A Bayesian account of the perceptual magnet effect

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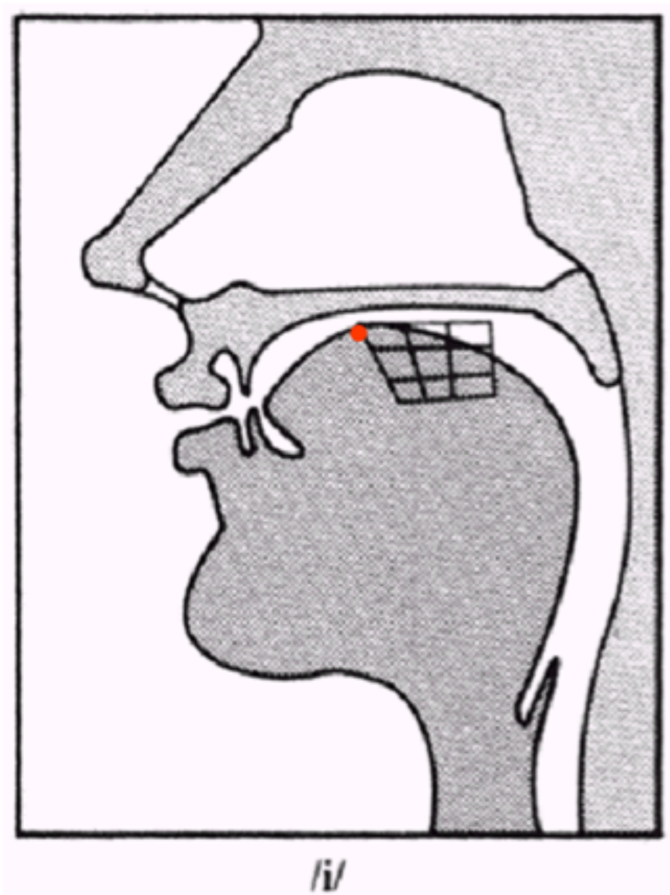
Producing vowels



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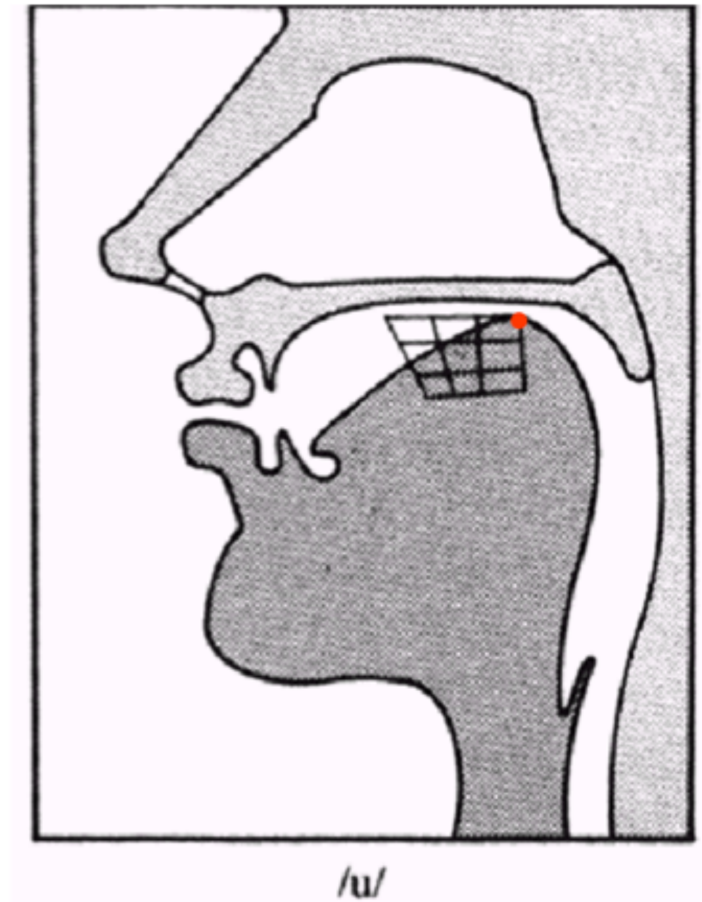

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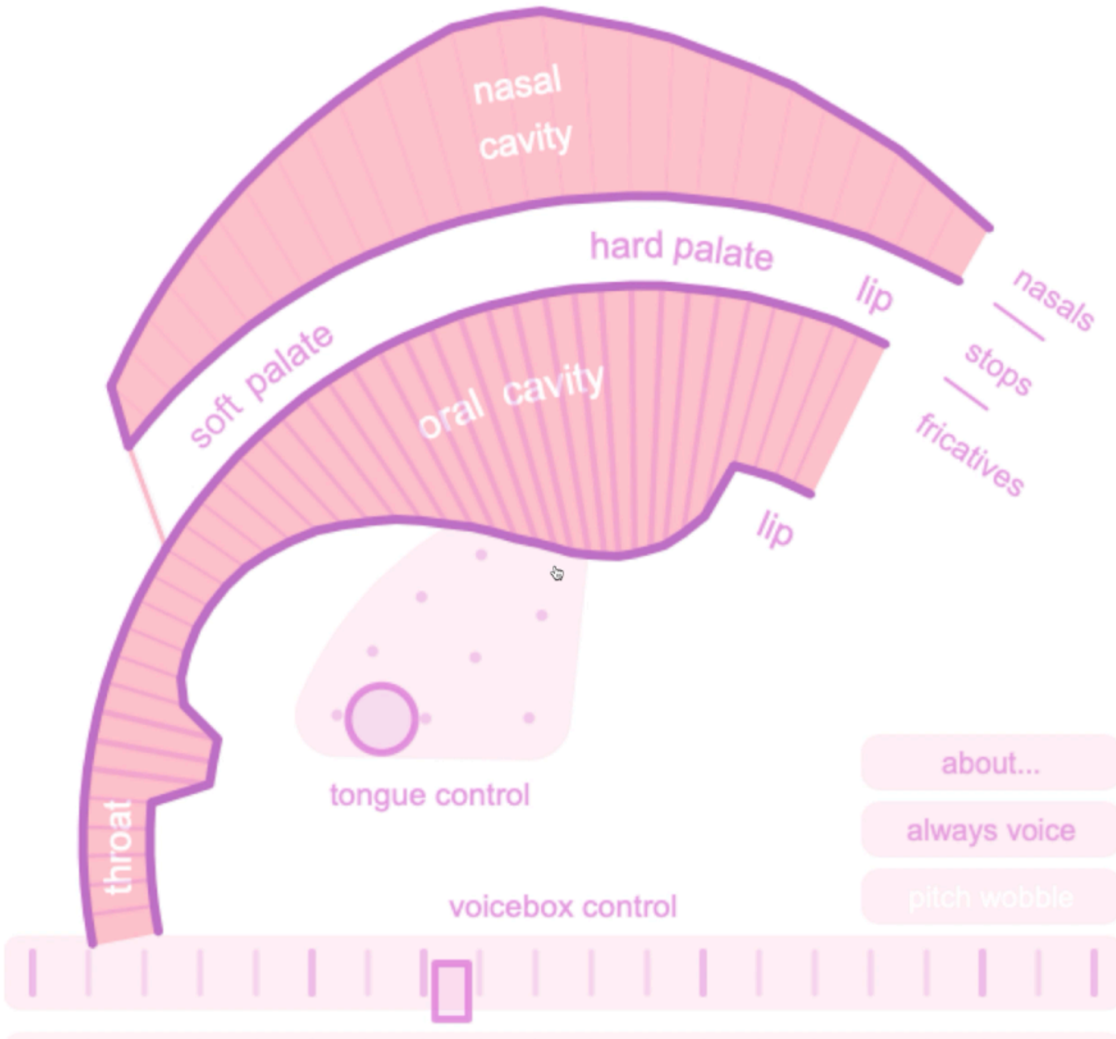
Vocal tract simulator

