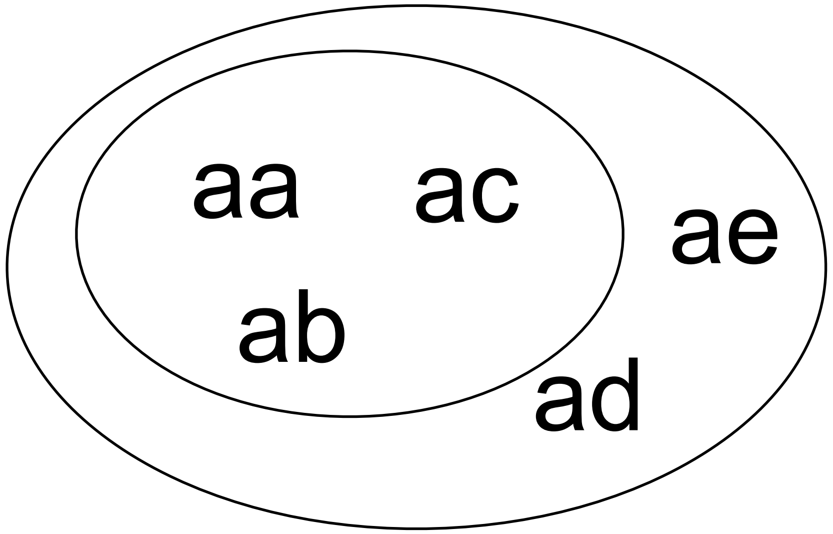

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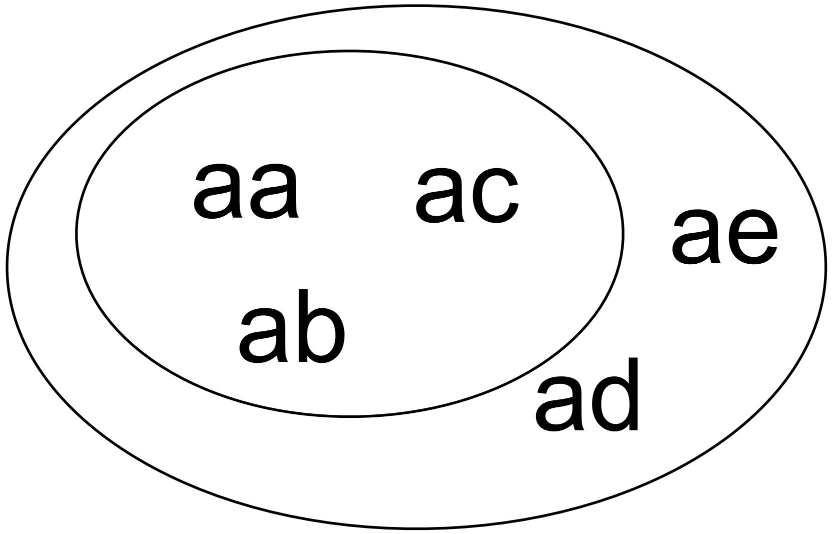

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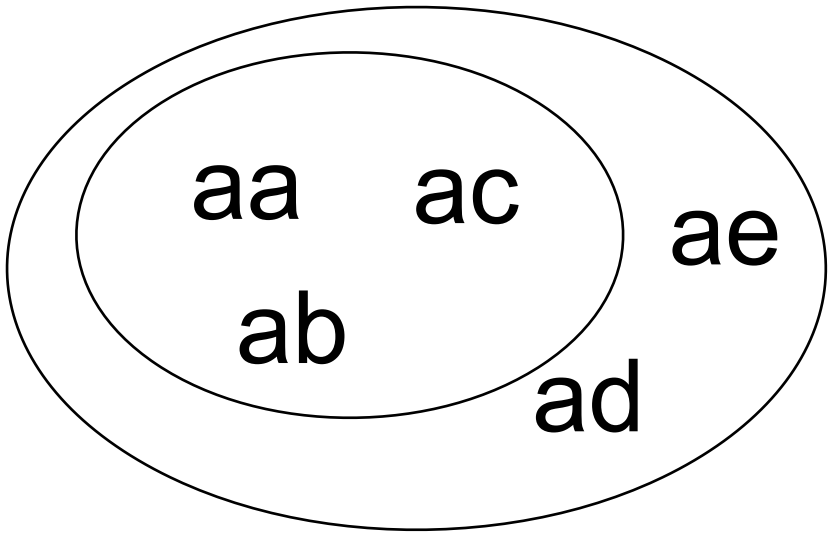

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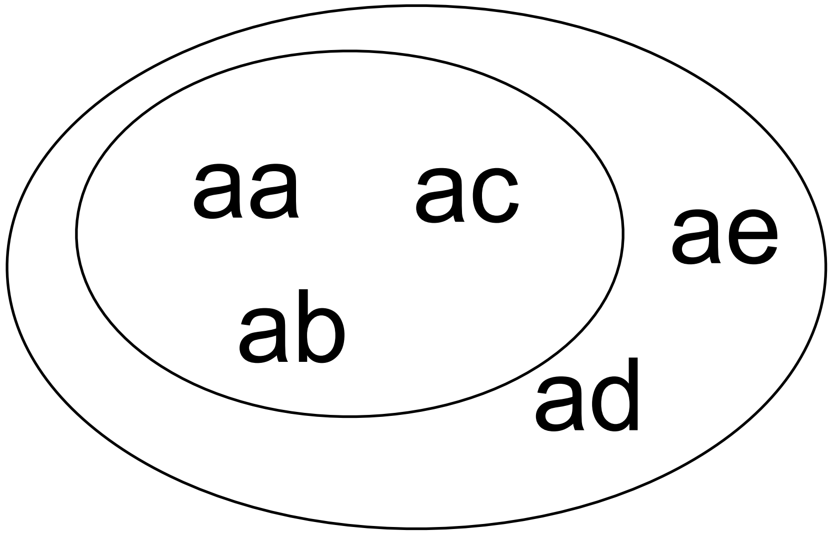

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Evil Mom

- To find out whether Baby is perfect, we have to see whether it gets 100% even in the most adversarial conditions
- Assume Mom is trying to fool Baby
  - although she must speak only sentences from L
  - and she must eventually speak each such sentence
- Does Baby's strategy work?

An Unlearnable Class

- Class of languages:
  - Let L_n = set of all strings of length < n
  - What is L_0?
  - What is L_1?
  - What is L_∞?
    - If the true language is L_∞, can Mom really follow rules?
    - Must eventually speak every sentence of L_∞. Possible?
    - Yes: ε; a, b; aa, ab, ba, bb; aaa, aab, aba, abb, baa, …
  - Our class is C = $\{L_0, L_1, \ldots L_\infty\}$

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  - What is L_1?
  - What is L_∞?
- Our class is $C = \{L_0, L_1, \ldots L_\infty\}$
- A perfect C-baby will distinguish among all of these depending on the input.
- But there is no perfect C-baby …

An Unlearnable Class

An Unlearnable Class

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An Unlearnable Class

- Our class is C = {L_0, L_1, … L_∞}
- Suppose Baby adopts conservative strategy, always picking smallest possible language in C.

