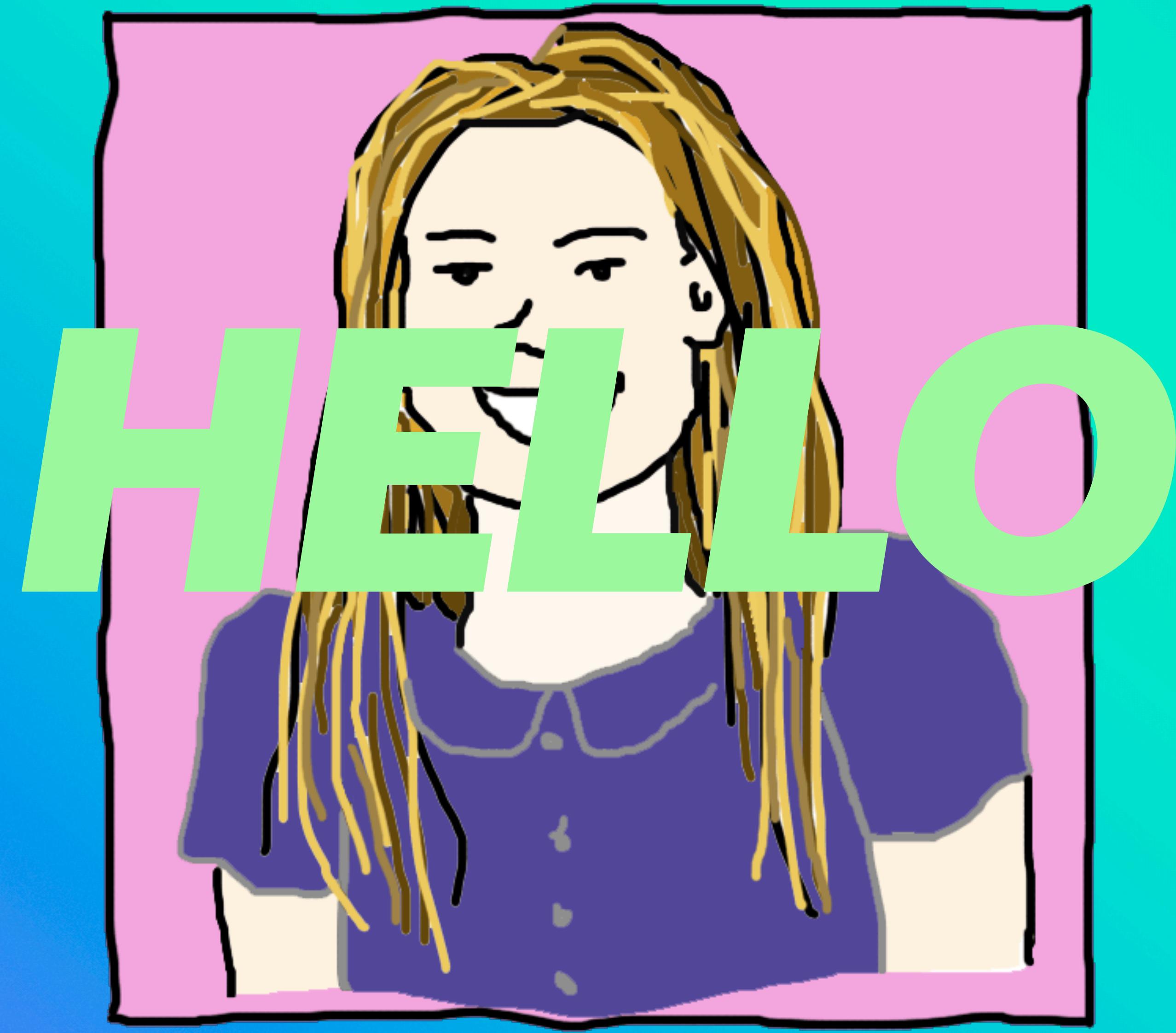


# **MAKING MUSIC WITH MARKOV (MMM...)**

**GINA COLLECCHIA // 08.12.23 // THEORY CLUB NO. 1**



Nudge



SENNHEISER



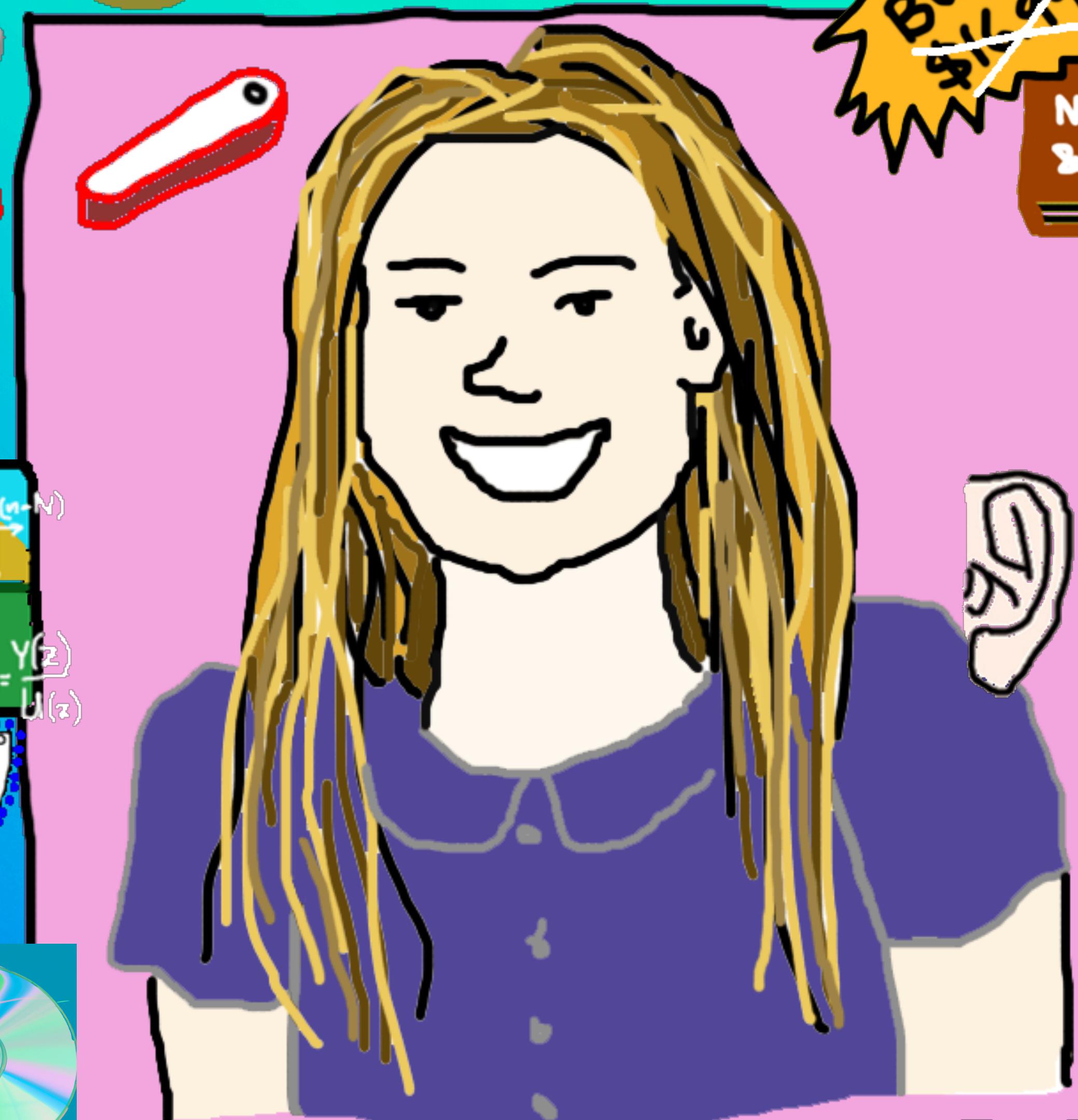
$$\frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x(n) e^{-j \omega_k n}$$
$$K_y'' = \epsilon y$$
$$H(z) = \frac{Y(z)}{U(z)}$$