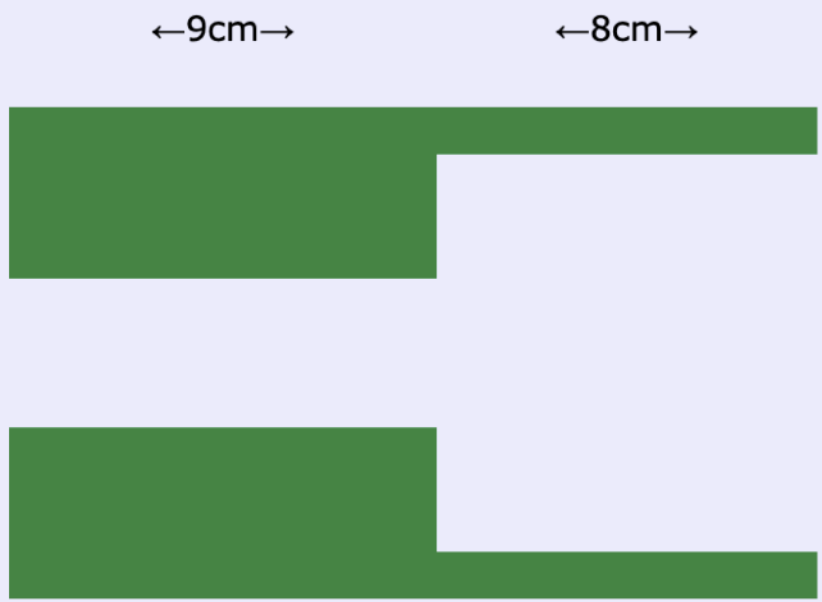


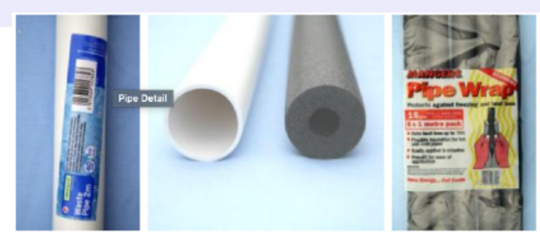
https://dood.al/pinktrombone/

Vocal tract cavity shape→vowel quality

An "AH" vowel resonator

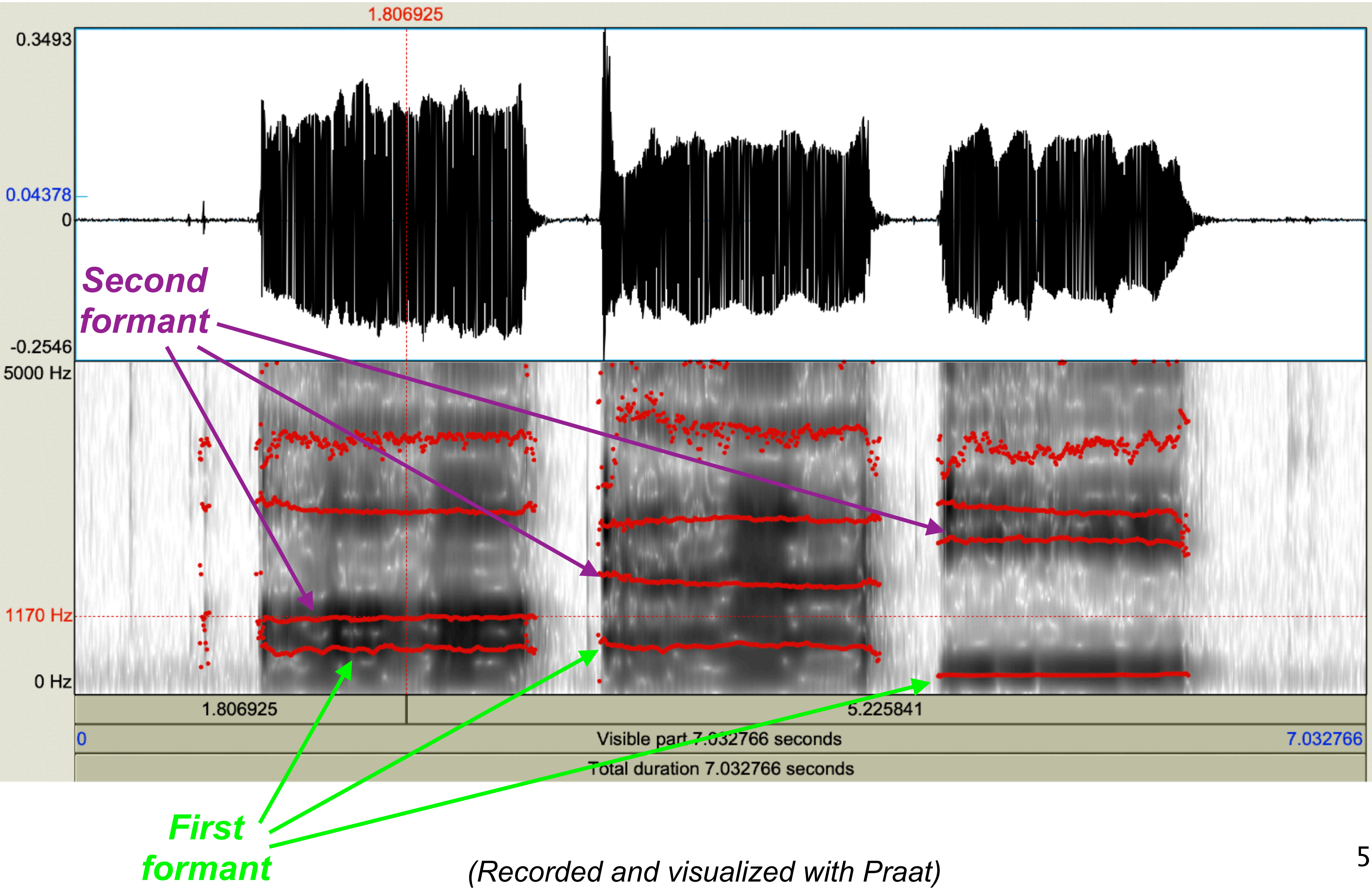
This resonator sounds like the long /A/ vowel that you find in words like "palm". You will need 9cm length of the foam sleeving and 8cm length of pipe. The narrow part of the resonator is analogous to the narrow part of the vocal tract from larynx to the back of the mouth, while the wide part of the resonator is analogous to the oral cavity.





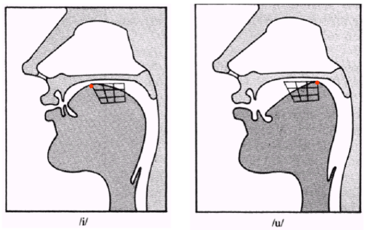
Credit to Mark Huckvale: https://www.phon.ucl.ac.uk/home/mark/vowels/

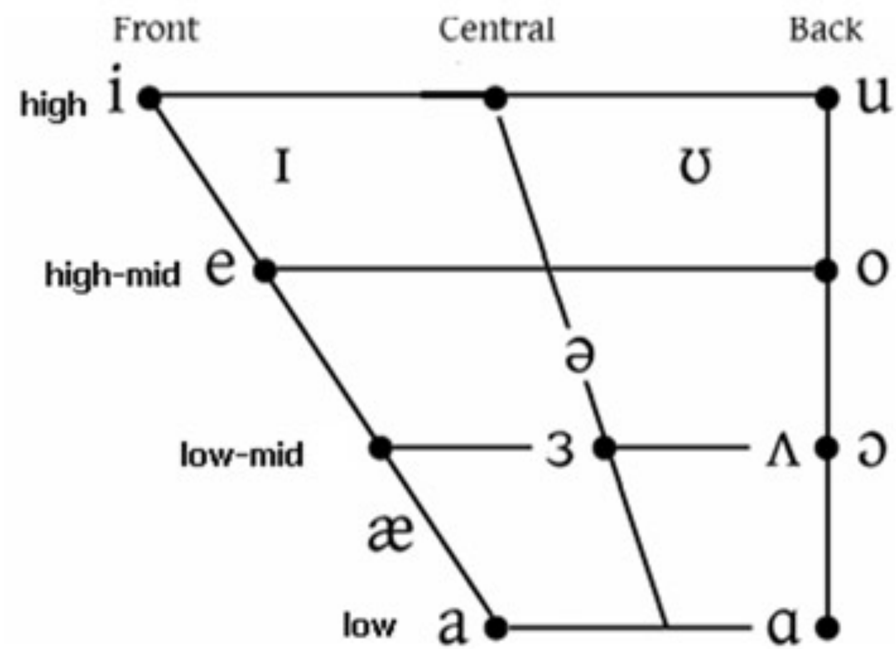
Formants and vowel quality

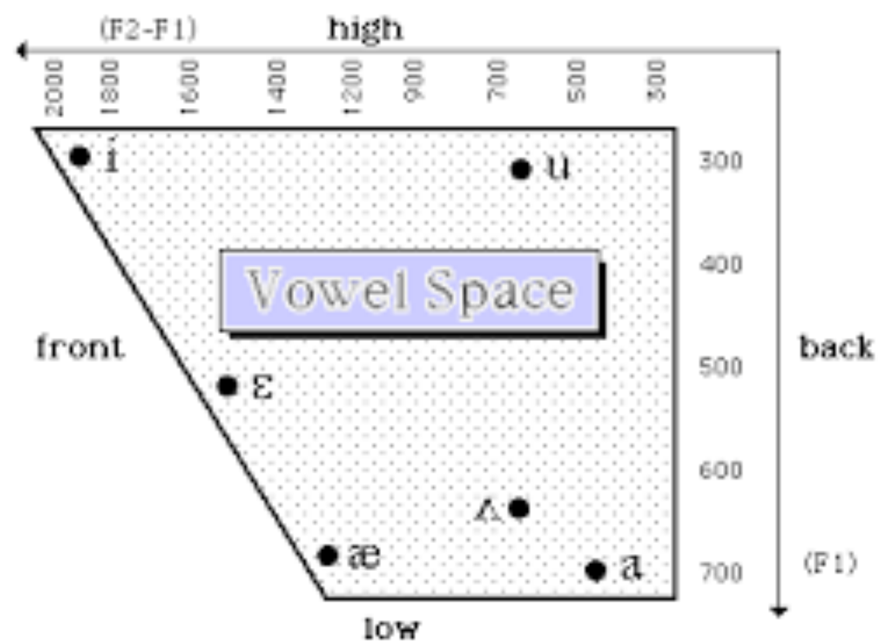


(Recorded and visualized with Praat)