An Unlearnable Class

- Our class is $C = \{L_0, L_1, \dots L_\infty\}$
- Suppose Baby adopts conservative strategy, always picking smallest possible language in C.
- So if Mom's longest sentence so far has 75 words, baby's hypothesis is L_{76}.

An Unlearnable Class

- Our class is $C = \{L_0, L_1, \ldots L_\infty\}$
- Suppose Baby adopts conservative strategy, always picking smallest possible language in C.
- So if Mom's longest sentence so far has 75 words, baby's hypothesis is L_{76}.
- This won't always work: What language can't a conservative Baby learn?

An Unlearnable Class

An Unlearnable Class

- Our class is $C = \{L_0, L_1, \ldots L_\infty\}$

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  - If true language is L_{76}, and baby posits something else, baby must still eventually come back and guess L_{76} (since it's perfect).

An Unlearnable Class

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  - So if longest sentence so far is 75 words, and Mom keeps talking from L_{76}, then eventually baby must actually return to the conservative guess L_{76}.

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  - So if longest sentence so far is 75 words, and Mom keeps talking from L_{76}, then eventually baby must actually return to the conservative guess L_{76}.
  - Agreed?

Mom's Revenge

If longest sentence so far is 75 words, and Mom keeps talking from L_{76}, then eventually a perfect C-baby must actually return to the conservative guess L_{76}.

- Suppose true language is L_∞.
- Evil Mom can prevent our supposedly perfect C-Baby from converging to it.
- If Baby ever guesses L_∞, say when the longest sentence is 75 words:
  - Then Evil Mom keeps talking from L_{76} until Baby capitulates and revises her guess to L_{76} – as any perfect C-Baby must.
  - So Baby has *not* stayed at L_∞ as required.
- Then Mom can go ahead with longer sentences. If Baby ever guesses L_∞ again, she plays the same trick again.

Mom's Revenge

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- Suppose true language is L_∞.
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- If Baby ever guesses L_∞, say when the longest sentence is 75 words:
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  - So Baby has *not* stayed at L_∞ as required.
- Conclusion: There's no perfect Baby that is guaranteed to converge to L_0, L_1, … or L_∞ as appropriate. If it always succeeds on finite languages, Evil Mom can trick it on infinite language.

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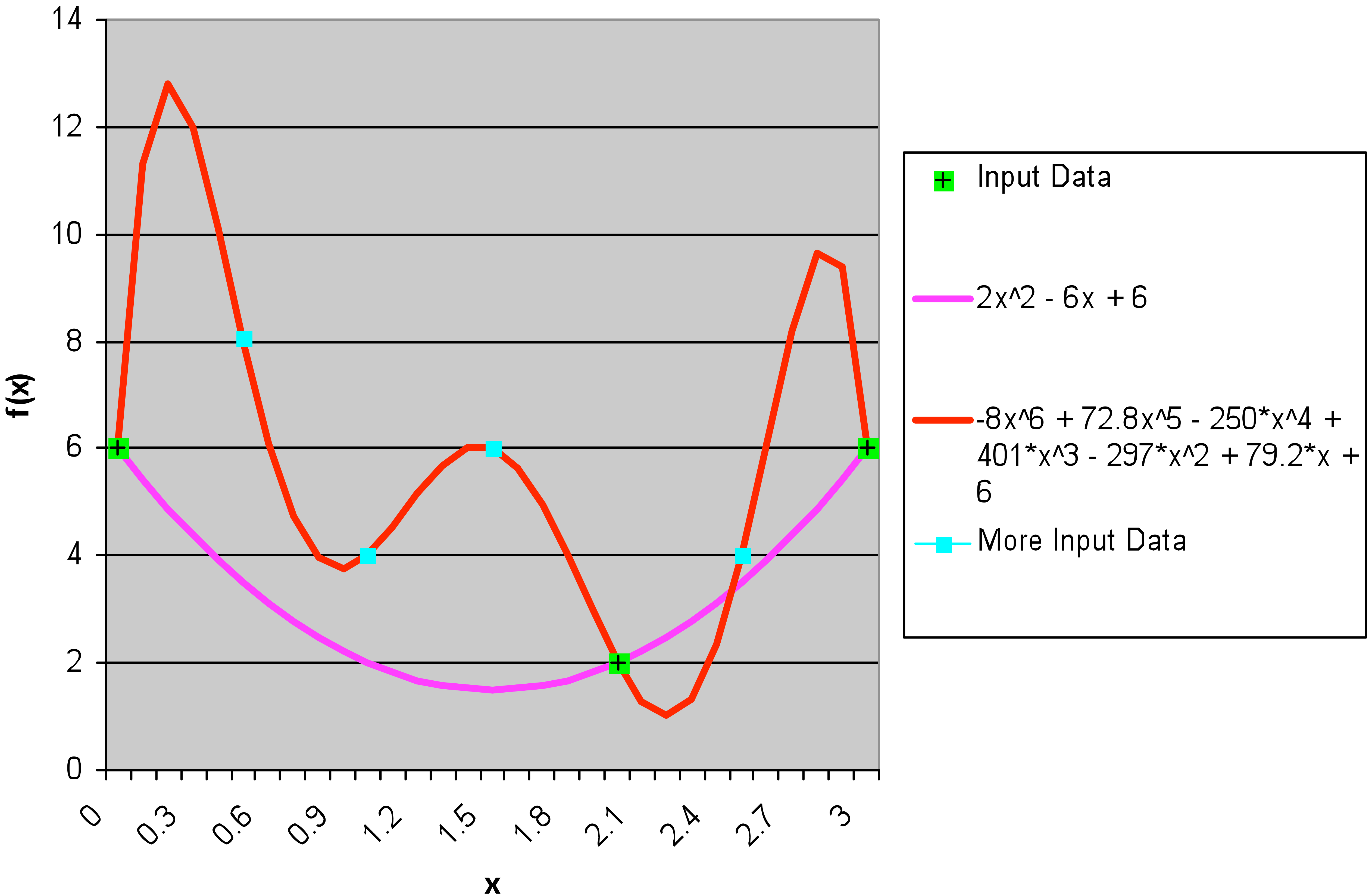
- How about class of context-free languages?
  - Not unless you limit it further (e.g., # of rules)

