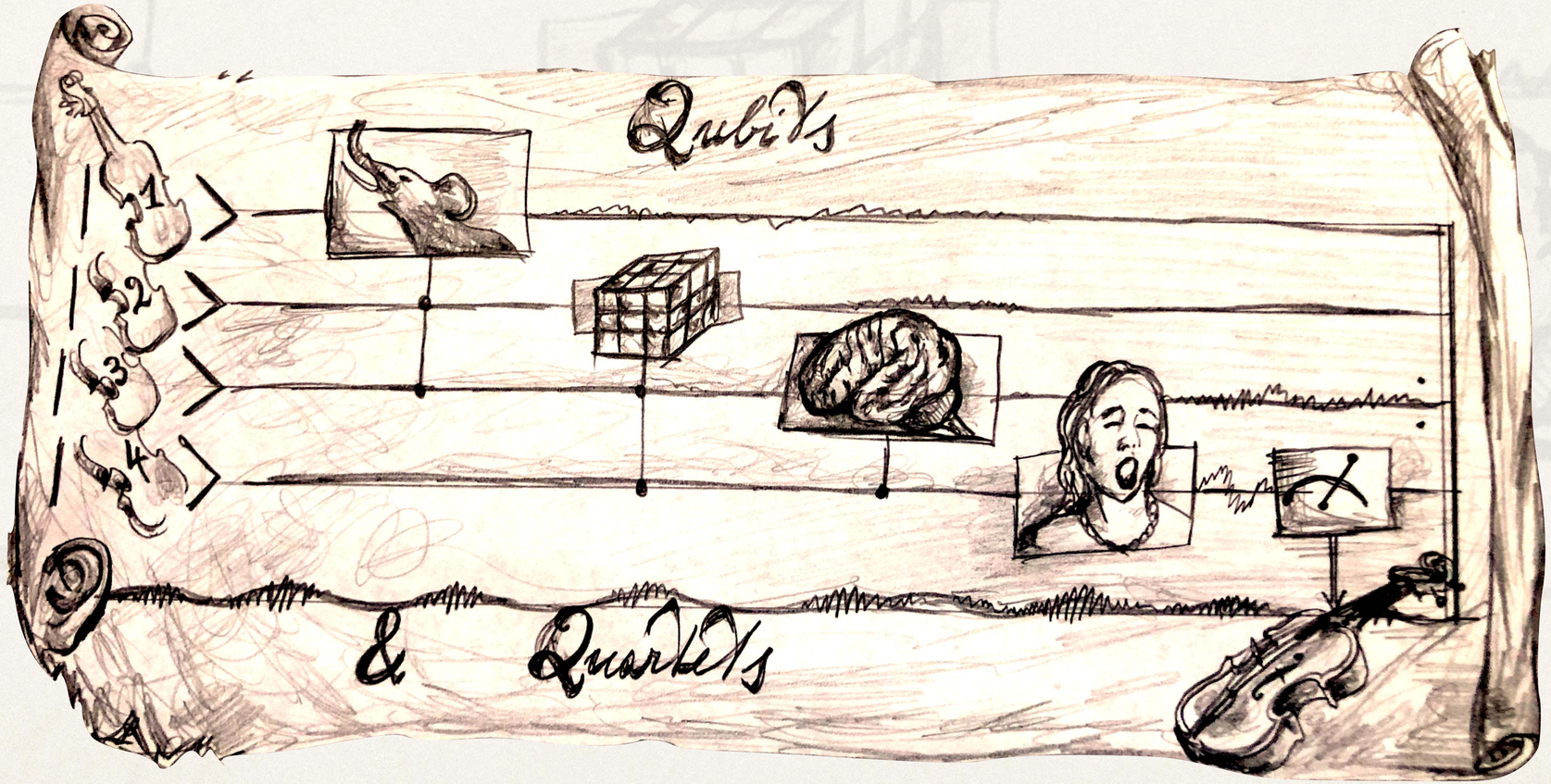
Qubits and Quartets:
memory, CubeHarmonic, neural activity, and voice



Maria Mannone

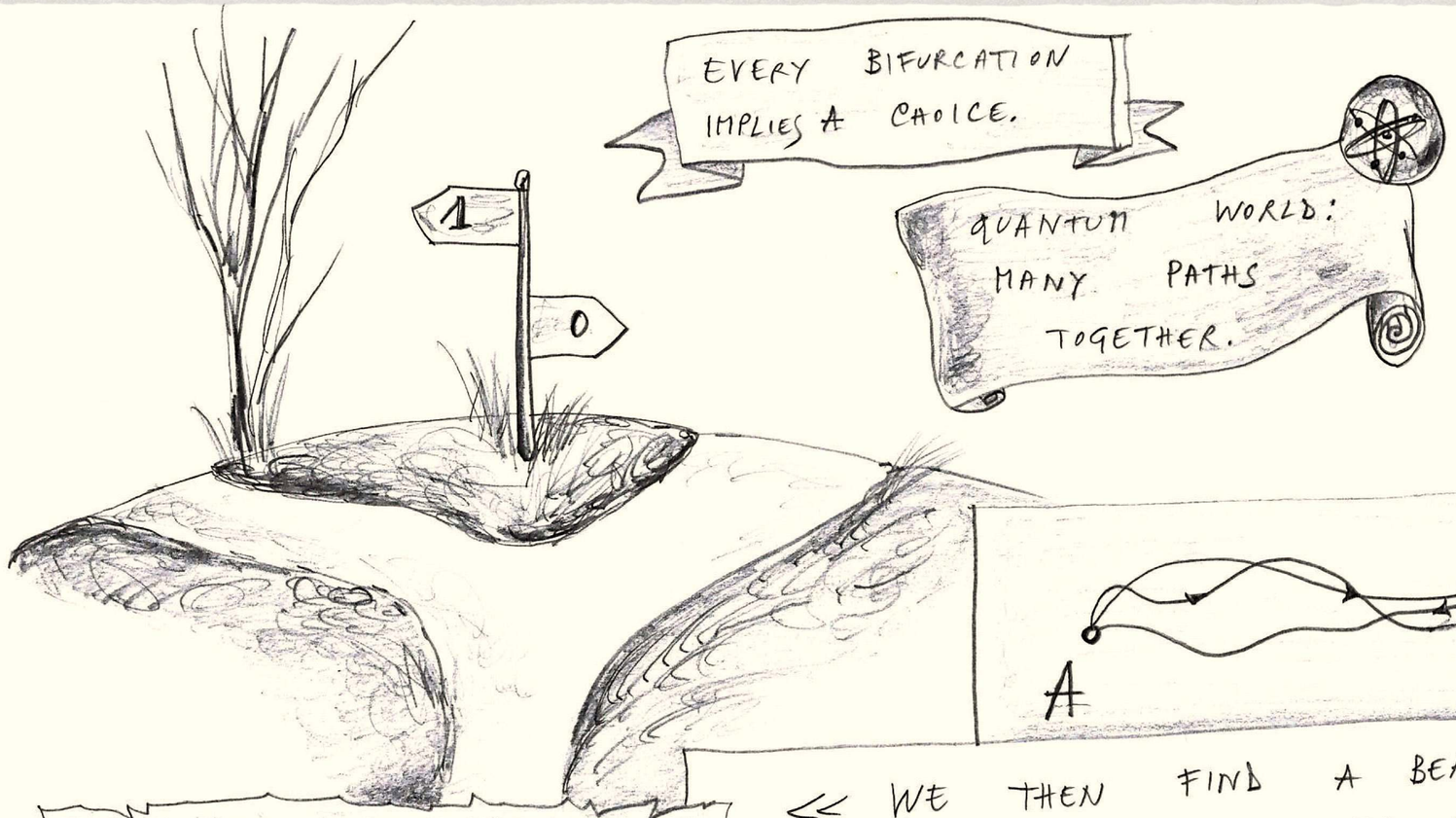
Oslo, December 3, 2025

"THE GARDEN OF FORKING PATHS"
(BRANCHING)

J. L. BORGES
(1899 - 1986)

<< In ALL WORKS OF FICTION, EACH TIME THE WRITER IS CONFRONTED WITH CHOICES, HE OPTS FOR ONE AND DISCARDS THE REST. IN THE INEXTRICABLE TS'UI PÊN, HE OPTS - AT ONE AND SAME TIME - FOR ALL THE ALTERNATIVES. BY SO DOING, HE CREATES SEVERAL FUTURES, SEVERAL TIMES OVER, AND IN TURN THESE PROLIFERATE AND BRANCH OFF. >>