Vowel space, articulatory



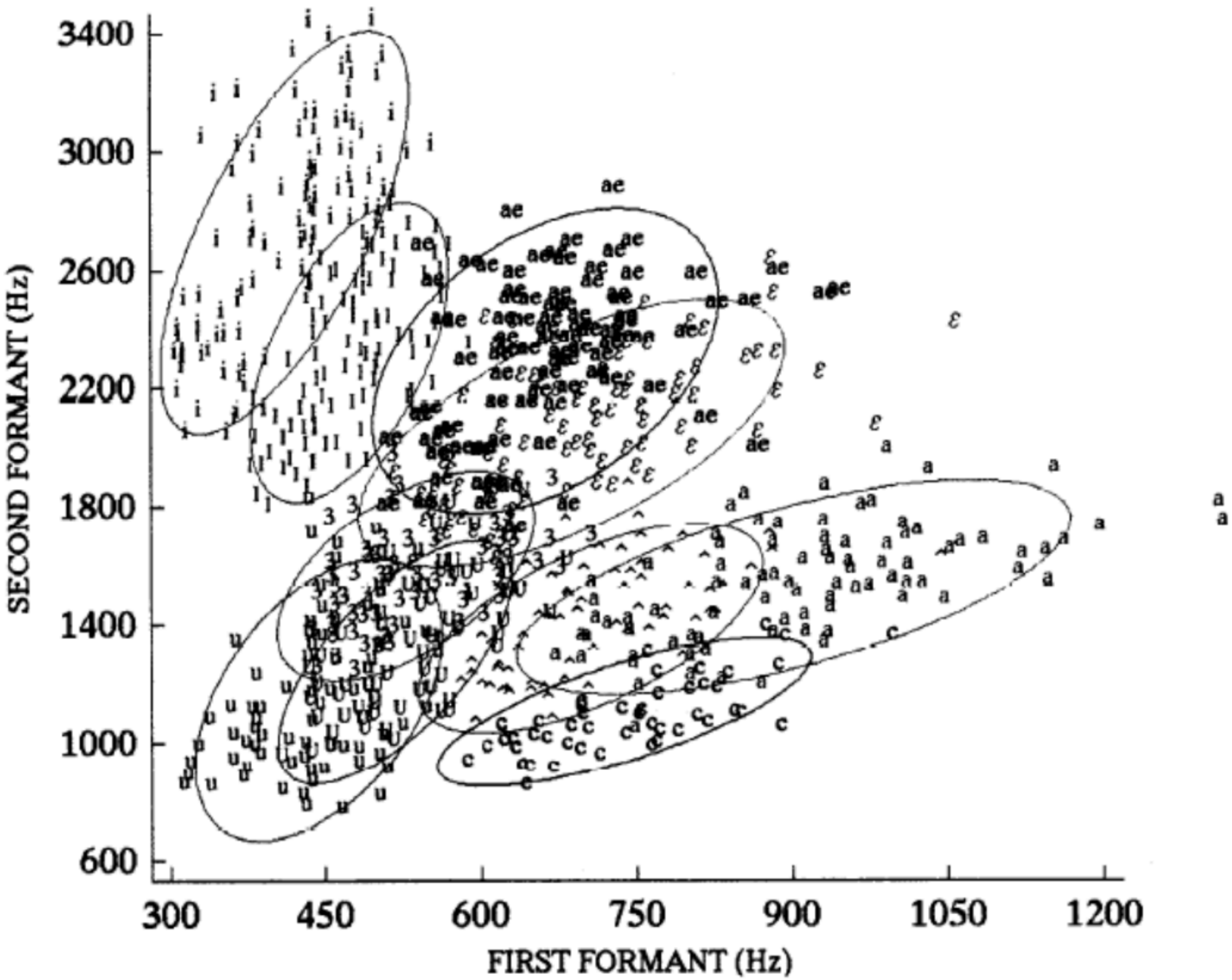




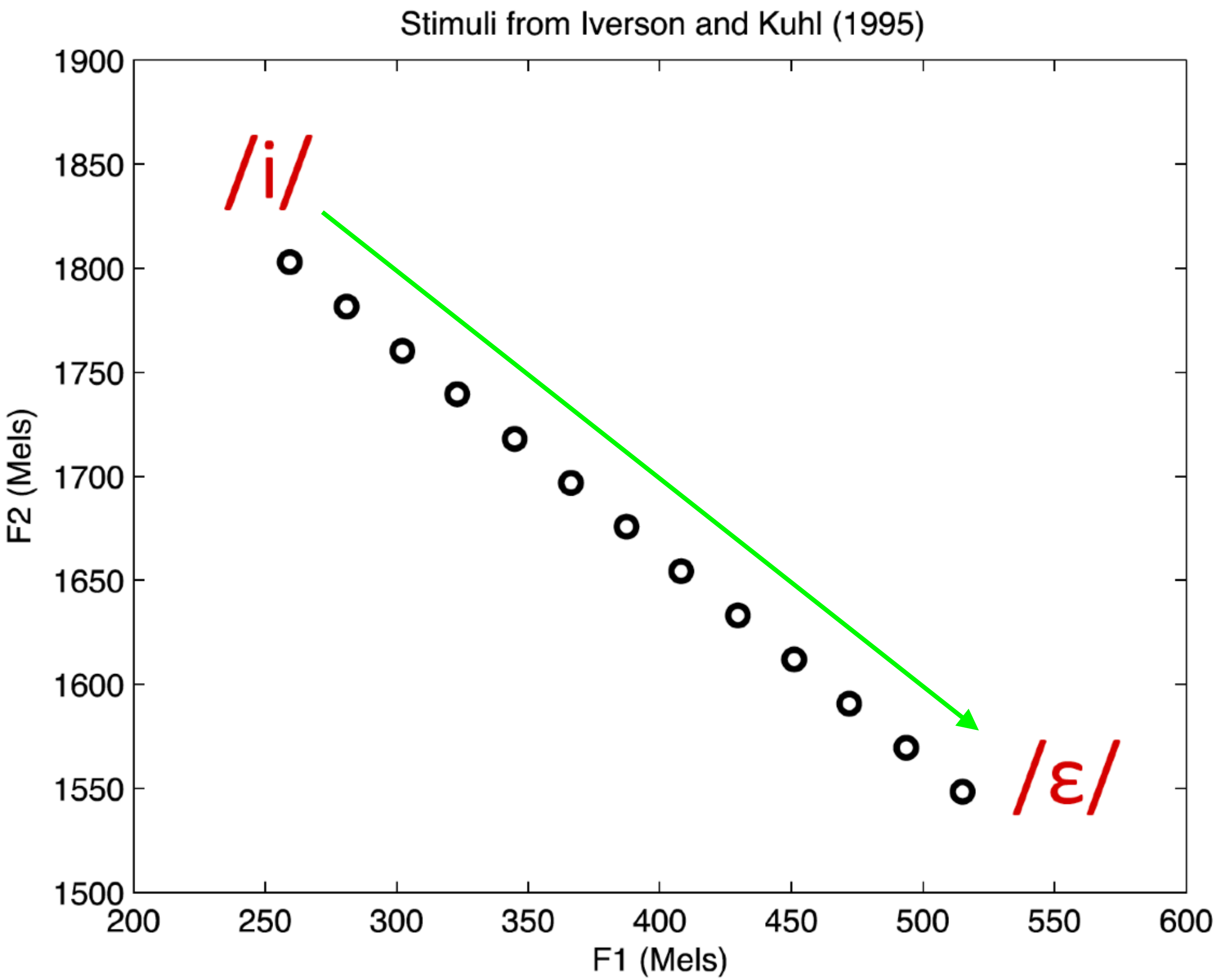
http://haskinslabs.org/about-us/features-and-demos/articulatory-synthesis/articulatory-synthesis-vowels

http://www.azlifa.com/pp-lecture-7/

English vowel inventory, in formant space



A vowel continuum



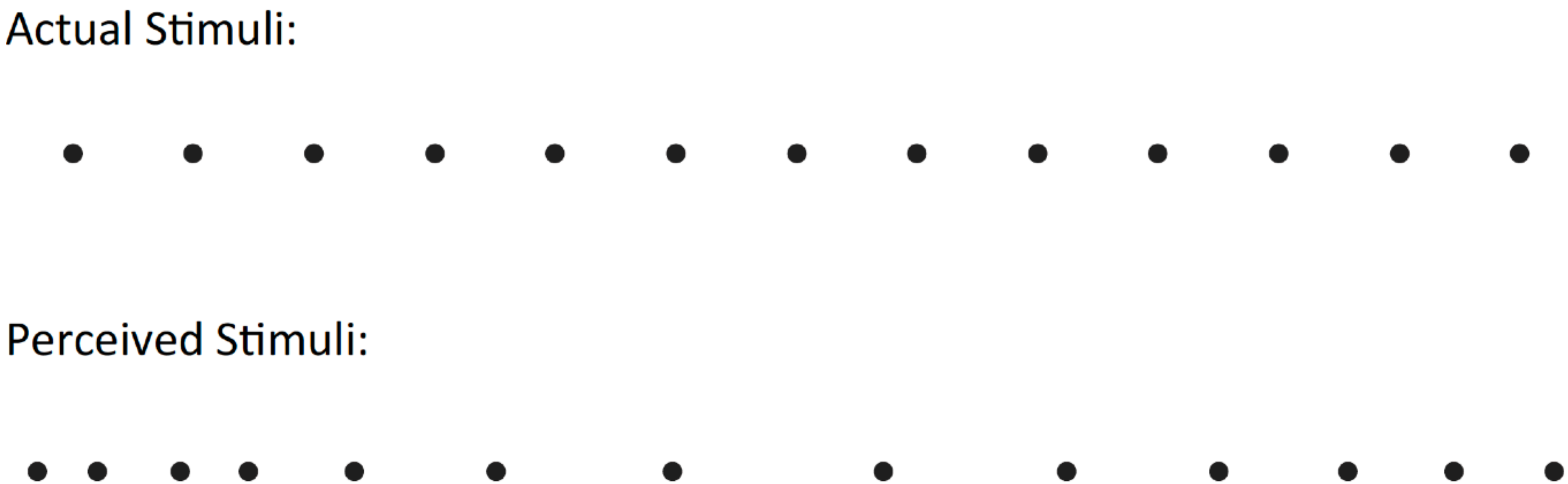
Same/different judgments

Percentage of Trials on Which Subjects Responded "Same" for Each Pair of Stimuli in the No-Noise and Noise Conditions

Stimulus no.	1	2	3	4	5	6	7	8	9	10	11	12	13
						No-noise condition							
1	98.8	82.5	82.5	40.0	22.5	7.5	5.0	5.0	0.0	0.0	2.5	0.0	2.5
2		97.5	95.0	70.0	52.5	10.0	5.0	0.0	2.5	2.5	0.0	0.0	0.0
3			91.3	97.5	75.0	32.5	12.5	5.0	2.5	0.0	2.5	2.5	0.0
4				97.5	87.5	40.0	12.5	5.0	2.5	0.0	2.5	0.0	0.0
5					97.5	77.5	27.5	12.5	5.0	2.5	0.0	0.0	0.0
6						92.5	75.0	30.0	15.0	2.5	2.5	2.6	0.0
7							91.3	75.0	42.5	17.5	5.0	5.0	0.0
8								95.0	80.0	50.0	32.5	7.5	5.0
9									93.8	87.5	67.5	27.5	22.5
10										92.5	87.5	76.9	37.5
11											97.5	87.5	65.0
12												96.3	97.5
13													100.0

(Feldman et al., 2009)

The perceptual magnet effect



How can we account for this phenomenon?