Punchline

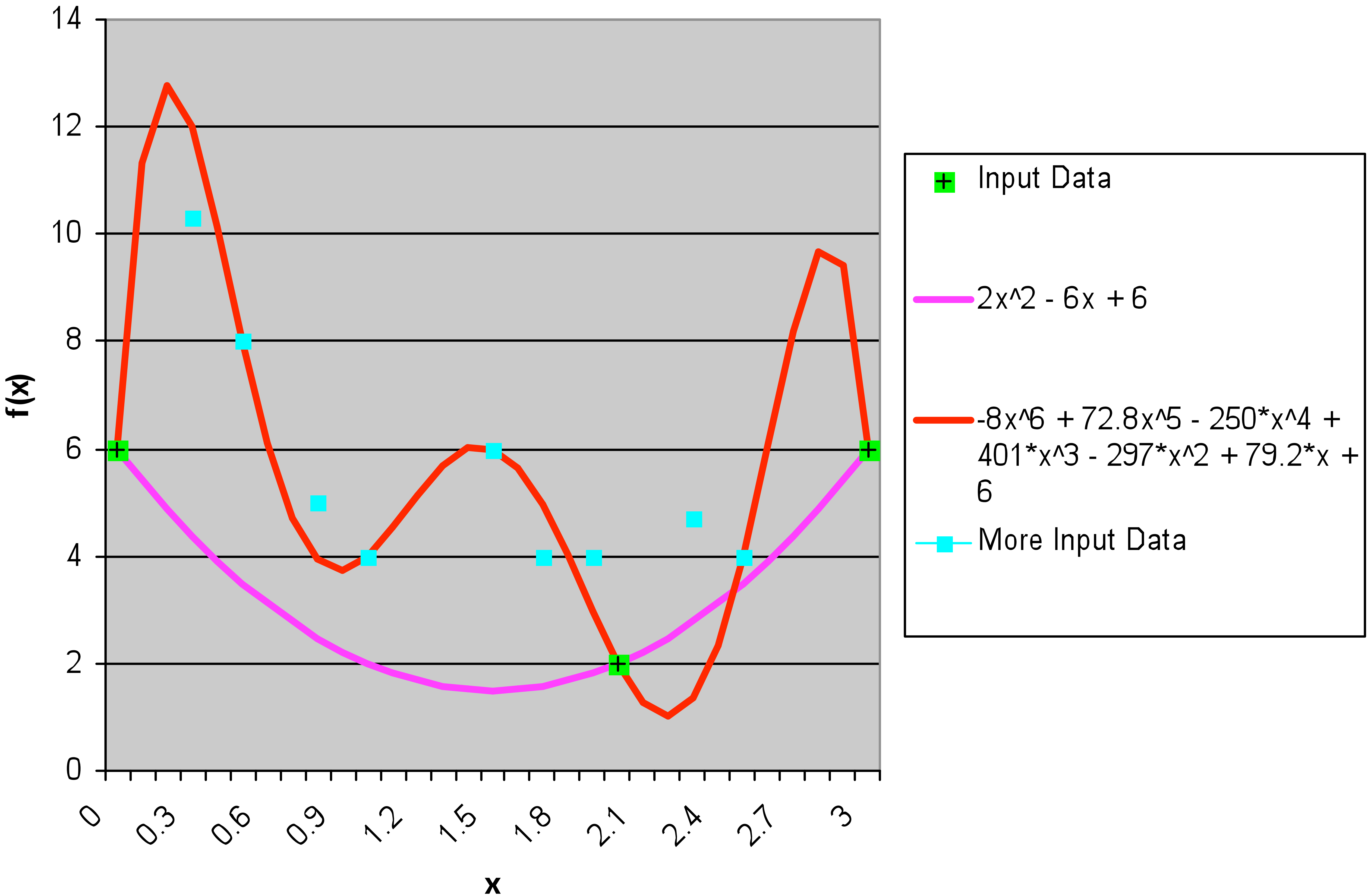
- But class of *probabilistic* context-free languages *is* learnable in the limit!!

- If Mom has to output sentences randomly with the appropriate probabilities,
  - she's unable to be too evil
  - there are then perfect Babies that are guaranteed to converge to an appropriate probabilistic CFG
- I.e., from hearing a finite number of sentences, Baby can correctly converge on a grammar that predicts an infinite number of sentences.
  - Baby is generalizing! Just like real babies!