CCRMA

dJz



REED COLLEGE



.SPATIAL



H Heuser Hearing Institute  
UNIVERSITY OF LOUISVILLE



# "THE ENTROPY OF MUSIC CLASSIFICATION"

# OR, MY REED COLLEGE UNDERGRADUATE THESIS IN MATHEMATICS, 2009

## Chapter 3. Information, E

transmission rate to determine how much information is available. In scheme B, also with 2 outcomes  $B_1$  and  $B_2$ , we would expect our system to transmit information at a rate of 990 bits/second, but this does not take into account the costs and replacement. We find that the entropy is  $(-0.99 \log_2 0.99 + 0.01 \log_2 0.01) = 0.081$  bits/second. The transmission rate is 81 bits per second, and see that the transmission rate is 919 bits/second of information.

The finite probability scheme  $(\Omega, \mathcal{F}, P)$  alluded to earlier, the Shannon entropy  $H(p_1, p_2, \dots, p_n)$ , which are the probabilities assigned to  $n$  events  $\omega_1, \omega_2, \dots, \omega_n$ , and if  $A$  is a subset of  $\Omega$ , then  $H(A) = H(p_1, p_2, \dots, p_n)$  is the probability of entropy to the measure  $\mu_A$  defined by  $\mu_A(\omega_i) = p_i$ ,  $i = 1, 2, \dots, n$ . The notion of entropy to the measure  $\mu_A$  is called the conditional entropy of  $A$  given  $B$ , and if  $A$  and  $B$  are two sets of events, then  $H(A|B) = H(A) - H(A \cap B)$  (the characteristic we just showed).  
 $H(A|B) = H(A) + H(B|A)$ , and adding an

As alluded to earlier, the measure of uncertainty in a discrete random variable with  $n$  possible outcomes, i.e., with  $n$  symbols per symbol, needed to describe the outcome of which is given by the entropy function. The entropy function involves the notion of entropy to the function of the probabilities of the possible outcomes, i.e., the probabilities of the possible values of the random variable. Let  $H(p_1, p_2, \dots, p_n)$  be a function of the probabilities  $p_1, p_2, \dots, p_n$ , which are the probabilities of the finite probability scheme  $A$  such that  $p_i \geq 0$  and  $\sum_{i=1}^n p_i = 1$ . The function is continuous  $\forall p_i$ , and if  $H$  is maximized when  $p_k = \frac{1}{n} \forall k$  (the characteristic we just showed), the product scheme  $AB$ ,  $H(AB) = H(A) + H(B|A)$ ; and  $H(p_1, 0) = H(p_1, p_2, \dots, p_n)$ , i.e., adding an extra symbol with zero probability does not change  $H$ ;  $H(p_1, p_2, \dots, p_n) = -\sum_{i=1}^n p_i \log p_i$ .

me AB,  $H(A, B)$ , i.e.,  
 $H(0, 0) = H(p_1, p_2, \dots, p_n)$ , i.e.,  
not change H;  
 $H(A) = H(p_1, p_2, \dots, p_n) = -K \sum_{k=1}^n p_k \log_2 p_k$   
constant.  
 $\phi(n)$ . We will  
 $\frac{1}{n} \forall k,$

positive cons  
 $H(A)$

where  $\gamma$  is a positive constant. Proof. Let  $H(p_1, p_2, \dots, p_n)$  be the function defined by the formula

$$\begin{aligned}
 \phi(n) &= H\left(\frac{1}{n}, \frac{1}{n}, \dots, \frac{1}{n}\right) = \phi(n), \\
 &\text{is maximized when } p_k = \frac{1}{n} \forall k \text{ by } \\
 &= H\left(\frac{1}{n}, \frac{1}{n}, \dots, \frac{1}{n}, 0\right) \\
 &= H\left(\frac{n}{n+1}, \frac{1}{n+1}, \dots, \frac{1}{n+1}\right) = \phi(n+1).
 \end{aligned}$$

$\lambda \log(n)$ , where  
have

have

y, we'll

1 / 2

$$\therefore \frac{1}{n+1}$$

$\frac{1}{x+1}$ .