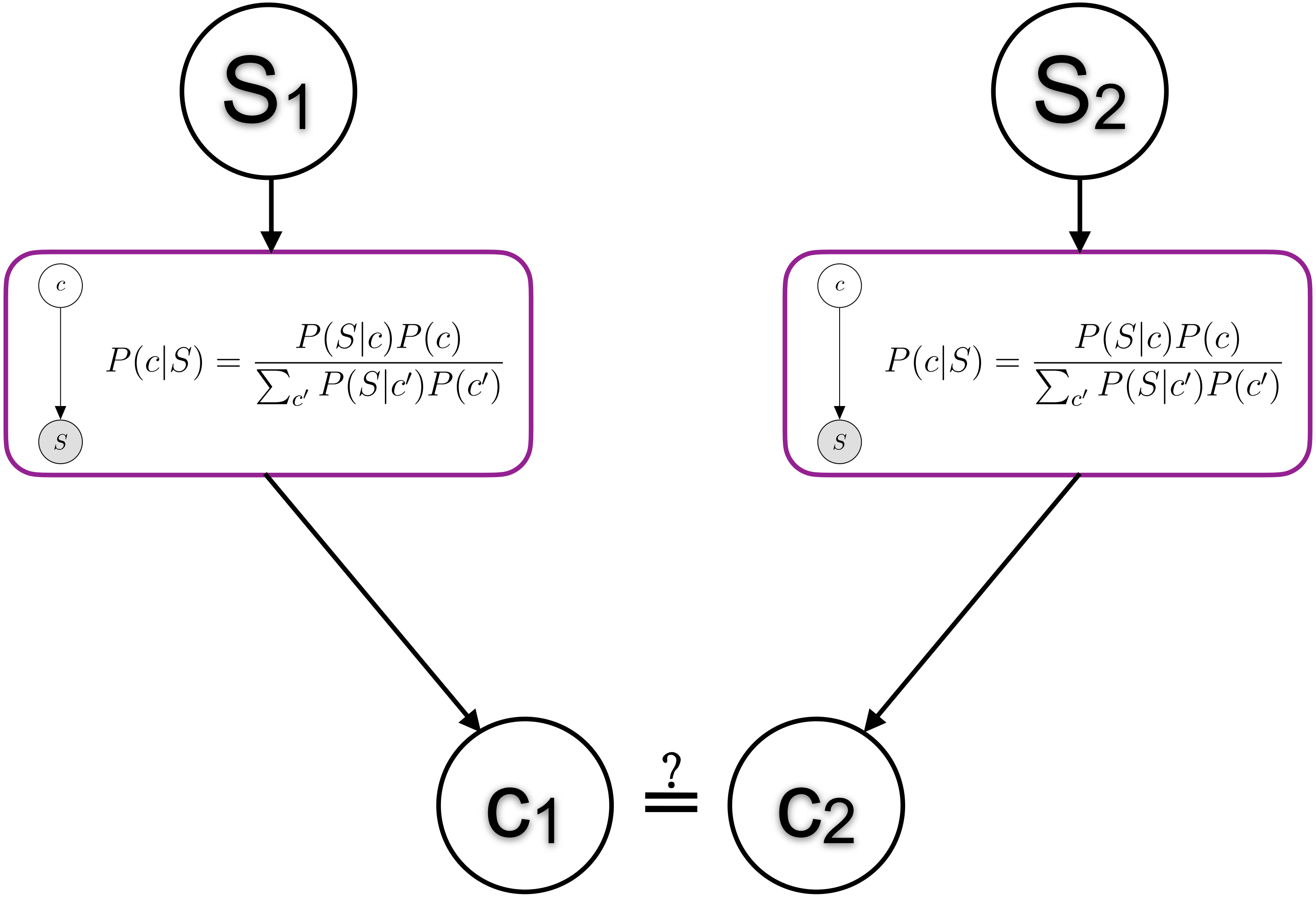
Rational analysis

- Background assumption: cognitive agent is optimized via evolution and learning to solve everyday tasks effectively

1. Specify precisely the goals of the cognitive system
2. Formalize model of the environment to which the cognitive system is adapted
3. Make minimal assumptions re: computational limitations
4. Derive predicted optimal behavior given 1—3
5. Compare predictions with empirical data
6. If necessary, iterate 1—5

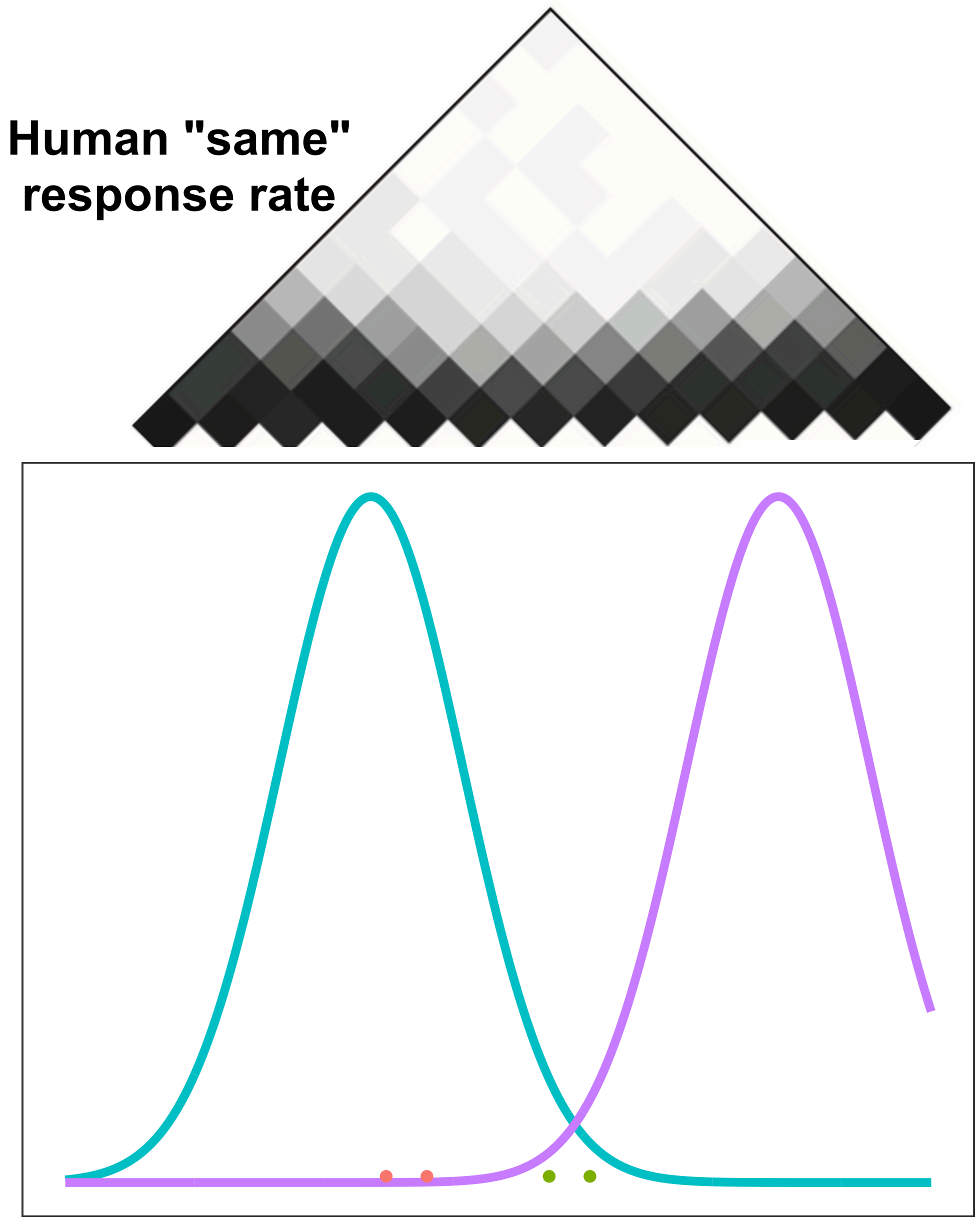
(Anderson, 1990, 1991)