Perfect fit to perfect, incomplete data



Imperfect fit to noisy data



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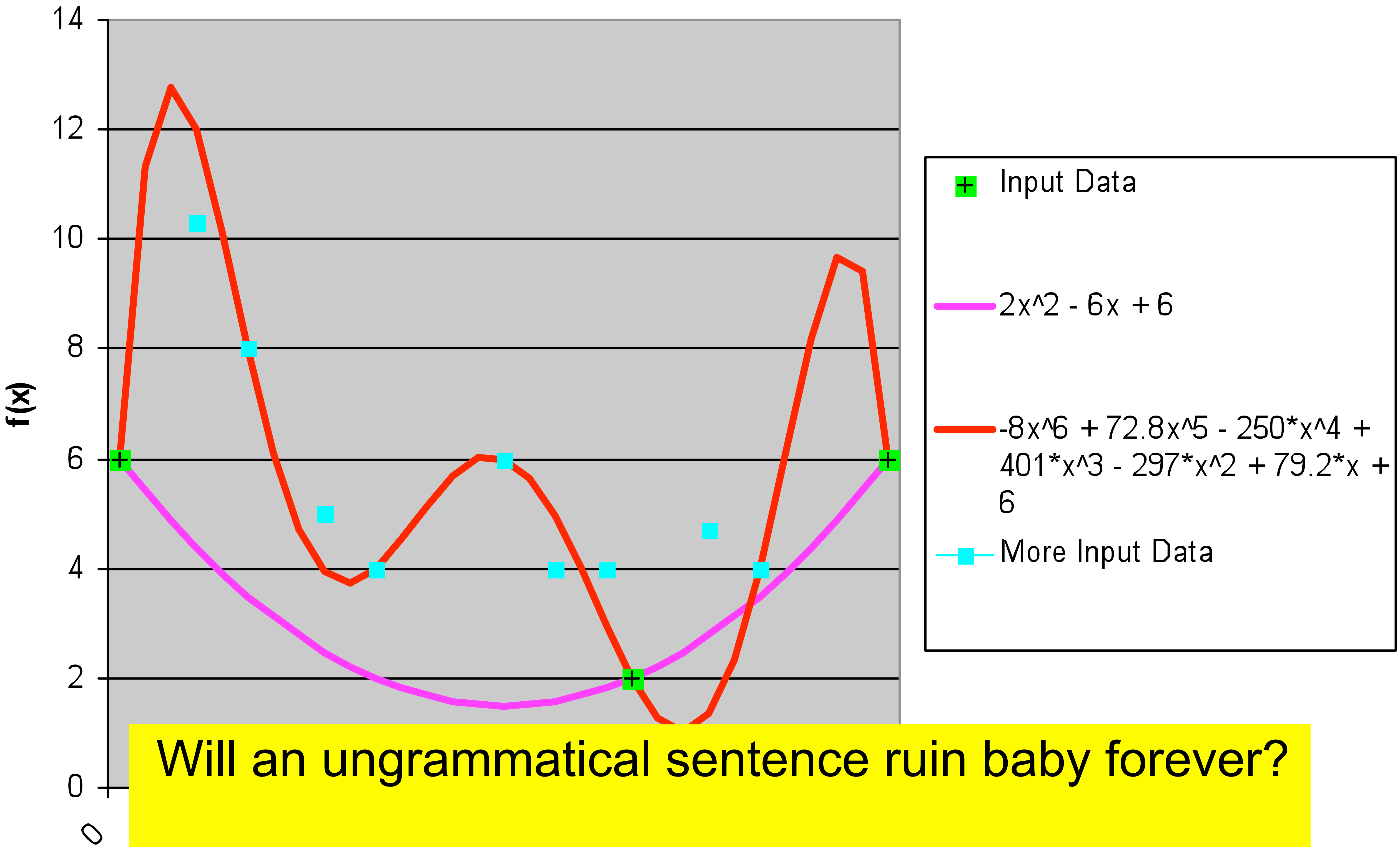
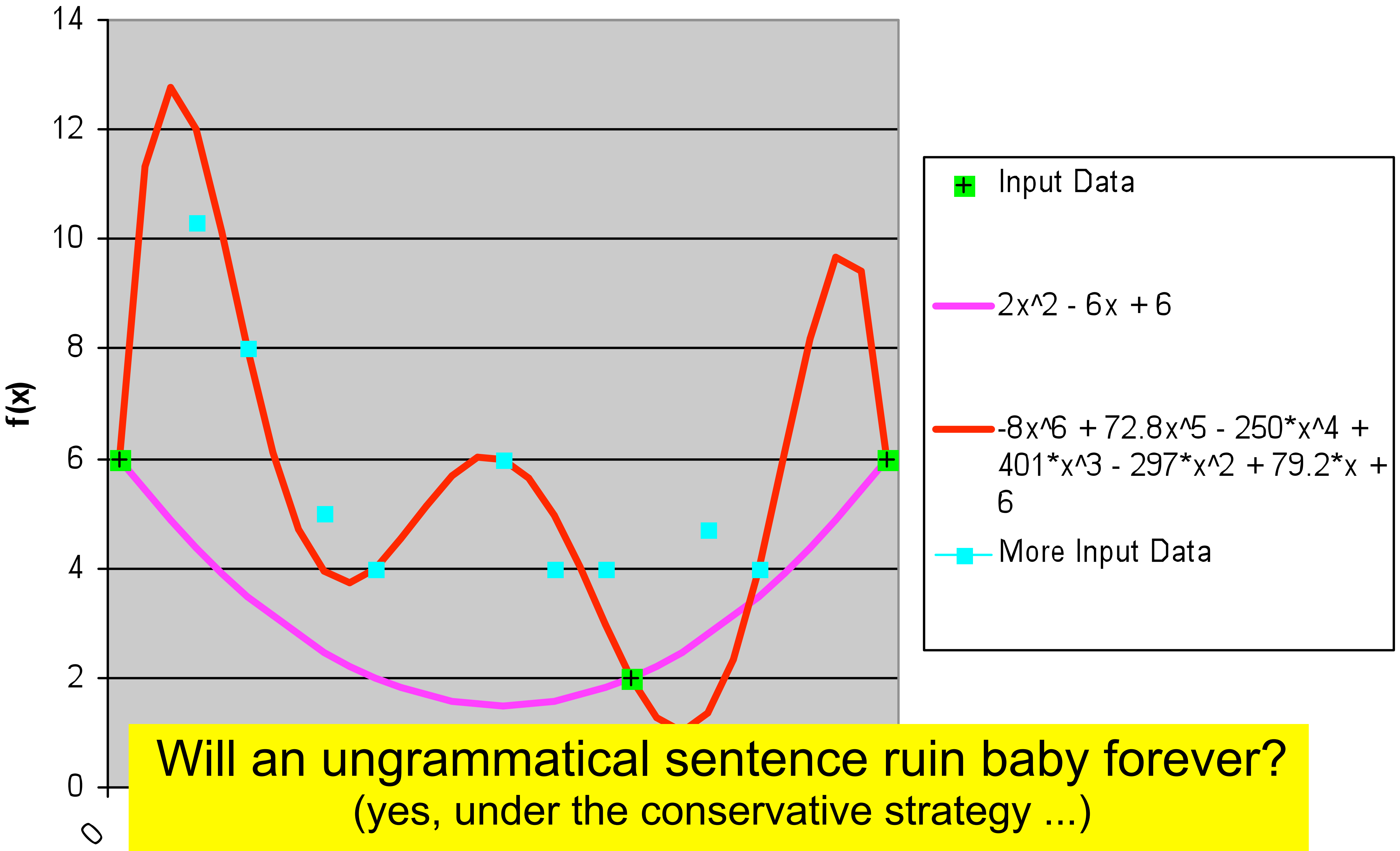


Will an ungrammatical sentence ruin baby forever?

Imperfect fit to noisy data



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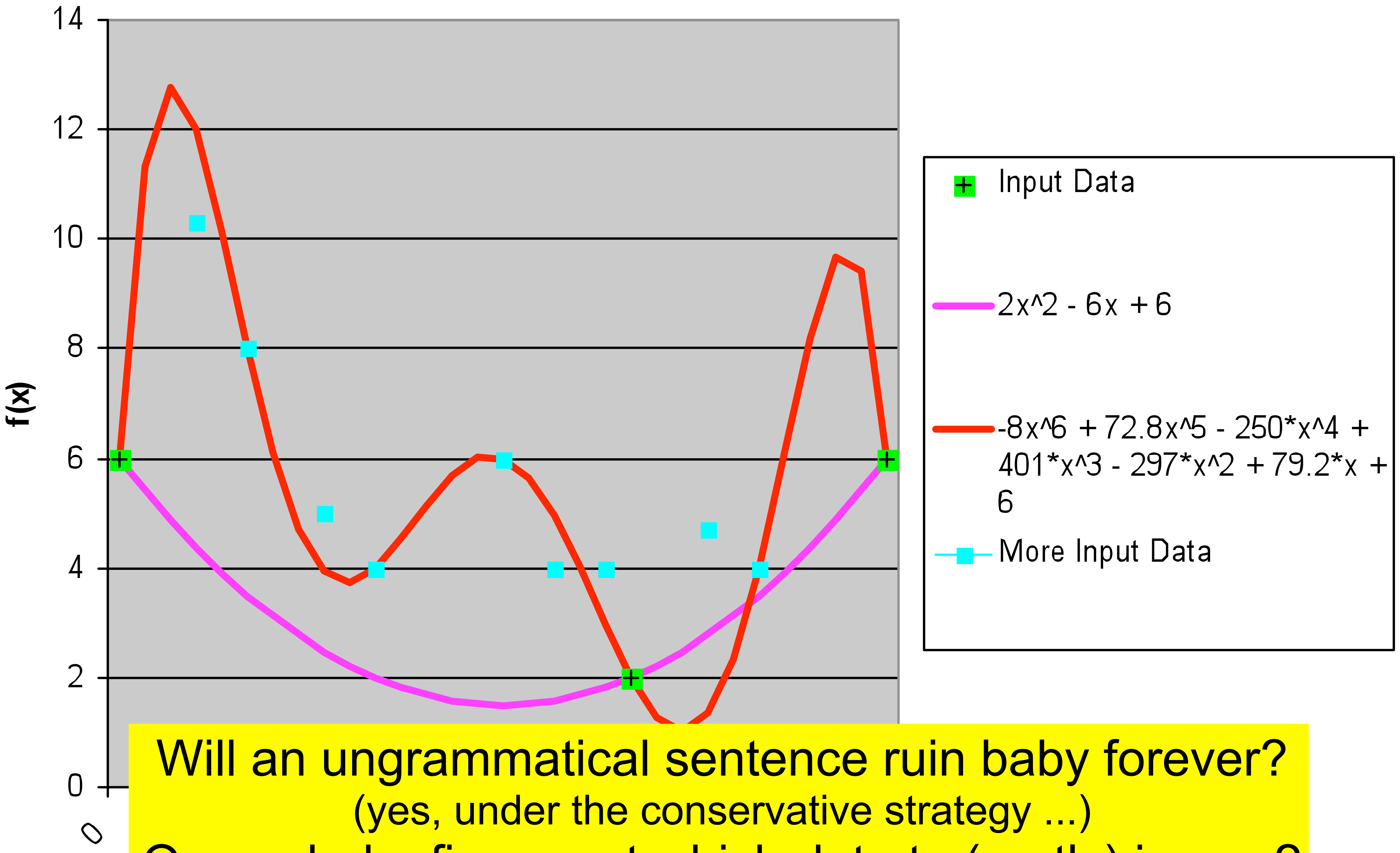

