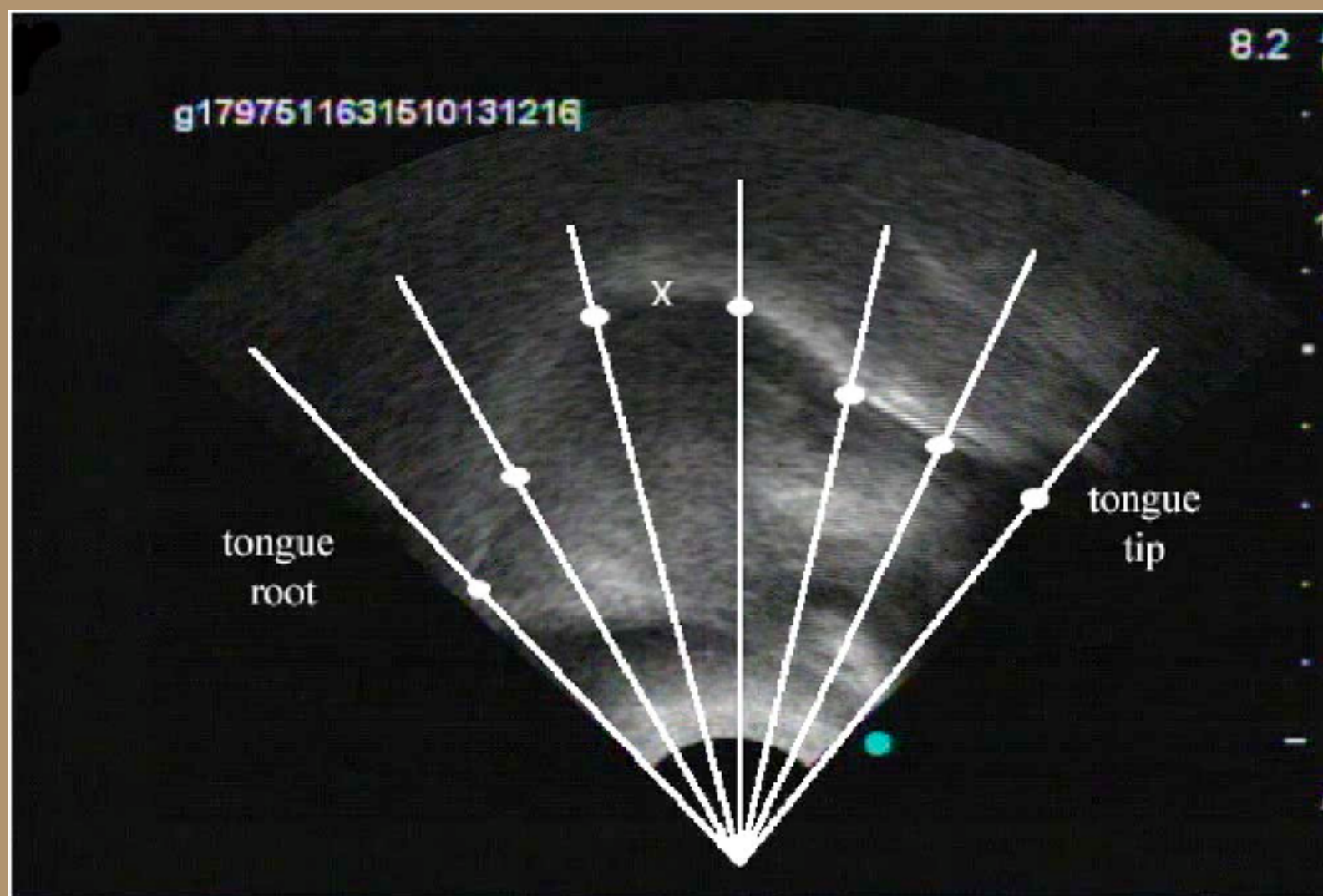


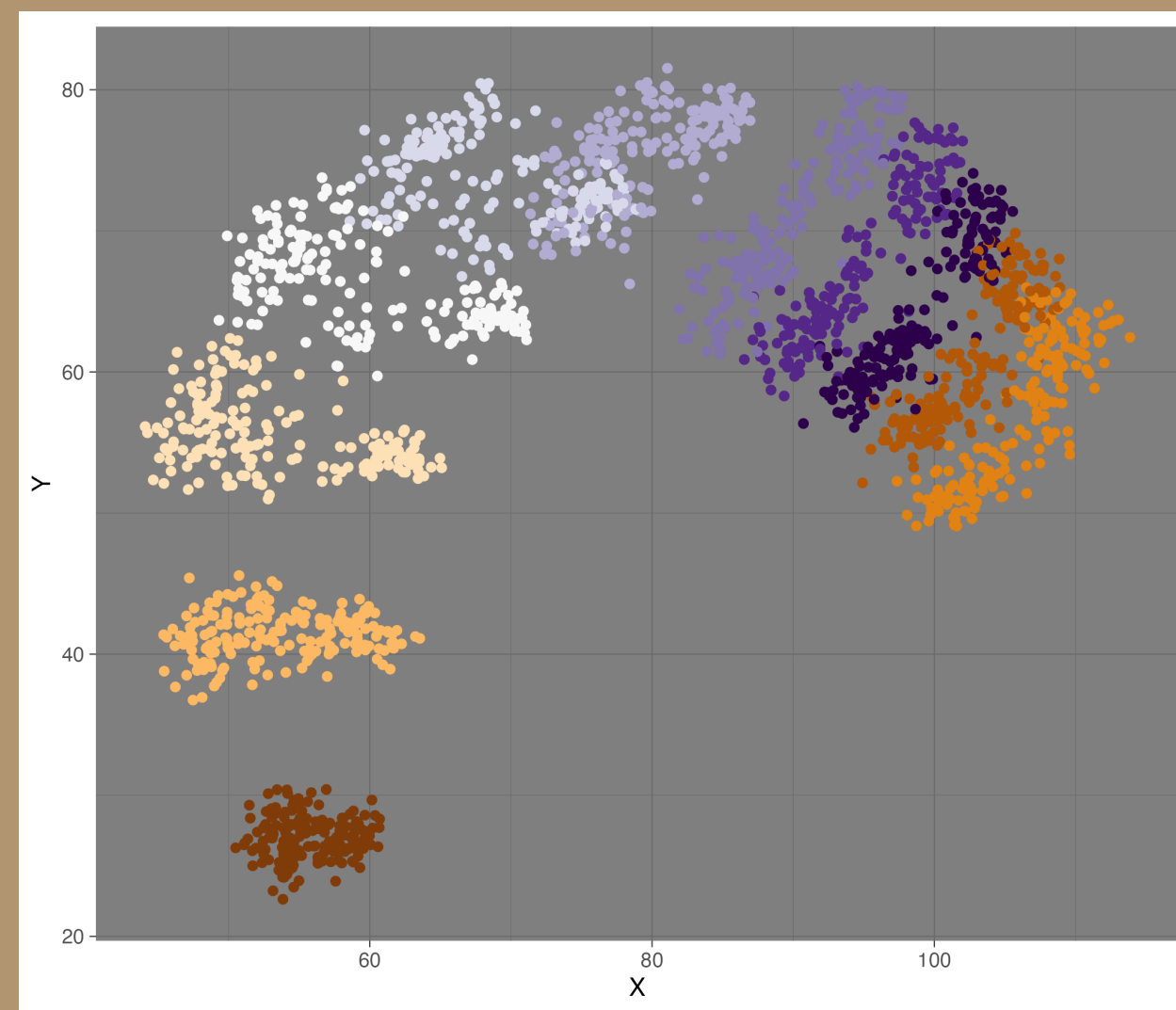
# Analysing tongue contours with multivariate Generalised Additive Models