Candidate theory: categorize then check match

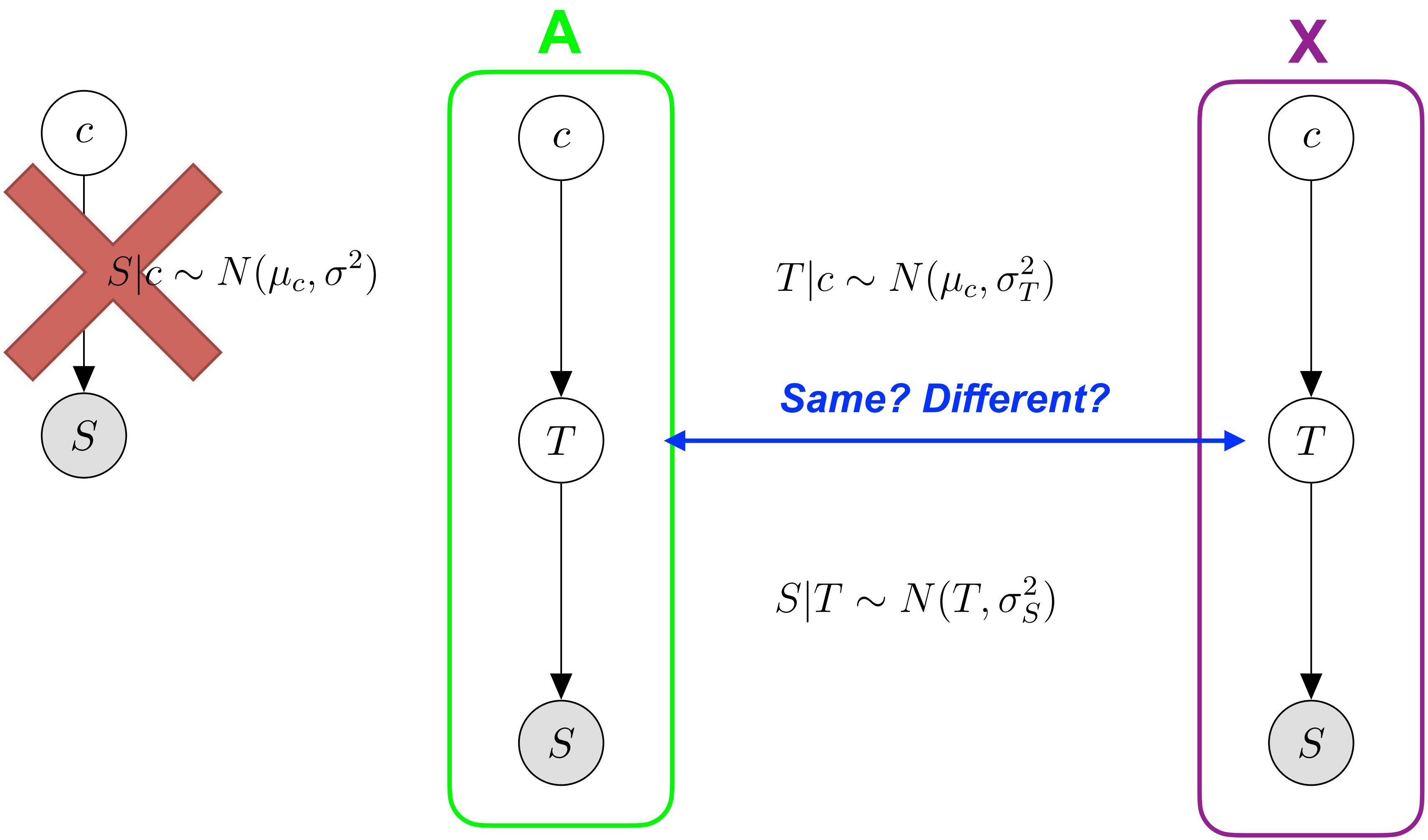


Is this adequate?

The problem with categorize-then-check



A more complex proposal



(Feldman et al., 2009, Psychological Review)

Noisy-channel models

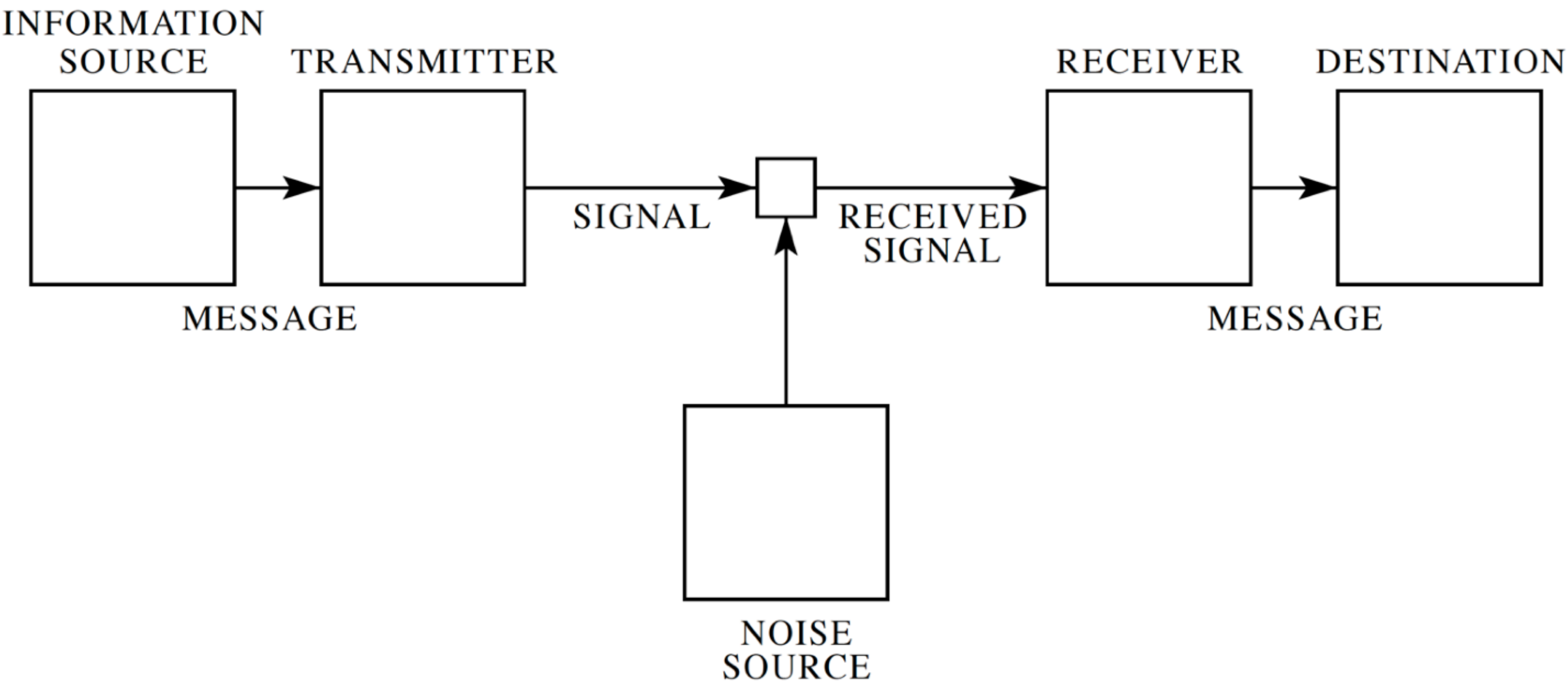
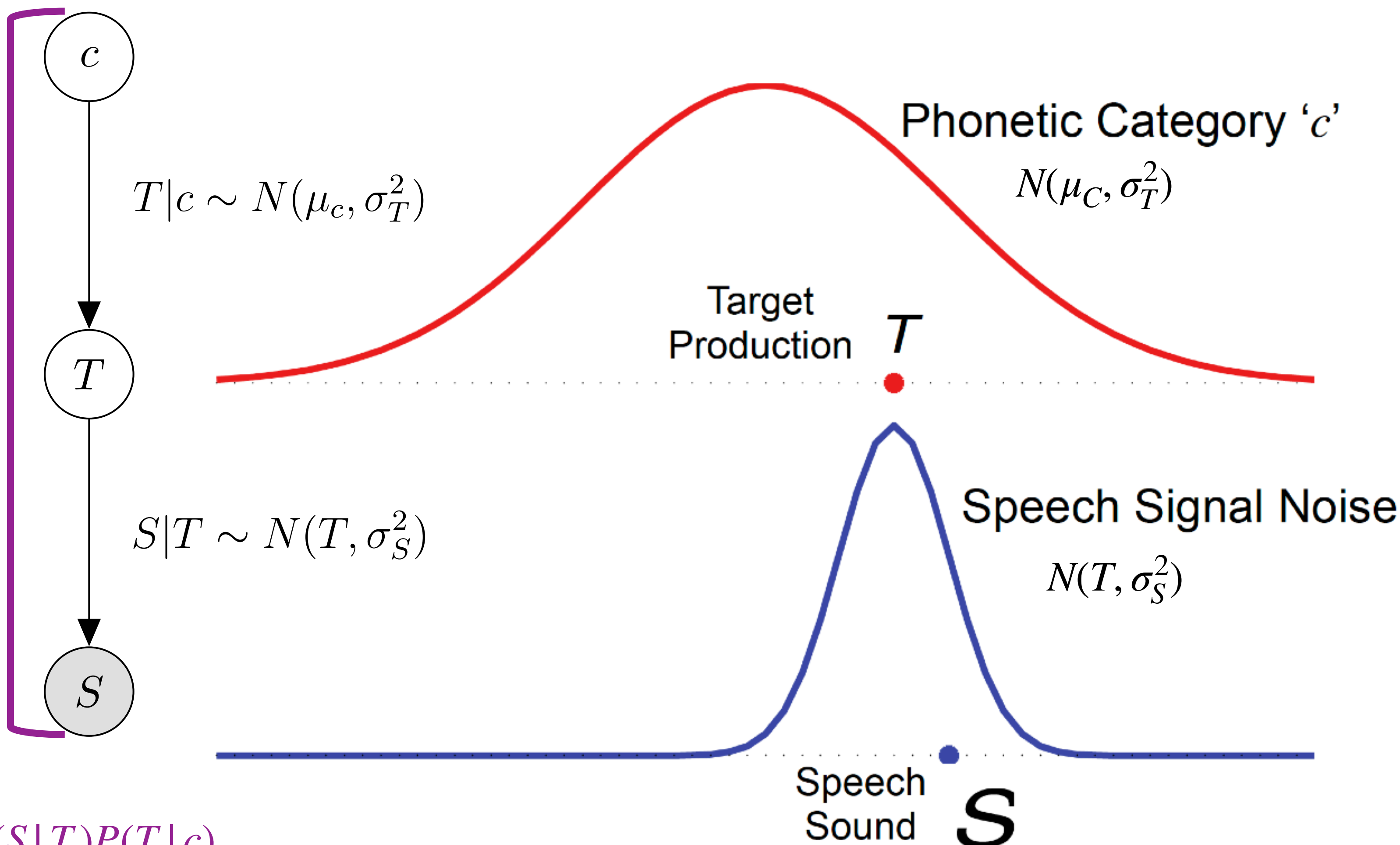


Fig. 1 — Schematic diagram of a general communication system.