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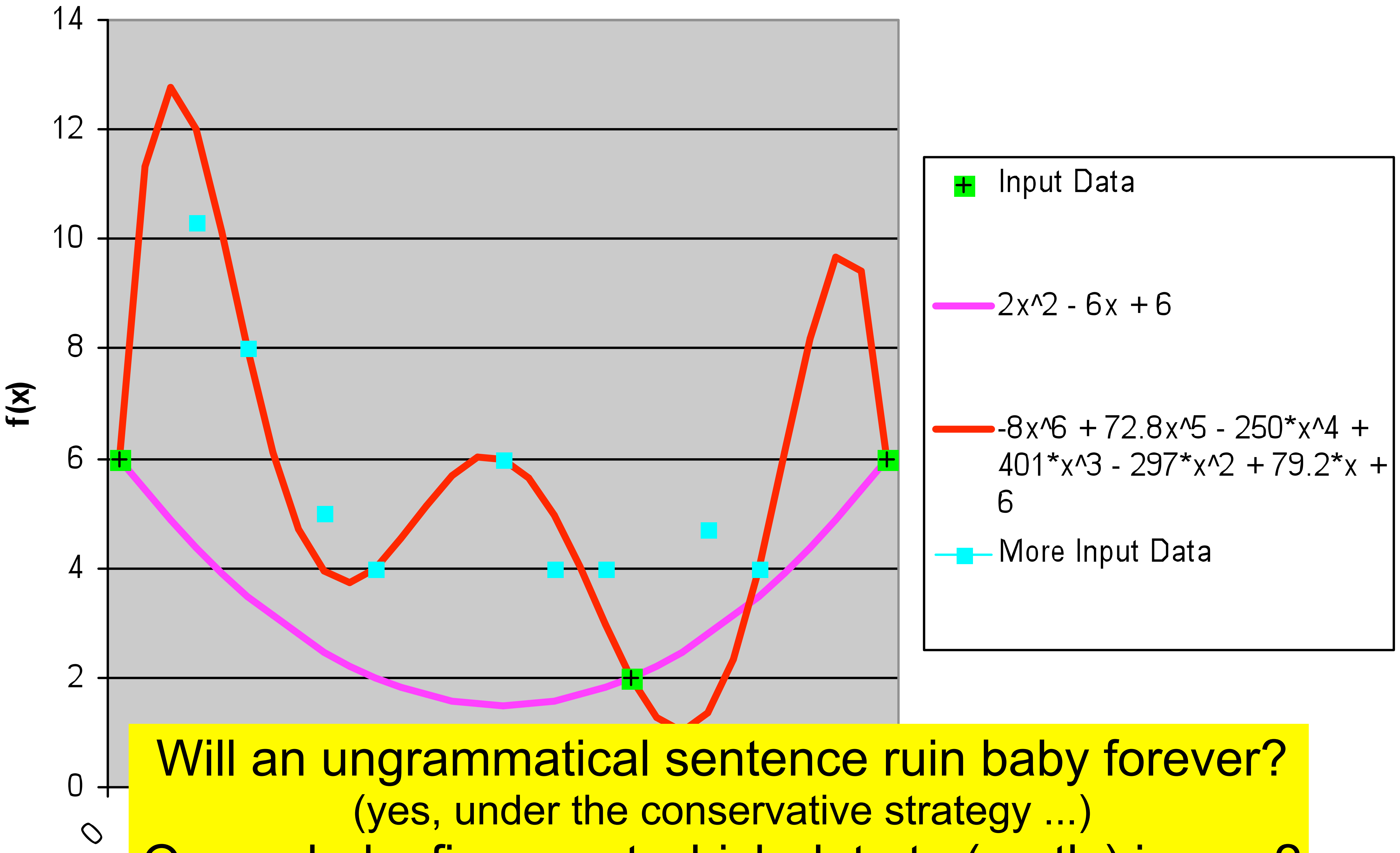

