

# The geometry of admixture in population genetics: the blessing of dimensionality

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## Abstract

We present a geometry-based interpretation of the  $f$ -statistics framework, commonly used to determine phylogenetic relationships from genetic data. The focus is on the determination of the mixing coefficients in population admixture events subject to post-admixture drift. The interpretation takes advantage of the high dimension of the dataset and analyzes the problem as a dimensional reduction issue. We show that it is possible to think of the  $f$ -statistics technique as an implicit transformation of the genetic data from a phase space into a subspace where the mapped data structure is more similar to the ancestral admixture configuration. The positive effect of the map can be explicitly assessed. The overarching geometric framework provides slightly more general formulas than the  $f$ -formalism by using a different rationale as a starting point. Explicitly addressed are two- and three-way admixtures. The mixture proportions are provided by suitable linear fits in two or three dimensions that can be easily visualized. The developments and findings are illustrated with numerical simulations from real world datasets.

**Keywords:** population admixture;  $f$ -statistics; genetic drift; dimensional reduction

## Introduction

The determination of admixture proportions in hybrid populations is a central topic in population genetics. At large evolutionary time scales, a population admixture event can be thought of as a sudden process in which a new lineage emerges as the genetic weighted combination of two or more donors, in its simplest formulation.

The formalism known as  $f$ -statistics Patterson *et al.* (2012); Haak *et al.* (2015); Lazaridis *et al.* (2016); Peter (2016); Lipson (2020); Eadaoin Harney *et al.* (2021); Peter (2022), which deals with allele-sharing correlations between two, three and four populations, is a commonly used technique to determine the admixture coefficients. Despite their simple computation and definition, the  $f$ -statistics outcome assessment may not be straightforward Lipson (2020). We develop a geometry-based interpretation of  $f$ -statistics intended to deepen understanding of the population admixture problem. Geometric-like methods have already been raised in the past Cavalli-Sforza (1966); Cavalli-Sforza and Piazza (1975); Cavalli-Sforza *et al.* (1994); Long (1991); Oteo-García (PhD thesis, 2020); Agrawal-Tamir *et al.* (2021). The strength of our approach is to take advantage of the high dimensionality of the problem, broadening the  $f$ -formalism toolkit.

Whenever the genetic information from the original populations is available, determining the admixture proportions is straightforward. However, the evolutionary history of the original populations manifests itself, for example, in random changes in allele frequencies, a phenomenon known as genetic drift. Although ancient DNA can sometimes aid in estimating admixture proportions by providing better proxies, the time elapsed since

admixture and the possibility that the putative parents themselves are extinct make accurate estimates difficult. Moreover, a population may experience over time continuous, discrete, occasional, or repeated genetic influx from other or multiple others, which makes the issue more challenging. The present study is concerned with the approximation of admixture proportions in populations that are assumed to have evolved in time via genetic drift. A dataset with population allele frequencies corresponding to a large number of Single Nucleotide Polymorphisms (SNPs) is the common starting point for dealing with this question.

The population admixture problem may be posed as a geometric issue in a phase space, the allele frequency space, where each population is represented by a point and each axis corresponds to a SNP in the dataset Oteo-García and Oteo (2021). With only three SNP, Figure 1 outlines the nature of the problem. Populations  $i, a', b', x, b, j$ , are assumed to be related by phylogenetic trees and are located in phase space by their position vectors whose coordinates are given by the allele frequencies in the dataset. At the time of admixture, we have three co-linear points,  $a', x', b'$ , with  $a'$  and  $b'$  the donors and  $x'$  the hybrid. Then, they describe Brownian-like trajectories because allele frequencies undergo small random changes as a result of genetic drift, resulting in population proxies  $a, x, b$ .

Populations  $i$  and  $j$ , which appear as spectators in the Figure 1, will be referred to as auxiliary populations and will play an important role. Any population related to the admixture contributors via phylogenetic trees may be considered as auxiliary. The Brownian-like trajectory depicted from  $b$  to  $j$  is

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