(Shannon, 1948)

Noisy-channel model of target production

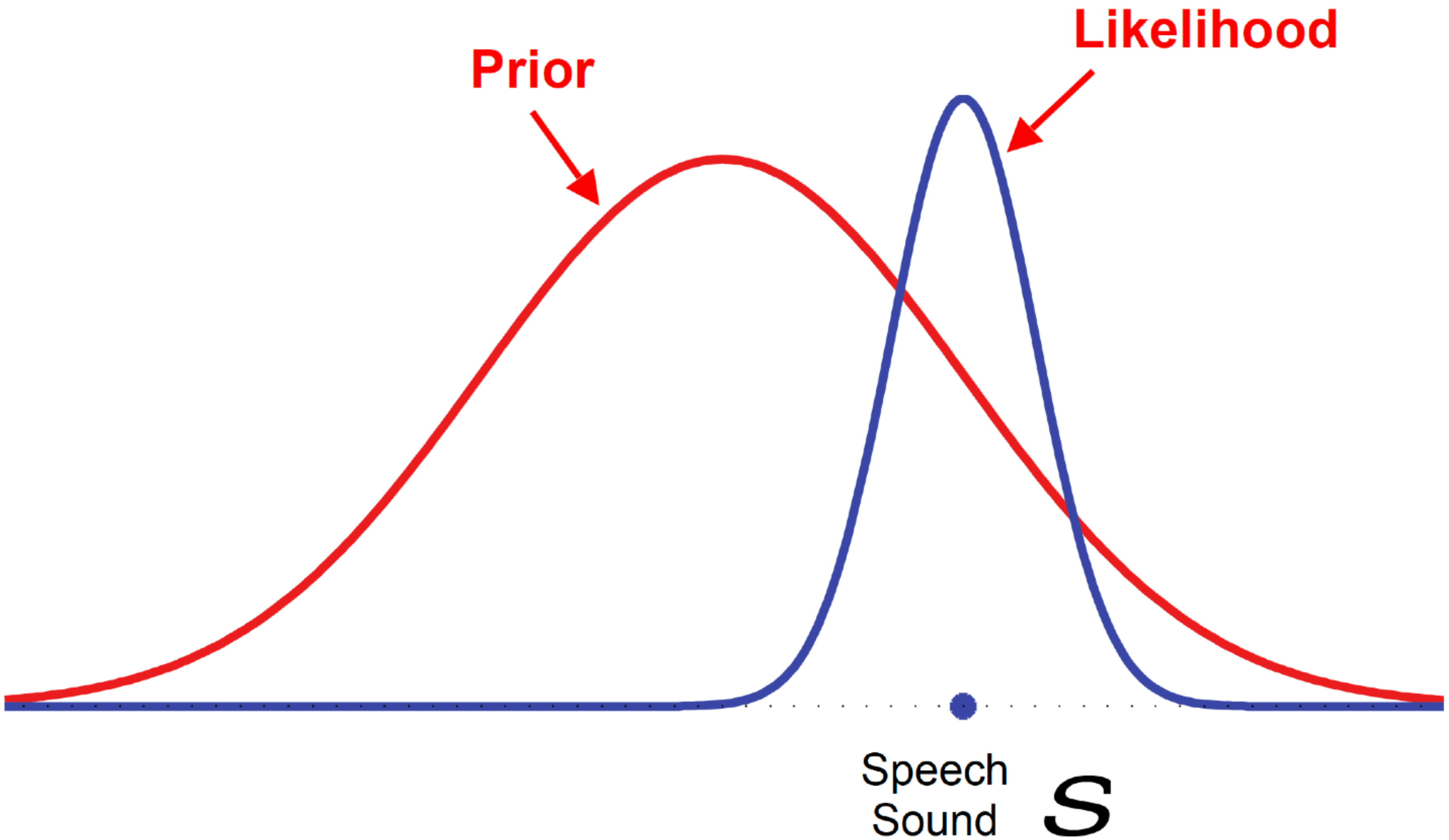


c and *S* are **conditionally independent** given *T*

$P(S, T \mid c) = P(S \mid T) P(T \mid c)$

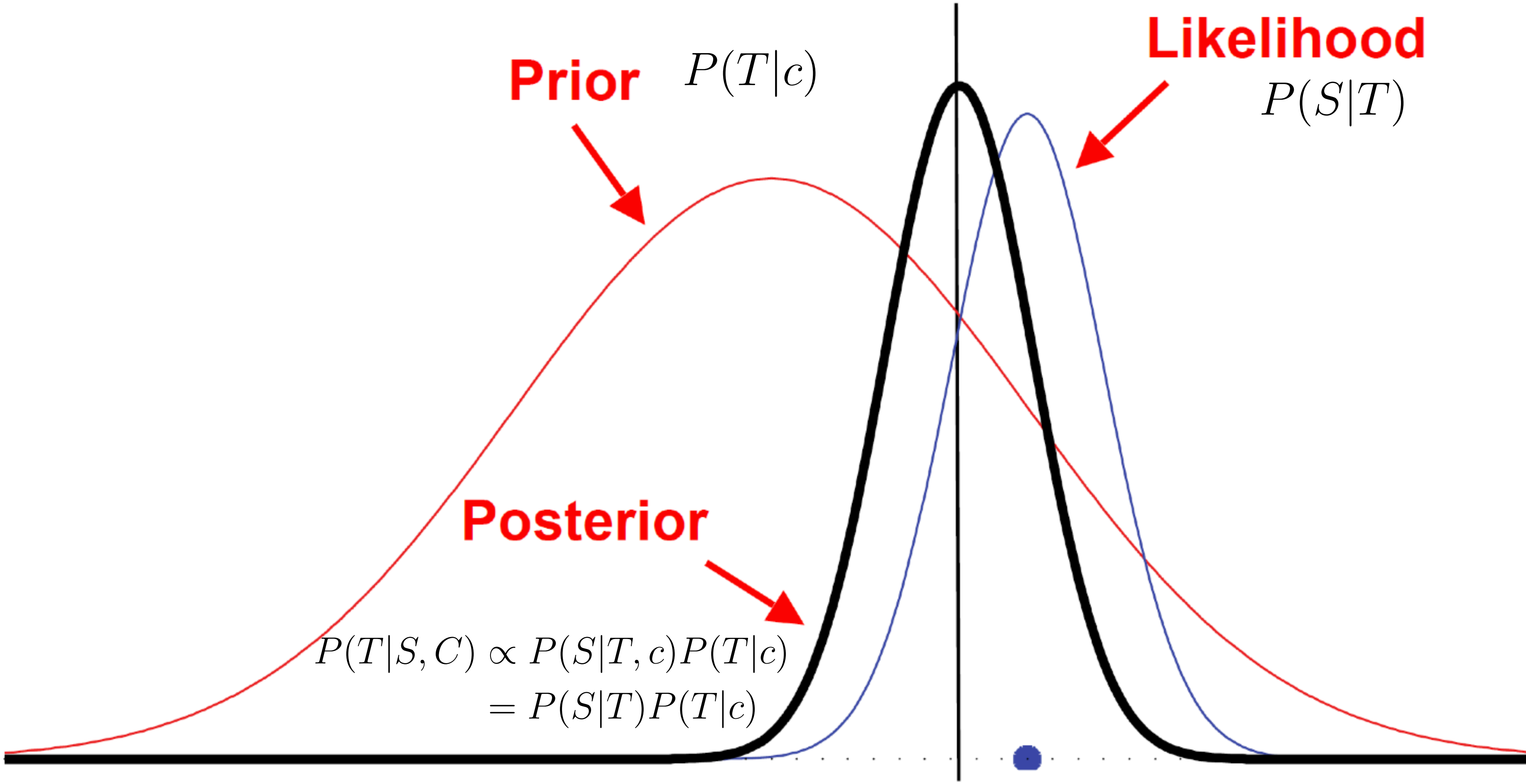
(Feldman et al., 2009)

Inferring target production (1 category)



(Feldman et al., 2009)

