Mixed Sounds Drift Toward the Gaussian, So the Direction Farthest from the Gaussian Is the Original Sound

— searching for the directions of greatest and least kurtosis returns the original sounds with correlation **0.999994**, without knowing the mixing matrix — the separator is whether the sources are non-Gaussian —

[Paper 655]

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— From thinking to syncing. —

Abstract

Set up two microphones in a room where two people speak at once, and each microphone picks up both voices in different proportions. Can the two voices be separated without knowing how they were mixed (the mixing matrix)? Independent component analysis solves this using only that the sources are independent of each other and not Gaussian.Why it can be solved, and where it stops being solvable, are counted.No new theorem or law is claimed. First, mixing moves toward the Gaussian——mixing a uniform source (kurtosis −1.2180) and a Laplace source (kurtosis 2.9725) with a matrix of condition number 5.5904 gave microphone signals of kurtosis −0.0172 and 1.5013, closer to the Gaussian's 0 (Section 2). **Second, and this is the core.The direction farthest from the Gaussian is the original sound——whitening the microphone signals and measuring kurtosis in each direction gave a maximum of 2.9725 and a minimum of −1.2180, the kurtoses of the two sources themselves. Rotating to those directions returned the original sounds with correlation 0.999994** (Section 3). **Third, Gaussian sources cannot be separated ——with two Gaussian sources, the kurtosis landscape was nearly flat, with a maximum of 0.0833, and over 12 different starting points the correlation with the original sounds reached only 0.853026** (Section 4). **Fourth, with fewer microphones than sources, they cannot be separated——with 3 sources and 2 microphones, even knowing the mixing matrix, the correlations obtainable linearly were at most 0.963938, 0.681459 and 0.777127. The separator is whether the sources are non-Gaussian, and whether there are not fewer microphones than sources** (Section 5).
Keywords: independent component analysis, source separation, kurtosis, central limit theorem, blind signal separation.

Scope of this paper (scope note): **No new theorem or law is claimed——independent component analysis (Comon 1994), separation by information maximization (Bell and Sejnowski 1995), the fixed-point method (Hyvärinen and Oja 2000), and the impossibility of separating Gaussian sources are all known.What is not treated——real recordings, room reverberation and mixtures in which sounds arrive with delays are not treated; all lie beyond instantaneous mixing.Order and scale are not determined——the order, sign and size of the extracted sounds are not determined (known). Correlations were measured in absolute value after matching the pairs.Methods using sparsity are not treated——there are methods that use sparsity to separate more sources than microphones, but they are not included in this paper's linear separation.Relation to earlier papers**: **Paper 187 showed that only the Gaussian keeps its product density under rotation, and that uncorrelated is not independent——here that theorem is shown to be the boundary between sounds that can and cannot be separated.Paper 188 showed that with fewer measurements than unknowns, the answer is still exact if the signal's sparsity and the measurement's spread supply the missing information——here what supplies the missing information is non-Gaussianity, and it could not make up for missing microphones.**What is added is **counting how mixing brings kurtosis toward 0**, **showing that the extremes of the kurtosis landscape are the sources' own kurtoses**, **setting Gaussian sources and the underdetermined case side by side as contrasts**, and **placing the separator on non-Gaussianity**.

1. Notation and the Question

Setting: **two sources $s = (s_1, s_2)$ are mixed into two microphones by a mixing matrix A.**

$$x = A\,s, \qquad A = \begin{pmatrix} 1.0 & 0.8 \\ 0.6 & 1.0 \end{pmatrix}$$

s_1 is uniform and s_2 Laplace, both of variance 1, with 20000 samples.The (excess) kurtosis is $E[y^4]/E[y^2]^2 - 3$: 0 for the Gaussian, negative for the uniform and positive for the Laplace.The separation first whitens the microphone signals (removing correlation and equalizing variance), then rotates to the directions where kurtosis is extreme (the fixed-point method).

Question: **why can the sounds be separated without knowing the mixing matrix, and where does separation fail?**

2. Mixing Moves Toward the Gaussian

Computation 2.1: **the sources had kurtosis -1.2180 (uniform) and 2.9725 (Laplace). The mixing matrix had condition number 5.5904, and the two microphone signals had correlation 0.9370.The microphone signals had kurtosis -0.0172 and 1.5013.**

Observation 2.2

mixing brings kurtosis toward 0.The direction of the central limit theorem, that adding independent things approaches the Gaussian, is already visible after mixing only two——to mix is to move toward the Gaussian.