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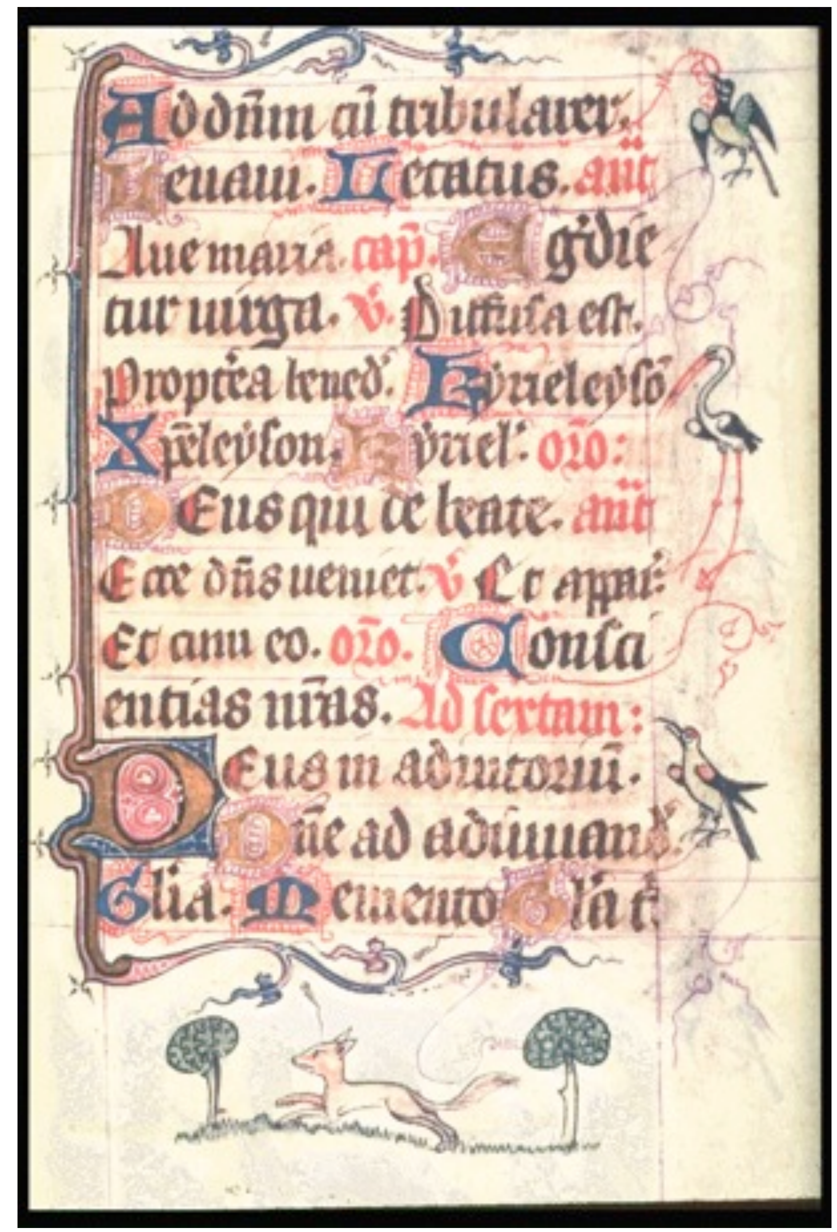
Statistics can help again ... how?

Frequencies and Probabilities in Natural Languages

Chris Manning and others

Models for language

- Human languages are the prototypical example of a symbolic system
- From the beginning, logics and logical reasoning were invented for handling natural language understanding
- Logics and formal languages have a language-like form that draws from and meshes well with natural languages
- Where are the numbers?



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Dominant answer in linguistic theory: Nowhere

Chomsky again (1969: 57; also 1956, 1957, etc.):

- “It must be recognized that the notion ‘probability of a sentence’ is an entirely useless one, under any known interpretation of this term.”
- Probabilistic models wrongly mix in world knowledge
  - New York vs. Dayton, Ohio
- They don’t model grammaticality [also, Tesnière 1959]
  - Colorless green ideas sleep furiously
  - Furiously sleep ideas green colorless
  - [But see Pereira 2005]

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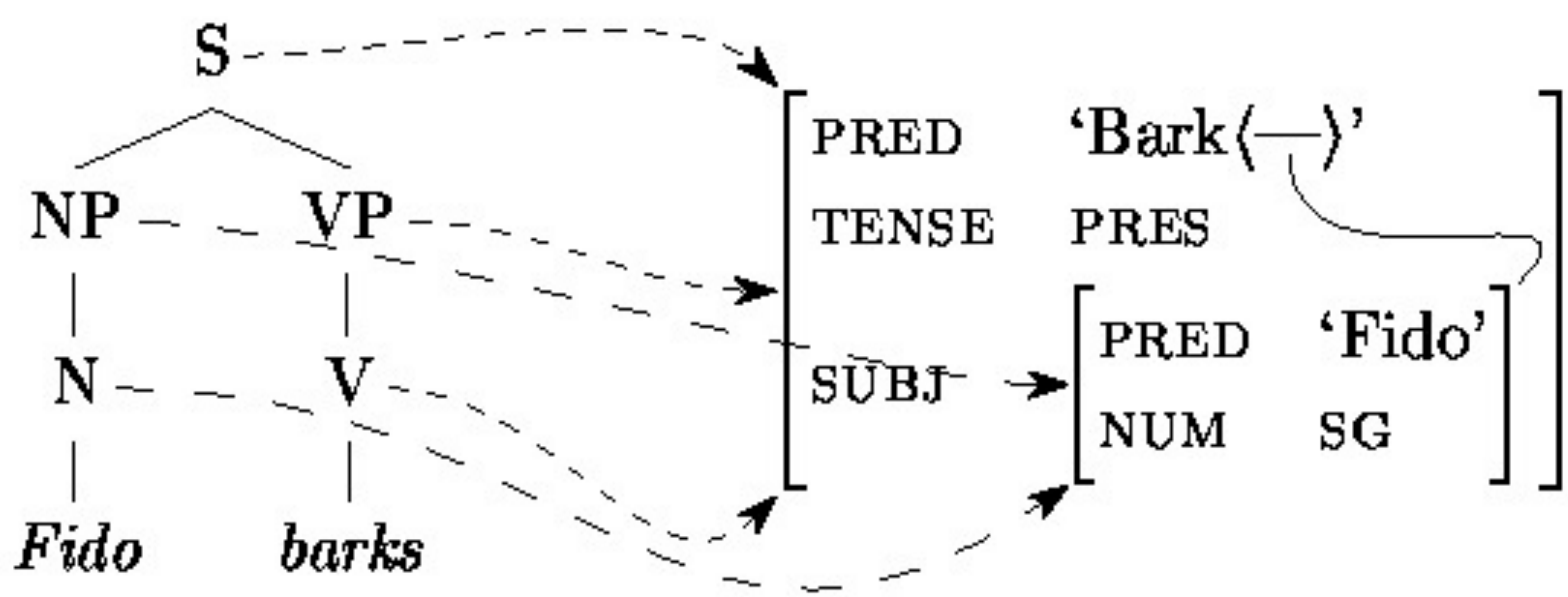
Categorical linguistic theories (GB, Minimalism, LFG, HPSG, CG, …)

- Systems of variously rules, principles, and representations is used to describe an infinite set of grammatical sentences of the language
- Other sentences are deemed ungrammatical
- Word strings are given a (hidden) structure



The need for frequencies / probability distributions

The motivation comes from two sides:

- 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
    - Something that language educators, computational NLP people – and historical linguists and sociolinguists dealing with real language – usually want to know about

1. The hard constraints of categorical grammars

- Sentences must satisfy all the rules of the grammar
  - One group specifies the arguments that different verbs take – lexical subcategorization information
    - Some verbs must take objects: *Kim devoured
      [* means ungrammatical]
    - Others do not: *Kim's lip quivered the straw
    - Others take various forms of sentential complements
- In NLP systems, ungrammatical sentences don't parse
- But the problem with this model was noticed early on:
  - "All grammars leak." (Sapir 1921: 38)

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Example: verbal clausal subcategorization frames

- Some verbs take various types of sentential complements, given as subcategorization frames:
  - regard: __ NP[acc] as {NP, AdjP}
  - consider: __ NP[acc] {AdjP, NP, VP[inf]}
  - think: __ CP[that]; __ NP[acc] NP
- **Problem:** in context, language is used more flexibly than this model suggests
  - Most such subcategorization ‘facts’ are **wrong**