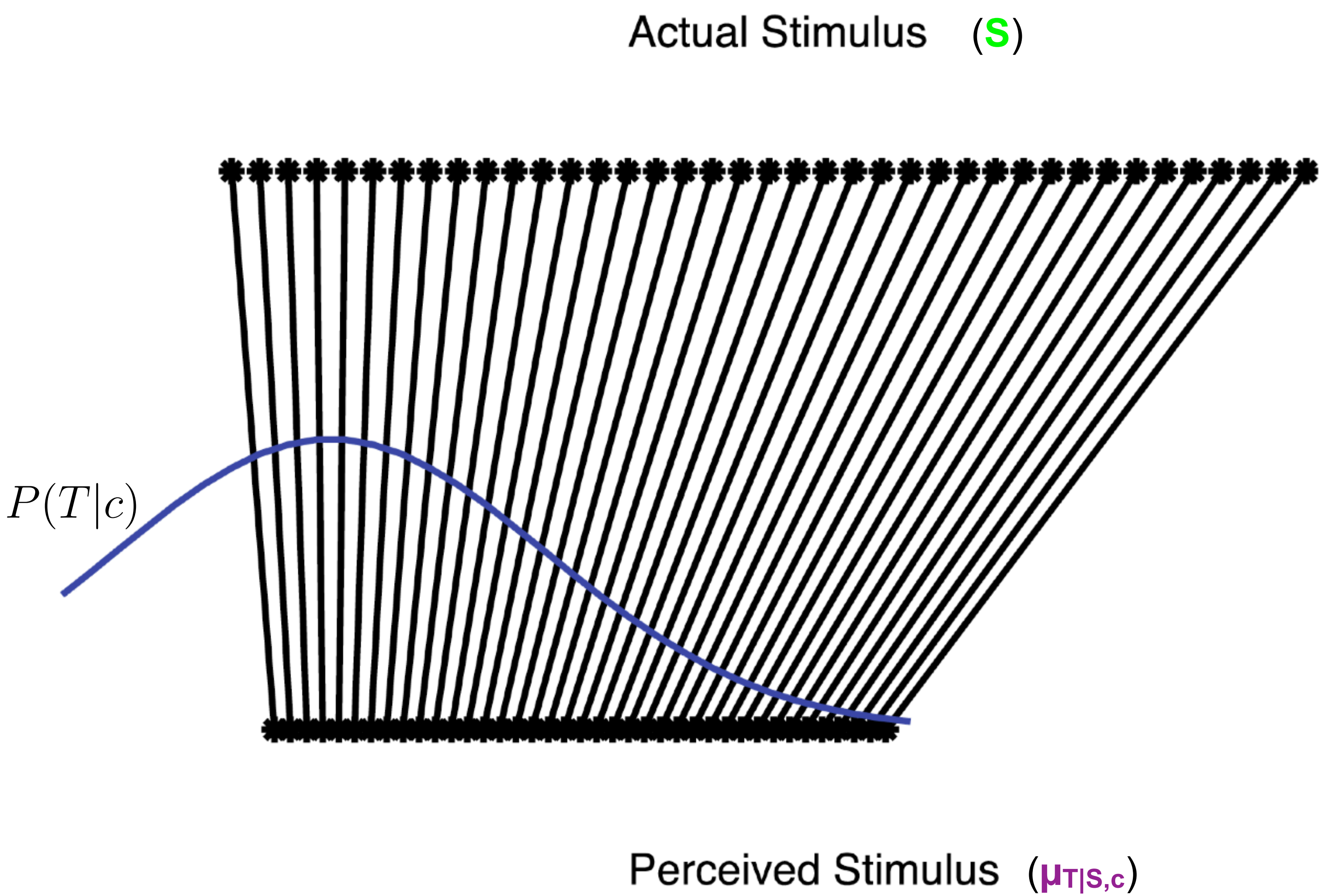
Inferring target production (1 category)



$$T \mid S, C \sim N\left(\frac{\sigma_T^2 S + \sigma_S^2 \mu_c}{\sigma_T^2 + \sigma_S^2}, \frac{\sigma_T^2 \sigma_S^2}{\sigma_T^2 + \sigma_S^2}\right)$$

(Feldman et al., 2009)

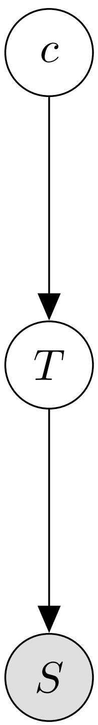
Perceptual warping



(Feldman et al., 2009)

Warping with multiple categories

- We want to compute P(*T*|*S*,*c*), but we don't know *c*
- Solution: **marginalization!**



$$P(T|S) = \sum_c P(T|S,c)P(c)$$

Bayes Rule!

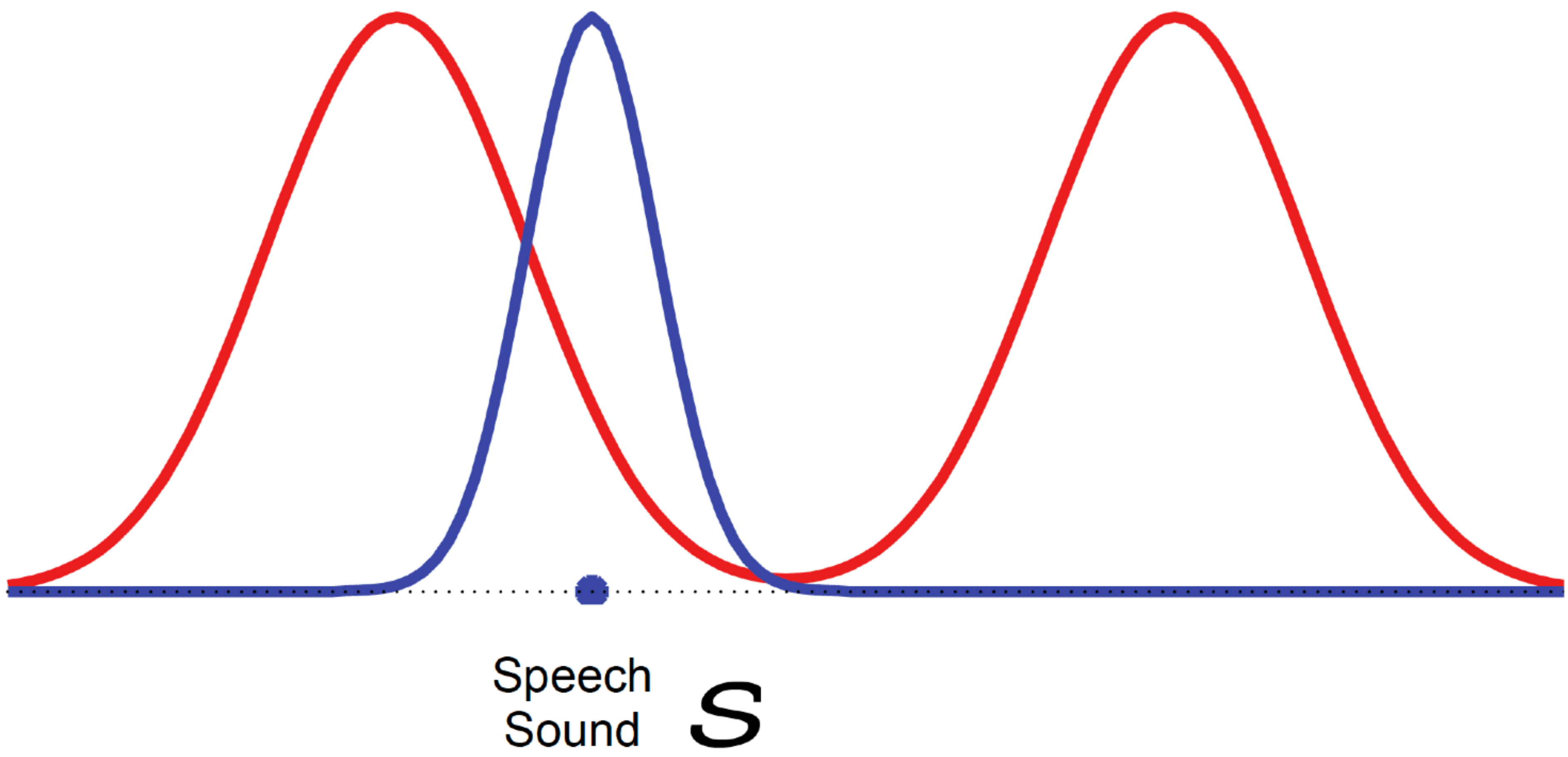
$$P(X|Y,I) = \frac{P(Y|X,I)P(X|I)}{P(Y|I)}$$

Likelihood ***Prior***

$$= \sum_c \frac{P(S|T)P(T|c)}{P(S|c)} P(c)$$

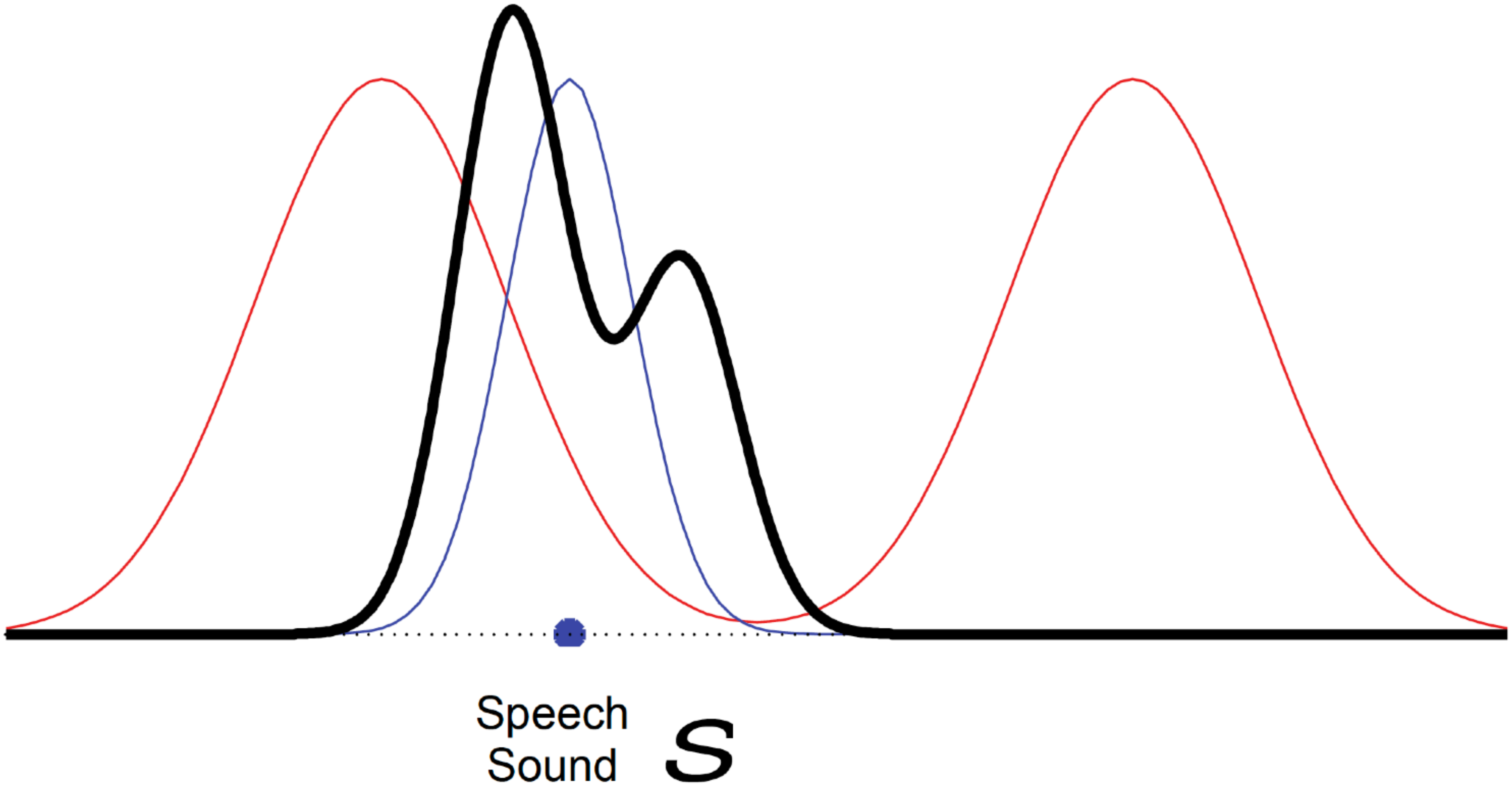
(Feldman et al., 2009)