probability scheme features  $a_1$   
 $\epsilon + \frac{1}{1}$



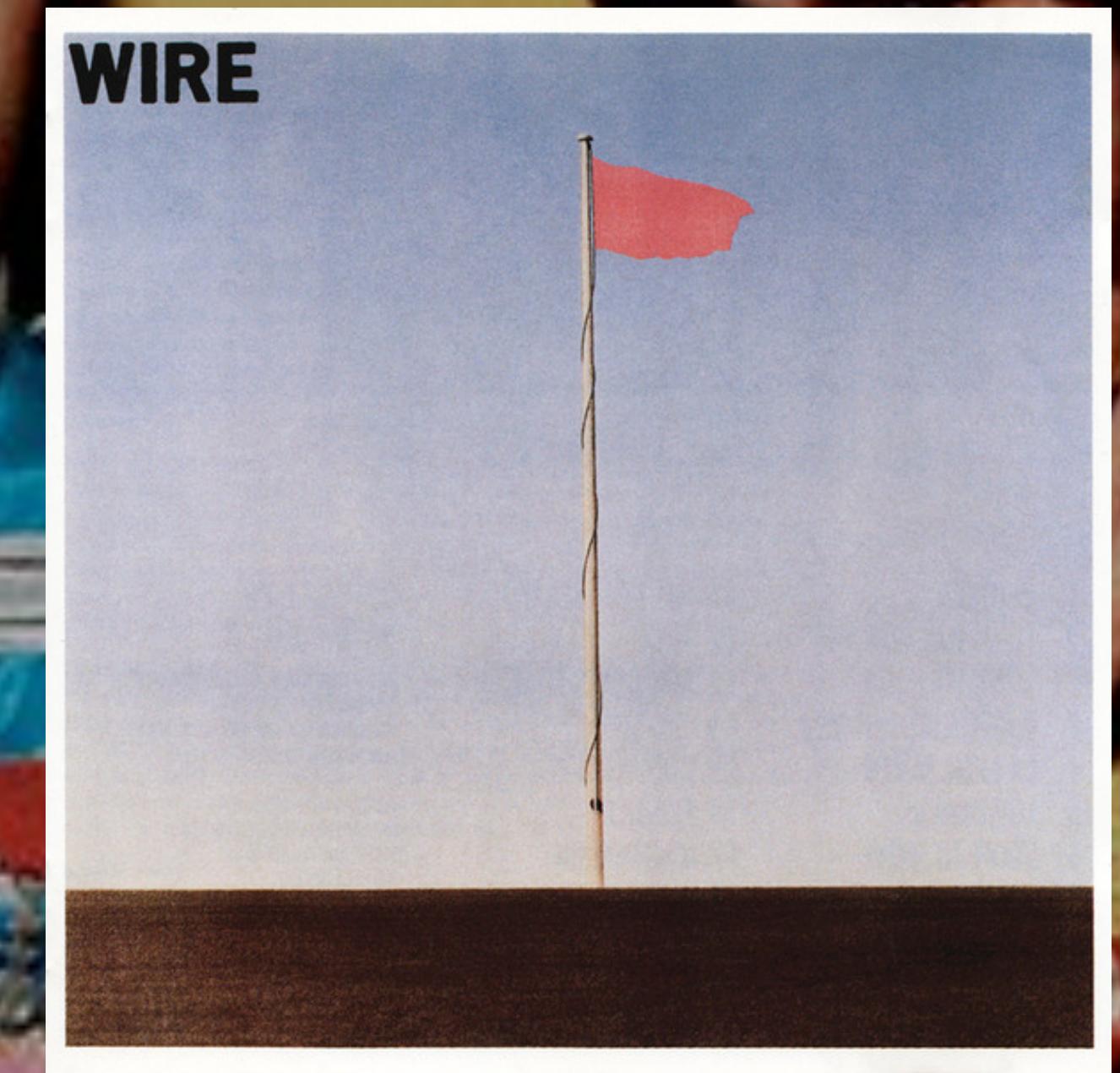
The Beatles (whole discography + solo work)



Beethoven, Piano Sonata No. 8, "Pathetique"



The Beatles (whole discography + solo work)



Wire, *Pink Flag* (1977)

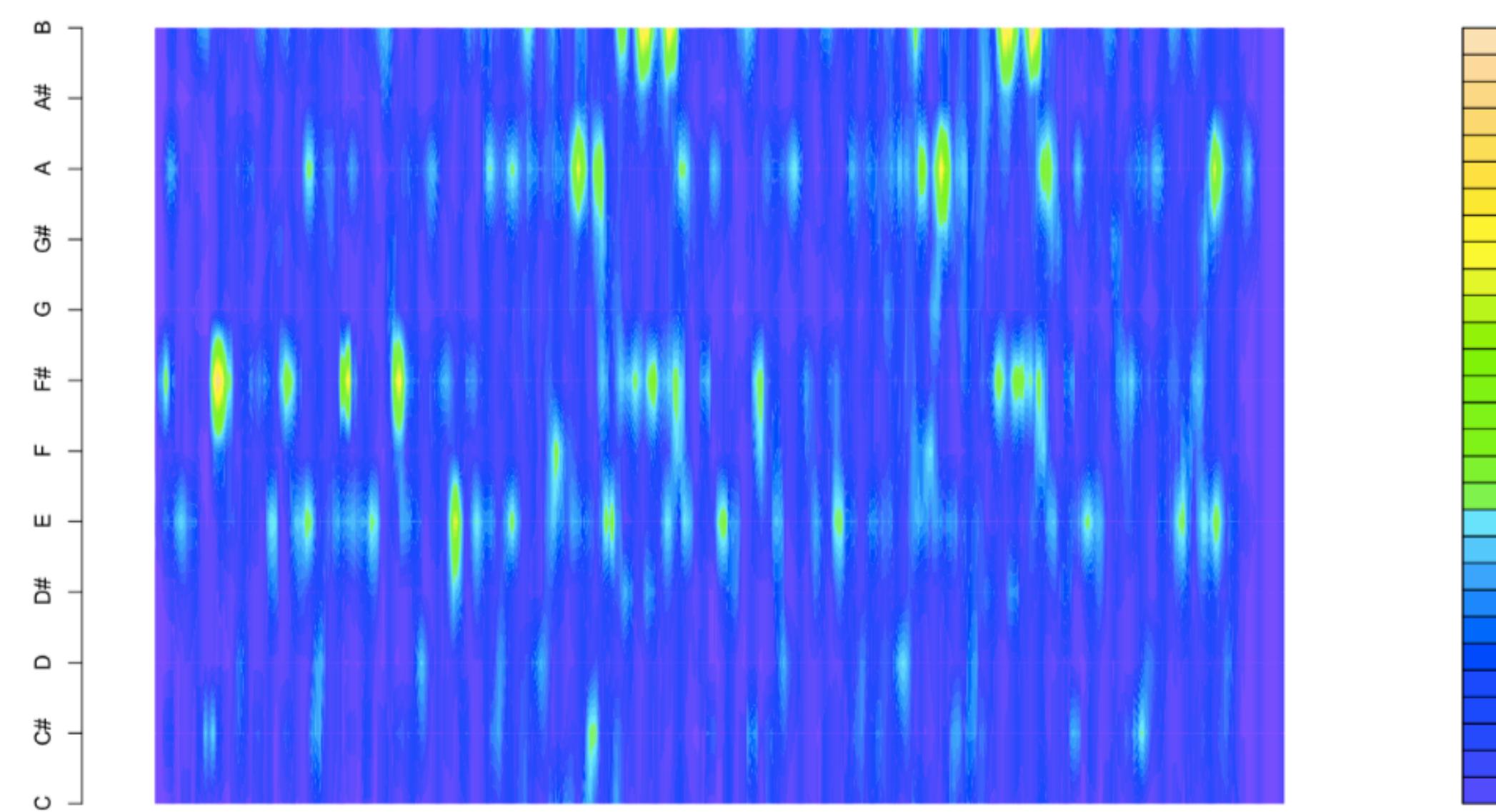


Figure 1.12: Smoothed contour plot of “Oh! Darling”.

Working on my thesis with a manually acquired dataset (2009)

Classification	True Entropy Rate
“Tell Me Why” from <i>A Hard Day’s Night</i>	0.2437552
“You’re Going Lose That Girl” from <i>Help!</i>	0.1828974
“When I’m 64” from <i>Sgt. Pepper’s</i>	0.2822246
“Oh! Darling” from <i>Abbey Road</i>	0.3168579
“Two of Us” from <i>Let It Be</i>	0.2249230
<i>A Hard Day’s Night</i>	0.3943230
<i>Help!</i>	0.4842243
<i>Sgt. Pepper’s</i>	0.4727886
<i>Abbey Road</i>	0.4709648
<i>Let It Be</i>	0.3357670
First mvmt. of Beethoven	0.3933457
Second mvmt. of Beethoven	0.2513897
Third mvmt. of Beethoven	0.3841676
All of Beethoven	0.4578376

Christopher Harte’s rich Beatles datasets (2010): <http://isophonics.net/>

## Reference Annotations: The Beatles

**Note:** Please be sure to read [the page describing these annotations](#) before use. In particular, the level of confidence we have in the individual annotations is described there, as well as the original CD issue numbers from which we worked.