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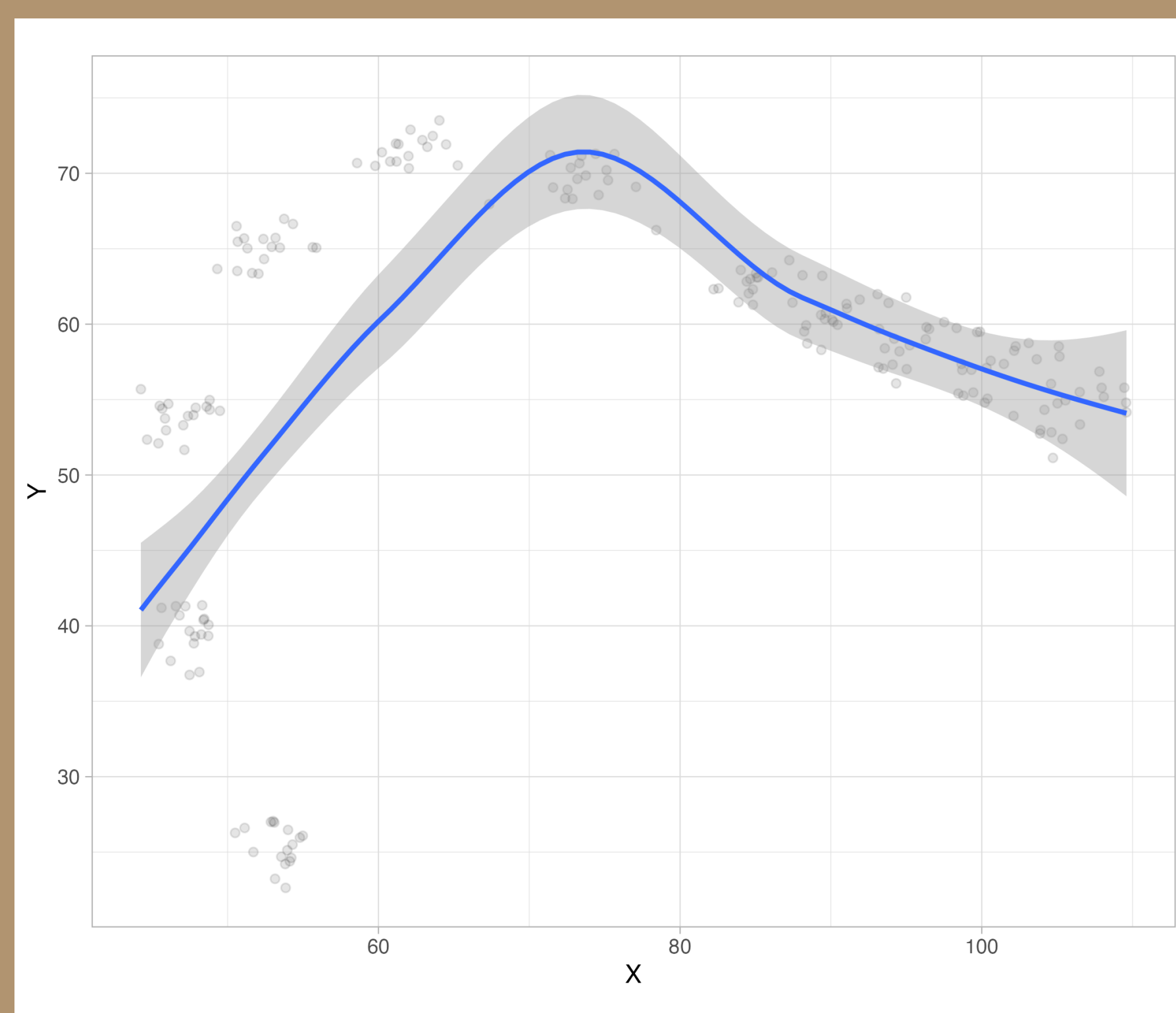
Fan-line coordinate system.



DLC 11 points on tongue surface.

- Wrench and Balch-Tomes (2022) have trained a **DeepLabCut** (DLC) model for markerless estimation of tongue surface points.
- DLC output **X and Y coordinates of tracked points (knots) on the tongue surface** which move in the 2D space.
- This differs from the use of a fan-line coordinate system of line-vectors which the tongue surface intersects with.

- Generalised Additive (Mixed) Models of the form  $Y \sim s(X)$  don't work with DLC knot data, as illustrated in the figure below.
- Since the **tongue surface curls on itself**, the smooth generates an incorrect flat line at the back of the tongue.



Tongue surface knots (transparent points) with GAM smooth.



- We can use instead **multivariate Generalised Additive (Mixed) models**.
- Multivariate models are models with more than one outcome (aka response) variable.
- The X and Y coordinates of the 11 DLC points are the two outcome variables and we smooth over knot (as a numeric variable of sequential knot numbering).

$$\mathbf{c}(X, Y) \sim \mathbf{s}(\text{Knot})$$

## THE DATA

- 5 speakers of Central Mount Lebanon Lebanese.
- /CVb/ nonce syllables.
- C = /t, d, s, z, ʈ, ɖ, ʃ, ʒ/.
- V = /a, e, i, o, u/ (approximately).

- The figure to the left shows the predicted tongue shapes of the first consonant in /CVb/ nonce syllables, 35 ms before the vowel onset.
- Each vowel (columns) and each speaker (rows) is plotted separately.
- Tongue retraction can be observed especially in /a/ and /u/, but there is a lot of variability between and within speakers.

## PROS AND CONS

- **PRO:** Data from multiple speakers can be modelled together.
- **PRO:** It can fit any tongue shape and many predictors (categorical and numeric).
- **CON:** It takes a long time to fit multivariate GAMs.
- **CON:** Obtaining uncertainty estimates is not straightforward.

## R CODE

```
library(mgcv)
```

```
gam(list(  
  X ~ s(Knot, by = Vow.Emph, k = 4) + s(Knot, Subject, by = Vow.Emph, bs = "fs", m = 1),  
  Y ~ s(Knot, by = Vow.Emph, k = 4) + s(Knot, Subject, by = Vow.Emph, bs = "fs", m = 1)),  
  family = mvn(d = 2))
```