3. The Kurtosis Landscape

Computation 3.1: **the whitened signals were projected onto direction θ (0 to 180 degrees, 361 values) and the kurtosis measured. The maximum was 2.9725 and the minimum -1.2180, agreeing with the two sources' kurtoses within 0.01.Rotating to those directions by the fixed-point method, the correlation of the extracted with the original sounds (the smaller of the matched pair) was 0.999994. Over 12 different starting points, every one gave 0.999994.**

Observation 3.2

this is the core: the direction farthest from the Gaussian is the original sound.If mixing moves toward the Gaussian, then conversely, searching for the direction that moves farthest from the Gaussian returns to before the mixing. The peak and trough of the kurtosis landscape lay exactly in the directions of the sources ——without knowing the mixing matrix, the fact that the sources are not Gaussian shows the way back.

4. If the Sources Are Gaussian

Computation 4.1: **two Gaussian sources were mixed by the same matrix, whitened, and their kurtosis landscape measured. The maximum was 0.0833 and the minimum -0.0046.Over 12 different starting points of the fixed-point method, the correlation with the original sounds was 0.853026 every time, and the two extracted kurtoses were 0.0823 and 0.0339.**

Observation 4.2

Gaussian sources cannot be separated.The kurtosis landscape is nearly flat, with no peak in any direction. The extracted kurtosis 0.0823 is close to the landscape's maximum 0.0833, so the fixed-point method appears to have settled on a small peak made by sampling fluctuation. That is not the direction of the sources——as Paper 187 showed, only the Gaussian keeps its product density under rotation. Whitened Gaussian sources look independent however they are rotated, and nothing remains to show their original direction.

5. When Microphones Are Too Few

Computation 5.1: **there were 3 sources (uniform, Laplace, Laplace) and 2 microphones. Even knowing the mixing matrix, the largest correlations obtainable linearly from the two microphone signals were 0.963938, 0.681459 and 0.777127.**

> **Observation 5.2**
>
> **with fewer microphones than sources, linear separation fails.Two microphones span only two directions, so there is no direction that extracts each of three sources alone——Paper 188 showed that with fewer measurements than unknowns the answer can still be exact if the signal's sparsity supplies the missing information. In this paper's linear separation, non-Gaussianity could not make up for the missing microphone.**

6. The Separator

> **Observation 6.1**
>
> **the separator is whether the sources are non-Gaussian, and whether there are not fewer microphones than sources.Non-Gaussian and with enough microphones, the sources can be separated without knowing the mixing matrix. Gaussian, the direction of rotation after whitening is not determined. With too few microphones, the directions themselves are too few——whether sounds can be separated is set not by their loudness or how strongly they are mixed, but by the shape of their distributions and the balance of numbers.**

> **Observation 6.2**
>
> **what is not said.Real recordings, reverberation and delayed mixtures are not treated. The order, sign and size of the extracted sounds are not determined (known). Methods using sparsity are not included——what is shown is what makes separation possible, and what makes it impossible, for instantaneous mixing.**

7. Roll Call and Closing

1. **source kurtoses -1.2180 and 2.9725** (Computation 2.1): **uniform and Laplace.**
2. **microphone kurtoses -0.0172 and 1.5013** (Computation 2.1): **mixing moves toward 0.**

3. **landscape extremes equal source kurtoses** (Computation 3.1): **peak and trough in the sources' directions.**
4. **correlation after separation 0.999994** (Computation 3.1): **back without the mixing matrix.**
5. **farthest from Gaussian is the original** (Observation 3.2): **the core.**
6. **Gaussian landscape maximum 0.0833** (Computation 4.1): **nearly flat.**
7. **Gaussian correlation 0.853026** (Computation 4.1): **cannot separate.**
8. **only the Gaussian is unchanged by rotation** (Observation 4.2): **Paper 187.**
9. **at most 0.963938 with 2 microphones and 3 sources** (Computation 5.1): **too few.**
10. **non-Gaussian, and enough in number** (Observation 6.1): **the separator; Paper 188.**

Closing: **Mixed sounds move toward the Gaussian.So searching for the direction farthest from the Gaussian returns to the original sounds without knowing the mixing matrix, and the uniform and Laplace sources separated with correlation 0.999994.With Gaussian sources the kurtosis landscape became flat (maximum 0.0833) and the correlation reached only 0.853026; with more sources than microphones, even knowing the mixing matrix did not allow linear extraction——what makes separation possible is that the sources are not Gaussian.The separator is whether the sources are non-Gaussian, and whether there are not fewer microphones than sources.Placed among the earlier papers——Paper 187's "only the Gaussian is unchanged by rotation" became the boundary of what can be separated.To be honest——only instantaneous mixing is treated, and reverberation, delay and sparsity are not included.**

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