Chris Harte’s PhD thesis (2010) which describes the chord syntax, transcription process and verification process for the Beatles collection can be downloaded [here](#).

The chord transcription files currently available on this page are version 1.2. of the collection.

[All Beatles annotations in a single tar.gz file](#)

Please Please Me

### 1. I Saw Her Standing There

- Structural segmentation: [csv](#) [rdf](#)
- Key changes: [csv](#) [rdf](#)
- Chords: [csv](#) [rdf](#) [svl](#)
- Beats: [csv](#) [rdf](#)
- All of the above: [rdf](#)

### 2. Misery

- Structural segmentation: [csv](#) [rdf](#)
- Key changes: [csv](#) [rdf](#)
- Chords: [csv](#) [rdf](#) [svl](#)
- Beats: [csv](#) [rdf](#)
- All of the above: [rdf](#)

### 3. Anna (Go To Him)

A quick introduction to

# **MARKOV CHAINS**

# WHAT IS A MARKOV PROCESS?

A.K.A., A *MARKOV CHAIN*

- A system in which the probability of each "state" depends *only* on the previous state
- When a state changes, it's said to "transition"
- Characterized by a square  $N \times N$  matrix of "transition probabilities" where  $N$  is the size of the state space:

$$p_{ij} = \Pr(X_{n+1} = j \mid X_n = i)$$

New York  
69° | Clear

10-DAY FORECAST

Today  67° — 85°

Sat  69° — 86°

Sun  73° — 90°

Mon  69° — 81°

Tue  50% 71° — 85°

Wed  69° — 85°

Thu  70° — 87°

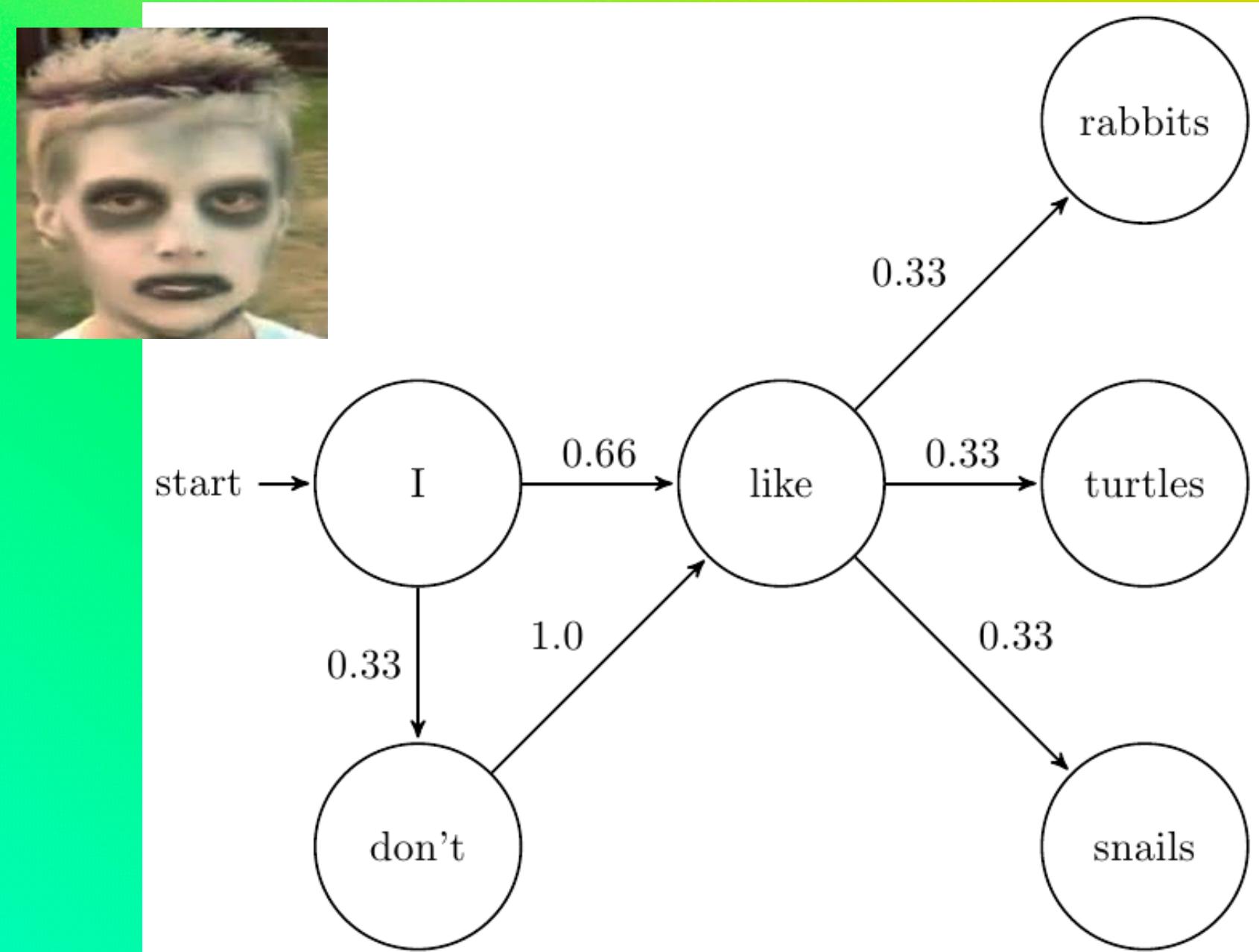
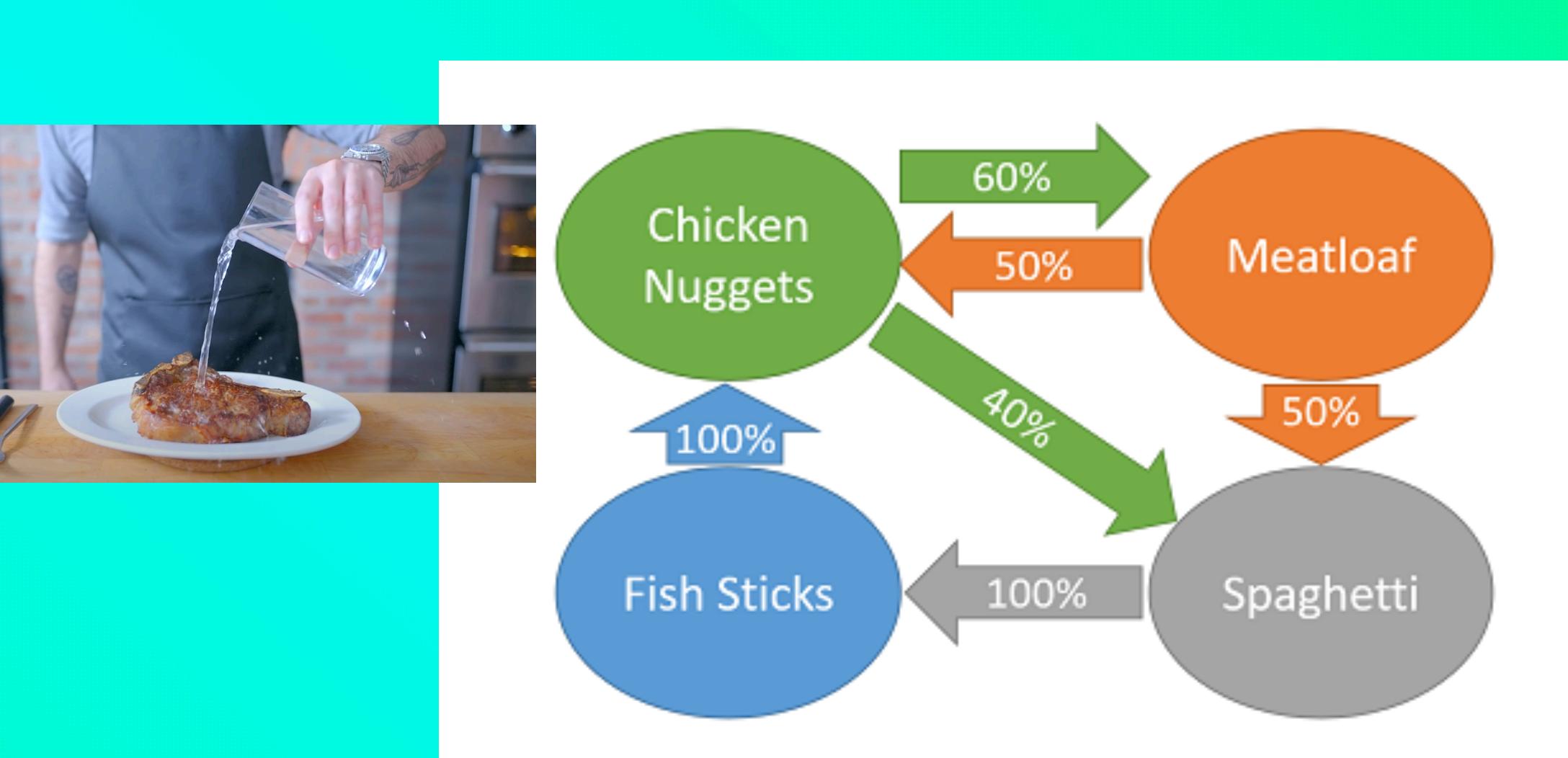
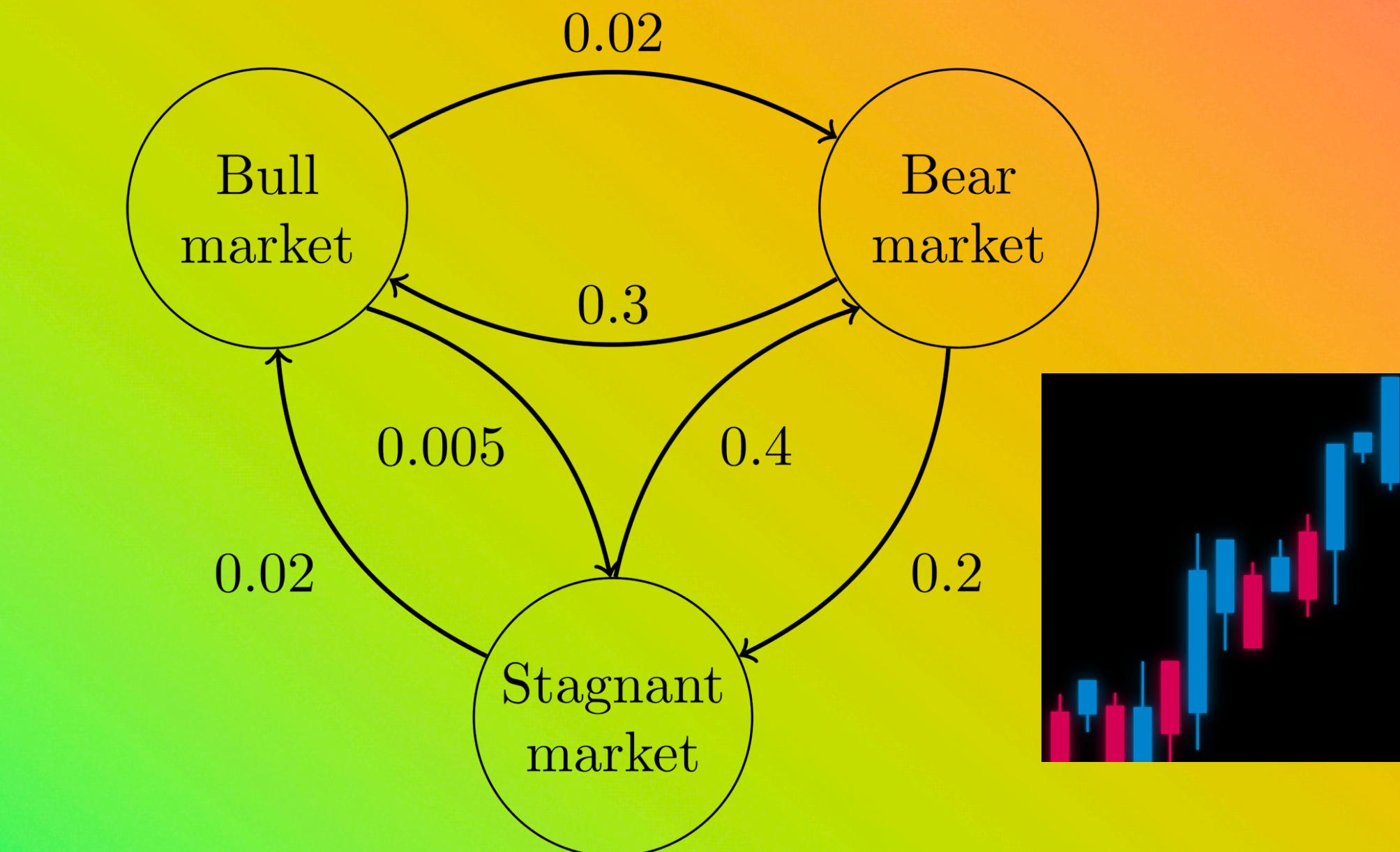
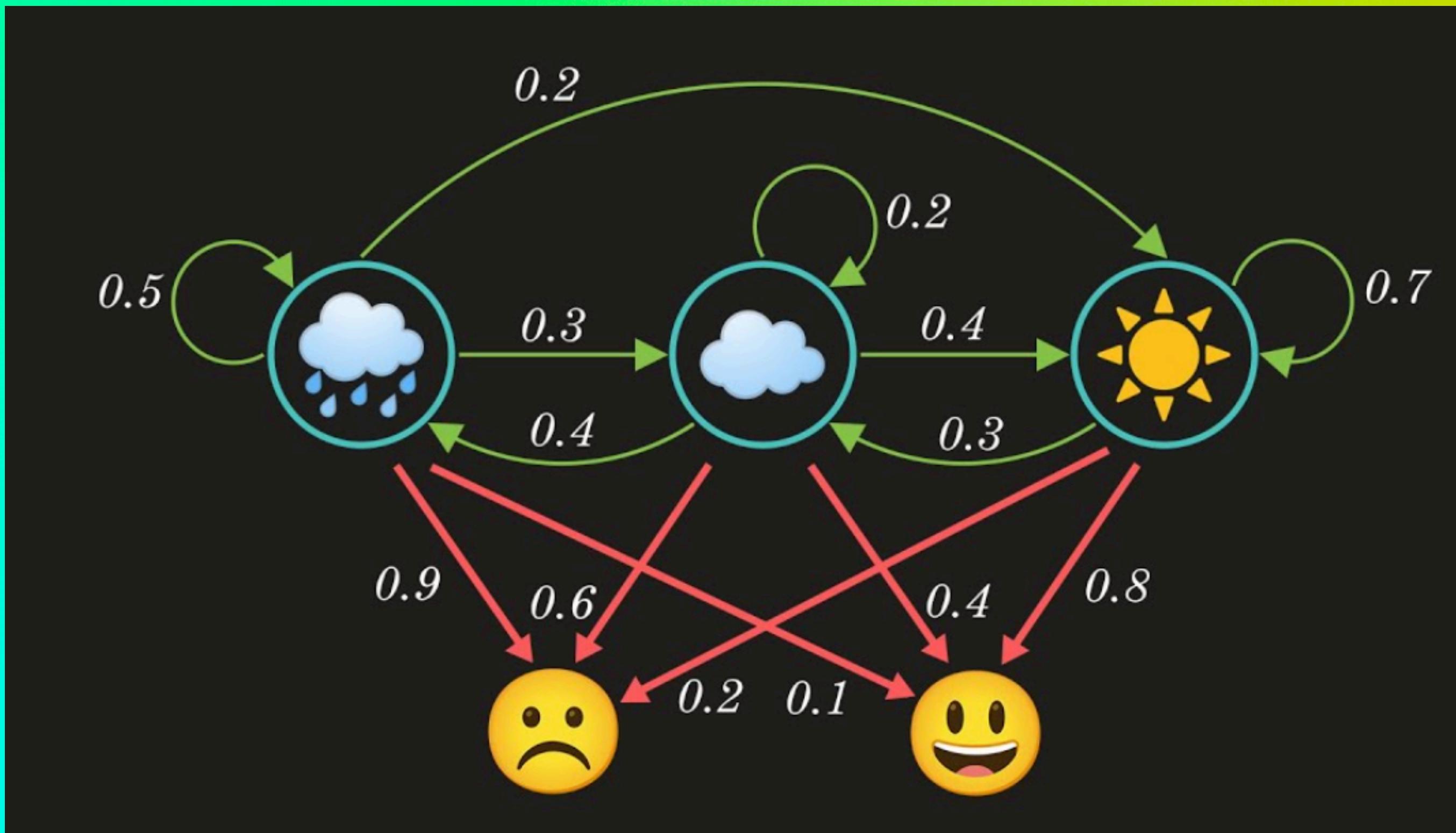
Fri  70° — 86°