Warping with multiple categories



(Feldman et al., 2009)

Warping with multiple categories



(Feldman et al., 2009)

Summarizing the posterior

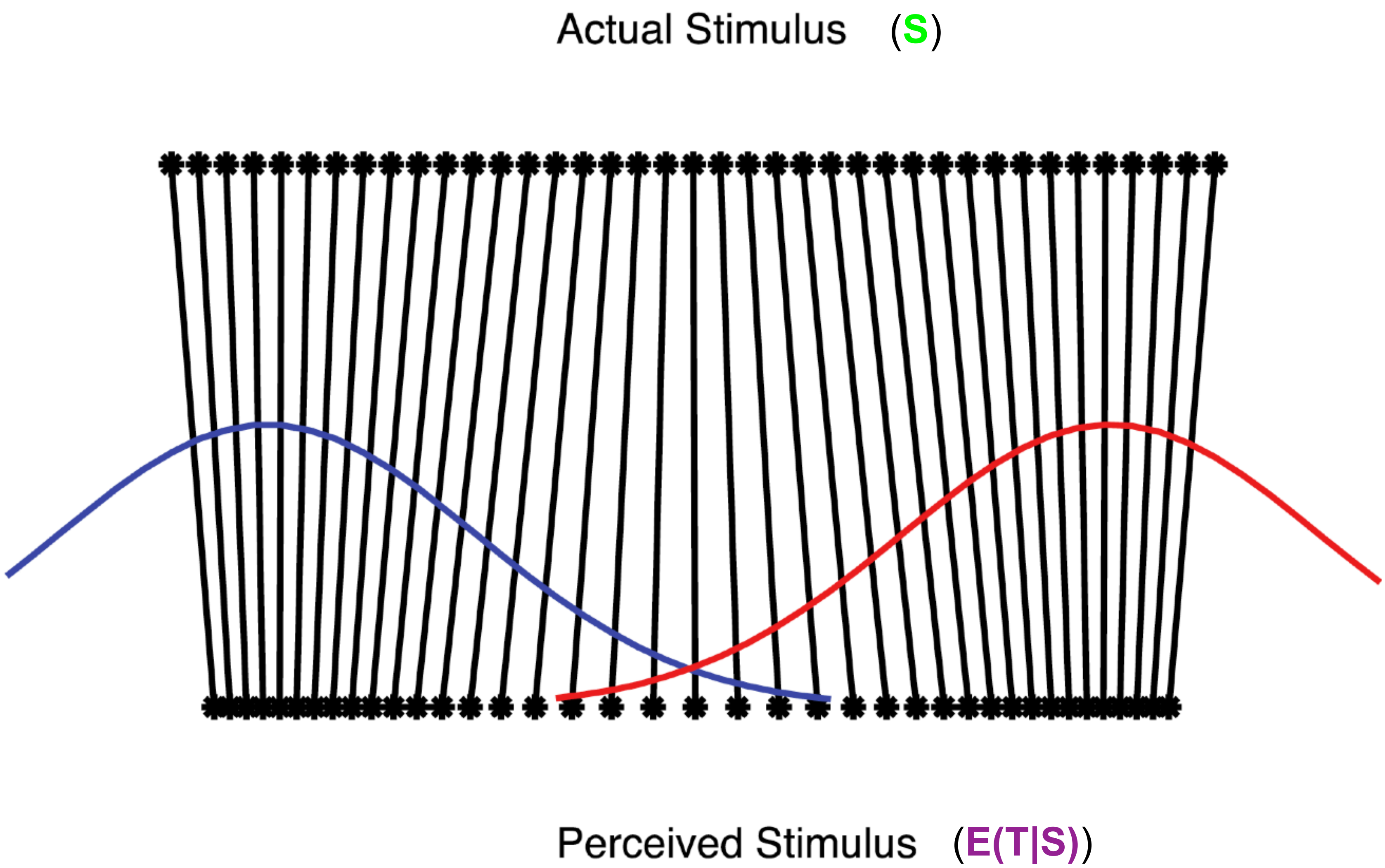
- We'll compare the *posterior mean* to human responses
- Mathematically, this is the ***expectation***
  - Case for a discrete random variable:

$$E(X) = \sum_x x\, P(X = x)$$

  - Case for a continuous random variable:

$$E(X) = \int_{-\infty}^{\infty} x\, p(X = x)\, \mathrm{d}x$$

Warping with multiple categories



(Feldman et al., 2009)

Comparing with human data

To compare model to humans

- we have a 13-step continuum

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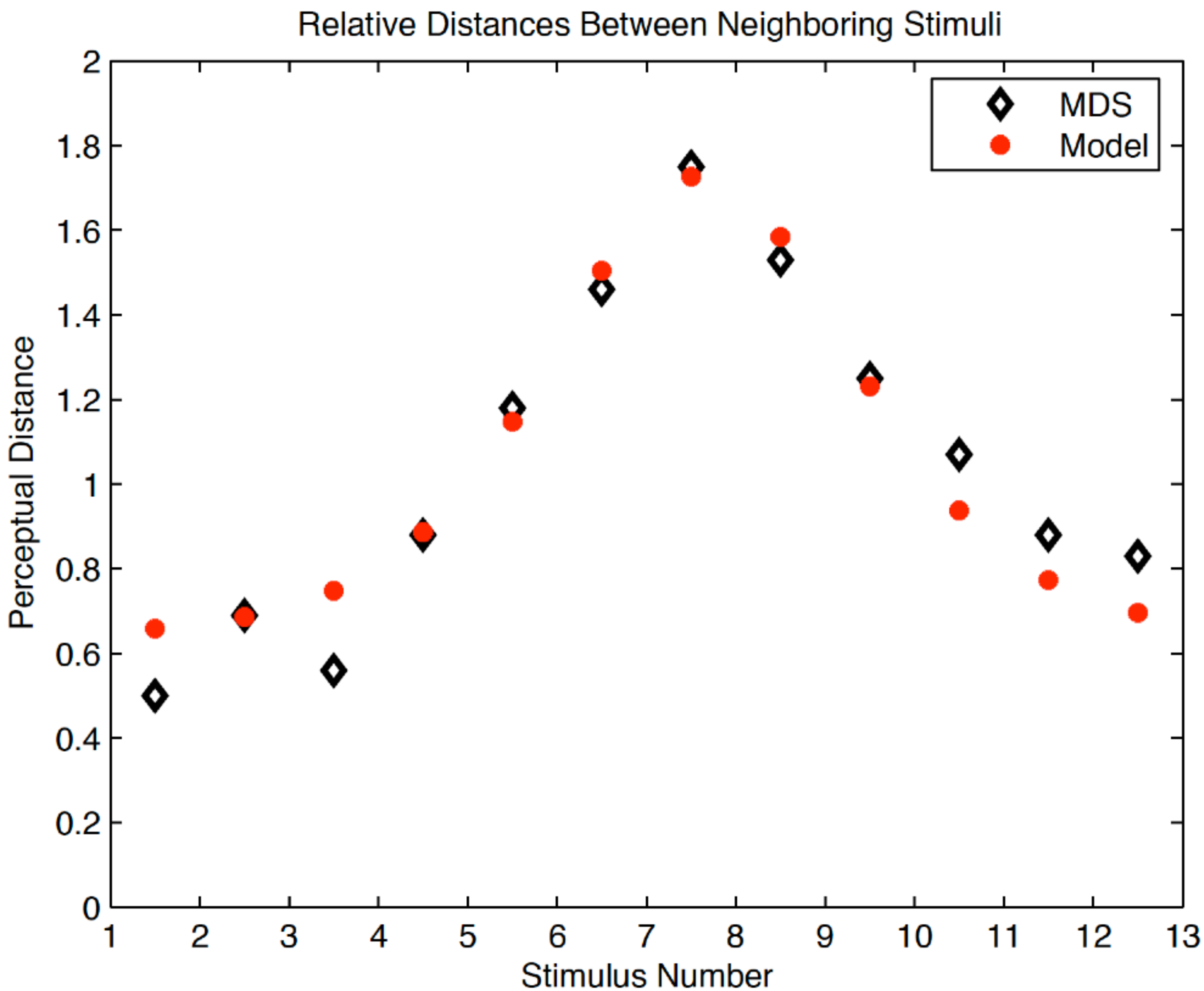
- estimate perceptual distance between each adjacent pair in humans and model

(Feldman et al., 2009)

Comparing with human data



(Feldman et al., 2009)

Summary

- Our subjective experience of phonetic similarity is *warped* relative to acoustic space by phonetic categories
- A simple directed graphical model offers a *noisy-channel* account of this *perceptual magnet effect*
- This is another example of successful application of *rational analysis* to human language understanding

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