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Standard subcategorization rules (Pollard and Sag 1994)

- We consider Kim to be an acceptable candidate
- We consider Kim an acceptable candidate
- We consider Kim quite acceptable
- We consider Kim among the most acceptable candidates
- *We consider Kim as an acceptable candidate
- *We consider Kim as quite acceptable
- *We consider Kim as among the most acceptable candidates
- ?*We consider Kim as being among the most acceptable candidates

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Subcategorization facts from The New York Times

Consider as:

- The boys consider her as family and she participates in everything we do.
- Greenspan said, "I don't consider it as something that gives me great concern.
- "We consider that as part of the job," Keep said.
- Although the Raiders missed the playoffs for the second time in the past three seasons, he said he considers them as having championship potential.
- Culturally, the Croats consider themselves as belonging to the "civilized" West, …

More subcategorization facts: regard

Pollard and Sag (1994):

- *We regard Kim to be an acceptable candidate
- We regard Kim as an acceptable candidate

The New York Times:

- As 70 to 80 percent of the cost of blood tests, like prescriptions, is paid for by the state, neither physicians nor patients regard expense to be a consideration.
- Conservatives argue that the Bible regards homosexuality to be a sin.

More subcategorization facts: turn out and end up

Pollard and Sag (1994):

- Kim turned out political
- *Kim turned out doing all the work

The New York Times:

- But it turned out having a greater impact than any of us dreamed.

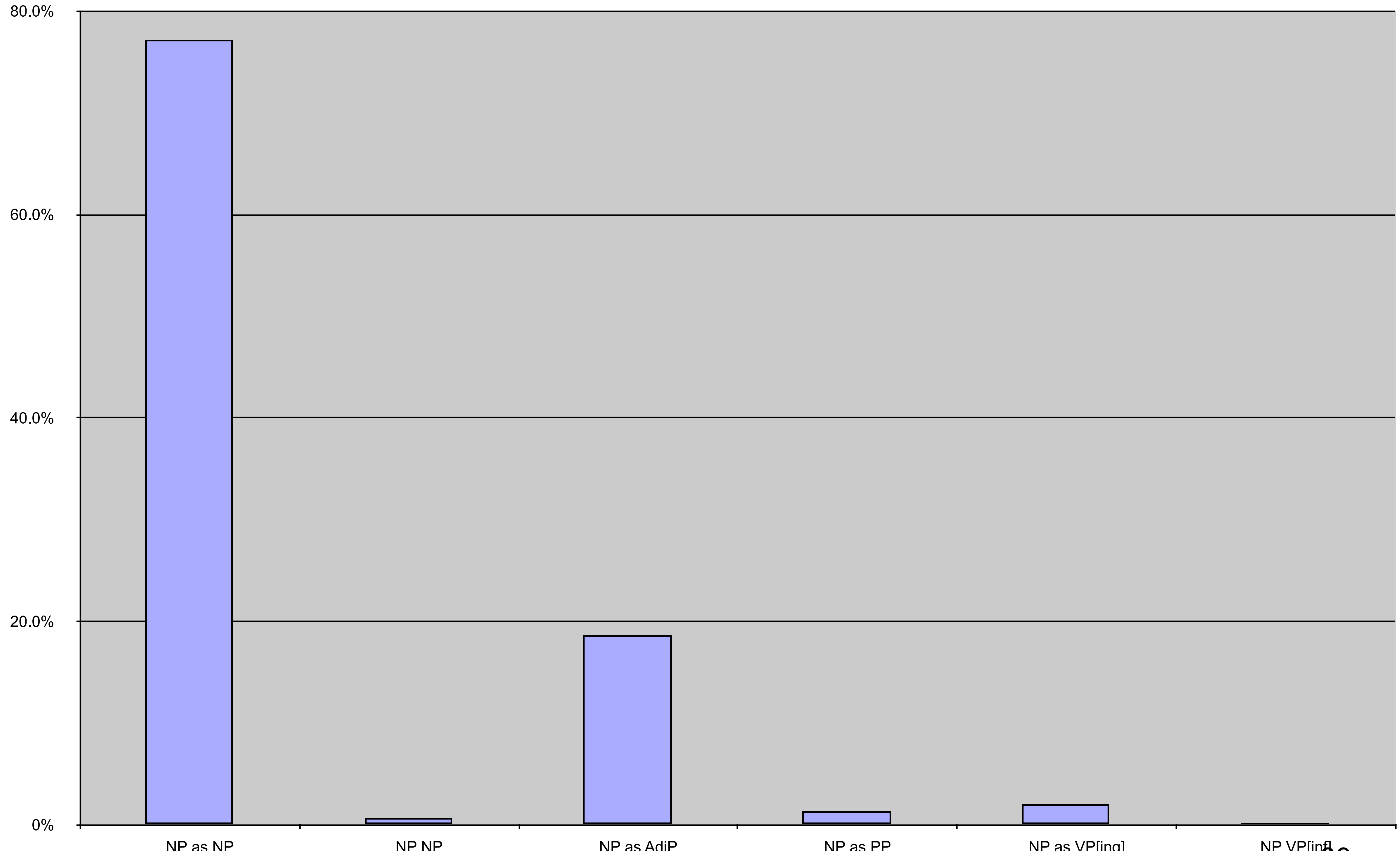
Pollard and Sag (1994):

- Kim ended up political
- *Kim ended up sent more and more leaflets

The New York Times:

- On the big night, Horatio ended up flattened on the ground like a fried egg with the yolk broken.