Sat  73° — 88°

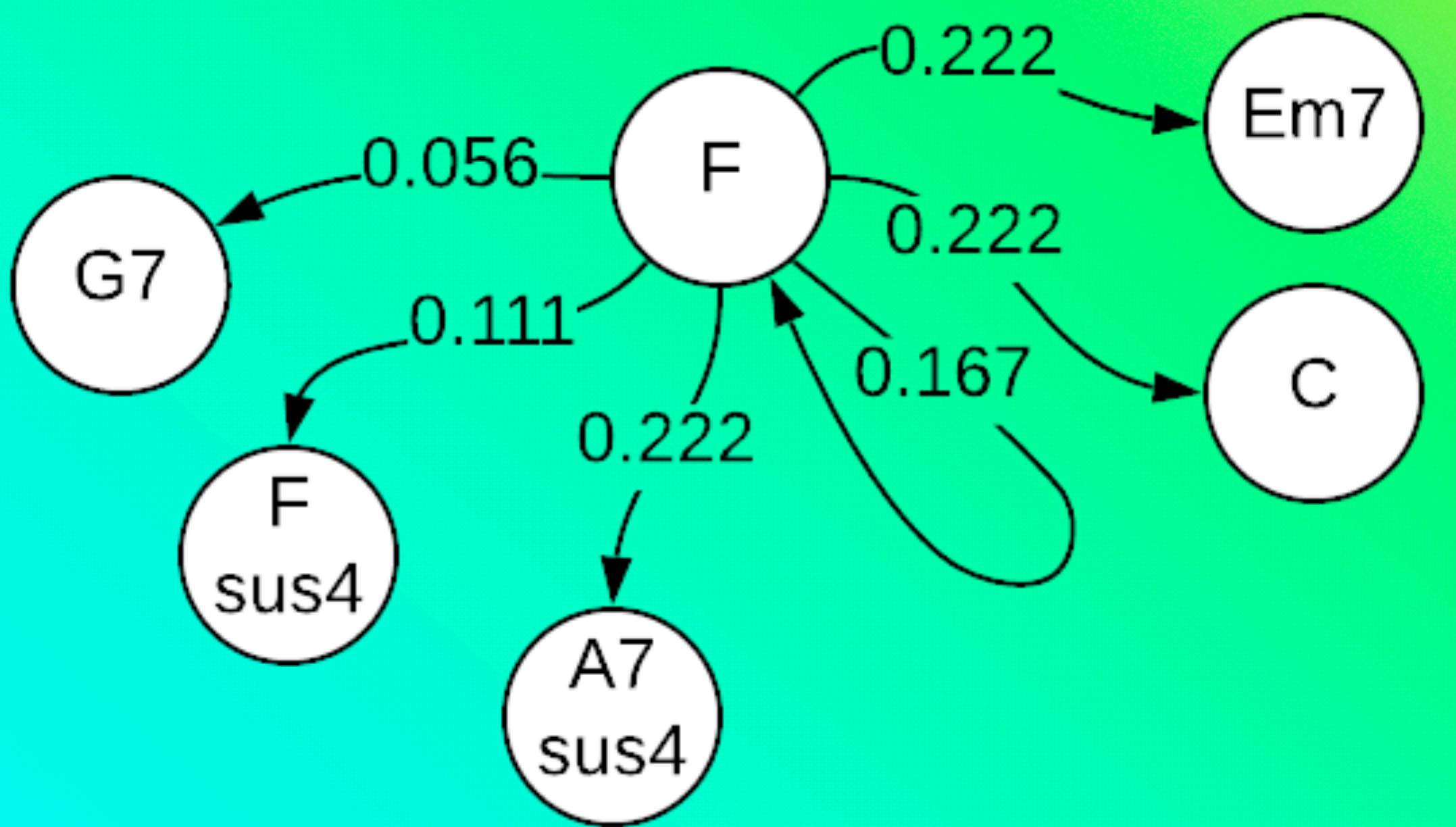
Sun  71° — 90°



**NO DICE**



# THE