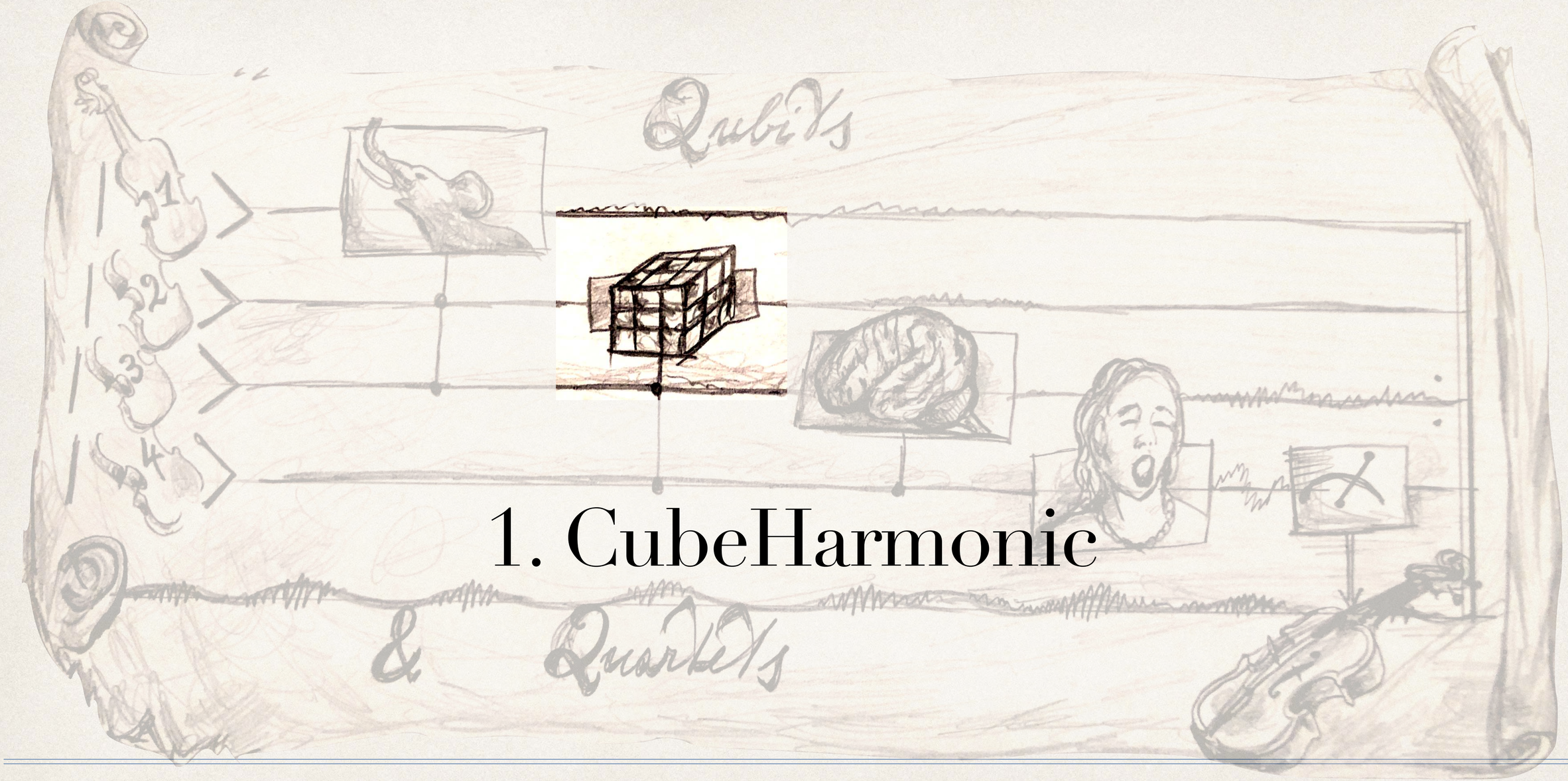
J. L. Borges, "The Garden of Branching Paths", pg. 34, Translation by N. T. Di Giovanni.



$$\int_{q(T_i)=q_i}^{q(T_f)=q_f} [dq]\, q(t_1)\dots q(t_m)\, e^{iS} = \langle q_f, T_f | T\{\hat{q}(t_1)\dots\hat{q}(t_m)\} | q_i, T_i \rangle$$

<< WE THEN FIND A BEAUTIFUL PHYSICAL PICTURE, DUE TO FEYNMAN, OF QUANTUM MECHANICS: A PARTICLE "EXPLORES" ALL POSSIBLE PATHS SIMULTANEOUSLY, AND THE QUANTUM AMPLITUDE IS OBTAINED BY SUMMING OVER ALL TRAJECTORIES WHICH INTERPOLATE BETWEEN THE INITIAL AND THE FINAL POINT. >>

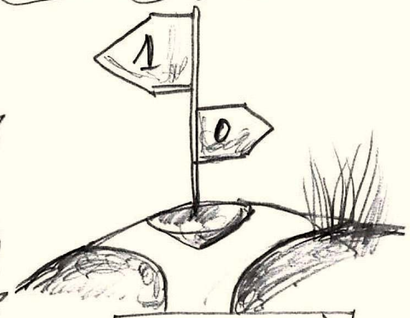
M. Maggiore, "A Modern Introduction to Quantum Field Theory", Pg. 222



1. CubeHarmonic

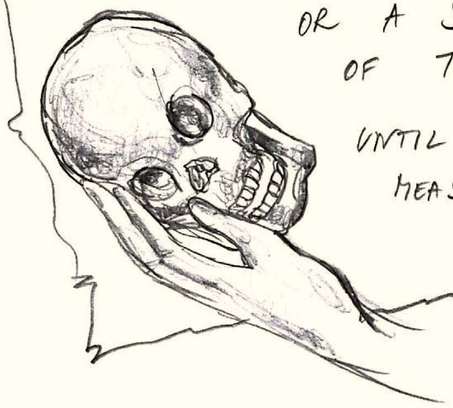
AGAIN: EVERY BIFURCATION IMPLIES A CHOICE.

MANY (MUSICAL) POSSIBILITIES, UNTIL WE ROLL A DICE?



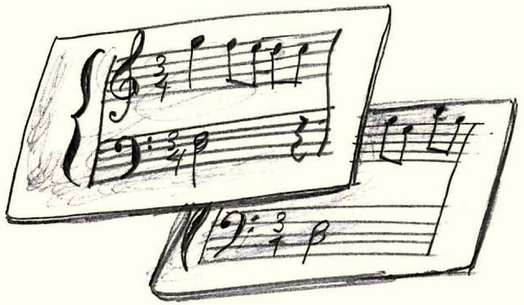
$\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$

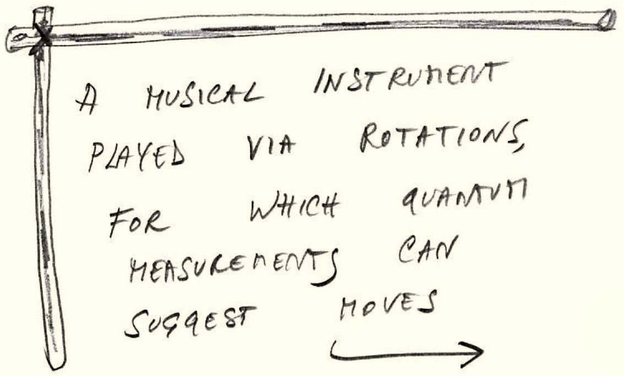
"TO BE OR NOT TO BE?" OR A SUPERPOSITION OF THEM, UNTIL WE MEASURE?



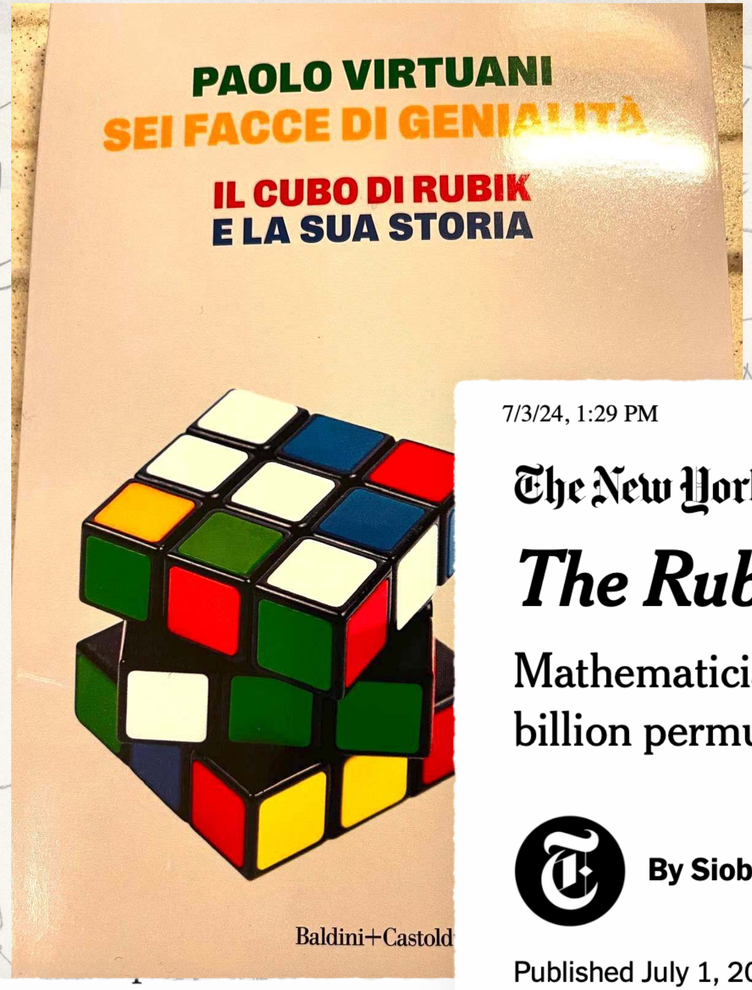
MOZART'S

„Musikalisches Würfelspiel"





A MUSICAL INSTRUMENT PLAYED VIA ROTATIONS, FOR WHICH QUANTUM MEASUREMENTS CAN SUGGEST MOVES



civo a risolvere il Cubo, mi sono
possibile suonarlo.»