Probability mass functions: subcategorization of regard



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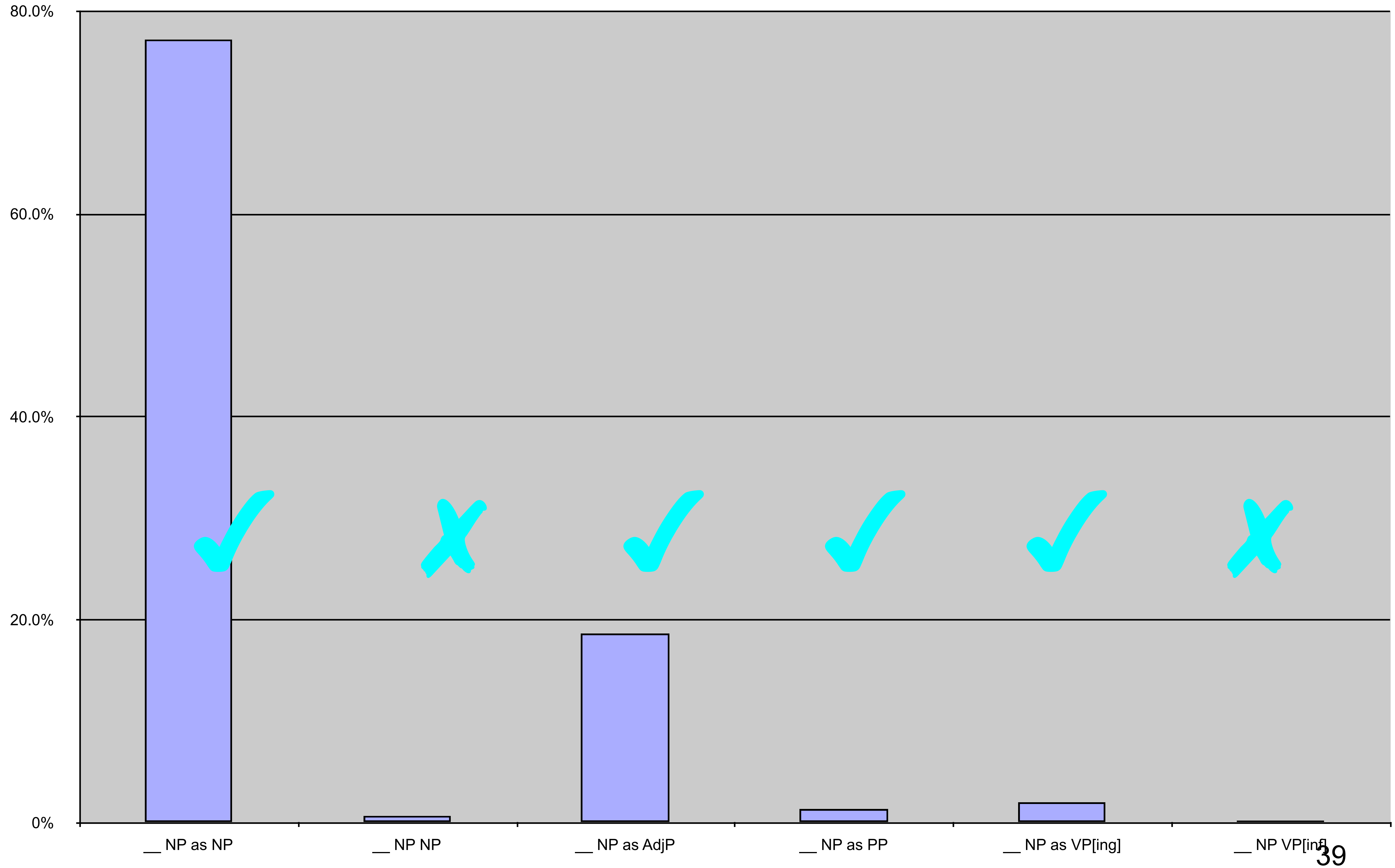

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Leakage leads to change

- People continually stretch the 'rules' of grammar to meet new communicative needs, to better align grammar and meaning, etc.
- As a result language slowly changes
  - **while:** used to be only a noun (That takes a while); now mainly used as a subordinate clause introducer (While you were out)
  - **e-mail:** started as a mass noun like mail (most junk e-mail is annoying); it's moving to be a count noun (filling the role of e-letter): I just got an interesting email about that.

Blurring of categories: "Marginal prepositions"

- An example of blurring in syntactic category during linguistic change is so-called ‘marginal prepositions’ in English, which are moving from being participles to prepositions
- Some still clearly maintain a verbal existence, like following, concerning, considering; for some it is marginal, like according, excepting; for others their verbal character is completely lost, such as during [cf. endure], pending, notwithstanding.

Verb (VBG) ➡ Preposition IN

As verbal participle, understood subject agrees with noun:

- They moved slowly, toward the main gate, following the wall
- Repeat the instructions following the asterisk

A temporal use with a controlling noun becomes common:

- This continued most of the week following that ill-starred trip to church

Prep. uses (meaning is after, no controlling noun) appear

- He bled profusely following circumcision
- Following a telephone call, a little earlier, Winter had said ...

Mapping the recent change of following: participle ➡ prep.

- Fowler (1926): “there is a continual change going on by which certain participles or adjectives acquire the character of prepositions or adverbs, no longer needing the prop of a noun to cling to … [we see] a development caught in the act”
- Fowler (1926) -- no mention of following in particular
- Fowler [Gowers] (1948): “Following is not a preposition. It is the participle of the verb follow and must have a noun to agree with”
- Fowler [Gowers] (1954): generally condemns temporal usage, but says it can be justified in certain circumstances

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2. Explaining more: What do people say?

- What people do say has two parts:
  - Contingent facts about the world
    - People in Minnesota have talked a lot about snow falling, not stocks falling, lately
  - The way speakers choose to express ideas using the resources of their language
    - People don't often put <u>that</u>-clauses pre-verbally:
      - That we will have to revise this program is almost certain
- The latter is properly part of people's Knowledge of Language—i.e., part of linguistics.

What do people say?

- Simply delimiting a set of grammatical sentences provides only a very weak description of a language, and of the ways people choose to express ideas in it
- Probability densities over sentences and sentence structures can give a much richer view of language structure and use
- In particular, we find that the same soft generalizations and tendencies of one language often appear as (apparently) categorical constraints in other languages
- A syntactic theory should be able to uniformly capture these constraints, rather than only recognizing them when they are categorical

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Example: Bresnan, Dingare & Manning

- Project modeling English diathesis alternations (active/passive, locative inversion, etc.)
- In some languages passives are categorically restricted by person considerations:
  - In Lummi (Salishan, Washington state), 1/2 person must be the subject if other argument is 3rd person. There is variation if both arguments are 3rd person. (Jelinek and Demers 1983) [cf. also Navajo, etc.]
    - *That example was provided by me
    - *He likes me
    - ✓I am liked by him

Bresnan, Dingare & Manning

- In English, there is no such categorical constraint, but we can still see it at work as a soft constraint.
- Collected data from verbs with an agent and patient argument (canonical transitives) from treebanked portions of the Switchboard corpus of conversational American English, analyzing for person and act/pass

	Active	Passive
1/2 Ag, 1/2 Pt	158	0 (0.0%)
1/2 Ag, 3 Pt	5120	1 (0.0%)
3 Ag, 1/2 Pt	552	16 (2.8%)
3 Ag, 3 Pt	3307	46 (1.4%)

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Bresnan, Dingare & Manning

- While person is only a small part of the picture in determining the choice of active/passive in English (information structure, genre, etc. is more important), there is nonetheless a highly significant (X^2 $p < 0.0001$) effect of person on active/passive choice
- The exact same hard constraint of Lummi appears as a soft constraint in English
- This behavior is predicted by the universal hierarchies within a stochastic OT model (which extends existing OT approaches to valence – Aissen 1999, Lødrup 1999)
- Conversely linguistic model predicts that no "anti-English" [which is just the opposite] exists

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Conclusions

- There are many phenomena in language that cry out for non-categorical and probabilistic modeling and explanation
- Probabilistic models can be applied on top of one's favorite sophisticated linguistic representations!
- Frequency evidence can enrich linguistic theory by revealing soft constraints at work in language use

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