TRANSITION MATRIX

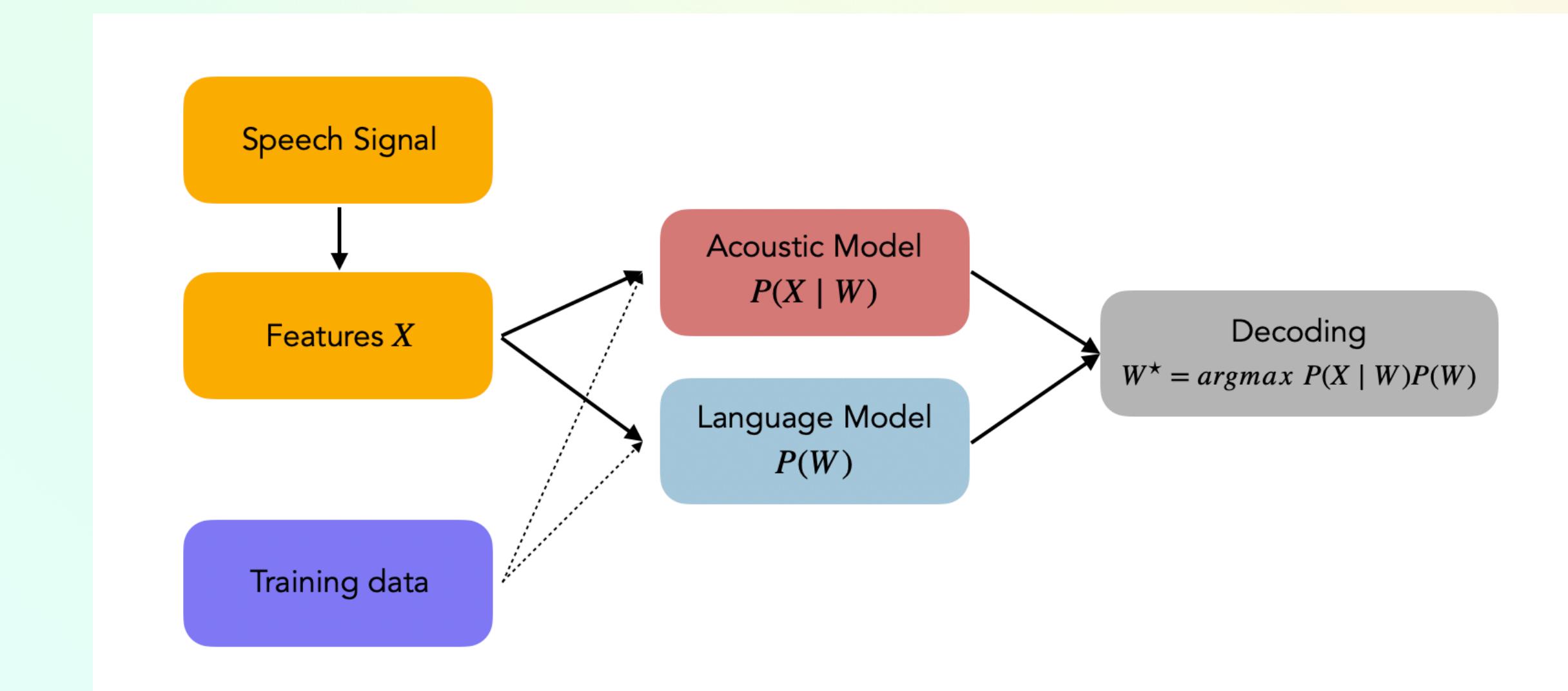
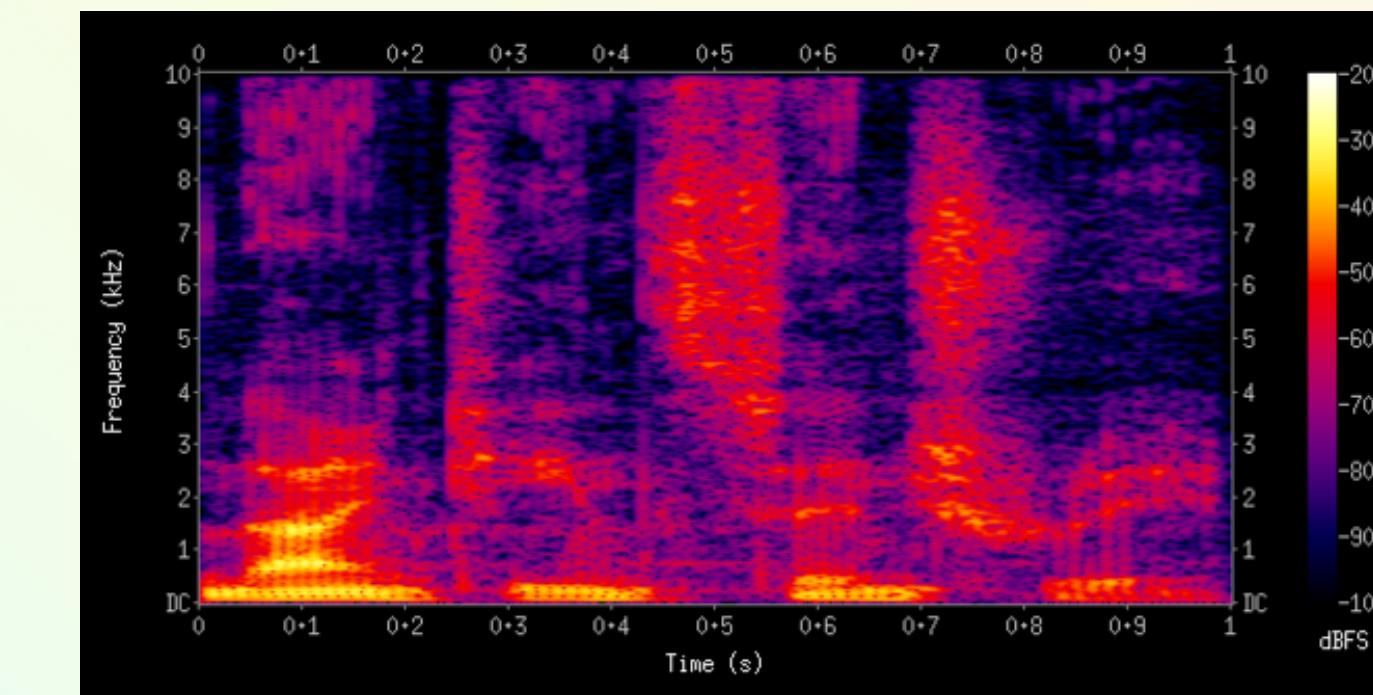