Maria Mannone
Ideatrice di CubeHarmonic

si trova dal dicembre 2023 a
Park: misura tre metri per lato

geometrica. Mannone continua a studiare tutte le possibilità musicali offerte dal Cubo e in estate ha cercato di includere un aspetto quantistico. «C'è già stata una primissima applicazione della quantistica alla musica. È un settore che si sta sviluppando velocemente, sono già stati organizzati convegni dedicati a questo aspetto». Un suo poster sull'argomento è stato recentemente premiato a un convegno a Erlangen, in Germania.

one d orchestra e Pianoforte,
in Acustica, trattamento del
a musica e molto altro ancora.

The New York Times https://www.nytimes.com/2024/07/01/science/rubiks-cube-puzzles.html

The Rubik's Cube Turns 50

Mathematicians and hobbyists have had a half-century of fun exploring the 43 billion billion permutations of Erno Rubik's creation.

By Siobhan Roberts

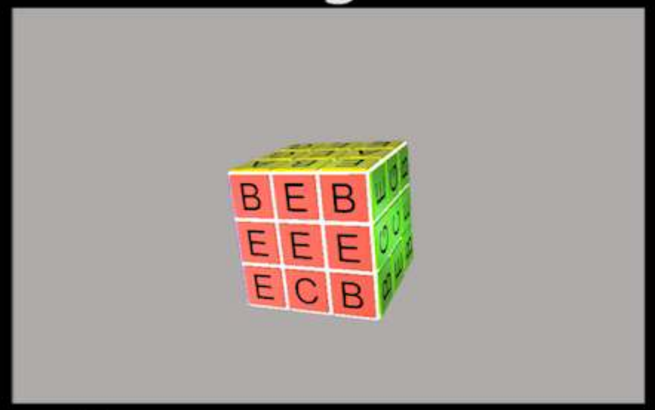
Published July 1, 2024 Updated July 2, 2024

And Maria Mannone, an Italian theoretical physicist and composer, invented the "CubeHarmonic," a musical instrument, developed with Japanese collaborators. "It is a Rubik's Cube where, on each face, there are musical chords, a note on each facet," she explained in an email. "Scrambling the cube, we scramble musical chords."

CubeHarmonic

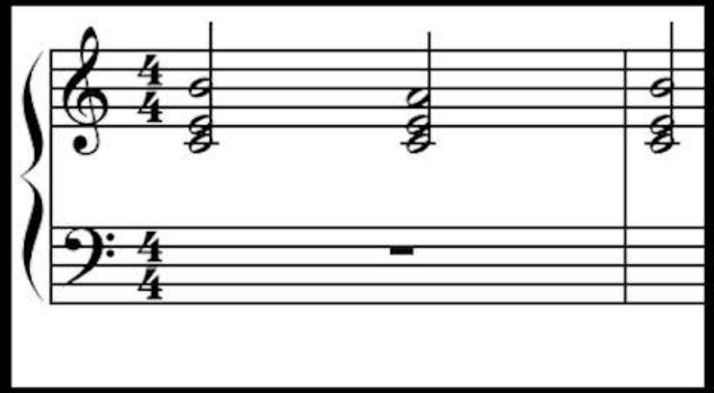
User can join the playfulness of the cube
with an embodied geometry of chords

Scrambling the cube



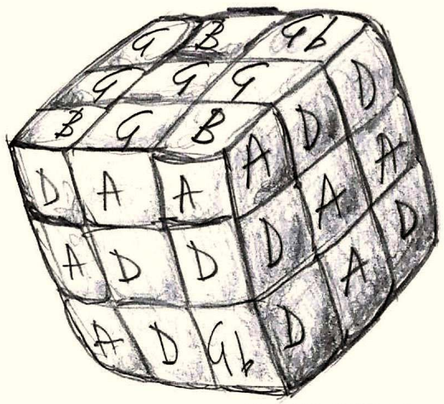
B
E
C

Musical chords



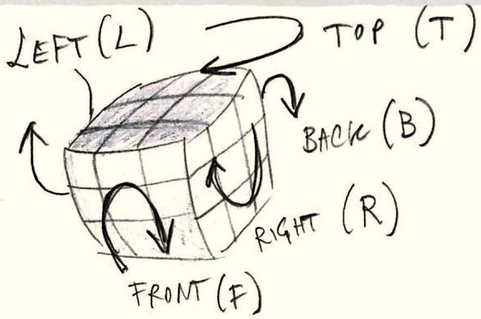
B
E
C

Sendai (Japan), Prof. Kitamura Lab, 2017



Cube Harmonic

PROTOTYPE: CONCEPT BY M. MANNONE, REALIZATION BY JAPANESE ENGINEERS AT KITAMURA LAB



$$|\psi\rangle_{i,x} = \alpha_i |L\rangle + \alpha_i' |R\rangle$$

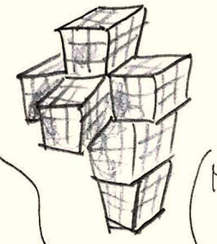
$$|\psi\rangle_{i,y} = \beta_i |T\rangle + \beta_i' |D\rangle$$

$$|\psi\rangle_{i,z} = \gamma_i |F\rangle + \gamma_i' |B\rangle$$

$$|\alpha_i|^2 + |\alpha_i'|^2 = 1$$

i-th PLAYER

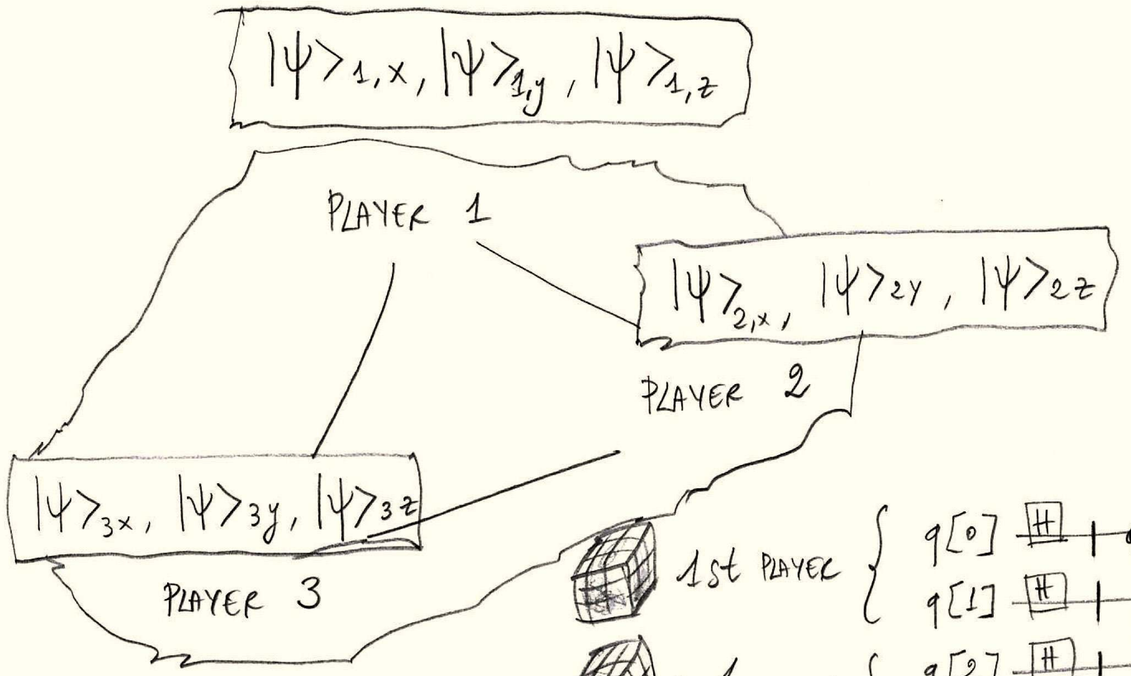
+ 4D Cube Harmonic



(MANNONE & YOSHINO, ET al. 2024)

M. MANNONE et al., "CUBE HARMONIC: A NEW MUSICAL INSTRUMENT BASED ON RUBIK'S CUBE WITH EMBEDDED MOTION SENSOR", ACM SIGGRAPH '13, USA

M. MANNONE & L. TURCHET, "DICE CUBES: QUANTUM-BASED NETWORKED PERFORMANCE WITH CUBEHARMONIC", IEEE 5th INTERNATIONAL SYMPOSIUM OF THE INTERNET OF SOUNDS, 2024. Best Poster award