Source: "Markov Chain for music generation", Alexander Osipenko:  
<https://towardsdatascience.com/markov-chain-for-music-generation-932ea8a88305>

	F	Em7	C	A7sus 4	Fsus4	G7
F	0.167	0.222	0.222	0.222	0.111	0.056
Em7	0.0	0.0	0.5	0.5	0.0	0.0
C	0.3	0.1	0.0	0.1	0.1	0.4
A7su s4	0.0	0.667	0.0	0.0	0.0	0.333
Fsus4	0.1	0.0	0.4	0.0	0.0	0.5
G7	0.3	0.0	0.4	0.0	0.2	0.0

# SPEECH RECOGNITION WITH MARKOV MODELS

- Until about 2010, the acoustic model might use a Hidden Markov Model (HMM) to predict the sequence of phonemes in speech
- Recently these were replaced with other machine learning models such as a Long Short Term Memory (LSTM) model



# **MUSIC IS A LANGUAGE**

**I AM PRETTY SURE**

**GRAPHEMES <=> NOTES**

**PHONEMES <=> TIMBRE, PITCH**

**MORPHEMES <=> HARMONY**

**MEANING <=> MEANING**

Don't use second inversions other than in IC - V - I

Keep most of the harmony simple by starting from stage I and only make harmonic changes that complement the bassline

I<sup>b</sup> and VI are the best approach chords to II<sup>b7</sup> in the run up to a cadence

All other things being equal, it is a good idea to be in root position I on the first strong beat of a chorale or its upbeat

## BACH DOS AND DON'TS

Root progressions using falling thirds (e.g. VI to IV and I to VI) are much better than those using rising thirds

If you use the same chord twice in a row, make sure that one is in root position and the next is in first inversion

Avoid progressions using II other than as an approach chord to V. Chord II<sup>b</sup> can also be used as an approach to IC at a cadence.

Don't use II in root position in minor keys

Don't use III other than as an approach to vi and avoid in minor keys altogether

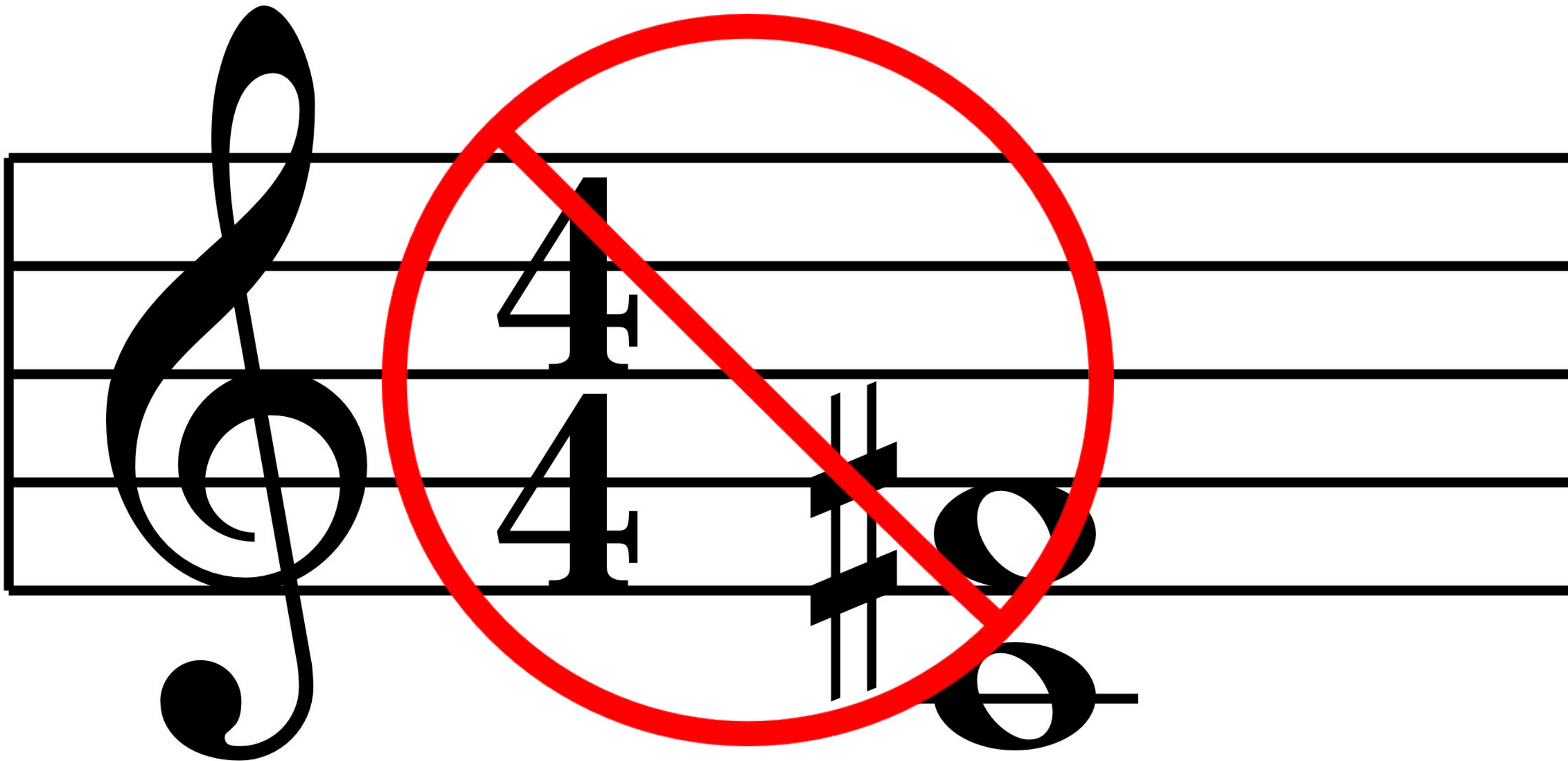
Avoid progressions between IV and V unless the melody is going in the opposite direction to the root progression of the two chords

Only use VI in root position

Don't use viio other than as vii<sup>b</sup>o resolving either to I or I<sup>b</sup>

Don't repeat the bass note (except from the upbeat to the first beat of a phrase)

# TRITONE ALERT!!



## DEVIL MUSIC

# **DEMONSTRATION**

***PLEASE STAND BY***

# FUTURE WORK

**COOL IDEAS I DIDN'T HAVE TIME TO DO YET SO ACTUALLY UNSURE HOW COOL THEY ARE BUT WHATEVER**

- MIDI data, Guitar tabs (chords) -> Markov model
- Increase or decrease randomness of output
- Introduce rules about repetition or specific beats
- Whole album models
- Songwriter models

**THANK U:)**