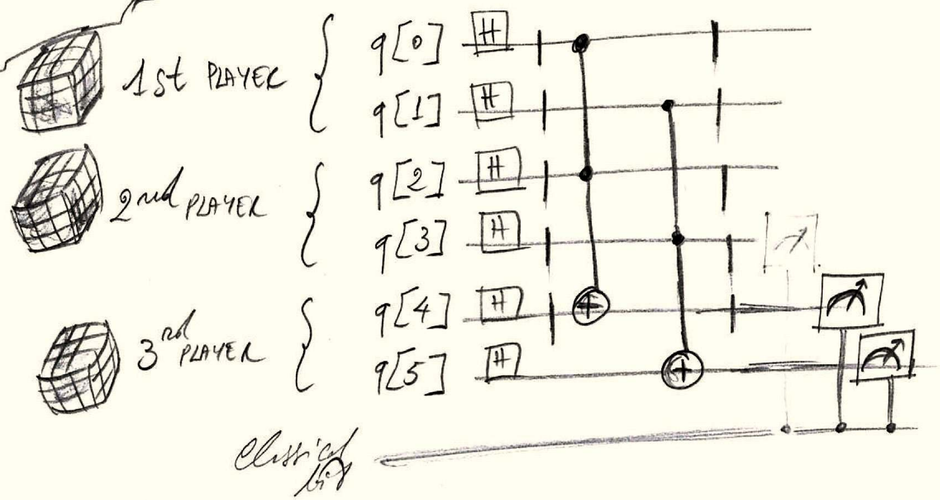
q_0 : $|0\rangle$ => ROTATION LEFT

$|1\rangle$ => ROTATION RIGHT

q_1 : $|0\rangle$ => ROTATION TOP

$|1\rangle$ => ROTATION bottom

similarly $\{q_2, q_3\}$, $\{q_4, q_5\}$



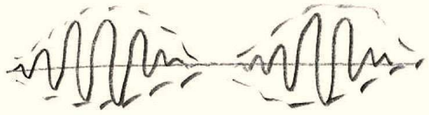
2. Voice

QUANTUM MEASUREMENT AS A FILTER

1947: DENNIS GABOR DESCRIBED SOUND THROUGH QUANTUM MECHANICS.

φωνή

DENNIS GABOR (1900 - 1979)



PHON: UNIT IN THE TIME-FREQUENCY PLANE

2018 - 2021 APPROX.:

QUANTUM VOCAL THEORY OF SOUNDS (QVTS)

PHONATION

MYOELASTIC PULSATION

pitch

PH (UP)

MYOEL. (SLOWER)

LOW-SP.

MYOELASTIC (FASTER PULSE)

TURB. (HIGH-SPECTRAL CENTROID)

PH (DOWN)

PITCH-UP $|u\rangle$,
PITCH-DOWN $|d\rangle$

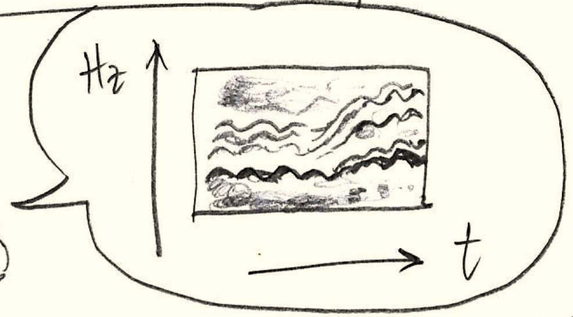
PHON: $|\psi\rangle = (\langle u|\psi\rangle)|u\rangle + (\langle d|\psi\rangle)|d\rangle$

$\langle \sigma_z \rangle := \langle \psi | \sigma_z | \psi \rangle$

$\sigma_z |u\rangle = |u\rangle, \quad \sigma_z |d\rangle = -|d\rangle$

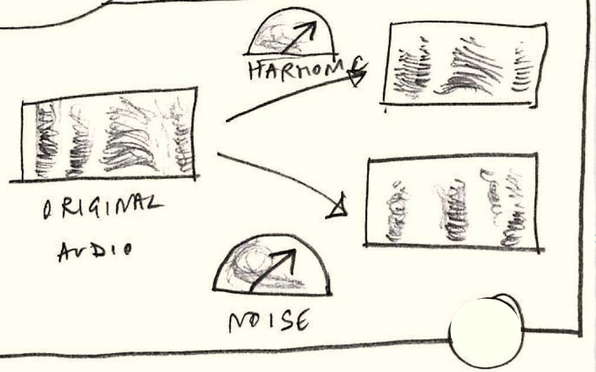
... AND SO ON.

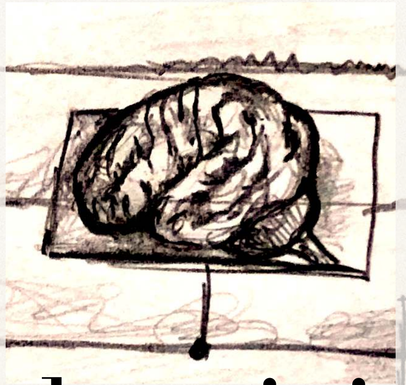
MANNONE & ROCCHESSO, "A QUANTUM VOCAL THEORY OF SOUND". QUANTUM INFORMATION PROCESSING, 2020



= MYO = PHONATION = TURBULENCE

QVTS AS A FILTER





3. Neural activity

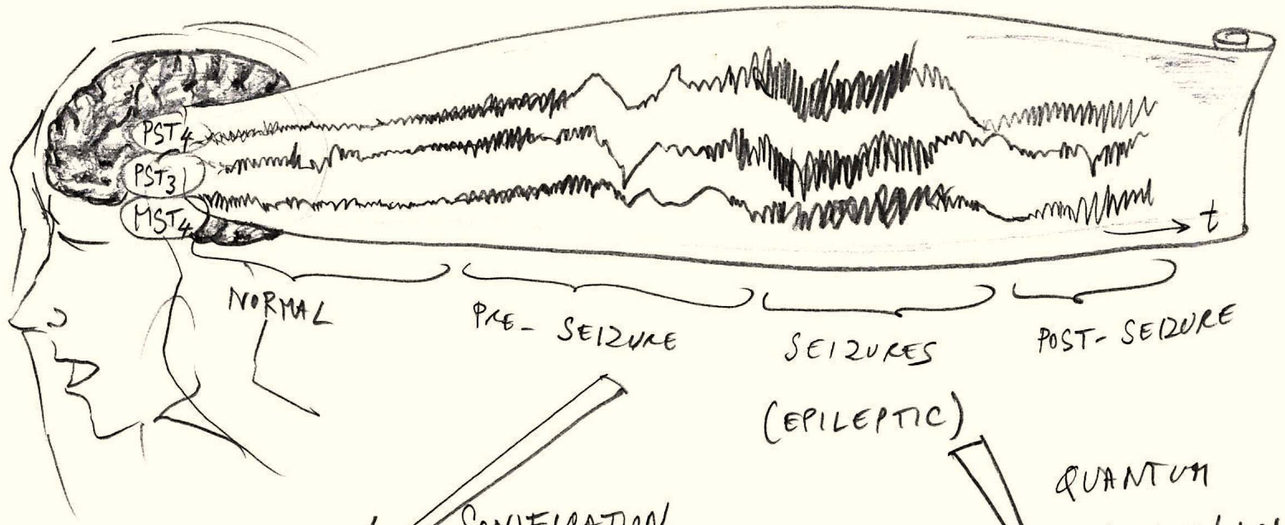
SONIFYING MULTIPLE LINES, & AGGLOMERATES...

QUANTUM SEIZURES

MUSIC & QUANTUM TO INVESTIGATE MEDICINE

PST = POSTERIOR SUPERIOR TEMPORAL SULCUS

MST = MIDDLE SUPERIOR TEMPORAL AREA

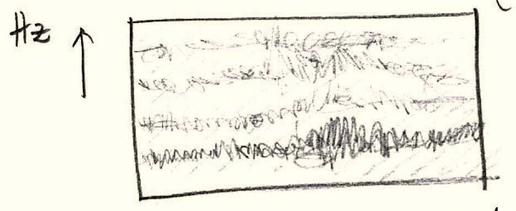


SONIFICATION (AS A COUNTERPOINT)

QUANTUM MODELING

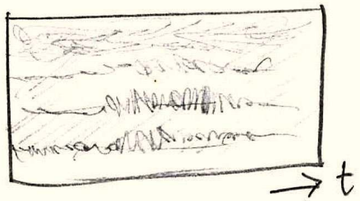
$$H(t) = \sum_{n=0}^{N-1} J_n(t)\,\sigma_n^z\,\sigma_{n+1}^z + \sum_{n=0}^{N-1} h_x(t)\,\sigma_n^x$$

ISING MODEL & OTHERS TO MODULATE



COMPARISON

SONIFICATION



MANNONE ET AL. (WITH OCH & P. ITABORAÍ & N. GOLDACK "SONIFIED QUANTUM SEIZURES", Under review.

4. Memory

QUANTUM MEMORY

QUANTUM

IF TWO DIFFERENT SYSTEM PRESENT MORE AND MORE SIMILAR STATES!

MEMORY (OF THEIR "IDENTITY") LOST

$$\sigma(\varrho_1, \varrho_2) = \frac{d}{dt} D(\varrho_1, \varrho_2)$$

$$\mathcal{N} = \max_{\varrho_{1,2}(0)} \int_{\sigma>0} dt\, \sigma(t, \varrho_{1,2}(0))$$

DEGREE OF NON-MARKOVIANITY

MUSIC

THE MORE SIMILAR THE SEQUENCES, THE HIGHER THE MEMORY.

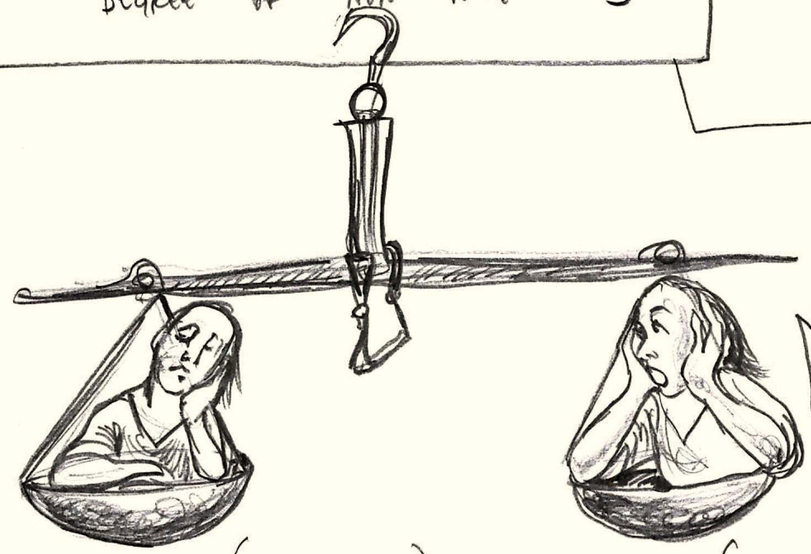
$$\mathcal{M} = 1 - \mathcal{N}^*$$

$$= 1 - \sum_{\Delta D_i / \Delta t_i > 0} \frac{\Delta D_i}{\Delta t_L}$$

DEGREE OF MUSICAL NON-MARKOVIANITY

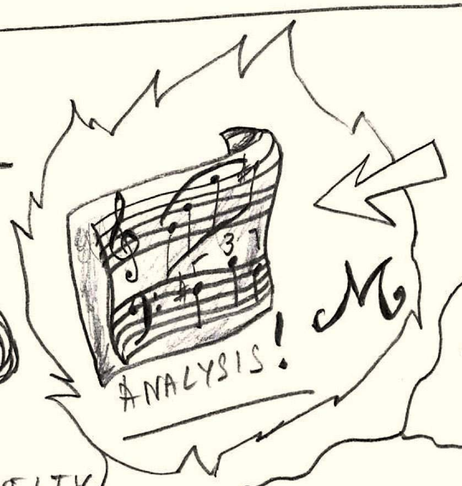
MUSICAL MATRICES

AS DISTRIBUTION OF OCCURRENCES OF NORMALIZED PITCH, ONSETS... IN EACH SEQUENCE



EXPECTATION (REPETITION)

SURPRISE (NOVELTY)

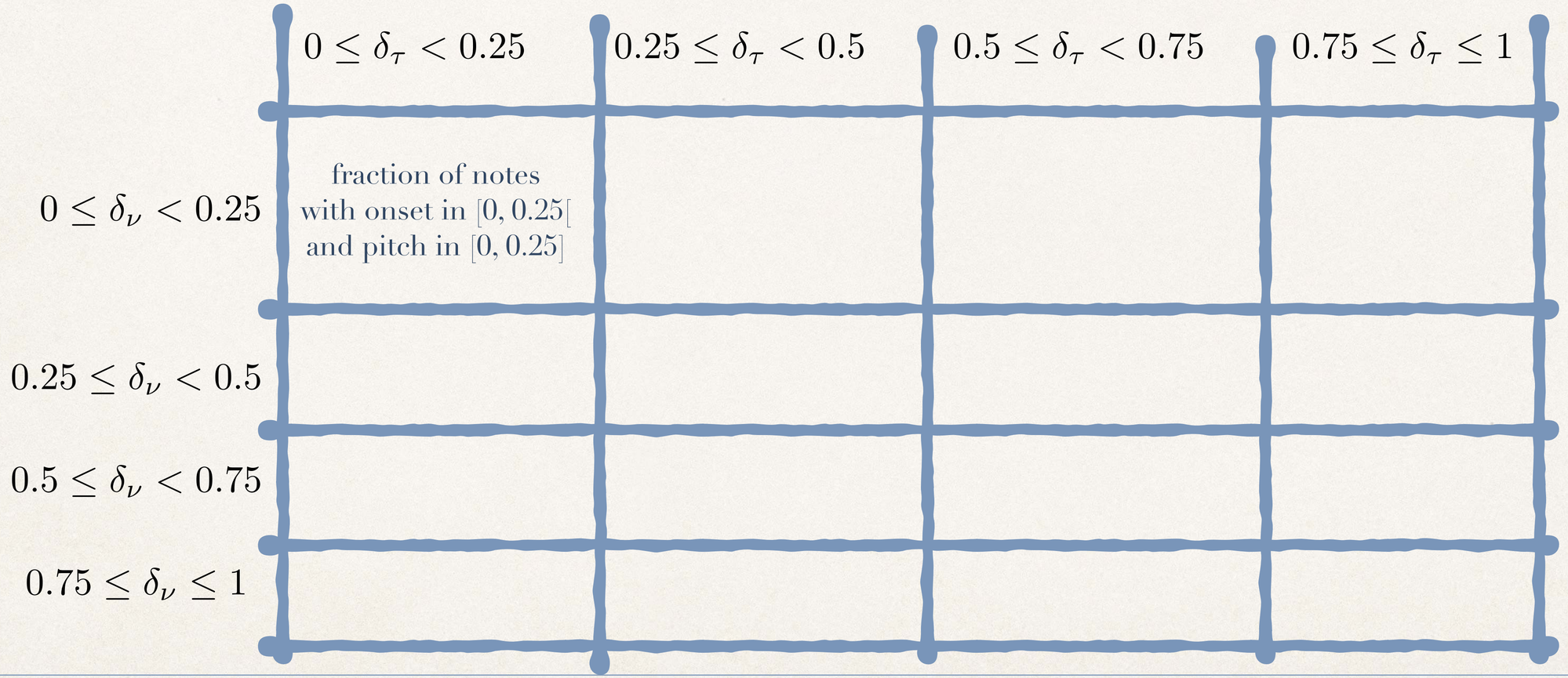


MANNONE & COMPAGNI, "CHARACTERISATION OF THE DEGREE OF MUSICAL NON-MARKOVIANITY", 2022

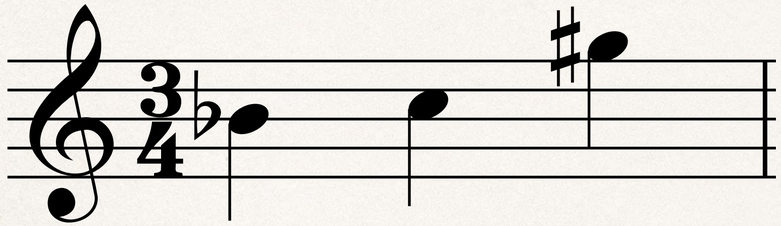
MANNONE & COSTA-HAMIDO, "MEASURING THE DEGREE OF N.M. OF ORCHESTRAL MUSIC",

Musical matrices

Analysis: pairs of parameters.
A matrix for each musical sequence.
An example with frequency-onset

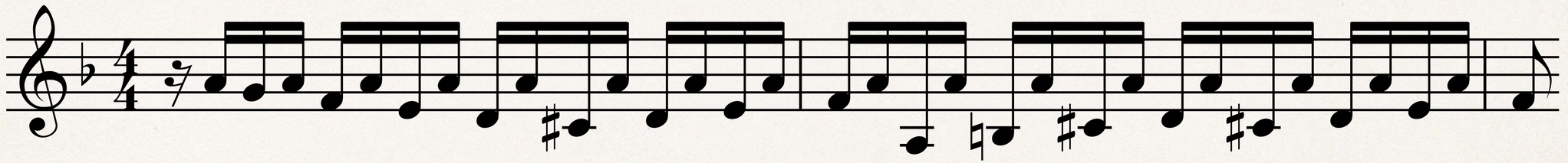


A toy example



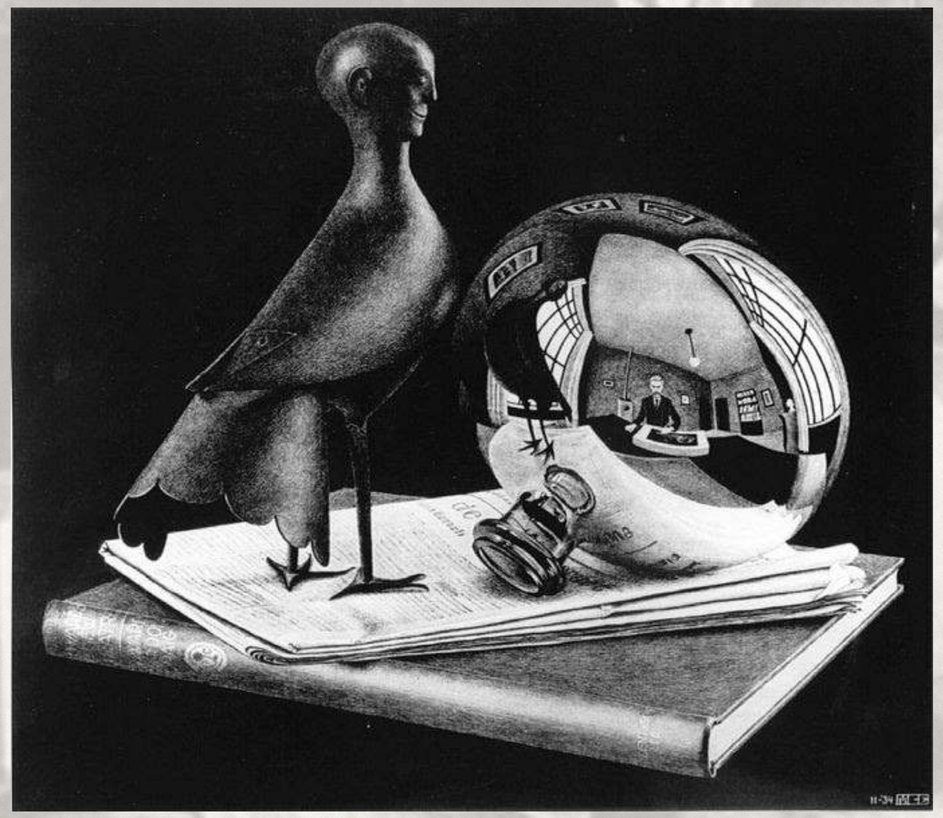
$$\rho_1 = \begin{pmatrix} 0.33 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.33 \\ 0 & 0 & 0 & 0.33 \end{pmatrix}$$

A less toy example



$$\rho_2 = \begin{pmatrix} 0.06 & 0 & 0.03 & 0.12 \\ 0.12 & 0.19 & 0.19 & 0.12 \\ 0 & 0.06 & 0.03 & 0.00 \\ 0.06 & 0 & 0 & 0 \end{pmatrix}$$

Some results



M. C. Escher, *Still Life with Spherical Mirror*, 1934

Original code in C: M. Mannone

Max MSP re-writing: O. C. Hamido

Liebestod

R. Wagner

Santa Rosalia

M. Mannone

[a keyboard improvisation]

Macro-sequences (halves) from midi files

$A,\ B$ e.g., frequency-start matrices of first and second half of the piece

$$AB = abs(A - B), \quad DAB = 0.5 * trace(AB)$$

M_c coefficient	Tristan	Rosalia	improvisation
frequency - start	0.9390	0.9132	0.8850
frequency - duration	0.9950	0.9524	0.8734
frequency - intensity	0.8475	0.9479	0.9390
duration - intensity	0.7722	0.9950	0.8264
start - intensity	0.9259	0.9091	0.8850

M. Mannone and O. C. Hamido, *Quantum Memory: Measuring the Degree of Non-Markovianity of Orchestral Music*, In: E. Miranda, *Advances in Quantum Computer Music*, WSPC Book Series in Unconventional Computing, World Scientific, Singapore, 2025

Vice versa: from density matrices to music

Which density matrices?

Description of a swarm of robots as a whole physical system

A density matrix $\varrho(t)$ for a swarm at time t

M. Mannone, M. Anand, P. Fazio, A. Swikir, *A Novel Theoretical Approach on Micro-Nano Robotic Networks Based on Density Matrices and Swarm Quantum Mechanics.* Under review

A qubit for position along x, a qubit for position along y

Robot 1 $$|\psi_1(t_0)\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$$

Robot 2 $$|\psi_2(t_0)\rangle = |00\rangle$$

Density matrices

$$\rho_1(t_0) = \frac{1}{2}(|00\rangle\langle 00| + |11\rangle\langle 11|) = \frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 \end{pmatrix}$$

$$\rho_2(t_0) = |00\rangle\langle 00| = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

M. Mannone, M. Anand, P. Fazio, A. Swikir, *A Novel Theoretical Approach on Micro-Nano Robotic Networks Based on Density Matrices and Swarm Quantum Mechanics.* Under review

$$\rho_1(t_0) = \frac{1}{2}(|00\rangle\langle 00| + |11\rangle\langle 11|) = \frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 \end{pmatrix}$$

$$\rho_2(t_0) = |00\rangle\langle 00| = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

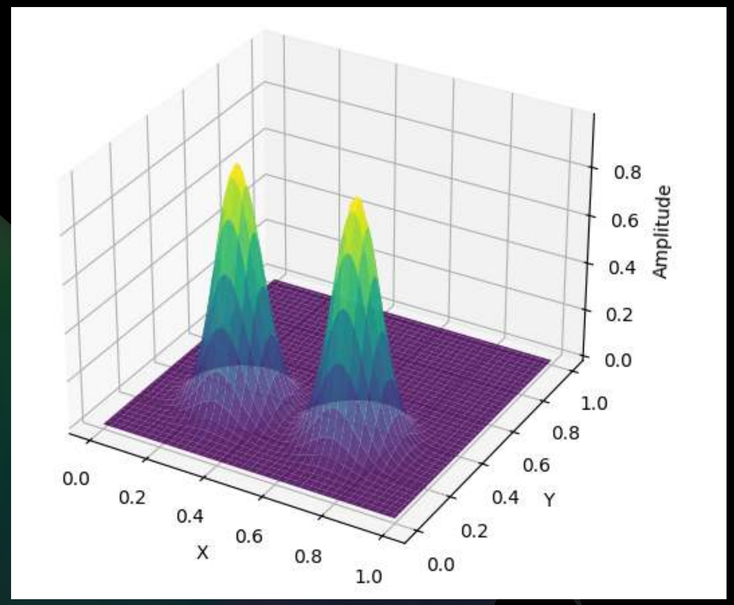
$$\rho_{mix}(t_0) = \frac{\rho_1(t_0) + \rho_2(t_0)}{2} = \begin{pmatrix} 0.75 & 0. & 0. & 0.25 \\ 0. & 0. & 0. & 0. \\ 0. & 0. & 0. & 0. \\ 0.25 & 0. & 0. & 0.25 \end{pmatrix}$$

The toy swarm

M. Mannone, M. Anand, P. Fazio, A. Swikir, *A Novel Theoretical Approach on Micro-Nano Robotic Networks Based on Density Matrices and Swarm Quantum Mechanics.* Under review

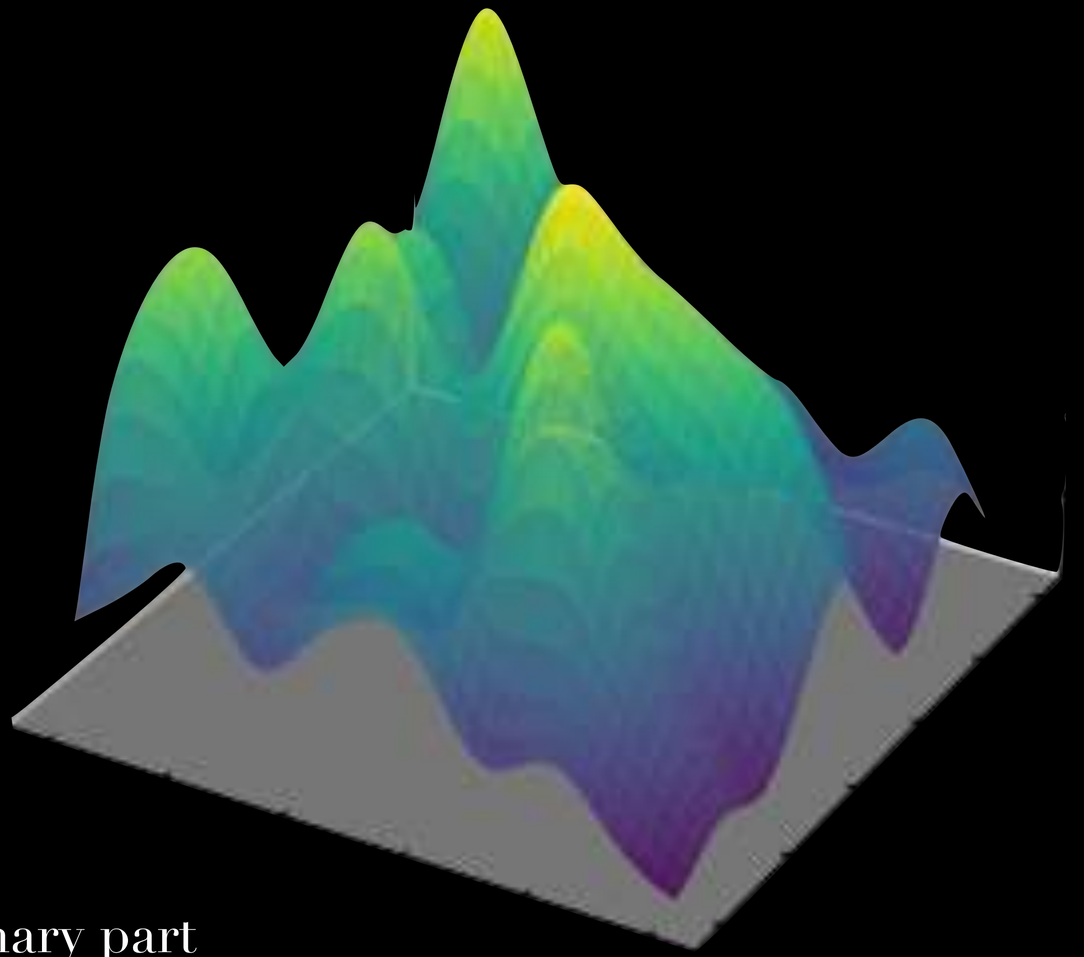
A density matrix ϱ(t) for a swarm at time t

…and its sonification.



100 robots

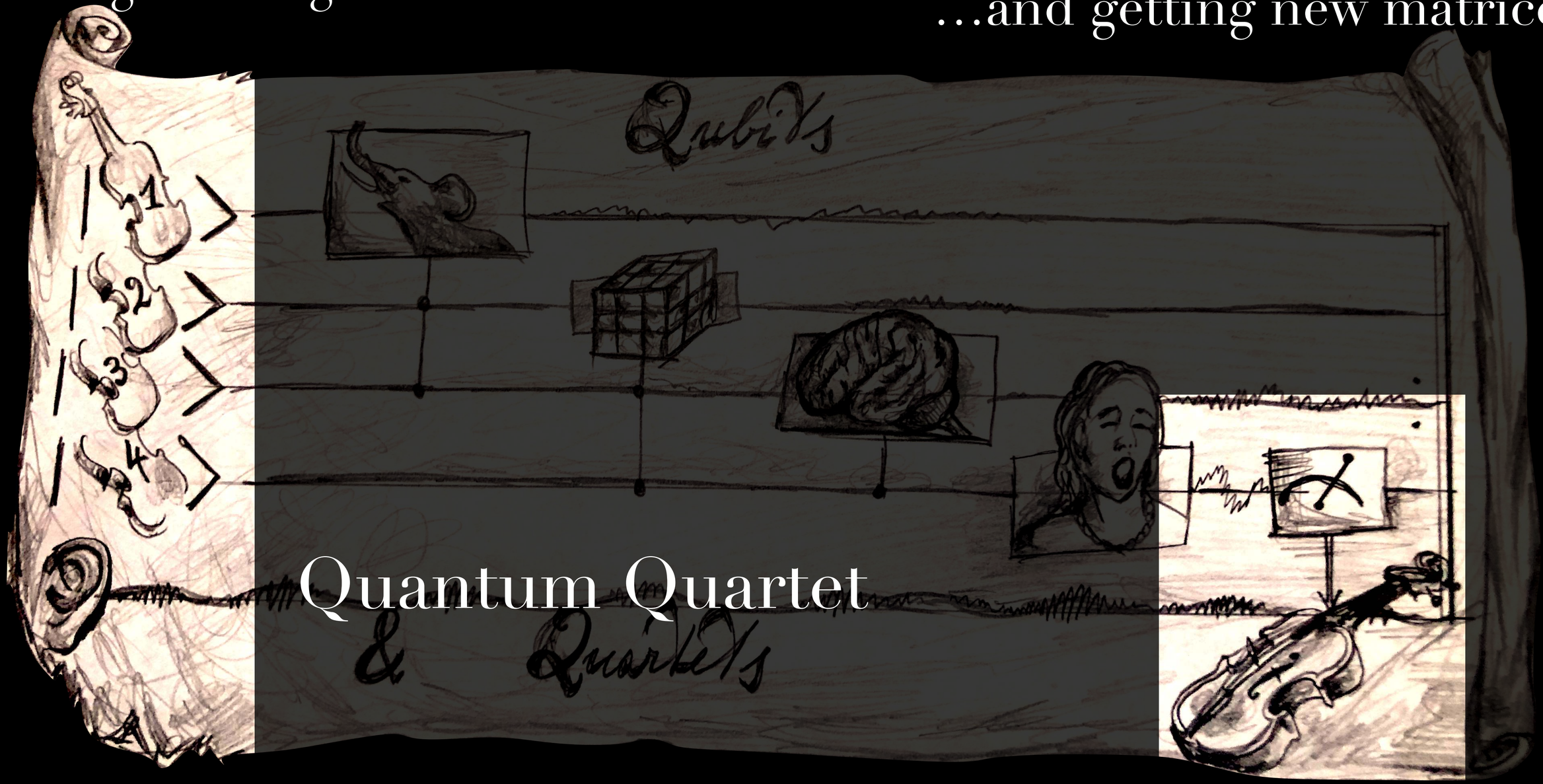
$$\rho_2(t_i) = \begin{pmatrix} 0.237 + 0.j & 0.174 + 0.009j & 0.153 - 0.007j & 0.183 + 0.j \\ 0.174 - 0.009j & 0.258 + 0.j & 0.179 - 0.022j & 0.207 - 0.007j \\ 0.153 + 0.007j & 0.179 + 0.022j & 0.227 - 0.j & 0.188 + 0.014j \\ 0.183 - 0.j & 0.207 + 0.007j & 0.188 - 0.014j & 0.278 - 0.j \end{pmatrix}$$



With frequency modulation for the imaginary part

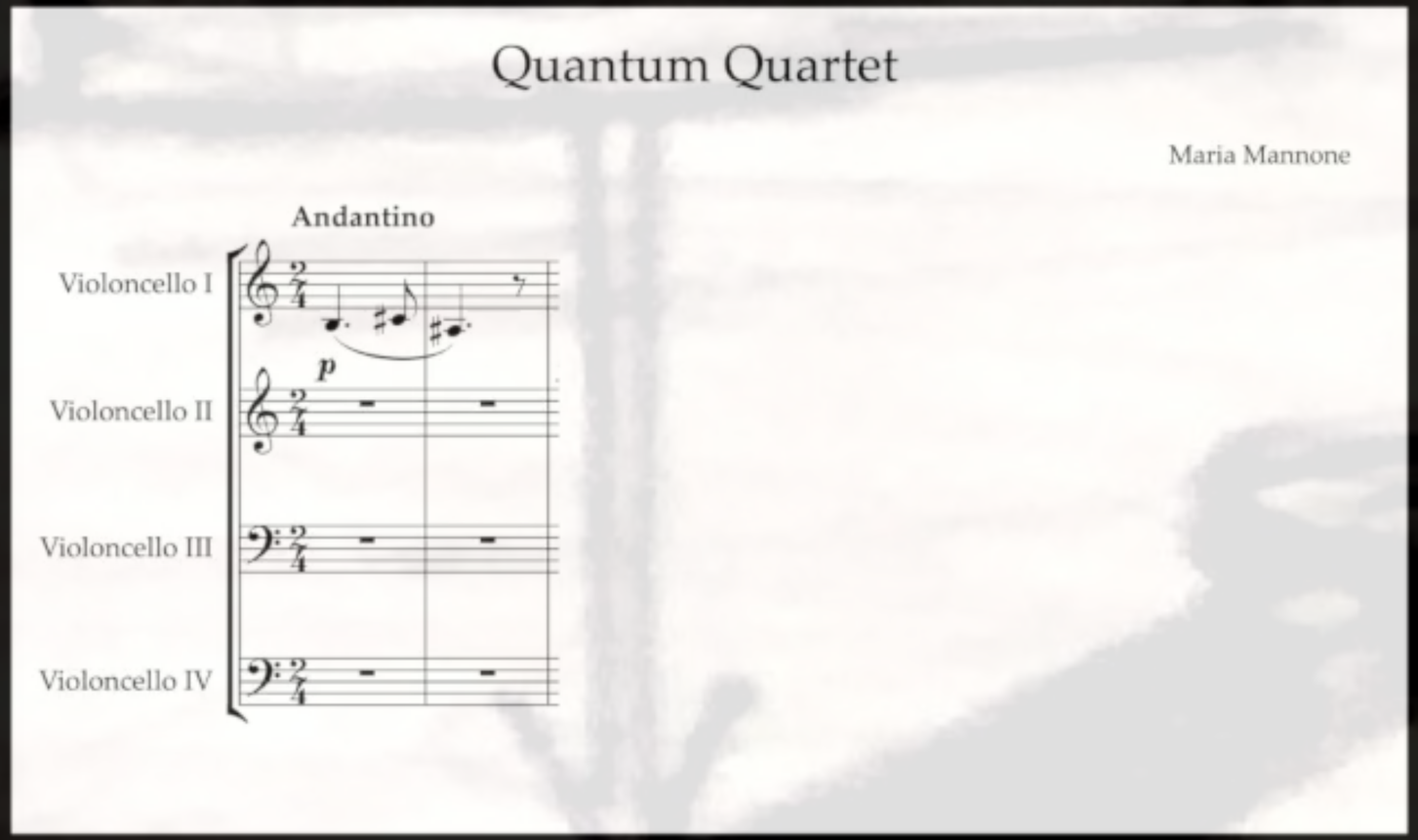
Using the fragments as themes…

…and getting new matrices.



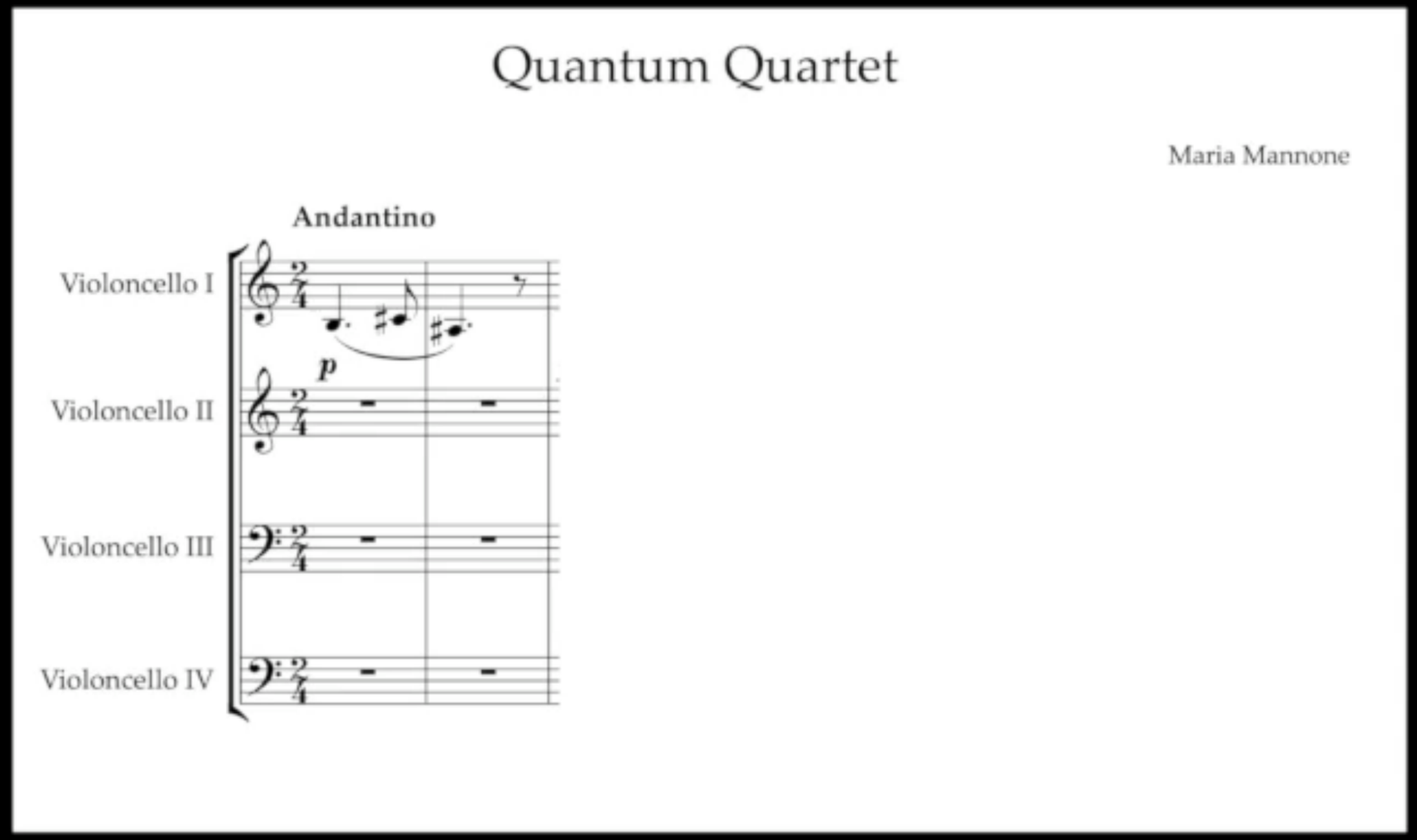
(…distribution matrices, non “density” ones)

$$\rho_{bars\ 1\text{–}2} = \begin{pmatrix} 0.57 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.14 \\ 0.14 & 0.0 & 0.14 & 0.0 \end{pmatrix}$$



The piece played by Magdalena Chudy

$$\rho_{bars\ 1-2} = \begin{pmatrix} 0.57 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.14 \\ 0.14 & 0.0 & 0.14 & 0.0 \end{pmatrix}$$



ISQCMC

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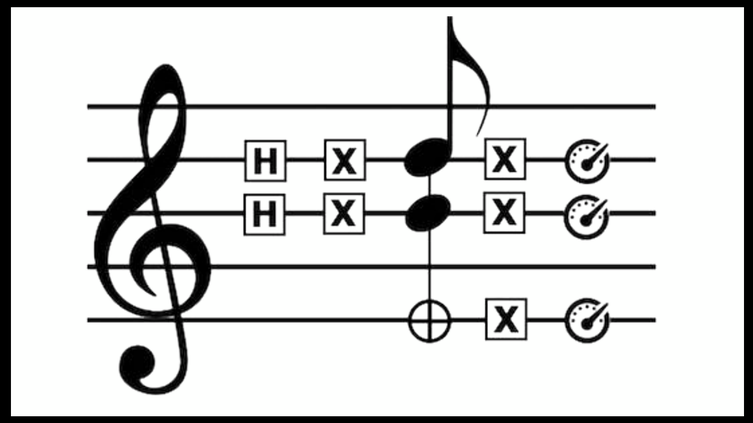

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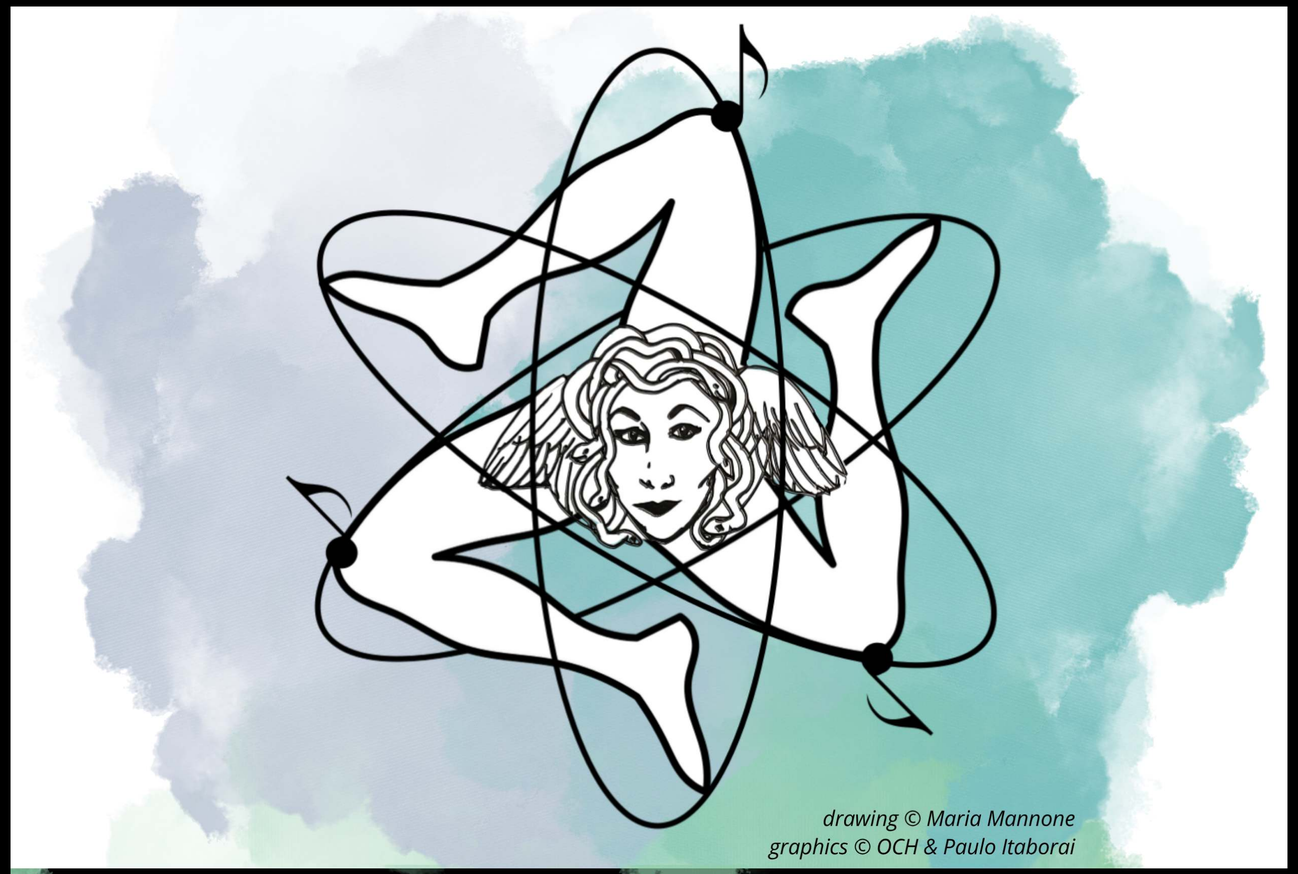

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ISQCMC '25

University of Palermo, Italy

October 28 2025, Orto Botanico

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Thank you for your attention!

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